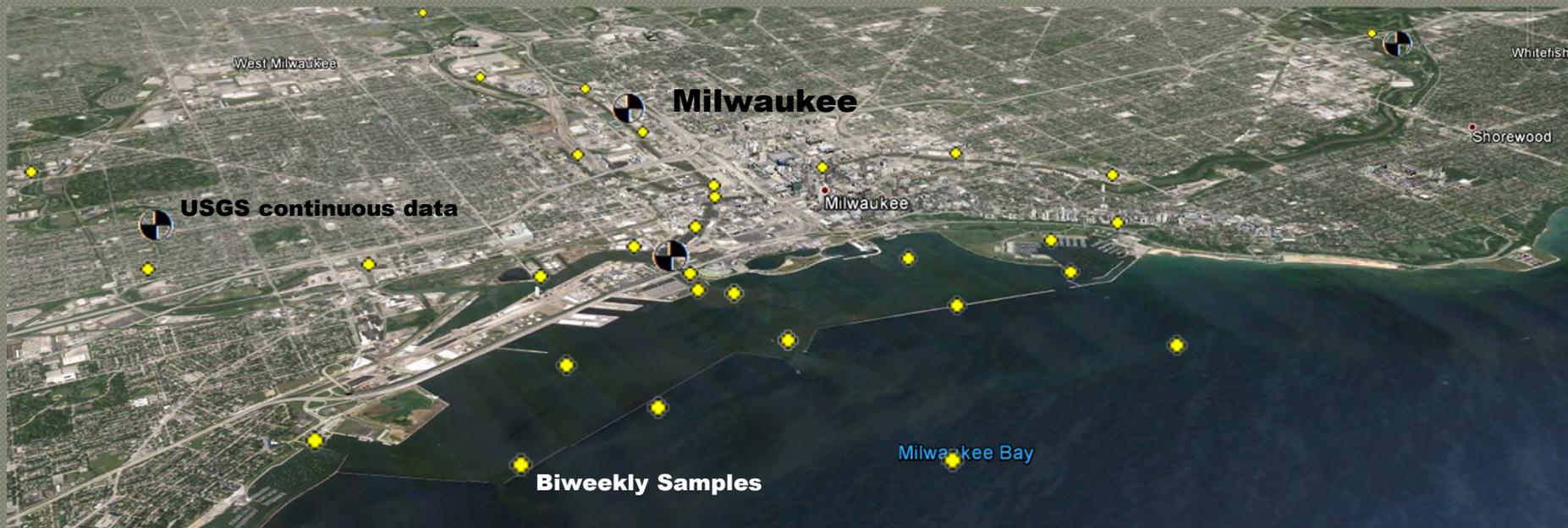


Results from a National Monitoring Network Lake Michigan Pilot Study:

Integrated surveys of water quality and hydrodynamics in rivermouth mixing zones using an autonomous underwater vehicle



U.S. Department of the Interior
U.S. Geological Survey

P. Ryan Jackson
USGS Illinois Water Science Center
Paul Reneau
USGS Wisconsin Water Science Center

National Monitoring Network Lake Michigan Pilot Study

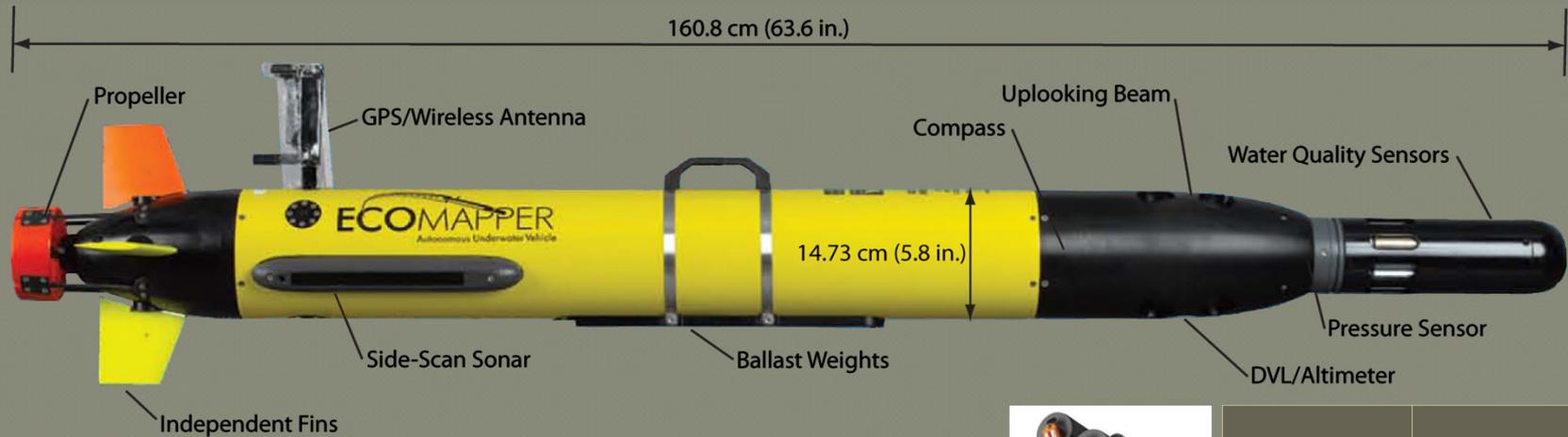
Objectives:

- 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)



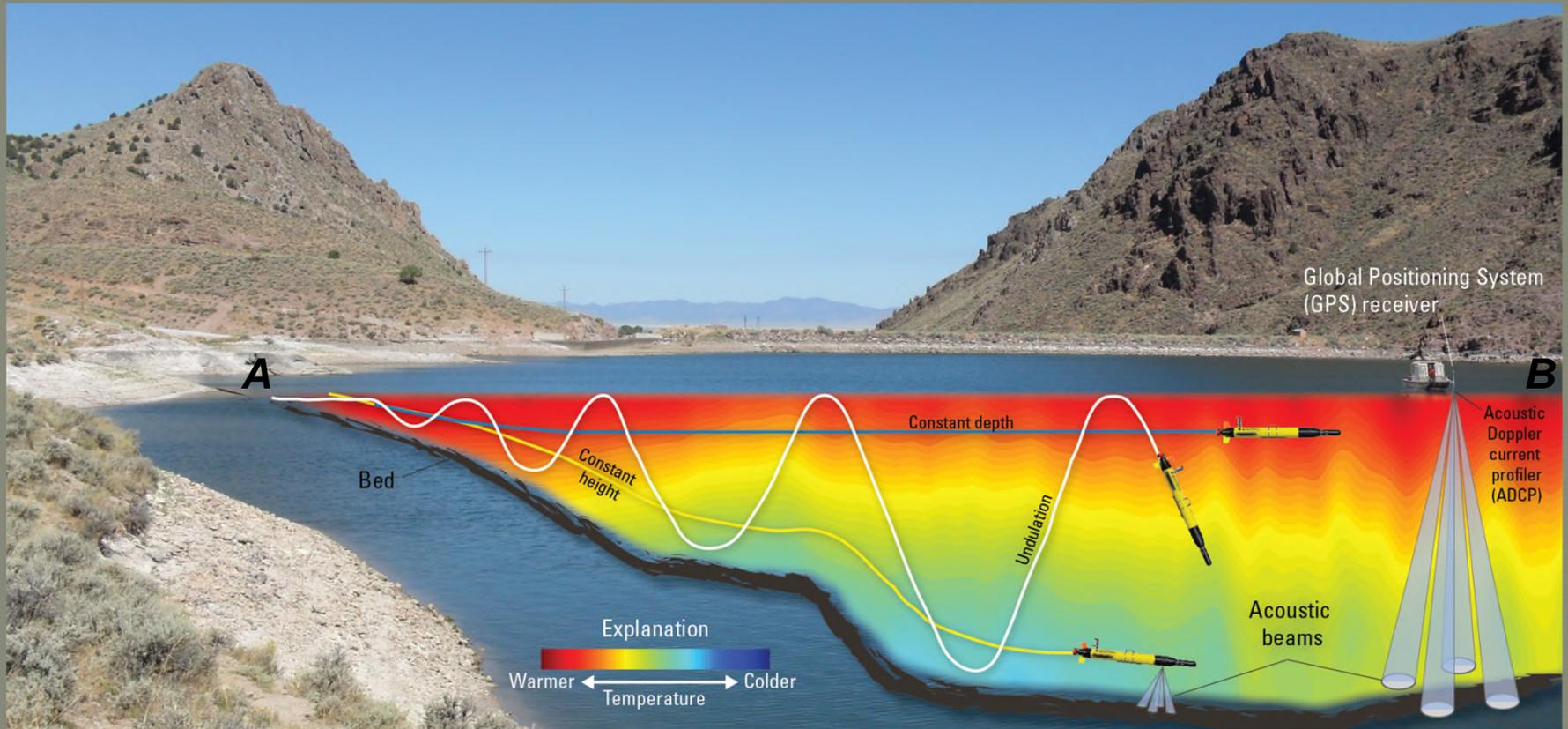
- 200 ft dive capability
- Full suite of water-quality sensors (right)
- 6-beam DVL/ADCP
 - Bottom tracking
 - Echo sounder
 - Current profiling
- Dual pressure sensors, multi-axis compass
- Imagenex 330/800 kHz side scan sonar
- Differential GPS



