VANGUARD TECHNOLOGY: THE CRUCIAL IMPORTANCE OF THE BATHYMETRY ECHOGRAM FOR RELIABLE SLUDGE QUANTIFICATION AND SILTING MONITORING IN SANITATION SYSTEMS

J. B. Fontes[1]
Geographer (UFPE) with a postgraduate degree in Oceanography and Coastal Management. Founder and CEO of Hydrocon Ltda., specializing in hydrography, bathymetry, and engineering consultancy. Lead hydrographer with extensive background in inland waterway surveys, subaquatic rock dredging control, and high-precision hydroacoustic processing.
M. Schlosser[2]
Specialized hydrographic consultant with an educational background in Geomatics from HafenCity University Hamburg, Germany. Partner and Technical Director at Warnow C Consultoria e Serviços Ltda., bringing extensive technical expertise in high-precision bathymetry, marine electronics, hydroacoustic instrumentation, and specialized offshore communications.
L. F. Fontes[3]
Doctor of Veterinary Medicine (DVM) with a postgraduate specialization in Small Animal Clinical Practice and General Surgery. Founder and Technical Director of Policlínica Vet in Buritama, São Paulo. Experienced veterinary surgeon dedicated to small animal clinical care, surgical procedures, and healthcare management.

Endereço[(1)]: Rua Eduardo Borges, 370 – Caminho das Águas- Buritama – SP - CEP: 15 290 000 – Brazil - Tel: +55 (13) 991834134 e-mail: bartolomeu@hydrocon.com.br

RESUMO

Maintaining navigable depths along the Tietê–Paraná Waterway requires continuous dredging operations, particularly where subaquatic rock formations restrict the navigation channel. This paper demonstrates the critical importance of digital single-beam echogram interpretation for identifying the true bottom and optimizing dredging volume estimates. A comparative study was conducted between two independent hydrographic surveys: Survey A, utilizing basic automated depth profiles without echogram recording, and Survey B, employing high-resolution digital echogram analysis. Although both surveys operated at a frequency of 200 kHz, omitting echogram data resulted in severe misinterpretation of loose material and blasted rock fragments remaining in the channel. The integration of digital echogram recording revealed a volume discrepancy of 10,445.04 m³, representing an unestimated financial impact of approximately US$ 455,000.00. The contracting authority approved the echogram-based survey as the only reliable representation of the true bottom, avoiding critical operational risks and contractual disputes.

KEYWORD: bathymetry, volume calculation, dredging control, blasting, single-beam, Tietê–Paraná Waterway.

INTRODUCTION

The acoustic penetration signature in the subaquatic substrate has long been recognized as a fundamental element for accurate underwater characterization. Instrumental records—including time, date, vertical corrections, positioning, and auxiliary sensor data—provide the baseline for high-precision hydrographic modeling. Depending on the survey objectives, acoustic backscatter data can be leveraged for sediment classification, sub-bottom profiling, paleochannel mapping, and underwater obstacle detection (Hamilton, 2001).
Traditional hydrographic systems recorded analog echograms on thermal paper. These hardcopies served as permanent documentary evidence and critical validation tools, allowing hydrographers to visually distinguish between real physical obstacles and acoustic noise or secondary reflections. However, the physical preservation, duplication, and management of extensive paper rolls presented significant logistical challenges during large-scale operations. Modern digital single-beam echosounders store raw acoustic data in binary formats, allowing simultaneous processing alongside conventional depth profiles. Despite these computational advancements, a fundamental question persists: in the absence of an echogram record, how can the true bottom be verified? Discrete depth values alone fail to differentiate between a consolidated rocky bed and accumulated loose material. The echogram addresses this limitation by providing a continuous visual profile of acoustic impedance and substrate density variations.

METHOD

Hydrographic operations in Brazil are strictly regulated by the Brazilian Navy's Directorate of Hydrography and Navigation through the NORMAM-501/DHN standard (Director de Hidrografia e Navegação, 2021). This regulation mandates the use of continuous echogram recordings for equipment calibration, data validation, and the elimination of false acoustic peaks. In complex inland waterways, single-beam and multibeam systems should be deployed as complementary methodologies rather than mutually exclusive choices. Single-beam echosounders equipped with digital echogram recording provide excellent acoustic penetration and substrate hardness insights, which are indispensable for identifying fluid sediment layers and rock debris. Conversely, multibeam systems deliver full-coverage bathymetric digital terrain models (DTM) optimized for final volumetric verification and clearance surveys.

