

Preserving Willow Creek as a Coastal Resource

Watershed Monitoring and Assessment Project

N. Turyk, and K. Homan

Center for Watershed Science and Education
University of Wisconsin-Stevens Point

Introduction

Willow Creek is located within the Sheboygan River Watershed in Southeastern Wisconsin in Sheboygan County. Willow Creek is roughly 5 miles long with a watershed that drains approximately 2,700 acres and discharges into the Sheboygan River in the city of Sheboygan. Willow Creek flows through five municipalities: the City of Sheboygan, the Town of Sheboygan, the Village of Kohler, the City of Sheboygan Falls, and the Town of Sheboygan Falls (Figure 1). It is the only known coldwater tributary to Lake Michigan in Sheboygan County that supports reproducing anadromous salmonid populations, making Willow Creek a unique feature on the Lake Michigan Coast in Wisconsin.

This stream was the focus of a one year study conducted by Center for Watershed Science and Education (CWSE).

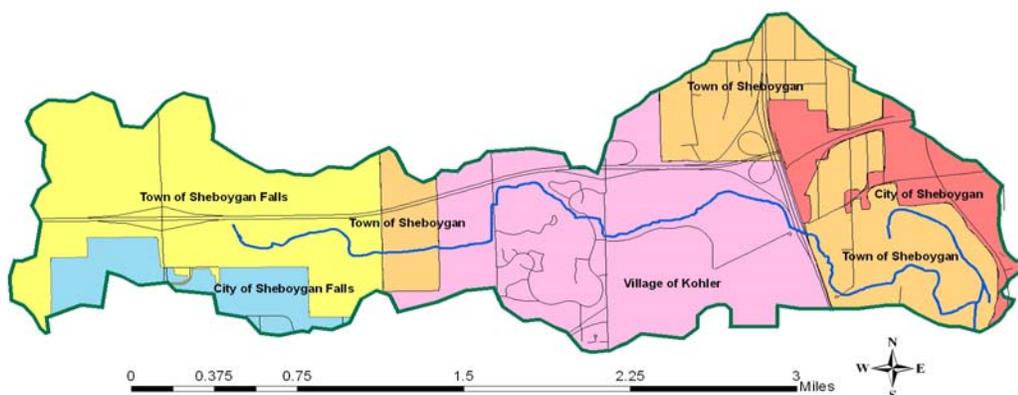


Figure 1. Municipalities within the Willow Creek Watershed.

Sheboygan River Basin Team, (SRB), Glacierland RC&D, the Sheboygan County Planning & Resources Department (SRBP), and WDNR. This study along with others studies associated with the biota and habitat in Willow Creek should be used by citizens and public officials to develop a

protection plan that will address land use and water resource issues that threaten the Willow Creek.

Land Use

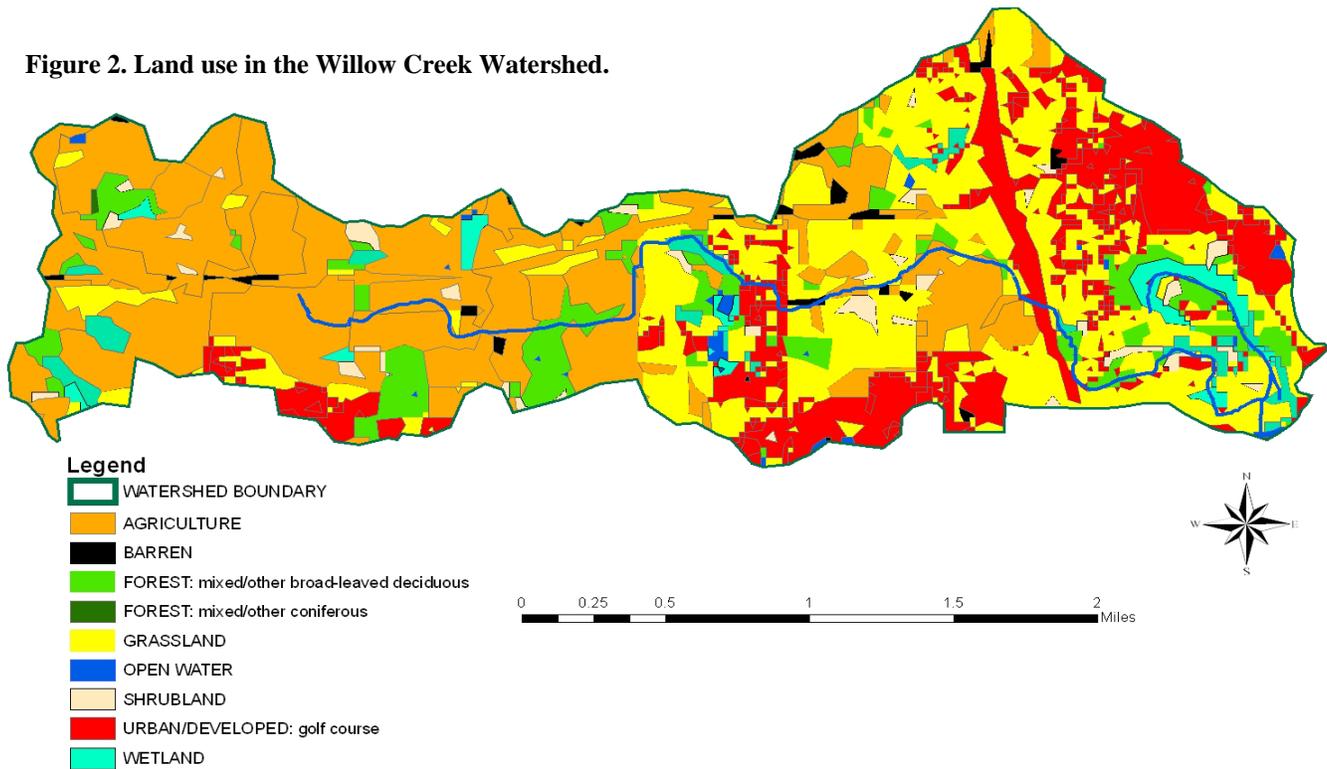
The Willow Creek Watershed is comprised predominantly of agricultural and urban land uses (Figure 2). Agriculture is the most dominant land use in the watershed (37%), grassland is the second most dominant land use (28%), and urbanized areas are the third most dominant land use (18%). Shoreland management practices adjacent to Willow Creek are variable. Along some stretches of the stream there are vegetative buffers that are sufficient to provide habitat and protect water quality but along other stretches the buffer is either missing or insufficient.

