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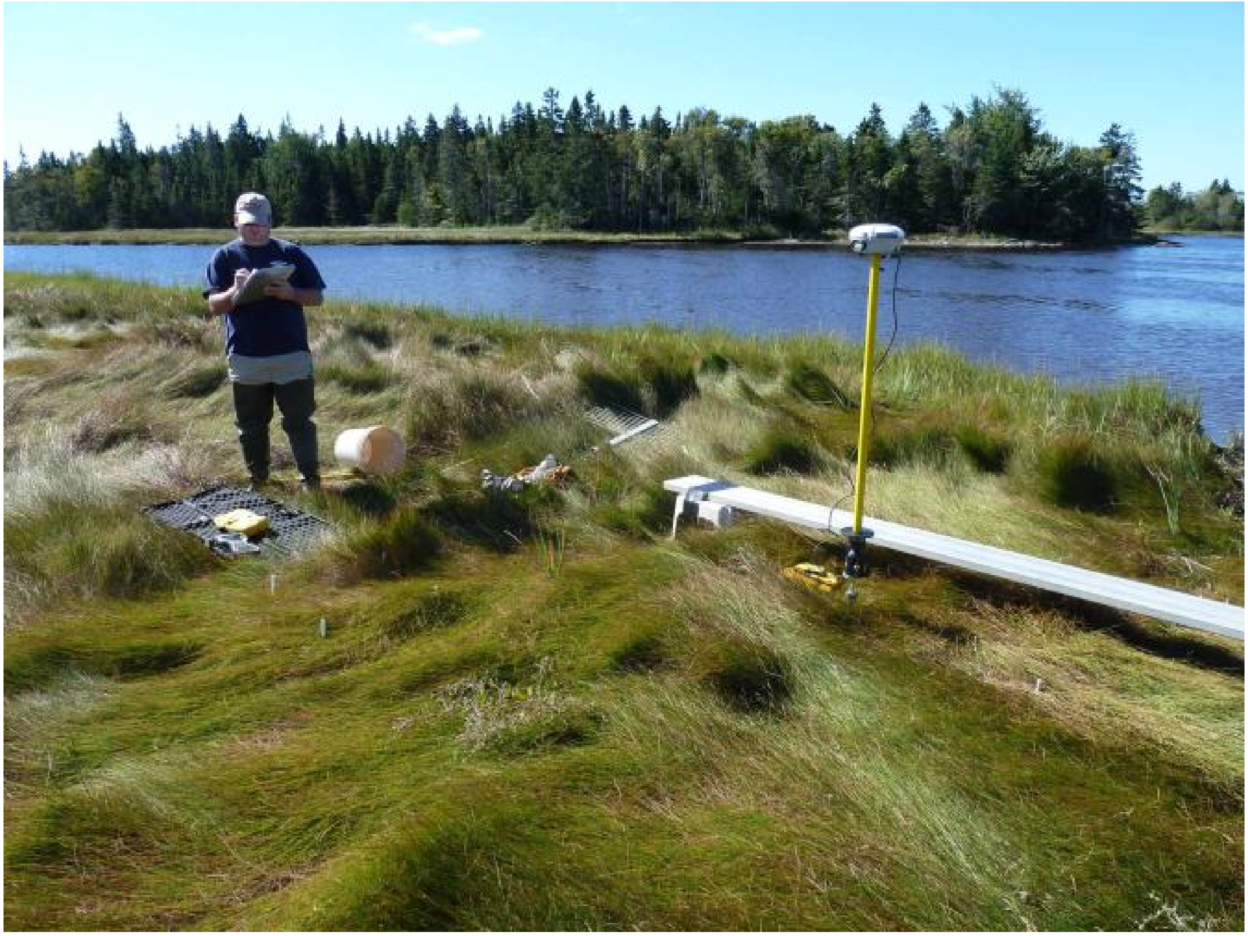
Natural Resource Stewardship and Science

The Surface Elevation Table and Marker Horizon Technique

A Protocol for Monitoring Wetland Elevation Dynamics

Natural Resource Report NPS/NCBN/NRR—2015/1078



ON THIS PAGE
Recording data from a GPS occupation of an SET mark at Acadia National Park, Maine.

ON THE COVER
Top: Measuring a rod Surface Elevation Table at Acadia National Park, Maine. Lower left: Collecting a cryogenic soil core from a marker horizon plot at Gateway National Recreation Area, NY. Lower right: Soil core extracted with a knife showing a marker horizon (white layer) sampled at Tijuana Slough NERR, CA.

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Executive Summary

The National Park Service, in response to the growing evidence and awareness of the effects of climate change on federal lands, determined that monitoring wetland elevation change is a top priority in North Atlantic Coastal parks (Stevens et al, 2010). As a result, the NPS Northeast Coastal and Barrier Network (NCBN) in collaboration with colleagues from the U.S. Geological Survey (USGS) and The National Oceanic and Atmospheric Administration (NOAA) have developed a protocol for monitoring wetland elevation change and other processes important for determining the viability of wetland communities. Although focused on North Atlantic Coastal parks, this document is applicable to all coastal and inland wetland regions.

Wetlands exist within a narrow range of elevation which is influenced by local hydrologic conditions. For coastal wetlands in particular, local hydrologic conditions may be changing as sea levels continue to rise. As sea level rises, coastal wetland systems may respond by building elevation to maintain favorable hydrologic conditions for their survival.

This protocol provides the reader with instructions and guidelines on designing a monitoring plan or study to:

A) Quantify elevation change in wetlands with the Surface Elevation Table (SET).

B) Understand the processes that influence elevation change, including vertical accretion (SET and Marker Horizon methods).

C) Survey the wetland surface and SET mark to a common reference datum to allow for comparing sample stations to each other and to local tidal datums.

D) Survey the SET mark to monitor its relative stability.

This document is divided into two parts; the main body that presents an overview of all aspects of monitoring wetland elevation dynamics, and a collection of Standard Operating Procedures (SOP) that describes in detail how to perform or execute each step of the methodology. Detailed instruction on the installation, data collection, data management and analysis are provided in this report and associated SOP's.

A better understanding of these processes will help to determine the present and future viability of coastal wetlands managed by NPS and can help address measures that will ensure these communities exist into the future.

Acknowledgements

The authors would like to thank Geoff Sanders of National Park Service, National Capital Region Network for his work on the SET database described in the text and SOP #7. Additional thanks to SET colleagues in academia, the United States Fish and Wildlife Service, The National Oceanic and Atmospheric Administration and the National Park Service for reviewing this protocol and offering suggestions to improve it. Don Cahoon of the USGS managed the peer review of this document and was funded by the U.S. Geological Survey, Climate and Land Use Research & Development program, and the Ecosystems Mission Area. Robin Baranowski of the NPS kindly performed the final formatting of the document. Use of trade names does not constitute endorsement by the U.S. Government.

Glossary

Accretion: the accumulation of matter, both mineral and organic, carried by a river or stream. **Vertical accretion** refers to the buildup of the sediment substrate while **lateral accretion** refers to horizontal expansion of the sediment substrate.

Bioturbation: the reworking of soils and sediments by animals or plants.

Compaction: the process by which wetland sediments progressively lose porosity due to the effects of the loading of the material above it.

Covariate: an observable, continuous secondary variable that may affect the response variable. Covariates are often used in a statistical model to help control variability, so that the response to the primary factors of interest can be discerned. Example: wetland elevation relative to mean high water is a secondary variable that may help determine the effect of vegetation type on **Elevation Change**.

Datum: a reference frame or surface from which positions and elevations are measured.

Elevation Change (wetland): change in the height of the wetland surface relative to the base of the **SET Mark** as measured by the **SET**.

Experimental Unit: the smallest piece of experimental material to which independent factor levels can be assigned.

Factors: within an experimental design, a factor is an independent variable (e.g., tidal regime) that is hypothesized to affect the response (i.e., dependent) variable (e.g., **Vertical Accretion** or **Elevation Change**).

> **Fixed Factor**: a variable whose value can be controlled (e.g., wetland type or vegetation)
>
> **Random Factor**: a variable whose value cannot be controlled (e.g., location effects, sample effects)
>
> **Continuous Factor**: either fixed or random factor that can take on a continuous range of values (e.g., temperature, water level)
>
> **Discrete Factor**: a fixed factor that takes discrete levels (**Factor Levels**). Example: low, medium, and high inundation regimes or fertilization treatments.

GNSS - Global Navigation Satellite System: a global satellite system used to provide geo-spatial positioning. GPS, GLONASS, Galileo and Beidou are GNSS satellite systems.

Growth Range: range of wetland elevations over which a particular species of wetland plant will grow.

Hypothesis testing: evaluate one or more specific research questions by statistical comparisons among specific levels of independent variables. Example: comparing the wetland **Elevation Change** and **Vertical Accretion** between a restored marsh and an adjacent reference marsh.

Leveling, Geodetic: the precise measurement of vertical differences among surfaces using high precision (typically < 0.0001 or better) optical or digital leveling instrumentation.

Marker Horizons: an artificial soil horizon placed on a wetland surface to measure **Vertical Accretion** (i.e., the accumulation of material above the marker horizon). Feldspar is a common marker material.

Monitoring (wetland elevation and accretion): a sampling scheme designed to document overall rates (trends) of **Elevation Change** or **Vertical Accretion** within a particular **Sample Space**, which is an area of broad geographic extent. Example: evaluating wetland elevation change over time throughout an entire refuge or park.

NAD 83 - North American Datum of 1983: official datum used for horizontal positions (latitude and longitude) and ellipsoid heights.

NAVD 88 - North American Vertical Datum of 1988: official vertical datum in the National Spatial Reference System (**NSRS**). NAVD 88 is based on a leveling network on the North American Continent affixed to a single origin point.

NSRS - National Spatial Reference System: a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States.

NTDE - National Tidal Datum Epoch: the time period used to determine **Tidal Datums**. A span of 18.7 years. At the time of this writing, the current NTDE spans from 1983 – 2001.

Orthometric Height: for practical purposes "height above sea level" based on the current NAVD 88 datum tied to a defined elevation at one point rather than to local mean sea level.

Randomization: a process of assigning **Sample Sites** or **Sample Stations** such that each site or station has an equal chance of being included in the sample. Randomization is typically used in an attempt to ensure a representative sample without the inclusion of bias. Note that with small sample sizes, pure randomization does not guarantee representative sampling. **Restricted randomization** is a variation where randomization occurs within *a priori* limits (e.g. randomly choosing sample stations within pre-determined sample sites).

Refusal: the point in time when the deep mark rod no longer moves (often an abrupt stop) during installation (e.g., hits bedrock or limestone). If refusal is not met, installation continues until substantial resistance occurs (see **Resistance, substantial**).

Replicate: one of several experimental units to which the same **Factor Levels** are applied or assigned (see **Experimental Unit**, above)

Resistance, substantial: the point in time at which the insertion rate of rods into the ground reaches an agreed-upon minimum rate (e.g. 60 seconds per foot of rod). After reaching this threshold, installation of the mark typically stops.

RTK – Real Time Kinematic surveying: a differential **GNSS** surveying technique that uses multiple receivers (Base and Rover). A stationary base receiver sends real-time corrections to the rover. RTK surveys provide vertical precision in the range of several centimeters.

RTN – Real Time Network surveying: a **GNSS** surveying technique similar to **RTK** but only requires a single receiver connected to a "virtual" base that provides corrections. Accessing this "virtual" base usually requires a connection to the internet or cell phone service.

Sample: a group of **Replicates** (see above)

Sample Site: a distinct unit within the **Sample Space** where SET **Sample Stations** may be deployed. Sample sites may be identified based on their geographic locations, their vegetation communities, elevation within the tidal frame, etc. Examples: a specific wetland area along a coast, or a vegetated area within one wetland.

Sample Size: the number of **Replicates** in any given **Factor Level.**

Sample Space: a landscape-scale unit area that represents the study's area of interest. This is the area within which inferences will be made. **Sample Sites** are delineated within the sample space, or individual **Sample Stations** may be distributed within the sample space. Example: a wildlife refuge, entire state or county coastline, a given wetland type, or an individual marsh.

Sample Station: The physical location within a **Sample Site or Sample Space** where SET and/or marker horizon measurements are collected.

Sea-Level Rise, Eustatic: Vertical rate of increase in local sea level; typically determined from long term sea level records.

Sea-Level Rise, Relative: the combination of eustatic sea-level rise and local vertical land motion (i.e., subsidence or uplift).

Serial correlation: Also known as autocorrelation, this is the similarity among observations of the same sample over time. For example, repeated SET measurements for the same pin in the same position (i.e. repeatedly sampling the same point on the wetland surface) will be correlated over time. Serial correlation may misrepresent the true variability in the data.

SET Mark: The permanent infrastructure established in the **Sample Station**, from which SET measurements are taken; also colloquially referred to as a SET benchmark in early SET literature. If a SET mark meets National Geodetic Survey bluebook standards, it can be referred to as a bench mark. There are three types of SET marks: pipe SET mark, deep-rod SET mark (deep RSET mark), and shallow-rod SET mark (shallow RSET mark).

Shallow Subsidence: the sinking or downward movement of the wetland surface relative to the base of the **SET Mark** calculated as the difference between **Vertical Accretion** as measured by a marker horizon and **Elevation Change** as measured by the SET (i.e., vertical accretion minus elevation). Shallow subsidence only applies to the portion of the substrate above the base of the SET Mark, and not that portion below it.

Subsidence: The sinking or downward movement of a surface relative to a datum.

Surface Sediment Deposition: the process of suspended sediment deposition on the wetland surface; which contributes to wetland **Vertical Accretion**.

Surface Elevation Table (SET): a portable mechanical device that provides high-resolution measurements of relative **Elevation Change** in wetland sediments or shallow water bottoms relative to the depth of the **SET Mark** to which it is attached. The original SET was designed to attach to a hollow pipe mark. The rod SET (RSET) was designed to attach to either a stainless steel rod mark (deep RSET mark) or a shallow hollow-legged mark (shallow RSET mark).

Tidal Datum: the elevation of a specific phase of the tide cycle averaged over a specific period of time.

Vertical Accretion: the building up of a wetland surface through the deposition and accumulation of sediments. See **Accretion**.

Wetland: Land consisting of marshes or swamps with saturated soils where plant organic matter accumulates and soils are wet for some period of time, and plants and animals are adapted to this environment.

Introduction

The purpose of this Natural Resource Report is to provide a scientifically valid and standardized set of guidelines for measuring elevation change and vertical accretion in coastal wetland habitats. Knowledge of these processes is essential for assessing the vulnerability of wetland resources to changes in local hydrology.

These guidelines follow a standardized format used by the National Park Service, Inventory & Monitoring Program. The report is organized into two main sections: 1) background and explanation of the rationales and methodologies used for measuring wetland elevation change and vertical accretion, and 2) detailed Standard Operating Procedures (SOP) for all phases of an inquiry-based study of wetland vertical accretion and elevation change, including experimental design, site establishment, data acquisition and analysis. For some SOPs, appendices are provided to give additional background and information on the technology and methods employed.

This report addresses the urgent need to develop a consistent program of coastal elevation monitoring that is national in scope. The impetus for this effort arose within the National Park Service (NPS) and their collaborations with the U.S. Geological Survey (USGS) in the measurement of wetland elevation change using the Surface Elevation Table (SET), and with the National Oceanic and Atmospheric Administration (NOAA) to relate SET data and other wetland datasets to local water levels within local geodetic control networks, as well as the National Spatial Reference System. These guidelines are therefore an interagency collaboration designed to develop a consistently applied methodology for monitoring the vulnerability of coastal wetlands to present and future sea level rise.

Protocol Objectives

This protocol provides the reader with instructions and guidelines on designing a monitoring plan or study to:

A) Quantify elevation change in wetlands with the Surface Elevation Table (SET).

B) Understand the processes that influence elevation change, including vertical accretion. (SET and Marker Horizon methods).

C) Survey the wetland surface and SET mark to a common reference datum (NAVD 88) to allow for comparing sample stations to each other and to local tidal datums.

D) Survey the SET mark to monitor its relative stability.

The specific information needs of a research study or monitoring program will drive the choice of what to measure and monitor, and which techniques to use. Not every objective needs to be met in any one study or monitoring programIt is highly recommended, however, that any study of coastal vertical dynamics include an elevation survey so that the results of the study can be related to the elevation of the wetland surface and local water levels. Elevation monitoring in general can provide managers and researchers with a feasible and valid means of quantifying processes which are essential in determining the long term viability of these ecosystems.

Although this document focuses on the specific needs for monitoring coastal wetland elevations with respect to local sea level, the main techniques are applicable to all wetland types including non-coastal wetlands and shallow water habitats.

Background

Wetland sensitivity to sea-level rise

Tidal wetland plant communities (i.e., salt marshes, brackish marshes, tidal freshwater marshes, and mangroves) exist within a narrow range of elevation which is influenced by the local tidal patterns and inundation (Figure 1). Tide ranges vary from area to area, thus the growth range of wetland plants will also vary according to these local conditions. If an area has a large tidal range, then there will be a large growth range for the vegetation in that area. Conversely, if an area has a small tidal range, the growth range will also be comparatively small (McKee and Patrick 1988, Cahoon and Guntenspergen 2010).

Figure 1. Salt marsh platform at Cape Cod National Seashore, Massachusetts.

The ability of wetland plant communities to maintain their position within their growth range is tied to local hydrology. In areas of rising sea levels (e.g. due to a combination of global sea-level rise and local land motion, such as subsidence), a tidal wetland needs to build vertically to maintain its relative elevation within its growth range (Figure 2). Wetlands have existed – even flourished – during an extended period of rising sea level (over the past 7,000 years) through processes of vertical development. Vertical development in the marsh is the result of a number of factors, including accretion, erosion, organic soil (peat) formation, decomposition, compaction, and groundwater flux (shrink-swell of the soil) as well as deeper processes such as regional subsidence or uplift.

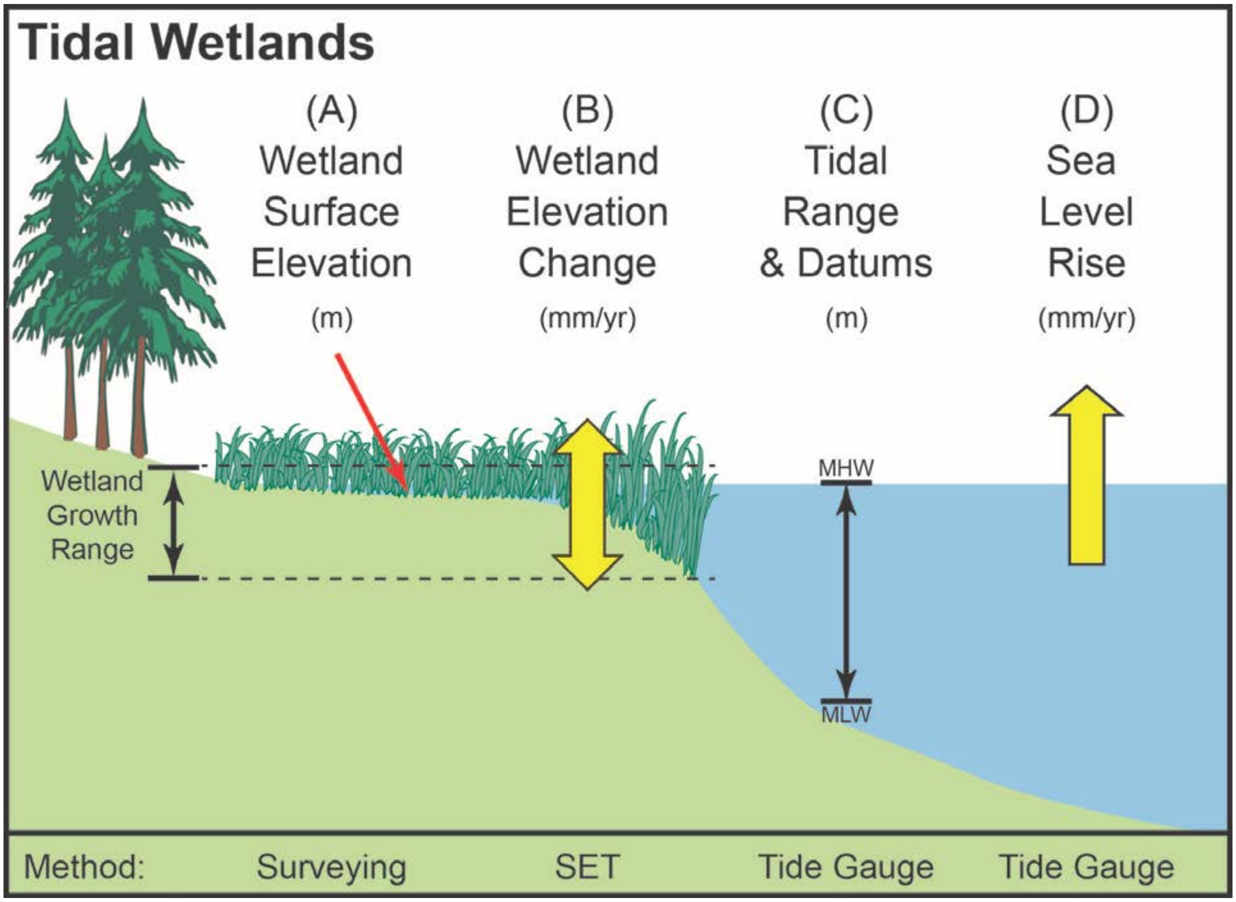


Figure 2. Conceptual diagram showing the relationship among wetland surface elevation (A), tidal datums (C), and their respective rates of change (B and D). Understanding these relationships is important for evaluating the sustainability of a wetland community to sea-level rise.

As sea levels rise, wetland plant communities need to build vertically through the accumulation of sediment and plant matter, thereby maintaining their relative position within the growth range. Plants which exist low in their growth range are exposed to a higher frequency and duration of flooding that can limit vegetative growth, causing a decrease in the contribution of organic matter to soil formation both above and below ground (Morris et al. 2002). Under these conditions, plant survival is at risk and once the vegetation dies, there is little chance of maintaining sufficient elevation for successful recolonization to occur and the habitat becomes an intertidal mud flat or a shallow submerged water bottom.

Accelerating rates of sea-level rise are considered to be the primary impact of climate change on these communities (Kirwan and Guntenspergen 2009, Kirwan and Temmerman 2009). If wetland elevation does not increase at a rate commensurate with the rate of sea-level rise, the wetland is said to be experiencing an “elevation deficit” (Cahoon et al. 1995, 1999). Conversely, some coastal wetland plant communities are currently buffered against sea-level rise due to their relatively high elevation with respect to water levels. The elevation above the threshold for plant survival has been called “elevation capital” (Reed 2002). Even if vertical processes are insufficient to counter local sea-level rise, coastal wetlands with high elevation capital will survive longer than those with little capital.

Although national wetland loss rates in the United States declined over the past several decades due in part to changes in regulatory enforcement (Dahl 2011), wetland loss is still occurring, and many coastal areas are increasingly vulnerable to wetland loss due to the combination of local land subsidence and sea-level rise. This is especially true in micro-tidal habitats and areas of rapid subsidence, such as the Mississippi Delta (e.g. Coleman and Smith 1964, Penland and Ramsey 1990, Rybczyk and Cahoon 2002, and Törnqvist et al. 2006) and the mid-Atlantic seaboard (e.g. Stevenson et al. 1985). With global rates of sea-level rise predicted to increase over the coming decades (Church et al. 2010), many more coastal wetlands may become vulnerable to increased inundation. Additionally, certain areas of the coast, such as the mid-Atlantic region, can undergo even greater sea-level rise due to changes in coastal ocean circulation (Sallenger et al. 2012).

Given these patterns of wetland loss and vulnerability, the coastal manager/investigator may have specific questions in mind when planning a study of wetland elevation dynamics.

Such as;

1. “What are the elevation characteristics of our wetlands?” (Figure 2A)
2. “How is elevation change occurring and what is the role of surface and subsurface processes?” (Figure 2B)
3. “How do local wetland elevation dynamics relate to the local hydrology (e.g., local tidal datums)?” (Figure 2C)
4. ”Is elevation gain sufficient to keep pace with current and predicted sea level rise?” (Figure 2D)

All of these questions relate to quantifying the marsh and hydrologic factors described in Figure 2. To answer questions 1 & 2 regarding wetland elevation change, the Surface Elevation Table (SET) technique is used. Note that it can be used in isolation from other data types and still address these first two questions. To answer question 3, however, the SET data will need to be expressed with respect to local water levels and local water level changes. This will normally involve measuring and monitoring local water levels and conducting an elevation survey to connect both measurements. For question 4, a combination of techniques is required, such as pairing SET data with the marker horizon technique.

Coastal researchers might also be more specifically interested in conducting manipulative experiments and testing hypotheses to understand wetland elevation responses to specific environmental variables. Such investigations will require SETs as well as other techniques (e.g. marker horizons, tide gauges, surveying techniques) and appropriate experimental designs. Again, the specific needs of the study will decide the combination of techniques required and the kind of experimental design chosen.

Surface elevation table

The Surface Elevation Table (SET) method consists of two parts: the SET instrument and the mark to which it attaches. The SET instrument is a portable mechanical device (Figure 3) that provides high-precision measurements of relative elevation change in wetland sediments or shallow water bottoms relative to the base of the rod SET (RSET) mark to which it is attached. The measurements are repeatable (each pin re-occupies the same point on the wetland surface at each sampling), can be made over long periods of time, and are of sufficiently high resolution to compare to long term sea-level trends measured by tide gauges (Cahoon 2014). The design of the original SET, developed by Boumans and Day (1993) is derived from the Sedi-Eros Table created by Schoot and de Jong (1982). The original SET was revised several times during the 1990’s to improve its precision (Cahoon et al. 2002a). The RSET instrument developed in 2000 attaches to RSET marks that can be both deeper and shallower than marks used with the original SET (Cahoon et al. 2002b).

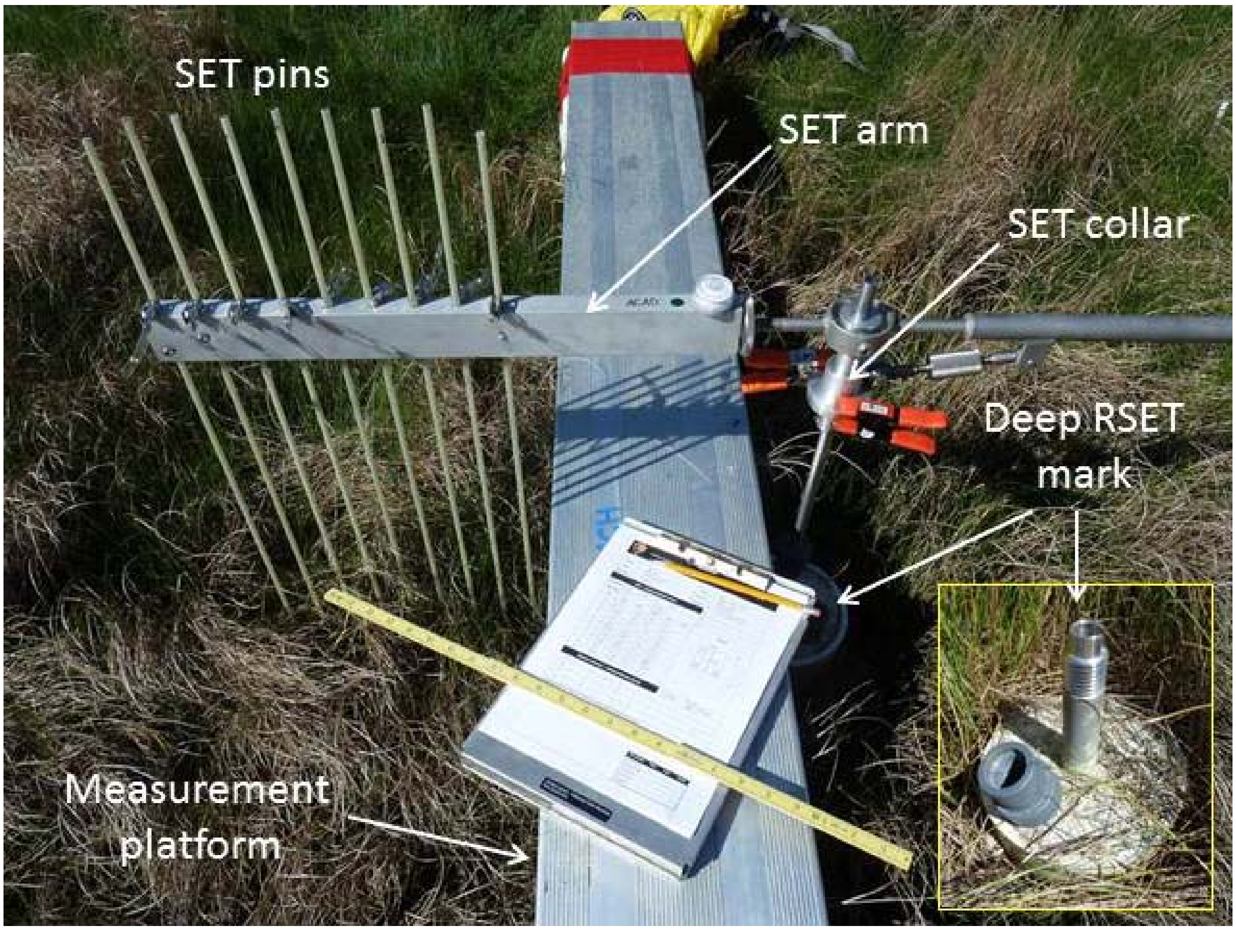


Figure 3. Rod SET instrument deployed in a tidal salt marsh (Acadia National Park, Maine). The instrument attaches to the deep RSET mark and the SET arm is extended over the marsh surface at fixed directions. The arm is carefully plumbed so it is horizontal, and each of nine pins is lowered until it makes contact with the wetland surface. The height of each pin remaining above the arm is measured to the nearest millimeter at every sampling. Change is recorded as the change in height of each pin over time. Four positions provide 36 pin readings covering an area of approximately 1.5m^2.

The essential components of SET technology include:

- An *in situ* permanent SET mark anchored within the sediment.
- A custom made, portable instrument which is attached to the SET mark only at the time of measurement. The instrument arm takes surface measurements from portions of the sediment surface that are unaffected by the SET mark.
- The instrument occupies up to eight fixed positions around the SET mark.
- The instrument occupies the same position in space with respect to the SET mark at each measurement session.
- The strength of this technique is that the same wetland surfaces are repeatedly measured over time, with the ability to detect millimeter-scale changes.
- The SET sample station is established to measure elevation change over long time periods. (Long term monitoring).

The SET can resolve millimeter level changes (Cahoon et al. 2002a,b) in wetland and shallow water bottom surfaces by measuring relative elevation change over time at distinct, repeatable locations around a permanent SET mark anchored in the sediment (Figures 3, 4). Measurements are collected from nine distinct points on the wetland surface at up to eight individual positions around the SET mark. At each fixed position, the SET is extended horizontally over the wetland and leveled. Nine pins are lowered from the SET arm until they make contact with the wetland surface. The remaining length of pin above the SET arm (or "Table" in the original design SET) is measured to the nearest millimeter. At the next measurement event (weeks or months later), the pins reoccupy the same surface of the wetland and are measured again. Four positions yield a total of 36 observations. The possibility of measuring eight positions (72 observations) allows for flexibility when encountering obstructions which may limit readings in a particular direction (i.e., mangrove prop roots, branches, crab holes,, rocks). The SET instrument samples an area of approximately $1.5m^2$. Over time, the change in the height of each pin is a reflection of the changing elevation of the sediment surface with respect to the base of the SET mark. Changes are typically reported as mm y^{-1}. It may take up to 5 or more years of elevation change data to overcome short term variability and obtain trends that are representative of wetland responses to sea level.

The strengths of the SET technique are the repeated measurements through time of the same patch of sediment surface and the ability to measure millimeter-scale changes in elevation. The vertical changes at the soil surface are the net result of surface and subsurface processes occurring down to the bottom of the SET mark to which it is attached (typically 2 – 20 meters; Figure 4). These processes include accretion, erosion, soil organic matter accumulation, decomposition, compaction, and groundwater flux (shrink-swell of the soil; Figure 5). The SET does NOT measure processes that occur below the SET mark such as deeper subsidence processes (e.g. > 20 meters deep).

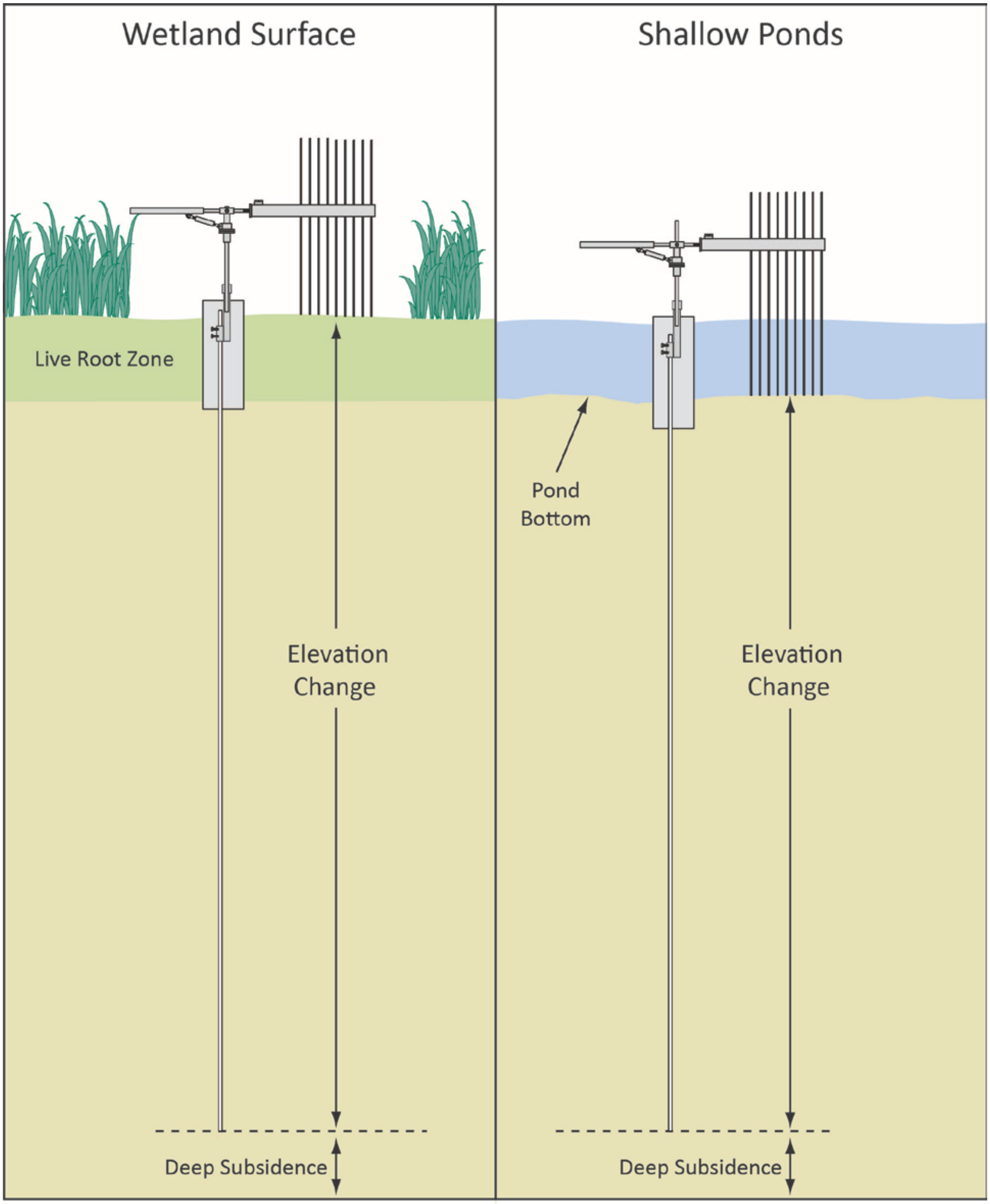


Figure 4. Conceptual diagram showing how SETs can be used on vegetated wetlands (left panel), mud flats and shallow ponds (right panel). In both cases, a deep RSET mark is established in the soil and the pins are placed on the sediment surface. The SET measures relative elevation change occurring from the base of the SET mark to the sediment surface. Relative elevation is measured as the height of the pins above the horizontal arm of the SET.

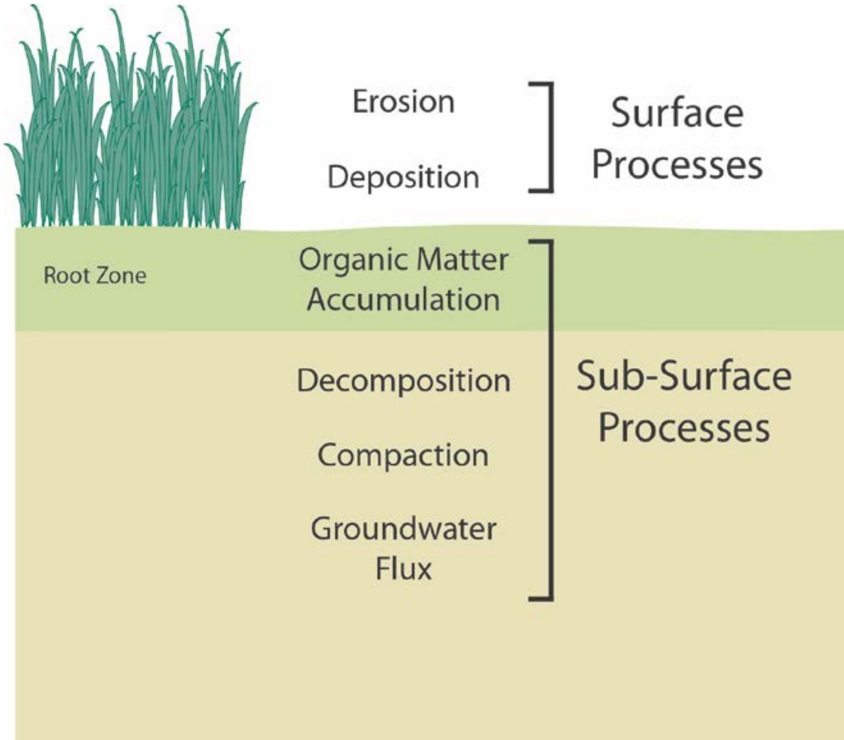


Figure 5. Surface and sub-surface processes measured by the SET – Marker Horizon method that determine elevation change in a wetland.

The SET instrument has gone through numerous changes in design over the years and there are several current designs which are in use today (Cahoon et al. 2002a, b). The RSET has become the most commonly used SET instrument, as it is very portable and the RSET mark it attaches to can attain much greater depths than previously possible with the original, pipe SET mark (Cahoon et al. 2002b), anchored from six to nine meters in depth. The RSET mark is constructed with 1.2 m (4 foot) long rods that are threaded together as they are driven into the ground to refusal or substantial resistance, often to a depth greater than 10 meters. Installation of these marks can be accomplished using the same techniques as deep-driven rod vertical control marks (Floyd 1978). Some developments in SET technology were also driven by the requirements of specific research projects. The Shallow RSET (Figure 6) was designed to collect measurements in the root zone of wetland plants (Cahoon et al. 2002b). Changes in the heights of the pins over time reflect vertical dynamics occurring from the wetland surface down to the bottom of the root zone (e.g., about 30 – 50 cm). By coupling deep and shallow RSET techniques, researchers have been able to better understand where in the soil profile vertical processes are occurring (Figure 6; Figure 20, e.g. Whelan et al. 2005). This information has led to a more complete understanding of the processes controlling coastal wetland elevation and vulnerability to local sea-level rise. Users have also developed SETs with very long arms (See Sampling Design, Figure 16), so one SET mark can support observations both inside and outside enclosures or treatment applications (Langley et al. 2009). Others have developed a "mini" SET to use in greenhouse studies (Cherry et al. 2009). Other modifications have sought to enable better vertical control and higher accuracy observations. This protocol generally focuses on the instrument most commonly used at the time of this writing, the RSET (Cahoon et al. 2002b).

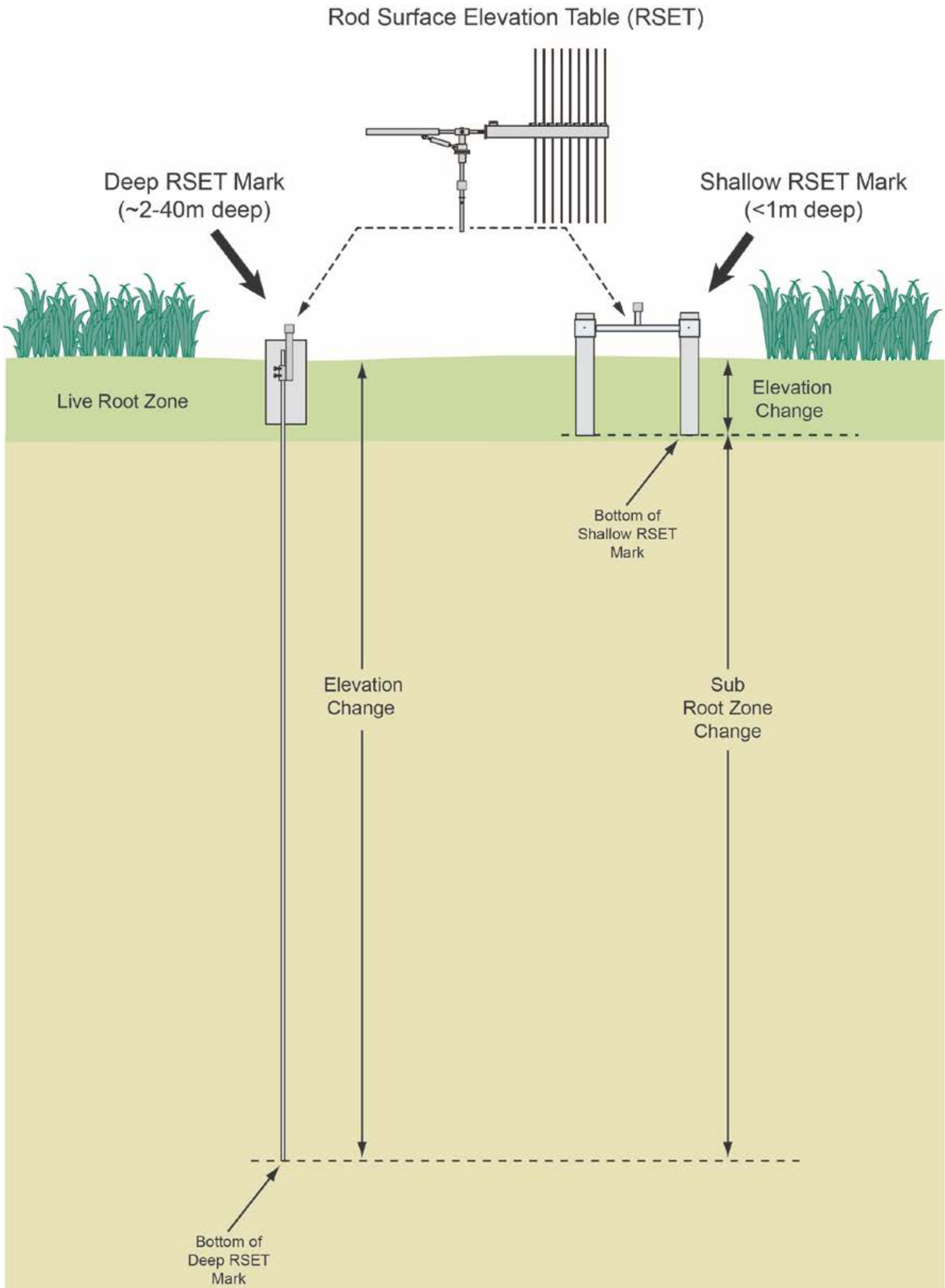


Figure 6. Conceptual diagram showing how the two RSET methods can be used together to partition vertical processes influencing wetland elevation between the live root zone and that portion of the substrate below the shallow RSET mark but above the base of the deep RSET mark (e.g., sub-root zone).

Marker horizons

Marker Horizons (MH) are artificial soil layers established on the surface of the wetland or shallow water bottoms to measure vertical accretion (Bauman et al. 1984, Cahoon and Turner 1989; Figure 5). Numerous materials such as sand, feldspar, brick dust and glitter are used as marker horizons. Powdered white feldspar clay is the most common; its main advantages are that it is bright white and easily distinguishable from surrounding sediments, has a higher density than water, and forms a colloidal layer when wet (so it can be deposited as a contiguous layer even in open water). Cores are taken through this layer, and the thickness of the sediment (both mineral and organic) accumulated above the layer is measured as vertical accretion. Accretion rates are typically expressed as millimeters of accretion per year.

Marker horizons primarily provide data on surface processes of sediment deposition and erosion (Figure 5, Figure 7). However, it is important to note that marker horizon data are biased towards positive values. If a marker horizon is not found, no data are recorded, even though an erosion event (negative accretion) may have occurred. In areas of high biological activity, bioturbation may lead to extensive losses in the integrity of the marker horizon. High energy areas also can lead to the loss of horizons through erosion after a short time period.

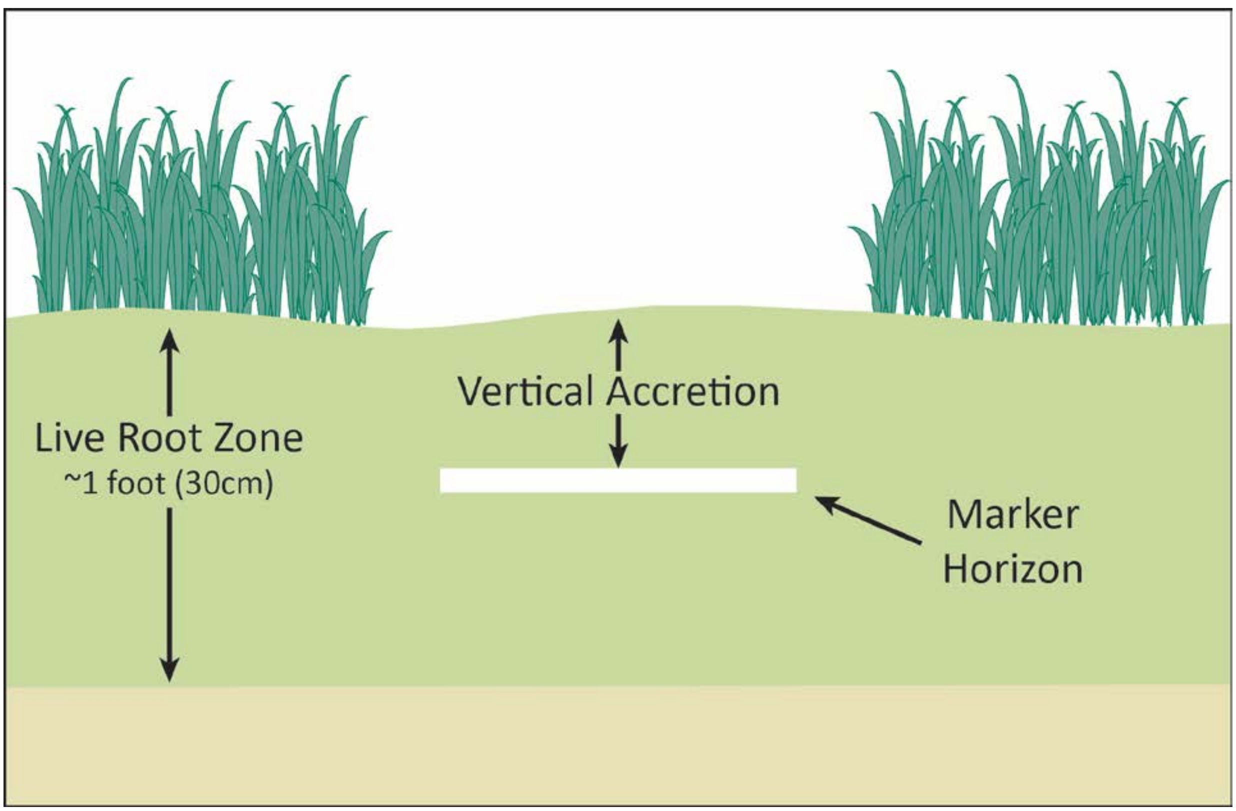


Figure 7. Conceptual diagram showing the marker horizon and the vertical accretion occurring above it.

As a result of these issues, marker horizons have a variable and shorter lifetime than the SET. In high energy areas or areas with a lot of bioturbation, they may not persist for more than 1-2 years. Under other conditions, they may last many years. When a marker horizon is no longer found or usable, then new marker horizons will have to be established on the surface adjacent to the original horizon. As a marker horizon becomes more deeply buried over time, it integrates more and more subsurface processes as well (e.g., the accumulation of root material below the sediment surface, compaction, or decomposition, Figures 5 and 8).

SET – marker horizon technique

When used simultaneously, the SET and MH (SET – MH) techniques provide information on both surface and below ground processes that influence elevation change (Cahoon et al. 1995). Prior to the development of the SET, most vertical accretion studies assumed the surface deposition of sediments represented an equivalent gain in elevation, followed by slow compaction over time as the accretionary layer became progressively buried. Most published SET – MH studies have shown instead that surface accretion largely overestimates elevation gain due to below-ground processes occurring above the base of the SET mark (Cahoon et al. 1995). Some SET – MH studies in rapidly subsiding marshes have actually shown elevation loss despite very high rates of accretion. This reduction in the net gain from accretion, as measured by the SET – MH method, has been termed "shallow subsidence" (Figure 9; Cahoon et al. 1995). In a few SET – MH studies, the opposite response has been observed. The measured elevation trend is greater than the accretion trend, indicating shallow expansion is occurring in the soil above the base of the SET mark. Shallow expansion has been attributed to swelling of soils by water storage (Whelan et al. 2005) and increased root volume (McKee et al. 2007, Langley et al. 2009). Thus when used together, the SET-MH techniques make it possible to distinguish between the contributions of surface and subsurface processes to elevation change. This information can be very important in evaluating why a wetland may or may not be keeping pace with local sea level rise, and may therefore suggest compensatory management actions (e.g. take steps to increase surface sediment deposition in order to increase plant root growth and wetland elevation). Note that the combined SET – MH technique does not measure processes occurring below the RSET mark (called deep subsidence, Figure 9). However, there are surveying techniques available to track vertical motion of the RSET mark, which can help estimate deep subsidence.

Figure 8. Marker horizon sample plug/core shows that after substantial burial, the marker horizon technique begins to incorporate both surface and subsurface processes (note root material above marker layer).

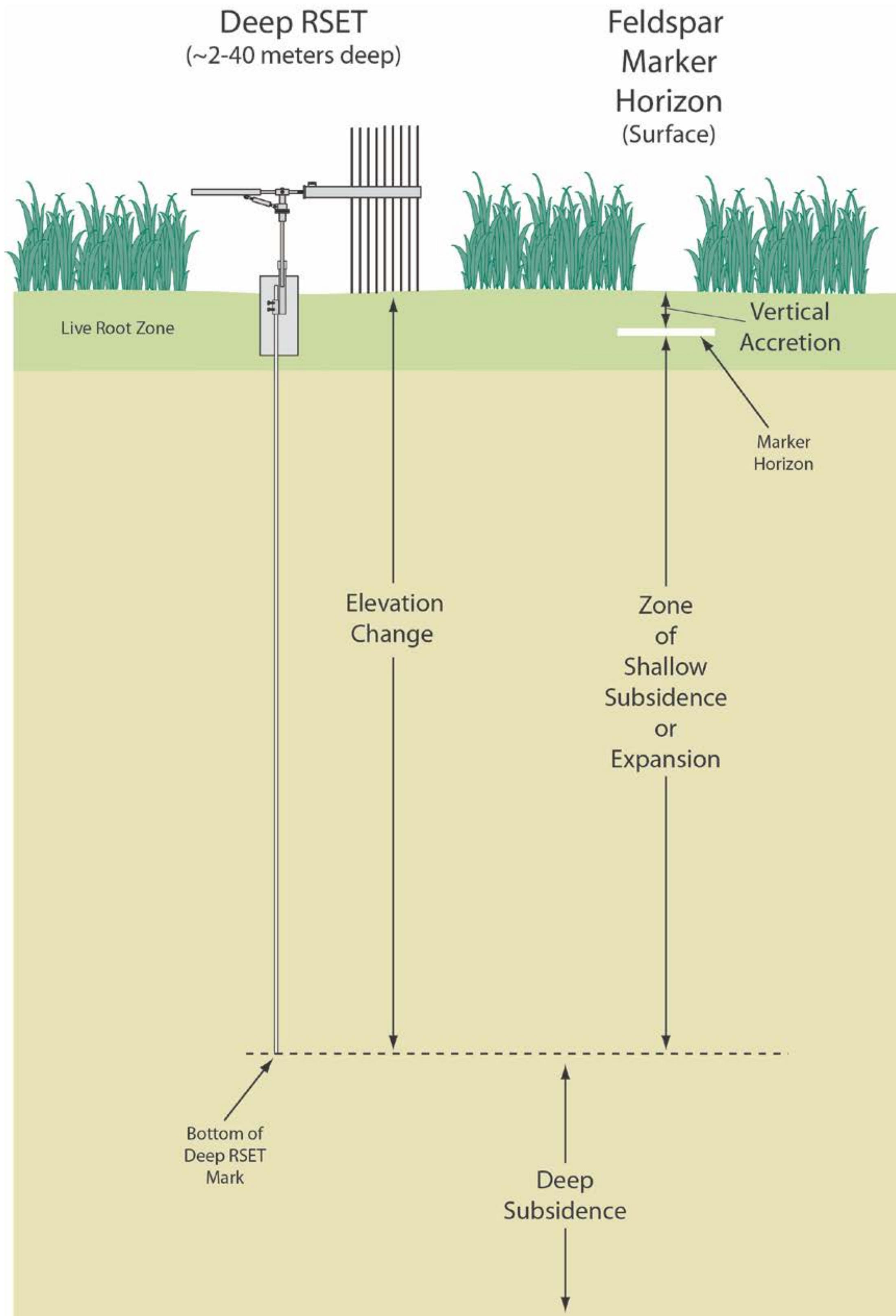


Figure 9. The combined Surface Elevation Table – Marker Horizon technique enables estimates of both above and below-ground process contributions leading to wetland elevation change.

Relating wetland elevation, tidal datums, sea level trends, and wetland elevation trends

In addition to quantifying the processes directly influencing elevation in a wetland (Figure 2B), it is also important to determine the hydrologic processes occurring in the adjacent waters that are likely to affect wetland dynamics. Four pieces of information are needed to evaluate the sustainability of wetland environments in the face of sea level rise:

1. Wetland Elevation: The elevation of the wetland surface (typically with respect to a geodetic datum; Figure 2A).
2. Tidal datums: The elevation of local sea levels (Figure 2C).
3. Sea level rise: long term trends in sea level (Figure 2D).
4. Wetland elevation change: long term trends in wetland surface elevation change (Figure 2B)

<u>Wetland elevation</u>

By knowing the elevation of SET - MH stations and local water levels, the wetland surface elevations (and elevation changes) can be related to tidal datums and associated patterns of inundation. Other vertically sensitive environmental data, such as wetland vegetation plots, groundwater levels, etc., should also be related to these datums to help understand how these processes are related vertically.

There are several vertical datum options available for the typical SET - MH study (Table 1). If only local comparisons are made, local tidal datums can serve as the fundamental vertical datum, and all local heights (e.g. SET and MHstations) can be referenced to them. Leveling is typically the best option to transfer elevations locally.

If comparisons are to be made to datasets outside the local site, then the national orthometric datum, NAVD 88 should generally be used, as it is consistent regionally and is the national standard for heights with respect to gravity (how water flows). NAVD 88 is defined by heights on bench marks, which traditionally were obtained via leveling. If there are no NAVD 88 bench marks close to your field sites, then Global Navigation Satellite System (GNSS) methods and a geoid model are typically used to compute orthometric heights.

If one is interested in the long term vertical stability of a deep RSET mark (deep subsidence, Figure 9), two techniques can be used. One can use orthometric heights derived from leveling, or ellipsoid heights based on long term GNSS techniques and expressed with respect to a global ellipsoid reference frame such as the International Terrestrial Reference Frame (ITRF).

These different datums or reference frames imply different surveying techniques likely are used, each having their own advantages and disadvantages (Table 1). Leveling will provide the highest precision, and is ideal for measuring height differences at the site scale (e.g. leveling among SET marks, leveling to a water level recorder, tidal bench marks, etc.). Different leveling instrumentation and methodologies are available, and some training is required. Overall, leveling can provide excellent results over small areas. Total stations now span from easy-to-use construction-grade precision (9 arc-seconds, relatively inexpensive) to computerized high precision scientific grade (0.5 arc-seconds, very expensive). Modern integrated survey-grade GNSS antenna/receiver units are relatively inexpensive (as low as $2,000) and provide relatively easy access to satellite-based positioning (centimeter error). GNSS campaigns require multiple units deployed simultaneously, increasing cost and logistics. Real-time GNSS can be both complex and expensive. Real Time Kinematic (RTK) requires significant training for successful operation, as well as significant investments in equipment. Real Time Networks (RTN) techniques are cheaper, but require a thorough understanding of how positions are computed and modeled with respect to national or international geodetic reference frames (e.g. NAD 83 (2011) 2010.00, IGS 08, etc.), and a reliance on often unpublished network characteristics.

Table 1. Considerations for obtaining accurate wetland elevations at a study area.

Scale of interest	Method	Datums	Vertical accuracy	Ease of use	Notes
Local site (particular wetland)	Leveling (digital)	Local tidal datums	< 1 mm over short distances (e.g 100 m)	Most labor intensive	Highest precision and accuracy connecting on-site measurement infrastructure; need at least 3 people
	Total station	Local tidal datums	~1 mm over short distances (50 m)	Less labor intensive	Good for local, on-site measurements
Local to regional (single to multiple wetlands)	Leveling (digital)	NAVD 88	< 1 mm over short distances (e.g 100 m)	Most labor intensive	Highest precision; very labor intensive for distances over several km's
	GNSS (RTN or RTK)	NAVD 88, NAD 83	< 10 mm local, 10 cm regional	Complex, requires experience	Better for local than regional
Regional	GNSS (single static)	NAVD 88, NAD 83	20-40 mm	Easy	Easy, cost-effective
	GNSS (multiple static)	NAVD 88, NAD 83	< 20-40 mm	Easy but expensive; complex to analyze	Moderate difficulty, requires some significant investment

Tidal datums

Wetland vegetation communities respond directly to patterns of inundation that are correlated to their height in the tidal frame (Figure 2). Tidal datums, which are the average heights of specific stages of the tide, such as low, mean, or high water levels, provide an easy way to relate wetland communities to inundation, so long as both are expressed on the same reference datum. The more commonly used tidal datums include Mean Sea Level (MSL), Mean Low Water (MLW) and Mean High Water (MHW). Tidal datums published for NOAA's National Water Level Observation Network are referenced to a local network of tidal bench marks, which typically include a vertical reference to NAVD 88 (Figure 10).

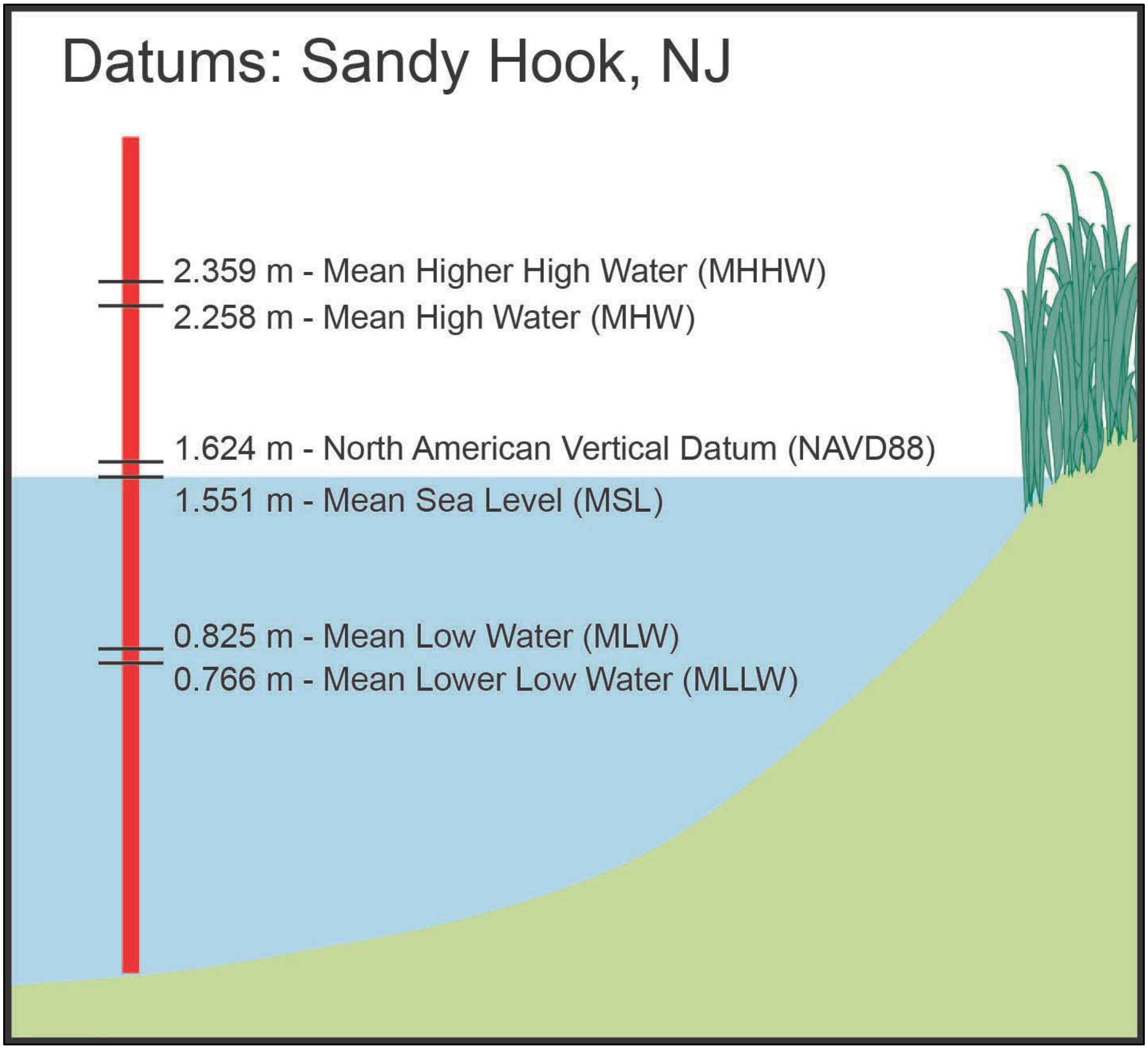


Figure 10. Schematic showing the vertical relationships among tidal datums at a tide station. All values are given with respect to the (arbitrary) local station datum. Note the reference to the orthometric datum, NAVD 88 is also given (source: NOAA Center for Operational Oceanographic Products and Services).

Tidal datums are locally defined. Tidal datums from a nearby permanent tide station are generally not accurately transferrable to a nearby wetland without first monitoring local water levels and using simultaneous datum comparison techniques (see NOAA's Computational Techniques for Tidal Datums Handbook). Although the installation of a temporary tide station and the computations of tidal datums are within the reach of a competent technician, these oceanographic techniques are beyond the scope of this document; the user is urged to refer to reference texts and seek professional guidance.

Unfortunately, the lengthy time interval (18.7 years) encompassed by the National Tidal Datum Epoch (NTDE) means that, in an era of rapid sea level rise, the static tidal datum may not be a very accurate representation of where true mean sea level, or mean high water are today. For this reason, tidal datums should be evaluated over a time period consistent with your elevation data and related to present-day wetland vegetation distribution patterns and responses.

Sea level rise

Sea level trends are generally obtained from published, long term rates derived from tide gauges, such as those available from the National Ocean Service (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml). Although a local water level recorder can be used to transfer tidal datums to a local wetland or other coastal resource (following rigorous procedures), substantial investment is required to obtain long term sea level trends. Generally, time series of greater than 30 years are required for reliable estimates of trends from a tide station. In addition, there are rigorous requirements including sensor accuracy, sensor stability, calibration verification, etc. (Zervas 2009).

Wetland elevation change over time

The elevation of the surface of a wetland will change over different time scales, from daily to seasonal, annual, and even longer cycles, depending on specific physical and biological processes. An SET study will need to address the time scale(s) of interest to make sure they are well sampled. Additionally, an SET study may have either long term monitoring objectives, or may be testing specific short term research hypotheses. Wetland elevation change and elevation trends, as measured by the SET technique, are the main focus of this report. In the succeeding sections, the report will provide an overview of the design and implementation of a SET project. It will also provide guidance for the analysis of SET data to arrive at both incremental change detection and cumulative change trajectories.

Sampling Design

Rationale for Selecting a Sampling Design

The sampling design will specify the locations within a wetland where SET, marker horizon, and elevation measurements will be taken, and how measurements will be taken over time. Proper quantity, selection and distribution of sample stations over space, and sampling events over time will ensure:

1. Conclusions are able to be extended over entire geographic area of interest
2. There is sufficient statistical power to discern real changes
3. Temporal patterns are appropriately characterized

All these aspects to sampling design should be well thought out prior to establishing the sample stations.

The sample space (Figure 11) refers to the population that is the broad target of interest. In the case of a coastal park, the sample space might be the entire park, all wetlands in the park or a subset of wetland types found within the park. The sample site is a smaller, independent habitat unit within the sample space. This might be an individual marsh within a coastal refuge or park. Finally, the sample station is where SET and MH measurements are made.

For the purposes of sampling design, SET studies can be divided into two types: sampling for monitoring and sampling for hypothesis testing. Sampling for monitoring will generally involve sample stations that are dispersed throughout the area of interest (sample space), to ensure representation. Sample stations might also be installed in critical areas to provide an early warning of change. Hypothesis testing would involve the investigation of specific factors that affect the elevation change (e.g. restored vs. natural marsh, sediment-amended vs. sediment-restricted marshes, etc.). Hypothesis testing focuses on specific factors of interest, and may attempt to exclude other, non-targeted factors. This often leads to clustering sample stations within a wetland or within a specific wetland habitat to reduce unwanted variability. Although we make the distinction between sampling designs for monitoring and those for hypothesis testing, it is important to note that these two approaches are never mutually exclusive. A hypothesis testing design can also inform long term monitoring, even if its design is not ideally suited for it. Similarly, a long term monitoring effort can also be used to test certain hypotheses.

For hypothesis testing, at least three sample stations are required as replicate samples for each fixed factor level (sample size = 3). For example, if there are two treatment factors or levels (e.g. fertilized vs. unfertilized), a minimum of six sample stations would be required (three per treatment). A second factor with two levels (e.g. salinity: high and low) would double the sample size requirement. This is an absolute minimum: larger sample sizes greatly increase the power of an analysis, meaning that the ability to discern real differences among the experimental factors and treatments generally increases rapidly over very small sample sizes. Researchers testing hypotheses should run power analyses to determine sample size, keeping in mind that the experimental unit is the sample station, and that the measurement error at the station level is on the millimeter order of magnitude.

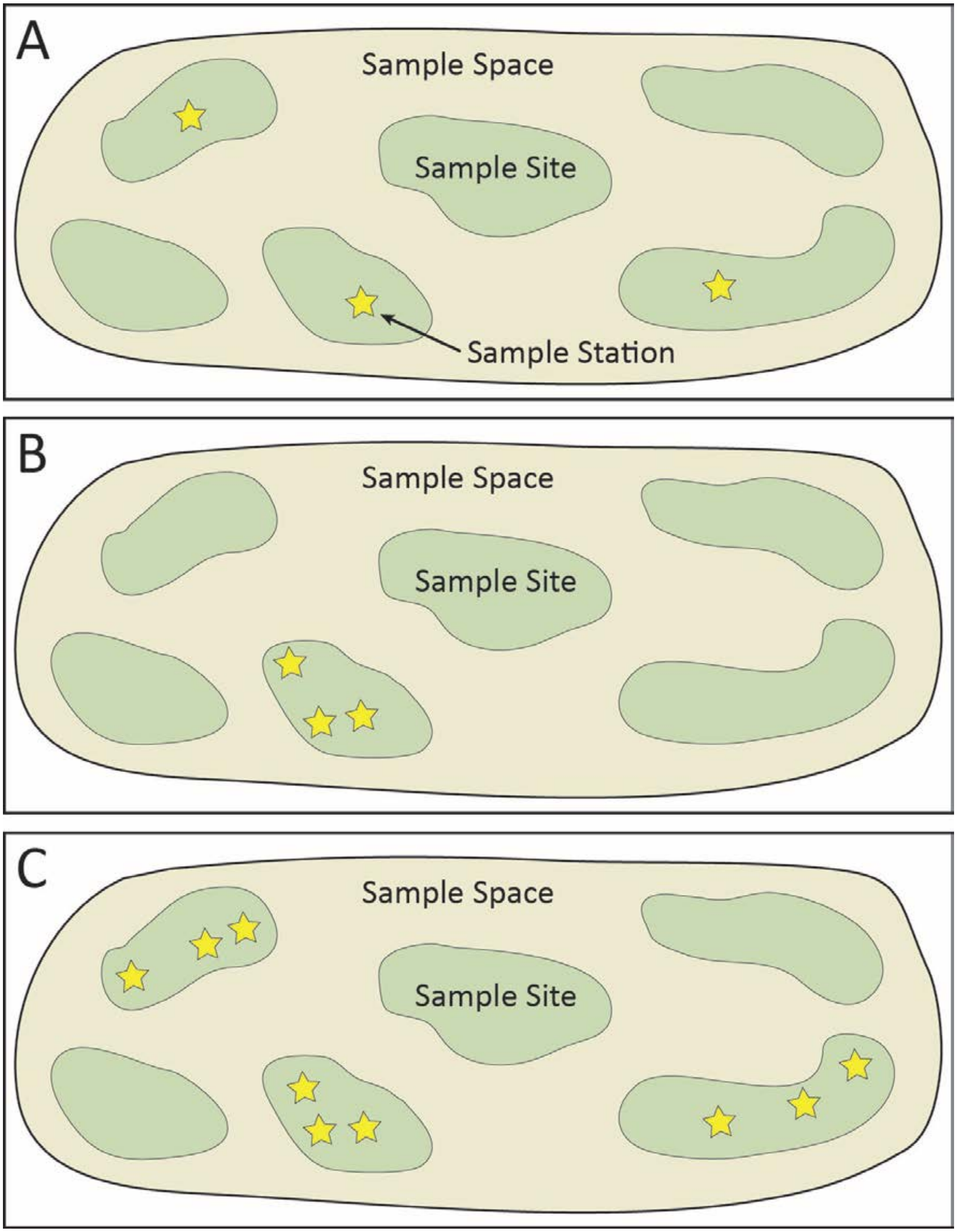


Figure 11. Conceptual diagram showing distinctions among sample space (tan), sample sites (green) and sample stations (yellow stars). In panel (A), three sample sites are randomly selected from the population of all possible sites within the sample space, and one sample station is established at random within each chosen sample site. In panel (B), one sample site is chosen within the sample space, and three replicate sample stations are randomly assigned within the site. Panel (C) presents a sample design that combines the designs of panels A and B thereby providing replication both across and within sample sites.

Most SET – MH studies will have small sample sizes due to the following constraints:

- Installation: the high cost of labor and materials in establishing SET – MH sample stations.
- Sampling: recurring logistic and financial constraints involved with getting to each SET – MH station and performing all the necessary measurements.

A small sample size means that the spatial distribution of sample stations is critical.

Spatial Distribution

Spatial distribution of sample stations can theoretically take several main strategies:

1. replication across the larger sample space (e.g., multiple wetlands; Figure 11 panel A), but no within-wetland replication;
2. geographic restriction, with replication within a wetland habitat (Figure 11 panel B).
3. a combination of 2 and 3, replication across and within wetland sites (Figure 11 panel C).

The choice among these strategies may depend on the specific purpose of the study. For monitoring, the interest may be in distributing sample stations across a large extent of coastal habitat. Replication here might be on the level of discrete wetlands (e.g., one sample station per wetland, Figure 11 panel B). Hypothesis testing is typically more specific in addressing a particular question of interest (is wetland A different from wetland B; does fertilization or burning of the surface significantly alter elevation trajectories, etc.). To address these questions, one may want replicate sample stations within a given wetland to reduce the confounding effects associated with non-target variables (e.g. different species, different locations upstream/downstream, different sediment source; Figure 11, panel C).

Table 2 presents three sample design scenarios, including the nature of constraints involved, the requirement of prior wetland habitat knowledge, the spatial coverage, and the kinds of data and analyses supported.

Table 2. Three general scenarios for distributing sample stations within a sample space.

Sample Design	Use	Financial Constraints	Logistic Constraints	Spatial Coverage	Spatial inference	Outcome	Data
A) Multiple sample stations randomly distributed throughout sample space	Monitoring Sample size ≥ 3	High	High	High	Moderate	Spatial monitoring & trends	High spatial coverage; Low site-specific knowledge; Best variance estimate for sample space; No site variance
B) One sample site chose in sample space; multiple sample stations distributed within the site	Hypothesis testing Sample size ≥ 3 per site	High	Moderate	Moderate	Moderate	Hypothesis testing	Moderate spatial coverage; High site-specific knowledge; Some variance estimate for sample space; Best estimate of variance for one site
C) Multiple sample stations randomly distributed within multiple sample sites	Hypothesis testing and monitoring Sample size ≥ 3 per site	High	High	High	High	Spatial monitoring, trends & hypothesis testing	High spatial coverage; High site-specific knowledge; Best variance estimate for sample space; Best estimate of variance for sites

Spatial distribution for monitoring

The precise objectives of a monitoring program need to be made very clear, as they will influence both the number of replicate sample stations as well as their location. If the goal is to monitor a large coastal wetland area, sample stations will be distributed throughout the environment so that the data are representative of the larger area of interest. Note that the SET sample station covers a very small area, and the inferences from a station are limited to the vicinity of that station.

Sample stations need to be representative of the target habitat: random sampling is a traditional approach to ensure unbiased representation. There are many ways of generating a random sample, from low-tech gridding on a map to more sophisticated techniques in Geographic Information System (GIS) software using specialized sampling tools. At the heart of most random sampling techniques is the concept of parcel or grid size (e.g. 100 m^2). With random sampling, all parcels or grids will have the same likelihood of being included in the sample. This also means that the sample will theoretically reflect the different proportions of habitats in the sample space. However, this is not guaranteed, especially with very small sample sizes. As shown in Figure 12, random sampling can easily lead to plots representing different habitats. If the goal is to monitor the dominant mid-marsh habitat, a better sampling scheme might include restricting the sample space to the mid-marsh, and then randomly sampling from that space. This is, in essence, representative sampling (Underwood 1997).

