

## **SWMP Phase III: Land Use, Land Cover, and Habitat Change**

*“Whoever thinks they can achieve their goals without partnerships is setting their bar too low.”*

Jeff Bishop, Director  
International Port of Coos Bay

**October 1, 2008**

## ABSTRACT

National Estuarine Research Reserve's (NERRs) intensively monitor environmental parameters in a coordinated and consistent manner and therefore are valuable sites for developing an in-depth understanding of the status of, and trends in, the extent and quality of coastal habitat at local, regional and national scales. Coordination, consistency, flexibility, and partnerships are key components of the NERR Phase III Land Use and Habitat Change (LUHC Plan) as well. The combination of remote sensing, in-situ monitoring and the integration of standards and protocols used by other NOAA and non-NOAA partners enhances the opportunity for partnerships to support NERR mapping, monitoring and related research. By building on SWMP I and II, implementation of SWMP Phase III will enable the NERRS to relate environmental observations of water quality, nutrients, and estuarine habitats to land use and climate change impacts.

The goal of the LUHC Plan is to track and evaluate short-term variability and long-term changes in the extent and type of habitats within NERRs and how these changes are impacted from land uses within adjacent watersheds and changes in local sea level. This LUHC Plan will address this goal with the following objectives: 1) to map land cover and land use in reserves and their watersheds; 2) to model elevation and tidal datums in reserves and elevation in adjacent watersheds; and 3) to enhance capacity within the NERRS to map, model and disseminate information on estuarine habitat trends and associated linkages with anthropogenic and climatic stressors. Implementation of Phase III will provide an important context to the abiotic and biological trends observed in Phases I and II of SWMP. With the exception of producing base maps that conform to the standards and protocols established by this Plan, participation in the LUHC plan will be voluntary. Those reserves that choose to develop habitat mapping and change plan will be in a position to receive priority support from ERD and other NOAA partners. These plans provide the context for budget initiatives and partner investments that are based on comprehensive planning within the reserve.

This final LUHC Plan responds to numerous comments submitted by the NERRS. In response to these comments, key changes from the draft include: 1) a modified timeline from 4 years for high resolution mapping to 10 years with a base year identified within two years of 2010; 2) flexibility in the application of micro-topographic elevation monitoring to include both bio-monitoring transects and other important habitats; 3) clarifying the objectives to focus on strategies for acquiring and disseminating habitat and land use data and deferring to the reserve plans for identifying strategies to influence coastal management with this information; and 4) identification of elements in the plan that are mandatory and those that are voluntary. Appendix A identifies the comments received on the first draft of the LUHC Plan and associated responses.

The key strategies reflected in this HMC Plan are:

- Using the NERR classification scheme, each reserve will acquire, process, and classify remotely sensed high resolution imagery of reserve habitats and conduct a change detection analysis on a 10-year time frame using a year between 2008-2012

as the base year. Change analysis of land use and land cover (LULC) in reserve watersheds will be consistent with C-CAP's five-year acquisition cycle; Submission of these maps with FGDC compliant metadata will be **mandatory** for all reserves to ensure that we have a baseline set of maps reflecting reserve habitats within a relatively consistent time frame for the entire system.

- Participating reserves will establish tidal datums with the assistance of NOAA's Center for Operational Oceanic Products and Services (CO-OPS) – This element is **voluntary**;
- Participating reserves will establish vertical control infrastructure with support from the National Geodetic Survey. The infrastructure will provide data that will: 1) support elevation modeling in key habitats to support research, monitoring and stewardship applications; and 2) tie all reserve datums to the same local reference system with mm level accuracy and to the National Spatial Reference System at cm level accuracy. **This is voluntary.**
- The CDMO Web site will maintain map products derived from medium and high resolution imagery, and tidal and vertical control datums. This is **mandatory.**
- Participating reserves will develop a reserve LUHC Plan that identifies: 1) reserve-specific climate change and other local priorities; 2) mapping strategies, timelines, and image and infrastructure requirements; and 3) hardware, software, staff time, and analytical gaps and associated resource needs to achieve successful LUHC Plan implementation. Funding strategies will be based on the needs expressed from these site-based plans. This is **voluntary.**
- ERD will pursue MOU's with NOAA's National Geodetic Survey (NGS) and CO-OPS to secure support for LUHC Plan implementation for participating reserves (i.e., those reserves that develop LUHC plans detailing their image acquisition, tidal datum and vertical control requirements).

Key NOAA partners will include:

- NOAA's National Geodetic Survey - geodetic control and training support;
- NOAA's Center for Operational Oceanographic Products and Services – support in determining tidal datums within reserves and associated training;
- NOAA's Coastal Services Center – watershed maps classified to C-CAP, watershed digital elevation models, capacity building, geospatial tools;
- Central Data Management Office – Data management and dissemination support;
- Cooperative Institute for Coastal and Estuarine Environmental Technology – support in data synthesis and analysis on five-year time frames and development of innovative technology to acquire high resolution imagery inexpensively.

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# Introduction

## 1. Overview

Phase III of the System-wide Monitoring Plan Land Use and Habitat Change (LUHC) focuses on tracking and evaluating changes over time in coastal and estuarine habitats and understanding how those changes relate to anthropogenic influences from the watershed and environmental stressors related to climate change. This approach goes beyond what Nieder et al. (2002) originally envisioned for Phase III by including sea level change as well as anthropogenic stressors on estuarine habitats. Phase III of SWMP will focus on land use and habitat change in reserves and their watersheds, acquiring elevation data at watershed and reserve-appropriate scales, and monitoring micro-topographic elevation changes along already-established SWMP bio-monitoring transects and other areas of interest within the reserve. Implementing this mapping strategy will provide an important context for understanding abiotic and biological trends observed in estuarine habitats to changes in adjacent watersheds, local sea level, and climate.

Since the NERRS intensively monitors the environment in a coordinated and consistent manner, individual reserves are valuable sites for developing an in-depth understanding of the status and trends observed within estuarine habitats, and the anthropogenic and climate stresses operating on estuarine habitats. Remote sensing, in-situ monitoring and the integration of standards and protocols used by other NOAA, federal and state partners enhances the opportunity for partnerships to support NERR mapping, monitoring and related research.

This LUHC Plan promotes the use of consistent status and trend assessment methods at all reserves. When correlated to trends identified through Phases I and II, SWMP Phase III data can be used to identify land use practices and non-anthropogenic stressors that most influence the health and resilience of estuarine habitats. This Plan provides an implementation strategy for SWMP Phase III that will improve the NERRS capacity for monitoring habitat changes, and individual reserves' ability to understand these changes and provide decision-support to those managing, protecting and conserving coastal resources.

### *1.1 The Plan's Priorities*

At a minimum, this LUHC Plan presents a long-term strategy to develop a standardized inventory of land use and land cover at a base year and changes over time in reserves and adjacent targeted and larger watersheds of influence. Full implementation of the LUHC strategy will also monitor trends in local sea level relative to elevation changes based on data from individual reserves derived from vertical control and local tidal datums. Participation in this latter component of monitoring the impacts of climate change in the form of sea level change as it relates to trends in local land elevation is voluntary. The strategies presented in this Plan offer flexibility to respond to the unique local context at each reserve, while enabling each reserve to be connected to a NERRS network of sentinel sites for monitoring the ecological impacts of climate change. Thus, the Plan promotes a

system-wide national priority focusing on climate change while addressing unique site-based priorities.

The Plan outlines a number of actions to guide reserves in generating and distributing land use and land cover change information efficiently and comprehensively. For example, the Plan recommends increasing the NERRS' capacity for spatial analysis and modeling so that data collected can be analyzed to generate relevant information. Generating elevation data for watersheds and reserves provides the context to apply land use and habitat data to issues related to non-point source pollution at the watershed scale, and habitat restoration and migration at the reserve scale. Establishing vertical control at reserves provides the infrastructure for reserves to establish and monitor elevation changes over time at a resolution relevant to sea level change impacts on estuarine environments. A multi-dimensional approach is recommended, which involves:

- Developing a NERRS land-use and land-cover classification system, associated protocols, and documentation;
- Acquiring, processing, and disseminating remotely sensed imagery;
- Monitoring and modeling elevation in NERRs and their adjacent watersheds to support applications such as runoff modeling and conservation and land use planning; and
- Strengthening GIS and Remote Sensing Capacity within the NERRS.
- Developing the organizational relationships within NOAA to support Plan implementation
- Developing the information to communicate LUHC budget requirements effectively within RFP's, state agencies, and within NOAA's budget process.

A number of these actions are in various stages of development and are detailed in subsequent sections. A summary of responsibilities at the reserves and within NOAA are detailed in Appendix B.

This Plan will be implemented consistently at all reserves to achieve system-wide goals, while allowing the flexibility necessary to address site-specific needs. Consistency will be achieved through standardized classification protocols and accuracy targets, while flexibility will be maintained through data acquisition and processing methods, establishment of a base year and subsequent years for mapping, and determination of priority areas for high resolution mapping and vertical control.

While various elements of the Plan will be implemented opportunistically based on the expressed needs of individual reserves, the NERRS will strategically target reserves that have sufficient existing capacity such that small investments will bring these reserves into 100 percent compliance with the objectives of this Plan. These reserves will be nearly, if not fully representative, of a NERR sentinel site for monitoring climate change.

## 1.2 Guiding Principles

The following principles will shape the implementation strategies within this plan:

- **Consistency** - Reserves will adhere to standardized protocols regarding classification, data accuracy, spatial and temporal scales, and the establishment of geodetic controls;
- **Flexibility** – Reserves will develop strategies to collect and classify high resolution LULC data , determine mapping needs, and identify areas of particular interest for mapping change based on site-based priorities;
- **Partnerships** - Phase III will rely on cooperative efforts among state and federal entities; and
- **Integration** - Successful implementation of this Plan requires staff coordination at reserves to identify multi-sector mapping priorities and associated infrastructure needs.
- **Quality Assurance and Control** – all data developed as a result of this plan and posted on a NERR web site will meet QA/QC standards and have attached FGDC compliant metadata.

## 1.3 Audience

There are four targeted audiences for this Plan:

- **The NERR System.** By implementing this LUHC Plan system-wide, the NERRS will play a significant role addressing local, regional and national coastal land use and land change and climate issues. This will enhance the NERRS attractiveness as a partner. This Plan complements Phases I and II of SWMP and supports the NERRS Strategic Plan, the NERRS Research Plan, and the efforts of various workgroups, and education, stewardship, research, and coastal training sectors.
- **Estuarine Research Reserves.** Each reserve is encouraged to develop local strategies for implementing this Plan to guide funding and partnership strategies. Reserve staff will receive necessary training in acquiring and interpreting remotely-sensed high resolution imagery either by contracting with firms providing these services, or through state or federal training partnerships.
- **NOAA.** The Plan informs NOAA of the NERRS infrastructure, priorities, capabilities and opportunities related to mapping land use/land cover, habitat change, and local sea level change and identifies critical internal partners including:
  1. **National Geodetic Survey (NGS)** – Establishes geodetic controls and benchmarks at NERRS, ties geodetic control to the National Spatial Reference System, and provides training in mapping and monitoring elevations and establishing vertical control;
  2. **Center for Oceanographic Operational Products and Services (CO-OPS)** – Establishes local tidal datums and provides associated training in their use;

**3. Coastal Services Center (CSC)** – Provides digital elevation models for all reserve watersheds and on a five-year cycle Coastal Change Analysis program (C-CAP) classification of land use/land cover and change detection at watershed scale, canopy cover and impervious surface; supports automated classification procedures for high resolution imagery; and training in the use of remote sensing, GIS, and other geospatial tools;

**4. Central Data Management Office (CDMO)** – Collects, maintains, and distributes all SWMP data; and

**5. Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET) – or CICEET successor** - Researches and develops technologies to enhance the NERR's capability to, among other things, map intertidal and benthic habitats and model effects of environmental and anthropogenic factors on land cover.

