



On-the-Ground Collection of High Resolution Elevation Data in Salt Marsh Environments

A Northeast Coastal and Barrier Network Methods Document

Natural Resource Report NPS/NCBN/NRR—2017/1371



ON THE COVER

Photograph of Watch Hill marsh, Fire Island National Seashore, NY.
Photograph courtesy of Sarah Gulick and Erin Finicane, NPS

On-the-Ground Collection of High Resolution Elevation Data in Salt Marsh Environments

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Glossary

Accuracy – For the purposes of this document, accuracy refers to the uncertainty of a GPS/GNSS measurement; 5 cm accuracy means that there is 95% confidence that the measurement is within 5 cm of the true value.

Almanac – Data transmitted by GPS satellites that tell GPS receivers the precise location, signal to noise ratio, and time synchronization data of each satellite at any given time during the day. Typically it contains ephemeris data (see below).

Base Station – A stationary GNSS/GPS receiver placed at a known point that collects continuous GNSS/GPS data over the time period of a survey and is used for differential correction (see below) of GNSS/GPS data from a roving GNSS/GPS receiver.

Baseline – A vector (line) that connects a pair of GNSS stations (receivers) for which simultaneous GNSS data have been collected. It is mathematically expressed as a vector of X, Y, Z coordinate differences between the base or reference station and the rover or unknown station.

Benchmark – see Geodetic Monumentation.

Baud Rate – A measure of the speed of data transmission from one digital device to another. This is typically associated with radio equipment.

CMRx (Compact Measurement Record) – A real-time message format, developed by Trimble, for broadcasting GNSS corrections from a base receiver to a rover receiver. Similar to CMR and CMR + but designed to include more satellite corrections, signals, and constellations.

Datum – A reference point, plane or surface to which other points are referred to in order to maintain a consistent system of measurement.

Geodetic Datum – Set of constants specifying the coordinate system used for geodetic control, i. e., for calculating the coordinates of points on Earth. Geodetic datums are based on mathematical models of the Earth's surface and define the size and shape of the Earth as well as the origin and orientation of the coordinate system used to map the Earth. In the U. S. and its territories the National Geodetic Survey (NGS) of the National Oceanic and Atmospheric Administration (NOAA) is responsible for defining, providing access to, and maintaining Geodetic Vertical datums. See Geoid and Ellipsoid.

Horizontal Datum – A collection of specific points on the Earth that have been identified by their precise locations (latitude and longitude or Northerly/Southerly and Easterly/Westerly) and connected, by surveying methods, to relate them in a common system.

Tidal Datum – Determined by averaging the water level for a certain phase of the tide at a tide gage over time. Some simple examples of these are Mean Sea Level (MSL), Mean Low Water (MLW) and Mean High Water (MHW). The Center for Operational Oceanographic Products and Services (CO-OPS) of NOAA is responsible for calculating tidal datums as part

of the National Tidal Datum Epoch (NTDE). The NTDE is a specific 19 year period adopted by the National Ocean Service (NOS) as an official time period for determining mean values for tidal datums.

Vertical Datum – A base elevation used as a reference from which to determine heights or depths. This is sometimes described as a surface of zero elevation.

Differential Correction – The process of improving the accuracy of GPS/GNSS data by comparing measurements at unknown locations with measurements of a known location during the same time period. In practice this is done by correcting data collected on a rover receiver (which is mobile) with data collected simultaneously at a base station (which is stationary at a known location). Differential correction can be done in real-time, or after the data is collected by post-processing techniques.

Digital Elevation Model (DEM) – A representation of continuous elevation values over a topographic surface usually represented as pixel or raster data..

Dilution of Precision (DOP) – A unitless value that describes the quality of the configuration, or geometry, of the satellites used to compute positions with GNSS equipment. Having a strong geometry of satellites will provide more confidence in data accuracy. A high DOP value indicates bad geometry and therefore less confidence in data accuracy. Lower DOP values indicate good geometry and greater confidence in data accuracy.

Horizontal Dilution of Precision (HDOP) – DOP value that indicates the precision of horizontal measurements based on satellite geometry.

Position Dilution of Precision (PDOP) – An overall rating of precision based on horizontal and vertical DOP. This is the most common value presented in GNSS surveying.

Vertical Dilution of Precision (VDOP) – DOP value that indicates the precision of vertical measurements based on satellite geometry.

Dual-Frequency – A type of GNSS receiver that uses both L1 and L2 radio signals from GPS and GLONASS satellites. The L1 and L2 radio signals are the primary and secondary L-band carrier signals used by satellites. A dual-frequency receiver can compute more precise position fixes over longer distances and under more adverse conditions because it compensates for ionospheric delays.

Elevation – Height above a given level (datum), especially sea level. Elevation values comprise what is referred to as the Topography of the Earth.

Elevation Mask – A filter in GNSS equipment used to ignore satellites that are below a certain angle on the horizon. This is set (typically around 10 degrees) to avoid using satellites low in the horizon which may be obscured by buildings, canopy, or mountains.

Ellipsoid – A three-dimensional model of the overall shape of the Earth. It is almost spherical and “smooth” as if the Earth were totally homogenous without mountains or trenches. GNSS and GPS provide heights (elevations) in reference to the ellipsoid.

Ellipsoid Height – The difference between a topographic elevation and the ellipsoid.

Ephemeris – Data transmitted by a GPS satellite that contains important information about the status of the satellite. This includes the current date and time and whether the satellite is healthy (performing correctly) or unhealthy (not performing correctly).

Epoch – The measurement interval (time) of a GNSS receiver, determining when observations are taken. The epoch varies according to the measurement type: for real-time measurement it is set at one second; for post-processed measurement it can be set to a rate of between one second and one minute.

Error – The difference between a measurement and the true or accepted value. In GNSS surveying it is the uncertainty of a measurement.

Feature Class – In ArcGIS, a collection of geographic features with the same geometry type (point, line polygon), the same attributes, and the same spatial reference.

Frequency – The number of vibrations per second of an audio or radio signal, measured in hertz (Hz), kilohertz (kHz), or megahertz (MHz). Dual frequency GNSS receivers receive radio signals on the L1 and L2 frequencies. External radio equipment will have a unique radio frequency to transmit and receive data.

Geodatabase – In ArcGIS a collection of geographic datasets of various types held in a common file system folder. Geodatabases can contain; feature classes, raster datasets, and tables.

Geodesy – The science of accurately measuring and understanding the geometric shape, orientation in space, and gravity field of the Earth.

Geodetic Monumentation – Survey markers, also referred to as Benchmarks, that represent known locations with precise X (Easting), Y (Northing), and Z (Elevation) coordinates. These are permanent, stable markers typically in the form of a brass disk, metal rod, cement or stone platform, or other permanent structure. GNSS equipment can be used to survey from these known points

Geoid – A model of global mean sea level with tides and currents removed. It is the equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level. This surface defines zero elevation.

Global Orbiting Navigation Satellite System (GLONASS) – A Russian satellite system comparable to the American GPS system. See Global Positioning System for more information.

Global Navigation Satellite System (GNSS) – A global system made up of networks of satellites that transmit ranging signals used for positioning and navigation. The GNSS includes the US GPS system and the Russian GLONASS system. The addition of other satellite systems is planned for the future. GNSS provides a denser coverage of satellites in the sky than GPS alone.

Global Positioning System (GPS) – A U. S. owned utility, which provides users with positioning, navigation, and timing (PNT) services. The system is made up of a constellation of 24 or more satellites. These satellites circle the Earth twice a day in very precise orbits and transmit radio signals with information about their location, status, and precise time. Receivers on Earth can receive a signal, note its exact time of arrival and calculate distance from the satellite. When a receiver acquires its distance from at least four satellites it can use geometry to determine its location on Earth in three dimensions.

Ionospheric/Tropospheric Delay – Delays in the speed of satellite signals as they pass through the atmosphere. Current GNSS systems have built in models that can partially correct this error by calculating an average amount of delay for the signals.

Light Detection and Ranging (LiDAR) – A remote sensing technique that uses light in the form of a pulsed laser to measure distances. The most common use of LiDAR is to measure the topographic surface of the Earth from an airborne vessel. The LiDAR unit does this by shooting pulsed lasers at the Earth's surface. The pulsed lasers then reflect off the Earth's surface and return to the system where a sensor records the information and combines it with scan angles, calibration data, and position and orientation data from integrated GPS and Inertial Measurement Unit systems running alongside the LiDAR unit. The result is a dense point cloud of elevation points that have three dimensional coordinates associated to them. LiDAR data is often used to create Digital Elevation Models (DEMs)

Metadata – Information that describes the content, quality, condition, origin, and other characteristics of data. Metadata for spatial data should describe and document its subject matter; how, when, where, and by whom the data was collected; availability and distribution information; its projection, scale, resolution, and accuracy; and its reliability with regard to some standard. Data collected for the NPS require Federal Geographic Data Committee (FGDC) Standards.

Multipath – Signal interference that occurs when GNSS signals reflect off objects before reaching the receiver's antenna. Multipathing can occur from reflections off the ground or off structures such as tall buildings, canopy, or large rock surfaces.

National Spatial Reference System (NSRS) – A consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States.

North American Datum of 1983 (NAD 83) – The Horizontal control datum for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the Geodetic Reference System of 1980. NAD83 is the current geodetic reference system for the U. S. It is based on the adjustment of 250,000 points, including 600 satellite Doppler stations, which constrain the system to a geocentric origin.

North American Vertical Datum of 1988 (NAVD 88) – The official vertical datum in the National Spatial Reference System (NSRS) for the Conterminous United States and Alaska. The datum was derived from a general adjustment of the first order terrestrial leveling nets of the United States, Canada, and Mexico. In the adjustment, only the height of the primary tidal benchmark, referenced to

the International Great Lakes Datum of 1985 (IGLD 85) local mean sea level height value, at Father Point, Rimouski, Quebec, Canada was held fixed, thus providing minimum constraint. This is the reference datum for elevations determined by geodetic leveling.

Online User Positioning System (OPUS) – A National Geodetic Survey (NGS) internet program that processes GNSS and GPS data files. OPUS sends the user highly accurate, computed coordinates in the National Spatial Reference System (NSRS).

Orthometric Height – The height (elevation) of a point on the topography (Earth's actual surface) above the Geoid. It is the distance along a plumb line from the point to the geoid. The Orthometric Height (H) = the Ellipsoid Height from GPS/GNSS (h) – the Geoid Height (N).

Post Processed Kinematic (PPK) – A GPS/GNSS survey technique whereas two receivers collect data at the same time independently of each other (no radio connection) and differential corrections are made after the survey has ended. This is done with one base station located at a known location and at least one rover receiver taking measurements away from the base station. Corrections are made after the survey has ended with GNSS software on an office or laptop computer.

Post-processing – The processing of GNSS data after it is collected with GNSS software on an office or laptop computer. The most typical form of post-processing is performing differential correction.

Precision – The repeatability of a measurement independent of accuracy.

Raster – A spatial data model that defines space as an array of equally sized cells arranged in rows and columns, and composed of single or multiple bands. Each cell contains an attribute value and location coordinates.

Real-Time Kinematic (RTK) – A GPS/GNSS survey technique whereas differential corrections are sent in real time from one receiver to another. Corrections are calculated at a base station which is collecting data at a known location and sent to the rover receiver through a radio link. The rover receiver then applies the corrections to its position to acquire very accurate position in the field.

Root Mean Square (RMS) – A measurement of accuracy associated with the difference between predicted and observed values. In GNSS surveying RMS is used to show the accuracy of collected points.

Rover Receiver – A mobile GNSS or GPS receiver that is used to collect or update data in the field, typically at an unknown location. A rover receiver can connect (through radio) with a base station to receive real time differential corrections in the field (RTK). It can also collect data autonomously, however the data must be post processed to achieve better accuracy (PPK)

Sediment Elevation Table (SET) – Also known as Surface Elevation Tables. Portable mechanical leveling device used to measure the relative elevation change in wetlands. SETs consist of a stable monument driven into the Earth upon which the SET instrument is placed. A series of pins are used to measure accretion or subsidence on the wetland surface from the SET instrument.

Spatial Reference – The georeferencing and coordinate system assigned to any geographic data. The spatial reference defines how the geographic data is mathematically transformed onto a flat map with the least amount of distortion.

Universal Transverse Mercator (UTM) – A grid coordinate system that provides horizontal positioning representation similar to latitude and longitude. UTM divides the Earth into 60 north-south zones, each 6 degrees wide in longitude. In each zone coordinates are measured north and east in meters. Positions are expressed as Northing and Easting.

World Geodetic System 1984 (WGS-84) – A global reference frame (datum) used by the U. S. Department of Defense (DoD) and defined by the National Geospatial-Intelligence Agency (NGA). This is the datum used by GPS satellites and receivers. Coordinates computed from GPS receivers are likely to be provided in terms of the WGS84 datum and heights in terms of the WGS84 ellipsoid. These coordinates can then be converted to other reference systems

Overview

This methods document (hereinafter referred to as standard operating procedure (SOP)) represents an effort to provide best practices and guidelines for on-the-ground high resolution elevation data collection in salt marshes through the use of Global Navigation Satellite System (GNSS) equipment. It is written for coastal parks in the Northeast Coastal and Barrier Island Network (NBCN) but may be applicable to other parks and other networks. Specifically these methods were developed while conducting field work at Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS), and Gateway National Recreational Area (GATE). This procedure is meant to provide users with the knowledge and skills to perform elevation surveys in the field with GNSS equipment. It also acts as a standard to which data should be collected.

The SOP is set up into three major sections; “before the field,” “in the field,” and “after the field.” These sections should guide the user through the complete survey process from start to finish. Understanding the basics of GNSS surveying is essential to collecting good quality data. Therefore it is the goal of this document to give the user insight into these topics in addition to providing workflows. A technical glossary is provided at the end of the document for common terms used throughout the report.

The GNSS methods and procedures set forth in this SOP are based on the use of Trimble R10™ multi-frequency GNSS receivers, Trimble TSC3™ handheld controllers, Trimble Access™ Version 2014.12, and Trimble Business Center™ (TBC) Version 3.51. ArcGIS™ Version 10.2 and 10.3 were used for all geographic information system (GIS) related tasks. While GNSS and GIS equipment and software versioning may change in the future the basic principles and procedures should remain similar with ongoing software and firmware updates.

The elevation survey method includes:

1. Delineating site boundaries from aerial imagery with Geographic Information System (GIS) software.
2. Creating a 20 meter (m) grid of points within salt marsh sites using GIS.
3. Creating a GNSS survey Job and loading grid points into GNSS equipment.
4. Setting up a Real Time Kinematic (RTK) or Post Processed Kinematic (PPK) Survey.
5. Navigating to grid points with GNSS equipment.
6. Collecting elevation data in the North American Vertical Datum of 1988 (NAVD88) at each grid point.
7. Collecting a “check-in” elevation point at a known location during the survey for quality assurance.
8. Uploading the elevation data into GNSS desktop software or a GIS platform for processing.

Introduction

Salt marsh habitats are especially vulnerable to sea level rise (SLR) and increases in storm surge associated with climate change (Holgate & Woodworth, 2004); (Kemp, et al., 2011), (Murdukhayeva, August, Bradley, LaBash, & Shaw, 2013). The current elevation of these marshes relative to specific tidal datums, such as Mean High Water (MHW), is critical to understanding how these habitats will respond to climate change. Salt marshes have specific growth ranges that are influenced by the frequency, duration, and depth of flooding of the marsh surface. Changes in sea level or marsh elevation can have direct consequences on plant growth, sedimentation, and marsh sustainability (Cahoon, et al., 2006). Elevation data exists for most coastal parks in the form of Light Detection and Ranging (LiDAR) data. LIDAR however, fails to accurately represent the elevation of salt marsh environments (Morris, Sundareshwar, Nietch, Kjerfve, & Cahoon, 2002); (Gesch, 2009); (Hladik & Alber, 2012); (Schmid, Hadley, & Wijekook, 2011). Dense salt marsh vegetation and standing water obstruct the LiDAR laser pulse from hitting the peat surface. This causes an overestimation of the marsh surface elevation. To acquire higher accuracy elevation data than provided by LIDAR and to ensure elevations represent the entire salt marsh surface (peat or platform), we partnered with the NPS Northeast Coastal and Barrier Network to create a standard method for collection of on-the-ground elevation data using GNSS in salt marshes.

GNSS Surveying

The most practical method of accurately determining the elevation of the salt marsh platform (relative to a published datum) is by on-the-ground measurement using Global Positioning System (GPS) (National Ocean Service, 2010). GNSS surveying uses GPS and Global Orbiting Navigation Satellite System (GLONASS) satellites to determine locations and elevations on the earth. RTK and PPK GNSS surveying involves the use of at least two GNSS receivers and one controller or data collector that configures the survey style. One GNSS receiver acts as a base station while the other acts as a rover. The base station consists of a GNSS receiver, mounted on a tripod, placed at a known position. The base receiver continuously collects data at this one position over the entire survey period (Figure 1). The second GNSS receiver, known as the rover, is typically mounted on a bipod or a pole and is used to collect GNSS information away from the base station. The base station data is used to differentially correct the data collected at the rover. These corrections greatly improve the accuracy of the rover data in real time.

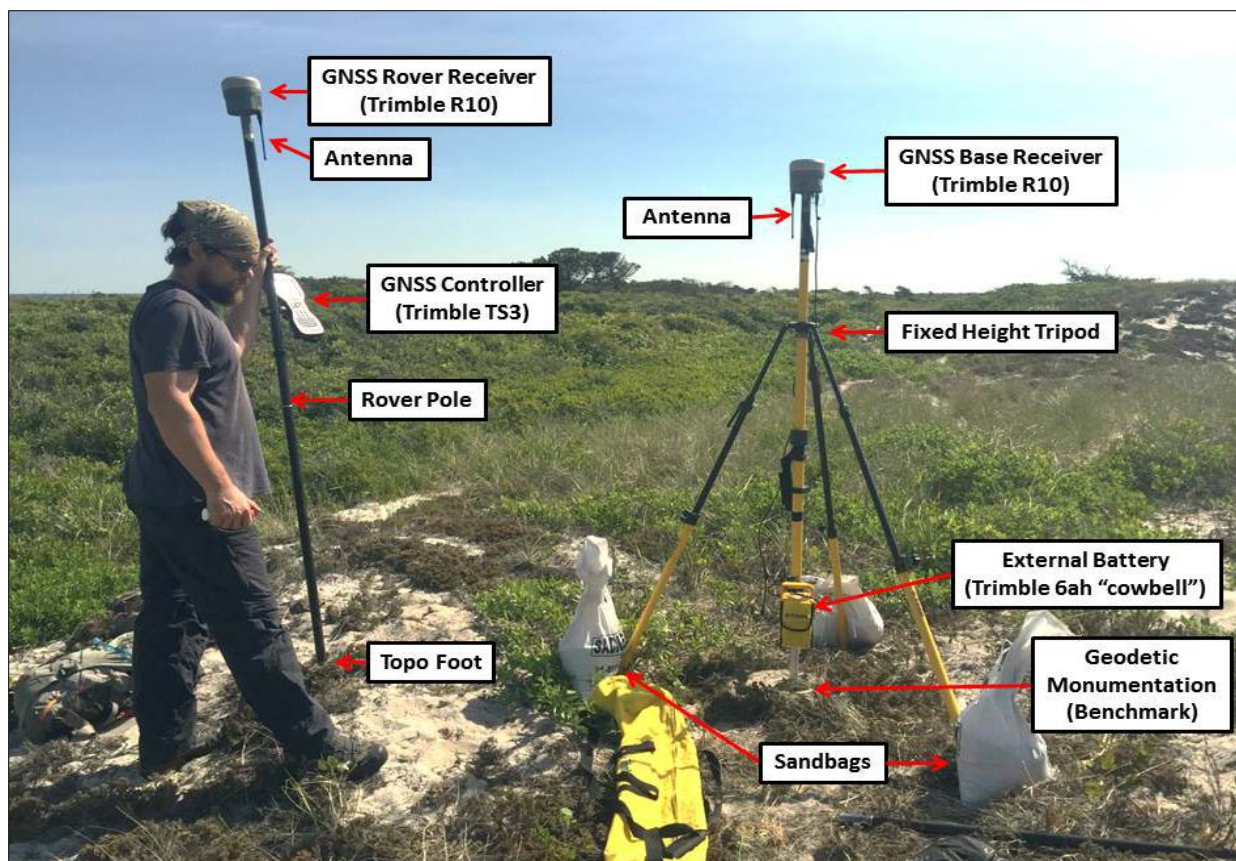


Figure 1. A GNSS survey setup, showing a base receiver occupying a known bench mark, and a rover receiver taking measurements away from the base.

1. Before the Field

1.1 Delineating Site Boundaries

Once general locations have been selected, site boundaries should be delineated (Figure 2). The quickest way to do this is with aerial or satellite imagery in GIS. Natural boundaries can often be used to form the edges of sites such as large creeks or ditches, tidal rivers, bay edges, or the abrupt vegetation change at the upland marsh edge. Typically upland shrub habitat can be identified in imagery and the user should use their best judgement to form a boundary near this area. Including some upland environment in the site is important for understanding future migration of salt marsh environments. However navigating to and collecting points in the upland can be difficult, so limiting these points is advised. It can be difficult to accurately delineate natural boundaries and edges using dated aerial imagery with poor resolution. If possible, having a field crew walk the marsh site with a GPS/GNSS receiver is the best option. The size of the site should be carefully considered as it dictates the amount of time and work needed. The average site size from 26 marsh units that were surveyed at ASIS and FIIS in 2014 and 2015 was 6.5 hectares (ha). The largest site was 13.3 ha while the smallest was 3.1 ha. Most of these sites existed previously as long term vegetation and nekton monitoring sites in the NCBN. Additional sites were chosen and delineated by park personnel based on their resource needs.

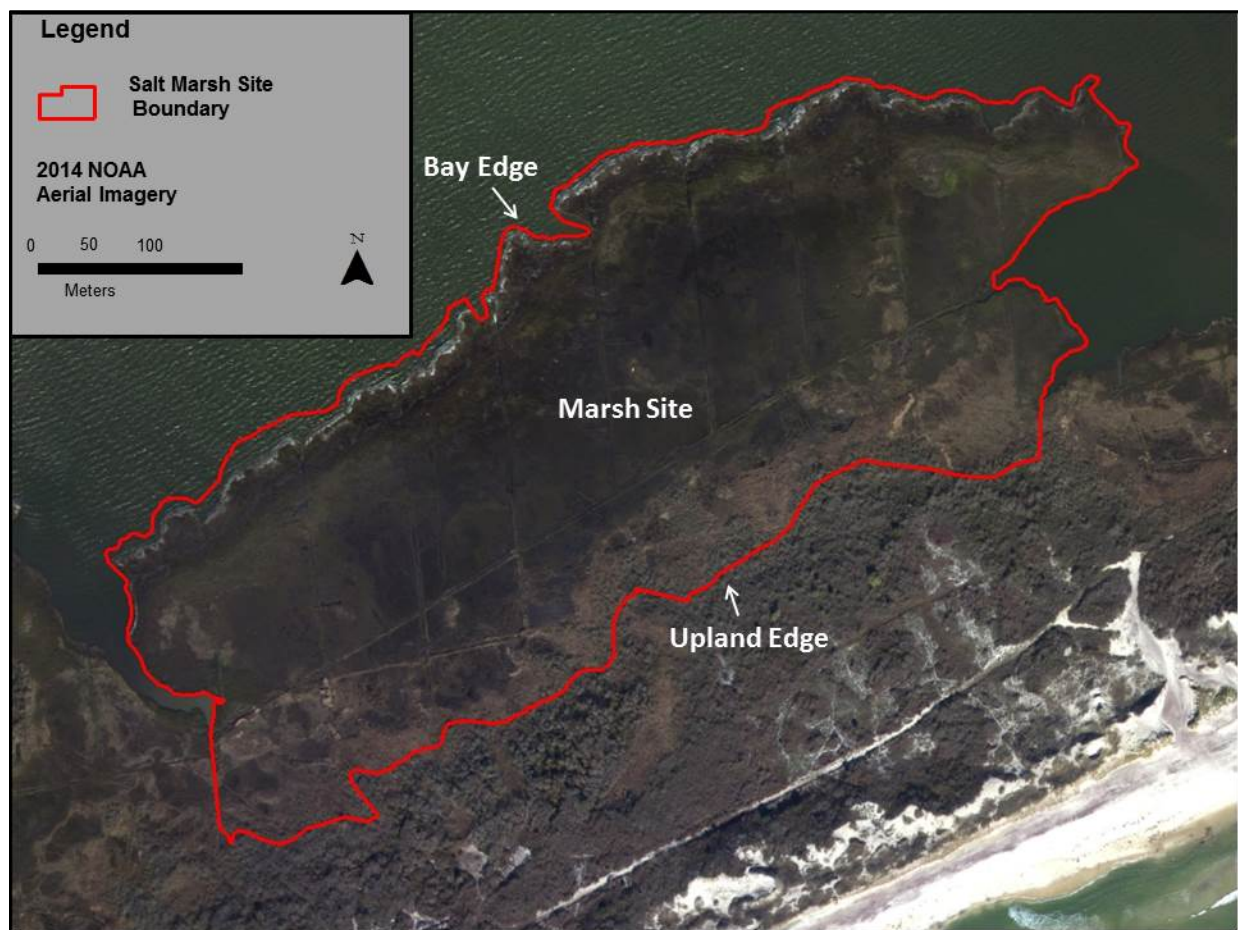


Figure 2. A map of a salt marsh site boundary delineated through aerial imagery.

To create marsh site boundaries in ArcGIS (version 10.2 or 10.3) (Figure 2):

Create a **Shapefile** (Figure 3):

1. Open **ArcMap** (an existing document or a new one).
2. Add Imagery by using the **Add Data** tool on the standard toolbar
 - a. Select **Add Basemap**.
 - b. Add the Imagery or Imagery with **Labels Basemap**.
3. Open **ArcCatalog** by selecting the ArcCatalog icon on the menu bar.
4. **Right click** on a folder and select **New** → **Shapefile**
 - a. **Name** the shapefile with an appropriate identifying title.

Note: Avoid spaces and special characters when naming files in GIS as they can cause issues with the data. Underscores are recommended to separate text.

- b. Select **“Polygon”** for **Feature type**.
- c. Select **Edit** and select a **Spatial Reference: Projected Coordinate System** → **UTM** → **North America** → **NAD 1983 (2011) UTM Zone “##”**.
- d. Select **OK**.

Note: The NPS Northeast Region typically uses the Universal Transverse Mercator (UTM) coordinate system. It is a good practice to set the spatial reference of the ArcMap document to UTM coordinates as well. To change the coordinate system of the map document: Right click on Layers in the Table of Contents → Select Properties → Coordinate System → NAD 1983 (2011) UTM Zone “##” Reference a UTM Zone Map to determine the correct zone for a park unit (National Geospatial Intelligence Agency, 2014).

