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Waukegan River
Illinois National Nonpoint Source Monitoring Program Project

William White, John Beardsley, Scott Tomkins

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Illinois State Water Survey
Institute of Natural Resource Sustainability
University of Illinois at Urbana-Champaign

Champaign, Illinois

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William P. White
Illinois State Water Survey, University of Illinois at Urbana-Champaign

John Beardsley
Illinois State Water Survey, University of Illinois at Urbana-Champaign

Scott Tomkins
Illinois Environmental Protection Agency, Division of Water Pollution Control

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Introduction

The Waukegan River watershed is located in Lake County, Illinois, about 56.3 kilometers (km) (35 miles) north of Chicago (Figure 1). The watershed is 11 km (7 miles) long and has a drainage area of 2,994 hectares (7,397 acres), with major land uses consisting of single- and multi-family dwellings (35%), transportation infrastructure (24%), and public and private open spaces (12%) (Table 1).

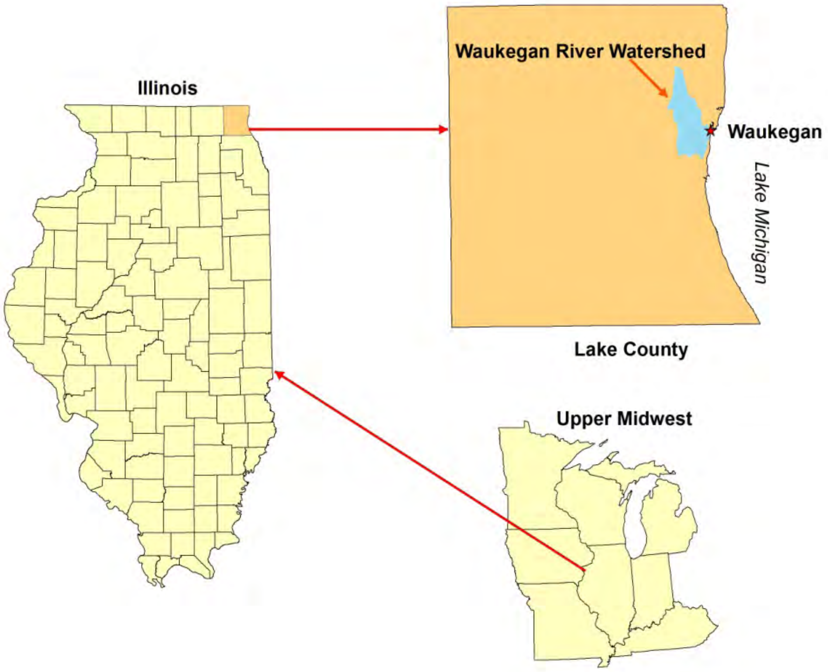


Figure 1. Location of the Waukegan River watershed

Table 1. Land Use of the Waukegan River Watershed

Land Use	Hectare	%
Agricultural	2.8	0.1
Disturbed Land	56.3	1.9
Forest and Grassland	200.7	6.7
Government and Institutional	181.7	6.0
Industrial	82.7	2.8
Multi-Family	68.7	2.3
Office	0.5	0.0
Public and Private Open Space	353.2	11.8
Retail/Commercial	195.1	6.5
Single Family	978.1	32.7
Transportation	729.2	24.4
Utility and Waste Facilities	65.4	2.2
Water	11.5	0.4
Wetlands	67.6	2.2
TOTAL	2993.5	100

Source: Lake County Planning, Building and Development, 2000
(Kabbes Engineering, Inc. and Geosyntec Consultants, 2007)

The Waukegan River descends from 222 meters (m) (728 feet) in the headwaters to 177 m (581 feet) above mean sea level (msl). The river discharges into Lake Michigan approximately 1.8 km (1.12 miles) from the city's Lake Michigan water intake located just east of downtown Waukegan. The Waukegan River watershed receives a mean annual precipitation of 834 millimeters (mm) (32.8 inches) and has a mean annual temperature of 8.8°C (47.8°F) (Midwestern Regional Climate Center, 2009).

Soils in the watershed are dominated by Hydrologic Soils Group C (low permeability) covering 66% of the watershed and Hydrologic Soils Group B (medium permeability) covering 32%. Group C soils have wetland and marsh areas covering 2.3% of the watershed area. The presence of hydric soils indicates that 15% of the watershed was once occupied by wetlands (Kabbes Engineering, Inc. and Geosyntec Consultants, 2007). Original wetland and marsh areas were also recorded in plat surveys of 1839 (Federal Township Plats of Illinois 1804-1891) (Figure 2). The original wetland and marsh areas were reduced in acreage by land-use conversions from agriculture and urbanization over the past 170 years.

The Waukegan River watershed is largely urbanized, containing more than 80% of the City of Waukegan within the watershed boundaries (Figure 3). After Waukegan became the county seat in 1841, the population grew rapidly, beginning a long history of urbanization (Waukegan Historical Society). By 1850, Waukegan was ranked as the seventh largest city in Illinois with a population of 2,949 people (U.S. Census Bureau, 1850). The 2000 census indicated 87,901 people lived in Waukegan with a density of 1,475 people per square kilometer (km^2) (U.S. Census Bureau, 2000). Urban sprawl occurred prior to current requirements for stormwater runoff control. The resulting lack of control over stormwater quantity and quality led to flashy runoff rates and heavy stormwater pollutant loads. Water quality concerns also included cross-connections between sanitary and storm sewers, potential sanitary sewer overflows during wet weather, leaks in piping infrastructure, severe streambank erosion, channel downcutting, and fluvial/hydraulic disequilibration caused by concrete armored channels.

Figure 2. The Waukegan River (formerly the Little Fort River) watershed in 1839. (Federal Township Plats of IL 1804–1891)

Figure 3. The 1993 urban area (United States Geological Survey 7.5’ quadrangle maps–Libertyville, Wadsworth, Waukegan, and Zion) overlain with 2002 wetland and hydrology information (courtesy of Lake County Dept. of Information & Technology)

As expected, urbanization significantly impacted stream biota in the Waukegan River. Fitzpatrick *et al.* (2004) stated in a study of urban influences on aquatic communities that most watersheds with a population higher than 193 people/km^2 had Alternate Index of Biotic Integrity (AIBI) scores under 40 (fair or poor). The State of Illinois has used the Index of Biotic Integrity (IBI) and the AIBI since the mid-1980s (Hite and Bertrand, 1989). The IBI or AIBI scores have been used as principal indicators of stream quality in northeastern Illinois as well (Dreher, 1997). Fitzpatrick *et al.* (2004) data also showed that 193 people/km^2 corresponded to a range of 10 to 18% urban land in northeastern Illinois and about 7% total impervious areas for Chicago-area streams. In addition, Macroinvertebrate Biotic Index (MBI) scores generally increased to 5.0 (fair) or above (poor) for streams within a watershed of greater than 10% urban land (Fitzpatrick *et al.*, 2004). This implies that watersheds with a high percentage of urban land will have poorer water quality. The MBI scores are used as an indicator of water quality (Resh and Unzicker, 1975).

During 1990, the Waukegan Park District experienced infrastructure damage from extreme storm events (Figures 4 and 5). As a result, in 1992 the Illinois State Water Survey (ISWS) was asked to adapt and apply previously demonstrated stream habitat enhancement and stabilization practices to stream bank erosion sites in Washington and Powell Parks.

Figure 4. Damaged infrastructure on the South Branch from "flashy" storm events during 1990 in Washington Park

Figure 5. View upstream at the South Branch erosion site at Washington Park in 1990

Stream Restoration for the Waukegan River Section 319 National Monitoring Program Project

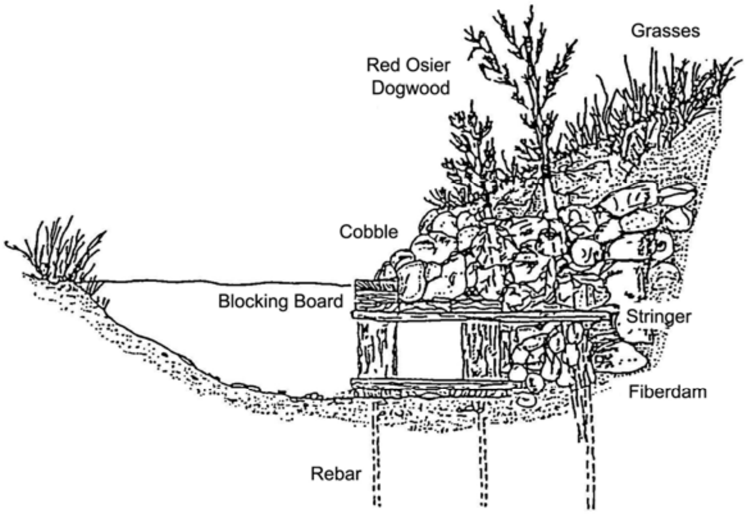
The 1992 stream restoration projects and sampling and restoration project sites for the Waukegan River Section 319 National Monitoring Program were located in Washington and Powell Parks in the City of Waukegan, Illinois (Figure 6). Washington Park is located at the confluence of the North Branch and South Branch of the Waukegan River, about 0.8 km upstream from the river mouth on Lake Michigan, and is situated in an area that represents the most urbanized reach of the river. Powell Park is located on the North Branch 1.6 km from the river mouth and within a residential area.

The core of habitat enhancement included the use of streambank stabilization structures called LUNKERS (Little Underwater Neighborhood Keepers Encompassing Rheotaxic Salmonids) (Vetrano, 1988). LUNKERS were originally designed and tested in Wisconsin for improving trout habitats and used as an alternative to single-wing dam deflectors made of logs, wire, and rock. In 1982, the first prototype LUNKERS were installed at Spring Coulee Creek in Vernon County, Wisconsin. In 1984, the stream was subjected to a 500-year flash flood. Inspection of the site after the flood event showed only minor damage in which a few rocks had been moved, and some of the topsoil was scoured. LUNKERS were installed in Illinois at Franklin Creek State Park by the Illinois State Water Survey (ISWS) (Roseboom *et al.*, 1992); habitat conditions improved and game fish populations increased as a result. LUNKERS were used to stabilize the streambed below the water line and form a base for grasses, dogwoods (*Cornus sericea*), and willows (*Salix exigua Nutt*) on the bank. LUNKERS also improve instream habitat conditions by providing a sanctuary for fish. In Illinois, LUNKERS have been used in targeted areas as habitat for game fish such as smallmouth bass (*Micropterus dolomieu*) and channel catfish (*Ictalurus punctatus).* The Waukegan River is the only known stream in Illinois where non-native salmon enjoyed the use of LUNKERS along with native Illinois fish. Because salmon require specific habitat conditions to spawn (Moyle *et al.*, 1995; Hassler, 1987), they are rarely found in Illinois streams unless associated with areas that are stocked.