As the cities of Sheboygan, Kohler, and Sheboygan Falls grow, urban land use will increase within the watershed. Although increased urbanization puts pressure on water resources, thoughtful development patterns and land use practices can reduce these impacts. When urbanization occurs there is an increase in the amount of impervious surfaces, such as parking lots and rooftops. By increasing the amount of impervious surfaces there is both a decrease in water that infiltrates into the ground, which may become groundwater, and an increase in surface runoff. Increased runoff increases flow and erosion in the short term and reduces groundwater that feeds the creek over the long term, often providing the only stream flow during dry periods of

the year. Runoff can become problematic because it can transport sediments, nutrients, and contaminants to streams. An increase in fine sediment into streams can reduce the quality of habitat for organisms at the bottom of the food chain and fish spawning beds. Contaminants carried down storm drains, such as metals and organic chemicals can have toxic

effects on aquatic life. Nutrients carried by runoff can also cause excess aquatic plant growth and algal blooms. Sediment and nutrient inputs can affect Willow Creek, Sheboygan River, and Lake Michigan. In addition, runoff can also alter the flow regime of a stream. Initially after rain events and snowmelt the flow to the

Figure 2. Land use in the Willow Creek Watershed.



stream becomes much greater than natural flows. This can cause more erosion and reduces the amount of water stored as groundwater. Groundwater feeds local streams throughout the year and provides water when there is no precipitation.

Geology & Topography

The geology of the Willow Creek Watershed is very uniform; it consists of dolomite bedrock of the Niagara Escarpment which is comprised primarily of carbonate rich minerals. The Niagara escarpment gently slopes to the east toward Lake Michigan. Bedrock that contains high amounts of carbonates is readily dissolved by groundwater.

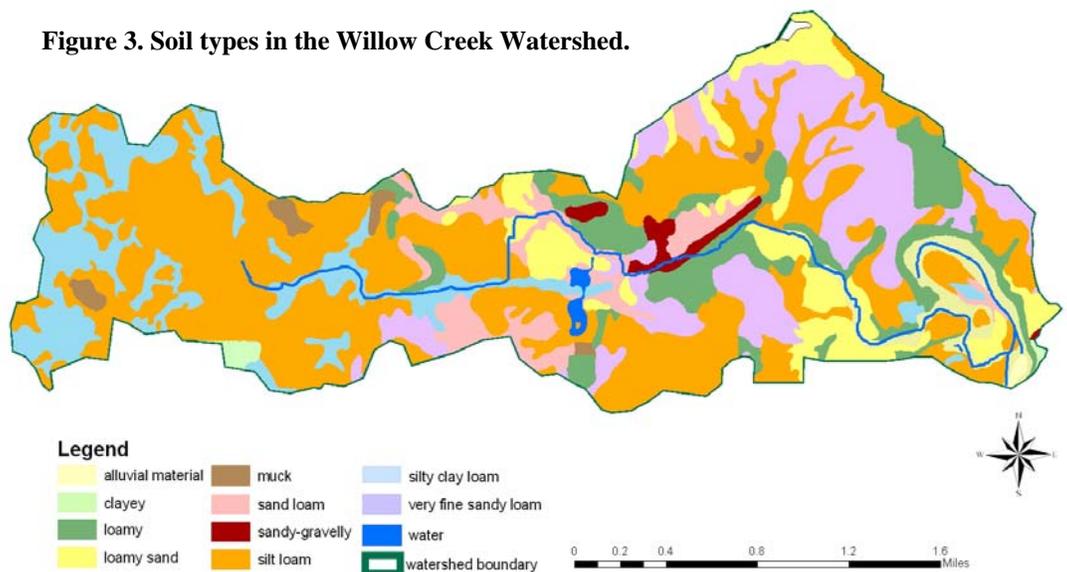
The topography of the watershed is characterized by smooth rolling hills which is the result of several glacial advances of the previous ice age. Elevation of the stream drops 120 feet ranging from approximately 700 ft. above sea level at its headwaters to 580 at the confluence with the Sheboygan River.

Soil

Soil type can significantly affect the characteristics of a watershed including how water moves through the landscape. Throughout the landscape soil controls how much water runs off the land and how much soaks into the ground to become groundwater. In general, soils that have larger particle size have greater infiltration rates than those that have small particle size. Soils that have small particle size are typically “poorly drained” soils and those with larger particle sizes such as sandy soils are considered to be “well drained” soils. Well drained soils allow faster infiltration and recharge of groundwater.

Most soils (76%) are well drained in the Willow Creek

Figure 3. Soil types in the Willow Creek Watershed.



watershed, only 7% of soils within the watershed are very poorly drained. Much of the area surrounding the channel of the creek is surrounded by poorly drained and moderately poorly drained soils. The dominant soil texture of the Willow Creek Watershed is the silt loam. Sand loams and clay loams are also common in the watershed (Figure 3). Loams tend to be a soil that is considered desirable for agriculture.

Results and Conclusions

The health of the Willow River was evaluated using a number of techniques. Water quality and storm response were measured, changes in the stream's morphology (erosion, sedimentation, bed material, etc) were evaluated, and areas of groundwater inputs were identified.

Water Quality

One of the focuses of this study was to begin to establish the baseline conditions of Willow Creek. Various water quality parameters were measured to assess the general health of the Willow. Samples were collected during baseflow and events to observe differences in water quality from events dominated by runoff versus those dominated by groundwater input.

Samples were collected in January, March, May, and November representing water quality in the creek at different times of the year. Most samples were collected at Greendale Rd and Woodland Rd. Baseflow samples were collected in January and November. The water in the creek during baseflow conditions is predominantly groundwater that is discharging into the river. A snowmelt sample was collected on March 20, 2007 and rain event samples were collected on May 1 and 23, 2007.

