

9.0 REMOTE SENSING PROCEDURES

9.1 Purpose

The purpose of the remote sensing chapter is to provide guidelines in the selection, acquisition, processing, analysis, and interpretation of remotely sensed data for CERP projects. These guidelines should be used by scientists/project managers and others who have responsibilities for developing contracts for remote sensing services. The term “remote sensing” (RS) is used here in the broadest sense, and includes the use of digital imagery and photography, the collection of data from satellite and aerial platforms, the capture of data in electronic, film and print formats, and the analysis of data digitally, photogrammetrically, or manually.

CERP is a joint partnership of Federal, State and Tribal agencies. The guidelines developed here reference existing documentation developed by CERP, USACE, US Geological Survey (USGS), FDEP, SFWMD, and others. Each section of this chapter is comprised of a topical discussion, including both theoretical and practical information, with Internet links to relevant guidelines, examples, and reference materials. This chapter is intended to supplement, not supersede, existing CERP guidelines and standards.

9.2 Scope

The goals of this chapter of the QASR are to outline the minimum QA requirements for evaluating and planning RS activities and to provide specific procedures for conducting collection activities. The chapter discusses the following:

- General considerations for RS
- Pre-field evaluation activities
- Applicable guidelines and standards
- Description of RS sensors
- Comparison of RS platforms
- Methods and their application to CERP requirements
- Data Processing and Analysis
- QA/QC considerations

This chapter is not intended to be “prescriptive,” but is intended to assure that acceptable methods and QA/QC procedures are used when performing environmental investigations. It is intended to be a dynamic document that will be periodically reviewed and updated.

The methods and QA/QC procedures in this manual should be incorporated by reference into any monitoring activity conducted for the CERP. This document does not negate the requirement for field SOPs or the need for FSQM that is specific for each sampling agency.

9.3 Requirements and Regulations

During the planning of a project where RS technologies are to be used, it will be imperative that the project team discuss and understand the specific requirements and regulations associated with a particular platform and sensor. Any nationally or internationally recognized requirements and regulations for remote sensing activities should be recognized and incorporated to the extent possible. Due to the nature of remote sensing activities, many government organizations have general rules and standards that must be followed when conducting remote sensing activities. The guidelines described in this chapter of the QASR manual are intended to supplement, not supersede, existing guidelines and standards. In addition to the requirements presented in this document, all data collection performed for CERP projects must conform to the relevant requirements in the following:

9.3.1 Federal Requirements and Regulations

- CGM 28, Technical specifications for CERP GIS Data
- CGM 036, Technical Guidance for Use of the CERP Geodetic Vertical Control Surveys Monuments and Referenced Control
- CGM 040, CERP Technical Guidance for the Project Level Water Quality and Hydrometeorologic Monitoring and Assessment
- USACE EM-200-1-3, 1, Requirements for the Preparation of SAP
- USACE EM-1110-2-2907, Engineering and Design - Remote Sensing

9.3.2 State Requirements and Regulations

- FDEP Quality Assurance Rule Chapter 62-160, FAC
- FDEP collection and quality control protocols and requirements in DEP-SOP-001/01, incorporated by reference in Chapter 62-160.800, FAC

9.3.3 Other Requirements and Regulations

- Any other regulations dictated by project requirements in the SOW, QAPP or MP.
- Relevant Websites Documents relevant to remote sensing requirements and regulations are available at numerous organization websites. Links for the following organizations should be used as a starting point to search for relevant information, since guidelines and standards are subject to change.
 - CERP
 - USACE
 - SFWMD
 - FDEP
 - US Federal Government

- Federal Geographic Data Committee (FGDC)
- Federal Emergency Management Agency (FEMA)
- National Aeronautics and Space Administration (NASA)
- Remote Sensing Professional Associations

A list of common RS terminologies and definitions can be found in **Appendix 9-B**.

9.4 Responsibilities

Any and all CERP agencies performing or contracting for RS services should refer to QASR **Chapter 2** for general guidelines and responsibilities associated with spatial data collection practices. Although **Chapter 2** requirements refer mostly to field data collection and laboratory analyses, similar reporting and documentation methods can be applied to data collected remotely. Additionally, information about the elements and structure of a QAPP can also be found in this chapter. A robust QAPP should be developed when performing any kind of RS. More detailed information on QA/QC specific to RS projects can be found in **Section 9.8**. It is of particular importance to make every attempt to follow the appropriate standards and guidelines for the type of activities in question and this information is readily available in **Section 9.3.2** above. Reporting standards, especially with regard to the creation and maintenance of appropriate and complete metadata information, should be robust and consistent with similar or related projects and national standards (See **Section 9.10**).

Understanding the needs of the particular project for which the remotely sensed data is being collected is essential in designing a mission that will lead to a successful outcome. The success of a RS project is not defined by a positive or negative answer to the question or questions that are being asked, but by the applicability, integrity, and accuracy of the data being generated to help answer the question(s). The DQOs process detailed in **Chapter 2** can help ensure that the resulting data satisfies the needs of the parent project. Pre-project planning is essential for choosing the appropriate data collection sensor(s), platform, spatial resolution and accuracy, and classification resolution and accuracy to ensure data usability. Temporal resolution can also be a major consideration when using remotely sensed data to portray a change in the environment.

CERP agencies performing RS activities either in-house or through a vendor should ensure that all personnel working on the project are aware of the standards and requirements set forth by the CERP QAOT and the QASR. This is normally handled by a designated QAO whose responsibility is to ensure consistency and integrity of the process. All in-house and/or contract personnel should have the adequate training and background to perform the required tasks including a complete understanding of the technologies being deployed.

Standardized contract language should be used whenever possible to help ensure consistency between similar or repetitive projects. Scopes of Work must include the components listed in **Section 9.8.1** and be submitted for a compliance review by the QAOT or appropriate designee before work begins. This is especially important if the method for data collection and synthesis being proposed is non-standard or considered “new and innovative”.

Collaboration and cost-sharing practices should be utilized whenever possible to reduce waste and duplicative data collection. During the initial RS project planning process, a thorough inventory of existing available spatial data should be conducted to determine whether appropriate information already exists with other Agencies. Even during the interpretation phase of remotely sensed data, Agencies should make every attempt to work within already established classification systems whenever possible to maintain consistency and comparability with existing and future products.

9.5 Training

For CERP/RECOVER RS activities, it is necessary that staff participating in these activities be appropriately supervised by scientists/engineers who are skilled in the operation of the particular platform/sensors to be used. Because RS equipment and platforms may require special certifications to operate, all staff, contractors and/or subcontractors who will be directly conducting the RS operations must have the appropriate licenses and certifications.

9.6 Project Planning and Review

9.6.1 General Characteristics and Considerations of Remote Sensing Systems

A number of characteristics and tradeoffs common to all RS systems should be considered when designing RS projects. The following elements have been modified from Liles and Kiefer (2000) and should be considered in the planning process for RS collections.

9.6.1.1 Energy Source

Passive RS systems rely on energy that is reflected and/or emitted from the Earth's surface (Radar and LIDAR are active sensors that are discussed in **Section 9.7.2.2**). The spectral distribution of reflected sunlight and emitted energy is far from uniform. Likewise, solar energy levels vary with respect to time and location, and surface materials emit energy with varying degrees of efficiency. While the operators have some control over the energy sources for active remote sensing systems, for passive systems the energy sources are generally non-uniform and vary with time and location. Consequently, there is a need to calibrate for source characteristics on a mission-by-mission basis or simply deal with relative energy units sensed at any given time and space.

9.6.1.2 Atmosphere

To a certain extent, the atmosphere modifies the strength and spectral distribution of the energy received by a sensor. Atmospheric effects can add noise to a signal. Techniques and models for atmospheric corrections are applied to remove these effects. Atmospheric correction has been shown to significantly improve the accuracy of image classification. This is particularly important for applications where repetitive observations or multi-sensor collections are involved, and data fusion or change detection is planned.

9.6.1.3 Energy-Matter Interactions at the Earth's Surface

Not every material reflects or emits energy in a unique, known way. Since spectral response patterns (signatures) play a key role in detecting, identifying and analyzing land and water features, there can be a great number of ambiguities with respect to spectral signatures. Radically

different material types can be spectrally very similar, making differentiation difficult. Likewise, an understanding of energy-matter interactions for land/water features exists at an elementary level for some features and is nonexistent for others.

9.6.1.4 Sensors

No single sensor is sensitive at all wavelengths – they have fixed limits of spectral sensitivity. In addition, there is also a limit on how small an object on the Earth’s surface can be and still be recognized as separate from its surroundings. Finally, there are temporal considerations. Basically, sensors that have a one-day repeat cycle generally have a large footprint (i.e. 1 km spatial resolution), whereas sensors that have a finer spatial resolution (e.g. 30 m), typically have a longer repeat frequency (e.g. 14 days for NASA’s Landsat satellite). Ultimately, the choice of a sensor involves tradeoffs between spectral, spatial, and temporal resolution/coverage.

9.6.1.5 Data Processing and Supply System

The current capability of modern remote sensors to generate data far exceeds the capacity of today’s computers to handle these data. Processing sensor data into an interpretable format is often an effort entailing considerable planning, improved hardware, advanced processing techniques, time, experience, and reference data. Although in some cases data users would like to receive their data immediately after acquisition by the sensor in order to make timely decisions, this is often not possible. In addition, many sources of RS data are unable to supply imagery over an exact geographic area, at the required time, and/or under ideal conditions (e.g. low tide and no cloud cover).

9.6.2 Multiple-View Approach

The success of many RS applications is improved considerably by taking a multiple-view approach to data collection. This may involve multi-sensor data collection efforts, where, for example imagery is collected from multiple sensors over one site of interest. It may involve multi- or hyperspectral sensing, where data are collected over a range of the electromagnetic spectra (covering the visible, near infrared, and thermal infrared portions of the spectra), or it may entail multi-temporal sensing, where data are collected on numerous occasions over one site of interest.

9.6.2.1 Multi-sensor Data Collections

In a multi-sensor approach, data may be collected using either multiple sensors on a single platform, or multiple sensors from different platforms. An example of the latter is a collection effort that may involve a concurrent satellite-based Landsat overpass, aerial photography, and ground observations. Each successive collection provides more detailed information. By combining data from multiple sensors with reference information, data fusion techniques are used to improve accuracies and generate more specific inferences compared to methods that use a single sensor. While data fusion is not a new concept, the emergence of new sensors, advanced processing techniques, and improved processing hardware make real-time fusion of data increasingly possible.

9.6.2.2 Multispectral Sensing

A large number of RS applications involve discrimination of land and water resources using a multi- or hyperspectral approach. Multi-spectral and hyperspectral sensors acquire data from tens (multi-spectral) to hundreds (hyperspectral) of wavebands over a specified range of the electromagnetic spectrum. When analyzed together, these wavebands produce more information than if only a single band was used or if multiple bands were analyzed independently. New advances in hyperspectral sensing are revolutionizing the utility of remotely sensed data for mapping and monitoring wetlands. It is now possible to map individual wetland species, as well as detect very subtle changes in wetland ecosystems such as early signs of stress.

9.6.2.3 Multi-temporal Sensing

Multi-temporal sensing involves capturing data over the same geographic area at multiple time periods in order to discover trends in vegetation or surface conditions. Change detection, or change analysis, is frequently used to monitor vegetation, land use change (e.g. rate of wetland loss), and can also be applied to address changes to water quality. Change detection can be employed to characterize and track the rate and spread of invasive species over time. Multi-temporal collections can provide unique information regarding the growth and development (phenological stages) of vegetation. Critical to this approach is a careful selection of time periods, keeping in mind the primary question(s) being asked. The following section addresses questions that should be considered when planning a change detection project. These questions are relevant to many other RS projects as well.

9.6.3 Planning Questions for Data Acquisition

In order to identify the image technology most appropriate for a particular data collection need, the DQOs (**Chapter 2, Section 2.5**) should be identified so that the right type and quantity of data are collected. The following questions, adapted from Chapter 3, Section 3 of the USACE Remote Sensing Engineer Manual EM-1110-2-2907, Oct. 1, 2003, should be answered to define basic information needed to select the appropriate technology.

- What is the primary goal of the project? Define the performance measure to be used for evaluation or assessment, and determine how remote sensing can be applied to assist in solving the problem.
- What is the appropriate remote sensing technology for your application? Different remote sensing data have different physical meanings and contain different information. Instead of using whatever types of data are available, you should consider which remote sensing technology gives you the right answers.
- Are several technologies required to meet all the assessment needs, or can a single technology serve all the needs?
- What spatial resolution is needed? For imagery or digital photography, determine the pixel size that is required, and for film photography, determine what scale is required.
- What is the target, or what is being mapped? Define what spectral bands are needed. Determine what detail is needed from the imagery.

