Chapter 13
Airborne LIDAR Hydrographic Surveying

13-1. Introduction: Summary of Technology

This chapter provides an overview on airborne hydrographic survey methods currently employed by the Mobile District.

a. The Scanning Hydrographic Operational Airborne LIDAR Survey (SHOALS) system was developed by USACE and has demonstrated the ability to achieve orders of magnitude increase in survey speed while collecting densely spaced high resolution data. The term LIDAR stands for LIght Detection And Ranging. The USACE accepted the SHOALS system in March 1994 following field testing which indicated that the system met or exceeded all design specifications. Since then, SHOALS has surveyed a wide range of Corps projects from navigation and shore protection, to coastal structure evaluation, and emergency response operations. SHOALS has also performed several missions for the National Oceanic and Atmospheric Administration (NOAA), as well as the U.S. Navy with projects varying from coral-reef damage assessment to nautical charting of international waters.

Figure 13-1. SHOALS field data collection and processing system

b. SHOALS is a fully-operational bathymetric survey system capable of surveying a variety of project types. SHOALS operates from the Joint Airborne LIDAR Bathymetry Technical Center of Expertise (JALBTCX), which is headquartered at US Army Engineer District (USAED), Mobile. The JALBTCX mission is to operate the SHOALS system and to develop new products and applications. Additional goals for the JALBTCX include expansion of mapping and charting capabilities and the fusion of LIDAR bathymetry with auxiliary sensors such as multi-spectral imaging systems and Synthetic Aperture Radar (SAR).

13-2. Operating Principle

SHOALS consists of an airborne data collection system and a ground-based data processing system (Figure 13-1). The system operates by emitting laser pulses 400 times per second while being scanned in a 180 deg arc pattern across the flight path of the airborne platform (Figure 13-2), which can be a helicopter or fixed-wing aircraft. Each laser pulse travels from the airborne transmitter to the water where some light energy is reflected and detected by onboard optical sensors. The remaining light passes through the water column, reflects from the sea bottom, and returns to the optical sensors as illustrated in Figure 13-2 (Guenther, Thomas, and LaRocque, 1996). The time difference between the water-surface and sea-bottom returns indicates the water depth. Operating from an airborne platform at an altitude of 300 to 500 m and a speed of up to 70 m/s allows the ability to provide depth measurements on a 4 to 8 m horizontal grid and covering up to 35 km^2 per hour. Sounding densities can be adjusted by flying higher or lower, at different speeds, or by selecting different scan widths.

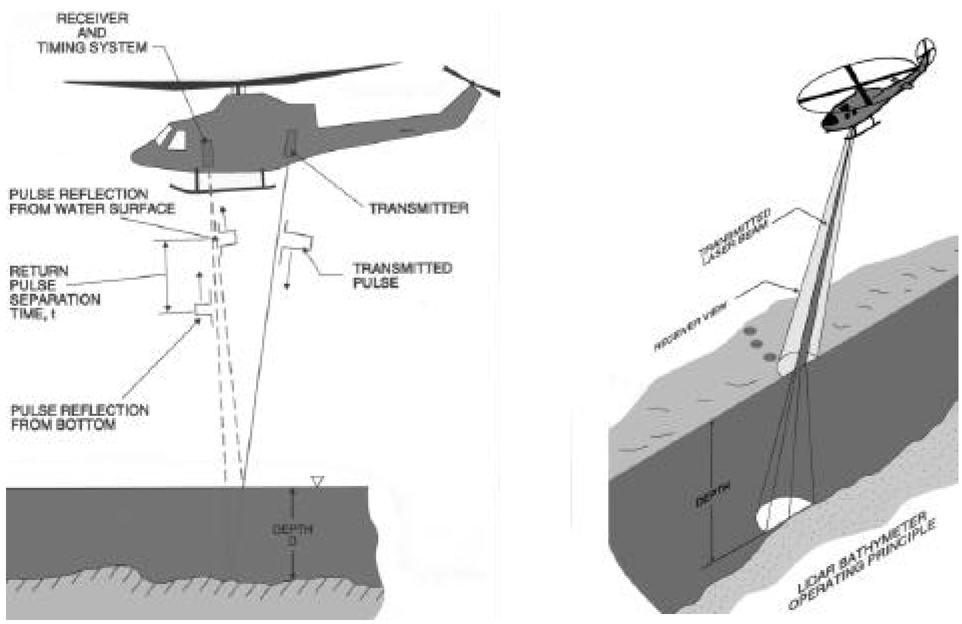

Figure 13-2. SHOALS operating principle

13-3. Typical Survey Products

SHOALS produces high density measurements that can be used for creating three dimensional digital elevation models from which navigation and shore protection projects can be monitored and managed. This is a unique product that allows the USACE engineers the ability to manage sediment on a regional scale rather than on a project by project basis. Typical products include: a) metadata file for compliance with the FGDC requirements, b) plan view engineering drawings of the entire survey area consisting of contour maps with elevation points for data review at a customer specified scale, c) information and references pertaining to the SHOALS system, d) digital corrected survey data files on CDROM composed of ASCII XYZ files containing all the data for the entire survey area and corrected to a designated local vertical and horizontal datum, and e) geo-referenced color video of the surveyed sites.

13-4. System Characteristics, Performance Specifications, and Accuracy

a. Accuracy and data quality meet or exceed all USACE and International Hydrographic Organization (IHO) Order 1 standards. Through independent testing both the National Oceanographic Service (NOS) (Riley, 1995) and U.S. Navy have verified that SHOALS meets the IHO accuracy standards for nautical charting; the IHO being the organization that sets these standards. Canada, Sweden, Australia and private industry have similar airborne LIDAR systems that are being used for nautical charting surveys. In addition, the USACE has conducted extensive field tests to determine that SHOALS meets its accuracy requirements for navigation surveys, which are more stringent than the charting standards set forth by IHO (Lillycrop et al., 1994). The performance characteristics and accuracy specifications are shown in Table 13-1.

b. In response to USACE increased needs to map beaches, dunes, and above-water structures, SHOALS was enhanced with the capability to utilize kinematic GPS (KGPS). Since the need to use water surface as a vertical reference is eliminated, KGPS allows more extensive measurements of beaches and dunes. With the ability to collect both hydrographic and above water survey data, SHOALS can simultaneously conduct complete navigation and shore protection project surveys. Data acquired by SHOALS is being used to generate channel condition reports, beach profiles, cross sections, and contours, perform volumetric analysis, and create complete 3-D digital elevation models of Federal projects and their adjacent regions.

