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I. Introduction

Marsh Analysis and Planning Tool Incorporating Tides and Elevations (MAPTITE) is an ESRI ArcGIS Add-in tool to aid in the selection of vegetation types for different restoration elevations based on a combination of a digital elevation model (DEM) derived from GPS observations, local tidal datums, and grass type information. By delineating planting areas and providing point data that can be uploaded to GPS receivers for those areas, MAPTITE creates files that allow users to accurately plant appropriate species during restoration. The methodology and program were developed by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS), National Geodetic Survey (NGS), National Centers for Coastal Ocean Science (NCCOS), and Special Projects Office (SPO), in coordination with key restoration partners, including the National Aquarium in Baltimore (NAIB).

As understanding of the critical part that wetlands play in the health of the world's oceans and as protective, productive buffers against wave action and storms has grown, so has awareness of a critical need to both protect remaining wetlands and to begin a focused and coordinated effort to restore wetlands that have been lost. The first step in wetlands restoration is the re-introduction of various types of native marsh grasses. These grasses are often very sensitive to changes in salinity and water levels. In tidal areas, a small change in elevation can strongly affect salinity and saturation levels and thus affect the ecosystems that can develop in an area. It is therefore critical that restoration planning include a thorough knowledge of geodetic datum that topography data referred to, tidal datums and grass species for a restoration area.

The DEM derived from GPS observation is referred to ellipsoidal datum. Ellipsoid is a smooth mathematical surface that is used to represent the Earth's surface. The ellipsoidal height is the distance along the ellipsoidal normal to a point on the Earth's surface. Many different ellipsoids and datums have been defined and used over the years. Currently the Geodetic Reference System 80 (GRS80) ellipsoid in conjunction with the North American Datum of 1983 (NAD83) is used for the official horizontal datum of the United States. Most topography maps are referred to the North America Vertical Datum 1988 (NAVD88), which is an orthometric datum and measured by classical leveling. The conversion between NAD83 and NAVD88 can be achieved by a Geoid model.

A tidal datum is defined in terms of a certain phase of the tide: Mean Low Water (MLW), Mean Higher High Water (MHHW), etc., and is based on a 19-year period of water level averaging, the *National Tidal Datum Epoch (NTDE)*. The present NTDE adopted by NOAA/NOS in the United States is 1983 through 2001. Water level (tidal) datums are local vertical datums which may change considerably within a geographical area due to changes in tidal hydrodynamics and range of tide. At each tide station, a network of brass, bronze, or aluminum alloy survey disks, called bench marks, is installed in the vicinity of the station. The local tidal datums are referred to each these bench marks. The relationships among the tidal, orthometric and ellipsoidal datums can be established by classical leveling and GPS observations at those benchmarks.

II. Requirements and Installation of MAPTITE Software

a. Requirements for MAPTITE Operation

In order for MAPTITE to have full functional and capabilities the minimum hardware and software requirements are listed below.

System Requirements for MAPTITE operation:

Software applications(s)/version:

ArcGIS 10.2

ArcGIS Spatial Analyst extension

b. Installing MAPTITE

To install the MAPTITE ArcGIS 10.2 add-in, double click on the file “MAPTITE_102.esriAddIn” on your computer. Open ArcGIS, the MAPTITE toolbar should appear in the menu.

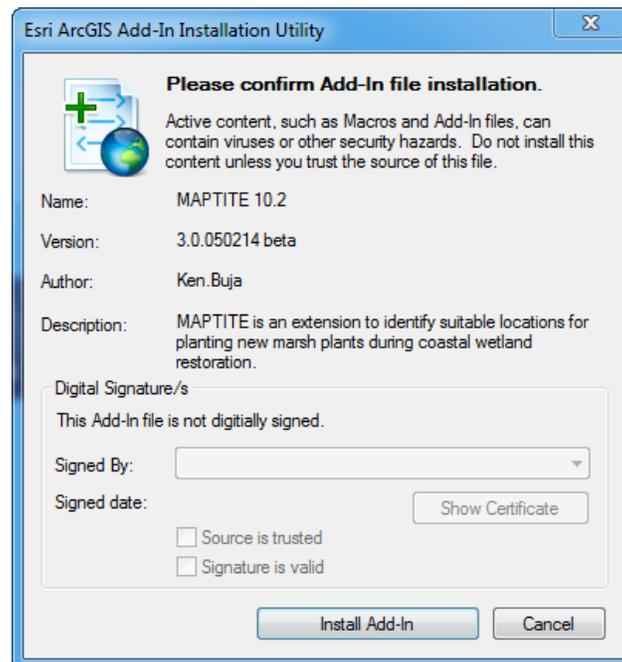


Figure 1. MAPTITE Add-In installation utility

If the toolbar is greyed out, turn on the Spatial Analyst in ArcMap by clicking Customize drop down menu and selecting Extensions.

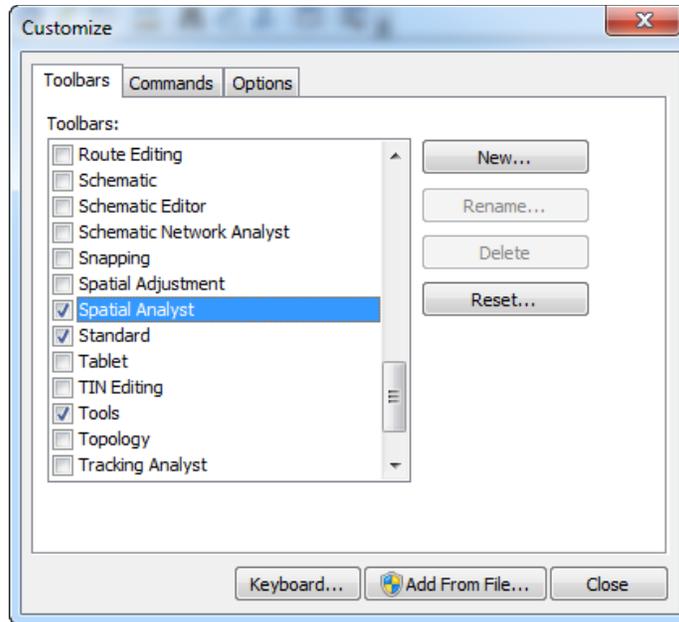


Figure 2. ArcGIS Customize dialog used to select Spatial Analyst.

c. MAPTITE Toolbar

The dockable MAPTITE toolbar has three buttons (see Figure 3):

The first button (“Open Selection Form”) opens a dialog that will utilize an input Digital Elevation Model (DEM), tide station elevations, and the user’s knowledge of marsh grass species requirements to create a grid dataset of grasses/plant spacing (Figure 4). This button will be activated when the Spatial Analyst Extension is enabled.

The second button (“Export grid to polygon”) opens a dialog to export the grass grid into either a single polygon or a series of polygons for each grass/plant spacing combination.

The third button (“Export features to GPS”) exports the coordinates of the vertices of the grass/plant spacing polygons as a text file that can be uploaded into a GPS receiver.

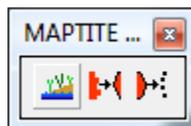


Figure 3. The MAPTITE dockable toolbar

III. Operation and Features of MAPTITE

Figure 4. MAPTITE selection form used to create grass/planting grid.

a. Create Grid Using Selection Form

1. **DEM Layer:** This is the input DEM layer that all calculations will be made from. Generally, it will be created from GPS data collected at the restoration site. A dataset that already exists in the project may be selected from the pull down menu or the open folder button can be used to navigate to select a DEM from another location. The selected DEM will be added to the ArcMap layer. The DEM must be in a **projected coordinate system** (i.e., UTM or State plane). Selection of the DEM automatically populates the DEM Ground Units (2) and DEM Z Units (3) boxes. See **Digital Elevation Models (DEMs)** under **IV. Obtaining Additional Data Integral for MAPTITE Analysis** for a discussion of DEMs in wetlands areas.
2. **DEM Ground Units:** Units of the Digital Elevation Model. This value is automatically selected from the projection information of the DEM.
3. **DEM Z Units:** Vertical units of measurement that are automatically selected from the DEM. If the Z Units are different than the ground units, select the correct units from the dropdown list. All units used in this dialog will be in the units specified in this box.
4. **Clip Polygon Layer:** Allows user to select a polygon dataset to use as a mask in order to exclude all data that falls outside of the polygon. **The Clip output to polygon** checkbox must be checked to use the layer as a mask.

5. **Output Grid:** The integer output grid that will be created when the selection form is completed and run. When this grid is created, a separate lookup table having the suffix “_lut” will be created. The lookup table will contain information about the fields of the grid and the grass/spacing combination they represent. The lookup table will be used by the tool that exports polygon datasets from this grid dataset.

6. **MSL Adjustment:** This adjustment corrects the elevation values of the DEM layer to a local Mean Sea Level (MSL) based on values derived from a relative tide station. If a DEM layer is referenced to NAVD88, the MSL adjustment = NAVD88 – MSL.

7. **Default Spacing:** This is a spacing value (per ground unit) that will be automatically applied to each grass added to the table (See 20.).

8. **Elevation Uncertainty:** The allowable extent to which actual planting areas for given plants can vary from the model output given the uncertainty of the elevation measurements used to create the DEM and the modeled planting areas.

9. **Load Parameters:** A previously created parameter file can be loaded using this button. All fields except DEM Layer, Clip Polygon Layer, and Output Grid will be populated when the parameter file is loaded.

10. **Save Parameters:** The parameters entered into the Selection Form can be saved into a parameter file using this button.

11. **Get Datum Info:** This button opens the NOAA website where vertical datum information can be found for boxes 13 through 17. See Part **IV. Obtaining Additional Data for MAPTITE Analysis** for a fuller description of this web site and the data it provides.

Text boxes 12 through 17 are elevations that are be used in creating the output integer grid. All of the datums values should be relative to MSL:

12. **Upland:** The elevation of the upland extent and highest elevation in the project area DEM. This value must be higher in elevation than the MHHW datum.

13. **MHHW:** Mean Higher High Water elevation.

14. **MHW:** Mean High Water elevation.

15. **MSL:** Mean Sea Level elevation.

16. **MLW:** Mean Low Water elevation.

17. **MLLW:** Mean Lower Low Water elevation.

18. The Plant/Spacing/Elevation Table: The entry boxes of this table allow the user to define the types of grasses that will be planted and the tide ranges appropriate for the growth of those grasses. A new row will be added after the information for a selected/entered grass type is complete. The values selected in a row will be verified (a check will be made that the Upper Limit is higher than the Lower Limit, for example), and an error message will appear if values in the row are not valid.

19. **Plant:** A list of species can be accessed from the pull down menu. Selecting a grass activates the default values for the other selections in that row – Plant Spacing, Upper and Lower Limits, elevation range checkboxes, and the Delete button. If a desired species is not included, select **Other**. Enter the name of the species into the message box and fill in the appropriate tide zones. A new species can only be added once to the list. Note: The list will appear to have selected “Other” until you click on one of the other selections in the row. The new species name will then appear as the selected grass.

20. **Plant Spacing:** This textbox is automatically populated with the Default Spacing value (See 8) when a grass is added. The default value can be replaced with any positive value.

