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**Monitoring Program for
Coastal Wetlands Planning, Protection, and
Restoration Act Projects**

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EXECUTIVE SUMMARY

Louisiana's coastal wetland loss, estimated at 79.5 km²/year, has drawn national attention. In response, the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) was created to provide the guidance and means to develop and implement a project-oriented program to combat this coastal wetland loss. The CWPPRA requires a monitoring program be established to evaluate the effectiveness of these projects.

Projects developed under this program range from massive freshwater and sediment introduction to small scale vegetative plantings. Currently, there is no available standardized method for monitoring variables that can determine success or failure of wetland restoration projects. Consequently, data collected by Federal, State, and local entities within the coastal zone of Louisiana have not been comparable, and thus of limited use. The committee charged with the development of this monitoring program felt it was imperative to develop standardized protocols that could be used to judge project success or failure. Over 100 Federal and State restoration projects are currently being planned, and with standardized protocols, usable and comparable information will be generated, aiding in resource management and future planning and design.

These monitoring protocols were developed in response to the mandate for procedures that would evaluate the effectiveness of each coastal wetlands restoration project in achieving long-term solutions to arresting coastal wetlands loss in Louisiana. Specifically, this mandate requires that a scientific evaluation be conducted to test the effectiveness of these projects in creating, restoring, protecting, and enhancing coastal wetlands in Louisiana.

These monitoring protocols broadly categorize project types, goals, and biological variables, and standardize data collection methodologies using a matrix design. This organization provides accessibility to three levels of information: project type, category of variable, and variable. These three levels are cross-referenced and ranked to guide personnel in the development of appropriate monitoring plans.

The goal of the monitoring protocols is to provide a guidance document that can be used to develop project-specific and basin-wide monitoring plans and monitoring cost estimates. In addition, the protocol should help determine the minimum monitoring standards necessary to provide sufficient information to determine whether project-specific goals are met.

Monitoring protocols were developed by subgroups of technical experts for seven categories of monitoring variables: water quality, hydrology, soils and sediments, vegetative health, habitat mapping, wildlife, and fisheries. Some variables were identified as a monitoring priority by more than one subgroup, but only one subgroup will describe specific methodologies and costs (Table 1). The results of each subgroup are represented in the following sections of this document. Each section described protocol design, cost estimates, priority rankings, and existing data bases. Following is a general overview of the monitoring protocols each monitoring subgroup developed.

Water Quality

The water quality monitoring subgroup identified physical variables, salinity, temperature, nutrients, and priority pollutants as essential in designing a water quality monitoring plan for CWPPRA projects. Sampling methodologies vary widely in degree of sophistication as well as frequency (instantaneous, continuous recorder, realtime). The water quality monitoring subgroup feels that specification of sampling frequency is premature at this time and that sampling frequency will vary according to the availability of preexisting data, size of the project area, type of restoration project, and cost. Costs were estimated on a per sample basis and are illustrated by project type in Table 2.

Hydrology

The hydrologic monitoring subgroup identified variables to be monitored that would assist in determining project success as well as design of future projects. The variables are precipitation, evaporation, wind speed and direction, water level, bathymetry, topography, salinity, discharge, suspended sediment, ground water, and soil salinity. A majority of these variables can be monitored on a single data collection platform to provide realtime data, reduce maintenance costs, and minimize data loss. Cost estimates will vary according to frequency of data collection and number of sampling stations (Table 2).

Soil and Sediments

The soil and sediments monitoring subgroup identified variables that can be measured in the field to evaluate the success of CWPPRA projects in promoting soil development. The variables are organic matter content, bulk density, water content, grain size, soil redox, soil nutrients, soil contaminants, vertical accretion, subsidence, and soil erosion or creation. Vertical accretion and subsidence measurements can use three different methodologies depending on monitoring intensity: feldspar markers, sediment erosion table or radionuclide dating for accretion and carbon-14 dating, global positioning systems (GPS), and extensometers for subsidence. Estimates of total will vary tremendously depending on monitoring intensity and frequency as illustrated in Table 2.

Vegetative Health

The vegetative health monitoring subgroup determined that the following four variables were essential in evaluating vegetative health responses to CWPPRA projects: species composition, relative abundance, aboveground biomass, and herbivory. It was recommended that the Braun-Blanquet method be used for quantifying shifts in community compositions and abundances; that the clip-plot method be used for quantifying aboveground biomass; and that exclusion techniques be used to estimate the impacts of herbivory. Project-specific goals and available resources will dictate what and how frequently vegetative health variables will be monitored. Cost estimates by project type are illustrated in Table 2.

