Results from a National Monitoring Network Lake Michigan Pilot Study:
Integrated surveys of water quality and hydrodynamics in rivermouth mixing zones using an autonomous underwater vehicle
Objectives:

- Collect continuous water-quality data from the fluvial to the lacustrine zones of a rivermouth
- Bridge the gap between the last gage on a tributary and the nearshore sampling stations
- Examine the mixing, dispersion, and hydrodynamics within rivermouths
- Determine if synoptic surveys can be beneficial to continuous water-quality monitoring programs & modelers

Lake Michigan shoreline near Burns Ditch and Burns Harbor, Indiana
New Tools for Synoptic Mapping:
The Autonomous Underwater Vehicle (AUV)

- 200 ft dive capability
- Full suite of water-quality sensors (right)
- 6-beam DVL/ADCP
  - Bottom tracking
  - Echo sounder
  - Current profiling
- Dual pressure sensors, multi-axis compass
- Imagenex 330/800 kHz side scan sonar
- Differential GPS

<table>
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<th>Sensor</th>
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<td>Conductivity</td>
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<td>Temperature</td>
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AUV Survey Methods

Newcastle Reservoir, Utah
Integrated Synoptic Surveys of the Hydrodynamics and Water-Quality Distributions in Two Lake Michigan Rivermouth Mixing Zones using an Autonomous Underwater Vehicle and a Manned Boat
850 mi² drainage area

Most populated basin that flows directly into Lake Michigan

Three rivers converge
- Milwaukee River (2010 AM 641 cfs)
- Menomonee River (2010 AM 215.4 cfs)
- Kinnickinnic River (2010 AM 32.5 cfs)

Designated an Area of Concern (AOC) in 1987
- Conventional contaminants (phosphorous and suspended solids)
- Toxic contaminants (metals and organic chemicals)

Industrial point sources
- Valley Power Plant (~250 cfs)
- Jones Island Wastewater Treatment Plant (~230 cfs)

Subject to combined sewer overflows
September 7-9, 2010

Inner and outer harbors surveyed with the AUV in undulation mode

Rivers surveyed with the manned boat
- Profiles and discharge measurements at 16 stations

All data compiled into an integrated dataset
AUV survey
September 9, 2010

Processed with custom Matlab® scripts and visualized in Tecplot®
Menomonee River Section

B. Menomonee River

Distance upstream from the harbor mouth, in miles

Lake water ——— River inflow

DO minimum

Temperature, in degrees Celsius
Specific conductance, in millisiemens per centimeter
Density, in kilograms per cubic meter
Turbidity, in Nephelometric turbidity units
Dissolved oxygen, in milligrams per liter
Milwaukee River Estuary, Milwaukee, WI

AUV and manned boat survey
September 7-9, 2010

Surface Water (0 – 5 ft)
Can synoptic distributions help explain variations in point samples?

2010 Milwaukee Metropolitan Sewerage District monitoring data

Yes.
Specific Conductance

MMSD 2010 median vs. synoptic

MIN: ~300 µs/cm
MAX: ~830 µs/cm
MMSD 2010 median vs. synoptic

Local minima in DO

Dissolved Oxygen

MMSD 2010 median vs. synoptic
Local minima in DO

At an SOD of 1.12 g/m²/day and mean depth of about 1 meter, DO decline is approximately 1.1 mg/L every day.

To drop from 14.8 to 5 mg/L in 2 km requires a velocity of about 3 mm/s. We measured mean velocities of 5 mm/s.
Application: Manitowoc Rivermouth (WI)
National Monitoring Network
Lake Michigan Pilot Study

Scientific Investigations Report 2014-5043
Overall Conclusions

- **AUV technology is highly efficient**
  - Rapid collection of water-quality data in relatively open water (harbors, nearshore, etc.)
  - Example: 600 profiles in 7 hr with the AUV compared to ~150 hours with traditional methods (Harbor)

- Synoptic surveys provide great insight into mixing and dispersion in highly unsteady mixing zones

- High resolution data can help explain variation in periodic point samples and assess point sampling strategies
  - Example: MMSD sampling points are well distributed to capture spatial variations

- High resolution synoptic datasets can provide modelers with valuable calibration and/or validation data

- **AUVs are generally not designed for riverine surveys**
  - should be integrated with manned boat measurements in rivers

- While manned boats can be equipped for synoptic mapping, it is generally less efficient and results in lower resolution data (towed instruments would be the exception)

- Velocity surveys are still most efficient and accurate using a manned boat
Great Salt Lake Dye Study
An investigation of freshwater and selenium inputs into a hypersaline lake

Lee Creek Freshwater Inflow Plume
Surveyed by the AUV and a manned boat
November 2, 2011
Photo courtesy of KSL News
Extra Slides

Manitowoc Rivermouth
Manitowoc Rivermouth

- 526 mi² drainage area
- Impaired due to:
  - Phosphorus
  - Sediment
  - Coliform bacteria
- Heavily agricultural watershed with cropland and dairy waste runoff
- Dredged navigation channel in lower 2 miles
- 2011 mean annual flow of 460 cfs
- Small 20-acre harbor
- Two offshore wastewater effluent outfalls and six offshore intakes south of the harbor
- 9-acre spoil pond north of the harbor
- Part of the Great Lakes Rivermouth Collaboratory study
NOTE: Lake water pushes 2 mi upstream

NOTE: Similar distributions

NOTE: DO min. (~ 0 mg/L near bed)
Conclusions: Manitowoc Pilot Study

- The lower 1.5 miles of the Manitowoc River is the primary mixing zone and exhibits a significant DO minimum in this zone.
- Point sources along the lakeshore both north (spoil pond, Little Manitowoc River) and south of the harbor (wastewater outfalls) combine with the river plume and affect nearshore distributions.
- Offshore water intakes located south of the harbor can lie within the river and outfall plumes.
- Bi-directional nearshore currents exist and surface water observations may not always predict river plume dynamics.
- Specific conductance and FDOM are highly correlated and both provide good tracers for river plumes and wastewater effluent plumes.
- Monitoring data from the GL Rivermouth Collaboratory is not yet available for comparison, but sampling points are few and far between and may not resolve the variability in the system.