University of Puerto Rico at Mayagüez
Department of Civil Engineering and Surveying

TR-HERG-0501

An Infrastructure for Wide-Area Large Scale Automated Information Processing

A Proposed Framework for Hydro-Ecological Surveillance of Wetlands

Hydro-Ecological Research (HER) Group

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1. Introduction

The main objective of this research project is to: develop working prototypes to aid and support a network infrastructure for the automated processing of signal based information acquire from sensors in heterogeneous, wide-area, large scale, distributed systems. The local tropical hydro-ecological system has been selected as an appropriate setting to proof concepts for its dynamic sequential complexity, spatial and temporal stochastic variations including marked trends and catastrophic extremes, and ecological sensitivities. Although most complex physical systems show scarce and heterogeneous data, inferences of the systems behavior can significantly be enhanced by means of the most promising integrated computational hardware and software being under research herein.

Wetland, deep water and upland environments are somehow interrelated and physically interconnected through the hydrologic cycle, and the flora and fauna natural dynamics. Their physical, chemical and biological processes are closely related and dependent by means of their interaction. Significant research work published in the literature has addressed single and multiples elements of the hydro-ecological system, however, limited approaches have addressed hydro-ecological problems from an integrated data management perspective.

It is our expectation that this complex setting will serve not only as a test case for all the integrated computational capabilities and the algorithms and software that need to be developed, but also we expect that this framework will serve as a model to ease the surveillance of water resources systems in remote regions, particularly with analogous complexities to the tropical ecosystems.

This progress report addresses the conceptual framework developed to date during one month summer work to identify, describe, represent, monitor, assess, an manage the regional hydro-ecological systems in the tropic. Most concepts respond to basic hydrological and hydraulic principles applied to wetlands and floodplains, however, we envision a better and broader understanding of the behavior and changes of the natural tropical hydro-ecological system. Particularly, we expect that data integration through state of the art signal processing and data management can provide new knowledge and understanding of the natural Earth components behavior.

A particular case study setting, the Boquilla Nature Reserve, located nearby the downstream portion of the Río Grande de Añasco floodplain, has served to initiate the conceptualization of the generalized framework which will help synthesize a water resources planning and management system that will allow a robust decision support system.

At this stage the surveillance will be based on mass conservation principles. The elements and interaction of the system has been identified and simplified in order to allow conceptual applications. The environmental and ecological stages of this project are not the object of this report.

2. Methodologies – The Conceptual Approach

In the following various tasks performed during past summer are identified. They will be addressed more extensively later in the report.

- Wetland definitions
- Cowardin's wetland classification system
- Conceptualization of the hydrologic process of a wetland
- Factors influencing wetlands hydro-periods
- Conceptual wetland information management
- Typical data collection sources
- Case Studies (Boquilla Nature Reserve; Puerto Rico wetlands)

3. Wetland Definitions

Wetlands have been broadly studied worldwide. They constitute the niche for special vegetation and animals where they develop their habitat. For animals they constitute a unique place to hatch, born, grow and live. Special hydrophytic flora species particularly grow in wetlands. These species vary from those that tolerate permanent levels of humidity to those that are permanently under water. Wetlands have been defined by various sources. Within each definition, they have been categorized by their particular characteristics. Three different definitions of wetlands are presented in the following.

- The CE (*Federal Register* 1982) and the EPA (*Federal Register* 1980) jointly defined wetlands as (USACE 1987): "*Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.*"
- Cowardin et al. (1979) defined wetlands as: *"lands where saturation with water is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface."*
- NRCS defines wetlands as: "*lands inundated for 7 days or saturated for 14 days during the growing season at least once every 2 years.*
    - *Inundation means standing water on the surface.*
    - *Saturated means wet surface by capillary action.*
    - *Growing season means between last 28oF in Spring and first 28oF in the Fall.*

- *Each segment must be at least one-half acre in size."*

The differences between the classification systems (USACE,1987 and Cowardin et al. 1979) are:

- The technical guideline for wetlands (USACE, 1987) does not constitute a classification system. It only provides a basis for determining whether a given area is a wetland for purposes of Section 404, without attempting to classify it by wetland type.
- The Cowardin's classification system includes all categories of special aquatic sites identified in the EPA Section 404 b.(l) guidelines. All other special aquatic sites are clearly within the preview of Section 404; thus, special methods for their delineation are unnecessary.
- The Cowardin's system requires that a positive indicator of wetlands be present for any one of the three parameters, while the technical guideline for wetlands requires that a positive wetland indicator be present for each parameter (vegetation, soils, and hydrology), except in limited instances identified in the manual.

As it can be seen, although wetlands definitions vary from source to source, they are basically dependent on three main factors, namely: wetland hydrology, nature of soils and vegetation type.

4. Cowardin's Wetland Classification System

Cowardin's classification system is shown in figure 4.1. They are classified in system, subsystem, and class. It is relevant to this project the class description because it provides an intersection of physical and biological characteristics that may constitute indexes for wetland recognition and assessment. Figures 4.2 to figure 4.6 show physical representations of various systems.

