CHAPTER 11

Coastal Engineering Surveys for Beach Renourishment Projects and Shoreline Protection Structures

11-1. Introduction. This chapter provides guidance in performing coastal engineering surveys on USACE projects. Coastal engineering surveys are performed in support of sand transport studies, berm movement studies, beach renourishment placement measurement and payment, offshore borrow area dredging, jetty and breakwater construction, underwater investigation, and construction of shore and hurricane protection structures. An important component in this process is selecting the appropriate survey tools to collect data that meet project requirements and the needs of end users. Guidance in this chapter is intended to assist project planners and designers in reaching a common knowledge base for specifying effective survey data collection programs. This chapter also presents summary information on traditional, as well as newer, technologies for coastal surveying. Recommended accuracy standards and procedural methods are outlined for various coastal engineering projects.

Figure 11-1. Coastal surveys involve both topographic and hydrographic survey techniques. (Arc Surveying and Mapping, Inc.)

11-2. Required Supplemental Reference. Chapter 5, Procedures for Referencing Datums on Coastal Hurricane and Shore Protection Projects, of EM 1110-2-6056, Standards and Procedures for Referencing Project Elevation Grades to Nationwide Vertical Datums, is incorporated by reference into this chapter. This reference describes the requirements for establishing primary control for all types of coastal engineering projects, to include Primary Project Control Points (PPCP) and Local Project Control Points (LPCP). It also describes how to establish firm geodetic connections and relationships between tidal, ellipsoidal, and geodetic (orthometric) datums. EM 1110-2-6056 supplements ER 1110-2-8160, Policies for Referencing Project Elevation Grades to Nationwide Vertical Datums, that requires project elevation grades shall be referenced to nationwide vertical datums established and maintained by the U.S. Department of Commerce.

11-3. General Procedures. A variety of topographic and hydrographic methods, equipment, and floating plant are used in performing coastal surveys. These technologies range from basic differential leveling methods to complex airborne platforms. Some methods directly measure topographic elevations through direct contact with the surface being surveyed, while others remotely measure water depth and must be corrected for water surface conditions such as waves and tides. Each method has its own inherent performance specifications, operational limitations, costs of operation, and special considerations. The type of technology selected to survey a project will largely depend upon a combination of requirements related to data end use accuracies, spatial data density, and survey budget. The selection of a particular system also depends on the project location, size, and environment. Coastal engineering studies typically do not need the high data density required for beach renourishment construction, jetty construction, or offshore breakwater construction. The following sections describe some of the techniques used for different types of coastal projects.

a. Beach surveys. Beach surveys combine land topographic cross-sections with offshore hydrographic sections—Figure 11-1. Beach profile lines (i.e., cross sections) are run perpendicular to the shoreline relative to the project baseline. Permanent benchmarks (PBM) are typically maintained along the entire project length. These benchmarks are set and published in the horizontal and vertical project datums. Temporary benchmarks (TBM) are used during beachfill operations or when total stations or levels are used for portions of the surveys. The fixed baseline is normally established well beyond (inland from) the dune line to ensure permanency for subsequent construction or periodic monitoring surveys. Permanent reference azimuths for each profile line are established relative to the fixed baseline. Profile elevations are obtained using boats, sleds, aircraft, hand-held rods, and other topographic measurement methods described in the remainder of this chapter.

(1) Profile spacing is highly project-dependent. For general coastal erosion or sand transport studies, profile lines may be spaced from 500 to 5,000 ft, depending on the regularity of the coast. Often funding availability drives the density of coverage for studies. Beach renourishment construction surveys for payment require denser spacing--typically at 100-ft intervals.

(2) Both topographic and hydrographic survey methods are employed to obtain continuous coverage of a beach profile line. As shown in Figure 11-2, topographic surveys are

run as far into the water as possible, usually at low tide. Single beam echo soundings are obtained at high tide to cover the surf zone and the offshore portions of the line. Topographic methods may only be needed for beach fill placement if material is placed out to wading depths. Coastal studies usually require depths out to a specified depth of closure; necessitating a hydrographic survey vessel to reach this point. The depth of closure is a depth where the ocean floor is generally stable and does not change with seasonal variation or storms.

(3) Although beach studies have traditionally been performed by running spaced profile lines, some districts (Los Angeles) have recently adopted full coverage surveys of the land and offshore areas. This can be accomplished by employing airborne LIDAR bathymetric and topographic techniques, along with multibeam full coverage surveys. This results in a complete topographic surface model of the study site rather than sparse cross-sections.

