What’s in a lake? An overview of cutting-edge lake survey technologies

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U.S. Geological Survey

water quality
water supply
turbidity
drinking water
weeds
sedimentation
irrigation
swimming
management
energy
ecology
toxins
algae
LAKES
watershed
bacteria
flood control
fishing
infrastructure
ecosystems
boating
recreation
capacity
invasive species

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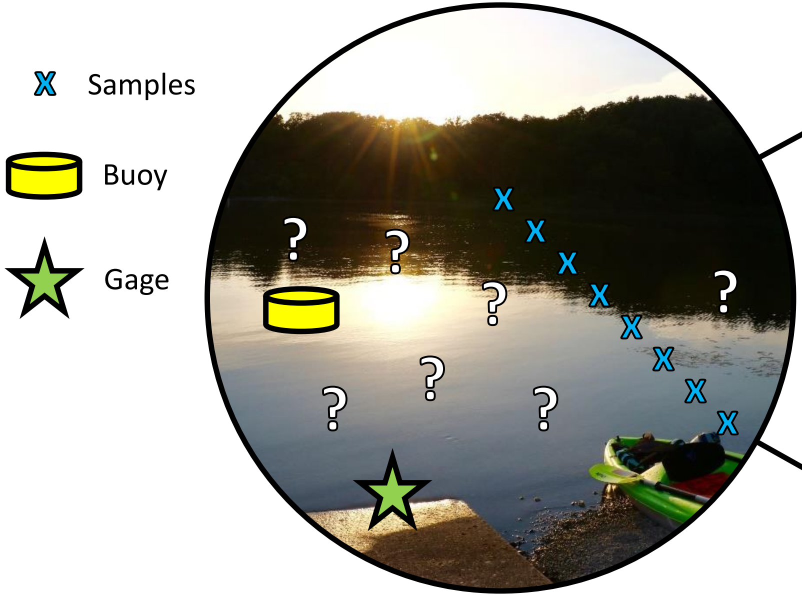
What do we want to know?



QUALITY

- Temperature
- Turbidity/suspended sediment
- pH/alkalinity
- Dissolved oxygen
- Bacteria
- Algae
- Nutrients
- Specific conductance
- Etc.

QUANTITY

- Water level
- Bathymetric maps
- Lake capacity (surface area – capacity tables)
- Sedimentation or erosion rates

Photo: Cedar Lake, Carbondale, IL (cr: City of Carbondale)

How can we fill the gaps between gages/buoys/samples?

How can we get at water **quantity**?

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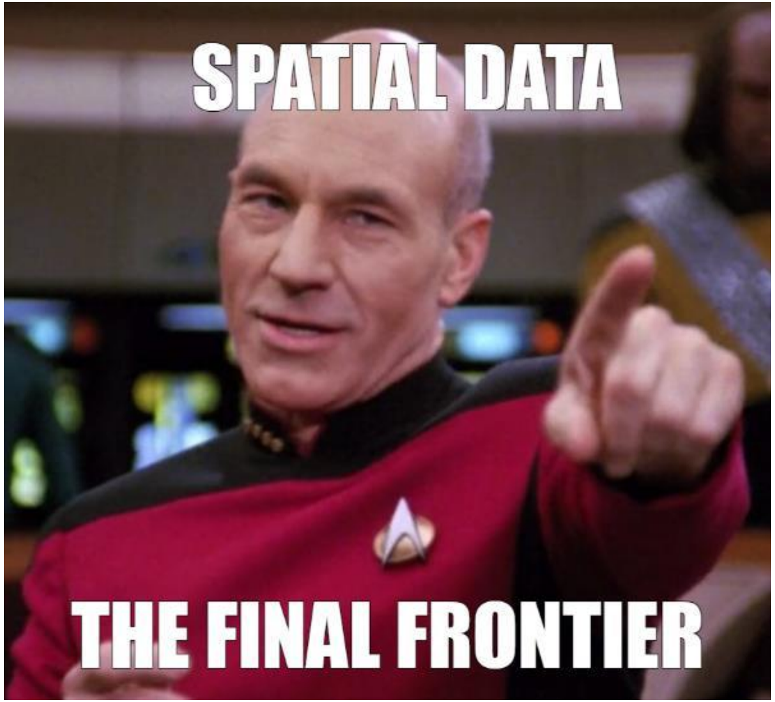
Mapping bathymetry and water quality in lakes

A mapping approach fills **SPACE** with data in three-dimensions



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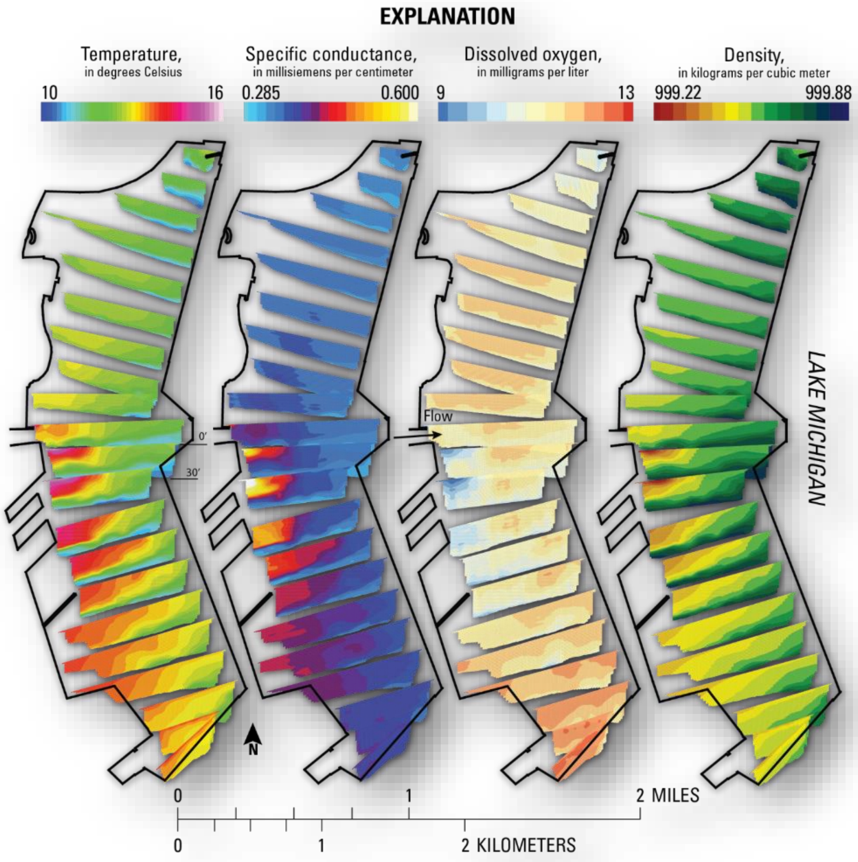
Mapping bathymetry and water quality in lakes

A mapping approach fills **SPACE** with data in three-dimensions

✓ QUANTIFY
✓ VISUALIZE
✓ CONNECT

↓

UNDERLYING PROCESSES



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What can we measure?

Hydroacoustics

WATER SOUND

Bathymetry: single-beam echosounder, multi-beam echosounder (MBES)

Velocity: acoustic doppler current profiler (ADCP)

Water quality sensors

Temperature
Specific conductance
pH
Turbidity
Dissolved oxygen
Chlorophyll
Blue-green algae

Integrated with GPS

USGS

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Mapping bathymetry and water quality in lakes

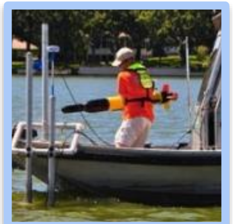
spatially dense, georeferenced data is needed for mapping bathymetry and water quality

It helps to be mobile!

Manned Boat

(boat-mounted and towed instruments)

RC Boat



Autonomous Underwater Vehicles (AUV)

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Global positioning system antennae
Flow-through chambers and flowmeter
Acoustic Doppler current profiler
epth sounder
d fluid intake
Multiparameter sonde (for profiling)