The stream's water quality was evaluated for nutrients (nitrogen and phosphorus), suspended solids, chloride, and dissolved oxygen. Excessive nutrients in a stream can be problematic because high levels can result in excessive aquatic plant growth and algae blooms which can alter the aquatic ecosystem and can be aesthetically displeasing. Nutrients can be delivered to the stream in surface runoff and groundwater. Sources of nutrients on the landscape can be from eroding soil, lawn/garden/agricultural fertilizers, animal waste, and septic systems. Total phosphorus (TP) was always elevated in the Willow Creek

samples; at Woodland Road concentrations ranged from 153-752 $\mu\text{g/L}$ and at Greendale Rd TP concentrations ranged from 28-344 $\mu\text{g/L}$. USEPA's recommended TP concentrations for streams in this eco-region is 33 $\mu\text{g/L}$. Soluble reactive phosphorus (SRP) is a form of phosphorus that is easily used by aquatic plants and algae. On average, SRP comprised about 69% of the TP at Woodland Road and 80% of the TP at Greendale Road. These are high ratios of SRP:TP and indicate that much of the phosphorus in Willow Creek is readily used by aquatic plants and algae. Phosphorus is also released during the decomposition of the Lake Michigan fish that spawn and die in Willow Creek. However, water quality was not assessed during this period.

Nitrate was elevated in all samples collected at Woodland Road and most samples at Greendale Road during both event and baseflow conditions. Nitrate-N concentrations in Willow Creek ranged from 3.9-8 mg/L at Woodland Rd. and 1.1-3.2 mg/L at Greendale Rd. These elevated concentrations are likely related to agricultural and lawn fertilizers within the watershed. The high nitrate concentrations were the principal form of nitrogen in total nitrogen (TN) calculations. TN ranged from 1.7-8.9 mg/L, well above USEPA's recommended 0.54 mg/L.

As would be anticipated, suspended solids increase during runoff events. These particles are carried to the stream with snow or rain runoff and usually have nutrients associated with them. During a storm, sediment on the stream bed can also be stirred up into the water column. Total suspended solid concentrations ranged from 3-47 mg/L at Woodland Rd and 4-68 mg/L at Greendale Rd.

Elevated chloride concentrations were consistently reported for all samples from the Willow Creek. Chloride is typically an indicator of influence by humans. Sources can include lawn/garden/agricultural fertilizer, animal waste, and road-salt. In addition, the local geology may also be associated with the high chloride concentrations. Since the bedrock of this region is of marine origin there may have been trapped pockets of high salinity sediment within the bedrock resulting in higher chlorides in the groundwater.

Oxygen that is dissolved in water is critical to support healthy aquatic communities. Willow Creek supports trout and other salmonids; these species require high

concentrations of dissolved oxygen (7 mg/L, Shaw et al 2004). In late August 2006 five sites in the Willow Creek were measured in the early morning when DO is typically at its lowest level. Concentrations were variable throughout the creek, ranging from 0.4-8.4 mg/L (Table 1). The lowest concentration is well below the 5 mg/L required for even warm water fish. This suggests that salmonids are restricted to certain parts of the stream during some of the year, predominantly in the stretch of stream near Greendale Rd. During biological surveys conducted in 2006 trout and salmon were observed in this stretch of the stream (Masterson 2006).

dissolved minerals and contaminants to the stream. In January 2007 areas of the Willow Creek that remained open were mapped as possible areas of groundwater input, however, due to warmer than normal winter temperatures much of the creek was not frozen. Later in May 2007 the stream was assessed by other means to evaluate groundwater inflow; only two sites were positively identified. Additional groundwater sampling sites were identified by locating plants that are indicative of groundwater input; forget-me-nots (*Myosotis spp.*) and water cress (*Nasturtium officinale*). These were confirmed with insertion of small wells (mini-piezometers) into the streambed. The areas confidently identified as groundwater input zones were all upstream of Greendale Rd. However, the areas that are downstream of Greendale Rd are questionable. During the survey some of the parameters indicated sites were likely to be areas of groundwater inflow, but could not be confirmed with other measurements.

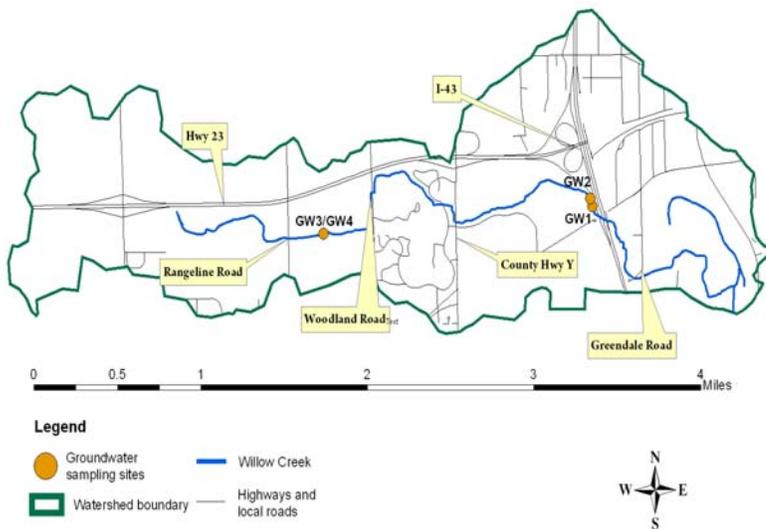


Figure 4. Locations of groundwater quality sampling sites in the Willow Creek Watershed.

| Site | Time | DO mg/L | DO% |
|----------------|---------|---------|------|
| County Hwy Y | 6:38 AM | 5.12 | 56.3 |
| Woodlake Road | 6:42 AM | 5.27 | 59.2 |
| Greendale Road | 6:52 AM | 8.4 | 85.8 |
| Rangeline Road | 7:12 AM | 0.38 | 3.9 |
| I-43 Onramp | 7:22 AM | 6.9 | 69.3 |

Table 1. Dissolved oxygen measurements in Willow Creek 8/29/2006.

Groundwater Chemistry

Groundwater feeds Willow Creek throughout the year. During most of the winter, and periods with little to no precipitation, this is the primary source of water to the creek. Groundwater can help to regulate stream temperatures by keeping the water warmer in the winter and cooler in the summer. Groundwater can also carry

Once groundwater inflow sites were identified, temperature, pH, and conductivity were measured in the field and samples were collected for lab analysis at UWSP. Temperature is often used as an indicator of groundwater and can suggest something about the flow path of groundwater, colder groundwater indicates that it is from a deeper flow path and infiltrated into the ground at a greater distance from the stream. The colder sites located in Willow Creek indicate that the groundwater may have originated from quite a distance out in the watershed. Samples collected in the middle stretch of the creek exhibited the coolest temperatures. A drain tile was also sampled (GW4), it had a slightly warmer temperature (14.5°C) than a nearby groundwater sample (GW3 12.8°C).

