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UAV-Based Remote Sensing Survey for Quantification of Beach Fill Construction Projects

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Abstract: This research paper explores the integration of Unmanned Aerial Vehicle (UAV)-based remote sensing survey methods, specifically LiDAR and photogrammetry, into the measurement and payment processes of beach fill construction projects managed by the U.S. Army Corps of Engineers (USACE). The primary objective is to evaluate the feasibility, accuracy, and cost-effectiveness of UAV technology in contrast to traditional topographic and hydrographic survey methods. The methodology includes a comprehensive literature review, case studies, accuracy standard assessments, and a detailed cost comparison between conventional and UAV-based survey techniques. The findings reveal that UAV-based remote sensing can offer significant improvements in terms of efficiency and cost savings. UAVs are capable of capturing large data volumes quickly with reduced manpower and equipment needs. However, the accuracy of UAV surveys is contingent upon environmental conditions and the proper staging of control points. Moreover, the initial investment and operational costs of UAV equipment are substantial and warrant further analysis. The paper argues for flexibility in measurement and payment methodologies during the project design phase to accommodate UAV technology. While environmental conditions may occasionally necessitate traditional survey methods, the study suggests that regions like the Florida Peninsula, with clearer water and more favorable weather, are particularly well-suited for the implementation of UAV-based surveys. The significance of this study lies in its potential to guide future beach fill construction projects, promoting more efficient and cost-effective survey methods while adhering to accuracy standards and environmental considerations.

Key words: Dredging, Quantification, Remote Sensing, UAV, USACE

1. INTRODUCTION

In 1956, the U.S. Army Corps of Engineers (USACE) was authorized to conduct beach nourishment for shoreline protection. Since then, the Corps has participated in beach nourishment projects on approximately 350 miles of shoreline, mainly on the Atlantic and Gulf coasts of the United States. For Fiscal Year 2023, USACE has budgeted $1.9B for Coastal Construction under Navigation and Flood and Coastal Storm Damage Reduction authorities included within the Defense Appropriations Act [1]. Typical beach placement consists of dredging offshore sediment onto a beach and constructing designed dune and berm features that extend oceanward and then slope down until they meet the existing bottom. Beach nourishment dredging contracts usually entail volumes ranging from 500,000 to 2 million cubic yards, covering multiple miles of beach, with dredges and upland earth-moving equipment operating 24 hrs/day and 7 days/week. Beach construction contracts are designed to be measured and paid on a per-cubic-yard basis, and measurement of the fill historically involves conventional topographic and bathymetric/hydrographic survey combinations to capture the upland portion of the dune and berm fill, as well as the slope that extends into the ocean, sometimes past the surf zone. Depending upon the speed of dune and berm production, surveying efforts are necessary to capture pre and post-placement surfaces, often requiring daily collection by survey crews and hydrographic survey equipment. The development and submission of survey deliverables are required for overrun or underrun analysis of the fill material as the beach fill progresses linearly along the beach.

Beach fill placement projects require precise measurement and payment for project success. Survey profiles of the beach fill extend from the project baseline perpendicularly to the beach along 100-foot stations or where significant changes to the baseline will occur, and the resulting volume is measured by average-end-area methods or surface-to-surface methods, whichever is specified. This method allows for efficient measurement and payment for the contractor and provides a reasonable sample size of the beach fill to meet local/state agency permit requirements. Methodologies of survey collection for measurement and payment have evolved as technology has changed from differential level and level rod with tape measurement increments to high-accuracy RTK and GPS-based collection of the dune, berm, and slope in combination with sonar-based bathymetry collected by survey vessels. Survey deliverables are processed with the collected data by technicians through post-processing software in accordance with the deliverables specified within each contract. Deliverables typically include cross-sectional views of the beach profiles of the pre and post-placed surfaces with the beach fill template and tolerance lines for each 100-foot station. Procedures and standards for collecting and processing the surveys for measuring and paying beach fill are referenced in USACE Engineering Manual EM 1110-2-1003 Hydrographic Surveying Engineering, with the most recent version published in 2013 [2].