Water-quality sensor suite

Sensor	YSI #
Conductivity	6560FR
Temperature	6560FR
Depth	
Blue-green Algae	6131
Chlorophyll Fluorescence	6025
Dissolved Oxygen	6150FR
pH	6589FR
Rhodamine	6130
Turbidity	6136

AUV Survey Methods



Newcastle Reservoir, Utah

Prepared in cooperation with the National Monitoring Network for
U.S. Coastal Waters and Tributaries

**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**



Scientific Investigations Report 2014-5043

U.S. Department of the Interior
U.S. Geological Survey

Application: Milwaukee River Estuary and AOC (WI)

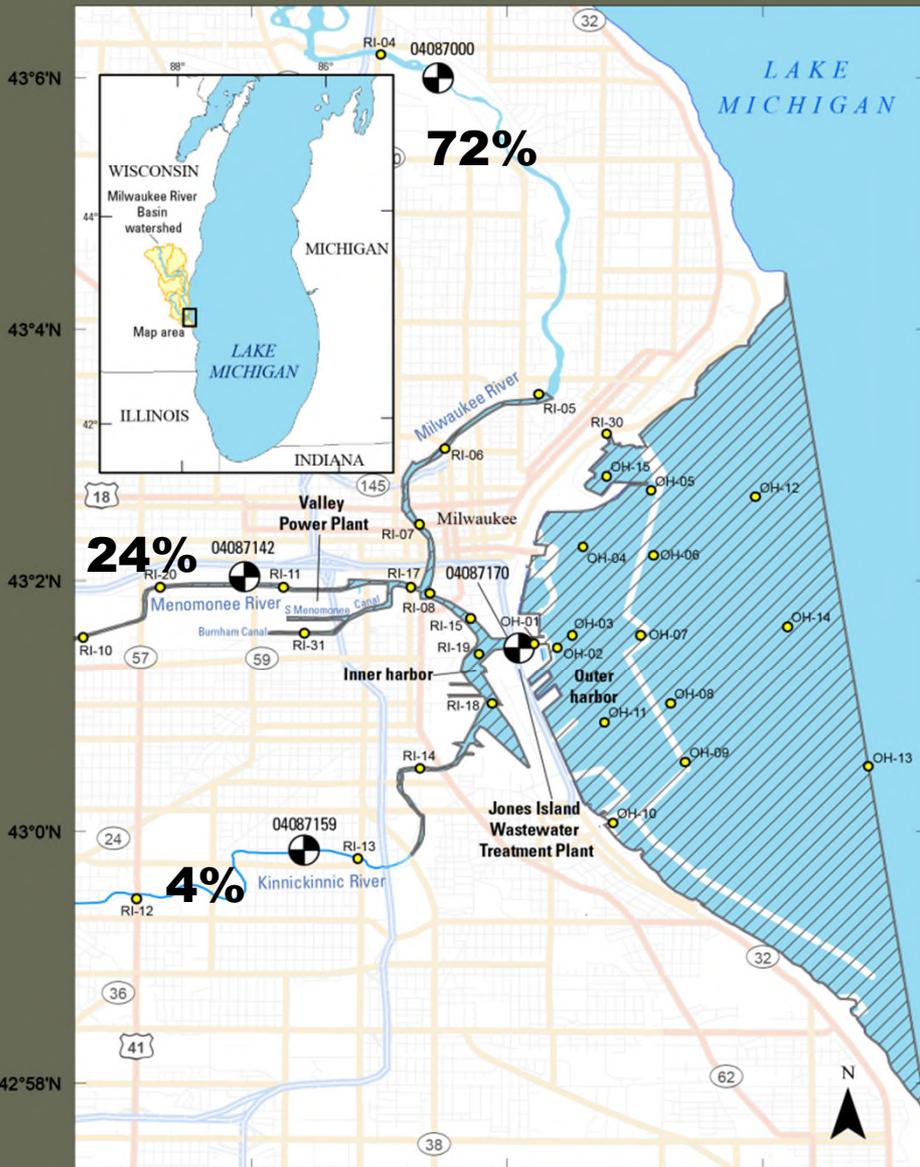
National Monitoring Network
Lake Michigan Pilot Study

USGS Scientific Investigations Report 2014-5043

87°56'W

87°54'W

87°52'W



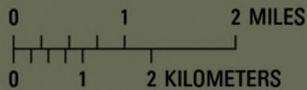
Milwaukee AOC

- 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

Base from U.S. Geological Survey National Hydrography Dataset and ESRI digital data

EXPLANATION

-  Milwaukee River Estuary Area of Concern
-  Milwaukee Metropolitan Sewerage District sampling point (with site number)
-  U.S. Geological Survey streamflow-gaging station with station number

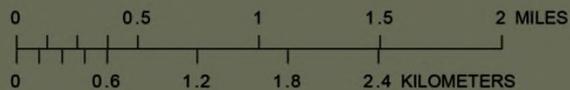


Data Collection

- 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



Base image from ESRI World Imagery Layer (http://go.to.arcgisonline.com/maps/World_Imagery)



