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Integrated Synoptic Surveys Using an Autonomous Underwater Vehicle and Manned Boats

New Technology Answering Age-Old Questions

Traditional surface-water surveys are being combined with autonomous technology to produce integrated surveys of bathymetry, water quality, and velocity in inland lakes and reservoirs. This new technology provides valuable, high-resolution, integrated data that allow a systems-based approach to understanding common environmental problems.

What are Integrated Synoptic Surveys?

A synoptic survey produces a nearly instantaneous picture of a characteristic of interest (for example, water temperature) over a broad area. Synoptic surveys of a water body often require many people and many hours to complete, depending on the extent of the survey and the purpose of the study. Typically, these surveys target only a single characteristic, such as bathymetry or the extent of algal blooms. Interdisciplinary studies require integrated datasets that include geologic, biologic, hydraulic, and chemical data collected simultaneously and under a common sampling strategy and with similar spatial and temporal resolutions. To complete these complex synoptic surveys, a combination of new technology and proven survey techniques is used. Traditional manned-boat surveys might use acoustic Doppler current profiling, single-beam echo sounding, sediment sampling, and water-quality point sampling to meet data needs. Generally, these traditional surveys are not run simultaneously; however, running these surveys simultaneously with a high-resolution three-dimensional survey of bathymetry, water quality, velocity, and side-scan sonar imagery using an autonomous underwater vehicle can greatly enhance the dataset. Because the surveys are integrated, the datasets can allow for a systems-based approach to analysis.

The Autonomous Underwater Vehicle (AUV)

The autonomous underwater vehicle (AUV) is a specialized submersible instrument equipped with integrated water-quality sensors, acoustic Doppler current profiler and Doppler velocimetry log (DVL), single-beam echo sounder, side-scan sonar, and a differential global positioning system (GPS) receiver (fig. 1). The AUV operates by propelling itself through the water body (surface or subsurface) between way points along a constant depth, constant height above bottom, or undulating survey path (fig. 2), as set by the user in the mission plan. The AUV monitors its position using a GPS receiver and bottom-tracking DVL. The AUV dataset is unique, providing high spatial resolution of key physiochemical water-quality characteristics (temperature, specific conductance, dissolved oxygen, pH, and turbidity). Additional optical sensors provide measurements of chlorophyll, blue-green algae, and rhodamine WT dye concentration. Depth soundings, water-velocity profiles, and side-scan sonar imagery also are collected. Data are collected at 1 hertz. Operational limits of the vehicle include speeds up to 4 knots (7 feet per second) and dive capability to 200 feet.

