Chapter 9 – Hydrographic Surveys (Draft)

General Statement

Hydrographic surveys are performed to capture underwater topographic data which may be inaccessible by ordinary surveying techniques.

Policy Statement

In lieu of establishing a rigid criteria for all hydrographic surveys, this document has been created for use as a "best practice" guide, in recognition of the fact that each project will have its own unique set of requirements and conditions, and no single accuracy standard, data collection procedure, or Quality Assurance/Quality Control (QA/QC) strategy can be defined which would cover all possible variables. Departure from the best practice recommendations laid out herein must be authorized by the Deputy County Surveyor, Field Services, or by the County Surveyor.

Applications

Hydrographic Survey methods may be employed by OC Survey on the following types of projects:

- Scour Study Surveys
- Condition Surveys - County Lakes, Reservoirs, Harbors, and Navigation Channels
- Coastal Engineering Transect Surveys
- Dredging Measurement Surveys (Pre and Post)

Although applicable to all of the surveys listed above, the bulk of this document will be dedicated to Dredging Measurement Surveys.

Components of a Hydrographic Survey System

Note to David Evans and Associates:

Please provide specifications for each of the components listed below. Include specific details as to what type of equipment and software is to be used for the different types of surveys under different project conditions.

Survey Vessel:

The Survey vessel may range in size and complexity from small remotely operated units up to large ocean-going vessels. A number of conditions must be considered when selecting the appropriate vessel for a specific project including:

- Project depth
- Project water conditions - current strength, wind strength, swell height, density of boat traffic, etc.
- Project location in relation to the nearest launch facility
- Project budget

Motion Reference Unit (MRU):

Most hydrographic survey vessels are equipped with some type of motion compensation instrumentation. These inertial measurement instruments, which compensate for pitch, roll, yaw, and/or heave of the survey vessel, are generally referred to as MRUs.

Positioning System:
The most widely accepted method for positioning of the survey vessel is Real Time Kinematic (RTK) GPS. The survey vessel is outfitted with either one or two GPS receivers, which are used to establish the horizontal and vertical position of the vessel.

Acoustic Depth Measurement System:
Although the positioning system described above will be used to establish the horizontal and vertical position of the vessel, additional equipment is needed to obtain the vertical position of the actual ground surface (sea floor) beneath the vessel. Acoustic depth measurement systems compute depths by measuring the elapsed time an energy pulse takes to travel from the transducer to the sea floor and back. Following are the most commonly used types of acoustic depth measurement systems:

- Single Beam Systems – Pulses from a single transducer capture lines of points along the sea floor in the direction of travel
- Multiple Transducer Systems – Multiple single beam transducers, mounted perpendicular to the direction of travel, capture lateral swaths of the sea floor
- Multi Beam Systems – Pulses from a single transducer form an array of narrow beams which capture lateral swaths of the sea floor

Computer System:
The computer system, consisting of a laptop computer, tablet, or hand held data recorder, is used for navigation along predetermined lines, collection and storage of survey data, and for real-time QA/QC.

Selection of Depth Measurement System

Successful completion of a hydrographic survey project will depend upon selection of equipment appropriate to the required accuracy of the survey and the existing conditions. The discussion in this section will be limited to selection of the depth measurement system and the related components. Note that Multiple Transducer Systems are not included in the discussion at this time.

Single Beam Systems

Advantages:

- Inexpensive (an MRU is generally not incorporated)
- Easy to operate
- Simple calibration procedure
- Accurate measurement under optimal conditions
- Processing of data is not complex

Disadvantages:

- Considered a cross-sectional survey (5% to 25% ensonification)
- Less effective in deep water (d > 50 feet)
- Longer data collection time
- Less effective at mapping obstructions
- Less accurate representation of uneven topography
- Less accurate when vessel is subjected to pitch and roll (in the absence of an MRU)
- Less effective in turbid water

- Less accurate terrain model generated
- May present possible pay quantity dispute

Best Uses:

- Scour study surveys
- Coastal Engineering Transect Surveys
- Channel Condition Surveys
- Dredging measurement projects meeting the following conditions: smaller project size; shallow water (d < 20 feet); uniform bottom topography; calm water conditions; lower accuracy requirements; tight budget constraints
- QA tool, used as a performance test or independent check against a multi beam survey

