The city of Toledo has a population of approximately 273,000 people and covers about 80 square miles on the Western Lake Erie basin at the mouth of the Maumee River. Image courtesy of the city of Toledo

Machine Learning and Impervious Surfaces: Where GIS Technology Meets the Road

By Brian Stevens, CP, GISP, Woolpert Vice President and Geospatial Market Director

Geospatial technologies enable local governments to build virtual maps of their cities and counties for a wide range of applications, including economic development, roadway safety and improvements, and managing storm water utilities. As a result, high-resolution lidar data and orthoimagery have become increasingly important. They are being integrated with geographic information systems (GIS) and machine learning capabilities to help governments improve efficiencies and solve problems.

Impervious surface mapping enables a city to update its equivalent residential unit (ERU) database, which is used to determine how much to charge customers for a storm water utility. In Toledo, for example, single-family and residential duplex properties are considered one ERU and are charged a flat rate. Commercial and industrial properties in the city are charged the same rate, but the number of ERUs per commercial site may be higher based on the total amount of impervious surface, which includes pavement, rooftops, buildings and any surface that prevents the natural filtration of storm water into the earth.

Toledo's storm water utility was created in 2000, and the original GIS data was compiled by interns. That GIS data was manually updated and edited over time, leading to human error and data inconsistencies. In 2015, Toledo contracted with Woolpert to acquire aerial imagery and lidar data to perform impervious surface mapping. Aerial imagery was collected in 2017 and the evaluation of that data began in February 2019.

Lorie Haslinger, senior professional engineer for Toledo, said this mapping provides a more consistent and accurate measurement of the city's impervious surfaces to produce more precise and defensible storm water utility data.

“The goal of this project is to ensure fair, accurate and consistent billing for property owners,” Haslinger said. “The city previously only measured the impervious surfaces of non-residential customers and did not measure surfaces such as gravel or stone. This project will measure that data. I anticipate that this will lead to internal discussions on how the storm water rate is calculated and will give the city a better representation of the amount and types of impervious surfaces we have.”

The colorization of impervious surfaces in this image was made transparent to show the homes and buildings from the aerial photo. Image courtesy of the city of Toledo

The Glass City

The city of Toledo is spread out across approximately 80 square miles on the western edge of Lake Erie in Lucas County, Ohio. A busy port city with a population of about 273,000, Toledo is the fourth most populous city in Ohio. Toledo is bisected by the Maumee River, which empties into Lake Erie and is the city’s primary water source. There is significant commercial boat traffic through Toledo, which is considered the fifth busiest port city among the Great Lakes. It was once considered the glass capital of the world, earning the nickname “The Glass City,” and still maintains strong industrial roots.

Like many other medium-to-large cities, managing storm water runoff is both a priority and challenge for Toledo. The city maintains approximately 986 miles of storm sewers and 64 miles of drainage ditches. A highly developed city, Toledo features older neighborhoods with combined sewer areas and homes built near streams and filled-in natural floodplains. Haslinger said the area has seen a nearly 20% increase in rainfall in recent decades, and some homes are vulnerable to sewage backups in basements during large rain events.

“The storm water system is designed to only handle certain storm events, and intense storms will overload aging infrastructure,” Haslinger said. “More intense storms lead to greater runoff from impervious areas and therefore a greater chance of pollutants being carried into the storm system and receiving stream. Intense rainfall also leads to increased erosion of our stream banks and decreased water quality and habitat within the stream.”

In 2014, water quality became a very public concern in Toledo when a toxic algae bloom on Lake Erie led to a state of emergency. The city was forced to shut off water service to residents and businesses for three days as a safety precaution. Agricultural runoff is believed to be the primary cause of the algae growth, which is very visible and

turns the water fluorescent green. Toledo is impacted by the runoff from its rural surroundings as well as urban runoff from its paved industrial and commercial sites.

In addition to measuring impervious surface areas, Haslinger said the maps provided by Woolpert can be used as an educational tool to help generate support for the city's efforts in combating the environmental impacts of storm water runoff.

The Toledo Mudhens stadium is a prominent feature in the city's downtown area, and it stands out in this aerial image taken in 2017. Image courtesy of Woolpert

AI and Mapping Impervious Surfaces

The combination of orthoimagery, lidar data and GIS data enables cities and counties to conduct change analysis to help manage, visualize and disseminate information. Algorithms have been developed to integrate impervious surface data with machine learning, which is a subset of artificial intelligence, and enables computers to identify objects in the built and natural environments. This automated process delineates pavement from grass and rooftops from trees, while incorporating accuracy and quality control measures supervised by a GIS technician on the front and back ends.

The impervious surface maps that have been delivered to Toledo show not only the vast commercial and industrial sections in the downtown area along the river where rainwater runs directly into perennial waterways, but each of the impervious surface areas on each of the city's more than 119,000 parcels of real estate.

Having an accurate account of how much impervious surface area exists for each of the city's parcels provides the data to make informed decisions on how city leaders can consistently and equitably bill customers for storm water utility management. The revenue generated from the storm water utility pays for the maintenance and capital project programming for the city's storm water system.

Woolpert Geospatial Specialist Frank Orr is working with the city to update their parcel data to match the county's parcel data and developing a semi-automated workflow to provide monthly updates. In addition, Orr is working to update Toledo's SAP storm water customer billing and account information based on changes to the parcel data.

"This connection will be made by linking the updated parcel information with the storm water customer account information and maintaining that linkage going forward," Orr said. "The city will be able to provide better service to its customers and potentially capture missing revenue by ensuring that all changes to ownership and impervious surfaces are represented in the billing system."

Doug Stevens, deputy director of the Toledo Public Utilities Department, said having the maps available to show the public will help the city create a “fair, consistent and defendable storm water utility program.”

“Having transparency in how the bills are created can lead to other questions for the public,” Stevens said. “Providing answers to those questions—about the necessity of storm water bills, what services are provided by the utility and how impervious surfaces impact runoff—can help drive adjusting utility rates.”

The integration of machine learning capabilities into proven geospatial technologies makes mapping the impervious surface area in an urban landscape cost-effective, consistent and repeatable. The automation driven by GIS algorithms can empower municipal leaders to make informed policy decisions that are fair and transparent.

The new and existing applications of geodatabase technologies continue to be identified and refined. In managing storm water runoff, geospatial technologies can be used not only for impervious surface mapping, but also for hydrography and hydrology mapping, which can show how water is flowing through communities and identify why flooding may be occurring in certain areas as well as assist in identifying the best solutions to flooding problems.

“We would like to see impervious surfaces remapped on large scale every three to five years as new aerial data is acquired,” Haslinger said. “The billing data is a moving part to the impervious surface mapping, and this will likely need to be updated more frequently to be able to keep up with parcel and ownership changes. Over time, we hope to fund improvements to the storm water system in part through the revenue generated by the utility to create a safer, more efficient system to manage storm water runoff.”

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