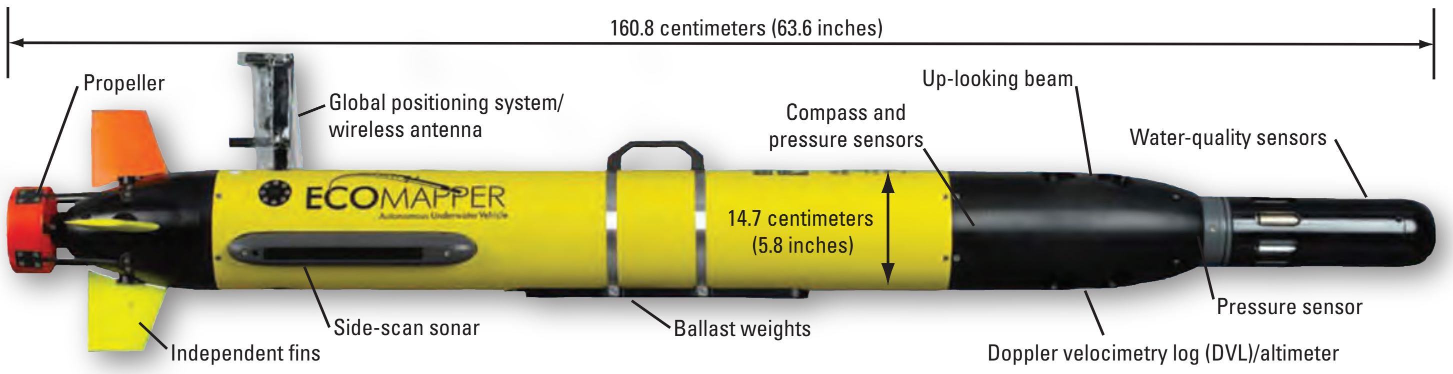

Figure 1. Schematic of an autonomous underwater vehicle (Yellow Springs Instruments EcoMapper®).

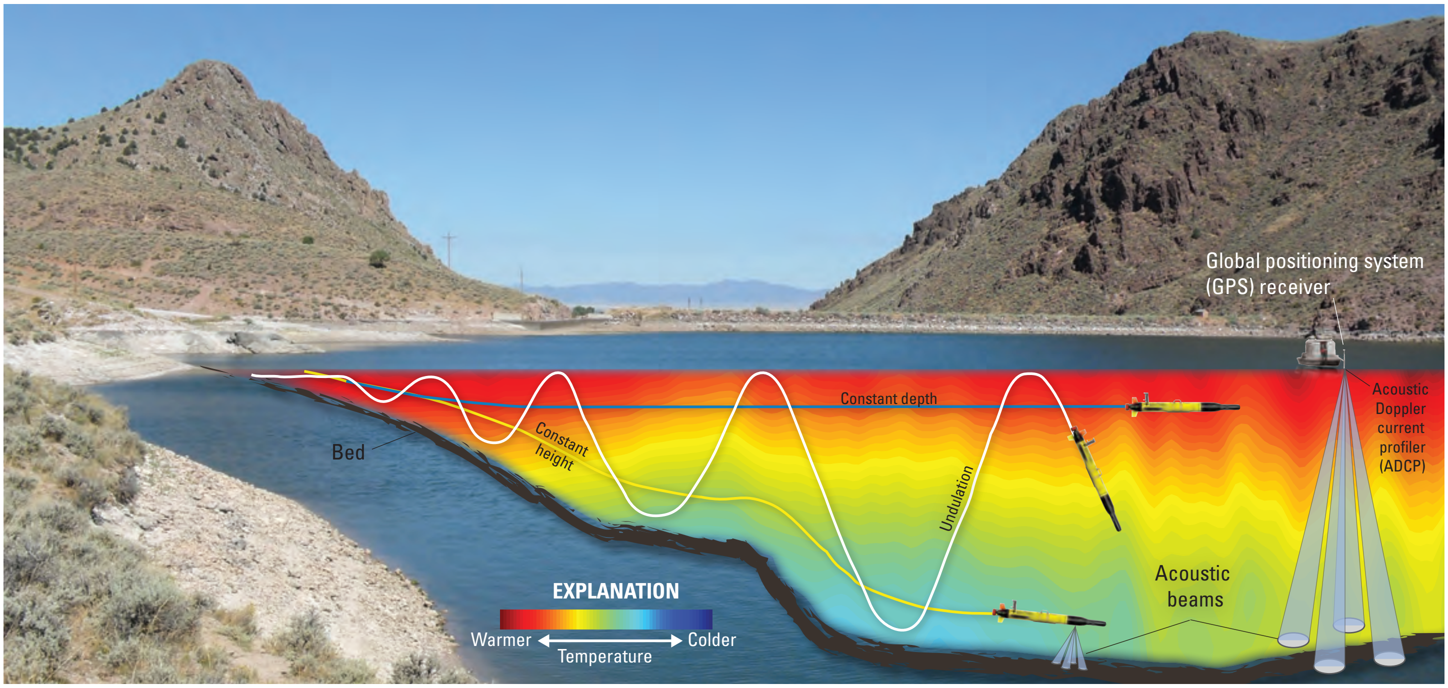

Figure 2. Schematic of a typical integrated survey with a manned boat equipped with an acoustic Doppler current profiler (ADCP) and differential global positioning system (GPS) receiver and the autonomous underwater vehicle (AUV) equipped with a suite of water-quality sensors, ADCP and Doppler velocimetry log, and side-scan sonar. The three primary survey modes (constant depth, constant height above bottom, and undulation) are shown for the AUV.