Additional Notes:

- If a single beam system is to be used without an MRU, surveys should only be conducted under ideal conditions, e.g. calm water (minimal tidal influence, swells, or wake from other vessels), minimal turbidity, minimal wind, etc.
- A high frequency transducer will provide more precise depth measurements under optimal conditions; a low frequency transducer is better able to penetrate suspended sediment and sea floor vegetation
- Transducers with a narrow beam width will provide higher resolution but will be more adversely affected by vessel pitch and roll (in the absence of an MRU); transducers with a wide beam will create a larger footprint and thus are better suited for "strike detection"
- Amplification of the echo signal (gain) must be adjusted according to the existing conditions, e.g. sea floor material, water column noise level, etc.

Multi Beam Systems

Advantages:

- Considered a full coverage survey (100% ensonification)
- Very fast rate of data collection
- Accurate terrain model generated, regardless of irregularities in the sea floor
- Accurate measurement in deep water conditions
- Effective at mapping obstructions

Disadvantages:

- Expensive - MRU and additional GPS receiver are required
- Complicated to operate - more crew training is required
- Complicated and time consuming calibration procedure; resultant data may be compromised if calibration is skipped or incorrectly conducted
- Processing of data is complex and time consuming

Best Uses:

- Coastal Engineering Transect Surveys
- Channel Condition Surveys
- All Dredging measurement projects, especially those meeting the following conditions: larger project size, deeper water, critical clearances, high value (rock cut) dredging

Additional Notes:

- Although multi beam transducers are capable of projecting very wide angle beams, beam widths should be limited to 90 degrees (45 degrees each side of a plumb line), as accuracy tends to degrade towards the outer portions of the swath.

Accuracy Standards

The accuracy standards recommended herein reflect those defined in ***Chapter 3*** of the ***US Army Corps of Engineers Publication EM 1110-2-1003.*** As stated in this USACE document, although the recommended procedural and accuracy standards reflect current equipment, positioning methodology, and QA/QC practices, *"… it must be recognized that no single accuracy standard will be applicable to every* (OC Survey) *civil works project; therefore* (OC Survey) *should tailor their survey procedures and required accuracies to each specific project."* Note that the ***"National Oceanic and Atmospheric Administration (NOAA) Field Procedures Manual"*** and the "***IHO Standards for Hydrographic Surveys"*** were developed specifically for nautical charting purposes, and therefore although they provide a valuable resource, they do not specifically apply to hydrographic surveys performed by OC Survey.

When project specifications state required accuracies for depth measurements, the statistical measurement criteria must also be defined, along with the confirmation process to be followed. On dredging measurement surveys, project specifications should require that Performance Tests be the basis for this confirmation.

Recommended accuracy standards for OC Survey dredging measurement surveys up to a depth of 50 feet are as follows:

Repeatability of Depth Measurement: 0.3 feet
Standard Deviation of Depth Measurement: +/- 0.8 feet
Positioning System Horizontal Accuracy: 0.15 feet
Positioning System Vertical Accuracy: 0.15 feet

Notes:

- These are recommended standards, which may be modified to meet specific project requirements or survey capabilities
- Repeatability is computed from Performance Test data as the mean difference between cross-line check observations
- Standard deviation is computed at the 95% confidence level from Performance Test data, e.g. cross-line check observations (single beam system) or coverage overlap (multi beam system)
- Horizontal and Vertical Accuracy of the positioning system are computed from the shoreline control point check shots (see Quality Assurance section below) and do not imply the same accuracy for the horizontal and vertical position of sea floor data points.
- Resultant accuracies should be reported within the project deliverables, along with a statement explaining the method used in computing the accuracies.