Nitrate can infiltrate easily to groundwater. Concentrations in groundwater samples were variable but two of the samples were elevated (11.9 and 21 mg/L). Both exceeded the federal drinking water standard of 10 mg/L. The nitrogen in the drain tile sample was in the form of ammonium with a concentration of 3 mg/L; this is quite high. Other elevated concentrations in the drain tile sample included SRP (139 µg/L), TP (1,028 µg/L), sodium (23.1 mg/L), and iron (8.2 mg/L). TP concentrations in the groundwater samples ranged from 10-22 µg/L. Triazine (the

herbicide Atrazine) concentrations were below the detection level in all four samples (Appendix).

Several drinking water quality data sets were examined to obtain additional data about the quality of groundwater in the Willow Creek Watershed. Only one sample originated from the watershed (Appendix).

Stream Flow

Sources of water to Willow Creek include direct precipitation, runoff, and groundwater. Measuring stream flow provides information about how much water is in the creek during low flow, how the stream flow changes during a runoff event, and if there is seasonal variability in the stream flow. In an undeveloped landscape in this region of the state, about a third of the precipitation falling in a watershed soaks into the ground and becomes groundwater. This water is slowly released to the creek and is the major source of water during periods of little or no precipitation. As a watershed is developed, compacted soil or hard surfaces like roads and rooftops prevents the precipitation from soaking into the ground to become groundwater and may instead run off towards wetlands, storm sewers, and streams. This extra runoff results in an increase in stream flow during snowmelt or storm events and reduces the amount of groundwater that later feeds the creek. Because of reduced groundwater storage, the stream flow can be significantly less during dry periods which results in warmer water temperatures and potentially lower concentrations of dissolved oxygen. Low water levels may also make passage by spawning salmonids

difficult or impossible.

Stream discharge was measured at two sites in Willow Creek; at Greendale Rd and at Woodland Rd (Figure 5). Level loggers (which recorded continuously) were placed at both of these sites which allowed the evaluation of stream flow during dry periods and during events. As would be expected there was a difference in the volume of water between the two sites. The upstream Woodland Rd site always had a less water than at Greendale Rd.

The continuous monitoring data from Greendale and Woodland Rd show the creek at Woodland Rd responds more dramatically to runoff when compared to the Greendale Rd site. This is because the Woodland Rd site is located downstream from a roadside drainage ditch the discharges to the creek near the location of the transducer. This additional flow demonstrates how water running off impervious road surfaces can affect stream flow, making it flashier during storm events.

Willow Creek at the Woodland Rd crossing went dry for at least one month this summer. The creek was not flowing on June 30, 2007 and this condition continued through July 26. During this period a minimal amount of water upstream from Woodland Rd was flowing. Before the Willow reaches Woodland Rd it flows through a small vegetated wetland area. This dense vegetation, predominantly grasses, likely depleted much of the minimal water in the creek. Further downstream from Woodland Rd water was observed flowing into the creek from State Hwy 23 and from the outflow of Wood Lake in Kohler. During low flow it

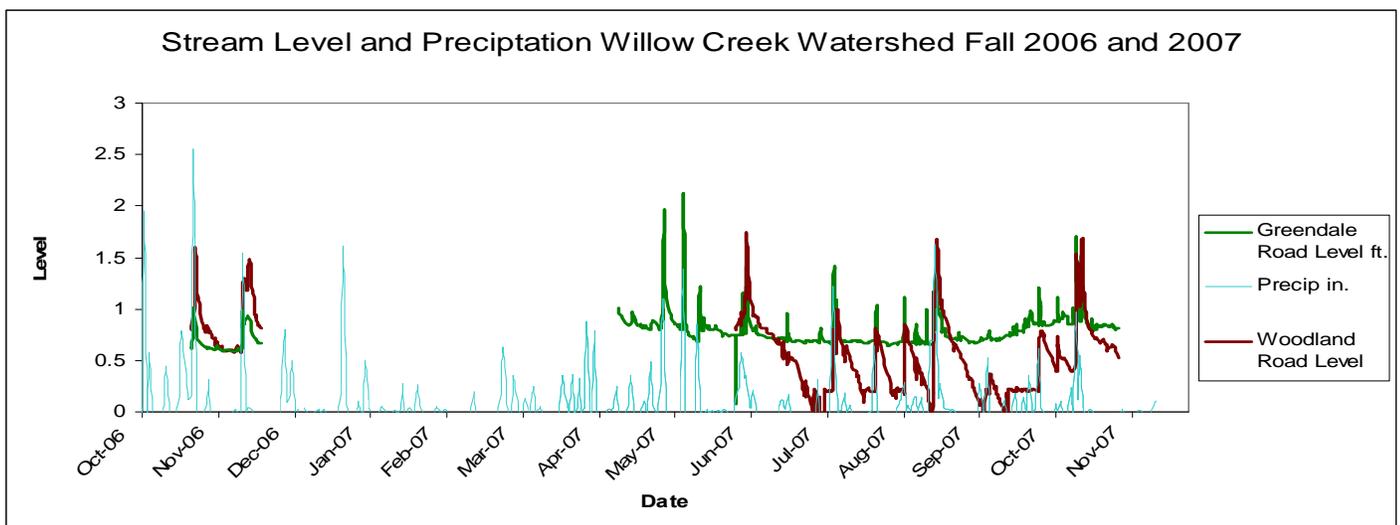


Figure 5. Precipitation and stream flow measures at Woodland and Greendale Rds. (Stream flow measures are relative)

appeared that these two sites may be major input sources for the Willow upstream from Cty Hwy Y. The flow downstream of Greendale Rd is significant indicating that much of the baseflow input in the Willow occurs downstream of Cty Hwy Y and upstream of Greendale Rd.

Changes in Riparian Area and Wetlands

One of the goals of this project was to examine the historic morphology of Willow Creek. The extent of the channel, riparian areas, and wetlands near Willow Creek prior to development were evaluated using maps of soil, current land use, and historic air photos.