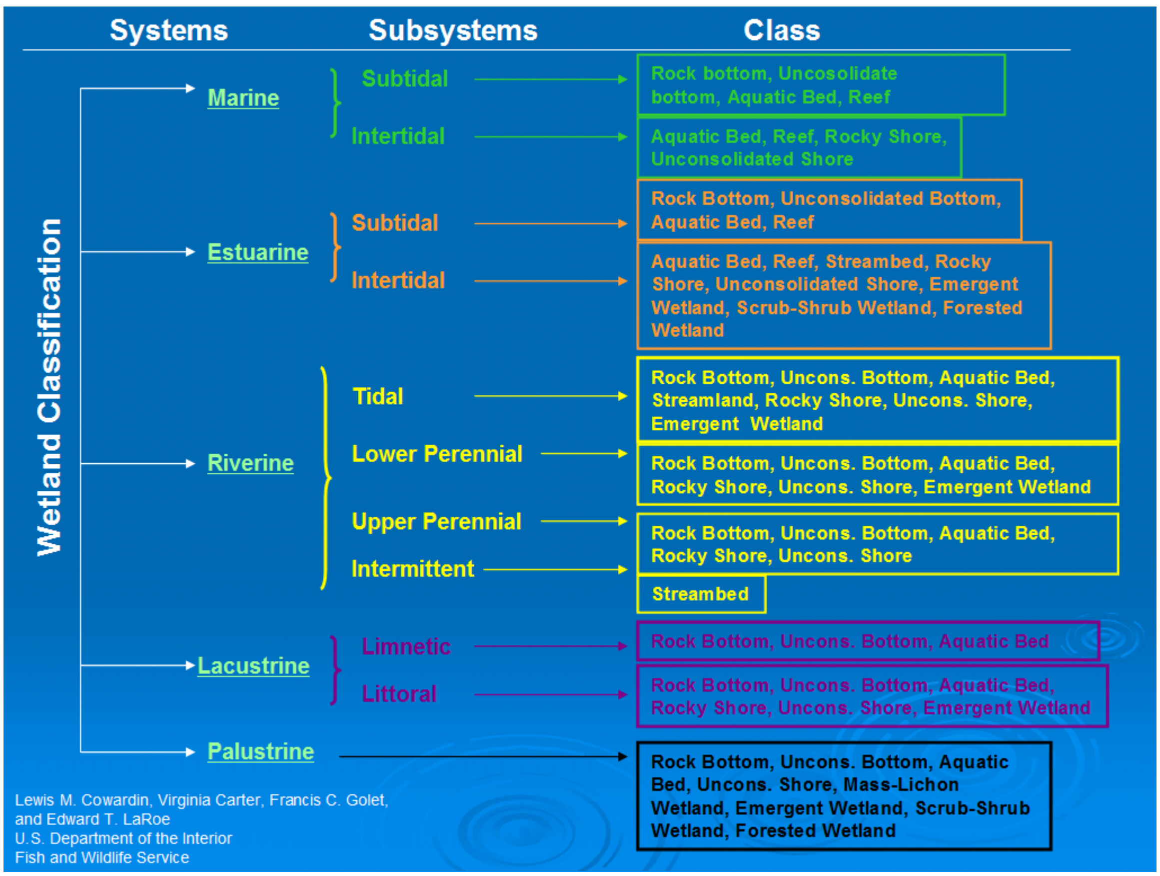

Figure 4.1 Wetland Classification scheme by Cowardin et al, 1979

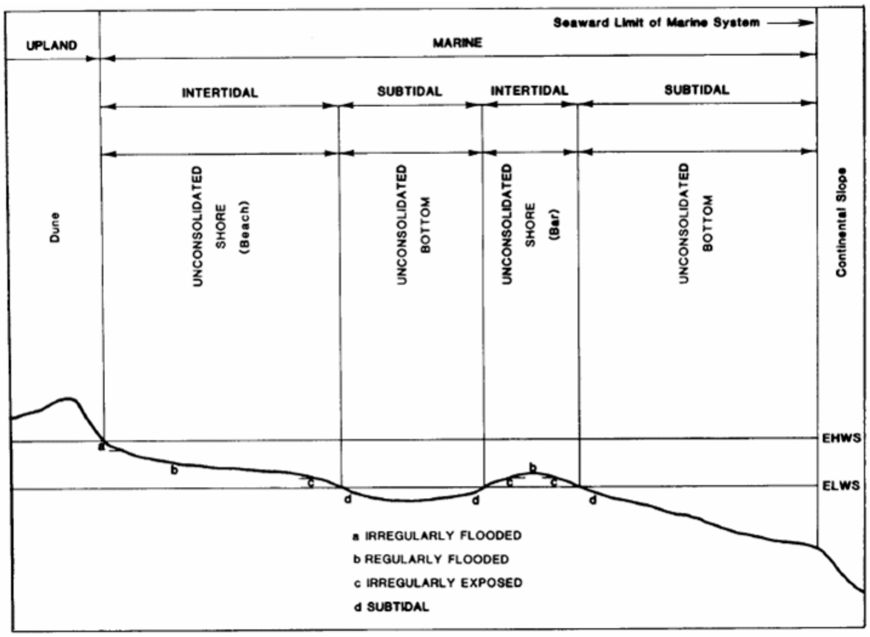

Fig. 2. Distinguishing features and examples of habitats in the Marine System. EHWS = extreme high water of spring tides; ELWS = extreme low water of spring tides.

Figure 4.2 Marine wetland systems

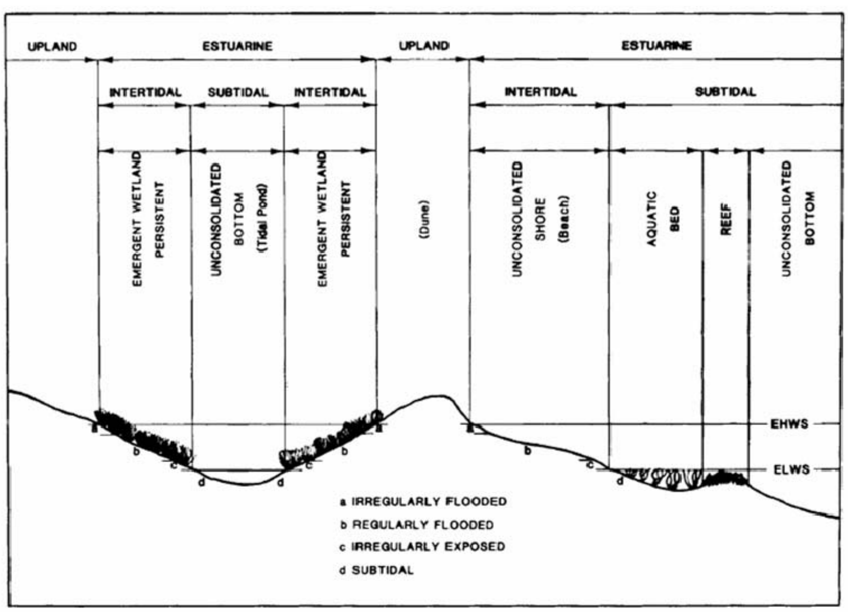

Fig. 3. Distinguishing features and examples of habitats in the Estuarine System. EHWS = extreme high water of spring tides; ELWS = extreme low water of spring tides.

Figure 4.3 Estuarine wetland systems

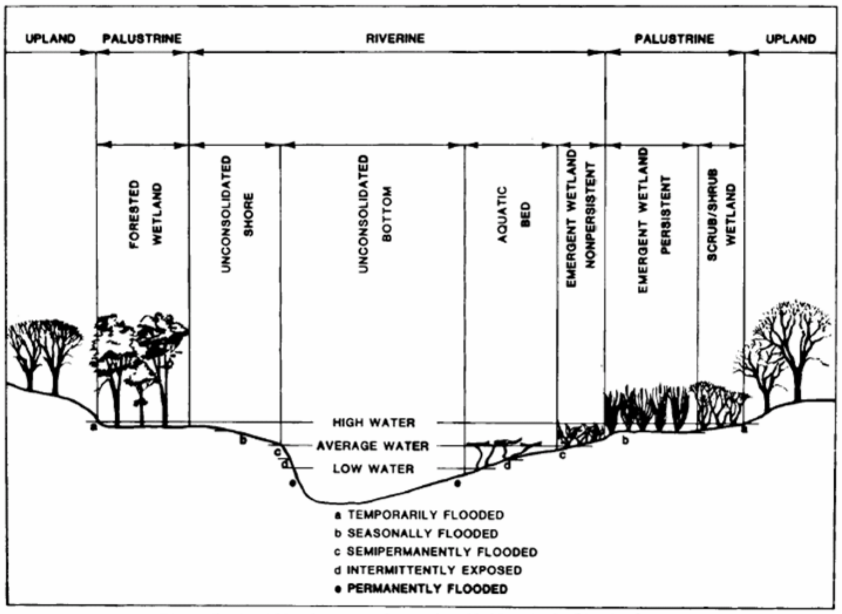

Fig. 4. Distinguishing features and examples of habitats in the Riverine System.

Figure 4.4 Riverine wetland systems

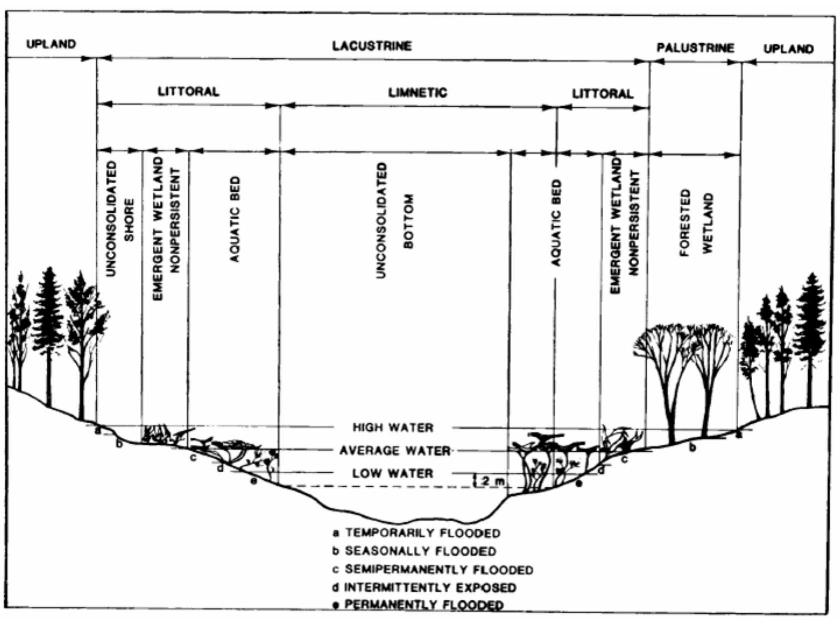

Fig. 5. Distinguishing features and examples of habitats in the Lacustrine System.

Figure 4.5 Lacustrine wetland systems

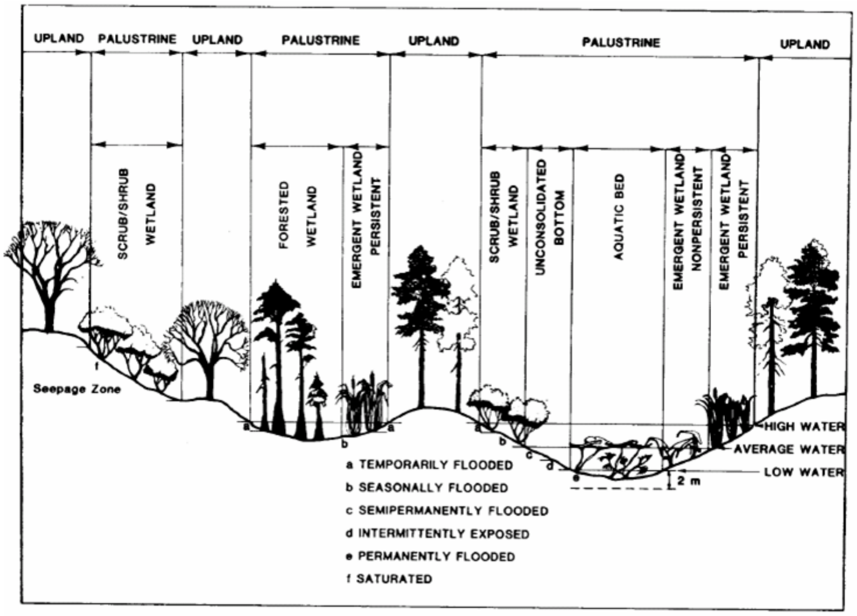

Fig. 6. Distinguishing features and examples of habitats in the Palustrine System.