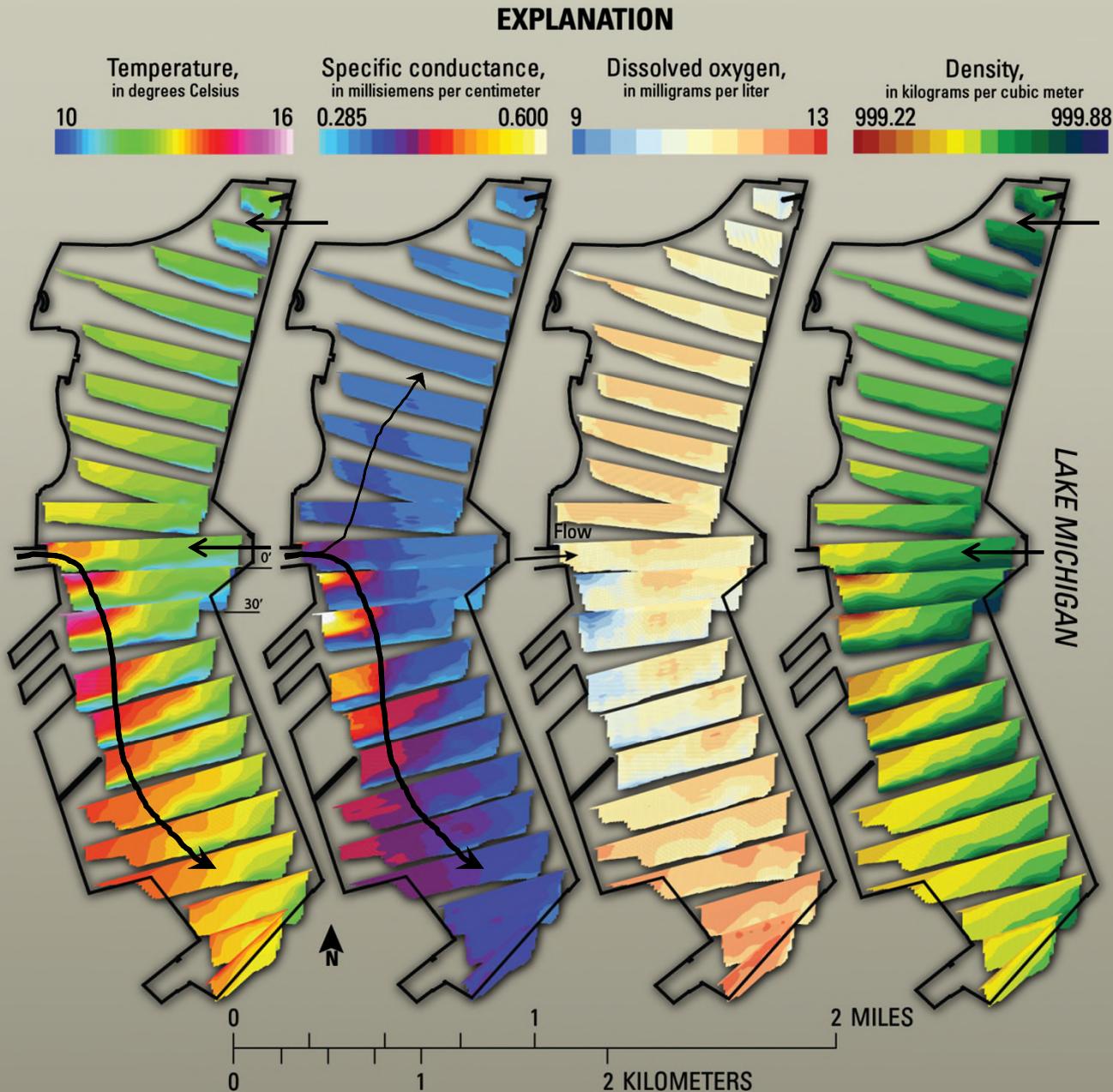
EXPLANATION

- Autonomous underwater vehicle (AUV) survey path, September 9, 2010
- AUV survey path, September 8, 2010
- ⊕ U.S. Geological Survey streamflow-gaging station with station number
- Vertical profiling station with station number

Milwaukee Harbor, Milwaukee, WI

AUV survey
September 9,
2010

Processed with
custom Matlab[®]
scripts and
visualized in
Tecplot[®]



Milwaukee Harbor, Milwaukee, WI

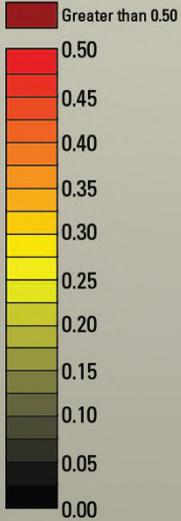
AUV and manned boat survey
September 7-9, 2010

Currents

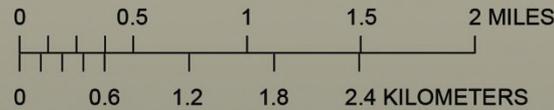
A. Near-surface (0 to 13 feet depth)

B. Near-bed (0 to 10 feet above bed)

EXPLANATION
Layer-averaged velocity magnitude, in feet per second



 U.S. Geological Survey streamflow-gaging station



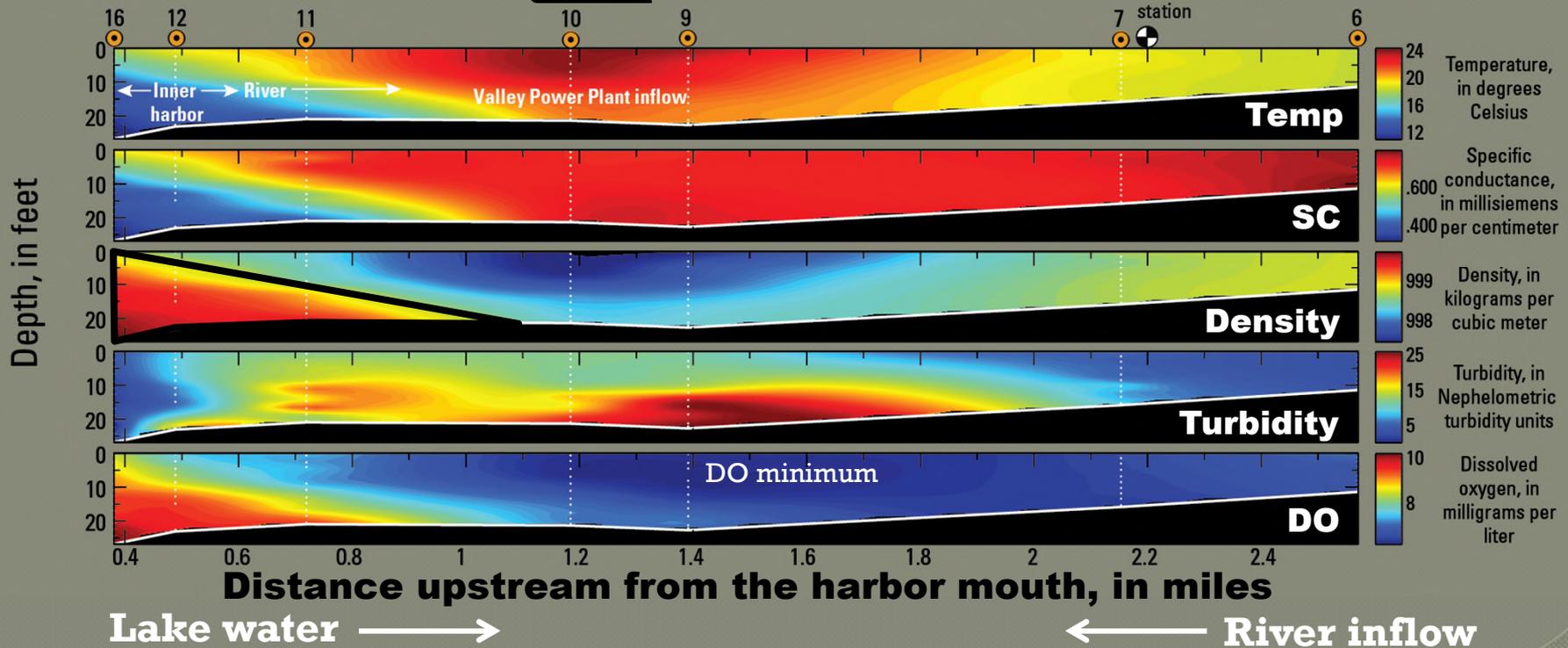
Menomonee River Section



B. Menomonee River



U.S. Geological Survey
streamflow-gaging
station

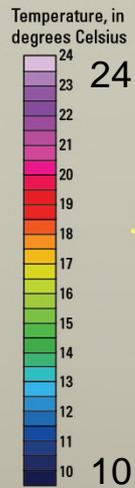


Surface water (0 to 5 feet depth)