The channel of Willow Creek has undergone a number of changes. The original channel traveled through what is now the area that contains Wood Lake in the City of Kohler. After the construction of Wood Lake, Willow Creek initially flowed through it, but later was relocated north where it bends to the south to join the outflow of Wood Lake. This stretch of creek is surrounded by the purple box in Figure 6.

The channel has also been altered after Willow Creek

travels beneath Cty Hwy Y. In this section the channel has been diverted partially underground through a culvert (red box Figure 6).

Prior to traveling beneath I-43 Willow Creek is in a more natural state but has been channelized and rerouted beneath I-43 (orange box Figure 6) Downstream of I-43 Willow Creek seems to have gone through less change with relatively natural conditions (blue box Figure 6).

The amount of wetlands in the Willow Creek watershed has been significantly reduced. An estimate of the historic wetlands extent was estimated using soil and historic vegetation maps and air photos. Historically, wetlands comprised approximately three times more area than they currently do (Figure 7). This reduction in wetlands may not only affect the habitat near Willow Creek, but also the hydrology. Wetlands act as sponges, reducing the amount water that runs off on the land and slowly releasing water to the creek. In addition, wetlands can improve water quality, slowing and filtering water as it moves towards Willow Creek.

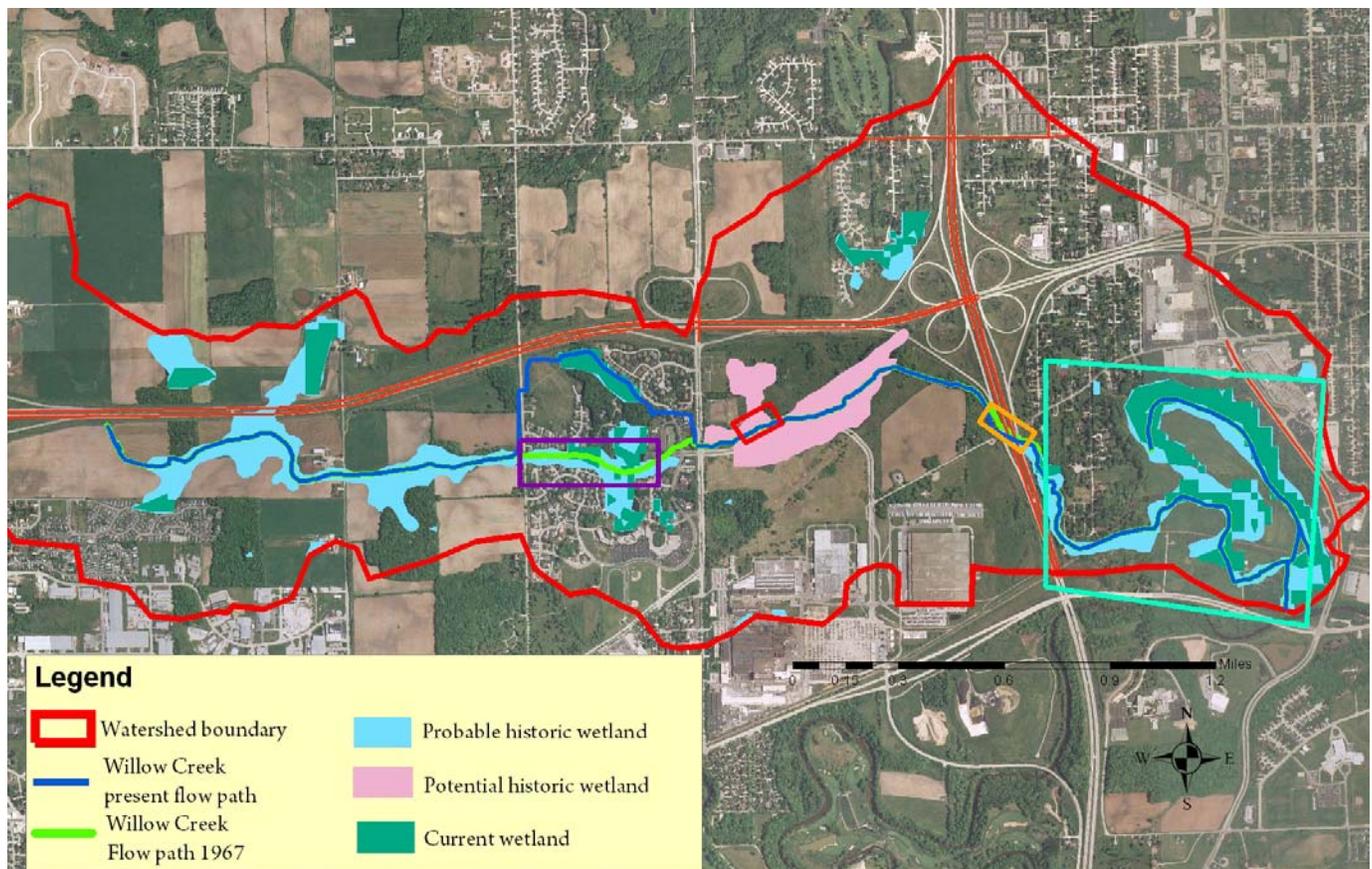


Figure 6. Areas of significant changes in the Willow Creek stream morphology.

The degree of urbanization within the Willow Creek Watershed has increased. This is illustrated for a part of the watershed shown in Figure 8 where most of the watershed downstream of Woodland Rd shows a similar trend. Urbanization in the watershed also affects the hydrology of the Willow Creek. Creation of impervious surfaces (pavement, buildings, etc) increases the amount of runoff and decreases groundwater recharge and eventually stream flow. Using the SCS Curve Number runoff method, reductions in stream flow were estimated. It is assumed that water that was considered runoff is no longer available for groundwater recharge. Runoff estimates were made for three scenarios (Figure 9). The first scenario assumed current land use conditions, the second scenario simulated a more historic condition 125 fewer acres urban and 250 fewer acres of agriculture (transferred to shrubland) and the third scenario represented a future condition with 500 fewer acres of agriculture and 30 fewer acres of wetlands (transferred to urban developed). The land use changes from the historic scenario to current conditions represent an increase in runoff of about 3%. Land use changes from current conditions to the future scenario represent an increase in runoff of about 6% and land use changes from the historic scenario to the future scenario represent an increase in runoff of about 9%.