To clump or not to clump?

By grouping sample stations, within-wetland variability can be modeled and tested, at the cost of spatial extent and distribution. Spatial distribution needs to balance the need for spatial extent/representation versus statistical comparisons.

Transects

Sample stations are often established using the concept of random transects, with random locations along each transect. Although this technique incorporates some elements of random sampling, it does not necessarily ensure equal probability of station selection as would occur with gridding (a requirement of pure random sampling).

Another consideration is dispersion: if the goal is monitoring a broad area with a small sample size, it may be ideal to have the sample stations distributed widely. A purely random sample can, by chance, lead to stations being selected adjacent to each other. Stratified random sampling is a way to ensure broad dispersion, where a sample site is divided into sub-areas within which one or more sample stations will be located. Random or representative sampling can then be applied within each sub-area, ensuring broad dispersion throughout the target area.

Note that the upper right-hand station in Figure 12 may have logistic problems, given how far it is from the access point along the stream. Logistic constraints may also be considered to limit the population of potential stations prior to applying a randomization scheme. Potential sample stations might also be restricted to ensure they are out of public view and/or less likely to be vandalized. However, restrictions need to be used with care to avoid introducing biases in the study.

Figure 12. Example of three randomly selected sample station locations. Marsh area (sample site) was gridded, numbered (not shown), and sampled once at random with a random number generator. The left-most station appears to represent mid-marsh, the middle station is creek-side, and the right station is in transition into an upland area.

<u>Monitoring example:</u> National Park Service, Assateague Island National Seashore, Berlin, MD USA.

Problem: NPS managers at Assateague need information on the salt marsh habitats within the park boundaries.

Solution/Design: It was decided to install 16 SET sample stations at four marsh sites along the bay side of Assateague Island to provide long term records of wetland elevation change. This is a monitoring design similar to Figure 11C, but with replication among multiple sample sites (multiple sample sites with replicate sample stations within each site). Four wetland sites were randomly selected from nine marshes already being sampled for vegetation change (Figure 13). Within each site, 4 SET sample stations were randomly located within the dominant habitat (*Spartina alterniflora, Spartina patens, Distichlis spicata*). Each sample station is composed of an SET and 3 marker horizon plots. Vegetation data is collected in the same site separately from the SET sampling. An example of the resulting accretion and elevation change data is presented in Figure 14.

Figure 13. Map showing locations of 9 randomly selected wetland sites used for long term vegetation monitoring. Four of these sites were randomly selected for the installation of SETs.

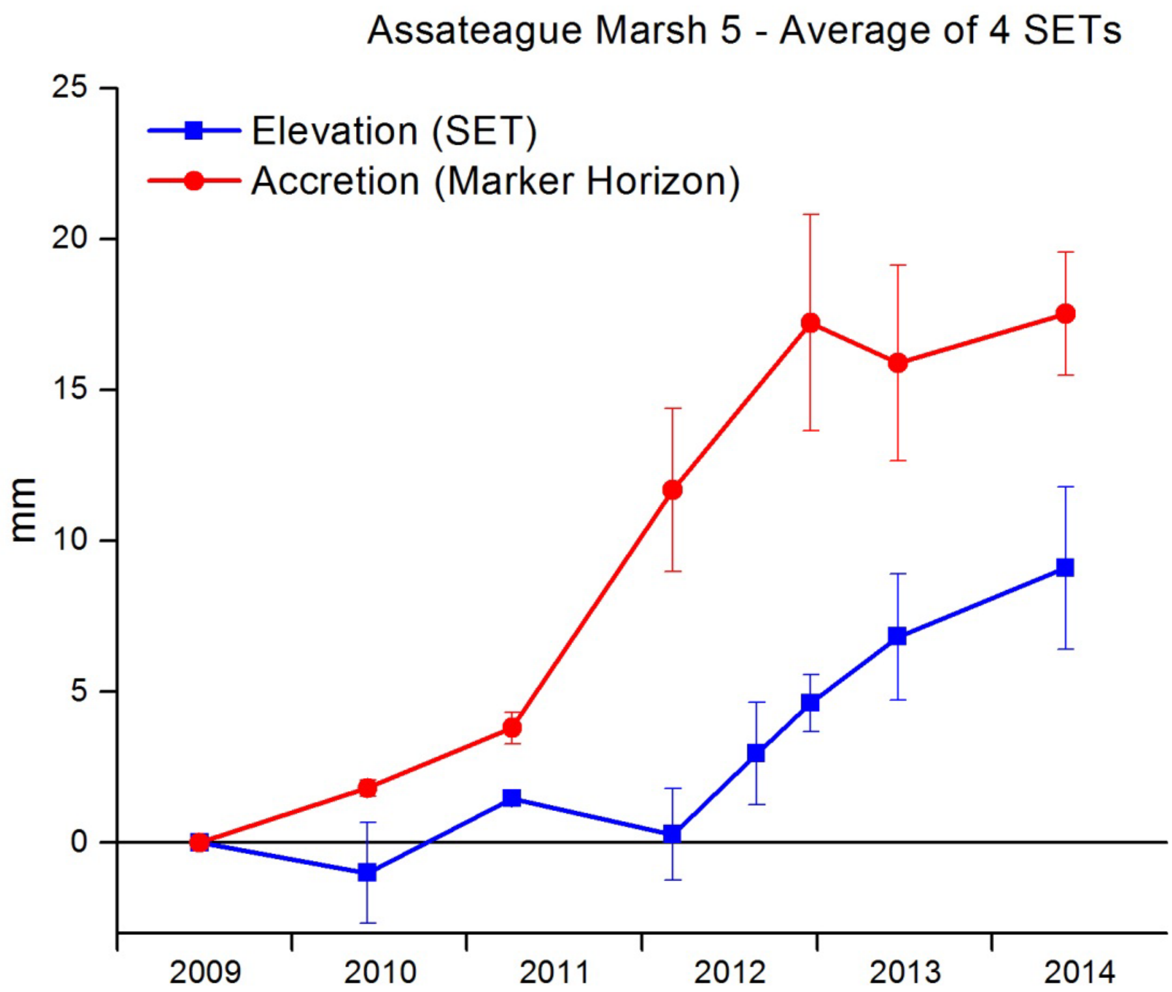


Figure 14. Example showing vertical accretion and elevation change trends from one of four wetland sample sites located at Assateague Island National Seashore.

Spatial distribution for hypothesis testing / impact analysis

The basic experimental unit is the SET-MH sample station, which means that if there are three sample stations in a wetland or habitat of interest, there are three replicates and the sample size is three. Although many individual pin measurements of elevation change are made around the SET mark (e.g. usually 36), they are all measuring the one station and are therefore considered *pseudoreplicates* or not true replicates (Hurlbert 1984).

The selection of sample station locations for a hypothesis-driven experimental design is complicated by the typically very small sample sizes involved with SET studies (see above). Small sample sizes chosen purely at random can wind up doing a poor job of characterizing the targeted habitat. In addition, non-target factors (e.g. vegetation type, wetland elevation, and distance from tidal channel) are more likely to influence data collected from a small sample than from a large sample, where the effect of multiple levels of these factors would be averaged over. Additionally, variables can be more easily confounded when there is little replication. Restricted randomized and representative sampling (see example in section above) may help exclude some of these factors, reducing the underlying variability among sample stations. Small sample sizes often suffer from low power (the ability to distinguish real differences) due to the influence of these unexplained, underlying variables. Restricted randomization helps increase power by removing these variables from the equation. However, too much restriction can severely reduce the scope of the research questions being addressed. Another approach to dealing with the influence of non-target factors or variables is to measure them, instead of excluding them. In this way, the variables can be included in the statistical analysis and explained by the data. This is the role of *covariates*.

Statistical analyses typically require independent samples to guard against correlation. If there is correlation among the observations, the variance estimate will be artificially low and the degrees of freedom used in the statistical analysis will be larger than warranted. The result may be a Type I error, leading to claims of significant differences where they do not necessarily exist. Although unlikely, purely random sampling can actually result in correlation if two sample stations happen to be chosen close together. Ideally, the chosen grid size within the randomization scheme is large enough such that adjacent grid centers are far enough apart to limit correlation.

Example: Confounding Variables

A hypothesis compares the elevation response of two wetland vegetation communities to a storm event (vegetation community "A" vs. vegetation community "B"). The two communities chosen in the sample are situated in two different marshes: one is in an impoundment, the other has unrestricted hydrology. The SET data will therefore be reflective not only of the different vegetation communities, but also – and likely to a greater extent – of the different hydrology. In other words, the vegetation community and hydrology will be confounded, and the statistical analysis will not be able to separate these two effects. If there is a statistically significant difference between the elevation responses of A compared to B, you will not know if this is due to the hydrology effect or the vegetation community effect, or both.

Solution:

Select samples such that both vegetation communities (A and B) are sampled within the same marsh. If only one marsh has both vegetation communities, then replicate samplestations will be chosen within both vegetation communities within that one marsh. This unfortunately will limit inferences to this marsh. A better scenario would be to sample several marshes; there would be no requirement to have replicate sample stations within each marsh, if the marshes themselves are replicated in the environment (this would be a "blocked" design, with the block being the marsh).

Tips for maximizing power:

- Replicate as much as possible within habitats or treatments, each with n≥3 sample stations, to create as large a sample size as possible.
- Restrict sample space to a specific habitat type, plant community, etc.
- Ensure all experimental factors and levels (i.e. "treatments") are sampled at least once within the same wetland (if only one sample of each factor and level per wetland, then replicate wetlands are required).
- Ensure that a wide range of responses can be sampled.
- Measure important covariates.

The SET mark as the experimental unit does not mean that a SET instrument samples a uniform area. Indeed, the length of the horizontal arm (about 65 cm for the RSET) can result in different habitats being included within a station. For example, one side of the station may be in a mudflat, whereas the other side is vegetated. Even within a SET arm position, some of the nine pins may land on vegetated hummocks (clumps), whereas other pins may land in the sediment between clumps. These different conditions may result in very different elevation change trajectories occurring within a given sample station. If this variability is not explained, it may reduce the power of the analysis. A corrective strategy would be to include covariates within the pin observations (e.g. is the pin on vegetation or not), or consider the station as a blocking effect (mudflat vs. marsh).

Some researchers have developed customized SET instruments which are much longer than normal: this enhances the ability of the SET instrument to encompass and measure different treatment effects (Langley et al. 2009; Figure 15). Note that these adaptations result in more complex sampling designs, such as split-plot designs.

Hypothesis testing example: Gateway National Recreation Area, New York, NY USA

Problem/Questions: Jamaica Bay is part of the NPS Gateway National Recreation Area in New York and New Jersey (Figure 16). Salt marshes in Jamaica Bay have been decreasing in area and many are in poor condition. Big Egg Marsh is one such area. Big Egg Marsh appears to be very low in elevation and stressed due to frequent inundation and erosion.

Solution: It is hypothesized that increasing the elevation of the marsh surface would benefit the marsh. A pilot study was conducted at Big Egg Marsh to add sediment to the marsh surface dredged from an adjacent channel. The goal was to add approximately 45 cm of material to the treatment marsh area.

Figure 15. The Smithsonian Institution's "Monster SET" in operation. The RSET instrument, with a 4 meter long arm incorporating 100 pins, is able to cross both treatment (CO_2 enclosure = PVC structure) and control areas outside the treatment enclosure (Smithsonian Environmental Research Center, MD, USA).

Design: Prior to dredging, 6 SET sample stations (SET + Marker Horizons) were established in Big Egg Marsh (Figure 17). Three were installed in the area to be sprayed and three in a control area across the channel. All six plots where restricted to areas dominated by *Spartina alterniflora*, the dominant vegetation in these marshes. The sample stations were also restricted to the interiors of the marshes, excluding both the marsh edge and the upland transition zone. The SETs were installed in the summer of 2002. Dredging occurred in the fall of 2003. Sites were initially sampled multiple times per year (3 to 4) and are currently sampled twice a year (Figure 18).

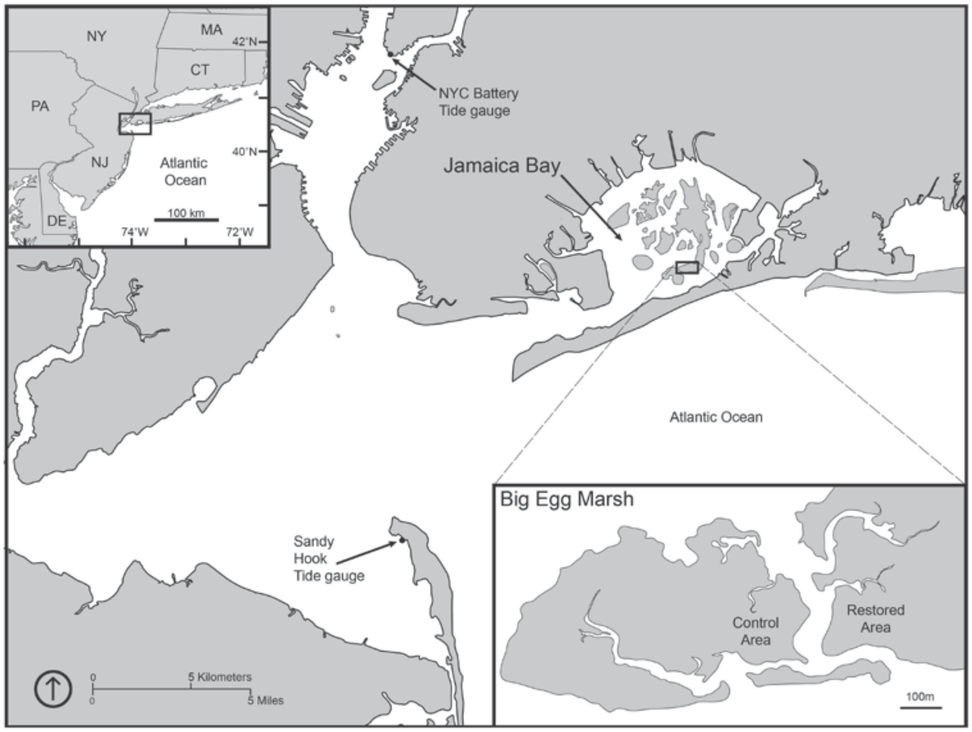


Figure 16. Map showing Big Egg Marsh.

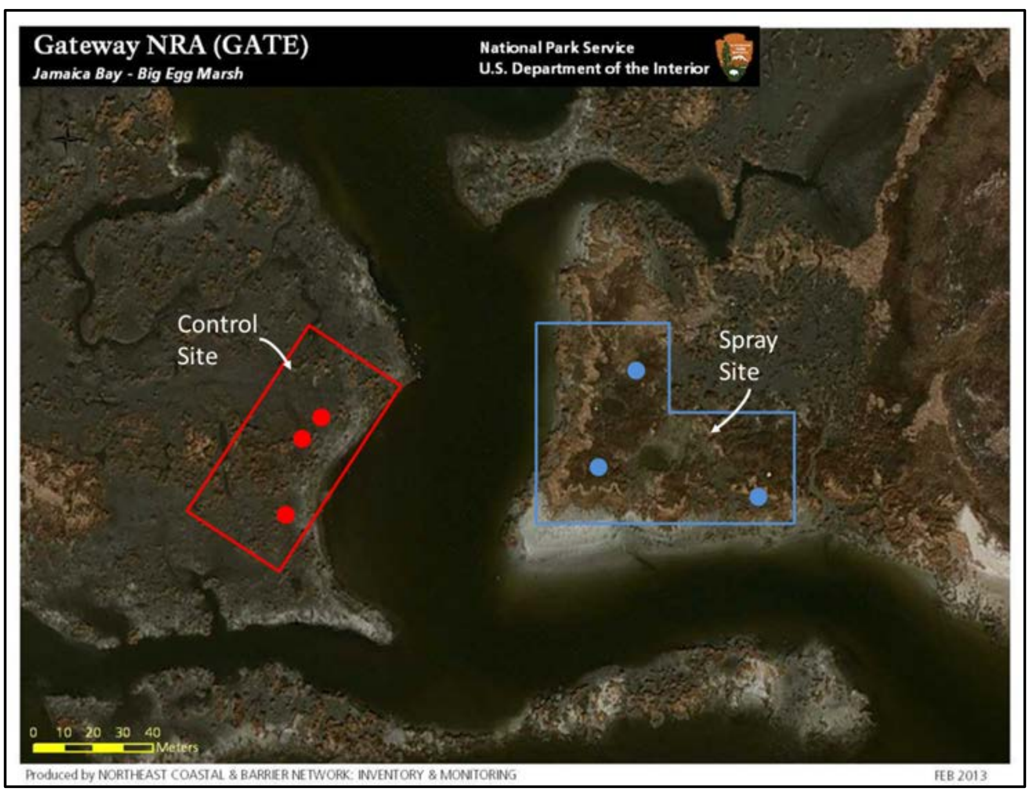
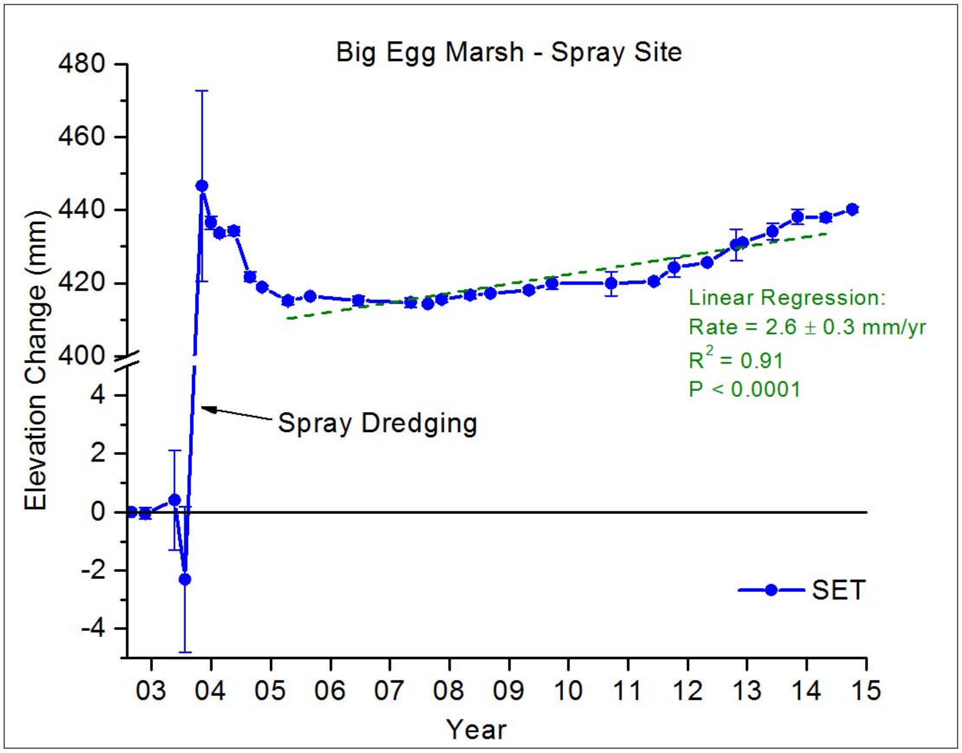


Figure 17. An aerial image showing Big Egg Marsh (sample space) with sample sites (red and blue rectangles) and sample station locations (solid circles).



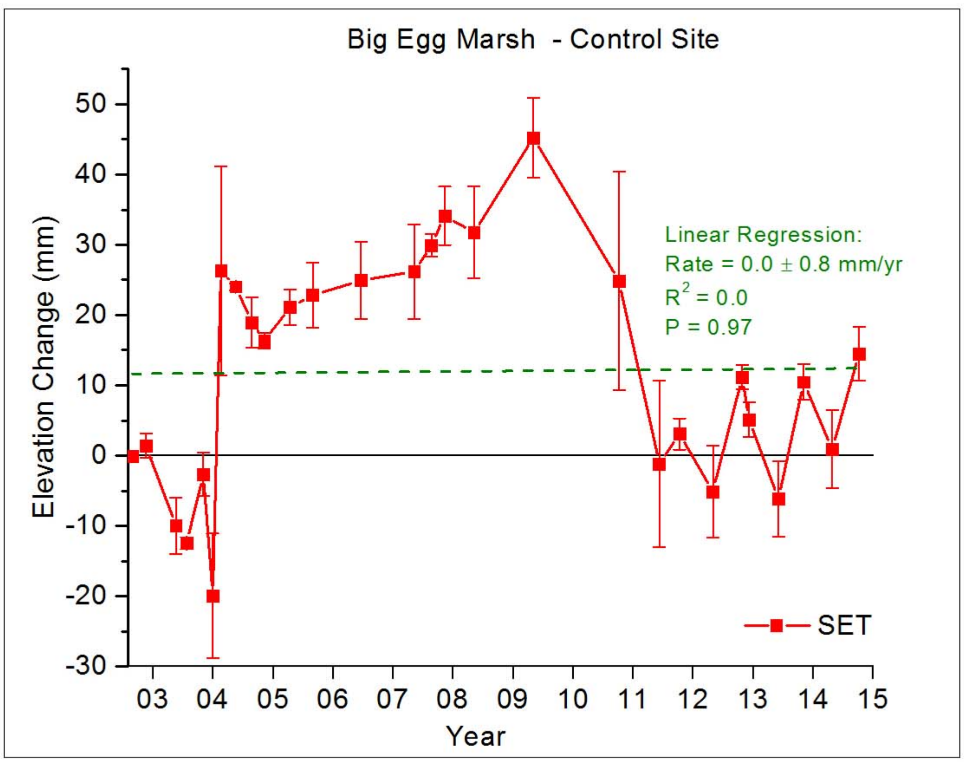


Figure 18. Elevation trends as measured by the SET method at Big Egg Marsh. Linear trends for the restored site cover a subset of the entire record (2005 – present) whereas trends for the control site cover the entire record (2002- present).

Sampling Over Time

The strength of the SET technique is that the same patch of wetland surface is re-measured over time. This means that SET data are always a time series. A typical use of SET data is to estimate a linear trend over the entire data series, answering the question: what is the rate of wetland surface elevation change? This is a typical monitoring objective. However, one may also be interested in comparing change during different periods of time. This is especially the case in locations with pronounced seasonality, or where there has been a "before impact" period followed by an "after impact" period. The decision of whether to analyze overall cumulative trends or separate (or recurring) time periods will affect the degree to which the sampling over time needs to follow a rigorous schedule. One may consider a flexible, adaptive approach to sampling over time to help understand key processes.

Cumulative trends (all data)

When SETs are used for monitoring, it is most common to compute an overall linear trend through the entire data series or sections of it (Figures 18, 19). Hypothesis testing can also rely on long term cumulative data. The ideal situation for cumulative data analysis is to have numerous observations distributed across the entire time series. The user should also consider spacing observations consistently through time (at least on a yearly basis). When there is a comparatively long gap between start and end of a time series dataset, this may lead to a Type I error because the ends of the observation period will be overly influential in determining the slope of the linear regression, which will have an inflated R^2 and smaller than expected P-value. However, this should never discourage a user from continuing to take observations, even if a substantial amount of time has passed. New insights into elevation dynamics can always be gained by obtaining new data even a number of years after the initial study was completed.

Seasonal Signals

If there are strong seasonal signals (e .g. weather, riverine discharge) reduce variability in the data by sampling consistently within the same season each year.

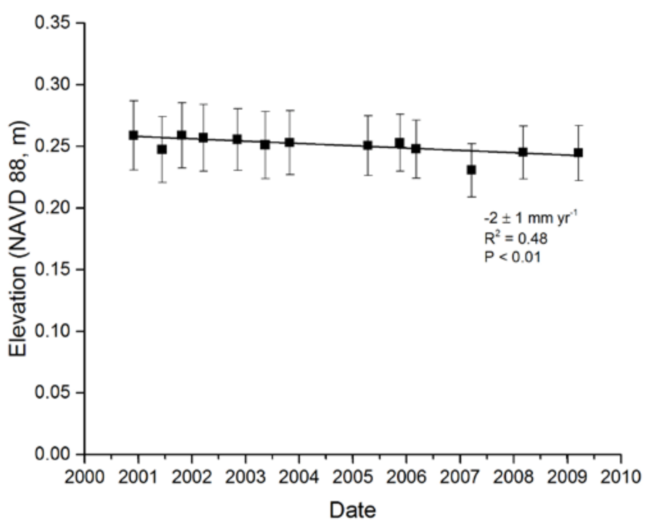


Figure 19. Example of an eight-year time series of SET data showing a computed simple linear regression to determine the slope (linear change in elevation rate over time).

Time period comparisons (splitting data per period)

An analysis of incremental change data (change from one sampling event to another) is typically used when testing for seasonal or other time-dependent effects. The temporal spacing of sampling events is very important in such situations (e.g. Whelan et al. 2005). If some intervals are larger than others (e.g. growing season >> dormant season), the longer intervals may record a larger signal than would be expected from shorter intervals. In addition, the results could be biased with the differential effect of time being confounded with the effect of season. For example, this could be the case if only one year of pre-impact change is recorded, but three years of post-impact are monitored. The post-impact interval will have had more time to estimate the elevation trajectory, which might also lead to a difference in variance (which can cause problems in a statistical analysis). Therefore, with incremental data, one needs to pay careful attention to the timing of sampling, and possibly correcting the data for unequal sampling intervals.

Example of incremental data analysis: Shark River, Florida (Whelan et al. 2005)

In this study, three groups of three samplestations were deployed in a mangrove forest along the Shark River, Florida (Figure 20). Within each group there were three SET marks: one deep RSET mark, one traditional pipe SET mark, and one shallow RSET mark (Cahoon et al. 2002a, b). Each SET mark was inserted to a different depth in the soil. The study investigated the relationships between the depth over which vertical change was measured and changes in groundwater level or river stage. The SET data were collected regularly, once a month over the span of one year: daily elevation rates (averaged monthly) were compared to daily groundwater levels or river stage (also averaged monthly; Figure 21). For this analysis, it was critical to express all measured variables at the same frequency.

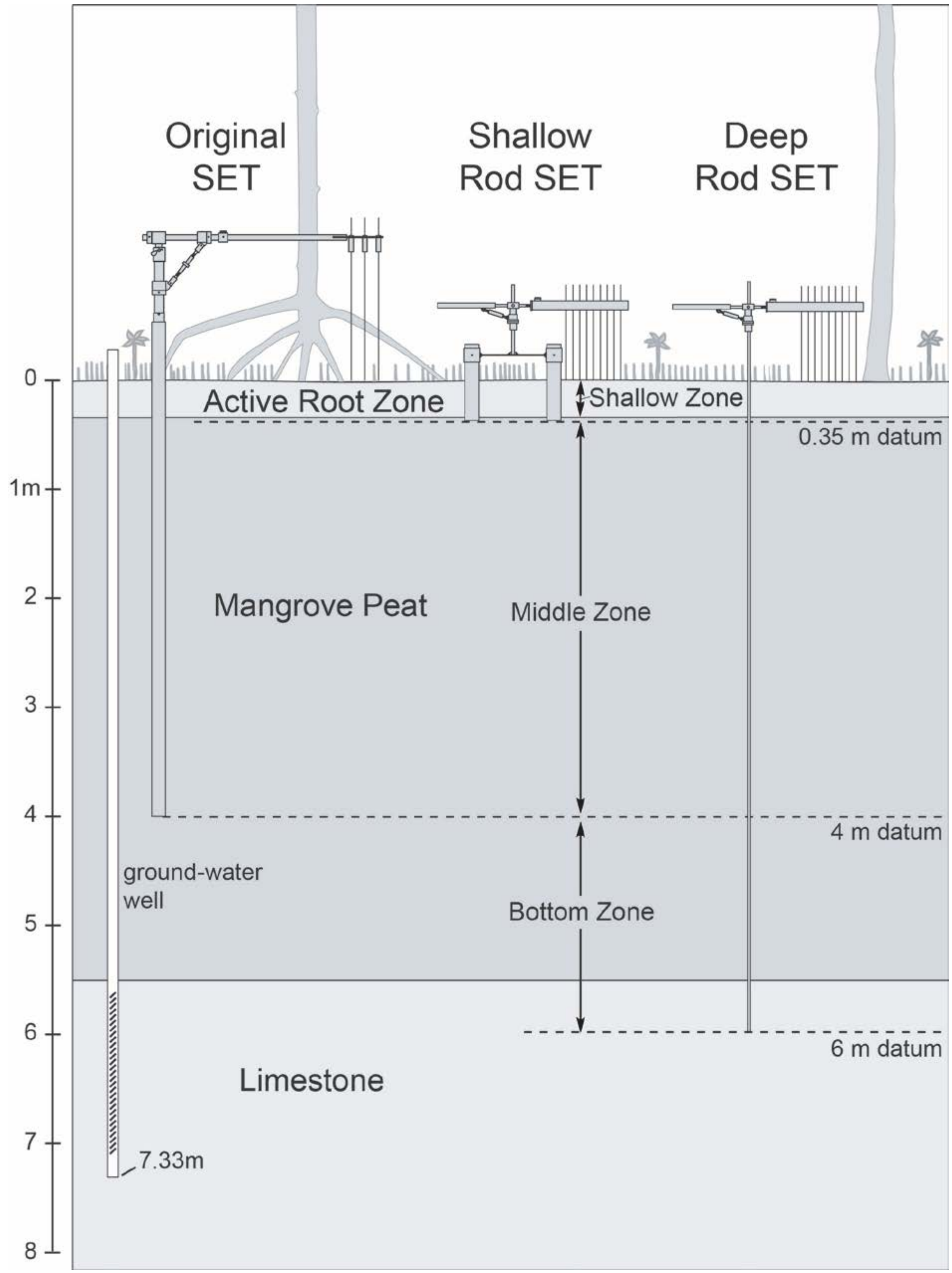


Figure 20. Conceptual diagram showing the three types of SET marks installed to partition vertically soil processes occurring in a mangrove forest.

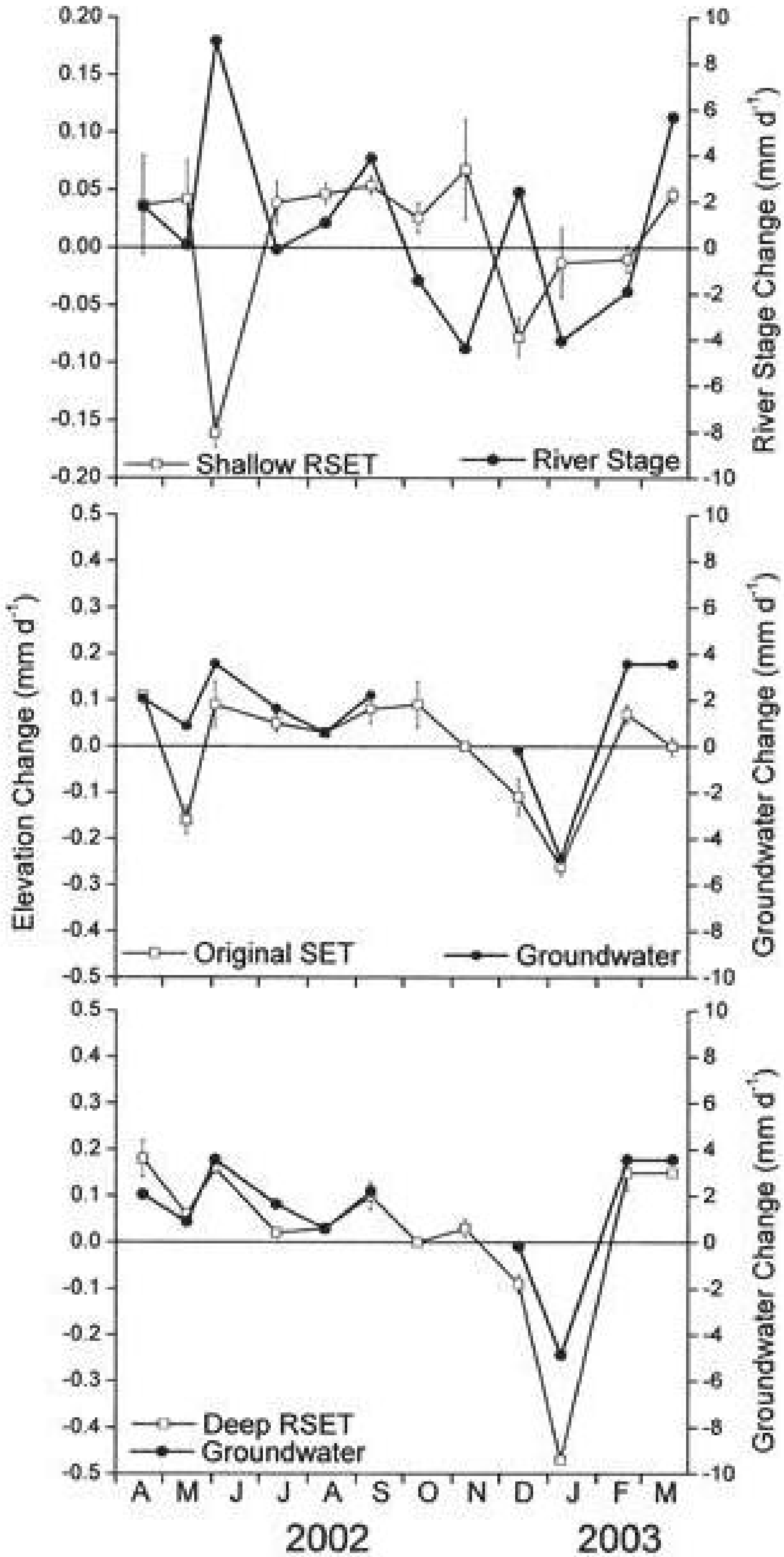


Figure 21. Example of data analysis based on incremental rates of elevation change measured by the SET method. Data expressed as incremental change rates (mm d^{-1}) and compared to groundwater level or river stage (Whelan et al. 2005).

Comparing SET Data With Other Data Sets

SET data can be combined and compared with other data, such as marker horizon data, or even other SET data, to create new variables. These comparisons should be made at the sample station level whenever possible. For example, comparing the average depth of the feldspar marker horizon to the corresponding cumulative elevation change at the sample station level will provide an estimate of shallow subsidence (Cahoon et al. 1995):

Shallow Subsidence (mm yr^{-1}) = Accretion rate (mm yr^{-1}) – elevation change rate (mm yr^{-1})

Accretion rates are obtained from marker horizon data, and elevation change rates from SET data, both averaged to the sample station. Note that rates have to be computed over the same time intervals to match.

Similarly, as shown in Figure 20, different SET marks can be used to partition soil processes among the different sediment layers in the soil profile. In that example (Whelan et al. 2005), the following rates can be derived:

1. Elevation change rate across the entire mangrove peat layer (6 m)
   Rod SET rate (e.g. mm yr^{-1})
2. Elevation change across the top 4 m of mangrove peat
   Original SET rate (e.g. mm yr^{-1})
3. Elevation change over the root zone depth (0.35 m – shallow zone)
   Shallow SET rate (e.g. mm yr^{-1})
4. Elevation change of mangrove peat below the root zone (0.35 m – 6 m – middle zone)
   Rod SET rate – Shallow SET rate
5. Elevation change of deep mangrove peat (4 m – 6 m – bottom zone)
   Original SET rate – Rod SET rate

Time to Stability

How long a data record is needed to calculate a meaningful elevation trend? As of this writing, there are no published reports definitively addressing this point. Nevertheless, analysis of unpublished data suggests that less than three years is too short of a time period to place much confidence in linear elevation trends. This is especially the case when observations are only taken once a year. Most data sets analyzed show an initial period of rate instability (note size of error bars in Figure 22). After several years, however, rates and rate errors tend to stabilize and approach a consistent average – except in the case of large storm impacts, major flooding events, and other important changes in the environment. Increasing the sampling frequency will not decrease the time to stability, although it may provide the user with better information on short term variability. Due to the episodic nature of impact events, and the short term variability of SET observations, an SET study should be designed with the expectation that measurements will be taken over a number of years (e.g. at least 5 years or more).

SOP #1 provides specific guidance on designing an SET project, including spatial and temporal data distributions, and their ramifications in data analyses.

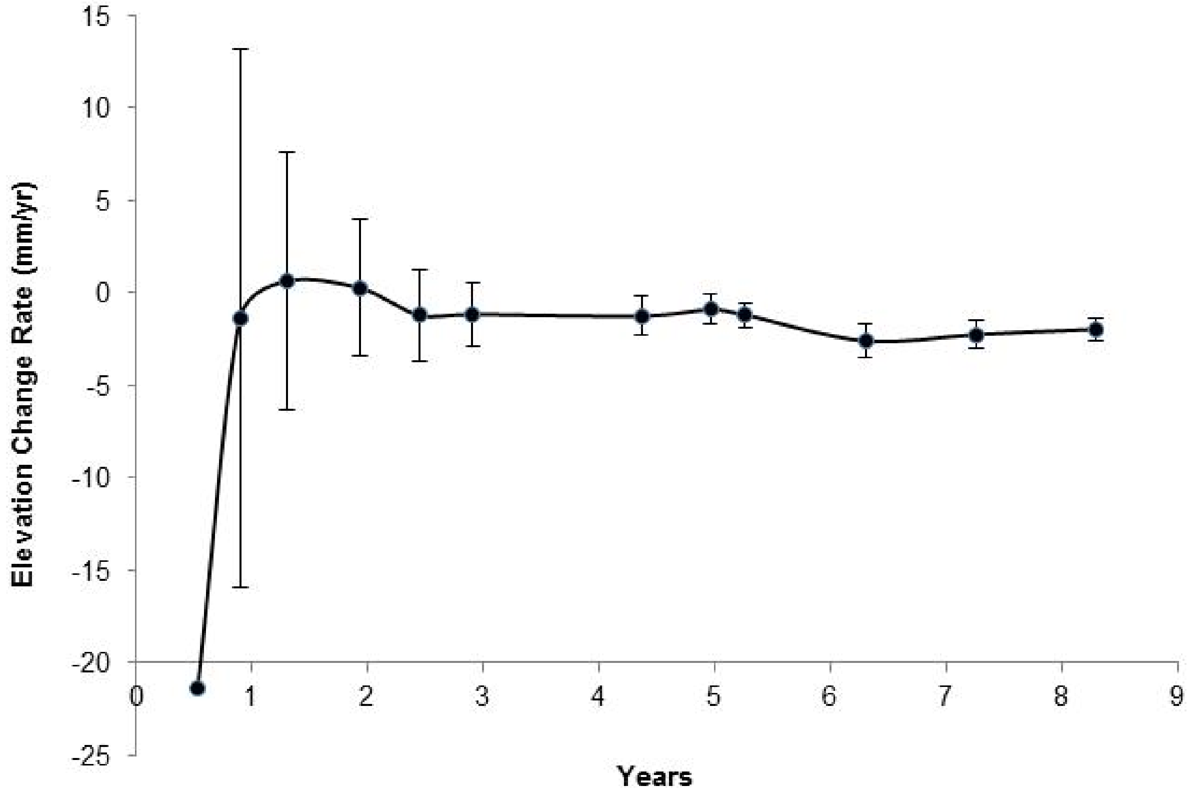


Figure 22. Linear elevation change rates may show an initial period of high variability (note large error bars); in this eight-year study of elevation change in a brackish Chesapeake Bay wetland (Maryland), long term elevation change rates appear to have stabilized after about three years (unpublished data).

Field Methods

Installation of SET Marks and Marker Horizons:

After determining the specific design for your project, a permanent SET mark will be installed at each sample station. Installation normally involves a minimum of three people. All installation and subsequent sampling activities should take place on a platform installed above the wetland surface to minimize disturbance of the sediments around the SET mark (Figure 23). A sampling platform can be either temporary or permanent. Refer to SOP #2 for additional information on platform design. SOP #3 provides details on equipment and supplies needed for installing SET marks. It also provides sample datasheets which can be used to record pertinent information from a new installation.

Figure 23. Installing a deep RSET mark in a Chesapeake Bay brackish marsh. In this example, a portable gasoline powered jackhammer is being used to drive rods. Note the permanent sampling platform installed to minimize human disturbance of the marsh surface where the readings will be taken. A removable, portable platform could also be used (Chesapeake Bay Environmental Center, MD, USA).

This protocol focuses on the deep RSET mark, the most widely used mark, which is based on the design of deep rod survey marks (Floyd 1978). These marks consist of 1.2 m (4 foot) sections of 15 mm (9/16th inch) diameter, stainless steel rod which are threaded together and driven to substantial resistance or refusal within the sediment (Figure 23). Depending on the underlying substrate and what equipment is used to drive the rods into the ground (jack hammers, or demolition hammers), the SET mark could use anywhere from one to 40 meters of steel rod anchoring it to the substrate. Note that we cannot presume to know the actual depth of the RSET mark itself due to the possibility of the rods bending beneath the substrate. In coastal salt marshes of the eastern U.S., 10 – 30 m of rod is commonly used in a SET mark installation. Following rod installation, the remaining rod section is cut at the sediment surface and is encased in a 60 cm to 120 cm (two to four foot) long, 15 cm (six-inch) diameter PVC pipe. A custom built SET receiver is bolted on to the upper rod section, and the entire PVC tube is filled with concrete (Figure 24). After installation, SET marks should be allowed to settle for a few weeks (if possible) before the first measurements are taken.

If accretion measurements are being taken, marker horizons are established at the time of the first SET readings (i.e., time zero). Refer to SOP #5 for detailed instructions on installing marker horizons. Typically, 3 marker horizon plots are established from the platform in the immediate vicinity of the SET mark. Many materials can be used for marker horizons, but feldspar clay is the most commonly used. The marker horizon material is evenly sprinkled on the surface of the wetland within the MH plot, upon which sediments naturally settle and accrete.

Figure 24. Deep RSET mark. The RSET instrument attaches to this mark via the threaded receiver. The grey cap is for protecting the mark when the instrument is not attached. The brass disc is for site identification and is NOT used for surveying.

Sampling Methods

Field preparation and equipment

Below is a list of the items normally needed for each sampling trip.

1. The SET instrument – The instrument is kept in a carrying case and brought to the site for each sampling session. Always use the same instrument for each measurement in order to minimize error or bias from multiple instruments. The instrument includes pins and a

mechanism to restrain pins on the arm or table. A millimeter-scale ruler with true zero point is used to measure the height of each pin above the arm or table.

2. Coring device – examples include cryogenic coring system, knife, soil corer, etc.
3. Portable sampling platform – necessary if a permanent platform is not established at the sample station.
4. Weatherproof data book or data sheets and pencils or permanent pens for recording data; a field map and/or GPS unit for locating the sample station.

Refer to SOP #4 and SOP #5 for detailed instructions on sampling with the SET instrument and marker horizons.

Sampling schedule

There are numerous factors to consider when establishing your sampling schedule, including sampling frequency, funding, weather, and tides. Try to keep a consistent schedule over time to avoid unwanted noise in the data and to avoid large gaps in data collection because these can disproportionately influence the rate calculations. Any hypothesis testing for differences over time (such as investigating seasonal dynamics) should dictate the specific sampling schedule.

Number of sampling trips per year - This is a very important consideration and may change over time. Keep in mind that SET's are used for the long term monitoring of wetland elevation, so your ability to sample them may change over time. In general, the SET-MH stations are sampled one to four times per year. Initially, try to sample two or more times per year for the first 3 or 4 years. This will provide enough sampling points which can be used in calculating initial elevation trends.

Sampling dates should be driven by seasonal patterns of sediment delivery and plant growth at the particular location (e.g., wet/dry seasons affecting watershed inputs; seasonal storm inputs). It may also help to visualize any seasonal fluctuations in elevation and accretion that may occur over the course of the year, and that the sampling occurs at the same time of year or season. A common example in temperate marshes would be to sample the SET-MH stations twice a year; at the beginning of the growing season (spring), and then again at the end of the growing season (fall). A third or fourth sampling could be added during the growing season. Table 3 provides a summary of the recommended sampling frequencies.

Funding - This is the ultimate factor in determining how often to sample an SET-MH station. The costs associated with visiting the site and taking measurements may end up influencing the sampling schedule.

Weather – In colder climates, ensure the marsh is not frozen when reading the SET. Consequently, sampling in the winter months does not normally occur. The sampling schedule in tropical and subtropical climates may vary based on the timing of the wet and dry seasons.

Tides - It is preferable to sample the SET-MH stations at similar tide levels each time because the substrate may shrink and swell with the variation in water level during a tidal cycle. Sample the SET-MH stations when the surface is free of water (i.e., low tide), if possible.

Table 3. Suggested sampling frequency for different measurements involved in a SET and marker horizon study.

Measurement	Typical Sampling Frequency	Notes
Surface Elevation Table (SET)	1 to 4 times a year (2x or more initially).	Seasons: wet/dry
Marker Horizon	1 to 3 times a year (2x or more initially)	Normally sampled when reading the SET
Elevation Surveying	Initially, and then every 5 years	Leveling vs. GPS; connection to NSRS vs. within-local network connection
Stability of SET mark	Annually, if feasible	Leveling or static GPS observation

Elevation change measurements (SET)

The RSET instrument is attached to the deep or shallow RSET mark to measure directly the relative elevation of the wetland surface, repeatedly over time to generate a trend in elevation change. SOP #4 provides details on reading the SET. A very important consideration is who will take the measurements with the SET instrument. It is preferable to have the same person take the SET measurements during each sampling since there are some subjective decisions that need to be made. The primary decision is determining what constitutes the wetland surface and placing the pins on this surface. In many wetlands this is a very straightforward decision, but in some situations it may not be clear, and the SET operator has to develop a consistent rule for determining the surface, which is effectively a bias. This rule should be documented and followed on all subsequent sampling events. There should be accurate notes taken on who is reading the SET instrument each time. If there is a change in readers it is advised to perform a “double read” of each SET mark. This is where Person 1 takes their last reading and Person 2 takes their first reading immediately after Person 1 during the same sampling trip. This will provide an estimate of bias between the two readers which can be used to adjust the long term trend (SOP #8).

Accretion measurements (marker horizon)

The marker horizons are sampled at the same time as the RSET measurements to determine how much vertical accretion occurred on the wetland surface since the previous sampling event. SOP #5 provides detailed instructions on sampling marker horizons. Coring the marker horizon needs to be accomplished without disturbing a large area of the plot. The most common method uses liquid nitrogen to take a small diameter frozen core from the plot that can be measured immediately in the field (Cahoon et al. 1996). Other methods for coring the marker horizons include cutting plugs with a knife, or using a soil corer.

Surveying

There are five basic steps involved with bringing high accuracy elevations to a sample station (see section titled Relating Tidal Datums, Sea-Level Trends, and Wetland Elevation in the Introduction for why surveying is needed):

1. Evaluation of elevation needs: – are only local elevation connections needed, or is a connection to the National Spatial Reference System required?

2. Development of a survey plan.

3. Installation of any additional geodetic infrastructure, if necessary (e.g. additional survey marks).

4. Establishment of high accuracy geodetic connections between local reference marks and the National Spatial Reference System (only required for regional scales of interest; Figure 25)

5. Local surveying to connect elevations among local monitoring infrastructure (additional SET marks, marker horizon plots, water level recorders, vegetation plots, etc.; Figure 26)

The first task is to evaluate whether local elevation connections (such as between SET-MH stations and a local water level recorder), or elevation comparisons (including water levels) over a wider area is required. This decision will influence the type of surveying instrumentation and techniques used, as well as any requirements for additional reference marks. It is recommended to seek the advice of licensed, professional surveyor to help determine your needs, especially with regards to instrumentation. A survey plan should also be vetted by an experienced surveyor. Refer to Surveying SOP #7 for specific instructions and guidance.

Note that surveying techniques can also be used to compute the vertical offset between the SET mark and the wetland sediment surface. This can be useful to express SET pin measurements with respect to a vertical datum such as NAVD 88 (Figure 27).

Figure 25. GPS receiver deployed on an SET mark for a static occupation (Acadia National Park, ME, USA).

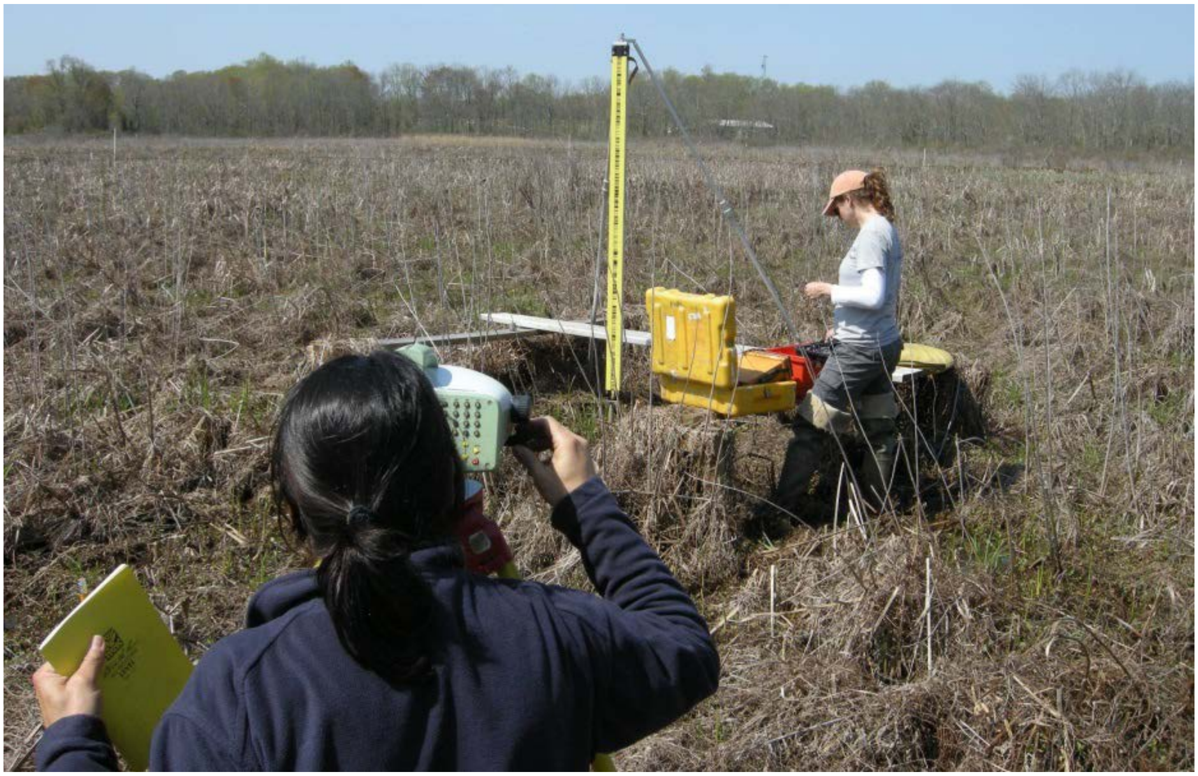


Figure 26. Digital barcode leveling is used to transfer elevations from a SET mark to other vertical infrastructure (Jug Bay, MD USA).

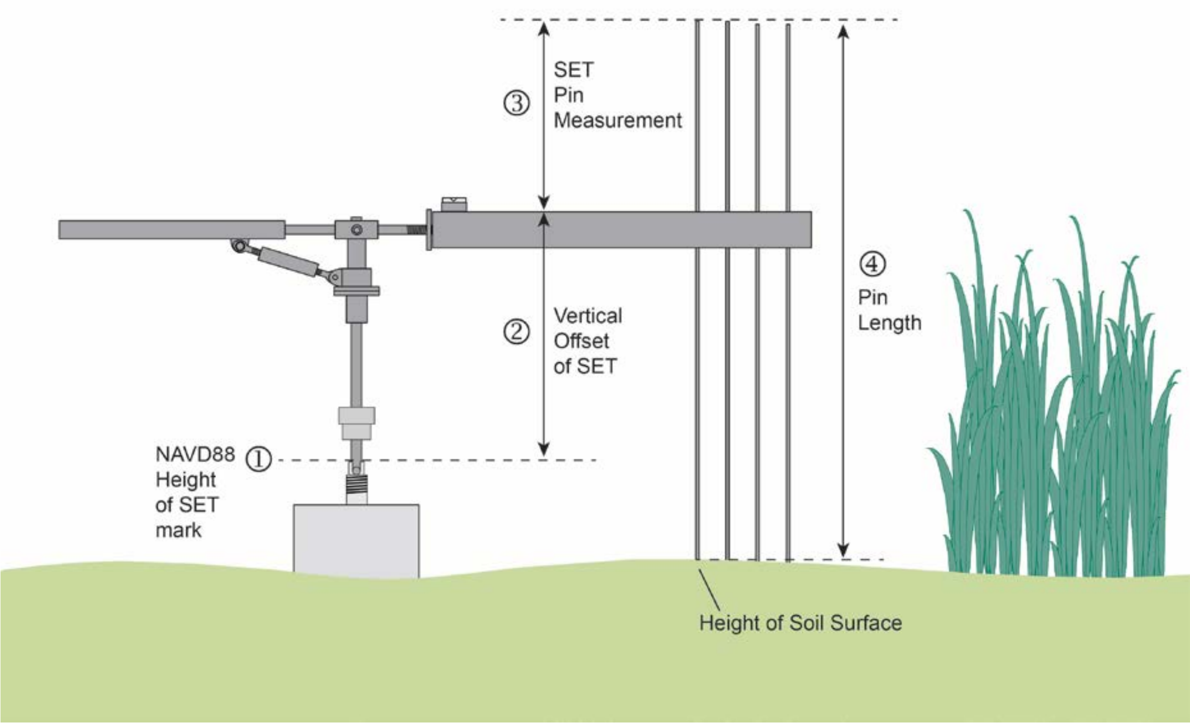


Figure 27. Diagram displaying data involved in transferring elevation of an SET mark to individual SET pin measurements (not all pins shown).

Data Handling, Analysis and Reporting

The SET and MH methods generate fundamentally different data such that the two datasets are treated differently in collection, recording, and analyses. With SET data, elevation change of each pin is followed over time and these repeated measurements result in serial correlation that has implications for statistical analyses. With marker data, the evolution of the marker horizon plot is followed, not any one given core. SET data can easily be converted from cumulative to incremental change while marker data are inherently cumulative and must be appropriately converted into incremental change at the marker horizon plot level.

Metadata

For both SET and MH datasets, there are a number of factors that can result in a bias in the data and therefore need to be documented in metadata (e.g., the observer, the nature of the sediment surface, and the phase of tide, etc.). Any dataset compiled by NPS inventory and monitoring program networks must be accompanied by Federal Geographic Data Committee (FGDC) compliant metadata. This rule applies to both spatial and non-spatial data. NPS has developed both a stand-alone database that can be shared, as well as a central database managed by the NPS Inventory and Monitoring program.

Specific metadata requirements can be found in the data management SOP #8.

Metadata for both SET and marker horizon datasets will include the following considerations:

- Types of data taken (SET, marker horizon)
- Location of the station
- Date and time of sampling
- Originator of the data (observer) and other field help.
- Date that the station was established and subsequent sampling dates

Metadata specific to SET data:

- Type of SET mark (pipe mark or deep rod mark), including presumed depth and date installed.
- Type of SET instrument (e.g. SET, RSET)
- SET instrument ID
- SET reader
- Station map and direction of approach
- Compass direction and layout of SET positions sampled

Metadata specific to marker horizon data:

- Type of accretion marker and date established
- Location of marker horizons around (SET) station and identification (e.g. numbering)

- Marker horizon sampling method (e.g. coring tube, extraction with knife, cryo-coring)

Metadata should be recorded in a field notebook that is carried to the field on future sampling dates, so that the operators can cross-check original orientation, positions, locations, etc. Of course, metadata are also stored and archived digitally. Waterproof datasheets are very useful for recording data; a digital voice recorder is also valuable for note-taking and serves as an excellent back-up to written notes (also useful in the quality control – see below).

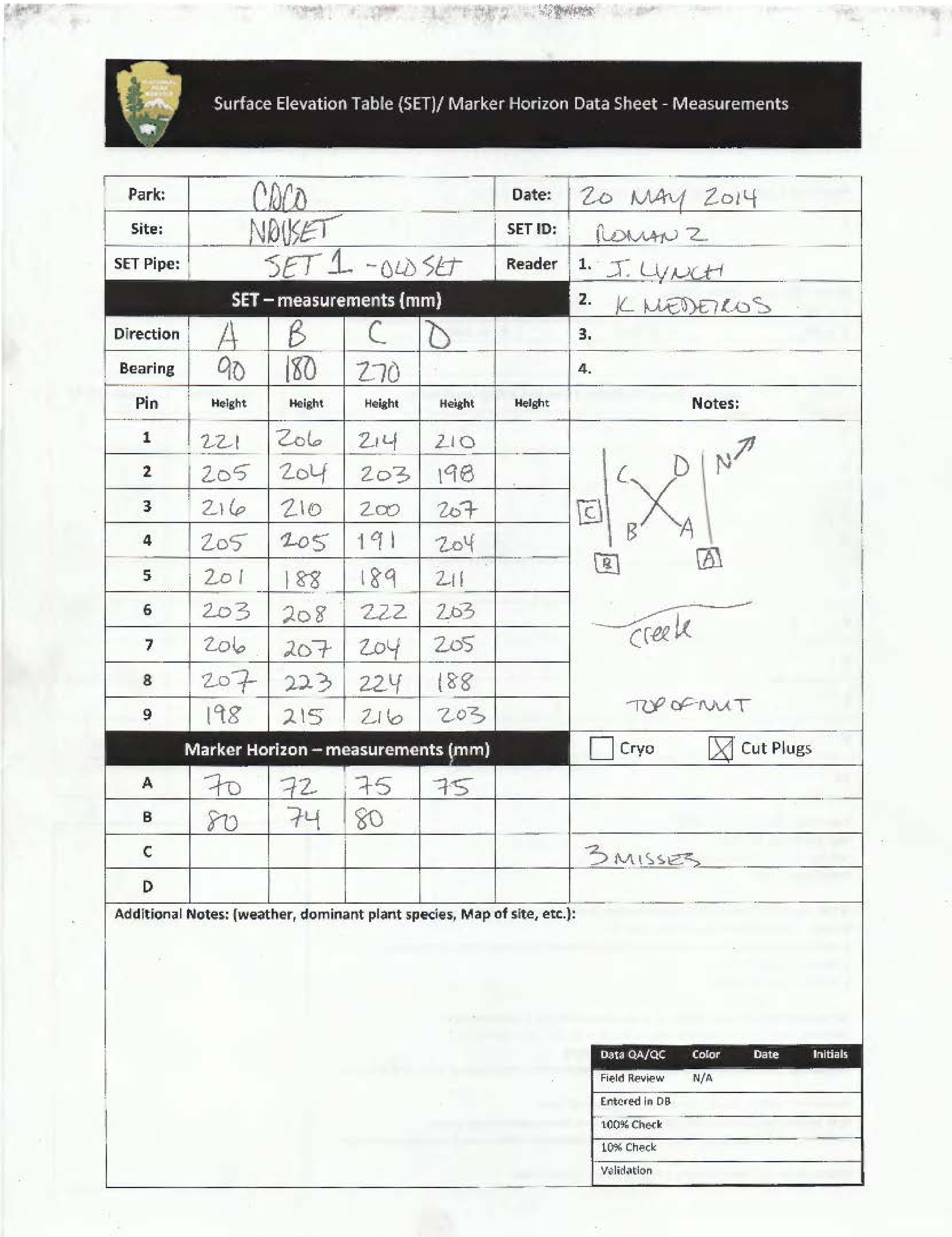
Field Documentation and Data Entry and Manipulation

Data collection, data entry, quality control and analysis are a four-step process:

1. field documentation;
2. data entry into a spreadsheet or database with quality control;
3. computation of incremental data/quality control;
4. statistical analyses of the data.

These guidelines provide a set of consistent methods to ensure that the data are accurately recorded and allow for careful quality assurance and quality control. Subsequently, the data can be exported for subsequent analysis.

Field documentation involves both collecting SET and marker horizon data and recording the data in a field notebook (Figures 28 and 29) or other recording device. These are generally separate tasks involving at least two people. Specific data entry protocols and QA/QC review provide backup protection and quality checks. Data entry in a spreadsheet or database allows consistent formatting (an easy way to see changes over time), error/outlier detection, quick exploratory data analysis and trend computation, as well as the ability to express SET data as both incremental elevation change (from one sampling period to another) and total cumulative change (Figure 30). Quality control is required to evaluate whether individual SET measurements represent an actual change in the wetland sediment surface elevation, or whether there was a bias due to any one of numerous factors (e.g. crab hole, footprint, detritus, etc.). Quality control requires the use of incremental elevation change, regardless of which kind of analysis is eventually done on the data. See SOP #8 for detailed information on data management.



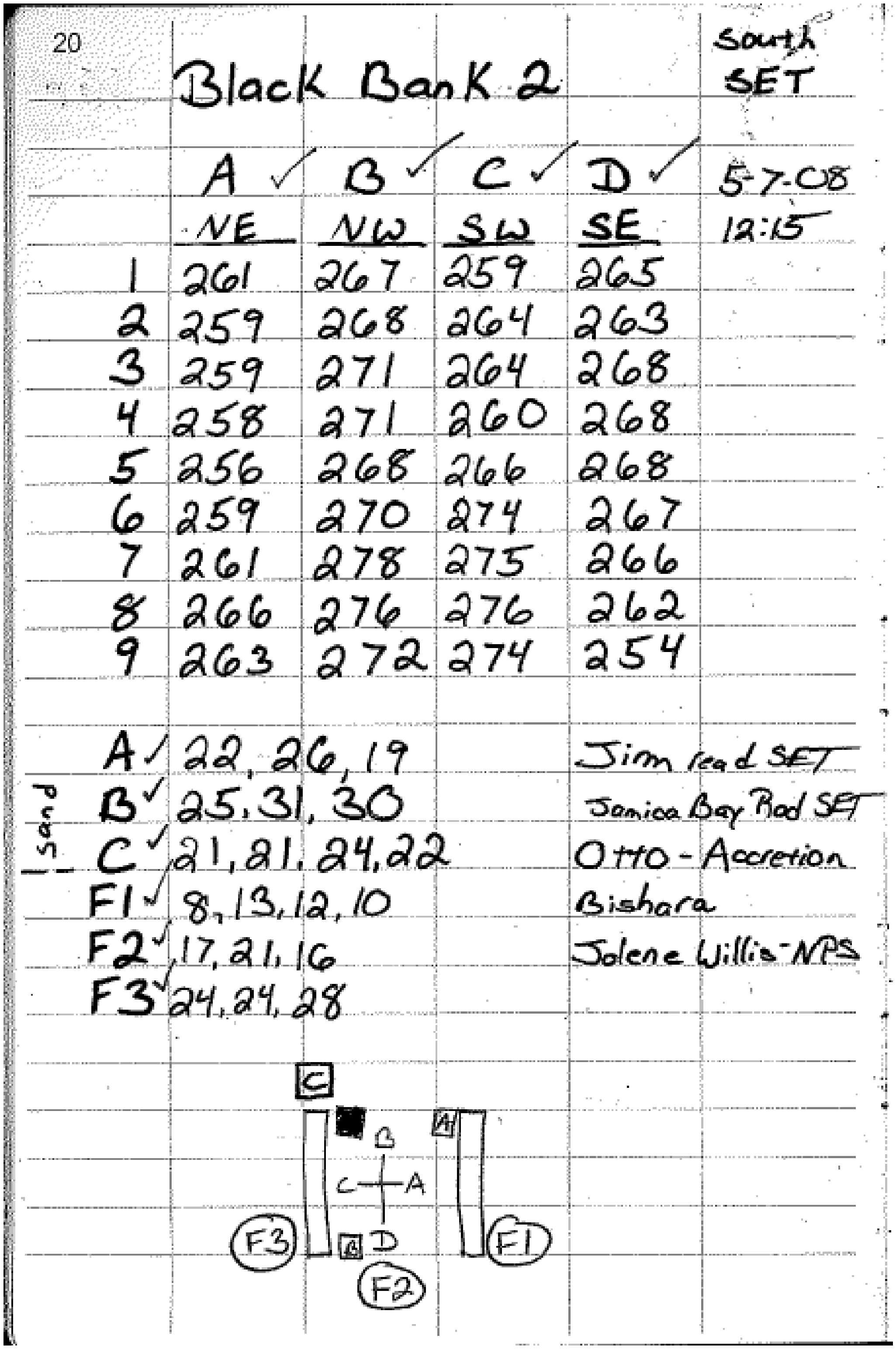
Surface Elevation Table (SET)/ Marker Horizon Data Sheet - Measurements

Park:	CACO				Date:	20 MAY 2014
Site:	NAUSET				SET ID:	ROMAN 2
SET Pipe:	SET 1 - OLD SET				Reader	1. J. LYNCH
SET – measurements (mm)						2. K MEDEIROS
Direction	A	B	C	D		3.
Bearing	90	180	270			4.
Pin	Height	Height	Height	Height	Height	Notes:
1	221	206	214	210		
2	205	204	203	198		
3	216	210	200	207		
4	205	205	191	204		
5	201	188	189	211		
6	203	208	222	203		
7	206	207	204	205		
8	207	223	224	188		
9	198	215	216	203		TOP OF NUT
Marker Horizon – measurements (mm)						☐ Cryo ☒ Cut Plugs
A	70	72	75	75		
B	80	74	80			
C						3 MISSES
D						

Additional Notes: (weather, dominant plant species, Map of site, etc.):

Data QA/QC	Color	Date	Initials
Field Review	N/A		
Entered in DB			
100% Check			
10% Check			
Validation			

Figure 28. Example of an NPS datasheet as recorded in the field. Note the various data fields that are filled out during the data collection. Pin height data refer to measurement 3 in Figure 27. Note too, the QA/QC box in the lower right corner which is for documenting later tasks such as the review of the data and entry into a database.



20

Black Bank 2 — South SET

	A ✓	B ✓	C ✓	D ✓	5-7-08
	NE	NW	SW	SE	12:15
1	261	267	259	265	
2	259	268	264	263	
3	259	271	264	268	
4	258	271	260	268	
5	256	268	266	268	
6	259	270	274	267	
7	261	278	275	266	
8	266	276	276	262	
9	263	272	274	254	

A ✓ 22, 26, 19 — Jim lead SET

B ✓ 25, 31, 30 — Jamica Bay Rod SET

sand C ✓ 21, 21, 24, 22 — Otto - Accretion

F1 ✓ 8, 13, 12, 10 — Bishara

F2 ✓ 17, 21, 16 — Jolene Willis - NPS

F3 ✓ 24, 24, 28

Figure 29. Typical SET-MH data book entries as recorded in the field. Note date, sample site and station ID, SET positions, pin numbers, pin heights and sample station sketch.

Pin height data refer to measurement 3 in Figure 27.

Station				Raw Pin Heights (mm)							Incremental Pin Heights (mm)					
CODE	SITE	POSITION	PIN	6/14/2007	2/19/2008	7/3/2008	12/3/2008	3/23/2009	6/25/2009	9/30/2009	2/19/2008	7/3/2008	12/3/2008	3/23/2009	6/25/2009	9/30/2009
NA-SS	North	NE	1	363	342	362	349	342	377	374	-21	20	-14	-7	35	-3
NA-SS	North	NE	2	368	344	331	352	343	377	380	-24	**-13**	21	-9	34	3
NA-SS	North	NE	3	369	333	370	357	344	375	382	-36	37	-13	-13	31	7
NA-SS	North	NE	4	366	336	362	353	344	369	384	-30	26	-9	-10	26	15
NA-SS	North	NE	5	368	335	363	361	350	371	379	-33	28	-2	-11	21	8
NA-SS	North	NE	6	371	337	371	359	360	374	385	-34	34	-12	1	14	11
NA-SS	North	NE	7	369	334	371	381	349	372	386	-35	37	10	**-32**	23	14
NA-SS	North	NE	8	374	321	369	371	360	373	386	-53	48	2	-12	13	13
NA-SS	North	NE	9	373	333	372	367	360	371	390	-40	39	-5	-8	12	19
NA-SS	North	NW	1	321	317	331	327	293	320		-4	14	-4	-34	27	
NA-SS	North	NW	2	352	360	362	359	348	325		8	2	-3	-12	-23	
NA-SS	North	NW	3	414	402	395	412	375	370		-12	-7	17	-37	-6	
NA-SS	North	NW	4	328	324	334	328	313	318		-4	10	-6	-16	6	
NA-SS	North	NW	5	352	367	359	358	352	329		15	-8	-1	-6	-23	
NA-SS	North	NW	6	419	421	397	415	389	378		2	-24	18	-26	-12	
NA-SS	North	NW	7	330	324	336	325	310	321		-6	12	-11	-15	11	
NA-SS	North	NW	8	385	395	373	380	368	339		10	-22	7	-12	-29	
NA-SS	North	NW	9	411	418	412	411	390	391		7	-6	-1	-21	1	
NA-SS	North	SE	1	363	346	369	357	337	353	375	-17	23	-12	-20	16	22
NA-SS	North	SE	2	363	331	369	362	343	359	376	-32	38	-8	-19	16	17
NA-SS	North	SE	3	364	339	370	367	345	370	380	-25	31	-3	-22	25	10
NA-SS	North	SE	4	354	348	370	351	336	364	386	-6	22	-19	-16	29	22
NA-SS	North	SE	5	355	344	365	364	345	366	379	-11	21	-1	-19	21	14
NA-SS	North	SE	6	356	343	373	366	350	375	391	-13	30	-7	-16	25	16
NA-SS	North	SE	7	349	343	371	372	348	376	386	-6	28	1	-24	28	11
NA-SS	North	SE	8	340	341	370	366	351	377	387	1	29	-4	-15	26	11
NA-SS	North	SE	9	342	339	373	357	343	377	385	-3	34	-17	-14	35	8
NA-SS	North	SW	1	491	473	540	471	461	467	467	-18	67	-70	-10	7	0
NA-SS	North	SW	2	455	462	534	465	446	447	459	7	72	-69	-20	2	12
NA-SS	North	SW	3	475	473	531	458	445	452	452	-2	58	-73	-14	8	-1
NA-SS	North	SW	4	469	467	530	465	441	449	453	-2	63	-65	-24	8	4
NA-SS	North	SW	5	460	456	526	465	438	444	454	-4	70	-61	-27	6	10
NA-SS	North	SW	6	488	472	527	462	449	450	457	-16	55	-66	-13	2	7
NA-SS	North	SW	7	444	456	535	469	433	442	452	12	79	-66	-36	9	10
NA-SS	North	SW	8	452	462	534	468	440	454	455	10	72	-66	-28	14	2
NA-SS	North	SW	9	494	468	531	464	448	455	461	-26	63	-67	-16	7	6

Figure 30. Example of SET data spreadsheet produced from field measurements. Note raw pin heights (See Figure 27, item number 3) and incremental height calculations (mm) for quality control. Two observations (highlighted in yellow) fall outside the assumed 95% confidence interval around the mean for the position.

Data Analyses

Different kinds of data analyses are used depending on the specific goals and questions of a study. Two common types of analyses applicable to both SET and MH data are:

1. the estimation of cumulative trends over the entire time series (e.g. entire data record)
2. the comparison of elevation or accretion change as a function of a time-dependent factor (e.g. seasons, pre/post impact, etc.)

The first scenario is clearly applicable to a monitoring program, but it is also routinely used to support hypothesis testing. The second scenario is generally limited to hypotheses testing time-dependent factors. Analyses can be restricted to either just SET or marker horizon data, or can be combined to evaluate the contribution of above-ground and below-ground processes to elevation change. Similarly, different kinds of SET data (deep SET, shallow SET) can be compared. See SOP #9 for detailed explanation of statistical analyses.

Cumulative trends

<u>Cumulative SET analysis</u>

Cumulative trends are analyzed (regressed) at the pin level to increase precision and properly deal with serial correlation. Thus SET data from a sample station results in 36 estimates of linear trends, which are averaged to the positions and then to the entire station.

<u>Cumulative accretion data</u>

Marker horizons provide cumulative accretion, and trends are computed at the marker plot level. Unfortunately, there is no way to account for missing marker horizon layers in the regression analysis, so the trends may be biased upwards.

<u>Comparing SET and marker horizon data</u>

SET and MH data can be compared to evaluate the role of surface vs. subsurface processes in affecting elevation change. There are three potential outcomes:

1. Accretion > Elevation: shallow subsidence may be occurring
2. Accretion = Elevation: surface accretion is driving elevation change (no subsurface influence)
3. Accretion < Elevation: shallow expansion may be occurring

These comparisons are typically made on cumulative trends averaged to the sample station level, but can also be analyzed within specific time periods (see below).

Incremental change analysis

Incremental analyses are required when testing the effect of a time-dependent factor, such as seasons (e.g. growing vs. dormant), specific years (e.g. El Niño vs. non-El Niño), pre and post-impact, etc. A main concern with incremental data is the length of time over which each factor level occurs, and the consistency of these intervals over the course of the study. For example, if considering growing vs. dormant seasons, and the growing season is nine months long (dormant season only 3 months long), then the analysis will be heavily biased towards the growing season dynamics. A remedy for unequal time intervals is to compute linear rates of change for each time interval. If multiple observations are taken within each time period of interest (e.g. pre and post impact), then cumulative trend analysis is conducted for each time period. If only one observation is taken within each time period, then a simple rate of change is computed.

Incremental SET data

As with cumulative trends, incremental SET analysis is based on computing elevation change rates at the pin level. If multiple observations are taken within a time period, then a simple linear regression is used, similar to above. The main difference is that rates are computed on different subsets of the entire time series. Change rates are averaged across the nine pins per position, and then across the different positions around the SET mark. These rate estimates are then used as input data into an analysis of variance model testing for the time-dependent effect. This requires advanced statistical tests.

Incremental accretion data

Similarly, incremental accretion data are expressed at the marker horizon level. If multiple sampling events occur within a time period of interest, then simple linear regression can be used to estimate the accretion rate over the interval. If only one sample event occurs within a time period of interest, then a simple rate calculation is made for each marker plot, based on the difference in marker depth between the previous and the current sampling period. These accretion rates, expressed at the marker horizon level, are the input data in an analysis of variance model testing for the time-dependent effect, as above.

Comparing SET and marker horizon data

Testing the different responses of accretion and elevation change to a time-dependent factor involves the same procedures as outlined above for determining incremental rates for accretion and elevation change (e.g. Whelan et al. 2005). The input data set for the analysis of variance model contains the rate estimates for both SET and marker horizon measurements.

