FIRST DRAFT: 01 FEBRUARY 08
THIS DRAFT DOCUMENT PROPOSES CHANGES TO CURRENT CORPS PRACTICES AND STANDARDS BASED ON S&M-COP/DCA AND NAD/MUG CONFERENCES.
AN INDEPENDENT TECHNICAL REVIEW BY ERDC (CHL/TEC), NOAA, CORPS FOA, AND THE DCA IS RECOMMENDED. SOME OF THE MORE SIGNIFICANT ITEMS REQUIRING REVIEW & RECOMMENDED CHANGES ARE HIGHLIGHTED WITH COMMENTS.

DEPARTMENT OF THE ARMY EC 1130-2-XXXX
US Army Corps of Engineers
CECW-CO **Washington, DC 20314-1000**

Circular
No. 1130-2-XXXX 1 July 2008

Expires: 30 June 2010
Project Operations
ASSESSMENT AND REPORTING OF ACOUSTIC CLEARANCE SURVEYS IN DEEP-DRAFT NAVIGATION PROJECTS

1. Purpose. This circular establishes new Corps of Engineers policies and reporting procedures for the probabilistic uncertainty analysis of depths derived from acoustic surveys in deep-draft navigation projects. Its primary purpose is to formally document agreements with the dredging industry to standardize clearance evaluation tolerances and methods, and to provide consistent and equitable payment procedures for contracted construction based on unit price/in-place measurement surveys. This circular provides new channel depth clearance reporting criteria that contain risk-based statistical probabilities and uncertainties that are consistent and compatible with DOD, federal, and international standards for assessing depth measurement uncertainties in navigation projects. In addition, and most critically, it implements a standardized Corps policy for consistently communicating channel clearance risk and reliability to the public. This circular also provides updated policy and technical guidance to cover the expanding use of high-density, multibeam acoustic survey systems and real-time-kinematic (RTK) technology for the direct measurement of water surface elevations relative to the GPS-based National Spatial Reference System (NSRS) ellipsoid. This circular updates, supplements, and supersedes portions of ER 1130-2-520 and EM 1110-2-1003.

2. Applicability. This circular applies to all USACE commands having responsibility for the planning, engineering, design, construction, operation, and maintenance of deep-draft navigation projects. This circular does not apply to inland or intracoastal waterways, or coastal shallow-draft projects less than 15 feet in depth. This circular applies to government, Architect-Engineer, and contracted construction forces performing clearance surveys and shall be included by reference in all dredging contracts. Procedural and technical guidance in this circular is mandatory.

3. References.

a. ER 1130-2-520, Navigation and Dredging Operations and Maintenance Policies.
b. EM 1110-2-1003, Hydrographic Surveying.
c. EM 1110-2-1613, Hydraulic Design of Deep-Draft Navigation Projects.
d. EM 1110-2-1619, Risk-Based Analysis for Flood Damage Reduction Studies.
e. EP 1130-2-520, Navigation and Dredging Operations and Maintenance Guidance and Procedures.
f. EC 1110-2-6065, Comprehensive Evaluation of Project Datums: Guidance for a Comprehensive Evaluation of Vertical Datums on Flood Control, Shore Protection, Hurricane Protection, and Navigation Projects.

g. FAR 52.236-16, "Quantity Surveys," Federal Acquisition Regulation, April 1984.

h. FGDC-STD-007.3-1998, "Geospatial Positioning Accuracy Standards, PART 3: National Standard for Spatial Data Accuracy," Federal Geographic Data Committee (FGDC), 1998.

i. IHO 1998, "International Hydrographic Survey Standards," Special Publication S-44, International Hydrographic Organization, Monaco, 14th Edition, April 1998.

j. IHO 2005, "Manual on Hydrography," Publication M-13, International Hydrographic Organization, Monaco, 1st Edition, May 2005.

k. NIST 1994, "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," NIST Technical Note 1297, National Institute of Standards and Technology, 1994.

l. NAVOCEANO/Hare 2001, "Error Budget Analysis for US Naval Oceanographic Office (NAVOCEANO) Hydrographic Survey Systems: Final Report for Task 2, FY 01," Hare, R., University of Southern Mississippi, Hydrographic Science Research Center, September 2001.

4. Distribution. This circular is approved for public release; distribution is unlimited.

5. Expiration and Rescission. This circular shall expire on the above date or when applicable policy portions are incorporated into ER 1130-2-520 and technical guidance from Appendix A is incorporated into EM 1110-2-1003, whichever is later.

6. Policy. It is the policy of the Corps of Engineers that:

a. Survey tolerance. Dredged channel depths, and related channel clearances, shall be assessed, evaluated, and reported at tolerances commensurate with the estimated uncertainties of the survey measurements, fully considering all global and local random/systematic variables involved in arriving at the total propagated error (TPE) in acoustically measured elevations or depths. All dredging contract specifications shall clearly indicate the survey tolerance that will be used in clearance and acceptance assessment.

b. Reported depth data. Depth or channel clearance plan drawings or reports provided to outside users, project sponsors, pilots, and other interests, shall be rounded to a representative significant figure level and contain clearly noted statistical confidence estimates of the data reliability based on the estimated survey tolerance applicable to the project. An uncertainty or risk-based assessment of a navigation project's expected performance is comparable to reliability assessments developed for flood control projects—see EM 1110-2-1619.

c. Development of contract specifications. Contract specifications for in-place measurement and payment surveys shall be structured to fit specific project conditions based on the estimated uncertainty tolerances in the acoustic measurement process. During the preconstruction engineering and design (PED) phase, these survey uncertainty/tolerance estimates shall be developed and documented by an engineer or surveyor assigned to the project delivery team (PDT) who is fully knowledgeable of the propagated errors inherent in the acoustic measurement system, tidal hydrodynamic model, horizontal positioning system, water column velocity and density variations, and subsurface conditions existing at the project site. This individual shall also be included on pre-construction meetings and subsequent meetings involving contract clearance or payment disputes. A PED specification development checklist for contract measurement and payment is attached at Appendix B.

d. Survey tolerance overdepth grade—new work deepening projects. In new deepening work involving hard bottom material (rock, hard clays, or highly consolidated/cemented materials), an additional "survey tolerance overdepth grade" template shall be specified below the required grade to assure that all material is removed from the required prism (Project Depth). This overdepth grade shall be based on the computed/propagated measurement uncertainty at the project site. Full-coverage multibeam or multi-transducer sweep systems are required on deepening projects involving hard bottom materials.

e. Survey tolerance on maintenance dredging projects In maintenance dredging of soft, non-consolidated material, a survey uncertainty tolerance window shall be developed about the required prism, within which dredged clearance will be deemed acceptable. This survey tolerance window shall be based on the computed/propagated measurement uncertainty at the project site. Depending on material or shoaling irregularities, either single-beam or multibeam survey systems may be specified on maintenance dredging projects.

f. Standardized quantity computation procedures. Estimated construction quantities and contract payment quantity computation methods shall be standardized using the Contour Dredging surface-to surface modeling procedures developed by the North Atlantic Division, as described in this circular.

g. Contract specification reference. This circular, and its subsequent derivative regulation, shall be incorporated by reference in all contract specifications involving in-place dredging measurement and payment. The policies and related technical guidance in this circular, and referenced engineering manuals, applies equally to government or contractor performed surveys (FAR 52.236-16).

h. Existing technical guidance. Survey procedures shall follow the technical guidance and calibration standards in EM 1110-2-1003, which supplements this circular. This circular updates and supersedes portions of the guidance in ER 1130-2-520, EM 1110-2-1003, and EP 1130-2-520, and supplements EM 1110-2-1613.

7. Survey Tolerances on Dredging Measurement and Payment Projects. The design or required dredging template shall be modified to account for a survey tolerance or confidence allowance. The survey tolerance is defined as the estimated repeatability or reproducibility of the statistical average of multiple acoustic measurements made over a finite area or cell, and at a specific project site using the same or different measurement systems. It is roughly equivalent to a statistical "confidence level" of the mean deviation when multiple depths with large uncertainties (TPE) are averaged within a finite sample (cell) area. The survey tolerance is dependent on (1) a statistical analysis of the total propagated error (TPE) of individual depth measurements made by the acoustic measurement system along with estimated hydrodynamic, meteorological, and environmental conditions occurring at a specific project site, and (2) the typical number of depths averaged or evaluated in a particular region or cell. Given the statistical complexity involved in determining (1) and (2)—see NAVOCEANO/Hare 2001 and IHO 2005—practical engineering judgment necessitates that an estimated "average survey tolerance" be assigned to a specific condition survey or dredge measurement and payment survey of a navigation project.

a. Required survey tolerance and allowable overdepth allowance. An estimated survey tolerance shall be determined for each specific navigation project and/or dredging contract and shall be specified in the contract. The allowable overdepth allowance shall not be reduced to compensate for the estimated survey tolerance. Technical guidance for estimating the survey tolerance for a project is at Appendix A.

b. Survey tolerance grades in new work deepening projects. A dredging grade below the required depth prism shall be specified based on the estimated survey tolerance, as shown in Figure 1 below. The overdepth allowance is measured relative to the survey tolerance grade. Payment for quantity of material removed will be measured relative to the required depth prism along with contract specified allowances down to the overdepth prism. Material falling between the required depth and survey tolerance overdepth grade need not be removed. Estimated quantities in the contract shall be based on the survey tolerance overdepth and allowable overdepth grades.

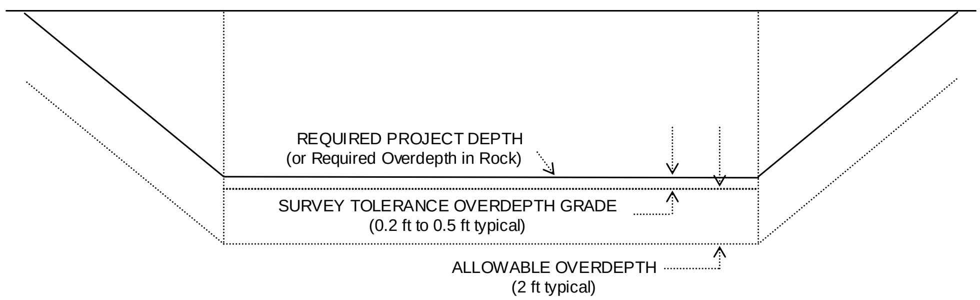

Figure 1. Survey tolerance overdepth grade in hard bottom projects (rock, dense clay, or manmade materials)

c. Survey tolerances in maintenance dredging projects. A survey uncertainty tolerance about the required prism shall be specified, as shown in Figure 2 below. The overdepth allowance is measured relative to the required depth grade. Payment for quantity of material removed will be relative to the required depth prism along with contract specified allowances down to the overdepth prism. Material falling within the survey uncertainty tolerance window need not be removed. Estimated quantities in the contract shall be based on the required depth and allowable overdepth grades.