U.S. GEOLOGICAL SURVEY


M/V Iroquois
U.S. Geological Survey
Urbana, Illinois

Bathymetry

USGS

Bathymetry

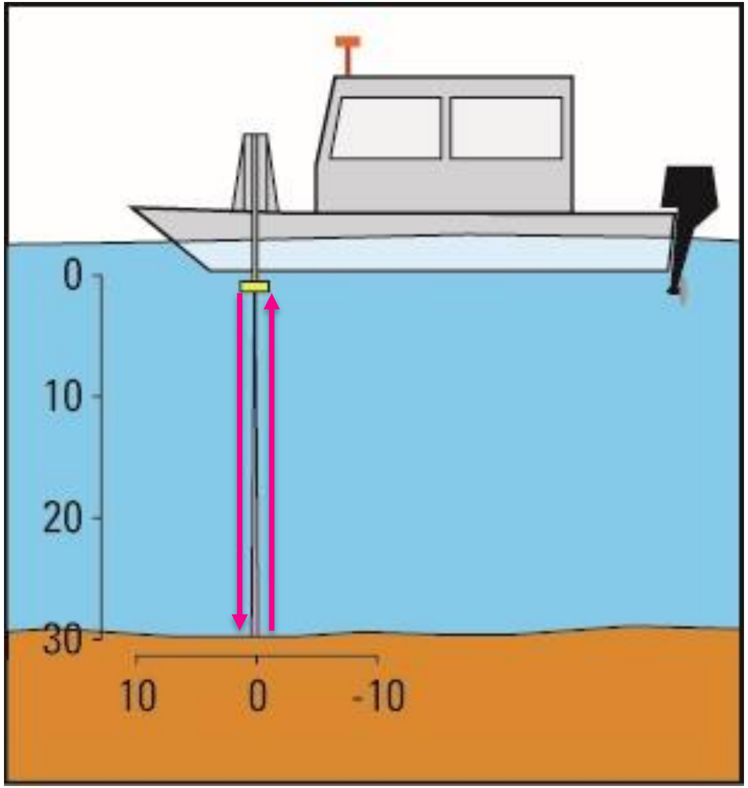
Echosounders measure depth by timing how long it takes for a "beam" of sound to travel from the instrument to the bed and back

$$speed = \frac{distance}{time}$$

$$speed\ of\ sound\ in\ water = \frac{2\ x\ depth}{time\ elapsed}$$

known

measured



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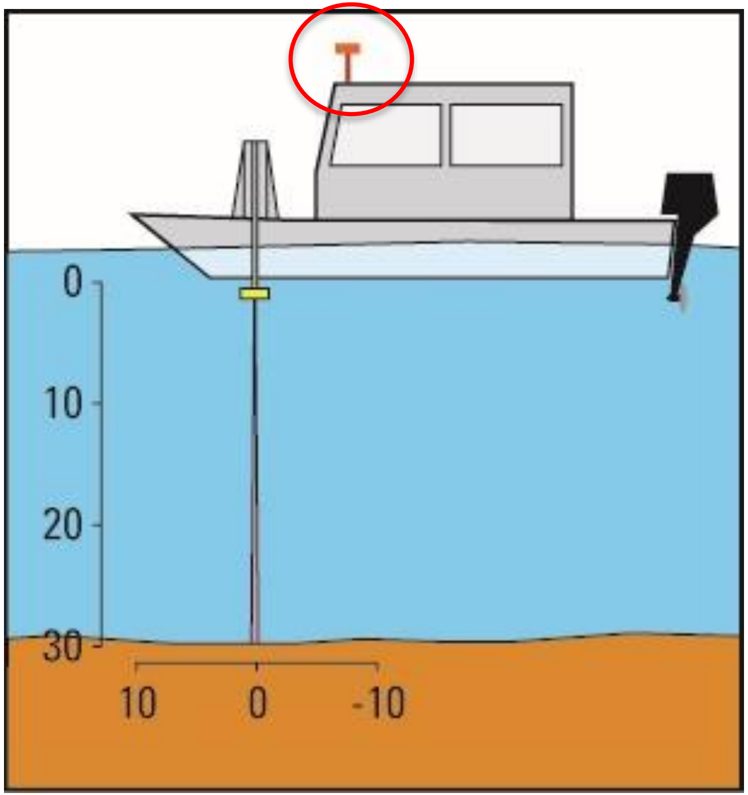
Bathymetry

GPS data allows the measured depths to be mapped in space

If the vertical accuracy of the GPS is good enough, the depths can also be converted to bed elevations



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Bathymetry

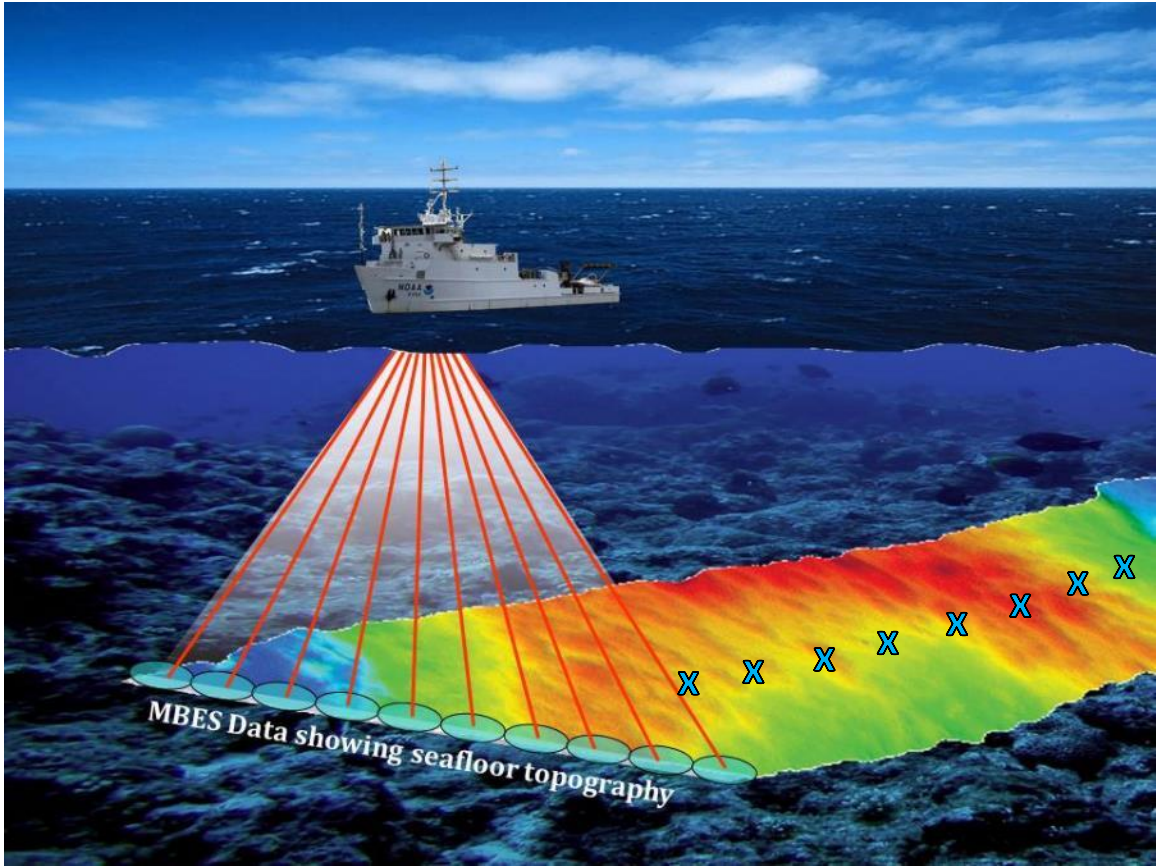
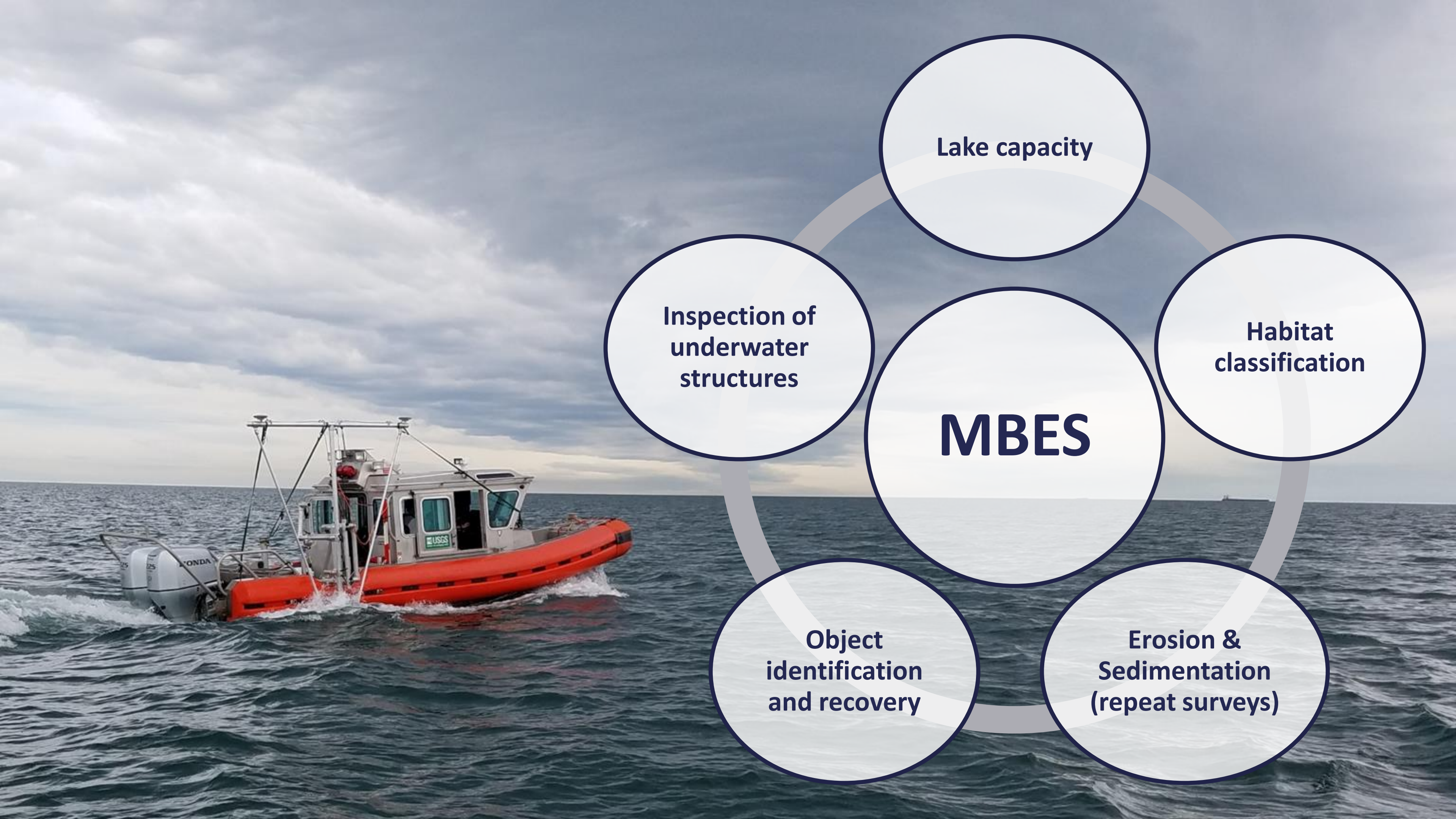