Figure 6. A 1998 aerial photograph shows the location of the sampling stations and project areas established by the ISWS. Station S2 is the control station (non-treated). Stations S1, N1, and N2 are restoration sites (treated).

North Branch

On the North Branch of the Waukegan River in Powell Park, a stormwater sewer line was exposed by erosion, increasing the risk of contaminating the stream and limiting access to downstream park areas (Station N2, EPA Station QC-02). In May 1992, LUNKERS were constructed and installed along the bank at N2. These LUNKERS were made from recycled plastic lumber to prevent deterioration during low summer flows. The upper and lower ends of the LUNKERS were stabilized with A-jacks, stone, and vegetation (e.g., Figure 7). After one year of growth, the sheer vertical face of the eroding streambank was stable and the dogwoods and wetland plants were already thriving (Figure 8).


LUNKERS Installation Design

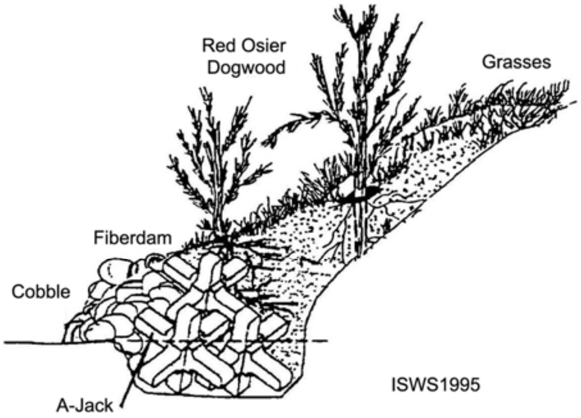

A-Jack Design and Installation

Figure 7. LUNKERS and A-Jack designs

Figure 8. Stream restoration at station N2 shows pre-restoration conditions in 1991 (photo on left), mid-restoration in 1992 (middle photo), and post-restoration in 1993 (photo on right)

In September 1992, the Public Works Department and the Park District built and installed wooden LUNKERS at an erosion site along North Branch at Washington Park designated as station N1 (EPA Station QC-03) (Figures 6 and 9). Just downstream of this site, the network of the city's major sewer lines connected before entering the sewage treatment plant. Stream channel stability issues were of concern in this area because of the need to protect the piping system from erosion. Oak LUNKERS were used here because the base of the stream bank needed protection, the stream was wider in this area, and the base and higher flows were deeper. LUNKERS in this segment and at station N1 would remain under water since oak species do not deteriorate in water as fast as many other species available. The oak LUNKERS followed the curve of the channel and were secured with rebar. A-jacks, stone, and soil were then placed on the LUNKERS. Cut stone was then laid over the reworked embankment soil above the LUNKERS, and small willow stock was planted between the stone joints. Vertical bank sections were sloped to a 1-to-1 grade. The lower edge of the sloped bank was sprigged with prairie cord grass and bulrush, while the upper bank was planted with grasses and red osier dogwood. In addition, an excelsior blanket was used on the upper bank to promote rapid seed germination. By October 1992, the riparian vegetation exhibited substantial growth, greatly reinforcing the bank soil.

During 1993, Waukegan experienced a series of flood events, with the greatest flow occurring when 102 mm (4.0 inches) of rain fell in one hour in July. Rapid runoff quickly flooded low areas with the greatest floodwater velocities occurring in the lower end of the Waukegan River in Washington Park where runoff was concentrated. The N1 site was submerged by a major flood in 1993 (Figure 10). Biotechnical bank stabilization effectively protected the parklands from erosion at both project sites on the North Branch.

Even with the success of streambank stabilization efforts at stations N1 and N2, the fish population was limited because of the lack of high quality instream habitat such as cobble substrates and consistently deeper pools. During high stream flows, larger game fish could be found within the sites where LUNKERS were installed, but during the summer and fall, water in the stream was too shallow for game fish, even in meander pools. In the summer, low stream flows place significant stress upon fish communities and contribute to a general reduction in the quality and availability of stream habitat conditions (Biological Stream Characterization (BSC) Work Group, Hite and Bertrand, 1989). Urban watersheds tend to have large, impervious surface areas that reduce stormwater infiltration, increase peak discharge, and minimize enhancement of already low base flow conditions. This results in further negative impact to biota; especially during drier weather episodes that occur within seasonally dry periods.

Figure 9. Stream restoration applied at station N1 before restoration in 1991 (photo on left) during construction in 1992, and post-restoration in 1993

Figure 10. Photo of flooding at station N1 in July 1993

South Branch

In 1993, the Illinois Environmental Protection Agency (IEPA) and the United States Environmental Protection Agency (USEPA) Region 5 requested that the ISWS collect more detailed data on the South Branch of the Waukegan River under the auspices of the National Nonpoint Source Monitoring Program (NNPSMP).

The goal was to restore fish habitats in the South Branch of the Waukegan River by installing and monitoring best management practices (BMP) to evaluate the effectiveness of restoration efforts. The stream restoration project was evaluated on the basis of channel stability and impacts to instream fish habitats. The South Branch was divided into an upstream untreated reference site designated as station S2 (EPA Station QCA-03) and a severely eroding downstream treatment area designated as station S1 (EPA Station QCA-01). In this setting, water quality characteristics affect both the control (S2) and the rehabilitated station (S1) uniformly. From 1994 through 2006, fish, macroinvertebrates, and habitat conditions were sampled at each location during the spring, summer, and fall. The IEPA and ISWS agreed to include the North Branch restoration stations N1 and N2 in the NNPSMP as additional reference sites (ISWS, 1994). Therefore, during these same years, the North Branch stream site segments were also sampled in the spring, summer, and fall.

In 1994, the streambank at station S1 was eroding rapidly and fish were limited in number by the lack of pool depth in both monitored stream segments. Fish found at the site consisted of species that are very pollution tolerant. Therefore, biotechnical streambank stabilization techniques (LUNKERS, A-jacks, and bank revegetation identical to the North Branch restoration project) were installed to improve habitat and water quality conditions. The 1994 restoration project work on the South Branch coincided with the time of the Second National Nonpoint Source Monitoring Workshop held in Northbrook, IL. This provided an opportunity for many workshop attendees to participate in fish monitoring and installation of a restoration project (Figure 11).

Figure 11. Stream restoration at station S1 shows pre-restoration conditions before 1991 (photo on left), mid-restoration conditions in 1994 (middle photo), and post-restoration conditions in 1995 (photo on the right)

Starting in 1994 at the downstream end of station S1, more than 61 m (200 feet) of eroding banks were stabilized by installing rolls of coconut fiber along the toe of the bank. The rolls were secured into a shallow trench with several rebars bent down to form a hook. The fiber rolls were then perforated with small willow cuttings. Grass seed and additional willow cuttings were placed on areas of exposed bank. The dogwoods and grass seedlings grew quickly, but the willow cuttings had limited growth likely due to the high density of the canopy shadowing the stream reach (White *et al.*, 2003). This stream reach was in an early stage of channel evolution. A channel evolution model (CEM) is often used to assess present channel geomorphic conditions and predict future channel adjustment conditions associated with intrinsic channel evolution factors and/or more extrinsic watershed disturbances (see Simon, 1989; Simon and Downs, 1995; Simon and Rinaldi, 2000; USACE, 1990; Federal Interagency Working Group, 1998; White *et al.*, 2005, 2006). Restoration efforts significantly reduced channel erosion, consequently reducing sedimentation. Field reconnaissance, site-specific monitoring, and video documentation from 1994 to 2006 indicate the reach has remained stable since 1994.

Shallow pool depths were still considered to be a limiting habitat for stream fisheries during the summer low flows, however, as was also the case in the North Branch. The stream channel functioned as a ditch with a uniform streambed lacking a defined pool and riffle pattern. The ditch-like characteristics of the stream limited aeration and promoted deposition of fine textured mineral and organic materials in the shallow pools. In January 1996, the Waukegan Park District and the Illinois State Water Survey provided more pool depth by constructing seven rock-grade control riffle structures (Newbury weirs) and pools within the South Branch. The locations and height of the riffles were based on designs by Dr. Robert Newbury, a Canadian hydrologist accredited with developing this technique of stream restoration (Newbury and Gaboury, 1994; Roseboom *et al.*, 1998). The riffle structures started at the confluence with the North Branch (Figure 12). In March 1996, two additional riffles were constructed in the North Branch upstream of the confluence at station N1.

The overall riffle project design relies on discharge estimates, channel profile and cross-section surveys, and observation of substrate types as explained by Newbury and Gaboury (1994). The riffle itself uses a line of large crest stones that forms a foundation and helps control pool elevation. The crest stone was “keyed” 3 to 4.5 m (10 to 15 feet) into the streambank.

