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The Great Lakes, a diverse proving ground for AUVs

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North America's Great Lakes present a wide range of challenges and opportunities for the use of autonomous underwater vehicles

The Great lakes – Michigan, Superior, Huron, Ontario and Erie – combine to make up one-fifth of the Earth's surface freshwater and are a critical resource on many fronts to the almost 34 million US and Canadian citizens living around them. The lakes combine to cover an impressive 246,463 square kilometres and are a vital resource for fishing, recreation, historical shipwrecks, transportation of goods and an environmentally sensitive water supply that needs to be managed closely. While not always publicised, this vast region has also been a key testing ground for autonomous underwater vehicles. Over the last 10 years underwater vehicles have been adopted and utilised for a wide range of applications by the University of Michigan, University of Wisconsin, Northwestern University, Purdue University, Michigan Tech and Buffalo State. In addition to these universities, ongoing environmental monitoring operations by the US Geological Survey, search and recovery operations by the Michigan State Police and commercial operations (survey work, sensor development and pipeline inspection) can have a dozen or more AUVs operating across the five lakes.

The Great Lakes have been an important proving ground for the Iver AUV where the very first commercial AUVs were sold to multiple universities. One example is the Perceptual Robotics Lab (PeRL) at the University of Michigan which purchased two Iver2 systems in 2006. PeRL, founded by

Figure 1. Michigan Tech loads an Iver3 vehicle for research in the Great Lakes

Professor Ryan Eustice, studies problems related to autonomous navigation and mapping for mobile robots in a priori unknown environments with a directed focus on computer vision techniques for perceptual sensing. The Iver2 platform was chosen (and modified) to serve as a convenient, cost-effective platform for research, development and experimental validation of vehicle control systems and navigation techniques. The engineering research focused on multi-vehicle, multi-scalar simultaneous localisation and mapping (SLAM) – the capability for a robot(s) to map an unknown environment while simultaneously using that map to navigate. The algorithmic advancements developed and tested using the University of Michigan Iver2 AUV platforms will advance the multi-resolution navigation and mapping capabilities of robotic AUVs in benthic environments. In addition, Professor Eustice points out that there are some carry overs to other markets such as "driverless cars that typically use lane-level priori maps for navigation, and localise into the maps using camera and LiDAR sensing so that they can drive GPS-free, which is a research area and something that my group has been doing with AUVs".