21. **Upper Limit:** The Upper Limit is automatically populated by the higher elevation in each of the elevation range checkboxes (See 22). A different value can be added to this textbox. However, checking one of the elevation ranges will cause the Upper Limit to revert to the higher elevation of that elevation range.

22. **Habitat Elevation Ranges:** These are the elevation ranges in which each of the given plant types can be expected to grow. The values are derived from **12 through 17**, and include **OW** (Open Water).

23. **Lower Limit:** The Lower Limit is automatically populated by the lower elevation in each of the elevation range checkboxes (See 22). A different value can be added to this textbox. However, checking one of the elevation ranges will cause the Lower Limit to revert to the lower elevation of that elevation range.

24. **Delete:** This button will remove the row from the table.

25. **Run:** The run button will be enabled once the DEM Layer and Output Grid selections have been made and at least one row of grass data has been added to the table and successfully verified. Clicking the Run button will start the process of creating a grid from the information entered in the table. As the process progress, messages along the bottom of the dialog box will indicate which process is running. A message box will pop up at the end of the process to notify that it has completed successfully. The output files are the Grid files of planting zones and uncertainty elevation for the input grass species.

b. Export Grid to Polygon

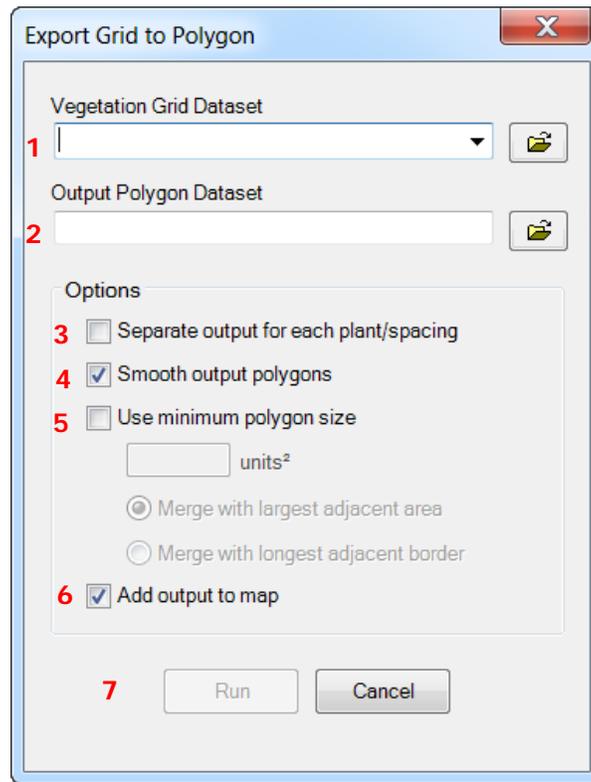


Figure 5. MAPTITE window used to export grid to polygon.

- 1. Vegetation Grid Dataset:** Select the grass grid to be converted into polygons. The dropdown list will be populated with grids in the map document that have a lookup table generated in the previous step.
- 2. Output Polygon Dataset:** The name of the output file or directory. If the Separate output option (see 3 in Figure 5) is selected, a directory folder name should be navigated to. Otherwise, a file name should be entered.
- 3. Separate output for each plant/spacing:** Check this box to create a separate polygon dataset for each grass/plant spacing combination.
- 4. Smooth output polygons:** Check this box to smooth the edges of the polygons. If this box is not checked the polygons will have a stair step border.
- 5. Use minimum polygon size:** Check this box to remove polygons smaller than the specified area. Any positive value can be entered into the area size box. The units will be derived from the projection information of the grass grid layer. Select the criteria for merging polygons not meeting the minimum area requirements with its neighbors. Note: this will not remove empty polygons that correspond to No Data areas in the original grid dataset.

6. **Add output to map:** Click this box to add the output dataset(s) to the ArcMap document.

7. **Run:** The Run button will be activated when a grid layer and output dataset have been selected. As it progresses, messages along the bottom of the dialog will indicate which process is running. A message box will pop up at the end of the process to notify that it has completed successfully and showing the names of the dataset(s) exported as well as the number of each plant species needed.

c. *Export Polygon(s) to GPS File*

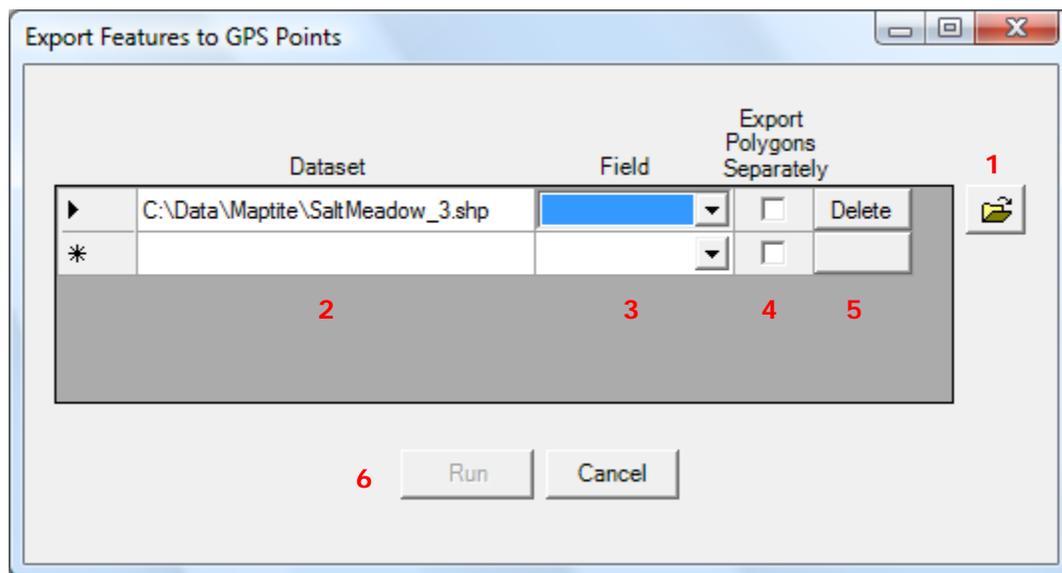


Figure 6. MAPTITE window used to export polygons to points

1. This button allows the user to navigate to a polygon dataset and add the dataset to the window for export to points. Adding the polygon will enable the other selections in the row.

2. **Dataset:** The dataset to be exported to points. The output text dataset will have the same name as the input dataset and will be in the same directory.

3. **Field:** This allows selection of an attribute field that contains unique information about the polygons. After selecting a field, it will be necessary to click on another column in the row in order to apply the field selection. The selected attribute will be added to the output file.

4. **Export Polygons Separately:** This allows each separate polygon to be exported into a separate point file.

5. **Delete:** This button will remove this row from the list of datasets to be exported.

6. **Run:** The Run button will be enabled when a row has been added and an attribute field selected. The program converts each vertex of a polygon to a point. The output files(s) will contain a line for each vertex of the polygon(s). The format of the line is:

Polygon OID, Vertex number, X-coordinate, Y-coordinate, Polygon Attribute

These output files can now be loaded into a GPS receiver and used to select planting points in the field.

IV. Obtaining Additional Data Integral for MAPTITE Analysis

a. Tide and Tidal Datums

CO-OPS manages a network of permanent tide and water level stations, the National Water Level Observation Network (NWLON), along U.S. coastlines, estuaries and bays, including the Great Lakes and ocean island territories. The NWLON provides the national standards for tide and water level reference datums used for nautical charting, coastal engineering, International treaty regulation, and boundary determination. Tidal datum information relative to the restoration study site (MSL, MHHW, etc.) can be found at CO-OPS website (tidesandcurrents.noaa.gov). These datums are critical to understanding and calculating the grass zones computed in MAPTITE and will be used to create the parameter file. Other information such as real time water level data, sea level trends, and other oceanographic information which may be useful to the restoration/wetlands expert can also be found at the CO-OPS web site. For additional information about tide and tidal datums, please see the Appendix I.

Navigating to Tidal Data and Tidal Datums in your Restoration Area.

1. Use an internet browser to access www.tidesandcurrents.noaa.gov
2. Click the map in the center of the page to access data and products (Figure 7).



Figure 7. Center for Operational Oceanographic Products and Services website with data map highlighted in a yellow box.

3. A new page will open entitled *NOS/CO-OPS Observational Data Interactive Navigation (ODIN)*. Zoom in to your project area to show individual stations with available data present.

4. From the drop down list in the top right hand corner entitled “Require type:” select **Datums**. This will map all stations that have a current Tidal Datum on the 1983-2001 Epoch (Figure 8).

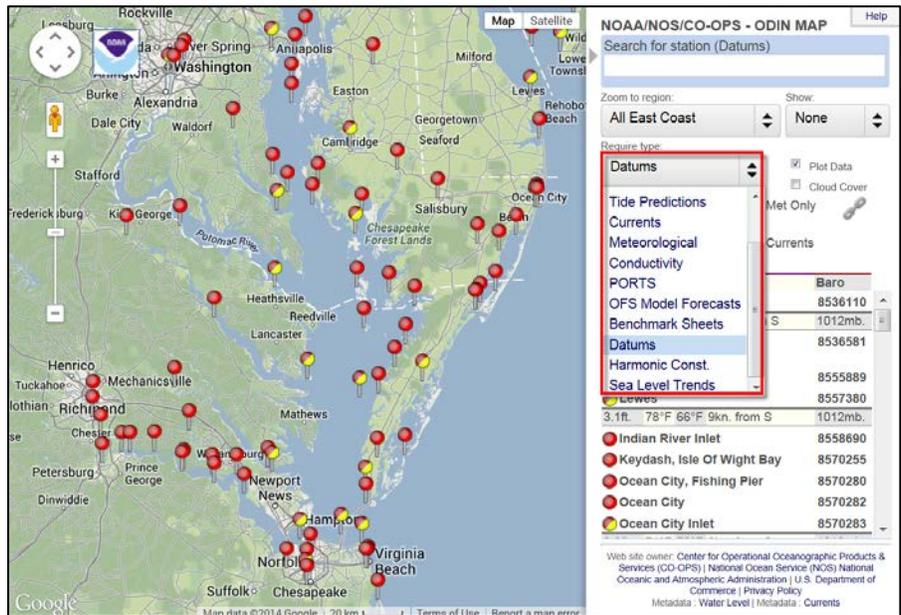


Figure 8. Data and other information available at individual stations after selecting the red station marker.

5. Zoom in and mouse over individual stations (red marker) to reveal the name and information about the station. Clicking on the red marker will reveal the type of data available at the station (Figure 9).