Sources of Error Unique to Depth Measurement

It can be confidently stated that no measurement is without error; however accurate depth measurement presents unique challenges due to the many variables inherent to an acoustic measurement system:

- Manufacturer's reported "precision" of the measurement system
- Latency in the measurement system
- Varying magnitudes of noise in the acoustic signal
- Variations in water temperature and salinity

- Variations in the amount of suspended sediment within the water column
- Variations in sea floor material (reflectivity)
- Irregularity of sea floor topography
- Effects of pitch, roll, yaw, and/or heave of the survey vessel

Much of the resultant random and systematic error from these factors can be modeled and/or compensated for by onboard equipment through beam width, frequency, and gain selection, use of a sound velocity probe, and by the MRU. Use of other calibration measures (see Quality Control section below), e.g. the "bar check" or "ball check" will quantify the transducer index constant and compensate for variations in sound velocity. Resultant accuracy, and thus repeatability, can then be computed after performance testing has been completed (see Quality Assurance section below).

Quality Control Procedures (QC)

Acoustic depth measurement systems compute depths by measuring the elapsed time an energy pulse takes to travel from the transducer to the sea floor and back. The accuracy of these depth measurements is dependent upon multiple factors:

- Modeling of any electrical or mechanical delays inherent to the depth measurement system and accurate measurement of the true distance between the GPS receiver and transducer (index constant)
- Determination of the actual velocity of the energy pulse through the water column
- Orientation of the energy pulse relative to a plumb line (single beam systems)
- Orientation of the beam array with relation to vessel heading, a level line, and a plumb line (multi beam systems)

The QC procedures detailed below will help to improve the accuracy of depth measurements by removing systematic errors (calibration of depth measurement systems) and random motion related positioning errors (MRU systems).

Dock Check:

The Dock Check serves as the initial check on the entire hydro system. This check is performed by comparing two measurements to a common point on the sea floor adjacent to the dock, one using a survey layout rod and one using the hydro system itself. The dock check must be performed at the beginning of each day, throughout the duration of the project.

Velocity Probe Test:

A Velocity Probe is used to measure the velocity of sound through the water column. Sound velocity will vary with water temperature and salinity. Results of the test are entered into the depth measurement system or recorded for post-processing. In addition, it is imperative that a log book documenting results of the velocity probe test be maintained. The Velocity Probe Test must be performed daily throughout the duration of the project.

Bar Check:

The Bar Check, the primary test of a depth measurement system, is used to minimize systematic errors introduced by instrumentation, draft measurement, and variations in sound velocity through the water column. A bar is lowered to multiple known depths below the water line (on five to ten foot intervals, down to the ultimate project depth) and suspended beneath the transducer. Measured depths are compared with the known depth in order to model index error and the variable depth-dependent error. Results of the test are entered into the depth measurement system or recorded for post-processing. In addition, it is imperative that a log book documenting results of the bar check be maintained. An alternative to the bar check, especially well-suited to an over-the-side mounted transducer, is the Ball Check. The “Ball” (or a flat plate) is suspended beneath the transducer at multiple depths as described above. The Bar/Ball Check should be performed upon assembly of the hydrographic survey system, at the beginning of each project, and at regular intervals throughout the project (to be determined by the Senior Land Surveyor).

Latency Test:
The Latency Test is performed to identify time related bias due to delay between the GPS time tag and the echo sounder time tag. This is achieved by collecting data on multiple passes along a predetermined line, at different speeds and in both directions. The line selected should include a steep slope or some other prominent topographic feature. The Latency Test should be performed upon assembly of the hydrographic survey system and at the beginning of each project.

Alignment and Calibration of the Motion Reference Unit (MRU):
Upon installation, components of the MRU must be properly aligned and calibrated. A thorough explanation of this process can be found in ***Chapter 6*** of ***US Army Corps of Engineers Publication EM 1110-2-1003*****.**

Quality Assurance Procedures (QA)

Quality Assurance (QA) is achieved through performance testing, both inside and outside of the project area. Performance tests capture redundant measurements, allowing for computation and documentation of repeatability and reliability of depth measurements. Results of performance tests provide verification that project accuracy standards have been met and documentation of the actual reported accuracy of the survey. In order to compute a realistic statistical analysis, at least 100 pairs of points should be analyzed. Note that for performance tests to be truly independent in nature, measurement data sets must have been collected by different survey vessels. Results of statistical analysis on non-independent data are only an estimate of system *precision* and do not truly represent a model of the *accuracy* of the data. Non-independent tests will not reveal constant system bias (systematic errors).

