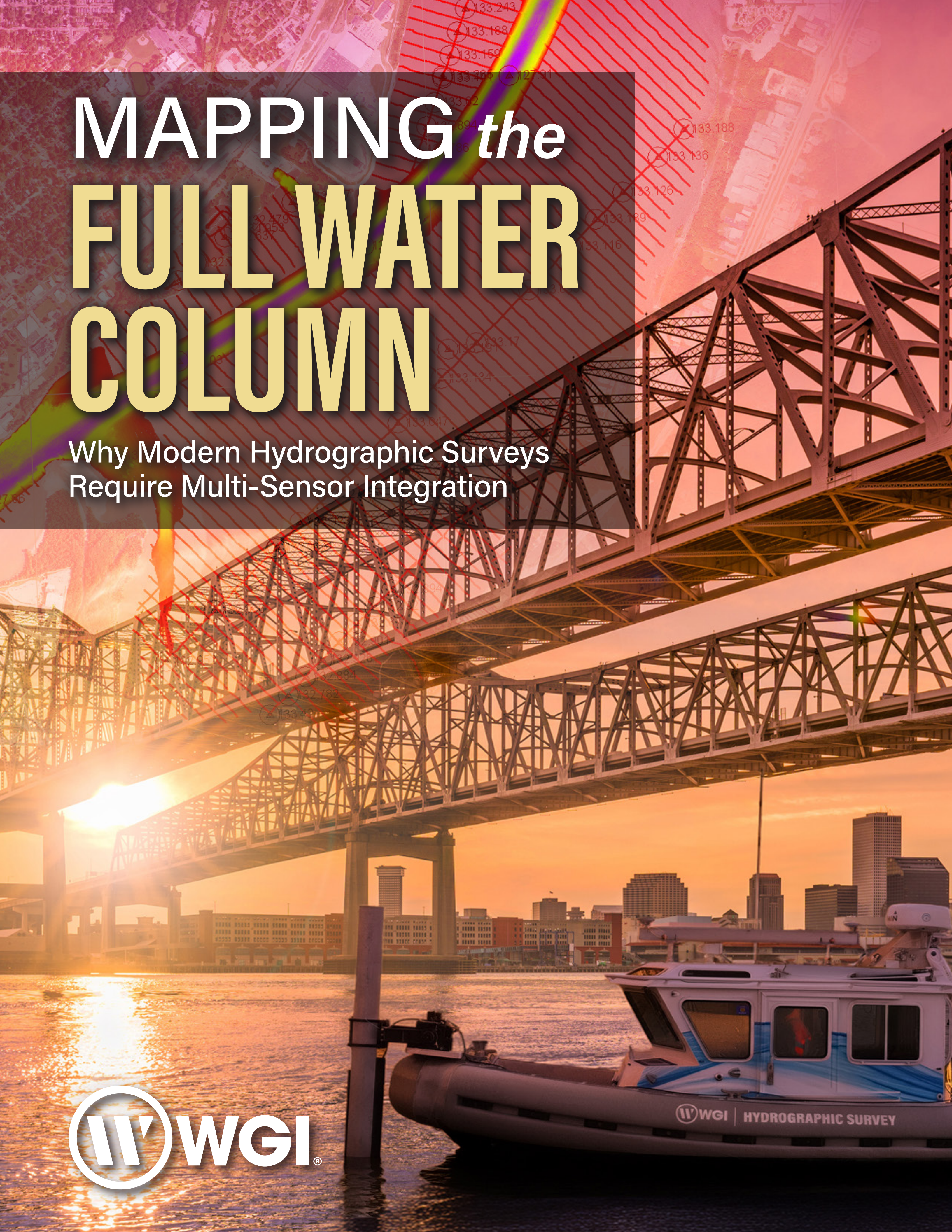
MAPPING *the* FULL WATER COLUMN

Why Modern Hydrographic Surveys Require Multi-Sensor Integration



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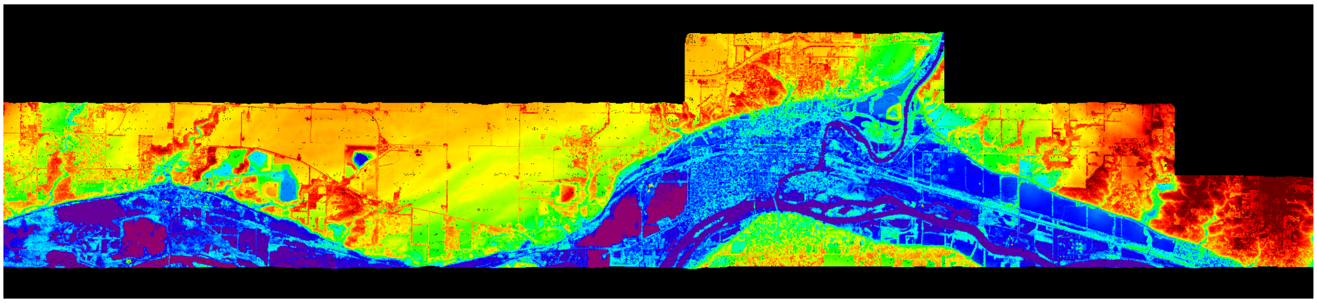
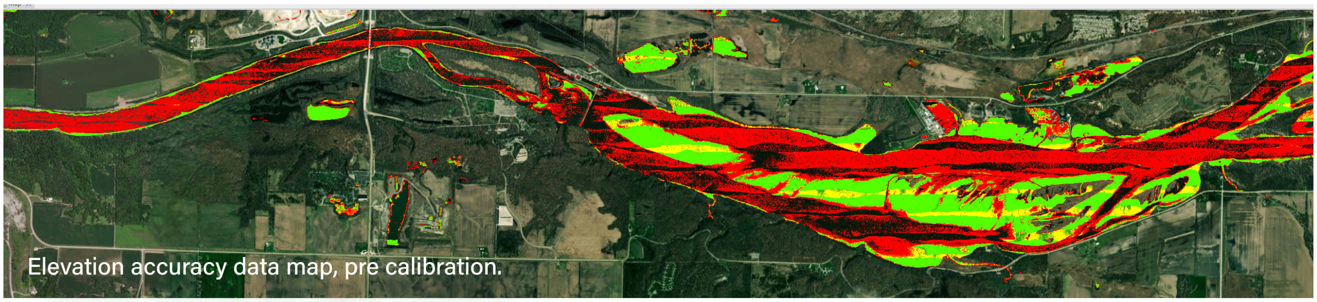




Elevation accuracy data map, pre calibration.

THE GROWING DEMAND FOR UNDERWATER CLARITY

America's relationship with its waterways is entering a new era of urgency. Aging navigation infrastructure, intensifying flood cycles, accelerating coastal erosion, and billions in newly authorized federal investment are converging to create unprecedented demand for one foundational capability: knowing exactly what lies beneath the water's surface.