This exercise was conducted to evaluate the changes in runoff to Willow Creek (and hence changes in groundwater recharge); however, depending upon how development in the watershed is conducted these conditions may be moderated. Some of the factors that could moderate an increase in runoff yet allow development of some land may include restoration of wetlands, protection of the riparian corridor, enhancing infiltration, and using development designs that minimize impervious surfaces.

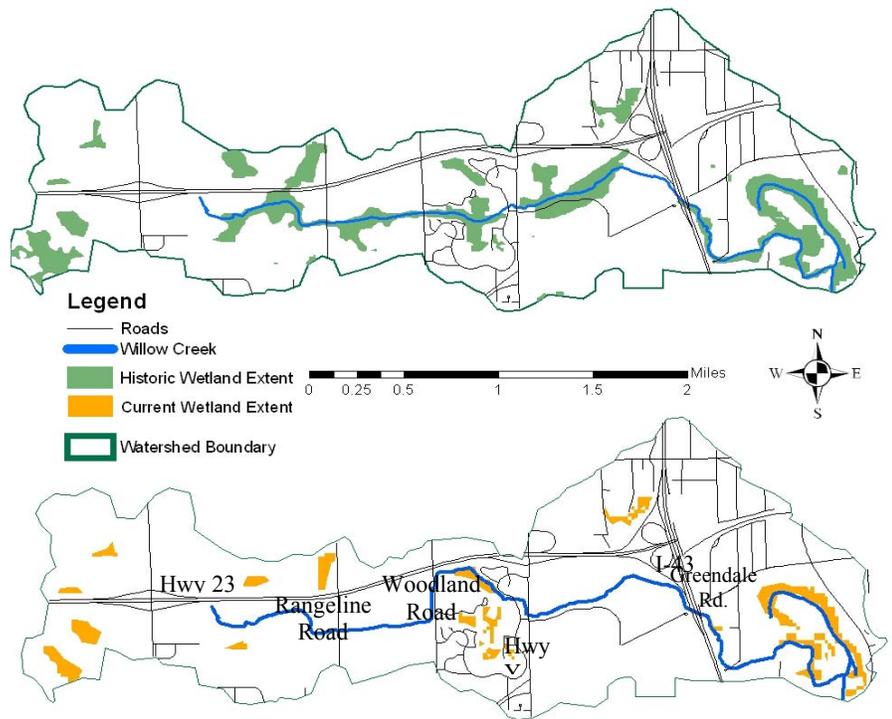


Figure 7. Historic and current wetlands in the Willow Creek Watershed.

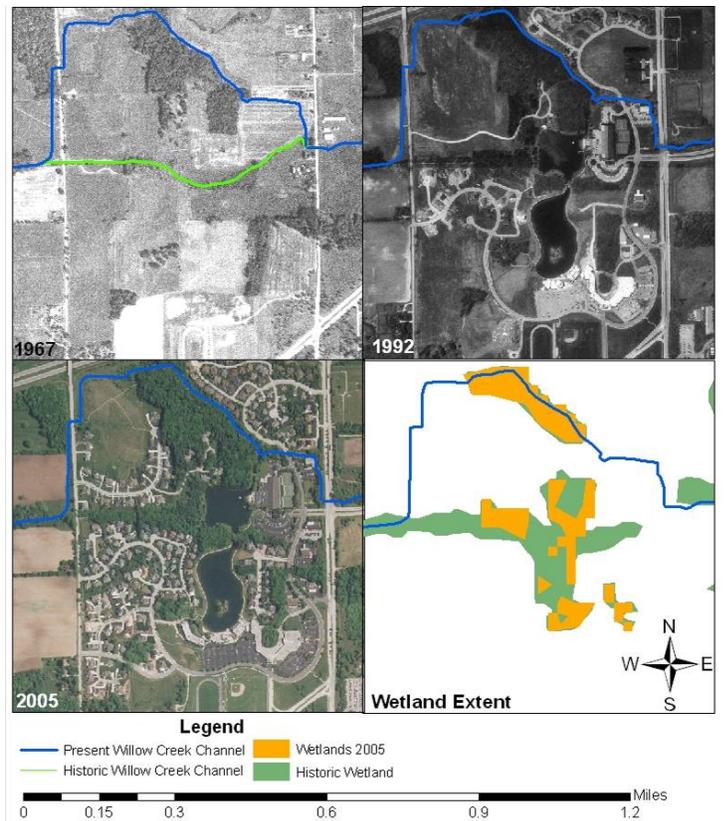


Figure 8. Areas of significant change in stream morphology.

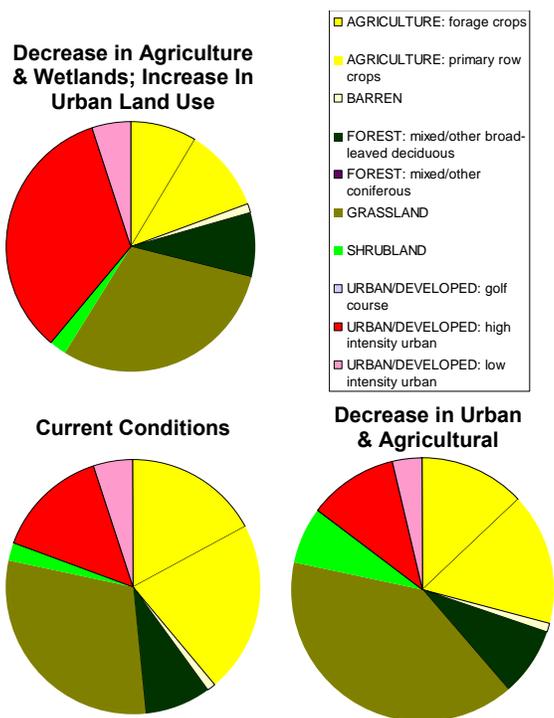


Figure 9. Land use scenarios used in runoff calculations in the Willow Creek Watershed.

Conclusions and Recommendations

Willow Creek is a unique tributary of the Sheboygan River. Efforts should be made to protect the water quality and habitat to maintain the creek as the only known (Lake Michigan) tributary that supports reproducing anadromous salmonid populations. In addition, a healthy creek and vegetated corridor provides an aesthetically pleasing residential environment and recreational opportunities for local citizens.