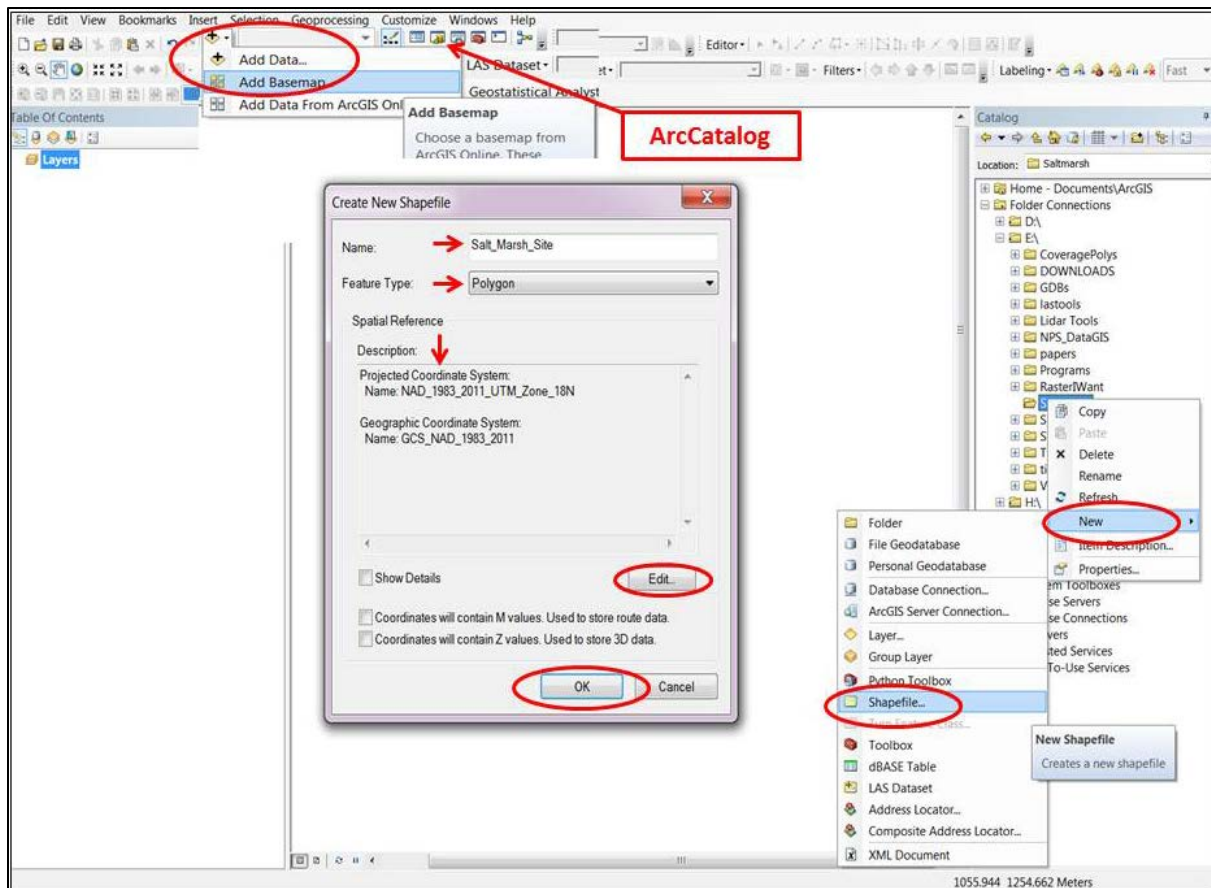


Figure 2. Creating a shapefile in ArcGIS.

Create the marsh boundary using Editor and the ESRI Imagery Basemap (Figure 4):

Note: This is a continuation of **Create a Shapefile** (above) and should be performed by using the **ESRI Imagery Basemap** as guidance for the site boundaries.

1. Select **Start Editing** under the **Editor** drop down.
2. Select **Create Features** on the Editor Toolbar.
3. Select the appropriate shapefile at the top of the Create Features window and select **polygon** under the **Construction Tools** section.
 - a. Use the mouse to **create vertices** that will make the boundaries of your site. You can right click a vertex to delete it, or insert a new vertex by right-clicking anywhere on your map.
 - b. To complete the polygon, double clicking on the last vertex.
 - c. Select **Save Edits** under the Editor drop-down to frequently save your work and select **Stop Editing** to complete an area.

Note: If the **Editor toolbar** is not visible; select **Customize** → **Toolbars** from the main menu. Then select **Editor** from the drop down list.

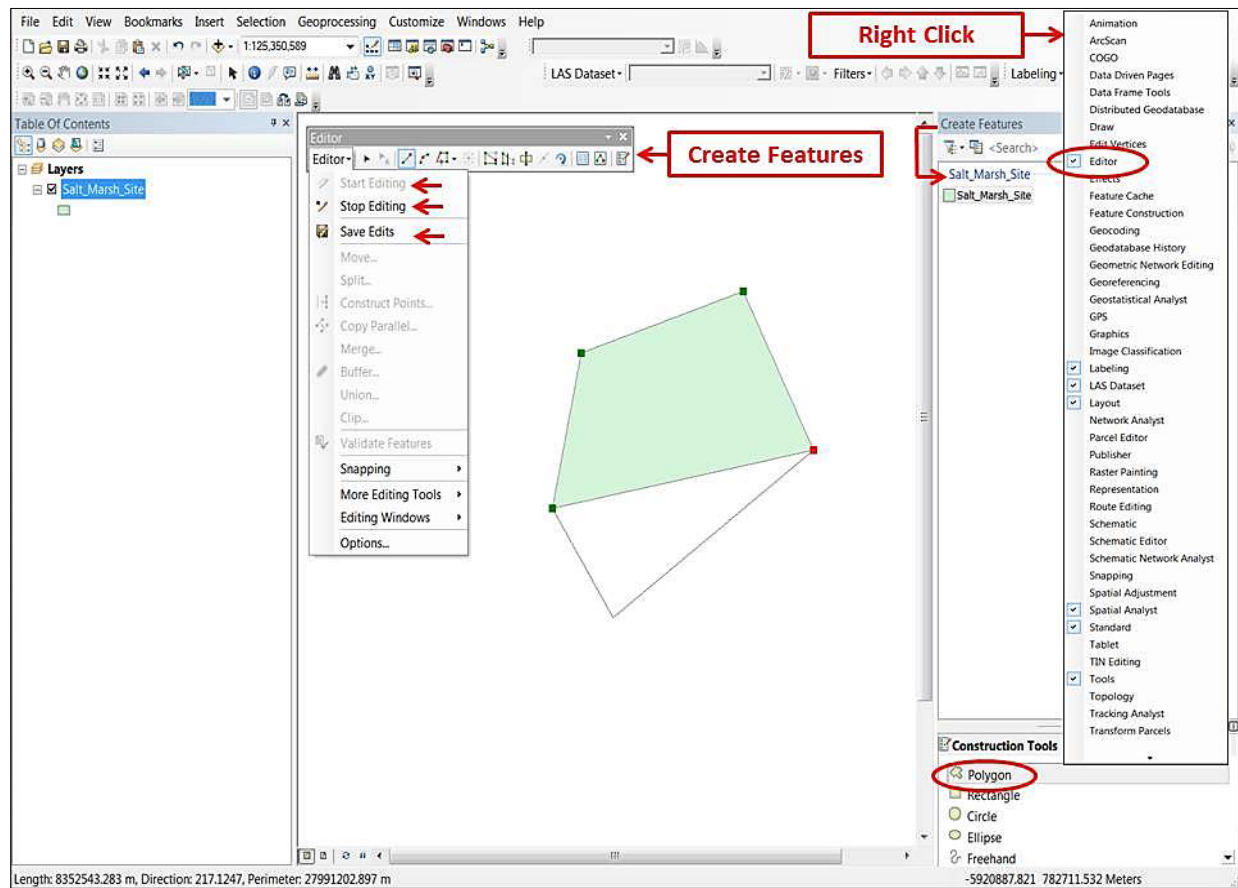


Figure 3. Editing a shapefile in ArcGIS.

Edit the Attribute Table to distinguish sites (Figure 5):

Note: This is only necessary if more than one site was created in a single shapefile.

1. Right click on the shapefile and select **Open Attribute Table**.
2. Select **Add Field**.
 - a. Name the Field
 - b. Select the **Type** of field (e. g. text, float, date, etc.) and the character **Length**.
 - c. Select **OK**.

Note: **Text** should be chosen for attribute that will be text based such as name. For attributes that will have numbers in them the select **Float** or **Double**.

3. Select **Start Editing** on the Editor Toolbar.
 - a. Click in the Attribute Table to enter a value.
 - b. Select **Save Edits** and **Stop Editing** from the Editor Toolbar.

Note: The **Calculate Geometry** function in the **Attribute Table Menu** is useful for calculating the area of each site. Make sure to choose the correct coordinate system and the desired measurement units. This can be done outside an edit session.

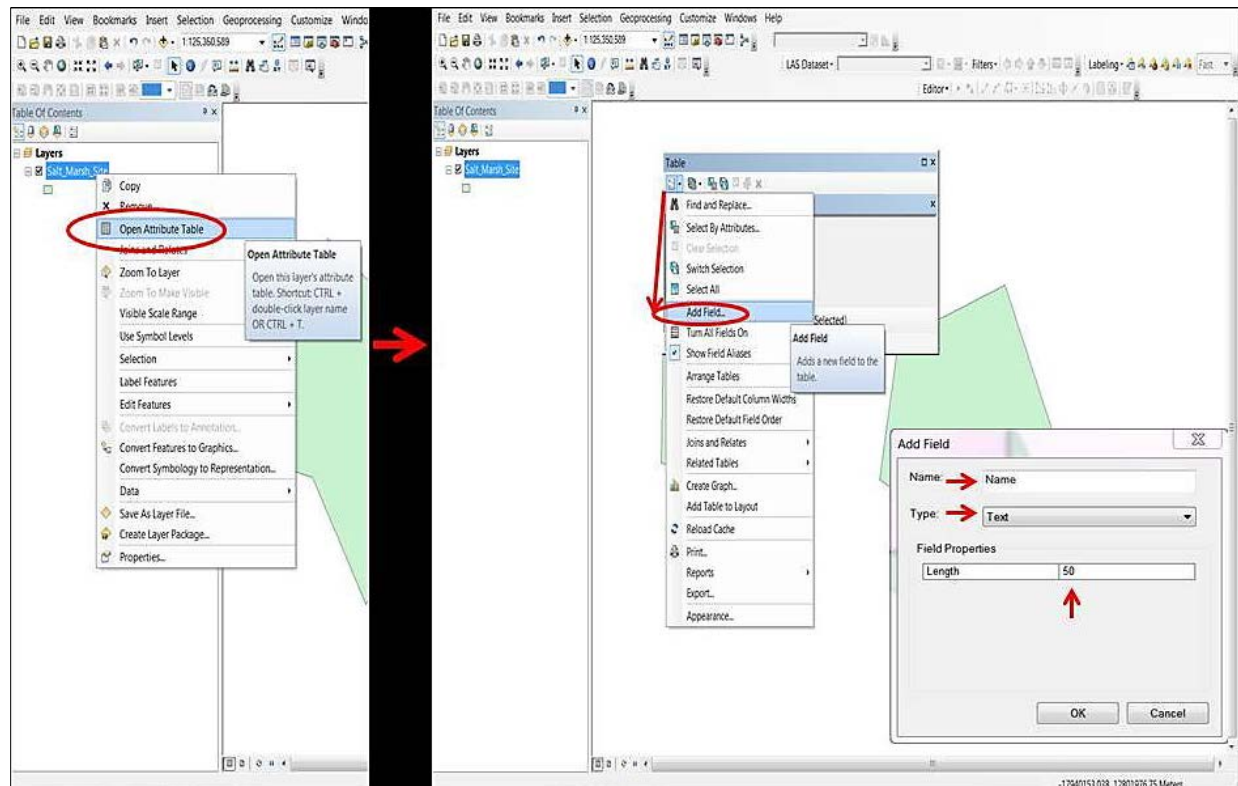


Figure 4. Adding fields to the Attribute Table.

1.2 Grid Spacing

Determining where to collect elevation points is a critical piece in creating a meaningful survey. For specific features on a landscape, elevation points can be collected in close vicinity of the feature, but when trying to represent large areas, such as salt marshes, a different approach must be taken. To achieve full spatial coverage of a salt marsh a uniformly spaced grid of points should be used to capture elevations. For example, in order to cover a 1 hectare marsh at a 2 m point resolution it would require a total of 2500 points to be collected (Table 1). The spacing between grid points, and therefore elevation measurements, is an important parameter to establish to ensure efficiency and accuracy in the survey. Fine spacing (short distance between points) will allow dense spatial coverage of a marsh but will require an inordinate amount of time to collect. Coarse spacing, while requiring less time and effort, leads to a lack of detail in representing the true marsh surface. Having a dense enough spatial coverage is essential for creating digital elevation models (DEMs). Finding

the balance between spatial coverage and the desired amount of time in the field will determine appropriate grid spacing.

Table 1. The number of points in a 1 Hectare (square) at different grid spacing intervals.

1 Hectare Marsh Site	
Grid Spacing (m)	# Pts
30	9
20	25
10	100
5	400
2	2500

To better understand this relationship, the effect of point spacing was analyzed on DEM creation (Figure 6). Bare earth LiDAR data (1 meter point spacing) was used as a surrogate for GNSS marsh elevation data. Elevation values were associated from a LiDAR surface to point datasets at different grid spacing intervals (2m, 5m, 10m, 20m, and 30m). These point datasets were then interpolated to create new DEMs. An “accuracy” assessment was then performed to show which of the newly created DEMs best replicated the original LiDAR surface. For this analysis, accuracy was defined as the average difference in elevation value, at a random selection of points, between the original LiDAR dataset and the DEM created from a sub-set of points (from the original LiDAR) at different spacing.

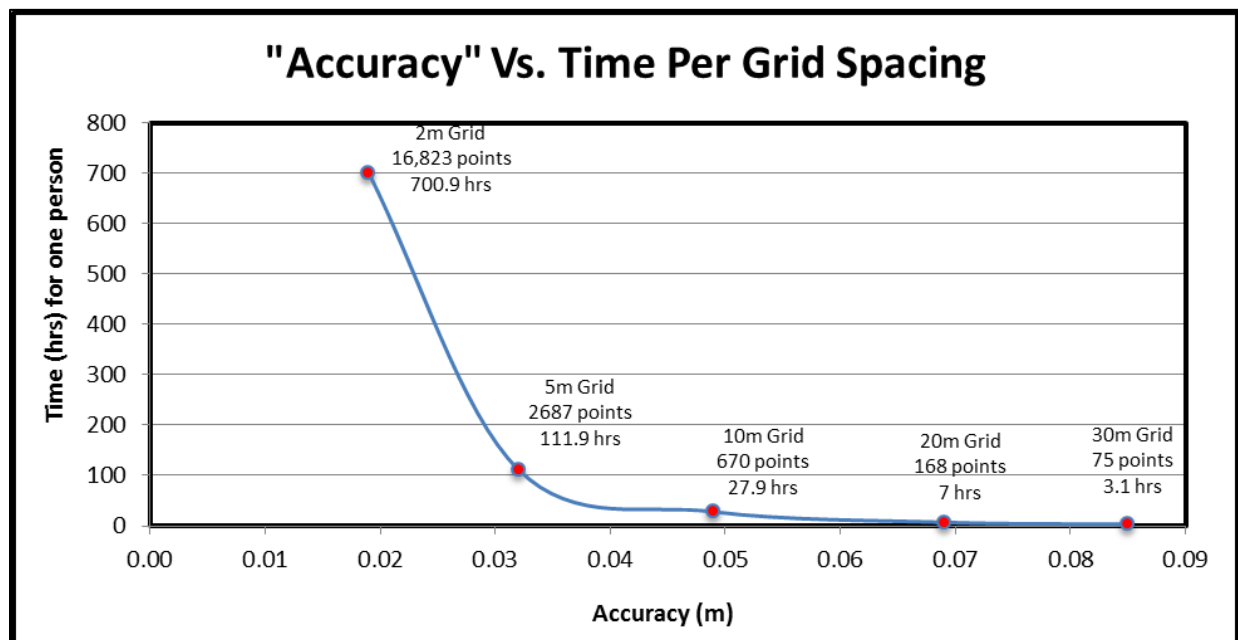


Figure 5. The number of points and time estimates are based on a 6.7 hectare marsh study site at ASIS. In this graph “accuracy” refers to the average difference in elevation values, at a random selection of points, between an original LiDAR dataset and a DEM created from a sub-set of points (from original LiDAR) at different grid spacing.

It took an average of 2.5 minutes for a field worker to survey a point during elevation surveys completed at ASIS at a 20 m grid spacing. This estimate is based on total survey time (start of survey to end of survey) divided by the number of field workers. It does not include time spent traveling to sites, setting up, or taking down equipment. This can be used to estimate the time it will take to survey an entire marsh site, based on the number of points and the number of field workers.

A 20 m grid spacing is recommended as it seems to balance point spacing resolution and field time. By collecting points at 20 m detail in our representation of the marsh surface is ensured and managers can be confident that surveys will be done in a timely manner. While grid spacing intervals less than 20 m will cover more marsh surface and produce more accurate DEMs, they will also allocate much more time and resources. Park managers will have to assess if this gained “accuracy” is necessary to meet project goals. In order to collect points every 20 m, we recommend creating a 20-m grid of points first using ArcGIS (next section below) and then loading this grid into the handheld controller (see 2.10 Navigating to Grid Points).

To create a grid of points in ArcMap:

1. Use the **Create Fishnet Tool** (Figure 7) – (found in: **ArcToolbox** → **Data Management Tools** → **Feature Class** → **Create Fishnet**).

Note: Use the **Search** Menu to quickly locate tools in ArcMap.

2. Name the grid (with a specific folder path) in the **Output Feature Class** tab. This will create a new shapefile.
3. Select the marsh site polygon of interest (created in 1.1 Delineating Site Boundaries) in the **Template Extent** dropdown.
 - a. The **Fishnet Origin Coordinate** fields will auto-populate with the spatial extent of the marsh site.
4. Enter the **Cell Size Width and Height**.

Note: **20 meters** is recommended. The units are designated by the coordinate system of the **Template Extent** shapefile. To verify this; select the **Environments** tab → Select **Output Coordinates** → **Output Coordinate System** → **Same as Input**.

5. **Check** the box for **Create Label Points**.

Note: This command produces the actual grid points. The fishnet tool itself creates square or rectangular grids. The grid point file will have the suffix “_label”.

6. The **Geometry Type** box can be set to **Polyline** or **Polygon**.
7. Select **OK**.

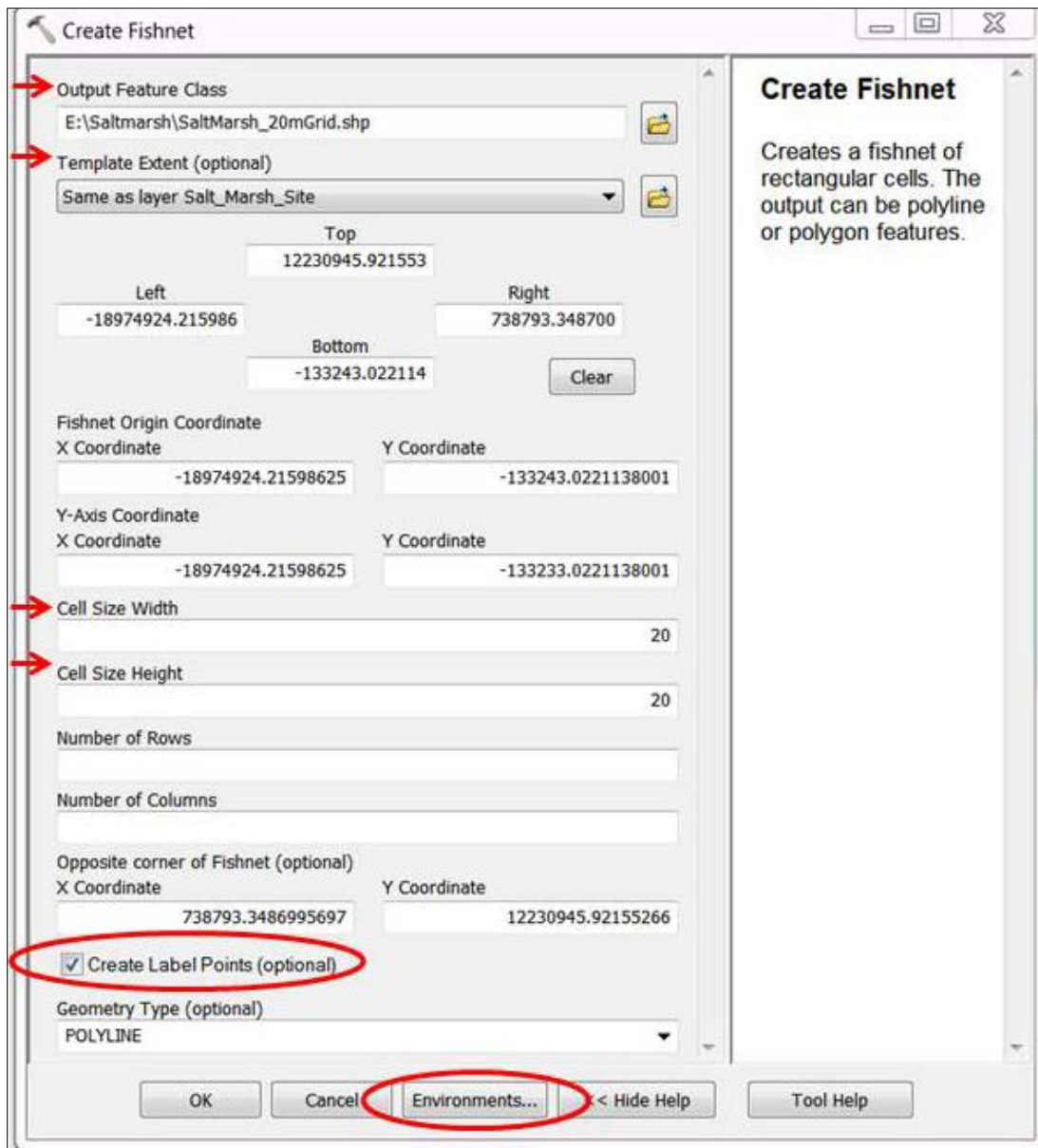


Figure 6. The Create Fishnet Tool is used to create a grid of points at a specific interval.

Clip the grid points (Label Points) to the marsh site (Figure 8)(Figure 9):

1. Use the **Clip** tool – **ArcToolbox** → **Analysis Tools** → **Extract** → **Clip**.
2. Select the grid points “_label” as **Input Features**.
3. Select the Salt Marsh Site polygon as the **Clip Features**.
4. Name the **Output Feature Class** to a specific folder path.
5. Select **OK**.

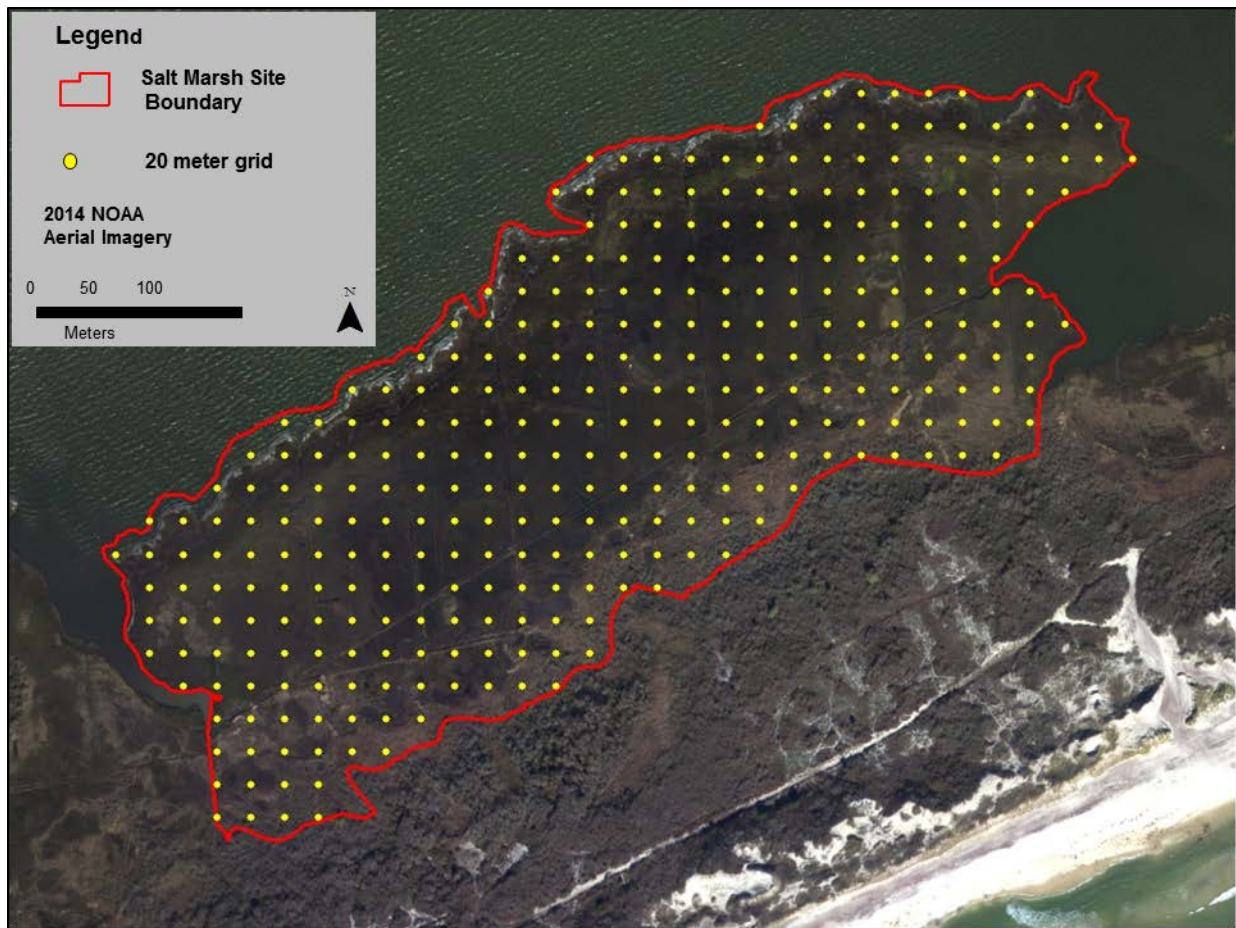


Figure 7. A 20 meter grid of points overlaid on a marsh site.

Add Northing and Easting coordinates to the grid points (Figure 9):

1. Open the **Attribute Table** of the new grid point file.
2. Select **Add Field** from the menu dropdown.
 - a. Add fields: **Northing** and **Easting**. Type -> **Double**.
3. Right Click on the fields and select **Calculate Geometry**.

Note: Select Yes to the popup that you are about to calculate outside of an edit session.

4. Select **X coordinate of point for Easting**, and **Y coordinate of point for Northing**.
5. Select **Use** coordinate system of the data source.
6. Select **Meters** for **Units**.
7. Select **OK**.

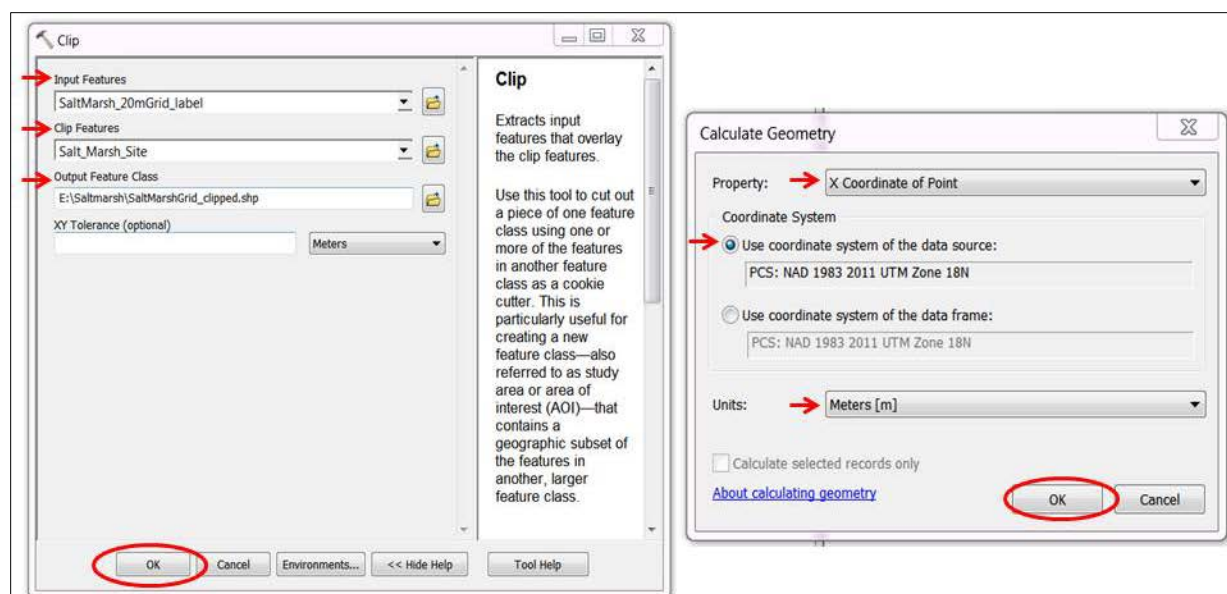


Figure 8. Screenshots from the Clip Tool and Calculate Geometry Tool.

In order to use the grid points in GNSS equipment they must be exported from ArcMap and saved in a compatible format. We recommend using a comma space delimited (.csv) format.

To Export the grid points:

1. From the **Attribute Table** dropdown menu select **Export**.
2. Select **All Records**.
3. Choose a folder location to save the file and choose **Text File** in the **Save as Type**.
4. Select **OK**.

To save as a .CSV and Edit the Text file:

1. Open **Microsoft Excel** and select **File** → **Open**.
2. Select **All Files** for the **File Type** (next to file name).
3. Select the **Grid Points Text File**.
4. On the **Text Importer Wizard** select **Delimited** on the first page.
5. Select **Next**.
 - a. Check the box for **comma** on the second page.
6. Select **Finish**.
7. **Edit** any fields necessary.