Image from NOAA Photo Library

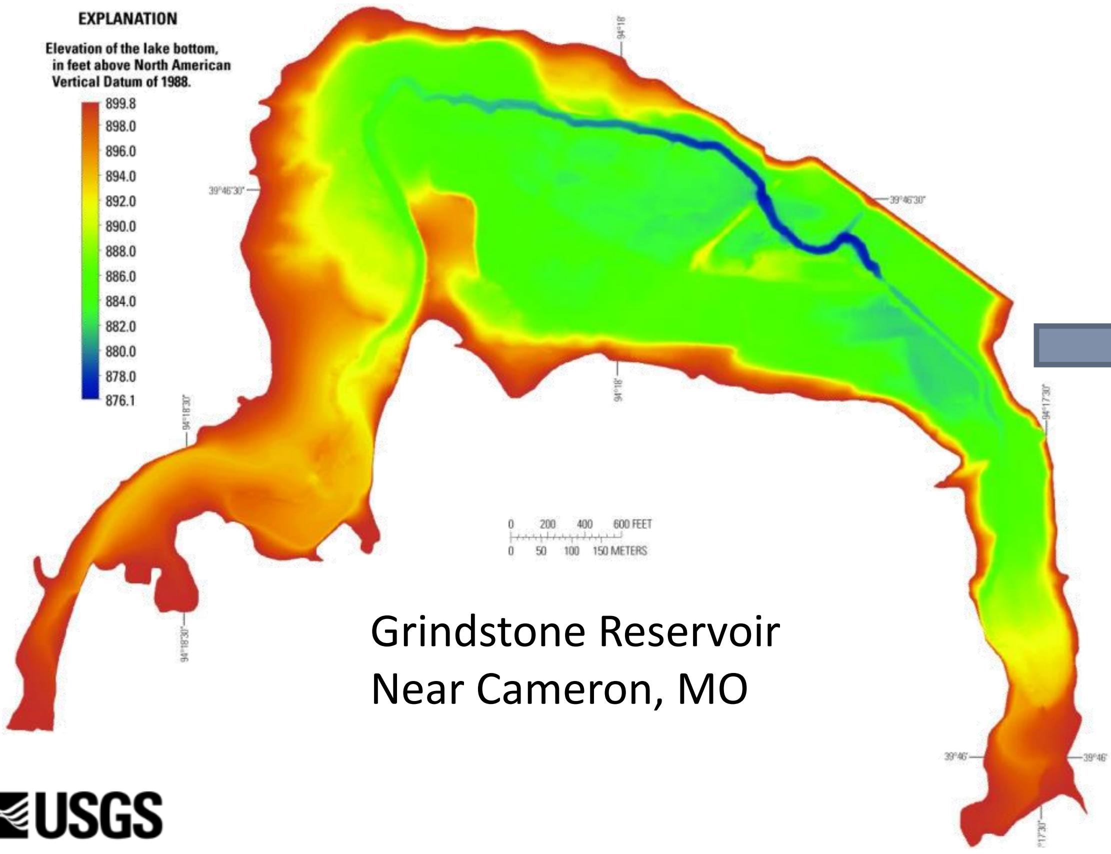
Single-beam: point
Multi-beam (MBES): “swath”

MBES are integrated with a dual antenna GPS system AND a motion sensor…high resolution and high accuracy bathymetry



MBES
Lake capacity
Habitat classification
Erosion & Sedimentation (repeat surveys)
Object identification and recovery
Inspection of underwater structures
USGS
HONDA

Bathymetry → Surface Area – Capacity Table



Grindstone Reservoir
Near Cameron, MO

Table 7. Area and capacity at specified elevations for Grindstone Reservoir near Cameron, Missouri, on July 2, 2013.

[The average water-surface elevation during the survey was 900.4 feet above the North American Vertical Datum of 1988; volumes calculated from bathymetric surface with mean total propagated uncertainty of 0.51 feet]

Elevation, in feet	Area, in acres	Capacity, in acre-feet
878.0	1.38	1.10
880.0	2.66	5.01
882.0	8.61	13.8
884.0	41.3	58.0
886.0	74.0	175
888.0	90.8	342
890.0	107	540
892.0	119	766
894.0	134	1,020
896.0	155	1,310
898.0	175	1,640
899.8	196	1,960

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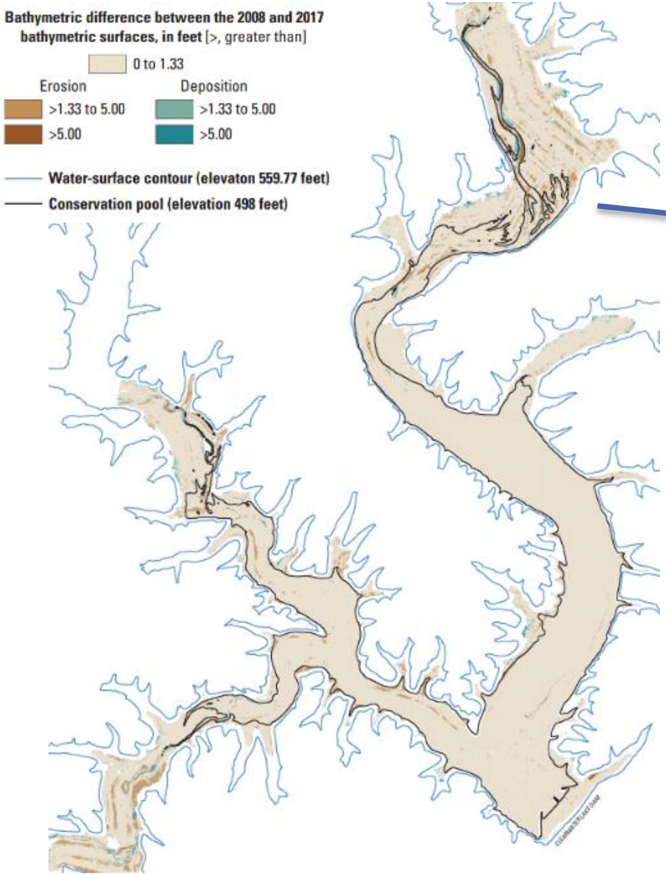
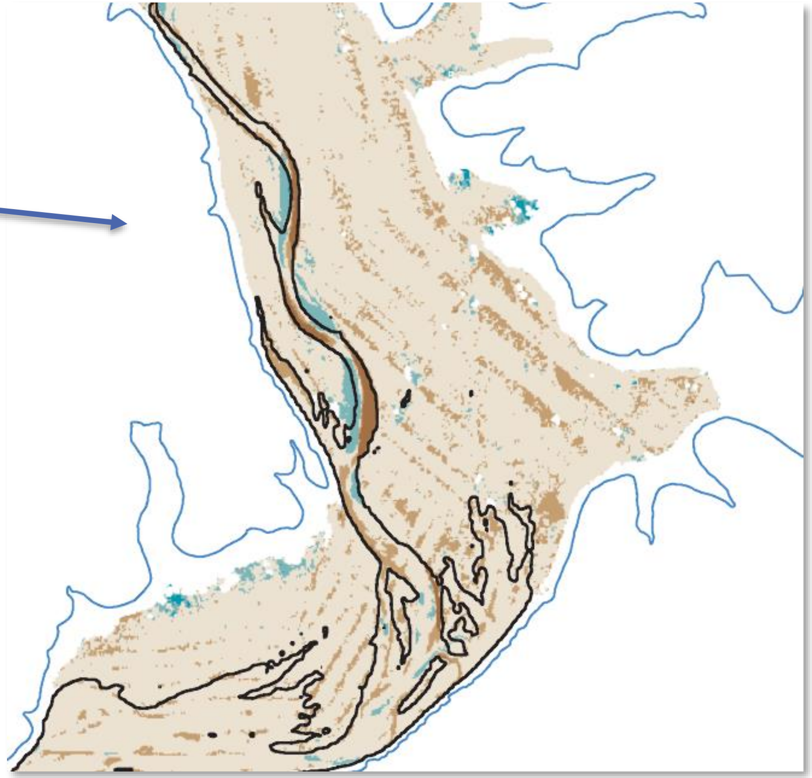
https://pubs.usgs.gov/of/2014/1005/pdf/of2014-1005.pdf