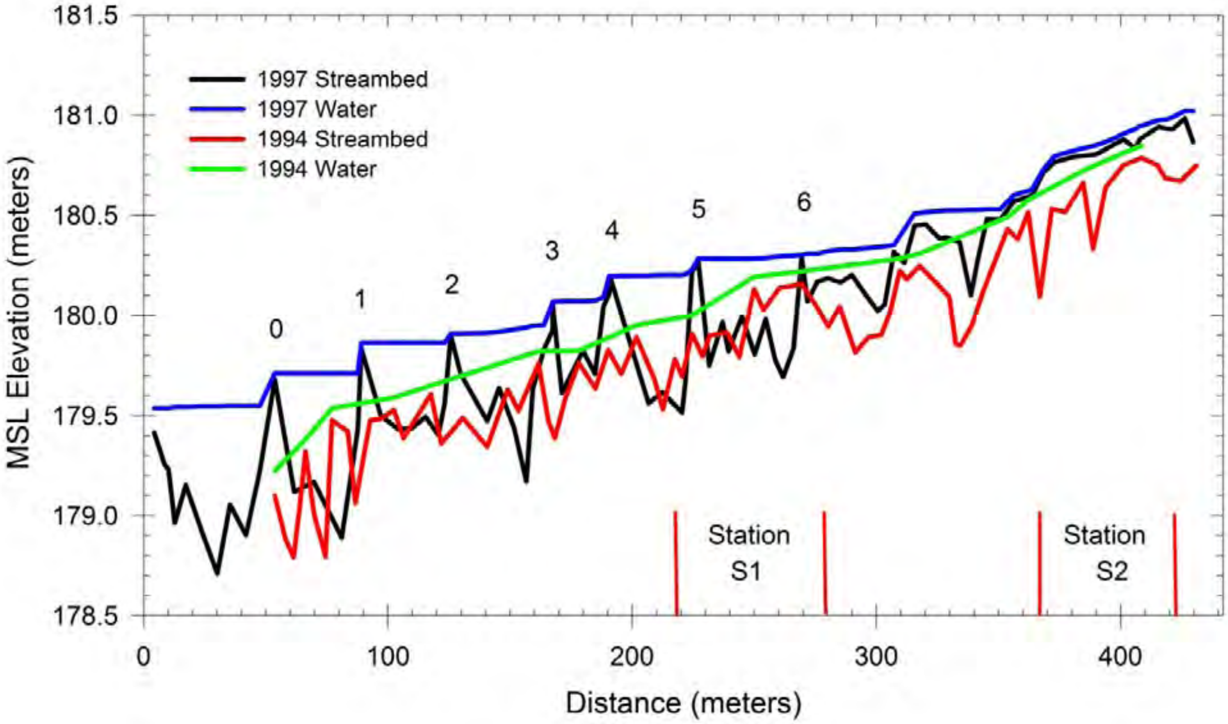
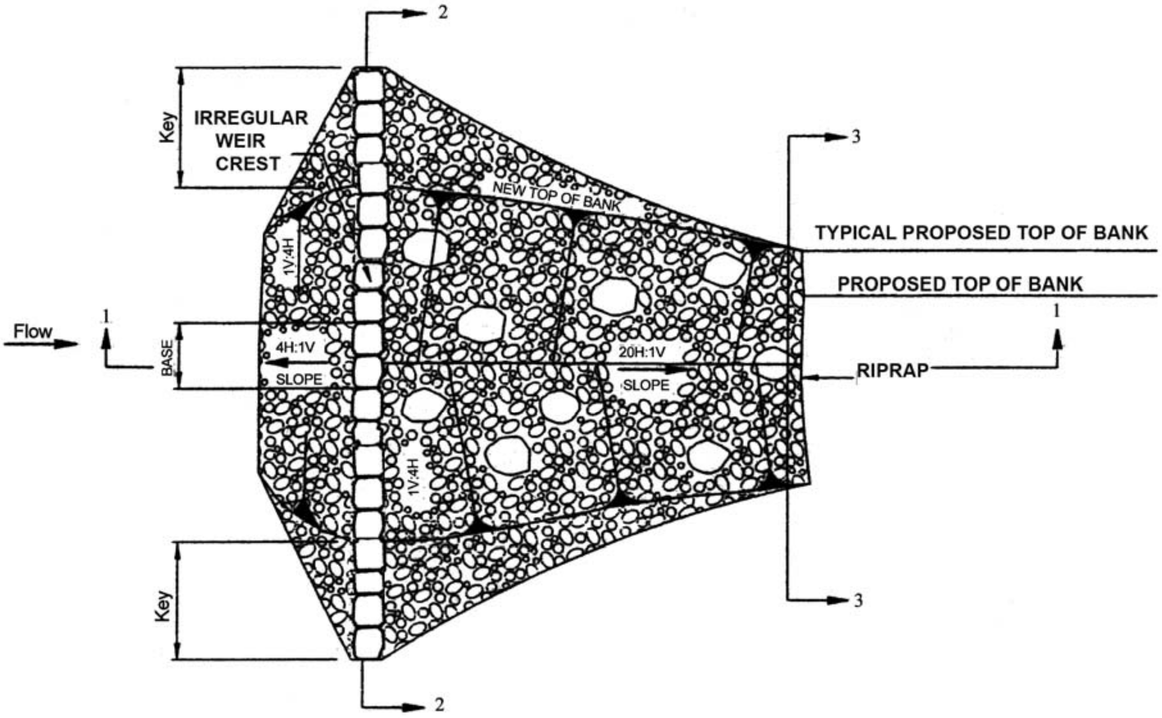
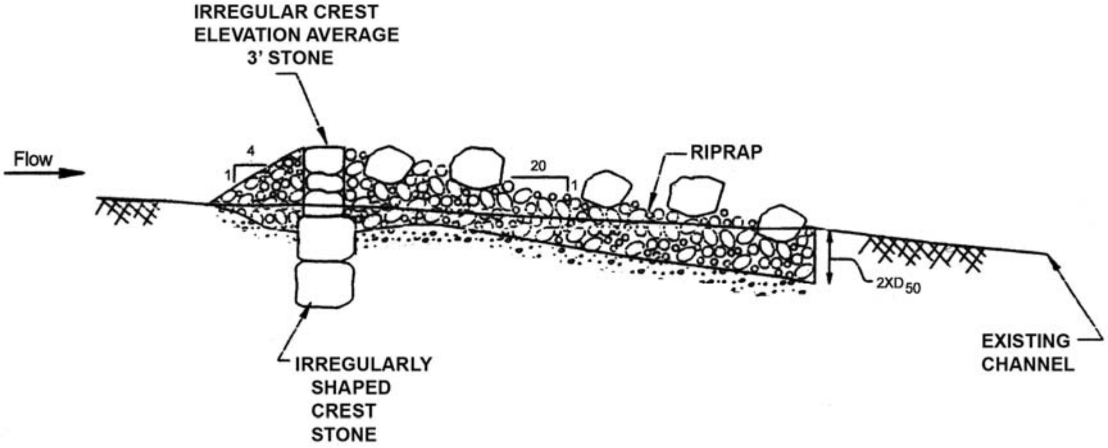


Figure 12. The profile of the South Branch of the Waukegan River showing riffle locations (below the numbers along the profile) after construction of riffles in January 1996. The vertical red bars indicate the extent and location of the monitoring stations. The 1997 water level line (blue) shows the pool depth is higher than the water depth in 1994 (green line). Both surveys were conducted during base flow.

Where bank heights and stream widths exceed the reach of equipment, the “key” was laid into a ramp excavated by heavy equipment. As crest stone was being added, smaller stone was packed around and upstream of the crest, forming a front face and a back face (or “tail”) on the downstream side of the crest stone. Laying the crest in front of the excavator builds a support base for the excavator to cross the stream and reach the other side. While the excavator worked its way across the stream, the front face was created at a 4:1 slope and tail at a 20:1 slope (Figure 13). Elevations were set on the crest stones located at the center of flow. Once the bank opposite the ramp was “keyed,” a “shoulder” was built over the crest stone to help form a V-shaped cross-section at a 4:1 slope. The equipment operator then finished the slope on the tail and extended the shoulder in accordance with design specifications. Large boulders similar to crest stones were placed around the tail to agitate the flow to create hydraulic diversity, add roughness, and provide a place for fish to rest as they navigate super-critical flows coming down the tail of the riffle (see Newbury and Gaboury, 1994, for an explanation of hydraulic flow conditions associated with riffles). After the tail was completed, the shoulder was built up the slope of the tail and along the bank. As the excavator exited back up the ramp, the final shoulder was completed and the ramp then filled while reforming the remainder of the bank area. During this entire process, trucks or a track loader fed a constant supply of rock over the bank to the excavator. The work area was then cleaned of excess rock, leveled, seeded, and mulched. Figure 14 shows an upstream view of riffle 3 and 4 in May 2006.



TYPICAL RIFFLE STUCTURE PLAN VIEW



PROFILE VIEW

Figure 13. A typical design of a riffle structure, modified by ISWS from original work by Newbury (1994)