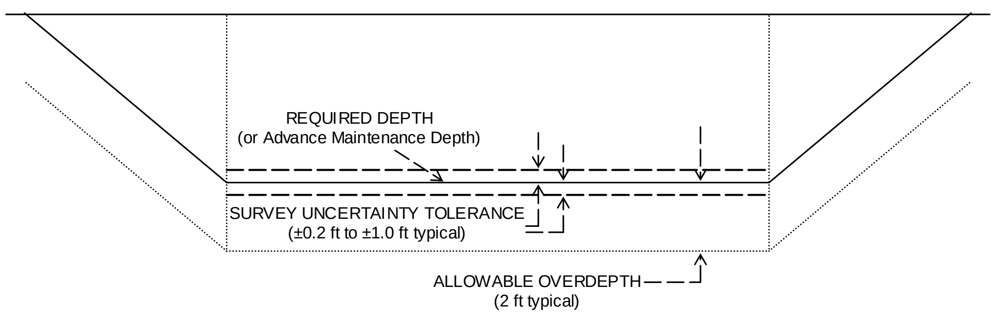

Figure 2. Survey uncertainty tolerances in soft bottom maintenance dredging projects

d. Minimum survey tolerance. The minimum survey tolerance on deep-draft navigation projects shall not be less than ±0.2 ft. This minimum tolerance would be applicable only on projects where the water surface elevation can be accurately modeled relative to the reference gage (e.g., visual proximity to a tidal gage or RTK surface elevation measurement), water column velocities are consistent throughout the project, and no unconsolidated sediments or acoustic reflectivity issues are present.

e. Tolerances on Project Condition and other surveys. The above survey tolerance criteria are applicable to all surveys performed over a navigation project, regardless of the intended engineering, operations, or maintenance purpose (e.g., feasibility studies, reconnaissance surveys, project condition surveys, contract plans and specifications (bid) surveys).

8. USACE Standards and Specifications for Acoustic Surveys. The following standards apply to all surveys of deep-draft navigation projects. They shall be included in all contract measurement and payment specifications, either directly or by reference.

a Cell size. The grid cell size used for assessing depth clearances shall be exactly 3 ft x 3 ft in hard material and 5 ft x 5 ft in soft material. The cell size on single-beam or multi-transducer systems shall be a linear/rectangular cell of estimated footprint width by velocity (ft/sec) x 1-sec length.

b. Representative depth selection procedure. Representative depths collected on single-beam, multi-transducer, or multibeam acoustic surveys, and used for clearance assessment and/or dredged quantity take-offs, shall be computed based on the average of all edited depths collected in a defined cell. Alternatively, the median depth in a cell sample may be selected as the representative depth.

c. Acoustic frequency standard. The standard acoustic frequency shall be 200 kHz (± 10%). This frequency best represents a consistent and recognized standard for the acoustic return from rock and semi-consolidated soft sediment materials found on most projects. Deviations from this standard (e.g., use of lower frequencies in unconsolidated or unconfined sediments) shall be clearly defined in the contract specifications. Single-beam system transducers shall have narrow beam widths not exceeding 6° (-3dB) and shall be internally calibrated such that the recorded depth represents a fixed 60% (±10%) of the maximum return echo voltage available for a saturated echo—see Appendix A and IHO 2005.

d. Bar-Plate calibration. The "bar-check" remains the standard calibration method for all acoustic systems. Irrespective of known uncertainties in the bar-check calibration process itself, it remains the USACE "gold standard" by which channel clearance and payment is ultimately established. Single-beam, multi-transducer, and multibeam depth sensors shall be calibrated by plate bars placed as close as possible to the project depth such that the signal threshold processing of the acoustic return from the calibration plate best matches (or correlates with) the acoustic return from the channel bottom without subsequent adjustment for gain, sensitivity, or intensity variations.

e. Vessel motion filtering. Vessel motion (roll, pitch, yaw, and heave) relative to the water surface shall be minimized using GPS carrier phase and/or inertial motion unit (IMU) filtering techniques.

f. Performance Tests. Performance tests shall be performed on dredging measurement and payment surveys. Performance tests are indirect methods of verifying the stability, repeatability, and reproducibility of a particular survey system—see EM 1110-2-1003. Multibeam system array confidence shall be tested and evaluated against reference surfaces that are derived from narrow-beam, motion-stabilized, single-beam systems—reference the technical guidance in EM 1110-2-1003.

g. Frequency of calibration and performance testing. There is no definitive standard for the periodic calibration of acoustic survey systems—engineering judgment is required based on the documented past performance of the survey system, the required project tolerance, potential contract clearance disputes, etc. On critical clearance surveys over hard materials, frequent (i.e., daily) calibration and performance testing would be warranted.

9. Channel Clearance and Acceptance Procedures. Government channel clearance surveys shall be expeditiously performed and processed, such that a preliminary evaluation of acceptable or unacceptable clearance can be made within 24 hours after completion of the survey. In new work or deepening projects in hard material, authoritative government and contractor representatives shall be present during clearance surveys so that potential strikes or shoals above grade can be immediately assessed and/or resurveyed for either confirmation or acceptable clearance, fully considering the survey

Comment [WAB1]: WAB: These arbitrary cell size standards were developed in 2004 by agreement of the North Atlantic Division & Corps Multibeam Users Group and incorporated in EM 1110-2-1003. A single-beam standard is proposed.

Comment [WAB2]: Verify this standard is technically correct and applicable to all single-beam systems (Ross, Odom, Innerspace, Knuedson) tolerances in the preceding paragraph. In such cases, near-real-time data processing shall be performed at the site so that additional verification surveys can be immediately performed over questionable areas.

a. Strike verification (new work or rock). When multiple adjacent/contiguous cells on a single acoustic multibeam survey sweep over an area contain averaged depths above the required grade shown in Figure 1, then a confirmed strike above the required grade may be inferred and additional dredging clearance may be indicated. When an isolated cell indicates an averaged depth above the required grade, further confirmation shall be made to verify the strike by making at least two (2) additional “dead slow” separate survey passes [sweeps] over the suspected strike area in order to accumulate a statistically significant number of depths from which to evaluate the confidence of the average representative depth.

b. Shoal verification (maintenance dredging/soft bottom material). When multiple adjacent/contiguous cells on a single acoustic survey (single-beam or multibeam) over an area contain averaged depths outside (i.e., above) the survey tolerance limit shown in Figure 2, then a confirmed shoal above grade may be inferred and additional dredging clearance may be indicated. When an isolated cell indicates an average depth above grade, further confirmation shall be made to verify the shoal by making at least two (2) additional “dead slow” separate survey passes over the suspected shoal area in order to accumulate a statistically significant number of depths from which to evaluate the confidence of the average representative depth.

c. Minimum number of depths in a cell for assessing clearance. A minimum of 10 depths shall be required to be considered statistically significant to fall within the resolution confidence (or survey tolerance) of the averaged representative depth in the cell—i.e., when the confidence of the mean of the depths in a cell approaches the estimated survey tolerance.

d. Evaluation of individual recorded depths. In no case shall shoal or strike detection and/or channel clearance assessment be based on a single recorded depth measurement; in particular, the "minimum" or "shoal-biased" depth in an area or cell shall never be used (see EM 1110-2-1003). Clearance depths shall be assessed considering the TPE and confidence tolerance of all the measurements in a cluster or cell.

e. Combined Uncertainty and Bathymetry Estimator (CUBE). Statistical hypothesis testing algorithms such as CUBE (Calder and Mayer 2003, NOAA 2005) have been developed to search for and assist in evaluating the potential existence of strikes or shoals above grade. CUBE is especially useful in locating multiple depth clusters in a defined region (node or cell) that may indicate isolated strikes above grade but are masked by an average or median depth. CUBE also develops a most probable representative depth (or multiple hypothetical strike depths) at each nodal location, along with an estimate of its statistical uncertainty. If such algorithms are used in lieu of the above averaged cell depth assessment procedures, then the contract specifications shall fully describe the detection and rejection procedures applicable to dredge measurement. CUBE is recommended as a detection tool on critical projects involving rock near the project grade.

f. Dispute resolution procedures. In the event that repeatable (and unaccountable) biases exist between government and contractor surveys that exceed the allowable survey tolerances specified in the contract, and both survey systems are functionally equivalent and procedurally performed in technical compliance with this circular and EM 1110-2-1003, then the government survey shall be presumed as the payment/clearance standard.

10. Policy on the Use of Multibeam Survey Systems on Maintenance Dredging Projects. Full bottom acoustic coverage (i.e., multibeam or multi-transducer sweeps) is only required on surveys involving newly authorized navigation projects containing hard bottom material, such as rock, compacted clays, or other highly compacted material. Full-bottom acoustic coverage may be specified on

Comment [WAB3]: Need to come up with reasonable and statistically significant number of depths per cell—without getting bogged down in statistical sampling noise, t-distributions, etc. One simple standard needed. Not easy, many variables. "Previous "3-depths hit" rule is obviously too low ... 30 is probably too high. "10" may or may not be the right number.

Comment [WAB4]: WAB ... what exactly is it? average, median, mode, ?

Comment [s5]: WAB: may need some caveat in that CUBE was developed for nautical charting applications ... not dredge clearance assessment. A "DREDGECUBE" development is recommended for future work.

maintenance dredging of existing navigation projects where low under-keel clearances are anticipated over potentially hazardous bottom conditions, hazardous cargo is transported, or where bottom sediment could adversely impact naval vessels transiting a project. Other special maintenance dredging cases may include highly varying topography, historical small isolated shoaling areas falling between the nominal section stationing interval, suspected debris, or in environmentally sensitive areas.

a. Contract specifications. Dredging contract specifications shall clearly indicate the specific survey requirement for full-bottom acoustic sweep coverage for assessing clearance and measuring payment on maintenance dredging projects in soft materials.

b Justification. Justification for use of full-bottom acoustic coverage on maintenance dredging projects shall be documented in the project file.