The Infrastructure Investment and Jobs Act (IIJA) of 2021 authorized more than $17 billion for ports, waterways, and coastal resilience programs alone — the largest single federal investment in water infrastructure in a generation.[1] The U.S. Army Corps of Engineers (USACE), FEMA, NOAA, state departments of transportation, and coastal municipalities are all being asked to plan, design, and deliver complex water-related projects at a pace that has no modern precedent.

Every one of those projects depends on accurate bathymetric data — precise, high-resolution maps of the underwater environment. Without them, hydraulic models are unreliable, engineering designs are built on assumptions rather than facts, and environmental assessments are incomplete. The consequences of poor bathymetric data range from inefficient dredging programs to undersized flood control infrastructure to bridge foundations designed without knowledge of scour conditions beneath them.

Yet despite this surge in demand, a persistent gap exists between what many agencies and municipalities expect from a hydrographic survey and what modern aquatic environments may require. That gap — between single-method survey thinking and the multi-sensor reality of complex water bodies — is where projects succeed or fail.

This paper examines why multi-sensor hydrographic integration has become the standard for serious water resource projects, what owners and agencies should understand before scoping and procuring a survey, and how this approach was applied at scale on a major federal project along the Illinois River.

THE PROBLEM WITH SINGLE-METHOD THINKING

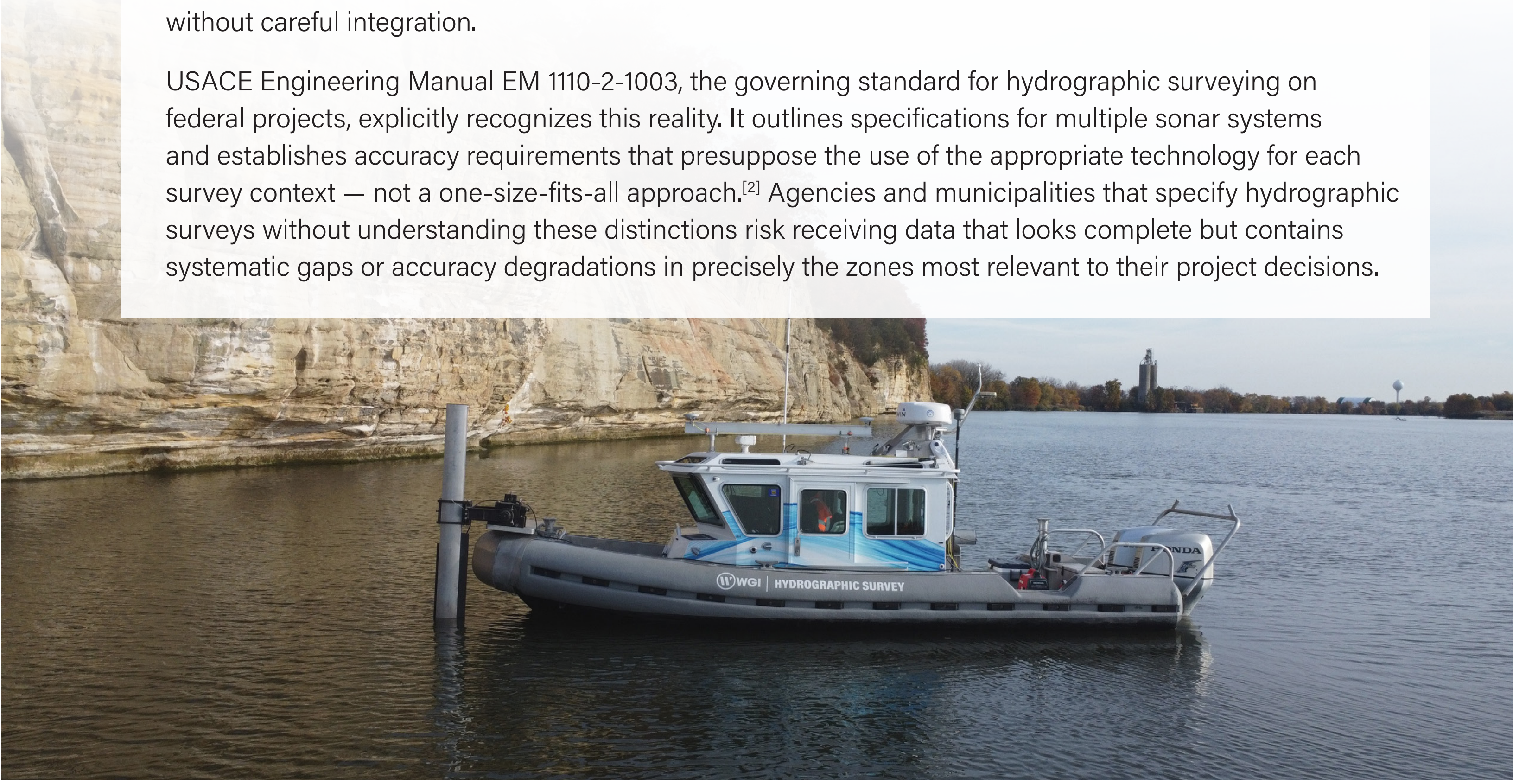
The starting assumption of many survey specifications is that a water body has a reasonably consistent depth range — and that a single survey technology, properly deployed, can capture it accurately. In controlled environments, that assumption holds. In the real-world aquatic environments where most infrastructure decisions are made, it almost never does.

Consider a typical inland river system. The navigation channel may run 30 to 40 feet deep. The adjacent floodplain transitions through mid-depth zones of 10 to 15 feet before giving way to backwater areas and wetland margins where water depth drops below 3 feet — or even below 1 foot during low water periods. Add fluctuating seasonal water levels, variable current velocities, turbidity that changes with precipitation events, and submerged obstructions that shift with flood cycles, and the survey challenge becomes immediately apparent.

No single acoustic or optical technology addresses this full range effectively. Multibeam sonar provides exceptional resolution and coverage efficiency in navigable water depths but loses accuracy — and eventually loses bottom detection entirely — as depths become too shallow relative to vessel draft and sonar geometry. Single beam echosounders extend coverage into shallower zones but sacrifice the complete bottom coverage that multibeam provides. Airborne lidar can penetrate optically clear water and produce continuous elevation data from terrestrial environments through the water surface, but its effectiveness degrades in turbid conditions common to inland rivers. Side scan sonar adds critical acoustic imagery of bottom conditions and submerged features that neither bathymetric system reveals on its own.

Each of these technologies performs extremely well within a specific range of conditions. Problems arise when a system is pushed beyond those conditions, or when data from multiple systems are merged without careful integration.