Note: The .csv grid point file should be formatted as 3 columns, point ID, Northing, and Easting. Avoid spaces and special characters and make sure there is no formatting for the columns.

8. Save the file as a **CSV (Comma Delimited)** .csv file.

Note: To import the .csv grid point file into the GNSS handheld controller use an external hard drive / thumb drive (See 2.11 Active Map). It is recommended to do this in the office to ensure the files upload properly. If there are any issues, re-check the formatting of the .csv file.

1.3 Creating a Feature Library

A feature library is a template of attributes that can be associated to points collected in the field. An example of an attribute that would be stored with a GNSS elevation point is habitat type (i.e. marsh, upland, mudflat, etc.). Feature libraries can be created with GNSS software such as TBC and Trimble Access and are loaded into GNSS handheld controllers used in the field. It is recommended to create a feature library for salt marsh elevation projects. For each elevation point collected in the field, the user must select an attribute, or attributes, that best represents the location of the point. These attributes are useful in post processing of the data and for further analysis and landscape classification. The most practical attribute associated with elevation is topographic feature, but for more intensive research projects attributes such as vegetation, salinity, or soil characteristics may be added (Figure 10). When developing a feature library, consider how the features and attributes address the research question and can be easily identified in the field. It is best practice to keep feature libraries simple. This helps to limit the amount of input for field crews and avoids collecting unnecessary data.

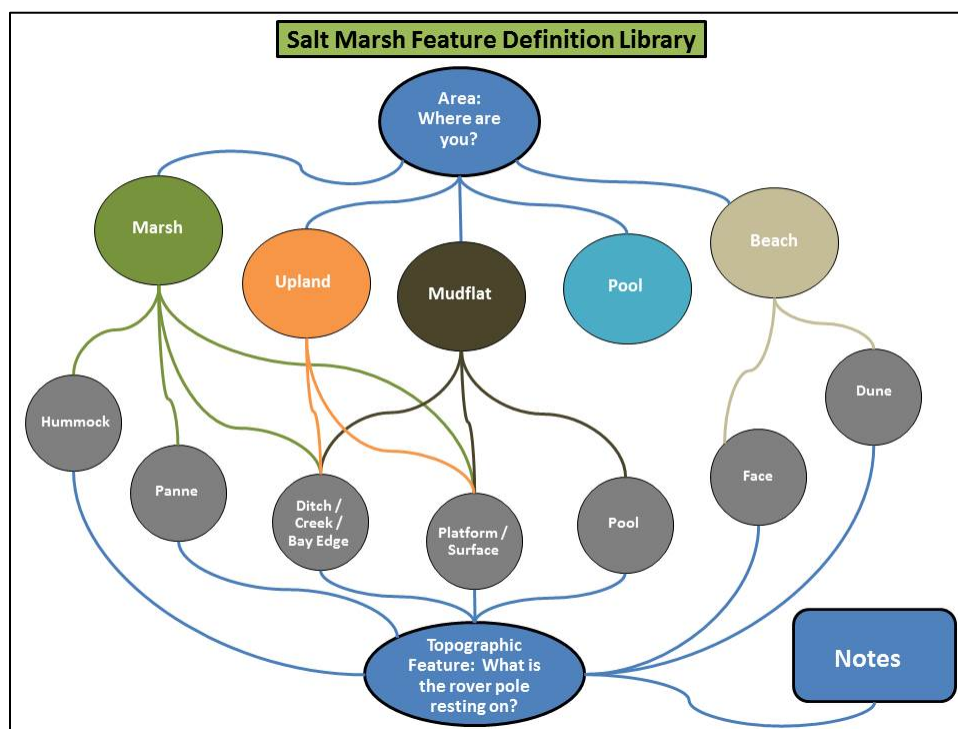


Figure 9. An example data structure that can be used to associate landscape characteristics to elevation points. See Appendix D: Topographic Feature Definitions for common definitions.

Note: The “GIS package” in TBC (which requires advanced licensing and not discussed in this SOP) can enable users to interact directly with geodatabases. This allows fields or attributes in geodatabases to transfer directly into TBC. If the “GIS package” is not installed follow the steps below to create a feature library.

There are two ways to create a feature library:

- A simplified feature library can be created in GNSS software (Trimble Access) on the handheld controller. This functionality is built into the Trimble Access software.
- A more detailed feature library can be created in GNSS desktop software (TBC). Users will need a TBC advanced license to access the **Feature Definition Manager** used to create feature libraries.

To create a feature library on the GNSS (Trimble) controller (Trimble Access) (Figure 11):

1. Turn on the controller and open **Trimble Access**.
2. Select **Settings** → **Feature Libraries** from the Trimble Access homepage.
3. Select **New** from the Feature Libraries page.
 - a. Name the Feature Library (i.e. Salt_Marsh_Elevation).
4. Highlight the Feature Library from the list and select **Edit**.
5. Select **Add**.
 - a. Enter a **Feature Code** (i.e. Ma, Up, Ce, Be), a **Description** (i.e. Marsh, Upland, Creek Edge, Bay Edge), and the **Feature Type** (point).
6. Select **Accept**.
7. Select **Store**.

Note: This type of feature library only allows the user to select one feature code (attribute) per point. If more than one attribute is needed, TBC should be used to create the feature library and then imported into the GNSS handheld controller.

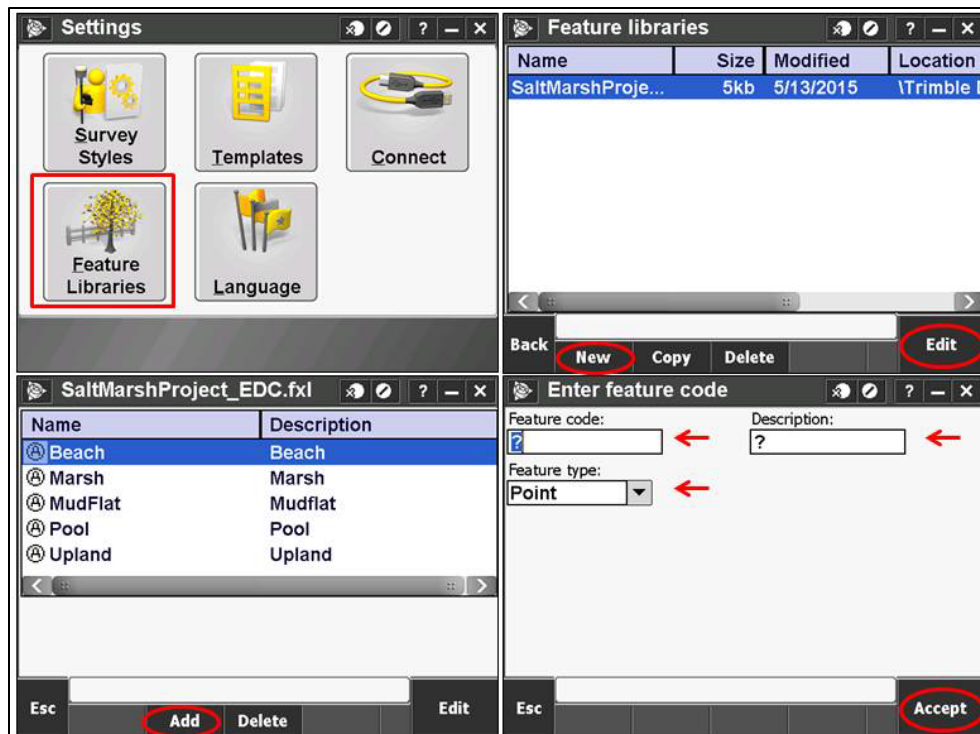


Figure 10. Creating a Feature Library in Trimble Access.

To create a feature library in TBC (Figure 12):

1. Select **File** → **Tools** → **Feature Definition Manager** from the TBC homepage.
2. Select **File** → **New File**
3. Select **Edit** → **New Category**
 - a. Name the new Category (i.e. Area).
4. Select **Edit** → **New Point Feature Definition**.
 - a. Name the new Point Feature Definition (i.e. Marsh).
 - b. Create a Code for the new Point Feature Definition (i.e. Ma or Marsh).

Note: The default values can be left in the Layer and Color fields which denote how the points will be displayed. The “include in surface” box can be left unchecked.

5. Select the new category and select: **Edit** → **New** → **New Attribute** → **List**
 - a. Name the list (i.e. Topographic Feature)
 - b. Enter a **Description**
 - c. Select **Required** for **Entry Mode**.

6. Select **Add**

- a. Name the attribute/s (i.e. surface, ditch edge, mudflat, panne).

Note: It is recommended to add a Text attribute entitled Notes. This will allow users to always have the option to input any relevant notes about a point in the field.

7. Select **File** –> **Save** (as a .fxl file).

Note: To load the file into a GNSS handheld controller use an external memory stick and import the file into the same folder directory where the survey Job will be housed.

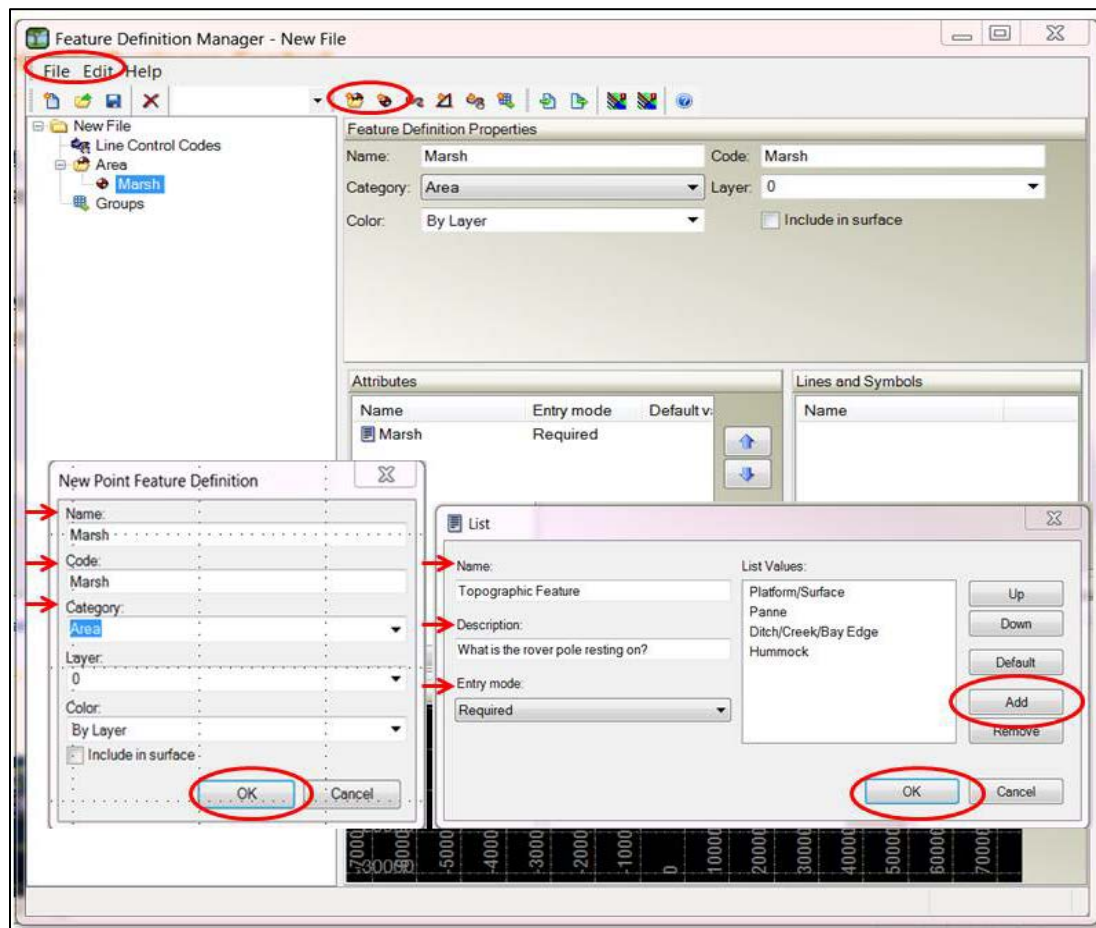


Figure 11. Creating a Feature Library TBC's Feature Definition Manager.

1.4 Creating a Survey Job

Trimble controllers require the user to create a Job file in which survey data will be organized and stored. This is done in the Trimble Access software on the Trimble controller. For salt marsh elevation surveys it is recommended that each salt marsh have its own separate Job file with the same settings. This will be helpful in organizing and storing data from elevation surveys. A Job Template can be created and stored on the controller and used within multiple wetland sites to assure that the same settings are used for all surveys.

To create a survey Job (Figure 13):

1. Turn on the Trimble controller and Open **Trimble Access**.
2. Select **General Survey**.
3. Select **Jobs**.
4. Select **New Job**.
 - a. **Name** the Job.
 - b. Select a pre-defined **Template** or edit the **Properties** as necessary.

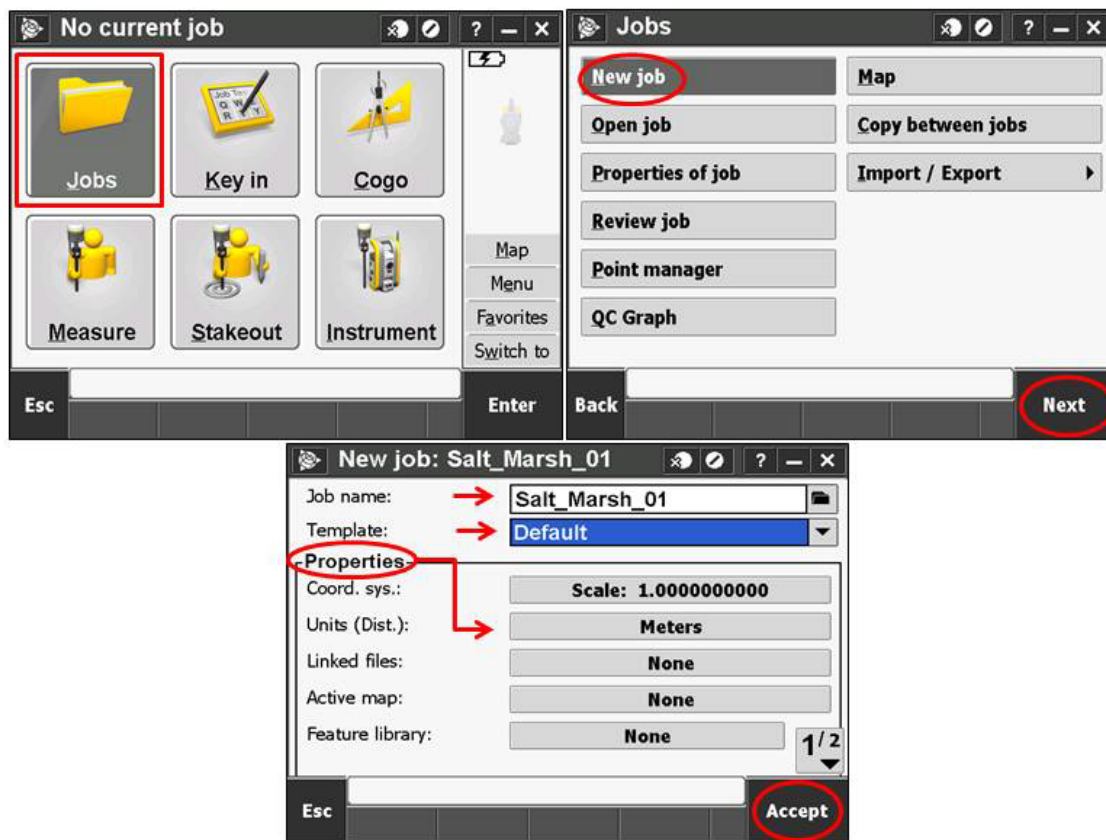


Figure 12. Creating a survey Job in Trimble Access.

Note: Jobs can also be created in TBC and exported into the controller. However, there can be compatibility issues between updated versions of TBC and Trimble Access. Creating the Job in Trimble Access ensures that the file will be in the correct format for data collection.

To create a Job Template (Figure 14):

1. Select **Settings** from the **General Survey** screen.

2. Select **Templates**.
3. Select **New**.
 - a. **Name** the template.
 - b. Select appropriate **Properties**.

Note: An example of a Job Template is included in Appendix A: Job Template.

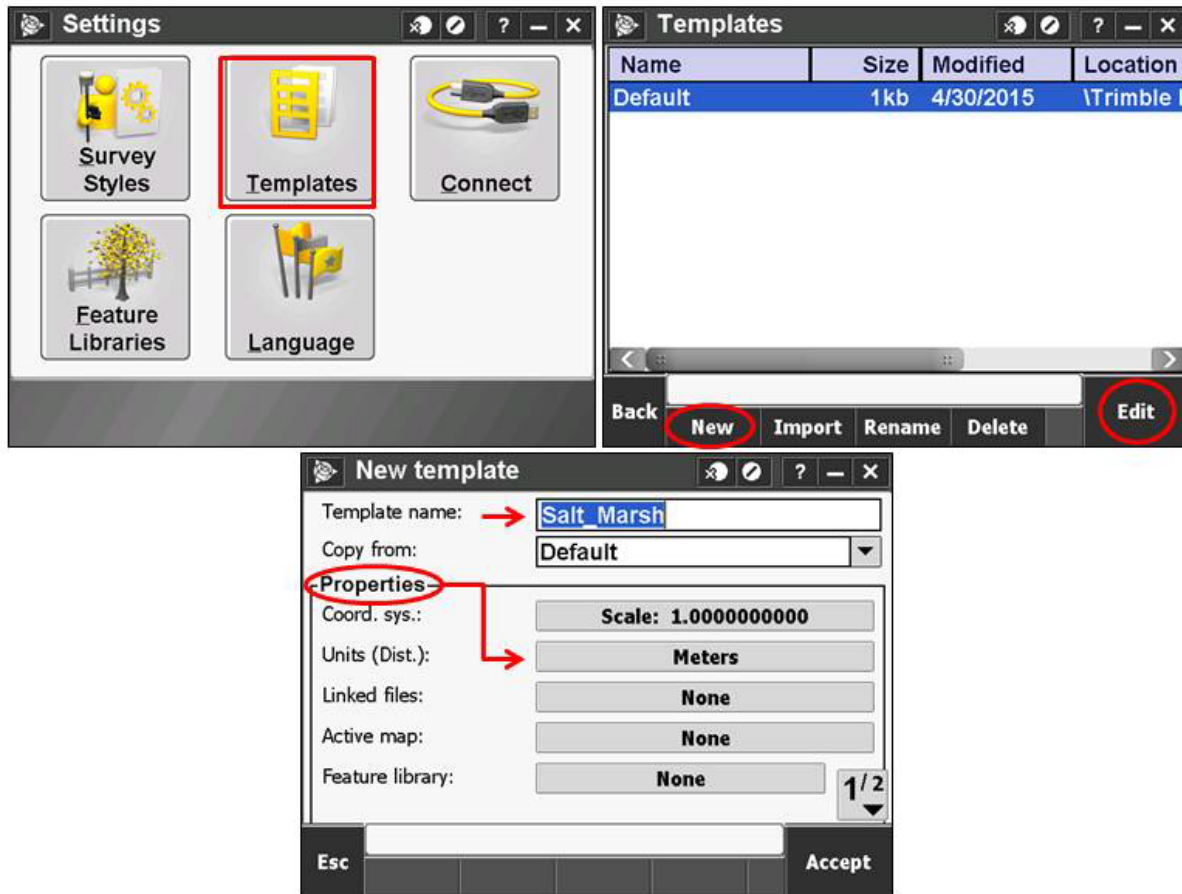


Figure 13. Creating a custom Template in Trimble Access.

When creating a survey Job, you will need to be familiar with the following topics and settings:

1. Coordinate System

A coordinate system is a system of numbers or coordinates used to precisely determine positions relative to a specific datum or reference point. Autonomous GNSS measurements taken in the field are automatically referenced to the 1984 World Geodetic System ellipsoid (WGS-84). To work in local grid coordinates, a projection and datum transformation must be specified. A datum transformation applied to the WGS-84 coordinates, produces local geodetic coordinates. A projection transforms local geodetic coordinates into local grid coordinates. Surveys should use the Universal

Transverse Mercator (UTM) grid coordinate system units (Northing and Easting) with the appropriate zone number for the wetland in which surveys are conducted (Figure 15).

Note: When in RTK mode and after PPK processing, coordinates are inherently adjusted to the North American Datum of 1983 (NAD83) since that is the coordinate system chosen in the Job properties.

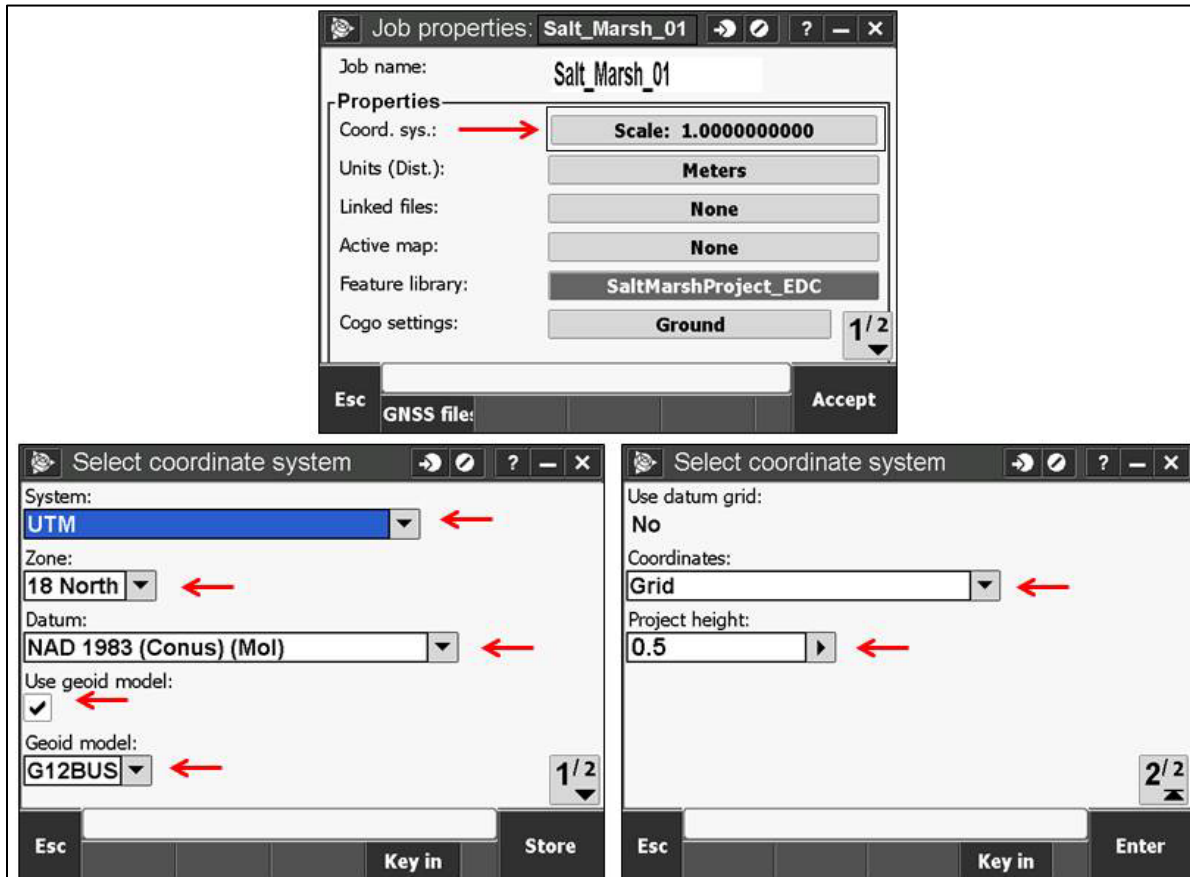


Figure 14. Selecting a coordinate system for a survey job in Trimble Access.

2. Geoid

A Geoid is a model of global mean sea level with tides and currents removed. It takes into account differences in gravity on Earth and is a surface that defines zero elevation. Geoid models are used to precisely and accurately measure surface elevations. GNSS and GPS equipment collect data on an ellipsoid, which is a different model of the Earth that does not take gravity into account. GNSS software then uses this information to calculate accurate elevation values by comparing the ellipsoid and geoid heights to acquire orthometric heights. Orthometric heights represent the elevation of features on the topography (above the Geoid). The user should always choose the most recent geoid available (Figure 15). The NGS Geoid Web Page has information about the latest Geoid models (National Geodetic Survey, 2015). New geoid models can be downloaded from the NGS Geoid webpage and imported into the Trimble TSC3 handheld controller. The file must be saved in the Trimble Data folder where the survey jobs will be stored.

The Geoid used to calculate the orthometric height of the benchmark used in a survey must match the Geoid used to collect field data. The OPUS Shared Solutions page will have coordinates and elevations in the most recent Geoid. The user should ensure that this Geoid is the most recent model and that it matches the Geoid in the survey Job properties. Different Geoid models will have different values and all the values must be in the same Geoid to be able to compare values. If a benchmark has values associated to an old Geoid a new 4+ hour survey may be required to get coordinates in the most recent Geoid. Alternatively the VDatum Tool (Service, 2016) can be used to transform coordinates from one Geoid to another. Old survey data should be updated into the newest Geoid model using the VDatum Tool. This allows users to compare data over multiple years and keep all data in the same reference frame.

3. Project height

Project height is the height above the ellipsoid of the selected coordinate system. It is used with 2D points to calculate grid and ellipsoid distances from measured ground distances. For salt marsh sites, an approximate height of 0.5 m (or similar) should be applied (close to sea level) (Figure 15).

4. Units

Local grids are projected as UTM coordinates. Therefore, meters are the appropriate units entered for the Job (Figure 16). The default values can be left for other settings in the Units menu.

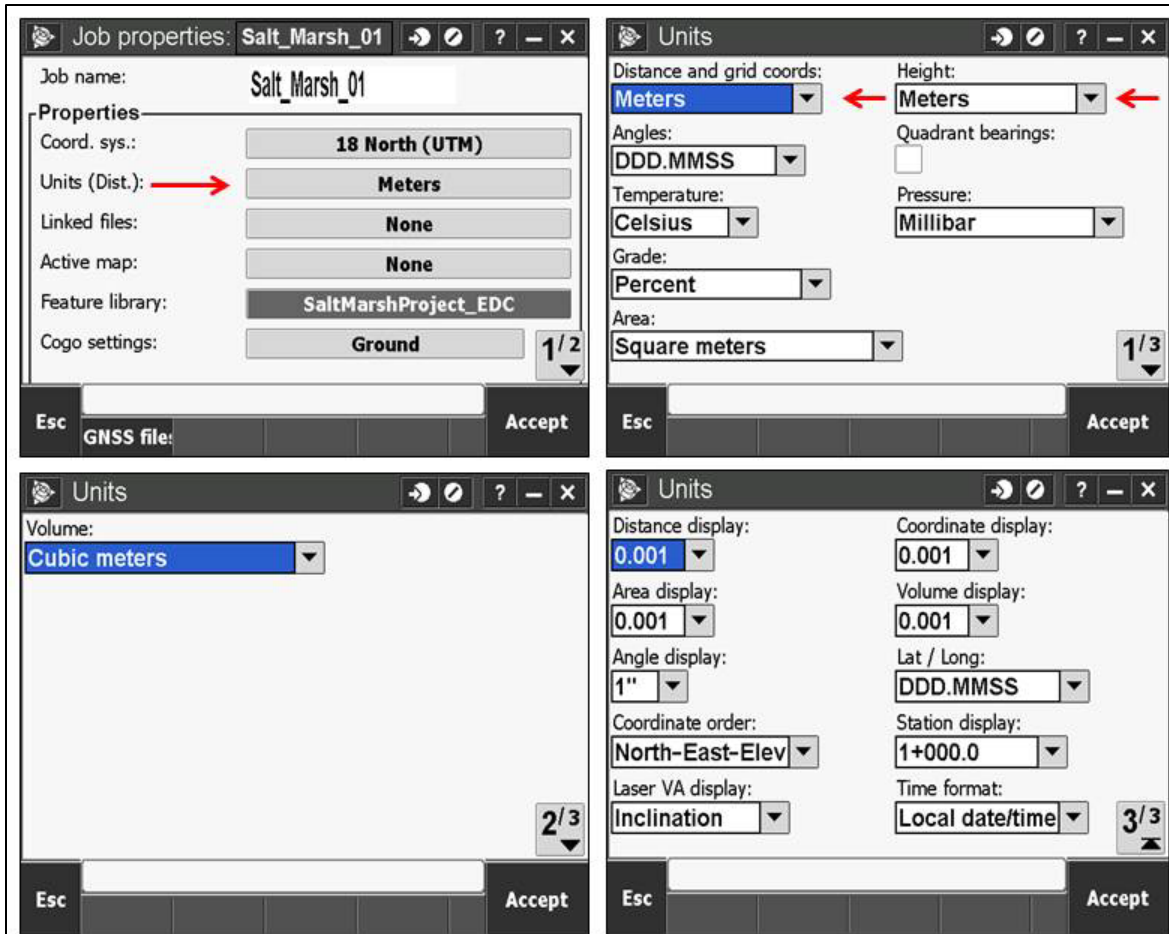


Figure 15. The Units menu in the Job Properties.