11. Policy on Determining Payment Grades in Suspended Sediments or Unconsolidated Materials. Detailed contract payment procedures shall be developed during the PED phase and shall be included in the contract specifications when known issues with unconsolidated or suspended sediments exist at a project. At minimum, the contract specifications shall include the acoustic frequency and/or alternative mechanical or density measurement method. Reference the technical guidance in Chapter 11 (Depth Measurement over Irregular or Unconsolidated Bottoms) of EM 1110-2-1003.

12. Reporting Channel Condition and Clearance Grade Tolerances—Significant Figures. Depths shown on final as-built drawings, channel condition reports, and other related documents furnished to federal agencies, pilots, project sponsors, and other interests, shall be rounded to the significant figures based on the computed survey tolerances, as indicated in Table 1 below. Depths shall be rounded using standard engineering rounding convention.

Table 1. Required Rounding Criteria for Depths and Channel Clearances Furnished to the Public

Estimated Survey Tolerance	Round Depths to Nearest	Examples
±0.2 ft to ±0.5 ft	half (0.5) foot	39.7 rounds to 39.5 39.8 rounds to 40.0 40.2 rounds to 40.0 40.3 rounds to 40.5
Greater than ±0.5 ft	Even foot	39.4 rounds to 39 39.5 rounds to 40 40.5 rounds to 40 40.6 rounds to 41

a. Internal database resolution. Acoustically measured depths, and internal corrections thereto, shall be edited, corrected, and processed in the internal database maintaining a 0.1 ft resolution. Thus, the above table does not apply to working survey datasets or drawings involving contracted construction measurement and payment. These interim construction documents/databases will retain the nearest 0.1-foot resolution and will not be released to the public.

b. Contract plans. Dredging contract plans and estimated dredging overdepth contour limits shall be based on the plotted channel shoaling conditions represented by the rounded depths in Table 1. Actual estimated quantities shown in the contract plans (and Contour Dredging limits) shall be based on the dense dataset maintained at the 0.1-foot level.

Comment [s6]: WAB: *... too tough to develop any firm policy on this topic ... no one has in the last 40 years ... perhaps CHL/Tim Welp has written up more definitive technical guidance on this topic based on his recent research?]*

Comment [WAB7]: WAB: The NOAA "7/10" rounding convention is not recommended since this arbitrary method has no statistical basis for biasing the data, inconsistent with CUBE, etc.

13. Required Accuracy Statement on Published Plans, Studies, and Channel Condition Reports. All released plans, reports, studies, databases, and related documents containing channel depth or clearance data shall contain a statement (note) attesting to the estimated accuracy (confidence) of the geospatial data. Since hydrographic survey data are rarely, if ever, tested against a higher accuracy source, this statement shall indicate that the accuracy is estimated. This statement should also indicate that the depth or clearance confidence estimate is relative to a local reference benchmark/gage and not all global variables and biases have been accounted for in the confidence estimate. Federal requirements for this statement are contained in FGDC-STD-007.3-1998, along with sample formats. Additional details are at Appendix A.

14. Selection of Controlling Depths for Channel Condition Reports. The controlling depth selected to represent an entire channel reach/quarter shall be determined by searching for the shoalest average/median/node representative depth that occurs in all the cells or digital terrain model covering that defined reach. In no case shall the raw "minimum" depth of all observed depths be used. Reported controlling depths shall be rounded to their significant uncertainty level in accordance with paragraph 11 above and a confidence statement shall be included on all channel condition reports (ENG FORM 4020-R/4021-R) issued to other federal agencies and the public.

15. Requirements for Carrier-Phase GPS Water Surface Elevation Measurement. RTK position and elevation control shall be specified on all projects involving critical underkeel clearances (e.g., new work deepening in rock). On maintenance dredging projects, when systematic biases due to tidal phase latencies (or river flowline slope) between the reference gage and project site approach or exceed 0.5 ft, water surface elevations shall be measured using RTK methods. Either single base or virtual networked RTK solutions may be used. In project areas beyond the range of standard or networked GPS baseline solutions and/or telecommunication operability, the contract specifications shall detail the method for measuring and compensating for tidal phase latencies.

a. Tidal datum updates. Tidal datums on Corps coastal navigation projects shall be referenced to tidal gages, tidal benchmarks, and the latest tidal epochs established by the US Department of Commerce (NOAA). Reference the guidance in EC 1110-2-6065.

b. Reference benchmarks. Contract specifications shall clearly describe the permanent benchmarks (PBM) from which the defining project grade is referenced. The NOAA NSRS and/or tide station identifier for this PBM shall be clearly indicated in the contract specifications.

16. Corps-wide Standard for Dredging Payment Quantity Computations. All USACE dredged payment determination within the channel prism and side slopes shall be delineated and computed using "Contour Dredging" procedures and surface-to-surface payment modeling methods developed and implemented by the North Atlantic Division (Philadelphia District). This standard employs three-dimensional (3D) digital terrain models and triangulated irregular network (TIN) methods to link and difference all representative depths of triangulated cell elements between the actual dredged surface (Post-Dredge survey) and the original Pre-Dredge surface, or between the Pre-Bid survey and the Required and Overdepth prisms for estimated contract quantities. This standard represents the most accurate, equitable, and consistent contract payment method. These standardized payment methods shall apply to either single-beam cross-section coverage or full coverage multibeam surveys and shall be used on new work or maintenance dredging. Technical details on this standard are at Appendix A.

17. Response Times for Dissemination of Survey Data. On contracted construction surveys, data shall be provided to the construction contractor within the time frames indicated in Table 2 below.

Recommended response guidance for mobilizing survey forces to the project site, and alternate options, are outlined in EP 1130-2-520, and should be reiterated in the contract specifications.

Table 2. Required Response Times for Disseminating Survey Data on Contracted Construction

Comment [WAB8]: WAB: Need field/DCA review consensus on these time standards

	Delivery after Completion of Survey		
Survey	Raw, unedited unprocessed dataset	Preliminary edited and processed dataset (field processed)	Final reviewed dataset, plots, and/or pay quantities
Before (Pre) Dredge (Pay)	24 hours	48 hours	30 days
Intermediate Progress Payment Surveys (contractor performed)	n/a	n/a	per contract specs (30 days typical)
Acceptance Section Clearance	real-time assessment on board survey vessel	< 24 hours	N/A
Final Post-Dredge As-Built (Pay)	24 hours	48 hours	30 days

18. PDT Design Checklist for Measurement and Payment Clause in Dredging Contracts. Appendix B contains a design checklist that shall be used in developing the survey specifications in dredging contracts.

19. Proponency and Waivers. Technical development of this circular was coordinated by the Engineer Research and Development Center (ERDC), Topographic Engineering Center. The circular was reviewed by both USACE field activities and representatives in the dredging industry. The HQUSACE proponent for this circular is the Operations and Regulatory Community of Practice, Directorate of Civil Works. Comments, recommended changes, or waivers to this circular should be forwarded through MSC to HQUSACE (ATTN: CECW-CO).

FOR THE COMMANDER:

~~YVONNE J. PRETTYMAN-BECK~~
~~Chief of Staff~~ DCW/O&R COP ?

2 Appendices
1. Appendix A: Supplemental Technical Guidance for Estimating Acoustic Survey Measurement Tolerances
2. Appendix B: Project Delivery Team Design Checklist for Dredge Measurement & Payment Contract Clauses

APPENDIX A
Supplemental Technical Guidance for Estimating Acoustic Survey Measurement Tolerances

The following technical guidance supplements the policy in this circular. It contains updated technical information and references that is not found in current USACE guidance publications. Applicable portions of this guidance will be incorporated into the next update of EM 1110-2-1003 or other guidance documents.

Comment [WAB9]: WAB: This appendix is a rough draft--requires thorough technical review and considerable editing.

A-1. Background and Discussion

The increasing use of multibeam survey systems on dredging measurement and payment surveys over the past five years has resulted in a need to evaluate the quality and confidence of data being obtained and reported, in particular, during construction clearance assessment. Previous technical guidance for clearance assessment in EM 1110-2-1003 is largely based on single beam technology. The evolving multibeam measurements require a more probabilistic approach that considers the inherent uncertainties in the data along with risk and reliability reporting issues. This reliability analysis applies to single-beam surveys as well. Calder and Hare 2003 point out the added complexity of analyzing and processing multibeam data:

> "While our ability to gather bigger and denser data sets has increased dramatically, our ability to process and make sense of these data sets has not. Unlike single beam sonar data sets, the complex geometry and sensor integration associated with multibeam sonars leads to demanding processing requirements."

Other federal and international hydrographic survey agencies (e.g., USNAVOCEANO and NOAA) are developing standards and procedures that deal with the uncertainties of echo-sounding data. This is illustrated by the following excerpt from NOAA's contract specifications (NOS 2007):

> "The Navigation Surface requires that each sounding have a horizontal and vertical uncertainty. To do this effectively, an error model is needed for all systems supplying measurements to compute the sounding; including not only the multibeam echo-sounder, but the GPS sensors, the heave, pitch, and roll sensors, the sound speed measuring devices, tide gauges, draft measurements, dynamic draft, or anything else that contributes to the calculation of a sounding. Once this comprehensive error model is assembled, then all the inherent errors in each measurement can be propagated from the measurement platform to each individual sounding. Only when each sounding has an associated Total Propagated Error (TPE), can we combine the soundings into a Navigation Surface with each node having a depth and uncertainty attribute."

Current USACE regulations and design guidance documents are largely silent on the magnitude of acoustic survey uncertainties. Much of this guidance was developed based on the accuracies associated with older lead line or topographic survey techniques in shallow draft projects. Neither ER 1110-2-1414 nor EM 1110-2-1613 prescribes an allowance for acoustic survey uncertainty or TPE in developing the underkeel clearance allowance for a deep-draft navigation channel—see Figure A-1 below. The gross underkeel clearance allowances developed during the planning phase—typically 1 to 3 feet below the design vessel—are not considered as a "tolerance" when dredging to a required depth prism, nor is this underkeel clearance allowance rigidly maintained by transiting vessels that load close to the authorized depth rather than the design channel depth. In effect, the reported controlling depths from Corps project condition or dredge clearance surveys are assumed as absolute with no tolerance or confidence attribution.