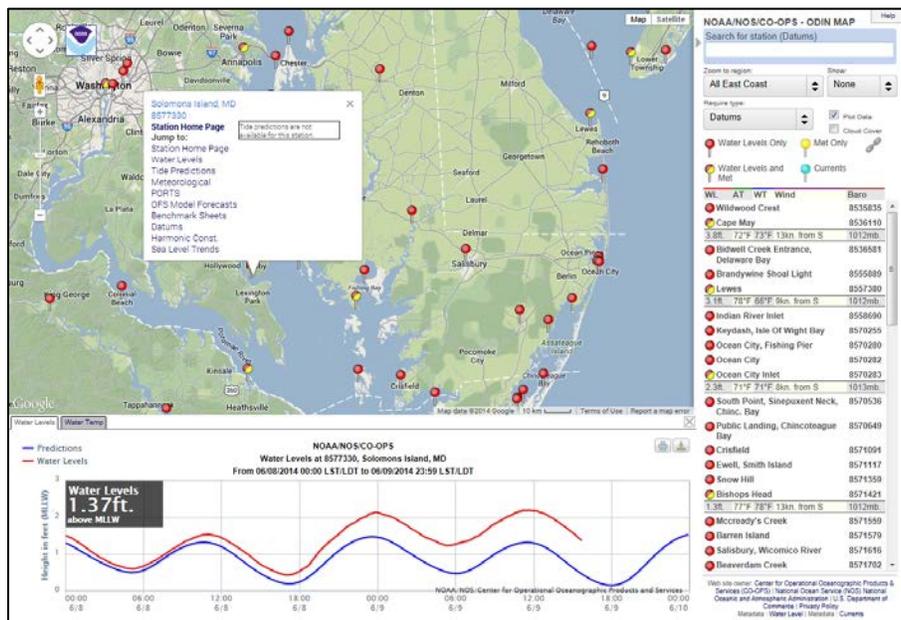


Figure 9. Data and other information available at individual stations after selecting the red station marker.

- Select the station closest to your project as a tidal representative of your area. Ideally the station should be within a 1-5 mile radius, on the same water body and facing side as your project. This will help ensure the tidal datums computed for a NOAA station are similar to your project site.
- From this station pop-up box select “Datums”, or use the “Get Datum Info” button in the MAPTITE Selection form to bring you to a list of stations with tidal datums on the present 1983-2001 Epoch.
- The Datums page for this station will open in a separate browser window revealing all tidal datums for this station. It will also provide links to all other supporting information (e.g., Water Level Data, Tide Predictions, Meteorological Observations, Sea Level Trends, if available) relative to the station on the left (Figure 10).

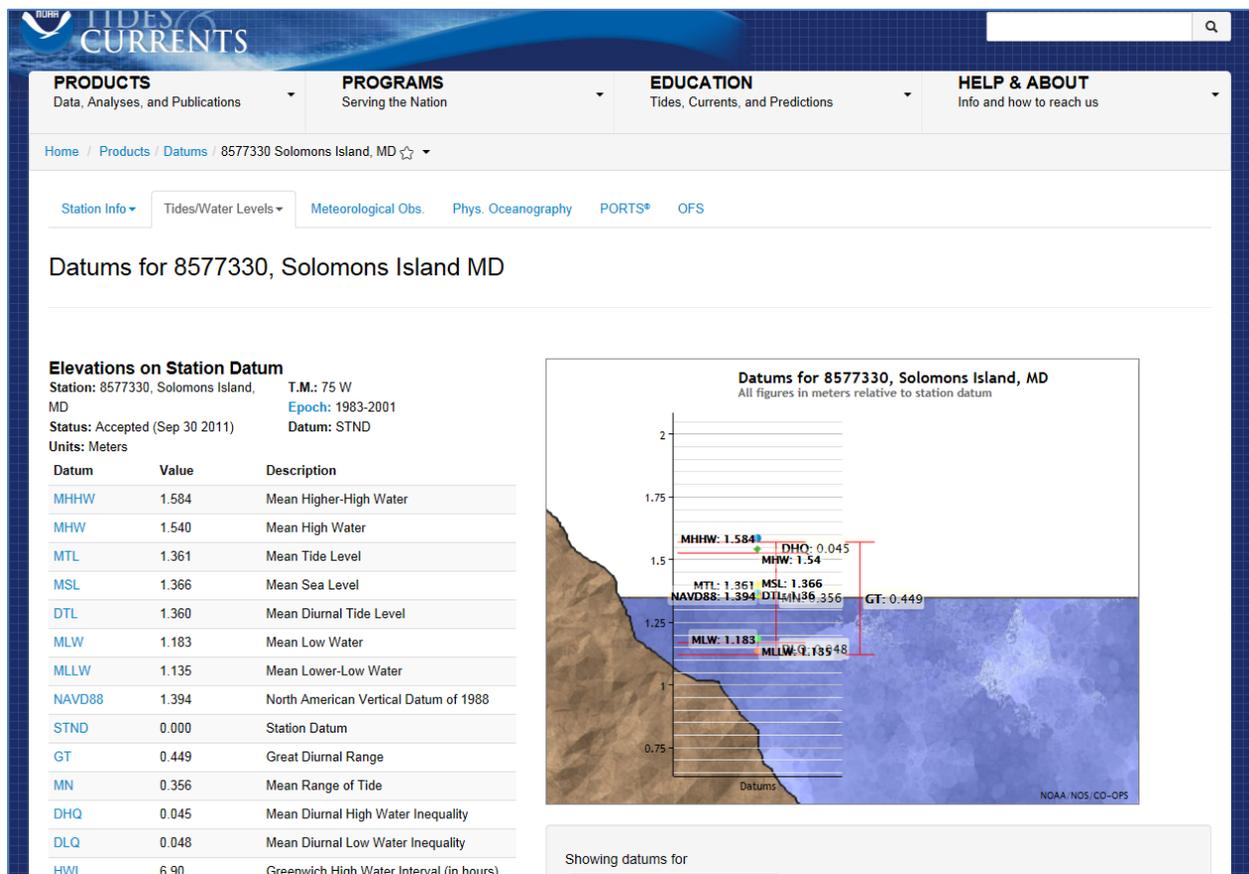


Figure 10. Tidal Datums for Solomons Island, MD found on the Datums page.

9. All datums listed on the Datums page are relative to *Station Datum*; a datum set specifically for this station and is unique to every station. The user must select the data units that are used for the DEM’s projection information. The website default unit is in Feet and it should be changed to Meters. *Enter the provided Tidal Datum values relative to MSL from this page into the MAPTITE Tidal Datums Section in to MAPTITE form (Figure 4, #9, 12-17) as follows.*

- 9 – *MSL Adjustment = NAVD88 - MSL*
- 12 – *Upland – Highest value in your DEM relative to MSL*
- 13 – *MHHW - MSL*
- 14 – *MHW-MSL*
- 15 – *0*
- 16 – *MLW-MSL*
- 17 – *MLLW-MSL*

Tidal datums are used as references to measure local water levels and should not be extended into areas having differing oceanographic characteristics without substantiating measurements. If there are no published tidal datums near a restoration site, it is recommended that users install a tidal station to get local tidal datums for marsh restoration.

b. Tidal and Geodetic Datum Relationship

NGS develops and maintains the current national geodetic vertical and horizontal datum, NAVD88 and NAD83 (Appendix II). CO-OPS publishes tidal bench mark information and the relationship between NAVD 88 and various water level/tidal datums (e.g., MHHW, MHW, MTL). The relationship between geodetic and tidal datums is critical to performing a MAPTITE calculation as DEM files or topography maps are referenced to NAVD88 or NAD83. At each tide station, a network of brass, bronze, or aluminum alloy survey disks, called bench marks, has been set. The local tidal datums are referenced to each of these bench marks. A concerted effort has been made to tie tide station bench mark networks to NAVD 88 through leveling wherever feasible and to tie the tide station bench mark networks to the Ellipsoid through a program that combines both classical leveling and GPS observations. This enables relationships among the tidal, orthometric and ellipsoidal datums to be established. The conversion between NAVD88 and NAD80 needs a Geoid Model (Appendix I).

The NAVD88 value is published on the datums page at some tide stations (Figure 10). The published NAVD88 value is the average of NAVD88 values from at least 3 bench marks. The NAVD88 at an individual bench mark can be derived from the published benchmark sheet. Provided with this manual are three methods of relating the Orthometric/Ellipsoidal to Tidal datums at a bench mark for a correct MAPTITE analysis. The value determined from either of these methods will be input into #6 of Figure 4 – MSL Adjustment. The first method is a graphical / hands on approach to obtaining the offset, the second is a modified Excel application that asks the user for specific information and calculates the offsets in the background and the third method is to use the NOAA VDatum tool.

1). Graphical Datum Worksheet Offset Application

The first is a diagram, Appendix II - MAPTITE Datums Worksheet, which can be printed and used to graphically produce an offset. Each datum offset has a corresponding letter in which a value will be placed (Figure 11).

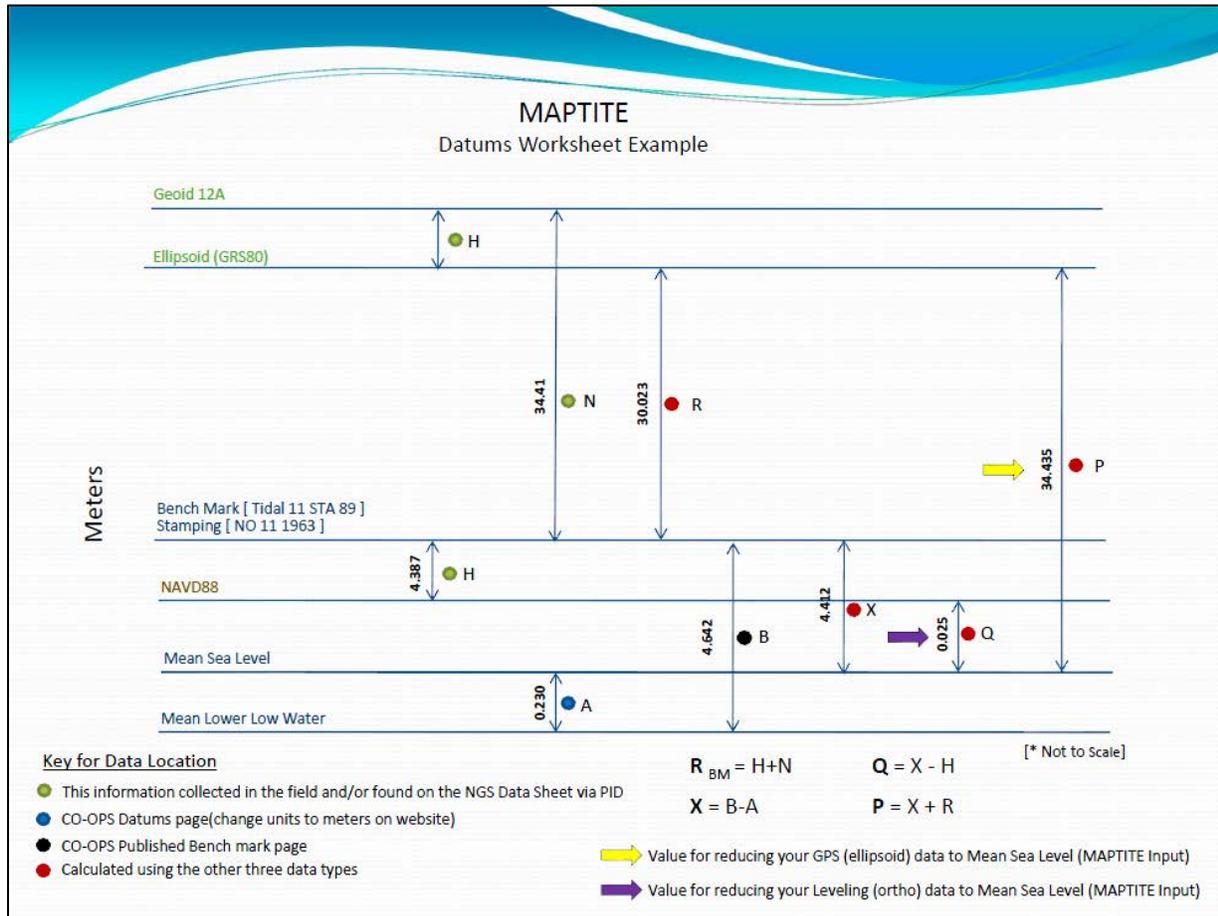


Figure 11. MAPTITE Datums Worksheet with Solomons Island, MD example

To calculate the offset with this method the user should:

1. Select “Bench Mark Sheets” from the menu on the bottom of the Datums page (Figure 12).

Note: This page can also be reached via the station pop-up menu mentioned in step 5 of Tide and Tidal Datums section, named “Benchmark Sheets”.