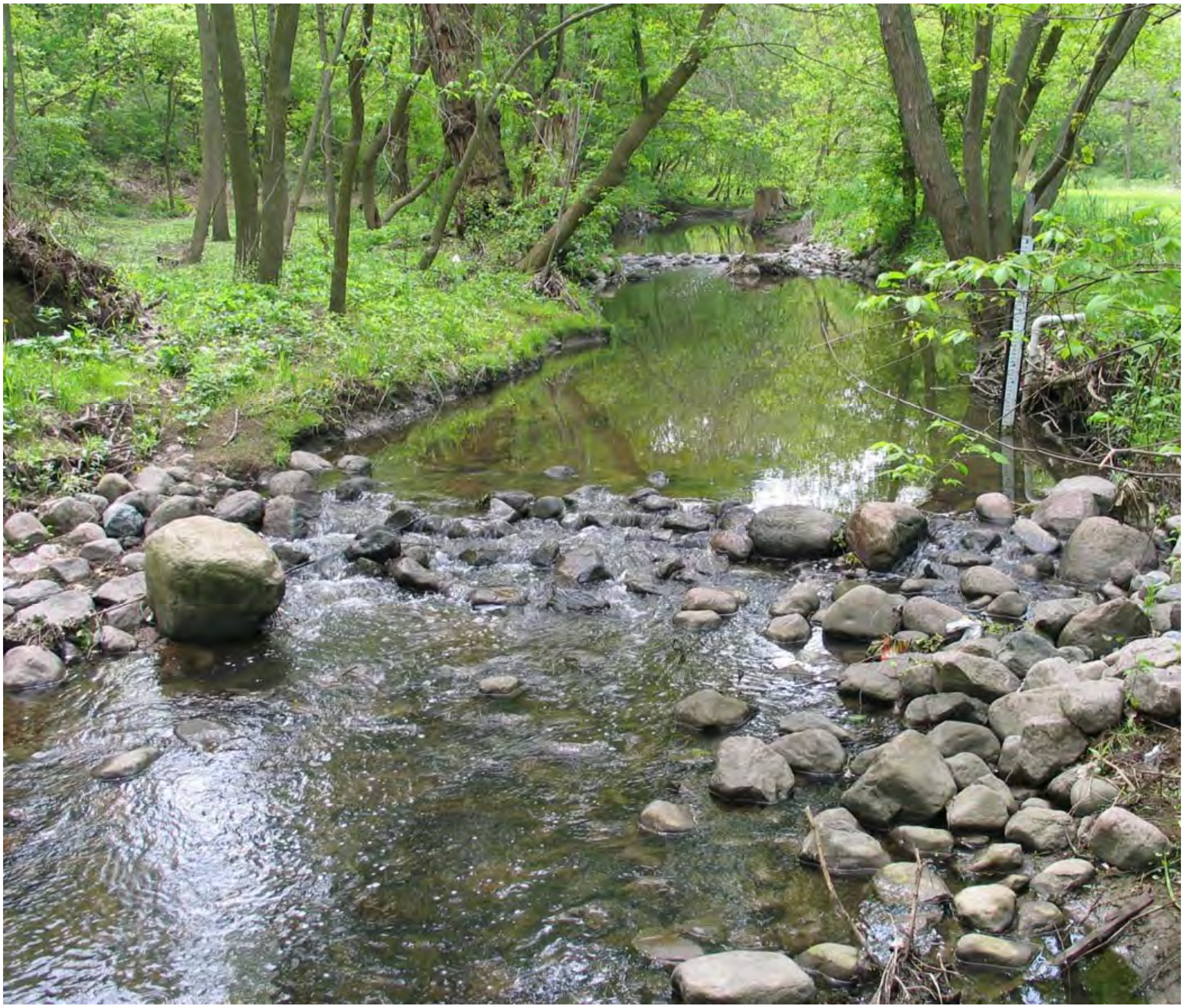


Figure 14. Upstream view of riffle 3 and 4 on the South Branch in May 2006. The staff gage at the right of the picture measures up to 2 m (6.7 feet).

Monitoring Methods

The IBI, a metric that considers a variety of attributes of lotic fish communities, allows one to develop a biological stream site characterization score. Stream biologists from the Illinois Department of Natural Resources (IDNR) and the IEPA have used the IBI since 1984 (Hite and Bertrand, 1989). These agencies, along with specialists from the Illinois Natural History Survey, formed the Biological Stream Characterization Work Group. This group reviewed 12 IBI metrics used to evaluate streams based on Illinois statewide stream fisheries data (Bertrand *et al.,* 1996). The 12 metrics encompass trophic condition, fish abundance, and condition of fish communities (Karr *et al.,* 1986; Hite and Bertrand, 1989). The index accounts for changes in species richness, where Fausch *et al.* (1984) described scoring criteria, and allows comparison of fish community composition with maximum known values for similar-sized streams in the state. Stream size is determined by the standard stream order classification (Strahler, 1957).

Fish Community Sampling

Each monitoring station consisted of a single pool and associated upstream and downstream riffles. The stations ranged from 36.6 m to 62 m (120 to 200 feet) in length. Blocking seines positioned at both the upper and lower ends of the riffles isolated the reach during sampling periods. Fish were collected using a backpack electrofishing unit that stuns fish to bring them to the surface. The fish survey crew included the shocker operator and a single “netter” to collect the stunned fish. Electrofishing normally requires 10 to 15 minutes depending upon habitat and pool depth. Time was accurately recorded to calculate the catch per unit effort. Larger fish were identified on site and returned to the stream. Smaller fish were stored in 95% ethanol and identified at a later date by IDNR fishery biologists. Fish species were identified, and individual fish were examined for disease and physical condition.

Macroinvertebrate Surveys

Aquatic macroinvertebrates, as defined by Weber (1973), are invertebrates large enough to be seen by the naked eye and retained on a U.S. Standard 30 (0.595 mm) sieve. Macroinvertebrates spend at least part of their life cycle within or upon aquatic substrates. Invertebrates included in this group are typically annelids, crustaceans, aquatic insects, and mollusks (Isom, 1978), and are commonly useful in water quality monitoring as indicator species (Resh and Unzicker, 1975). At each sampling station, substrates were sampled at three locations with a Hess bottom sampler and a 500-micron net. The screened material was removed from the Hess sampler and the invertebrates were picked from the screened materials, preserved in 95% ethanol, and identified to genus level later in the laboratory. Macroinvertebrate data were analyzed by examining community attributes such as community structure, taxa richness, and use of the Macroinvertebrate Biotic Index (MBI) (Hite and Bertrand, 1989). Interpretation of available data relied heavily on MBI assessment data, which provide summation or average tolerance values that are assigned to each taxon collected and weighted by its abundance. The values are used as surrogate information to discern an organism’s tolerance to pollution. Low values indicate better water quality (for example, a rural Franklin Creek LUNKERS project had an MBI of 5.5, good range) (Roseboom *et al.*, 1992). High MBI values indicate degraded water quality. The index has a scale ranging from 0 to 11, rather than the 0 to 5 scale proposed by Hilsenhoff (1977, 1982) for Wisconsin streams (Hite and Bertrand, 1989).

Instream Habitat Monitoring

Instream habitat monitoring followed IEPA Potential Index of Biological Integrity (PIBI) guidelines outlined in the BSC (Hite and Bertrand, 1989). Variables used to develop the PIBI scores are the same used to develop IBI scores. Regression analysis of habitat data generated by IEPA/IDNR Cooperative Intensive Basin surveys found the percentages of silt-mud substrate, claypan substrate, and pool habitat, and the mean stream width accounted for the greatest variance in IBI values. For typical Illinois streams, the PIBI values will range from 35 to 50 for third- to sixth-order streams using Strahler's (1957) stream order classification system. Smaller streams typically have lower PIBI values. This result is similar to IBI values for smaller streams because smaller streams have fewer species and less abundance than larger streams with a similar habitat.

The PIBI was developed from data generated by wadable stream transect methodology (IEPA, 1987, 1994). The transect assessment procedures used in the IEPA's wadable streams method, used in conjunction with IEPA/IDNR Cooperative Intensive Basin surveys, special studies, or appropriate elements of the BSC effort, combine the habitat assessment approach published by Gorman and Karr (1978). Additional metrics important to stream quality (e.g., pool/riffle development, instream cover, and shading) (IEPA, 1987, 1994) are also used to score the PIBI.

The Waukegan River PIBI assessment process used the wadable transect methodology in which sampling stations were divided into 10 segments of equal length using 11 transects to collect habitat data. Variables of habitat data included stream width; stream depth; streambed substrate (defined as the mixture of particles comprising the streambed (Bovee, 1982; Lane, 1947); instream cover (features where fish can hide under or behind [Bovee, 1982]); percentage of riffles, pools, and runs (Platts *et al.*, 1983; Keller and Melhorn, 1978); shade canopy; and base flow stream discharge. Stream width, stream depth, and bottom substrates were determined by direct measurement at each of the 11 transects. The extent of shade canopy, pool, riffle, and run were recorded at each of the 10 stream segments. Stream discharge was measured at 30.5 cm (1 foot) intervals along one transect within each sampling station. Discharge measurement methods followed established United States Geological Survey (USGS) procedures and guidelines (Buchanan and Somers, 1969).

Sondes (Shipboard Oceanography Network Data Environment) are devices for testing physical conditions and are often used in remote or underwater locations. For the Waukegan River project, sondes were installed at stations S1 and N1, with the help of Lake County Health Department, to record temperature, conductivity, pH, and dissolved oxygen (DO). They were used to record data from June 2003 through October 2006 with the exception of the winter months (November through April).

Monitoring Results and Discussion

South Branch

Monitoring data collected in 1994 (pre-LUNKER construction) and 1995 (post-LUNKER construction) revealed that after LUNKER construction, the total number of fish and a more consistent number of fish species increased at station S1 compared with data from the upstream control area at S2 (Figure 15). Based on this data alone, an increase in the fish population and diversity suggested that stream "health" improved after LUNKERS were constructed. At station S1, the seasonal average percentage of cobble in the streambed increased after installing the riffle and pool structures, and the seasonal average percentage of gravel in the streambed decreased. Untreated station S2 exhibited a higher percentage of gravel substrates overall with an

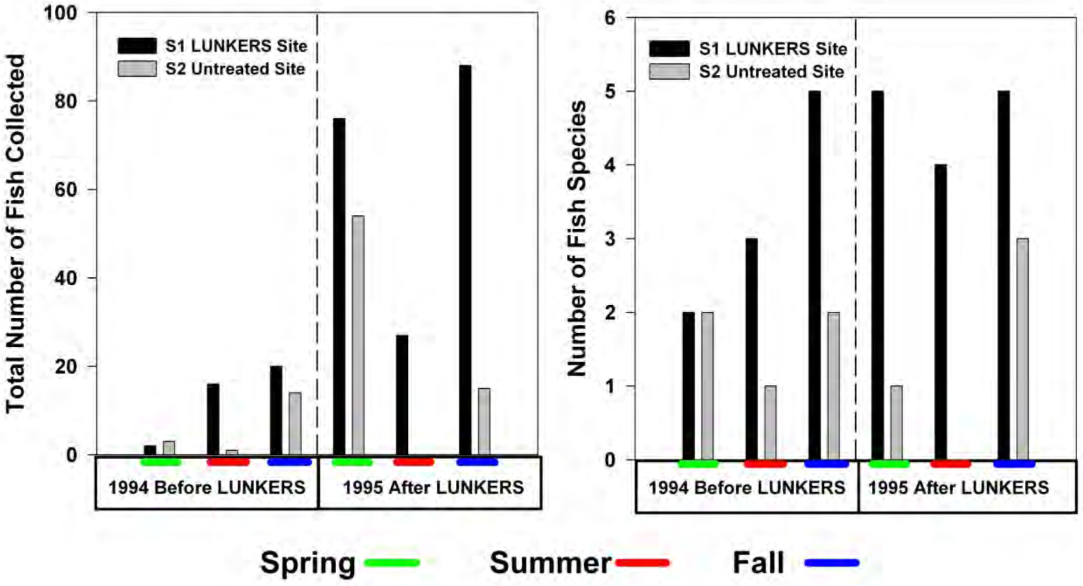


Figure 15. Comparison of diversity and abundance of fish at stations
S1 and S2 prior to and one year after construction of LUNKERS installed in 1994

increase in cobble substrate percentages from 1998 through 2002. The seasonal average percentage of sand and silt substrates increased slightly at station S1, thus remaining consistent for the period, while station S2 had varying percentages all below 20% over the period. The seasonal average percentage of claypan substrate was minimal at both stations (Figure 16).

