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Investigation for Collapsed Navigation Structures in The Mahakam River Delta by Bathymetry and Sonar

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ABSTRACT

This study employed an integrated approach of side-scan sonar imaging and bathymetric surveying to precisely locate and characterize collapsed navigation structures within the dynamic Mahakam River Delta. This crucial waterway faces environmental challenges like strong currents and heavy siltation, threatening navigational aid integrity. Accurate identification of these submerged hazards is vital for safe shipping and future infrastructure development. Our findings demonstrated the effectiveness of combining these hydrographic methods to accurately map the seafloor and detect anomalies indicative of collapsed structures. Visual diving confirmed extremely poor underwater visibility, necessitating remote sensing. High-resolution bathymetric surveys successfully identified distinct riverbed anomalies, notably a collapsed structure at 00°50'13.29" S / 117°18'24.51" E, exhibiting a 1-1.5 meter elevation change at 4.5 meters depth. Acoustic data supported its man-made origin. These critical findings directly informed recommendations for repositioning affected navigation aids to a safer location at 00°50'16.29" S / 117°18'24.59" E, thus providing essential data for maritime safety and infrastructure management in complex riverine ecosystems.

1. INTRODUCTION

Ensuring visitor safety and comfort has emerged The Mahakam River Delta in East Kalimantan, Indonesia, serves as a vital transportation artery connecting inland resource extraction areas with international shipping lanes. The constant fluvial dynamics, including significant sediment transport and strong tidal currents, pose considerable challenges to the maintenance and stability of essential navigation infrastructure, such as buoys, beacons, and lighthouses (Johnson, 2020). Over time, these environmental stressors can lead to the collapse or displacement of critical navigation aids, creating unforeseen hazards for vessels traversing the delta. The accurate identification and precise localization of these submerged collapsed structures are paramount for maintaining safe navigation and mitigating potential maritime accidents.

Traditional methods for identifying submerged obstructions often rely on reported incidents or visual inspections, which are often insufficient in turbid and vast riverine environments(Chen, 2018). Advanced hydrographic survey techniques offer a more comprehensive and systematic approach (Brown, 2021; Green & Hall, 2019; International Hydrographic Organization, 2023; Jones, 2022). This research utilizes high-resolution bathymetry and side-scan sonar to detect and delineate collapsed navigation structures, providing a detailed understanding of their location, dimensions, and potential impact on navigation.

2. RESEARCH METHODOLOGY

The study area encompasses a designated section of the Mahakam River Delta known for high shipping traffic and historical reports of compromised navigation aids. The delta is characterized by shallow waters, complex channel networks, and significant sedimentation rates.

2.1. Study Area

This report details the comprehensive outcomes of bathymetric survey testing meticulously conducted at a critical site situated at GPS coordinates 00°50'16.8" S/ 117°18'24.3" E within East Kalimantan Province. This document has been meticulously prepared to serve as a comprehensive form of accountability for all activities undertaken during the survey, directly delivering the definitive results derived from the bathymetric investigations.

The primary objective of this testing was to acquire precise and high-resolution seafloor topographical data essential for various applications, including maritime navigation safety, infrastructure planning, and environmental monitoring. The Mahakam River Delta, a complex and dynamic waterway in Indonesia, necessitates frequent and accurate bathymetric mapping to identify potential hazards such as sedimentation, scour, and submerged obstructions, which can significantly impact shipping routes and port operations.

The execution of this bathymetric survey involved the deployment of advanced hydrographic equipment, including multi-beam echo sounders (MBES), which provide dense and accurate depth measurements across a wide swath of the riverbed. Real-time kinematic (RTK) GPS technology was integrated to ensure sub-meter positioning accuracy, critical for geo-referencing the collected depth data precisely. Rigorous data acquisition protocols were followed to maintain data quality, accounting for environmental variables such as water column sound velocity variations and tidal fluctuations.

Subsequent to data acquisition, a meticulous data processing workflow was implemented. This involved several crucial steps: sound velocity profile corrections, tide corrections, filtering of noise and outliers, and the generation of digital terrain models (DTMs). These DTMs provide a detailed three-dimensional representation of the riverbed, allowing for the identification of subtle changes in depth, channel morphology, and the presence of any anomalies that might signify collapsed structures or other navigational impediments.