Temp

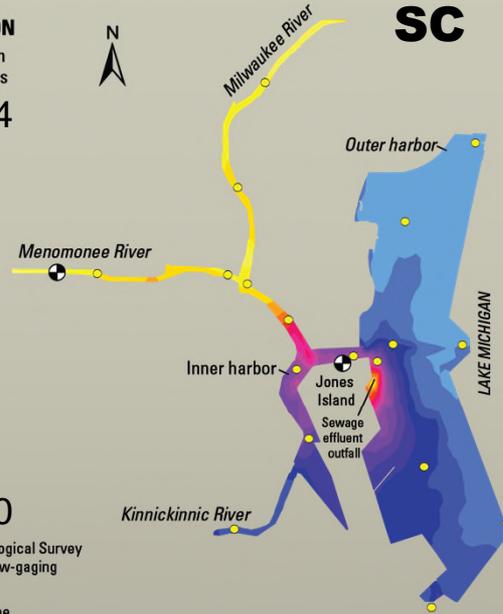


EXPLANATION

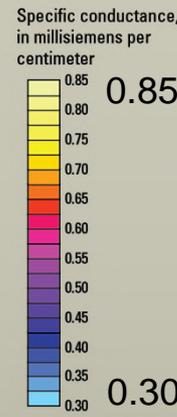


- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point

SC

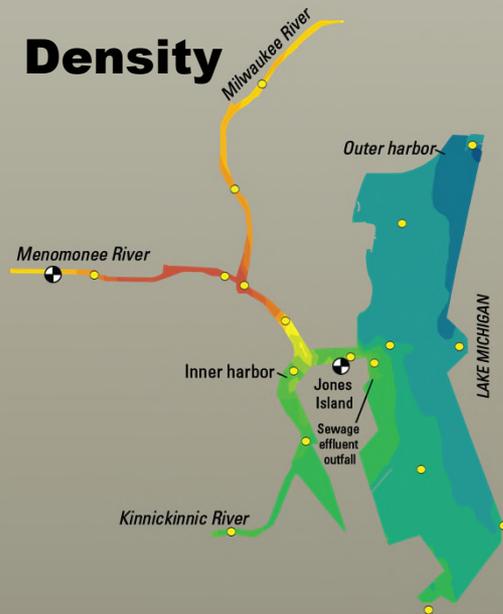


EXPLANATION

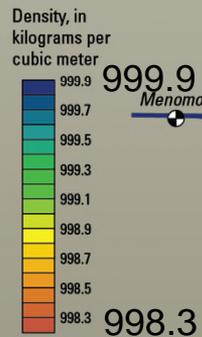


- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point

Density

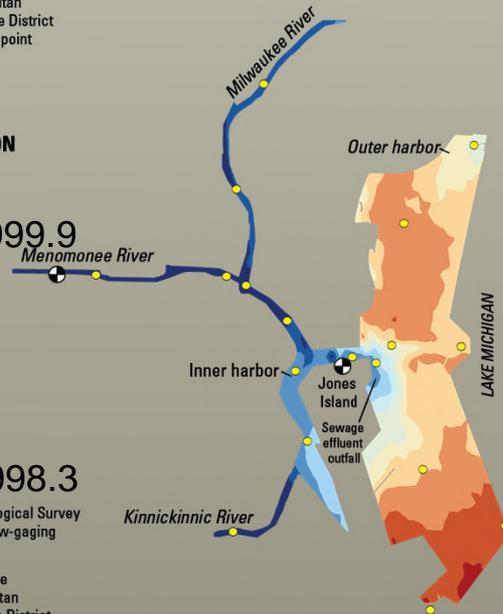


EXPLANATION

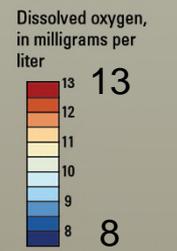


- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point

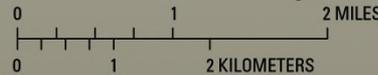
DO



EXPLANATION



- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point



Milwaukee River Estuary, Milwaukee, WI

AUV and manned boat survey
September 7-9, 2010

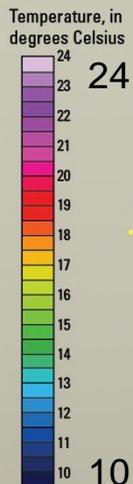
Surface Water (0 - 5 ft)

Near-bed water (0 to 10 feet above bed)

Temp

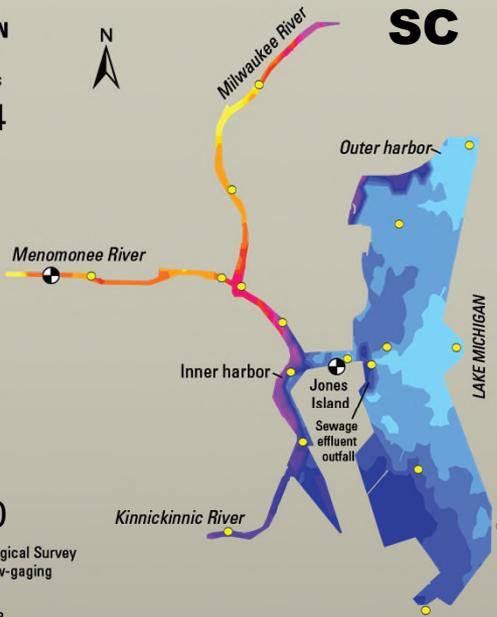


EXPLANATION

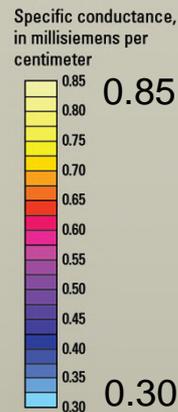


- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point

SC

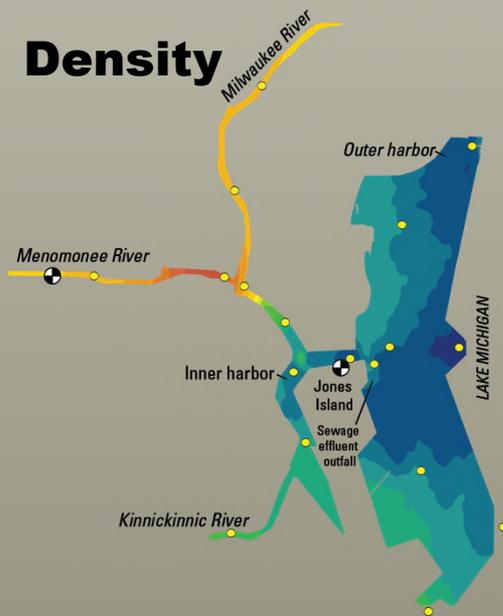


EXPLANATION

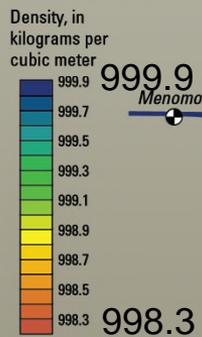


- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point

Density



EXPLANATION

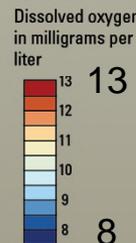


- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point

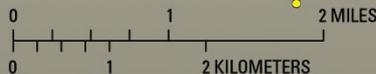
DO



EXPLANATION



- U.S. Geological Survey streamflow-gaging station
- Milwaukee Metropolitan Sewerage District sampling point



Milwaukee River Estuary, Milwaukee, WI

AUV and manned boat survey
September 7-9, 2010

Bottom Water (0 - 10 ft above bed)