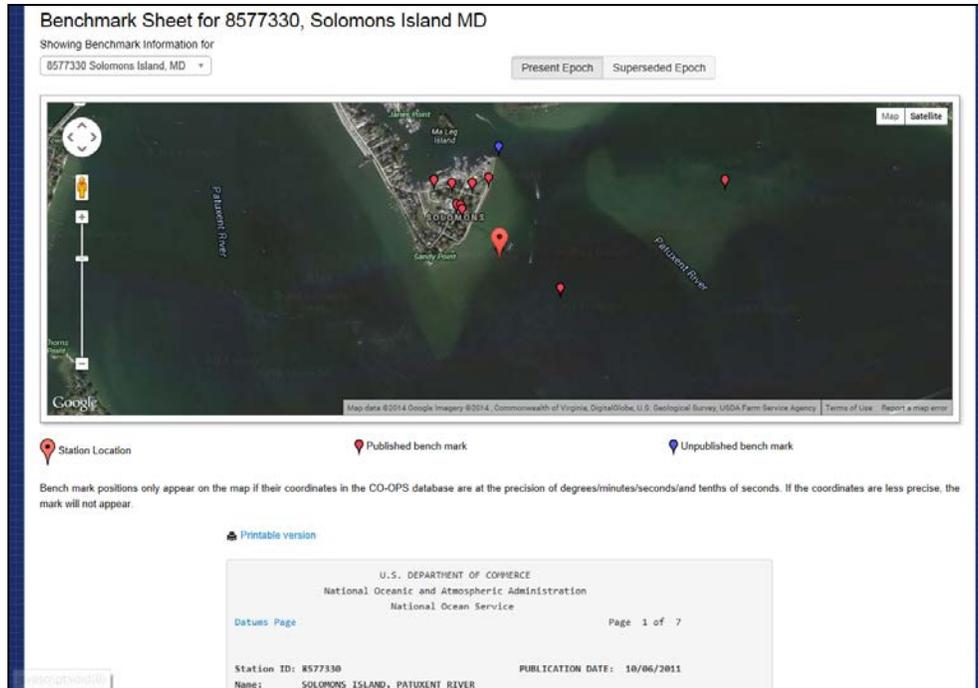


Figure 12. Benchmark Sheet page with description of marks and “To-Reach” statements for finding the current or past station location.

Ideally the Bench mark should have a connection to orthometric (NAVD88) / ellipsoid (GRS80) through NGS database through their Personal Identification (PID) number (Figure 13). By clicking the hyperlink of PID#, the orthometric (NAVD88), Geoid height (GEOID12A) or NAD 83 values can be retrieved from the NGS Data sheet. This Bench mark should be surveyed during field data collection via survey line or GPS static data collection.

	BENCH MARK STAMPING:	NO 11 1963	
	DESIGNATION:	TIDAL 11 STA 89	
MONUMENTATION:	Tidal Station disk	VM#:	451
AGENCY:	US Coast and Geodetic Survey (USC&GS)	PID#:	HV0369
SETTING CLASSIFICATION:	Concrete step		

The bench mark is a disk set in the east corner of the top concrete step, located at the SW entrance to the two story brick Biological Research Laboratory building, 13.81 m (45.3 ft) SE of the west corner of the building, 10.73 m (35.2 ft) NW of the SE corner of the building, 1.76 m (5.8 ft) ESE of the SW edge of the steps, and 0.21 m (0.7 ft) above the level of the ground.

Figure 13. A bench mark at Solomons, MD station with a PID#. The PID# is connected to NGS Data Sheet

The NGS Data Sheet

See file [dsdata.txt](#) for more information about the datasheet.

```

PROGRAM = datasheet95, VERSION = 8.4
1      National Geodetic Survey,  Retrieval Date = JUNE 11, 2014
HV0369 *****
HV0369 TIDAL BM      -  This is a Tidal Bench Mark.
HV0369 DESIGNATION -  TIDAL 11 STA 89
HV0369 PID          -  HV0369
HV0369 STATE/COUNTY-  MD/CALVERT
HV0369 COUNTRY      -  US
HV0369 USGS QUAD    -  SOLOMONS ISLAND (1987)
HV0369
HV0369                                *CURRENT SURVEY CONTROL
HV0369
HV0369* NAD 83(1986) POSITION- 38 19 06.5      (N) 076 27 14.2      (W)  HD_HELD2
HV0369* NAVD 88 ORTHO HEIGHT - 4.387      (meters)      14.39      (feet)  ADJUSTED
HV0369
HV0369 GEOID HEIGHT      -  -34.41      (meters)      GEOID12A
HV0369 DYNAMIC HEIGHT   -  4.384      (meters)      14.38      (feet)  COMP
HV0369 MODELED GRAVITY  -  980,019.7      (mgal)      NAVD 88
HV0369
HV0369 VERT ORDER      -  FIRST      CLASS II
HV0369
HV0369.The horizontal coordinates were established by autonomous hand held GPS
HV0369.observations and have an estimated accuracy of +/- 10 meters.
HV0369.

```

Figure 16. NGS Data Sheet example with highlighted orthometric (NAVD88) and geoid height (Geoid12A).

5. Use the mathematical equation (1) to determine the ellipsoidal value of the Benchmark. This will be used later to determine the offset of GPS data to Mean Sea Level in MAPTITE. Fill in **R** in the Graphical Worksheet. For example, according to equation (1), the ellipsoid height is -30.023 m so the bench mark is 30.023 m **below** the ellipsoid model.

$$(1) \quad R_{BM} = H + N$$

6. Next use the equation (2), with values determined previously in this section to determine the elevation of bench mark above MSL. Fill in **X** in the Graphical Worksheet. In this case, the bench mark is 4.412 m above MSL.

$$(2) \quad X = B - A$$

7. Once you have found **X** and **R**, you can now find the offset need to bring your data collected in the field to the appropriate datum in MAPTITE.

If you collected data relative to *NAVD88 (orthometric) datum*, use the derived values in the equation (3) to determine the MSL adjustment. In this case, NAVD88 is 0.025 m above MSL. You

add 0.025 m to your data to adjust the DEM file to MSL. If NAVD88 is below MSL, you add a negative number to your data to adjust the DEM file to MSL.

$$(3) \quad \mathbf{Q} = X - H$$

Whereas if you are trying to solve the MSL adjustment relative to the ellipsoid (such as GRS80) use the values derived above in the equation:

$$(4) \quad \mathbf{P} = X + R$$

Complete the Diagram by listing **P** and **Q** in the appropriate places to complete the overall Datums Diagram for your project area. The Yellow and Purple arrows signify the specific MSL adjustment value required by MAPTITE to properly adjust your data set.

Place the value of **Q** in the MSL adjustment (#6 of Figure 4) if acquiring data relative to *NAVD88*.

-Or-

Place the value of **P** in the MSL Adjustment (#6 of Figure 4) if acquiring data relative to the *Ellipsoid*.

Also keep in mind that tidal, orthometric, and ellipsoidal datums are changing from one coastal habitat to another, so the user may find that some of the datum lines may be above or below those represented in the graphical worksheet. However, the mathematical computations and results will be the same.

2). Excel Datum Worksheet Offset Application

The second method is an excel program that the user can load information from specific datum values to produce the needed MAPTITE MSL Adjustment and also produce a graphical representation of the various datums relative to station datum.

1. First start by opening the Excel file entitled "MAPTITE – Datum MSL Adjustment Worksheet.xls" (Figure 17).

Marsh Analysis and Planning Tool Incorporating Tides and Elevations			
Datum MSL Adjustment Worksheet			
for			
	[Oyster Landing, MD]	[8662245]	
Using NGS PID Sheet for Orthometric/ Geodetic Values?	YES		
	Meters		Relative to MLLW
Parameter: Ellipsoid (GRS80) Of Selected Benchmark	-33.839	Above Selected Bench Mark	35.586
Geoid 12A Of Selected Benchmark	-34.76	Above Selected Bench Mark	36.507
NAVD88 Of Selected Benchmark	0.921	Below Selected Bench Mark	0.826
Bench Mark: (above MLLW)	1.747		1.747
Stamping: 2245 A 1982			
Designation: 866 2245 A Tidal			
PID (if present): DD1345			
Mean Sea Level *	0.816		0.816
Mean Lower Low Water *	0.000		0.000

MAPTITE	
Mean Sea Level Adjustment:	Meters
Ellipsoid	34.770
NAVD88	0.010

Notes:

- Completing this worksheet will allow the user to apply the correct offset to their geodetic or ellipsoidal data collected in the field in MAPTITE.
- After filling in the station name and number the user should be able to click on the Parameter (blue) hyperlink and have it take them to the appropriate webpage.
- * - Apply Change on CO-OPS website to correct for Meter units

Figure 17. MAPTITE – Datum MSL Adjustment Worksheet with user input areas highlighted in orange.

2. Once the Excel application has been opened fill in the Metadata about the station, such as the Station Name, State, and Station Number. (It is assumed that the user has used the section of the User Guide – *Tidal Data and Tidal Datums* to determine which station and benchmarks are appropriate for their site.)

3. Fill in the information just below “[Bench Mark: \(above MLLW\)](#)” with the specific Bench mark that will be used to relate the topographic data to the tidal datum and orthometric and/or ellipsoidal datum in the area.

Note: If needed the user can click on the [Bench Mark: \(above MLLW\)](#) in Excel and follow its hyperlink to the CO-OPS Benchmark Sheets page. Scroll to the station number of interest and follow the steps

4. Find an appropriate Bench mark relative to the project site from the list. Ideally the Bench mark should have a connection to orthometric (NAVD88) / ellipsoid (GRS80) through NGS PID,

as showed in Figure 13. This Bench mark should be surveyed during field data collection via survey line or GPS static data collection.

5. Scroll to the bottom of the page where the elevation of MSL above MLLW and Bench marks relative to MLLW values are located, find specific Bench mark of interest in the table. Place the MSL value and value for the benchmark relative to MLLW in the cell to the right of MSL and **Bench Mark: (above MLLW)**.