USACE Engineering Manual EM 1110-2-1003, the governing standard for hydrographic surveying on federal projects, explicitly recognizes this reality. It outlines specifications for multiple sonar systems and establishes accuracy requirements that presuppose the use of the appropriate technology for each survey context — not a one-size-fits-all approach.[2] Agencies and municipalities that specify hydrographic surveys without understanding these distinctions risk receiving data that looks complete but contains systematic gaps or accuracy degradations in precisely the zones most relevant to their project decisions.



THE TECHNOLOGY LANDSCAPE:
WHAT EACH SYSTEM DOES AND WHERE IT FITS

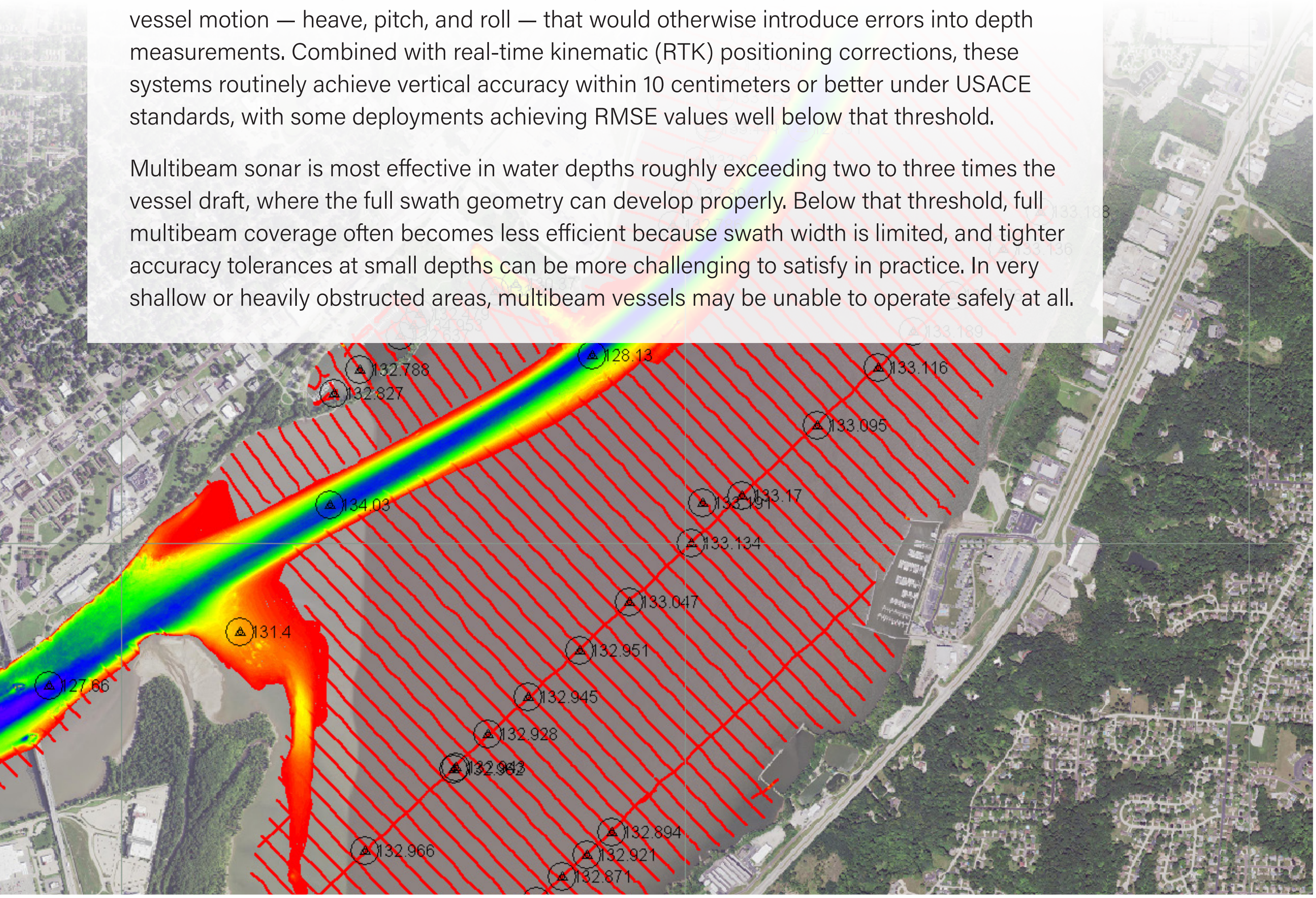
Understanding the capabilities and constraints of each survey technology is the first step toward scoping, planning, and executing a hydrographic survey effectively.

Multibeam Sonar

Multibeam echosounders represent the current standard for high-resolution underwater mapping in navigable water depths. Unlike traditional single-beam systems that measure depth at a single footprint directly beneath the vessel, multibeam systems transmit an acoustic swatch, or "wedge" perpendicular to the vessel's direction of travel — covering an area up to several times the water depth in a single pass. At survey speeds of 3 to 5 knots, a properly configured multibeam system combined with proper collection methods can achieve complete bottom coverage across wide channels with optimal swath overlap, providing the redundancy that quality assurance requires.

Modern multibeam systems operate with integrated inertial navigation that compensates for vessel motion — heave, pitch, and roll — that would otherwise introduce errors into depth measurements. Combined with real-time kinematic (RTK) positioning corrections, these systems routinely achieve vertical accuracy within 10 centimeters or better under USACE standards, with some deployments achieving RMSE values well below that threshold.

Multibeam sonar is most effective in water depths roughly exceeding two to three times the vessel draft, where the full swath geometry can develop properly. Below that threshold, full multibeam coverage often becomes less efficient because swath width is limited, and tighter accuracy tolerances at small depths can be more challenging to satisfy in practice. In very shallow or heavily obstructed areas, multibeam vessels may be unable to operate safely at all.

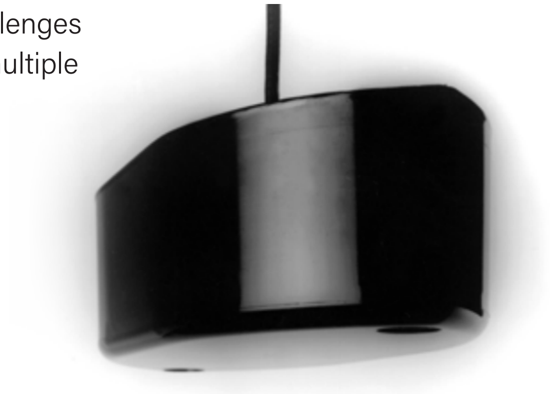


Single Beam Echosounders

Single beam echosounders extend survey coverage into areas where multibeam systems cannot effectively operate — shallow water zones, constricted waterways, areas with submerged obstructions, and locations requiring slower survey speeds. Modern dual-frequency systems operating at both high frequency (200 kHz) and low frequency (24 kHz) provide flexibility across varying conditions: high frequency delivers superior resolution in shallow water, while low frequency penetrates better in deeper or more turbid environments to identify and validate soft bottoms.