Statistical models

A number of different experimental designs and models are supported by the SET – MH technique, from simple Student's T-tests to completely randomized, factorial, or mixed (nested) linear models. In most cases, the experimental unit would be the sample station (SET mark). More advanced statistical techniques such as model selection can be employed to take better advantage of the fact that trend or change estimates are derived at sub-station levels (e.g. SET positions or even pins, and individual marker horizon plots). Instruction on these analysis procedures is beyond the scope of this report, but the user is urged to discuss sampling design and data analyses with a statistician prior to engaging in the SET study.

Personnel Requirements and Training

Below are some of the personnel and training requirements for the National Park Service. Personnel requirements may vary from one organization to another. The basic principles outlined below for the NPS will apply to other groups as well and should be considered.

National Park Service: The Northeast Coastal and Barrier Network (NCBN) is responsible for the development and implementation of SET – MH protocols used in NPS parks in the northeast region of the U.S. and has assigned a Network staff-person as project leader. The NCBN project leader is responsible for coordinating development of this document as well as an implementation plan and schedule that is suited to the needs of the individual Network parks. The project leader will work closely with Network parks and their staff to develop and implement SET – MH protocols. Since the various activities associated with these protocols can be rather complex, it is best to coordinate your activities with the project leader in your network.

Network and local park staff can employ this report/guideline/protocols for the collection of data on Park Service property. Elevation monitoring using the SET instrument is a long term measurement that hopefully will occur for many years. It is recommended to have a single, permanent employee taking these measurements. A seasonal or other short-term employee will not suffice. Reading the SET instrument involves some qualitative decisions on where the marsh surface is located, so it is best to have the same person take these measurements from year to year.

Data management will involve the NCBN project leader, the person collecting the data (if different) and Network data managers. The person reading the SET instrument and collecting the marker horizon data is responsible for backing up the data collected, initial QA/QC and providing data essential for the metadata file. The NCBN project leader is responsible for data documentation (metadata), data summary, and basic analysis and reporting.

Training for installation and sampling of the SET-MH stations will come from the project leader in your network and/or from the SOP's contained in this report. The project leader will also work with the Network parks to ensure that local staff members are appropriately trained as necessary to meet the requirements necessary for sampling throughout the year.

Other related activities such as leveling and/or GPS surveying should be carried out by qualified personnel as directed by the pertinent SOP's. Check with your project leader to ensure that any personnel conducting surveys are properly trained.

Operational Requirements

Annual Workload and Field Schedule

The annual workload and field schedule will vary depending on the requirements for the particular project. SET-MH stations are commonly sampled 2 or 3 times per year, especially in temperate climates, but actual schedules will be based on the requirements established for your particular design. Surveying the SET-MH stations to monitor stability and wetland elevation will typically happen on an annual basis or longer. Schedules will vary depending on the needs of the particular design. Surveying costs are not described below. Refer to SOP #7 for details on organizing a survey for the study area.

SET-MH Installation and Sampling Costs

There are two types of costs associated with SET-MH studies described in this protocol. Installation costs and Sampling costs:

Installation Costs: These are upfront expenses associated with starting a new SET-MH project (Table 4). This will involve the installation of SET marks, marker horizons, and associated platforms and equipment needed to install them. Be aware that some of the equipment needed for installing the SET marks (Jack Hammer or Demolition hammer) can be expensive. Fortunately, they can be rented or possibly borrowed from a colleague. Details on the installation of SET-MH stations can be found in SOP #3 and SOP #5.

Table 4. Estimated SET-MH installation costs in 2015.

Installation Costs	Price	Number	Total Price	Notes
Stainless Steel Receivers	$125 - $175	1 per sample station	$125-$175	Custom built
Stainless Steel Rods (4’)	$15-25	15-20 per sample station	$225-500	Actual number may vary considerably depending on local conditions and the equipment used to install the mark.
Jack Hammer or Demolition Hammer or Hand Pounder	$4500 or $1000 or $300	1	$300-4500	Investigate renting or borrowing the jack or demolition hammers.
Miscellaneous (Cement, PVC pipe, etc.)	$50		$50	This is price per station.
Feldspar Clay (50lb bag)	$15	1 bag per 2 stations		One 50lb bag will provide 6 marker horizon plots (50cm x 50cm).
Platform (optional)	$100	One per station	$100	Price will depend on the size and length of the platform constructed.
Site access costs	$??		??	Costs getting to and from the study area

Sampling Costs: These are expenses associated with the long term monitoring of the SET-MH sample stations (Table 5). This would include the logistical costs of accessing the sample stations and taking measurements on a particular schedule. Note that many of the measurement costs in table 5 are mainly one-time costs. The recurring costs for measuring SET-MH stations will come primarily from the costs of getting to and from the study area and the costs for liquid nitrogen, if applicable. Details on the sampling can be found in SOP #4 and #5.

Table 5. Estimated SET-MH sampling costs in 2015.

SET Sampling Costs	Price	Number	Total Price	Notes
ROD SET instrument	$1300-2000	1	$1300-2000	Need only one SET instrument for most situations because it is portable. Instrument is custom built.
Cryogenic Coring system or knife to cut the substrate	$10-2000	1 or more	$10-2000	Cryogenic system will work in all substrate types. Using a knife to cut a core will work only in firm substrates. Cryogenic coring may require 2 or more LN tanks in areas with many marker horizons to sample.
Portable Platform (optional)	$150	One plank	$150	If there is no permanent platform.
Liquid Nitrogen	$30-60	1 tank	$30-60	Price to fill a cryogenic tank.
Site access/sampling costs	??		??	Costs getting to and from the study area

Procedures for Revising and Archiving Previous Versions of the Report

Over time, revisions to both the Report Narrative and to specific Standard Operating Procedures (SOPs) are to be expected. Complete documentation of changes to the report, and a library of previous versions are essential for maintaining consistency in data collection and for appropriate treatment of the data during data summary and analysis. The database used by NPS staff for each monitoring component contains a field that identifies which version of the protocol was being used when the data were collected. The rationale for including a narrative with supporting SOPs is based on the following:

- The Report Narrative is a general overview of the report that gives the history and justification for doing the work and an overview of the sampling methods, but it does not provide all of the procedural details.
- The Report Narrative will only be revised if major changes are made to the procedures.
- The SOPs, in contrast, are very specific step-by-step instructions for performing a given task. They are expected to be revised more frequently than the Report Narrative.
- When an SOP is revised, in most cases, it is not necessary to revise the Report Narrative to reflect the specific changes made to the SOP.
- All versions of the Report Narrative and SOPs will be archived in a Report Library.

The steps for changing this report (either the Narrative or the SOPs) are outlined in SOP #10 - Revising the Report. Each SOP contains a Revision History Log that should be filled out each time a SOP is modified to explain why the change was made, and to assign a new Version Number to the revised SOP. The new version of the SOP and/or Report Narrative should then be archived in the Long Term Ecological Monitoring Report Library.

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SOP 1: Project Planning

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

This SOP provides guidance on designing a field study using the SET-Marker Horizon (SET – MH) technique to determine wetland surface elevation dynamics and vertical accretion (Figure 1.1). The first section introduces basic terms and concepts and outlines the steps required for successful study design planning. The second section provides guidance for determining whether the project is a monitoring study or a hypothesis testing study as well as determining the scope of the study, including variables and factors. This is followed by steps to determine the minimum, statistically-valid sample size and a representative distribution of the samples over the geographic area of interest. The final steps involve selecting potential sample stations and locating them in the field. The section concludes with two examples of experimental designs, illustrating how the process can be applied.

Please read the <u>entire</u> SOP before finalizing the project plan!

Figure 3.1. Back barrier marsh at Fire Island National Seashore, NY. USA.

Terms and Concepts

The following terms and concepts are used in this SOP, supported by specific examples. See the Glossary in the main text for full definitions.

- Continuous Factor
- Covariate
- Discrete Factor
- Factors
- Fixed Factor
- Hypothesis testing
- Marker Horizons
- Monitoring
- Random Factor
- Randomization
- Sample Sites
- Sample Space
- Sample Stations
- SET Mark

Defining the Study

Determining the type of project and sample space

To plan a successful study, take care to identify the type of project, the sample space, factors of interest, and other variables (i.e., covariates) influencing the measurements being collected.

Monitoring or Hypothesis Testing

The first step is to determine whether the project will be designed for monitoring or hypothesis testing. A monitoring design would have the general goal to quantify trends in elevation and/or accretion in wetland habitats within the defined sample space. A hypothesis testing design usually addresses a specific research question, like comparing elevation and accretion trends in a restored wetland to a control wetland.

Defining the Sample Space and variables

Table 1.1 provides examples of the ranges of different SET – MH study characteristics, and how they might differ between monitoring and hypothesis testing objectives. These examples are merely illustrative as individual study characteristics may vary. Both monitoring and hypothesis testing can co-occur within a project, but one of these will normally take precedence in the design.

A large number of experimental designs have successfully been used with the SET technique. This SOP does not provide specific guidance on any particular design, but offers general guiding principles to help determine sample size and their distribution within the sample space.

Sample Size – Choosing the number of sample stations

Due to the high cost of installing sample stations, the time-consuming measurements and logistic constraints, SET studies typically have a small total number of sample stations. This limitation makes identifying the sample space and choosing the distribution of sample stations in the sample space all the more critical to balance the needs of spatial coverage and spatial inference (see Table 2 of main text).

Table 1.1. Comparisons between monitoring and hypothesis testing across a suite of characteristics that define the scope of a study.

Sample Space	Monitoring	Hypothesis Testing
Geographic extent	Entire coastline Wildlife refuge or park Individual marsh	
Geomorphic setting	All settings Specific setting (back barrier, lagoon, open coast, etc.)	
Habitat type	All wetland habitat types *Spartina patens* high marsh *Typha* marsh Fringe or basin mangrove forest Shallow water habitats Creekside marsh Interior marsh or mangrove	
Elevation range and hydroperiod	Entire elevation / intertidal range Low marsh /High marsh Frequently flooded /Permanently flooded	
Factors	**Monitoring**	**Hypothesis Testing**
Habitat type	n/a	*S. alterniflora* vs. *S. patens* Creek vs. interior marsh Fringe vs. Basin mangrove
Elevation range and hydroperiod	n/a	High marsh vs. low marsh Simulated elevation gradients
Management	n/a	Impounded vs. control marsh Burned vs. unburned marsh
Restoration type	n/a	Sediment addition Vegetation planting Channel development
Dependent Variables	**Monitoring**	**Hypothesis Testing**
Elevation change	SET	
Accretion	Marker Horizons	
Shallow subsidence	SET + Marker Horizons	
Independent Variables	**Monitoring**	**Hypothesis Testing**
Site elevation	Survey	
Hydroperiod	Water level gage	
Vegetation	Biomass, stem density, spp. composition	
Soils	Bulk density, organic matter content	
Sample Size	**Monitoring**	**Hypothesis Testing**
SET sample stations	How many to install?	
Spatial placement of sample stations	Multiple wetlands?, single wetland?	
Statistical Comparisons	**Monitoring**	**Hypothesis Testing**
Elevation Trends	Rate of elevation change on the wetland surface	Trends within and among factors
Accretion Trends	Rate of accretion on the wetland surface	Trends within and among factors
Comparing Elevation and Accretion Trends		Above vs. below-ground processes

Sample Size for a Monitoring Study:
Sample size selection is an iterative process, starting from the selection of a sample space to the distribution of sample stations within the space.

1. First, define the sample space. Keep in mind how complex that space is, and what are important characteristics that need to be included in the monitoring. For example, is there a need to monitor specific sites, geomorphic settings, or habitats within the space?

2. Estimate the total number of sample stations to be installed and monitored over time (keep in mind financial, logistic, and time constraints).

3. If there is a need to monitor specific characteristics of the sample space (step 1, above), a minimum of three sample stations are required for each level of the characteristic (e.g. three stations per site). If there is no need to sample specific characteristics, the sample stations can be randomly distributed throughout the sample space (at least three stations in the sample space)

   - Example A: if two different geomorphic settings are being monitored (e.g. back-barrier marsh and lagoonal marsh), at least six sample stations will be required, three per geomorphic setting.

   - Example B: if two intertidal habitats are the focus of the monitoring (low marsh, high marsh), at least six sample stations will be needed, three per habitat.

   NOTE: These are the **minimum** number of sample stations required for analysis to determine statistical differences between elevation change in different settings or habitats.

4. Given the need for three or more sample stations for each sample space characteristics of interest, re-evaluate the number of sample stations needed. The total number of sample stations may need to be increased, or the sample space may need to be refined to cover a subset of all characteristics of interest.

   - Example: A monitoring project sample space contains five distinct marshes. Based on costs and logistics, a total of nine sample stations can be installed. To have three sample stations within each sample site, only three of the five marshes will be chosen as sample sites. Two of the marshes will not be sampled.

Sample Size for Hypothesis Testing:
As with monitoring, sample size selection for hypothesis testing may be an iterative process, ensuring adequate sample size (minimum of three sample stations) to statistically test for factors and factor levels of interest.

1. Define the Sample Space (factors and levels): If there is one factor (e.g. fertilization) that is present at two levels (e.g. fertilized, unfertilized), a minimum of six sample stations would be required (three per factor level). A second factor present at two levels (e.g. marsh type: low marsh, high marsh) would double the sample size requirement (Table 1.2). This is still the absolute minimum, but note that larger sample sizes greatly increase the power of an

analysis. This means that the ability to discern real differences among the experimental factors or treatments increases exponentially when increasing from very small sample sizes.

2. Estimate the total number of sample stations that can be installed and monitored for the study (keep in mind financial, logistic, and time constraints).

3. Power analysis: consider running a power analysis to help determine the ideal sample size for the hypothesis(es) being tested. If the ideal sample size is larger than the number of sample stations determined in step 2, consider reducing the number of factors or factor levels by prioritizing. What factors or factor levels are most important? Can any be omitted?

4. Covariates: If sample sizes are small (3-5 sample stations per factor/level), consider recording potentially important covariates, to enhance the ability to distinguish the signal of the treatment factors from the background noise; e.g. marsh elevation, vegetation stem density, plant biomass, etc.

Strategies for successful hypothesis testing:
Choose factor levels that span a broad range of possible influence, to maximize potential responses. This may maximize the signal compared to the background noise.

Reduce background variability by constraining sample space or considering covariates. Example: constrain to one type of marsh, one vegetation community type, or one intertidal level.

Distributing Sample Sites and Sample Stations

This section describes the options available for distributing sample stations for both monitoring and hypothesis testing studies. Small sample sizes mean that choosing the sample sites (single or multiple) and sample station locations is critical. There are six basic options by which sample stations can be selected and distributed in space, depending on whether the goal is monitoring or hypothesis testing (Figure 1.2).

Table 1.2. Example showing the relationship of factors and factor levels and the minimum number of sample stations needed for a hypothesis testing study (red text).

		Factor A - Fertilization				
		Factor A Levels				
		1	2	3	4	5
Factor B – Marsh Type	Factor B Levels 1	3	6	9	12	15
	2	6	12	18	24	30
	3	9	18	27	36	45
	4	12	24	36	48	60
	5	15	30	45	60	75

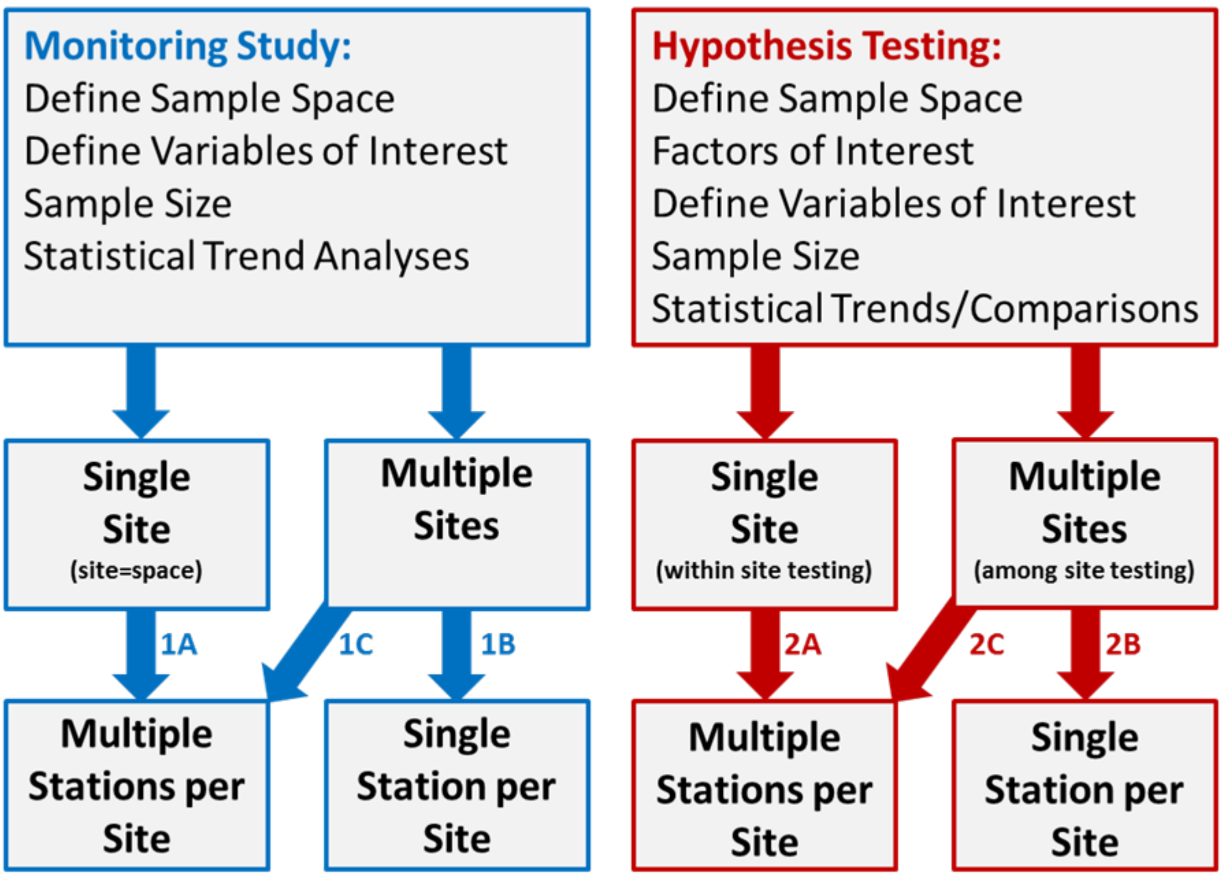


Figure 1.2. Sample station options for a monitoring study and a hypothesis testing study.

Monitoring Study

Below are some items to consider when distributing sample stations:

- Representative sampling: Sample station locations need to be representative of the habitat that is targeted for monitoring (sample space).
- Random sampling: Random sampling is a traditional approach for selecting sample station locations. However, with a small sample size, random sampling may not lead to a representative sample.
- Consider Restricted randomization: To ensure representative samples, a specific habitat or community of interest is selected first, and then a randomization scheme is applied.
- Ensure wide distribution: For monitoring, it is also ideal to have as wide a dispersion of sample stations as possible to include all areas of the sample space within the sample.
- Hierarchical sampling: The targeted habitat is divided into several large units; each unit is then divided into smaller subunits, which are further divided, etc. until the scale at which a plot can be chosen is reached. Randomization and selection are conducted at the smallest subunit scale, ensuring that sample stations are selected from several different units and subunits, ensuring wide dispersion.

Below are some logistical factors to consider for a sample station:

- need to consider site access,
- disturbance of the site,
- public access and site security,
- site restrictions (e.g. endangered species, breeding grounds, private property, etc.),
- costs associated with installing and sampling SET – MH sample stations

Hypothesis Testing

Below are some items to consider when distributing sample stations:

- Limit variability: by restricting unwanted factors (e.g. habitat type, elevation, & geographic extent), sample variability may be reduced, thereby maximizing the probability of being able to distinguish the effect of the factors of interest, even with a small sample size. The trade-off is a reduced sample space.
- Representative sampling: make sure samples are reflective of the factors of interest. Consider restrictive randomized sampling to ensure good representation.

Below are some logistical factors to consider for a sample station:

- need to consider site access,
- disturbance,
- public access and site security,
- site restrictions (e.g. endangered species, breeding grounds, private property),
- costs associated with installing and sampling SET – MH sample stations

Tables 1.3 and 1.4 provide examples of these designs.

Table 1.3. Options for the distribution of sample stations in monitoring studies. These examples are based on installing 6 sample stations within the sample space. Note that guidance for selection techniques is given in the section below.

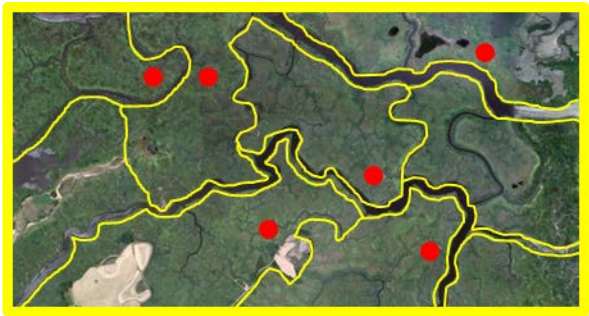
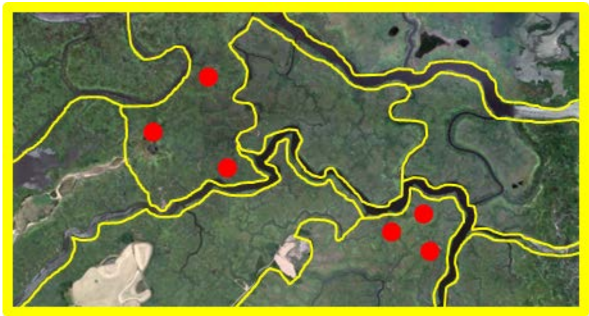
Monitoring Options:	
Option 1A: Entire Sample Space Assign sample stations to the entire sample space (Site=Space). **Pros:** Best choice for ensuring a representative sample. Spatial inference and coverage is good. **Cons:** Spatial coverage could be clumped. Logistic issues could be considerable. because of the large spatial coverage.	 Entire space is the site (yellow rectangle).
Option 1B: Select Sample Sites Choose sample sites within the sample space area of interest. Locate one sample station per site. **Pros:** Ensures large spatial coverage. **Cons:** Excluding entire sites may reduce representative nature of sample. No way of knowing if differences among stations are representative of differences among sites. Logistic issues could be considerable because of the large spatial coverage.	 Multiple Sites. One SET sample station per site.
Option 1C: Multiple Sample Stations within Multiple Sample Sites Choose multiple sample sites within the geographic area of interest. Choose three or more sample stations per site. **Pros:** Logistical issues are less burdensome because of the smaller spatial coverage. Allows for site comparisons and within-site variance estimates. **Cons:** Spatial inference and coverage is moderate (less than Option 1A). To ensure adequate spatial coverage, a large sample size is required.	 Multiple SETs per site. Example: Assateague Island NS, Colonial NHP.

Table 1.4. Options for the distribution of sample stations in hypothesis testing studies (three sample stations per factor). Note that guidance for selection techniques is given in the section below.

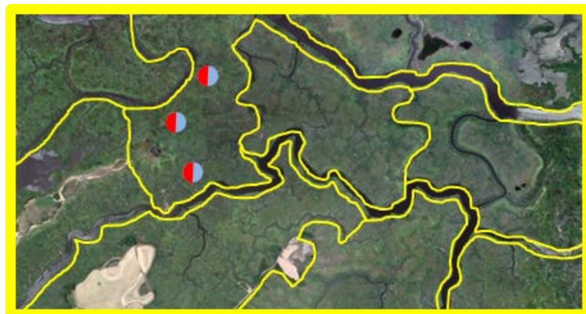
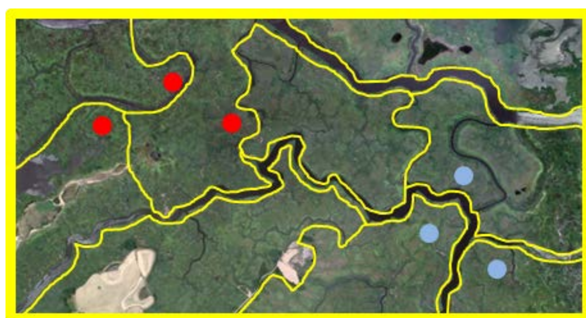
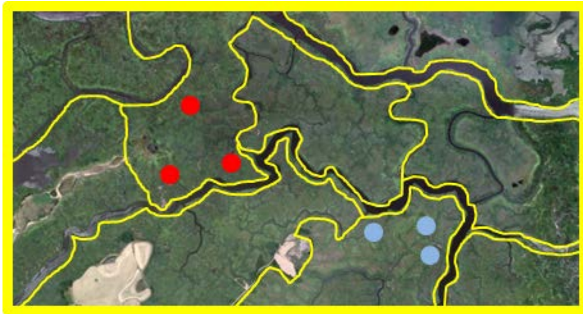
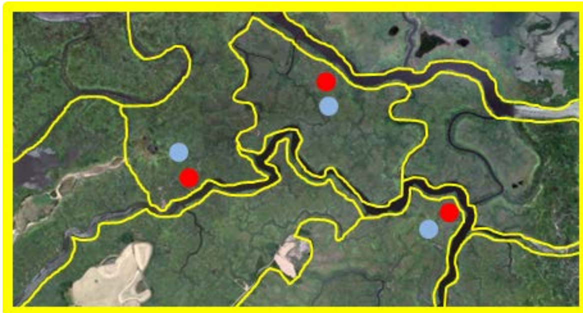
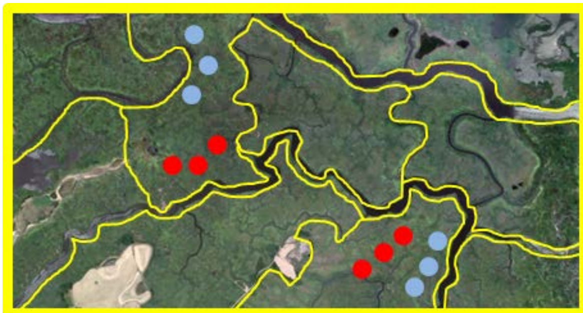
Hypothesis Testing Options:	
Option 2A: One Sample Site Select one sample site from the pool of available sample sites. Establish three or more replicate sample stations within the site. **Pros:** Logistical issues are less burdensome because of the smaller spatial coverage. More control over site-specific variables (less confounding with targeted variables). **Cons:** Spatial inference and coverage is very low. Within-site variability NOT able to be distinguished from among-site variability.	 Paired Plots within a single site. 6 stations. Example Blackwater NWR.  Split Plots within a single site. 3 stations. Two treatments within a single station. **Note: different colors indicate different factor levels.**
Option 2B: Single Sample Station per Site Choose multiple sample sites based on need to include different experimental factors and factor levels (e.g. multiple reference sites and multiple experimental/test sites; multiple wetland type A sites, multiple type B wetland sites, etc.). One sample station per site. **Pros:** Spatial inference and coverage is high. **Cons:** No within-site variance (possible confounding with site-specific variables). Logistical issues could be a problem because of the large spatial coverage.	 6 sites. Single station per site. **Note: different colors indicate different factor levels.**

Table 1.4. (continued) Options for the distribution of sample stations in hypothesis testing studies (three sample stations per factor). Note that guidance for selection techniques is given in the section below.

Option 2C: Multiple Sample Sites with Multiple Sample Stations per Site. Choose multiple sample sites as above. Establish three or more replicate sample stations per site. **Pros:** Within-site variability is estimated, good control of external variables. **Cons:** Spatial inference and coverage is moderate. Likely to be the most expensive option.	 2 sites. 3 stations per site.  3 Sites. 2 stations per site.  2 Sites, two treatment levels; 3 stations per site per treatment level. **Note: different colors indicate different factor levels.**

Choosing Sample Station Locations

Below is the general procedure to follow for determining the location of sample stations in a geographic information system (GIS) framework.

1 - Selecting a Sample Space – GIS

Delineate the sample space as a separate layer in a GIS.

2 - Selecting Sample Sites – GIS

If needed, delineate subsets of the space according to characteristics of interest (e.g. specific sites, geomorphic settings, or habitats). Randomly select one or more of these subsets based on the design of the study and number of sample stations being installed.

3 - Selecting Sample Station Locations - GIS

Randomly locate points (with suitable buffer criteria) either within the sample space (step 1), or within each of the chosen sites (step 2), depending on the nature of the study. Random selection will help to avoid biases in choosing the locations.

1. For a particular site, generate 25 or more points (potential sample station locations) independently and using a randomization scheme (refer to examples in the following section).

2. If possible, limit some random points from consideration prior to field reconnaissance. For example, one might remove:

   - Points in open water
   - Points too close to a creek
   - Points too difficult to access
   - Points too close together

3. Number the random locations sequentially (1, 2, 3, …25) in the GIS and export the coordinates to a handheld GPS.

4. Create and print a map for each site showing the random points.

4 - Visit the sites and choose Sample Station locations

Field reconnaissance is critical for choosing the final locations:

1. Bring the map of randomly selected sample station locations to the field.

2. Using a handheld GPS, visit each sample station in the order in which it was generated or chosen. Start with random point number 1.

3. The goal is to choose unbiased sample station locations representative of the site.

   - Does the random point appear to be representative of the habit of interest?

   - Is it too close to a creek?

   - Is there a log in the plot?

Table 1.5 provides examples of hypothetical criteria to apply when rejecting a sample station location. Specific criteria have to be generated for each study. Some of the criteria can be applied in the GIS.

4. If a random point is rejected, make a note of the reasons for not selecting it and move on the next random point location until a suitable sample station is selected.

5. Repeat these steps at, or within, each sample site (or in the larger sample space) until the designated number of SET sample stations required for the study is chosen.

Table 1.5. Examples of criteria used for rejecting a random sample station location.

Characteristic	Example Criteria
Vegetation	Station location is not dominated by vegetation community of interest.
Dispersion	Station locations are within 10 m of each other (too close together).
Tidal creeks	Station location is within 2 m of tidal creek (too close to creek).
Disturbance	Station location is within 2 m of muskrat mound or other disturbance.
Access to station	Station location is more than 100 m from access point (too far logistically).
Station security	Public has easy access to the station location. High potential for vandalism

Examples of Project Planning

Below are two examples of SET - MH sampling projects, one based on a monitoring design and the other on a hypothesis-testing design.

Example 1 – Monitoring Example:

Elevation and Accretion monitoring at Colonial National Historical Park, Jamestown, Virginia, USA.

1. Determine the space within which sample stations will be installed (Figure 1.3).
   Space = tidal wetlands within the area of Jamestown Island, VA.
2. Divide the sample space into sites if required by the sampling design for the project (Figure 1.4).

   CRITERIA FOR THIS PROJECT:
   Project – Monitoring Elevation and Accretion in the tidal marshes of Colonial NHP, Virginia.
   Habitats – 2 general types of wetland habitat in the area of Jamestown Island.

   a. Habitat 1 – *Peltandra* and *Spartina cynosuroides* marshes (Fresh tidal marsh)
   b. Habitat 2 - *Spartina cynosuroides* marsh (Oligohaline tidal marsh)
   c. Installing 12 SETs, 4 Sites, 3 sample stations per Site.
   d. Choose 2 sites in each of the two habitats.
   e. This is a monitoring study with site comparisons (Table 1.3, option 1C).
   f. Restrictions: Many of the sites are very difficult to access. Need access by foot or with a canoe.

Figure 1.3. Jamestown Island, Virginia showing the NPS park boundaries in yellow.

Figure 1.4. Delineated wetland sites on and around Jamestown Island.

3. Delineate the site or sites (in a GIS) such that they are similar in size and contain similar habitats.

   Delineation of sites:
   a. Tidal marshes only (no forested areas).
   b. Each site is approximately 3-10 hectares in size.

4. Randomly choose a sample site (or sites) as required by the criteria for the project (Figure 1.5).

   Site Selection Criteria:
   a. 2 marshes chosen in habitat 1.
   b. 2 marshes chosen in habitat 2.
   c. Rejected marshes that were too difficult to access.

Figure 1.5. Four sample sites randomly selected in ARCmap. Red are fresher tidal sites of Habitat 1 (Peltandra and Spartina cynosuroides). Blue are saltier sites of Habitat 2 (Spartina cynosuroides).

5. Randomly choose 20 to 30 sample station locations within each site. Number them accordingly and put them on a map (Figure 1.6).

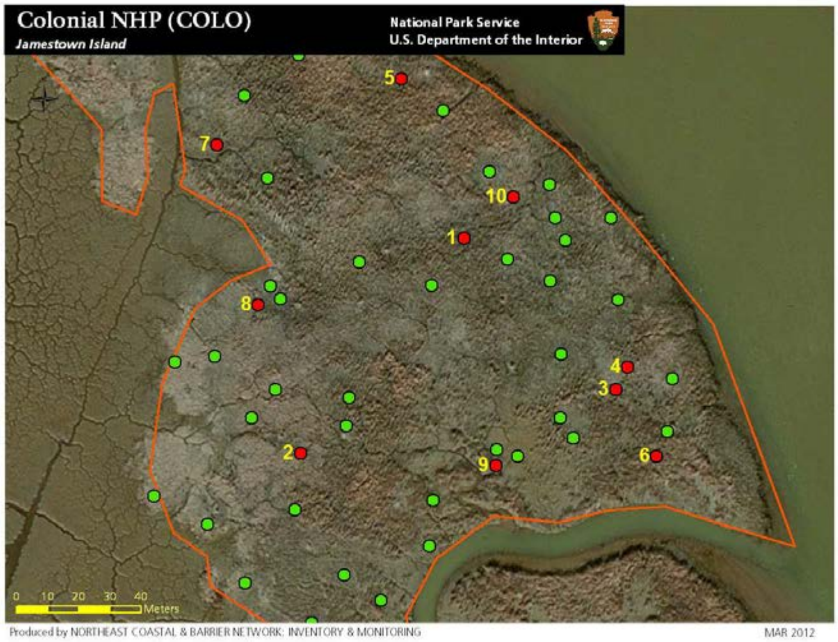


Figure 1.6. Example of potential sample stations randomly located within a delineated wetland site (Marsh 30) using ARCmap. Points 1 through 10 are numbered (RED).

6. Visit the potential sample station locations starting with random point #1. Based on the criteria, determine if this point is a suitable sample station location. Continue to visit the random points until all sample stations needed for the particular site are chosen (3). Mark the sample stations with PVC poles (and flagging) for later installation of the SET mark (Figure 1.7). Be sure not to trample inside the area staked off.

Figure 1.7. Selection of sample station location at Marsh 30.

Example 2 – Hypothesis Testing Example:
Comparing elevation change and accretion in a restored marsh and a control marsh at Gateway National Recreation Area, New York, New York, USA.

1. Determine the space within which sample stations will be located (Figure 1.8).
   Space = Big Egg marsh in Jamaica Bay, NY.

   Big Egg is a tidal salt marsh vegetated predominately by *Spartina alterniflora*. The marsh is deteriorating and sparsely vegetated in many areas.

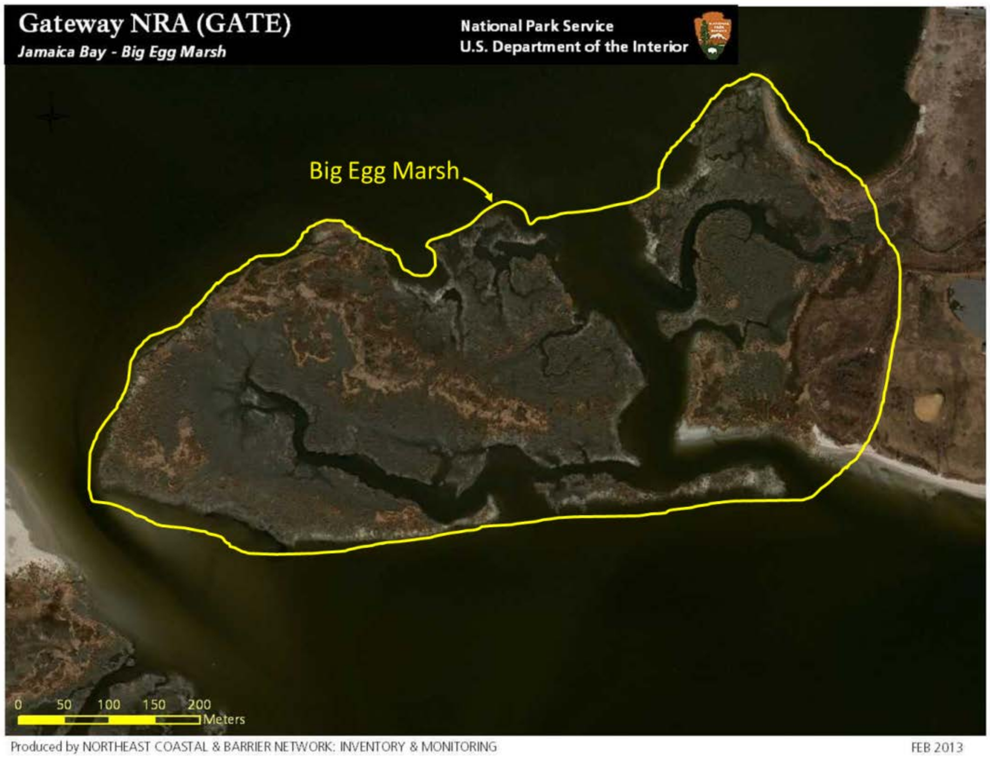


Figure 1.8. Big Egg marsh in Jamaica Bay, NY USA.

2. Divide the sample space into sites as required by the sampling design chosen (Figure 1.9).

   CRITERIA FOR THIS PROJECT:

   Project – Saltmarsh Restoration pilot project at Big Egg Marsh

   a. Hypothesis-Testing study –What is the issue? Large parts of Big Egg marsh are deteriorated and sparsely vegetated. Sediments from an adjacent channel will be sprayed onto a section of Big Egg marsh to raise the elevation by approximately 30-40cm. An adjacent marsh will be used as a control. Elevation change and accretion will be monitored at both sites before and after the restoration.

   b. Installing 6 SETs, 2 Sites (Spray Site, Control Site), 3 SET sample stations per Site (Table 1.4, option 2C).

c. Restrictions: Both spray and control sample stations need to be located close to the tidal channel due to the limitations of spraying the dredged material onto the spray marsh.

Figure 1.9. Site locations at Big Egg marsh.

3. Delineate the two sites such that they are similar in size and contain similar habitats (Figure 1.10).

Figure 1.10. Spray site and control sites delineated at Big Egg marsh.

4. Randomly choose sample station locations as required by the criteria for the project (Figure 1.11).

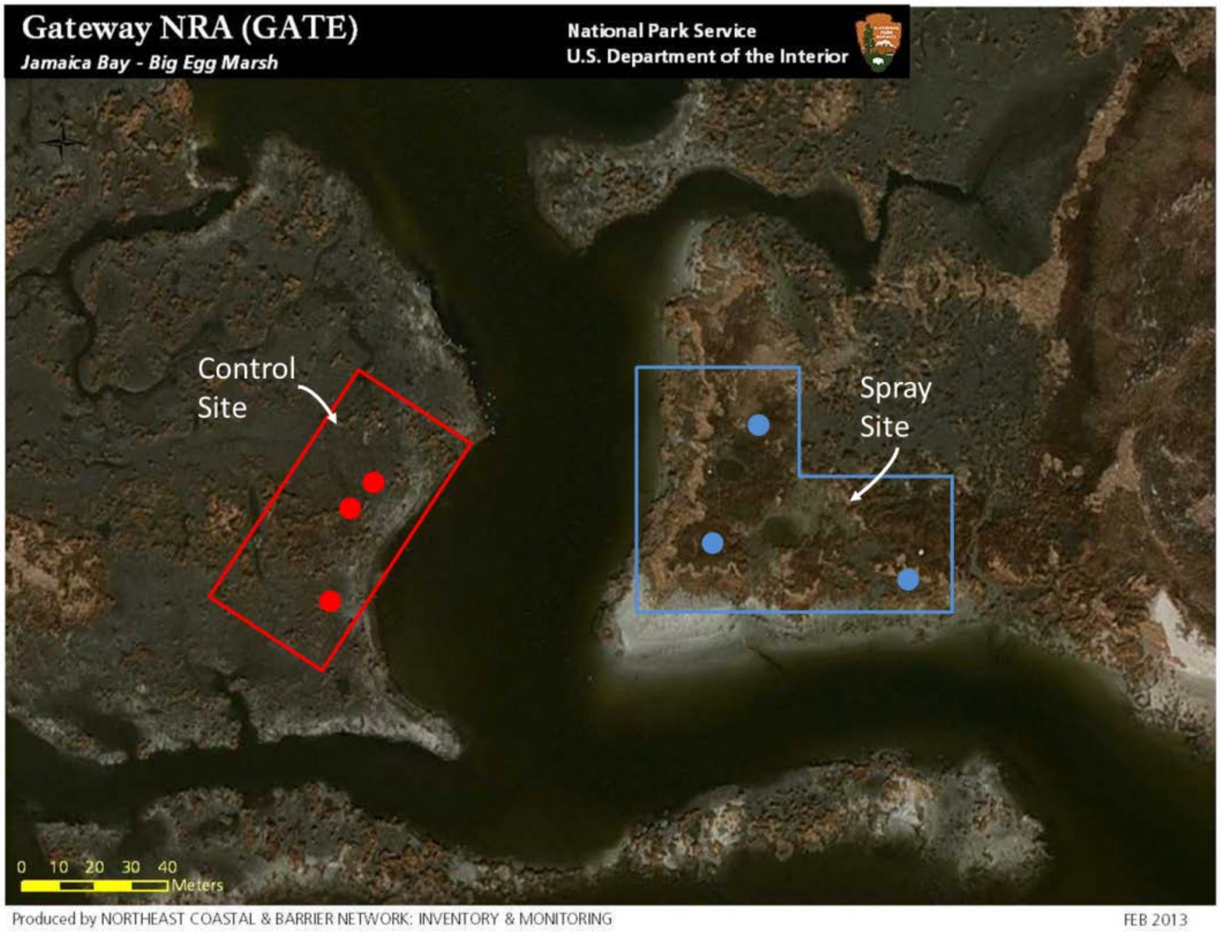


Figure 1.11. Random location of sample stations.

Table 1.6. Checklist to assist in defining an SET-MH project.

Item	Answer
Does the project involve monitoring or hypothesis testing?	Monitoring or Hypothesis testing
Describe the Space being worked in.	
How many Sites are there?	
What are the important variables of interest?	
What are the logistical constraints?	
How are the sample stations being distributed?	Monitoring - 1a, 1b, 1c Hypothesis testing – 2a, 2b, 2c Other:
How many SET sample stations are needed?	
Were sites delineated and sample stations randomly selected in a GIS?	Yes (date) ______________________________
Were the sites and random points visited to choose the sample stations?	Yes (date) ______________________________

SOP 2: Sample Station Layout and Platform Options

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

This SOP provides guidelines for the layout of a Surface Elevation Table (SET) and Marker Horizon (MH) sample station and instructions on the construction of permanent or temporary platforms. This SOP assumes that the Rod SET (RSET) is being used for measurements and that sample station locations have already determined (See SOP #1).

SET sample stations typically consist of an SET mark (deep and/or shallow) and marker horizons. The wetland surface around a sample station may be soft and unconsolidated and will more than likely be vegetated. To minimize impacts to the surface and the vegetation around the station, it is recommended to work on a raised platform (Figure 2.1). A sampling platform can be either a permanent or temporary structure depending on the needs for a particular project. Table 2.1 outlines some of the criteria to consider when deciding what type of platform to use.

Figure 2.1. Permanent sampling platform (Fishing Bay WMA, MD, USA).

Table 2.1. Permanent and temporary platforms.

Type of Platform	Description	When to use	Pros	Cons
Permanent Platform	Platform is built on site. Supports are usually constructed out of treated wood. Typically uses wooden planks or fiberglass grating to walk on.	Can be used in all wetland types. Required in wetlands with soft sediments. Can be used in shallow ponds or open water. Normally used when a temporary platform is not feasible.	Stable platform to work from. Less trampling of the wetland surface.	Visibility may attract attention from the public and wildlife. Using wood will shade the vegetation below. May alter the habitat by accumulating wrack or causing local scouring. Can be expensive. Can be damaged by ice in the winter.
Temporary Platform	Small platform comprised of a plank attached to two stools or similar structures which is brought to the site when sampling.	Can be used in wetlands with firm sediments. Used when permanent platforms are not allowed. Good for remote or hard to access areas where a permanent platform is not feasible.	Lightweight and portable. Inexpensive.	Small area to work from when sampling. May end up trampling more of the site. More gear to transport to the site.

Sample Station Layout

There is a general layout for a sample station based on one or two SET marks and multiple marker horizons. The typical station is square or rectangular in shape and consists of the following:

1. SET measurement area – the area within a sample station with a deep and/or shallow SET mark around which pin measurements are taken (yellow or green circle in Figure 2.2, 2.3). No other sampling occurs within this area in order to avoid any disruption of the wetland surface measured by the SET instrument. This area is usually near the center of the sample station and may vary in size based on the design of the RSET. If installing both deep and shallow marks adjacent to each other in the same station, the measurement area will be twice the size (Figure 2.3).

2. Marker horizons – Three or four plots (50cm x 50cm) with a marker horizon (blue boxes in Figure 2.2 and 2.3) for measuring vertical accretion. Plots are typically located around the perimeter of the sampling area, commonly near the corners, in close proximity to the SET measuring area.

3. Platform – All sampling occurs from a platform that is either temporary or permanent in order to avoid disruption of the wetland surface. A platform is not shown in Figure 2.2 and 2.3. See Table 2.1 for various platform options and pros and cons.

4. Stakes – PVC or fiberglass stakes are commonly used to mark the various sampling areas within the station (black circles in Figure 2.2 and 2.3). Stakes will vary in length from about 2-3' (0.6 - 1.0 m). Note that stakes which protrude high above the wetland surface may accumulate wrack and get removed by ice in cold weather areas. It is very important to clearly mark the following areas of the sample station:

    a. Corners of the sample station – Avoid walking on the surface within the sample station. Staking the 4 corners would clearly delineate the boundaries.

    b. Marker Horizons – Marker horizons will normally become buried after being placed on the wetland surface, so it is critical to mark their locations to allow for sampling in the future.

    c. SET orientation – In general, SET measurements are taken in 4 directions (labelled ABCD, typically every 90 degrees). The SET can read 8 different directions so it's important to mark where the measurements are being taken. Marking the "A" direction with a short stake is a common way to help orient the SET.

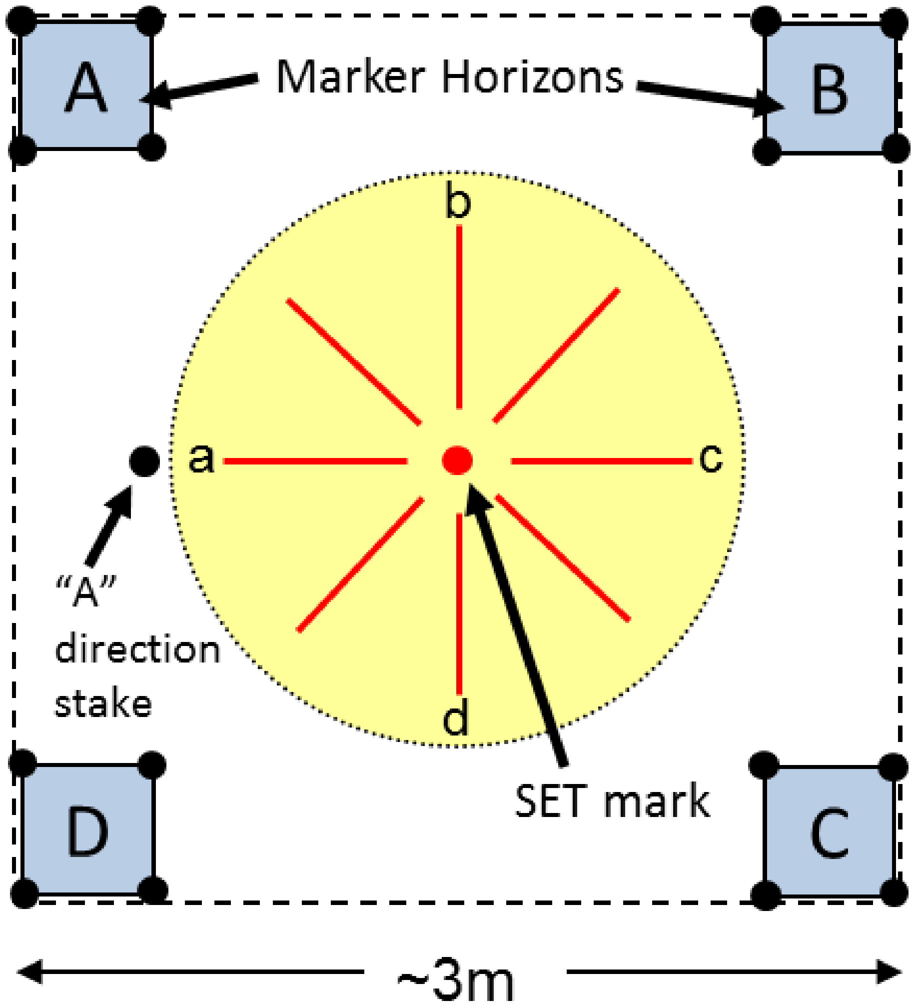


Figure 2.2. Sample station layout showing a single deep RSET mark and four marker horizons and the 8 potential directions for measurements. Yellow circle = SET measurement area, Blue boxes = marker horizons, Black circle = stakes (not to scale), Red line = Potential direction for measurement.

Other types of data are commonly collected at the sample station (soil cores, pore water, vegetation, etc.). Be aware that layouts described in this document are only guidelines. Exact dimensions and layout of a sample station will depend on the measurements being taken and the type of platform being used.

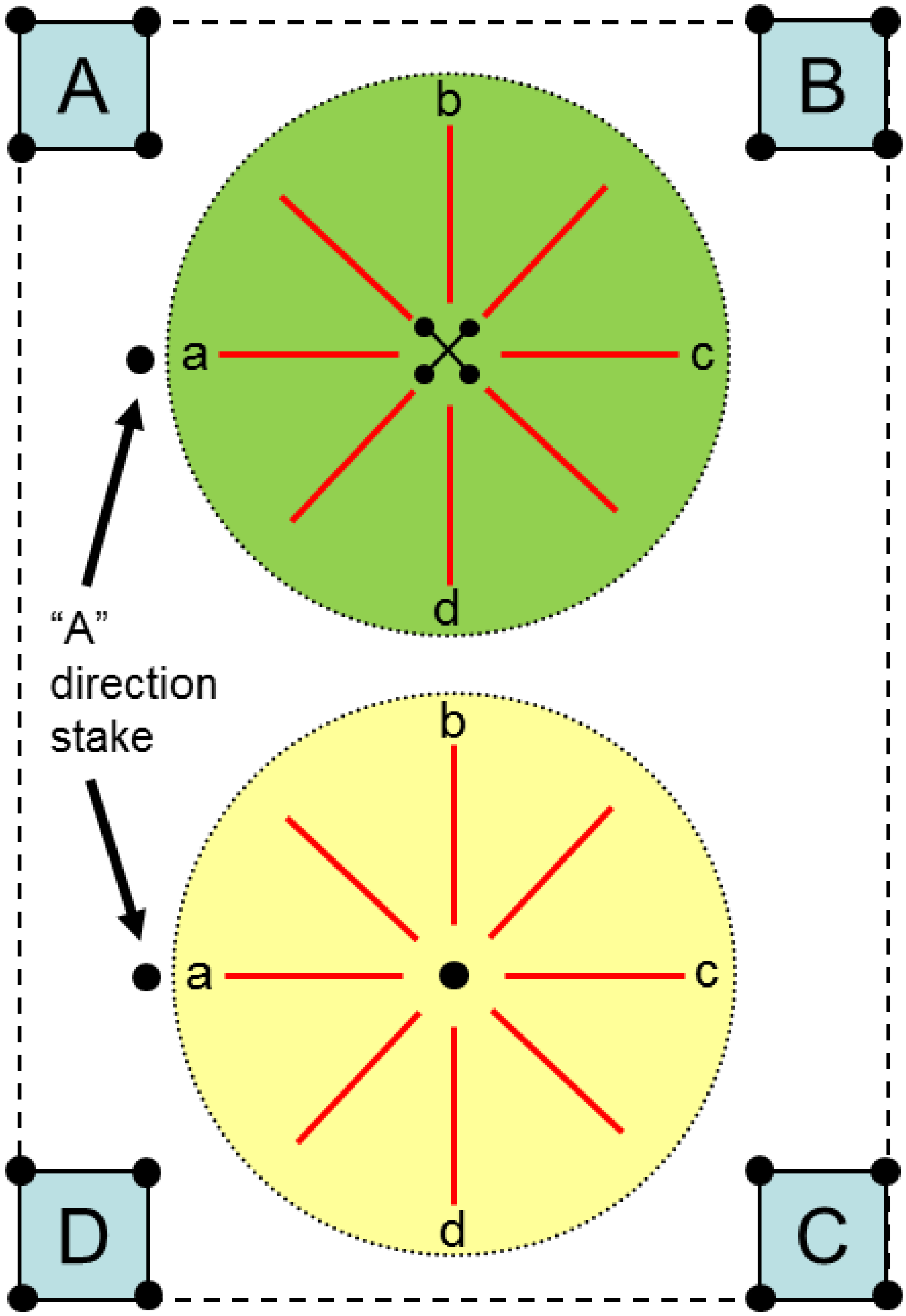


Figure 2.3. Sample station layout with a shallow and deep mark and marker horizons. Yellow circle = Deep RSET mark measuring area, Green circle = Shallow RSET Mark measuring area, Blue boxes = Marker horizons, Black circle = stakes.

Permanent Platforms

Permanent platforms (Figures 2.4, 2.5, 2.6) are installed directly into the sediment at the sample station and are not removed, although the planks may be removed to reduce the impact of the plank on the habitat (shading, animal perch, wrack accumulation, etc.). Note that permanent platforms in cold environments can be impacted by ice.

Figure 2.4. Permanent platform in a brackish marsh (Fishing Bay WMA, MD, USA).

Figure 2.5. A permanent platform in a shallow pond (Delta NWR, Venice, LA, USA) with an original pipe SET mark. Note the mark is raised above the water to accommodate the SET, which requires longer SET pins to reach the water bottom.

Figure 2.6. Permanent platform in a brackish marsh (Fishing Bay WMA, MD, USA).

Permanent Platform Options:

There are many ways to construct a permanent platform. Most are built using pressure-treated lumber to improve longevity. Two commonly used methods are described below.

<u>A: Platforms with individual corner supports (teeth)</u>

Platforms built with individual corner supports, colloquially called teeth, consisting of a crosspiece and two legs (Figure 2.8), will have slightly different layouts than other platform designs because of constraints imposed by the design of the teeth and the length of the planks. Figure 2.7 and 2.8 show the typical sample station layout and construction used for this design.

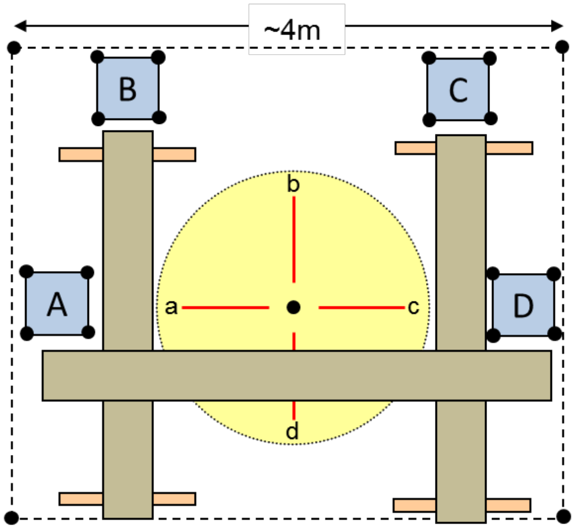


Figure 2.7. Schematic showing the sample station layout when using a permanent platform with teeth. Note that the two parallel planks are typically permanent and the middle plank is only deployed during measurements.

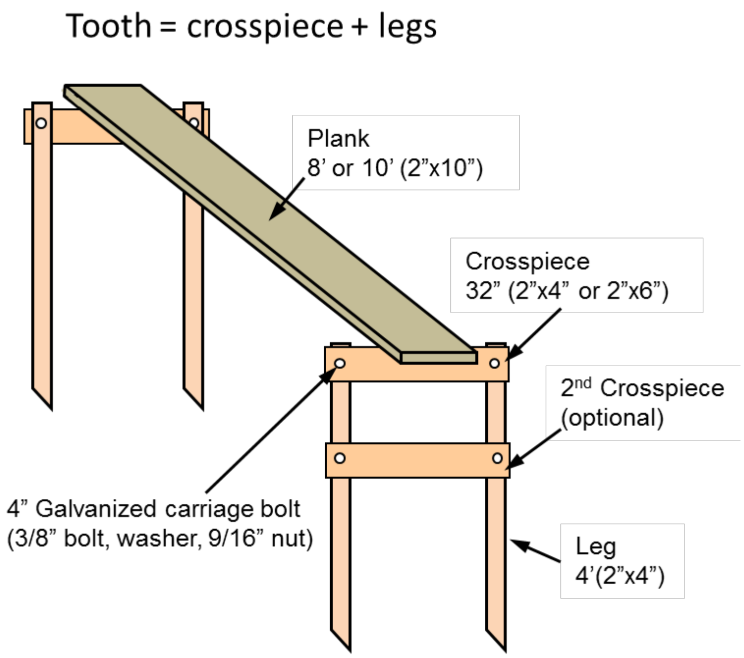


Figure 2.8. Detail of one side of an SET platform, showing approximate dimensions of the component parts.

Supplies:

1. Planks – Treated, 2"x10" wooden planks are normally used though other materials such as fiberglass grating or aluminum bleachers are also suitable. Planks are usually 8'-12' in length. Multiple planks will be needed. Two for the fixed, parallel planks, and an additional plank for the movable center piece.

2. Teeth – A platform will normally consist of 4 (or more) corner supports, or teeth. The teeth are installed using a sledgehammer (Figure 2.8).

    a. Legs – Normally legs are constructed out of a pressure treated 2"x4"x8' board. Other materials, such as PVC pipe, may also work. Each 8' piece of lumber is cut in half at an angle to create 2, 4' legs. Shorter legs may be needed in firm sediments or longer legs in very soft sediments.

    b. Crosspiece - The crosspiece is typically made out of a treated 2"x 6" board and is cut to about 32" in length. An 8' length of lumber will result in 3 crosspieces. In very soft sediments, a second crosspiece can be attached below the first one to keep it from sinking too far into the ground. Be sure to have the 2 vertical legs stick up above the crosspiece a few inches. This will provide a guide to keep the planks from sliding off the tooth.

    c. Bolts – Holes (3/8") are drilled into the leg and crosspiece for each tooth. A 3/8" galvanized carriage bolt (4") is inserted in the hole and secured with a washer and nut.

3. Tools – Sledgehammer, hammer, 9/16" wrench, cordless saw, cordless drill, 3/8" drill bit.

Installation:

Figure 2.9. Preparing a tooth for installation (Everglades NP, FL USA.)

1. Assemble the legs and crosspiece. Do this ahead of time before heading to the field. Loosely secure the legs and crosspiece with the bolts and nuts (Figure 2.9). Tightly secure the bolts after the teeth are in the ground. Note that teeth are normally installed in pairs.

2. Using a sledgehammer, pound the 1st tooth into the ground (Figure 2.10). Be aware of the dimensions of the sample station. Make sure the teeth are close enough to allow a plank to lie across.

3. Lay a plank on this tooth. The far end will be laying on the wetland surface. The close end of the plank will be on the crosspiece of the first tooth, about 10-18” (25-45 cm) off the ground.

4. Walk out onto the plank with the next tooth. Install this tooth while standing on the plank.

5. Walk off the plank after the tooth is installed. Slide the plank off the wetland surface and onto the other tooth (Figure 2.11).

6. Repeat this process for the remainder of the platform. Adjust the height of the platform with the sledgehammer after the planks are on it. The platform should not to be too high since it will make working with the SET difficult. A good height for the plank is about 10-18” (25-45 cm) off the ground. When satisfied with the height and layout of the platform, use a wrench to fully tighten the bolts on all of the legs. This will help to further stabilize the platform.

7. Planks – If necessary, attach the planks to the teeth with nails or screws. Do not do this for the cross plank which lies across the SET plot. This plank will need to be moved around when taking SET measurements.

Figure 2.10. Installing the first tooth (McFaddin NWR, TX USA).

Figure 2.11. Installed platform (Blackwater NWR, MD USA).

B: Square platforms

Square platforms are usually smaller in size than platforms using teeth (Figure 2.12, 2.14). They typically use a single plank for taking measurements (Figure 2.13).

Figure 2.12. SET mark installation on a square platform (Waquoit Bay NERR, MA, USA).

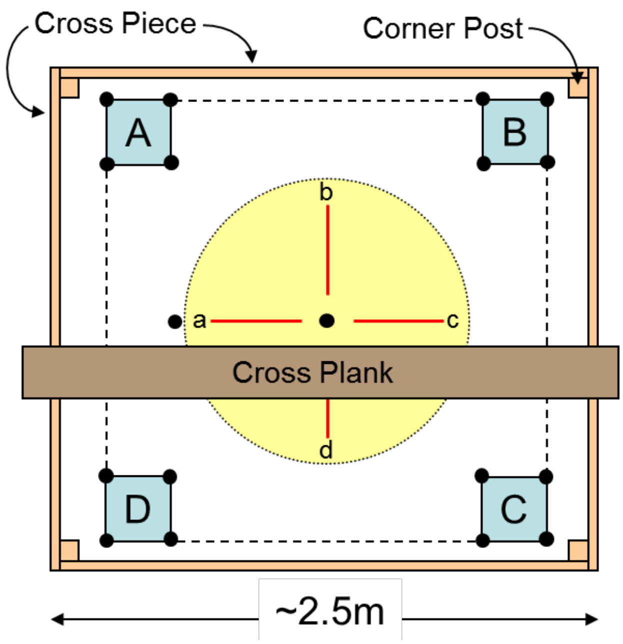


Figure 2.13. Square platform design.

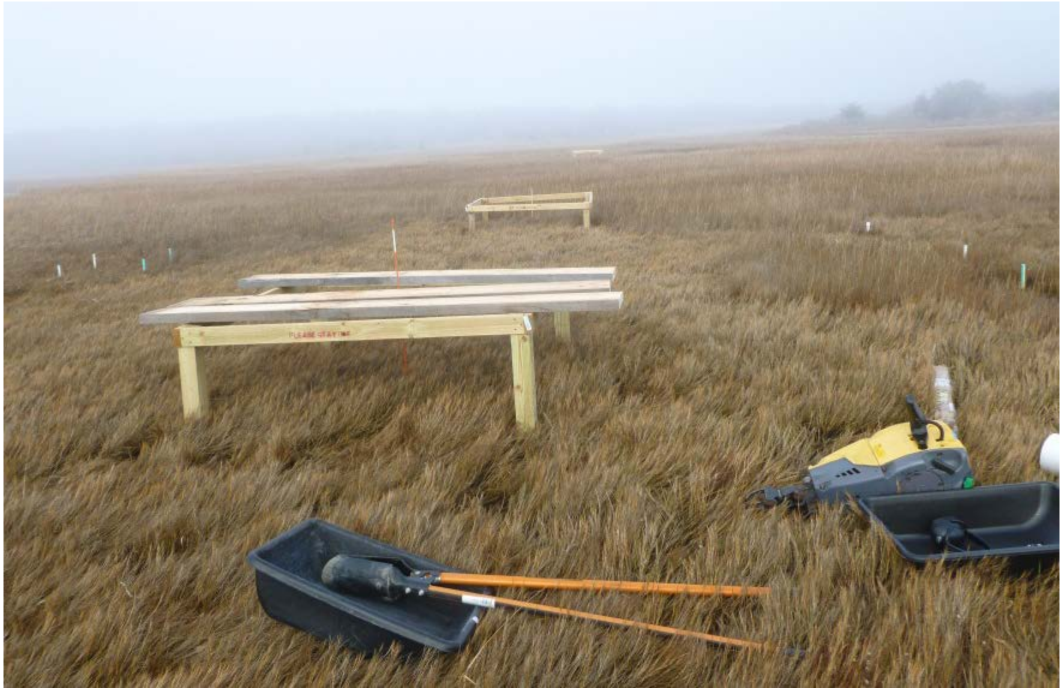


Figure 2.14. Square Platforms (Waquoit Bay NERR, MA, USA).

Supplies:

1. Planks – Treated, 2”x10” wooden planks are normally used. They are usually 8’ or 10’ in length. Aluminum “bleacher” planks also work very well.
2. Corner post –For the square platforms, treated 4”x4” posts usually 4’ in length are installed at each corner.
3. Crosspiece - The crosspiece is typically made out of a treated 2”x4”x8’ or a 2”x6”x8’.
4. Bolts, screws, nail – 5/16” x 6” carriage or hex head bolts. Washer and nuts. Need one bolt at each end of the crosspiece. 8 per platform.
5. Tools – Sledgehammer, hammer, 9/16” wrench, cordless saw, cordless drill, 3/8” drill bit.

Installation:

1. Install the 4 corner posts with a sledgehammer. Use a crosspiece as a guide when installing the corners to make sure they are positioned correctly.
2. Attach the 4 crosspieces. Consider the height of the crosspieces and figure out the optimal height for the platform before attaching the wood.
3. Pre-drill holes (3/8”) into the corner post. Hammer in the bolt, attach the washer and nut and tighten with a wrench. Bolts are recommended for added strength and longevity, but wood screws or nails will also work.

4. If the 4x4 corners protrude above the crosspiece, cut them off with a saw after installation with a reciprocating saw (battery powered).

Temporary Platforms

The temporary platform is brought to the field when taking measurements and is removed when finished (Figure 2.15, 2.16, 2.17).

Figure 2.15. Temporary sampling platform below (Acadia National Park, ME, USA).

Figure 2.16. Temporary platform (Acadia National Park, ME, USA).

Figure 2.17. Temporary Platform (Barn Island, CT, USA).

The need to carry a platform into the field means that it is needs to be as lightweight as possible. A portable platform normally consists of one or more wood or aluminum planks with “milk crates” or “step stools” taped to the bottom to elevate the planks above the wetland surface. The step-stools typically have small pieces of wood bolted to the bottom to keep the legs from sinking into the wetland soil (Figure 2.15, 2.16, 2.17). Aluminum planks (bleacher planks) are recommended as they are lighter than wood planks and result in a lighter platform which is easier to transport.

For portable platforms to be successful, the sample station has to have firm or relatively firm sediments. Mark the boundaries of the sample station with PVC or fiberglass stakes to know where to position the portable platform each time the station is visited.

Figure 2.18. Plastic Step Stool and hardware.

Temporary Platform Construction

Supplies:

1. Wooden or aluminum planks – A wood plank is normally a 2”x8” or 2”x10” and approximately 10’ in length. If they are available, it is recommend to use aluminum planks (bleacher seats) which are about 10’ in length and about 9.5” wide. Aluminum

planks are lighter than wood and last much longer. One to three planks will be needed when visiting a sample station.

2. Plastic step stool, milk crate or other suitable base. The instructions in this document assume the use of a plastic step stool (Figure 2.18, 2.19).

3. Wooden base – The strips of wood are attached to the legs of the step stool and help to keep the stool from sinking while working on the platform.

    - Option 1 - 16-18" long treated boards, 2 per step stool. Try to use treated lumber of the following dimensions: 1"x2", 1"x 3" or 1"x4" (Figure 2.19).

    - Option 2 - A single piece of plywood (16" x 12") bolted to the bottom of the 4 legs to increase the surface area in contact with the sediment. One per step stool. This design would help to decrease the sinking of the platform when working in softer sediments or on mudflats.

Figure 2.19. Step stool with wooden bases attached.

4. Nuts, bolts washers. – 1.25" long bolt (5/16", 8 mm), aircraft nuts (nuts with a plastic locking mechanism), washers (4 each per step stool) - used to bolt the wooden supports to the legs of the step stool.

5. Electric or battery powered saw and drill.

6. Duct tape or nylon strap – Duct tape or a nylon strap will work to secure the step stool to the plank (Figure 2.20).

Instructions:

1. Drill a hole through the end of each leg of the step stool. Four holes per stool.
2. Cut the wooden strip to appropriate size. Place stool on the wooden strip and mark the hole locations with a pencil or pen.
3. Drill 3/8” holes in the wooden base.
4. Place the bolt through the hole in the leg and then through the wooden base
5. Attach the washer and nut. Tighten with a 9/16” wrench.
6. Attach the step stool to the plank with duct tape or a nylon strap (Figure 2.20).

Figure 2.20. Temporary platform (Acadia National Park, ME, USA). Note the step stools are attached to the plank with duct tape.

SOP 3: Installing an RSET Mark

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

Once the study design and layout have been established for a particular project (SOP #1, SOP #2), the next step is the installation of the SET mark(s) at each sample station. A Rod SET (RSET) mark is designed to provide a vertical reference point from which elevation measurements can be collected for many years. Two types of marks can be used with the RSET instrument: deep and shallow, and both are designed to be stable for many years (Figure 3.1). Both mark types integrate processes occurring from the bottom of the mark to the wetland surface. A shallow mark integrates processes occurring near the surface since it is typically driven to a depth of less than 1 meter. A deep mark integrates over a greater depth of the soil profile since it is driven much deeper than a shallow mark. Processes occurring below the mark (i.e. deep subsidence) are not measured by the RSET. There are numerous options for driving the rods used in a deep mark; from a hand pounder to a gasoline powered hammer drill. The shallow mark design differs from the rod mark and has a different installation procedure. A shallow mark is commonly installed in conjunction with a deep mark. The measurement of both marks simultaneously can be used to determine where elevation change is occurring in the soil profile.

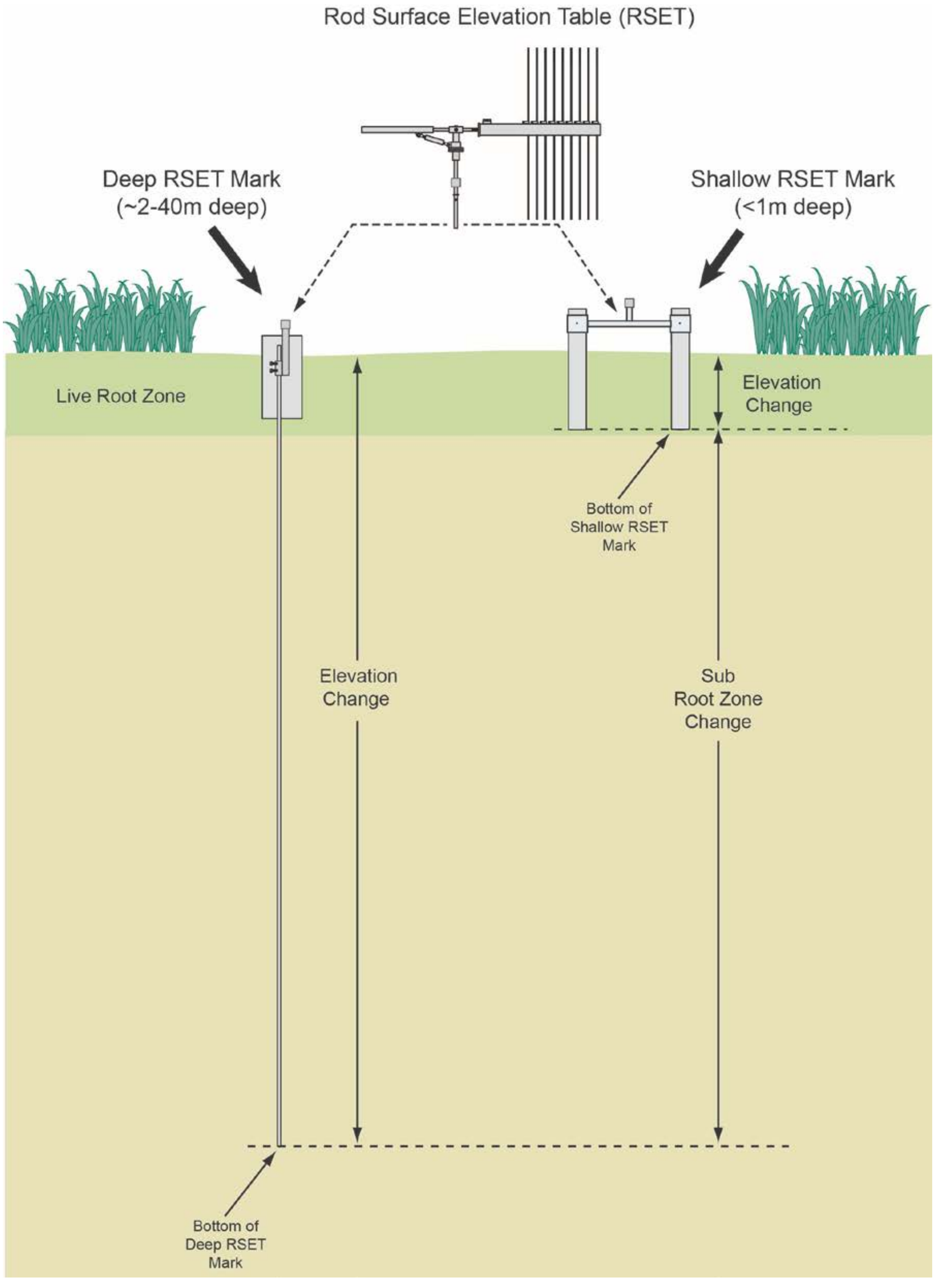


Figure 3.1. Cross section of a wetland showing the deep and shallow RSET marks commonly used for monitoring elevation change. The deep mark consists of 4 foot (1.2 m) sections of stainless steel rod threaded together.

Deep RSET Mark

A deep RSET mark is installed using stainless steel (SS) rods driven into the wetland sediment to a considerable depth. A custom built receiver, which couples with the SET instrument, is securely attached to the top of the deep mark.

The general procedure for installing a deep RSET mark is as follows:

1. Install a temporary or permanent platform to work on.
2. Dig a hole and drive multiple sections of stainless steel rod into the ground.
3. Cut the rod (if necessary).
4. Insert PVC collar.
5. Attach the receiver to the rod.
6. Fill PVC pipe with cement.

Supplies for Installing a Deep RSET Mark

Refer to Appendix A for a detailed list of supplies.