Figure 4.6 Palustrine wetland systems

5. Conceptualization of the Hydrologic Process of a Wetland

Figure 5.1 shows a schematic diagram showing the concept of system and components interactions in a wetland. Dashed lines separate subsystems to show how the watershed subsystem interacts as a source to the wetland subsystem. Various components in each subsystem are identified. Each one is not discussed herein for the sake of brevity in this report.

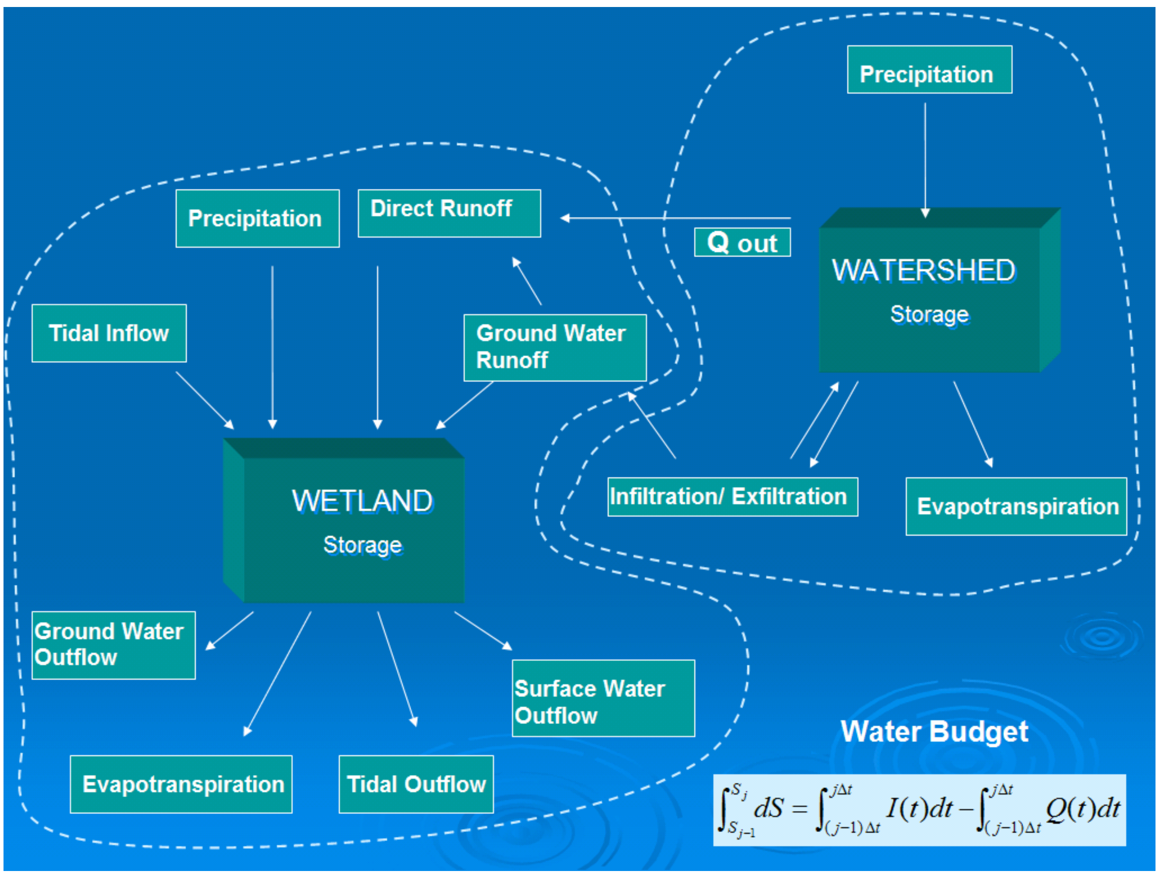

Figure 5.1 Conceptualization of the hydrologic process of a wetland

A mass balance approach is expressed by the following equation:

$$\int_{S_{j-1}}^{S_j} dS = \int_{(j-1)\Delta t}^{j\Delta t} I(t)dt - \int_{(j-1)\Delta t}^{j\Delta t} Q(t)dt \qquad (1)$$

This equation states the volume conservation within a particular system and among the two systems. This applies principally to water volumes. Mass balances are analogous except the particular mass may be expressed by:

$$m_i = \int_i Q_i dt \qquad (2)$$

6. Factors Influencing Wetland Hydro-periods

Figure 6.1 schematically shows factors influencing wetland hydro-periods. Rainfall history triggers hydrological mechanisms and processes in the basin. At the same time the basin response to rainfall inputs affect wetland hydrological processes. As it can be observed the factors identified may be classified as stationary or non-stationary parameters. Those non-stationary parameters and characteristics need to be monitored for their variabilities which affect the non-stationarity of the wetland.

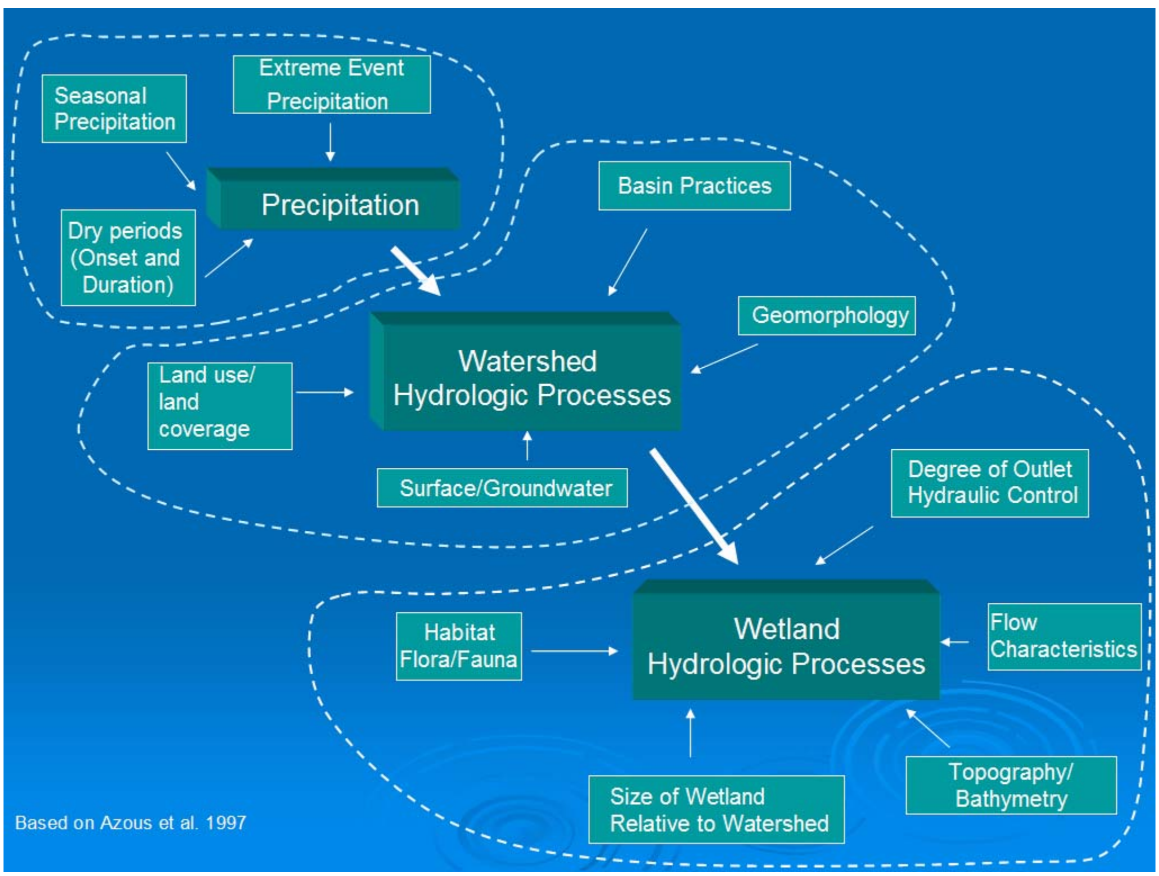

Figure 6.1 Factors influencing wetlands hydro-periods

Similarly, Carter (USGS,) presented various physical, chemical and biological characteristics that determine predominantly the hydrologic and water-quality fluctuations of a wetland. Figure 5.2 summarizes schematically Carter's concepts.

