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National Water Quality Monitoring Council

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Autonomous Underwater Vehicles for Spatially and Temporally Dense Data Collection

P. Ryan Jackson

USGS Illinois Water Science Center

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

NATIONAL WATER QUALITY MONITORING COUNCIL
Working Together for Clean Water
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The National Water Quality Monitoring Network for

A Network of Networks

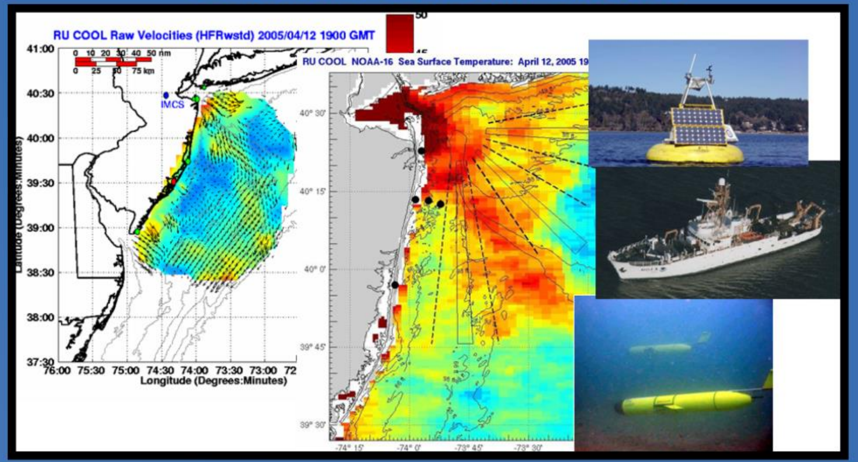
- Existing federal efforts augmented with state and local network compliant data
- National network at specified spatial and temporal density
- Conditions and trends identified at national scale
- Eighty participants in the National Water Quality Monitoring Network Design

Structure of the Design

- A continuum of observations
- Estuaries
- Nearshore
- Offshore and Exclusive Economic Zone
- Great Lakes
- Coastal Beaches
- Wetlands
- Rivers
- Atmosphere
- Groundwater

Spatially? Temporally? Both?

Offshore Coastal Waters



The offshore environment is so vast that the primary means of monitoring will be remote-sensing, shipboard surveys, and moored or drifting buoys. Similar technologies may be used to supplement observations from fixed sampling sites in coastal waters.

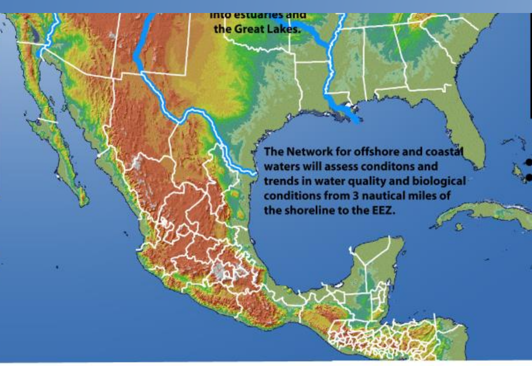
... Network for estuaries is designed ...ssess:
- ...onditions of estuarine ecosystems ...ationwide and by IOOS region,
- ...onditions of individual estuaries,
- ...ansport of contaminants through ...stuaries,
- ...hort term variability in conditions.

Samples to be Analyzed

- Physical characteristics
  - Flow, magnitude and direction; sediments, physical habitat
- Chemical constituents
  - Inorganics - major ions, nutrients, metals, mercury
  - Organics - carbon, pesticides, PCBs, PAHs, emerging contaminants
- Biological
  - Chlorophyll and algae
  - Bacteria and viruses
  - Macroinvertebrates and fish

Atmosphere

The National Atmospheric Deposition Network, National Trends Network (NADP/NTN) will be used to estimate loads of contaminants from wet and dry atmospheric deposition to rivers, estuaries, and the nearshore.



The Network for offshore and coastal waters will assess conditons and trends in water quality and biological conditions from 3 nautical miles of the shoreline to the EEZ.

...e Coastal Waters

The Network for nearshore coastal waters is designed to assess:
- conditions at nationwide and IOOS regional scales;
- regions which exceed threshold concentrations of nutrients or other constituents and the extent of hypoxia.

The Road to a Continuum of Observations…

Photo: E. Johansson; http://erikjohanssonphoto.com/work/go-road/

Rapid Development of New Sensors

- New technology, techniques, and materials have led to new and improved sensors
- Many of you are aware of these advances and some or you may be driving the R&D

- However, fewer researchers and companies are focused on development of advanced sensor platforms for inland water bodies

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Why?

- Most researchers and agencies are focused on collection of continuous time series at a point (i.e. filling the gap between samples)
- For such cases, little R&D is required aside from sensor (or surrogate) development
- However, mobile sensor platforms are incredibly useful for collection of spatially and temporally dense data (fill the gap between gages)

Mobile Sensor Platforms

Examples:

- Boat-mounted systems
- Towed instruments
- Drogues and drifters
- R/C boats
- Autonomous Underwater Vehicles (AUVs)

UAVs not AUVs are Getting the Most Attention

Development of mobile sensor platforms for terrestrial and atmospheric applications is BOOMING

5 Civilian Drone Applications:

1. Tracking evolution of hurricanes
2. 3-D mapping
3. Protecting Wildlife
4. Precision farming
5. Search and rescue

+ high altitude remote sensing

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Some drones even sample surface water

A water-collecting drone hovers at a testing site in Lincoln, Neb., in 2013.
Photo: Nati Hamik/AP

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Autonomous Underwater Vehicles (AUVs)

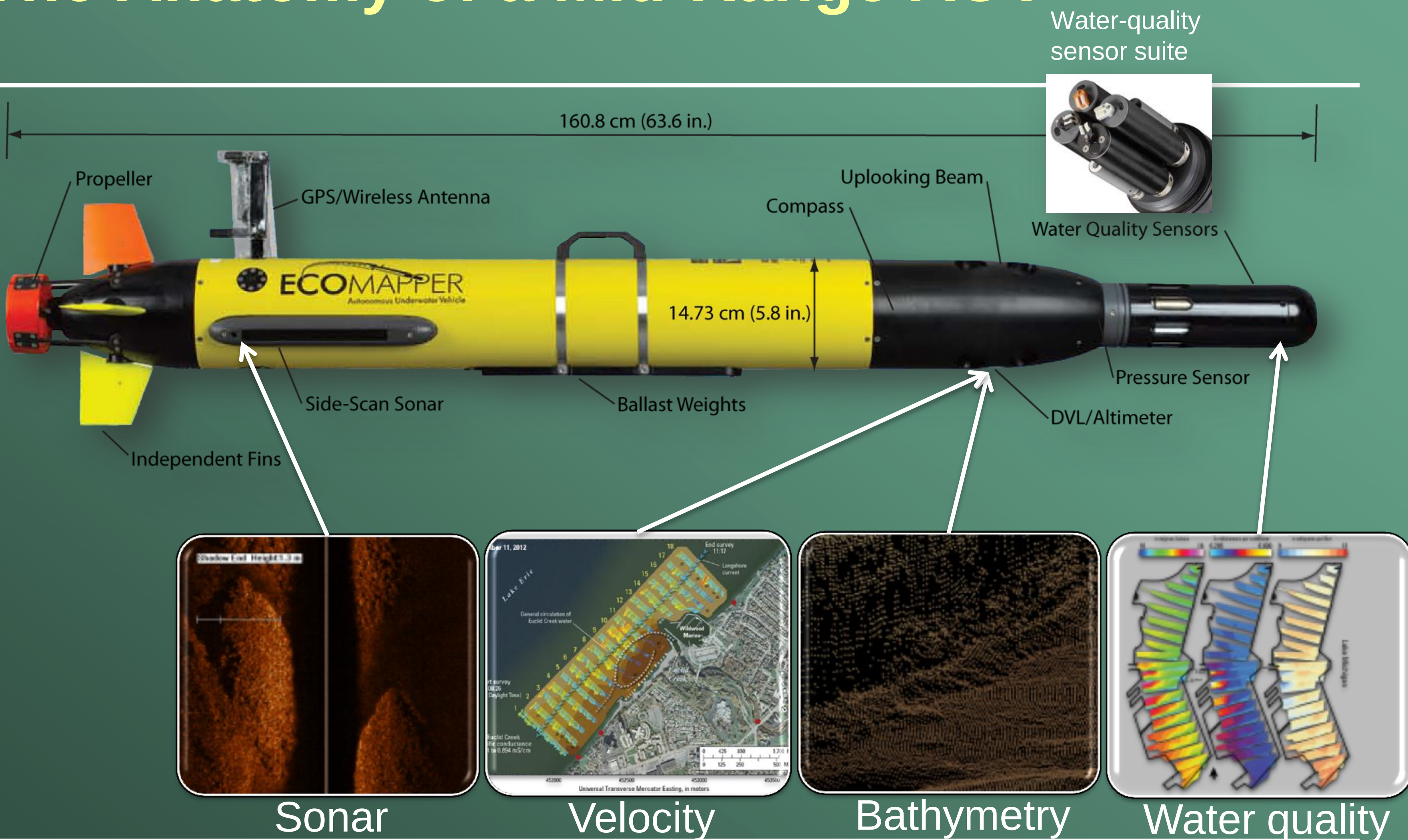
- Think of them as subsurface drones
- They come in all shapes and sizes