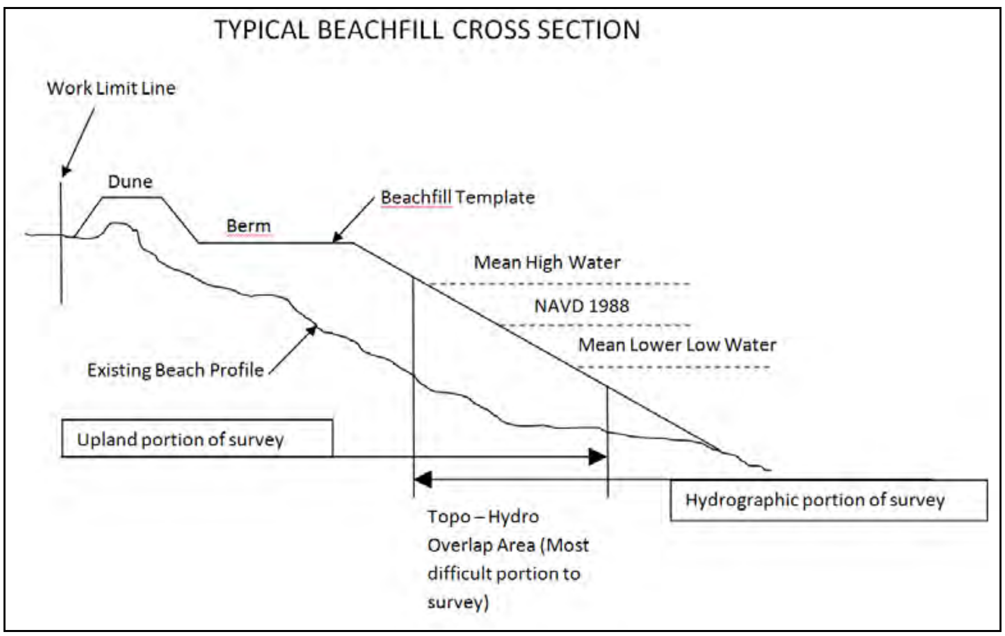

Figure 11-2. Topographic and hydrographic profile overlaps of typical beach renourishment sections.

b. Jetty, groin, and breakwater surveys. Construction and condition assessment surveys of shore protection structures requires far more detail than beach surveys described above. Although these structures can be surveyed using traditional topographic and hydrographic cross-sectioning methods, recent advances in acoustic multibeam and terrestrial LIDAR systems allow for detailed above- and below-water georeferenced cloud images of these structures.

c. Primary and local project control. Reference Chapter 5 of EM 1110-2-6056. EM 1110-2-6056 provides detailed guidance on establishing and maintaining primary control for coastal engineering projects. Figure 11-3 (taken from EM 1110-2-6056) depicts a typical reference baseline established for a beach renourishment project. Prior to the start of a project, all local project control points (LPCP) should be connected to the primary project control point (PPCP), either by differential leveling or RTK. In accordance with the guidance in EM 1110-2-6056, every project should have at least one PPCP that has established orthometric and tidal elevation relationships. Supplemental LPCPs may be PBMs or TBMs. Beach renourishment projects often have established (permanent) baselines with PBMs at 500 ft or more intervals. During construction, temporary hubs may be set between these PBMs at 100-ft intervals. Jetties, seawalls, breakwaters, etc. will also have a PPCP from which local construction control (LPCPs) can be established during maintenance work. Appendix G in EM 1110-2-6056 contains an actual example of control established for a Wilmington District project—"Fort Fisher Shore Protection and Beach Stabilization Project."