A deeply incised tributary at the upstream end of station S2 is believed to be a major source of substrate material accumulating at that station. Fluctuation in the percentage of cobble in the substrate at station S2 may be caused by deposition of sediment from the tributary along with exposure of a cobble substrate by repeated scouring and deposition of gravels and additional finer textured sediment at this station. Clearly, the substrate of the stream segment changes as the system dynamically adjusts to transport materials efficiently.

At station S2, the annual average depth (average of the seasons and of the period) was only 58 mm (2.3 inches) at all 11 cross-sections during the entire monitoring period. Figure 12 shows evidence of the streambed filling at station S2 between 1994 and 1997. Figure 17 shows an upstream view of the station S2 untreated control area. The formation of stream bars in the center of the channel at station S2 is typical of stream segments elsewhere that are hydraulically adjusting to transport a heavier bedload. As a result of streambed aggradation, the channel widened and eroded around the right bank footbridge abutment. Repairs performed by the Park District at the abutments of the footbridge and on the upstream right bank required using rock to armor the streambank. It is possible that some of this rock may have added cobble to the assessed reach, but not all cobble came from this source. Analysis of the habitat transect data from 1995 to 2006 at station S2 indicated a 23% annual average increase in average width of the water line when compared to 1994 data (Figure 18). In addition, the 1994 percentage of the average pool

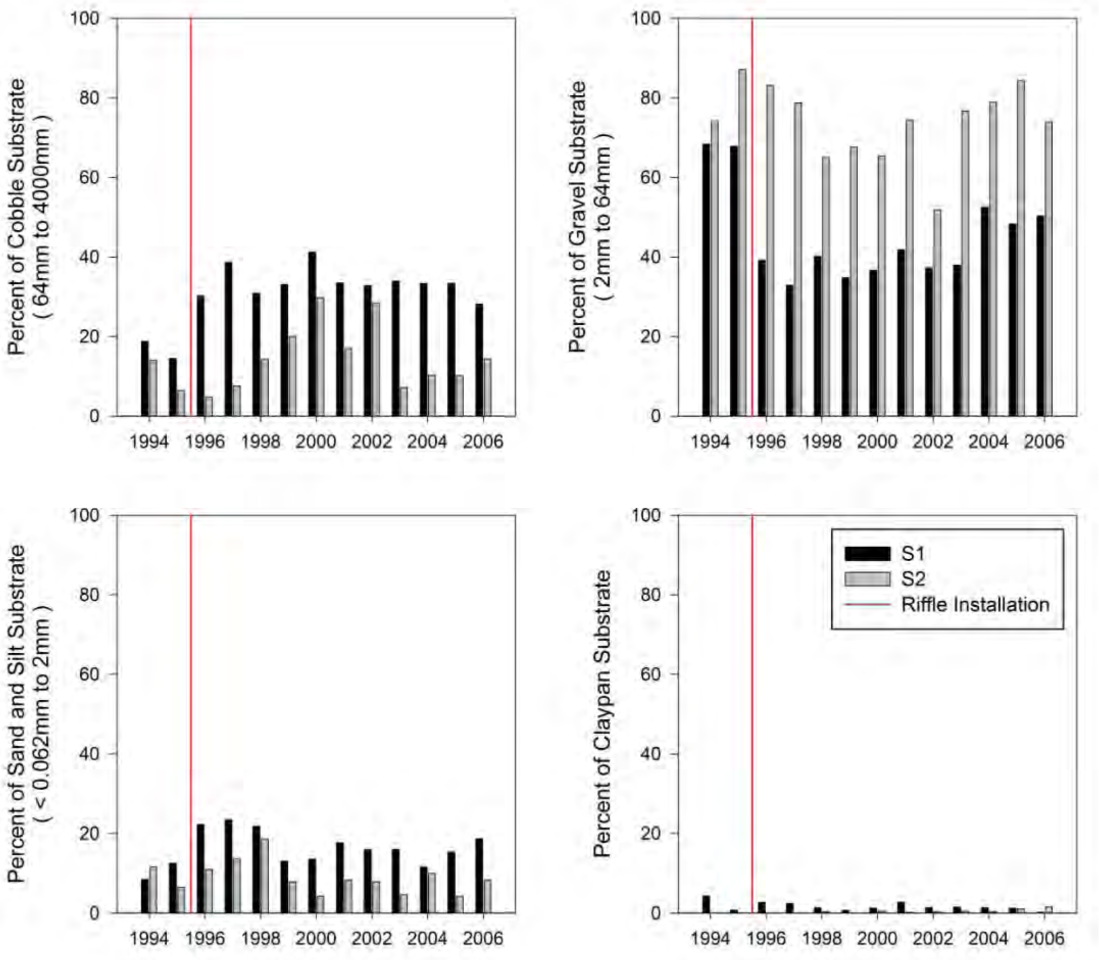


Figure 16. Seasonal average comparison of cobble, gravel, sand, silt, and claypan substrates at stations S1 and S2 before and after construction of riffles and pools in January 1996

Figure 17. Looking upstream at station S2 in 2004 where the pool depth remains insufficient

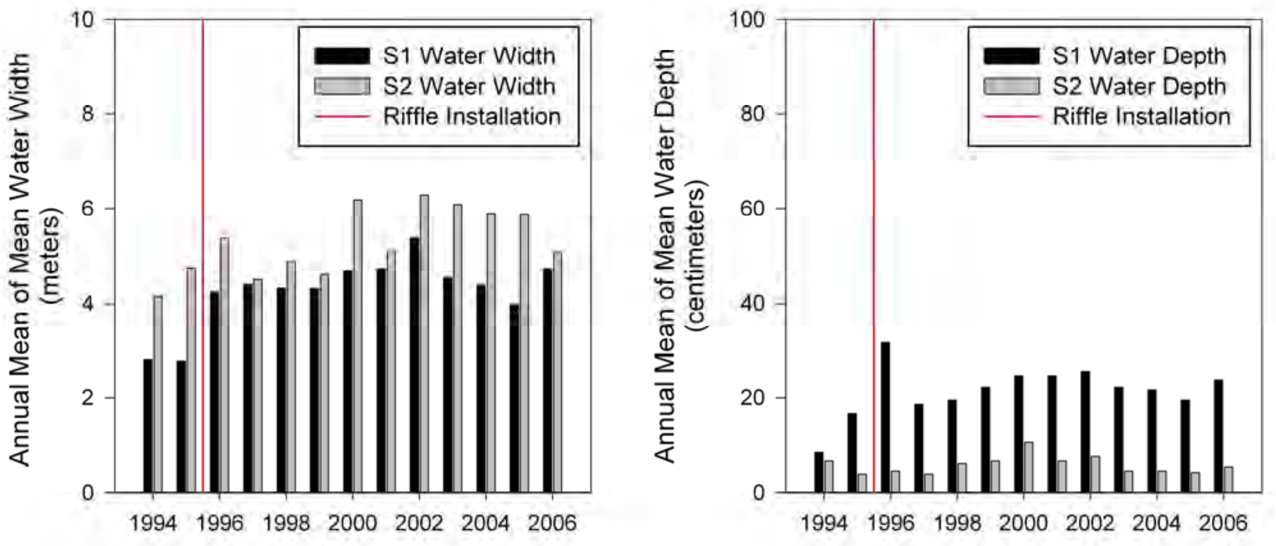


Figure 18. Mean of spring, summer, and fall mean cross-section data for stations S1 and S2

area at station S2 decreased from 23.4% to an annual average of 2.5% from 1995 to 2006. From 1994 to 2006, the average pool area at this control station decreased by 89% (Figure 19). In contrast, station S1 had a 37% increase in the annual mean water width from 1995 to 2006 in comparison to that of 1994. Annual mean depth increased by an average of 62%. The annual average mean depth was 23.1 cm (9.1 inches) over the 1995–2006 period (Figure 18).