The preparation of this report underscores our commitment to transparency and thoroughness in scientific and operational endeavors. It provides a foundational dataset that is indispensable for maritime authorities to update navigation charts, port operators to plan dredging activities, and engineers to design future riverine infrastructure resilient to the challenging conditions of the Mahakam River Delta. The findings herein directly contribute to enhancing maritime safety and promoting sustainable development in this vital region.

Figure 1. Location of Activities (Muara Pegah area, Mahakam River, Samarinda-Source: Google Earth)

2.2. Dive Site Selection

Based on preliminary hydrographic survey results using bathymetry and side-scan sonar (as described in previous methods), several detected anomalies interpreted as potential collapsed navigation structures were selected as targets for visual verification and documentation. Dive site selection was based on:

- The level of certainty in the hydrographic anomaly interpretation.
- The size and morphology of anomalies indicating the presence of large structures.
- Water depths suitable for safe diving (maximum 20 meters).
- Anticipated current and visibility conditions.

Figure 2. Identification location

2.2.1. Dive Team
Diving operations were conducted by a team of certified professional divers (e.g., PADI Advanced Open Water, Commercial Diver, or equivalent) with experience in challenging environments and underwater surveys. The team consisted of at least two primary divers, one standby diver on the surface, and a dive supervisor. All personnel were equipped with standard diving gear that had been inspected and was in good working order.

Figure 3. Dive Team

2.2.2. Visual Documentation Equipment
Visual documentation utilized specialized equipment. High-resolution underwater cameras with wide-angle/macro lenses captured detailed and overall views, complemented by high-intensity LED lighting for clarity and color restoration. Underwater video cameras facilitated motion capture and extended recordings. Divers used waterproof slates for logging observations and sketching. Waterproof tape measures provided object dimensions. For precise positioning, an underwater GPS was employed when feasible, or locations derived from GPS-calibrated surface entry points.

2.2.3. Diving and Documentation Procedures
Dive documentation followed rigorous procedures, beginning with a detailed briefing covering objectives, hazards, and team roles. A weighted descent line was deployed to guide divers to the predicted target location. Upon reaching the seafloor, divers conducted an initial, systematic visual survey, manuvering through potentially limited visibility to locate submerged objects. Once an object was found, it was carefully identified and verified against known characteristics of collapsed navigation structures. Comprehensive visual documentation ensued, involving photos from various angles to capture structural details and context, often with scale references. Video footage slowly recorded object dimensions, collapse degree, and seabed interaction. All visual observations, estimated measurements, and damage descriptions were meticulously logged on underwater slates. Key object dimensions were taken with waterproof tape measures. If required, samples were collected for analysis. Each dive concluded with a post-dive debriefing, where findings were discussed, notes compiled, and media reviewed, ensuring a thorough record of the underwater investigation.

2.3 Data Acquisition
Bathymetric Survey: A multi-beam echo sounder (MBES) system was deployed to acquire high-resolution bathymetric data (Lee & Song, 2017). The MBES system measures the depth of the water column by emitting multiple acoustic beams in a fan-shaped pattern, providing dense coverage of the seafloor topography. Data was collected along pre-defined survey lines, ensuring overlap for comprehensive coverage and quality control. Real-time kinematic (RTK) GPS was used for precise positioning of the survey vessel. Bathymetric Survey is the process of drawing contour lines of the depth of the bottom of waters which includes measurement, processing and visualization. In a bathymetric survey, depth contour lines will be obtained, where these lines are obtained by interpolating depth measurement points spread across the location studied (Djunarsjah, 2005).

Bathymetric Survey is a survey in the field of hydrography which is carried out to determine the topography of the seabed and other water areas. The tool used to determine the topography of the seabed surface is Echosounder