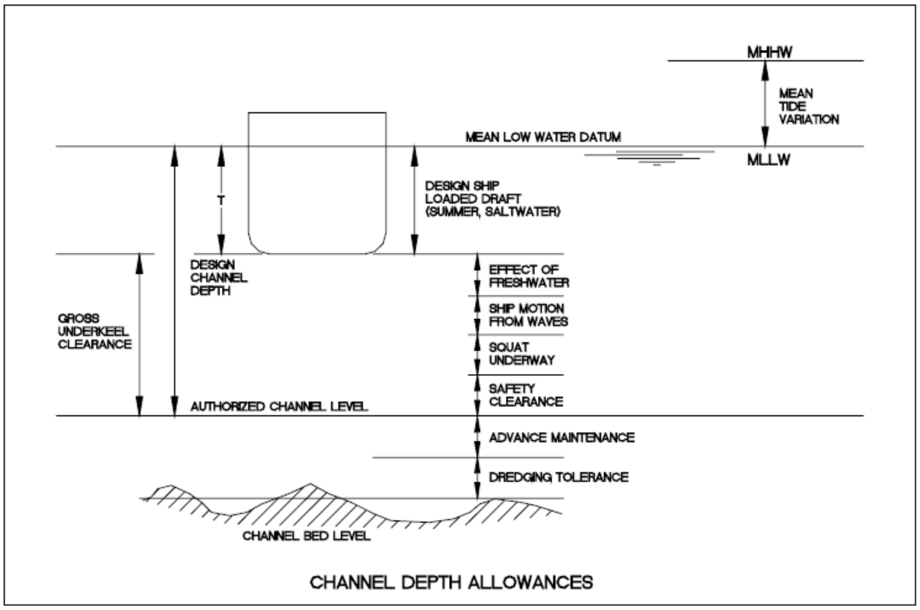

Figure A-1. Channel design depth allowances in deep-draft navigation projects
(From Figure 6-17 EM 1110-2-1613, Hydraulic Design of Deep-Draft Navigation Projects)

ER 1130-2-520 does provide discretion to the Contracting Officer to release the contractor from removing material above the required prism if "...deviations from the maintained dimensions can be attributed to the *inaccuracies* in the surveying measurement process, material characteristics, extreme weather conditions, or when the government is at fault." EP 1130-2-520 states that:

> "...Sweep surveys shall be performed as necessary to locate underwater obstructions within the navigation channel limits or when dredging is performed in hard material (e.g., dense clays, rock, or manmade materials). Equipment capable of detecting obstructions will be used to ensure that the project is clear for navigation. Mechanical sweeps may be used for all bottom conditions and shall consist of a drag capable of being moved for complete coverage of the dredged area. Acoustic sweep systems (multiple transducers on booms or interferometric, multi-beam swath/sweep transducer systems) may be used when appropriately designed to provide *accurate* and full coverage of bottom conditions."

Survey "*inaccuracies"* is not defined in either of the above documents. The following excerpts from ERDC/TN EEDP-04-37 2007 and USACE 2006 illustrates that uncertainties in the survey measurement process are essential in defining and designing various project grades:

> **a. Authorized Dimensions.** The authorized dimensions are the depth and width of the channel authorized by Congress to be constructed and maintained by the USACE. These authorized channel dimensions are generally based on maximizing net transportation savings considering the characteristics of vessels using the channel and include consideration of safety, physical conditions, and vessel operating characteristics. For entrance channels from the ocean into harbors, the authorized dimensions often include an additional allowance of safety for wave action for that portion of the channel crossing the ocean bar. For example, a 45-foot entrance channel may have an authorized 47-foot depth over the ocean bar.

b. Advance Maintenance. Advance maintenance is dredging to a specified depth and/or width beyond the authorized channel dimensions in critical and fast shoaling areas to avoid frequent re-dredging and ensure the reliability and least overall cost of operating and maintaining the project authorized dimensions. For maintenance dredging of existing projects, Major Subordinate Commanders (MSC) (Division Commanders) are authorized to approve advance maintenance based on written justification. For new navigation projects, advance maintenance is approved as part of the feasibility report review and approval process based on justification provided in the feasibility report.

c. Paid Allowable Overdepth. Paid allowable overdepth dredging (depth and/or width) is a construction design method for dredging that occurs outside the required authorized dimensions and advance maintenance (as applicable) prism to compensate for physical conditions and inaccuracies in the dredging process and allow for efficient dredging practices. The term "allowable" must be understood in the contracting context of what dredging quantities are eligible for payment, rather than in the regulatory context of what dredging quantities are reflected in environmental compliance documents and permits. Environmental documentation must reflect the total quantities likely to be dredged including authorized dimensions, advance maintenance, allowable overdepth, and non-pay dredging. The paid allowable overdepth should reflect a process that seeks to balance consideration of cost, minimizing environmental impact and dredging capability considering physical conditions, equipment, and material to be excavated. ER 1130-2-520 provides that District Commanders may authorize dredging of a maximum of two feet of allowable overdepth in coastal regions and in inland navigation channels. Paid allowable overdepth in excess of those allowances or the use of zero paid allowable overdepth requires the prior approval of the MSC Commander. The USACE recognizes that there may be circumstances where there is a need for increased excavation accuracy in the dredging process, for example in environmental dredging of contaminated material, which dictate trading potential increased costs for a reduction in paid allowable overdepth, i.e., reducing the quantity of material required for special handling/placement or treatment.

d. **Non-pay Dredging.** Non-pay dredging, also known as non-paid overdepth, is dredging outside the paid allowable overdepth that may and does occur due to such factors as unanticipated variation in substrate, incidental removal of submerged obstructions, or wind or wave conditions that reduce the operators' ability to control the excavation head. In environmental documentation, non-pay dredging is normally recognized as a contingency allowance on dredging quantities, and may and does occur in varying magnitude and locations during construction and maintenance of a project.

e. **Characterization Depth.** Regulatory compliance necessitates that material to be dredged be characterized and evaluated with regard to its suitability for the proposed placement of the material. Characterization and evaluation of dredged material must consider the entire dredging prism, including paid allowable overdepth and non-pay dredging.

f. Required Project Grade. This is the depth specified by the Corps for each dredging contract. Often it is the federally authorized depth, but in some cases can be less or more (for example when advance maintenance has been authorized). The dredging contractor (or the Corps when a government owned dredge is used), is required to have all of the channel sections defined in the contact at this depth.

Physical Environment Impacts on Hydrographic Surveying and Dredging Accuracy. Because hydrographic surveying is used to measure the depth to the bottom before and after dredging, the accuracy of the hydrographic survey is a critical component in determining characterization depth. In the relative calm of sheltered harbors, bays, and estuaries, typical hydrographic survey accuracies of +/- 0.5 ft are achievable for a majority of the soundings at a 95-percent statistical confidence level. As exposure to the elements increases, so can the motion of the hydrographic survey vessel, reducing the accuracy of the individual soundings. Additionally, the water surface's relationship to the dredge datum must be established and measured during times of surveying and dredging (USACE 2002). This is typically achieved by using a tide gage or Real Time Kinematic (RTK) methodology. Either selection requires accurate modeling to avoid height/time tide errors. For example, if the tide gage is a long distance from the dredging area, the water surface at the dredging site can be a different elevation from the tide gage, further reducing accuracy of the hydrographic survey. The dredge often relies on the same methodology for determining the depth of the excavation head, therefore reductions in accuracy that impact the hydrographic surveying will also impact dredging accuracy. Increased wave heights also impact the dredge, reducing accuracy as the increased hull motion is transmitted to the excavation head. Hopper dredges, which are designed to work in the open ocean, have heave compensators to reduce wave impacts, but accuracy is reduced as wave heights increase.

This leaves an assumed "accuracy" of these various grades, depths, and overdepths based on the display resolution of the depth data—in effect, this is often interpreted as an absolute depth measurement certainty at the ±0.05 foot level given the 0.1 ft plotted resolution (even 0.01 ft plotted depth resolution in some instances) typically portrayed on plans, documents, maps, or charts furnished to dredge contractors, port authorities, bar pilots, and other federal agencies. In reality, the absolute depth accuracy is typically closer to ±0.50 foot to ±1.0 foot (at the 95% confidence level). In addition, biased outlier data (i.e., "noise") is often misinterpreted to represent strikes above grade and requiring additional dredging, resulting in contract disputes and claims.

To rectify the above problems, an allowable depth confidence estimate or "survey tolerance" must be developed and applied during construction that includes estimates for the overall depth measurement model, which is made up of (1) functional or deterministic properties and (2) stochastic (nondeterministic) or probabilistic properties of the observational variables (Mikhail 1976 and Papoulis 1965). Statistical uncertainties in the depth measurement process that must be reviewed and evaluated during the PED phase shall include local system variables, (positional uncertainties, acoustic calibration precisions, vessel motion correction, acoustic depth resolution, sound velocity and outer beam refraction, etc.) and other systematic biases (tidal phase variations, draft variations, etc.) that may be present in the depth error budget—often referred to as "total propagated error" or TPE. The basic concepts behind the depth error budget or TPE are covered in Chapter 4 of EM 1110-2-1003 (single beam systems) and NAVOCEANO/Hare 2001 (multibeam and LIDAR survey systems).