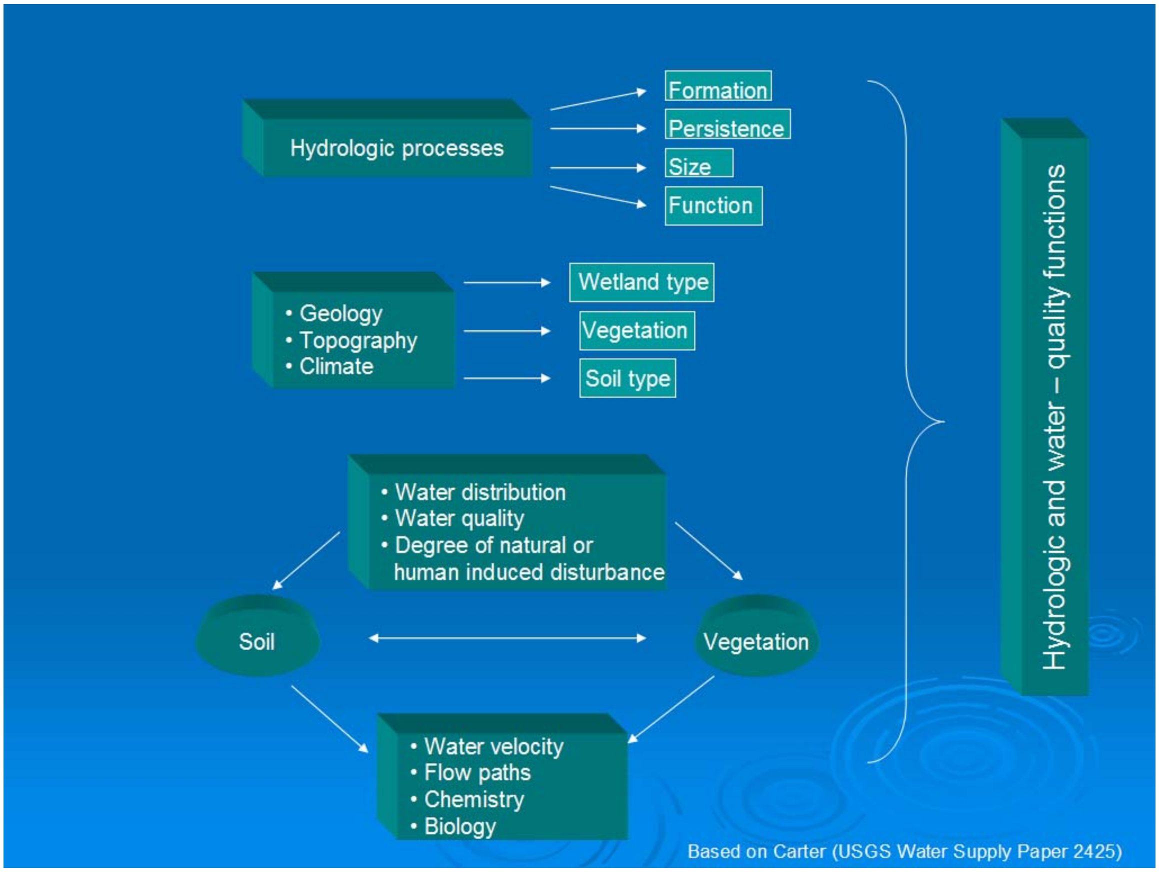

Figure 6.2 Wetland settings

7. Conceptual Wetland Information Management

Based on various factors influencing the wetland behavior, extracted from the literature, figure 7.1 has been conceptualized in this study to represent the wetland information management system for decision making purposes. Multivariate-multidimensional-heterogeneous information can be observed and monitored at wetlands. Six principal elements, namely, water quality, hydrology, soil types, flora, fauna, and geomorphology, appear to be prominent observational elements at a wetlands system. These have been selected as main parameters for the purpose of this study. A heterogeneous information matrix may be generated from various sensor-based data. Based on the holistic decision process for wetlands needs, goals and constrains will determine the nature of data extraction, merge and processing. The analytical process of the information will help guide and assist the level of achievement of surveillance goals established. A decision making process will be supported based on the most efficient extraction of relevant information for particular set of goals set forth in the process. A robust data management process will guarantee the most efficient learning process for surveillance purposes.

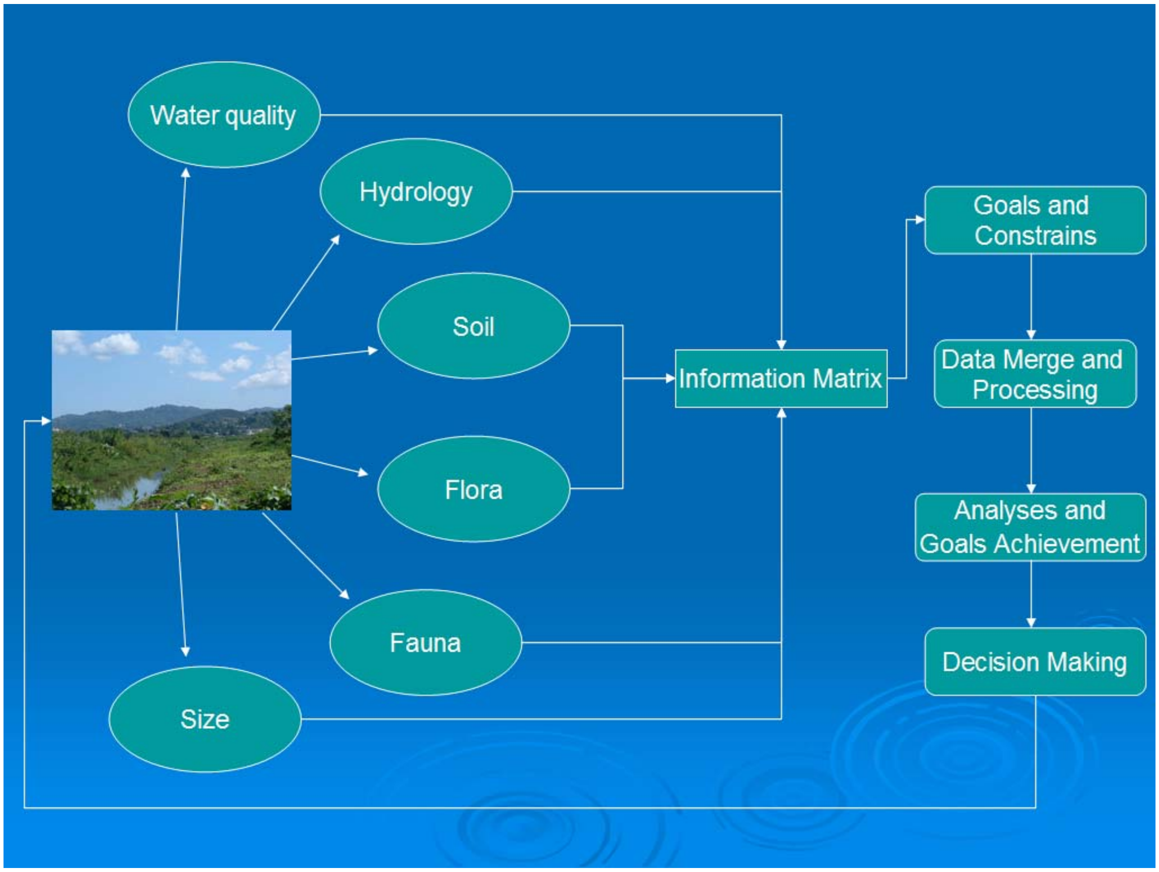

Figure 7.1 Conceptual Wetland Information Management

8. Typical Data Collection Sources

Figure 7.1 suggested that a multivariate-multidimensional-heterogeneous set of sensors will produce a matrix of similar information. Figure 8.1 shows instrumentation sensors that collect specific field data. It suffices it here to document some of the available instrumentation to demonstrate the complexity of the information matrix that could be developed.

