RECORDING AQUATIC RESOURCE DELINEATIONS USING GLOBAL NAVIGATION SATELLITE SYSTEMS

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U.S. ARMY CORPS OF ENGINEERS **BUILDING STRONG**

1. General: This document provides recommendations for the use of high-accuracy Global Navigation Satellite System (GNSS) receivers and Geographic Information Systems (GIS) in electronically mapping aquatic resource boundaries pursuant to Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act, applicable to all U.S. Army Corps of Engineers (USACE) Districts. These guidelines support individuals conducting aquatic resource delineations and jurisdictional determinations by promoting consistent, accurate data collection methods. They may also be used when quantifying the extent (e.g., areas and/or lengths) of aquatic resources in a project area or assessing the spatial extent of proposed impact areas in Department of the Army permit applications. In accordance with U.S. Army Corps of Engineers Regulatory Guidance Letter 05-02, this document outlines methods for collecting spatial data that facilitate accurate replication of delineation documentation. While these are recommendations rather than mandatory standards, adhering to consistent practices will enhance accuracy and consistency across all USACE Districts.[1]

While Global Position System (GPS) is a general term for satellite-based navigation, GNSS is the term used by professional practitioners to characterize the broad suite of all major global navigation systems such as GPS (United States), GLONASS (Russia), Galileo (European Union), and BeiDou (China). This document will refer to GNSS rather than GPS to encompass all these systems collectively, as most commercially available GNSS receivers utilize multiple positioning systems.

Recent advancements in GNSS technology, combined with its increased affordability, have made Real-Time Kinematics (RTK) a practical choice for achieving sub-meter accuracy in GNSS positioning for routine applications, including data collection to document aquatic resource delineation boundaries. RTK-capable GNSS sensors can now be purchased for as little as $800, delivering 30cm horizontal accuracy out of the box and less than 2cm with RTK differential corrections. This shift marks RTK's transition from a costly option to a more accessible tool for reliable electronic mapping of aquatic resources.

While maps or sketches of aquatic resource delineation can be generated using GNSS sensors with lower accuracy (>50cm), **this data may not be suitable for accurately calculating the size of aquatic resources and associated impacts or determining requirements for compensatory mitigation**. In situations where high-precision GNSS data is unavailable, impacts to waters of the United States should be measured using

[1] Notwithstanding the specifications described in this document, USACE districts retain the flexibility to adjust spatial accuracy standards based on individual project needs. In general, spatial accuracy for data collection should be commensurate with the scope of potential environmental impacts.

other reliable methods, such as a field tape measure, a professional survey, or other such reliable means.

2. Reevaluation: These recommendations will be regularly reevaluated to ensure they remain current and effective. This reevaluation will consider technological advancements, feedback from stakeholders, changes in regulatory requirements, and evolving best practices in GNSS data collection and delineation.

3. Data Collection: This section offers recommendations for the collection of spatial data using high accuracy GNSS equipment (≤50cm horizontal and vertical). Proper collection of high-accuracy GNSS data will help to ensure that the proposed impacts to waters of the United States associated with proposed projects are properly assessed and mitigated and is expected to help prevent regulatory compliance issues that may arise from inaccurate data collection methods.

a. Aquatic resources are often marked in the field with physical flags. As a best practice, these flags are typically positioned along the boundaries of each aquatic resource, such that no areas of the delineated aquatic resource are excluded between adjacent flags.

   When GNSS data are collected to document an aquatic resource delineation, GNSS point data should be collected at each point that is being used to mark the aquatic resource boundary. This point data can then be transformed into lines and/or polygons using GIS software to create graphical representations of the aquatic resource boundaries within the review area. Typically, GNSS point data is recorded in latitude and longitude using the World Geodetic System 1984 (WGS84) coordinate system, which defines geographic coordinates on a spherical surface. Care should be taken when calculating areas and lengths based on these geographic coordinates. It is strongly advised to retain the original coordinate system used by the GNSS receiver and to use geodesic tools for calculating area and length measurements. Commercial GIS software like ArcGIS Pro provides tools for geodesic area and length calculations. Geodesic calculations employ shape-preserving algorithms that account for the Earth's curvature, making them reliable for calculating areas and lengths for aquatic resources and impacts. If geodesic calculations are not possible, it is recommended to project these coordinates onto a flat surface. This can be effectively accomplished using map projections such as the State Plane coordinate system or the Universal Transverse Mercator (UTM) projection, which are designed to minimize distortion in localized areas, thus enhancing the accuracy of area and length measurements.