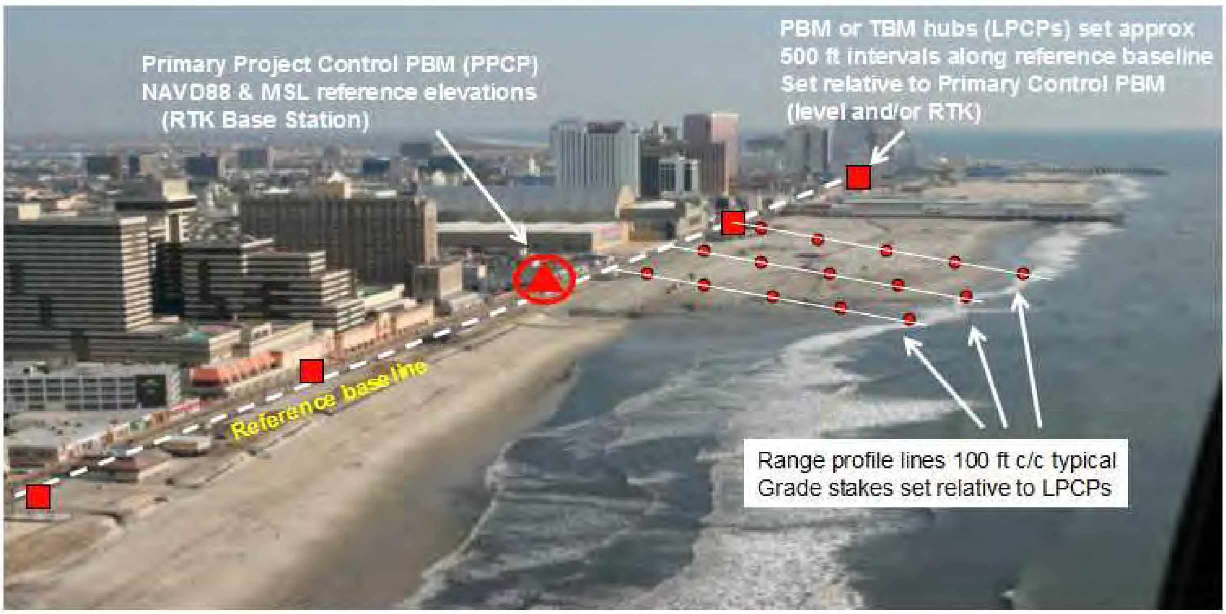

Figure 11-3. Primary and secondary construction control on reference baseline. Beach renourishment project at Atlantic City, NJ. (Philadelphia District)

d. Elevation and grading accuracy. Depending on the survey technique, the accuracy (or propagated uncertainty) of elevation data along the profile will be highly variable. Topographic sections can generally be measured to 0.1 ft relative to the baseline PBM or TBM control. In the surf zone, topographic elevation accuracy begins to degrade in deeper water, notwithstanding the temporal variations of the seabed due to the turbulent surf. Thus, any "accuracy standard" for measurements in the land sections or surf zone cannot be specified given the short-term changes of the topography, which may occur in minutes after the observation. The deviations shown in Table 11-1 for these areas are representative of the typical survey accuracies over changing, irregular terrain, not repeated survey comparisons. Therefore, any stated "accuracy" is temporal and valid only for the point in time the observation was made. Offshore hydrographic depth measurement accuracy will vary with the depth of water. In the near-shore surf zone, extreme vessel motions must be corrected with either inertial and/or inertial-aide GPS methods. Table

11-1 also lists recommended datum connections and relative accuracies generally required on beach and shoreline protection projects. Since the accuracies are shown relative to a local fixed reference monument (LPCP), they will approach the achievable repeatability levels for beach fill measurement & payment surveys. This table is intended as general guidance. Site-dependent factors may require variations from this guidance.

Table 11-1. Recommended Survey Elevation Accuracies Common to Various Shore Protection Projects.

Bench Mark/Activity	Std Dev (95%)	Relative to
Primary Project Control Point (PPCP)	± 0.25 ft	Regional NOAA/NGS NSRS and NOAA tidal NWLON network
Local Project Control Points (LPCP)	± 0.02 to 0.05 ft	PPCP
Construction TBMs (hubs, nails, etc)	± 0.02 to 0.05 ft	LPCP
Beach fill construction grade stakes	± 0.1 ft	LPCP or TBMs
Beach fill grading tolerance	± 0.5 ft	LPCP or TBMs
Beach profile surveys		
Topographic—land section	± 0.25 ft	LPCP or TBMs
Topographic--surf area [1]	± 0.4 ft	LPCP or TBMs
Hydrographic--surf area [1]	± 0.5 to 1 ft	LPCP or TBMs
Hydrographic—offshore [1]	± 0.25 to 0.5 ft	LPCP or TBMs
Feasibility or Sand Transport Studies	± 0.2 ft	LPCP or TBMs
Offshore borrow area excavation	± 0.5 to 1 ft	PPCP
Shore protection breakwater caps	± 0.2 ft	LPCP or TBMs
Offshore stone placement (jetties, breakwaters, etc)	± 0.5 to 1 ft	PPCP, LPCP, or TBMs