1. Sampling Platform – See SOP #2
2. Stainless Steel Rods – A deep mark consists of 15 mm (9/16th inch) diameter, 1.2 m (4 feet) long stainless steel rods that are threaded together (Figure 3.2). Costs per rod range from $15-$25. Prices can vary considerably from year to year. Rods are driven into the sediment to a depth ranging from 2m to over 40m (~6-130 ft.) depending on the particular conditions found at each wetland and the equipment used to install them. Driving points are short pieces of SS rod with a point on the end (Figure 3.2). These are placed on the leading edge of the first rod in a deep mark. So, only a single driving point is needed for each mark.

   Estimate the number of rods per deep mark and order them ahead of time. How many to order depends on:

   a. The depth of unconsolidated wetland sediments, geologic history of the sediment vertical profile, and the nature of the underlying geology.
   b. The equipment used to drive the rods.
   c. Budget.

   Since the rods are rather expensive, the budget for installation may impact the number of rods available for deep marks. In addition, the different tools used to install them could also affect the number of rods used. For example, the hammer drill can easily use 20 or more rods for each mark, whereas the hand pounder will commonly use less than 20 rods. A good estimate would be 15-20 rods per mark if NOT using the hammer drill and 20 or more if using one. In wetlands where one might expect to hit bedrock or limestone, fewer rods may be needed.

Figure 3.2. Stainless steel rod showing the driving point used on the first rod. Note the threaded studs used to couple sections of rod together.

3. Hammer or pounder for driving rods into the wetland sediment:

   There are three commonly used tools for driving the rod into the ground:

   a. Hand Pounder – Figure 3.3

   b. Demolition Hammer – Figure 3.4

   c. Hammer Drill – Figure 3.5

   Table 3.1 gives an overview of these three devices. Method B or C is recommended for the installation of a deep mark even though they are expensive. Consider renting or borrowing this equipment if it cannot be purchased.

Figure 3.3. Hand pounder (Waquoit Bay NERR, Massachusetts, USA).

Figure 3.4. Demolition hammer and generator (Cape Cod NS, Massachusetts, USA).

Figure 3.5. Gasoline powered hammer drill (Chesapeake Bay Environmental Center, MD, USA).

Table 3.1. Comparison of features in the equipment commonly used to install a deep RSET mark.

	Hand Pounder	**Demolition Hammer**	**Hammer Drill**
Manufacturer	Custom Built	Bosch 11316EVS	Cobra Combi
Weight of tool	~15 lbs.	~28 lbs.	~55 lbs.
Cost of tool (US $)	~$100-200	~$700-800	~$4500
Operation of tool	By hand	Electric. Need a generator	Gasoline powered
Minimum number of people to operate.	One	Two	Two
Typical depth of mark	0-60 feet	0-80 feet	0-130 feet
Pros	Very light and easy to handle.	Relatively light and easy to operate.	Generates the most power. Can drive rods the deepest.
Cons	May require considerable physical labor to drive in the rods. Doesn't usually get as deep as other techniques.	Requires a generator. Not as powerful as the hammer drill.	Expensive and Heavy. More involved to carry and operate.

1. Driving head - Attaches to the top-most stainless steel rod (Figure 3.10). It takes the blows from the hammer or pounder. The head protects the 4’ sections of rod from getting deformed from the pounding. They can be ordered when purchasing rods or cut from a 4’ rod to use for this purpose. It needs to have threads on one end so it can couple with each new rod added to the mark. The driving head is usually 4-12" in length. After a rod is pounded into the ground, the driving head is removed and a new rod attached. The driving head is attached to the new rod and this step is repeated until the driving stops.

2. Angle Grinder or Bolt Cutter - When the mark can no longer be driven into the ground, the rod may need to cut if it is not level with the surface (i.e., some of the rod protrudes above the wetland surface). An angle grinder is recommended to cut the rod at the wetland surface (Figure 3.15). It should be battery powered or electric (if a generator is available). A hydraulic bolt cutter can also be used to cut the rod (Figure 3.17) but is not recommended. A hacksaw will work with considerable effort and is also not recommended.

3. Narrow bladed “sharpshooter” shovel or post hole digger – To dig the shallow hole for the deep rod (Figure 3.7). The shovel is also used for mixing cement.

4. Receivers– Receivers are custom built out of stainless steel. They cost $125 - $175 each (US$). Receivers are designed to bolt onto the last section of rod and couple with the RSET instrument (Figure 3.6). The receiver allows for a fixed and repeatable coupling so the SET instrument is in the exact same position for each sampling. One receiver is needed for every deep mark.

5. Concrete – “redi-mix” concrete (with stones) or mortar (without stones) work fine. The depth of the hole (and PVC collar) will determine how much concrete is needed for a mark. It typically takes ½ - 1 bag of cement (60 lb.) for a single deep mark.

6. PVC Collar – 15cm (6") diameter PVC pipe (Schedule 40) - ~18-48" long. The PVC pipe goes into the hole after the rod is finished being driven (Figure 3.19). After the receiver is attached to the rod, the PVC pipe is filled with cement.

7. Tools/Gear: Vice Grips (2-3), box wrench (9/16”), small sledgehammer, bucket, paper towels, duct tape, hand pump, gloves, hearing protection, thread locker glue, dust mask.

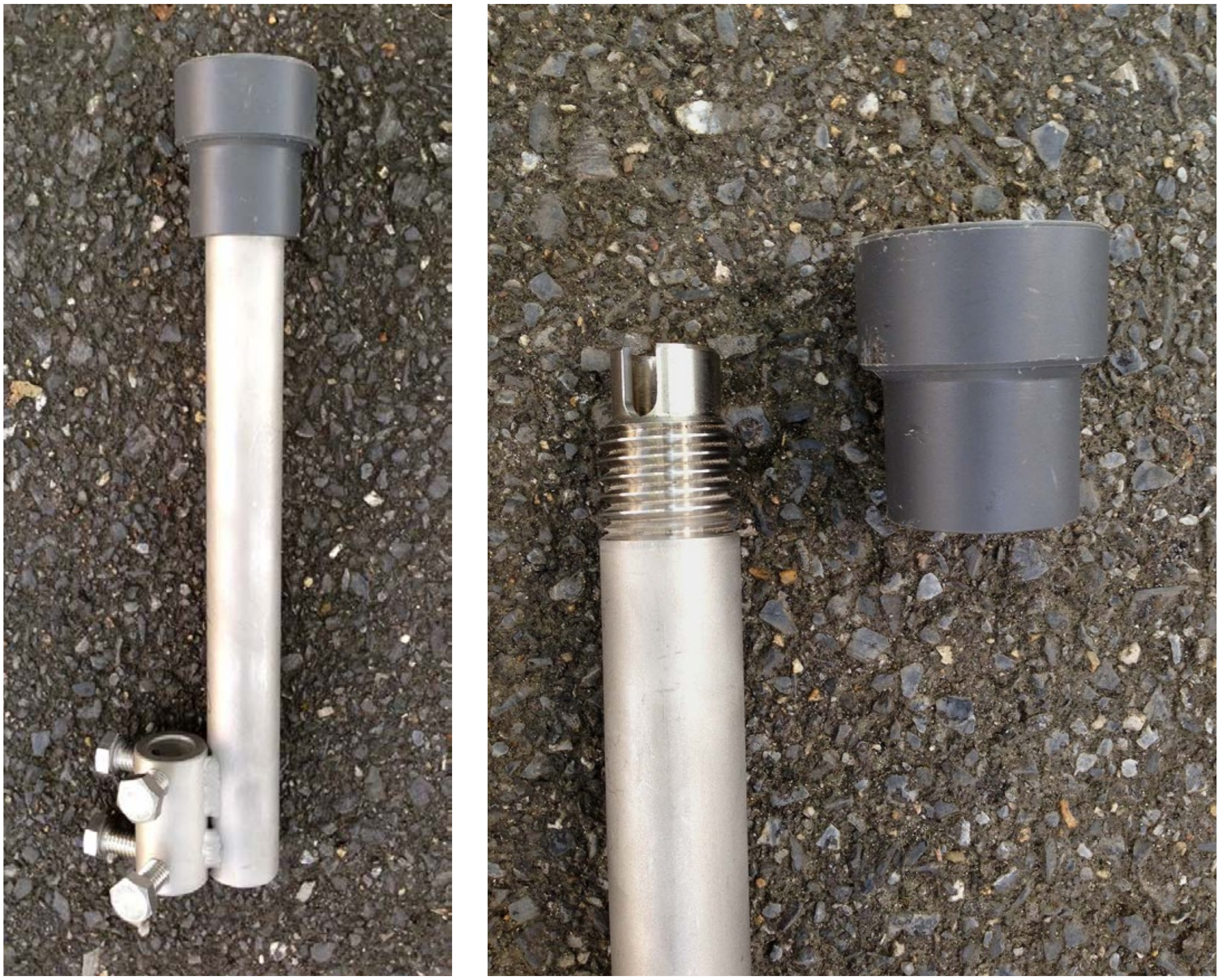


Figure 3.6. Receiver.

Deep Mark Installation Instructions

1. Use a temporary platform or build a permanent platform. Refer to SOP #2 for details.

2. Drive Rods into the wetland sediment.

   a. Dig a hole and drive the stainless steel rods into the ground: Determine the location of the deep mark. Using a post-hole digger and/or narrow blade shovel, dig a 6" diameter hole (the diameter of the PVC collar) to the appropriate depth (Figure 3.7). Note that the hole may have water in it (Figure 3.9). This is normal.

   b. The depth of the hole is determined by the length of the PVC Collar which may vary in length from 18”- 48”. Place the soil from the hole in a bucket and remove it from the immediate area of the sample station. The hole should be shallower than the length of the 6" PVC collar.

For example, if using a 24" length of 6" PVC for the collar, dig a hole about 6” wide about 12-15" deep (Figure 3.8). This ensures that the bottom of the PVC pipe will be driven into the underlying substrate when installed. This will help to anchor and stabilize the collar and mark. Note that this normally occurs AFTER the rods are driven into the ground.

Note, that it is also possible to dig the hole for the PVC pipe after installation of the rods and not before.

c. Screw together the first two sections of stainless steel rod. Apply thread locker to both sides of the threads on the stud (wear gloves). Install the driving point on the leading edge.

d. Make sure the rod is vertical and push it into the center of the hole in the ground. The first few rods can usually be pushed in by hand.

e. Attach the driving head which is a short piece of stainless steel rod that will take the blows from the pounder or hammer (Figure 3.10).

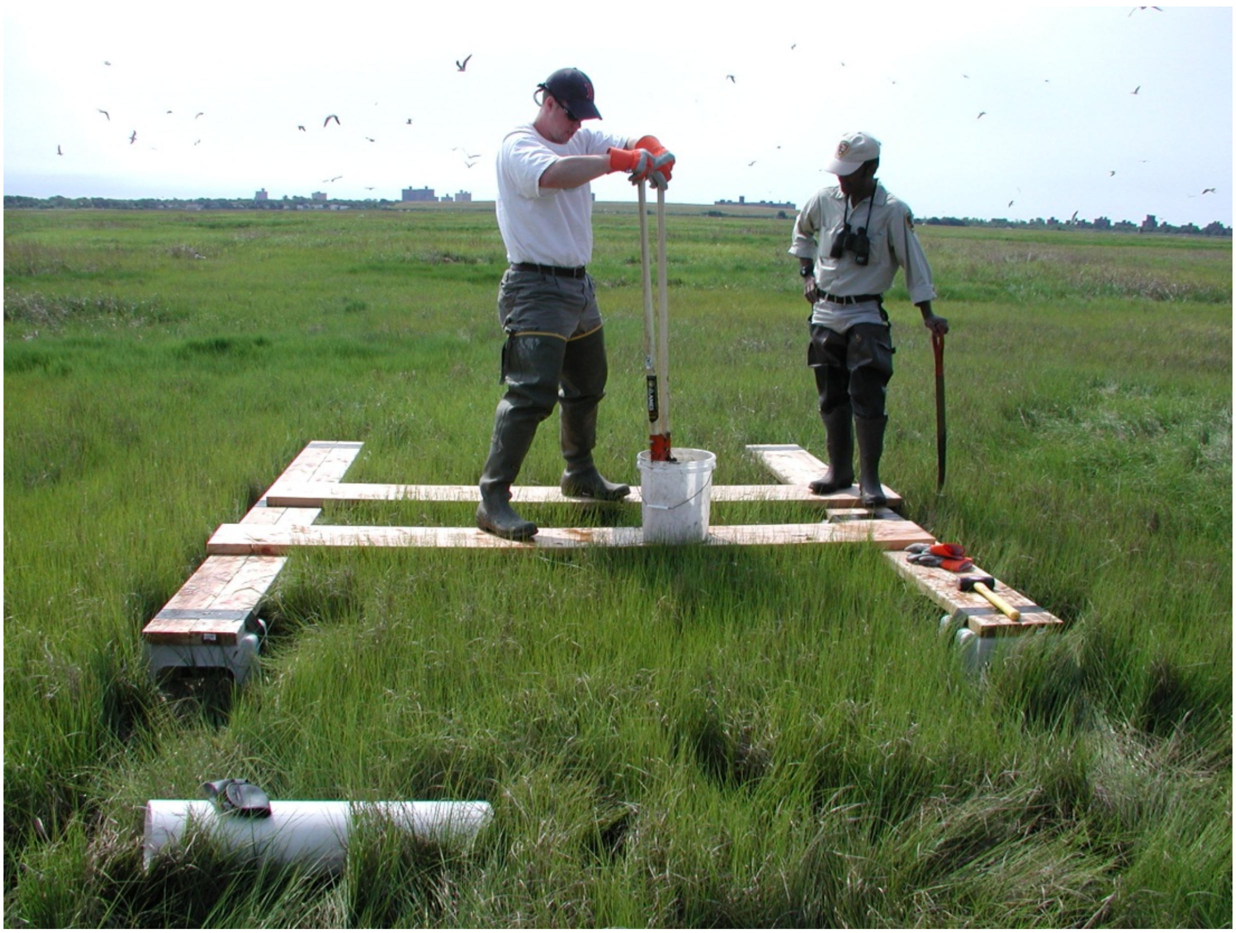


Figure 3.7. Digging the hole (Gateway NRA, New York, NY USA).

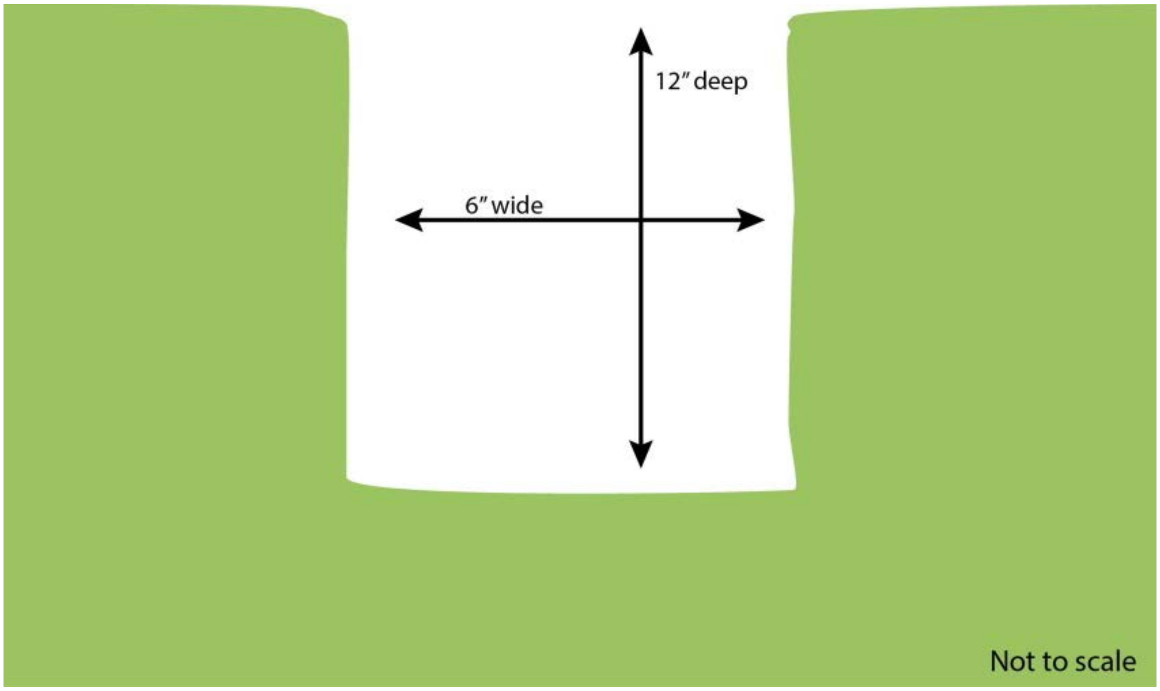


Figure 3.8. Approximate dimensions of the deep mark hole. Depth of the hole may vary.

Figure 3.9. It is common for the hole to have water in it.

Figure 3.10. Attaching the driving head (Waccamaw River, South Carolina, USA).

f. Start pounding the rods into the ground with the hand pounder, demolition hammer or hammer drill (Figure 3.3, 3.4, 3.5). Be sure to wear gloves, a hardhat, hearing and eye protection. Stop pounding each section when the driving head is about 6” above the wetland surface. Remove the driving head. Add a new rod (use thread locker glue), attach the driving head (Figure 3.10), tighten with vice grips (Figure 3.11) and resume pounding (Figure 3.12). Repeat this process until significant resistance is met or the rod hits limestone or bedrock. Refer to table 3.2 for guidance on when to stop pounding rods.

Deep RSET mark installation notes:

- The threaded connections between rods can get loose from the pounding. Especially the top most sections. When adding a new rod, use vice grips to screw the entire rod mark clockwise to keep all the rods snugly connected (Figure 3.11). Also use thread locker glue on the studs when adding a new rod. When only a few rods have been installed, the entire deep rod mark may spin when tightening with the vice grips. This will stop once the rods get deeper into the sediment.
- While pounding, the driving head will come loose. Be sure to keep the driving head screwed on snugly when actively pounding on the rods (wear gloves).

- Swap out the threaded stud (Figure 3.2) on the pounding head from time to time. The threaded stud takes a lot abuse and may break if used for too long. It is good to swap it out with a new stud every 5 rods or so.

- Number of Rods: VERY IMPORTANT: Keep an accurate count of rods used. It's very easy to get confused and lose track of how many rods that have been sunk into the ground. Start all installations with bundles of 10 rods to minimize the chances for error (Figure 3.12). In the data book, record the total number of rods used for the mark.

- Depth of the mark: The number of rods used for a deep mark will only give an approximation of the final depth of the mark since rods have been known to bend (i.e. curve) as they are driven into the substrate.

Figure 3.11. Tightening rods (Waquoit Bay NERR, MA USA).

Table 3.2. When to stop driving rods.

Unless the rod point hits bedrock or limestone (refusal), determining when to stop driving rods into the ground is not always a straightforward decision. In many coastal wetlands in the U.S., the first 1 to 5 rods (4 to 20 feet) may go into the ground easily. At deeper depths, driving the rods slows down and takes more time and energy. Every wetland substrate is different and how the installation proceeds will usually change as more rods are added to the deep SET mark. Keeping track of this change will help determine when to stop pounding. The recommended procedure is to time the installation (in seconds) of each 4' rod. As the mark gets deeper and there is more resistance, it will take longer to drive in each rod. Pounding on the rod is stopped when "susbstantial resistance" is achieved. This occurs when the installation of a deep SET mark goes beyond some agreed upon time interval. For example, pounding stops when it takes 120 or more seconds (30 seconds/foot for a 4' rod) to drive fully a single rod into the ground with a demolition hammer. The National Geodetic Survey (NGS) has a rule of 240 seconds (60 seconds/foot for a 4' rod) when using a hammer drill to install geodetic marks. Below is an example for a U.S. coastal wetland using a demolition hammer: 1) Rods 1-5 (0-20') – Rods go in easy. Very fast. (20-30 seconds per rod) 2) Rods 6-11 (24-44')- Rods go in moderately fast and easy. (45 seconds per rod) 3) Rods 12, 13 (44-52') – Rods go in slow, then very slow. (60-90 seconds per rod). 4) Rod 14 (52-56') - Very slow – (120 or more seconds per rod) .Stop pounding. Finished. If it takes longer than 2 minutes to install a 4' rod with a power tool, the sediments are likely to be very firm. There are some situations when the rods may not slow down to the point where pounding can stop. This may happen in some sandy soils like on a barrier island. In this case, the pounding may have to stop without achieving "significant resistance" and stopping at 20 rods (80') would be adequate. Realize that choosing when to stop is a decision based on the materials on hand, the equipment being used to drive the rods and the conditions present at the site. Be aware that once pounding has stopped, a deep SET mark should freeze up quickly and provide a very stable mark for taking measurements with the SET instrument. The main point of the deep SET mark installation is to ensure the mark is deep enough to provide a vertically stable platform for many years of SET measurements.

Figure 3.12. Driving rods. Note the bundle of rods on the end of the platform (Acadia NP, ME USA).

1. Stop pounding and cut the rod (if necessary) – As the downward movement of the deep SET mark slows and the pounding is about to stop, the goal is to have the joint between rods close to the wetland surface or a few inches above it. Under these circumstances, the rod will not need to be cut (Figure 3.13, 3.14). Unscrew the top section of rod and tighten the last rod in the ground with a vice grip in case it has become loose from the pounding.

   If this is not possible and the rod needs to be cut, it is recommended to use an angle grinder with a 4 1/2" steel/stainless steel cutting wheel (battery powered or electric). This is a fast and safe way to cut a rod (wear eye protection and gloves, Figure 3.15 and 3.16). A hydraulic bolt cutter will also work but is not recommended. It is more difficult and potentially dangerous (Figure 3.17). If using a bolt cutter, have someone hold the top piece as it is cut. Otherwise, it may be launched into the air and could be a hazard.

2. When finished installing the deep mark, the final rod in the ground should be at the wetland surface or a few inches above it (Figure 3.14).

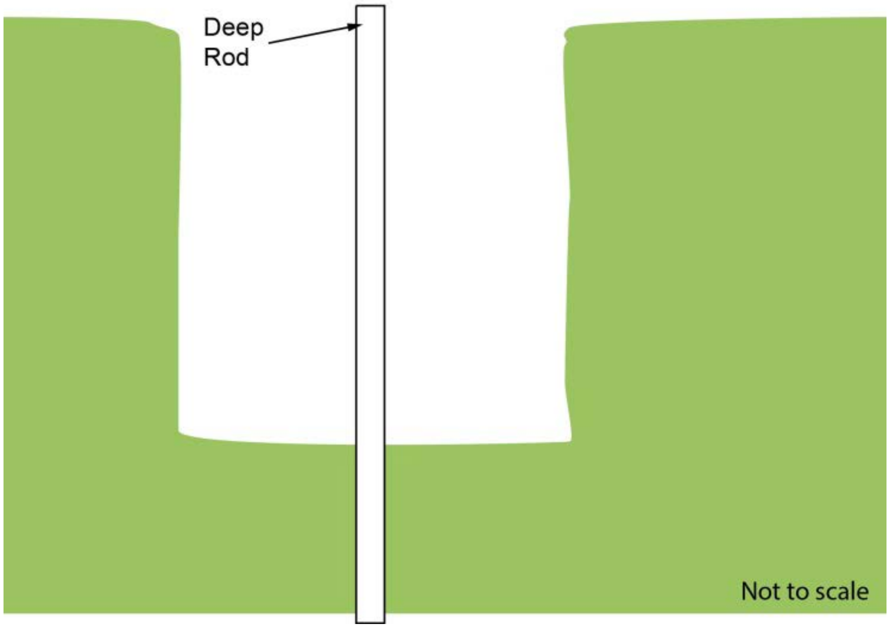


Figure 3.13. The top of the deep SET mark will be just above the wetland surface after installation is complete.

Figure 3.14. Deep SET mark in the hole after pounding has stopped. Note that pounding was stopped at a joint.

Figure 3.15. Electric angle grinder (Boston Harbor Islands NRA, MA, USA).

Figure 3.16. Cutting the rod with an angle grinder (Boston Harbor Islands NRA, MA, USA).

Figure 3.17. Hydraulic bolt cutter attached to the deep rod.

3. Install PVC Collar – Push the 6" PVC pipe into the hole around the rod (Figure 3.18, 3.19). Step on it and/or use a sledgehammer to knock it down to the appropriate depth (Figure 3.20). Try to get the bottom of the PVC pipe into the sediments below the bottom of the hole to improve stability. The top of the PVC pipe should stick up about 4-6" (10-15 cm) above the wetland surface. Be sure that the top of the stainless steel rod remains below the top of the PVC pipe. It is also very common to have water in the bottom of the hole. Remove excess water in the PVC pipe with a hand bilge pump or small plastic cup.

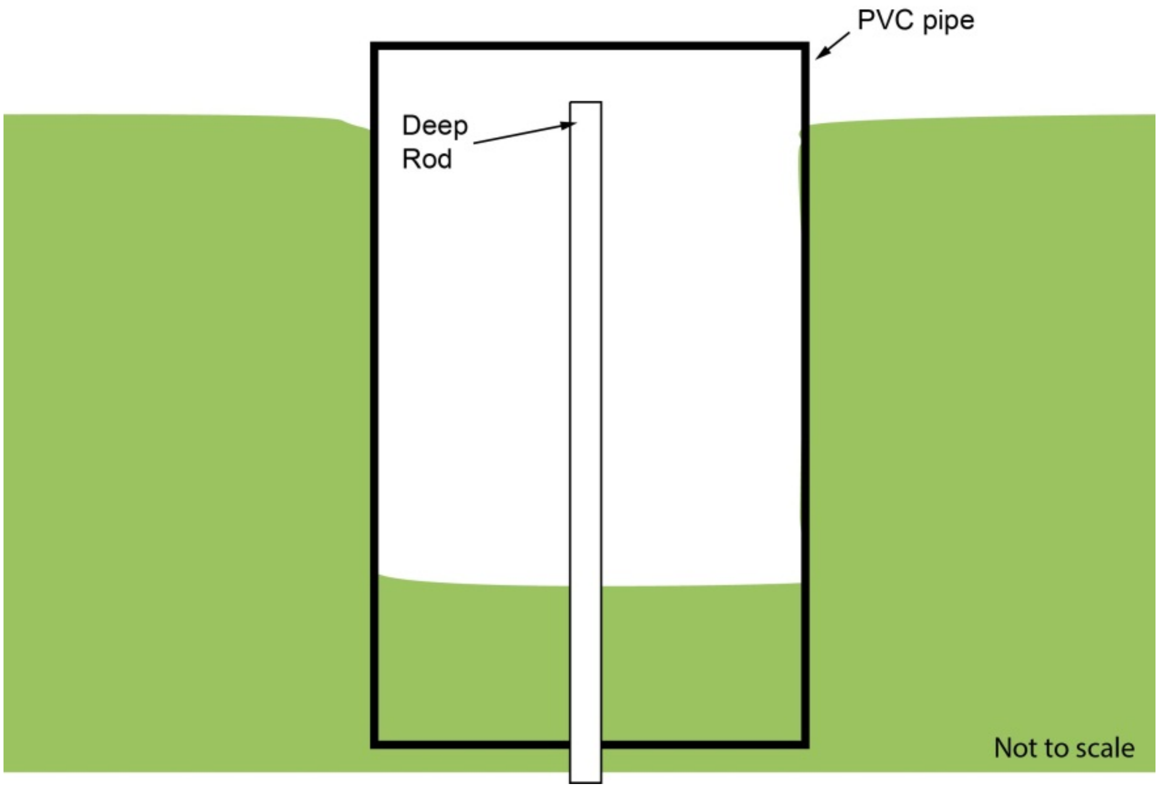


Figure 3.18. PVC collar in the ground.

Figure 3.19. PVC collar (Barn Island, CT USA).

Figure 3.20. Installing the PVC collar (Boston Harbor Islands NRA, MA USA).

4. Attach the receiver – Slide the stainless steel receiver over the rod and into the hole (Figure 3.21, 3.22, 3.23). Tighten the bolts on the receiver with a 9/16" wrench, thereby attaching it to the deep mark. Make sure the rods are snug and tight before attaching the receiver. Use the notch in the top of the receiver to align the receiver in the desired orientation for the SET measurements. Once the receiver is attached to the deep rod and encased in cement, the directions available for SET measurements will be fixed. It is important to be aware of the directions prior to attaching the receiver and adding cement to the PVC pipe.

Figure 3.21. Receiver (on wooden plank) prior to attachment to the deep SET mark.

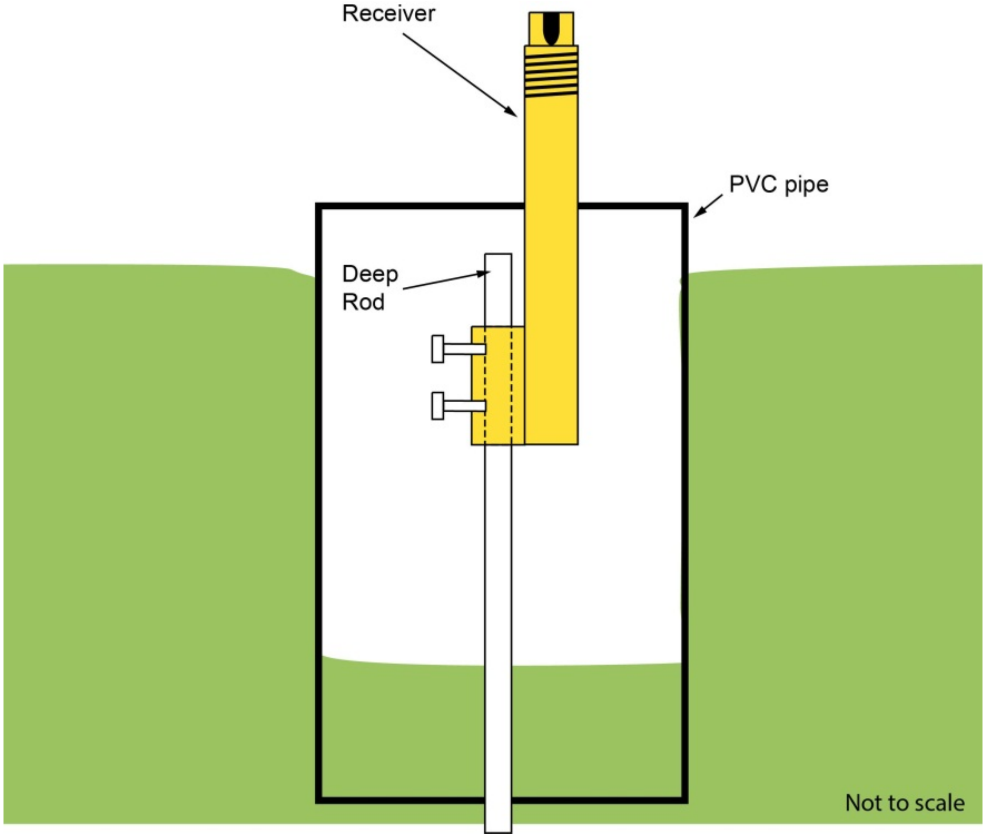


Figure 3.22. Receiver (yellow) attached to the deep SET mark (white).

Figure 3.23. Receiver attached to the deep SET mark before cement is added.

5. Fill the pipe with cement (figure 3.24) – It is normal for there to be water inside the hole. Remove as much of the water as possible from within the PVC pipe. Put some dry cement into the bottom of the pipe if there is a lot of water which can't be removed. Pre-mix the cement (concrete or mortar mix) with fresh water in a plastic bucket (Figure 3.25). Saltwater will work if fresh water is not available. Fill the PVC pipe with cement using a narrow blade shovel or cement trowel. (Figure 3.26) Shake the receiver (attached to the rod) after adding cement to the PVC pipe. This will help settle the concrete and remove air bubbles. Fill the PVC pipe to the top with cement. Try to make a dome at the top to allow water to run off.

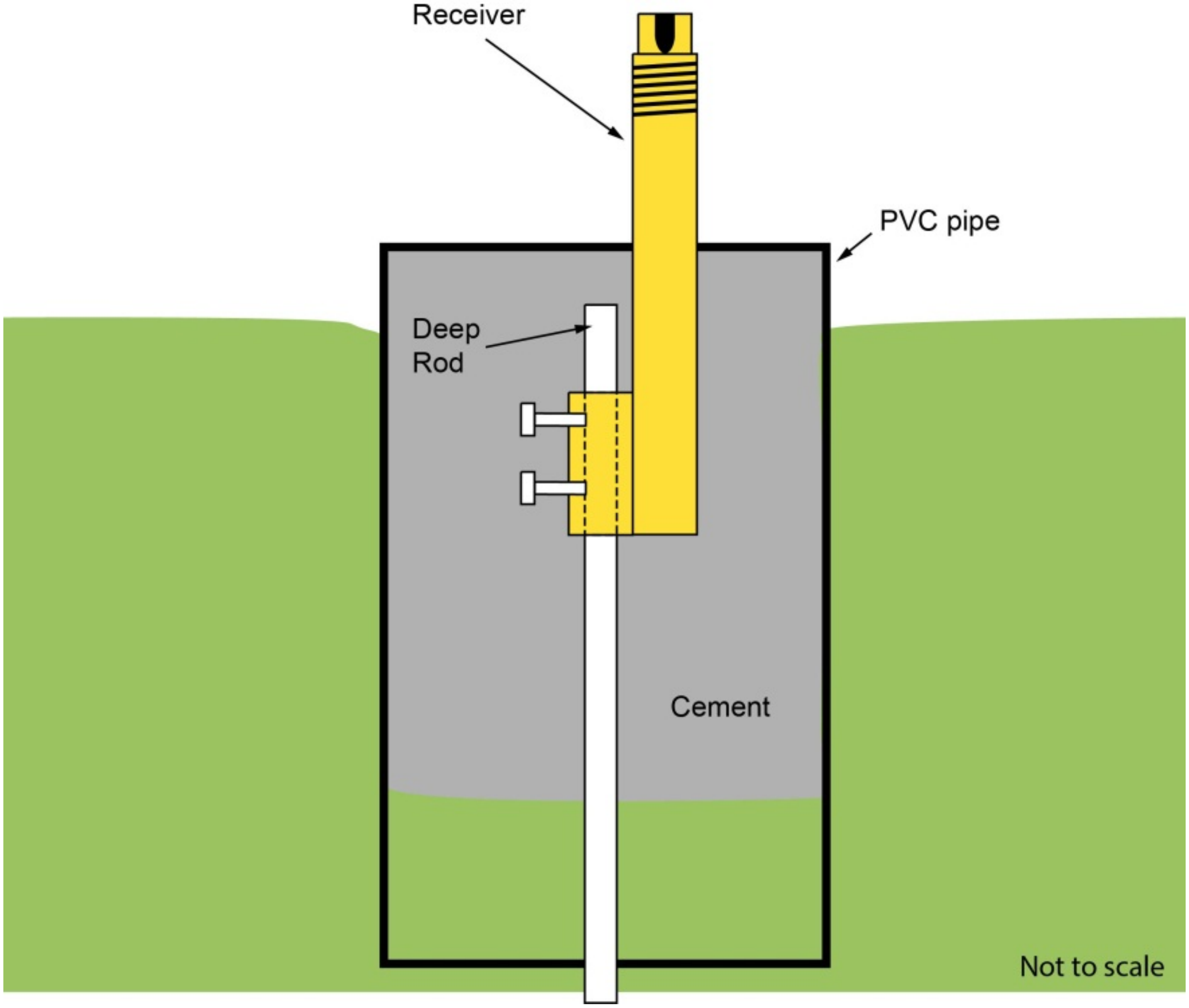


Figure 3.24. Receiver attached to the deep SET mark and cemented in place.

Figure 3.25. About to add cement.

Figure 3.26. Adding cement (Fishing Bay WMA, MD, USA).

6. If using a brass ID marker, place it into the cement before it sets. Note that markers are for ID purposes and are not to be used for surveying (Figure 3.27).

7. Installation of the deep rod RSET mark is complete (Figure 3.28). If possible, wait a few weeks before taking the first measurements with the RSET instrument.

Figure 3.27. Brass ID marker on a deep SET mark.

Figure 3.28. Completed deep SET mark.

How many deep SET marks can be installed in an 8 hour day? How many people are needed?
The process of installing a deep SET mark goes relatively quickly after all the gear and people are in place. In terms of logistics, it should be somewhat straightforward to install at least 3 SETs in a single 8 hour day. This obviously depends on how far apart the stations are and what's involved in travelling between them. This is a minimum under most circumstances. If sample stations are relatively close together 6 or more marks could easily be installed in a day. It is best to have 3 or more people when installing SET marks. Any less is not efficient considering all the gear that must be transported.

Shallow RSET Mark

A shallow RSET mark is installed into wetland sediment about 1 meter or less, typically to the depth of the root zone (about 30cm/1 foot). Because of the shallow depth, the design consists of 4 aluminum legs which help to stabilize and secure the shallow mark (Figure 3.29).

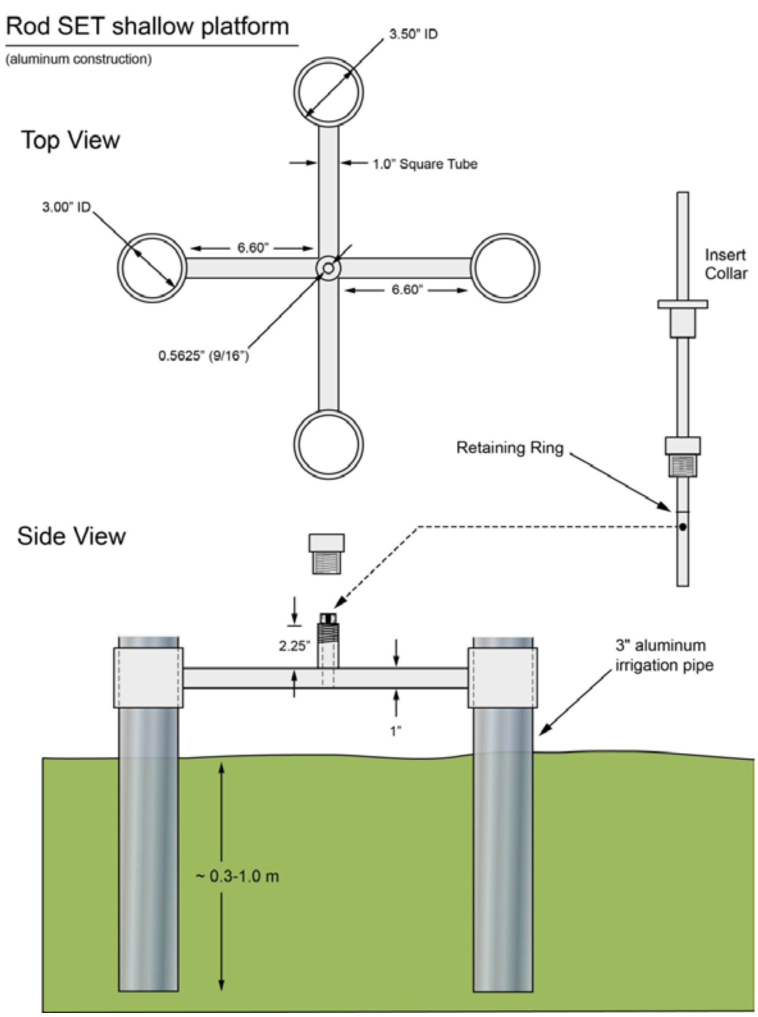


Figure 3.29. Shallow RSET mark (Callaway et al. 2013).

The general procedure for installing a shallow mark is as follows:

1. Build a sampling platform (See SOP #2).
2. Lay down the shallow platform and install the 4 legs.
3. Slide the platform to the appropriate height.
4. Level the platform.
5. Secure the platform to the legs.

Supplies for Installing a Shallow Mark

Refer to Appendix A for a detailed list of supplies.

1. Sampling Platform - refer to SOP #2.

2. Shallow SET platform **–** Custom built out of aluminum. Cost about $500 each (Figure 3.29, 3.31).

3. Legs (4) **–** Legs are constructed out of 3" (7.6 cm) aluminum irrigation pipe (3” OD, 0.05” thick). The pipe typically comes in 20’ (6.1 m) lengths for ease of handling. The length of each leg will depend on the depth of installation and how high off the ground the shallow platform is (Figure 3.32).

   For example, suppose the legs for a shallow mark go into the wetland sediment 35 cm (~14”) and the Shallow SET platform needs to be about 15 cm (6”) above the wetland surface. In addition, extra length is needed when installing a leg.

   - Length in the wetland = 35 cm
   - Length above ground = 15 cm
   - Excess needed for installation = <u>40 cm</u>
   - TOTAL length of each leg = **90 cm**

   Drill a 9/16" or 5/8” hole through the entire pipe at the top of each leg. A metal 18” rod is slid through this hole to make a T-handle that is used to twist the leg into the wetland soil. It is common to use a section of the 9/16” stainless steel rod used for the deep mark for the handle.

   The leading edge of the leg can be sharpened with a metal file to help when twisting the leg into the ground. All of this preparation can occur prior to heading to the field.

4. Stainless Steel Self tapping screws - #10, 3/4" hex head (Figure 3.30) **–** Self-tapping screws are used to attach the shallow platform to the legs. These may need to be special ordered. Eight screws are required per shallow mark. They are attached using a cordless drill with a hex-head adapter.

5. Cordless drill and reciprocating saw. These are essential for installing a shallow mark.

6. Bubble level.

Figure 3.30. Self-tapping screw (metric ruler above).

Installing a Shallow Mark

1. Work from a platform when installing the shallow mark. Refer to SOP #2 for platform construction. It is common to install deep and shallow marks together at a single sample station.

2. Choose the location and install the four legs;

    a. Lay the shallow platform on the wetland surface where the legs are to be installed. The circular holes in the platform will serve as a guide for properly placing the 4 legs (Figure 3.31).

Figure 3.31. Shallow platform laying on the wetland surface before inserting the legs.

b. Install the legs of the shallow mark: Determine how deep the 4 legs need to go into the ground and mark this depth on the leg with a permanent marker. This will assist in getting each leg to the proper depth (Figure 3.32).

c. Take a leg and insert the T-handle. Wearing gloves, twist the leg through one of the 4 collars on the platform. Stop twisting the pipe when it gets to the proper depth (Figure 3.33).

d. Do this for all 4 legs (Figure 3.34).

Figure 3.32. Shallow platform leg installation. Two legs have already been twisted into the soil. Note that the legs have a hole in the top to allow a section of stainless steel rod to be used as a handle to aid twisting the leg into the ground.

Figure 3.33. Twisting the last leg of the platform into the soil.

Figure 3.34. Shallow platform prior to securing the four legs in place with screws.

3. After twisting in all 4 legs, slide the SET shallow platform up to a suitable height above the wetland surface. Usually 15-20 cm (Figure 3.34).

4. Level the platform as best as possible with a bubble level. This is not critical since the SET is designed to level itself.

5. Secure the shallow platform to the 4 legs. Using stainless steel self-tapping screws (hex head) and a battery operated drill with the appropriate fitting for the screws, drill the screws into the legs through pre-drilled holes in the shallow platform collars. Once the platform is secured in place, can cut the excess 3" pipe that extends above the platform with a cordless reciprocating saw. Installation is complete (Figure 3.35).

Figure 3.35. Completed installation of a shallow SET platform. Note that the legs are now attached to the framework with screws.

Literature Cited

Callaway, J.C., D.R. Cahoon, and J.C. Lynch. 2013. The surface elevation table – marker horizon method for measuring wetland accretion and elevation dynamics. In: R.D. DeLaune, K.R. Reddy, C.J. Richardson, and J.P. Megonigal, editors, Methods in Biogeochemistry of Wetlands. Soil Science Society of America Book Series no. 10, Chapter 46, pp. 901 – 917.

SOP 3 Appendix A: Deep/Shallow RSET installation supply list

1. This list is based on the installation of 3 deep and/or shallow RSET marks.

2. NOTE: Marker horizons are not established until the first SET measurements are taken.

General Equipment :

- ☐ map/aerial photo showing station locations
- ☐ GPS with location of stations stored.
- ☐ extra batteries for GPS
- ☐ data book or datasheet & clipboard
- ☐ pencils (2)
- ☐ trash bags (box)
- ☐ temporary platform (1 or more)
    - ☐ step stools
    - ☐ duct tape or straps
- ☐ knife
- ☐ miscellaneous tools (hammer, etc)
- ☐ gloves

Deep RSET Supplies (for 3 sample stations)

- ☐ **Pounding Tool (pick one!)**
    - ☐ Gasoline Jackhammer
        - ☐ Rod driving attachment
        - ☐ gas can with gas/oil mix for jackhammer
    - ☐ Electric Demolition Hammer
        - ☐ Ground Rod attachment
        - ☐ Electric Generator (2-5 kw)
        - ☐ Gas for generator
    - ☐ Hand Pounder
- ☐ SS driving heads – 4-6” long, portions of a SS rod to take the blows from the hammer (2)
- ☐ 4’ SS rods (~60) assuming 20 per station
- ☐ Threadlocker
- ☐ SS driving points (3)
- ☐ extra threaded studs (3)
- ☐ 6” PVC pipe ~18-48” in length (3)
- ☐ 2-4’ long, PVC or fiberglass stakes (~45)
- ☐ 60 lb bag of concrete (2-3)

- ☐ SS receiver (3)
- ☐ five-gallon buckets (3)
- ☐ small plastic cups (3) or hand bilge pump
- ☐ narrow planting (sharpshooter) shovel
- ☐ post hole digger
- ☐ concrete trowels (2)
- ☐ small sledge hammer
- ☐ larger sledge hammer (for permanent platforms)
- ☐ large vise grip pliers (2)
- ☐ battery powered reciprocating Saw with metal cutting blades.
- ☐ battery powered angle grinder with metal cutting blade
- ☐ extra batteries fully charged
- ☐ box wrench (9/16 inch)
- ☐ Gloves
- ☐ Hearing protection (plugs/muffs)
- ☐ Safety glasses
- ☐ Hardhat

Shallow RSET Supplies (for 3 sample stations)

- ☐ Shallow platform (3)
- ☐ 3” diameter, 3’ long aluminum legs with 9/16”-5/8” hole at top for the handle (12).
- ☐ 18” long, 9/16” SS rod – handle for legs (2)
- ☐ #10, ¾” long SS, hex-head, self-tapping screws (~30)
- ☐ Cordless Drill with battery (1)
- ☐ Hex head adaptor for cordless drill (1)
- ☐ Small bubble level (1)

SOP 4: Taking Measurements with the Surface Elevation Table

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

The Surface Elevation Table Instrument

The first measurements with the Rod Surface Elevation Table (RSET) are taken after the deep or shallow RSET marks (SOP #3) have been installed. The RSET instrument, is a mechanical leveling device used to repeatedly measure elevation change of wetland sediments (Figure 4.1). Repeated measures of sediment elevation in wetlands are necessary to determine rates of elevation change, particularly relative to sea level rise, and to gain an understanding of the processes responsible for elevation change. The SET provides a nondestructive method for making highly accurate and precise measurements of sediment elevation of intertidal and subtidal wetlands over long periods of time relative to a fixed subsurface datum. This technique overcomes many of the limitations of methods currently used to estimate elevation such as sedimentation pins, and precision surveying.

Figure 4.1. Rod SET attached to a deep rod mark (Acadia National Park, Maine, USA).

The original SET (figure 4.2) was designed by Boumans and Day (1993) and Cahoon et al. (2002a) (based on an earlier design by Schoot and deJong 1982) and was commonly used through the late 1980's, 1990's and into the new millennium. It has generally been replaced by the Rod SET (RSET) designed by Cahoon et al. (2002b). The RSET can attach to both deep and shallow marks. The ability to couple with various types of marks and the fact that the design can be easily customized has made the Rod SET a very popular instrument for measuring elevation change in wetland environments. The Rod SET is the recommended instrument to use in new SET installations.

Figure 4.2. The original SET.

There are two designs of the Rod SET commonly in use today.

1. RSET instrument, original design – The original design Rod SET is a custom built instrument constructed out of aluminum and stainless steel components (figure 4.3, 4.4). Costs run about $1300-1500 (US $) in 2014. The instrument consists of the following;

- Rod SET instrument – custom built, consisting of:

    A) Aluminum Horizontal arm

    B) Insert collar (base)

    C) 30” long, ¼” Fiberglass pins. Quantity = 9,

    D) Pony clamps. Quantity = 2

    E) Badge Clips. Quantity = 9

- Carrying Case

Figure 4.3. RSET instrument: A = Horizontal arm, B= Insert collar, C = fiberglass pins, D= Pony clamps, E = Badge clips.

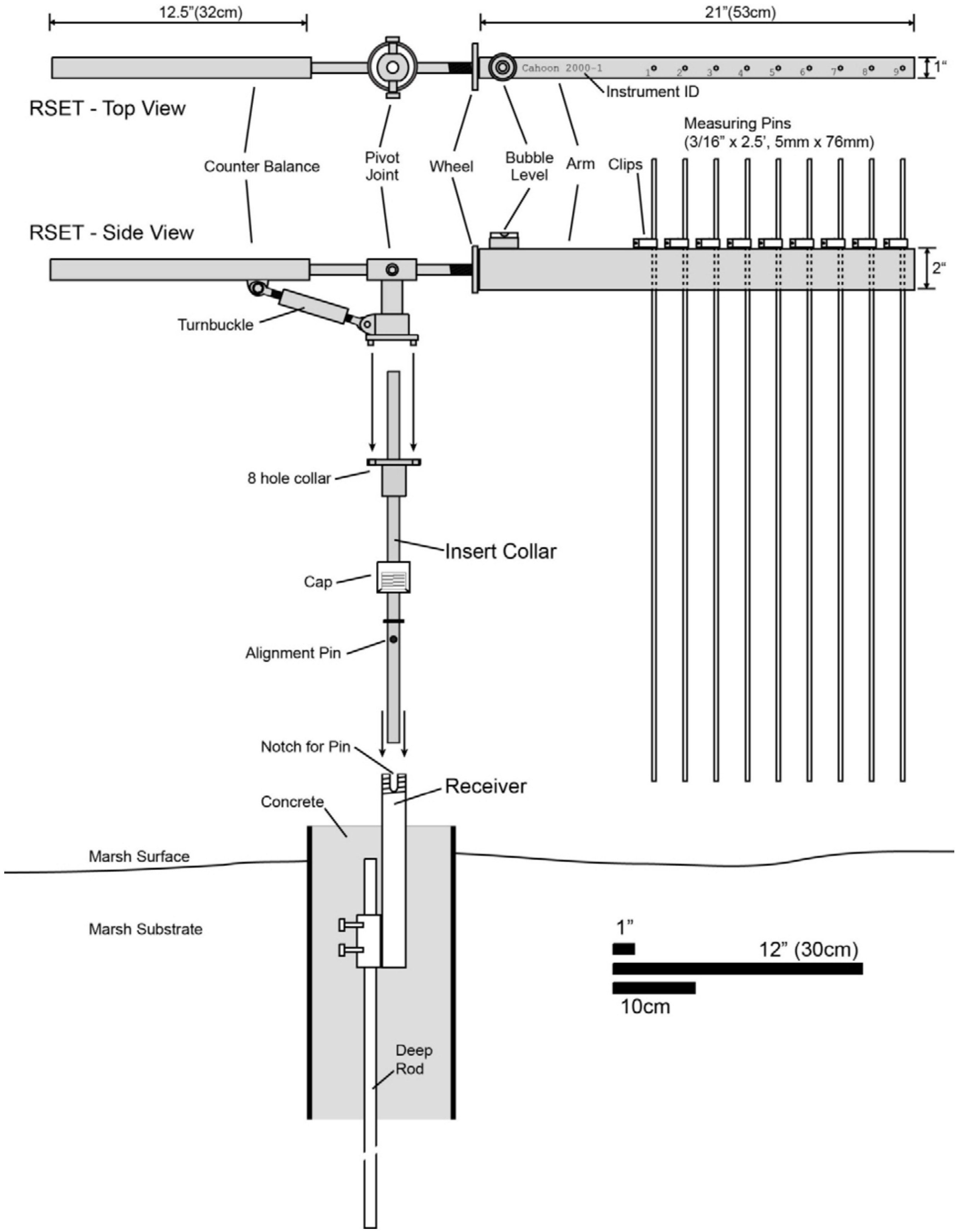


Figure 4.4. Original design ROD SET (RSET) showing the SET arm, Insert Collar and Receiver (from Callaway et al. 2013).

2. Fixed Dimension RSET (FDRSET) - The fixed dimension RSET is a custom built instrument constructed out of aluminum (figure 4.5, 4.6). Costs run about $2000 (US $) in 2015. The instrument consists of the following;

   - FDRSET instrument – Custom built, consisting of:

     A) Aluminum horizontal arm

     B) Instrument base

     C) 30” long, ¼” fiberglass pins. Quantity = 18

     D) Badge Clips. Quantity = 18

     E) Pony Clamps. Quantity = 2

   - Carrying Case

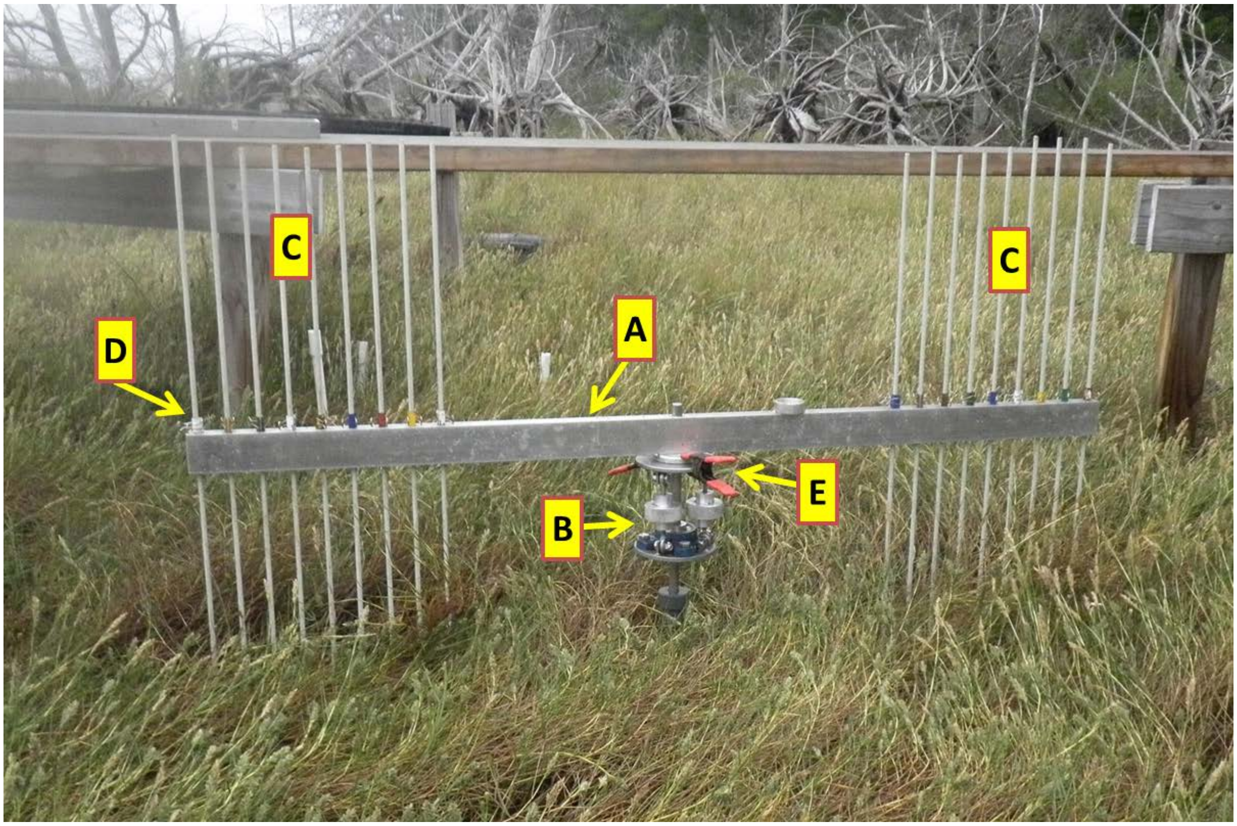


Figure 4. 5. Fixed Dimension RSET instrument. A = Horizontal arm, B= Instrument base, C = fiberglass pins, D= Badge clips , E = Pony clamps.

Figure 4.6. FDRSET (CBEC, MD, USA).

Both the RSET and FDRSET instruments operate in a similar fashion (pins lowered to the surface from a horizontal bar) and are used for long term measurements of elevation change. Both typically collect 36 pin readings from a mark. The FDRSET has a more precise levelling mechanism and is typically built to hold 18 pins versus 9 in the original RSET. See Table 4.1 for a comparison of the features of the two instruments.

Table 4. 1. Comparison of the RSET and FDRSET.

Instrument	Rod SET	Fixed Dimension Rod SET
Cost	~$1300	~$2000
Pros	Less expensive Smaller and easier to maneuver on the platform.	Very stable arm for measurements. Can measure two directions at once. Only need to level once per SET mark.
Cons	Less stable arm than FDRSET. Have to re-level in each direction.	Larger in size. Bulkier carrying case

3. Custom SET designs – Both models of the SET described above are easily customized for a particular situation. Below are a few examples of customized SETs:

   a. "Monster Arm" RSET (Figure 4.7) – Designed by Dr. Pat Megonigal and Jim Duls at the Smithsonian Environmental Research Center (Edgewater, MD USA). This SET was designed to collect pin readings inside a growth chamber and in an adjacent reference area. The horizontal bar on the SET is over 4 meters long and has over 100 pins (Langley et al 2009).

   b. Mini SET (Figure 4.8) – Designed by Dr. Karen McKee at the USGS, National Wetlands Research Center (Lafayette, LA USA) for use in a greenhouse study collecting elevation measurements of wetland plants growing in a bucket (Cherry et al. 2009).

Figure 4.2. Monster Arm SET (Smithsonian Environmental Research Center, Edgewater, MD USA).

Figure 4.3. Mini SET (National Wetlands Research Center, Lafayette, LA USA).

Baseline Reading: Reading the SET for the first time

The first measurements taken with the SET are called the "baseline" readings and are the values to which subsequent readings will be compared. Prior to taking the first measurements, it is important to establish the sampling directions, consider the sampling schedule and have an appropriate plan to record the data collected. Be sure to work from a platform when reading the RSET. See SOP #2 for instructions on platforms. Refer to Appendix A for a list of supplies for reading the SET.

1. Choose sampling directions:

    The RSET can take measurements in 8 directions (every 45 degrees) around the RSET mark. Readings are normally collected at only 4 of the 8 directions. If there is some local anomaly in the future at one of the initial four directions, one or more of the other directions can be used.

    Consider the 8 directions that are available when the SET is attached to the receiver (Figure 4.9). Choose one direction and call it "A". Then select the remaining 3 directions B, C, and D. The four directions are typically 90 degrees apart from each other.

    Place a stake at the end of the RSET arm for the "A" direction (Figure 4.9). This is used to quickly orient the SET on future sampling trips. Draw a map in the data book of the sample station, showing the marker horizons, SET arm directions and stakes and any other features that will help to clearly define the layout. Record the bearing of each of the 4 directions with a compass. Many of the traditional RSETs (Figure 4.3, 4.4) have the 8 holes on the insert collar numbered so it is also possible to record the numbers of two holes the alignment pins sit in for each direction. The point of recording all this information is to clearly note and distinguish the 4 sampling directions so that the SET can be properly oriented on subsequent visits (Figure 4.10). It is essential that the SET arm is in the same orientation from reading to reading.

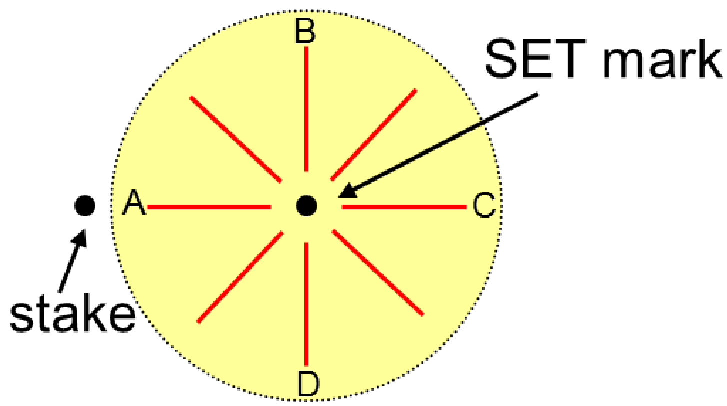


Figure 4.9. A method for identifying the orientation of SET measuring directions using a single stake to indicate direction A. Only the ABCD directions are measured in this example, which is typical for most sample stations.

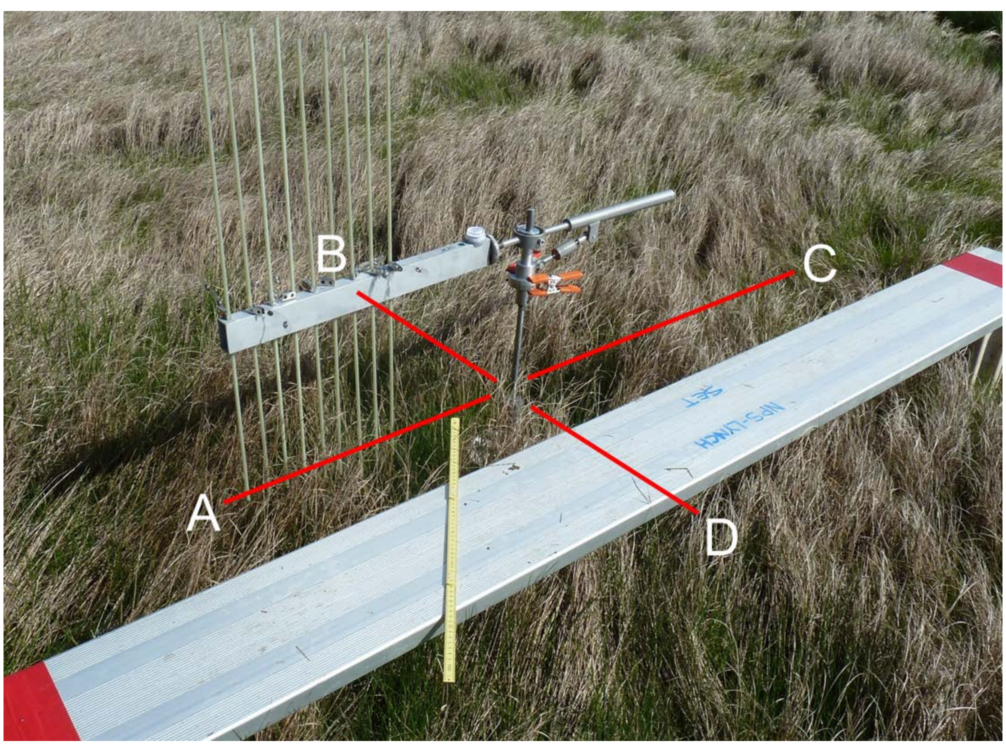


Figure 4.10. Rod SET on a deep rod mark showing the 4 directions measured (note: the Direction A stake is hidden by the vegetation an plank and is not visible in the photograph).

Sample Schedule: Determining the sample schedule is important to consider ahead of time. Ideally, try to sample at similar times of the year under similar conditions. The total number of trips per year will depend on logistical, personnel and budget issues.

Here are some guidelines to consider:

a. Samples per year: Sample at consistent time intervals from year to year. It is common to read the SET once or twice a year. It may also be advisable to read it two or more times a year for the first few years to help show seasonal changes that may exist at a study site. It is ok to miss measurements and or change the sampling schedule, but long gaps in readings should be avoided, if possible.

b. Timing of sampling: Be consistent in sample dates. If measurements are collected in April/May and October/November, try to keep the schedule into the future.

c. Tides: Try to sample at similar tides from trip to trip. Trips are usually scheduled at low or falling tides though this may not always be the case. Note water levels on the datasheet.

d. SET Reader: It is recommended that a single operator make all SET measurements because it is reasonable to expect operator bias in the determination of the sediment surface, the placement of the pin on the surface, and reading the ruler. Therefore, it is recommended to have an SET reader who is able to take reading for a number of years or longer. It is not recommended to have a new reader every year. It should be noted who is reading the SET each time.

   Double Read: If there is a change in SET readers a "double read" of the SET marks is recommended. A double read is where "SET Reader 1" takes their final reading with the RSET instrument and "SET reader 2" takes their first reading immediately after Person 1. All of this occurs during the same sampling trip.

2. Recording the data: It is important to properly record the data and other information when visiting a sample station.

Types of information to record when sampling are:

a. The date (on each page!)

b. People in the group. Record their names and any specific task they may have conducted.

   For Example:

   Jim Lynch - SET reader

   Karen Anderson – Recorder/Sampled marker horizons

c. Pertinent weather or tide data.

For example:

Sampling station is flooded with 10cm of water

d. A map showing the sample station layout, including SET, MH and any other sampling locations (e.g., soil cores or water level recorder).

e. Sample Station Information: Sample Site and Station location and Station ID.

f. SET ID – If the SET is stamped with an identification of some sort.

g. The SET data

h. The Marker Horizon Data

A data book (Figure 4.11) or datasheet (Figure 4.12) is commonly used for recording this information. Both the data book and datasheet are printed on waterproof paper. It is recommended to scan the data book or datasheets as an electronic backup.

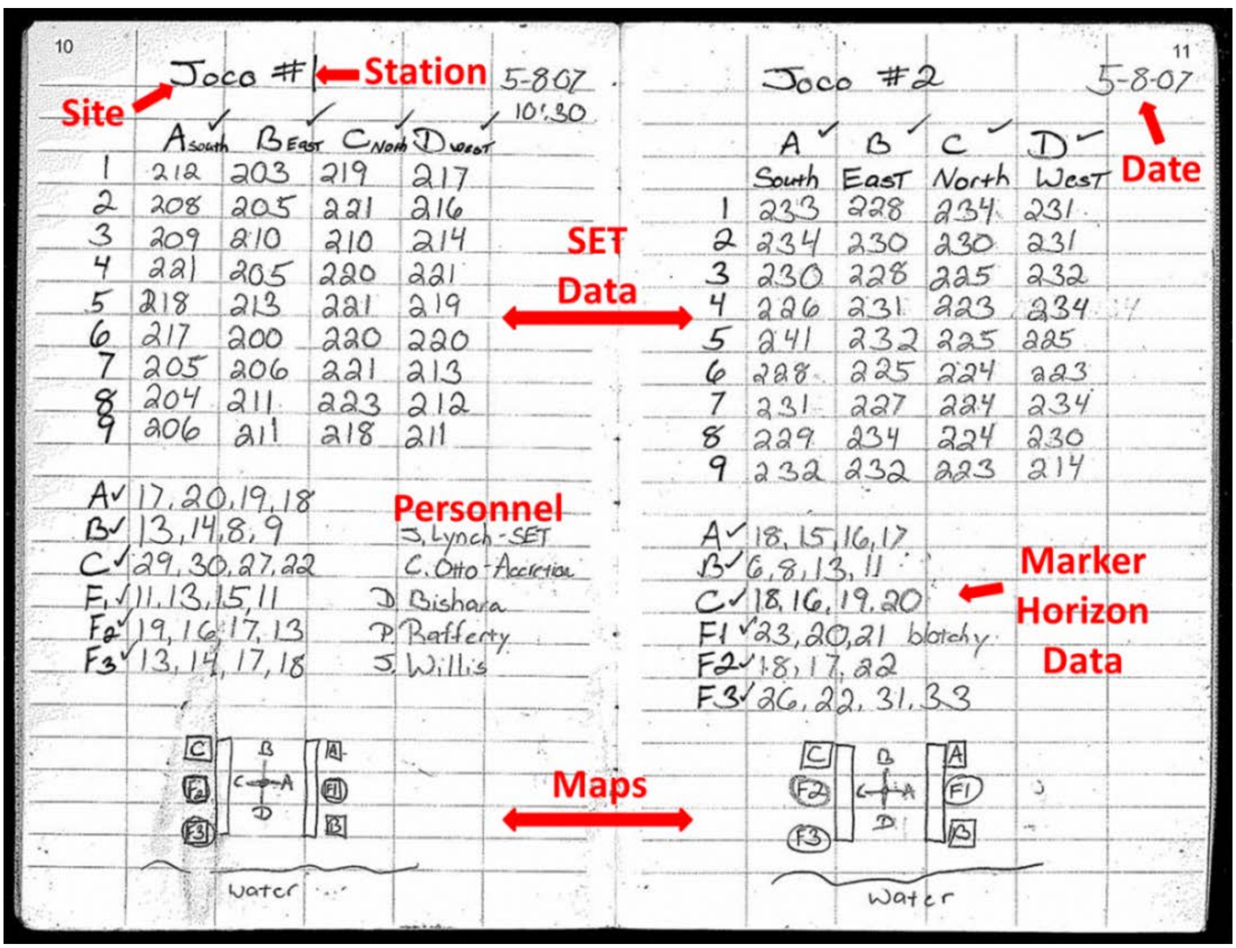
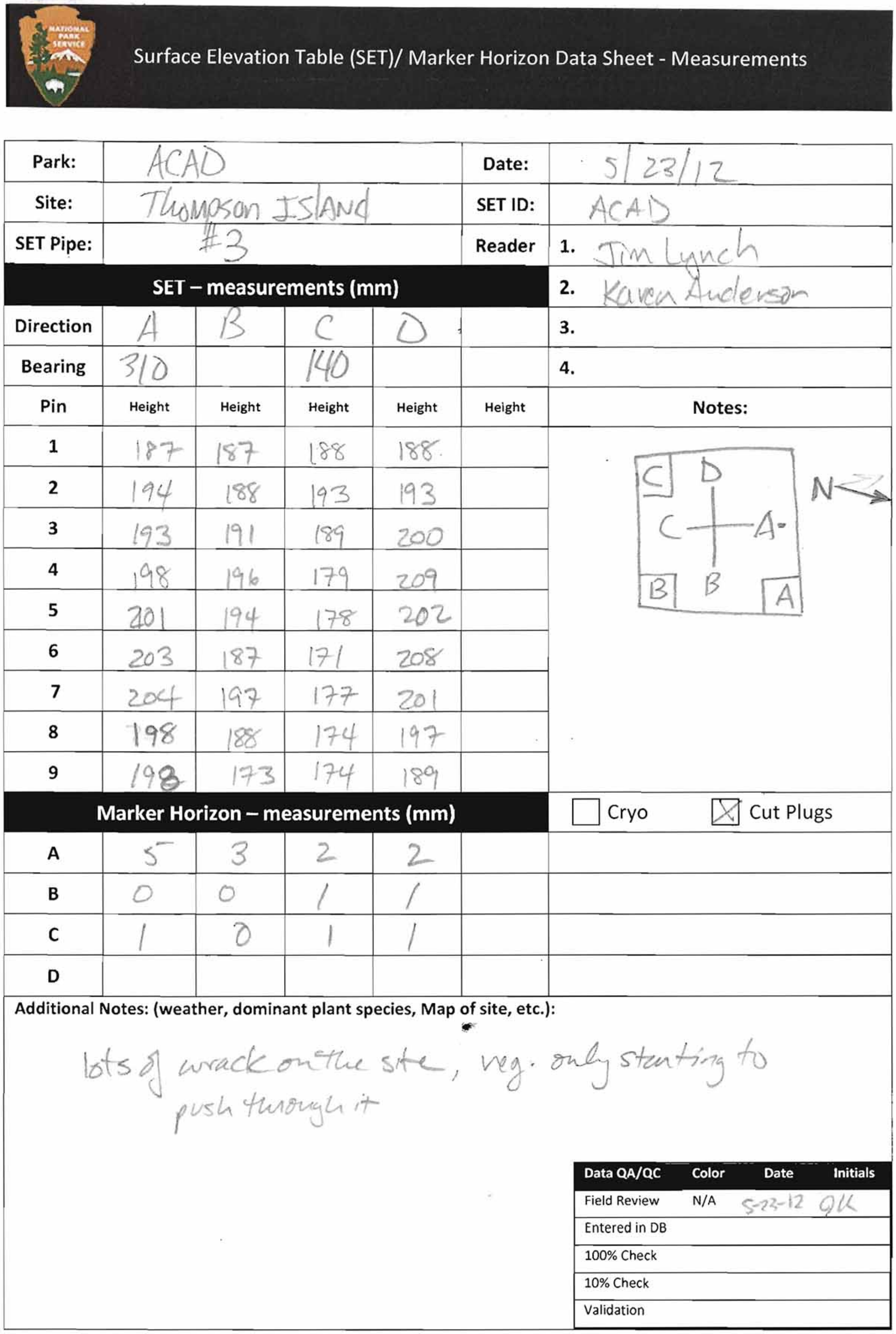


Figure 4.11. Data book example.



Surface Elevation Table (SET)/ Marker Horizon Data Sheet - Measurements

Park:	ACAD				**Date:**	5/23/12
Site:	Thompson ISlANd				**SET ID:**	ACAD
SET Pipe:	#3				**Reader**	1. Jim Lynch
SET – measurements (mm)						2. Karen Anderson
Direction	A	B	C	D		3.
Bearing	310		140			4.
Pin	Height	Height	Height	Height	Height	**Notes:**
1	187	187	188	188		
2	194	188	193	193		
3	193	191	189	200		
4	198	196	179	209		
5	201	194	178	202		
6	203	187	171	208		
7	204	197	177	201		
8	198	188	174	197		
9	198	173	174	189		
Marker Horizon – measurements (mm)						☐ Cryo ☒ Cut Plugs
A	5	3	2	2		
B	0	0	1	1		
C	1	0	1	1		
D						

Additional Notes: (weather, dominant plant species, Map of site, etc.):

lots of wrack on the site, veg. only starting to push through it

Data QA/QC	Color	Date	Initials
Field Review	N/A	5-23-12	OK
Entered in DB			
100% Check			
10% Check			
Validation			

Figure 4.12. Datasheet example.

Place the SET on the Mark

1. Remove the cap from the receiver (Figure 4.13).

Figure 4.13. A receiver with cap removed showing the notch in the receiver; and the brass marker used to ID the SET mark

2. Slide the RSET instrument (RSET insert collar or FDRSET base) into the receiver (Figure 4.13) making sure the alignment pin on the insert collar slides into the notch on the receiver (Figure 4.14). Screw the cap on the base to the receiver. Clamp the RSET in place with two pony clamps. The RSET is now attached to the receiver (Figure 4.15).