Beyond a Typical Bathymetric Survey

A high-resolution bathymetric survey of a surface-water body might require significant time on the water and as many as 200 transects of the lake or reservoir spaced at 0.5 percent of the length of the water body (Wilson and Richards, 2006). Although a traditional single-beam survey of a lake will provide only a bathymetric map such as that shown in figure 3*A*, an integrated survey can include water-quality and velocity data with little additional effort in the field. These additional data can provide valuable information about the water body; for example the distribution of chlorophyll *a* for better understanding of the extent of an algal bloom (fig. 3*B*), the distribution of dissolved oxygen in a lake during an algal bloom in the vicinity of a tributary inflow (fig. 3*C*), or the depth-averaged velocity distribution in a shallow basin driven predominately by wind (fig. 3*D*).

Supplementary data collected during integrated surveys can be processed and analyzed if deemed important for the study or archived for future use. Processing any supplemental data requires additional resources; however, automated processing via computer scripts reduces time requirements. At their basic level, these scripts can be used to generate quick visualizations of each of the datasets to allow review in the field. The full functionality of the scripts allows for complete review, screening, and correction of the data. Processed data can be exported to two- and three- dimensional mapping and visualization applications for additional processing, visualization, and analysis when required.

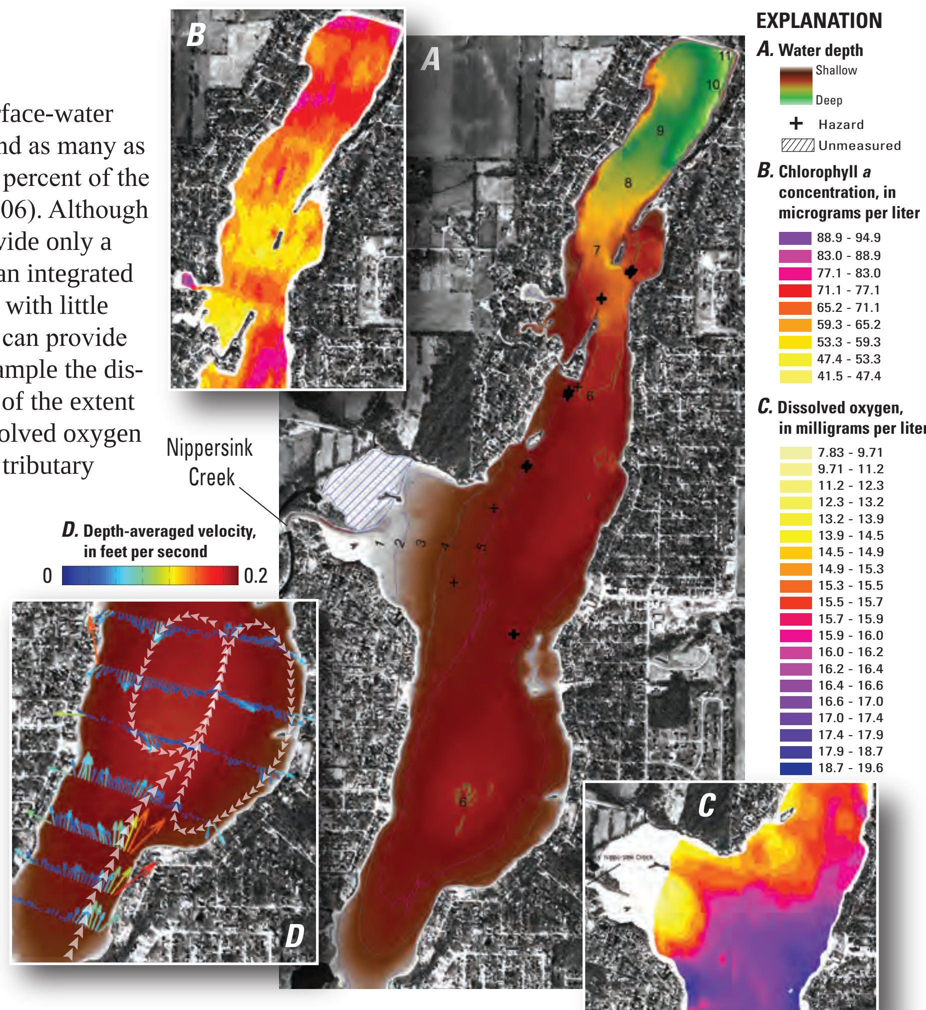

Figure 3. Several products of an integrated synoptic survey of Wonder Lake, Illinois, August 2010: *A*, Bathymetric map with 1-foot contours. *B*, Near-surface chlorophyll *a* concentration. *C*, Near-surface dissolved oxygen concentration. *D*, Depth-averaged velocity with generalized circulation patterns.