A-2. Depth Measurement Uncertainty

No measured depth is without error. Unlike visual topographic survey measurements, acoustic depths are indirectly measured using various forms of time difference (amplitude detection) or phase difference (interferometric) measurements. These measurement methods contain varying magnitudes of signal/noise that must be resolved into a "best estimate" of the depth. This "best estimate" of a single resolved depth can have uncertainties ranging from ±0.2 ft to more than a foot in deep-draft navigation projects. The resolved depth typically represents the acoustic return over a relatively large area (footprint) on the bottom—the acoustic footprint often being larger than the grid cell size being assessed for clearance. The horizontal position of the depth's footprint on the bottom will also have uncertainties ranging from 2 to 10 feet. In addition, numerous corrections must be applied to the resolved depth to account for often significant variables in the measurement system or water column, each of which contains uncertainties, both random and systematic. The total propagated magnitude of all these errors is termed uncertainty—or "total propagated error."

a. Root Mean Square Error. The uncertainty of an individual depth measurement (or all the depths collected over an entire survey of a project) is usually represented by some statistical uncertainty measure, such as its estimated standard deviation. This uncertainty measure is obtained by combining the individual uncertainties arising from Type A (random) errors and/or a Type B (systematic) errors—see NIST 1994. This combined uncertainty of random and systematic variables may be estimated by traditional error propagation methods—from the "mean square error" (MSE), or its square root, the "root mean square" (RMS) error (Mikhail 1976). Thus estimates of systematic errors (i.e., biases) that commonly occur in a hydrographic depth measurement (e.g., water surface error, draft error, etc.) are practically treated as random in arriving at the MSE/RMS statistic for uncertainty.

b. Averaged Depth Accuracy Measures. The uncertainty of the resultant average of a series of depth measurements over a fixed area is usually represented by the estimated standard deviation of the resultant mean—i.e., the "standard deviation of the mean" or "confidence level." This statistical estimate of dispersion is applicable when multiple depths are grouped in a defined bin, cell, or DTM node, as is done on dredge clearance assessment surveys. The multiple depth measurements in a defined cell area may have been obtained from a single pass by a multibeam system or accumulated from different multibeam passes on different days—see example at Figure A-2. In this example, the 95% standard deviation of the 59 depths in the cell sample is ±0.8 ft. The 95% confidence of the representative 42.2 ft average depth may be estimated based on the standard deviation of the mean. Estimates of the uncertainty of the mean or average depth in the cell relates to the "survey tolerance" used in evaluating clearance.

A-4. Precision or Repeatability of a Depth Measurement Cell Samples

Precision is defined as the closeness of observations to their mean, and is directly related to the dispersion of a distribution (Mikhail 1976). Precision is the "repeatability" or closeness of agreement between the results of successive measurements carried out under the same conditions of measurement. These conditions include: the same measurement procedure, the same observer, the same measuring instrument used under the same conditions, the same location, and repetition over a short period of time. For dredging measurement and payment surveys of a specific navigation project, these conditions of measured repeatability would include: using the same vessel, survey system, calibration procedures, tide/water level measurement methods, and performed over a short environmental time interval. Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results—e.g., the "standard error of the mean" (NIST 1994). When multiple depths are observed over the same area (e.g., a cell), the repeatability of these depth observations may be statistically estimated by computing the standard deviation of their meaned value, considering the estimated uncertainty of each individual depth. This is often expressed as a "confidence."

A-5. Reproducibility of Depth Measurements in a Cell Sample

Reproducibility is defined the closeness of the agreement between the results of measurements carried out under changed conditions of measurement (NIST 1994). For hydrographic surveys, changed conditions would involve depth measurements made over the same area (or cell) by different vessels, different measurement systems, different environmental conditions, different calibration methods, different acoustic frequencies, different tidal conditions, different times (e.g., days apart), etc. A measure of reproducibility is observed when two vessels survey the same area, a common occurrence on dredging contracts when the government and dredging contractor's survey vessels survey the same acceptance section. Both vessels have differing TPE estimates and differing precisions or repeatability over a given area or cell. Reproducibility may also be seen when the same vessel repeats a survey under differencing tidal and wind conditions and RTK is not used to compensate for these biases. Reproducibility is typically evidenced as a "bias" in the average depth over a given point/cell. All things being equal, the magnitude of any "reproducibility" biases should be within the allowable "survey tolerance" window.

A-6. Survey Tolerance or Confidence

"Survey Tolerance" is roughly defined as an approximation of the estimated reproducibility and repeatability of depth measurements in a sample. It is the ability to repeat or reproduce depth measurements over a given point, or actually the ability to repeat the average (or mean/median) of multiple sampled depths measured over a given area, such as a defined cell. The tolerance is determined given the estimated error budget (TPE) of the individual depths in the entire survey coupled with the deviation or dispersion of the depths within the specified area or cell. It may also be estimated based on the deviation of the meaned depths collected in that cell—i.e., their repeatability. It is analogous to a statistical confidence level, represented by the expected value of the confidence (i.e., tolerance) of the mean depth in a cell sample containing multiple depths.

a. Confidence level of a sample. For example, if 10 depths are collected within a 5 ft x 5 ft cell, and the standard deviation or estimated uncertainty (TPE) of all depths in the survey project (universe) is ±1.0 ft, then the estimated precision (or confidence) of the average of the 10 depths in the defined area may be roughly estimated from:

$$\sigma_x \approx \sigma / \sqrt{n} = \pm 1.0 / \sqrt{10} = \pm 0.3 \text{ ft}$$

where:

σ_x - standard deviation of the mean (approximate confidence)

σ - estimated uncertainty of the individual depths (TPE)
n - number of depths in cell sample

Depending on the number of depths in a cell, the confidence of the mean will be less than the estimated TPE of the individual depths. This is why repeated surveys (performed over different days, tide phases, or even with different vessels) over a suspected shoal or strike will generally "repeat" or "reproduce" each other to the 0.2 to 0.5 foot level when the average representative depth is evaluated, even though the dispersion (TPE) of the individual depths in the cell may be ±2.0 ft. As the number of depths in a cell increases, the more confidence in the mean is obtained. Although in theory the confidence level of the average depth in each cell should be evaluated (computed), such a procedure is currently not a practical engineering option—an estimated confidence (survey tolerance) based on an average measurement repeatability needs to be established for a given survey and project site.

b. Cell size. These is no statistical validation for the standard USACE 3x3 ft or 5x5 ft cell sizes, relative to the echo sounder footprint size, horizontal positioning accuracy, and numerous other factors entering into the TPE estimate. These standard cell sizes represent practical engineering practice so that consistent clearance and pay computation practices can be performed Corps-wide. In the future, more statistically relevant procedures may be developed to replace rigid cell definitions—e.g., a CUBE specifically tailored to dredge clearance assessment.

c. Number of sample depths in a sample The more depths that can be collected in a 3x3 ft or 5x5 ft cell, the more reliable is the precision/confidence statistic computed based on the average cell depth. In critical channels (rock or hard clay) the vessel speed should be set at dead slow over suspected strikes above grade, and multiple passes made over the strike using different aspects of the multibeam array. In this manner, 20 to over 100 depths may be collected within a 3x3 ft cell—over 30 typically being considered statistically significant, although lesser numbers will still have validity for strike assessment. In large samples, the average representative depth in the cell will have maximum validity for clearance assessment, or hypothesis testing if multiple depth levels appear—i.e., the "Combined Uncertainty and Bathymetry Estimator—CUBE," Calder and Mayer 2003. For practical engineering use, a fixed standard for the minimum number of depths in a cell is specified.

d. Average or median representative depth. When large samples are available in a defined cell, the difference between the statistical mean (average) depth and the median depth will be insignificant, and is not likely to bias over an entire project area. Thus, either value may be selected as the representative (and reported) depth for the cell. When an even number of depths result in the cell, the representative median depths must be computed as the average of the two depths closer to the median. Given the typical echo-sounder footprint size coupled with the horizontal positioning uncertainties, in small USACE cell sizes (3x3 ft or 5x5 ft) the horizontal location of the actual median depth should be ignored—use the cell center (centroid) at the location for the represented depth.

A-7. Computation of Survey Tolerance

Determining the uncertainty or TPE of individual depth measurements collected over a project survey is complex, and includes numerous variables based on the measurement system and environmental conditions (NAVOCEANO/Hare 2001). Likewise, determining the survey tolerance is also complex in that the precision of a group of depths measured over a given cell may be spatially variable, depending on the number of depths collected or the number of separate survey passes over the cell, the size of the defined cell relative to the acoustic footprint size, horizontal location errors, beam angle, among other factors.

a. It is impractical at present to apply TPE computations and estimated confidence precisions to individual cells when assessing clearances on dredging surveys—a practical engineering assessment must be derived. Thus, a constant "survey tolerance" (i.e., confidence) must be estimated for a specific navigation project, and that tolerance used for the entire survey or dredging contract. The survey tolerance may be estimated from past results, such as from deviations and biases in past Performance Tests. It may also be determined using generic ranges in typical project conditions. Options for estimating the survey tolerance are outlined in the following sections.

b. Since the most critical (and usually by far the largest) variable in the estimated survey tolerance is the water surface elevation uncertainty, the impact of river gradients and tidal phase lags must be realistically factored into its determination.

c. In cases of extremely soft or suspended sediment bottoms, errors in acoustic reflectivity (or impedance changes) from different density grades may exceed all other propagated errors. In such cases, the use of a Survey Tolerance is problematic and alternative payment methods need to be considered—see EM 1110-2-1003 (Chapter 21--Depth Measurement Over Irregular or Unconsolidated Bottoms).
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A-8. Determination of Total Propagated Error

The Total Propagated Error of the individual depth measurements in a project dataset can be estimated using the general guidance in Chapter 4 of EM 1110-2-1003 ("Survey Accuracy Estimates for Dredging and Navigation Projects"). The estimated (albeit simplified) propagated error budget for a single beam survey is shown in Table 4-1 of that chapter, reproduced below. The high depth uncertainties resultant in that table are largely due to the large magnitude of the "tide/stage correction accuracy" and lack of heave compensation (platform stability error)—this table was developed prior to refined GPS-aided inertial measurement unit (IMU) technology. The error budgets in this table are still relevant when tidal/stage measurements are observed from extrapolated or interpolated gage readings or when GPS/IMU alignment stabilization/heave systems are not used. (Keep in mind that the Total Propagated Error is not the same statistic as Survey Tolerance—the TPE is a statistic that is used in computing the estimated Survey Tolerance, which is an estimate of precision, not TPE).