With the advent of remote sensing survey technology through fixed and rotary wing UAVs, the options and capabilities for measurement and payment survey collection have expanded within the past decade. However, new methods of survey collection have not been incorporated into USACE beach fill contracts due to many factors, including costs, testing, cyber security, accuracy, and regulations, to name a few. This paper seeks to analyze the feasibility of incorporating UAV-based remote-sensing survey equipment and technology, such as Light Detection and Ranging (LiDAR) and photogrammetric, into these projects by evaluating the most recent information and future outlook for expansion into this realm of heavy civil construction from a construction management perspective.

2. LITERATURE REVIEW

A beach fill project utilizing UAV remote sensing technology for measurement and payment during construction has not been investigated or documented within the USACE Engineering and Research Development Center’s literature database. Much of the publicly available literature on UAV use at beaches focuses on collecting field data for geomorphological studies on existing beaches. UAV use has been documented in numerous journals and papers that address post-construction monitoring of past fill projects, specifically sediment transport [3]. LiDAR and Photogrammetry sensors mounted on UAVs allow for collection of large amounts of data over a large expanse of area cost-effectively and efficiently as compared to terrestrial-based conventional topographic and vessel-based hydrographic methods, which makes it an ideal tool for conducting coastal research [4]. Numerous case studies globally have investigated the precision of beach morphology measurements using aerial-based LiDAR and photogrammetry collection methods, and these studies are well-documented in various scientific and engineering journals. However, it is worth noting that a predominant focus of these studies is on topographic data collection, with limited inclusion of bathymetric data. LiDAR-based bathymetry is collected with a green laser at a lower frequency than topo infrared-based laser systems, which have not been commercially available until the last decade with the advancements in drone technology [5]. Before UAV-based technological advancements, these instruments were mounted on airplanes and helicopters and covered large areas of beaches for studies. Therefore, their applications for construction measurement were not cost-effective nor feasible for the collection frequency necessary to study the effectiveness of daily collection over shorter spans.

Multiple case studies involve commercial off-the-shelf fixed-wing and rotary-wing UAVs flown at various heights above a beach to compare the accuracy of the LiDAR sensor against surveyed ground-truthed data. One of the more relative case studies conducted by Pietro, O'Neal, and Puelo [6] sought to examine the comparison between volumes calculated from beach profiles and volumes obtained from LiDAR-derived surfaces. Some notable advantages of using LiDAR data for volume calculations are the high point density and LiDAR 's capability to capture intricate variations on the entire surface within the study area. In the context of USACE beach renourishment projects, beach profiles are measured at specific intervals and are strategically determined to be as widely spaced as possible to minimize the frequency of required surveys while ensuring a representative sample size for assessing changes across the entire beach. In the case of the State of Florida, the distance between these profiles along the shoreline is approximately 305 m (1,000 ft). Notably, Pietro, O'Neal, and Puelo [6] observed that when they compared volumes derived from profiles spaced at 152 m (500 ft) intervals with those derived from the LiDAR-generated surface, the profile-based volumes underestimated the volume change by approximately 8% between the surfaces captured pre and post fill operations versus the average-end-area method during construction. Alarming at first, but the findings also note the time between construction and the loss of beach fill due to storms that passed before the LiDAR data collection.

Another relevant survey conducted in 2018 by Jeong, Park, and Hwang [7] in South Korea sought to evaluate the accuracy of UAV photogrammetry for beach morphology study as compared to RTK-GPS terrestrial LiDAR data. The vertical accuracy tests were compared with surveyed ground control points (GCPs) arranged in a pattern over the survey area. The GCPs are necessary because most beaches are composed of monochromatic sandy sediments; therefore, they must validate UAV photogrammetry's applicability by matching points from geographical features within images to create the 3D topographic data in beach topographic mapping. A series of patterned flights were flown at various altitudes and percentages of scan overlap with a fixed-wing UAV (eBee) and a rotary-wing UAV (BHRS-1) over the collection area to compare results. Accuracy standards for the survey are measured by root mean squared error (RMSE), which measures the collected data against what would be expected (in this case, the GCPs). The research results concluded that in both the fixed-wing and rotary-wing UAVs, the RMSEs were less than 4.9 cm (1.93 in) at flight altitudes below 150 m (492 ft) with 70% overlap of data collection and GCPs spaced at 50 m (164 ft) in a grid pattern [7]. It is important to note for this research paper that this study was restricted to upland beach measurement, but has contributed to the use of UAVs on beach fill projects by estimating the number of ground control points necessary to meet vertical accuracy standards.