Shoreline Control Point Check Shot:
Horizontal and vertical accuracy of the positioning system itself are computed from check shots taken on shoreline control points using a survey layout rod. These check shots must be performed at the beginning and end of each day, throughout the duration of the project.

External Check-Line Method (single beam systems):
The check-line method involves the establishment and repeated measurement of a baseline outside of the project limits. This line is run daily before any data is collected within the project limits. The check-line should be located in an area of light boat traffic and devoid of abrupt changes in sea floor contours.

Cross-Line Check Method (single beam systems):
The cross-line method requires that additional lines be run perpendicular to the primary navigation lines, resulting in coincident data points at the intersections of these lines.

Extended Cross Sections (single or multi beam systems):
Extending cross sections outside the project limits provides a check against a previous survey, e.g. the pre-dredge surface.

Data Overlap (multi beam systems):
Navigation lines run with a multi beam system are designed to provide a pre-determined percentage of data overlap. The data falling within these overlap areas provides the basis for performance testing. An independent performance test can be performed by collecting single beam data within the multi beam data set.

Survey Control Network

Horizontal and vertical positioning of the vessel is typically established by Real Time Kinematic (RTK) or Post Processed Kinematic (PPK) GPS in conformance with ***Chapter 2 – RTK GPS***. This RTK/PPK survey must be tied to a survey control network which is based upon the California Coordinate System of 1983 (CCS83). Below are specifics related to establishment of the survey control network:

Horizontal Control: The RTK survey may be based upon the Orange County Real Time Network (OCRTN), the California Real Time Network (CRTN), or a traditional base/rover configuration. If OCRTN or CRTN are used, the base station selected should be no more than 10 miles from the project. In the event that OCRTN or CRTN are used and it is necessary to constrain to existing project control, a site calibration shall be performed (see ***Appendix A - Site Calibration Procedures***). If the decision is made to use a base/rover configuration and there is no existing project control, the base station and other shoreline control points within the project area shall be established by static GPS in conformance with ***Chapter 1 – Static GPS***. If existing project control is to be used as the basis of the horizontal control scheme, the integrity of the network shall be verified before the hydrographic survey commences.

Vertical Control: Elevations of Temporary Benchmarks (TBMs) and shoreline control points shall be established by OC Survey Third Order Leveling procedures in conformance with ***Chapter 4 – Differential Leveling***, and a vertical site calibration shall be performed. If existing project control is to be used as the basis of the vertical control scheme, the integrity of the network shall be verified before the hydrographic survey commences.

Vertical Datum:
Hydrographic surveys are often tied to a different vertical datum (e.g. Mean Lower Low Water) than that of conventional surveys performed by OC Survey. It is essential that elevations of project control points are converted to the desired vertical datum.

Monumentation

Monuments set as control points during the course of a hydrographic survey shall meet the following criteria:

- Monuments which fall on concrete curbs or in the surface of concrete paving shall consist of a tag secured in a lead plug or set in epoxy.
- Monuments which fall on asphalt dikes or in the surface of asphalt paving shall consist of a spike or "MAG" nail with a washer.