5. Linked Files

Linked files are additional data files that the user might want to use in the current Job. These can be in .csv, .txt, or .job formats files. This is particularly useful if the user wants to navigate to a desired point for a stakeout or to a bench mark to perform a check-in.

The user can link files from an office computer via cable, memory stick or Bluetooth connection. Linked files can also be transferred between GNSS controllers or brought in from another Job. The linked files must be in the same folder as the Job it is linked to. Additionally, the coordinates of the linked data points must be in the same coordinate system as the Job they are brought into. Finally, if linking a .csv file which contains coordinates for a point, the first and second ordered pair (Northing and Easting) must be entered in the same order as specified in the Coordinate Unit Field.

Note: Selecting the Linked Files box from the Job Properties page opens a file directory window where the user can select files to link to the Job.

6. Active Map

The Active Map screen (Figure 28) on the GNSS controller projects graphical images and features, and is a very useful tool to help the user navigate to grid points. Files brought into the Active Map can be from the Linked Files menu (.csv and .txt) or brought into the Job externally such as .dxf, .shp, and .xml. Georeferenced imagery in .bmp, .jpg, and .png format are also supported on most GNSS devices but are often difficult to see while in the field. The user can upload files from an office computer via cable, memory stick or Bluetooth connection. Once loaded, the user can easily view their position along with imported features and points on the Active Map screen.

7. Media Files

Most GNSS controllers are equipped with a camera which the user can use to capture an image at a point. This media file can be linked as an attribute and stored in the same Job folder (Figure 17).

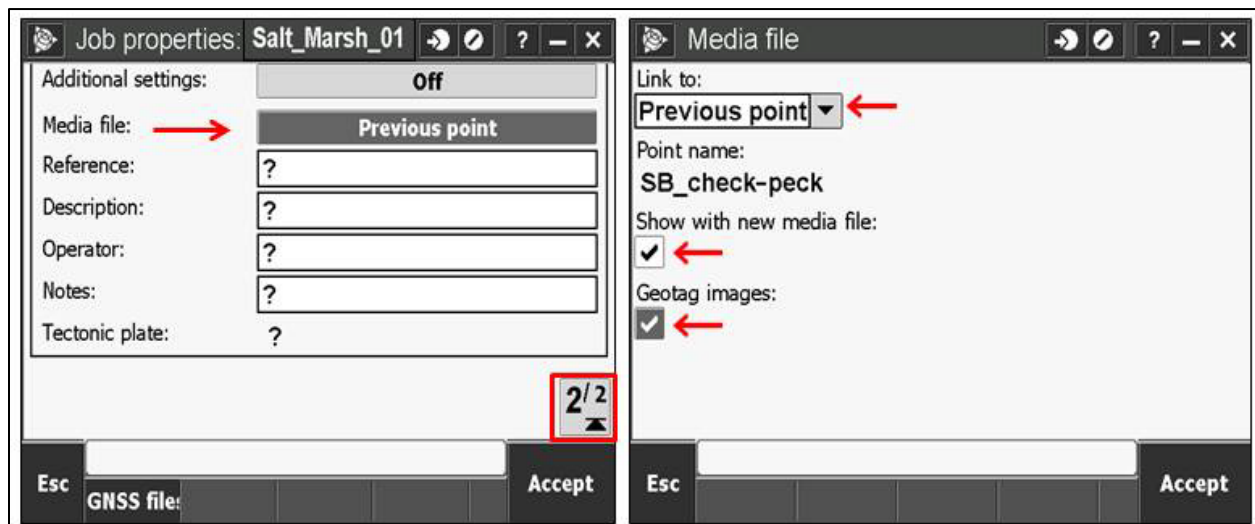


Figure 16. The Media file menu in the Job Properties.

8. Coordinate Geometry (COGO) Settings

The Distance Display setting defines how distances are displayed and which distances are used for calculations in the GNSS software. Typically, the user can choose Ground, Ellipsoid, or Grid (Figure 18).

- **Ground distance:** A ground distance is the horizontal distance calculated between the two points at the mean elevation parallel to the chosen ellipsoid.
- **Ellipsoid distance:** A correction is applied and all distances are calculated as if on the local ellipsoid.
- **Grid distance:** This is the simple trigonometrical distance between the two sets of two-dimensional coordinates.

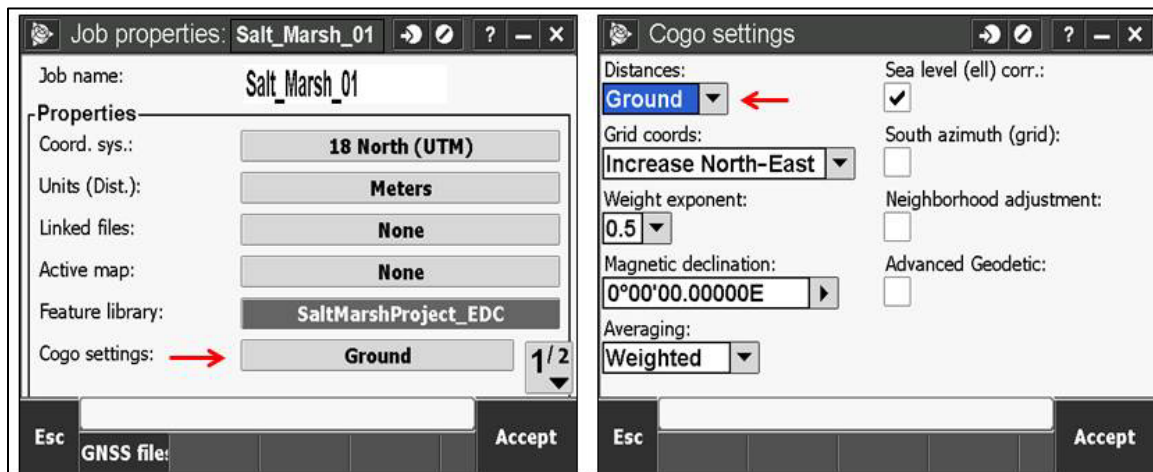


Figure 17. COGO settings in the Job Properties.

1.5 Survey Styles

Survey styles define how GNSS data is collected in the field and stored by the GNSS equipment. There are two main types of survey styles; Real Time Kinematic (RTK) and Post Processing Kinematic (PPK). All other factors affecting accuracy being equal (e.g. proximity of rover receiver to base station, atmospheric interference, multipathing effects) both RTK and PPK style are similar, on the 2-5 cm range. Generally, the technique you choose will depend on factors such as time constraints, equipment issues, and if real time accuracy is needed in the field.

1.5.1 RTK vs. PPK

For RTK surveys there is a direct connection (via radio) between the base station and the rover receiver. This allows for differential corrections from the base to be sent in real time to the rover while surveying in the field. The radio connection in RTK can be via either an internal or external radio. The internal radio is housed in the GNSS receiver while an external radio must be set upon a tripod. The internal radio can be used when distances between the base and rover are less than 1.5 km. An external radio should be used for surveys when rover receivers will be greater than 1.5 km

away from the base station. External radios also help negate the effects of obstacles in the way of the radio signal (e.g., dunes, trees, or buildings) since they are more powerful.

Note: The internal radio in an R10 Trimble GNSS receiver has a range of about 1 to 1.5 km. An external radio (based on a Trimble TDL 450) can increase the signal range to 5 to 8 km.

In PPK surveys the base station and the rover receiver are not communicating with each other but are collecting data separately, at the same time. In this method corrections are made by the user with GNSS processing software after the survey. The lack of an external radio makes for a simpler base station setup and decreases the possibility of equipment malfunction. However without a direct radio connection to the base station, PPK surveys are somewhat “in the dark”. This means that if the base station powers down for some reason the user will not know until the survey is over. Also, while performing a PPK survey the user will not know the relative accuracy of points collected in the field. Due to this limitation, there is the potential that survey data could be lost or in error. In RTK the user will always know the status of the base station and the relative accuracy of points collected in the field. For salt marsh elevation surveys the RTK method should be used with an external radio. The external radio helps ensure a constant radio signal if the distance between the base station and the marsh site is greater than 1.5 km and if there is danger of radio signal blockage by dense vegetation. PPK surveys can be done when radio connectivity is not possible between the base station location and the salt marsh site.

There are also differences in the way the GNSS data is stored by the GNSS controller and receivers. When RTK is the chosen method there will be one file associated with the data in the GNSS handheld controller, the Job file that was created for the survey. When PPK is chosen there will be a raw GNSS file (in the form of a .T02 file) for both the base station and for the rover points along with the Job file. PPK surveying creates and stores more data than RTK surveying. This is because in PPK the base receiver is actually recording and storing GNSS information whereas in RTK it is merely applying corrections to the rover receiver in real time. Field crews must be aware of storage capacity on GNSS receivers and be sure that there is ample storage space for new surveys.

1.5.2 RTK vs. PPK: Navigation

An important factor for salt marsh elevation surveys lies in the ability to accurately navigate to a point. With this type of survey, one expects to navigate as close as possible to grid points spaced throughout the marsh. If you plan to go back to the grid points or if there is another crew collecting other data at the grid points (such as vegetation) it is important to navigate to these points as accurately as possible. It is recommended to navigate to within 50 cm of the pre-loaded 20 m grid points.

For both RTK and PPK surveys, the GNSS controller can display the rover’s position in relation to a keyed in point (a grid point). In the RTK style, the rover’s position is being corrected in real time by the base station so its position is very accurate. For PPK, the rover receiver is working autonomously from the base station. It is using the GNSS handheld controller’s onboard GPS for navigation ($> \pm 1\text{m}$). This is uncorrected data, and although the position looks accurate in the field it may be in error (Figure 19). It is recommended to use an RTK survey style to get real time corrections in the field. If

this is not possible the user can choose a PPK survey, knowing that there will be error in the navigation to the grid points.

Note: It is important to remember that the quality (accuracy) of the elevation data collected will be similar for both RTK and PPK.

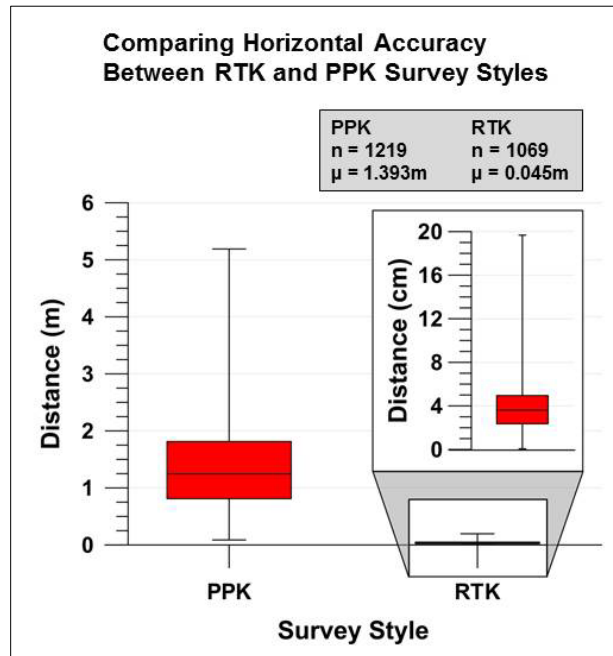


Figure 18. The difference in horizontal accuracy between RTK and PPK survey styles when navigating to a point. This represents the horizontal offset to a desired grid point from surveys at ASIS in 2014. The mean distance for PPK was 1. 393m. For RTK it was 0. 045m.

1.6 Creating Custom GNSS Survey Styles

It is recommended to have preset survey styles loaded into GNSS handheld controllers. Three essential survey styles to have preloaded are:

1. **RTK Internal Radio** style (for surveys less than 1. 5 km from the base station).
2. **RTK External Radio** style (for surveys greater than 1. 5 km from the base station).
3. **PPK** style (for surveys when an external radio is not available and the site is greater than 1. 5 km from the base station).

Both RTK and PPK survey styles can have different settings associated with them. Three important settings to understand for RTK surveys are regular **RTK**, **RTK & Infill**, and **RTK & Logging**. While the regular RTK setting is only viable if radio communication is present between the base and rover, the other two options allow for the base and rover to collect stand-alone GNSS data during the survey. If radio communication is lost, the base will continue to collect raw data which can be used to post process any data collected from the rover during this period. The **RTK & Infill style is recommended** for most surveys.

1. **RTK** – Selected when the base station is going to occupy a known location and a strong radio connection is expected throughout the survey.
 - a. Base station must be on a known location.
 - b. Base station transmits corrections but does not collect GNSS data during the survey.
 - c. Rover must have radio connection to the base to collect GNSS data.
2. **RTK & Infill** - Selected if there is a risk of radio link interruption during the survey or if the base station will be placed at an unknown location.
 - a. Base station can be on a known or unknown location.
 - b. Base station transmits corrections and collects GNSS data during the survey.
 - i. The base station GNSS data can be processed through OPUS to acquire an X, Y, Z solution for the location.
 - c. Rover receiver collects RTK data while radio connection is present to the base station. If the radio connection is lost it can be switched to PPK mode to collect stand-alone GNSS data.
 - i. The PPK data can be post-processed by the base station solution in TBC.

Note: The user must manually switch the rover to PPK survey style when the radio connection is lost. Once the radio link is reestablished, the user may then switch the rover settings back to RTK survey style.

3. **RTK & Logging** – Selected if there is a risk of radio link interruption or if the user needs stand-alone GNSS data as well as RTK data for all points collected.
 - a. Base station can be on a known or unknown location.
 - b. Base station transmits corrections and collects GNSS data during the survey.
 - i. The base station GNSS data can be processed through OPUS to acquire an X, Y, Z solution for the location.
 - c. Rover receiver collects RTK data through a radio connection to the base station and collects stand-alone (PPK) GNSS data for all points collected.
 - i. The stand-alone (PPK) data can be post-processed by the base station solution in TBC.

Note: This option records and stores the most data. Users should be aware of storage capacity on their devices and plan accordingly.

To create a survey style (Figure 20):

1. Select **Settings** from the Trimble Access homepage.
2. Select **Survey Styles**.
3. Select **New**.
 - a. **Name** the survey style. (i.e. PPK, RTK_Internal, RTK_External)
 - b. Select **GNSS** for **Style Type**.
 - c. Select **Accept**.
4. Select the new survey style from the list and select **Edit**.
5. Select survey options and select **Edit**.

Note: Users should **Edit the; Rover options, Rover data link, Base Options, Base data link, and Topo Point**. See Appendix B: Survey Style Settings for recommended settings.

6. Select **Store**.

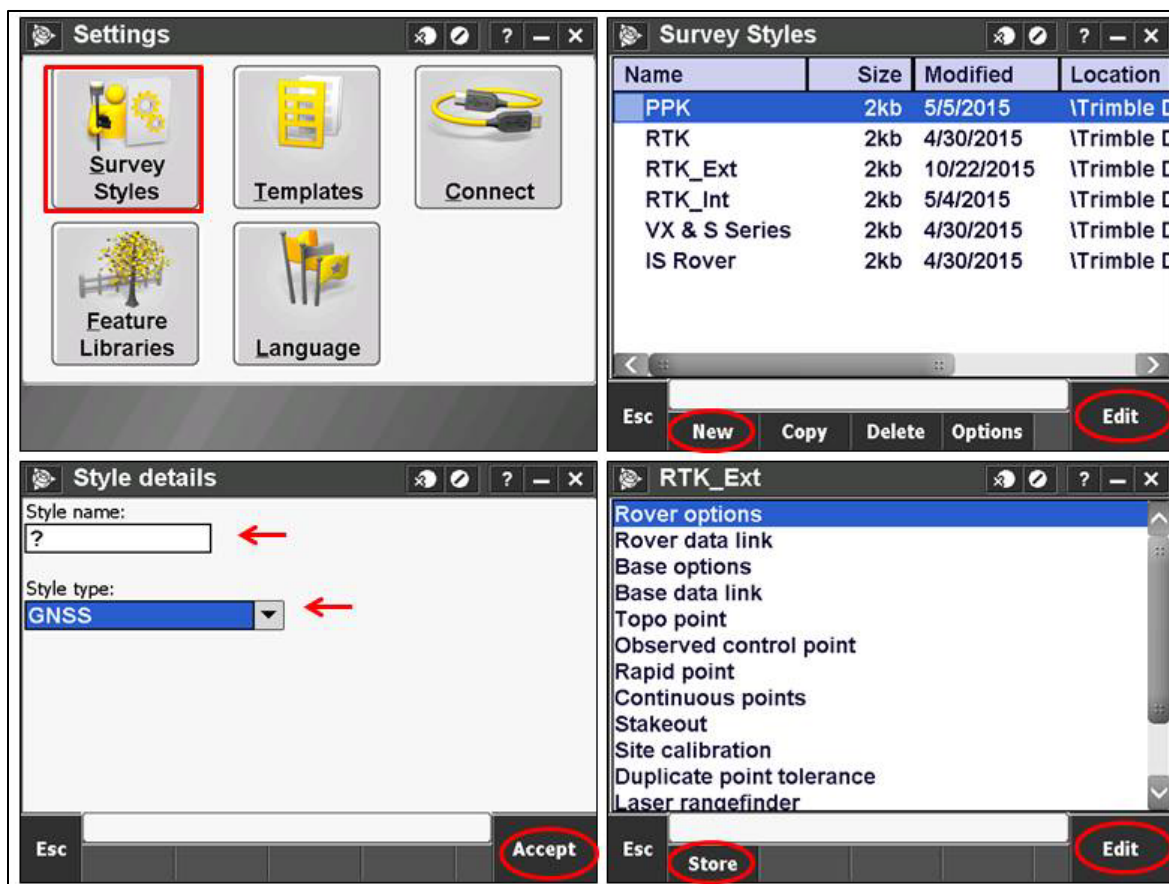


Figure 19. Creating a Survey Style in Trimble Access.

1.7 Mission Planning

Mission planning refers to pre-survey planning to ensure productive data collection, avoid problems in the field, and simplify post processing efforts.

Field crew must plan for:

1.7.1 Geodetic Monumentation

Geodetic monumentation refers to local bench marks, that act as known locations with exact X, Y, and Z (Easting, Northing, and Elevation) coordinates (Figure 21). Geodetic monumentation is essential for ensuring the accuracy of elevation surveys. For GNSS surveys it is preferable to have 2 bench marks within 5-8 km of marsh sites. One bench mark is used to set up a base station and the second bench mark is used a quality check, also known as a “check-in”. If the bench marks are farther than 8 km, the GNSS equipment may not work properly due to the GNSS receiver’s radio strength. Permanent bench marks are typically either a brass disk that has been sealed into a stable structure (such as a concrete pad or bedrock) or a steel rod that has been driven into the earth until it has hit refusal (Smith C., 2007).



Figure 20. **A.** bench mark in the form of a steel rod driven to refusal. **B.** A bench mark in the form of a brass disk encased in concrete in a solid structure.

Knowing the location of bench marks in or around a wetland is crucial for any elevation survey. To locate bench marks near salt marsh sites the National Geodetic Survey (NGS) Data Explorer and the NGS’s Online Positioning User Service (OPUS) Shared Solutions page should be used (National Geodetic Survey, 2012) (National Geodetic Survey, 2016). The Opus Shared Solutions webpage will have the most up to date list of benchmarks and should be the first place to look for local benchmarks.

The NGS Data Explorer includes historical bench marks that may have been destroyed, damaged, or lost. Furthermore, some of the coordinates may be inaccurate and they may not have published elevations. If a bench mark is located and it is evident that the coordinates or elevation are not up to date (from the NGS bench mark data sheet), then it needs to be surveyed with GNSS equipment before it can be used in salt marsh surveys.

To survey a bench mark (Figure 22):

1. **Setup** a GNSS receiver on the bench mark. See 2.1 GNSS Equipment Setup.
2. **Survey** the bench mark for **4+ hours**.

Note: A GNSS observation of 15 minutes on a bench mark is suitable to send the data to NGS's OPUS website (National Geodetic Survey, 2016). The accuracy of the coordinates increases with longer occupations though and 4+ hours is recommended.

3. **Process** the data using OPUS
 - a. Upload the data from the GNSS receiver to a desktop computer.
 - b. Use Convert to RINEX software to convert the GNSS data (.T02 file) into a RINEX file (Trimble, 2016).
 - c. Upload the RINEX files to NGS's OPUS to obtain solutions for the Easting, Northing, and Elevation (National Geodetic Survey, 2016).

Note: When using a Trimble R10 receiver the adapter height will need to be entered in OPUS.

- d. Share the solution on the OPUS Shared Solutions webpage (optional). This requires more detailed information about the survey including pictures (National Geodetic Survey, 2016).

Note: To achieve the best results the user should perform a second observation on a different day at a different time of the day to account for different satellite geometry. If the results are very different (> 5 cm vertically) the user should perform a third observation. If the results of the two occupations are similar, then there is confidence in the solution. The user can choose the solution that has a better Root Mean Square (RMS) value, or average the two solutions together.

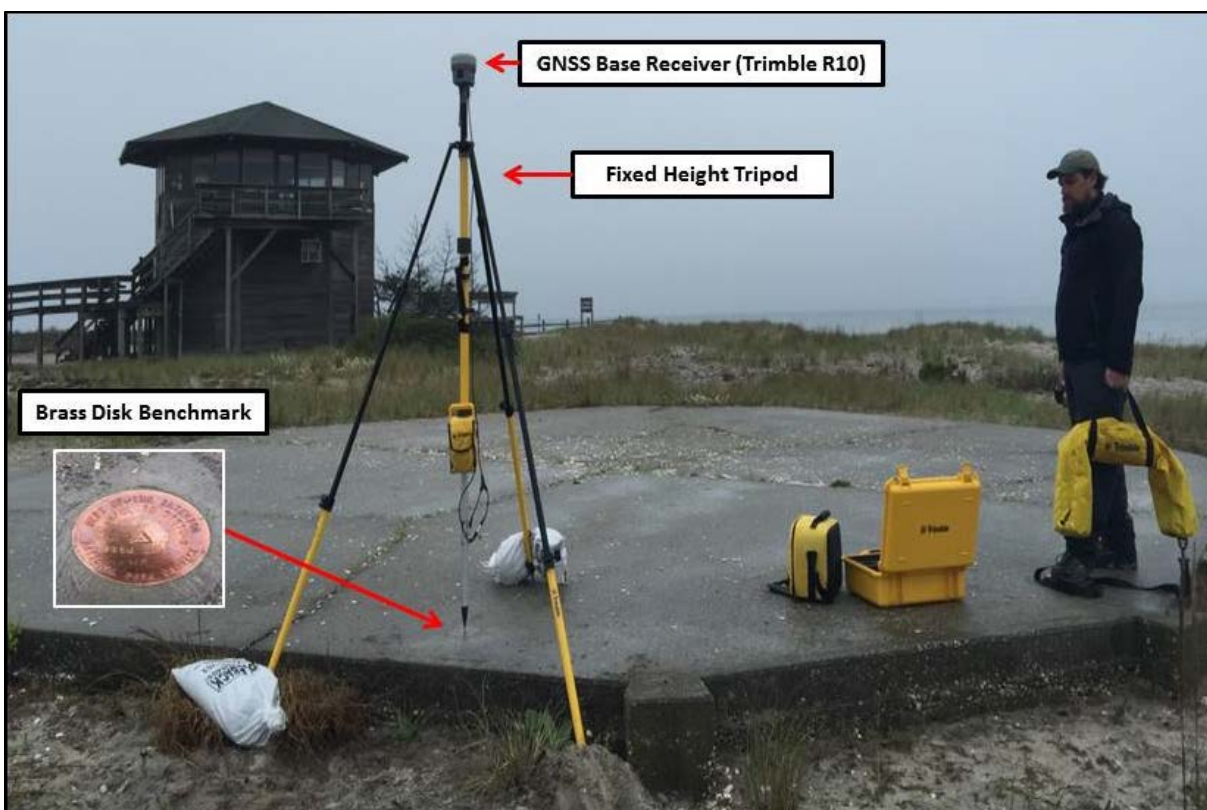


Figure 21. A static (4+ hour) GNSS occupation of a bench mark.

If a suitable geodetic monumentation in proximity to a salt marsh site does not exist, you may be required to install either a permanent or temporary bench mark. Installing a permanent bench mark requires more time, effort, and resources but it also provides a more stable control point that may be used for years to come. Permanent bench mark installation requires the use of power tools which may be an issue in certain parks or certain areas within parks. Resource managers may need to issue special permission for a permanent bench mark to be installed. Methods for installing either a deep rod monument or a brass disk are described in detail at the URI EDC Monumentation Protocols webpage and at the URI EDC National Park Service Sea Level Rise and Monumentation webpage (University of Rhode Island: Environmental Data Center, 2016) (University of Rhode island: Environmental Data Center, 2015).

For each salt marsh site a base station benchmark and a check-in benchmark should be identified within 8 kilometers (km) of the site. These locations should be mapped and scouted out prior to performing elevation surveys.

Note: Print data sheets (from the NGS Data Explorer) for the bench marks that will be used in the survey. The coordinates from these will need to be entered in the GNSS handheld controller for the base station location (National Geodetic Survey, 2012). The check-in measurement should also be cross referenced against the data sheet to assess accuracy.

1.7.2 Weather

Extreme and even moderate weather conditions can make surveying efforts in the marsh complicated. Marshes tend to be exposed to heavy winds and have little cover from rain events. Marsh flooding from rain events can make navigation difficult. Extreme heat can also be an issue. Surveying should be targeted for fair weather conditions with cool temperatures. Surveying should not take place in thunder storms or other extreme weather events that may be dangerous to field staff. Also while GNSS equipment is built to work in adverse conditions, storms can influence GNSS measurements due to atmospheric delay issues. The National Weather Service is one of many resources to plan for weather conditions in the field (National Weather Service, 2016)

1.7.3 Tides

Navigating in the marsh is easiest at low tide. If possible field crews should plan around the tide cycle and conduct marsh surveys during the lowest tides. Having a lunar calendar and a tide schedule is helpful for planning purposes. The NOAA Tides and Currents Map is a helpful resource to view nearby tide stations and predicted tide levels and times (Center for Operational Oceanographic Products & Services, 2013).

1.7.4 GNSS Satellite Conditions

The geometry of the satellites in the sky, space weather, and atmospheric conditions during surveys can all be assessed prior to a survey. This information can help to maximize precision and accuracy and ensure a solid GNSS campaign.

Trimble GNSS Planning Online allows users to:

Note: Trimble online GNSS planning is not compatible on all web browsers. Internet Explorer seems to work best (Trimble, 2104) (Microsoft, 2016).

- Analyze satellite statuses.
- Plot satellite geometry in the sky.
- Look up the Position Dilution of Precision (PDOP) (a unitless value of accuracy based on the relative position of GNSS satellites in respect to a GNSS receiver) for a survey period.
- Map ionospheric conditions

Note: Surveys should be conducted when there are ample satellites in the sky with good coverage in all directions. The lower the PDOP value the better for surveying.

Space weather information can be found at NOAA's Space Weather Prediction Center (National Weather Service, 2016). GNSS surveys should not be performed during level G3 – G5 geomagnetic storms, S4 – S5 solar radiation storms, and R3 – R5 radio blackouts.

1.7.5 Survey Logistics

Field crew should print maps of the marsh sites with the grid points, local bench marks, water level loggers, Surface Elevation Tables (SETs), and any other important features on them. Water proof

paper or laminate is recommended. These are used to help field crew devise work plans in the field and orient themselves in the marsh. The date of the survey, the field crew's names, and "X" marks at any points that were skipped should be written on the map as well as any important notes.

1.7.6 Equipment Conditions

A thorough check of all necessary equipment should be made before heading out into the field. All batteries should be charged prior to a survey. If conducting the first survey with new equipment, a test should be done to ensure that GNSS receivers and radios work properly and that the correct survey settings have been entered into the controller. GNSS receivers as well as controllers require regular calibrations. This should be done prior to a survey to avoid lost time in the field. See 2.3 Receiver Calibration.