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- Were past RS projects performed in this area, such that their database could be expanded upon?
 - What spectral resolution is needed? Set bandwidths and proximity.
 - What are the requirements for timing and temporal resolution? Select season(s) and time frequencies. Each sensor system operates on a different repeat cycle.
 - How urgently are the data needed? Determine acceptable coverage dates. Determine the turn-around time from data capture to delivery.
 - When will ground-truth data be collected? Image data acquisition ideally coincides with ground-truth data collection for training, analysis, and accuracy assessment.
 - What are the weather and light conditions? Sensor limitations vary for use in rainy, cloudy, or nighttime conditions. Specify maximum percent of cloud cover acceptable for visible and NIR sensors.
 - What accuracy is required? Set vertical and horizontal accuracy limits.
 - Where is the project located geographically? Specify the boundary coordinates for the area of interest (AOI). Specify the scene, if applicable (e.g. path & row; orbit & frame).
 - What funds are available? Determine if cost-sharing with another department or agency is possible. Determine if lower-cost archived data will suffice, or if new data are required. For a list of archived data costs, see Chapter 4, Section 4 of the USACE Remote Sensing Engineer Manual EM-1110-2-2907, Oct. 1, 2003.
 - What field of view is needed? Specify image overlap, if one image is not sufficient. Specify that overlapping flights must be flown in the same direction.
 - What acquisition look direction is needed? Specify time of day, flight direction and sun angle to minimize sun glint. Specify off nadir angle limit. For satellite orbital elements, see <http://www.amsat.org/amsat/keps/kepmodel.html>
 - What level of processing will be performed by the vendor? Basic processes such as radiometric, atmospheric and geometric corrections should be considered.
 - What commercial analytical services are needed? Determine whether external expertise is required for specialized processing. See Chapter 3, Section 4 of the USACE Remote Sensing Engineer Manual EM-1110-2-2907, Oct. 1, 2003, for examples of value-added products.
 - In what format is the image data to be delivered?
 - Media type (e.g. Compact Disc Read-Only Memory (CDROM), digital tape or file transfer protocol (FTP) retrieval)
 - Compressed or uncompressed,
 - Tiled or untiled
 - File type (e.g. satellite format, or Geo Tag Image File Format (TIFF))
 - Electronic or hardcopy maps

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- If there are license restrictions on the data received, are they acceptable for project purposes? Ownership and rights to share data vary. Consider a multi-user license for sharing data across agencies.

9.6.4 Planning Questions for Change Detection

A careful definition of RS requirements will have a major impact on project costs, product quality, and the eventual usefulness to the end user. The following points have been modified from Klemas (2001) and should be considered carefully for relevance to CERP.

9.6.4.1 General Requirements and Problem Definition

- Define the decision points that will be made from the RS information.
- Determine the data layers to be used for monitoring/modeling.
- If models are used, determine what type (e.g. watershed, hydrodynamic, water quality, and ecosystem).
- Establish the region/boundary of concern (e.g. watershed, drainage area, water body).
- Select the land use classification system to be used.
- Determine the minimum mapping unit that is acceptable and relevant to project.
- Determine the frequency of change detection.
- If mapped output is required, state the desired accuracy of maps, and identify ground resources needed to conduct accuracy assessment.

9.6.4.2 Sensor Selection and Data Acquisition

- Determine the data availability, quality, and format.
- Select the RS system (consider the cost and resolution: temporal, spatial, spectral, or radiometric)
- Select the RS image (years, season, tidal stage, atmosphere, cloud cover, soil moisture, etc.)
- Gather *in situ* and collateral data (measurements, sites, transects, frequency, etc.)
- If multiple sensors are used, identify methods for fusing different products in spatial, temporal, and radiometric domains.

9.6.4.3 Data Analysis and Image Processing

- Determine and conduct image preprocessing (geometric or atmospheric corrections, radiometric normalization, and calibration)
- Determine image classification procedures (supervised, unsupervised, or hybrid)
- Develop change detection algorithms (post classification, image differencing, etc.)
- Ground-truth data for training and accuracy assessment
- Develop a base map for GIS layers (Digital Elevation Model (DEM), bathymetry, etc.)

- Develop algorithms for new products (e.g., salinity or a region-specific vegetation index)

9.6.4.4 Quality Assurance and Quality Control

- Define spatial data quality
- Determine statistical accuracy and precision of individual data classifications
- Determine statistical accuracy and precision of change detection products

9.6.4.5 Data Storage and Distribution of Results

- Determine if data are to be distributed and stored as digital products that may be accessed via the internet (Internet access)
- Determine if analog (hardcopy) products will be required
- Develop a database archive and distribution system for multiple users
- Create Metadata for all data products

9.7 Procedures

9.7.1 Background Information

9.7.1.1 Applicability of Remote Sensing Technologies to CERP and Other Projects

Table 9.1 lists a number of CERP monitoring applications, and which sensors may be appropriate for use in data collection for that particular application. **Table 9.2** presents the applicability of different remote sensing technologies to various projects (CERP or non-CERP).

Table 9.2 also includes the relative cost for each technology, and a ranking of how applicable the RS technologies are to various projects.

Table 9.1 Summary of the Possible CERP Applications for Some Airborne and Satellite Data and Sensors

CERP Applications	AVHRR	AVIRIS	ESSI's Probe-1	HyMap	Hyperion	Quickbird/IKONOS	IRS	ETM	MODIS	RadarSat	LiDAR
Sawgrass vegetation patterns in WCAs	X										
Mangrove vegetation patterns	X		X								
Water clarity in Estuaries and Lake Okeechobee		X	X	X	X	X	X	X	X		
SAV vegetation in Lake Okeechobee		X	X	X	X	X	X	X			
Sea grass bed patterns in Northern and Southern Estuaries		X	X	X	X	X	X	X			
Native vegetation patterns in Lake Okeechobee		X	X	X	X	X	X	X		X	
Vegetation mosaics in Greater Everglades Wetlands		X	X	X	X	X	X	X	X	X	
Algal Bloom patterns in Lake Okeechobee and Estuaries		X	X	X	X	X	X	X	X	X	
Oyster patterns in Northern Estuaries		X	X	X			X	X			
Sulfate concentrations in CERP Reservoirs		X	X	X	X	X					
Exotic vegetation patterns in Greater Everglades				X		X					
Salinity patterns									X		
Planning level Mapping										X	X
Planning level topographic engineering										X	X
Water depth determination											X

Note: Remote sensing science is constantly evolving with new sensors coming on-line as old ones become obsolete. A periodic re-examination of the status and technology of a chosen sensor should be performed before being considered for a particular application.

Source: SFWMD, *White Paper of Remote Sensing Assessment Team*, March 2001.

Table 9.2 Applicability of Different Remote Sensing Technologies

Remote Sensing Applications	Remote Sensing (RS) Technologies							
	Passive RS					Active RS		
	Panchromatic	Multi-spectral/ Hyperspectral	Thermal	Microwave	Aerial Photography		Radar	LIDAR
Film					Digital			
Text Section	9.7.2.1	9.7.2.1; 9.7.2.3	9.7.2.1	9.7.2.1	9.7.2.1	9.7.2.1	9.7.2.2; 9.7.2.3	9.7.2.2; 9.7.2.3
Relative Cost	low	low/ high	moderate	low	low	low/ moderate	moderate	high
Typical Spatial Resolution	~0.5-15 m	1 m – 1 km	20-120 m	> 1 km	~0.1-3 m	0.25 – 3 m	~3 m -1 km	0.1-1 m
Water Quality Applications								
•Temperature/ Sea surface temperature	0	1	2	2	0	0	0	0
•Salinity mapping	0	2	2	2	0	0	0	0
•Color	0	2	0	0	1	1	0	0
•Suspended materials/ Turbidity	1	2	0	0	1	1	0	0
•Chlorophyll	0	2	0	0	0	1	0	0
•Thermal discharges	0	1	2	1	0	0	0	0
•Sewage plumes	1	2	1	0	1	1	0	0
•Runoff (nutrients, fertilizers)	1	2	0	0	1	1	0	0
Hydrological Applications								
•Topography	2	1	0	0	1	1	0	2
•Land cover	1	2	0	0	1	2	0	1
•Latent/ Sensible heat determination	0	0	2	1	0	0	0	0
•Soil moisture	0	1	1	2	0	0	2	0
•Surface albedo	1	2	1	0	1	1	2	0
•Evapotranspiration (ET)		2	2	2	1	1	0	0
•Seepage	0	2	1	0	1	1	0	0
Ecosystem and Vegetation Assessment								
•Native/ Exotic vegetation type and distribution	0	2	0	0	1	2	0	1
•Seasonal dynamics/ Change analysis	0	2	0	0	1	2	0	1
•Vegetation vigor and growth status	0	2	0	0	1	2	0	1
•Indicator species/ Habitat mapping	0	2	0	0	1	2	0	1
•Riparian ecology	0	2	0	0	1	2	0	1
Agricultural Applications								
•Crop type and density	0	2	0	0	1	2	0	1
•Crop growth and health	0	2	0	0	1	2	0	1
•Soil type	1	2	0	0	1	1	1	0
•Agricultural runoff	1	2	0	0	1	1	0	0
•Vegetation stress	1	2	0	0	1	1	0	0

Remote Sensing Applications	Remote Sensing (RS) Technologies							
	Passive RS					Active RS		
	Panchromatic	Multi-spectral/ Hyperspectral	Thermal	Microwave	Aerial Photography		Radar	LiDAR
Film					Digital			
Limnology, Marine/Lake, Coastal Management								
•Coastal erosion/ Shoreline and beach delineation	1	2	0	0	1	1	1	2
•Phytoplankton pigments	0	2	0	0	1	1	0	0
•Corals	0	2	0	0	1	1	0	0
•Submerged aquatic vegetation (SAV)	0	2	0	0	1	1	0	0
•Oysters beds/ Reefs	0	2	0	0	1	2	0	0
Atmospheric Applications								
•Water vapor	0	2	1	2	0	0	1	0
•Cloud type/ Cloud penetration	0	2	0	1	1	1	0	0
•Aerosol/ Chemical pollutants	0	1	1	0	1	1	1	1
•Weather monitoring/ Rainfall intensity	0	1	1	2	0	0	2	0
Emergency Management								
•Biomass fires monitoring & assessment	1	2	2	0	0	0	1	1
•Base map & normal conditions	1	1	0	0	2	2	0	0
•Hurricane wind flood damage	1	1	0	0	2	2	0	0
•Flood damage	1	2	0	0	2	2	0	1
•Post-disaster damage assessment	1	1	0	0	1	2	0	1
•Oil spill	0	2	0	0	2	2	2	0
Land and Water Resources Management								
•Land use	1	2	0	0	1	2	0	0
•Watershed & basin monitoring (canal seepage detection)	0	2	0	0	1	1	0	0
•Regulatory compliance	0	2	0	0	1	2	0	0
•Water permitting	0	2	0	0	1	2	0	0

^aGround sample distance.

Note: RS has broad applications and is project-specific; RS technology (sensors) may become quickly outdated and any specific project undertaken in the future should re-examine the status per technology. RS Technology Ranking Codes are as follows: 0 = Not applicable; 1= Possibly applicable; and 2 = Applicable

9.7.1.2 Water Quality Considerations in Remote Sensing

RS has the potential for use in monitoring many water quality (WQ) parameters, as these parameters are measured spectrophotometrically. Theoretically, spectral image data could be measured, processed, and related to WQ parameters. To date, this has only been successful with a limited number of measurements, including total suspended solids, turbidity, chlorophyll, and total phosphorus.

The use of remote sensing for WQ has been limited by two challenges:

- Relationship of spectral data with real time WQ measurements (i.e. ground-truthing)
- Interference due to reflectance in shallow water bodies

Similar to most data collection efforts, inferences about WQ require that a sufficient number of data points be obtained to develop a valid statistical relationship. For RS activities aimed at evaluating WQ, this means that sufficient numbers of discreet WQ samples must be collected concurrently with the RS collection effort. If the areas are large and remote, this becomes a major logistical effort. It may be logistically impossible to have sufficient personnel to collect and process samples within the time constraints of the particular sensor. In addition, many WQ parameters are dynamic and can vary over the course of a day, further shortening the data collection window.

Radiative transfer models have been developed to help us understand and predict how photons propagate through the complex dynamics of shallow coastal waters. The results enable the monitoring of biological processes and the removal of bottom characteristics. These models are being used to develop regionally appropriate algorithms, which can be applied to ocean color RS images obtained from a variety of platforms (e.g. Moderate Resolution Imaging Spectroradiometer (MODIS) and hyperspectral sensors).

