CHAPTER 3

Recommended USACE Accuracy Standards for Federal Navigation Projects

3-1. Purpose and Scope. This chapter provides recommended accuracy standards for USACE hydrographic surveys of federal navigation projects. These standards are summarized in Table 3-1. This chapter, along with Appendix D, describes the Performance Test procedures and Total Propagated Uncertainty methods that are recommended to estimate and report the accuracy of observed depths on navigation projects; in particular, on evaluating the quality of contracted construction dredging clearance and payment surveys. These standards are intended to provide Corps-wide uniformity in specifying and reporting accuracies of surveys performed on navigation and other civil works water control projects.

a. Limitations on prescribed accuracy standards. The procedural and accuracy standards recommended in this manual are designed to reflect current survey positioning methods, acoustic instrumentation systems, calibration practices, and typical bottom conditions encountered at average USACE navigation projects. However, as noted in Chapter 1, it must be recognized that no single accuracy standard will be applicable to every USACE civil works project; therefore, USACE commands should tailor their survey procedures and required accuracies to each specific project. For example, more stringent accuracy requirements should be established for a deep-draft coastal entrance project with tidal influence than those needed for a shallow-draft inland navigation project, or a reservoir sedimentation survey. Likewise, more stringent requirements are typically needed for new work construction in a rock-cut navigation project with a high cost per cubic yard payment rate than for subsequent maintenance dredging of soft material. Underwater scour surveys adjacent to locks, dams, bridges, and hydropower projects will require the most demanding accuracy standards. Conversely, it is unlikely the nominal accuracy standards recommended in this manual will be achievable in projects containing fluid mud, suspended sediment, extreme tidal ranges, or with highly irregular topography and geomorphology. In summary, accuracy standards, and related quality control and quality assurance performance tests outlined in this manual, must be considered as only recommended guidance.

b. Standards for other civil works projects. Recommended accuracy and performance criteria for other types of civil works surveys (e.g., reservoirs, locks and dams, revetments, breakwaters, underwater structure investigations, beach renourishment, etc.) are detailed in chapters covering those projects. However, in most cases, the recommended standards for navigation surveys will be applicable to many of these other civil works projects.

c. Survey calibration and testing. Recommended quality control and quality assurance procedural methods for acoustic depth measurement and positioning are covered in separate chapters in this manual—e.g., Chapter 4 (single beam), Chapter 5 (multi-transducer), Chapter 6 (multibeam), and Chapter 7 (GPS positioning and inertial orientation systems).

d. Use of standards. USACE organizational elements requesting hydrographic surveys should utilize these standards in requesting and specifying in-house or contracted surveys. However, in-house survey sections should be consulted to ensure that the required accuracy specifications for a particular project are realistic and achievable; and whether or not these accuracies should be independently tested for compliance in the field. This chapter may also be referenced in Corps hired-labor or A-E survey specifications, and in construction dredging contracts.

e. Supplemental references. The following references should be consulted in conjunction with this chapter.

(1) EM 1110-2-6056. "Standards and Procedures for Referencing Project Elevation Grades to Nationwide Vertical Datums."

(2) "IHO Standards for Hydrographic Surveys—SP 44, 5th Edition." (IHO 2008).

3-2. Discussion. No measured depth is without error. Unlike visual topographic or construction survey measurements, acoustic depths are indirectly measured using various forms and combinations of time difference (amplitude detection), phase detection, or phase difference (interferometric) measurements. These measurement methods contain varying magnitudes of acoustic reflectivity and signal/noise that must be resolved into a "best estimate" of the depth. Spatial variations in bottom soil materials will also vary the recorded depth returns. Thus, an absolute "accuracy" of a depth measurement at a given point is rarely, if ever, known. In addition, hydrographic survey depth measurements are referenced to the local water surface, which will typically have tidal or river stage modeling uncertainties (biases) relative to a distant reference gage and datum. Vessel motion, orientation, and acceleration (i.e., velocity, roll, pitch, yaw, and heave) require corrections that include additional uncertainties. Also, numerous corrections must be applied to the resolved depth to account for often significant variables in the measurement system (e.g., latencies) and speed of sound or refraction variations in the water column. The total propagated magnitude of all the above random and systematic "errors" is termed "uncertainty," or "Total Propagated Uncertainty" (TPU). TPU is estimated using mean square error propagation techniques, resulting in a "±" root mean square (RMS) error estimate. This "best estimate" of a depth accuracy can have uncertainties ranging from ±0.2 ft in shallow-draft projects to more than ±1 ft in deep-draft navigation projects; the major uncertainty components being the water surface elevation measurement and geomorphological variations in the project area. The TPU of individual depth measurements is difficult to determine through any testing method; however, the Performance Test procedures described in this manual will often provide a general indication of the TPU.