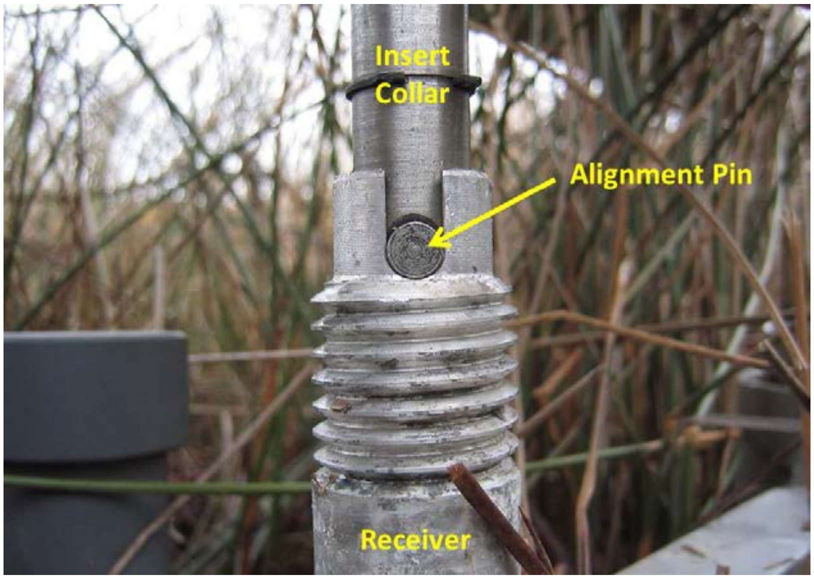


Figure 4.14. The base of the RSET instrument connects with the receiver using an alignment pin.

Figure 4.15. Receiver and RSET connected.

3. Label the fiberglass pins 1-9 and place them into their corresponding numbered holes on the RSET arm. Always use the same pin in the same hole. Do not allow the pins to fall to the wetland surface by securing a badge clip in the middle of the pin.

Figure 4.16. Badge clips are used to keep the pins from moving after placed on the surface.

Lower Pins to the Surface

1. Place the 9 pins into their corresponding holes held by clips. Pins should not be touching the surface. Level the instrument using the bubble level. When leveled and in position, the horizontal bar of the SET is in the same position as on previous measurements. Therefore, the pins are returning to the same wetland surface every time a measurement is taken. Changes in the readings from measurement to measurement are assumed to be due to vertical changes in the wetland surface.

2. Lower all the pins one by one to the marsh surface (Figure 4.17, 4.18).

   a. Hold on to pin.

   b. Remove the badge clip.

   c. Lower the pin until it is just touching the wetland surface. When the wetland surface is dry this can be done visually. If the surface has water on it, placing the pin would be based on touch and/or the feel of the pin hitting the firm surface of the wetland.

   d. Replace the badge clip to hold the pin in place.

   e. Proceed to the next pin until all pins are on the surface.

Clearing debris from the surface…

At many wetland sites, the vegetation, roots or other structures are pushed aside when placing pins. In addition, some sites will undoubtedly have detritus, leaves and other materials on the surface. A decision needs to be made on what to remove and what to leave in place.

It is normal to remove away any materials which are not attached to or incorporated into the sediment. For example, remove dead vegetation laying on top of the soil surface. Do NOT remove something like a mussel, shell or branch which is buried in the sediment. If a pin rests on an unusual surface, such as a branch or in a crab hole, recording the pin height may not be required. But, be sure to make a note in the data book. After measuring the pins, return any moved materials back to their original location.

Figure 4.17. Lowering pins to the surface (Blackwater NWR, MD USA).

Figure 4.18. Pins on the surface (Gateway NRA, New York, NY USA).

What to call the surface…

Determining the actual sediment surface can be a subjective decision, depending on the type of wetland environment being worked in.

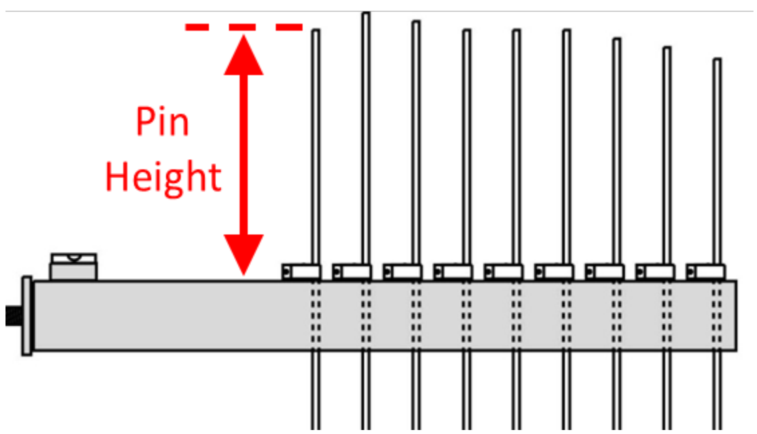
In general, tidal, saline wetlands (*Spartina alterniflora*, *Juncus roemerianus*, mangrove forests) and more mineral sediment sites are straightforward and easier for pin placement. Sites with more organic sediments (fresh and brackish marshes), can be more difficult for pin placement due to the uneven nature of the surface.

When the wetland surface is dry, pins are placed visually by the person taking measurements. If the wetland surface is under water, use your fingers to locate the surface and assist in properly placing the pins.

Regardless of the environment and conditions being worked in, it's important that to be consistent from sample to sample in determining the wetland surface. Establish a protocol and follow it. Record detailed notes in the data book.

Read Pin Heights

Once the pins are placed on the surface and clipped in place, record the pin heights in the data book or datasheet to the nearest millimeter (make sure the ruler starts at zero). Pin height is the distance of the pin above the horizontal bar of the RSET (figure 4.19 and 4.20, 4.21). Pin measurements are normally recorded in millimeters or centimeters. Be sure to record the units in the data book or datasheet.



4.19. Measurement of pin height.

It is common for pins to fall in a crab hole, on a shell, branch or other item. Taking a measurement in these situations may not be required. However, it is essential to note these conditions in data book or datasheet whether taking a reading or not. Taking good notes is essential for the QA/QC that will occurs later after visiting the field. Be sure to record any other important information about these readings before moving to the next direction.

Repeat for Other Directions

After completing the measurements for a given direction, raise all nine pins about one-half way up, clip them, and move the SET to the next direction. Repeat these steps until measurements have been taken at each of the four directions.

Figure 4.20. Reading pin heights (Eastern Neck NWR, MD, USA).

Figure 4.21. Reading pin heights (Acadia National Park, ME, USA).

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SOP 4 Appendix A: Supply checklist for SET data collection

- ☐ Temporary platform (if not using a permanent platform)
- ☐ RSET instrument
- ☐ Metric ruler (end starts at zero). About 50cm in length.
- ☐ Data book or datasheet (including maps of sample stations)
- ☐ Pencils
- ☐ Camera (optional)
- ☐ Compass

SOP 5: Establishing and Sampling Marker Horizons

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Establishing Marker Horizons

This SOP provides detailed instructions for establishing and sampling marker horizons. Both the marker horizon and SET techniques measure soil processes occurring in a wetland, shallow pond or water body. The SET measures wetland elevation change incorporating both surface and subsurface processes (including deposition, erosion, decomposition, root growth, etc.). Marker horizons measure deposition due primarily to surface processes (deposition and erosion).

Three to four marker horizons (Figure 5.1) are typically established in conjunction with the first SET measurements at a sample station (SOP #4). Following installation, marker horizons are normally sampled at the same time SET measurements are taken. Two commonly used techniques for sampling marker horizons will be described in detail (cryogenic coring and cutting plugs).

Figure 5.1. Establishing marker horizons at an SET sample station (Dipper Harbour, NB, Canada).

1. Supplies:

    a. Marker Horizon (50 lb. bags) - There are many materials which can be used to create a marker horizon. Brick dust, Grog, Sand, Kaolin, glitter and varieties of feldspar clay are all suitable for marker horizons. Feldspar clay (Figure 5.2) is the recommended marker material to use in wetlands and shallow water habitats. It is a brilliant white powdered material which forms a cohesive layer once it gets wet and is easily distinguishable from the surrounding sediment. Feldspar typically comes in 50 lb. bags and be purchased from a pottery supply warehouse. There are many types of feldspar clay. Check with a local vendor to see what is available. About 6 feldspar marker horizons can be established from a single bag.

    Be aware that any marker horizon may quickly disappear in high energy and low energy areas. In high energy sites, the marker may get washed away due to tidal and wave energy. In low energy areas, the marker never gets buried, and will wash away or get disturbed. Bioturbation, by burrowing crabs or other organisms, can also be a problem affecting the longevity of a horizon. Marker horizons will more than likely disappear over time and new marker horizons may need to be added in the future.

b. Stakes (½” PVC, 3/8” Fiberglass or ½” Rebar) – Stakes are used to mark the boundaries of the sample station and the marker horizon plots. The plot is typically 50cm x 50cm and is marked with 2 or 4 stakes. Stakes are about 2-4' in length. Longer stakes may be needed if working in soft sediments or a shallow pond.

c. Trash can (32 Gallon/120 liter) with bottom cut off – Needed if installing marker horizons in shallow water.

Figure 5.2. Feldspar clay (50 lb. bag).

d. Respirator – Feldspar clay should not be inhaled so a high quality respirator is essential when establishing the marker horizons. A respirator is not needed when sampling plots.

e. Square frame (50 cm x 50 cm) – This is the guide for laying marker horizons on the wetland surface. Typically constructed from ½” PVC pipe or aluminum clothes line wire.

2. Instructions for installation

Marker horizon plots are typically established when taking the first (baseline) SET readings.

a. Three or four marker horizon plots are deployed around the sample station (figure 5.3, 5.4). Plots are usually placed near the RSET mark and are accessed from the same platform used for SET measurements (see SOP #2) or from outside the perimeter of the sample station. There should be plenty of space around the sample station to add additional plots if the initial plots disappear. NEVER put a new marker horizon plot on top of an existing one

b. Select where to establish the marker horizon plots. Figure 5.4 shows common locations for marker horizons in a sample station using a temporary or square platform (see SOP 2).

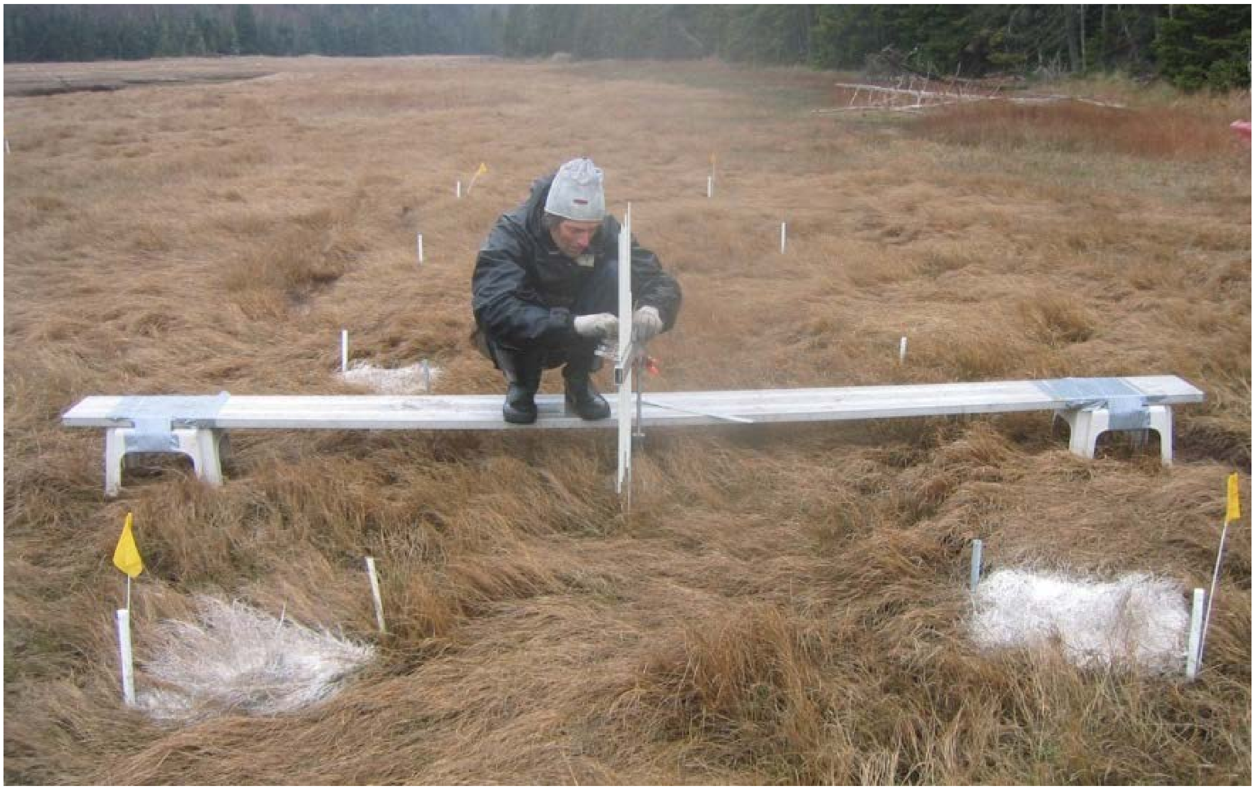


Figure 5.3. Three feldspar plots (Dipper Harbour, NB, Canada).

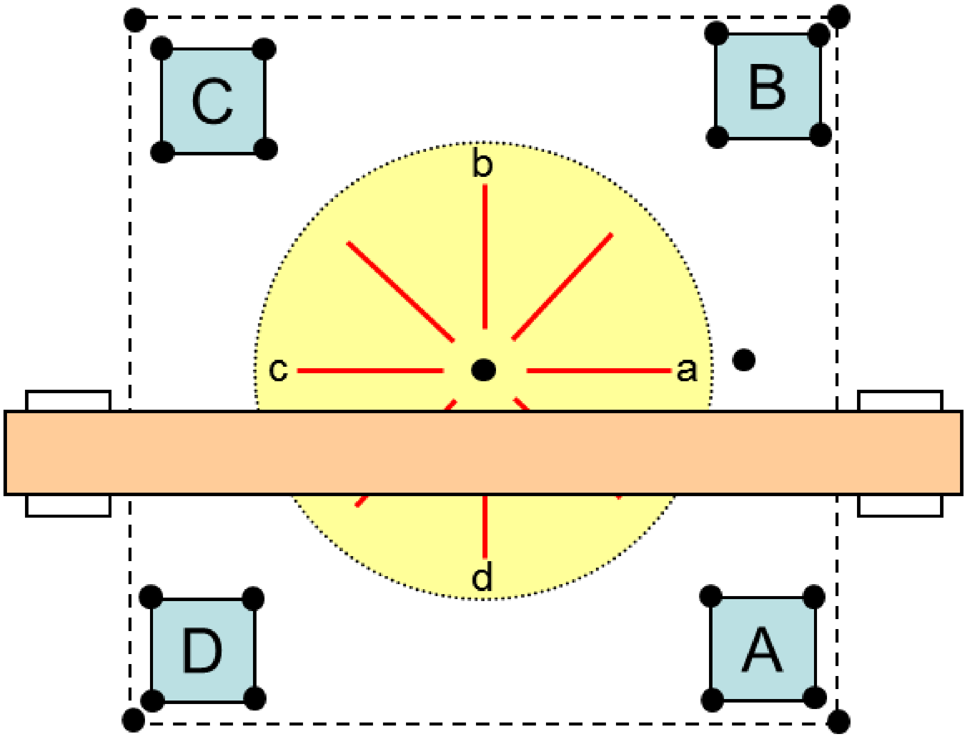


Figure 5.4. Common marker horizon locations (blue Squares) when using a square or temporary sampling platform. Yellow circle = SET measurement area.

c. Make a wire or PVC frame to approximate the size of the marker horizon plot, which is normally 50 cm x 50 cm (0.25 m^2 – Figure 5.5). Lay the frame on the wetland surface. If establishing layers in a pond or on a flooded wetland, use trash cans with the bottom cut off to define the plot (circular) and aid in establishing the horizon by confining the feldspar (Figure 5.6). It helps to push the trash can into the surface a small amount to keep the feldspar from leaking out the sides.

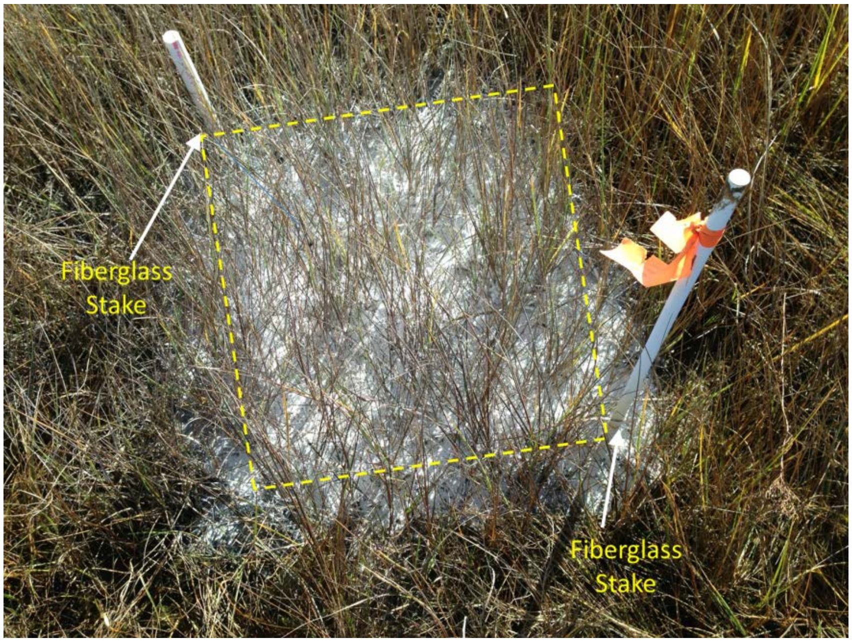


Figure 5.5. Feldspar marker horizon plot with two stakes.

Figure 5.6. Feldspar marker horizon plots established using trash cans in a shallow pond with about 8" (20 cm) of water (Delta NWR, Venice, LA USA).

d. Spread the marker on the marsh surface or into the trash can using a small plastic cup (8 oz., 230 ml). A single 50 lb. bag should provide about 6 plots (50 cm x 50 cm x 0.5 cm) using about 8 lbs. of feldspar per plot. Exact measurement is not necessary. Approximately 12-14 cups of feldspar are used. If there is water on the surface of the wetland, and a trash can is being used, wait at least 10-15 minutes to allow the feldspar inside to settle to the bottom (Figure 5.6, 5.7). Carefully remove the can when finished.

Figure 5.7. Feldspar marker horizon after removing the trash can (Delta NWR, Venice, LA USA).

e. Mark the plots with 2 or 4 stakes. If the plot is vegetated, use a stake to knock the feldspar off the vegetation and onto the wetland surface (Figure 5.8).

Note: The marker horizon will hopefully get buried and the stakes are used to find the plot in the future. If the site is periodically burned, consider using rebar or fiberglass stakes to mark the plots. PVC stakes will not survive a fire.

f. Be sure to draw a detailed map in the data book showing the relative locations of the feldspar plots in case the PVC stakes are lost or destroyed.

Figure 5.8. Knocking the feldspar off the vegetation (Bombay Hook, NWR, DE USA).

Sampling Marker Horizons

The marker horizons are sampled to quantify deposition occurring on a wetland surface. Sampling is normally done on the same day that the SET is measured and needs to be accomplished without disturbing a large area of the sample plot. There are two options for sampling marker horizons: cryogenic coring or cutting plugs.

Cryogenic Coring

Cryogenic coring uses liquid nitrogen to freeze a very small area of wetland soil and allows one to remove a small diameter core from a marker horizon plot. An inexpensive method for cryogenic coring uses a funnel attached to a copper tube into which liquid nitrogen is poured (Figure 5.9). The more common, but more expensive, method uses a small, self-pressurized liquid nitrogen dewar (Cahoon et al. 1996). This cryogenic coring system consists of the 15 liter tank, the flexible hose and the copper bullet probe (Figure 5.10, 5.11). The following pages provide detailed instructions on this method.

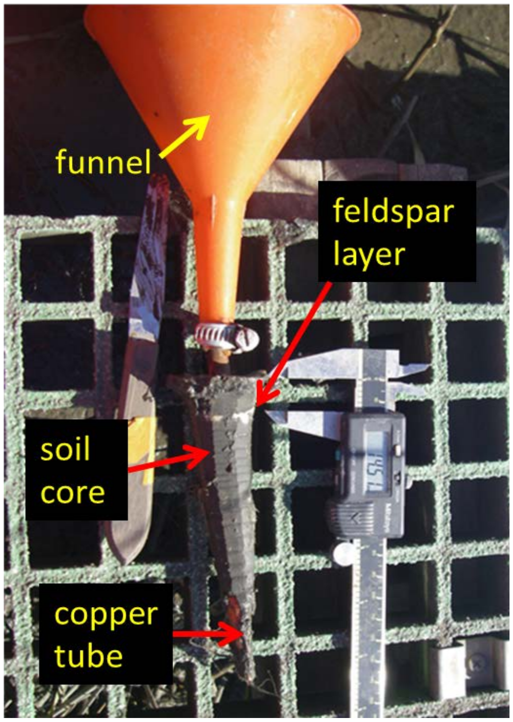
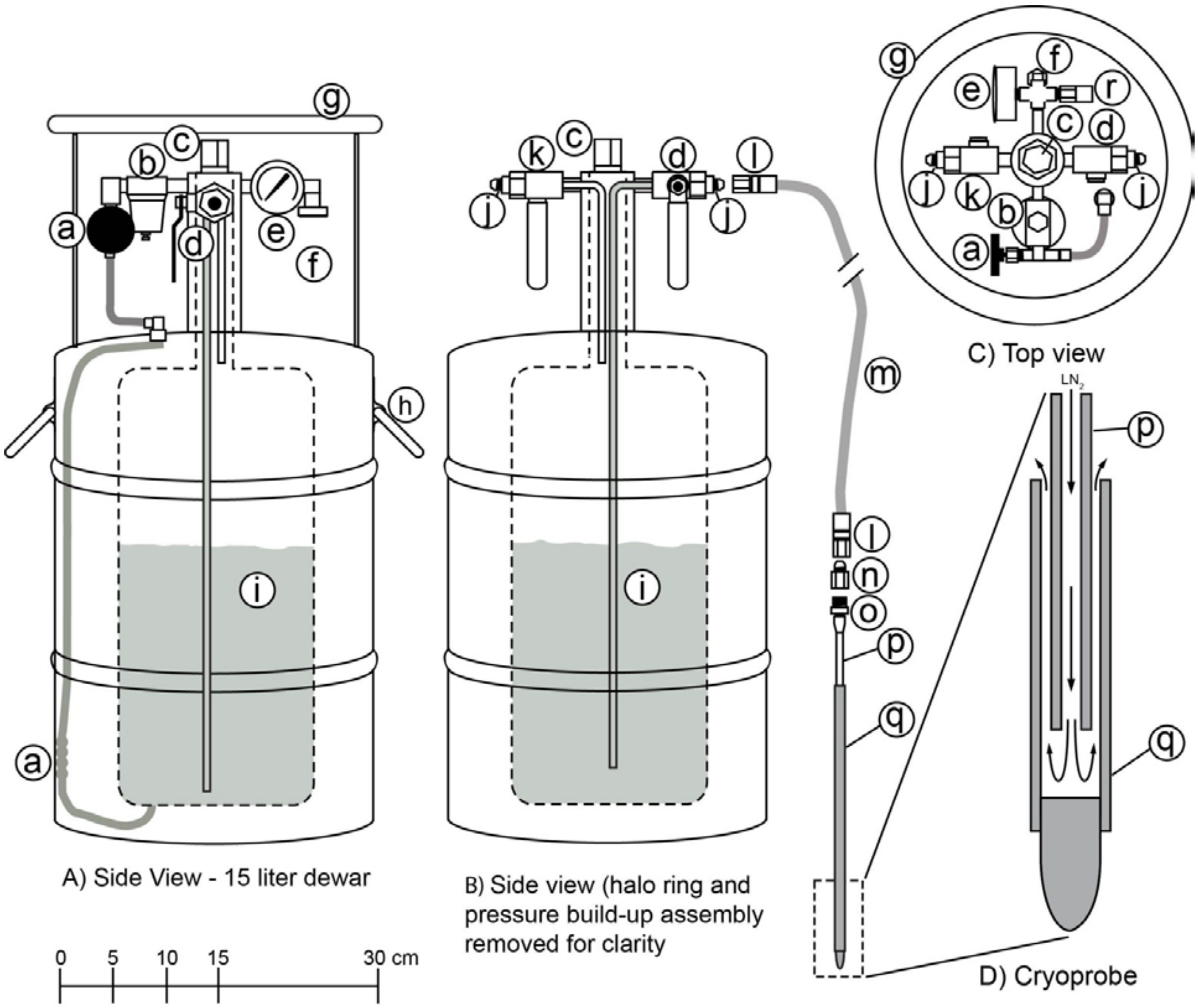


Figure 5.9. Frozen soil core taken with liquid nitrogen.

Figure 5.10. 15 liter dewar, stainless steel hose, and copper bullet probe.

SAFETY – Working with Liquid Nitrogen

Be very careful when working with Liquid nitrogen. It is very cold (-320° F, -196° C) and can easily burn the skin if not careful. Wear insulated gloves and glasses/goggles to protect the skin from coming in contact with the liquid. Keep the dewar vertical at all times. If travelling with it in a vehicle, make sure it is not in the cabin with the occupants of the vehicle.



a - Pressure build-up valve assembly
b - Pressure build-up regulator
c - Extra fill port (5/8”, 16mm)
d - LN_2 fill & withdrawal valve (3/8”,10mm, 90° ball valve)
e - Pressure Guage
f - Rupture disk (100 psi, ~700 kPa)
g - Halo Ring (handle)
h - Side handles
i - LN_2 (~15 liters maximum)
j - Hose connectors (6M-6JMS)
k - Vent valve (3/8”,10mm, 90° ball valve)
l - FJIC fittings (1/2”,13mm)
m - Flexible hose (1/2”x6’, 13mm x 1.9m)
n - Hose connector (4F-6JMS)
o - Flare adapter (1/4”x1/4”, 6mm x 6mm NPT)
p - Cryoprobe inner sleeve (1/4”, 6mm copper tubing)
q - Cryoprobe bullet (3/8”, 10mm copper tubing with 7.62mm bullet)
r - Safety valve (22 psi, ~150kPa)

Figure 5.11. Schematic of the 15 liter dewar (from Callaway et al. 2013).

1. **Supplies:**

   a. 15 liter self-pressurized dewar (Figure 5.10, 5.11, 5.12) - Cost about $1400-1600 (US $) in 2015. This is not a common size for a self-pressurized dewar. Consequently the tank may need to be custom made when ordered.

   15L DEWAR:
   Specifications for the dewar:

   - Stainless steel construction (better with saltwater environments)
   - Self-Pressurized (low pressure unit, 22 psi)
   - Halo ring on top for handling and protection
   - Handles on the side for easy transportation in the field (no wheels)
   - Top mounted fill port (optional).

   The valves on the dewar are screw-type which require about 3 or more turns to close or open the valve. The liquid valve is normally replaced with an inexpensive 90º degree ball valve (3/8”), which allows for very fast control over the flow of liquid nitrogen.

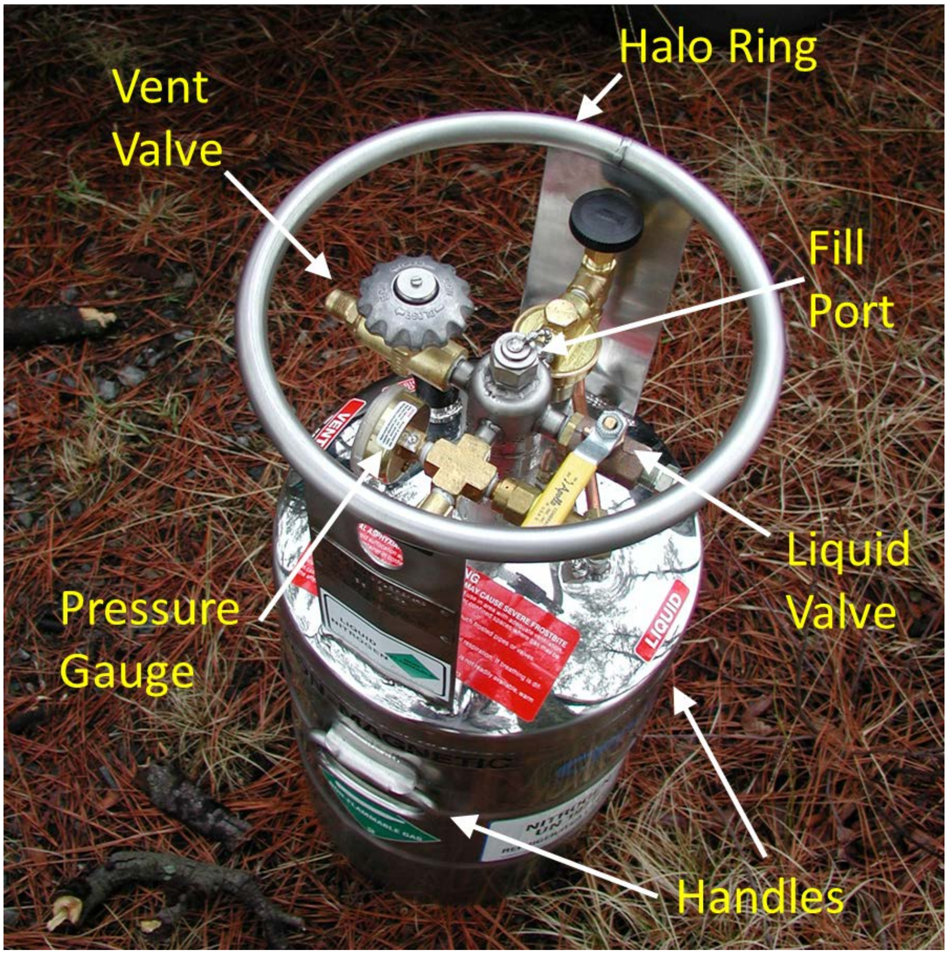


Figure 5.12. 15 liter dewar.

b. Stainless Steel flexible hose (purchase locally) - Cost $75-100 each.

The hose is constructed of 1/2" diameter x 6'-6.5' (~2m) long stainless steel flexible hose with 1/2" female hydraulic connections at each end (Figure 5.13). The hose is covered with a stainless steel mesh to protect the hose.

Figure 5.13. Flexible stainless steel hose.

c. Fittings

It is important to have the appropriate fittings to connect the flexible hose to the tank and the copper bullet probe. The LN_2 tank and hose uses 1/2" Joint Industry Council (JIC) fittings for connections (Tank and bullet = male fittings, Hose = female fittings). The ball valve on the tank and the connection for the copper bullet probe use national pipe thread (NPT) fittings. These fittings can be found at a local hose and fitting company. They are not normally available at a hardware store.

Dewar→Liquid Valve on Dewar → Fitting (a) → Stainless Steel Hose → Fitting (b) → Bullet

i. Fitting for 90º ball valve = 1/2" male NPT to 1/2" male JIC fitting. This is a common fitting and usually comes on a new dewar (Figure 5.14).

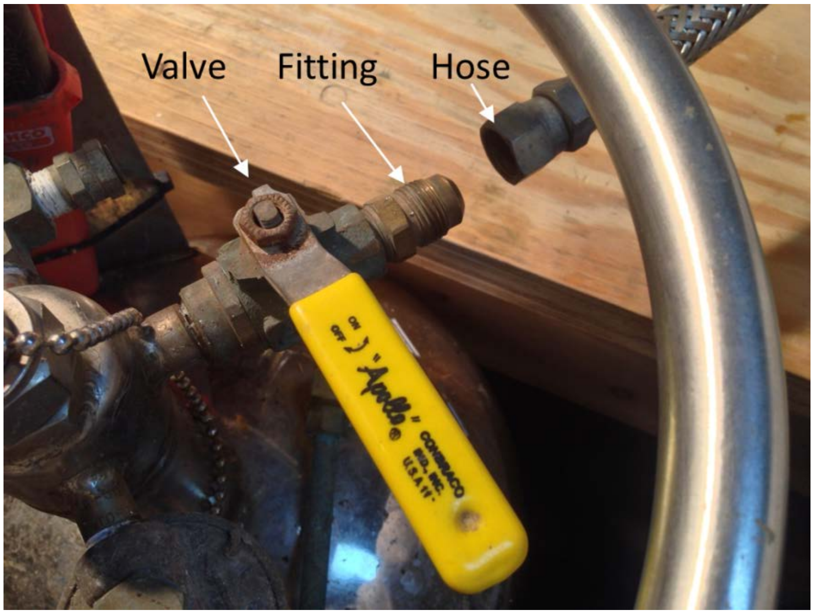


Figure 5.14. Close-up of the liquid ball valve and fitting.

ii. Fitting for bullet = 1/4" female NPT to 1/2" male JIC fitting (figure 5.15).

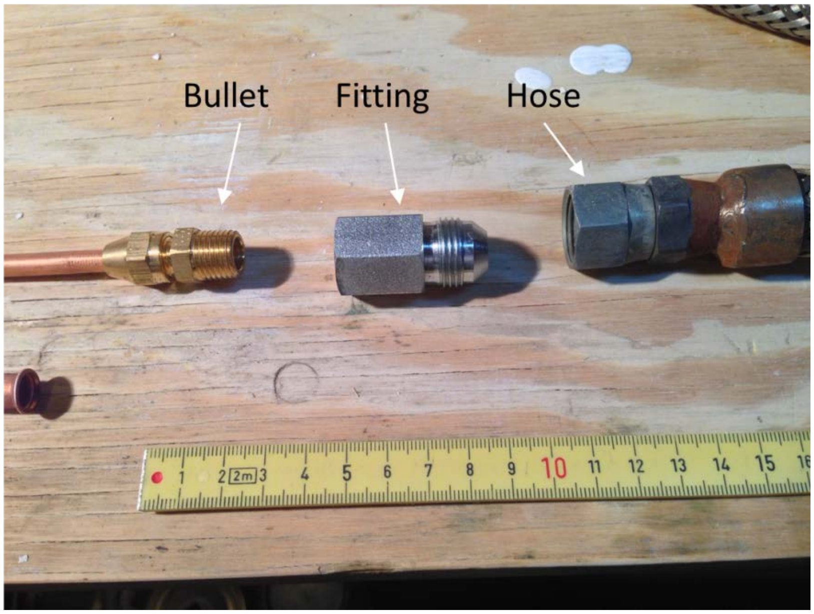


Figure 5.15. Fittings for bullet probe and hose.

Note that the descriptions of these fittings may differ from is found at a local hose company.

d. Copper probes for taking accretion cores – They are commonly called "bullets" because they normally use a 30 caliber bullet on the tip (Figure 5.16), and are custom made. See instructions below.

e. Knife – small knife for scraping frozen soil cores

f. Metric ruler – small ruler or calipers which can read to the millimeter (figure 5.17).

g. Gloves, safety glasses

Figure 5.16. Copper bullet probes (outer sleeves).

Figure 5.17. Metric ruler (note that it starts at zero).

2. **Instructions – Making "bullets"**

Bullet probes are inexpensive to make. There are two parts to a bullet probe (Figure 5.18), the inner sleeve and the outer sleeve.

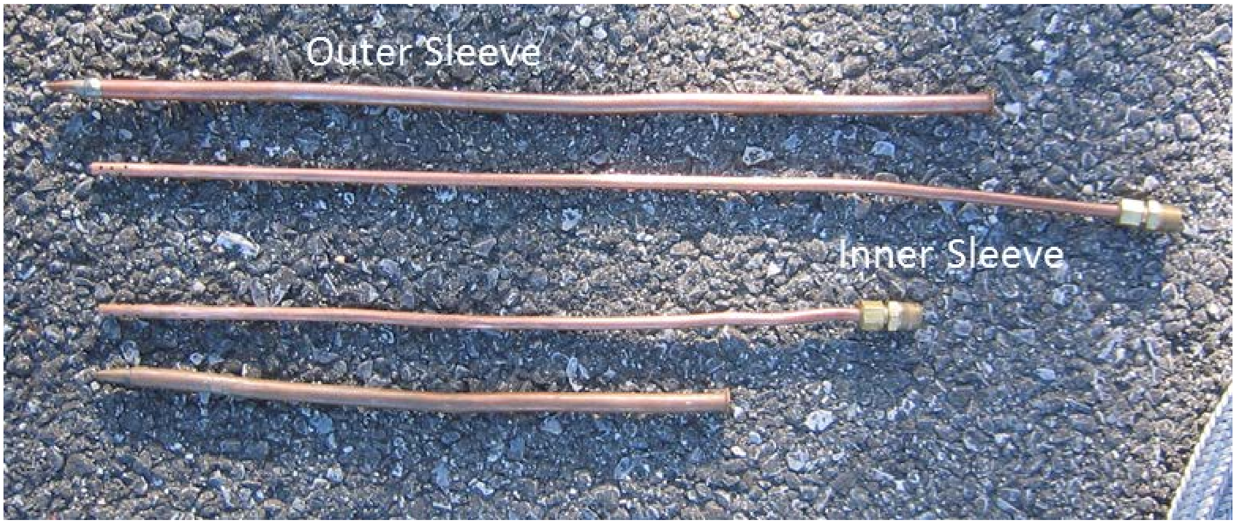


Figure 5.18. The "Bullet": The inner sleeve and the outer sleeve.

Supplies needed:

- Copper metal tubing (Figure 5.18), 3/8" (Outer Sleeve) and ¼" (Inner Sleeve). Use standard "utility" copper tubing which can be purchased at any hardware store. It typically comes in a coil, 10' or 20' in length.
- ¼" NPT compression fitting (for the inner sleeve, Figure 5.19).
- 30 Caliber bullets (optional) – loose bullets (no shell or gunpowder) , full metal jacket (Figure 5.16, Figure 5.20).

Figure 5.19. Compression fitting.

Figure 5.20. The bullet (top) and inserted in the copper tube (bottom).

- Pipe cutter tool (Figure 5.21).
- Tubing Flare kit – This is a hand operated tool for flaring the end of a piece of copper tubing (Figure 5.22).

Figure 5.21. Pipe cutting tool.

Figure 5.22. Tube flaring tool.

- Soldering Iron or butane torch, solder, flux. A butane torch is recommended (Figure 5.23).
- Safety goggles and gloves

Figure 5.23. Butane Torch.

a. Outer Sleeve construction:

i. Cut the copper tubing (3/8” OD, ¼” ID) to the appropriate length. The normal length is about 15-18” (Figure 5.24a). Create a variety of lengths for the bullet probes. Longer bullets (~24”) are useful if there is water on the wetland surface.

ii. Flare one end of the outer sleeve with the flaring tool (Figure 5.24).

iii. Attach a bullet to the other end of the outer sleeve. The end of the copper sleeve needs to be slightly opened up in order to get the bullet to fit. The best way to do this is to tap the pointed end of the bullet into the copper tube with a hammer (Figure 5.25 a,b). Don’t tap too hard, just enough to flare open the tubing a bit. The bullet will slide a bit into the copper tube and open it up slightly. Now remove it (Figure 5.25 c). The bullet may not come easily out. Use a pair of pliers to extract it from the tube. Remove the bullet, turn it around and insert it into the copper tube (Figure 5.25 d).

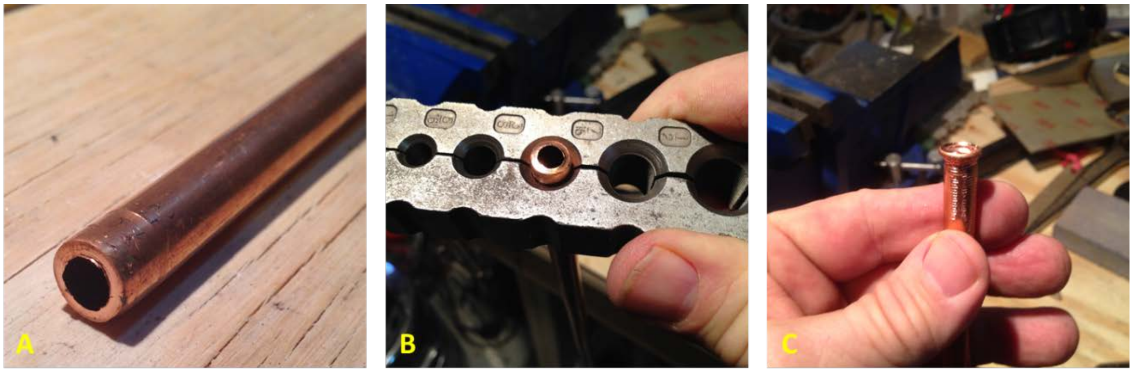


Figure 5.24. Flaring the outer sleeve of the bullet.

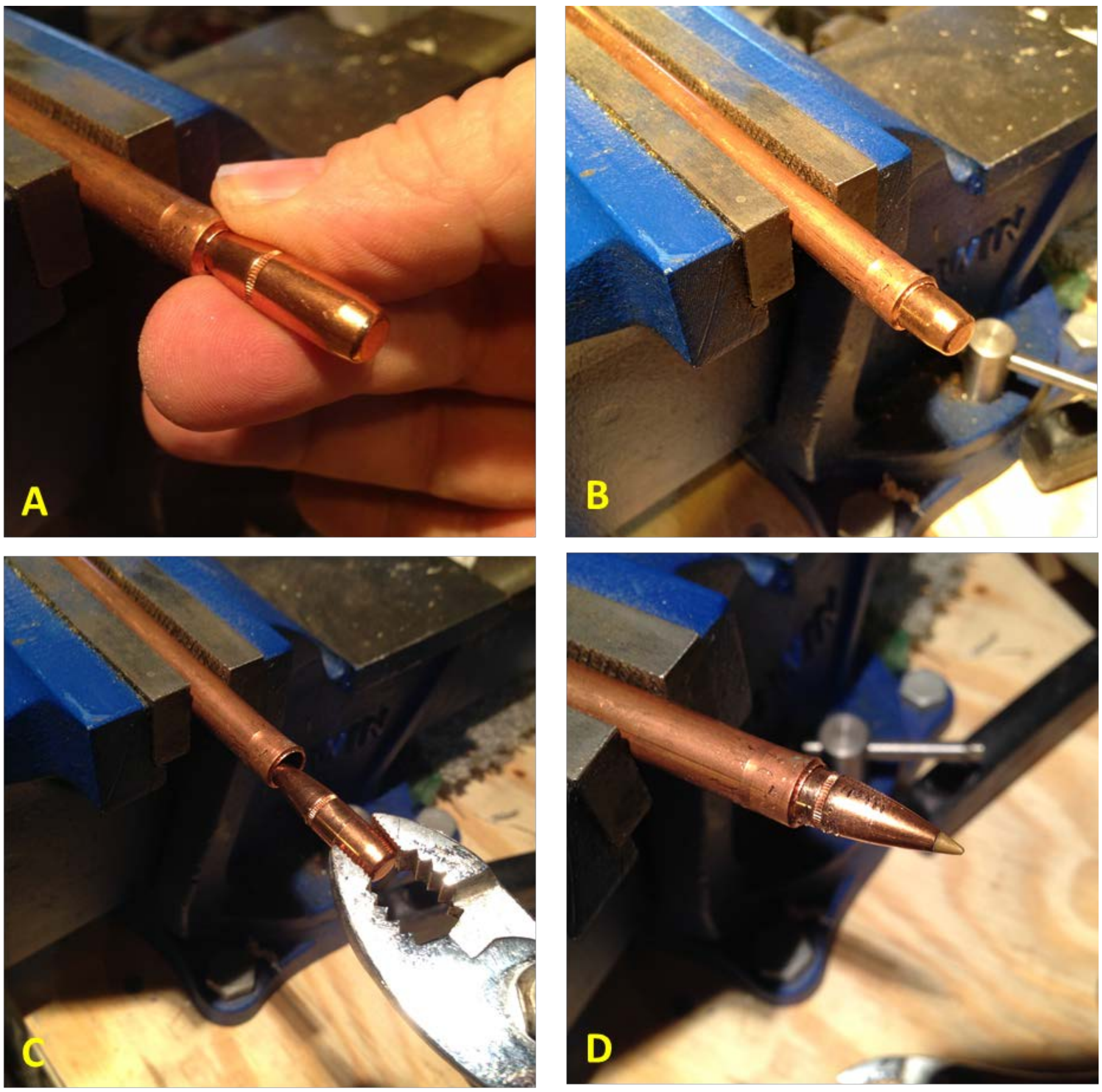


Figure 5.25. How to open up the end of the outer sleeve to insert the bullet. A) Place bullet "tip first" into the copper tube (use a vice to hold the sleeve), B) Tap the bullet into the copper tubing with a hammer, C) Remove the bullet with pliers, D) turn bullet around and place into the copper tubing. The bullet is now ready for soldering.

NOTE: Use of a bullet for the tip of the outer sleeve is optional. The end of the copper tube can be flattened in a vise and soldered shut.

iv. Insert the bullet and outer sleeve into the flare kit (Figure 5.26). Place this on flat surface and hammer the flare kit to compress the copper tube around the bullet. This will help to hold it in place until soldered.

v. Soldering: Dip the bullet assembly in flux. Secure the bullet in a vice. Heat the bullet and copper tubing with a butane torch. Solder the bullet to the outer sleeve.

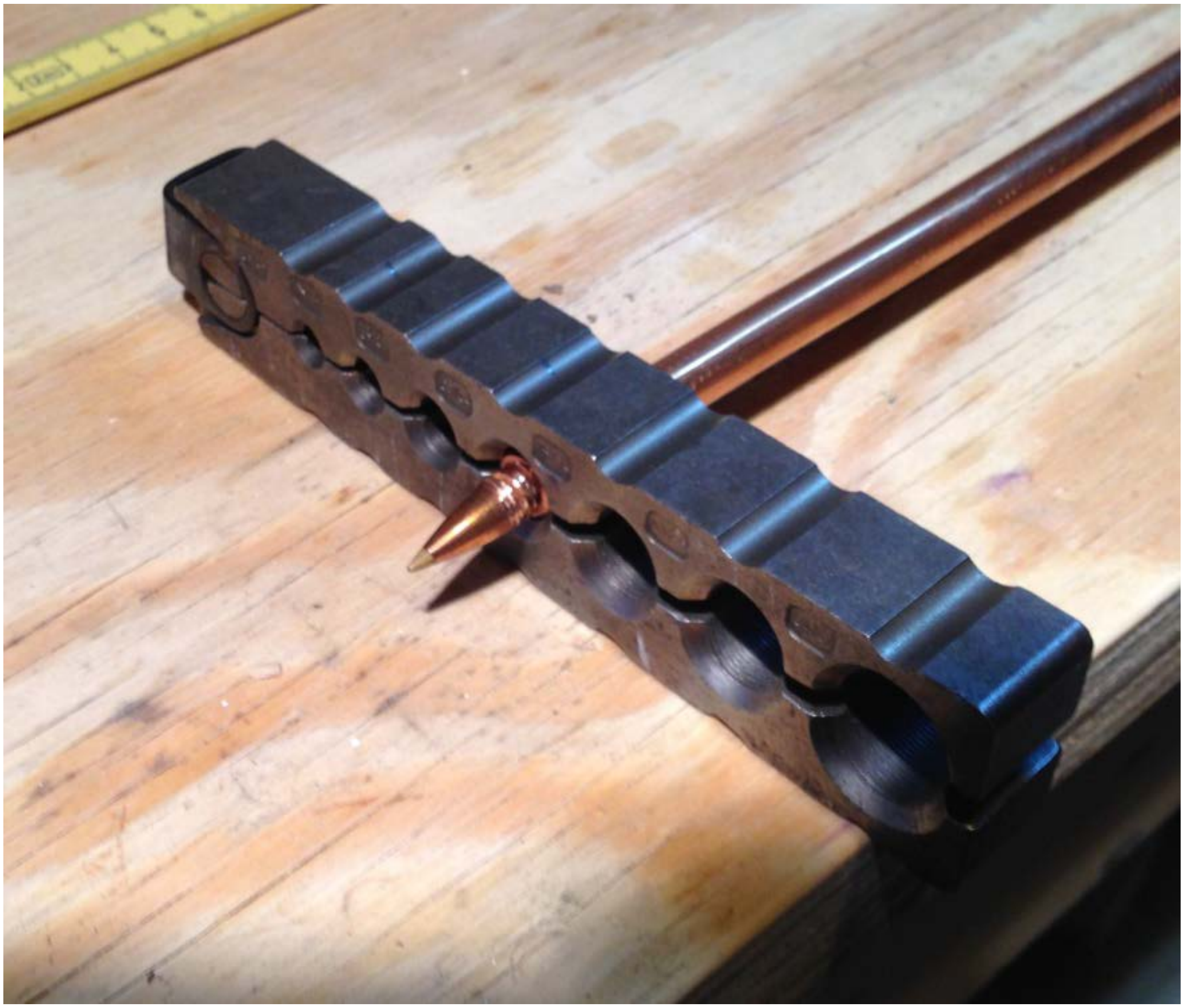


Figure 5.26. Compress the copper tube and bullet.

b. Inner Sleeve Construction:

i. Cut the appropriate length of copper tubing (¼" OD, 1/8" ID) to match the length of the outer sleeve. The inner sleeve should be about 2-3" longer than the outer sleeve which goes with it.

ii. One end of the inner sleeve attaches to the NPT compression fitting and the flexible hose.

iii. Flare this end with the flare tool and attach the compression fitting (Figure 5.27).

iv. The other end of the inner sleeve needs to have holes drilled in the end to help the flow of liquid nitrogen. Use a very small drill bit (1/16") put about 3-4 holes through the tubing. It would be best to use a drill press if available. Note that in addition to the holes, a small "notch" can easily be cut into the bottom of the inner sleeve with a hacksaw. This also helps to improve the flow of LN_2 through the bullet probe (Figure 5.28).

v. Smooth any burrs at this end with sandpaper or a grinder. The inner sleeve is finished.

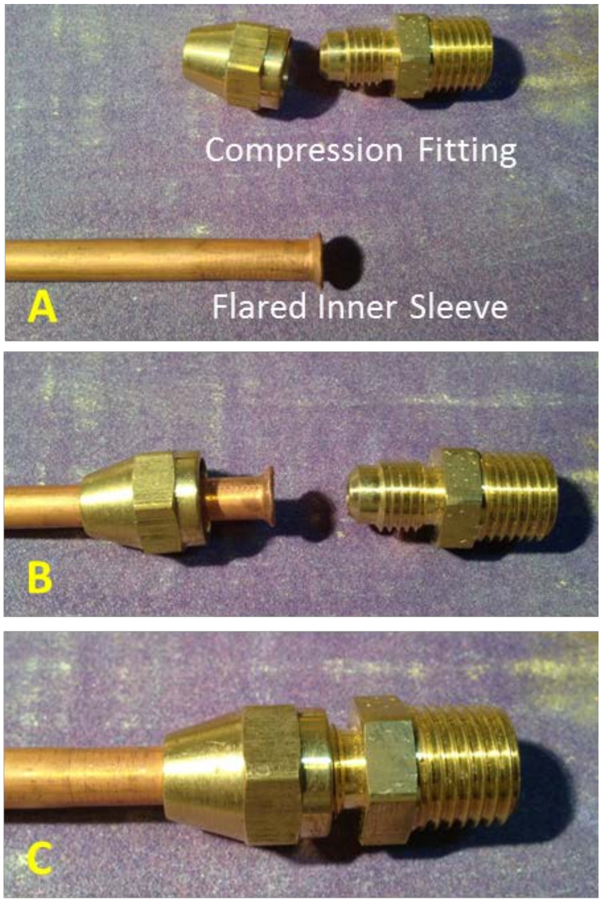


Figure 5.27. Inner sleeve fitting.

Figure 5.28. Tip of the inner sleeve.

3. Instructions - Filling the dewar

Prior to heading to the field, the 15 liter dewar needs to be filled with liquid nitrogen. The dewar used for cryo-coring are low pressure vessels and only build about 22 psi of pressure. Make sure that the 15 L dewar is filled from another low pressure dewar. Some larger dewars build a pressure of 250 psi. Do not use a high pressure tank to fill a low pressure dewar. It could damage the 15L dewar and is not safe.

There are two options for filling the dewars with LN_2;

a. Take the 15 liter tanks to a local compressed gas company and have them filled there. This is the most convenient solution but also the most expensive. The costs to fill a 15 liter tank can vary widely, ranging from $2-4 per liter. Call ahead and make sure they have LN_2 in stock. Some smaller companies only carry a small amount at their office.

b. Order a large LN_2 tank from the gas company and have it delivered to the office or lab (Figure 5.29). These tanks are typically 160 liters and can easily last for over a week. Use this large tank to fill the smaller 15 L tank (or tanks) as needed. It is not recommended to order a large tank if only filling the 15L dewar once. This is the most economical method for obtaining LN_2 if a lot of it is needed. A large LN_2 tank will cost around $100-150 filled and delivered (plus a monthly rental fee).

Figure 5.29. Large 160 liter dewar (rental) and two 15 liter dewars.

Steps to fill a 15 L dewar from a larger (160 L) "low pressure" dewar:

i. Open both valves (Liquid and Vent) on the empty 15 L dewar to remove any internal pressure. **Leave these 2 valves open!**

ii. Connect the flexible stainless steel hose to "Liquid" valve on the 15 L dewar.

iii. Connect the other end of the stainless steel hose to the “liquid” valve coming out of the large dewar (Figure 5.30). The 15 L dewar should now be directly coupled to the large dewar via the hose. NOTE: Depending on the dewars and hoses being used, some additional fittings may be needed to make the connection.

iv. Open the liquid valve on the large dewar and start the flow of LN_2 into the 15 L dewar. There will be a hissing sound coming from the open vent valve on the 15 L dewar. This is normal.

v. The 15 L dewar will get heavier as it fills. This is the only way to easily gauge how fast it is filling up. Gas will be venting from the vent valve throughout the fill.

vi. When the 15 L dewar is almost full, liquid nitrogen will start spurting from the vent valve and there will be a lot of white exhaust.

vii. The 15 L dewar is full.

viii. Close the liquid valve on the large “fill” tank.

ix. Shut off both valves on the 15 L dewar. All valves should now be closed.

x. **IMPORTANT**: When all the valves are closed, immediately use a wrench to crack the connection at one end of the stainless steel hose. This will allow the LN_2 still in the hose to be released. Do not forget to do this. After venting the hose, wait till it warms up before removing it completely.

xi. **NOTE:** It is best to fill the 15 L tanks just prior to heading into the field. Do not fill tanks days in advance since the tank will lose LN_2 even if it is not being used.

xii. **NOTE:** A self-pressurized dewar with LN_2 in it will hiss, even when not being used. This is normal and due to excess pressure bleeding off.

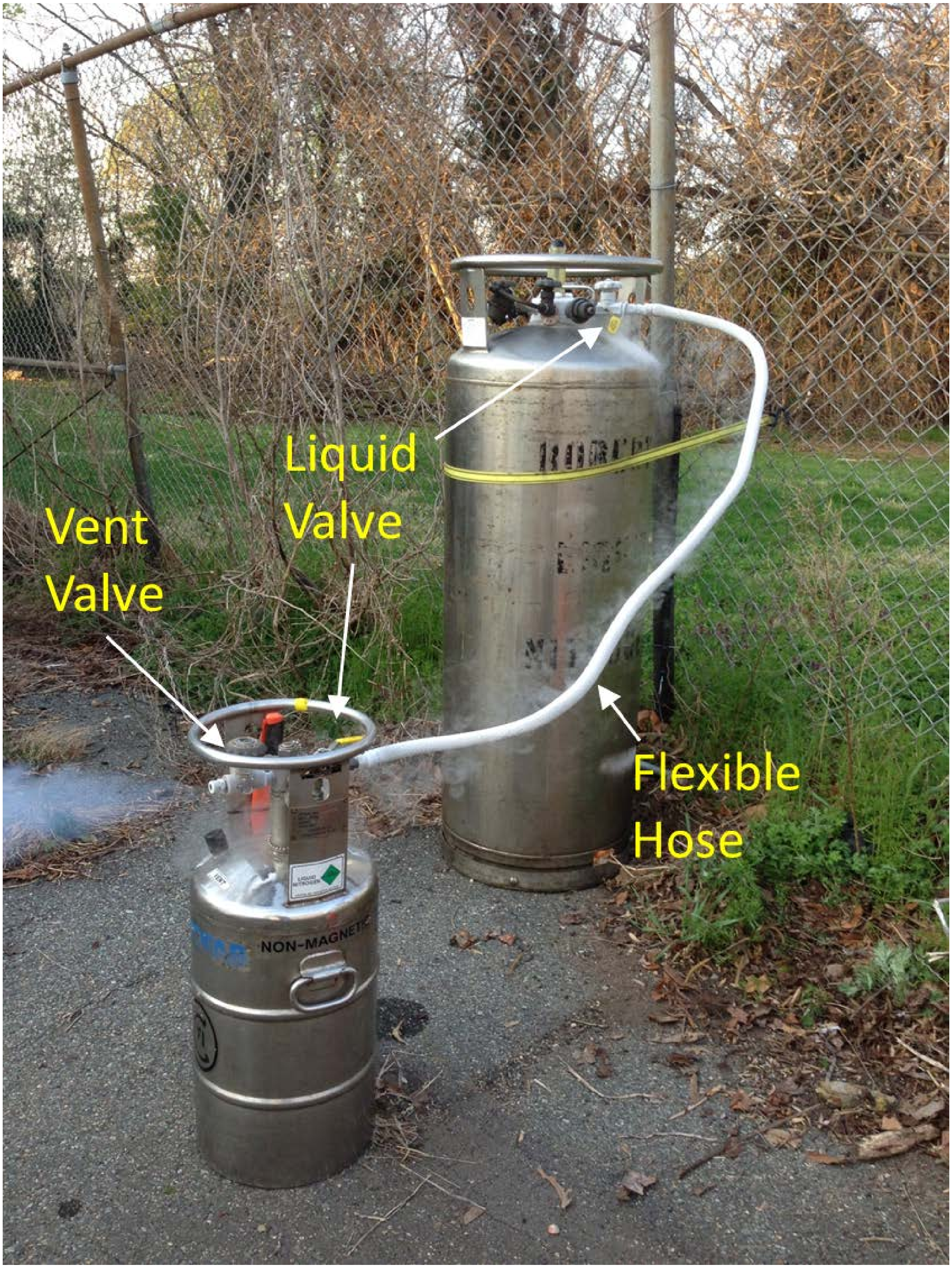


Figure 5.30. Filling a 15 L dewar from a larger tank. Note the white exhaust coming from the vent, which is normal.

4. Instructions – Taking a cryo-core

a. Carrying the dewar: A full 15 L tank will weigh about 50 lbs. (23 kg). It is best to have two people carry the tank using the two handles on the side (Fig 5.31).

Figure 5.31. Carrying a dewar (Cape Cod National Seashore, MA USA).

b. Locate the marker horizons. (Fig 5.32). They are typically marked with 2 or 4 stakes.

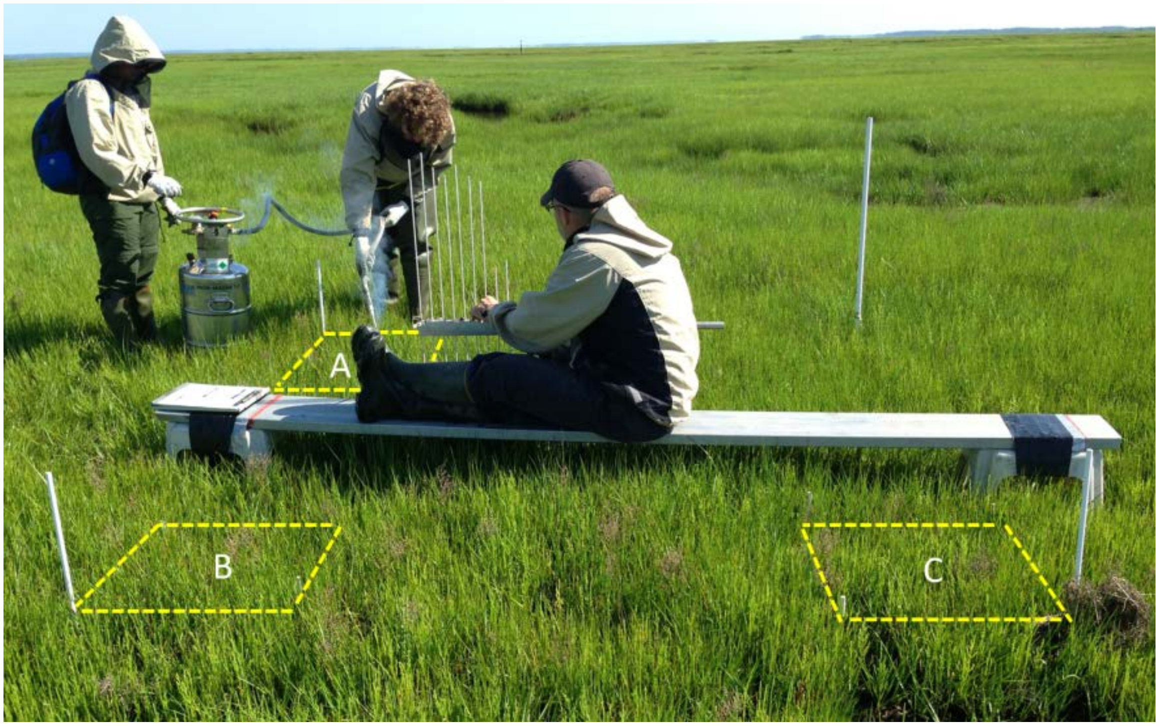


Figure 5.32. Sample station showing the three feldspar plots (dashed yellow lines). Note the corners of the sample station are marked with taller fiberglass stakes. Not all stakes are visible (Assateague Island NS, MD, USA).

c. Connect the stainless steel flexible hose to the "Liquid" valve on the 15 L dewar with an adjustable wrench. Connect the other end to a bullet. Do this at the site or sample station since it's easier to transport the tank without the hose and bullet attached.

   Locate the marker horizon plots at the sample station (Figure 5.32). Work from a platform, if possible, to minimize disturbance of the marsh surface. Gently push the bullet into the soil within the marker plot (Figure 5.33). Try not to push the bullet too far into the substrate. It may be difficult to remove the frozen core if pushed in too far. Two to three inches is usually deep enough. If the marker horizons are deep or if working on a flooded wetland or shallow pond, longer bullets may be needed.

   NOTE: If the feldspar is visible on the surface it may not be necessary to core the plot. Enter zero's for the value. Do NOT enter zero's in the data book if the marker horizon is not found. In this situation do not record any values but make a not that the horizon was not found.

d. Completely open the “liquid” valve on the dewar and start the flow of LN_2. Hold the hose to support the bullet as it starts to freeze (wear gloves). While the LN_2 is flowing, nitrogen gas will exit from the top of the bullet. This is normal.

Figure 5.33. Bullet being inserted into the wetland sediment (before freezing).

e. The first core may take longer (~30-60 seconds) since the entire hose and bullet assembly needs to freeze before the bullet gets cold enough to begin freezing the soil. Subsequent cores shouldn't take as long to freeze (<30 seconds). Especially if they are taken within minutes of each other.

f. Continue freezing the core until a white cloud of gas begins to exit the top of the bullet (Figure 5.34). This indicates that the entire hose and bullet are frozen and the liquid is making it to the bullet and escaping as exhaust. Turn off the LN_2 soon after this cloud forms. The bullet does not need to be supported any longer since it is now frozen in the sediment.

g. Close the “Liquid” valve on the dewar to stop the flow of LN_2.

h. Grab the top of the bullet (wear gloves!) and pull the core and hose out of the marsh. This core is commonly called a "Cryo-core" or "Marsh-sicle".

i. Remove the outer bullet sleeve from the inner sleeve (the part with the frozen soil core on it is attached to outer sleeve). Be sure to put an empty bullet (outer sleeve) on the inner sleeve to keep it from getting dirty.

Figure 5.34. Taking a cryo-core. Note white cloud from the LN_2 escaping the bullet (Fire Island NS, New York, NY USA).

NOTE: There is an art to taking frozen soil cores with liquid nitrogen. The core needs to be frozen long enough so there is enough frozen sediment to process and measure. Don't freeze the core long enough and the sediment may come off the bullet when pulled out of the ground or scraped with a knife. Freeze too long and the core may be difficult to remove from the soil. Do not insert the copper bullet too deep into the sediment since a deep frozen core can also be difficult to remove.

j. Scrape away the excess soil and roots from the core with a knife (Figure 5.35) making a smooth surface. Hopefully, there will be a distinct layer visible from the marker horizon. If the marker horizon is feldpar clay, it will be a bright white layer.

k. Measure how much material is on top of the marker horizon in millimeters (Figure 5.36, 5.37). This distance will vary within a single core, so take up to four measures on a single core to capture the variation. Note that some parts of the core may not produce a reading. Record the values and describe the quality of the marker horizon layer in the data book/datasheet. Write "Poor Layer", "Good Layer", or something similar when recording the data from cores. Record how many cores it took to find the marker horizon. These notes will help to determine the quality of the marker horizon and aid in the decision to establish new marker horizons.

l. Layer not found: If the marker horizon is not found core, take another core in a different part of the plot. It is common to take up to three cores in a plot before noting that the marker was not found. Before continuing to the next plot, make notes of core quality, number of misses, quality of marker, etc.

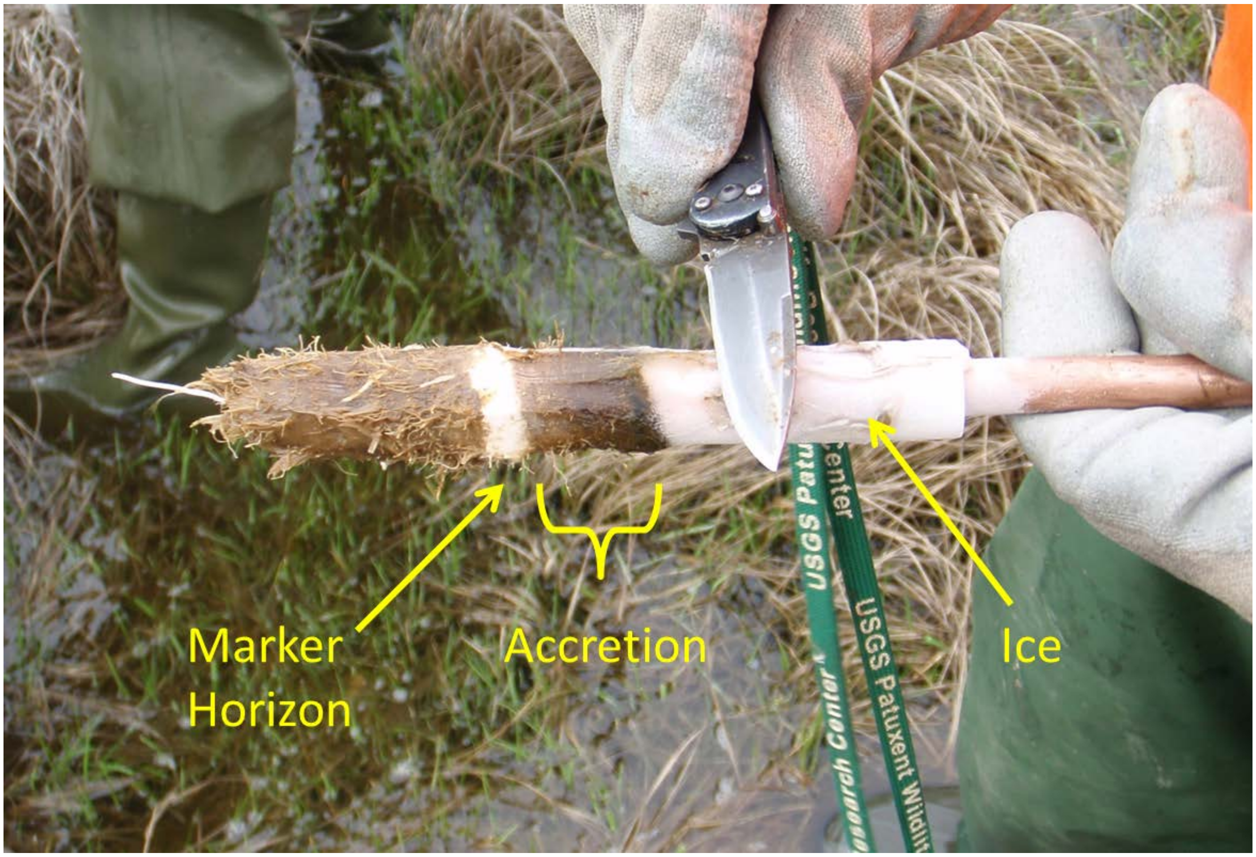


Figure 5.35. Scraping a frozen core. Marsh was covered in water which froze during coring (Gateway NRA, New York, NY USA).

Figure 5.36. SET measurements and cryogenic coring on a permanent platform (Gateway NRA, New York, NY USA).

Figure 5.37. Measuring a frozen sediment core (cryo-core) showing the feldspar marker horizon.

Cutting Plugs

In some situations it may be possible to use a sharp knife and cut small soil plugs from the marker horizon plot (Figure 5.38, 5.39, 5.40). This will work only if:

1. The sediments are quite firm and maintain their structure when cut and removed from the soil.
2. The surface is mostly dry and free from standing water.
3. The marker horizon is not too deep.

In general, tidal, saline wetlands with firm sediments work very well for cutting plugs.

Supplies:

- Sharp knife (6-8” long, serrated kitchen knife is recommended).
- Metric ruler or caliper – for measuring the thickness of the layer in millimeters.

Instructions:

1. Cut a small, four sided plug (approximately 3-5 cm on a side) from within the marker horizon plot.
2. Pry the plug out of the ground from one of the four sides. Make sure the core is deep enough to include the marker horizon. The depth of the plug is related to the length of the knife blade. It is recommended to use a longer knife for deeper marker horizons.
3. The marker horizon should be visible. (Figures 5.38, 5.39, 5.40). If the layer is not found, take additional cores in the plot. If after 3 or more cores without a layer, make a note that layer was not found in the data book.
4. Try to improve the visibility of the layer with the knife to clearly show the layer.
5. Record the thickness of the sediment above the marker horizon layer. Take up to 4 readings from a single core, one representative reading from each side. It may not be possible to get 4 readings. Record the data from the core in the data book.
6. Gently push the plug back into the ground.
7. Move on to the next marker plot and repeat the above steps.

Figure 5.38. Measuring a cut plug core. Note the thin feldspar marker horizon.

Figure 5.39. Measuring a core.

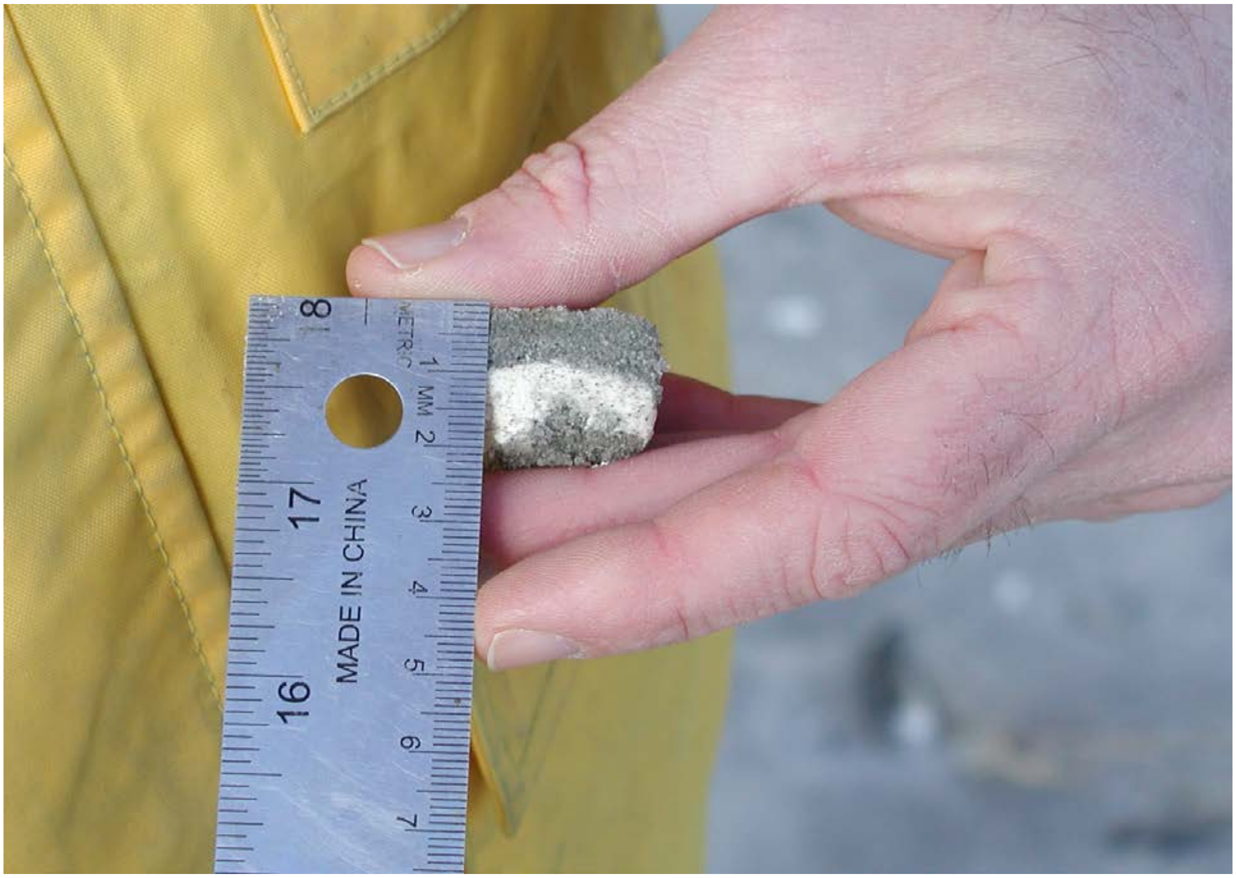


Figure 5.40. Cut plug core at a marsh restoration site.

Literature Cited

Cahoon, D. R., Lynch, J. C., Jr., & Knaus, R. M. 1996. Improved cryogenic coring device for sampling wetland soils. Journal of Sedimentary Research 66, 1025–1027.

Callaway, J. C., D. R. Cahoon, and J. C. Lynch. 2013. The Surface Elevation Table – Marker Horizon Method for measuring wetland accretion and elevation dynamics. pp 719 – 735. In Methods in Biogeochemistry of Wetlands. R. D. DeLaune, K. R. Reddy, C. J. Richardson, and J. P. Megonigal, editors. SSSA Book Series, no. 10. doi:10.2136/sssabookser10.c.