Table 13-1. SHOALS Specifications and Standards

SURVEY PARAMETER	PROJECT CLASSIFICATION: Navigation & Dredging Support Surveys — Bottom Material Classification: Hard	Soft	Other General Surveys & Studies
DEPTH MEASUREMENT SPACING	3 m	4 m	8 m
FLIGHTLINE OVERLAP	25%	25%	20%
CROSS LINE CHECKS	2 per flightline	2 per flightline	2 per flightline
MAXIMUM DEPTH	40 meters or 2 to 3 times Secchi depth		
VERTICAL ACCURACY	± 15 cm (1-sigma)		
HORIZONTAL ACCURACY	± 3 meters (1-sigma)		
SOUNDING DENSITY	4 to 8 meter grid … variable		
OPERATING ALTITUDE	300 TO 500 meters … variable		
SCAN SWATH WIDTH	150 to 250 meters … variable		
OPERATING SPEED	up to 135 knots (approximately 70 m/s)		
PLATFORM	Helicopter or Fixed-wing aircraft		

13-5. System Constraint

This technology is capable of rapidly collecting dense survey data over large areas. However, the main constraint of any LIDAR bathymeter is water clarity. In clear waters SHOALS is effective to about 60 meter depths. In less clear waters SHOALS is successful to depths of 2 to 3 times the visible depth, as measured by a simple device called a Secchi disk. LIDAR bathymetry systems should not be considered for areas with chronic high turbidity. There are locations where airborne LIDAR bathymeters cannot operate at certain times and/or conditions due to water clarity. However, this can many times be mitigated with proper planning and operations in a particular region when water clarity is optimal. To assure the highest possible data quality, certain quality control criteria have been established for SHOALS surveys and are presented in Table 13-3.

13-6. SHOALS System

SHOALS is comprised of two sub-systems: the airborne and ground-based data processing sub-systems. The airborne sub-system operates from a Bell 212 helicopter or DeHaviland Twin Otter fixed-wing aircraft (or equivalent) and performs the task of primary data acquisition. The ground-based data processing extracts an accurate water depth or elevation from each laser sounding and matches it with a horizontal position.

13-7. Platforms

SHOALS was originally developed to be installed and operated on a Bell 212 Helicopter. The helicopter platform provides a high degree of maneuverability and flight speeds while surveying coastal projects. SHOALS was later modified to fit into a Twin Otter DHC-6 fixed-wing or similar type of aircraft. Although giving up some of the inherent maneuverability of a helicopter, a fixed-wing provides a greater travel range to and from projects and allows more time in the air collecting data. On large, remote projects, a fixed-wing aircraft provides the ability to fly farther, high, and faster, thus, covering larger areas over a shorter period of time while maintaining the high data resolution.

13-8. Airborne System

The airborne sub-system is divided into three components (Lillycrop and Banic, 1993): Transceiver (TRS), Airborne Positioning and Auxiliary Sensors (APASS), and Acquisition, Control and Display (ACDS).

a. The Transceiver (TRS) consists of the laser, scanner, and receiver. The function of the TRS is to transmit laser pulses in a defined scan pattern and receive backscattered energy from these pulses to produce laser depth soundings and aircraft altitude information. The laser is a 400 Hz, Nd:YAG operating at a wavelength of 1064 nm (infrared) and frequency doubled to 532 nm (green). The laser backscatter energy (surface and bottom energy) is collected by a 20-cm catdioptric Cassegrain telescope and split into two green channels, two infrared (IR) channels, and a red channel at the water Raman wavelength (645 nm) (Guenther, Thomas, and LaRocque, 1996). Outputs from the two green channels, the main IR channels, and the Raman channel are digitized and time tagged along with various other system outputs and recorded on a high density, 8-mm magnetic tapes for post-flight data processing and depth calculation. One green channel senses light returning from depths greater than about 7-m and the other green channel senses heights above the water to a maximum of 12-m. The infrared and raman channels are used to detect the water surface. The fifth channel (infrared) is used to perform real-time discrimination between water and land. TRS also includes a real-time depth algorithm which provides and displays approximate depths to the airborne operator, which permits a first line of quality control and allows the operator to make in-flight decisions concerning mission activities such as the need to alter flight parameters to optimize coverage, refly a line, or move to a different area.

b. The Aircraft Positioning and Auxiliary Sensors (APASS) functions are to collect information from the Global Positioning System (GPS), inertial reference system, and to provide a video image of the area being scanned. Horizontal positioning for the SHOALS system is provided by the Global Positioning System and the inertial navigation system (Litton LTN-90), which provides aircraft attitude, including roll, pitch, heading, and vertical acceleration. Included as an auxiliary sensor is a video camera to record digitally annotated imagery of the area being scanned by the laser. A video frame at the time of any sounding can be viewed to help with the interpretation of any anomalies.

(1) Differential GPS (DGPS). For each depth sounding, SHOALS typically obtains horizontal position of the aircraft from differential GPS (DGPS) while vertical position is directly correlated with measured water-surface locations. Measurements consist of GPS horizontal corrections down loaded from the U.S. Coast Guard Beacon System or the Omni Star satellite system. During DGPS survey operations SHOALS uses the water surface as a reference plane, therefore, in order to reduce the data to a common vertical datum such as NGVD, MLLW, etc., it is necessary to obtain tidal or water level heights during the time of the survey. In response to USACE needs to map not just the nearshore, but also beaches, dunes, and above-water structures, SHOALS was modified to extract topographic elevations in conjunction with water depths. In DGPS mode elevation measurements are vertically referenced to the water surface and land measurements can only be collected if half of the survey swath is over the water or within 50m of the waterline.

(2) Kinematic GPS (KGPS). A further enhancement to the SHOALS system is the implementation of KGPS. This permits the precise 3-D positioning of the aircraft with respect to the ellipsoid to be determined to within several centimeters while the vertical distance from the aircraft to the sea bottom is measured simultaneously. This capability permits depths to be determined without wave and water level corrections. In fact, the use KGPS provides the capability to collect topographic survey data without the presence of a water surface.

(3) Aircraft Motion Compensation. To ensure a consistent survey swath and to correct for various other sources of error, compensation for aircraft motion is required. This information is provided by the system's Inertial Reference System (IRS) which is a Litton LTN-90. The main function of the IRS is to measure the attitude angles of the LIDAR sensor and to provide vertical acceleration data. The IRS generates digital outputs of altitude, heading, position, angular rates and linear accelerations, ground speed and track, horizontal and vertical velocity components, drift angle, flight path angle, and magnetic heading. This information is used in the determination of the horizontal coordinates of the laser footprint on the water's surface relative to the aircraft and in conjunction with the scanner angles enabling the onboard computers to continually adjust the scan pattern to compensate for the motion of the aircraft. The vertical acceleration data is utilized by the wave correction algorithm to isolate the motion of the aircraft in correcting for surface waves.