6. Next, if available, select the PID link for the Bench mark identified in step 4 above. This will bring you to the NGS Datasheet for this benchmark. From the NGS Data sheet place NAVD88 height in the cell adjacent right of **NAVD88**, and Geoid Height in the cell adjacent right of the cell entitled **Geoid12A**.

7. Once all Benchmark information is entered (MSL above MLLW, Benchmark above MLLW, NAVD88, and Geoid12A values), excel will provide you with (1) a list of the various datums relevant MLLW, (2) the MSL adjustment needed for MAPTITE, and (3) a diagram chart of datums relative to MLLW.

10. From the MAPTITE offset area in the Excel application, select the appropriate adjustment value for which data type was collected, and input in to the MSL adjustment in the MAPTITE Selection form (#6 of Figure 4). If your DEM file is referenced to NAVD88, apply the NAVD88 adjustment value (0.010 m) and if your DEM file is referenced to ellipsoid, apply the ellipsoid adjustment value (34.770 m).

3). Vertical Datum (VDatum) transformation

If none of the bench marks at a tide station have been tied to geodetic datums, there are two survey procedures used to make this connection. The first is to connect the tidal bench marks with traditional differential levels to nearby geodetic bench marks with known geodetic elevations. The second is to occupy the tidal bench marks using a static GPS survey to determine the geodetic elevations of the bench marks directly. In all cases it is advised to make the connections to more than one bench mark, preferably to three marks, in order to confirm the connection and identify unstable bench marks. The elevation relationship between geodetic datums and tidal datums should not be extrapolated away from a particular location without correction or interpolation as the relationships vary with parameters such as variations in range of tide, bathymetry, topography, geoid variations, and vertical land movement. Any interpolation should be done carefully, and where possible guided by the use of the National Ocean Service VDatum tool which can be obtained at: <http://vdatum.noaa.gov/>.

The VDatum is a web-interface software tool developed by the National Ocean Service (NOS) that allows users to transform elevations among 36 vertical datums of three categories: tidal (MSL), orthometric (NAVD88) and ellipsoidal (NAD83) vertical datums. The transformation can be applied to a single height/depth or a grid file and is based on hydrodynamic and Geoid models as well as the interpolation of the difference between modeled and observed datums

(Figure 18). The associated uncertainty of datum transformation in different regions is available at http://vdatum.noaa.gov/docs/est_uncertainties.html. The decision to use either a transformation tool or a direct measurement depends on the application and the desired accuracy.

The VDatum grids are currently available for East, Gulf of Mexico and West coasts as well as Great Lakes (Figure 19). Additional information, the software, user's guide, education material, and references to report and papers can be found on the Vdatum website (<http://vdatum.noaa.gov/>).

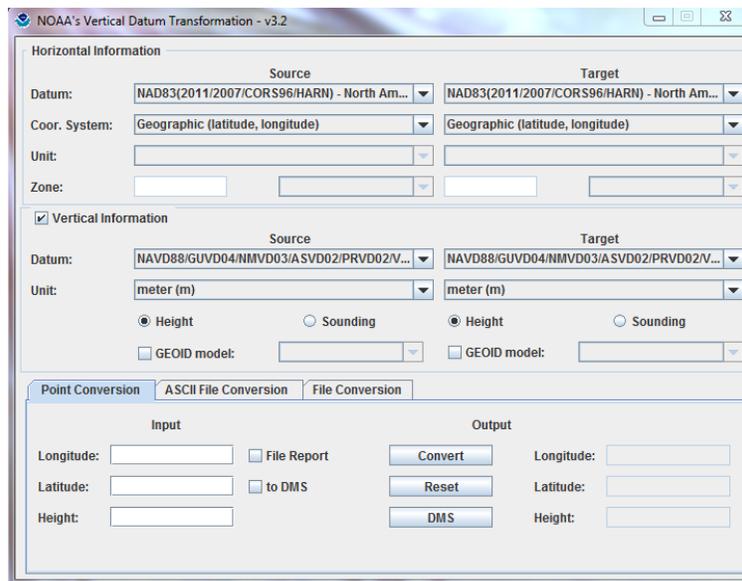


Figure 18. VDatum transformation tool interface.



Figure 19. Current VDatum coverage as of May, 2014

c. Digital Elevation Models (DEMs)

Because topographic variations in wetland areas are generally on the scale of centimeters rather than meters, small elevation changes can have a large impact on local ecosystems as water levels change. It is therefore crucial that accurate DEMs be used for wetlands restoration projects. While it is possible to use DEMs created from LiDAR observations, their accuracy is in meters rather than the centimeter level actually required. Real Time Kinematic (RTK) GPS observations, on the other hand, can reliably yield positions and elevations accurate at the centimeter level, and it is highly recommended that DEMs used for wetlands restoration projects be developed from RTK observations following guideline published at http://www.ngs.noaa.gov/PUBS_LIB/NGSRealTimeUserGuidelines.v2.0.4.pdf.

There are issues and challenges specific to observing in wetlands environments that must be taken into consideration during planning and observing an RTK project:

- Amount of cover, including height of vegetation, should be considered because of potential blockage of satellites.
- Optimal positioning of satellites must be planned, which means possible early morning or evening observations.
- The appropriate “foot” or wheels on survey instruments should be used.
- Location of the base station bench mark must be very stable and well positioned.
- Tidal marshes are flooded half of each day – observation times must take this into account. Surveys need to be timed around low tides.
- Working during an ebb tide should be considered. For example, start on the higher part of a marsh and work down to the lower elevations as the tide ebbs and then back up again as it starts to flood to maximize the time on an un-flooded marsh.
- Plan the survey to minimize walking through fragile sites. The surface being surveyed should not be compressed, and the marsh surface, particularly in those areas where there are wells, SETs, vegetation monitoring, etc., should be impacted as little as possible.
- Surveyors traveling from one site to the next with muddy boots can track invasive plant and/or invertebrate species from an infested marsh to an un-infested marsh. Therefore quick and easy (so they get used) protocols for washing off and disinfecting waders, boots and equipment should be established.
- Access to the site, which is often limited, will also have to be considered in planning.

Experience has shown that surveying a marsh in a grid pattern is the most effective way to collect the necessary data. It is important to define features such as channels and hummocks as well as the marsh plain surface. (is there a citation that can be provided) Three basic approaches for capturing channel morphology have been developed:

1. Survey the marsh surface in a grid pattern, including the marsh edges at the channels. Return to each channel and survey the channel bottoms, individually capturing the two channel bottom edges and thalweg while walking along the channel bottom.
2. Include channels (near marsh edge, near channel bottom edge, thalweg, far channel bottom edge, far marsh edge) in the survey as the marsh grid is observed.
3. Combine 1 and 2 by including all channel measurements where the grid crosses the channel, then returning to pick up the parts of channels that were missed with the grid.

Once the data is collected and processed, ArcGIS Spatial Analyst can be used to create a DEM for input into MAPTITE.

V. Example Demonstrating MAPTITE Functionality

North Inlet Winyah Bay, SC

1. Click on the “Open selection form” button on the MAPTITE toolbar (Figure 20):
2. Load DEM into ArcGIS ArcMap.

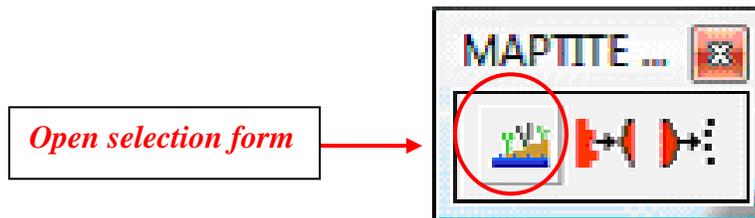


Figure 20. “Open selection form” button on MAPTITE toolbar.

3. Under “DEM Layer”, use the folder button to navigate to the example DEM (niwb.img) provided and select. ArcMap will automatically load the DEM, which is from the North Inlet Winyah Bay NERR in South Carolina. Or if the DEM is already loaded as a layer file use the drop down box to select it.
4. Under “Output Grid”, click on the open folder button. Navigate to a folder of choice and enter a name that incorporates no spaces, for example *niwgrd*, to name the output grid being created and click “Save”.
5. Select the “Get Datum Info” button to open the CO-OPS Datums page. In this example, the closest tide station to the North Inlet Winyah Bay is OYSTER LANDING, CRAB HAUL CREEK, SC (#8662245) and can be navigated to in a number of ways. (See Section *Tidal Data and Tidal Datums*.) Select this site. On the Datums page for the station, select “Meters” and click “Submit”. Leaving the Upland value at the default given, enter the appropriate values from the Datum list in the selection form (#12-17 of Figure 4).
6. In this case the elevation values of the DEM are orthometric and were collected relative to NAVD88. Enter the MSL adjustment for NAVD88 (0.009 m) so that MAPTITE can correct to local Mean Sea Level. The MSL adjustment for NAVD88 is calculated from the published NAVD88 and MSL from tidal datum page (Section IV, a). For the MSL adjustment for NAVD88 at an individual bench mark, please refer to Section IV, b.
7. Use the drop down list to select a default marsh grass, or in this example click on the drop down arrow under “Grass” and select “Other”. A box titled “Other grass” will pop up. Enter the

alternate grass name *Spartina alterniflora* in the box and click “OK”. A new blank line with *Spartina alterniflora* will have appeared below the entry box. Check “MLW to MSL” and “MLLW to MLW”. To add an additional grass selection click the blank line just below the first grass and a new entry box will appear. Repeat the process, entering *Spartina patens* with the range “MSL to MHW”.

8. Using the “save parameters” button, save the input as a parameter file. This will allow reloading of the tidal and grass information for other iterations of a MAPTITE run.

9. Click the “Run” button. Processing is tracked at the bottom left of the selection form and a “Processing complete!” message will appear when it is completed, and the grid representing the two species of *Spartina* will be added to the project automatically (Figure 20). Once the application has ‘cleared the temporary files’, close the selection form window.

MAPTITE Selection Form

DEM Layer: niwb_sp.img
 DEM Ground Units: Meter
 MSL Adjustment: 0.009
 Clip Polygon Layer: [empty]
 DEM Z Units: Meter
 Default Spacing: 1.5
 Elevation Uncertainty: 0.060960
 Output Raster: C:\MAPTITE\niwbgrd
 Upland: 5, MHHW: 0.745, MHW: 0.639, MSL: 0, MLW: -0.758, MLLW: -0.816
 Clip output to polygon
 Add output to map
 Load Parameters, Save Parameters, Get Datum Info

Plant	Plant Spacing	Upper Limit	MHHW to Upland	MHW to MHHW	MSL to MHW	MLW to MSL	MLLW to MLW	OW to MLLW	Lower Limit	Delete
Spartina alteriaflora	1.5	0	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	-0.816	Delete
Spartina patens	1.5	0.639	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	0	Delete
*			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		

Run, Cancel

Figure 20. Selection form.

This step of MAPTITE has calculated which portions of the DEM lie in what tidal areas relative to the suggested plant types.

The next step of MAPTITE will turn these raster products into planting zones and provide the user with species and plant coverages based on the inputs in the Selection Form (Figure 21).