Single beam surveys are typically planned as regularly spaced cross-sections or parallel lines, with line spacing calibrated to the accuracy requirements of the project. While single beam does not provide the complete bottom coverage of multibeam, it delivers reliable depth measurements along survey lines — and when properly integrated with multibeam data from deeper areas, creates a comprehensive dataset that neither system could achieve alone.

Low frequency single beam surveys can encounter challenges in very shallow water, where strong reverberation and multiple signal paths from the wide beam angle and longer wavelengths degrade data quality. Understanding these limitations — and documenting them clearly in survey reports — is essential for agencies interpreting the resulting dataset.



OTSBB200-SLASH-24 Dual
Frequency Single Beam Transducer.

Teledyne Odom Echotrac
E20 Dual Frequency Echosounder.

Airborne Topobathymetric Lidar

Airborne lidar systems using green-wavelength lasers can penetrate optically clear water and measure depths in the shallow littoral zone. This is due to the spectral refractive and reflective properties of light at the 532nm wavelength. The depth penetration capability and subsequent ability to map bathymetric elevations of aerial bathymetric lidar varies greatly by environmental conditions at the time of aerial survey. Primarily, the turbidity of the water column, which can be expressed as the Diffuse Attenuation Coefficient (Kd), is critical in estimating maximum depths where the laser pulse energy is attenuated beyond the sensor's signal to noise ratio (Dmax).

Given the above disclaimer, airborne bathymetric lidar can collect viable data from the water surface down to depths ranging from a few feet to over one-hundred feet with typical ranges around 5' to 15' (feet) in inland/riverine environments and 10' - 50' (feet), or more in favorable coastal environments depending on the sensor used. Airborne bathymetric lidar is complementary and often used in conjunction with hydrographic survey vessels collecting sonar since multibeam sonar performs better in deeper water can experience challenges in shallow-water environments. The critical advantage of topobathymetric lidar is its ability to collect continuous elevation data across the land-water interface, creating a seamless dataset that spans terrestrial environments, the shoreline, and the underwater nearshore zone. It is also extremely useful and cost-effective for mapping and modelling wetlands and coastal zones that are large or inaccessible with traditional means.

The primary limitations of bathymetric lidar are water clarity, ability to map deep water environments, and its precision in differentiating the water surface vs depths in extremely shallow waters. In deep, coastal environments as well as turbid inland rivers and estuaries, light scattering (attenuation) reduces depth penetration significantly, limiting effective coverage to very shallow areas or making acoustic methods necessary across most of the survey area. Successful integration of lidar and acoustic datasets requires careful attention to vertical datum consistency and overlap zone validation.

Side Scan Sonar

Side scan sonar complements bathymetric systems by producing acoustic imagery of the riverbed or seafloor — revealing bottom conditions, substrate variations, submerged objects, and features that depth measurements alone do not capture. The acoustic returns from side scan allow experienced interpreters to distinguish between hard and soft substrates, identify scour holes adjacent to bridge piers, locate submerged debris, and map aquatic habitat characteristics.

For environmental assessments, habitat mapping, and infrastructure inspection projects, side scan sonar data is often as valuable as the bathymetric dataset itself. Modern integrated systems — such as the Ping DSP 3DSS deployed by WGI on federal riverine projects — combine multibeam bathymetry and side scan imagery in a single sensor package, enabling simultaneous collection without additional vessel passes or multiple sonar sensors.

THE INTEGRATION CHALLENGE: WHERE SURVEYS SUCCEED OR FAIL

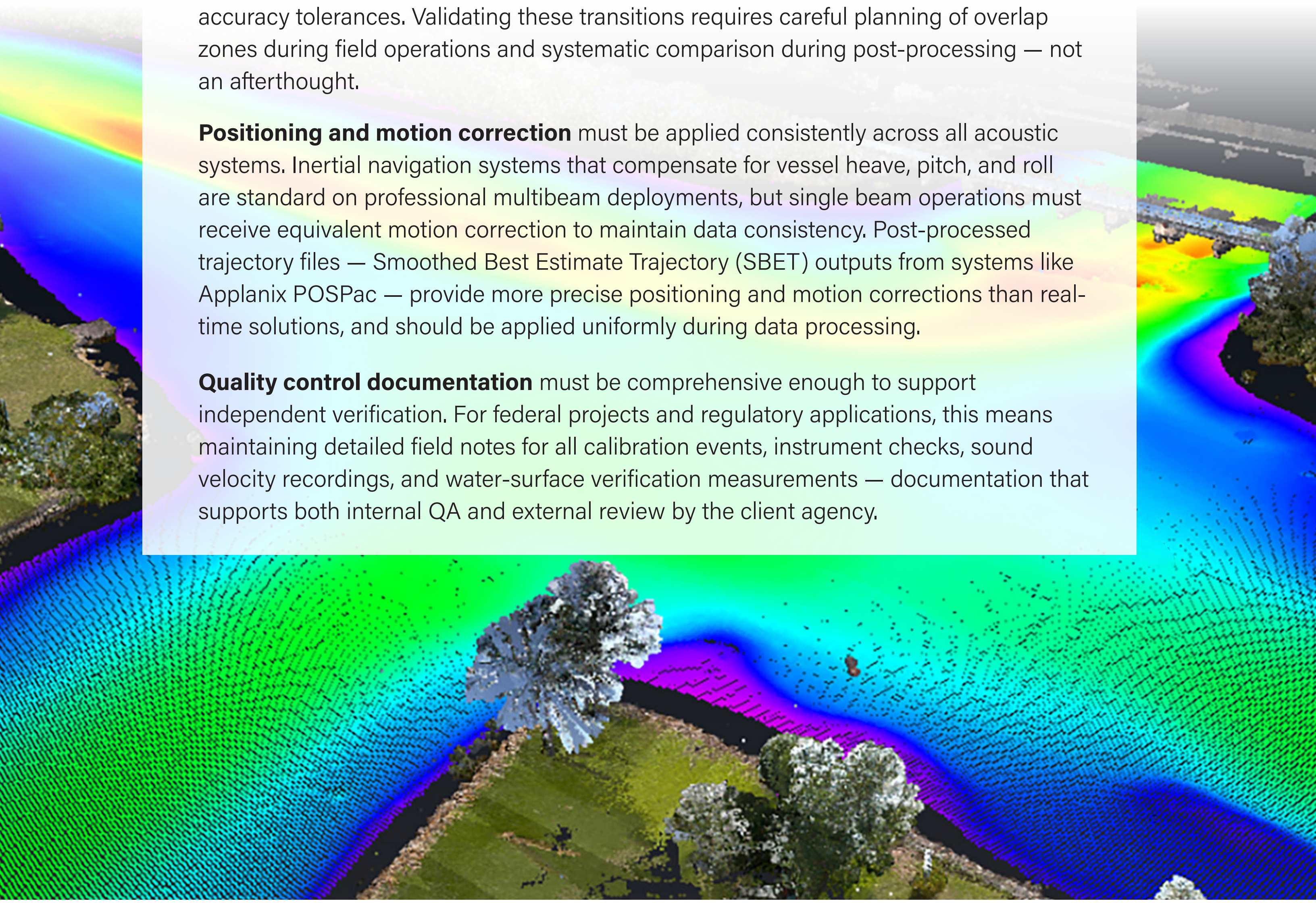
Selecting the right combination of technologies is necessary but not sufficient. In most large hydrographic surveys, the more challenging task is integrating the data, turning measurements from different sensors, scales, and environmental conditions into one consistent elevation dataset. This challenge has several dimensions that survey specifications and procurement processes often underestimate.