OceanServer has delivered two more systems to the University of Michigan for use

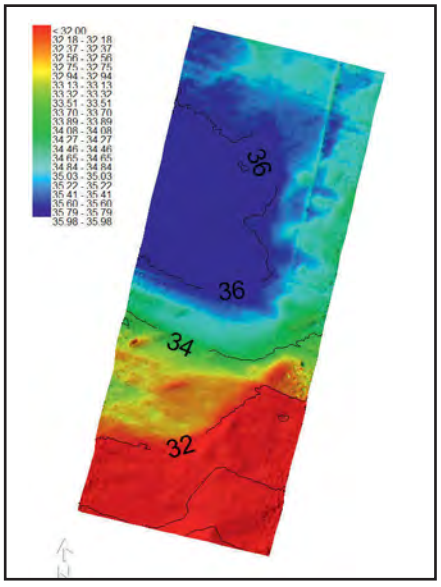

Figure 2: Michigan Tech bathymetric data over a pipeline

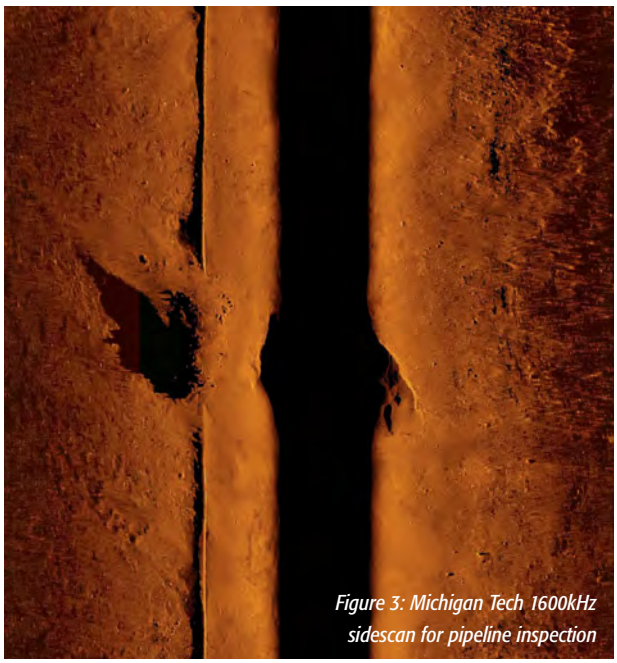

Figure 3: Michigan Tech 1600kHz sidescan for pipeline inspection

with the Tributary Monitoring Project with funding from the Great Lakes Restoration Initiative. The project looks at monitoring five separate areas of concern across all five Great Lakes, using different monitoring methods. The University of Michigan's part of the project included using two AUVs for surveying Saginaw Bay, an area of concern in Lake Huron. Researchers also used bottom classification software in conjunction with sonar to support an ongoing study of Cladophora growth that leads to unsightly and foul smelling muck on the beaches. The vehicles were also deployed for mapping fish habitats and reefs. Recently, the University of Michigan purchased its fifth system and first Iver3 model for a variety or research efforts.

To the north on Michigan's Upper Peninsula on the Keweenaw Waterway in central Lake Superior, Michigan Tech's Great Lakes Research Center (GLRC) provides state-of-the-art laboratories to support research, and has also invested in an Iver3 AUV. Michigan Tech's efforts have focused on detailed terrain mapping across the deep and dynamic Straits of Mackinac where multiple pipelines cross Lake Michigan (see Figures 2 and 3).

Michigan Tech has developed precise, operational procedures for detailed AUV measurements along submerged infrastructure in very strong currents, and transferred that technology to commercial partners. Its Iver3 has also been successful in acoustically identifying and mapping the spread of an invasive aquatic plant, Eurasian water-milfoil, mapping underwater archaeological sites along the vast Alpena-Amberley Ridge in central Lake Huron, and will be mapping historic, deep shipwrecks as part of a US National Oceanic and Atmospheric Administration (NOAA) Ocean Exploration effort with the Thunder Bay National Marine Sanctuary.

Teaming with Michigan Tech, outside the research space, the Michigan State Police Underwater Recovery Unit became the first law enforcement agency in the United States to invest in an AUV. Michigan State Police has a vast area of water to cover with thousands of inland lakes and shorelines on four of the Great Lakes. The Iver3 AUV allows the team to rapidly deploy the AUV not only in shallow water, but in depths of more than 50 metres (up to 200 metres) where towed sonar systems and diver operations are far more challenging. The equipment is a valuable tool when locating drowning victims. Michigan State Police called on the AUV to aid in the recovery of 13 bodies in 2016. The AUV system gives operators a quick tool to programme fixed lawnmower search patterns at two frequencies (1600kHz/600kHz) giving investigators the option for very fine resolution or wide area survey capability. Given the deep water of many locations in the Great Lakes, traditional diver operations are limited or not possible and the AUV, in combination with remotely operated vehicles, is essential to recovery efforts.

Other government agencies have also looked to AUVs to augment research methods. The US Geological Survey (USGS), in cooperation with the National Monitoring Network for US Coastal Waters and Tributaries, launched a pilot project in 2010 to determine the value of integrated synoptic surveys of river mouths using AUV technology in response to a call for river mouth research, which includes study domains that envelop both the fluvial and lacustrine boundaries of the river mouth mixing zone (Figure 4 and 5).

This pilot was successful and the techniques and methods employed in this pilot study were later applied to other Great Lakes coastal sites with similar success. The use of the AUV provided significant time savings compared to traditional sampling techniques. For example, the survey of outer Milwaukee Harbor using the AUV required less than seven hours for approximately 600 water column profiles compared to the 150 hours it would have taken using traditional methods in a manned boat (a 95% reduction in labour-hours). The integrated datasets resulting from the AUV and manned survey boat are of high value and present a picture of the mixing and hydrodynamics of