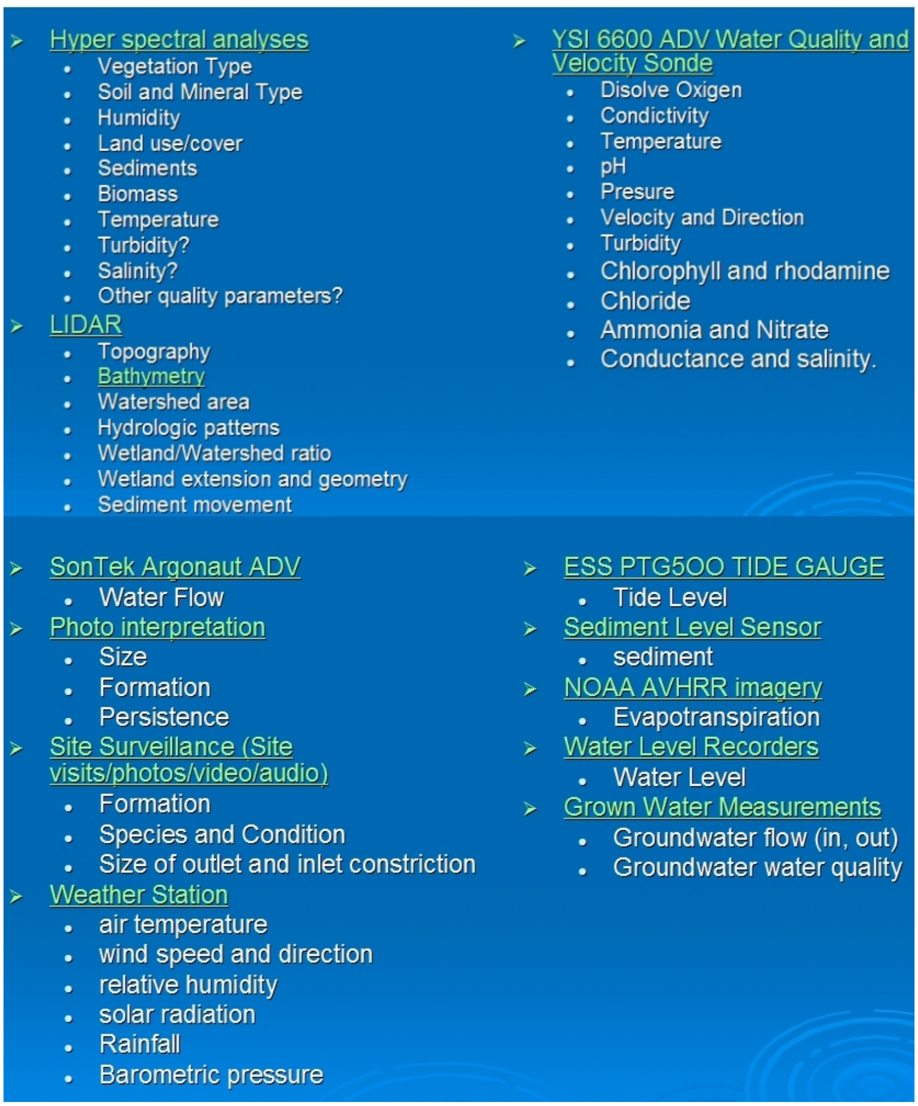

Figure 8.1 Instrumentation sensors

Details of the technical information many of these sensors are included in Appendix 1 for the benefit of the reader. It can be observed that sensors provide heterogeneous data that need to be preprocessed, processed and post processed to be useful for hydrological purposes. It is beyond the author's responsibility to address these issues herein, however it is important to address to representativeness of the data obtained.

Available hydrologic data obtained from sensors may be site versus aerial specific. They may also be continuous or discreet in time. Whichever the nature of the data, it is our recommendation to adopt a GIS based platform to represent, manipulate, and communicate this information. It will ease the communication among users and clients at the decision process level.

A significant effort has been spent on identifying available GIS databases in Puerto Rico and elsewhere. A sample of those available is shown in Appendix 2 for the reader's benefit. Significant efforts are under way to gain access by the author's to these databases for applications by the civil engineering research initiatives.

As a reference for the purpose of this research work, the Canada Center for Remote Sensing (www.nrcan.gc.ca) has published a list of remote sensing platforms and sensors and the data they collect which serve as an index for applications in this research project. As an example, table 8.2 shows the Thematic Mapper sensor's capabilities in function of the spectral bands used.

Appendix 3 shows some important issues related to data quality and management.

Table 8.2 Thematic mapper spectral bands and some of their applications

Band	Resolution	Spectral Definition	Some application
1	30 m	Blue-green 0.45-52 µm	Penetration of clear water; bathymetry; mapping of coastal waters; chlorophyll absorption; distinction between coniferous and deciduous vegetation
2	30 m	Green 0.52-0.60 µm	Records green radiation reflected from health vegetation; assesses plant vigor; reflectance from turbid water
3	30 m	Red 0.63-0.69 µm	Chlorophyll absorption important for plant type discrimination
4	30 m	Near infrared 0.76-0.90 µm	Indicator of plant cell structure; biomass; plant vigor; complete absorption by water facilitates delineation of shorelines
5	30 m	Mid infrared 1.55-1.75 µm	Indicative of vegetation moisture content; soil moisture soil mapping; differentiating snow from clouds; penetration of thin clouds
6	120 m	Far infrared 10.04-12.5 µm	Vegetation stress analysis; soil moisture discrimination; thermal mapping; relative brightness temperature; soil moisture; plant heat stress
7	30 m	Mid infrared 2.08-2.35 µm	Discrimination of rock types; alteration zones for hydrothermal mapping; hydroxyl ion absorption

9. Case Studies

For the purpose of developing this conceptual framework for the objectives of this research work, wetlands were selected as a subsystem of the total water resources system to test them as a case study. Figure 9.1 shows the assembly Island wide wetlands in Puerto Rico which was developed as a specific task for this project.

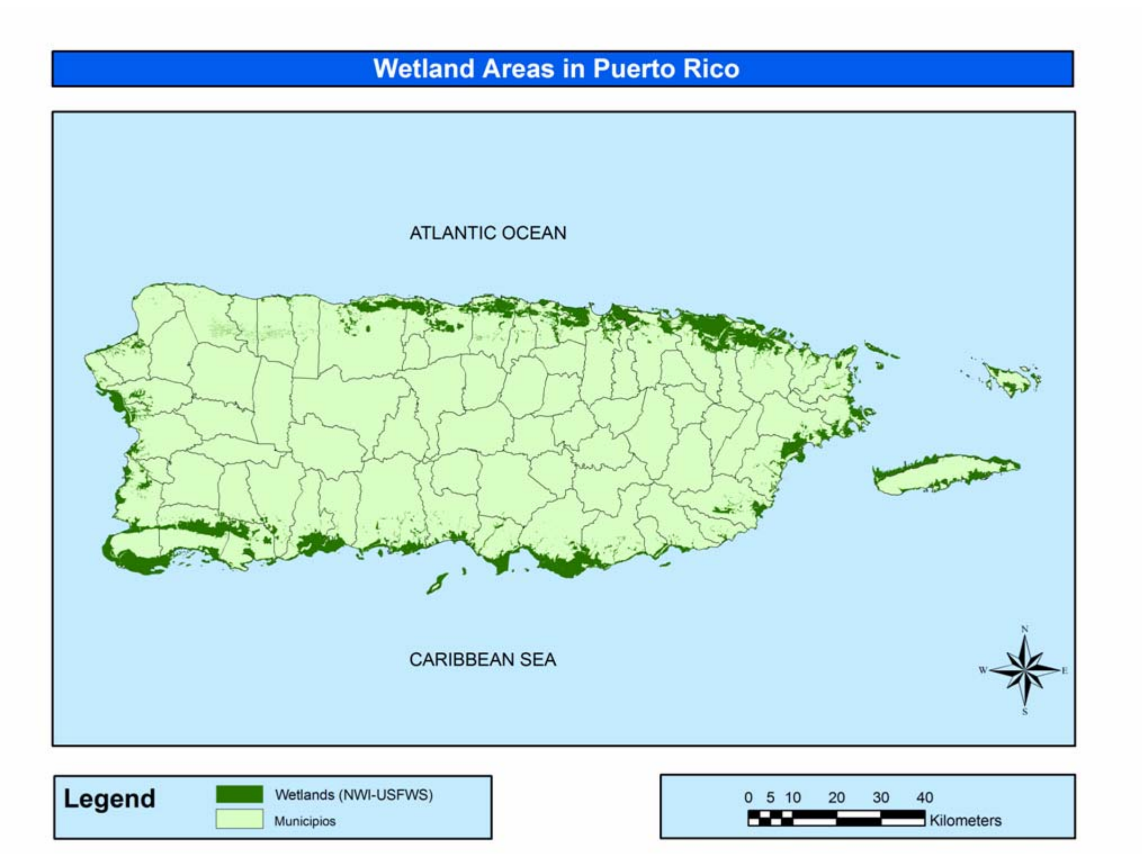

Figure 9.1 Puerto Rico wetland areas identified by National Wetland Inventory-FWS

Figure 9.2 shows flood prone areas in Puerto Rico as delineated by FEMA for the 100-year flood and a blow out of the flood prone areas overlaid with the wetland areas at the study site. This particular map has been developed for the project entitled "***Methodology to Estimate Flood Damages to Buildings in Puerto Rico"***. This map is property of the Insurance Commissioner Office of Puerto Rico and it is not intended for publication until its release. This ongoing project aims to estimate probable maximum losses due to riverine and tsunami floods wherever they occur.