Table A-1. (EM 1110-2-1003, Table 4-1). Quantitative estimate of acoustic depth measurement accuracy in different project conditions

Single-beam 200 kHz echo sounder in soft, flat bottom
USCG DGPS vessel positioning accurate to ± 2 m RMS
All values in ± feet

Error Budget Source	Inland Navigation Min river slope Staff gage < 0.5 mile 12-ft project <26-ft boat No H-P-R	Turning basin 2 ft tide range Gage < 1 mile 26-ft project <26-ft boat No H-P-R	Coastal entrance 4-ft tide range Gage < 2 mile 43-ft project <26-ft boat No H-P-R	Coastal offshore 8-ft tide range Gage > 5 mile 43-ft project 65-ft boat H-P-R corrn
Measurement system accuracy	0.05	0.05	0.1	0.2
Velocity calibration accuracy	0.05	0.1	0.1	0.15
Sounder resolution	0.1	0.1	0.1	0.1
Draft/index accuracy	0.05	0.1	0.1	0.1
Tide/stage correction accuracy	0.1	0.15	0.25	0.5
Platform stability error	0.05	0.2	0.3	0.25
Vessel velocity error	0.05	0.1	0.1	0.15
Bottom reflectivity/sensitivity	0.05	0.1	0.1	0.2
RMS (95%)	**± 0.37 ft**	**± 0.66 ft**	**± 0.90 ft**	**± 1.32 ft**
Allowed per Table 3-1	**± 0.5 ft**	**±1.0 ft**	**± 1.0 ft**	**± 2.0 ft**

A-9. Total Propagated Error Calculator

An estimate of the Total Propagated Error may also be computed using algorithms developed by Rob Hare of the Canadian Hydrographic Service (CHS)—see NAVOCEANO/Hare 2001. A TPE computation calculator, based on Rob Hare's algorithms, is openly available at www.hypack.com. A screen capture of this TPE calculator is shown in Figure A-3 below. This TPE calculator provides user input of the estimated accuracies of over 50 parameters making up the total depth error budget. It is applicable to either multibeam or single-beam systems. This calculator compares the resultant TPE with both Corps and International Hydrographic Organization (IHO 1998) accuracy standards. In addition, positional errors and target detection resolutions are estimated, as shown in Figure A-3. (Note that the TPE Calculator in Figure A-3 is still undergoing development and has not been fully tested for USACE dredging applications).

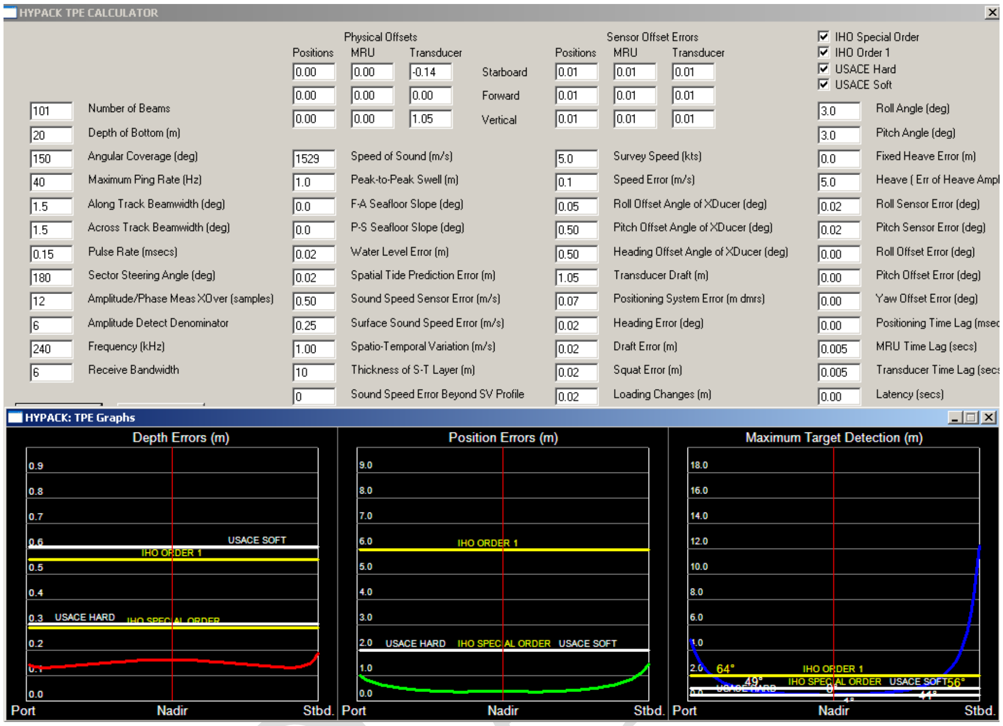


Figure A-3. HYPACK Total Propagated Error calculator for depth, position, and object detection. Values shown are for example only—users must insert estimated uncertainties for each parameter specific to their survey systems, procedures, and project. (HYPACK, Inc. and Rob Hare, CHS)

Alternative Total Propagated Error algorithms are also referenced in international hydrographic survey standards (IHO 2005).

A-10. Estimating Survey Tolerance from Past Performance Test Results

Repeated Performance Tests —i.e., evaluating the repeatability comparisons between multiple internal or external measurements made over the same region (cell or node)—may be used to estimate the Survey Tolerance. Performance Tests do not measure TPE. As detailed in Chapter 11 of EM 1110-2-1003, mandatory Performance Tests are not truly independent tests from a statistical standpoint—both the Reference Surface and the Tested Surface contain uncertainties (i.e., TPE). When the same vessel compares itself on repeated single-beam or multibeam passes over the same test area, the results provide a statistical indicator of "repeatability" and can be used to estimate the Survey Tolerance. When Performance Tests are conducted by different vessels over the same area, as shown in Figure A-4 below, then the results tend to indicate a measure of "reproducibility" and can be used in estimating Survey Tolerances. Repeated and varied Performance Tests by a survey vessel/system may trend, over time, toward a consistent estimate of Survey Tolerance that may be used for that vessel.

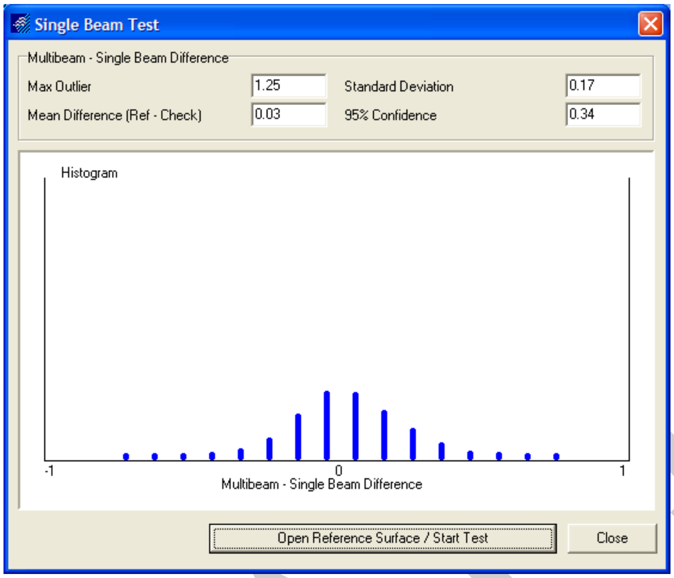


Figure A-4. Comparison of a multibeam system (S/V Shuman) against single-beam reference surface from a different vessel (S/V Cherneski)—Philadelphia District. The multibeam was 0.03 ft deeper with a 95% standard deviation of ±0.34 ft as compared to the assumed absolute single-beam reference

A-11. Approximate Method for Determining Survey Tolerance

The following table provides general estimates of survey tolerance ranges under nominal deep-draft project conditions, accounting for various measurement conditions largely dependent on the water surface measurement correction. These ranges may be used to roughly estimate the tolerance for a specific project.

Table A-2. Estimated Allowances for Survey Tolerances on Clearance and Acceptance Surveys		
Allowable Tolerance not less than	Water Surface Elevation Measurement Procedure	Tidal regime hydrodynamically modeled
Hard Bottom Materials		
±0.20 foot	Determined from carrier phase GPS (RTK)	Yes
±0.25 foot	Determined from carrier phase GPS (RTK)	No
±0.20 foot	Estimated from gage less than 1 mile from project site	Yes
±0.25 foot to ±0.50 foot	Estimated from gage 1 to 5 miles from project site	No
±0.50 foot to ±1.0 foot	Estimated from gage greater than 5 miles from project site	No
±0.50 foot to ±2.0 foot	Estimated from gage greater than 10 miles from project site	No
Soft Bottom Materials (Maintenance Dredging)		
±0.25 foot	Determined from carrier phase GPS (RTK)	Yes
±0.25 foot to ±1.0 foot	Estimated from gage 1 to 10 miles from project site	No
±0.50 foot to ±2.0 foot	Highly variable acoustic reflectivity due to suspended sediment, fluff, dense bottom vegetation, etc.	Yes
Selection of tolerances (including any interpolations between tolerance ranges) shall be made during the PED phase and shall be documented in the design file in case of subsequent disputes during construction		

Given the main variable in the above table is dependent on the gage location relative to the project site (non-RTK measurement) the magnitude of this error needs to be estimated, as shown in the following section.

A-12. Water Surface Correction Uncertainty due to Unmodeled Tidal Phase Lags

Aside from vessel motion corrections (roll, pitch, yaw, heave), the largest portion of the depth error budget (TPE) is attributable to unmodeled tidal phase lags—i.e., surface slope gradients between the reference gage and the project site. This error is significant is tidal estuaries, rivers, or when inshore gage readings are extrapolated out into a coastal entrance channel—see EM 1110-2-1003 and EM 1110-2-1100. This phase error is often a primary cause for disputes over dredged clearances. If the lag or latency on a flood or ebb tide is known (or estimated from NOAA tidal predictions), then the resultant slope difference can be estimated. This estimate does not account for environmental or meteorological effects (e.g., wind or current set up) which may be even more significant than the tidal latency. Figure A-5 below provides a rough estimate of the error uncertainty given an estimated tidal phase lag (in hours) and a given mean tidal range. This graph is based on a 50% probable difference—the likelihood that a pre-dredge and post-dredge survey are performed at differing tidal phases. This graph clearly indicates that the error due to unmodeled tide phase can be large as the mean tide range increases. It is also difficult to estimate the tidal wave phase lag time differences in a given project. Slope differences of a half-foot or more can occur over relatively short distances (less than one-half mile) during ebb or flood tides when gage readings are extrapolated to the project area. Carrier phase RTK methods are the only effective way to minimize or eliminate these tidal phase errors, and minimize the resultant Survey Tolerance value.

a. For example, sea level rise occurring between tidal epoch updates could be as much as 0.2 ft. Thus, the MLLW datum at the reference benchmark would have a constant bias of 0.2 ft and the reported channel clearance constantly off by that same amount. This equates to overdredging the project by a constant 0.2 ft, which may have significant budget impacts.