The MUN Explorer AUV
Source: AUVAC

The EcoMapper AUV
Source: YSI & OceanServer

The µAUV
Source: Jan Albiez, DFKI GmbH

The Anatomy of a Mid-Range AUV



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AUVs are capable of…

- Delivering sensor payloads to virtually any point in the water column
- Mapping both the water column and the bed (e.g. bathymetry, sonar imagery)
- Operating without human interaction (i.e. autonomous)
- Operating in hazardous conditions (24/7)
- Providing an integrated, geospatially-referenced data set
- <u>Saving significant man-hours in the field</u>

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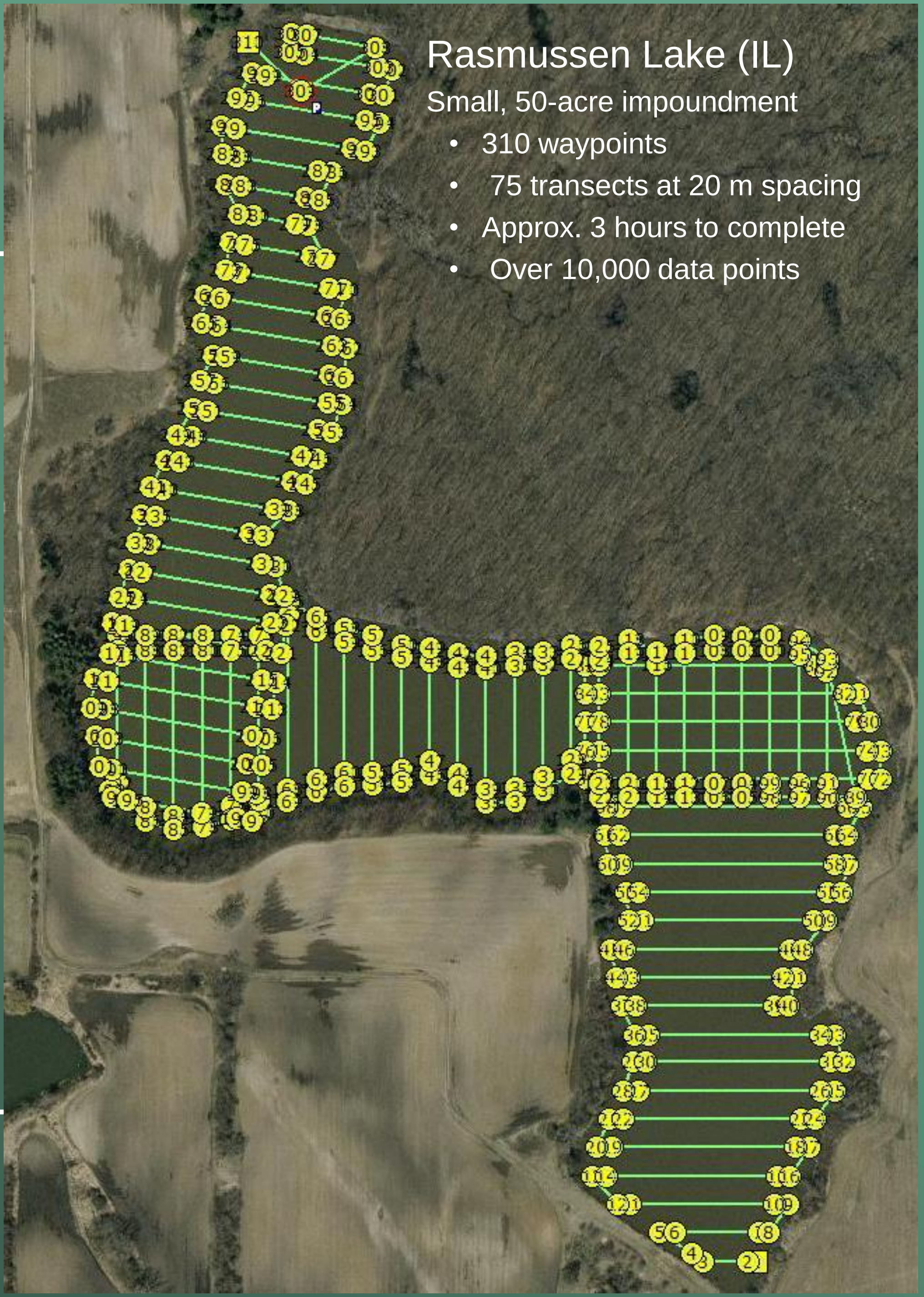
Programming a Survey

1. Import images, maps, or charts
2. Insert waypoints
3. Survey proceeds in order starting at waypoint 1
4. AUV parks at last waypoint and awaits recovery
5. If not recovered, AUV will beach itself



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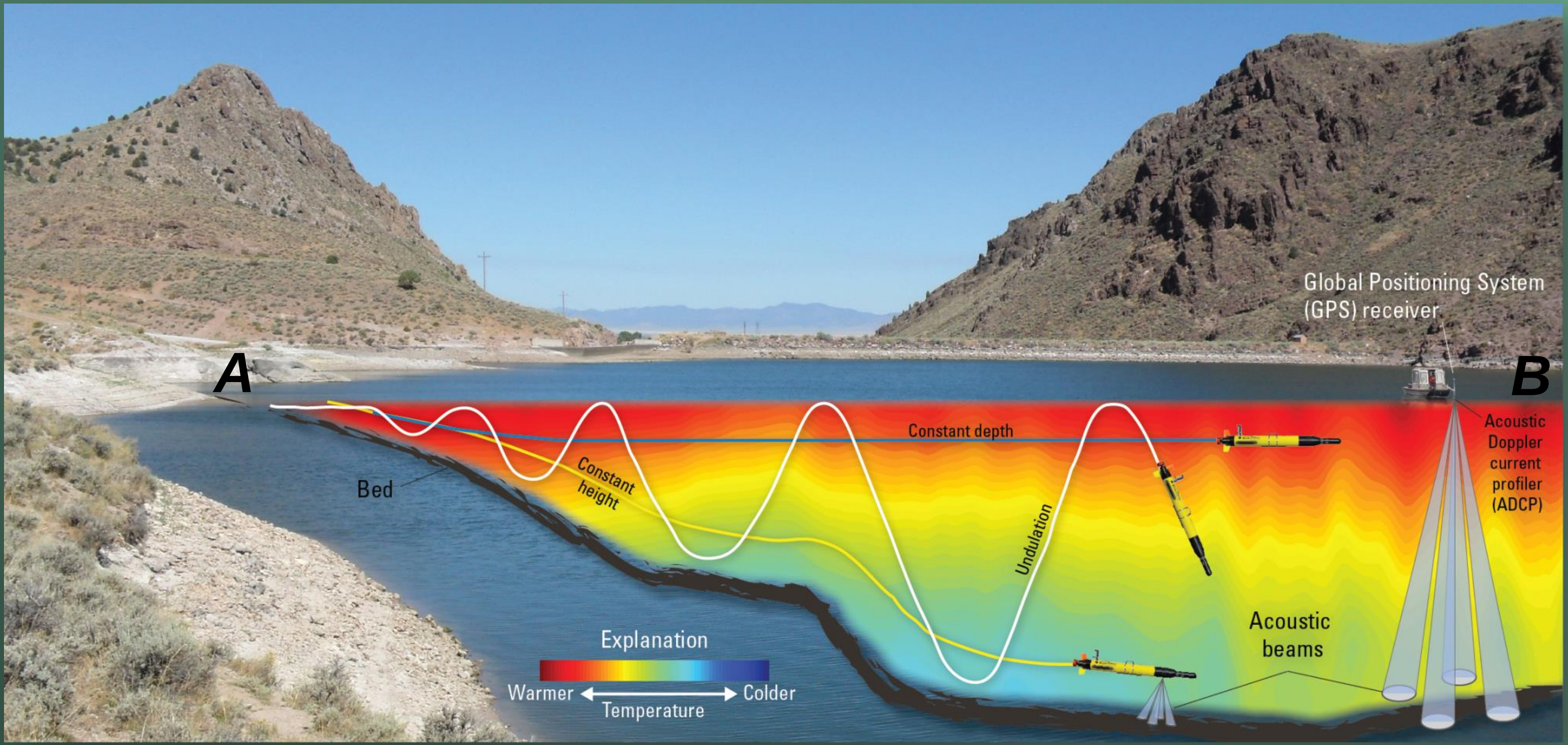
Typical AUV Survey Methods