- **Non-NOAA Partners.** The LUHC Plan will inform federal, state, and local partners of opportunities to work with the NERRS to document and analyze habitat changes in reserves and their watersheds. The Plan is relevant to the ACOE, USGS and the Seamless Network Partnership (National Park Service, Fish and Wildlife Service, National Marine Sanctuary and NERRS) to promote coordination in coastal monitoring within protected areas.

## 2. Accomplishments to Date

A number of actions have been completed prior to, and during, the development of the LUHC Plan:

**NERR Classification System and Implementation Protocols** - The NERRS has developed a land use/land cover classification scheme and mapping protocols for reserves and their watersheds (Kutcher, 2005), implementation protocols (Walker and Garfield, 2006), and classification scheme documentation (Kutcher, 2008). These documents can be found on the NERRS Intranet (see Habitat Mapping and Elevation Folder) and the NERRS revised web site (forthcoming). Approximately half of the reserves have used the scheme to test its efficacy, highlight system-wide issues needing further consideration, and otherwise fine-tune the classification system.

**Habitat Mapping and Change Analysis for all NERRS** - All reserve and watershed boundaries are available on the CDMO web site as shape files and image files. Watershed boundaries were determined by a flow analysis most closely corresponding to 8 or 6 digit USGS HUCs (Hydrologic Unit Codes). HUCs are watersheds scaled such that the higher the HUC code, the smaller the watershed. More targeted watersheds that directly impact reserves are identified by reserve staff and have been uploaded (forthcoming) to the CDMO web site as well. FGDC compliant metadata for all reserve and watershed boundaries are being developed and uploaded to the CDMO web site.

The CSC has provided the NERRS with a habitat change analysis within most reserve watersheds using a standardized map projection to enable system-wide analysis (the change

analysis for the watersheds of Kachemak Bay and Jobos Bay are forthcoming). The CSC used C-CAP classification at 30 m resolution Landsat TM imagery from 1997, 2001 and, where processing is complete, from 2006, to develop habitat maps for each year, and analyze changes in land use and land cover, percent impervious surface cover and percent canopy cover. Because of the resolution of the imagery, this analysis, while including reserves, is most appropriate to describe land use and land cover at a watershed scale.

**Demonstration of High Resolution Mapping using C-CAP Automated Classification Procedures** - A demonstration project highlighted the use of automated classification of high resolution imagery into the NERRS classification scheme. This project successfully applied automated classification of high resolution imagery to generate a map classified to the NERR classification scheme. This high resolution moderate accuracy product is an alternative for areas of large reserves where applying high resolution mapping protocols and standards would be prohibitive. Conclusions from the project indicate that automated classification is most effective with a variety of imagery including LIDAR so that classification of intertidal habitat imaged at high tide can be discerned.

**GIS/RS Capacity Assessment within the NERRS** - The Habitat Mapping and Change Technical Committee (HMCTC) surveyed the NERRS to assess its ability to analyze habitat change, and to determine how those abilities have changed since 2002. The assessment revealed an overwhelming interest in using GIS, spatial analysis and remote sensing to map habitat and analyze change, and a corresponding need for training in their use.

## Section II

# Acquiring, Processing, Classifying, and Distributing Land Cover Data

### 1. Context

In their 2002 conceptual plan, Neider et al. (2002) established a strategy to implement a system-wide Land Use/Land Cover (LULC) change analysis protocol. That document identified conceptual and technical objectives for tracking land use and land cover changes. It also proposed a stepped approach to developing and implementing a protocol that would satisfy Phase III of SWMP and meet additional geospatial needs of the NERRS. The concept involved boosting the capacity of the NERRS to generate land use/land cover data that might be used to address the following questions:

1. What is the magnitude and extent of habitat change in estuarine systems and their watersheds?

- *What are the current and projected trends in land use and land cover within reserves and their watersheds?*
- *What are the expected impacts of various land use and land cover changes on estuarine systems?*

2. What are the linkages between land use change in adjacent watersheds, local sea level change [added by the HMCTC since 2002], and habitat change in reserves?

- *What impacts do adjacent land uses have on water quality and nutrient inputs within NERRS?*
- *What are the temporal and spatial extent of impacts on living and non-living resources from land use changes?*
- *What are the direct effects of changes in local sea level on estuarine habitats?*
- *What are the direct effects of storms on estuarine habitats?*

The stepped approach was outlined as follows:

- Create technical and oversight advisory boards
- Conduct needs assessments to identify gaps in the ability of reserves to implement a LUHC initiative
- Develop data acquisition strategies
- Develop inventory (mapping) protocols and methods
- Build system capacity

Using this approach, the NERRS created a Habitat Mapping and Change (HMC) committee and appointed a Habitat Mapping and Change Technical Committee (the HMCTC). In 2004, the HMCTC began developing strategies for identifying and acquiring the appropriate imagery, interpreting and classifying data, and processing, formatting, and distributing the results. The technical tools and methods supporting those objectives are summarized in this section.

As part of the technical planning process, the NERRS established a partnership with the Coastal Services Center (CSC) for technical support and consultation. The NERRS has, in turn, acted as a field-based sounding board and testing ground for CSC development. The value of this partnership is evident in all segments of progress reported here.

## **2. Needs Assessment**

In 2002 the advisory group conducted a needs assessment to determine what kinds of products would be most helpful in analyzing changes in land use and land cover. The assessment identified specific objectives for habitat and land use/land cover mapping strategies. These objectives became a basis for all further technical planning. The needs assessment also directly guided ongoing technical planning efforts, including the development of a classification protocol, the development of a habitat classification system, and recommendations for implementation as discussed in detail below.

An updated needs assessment to determine, system-wide capacity, infrastructure, and priority applications of geospatial data was conducted in 2007 and informs the development of this Plan.

## **3. Two-level Approach**

Kutcher et al. (2005) recommended the implementation of a two-level approach to facilitate objectives identified by Neider et al. (2002), which require the characterization of land cover and land use both within reserve boundaries and in the watersheds that drain into them (refer to bulleted text in section 1). The approach utilizes existing resources within NOAA and the USFWS, using (1) C-CAP moderate-resolution (MR) automatically classified data to characterize reserve watersheds, and (2) recently developed classification and collection protocols (compatible with national wetland mapping standards—Heber 2007) to characterize land cover and habitat types on reserve properties at higher resolution (HR). This approach has the advantage of using the consistent, efficient, and readily available C-CAP protocols to track changes in land cover (also used as an indicator of land use), percent impervious surface, and crown canopy within reserve watersheds at no cost and minimal effort to the NERRS while utilizing the NERRS Classification to provide a standardized format to track habitat change within reserve boundaries.

The recommendation for a two-level approach was approved for implementation by the reserve system in 2007 (SWMP Revision, 2007). Progress and further recommendations for implementation concerning each of the two levels (Watershed-level—MR and reserve-level—HR) are discussed in the following sections of this chapter. Table 2.1 clarifies the two-level approach.

Table 2.1. Elements of the NERRS two-level approach recommended in this Plan.

<b>Element</b>	<b>Watershed Level</b>	<b>Reserve Level</b>
Scope	Entire watershed basin draining into estuary of concern defined by flow analysis	Reserve properties or <i>area of perpetual interest</i> .
Source Data	LandSat Thematic Mapper® multispectral satellite imagery	<ul style="list-style-type: none"> <li>- Aerial photography</li> <li>- Quickbird® hyperspectral imagery</li> <li>- DOQ digital photography</li> <li>- Other sources that provide the necessary imagery to meet NERR classification standards and protocols.</li> </ul>
Scale/Resolution	30-m pixel resolution (~1:100,000)	<ul style="list-style-type: none"> <li>- 1-m pixel resolution for 1:12,000 or less;</li> <li>- 3 m pixel resolution for 1:24,000 scale imagery (Reserves should defer to using higher resolution imagery if available)</li> </ul>
Data Processing Strategy	C-CAP semi-automated protocol conducted by NOAA CSC and delivered to reserves in final format	<p>Flexible protocols include:</p> <ul style="list-style-type: none"> <li>- Photo-interpretation for area of perpetual interest</li> <li>- Supervised automated classification for areas within reserves requiring high resolution imagery but lesser mapping accuracy than areas of perpetual interest.</li> <li>- More flexible approaches to meet standards as technology evolves</li> <li>- Ground-truthing will be necessary for all methods</li> </ul>
Output Data	<ul style="list-style-type: none"> <li>- C-CAP coded LULC dataset</li> <li>- Impervious surface dataset</li> <li>- Percent canopy cover dataset</li> <li>- C-CAP change detection</li> </ul>	NERRS Scheme-coded land use/land cover dataset with columnar attribute format

Table 2.1 continued. Elements of the NERRS two-level approach recommended in this Plan.

<b>Element</b>	<b>Watershed Level</b>	<b>Reserve Level</b>
Target Mapping Unit	0.09 ha (0.22 ac, 1 pixel)	0.10 ha (0.25 ac)
Data Type	Raster	Vector, polygon
Classification Scheme	C-CAP ordered list	NERRS hierarchical 4-level
Collection Interval	5-year	10-year
Secondary Data Products	<ul style="list-style-type: none"> <li>- Change analyses</li> <li>- Predictive models</li> <li>- Derived mapping products</li> </ul>	<ul style="list-style-type: none"> <li>- Change analyses</li> <li>- Predictive models</li> <li>- Derived mapping products</li> </ul>
Intended Applications	<ul style="list-style-type: none"> <li>- Watershed characterization (baseline)</li> <li>- Land use/Land Cover-water quality analysis</li> <li>- Watershed planning</li> <li>- Conservation planning</li> <li>- Population- land use analysis</li> <li>- Water body impairment</li> <li>- Large-scale ecological analysis</li> <li>- Predictive modeling</li> <li>- Map production</li> <li>- Outreach and education</li> <li>- Communication</li> <li>- Reports</li> <li>- Articles</li> <li>- Policy</li> </ul>	<ul style="list-style-type: none"> <li>- Reserve characterization (baseline)</li> <li>- Land use/land cover-water quality analysis</li> <li>- Inundation modeling</li> <li>- Predictive modeling</li> <li>- Restoration planning</li> <li>- Invasive species management</li> <li>- Landscape management</li> <li>- Facilitation of research</li> <li>- Ecological analysis</li> <li>- Education planning</li> <li>- Facilities planning</li> <li>- Map production</li> <li>- Runoff-infiltration modeling</li> <li>- Outreach and education</li> <li>- Communication</li> <li>- Reports</li> <li>- Articles</li> <li>- Policy</li> <li>- Conservation planning</li> </ul>

## **4. Data Acquisition and Processing Strategies**

### *4.1 Watershed-level (MR) Data*

CSC has provided MR classified geospatial data of each reserve's watershed to the Central Data Management Office (CDMO). The data characterize landscape cover, impervious cover, canopy cover, and change within each reserve's watershed and/or identified basin of interest. Data were acquired and processed through a repeatable semi-automated protocol developed by Dobson et al. (1995) and implemented on a rotating five-year collection cycle since 1996. The protocol uses Landsat TM 30-m resolution, multi-spectral satellite imagery which is run through a series of spectral analyses and field verifications. The protocol is developed to achieve 85% overall mapping accuracy.