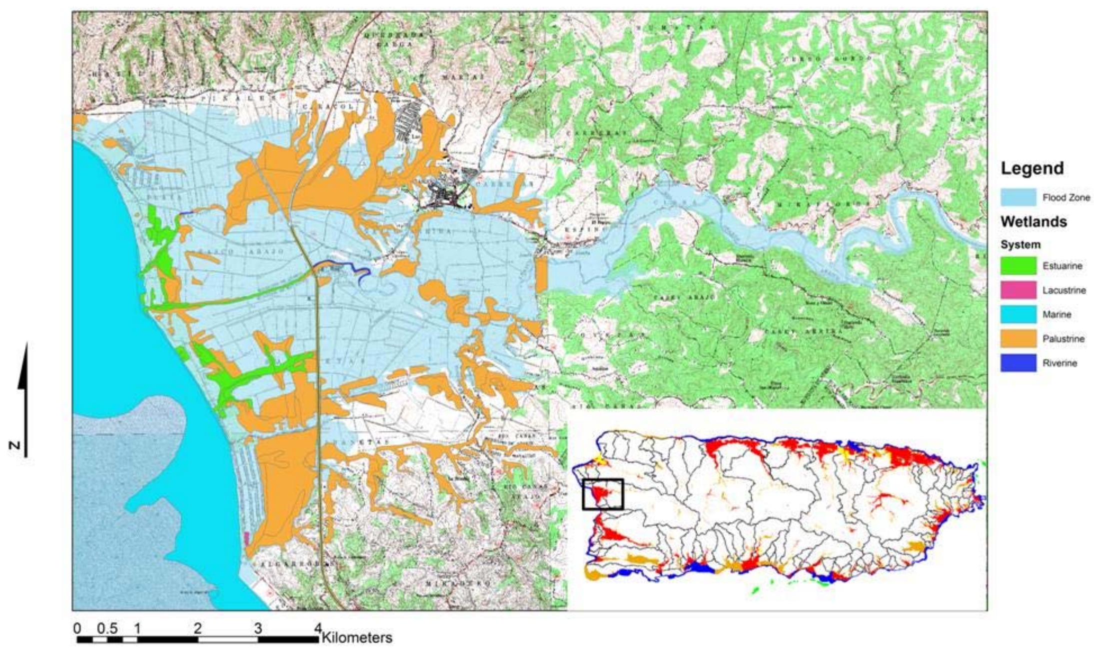

Figure 9.2 Flood prone areas for P.R. and Rio Grande de Añasco flood plain

Figure 9.3 shows marine estuarine and inland wetlands at the Boquilla Nature Reserve at the downstream part of the Rio Grande de Añasco river floodplain at Sabanetas ward in Mayagüez.

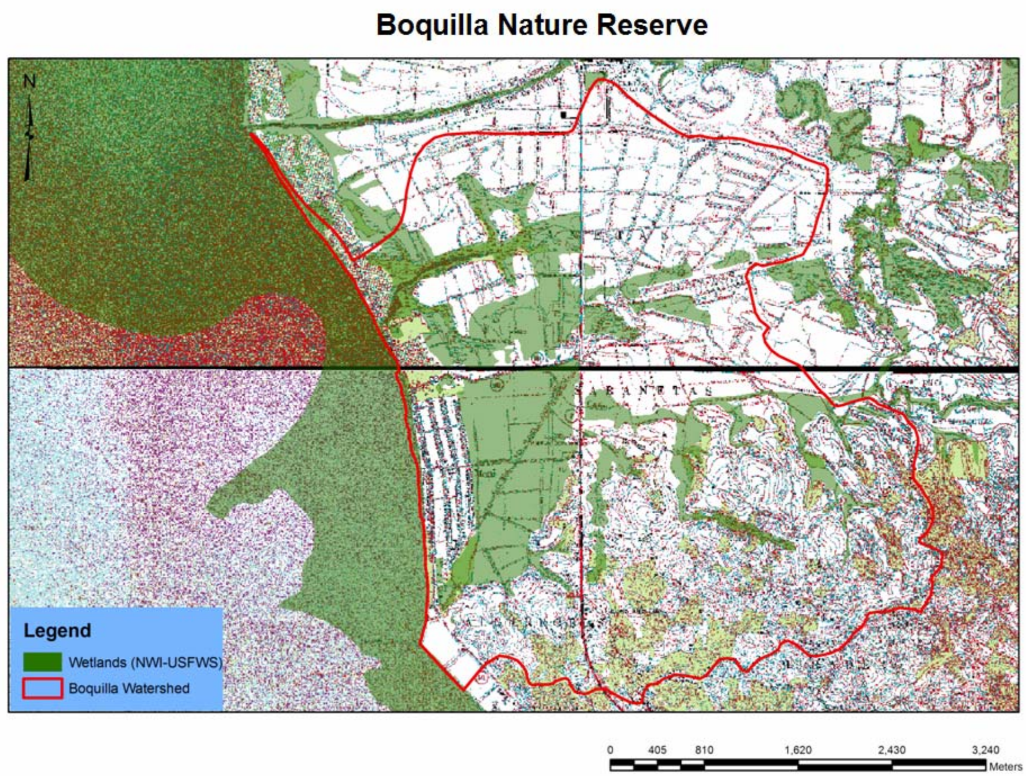

Figure 9.3 Wetlands at Boquilla Nature Reserve in Mayagüez

Figure 9.4 shows a temporal sequence of aerial photographs taken in 1937, 1999, and 2002 at a particular site of the Boquilla Nature Reserve. Significant obvious geomorphologic and ecological changes have been recorded since 1937. These changes can easily be correlated with basin changes, practices and processes. More significant changes can be identified in the center image close-up. The aerial photo of 1999 reflects the morphological and ecological consequences of the extreme floods (near 100-year return period) produced by Georges Hurricane along Rio Grande de Añasco floodplain.