Newcastle Reservoir, Utah

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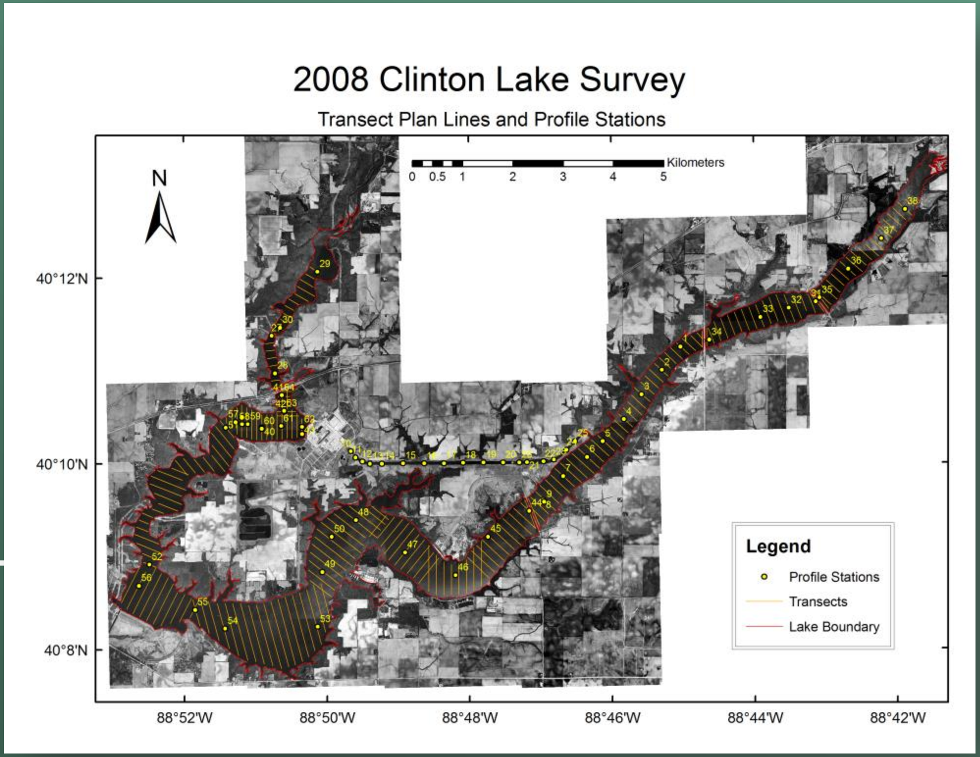
Spatially and Temporally Dense Data

- AUVs generally collect data at high rates (generally at least 1 hz)
- Survey missions can span 10’s of miles and produce hundreds of thousands of data points

Example: Clinton Lake (IL)

- 5,000 acre reservior
- 228 transects in 55 hours
- Over 190,000 data points
- 108 miles covered by AUV



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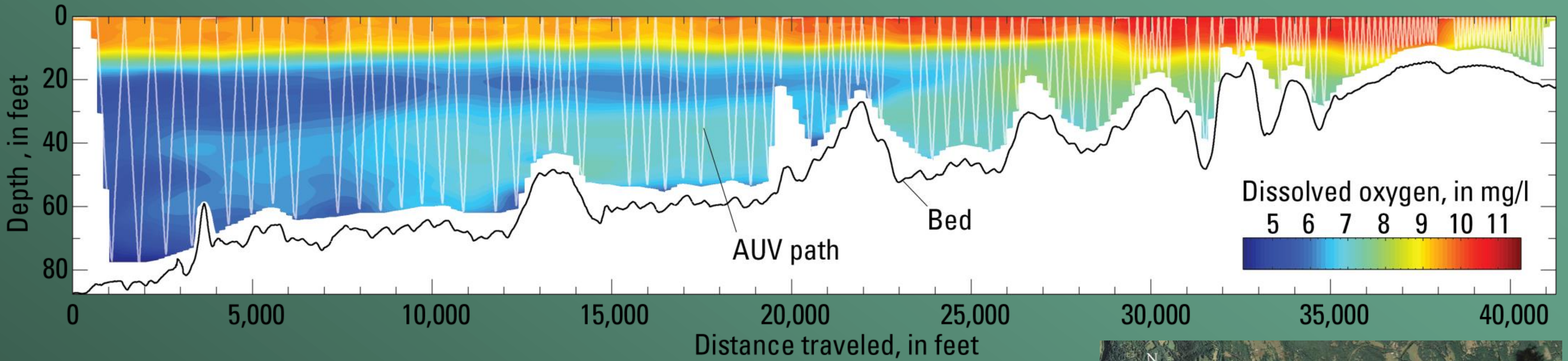
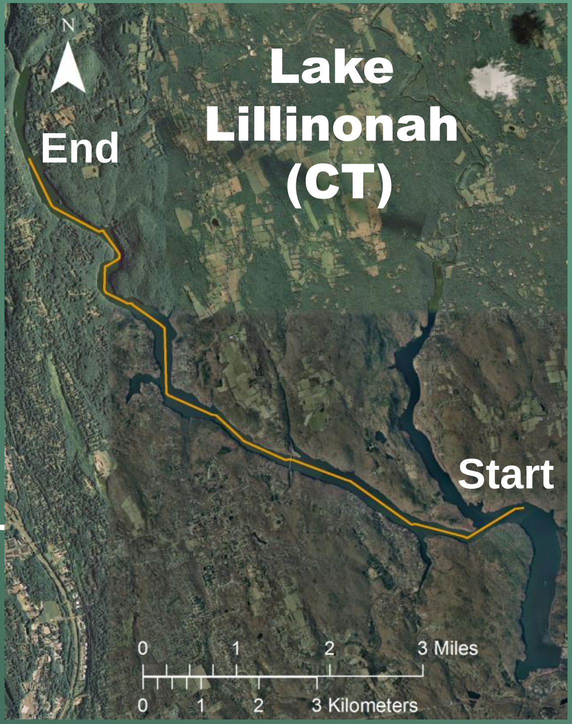
Spatially and Temporally Dense Data