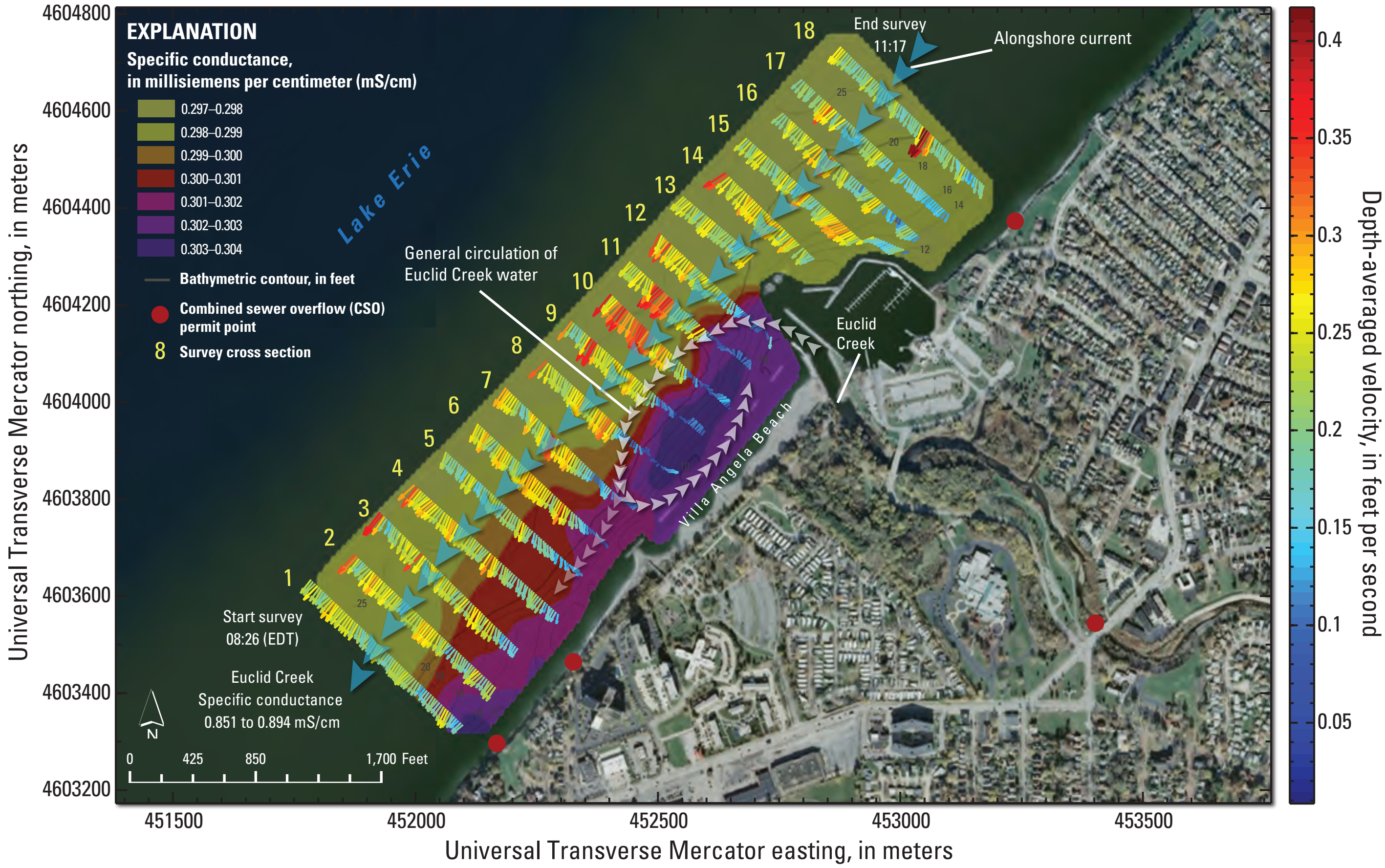

Figure 4. Distribution of near-surface specific conductance overlaid by depth-averaged velocity vectors, generalized circulation patterns, and alongshore-current distribution in Lake Erie near Villa Angela Beach and Euclid Creek, Ohio, on September 11, 2012. Specific-conductance data were collected with the AUV (undulating between the surface and 5 feet above the bed at a speed of 2 knots), and velocity data were collected with a boat-mounted ADCP and processed with the Velocity Mapping Toolbox (Parsons and others, 2013).

Currents Help Explain Water-Quality Distributions

Combining observed currents with water-quality distributions allows for an integrated analysis and greater understanding of the system being studied. For example, figure 4 shows nearshore Lake Erie near Villa Angela Beach and Euclid Creek, Ohio. A recirculation zone along the beachfront traps Euclid Creek water and related contaminants. Specific conductance, which was three times higher in the creek than in the lake, serves as an excellent tracer to map the river plume. This mixing pattern was observed in both 2011 and 2012 during integrated surveys; three-dimensional data from the AUV and ADCP show the formation of density currents along the lakebed and the subsequent mixing of the dense, near-bed river water to the surface through the action of large-scale eddies (fig. 5).