CSC has clipped historical and recent C-CAP data to watershed boundaries defined by a flow analysis approximating the 8 or 6 digit HUC boundary for each reserve's watershed. This data and metadata have been uploaded to the CDMO Web site for dissemination. These data are delivered in a single standardized projection, which enables site as well as system-wide analysis. (Instructions for converting the standardized projection to reserve-specific projections are provided on the CDMO web site as well). These products are delivered in a pre-processed C-CAP format and no further processing or quality assurance is required.

Reserves are also submitting boundaries of more targeted watersheds with attached FGDC compliant metadata. These targeted watersheds will be available through the CDMO web site and will be useful for applications that require analysis of land use/land cover and elevation data at a more localized scale

### *4.2 Reserve-level (HR) Data*

Individual reserves are responsible for the acquisition and processing of HR land cover data. Various methods for acquiring and processing these data are outlined in Neider et al. (2002) and Walker et al. (2006). Both documents recommend system-wide flexibility in data collection and processing to facilitate the varied partnership, funding, and scale needs of the reserves. Compatibility of data among the various reserves will be achieved principally through the use of a standard classification protocol, which includes a commonly applied scheme (NERRS Classification Scheme) and dataset format, and through the standardization of scale and accuracy.

While conventional digitization, photo-interpretation, and heads-up delineation of high-resolution true-color aerial photography plus field-checking presently remains the most accurate way available to classify land cover data, concerns have been raised that this method may be too labor-intensive and expensive to be practical. However, in a 2007 initial implementation of HR mapping in the NERRS, at least 15 participants utilized these conventional mapping methods, likely due to the straight-forward approach and time-tested accuracy they provide.

In 2007, CSC, working with ESNERR, used modified C-CAP protocols to classify high-resolution land cover according to the NERRS Classification Scheme. Protocols involved the automated classification (using Ecognition software) of Quickbird hyperspectral satellite imagery to produce a dataset with >75% mapping accuracy. HRNERR also piloted an automated classification protocol on its properties in 2005 and achieved similar accuracy. It is notable here that the accuracy achieved classifying HR data through automated methods is relatively low when compared with conventional mapping, and the technical skill and software requirements are high. For example, CSC and ESNERR have recommended the use of LIDAR, which is expensive to acquire and requires advanced skills to process, in enhancing automated accuracies (Van Dyke, personal communication, 2007).

The Reserve System must take into consideration the fact that technology to produce accurate HR land cover products is in fairly early stages of development, and the trade-off between data accuracy/utility and potential lower effort costs (plus advancing the cause of HR classification technological development) must be weighed carefully. Many changes in natural communities are relatively slow to occur, and may be reflected in the single digits. To ensure that changes are a reflection of actual landscape changes and do not just reflect data errors, producer errors must be low.

The FGDC Wetland Subcommittee has recently released a draft Wetland Mapping Standard (Heber, 2007), which outlines wetland mapping protocols intended to apply to any federally-funded inventory of geospatial wetland data. This standard is of significance to the Reserve System, since certain mapping efforts will need to comply with these protocols. FGDC protocols require vector data output derived from 1:12,000 scale (or less desirable 1:24000) source data at 1m resolution (1:63,360 at 5m for Alaska), 68% positional accuracy within 5m on the ground, and 98% producer's accuracy. Source data can be aerial photography or satellite imagery. This will apply to the NERRS mapping standards as well.

It is most notable here that 98% producer's accuracy is currently only attainable through manual photo-interpretation and field checking. The HMCTC therefore recommend's the use of conventional photo-interpretation when possible. This will be most labor intensive for each reserve's first base-map; however, in subsequent inventories, interpreters can lay the baseline (original) vector layer over the new source data and manually modify polygons and attributes to reflect actual changes in the landscape in a systematic manner. Across a ten-year cycle, stable-habitat polygons will remain unchanged and dynamic habitats or those under anthropogenic or climate-related stress will require classification or boundary changes. This method would cut production costs over entirely re-mapping and ensure that changes in the dataset are actual changes in land cover and not producer or technical inconsistencies.

If reserves have higher resolution imagery available than the minimum specified by the FGDC and NERR protocols, they should use this higher resolution imagery to classify to the NERR classification scheme. The resolution of imagery that is acquired should support the climate change and local priorities identified in the site-based LUHC Plans. Careful

consideration of local target audiences when identifying requirements for images and elevation infrastructure will ensure that follow-up dissemination of these products to target audiences will be effective in influencing coastal management.

## 5. Development of Inventory Protocols

### 5.1 Watershed-level (MR) Data

Further processing of watershed-level (MR) data is not necessary to produce useful products, as data will be delivered fully-processed by CSC. CSC will provide predictive modeling tools and training to individual reserves interested in applying these tools for a variety of purposes, such as analyzing impacts of land change on non-point source loadings. It will be the responsibility of each reserve to identify the appropriate applications, intent and models for their uses. The HMCTC will work with reserves and the CSC as reserves identify training needs associated with the various applications of these data. CSC has provided the following watershed-scale products:

- C-CAP classified LULC dataset(s) from 1996, 2001 and 2006, as available
- Impervious cover dataset(s) from 1996, 2001 and 2006, as available
- Canopy cover dataset(s)
- All available change per time datasets
- Predictive modeling tools, including NSPECT and Habitat Priority Planner (CSC)
- Training opportunities for Reserve System personnel

The CSC will provide products on five-year intervals and training and technical support as needed.

### 5.2 Reserve-level (HR) Data

Kutcher et al. (2008) and Walker and Garfield (2006) recommended a classification scheme and inventory protocols for the characterization of reserve system watersheds and habitats to support objectives identified by Neider et al (2002) and later by the HMC Committee. These documents further the LUHC effort by specifically detailing inventory methods and a data entry format that allows system-wide standardization of HR land cover data, while allowing flexibility for reserves to function within local and regional restrictions.

Independent of HR data processing methods applied by each reserve, the following will need to be described in site-based LUHC plans:

- **Each Reserve will identify a focus area for HR habitat inventory**  
Every reserve will identify at the minimum, the intertidal and supra-tidal areas and an additional buffer of 100m within its boundaries that will be the focus of the reserve's HR mapping efforts. Smaller reserves may be able to identify all intertidal and supratidal habitats whereas larger reserves may choose to select representative habitats

to monitor over the long term. Two options exist for characterizing the remaining uplands. First, a reserve can choose to characterize its remaining properties using clipped C-CAP MR data. Second, if resources and opportunity permit, the reserve may apply semi-automated classification methods to high resolution imagery for mapping habitats not identified as being of perpetual interest for change. This will take advantage of the high resolution imagery available for classification, but will not require the mapping accuracy required for mapping areas of perpetual interest.

Sub-tidal reserve properties should also be mapped to the highest level of detail possible, even if just a placeholder at the subsystem level (e.g. denoting *estuarine subtidal haline*) for purposes of baseline quantification. Phase III work, when fully implemented, will enhance protocols for subtidal mapping efforts.

- **HR Data inventories will be produced on a ten-year cycle**

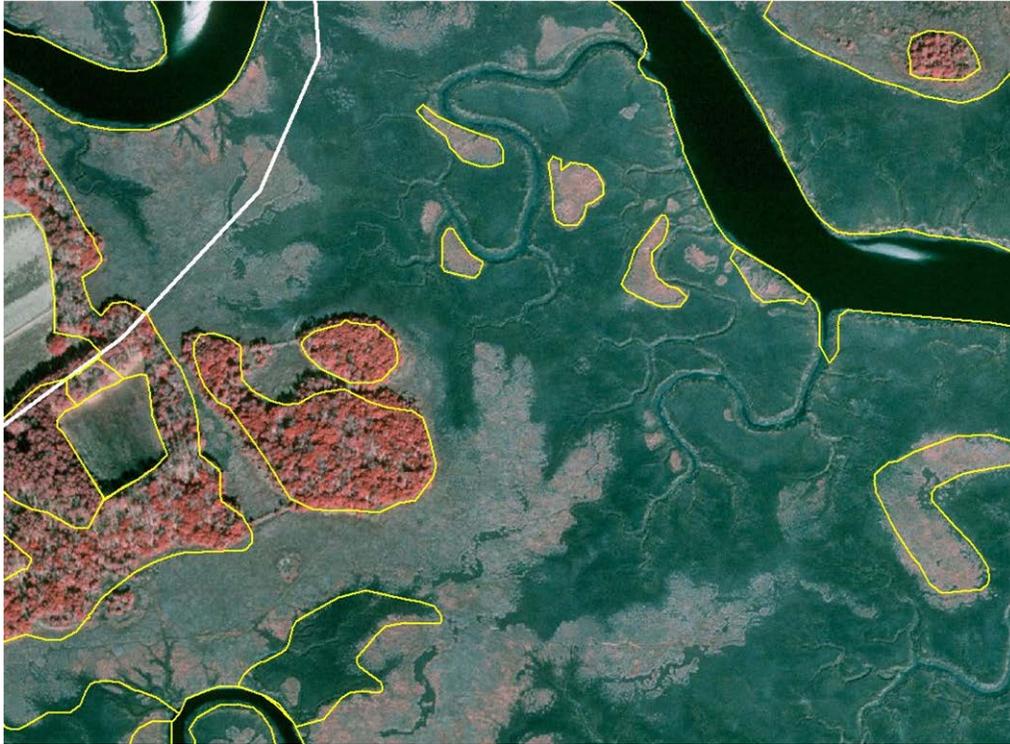
Each reserve will produce a HR land cover inventory of its targeted properties once every ten years with the base year established within a two year period of 2010 (2008-2012). Establishing the base year and the year in which high resolution mapping will re-occur, will result in a staggered mapping schedule that will provide a more realistic planning horizon for funding purposes.

- **All data will be submitted in GIS vector polygon shapefile format**

GIS provides the capability to inventory and analyze geospatial data in spreadsheet format while maintaining a topological connection to numeric and descriptive data. This is important to the resource manager for quantifying and otherwise analyzing geospatial data. Since the implementation of PAGIS funding, nearly every reserve is capable of producing GIS data from land cover inventories. Vector data is the most useful data format to characterize land cover, since land cover is generally defined by the composition of its components and not by any single homogeneous metric. Vectorization of data requires the producer to classify the components into ecologically significant units. This organizes the land cover in a useful and quantifiable ecological context rather than in a pixel-by-pixel context, as raster formats generally produce.

GIS technology allows the automated conversion of raster data to vector format, which can eliminate pixel scatter by the forcing of a minimum mapping unit (discussed below). Polygon vector data format allows two-dimensional quantification of land cover by area, and the overlay and analysis of these data against other polygon, point, line, and raster data. Vector format also allows the creation of a spreadsheet-style attribute data inventory design based on the area of individual polygons, each row representing a habitat unit (polygon) and each column providing attribute information describing that unit. This columnar format is the backbone of the HR land cover inventory, allowing seamless and logical data detail expansion, the use of hierarchical classifications of the mapped world, and data interoperability within the Reserve System and with other data producers and users. Walker et al. (2005) outlines the data table format to be used in HR data inventory (Fig. 2.1).

**Figure 2.1: Example Land Cover Features for Classification within a Reserve Boundary and Associated Relational Database (from Walker et al. 2005).** This figure depicts the relationship between the spatial features in the map and the tabular record attributes associated with these features. The combination of these two elements comprises the relational database structure that is inherent to any GIS.