b. USACE recommends that project proponents utilize the USACE Regulatory Request System (RRS) to submit their aquatic resources delineation for USACE review. A bulk-upload geodatabase template is available for download on the RRS website (https://rrs.usace.army.mil/rrs). This template includes point, line, and polygon feature classes: the point feature class is used for boundary flags,

while the line and polygon feature classes are designed for bulk-loading boundary data into the RRS. When collecting point, line, and polygon features in the field with a GNSS receiver, it is recommended to record GNSS metadata to document the quality of the collection.
The RRS geodatabase can be directly deployed to a feature service on Environmental Systems Research Institute, Inc. (ESRI) ArcGIS Online or Enterprise Portal. The feature service can then be used with ESRI mobile field data collection applications to automatically collect GNSS metadata into the attribute table of the point feature class. The geodatabase template also contains all the necessary fields in the line and polygon feature classes for directly transferring aquatic resources delineation data into the RRS and USACE database.

Alternatively, delineators can use free mobile applications like SW Maps to collect GNSS point data, including metadata, with external GNSS receivers. The GNSS data can be exported as a comma-separated values (CSV) file and imported into free desktop GIS software such as QGIS. In QGIS, the CSV data can be used to populate the point feature class in the RRS aquatic resources bulk upload geodatabase template, as well as to create polygons and lines representing the aquatic resources within the geodatabase.

GNSS points that represent delineated aquatic resources should include the following GNSS metadata fields in the feature attribute table:

Ideal Conditions:

- **Position Source Type**: Indicates the method or source used to determine the position (e.g. External GNSS Receiver).
- **Receiver Name:** The model or name of the GNSS receiver used to collect the data (e.g., Trimble R10, Garmin GLO, RTK Facet).
- **Latitude:** The geographic coordinate that specifies the north-south position. Expressed in decimal degrees (e.g., 34.052262).
- **Longitude:** The geographic coordinate that specifies the east-west position. Expressed in decimal degrees (e.g., -118.243762).
- **Horizontal Accuracy (meters):** The estimated error in the horizontal position (latitude and longitude). ≤ 50 cm is recommended when computing impacts or reproducing delineations.
- **Fix Time:** The time at which the position fix was obtained in a standard time format (e.g., UTC).
- **Fix Type:** Indicates the type of position fix (e.g., 2D, 3D, DGNSS, RTK Fixed, RTK Float). Preferably RTK Fixed then RTK Float.
- **Correction Age:** The time elapsed since the last differential correction was applied (< 5 seconds for best corrections).
- **Number of Satellites:** The count of satellites used to determine the position (≥ 7 satellites for reliable data).
- **PDOP (Position Dilution of Precision):** A measure of the overall quality of satellite geometry for positional accuracy (≤ 2 is recommended for best

positional accuracy). Not applicable when using averaging.

- **HDOP (Horizontal Dilution of Precision):** A measure of the quality of satellite geometry for horizontal positioning (≤ 1 is recommended for best horizontal accuracy). Not applicable when using averaging.

Optional and/or Situational:

- **Altitude (meters):** The elevation above mean sea level.
- **Vertical Accuracy (meters):** The estimated error in the vertical position (altitude). ≤ 50 cm is recommended for high accuracy.
- **VDOP (Vertical Dilution of Precision):** A measure of the quality of satellite geometry for vertical positioning (≤ 2 for high vertical accuracy).
- **Direction of Travel (°)**: The direction in which the GNSS receiver is moving. Expressed in degrees from north (0° to 360°).
- **Speed (kilometers per hours)**: The speed at which the GNSS receiver is moving.
- **Compass Reading (°)**: The compass direction the GNSS receiver is facing. Values: Expressed in degrees from north (0° to 360°).

If using GNSS averaging:

- **Average Horizontal Accuracy (m)**: The average estimated horizontal positional error. Values: ≤ 1 meter for consistent accuracy.
- **Average Vertical Accuracy (m)**: The average estimated vertical positional error. Values: ≤ 2 meters for consistent accuracy.
- **Averaged Positions:** The number of position fixes averaged to obtain the final position. Values: Indicates the count of averaged readings.
- **Standard Deviation (m):** The statistical measure of the spread of position fixes around the mean. Values: ≤ 0.5 meters for low positional variance.

c. For optimal results in mapping aquatic resource boundaries, it should be possible to consistently collect RTK GNSS data with an accuracy of at least 3 cm horizontally and 5 cm vertically. This level of precision is ideal for accurately assessing impacts and computing compensatory mitigation requirements. However, given the diversity in equipment capabilities and varying field conditions, a maximum permissible accuracy of 50 cm is recommended. This specification is in line with the capabilities of contemporary GNSS technology, effectively balancing the necessity for accurate and precise spatial data with the feasibility of implementation in various field scenarios.