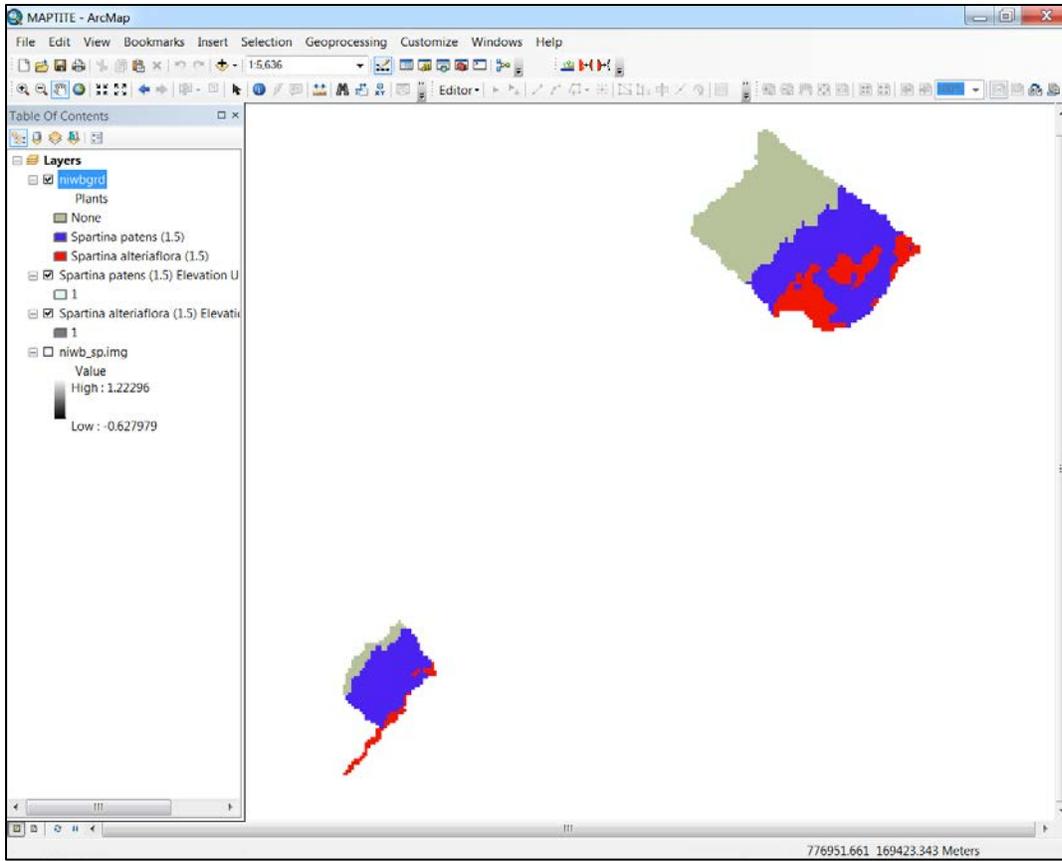


Figure 21. Output from “Open selection form”.

Each grid that has been created will be stored in the location set in the Selection Form. The elevation uncertainty grids will have “_eun” (where *n* will vary with the number of grasses selected) appended to the name. To find the name of each of the uncertainty grids, right click on the layer and select “Properties” to open the Layer Properties dialog. Click on the Source tab to show the name of the grid.

10. Click on the “Export grid to polygon” button on the MAPTITE toolbar (Figure 22):

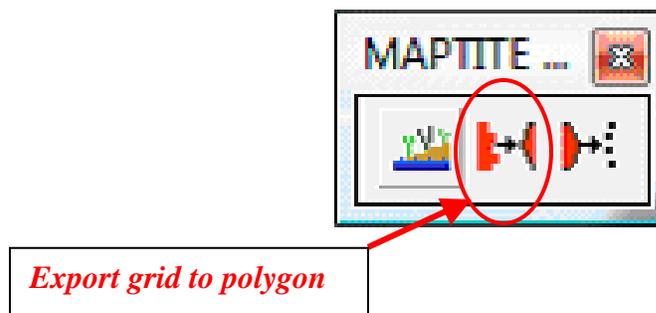


Figure 22. “Export grid to polygon” button on MAPTITE toolbar.

11. In the “export grid” window enter niwbgrd in the Input Grid Dataset window. MAPTITE provides an option to either create a single polygon including all grass types or to create individual polygons for each grass type (Figure 23).

Single Polygon: Use the open folder button to navigate to the appropriate folder and input “niwb_poly” as the output polygon dataset. If desired, “Use minimum polygon size” can be checked to merge polygons that are too small to be significant with other polygons (Figure 24).

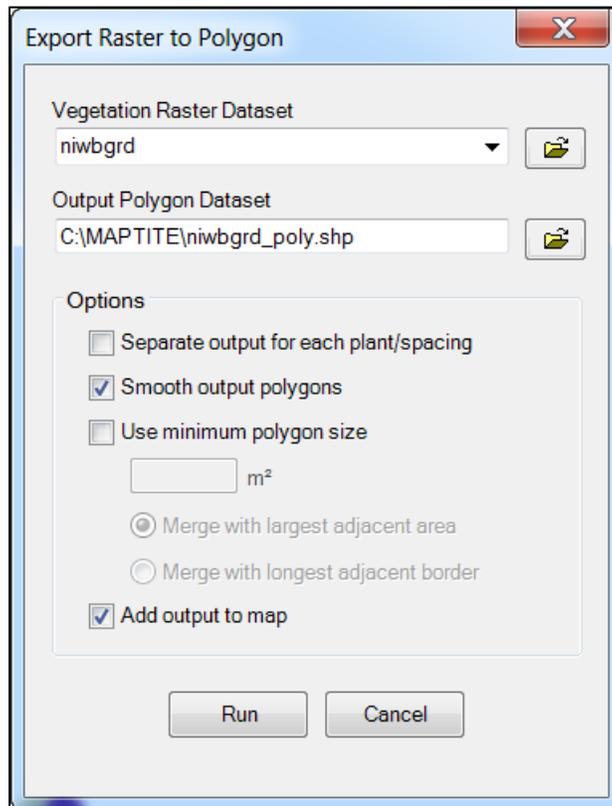


Figure 23. Single polygon option.

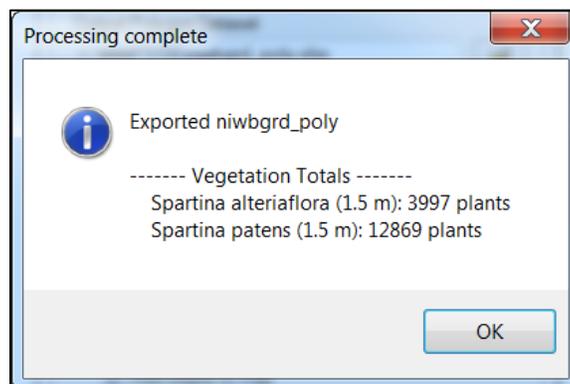


Figure 24. Single polygon output with plant totals.

Individual Polygons: As with the single polygon option, navigate to the desired folder. Check the “Separate output for each grass/spacing” box. The program will name the polygons individually based on grass type. As with the single polygon option, a minimum polygon size may be set (Figure 25 & 26).

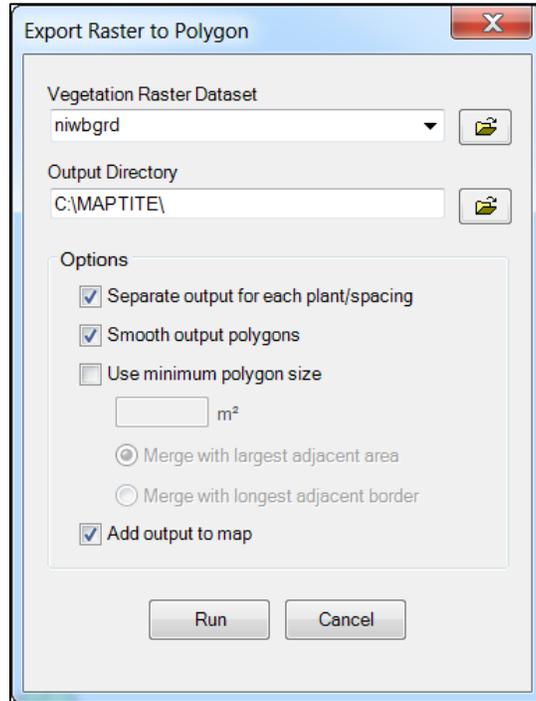


Figure 25. Individual polygon option.

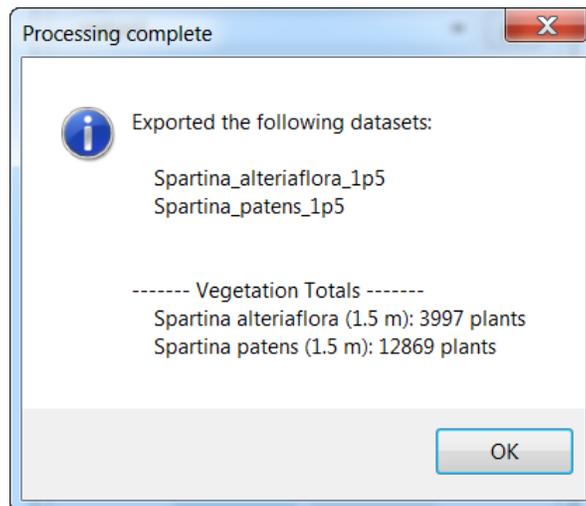


Figure 26. Polygon designations and plant totals.

12. Once the polygons are created, MAPTITE provides an option that allows the user to export files of appropriately spaced points from the polygons. These points can be uploaded into GPS equipment and used to layout planting grids for marsh plant restoration (Figure 27).

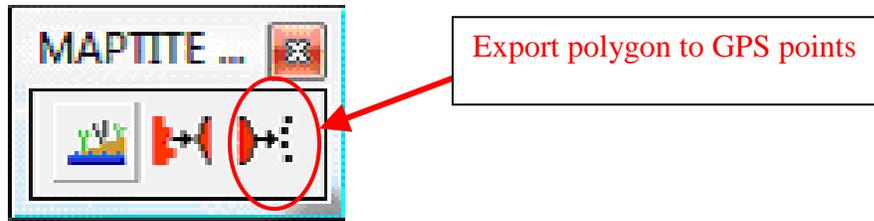


Figure 27. “Export polygon to points” button on MAPTITE toolbar.

13. Use the dropdown to select the polygon(s) that are to be exported to GPS points and select a field to group the points into the individual polygons. A file of positions will be created that represents the appropriate planting elevations and spacing for the selected plant types. This file can be uploaded to a GPS and used in replanting of the restoration site (Figure 28). The field that the user finds most useful to identify the polygons should be chosen.