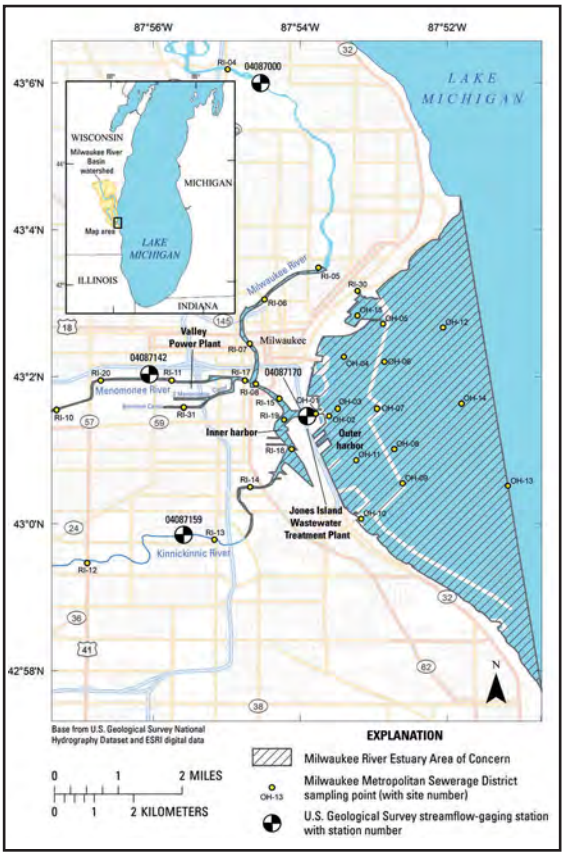

Figure 4: Milwaukee River Estuary and surrounding area including the mouths of the Milwaukee, Menomonee and Kinnickinnic Rivers in Milwaukee, Wisconsin. Source USGS: http://pubs.usgs.gov/sir/2014/5043/

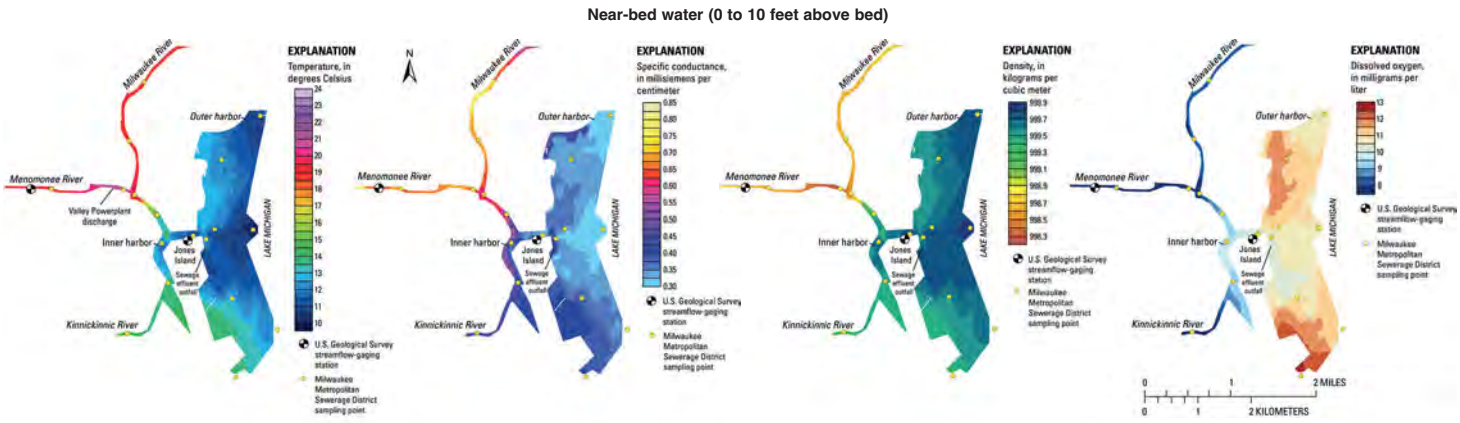

Figure 5: Autonomous underwater vehicles are a valuable tool in collecting multiple water quality parameters and providing data to better understand river mouth mixing zones and water circulation. Source USGS: http://pubs.usgs.gov/sir/2014/5043/

these highly dynamic, highly variable river mouth mixing zones from the relatively well-mixed fluvial environment through the river mouth to the stratified lacustrine receiving body of Lake Michigan. Such datasets not only allow researchers to understand more about the physical processes occurring in these river mouths, but they provide high-spatial-resolution data required for interpretation of relations between disparate point samples and calibration and validation of numerical models.