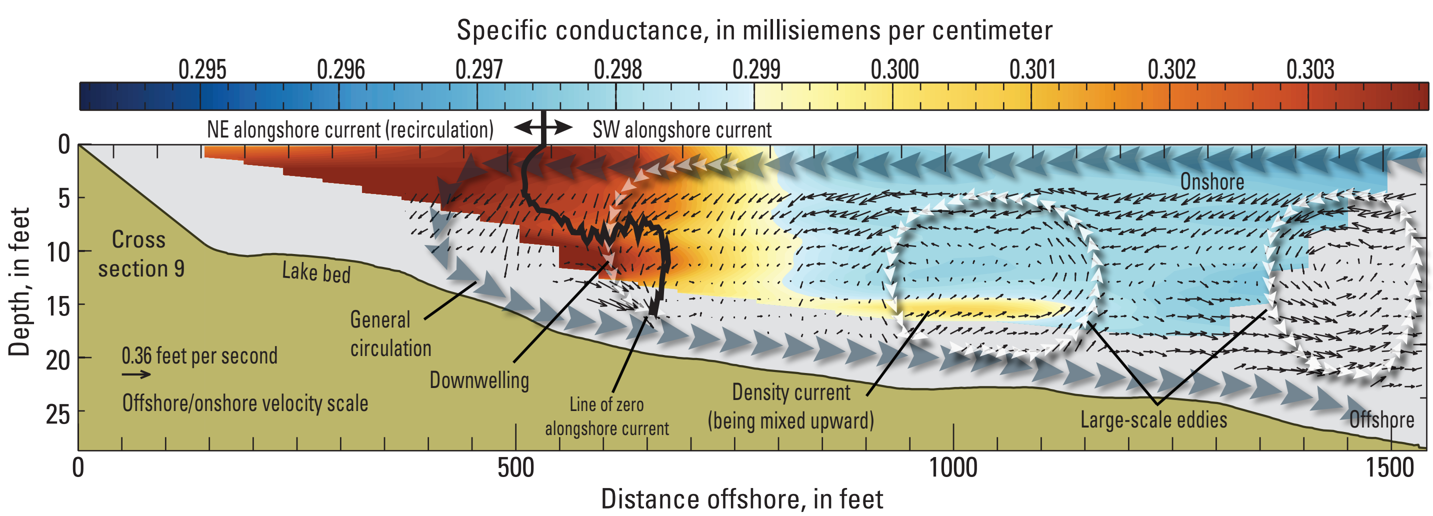

Figure 5. Distribution of specific conductance in cross section 9 (see fig. 4) overlaid by onshore/offshore velocity vectors, generalized circulation patterns, and alongshore-current distribution. Specific-conductance data were collected with the AUV (undulating between the surface and 5 feet above the bed), and velocity data were collected with a boat-mounted ADCP and processed with the Velocity Mapping Toolbox (Parsons and others, 2013).

Highly Resolved Datasets Allow Multi-Dimensional Analysis

Currents and water-quality distributions often vary with depth. A three-dimensional integrated synoptic survey provides the appropriate vertical resolution to allow data analysis in three dimensions. By using custom processing scripts, the full, three-dimensional dataset can be sliced along a horizontal plane to examine water-quality distributions in plan view (fig. 6) or sliced into a series of vertical planes along transect lines and aggregated into a single, three-dimensional visualization (fig. 7). A thorough analysis would incorporate both methods of visualization to take advantage of the strengths of each method. In the example provided for the Milwaukee River, Wisconsin, the three-dimensional distribution of specific conductance in the harbor (fig. 7) shows the river plume of high specific conductance entering the harbor and forming a plume to the south. This distribution is complicated by a wastewater-effluent outfall near the river mouth, which also has high specific conductance (fig. 6). The outfall is clearly visible when the distribution of specific conductance is viewed in plan view with data in the harbor and three tributaries (fig. 6). A manned boat was used to collect the riverine data while the AUV ran the survey of the