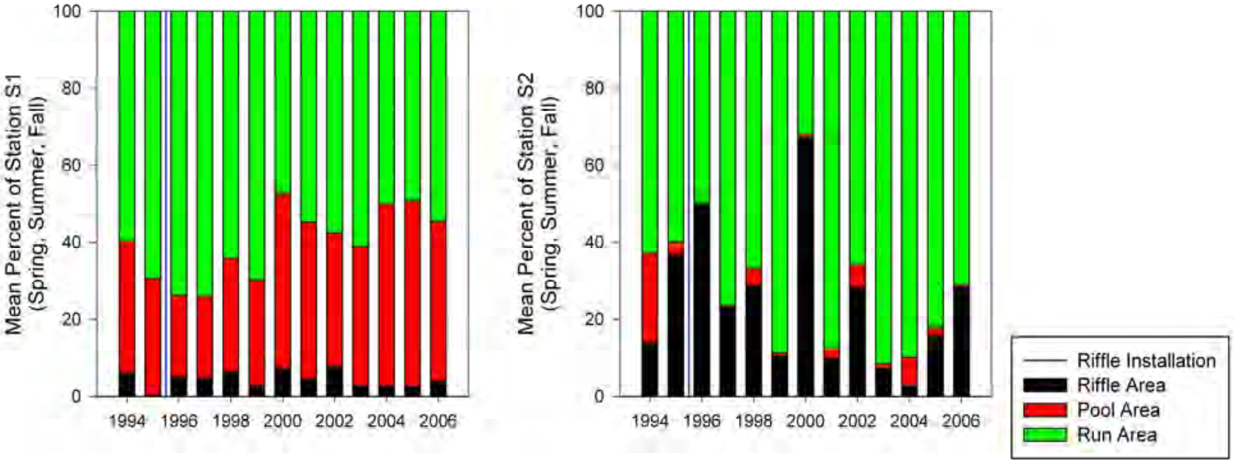


Figure 19. Mean of spring, summer, and fall of riffle, pool, and run areas for stations S1 and S2

North Branch

At station N1, the seasonal average percentage of sand/silt was the highest compared with all other stations, and its annual average was 33%. The percentage of sand/silt at N1 decreased after 1997, while the percentage of gravel and cobble substrates increased due to the 1996 installation of riffle and pool structures and bank armoring. Station N1 had an annual average of 40% for gravel substrates during the monitoring period from 1994 through 2006 and an annual average of 21% for cobble substrates from 1995 through 2006. This is a 58% increase in comparison with the gravel bed composition in 1994, which was 8.9%. Station N2 had an annual average of 40% for cobble substrates with an increase in the seasonal average occurring during 2005 and 2006 due to stream bed armoring conducted at that time by the City of Waukegan. At N2, the substrate averaged 36% gravel from 1995 through 2006, a 35% decrease compared with that of 1994, when gravel composed 55% of the substrate. The seasonal average percentage of sand/silt at station N2 was less than 20% over the monitoring period. The seasonal average percentage of claypan substrate was minimal at both stations during the monitoring period, with station N1 showing a slight decrease after 2002. Though minimal, station N2 had the highest annual average claypan substrate at 5% when compared with all other stations (Figure 20).

Analysis of the cross-section habitat data from 1995 to 2006 showed the mean annual water width at station N1 increased by an average of 35% compared with 1994 (Figure 21). At station N1, the annual average mean depth for the period 1994 to 2006 was 22.2 cm (8.7 inches). Station N2 had a 1995–2006 annual average mean depth of 14.3 cm (5.6 inches) and an annual mean water width of 4.3 m (14 feet). This width represents an increase of 36% over the 2.7 m (9 feet) in 1994 (Figure 21). At station N1 the annual mean pool area was 39%. The annual mean percentage pool area at station N2 was 41% in 1994 and only 27% in 2006, reflecting an overall decrease of 34% during this period. The annual mean percentage pool area at station N2 over the period 1994 to 2006 was 24% (Figure 22).

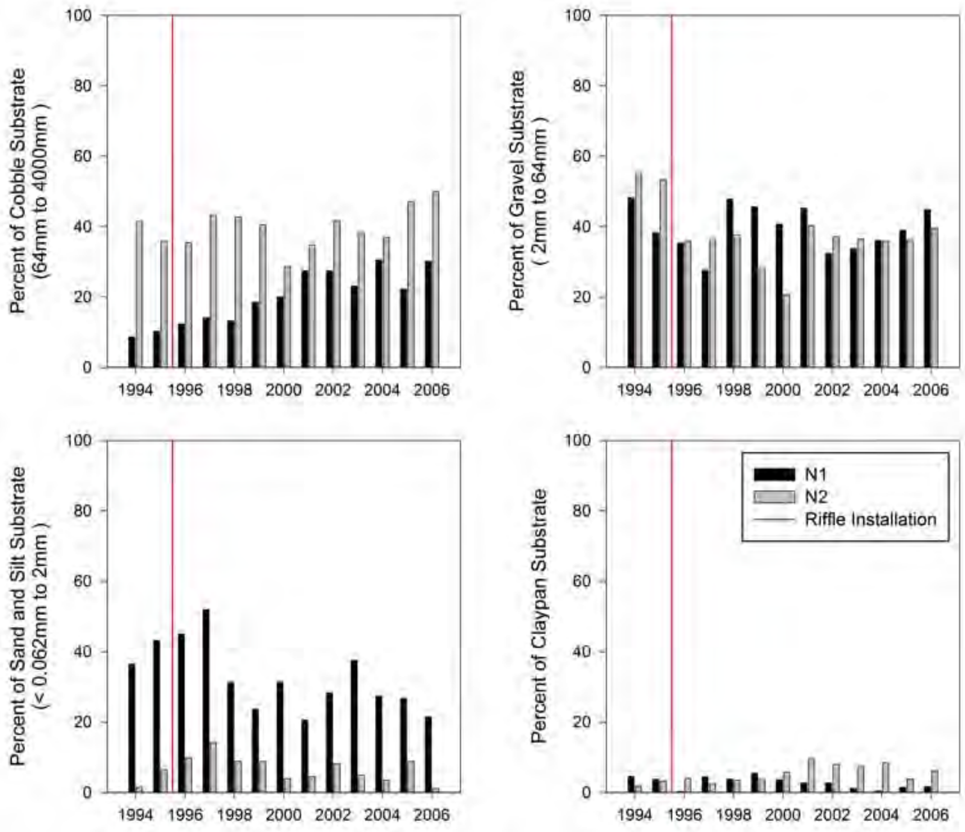


Figure 20. Seasonal average comparison of cobble, gravel, sand, silt, and claypan substrate at stations N1 and N2 before and after construction of Newbury weirs in 1996

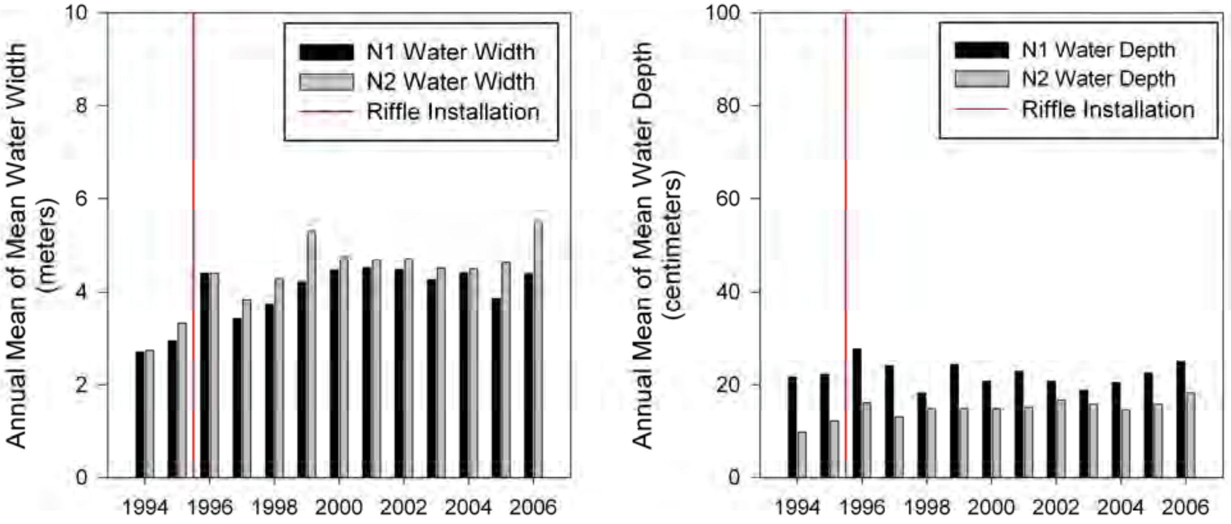


Figure 21. Mean of spring, summer, and fall mean cross-section data for stations N1 and N2

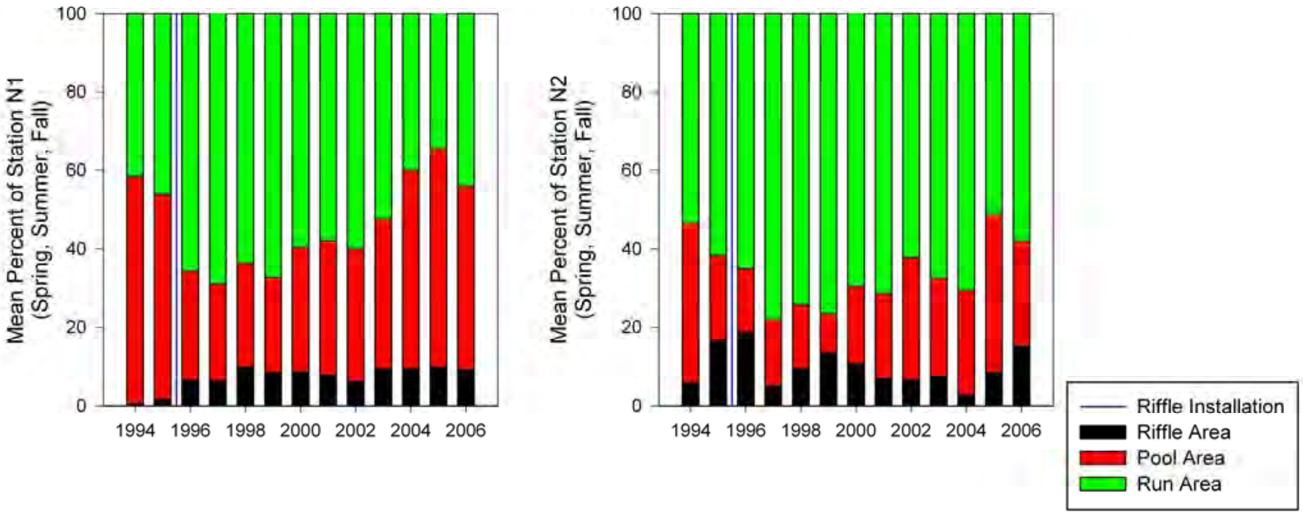


Figure 22. Mean of spring, summer, and fall of riffle, pool, and run area for stations N1 and N2

Fish and Biological Assessment Results

Pools and cobbled riffle areas were the most valuable instream habitat areas in the study location. Increased pool depth and cobble riffle habitat at station S1 provided improved habitat and species diversity over the sampling years 1994 and 1995. The specific Newbury weir riffle design served particularly well to maintain increased pool depth in the restored area. Deeper pools provided refuge for fish during summer low flows, while the upstream reference site (S2) remained extremely shallow and continued to fill with gravel. The long back slope of the riffles at station S1 offered rocky cobble substrate, more turbulence, and additional habitats for fish species as well as the aquatic insects on which they feed. Improved habitat conditions are also responsible for increased numbers of fish species. Bacteria and microflora thriving on the cobbles in the riffles transform ammonia and other soluble nutrients into needed organic material. Air bubbles in the riffle's turbulent water provided oxygen and substrate scour-enhancing microbial benefits. The natural geochemical nutrient transformation process is very important in maintaining or enhancing stream health and rarely performs in an optimal fashion in uniformly graded streambeds or modified urban streams.