	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Sys_Nam	Sys_Num	SubSys_Nam	SubSys_Num	Cls_Nam	Cls_Num	SubCls_Nam	SubCls_Num	Dsc_Nam	Dsc_Num	Mod1	Mod2	Acres	Hectares
2	Estuarine Habitats	2000	Intertidal Haline	2200	Emergent Wetland	2260	Persistent	2261	Irregularly Flooded				0.00021	0.0000
3	Estuarine Habitats	2000	Subtidal Haline	2100	Unconsol. Bottom	2120	Mud	2124	Saturated				0.00003	0.0000
4	Estuarine Habitats	2000	Intertidal Haline	2200	Unconsolidated Shore	2250	Organic	2255	Irregularly Exposed				0.11885	0.0481
5	Estuarine Habitats	2000	Supratidal Haline	2300	Forested Wetland	2360	Mixed	2365					0.63522	0.2570
6	Estuarine Habitats	2000	Supratidal Haline	2300	Forested Wetland	2360	BLD	2351					0.00116	0.0004
7	Estuarine Habitats	2000	Intertidal Haline	2200	Unconsolidated Shore	2250	Mud	2254	Regularly Flooded				0.23723	0.0960
8	Palustrine Habitats	5000	Intermit/Saturated	5200	Scrub-Shrub Wetland	5240	BLD	5241	Seasonal-Tidal				0.53576	0.2168
9	Estuarine Habitats	2000	Intertidal Haline	2200	Unconsolidated Shore	2250	Mud	2254	Regularly Flooded				0.27362	0.1107
10	Estuarine Habitats	2000	Intertidal Haline	2200	Emergent Wetland	2260	Persistent	2261	Irregularly Flooded				0.00728	0.0029
11	Upland Habitats	6000	Inland Upland	6200	Forested Upland	6250	BLD	6251					0.59047	0.2389
12	Upland Habitats	6000	Inland Upland	6200	Forested Upland	6250	Mixed	6255					0.34618	0.1400

Finally, although recent versions of GIS software have developed newer data formats such as the geodatabase, shapefile format is compatible with both newer and older software packages and can be converted to newer format, if needed, by the user. For the near future, shapefile format should be used.

- **Targeted Minimum Mapping Unit must equal 0.1ha (0.25ac)**

A minimum mapping unit (MMU) is the smallest unit characterized in a geospatial dataset. This ensures that the investigator will classify areas by the habitat or land cover type, each characterized by the sum of its components, rather than by the components themselves (e.g. a tree within a residential area is not a forest, but is a component of residential land cover). The targeted minimum mapping unit (TMU) differs from a strict minimum mapping unit in that it offers the user the flexibility to map ecologically important features falling below the MMU when the data will not otherwise confound the concept of classifying the data by cover type (e.g. as an exception to the general mapping protocol, inter-dune swales less than 0.1 ha might be mapped within a sand dune barren if they are thought to be ecologically significant). The application of a TMU is critical in ensuring data compatibility in resolution across reserves, for direct data comparisons. HR data mapped at a higher spatial resolution than 0.1 ha TMU may be aggregated to 0.1 ha TMU before submission to CDMO using automated tools generally available with newer GIS software.

- **Classification will be to the Subclass Level or Lower**

Every reserve should try to map to the finest level of detail possible. However, all reserves will be expected to map to the subclass level, which represents leaf-type for vegetated areas, substrate composition for non-vegetated areas, and development intensity for developed areas. If resources do not permit this, subclasses should be filled into the data for all that are evident, and class (structure) filled in for subclass as outlined in Walker et al. (2006). Because many mapping projects identify habitat types by the dominant vegetation species, including *dominant species* data is also highly recommended, as is the identification of the *Descriptor* type which identifies the cover by a common name.

- **Accuracy assessment will accompany each HR dataset**

The introduction of various types of error is unavoidable during land cover classification and change detection, whether manual or automated.

A standard tool for characterizing and quantifying interpretation errors is the *accuracy assessment matrix*, a table that ranks the number of test samples assigned to each land cover class against their "correct" assignments as verified through some type of ground truth (Congalton and Green 1999). Descriptive statistics provided by the matrix include *overall accuracy*, *producer's accuracy* (errors of omission – due to missing data), and *user's accuracy* (errors of commission – due to misclassification). A sample size sufficiently large to assess the accuracy of a representative set of habitat classes will be required. A combination of simple (across the entire image) and stratified (selected land cover classes) random sampling strategies provides a compromise between statistical power and practical limitations. Similarly, a combination of on-the-ground sampling (located by differential GPS) and sampling from reference imagery (e.g.

contemporary ortho photography) constitutes a workable compromise between rigor and field sampling and access limitations.

Registration error, resulting from misalignment or distortion in the imagery, generates false differences during change detection. Therefore an estimate of the source imagery's spatial accuracy should also be included in the accuracy assessment. Commercial vendors of orthorectified satellite and aerial imagery typically provide such an assessment. If the spatial accuracy of the source imagery is unknown (e.g. locally georeferenced aerial photography), a sampling procedure that compares points visible on the imagery with their "true" reference positions should be performed. Spatial accuracy assessment, from a combination of on-the-ground sampling and, if available, higher-accuracy reference imagery should employ reporting techniques similar to those described above for assessing mapping accuracy.

- Federal Geographic Data Committee (FGDC) compliant metadata will accompany all datasets

## **6. Integration with SWMP Phase II**

A great deal of concern has been raised in addressing the obvious overlaps in methods, products, and uses of Phase III HR mapping and Phase II mapping of emergent and submerged vegetation. Phase II calls for the high-resolution mapping of submerged and emergent estuarine vegetation communities in two-year cycles. Methods proposed include aerial photo-interpretation or automated classification of HR source data. Recognizing both the lack of stable state or federal funding for mapping purposes, and the limited change that is noticeable within a 2-4 year time frame, Phase III recommends a ten-year mapping cycle for high resolution imagery of key habitats including those intertidal habitats that are the focus of Phase II habitat monitoring. The mapping timeline will be identified by each reserve beginning with a base year between 2008-2012. In this way, the mapping cycle for reserves will be staggered providing for flexibility at the site level and a mapping budget at the federal level that can be projected into the future and be more feasible for budget planning purposes.

## **7. Leaf-off versus Leaf-on in Relation to Phase II and III Integration**

In conventional mapping efforts (e.g. NWI), the landscape is characterized using leaf-off source data, which allows the interpreter to easily distinguish between upland and wetland woody areas. However, the mapping of emergent and submerged estuarine communities is often most appropriately mapped in the height or at the end of the growing season (leaf-on). Automated classification generally uses leaf-on imagery as well. In all circumstances, the interpretation of both leaf-on and leaf-off imagery is ideal when possible. In some instances, it may be reasonable for a reserve to first delineate all non-tidal wetland basins with leaf-off imagery, and, given the fact that these basins generally change over geological rather than ecological time, thereafter use leaf-on imagery for mapping.

## **8. Data Management and Dissemination**

CDMO will be handling the storage and dissemination of the data (see below). Each reserve will be responsible for submitting completed shapefile representations of their HR habitat data that has complied with all the standards identified above to CDMO by the end of the grant period in which the mapping effort was funded. A LUHC technical oversight committee will review all geospatial data to ensure compliance with this Plan before forwarding the files to CDMO. CDMO will store organize and disseminate geospatial data produced by this LUHC Plan. A long-term strategy for data management is outlined as follows:

The following will be provided to CDMO:

- CSC will provide C-CAP 30-m resolution (raster format) land cover data and change analysis clipped to the contributing watershed every five years;
- Each reserve will submit polygon HR data of reserve habitats and change analysis classified to the NERRS classification system every ten years (approx.) beginning with the identified base year between 2008-2010;
- CSC and reserves will submit Federal Geographic Data Committee (FGDC) and Open Geospatial Consortium (OGC) compliant metadata for all datasets available with ESRI software (ARC Toolbox has metadata wizard) or the like, and documentation of the standards and protocols identified in this Plan including accuracy assessments;
- NGS and CO-OPS will provide updated google earth files of geodetic and tidal benchmarks within a 3-mile radius of each reserve on a yearly basis.

CDMO will provide the following support:

- Storage and dissemination for all land cover/land use and change analysis data in GIS and google earth formats and associated metadata in national standard projections;
- Staff to organize data and metadata, provide final QA/QC, populate the website, manage and archive all data.

## **9. GIS Application for End Users**

The GIS specialist will work with the CTP, Education and Stewardship sectors to develop the process of creating a dissemination protocol to target these data to specific audiences for education and training purposes.

## **10. Conclusion**

This plan strives for implementing a system-wide mapping initiative that will support national climate change priorities including establishing the reserve system as a network of sentinel sites for monitoring the ecological impacts from climate change. While attempting to implement a system-wide initiative, the Plan also maximizes flexibility for sites to plan their base-year and subsequent mapping cycles within a 4-year window from 2008-2012 which will also lead to a staggered and more realistic budget planning effort at the national level to support funding for this Plan.

## **Section III**

### **NERRS Elevation Products**

#### **1. Overview**

The overarching questions addressed by this Plan are; 1) to what extent are land uses and habitats changing in the watersheds and reserves; and 2) what are the linkages between land use, climate change, and habitat change? Models that can help identify these linkages rely, among other things, on elevation at the watershed and habitat scales. It is therefore the goal of this Plan to map elevation of reserve watersheds using USGS Digital Elevation Models (DEM's) and to map and monitor elevation change at the reserve level. Sea level change is expressed locally and requires local infrastructure to establish a common elevation framework from which to tie all abiotic and biotic monitoring. Thus establishing vertical control at all reserves, although voluntary, is a priority of this plan, and successful implementation at all participating reserves will be targeted for 2012, consistent with the time horizon for establishing baseline land use and habitat maps of all reserves.

With vertical control at participating reserves, all components of the SWMP will integrate into a common reference system resulting in a comprehensive suite of data to inform questions related to habitat change in relation to anthropogenic and climate-related impacts at multiple scales. This chapter will focus on strategies to establish vertical control at reserves to: 1) provide the infrastructure to tie all reserve data to a common site-specific reference; 2) develop elevation profiles along bio-monitoring transects, within monitoring quadrats, and at other areas of interest within reserves; 3) develop Digital Elevation Models (DEMs) of targeted regions within the reserve; and 4) monitor micro-topographic changes over time.

This section describes the nature of land and water elevations and the need for accuracy in these measurements within the coastal zone. Background information is given on how elevations and water levels are expressed, and how they can be used for effective management of coastal resources. The text in this chapter is a condensed version of a more detailed description of establishing elevations in the NERRS which is available in the LUHC Folder on the Home Page of the NERRS Intranet.

The specific objectives of the elevation component of the LUHC Plan are to:

- 1) Disseminate existing 30 m horizontal resolution elevation data of the Reserve watersheds in a useful format through CDMO.
- 2) Establish vertical control reference systems at every site to support local high (mm) accuracy elevation mapping and connection to the National Spatial Reference System. This includes integration of geodetic and water level datum reference systems in accordance with NGS and CO-OPS recommended protocols.
- 3) Establish Surface Elevation Table (SET) infrastructure to monitor micro-topographic elevation changes over time in key habitats and to serve as geodetic benchmarks.

These objectives support existing NOAA NERR, NGS and CO-OPS priorities.

## **2. Background**

### *2.1 Elevations*

Elevations are a critical structural component of coastal systems, as they determine everything from frequency and duration of inundation to sedimentation and erosion, the distribution of characteristic plant and animal communities, and the degree to which shorelines are exposed or protected from storm surges. Coastal elevations are a dynamic feature of the coastline, changing with response to watershed-scale processes (e.g. flooding, runoff, sedimentation) regional processes (e.g. crustal motion), and local phenomena (e.g. subsidence, erosion, and hydrological connectivity). Elevation and trajectories of elevation change over time can support decisions concerning navigation, coastal hazards, resource management, and coastal resiliency.