A similar case study was conducted in 2019 by Brodie, Bruder, Slocum, and Spore [8], in which a multi-orthogonal camera with rotary-wing aircraft was utilized to capture topography and bathymetry data in North Carolina and Virginia beaches. This study was conducted to show that photogrammetry can be used to collect topographic and bathymetric data simultaneously from photo/video imagery by analyzing the surface of the water by algorithms based on wave speed inversion. The study also compares the location of the UAV with satellite and inertia-based navigation systems instead of GCPs and evaluates the different results. Resultant RMSEs at both sites varied between 0.26 m and 0.17 m (10.2 in and 6.7 in), which falls within the standards for coastal monitoring purposes, but outside of the standards for construction measurement and payment of beach fill for most USACE projects [8].

It is important to note that recent remote sensing research study approaches have focused on airborne LIDAR and photogrammetry, which can rapidly produce and map 3-D coastal topography and bathymetry data. In optimal environmental conditions, airborne LiDAR collects accurate, seamless 3-D data of the coastal zone but requires expensive sensors for collection that can have limited effectiveness in penetrating the breaking, turbid waters of the shallow surf zone [9]. Historically, beach fill projects are constructed between November and April in the U.S. due to environmental windows for sea turtle nesting, which experience statistically higher winds and frontal conditions, discounting optimal conditions for reliability to UAVs to capture accurate data daily.

3. METHODOLOGY

The methodology of this research focuses on the feasibility of incorporating UAV-based remote sensing survey collection for measurement and payment into USACE beach fill construction by analyzing some of the essential standards, regulations, contract requirements, and costs that project design teams and survey contractors should evaluate from a construction management perspective. A cost comparison was conducted between the conventional topographic and hydrographic survey collection methods and UAV-based collection methods by utilizing 2023 USACE contracted survey costs and price quotes provided for a UAV and LiDAR system. Over the last decade, these products' technological advancement and availability have outpaced the federal government’s incorporation of standards and regulations to utilize this technology effectively. Project designers and contractors must be aware of today’s accuracy standards, specified procedures, cyber security regulations, and costs to utilize UAV technology efficiently and effectively to be profitable and provide deliverables as specified in beach fill contracts.

4. RESULTS AND DISCUSSION

4.1. Accuracy Standards

Typical beach fill measurement and payment surveys combine land topographic cross-sections with offshore hydrographic/bathymetric sections. Beach profile lines (i.e., cross sections) are run perpendicular to the shoreline relative to the project baseline. Both topographic and hydrographic survey methods are employed to obtain continuous coverage of a beach profile line. Topographic methods may only be needed for beach fill placement if the material is placed out to wading depths. Figure 1 shows the typical fill cross-section of a beach renourishment project with the slope extending into the surf zone with tidal datums referenced.

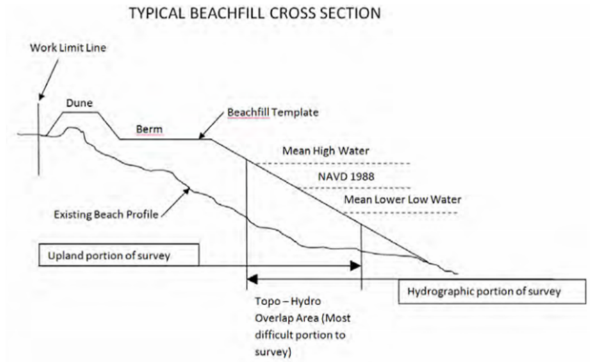


Figure 1: Typical beach nourishment fill cross-section with dune and berm construction [2].

As shown in Figure 2, surveyors typically wade out into the surf zone to collect pre and post-surfaces of the beach utilizing GPS or RTK-GNSS measuring techniques and use hydrographic survey vessels that utilize RTK-GNSS for horizontal position accuracy with single-beam sonar soundings to collect bottom depths beyond the surf zone.

(a) (b)

Figure 2: Topographic survey collection of the beach berm and slope in the surf zone [2].