Note: A check list of gear can be found in Appendix E.

1.7.7 Field Work Conditions

Working in salt marshes can present difficult working conditions. Being prepared for these conditions can help to alleviate them.

Crews should prepare for:

- Direct exposure to the elements (i.e. sun, wind, and rain).
 - Prepare with proper clothing and gear. Dress in layers and wear sunscreen, a hat and sunglasses. Always carry ample water and snacks.
- Mosquitoes, ticks, and other insects.
 - Bug repellent is recommended.
- Trekking through upland shrub habitat (i.e. poison ivy, briar, etc.)
- Walking through the marsh. Large creeks, mudflats, pools with very soft bottoms, and hummocky areas of high and low elevation present hazards.
 - Hip or chest waders are recommended.

2. In the Field

2.1 GNSS Equipment Setup

The following outlines the steps necessary to set up a kinematic GNSS survey (Figure 23). This includes setting up a base station, a rover receiver, and an external radio. For more information on these topics users may need to reference equipment specific guides.

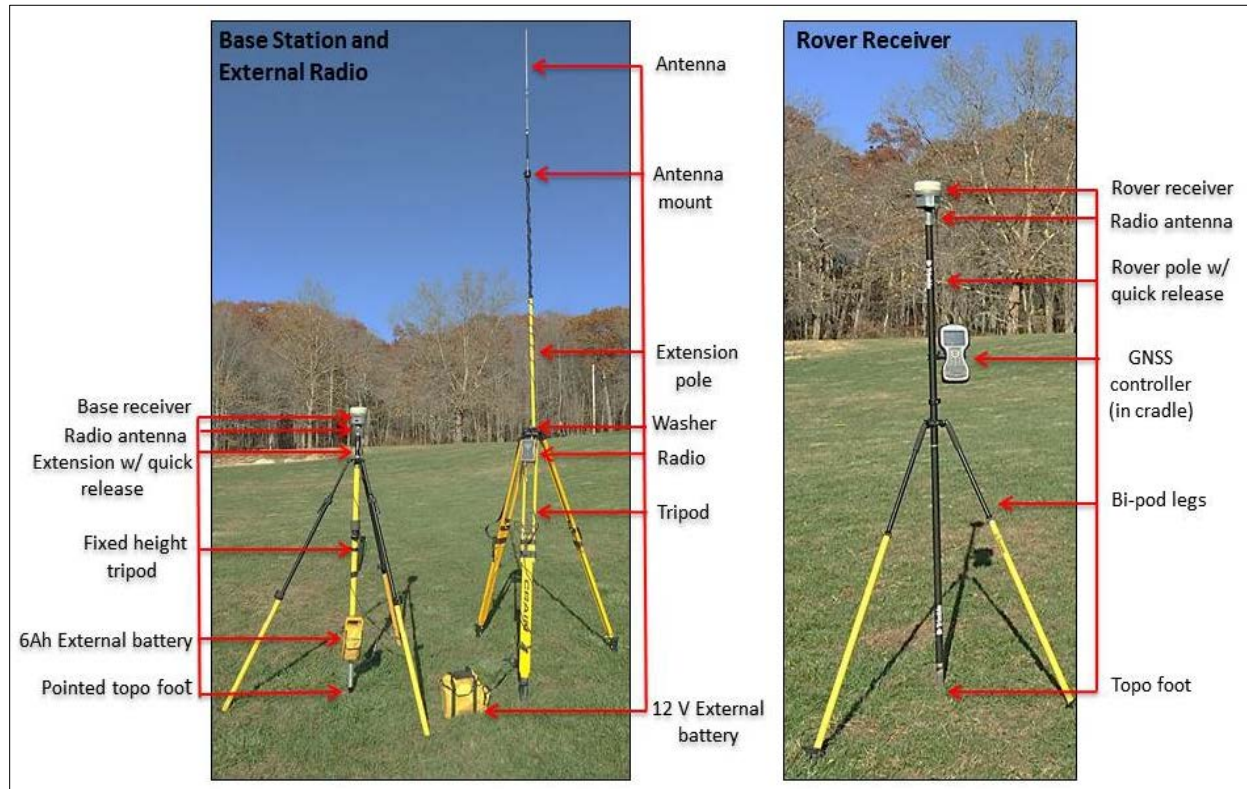


Figure 22. A GNSS setup including a base station, an external radio setup, and a rover receiver for an RTK-GPS survey.

2.2 Bluetooth Setup

GNSS receivers communicate with GNSS handheld controllers through Bluetooth technology. The receivers must be paired and associated in the GNSS software before surveying.

To pair and associate GNSS receivers with a GNSS controller (Figure 24):

1. Select **Settings** from the Trimble Access homepage.
2. Select **Connect**.
3. Select **Bluetooth**.

Note: An alternative path is: **General Survey** → **Instrument** → **GNSS Functions** → **Bluetooth**

4. Select **Config**.

5. Select **Add new device**,
 - a. Select the GNSS receiver (by serial number) when it is found.

Note: If the device is not found, cancel the task and try again. Make sure the GNSS device is powered on and in close proximity (within 50 feet) to the controller.

6. Select a paired GNSS receiver in the dropdown for **Connect to GNSS rover** and **Connect to GNSS base**.

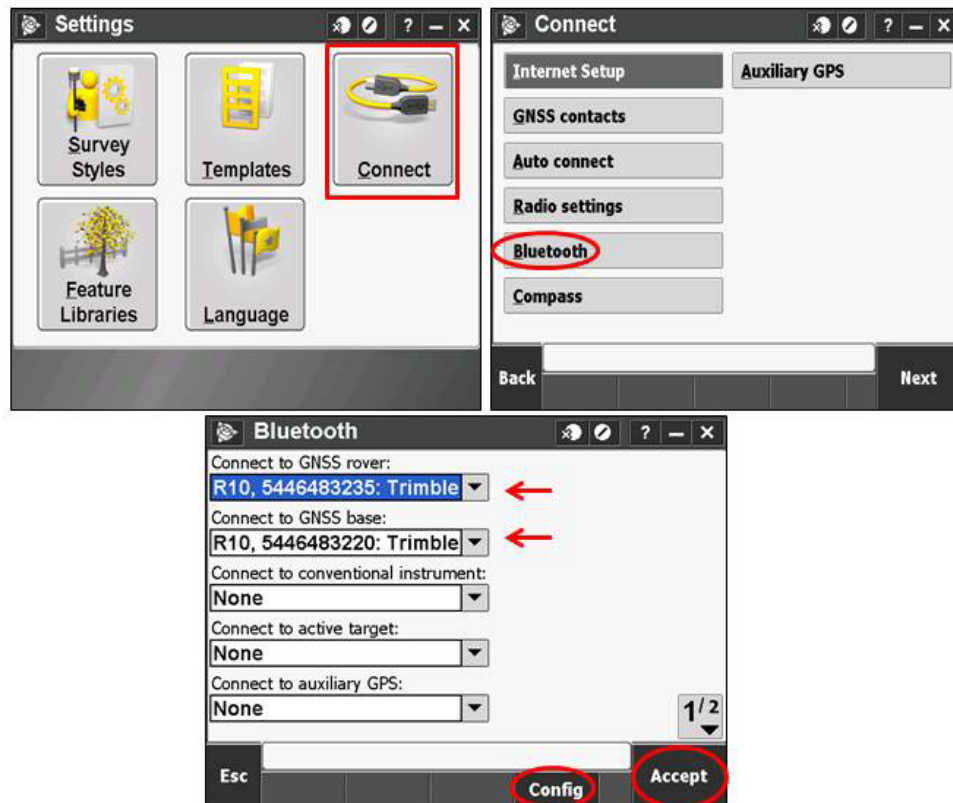


Figure 23. Bluetooth pairing for GNSS receivers and GNSS handheld controllers.

2.3 Receiver Calibration

GNSS receivers and controllers need calibration to be fully operational. Specifically the GNSS receivers need Tilt Calibration, Magnetometer calibration, and Magnetometer Alignment Calibration. The GNSS controller needs a Compass Calibration.

To calibrate the GNSS receiver:

1. Select **Menu** → **Instrument** → **ebubble options** → **calibrate**.
 - a. Follow the directions on the screen to calibrate the three sensors.

Note: This can only be accessed if the GNSS receiver is paired and connected to the GNSS handheld controller.

To calibrate the compass on the GNSS controller:

1. **Select** → **Settings** → **Connect** → **Compass**

- a. Follow the directions on the screen to calibrate the compass.

Note: The calibrations expire and need to be recalibrated over time. The time limit for calibration expiration can be set in the **ebubble options** menu by changing the **calibration age limit**. A typical calibration age limit is 30 days. The controller prompts the user when calibration is needed.

2.4 Base Station

The base station receiver should be set up on a bench mark, in a location that has a clear line of sight to the sky in all directions. Optimum bench marks should have 360 degrees clearance around the mark at 10 degrees and greater above the horizon. Avoid using bench marks that have obstructions from trees or buildings. This ensures that the base station will be able to track satellites as they pass through the sky and will avoid multipath effects. Multipathing refers to GNSS radio signals bouncing off obstructions before reaching the GNSS receiver. This causes error in the time delays calculated by the GNSS receiver and therefore error in the GNSS solution.

An adjustable height tripod is preferred for this type of survey. It consists of an adjustable center pole with three adjustable legs. A bulls-eye bubble is affixed to the center pole for leveling purposes. A pointed topographic (topo) foot should be fully screwed into the bottom of the center pole to sit correctly on a datum point in the bench mark.

To set up a base station (Figure 25):

1. Select a central pole height (tripod height) and extend the three legs, pressing the feet into the ground firmly. The tripod must be stable during observations; therefore, the tripod legs must be spread widely apart and secured, preferably with sandbags.

Note: It is recommended to carry sand bags with the fixed height tripod. These can be filled with sand right on the spot and placed on all three tripod legs. Additionally it may be necessary to support the center pole with a sandbag on windy days.

2. Attach the GNSS receiver to the top of the central pole, making sure it is fully screwed in and flush to the tripod. Pole extensions may be used to boost the height of the GNSS device.

Note: Trimble R10 GNSS receivers come equipped with a quick release mount that the GNSS receiver clips into. It is important to carefully tally up the tripod height, quick release height, and any pole extension heights to accurately record the antenna height.

3. Insert a battery into the GNSS receiver or connect the GNSS receiver to a battery source. If operating continuously for more than a few hours, use an external battery pack or 12 V power supply to avoid loss of power. Always make sure cable connections are secure and take care in not dropping the ends on the ground.

Note: It is a good practice to always put a battery in the GNSS device. This battery will act as a backup if there are any issues with an external battery.

4. Level and plumb the tripod over the bench mark until the plumb bubble sits in the circle on the bulls-eye bubble. If perfectly level, the bubble should remain in the circle when the pole is spun 180°. If the bubble falls out of the circle, spin the pole back halfway in the other direction and align the plumb bubble halfway in the circle.
5. Power on the GNSS receiver, making sure that the power lights flash on.
6. Open the correct survey Job on the GNSS controller.
 - a. **General Survey** → **Jobs** → **Open Job**
7. Start the base receiver.
 - a. **Measure** → “**survey style (RTK External)**” → **Start Base Receiver**
8. Enter the **Point name**.
 - a. **Key-In** the **Northing**, **Easting**, and **Elevation** of the bench mark.
 - b. Select **Store**.

Note: If the point information (name, northing, easting, elevation) has been entered into the controller it can be selected from the **List** option. If not, the user will have to choose **Key-In**. **Northing**, **Easting**, and **Elevation** can come from an OPUS solution or an NGS benchmark datasheet. If coordinates are not available the Here function can be used. This auto-populates the fields with an initial estimate of the coordinates. The base file will need to be sent to OPUS to determine a more accurate solution (see 1.7.1 Geodetic Monumentation). The base coordinates must then be changed in post-processing software to adjust all the measurements from the survey.

9. Enter the **Antenna height** of the receiver.

Note: Double check the Antenna height. GNSS software has precise corrections based on the antenna height. Pay attention to the **Measured** to field. It is recommended to take a picture of the setup for future reference.

10. Select **Start**.



Figure 24. Starting a base receiver in Trimble Access. The antenna height should be carefully recorded and double checked to ensure correctness.

2.5 External Radio

For an RTK survey style, an external radio is required if survey sites are greater than 1.5 km from the base station. If using an external radio, do not place the antenna near vertical obstructions such as buildings, vehicles, towers, or tree canopy. Setting the radio to its maximum wattage (**30 watts**) will ensure a stronger signal but will drain the battery of the radio at a much faster rate than smaller wattage settings. The external radio antenna should be extended to its maximum height. External radios may include different antenna types that disperse radio signals in different ways. The Trimble TDL 450 H External Radio includes a 0 decibel (db) and a 5 db antenna. The 0 db antenna, which is shorter in length, disperses radio waves in an umbrella pattern. This is best used if there is a line of trees or canopy between the marsh site and the base station. The 5 db antenna, which is longer in length, disperses radio waves in a straight line outward from the antenna. This is best used on open horizons or when the radio and base station are high on the landscape. If possible park staff should consider the antenna type when setting up a survey.

It is the responsibility of the user to comply with applicable rules and regulations concerning the operation of a radio transmitter. In the United States, the Federal Communications Commission (FCC) regulates the licensing of this type of equipment. The NPS has a specific radio frequency that should be used in conjunction with an external radio. Do not use other radio frequencies as it could go against FCC regulations.

Note: The frequency and baud rate of the radio must match what is entered in the GPS base receiver.

To set up an external radio:

1. Set up the radio tripod securely and reasonably level.
2. Select the appropriate antenna type to maximize the radio signal (consult the radio manufacturer's guide).
3. Extend antenna pole to its maximum height.
4. Connect the radio to GNSS base receiver.
5. Connect the radio to an external power source. Turn the radio on as a final step.

Note: External radios emit high frequency radio waves that can be dangerous to human health. Field crew should avoid standing near the radio transmitter for long periods of time while it is running.

To connect a base station to an external radio (Figure 26):

1. Connect the 7-pin Lemo connector to the serial port (Port 1 = black) on the GNSS base receiver or to the radio/power Y-cable if supplying external battery power to the base receiver.
2. Connect the 7-pin Lemo connector to the radio via the data/power Y-cable.
3. Connect 5-pin Lemo into the radio
4. Connect the antenna cable and mount to the radio.
5. Connect the DC power lead to an external power source (12 V battery).



Figure 25. Simplified schematic of cables and devices connecting a base receiver with an external radio.

2.6 Rover Receiver

To set up a rover receiver:

1. Screw the rover poles together completely; and screw in a flat “topo” foot into the bottom.

Note: Bi-pod legs add stability to measurements but are not necessary and are difficult to carry in salt marshes

2. Insert a battery into the GNSS receiver and attach it to the top of the rover pole with the quick release.
 - a. Screw an antenna into the GNSS receiver if using an RTK survey style.

Note: The antenna is not needed for PPK surveys because the rover and base receivers are not communicating

3. Attach the controller to the rover pole using a rover pole cradle.

Note: The controller should be placed at a comfortable height for the user to easily interface with the screen/buttons.

4. Power on the rover receiver.
5. Connect to the GNSS receiver using the handheld GNSS controller.
 - a. From the Job screen: **Instrument** → **GNSS Functions** → **Rover Mode**

Note: Make sure the GNSS receiver is associated as a Rover in the Bluetooth Options (by serial number).

If an RTK survey style is selected it is recommended to make sure the base and rover receivers are communicating before heading out to the marsh site. See Appendix C: GNSS Troubleshooting for information about communication issues between GNSS receivers

2.7 GNSS Initialization

Initialization is the process GNSS receivers go through to establish current locations and other correction parameters. Initialization must be established during a survey for the data to be useable. The receivers need the following satellite data:

1. A current almanac. An almanac contains information about the satellites such as orbits, positions, and statuses. This data is sometimes referred to as ephemeris data. This is typically downloaded automatically by the GNSS equipment when it is powered on
2. The GPS receiver’s current location.
3. The current date and time (usually obtained from the almanac).

2.8 RTK Initialization

For RTK surveys, initialization can occur only if the rover is receiving corrections from the base station which in turn must initially be tracking five or more satellites. After initialization has been gained, a position can be maintained with one satellite less than the number required to initialize. Poor initializations can occur when a clear view of the sky is blocked. If at any time initialization is lost during a survey, it must be regained before continuing. The user should reinitialize in an area with a clear view of the sky and free from obstructions which can cause a multipath effect. Initialization automatically begins once the base station is tracking enough satellites and can apply corrections.

With most GNSS receivers, after initialization has been achieved, the survey mode changes to **Initialized**. It will remain initialized if the receiver continues to track the minimum number of satellites. If the mode changes to **Not Initialized**, the user must reinitialize the survey.

Note: These messages appear on the GNSS handheld controller at the bottom of the screen.

2.9 PPK Initialization

The minimum satellite requirements for initialization for a PPK survey style are the same as in an RTK style. A key difference for a PPK style is the ability to begin the survey before initialization is gained. GNSS post processing software can back-process the data to calculate a solution as long as initialization is achieved prior to ending a survey. As in an RTK survey style, the GNSS receiver will display a **Not Initialized** message on the screen with a countdown until initialization is gained. Initialization for PPK takes longer than with RTK and is typically 7 – 15 minutes. Once initialization is gained, the mode will switch to **Initialized**. If initialization is lost during the PPK survey the user can still collect elevation data but will have to regain initialization before ending the survey.

Note: If initialization is not gained before ending a survey the data collected will not be able to be corrected and will be in error

2.10 Navigating to Grid Points

To navigate to grid points in the field, the user must first upload the grid points (as a .csv file) into the GNSS handheld controller. The grid points should be stored in the same folder directory as the Job file for the survey. Once the grid points have been uploaded they can be imported into a Job and viewed from the Active Map screen on the controller. There are two main methods for navigating to grid points in the field; Active Map or Stakeout.

To import the . csv Grid Point file into the GNSS handheld controller (Figure 27):

1. Select **Jobs** from the General Survey screen.
 - a. Open the desired Job.
2. Select **Import/Export**.
3. Select **Import custom format**.

- a. Select the desired Job.
4. Select **CSV Grid Points N-E**,
 - a. Select the .csv grid points file.
 - b. Check the **Import points as Control** box.

Note: The .csv grid point files should be formatted as 3 columns, point ID, Northing, and Easting. Avoid spaces and special characters and make sure there is no formatting if excel was used.

5. Select **Accept**.

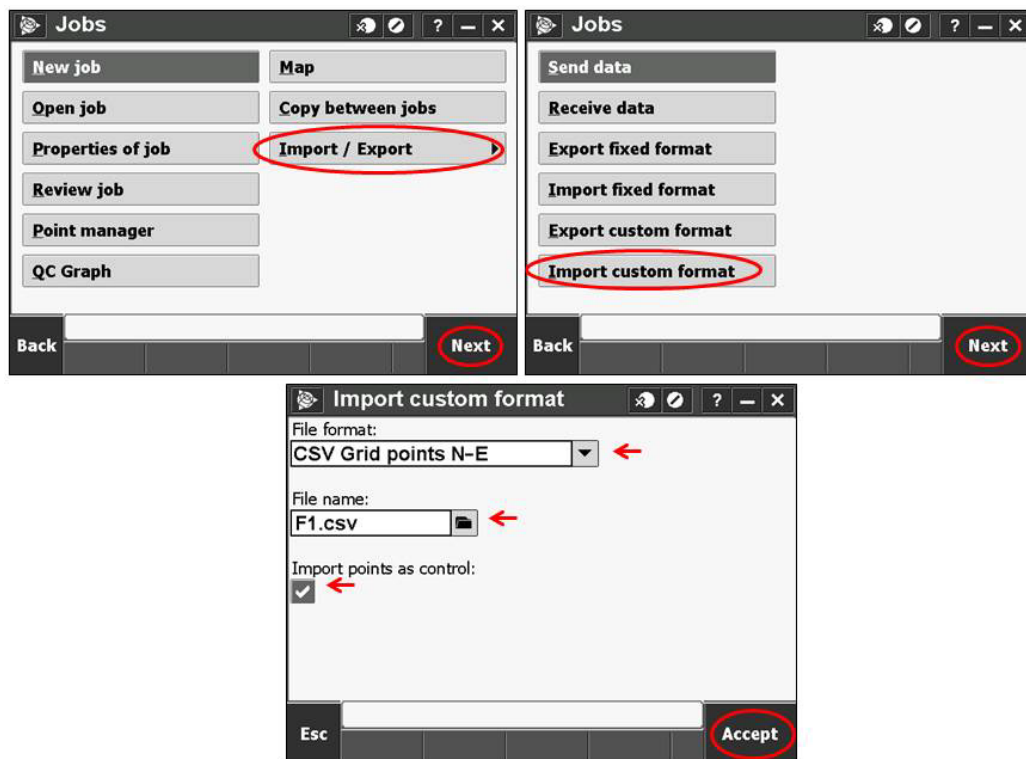


Figure 26. Importing a .csv grid point file into a survey job in Trimble Access.

2.11 Active Map

The Active Map screen will show the user's position as a satellite icon and the locations of grid points in relation to the user. The on-screen compass can be used to navigate in the direction of a grid point. The pan and zoom tools can be used to pan around the map and change the scale. By zooming in to a scale of 1 meter the user can align their position as close as possible (center of crosshairs) with the grid point, level the receiver, and collect an elevation point. Grid points are typically in rows, so after collecting a point the user can zoom out to a larger scale and navigate to the next point.

To use the Active Map method for navigation (Figure 28):

1. Select **Map** from the Job screen.
2. Use the **Pan**, **Zoom**, and **Compass** to navigate.

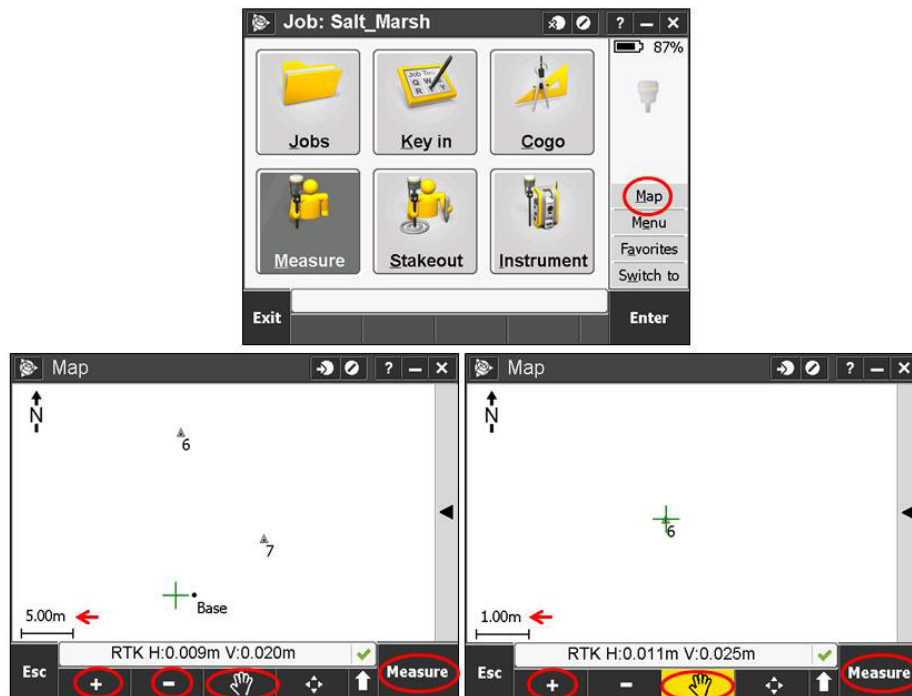


Figure 27. An Active Map screen at a 5 and 1 m scale showing the base station (black dot), the rover receiver's position (green plus sign), and grid points (black triangles). Select **Measure** to collect an elevation point.

2.12 Stakeout

To more precisely navigate to a grid point the Stakeout method is recommended. The main advantage to using the stakeout option is the navigational display on the user's controller. As in the Active Map navigation the grid points appear on the map along with the user's position. However, in this method the user will choose a desired point from a list of all the grid points. Then, a new screen appears displaying directions and distances to that point relative to the user's position. The user can then follow their progress until the desired distance to the point is reached. Once a point has been surveyed, it is taken off the list making it easy for the user to keep track of what points remain. The user can exit the stakeout screen at any time to view the Active Map or complete other tasks on the controller.

To use the Stakeout method for navigation (Figure 29 & Figure 30):

1. Select **Stakeout** from the General Survey screen.
2. Select **Points**.

3. Select **Add**.
4. Select **All Points**.

Note: The .csv grid point file must be imported into the same folder as the Job.

5. Select a point and select **Stakeout**.

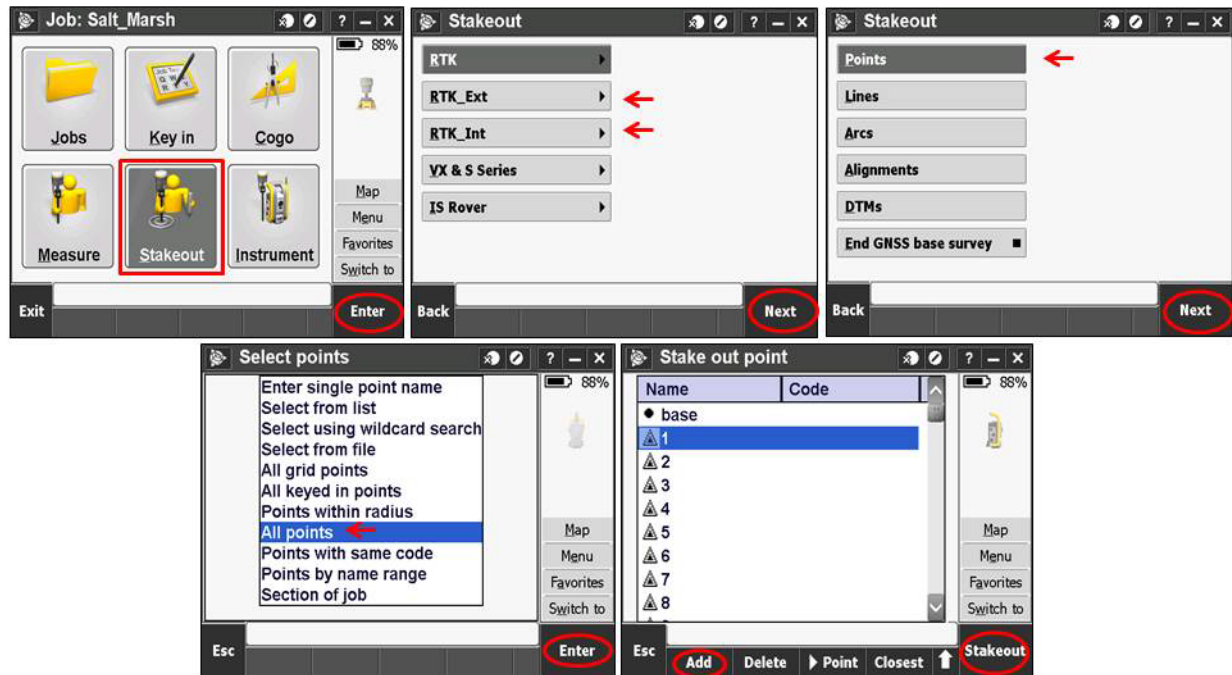


Figure 28. Accessing the Stakeout method in Trimble Access.

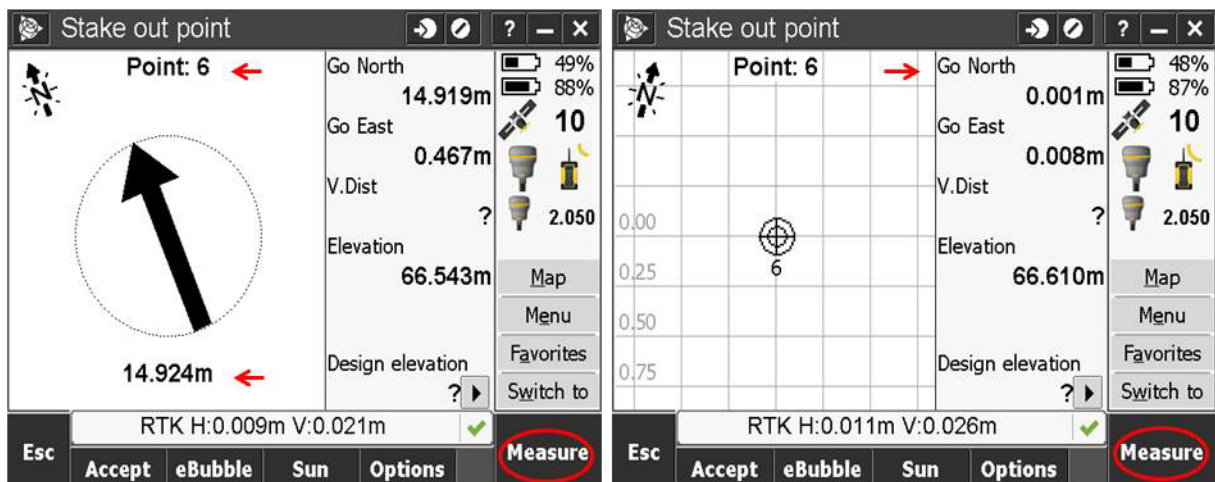


Figure 29. The Stakeout navigation screen guides the user to a specific point with directions, distances, and arrows. Select Measure to collect an elevation point

The stakeout method is only available when an RTK survey is being conducted. During a PPK survey the user will have to navigate to points using the Active Map. In both methods the Active Map is updated with collected points appearing on the map. In general it is a best practice to navigate as close to a grid point as possible. Therefore the Stakeout method is recommended as it makes it easier to precisely navigate to grid points. A list of recommended Stakeout settings can be found in Appendix B: Survey Style Settings.