Bathymetry → Erosion/Sedimentation





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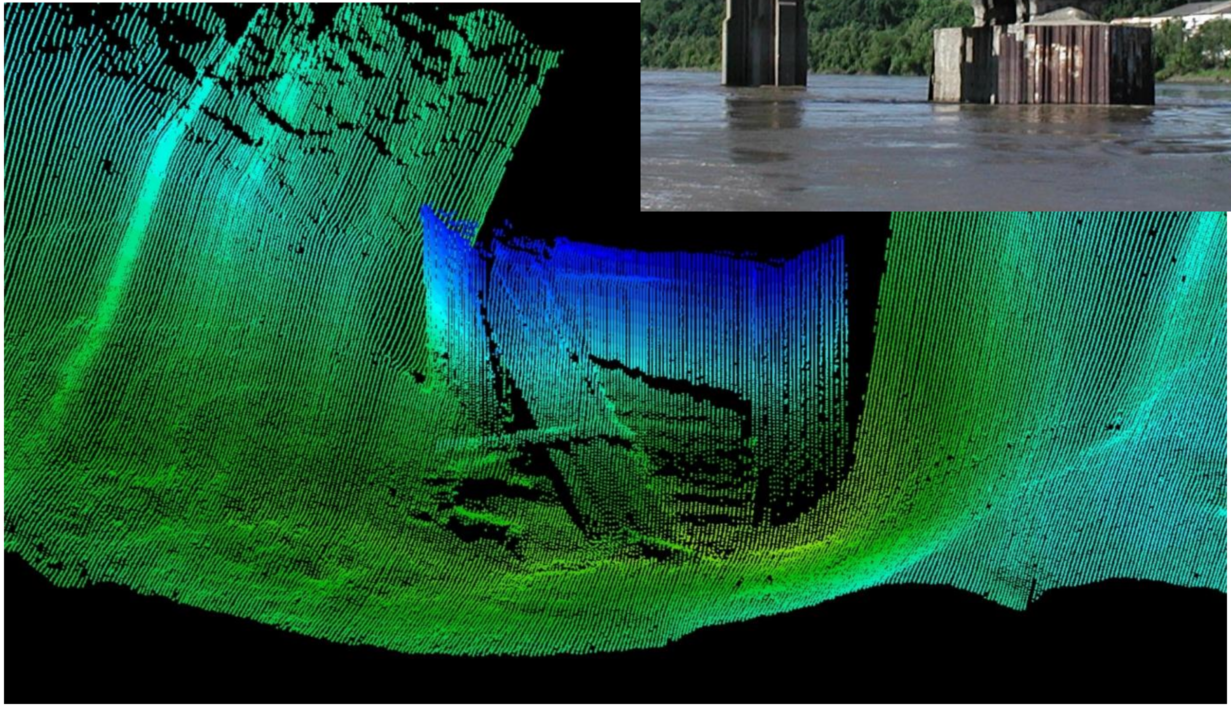
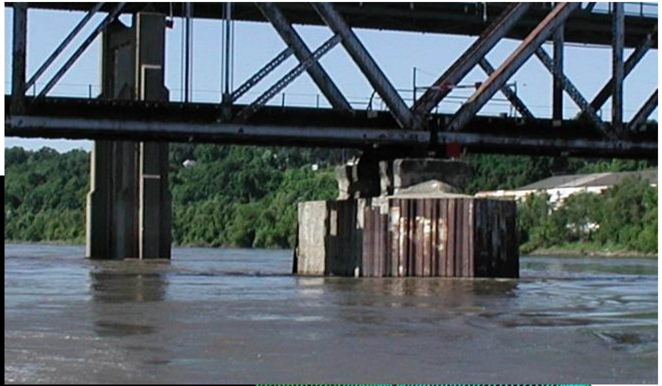
https://doi.org/10.3133/sim3409

Bathymetry → Inspection of underwater structures

Missouri River at
Atchison, Kansas

Oblique view of U.S.
Railroad bridge





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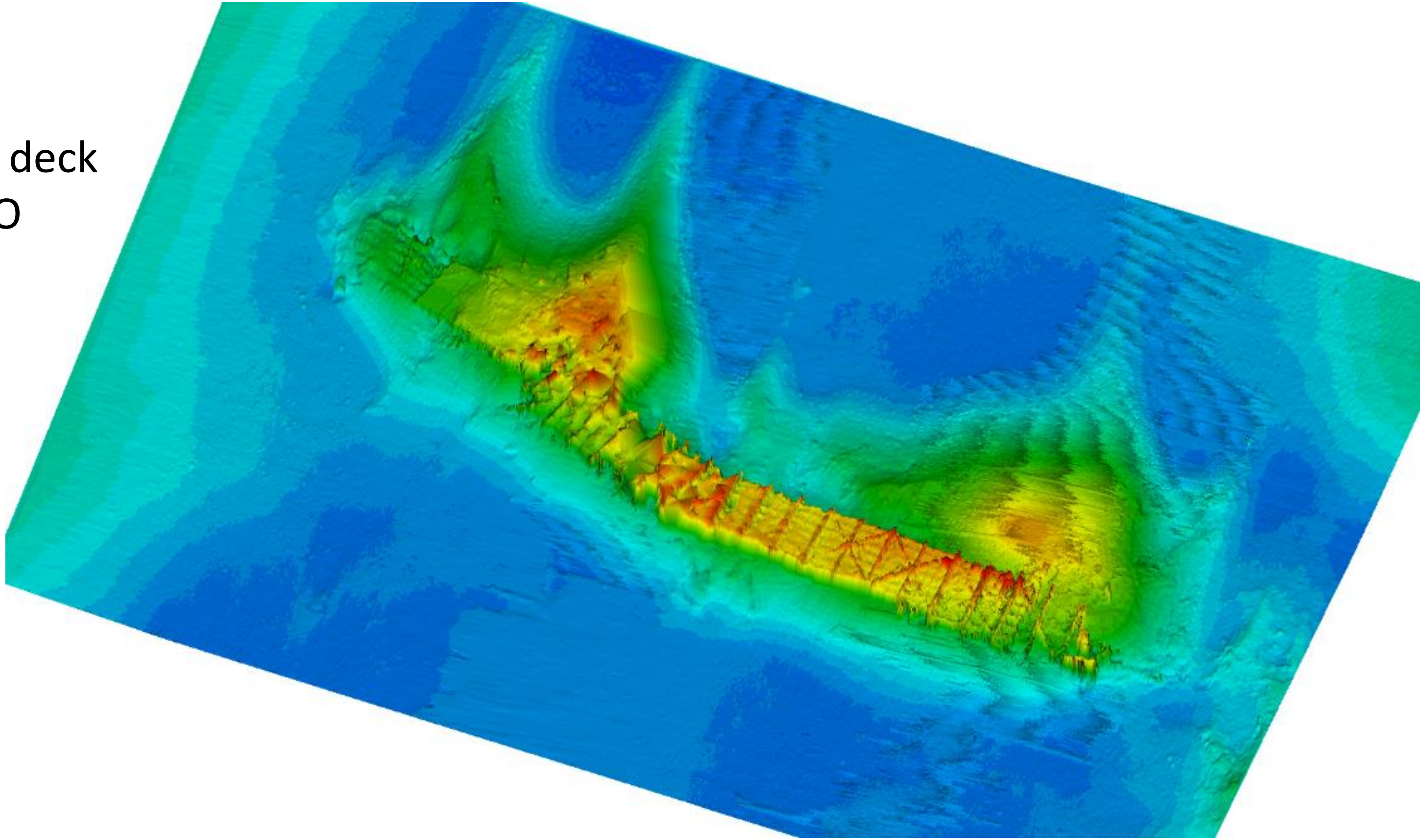
Bathymetry → Object identification