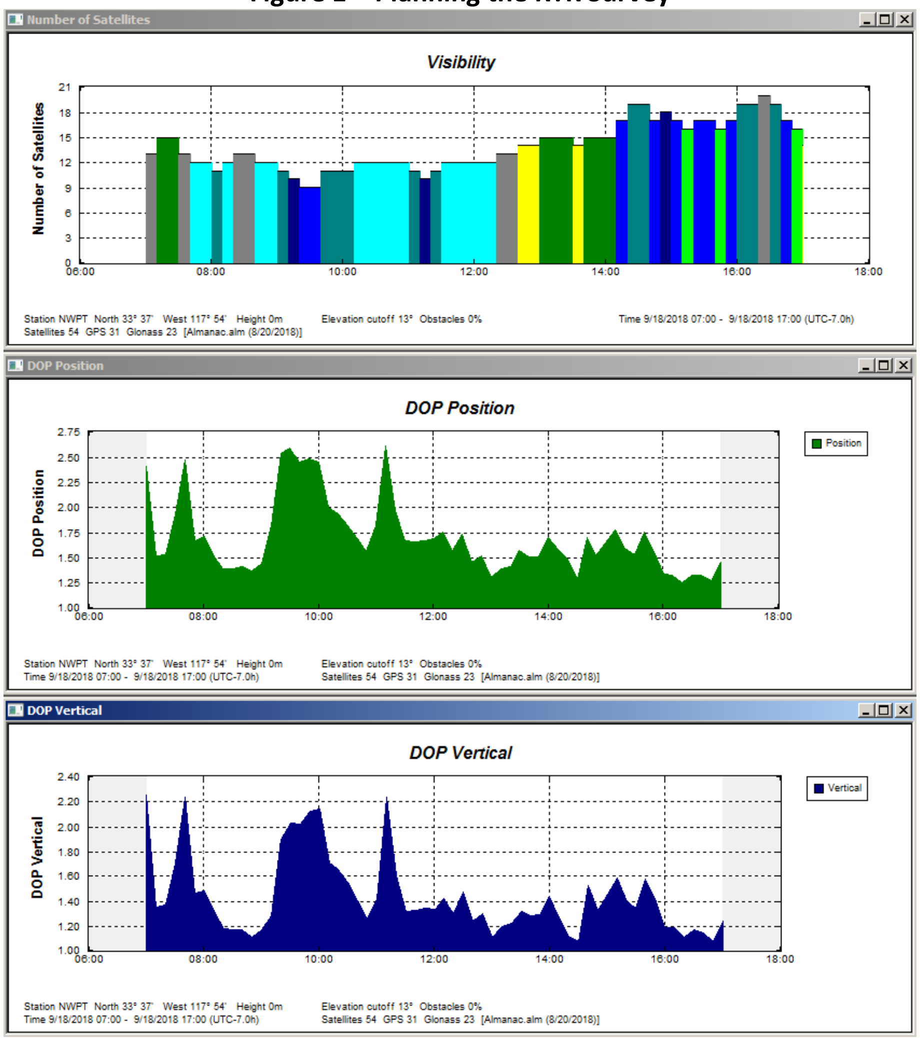
- Monuments which fall in non-paved areas shall consist of an iron pipe with a tag or disk, or a rebar with an aluminum cap. Rebar must be set a minimum of 3 inches below the ground surface.
- All tags/washers/disks/caps referenced above shall be stamped with the agency name or the license number of the surveyor in responsible charge, and shall also be stamped “CP” or “CONTROL POINT”.
- Tags set in iron pipes shall be of a diameter less than that of the inside diameter of the pipe. Disks affixed to iron pipes shall be of a diameter equal to that of the outside diameter of the pipe.
- Under no circumstances are plastic plugs to be used with iron pipe or rebar.

RTK Survey Requirements for Positioning of the Vessel

Below are specific requirements related to positioning of the vessel:

- For each day of the survey, planning software shall be utilized to identify and avoid periods of high DOP, especially in the vertical component (see Figure 1)
- Whenever possible, the RTN base station selected should include all available satellite systems (GPS + GLONASS + etc.)
- Whenever possible, a PPK survey should be conducted in lieu of a conventional RTK survey, provided the processing software is capable of interpreting PPK data
- Elevation mask shall be set to 15 degrees

Figure 1 – Planning the RTK Survey



Data Processing

Although data processing styles will vary depending upon the software platform used, some basics are covered below.

Single Beam Data Processing:

When working with single beam data, processing is initially performed within the field software and delivered to office staff as a .CSV file, which is then imported into Civil 3D. Data spikes are visually identified and manually removed. Survey line data is processed, and where longitudinal and cross sectional lines intersect, some method of smoothing or interpolation of coincident data points must be applied. Although single beam data is technically cross sectional in nature, collection of data on 25 foot longitudinal and cross sectional lines may provide up to 25% ensonification, which under normal conditions will result in generation of an accurate Triangulated Irregular Network (TIN) model. Volume calculations will be based upon this TIN model.