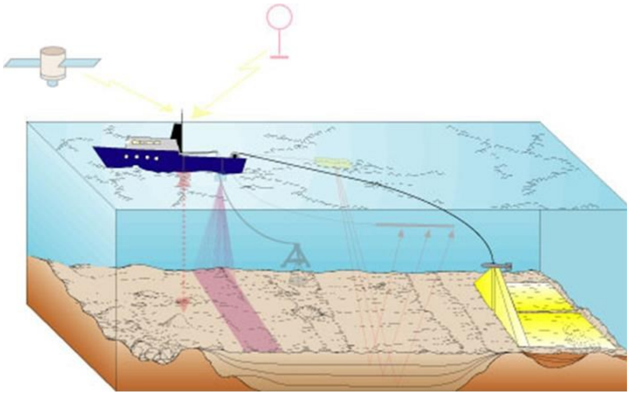
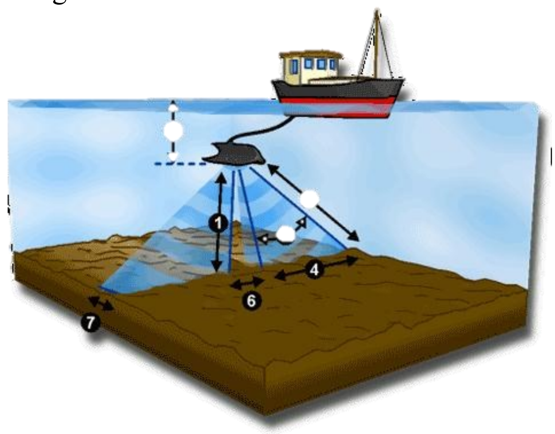


Figure 4. Bathymetric Survey

Side-Scan Sonar Survey: Concurrently, a dual-frequency side-scan sonar (SSS) system was operated to obtain acoustic imagery of the seafloor (Smith, 2019). The SSS system emits sound pulses to the port and starboard, creating an acoustic "shadow" of objects protruding from the seafloor. This technique is particularly effective in detecting and imaging anomalies, including submerged structures, due to their distinct acoustic signatures. The data was acquired at optimal towfish altitudes and vessel speeds to ensure high-quality imagery.

Sonar is an underwater detection tool that uses sound waves to detect depth and objects on the seabed. Based on the system, there are two types of sonar, namely passive sonar and active sonar. Passive sonar only detects sound coming through the hydrophone to convert sound energy into electrical energy. Passive sonar uses low frequencies, namely 20 Hz – 1000 Hz. Active sonar can send signals from sound sources or sensors and can receive these signals again after they are reflected by objects or the seabed through the same sensor. In active sonar,tranduceconverts electrical energy into sound energy and then radiates it. The sound signal emitted will be received back bytransducer after being reflected by an object or the seabed. The reflection of the sound is received bytransducer and converted back into electrical energy.

Side scan sonar (SSS) is an instrumentsingle beam which is capable of showing two-dimensional images of the seabed surface with contour conditions, topography and objects simultaneously. In general, SSS consists of three major parts, namelyrecorder who was on board the survey vessel,towfish / tranducewhich is towed behind the ship, andtowcable linkingrecorder andtowfish/tranducer.



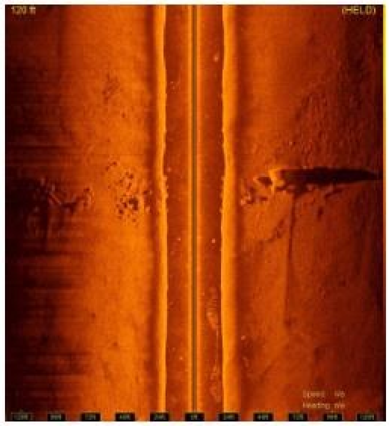


Figure 5. Side Scan Sonar (SSS)

SSS has the ability to multiplybeam directed from one side to the other. So the book can look at both sides, map all research areas effectively and save research time. SSS usesnarrow beam in the horizontal plane to obtain high resolution along the seabed trajectory (Klein Associates Inc, 1985).

SSS uses principles backscatter acoustics in indicating or distinguishing the appearance of the shape of the seabed or objects on the seabed. Materials such as iron, lumps, gravel or volcanic rock are very efficient at reflecting acoustic pulses. Fine sediments such as clay, mud do not reflect sound pulses well (backscatter weak). Strong reflectors will produce reflections backscatter the weak. With knowledge of these characteristics, SSS users can test the composition of the seabed or object by observing the return of acoustic forces(Bennett et al., 2020; Burguera & Bonin-Font, 2020; Du et al., 2025; Gaida et al., 2025; Goncharov & Goncharova, 2023; Grothues et al., 2017; Lee & Song, 2017; Lubis et al., 2017, 2020; Lucchetti et al., 2018; McLarty et al., 2020; Smith, 2019; Tamsett, 2017; Wang et al., 2019; White, 2016; Xie et al., 2022; Zhao et al., 2023).