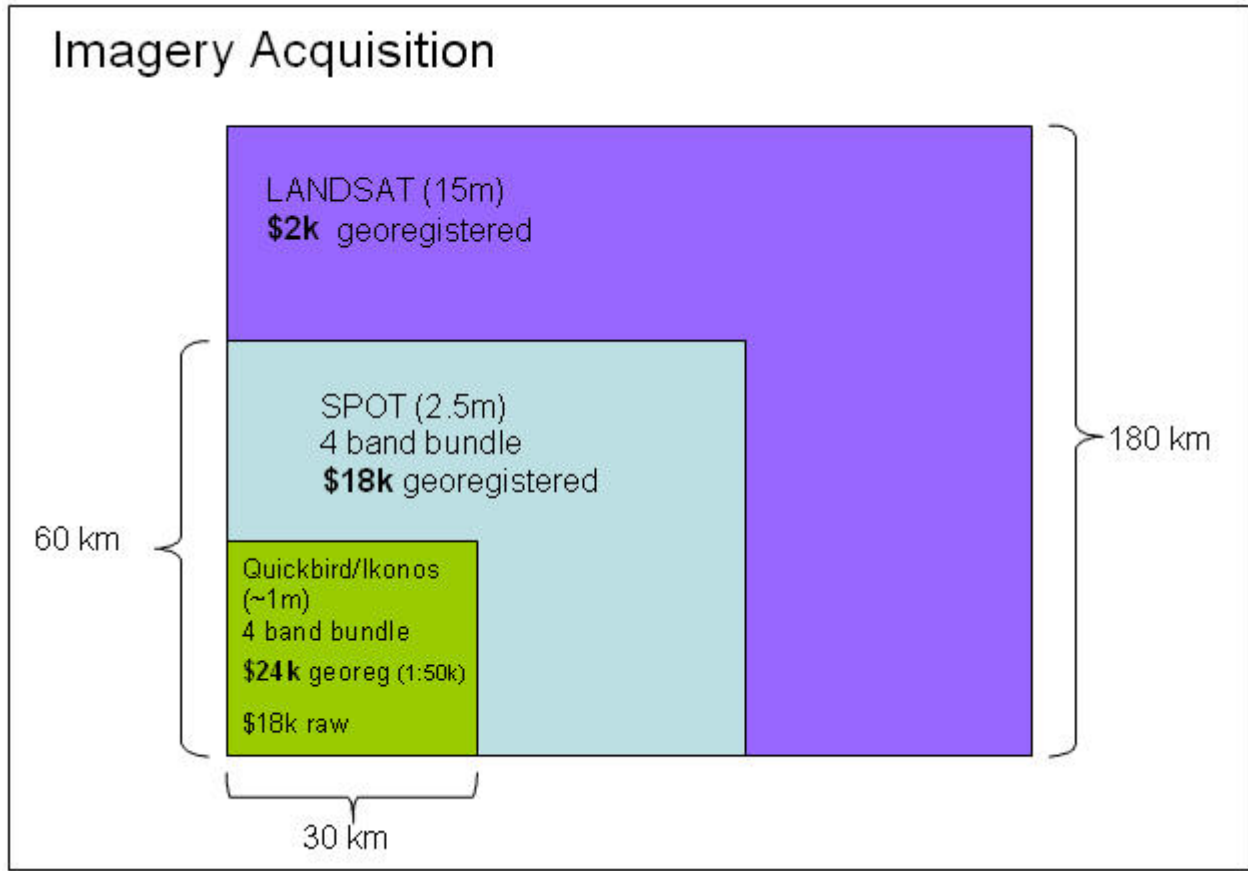
9.7.1.3 Comparison of Typical Remote Sensing Platforms

As discussed in **Chapter 9.7.2**, a variety of airborne and satellite platforms are available for environmental applications. These platforms can be grouped based on the region within which they typically operate. **Table 9.3** provides examples of five satellite sensors or types of sensors that are grouped from largest footprint (Sea-viewing Wide Field-of-view Sensor (SeaWiFS)) to smallest footprint (hyperspectral sensors). Each column indicates the wavebands within which the sensor operates. Note these range from numerous narrow wavebands (hyperspectral) to several larger bandwidth sensors (Landsat 7 Thematic Mapper (TM), SPOT 4, IKONOS).

Generally, as the spatial resolution of a sensor increases, the costs of acquisition and processing of the data increase as well. This is illustrated in **Figure 9.1**, which compares approximate costs for several commonly used sensors for environmental applications.

Table 9.3 Comparison of Spectral Characteristics for Several Commonly Used Sensors

Region of EM Spectrum	Wavelength (microns)	Sensor				
		SeaWiFS (8 bands)	Landsat 7 TM	SPOT4	IKONOS	Hyper-spectral
visible	0.4-0.5					210 Bands with nominal bandwidth of 0.01 microns <small>(for typical hyperspectral sensors)</small>
	0.5-0.6		Panchromatic	Band 1	Panchromatic	
	0.6-0.7			Band 2	Band 1	
near-infrared (NIR)	0.7-0.8			Pan	Band 2	
	0.8-0.9				Band 3	
	0.9-1.0					
	1.0-1.1					
	1.1-1.2					
	1.2-1.3					
	1.3-1.4					
	1.4-1.5					
	mid-infrared (MIR)	1.5-1.6				
		1.6-1.7		Band 5	Band 4	
1.7-1.8						
1.8-1.9						
1.9-2.0						
2.0-2.1						
2.1-2.2			Band 7			
2.2-2.3						
2.3-2.4						
Break						
far-infrared (thermal)	8.0-9.0					
	9.0-10.0					
	10.0-11.0					
	11.0-12.0		Band 6			
	12.0-13.0					
	13.0-14.0					
	14.0-15.0					



Note: Graphic image not to scale; costs reflect 2006 prices.

figure 9.1 Comparison of Approximate Cost vs. Spatial Coverage for Typical High to Moderate Resolution Sensors

9.7.1.4 Remote Sensing Reference Library

The following links provide tutorials, images, glossaries, descriptions of sensors, and FAQs (frequently asked questions) for a variety of RS topics.

- NASA Remote Sensing Tutorial
<http://rst.gsfc.nasa.gov/>
- Ohio View Remote Sensing Tutorial
http://dynamo.phy.ohiou.edu/tutorial/tutorial_files/frame.htm
- On-line Remote Sensing Guide
[http://ww2010.atmos.uiuc.edu/\(Gh\)/guides/rs/home.rxml](http://ww2010.atmos.uiuc.edu/(Gh)/guides/rs/home.rxml)
- Satellite Mission Catalogue and Satellite Instruments Catalogue
<http://www.ceos.org/>
- EROS Data Center Image Gallery
<http://eros.usgs.gov/imagegallery/>

9.7.2 Methods

RS provides cost effective methods for monitoring the Earth at scales, which vary from global to local. This is especially important to CERP as adaptive assessment will depend upon the measurement of regional responses to the individual components. Time series studies help us understand the processes occurring on the land surface, in the atmosphere and in water bodies. GIS, used in conjunction with RS applications, enables us to incorporate the results of image analyses into spatial databases for modeling and mapping.

RS technologies can be divided into two classes, namely, passive and active. Passive sensors measure available electromagnetic energy (reflected sunlight or radiated thermal heat), while active sensors send an energy signal to the target, which is then reflected back to the sensor.

Sensors are designed to detect the amount of energy within a specified range of wavelengths, referred to as the bandwidth. Within the visible spectrum, the various bandwidths are perceived as individual colors. Some types of sensors can detect energy at bandwidths outside the visible spectrum, such as infrared, thermal and microwave wavelengths. Sensors also vary in the number of bandwidths detected. Panchromatic scanners sense one broad bandwidth. Multispectral scanners sense several distinct bandwidths. Hyperspectral scanners detect hundreds of very narrow bandwidths. Spectral resolution is defined as the number and width (wavelength) of bands of electromagnetic energy that are detectable by a given sensor.

Like a picture being taken when a camera shutter is momentarily open, a sensor records the total amount of energy detected in its bandwidth, during a brief moment. The radiometric resolution refers to how sensitive the scanner is to variations in the amount of energy detected. Fine radiometric resolution would produce an image with many fine shades of gray tones. The minimum surface area captured by the sensor for that moment is the spatial resolution (for example 20 meters square) and is represented as one pixel in the resulting image. The scanner moves across the landscape, recording values for each pixel. Temporal resolution refers to how often the same geographic area is revisited by the sensor.

Electromagnetic energy, which is reflected and/or emitted from objects, can be detected and recorded by airborne or satellite platforms as remotely sensed data. A wide variety of airborne and satellite platforms are available for environmental applications. In addition, new platforms become available on a regular basis, just as older platforms are decommissioned.

Passive and active RS technologies are described in Sections **9.7.2.1** and **9.7.2.2**. Examples of platform and sensor combinations that are commonly used are presented, with specific information regarding operational history, resolutions, costs and potential applications. In addition, an example image of a region in Florida is provided for each specific example. Website links to other platforms within the same category are also listed. A list of additional satellite sensors with website links is provided in **Appendix 9-C**. A summary of the applicability of the various remote sensing technologies discussed in this chapter is provided as **Appendix 9-D**.

It is important to note that the information in this chapter and/or appendices may become quickly outdated, and any specific project undertaken in the future should re-examine the status of these sensors closely. Improvements in hardware and software and the availability of data with higher spectral and spatial resolutions are advancing the capabilities of RS science. New data collection platforms are constantly being developed world-wide for a myriad of different applications. New data extraction, analysis, and portrayal methods are constantly being developed and existing

methods improved. This makes it imperative for decision-makers and RS professionals to fully understand the needs of a given project and be able to assess which technologies will offer the most cost and time efficient solutions for their particular need.

9.7.2.1 Passive Remote Sensing Technologies

Passive sensors measure the available electromagnetic energy, such as reflected sunlight or radiated thermal heat. Most passive systems detect visible, infrared and/or microwave wavelengths.

Passive RS technology includes the following systems:

- Panchromatic and multi-spectral
- Hyperspectral
- Thermal
- Passive microwave
- Aerial photography

Panchromatic and Multi-spectral Remote Sensing

Panchromatic and multi-spectral sensors have been available for decades. Panchromatic data are collected in a single broad bandwidth, producing a gray scale image similar to a black-and-white photograph. Multi-spectral data generally consist of several broad wavebands, which are spectrally discrete, producing a natural color or false color image. Both panchromatic and multi-spectral images reveal spatial information (shapes) and limited spectral information. Frequently collected over many years by numerous sensors, these data are readily available at relatively low cost. Spatial analyses can include trend studies where a series of images are used to measure change in a parameter over time. Satellite-based panchromatic and multi-spectral systems (e.g. Landsat, SPOT) have the distinct advantage of providing synoptic coverage and therefore give an exhaustive view of broad geographic areas for land cover analysis. Proven applications include, but are not limited to, vegetation, hydrologic and ecosystem analysis, water and land resources management, and land cover mapping and monitoring. Panchromatic and multi-spectral RS has the potential for the following CERP-related monitoring needs:

- Northern Estuaries submerged aquatic vegetation (SAV)
- Lake Okeechobee native vegetation
- Greater Everglades Vegetation Mosaics
- Greater Everglades Ridge and Slough landscape patterns
- Southern Estuary SAV patterns
- Greater Everglades periphyton mat distribution

Several examples of multi-spectral sensors on various platforms are described below.