The importance of coastal elevation resides in its relationship to local sea level and subsidence and accretion processes. Local phenomena such as deep (crustal) or shallow subsidence may yield rates of local sea level rise that are quite different from the global average (eustatic) rate. Documented examples of this include the southeastern Mississippi Delta, where local subsidence, a result of several processes, leads to a local sea level rise of over  $10 \text{ mm yr}^{-1}$ . Another example would be the southern coast of Alaska, where post-glacial rebound is leading to local sea level drop.

Measurements of elevation require different scales of precision as one goes from the coastal fringe to the top of the watershed. The relationship between coastal fringe elevation, elevation change, and sea level rise is generally measured at the millimeter scale (or millimeters per year). Millimeter-level changes are very important for low-lying areas, since even slight changes in average relative sea level can mean the difference between a thriving wetland community and a drowning marsh leading to wetland loss. As one proceeds upslope and away from tidal influence, however, the need for precision in elevation data is somewhat less, as coastal communities would be affected less by chronic sea level conditions, but rather episodic events such as coastal storms. At the watershed level, elevations and how they change over the gradient from the drainage basin to the alluvial plain are important as they relate to patterns of runoff, percolation, and groundwater recharge. In this case the precision requirements for elevation are even less. Therefore the scale and precision at which elevation measurements are taken can vary across the spatial gradient from the coastal fringe to the top of the watershed.

### *2.2 Datums*

Elevation is the vertical component of geodesy, which attempts to define the size and shape of the earth. Elevation is based on datums, which are theoretical, modeled, or realized reference positions or surfaces on the earth. Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system. Vertical datums measure elevations or depths. Many different kinds of datums have

existed, and modern datums include those based on an ellipsoidal model of the earth, obtained from satellite data. Vertical datums in the coastal zone of the United States include tidal datums such as mean sea level, mean high water, and mean low water (See Appendix C for tidal datums), and geodetic datums tied to the National Spatial Reference System (NSRS), such as the North American Vertical Datum of 1988 (NAVD88).

Relationships between local tidal datums and geodetic datums are not constant across different regions, or in many cases within a region. The changes in that relationship are affected by tidal characteristics of the system (most importantly tidal range), as well as the slope of the coastline. It is important to consider these regional variations before relationships are extrapolated into areas of different physical or hydrodynamic characteristics.

### 2.3 *Sea Level Trends*

Many coastal regions are experiencing an apparent increase in sea level rise due to local land subsidence. Subsidence is a natural product of coastal sedimentation, as terrigenous sediments are deposited in deltas and along shorelines (Berman 2005). Over time, these recent deposits compact, eventually forming sedimentary rock. It is this compaction that leads to a loss in elevation. As sedimentation continues, the elevation lost through compaction may be replaced by new deposition. However, if sediments are deposited inland (such as behind dams), coastal sedimentation is curtailed. Subsidence can also be exacerbated by anthropogenic fluid withdrawal, such as occurs with oil drilling and tapping aquifers for human water supply (Berman 2005). Regardless of the cause of local subsidence it has the net result of increasing the rate of relative sea level rise. Examples of regions experiencing high rates of subsidence are southern Louisiana and Houston/Galveston Bay.

Some coastal regions are experiencing increases in elevation due to anthropogenic pressures from the watershed such as urban and agricultural development practices in areas characterized by steep slopes, highly erosive soils, and episodic high energy rain events. When wetlands receive the impact from rapid impulses of sediment, the impacts are exacerbated by changes in the tidal prism and the decreased inability of the tides to flush the system of sediments. This makes the balancing act between sea level rise and elevation change more precarious and requires that reserves have good information on both trends in local sea level and elevation to address resource management issues.

### 2.4 *Topographic / Bathymetric Digital Elevation Models (DEMs)*

DEMs are three-dimensional representations of a bare-earth surface which are useful for understanding the distribution of ground/surface elevation (and depth) over an area of interest.

DEMs are generally based on remotely sensed data, and involve very data-dense arrays, the density of which is related to the spatial coverage and vertical accuracy. Sub-centimeter accuracy would require a much denser spatial array than a sub-meter scale accuracy. There

is also an implied scale in the extent of data collection: at the finest vertical resolution, a reserve-wide DEM would be prohibitively expensive and unwieldy. A hierarchy of DEM scales and coverage could therefore be envisaged. At the finest scales, DEMs specific to certain key sites and habitats of interest could be most useful. High accuracy DEMs collected with permanent vegetation monitoring and SET bench marks could provide important covariates as well as corroborating evidence for habitat change over long periods of time. At the Reserve scale, a DEM based on LIDAR data would be feasible. The 14-cm accuracy would be sufficient to delineate broad elevation zones. DEMs at this scale could not be used to provide elevation covariates to a planned study, or to monitor elevation changes over time, but would provide information on how water flows through the reserve. A LIDAR-based DEM could be a useful transition from the watershed-scale 30 m DEM provided by CSC, to the site-specific high accuracy DEM produced from Real Time Kinematic (RTK) GPS surveying instruments.

LIDAR imagery may be available from various sources. State governments may fly coastlines for cadastral or transportation purposes; USGS may acquire LIDAR for mapping; NGS or Coast Survey may also acquire data for nautical charting purposes. The US Army Corps of Engineers and academic partners may also be potential sources. LIDAR data is not inexpensive, and may require strategic partnerships with data sources for acquisition and processing.

The major cost in any LIDAR project may be the post-processing that is required to remove the vegetation from the return signal, to end up with the bare earth model. This is a task best left to a technician highly experienced in LIDAR processing and should be factored into the site-based LUHC budgets.

The highest resolution DEMs would require ground-based surveys using combinations of leveling, GPS observations, and RTK techniques. The data intensity requirements would limit the extent of such work to specific sites of interest.

### *2.5 High Precision Measurements of Elevation Change*

For over a decade, coastal researchers have been investigating and monitoring millimeter-scale changes in wetland and shallow bottom surface elevation using Surface Elevation Table (SET) technology. Such high-precision measurements are required to understand fundamental processes leading to elevation change over time. Sediment surface accretion, erosion, shallow subsidence and organic soil formation generally occur on the scale of millimeters per year. Eustatic sea level rise also occurs at this scale (currently estimated at about 2 mm yr<sup>-1</sup>). In addition, SET technology allows one to estimate rates of these processes with good statistical confidence over relatively short periods of time (generally about 3 years). High precision measurements of surface elevation change are especially important in the coastal zone because by the time larger, more noticeable changes have occurred, the coastal habitats may have already changed beyond the point of natural recovery.

High accuracy elevation change data have also proven useful to measure and understand seasonal fluctuations in elevation due to processes such as groundwater storage and seasonal sea level changes. The SET technique integrates all processes acting on surface elevation change over the depth of the benchmark (generally between 7 and 25 meters). In this regard, the technique differs from other high accuracy measurements of surface elevation change, because it includes below-ground processes as well. No other technique has proven itself reliable and consistent in providing millimeter-level precision wetland elevation change.

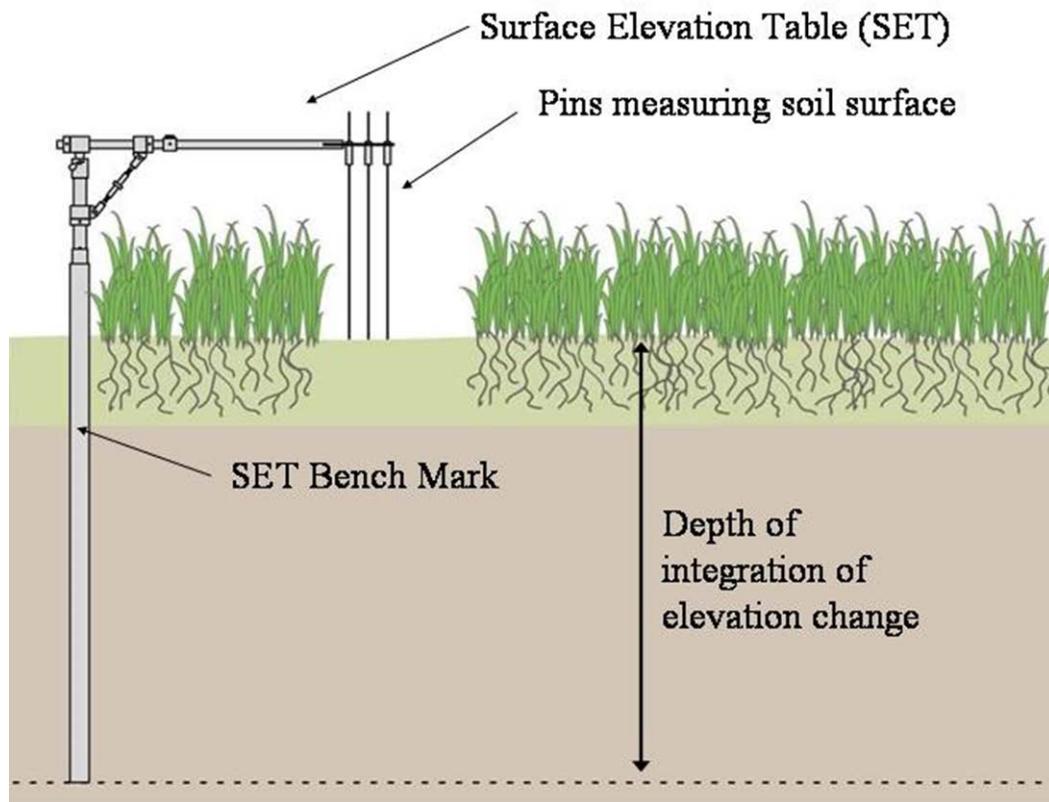


Figure 3.1 Diagram of Surface Elevation Table (SET) technology

### 3. Strategies for Obtaining Vertical Control

An inventory of catalogued National Spatial Reference System (NSRS) vertical control points – or benchmarks - residing within or in proximity to the NERRS has been conducted by NOAA’s NGS and is available on the NERR CDMO web site. Similarly, the CO-OPS has conducted an inventory of tidal datum infrastructure within and around NERRS – this inventory is also posted on the CDMO Web site. These inventories serve as a preliminary assessment of vertical control points at the disposition of the NERRS. All of these points will have to be verified on the ground through reconnaissance surveys, and many of them will require updated heights. Based on the inventories and verifications, each reserve can

determine its site-based vertical control needs. The site-based strategy for vertical control (to be included within each participating reserve's LUHC Plan) will begin with an assessment of site-based applications, elevation requirements, historical and existing infrastructure, and gaps. A strategy will be developed based on the gap assessment to bring the required vertical control to each reserve based on this analysis. This will be a critical part of the site-based HMC Plan that will inform ERD of budget and staff support needed to provide the vertical control at each reserve.

### *3.1 Strategies for Implementing a Surface Elevation Table (SET) Network*

Strategies for developing a SET network within each Reserve will focus on where existing SET resources are located, and whether they can be integrated within a comprehensive long-term abiotic and biotic monitoring protocol. Considerations will include whether the existing SETs fall within close proximity to permanent vegetation monitoring transects and/or other regions where elevation monitoring is a priority, and whether the current SET infrastructure can be utilized by NERRS staff. Gaps in available SET infrastructure will be evaluated and recommendations for SET resources will be reviewed for each Reserve. The SET infrastructure should be evaluated within the comprehensive context of elevation infrastructure as SETs can serve the function of a geodetic benchmark from which to provide vertical control as well. The inventory of SETs in the NERRS can be accessed on the home page of the NERR Intranet in the Land Use and Habitat Change Folder.