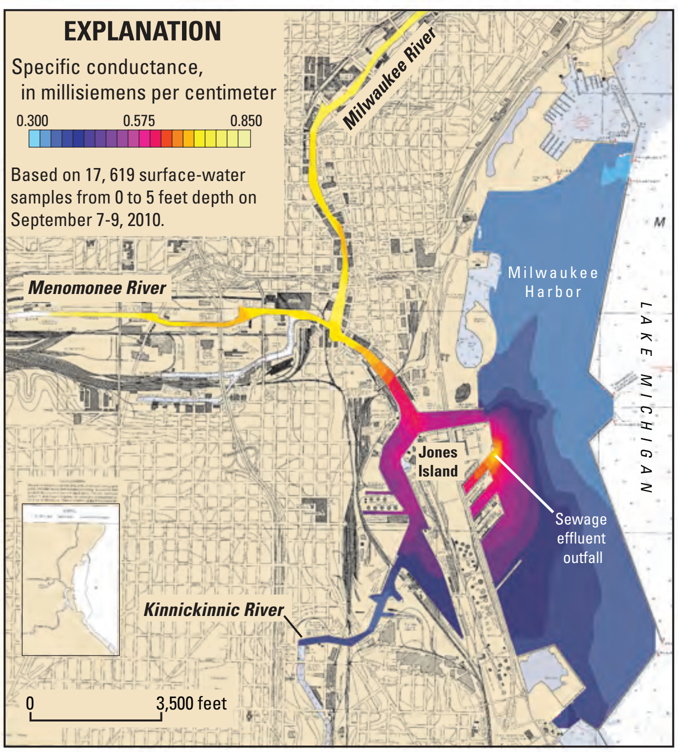

Figure 6. Distribution of near-surface (0 to 5 feet depth) specific conductance in Milwaukee Harbor and the lower Milwaukee, Menomonee, and Kinnickinnic River, Wisconsin, September 7–9, 2010. Data also show the location of the effluent outfall from the Jones Island wastewater treatment plant.

References Cited

Parsons, D.R., Jackson, P.R., Czuba, J.A., Engel, F.L., Rhoads, B.L., Oberg, K.A., Best, J.L., Mueller, D.S., Johnson, K.K., and Riley, J.D., 2013, Velocity Mapping Toolbox (VMT)—A processing and visualization suite for moving-vessel ADCP measurements: Earth Surface Processes and Landforms, online Early View, 17 p., DOI: 10.1002/esp.3367.

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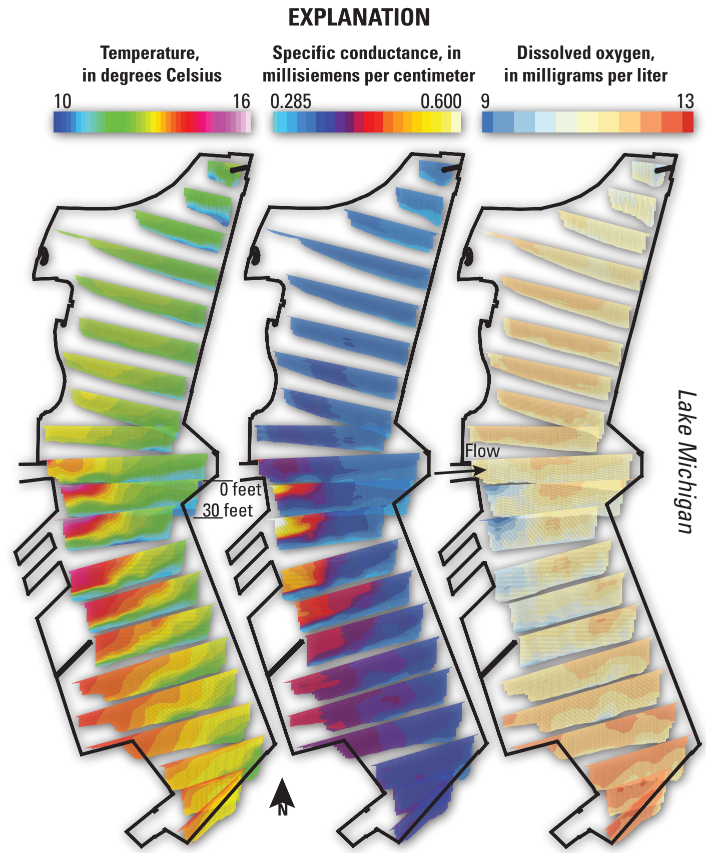

Figure 7. Three-dimensional views of water quality in outer Milwaukee Harbor on September 9, 2010. *A*, Temperature. *B*, Specific conductance. *C*, Dissolved oxygen. Images shown looking down and to the north. Flow into the harbor from the three tributaries is from the left, and Lake Michigan is on the right. Note how the river plume deflects to the south.

Front page boat photograph: Manned boat equipped with an ADCP, differential GPS receiver, single-beam echo sounder, and multiparameter sonde. The AUV is being recovered at the end of an integrated manned boat and AUV survey on Wonder Lake, Illinois, August 2010. Photograph by Peter Berrini, HDR, Inc., used by permission.

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