[1.] Assumes carrier phase RTK and/or inertial-aided GPS measurement systems are employed. Direct Measurement Techniques (i.e. CRAB or sea sled) accuracies in deeper water may be better than those shown. Temporal accuracies in varying beach and surf areas are a function of the survey technique and equipment, not those based on any repeated testing.

e. Horizontal accuracy. Relative horizontal accuracies obtainable using carrier phase RTK topographic or hydrographic survey methods should be in the order of ± 0.2 to 0.5 ft; again relative to the local PPCP or LPCP bench mark. These horizontal tolerances are acceptable for breakwater or jetty surveys. On beach profile surveys, acceptable horizontal tolerances are much larger, especially in the surf zone where visual topographic alignment is used by a wader with a level rod. In such cases, variations from the intended profile line can exceed 5 ft or more (i.e. cross track error). These variations are usually not significant to the end user or volume computation.

f. Florida standards for beach erosion control studies. The Florida Department of Environmental Protection (FL DEP) has published survey data collection and processing standards for erosion control projects—"Monitoring Standards for Beach Erosion Control Projects," (DEP 2004). The intent of these standards "is to provide for systematic physical data collection monitoring of erosion control projects along Florida beaches for beach management and regulatory purposes." These standards cover topographic and bathymetric profile surveys, bathymetric surveys for open water areas, aerial photography, and aerial photography for environmental assessments. An excerpt of some the requirements for beach and offshore profiling surveys in this document are listed in Table 11-2 below.

Table 11-2. Florida DEP Standards for Beach Profiling Study Surveys.

Hydrography	Upland Profiles	Offshore
Horizontal Datum	HARN NAD83 (1990)	HARN NAD83 (1990)
Vertical Datum	NAVD88	NAVD88
Reference PBM Accuracy	≥ 2nd Order	≥ 2nd Order
Control Surveys of Reference PBMs	[meet NGS guidelines for 5-cm GPS-derived heights]	
Profile Spacing	[approximately 1,000 ft typical or as specified in SOW]	
Accuracy-Horizontal (RMSE)	±3 ft	±2 ft
Accuracy-Vertical (RMSE)	±0.16 ft	±0.2 to ±0.5 ft
Coverage	150 ft landward of vegetation	3,000 ft or (-) 30 NAVD88
Density along profile	25 ft and breaklines	25 ft and breaklines

Off-line Horizontal Deviation	NTE ±3 ft	NTE ±30 ft
Topo-Hydro Time Difference	[NTE 14 days]	
Maximum Allowable Sea State	n/a	3 ft

SECTION I

Coastal Engineering Survey Techniques

This section describes the various techniques used by Corps districts to perform surveys in near shore areas. Advantages, disadvantages, and recommended quality control procedures for the various survey methods are outlined.

11-4. Differential Leveling Methods. A standard differential level and level rod is a simple method for obtaining beach profiles out to wading depths in the surf zone, as shown in Figure 11-4. A differential level can be set up at any location on the beach suitable for backsighting on a PPCP or LPCP, and foresighting elevations on a 25 ft expandable level rod along the profile line. Stakes (range poles) need to be preset along the range profile line so the rodman can maintain alignment visually. Distance along line can be measured using a lightweight tape or string tag line fixed at the baseline LPCP monument. Alternatively, a hand-held EDM can be used to measure the distance from the LPCP to the level rod. (Older stadia distance methods are rarely used today). The rodman progresses out along the profile range and shots are taken at preset distances (e.g., every 10 or 25 ft) or breaks in grade. If a tag line is used, even increments along line can be taken. The level instrumentman records the tagline/EDM distance and rod elevation in a field book. The rodman wades out into the surf as far as possible while holding line. Final grade elevations to the required reference datum are reduced manually in the field book. These profile offset and elevations are then input to a spreadsheet for subsequent conversion to georeferenced coordinates or volume computations. If an EDM (reflector type or reflectorless) is used, then increments are paced by the rodman and actual distances shot by the EDM. Some specifications require the use of electronic data collection in order to ensure cross track error tolerances are maintained and to reduce the chances of error in manually recording elevations.