3-3. Quality Assurance Performance Tests. The QA Performance Test is the primary USACE method by which the quality of a hydrographic survey can be estimated. This test compares depth measurements made over the same point (or many points) by two or more "independent" measurement systems. The test yields an estimate of the biases (i.e., repeatability) between the surveys, and the dispersion (i.e., standard deviation or approximate TPU) between the surveys, as described below. A Performance Test is not an absolute accuracy or uncertainty assessment. Tests made by the same vessel are not truly independent. In addition, the bottom conditions of a separate Performance Test site may differ from the actual project site. Bottom soil material and topography may also vary within the test site and/or the actual project site. Performance Tests comparing surveys of the same test site by different vessels and measurement systems are more independent and provide better estimates of the statistical repeatability (or reproducibility) and standard deviations. The most representative Performance Test is comparisons between different vessels of entire surveys of the actual project area (e.g., a dredging acceptance section) where thousands of points can be compared—see example at Appendix F. Not all surveys require Performance Tests to estimate their accuracy. If no Performance Test is conducted, then the survey accuracy can be estimated and reported based on error propagation techniques (e.g., TPU)—see Appendix D. Procedures for conducting Performance Tests are covered in Chapters 4 and 6.

a. Performance Test repeatability. Repeatability is defined as the closeness of agreement between successive depth measurements carried out at the same point under similar measurement conditions. The QA Performance Test estimates survey repeatability by computing the mean difference in depths observed between overlapping datasets. Constant differences between surveys over the same point(s) is an indication of potential biases between the surveys. Repeatability or bias is specified and measured as either a "plus" or "minus" quantity, e.g., “+0.06 ft.” It is not a "±" dispersion statistic. In practice, survey "repeatability" provides an estimate of the resultant quality or accuracy of a survey.

(1) Repeatability is especially critical on dredge measurement and payment surveys. Resultant biases, if large, can adversely impact channel clearance assessment and construction payment. The repeatability measured in the QA Performance Test is, in effect, a quality control check. Repeatability results outside tolerances indicate site or system calibrations are inadequate and should be investigated.

(2) The recommended standards in this manual focus on assessing a survey's repeatability through the use of Performance Tests. It is important to reemphasize that repeatability estimates from Performance Tests are usually specific to a vessel, survey system, and the test site; in other words, they are not always statistically independent tests.

b. Performance Test Standard Deviation. Standard Deviation (or standard error) is a measure of dispersion when multiple depth measurements are made of the same point(s). Performance Tests typically compare the deviations between overlapping datasets (single beam and/or multibeam) in a large area—either over the entire project or in a separate test site. Standard deviation is expressed as a "±" deviation at the 95% level. Standard deviation statistics obtained from the same survey vessel should be used with caution in that these are not independent tests. Standard deviations from repeated Performance Test comparisons may often be used as estimates of Total Propagated Uncertainty over a test site or project area, assuming systematic biases have been either eliminated or properly minimized (randomized) through QC calibrations. In addition, large resultant standard deviations do not necessarily indicate that a survey is "inaccurate"—numerous factors impact dispersions in Performance Test comparisons.

3-4. Total Propagated Uncertainty Accuracy Estimates. TPU is a statistical dispersion estimate based on the total propagation of all random and systematic errors present in a measurement system, from the reference tide/staff gage, through the vessel positioning and motion orientation systems, to the acoustic depth return from the bottom. It is based on a Mean Square Error estimation of the total error budget in a depth measurement, and is usually expressed as a "±" root mean square (RMS) error at the 95% level. TPU is broken down to its horizontal and vertical components—i.e., THU and TVU. Data processing software can estimate TVU and THU for each individual depth observation. Alternatively, an average TPU for a given project site can be estimated (e.g., from Performance Test results). These TPU estimates are dependent on the estimated accuracy of each error component.

a. Survey specifications and accuracy reporting. Since Performance Tests are not performed on most USACE surveys, TPU may be used as a criteria for specifying survey accuracy requirements. Such a specification entails consideration of the error parameters listed in Appendix D. Reported survey accuracies on published drawings would reflect these same estimates. (TPU is increasingly being recognized as a hydrographic measurement accuracy statistic by international standards organizations. Therefore, USACE districts are encouraged to utilize this reporting statistic on published survey drawings.)

b. TPU estimates from Performance Tests. The TPU (and TVU or THU) of a hydrographic survey usually cannot be tested in practice—it is estimated based on assumed error propagation. However, as noted above, Performance Tests may yield, over the long term, a good estimate of an average TPU at a project site. (Note that TPU deviation estimates do not provide survey bias assessments. These biases can only be evaluated by Performance Tests in the field.)

c. Examples for estimating TPU in navigation projects are shown in Appendix D. Refer also to Section 5 of "NOS Hydrographic Surveys Specifications and Deliverables" (NOS 2011) and Special Publication No. 44, "IHO Standards for Hydrographic Surveys," (IHO 2008) for additional discussions on TPU and error propagation estimates.