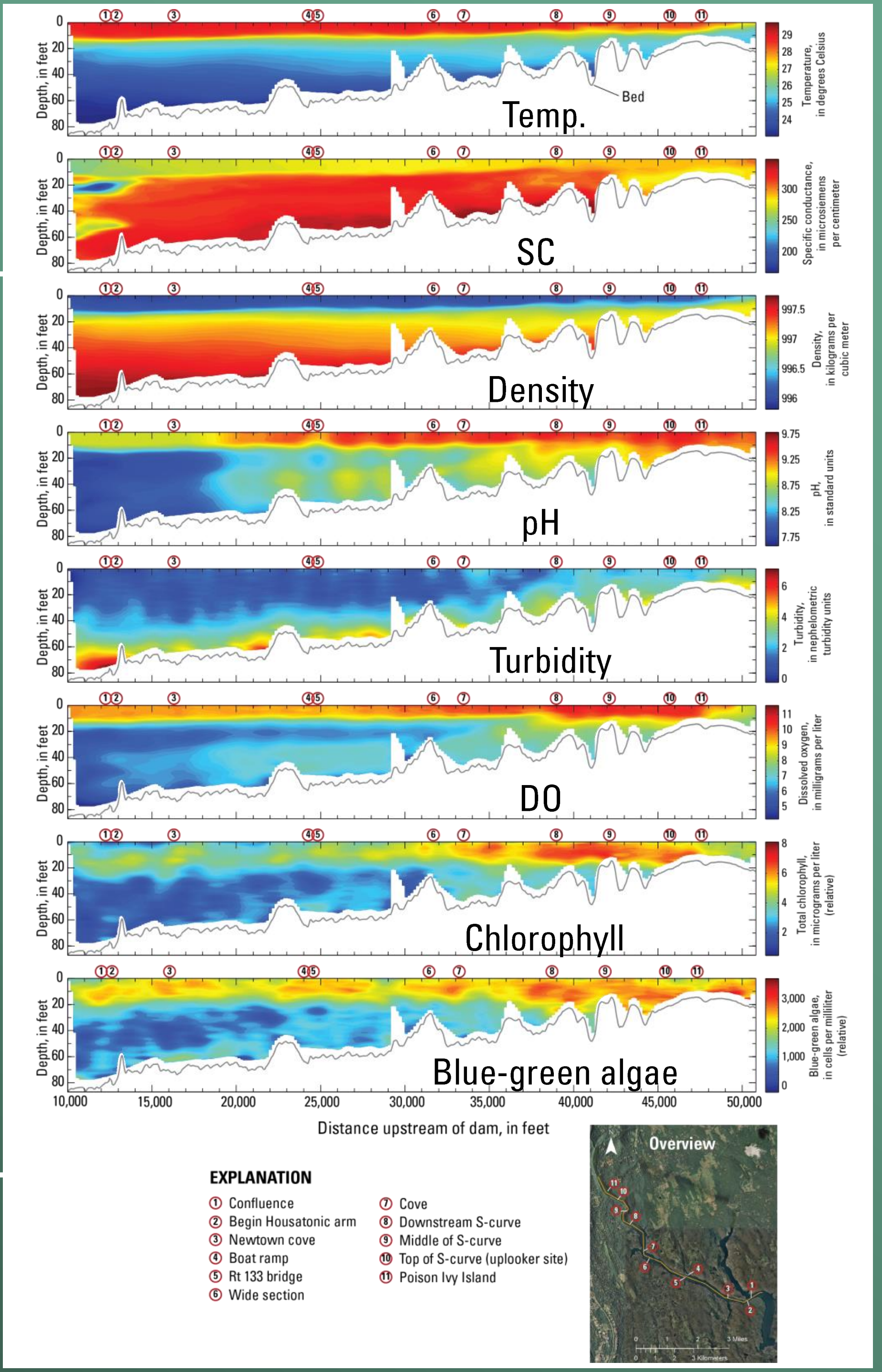
- 7.8-mile longitudinal transect
- 224 profiles of the water column
- 3.5 hours to complete*
- 12,000 data points



*minimizes temporal changes captured in spatial distribution

Multiple Parameters, One Survey

- Compatible with 6-series sensors
- EXO bulkhead is coming, but firm date
- Can add Turner sensors (e.g. hydrocarbon, FDOM)



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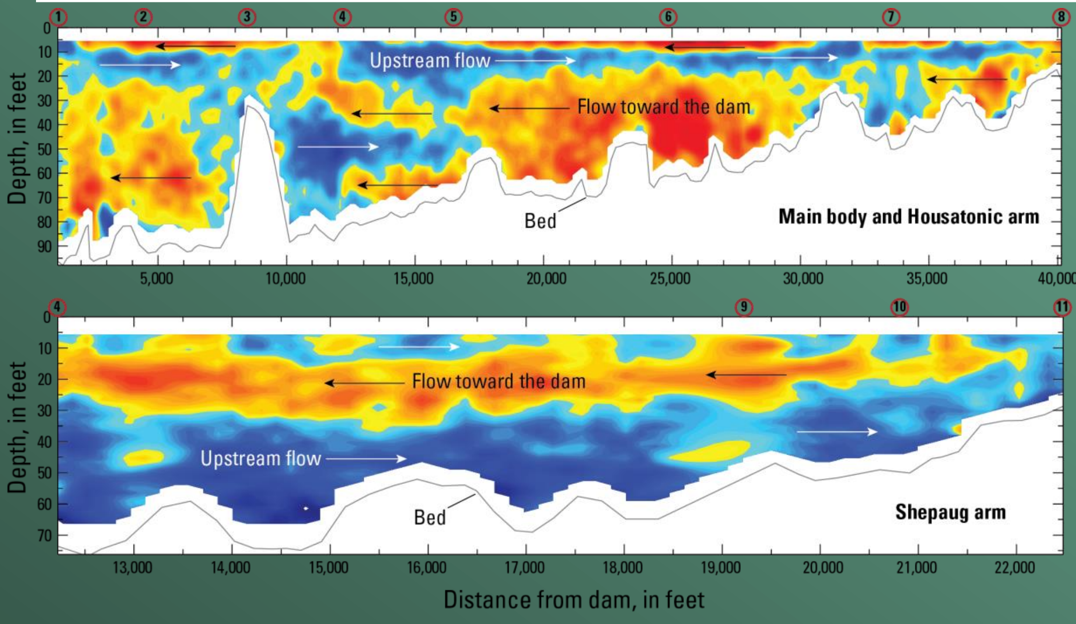
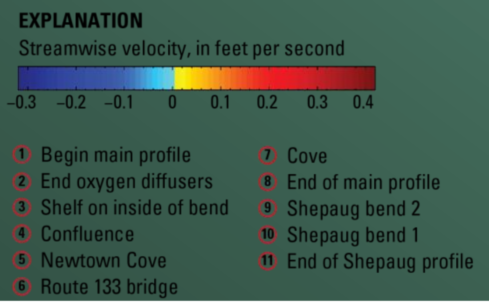
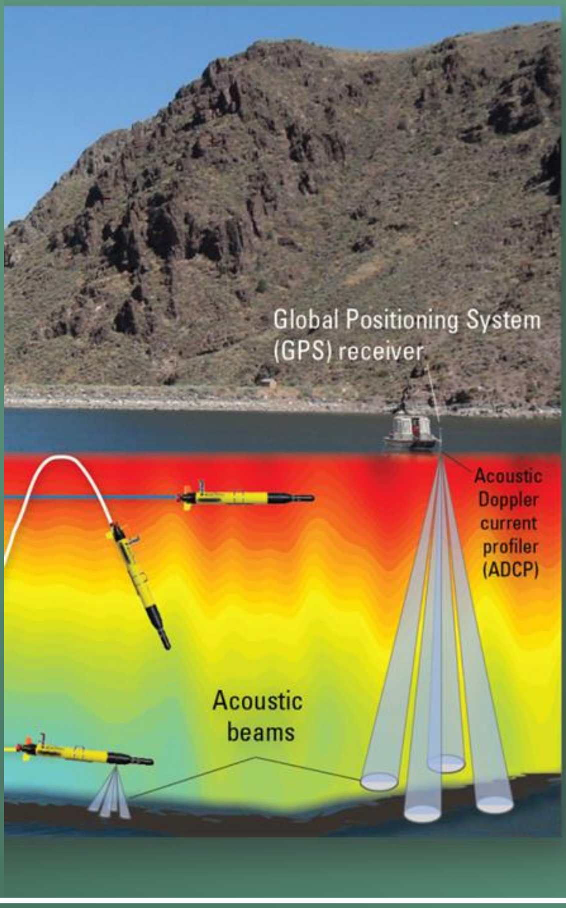
Added Value from Manned-Boat Data