Old fallen bridge deck
near Warsaw, MO



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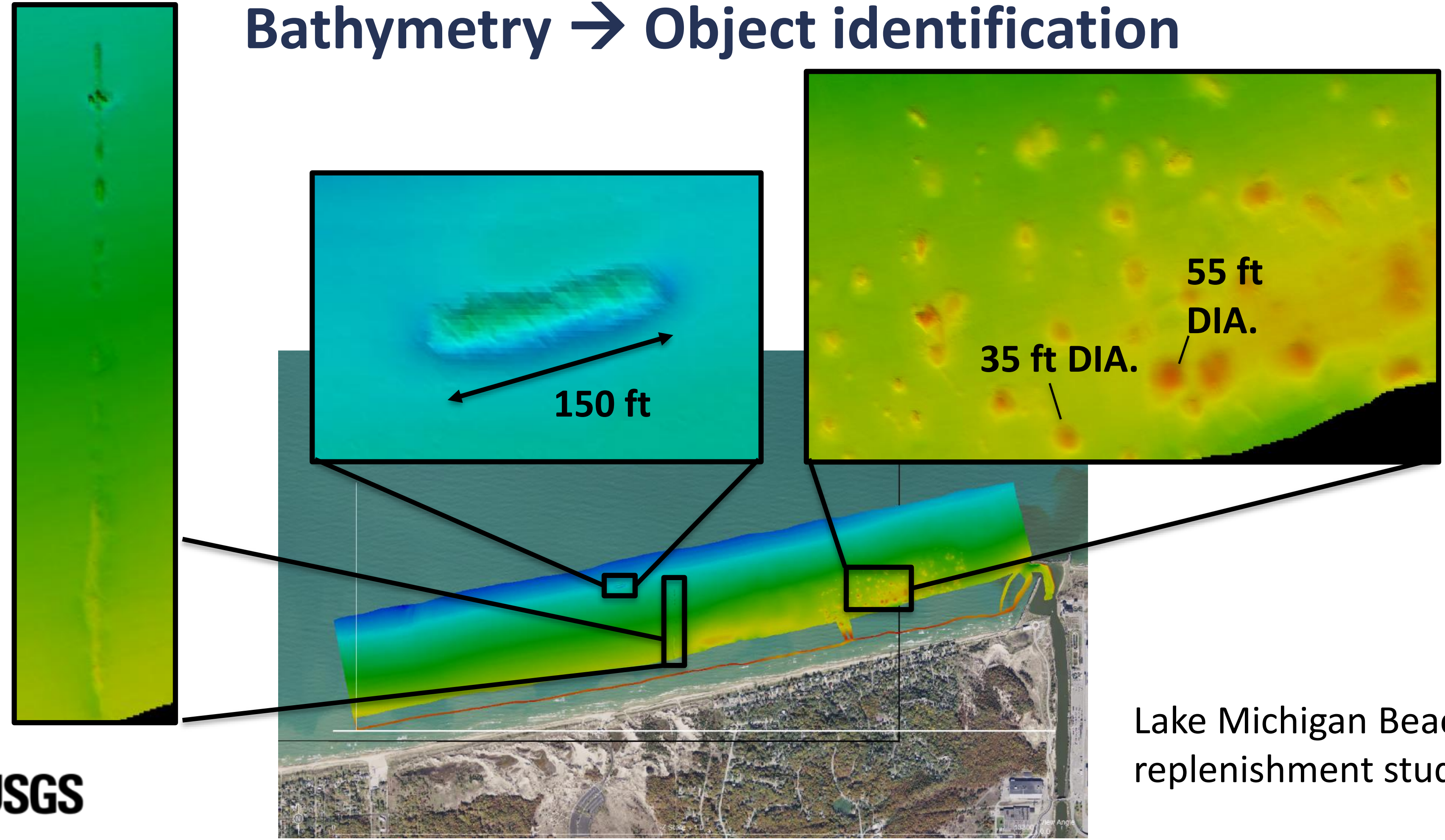
Bathymetry → Object identification

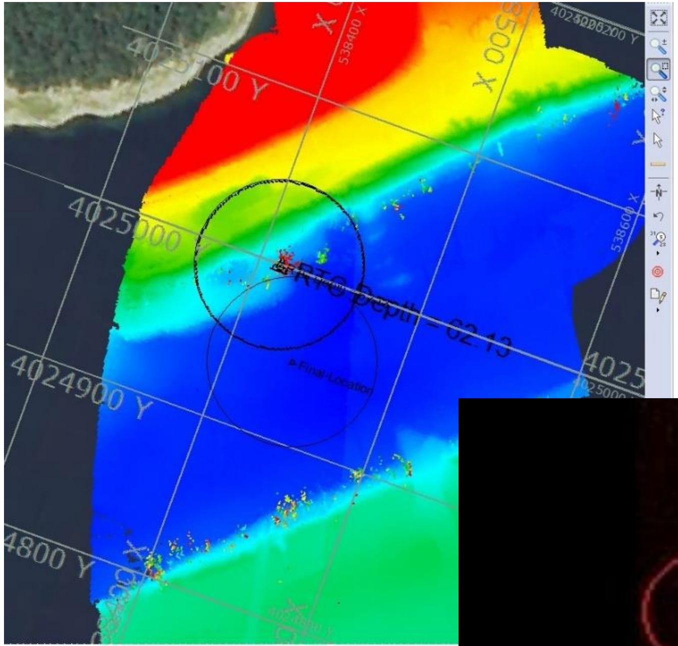


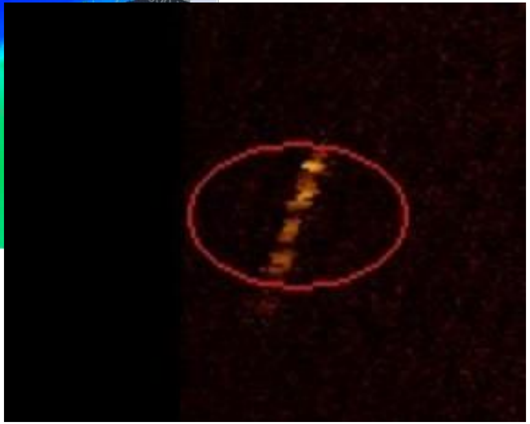
Lake Michigan Beach
replenishment study

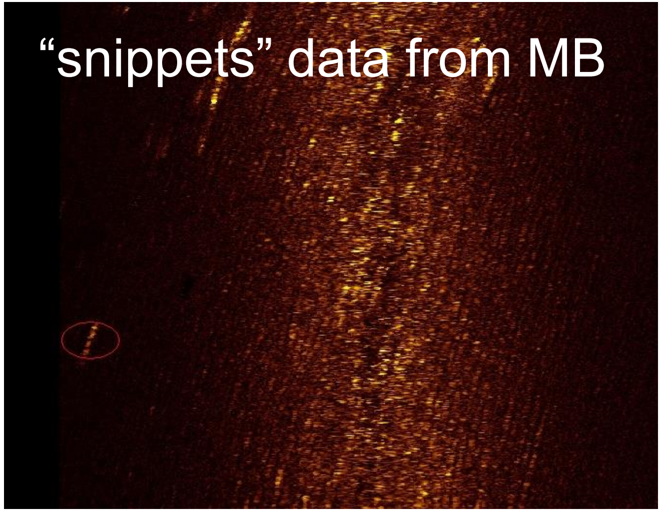
USGS

Bathymetry → Object identification

(and side-scan)







MBES Tradeoffs

Benefits

- Extremely high resolution bathymetric data
- Accurate means of determining reservoir capacity
- Repeat surveys can reveal variations over time
- Inspection/identification of submerged objects without divers
- Newer systems are compact and can be deployed from “vessels of opportunity”

Limitations

- minimum of 3 feet of depth
- up to 900 feet of depth (for our systems)
- processing time (1 day survey ~ 1 week processing)
- more components = more things that can go wrong in the field (newer systems are a significant improvement)