(4) Video. A down-looking video camera is used to provide an audio/visual record of the scanned area and is stored on 8-mm video tape. The main function of the video is to provide a record of the area surveyed and to assist hydrographers while processing and mapping the data. When anomalous data are identified, the hydrographer can review video of the area to obtain information about the anomaly in question. The audio track may also contain verbal notations from the operator that may also be used to provide some indication of the data characteristics. Each video frame contains digital annotations providing a continual display of the time, latitude, longitude, altitude, and the pitch, roll, and heading of the aircraft as shown in Figure 13-3. Each frame also contains a cross hair that tracks the nadir of the aircraft. The cross hair is calibrated to 30-m across in both the horizontal and vertical. The cross hair provides the ability to obtain rough position and measurements of structures, navigation aids, and objects in the water.

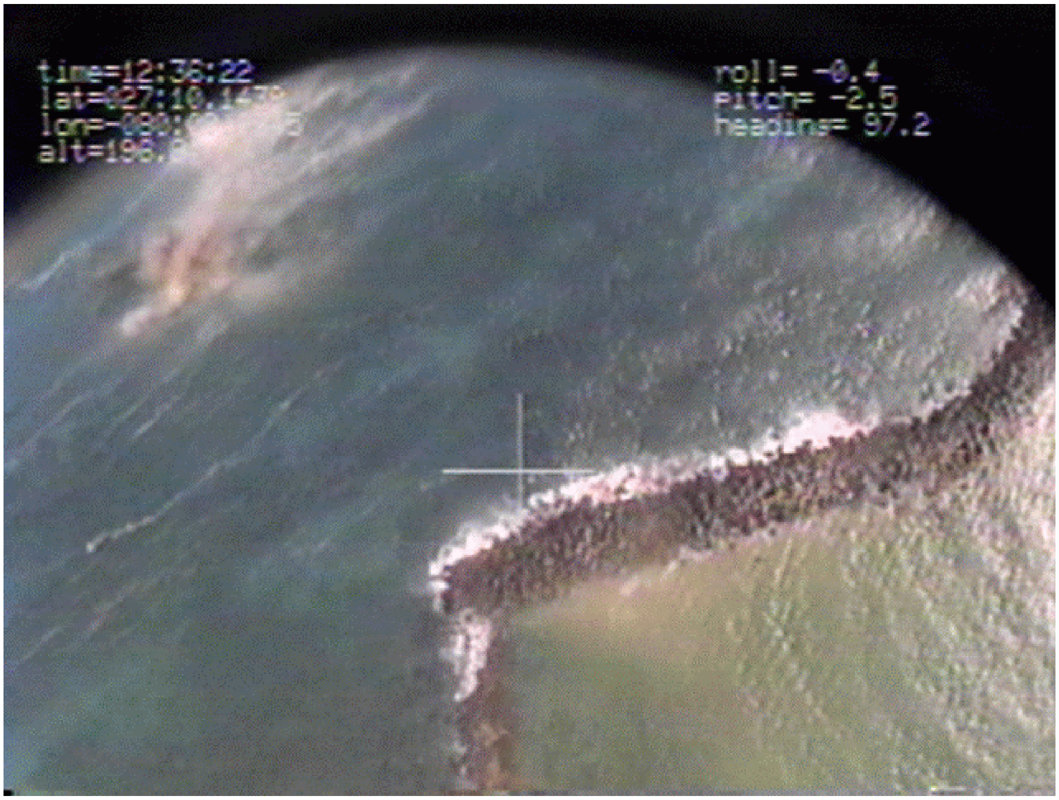

Figure 13-3. Digital annotations

c. Central to the SHOALS airborne system is the ACDS, which provides an operator interface to monitor and control the airborne system. The ACDS provides five functions: data collection, operator interface, pilot guidance, airborne depth processing, and system integrity. The data collection function acquires data from all sub-system components and manages data as it flows through the system and is recorded onto magnetic tape at a rate of over 300 Kb per second. The operator interface allows human interaction between the operator and the system with access to all elements of the airborne system. The pilot guidance function provides a navigation system that guides the pilot from the airport to the survey site and along each survey line. The airborne depth processing function calculates and displays preliminary water depth in real time, at 200 soundings per second, to provide the operator a tool for quality checking data during a survey mission. The last and perhaps most important function is system integrity. Through this function, the entire airborne system is constantly interrogated and monitored.

13-9. Data Processing Sub-system

Preliminary data processing occurs on-site in the mobile field facility shown in Figure 13-1. This 40-foot, air conditioned, tractor trailer facility travels from site to site with the airborne system. It contains all of the data processing and mapping systems including space for mission planning, meetings, storage of spare parts, tools, and supporting survey equipment. The Airborne Sub-system acquires a tremendous volume of raw data during a single mission. The Data Processing Sub-system (DPS) is the hardware and software that provides the capability to post-process this enormous data set. Its main functions are to: 1) import airborne data recorded on high density data tape ; 2) calculate depth and position (XYZ) values for each sounding; 3) perform quality control checks on initial depths and horizontal positions of soundings; 4) provide display and edit capabilities; and 5) output final XYZ positions for each sounding. The DPS software is organized into three operational functions: 1) Data Stripping (DS); 2) Automated Processing (AU); 3) Manual Processing (MP).

a. The interface between the airborne system and DPS is via the high density 8-mm tape containing the raw data acquired during the airborne mission. All of the airborne data are collected at varying rates and recorded in an asynchronous format producing a massive amount of data. Therefore, the primary task of the Data Strip (DS) is to read and unload the raw data from the data tape. As data are being unloaded they are parsed according to data type and rate of collection. This requires some extrapolations/interpolations so that the information can be synchronized into a complete 400 Hz data set. Following this step the data are initially interrogated for quality, and a preliminary quality assessment value is assigned to the various data.

b. The AU function provides a fully automated capability to post-process data prepared by DS and compute depth and horizontal positions to within the accuracies presented in Section 2. The first step is to accurately identify the surface and bottom returns utilizing the pre-recorded airborne sensor data. Depths are then determined by computing the differences between the arrival times of the surface and bottom returns and applying corrections for depth errors and biases associated with light propagation and various inherent system characteristics (Guenther and Thomas, 1984a and Guenther and Thomas, 1984b). AU utilizes sophisticated modeling algorithms to predict and apply corrections associated with these errors (Guenther, 1985).