This study analyzes a critical dredging sector along the Tietê–Paraná Waterway, spanning approximately 15 km in length and 60 m in width. The channel characteristics are highly complex due to historical dredging interventions, irregular underwater topography, dense subaquatic vegetation, and significant seasonal water level fluctuations. To evaluate the impact of acoustic data visualization on volume calculations, two independent pre-dredging surveys were executed using a cross-section line spacing of 1 meter:

Survey A (Without Echogram): Conducted using a SyQwest single-beam echosounder operating at a frequency of 200 kHz, tracking only automated digitizer depth profiles without saving or analyzing the underlying echogram data.

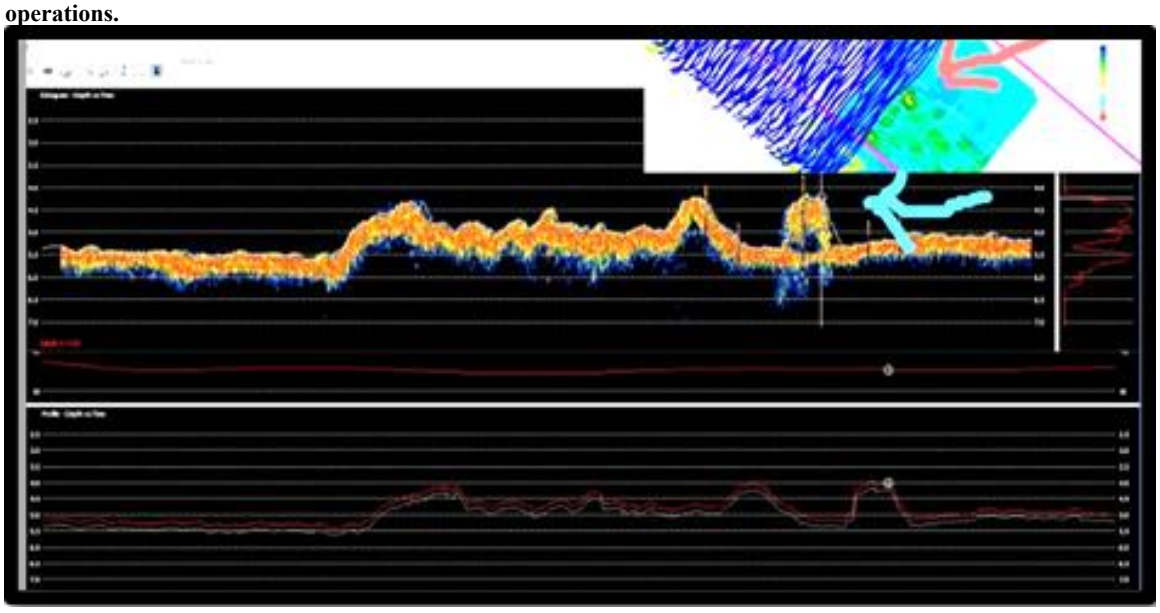
Survey B (With Digital Echogram): Conducted by our team utilizing a Teledyne Odom single-beam echosounder operating at the same contractual frequency of 200 kHz, with full binary logging of the digital echogram and manual post-processing verification.

Dredging volume computations for both surveys were executed by means of standardized hydrographic software applying the cross-sectional end-area method. For final operational clearance and spatial validation, a high-resolution multibeam survey was conducted to correlate single-beam echogram profiles with a 3D bathymetric surface model.