The Waukegan River was typical of most streams in that it lacked instream habitat. The combination of biotechnical bank stabilization and creation of functioning riffle and pools in the North and South Branch provided necessary additional habitats and promoted healthy fish populations. In 1997, the restored segments of the stream channel in the North and South Branches were stable and well vegetated. The red osier dogwoods were thriving, and monitoring at stations S1 and N1 found that the deeper pools and rock riffles functionally persisted.

Biological sampling since 1994 indicated that the abundance of fish and increased number of fish species in the South Branch had improved following the construction of LUNKERS and the Newbury weir design for riffle and pools. At restoration sites S1, N1, and N2, the IBI rose sharply from a limited aquatic resource into the moderate category after construction of the riffles in 1996 (Figure 23). Sampling dates when no fish were discovered were assigned the lowest possible IBI score of 12 (Pescitelli, personal communication).

The annual average (average of the seasons and of the period) for stations N1 and S1 were in the limited category at 28. Station N2 had an annual average of 25, and station S2 had an annual average of 21, placing both stations in the limited category. Both N1 and S1 where LUNKERS and Newbury weir riffle and pools were applied averaged higher IBI scores, greater fish numbers, and more fish species than the untreated control at S2 or the N2 bank armored site for the entire period, despite all stations averaging in the limited category. An annual average of all stations throughout the monitoring seasons and throughout the entire monitoring period was 25 (limited). These average scores concur with Fitzpatrick *et al.* (2004), whose data showed that streams with a high population density had low AIBI scores. Fitzpatrick *et al.* (2005) also maintained that streams with 40% of the watershed in urban areas tended to have IBI scores below 30. As would be expected, the low IBI scores found in the Waukegan River corroborate these findings and those of other studies in watersheds with relatively high population densities.

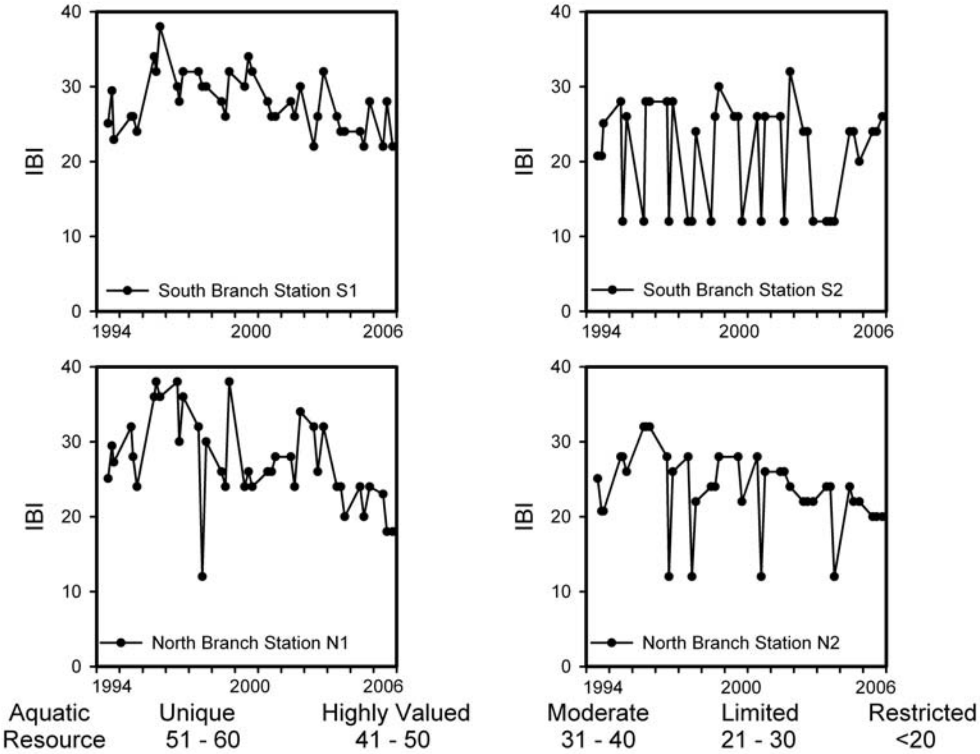


Figure 23. IBI scores from monitoring stations in the Waukegan River

Fish kills, which were documented in the South Branch in 1998 and 1999, were observed during very low flow conditions when turbidity was minimal. Fish kills were not observed during sampling after 1999. After 1996, peak IBI scores continued to decline. Tolerant fish species dominated the fish population at all four stations, which factored in to drive down the IBI scores. The mottled sculpin (*Cottus bairdii*) was the only intolerant species caught during the entire period, making up less than 1% of the total catch. Coho salmon (*Oncorhynchus kisutch)* had the highest overall percentage of species with intermediate tolerance. This non-native species exists at this site because of annual spring stocking of Lake Michigan. Since 1976, approximately 14.7 million salmonids had been stocked annually into Lake Michigan.

This figure includes annual stocking of 100,000 Coho salmon in the Waukegan Harbor (Robillard, 2009). Eighty percent of the Coho salmon recorded overall were caught during the spring sampling period. Table 2 shows the percentage of the total catch of fish species for each station during the 13-year period.

MBI scores indicated a poor stream condition in the North and South Branches following a pattern similar to the IBI scores (Figure 24). Though the annual average at station S1 scored 7.2 (fair), some individual scores at S1 and S2 on the South Branch were in the very poor stream condition category. Station S2 had MBI scores that indicated a fair stream condition after restoration, which occurred in 1996, persisting up to 2001 when the scores began to move back up indicating poor stream condition. Station S2 had the highest annual average score of 7.5 and remained in the fair category, although on the borderline between a fair and poor condition. The station N1 restoration site also had MBI scores in the fair stream condition category from 1995 through 2001 (during and after stream restoration) when the scores then began to rise slightly indicating a transition to poor stream condition. The annual average MBI score at station N1 was 6.9 (fair). Station N2 maintained fair scores, indicating better quality throughout the project period with the exception of 2004 and 2006 when scores exhibited poor stream conditions. The annual average MBI score at station N2 was 6.6, also in the fair category.

Pollution-tolerant taxa such as Chironomidae (bloodworms or midge fly larvae), Oligochaeta (aquatic earthworms), and Caecidotea (pillbugs or sowbugs) dominated the overall population of collected species (Table 3). The average taxa richness for the 13-year period at stations N2, N1, and S2 was 8 (poor), while station S1 averaged a 10 (fair). An overall average of the EPT (Ephemeroptera + Plecoptera + Trichoptera) taxa richness for stations N1 and N2 were in a fair category with a score of 3 where 23% of the 39 sampled dates at station N1 fell into the fair, good, or excellent categories, and 13% of the sampled dates at station N2 were in the fair, good, or excellent categories. The remaining percentages fell into the poor or very poor categories. At stations S1 and S2 the overall average EPT taxa richness score was less than 1 (very poor). Approximately 8% of the sampled dates at both stations fell into the fair, good, or excellent categories.

Review of the functional feeding designations of species collected at sites S1, S2, N1, and N2 from 1994 through 2006 revealed that gatherer/collectors averaged 87% of the populations from all stations; 6% were predators, and 4% were scrapers. The remaining 3% included filter/collectors, omnivores, and shredders. Generalists, such as collectors and filterers, have a broader range of acceptable food materials than specialists (scrapers, piercers, and shredders), and thus are more tolerant to pollution that might alter the availability of certain foods (Cummins and Klug, 1979).

All stations remained within the moderate to highly valued category as indicated by PIBI scores (Figure 25). The PIBI scores climbed slightly throughout the period at treated station S1. Station N1 scores also climbed slightly because of the decreasing percentage of silt-mud. The untreated station S2 stayed fairly consistent during the monitoring period. Project scores from bank armored station N2 also remained fairly consistent. This site exhibited an increase in the percentage of claypan substrate driven by local scouring which affected the scores. The annual average PIBI score was 42 at all stations, remaining in the highly valued aquatic resource category.

Table 2. Percentage of Total Fish Recorded from Monitoring of Waukegan River Stations from 1994 to 2006

Fish Species	**Tolerance**	**Native Status**	**Station S1**	**Station S2**	**Station N1**	**Station N2**
Common Name (Scientific Name)			**%**	**%**	**%**	**%**
Green Sunfish (*Lepomis cyanellus*)	Tolerant	Native	38.0	13.4	15.2	48.8
Mosquitofish (*Gambusia affinis*)	Tolerant	Native	8.4	37.6	1.6	0.5
Threespine Stickleback (*Gasterosteus aculeatus*)	Intermediate	Non-Native	12.2	31.1	43.5	1.2
Fathead Minnow (*Pimephales promelas*)	Tolerant	Native	12.8	8.7	7.5	9.2
White Sucker (*Catostomas commersoni*)	Tolerant	Native	8.5	2.2	6.4	23.7
Goldfish (*Carassius auratus*)	Tolerant	Non-Native	0.9	0.0	0.9	3.7
Bluegill (*Lepomis macrochirus*)	Tolerant	Native	1.5	0.2	4.6	2.9
Coho Salmon (*Oncorhynchus kisutch*)	Intermediate	Non-Native	0.9	4.3	1.5	2.5
Longnose Dace (*Rhinicthys cataractae*)	Intermediate	Native	4.0	0.2	1.6	0.0
Largemouth Bass (*Micropterus salmoides*)	Tolerant	Native	3.5	0.7	1.6	0.0
Golden Shiner (*Notemigonus crysoleucas*)	Tolerant	Native	2.4	0.7	1.6	0.0
Carp (*Cyprinus carpio*)	Tolerant	Non-Native	1.8	0.0	1.1	1.9
Number of remaining species <1% & percentage			(12) 5.1%	(3) 0.9%	(13) 12.9%	(8) 5.6%