Another area of concern and study is the mouth of Euclid Creek on the shore of Lake Erie near Cleveland, Ohio. The USGS deployed an AUV and a manned boat equipped with an acoustic Doppler current profiler to measure currents and basic water-quality distributions including temperature, specific conductance, pH, dissolved oxygen, turbidity and blue-green algae concentrations. Concerns over high concentrations of *Escherichia coli* (*E. coli*) in water samples taken along the beach adjacent to the creek and frequent beach closures led to the collection of synoptic data in the nearshore area in an attempt to gain insights into mixing processes, circulation and the potential for transport of bacteria and other CSO (combined sewer overflow)-related pollutants from various sources in Euclid Creek and along the lakefront. Figure 6 provides an example of AUV-derived bathymetry and water-quality distribution combined with depth-averaged currents to visualise the plume from Euclid Creek trapped in a zone of recirculation offshore Villa Angela Beach near Cleveland, Ohio, on 12 September 2012.

The Great Lakes present many challenges and opportunities for the use of AUVs and other robotic platforms. OceanServer Technology has worked closely with both researchers and commercial companies such as Marine Magnetics (located on Lake Ontario) to develop both towed magnetometers and integrated AUV mag solutions. AUV research, in the lakes, has been pivotal in the development of critical sensors, behavioural/research studies and data collection methods. The use of AUVs on a daily basis and in pilot programmes in the Great Lakes gives all users insight into new data collection options and valuable feedback on how traditional survey methods can be used alongside new technology. ■

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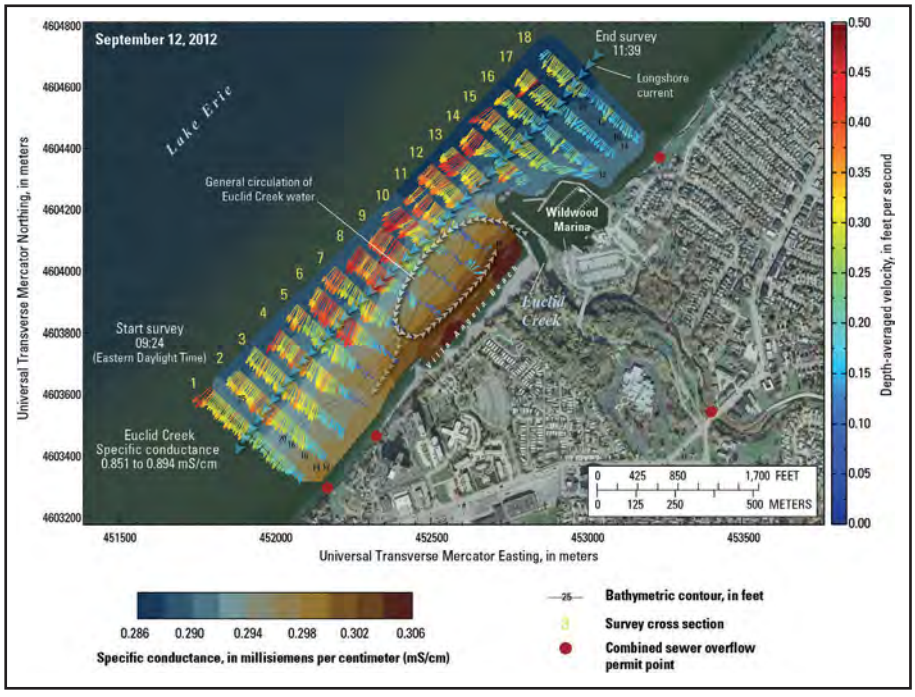

Figure 6: Depth-averaged currents and distribution of near-surface specific conductance in coastal Lake Erie in the vicinity of Villa Angela Beach and Euclid Creek, Cleveland, Ohio, 12 September 2012. Source USGS: http://pubs.usgs.gov/sir/2013/5198/pdf/sir2013-5198.pdf