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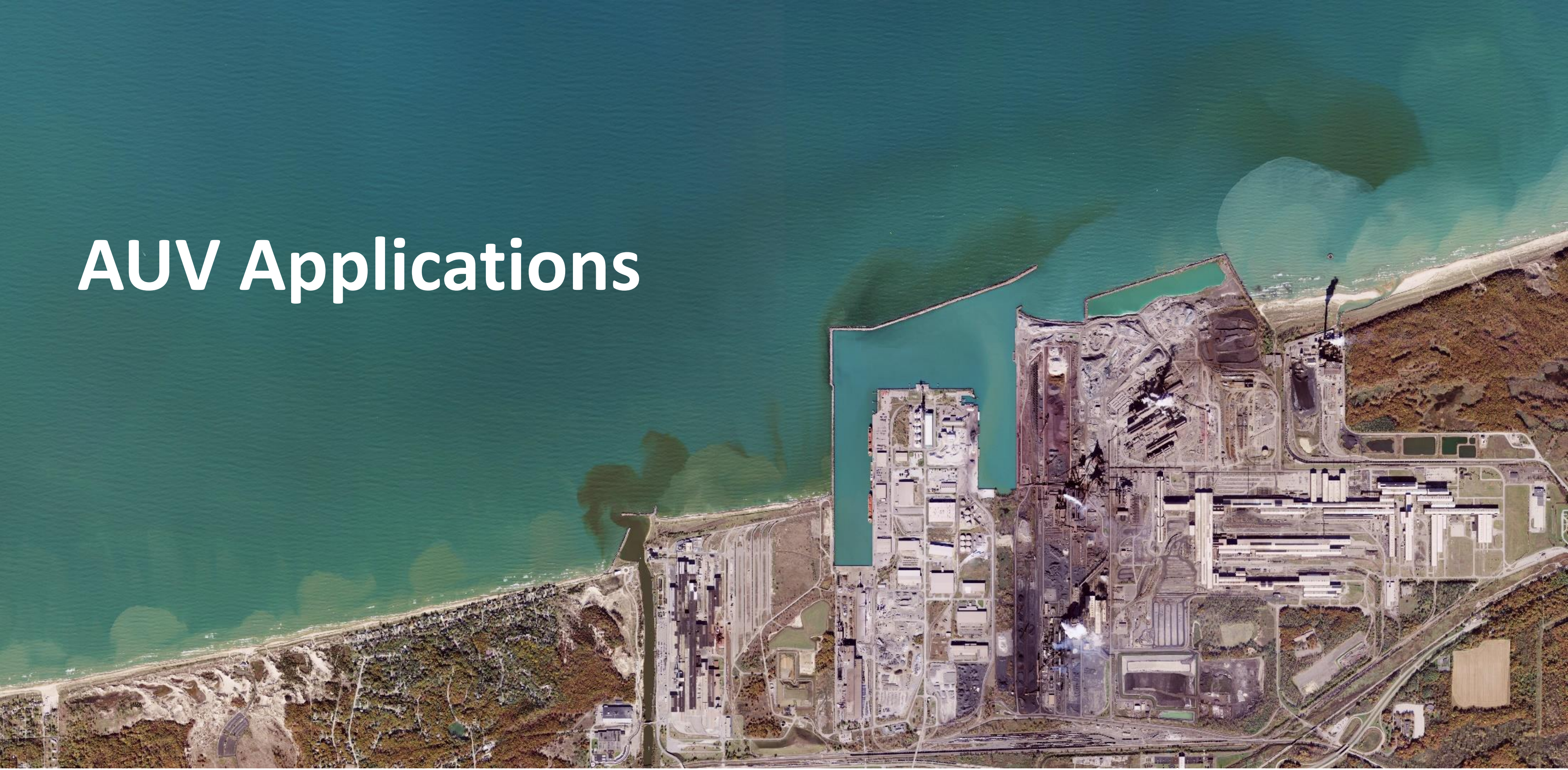
AUV Applications



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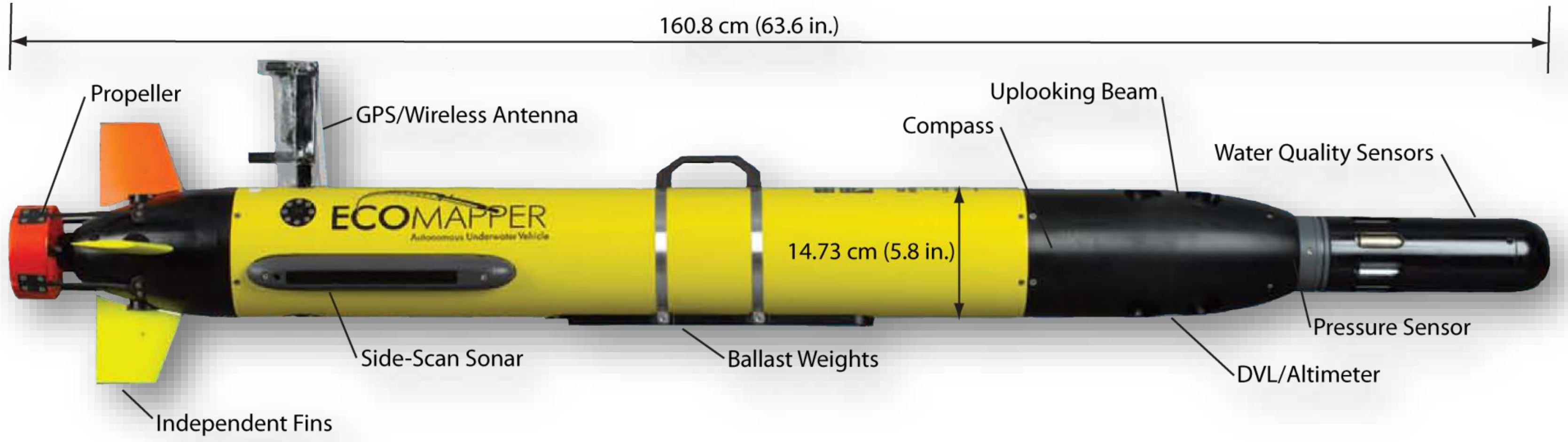
AUV applications



What kind of data?

- Bathymetric mapping
- Side-scan sonar imagery
- Water quality mapping
- Pressure sensors for depth
- GPS
- Integrated and geospatially referenced

Autonomous

- Hazardous conditions
- 24/7
- Saves man-hours

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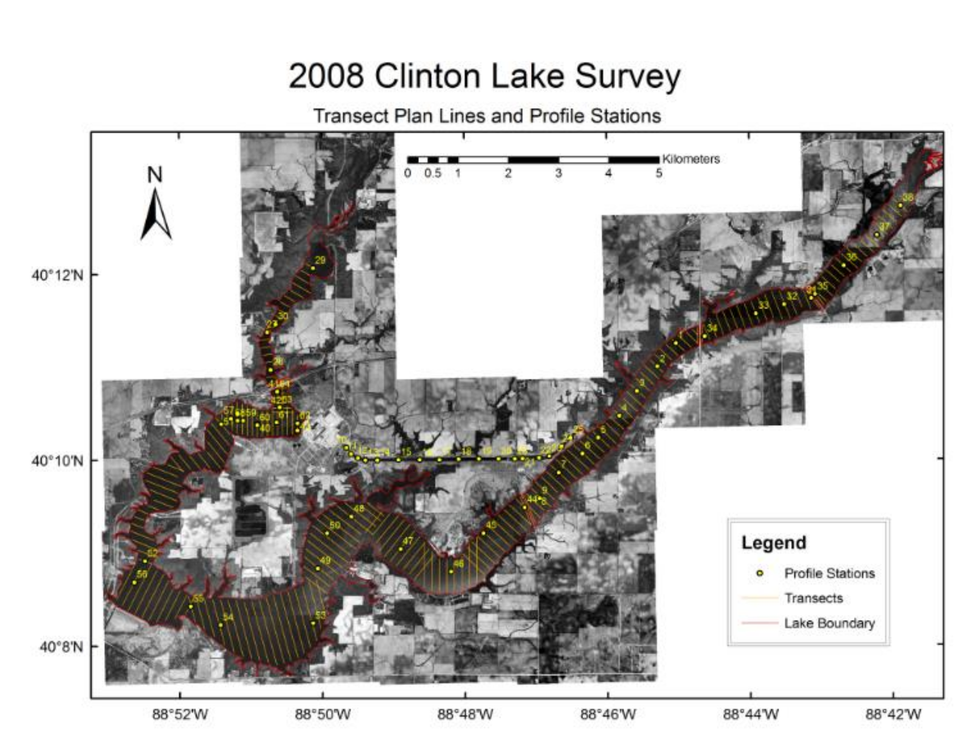
AUV applications – Data density