Passive Multi-spectral – Low Resolution (>50m) - Example: MODIS - MODIS specifications are listed in **Table 9.4**, and a MODIS scene over Florida is shown in **Figure 9.2**. Similar RS Platforms are listed below:

- AVHRR - <http://edc.usgs.gov/guides/avhrr.html>
- ERS-2 - <http://earth.esa.int/ers/>
- TOMS - <http://toms.gsfc.nasa.gov/>
- SeaWiFS - <http://oceancolor.gsfc.nasa.gov/SeaWiFS/>
- IRS-P4 - <http://www.isro.org/irsp4.htm>
- CBERS2 - http://www.cbers.inpe.br/en/index_en.htm
- RESURS-3 - <http://sputnik.infospace.ru/resurs/engl/resurs.htm>
- ENVISAT - <http://envisat.esa.int/instruments/tour-index/>
- TRMM - http://trmm.gsfc.nasa.gov/overview_dir/virs.html

Table 9.4 MODIS Specifications

Name	MODIS http://modis.gsfc.nasa.gov/about/specifications.php
Bands	36 bands, spectrally discrete
Resolutions	Spatial resolution: 250m, 500m, 1000m bands Spectral resolution: ~15 nm - 300 nm Temporal resolution: twice daily Temperature resolution: >0.05 K Radiometric resolution: 12 bits
Sensor description	Space-borne visible/NIR/TIR sensor, narrow- to broad-band and low spatial resolution
Spectral range or frequency	36 spectral bands from 405-14,385nm
Swath width	2,330km
History of data availability	Owned and maintained by NASA. Not commercially operational, but available.
Data cost	Raw: Free Processed: Free
Proven uses	Cloud top altitude, surface/cloud temperature, ozone, cloud properties, atmospheric water vapor, biogeochemistry (ex. Phytoplankton), land properties, aerosol properties
Uses being researched	Improvement on information details and accuracy for all of the above applications. Atmospheric, land, and ocean imaging in a single instrument
Equipment/software needed	Handheld spectrometer desirable, image processing software such as ENVI and ERDAS Imagine
Possible CERP Applications: <ul style="list-style-type: none"> • Water clarity in Estuaries and Lake Okeechobee. • Salinity patterns • Vegetation mosaics in Greater Everglades Wetlands • Algal Bloom patterns in Lake Okeechobee and Estuaries 	



Figure 9.2 MODIS Scene Over Florida (February 17, 2002)

Passive Multispectral – Medium Resolution (<50m, >15m) Example: Landsat 7 – Landsat 7 specifications are listed in **Table 9.5** and a Landsat 7 image of the Florida Everglades is shown in **Figure 9.3**. Similar Remote Sensing Platforms are listed below.

- IRS-1C, -1D - <http://www.isro.org/programmes.htm>
- SPOT-4 - http://spot4.cnes.fr/spot4_gb/index.htm
- ROCSAT-2 - http://www.skyrocket.de/space/doc_sdat/rocsat-2.htm
- FORMOSAT - http://www.skyrocket.de/space/doc_sdat/formosat-3-cosmic.htm
- ASTER - <http://asterweb.jpl.nasa.gov/>
- EO-1 - <http://eo1.gsfc.nasa.gov/new/extended/>
- SPOT-5 - <http://spot5.cnes.fr/gb/satellite/satellite.htm>
- CBERS2 - http://www.cbers.inpe.br/en/index_en.htm
- IRS-P6 - <http://www.isro.org/pslvc5/index.html>

Table 9.5 Landsat 7 Specifications

Name	Landsat Enhanced Thematic Mapper (ETM+) http://landsat.gsfc.nasa.gov/
Bands	1 pan and 7 multi-spectral bands
Resolutions	Spatial resolution: 15m pan, 30m multi-spectral, 60m thermal Spectral resolution: >60 nm Temporal resolution: 16 days Radiometric resolution: 8 bits
Sensor description	Space-borne multi-spectral sensor, broad-band and medium spatial resolution
Spectral range or frequency	0.450-2.35 um (thermal band: 10.40-12.50 um)
Swath width	185 km
History of data availability	Commercially operational and available
Data cost	Raw: \$600/scene Processed: ~\$2K geo-registered scene SLC-off is currently \$250 at the USGS
Proven uses	Water color, landscape and land use, general vegetation/ecosystem mapping, land change detection, vegetation spatial variation/seasonal dynamics, coastal line change, emergency preparation and damage assessment, regulatory compliance, water permitting
Uses being researched	Improvement on information details and accuracy for all of the above applications
Equipment/software needed	Handheld spectrometer desirable, image processing software such as ERDAS Imagine
Possible CERP Applications: <ul style="list-style-type: none"> • Water clarity in Estuaries and Lake Okeechobee. • SAV vegetation in Lake Okeechobee • Sea grass bed patterns in Northern and Southern Estuaries • Native vegetation patterns in Lake Okeechobee • Vegetation mosaics in Greater Everglades Wetlands • Algal Bloom patterns in Lake Okeechobee and Estuaries • Oyster patterns in Northern Estuaries 	

Landsat Internet Links:

<http://landsat.gsfc.nasa.gov/>
<http://landsat7.usgs.gov/index.php>
<http://www.tec.army.mil/tio/LANDSAT.htm>
http://www.rsi.ca/products/sensor/landsat/lsat45_price.asp
<http://www.rsi.ca/products/sensor/landsat7/lsat7.asp>
<http://edc.usgs.gov/products/satellite/tm.html>
<http://edc.usgs.gov/products/satellite/landsat7.html>
<http://edc.usgs.gov/products/satellite/mss.html>
<http://www.landsat.org/>

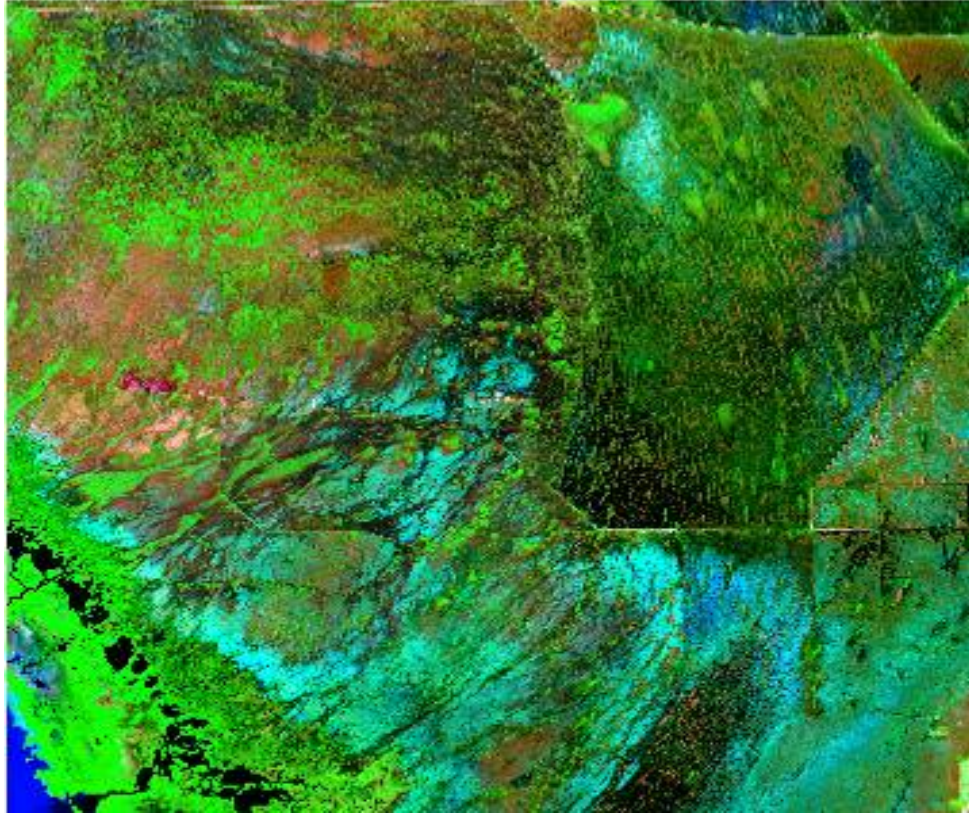


Figure 9.3 Landsat 7 Image of the Florida Everglades (May 2, 2000)

Passive Multi-spectral – High Resolution (<5m) – Example: Quickbird - Quickbird specifications are listed in **Table 9.6** and a Quickbird image of the Florida Keys is shown in **Figure 9.4** Similar Remote Sensing Platforms are listed below.

- IRS-1C/1D
http://directory.eoportal.org/d_ann.php?an_id=8155
- ROCSAT
http://www.skyrocket.de/space/doc_sdat/rocsat-2.htm
- IKONOS
<http://www.satimagingcorp.com/satellite-sensors/ikonos.html>
- EROS-A1
http://www.spaceandtech.com/spacedata/logs/2000/2000-079a_erosa1_sumpub.shtml
- SPOT-5
<http://www.satimagingcorp.com/satellite-sensors/spot-5.html>
- ORBVIEW3
http://www.orbital.com/NewsInfo/Publications/OV3_Fact.pdf

Table 9.6 Quickbird Specifications

Name	Digitalglobe QuickbirdName: http://www.digitalglobe.com/
Bands	1 pan and 4 multi-spectral channels
Resolutions	Spatial resolution: 0.61m pan, 2.44 multi-spectral Spectral resolution: >70 nm Temporal resolution: 1-14 days Radiometric resolution: 11 bits
Sensor description	Space-borne multi-spectral sensor, broad-band and high spatial resolution
Spectral range or frequency	450-900nm
Swath width	16.5km at nadir
History of data availability:	Commercially operational and available
Data cost	Raw: \$14/km ² Processed: \$24/km ²
Proven uses	Invasive species mapping, photogrammetric mapping, aerial photo substitute, data fusion with other lower resolution sensors, coastline change, emergency response, coral reef mapping, land cover assessment
Uses being researched	Improvement on information details and accuracy for all of the above applications
Equipment/software needed	Handheld spectrometer desirable, image processing software such as ERDAS Imagine
Possible CERP Applications: <ul style="list-style-type: none"> • Water clarity in Estuaries and Lake Okeechobee. • SAV vegetation in Lake Okeechobee • Seagrass bed patterns in Northern and Southern Estuaries • Native vegetation patterns in Lake Okeechobee • Vegetation mosaics in Greater Everglades Wetlands • Exotic Vegetation patterns in Greater Everglades • Algal Bloom patterns in Lake Okeechobee and Estuaries • Oyster patterns in Northern Estuaries • Sulfate concentrations in CERP Reservoirs 	



Figure 9.4 Quickbird Image of the Florida Keys (November 7, 2004)

Hyperspectral Remote Sensing

Hyperspectral sensors acquire images in hundreds of co-registered, continuous spectral bands with narrow bandwidths such that for each picture element (pixel) it is possible to derive a more precise spectral signature than is possible with multi-spectral sensors, which acquire fewer and broader bands. The hyperspectral data provide two domains of information for evaluation: spatial patterns (x and y directions) and spectral dimension (z direction).

All natural and man-made materials have a unique signature of reflected light from the sun. The finer spectral resolutions of hyperspectral systems are able to measure this signature and uniquely identify materials. Hyperspectral systems are currently being used to map individual wetland species, as well as detect very subtle changes in wetland ecosystems such as plant vigor and health, or the early signs of stress.

An important challenge associated with the use of hyperspectral sensors is the volume of data generated. Hyperspectral data contain hundreds of spectral bands for each pixel. It is not uncommon to generate hundreds of gigabytes of data in a typical aerial hyperspectral survey. A new generation of processing software, spectral libraries, and automatic feature extraction algorithms have been developed to address these challenges.

Due to the wealth of detailed spectral information that hyperspectral remote sensing provides, hyperspectral data have been widely used for quantitative analysis to support a variety of applications. A partial list of promising applications supported by hyperspectral remote sensing includes terrestrial ecology, vegetation mapping, oceanography, limnology, geology, volcanology, climatology, agriculture, agronomy, snow and ice hydrology, and environmental management.

Hyperspectral technology can be applied to the detection of both vegetation and WQ features. Potential CERP applications include:

- St. Lucie salinity patterns
- Caloosahatchee salinity patterns
- Lake Worth Lagoon salinity patterns
- Northern Estuaries Oysters
- Northern Estuaries SAV
- Lake Okeechobee native vegetation
- Lake Okeechobee water clarity
- Greater Everglades vegetation mosaics
- Greater Everglades Ridge and Slough landscape patterns
- Southern Estuary SAV patterns
- Greater Everglades Mangrove vegetation patterns
- Southern Estuary water clarity

It is important to note, that many WQ parameters, such as salinity, may not be directly measured by the RS equipment, but may be correlated to other WQ parameters that can be directly measured. Algorithms to estimate parameters such as salinity can therefore be derived, if not directly measured. An example of a hyperspectral sensor on an airborne platform is described below.

Passive Hyperspectral (>36 spectral bands) – Example: Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) – AVIRIS specifications are listed in **Table 9.7** and an AVIRIS true color image of Key West, Florida is shown in **Figure 9.5**. Similar Remote Sensing Platforms (space and airborne) are listed below.