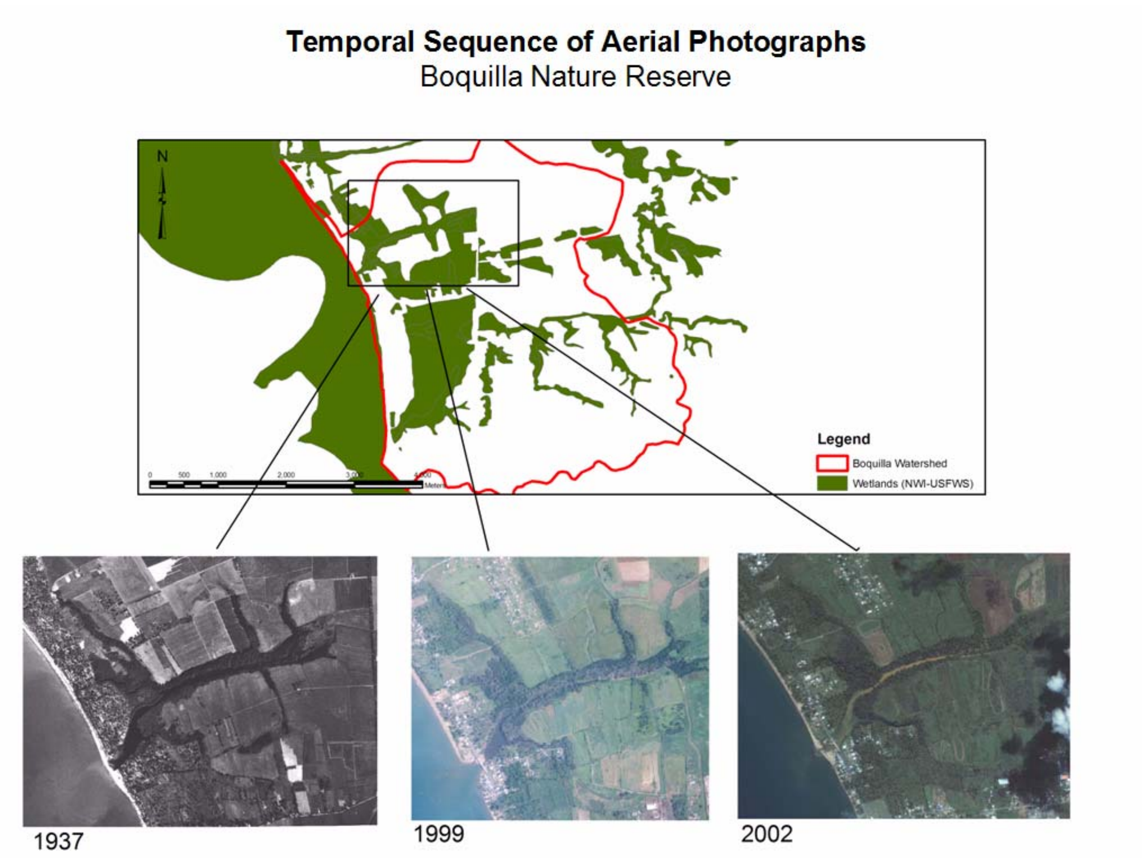

Figure 9.4 Temporal sequences of aerial photographs of Boquilla Nature Reserve

Although it suffices it here to show evident changes in wetland geomorphologic and ecological characteristics, it is promising that the proposed methodologies in this project will enhance and improve the decision making process pertaining wetland surveillance.

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Appendix 1: Technical Details of Sensors

A. Hyperspectral Analysis

- **Hyper-spectral-** The use of many narrow sections of the electromagnetic spectrum in remote sensing. *Glossary of GIS and Remote Sensing Terms*
- Hyper-spectral images are produced by instruments called imaging spectrometers:
    - *Spectroscopy*
    - *remote imaging* of Earth
- These measurements make it possible to derive a continuous spectrum for each image cell.
- Hyper-spectral images contain a wealth of data, but interpreting them requires an understanding of exactly what properties of ground materials we are trying to measure, and how they relate to the measurements actually made by the hyper-spectral sensor.
- Spectral Libraries
    - ASTER Spectral Library (http://speclib.jpl.nasa.gov)
    - USGS Spectral Library (http://speclab.cr.usgs.gov/spectral.lib04/spectral-lib04.html)

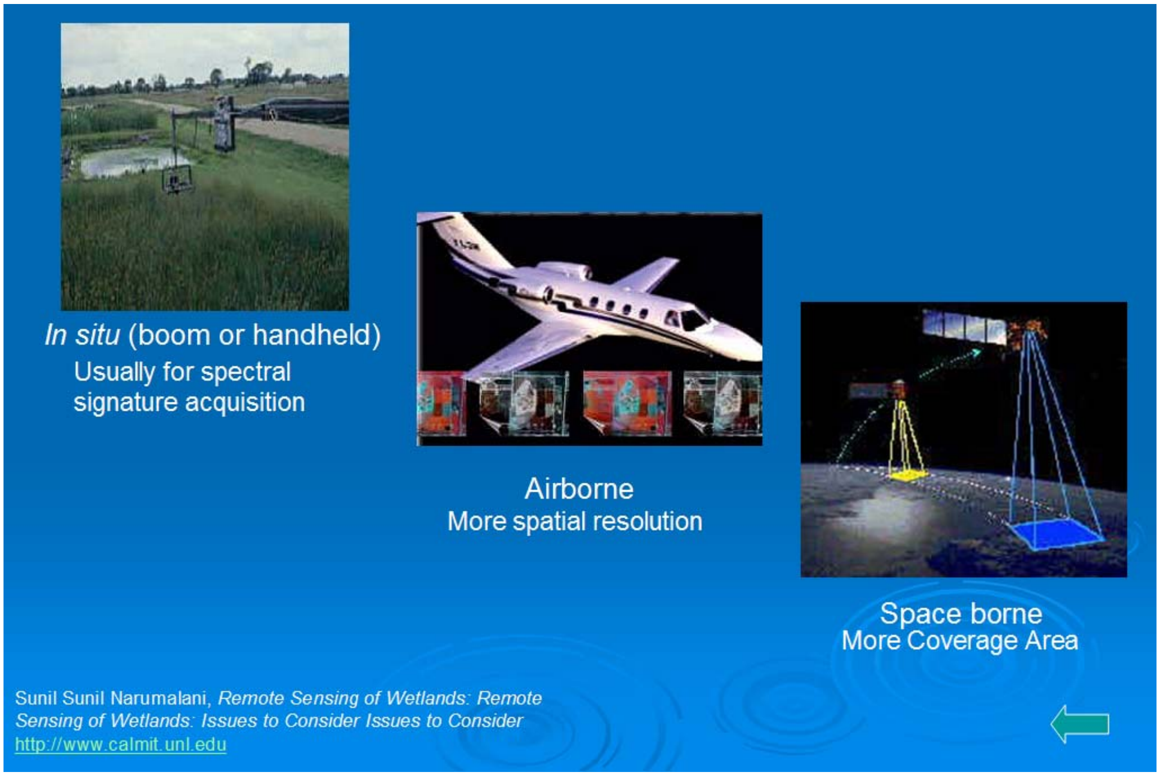


Figure A1-1. Possible platform locations for remote sensing instruments

B. LIDAR

Light Detection And Ranging uses the same principle as RADAR.

- During the flight, the LIDAR sensor pulses a narrow, high frequency laser beam toward the earth.
- The LIDAR sensor records the time difference between the emission of the laser beam and the return of the reflected laser signal to the aircraft.
- The LIDAR instruments only collect elevation data. To make these data spatially relevant, the positions of the data points are recorded with a GPS. The end product is accurate, geographically registered longitude, latitude, and elevation (x,y,z) positions for every data point.

There are three basic generic types of lidar (Kavaya, 1999)

:

- Range finders - Range finder lidars are the simplest lidars. They are used to measure the distance from the lidar instrument to a solid or hard target.
- DIAL - DIfferential Absorption Lidar (DIAL) is used to measure chemical concentrations (such as ozone, water vapor, pollutants) in the atmosphere. A DIAL lidar uses two different laser wavelengths which are selected so that one of the wavelengths is absorbed by the molecule of interest whilst the other wavelength is not. The difference in intensity of the two return signals can be used to deduce the concentration of the molecule being investigated.
- Doppler lidars - Doppler lidar is used to measure the velocity of a target. When the light transmitted from the lidar hits a target moving towards or away from the lidar, the wavelength of the light reflected/scattered off the target will be changed slightly. This is known as a Doppler shift - hence Doppler Lidar. If the target is moving away from the lidar, the return light will have a longer wavelength (sometimes referred to as a red shift), if moving towards the lidar the return light will be at a shorter wavelength (blue shifted).

C. Bathymetry

- SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system
    - Developed by U.S.A.C.E
    - Is a tool for monitoring the near shore bathymetric environments
    - Developed in many tidal inlets, provide:

- Concentrating channel shoaling
- Change in shape of the ebb (receding tide)
- Flood tidal shoals

o System Performance Specifications

Table 3.1 SHOALS performance specifications

Maximum Depth	60 m (or 2 to 3 times the Secchi depth)
Vertical Accuracy	±15 cm
Horizontal Accuracy	
DGPS	±3 m
OTF KGPS	±1 m
Sounding Density	4-m grid to 8-m grid
Operating Altitude	200 m to 400 m
Scan Swath Width	110 m to 220 m
Operating Speed	115 to 230 m/s

Irish,J.L et al, 2000

D. Photo Interpretation (http://www.nwrc.usgs.gov/about/sab/photogra.htm)

- Aerial photography is used to determine baseline information on wetlands, including the location and extents of wetlands, upland, and sea-grass habitats.
- Historical photography are used to study the wetland behavior through the time, and to predict it.
- Various scales of high altitude and low-level photography are obtained through private and government contractors.

E. Gauging Instruments

Weather Station

- This system provides with automatic data collection and processing of weather conditions. Standard sensors include:
    - Air Temperature
    - Wind Speed and Direction
    - Relative Humidity
    - Solar Radiation
    - Rainfall
    - Barometer
    - Precipitation and Snow Level

Water Level Recorders

The project of Evaluation of an In-Stream Constructed Wetland (http://www.bae.ncsu.edu/research/evans_web/instream) employs the use of a specific water level recorder and it is presented herein as an example. The recorders work on a pulley/float mechanism and the data and readings are controlled by Blue Earth microprocessors. The data recorded can be downloaded onto a palmtop computer and brought back to NCSU for analysis. The data is used to produce hydrographs that depict changes in water levels over time and can be used to analyze wetland hydrology.