RESULTS

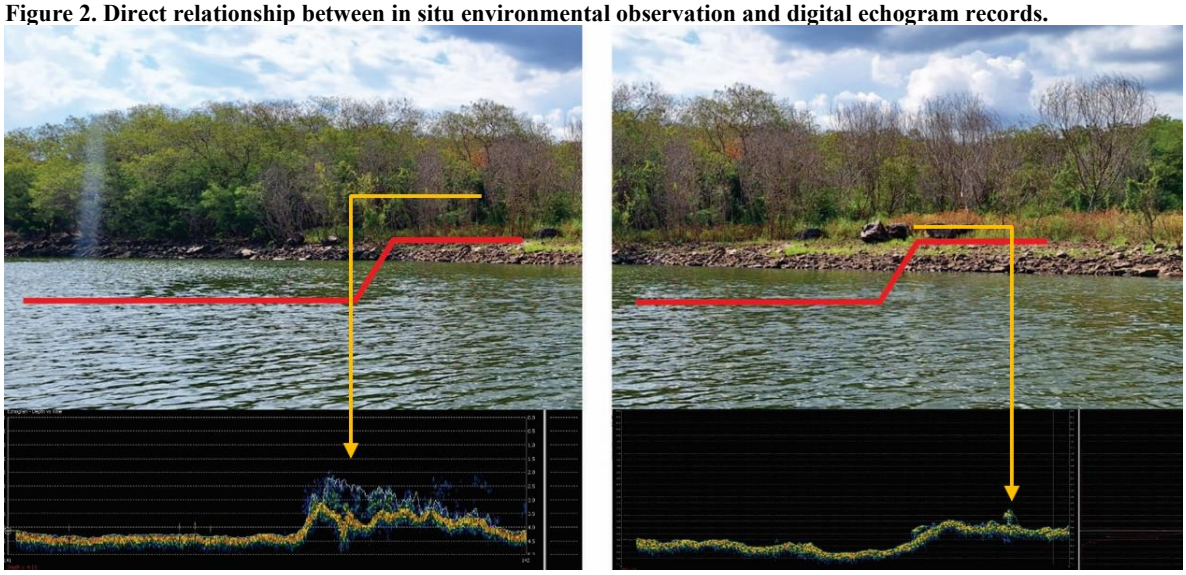
The comparative analysis between the two single-beam surveys revealed severe discrepancies in bottom profile interpretation. Survey A (without echogram) relied strictly on the automated acoustic tracking line. Because the system's digitizer locked onto the uppermost boundary of suspended sediments and loose rock fragments left behind by previous blasting operations, it failed to identify the underlying consolidated geological stratum. In contrast, Survey B (with digital echogram) allowed the operator to analyze the complete acoustic backscatter signature, effectively mapping the true bottom beneath the loose debris layer (Figure 1).

Figure 1. The digital echogram profile showing loose material and acoustic nuances remaining after dredging operations.



Source: Generated by the authors during post-processing analysis.
The visual verification provided by the echogram prevented the inclusion of transient features, such as seasonal subaquatic vegetation and dense suspended sediment clouds, which would have compromised the survey's integrity. Figure 2 demonstrates the direct spatial correlation between in situ bank observations and the corresponding digital echogram reflections, confirming the system's capability to isolate non-consolidated elements from the true solid riverbed.

Figure 2. Direct relationship between in situ environmental observation and digital echogram records.



Source: Generated by the authors during post-processing analysis.

The variations in bottom detection directly altered the volumetric calculations for the excavation project. Table 1 outlines the quantified volumes and the resulting financial divergence. A rigorous mathematical verification of the dataset yields an absolute difference of exactly 10,445.04 m³ of rock excavation material.

Tabela 1 - Computed volume comparison and estimated financial impact between survey methodologies.

Survey A (With Echogram)	Survey B (No Echogram)	Net Diference (m³)	Impact (USD)
540,555.22	551,000.26	10,445.04	**455,000.00**

Source: Compiled by the authors from primary survey data.