d. Detailed documentation of the specific type of GNSS equipment used, including the make, model, and any relevant specifications of the equipment should be provided.

e. For optimal consistency across all Districts (including all U.S. territories), it is recommended to capture and submit spatial data in WGS84 using decimal degrees format. This format should maintain a precision level of at least six digits after the decimal point, ensuring uniformity and accuracy in the data recorded.

f. In instances when GNSS field data collection conditions are not optimal and may compromise data quality and accuracy, it is recommended to return to the site later when conditions improve or have the boundaries professionally surveyed.

g. Base stations used for differential corrections should be placed in areas with a clear view of the sky and away from tall buildings, large metal surfaces, dense foliage, reflective surfaces like glass or smooth water bodies, and other structures like bridges and overpasses that are known to cause multipath interference.

h. When measuring elevations or altitudes, it is crucial to enter the antenna height into your field data collection software. To obtain consistent elevation readings, a survey pole or monopole should be used. The antenna height is defined as the distance from the top of the GNSS antenna to the base of the survey pole or monopole. Most GNSS receivers record the Height Above Ellipsoid (HAE) for elevation or altitude measurements. However, some districts require orthometric elevation values, which are based on vertical datums such as EGM96 (Earth Gravitational Model 1996) or IGLD 1985 (International Great Lakes Datum of 1985). The HAE can be converted to orthometric height using readily available online tools, typically provided by the National Oceanic and Atmospheric Administration.

i. If using corrections, GNSS data should be collected in a way that ensures high positional accuracy throughout the duration of data collection using either **RTK** or **post-processing**. It is recommended that GNSS data corrections be accomplished in one of three ways:

   i. **RTK Base Station with Rover Setup:** This setup consists of two main components, an RTK capable GNSS base station and an RTK capable GNSS rover.

      1. **Base Station:** A stationary GNSS receiver is placed at a known location. It continuously collects satellite data and calculates its position. The base station should be positioned over a known benchmark or monument during the entirety of the GNSS data collection. To achieve the highest vertical accuracy possible, the user should ensure an accurate antenna height is entered into your GNSS software. The antenna height is taken from the known benchmark/monument to the Antenna Reference Point (typically the base of the antenna).

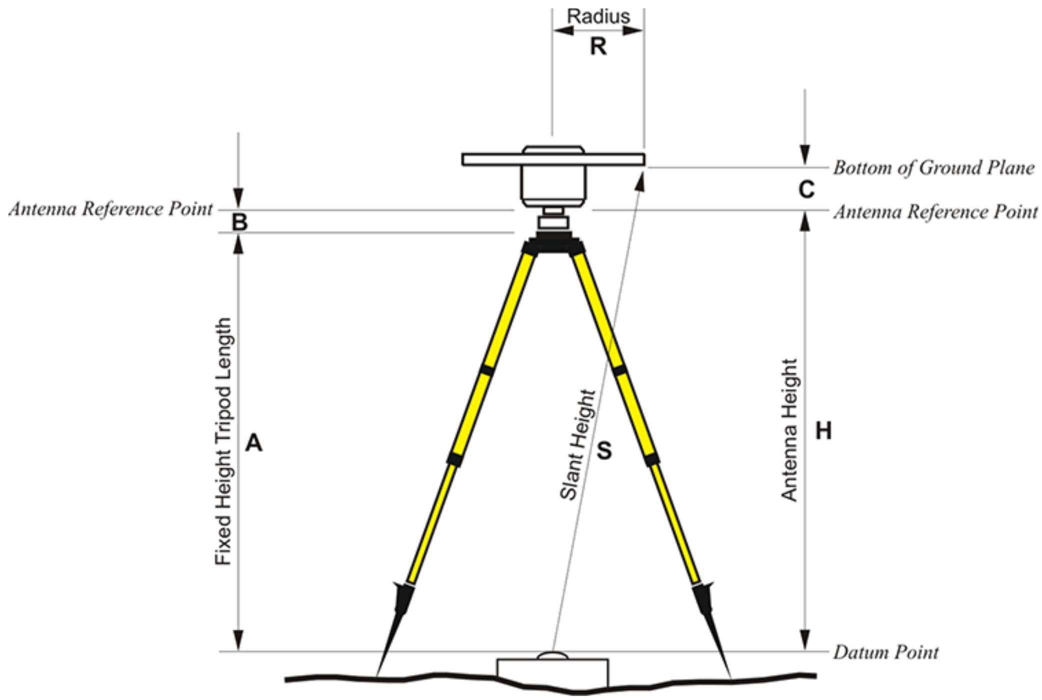

Figure 1. Height of Instrument Diagram, Source: GPS for Land Surveyors

2. **Rover:** A mobile RTK capable GNSS receiver that moves around collecting position data.