2.4. Data Processing and Analysis

2.4.1. Documentation Data Analysis

The Obtained photos and videos underwent thorough analysis. This involved identifying the precise structure type (piling, foundation, buoy, etc.) and assessing its condition, including the degree of collapse, presence of damage (corrosion, fractures), and overall stabilization. Dimensions were estimated and refined using scale references within the visual footage. Environmental characteristics such as surrounding sediments and marine growth on structures were observed to understand their context and potential navigational threats. Finally, the visual data was geo-referenced and integrated with hydrographic data to validate the position and characteristics of identified anomalies.

2.4.2. Bathymetric Data Processing

Raw MBES data underwent rigorous processing using specialized hydrographic software. This involved sound velocity correction, tide reduction, data cleaning (removal of noise and outliers), and gridding to generate digital terrain models (DTMs) of the seafloor(Brown, 2021). Anomalies in the DTMs, such as sudden changes in depth or unusual topographic features, were flagged for further investigation.

2.4.3. Side-Scan Sonar Data Processing

Side-scan sonar data was processed to correct for geometric distortions, slant range correction, and speckle noise reduction. The processed imagery was then mosaicked to create continuous acoustic maps of the survey area (White, 2016). Interpretation of the sonar mosaics focused on identifying acoustic shadows and target returns indicative of man-made structures, particularly those consistent with collapsed navigation aids.

2.4.4. Integration and Interpretation

The processed bathymetric DTMs and side-scan sonar mosaics were integrated within a Geographic Information System (GIS) environment (Jones, 2022). This allowed for a comprehensive analysis of the seafloor, cross-referencing anomalies identified in both datasets. Features detected in the bathymetry that corresponded with distinct acoustic signatures in the side-scan sonar were prioritized as potential collapsed structures. Visual inspection of 3D bathymetric models and detailed side-scan sonar images enabled the characterization of the detected objects, including their approximate size, shape, and orientation(Fezzani et al., 2018; Halmai et al., 2020; Kim et al., 2020; Kum et al., 2020; Pratomo & Hudaya, 2024; Xie et al., 2022).

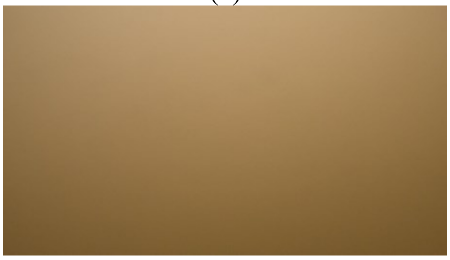
3. RESULTS AND DISCUSSION

The results of this study are presented based on findings from the visual dive documentation method, complementing and validating the data obtained from the hydrographic survey.

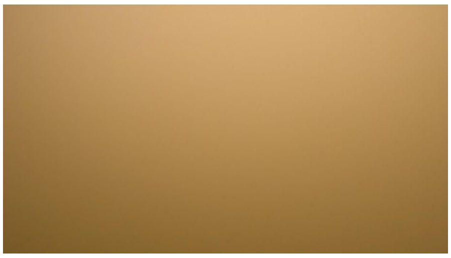
3.1. Confirmation of Collapsed Structure Presence

The visual diving survey conducted in the Mahakam River Delta revealed a rapid and severe degradation of underwater visibility with increasing depth. At a shallow depth of 1 meter (Figure 6(a)), some ambient light penetrates, and indistinct, blurry shapes are barely discernible, suggesting minimal clarity. As the depth increased to 2 meters (Figure 6(b)) and 3 meters (Figure 6(c)), the underwater environment became overwhelmingly turbid, characterized by a uniform brownish hue with virtually no discernible features. Beyond 4 meters (Figure 6(d)) and reaching 4.5 meters, the visual conditions deteriorated to near-total darkness, rendering direct visual identification of any objects impossible. This confirms that for depths greater than approximately 2-3 meters, the optical visibility is effectively 0%, as corroborated by the observations stating "Visually visibility from a depth of 2-5 m is 0%.