### *3.2 Strategies for Developing a Vertical Reference System for Tidal Datums and Water Level Measurement.*

The initial step of discovering the locations of existing tidal control, including existing stations, historical stations, and tidal benchmark locations, is followed by an assessment of the tidal characteristics and water level variations expected in the local region of each NERRS. Using data summaries from the tide stations, cotidal lines can be estimated and overlaid on the NERRS boundary, as shown in Figure 3.2 below for the North Inlet-Winyah Bay NERRS. Co-tidal lines provide information on changes in range of tide and time of tide. An understanding of the tidal hydrodynamics helps to understand where gaps in information may be. For North Inlet-Winyah Bay, for instance, the tide enters the Reserve both at North Inlet to the north and at Winyah Bay. This results in a slope in the tidal datum elevations across the Reserve due to the changing range of tide. Tidal currents would be expected to be strong, but highly variable throughout the Reserve.

This type of desktop assessment will be made for each NERRS with support from CO-OPS. This assessment would include an examination of tidal and geodetic datum relationships, where available, including variations over the region.

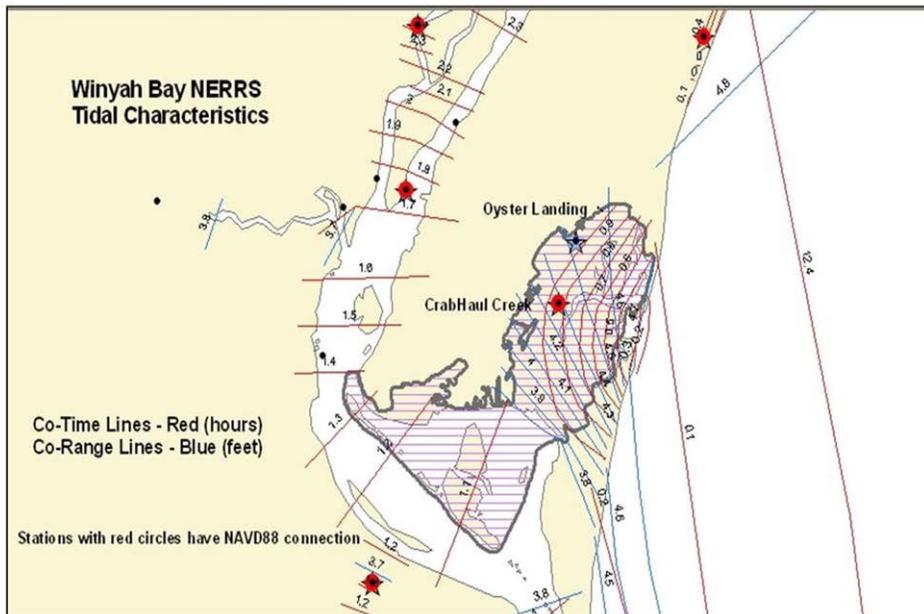


Figure 3.2. Cotidal lines for range of tide and time of tide at North Inlet-Winyah Bay NERRS.

#### 4. Conclusion and Implications

By 2012, each participating reserve will have a watershed DEM, vertical control that will integrate all monitoring infrastructure to a common reference datum, and surface elevation tables that will be monitoring micro-topographic changes within estuarine ecosystems vulnerable to impacts from sea level rise and land use. Watershed DEMs and vertical control benchmarks are available on the CDMO's Web site.

ERD will work with NGS and CO-OPS to establish vertical control, provide necessary training support, and upload relevant data to the CDMO web site to ensure that all reserve elevation data can be accessed at a central data location in combination with reserve habitat data. ERD has purchased an RTK unit and a auto-leveling system to support reserves in establishing elevation needs. A formal inter-office agreement will be developed to articulate the roles of NGS, ERD, and CO-OPS in achieving the goals of this Plan.

Reserves will develop, with the support of NGS, NGS state advisers, and CO-OPS, site-based strategies for planning and installing vertical control and SETS to assist reserves in developing their site-based HMC plans. The elevation component of the site-based HMC Plans will include:

- Identification of vertical control (geodetic and tidal datum) requirements (e.g., accuracy, location, type of benchmarks including SETS) in support of reserve

research, monitoring and stewardship applications including existing control and gaps;

- Development of a vertical control plan in partnership with NGS state advisers;
- Identification of appropriate strategies to establish and monitor elevation over time; and
- Training of designated staff in surveying techniques.

## **Section IV**

### **GIS and Remote Sensing Capacity in the NERRS**

#### **1. Overview**

Nieder et. (2002) highlighted the need for building and maintaining GIS and remote sensing capacity in the NERRS to implement the habitat and land use/land cover change analysis in the NERRS. In 2006, the HMCTC developed and implemented an updated needs assessment in the NERRS to assess current capacity (hardware, software, and human resources) within the system. The HMCTC used the results of that assessment to match the current capacity with the capacity needs that will be required to implement this Plan.

With the implementation of a system-wide LUHC Plan, the goal associated with building and maintaining capacity is to support the hardware, software and human resources to acquire imagery, keep current in technology, licenses and analytical ability, and conduct studies to apply geospatial information to management priorities. The recommended strategy for maintaining and enhancing analytical capability within the system focuses on establishing a technical support network within the NERRS and among partners outside the system, and providing continual training for all sectors to enhance and keep current with mapping technologies associated with GIS and remote sensing, and the standards and protocols detailed within this Plan.

The funds to maintain and enhance capacity will need to come from the NERRS operations budget. Due to limited funding opportunities within the current budget climate, this LUHC Plan cannot prescribe an increase in funding to support GIS capacity within the NERRS. However, due to the skill level and time required to classify, ground truth, analyze, integrate data sets, train, apply GIS-based models to site-specific applications, and update and purchase software licenses, it is highly recommended that adequate budgets are allocated to support a full-time GIS staff person with the hardware and software necessary to support site-based needs. GIS is an integral part of all reserve functions, and the NERRS would be well served by a fully-functioning site-based GIS capability to communicate to coastal decision makers and effect change. This funding support will need to be determined at the site level. Site-based LUHC Plans will inform the NERRS and the states of budget requirements that can be supported by NOAA and state budget planning processes. Site-based plans will be critical in making the case within the NOAA planning and budgeting process for increased funding to support site-based mapping efforts.

This section of the Plan: 1) reviews past GIS support within the NERRS; 2) clarifies the current capacity and capacity needs in the NERRS based on the 2007 needs assessment; and 3) puts forth a strategy for addressing capacity gaps.

#### **2. Building GIS and Remote Sensing Capacity in the NERRS**

GIS capability within the NERRS was initiated with the Protected Area GIS (PAGIS)

Project from 1997-2000. The partnership included CICEET (provided computers), CSC (provided software, training, and technical assistance), and the NERRS (provided funding and staff). The goal of this effort was to have an operating GIS capability at each of the NERRS within a two-three year time frame. This capability included both the appropriate set of tools, the availability of a trained operator, and a starter set of data for each site. This project was effective in achieving a beginning level GIS capability and capacity at all reserves. By 2002, most sites had GIS capacity and were applying the technology to produce maps. There was limited human capability to utilize the amount of data available at that time.

Following this infusion of support into the NERRS, each reserve supported GIS functions with \$10K in targeted funds within the operations awards beginning in 1999 which increased to \$25K in 2003. In 2006 the system shifted from allocating specific targeted dollar amounts for outcomes to enable the managers to have flexibility in allocating funds as needed. Enough funds are targeted by each manager in the operations awards to provide varying levels of GIS support for reserves.

### 3. Current GIS and Remote Sensing Capacity in the NERRS

While GIS and remote sensing support numerous cross-sector efforts at reserves, support is currently ad hoc and often funded by outside sources which limits the flexibility of GIS staff to support reserve and system-wide GIS needs.

A needs assessment was conducted within the NERRS in 2002 to assess GIS capacity within the system. In 2007, the NERRS conducted a follow-up needs assessment to determine the current level of capacity compared to the capacity that existed in 2002. Many of the questions in the 2007 survey were based on those asked in 2002 to provide a basis of comparison.

The 2007 survey inquired about the:

- Number of GIS FTE's available, the source of funding, and whether they are located on-site, within partner agencies, or both;
- Staff/sectors supported by GIS;
- GIS level of experience with mapping and analysis and with remote sensing;
- Need for additional staff and training, and hardware and software;
- Highest priority applications of remote sensing and GIS at each reserve;
- Site-based analysis needs that cannot be accomplished due to lack of capacity;
- Data sets/imagery readily available; and
- Key GIS bottlenecks at each site.

The 2002 assessment of capacity in the NERRS revealed a limited GIS and remote sensing capacity within the system. In 2002, GIS was used primarily to create maps with no application of spatial analysis identified. Reserves lacked staff and time to apply GIS and had more data than they could use. Most GIS staff in 2002 had only basic GIS training. The greatest need at the time was for high resolution imagery, benthic data, remote sensing

software to conduct more detailed analysis, and increased staff time and training on remote sensing and advanced GIS. The issues that were being addressed in 2002 by GIS included acquisition, assessment of management strategies, restoration, policy/planning and education and research.

The 2007 results reflect a great deal of evolution within the NERRS with respect to GIS capacity and provide the basis upon which the LUHC Plan will recommend maintaining and enhancing capacity within the system. The existing capacity as reflected in the 2007 survey is summarized below.

- **Staff Capability**

All but two reserves have GIS staff available to them with 50% having at least one FTE. Over 62% of GIS staff rate themselves as highly experienced in GIS and 27% rate themselves as having medium experience. Nearly 40% of the reserve GIS staff rate themselves as highly skilled in remote sensing and 42% have medium level capability to work with remote sensing analysis. This reflects that nearly 80% of GIS staff have a medium to high skill level in GIS and remote sensing. This experience in GIS and remote sensing is significant as it reflects a major leap in the capacity within the NERRS, the corresponding ability to reach within the system for technical support, the system's ability to provide support to external partners, and direct future needs to maintain and enhance hardware, software and training.

- **Priority Applications**

The priority applications of GIS and RS in 2007 are habitat mapping and change analysis (89%), invasive species mapping (42%), restoration (42%), land use (39%), research (35%), land acquisition (19%), and other (15%) (erosion monitoring, policy and planning, trails planning, GIS education for decision makers, outreach).

- **Staff Capacity Gaps**

The GIS/RS analytical gaps in skills that could be addressed with added resources were in the areas of land use change (85%), impervious surface (55%), water quality (50%), and erosion analysis (35%). An overwhelming majority of GIS staff identified the biggest bottleneck as training (96%), and 61% of sites indicated that they need more staff (11 sites needing 1 FTE or more and 5 sites needing a 0.5 FTE position).

Staff training needs were identified as:

- Decision support tools (84%);
- Remote sensing (image classification) (68%);
- Spatial analysis (68%);
- Basic GIS (32%);
- GPS (28%); and
- Other (36%) (LIDAR analysis, visualizations for coastal hazards and for coastal decision makers, inundation projection mapping, invasive species,

intermediate/advanced GIS, software and industry changes, training in new software and to stay current in new technologies, web mapping training.).

Software training needs were identified as:

- ENVI - to classify imagery and perform analysis on efficacy of imagery to discriminate between Phragmites and Spartina;
- Geo-database management;
- ARC extensions;
- Intermediate/advanced course on ArcGIS 9.x and add-on availability;
- Habitat mapping techniques;
- Remote sensing applications and troubleshooting;
- Modeling; and
- Software upgrades and industry changes.

- **Hardware Capacity and Needs**

The hardware capacity within the system is fairly uniform across reserves with 70% of reserves reporting having a dedicated GIS computer, and 87% having a large format plotter. Available GPS units with greater than 1 m accuracy are available at 13 reserves, sub-meter mapping grade accuracy is available at 14 reserves, and 4 reserves have cm survey grade GPS units. The greatest hardware need is reported to be for GPS units (67%) followed by dedicated computers (53%) and large format scanners (40%).