- Protect existing natural land in the stream corridor through the use of stewardship funds, conservation easements, zoning, etc.
- Improve disturbed portions of the riparian corridor through restoration using a mixture of forbs, grasses, shrubs, and trees.
- Restore wetlands within the Willow Creek Watershed.
- Developments should be designed in a way that minimizes impacts to Willow Creek.
- When ever possible, reduce runoff and encourage infiltration by use of rain gardens, buffers, infiltration ponds, wetlands, etc.
- Return flow that was diverted from the river during construction of I43 back to Willow Creek.
- Eliminate/minimize the use of phosphorus fertilizers

The Willow Creek Watershed includes five municipalities making uniform protection challenging.

- Develop a river/watershed plan that addresses design standards, zoning, remediation, and identifies areas and actions for protection.

A Special thanks to the following people that assisted in the project:

- ~ Jon Gumtow for inspiring this project and many hours of dedication
- ~ John Masterson WDNR for supporting and providing funding for this project and assistance with stream flow measurements.
- ~ Brian Henriksen and Sheboygan South High School Students for volunteering to collect river samples.
- ~ Brett Zemba and the Sheboygan County Land Use Planning Office for providing historic coverages of the watershed
- ~ Student Staff at the Center for Watershed Science and Education (CWSE) for assistance with sample collection
- ~ Staff at the UWSP WEAL for providing assistance with analyses.
- ~ Kevin Lawton UWSP ACL lab for aiding in use of GIS.

References

- Booth, D.B., J.R. Karr, S. Schauman, C.P. Konrad, S.A. Morely, M.G. Larson, and S.J. Burges. 2004. Reviving Urban Streams: Land Use, Hydrology, Biology, and Human Behavior. *Journal of the American Water Resources Association* 40:1351-1364.
- Masterson, J. 2006. Willow Creek Baseline Monitoring Report, Sheboygan River Basin. Wisconsin Department of Natural Resources December 2006.
- Shaw, B., C. Mechenich, and L. Klessig. 2004. Understanding Lake Data. UWEX Pub RP-6/2000-1M-350

APPENDIX

Methods

Field and Lab Procedures

The equipment and techniques used in the field and laboratory were selected because they are appropriate for water quality analysis and habitat assessment of the Willow Creek. All information was gathered and placed into the CWSE computer database for analysis in programs such as Microsoft Excel and ArcMap GIS. Water samples were collected by CWSE Staff, unless otherwise noted. Training and guidance for citizen volunteer sample collection was provided by CWSE staff.

Baseflow Sampling

Baseflow is the streamflow that occurs during periods of low rainfall. In general, baseflow represents the streamflow generated by groundwater. Baseflow samples were collected in the winter and summer of 2007 at two locations located in Willow Creek. Samples were gathered using three different polyethylene bottles that contained preservatives appropriate for the specific analysis. The sample was collected by lowering a capped bottle to the mid depth of the stream with the lid facing downstream and then opening it, allowing the bottle to fill with water. Water from this bottle was transferred to the other bottles. Baseflow samples were analyzed for nitrate+nitrite-N ($\text{NO}_2+\text{NO}_3\text{-N}$), ammonium-N ($\text{NH}_4\text{-N}$), total Kjeldahl nitrogen (TKN), total phosphorus (TP), soluble reactive phosphorus (SRP), chloride (Cl), and total suspended solids (TSS). Field measurements including pH, conductivity, temperature, dissolved oxygen, and streamflow were made the day of collection of samples.

Event Flow Sampling

Runoff event samples were collected from two sites in Willow Creek. Event flow sampling took place three times over the course of the project. The first round took place in March during the winter snowmelt of 2007, the second during and third in May during two large rainfall events in the spring. Runoff event sampling was conducted by volunteers using of grab sample methodology. Sample analyses and preparation is the same as those outlined in baseflow sampling.

Groundwater Sampling

GPS locations of the springs and visual observations were used to identify areas best suited for collection of groundwater samples on May 29, 2007; four samples were collected. A digital thermometer was used to verify that the temperature was cool enough to be groundwater. Other field measurements included pH and conductivity (Oakton Instruments, Inc.). Samples were collected from the springs using mini-piezometers and extracted using a 60cc syringe. Groundwater samples were collected in three separate polyethylene bottles which were preserved and field filtered according to analytical requirements. Groundwater samples were analyzed at the UWSP WEAL for nitrate+nitrite-N ($\text{NO}_2+\text{NO}_3\text{-N}$), ammonium ($\text{NH}_4\text{-N}$), soluble reactive phosphorus (SRP), chloride (Cl), calcium (Ca), magnesium (Mg), manganese (Mn), potassium (K), sodium (Na), sulfate (SO_4), arsenic (An), iron (Fe), lead (Pb), and triazine.

Sample Analysis

After collection, all water samples were stored and transported on ice to the state-certified Water and Environmental Analysis Lab (WEAL) at UWSP. The analyses run in the WEAL followed the methodology shown in Table 1.

Dissolved Oxygen

Dissolved oxygen is the total amount of oxygen dissolved in water measured as both a percentage and as mg/L. Measurements were collected at five sites in late August of 2006 using a YSI Model 50B and 5700 Series Oxygen Probe to determine if low dissolved oxygen occurred in any area within the stream.

Stream Flow Measurements

Stream flow, the amount of water passing a location within a specific time period, was measured in Willow Creek multiple times throughout the project. Stream flow was measured by CWSE and WDNR using a Marsh-McBirney Flo-Mate Model 2000 personal flowmeter to determine flow velocity and a 100' tape/wading rod to measure stream area through which that flow passes.

Continuous Flow Monitoring

Pressure transducers were used at two points along the stream to obtain continuous measurements of stream height (“stage”) which were used to estimate stream flow. The pressure transducers were Solinst Level Loggers. When the pressure of the water increased more than .8% from the previous reading, the level logger collected the measured pressure and temperature. The instruments were set to check for changes in stream height at 15 minute intervals. A rating curve was then developed for each site by using discharge measurements that were made by John Masterson and CWSE at varying water levels. The level logger data was adjusted for changes in barometric pressure by using another logger stationed at the Plymouth WDNR Office.