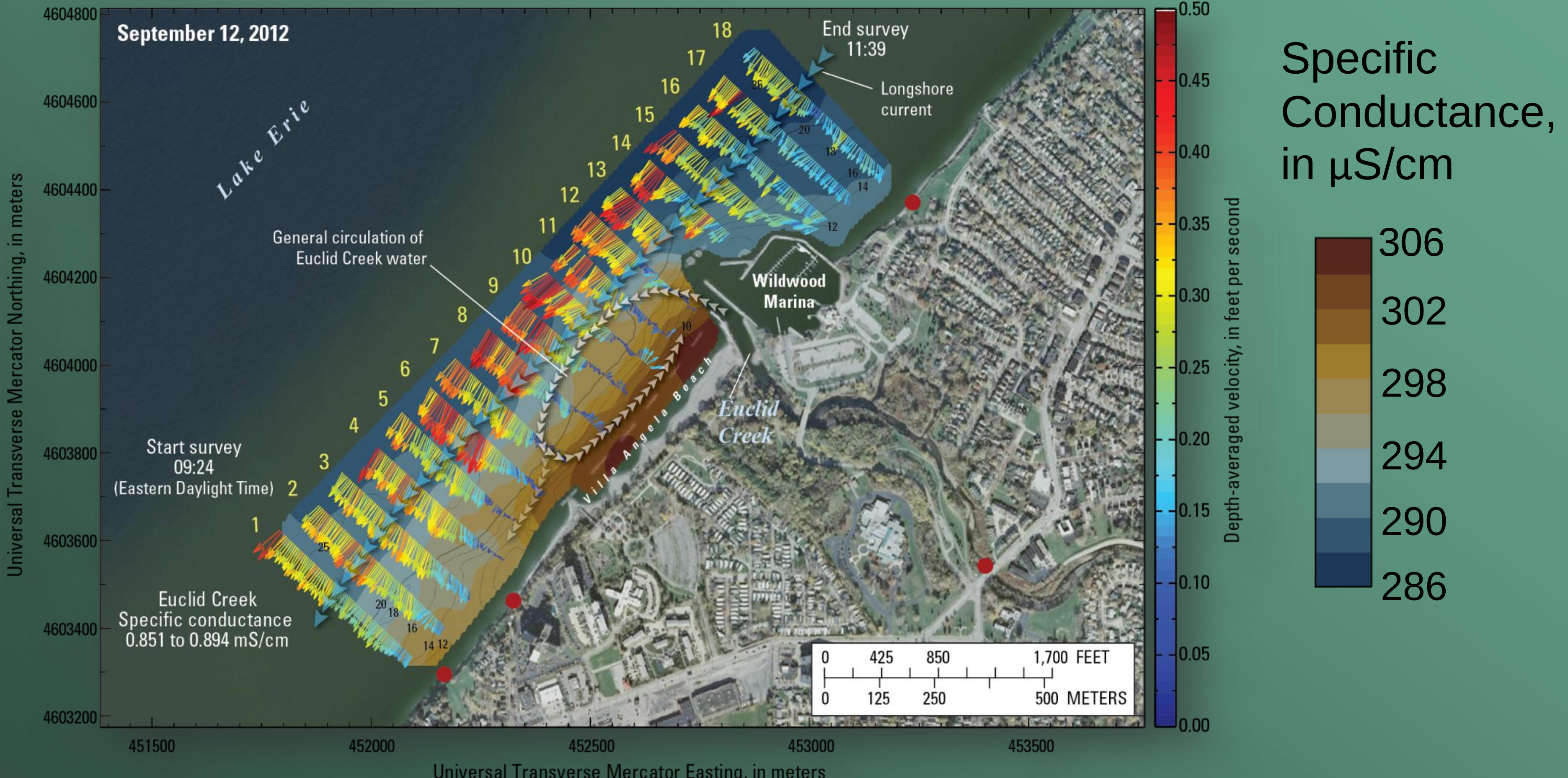






DENSE DATA CAN…

Reveal Mixing Processes



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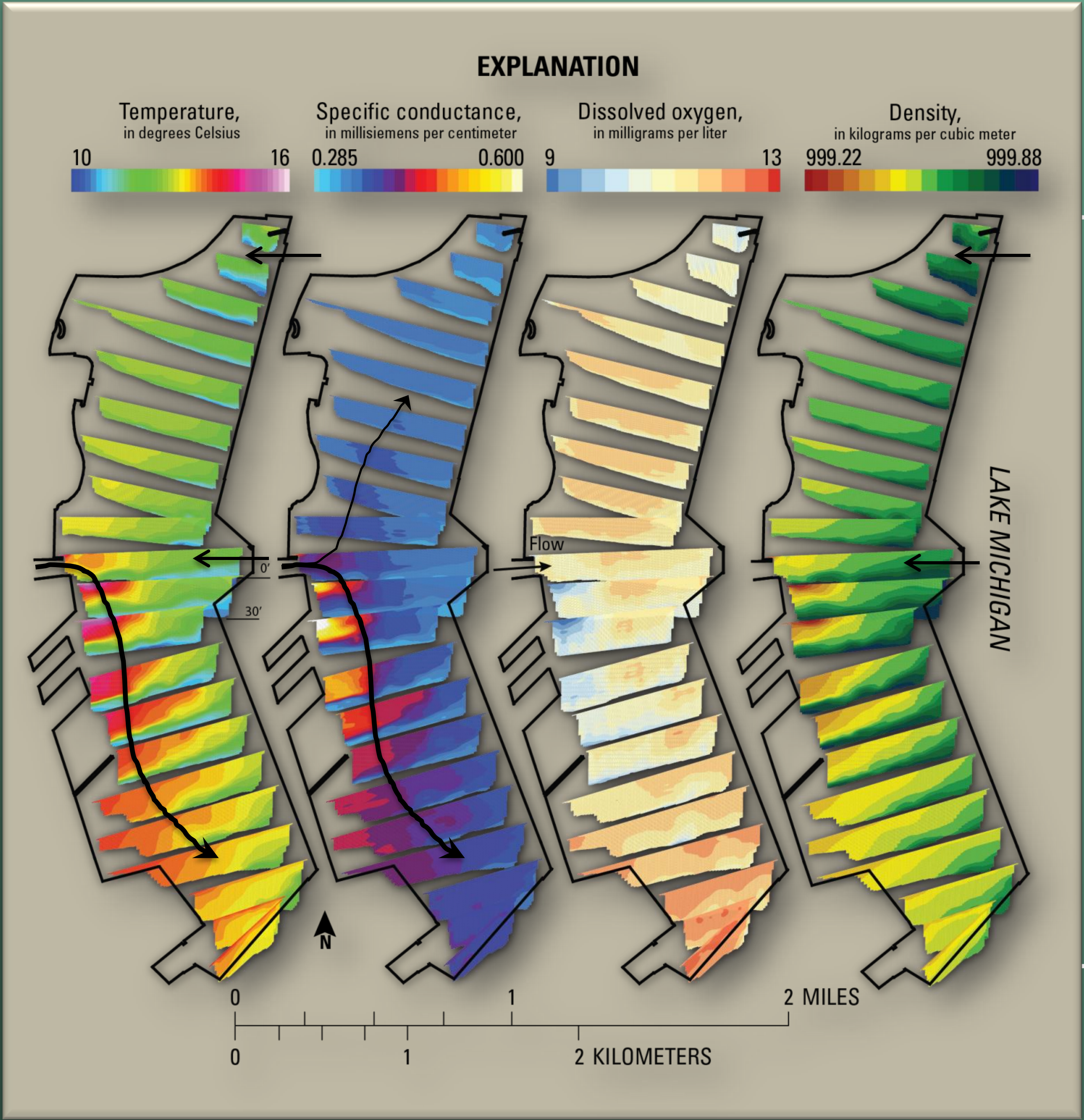