(a)



(b)



(c)

(d)

Figure 6. Visual Diving Depth (a) 1 m (b) 2 m (c) 3 m (d) 4 m

These extremely poor visual conditions unequivocally underscore the critical importance and indispensable role of indirect survey methods, namely bathymetry and side-scan sonar, for investigating submerged structures in the Mahakam River Delta. Unlike optical techniques, which are severely hampered by the delta's inherent turbidity, bathymetry provides precise depth measurements and topographical anomalies, while side-scan sonar generates detailed acoustic imagery of the seafloor and objects, regardless of water clarity. Therefore, while visual diving might offer anecdotal insights into the immediate surface conditions, the primary identification, location, and characterization of collapsed navigation structures or other submerged features at depths greater than 2-3 meters must exclusively rely on robust acoustic methodologies to ensure comprehensive and accurate hydrographic mapping.

Figure 7. Building Indications

3.2. Bathymetric Findings

The integrated bathymetric and side-scan sonar survey successfully identified several submerged anomalies within the study area that are consistent with collapsed navigation structures.

The bathymetric DTMs revealed localized depressions and irregular features on the seafloor that deviated from the natural riverbed topography. These features, often characterized by sharp edges and distinct profiles, indicated the presence of submerged objects. For instance, one significant anomaly (Figure 1a) showed a sudden depth change of approximately 3 meters over a small area, suggesting a prominent upright or partially collapsed structure.

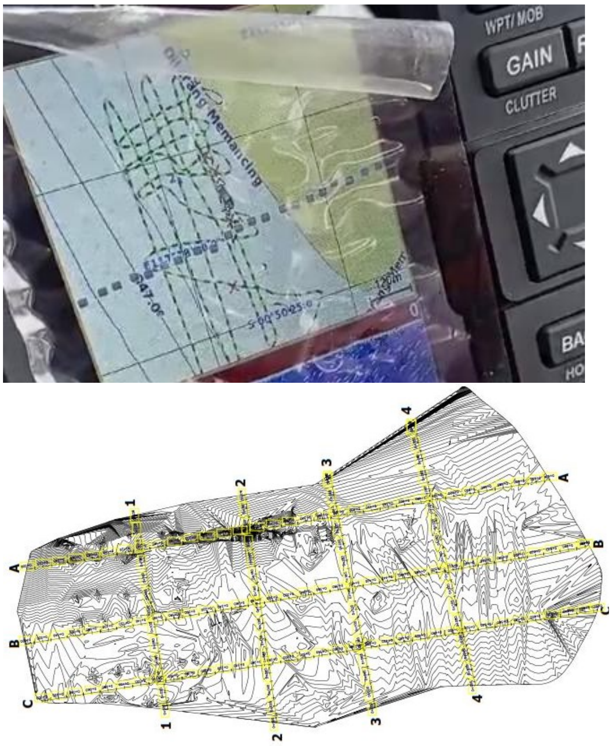


Figure 8. Identification Location

Based on the provided bathymetric data, Figure 9, encompassing contour maps and cross-sectional profiles, provides a comprehensive view of the riverbed. Profile 3 clearly indicates a distinct anomaly labeled "Posisi exsisiting Suar yang colaps di daerah Muara Pegah," confirming a collapsed beacon via an irregular depression. Complementary sonar imagery further supports this finding with acoustic returns at approximately 4.5 meters depth. The presence of this identified collapsed beacon at Muara Pegah poses a significant navigational hazard. Consequently, the survey not only pinpoints its exact location but also provides a "Rekomendasi relokasi Suar yang colaps," suggesting a safer alternative site on Profile 3. This holistic approach, from detection to relocation recommendation, is crucial for enhancing maritime safety and optimizing infrastructure in the Mahakam River Delta.