Vertical datum consistency is foundational. All datasets — multibeam, single beam, lidar, and any existing survey data being incorporated — must reference a consistent vertical datum and geoid model. In federal project contexts, this typically means NAVD88 with an appropriate geoid model. Errors in datum alignment compound across large project areas and can introduce systematic biases that undermine the entire dataset's utility for hydraulic modeling or engineering design.

Transition zone validation is where integration quality is most directly tested. Where multibeam coverage ends and single beam begins, or where acoustic surveys transition to lidar coverage in the shallow littoral zone, the datasets must agree within the project's accuracy tolerances. Validating these transitions requires careful planning of overlap zones during field operations and systematic comparison during post-processing — not an afterthought.

Positioning and motion correction must be applied consistently across all acoustic systems. Inertial navigation systems that compensate for vessel heave, pitch, and roll are standard on professional multibeam deployments, but single beam operations must receive equivalent motion correction to maintain data consistency. Post-processed trajectory files — Smoothed Best Estimate Trajectory (SBET) outputs from systems like Applanix POSPac — provide more precise positioning and motion corrections than real-time solutions, and should be applied uniformly during data processing.

Quality control documentation must be comprehensive enough to support independent verification. For federal projects and regulatory applications, this means maintaining detailed field notes for all calibration events, instrument checks, sound velocity recordings, and water-surface verification measurements — documentation that supports both internal QA and external review by the client agency.



CASE STUDY:

Upper Mississippi River System, Illinois River

The U.S. Army Corps of Engineers (St. Louis and Rock Island Districts) and its federal and state partners in the Upper Mississippi River System (UMRS) — including the U.S. Geological Survey Upper Midwest Environmental Science Center — needed high-resolution bathymetric data for the Peoria and Starved Rock Pools along the Illinois River. The project encompassed approximately 356 square miles of dynamic riverine environment presenting nearly every challenge that complex hydrographic surveys face.

The Illinois River system spans an extreme range of aquatic conditions. Navigation channels exceed 40 feet in depth. Adjacent backwater areas drop below 3 feet, with some zones inaccessible to any conventional survey vessel during low water periods. Seasonal flow variations produce current velocities that challenge vessel control during high water, and historic low water levels during one survey phase limited access across significant portions of the project area.

The survey was also required to integrate seamlessly with aerial topobathymetric lidar data being collected concurrently, producing a continuous elevation dataset across both terrestrial and submerged surfaces — a data integration challenge that demanded consistent datum management across fundamentally different sensor types.

The Multi-Sensor Approach

WGI deployed a comprehensive suite of hydrographic survey equipment aboard a 25-foot SAFE Boat configured for shallow water bathymetric operations, integrating the following primary systems:

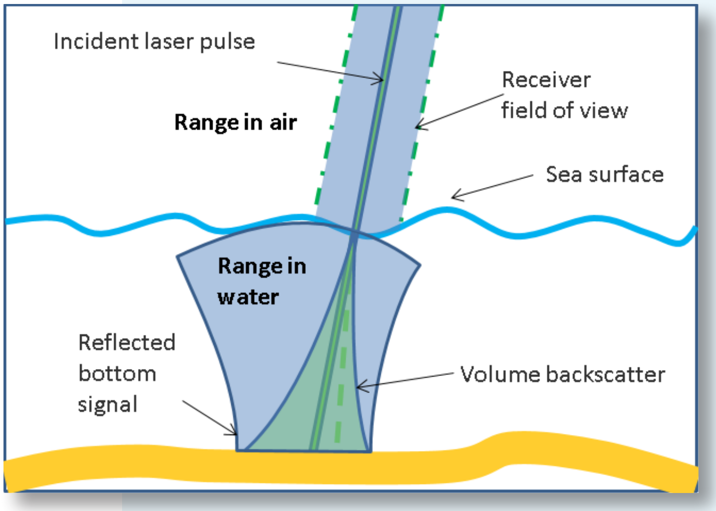
- **Ping DSP 3DSS** — Integrated multibeam sonar and side scan sonar for simultaneous bathymetry and acoustic imagery in navigable water depths
- **Teledyne Echotrac E-20** — Dual-frequency single beam echosounder (200 kHz / 24 kHz) for shallow water zones beyond multibeam coverage
- **Applanix POS M/V Wavemaster II** — Integrated GNSS/IMU inertial navigation for positioning and motion compensation across all acoustic systems
- **AML-3 Sound Velocity Profiler** — Water column corrections applied before each survey day, at midday, at day's end, and whenever stratification changes became apparent
- **Trimble R12i GNSS** — RTK positioning via Trimble's RTX network for centimeter-level horizontal and vertical control

Multibeam operations prioritized deeper water areas with six feet or more depth at time of collection, executing carefully planned parallel lines at an average speed of 3.8 knots with 25 percent or greater swath overlap. Total multibeam coverage reached 644.55 nautical miles in the Peoria Pool and 194.84 nautical miles in the Starved Rock Pool.