Vertical and Horizontal accuracy standards are project-specific, but general guidance is provided in the U.S. Army Corps of Engineers Engineering Manual EM-1110-2-1003 Hydrographic Survey. Topographic Measurements [2] of the dune and berm above the surf zone require more accurate measurements, generally within 0.1 ft relative to project benchmarks or temporary control points. The surf zone topographic measurements offer a higher degree of error due to the changing fill placement, which degrades rapidly following the final grading of the slope, thus causing the need for regular surveys to capture the constructed berm. Table 1 references the vertical accuracy standards referenced in E.M. 1110-2-1003 Hydrographic Surveying [2]:

Table 1: Recommended Beach Nourishment Elevation and Horizontal Accuracy Standards [2]

Activity	**Std. Dev. (95%)**	**Relative to**
Beach fill grading tolerance	+/- 0.1 ft	Control Point
Beach fill topo-land section	+/- 0.25 ft	Control Point
Beach fill topo-surf zone	+/- 0.4 ft	Control Point
Bathymetric-surf zone	+/- 0.5 to 1 ft	Control Point

Bathymetric-offshore	+/- 0.25 to 0.5 ft	Control Point

Horizontal accuracies using GPS or RTK-based geolocation should be in the order of +/- 0.2 to 0.5 ft relative to the project control points [2].

Standards for LiDAR and Photogrammetry are referenced in U.S. Army Corps of Engineers Engineering Manual EM 1110-1-1000 Photogrammetric and LiDAR Mapping. Recommended vertical accuracy for topographic data collected by UAV-mounted sensors is 10 cm RMSE, and horizontal positional accuracy is 0.5 m RMSE from ground-truthed data. Standards recommended within this manual align with the American Society for Photogrammetry and Remote Sensing (ASPRS) Positional Accuracy Standards for Digital Geospatial Data [10].

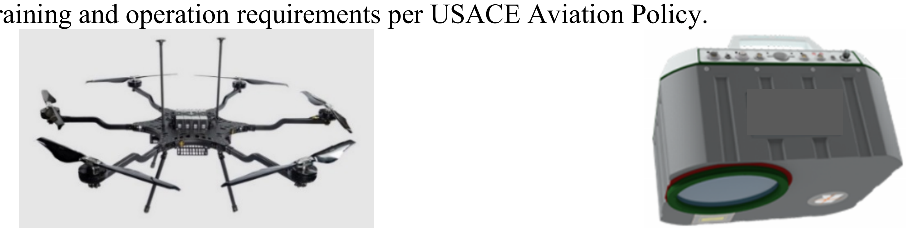
4.2. Aviation Policy Requirements

Since 2017, U.S. Department of Defense (DoD) agencies have been constantly changing to address cyber security concerns using UAVs and payloads on Federal projects. Guidance is updated annually, or sometimes more frequently, to try and keep up with commercial production of the latest technology and cyber security concerns in the growing field of UAV use. The overarching policy that all USACE UAV flights and data collection processes must comply with is identified in Aviation Policy Letter APL 95-1-1 USACE Aviation Policies and Standards [11], which aligns with FAA regulations and Army and DoD requirements. The policies and processes in this document cover mission planning, aviation safety, aircrew standardization, reporting requirements, data protection, and contractor surveillance for all flights and payloads on USACE projects and lands. APL 95-1-1 also refers to DoD’s current unmanned aircraft systems (UAS) classification system by distinguishing UAS and payloads as small unmanned aircraft systems (SUAS) consisting of Groups 1 and 2, 55 lbs. and less, and UAS Groups 3 – 5, greater than 55 lbs. USACE policies and procedures for Groups 3 – 5 are currently being developed by USACE Aviation H.Q. They will further define the lists of approved aircraft of this size and their use on USACE projects. The policy letter refers to contractors registering and documenting flight information under the surveillance of a USACE Trusted Agent, who oversees the equipment and personnel and assists in mission planning, approvals, tracking, and archiving mission documents [11]. Further guidance is provided in Aviation Policy Letter APL 20-06, Small Unmanned Aircraft Contractor and Third-Party Flights on USACE Projects and Lands [12], and APL 19-08 SUAS Policies and Procedures [13].

The most recent Exception to Policy Waiver (ETP) - Commercial Off-the-Shelf Small Unmanned Aircraft Systems Field Operations document is crucial to all current policies, valid until 24 January 2024. This document specifies the most recently approved UAV aircraft list, by user category, for missions on Federal projects and lands. The ETP identifies approved aircraft listed in the DIU Blue Cleared List and those with exceptions for government and civilian use for service contracts. This document is critical to service contractors providing UAV-based operations on USACE projects. LiDAR and photogrammetry sensors/camera payloads must also comply with the data security waiver requirements listed in this document. Exceptions to approved systems must submit a waiver request to USACE Aviation H.Q. for evaluation before use on Federal contracts [14].