How It Works: The base station calculates errors in the GNSS/GNSS signal (due to atmospheric interference, satellite orbit errors, etc.) by comparing its known position to the position it calculates from the satellite data. It then sends these error corrections via radio signal (using the Radio Technology Commission for Maritime Services (RTCM) protocol) to the rover. The rover's range is limited to the radio signal's reach, often 1,000 feet to a few miles. The act of sending the real-time corrections is why this technology is called Real-Time Kinematics.

Use Cases: Common in areas without cellular or satellite service or where a dedicated base station is needed for ongoing, localized work.

ii. **RTK Rover with Networked Transport of RTCM via Internet Protocol Setup:** This setup also involves a rover, but instead of using a dedicated base station to send real-time corrections, it uses a network service.

1. **Rover:** A mobile RTK capable GNSS receiver that moves around collecting position data.

2. **RTK Network (NTRIP):** A network of base stations that provide correction data over a network.

How It Works: The rover connects to the RTK NTRIP network to receive RTCM correction data from known base stations. These corrections are typically transmitted via cellular telephone service over HTTP (normally via a mobile apps like SW Maps) but can also be received via satellite, such as the ublox PointPerfect or PointOne Navigation's Polaris. These base stations can be private or managed by local or state agencies.

Use Cases: Ideal for projects covering larger areas or where it's impractical to set up a dedicated base station and where a NTRIP network connection is possible.

iii. **Post-Processing Data Correction:** If real-time data correction is not utilized, post-processing differential correction should be completed and documented to ensure positional accuracy. This setup also involves using only a rover.

1. **Rover:** The GNSS receiver (rover) collects raw satellite data during the field survey without requiring real-time corrections. The GNSS does not need to be RTK capable but should be as accurate as possible.

How It Works: In post-processing GNSS, a standard GNSS receiver is used to collect raw satellite data, without real-time correction. This data is later processed against reference data from a stationary GNSS base station, which has been collecting data over the same time period. The post-processing software analyzes both sets of data to identify and correct discrepancies, effectively reducing errors caused by atmospheric conditions, satellite orbits, and other factors. This correction process enhances the accuracy of the collected GNSS data, bringing it to a level comparable to real-time RTK systems, but with the flexibility of processing after the data collection is complete.

Use Cases: This method is suitable for scenarios where real-time accuracy is not critical, and where there is access to reliable reference station data for the post-processing phase.

4. Data Submission: This section presents recommendations for the submission of collected GNSS data. It outlines the expectations for file naming conventions, attribute data requirements, and map standards.

a. Submitted spatial directories and files names should not contain non-alpha-numeric characters and/or spaces, with the exception of underscores. A logical naming convention for submitted files should include:
    i. USACE file/reference number (when possible);
    ii. Unique file name;
    iii. Date of acquisition/creation (YYYYMMDD).

b. All submitted spatial data layers should include the attribute fields specified in the most recent version of the RRS geodatabase for each polygon, line, or data point surveyed and mapped.

   The attribute table should include the following information for each point surveyed using GNSS:
   i. Flag/point number;
   ii. Waters name (Wetland A, Stream A, etc.);
   iii. Feature type (Wetland, Ordinary High Water, Mean High Water, Upland).
   iv. GNSS metadata (see Section 3(b));
   v. Inspector or creator name;
   vi. Comments (optional).

c. Metadata is required for all submitted spatial data layers. The following details should be incorporated provided in the feature metadata and/or Aquatic Resources Delineation Report:
   i. Complete reference/file number (when possible);
   ii. Name of project;
   iii. Name(s) of data collectors;
   iv. The range of field collection dates;
   v. Make and Model of any base station (s) used for corrections;
   vi. Name and version of software used for downloading data and any corrections;
   vii. Any editing performed on the raw data.

d. Digital Submission should include the geodatabase (preferred) or other geospatial file format. Digital data may be transmitted via either:
   i. the Regulatory Request System; (recommended)
   ii. Email. (Note that file sizes in excess of ~40MB may exceed the email file size limits of some USACE offices)

5. <u>Conclusion</u>: This document outlines recommended practices for the collection and submission of GNSS and GIS data for aquatic resources delineations across all U.S. Army Corps of Engineers Regulatory Districts. These recommendations are intended to promote consistency, accuracy, and efficiency in the delineation process and to ensure accurate computation of impacts to waters of the United States and compensatory mitigation requirements. This document replaces all previous recommendations and provides each District with the flexibility to adjust spatial accuracy standards based on individual project needs.