Note: Both the Active Map and Stakeout screens display the battery life of the GNSS receiver and the handheld controller, the number of satellites being tracked, the radio connectivity to the base receiver, the antenna height of the rover receiver, menu options, and RTK horizontal (H) and vertical (V) precisions.

2.13 Collecting a Point

Once a grid point has been navigated to, an elevation point can be collected (Figure 31).

To collect an elevation point:

1. Select **Measure** from the General Survey screen.
2. Select **Measure Points**.
3. Select the survey style (i.e. **RTK External**).
 - a. Select the base station when it is found by Index number.

Note: The **Reliability** of the base station should be close to **100%** if the radio signal is strong. If Reliability is low or the base station is not found, there is a communication error with either the base station or the radio. See Appendix C: GNSS Troubleshooting for troubleshooting information.

4. Enter **Point name**.

Note: It is recommended to name the points in a manner such as marsh site name_ grid point number. The number will automatically increase as points are collected if the **Auto Point Step Size = 1** in the **Options** menu. The user must be aware of this and edit the number appropriately if backtracking to lower grid point numbers.

5. Enter **Topo point** for **Method**.
6. Enter the **Antenna height (Uncorrected)**.

Note: Ensure the antenna height for the rover is entered correctly. A typical rover pole is 2 m and the quick release is 0.05 m. Therefore antenna height is **2 m** to the **Bottom of the quick release** or **2.05 m** to the **Bottom of the antenna mount**.

7. Level the rover pole using the bulls-eye bubble on the pole and the electronic **eBubble** on the handheld controller.

Note: Tilt tolerances set the limits for how much the rover pole can move out of level during occupation time. A warning message will appear if the rover pole exceeds the tilt tolerance. Tilt tolerances can be adjusted in the **Options** menu. Users should try to keep the rover pole as steady and level as possible while collecting a point, but can still store a point after receiving a tilt error message

8. Select **Enter**.

9. Select **Measure**.

- a. Collect 5 seconds (5 measurements) of GNSS data for RTK survey styles or 10 seconds (10 measurements) for PPK survey styles.

Note: This can be changed in the Options menu by changing the **Occupation time** and **Number of measurements**.

10. Enter any attributes that are associated from a **Feature library**.

Note: The **Feature Library** must be linked to the survey in the **Job Properties**. Check the **Prompt for Attributes** box in the **Options** menu to ensure that the user is prompted to enter attributes for every point.

11. Select **Store**.

Note: Check the **Auto Store Point** box in the **Options** menu on the **Measure Points** screen to automatically store a point once the desired time and accuracy are met.

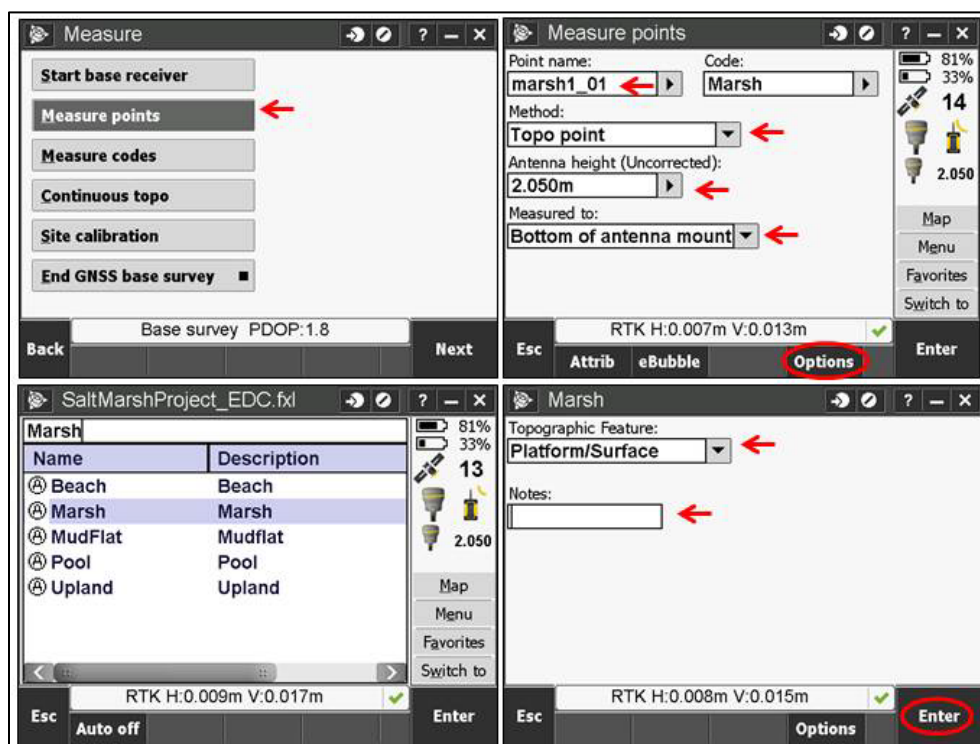


Figure 30. Measuring a point in Trimble Access.

The horizontal and vertical precision of the rover receiver is displayed at the bottom of the controller screen in RTK surveys. This allows the user to know the accuracy of the points as they are being collected. Tolerances are set for horizontal and vertical precisions in the GNSS controllers. If the rover receiver is experiencing precisions worse than the defined tolerances the user will not be able to collect a point. Poor precisions can occur from bad satellite data, multipathing from obstructions overhead, or bad radio signals from a base receiver. The user should avoid collecting points with precisions greater than 5 cm vertically or horizontally. In PPK surveys the actual precision of collected points will not be known until post processing is done to differentially correct the data

When measuring a point, it is important to make sure that the rover pole is resting on the surface of the marsh. If there is dense vegetation, wrack, or algal blooms obstructing the rover pole, take the time to move it away and maneuver the rover pole so that it is flush on the marsh surface (Figure 32). When the grid point is in a mudflat or hummocky area where the sediment is very loose and muddy the rover pole should be allowed to rest, by only the weight of the GNSS equipment, until it meets resistance. Do not hold the rover pole above or push the pole into the mud.



Figure 31. A. Keep the rover pole as level as possible. B. Make sure the rover pole is resting on the marsh surface (bare earth). Move thick vegetation, algal mats, or wrack out of the way. C. If a grid point falls within a creek, ditch, or bay; measure the point on the edge of the marsh surface closest to the grid point.

In certain circumstances a grid point may be located in a tidal creek, ditch, or bay. If this is the case the elevation point should be collected on the marsh surface at the edge of the water body (Figure 32). Crew should navigate as close to the point as possible and document the location of the point in the attributes or notes section. In certain circumstances park staff may be interested in the elevation difference between a creek and the surface. In this situation three elevation points can be collected, one point at each edge of the creek and one in the middle of the creek. In these situations a code should be associated with the point in the feature library.

It may also be necessary for field staff to collect elevations at other locations other than a grid point. For instance, if a local water level logger or tide gauge exists at a marsh site, a GNSS elevation

measurement should be collected on the device. This measurement allows the conversion of water levels into the same datum (NAVD88) as marsh elevations. The staff member in charge of the water level device should inform field staff as to where to take the measurement. It is recommended to take at least 2 separate measurements on the device for at least 5 seconds each.

2.14 Check-Ins

To validate the accuracy of the elevation points collected in the salt marsh, it is essential to collect a check-in point at a known location (Figure 33). This check-in can occur before, during, or after a survey on a marsh but must be collected while the base station is still running. It is recommended to collect at least 15 seconds of data on the check-in point. Possible check-in points include permanent bench marks within a reasonable distance of the marsh and base station, temporary bench marks that have been occupied by static GNSS equipment and have a solution through the NGS OPUS website, SETs that have good GNSS elevations, or some other type of solid monument that can be re-measured to obtain a survey grade elevation. After the Job has ended and the data has been uploaded to a computer, the check-in point measurement can be compared to the known elevation to get an idea of how accurate the survey was.



Figure 32. A. Taking a measurement at a Check-In. B. A close up of the rover pole on the bench mark. C. Locating local bench marks for Check-Ins ensures the accuracy of surveys.

2.15 Ending a Survey

When all elevation points have been collected at all the grid points, water level loggers (if applicable), and check-ins, the user can end the survey. This involves ending the survey in the GNSS controller for both the rover receivers and the base station (Figure 34). After the survey has ended, the crew can power down, disassemble, and pack up the equipment.

To end a rover receiver survey in the GNSS controller:

1. Select **End GNSS survey** from the **Measure** screen.
 - a. Select **Yes** or **No** when prompted: **Power down receiver**.

To end a Base Receiver survey in the GNSS controller:

1. Select **End base survey** in the **Measure** menu.
 - a. Select **Yes** to **Power down receiver**.

Note: This can also be done by: **General Survey** → **Instrument** → **GNSS Functions** → **End survey** or **Power Down Receiver**.

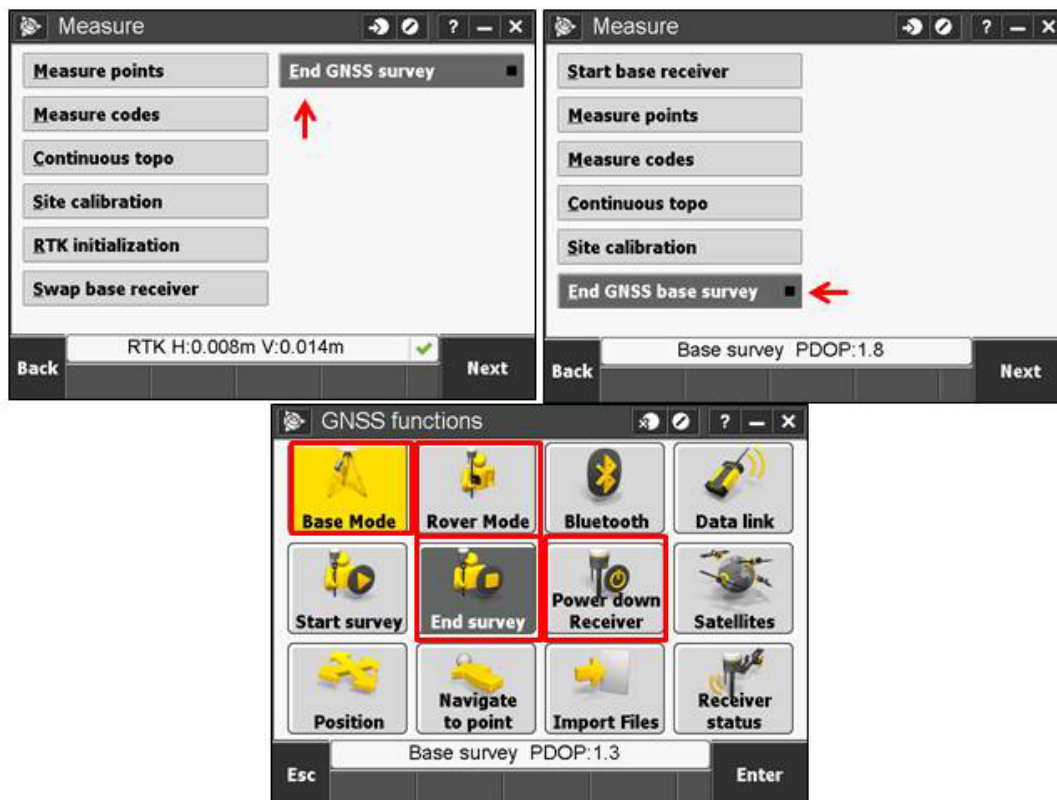


Figure 33. Ending a survey in Trimble Access.

Note: The GNSS controller must be within Bluetooth range (50 ft.) of the GNSS receivers to connect and power down.

2.16 Splitting the Workload

The most efficient way to complete salt marsh elevation surveys is to have at least two crew members collecting data with rover poles. Although having more than two field staff will speed up data collection, the number of staff is limited to the number of GNSS rovers and handheld controllers available. There are many ways to coordinate data collection efforts in the field. Here we offer two slightly different methods that can be used for different situations.

The “divide and conquer” method splits the amount of grid points in a marsh amongst the field staff. Field staff will navigate to their assigned grid points in different areas of the marsh and start collecting. This method is often used to send two crew members to opposite sides of a marsh,

collecting points and meeting somewhere in the middle. This approach allows for a more productive field member to do more points than his or her partner. This approach also works well for teams of three or more dividing the grid points into blocks of numbers. Staff can reorganize when they complete their respective blocks to help others finish.

The “leapfrog” method allows field staff to start at the same location in the marsh and work alongside each other throughout the survey. The simplest way to do this is to split the grid points up as odd and even numbers. This allows crew members to leapfrog each other down rows or columns. This method can be very helpful for inexperienced staff, and is good in adverse conditions. By staying close to one another, crew can help each other if problems arise. Leap frogging can also be beneficial for navigation in the marsh by following each other’s path.

Note: For both methods it is highly recommended to carry handheld radios (walkie-talkies) to aid in communication.

2.17 Field Notes and Pictures

It is recommended to keep a log of field notes for every survey. These notes should include basic information such as the date, the weather, and the staff working. It should also include information about where the base station was set up, which marsh was surveyed, where the check-in occurred, and additional items, such as whether water level loggers were surveyed. The field notes should also be used to describe any technical difficulties or any extraordinary circumstances that occurred.

Pictures should also be taken regularly in the field. Pictures can be helpful when looking back at data to give insights into a survey. For instance a picture of the GNSS base station can help to validate the antenna height, or a picture of an elevation measurement on a water level logger can be used to validate the height of the water.

It is recommended to take pictures of:

1. The **base station**.
 - a. One close-up of the tripod point resting on the bench mark and one horizon view showing the antenna height.
2. The **check-in**.
 - a. One close-up of the check-in bench mark and one of a crew member taking a measurement.
3. Crew taking elevation **measurements on water level loggers**.
4. Marsh **conditions**.
5. **Staff** conducting surveys.

Note: Pictures from the field can also be used for outreach materials, presentations, and report writing.

2.18 General Equipment Care

- Avoid use in vicinity of powerful radar, television, or other transmitters. High power signals can overwhelm the receiver's circuits.
- Use care when connecting cables to the receivers. Excessive force can damage the pins of the connectors.
- Pull cables straight out when disconnecting cables from the receivers, do not twist.
- Wash down and dry tripods, poles, and topo feet if working in a marine environment. Occasional cleaning and greasing of movable parts will keep these operating well.
- If any GNSS equipment is wet, leave out to dry naturally before storing in their cases.

3. After the Field

3.1 Uploading Survey Data to TBC

There are two methods for uploading the survey data;

1. Uploading the data into TBC using Trimble file formats (.job, .T02, and .t02)
 - a. This is required for PPK data that need post-processing (differential correction), RTK surveys that require post-processing, and for raw GNSS data from base station occupations. Once post-processing is completed in TBC the data can be exported in a different format (i.e. .csv, .txt, or shapefile) to be used in other software if needed.
2. Uploading the data into other software (i.e. Microsoft Excel, ArcGIS, etc.) using a custom format (.csv, .txt, or shapefile).
 - a. This can only be done for .JOB files collected in RTK mode. For RTK surveys, the GNSS data is in corrected form and will not need to be post-processed. Raw GNSS files (that may have been collected if RTK & Infill or RTK & Logging were used) will not be included in the .JOB file. Those files (.T02 or .t02) will need to be uploaded to TBC.

TBC displays survey data in a unique way, showing baselines that connect the base station to the rover data. This visualization can be extremely helpful in analyzing surveys and in quality control of the survey data. It is recommended to upload the data in Trimble format into TBC, perform visual analysis and quality assurance measures, and then export the data from TBC into a format that can be used in other software (.csv, .txt, or shapefile).

Note: Trimble file formats (.job, .T02, and .t02) are not compatible with all software (i.e. Microsoft Excel, ArcGIS, Google Earth, etc.) and will need to be uploaded into TBC before they can be exported into other formats.

In either process the GNSS data must be transferred from the base receiver and handheld controller into an office computer. This can be done via a Bluetooth connection, connection cables, or an external memory device. Raw GNSS data that is stored in the receiver will need to be imported into the handheld controller first and then transferred to an external memory device or a computer. This is done by connecting the handheld controller to the GNSS receiver and importing the appropriate file.

To upload GNSS files from a receiver to a handheld controller (Figure 35):

1. **Power on** the **GNSS receiver** and **handheld controller**.
2. Select **General Survey**.
3. Select **Jobs**.
 - a. Select the appropriate Job.
4. Select **Instrument**.

5. Select **GNSS functions**.

6. Select **Base Mode** to connect to the base receiver or **Rover Mode** to connect to the rover receiver via Bluetooth.

Note: This will only be done for base station as long as the **Logging device** was set to **Controller** for the rover receiver.

7. Select **Import Files**.

a. Select the appropriate .T02 file.

Note: Sorting the files by date may help to identify the correct file.

8. Select **Import**.

9. Select **Start**.

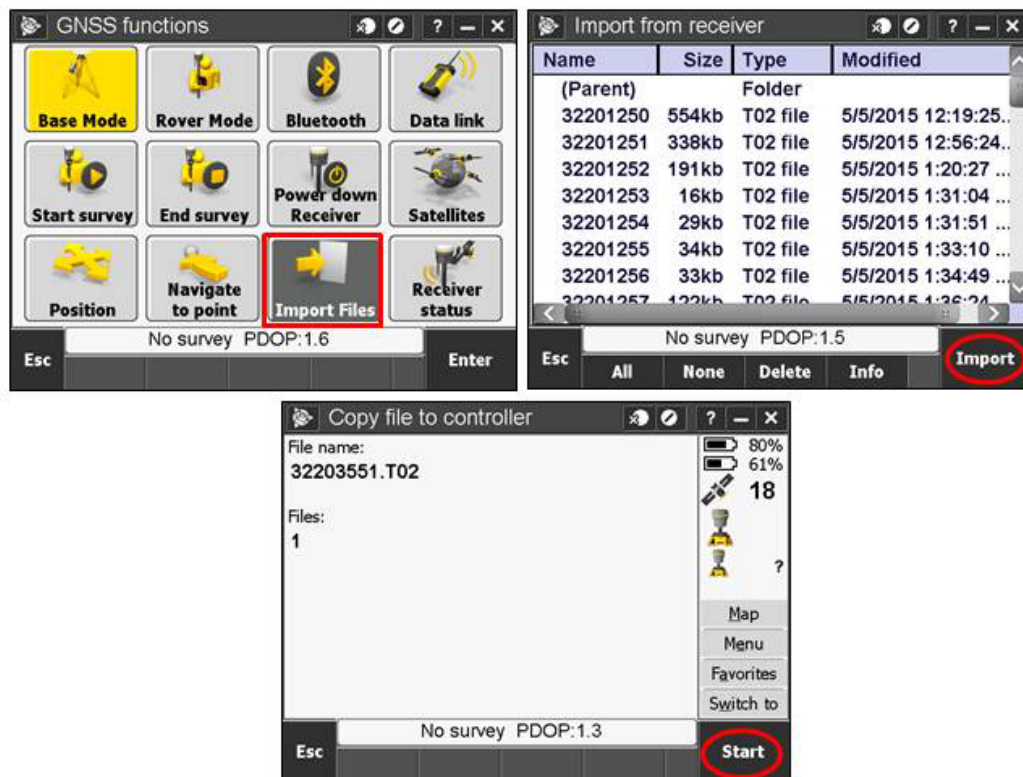


Figure 34. Importing files from a GNSS receiver to a handheld controller.

Note: The GNSS data file has now been imported onto the controller in the folder that stores all the GNSS data (**Trimble Data**).

To export a .JOB file in .csv or shapefile format (Figure 36):

1. Select **Jobs** from the General Survey screen.

2. Select **Import / Export**.
3. Select **Export fixed format**.
 - a. Select **Comma Delimited (*.CSV,*.TXT)** or **ESRI Shapefiles** in **File Format**.
 - b. Enter a **File name** and choose a **folder path**.
 - c. For Comma Delimited (*.CSV,*.TXT) select field numbers for the attributes.
 - d. For **ESRI Shapefiles** enter **Grid** as the **Coordinates** field.
4. Select **Accept**.

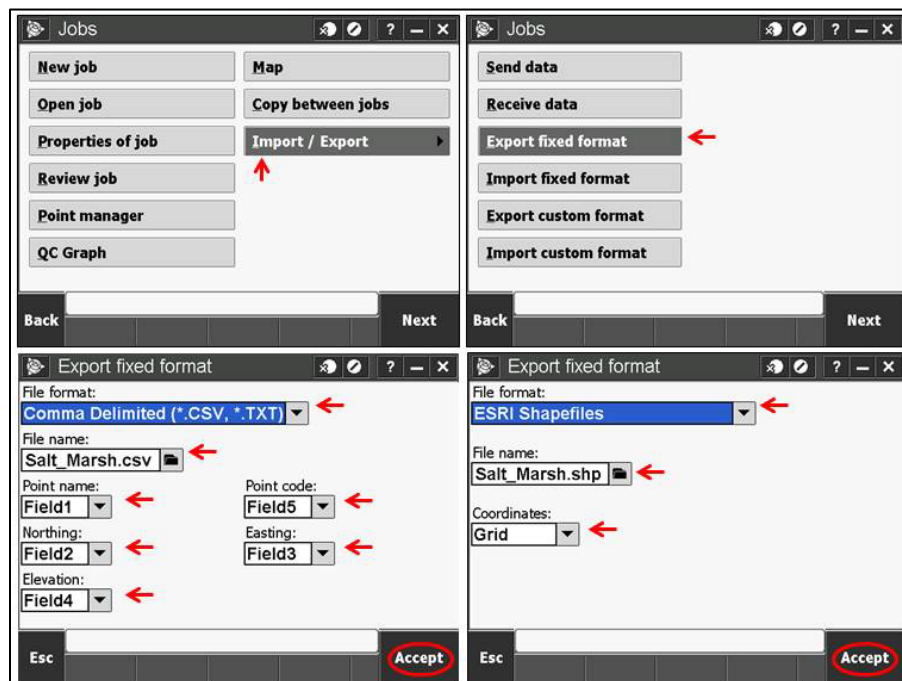


Figure 35. Exporting in a fixed format (.csv, .txt, shapefile) from Trimble Access.

To upload GNSS files from a handheld controller to a memory stick or computer:

1. Open **File Explorer**.
2. Select the folder where all the GNSS data is stored (**Trimble Data**).
3. Select all **.job**, **.T02**, and **.t02** files associated with the survey.

Note: It is important to upload all files that are associated with a survey. If a file is missing there may be issues when post processing the data.

- a. **Copy** all the files associated to the survey.
4. Navigate to the Hard Disk (memory stick) folder or Computer folder (cable connection).

5. **Paste** the files into the Hard Disk (memory stick) folder or Computer folder (cable connection).

Note: Trimble TSC3 handheld controllers use Windows mobile embedded software. To **Select** multiple files use the ctrl key, select all appropriate files with the stylus, and press the ctrl key again. To Copy hold the stylus on the highlights files until a popup menu displays. To Paste hold the stylus on an empty part of a folder screen.

3.2 Processing Elevation Data

GNSS software, such as TBC, can be used to display and process the GNSS data (.JOB, .T02, or .t02) that has been collected. The user can edit point names or antenna height, delete erroneous points if necessary, and perform post-processing (differential correction). TBC is a free download; however the free version only provides basic functionality such as uploading, viewing, and exporting data. To perform post processing functions such as differential correction an advanced license is required. Differential correction is only required for data collected using a PPK survey style.

Note: It should be noted that different versions of Trimble Access and TBC can have compatibility issues. For instance a job file created in Trimble Access Version 3.7 cannot be opened in Trimble Access Version 5.0. Users should consult to Trimble Field Software Services Site (Trimble, 2016) for further information on versioning.

To differentially correct GNSS data in TBC (Figure 37 & Figure 38 & Figure 39):

1. Select **Start** a new project from the home screen.

Note: A project template can be created for each park. Select a blank template and then select Project Settings. From this page the user can set the Coordinate System and Zone, the Geoid Model, the Units, and other customizable settings (Figure 37). At this point the user should not set the datum to NAD83 (2011) as there can be transformation failures in TBC. After importing the points the user should choose the option to “convert to the imported files definition”.

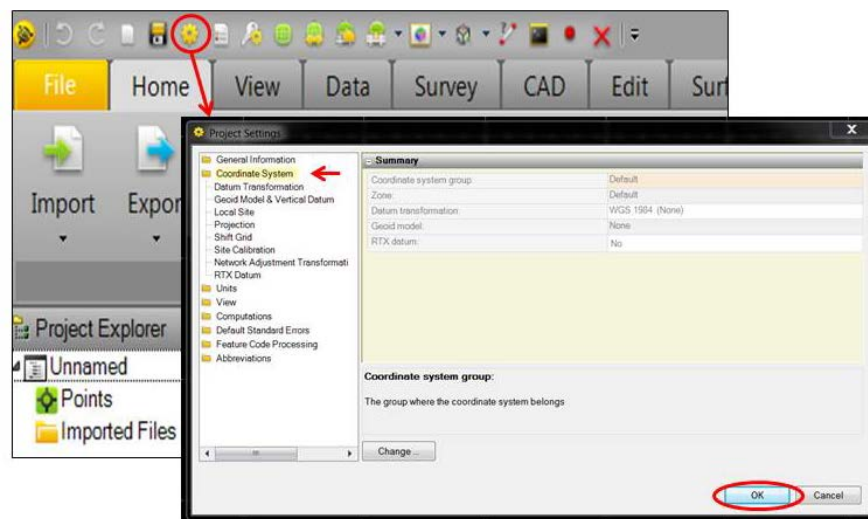


Figure 36. Accessing the Project Settings menu in TBC.

2. From the **Home** tab select **Import** (Figure 38).
3. Navigate to the location of the GNSS data in the import window.
4. Select the base **.T02** file and press Import at the bottom of the screen.
5. Select **Import**.
6. Uncheck the **Send to RTX-PP** box.
7. Select **OK**.
8. Repeat this process for all **rover .job** files as well as any rover **.T02** files.

Note: The “merge points” message will appear if there is more than one point with the same name. This is often the case with a check-in or water logger survey. It is important in this case **NOT** to merge these points.