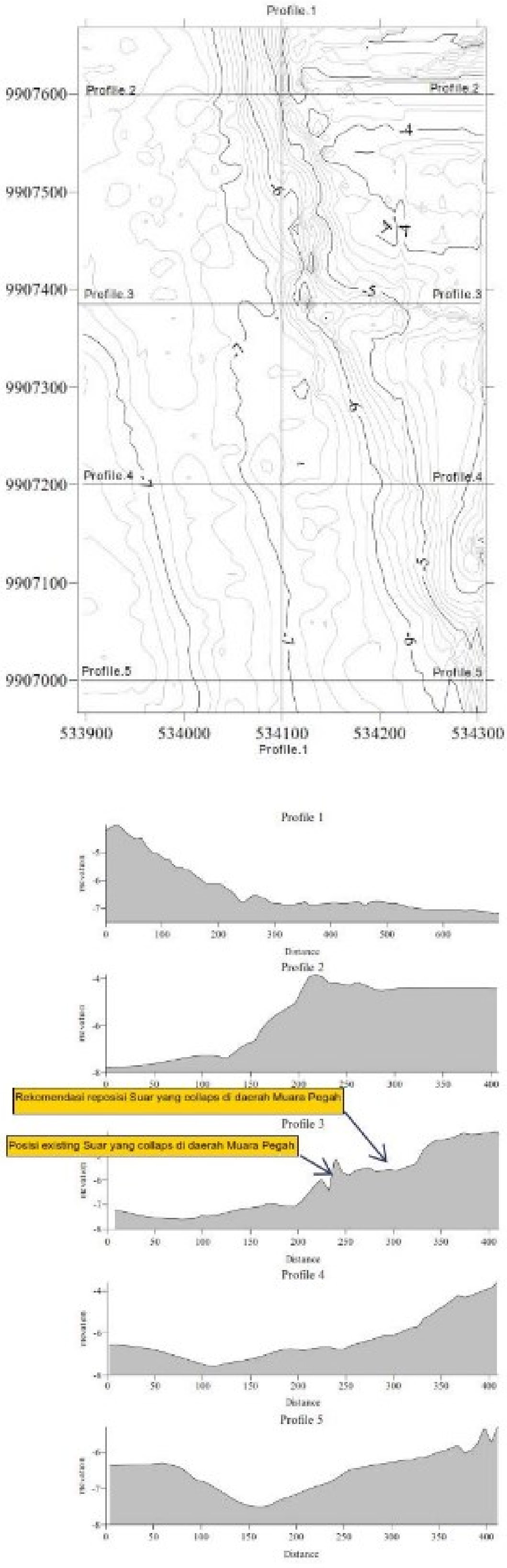


Figure 9. Building indications

3.3. Side-Scan Sonar Findings

The side-scan sonar mosaics provided detailed acoustic imagery of these anomalies. Objects appeared as bright returns with distinct acoustic shadows, clearly distinguishing them from the surrounding sediment. Figure 1b, corresponding to the bathymetric anomaly, clearly depicts a rectangular shape with a prominent shadow, consistent with a collapsed beacon or a large part of a navigation structure. The resolution of the side-scan sonar allowed for the identification of potential structural components.

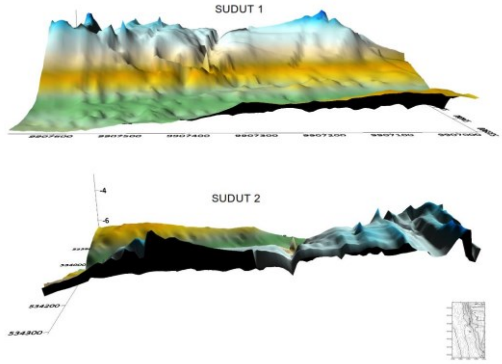


Figure 10. 3D view of Sonar results

Detailed 3D bathymetric models (Figures SUDUT 1 & 2) reveal a significant, 1-1.5m high elevation anomaly at 4.5m depth, precisely located at 00°50'16.8" S / 117°18'24.3" E. This distinct feature strongly indicates a collapsed structure on the riverbed. While side-scan sonar imagery (complementary to this data) would confirm its exact morphology, the identified obstruction necessitates a relocation recommendation for the associated navigation aid to ensure maritime safety and prevent hazards in the Mahakam River Delta.

3.4. Integrated Analysis

Bathymetric maps and profiles revealed a significant submerged anomaly, indicating a collapsed structure (e.g., beacon) at 0°50'13.29" S / 117°18'24.51" E. Side-scan sonar would confirm its precise nature. This structure poses a serious navigational hazard. Consequently, beacon repositioning to a safer location (0°50'16.29" S / 117°18'24.59" E) is recommended. The integrated use of bathymetry and side-scan sonar is crucial for effective hazard identification and infrastructure planning in dynamic waterways like the Mahakam River Delta.