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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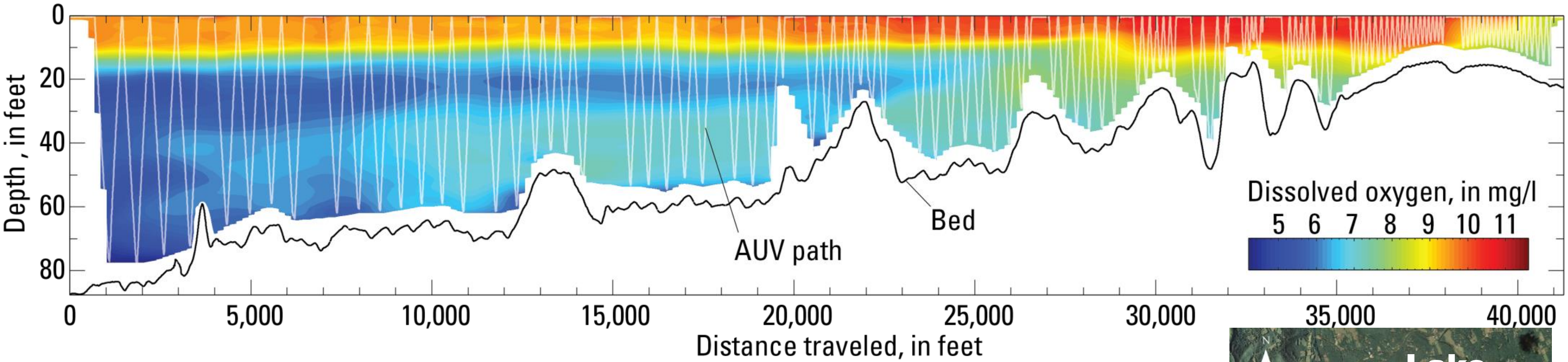
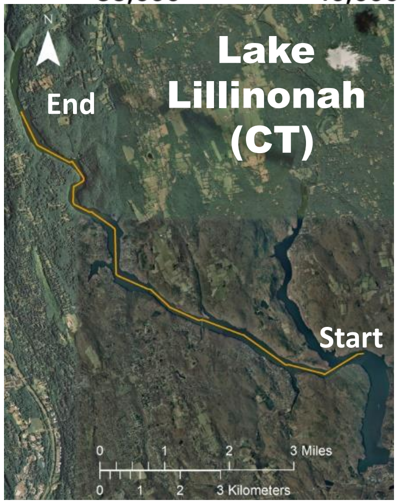
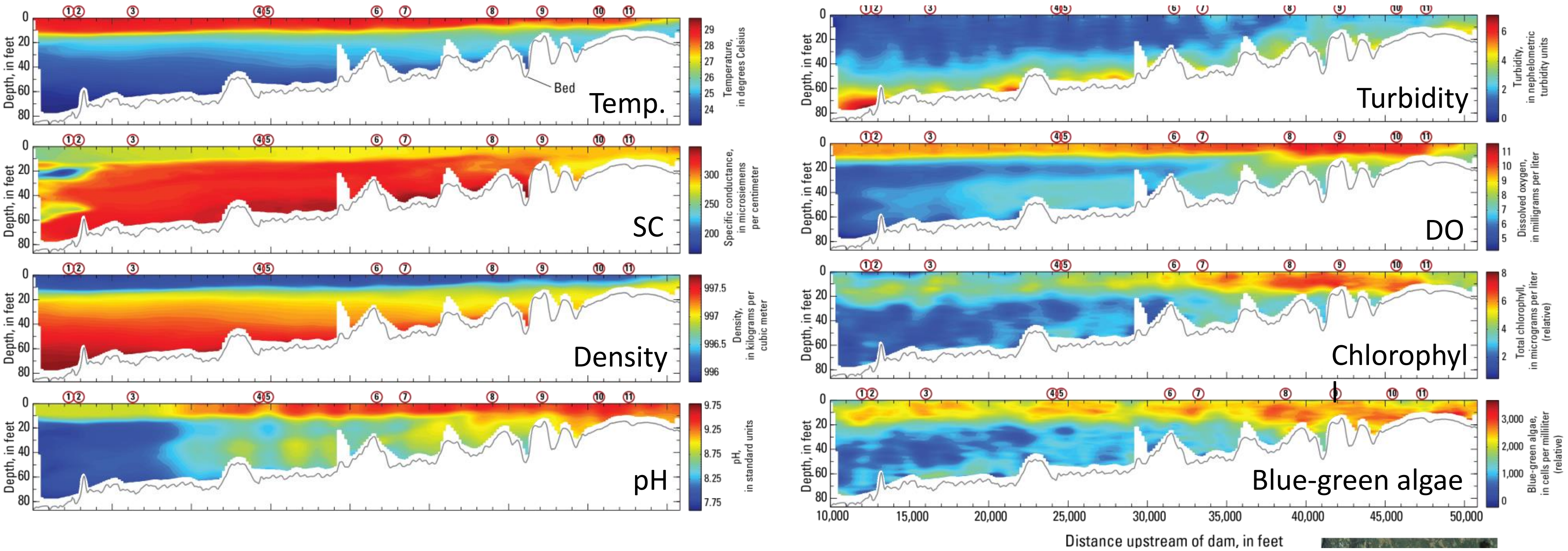
AUV applications – Data density





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

AUV applications – One survey, multiple parameters



Lake Lillinonah

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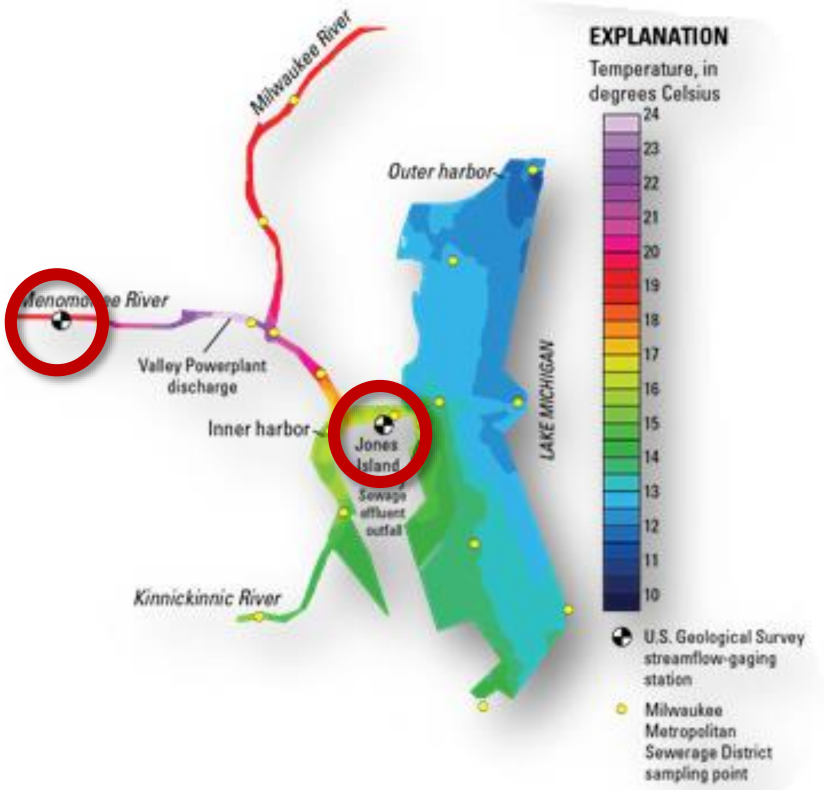
AUV applications – Fills the gap between gages



Milwaukee Harbor

***NMN Lake Michigan Pilot Project**

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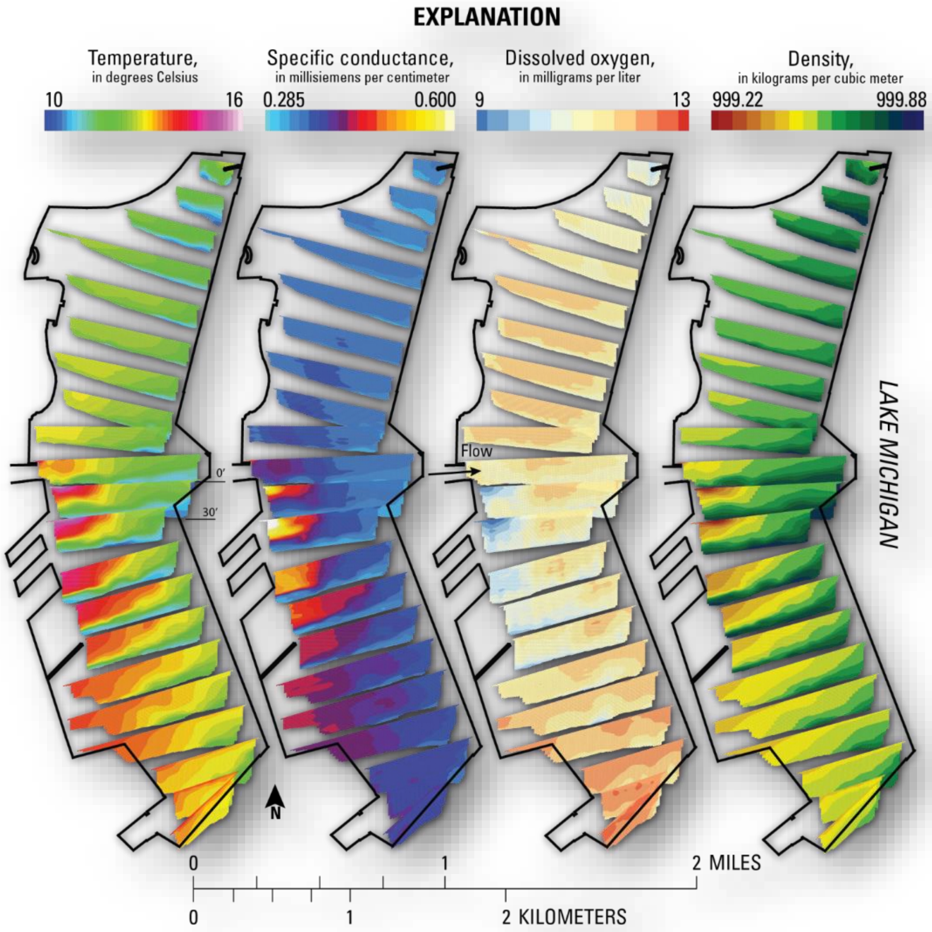
AUV applications – Mapping in 3D