SOP 6: Surveying the SET Mark

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP 10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

This SOP describes the options for accurately determining elevations at and around SET-Marker Horizon sample stations. Accurate elevations at sample stations enable a number of important insights:

1. Elevation of the wetland surface – Being able to determine and compare the elevation of wetland surfaces in a common spatial reference system. Surveying can be used to directly measure the surface around the SET mark. It can also be used to measure the elevation of the SET mark. These measurements can be used to convert SET pin readings to actual elevations by measurement of the vertical distance between the SET mark and the SET instrument (Figure 6.1, inset A).

2. Elevation of additional infrastructure on site or in the area – The ability to survey local wetland surface elevations (e.g. permanent vegetation transects, water level recorders, and any other structure or device of interest).

3. Measurement of SET mark stability - Establishing an elevation on the SET mark from which to measure local vertical land motion (uplift or subsidence; Figure 6.1, labeled B).

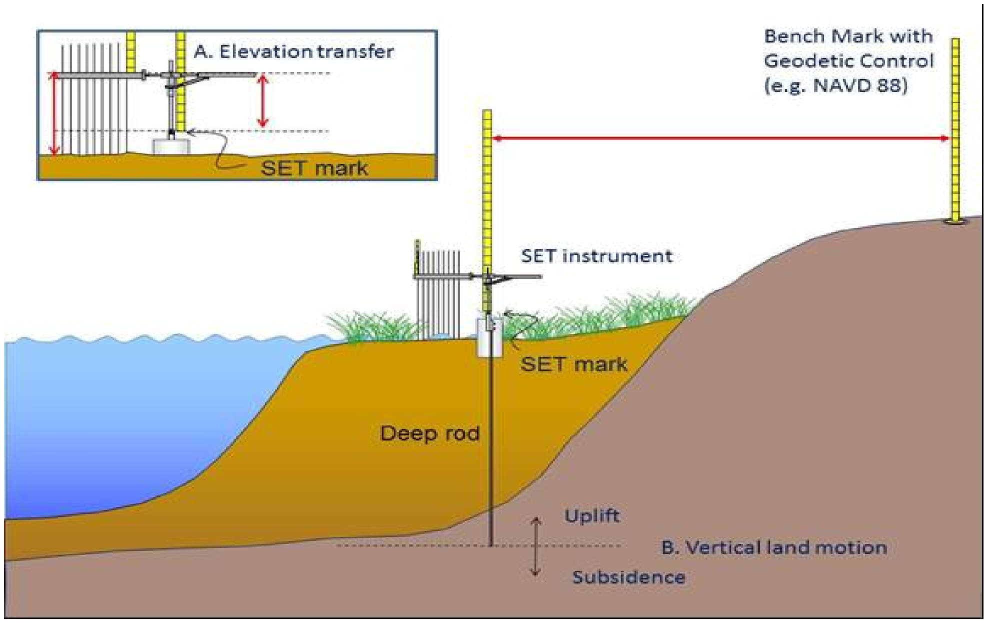


Figure 6.4. Surveying to an SET mark. Elevations can be transferred to a SET mark from a nearby bench mark by leveling. The elevation can then be transferred to the wetland surface measured by the SET (inset A) and to any nearby infrastructure of interest. A time series of repeated surveys can allow for the monitoring of vertical movement below the SET mark (B).

Obtaining elevations at a study site is a two-step process.

1. Obtaining a high accuracy elevation at one (or more) SET marks.
2. Local surveying from this SET mark to other SET stations and items of interest on site.

Step one involves obtaining a high accuracy elevation aligned with the National Spatial Reference System (NSRS) on a local reference mark, called the Local Control Mark (LCM). This is typically a deep SET mark. There are a number of survey techniques that can be used to connect this mark to the NSRS. They differ in cost, accuracy, and the need for specialized training. Table 6.1 lists some of the more common techniques to get high precision elevations at SET marks.

Geodetic leveling (using high precision instrumentation; see Glossary) to an existing, high accuracy published level line bench mark will result in the most precise connection to the national vertical datum (the National Vertical Datum of 1988, or NAVD 88). Unfortunately, high precision leveling, especially over long distances, may require expensive equipment (e.g. digital barcode level and invar rods), takes a long time for a minimum of a three-person field crew, and requires substantial training and expertise. Furthermore, to connect by leveling to the NSRS requires proximity to an existing, published level line, which may be very rare for typical SET sample stations. In addition, SET sample stations may be dispersed throughout a larger wetland area with stations separated by water and distance, further complicating the use of leveling techniques.

Because of the constraints with leveling, GPS-based positions may be much more expedient in terms of cost and time. Basic GPS surveying and analyses can be accomplished with far less technical training than is required for leveling, except for locations with severely obstructed view to the sky (e.g. forested wetlands). Note that simultaneous GPS observations can be analyzed as part of a network and will provide significant gains in precision and accuracy. Network solutions require significantly more training and resources, and are therefore beyond the scope of this SOP, and best left to the professional surveyor. This SOP therefore will focus on the minimum required positional accuracy through independent, static GPS observations (#3 in Table 6.1).

Step two involves surveying from the LCM to other local SET marks and other items of interest at the site. This can be accomplished through a variety of techniques: the recommended procedure is leveling to keep vertical errors to a minimum.

Table 6.1. Strategies for obtaining a National Spatial Reference System (NSRS) elevation on a Local Control Mark (LCM). This SOP focuses on method #3, independent GPS observations.

Survey Method	Elevation Error	Pros	Cons
BEST STRATEGY			
1. Geodetic Leveling	± 0.8 cm/√km or better	Highest precision connection to orthometric datum (e.g. NAVD 88)	Significant training required Labor intensive Slow Requires proximity to existing leveled elevations Significant post processing required to publish
SECOND – BEST STRATEGY			
2. Simultaneous GPS observations	≤ 2 cm	Relatively rapid, easy Allows for better connection to orthometric datum than independent static GPS observations	Significant training required Requires numerous GPS units (2 or more) for 5 hours or more of occupation Requires post processing Ability to conduct network analysis
3. Independent GPS observations	± 2 – 4 cm	Rapid, easy Minimal post processing	Greater error than simultaneous GPS observations
LESS RECOMMENDED			
4. Real-Time GPS (RTN/RTK)	± 6 cm	Rapid Little or no post-processing	Most expensive technique Extensive training required Largest vertical error with respect to NSRS
5. Total Station	± 0.1-0.4 cm/100m	Relatively rapid Precision is better than GPS	Some training required Not applicable to long distances Requires additional reference marks Requires post processing

Development of the Survey Plan

The survey plan is the roadmap for all surveying activities associated with the SET study. It will specify the goals of the survey, how the survey will be conducted, the techniques and equipment used, and how the data will be processed. It is recommended to have the plan reviewed by someone familiar with surveying, to make sure that the results are consistent with the goals.

The user may consult the publications “Accurate Elevations for Sea Level Change Sentinel Sites” (Hensel et al. 2015) and “Procedures for Connecting SET Bench Marks to the NSRS” (Geoghegan et al. 2011) for more in-depth presentation of instrumentation and procedures for high accuracy surveying to SET marks. Note that the specific procedures presented in these documents are not required for this SOP unless they are specifically stated here.

Step 1: Marks: Identify the locations of all the SET marks to be surveyed on a map. Note that SET marks (sample stations) may typically be found clustered in groups within sample sites. Only one mark within a cluster will have a direct connection to the NSRS via GPS. This will be called the local control mark (LCM; Figure 6.2). A project may therefore entail several LCM’s, one in each sample site. Elevations can subsequently be transferred from the LCM to the other nearby SET marks with higher precision methods, such as leveling. The LCMs should therefore be close enough to the other SET marks (or other points of interest) to enable leveling across the marsh surface.

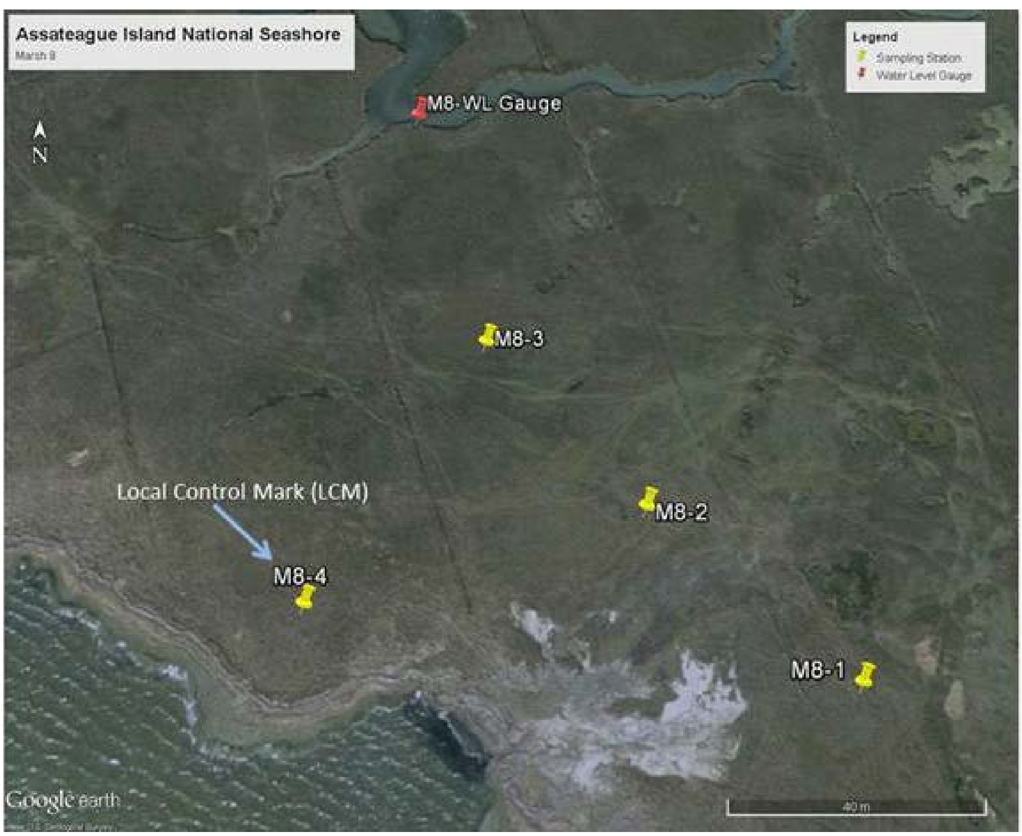


Figure 6.2. Map showing locations of four SET stations: M8-1 through M8-4. Map also shows location of a local water level recorder (M8-WL Gauge). Only one SET station will be chosen as the local control mark (LCM), in this example, M8-4.

LCMs should be in open areas with little to no obstructions to the open sky higher than 20 degrees above the horizon (typically the height of an extended fist above the viewer's horizon). Avoid high tension electricity wires and any metallic, reflective surfaces (e.g. metal panels such as vehicles) adjacent to the LCMs. LCMs should also be very stable marks, such as deep rod marks. The locations of the LCMs should be readily accessible by the user, but should preferably be in a secure environment, to avoid equipment damage or loss.

> **For the advanced user:** multiple GPS antennas (ideally the same make and model) deployed simultaneously would allow for a more precise network analysis (not covered in this SOP), or at the least, a computation of consistent height differences among LCMs.

Step 2: Equipment: Identify the equipment that will be used in the survey. Refer to Table 6.2 for guidance. Although advanced GPS survey techniques are available, these require multiple GPS units operating simultaneously, which requires a significant investment in equipment. An acceptable GPS survey can be conducted with only one setup (as described in this SOP). Fixed height GPS tripods are recommended. Adjustable-height tripods or custom adapters for the SET mark can also be used (Figure 6.3). These will require the user to carefully measure the resulting antenna height above the mark.

Figure 6.3. Foreground: a static GPS occupation of a SET mark (the Local Control Mark) using a custom GPS antenna adapter; in the background is another, nearby SET sample station being measured (Acadia National Park, ME, USA).

Table 6.2. Recommended equipment and supplies for a GPS (static) survey.

Quantity	Description	Notes
1	GPS antenna	Antenna should be survey-grade, capable of receiving at least the L1 and L2 bands of GPS frequencies. Access to other global navigation satellite systems (GNSS) is not required. Requires antenna cable if unit is separate from receiver
1	GPS receiver	If separate from antenna. Many modern GPS receivers incorporate the antenna and receiver in the same unit (Figure 6.3)
1	GPS Tripod	Or other GPS antenna adapter (Figure 6.3)
1	External 12V battery	To ensure long (> 4 hour), continuous GPS occupation
1	Temporary Platform	To access the SET mark without disturbing site and to keep battery from getting flooded.
1	Punch	For marking the vertical reference point on an SET mark (Figure 6.4, 6.5).
1	Digital camera	Used for photographs of equipment setup; to record the height of the antenna above mark; close-up photo of mark to show both mark and tip of tripod; close-up of antenna to show make/model/serial number.
1	Dry erase board & markers	Record mark ID, antenna height and other information on the board and photograph for a record of the setup being used (Figure 6.10).
1	Field data sheet	Includes all important recordable information, including mark ID, GPS equipment, obstructions, weather, start and end times, etc.

Step 3: The Survey: The GPS survey should include at least two independent, long (> five hour long) static GPS observations separated by at least 24 hours – per LCM. If at all possible, multiple (replicate) 24-hour static sessions are recommended, but not required. If shorter sessions are used, stagger repeat sessions so that they encompass different parts of the day. This will ensure different GPS satellite constellations and satellite geometries are used in the survey. Note that in general, one long session (e.g. more than eight hours) is preferable to two shorter sessions of less than four hours, even though there might be no replication. Replication is important, but there is little point to replicate poor solutions, which are more likely in surveys of less than 5 hours duration (Table 6.3). Make sure there is enough time allotted to obtain multiple, long GPS observations. Plan for extra time in case a given observation goes wrong (e.g. loss of battery power or the antenna is disturbed) and it has to be redone. GPS antennas/receivers (note that many modern GPS units have the receiver integrated with the antenna; Figure 6.3) need to be randomly assigned to each LCM, with the restriction that a given LCM cannot use the same equipment twice. This helps minimize the bias for a particular piece of gear. This also assumes there is more than one antenna/receiver available for the survey.

Identify within the survey plan which equipment (GPS units, tripods, antenna adapters, etc.) will be used at which locations/SET marks, when they will be deployed and for how long. Document serial numbers, especially of the GPS antennas and receivers, to ensure the equipment can be tracked throughout the course of the survey (one unit may have an unknown bias).

Table 6.3. Options, ordered from best to worst, for a static GPS survey on the LCM. Options 4 and 5 are not recommended.

Static Session Options	
Option 1 (best)	2 long sessions (≥ 5 hours each) separated by at least 24 hours.
Option 2	Single long session (8-24 hours)
Option 3	2 short sessions (<5 hours each) separated by at least 24 hours
Option 4	Single session (~5 hours)
Option 5 (worst)	Single session (<5 hours)

It is recommended to check the atmospheric conditions and other factors before conducting the survey. Online GPS survey planning software is available and provides information on space weather, the performance metrics of available satellites, and even the availability of GPS reference data (used in the analysis phase) to help plan the survey. Although not required, planning software can help ensure a successful GPS survey.

Step 4: Post-processing: GPS data will be processed after the survey (post-processing) to derive high accuracy positions. In most cases, the raw data can be directly loaded into the National Geodetic Survey's On Line Position User Service, or OPUS, although GPS equipment vendors may have their own software. We recommend the use of OPUS, as it guarantees alignment with the NSRS. Note there will be a three-week time delay in obtaining the precise satellite orbits. Assign positional error limits (e.g. vertical error) in the survey plan. Determine those outcomes (e.g. exceedance of error limits) will require any re-observation.

As a result of the post-processing, at least two acceptable positional solutions will be provided for each LCM. The user will average over the different solutions to compute an average position (latitude, longitude, and elevation). Document in the survey plan how the data will be processed and by whom.

Step 5: Have the plan reviewed by a professional surveyor, or other trained technician. Consider having the plan reviewed by the National Geodetic Survey's Ecosystem and Climate Operations (ECO) team, or a local, federal, or state surveyor's office. For the National park Service, contact the national GPS coordinator.

A sample survey plan can be found in Appendix A of this SOP.

Connect SET Marks to the National Spatial Reference System (NSRS) via GPS Observations

This SOP provides recommendations for how a GPS survey should be run to ensure a minimum acceptable accuracy for NSRS-aligned elevations. There may be subtle differences between how users will run GPS surveys, typically entailing varying durations of GPS observations, as well as the number of replicate observations on a given mark. Note that this SOP only describes methods for analyzing independent static GPS occupations. It does not describe how to perform simultaneous occupations, which may provide higher accuracy or real-time kinematic (RTK) GPS campaigns, which may be faster (Table 6.1). These and other techniques are beyond the scope of the typical SET user.

Step 1: Identify the vertical point of reference (VPR) of the SET mark that will be observed with GPS (Figure 6.4). The VPR may be a dimple on a brass disk, the center of a convex brass disk, the top of rounded steel rod, or the highest point on the SET "receiver" (Figures 6.4, 6.5). The VPR of the RSET can be determined using a rod level to discern the tilt of the receiver. The top side is opposite the bubble (left panel of Figure 6.4). The same method can be used to identify the VPR of a pipe SET mark (left panel of Figure 6.5). Once identified, the VPR should be marked with an indentation or chisel mark. A diagram could be useful for future reference.

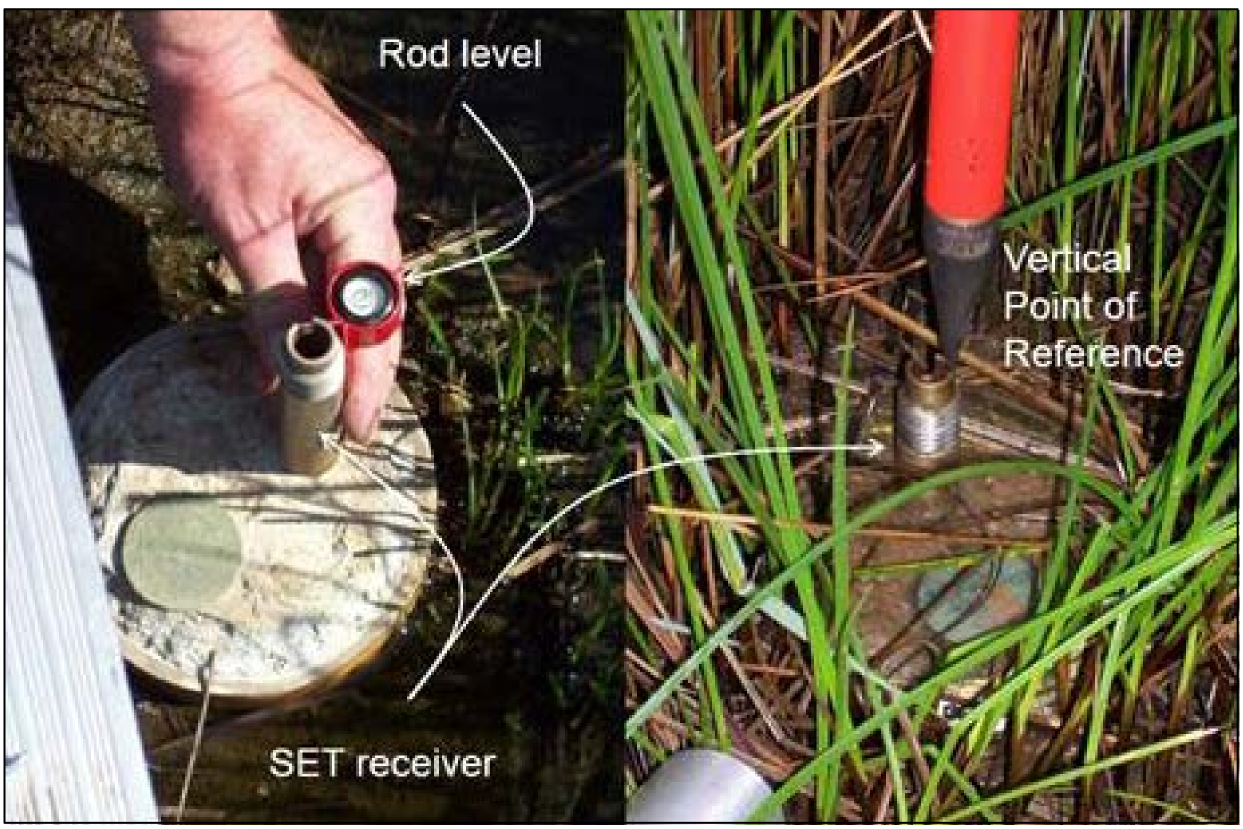


Figure 6.4. Finding the vertical point of reference (VPR) on a deep rod SET monument (left panel); central tip of GPS tripod on VPR. Note that the VPR is NOT the brass disk set in concrete next to the receiver.

Figure 6.5. Finding the vertical point of reference (VPR) on an older, first generation SET pipe mark using a rod level (bubble gauge).

Step 2: Install a tripod or GPS antenna adapter on the VPR.

There are several kinds of tripods that can be used for setting up a GPS antenna on a VPR. The Fixed Height GPS tripod with a central (4th) leg that ends in a point is recommended (Figures 6.9 and 6.10). Slip-leg tripods which are designed to hold other surveying instrumentation can also be used, but are not recommended since the antenna height cannot be easily measured. There are also custom-made GPS adapters made specifically for SET marks.

a. **Fixed Height GPS tripod:** These can either come as a fixed-height tripod (usually 2 m tall), or a collapsible tripod where the central rod can be fixed at one of several, pre-determined heights (e.g. 1.250, 1.500, and 2.000 m).

   It is advisable to measure the distance from the center point to the top of the tripod to assure accurate measurement. Many adjustable type poles have printed height values but they can be off by several millimeters (Figure 6.6).

   1. Loosen the thumb screw that holds the brass screw plug at the top of the tripod. Remove the plug and screw the plug into the base of the GPS antenna (Figure 6.7). Place the antenna + plug assembly onto the top of the tripod (Figure 6.8). Make sure the knurled knob securing the brass plug is nice and tight.

Figure 6.6. Verifying the length of the central leg of a fixed height GPS tripod.

Table 6.7. Removing the threaded brass plug at the top of a Fixed Height GPS tripod and threading into the base of a GPS antenna.

Figure 6.8. Placing GPS antenna on top of fixed height tripod.

2. The central leg of a GPS tripod ends in a sharp point which needs to be placed on the VPR, and the leg plumbed according to tripod instructions (Figure 6.9).

3. When occupying a SET mark, consider lowering the height of the central leg (if it is adjustable) to ensure that the tripod legs will extend outside the SET plot (Figure 6.10).

4. Once the central leg is plumb, tighten all legs and verify the height of the central leg (antenna height).

5. Place the GPS antenna atop the tripod by fitting the brass plug-GPS antenna combination into the recessed cavity at the top of the tripod. Once securely in place, tighten the thumb screw to fix the plug and GPS antenna. Verify the central leg is still plumb.

b. **Custom Built GPS adapter for the SET:** Specially constructed GPS adapters have been designed to eliminate the tripod entirely (Figures 6.11 and 6.12). In either case, the vertical offset from the VPR to the base of the antenna mount needs to be carefully measured after the adapter is plumbed. Leveling can be used to measure the offset directly in the field (backsight to top of mark, foresight to top of adapter).

Figure 6.11. Custom adapter used to place a GPS antenna on a deep rod SET mark for a static GPS occupation.

Figure 6.12. Custom adapter used to place GPS antenna atop deep rod SET mark.

Step 3: Place the GPS antenna/receiver carefully on the top surface of the tripod or adapter (screw in snugly), turn GPS unit on and let it run as described in the study plan. Use an external power source if the occupation is longer than a few hours (Figure 6.13). Take a photograph of the antenna set up on the mark, a close-up of the rod point on the VPR, as well as a close-up of the antenna/receiver itself (preferably, one showing the make, model, and even serial number). Document in the datasheets: the mark identification (e.g. ASIS SET 5), antenna height (e.g. 2.000 m), antenna model, serial number, and start time (Figure 6.14). Also consider recording local weather observations and potential obstructions or sources of multipath.

Figure 6.13. GPS antenna with ground plane atop a two meter fixed-height tripod. Note that in this case the GPS receiver is a separate unit, connected to the antenna via a coaxial cable. Also note external power source (12 volt automobile battery) to ensure uninterrupted power during long observations (in this case, up to 12 hours).

Figure 6.14. Photo-documentation required for a static GPS observation. Upper left: photo showing placement of GPS tripod over VPR of survey mark. Right panel: horizon photo showing deployment of entire GPS static assembly (GPS tripod, antenna, and receiver). Lower left: close-up of GPS antenna identification information.

Step 4: Let the GPS unit run for **at least** five hours (the longer the better). Many users find 24-hour observations desirable from the standpoint of resulting confidence and accuracy if the GPS unit can be left out in the field overnight. Record the end time, weather conditions and any other local observations in the field data sheet.

Step 5: To ensure that the quality of the GPS data collected was adequate, download the GPS observation files as soon as possible and submit them to the National Geodetic Survey's Online Position User Service (OPUS) for a post-processed positional solution (http://www.geodesy.noaa.gov/OPUS/; Figure 6.15). An initial positional solution will use modeled/predicted GPS satellite orbits (ultra-rapid or rapid orbits). The solution is used as an initial check of the GPS observation (see solution statistics in Step 6, below). If the solution shows that the data collected are poor, the GPS observation will have to be repeated.

1. To upload the data to OPUS, select the file using the "Choose File" button.
2. Select the make and model antenna used in the survey. Be careful to choose the correct one!
3. Input the antenna height from field datasheets.
4. Provide the email to which the OPUS solution will be sent.
5. Click on the "Upload to Static" button.

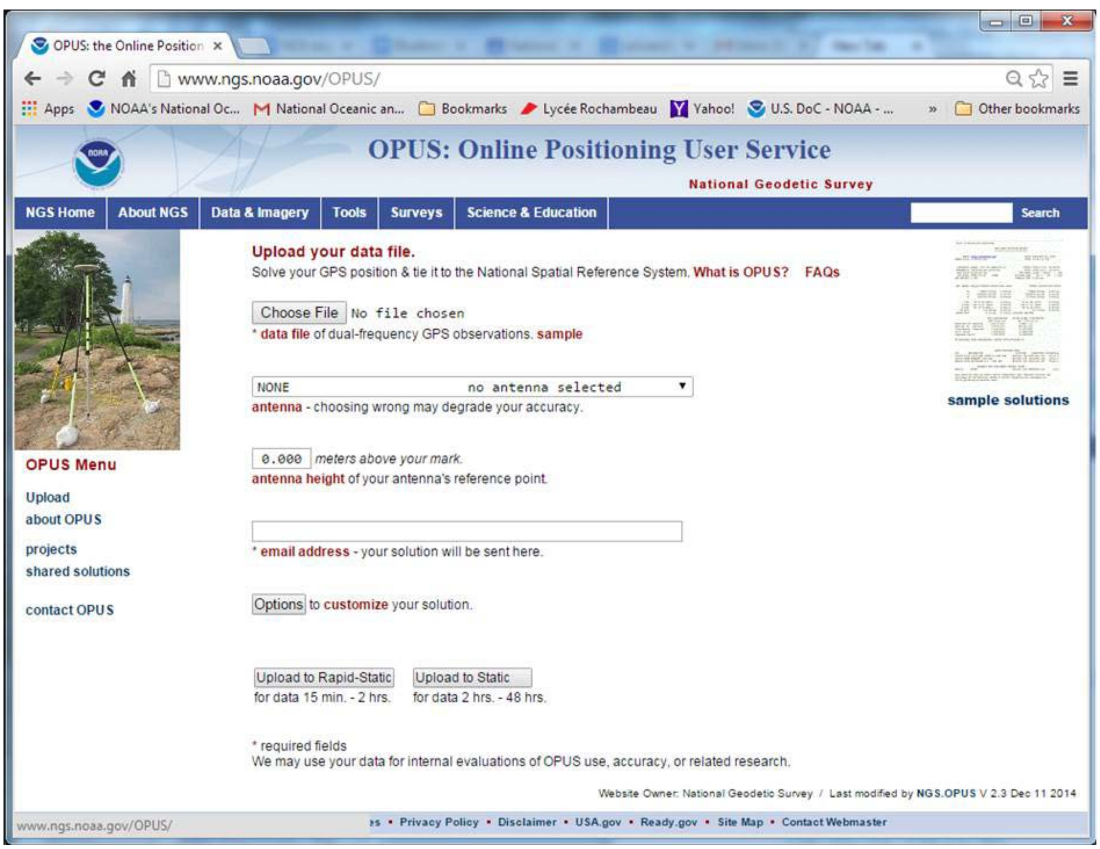


Figure 6.15. Sample OPUS GPS processing upload page, showing required input fields.

If the native GPS observation file type from the GPS receiver is not supported by OPUS, use software to convert the file to the Receiver-Independent Exchange file format (RINEX). In all cases, archive any and all GPS data files with multiple copies for safekeeping and possible re-analysis at a later time, such as to compare over time and estimate mark stability and/or vertical rates of change.

Step 6. After submitting a GPS file to OPUS, a post-processed solution will be sent to the email address indicated in the upload page (Figure 6.15). Make sure the antenna height indicated matches the field records. A "good" OPUS solution will have the following characteristics (Figure 6.16):

1. Observations used: should be ≥ 70%
2. Fixed ambiguities: should be ≥ 70%
3. Overall RMS (residual mean square error – the 3D error): This value combines error in all three dimensions (i.e. latitude, longitude, and elevation), and an error of less than 0.03 m (3 cm) is good. The 3D error gives a good indication of the overall precision of the solution.
4. Positional errors: Recommended orthometric elevation error (shown under "ORTHO HGT" in OPUS report) should be **at least** ≤ 0.08 m (8 cm), and a good solution would be closer to 0.02 – 0.03 m.

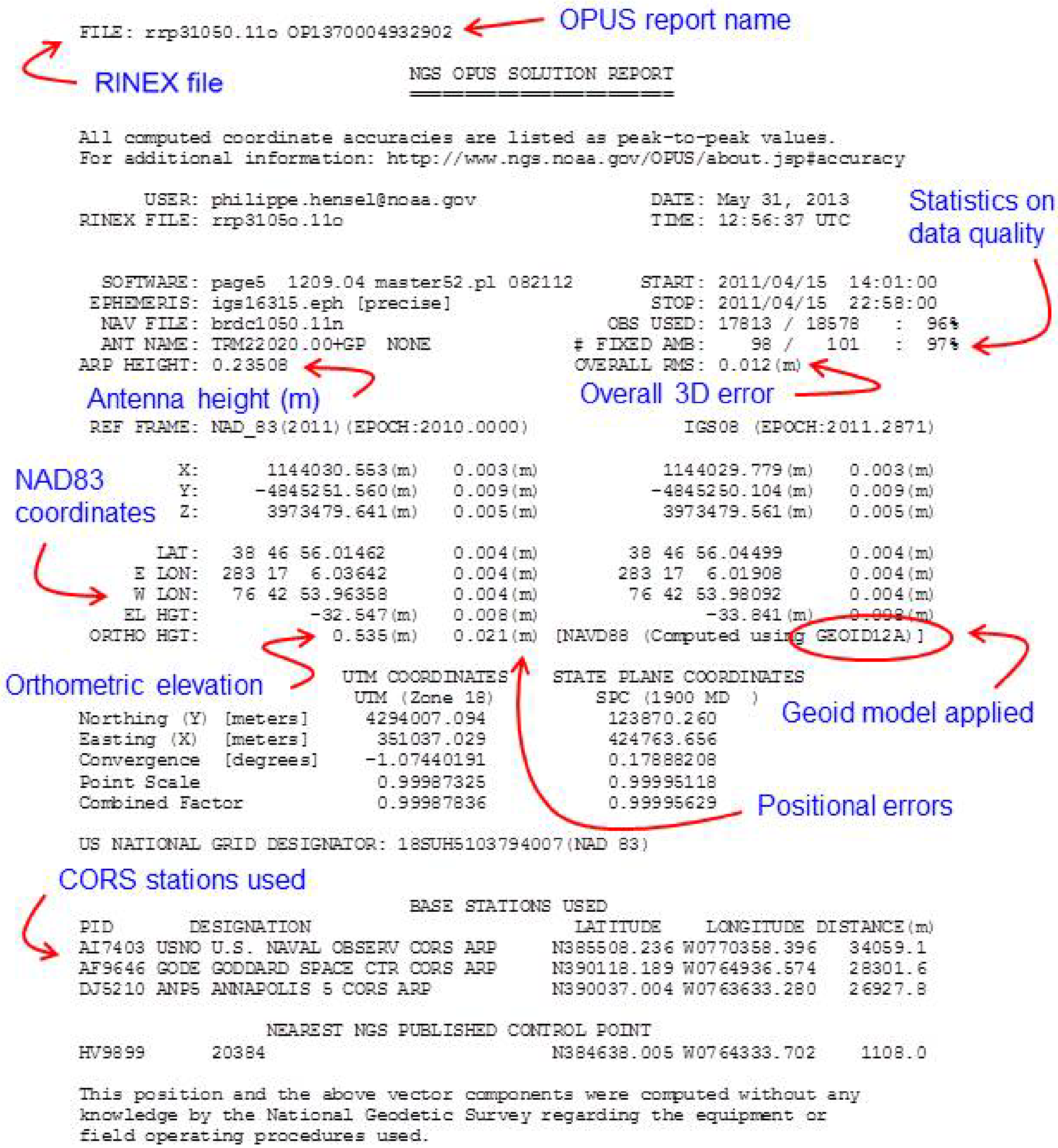
If these quality metrics are not met, consider reobserving the mark. Bad metrics might be caused by atmospheric conditions occurring during the observation period, but are likely a result of poor view of the satellites (obstructed view of the sky) or multipath (GPS signals bouncing off reflective structures like metal surfaces near the GPS antenna). If consistently bad metrics arise at a mark, consider choosing another LCM. The use of GPS planning software and space weather predictions (see Survey Planning Step 3) will help reduce chances of poor quality GPS data.

NOTE: Repeated GPS surveys of a site that are years apart will more than likely have different reference frames and models. They will not be directly comparable unless they are all using the same reference frame and geoid model.

It is important to record two things from an OPUS solution:

1. NAD reference frame: the particular realization of the North American Datum of 1983 (NAD 83), the reference frame used in the continental United States. In the example above (Figure 6.16), the reference frame is "NAD 83(2011) epoch 2010.00."
2. Geoid model used. The geoid is used to convert a GPS-based elevation to an orthometric height. In the example above, (Figure 6.16), "Geoid12A" is the geoid model used.

Diligently archiving all GPS data files is extremely important because over time, the reference frame and geoid model change. When they are changed, the previous solutions will be incompatible with any data processed with respect to the newer frames and models. To keep all results consistent, older solutions will have to be updated which will require the re-processing of older GPS data with the newer version of OPUS.



```
FILE: rrp31050.11o OP1370004932902

                        NGS OPUS SOLUTION REPORT
                        ========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

      USER: philippe.hensel@noaa.gov                 DATE: May 31, 2013
RINEX FILE: rrp3105o.11o                             TIME: 12:56:37 UTC

  SOFTWARE: page5  1209.04 master52.pl 082112      START: 2011/04/15  14:01:00
 EPHEMERIS: igs16315.eph [precise]                  STOP: 2011/04/15  22:58:00
  NAV FILE: brdc1050.11n                        OBS USED: 17813 / 18578   :  96%
  ANT NAME: TRM22020.00+GP  NONE               # FIXED AMB:    98 /   101   :  97%
ARP HEIGHT: 0.23508                          OVERALL RMS: 0.012(m)

 REF FRAME: NAD_83(2011)(EPOCH:2010.0000)             IGS08 (EPOCH:2011.2871)

         X:      1144030.553(m)   0.003(m)          1144029.779(m)   0.003(m)
         Y:     -4845251.560(m)   0.009(m)         -4845250.104(m)   0.009(m)
         Z:      3973479.641(m)   0.005(m)          3973479.561(m)   0.005(m)

       LAT:   38 46 56.01462      0.004(m)        38 46 56.04499      0.004(m)
     E LON:  283 17  6.03642      0.004(m)       283 17  6.01908      0.004(m)
     W LON:   76 42 53.96358      0.004(m)        76 42 53.98092      0.004(m)
    EL HGT:          -32.547(m)   0.008(m)               -33.841(m)   0.008(m)
 ORTHO HGT:            0.535(m)   0.021(m) [NAVD88 (Computed using GEOID12A)]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 18)         SPC (1900 MD  )
Northing (Y) [meters]     4294007.094           123870.260
Easting (X)  [meters]      351037.029           424763.656
Convergence  [degrees]    -1.07440191           0.17888208
Point Scale                0.99987325           0.99995118
Combined Factor            0.99987836           0.99995629

US NATIONAL GRID DESIGNATOR: 18SUH5103794007(NAD 83)

                         BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
AI7403 USNO U.S. NAVAL OBSERV CORS ARP      N385508.236 W0770358.396   34059.1
AF9646 GODE GODDARD SPACE CTR CORS ARP      N390118.189 W0764936.574   28301.6
DJ5210 ANP5 ANNAPOLIS 5 CORS ARP            N390037.004 W0763633.280   26927.8

                  NEAREST NGS PUBLISHED CONTROL POINT
HV9899      20384                           N384638.005 W0764333.702    1108.0

This position and the above vector components were computed without any
knowledge by the National Geodetic Survey regarding the equipment or
field operating procedures used.
```


Figure 6.16. Sample OPUS report for a static GPS eight hour, 57 minute observation.

Step 6. Repeat Steps 1-6 for all LCMs to obtain at least two good solutions, preferably at different times of the day such as morning and evening, and under different atmospheric conditions. The different days and atmospheric conditions help ensure that the solutions are independent. Compare the two preliminary coordinates: the horizontal coordinates (X and Y) should match within one centimeter (0.01 m); the vertical coordinates (Z) should match within 2-4 cm (0.02 – 0.04 m). Since there will be multiple OPUS solutions for the same point, take the average of the positions; consider weighing the values by the 3D error.

Note that more advanced GPS techniques for obtaining an NSRS position are available, and are increasingly within the reach of a non-professional surveyor. In 2014, NGS released OPUS-Projects (http://www.geodesy.noaa.gov/OPUS-Projects/) which, although requiring specialized training available through NGS, allows the user to compute a least-squares adjustment of multiple, simultaneously run GPS onservations. The benefit to these kinds of analyses is significantly reduced error in the resulting coordinates (lat/long/height) and consistent coordinates within an entire project area ("sample space" as defined in SOP 1).

Step 8. Three weeks after a GPS observation, re-submit the GPS data to OPUS to compute a final solution using the precise satellite orbits. Precise satellite orbits will provide the definitive set of coordinates and error statistics for the observation. The values should not change significantly from the initial, rapid orbit solution.

Local Site Surveying (leveling)

Once an accurate elevation with respect to the NSRS is obtained on a Local Control Mark (LCM), which is usually a SET mark, leveling should be used to transfer that elevation to the other nearby SET marks and any other vertically sensitive monitoring system (marker horizon plots, water level recorders, vegetation plots, etc.). Leveling is recommended due to its very high precision and the fact that distances between SET marks will be relatively short at the site level. Therefore in this SOP, local site surveying will only address leveling. Some guidance on leveling, especially as it relates to the wetland environment, is given below. If leveling is not an option, other surveying techniques such as a total station or real-time GPS can be used. Try to use the method with the lowest vertical errors that are available for the particular situation (Table 6.1).

Leveling essentially entails measuring the relative elevation difference between two points (Figure 6.17). In the example, the elevation difference is the backsight reading (rod height at bench mark A) minus the foresight reading (rod height at mark B). If the elevation at one point is known (bench mark A), the elevation difference can be applied to the second point (mark B) to determine its corresponding elevation:

Elevation at bench mark B = (Backsight – Foresight) + (Elevation at bench mark A)

Geodetic leveling usually involves two level runs: a "forward run," from a point with a known elevation (bench mark A) to a point whose elevation is unknown (mark B); and a "backwards run" from the unknown point back to the known point. This "double run" provides two independent estimates of the elevation difference between the two marks. The difference between the two runs should be minimal, and within an *a priori* set tolerance (expressed as millimeters per square root of kilometer distance involved in each running; this SOP recommends a tolerance of $4\sqrt{D_{km}}$). Since the runnings are in different directions, their difference is merely the sum of the two runnings. The accepted height difference will be an average of forward running and the negative of the backwards runnings (the negative sign required to keep the elevation differences relative to the forward running).

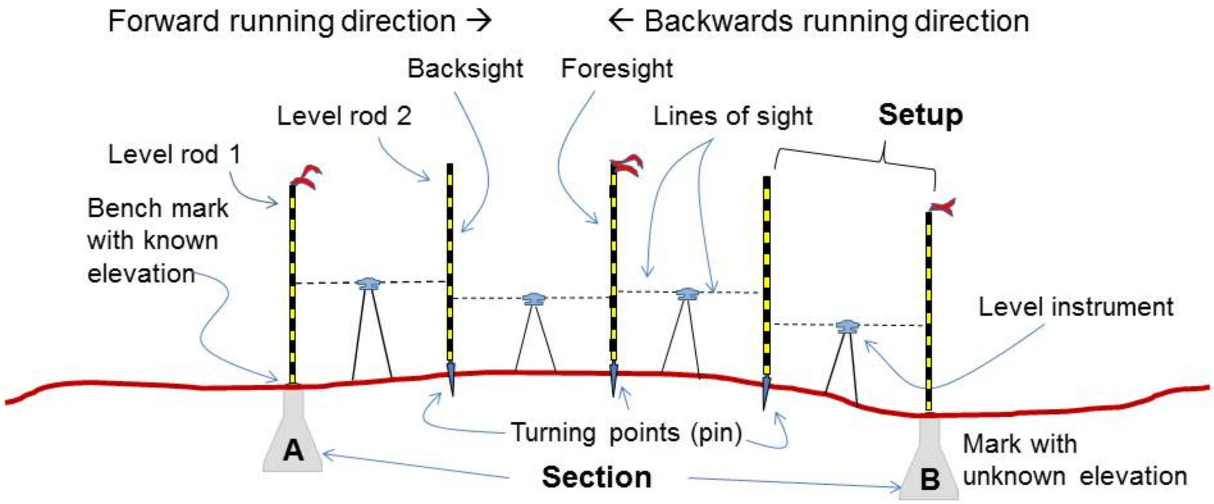


Figure 6.16. Schematic showing basic concepts involved with leveling. The elevation is transferred from a bench mark (with known elevation) to a mark whose elevation is unknown. This transfer is accomplished by measuring the height difference between the two marks. Temporary points (turning points) are used to hold an elevation as the level moves from Point A to Point B and then back again.

The below sections give a general overview of leveling in and around SET sample stations. The details of geodetic leveling are outside the scope of this SOP: the user is referred to training available through the NGS. The guidelines document "Accurate Elevations for Sea Level Change Sentinel Sites" (Hensel et al., 2015) also provides additional guidance the user may find useful. Note that double-run leveling is recommended for establishing new elevations on nearby marks (e.g. SET marks). Once elevations are obtained, any subsequent checks on mark elevations need only employ single-run leveling. Leveling to anything that is not a reference mark (e.g. marker horizon plot, vegetation plot, wetland soil surface) can be single-run (only one direction).

Leveling in the wetland

Leveling on unconsolidated surfaces can be very challenging due to the difficulty in keeping everything stable and plumb. Leveling requires lines of sight, and shorter sighting distances may help the accuracy of the measurements. This means that transferring the elevation from one mark to another will require a number of intermediate sightings ("shots"), which in turn means that there will have to be temporary points ("turning points") installed to hold an elevation over the duration of a level run. In a wetland, establishing a turning point may require driving a long stake into the mud; traditional turning points are meant for hard surfaces such as concrete or compact soil. Probably the most difficult part of leveling in a wetland is finding a stable surface on which to place the instrument and ensuring it does not move between shots.

Suggestions to keep leveling instrument stable in a wetland:

- Splay out the tripod legs to between 45^{o} and 60^{o} or so (Figure 6.18)
- Place barbell weights under each tripod leg. Make sure to wrap flagging tape or a rope to each weight, or they'll quickly disappear.
- Place each tripod leg on a clump of vegetation. Grasses like Spartina and rushes like Juncus grow multiple stems from a central node just under the ground surface: oftentimes, the node is sturdy enough to keep the tripod steady.
- Stay as far away from the tripod legs as possible. If taking the measurements optically, consider setting up a board on the marsh surface to distribute the weight of the observer. If using an electronic level, try to make the measurement as far from the level as possible (Figure 6.19).
- If possible, set up the instrument lower than normal and in a spot where both rods can be seen. Try to keep both feet planted when taking the measurements.

Figure 6.18. Leveling in the wetland: note splayed legs of tripod to enhance stability.

Figure 6.19. Leveling in the wetland: Operator(s) standing away from tripod, while activating electronic measurement.

Another difficulty in wetlands can be the height of the vegetation. In fresh water wetlands, cattail (*Typha* spp.) can easily grow to a height of two meters. Similarly, in brackish wetlands, the common reed (*Phragmites*) can also grow in excess of two meters. Such vegetation quickly obscures line-of-sight, rendering leveling virtually impossible.

Recommendations to help when leveling through tall vegetation:

- Shoot short distances
- Create a line of sight by using stakes and rope to tie back the vegetation
- Conduct leveling operations in the later winter or early spring, after last year's growth has fallen down to the soil, and before new growth has begun. Vegetation may still have to be managed (tied back, pushed down), but it'll be a lot easier than when fresh growth is two meters tall.

- Use an optical level: a digital level requires that a larger section of the rod is visible, and the human eye can often see more clearly through moving vegetation than the laser.

Leveling in the wetland requires patience and care. In addition, the mud and water can damage any piece of instrument, especially electronic ones). Make sure all leveling equipment is kept and stored clean.

Leveling to SET marks

As discussed in the previous section, the user will need to determine the vertical point of reference (VPR) for each SET mark.

Rod SET Marks: On the shallow and deep rod SET marks, the foot of the level rod covers the entire SET “receiver,” so the level rod will naturally find the top-most side of the receiver, which is considered to be the VPR (Figure 6.20).

Figure 6.20. The base of a level rod is usually sufficiently large as to automatically find the top-most side of a typical Rod Surface Elevation Table (SET) monument.

First Generation, Pipe SET Marks: Older, first-generation pipe SET marks will be more problematic. In this case, the VPR will have to be identified by using a small hand-held level, and finding the top-most side by hand (Figure 6.5). This VPR should be dimpled and labeled for future reference. The level rod can be placed so that a corner of the rod rests on the VPR; otherwise, a small leveling tape can be placed directly on the VPR, as shown in Figure 6.21.

SET marks should be leveled both in a forward running (e.g. from the LCM to the SET mark) and in a backwards running (e.g. from the SET mark back to the LCM), and the height differences checked for agreement within tolerance: $4\sqrt{D_{km}}$. Tolerance is expressed as four times the square root of the distance between the two marks, in kilometers; the units are in millimeters. If the differences between the forward and backward runnings are greater than this value, re-measure the backwards running.

Figure 6.21. Example showing how to identify and level to the Vertical Point of Reference (VPR) of a pipe Surface Elevation Table (SET) mark.

Errors

There are many ways errors can creep into a leveling survey. By adhering to the following tips, many errors can be reduced:

- Make sure equipment is properly functioning prior to the survey; have equipment serviced if there is any doubt. Keep rods clean.
- Do not rush taking the shots, especially when reading the rods optically. Take time in carefully placing rods on the VPRs of the marks; keep rods plumb.

- Ensure balanced shots; keep level instrument half-way between the foresight and backsight rods. It may help to pace distances ahead of time and label where the rods and tripod will be placed for each shot.

- Make sure turning points do not move between a foresight and backsight; place them firmly into the ground; do not move them until signaled by the operator of the level.

- Avoid placing turning points or the level on an asphalt surface; if at all possible, place in/on firm soil.

- Short shots may lower error, although it increases the number of setups required.

Transform SET Pin Measurements to a Vertical Datum

This procedure allows the user to transfer a vertical datum (geodetic, tidal) from the VPR of the SET mark to the actual SET pin measurements. In this way, SET data can be expressed on the same scale as other, local vertical observations (wetland elevations, Digital Elevation Models, water level data, tidal datums, etc.).

The vertical datum is transferred by measuring the height difference from the SET mark to the reference surface of the deployed SET instrument (for the typical Rod SET, this would be the top of the horizontal bar, once it is plumbed). This height difference is often called the "vertical offset" of the SET instrument (Figure 6.22). Typical Rod SET instruments (except one specifically designed for this purpose, such as the Fixed Dimension Rod SET) do not necessarily maintain the same vertical offset for each SET mark and in each position. Therefore, the vertical offset may have to be measured at each individual SET mark.

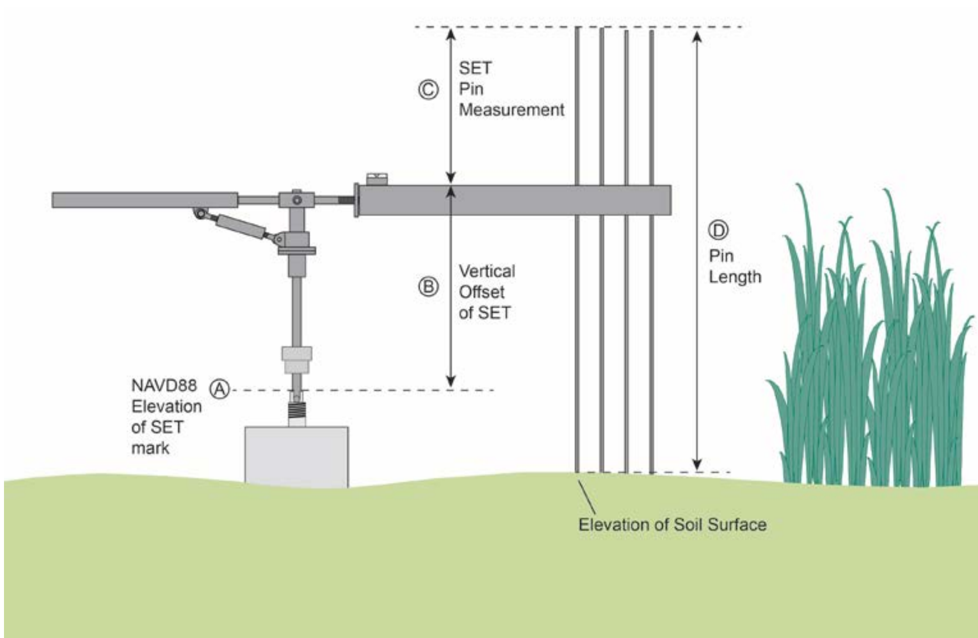


Figure 6.22. Diagram displaying steps involved in transferring elevation of an SET mark to individual SET pin observations (not all pins shown).

The typical method for computing the vertical offset uses leveling, following similar techniques outlined in section *Leveling to SET Marks*.

1. Set up the level tripod on as firm a surface as can be found near (within 10 m) the SET mark. Secure the level instrument firmly on top of the tripod. Plumb the level. Make sure the level will be able to read the survey rod when placed atop the reference surface of the SET mark (e.g. the tripod may have to be set higher when measuring the arm of the Rod SET than when leveling across the wetland). There may be some tradeoff between tripod stability and the ability to read the rod.

2. Place the level rod on the VPR of the SET mark. Read the height of the rod using the level (backsight).

3. Remove the rod (only one rod needed) and deploy the SET instrument on the mark. Plumb the instrument over a specific position with respect to the SET sample station.

4. Gently place level rod on the reference surface of the deployed SET. Take care not to place too much weight on the arm of the SET so as to move it downwards. In the case of the Rod SET, place the rod by the first pin hole, close to the center of the SET instrument (Figure 6.23).

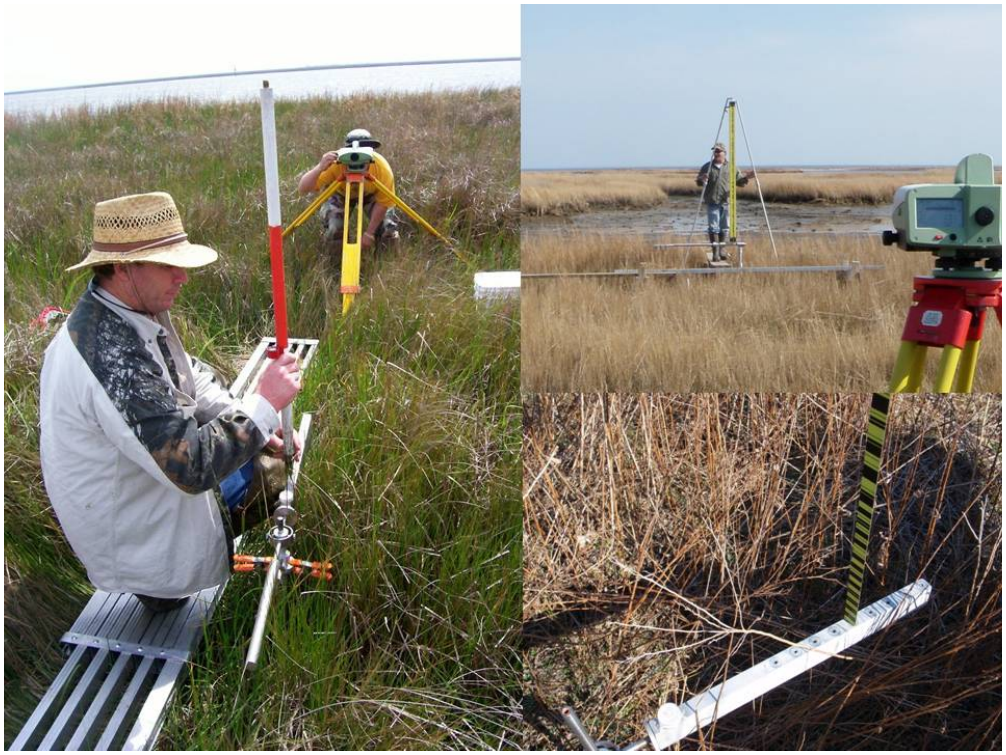


Figure 6.23. Examples of techniques for leveling to the top of deployed SET instruments. Left panel: digital barcode leveling. Note rod level against invar strip (rod) to keep rod plumbed. Top right: Two meter level rod placed on top of a first generation SET. Note that rod is placed near the base; additional measurements are needed to transfer elevation differences to the SET plate. Bottom right: digital barcode invar strip on RSET arm.

1. Read the new height of the rod on the SET instrument (foresight). Record the height as in step (2) above. This is the “forward running” measurement.

2. Remove the rod; remove the SET from the mark. Re-mount the SET on the mark and re-plumb as before.

3. Place rod on SET and take a backsight to the SET instrument.

4. Remove the rod again, remove the SET, and take a foresight to the VPR of the SET mark. This is the “backwards running.”

5. There are now two pairs of heights, the forward running and backwards running. Compute the height differences for each according to the following formula:

   $H_{difference} = H_{backsight} – H_{foresight}$

   Note that one running will be the negative of the other. Add the two runnings together: the sum should be about one millimeter or less. The average offset will be the forward running **minus** the backwards running for that position.

6. Repeat steps 1 – 8 for all other positions of the SET sample station. One can empirically determine the degree to which the SET instrument has a constant height offset (note that this is also dependent on the verticality of the SET receiver within the SET mark). If readings remain within 1 – 3 mm, consider the vertical offset constant.

7. To express elevations from the VPR of the mark to the actual pin measurements, apply the offset from the mark to the reference surface of the SET and take into account the exact length of each pin (Figure 6.22):

   Elevation of soil surface with respect to vertical datum
   = A + B – (D - C)

   A = NAVD 88 or tidal datum elevation of the SET mark
   B = Vertical offset of SET
   C = SET pin measurement
   D = Length of pin

Monitoring the Stability of the SET Mark

The SET technique measures elevation change which integrates all vertical processes occurring between the bottom of the SET mark and the wetland soil surface. It is assumed that the mark itself is not moving over this distance (Figure 6.24). If the SET mark moves relative to a vertical datum, it is assumed that this movement is occurring below the bottom of the mark. The SET technique does not measure processes occurring below the bottom of the mark (only above it). If it is of interest to measure vertical processes occurring deeper in the soil, such as regional uplift or subsidence, measuring the elevation of the mark with respect to the NSRS over time may give an estimate of these deeper processes. To evaluate both of these issues (mark stability and regional vertical movement), repeated connections of the marks to the NSRS are required over many years. The frequency of repeated measurements will depend on the amount of change detected. For very small rates of change (1-2 mm/yr), annual GPS occupations may require up to a decade to reveal any significant change.

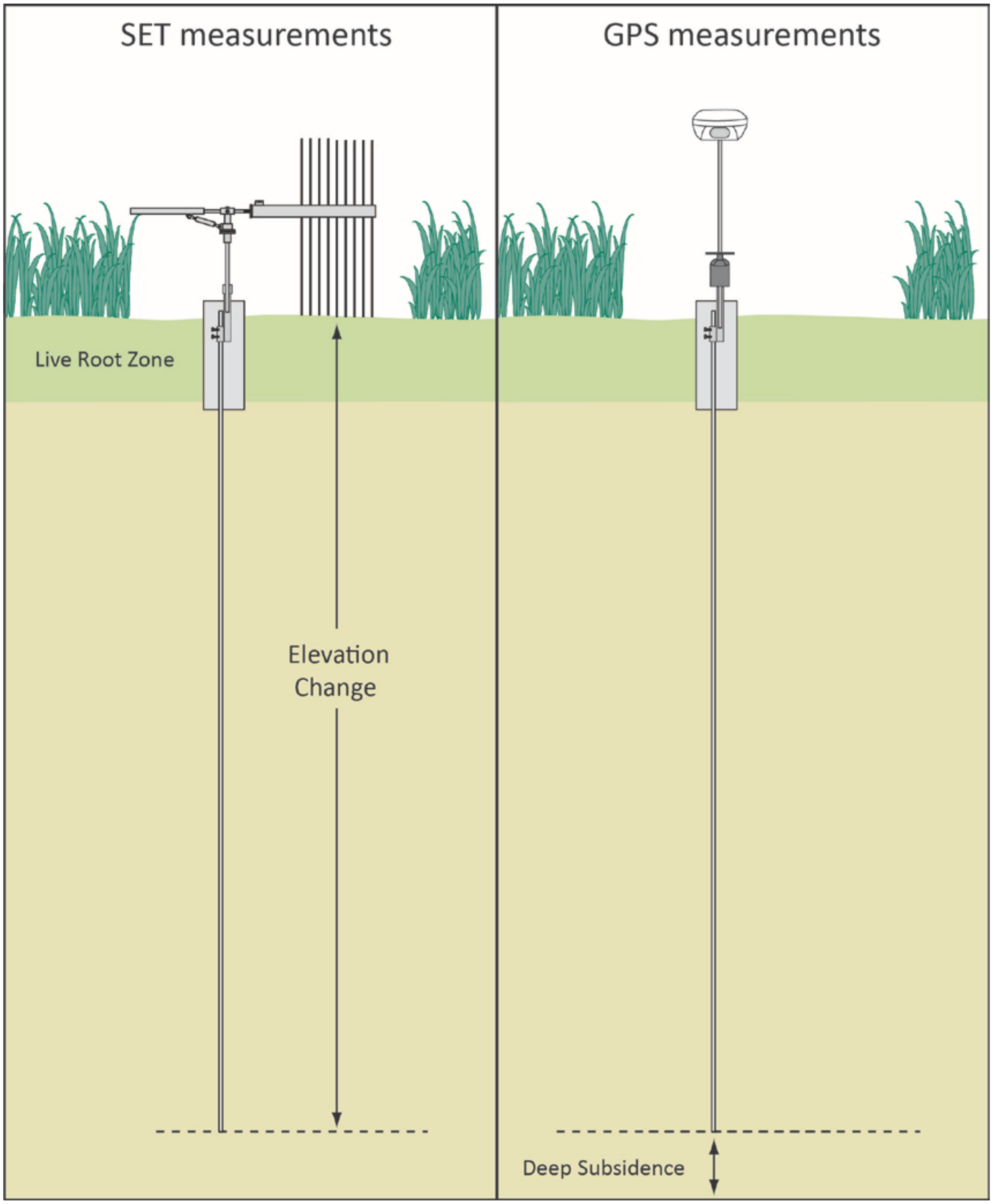


Figure 6.24. The SET measures vertical change over the depth of the mark, but does not measure processes occurring below the mark, such as uplift or subsidence (left panel). Repeated GPS measurements on top of the SET mark can be used to monitor processes occurring below the mark (right panel).

Essentially, monitoring the stability of a SET mark involves repeating the survey process described above. However, the error in the GPS solution on the LCM needs to be controlled as much as possible to be able to discern a trend from the noise. Considerations regarding the GPS survey would involve:

1. Emphasis on long GPS observations (ideally should span a full 24-hour period).
2. Since GPS-derived heights have errors at the level of several centimeters, many repeated observations over many years will be required to discern any consistent trend (or prove that no trend exists). At least one GPS observation should be taken on each LCM every year.
3. Annual surveys should be seasonally consistent. Repeated observations over time should consider seasonal effects to elevation change. In other words, if only one GPS campaign is run per year, then the campaign should be repeated every year at the same time.
4. If at all possible, use the same equipment to keep any biases consistent.
5. If measuring many LCMs, it is recommended to use simultaneous GPS deployments, to help reduce the errors within a set of SET marks. If not enough GPS antenna/receivers are available, the user can leap-frog units, keeping at least one unit observing while another one is re-deployed on another mark. Simultaneous and overlapping observations are also required for conducting a network solution, which would also be recommended in the long run, to more precisely determine stability or motion.

Literature Cited

Geoghegan, C. E., S. E. Breidenbach, D. R. Lokken, K. L. Fancher, and P. F. Hensel. 2011. Procedures for connecting SET bench marks to the NSRS: Establishing GNSS-derived ellipsoid/orthometric heights on Surface Elevation Table bench marks. NOAA Technical report NOS NGS-61, Silver Spring MD.

Hensel, P. H. C. Gallagher, A. Johnson, and S. Lerberg. 2015. Accurate elevations for sea level change sentinel sites. NOAA Technical Report NOS 2015-1, Silver Spring MD.

SOP 6 Appendix A: Survey Plan Example

18 February 2015

National Park Service, Assateague Island National Seashore
SET Survey plan for Marsh 8

The National Park Service conducts long term elevation monitoring at four wetland sites at Assateague Island National Seashore. Marsh 8 is one of these four sites (Figure 1). Marsh 8 has 4 Rod Surface Elevation Table (RSET) sample stations which each include an deep RSET mark and 3 marker horizon plots. Water level is recorded along a creek just north of the SET sample stations.

The goals of this survey plan are:

1. to obtain an NSRS orthometric elevation with respect to NAVD 88 at a chosen NSRS connection point (local control mark) with an elevation accuracy of 2-4 cm.

2. to obtain local elevation accuracies relative to the NSRS connection point (local control mark) at the ± millimeter level (0.001 m)

Overview of existing benchmarks:

There are no local NSRS (National Spatial Reference System) benchmarks near these SET sample stations, so static GPS observations will be used to establish an NSRS connection.

Equipment:

1. NSRS Connection:
   a. 1 Javad Triumph 2 GNSS receiver (serial # 00290) with external battery.
   b. 1 SECO 5119 - 00 - YEL fixed height tripod

2. Local Network Surveying:
   a. Trimble DINI digital barcode level (serial # 736559)
   b. 50 cm invar strip
   c. 2, 2 m invar rods, with bracing bipods (serial # 57703 and 57706)
   d. Temporary marks/Turtles

Survey overview:

NSRS Connection: SET M8-4 will be occupied with a GNSS receiver.

Mark Name:	M8-4
Latitude:	38.088311°
Longitude:	-75.222100°
Description:	SET #4 at Marsh 8

- Tripod will be set up on M8-4.
- Tripod will be set at 2m.
- GNSS receiver sampling rate: 15 seconds
  The GNSS receiver will record data at M8-4 for two sessions, one per day. Each session will range from 4-24 hours in length.

Personnel: Neil Winn, Lauren Kramer, James Lynch.

Digital Leveling: Following the establishment of a local control mark (M8-4), elevations will be carried to the other SET marks, the water level gauge and other items of interest (Figure 1). Sight lengths will be balanced and will not exceed 60 m in distance. Leveling to all marks and the water level gauge will be double-run. The leveling survey will be conducted in the following order:

1. Forward Running Sections (forward loop):
   a. M8-4 to M8-1
   b. M8-1 to M8-2
   c. M8-2 to M8-3
   d. M8-3 to M8-WL Gauge
   e. M8-WL Gauge to M8-4

2. Backwards Running Sections (backwards loop):
   a. M8-4 to M8-Wl Gauge
   b. M8-WL Gauge to M8-3
   c. M8-3 to M8-2
   d. M8-2 to M8-1
   e. M8-1 to M8-4

Each forward and backwards section pair will be checked for error tolerance at $4\sqrt{D}$km, where D is the distance between marks within a section, in kilometers. Loop closure error (misclosure) will also be computed and evaluated at the same tolerance (both forwards and backwards). Any out-of-tolerance results will require the re-observation of the backwards running; if misclosure persists, a new forwards running will be required.

The offset of the SET instrument will be measured at each SET mark to allow the conversion of pin readings to NAVD 88. A backsight will be taken to the SET mark, and a foresight to the deployed arm of the SET, using the 50 cm invar strip. This will also be double-run for replication. All four orientations around the SET mark will be measured.

Post Processing:

NSRS Connection: Data files from the GNSS survey will be downloaded from the Javad receiver to a personal computer and processed in OPUS (static) to determine the NSRS-aligned positions. CORS will be automatically selected by OPUS. Preliminary positions will be derived using the rapid satellite orbits available at the time of data downloading; preliminary results will be evaluated according to the following metrics:

1. >70% of observations used
2. >70% of ambiguities fixed
3. Overall RMS ≤ 0.030 m
4. Ortho Height Error ≤ 0.080 m

If a preliminary result does not meet these metrics, then an additional session will be observed. The final coordinates will be an average of the two good replicate session solutions based on the precise orbits available about three weeks after the end of the survey.

Digital leveling: Data will be processed in Trimble Business Center, converting field height differences to NAVD 88 elevations using the final average NAVD 88 elevation computed in the GPS post-processing (above). No corrections (e.g. temperature, gravity) will be applied to the data, as the section distances will be short and the NSRS connection will be at the centimeter level.

Timeline:
The GNSS survey will be conducted between March 15-21, 2015. The exact days and times will be determined based on Trimble's GNSS planning software and in consideration of space weather. The levels will be run after the initial GNSS results have been processed, and will be completed by March 31 2015.

Study Plan Review: Plan Reviewed and approved by Philippe Hensel (NOAA NGS) on Feb 12, 2015.

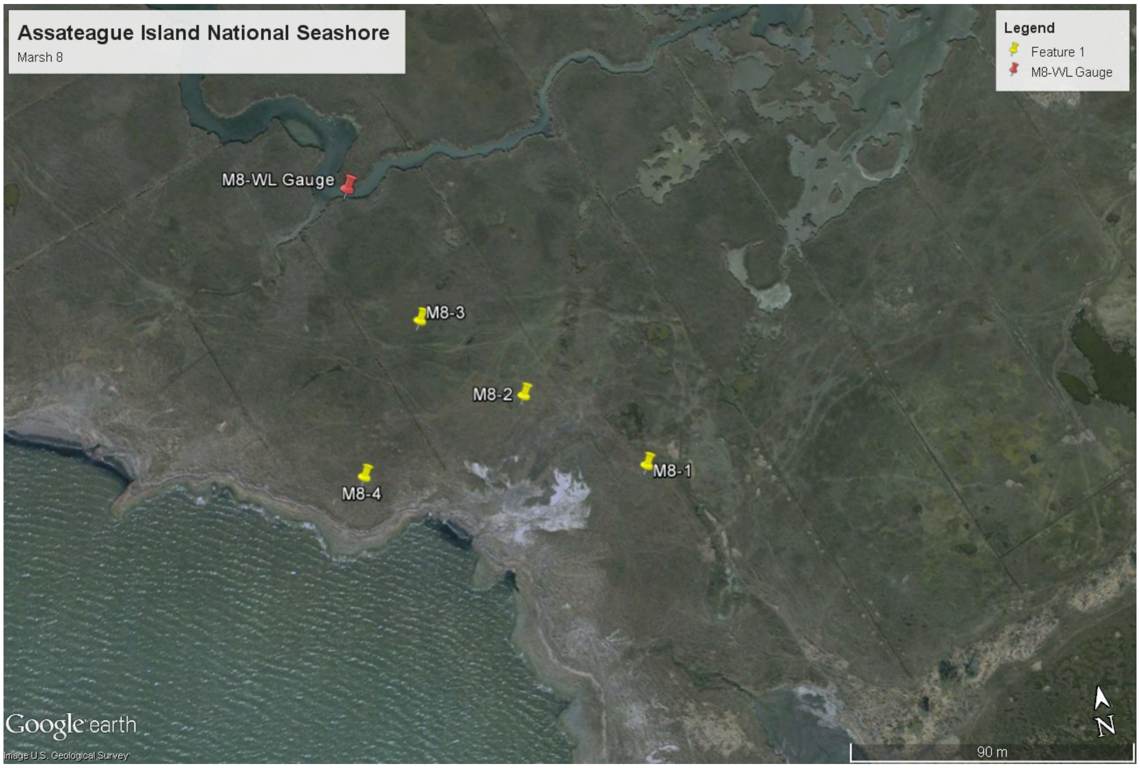


Figure 1. Marsh 8 SET marks (Yellow) located at Assateague Island National Seashore. Location of a water level record is shown in red.

SOP 7: Data Management

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

SET sampling stations are designed for long-term data collection and ultimately result in large data sets that need to be organized and analyzed. Data from this sampling is normally stored in a spreadsheet or database. A spreadsheet is suitable for data entry and analysis but can become cumbersome to work on with large data sets. For that reason, it is recommended to use a database to store your data. The National Park Service has developed a Microsoft Access® database that is specifically designed for storing data collected at SET sample stations. Whether you adopt this database or not, it is recommend that you develop some type of database solution to store your data.

This SOP presents instructions on data entry and QA/QC procedures for SET and Marker Horizon data collected in the field. Two options for data entry are described:

1. Data entry into a spreadsheet.
2. Data entry into a Microsoft Access® database designed by the National Park Service.

Data Entry

Data entry includes both transcribing raw data from field forms into a spreadsheet or database and uploading, naming, and filing any ancillary data (e.g. maps, photos) acquired during a sampling trip. Both activities are the responsibility of the Project Leader, and ideally take place as soon as a data collection trip is complete. It becomes more difficult to track down questionable information on a field form as the time period increases after data collection.

The Project Leader will double check all spreadsheet and/or database entries, correct discrepancies, and initial each datasheet prior to advancing to and transcribing the next datasheet. Errors or questions about the data content can be recorded in separate data entry notes; such notes are useful during data verification. Any ancillary data (e.g. photos) that were collected from each site should also be located, named, and filed in a logical directory structure. Following a standardized naming convention will insure that these data remain associated with the survey event (See below section on Naming Conventions).

At the end of each data entry session, sequential backups of the data files should be made. The copies of previous versions can be useful if data are inadvertently deleted.

Data Verification

Data verification is used to ensure that data collected in the field is accurately entered into a spreadsheet or database. Both data entry options described in this SOP are designed to allow the "double entry" of raw SET data to ensure accuracy. This means that SET data is entered twice and the entries are compared to note any differences. This "double entry" is normally performed by the same person and is considered to be the 100% verification check.

If the data is not "double entered" as described above, a crew member shall review 100% of the records entered to ensure that values present on field forms were accurately and completely transcribed into digital form.

The 100% check should include running simple summary statistics for the data entered. This is important because even when care is taken up to this point, a duplicate or omitted entry could have been overlooked. For example, the number of known constant elements, such as the number of sample sites, measurements per site, or sites per date can be viewed. Ask the same question in different ways to find differences in the answer that will provide clues to errors. The more variety of checks to test the completeness of the data, the greater is the confidence that the data are completely verified. Notes should be maintained on the specific discrepancies found. If the same type of mistake is found repeatedly, corrections to the protocol or datasheets may need to be made.

Any changes made to entries in the spreadsheet or database due to errors in the datasheet should be noted on both the original datasheet as well as in the spreadsheet or database.

Data Validation

Data validation is the process of reviewing computerized data for range and logic errors. Although data may be correctly transcribed from the original field forms, the original values may not always be accurate or logical. Although many validation problems can be addressed by a well-designed spreadsheet or database, the wetland elevation monitoring Project Leader must also conduct exploratory data analyses to look for outliers and omissions. The Project Leader is the authority on the methodologies and measurements involved.

Although step-by-step instructions are not possible for data validation because each data set has unique measurement ranges and accuracy requirements, the following generic procedures can be used to develop a validation strategy for most data sets:

- Simple validation queries can be used to identify generic errors such as missing, mismatched, or duplicate records.
- Data can be compared to previous years to identify gross differences.
- Histograms, line plots, and basic statistics reveal possible logic and range errors.
- Database, graphic, and statistical tools can be used for ad-hoc queries to identify obvious outliers.
- Some of these data results could appear unusual but prove to be quite valid after confirmation. Noting correct but unusual values in documentation of the dataset saves other users from repeating the same confirmation.

File Naming Conventions

This protocol uses standardized naming conventions for organizing and storing digital data files. Three main types of files include scanned data sheets (or data books), sequential versions of the database, and ancillary data files (photographs, maps, GIS files, etc.).

In the conventions below, brackets [ ] indicate a mandatory variable; < > indicate an optional variable.

1. <u>Raw field data</u> – Data from a single sampling trip are typically scanned and can be saved as

    a. One file per sample station (many files, one page each).

    b. Multiple page document with all data from a sampling trip (single file, many pages).

    A file naming protocol is described below.

    Formula:
    [Unit]_SET_<Site>_<Station>_[Date]
    Definitions:
    Unit = Short code for a Park, Refuge or other unit
    Site name = Name or code for the Sample Site where data was collected
    Station name = Name or code for the Sample Station where data was collected
    Date = YYYYMMDD of survey
    Examples:
    GATE_SET_20140511.pdf (All datasheets from Gateway NRA on May 11, 2014)

ASIS_SET_Marsh6_SET1_20140422.pdf (Single sample station sheet from SET1 at Big Egg Marsh)

2. Database or spreadsheet files – sequential copies of the spreadsheet or database files are kept organized by adding the date it was saved as a suffix. The database includes a utility for saving backup copies of the back-end. It automatically renames the backup file with a Date/Time tag.