4.3. Cost Comparison

Recent price quotes were provided for an aircraft UAV-1 and an L-1 laser scanner (proprietary information of the UAV and the laser sensor were removed for publication) for topographic and bathymetric surveying (see Figure 3) for a comparison of costs with a current survey contract for a USACE beach renourishment contractor operating within peninsular Florida. This aircraft and LiDAR scanner combination, which represents one of the higher-end models available on the market, utilizes the latest technology for accurate survey collection and is recommended by the manufacturer of the LiDAR scanner. The aircraft's weight and payload exceed 55 lbs., thus falling within the Group 3 UAV training and operation requirements per USACE Aviation Policy.



(a) (b)

Figure 3: (a) UAV-1 and (b) L-1 laser scanner used for topographic and bathymetric surveying

The line items in Table 2 represent 2023 prices for a 160-day survey order awarded under an indefinite delivery and quantity (IDIQ) service contract, typical of a USACE beach placement project in Peninsular Florida. The prices are estimated for a daily beach fill survey effort, to which time is invoiced per unit of measurement (H.R.) based on active engagement in the survey collection and data post-processing. Additional support personnel, equipment, mobilization, per diem, and incidental costs are negotiated as part of each order, dependent upon location and access requirements. For this comparison, additional support prices are not included in the tables below and are considered mutually consistent between conventional survey and UAV collection efforts.

Table 2: Topo and Hydro Survey Estimate for Beachfill Construction Projects - 2023

Category	Item	Unit Price	Unit of Measure	No. Units	Item Total
Vehicles	ATV	$6.22	HR	8	$49.76
	Hydrographic Survey Vessel	$28.74	HR	8	$229.92
Equipment	GPS Unit	$3.93	HR	8	$31.44
	IMU (hydro)	$18.88	HR	8	$151.04
	Hydrographic Survey System	$12.13	HR	8	$97.04
Personnel	2-Man Survey Crew (topo)	$142.10	HR	10	$1,421.00
	2-Man Survey Crew (hydro)	$142.10	HR	10	$1,421.00
	Specialist	$133.30	HR	1.5	$199.95
	Analyst	$96.70	HR	3.5	$338.45
	Technician	$70.65	HR	2	$141.30
Subtotal Day without Hydro Survey					$2,181.90
Subtotal Day with Hydro Survey					$4,080.90

Typical construction durations range between 90 – 160 days from November through April each year due to sea turtle nesting windows along the coasts of the Southeast U.S., and scopes of work usually specify daily survey collection for estimating/pricing purposes. Additionally, hydrographic survey support is generally estimated at half the days necessary for survey collection. Volume computation, CADD drawings, deliverables, standards, and payment practices are specified in each scope of work but are also considered mutually inclusive for price comparison between each surveying technique.

Table 3 represents an estimated day of survey collection efforts with a UAV-based survey 2-man team and associated equipment/personnel necessary for collection and data processing analysis. For comparison purposes, the unit prices of the vehicles, equipment, and personnel remain the same as the efforts shown in Table 2. Further analysis and discussion of the comparison efforts are discussed for this scenario in the following section.

Table 3: UAV LiDAR/Photogrammetry Topo/Hydro Survey Estimate for Beachfill Construction Projects - 2023

Category	Item	Unit Price	Unit of Measure	No. Units	Item Total
Vehicles	ATV	$6.22	HR	4	$24.88
Equipment	GPS Unit	$3.93	HR	4	$15.72
	IMU (hydro)	$18.88	HR	4	$75.52
Personnel	2-Man Survey Crew (UAV)	$142.10	HR	4	$568.40
	Specialist	$133.30	HR	1.5	$199.95
	Analyst	$96.70	HR	3.5	$338.45
	Technician	$70.65	HR	2	$141.30
Subtotal Day UAV Survey					$1,364.22