- **Software Capacity and Needs**

Nearly all sites have ARC 9.x software (83%). Other software available at NERRS is ENVI (29%) and ERDAS (20%). The highest need is for ERDAS (55%), Spatial Analyst Extension Tool (35%), ARC 9.2 (17%), ENVI (30%), Ecognition (20%), and other (45%).

The key outcome from this survey is that the key bottlenecks preventing reserve staff from applying GIS and remote sensing to its fullest capability are:

- Training (96%);
- Time (62%);
- Software-lack of funds to purchase extensions and upgrades (38%);
- Tools to connect reserve and watershed scale imagery; analyze impervious surfaces, visualization, modeling, etc.; and
- C-CAP and high resolution imagery; topographic and bathymetric data (53%)

The strategies for enhancing capacity maintaining GIS capability within the NERRS to support this LUHC Plan will address the key bottlenecks of time, data, training, and access to software.

#### 4. Strategies for addressing Capacity Gaps in the NERRS

The objective of the capacity building section of this Plan is to provide and maintain the expertise to address site-based needs and system-wide capacity to conduct habitat change analysis and explore linkages between watershed land use/land cover and local sea level change on the extent and quality of key habitats in the NERRS.

The following strategies and actions will be pursued to meet this objective:

**Strategy 1.** Provide training opportunities that respond to site-based needs for enhancing and maintaining expertise within the NERRS

*Actions*

- Conduct a needs assessment that can be implemented on a yearly basis to assess highest priority training needs within the NERRS to implement the mapping, elevation, and analysis priorities of this Plan. Coordinate with CSC and other NOAA partners to design and deliver trainings to NERRS staff in a variety of venues to minimize cost and maximize efficiency.
- Identify expertise within the NERRS and identify skill sets on the intranet to foster an intra-system-based support network for technical assistance.
- Develop a technical assistance support network within NOAA to address technical needs that cannot be met by existing expertise within the system.

**Strategy 2.** Maintain and enhance software and hardware capacity within the NERRS.

*Actions*

- Periodically inventory software and hardware upgrade needs (recommended on a two year basis to ensure that the system remains current with technology trends).
- Identify training needs for hardware (GPS and surveying) and software upgrades. (two-year cycle for assessments)
- Develop yearly or biannual strategic budget proposals to support reserves in maintaining hardware and software capacity to keep current with emerging GIS/RS technology.

## Section V

### Organizational and Budget Recommendations and Next Steps

Adequate resources and an appropriate organizational structure are essential components of the Plan. Implementation of this Plan will be somewhat opportunistic and strategic and based on information provided in the site based plans. Participation in the Plan will also be somewhat voluntary. All reserves will be required to classify their habitats to the NERR classification scheme and implement the protocols and standards set forth by this Plan so that accurate high resolution imagery of key habitats within each reserve are available on the CDMO web site for a base year between 2008-2012. Developing the additional habitat mapping and change plans with elevation control and outreach strategies is voluntary. Those reserves that choose to develop and implement a habitat mapping and change plan will be given priority support by ERD and other NOAA partners in partnership opportunities and budget initiatives. The site-based plans will provide ERD with the information necessary to seek budget support and will ensure that NOAA partners investing in reserves are operating from a comprehensive assessment of site-based needs within each participating reserve.

Site-based plans will articulate applications of mapping initiatives, mapping strategies, timelines, and image and infrastructure requirements, and physical and human infrastructure needed to implement the Plan. Funding strategies will be based on the needs expressed in the site-based plans. Elements of site based plans are included in Appendix B. Plan guidelines will be developed to guide reserves in their planning process.

Reserves also are encouraged to seek funding and other support in response to RFP's, state and federal funding opportunities, through partnerships with other state and federal agencies conducting mapping efforts, and through the NERR and NOAA planning process. In addition, the formulation of MOU's with key partners such as NGS and CO-OPS will solidify the relationships necessary to establish and maintain an elevation control infrastructure at the site-level and provide training.

The following organizational and budget actions are identified to support successful long-term implementation of the LUHC Plan.

- **FY09-FY11 Operations Awards.** Implementation of this Plan between 2008-2012 will require each reserve to develop a base year habitat map that conforms to the standards and protocols established by this Plan. For those reserves choosing to fully participate in the Land Use and Habitat Change Program, development of a habitat mapping and change plan should be an outcome of operations awards as well.
- **Operations awards should allocate an appropriate budget to support GIS training, hardware and software purchases, data acquisition, and other resources needed to satisfactorily implement the HMC Plan.** This investment proved to be very effective in advancing the capability of our system. The system has clearly advanced since 2002, yet time and capability are the key constraint to effectively implement this Plan. If the NERRS does not invest in the human resources in the system (both time and training),

and keep the hardware and software current, our ability to apply the imagery and conduct meaningful analysis will be compromised. The technologies are continually evolving and the NERRS needs to invest in its site-based staff to keep current with GIS/RS technologies.

- **The HMCTC, now called the LUHCTC, will be integrated into the CDMO's Data Management Committee (DMC) as the LUHC data oversight committee with a representative on the SWMP Oversight Committee.** CDMO will provide technical assistance to the system in implementing the LUHC Plan and maintain data provided by this Plan. The newly LUHCTC will ensure QA/QC protocols identified in this Plan are met, develop performance measures and monitor associated compliance. Two NERR GIS/SC representatives from the LUHCTC will be represented on the DMC and the chair of the LUHCTC will be represented on the SWMP oversight committee.
- **NOAA Programs (ERD, CO-OPS, NGS and CSC) will collaborate on developing programmatic MOUs, budget proposals, and collaborate opportunistically to support implementation of this Plan.** NOAA will also seek collaborative opportunities with other Federal partners.
- **Partnerships with the ACOE and CSC will be pursued to acquire and process topographic and benthic LIDAR imagery of reserves in regions where the ACOE is conducting LIDAR acquisition missions for their purposes.**
- **ERD and CSC will identify and deliver priority GIS/RS trainings to support the NERRS.** This training will be based on prioritized needs within the system. Each year, the NERRS staff will be surveyed to identify training needs. ERD and CSC will plan trainings on a yearly basis.
- **A technical support system will be established to support the GIS community within the NERRS.** One component of this system will be the identification of expertise on the intranet of all GIS staff within the NERRS. This directory will be a useful database for NERRS staff to solicit technical support within the system and among NERRS partners. In addition, ERD and CSC will identify a strategy by which CSC can provide technical support on an as-needed basis.
- **Funds will be sought to support regular meetings of the NERR GIS staff to ensure that the NERRS Land Use and Habitat Change Plan is implemented successfully, to ensure QA/QC protocols are met, to acquire training, and for planning purposes.**
- **Guidelines will be developed for "converting" the C-CAP classification scheme to the NERRS classification scheme.** This will facilitate comparison of within-reserve and watershed landscape patterns using spatial analyst.
- **The Requirements for the LUHC Plan will be re-evaluated periodically to account for advances in technology and its impact on the mapping goals of the NERRS.**

## Appendix A. Comments and Responses on the Draft LUHC Plan.

### Planning/Budgeting/Timing

- Need guidelines for site based plans

Noted – they have been developed and included as as an appendix to the Plan (forthcoming)

- The plan should identify the need for more FTE support for GIS specialists. –

The plan will be amended to identify the likely need for increased GIS support both at headquarters and reserves. Site based needs should be articulated in the reserve HMC plans with associated budget needs so that both the reserves and ERD can use the information to justify budget requests. The importance for supporting on-site GIS personnel and infrastructure is noted in Section V of the Plan: Organizational and Budget Recommendations.

- Need to innumerate/describe the partnerships in the organizational/budget recommendations section.

Noted. The final plan will clarify how each partner supports elements of the plan.

- Need a more solid budget and funding plan. -

Noted. The function of the plan is to set out broad goals and priorities for the system. Embedded in the plan is the development of site-based HMC plans. These plans will provide information that will inform site-based and system wide funding strategies. The HMC Plan will highlight the strategies that ERD and the NERRS can pursue to seek funding support including planning within the NOAA budgeting process and supporting reserves in developing strategic committee proposals that further the goals of this plan.

- A 4-5 year timeframes outlined in plan is problematic from a change and budget perspective. Will likely not see change within 5 years with a TMU of ¼ acre. Aligning the mapping and bio-monitoring cycles is un-necessary since SWMP bio-monitoring is not funded with any regularity. The cost of producing the maps is prohibitive on a 5-year time frame for many sites. -

Noted. The 4-5 year time frame was identified to offer a compromise between when change would be identified and maintaining connection with the HMC priorities within the NERRS. The planning team has decided to move to a 10-year mapping cycle for high resolution imagery using 2010 as a target baseline year give or take 2 years. This recognizes that having the high resolution data set for each reserve will be valuable for site-based and national applications. Each reserve will identify which year they will be

acquiring the imagery for their baseline maps from which we will develop a long-term staggered mapping and budgeting plan.

- Carrying out this work by the 2010 timeline proposed is too ambitious.

We will clarify that 2010 is the target year, and that we will strive to have all reserves acquire and map their core habitats within two years of 2010. Some reserves will have ground truthed imagery from 2008 which will qualify as well. The baseline mapping time frame is from 2008-2012.

- It's important to take a much longer look at this than just a few short years (50 years is just a few short years)

We will put in place a mapping cycle that will be updated over time. The cycle will be timeless. It will be evaluated every 5 years to check in with how emerging technology can enhance plan implementation.

- Since a guiding principle is partnerships, reserves should take advantage of existing data at the state and federal level. They often can provide data at a higher resolution than is required by the NERR HMC plan.

Agreed. This plan sets out a minimum requirement for high resolution mapping at 1-5 meters to accommodate the broad spectrum of mapping realities in the NERRS. Some sites such as Kachemak Bay NERR may find 1meter resolution unrealistic, even for a sub-component of their reserve and may choose to do a larger mapping area at 5 meter resolution. A smaller site such Delaware have access to state acquired imagery at a higher resolution than 1 meter. We encourage use of imagery acquired by non-federal partners that are higher resolution than identified within this plan. But the plan requires that the imagery be classified to the reserve classification scheme to conform to the NERR mapping standards.

- HMC Committee representatives should have seats on the SWMP oversight and DMC committees. - Nina

Agreed. This is noted in Section V of the draft plan.

### Scope

- Elevation was incorporated into the plan at the last minute, is a tremendous commitment in terms of time, fieldwork, and expertise, and has no additional resources allocated to it.

Elevation mapping is not a last minute consideration within the NERRS. This approach was developed by the HMCTC in partnership with the NGS and CO-OPS and after much vetting and input from all sectors within the NERRS at the 2007 annual meeting. It has been discussed by the research coordinators prior to the development of the plan, and was seen as a critical parameter in habitat mapping and land use change. The

developers of the HMC plan saw an opportunity to address elevation in this plan and integrate all aspects of elevation within one mapping context.

While no plan can guarantee commitment of funds, it serves to identify priorities and applications to justify pursuit of funding and partnerships to support the plan. We will work with our partners in NGS and CO-COPS to provide training, support, and funding to build out the reserve vertical control infrastructure that will integrate the reserve system into the priorities of other NOAA programs. This will be a phased-in process as resources allow.

- Micro-topographic elevation monitoring along bio-monitoring transects is too restrictive. While reasonable, there might be reasons why additional sites would be needed or that these transects might not be suitable.

Noted. The coupling of elevation mapping and monitoring along bio-monitoring transects offers an integrated biological and geodetic tie that supports sentinel site monitoring for climate change in a consistent manner within the NERRS. However, there are other applications for elevation monitoring that address important site-based needs. We will modify this recommendation to offer a more flexible approach.