a. Limitations on this method include large grade differentials between the LPCP (often atop a dune) and the project grade. The instrument "HI" needs to be set near the LPCP elevation in order to maximize shots on the 25-ft rod at the furthest offshore reaches. In some cases, a TBM will need to be established on the intermediate beach area. Maintaining horizontal alignment relative to the required profile line becomes difficult for the rodman out in the surf zone. Deviations of 5-ft or greater are common. Alongshore currents affect the ability of the rodman to maintain adequate tension on the tape or tagline, thus affecting the accuracy of the offshore distance measurement.

b. The rodman has a most difficult position on this crew. He must maintain tag line intervals, hold alignment visually on the range, and stabilize a 25-ft rod vertically.

c. A three-man crew is generally required on these surveys—an instrumentman, rodman, and helper to set ranges and maintain the fixed end of the tag line or operate the EDM.

d. An EDM is the recommended method for measuring distances along line, as opposed to a tag line. Tag line measurements over 500 ft degrade rapidly; thus, an intermediate turn point may need to be set along line. Similarly, since some hand held EDMs have limited ranges, an intermediate point may need to be set along the profile line.

e. The major advantage of leveled profiles is its use in daily beach fill monitoring surveys. Sometimes the rodman can reach the offshore limit of fill by wading. A small kayak or inflatable raft may also be used to obtain the deep water shots—Figure 11-5. This eliminates the need to launch a full-size survey boat each day to monitor construction progress and verify fill grades.

Figure 11-4. Beach profiles using a level and tagline for control. On left photo, fixed end of tag line is held at TBM next to grade stake. Range poles or grade stakes are used for visual alignment. Rodman on right photo is shown with 25-ft level rod.

f. Elevation accuracy of shot points is usually at around ±0.2 ft since a differential level is being used. The level should be frequently "peg tested" since backsight and foresight distances are highly unequal. Levels should also be "closed" between two LPCPs on the baseline—before and after profile line elevations are observed. Horizontal accuracy relative to the profile line is typically ±5 ft.

Figure 11-5. Kayak for obtaining deep water points just beyond wading range in Gulf of Mexico. Note that updated (2012) Corps policy requires surveyors to wear approved PFDs when working on a platform such as this.

11-5. Total Station Methods. The Total Station (Figure 11-6) is used for controlling topographic survey position and elevation measurements on coastal engineering surveys. The Total Station is set up over a known PPCP or LPCP and backsighted on another PPCP or LPCP. The instrument is sighted on a reflector attached to a fixed height pole held by the rodman. The instrument records the horizontal and vertical angles to the reflector and automatically adjusts and records the absolute elevation of the point on the project datum. The Total Station does not directly provide alignment for the rodman. Normally range poles are previously set along the desired profile line using the Total Station software, and the rodman visually aligns himself out to wading depth. If the Total Station is set up over the range profile LPCP bench mark, then the rodman can be aligned using hand signals. Alternately, stake-out software in the data collector can be used to align the rodman along the profile line. Points are taken along the profile line at paced distances and/or at breaks in grade. Profile line distance and elevations are automatically recorded and georeferenced in the controller.

a. Limitations of this method are the distance from the LPCP on the baseline to the offshore end of the profile line. Often these distances (over 1,500 ft) may be beyond the range of the Total Station EDM and the trigonometric elevation accuracy. Having to establish supplemental Total Station traverse TBMs out on the beach may be involved or not feasible—especially during beach fill construction. In some instances, a Total Station may be used to control an offshore survey vessel out to limited distances. Tracking a moving reflector aboard the survey vessel is usually difficult, so this positioning method is rarely employed.

b. QC checks should include tests over an adjacent LPCP at a distance comparable to those observed on profile lines. Elevations should check to ±0.2 ft.

c. A minimum crew of two persons is required for performing a Total Station beach survey. A robotic Total Station may be used for the topographic or wading portion. The advantage of a robotic is that the prism is constantly tracked by the total station, eliminating the need to manually sight in the prism. The range of a robotic system will generally exceed a conventional total station. A robotic Total Station would entail use of a 2-m fixed height pole and remote controller.

Figure 11-6. Total station control of topographic beach profiles.