(1) Wave Correction. Horizontal positioning for each sounding is established through the GPS and IRS data collected during airborne acquisition combined with various other system parameters. This information combined with the optical properties of the water makes it possible to transform the coordinates of the transceiver to an X,Y bottom position. The database is then updated with corrected XYZ coordinates and the final output is in ASCII format. Additional processing is performed to remove the errors introduced by surface waves and swells from each sounding and producing depths that are relative to a common mean water surface. Both the aircraft and water surface exhibit random vertical fluctuations that, if not removed, would contribute directly to the depth error. Determining a mean water surface and isolating the aircraft's vertical fluctuations allows for an accurate estimation of the aircraft height above the mean water level. Applying corrections for tide then produces a depth reference to a known water level datum such as mean low water.

(2) Tide and Water Level Adjustments. SHOALS surveys are based on measuring water depth. In doing so, an average water surface must be determined as a reference for each depth measurement. Topographic measurements using SHOALS also must rely on the determination of an average water surface to determine the height above the water's surface. While collecting survey data, the airborne system measures the slant range or distance between the platform and the water surface for each laser sounding. The average water surface is then determined by calculating a running average of the slant ranges over a specified time interval. When conducting surveys using DGPS it is necessary to collect tidal or water level information at the time of the survey. Data can be obtained from an instrument as simple as a tidal staff or as sophisticated as a self-recording tidal or water level gage. It is required, however, that the tidal/water level station be referenced to a known vertical datum. The water level information recorded at the time of the survey is then used to correct the depth measurements to the desired vertical datum such as NGVD, MLW, or MLLW.

c. Manual Processing. The Manual Processing (MP) is used for quality control of the results from the AU and allows evaluation and editing of anomalous data. This function provides the ability to color-code geographic displays of outputs for selected areas of the survey such as real-time and post-processed data for both hydrographic and topographic data along with various other data information and system parameters. Zoom features allow for viewing the data at different scales and to the level of individual soundings as illustrated in Figure 13-4. When selecting individual soundings, raw data and various associated output parameters can be viewed. A typical manual processing display showing individual LIDAR waveforms is presented in Figure 13-4. After making edits, data are returned to AU where they are re-processed and updated. As mentioned above, a video image of the survey area is also available for visual scrutiny and aid in the interpretation of anomalies. When the hydrographer has addressed all the identified anomalies and is confident that the data are ready, the final adjusted X,Y,Z data file is created. The final data set is imported into a CAD package for mapping and charting.

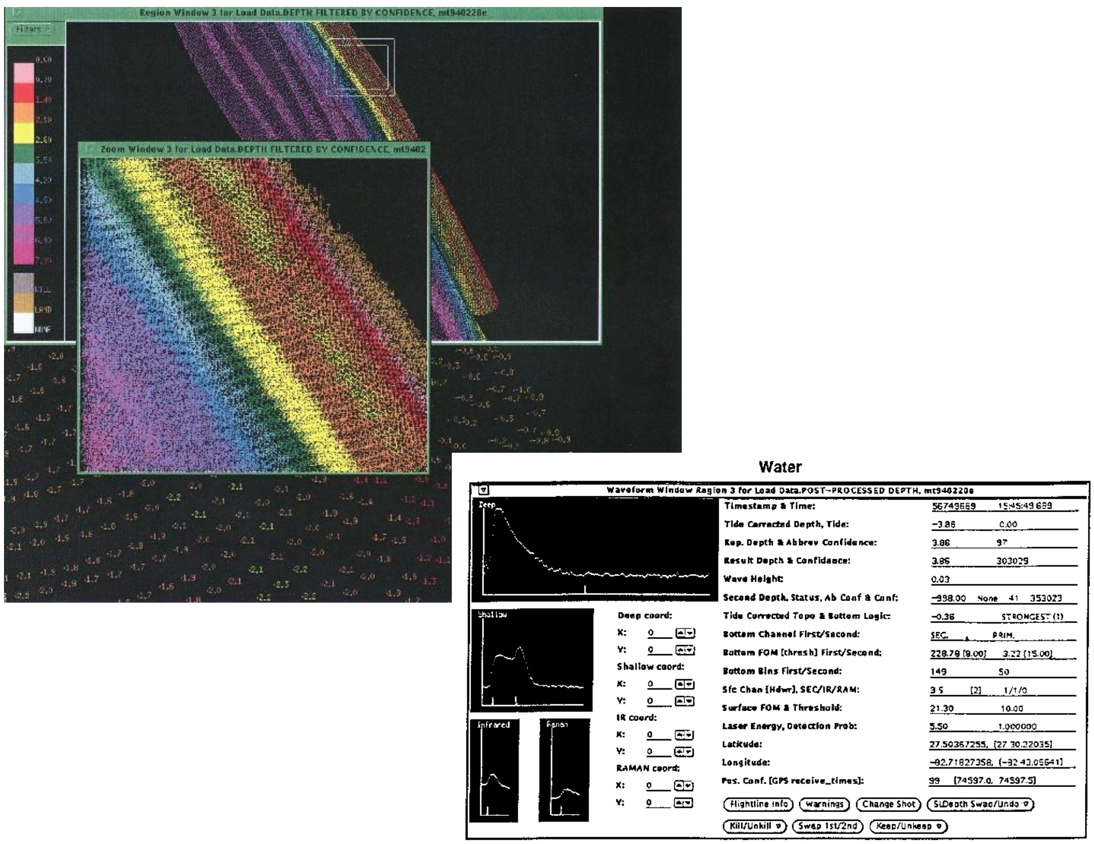

Figure 13-4. Zoom options

13-10. Product Generation

Final products vary greatly depending on the scope of each survey and how the data are to be used. A CAD program is used to produce final products that have included a variety of engineering drawings of navigation projects, plots of navigation structures, and shoreline and depth contours as well as other products. Three-dimensional color plots can also be produced for use in study reports and other publications. Examples of some of these products are shown in the following section and can also been seen at http://shoals.sam.usace.army.mil. For nautical charting, depths are plotted on smooth and field sheets which represent a subset of the most shoal depths as well as potential navigation hazards such as rocks or sunken vessels. Each LIDAR survey mission is unique, therefore the capability for producing final products must be versatile. In additional to the products mentioned above, SHOALS has the capability to calculate volumes between successive data sets, which is often required to quantify sediment that has eroded or deposited since the last survey. All of the final output products as well as the ASCII X,Y,Z file are written to CD ROM for distribution to the customer.