b. The use of outdated or undefined local reference datums will also cause systematic biases in the maintained or reported project depth—see IPET 2006. Datum biases of upwards of 2 ft have been known to occur, resulting in incorrectly reported or interpreted clearance depths—see IPET 2006 and EC 1110-2-6065.

c. Tidal benchmark elevations used to reference measurement, payment, and clearance surveys at a project are also subject to uncertainties. The stability of the benchmark could be subject to regional settlement or uplift. The MLLW datum has an uncertainty dependent on the length of the time the gage was in place, the distance from a primary gage, and other factors. The uncertainty of the computed MLLW datum at a gage site can range from ±0.1 ft to as much as ±0.25 ft—see NOS 2001 and NOS 2003. It is also assumed that a primary reference benchmark is used to control all surveys performed at a given project site. If different benchmarks are used, and any inconsistencies between these benchmarks exist (height or MLLW datum), then these errors would be propagated into the TPE or Survey Tolerance estimates. An example would be uncertainties in a tidal zoning model.

d. Tidal datum variations over a project may be subject to uncertainties if not minimized by some form of hydrodynamic modeling, such as TCARI or VDatum methods—see Brennan 2005 and Meyers 2005.

e. Geoid undulations occurring over a project must be modeled if RTK methods are used to measure the water surface elevation—refer to Meyer 2006 and EC 1110-2-6065. Geoid model uncertainties in coastal areas are typically at the 1 to 3 cm range, with predicted uncertainties slightly larger (5 cm) in offshore entrance channels. There are no practical methods of refining the model in offshore models; however, since these errors are systematic to all users of the same model, survey repeatability (or more importantly, reproducibility) is not impacted.

f. Summary. The accumulation of these global uncertainties can range from 0.1 to 0.5 ft. The addition of these global uncertainties to the local survey tolerance uncertainties can propagate to an overall uncertainty in the reported project clearance. For example, a project with an estimated local survey confidence of ±0.25 ft relative to a fixed benchmark/gage and an estimated global uncertainty of ±0.25 ft would have an overall uncertainty of nearly ±0.4 ft. Given these uncertainties, reporting project clearances to an implied 0.1 ft confidence level is problematic.

A-14. Theoretical Required "Hits" to Confirm Strike Detection

Figure A-6 below depicts an approximation on the number of "hits" required to statistically confirm a strike or shoal above a required grade. These plots for an assumed depth TPE of ±1.0 ft are computed based on a t-distribution sampling statistic. They indicate decreasing detection probabilities as the relative height of the strike above grade decreases. There is no relationship between this plot and "survey tolerance" or the size of the object—this plot simply shows that a statistically significant number of confirmed "hits" are required to obtain confidence in the detection of small objects or shoals.

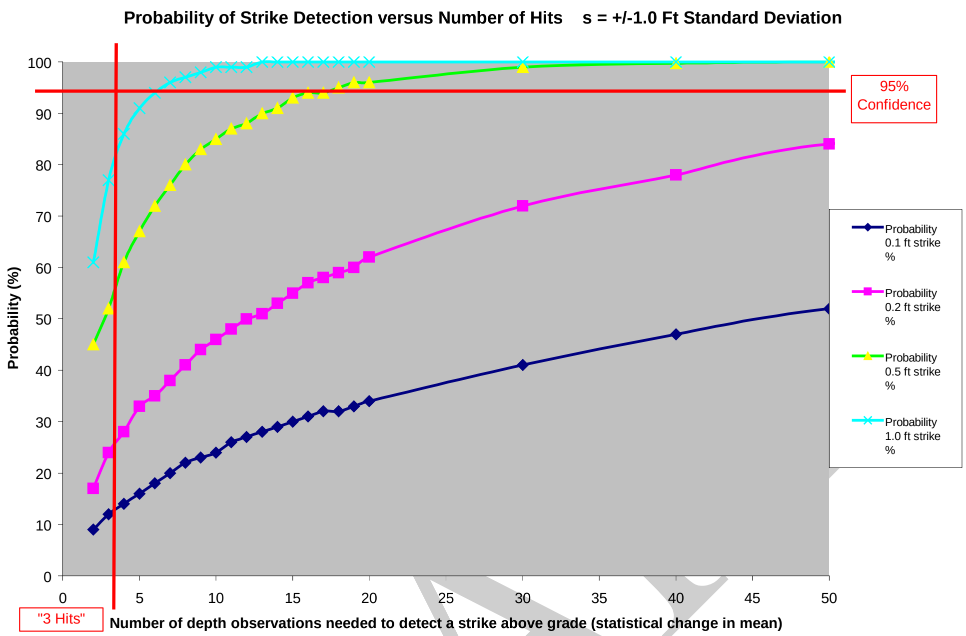


Figure A-6. Strike detection probabilities for varying clearance levels

A-15. Single Beam Receiver Sensitivity Effects on Survey Tolerances

The proper setting of the receiver's gain or sensitivity control must be maintained when conducting single beam hydrographic surveys. Up to a 0.3 ft error can be induced with too low of a setting. The leading edge of the return echo must be a nearly vertical straight line in order to obtain the correct sounding.

a. Most survey sounders take a point for the sounding depth that is at 60% of the maximum return echo voltage available for a saturated echo. If the return echo is nearly vertical, there will be no time or depth delay from the point where the received echo starts to return from the bottom and the point where if reaches the 60% of maximum which is the digitized depth point on the echo. If the receiver gain setting is too low, the received echo will have a more rounded shape. If the gain is quite low, the slope of the echo can induce a significant difference in time between when the echo is first being received to when the 60% point is reached, resulting in a depth error showing a deeper depth than the true bottom.

b. The correct gain setting is reached when the top most color of the echo trace on the sounders display is at its maximum, typically red. It should stay at this color without breaking up or changing to the next color in the palette—approximately one third of the total echo trace. If a bottom tracking line is displayed, the line should be fairly stable without jumping up and down while on a flat bottom. This can also be an indicator of a weak echo as the slope of curve is changing as the weak echo fades, causing the 60% point and resulting depth indication to move around.

c. Caution must also be used in not setting the gain too high, as this results in false soundings from fish targets, vegetation, suspended sediments, and noise in the water column, which can reach a 60% level and become erroneous depths—i.e., shallower than the grade.

A-16. Accuracy/Uncertainty Statement for Channel Condition or Dredging As-Built Surveys

Federal guidelines prescribe mandates for including accuracy or uncertainty statements for all developed and disseminated geospatial data (FGDC-STD-007.3-1998). Such statements provide users with a confidence and reliability in the data—including any implied risks associated with its use. Data accuracy and reliability statements are currently rarely provided for USACE hydrographic survey data, leaving the user to assume accuracy based on the displayed depth resolution—typically 0.1 ft. The need for providing specific uncertainty estimates in survey data is best captured in the following excerpt from Deick 2007.

Comment [WAB10]: WAB: Confirm reference ... obtained indirectly from David Wells correspondence.

> " ... procedures and models [should] be developed for providing decision makers [e.g., construction QC/QA reps] with a clear, unambiguous statement of the . . . uncertainty of their [depth] data. No manager [e.g., construction QC/QA reps] should ever be without a statement of [depth] measurement uncertainty attendant to each piece of data on which decisions are based. No experimenter [e.g., surveyor] should permit management [e.g., construction QC/QA reps] to consider [depth] measurement data without also considering its measurement uncertainty. The manager has responsibility for requiring [depth] measurement uncertainty statements. The experimenter [e.g., surveyor] has the responsibility for never reporting . . . [depth] results without also reporting their measurement uncertainty." (page 36, "Measurement Uncertainty: Methods and Applications")

a. As stated earlier, the overall global uncertainty of a channel clearance is difficult to quantify. Since most navigation projects are referenced to a single gage or tidal benchmark, the "local relative accuracy" of that benchmark is assumed absolute; thus, the only uncertainties are attributed to the TPE of the survey itself. Factoring in the global (or "network") uncertainties of that reference gage/benchmarks (MLLW datum, settlement, sea level rise) accumulates additional uncertainty onto the survey TPE.

b. Since hydrographic survey data is not tested against a higher reference source, FGDC guidance in FGDC-STD-007.3-1998 specifies that accuracies shall be reported "*... at the 95% confidence level for data produced according to procedures that have been demonstrated to produce data with particular horizontal and vertical accuracy values ... Compiled to meet ____ (meters, feet) horizontal accuracy at 95% confidence level [and] ____ (meters, feet) vertical accuracy at 95% confidence level.*"

c. A sample USACE accuracy statement included on plan drawings or channel condition reports is shown below. Accuracies are defined as "relative"—not global or "network" in a geodetic control sense. The estimated "survey tolerance" is inserted into the vertical confidence—typically ranging between ±0.2 and ±1 ft for most projects. The specified horizontal accuracy is estimated based on the positioning system—typically ranging between ±1 ft and ±10 ft for most DGPS, RTK, or total station positioning systems.

> Depths shown on this [plan][report] have an estimated vertical accuracy of ±[____] ft at the 95% confidence level and an estimated horizontal accuracy of ±[____] ft at the 95% confidence level. These estimated accuracies are defined relative to local NSRS geodetic control at the project site. The depths shown are representative of observations collected over a defined area and have been rounded to the nearest [_____] ft to reflect their confidence uncertainty levels.

d. Additional background information related to GIS users of undefined geospatial data is at ASPRS 2005.

A-17. Significant Figures: Rounding Depths to their Uncertainty Levels

USACE hydrographic surveyors have recognized for decades the impropriety of displaying echo sounding depths to the 0.1 ft in deep water channels. This recognition is based on their first-hand intuitive knowledge of the inaccuracies inherent in depth measurements collected on a dynamic platform in deep open water—a sophisticated TPE depth uncertainty calculator is not required. This practice of displaying depths to the nearest 0.1 ft (with an implied accuracy of 0.05 ft) when the uncertainty may actually be at the ± 1 ft level or more, conflicts with nearly all the guidance in civil engineering and surveying texts, as is evident in the excerpts below. Therefore, depths shown on plans or reports must be rounded to a level that is consistent to their relative confidence.