Provide Modelers with Valuable, Multi-dimensional Data

Milwaukee Harbor

***NMN Lake Michigan Pilot Project**

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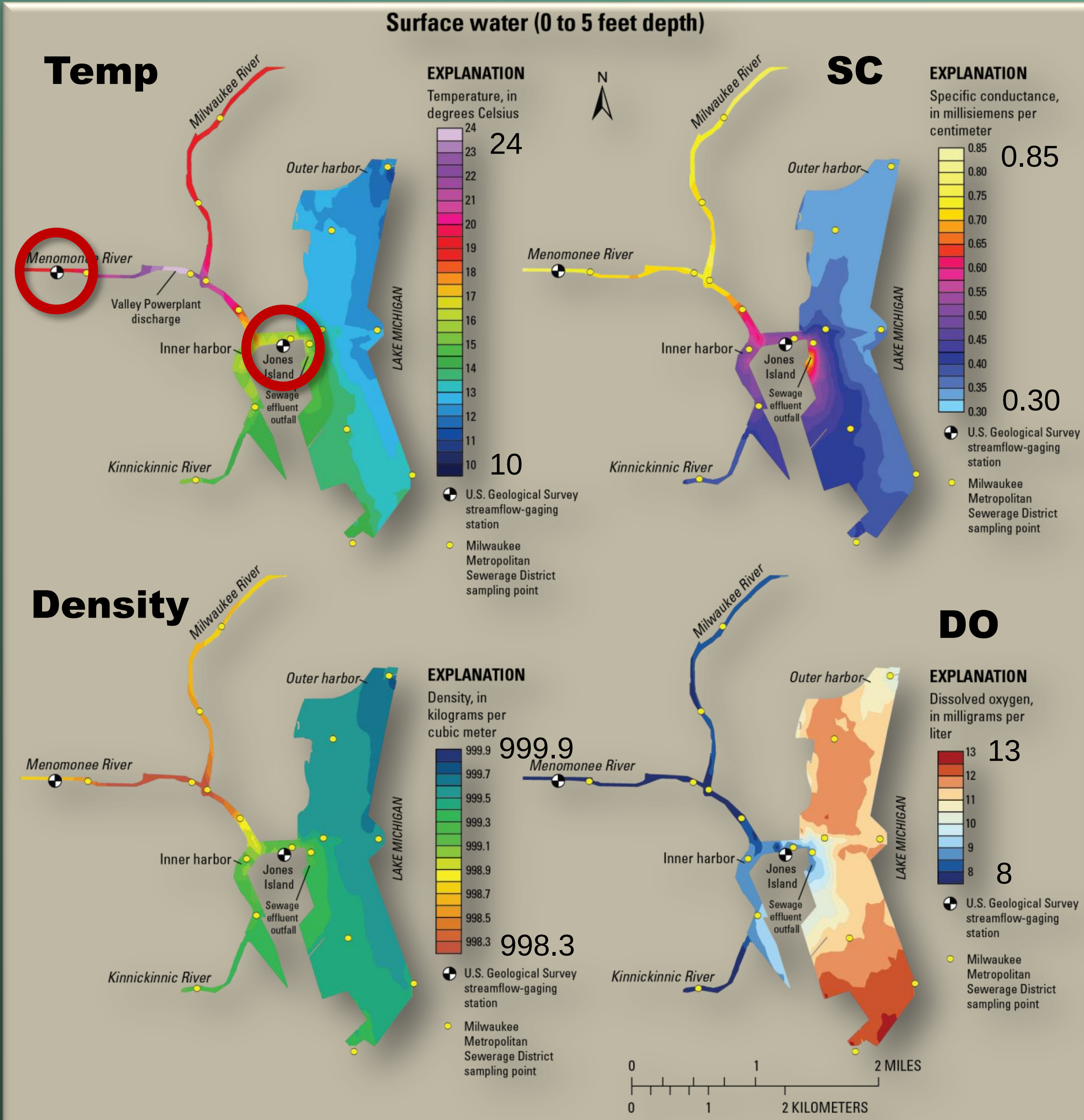
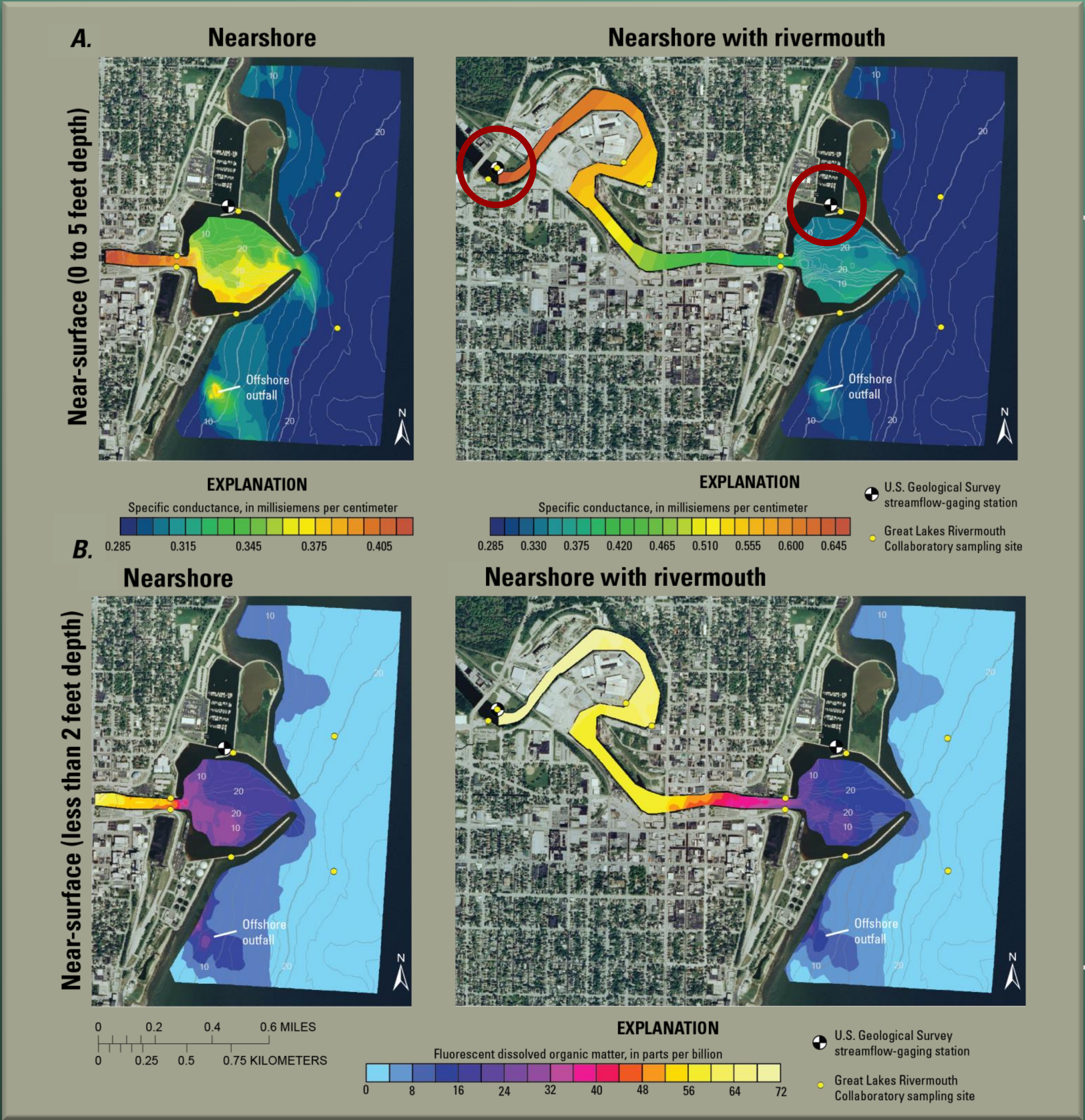


Fill the Data Gap Between Gages

Milwaukee River Estuary

SURFACE WATER
(0 – 5 FT)



Provide a Continuum of Observations

Manitowoc Rivermouth 2011

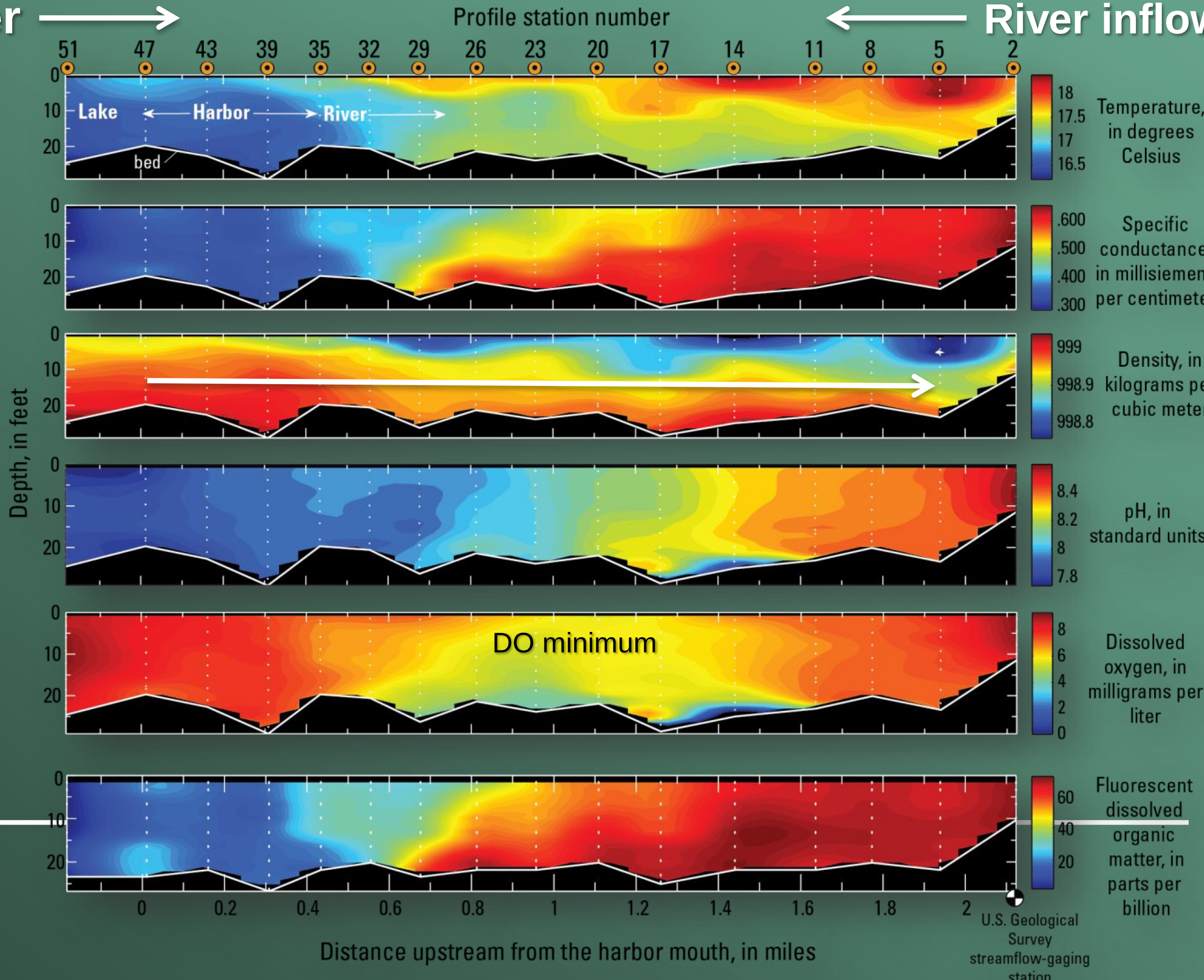
Specific Conductance

Fluorescent Dissolved Organic Material (FDOM)