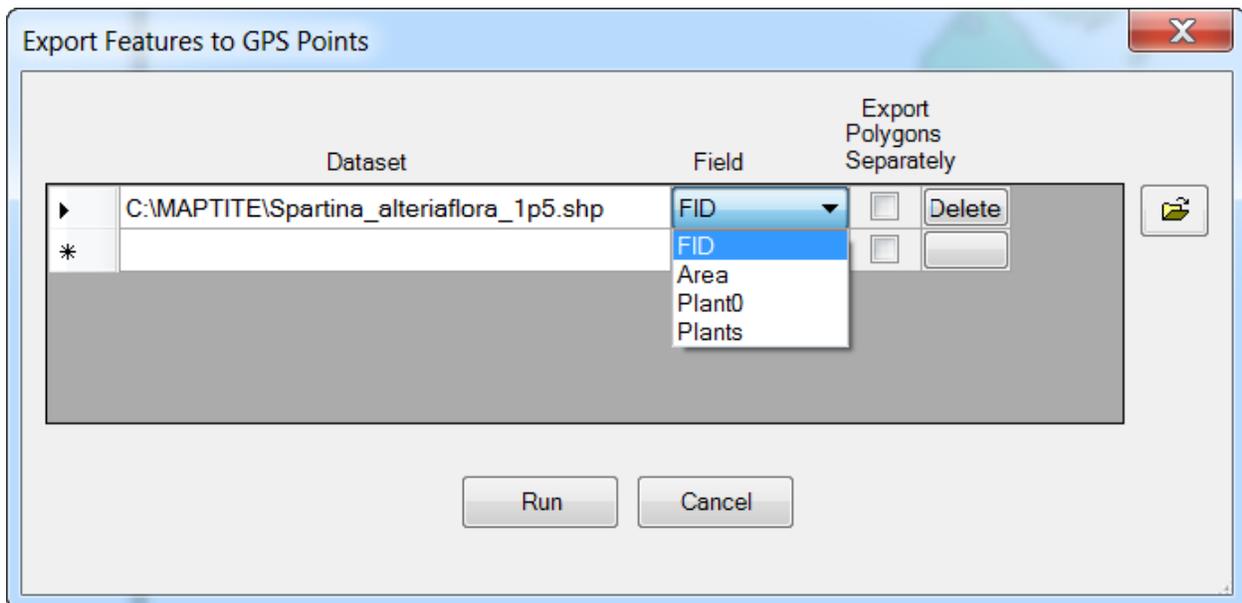


Figure 28. Select a polygon to be exported to GPS points.

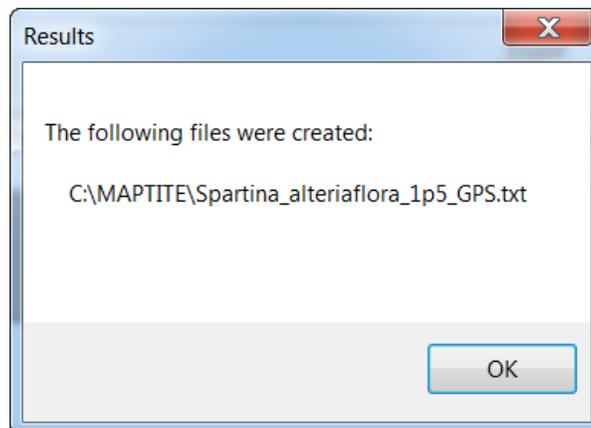


Figure 29. A GPS point file created

VI. Discussion of Uncertainties

Users of MAPTITE application should be aware of the uncertainties associated with DEM elevations, and with tidal and geodetic datum elevations and how these uncertainties may translate into applications of MAPTITE. The total vertical elevation uncertainty for MAPTITE is a combination (root-sum-square) of the independent errors from the DEM elevations, tidal datum elevation errors, and geodetic datum elevation errors. Constraining vertical errors is important as vertical errors can translate to large horizontal uncertainty for gently sloping surfaces.

1) DEMs: Users are responsible for understanding the elevation uncertainty associated with source DEM files. Their elevation accuracy largely depends upon the technology used to collect the local topography. Local GPS surveys can yield relative elevation accuracies to the centimeter level relative to NAVD88. Topographic elevations obtained with LiDAR will be only accurate to approximately 15cm relative to NAVD88. Other DEM interpolation modeling algorithms may add additional uncertainty.

2) Tidal Datums: The accuracy of tidal datums depends largely on the length of the water level data series analyzed, which can be found at the bottom of the Datums page (Figure 10). If tidal datums are calculated from a 19-year continuous water level data series (i.e. a NOAA NWLON station), the datum error is considered to be 0. Generalized accuracies for datums computed at short-term stations for the length of the record are summarized in Table 1 (Swanson, 1974). These values were calculated using control stations with 19-year tidal datums. The accuracies of the short-term datums can be interpreted as known to within plus or minus the appropriate value in Table 1. That is, the values in Table 1 are the confidence intervals for the tidal datums based on the standard deviation.

Table 1. Generalized accuracy of tidal datums for East, Gulf, and West Coasts when determined from short series of record and based on +/- sigma (Swanson, 1974).

Series Length	East Coast		Gulf Coast		West Coast	
	(cm)	(ft.)	(cm)	(ft.)	(cm)	(ft.)
1	4.26	0.13	5.91	0.18	4.26	0.13
3	3.28	0.10	4.92	0.15	3.61	0.11
6	2.30	0.07	3.94	0.12	2.62	0.08
12	1.64	0.05	2.95	0.09	1.97	0.06

For datums calculated from data series greater than one year but less than 19 years, the uncertainty is a linear interpolation between 1 year and 19 year datum. As an example, if a 12-month datum S12M equals 0.06 feet, then the accuracy for a 5 year data series (S60M) at the same subordinate station, compared with the same control station, would be:

$$S_{60M} = 0.06 \frac{19 \text{ yr.} - 5 \text{ yr.}}{18 \text{ yr.}} = 0.05 \text{ feet}$$

As shown above, having local tidal datums computed using 1-year or more of data greatly increases the accuracy in the tidal datum elevations.

3) Geodetic Datum Elevations.

MAPTITE requires knowing an elevation relationship between the tidal datums (notably local mean sea level (MSL)) and NAVD88 as NAVD88 is typically the reference elevation for DEMs. NAVD88 elevations are established at the project site by directly tying in to existing nearby NGS bench marks that are part of the existing High Accuracy Reference Network (HARN), or establishing new elevation points using static GPS surveys. Published HARN elevations for NAVD88 have accuracies at approximately 1 cm level, while static GPS surveys can establish NAVD88 at the 2-5 cm accuracy level. Elevation relationships between NAVD88 and MSL and other tidal datums are established by level connections between the tide station bench marks and the geodetic bench marks or control points. Many existing and historical tide stations have accurate relationships already established (see the User's Guide), however new tide stations will need a connection established as appropriate using leveling or static GPS observations.

4) Use of VDatum to obtain elevation relationships.

The most accurate way to establish datum elevations and datum relationships for tidal and geodetic datums is to use local tidal datums established by measurement at tide stations near the project, and local survey ties to geodetic control bench marks with established NAVD88 elevations. Estimation using the tidal interpolation models and geodetic interpolation models contained in the NOAA VDatum tool can also be used, however, accuracy of datum elevation relationships determined by VDatum are typically several centimeters and would not be the primary choice for source information to be used in MAPTITE.

VII. References

- National Oceanic and Atmospheric Administration (NOAA), 2003. *Tide Datum and Their Applications*. NOAA Special Publication NOS CO-OPS 1.
- National Oceanic and Atmospheric Administration (NOAA), 2003. *Computational Techniques for Tidal Datums Handbook*. NOAA Special Publication NOS CO-OPS 2.
- National Oceanic and Atmospheric Administration (NOAA), 2003. *Tide and Current Glossary*. National Ocean Service.
- National Oceanic and Atmospheric Administration (NOAA), Draft 2004. *Addressing elevation and inundation issue in habitat restoration planning and implementation*. National Ocean Service.
- National Oceanic and Atmospheric Administration (NOAA), Draft 2008. *National Geodetic Survey User Guidelines for Classical Real Time GNSS Positioning*. National Ocean Service.

VIII. Appendix I

a. Tides and Tidal Datums

Tides are the periodic motion of the waters of the sea caused by the changing gravitational effects of the moon and the sun as they change position relative to the rotating Earth (CO-OPS Special Publication 1). These periodic fluctuations in heights and times of water, in conjunction with substrate type, water chemistry, and biota, shape the land – water interface. For this reason it is important to understand these varying tidal cycles to properly characterize an area on which a restoration project will take place. This section will help the user understand the tidal regime in which the project area resides, plus give the necessary background data for input into a MAPTITE analysis.

Water level (tidal) datums are **local** vertical datums which may change considerably within a geographical area due to changes in tidal hydrodynamics and range of tide. While the main cause of tides is the gravitational interaction of the earth with the moon and sun, they are also highly influenced by local topographic/hydrographic features. A tidal datum is defined in terms of a certain phase of the tide: Mean Low Water (MLW), Mean Higher High Water (MHHW), etc., and is based on a 19-year period of water level averaging, the *National Tidal Datum Epoch (NTDE)*, which has been established by NOAA/NOS in the United States (presently the 1983-2001 NTDE, [Tidal Datums](#)). The basic definitions used with respect to these datums are:

- Mean Sea Level (MSL) – Arithmetic mean of hourly water levels observed during current NTDE.
- Mean Higher High Water (MHHW) – Mean of higher high water heights during current NTDE.
- Mean High Water (MHW) – Mean of all high water heights observed during current NTDE.
- Mean Low Water (MLW) – Mean of all low water heights observed during current NTDE.
- Mean Lower Low Water (MLLW) – Mean of lower low water heights during current NTDE.
- Mean Tide Level (MTL) – A datum located midway between MHW and MLW; i.e., $MTL = \frac{1}{2} (MHW+MLW)$.