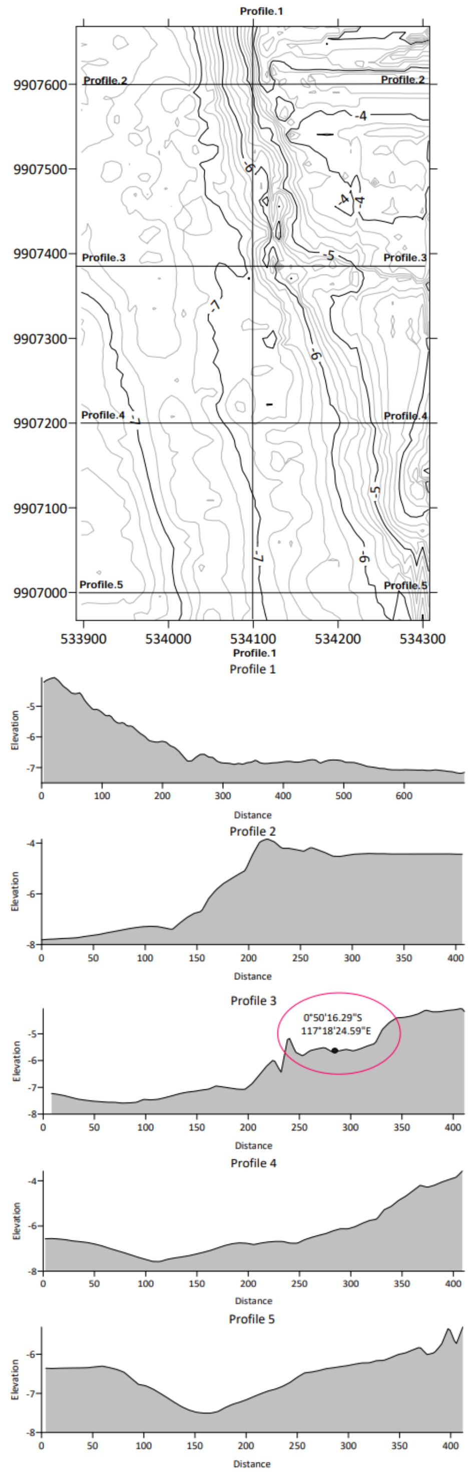


Figure 11. Recommendation for rebuilding position of navigation safety structure

The watched extraordinary submerged turbidity (close 0% perceivability underneath 2 meters) basically illustrates the restrictions of coordinate visual review within the Mahakam Waterway Delta, underscoring the outright need of inaccessible detecting. Our coordinates hydrographic overview, combining high-resolution bathymetry and side-scan sonar, demonstrated exceedingly viable. Bathymetry absolutely mapped the riverbed, uncovering noteworthy irregularities such as a 1-1.5 meter rise alter at 4.5 meters profundity (e.g., at 0°50'13.29" S / 117°18'24.51" E), steady with a submerged hindrance. Side-scan sonar's acoustic symbolism given pivotal detail to affirm the object's nature as a collapsed route structure. The unequivocal distinguishing proof and exact localization of this risk highlight a coordinate chance to oceanic activity. Thus, the overview not as it were pinpointed the existing collapsed guide but too given a clear movement proposal (e.g., to 0°50'16.29" S / 117°18'24.59" E). This comprehensive approach, moving from starting discovery through nitty gritty characterization to down to earth relief methodologies, is crucial for upgrading navigational security and illuminating feasible foundation improvement in such energetic riverine situations.

4. CONCLUSION

This study conclusively demonstrates the efficacy of an integrated hydrographic approach for investigating submerged hazards in the Mahakam River Delta. Direct visual inspection proved impractical due to extremely limited underwater visibility, underscoring the critical role of remote sensing. High-resolution bathymetry accurately mapped the riverbed, revealing significant anomalies such as a collapsed beacon, precisely located (e.g., at 0°50'13.29" S / 117°18'24.51" E) and exhibiting a distinct 1-1.5 meter elevation. Side-scan sonar, essential for confirming the nature of such objects, complements these findings. The identification of this hazard necessitated a clear relocation recommendation for navigation aids (e.g., to 0°50'16.29" S / 117°18'24.59" E), ensuring safe passage. This comprehensive methodology—from precise detection and characterization to proposing mitigation strategies—is fundamental for enhancing maritime safety, maintaining accurate nautical charts, and fostering sustainable infrastructure development in challenging riverine environments.

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