11-6. Real Time Kinematic GPS Methods. RTK survey methods are largely replacing the above leveling or total station techniques. RTK methods are readily adaptable for performing both the land topographic and offshore hydrographic surveys. In addition, both portions are on the same horizontal and vertical reference systems. Most coastal projects can be easily covered by a local GPS base station set over a PPCP. If a regional Real Time Network (RTN) coverage is available, then a local RTK base is not needed. A rodman obtains topographic range profiles with a GPS antenna/receiver atop a fixed-height 2-m pole. Both dune and offshore wading portions of the profile are simultaneously obtained. A survey controller (e.g., Trimble Survey Controller) records and transforms data using wired or Bluetooth connections to the GPS antenna. LPCP and range profile data are pre-entered into the controller and guidance/alignment is obtained using stake-out software. Profile data are recorded continuously along the range by time or incremental distances, along with grade breaks. Offshore hydrographic profile data is recorded using single beam and RTK systems as described in Chapters 4 and 7. Recorded data from the topographic and hydrographic portions is transferred from the data collection controllers (or HYPACK) to a computer/CADD system for subsequent processing or volume computations.

a. Wading depths in the surf zone are limited by the antenna height and ability to waterproof recording instruments. A 3- or 4-m fixed height pole allows for deeper depths to be obtained if deploying off a floating platform (e.g., an inflatable raft).

b. If a permanent RTK base station has been established, or a RTN network is available, only one person is required to perform the topographic portion of the beach profile. A two-person crew is recommended in remote areas outside the established beach fill construction zone. When working in an active construction zone, where there are bulldozers, front-end loaders, etc. working, a second person is highly recommended to maintain a lookout for moving construction equipment. It is common practice for the dredging company to require crews to check in with the beachfill foreman prior to working in the active area. Dredging companies may also require all personnel working on a project to complete required safety training.

c. RTK QC check shots should be periodically taken on baseline LPCPs—e.g., every few profile lines. A tolerance of ±0.2 ft is typically allowed.

11-7. Coastal Amphibious Research Buggy (CRAB). The CRAB is a topographic survey platform developed by the ERDC Coastal and Hydraulics Laboratory (CHL) at its field research facility in Duck, NC. It has been in operation since the 1980s. As shown in Figures 11-7 and 11-8 it is a self-powered rigid platform capable of surveying profile lines out to approximately 20 feet of water. The top of the platform is positioned using either Total Station or RTK methods described above. The elevation of the grade is projected down from the top, with applicable tilt corrections applied. Data are recorded and processed by a GPS controller device. The CRAB is limited to hydrographic surveys of smooth sand beaches due to its size, instability, lack of mobility, and slow speed. The CRAB is especially useful during winter conditions, where sharks are present, or in contaminated water. Its ability to survey out to 20 ft water depths provides an accurate measurement profile in these depths—estimated at ±0.3 ft at the time the measurement is taken.

a. Great Lakes Dredge & Dock Co. currently operates CRABs on renourishment projects to obtain offshore survey data during beach construction. RTK elevation data at the upper platform is recorded on a Trimble Survey Controller. When pre- and post-fill sections are run at 100-ft spacing, typically, 30 to 50 sections can be run in one day. The CRAB can obtain some beach topo data but upland data to the dune line is obtained by traditional RTK topo methods.

b. The CRAB is typically operated by one person, who both drives the platform and performs the data acquisition. A second person may be required for safety reasons. Mob and demob costs are high; thus, the CRAB is most effective when deployed on long-term beach renourishment projects.

11-8. Survey Sled Methods. Sled survey systems were developed to collect continuous survey data from the dry beach, through the surf zone, and into the nearshore. Similar in concept to the

CRAB platform, sled surveys provide direct elevation measurements from the seabed. The system consists of a mast some 30 ft high with a cluster of reflective prisms or a GPS antenna at the top--see Figure 11-9. The mast is mounted to an aluminum frame sled. The sled is pulled along predetermined lines across the beach and into the nearshore by a LARC to a maximum

Figure 11-7. CRAB. Hydrographic survey platform used for research purposes by the ERDC Coastal and Hydraulics Laboratory research facility at Duck, NC. (ca 1980s)

depth of about 30 ft. A land vehicle may be necessary for winching the sled back onto the beach from the water. As the sled is being towed, a Total Station set over a LPCP is used to track the prism on top of the mast and record the horizontal and vertical positions at regular time intervals. Using GPS, a cable is extended from the sled to the LARC. Alternatively, the GPS positions can be broadcast to the shoreline via radio telemetry. The sled provides a relatively accurate method of collecting complete profile surveys. Approximately 25 - 30 minutes are required to sample along a 1,000 ft profile line. Thus, only 10 to 20 profiles can usually be obtained in one day. Sled surveys are now rarely performed by USACE districts.

a. Surveys can be conducted using this method in areas where the beach is easily accessible. Survey sleds do not perform well on irregular bottoms or areas where rock or reef outcroppings are prominent. Such conditions can cause the sled to tip over or become snagged. Sleds have been known to be stable in breaking waves up to 15 ft; however, since the sleds are typically towed by LARC through the surf, the working conditions are limited by that of the towing vessel.