13-11. Data Preparation

After the raw LIDAR data have been processed by the DPS, the resulting ASCII X-Y-Z file is output. This file contains a information about each data point collected, such as geographic coordinates, time stamp, and the calculated depth for each data point.

a. *Datums.* At this time the vertical datum has already been defined by the DPS. However, the depths are in meters and it is at this point that they are converted to feet if required by the customer. The horizontal input format for the each data set is geographical latitude/longitude coordinates, but typically transformed from geographical coordinates to State Plane Coordinates (SPC)--on NAD 1927 or NAD 1983 or to the Universal Transverse Mercator (UTM) system.

b. After the data are input into the mapping system and transformed to the proper coordinate system, a process of comparing each data set to expected values is conducted. These expected values are based on existing charts, maps and other information available to the project engineer. The data are also compared to each other to make sure that each falls within the system requirements. If any of these comparisons do not yield satisfactory results, the problem area is isolated and further evaluations made to correct the problem. In the event that the problem cannot be corrected, these data are deactivated and not used in mapping.

c. When the comparisons fall within the expected limits and any problem areas addressed, the data set is cleaned to remove anomalies. These points are typically returns from trees, buildings, fish, boats, or floating or suspended matter in the water. Any point that is not considered a natural part of the terrain is deactivated from the data set or Digital Terrain Model (DTM). This DTM is to be used to create the Triangulated Irregular Network (TIN).

13-12. Mapping

Once the data preparation process is complete the data are ready for mapping. The standard SHOALS mapping package includes E-sized sheets of a color contour map, plan and profiles of any existing structures and cross sections of those structures.

a. Contour maps. The maps consist of color contours usually at a two foot or one meter interval (project dependent). Overlaid on the color contours are depths to provide the engineer with greater detail about the project. A review of this map provides the greatest comprehensive management information for the engineer. An entire project can be easily reviewed and problem areas immediately identified, such as shoal channels, jetty scour, structure failure, and many other critical evaluations necessary to provide effective project management.

b. Structure plan and profiles. The plan and profiles are created for any existing structures within the project limits. If the alignments for these structures are not furnished by the client, the apparent centerline is determined based on the contours. Once the centerline is determined, a typical plan and profile sheet with stationing and centerline information (coordinates) is created for each structure, with scale and units being project dependent. Such information is useful in performing structure condition evaluations. The profiles along the crest of the structure indicate areas where there is a loss in elevation or possible breaching.

c. Cross-sections. The cross sections are created for the same alignments as the profiles. The scale and units for these sheets are also project dependent. These cross sections can be used to identify areas within a structure, such as a jetty, where there may a deterioration of the structure side slope caused by slumping or armor stone displacement.

d. Point reduction. For some applications, a high density data set may not be required. The current method of reduction is spatial binning and thinning. A bin size is chosen based on the scale of the project or changes in elevation. The data are then placed in the selected bin. The data within each bin are analyzed and the shoalest point within the bin is written to a file. While this method works well in areas of consistent grade, in areas where elevation vary significantly (i.e. structures, dunes, channel sides) it is to reduce the bin size.

e. Final Products. Once the sheets for the color contours, plan and profiles, and cross sections are created digitally they are plotted or printed for review. The printed sheets are proofed and corrections are made for the final printing and plotting. With the final plots in hand the project booklet is created. The project booklet contains a metadata file which describes the data and format for the project, the plots, a history and reference section, and the digital data for the project.

13-13. Applications: Navigation and Structures

Since becoming operational, SHOALS has performed a wide variety of missions (over 230 project surveys as of 6/98) including many navigation projects at tidal inlets, where the USACE is typically concerned with channel depths, disposal areas, navigation structure condition, and project impacts to adjacent shorelines (Lillycrop, Irish, and Parson, 1997). Using SHOALS these types of surveys are completed in a few hours, resulting in high-resolution coverage of an entire inlet system as well as associated structures and adjacent beaches. The survey provides information to perform regional sediment management, quantify channel dredging requirements, indicate condition of the associated jetties both above and below the water including the structure toe, and the entire beach and nearshore areas adjacent to the inlet. Figure 13-5 presents the result of a SHOALS survey conducted at Ft. Pierce Inlet on the east of Florida. Ft. Pierce was among the first missions completed with KGPS during the winter of 1997. Analyses of the data show exceptional coverage of the upland beach and dune system along with the nearshore bathymetry. This high-resolution survey quantifies several of the inlet's features such as reef and rock outcrops, the rock-blasted channel, navigation jetties, shoal features, and beach and nearshore morphology.