Water Quality Monitoring Data

Summary Statistics 2010



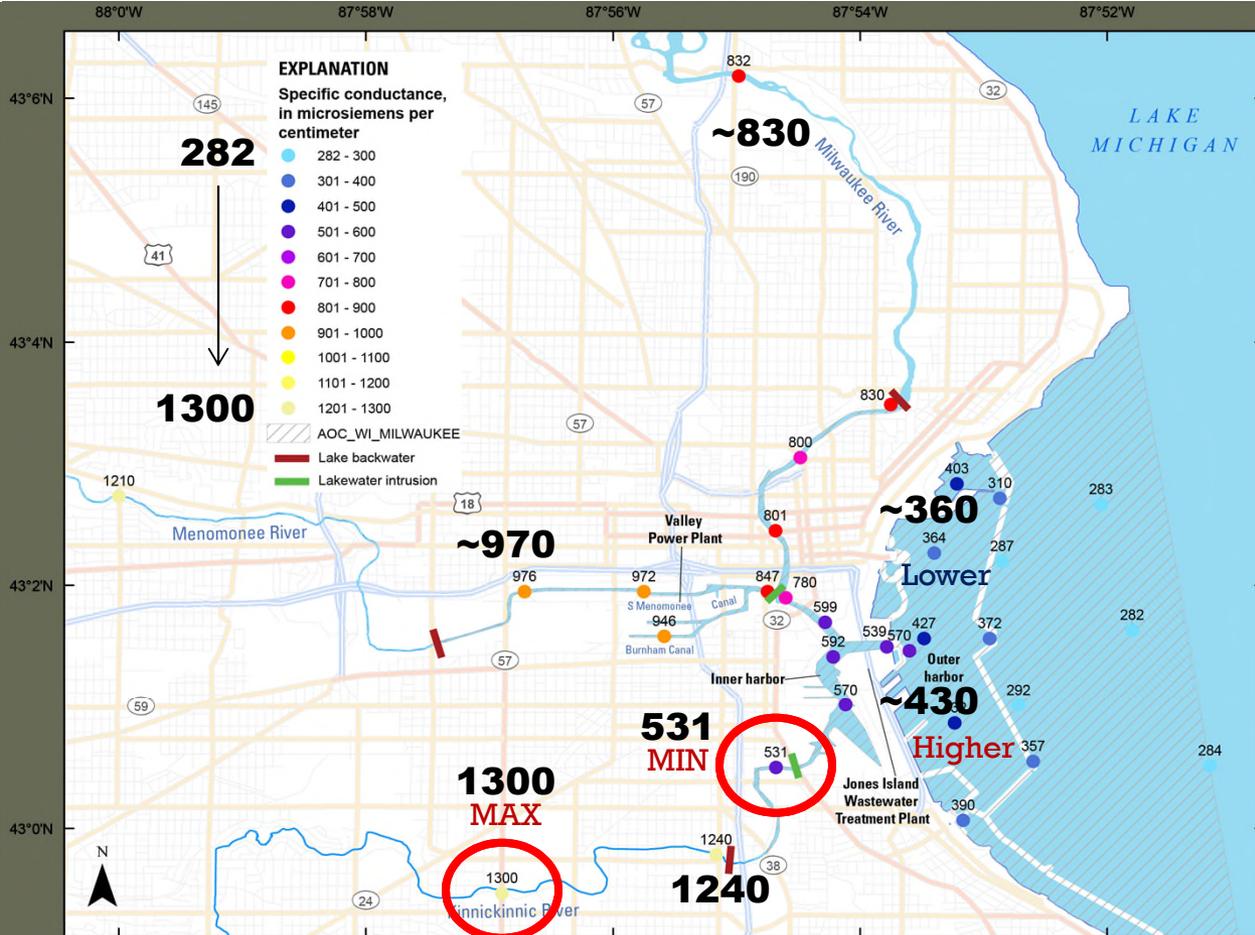
*Compiled by the Water Quality Research Department
Milwaukee Metropolitan Sewerage District*

11/29/2011 11-008

Can synoptic
distributions
help explain
variations in
point samples?

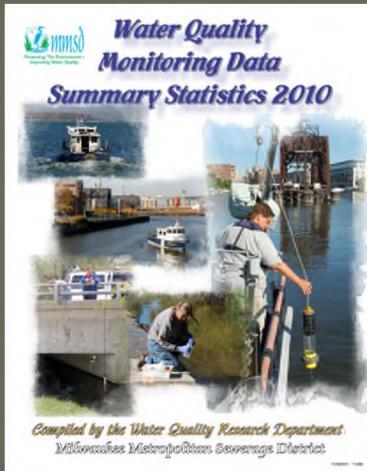
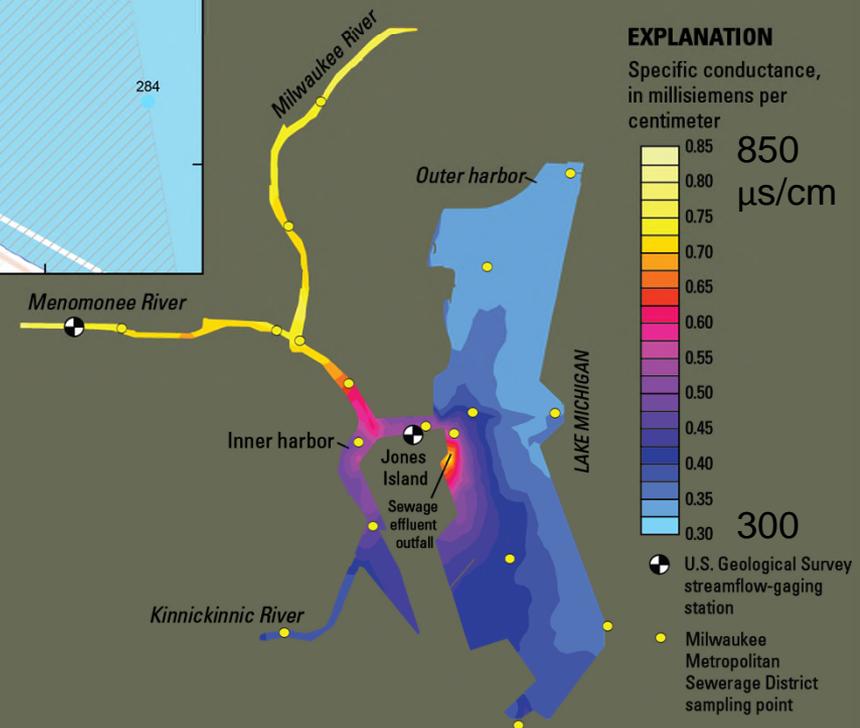
2010 Milwaukee Metropolitan
Sewerage District monitoring
data