> "... significant figures refers to those digits in a number which have meaning; that is, those digits the value of which are known ... Confusion in the matter of computations involving measured quantities arises from the failure of the novice to distinguish between exact numbers and numbers which carry with them the inevitable errors of measured quantities. Obviously then, the number of digits that will have meaning and that may be used to indicate the [measured] length of a line [a depth] is strictly limited by the precision with which the measurement has been made ... it cannot be said offhand how many significant figures there are in any measured quantity [depth] until the character and magnitude of the errors have been examined." "*Surveying Theory & Practice*," Davis, Foote & Kelly (5th Ed)

> "Any properly recorded measurement can be presumed to have a maximum uncertainty of plus or minus half of its last digit ... Field measurements are given to some specific number of significant figures, thus dictating the number of significant figures in answers derived by computing using them. In an intermediate calculation, it is common practice to carry at least one more digit than required and than round off the answer to the correct number of significant figures." "*Elementary Surveying*," Wolf & Brinker, 9th Ed.

A-18. USACE Standard Volume Computation Methods

Currently there are numerous dredged quantity computation methods, options, and reporting variations unique to Corps Districts and even separate Area Offices. These variations involve nuances (and unnecessary complexities) in overdepth allowances, dredging limits, side slope allowances, box cuts, and reporting formats—see Chapter 15 of EM 1110-2-1003. These individualized payment methods have necessitated duplicative procurement of dedicated software and training by the Corps and dredging industry personnel. The following standards simplify the process of determining in-place quantities, and most importantly, provide for a more consistent, equitable, and accurate contract payment. The Contour Dredging standard payment method is illustrated in the typical cross-section at Figure A-7.

a. Dredge Payment Computation Standards. Dredging limits shown in contract plans, estimated quantities, and dredge payment shall be determined using the "Contour Dredging" method. Estimated quantities shall be determined by differencing the 3D/TIN (surface-to-surface digital terrain model) cells containing representative depths (average or median) between the Pre-Dredge and After-Dredge surveys, factoring in limits in the modeled Required and Overdepth prisms. In Contour Dredging, all material removed above the Required Depth prism (including the side slopes) is paid for and overdepth quantities are paid only where material delineated on the Pre-Dredge survey exists above the Required Depth prism, including the side slopes. (Note that in new work the Required Depth Grade is modified to the Survey Tolerance Overdepth Grade).

b. Side Slope Dredging Payment Restriction Options. Payment for dredging side slopes (and including overdepth payment in the side slopes) may optionally be restricted to a defined extension distance outside the channel toes, as specified in the contract. Side slope restrictions, if any, shall be developed specific to each project. If no side slope restrictions are specified, then full payment for Required Depth and Overdepth is assumed. Side slope payment optionally may be restricted to the existence of material at the toe of the slope.

c. Box Cut Allowance Payment Options. Box cut payment allowances below the overdepth payment prism are optional, and typically are used in new deepening work. Box cut payment allowances apply only outside the channel toes, and shall be determined by extending the Allowable Overdepth prism outside the toes by the defined side slope dredging restriction distance specified in the contract. Payment will be made for all material removed within the extended Overdepth prism out to the defined extension limit. (No allowance shall be computed or made for material dredged outside the extended box prism—i.e., a "sloughing" allowance).

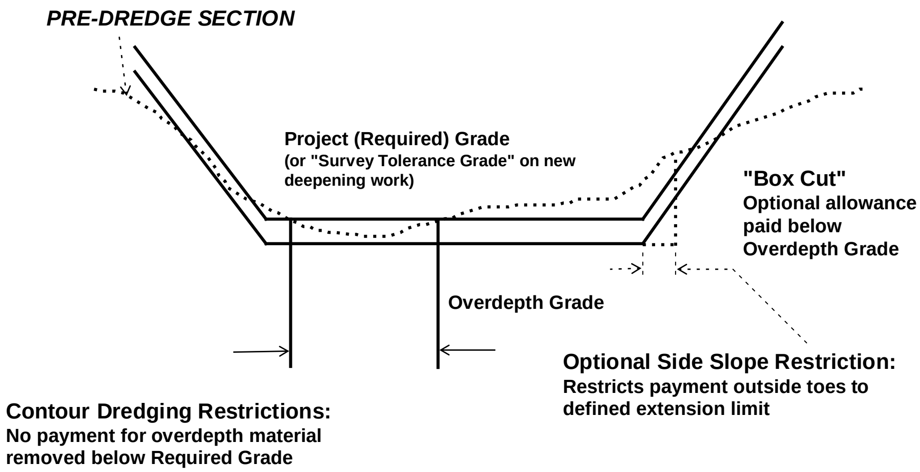
d. Estimated Quantities and Dredging Limits in Contract Plans. Estimated quantities of Required Depth and Overdepth quantities for each Acceptance Section shown in the contract plans shall be computed based on the 3D/TIN digital terrain model of the Project Condition or P&S Survey referenced in the contract. Quantities shall be estimated based on the spatial differences between the Pre-Bid survey and the 3D models of the Required and Overdepth templates.

e. Restricted Dredging Limits. General dredging limits or restrictions may be specified in contract plans as required to delineate environmental or structural restrictions. However, within these limits, the above "Contour Dredging" payment methods shall apply.

f. Quantity Tolerances. Software used in performing quantity computations should yield volumes within a 1% tolerance level. This tolerance allows for variations in developing TIN models from digital terrain matrix models, especially when developed from sparse single-beam cross-sections in irregular channels or basins.

g. Average-End-Area Quantity Computations. Approximate "Average-End-Area" volume computation methods shall not be used for estimating dredge quantities. This method may be used for computing quantities placed in upland (beach) or underwater disposal sites.

b. Quantity computation software. 3D/TIN surface-to-surface volume routines in any existing CADD package may be used for determining payment quantities, provided they (1) report accumulated 3D/TIN volumes by incremental channel station, and (2) compute box cut allowances consistent with the above parameters. Technical guidance on Contour Dredging and 3D/TIN computation procedures may be obtained by contacting the Operations Division of the Philadelphia District (CENAP-OP-TS).


PRE-DREDGE SECTION
Project (Required) Grade
(or "Survey Tolerance Grade" on new deepening work)
"Box Cut"
Optional allowance paid below Overdepth Grade
Overdepth Grade
Optional Side Slope Restriction:
Restricts payment outside toes to defined extension limit
Contour Dredging Restrictions:
No payment for overdepth material removed below Required Grade

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Part II: Physics and Gravity
Part III: Height Systems
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APPENDIX B
Project Delivery Team Design Checklist for Dredge Measurement & Payment Contract Clauses

The following checklist outlining contract "Measurement and Payment" specifications shall be utilized during the PED phase by a member of the PDT that is familiar with the project and the likely survey system that will be deployed during construction. All of the following items in the table below shall be clearly and separately addressed in the contract plans and/or specifications.

Comment [WAB11]: WAB: This is very rough. Design checklist recommended by DCA/Holliday

Table B-1. Checklist for Development of Measurement and Payment Clause in Dredging Contracts

Survey Specification	Required or Detailed Standard
Dredging Limits	Delineate Acceptance Section limits with overdepth payment restrictions based on the below grade contours
Plans & Specs (P&S)/Bid Survey	Specify file location (Web access) for dense bid survey from which estimated quantities were derived Verify P&S survey reference datums are noted on plans Verify tidal model is noted on plans by source and date Verify tidal reference gage PBM is noted on plans Verify plans note that that contours and depths shown on plans are based on rounded depths and estimated quantities are based on original detailed survey dataset
Side Slope Payment	Reference Appendix A (paragraph A-18)
Extension outside channel toes	Specify limiting distance, if any, in feet payment will be made outside toes
Box Cut allowance	Specify if a box cut allowance will be made to the above extension limit
Survey Tolerance Allowance	
New Work	Specify tolerance below Required Depth in feet
Maintenance	Specify tolerance about Required Depth in ± feet
Survey Procedures and Calibrations	Reference technical guidance in EM 1110-2-1003
Acoustic Frequency	Reference Paragraph 8 200 kHz (±10%) (Specify alternate frequency in unconfined sediments, if applicable)
Acoustic Survey System	Specify single-beam or multibeam per criteria in Paragraph 10
Density of Survey Coverage	
Single-beam	Specify cross-sectional spacing in feet (NTE 200 ft) (Note planned coverage methods in irregular basins)
Multibeam/Multi-transducer	Specify percentage of bottom coverage and overlap coverage
Horizontal Reference	
Datum	NAD83, SPCS & local chainage-offset
Positioning system	Specify system to be deployed: DGPS, RTK, tag line, topo, etc.
Reference PBMs	Specify/list/reference control data sheets for PBMs

Table B-1. (Concluded) Checklist for Development of Measurement and Payment Clause in Dredging Contracts

Survey Specification	Required or Detailed Standard
Vertical Reference	
Orthometric Datum	NAD83 (NAVD88)
Low Water Datum	Specify
Tidal Epoch	Specify model/year
Geoid Model/Ellipsoid Reference (Optional)	Specify (applicable to RTK surveys only)
Reference PBMs/gage	NSRS PIN or Station ID
Tidal Range Model	Specify along with source and date of model
Tidal or River Gradient Model	Provide file detailing tidal phase corrections or river slope gradient interpolations, as applicable
Water Surface Correction Procedure	Gage interpolation, extrapolation, or RTK (detail site calibration procedures & reference PBMs)
Vessel motion corrections:	
Heave filtering	Specify method/system
Roll-pitch-yaw-latency correction	Specify method/system
QA Performance Testing	Describe QA requirements, location, frequency, etc.
Data Editing & Processing	
Outlier Rejection Limit	3σ
Bin/Cell Size	3 ft x 3 ft (New Work) or 5 ft x 5 ft (Maintenance) – reference Paragraph 8 for single-beam
Representative Depth/ per Cell	Reference Paragraph 9 above--Average or Median
Volume Computations for Payment	Reference Paragraph A-19--3D TIN Surface-to-Surface
Software	Specify by manufacturer/provider
Survey Request Notifications	Specify advance notification in days for a pre-dredge or after-dredge clearance—or reference EP 1130-2-520
Data Processing Time Standards	Reference Paragraph 17
Dredge Clearance Assessment	Reference Paragraph 9
Unconsolidated sediments (fluff)	Specify alternate and specific measurement & payment method
CUBE Assessment	Indicate if CUBE will be used along with evaluation parameters

Contract specifications shall not contain general options for duplicate systems, methods, or control unless the rationale or conditions for having the options is clearly spelled out.