- AAHIS - <http://hydrolab.arsusda.gov/rsbasics/sources.php>
- AHI - <http://www.higp.hawaii.edu/>
- AIS - <http://www.itc.nl/>
- AISA - <http://hydrolab.arsusda.gov/rsbasics/sources.php>
- APEX - <http://www.apex-esa.org/>
- ARES - http://www.ares.caf.dlr.de/intro_en.html
- ASAS - <http://www.itc.nl/>
- CAMODIS - http://www.cis.rit.edu/class/simg707/Web_Pages/Survey_report.htm
- CIS - <http://www.itc.nl/>
- CASI-2 - <http://arsf.nerc.ac.uk/documents/casi2.pdf>
- EKWAN-1 - http://scs.gmu.edu/~rgomez/Hyperspectral_Imaging_Systems.doc
- FLI/PMI - http://rst.gsfc.nasa.gov/Sect13/is_list.html
- GER EPS-H - <http://www.ger.com/epsh.html>
- HYMAP - <http://hydrolab.arsusda.gov/rsbasics/sources.php>
- HYPERCAM - <http://www.isprs.org/.isprs.org/>
- IRIS - <http://www.itc.nl/>
- MAIS - http://rst.gsfc.nasa.gov/Sect13/is_list.html
- MIDIS - http://rst.gsfc.nasa.gov/Sect13/is_list.html
- MISI -
- MIVIS - <http://www.lara.iaa.cnr.it/inglese/mivis/mivis.html>
- PHI - <http://www.gisdevelopment.net/aars/acrs/1999/ts10/ts10399.shtml>
- PHILLS - http://rsd-www.nrl.navy.mil/7212/pdf/20020225_OE.pdf
- PROBE-1 - <http://www.earthsearch.com/index.php?sp=10>
- ROSIS -
- SEBASS - <http://www.lpi.usra.edu/science/kirkland/Mesa/text.html>
- SCSI - <http://www.borstad.com/papers/peterstmw.html>
- SMIFTS - <http://www.itc.nl/>
- TRWIS-III - http://scs.gmu.edu/~rgomez/Hyperspectral_Imaging_Systems.doc
- VIFIS - <http://www.unitus.it/dipartimenti/dpv/R.Casa-PhD%20Thesis,2003.pdf>
- MUSIC -
- OMAIS - <http://www.cossa.csiro.au/reports/kaiyang/beijing.htm>

Table 9.7 Airborne Visible and Infrared Imaging Spectrometer Specifications

Name	AVIRIS http://aviris.jpl.nasa.gov/
Bands	224 bands, spectrally continuous
Resolutions	Spatial resolution: varies. Regularly 3-20 m/flown @20km altitude Spectral resolution: ~10 nm Temporal resolution: N/A Radiometric resolution: 10 bits
Sensor description	Airborne hyperspectral sensor, narrow-band and high to medium spatial resolution
Spectral range or frequency	~400 to 2,500 nm
Swath width	512 pixels = 1.5-10km
History of data availability	Owned and maintained by NASA JPL. Not commercially operational, but available (both archival data and programmed acquisitions)
Data cost	Raw: regularly \$100,000/flight hour. \$0 to a few thousands dollars for NASA PIs. Processed: archived: \$500/tape
Proven uses for hyperspectral RS technology	Water color/turbidity/chlorophyll, marine plants, landscape and land use, change analysis, vegetation spatial variation/seasonal dynamics, vegetation species identification and classification, leaf chlorophyll, leaf water, cellulose, lignin, biomass fires, clay/iron minerals, carbonates, sulfates, water vapor
Uses being researched	Water and air pollutants dissolved organic compounds, surface albedo, vegetation vigor/stress, exotic vegetation type and distribution, riparian vegetation, cloud types, aerosols, ice studies
Equipment/software needed	Handheld spectrometer required, image processing software such as ENVI
Possible CERP Applications: <ul style="list-style-type: none"> • Detailed analysis of land and water features • Water clarity in Estuaries and Lake Okeechobee. • SAV vegetation in Lake Okeechobee • Sea grass bed patterns in Northern and Southern Estuaries • Native vegetation patterns in Lake Okeechobee • Invasive species mapping • Vegetation mosaics in Greater Everglades Wetlands • Algal Bloom patterns in Lake Okeechobee and Estuaries • Oyster patterns in Northern Estuaries • Sulfate concentrations in CERP Reservoirs 	

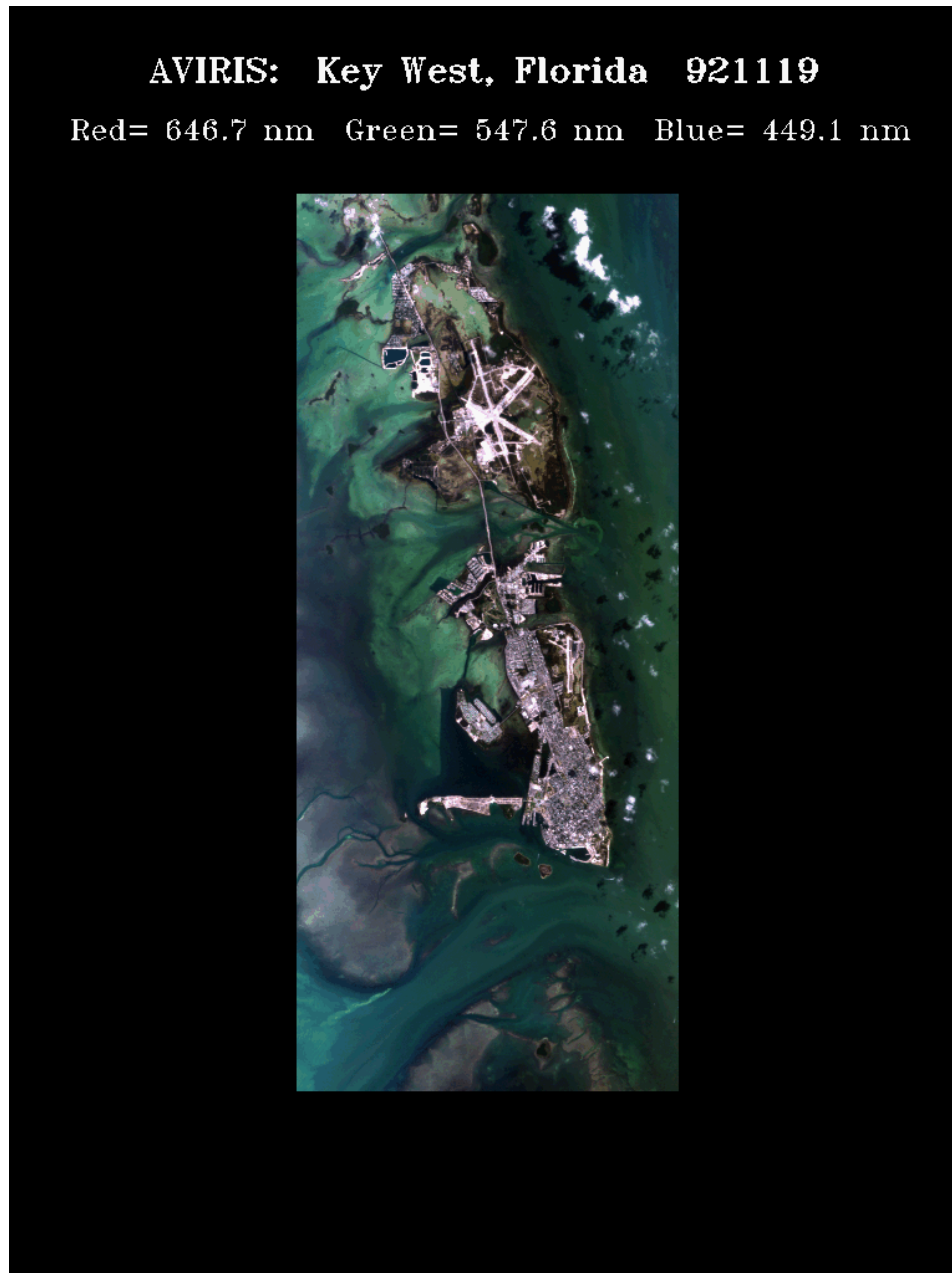


Figure 9.5 AVIRIS True Color Image of Key West, Florida (November, 1992)

Thermal Remote Sensing

In the thermal infrared (TIR) spectral region, most natural surfaces emit electromagnetic radiation that can be used for passive detection. Advances in infrared technologies over the past two decades have been made possible by the development of modern electronics and new detector materials. The result is that high-performance TIR imaging systems, utilizing both 3-5 micrometer (μm) and 8-12 μm wavelengths, have become available.

A list of applications supported by thermal RS include geology (e.g. rocks discrimination and mineral deposits mapping), water pollution studies (e.g. thermal plumes and oil spills), earth and

water surface temperature mapping, soil moisture determinations, snow and ice hydrology, volcanology, hydrologic modeling (e.g. latent/sensible heat determination), and agriculture and vegetation monitoring. While this is an important technology for RS, it does not have many applications related to CERP and adaptive assessment.

Passive Microwave Remote Sensing

Beyond the infrared wavelengths, wave energy in the range ~0.15 cm to ~30 cm (~200 gigahertz (GHz) to ~1 GHz) forms the basis of remote sensing by microwave radiometry. Passive microwave radiometry, applied to investigations of the Earth's surface, involves the detection of thermally generated microwave radiation. Although the naturally emitted microwave radiation intensities are much lower than those in the infrared, resulting in poorer brightness temperature resolution, the longer wavelengths allow sensing through cloud cover. Passive microwave sensors also have the advantage of gathering data at night as well as during the day.

Microwave RS has been utilized mainly in the following areas: water salinity mapping, surface temperature measurement, monitoring of soil moisture content, floodplain delineation, and canal seepage detection.

This technology has some limited utility for CERP principally for measurement of salinity. This is especially critical for projects such as Indian River Lagoon, C-43 Reservoir, and Biscayne Bay Coastal Wetlands, where salinity regime management is the project purpose. Potential CERP monitoring applications include:

- St. Lucie salinity patterns
- Caloosahatchee salinity patterns
- Lake Worth Lagoon salinity patterns
- Southern Estuary salinity patterns

Aerial Photography

Aerial photography was traditionally collected by an airborne camera using panchromatic (black and white) or color film. The first aerial photographs were taken in the 1850s from balloons and kites. Modern advances in aerial photography, typically taken from aircraft, include film that is sensitive beyond the visible spectrum and digital cameras. Vertical photographs are acquired when the camera is aimed directly at the ground below. Orienting the camera diagonally at a target produces oblique photographs with a much larger field of view and much greater distortion of geometry, resulting in distant objects looking much smaller than nearby objects. Vertical photographs typically have less distortion and can be more easily geometrically corrected to produce consistent scale across the entire photograph.

9.7.2.2 Active Remote Sensing Technologies

Active sensors send an energy signal to the target that is then reflected back to the sensor. The difference in range and intensity between the source and return signals are measured and recorded by the sensor. Most active systems operate at microwave wavelengths, which can penetrate through clouds. Therefore, active sensors can be utilized at night or during storms, which is an advantage over most passive systems.

Active RS sensing technologies include:

- Radar
- Light Detection and Ranging (LiDAR)

Radar Remote Sensing

Radar is an active sensing system, sending microwave energy and capturing the return signal. Synthetic aperture radar (SAR) systems use the distance an aircraft flies to synthesize a large antenna. With a synthetically large antenna, SARs can produce improved resolutions over other radars. The uniqueness of radar RS can be characterized as follows:

- SAR technique gives fine resolution in both azimuth and range dimensions.
- Properly selected frequencies are not affected by the atmosphere, i.e. clouds, dust, gas content, and rain.
- Radar provides its own illumination; therefore, radar data can be acquired during day or night.
- Microwaves are strongly affected by target physical properties; thus, radar remote sensing is complimentary to visible/infrared measurements, which are sensitive to chemical composition and thermal properties.
- The polarimetry (polarization) capability helps in understanding the physics of the backscattering, therefore widening the range of applications for radar backscatter measurements.
- Interferometric synthetic aperture radar (IFSAR) data can be acquired using two antennas on one aircraft or by flying two slightly offset passes of an aircraft with a single antenna. IFSAR can be used to generate very accurate surface profile maps of the terrain.

Due to the above unique features of SAR technology, radar remotely sensed data are being frequently utilized in a wider range of disciplines. A partial list of promising applications supported by radar remote sensing includes disaster monitoring (e.g. monitoring of hurricane induced flooding), environmental monitoring, hydrology and oceanography, geology and volcanology, agriculture, cartography, and military intelligence.

Doppler radar, a ground-based upward-looking technology, measures the speed of moving targets by detecting the change in frequency of the reflected wave, caused by the Doppler effect. A common application is weather monitoring.

An example of Active Radar is Radio Detection and Ranging: RadarSaT. RadarSaT specifications are listed in **Table 9.8** and ERS-1 (no longer operational) radar images of the Everglades are shown in **Figure 9.6**. Similar RS Platforms are listed below.