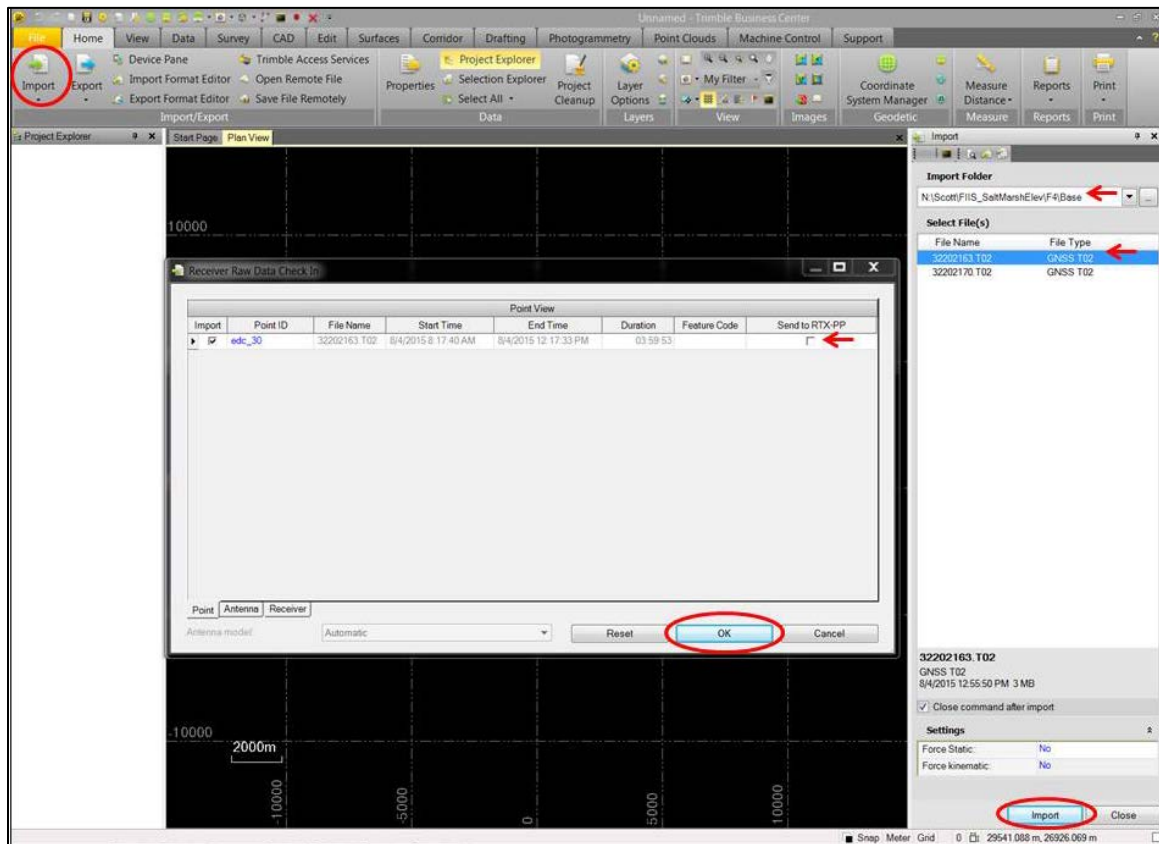


Figure 37. Importing GNSS data into TBC.

Note: If a popup message appears stating that “The imported file and the project coordinate systems are different” the user should select the option to “**convert to the imported file’s definition**”. TBC and Trimble Access can have slight differences in coordinate systems it is important to maintain the coordinate system that the data was collected in.

Along with the elevation points, the GNSS software will display lines, or vectors, that connect the GNSS base station to each elevation point collected in the field. These vectors are called baselines and they represent the connection between the base station and the rover receiver during the survey.

9. Right click the base station point in the Project Explorer window (Figure 39).

10. Select **Add Coordinate**.

a. Enter **Grid** for **Coordinate type**.

b. Enter the **Easting**, **Northing**, and **Elevation** values.

Note: These values should come from either an OPUS solution (4 + hours) or an NGS data sheet with accurate coordinates.

11. Select **Control Quality** in the **quality type** boxes next to the coordinates.

12. Select **OK**.

13. Select all the points and baselines, using the mouse to highlight them (click and drag).

14. Select **Process Baselines** under the **Survey** tab.

15. Select **Save** on the **Processing Results** page.

Note: The vector baselines will change color after differential processing has been performed (teal for unprocessed and indigo for processed). This signifies that the data has been differentially corrected and the coordinates(x, y, and z) have changed.

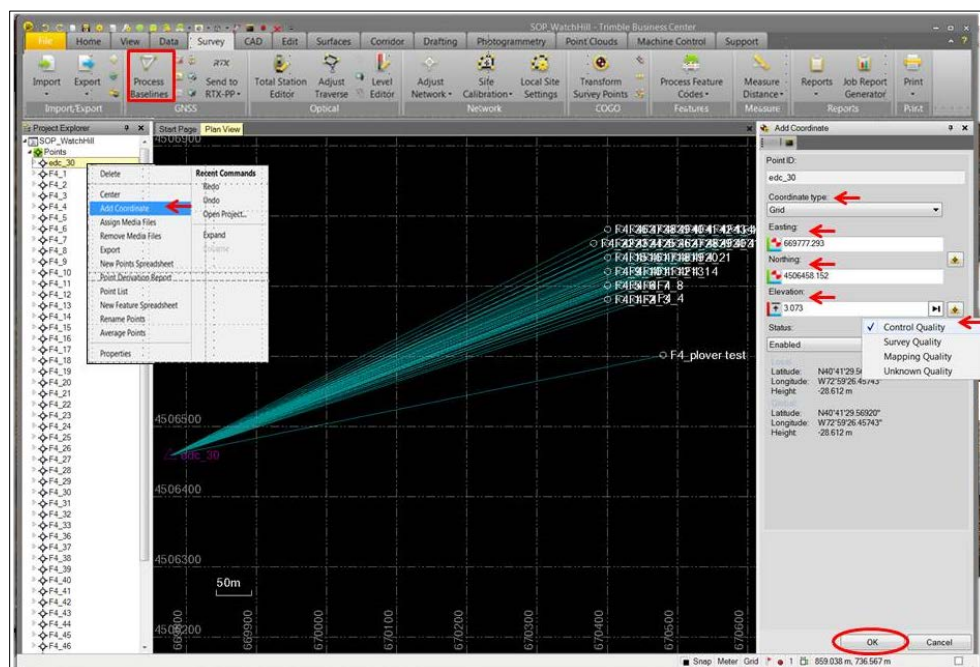


Figure 38. Processing baselines (performing differential correction) in TBC.

3.3 Quality Checking the Data

The quality and accuracy of elevation points and survey baselines can be checked by generating reports and viewing statistics in the GNSS software. Point reports (i.e. Vector Processing Report, Point Derivation Report) should be generated to view the uncertainties associated with all point vectors. Typically the GNSS elevation points should have errors on the scale of 2 – 5 cm. Larger errors than this should be flagged for further review. Reports should be generated and saved for each salt marsh site.

To generate reports in TBC:

1. Select **Reports** on the **Home** menu toolbar.
 - a. Select **Baseline Processing Report**.
 - b. Select **Point Derivation Report**.

Note: Users should check the **horizontal** and **vertical precision** of the points and baselines as well as check for any inconsistencies in the data. For instance points with extreme high or low elevation values.

A quality check should also be performed on the raw GNSS data from the base station. This can be done by obtaining an OPUS solution of the raw .T02 base file. A comparison can be made from the survey result with that of the published value. If the result is within 5 cm of the published value, then the survey has acceptable accuracy. Coordinates from the check-in point should also be compared with that of the published value. In addition, each surveyed point should be visually inspected to assure it has a baseline connecting to the base station, and that it has the same name as the grid point.

Once a quality check has been performed, the point elevation data can be exported from the GNSS software into various formats (e.g. .shp or .csv file).

To export GNSS data from TBC (Figure 40):

1. Select **all** of the **rover points** and **base point** and the **all** of the **baselines** by highlighting them on the screen.
2. Select **Export** on the **Home** menu toolbar.
3. Select **Custom** to export as a .csv file.
 - a. Select **P, N, E, elev, Code** (Point name, Northing , Easting , Elevation, Feature Code).
 - b. Enter a **File Name** and folder path.
4. Select **GIS** to export as a **.shp** (shapefile).
5. Select **Export**.

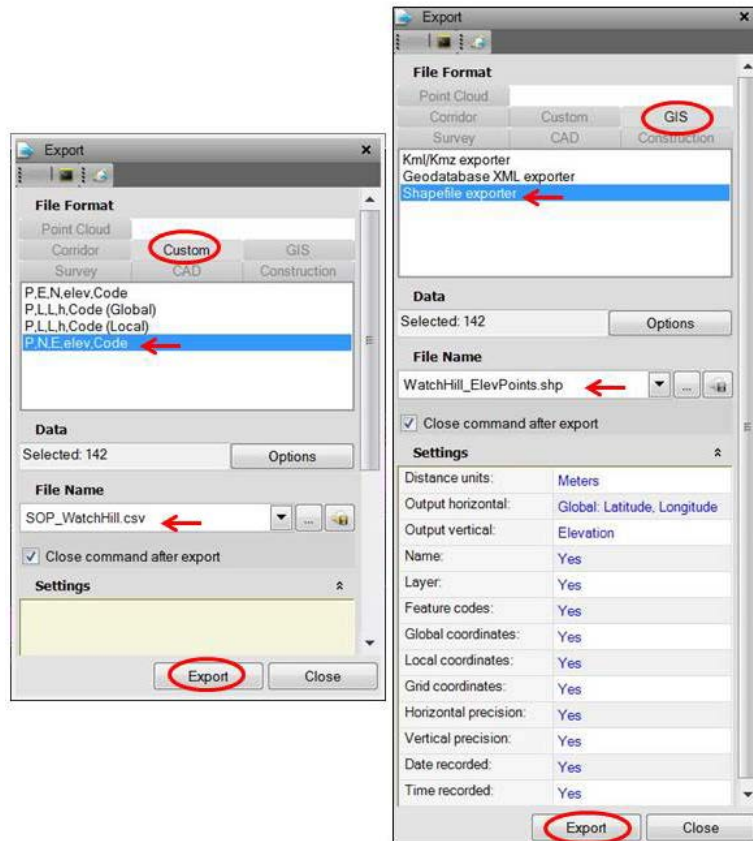


Figure 39. Exporting the data from TBC.

Note: The elevation points can also be exported in other formats such as a KML/KMZ for use in Google Earth or as a Point Cloud (.las) for use in GIS.

3.4 Uploading the Elevation Points in GIS

Once all processing of the elevation data is complete it can be uploaded into ArcGIS for visualization and analysis. For best results the data should be stored as a **feature class** in a **file geodatabase**. File geodatabases act as a common file folder system and are ideal for storing and managing geospatial data such as elevation points. Related data can also be stored in the geodatabase such as marsh site boundaries, digital elevation models, and vegetation data.

The user must:

1. Create a file geodatabase in ArcCatalog.
2. Import the elevation point shapefile or CSV into ArcMap.
3. Export (save) the elevation points as a feature class in the file geodatabase.

To create a File Geodatabase:

1. Open ArcMap.

2. Open ArcCatalog within ArcMap.
3. Navigate to a folder where the File Geodatabase will be stored.
4. **Right Click** on the folder.
5. Select **New**.
6. Select **File Geodatabase**.
7. **Name** the File Geodatabase as appropriate.

To display a shapefile in ArcMap:

1. Open ArcMap.
2. Open ArcCatalog within ArcMap.
3. Navigate to the folder where the file is stored.

Note: To connect to a folder select the **Connect To Folder** (folder with a plus sign) icon on the **Catalog** toolbar (Figure 41).

4. Select the shapefile.
5. Drag the shapefile onto the map or Table of Contents Screen.

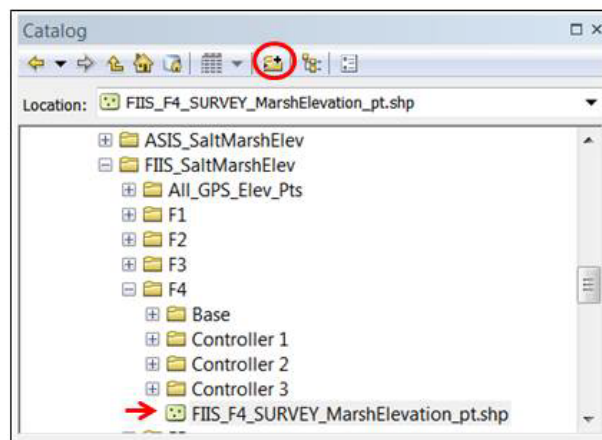


Figure 40. Importing a shapefile into ArcGIS.

To export the shapefile into a file geodatabase as a feature class (Figure 43):

1. **Right click** on the shapefile in the Table of Contents.
2. Select **Data**.
3. Select **Export Data**.

4. Select **All features**.
5. Select **this layer's source data** for **Use the same coordinate system as**.
6. Select the **folder icon** under **Output feature class**.
7. Navigate to the file geodatabase.
8. Select **File** and **Personal Geodatabase feature classes** under **Save as Type**.
9. **Name** the feature class.

To display a CSV file in ArcGIS (Figure 42):

1. Select the **Add Data** icon on the **Standard Toolbar**.
 - a. Select the .csv file to import.
 - b. Select **Add**.
2. **Right click** on the .csv file in the Table of Contents.
 - a. Select **Display XY Data**.
 - b. Select an **X Field**, **Y Field**, and **Z field** as well as a **Coordinate System of Input Coordinates**.
 - c. Select **OK**.

Note: X Field is the Easting, Y Field is the Northing, and the Z Field is the elevation.

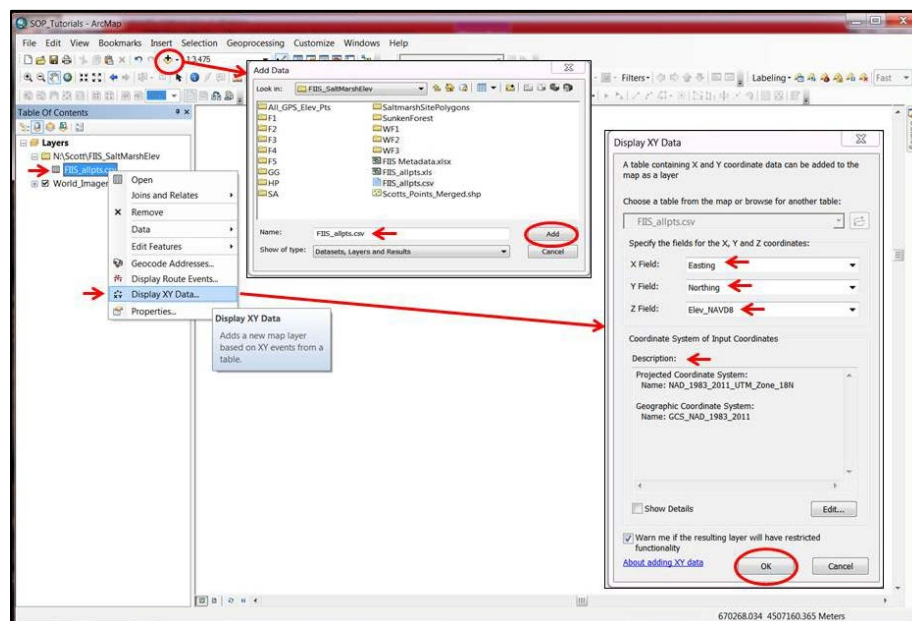


Figure 41. Importing a .csv file into ArcGIS.

This creates a new **Events** file in the **Layers** section of the Table of Contents. This is a temporary file that is simply displaying the .csv file geographically as specified by the Display XY Data command. The Events file must be exported as a feature class in a geodatabase for these changes to be permanent.

To export the Events file into a feature class (Figure 43):

1. **Right click** on the **Events** file in the **Layers** menu of the **Table of Contents**.
2. Select **Data**.
 - a. Select **Export Data**.
 - b. Select **All features** as **Export**.
3. Select the **Browse** folder icon.
 - a. Navigate to the **geodatabase** where the data will be saved.
 - b. **Name** the file.
 - c. Select **Personal Geodatabase feature classes** for **Save as type**.
4. Select **Save**.
5. Select **Ok**.

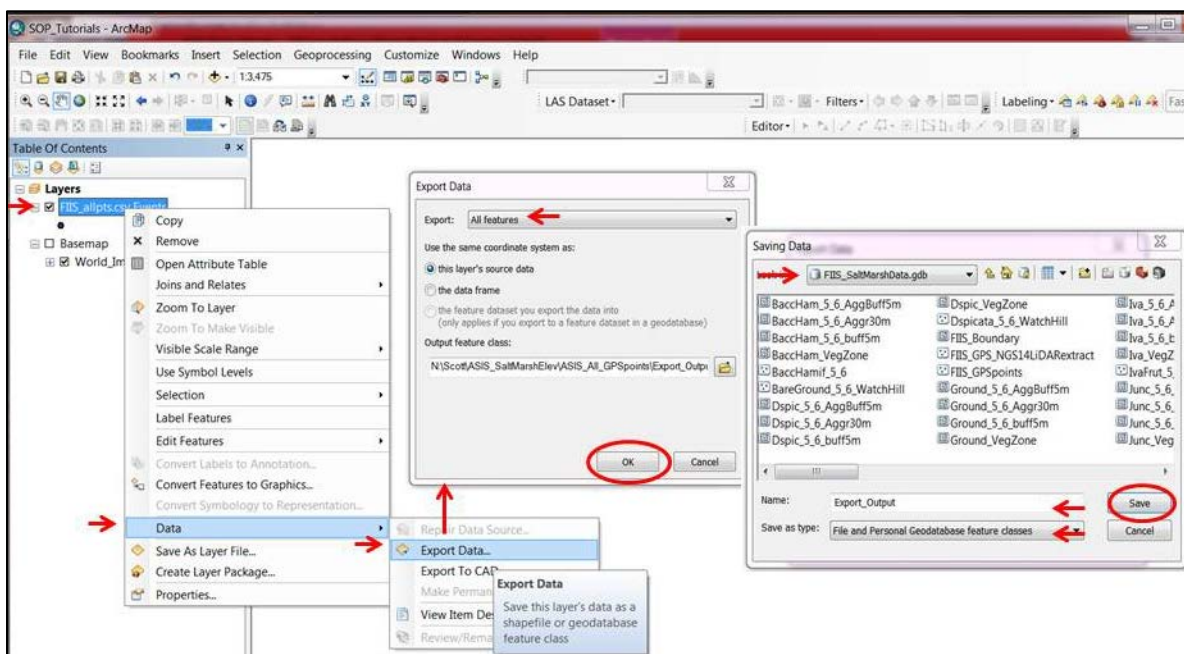


Figure 42. Exporting an Events file into a shapefile in ArcGIS.

3.5 Visualizing Elevation Points in GIS

There are many ways to view the elevation data in ArcGIS. Presented below is one method for symbolizing the data.

To visualize the data by elevation (Figure 44):

1. **Right click** on the **shapefile** in the Table of Contents.
 - a. Select **Properties**.
2. Select the **Symbology** tab.
3. Select **Categories** in the **Show** menu.
 - a. Select **Unique values**.
4. Select the **elevation** field in the **Value Field**.
 - a. Select **Add All Values**.
5. **Select multiple points** with similar elevations.
 - a. **Right click** and select **Group Values**.
 - b. Repeat this step to group the elevations into distinct elevation ranges.
 - c. Rename the label field to match the elevation range.
 - d. **Double click** on a symbol to change the **color** or **style**.
6. Select **Apply** and **OK**.

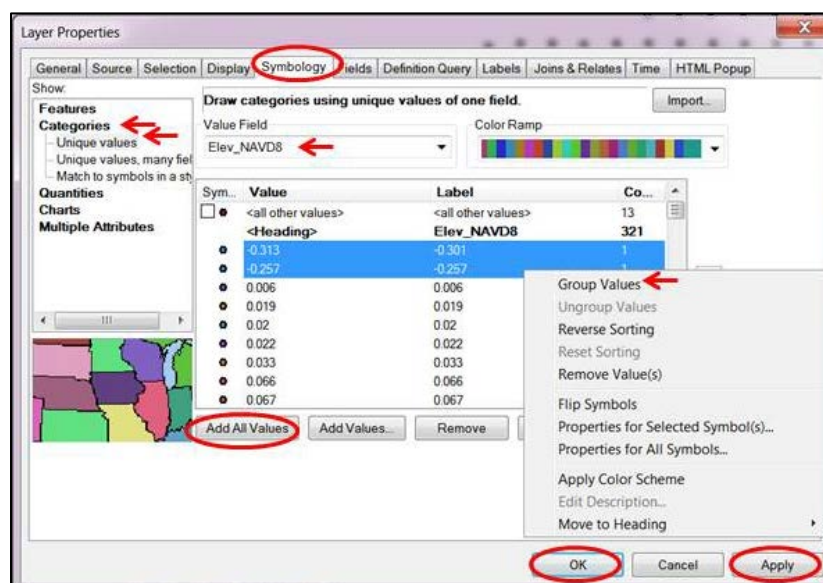


Figure 43. Changing the symbology of elevation points in ArcGIS.

Once the data has been uploaded and symbolized maps can be created for each salt marsh (Figure 45).

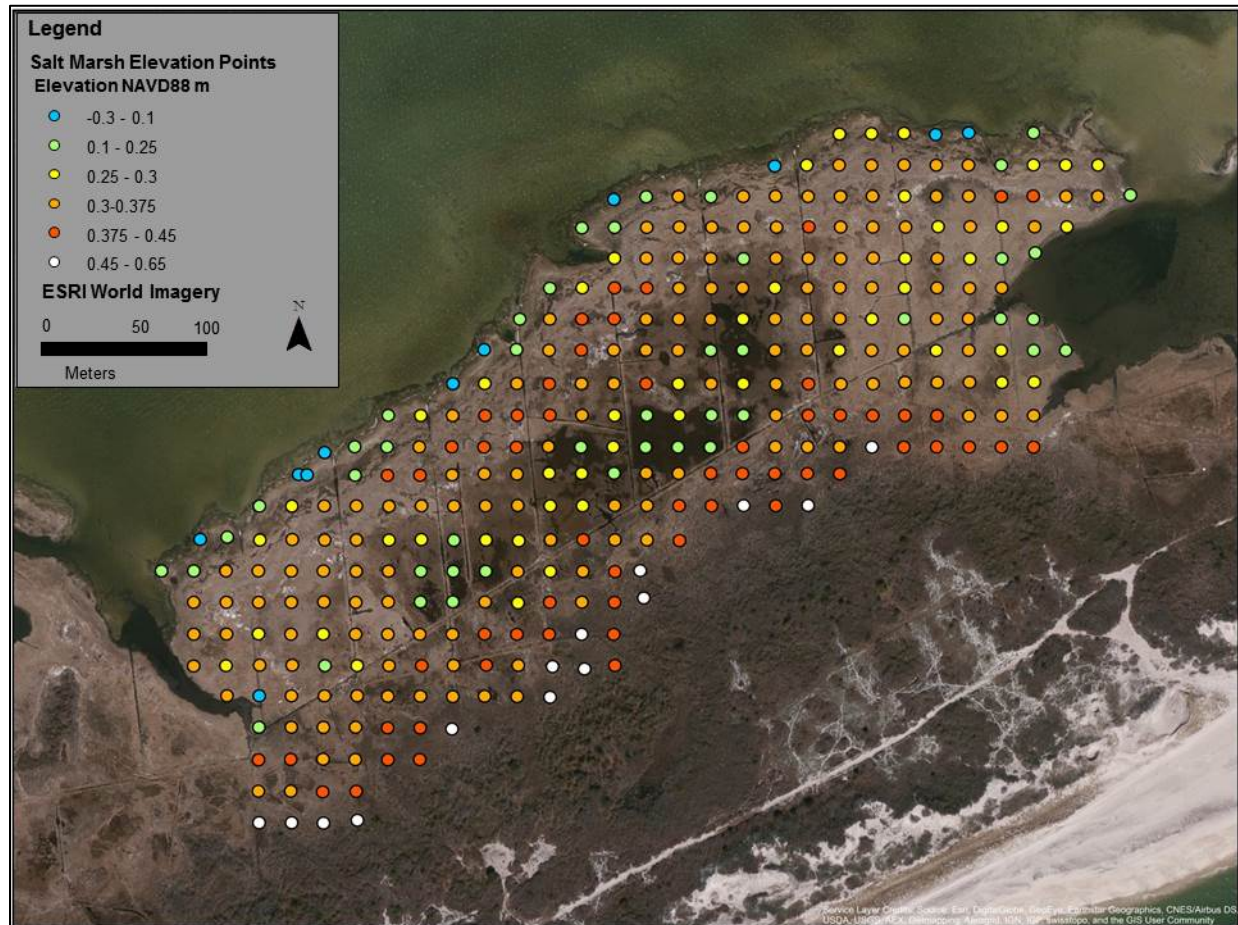


Figure 44. An example of a salt marsh elevation map.

Note: Elevation ranges may differ between salt marsh sites. Park managers should group and symbolize survey points based on site specific elevations.

3.6 Data Management

Salt marsh elevation surveys produce large amounts of data. Having a good data management system in place will help to avoid confusion when processing the data. Users should set up a folder structure that clearly organizes and identifies GNSS survey data, GIS data, and other file types produced during salt marsh elevation surveys (Figure 46).

Note: Include a “Read Me” text file in the marsh folder with notes about who collected the data, the devices used, the dates and times of the survey, the base station and check-in details, and any other important information about the survey. This file can be very helpful as a quick reference in the future to explain the marsh survey and to write metadata.

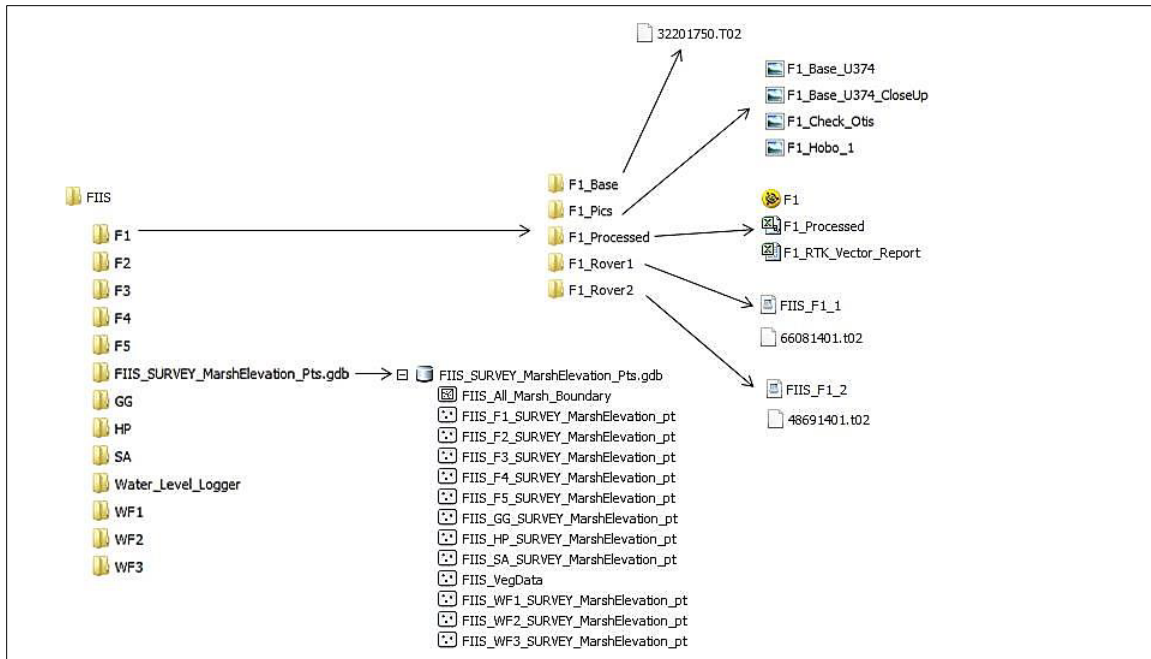


Figure 45. An example of a folder structure used to manage salt marsh elevation data.

3.7 Metadata

Each salt marsh survey needs an associated metadata file which conforms to Federal Geographic Data Committee (FGDC) standards (Federal Geographic Data Committee, 2016). A metadata file is a file that describes another file. Its purpose is to explain the dataset well enough that a third party could use the data appropriately. FGDC metadata is required if the elevation points will be shared as geographic information (i.e. a shapefile, feature class, geodatabase, etc.).

Metadata should contain:

1. A description of the project.
2. A description of the data (i.e. elevation points of salt marsh site “A”).
3. Dates of the survey.
4. Information about how the survey was performed (RTK vs. PPK).
5. Information about the bench mark used as a base station and as a check-in.
6. Estimated accuracy of the survey (from GNSS reports).
7. Any other pertinent information.

There are many different tools to help write metadata, such as the US Geological Survey (USGS) TKME Metadata Tool and the US Environmental Protection Agency (EPA) EME Metadata Editor (United States Geological Survey, 2016) (United States Environmental Protection Agency, 2014). One method for creating FGDC compliant metadata is presented below, using ArcCatalog in ArcGIS

(ESRI , 2016). This method is adapted from the Rhode Island Geographic Information Systems (RIGIS) & The University of Rhode Island Environmental Data Center's Minimum Metadata Requirements (Tefft, 2016).

Note: Metadata records include fields that are **Mandatory**, **Mandatory if Applicable**, and **Optional**. Mandatory fields must be filled out, Mandatory if Applicable fields must be filled out only if they apply to the dataset, and Optional fields can be included at the author's discretion. The following procedure outlines the fields necessary for completing FGDC-compliant metadata records (Mandatory if Applicable and Optional fields may be included).