3-5. Recommended USACE Depth Accuracy Standards for Engineering and Construction Surveys. Table 3-1 contains recommended standards for hydrographic surveys of various types of navigation projects. These standards are based on typical project conditions and average results from USACE historical performance tests on coastal projects; therefore, they shall not be considered as absolute Corps-wide specifications. The standard deviations will likely be met on shallow draft projects in confined (calm) waters. They may not be easily met on deep-draft projects with adverse environmental or bottom conditions. As such, these standards should be considered as recommended guidance that may be modified to a specific project site condition. Additional accuracy and performance guidance for specific projects are outlined in other chapters and appendices in this manual. This additional guidance includes such items as quality control calibration requirements, vessel positioning and orientation criteria, acoustic return assessment, data processing and bin sizes, representative depth selection, depth rounding, volume computation methods, and depth metadata reporting.

a. Specifying required survey accuracy. When specifying that survey depth measurements should meet a required "accuracy" to some "±" dispersion level, it is essential that the statistical measurement criteria be precisely defined, along with the process by which it will be confirmed or tested. If no confirmation tests of the resultant accuracy are performed (and these tests are not often performed in practice), then it can only be stated that the survey should be performed using quality control procedures that will "likely" or "probably" meet the desired (or intended) standard in Table 3-1, or alternatively an estimated TPU measure. On critical dredge measurement, clearance, and payment surveys, specifications should require that quality assurance Performance Tests be performed to assess the existence of any biases in the observations—i.e., "repeatability"—and the dispersion (standard deviations) in the measurements.

b. Unachievable accuracies. A desired (required) accuracy standard may or may not be achievable in practice due to varying or adverse project conditions. For example, a specified ±0.8 ft depth accuracy standard may be easily achievable on a federal navigation project in the Gulf of Mexico with a 1 ft tide range but is likely difficult to meet on the Pacific Columbia River Bar entrance channel with a 6-ft tide range and 10 ft swells. Thus, any nominal accuracy standard (such as those in Table 3-1) must be modified to meet "real-world" project conditions.

c. FGDC accuracy reporting guidance. Most traditional mapping accuracy standards, such as those prescribed by the Federal Geographic Data Committee (FGDC), require testing measurements against an independent source of higher accuracy. Independent sources of higher accuracy are rarely available for testing hydrographic surveys, other than in some inland districts with lock chambers. These FGDC standards do allow for reporting untested data accuracies if quality survey procedures were used that would likely meet the estimated accuracy. These FGDC standards state "regardless of whether the data was tested by an independent source of higher accuracy, or evaluated for accuracy by alternative means, provide a complete description on how the values were determined in metadata, as appropriate to dataset spatial characteristics." Performance Tests and TPU accuracy estimates would be considered as a FGDC "alternative means" evaluations.

d. Accuracy statements on drawings. Distributed drawings, plans, reports, studies, databases, and related metadata documents containing channel depth or clearance data should contain a statement (note) attesting to the tested (Performance Test) or estimated (TPU) accuracy of the survey data. On construction dredging projects, this accuracy statement will normally be based on results from actual or historical Performance Tests. If no Performance Tests were performed an estimated TPU may be indicated in the accuracy statement.

Table 3-1. Recommended Depth Accuracy Standards for Corps of Engineers Surveys of Federal Navigation Projects based on Performance Test Results. [1]

Project	Typical [2] Repeatability (feet)	Typical [3] Standard Deviation (± feet at 95%)
Coastal Deep Draft Projects (15>d<75 ft):		
Dredge measurement & payment surveys		
Channel clearance/acceptance		
Project condition surveys		
Maintenance Dredging (soft sand/silt bottom)	0.3 ft	±0.8 ft
New Work or Rock Cuts [4]	0.2 ft	±0.8 ft
Coastal Shallow Draft Projects (d<15 ft)	0.3 ft	±0.8 ft
Inland Navigation Projects (d<15 ft)	0.3 ft	±0.5 ft