Habitat Mapping

The habitat mapping subgroup developed a two-phased monitoring approach. At the first level, basin-wide mapping at a scale of 1:100,000 is proposed. Data at this level could provide a quick

land and water classification to assess wetland trends for large restoration projects and entire hydrologic basins. The second level mapping is at scales ranging from 1:6,000 to 1:12,000. The Cowardin et al. classification is used for those restoration projects that require a greater level of detail. Habitat mapping will be conducted on all projects and will be prioritized based on project implementation timetables. Cost estimates by project type are illustrated in Table 2.

Wildlife

The wildlife monitoring subgroup recognized that wildlife populations are secondary to full recovery and conservation of coastal wetlands. The subgroup further recognized that wildlife populations are influenced by a broad range of factors, many of which are external and unrelated to basin-wide habitat conditions. For these reasons, the subgroup felt strongly that project evaluation should be based on monitoring variables that are expected to respond directly to restoration projects, namely water quality, hydrological, and vegetative variables. The subgroup agreed that, over the long term, recovery of coastal wetlands would benefit wildlife populations in the region. Wildlife populations or the effects of herbivores on vegetation will have to be monitored in case of herbivore demonstration projects.

Fisheries

The fishery monitoring subgroup determined that monitoring should target juvenile fish and crustaceans with emphasis placed on the collection of quantitative samples using high catch-efficiency gear. In addition to measuring animal density as an indicator of project area or habitat value, information on animal size, biomass, and species richness should also be collected. For oysters, measurements of growth, survival, and spat settlement should be collected. The gear type selected for sampling is throw traps. Sampling intensity and frequency depend on size of project area, number of different habitats present, and cost. Cost estimates by project type are illustrated in Table 2.

The standardized monitoring protocols developed in this document will provide statistically defensible, scientific procedures for monitoring those variables critical for determining project success or failure. It provides the framework and flexibility to develop basin-wide and project-specific monitoring plans while at the same time identifies the degree of effort and resources needed to accomplish this monitoring.

the monitoring work group.

II. OBJECTIVE

The monitoring work group consisted of representatives from Federal and State agencies, as well as academia. The specific responsibilities of the monitoring work group were 1) to develop a monitoring program to evaluate the effectiveness of each coastal wetland restoration project in achieving long-term solutions to arresting coastal wetland loss in Louisiana, 2) to document the effectiveness in reports to the U.S. Congress and Louisiana legislature, and 3) to make recommendations to the CWPPRA Task Force for the allocation of monitoring funds properly.

To accomplish these responsibilities, the following goals were established: 1) to develop standardized protocols for monitoring variables, 2) to develop statistical review procedures, and 3) to develop quality assurance and quality control procedures. All three goals will lead to detecting change between the pre-project condition and the post-project condition in Louisiana wetlands. This will help determine if the project is working and whether midcourse corrections are necessary.

In pursuit of these goals, group members envisioned a monitoring program that would consider

- 1) Nine types of restoration projects;
- 2) Project-specific goals (hypotheses);
- 3) Wetland values as determined by a wetland value assessment (WVA) procedure;
- 4) Site-specific as well as basin-level effects of projects; and
- 5) Existing monitoring activities occurring in coastal Louisiana.

Similar monitoring needs exist within and between each type of restoration project, and the development of standard protocols for these similarities are the backbone of the monitoring program. Monitoring methods and protocols for restoration projects were developed by technical experts for seven categories as follows:

- 1) Water quality
- 2) Hydrology
- 3) Soil and sediments
- 4) Vegetative health
- 5) Habitat mapping
- 6) Wildlife
- 7) Fisheries

The protocol design was developed to broadly categorize project types, goals, ecological variables, and data collection methodologies.

III. DESIGN

Restoration Project Types

Under Act 6 and the CWPPRA, all projects were categorized into nine types: freshwater introduction and diversions, sediment diversions, marsh management, hydrologic restoration, beneficial use of dredged material, shoreline protection, barrier island restoration, vegetative planting, and sediment and nutrient trapping.