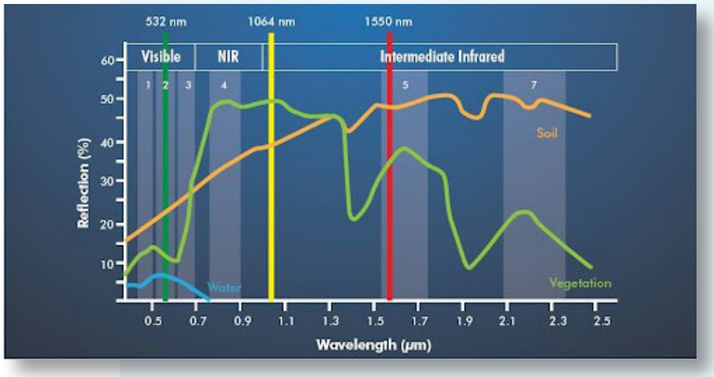
Single beam surveys extended coverage into shallow water areas using regularly spaced cross-sections at 200-foot intervals, operating at an average speed of 3.0 knots. The 200 kHz frequency was prioritized in shallow areas where the low-frequency 24 kHz dataset was affected by acoustic complications from historic low water conditions — including strong reverberation and multiple signal paths that degraded bottom detection.

Side scan sonar imagery was collected simultaneously with multibeam bathymetry, providing acoustic imagery that enabled bottom-type classifications and enhanced environmental interpretation of the underwater environment.

Survey control was established through Trimble's RTX network and post-processed workflows. A total of 124 control checks and 564 water surface elevation GNSS observations were collected throughout both survey phases, achieving horizontal RMSE values of 0.004 to 0.016 meters and vertical RMSE values of 0.019 to 0.031 meters — establishing the positioning foundation upon which the entire dataset's accuracy rests.[5]



Aerial topobathy lidar returns.



Common lidar wavelengths vs. feature reflection.

Navigating Real-World Constraints

Two significant operational challenges tested the multi-sensor approach during this project.

Historic low water levels during spring 2025 single beam collection limited access across portions of the project area and degraded low-frequency sonar performance in very shallow zones. WGI documented these limitations explicitly in field records and survey reports — communicating coverage constraints clearly to USACE rather than allowing gaps to propagate silently into the dataset.

Swift current conditions during high water multibeam operations required systematic adjustments to line planning and vessel speed to maintain adequate swath overlap and heading control. Survey crews conducted additional passes in current-affected areas and monitored real-time coverage to identify gaps requiring fill lines.

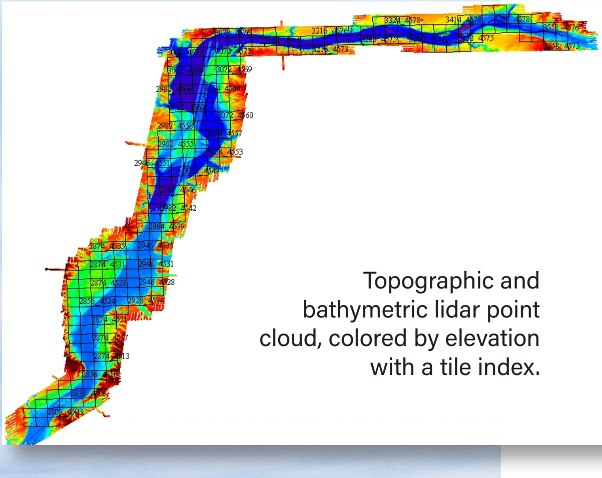
The integration with aerial lidar required careful post-processing validation in transition zones, verifying datum consistency and identifying any systematic offsets before final dataset assembly.

Results

The final accuracy assessment confirmed that both the multibeam and single beam datasets met or exceeded the 10-centimeter vertical accuracy standard specified for the project.

Multibeam accuracy, assessed against 53 GNSS manual soundings and 140 lead line measurements, produced a mean error of -0.007 meters and RMSE of 0.069 meters — well within specification. Single beam accuracy, assessed against 125 GNSS manual soundings, produced a mean error of -0.058 meters and RMSE of 0.094 meters, also within specification across the vast majority of survey areas.[5]

The resulting integrated dataset — delivered in multibeam and single beam LAZ, XYZ, and ASCII formats; side scan mosaics in GeoTIFF; bottom type classifications; one-meter bathymetric surface grids; and FGDC-compliant metadata — supports hydraulic modeling, geomorphologic analysis, engineering design, sedimentation studies, environmental assessment, and long-term monitoring across the Upper Mississippi River System.



Topographic and bathymetric lidar point cloud, colored by elevation with a tile index.

WHAT OWNERS AND AGENCIES SHOULD CONSIDER WHEN SPECIFYING A HYDROGRAPHIC SURVEY

The UMRS project illustrates principles that apply broadly to any complex hydrographic survey. Owners and agencies specifying or procuring these surveys benefit from understanding several key considerations before releasing a scope of work.

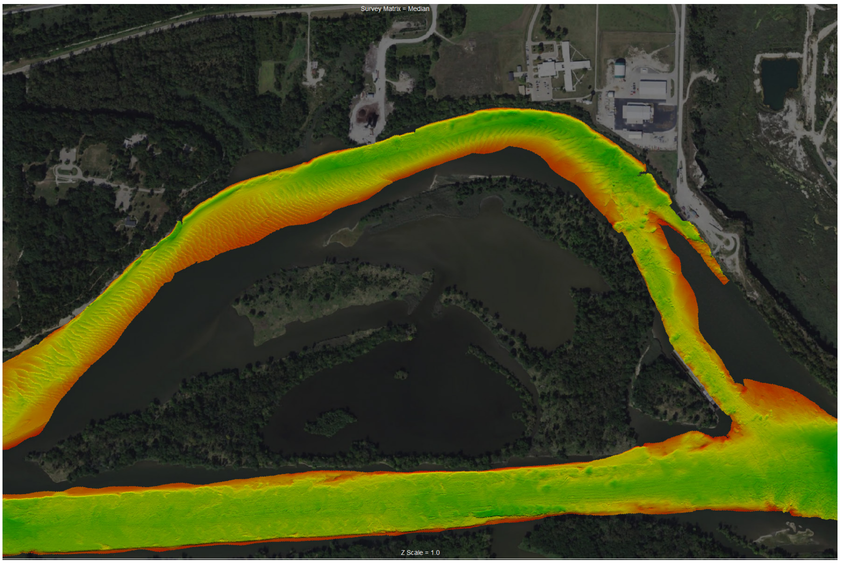
Define your end use, not just your coverage area. The accuracy requirements and data formats appropriate for a hydraulic model are different from those needed for dredge quantity calculations or environmental permit support. Hydrographic survey specifications should be driven by the downstream uses of the data, not just the geographic extent of the project area.

Account for the full depth range of your project area. Single-technology specifications are appropriate for environments with consistent, navigable water depths. For projects spanning tidal flats, river backwaters, nearshore coastal zones, or any environment with significant depth variation, multi-sensor approaches should be anticipated in scope and budget.