- ERS-2 - <http://earth.esa.int/ers/>
- ENVISAT-1 - <http://envisat.esa.int/>

Table 9.8 RadarSaT Specifications

Name	RadarSaT http://radarsat.space.gc.ca/asc/eng/satellites/radarsat1/components.asp
Bands	1 band
Resolutions	Spatial resolution: ~8-100 m depending upon beam modes and beam positions Spectral resolution: RF Bandwidth 11.6, 17.3, or 30.0 MHz Temporal resolution: repeat cycle is 24 days (but 0.5-5 days if combining beam modes and positions, depending upon latitudes) Radiometric resolution: 8 bits
Sensor description	Space-borne SAR sensor
Spectral range or frequency	5.3 GHz (C-band), single frequency, single polarization (HH)
Swath width	45-500km depending on acquired resolution
History of data availability	Owned and maintained by RadarSaT International. Commercially operational and available
Data cost	Raw: >\$2,700/scene (\$1,500/scene for data older than 01/01/99) Processed: >\$2,700/scene (\$1,500/scene for data older than 01/01/99)
Proven uses	Surface roughness (micro-topography), topography, (DEM generation) and/water boundaries, soil moisture, vegetation mapping, anthropogenic features, oil spill and pollution, hurricane and storm induced flooding, emergency response/recovery/damage assessment for hurricane/storm caused flooding
Uses being researched	Improvement on information details and accuracy for all of the above applications
Equipment/software needed	Image processing software such as ENVI and ERDAS Imagine
Possible CERP Applications: <ul style="list-style-type: none"> • Detailed analysis of land and water features • Topographic/bathymetric analyses of land and water features • SAV vegetation in Lake Okeechobee • Sea grass bed patterns in Northern and Southern Estuaries • Native vegetation patterns in Lake Okeechobee • Invasive species mapping • Vegetation mosaics in Greater Everglades Wetlands • Algal Bloom patterns in Lake Okeechobee and Estuaries 	
Internet Links: http://gs.mdacorporation.com/products/sensor/radarsat/radarsat1.asp http://gs.mdacorporation.com/products/sensor/radarsat2/overview.asp http://www.tec.army.mil/tio/RADARSAT.htm http://www.crisp.nus.edu.sg/~research/tutorial/radarsat.htm	

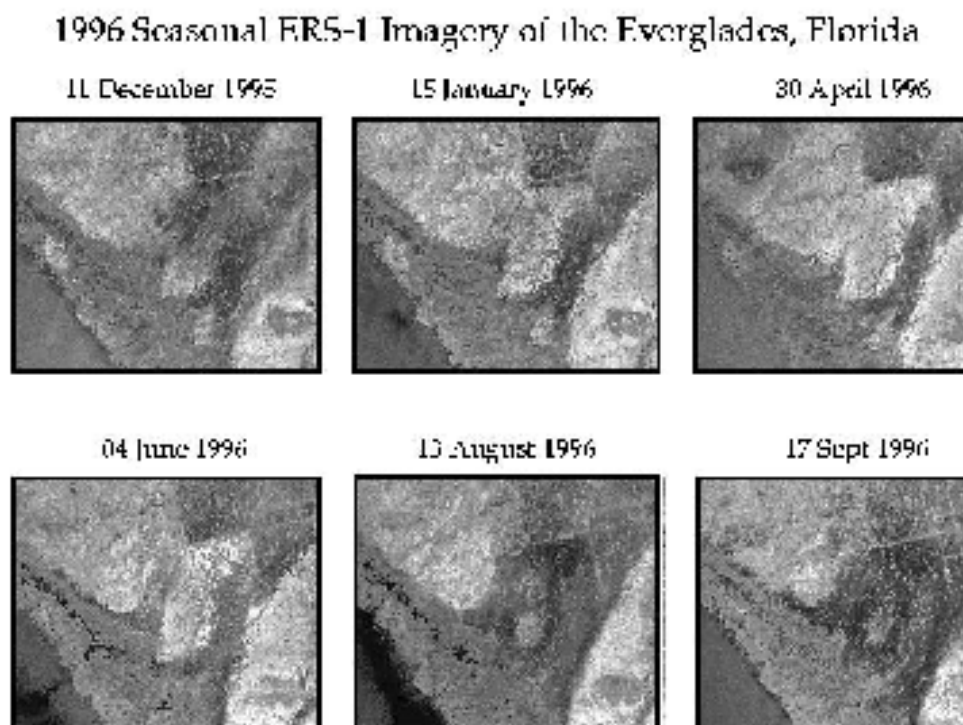


Figure 9.6 ERS-1 Radar Images of the Everglades Showing the Changes in Seasonal Soil Moisture (ERS-1 is no longer operational.)

Light Detection and Ranging Remote Sensing

LiDAR is an active system similar to microwave radar, but operates in the ultraviolet to near infrared regions of the spectrum. It consists of a laser that emits radiation in pulse or continuous mode through a collimating system. The use of lasers mounted on remote sensing platforms is currently restricted to aircraft. Lasers are not yet used on satellite platforms because of their requirements for large collection optics and extremely high power sources.

Three types of LiDAR are presently available: an altimeter type, which can plot a terrain profile; a scanning type, which can be used as a mapping instrument; and spectroscopic type, which can be used for mapping air pollutants and water quality.

LiDAR has been used in CERP for planning level elevation surveys. When developing topographic maps using LiDAR technology, the return signals from surface features such as buildings and vegetation cover are typically removed using a number of dedicated extraction algorithms resulting in a “bare earth” digital terrain model. For a number of reasons, wetland vegetation cover and standing water confound elevation interpretation. In the Everglades, LiDAR use has been limited to surveys performed after the large burns and/or during drought periods.

The Bullets below present examples of Active High Resolution LiDAR. LiDAR specifications are listed in **Table 9.9** and a Shoals LiDAR relief map near Port Everglades is shown in **Figure 9.7**.

- ICESAT <http://icesat.gsfc.nasa.gov/>

- LiDAR and IFSAR: Pitfalls and Opportunities for Our Future
<http://www.dewberry.com/uploadedFiles/LIDARandIFSAR.pdf>
- Measuring and Mapping the Topography of the Florida Everglades for Ecosystem Restoration - <http://erg.usgs.gov/isb/pubs/factsheets/fs02103.html>
- Mapping the Surface of Sheet Flow Water in the Everglades
<http://www.isprs.org/commission3/annapolis/pdf/Carter.pdf>
http://www.optech.ca/pdf/Brochures/shoals_shoals.pdf

Table 9.9 Light Detection and Ranging Specifications

Name	LiDAR
Bands	1 or 2 bands
Resolutions	Spatial resolution: varies (0.5-30 meters common) Spectral resolution: N/A Temporal resolution: N/A Radiometric resolution: N/A
Sensor description	Airborne LiDAR sensor, 6-inch (15.24 cm) vertical accuracy achievable. Detectable water depth is up to three times the Secchi Depth.
Spectral range or frequency	Commonly an infrared channel (e.g. 1064 nm) is used for surface detection, while bottom detection is from a blue-green channel (e.g. 532 nm)
Swath width	Dependent on altitude of aircraft
History of data availability	Commercially operational and available. Such as USACE's Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system, which has become CHARTS (Compact Hydrographic Airborne Rapid Total Survey); 3001's AeroScan Laser Mapping system; NASA's Airborne Topographic Mapper (ATM) etc.
Data cost	Raw: unknown Processed: - \$100-\$300 per sq mile (2.59 sq km) (LiDAR data collection & processing) - \$300 -\$500 per sq mile (average cost of LiDAR topography, depending on deliverables (LiDAR Mapping conference, Spring 2004))
Proven uses	Topography, tree height and stand mapping, cultural feature delineation, vegetation structure and community mapping, bathymetry, nautical charting, clear and shallow waters
Uses being researched	Water quality (e.g. turbidity) and improvement on information details and accuracy for all of the above applications
Equipment/software needed	- Image processing software such as ENVI and ERDAS Imagine. - Raw LiDAR data is generally only accessible to the sensor vendor's post-processing software. Post processed and geo-referenced LiDAR data can be delivered in any number of formats, including ASCII, TerraScan, BIN and LAS.
Possible CERP Applications:	
<ul style="list-style-type: none"> • Planning level mapping • Water depth determination • Planning level engineering 	
Internet Links:	
http://coastal.er.usgs.gov/lidar/ http://lidar.jpl.nasa.gov/ http://earthobservatory.nasa.gov/ http://www.opticsjournal.com/LIDARBibliography.pdf http://lidar.ssec.wisc.edu/ http://www.geospatial-online.com/geospatialsolutions/article/articleDetail.jsp?id=58326&&pageID=2	

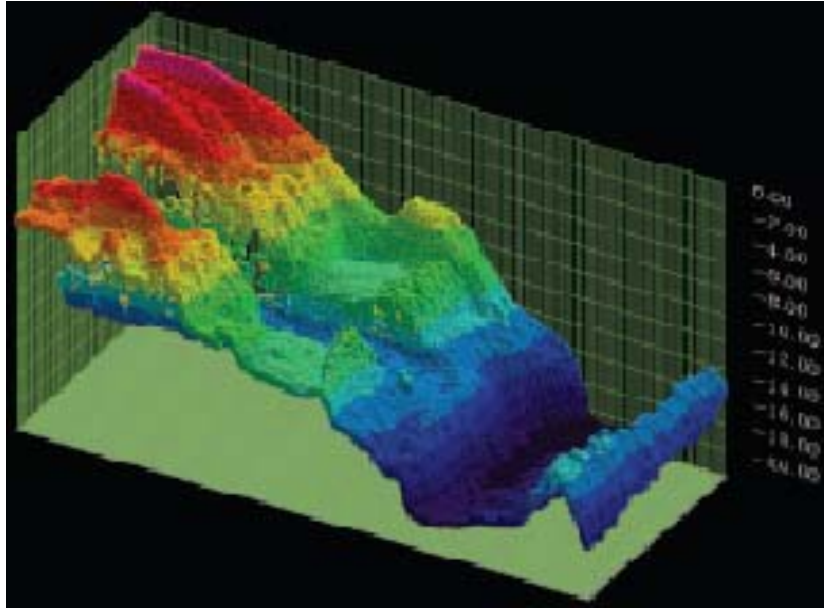


Figure 9.7 Shoals LiDAR Relief Map Near Port Everglades

9.7.3 Data Processing and Analysis

9.7.3.1 Photogrammetry and Photo Interpretation

Photogrammetry is the science of deriving measurements from photographs. Common tasks can include rectifying an aerial photograph to minimize inherent distortion of size, distance, and scale, linking features on a photograph to a spatial coordinate system, and/or integrating multiple photos to create a stereo model for 3D viewing. Photo interpretation is a sub-science of photogrammetry and includes the identification and classification of the features on an aerial photograph. Digital processing techniques can also be applied to images derived from scanned air photos.

9.7.3.2 Digital Image Processing and Analysis

Digital image processing includes image correction (atmospheric and geometric), analysis for information extraction, and visual display of images or derived maps. Image processing software is available commercially or as shareware.

9.7.3.3 Positional Accuracy

Correcting images for geographic distortion requires accurate reference data. The coordinate locations of identifiable points can be manually captured through GPS technology. The accuracy and quality of USGS Digital Orthophoto Quadrangles (DOQs) meet National Map Accuracy Standards, and are often used as the reference data for geo-rectification. Accurate elevation data can be obtained from USGS Digital Elevation Models (DEMs).

Ground Control Points (GCP) for Image Rectification

Ground control points (GCPs) are physical points on the ground whose positions are known with respect to some horizontal coordinate system and/or vertical datum. When mutually identifiable on the ground and on a map or photographic image, ground control points can be used to establish the exact spatial position (x, y, and z coordinates) and orientation of the image to the ground. Examples of GCPs are sidewalk corners and intersections in roads and airports, piers and pier abutments. Less desirable GCPs are banks of streams, corners of buildings, trees and areas of heavy vegetation cover.

A simple way to measure such geographic distortion is to compute the root-mean-square-error (RMSE) for each ground control point by using the following equation (Jensen, 2005):

$$\text{RMSE} = \sqrt{(x' - x_{\text{orig}})^2 + (y' - y_{\text{orig}})^2}$$

where x_{orig} and y_{orig} are the original row and column coordinates of the GCP in the image and x' and y' are the computed or estimated coordinates in the original image. The square root of the squared deviations represents a measure of the accuracy of this GCP in the image. By computing RMSE for all GCPs, it is possible to see which GCP has the greatest error, and determine the sum of RMSE.

The methods used by different agencies to measure positional accuracy of spatial data are discussed below:

- The Federal Geographic Data Committee (FGDC) released the Geospatial Positioning Accuracy Standards (GPAS) in 1998. The National Standard for Spatial Data Accuracy component of the GPAS uses the concept of well-defined points to test for error. The preferred test for positional accuracy is to test the data against an independent source that is of higher accuracy. The standards define a minimum number of points to test (i.e. twenty) and the preferred arrangement of these points within the dataset. The standards (FGDC, 1998) states:

The NSSDA uses RMSE to estimate positional accuracy. RSME is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points.

Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates; compilation and final computation of ground coordinate values in the product.

- The USACE “NAVSTAR GPS Surveying” Manual, EM 1110-1-1003, Chapter 11 discusses RMSE in more detail. RMS statistics can have varying confidence levels. A **1- σ RMS** error equates to the radius of a circle in which there is a 63% probability that the computed position is within this area. A circle of twice this area (i.e. **2 – σ RMS** or **2 DRMS**) represents approximately a 98% positional probability circle, and **3 DRMS** represents 99+ % probability. FGDC and the US Army Corps of Engineers require

horizontal and vertical geospatial accuracies to be reported at the 95% RMS confidence level (equivalent to 2 DMRS).

The USACE RS Manual (EM 1110-2-2907, Section 5-17) uses a program where RMS calculation required an entry of at least three or four GCPs. RMS error should decrease as more GCPs are added to the image. RMS below 1.0 is an acceptable level of accuracy, and the image can be projected and saved. For RMS higher than 1.0, reposition GCPs with high individual errors or delete them and select new GCPs.

9.8 Quality Assurance and Quality Control

QA is an integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item or service is of the type and quality needed and expected by the customer. QC is the system of technical activities that measures the performance of a process against defined standards set by the customer. For any RS applications, including those related to CERP projects, the goal of QA/QC is to help ensure that environmental decisions supported by remotely sensed data are as reliable, consistent and accurate as possible given the variety of RS technologies that may be applied.

The application of QA/QC processes to RS is complex because RS is a very integrated and dynamic science; the type of data generated and the volume of data generated challenge traditional QA/QC procedures. There are no “one-size-fits-all” QA/QC procedures for RS activities. Generally, these procedures will vary depending on the type of sensor and platform. To date, few documents exist that address remote sensing QA/QC. In 1999 the U.S. EPA began to consider the issues related to QA/QC of RS under their Geospatial Quality Council. Because the products of RS are used in conjunction with other products and processes, the potential for human induced and computer error is high. Errors may occur during the various phases of a remote sensing project including data collection, data input, data storage, data manipulation/transformation, data output and use/interpretation of results. Therefore, it is critical that investigators describe QA/QC procedures and detailed descriptions of how they will control potential errors for each of these phases in the project MP or QAPP. The description of QA/QC procedures should document to the extent possible, all judgments and interpretations such that another researcher can reproduce their results.

9.8.1 Quality Assurance for Remote Sensing Projects

The successful application of RS to a data need is based on the appropriate integration of multiple, interrelated data sources and analysis procedures (Lillesand and Kiefer, 2000). There is no single combination of sensor and interpretation procedures that is appropriate for all resource inventory and environmental monitoring applications. Furthermore, among appropriate applications, a wide variety of data acquisition and analysis approaches exist. However, conceptually, all successful RS projects involve, at a minimum, the following parameters adapted from Lillesand and Kiefer (2000):

- clear definition of the problem and question(s) being asked;
- an evaluation of the appropriateness for applying remote sensing technologies;
- identification of appropriate data acquisition procedures;

- identification of appropriate data interpretation techniques;
- identification of needed reference (ground-truth) data; and
- establishment of criteria upon which the quality of collected information can be judged.

The clear articulation of the information requirements of a particular problem and the extent to which remote sensing can meet these needs cannot be stressed enough. In many cases, one or more of the above criteria are overlooked, resulting in less than satisfactory results (Lillesand and Kiefer, 2000). Numerous resource management programs exist with little or no mechanism for evaluating the performance of RS systems in terms of information quality. Alternatively, vast quantities of remotely sensed data have been collected without the capability to analyze or interpret the data to the extent needed. And finally, the most common mistake is the inappropriate use of remotely sensed data simply because the problem has not been clearly defined. Clearly, articulating the information requirements of a particular problem is critical to the success of any RS project.

For more on the application of QA/QC principles to RS procedures, see the following links:

- NASA Remote Sensing Tutorial
http://rst.gsfc.nasa.gov/Sect13/Sect13_1.html
- CalSpace Ground-Truthing Tutorial
<http://www.cstars.ucdavis.edu/classes/hsgrdtutorial.html>
- Guide Specification for Photogrammetric Mapping and Aerial Photography Services
<http://140.194.76.129/publications/eng-manuals/em1110-1-1000/toc.htm>

The types of RS projects that may be conducted as part of CERP are varied including the types of sensors required, the spatial scales required, the target (terrestrial or aquatic), spectral resolutions, and technical complexity. For this reason, it is important that QA procedures are implemented during the design, execution, and analysis of projects.

QA during the planning stage should focus on ensuring that detailed, written procedures describe data collection, data input, data storage, data manipulation/transformation, data output and use/interpretation of results such that data are complete, accurate, and traceable. The SOW must be detailed and include at a minimum the following components:

- Project goal(s), objectives, and background
- Location
- Sensor to be used and justification
- Detailed ground-truthing/field sampling plan
- Detail of proposed data analysis, classification, and interpretation of imagery
- Accuracy assessment, including any calibration and maintenance requirements
- Documentation procedures
- Hardware and software requirements, including periodic downloads, battery replacement schedules, back-up procedures
- Metadata

- Quality Assurance Plan
- Deliverables (including graphic formats, map, database, imagery, delivery media and format)

The SOW should be reviewed not only by the QAOT/designee/RS sub-team, but also by at least one other outside peer reviewer with expertise in the field of RS, preferably with experience in the type of project being reviewed. This will ensure that important details are not omitted, and that the project has the greatest chance for success.

QA assessments will primarily involve reviews of data management or documentation procedures. These assessments will be performed by the project or sponsor agency QA representative. In addition, QA activities should assess whether the technical team has met the required performance specifications as stated in a SOW. During this review the deliverables may be tested to obtain a statistic measure of certain accuracy parameters, including positional or thematic accuracy and an estimation of uncertainty.

9.8.2 Quality Control for Remote Sensing Projects

The overall success of any RS project will be predicated on a thoughtful project design with clearly achievable goals and outcomes in mind. A successful project is also dependent on the integration of multiple, interrelated data sources and analysis procedures. Because of the complex nature of RS and the rapidly changing nature of the technology, all projects should have the involvement of a RS specialist, preferably one with experience in the type of application being addressed. Additional personnel should include scientists and resource managers familiar with the scope and nature of the problem being addressed.

This section provides general guidance on QA/QC issues that are commonly encountered in the field of remote sensing. However, in part due to the wide variety of CERP projects that could benefit from RS technology, and the technical nature of RS technologies, this document cannot begin to address the detail necessary for carrying out individual projects. As each project is developed, a QAPP needs to be written specifically for that project. RS is not an exact science, and methods and sensors are continually being improved. Information and lessons learned from one project should be passed on for future project planning designs. With proper planning, RS can play an important and critical role in CERP.

9.8.2.1 Water Quality

From a RS perspective, WQ is affected by a variety of components including point source pollutants, non-point source pollutants, oil slicks, turbidity, harmful algal blooms, chlorophyll concentration, and dissolved organic matter.

Because of the complex and dynamic nature of the water column, whether it is in estuarine systems or inland waters, a well-thought out ground-truth campaign is imperative in order to establish the most accurate relationship between remotely sensed data and *in situ* components of the water column. The following are key components that must be addressed for QA purposes:

Time frame: The dynamic nature of the water column requires that ground-truth data be collected relatively concurrent with any over-flight or satellite overpass. The allowable time period is dependent upon practical logistics, the nature of the water body, and any currents or vertical daily fluctuations that may occur in the area of interest. A one to two hour time period on

either side of an over-flight is not uncommon, however this should be determined on a case by case basis.

Spectral returns: In many shallow water bodies, particularly those with good water clarity, spectral returns can be confounded by the reflectance characteristics of the bottom substrate. In some cases, that portion of the spectral signature being contributed by the bottom can be identified through *in situ* field observations and/or modeled to understand and predict the resulting reflectance values (see **Section 9.7.1.2**, WQ Considerations in RS). Nevertheless, care must be taken in interpreting any data that is collected in clear, shallow waters.

Data needs: The number of ground-truth points needed for any water quality study can vary, depending on the specifics of the collection activity. It is important to collect a range of data from anticipated minimum values for any parameter to the highest values typically seen. This may also mean that multiple ground-truth efforts are needed, including days when conditions are fairly calm as well as days just following storm events. Seasonal considerations may need to be taken into account as well. This may be more easily accomplished with satellite imagery when multiple scenes are available, as compared to aerial data collections. In either case, this will ensure a more robust dataset.

An example of SOW for a representative WQ case study is shown in **Appendix 9-G**.

9.8.2.2 Wetlands

As with WQ, some consideration must be given to the dynamic nature of water movement, water depth, and hydro-period. In that regard, the development of formal mapping conventions in association with an image interpretation key early in the mapping process can help ensure that consistency and integrity are maintained regardless of hydrologic conditions (especially true for manual air photo interpretation projects). For CERP monitoring efforts, wetland delineations can aid in the following ways:

- determining status and trends in performance measures;
- detecting unexpected responses of the ecosystem to changes in stressors resulting from CERP activities; and
- supporting scientific investigations designed to increase the understanding of the complexities of the ecosystem over a broader scale.

Special considerations should be given to the following:

Scale: Because Everglades wetlands are such a large expanse of territory, special consideration should be given to the overall monitoring effort when planning for the acquisition of imagery. It is often advantageous to combine the RS missions of a number of associated mapping/monitoring projects that can benefit from the same type of sensor data. Not only is there a cost advantage due to the economy of scale, but continuity, consistency, and comparability are more easily maintained. The overall data acquisition process is also more efficient and streamlined.

Seasonality: Consideration should be given to the seasonal aspects of remotely sensed data that are collected for wetlands work. Collections during the dry season may possibly be more useful scientifically with the added advantage of reduced cloud cover. The importance of repeat

collections during the same time periods on an inter-annual basis is important for change detection as well.

Stand age/successional state: Recent advances in LiDAR technologies allow for the collection of multiple pulse returns, which represent canopy structure, e.g. ground topography shrubs, and tree tops. When coupled with species composition and site quality information, height serves as an estimate of stand age or successional state. It is important that experienced and qualified vendors are utilized to collect the most up-to-date imagery and to take advantage of recent advances in laser mapping techniques (e.g. data processing, analysis, extraction algorithms), and to assess the technologies usefulness for specific objectives.

Example statements of work for representative wetland case studies are presented in **Appendices 9-E, 9-F, 9-G, and 9-H.**

9.8.2.3 Land Use and Land Cover

Knowledge of land use and land cover is important for a number of CERP planning and management activities. Land cover maps can be developed from a local to a regional scale depending on the context of the questions being asked. Land cover mapping can be closely correlated to wetland mapping. In an ideal world, accurate wetland data (e.g., National Wetlands Inventory) should have a perfect fit within land cover maps of a similar vintage. Unfortunately, due to differences in classification systems and wetland definitions, this is often not the case. A greater effort should be made to integrate similar data sets such as these during the preliminary cross-project planning effort, rather than after the data are processed. Considerations for land cover mapping include the following:

Mapping scheme: A number of mapping schemes are available for land cover classifications. It is important to select an appropriate scheme and utilize all decision rules and processes associated with it. Trained personnel should be utilized at all times to conduct the imagery analysis and interpretation of the remotely sensed data. Whenever possible, project managers should make every effort to coordinate classification systems between projects. In that regard, development of a classification system should include considerations for cross-project interoperability such as using a flexible hierarchal structure with more regional or global categories. This will ensure greater consistency, repeatability, and comparability during analyses.

Quality Assurance: Historically, color infrared photography (CIR) has been used for mapping portions of the Everglades. The advantage is that extensive methodologies and QA procedures have already been established and products are consistent. The disadvantages include lengthy photo-interpretation times on a regional scale and undemonstrated accuracy for mapping a large number of Florida vegetation classes. Some vegetation responses to CERP hydrological changes may occur within two years (e.g. Taylor Slough, Everglades National Park), yet it is questionable whether a regional vegetation map can be produced from photos every two years. One of the most comprehensive CIR mapping projects in the region took place within Big Cypress National Preserve and Everglades National Park using interpreted NAPP photos. An accuracy assessment of the maps derived from the NAPP photos (currently underway), indicates preliminary accuracies below 50%. However, more recently, other high resolution satellites and hyperspectral platforms are being explored as alternatives or complements to CIR. Careful consideration should be given to QA when implementing these tools to ensure high quality products that are consistent and repeatable.

Ground-truthing: Ground-truthing of land cover is an important component of any successful mapping project. While some areas may be easily accessible, other areas may only be accessible by airboat and/or helicopter. Adequate funding should be provided to insure that ground-truthing can be conducted to a degree necessary to satisfy the project accuracy requirements as well as the MP or QAPP.