Formula:
[Unit]_SET_<DB>_<BE>_[Date]
Definitions:
Unit = 4 letter NPS park code or Inventory and Monitoring Network code.
SET = SET data
DB = Database
BE = Back End File
Date = YYYYMMDD of file
Examples:
NCBN_SET_DB_BE_20140511.mdb (Backend database of the Northeast Coastal & Barrier network on 5 May 2014).
FIIS_SET_20140602.xlsx (SET data spreadsheet from Fire Island on 2 June 2014).

3. Ancillary data – file name is used to link the ancillary data (e.g. photographs, maps, GIS) to a record in the database

Formula:
[Unit]_[Site name]_[Station name]_[Date]_[Purpose]_<Sequence>
Definitions:
Unit = 4 letter NPS park code
Site name = Name or code for the Sample Site where data was collected
Station name = Name or code for the Sampling station where data was collected
Date = YYYYMMDD of survey
Purpose = Short reason why photo was taken
Sequence = 2 digit sequential number used when numerous photos are taken for the same purpose.
Example:
GWMP_DykeMarsh_River2_20110415_DamageToPlot_02.jpg
(second picture in DamageToPlot series)

The use of a file naming utility can greatly speed up naming large numbers of files. Bulk Rename Utility is a free and very adaptable program and can be obtained here: http://www.bulkrenameutility.co.uk/Main_Intro.php

Season Wrap-Up

Good data stewardship practices play a critical role in long-term data security and help prevent irretrievable loss of information. These steps will be implemented by the Project Leader:

- Once the computerized data are verified (to accurately reflect the original field data) and validation is complete (range and logic errors have been checked for), all paper forms shall be delivered to the appropriate data manager for archiving.

- Verify that all digital files are named and filed properly. This includes, but is not limited to, scanned datasheets, database versions, and ancillary data files (photographs, maps, GIS).

- Ensure that the master database file and all incremental digital data files have been archived to a secure location (i.e. write protected) on the network file server. A copy of the front-end database application should be archived along with the data files. If the multiple versions of the front-end application were used during the field season, all versions should be archived to ensure back-end compatibility.

Use lessons learned during data collection, entry, verification, and validation steps to make procedural changes that will improve data quality, including changes to this SOP. Often minor changes, small annotations, or adding check boxes to a field form can remove ambiguity about what to enter on the form. In fact, any time the same type of validation error occurs repeatedly in different data sets, the field form --not the field crew-- is usually at fault. Repeated validation errors can also mean that protocol(s) or field training is faulty, which must be recognized and corrected.

Data Entry – Spreadsheet

SET Data Entry

The spreadsheet (Figure 7.1) is designed to allow for entry of raw data collected in the field. It is also organized to allow for data exploration (Verification, Validation and QA/QC analyses). The example in this SOP shows data from 3 SET sample stations though only some of the data from Station 1 is visible in the figures. The excel spreadsheet used in this SOP can be downloaded at <LINK HERE>.

The Study Site and/or Project Name are identified at the top of the spreadsheet (Figure 8.1, row 3 and 4). Each Sampling Date occupies a single column and space provided for observer name/initials at each sampling event (row 10). This allows any change in observer to be easily identified. Raw SET pin data from the field datasheet or data book are entered below (row 29+). The spreadsheet is organized to enter the SET data twice to help catch data entry errors (green columns L and M). The differences between the two entries are computed, and any difference from zero indicates the data were not entered correctly (either the first or second time – the user will have to check to verify).

Notes can be written in the spreadsheet to identify problematic data, such as crab holes, mangrove roots, vegetation clumps, etc. For example, row 32 (Figure 7.2) has an entry of “236H” highlighted in red. “H” indicates the pin is in a crab hole as described in the data book. Note that this entry is not stored as a number, but as text, and will be ignored in subsequent calculations in the spreadsheet (Figure 7.3, 7.4). Be aware that leaving comments in a cell will keep that entry from being involved in calculations. Do not enter text in these cells if you want them included in the analysis.

Average pin height across all pins within a SET station (along with the standard error, Rows 8 and 9) is computed below each date. This is only provided for data exploration, not for statistical analyses.

Each pin has its own row in the spreadsheet (rows 29 -46), and the evolution of pin measurements is read from left to right. Color coding can be used to separate each position (9 pins per position, four positions per SET station) and assists with data entry. Additional stations would appear below in the same manner. As new data is collected, new columns are added to right of the previous data.

Spreadsheet – SET Data – Interval Calculations

Incremental change from one sampling event to the next is computed in Figure 7.2 (columns R- X, Rows 29-46). This figure is a continuation of the raw data presented in Figure 7.1. Conditional formatting can be used to highlight large changes in pin readings, to see if they are consistent with the other pins or with prior readings. This can also help detect errors, outliers, or observations that should otherwise have special consideration in the subsequent analysis.

For example, in Figure 7.2, interval values which are greater than 25 millimeters are highlighted with a pink background color. Changes which decrease more than 25 millimeters are highlighted with a blue background. Note too, that cells with no value are also highlighted with the pink background. Conditional formatting does not affect any of the calculations occurring in the spreadsheet. It is only for visualizing changes in the data.

The top rows of the spreadsheet (rows 6-27) are used to summarize the interval data from the below rows. Average change for each position (North, South, etc.), and then for each SET (example shows a total of three SET stations) are shown here. These averages provide the user with an idea of elevation change over each time interval both within and among SET stations. This can be useful to check for mistakes in data entry as well as for initial exploratory data analyses. The standard errors are also computed, providing a first check of constancy of variance.

At this stage, the analyst will perform quality control, and will make a preliminary triage of data to be used in subsequent analyses. The analyst will have to go over the accepted data with the observer, to make sure there is agreement regarding the rejection of any outliers, or any disaggregation of the dataset (such as on vegetation vs. on exposed soil).

Spreadsheet – SET Data – Cumulative Calculations

Once the raw data and intervals are checked and no problems are found, the results can be expressed in terms of **cumulative change.** Cumulative change is what is used for determining trends in the data. There are numerous methods for determining trends, but we recommend that you compute cumulative change directly from raw pin data by differencing each pin reading from its original value at T_0 (e.g., $T_1 – T_0$, Figure 7.3). More information on rate calculations will appear in SOP9.

Notice that the trend data starts at time zero (T_0) and that each pin begins with a value of zero. All readings thereafter are showing changes in elevation relative to T_0.

Like the interval data (figure 7.2), summaries are provided for the positions and stations. Note that a rate of change for each pin is calculated in Column AK. This is a simple linear regression of the pin data and date (Pin value vs. Year). Comparison of the rates from the pins can also be used to point out data that might be in need of checking.

Raw Data Input Here

Wetand XX SET Data (all values in mm)

Data last updated by John Doe on 7-26-2005

	A	B	C	D	E	F	G	H
	11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05
	Baseline	1st	2nd	3rd	4th	5th	6th	7th
Avg	264.10	287.05	279.15	279.21	277.28	282.05	267.52	276.50
Std Error	2.11	1.88	1.67	1.69	1.67	1.76	1.85	1.91
Reader	J.D.	J.D.	J.D.	C.R.	J.D.	J.D.	J.D.	J.D.

			Baseline	1st	2nd	3rd	4th	5th	6th	7th	Double Data Entry	
Station	Position	Pin	11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05	Duplicate	Check
1	North	1	241	266	256	261	250	265	248	257	257	0
		2	245	269	265	267	267	268	249	264	264	0
		3	241	255	258	258	265	264	251	269	269	0
		4	250	268	260	264	236H	266	247	252	252	0
		5	238	269	262	263	262	264	257	256	256	0
		6	243	265	258	257	262	264	254	262	262	0
		7	242	269	263	264	263	267	250	258	258	0
		8	239	269	257	259	262	263	251	257	257	0
		9	243	268	256	257	260	260	245	245	245	0
1	East	1	242	270	263	261	255	257	231	251	251	0
		2	245	272	261	258	266	227	249	255	255	0
		3	253	261	266	268	270	268	250	255	255	0
		4	251	270	262	260	264	262	247	255	255	0
		5	241	270	264	265	269	258	249	260	260	0
		6	249	269	265	266	269	268	249	255	255	0
		7	242	272	268	260	263	263	249	262	262	0
		8	242	271	261	261	260	265	246	255	255	0
		9	244	271	263	265	266	263	242	253	253	0

Quality Control - Interval Data

		B-A	C-B	D-C	E-D	F-E	G-F	H-G
	11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05
Years	0.00	0.48	1.01	1.21	1.52	2.49	3.65	4.47
3 Station Avg		22.91	-7.93	0.22	-2.11	4.96	-14.59	9.70
Std Error		1.70	1.51	0.65	1.35	1.49	0.80	0.47
Station 1 Avg		22.92	-6.75	0.42	0.32	2.11	-16.19	8.83
Std Error		1.01	1.10	0.58	1.04	2.69	1.64	0.93
Station 2 Avg		25.86	-6.11	-1.00	-4.33	7.17	-13.86	9.82
Std Error		1.55	2.66	1.09	1.72	1.93	1.36	1.99
Station 3 Avg		19.96	-10.93	1.24	-2.32	5.60	-13.72	10.46
Std Error		5.21	0.75	1.75	1.17	1.67	1.28	1.25
Average Positions		22.91	-7.93	0.22	-2.11	4.96	-14.59	9.70
Std Error		1.82	1.10	0.70	0.91	1.29	0.82	0.79
Station1 (AVG)	North	24.00	-7.00	1.67	0.63	3.00	-14.33	7.56
	East	24.11	-5.89	-1.00	2.00	-5.67	-13.22	9.89
	South	23.67	-9.67	1.00	-2.67	6.56	-16.56	7.00
	West	19.89	-4.44	0.00	1.33	4.56	-20.67	10.89
Station2 (AVG)	North	29.44	-12.78	0.00	0.00	3.22	-10.44	9.22
	East	23.56	-6.78	1.56	-8.00	11.11	-14.89	10.89
	South	27.44	-5.00	-2.33	-5.89	9.78	-13.22	4.78
	West	23.00	0.11	-3.22	-3.44	4.56	-16.89	14.38
Station3 (AVG)	North	21.50	-9.17	5.83	-4.17	6.83	-17.00	14.17
	East	5.22	-10.22	0.22	0.22	2.11	-12.89	9.67
	South	29.67	-12.33	-2.56	-4.44	9.67	-10.89	9.00
	West	23.44	-12.00	1.44	-0.89	3.78	-14.11	9.00

#	Pos	Pin	Interval Pin Change in millimeters						
1	North	1	25	-10	5	-11	15	-17	9
		2	24	-4	2	0	1	-19	15
		3	14	3	0	7	-1	-13	18
		4	18	-8	4			-19	5
		5	31	-7	1	-1	2	-7	-1
		6	22	-7	-1	5	2	-10	8
		7	27	-6	1	-1	4	-17	8
		8	30	-12	2	3	1	-12	6
		9	25	-12	1	3	0	-15	0
1	East	1	28	-7	-2	-6	2	-26	20
		2	27	-11	-3	8	-39	22	6
		3	8	5	2	2	-2	-18	5
		4	19	-8	-2	4	-2	-15	8
		5	29	-6	1	4	-11	-9	11
		6	20	-4	1	3	-1	-19	6
		7	30	-4	-8	3	0	-14	13
		8	29	-10	0	-1	5	-19	9
		9	27	-8	2	1	-3	-21	11

Quality Control - Cumulative Data

		A-A	B-A	C-A	D-A	E-A	F-A	G-A	H-A	Pin Rate
		11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05	mm/yr
YEARS		0.00	0.48	1.01	1.21	1.52	2.49	3.65	4.47	
3 Station Avg		0.00	22.91	14.98	15.20	13.14	18.03	3.44	10.59	-0.01
Std Error		0.00	1.70	3.15	2.55	2.71	2.37	2.31	0.51	0.01
Station 1 Avg		0.00	22.92	16.17	16.58	17.05	18.97	2.78	11.61	-0.03
Std Error		0.00	1.01	0.92	0.84	1.71	1.93	1.72	1.32	0.01
Station 2 Avg		0.00	25.86	19.75	18.75	14.42	21.58	7.72	10.14	0.01
Std Error		0.00	1.55	1.75	0.80	1.47	0.87	1.49	7.11	0.01
Station 3 Avg		0.00	19.96	9.03	10.26	7.94	13.54	-0.18	10.03	-0.03
Std Error		0.00	5.21	4.85	5.13	4.23	5.44	5.29	5.59	0.03
Average Positions		0.00	22.91	14.98	15.20	13.14	18.03	3.44	10.59	-0.01
Std Error		0.00	1.82	2.07	1.92	1.85	2.03	1.99	2.77	0.01
Station1 (AVG)	North	0.00	24.00	17.00	18.67	19.88	22.11	7.78	15.33	0.01
	East	0.00	24.11	18.22	17.22	19.22	13.56	0.33	10.22	-0.04
	South	0.00	23.67	14.00	15.00	12.33	18.89	2.33	9.33	-0.04
	West	0.00	19.89	15.44	15.44	16.78	21.33	0.67	11.56	-0.03
Station2 (AVG)	North	0.00	29.44	16.67	16.67	16.67	19.89	9.44	18.67	0.02
	East	0.00	23.56	16.78	18.33	10.33	21.44	6.56	17.44	0.02
	South	0.00	27.44	22.44	20.11	14.22	24.00	10.78	15.56	0.00
	West	0.00	23.00	23.11	19.89	16.44	21.00	4.11	-11.11	0.01
Station3 (AVG)	North	0.00	21.50	12.33	18.17	14.00	20.83	3.83	18.00	0.03
	East	0.00	5.22	-5.00	-4.78	-4.56	-2.44	-15.33	-5.67	-0.12
	South	0.00	29.67	17.33	14.78	10.33	20.00	9.11	18.11	0.02
	West	0.00	23.44	11.44	12.89	12.00	15.78	1.67	9.67	-0.04

#	Pos	Pin	Cumulative Pin Change in millimeters								mm/yr
1	North	1	0	25	15	20	9	24	7	16	0.01
		2	0	24	20	22	22	23	4	19	0.00
		3	0	14	17	17	24	23	10	28	0.10
		4	0	18	10	14		16	-3	2	-0.08
		5	0	31	24	25	24	26	19	18	0.02
		6	0	22	15	14	19	21	11	19	0.07
		7	0	27	21	22	21	25	8	16	-0.01
		8	0	30	18	20	23	24	12	18	0.01
		9	0	25	13	14	17	17	2	2	-0.07
1	East	1	0	28	21	19	13	15	-11	9	-0.05
		2	0	27	16	13	21	-18	4	10	-0.03
		3	0	8	13	15	17	15	-3	2	-0.07
		4	0	19	11	9	13	11	-4	4	-0.09
		5	0	29	23	24	28	17	8	19	-0.01
		6	0	20	16	17	20	19	0	6	-0.06
		7	0	30	26	18	21	21	7	20	0.00
		8	0	29	19	19	18	23	4	13	-0.03
		9	0	27	19	21	22	19	-2	9	-0.05

Figure 7.1. Spreadsheet showing raw SET data from three SET sample stations and the calculations that result. Not all raw data is shown.

Raw Data Input Here

Wetand XX SET Data (all values in mm)

Data last updated by John Doe on 7-26-2005

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
	11/24/00	**05/20/01**	**11/29/01**	**02/09/02**	**06/02/02**	**05/23/03**	**07/18/04**	**05/15/05**
	Baseline	1st	2nd	3rd	4th	5th	6th	7th
Avg	264.10	287.05	279.15	279.21	277.28	282.05	267.52	276.50
Std Error	2.11	1.88	1.67	1.69	1.67	1.76	1.85	1.91
Reader	J.D.	J.D.	J.D.	C.R.	J.D.	J.D.	J.D.	J.D.

			Baseline	1st	2nd	3rd	4th	5th	6th	7th	Double Data Entry	
Station	Position	Pin	11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05	**Duplicate**	**Check**
1	North	1	241	266	256	261	250	265	248	257	257	0
		2	245	269	265	267	267	268	249	264	264	0
		3	241	255	258	258	265	264	251	269	269	0
		4	250	268	260	264	236H	266	247	252	252	0
		5	238	269	262	263	262	264	257	256	256	0
		6	243	265	258	257	262	264	254	262	262	0
		7	242	269	263	264	263	267	250	258	258	0
		8	239	269	257	259	262	263	251	257	257	0
		9	243	268	256	257	260	260	245	245	245	0
1	East	1	242	270	263	261	255	257	231	251	251	0
		2	245	272	261	258	266	227	249	255	255	0
		3	253	261	266	268	270	268	250	255	255	0
		4	251	270	262	260	264	262	247	255	255	0
		5	241	270	264	265	269	258	249	260	260	0
		6	249	269	265	266	269	268	249	255	255	0
		7	242	272	268	260	263	263	249	262	262	0
		8	242	271	261	261	260	265	246	255	255	0
		9	244	271	263	265	266	263	242	253	253	0

Figure 7.2. Example of Surface Elevation Table (SET) raw data entry in a spreadsheet. Partial data for one of three stations is shown (Station #1).

	N	O	P	Q	R	S	T	U	V	W	X
2			Quality Control - Interval Data								
3					B-A	C-B	D-C	E-D	F-E	G-F	H-G
4				11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05
5			Years	0.00	0.48	1.01	1.21	1.52	2.49	3.65	4.47
6			3 Station Avg		22.91	-7.93	0.22	-2.11	4.96	-14.59	9.70
7			Std Error		1.70	1.51	0.65	1.35	1.49	0.80	0.47
8			Station 1 Avg		22.92	-6.75	0.42	0.32	2.11	-16.19	8.83
9			Std Error		1.01	1.10	0.58	1.04	2.69	1.64	0.93
10			Station 2 Avg		25.86	-6.11	-1.00	-4.33	7.17	-13.86	9.82
11			Std Error		1.55	2.66	1.09	1.72	1.93	1.36	1.99
12			Station 3 Avg		19.96	-10.93	1.24	-2.32	5.60	-13.72	10.46
13			Std Error		5.21	0.75	1.75	1.17	1.67	1.28	1.25
14			Average Positions		22.91	-7.93	0.22	-2.11	4.96	-14.59	9.70
15			Std Error		1.82	1.10	0.70	0.91	1.29	0.82	0.79
16			Station1	North	24.00	-7.00	1.67	0.63	3.00	-14.33	7.56
17			(AVG)	East	24.11	-5.89	-1.00	2.00	-5.67	-13.22	9.89
18				South	23.67	-9.67	1.00	-2.67	6.56	-16.56	7.00
19				West	19.89	-4.44	0.00	1.33	4.56	-20.67	10.89
20			Station2	North	29.44	-12.78	0.00	0.00	3.22	-10.44	9.22
21			(AVG)	East	23.56	-6.78	1.56	-8.00	11.11	-14.89	10.89
22				South	27.44	-5.00	-2.33	-5.89	9.78	-13.22	4.78
23				West	23.00	0.11	-3.22	-3.44	4.56	-16.89	14.38
24			Station3	North	21.50	-9.17	5.83	-4.17	6.83	-17.00	14.17
25			(AVG)	East	5.22	-10.22	0.22	0.22	2.11	-12.89	9.67
26				South	29.67	-12.33	-2.56	-4.44	9.67	-10.89	9.00
27				West	23.44	-12.00	1.44	-0.89	3.78	-14.11	9.00
28		#	Pos	Pin	Interval Pin Change in millimeters						
29		1	North	1	25	-10	5	-11	15	-17	9
30				2	24	-4	2	0	1	-19	15
31				3	14	3	0	7	-1	-13	18
32				4	18	-8	4	.	.	-19	5
33				5	31	-7	1	-1	2	-7	-1
34				6	22	-7	-1	5	2	-10	8
35				7	27	-6	1	-1	4	-17	8
36				8	30	-12	2	3	1	-12	6
37				9	25	-12	1	3	0	-15	0
38		1	East	1	28	-7	-2	-6	2	-26	20
39				2	27	-11	-3	8	-39	22	6
40				3	8	5	2	2	-2	-18	5
41				4	19	-8	-2	4	-2	-15	8
42				5	29	-6	1	4	-11	-9	11
43				6	20	-4	1	3	-1	-19	6
44				7	30	-4	-8	3	0	-14	13
45				8	29	-10	0	-1	5	-19	9
46				9	27	-8	2	1	-3	-21	11

Figure 7.3. Interval calculations for SET data. See text for further explanation.

	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
2			Quality Control - Cumulative Data										
3					A-A	B-A	C-A	D-A	E-A	F-A	G-A	H-A	Pin Rate
4					11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05	mm/yr
5				YEARS	0.00	0.48	1.01	1.21	1.52	2.49	3.65	4.47	
6			3 Station Avg		0.00	22.91	14.98	15.20	13.14	18.03	3.44	10.59	-0.01
7			Std Error		0.00	1.70	3.15	2.55	2.71	2.37	2.31	0.51	0.01
8			Station 1 Avg		0.00	22.92	16.17	16.58	17.05	18.97	2.78	11.61	-0.03
9			Std Error		0.00	1.01	0.92	0.84	1.71	1.93	1.72	1.32	0.01
10			Station 2 Avg		0.00	25.86	19.75	18.75	14.42	21.58	7.72	10.14	0.01
11			Std Error		0.00	1.55	1.75	0.80	1.47	0.87	1.49	7.11	0.01
12			Station 3 Avg		0.00	19.96	9.03	10.26	7.94	13.54	-0.18	10.03	-0.03
13			Std Error		0.00	5.21	4.85	5.13	4.23	5.44	5.29	5.59	0.03
14			Average Positions		0.00	22.91	14.98	15.20	13.14	18.03	3.44	10.59	-0.01
15			Std Error		0.00	1.82	2.07	1.92	1.85	2.03	1.99	2.77	0.01
16			Station1	North	0.00	24.00	17.00	18.67	19.88	22.11	7.78	15.33	0.01
17			(AVG)	East	0.00	24.11	18.22	17.22	19.22	13.56	0.33	10.22	-0.04
18				South	0.00	23.67	14.00	15.00	12.33	18.89	2.33	9.33	-0.04
19				West	0.00	19.89	15.44	15.44	16.78	21.33	0.67	11.56	-0.03
20			Station2	North	0.00	29.44	16.67	16.67	16.67	19.89	9.44	18.67	0.02
21			(AVG)	East	0.00	23.56	16.78	18.33	10.33	21.44	6.56	17.44	0.02
22				South	0.00	27.44	22.44	20.11	14.22	24.00	10.78	15.56	0.00
23				West	0.00	23.00	23.11	19.89	16.44	21.00	4.11	-11.11	0.01
24			Station3	North	0.00	21.50	12.33	18.17	14.00	20.83	3.83	18.00	0.03
25			(AVG)	East	0.00	5.22	-5.00	-4.78	-4.56	-2.44	-15.33	-5.67	-0.12
26				South	0.00	29.67	17.33	14.78	10.33	20.00	9.11	18.11	0.02
27				West	0.00	23.44	11.44	12.89	12.00	15.78	1.67	9.67	-0.04
28		#	Pos	Pin	Cumulative Pin Change in millimeters								mm/yr
29		1	North	1	0	25	15	20	9	24	7	16	0.01
30				2	0	24	20	22	22	23	4	19	0.00
31				3	0	14	17	17	24	23	10	28	0.10
32				4	0	18	10	14		16	-3	2	-0.08
33				5	0	31	24	25	24	26	19	18	0.02
34				6	0	22	15	14	19	21	11	19	0.07
35				7	0	27	21	22	21	25	8	16	-0.01
36				8	0	30	18	20	23	24	12	18	0.01
37				9	0	25	13	14	17	17	2	2	-0.07
38		1	East	1	0	28	21	19	13	15	-11	9	-0.05
39				2	0	27	16	13	21	-18	4	10	-0.03
40				3	0	8	13	15	17	15	-3	2	-0.07
41				4	0	19	11	9	13	11	-4	4	-0.09
42				5	0	29	23	24	28	17	8	19	-0.01
43				6	0	20	16	17	20	19	0	6	-0.06
44				7	0	30	26	18	21	21	7	20	0.00
45				8	0	29	19	19	18	23	4	13	-0.03
46				9	0	27	19	21	22	19	-2	9	-0.05

Figure 7.4. Example of spreadsheet layout showing cumulative change calculations for a hypothetical Surface Elevation Table (SET) sample station. Not all data is shown but figure is referencing data from 3 sample stations.

Spreadsheet – Marker Horizon Data – Data Entry

Marker horizon data is usually entered in the same spreadsheet with the SET data, but typically in a sheet by itself. Figure 7.5 shows marker horizon data for 3 SET sample stations with 3 marker horizons per station (9 total marker horizons) at two different dates.

Raw data for marker horizons are the measurements of the distance from the top edge of the horizon to the soil surface in millimeters. These usually consist of from one to four values. Raw data entries are shown above in Rows 31-39 and 44-52 for two different sampling trips. Average values for each horizon are calculated in column C.

	A	B	C	D	E	F	G
25							
26		**Wetland XX - Marker Horizon RAW DATA**					
27							
28		**Raw Data - From data book - Marker Established on 11/24/00**					
29		Sample Date =	**5/20/2001**	1	2	3	4
30		**Wetland XX**	**Avg**	**Raw numbers (mm)**			
31		Plat 1 A	**1.00**	1	1	1	1
32		Plat 1 B	**2.50**	2	2	3	3
33		Plat 1 C	**1.50**	2	2	1	1
34		Plat 2 A	**1.50**	1	2	2	1
35		Plat 2 B	**2.00**	2	1	2	3
36		Plat 2 C	**0.50**	0	0	1	1
37		Plat 3 A	**1.00**	1	1	1	1
38		Plat 3 B	**0.75**	1	1	1	0
39		Plat 3 C	**0.50**	0	0	1	1
40							
41		**Raw Data - From data book - Marker Established on 11/24/00**					
42		Sample Date =	**11/29/2001**	1	2	3	4
43		**Wetland XX**	**Avg**	**Raw numbers (mm)**			
44		Plat 1 A	**5.75**	7	6	6	4
45		Plat 1 B	**8.75**	9	10	9	7
46		Plat 1 C	**2.25**	2	3	3	1
47		Plat 2 A	**1.50**	1	2	1	2
48		Plat 2 B	**2.00**	2	2	2	2
49		Plat 2 C	**2.25**	1	3	2	3
50		Plat 3 A	**2.00**	2	1	2	3
51		Plat 3 B	**1.50**	2	1	2	1
52		Plat 3 C	**1.75**	3	2	1	1
53							

Figure 7.5. Raw data entry of marker horizon data for two sampling dates.

Spreadsheet –Summarizing Marker Horizon Data

Raw marker horizon data is summarized in Figure 7.6 using the averages calculated from each marker horizon (Figure 7.5). These appear in rows 16-24. Summaries of this data appear above in Rows 6-15. Note that an annual rate of change for each marker horizon can be calculated (Column K) using the SLOPE function.

Wetland XX - Marker Horizon Summary

Date	11/24/00	05/20/01	11/29/01	02/09/02	06/02/02	05/23/03	07/18/04	05/15/05	Plot Rate
Year	0.00	0.48	1.01	1.21	1.52	2.49	3.65	4.47	mm/yr
Average all stations	0.00	1.25	3.08	3.70	3.81	4.06	5.12	5.50	0.51
SE	0.00	0.27	1.25	0.92	0.73	0.85	0.47	0.33	0.13
Station 1 avg	0.00	1.67	5.58	5.42	5.28	5.75	5.50	6.13	0.34
SE	0.00	0.44	1.88	1.67	0.31	0.88	0.25	1.38	0.09
Station 2 avg	0.00	1.33	1.92	3.42	3.17	3.08	4.19	5.38	0.76
SE	0.00	0.44	0.22	0.22	0.08	0.58	1.03	1.63	0.33
Station 3 avg	0.00	0.75	1.75	2.28	3.00	3.33	5.67	5.00	0.44
SE	0.00	0.14	0.14	0.43	0.00	0.68	0.94	0.00	0.24
Average all plots	0.00	1.25	3.08	3.70	3.81	4.06	5.07	5.50	0.51
SE	0.00	0.23	0.83	0.68	0.38	0.56	0.53	0.59	0.14
Plat 1 A	0	1.00	5.75	2.75	5.50	6.50	5.25	7.50	0.46
Plat 1 B	0	2.50	8.75	8.50	5.67	6.75	5.75	4.75	0.41
Plat 1 C	0	1.50	2.25	5.00	4.67	4.00			0.15
Plat 2 A	0	1.50	1.50	3.75	3.00	2.00	3.33		1.37
Plat 2 B	0	2.00	2.00	3.50	3.25	3.25	3.00	3.75	0.25
Plat 2 C	0	0.50	2.25	3.00	3.25	4.00	6.25	7.00	0.65
Plat 3 A	0	1.00	2.00	2.33	3.00	2.00	4.00	5.00	0.28
Plat 3 B	0	0.75	1.50	1.50	3.00	4.25	5.75	5.00	0.91
Plat 3 C	0	0.50	1.75	3.00	3.00	3.75	7.25		0.13

Figure 7.6. Summarizing marker horizon data (values in mm).

Data Entry – Database

It is recommended that a database be used to store SET sample station data. This is the best method for easily storing and accessing the large amounts of data generated by years of sampling.

The National Park Service has developed a database application using Microsoft Access© which allows for the entry and storage of SET and marker horizon data (Figure 7.7). It is specifically designed for use by the SET monitoring programs in the NPS, but could easily be adapted for use by other agencies and groups.

The NPS Marsh Elevation Monitoring database has the following features:

- Can store SET and maker horizon data for multiple projects and/or sites.
- Stores information on SET mark installation.
- Stores position data of SET marks (ie., Latitude, Longitude, elevation).
- Allows for entry of SET and marker horizon data (double entry of SET data).

- Stores notes on sites, stations, positions and pin data.
- Allows for data summary, simple graphing and QA/QC of the marker and SET data
- Records field crew information (names and roles).
- Can store water level recorder information (Start/Stop dates, sensor info, etc).
- Tracks data entry dates and user names.
- Data export as text and spreadsheet files for analyses in other products.
- Data import of text files.

This product requires Microsoft Access in order to use it. Contact Geoff Sanders (Geoff_Sanders@nps.gov) or James Lynch (james_lynch@nps.gov) to get a copy of the database files. The database files come with detailed instructions on how to use the database.

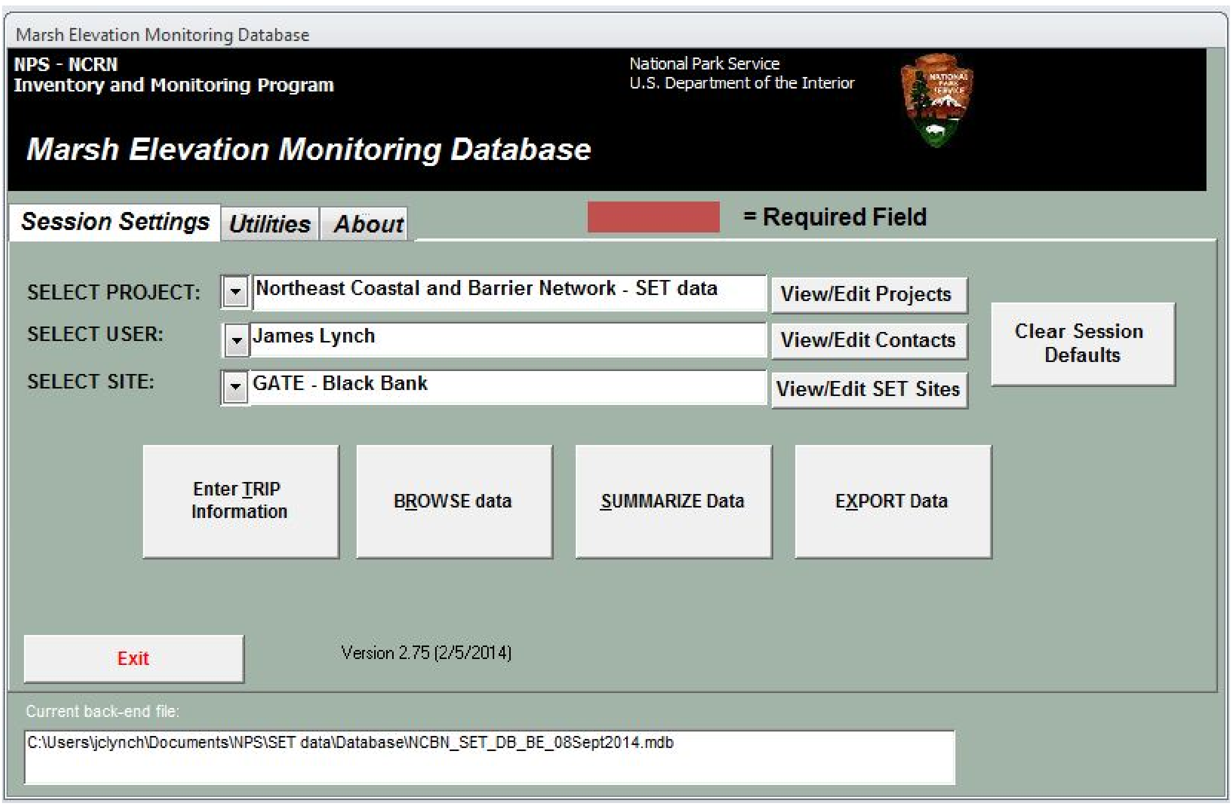


Figure 7.7. Main page of SET marker horizon database.

SOP 8: SET and Marker Horizon Data Analysis

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP #10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

The analysis of SET and marker horizon data depends on the specific question or questions of interest. This SOP does not attempt to cover all types of questions; rather, this document focuses on what are the most basic and common analyses that result from an SET study. At a fundamental level, five basic questions arise when considering an entire time series data set:

1. What is the overall rate of vertical accretion and elevation change?
2. Is the rate of elevation change less than or equal to local sea level rise?
    - Are the wetlands keeping pace with local sea level rise?
    - Are the wetlands at risk of becoming submerged?
3. Is the rate of elevation change the same as the rate of surface accretion?
    - Is surface accretion alone responsible for elevation change?

- Are below-ground processes involved in either elevation gain or elevation loss?

4. Is the rate of accretion or elevation change the same across different sites or treatment factors?

    - Are different areas of the coast more or less sensitive to local sea level rise
    - Are different management options able to enhance a wetland's sustainability in the face of sea level rise?

5. Is the relationship between elevation change and surface accretion the same across different sites or treatment factors?

The five questions above relate to the rates of accretion or elevation change over the entire time series, and span both monitoring and hypothesis testing goals. In the monitoring framework, the most basic question seeks to discern the overall vertical rate of change, and whether the marshes are at risk of drowning due to local sea level rise. Diving deeper, a researcher may additionally be interested in understanding the processes leading to the observed elevation change: is elevation change driven by surface processes of accretion, by subsurface processes such as compaction, shallow subsidence, or shallow expansion; or both surface and subsurface processes? These questions will entail comparing elevation change to surface accretion. Additionally, the researcher may have established an experimental design testing for differences in rates across different wetland types or experimental treatments.

Other questions may require breaking up the time series of SET and marker data into either sequential or repeating time intervals. Instead of computing one overall linear rate for each sampling station, any number of different rates will be computed according to the nature of the specific question being posed. Two additional comparisons typically present themselves:

6. Are pre and post-treatment trends different?

7. Are there seasonal changes in the trends?

Note that all of the original five questions above can be incorporated in these two comparisons. At a basic level, the investigator may just want to know what the trends were prior to an impact (such as a major storm), and what the trends were after the impact, and whether each of these were less than local sea level rise trend. There might also be a reason to compare sites or treatment factors over these different time periods. A comparison of repeating time intervals is more complex, as it requires computing rates for a larger number of intervals, which themselves may not be constant over time (e.g. pre-impact time series may be much shorter than post-impact).

Mirroring these different levels of complexities, this SOP first provides a fundamental statistical framework for addressing questions 1-5 ('*Long term, linear trend analyses'* section). The '*Linear trends in SET data over different time periods*' section then addresses questions 6 and 7, and provides some basic principles that can be applied to the analysis of sequential or repeating time series. Again, this SOP is not designed to provide a solution to all types of experimental designs using the SET or marker horizon techniques. Rather, it describes a fundamental framework that addresses the most basic of analyses, and hopefully provides a robust and consistent starting point for more complex models and analyses.

Long Term, Linear Trend Analyses

The estimation of long term trends requires a complete, quality assured/quality controlled time series data set for SET and/or marker horizon observations. Figure 8.1 illustrates the steps involved in the analysis, the questions that can be addressed, and statistical tests that can be (in most cases) used to answer them.

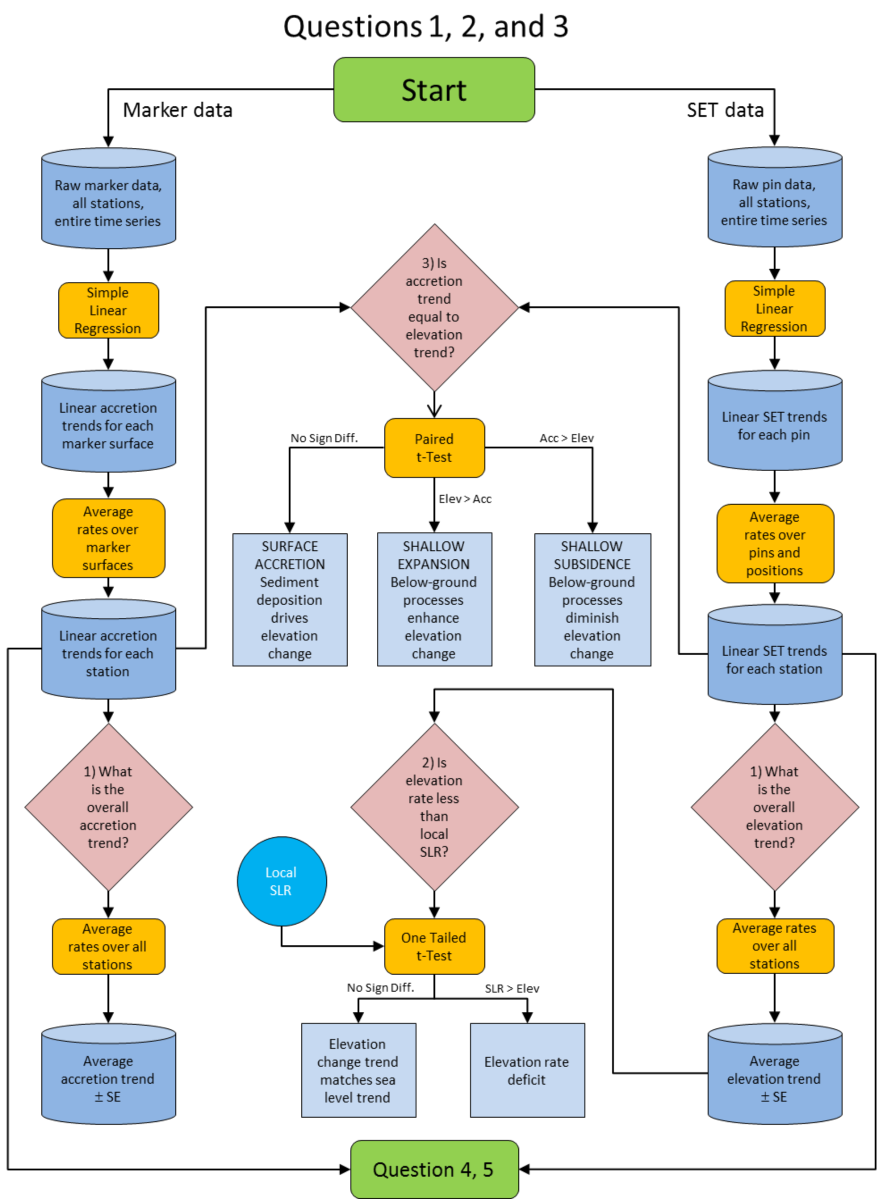


Figure 8.1. Conceptual diagram of statistical analysis of SET and marker data addressing three basic questions (red diamonds). Data are shown in the blue cylinders; computations are shown in orange rounded rectangles, and the results are shown in light blue.

What is the overall rate of surface accretion and elevation change?

The first step in analyzing elevation and accretion data is to determine whether a linear trend is appropriate. Plot the cumulative elevation change data (and/or accretion data) over time. Does a straight line come close to explaining overall cumulative elevation change over time (Figures 8.2)? If the data exhibit distinct non-linear trends, other techniques may be required, such as splitting the data into smaller time series over which the trends are linear (Figure 8.3).

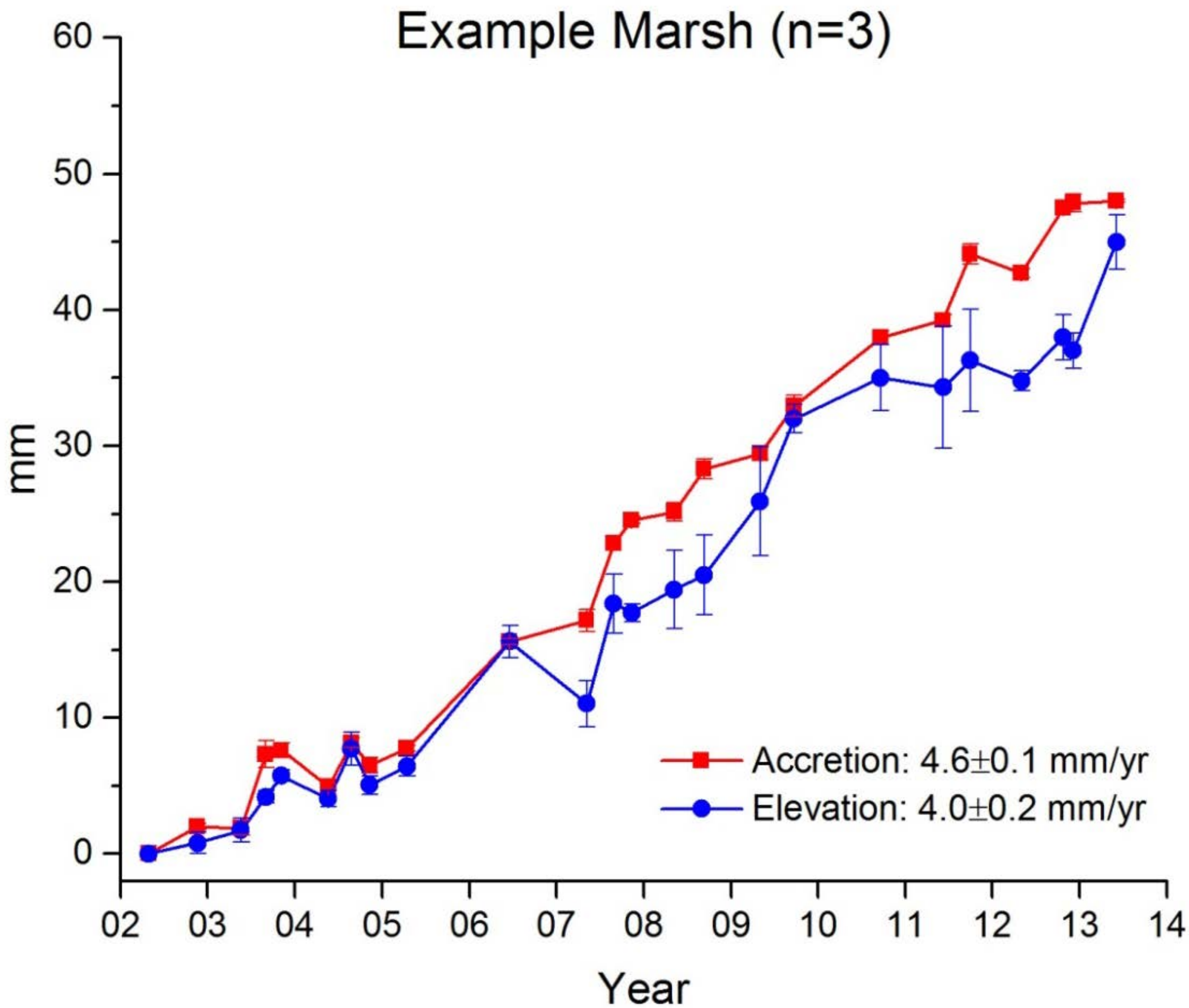


Figure 8.2. Example of plotting cumulative SET and Marker horizon data over time to verify whether or not a linear trend is reasonable for the data. In this case, an overall linear trend would appear to fit each time series.

Are the data evenly distributed over time? Linear slope estimates are very sensitive to the distribution of data over time. If the data are clustered at either end of a timeline with large data gaps in the middle, the rates will be very sensitive to initial and final elevation estimates (Figure 8.4).

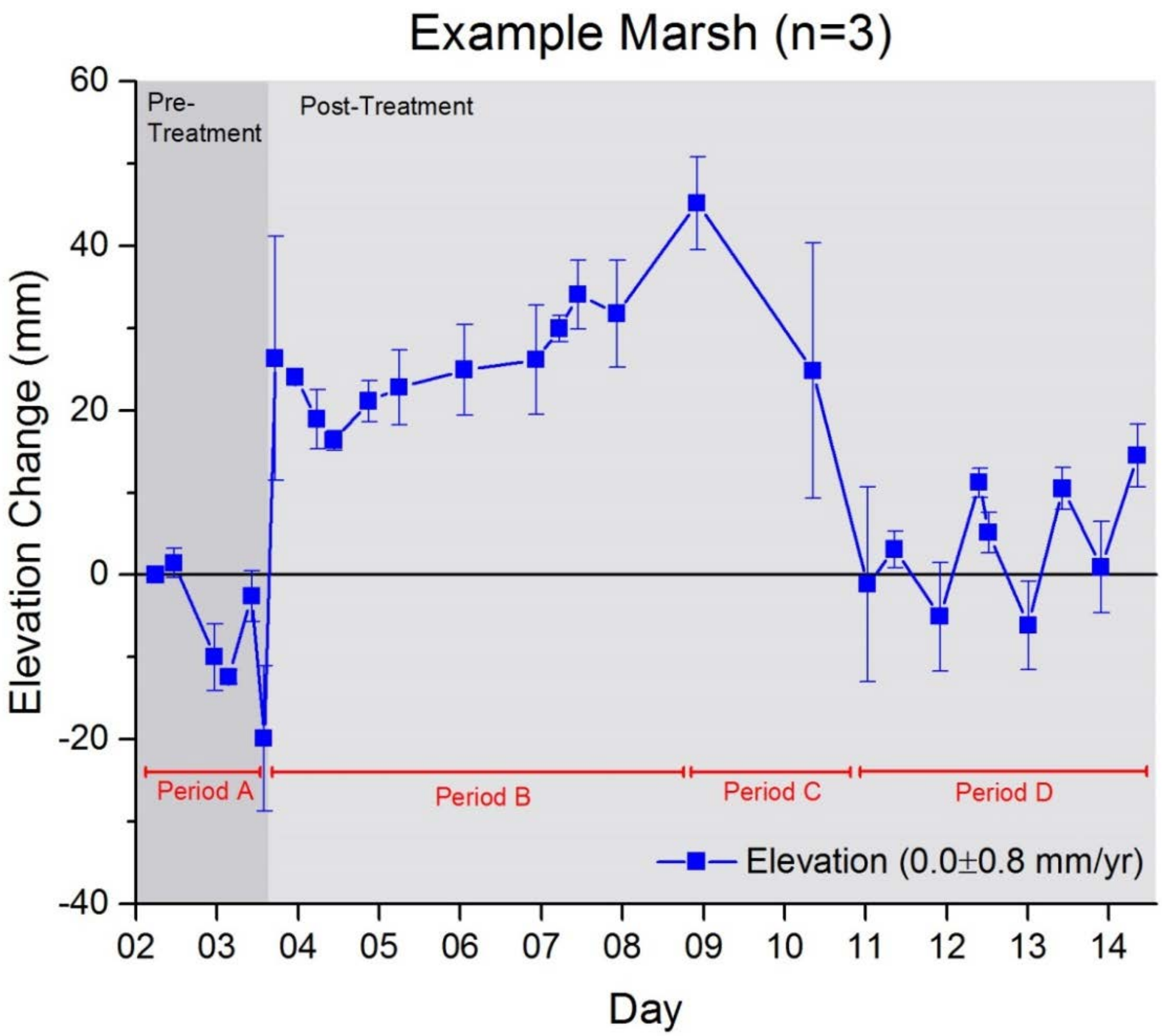


Figure 8.3. Example of a non-linear time series. The trend for the entire record is not linear. Dividing the record into two or more periods may be the better analytic approach. Linear trends would be estimated separately for each period.

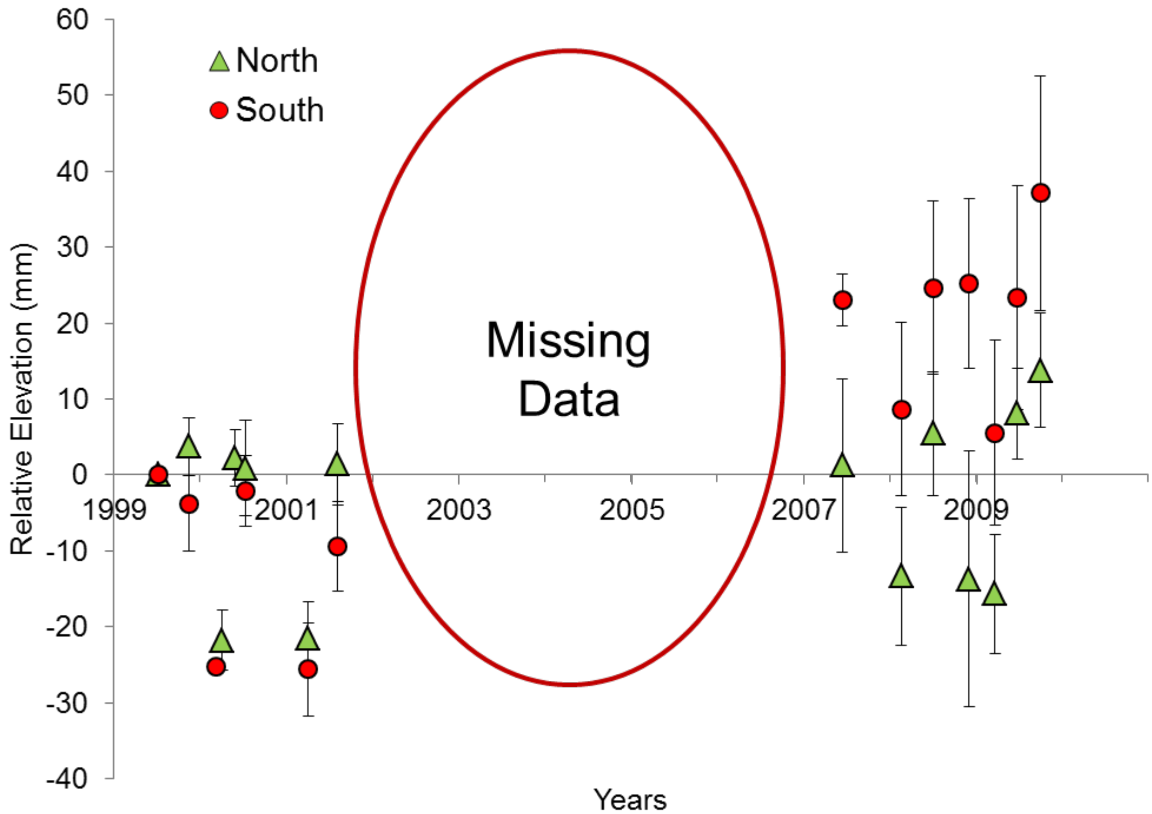


Figure 8.4. Example showing data clustered at either end of the time series. In this case, the slope estimates will be overly sensitive to the starting and ending readings.

Step 1: To avoid serial correlation, compute slopes using simple linear regression for each individual pin within each position and each SET station (SET data; Figure 8.5). Similarly, for marker horizons, compute slopes for each separate marker horizon within a sample station (marker data; Figure 8.6). Note that for SET data, there is only one observation at each time period, since any given pin is read only once. For marker data, however, it is possible that multiple readings are taken from each core. If so, then multiple observations may exist at each time period within the regression analysis.

Slope computation can be easily calculated in both common spreadsheet applications, as well as statistical software. Slopes are commonly expressed as mm yr^{-1}. Time needs to be expressed as fractional years (or days) since the start of the dataset, and SET and marker data should be expressed in millimeters.

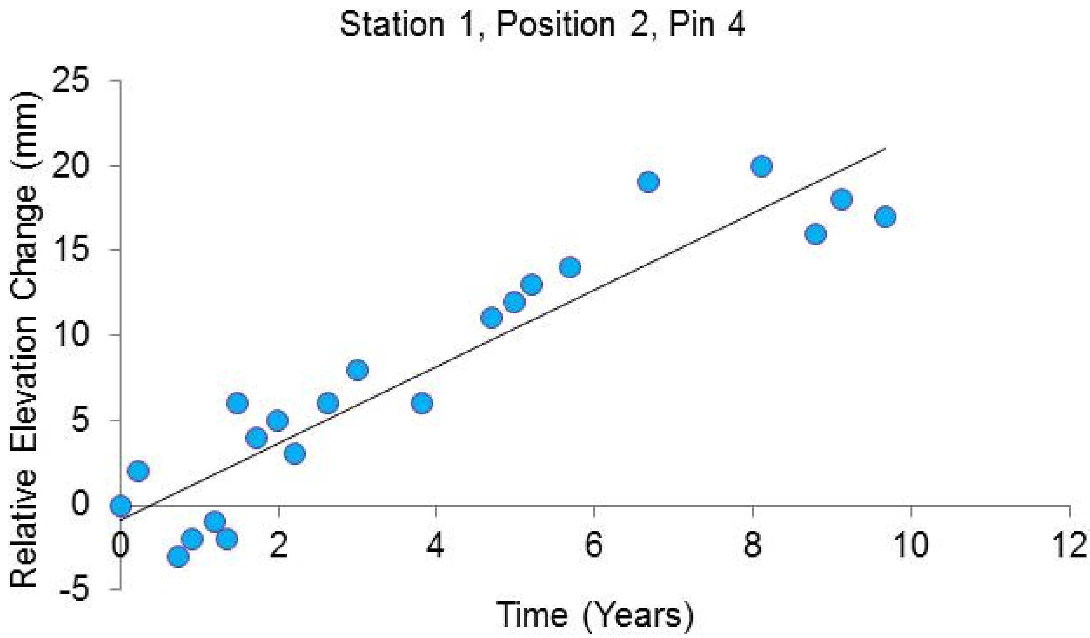


Figure 8.5. Example of regressing an individual SET pin's height over an entire time series to obtain a long term linear rate of change. Note that the pin heights are expressed with respect to the initial reading.

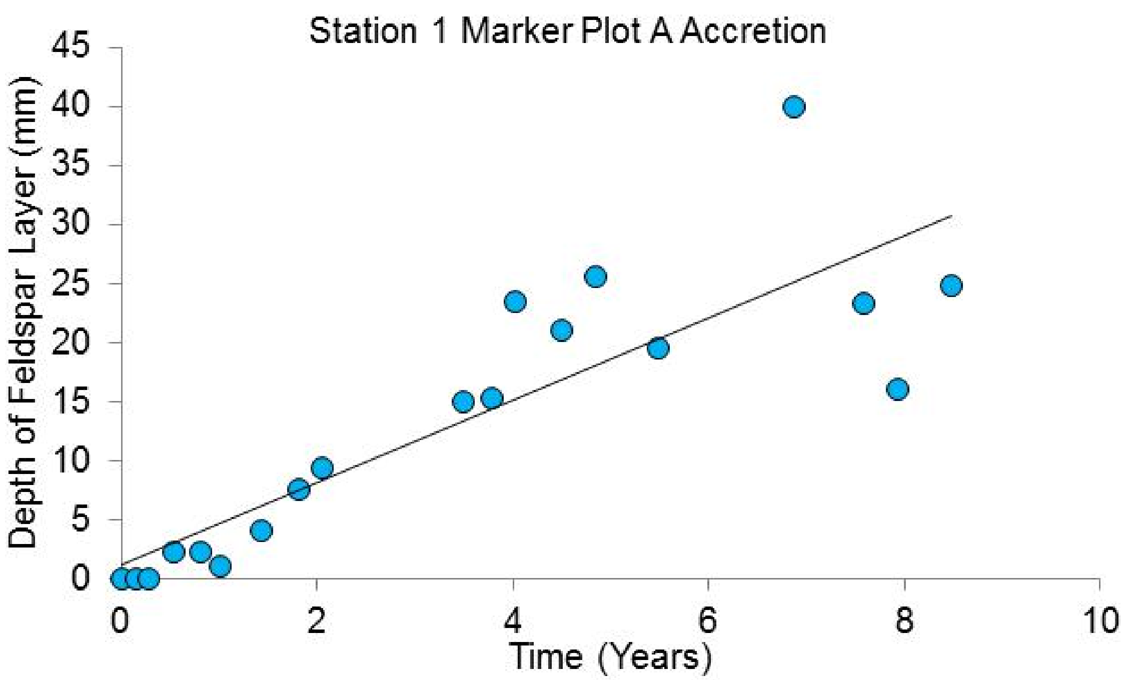


Figure 8.6. Example of estimating a regression line over a time series for a single marker horizon surface within a SET sample station. Note that the initial recorded marker depths were zero (marker still visible on sediment surface)

Step 2: Average the 9 slope estimates for each position over all of the positions (4) and then average to the level of the SET sample station. For marker horizons, the slopes are also averaged for each plot and then to the sample station. Compute the standard error of the average, which will provide an implicit error envelope around the estimate (precision).

Step 3: The average rates can be compared to zero to determine if they are statistically significant. A *t*-test is computed using the mean and standard error (Table 8.1). The user can use either a two-sided test or a one-sided test, as appropriate.

Table 8.1. Example of determining the statistical significance of an elevation change rate using a *t*-test.

Ha: Wetland elevation change rate is different from zero.	**Ho: Wetland elevation change rate is equal to zero.**	
Item	**Value**	**Notes**
Elevation change rate (y_1, in mm yr^{-1})	2.6	Value from analyses of SET data (full record)
Standard Error of rate (mm yr^{-1})	0.2	Value from analyses of SET data (full record)
$t = (y_1 – 0)/SE_{(y1)}$	13	The *t*-test compares the rate to zero
$t_{crit\ (df\ =\ 5)}$	2.57	
Prob ($t < t_{crit}$)	< 0.0001	
Result: Wetland elevation change is significantly different from zero.		

Step 4: At this stage, the average rates (trends) are now ready for input into other statistical models to address additional questions (see both Figure 8.1 and sections below).

Is the rate of elevation change less than or equal to local sea level rise?

Step 1: Compute linear slope estimates for each individual pin within each position and each SET station, or for each separate marker surface within a sampling station, as explained in '*What is the overall rate of surface accretion and elevation change?*' section.

Step 2: Average the rates over the positions (or marker surfaces), SET sample stations, and sites, if applicable. The user should end up with an average rate ± standard error ('*What is the overall rate of surface accretion and elevation change?*' section).

Step 3: Provide the rate of local sea level rise. This is assumed to be a known (parametric) value, with no significant error. A nearby NOAA tide gauge will normally provide a value for local sea level rise. This will be the value to which we compare the average rate of elevation change (Figure 8.1)

Step 4: Compute a Student's *t* statistic, differencing the average estimated elevation change rate (step 2) and the local sea level rise rate, and dividing by the standard error of the elevation change rate estimate (Table 8.2).

Table 8.2. Example of a Student's T-test used to test whether or not a SET linear trend (2.6 mm yr^{-1}) is greater than or equal to local sea level rise (3.5 mm yr^{-1}), based on a sample size of six SET sample stations.

Ha: Wetland elevation change rate is greater than or equal to local sea level rise.	**Ho: Wetland elevation change rate is less than local mean sea level rise**	
Item	**Value**	**Notes**
Elevation change rate (y_1, in mm yr^{-1})	2.6	Value from analyses of SET data (full record)
Standard Error of rate (mm yr^{-1})	0.2	Value from analyses of SET data (full record)
Local sea level rise rate (μ, in mm yr^{-1})	3.5	From NOAA Tide gauge
$t = (y_1 - \mu)/SE_{(y1)}$	-4.5	
$t_{crit\ (df = 5)}$	-2.01	
Prob ($t < t_{crit}$)	0.003	
Result: Wetland elevation change is significantly LESS than local sea level rise at the 99% confidence level		

Step 5: Compare this computed *t* statistic to a one-tailed critical *t* value, with the appropriate degrees of freedom (number of sample stations minus one) and Type I error (typically 0.05 or 0.1). Note that this is a one-tailed test since we are only interested in knowing if the elevation change rate is significantly less than local sea level rise.

Step 6: Critical *t* values are typically given as positive numbers, although the distribution of the *t* statistic is centered at zero, and extends equally to both positive and negative infinity. If the computed *t* statistic is positive, the result is that wetland elevation change outpaces local sea level rise, and the wetland presently is not vulnerable to sea level rise. If the computed *t* statistic is more negative than the (negative of the) critical *t* statistic, then local sea level rise is significantly greater than elevation change at the chosen Type I error rate, and the wetland is vulnerable to sea level rise. Computer programs allow the computation of the actual P-statistic associated with this test. Report the P-value of the test. See Table 8.2 for an example of such a test.

One-sided vs. Two-sided *t*-test: We have focused on a one-sided *t* -test because 1) most users will be concerned if elevation change is *less* than local sea level rise, not if it is equal to or greater than sea level rise; 2) most studies suffer from very small sample sizes, so it is important to maximize power. Nevertheless, if the user is interested in a two-sided *t* -test, testing the more general hypothesis that elevation change is *not equal to* local sea level rise, then a two-sided critical *t* value will have to be looked up, and a two-sided P-value computed.

Is the rate of elevation change the same as the rate of surface accretion?

Step 1: Compute linear slope estimates for each individual pin within each position and each SET station, and for each separate marker surface within a sampling station, as explained in '*What is the overall rate of surface accretion and elevation change?'* section.

Step 2: Average the rates over the positions/marker surfaces and SET sample stations. The user should end up with an average rates of both accretion and elevation change for each SET sample station.

Step 3: Compute the standard errors for these average of accretion rates and elevation change rates (using sample stations as replicates): compare these two standard errors. If they appear of similar size and magnitude, the user can employ the pairwise T-test assuming equal variance. If the standard errors are very different, the user will have to use the pairwise T-test for unequal variances.

Step 4: Match the average elevation change rates and average accretion rates for each sample station (Figure 8.1).

Step 5: Run a pairwise *t* -test on the sets of pairs (typically, the first group is elevation change, the comparison group is accretion; Table 8.3). Pairwise *t* -tests (for both equal and unequal variances) are available in typical computer spreadsheet programs, as well as more advanced statistical software.

Step 6: Compare the computed pairwise *t* value to the critical two-sided *t* statistic based on the correct degrees of freedom (number of sample stations minus one) and Type I error (0.05 or 0.10). See Table 8.3 for an example.

- If the computed *t* value falls between both the positive and negative of the critical *t* -value, then accretion is not different from elevation change, and we can assume that surface accretion is driving elevation change.

- If the computed pairwise *t* statistic is less (more negative) than the negative of the critical *t* statistic, that means elevation change is significantly less than accretion, so shallow subsidence processes are affecting elevation change

- If the computed *t* value is greater than the (positive) *t* statistic, that means that elevation change is significantly greater than accretion, so subsurface expansion processes are affecting elevation change.

Table 8.3. Example of a Pairwise *t* -test used to test whether or not a SET linear trend (2.6 mm yr^{-1}) is statistically similar to the rate of accretion (4.2 mm yr^{-1}), based on a sample size of six sample stations.

Ha: The difference between the wetland elevation change and the rate of surface accretion is not zero	**Ho: The difference between the wetland elevation change and the rate of surface accretion IS zero**	
Item	**Value**	**Notes**
Average difference between elevation change rates and accretion rates (y_1, in mm yr^{-1})	-1.6	Compute pairwise differences between SET trends and marker horizon trends for each station (full record)
Standard Error of the difference between elevation rates and accretion rates (mm yr^{-1})	0.41	Computed from pairwise differences between SET trends and marker horizon trends for each station (full record)
$t = (y_1 - 0)/SE_{(y1-y2)}$	-3.89	
$t_{crit\ (df = 5)}$	±2.01	
Prob ($t < t_{crit}$)	0.006	
Result: Wetland elevation trend is significantly less than surface accretion trend at 99% confidence		

Is the rate of accretion or elevation change the same across different sites or treatment factors?

In this analysis, we compare the average rates of accretion or elevation change of groups of sample stations distributed across different wetland sites, or groups of sample stations with different experimental factors applied (or both; Figure 8.7). As with the previous section, we first need to make sure that the appropriate statistical test is used. The same analysis can be used for either SET or marker data.

Step 1: Compute linear slope estimates for each individual pin within each position and each SET station, or for each separate marker surface within a sample station, as explained in '*What is the overall rate of surface accretion and elevation change?'* section.

Step 2: Average the rates over the positions (or marker surfaces) and SET sample stations, as described in '*What is the overall rate of surface accretion and elevation change?'* section.

Step 3: Carefully label each average slope estimate derived in step 2 according to its sample station and the particular site or (combination of) treatment factors applicable to each station. Each of these variables describing the sample station (e.g. site and/or treatment factor) will require its own separate column in the spreadsheet: each row in the spreadsheet will relate to a different SET sample. The final column will contain the average rates (accretion or elevation change).

Step 4: Compute the variances for each site and/or combination of treatment factors. If the variances appear to be similar throughout, proceed to step 5. If one or more site or combination of factors have very different variances compared to the rest, then a non-parametric equivalent to analysis of variance will have to be used (e.g. Kruskal Wallis test, Mann-Whitney U test, etc.; the user will have to refer to statistical manuals for more information on use).

Step 5: Run an analysis of variance with the average slope estimates as the dependent variable (y_{ijk} in Equation 8.1), and the sites and/or treatment factors as the independent variable(s) (Equation 8.1). In equation 8.1, two different treatment factors are given as Trt1 and Trt2. Do not forget to include an interaction effect if two different factors (or the combination of sites and factors) are being investigated. The experimental unit (replicate) is the SET sample station (the level at which the elevation change rates are averaged – in equation 8.1, there are three SET stations, k = 1,2,3).

Many statistical software packages (e.g. R) analyze the analysis of variance model as a linear equation with the dependent variable on the left and the terms relating to the experimental design (e.g. site comparisons or treatment factors) on the right. For example, a user may be interested in comparing the elevation change rates of two different wetland sites and the effect of fertilization on these rates. Equation 8.1 provides an example of the linear model for this kind of analysis. Note that there are separate terms for each of the two treatment factors (wetland sites and fertilization), their interaction, and the overall error term.

Equation 8.1:

$$y_{ijk} = \beta_0 + \beta_1 \times Trt1_i + \beta_2 \times Trt2_j + \beta_3 \times Trt1_i \times Trt2_j + \varepsilon_{k[i,j]}$$

$$\varepsilon_{k[i,j]} \sim N(0, \sigma^2); i = 1, \dots n_i; j = 1, \dots n_j; k = 1,2,3$$

In Equation 8.1, y_{ijk} is the average (elevation change or accretion) rate for sample station k (k = 1,2 or 3 – assuming only three replicate SET sample stations) under the i^{th} level of treatment 1 (e.g. wetland site) and the j^{th} level of treatment 2 (e.g. fertilization effect). The intercept β_0 is the average (elevation change or accretion) rate for the first level of treatment 1 (i = 1) and the first level of treatment2 (j = 1). The other coefficients (β_1 , β_2 and β_3) are differences between this rate at the rates relative to the other levels of treatments 1 and 2 (intercept adjustors). The error term in the model corresponds to the individual sample stations.

Step 6: Evaluate the significance of the model (Table 8.4) and test for contrasts of interest if warranted (make sure to control error if using non-orthogonal contrasts; Table 8.4).

Table 8.4. Example of an Analysis of Variance (ANOVA) model testing for significant differences in linear wetland elevation trends among two wetlands, with both fertilized and unfertilized treatments within each wetland, and with three SET stations per treatment-level combination.

Ha: Some treatments have different linear wetland elevation trends than others **Ho: All treatments have the same linear wetland elevation trend**					
Source	**Degrees of Freedom**	**Sums of Squares**	**Mean Square**	**F**	**P**
Entire Model	2	37.9	12.6	16.9	< 0.001
Wetland	1	32.3	32.3	43.3	< 0.001
Fertilization	1	0.4	0.4	0.5	0.503
Wetland x Fertilization	1	5.2	5.2	7.0	0.030
Error	8	6.0	0.7		
Total	11	43.9			
Result: Wetland elevation trends differ significantly between reference and restored wetlands, and the fertilization effect on elevation trends differs significantly among the two wetland types.					

Table 8.5. Example of using multiple contrasts for testing for significant differences in linear wetland elevation trends among two reference and restored wetlands, with or without a fertilization effect.

Contrast	**Estimate**	**Standard Error**	**T**	**P**
Reference vs. Restored Wetland (both non-fertilized)	1.9667	0.7059	2.786	0.0237
Fertilized vs. Non-fertilized Restored Wetland	-0.6667	1.5785	-0.422	0.684
Non-fertilized Reference Wetland vs. Fertilized Restored Wetland	-2.7333	0.8646	-3.161	0.0134

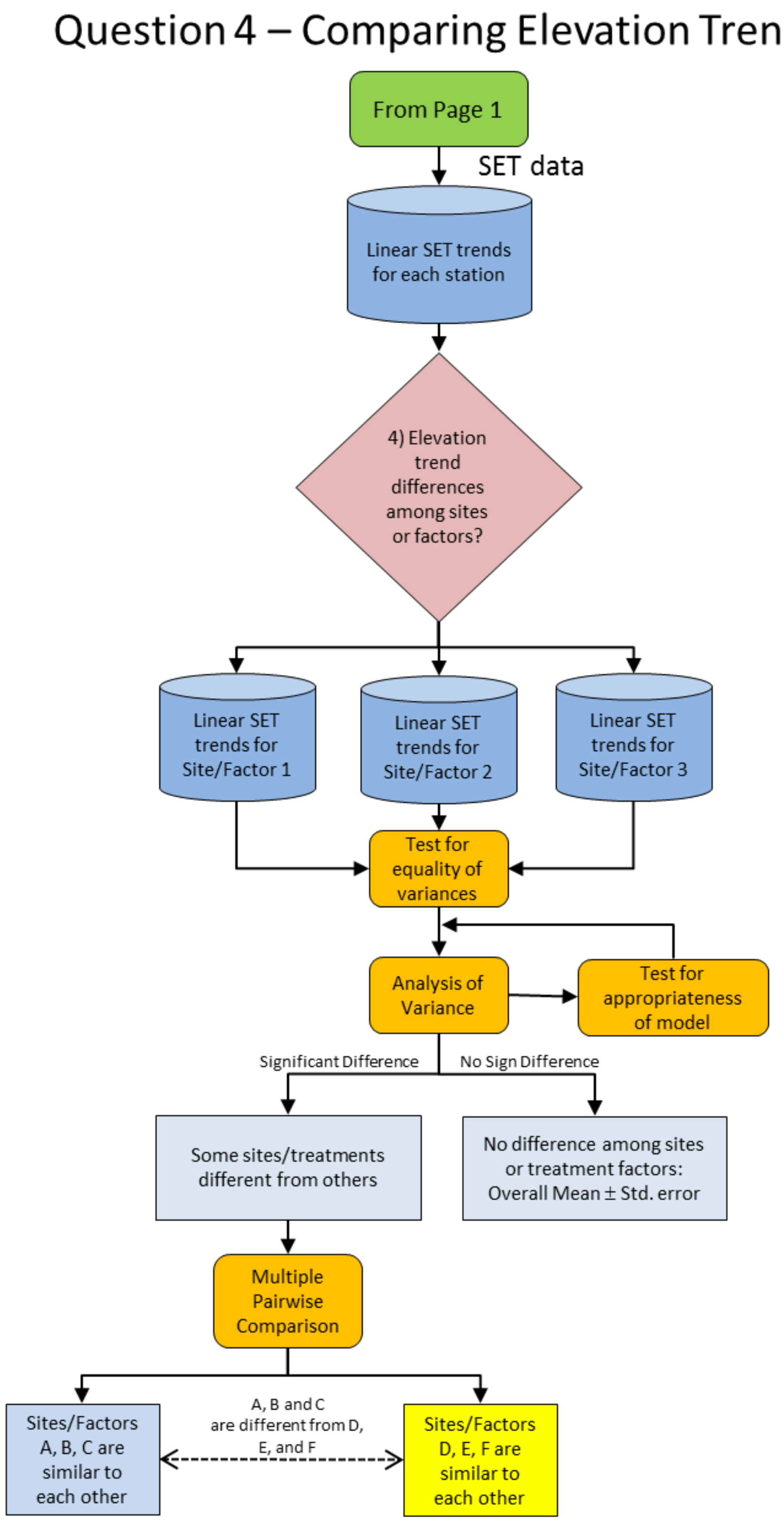


Figure 8.7. Conceptual diagram of statistical analysis of SET data to compare elevation change trends among sites or treatment factors.

Is the relationship between elevation change and vertical accretion the same across different sites or treatment factors

In this variation of the '*Is the rate of accretion or elevation change the same across different sites or treatment factors?*' section, the dependent variable is the difference between the average elevation change slopes and the average accretion slopes at the sample station level (Figure 8.8). Otherwise, the analysis follows similar steps to above.

Step 1: Compute the difference between the average elevation change rate and the average accretion rate at the sample station level. Do this for each sample station.

Step 2: Carefully identify these differences according to both sample stations and the particular sites or treatment factors relating to each station

Step 3: Compute the variances for each site or treatment factor. If the variances appear to be similar, proceed to Step 4. If one or more groups have very different variances compared to the rest, then a non-parametric equivalent to analysis of variance will have to be used (e.g. Kruskal Wallis test, Mann-Whitney U test, etc.; the user will have to refer to statistical manuals for more information on use).

Step 4: Run an analysis of variance with the differences between elevation change and accretion as the dependent variable, and the sites and/or treatment factors as the independent variable. Proceed as in the '*Is the rate of accretion or elevation change the same across different sites or treatment factors?*', above.