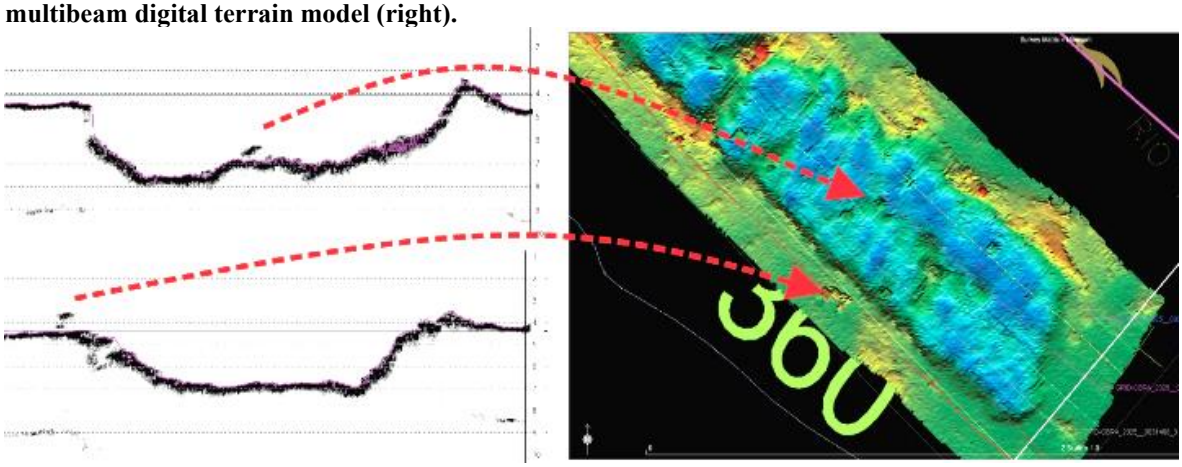
This discrepancy of over 10,000 m³ of underwater rock excavation represents a substantial financial threshold that would render the engineering project commercially unviable for the dredging contractor if uncorrected. Based on the verifiable acoustic evidence provided by the digital echogram records, the contracting authority formally approved the results of Survey B as the official contractual baseline.

DISCUSSION

Hydrographic surveying in dynamic river environments remains highly susceptible to physical and acoustic interferences. In commercial dredging operations, project managers frequently prioritize multibeam surveys to satisfy rigid contractual clauses, occasionally disregarding the distinct technical merits of single-beam acoustic soundings. While multibeam systems offer unmatched spatial resolution and exceptional precision for grid-based volume calculations, they can struggle to accurately differentiate between a solid rock interface and highly reflective loose debris or blast remnants scattered on the riverbed.
As demonstrated in this project, single-beam systems operating with low-frequency or dual-frequency options provide superior sub-bottom penetration, offering a cost-effective and highly reliable solution for sediment layer interpretation and dredging control. To validate these findings, the cross-sectional single-beam echograms were spatially correlated with the final multibeam terrain model. Figure 3 demonstrates that the acoustic profiles match the 3D morphological features captured by the multibeam array, confirming that when

single-beam profiles are executed with tight line spacing (1 m), they yield highly accurate and consistent results.

Figure 3. Spatial correlation and structural comparison between singlebeam echogram (left) and multibeam digital terrain model (right).



Source: Generated by the authors during post-processing analysis.

CONCLUSIONS

Accurate hydrographic monitoring for dredging control cannot rely exclusively on fully automated data processing algorithms and black-box equipment. The technical expertise of experienced hydrographers remains essential for evaluating acoustic anomalies and interpreting complex backscatter profiles. The digital echogram serves as an irreplaceable diagnostic tool and permanent legal record, providing indisputable empirical evidence to resolve volume disputes between contractors and supervising authorities. By ensuring the definitive identification of the true bottom, echogram recordings eliminate costly volume calculation errors, minimize operational risks during underwater blasting, and guarantee the economic and structural success of major waterway infrastructure developments.

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REFERENCES

1. Director de Hidrografia e Navegação. (2021). NORMAM-501/DHN: Normas da Autoridade Marítima para Levantamentos Hidrográficos. Marinha do Brasil.
2. Fontes, J. B. (2010). Deepening of the Port of Santos – Dredging to Results: Multibeam x Single Beam. Proceedings of Hydro 2010, Rostock-Warnemünde, Germany.
3. Hamilton, L. J. (2001). Acoustic Seabed Classification Systems. DSTO Electronics and Surveillance Research Laboratory. DSTO-TN-0401. Victoria, Australia.
4. Lurton, X. (2002). An Introduction to Underwater Acoustics: Principles and Applications. Springer-Praxis Publishing. Chichester, UK.