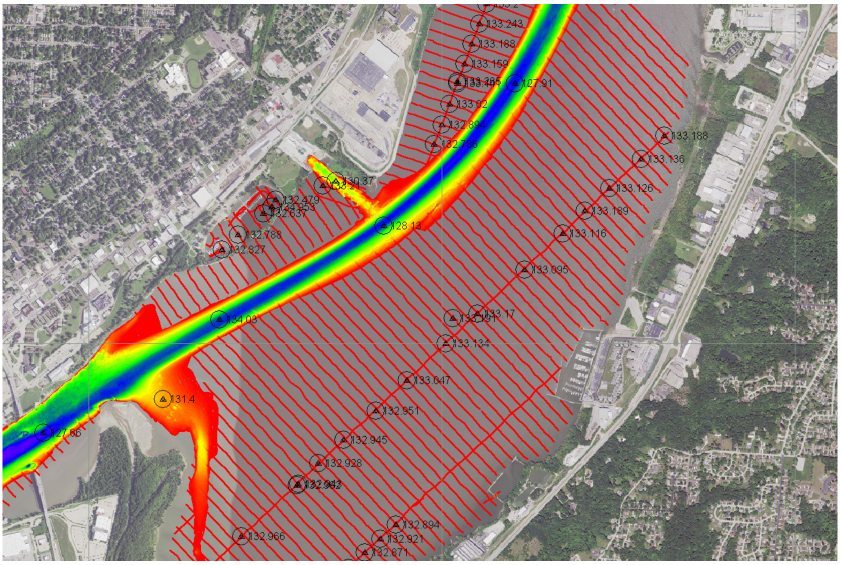
Require explicit documentation of coverage limitations. Water conditions — low water periods, high turbidity, ice, submerged obstructions — will affect coverage in virtually every real-world survey. Professional survey firms document these limitations systematically. Specifications should require this documentation, and agencies should review it carefully rather than assuming a submitted dataset represents complete coverage.

Understand vertical datum requirements before the survey begins. Datum conflicts between survey datasets and existing project data are among the most common — and most costly — sources of rework in hydrographic projects. Aligning all datasets to a consistent vertical datum and geoid model from the outset is far less expensive than correcting systematic offsets after the fact.

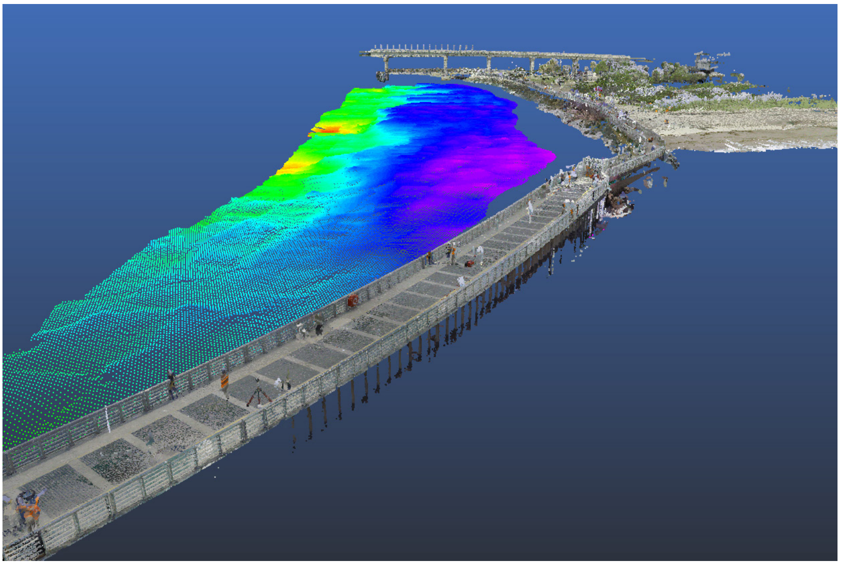
Verify that accuracy assessment methodology matches project standards. For federal projects, USACE EM 1110-2-1003 defines the accuracy assessment procedures that demonstrate compliance with survey specifications.[2] For coastal and nearshore projects, NOAA's NOS Hydrographic Surveys Specifications and Deliverables document establishes equivalent standards.[6] Specifications should require accuracy assessments that meet the relevant standard — and survey reports should present those results transparently.



Multibeam matrix in the Starved Rock Pool of the Illinois River.



Aerial view of the multibeam matrix single beam transects manual soundings and lead line soundings in the Peoria Pool of the Illinois River.



Inlet topographic and bathymetric survey.

WGI'S HYDROGRAPHIC SURVEYING CAPABILITY

WGI's Geospatial Division brings advanced hydrographic surveying capability to federal, state, and municipal clients across a wide range of aquatic environments — from Gulf Coast and Atlantic coastal waters to inland river systems in the Midwest and Great Lakes region.

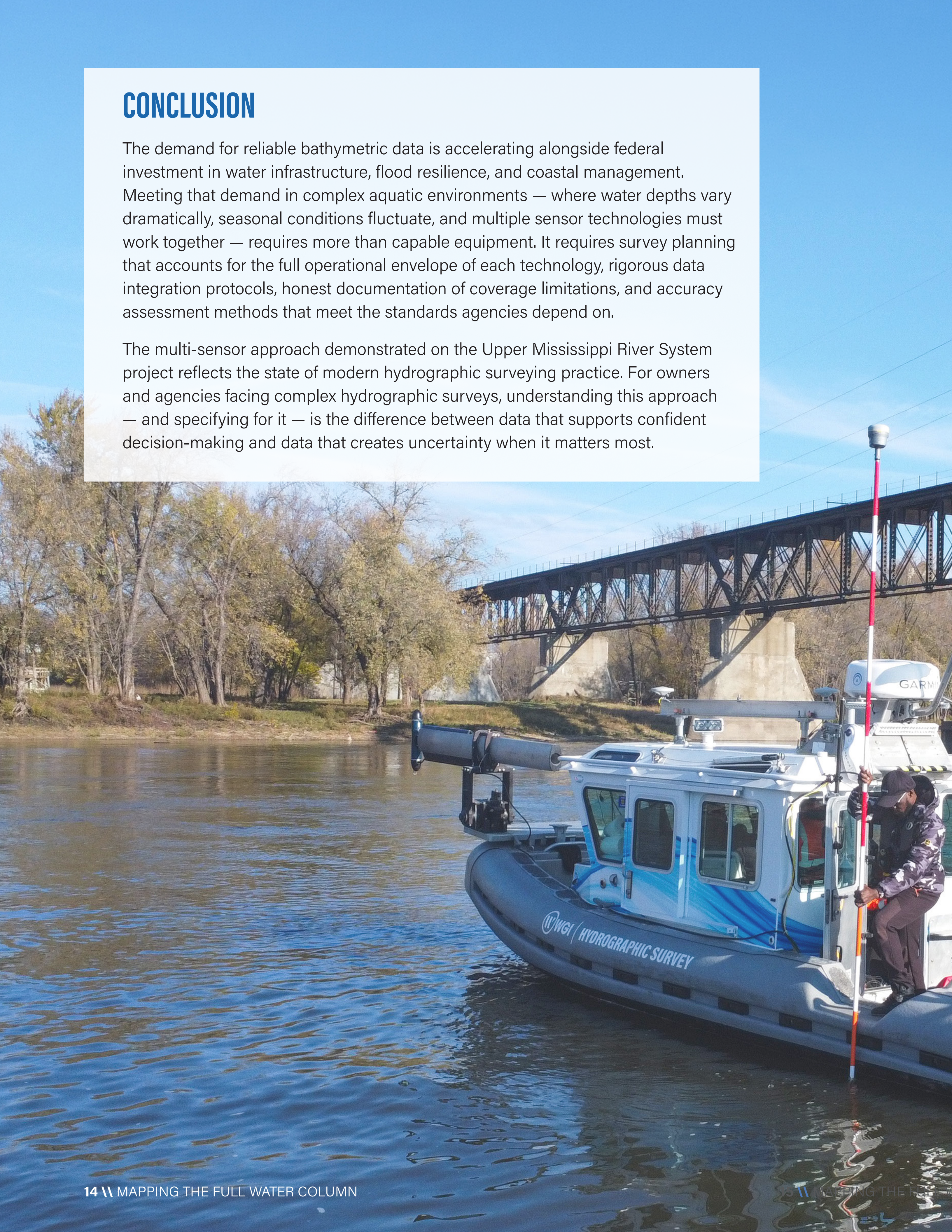
Our team integrates multibeam and single beam echosounders, side scan sonar, sub bottom profilers, magnetometers, tidal modeling instruments, and lidar datasets under rigorous quality assurance protocols aligned with USACE, NOAA, IHO, and FEMA standards. We have delivered hydrographic surveys supporting modeling, flood risk mapping, navigation channel assessment, environmental permitting, and infrastructure design — providing clients with data they can rely on for consequential decisions.