NOTES:
1. These standards are recommended "target" tolerances that may be specified for the various navigation projects listed. They are primarily applicable to dredging measurement and payment surveys where Performance Tests are conducted. They are representative of "typical" or "average" USACE navigation projects, and should be modified to meet specific project conditions and survey capabilities; as such, they are not mandatory standards. Refer to the discussions and definitions in this chapter and in Appendix D.
2. Refer to Chapters 4 and 6 for performance testing procedures and survey bias assessment.
3. Standard Deviations are usually derived from Performance Tests. In certain cases, these standards may be considered nearly equivalent to Total Vertical Uncertainty; and, as such, they are an IHO "Special Order" standard.
4. These recommended tolerances may be difficult to meet on some single-beam system cross-line Performance Tests if an insufficient number of comparison points are tested.

If no Performance Test was conducted on a specific dredging project, then the drawing (metadata file) should note whether these target standards were likely met based on historical (long-term) repeated Performance Test capabilities of the vessel/system. Alternatively, for any dredging or project condition survey, an estimated TPU (or IHO Standard) may be noted.

Accuracy, QC, and QA performance criteria for coastal engineering and other civil works water control projects are found in their respective chapters.

3-6. Horizontal Accuracy Standards. Specifying that a hydrographic survey depth measurement meet some required horizontal accuracy standard is difficult in practice. The horizontal positioning uncertainty of a measured depth is a function of various factors, primarily the GPS positioning method (code DGPS or carrier RTK), multibeam outer beam array limits, acoustic footprint size, and vessel motion compensation employed. No specific Performance Test type procedure exists to quantify the resultant horizontal accuracy of a depth observation—positional uncertainties are buried within the error budget of the depth results in a traditional Performance Test, and any standards based on that test. Thus, horizontal accuracies can only be roughly estimated using TPU techniques described in Appendix D.

a. Reporting depth horizontal accuracy. Drawings and metadata files should indicate the positioning method used on the survey, including the estimated accuracy of that system (which may not necessarily be the horizontal accuracy of the propagated depth on the bottom). For survey drawings furnished to the public, or other federal agencies, estimated horizontal accuracies of depth measurements may be noted as meeting one of the IHO "Total Horizontal Uncertainty" (THU) standards. This untested estimate can be based on the type of project (e.g., IHO Special Order or Order 1a—a 2 m standard), the positioning system used, and outer beam footprint size on a multibeam system.

b. Topographic feature accuracy. Horizontal accuracy standards for topographic features near navigation or other civil works structures are specified in EM 1110-2-1005, Topographic Surveying. Topographic and planimetric features shown on USACE navigation drawings or charts should be located to accuracies consistent with the project drawings. Feature positional accuracies are estimated and reported at the 95% RMS level. Fixed planimetric features include dredging limits, rights-of-way, harbor lines, bulkheads, piers, etc. Fixed navigation aids are lighthouses, ranges, beacons, daymarks, etc. In general, code-phase DGPS accuracy is sufficient for positioning fixed navigational features; however, it is not applicable to design or construction of marine facilities or structures. Contract plans for such facilities should require conventional topographic mapping accuracies.

3-7. IHO Standards for Hydrographic Surveys. IHO hydrographic survey accuracy standards (IHO 2008) were developed specifically for nautical charting purposes. They do not necessarily apply to the engineering and construction (dredging) survey standards in this manual. IHO standards may be specified for (and reported on) coastal project condition survey drawings of federal navigation projects that are furnished to NOAA and the general public. IHO standards are based on TPU estimates, which, as noted above, may be difficult to test or substantiate.

a. IHO Special Order (areas where under-keel clearance is critical) and Order 1a (areas shallower than 100 meters where under-keel clearance is less critical but features of concern to surface shipping may exist) are most applicable to USACE surveys of shallow-draft and deep-draft navigation projects. Most USACE surveys of federal navigation projects fall within the IHO Special Order standard.

b. If an IHO standard is noted on a USACE drawing, then it should clearly indicate that a survey was performed to meet a particular IHO accuracy standard and that this was not proven by testing.

c. IHO standards have other Orders and specifications that may be of use in some USACE survey specifications for non-navigation projects. These other IHO Orders include specifications for total vertical uncertainty (TVU), total horizontal uncertainty (THU), bottom coverage (line spacing) requirements, and object detection requirements. IHO standards may also be referenced for surveys of deep-water disposal sites.

d. A complete copy of the current IHO S-44 Standard is at Appendix E.