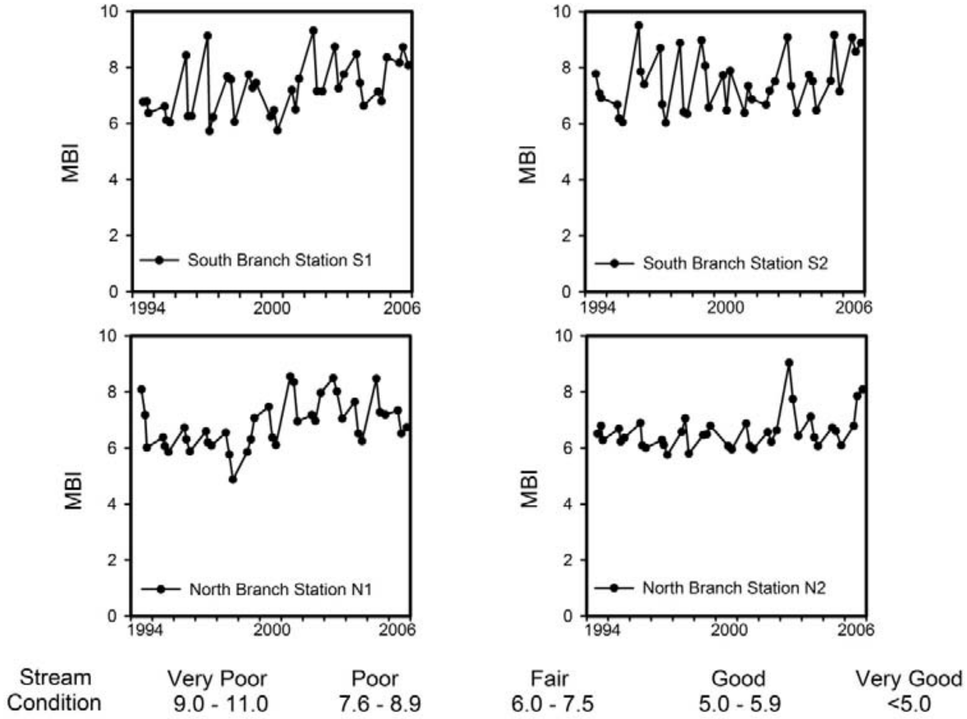


Figure 24. MBI scores from monitoring stations in Waukegan River

Table 3. Percent of the Total Macroinvertebrates Sampled during the Project Period (1994–2006) in Waukegan River

Taxon	**Functional Feeding**	**Tolerance**	**Station S1**	**Station S2**	**Station N1**	**Station N2**
			%	**%**	**%**	**%**
Chironomidae	Gatherer/Collector	6	39.29	37.12	24.42	24.17
OLIGOCHAETA	Gatherer/Collector	10	30.02	27.83	16.35	9.00
Caecidotea intermedius	Gatherer/Collector	6	4.57	1.67	35.83	25.42
Caecidotea	Gatherer/Collector	6	9.30	15.82	12.16	29.17
Physella	Scraper	9	4.42	6.46	1.76	3.23
Erpobdellidae	Predator	8	3.48	2.55	2.76	2.13
Gammarus	Omnivore	3	0.89	0.41	3.19	1.91
Glossiphoniidae	Predator	8	0.76	1.01	0.83	1.85
Ischnura	Predator	6	2.08	1.34	0.05	0.01
Crangonyx	Gatherer/Collector	4	0.03	0.68	0.39	0.94
TURBELLARIA	Predator	6	0.41	1.29	0.03	0.49
Hydropsyche	Filter/Collector	5	0.19	0.22	0.74	0.70
Number of remaining taxa & percentage		--	(55) 4.56	(45) 3.60	(25) 1.49	(30) 0.98

Funding was not available to monitor nutrients in the river. However, data collection began in 2003 from sondes recorded temperature, conductivity, pH, and DO at stations S1 and N1. The sonde data and other field observations indicated that the Waukegan River is highly eutrophic. Extensive periphyton growth was routinely observed during onsite vists when technicians exchanged field monitoring equipment to download data and refurbish Sondes (Pfister, personal communication). Dissolved oxygen data indicated that, at times, DO levels dropped below the Illinois Pollution Control Board (IPBC) 5 milligrams per liter (mg/l) DO limit for aquatic life and did so for long periods during the summer months. Illicit sewer hookups were discovered during a 2006 stream survey. Disharges in situations like this can contribute to elevated fecal coliform levels (Kabbes Engineering, Inc. and Geosyntec Consultants, 2007), eutrophication, and perhaps other water quality impairments.

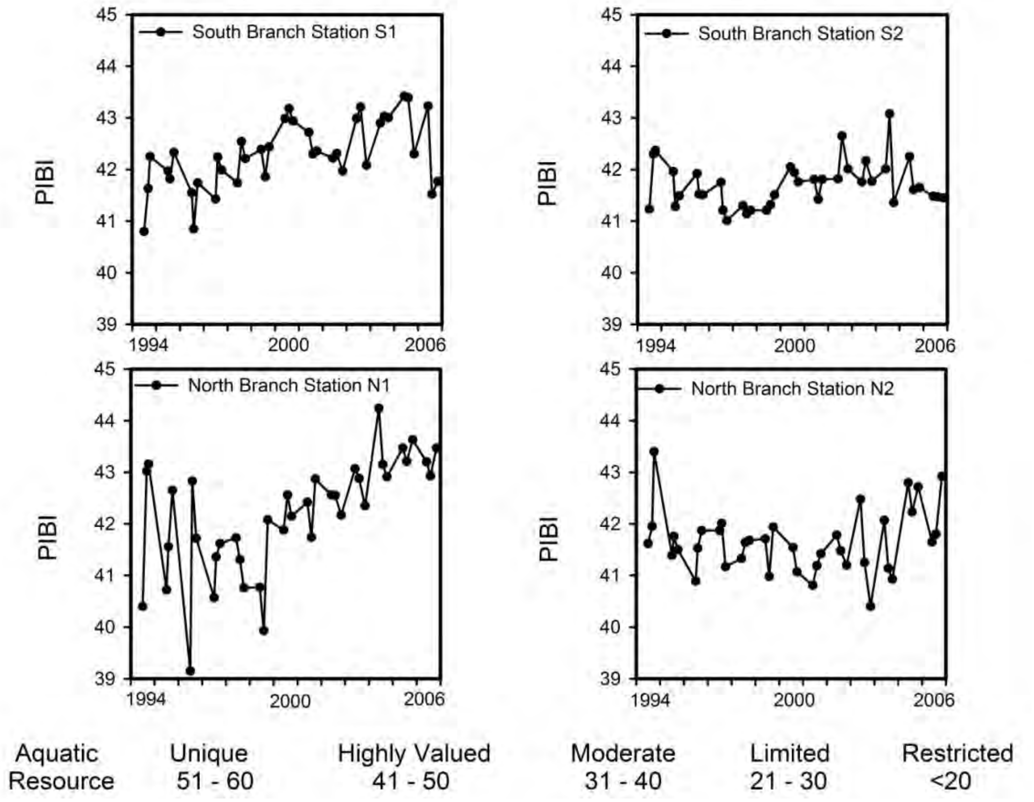


Figure 25. PIBI scores from monitoring stations in Waukegan River

Conclusions

The USEPA-funded and IEPA-administered Waukegan River Illinois National Nonpoint Source Monitoring Program Project provided for the collection and analysis of a wealth of scientific information. Although local restoration efforts applied in the Waukegan River failed to overcome the impact of water quality degradation from the watershed, the study was a success by defining issues more clearly and drawing attention to the need to address causes of watershed degradation in its entirety. Efforts to take positive actions throughout the watershed clearly came to fruition in 2005 when a Waukegan River watershed planning initiative began in earnest. This planning effort included the selection of a watershed coordinator, formation of stakeholder and technical planning committees, stakeholder workshops, watershed data evaluation and resource inventory, and a proposed action plan to improve water quality and identify and reduce pollutants while protecting, restoring, and enhancing the natural habitat and aesthetics. The planning effort brought together the general public, governmental entities, local businesses, educational institutions, and homeowners in the Waukegan River watershed to improve the quality of life for their community.

The comprehensive Waukegan River Watershed Plan was completed in 2007. The Waukegan River Illinois National Nonpoint Source Monitoring Program Project served as the catalyst to develop a more comprehensive Waukegan River watershed planning initiative and to justify funding to implement progressive projects based on application of sound science.

The Waukegan River Illinois National Nonpoint Source Monitoring Program Project demonstrated that biotechnical streambank stabilization helped reduce erosion and provided additional water quality and instream habitat benefits. Evidence continues to suggest that Newbury weir riffle and pool design structures successfully mimic natural riffle and pool sequences and increase instream habitat and biodiversity. In addition to enhancing habitat and biodiversity, riffle and pool structures effectively reduce streambed and streambank erosion and improve stream stability and aeration.

Overall, the project showed that naturalization of stream channel morphology and enhancement of habitat does improve biological diversity, at least temporarily, but sustaining biological diversity is not necessarily achievable by those efforts alone. Often, more comprehensive conservation efforts are required to address other systemic problems relating more specifically to water quality impairments associated with development and water sewer management operations, hydrologic alterations and discharge extremes, and summer base flow reduction.

In the Waukegan River watershed there is a need to update sewage and stormwater infrastructure and maintenance operations as well as adopt comprehensive plans and management ordinances that implement and enforce alternative conservation practices that infiltrate and treat stormwater. Habitat enhancements, naturalization of hydrologic regimes, and reduction of current sources of water quality impairments are essential components of comprehensive watershed management plans.

These problems need to be addressed with innovative, environmentally sound practices if biologically sustainable floral and faunal communities and other value-added natural watershed amenities are to be sufficiently available to elevate overall quality of life for citizens who live, work, and "play" in a watershed (White et al., 2006).

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