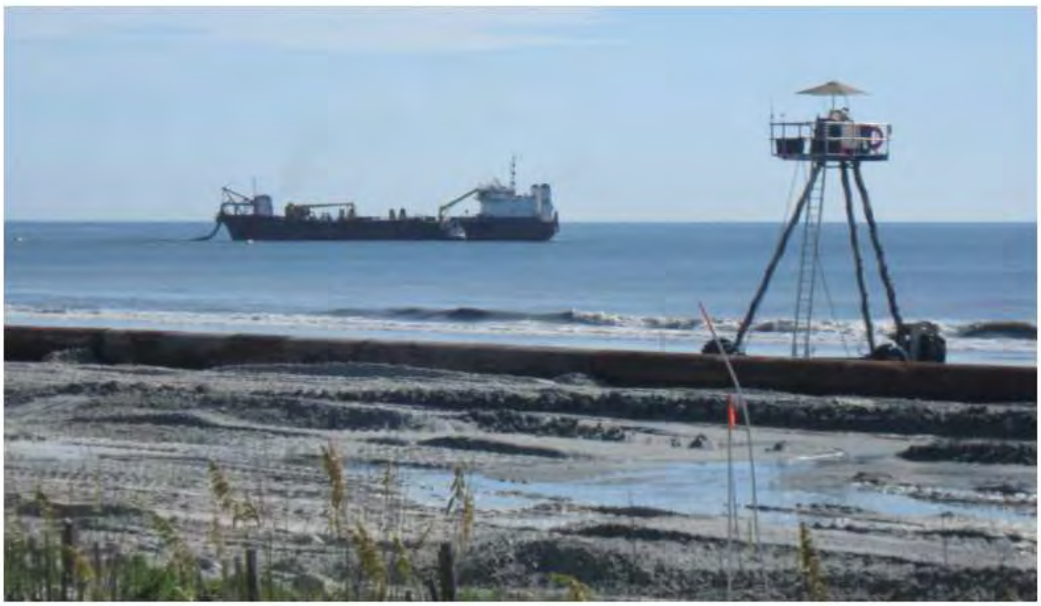

Figure 11-8. One of the CRABs operated by Great Lakes Dredge & Dock on a 2011 Beach Renourishment Project at Jacksonville Beach (Duval County), FL. The dredge in the background is shown at the beach pump-out site. (Jacksonville District).

b. Sled surveys are extremely labor intensive, requiring a crew of six (6) or more persons. Given the high survey cost, the Corps and a few A-E firms rarely utilize this survey method. Like the CRAB, the sled provides accurate elevation data in the surf zone where traditional single-beam hydrographic surveys degrade. Those specifying requirements for sled surveys must weigh the added costs versus the required profile accuracy.

11-9. Nearshore and Offshore Profile Acoustic Measurement Methods. Single beam hydrographic survey systems and methods outlined in Chapter 4 are used to obtain profile data offshore of the topographic survey limits. When possible, hydrographic surveys are performed at high tide in order to maximize overlap with the land topographic section. Survey or study requirements will normally specify the outer limit by distance (e.g., "3,000 ft from the baseline range monument") or to a maximum depth of closure (e.g., "-30 ft NAVD88").

Figure 11-9. Sled profiling system—LARC ("Lighter, Amphibious, Re-Supply, Cargo") with towed sled. Used to collect profile data through the surf zone and into the nearshore areas. (New York District)

a. Survey vessels. USACE Districts have used nearly every type of boat on beach profile surveys. These range from 12-ft open skiffs to 65-ft survey boats. In general, conventional survey boats in the 19- to 26-ft range are employed. The type of vessel selected is highly dependent on the surf zone depths and potential adverse wave actions at the near-shore end of each line. Due to the possibility of taking in water while broaching in the surf (and perhaps overturning), the vessel stability, power, and instrumentation must be designed to extricate and recover from such an event. Boat maneuverability in the surf zone turn is also a major factor—dual outboard engines are strongly recommended on larger vessels operating in these environments. For these and other reasons, recent trends have been to utilize smaller platforms to perform these surveys. These include use of jet skies and inflatable rafts.