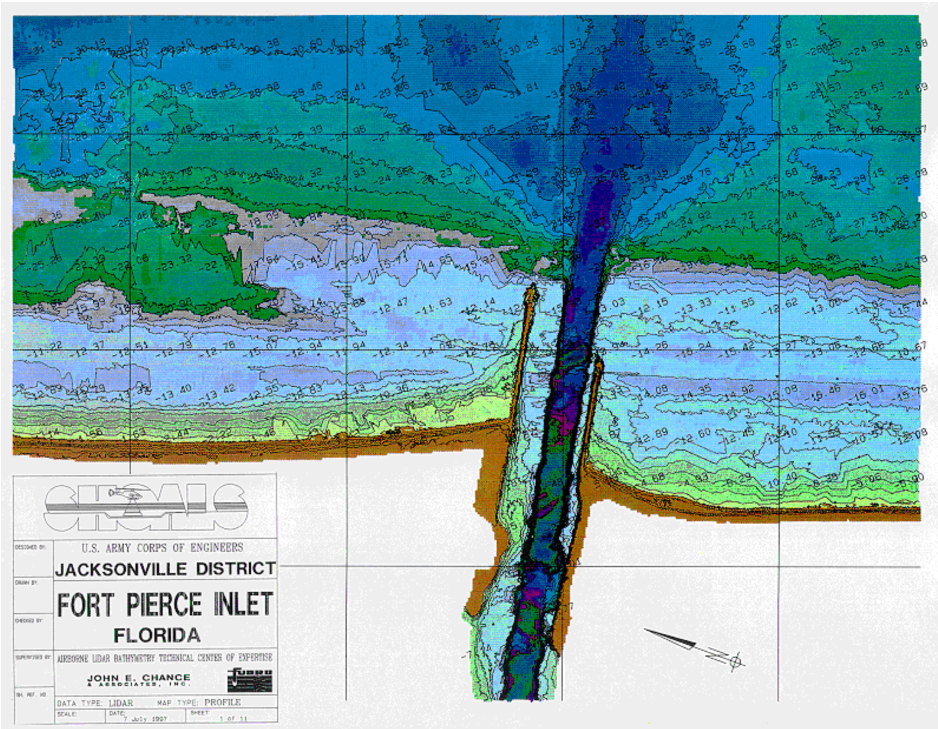

Figure 13-5. Fort Pierce, FL

13-14. Applications: Nautical Charting

Four SHOALS surveys were conducted for the NOAA National Ocean Service and one for the U.S. Navy explicitly for creation of nautical charts and identification of navigation hazards. These included Miami Harbor and Port Everglades, Florida, and Elwood and Gaviota, California, and SHOALS' first international mission off the Yucatan Peninsula, Mexico. The Mexico project, completed for the U.S. Navy, was the largest single survey mission for SHOALS (Figure 13-6). Over 56 days of data collection, SHOALS completed 800 km^2 totaling over 100 million depth measurements. In preparation for this mission, SHOALS auxiliary sensor capabilities were augmented to include a geo-referenced video for establishing positions of above-water features such as piers, lighthouses, and navigation aids as well as some underwater features in clear water. During the Mexico mission, SHOALS bathymetry and video located and mapped two previously uncharted shipwrecks.

Figure 13-6. Yucatan Peninsula, Mexico

13-15. Applications: Beach and Shoreline Surveying

a. Beach and nearshore survey data are required during the life cycle of coastal projects. For example, surveys of beaches are required in order to develop shoreline change maps to determine the effects a navigation project has on the surrounding area. Beach surveys are also used for planning, design, and construction and to monitor projects. Conventional beach surveys typically consist of a series of shore-normal profile lines extending from the beach into the nearshore at widely spaced intervals. Many times the results are sparse data sets that may not adequately represent the dynamic three dimensional environment and provide only gross shoreline change, missing smaller scale features such as scalloped beach faces, variations in nearshore shoals, or small reef and rock outcrops.

b. As previously discussed, SHOALS was modified in response to USACE's increased need to map beaches, dunes, and nearshore areas. Airborne LIDAR provides the capability to collect comprehensive hydrographic and topographic elevation data. Using specialized data processing techniques, above-water elevations from the SHOALS LIDAR signal can be computed. This produces not only depths but also elevations of the subaerial beach and other associated features above the water's surface. With the ability to collect both hydrographic and topographic survey data, SHOALS can simultaneously conduct complete beach and structure surveys above and below the waterline providing the most accurate data for calculating design volumes or post-storm erosion assessments. The data can be used to generate beach profiles, cross sections, contours, and is very accurate in performing volumetric calculations.

c. Figure 13-7 shows a 3-D plot from a SHOALS beach survey collected at Presque Isle on Lake Erie near Erie, Pennsylvania. Visible in the plot are detailed nearshore features that were missed using conventional beach survey methods. The survey was also able to completely capture the detached breakwaters placed to stabilize the shoreline. This high resolution data set provides detailed information of the structure and surrounding bathymetry extending onto the dry beach. Of additional interest is the geologic fault that was previously unknown. Features such as this may have an effect on the behavior of the immediate area, but it was not detected using conventional profiling methods. If desired, profiles can be cut through the LIDAR data at previously established profile locations for comparisons with historical data sets.

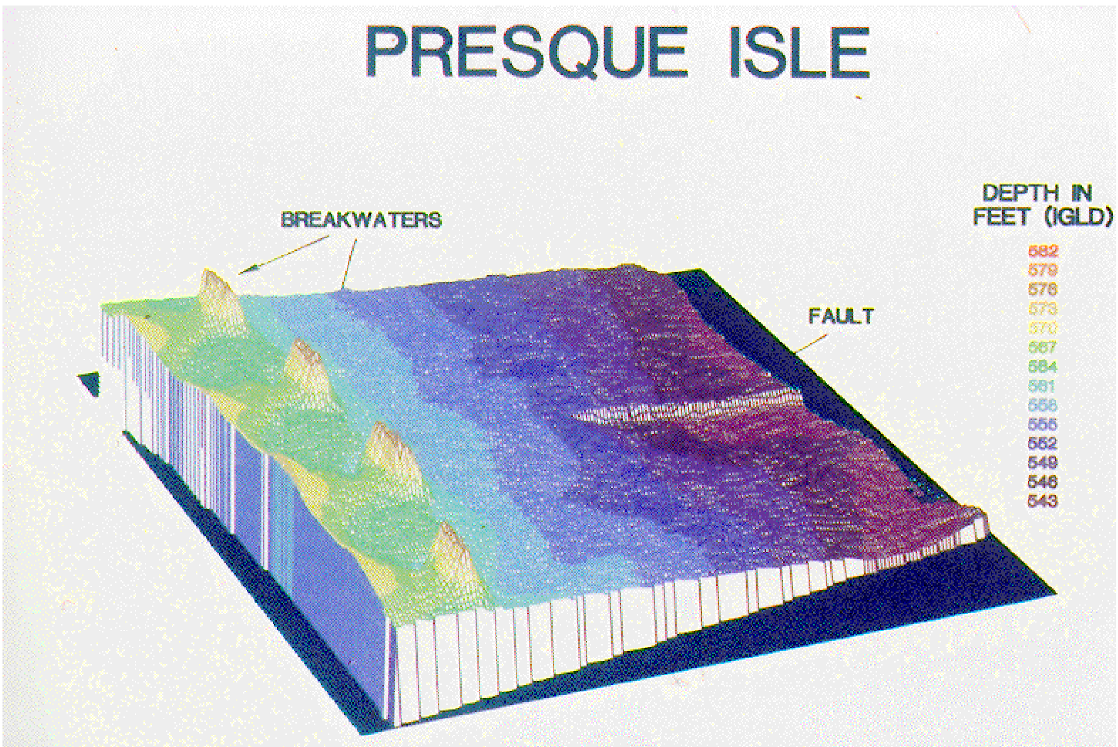

Figure 13-7. Presque Isle, Ohio

13-16. Applications: Emergency Response

a. Since SHOALS is rapidly deployable and quickly collects both bathymetry and elevations above the water, it is an ideal tool for emergency damage assessment. In 1997, SHOALS performed an emergency response survey to quickly assess coral reef damage at Maryland Shoal in the Florida Keys resulting from the grounding of a cargo vessel. The mission was completed in less than an hour and successfully quantified the damage to the reef system.

b. In October 1995, following Hurricane Opal, SHOALS surveyed two projects along Florida's panhandle: East Pass and Panama City Beach (Irish et al., 1996). East Pass is jettied on both sides and provides the only direct access from the Gulf of Mexico into Choctawhatchee Bay through a maintained navigation channel. On the east side of the pass is a sand spit, known as Norriego Point. The East Pass survey was completed (Figure 13-8) within an hour and included over 300,000 soundings within the 3 km^2 area. Elevation measurements ranged from the dry beach and above-water structures to 10-m depths and detailed the entire inlet system including Norriego Point, the two jetties, the inlet throat, and the ebb shoal. Within six hours of the survey, hard-copy maps were generated, dredging requirements inside the navigation channel were calculated, and jetty damages assessed.