4.4. Cost Comparison Discussion

By initial comparison with the typical survey personnel, equipment, and vehicles required daily, a UAV and LiDAR sensor, coupled with a photogrammetry camera, could result in potential cost savings while providing the survey data and deliverables more efficiently. The savings are attributed to less manpower, vehicle, and equipment used to collect topographic and bathymetric data, and far less time for a comparable 2-man crew to manage the field data. Hydrographic survey vessels require an additional 2-man crew to operate the vessel and utilize an IMU for positioning at a 1:1 ratio using the hydrographic survey system. The UAV equipment includes the IMU cost because it is necessary to position the UAV during survey collection. The additional personnel – Specialist, Analyst, and Technician are estimated to be used at the same rate, whether collecting topographic or hydrographic data for post-processing the survey data and deliverables. An ATV is optional but not necessary for UAV team effort, assuming a short walking distance from a truck to the launch/landing site. For estimating purposes, a crew size would still consist of a 2-man crew to operate and manage a UAV and payload of this size and weight. From a straight hourly comparison with the items shown in Table 2, if a 2-man UAV crew were to utilize 4 hours per day to collect data, this represents a 37% cost savings over the topographic survey efforts and a 67% cost savings over a combined topographic and hydrographic survey effort day. The estimated 4 hours for a UAV-day include setting control points, setting up ground control, calibration, and setting up the equipment. Therefore, there is potential to capture some savings based on the cost comparison scenario described above; however, the UAV and LiDAR sensor costs are still new to the market, and the current regulations restrict the options to the higher-cost equipment approved for use by USACE.

One of the factors that will heavily influence the feasibility costs of an approved UAV and LiDAR /photogrammetry system is the initial purchase of the equipment and ancillary costs to operate and deliver the specified deliverables. However, due to their sensitivity, the proprietary information and detailed quotes of the UAV, the laser sensor, and the accessories that were investigated in this research study can not be disclosed. As previously mentioned, field measurement efforts on projects of this size and frequency with UAV and remote sensing survey equipment have not been documented or studied in this construction field to contribute to the cost database for estimating purposes. By comparison, several UAV contracts utilized within the Jacksonville District of USACE have averaged about $1,400.00 per hour of flight time for the UAV and LiDAR sensor alone, but these contracts were for topographic collection on jetty construction, earthwork, and road construction collected within a brief period, less than a day. According to recent UAV contracts within this district, separate mobilization, operations, and demobilization costs have averaged about $120.00 per hour.

Without more accurate operational cost information, further research would need to be conducted to develop more precise cost savings for using this equipment on beachfill projects. Some projects also require measuring before-placement surveys in the mornings and post-placement surveys in the afternoons, which could require additional personnel hours and reduce cost-saving benefits. Using a UAV also limits the ability to easily spot-check elevations as opposed to an RTK unit in the field. UAVs are also subject to environmental conditions, such as wind, rain, sight distance, and battery life, which might prevent daily flights and the capture of accurate, timely survey data. The LiDAR and photogrammetry equipment are also subject to conditions that prevent precise collection, such as waves, fog, rain, humidity, water turbidity, and light; all factors that construction contractors and USACE should take into consideration in the pursuit of use of this technology during the construction efforts of beach fill projects.

5. CONCLUSION

This research paper addresses the prospective use of LiDAR and photogrammetry-based UAV surveys for measurement and payment processes in USACE beach fill construction projects. Research has shown that this technology has already offered high precision, efficient, and cost-effective surveys used for beach monitoring and morphology purposes, as documented within the USACE database. Field collection case studies have shown that survey-grade elevation and horizontal accuracies can be achieved within the standards identified for beach construction with the appropriate staging of control points to evaluate the point clouds collected by the sensors. Additionally, the regulations that have inhibited the use of UAVs on federal projects have been relaxed so that multiple aircraft manufacturers are available, and the list is updated regularly to incorporate new manufacturers. Cost comparison analysis shows that reduced manpower and equipment are offered with the use of a UAV to capture large amounts of data in a short amount of time, but initial purchase and operational costs of the equipment should be evaluated more in future research.

During the project design phase, designers should consider specifying flexibility in the measurement and payment methodology to allow for remote sensing technology coupled with topographic and hydrographic survey techniques. Environmental conditions can inhibit the frequent collection of survey data by UAV, thus necessitating the traditional topographic and hydrographic methods to collect data at the frequency required for this type of construction. Peninsular Florida offers clearer water and more favorable weather conditions throughout the year compared to other parts of the U.S., making implementing this measurement practice a highly effective and efficient alternative on USACE beach fill construction projects in the region.

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