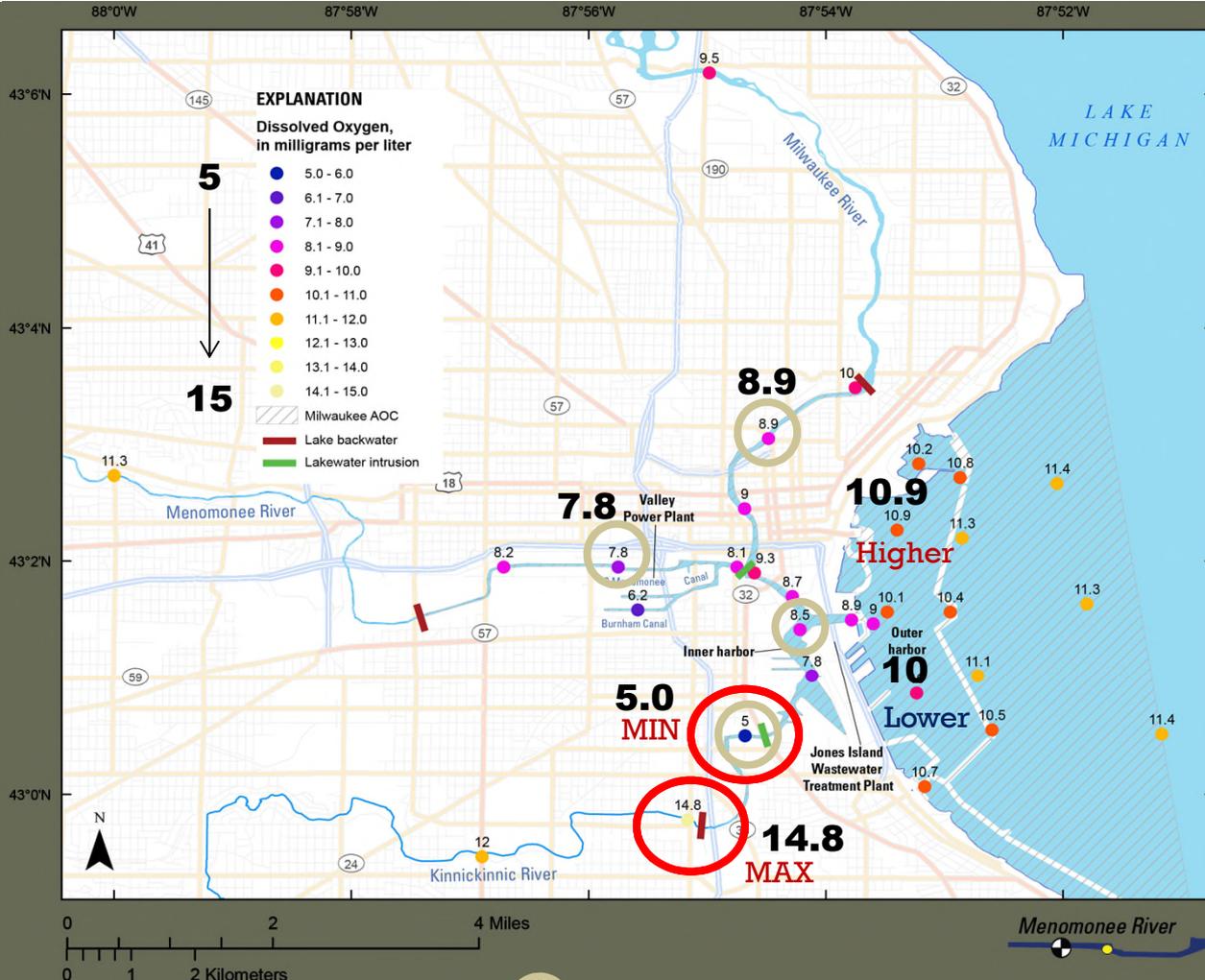
Yes.