Provide a Continuum of Observations

Manitowoc Rivermouth 2011

Lake water → **← River inflow**



Temp

SC

Density

pH

DO

fDOM

NOTE: Lake water pushes 2 mi upstream

NOTE: Similar distributions

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

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Speaking of continuous observations…

- St. Joseph River (IN/MI)
- 60 miles (100 km) of continuous observations
- For Asian carp spawning assessment

From: Murphy and Jackson (2013)

USGS SIR 2013-5106

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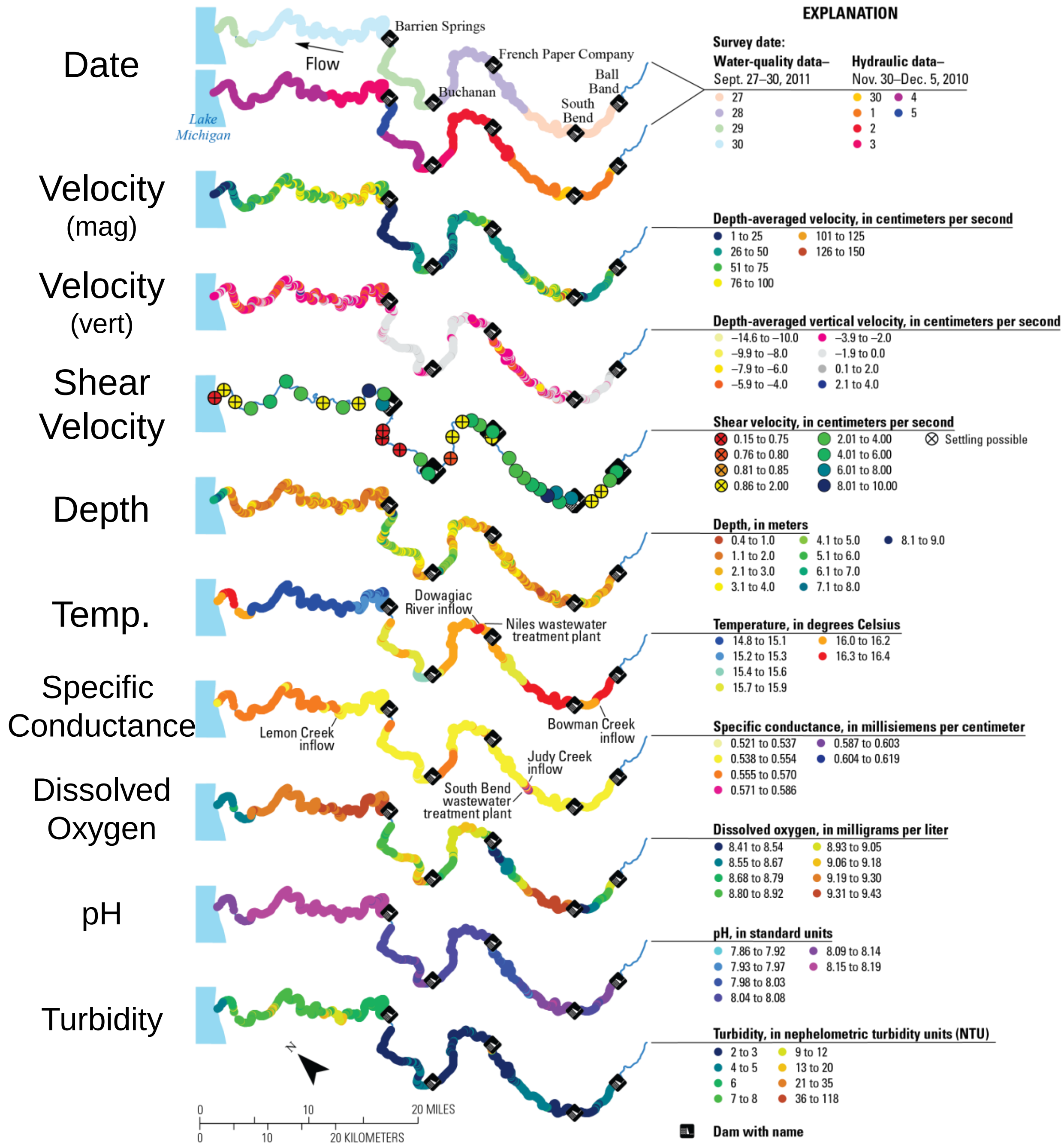
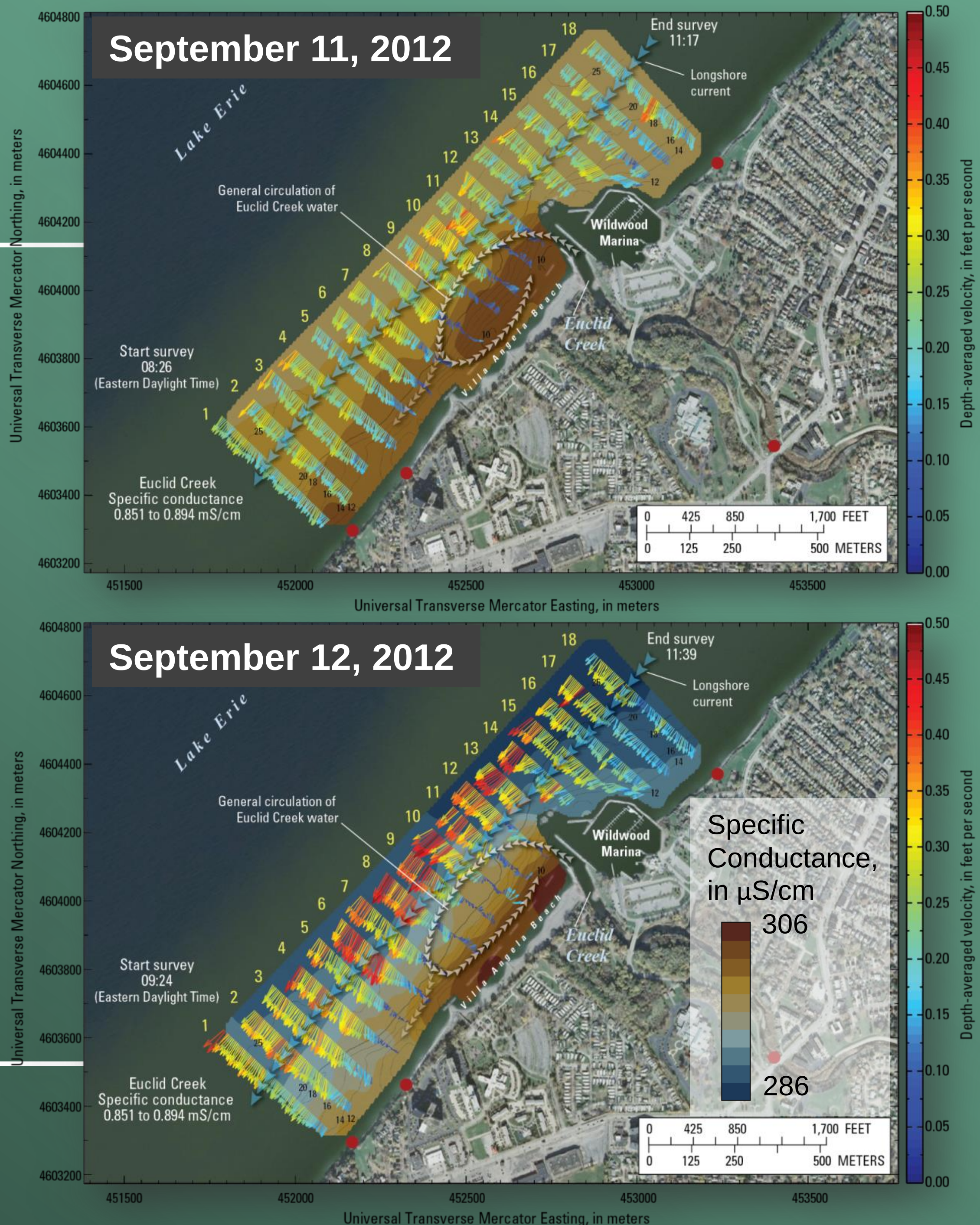


Figure 10. Hydraulic and water-quality data for the St. Joseph River, Michigan and Indiana, November 30–December 5, 2010 (hydraulic data), and September 27–30, 2011 (water-quality data).