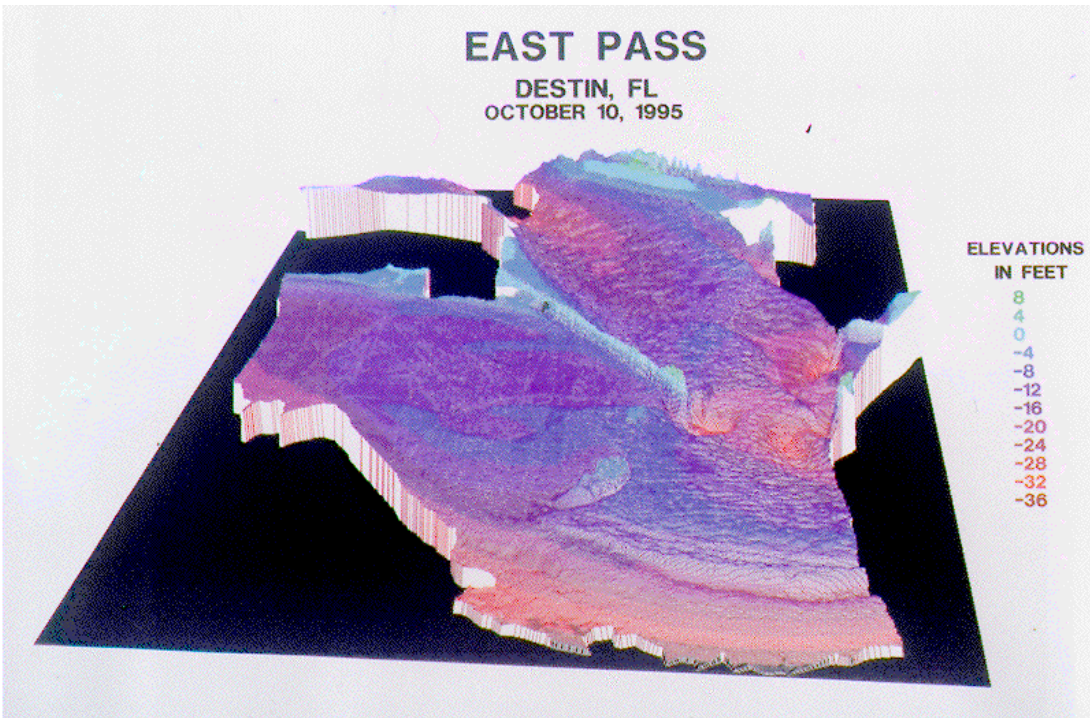

Figure 13-8. East Pass, Florida

13-17. Applications: Shallow Water

An additional benefit of remotely collecting bathymetric data is the ability to collect data in shallow and environmentally-sensitive waters that are typically inaccessible using conventional survey techniques. Additionally, environmentally-sensitive areas, like those with sea grass beds, may restrict boat usage making data collection with conventional techniques impossible. SHOALS is capable of collecting high-resolution shallow water bathymetry without disturbing the environment. In 1994 and in 1997, SHOALS performed surveys in the shallow areas of Florida Bay (Parson, et al., 1996). Florida Bay is the focus of an inter-agency program involving a modeling effort to define internal water circulation exchanges with surrounding waters. Models such as these require detailed resolution of the Bay's morphologic features which are characterized by extensive shallow-water networks of mud banks, cuts, and basins. Prior to the SHOALS mission, this shallow-water depth information did not exist. The area surveyed exhibited numerous channel cuts transecting shallow mudbanks that are believed to influence water flow between the Atlantic Ocean and Florida Bay. These channels range from 0.5 to 3 meters deep. SHOALS surveyed the 6 km^2 area in a few hours. The survey data clearly revealed these channel features and quantified their dimensions for use in the modeling effort.

13-18. Applications: Confined Disposal Facilities

Disposal sites consist of both upland (confined) sites and subaqueous (open-water) sites. To obtain maximum long-term usage of a site, an accurate account must be obtained of the changes in storage capacity resulting from gains or losses and consolidation of disposal material (Poindexter-Rollings, 1990). Obtaining comprehensive surveys of confined upland disposal facilities is not easily met using conventional topographic surveying methods. With the ability of SHOALS to collect high-resolution topographic survey data over large areas, monitoring confined dredge disposal facilities can be easily accomplished. The survey represented in Figure 13-9 is from an upland disposal facility near Mobile, Alabama. This survey was performed exclusively as a topographic survey and was collected using KGPS positioning. Apparent on this survey is the disposal dike surrounding the containment area and the detailed interior features formed by spur dikes and cross dikes. These structures are placed within the interior containment area to increase the water retention time, allowing for maximum settling of sediment from the dredged material. The high resolution of this survey will allow for accurate volume calculations when compared to future LIDAR surveys of the same density.