Milwaukee Harbor

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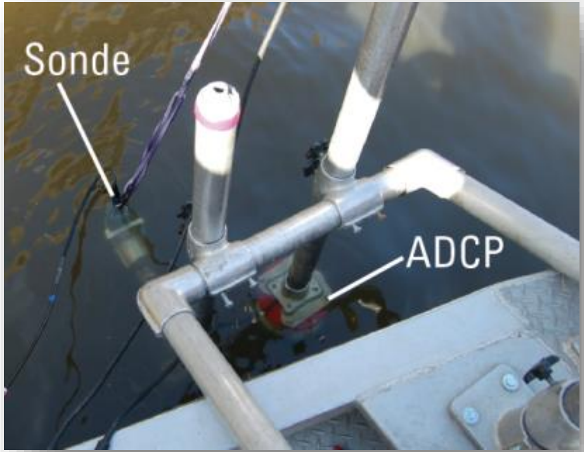
Combined AUV & Manned-boat surveys

Velocity data (ADCP)
Surface water quality
High-res bathymetry (MBES)



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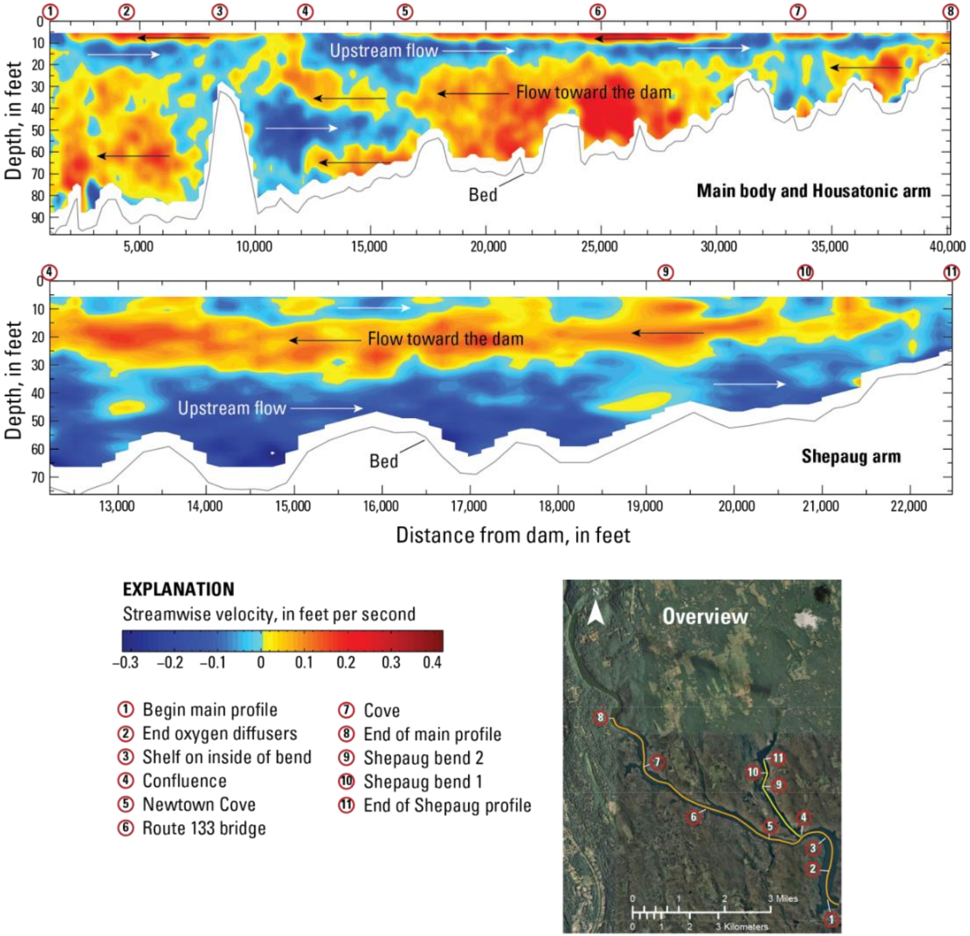
Combined AUV & Manned-boat surveys

Lake Lillinonah



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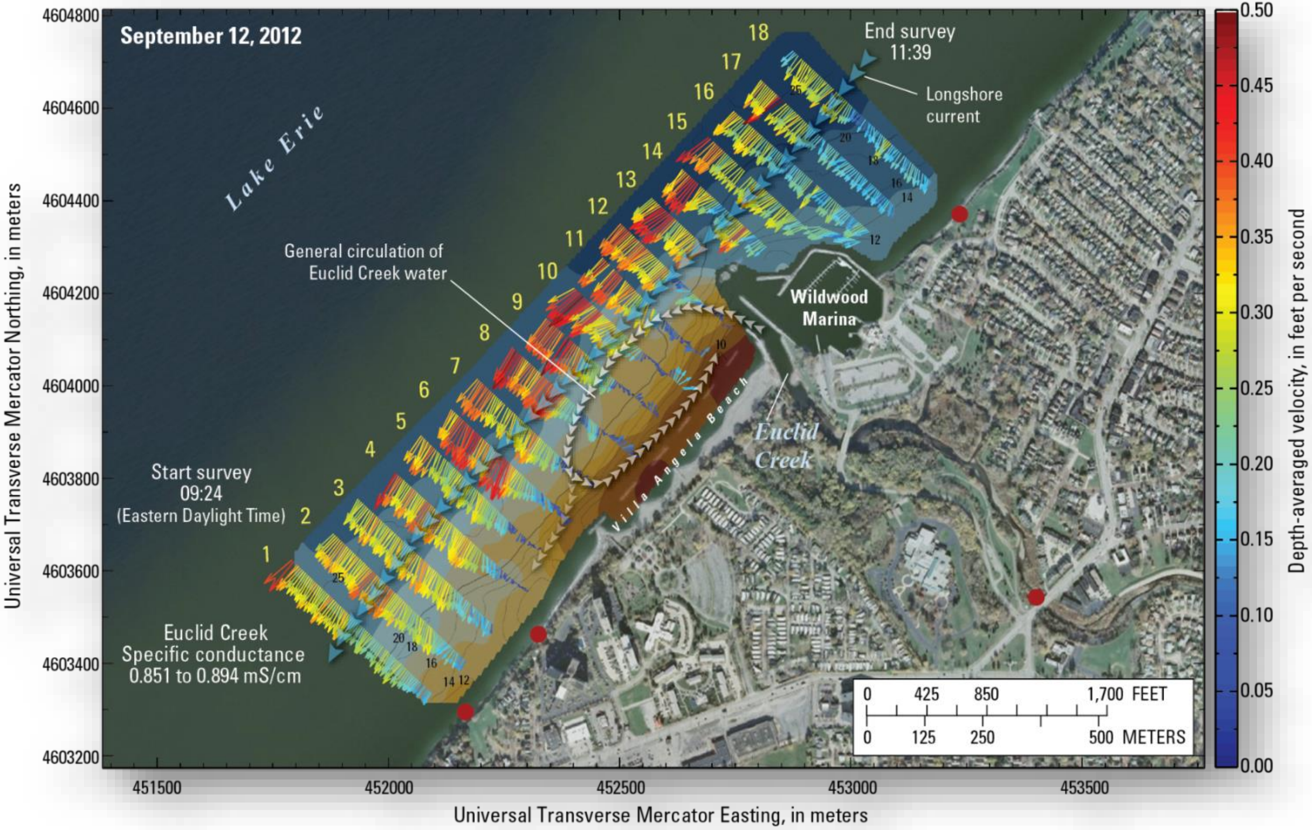
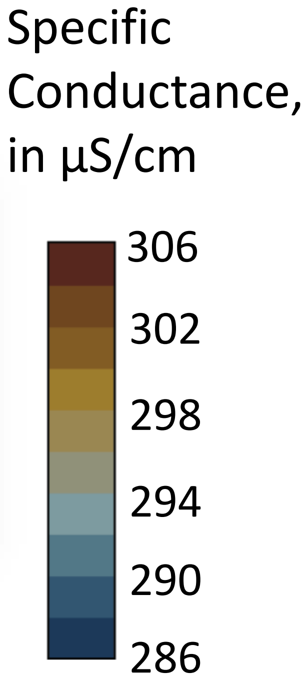
Combined AUV & Manned-boat surveys





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AUV Tradeoffs

Benefits

- Highly efficient
- Repeat surveys show changes in time
  - Useful for evaluating restoration efforts
- Dense integrated data "connects the dots" and can reveal underlying processes
- Can help guide future sampling strategies
- A tool for rapid response to emergencies (spills, flooding etc.)

Limitations

- High cost, high risk
- Accurate underwater navigation is not easy
- Sensor payloads are limited
- Poor performance in areas with strong currents
- Processing time

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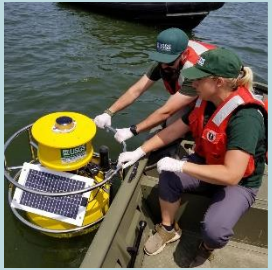
Point Locations

Profiles/Samples
Point locations

Snapshot(s) in time

Buoys and gages
Point locations

Continuous in time



Mapping

Moving-boat
Spatially dense

Snapshot(s) in time

AUV survey
Spatially dense

Snapshot(s) in time

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What can a map reveal about your site?

QUALITY

QUANTITY

Profiles/Samples

Moving-boat

Buoys and gages

AUV

USGS

Photo: Cedar Lake, Carbondale, IL (cr: City of Carbondale)