Multi Beam Data Processing:

Data spikes are visually identified and manually removed. Point cloud data from the survey lines is processed, data comparisons from overlapping sweeps are resolved, and the resultant data is compiled into a TIN model. Volume calculations will be based upon this TIN model. Note that although the sophistication of current computer hardware and software makes thinning of data unnecessary, ***Chapter 6*** of ***US Army Corps of Engineers Publication EM 1110-2-1003*** provides detailed procedures for data thinning, should the need arise.

Deliverables

Expected deliverables will vary from project to project, thus it is imperative that the Project Management team unambiguously defines the delivery requirements at the project planning phase. OC Survey staff must have a thorough understanding of and be in complete agreement with these requirements before commencement of the project.

The primary deliverable from a hydrographic survey project is a Triangulated Irregular Network (TIN) model. This is a 3D representation of the existing sea floor conditions at the time of the survey. Dredging measurement surveys will be comprised of two independent surveys – a pre-dredge survey and a post-dredge survey. After delivery of the pre-dredge TIN model, the Project Resident Engineer (RE) will define the payment prism, over-depth payment prism, side slope allowance, and box cut allowance. These definitions will be used in conjunction with the post-dredge TIN model to compute the volume of material removed which is eligible for payment. Volume computations are based upon a surface to surface comparison between the pre-dredge and post dredge surfaces.

Other deliverables may include sounding charts, color-banded depictions of contours, cross sections, survey control diagrams, and documentation of calibration procedures and accuracy statements.

Additional Resources

US Army Corps of Engineers Publication EM 1110-2-1003
National Oceanic and Atmospheric Administration (NOAA) Field Procedures Manual
International Hydrographic Organization (IHO) Standards for Hydrographic Surveys

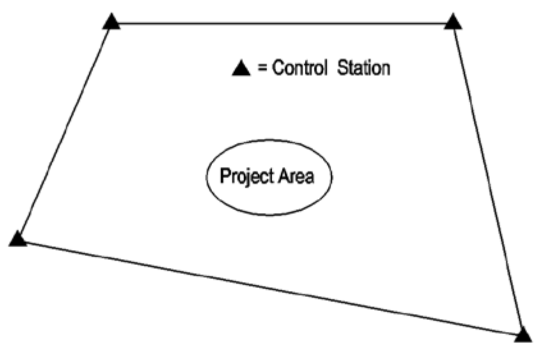
Appendix A - Site Calibration Procedure

A Site Calibration establishes a relationship between the observed WGS84 coordinates and the local grid coordinates.

General Requirements:

- The control stations shall be selected so as to create a polygon which fully encompasses the project area (see Figure 2). Selected control stations must be of the same epoch date as the current project and be located no more than six miles from the OCRTN Station or Base Station.
- Conditions which may generate multipath or obstruct view of the satellites, such as overhead power lines, nearby trees, or adjacent buildings, should be avoided.
- Elevation mask shall be set to 15 degrees.
- Each occupation shall consist of either one measurement of 180 epochs, or three sequential measurements of 60 epochs each.
- Upon computation of the Site Calibration, a control station with residual values greater than those defined below shall be discarded and another control station shall be used in place of this outlier.
- All subsequent measurements and staking activities shall use the same OCRTN Base Station or Base position as was used to generate the Site Calibration.

Figure 2 – Control Point Selection



2D Site Calibration:

- A minimum of 4 horizontal control stations shall be included in a 2D Site Calibration.
- Each horizontal control station shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 2 hours. These time differentials are required in order to ensure significantly different satellite geometry.
- The stations in a 2D Site Calibration shall not exceed a horizontal residual of 0.07 feet

3D Site Calibration:

- In addition to the requirements described above for a 2D Site Calibration, the following requirements shall be met for a 3D Site Calibration:
- A minimum of 5 vertical (or 3D) control stations shall be included in a 3D Site Calibration. To avoid creation of a distorted or tipped plane, the stations selected must have been tied together with one common leveling circuit. An alternative to this requirement is to collect data on these 5 vertical control stations but include just one of them in the Site Calibration. Analysis of the data will determine which vertical control

station represents a best-fit solution for the project. This may be a better alternative when working with vertical control that has not been recently tied together (OC Survey Benchmarks).

- Each vertical control station shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 4 hours.
- The stations in a 3D Site Calibration shall not exceed a vertical residual of 0.10 feet.