b. Single Beam and multibeam systems. Since individual profiles are being surveyed in relatively shallow water, single beam systems are used almost exclusively for these surveys. If additional bottom coverage is required, multibeam systems may be used at maximum array width (e.g., 8 to 15 times water depth), recognizing that data on the outer arrays is marginal in shallow water. Both single beam and multibeam systems become marginal in surf zones with aeration in the water; thus, maximum coverage using topographic methods and direct measurement techniques is obtained in these surf zones in order to minimize acoustic coverage. Traditional single beam echo sounders are used on larger vessels—e.g., Ross, Odom, Reson. On smaller platforms portable systems specifically designed for shallow water surveys are often used—e.g., the Seafloor Systems, Inc. HydroLite system that has both positioning and depth measurement components in a compact unit.

Figure 11-10. Inflatable raft on left is used on near-shore beach profile surveys. Water-proofed shallow-water depth sounder, RTK, and a laptop running HYPACK are installed aboard the raft.The Corps survey vessel on right must have sufficient engine power to maneuver through surf zones during turns at the inshore end of each profile line.

c. Positioning and orientation systems. Survey vessels may be positioned using either code phase DGPS or carrier phase RTK methods. Kinematic positioning is the preferred method for determining water levels during the hydrographic portion of the survey because it is nearly impossible to obtain accurate water levels from a remote tide staff or automated gage. Larger boats may have POS/MV and IMU systems to correct for vessel motion; however, larger vessels may be limited in how close they can get to the surf zone. Inertial orientation systems may or may not be used on a smaller open raft or 'jet ski' type survey platform. Due to the dynamic nature of the surf zone, heave should be measured with an IMU, MRU, or RTK.

d. Data recording. Survey data are recorded on a survey controller or a laptop using HYPACK software. HYPACK is used to process and edit the data and merge land and water profile sections for subsequent applications. During processing, overlap points should be verified to meet specifications for the project. Whether the hydrographic or wading portion of the survey is done first, the distance from the reference baseline should be noted such that it can be used to ensure adequate overlap is being obtained.

11-10. LIDAR Bathymetry and Topography Methods. A state-of-the-art LIDAR system coupled with high precision carrier phase RTK and inertial positioning is a technology that can be utilized for conducting hydrographic and topographic beach surveys. An airborne hydrographic LIDAR system operates by emitting laser pulses from an airborne platform that travel to the water surface. For each laser pulse, some of the light is reflected from the surface to onboard receivers. The remaining energy propagates through the water column, reflects off the sea bottom, and returns to the airborne sensor. The time difference between the surface light return and the bottom return corresponds to water depth. The maximum depth detection is limited predominately by water turbidity. As a rule-of-thumb, the system is capable of sensing depths equal to two or three times the visible depth. Sounding densities can be adjusted by flying higher or lower at different speeds or by selecting multiple scan widths. With the ability topographic and hydrographic survey data an airborne LIDAR system can simultaneously conduct complete beach and structure surveys above and below the waterline, and is particularly useful in areas where human access is difficult or restricted. The technology is also a useful tool for post-storm erosion assessments. Data acquired from LIDAR can be used to generate vertical profiles, cross sections, contours, and volumetric analysis.

a. Airborne LIDAR is capable of rapidly collecting relatively dense survey data over large areas in a short amount of time. However, the technology is highly dependent on water clarity and should not be considered for areas with chronic high turbidity. Costs pertaining to system mobilization can be high and may be a limiting factor when considered for surveying small projects. It is beneficial to schedule surveys along with other projects in the same general vicinity to share and minimize mobilization costs. Users of LIDAR survey data should possess data processing equipment and software capable of handling large data sets.

b. LIDAR observations are not as accurate as profile data obtained from traditional topographic and acoustic survey systems described previously. LIDAR accuracy also degrades in the turbulent surf zone. Therefore, LIDAR systems are not used for construction measurement and payment purposes. However, they are far more efficient than traditional survey methods for broad area coastal studies. LIDAR accuracies are typically ±0.5 ft on land and ±1 ft under water. Increased accuracies are possible with lower altitude flights, such as from unmanned aircraft or helicopters.

c. Additional details on the principles of LIDAR measurements can be found in the IHO Manual of Hydrography (IHO 2005).

Figure 11-11. RTK measurement and payment surveys for beach renourishment projects.