- What is the purpose and importance of monitoring adjacent watersheds. Do nearby sites automatically provide some sort of a reference system? If the goal is to monitor against reference sites, why aren't those reference sites specifically chosen to provide a stable reference point? Shouldn't they be selected in the same manner that reference sites are selected for restoration?

The LUHC Plan addresses the priorities of the Nieder et al (2002) HMC concept paper. Nieder et. al identified the following questions:

- What is the magnitude and extent of habitat change in estuarine systems and their watersheds?
- What are the linkages between land use change in adjacent watersheds and habitat change in reserves?

SWMP Phase III has identified the linkages between watersheds and estuarine habitats as a core component of SWMP implementation.

- Introduction – restrict the focus to estuaries – not entire watersheds.

See above.

- Do benthic habitats fall under the definition of land use/land cover?

This plan focuses in the near term on mapping land use and land cover from the lower low water to the top of the watershed as the technology is well developed. In the plan, we develop a strategy for moving forward with system-wide habitat mapping with readily available technologies. As benthic mapping and monitoring opportunities and

technologies are more accessible to the NERRS, we will address benthic mapping more systematically.

### Approach

- Unrealistic to expect that all reserves will have LIDAR for their sites and have the in-house expertise to develop bare earth DEMs.

Understood. The plan does not presume that reserves will be able to acquire and process LIDAR. The need for, and geographic scope of, this technology should be identified in the site based plans. This information will serve to inform partners that may be able to access and process LIDAR imagery.

- For larger reserves, they will need to sub-sample the area targeted for monitoring change at a higher resolution.

Absolutely. The approach should be detailed in the site-based HMC plans. The protocols identify various scales and accuracies for mapping with the highest resolution and accuracy targeted at the highest priority mapping area. The protocols offer an approach for higher resolution automated classification (lower accuracy) for areas of lower priority within and adjacent to the reserve.

- Partnerships with other federal agencies need to be well established and clear expectations set out at the ERD level.

Agreed. ERD is working with the ACOE to acquire LIDAR of reserve habitats when the ACOE is planning LIDAR missions. Codifying these NERR priorities also enhance the attractiveness of potential partners to support NERR priorities. At the NOAA level, ERD is working on an MOU with NGS and CO-OPS to clarify the partnership and program activities that will support implementation of the vertical control elements of this Plan.

- The plan does not address a strategy for achieving objectives 2 and 3 regarding coastal decision makers and influencing land management and stewardship. The data collected can be used within the reserve system but will require considerable funding and capacity development to influence land management in other contexts. The plan does not develop integration that would facilitate the application of the SWMP data to management. If the last two objectives of the plan are removed, this “dissemination protocol can be part of another plan. If the three objectives at the start of the plan are to remain, considerable work is needed to describe how such a dissemination protocol would be developed. (Chris Feurt) What are the methods we will use to disseminate the information and who is the target audience that will receive the information to create the change we are looking for? Use the CTP workgroup that is charged with integrating SWMP and CTP.

In response to this comment, we removed the two objectives that address outreach and dissemination and recognize that this plan provides the information in dissemination portals such as the CDMO web site and ultimately the NERRS Internet. But it does not provide the strategy that actively delivers the information to target audiences. We amended the site-based habitat mapping and change plan guidance to include a strategy for disseminating the land use/land cover maps to target audiences at the local level.

### Technical

- We need guidelines for converting C-CAP classification scheme to the NERRS classification scheme. Spatial analysis comparing within-reserve and watershed landscape patterns would be more straightforward if the same classification terminology was applied to both data sets.

The Plan has been amended to reflect this need.

- Need to re-evaluate the methodology periodically as the technology changes enabling higher resolution imagery acquisition. It would be helpful to build in a five-year technology review and evaluation plan.

Noted: The Plan identifies the need for periodic evaluation of technology.

- Should we identify target spatial resolutions regardless of ability to achieve them for the type of work that we are doing even if the ability to achieve that scale does not exist yet?

The Plan identifies a target spatial resolution for national level priorities based on FGDC standards. If reserves have higher accuracy requirements, they can pursue them independently.

- Will all reserves be tied to the same reference system to establish elevation or will each reserve use only a single reference system but not necessarily the same system as another reserve uses?

Each reserve will tie its vertical control infrastructure to the National Spatial Reference System (NSRS) according to NOAA's NGS standards but vertical control will also be established within each reserve that will enable higher accuracy vertical control within reserve boundaries.

- Sect. 1 – Intro – how does the NERR classification differ from standard habitat classification schemes (CMECs, Cowardin, etc)?

The NERR classification scheme is based on Cowardin but modifies Cowardin by defining estuaries by tidal influence rather than salinity. CMECS is more of an open water classification scheme that is based more on ecological factors rather than geospatial mapping. It was developed after the NERR Scheme was developed.

Communication has been consistent between the developers of the NERR and CMECS scheme and we are confident that we will be able to cross-walk between the schemes once CMECS has been finalized.

### Editorial

- Elevation section – part on sea level trends – although background, this section could use more information on the problem of increases in elevation due to sedimentation (particularly within wetlands) and decreased tidal prisms. This makes the balancing act between sea level rise and elevation increases more precarious, meaning that we need really good information on both.

The discussion has been amended to account for this issue.

- Do reserves actually process remotely sensed imagery? This is a specialized task.

The verbiage will be clarified to reflect that remotely sensed imagery will be acquired, not processed, by reserves.

## Appendix B. LUHC Plan Checklist

### NERRS and partner organization responsibilities:

#### 1. Technical Support/System-Wide Capacity

- Conduct GIS/Remote sensing needs assessment within the NERRS
- Provide training opportunities that respond to site-based needs for enhancing and maintaining GIS/Remote sensing expertise within the NERRS
- Develop technical support system on the NERRS Intranet so that GIS/Remote Sensing staff can solicit technical support from within the system or from NERRS partners

#### 2. Land Cover/Land Use

- Develop NERR Classification Scheme and Implementation Protocol
- Develop shapefiles of all reserve boundaries with FGDC compliant metadata – uploaded to CDMO website
- CSC will develop land cover/land use, impervious surface cover, and canopy cover maps of all reserve watersheds using C-CAP semi-auto classified data – conducted every five years, and uploaded with FGDC compliant metadata to the CDMO website
- CSC will conduct a habitat change analysis (land cover/land use, percent impervious surface cover, and percent canopy cover) at watershed-level for all reserves using C-CAP data (30-m resolution) – uploaded with FGDC compliant metadata to the CDMO website
- CSC will demonstrate the application of using automated classification of high resolution imagery into the NERR classification scheme
- NERRS will develop guidelines for “converting” C-CAP classification scheme to the NERRS classification scheme

#### 3. Elevation

- CSC will provide DEMs at a low resolution (30-m) for each Reserve watershed – uploaded to the CDMO website with FGDC compliant metadata
- NGS will provide a preliminary assessment of vertical control points (vertical control benchmarks and tidal datum infrastructure) within and around NERRS with FGDC compliant metadata

- Provide inventory of Sediment Elevation Tables (SETs) that currently exist within the NERRS

Reserve responsibilities:

1. On-site Capacity

Produce HMC Plan (specific guidelines for this will be provided in a future document) that specifies at the bare minimum mapping strategies for reserve habitats during baseline year (between 2008-2012) and on a 10 year cycle. Items to be considered/included in HMC plan are:

- Identify applications for GIS and Remote Sensing and Habitat Mapping as it relates to climate change and other site-based needs. - Mandatory
- Identify gaps in GIS/Remote sensing imagery, personnel, training, and hardware/software - Mandatory
- Identify budget requirements to support HMC Plan - Mandatory

2. Land Cover/Land Use Mapping Strategy:

- Identify targeted watershed that directly impacts reserve and upload shapefile with FGDC compliant metadata to the CDMO web site - Mandatory
- Identify focus area(s) for high-resolution/high-accuracy, high-resolution/lesser-accuracy, and moderate-resolution/high-accuracy imagery for reserve mapping (i.e., at minimum the intertidal and supra-tidal areas and an additional buffer of 100 m) and habitat inventory (NOTE: Larger reserves may choose to select representative habitats to monitor over long-term) - Mandatory
- Acquire and process high-resolution land cover data (i.e., digitization, photo interpretation, and heads-up delineation of high-resolution true-color aerial photography plus field checking) to produce baseline map between 2008-2012 - Mandatory
- Identify requirements for image acquisition and processing - Mandatory
- Identify Minimum Mapping Unit – must equal 0.1 ha (or less if thought to be ecologically significant) - Mandatory
- Conduct habitat classification to the subclass level (i.e., leaf-type if vegetated, substrate composition if un-vegetated, or development intensity if urbanized) using NERRS Classification Scheme and Implementation Protocols - Mandatory

- High resolution GIS data must be submitted as vector polygons to the CDMO with FGDC compliant metadata - Mandatory
- Conduct accuracy assessment of high-resolution data using the accuracy assessment matrix - Mandatory
- High-resolution land cover data will be reacquired 10 years after production of baseline data - Mandatory

### 3. Elevation:

- Identify sub-watershed areas where LIDAR could be used to produce higher resolution (cm accuracy) DEMs than those provided by CSC - Voluntary
- Identify priority areas where Real Time Kinematic GPS or auto leveling surveying instruments could be used to produce high-resolution (cm and mm accuracy) DEMs - Voluntary
- Conduct reconnaissance surveys of vertical control points (identified by NGS and CO-OPS; posted on the CDMO website) and verify heights - Voluntary
- Identify any existing SET resources -Voluntary
- Develop a SET Network within the Reserve by identifying priority areas where measuring micro-topographic changes with SETs would be useful (i.e., close proximity to abiotic and biotic monitoring transects) -Voluntary
- Determine site-based vertical control needs to support stated applications (i.e. elevation requirements, historical and existing infrastructure, and gaps) - Voluntary
- Assess the tidal characteristics and water level variations expected in the local region of each NERR with help from CO-OPS - Voluntary

Appendix C. Tidal Datums

Table 1: Tidal Datums (Source: The National Ocean Surface:  
[http://tidesandcurrents.noaa.gov/datum\\_options.html](http://tidesandcurrents.noaa.gov/datum_options.html))

<b>MHHW*</b> Mean Higher High Water	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
<b>MHW</b> Mean High Water	The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
<b>DTL</b> Diurnal Tide Level	The arithmetic mean of mean higher high water and mean lower low water.
<b>MTL</b> Mean Tide Level	The arithmetic mean of mean high water and mean low water.
<b>MSL</b> Mean Sea Level	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.
<b>MLW</b> Mean Low Water	The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
<b>MLLW*</b> Mean Lower Low Water	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
<b>GT</b> Great Diurnal Range	The difference in height between mean higher high water and mean lower low water.
<b>MN</b> Mean Range of Tide	The difference in height between mean high water and mean low water.
<b>DHQ</b> Mean Diurnal High Water Inequality	The difference in height of the two high waters of each tidal day for a mixed or semidiurnal tide.
<b>DLQ</b> Mean Diurnal Low Water Inequality	The difference in height of the two low waters of each tidal day for a mixed or semidiurnal tide.

<p style="text-align: center;"><b>HWI</b> Greenwich High Water Interval</p>	<p>The average interval (in hours) between the moon's transit over the Greenwich meridian and the following high water at a location.</p>
<p style="text-align: center;"><b>LWI</b> Greenwich Low Water Interval</p>	<p>The average interval (in hours) between the moon's transit over the Greenwich meridian and the following low water at a location.</p>

\*Some locations have diurnal tides: one high tide and one low tide per day. At most locations, there are semidiurnal tides; the tide cycles through a high and low twice each day, with one of the two high tides being higher than the other and one of the two low tides being lower than the other.

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