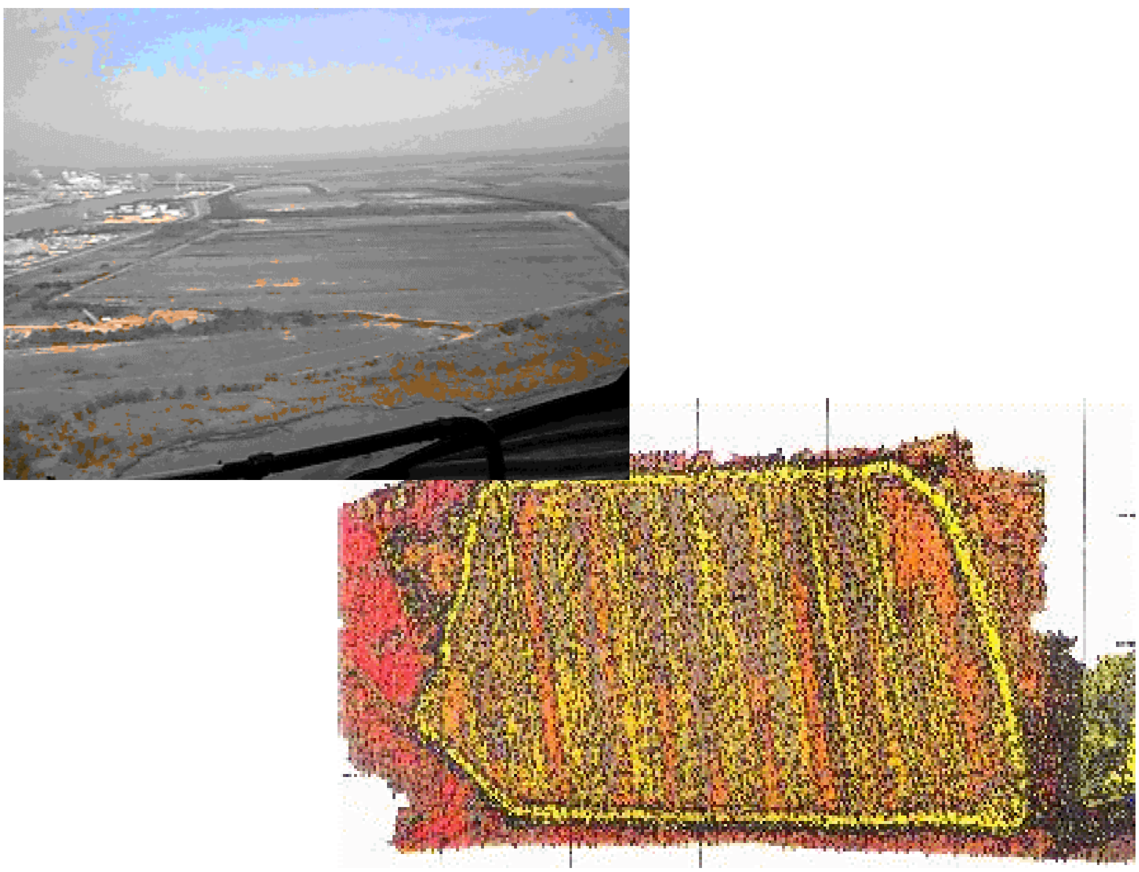

Figure 13-9. Confined disposal area, Mobile, AL

13-19. Applications: Hazard Detection

It is important to provide information concerning the condition of a navigation harbor, however, the ability to detect smaller objects that could compromise safe navigation is also a desirable feature. Objects such as coral heads, rock outcrops, displaced armor stone, sunken boats, storm debris, etc. can be hazardous to navigation. To accomplish the detection of such features, the standard SHOALS data processing and depth extraction techniques were modified to extract shoal depths by a feature that identifies the depth based on the first LIDAR pulse return signal. Typically for Corps surveys, depth determination is based on the pulse with the greatest signal to noise ratio. On projects where the primary mission is to locate and identify potential hazards to navigation, all depth are identified using this first pulse method. After the LIDAR data is processed, it is checked for outliers, where abrupt shoal depths were evident in the data. The individual waveforms for the outliers are checked using the manual processing capability to determine if the data represents a true hazard. If it is determined that a potential hazard exists, the area will be revisited to survey the site in greater detail. An example of locating and mapping a navigation hazard can be seen in Figure 13-10.

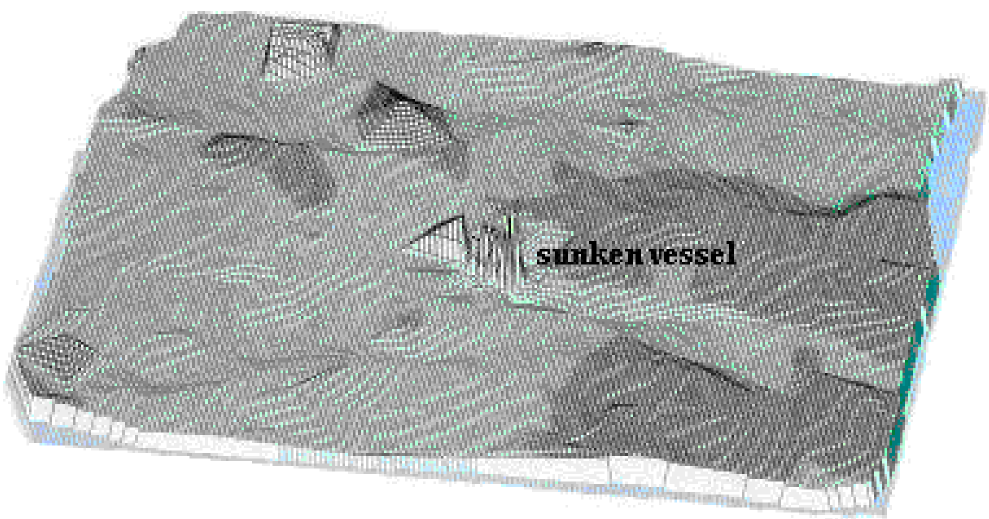

Figure 13-10. Hazard detection

13-20. Obtaining SHOALS Surveys

SHOALS is a government owned and contractor operated system. This approach was selected for two main reasons: first to achieve a long term goal of facilitating private sector interest, and secondly, to optimize operational flexibility necessary to implement an national and international survey program (Lillycrop, Parson, and Irish, 1996). The USACE provides the overall management of the system through the JALBTCX, including operation, maintenance, and system evolution required to pursue the long-term goals. John E. Chance & Associates, Inc. (CHANCE) of Lafayette, Louisiana was selected through a competitive bid process to operate and maintain SHOALS. SHOALS surveys are administered and conducted through the USAED, Mobile and the JALBTCX through a Task Order Contract (TOC) that Mobile District has procured with private industry to operate and conduct SHOALS surveys. To initiate SHOALS services from a Federal agency, interested parties should contact the JALBTCX. The first step is to provided a Statement of Work (SOW) which includes a map or chart of the project area defining the boundaries of the survey and specific survey requirements. Survey requirements should address special survey coverages and /or features, desired data density, required datums, and deliverable products. The SOW should also contain information pertaining to vertical and horizontal control data such as locations of nearby survey benchmarks and tide/water level gages. Upon review of the SOW the JALBTCX will respond with a proposal outlining survey operations and cost. When both parties have agreed to the cost and terms of the survey the funds are provided to the JALBTCX through a Military Interdepartmental Purchase Request (MIPR) or other interagency purchase request. Parties interested in obtaining SHOALS surveys should contact the JALBTCX at (334)690-3467.

13-21. References

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Note that additional references are listed in Appendix A.

13-22. Mandatory Requirements

There are no mandatory requirements in this chapter.