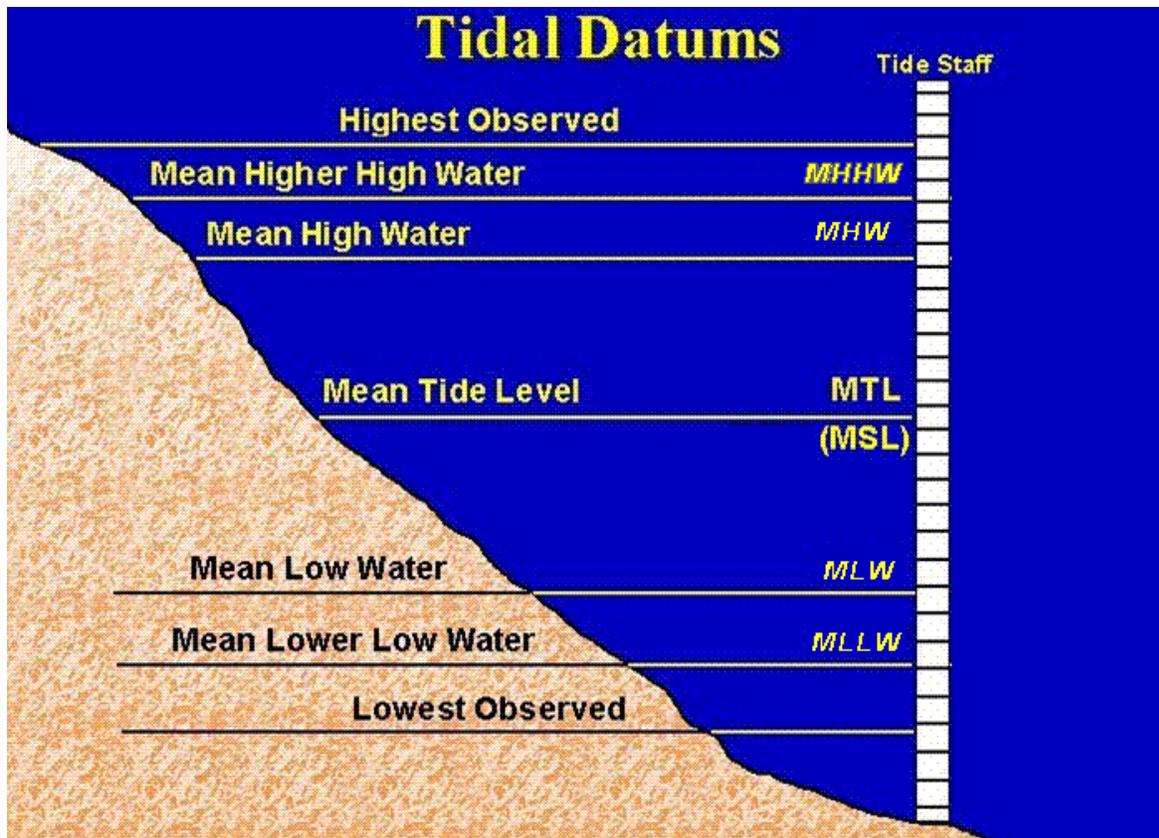


Figure 29. Tidal Datum definitions and their relationship to the shore.

In the case of many projects that will be undertaken by the user where a full epoch of tidal data (19 years) will not be available, CO-OPS does a comparative analysis with shorter term tidal data series to come up with an equivalent 19-year tidal datum. More information on this comparative analysis can be found in the Computational Techniques for Tidal Datums Handbook NOAA Special Publication NOS CO-OPS 2 (see tidesandcurrents.noaa.gov and publications).

b. Geodetic Datums and GPS Data

The irregularity of the surface of the earth makes it virtually impossible to make accurate computations of either horizontal or vertical measurements on that surface if an area of any size is involved. Instead, mathematical surfaces called geodetic datums are used to define the size and shape of the earth and provide orientation and origins for various coordinate systems used in mapping (Figure 30).

A computational surface for a datum is created by rotating an ellipse around its vertical axis to create an ellipsoid. The ellipsoid produced has defined characteristics such as vertical and horizontal axis length and amount of flattening at the poles. This information is combined with an origin and, generally, an orientation provided by an associated adjustment of survey control to produce a datum. Many different ellipsoids and datums have been defined and used over

the years. Currently the Geodetic Reference System 80 (GRS80) ellipsoid in conjunction with the North American Datum of 1983 (NAD83) is used for the official datum of the United States. Satellite technology allowed the development of this earth centered datum to replace the North American Datum of 1927, which has its origin and orientation derived from a point called MEADES RANCH in Kansas. The change created a much better fit for modern survey data.

As with horizontal measurements, vertical measurements are made and computed with respect to a datum. The North American Vertical Datum of 1988 (NAVD 88) is the accepted vertical datum of the National Spatial Reference System (NSRS) for the contiguous United States and Alaska and is officially supported by NGS. It 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 bench mark, 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. NAVD 88 should not be used as Mean Sea Level.

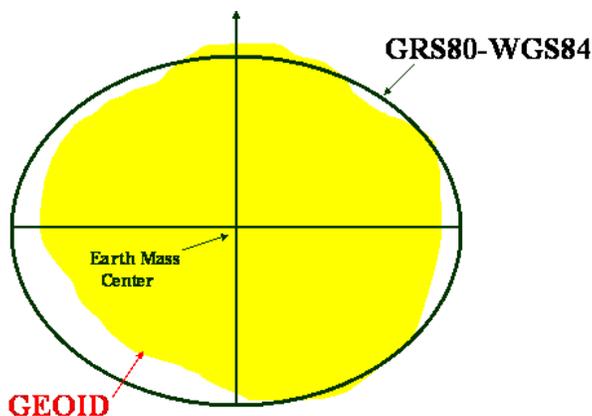


Figure 30. Relationship of ellipsoid and geoid surfaces.

Orthometric elevations - the type of elevations most people are familiar with from topographic maps - are referenced to a vertical datum and the geoid, which is the equipotential surface of the earth's gravity field that best approximates mean sea level.

While leveling is the most accurate way to determine elevations, evolving technology and research has allowed for development of techniques using GPS to determine fast, accurate heights. Unlike the orthometric heights derived from leveling, however, GPS elevations are referenced to the ellipsoid. This necessitates a well determined geoid for use in computing orthometric elevations (Figure 31). NGS has released GEOID12A (<http://www.ngs.noaa.gov/GEOID/GEOID12A/>).

H = Orthometric Height (NAVD 88)

h = Ellipsoidal Height (NAD 83)

N = Geoid Height (GEOID 03)

$$H = h - N$$

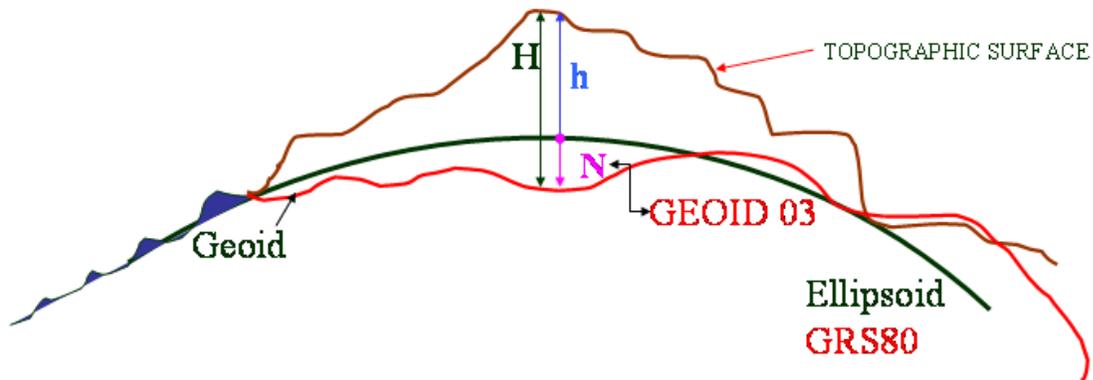
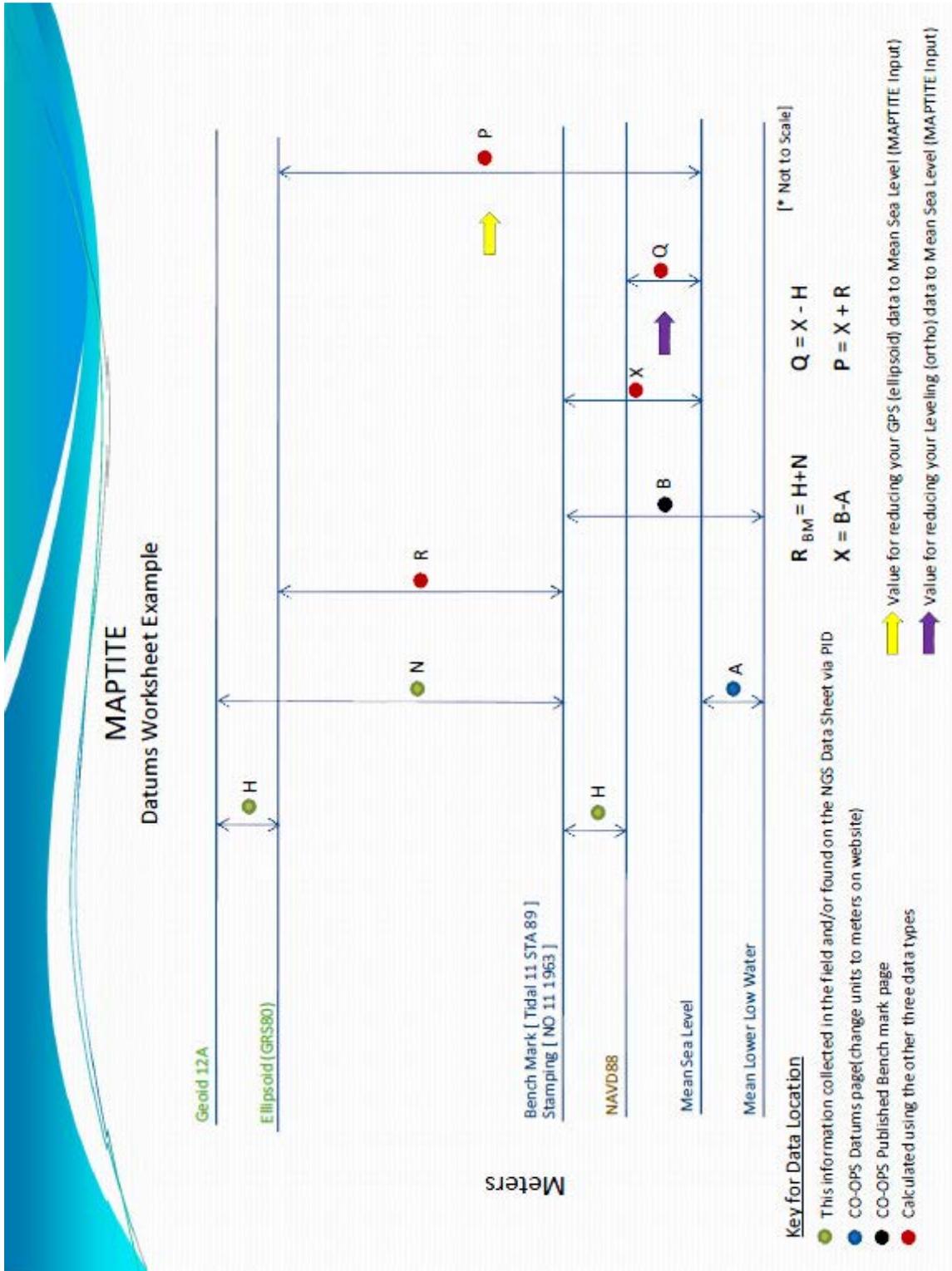


Figure 31. Elevations and their relationship to the topographic surface of the earth, the ellipsoid, and the geoid.

Appendix II. Graphical Datum Worksheet



IX. Contact Information / Office Contribution Information

Tidal Analysis and Tidal Datum Computation

Datums Team, Center for Operational Oceanographic Products and Services (CO-OPS)
nos.coops.datums@noaa.gov

Lijuan Huang – Center for Operational Oceanographic Products and Services (CO-OPS)
(301) 713-2890 ext. 192 ; Lijuan.Huang@noaa.gov

Geodetic / Ellipsoidal Quantification

Philippe Hensel – National Geodetic Survey (NGS)
(301) 713-3198 ext. 137 ; Philippe.Hensel@noaa.gov

ArcGIS Programming and Technical

Ken Buja – National Centers for Coastal Ocean Science (NCCOS)
(301) 713-3028 ext. 140 ; Ken.Buja@noaa.gov