Example SOW for of representative land use and land cover case studies are shown in **Appendices 9-F and 9-H**.

9.8.2.4 Benthic Habitat

One of the potential performance measures for CERP involves benthic habitat mapping using aerial photography. This discussion is based on *Guidance for Benthic Habitat Mapping: An Aerial Photographic Approach* (U.S. NOAA Coastal Services Center 2001) (<http://www.csc.noaa.gov/benthic/mapping/pdf/bhmguide.pdf>), based on the experience gained by the NOAA Coastal Services Center. This document provides technical guidance to data developers to produce a consistent benthic data set suitable for regional comparison and applicable to various coastal management issues. Examples from this document are used to illustrate some general areas of QA/QC concerns and applications of data validation methods related to spatial and thematic accuracy, specifically for benthic habitat mapping.

Field Surveys

Field surveys are critical to ground-truthing benthic data. Field surveys provide opportunities to verify the accuracy of data and document more detailed habitat character and conditions in the field. Some of the issues to be considered for conducting benthic field verifications are as follows:

- **Planning:** identify the goals and desired results of the fieldwork; determine whether the data will be used for signature development or accuracy assessment.
- **Weather:** check weather forecast, field conditions on the day of fieldwork.
- **Tides:** use bathymetry maps to determine accessibility during high and low tide.
- **Turbidity:** many observations can be made by swimming, snorkeling, scuba diving and using a video camera.
- **Phenology:** conduct field observations as close as possible to the date of photo acquisition.
- **Field equipment:** verify equipment (software and hardware) availability to conduct signature development and accuracy assessment.

Data Validation Methods

It is necessary to test the quality and correctness of the data prior to use and distribution. This accuracy assessment, falls into two categories: spatial and thematic. Spatial accuracy is the evaluation of the positional correctness of the data, while thematic accuracy is a measure of whether a habitat is correctly labeled. Both are of critical importance since errors in baseline data can be propagated through the change detection process, resulting in false estimates of habitat gain or loss.

Spatial Accuracy - Spatial or positional accuracy is the measure of the accuracy of the geometric placement of points, lines and polygon boundaries. Positional accuracy of photographic delineations of submersed habitat is of great concern; however, it has not often been a subject of independent verification. This is compounded by the fact that positional errors may be difficult to detect even when verifying a specific polygon in the field. For a single time period, positional errors may not greatly affect the aggregate area of each cover type. However, for change detection, positional accuracy is a crucial concern. Change data, especially data produced by post-classification comparison, will conspicuously record positional errors (e.g., greater than 10 meters in NOAA coastal benthic studies) as actual change when, in fact, they are artifacts of misalignment between data sets. This compounds the problem of recognizing real changes in the extent of habitat, which also tends to occur at polygon edges and class boundaries.

Registration of benthic habitat polygon edges is a function of a combination of factors:

- Metric quality of photographs
- Methods used to transfer the information to a planimetric map base
- Spatial accuracy of the base map
- Photo-rectification process (quality of source control points)
- Quality of the digitization performed

NOAA's Coastal Services Center recommends two tests of spatial accuracy, based on project work in Florida's Indian River Lagoon and in coastal Massachusetts.

The first test of spatial accuracy requires the following checks:

- Benthic habitat polygons are spatially buffered to produce a zone following the delineated lines.
- The width of the zone should be determined by the expected accuracy of the weakest source control.
- Differential GPS is used as the primary source control, with a buffer of 5 meters on either side.
- A maximum buffer width of 13 meters exists on either side of the polygon (which is also consistent with National Map Accuracy Standards).
- In multi-density habitat classes, an examination of the boundaries with high-density (continuous cover) polygons is conducted.
- At each sample point, a video or diver transect can be run across the buffer zone. If the actual polygon boundary falls within the buffer zone then the polygon boundary can be considered to have met the spatial accuracy requirements.

This test is highly recommended in large, open water areas and in more enclosed environmental settings to verify the accuracy of the benthic polygon data. Effects due to seasonal differences between the date of imagery, date of field verification and changes in phenology should also be considered.

The second test of spatial accuracy requires the following considerations:

- A fixed terrestrial linear feature, i.e. road, reinforced shoreline, is delineated during the mapping process. The closer this feature is to the center of the image and the water, the better.
- A differential GPS field measurement is made on this linear feature (on land) to be more certain of the measurement.
- The Aids to Navigation (AtoNs), if present and visible in the imagery, can also be used to assess spatial accuracy.
- If no existing coordinate data are available for AtoNs in the particular area, they can be measured using GPS.

Both tests should be done at several locations throughout the data set to determine overall spatial accuracy. If possible, measure fixed spatial accuracy points for every flight line. The results of any spatial accuracy assessment should detail whether each test location met or did not meet the standards established in the vendor contract. For tests that failed to meet the required standards, the distance, and azimuth of the error should be reported so that the line work or the entire spatial domain of the map can be edited/adjusted in an appropriate fashion. A statistical report should be generated for each spatial accuracy assessment to determine whether the overall accuracy of the map product meets the standards.

Thematic Accuracy - Thematic or attribute accuracy is a measure of the probability that the cover type for any given polygon is properly identified according to the classification scheme.

Assessment sites should be selected through stratified random sampling based on class size and distribution. Vector water body and bathymetry contours are useful and can be merged with the habitat data. Congalton and Green (1999) recommend as a rule of thumb a sample size of 50 samples (polygons) per class. In every thematic accuracy assessment effort, balance must be reached between the need to collect a statistically valid sample size and the challenges of visiting a large number of sites in small boats over project areas on the scale of major estuaries. During field verification, the following minimum number of items should be recorded:

- Latitude or northing of center of polygon
- Longitude or easting of center of polygon
- Depth
- Date
- Map classification
- Observed field classification
- Time
- Observation method (either snorkeling, boat, or video). In the case of video it is helpful to record the video tape number in which the recording resides.

At the conclusion of the field visit, the accuracy assessment database containing the field observations should be used to construct an error matrix. The error matrix should be used to calculate overall and category-specific accuracies as well as kappa coefficient and conditional

kappa for each class. The kappa coefficient is a statistical measure of the actual agreement minus chance agreement. The upper limit of kappa is 1.0, which occurs only when there is perfect agreement (Rosenfeld and Fitzpatrick-Lins, 1986). A kappa value of 0.0 is the same as the agreement that would occur from chance alone. Kappa values below 0.5 may suggest that the results of the accuracy assessment do not actually reflect the validity of the data. The result of the error analysis should meet an overall accuracy of 85 percent.

9.8.3 Ground-truth Data

In remote sensing, ground-truth is the process of gathering data at a particular location to aid in calibrating and interpreting remotely sensed data by comparing it to ground observations. Ground-truth data may include field survey data, in situ spectral measurements, photographic documentation, descriptive reports, inventory tallies and maps.

One of the considerations in remote sensing projects is to determine when it is appropriate to acquire ground-truth data. As stated in EO 12906, Section 4 (d) Agency Adherence to Standards:

Federal agencies collecting or producing geospatial data, either directly or indirectly (e.g. through grants, partnerships, or contracts with other entities), shall ensure, prior to obligating funds for such activities, that data will be collected in a manner that meets all relevant standards adopted through the FGDC process.

One such standard is the FGDC Geospatial Positioning Accuracy Standards Part 3 – National Standard for Spatial Data Accuracy (NSSDA), FGDC-STD-007.3-1998. (http://www.fgdc.gov/standards/standards_publications/). The NSSDA describes a method for calculating and reporting positional accuracy applicable to all digital spatial data. This method uses the differences between coordinates in the data set being evaluated and a set of checkpoints of higher accuracy collected independently. The set of checkpoints must meet appropriate quantity and spatial distribution requirements.

The NSSDA, together with EO 12906, seem to establish a requirement for “ground-truthing” all spatial datasets collected using federal funds. The time and resources for collecting the checkpoints should be considered and built in during the formulation of project management plan.

Some of the considerations for ground-truth planning, data collection, and usage in support of airborne and space-borne RS data processing and analysis are summarized below as a general guidance for user’s reference:

9.8.3.1 Ground-Truthing Preparation:

- Select project areas for aircraft, satellite or other single/multiple sensor collection efforts (e.g., simultaneous aerial and satellite over-flights).
- Provide input and control during the first stages of planning for analysis, interpreting and applying remote sensing data (e.g. identifying landmarks, logistics of access, etc.).
- Determine the number and distribution of ground-truthing and sampling points and the representativeness of targets of interest.
- Reduce data and sampling requirements (e.g. areas of needed coverage) for exploring, monitoring, and inventory activities.

-
- Select and arrange needed and appropriate ground-based instruments, check instrument performance and provide training as needed to instrument operators.
 - Determine a field sampling method (e.g. transects or matrices etc.).
 - Study local weather conditions and plan ground-truthing activities in coordination with remote sensing data acquisition schedule.
 - Determine a ground-truthing/field sampling window (e.g. 10 am – 2 pm)

9.8.3.2 Field Data Collection:

- Measure spectral and other physical properties needed to stipulate characteristics and parameters pertinent to designing new sensor systems or analyzing and interpreting remote sensing data.
- Collect physical samples for laboratory analysis of phenomena detected from remote sensing data (e.g. water quality, and insect-induced disease).
- Collect GPS readings of field target and sampling locations.
- Document field activities including taking photographs and videos.

9.8.3.3 Use of Ground-Truthed Data:

- Develop standard sets of spectral signatures and other data collected in the field or laboratory using ground-based instruments. Feed the standard ground-truth data into system for remote sensing data processing and interpretation.
- Determine what data are used for calibration or verification
- Correlate surface features and localities from ground perspectives with their expression in remote sensing imagery.
- Identify classes for unsupervised classifications.
- Select and categorize training sites for supervised classification.
- Verify accuracy of classification (error types and rates) using quantitative statistical techniques.
- Obtain quantitative estimates relevant to class distributions (e.g. field size; forest acreage).
- Acquire supplementary (ancillary) non-RS data for interpretive model analysis or for integration into GIS.

9.9 Considerations for Remote Sensing Data Acquisition

A list of some basic information concerning acquisition requirements should be compiled prior to image acquisition, such as:

- Geographic coordinates: upper left and lower right corner latitude–longitude coordinates or the path/row of Landsat scene, the K/J of a SPOT scene; the orbit and frame number for SAR image from ERS, Radarsat, JERS, or Envisat
- Acceptable coverage dates

- Acceptable percentage of cloud cover, image quality, and off nadir viewing angle
- Satellite sensor(s)
- Image format
- Media type
- Datum and map projection

9.10 Reporting

9.10.1 Data Formats

Digital data may be delivered in a variety of open or proprietary formats. The specifications should be clearly delineated in a contract or request for proposal. All spatial data collections for CERP projects must be referenced to the defined CERP control network (CGM 036). Referencing all CERP spatial data collections to the defined control network will facilitate data exchange, system-wide spatial data evaluation, and datum conversion. The locations, descriptions, coordinate values (x, y, z, Latitude, Longitude, and Elevation, respectively) of CERP network and other referenced control networks can be located at: <http://www.ngs.noaa.gov/>.

For information on spatial data collections and formats specific to CERP refer to QASR **Chapter 10** and the references below:

- CERP CGM Tech Specs for CERP GIS, CGM 28
http://www.cerpzone.org/documents/cgm/cgm_028.00.pdf
- CERP Technical Guidance for the Use of the CERP Geodetic Vertical Control Surveys Monuments and Referenced Control, CGM 36
http://www.cerpzone.org/documents/cgm/cgm_036.00.pdf
- CERP Technical Guidance for the Project Level Water Quality and Hydrometeorologic Monitoring and Assessment, CGM 40
http://www.cerpzone.org/documents/cgm/cgm_040.00.pdf
- SFWMD Data Steward Program User's Manual
http://www.sfwmd.gov/portal/page?_pageid=2754,19862620&_dad=portal&_schema=PORTAL

9.10.2 Metadata

Metadata is documentation about data, often referred to as “data about the data.” Metadata files document the source, acquisition date and time, projection, precision, accuracy, and resolution. Metadata should be created for all images, as well as imagery derived products. Executive Order 12906 provides for the establishment, through the FGDC, of metadata standards for geospatial data used by federal agencies. All GIS data in the SFWMD corporate database must be FGDC compliant, (see SFWMD’s GIS Data Steward Program User’s Manual). FGDC is in the process of integrating their standards with the ISO standard (ISO 11915:2003). This International Standard, entitled “Geographic Information – Metadata,” provides a structure for describing digital geographic data. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference and distribution of geographic data. Never

accept imagery, maps, or any other spatial data product from a vendor or other source without adequate metadata.