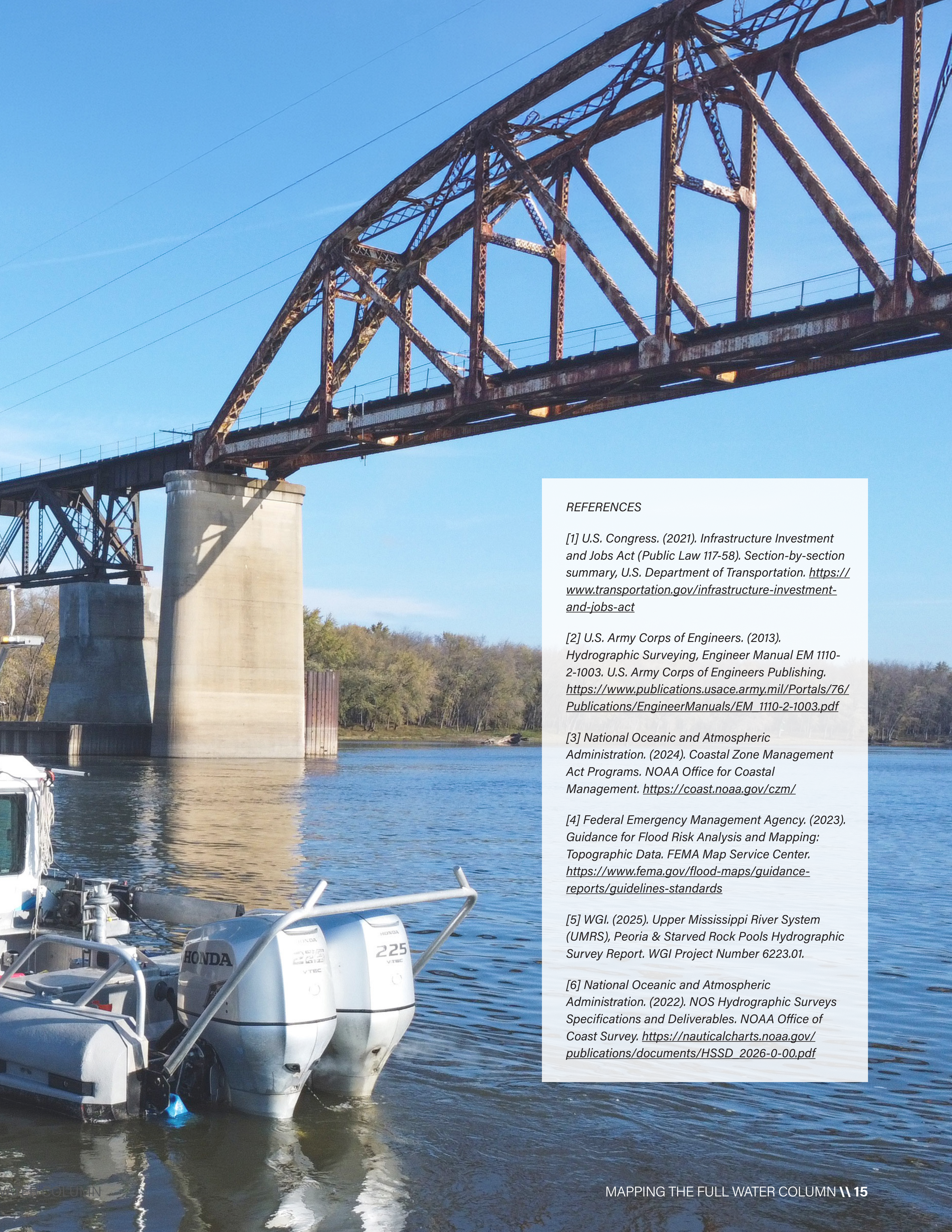
As a multidisciplinary firm, WGI uniquely connects hydrographic survey data to the engineering, planning, and design services that depend on it — bringing continuity from data collection through project delivery that reduces risk and improves outcomes across the full project lifecycle.

CONCLUSION

The demand for reliable bathymetric data is accelerating alongside federal investment in water infrastructure, flood resilience, and coastal management. Meeting that demand in complex aquatic environments — where water depths vary dramatically, seasonal conditions fluctuate, and multiple sensor technologies must work together — requires more than capable equipment. It requires survey planning that accounts for the full operational envelope of each technology, rigorous data integration protocols, honest documentation of coverage limitations, and accuracy assessment methods that meet the standards agencies depend on.

The multi-sensor approach demonstrated on the Upper Mississippi River System project reflects the state of modern hydrographic surveying practice. For owners and agencies facing complex hydrographic surveys, understanding this approach — and specifying for it — is the difference between data that supports confident decision-making and data that creates uncertainty when it matters most.





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LET'S TALK.

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