Water Quality

An example of an instrument used for monitoring water quality data is the YSI 6600 ADV Water Quality and Velocity Sonde. The 6600 ADV water quality monitor combines the acoustic Doppler velocity (ADV) capability of the established SonTek Argonaut ADV instrument with the highly accurate water quality sensors in the YSI multi-parameter sondes. This powerful instrument has the capability to measure DO, conductivity, temperature, pH, ORP, pressure, velocity, direction, turbidity, chlorophyll, rhodamine, chloride, ammonia, and nitrate along with calculated parameters such as specific conductance and salinity. Data is collected in text files and processed with computer software.

Figure A1-2. SI 6600 ADV Water Quality and Velocity Sonde

Evapotranspiration

Taylor & Francis (2000) used multiple regression analysis to relate evapotranspiration (ET), computed from a water balance technique, to both thermal infrared and normalized difference vegetation index data obtained from the Advanced Very High Resolution Radiometer (AVHRR) sensor on board on the National Oceanic and Atmospheric Administration (NOAA) satellite.

Appendix 2: GIS Data Sources

Relevant GIS coverage

- U.S. FWS National Wetland Inventory (1985)
  - Download from (Shapefiles):
    - http://www.nwi.fws.gov/downloads.htm
    - For Puerto Rico: http://www.nwi.fws.gov/shapedata/puerto_rico/
- NRCS Soil Survey Data (1975)
  - http://soildatamart.nrcs.usda.gov/
- USGS Geologic Formations
  - U.S. Geological Survey Minerals Team, 1998. Geology, Geochemistry, Geophysics, Mineral Occurrences and Mineral Resource Assessment for the Commonwealth of Puerto Rico, Editor: Walter J. Bawiec. U.S. Geological Survey Open-File Report 98-38.
- Digital Elevation Maps
  - DEM's : GIS Data Depot : http://data.geocomm.com/
  - Puerto Rico DEM's: http://data.geocomm.com/catalog/RQ/group4.html
    - HORIZONTAL_DATUM: North American Datum of 1927, PROJECTION: Transverse Mercator ZONE: 19,VERTICAL_DATUM: NGVD 1929
- USGS Topographic Quadrangles
  - USGS DLG's http://edcwww.cr.usgs.gov/products/map/dlg.html
  - Digital Line Graphs (DLGs) are digital vector representations of cartographic information derived from USGS maps and related sources.

- DLGs are available in Optional format, written as ANSI-standard ASCII characters in fixed-block format.

- USGS Orthophoto Quadrangles: Digital Orthophoto Quadrangles (DOQ) combines the image characteristics of a photograph with the geometric qualities of a map. The primary digital orthophotoquad (DOQ) is a 1-meter ground resolution, quarter-quadrangle (3.75-minutes of latitude by 3.75-minutes of longitude) image cast on the Universal Transverse Mercator Projection (UTM) on the North American Datum of 1983 (NAD83). Site: http://edcwww.cr.usgs.gov/products/aerial/doq.html

- Puerto Rico GIS Data Bases
  - EPA/DNRE
  - AFI
  - CRIM
  - Planning Board

Appendix 3: Data Quality and Management Issues

- The original data may have different errors like:
    - atmospheric interference
    - system noise
    - sensor motion
    - striping
- They must be preprocessed before the main analysis to correct those errors.
- Preprocessed data may have unwanted effects on digital values because data is altered from its original form.
- In spite of this, the benefits of preprocessing the data outweigh the potential unwanted effects resulting from the procedure.

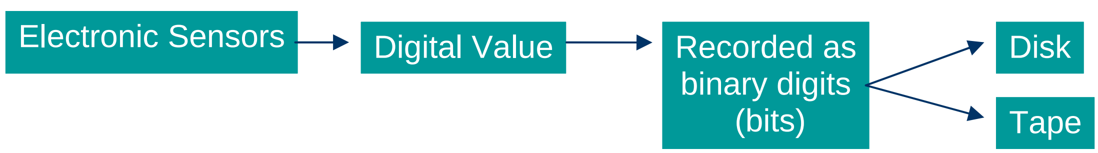
Preprocessing

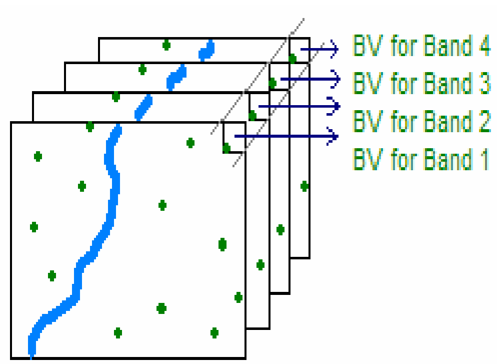
- Feature extraction→ Take the data that matters to specific application
    - Discards data that contain noise and errors present in the original data
    - Reduces the number of spectral channels that must be analyzed
- Radiometric Preprocessing
    - Remove the undesirable influence of atmospheric interference, system noise, and sensor motion
    - Physical models for radiometric preprocess
        - LOWTRAN and MODTRAN both from the U.S Air Force
- Destriping
    - Corrects the error known as sixth-line striping caused by small differences in the sensitivities of detectors within sensors.

- Subsets: Portions of larger images, selected to show only the region of interest.
- Map Projections for representing Satellite Images
    - Projecting Earth spherical surface into the flat surface of a map

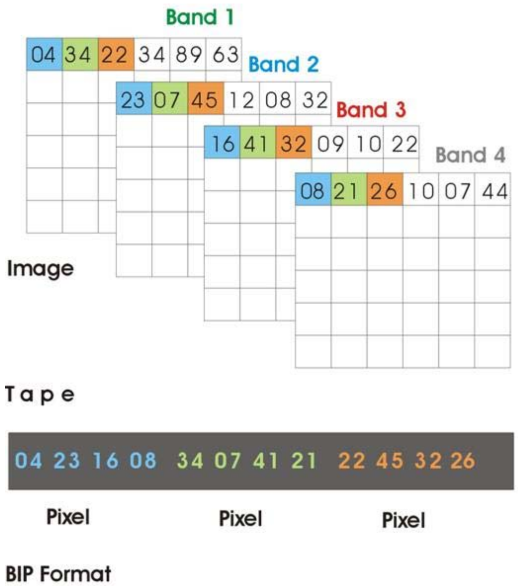
Digital Data

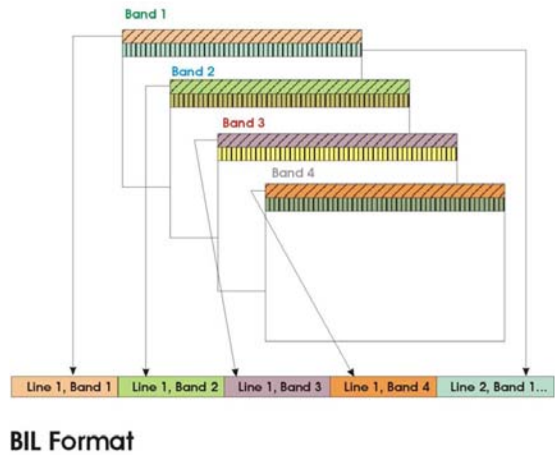
- Multispectral, Hyperspectral and digital photograph produce digital data.
- Numeric value representing brightness usually with separated value for each region of the electromagnetic spectrum, recorded from individual patches of the ground. (pixels)



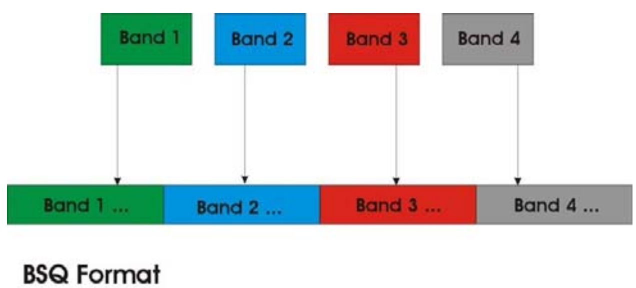


To convert the digital data from tape to raster use one of the three common formats used to organize image data





Band interleaved by pixel (BIP) Band interleaved by line (BIL)



Band sequential (BSQ)