To create FGDC compliant metadata in ArcCatalog:

Set up ArcCatalog to Write FGDC Metadata (Figure 47):

1. Open **ArcCatalog**.
2. Select **Customize -> ArcCatalog Options...** from the main menu toolbar.
3. Select the **Metadata** tab.
4. Select **FGCD CSDGM Metadata** from the **Metadata Style** dropdown.
5. Ensure the **check box** for “**Automatically update when metadata is viewed**” is selected.
6. **Uncheck** the box for “**Show metadata upgrade prompt**”.
7. Select **Apply** and **OK**.

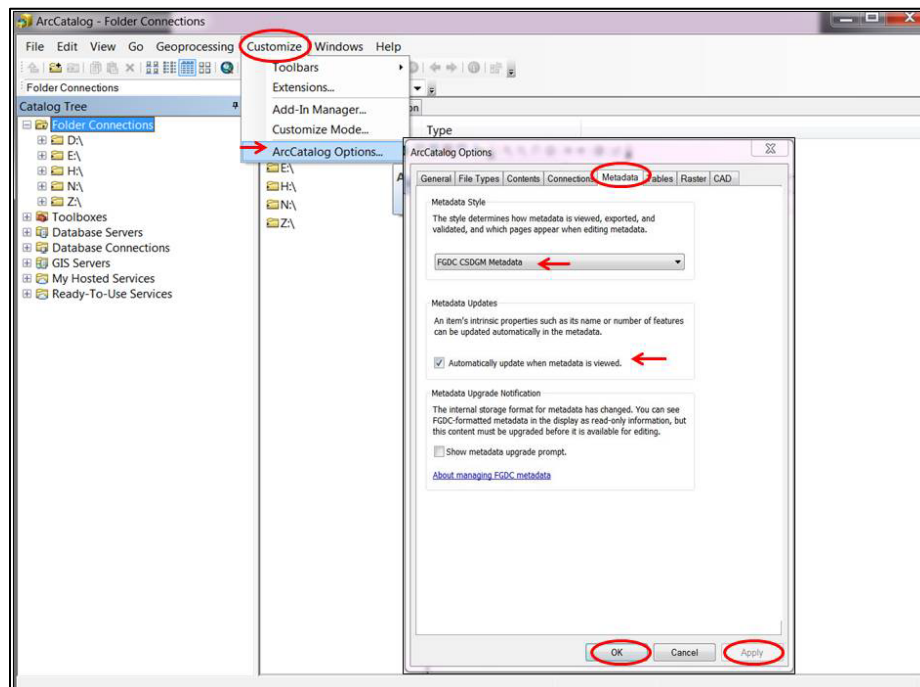


Figure 46. Setting up ArcCatalog to write FGDC metadata.

Edit and write the required fields of metadata for the file (Figure 48):

1. In ArcCatalog, navigate and select the appropriate file from the Catalog Tree.
2. Select the **Description** tab on the top of the window.
3. Select **Edit** on the top of the window.
4. Select **Item Description** in the **Overview** tab.
 - a. Enter information in the appropriate fields.
 - i. **Title** – name of the dataset
 - ii. **Tags** – terms related to the dataset that could be used to search for the resource.
 - iii. **Summary (Purpose)** – short synopsis of the goal of the dataset. This should explain why the dataset was created, what the dataset can be used for, and who can benefit from the dataset.
 - iv. **Description (Abstract)** – a short (3-4 sentence) summary of the dataset that describes exactly what the dataset is and what it can be used for.
 - v. **Credits** – *Mandatory if Applicable* - contributors to the dataset.
 - vi. **Use Limitations** – *Mandatory if Applicable* - the organization-specific use constraints.

Note: The NPS has standard Use Constraints and Use Limitations. Contact local or regional resource managers to obtain these.

- b. **Bounding Box** – this is automatically generated by ArcMap and ArcCatalog and will be in decimal degrees.

Note: Mandatory fields will be highlighted in Red automatically. These fields must be filled out to achieve the standard requirements.

5. Select **Topics & Keywords** in the **Overview** tab.
 - a. Enter information in the appropriate fields.
 - i. **Topic Categories** – primary themes that are associated with the dataset.
 - ii. **Theme Keywords** – keywords that are associated with the dataset.
 - iii. **Place Keywords** – Keywords that describe the place (s) associated with the dataset.
6. Select **Citation** in the **Overview** tab.

- a. Enter information in the appropriate fields.
 - i. **Title** – name of the dataset.
 - ii. **Presentation Form: FGDC Geospatial Data Presentation Form** – the form in which the dataset is provided.
 - iii. **Dates**
 1. **Created** – the date the dataset was created.
 2. **Published** – the date of publication of the dataset.
 3. **Revised** – *Optional*
7. Select **Resource Citation Contacts** in the **Overview** tab.
 - a. Enter information in the appropriate fields.
 - i. **Contact** – the dataset creator or person at the organization with the most knowledge of the dataset.
 1. **Name**
 2. **Organization**
 3. **Position**
 4. **Role**
 5. **Contact Information**
8. Select **Details** in the **Metadata** tab.
 - a. Enter information in the appropriate fields.
 - i. **Date Stamp** – the date when the metadata was created or updated. This will be automatically filled when the publication date is selected in the **Overview – Citation** section.
9. Select **Contacts** in the **Metadata** tab.
 - a. Enter information in the appropriate fields.
 - i. **Contact** – the dataset creator or person at the organization with the most knowledge of the dataset.
 1. **Name**
 2. **Organization**

3. **Position**
4. **Role**
5. **Contact Information**
 - a. **Email**
 - b. **Address Type**
 - c. **Address – Optional**
 - d. **City**
 - e. **State**
 - f. **Postal Code**
 - g. **Telephone**
 - h. **Instructions – Optional**

10. Select **Maintenance** in the **Metadata** tab.

- a. Enter information in the appropriate fields.
 - i. **Update Frequency – Mandatory if Applicable** - the frequency in which the metadata is anticipated to be updated.

11. Select **Constraints** in the **Metadata** tab.

- a. Enter information in the appropriate fields.
 - i. **New General Constraints - Mandatory if Applicable**
 1. **General Constraints**
 - a. **Use Limitation** – an organization-specific use constraints (can be the same of different than Use Limitations in Overview – Item Description).

12. Select **Details** in the **Resource** tab.

- a. Enter information in the appropriate fields.
 - i. **Status** – the status of the dataset (i.e. Completed).

13. Select **Extents** in the **Resource** tab.

- a. Enter information in the appropriate fields.

- i. **Extent**
 - 1. **Description** – what the extents specified below refer to (i.e. ground condition, publication date, etc.).
 - 2. **Temporal Period Extent** – the start and end dates associated with the dataset.
14. Select **Points of Contact** in the **Resource** tab.
- a. Enter information in the appropriate fields.
 - i. **Contact** – the dataset creator or person at the organization with the most knowledge of the dataset.
 - 1. **Name**
 - 2. **Organization**
 - 3. **Position**
 - 4. **Role**
 - 5. **Contact Information**
 - a. **Email**
 - b. **Address Type**
 - c. **Address** – *Optional*
 - d. **City**
 - e. **State**
 - f. **Postal Code**
 - g. **Telephone**
 - h. **Instructions** – *Optional*
15. Select **Maintenance** in the **Resource** tab.
- a. Enter information in the appropriate fields.
 - i. **Update Frequency** – how often the dataset will be updated in the future (i.e. not planned).
16. Select **Quality** in the **Resource** tab.
- a. Enter information in the appropriate fields.

i. **Report** - *Mandatory if Applicable*

1. **Report Type**

- a. **Quantitative Attribute Accuracy** – explains the accuracy attributes, in either horizontal or vertical direction, or the assignments of values in the data, and the tests used to determine this.

i. **Measure**

1. **Description** – what was measured / verified.

ii. **Report**

1. **Report Type**

- a. **Conceptual Consistency** – an explanation of fidelity of relationships within the data and the tests that were used to determine this.

i. **Measure**

1. **Description** – how were relationships tested or verified.

iii. **Report**

1. **Report Type**

- a. **Completeness Omission** – information about omissions, selection criteria, generalizations, definitions used and other rules used to derive the dataset.

i. **Measure**

1. **Description** – a list of omissions, rules and definitions used in the creation of the dataset.

iv. **Report**

1. **Report Type**

- a. **Absolute External Positional Accuracy** – description of the accuracy of horizontal and vertical positions of spatial objects.

i. **Dimension**

1. **Horizontal**

2. **Vertical**

ii. **Measure**

1. **Description** – explanation of the accuracy and description of tests used.

17. Select **Lineage** in the **Resource** tab.

- a. Enter information in the appropriate fields.
 - i. **Statement** – *Mandatory if Applicable* - a description of how the data were derived, sources used and major processes carried out.
 - ii. **Data Source** – *Mandatory if Applicable* - (repeat as many times as necessary)
 1. **Source Description** – description of the where the data came from.
 - a. **Medium Name** – *Mandatory if Applicable* - type of resource the data is.
 2. **New Source Citation**
 - a. **Title** – official source name
 - b. **Dates**
 - i. **Published**
 - c. **Edition** – *Mandatory if Applicable* - the version of the cited resource.
 - d. **Series** – *Mandatory if Applicable* - the name of the series the resource is part of.
 - i. **Name** – *Mandatory if Applicable* - name of the series.
 - ii. **Issue** – *Mandatory if Applicable* - issue number.
 - iii. **Page** – *Mandatory if Applicable* - page on which the resource can be found.
 - e. **Contact**
 - i. **Name**
 - ii. **Organization**
 - iii. **Position**
 - iv. **Role**
 - v. **Contact Information**
 1. **Email**

2. **Address Type**
 3. **Address – Optional**
 4. **City**
 5. **State**
 6. **Postal Code**
 7. **Telephone**
 8. **Instructions – Optional**
- vi. **Other Details**
- iii. **Process Step** - (repeat as many times as necessary)
 1. **Process Description** – how the dataset was developed; this can correspond to one specific step, or can be a description of all the steps it took to develop the dataset.
 2. **Process Step Date** – the date (or dates) on which the processes were carried out.
 3. **Processor**
 - a. **Name**
 - b. **Organization**
 - c. **Role**
 - d. **Contact Information**
 - i. **Email**
 - ii. **Address Type**
 - iii. **Address – Optional**
 - iv. **City**
 - v. **State**
 - vi. **Postal Code**
 - vii. **Telephone**
 - viii. **Instructions – Optional**

4. **Data Source** – *Mandatory if Applicable* - only included if a specific cited data source (from above) was used in a processing step.

- a. **Source Type** - *Optional*

- b. **Source Description** - *Mandatory if Applicable*

18. Select **Fields** in the **Resource** tab.

- a. Enter information in the appropriate fields.

- i. **Entity and Attribute Information: Details** - *Mandatory if Applicable*

1. **Label** – abbreviated name of the dataset.

- a. **Entity Type**

- b. **Object** – the type of resource (i.e. feature class).

- c. **Count** – *Mandatory if Applicable* - the number of features within the dataset

- d. **Definition** – the definition of what the dataset is.

- e. **Definition Source** – *Optional* – definition provider (i.e. dataset creator/metadata author)

2. **Attribute**

- a. **Label** – name of the field directly from the attribute table.

- b. **Alias** – *Optional* – alternate field name or a more descriptive field title (can use spaces and special characters).

- c. **Definition** – description of data contained by the field.

3. **Definition Source** – *Mandatory if Applicable* - definition provider (i.e. dataset creator/metadata author).

- a. **Enumerated Domain** – *Mandatory if Applicable* - the members of an established set of values.

- i. **Value** – description of a repeating value that may occur within the field.

- ii. **Definition** – description of the value/code stored within the field.

- iii. **Definition Source** – *Mandatory if Applicable* - definition provider (i.e. dataset creator/metadata author).

- b. **Range Domain – Mandatory if Applicable** - the minimum and maximum values of a valid values.
 - i. **Minimum** – the minimum value that can be stored in a field.
 - ii. **Maximum** – the maximum value that can be stored in a field.
 - c. **Codeset Domain – Mandatory if Applicable** - reference to a standard or list which contains the members of an established set of valid values.
 - i. **Name** – the title for the set of values (typically a standardized set of values in a published form).
 - ii. **Source** – the defining authority of this set of values.
 - d. **Unrepresented Domain – Mandatory if Applicable** - description of the values stored in the field and why they cannot be described as enumerated, Codeset, or range domains. An explanation of how this field's unique values were calculated.
- ii. **Overview Description - Mandatory if Applicable**
1. **Summary** – a detailed summary of the information provided by the resources data. This is an alternative place to list Attribute Field Information, or a place to provide additional information regarding the data.

Note: Other Optional fields exist. It is up to the user to decide which fields are necessary.

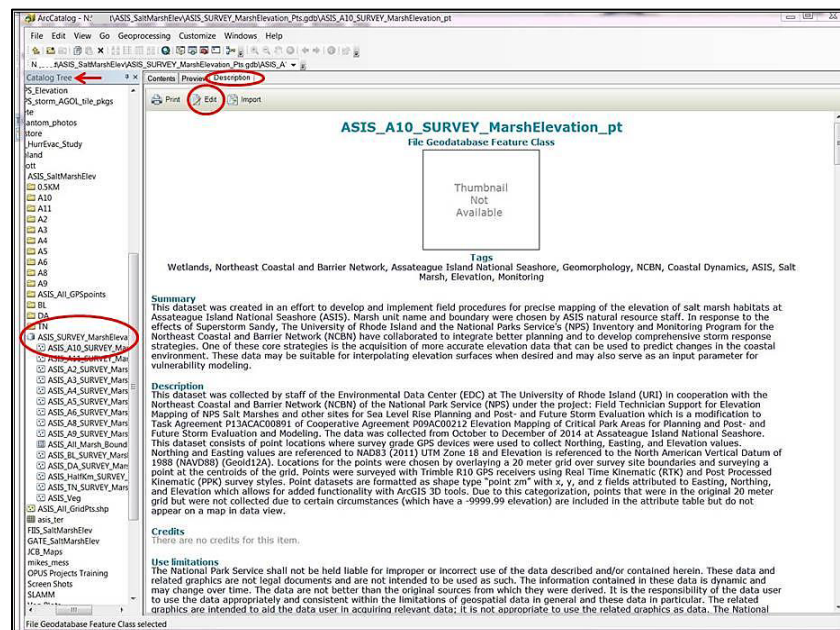


Figure 47. The Description page showing a metadata record in ArcCatalog. If no metadata record exists the sections will be blank.

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Appendix A. Job Template

Table 2. Recommended Job settings for GNSS surveys.

Option	Subcategory	Entry
Name		NPS park code_ marsh name
Template		Default or use appropriate template
Coordinate System		UTM – NAD 1983 (Conus)(Mol)
	Geoid Model	12A (or most recent)
	Datum Grid	No
	Coordinates	Grid
	Project Height	1
Units		
	Distance & grid cords	Meters
		Default
Linked Files		. csv of grid points
Active Map		None
Feature Library		
COGO Settings		Ground
Additional Settings		Off
Media File		Previous point
Reference		
Description		
Operator		ParkCode_UserInitials
Notes		

Appendix B. Survey Style Settings

Recommended settings for RTK Internal, RTK External, and PPK survey styles as well as Topo Point and Stakeout Options. These are based on R10 GNSS receivers and a TDL 450H Radio.

RTK Internal and External Base Options

The figure displays three screenshots of the 'Base options' dialog box, showing recommended settings for RTK Internal and External survey styles. The settings are as follows:

- Survey type:** RTK & logging
- Broadcast format:** CMRx
- Station index:** 7
- Logging interval:** 1s
- Elevation mask:** 10°
- Antenna Type:** R10 Internal
- Measured to:** Bottom of antenna mount
- Antenna height:** ?
- Part number:** 90909-XX
- GNSS Signal Tracking:**
 - Use L2e: Yes
 - GPS L2C: ☒
 - L5: ☒
 - Galileo: ☒
 - BeiDou: ☒
 - GLONASS: ☒
 - QZSS: ☒

Figure 48. Recommended Base options for an RTK Internal and External survey.

RTK Internal & External Rover Options

The figure displays five screenshots of the 'Rover options' dialog box, showing recommended settings for RTK Internal & External survey styles. The settings are as follows:

- Survey type:** RTK & logging
- Broadcast format:** CMRx
- Use station index:** Any
- Prompt station index:** ☒
- Satellite differential:** Off
- Logging interval:** 1s
- Elevation mask:** 10°
- PDOP mask:** 6.0
- Logging device:** Controller
- Auto file names:** ☒
- Antenna Type:** R10 Internal
- Measured to:** Bottom of antenna mount
- Antenna height:** 2.050m
- Part number:** 90909-XX
- GNSS Signal Tracking:**
 - Use L2e: Yes
 - GPS L2C: ☒
 - GLONASS: ☒
- Roving precision:** Auto tolerance
- xFill:** ☐
- Tilt:** ☒

Figure 49. Recommended Rover options for an RTK Internal & External survey.

RTK Internal Base and Rover Data Link Options

The figure shows two side-by-side screenshots of the data link configuration interface. The left screen is titled 'Base data link' and the right is 'Rover data link'. Both screens have a battery indicator at 94%. In the 'Base data link' screen, the 'Type' dropdown is set to 'Radio' and the 'Radio' dropdown is set to 'Receiver internal'. Red arrows point to both dropdowns. The 'Accept' button at the bottom right is circled in red. The 'Rover data link' screen shows identical settings for 'Type' and 'Radio', with red arrows pointing to the dropdowns and the 'Accept' button circled in red. Both screens have buttons for 'Map', 'Menu', 'Favorites', and 'Switch to' on the right side, and 'Esc' and 'Connect' on the bottom left.

Figure 50. Recommended Base & Rover data link options for an RTK Internal survey.

RTK Internal Base and Rover Data Link Options

The figure shows two side-by-side screenshots of the data link configuration interface. The left screen is titled 'Base data link' and the right is 'Rover data link'. Both screens have a battery indicator at 94%. In the 'Base data link' screen, the 'Type' dropdown is set to 'Radio', 'Radio' is set to 'Trimble TDL450', 'Controller port' is 'COM1', 'Receiver port' is 'Port 1', and 'Baud rate' is '38400'. Red arrows point to each of these fields. The 'Accept' button at the bottom right is circled in red. The 'Rover data link' screen shows 'Type' set to 'Radio' and 'Radio' set to 'Receiver internal', with red arrows pointing to these dropdowns and the 'Accept' button circled in red. Both screens have buttons for 'Map', 'Menu', 'Favorites', and 'Switch to' on the right side, and 'Esc' and 'Connect' on the bottom left.

Figure 51. Recommended Base & Rover data link options for an RTK External survey.

PPK Base and Rover Options

The figure displays six screenshots of the PPK Base and Rover options screens, arranged in a 2x3 grid. Red arrows indicate recommended settings for each screen.

- Base options (Top Left):**
 - Survey type: **PP kinematic**
 - Logging device: **Receiver**
 - Logging interval: **1s**
 - Elevation mask: **10°**
 - Antenna Type: **R10 Internal**
- Base options (Top Middle):**
 - Measured to: **Bottom of antenna mount**
 - Antenna height: **2.050m**
 - Part number: **90909-XX**
 - Serial number: **?**
 - GNSS Signal Tracking:
 - Use L2e: **Yes**
 - GPS L2C: **Yes**
- Base options (Top Right):**
 - GLONASS: **Yes**
 - Galileo: **Yes**
 - BeiDou: **Yes**
 - QZSS: **Yes**
- Rover options (Bottom Left):**
 - Survey type: **PP kinematic**
 - Logging device: **Controller**
 - Auto file names: **Yes**
 - Logging interval: **1s**
 - Elevation mask: **10°**
 - PDOP mask: **6.0**
- Rover options (Bottom Middle):**
 - Antenna Type: **R10 Internal**
 - Measured to: **Bottom of antenna mount**
 - Antenna height: **2.050m**
 - Part number: **90909-XX**
 - Serial number: **?**
 - GNSS Signal Tracking:
 - Use L2e: **Yes**
 - GPS L2C: **Yes**
- Rover options (Bottom Right):**
 - GLONASS: **Yes**
 - Galileo: **Yes**
 - BeiDou: **Yes**
 - Tilt: **Yes**

Figure 52. Recommended Base & Rover options for a PPK survey.

Topo point options

The figure displays two screenshots of the Topo point options screens, arranged side-by-side. Red arrows indicate recommended settings for each screen.

- Topo point (Left):**
 - Auto point step size: **1**
 - Auto store point: **Yes**
 - Number of measurements: **5**
 - Precision:
 - Auto tolerance: **Yes**
 - Quality control: **QC 1 & QC 2**
 - Occupation time: **0m5s**
- Topo point (Right):**
 - Tilt auto-measure: **Yes**
 - Auto abandon: **Yes**

Figure 53. Recommended Topo point options for all survey styles.

Stakeout Options

The figure displays four sequential screenshots of the Stakeout Options dialog box, showing recommended settings for RTK survey styles. Red arrows highlight specific options in each screenshot.

Screenshot 1 (Top Left): As-staked point details

- View before storage: ☒ (Red arrow)
- Horizontal tolerance: 0.020m (Red arrow)
- Point staked deltas format: Default
- Line staked deltas format: Default
- Arc staked deltas format: Default
- DTM staked deltas format: Default
- Road staked deltas format: Default
- Page indicator: 1/4

Screenshot 2 (Top Right): Alignment staked deltas format

- Alignment staked deltas format: Default
- As-staked name: Auto point name
- As-staked code: Design name
- Store grid deltas: ☒
- Page indicator: 2/4

Screenshot 3 (Bottom Left): Display

- Display mode: Surveyor centered (Red arrow)
- Display orientation: Direction of travel (Red arrow)
- Deltas (points): Δ Grid
- Deltas (other): Station and offset
- DTM: No files exist
- Display cut/fill to DTM: No
- V.Offset to DTM: 0.000m
- Compass: ☒ (Red arrow)
- Page indicator: 3/4

Screenshot 4 (Bottom Right): Remove staked point from list

- Remove staked point from list: ☒ (Red arrow)
- Auto measure: ☐
- Page indicator: 4/4
- Accept button is highlighted with a red circle.

Figure 54. Recommended Stakeout options for RTK survey styles.

Appendix C. GNSS Troubleshooting

Table 3. Common GNSS setup and survey issues, possible causes, and solutions.

Problem	Cause	Solution
The roving receiver is not receiving radio from the base station.	The base station is not broadcasting.	Use GNSS software to connect to the radio through the receiver. If no connection is made, connect directly to the radio and change the port settings.
	Incorrect over air baud rates between base station and rover.	Connect to the roving receiver's radio and make sure that it has the same setting as the base station receiver.
	Mismatched channel or network number selection.	Match the base station and rover radio channels/network number and try again.
	Incorrect port settings between the rover external radio and receiver.	If the radio is broadcasting data and the receiver is not receiving data, check the port settings of the receiver and radio using the GNSS software; match the settings and try again.
The base station is not broadcasting.	Port settings between base receiver and external radio are incorrect.	Use GNSS software to connect to the radio through the receiver. If no connection is made, connect directly to the radio and change the port settings.
	Faulty cable between receiver and external radio.	Do one of the following: -Try a different cable -Examine the ports for missing pins
The receiver does not turn on.	External power is too low.	Check the charge on the external power supply, and check the fuse if applicable. If required, replace the battery.
The receiver does not turn on.	External power is not properly connected.	Do the following: -Check that the Lemo connection is seated properly. -Check for broken or bent pins in the connector.
	Faulty external power cable.	Do the following: Try a different cable.
The receiver is not tracking any satellites.	The GNSS antenna does not have clear line of sight to the sky.	Ensure that the antenna has a clear line of sight.
The receiver does not log data.	Insufficient memory in the internal memory.	Delete old files. Press the Power button for 30 seconds.
The receiver is not responding.	The receiver needs a soft reset.	Turn off the receiver and then turn it back on again.
	The receiver needs a full reset.	Press the Power button for 30 seconds.

Appendix D. Topographic Feature Definitions

Marsh (Salt Marsh) – A coastal wetland area characterized by flooding and draining by the tides. Typically the marsh is composed of mud and peat (NOS, 2015). The marsh is zoned by vegetation; thought of as “low” and “high” marsh communities. The low marsh is located along the seaward edge and is frequently flooded by tides. The predominant plant species in the low marsh is the tall form of smooth cord grass (*Spartina alterniflora*). The high marsh is located between the low marsh and the upland border. The high marsh is at a slightly higher elevation than the low marsh, and is less frequently flooded (mostly at higher tide events). The most predominant plant species in the high marsh are salt hay (*Spartina Patens*), salt or spike grass (*Distichlis Spicata*), black grass (*Juncus Gerardii*) and the short form of *Spartina alterniflora*. Many other plant species may be found in the marsh including salt marsh aster (*Symphyotrichum tenuifolium*), sea lavender (*Limonium carolinianum*), glasswort or pickle-weed (*Salicornia maritima / depressa*), and three square (*Schoenoplectus (Scirpus) pungens*), to name a few (NH DES, 2004).

Platform Surface – Indicates that the rover pole was flush on the muddy/peat surface of the marsh.

Hummock – An area characterized by many pits/depressions as well as clumps of vegetation. Elevation can vary greatly in this area; therefore a note should be added as to where the rover pole was located (High or Low)

Panne – Areas of slight depression, in the marsh surface typically lacking marsh vegetation. These areas do not drain often and hold standing water for long periods of time, making it difficult for marsh plants to grow.

Ditch/Creek/Bay Edge – Grid points that fall in a ditch or edge should not be collected. The GNSS point should be taken on the marsh surface at the closest edge of the ditch, creek, or bay.

Mudflat – Sometimes referred to as a tidal flat. A stretch of land characterized by mud and a lack of vascular vegetation. Mudflats may be flooded at high tide and exposed at low tide.

Platform Surface – Indicates that the rover pole was flush on the muddy surface of the mudflat.

Pool – Larger, deeper, more permanent depressions, typically in the high marsh, that very rarely dry completely. Pools may contain submerged aquatic vegetation such as widgeon grass (*Ruppia maritima*) and are inhabited by salt marsh fish.

Ditch/Creek/Bay Edge – Grid points that fall in a ditch or edge should not be collected and the GNSS point should be taken on the mudflat surface at the closest edge of the ditch, creek, or bay.

Upland – Characterized by slightly higher elevation than the marsh, the upland typically sees minimal flooding from regular tide levels, but may be flooded under extreme tide levels. Vegetation includes grasses, herbs, shrubs, and even trees. This is the transition area between marsh edge and inland areas. Abundant plant species include marsh elder (*Iva frutescens*), sweet gale (*Myrica gale*), seaside goldenrod (*Solidago sempervirens*), switchgrass (*Panicum virgatum*), eastern baccharis (*Baccharis halimifolia*), and common reed (*Phragmites australis*) (NH DES, 2004).

Platform Surface – Indicates that the rover pole was flush on the soil surface of the upland.

Ditch/Creek/Bay Edge – Grid points that fall in a ditch or edge should not be collected and the GPS point should be taken on the upland surface at the closest edge of the ditch, creek, or bay.

Beach – Narrow, gently sloping land composed primarily of sand, pebbles, rocks, or seashells. Located along the shoreline, beaches are subject to sediment transport by waves, tides, and currents.

Face – The gently sloped seaward section of the beach exposed to waves.

Dune – A hill or ridge of sand that lies landward of the beach face. Various dune grass and shrub vegetation exist.

Appendix E. Equipment Checklist

Base Station:		Rover Receiver:	
GNSS Receiver	☐	GNSS Receiver	☐
Antenna	☐	Antenna	☐
Internal Battery w/ cables and charger	☐	Internal Battery w/ cables and charger (at least 2 for the field)	☐
External Battery (6ah) w/ cables and charger	☐		
Radio/Power Y-Cable (see Figure 26)	☐		
Base Tripod:		Rover Bipod:	
Fixed Height Tripod	☐	Rover Pole with <u>ebubble</u> attached	☐
Quick Release Adapter	☐	Quick Release Adapter	☐
Pointed Datum Foot	☐	Flat Topo Foot	☐
Extension Pole	☐	Controller Cradle	☐
Sandbags (3)	☐	Bipod Extension Legs (optional)	☐
External Radio:		GNSS Controller:	
Radio w/ cables and charger	☐	GNSS Controller w/ cables and charger	☐
External Battery (12v) w/ cables and charger	☐		
Antenna w/ extension pole and washer	☐	Other:	
Antenna Cable and Mount	☐	Laptop w/ charger	☐
Tripod	☐	External Drive (thumb drive / flash drive) w/ <u>.shp</u> and <u>.csv</u> files	☐
Data/Power Y-Cable (see Figure 26)	☐	Walkie-Talkies w/ charger	☐
		Field Maps	☐

Figure 55. An equipment checklist based on Trimble R10 GNSS receivers, Trimble TSC3 handheld controllers, and a Trimble TDL450H External Radio.

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