Benefits of AUVs

- Highly efficient
- Man-hours can be used for additional sampling
- Repeat surveys yield temporal variation
- Dense integrated data can reveal underlying processes driving changes at gages and sampling points



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Limitations of AUVs

- High cost, high risk
- Accurate underwater navigation is not easy and good position control comes at a price
- Sensor payloads are limited
- Riverine applications are generally not feasible
- Data processing can be time consuming
- The learning curve can be steep and intimidate many

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Current use of AUVs in the USGS

- USGS Coastal and Marine Geology Program
  - Likely used in collaboration with WHOI, Scripps, academia, and others
  - Many instruments used by the CMG program are towed and not autonomous
- USGS Water Science Centers
  - In possession: Illinois, South Carolina, Texas
  - Formed an AUV users group in 2014
  - Considered Purchase: Missouri, Ohio, Florida
- Other Science Centers (GLSC, CERC, UMESC, etc.)
  - No AUVs in operation to my knowledge

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Future use of AUVs in the USGS

- AUVs can help guide sampling strategies
  - Identify key sampling locations
- AUVs can be a valuable tool for rapid response to water-quality emergencies
  - Spills, inundation, CSOs, etc.
- AUVs can help evaluate restoration efforts
  - Repeat surveys can yield great insight

Lake Michigan shoreline near Burns Ditch and Burns Harbor, Indiana

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Application Drives Innovation

Parting thoughts…

If your organization had access to an AUV, how would you use it?

Example: Drone craze

What might dense data reveal that data from current monitoring strategies cannot?

Mobile platforms and dense data may be one key to obtaining "a continuum of observations"

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Questions?

P. Ryan Jackson
Hydrologist
U.S. Geological Survey
Illinois Water Science Center
pjackson@usgs.gov

Special thanks to the USGS Ohio and Wisconsin Water Science Centers, the USGS Office of Water Quality, and the National Monitoring Network

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

Reports:

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

Circulation, Mixing, and Transport in Nearshore Lake Erie in the Vicinity of Villa Angela Beach and Euclid Creek, Cleveland, Ohio, September 11–12, 2012
http://pubs.usgs.gov/sir/2013/5198/

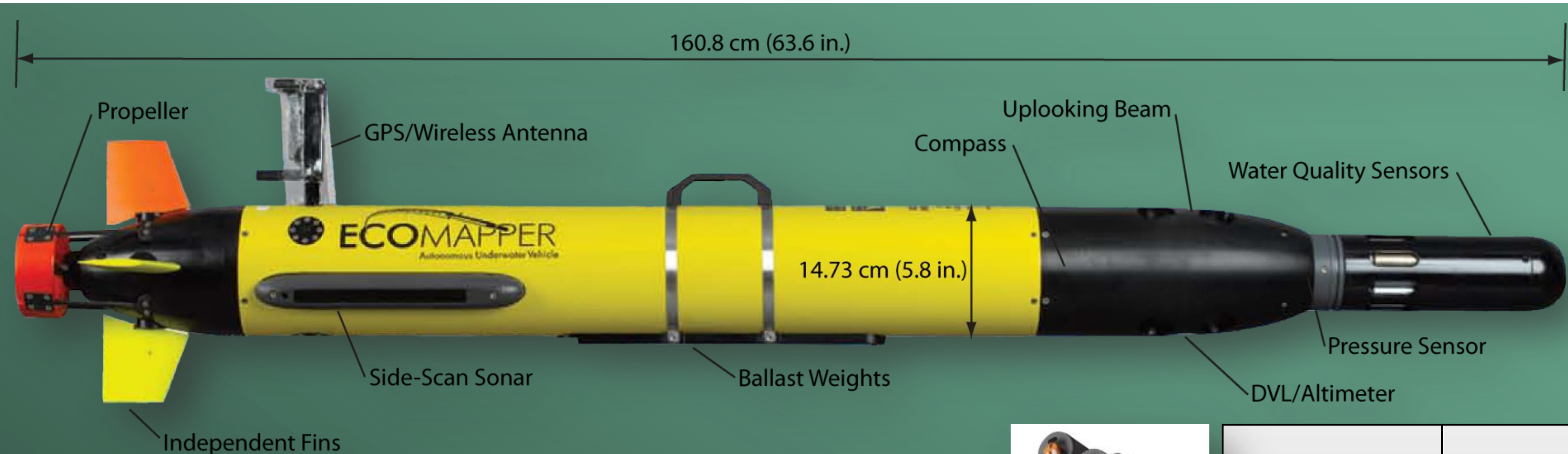
Fact Sheets:

Integrated Synoptic Surveys Using an Autonomous Underwater Vehicle and Manned Boats
http://pubs.usgs.gov/fs/2013/3018/

Visualizing Flow Fields Using Acoustic Doppler Current Profilers and the Velocity Mapping Toolbox
http://pubs.usgs.gov/fs/2013/3028/

EXTRA SLIDES

Tools for Integrated Synoptic Surveys:
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

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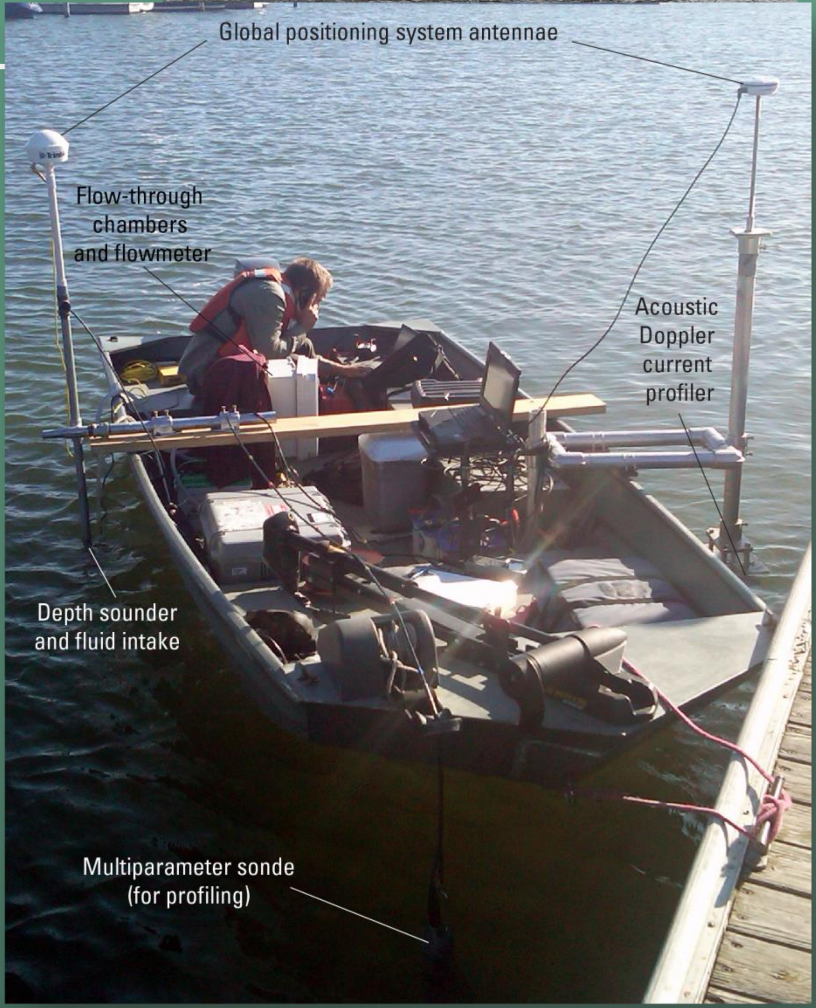
Instrumentation

Manned Survey Vessel

- **16-25 ft survey boat**
- **600 or 1200 kHz TRDI Rio Grande ADCP**
- **Hemisphere Crescent A100 Smart Antenna (dGPS)**
- **HYPACK® navigation software**
- **Multiparameter sonde**
  - **Insitu or flow-through system with FDOM**



Water-Quality Distribution

Sections September 11, 2012 (am)