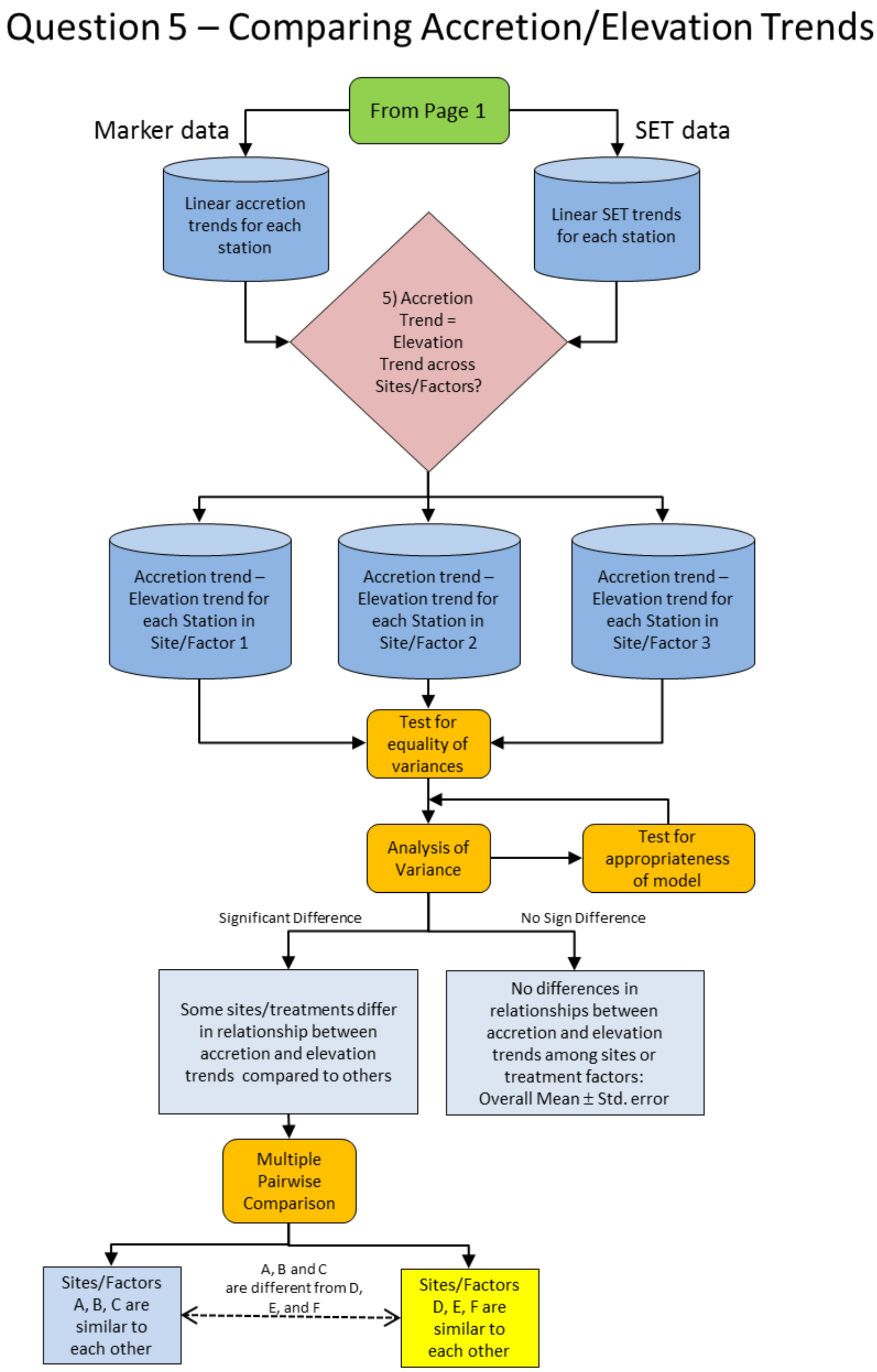


Figure 8.8. Conceptual diagram of statistical analysis comparing whether the relationship between accretion and elevation change is constant across sites or treatment factors.

Linear Trends in SET Data Over Different Time Periods

The user may be interested in comparing linear rates of elevation change or accretion among different time periods. For example, there may be interest in comparing pre impact to post impact rates of change. This involves *sequential* time periods (Question 6 in the '*Introduction to SET and Marker Horizon data analysis*' section; Figure 8.9, Panels A and B). Another user may be interested in comparing the rates of change among seasons over a number of years. This would involve *repeating* intervals (Question 7 in the '*Introduction to SET and Marker Horizon data analysis*' section; Panel C in Figure 8.9). Both situations require that the times series be disaggregated over time, and linear change rate estimates are generated in a manner similar to the '*Long term, linear trend analyses for each time period*' section. In either case, the user may simply derive the average rates per time period or time interval, and report the averages and standard errors.

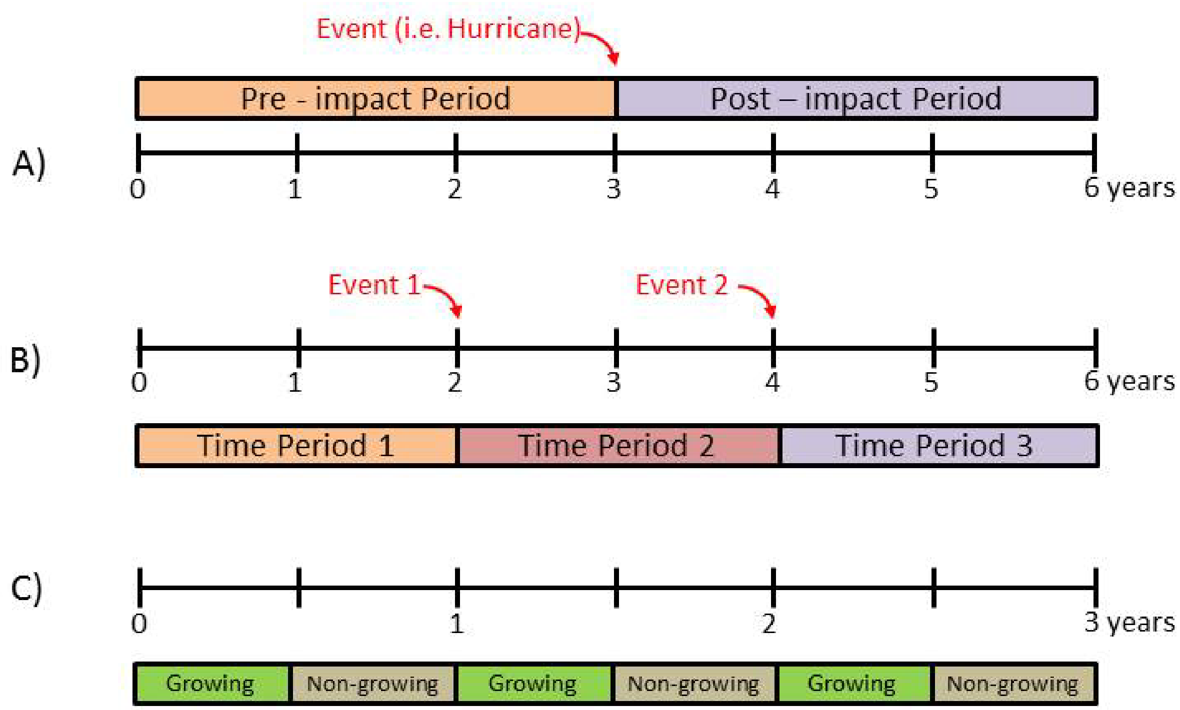


Figure 8.9. Conceptual diagram showing the nature of sequential time periods (panels A and B) and repeating time intervals (panel C). Panel A may represent the simplest of cases in which there are only two time periods (pre and post impact) and no other factors are present or of interest.

However, if the user wishes to compare the rates in a statistical model and make probabilistic statements, there is the complication that the computed rates might violate the assumption of independent sampling. The rates might not be independent over time (serial correlation) since the linear elevation change rate for any given pin in one particular time period may be related to both its previous or future rates, since it is measuring the very same patch of sediment surface. Similarly, the accretion rate of any given feldspar marker surface in one particular time period could be related to the rate that was measured at that same plot in the previous time period, as well as the rate in the following time period, since the same surface is being measured.

Serial correlation, however, can be easily mitigated in one particular case: when the user only wishes to compare the average rates among two time periods, and there are no other questions or factors of interest. This situation, which may be compared using a simple *t* -test, is explained in the '*Comparison of trends over two sequential time series*' section. If more than two time periods are compared, or if there are additional factors of interest (e.g. wetland type or fertilization effect, as illustrated in Tables 8.7 and 8.8), then more complex linear models will be required. This situation is explained in the '*Comparison of trends over multiple time series and multiple treatment factors*'section. Finally, the situation of repeated time intervals, which also engenders serial correlation, is addressed in the '*Comparison of trends over repeating time intervals*' section. These latter two situations require good familiarity with hierarchical models, random factors, and model selection procedures. If in doubt, it is recommended to seek the advice of a statistician familiar with these situations.

Comparison of trends over two sequential time series

An analysis of two sequential time periods may be necessary when either the time series is distinctly non-linear, or when something occurred to change the linear trajectory (e.g. a coastal storm; Figure 8.9 panel A and Figure 8.10). In any such cases, data need to be disaggregated over time, resulting in sequential, non-overlapping time series (pre-storm time period 1 vs. post-storm time period 2, in Figure 8.10).

In the procedures that follow (Figure 8.11), the example given is relative to SET data; similar concepts apply to marker data, the only difference being that rates are computed for each marker surface.

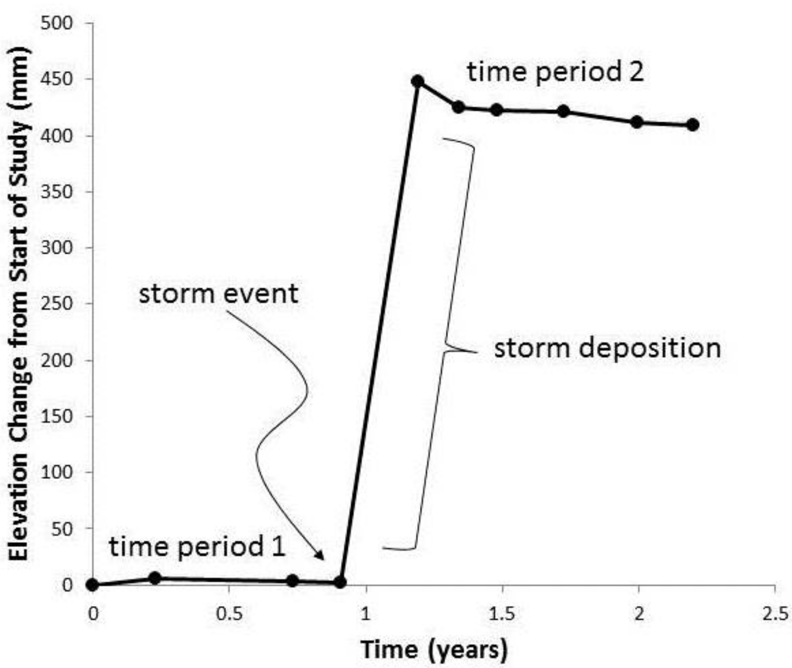


Figure 8.10. Example showing scenario in which storm deposition on the marsh surface results in two different elevation change trajectories. Time period 1 corresponds to pre-storm deposition and time period 2 corresponds to post-storm deposition.

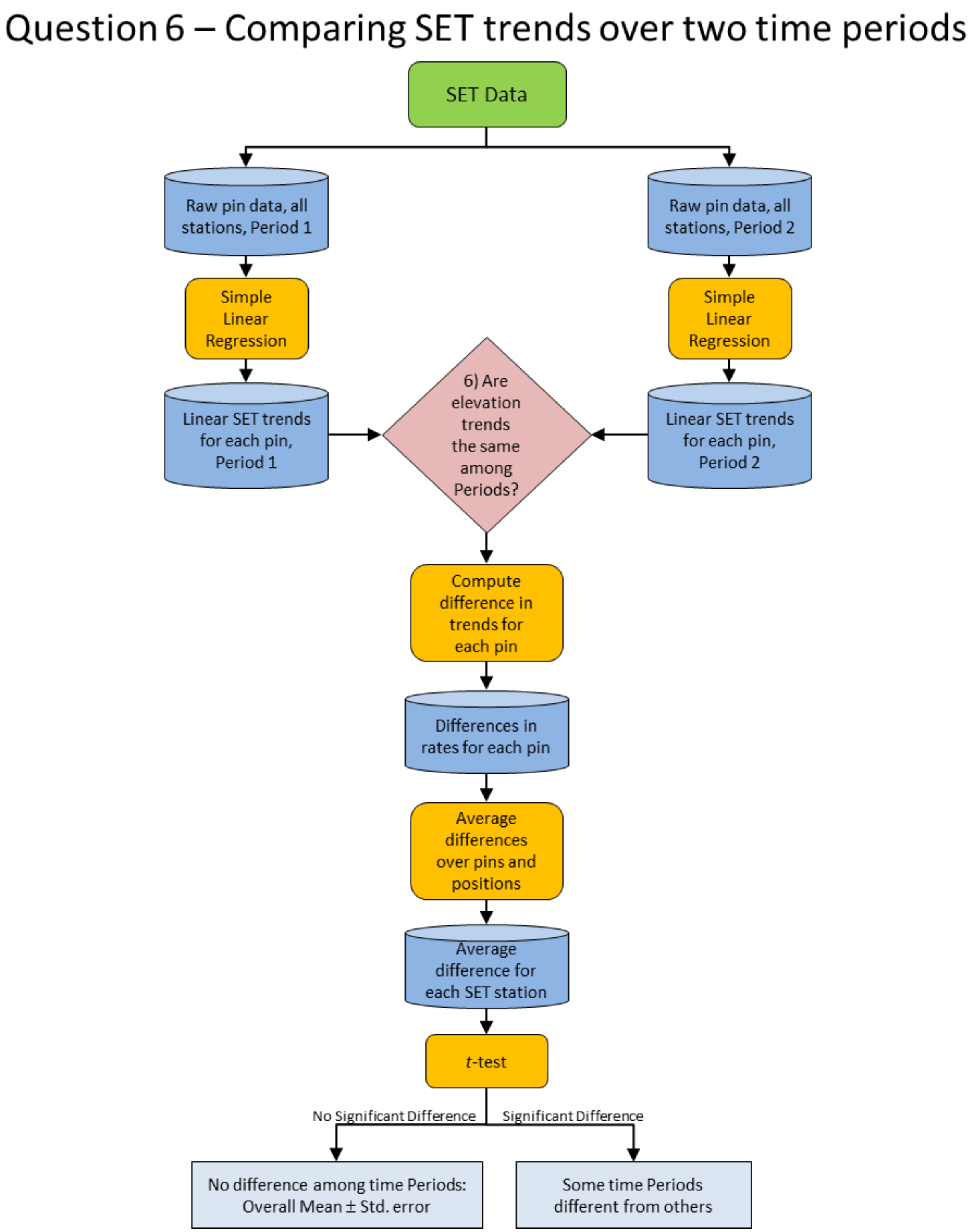


Figure 8.11. Conceptual diagram of statistical analyses comparing linear wetland elevation trends over two consecutive time periods (no other factors or tests of interest).

Step 1: SET data are disaggregated according to the two consecutive time periods (no need to change the units of measurements).

Step 2: Regressions are run separately on each pin and for each of the two time periods. As a result, two different rates are assigned to each pin (e.g. time period 1 rate, time period 2 rate)

Step 3: The difference between the two rates is computed for each pin, and the differences are averaged over the positions and SET stations. The user is now left with one series of data. Since the serial correlation exists at the level at which the user is comparing the rates, the serial correlation is explained and no assumptions of the analysis are violated.

Step 4: A *t* -test is run comparing the differences computed in Step 3 to zero (testing the hypothesis that the rates in the two time periods are the same; their difference is equal to zero). Refer back to the '*What is the overall rate of surface accretion and elevation change?*' section for an example of such a T-test). The test can be evaluated either as a one-sided test (if the user expects the test to go one way or the other) or as a two-sided test (if the user does not expect the test to go one way or the other). The P-value is recorded accordingly.

Comparison of trends over multiple time series and multiple treatment factors

This is a more involved/complex situation of the '*Comparison of trends over two sequential time series*' section involving either more than two time periods, or sequential time periods with additional treatment factors or combinations thereof. This sort of analysis will require advanced statistical capabilities, and the assistance of a statistician is highly recommended.

Step 1: SET data are disaggregated according to the different consecutive time periods (Panel B of Figure 8.9). Regressions are run separately on each pin and for each specific time interval.

Step 2: In the statistical analysis, a linear model will be specified with the accretion or elevation change rates as the dependent variable (y_{ijkl} in Equation 8.2), the appropriate independent fixed effects (e.g. time periods, treatment factors), and nested error terms in the form of sample stations and positions within sample stations (pins would comprise residual error; Equation 8.2). Note that serial correlation should be modeled in the variance-covariance matrix.

For example, the user might wish to compare the sequential impacts of multiple storm events on the wetland elevation change rates. In this example, there might be three time periods (Panel B of Figure 8.9; $n_i = 3$ in Equation 8.2 below). The model would specify intercept terms relating to the multiple storm events on the elevation (β_0 and β_1 in Equation 8.2). The model includes a covariance term explaining the serial correlation among rates over time (σ_i). The model includes random terms for the SET pins (ε_l), SET positions (ε_k), and SET sample stations (ε_j). A similar model would exist for marker data (specifying random terms for marker surfaces and sample station)

Equation 8.2:

$$y_{ijkl} = \beta_0 + \beta_1 \times Period_i + \sigma_i{}^2 + \varepsilon_{j[i]} + \varepsilon_{k[i,j]} + \varepsilon_{l[i,j,k]}$$

$\varepsilon_{j[i]} \sim N\left(0, \sigma_j{}^2\right); i = 1, \dots n_i; j = 1,2,3$

$\varepsilon_{k[i,j]} \sim N(0, \sigma_k{}^2); i = 1, \dots n_i; j = 1,2,3; k = 1,2,3,4$

$\varepsilon_{l[i,j,k]} \sim N(0, \sigma_l{}^2); i = 1, \dots n_i; j = 1,2,3; k = 1,2,3,4; l = 1,2, \dots ,9$

In Equation 8.2, y_{ijkl} is the (elevation change or accretion) rate for pin l in position k in sample station j (j = 1,2 or 3 – assuming only three replicate sample stations) at the i^{th} time period. The intercept β_0 is the average rate for the first time period (i= 1). The other coefficient (β_1) provides the difference between this rate and the rates at the other time periods. Note that there is a term expressing the serial correlation over time (σ_j), and the nested error structure of positions (j) within sample stations (k) and pins (l) within positions and sample stations.

If there are treatment effects, the linear model would increase in complexity (Equation 8.3).

Equation 8.3:

$$y_{ijklm} = \beta_0 + \beta_1 \times Trt1_i + \beta_2 \times Period_j + \beta_3 \times Trt1_i \times Period_j + \sigma_j{}^2 + \varepsilon_{k[i,j]} + \varepsilon_{l[i,j,k]} + \varepsilon_{m[i,j,k,l]}$$

$\varepsilon_{k[i,j]} \sim N(0, \sigma_k{}^2); i = 1, \dots n_i; j = 1, \dots n_j; k = 1,2,3$

$\varepsilon_{l[i,j,k]} \sim N(0, \sigma_l{}^2); i = 1, \dots n_i; j = 1, \dots n_j; k = 1,2,3; l = 1,2,3,4$

$\varepsilon_{m[i,j,k,l]} \sim N(0, \sigma_m{}^2); i = 1, \dots n_i; j = 1, \dots n_j; k = 1,2,3; l = 1,2,3,4; m = 1,2, \dots ,9$

Step 3: As with any statistical analysis, the distributional assumptions of the model should be verified. At the very least, rates can be averaged to the sample station level, and variances computed for each level of the fixed effects in the model: variances should be of similar size/magnitude. Additionally, most statistical software will allow the testing of the distributional assumptions by various analyses on the model residuals (e.g. homogeneous variance and normal distribution).

Step 4: Assuming the data meet the distributional assumptions of the model, model selection procedures would be recommended as a way of testing whether or not serial correlation truly exists or has a significant effect in the model. For example, a model without the serial correlation specified in the variance/covariance matrix can be compared for model fit. If the fit statistics (e.g. maximum likelihood estimates) are similar, then the simpler model can be used. Similarly, model selection procedures can be used to test for the significance of the hierarchical random effects (pins and positions within SET sample stations). In general, the most parsimonious model with the smallest number of significant terms is recommended, as it may have more power in determining true differences than a fully-specified model.

Step 5: The results of the linear model are interpreted, and any additional comparisons are made, testing for significant differences among fixed effects and their levels.

Comparison of trends over repeating time intervals

The user may wish to compare linear accretion or elevation change among a number of different, recurrent time intervals (Question 7, '*Introduction to SET and Marker Horizon Data Analysis*' section). A typical example is seasonality: a user may be interested in comparing elevation change between wet and dry seasons, or growing vs. non-growing seasons (Figure 8.9, panel C). In some cases, a user may also wish to compare changes in rates within a growing season.

As before, the analysis will require the calculation of linear change rates for each pin. However, an additional complication is that there are now two different concepts of "sample space;" the geographic space over which the replicate sample stations are distributed, and the temporal sample space, including the replicate years over which the repeating time periods have been observed. In comparing among sequential seasons, different years may be considered independent, random samples (assuming that the processes occurring in one year are independent of those occurring in a subsequent year). In comparing rates within a growing season, the different years may be considered random blocking effects.

In all cases, the user will have to compute rates of change for each pin over each of the repeating time intervals. This is the same as computing incremental pin height change divided by the length of time for each interval. In all but the simplest of cases, the correct analysis requires advanced statistical modeling methods. The data analysis procedure is conceptualized in Figure 8.11.

Step 1: SET data are disaggregated according to the different time periods (e.g. pre-growing season, growing season, and post-growing season, similar to the pre and post storm impacts shown in Figure 8.10). Regressions are run separately on each pin, and for each individual time interval, which will provide linear rate estimates for each pin and for each interval.

Step 2: To account for serial correlation, a linear model will be used in which the dependent variable is the computed rates (step 1, above; y_{ijk} in Equation 8.4, below), and the independent variables are the separate time periods and the corresponding random effects. The random effects include the SET sample stations, the positions within the sample stations, and the pins within the positions and stations (Equation 8.4). As in the '*Comparison of trends over two sequential time series*' section, the variance/covariance matrix is modeled to account for serial correlation at the pin level.

In the example from Figure 8.9, Panel C, there are two time periods (growing and non-growing), so there would be two intercept levels in the linear model, i=1,2 (Equation 8.4). As before, the equation specifies the nested error structure of positions (*k*; four positions 1-4) within sample stations (*j*; three stations 1-3) and pins (*l*; nine pines 1-9) within positions and sample stations.

Equation 8.4:

$$y_{ijkl} = \beta_0 + \beta_1 Period_i + \sigma_i{}^2 + \varepsilon_{j[i]} + \varepsilon_{k[i,j]} + \varepsilon_{l[i,j,k]}$$

$\varepsilon_{j[i]} \sim N\left(0, \sigma_j{}^2\right); i = 1, \ldots n_i; j = 1,2,3$

$\varepsilon_{k[i,j]} \sim N(0, \sigma_k{}^2); i = 1, \ldots n_i; j = 1,2,2; k = 1,2,3,4$

$\varepsilon_{l[i,j,k]} \sim N(0, \sigma_l{}^2); i = 1, \ldots n_i; j = 1,2,3; k = 1,2,3,4; l = 1,2, \ldots ,9$

If the term for the period effect is significant, (multiple) comparisons can be run to compare them. In the example given, since there are only two periods (growing and non-growing), there is no need for an additional test or comparison. If there are more than two periods, however, multiple comparisons should be used. If required, the error term for the tests can be specified as the time effect, $\sigma_i{}^2$. Note that if there are treatment factors of interest, the model becomes more complex, with intercepts for the factors and all necessary interaction effects, including time periods (Equation 8.5).

Equation 8.5:

$$y_{ijk} = \beta_0 + \beta_1 \times Trt1_i + \beta_2 \times Period_j + \beta_3 \times Trt1_i \times Period_j + \sigma_j{}^2 + \varepsilon_{k[i,j]} + \varepsilon_{l[i,j,k]} + \varepsilon_{m[i,j,k,l]}$$

$\varepsilon_{k[i,j]} \sim N(0, \sigma_k{}^2); i = 1, \ldots n_i; j = 1, \ldots n_j; k = 1,2,3$

$\varepsilon_{l[i,j,k]} \sim N(0, \sigma_l{}^2); i = 1, \ldots n_i; j = 1, \ldots n_j; k = 1,2,3; l = 1,2,3,4$

$\varepsilon_{m[i,j,k,l]} \sim N(0, \sigma_m{}^2); i = 1, \ldots n_i; j = 1, \ldots n_j; k = 1,2,3; l = 1,2,3,4; m = 1,2, \ldots ,9$

Step 3: The model is run, and residuals are checked for adherence to model assumptions

Step 4: Model selection procedures are used to test for the effect of serial correlation and spatial autocorrelation. If serial correlation is not significant, it may be removed from the model. The more simple and parsimonious model is selected as warranted.

Step 5: The results of the linear model are interpreted, and any additional comparisons are made, testing for significant differences among fixed effects and their levels.

SOP 8 - Appendix A: R code for analyzing SET data

```
# This code addresses questions 1 and 2 from SET SOP 9
# SET SLOPE SUMMARY AND ANALYSIS CODE
# Created by Philippe Hensel and Penelope Pooler
# Last edited on 9/24/2013

# SET WORKING DIRECTORY
setwd("C:/XXXXX") #Set working directory here

#IMPORT DATA SAVED AS .CSV FILE AND NAME IT 'set.data' IN R FOR USE
IN SUMMARY AND ANALYSIS CODE BELOW
set.data <- read.csv(file.choose()) #This allows you to browse to
the data file you want
# EXAMINE DATA
edit(set.data)

##################################################################
# CALCULATING SLOPE FOR PIN OVER TIME AND SUMMARIZING SLOPES BY
POS. AND BY SET

# CREATE ID TO INDEX DATA BY SITE, TREATMENT, SET, POSITION AND PIN
# THIS ASSUMES YOU HAVE COLUMNS IDENTIFYING PIN DATA BY
# SITE, TREATMENT, SET, POSITION, AND PIN
set.data$ID <- paste(set.data$site, set.data$treamtent,
set.data$set, set.data$pos, set.data$pin, sep="")
# EXAMINE RESULTS
edit(set.data)

# DO SEPARATE REGRESSIONS FOR EACH PIN WITH RESPONSE BEING CHANGE
IN MM FOR THAT PIN AND REGRESSOR BEING DECIMAL YEARS
# NOTE: PIN LENGTHS LISTED AS "value" AND TIME AS "years"
# NOTE: WE DO NOT FORCE REGRESSION THROUGH ORIGIN (WE USE RAW PIN
HEIGHTS)
attach(set.data)
tmp <- by(set.data, ID, function(x) lm(value ~ years, data=x))
detach(set.data)

# SAVE SLOPE COEFF FOR EACH PIN IN A DATASET
coeff <- as.data.frame(sapply(tmp, coef))
#TRANSPOSE COLUMNS INTO ROWS
tcoeff <- t(coeff)
# INSPECT DATASET
edit(tcoeff)
# EXPORT COEFF DATASET
#write.csv(tcoeff, "set.slope_coeffs.csv")
```

```
# SAVE ID FROM COEFF DATASETS AND DROP ENDING CHARACTERS SO THAT
ALL THAT IS LEFT IS SITE, TREATMENT, SET, AND POSITION
id.tmp <- rownames(tcoeff)
id.pos <- substr(id.tmp, 1, nchar(id.tmp)-1)

# CREATE NUMERIC SLOPE VARIABLE FROM COEFF DATASET
slope <- tcoeff[,2]

# CREATE AND EXAMINE SLOPE DATA
slope.data <- data.frame(id.pos,slope)
edit(slope.data)

# SUMMARIZE SLOPE DATA BY SITE, TREATMENT, SET, AND POSITION USING
ID.POS VARIABLE
meanslope.pos <- aggregate(slope~id.pos,data=slope.data,mean)

# EXPORT SUMMARY DATASET
#write.csv(meanslope.pos,"meanslope.pos.csv", row.names=FALSE)

# CREATE AN NEW ID, ID.SET THAT ONLY INDICATES SITE, TREATMENT, AND
SET
id.tmp <- as.character(meanslope.pos[,1])
meanslope.pos$id.set <- substr(id.tmp, 1, nchar(id.tmp)-1)

# SPECIFY MEAN AND STD ERROR FUNCTIONS THAT ELIMINATE MISSING OBS.
meanie <- function(x) (sum(x,na.rm=TRUE)/length(na.omit(x)))
stder <- function(x) sqrt(var(x,na.rm=TRUE)/length(na.omit(x)))

# SUMMARIZE DATA (MEAN AND SE) BY SITE, TREATMENT, AND SET AND
MERGE RESULTS INTO A SINGLE DATASET
meanslope.set <- aggregate(slope~id.set, data=meanslope.pos,
meanie)
se_slope.set <- aggregate(slope~id.set, data=meanslope.pos, stder)
mean.se.set <- merge(meanslope.set, se_slope.set, by="id.set")

# RENAME COLUMN HEADINGS
colnames(mean.se.set) <- c("ID","Mean.set","SE.set")
# VERIFY
edit(mean.se.set)

# OUTPUT SUMMARY DATASET
#write.csv(mean.se.set, "MeanSE.set.csv", row.names=FALSE)
```

SOP 9: Field Safety

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page. For complete instructions, refer to SOP 10: Revising the Protocol or SOPs.

Revision History Log:

New Version #	Previous Version #	Revision Date	Author (full name, title, affiliation)	Location in Document and Description of Change	Reason for Change

Introduction

While it is the goal of the National Park Service (NPS), Northeast Coastal and Barrier Network (NCBN) to ensure a safe working environment for all employees, cooperators, contractors, and volunteers, each individual is responsible for ensuring his or her own safety in the field. Safety concerns should be brought to the attention of either the NCBN Program Manager or the NCBN SET Project Leader as soon as possible. It is likely that staff will conduct monitoring in more than one park during the field season. It is critical that individual NPS park policies regarding safety are respected and followed. Field work is never conducted alone.

This SOP and supporting appendices are designed to provide NPS staff and seasonal employees with an overview of safety issues that should be considered when conducting elevation and accretion monitoring in wetland environments and should serve as a first reference in case of an incident. The safety procedures outlined below for the NPS will apply to other groups as well and should be considered.

Topics covered include emergency procedures and contacts, incident reporting, trip preparation, fieldwork procedures, vehicle safety, and workers compensation procedures. A Green-Amber Red Risk Assessment (GAR) has been conducted for this protocol and is included as an appendix (Appendix B). Additionally, a Job Safety Analysis (JSA), which documents hazards associated with this protocol and recommends approaches to mitigate these hazards, is included as an appendix (Appendix C) to this SOP. The JSA must be read and signed by all staff members who conduct field work for this protocol. This SOP does not cover first aid procedures.

Fieldwork Preparations

When planning to work in a wetland to sample SET and marker horizon plots, you should consider the below safety issues and make your plans accordingly.

Weather considerations

Be aware of the seasonal requirements for visiting and sampling your SET sites. Make sure you have the appropriate field gear for hot and cold weather. Be aware of the current forecast and the potential for severe weather while you are in the field.

Tide considerations

Be aware of the tides for each of the sites you are visiting. File a float plan if accessing SET sites by boat or canoe. Try to sample when the soil surface is not flooded. If travelling to the site via boat or canoe you need to schedule you trips to ensure the water is deep enough for the boat to get to and from the site.

Contact local park personnel

Contact local NPS personnel and make sure they are aware of your sampling schedule and plans. Work closely with the local NPS contacts and ensure they agree with your plans.

Work as a team

To ensure a safe and successful field trip, it is important that field crew members recognize their roles as part of the team, and that all individuals take steps to be informed about potential hazards and park policies. The Project Leader will review the equipment each crew member is expected to use in the field with them at all times (e.g., compass, batteries, cell phone or radio, field guides, water, sunscreen, insect repellant). In addition to equipment used for elevation and accretion monitoring, staff members are responsible for packing any personal items needed for working in a wetland.

Job Safety

An important tool used to promote safe conduct is the Job Safety Analysis (JSA; sometimes called a Job Hazard Analysis or JHA). This approach is consistent with NPS Directors Order 50 and Reference Manual 50B for Occupational Health and Safety. The JSA process is to (1) identify hazards associated with field and laboratory settings, as appropriate, and (2) develop approaches to mitigate those hazards. All monitoring staff for this protocol (including individuals who are observing or only participating for a short time) must read and sign the JSA in Appendix C. In addition, monitoring staff must read the entire Safety during pre-season training.

Safety Equipment needed for the Field

The following is a list of safety materials and personal items that are commonly used when conducting monitoring at SET sample stations:

- Cellular phone (required)
- 2-way radio (if required at a particular NPS park)
- First aid kit (required)
- Mosquito head netting or jacket (if needed)
- Insect repellant
- Boots (e.g., hip boots, waders, wetsuit booties)
- Drinking water and snacks / lunch
- Hat, sunscreen, and sunglasses
- Work gloves and goggles
- HEPA filter mask (if laying feldspar plots)

If a particular park requires the use of a two-way radio, it will be provided. A cellular phone is required regardless of whether or not a 2-way radio is used. First aid kit(s) for use during the field season are provided by the Network. A first aid kit must always be brought into the field. There should also be a first aid kit in the government vehicle. If needed, mosquito head netting and jackets will be provided. Staff members are responsible for providing and packing their own boots, food and drinking water, bug repellant, sunscreen and other personal items needed for each field day.

First Aid Kits and Training

Every project vehicle should have a first aid kit that is to remain with the vehicle at all times. In addition to the vehicle first aid kit, an additional first aid kit should be with the crew at all times while in the field. An inventory of first aid kits should be performed prior to each field season to ensure that all medical supplies are in sufficient quantity and have not expired. Each first aid kit will have an inventory list of the supplies it should contain. Items in first aid kits that are used should be promptly replaced.

Communication

NPS staff are expected to carry a primary and secondary mode of communication at all times while in the field. Unless they are water proof, these items should be stored in a water resistant or water proof container (e.g. Ziploc bag). At some NPS parks, a radio will be provided. An NPS or personal cell phone can be the secondary mode of communication. At other parks, two cell phones should be taken into the field. Be aware of the local conditions for cell phone and radio use and make alternative plans if there is a chance you will not have cell or radio coverage.

Monitoring staff must notify the Project Leader and the appropriate park resource manager with expected dates of field work. The designated park contact will be provided with the location(s) where sampling will be conducted, estimated departure and return time, vehicle or boat used for transportation to the field site, and monitoring staff contact information (e.g., cellular phone numbers). On each field day, staff must know which site they will be monitoring and how they will get there before going into the field. A trip plan must be filed with a supervisor or other designated office staff (DOS) who will not be in the field. If travelling in a boat or canoe, file a float plan. The DOS must be instructed to take failure to check in seriously. If the team fails to check-in on or before the planned check-in time for completion of field work, the DOS will immediately try to reach the team by all available methods. If the crew has not been reached within 30 minutes, the DOS must notify emergency services and initiate a search.

If the trip is cancelled or if the plan changes while in the field, staff must notify the DOS immediately.

All crew members are responsible for being aware of the time and ensuring that end of day check-ins occur on schedule; the DOS will call emergency services if the crew misses their check in and cannot be located within 30 minutes of the check-in time.

Field Procedures

When conducting elevation and accretion sampling in a wetland environment, care should be remain in visual contact with at least one other person at all time. Never work alone. SET monitoring will undoubtedly involve walking on various types of wetlands and shallow streams or tidal creeks. You will be carrying gear, some of which may be heavy.

In addition to wildlife and plant hazards, staff should be prepared to work in uneven or muddy terrain. Many wetlands, such as salt marshes, are generally in the open, without significant sources of shade. Therefore, steps must be taken to prevent heat injuries such as dehydration and heat exhaustion. Stay informed about the weather, and be prepared for sudden changes.

Walking on a wetland

- Be aware of ditches. Ditches can be much deeper than they look or may be partially covered by vegetation.
- If working in a forested wetland (i.e. mangroves), be aware of roots, debris and vegetation on the surface of the forest.
- Look for and test secure footing.
- Take slow and cautious steps when crossing tidal creeks and large pools—the sediment is often unconsolidated.
- Maintain good communication with co-workers.

Sampling gear

Most of the gear for SET sampling will be hand-carried (SET, planks, Liquid Nitrogen). Remember to slow down and rest frequently to avoid hand and arm fatigue. Some items like the liquid nitrogen tank should be carried by 2 people. Any person hand-carrying a heavy item should always try to have one hand free, for balance and so that the item can be shifted between hands.

Collecting accretion and elevation data

<u>Tides</u>

- Be aware of the tidal regime for the site you are sampling and whether the tide is falling or rising.
- Be alert for rising tides that may rapidly flood tidal creeks, ditches, and the wetland surface, isolating individuals from the upland or boat.
- High tides may cover the wetland in water, making it more difficult to walk and see potential hazards (like holes).

Weather concerns

Weather conditions can be hazardous and can change quickly. Monitoring staff are responsible for planning their day according to the local weather forecast and for being aware of their surroundings and changing conditions.

<u>Heat - dehydration, heat exhaustion</u>

- Be alert for early signs of heat-related illness, such as thirst, headache, confusion, crankiness, muscle weakness, or excessive or unusual fatigue. Monitor yourself and others.
- If you do notice signs of heat illness, take immediate steps to remediate the problem, such as drinking more water and resting in the shade for ½ to 1 hour. Apply ice or cool water to the neck or wrist. If symptoms do not lessen, seek medical assistance.

<u>Cold - hypothermia</u>

- Be aware of the risks of hypothermia. Hypothermia can occur in mild temperatures especially if it is windy or if clothing is wet. Dress in layers. Do not wear cotton if possible.
- Be alert for early signs of cold-related illness, such as chills, shivering, stiffening or whitening of extremities, confusion, slurred speech, muscle weakness, or excessive or unusual fatigue. Monitor yourself and others.
- If symptoms of cold illness occur, take immediate steps to remediate the problem, such as putting on more layers, moving to a warm place, drinking a warm beverage, and engaging in increased physical activity. If symptoms do not lessen, seek medical assistance.

<u>Adverse weather</u>

- Be acquainted with local park policies regarding safety during adverse weather (i.e., high wind, rough seas, and thunderstorms). You may be required to return from the field early.

- Re-schedule or shorten field days accordingly if thunderstorms are likely.
- Use a smartphone to get weather updates during the day or stay in contact the DOS to get weather updates.
- Cover is generally limited on non-forested wetlands, and you are usually the tallest point increasing the risk of a lightning strike. You are in danger from lightning if you hear thunder.
- If caught in a lightning storm, call the emergency contact to inform them you will be out of radio / phone contact until the lightning storm passes. Call back in after the storm has passed. If you cannot get inside and if you feel your hair stand on end, lightning is about to strike: Make yourself the smallest target possible and minimize contact with the ground (do not lie flat on the ground). Crouch down on the balls of your feet and keep your feet close together. Get into a dry ditch if possible. Stay away from metallic and electrical gear.

  Place your hands on your knees and lower your head. Members of a party should stay separated by at least ten feet. Information regarding lightning safety is available at http://www.lightningsafety.noaa.gov/

Other Concerns

<u>Allergies / Medical Conditions</u>
All allergies or special conditions must be brought to the attention of the Project Leader and other monitoring staff prior to the beginning of a field trip. Individuals are required to carry any necessary medications (i.e., EpiPens, inhalers) and medical alert tags on their person at all times.

<u>Boat Safety</u>
Any staff member who will be operating a motor boat during the field season is required to complete a week-long Department of the Interior Motorboat Operator Certification Course (DOI MOCC). Completion of the course does not necessarily mean that a field technician will be allowed to independently (without additional NPS supervision) operate an NPS vessel—this is at the discretion of individual parks. Personal Flotation Devices (PFDs) must be worn *at all times* while in a boat. Staff with MOCC training are responsible for making sure the boat has the appropriate type and number of PFDs, as well as any other US Coast Guard required safety equipment (e.g., flares, fire extinguishers, radio). Each park may implement specific boating requirements, and staff are responsible for following individual park protocols.

<u>Plants, insects, and wildlife</u>
Monitoring staff should be acquainted with potential wildlife/plant and marine organism hazards encountered during fieldwork, including ticks, mosquitoes, stinging insects, chiggers, jellyfish, and poison ivy. Staff should be able to identify and be alert to the presence of noxious plants (e.g., poison ivy, poison oak) so contact may be avoided whenever possible. Individuals should be aware of their individual sensitivity to noxious plants, pre-treat with a skin barrier product, and wash thoroughly at the end of the day (washing with liquid dish detergent helps to remove noxious plant oils from the skin). Warning labels on insect repellants should be read thoroughly and only the minimum amount

of repellant needed for protection should be applied. Insect repellant is only applied to clothing and not under clothing.

Guidelines for preventing tick borne illness:

- A good source of information regarding Lyme Disease and other tick borne illnesses is the Center for Disease Control website, available at http://www.cdc.gov/ncidod/dvbid/lyme/index.htm.

- If sampling is conducted in areas where ticks are present, precautions (e.g., light colored clothing, long sleeves and pants) should be taken to minimize exposure to tick bites. Pants should be tucked into socks and taped. Shirts should be tucked into pants.

- Apply insect repellant containing DEET (20-30% concentration) to your clothing for further protection. Permethrin kills ticks on contact. If using Permethrin, do not apply to clothes while they are being worn. Clothing should be treated and allowed to dry prior to wearing. Permethrin should be applied to clothing only—when applied to skin it loses effectiveness within 20 minutes.

- Check field clothes for ticks before entering living space or vehicles.

- Conduct daily self-checks for ticks immediately upon returning from the field. Pay particular attention to armpits, navel, ears, and groin, and use a mirror when doing self-checks.

- If a tick is found, remove it from the skin as soon as possible. Use fine-tipped tweezers to firmly grasp the tick very close to the skin. With a steady motion, pull the tick's body away from the skin. Clean the area with alcohol or soap and water. Avoid crushing the tick's body. Prior to removal, do not attempt to burn or smother the tick as this will increase the chances of it regurgitating fluids and increase the risk of disease transmission. The tick's mouthparts may remain in the skin after the tick is removed. As long as the tick's head and body are removed from the skin, it can no longer transmit disease.

- Document the tick bite; include the date and time of discovery as well as the location of fieldwork over the last two to four days.

- If a tick bite is found, monitor yourself closely for signs and symptoms of tick borne diseases for up to 30 days. Symptoms of tick-borne illnesses typically take several days to weeks to develop. Most people develop a single itchy red welt at the site of a tick bite. This welt can be up to the size of a quarter and may last for several weeks. This welt does not indicate infection with a tick borne illness. More severe rashes and rashes that spread, or cover a large area will require medical evaluation.

- Seek medical attention if symptoms of tick borne illnesses develop within 30 days of removing an attached tick. These symptoms may include a large bull's eye rash around the tick bite, a pronounced spotted rash on extremities, high fever, headaches, or unexplained joint aches. When seeking medical attention, select a doctor who is familiar with tick borne illnesses.

Guidelines for preventing mosquito-borne illnesses—West Nile Virus, encephalitis:

- A good source of information regarding West Nile Virus and encephalitis is the Center for Disease Control website:
- http://www.cdc.gov/ncidod/dvbid/westnile/index.htm and http://www.cdc.gov/ncidod/dvbid/arbor/eeefact.htm
- Stay informed about the presence of West Nile or encephalitis at or near monitoring sites
- To reduce mosquito bite, wear long pants and head-nets, consider wearing long sleeves. Tuck pants into socks and tuck shirts into pants. Reinforce thin areas of clothing (such as pockets) with duct tape.
- Spray clothing with insect repellent as a barrier or use clothing made of repellent-impregnated fabric.

Vehicle Safety

Staff is responsible for inspecting vehicles before every use to ensure the vehicles are in safe working condition. This includes visually checking tire pressure, adjusting mirrors, and making sure equipment is secure. Monitoring staff must perform preventative maintenance in a timely manner (e.g., having oil changed by a qualified mechanic), and report any potential hazards or needed repairs to their supervisor.

Rules that must be followed when operating a vehicle:

- Everyone in a government vehicle is required to wear a seat belt, and when using other vehicles seat belts are mandatory where required by law, and strongly recommended in all situations.
- Texting or any other cell phone use is strictly prohibited while driving a government vehicle and it is strongly recommended that staff avoid use of cell phones while driving any vehicle.
- Only federal employees or authorized volunteers, cooperators and contractors are allowed to operate a government vehicle.
- Passengers who are not federal employees, volunteers, or authorized cooperators and contractors are forbidden from riding in a government vehicle.
- Drivers must adhere to all federal and state vehicle regulations, including all posted speed limits. Drivers are responsible for any tickets.

Because government vehicles are self-insured, damage resulting from government vehicle accidents are generally paid by the driver's program (e.g., NCBN). However, in cases of severe negligence, the driver found at fault for the accident may be personally liable.

If you or other NCBN personnel are involved in a vehicle accident, contact emergency services immediately if a medical emergency is involved. Instructions for reporting a motor vehicle accident are outlined in detail in the NPS Personal Property Management Handbook #44 and relevant sections are included in the vehicle safety binder under the motor vehicle accident reporting section.

Operators of any government motor vehicle involved in an accident shall secure the site from further accident and immediately notify the direct supervisor to alert them of the motor vehicle incident and any relevant danger. If supervisor is unavailable contact the safety officer. It is important to make sure you have verbally contacted one of these individuals.

If an Interior vehicle is involved in an accident:

- Complete the Standard Form (SF)-91 Motor Vehicle Accident Report form and SF-94 Statement of Witness (if possible) located in the vehicle safety binder. These forms are also available as fill-in Portable Document Format (PDF) forms in the NCRN Safety Plan folder.

If a vehicle leased through General Services Administration (GSA) is involved in an accident:

- Contact the Accident Management Center (AMC) at 1-800-325-2958. The AMC has technicians trained in body damage repair, rental cars, towing, and accident reporting policy. The AMC's job is to administer accident reporting procedures, process necessary documentation, bill the responsible party, and answer customer questions.

Emergency Procedures

Life-Threatening Medical Emergency

1. **Call 9-1-1 or the park/refuge emergency number. If available, use an NPS radio to contact dispatch**. Administer first aid to the best of your knowledge, ability, and training. If appropriate, transport to emergency room.

2. As soon as it is practical to do so, inform your supervisor and the park's emergency contact (Appendix A, Table 1). If your supervisor is not an NPS employee, the supervisor must contact the NCBN Program Manager as soon as it is practical to do so.

3. For NPS staff and volunteers, Worker's Compensation paperwork must be done within 48 hours of incident. For contractors and cooperators, follow your organization's procedures for documenting accidents, and notify the NCBN Program Manager with details of the incident. See appendix A for a list of emergency contacts:

Non-Emergency Incidents

1. Contact supervisor immediately after incident. If your supervisor is not an NPS employee, the supervisor must contact the NCBN Program Manager as soon as it is practical to do so.

2. For NPS staff and volunteers, Worker's Compensation paperwork must be done within 48 hours of incident. For contractors and cooperators, follow your organization’s procedures for documenting accidents, and notify the NCBN program manager with details of the incident.

3. Seek medical attention, if needed.
NOTE: Never discard original paperwork related to workers compensation claims (including information from doctor's visits, and CA-1, CA-2, CA-16 or CA-17 forms).

SOP 9 Appendix A: Emergency Contact List – Set Sites at NPS Parks in the Northeast Region.

Table 1. Emergency contacts and procedures for SET parks in the Northeast region.

Site	Contact	Phone	Radio	Notes
ACAD	Dispatch	207-288-8791	Dispatch	When in the park, Dispatch is able to coordinate emergency responses (i.e. Search and Rescue, Ambulance, Police, etc.) faster than by dialing 911. Calling Dispatch by radio is the most reliable means, as cell coverage is poor throughout most of the park.
ASIS	Walt West , Chief Ranger, Incident Commander	410-629-6055	N/A	**Life-threatening emergencies** Dial 911
BOHA	Park Ranger	N/A		Park staff member with radio will be primary contact for emergency response communication. (7 AM to 11:30 PM)
	MA State Police Marine Unit	617-740-7820		If after hours, or if unsuccessful reaching 1 or 2
	Boston Emergency Response	617-343-4911		If after hours, or if unsuccessful reaching 1 – 3
	US Coast Guard Marine Emergency	617-223-3201		Additional Notes: Massachusetts DCR owns all rocky intertidal monitoring islands (781-740-1605 x201 for emergencies). Researchers with non-911 emergency needs can call either DCR (island-owners) headquarters or NPS Stewardship Manager (currently Marc Albert 978-360-0421)
CACO	Boston Dispatch (non life threatening)	617-242-5659		**Life-threatening emergencies** Dial 911
COLO	COLO Dispatch	757-898-2427	N/A	Check in and out with COLO dispatch at each site you visit.
GATE	NJ - Sandy Hook Unit – Call the NPS Rangers Office	732-872-5900/5932		
	NY - Jamaica Bay & Staten Island Unit, Call Park Police Dispatch	718-338-3988		
FIIS	Park Headquarters (non life threatening)	631-687-4750		**Life-threatening emergencies:** Dial 911 first; then over the radio '*Stand By For Emergency Transmission*....' and then state your emergency and location. **Non life-threatening:** Contact Park headquarters

SOP 9 Appendix B: Monitoring SETs: Green-Amber-Red Risk Assessment

(December 12, 2014)

This document describes the application of the GREEN-AMBER-RED (GAR) Risk Assessment Model as outlined in the NPS Operational Leadership Student Manual (Version 2; July 2011) to the NCBN Protocols for The Surface Elevation Table and Marker Horizon Technique.

The GAR model allows for a general assessment of a task or operation and generates communication concerning the risks of an activity. In this case, the activity is the field monitoring of SET sampling stations (accretion and elevation measurements). The most important part of the process is the team discussions leading to an understanding of the risks and how they will be managed.

The GAR is a seven step process. Each step is defined and explained in the context of the NCBN Protocols for Measuring and Understanding Wetland Elevation Change.

Step 1: Define the Mission or Task

The NCBN Protocols for Measuring and Understanding Wetland Elevation Change (also called the SET Monitoring Protocol) detail the theory and procedures used when monitoring elevation change and accretion in wetland ecosystems. This protocol includes instructions for a number of field-based monitoring activities:

1. Measurement of the wetland surface using a custom-built Surface Elevation Table (SET)
2. Collecting soil cores using liquid nitrogen and/or a small knife.
3. GPS surveying

All field work is conducted in all types of wetland environments (freshwater marshes, salt marshes, mangroves) located in both remote and urban settings. Potential safety hazards (along with mitigation measures) have been identified in a Job Safety Analysis (JSA).

Step 2: Define the Threats

A severe slip and fall while traversing uneven terrain or a capsized boat or canoe are possible and are the most significant risks encountered when conducting this activity. Additional threats / hazards for this activity along with mitigation measures are described in the associated JSA.

Step 3: Assess Risk and Assign a Numerical Value

The numerical ranks (Table 1) were assigned by James Lynch and Sara Stevens with input from other NCBN staff.

The activity risk can be visualized using the colors of a traffic light. If the total risk value falls in the GREEN ZONE (1-35), risk is rated as low. If the total risk value falls in the AMBER ZONE (36-60), risk is moderate and you should consider adopting procedures to minimize the risk. If the total value falls in the RED ZONE (61-80), you should implement measures to reduce or avoid the risk prior to starting the event or evolution.

The ability to assign numerical values or “color codes” to hazards using the GAR Model is not the most important part of risk assessment. What is critical to this step are team discussions leading to an understanding of the risks and how they will be managed.

Table 1. The NCBN Protocols for The Surface Elevation Table and Marker Horizon Technique are assigned risk codes of 0 (For No Risk) through 10 (For Maximum Risk) to each of the eight Green-Amber-Red Risk Assessment elements.

Element	Rating
Supervision	2
Planning	3
Communication	2
Contingency Resources	5
Team Selection	3
Team Fitness	4
Environment	5
Event/Evolution Complexity	5
Total Risk Score	29

Step 4: Identify Risk Control Options

Supervision

The NCBN SET Monitoring Project Leader (Jim Lynch) will always be on site overseeing the 1-4 additional staff or volunteers assisting in data collection and recording. The crew will always work as a group and not alone. A score of (2) was assigned due to the fact that the team will always be working with on-site, highly experienced, supervision.

(Risk Mitigation: A clear supervisory chain-of-command; on-site supervision by Project Leader; field training provided to other crew members)

Planning

The NCBN Protocols for Measuring and Understanding Wetland Elevation Change include numerous SOPs that detail the methodology needed for each of the tasks performed in the field during a trip. The NCBN SET Monitoring Project Leader plans all trips in conjunction with local NPS colleagues and trains all crew members in the operation of all sampling gear. Due to this advance planning, written documentation, and training procedures, a low score (3) was assigned.

(Risk Mitigation: Extensive, advanced planning; written documentation of safety procedures, site locations, and Park contacts; field training)

Communication

Field crew members are expected to carry a functioning primary and secondary mode of communication at all times while in the field. The field crew will follow appropriate check-in and check-out procedures with the Park Resource Management staff, rangers and/or park dispatch as directed at each particular park. This will ensure that a responsible party knows if someone has not returned from the field activity in a timely manner. Due to this advance planning, written documentation, and training procedures, and communication plan, a low score (2) was assigned.

(Risk Mitigation: Check-in / check-out procedures; open communication with park RM staff, rangers, or park dispatch; 2 modes of communication are carried at all times while in the field)

Contingency Resources

Contingency resources include communication equipment and procedures that explicitly involve park rangers, park dispatch, and 9-1-1. Crew members always have at least two modes of communication. Notification of emergency services should happen within minutes of an incident, but emergency services may not be able to reach the crew quickly due to the remoteness of many sites. A score of (5) was assigned instead of a lower score because some field sites are quite remote and there could be a delay before emergency services could reach the crew.

(Risk Mitigation: Advance planning, communication plan, check-in / check-out procedures are in place; Safety SOPs and JHA in place to help reduce the risk of an incident)

Team Selection

The SET Monitoring Protocol clearly identifies the essential skills and abilities required to execute this protocol in a competent manner. The SET Monitoring Project Leader will be present at all field sampling trips. Prior experience is not required for additional crew members. All training, if needed, will be provided by the Project Leader. A score of (3) was assigned due to the fact that the Project Leader (highly experienced) will be present during all field trips and that all other crew members will only be selected if they are able to conduct the field work responsibly and safely.

(Risk Mitigation: The Project Leader is highly experienced and selects additional crew members who are physically capable of completed the field work; field training provide to additional crew members based on experience)

Team Fitness

Team selection should ensure an overall high level of initial team fitness. SET monitoring field work can last for approximately 7-8 hours per day (not including drive times). Sampling always occurs during daylight hours. A score of (4) was assigned because the field days are long, and can be strenuous (especially when installing new sites). Monitoring staff must be physically fit, able to carry heavy equipment over uneven terrain, and be diligent about adequate rest and nourishment to ensure that fatigue does not become a factor.

(Risk Mitigation: Field work is conducted by a Project Leader and field crew who are physically fit and prepared to work under difficult field conditions; travel is scheduled with flexibility to ensure adequate rest)

Environment

Environment was assigned a score of (5) because field activities will occur during a variety of weather conditions (cold, heat, wind, rain), and at sites that may be remote and accessible only by boat or canoe. In addition, some sites require extensive walking over uneven, wetland terrain.

(Risk Mitigation: Crew members are physically prepared for working under difficult field conditions, and are aware of how to reduce the risk of cold/heat related illness; Crew members are trained in the use of canoes / kayaks; A canoe / kayak safety SOP is in place; Personal Flotation Devices (PFDs) will be worn whenever the use of canoe / kayak (or other boat) is required to access a site.)

Incident Complexity

Incident complexity was also assigned a higher score (5) mostly because daily field conditions can be highly variable due to weather and ocean conditions that could change unpredictably, and because some sites are remote and only accessible by boat or canoe. The SET Monitoring field crew must use judgment and experience to respond appropriately.

(Risk Mitigation: Crew evaluates weather/water conditions prior to field work and remains aware of changing conditions; field crew members are provided with emergency contact information; JHA in place to help reduce the risk of incident)

Step 5: Evaluate Risk vs. Gain

The NCBN Program Manager has determined that the activity, if carried out in accordance with all SOPs, has an acceptable level of risk.

Step 6: Execute Decision

The decision made by the NCBN Program Manager is to conduct the activity in accordance with the Measuring and Understanding Wetland Elevation Change using the Surface Elevation Table and Marker Horizon Techniques, Standard Operating Procedures (SOPs).

Step 7: Supervise – Watch for Change

The NCBN Program Manager and SET Monitoring Project Leader will continually solicit feedback from staff on safe execution of the protocol including risk control options not considered thus far.

SOP 9 Appendix C: Job Safety Analysis

JOB SAFETY ANALYSIS:	**JOB TITLE:**	☒ **NEW**
NCBN Elevation and Accretion monitoring. Travel to and from sites and within Parks.	SET field Crew Members **DEPARTMENT:** Northeast Coastal & Barrier Network **ANALYSIS BY:** James Lynch, NCBN Biologist and Sara Stevens, NCBN Program Manager	☐ **REVISED** ☐ **REVIEWED**

Required and/or Recommended Personal Protective Equipment:

Required: Cell phone (if only cell phones are used, must have two), radio (required at some parks); first aid kit, driver's license, Personal Flotation Device (PFD) if working from boat, or canoe.

Recommended as appropriate: rain gear, condition-appropriate footwear and clothing, hat, sunscreen, mosquito repellant, mosquito jackets/hats, dry change of clothes, sufficient food and water.

Tasks	**Potential Hazards**	**Recommended Action or Procedure**
Planning and Communication	Not being prepared and following plan/itinerary. Communication breakdowns.	• Plan ahead. Know where you and your crew will be going each day. Be aware of particular hazards associated with travel routes, and sites to be visited that day. • Check the weather and tides each day. If there's a possibility of thunderstorms, be aware of the weather while in the field. Check radar with a smart phone or the Designated Office Staff (DOS). • Understand itinerary of planned trip and follow carefully. Coordinate drop-off and pick-up times (or return times) and locations. • Check in with Designated Office Staff (DOS) prior to field work with a trip plan, and after field work to confirm crew safety. If return will be delayed, contact DOS before agreed-upon check-in time to establish a new check-in time. Always carry two methods of communication with full charges.
Emergency Preparedness	Not knowing emergency procedures. Not having emergency supplies.	• Know who to contact and how to reach them in the event of a life-threatening or non-life-threatening emergency. • Have current CPR and first aid certification (not required). • Keep a well-maintained first aid kit in each vehicle and with the field team. • Know the location of safety equipment

Tasks	Potential Hazards	Recommended Action or Procedure
Teamwork	Lack of awareness of other team members leading to delayed incident response	• Work together as a group. There should be no reason to split up. • Field work is never conducted alone. • If crew splits up into multiple pairs, the pairs should periodically check in with each other.
General foot travel in a wetland	Falling or tripping due to holes and/or wet areas, poor footing, uneven terrain, deep mud, tidal ditches Carrying gear, carts, etc.	• Use caution at all times. Walk carefully, watching footing. • Wear knee boots, hip boots or chest waders as necessary for the particular work and time of year. • Wear appropriate socks and stay aware of the condition of your feet. Address blisters and hot spots promptly. • Avoid carrying excessive weight loads or unbalanced loads. • Use extreme caution if you have to cross non-vegetated areas of the wetland (shallow pools/pannes) as the mud could be very deep. • Use extreme caution when traversing the wetland, and be aware of holes or unconsolidated areas in which you would sink. Avoid them if possible. Use a plank if available to assist your travels. • Try to avoid stepping in mosquito ditches. Some can be very DEEP. Use a plank to cross wide ditches if possible.
Wading across marsh pools and creeks.	Falling, deep mud, deep water	• Make sure you are with someone with local knowledge of the creeks and waterways. Do not cross waterways by foot without some knowledge of the depth and conditions in the creek/waterway. • Wear appropriate footwear (usually waders); pools and creeks can be ankle- to chest-deep. • Use a plank to cross narrow pools or creeks if possible.

Tasks	Potential Hazards	Recommended Action or Procedure
Working outdoors during storms	Being struck by falling trees or branches; being struck by lightning	• Listen to the weather forecast each morning (park radio and/or internet) and throughout the day if you suspect severe weather could occur or see threatening clouds. • Contact the DOS during the day to get weather updates. • Plan or adjust field work to avoid being out in thunderstorms. • Postpone work if safety will be compromised by storm conditions. If you see or hear a thunderstorm coming, retreat from high ground and exposed areas. Go inside a sturdy building or vehicle, if possible. • If you can't get inside and if you feel your hair stand on end, lightning is about to strike. • Make yourself the smallest target possible and minimize contact with the ground. • Crouch down on your pack on the balls of your feet and keep your feet close together. Place your hands on your knees and lower your head. • During a thunderstorm, members of the crew should stay separated by at least ten feet.
Use of power tools and/orgenerator when installing SETs	Loud noise and vibrations from equipment used to install SETs. Shock from electrical power tools (if applicable)	• Wear gloves, eye protection and ear plugs to protect your hands, eyes and ears. • If using an electric generator, make sure it stays dry. Always have a person watching the generator.
Establishing feldspar plots	Inhalation of feldspar dust. Feldspar is a finely powdered silica used in pottery and is commonly used as a marker horizon at SET sampling stations.	• Exposure to feldspar powder should be minimized. Use a HEPA filter mask when establishing new feldspar plots. Thoroughly wash your hands and face when finished working with it.
Working on planks when taking SET measurements	Falling off of a plank, Plank breaking	• Try to sit on the plank. Try to avoid squatting on the plank since that can be bad for your knees and raises your center of gravity. • Try to use aluminum planks which are lighter and not prone to sudden breakage like wooden planks.
Taking accretion soil cores with liquid nitrogen.	Liquid Nitrogen is very cold (-196º C,-321º F) and can cause burns if exposed to bare skin	• Always wear gloves and eye protection. • Keep exposure to the liquid at a minimum. Do not freeze cores for too long . Stop coring at the first signs of liquid escaping the coring apparatus (white cloud of gas). • Let any liquid burn off before trying to handle the frozen core (cloud will dissipate quickly). • Keep your gloves dry so they don't freeze to the cores. Have extra pairs available.

Tasks	**Potential Hazards**	**Recommended Action or Procedure**
Taking soil cores or scraping frozen accretion cores with a knife.	Working with a sharp edge can cut you	• Wear gloves when working with frozen cores • Always push away from you with the blade
Poisonous plants, especially poison ivy	Contamination/toxicity from contact with poisonous plants	• Learn to identify poison ivy in its many growth forms. • Wear long sleeves and pants. • Be aware of poison ivy and avoid coming in direct contact with it. • Thoroughly wash hands, equipment, and clothes with Tecnu or similar specialized soap if you come into contact with poison ivy.
Bee, wasp, or yellow-jacket stings	Multiple stings from disturbing or stepping into nest areas	• Bees, wasps, or yellow-jackets may be encountered while hiking to monitoring sites. • Be alert to hives in brush, ground holes, or hollow logs. Watch for insects traveling in and out of one location. • If you or anyone you are working with is known to have allergic reactions to be stings, tell the rest of the crew and your supervisor. Make sure you carry emergency medication with you at all times and that your co-workers know where you keep it. • Wear long sleeve shirts and trousers, tuck in shirt. Bright colors and metal objects may attract bees or wasps. • Avoid perfumes which may attract bees • If you are stung, a cold compress may bring relief. • If stinger is left behind, scrape it off of skin. Do not use tweezer as this squeezes the venom sack, worsening the injury. • If the victim develops hives, asthmatic breathing, tissue swelling or a drop in blood pressure, seek medical help immediately.
Bites from mosquitoes, flies, and other insects	Itchy reactions to multiple bites	• Wear long sleeves and pants. • Avoid sitting on the ground or on logs, especially in dry, sunny, grassy areas. • Use insect repellants. Do not apply Permethrin, Permanone, or greater than 30% DEET directly to skin, only to clothing. • Carry after-bite medication to reduce skin irritation.

Tasks	Potential Hazards	Recommended Action or Procedure
Ticks	Contracting diseases transmitted from ticks	• Use tick avoidance precautions, including pre-treating clothing with permethrin, tucking pants into socks and shirt into pants when hiking to and from sites. • Wear clothes (including pants and long-sleeved shirts) that are light colored and check for ticks on clothing after traveling through vegetation. • Conduct a thorough tick check every evening after completing field work. • Know how to identify tick life forms, and the signs & symptoms of tick-borne diseases.
Working in wetland Vegetation	Tall plants, plants with sharp points and standing dead plants can be an eye or laceration hazard.	• Be careful when working in or walking through *Juncus*, *Spartina cynosuroides* and *Phragmites* marshes. Wear eye protection when working around *Juncus*. • Wear pants and long-sleeved shirts to protect bare skin.
Walking through thick vegetation	Cut, scratched, or bruised by vegetation; eye or ear injuries	• Shield your eyes and face with your hands, glasses, or hat when moving through tall thick brush. Keep your head and eyes pointed somewhat downward so your head hits obstacles before your eyes. • Wear pants and long-sleeved shirts to protect bare skin. • Look before you grab vegetation to avoid grasping thorny stems. • Do not follow closely behind other people to avoid having branches snap back and hit you.
Working in heat, humidity, or cold	Heat exhaustion, sunburn, dehydration, hypothermia	• Evaluate the weather forecast each morning and plan field work accordingly. • Carry and drink plenty of water. Always bring more water than you think will need. • Take extra breaks during extreme weather events. Adjust the work routine to minimize exposure to extreme heat and humidity. • Take adequate garments for all possible weather conditions. Choose clothing that will keep you warm even if it gets wet. • If possible, have a cooler of ice in hot weather.
Hazard trees	Being struck by falling trees or branches	• Look up. Be alert for widow-makers, storm damaged trees with large broken limbs, and unstable standing dead trees. • Do not spend extended time in an area with hazard trees.

Tasks	**Potential Hazards**	**Recommended Action or Procedure**
Carrying a pack and other equipment	Injuries from improper packing, adjustment, and lifting of backpacks. Injuries from improper carrying of gear	• Learn how to properly pack, adjust, lift, and carry a pack. • When hand-carrying gear, keep one hand free. • If carrying long equipment, be aware of other people and never swing around quickly. Avoid allowing a long piece of equipment to project up and behind you, where you cannot see it.
Riding in landing craft or other small boat	Injuries from tripping while getting on and off boat; injuries from crossing waves/wakes; exposure to wind, sun, and rain	• Obey all instructions from the boat captain. • Personal Flotation Devices (PFDs) are required. • If unsure of footing, have someone help you on or off of boat. • Pass gear between people on boat and land rather than carrying the gear onto the boat. • When the boat is in motion, stay flexible and try to move with the boat motion; avoid bracing yourself rigidly. • Bring a jacket, even on warm days, since it is cooler on the water. • Check the weather and be prepared with hat, sunscreen, and rain gear.
Travelling with liquid nitrogen tanks	Nitrogen gas in a confined space can be a suffocation hazard. Nitrogen gas is VERY cold and can burn your skin if you come in contact with it.	• Never travel in the same cab as the liquid nitrogen tanks. For example, do not put full tanks in the cabin of your vehicle. • Keep LN_2 tanks secured to the floor of the vehicle to keep them from coming free in case of an accident. • The tanks used for sampling accretion plots only hold 15 liters of LN_2. If there is a leak in the tank which you can't control, try to move the tank to an open area and allow the tank to empty. You can open the "liquid" valve to speed up emptying a tank. • When finished with the LN_2 on a field trip, empty the tanks prior to putting them into the vehicle. • If transporting tanks in a boat, secure them with a strap or rope to keep them from falling over

Tasks	Potential Hazards	Recommended Action or Procedure
Using a canoe to transport gear and personnel	Injuries and loss of equipment from capsizing, injuries from tripping while getting on and off boat, injuries from improper rowing technique; exposure to wind, sun, and rain	• Personal Flotation Devices (PFDs) are required. • Get in and out of the canoe/kayak boat carefully, keeping center of gravity low. • When someone is entering or exiting the canoe/kayak, at least one other person should be helping to stabilize it. • The person with experience canoeing should be in the back and responsible for steering. • Do not overload canoes and kayaks and never stand up while canoe/kayak is in motion. • Consider wearing gloves while rowing to protect from blisters. • If you are inexperienced with rowing, take turns with other crew or let a more experienced crew member row. • Bring a jacket, even on warm days, since it is cooler on the water. • Check the weather and be prepared with hat, sunscreen, and rain gear.

Tasks	**Potential Hazards**	**Recommended Action or Procedure**
General operation of a vehicle	Injuries from vehicle accident; Damage to vehicle	• Perform pre-operational check of vehicle (oil, tire pressure, tire condition, fluids, wipers, brakes, lights, gas, etc.). Report all needed repairs to the crew leader or supervisor promptly. • Do not use the vehicle if it is unsafe. • Wear seat belts with shoulder harnesses whenever vehicle is in motion. • Review mirrors • Allow adequate time and anticipate heavy traffic delays. • Do not use cell phones or text while driving. • Only NPS employees, volunteers or authorized cooperators and contractors are allowed to <u>operate or ride in</u> a government vehicle. • Ensure full visibility from all windows and mirrors. Clean windshield regularly. • Always ride inside the vehicle. • Properly store and secure all tools, equipment, and cargo so that they will not shift during sudden starts or stops. • Plan your travel before you start. Know your route. • Practice defensive driving; be alert to potential hazards. • Obey all traffic laws and speed limits. • Adjust speed to changing weather or traffic conditions • Allow adequate following/stopping distance. • Avoid distractions such as eating while driving. • Be alert for pedestrians or bicyclists using roadways. • Be watchful for wildlife crossing roads, especially at early morning, dusk, and after dark. • Do NOT drive if fatigued. Stay alert!

SOP 10: Revising the Protocol or SOPs

Version 1.00 (January 2015)

The following table lists all changes that have been made to this Standard Operating Procedure (SOP) since the original publication date. Any recommended or required changes added to the log must be complete and concise and promptly brought to the attention of the Project Leader. The Project Leader will review and incorporate all changes, officially complete the revision history log, and change the date and version number on the title page.

Revision History Log:

New Version #	**Previous Version #**	**Revision Date**	**Author (full name, title, affiliation)**	**Location in Document and Description of Change**	**Reason for Change**

Introduction

The following Master Version Table (Table 10.1) tracks the relationships between the Protocol Narrative and the associated Standard Operating Procedures, as discussed in Instructions for Recording Revisions in this SOP.

Table 10.1. Master Version Table.

Date of Revision	Protocol	Narrative	SOP #1	SOP #2	SOP #3	SOP #4	SOP #5	SOP #6	SOP #7	SOP #8	SOP #9	SOP #10

Scope and Applicability

Due to the long-term nature of the NCBN monitoring program, periodic revisions to the Protocol Narrative and to individual SOPs will be necessary (O'Ney, 2005). Careful documentation of changes to the Protocol Narrative and its related SOPs, along with a library of previous versions, are essential for maintaining consistency in the collection, summary, analysis, and reporting of data.

The Revision History Logs found at the beginning of the Protocol Narrative and each SOP document contain any edits and/or changes to the section. Information entered in the logs should be concise and complete. The logs track the previous version date and number, date of revision and new version number, author(s) of revision, location of changes within the document, description of change, and the reason the change was made. Author information must include full name, title, and affiliation.

Instructions for Recording Revisions

Protocol users must promptly notify the Project Leader about recommended and/or required changes. The Project Leader will then review and incorporate all approved changes, update the Revision History Log and Master Version Table, and change the date and version number on the title page of the master document as well as any SOPs to which the revisions apply.

Minor revisions

Minor revisions are those that *do not* represent a change in the underlying methods or procedures used to generate data values for the protocol's existing data set. Minor revisions include small changes in, or clarification of procedures. Version numbers for minor revisions increase incrementally by hundredths (1.01, 1.02, 1.02, etc.).

Major revisions

Major revisions are those that involve changes in methodology that could influence the resulting data values and the ability to compare newly-collected data with data collected using a previous version. The Project Leader should consult with NCBN Salt Marsh Technical Group for input on major revisions. Major revisions are designated with the next whole number in the sequence (2.0, 3.0, 4.0, etc.) and include items such as:

- Addition of monitoring objectives
- Changes to the sampling design
- Changes to reporting requirements
- Addition of new monitoring parameters

Coordinating narrative and SOP versions

In order to track the most current version number of all SOPs in this protocol, the Project Leader maintains a Master Version Table (Table 10.1). A new entry must be made each time the Protocol Narrative and/or SOP(s) are modified. In cases where the Protocol Narrative and/or one or more SOP have undergone only minor revisions (Instructions for Recording Revisions, above), the protocol version number will itself increase incrementally by hundredths. In cases where the Protocol

Narrative and/or one or more SOP have undergone a major revision (whether or not other sections have undergone minor revisions), the protocol version number will increase incrementally by whole numbers (Figure 10.1).

The Project Leader updates all associated field data forms to reflect the change in protocol version. Users noting discrepancies in versions between the protocol, SOPs, data values, and field data forms should notify the Project Leader so that corrections can be made and documentation kept current.

Master Version Table: Salt Marsh Vegetation Monitoring Program and Standard Operating Procedures												
Date of Revision	Protocol	Narrative	SOP #1	SOP #2	SOP #3	SOP #4	SOP #5	SOP #6	SOP #7	SOP #8	SOP #9	SOP #10
1/1/2007	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
6/1/2007	1.01	1.01	1.01	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.01	1.01
8/2/2007	2.00	1.01	1.01	1.00	1.00	2.00	1.01	1.00	1.00	1.00	1.01	1.01
1/10/2008	3.00	2.00	1.01	1.00	1.01	2.01	1.02	1.00	1.00	1.01	1.02	1.01

Figure 10.1. Example of a Master Version Table reflecting possible revision scenarios and associated numbering of the protocol.

Reviewing Suggested Protocol Revisions

All suggested edits require review by the Project Leader for clarity and technical soundness. Small changes or additions to existing methods are reviewed by NCBN staff; however, if a significant change in methods is recommended, additional expert review may be required.

Communicating Changes to Investigators / Users

Once changes have been made, the updated document is posted on the NCBN web site (http://www.nature.nps.gov/im/units/ncbn/) and is added to the National Vital Signs Monitoring Protocol Database (http://science.nature.nps.gov/im/monitor/protocoldb.cfm). All previous versions are archived in the NCBN information system and can be obtained by contacting the Data Manager. Each time an SOP is revised, the Project Leader ensures that all known users obtain a current copy of the SOP and receive the necessary briefing material and/or training to understand and incorporate the change(s). Users are encouraged to visit the network web site and/or contact the Project Leader at least once per season to check for updates associated with the monitoring protocol.

Reference Documents

O’Ney, S. E. 2005. Standard operating procedure #11: Revising the protocol, Version 1.0. In: O’Ney, S. E. 2005. Regulatory water quality monitoring protocol. Version 1.0. Bozeman (MT): National Park Service, Greater Yellowstone Network

NPS 962/130486, November 2015

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