Metadata

ArcMap GIS 9.1 software was used with land use, soil, hydrology, road, and topography coverages for data interpretation and mapping. Source for the 2005 Land use coverage was the Wisconsin Initiative for Statewide Cooperation on Landscape Analysis and Data (WISCLAND). Statsgo was used for the soil coverage (WI general soils). DNR Geodisk3 coverages were used for hydrology (hydtopen) and watershed delineation (wsdnw924 – wsdwrwats). Tiger coverages were used for the designation of roads.

The watershed was delineated using the ESRI CRWR-Preprocessor and a 30 m resolution DEM with the hydrology coverage. Sample sites were located with a GPS unit.

Runoff Calculations

Runoff Calculations were derived using the SCS curve number method. Curve numbers were assigned based on hydrologic soil group and interpreted land use and cover type.

Table 1. Analytical methods and corresponding detection limits for water quality analyses run in the UWSP Water and Environmental Analysis Lab.

| Analyses | Method | Method Detection Limit |
|-----------------------------|---|-------------------------------|
| Nitrogen, Nitrate+Nitrite-N | Automated Cadmium Reduction 4500-NO ₃ F | 0.1 mg/L |
| Nitrogen, Ammonium | Automated Salicylate 4500-NH ₃ G | 0.01 mg/L |
| Nitrogen, Total Kjeldahl | Block Digester; Auto Salicylate 4500-NH ₃ G | 0.08 mg/L |
| Phosphorus, Reactive | Automated Colorimetric 4500 P F | 0.003 mg/L |
| Phosphorus, Total | Block Digester, Automated 4500 P F | 0.012 mg/L |
| Chloride | Automated Ferricyanide 4500 C1 E | 1.0 mg/L |
| Total Sulfur as Sulfate | ICP EPA 200.7 | .026 mg/L |
| Total Suspended Solids | Gravimetric 2540 D | 2.0 mg/L |
| Triazine | Enzyme Linked Immunsorbant assay | 0.05 µg/L |
| Metals | ICP Atomic Emissions Spectrometry EPA 200-7 | Varies with element |

Table 2. Groundwater chemistry in the Willow Creek.

| Site | Temp °C | NO ₂ +NO ₃ mg/L | NH ₄ mg/L | Reactive P µg/L | Triazine mg/L | As mg/L | Ca mg/L | Cu mg/L | Fe mg/L | K mg/L | Mg mg/L | Mn mg/L | Na mg/L | Total P mg/L | Pb mg/L | SO ₄ mg/L | Zn mg/L | |
|------|------------|--|-------------------------|--------------------|------------------|------------|------------|------------|------------|-----------|------------|------------|------------|-----------------|------------|-------------------------|------------|-------|
| 1 | 7.71 | 11.9 | <.01 | 16 | <.05 | <.003 | 55.9 | 0.003 | 0.03 | 0.8 | 28.9 | 0.045 | 8.1 | 0.01 | <.002 | 10.68 | 0.004 | |
| 2 | | | 1.6 | <.01 | 21 | <.05 | 0.003 | 191.8 | 0.002 | 0.011 | 2.9 | 106.8 | 0.009 | 423 | 0.012 | <.003 | 53.15 | 0.003 |
| 3 | 14.5 | <.1 | 3.03 | 139 | <.05 | 0.015 | 64.8 | <.001 | 8.223 | 8.2 | 30.1 | 1.765 | 23.1 | 1.028 | <.004 | 22.89 | 0.005 | |
| 4 | 12.8 | 21 | <.01 | 33 | <.05 | <.003 | 117.3 | 0.002 | <.001 | 3.7 | 62 | 0.002 | 13.3 | 0.022 | <.005 | 61.75 | 0.004 | |

Table 3. Event chemistry in Willow Creek.

| Site | Date | TSS mg/L | Cl mg/L | NO ₂ +NO ₃ mg/L | NH ₄ mg/L | Organic N mg/L | Total N mg/L | Total P µg/L | Reactive P µg/L | TKN mg/L |
|---------------|----------|----------|---------|--|----------------------|-------------------|-----------------|-----------------|--------------------|----------|
| Greendale Rd. | 5/1/2007 | 68 | 104 | 2.4 | 0.16 | 1.54 | 4.1 | 344 | 260 | 1.7 |
| Woodland Rd. | 5/1/2007 | 47 | 73.8 | 5.1 | 0.16 | 2.21 | 7.47 | 752 | 579 | 2.37 |

Table 4. Baseflow chemistry in Willow Creek.

| Site | Date | TSS mg/L | Cl mg/L | NO ₂ +NO ₃ mg/L | NH ₄ mg/L | Organic N mg/L | Total N mg/L | Total P µg/L | Reactive P µg/L | TKN mg/L |
|---------------|------------|----------|---------|--|----------------------|-------------------|-----------------|-----------------|--------------------|----------|
| Greendale Rd. | 8/29/2006 | 3 | 115 | 1.33 | 0.07 | 0.59 | 1.99 | 48 | 49 | 0.66 |
| Greendale Rd. | 8/29/2006 | <2 | 242 | 1.52 | 0.02 | 0.4 | 1.94 | 13 | 15 | 0.42 |
| Greendale Rd. | 11/18/2006 | <2 | 158 | 1.5 | 0.08 | 0.6 | 2.18 | 58 | 40 | 0.68 |
| Greendale Rd. | 1/9/2007 | <2 | 149 | 3.2 | <.01 | 0.62 | 3.83 | 42 | 39 | 0.63 |
| Greendale Rd. | 3/20/2007 | 10 | 128 | 2.7 | 0.02 | 0.73 | 3.45 | 72 | 51 | 0.75 |
| Greendale Rd. | 5/23/2007 | 4 | 118 | 1.1 | 0.08 | 0.59 | 1.77 | 28 | 23 | 0.67 |
| Woodland Rd. | 11/18/2006 | 13 | 139 | 3.9 | 0.04 | 1.42 | 5.36 | 198 | 143 | 1.46 |
| Woodland Rd. | 1/9/2007 | 54 | 113 | 8 | 0.02 | 0.91 | 8.93 | 215 | 142 | 0.93 |
| Woodland Rd. | 3/20/2007 | 3 | 63.1 | 3.9 | 0.03 | 1.88 | 5.81 | 153 | 94 | 1.91 |
| Woodland Rd. | 5/24/2007 | 21 | 109 | 7.4 | 0.13 | 0.63 | 8.16 | 378 | 384 | 0.76 |