Specific Conductance

MMSD 2010 median vs. synoptic

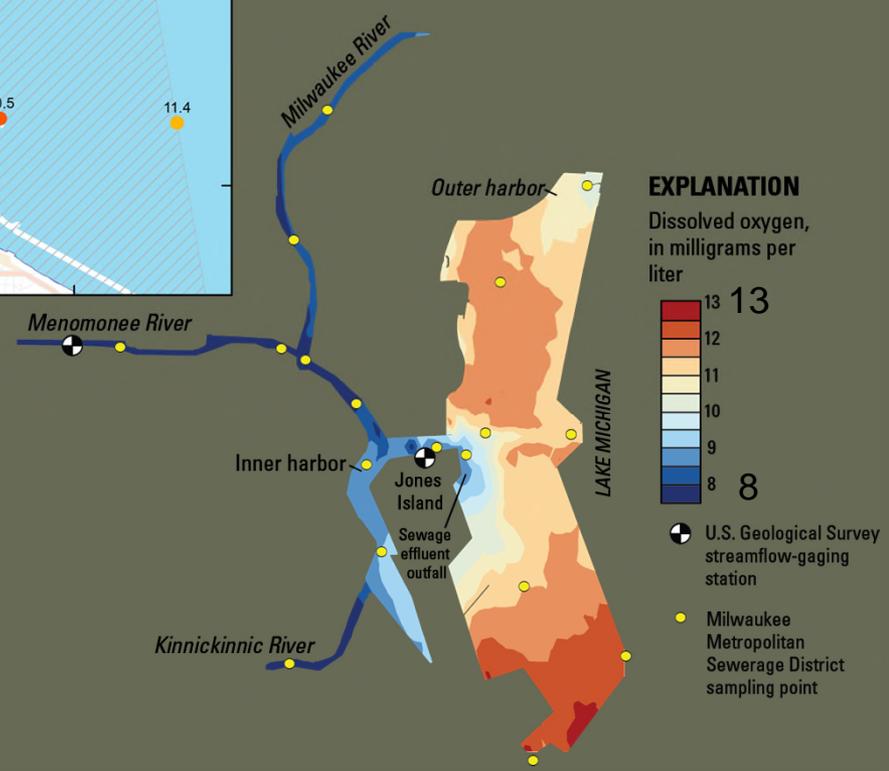




Dissolved Oxygen

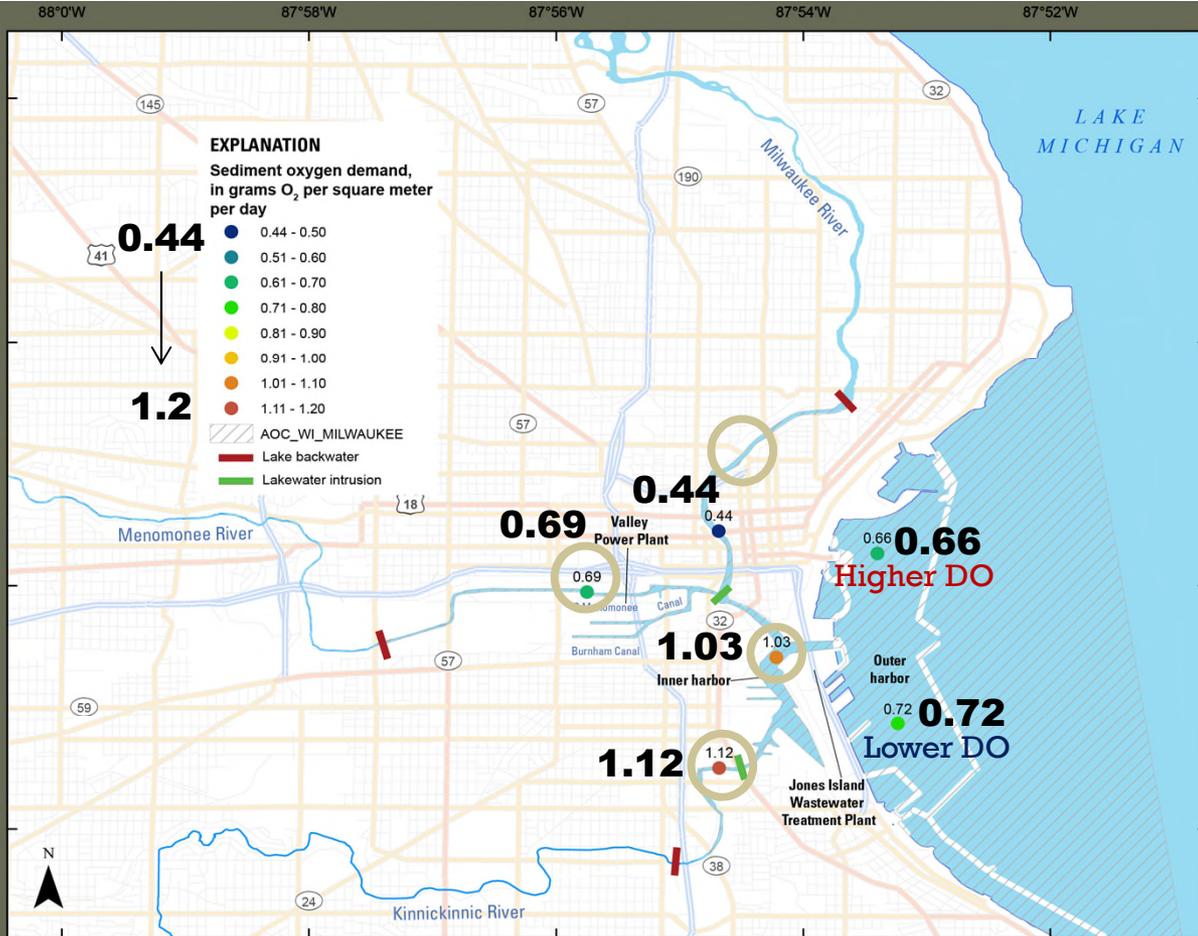
MMSD 2010 median vs. synoptic

Local minima in DO



Sediment Oxygen Demand

Val Klump et al. (2004) data vs. 2010 synoptic DO

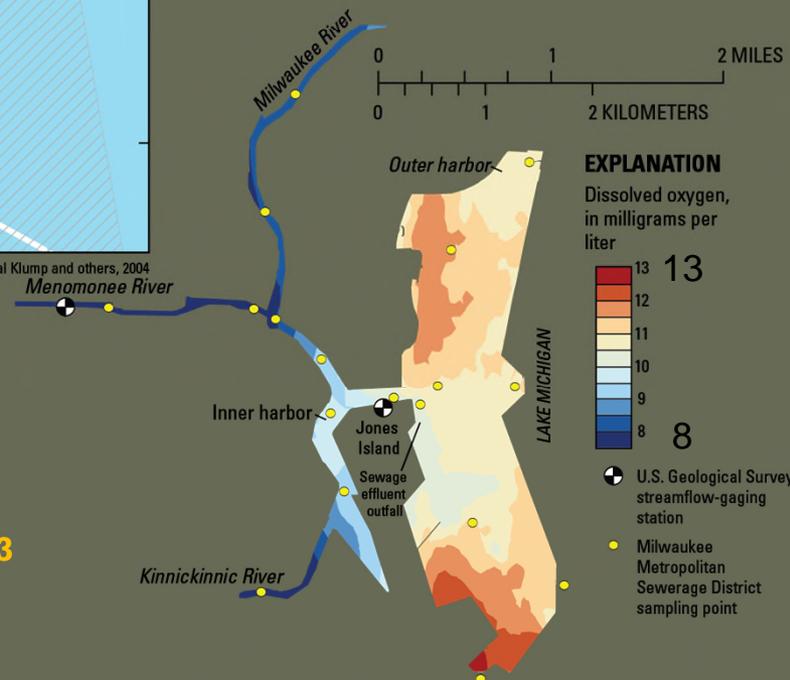


Local minima in DO

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.

Data from Val Klump and others, 2004



Near-bed water (0 to 10 feet above bed)

Prepared in cooperation with the National Monitoring Network for
U.S. Coastal Waters and Tributaries

**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**



Scientific Investigations Report 2014-5043

U.S. Department of the Interior
U.S. Geological Survey

Application: Manitowoc Rivermouth (WI)

National Monitoring Network
Lake Michigan Pilot Study

TEASER

USGS Scientific Investigations Report 2014-5043

Manitowoc Rivermouth

September 19-20, 2011

Specific Conductance

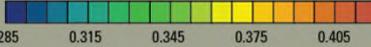
A. Nearshore

Near-surface (0 to 5 feet depth)

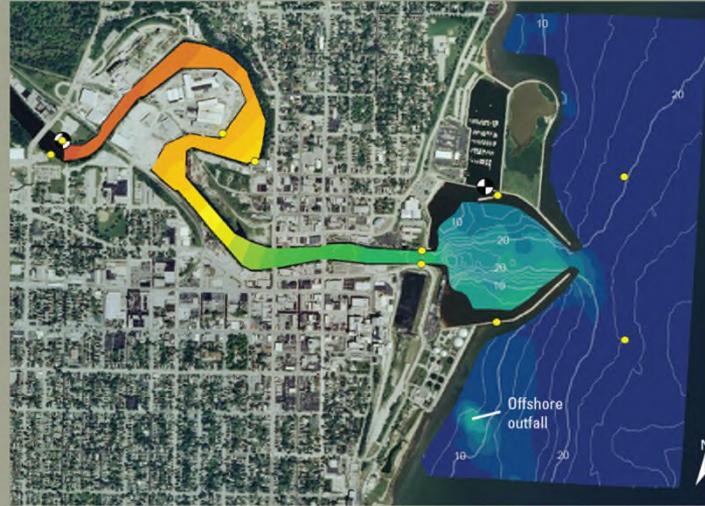


EXPLANATION

Specific conductance, in millisiemens per centimeter



Nearshore with rivermouth



EXPLANATION

Specific conductance, in millisiemens per centimeter



- U.S. Geological Survey streamflow-gaging station
- Great Lakes Rivermouth Collaboratory sampling site

B. Nearshore

Near-surface (less than 2 feet depth)



Nearshore with rivermouth

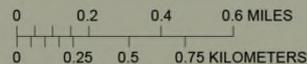


EXPLANATION

Fluorescent dissolved organic matter, in parts per billion



- U.S. Geological Survey streamflow-gaging station
- Great Lakes Rivermouth Collaboratory sampling site



Fluorescent Dissolved Organic Material (FDOM)

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

P. Ryan Jackson
pjackson@usgs.gov

Questions?

Report online:

<http://pubs.usgs.gov/sir/2014/5043/>

Acknowledgements:

National Monitoring Network

USGS Office of Water Quality

Milwaukee Metropolitan Sewerage District

USGS Wisconsin WSC

Paul Reneau

Dan Sullivan

Charlie Peters

Peter Hughes

USGS Iowa WSC

Kevin Richards

USGS Illinois WSC

Ryan Beaulin

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

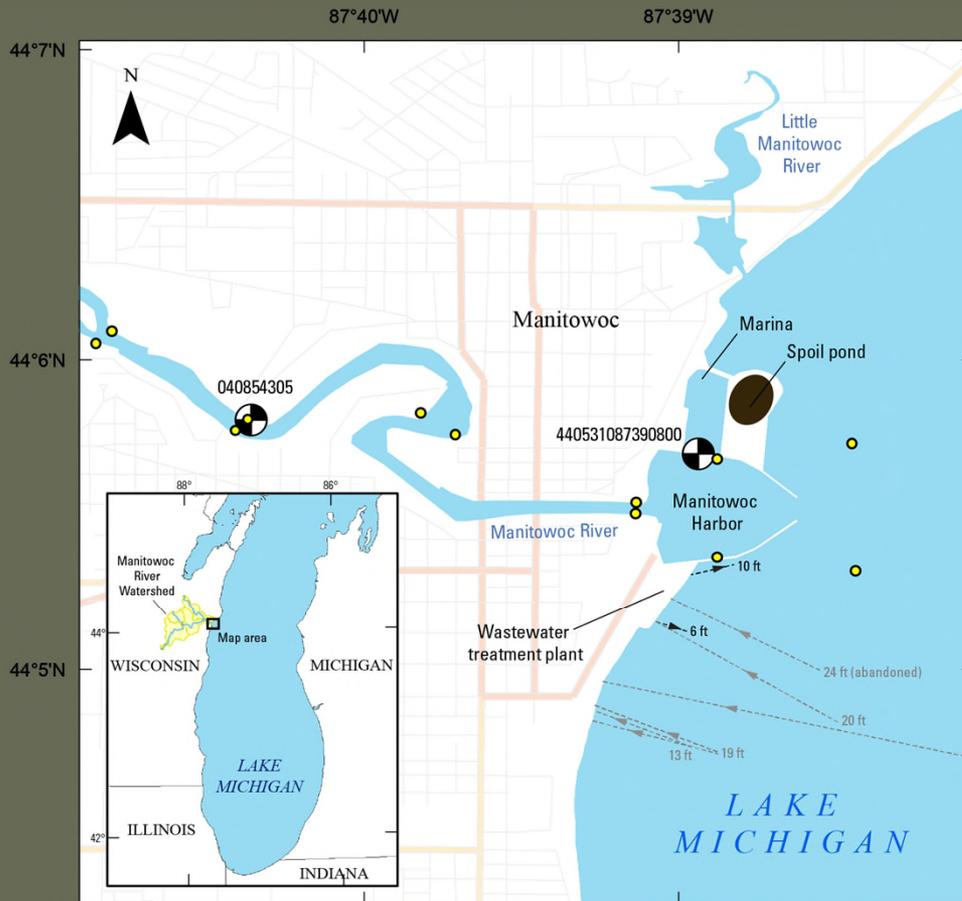
Photo courtesy of KSL News



Extra Slides

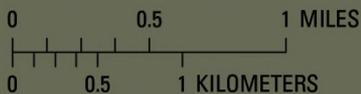
Manitowoc Rivermouth

Manitowoc Rivermouth



Base from U.S. Geological Survey National Hydrography Dataset and ESRI digital data

EXPLANATION



-  6 ft Sewage effluent outfall (with outfall depth)
-  6 ft Water intake (with depth above crib)
-  U.S. Geological Survey streamflow-gaging station with station number
-  Great Lakes Rivermouth Collaboratory monitoring locations

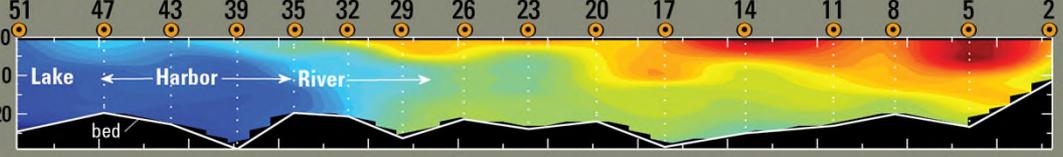
- 526 mi² drainage area
- Impaired due to
 - Phosphorus
 - Sediment
 - Coliform bacteria
- Heavily agricultural watershed with cropland and dairy waste runoff
- Dredged navigation channel in lower 2 miles
- 2011 mean annual flow of 460 cfs
- Small 20-acre harbor
- Two offshore wastewater effluent outfalls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

Manitowoc River Section



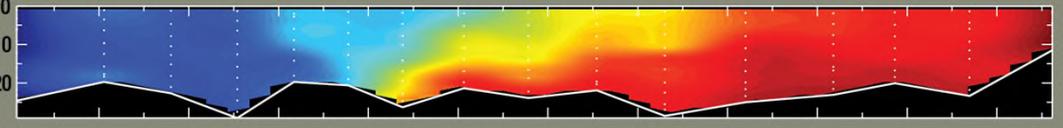
Lake water → Profile station number ← River inflow

Temp



Temperature, in degrees Celsius

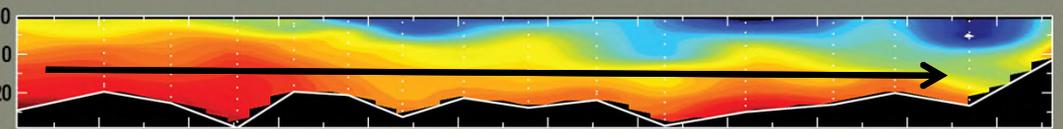
SC



Specific conductance, in millisiemens per centimeter

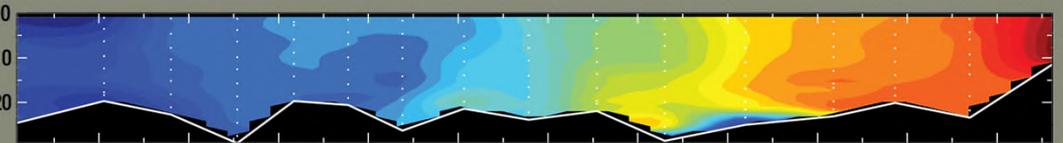
Density

Depth, in feet



Density, in kilograms per cubic meter

pH



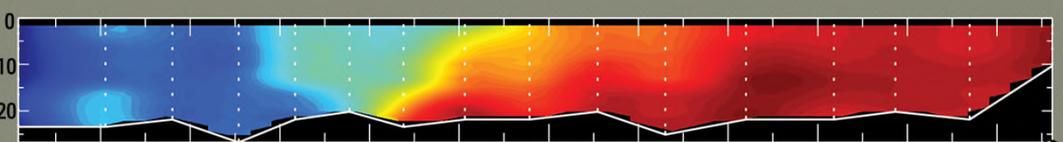
pH, in standard units

DO



Dissolved oxygen, in milligrams per liter

fDOM



Fluorescent dissolved organic matter, in parts per billion

NOTE: Lake water pushes 2 mi upstream

NOTE: Similar distributions

NOTE: DO min. (~ 0 mg/L near bed)

Distance upstream from the harbor mouth, in miles

U.S. Geological Survey streamflow-gaging station



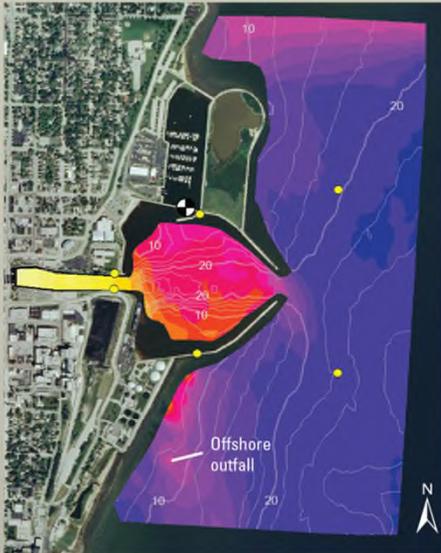
Dissolved Oxygen

September 19-20, 2011

A.

Nearshore

Near-surface (0 to 5 feet depth)



EXPLANATION

Dissolved oxygen, in milligrams per liter



Nearshore with rivermouth



EXPLANATION

Dissolved oxygen, in milligrams per liter

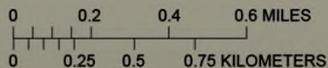
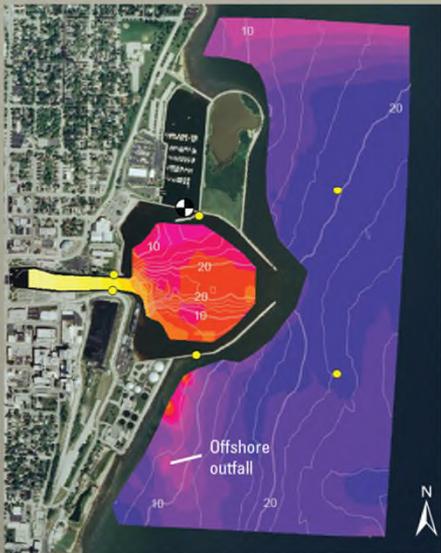


U.S. Geological Survey streamflow-gaging station

Great Lakes Rivermouth Collaboratory sampling site

B.

Near-bed (0 to 10 feet above 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