Freshwater introduction and diversion

Freshwater introduction and diversion projects are designed to introduce fresh water and alluvial material from available sources to shallow marsh estuaries. Areas targeted for freshwater diversion projects are characterized by saltwater intrusion, sediment subsidence, and shoreline erosion. The primary goal of these projects is to enhance wetlands by increasing the use of fresh water, nutrients, and sediments that will be provided by the freshwater diversions. Management of the outfall will route the fresh water through the wetlands and provide greater deposition of sediments in the marsh to offset subsidence, greater availability of nutrients to vegetation, and a more gradual release of fresh water to the benefit of wildlife, fish, and shellfish. Monitoring freshwater diversions will help to determine if any changes or modifications are needed in the operation.

Sediment diversion

Sediment diversions are projects that increase deposition of river-borne sediment in shallow bay areas that cannot keep pace with subsidence through sediment accretion. A small-scale sediment diversion project is designed around the concept of natural crevasse splay development, where a breach occurs in the bank of a river, sediment infilling begins within the surrounding distributary bays, and crevasse splay sediments eventually become subaerial and established with marsh vegetation. Large-scale sediment diversions on the Mississippi River are designed to be similar to the large natural crevasses such as the one at Baptiste Collette, LA. The primary goal of the project is to create and manage crevasses through the natural levee ridges of rivers and major distributary channels so that the natural land-building process can create emergent and submergent aquatic communities critical to the overall productivity of the deltaic systems. Monitoring of sediment diversions will help to determine the management of the crevasses.

Marsh management

In marsh management projects, structures actively manipulate local hydrology to control water levels and salinity and while at the same time allowing ingress and egress of marine organisms. Marsh management plans generally incorporate existing canal spoil banks, the construction of short levees to connect these spoil banks, the installation of water control structures, and/or the construction of pump and other control structures to introduce fresh water into the managed area and keep out saline water. The main goals of marsh management are to minimize the loss of emergent and submergent plant communities by reducing salinities, stabilizing water levels, and restricting tidal exchange. Monitoring of marsh management projects will help determine operation schedules for pumps and structures.

Sediment and nutrient trapping

Sediment and nutrient trapping projects use structural devices such as brush fences or earthen berms to reduce wave energies, promote the deposition of suspended sediments, and increase water clarity. The goals are to reduce erosion of windward marsh edges, promote the growth of emergent vegetation, and increase the overall productivity of the area. Monitoring will help determine the effectiveness of different sediment and nutrient trapping techniques.

Project-Specific Goals

A critical step in establishing a successful monitoring program is to define the goals of conducting the monitoring. If the goals are poorly defined, there will be no guidance in the establishment of protocols. The CWPPRA requires an evaluation of the effectiveness of each project in achieving its specific goals directed towards creating, restoring, protecting, or enhancing coastal wetlands. For example, a project using dredged material may be built to reduce wave energies and consequent physical erosion or develop a new soil and sediment base at a proper elevation to restore or maintain vegetated marsh. Each of these projects begin with a hypothesis or set of hypotheses related to the expected change in physical, biological, or chemical variables of the project area. These hypotheses then guide the monitoring program as to which variables will be monitored and how frequently.

Control Areas

The importance of using appropriate control areas cannot be over emphasized. Monitoring on both project and control areas provides a means to achieve statistically valid comparisons, and is, therefore, the most effective means of evaluating project success.

Selection of a control area should ideally be done before project initiation. Controls should be ecologically similar to the project area yet located far enough away so as to not be influenced by the project. Potential control areas can be selected by use of WVA methods or through more basic comparisons of structural and functional attributes. To ensure the selection of appropriate controls, an interagency team of experts should be convened. If there is any question concerning the similarity of the control and project areas, more than one control area should be selected.

It is recognized that in many areas of Louisiana, appropriate controls cannot be identified. In addition, the extent of wetland modification (both planned and unplanned) occurring in this region often results in the loss of control areas before monitoring efforts are completed. We also recognize that occasionally, especially in the case of very large projects (e.g., sediment diversions and freshwater diversions from the Mississippi River or watershed projects) it may be difficult to select control areas that adequately reflect the same marsh type and function as those being affected by the project. In these cases, two strategies could be adopted:

- (1) **Monitoring before and after project implementation.** The disadvantages of this strategy include delay in project implementation, temporal variability, and the inability to clearly identify cumulative impacts of the project in comparison to unaffected areas. In addition, before and after monitoring cannot ensure that the same events are being monitored for comparison; therefore, interpretation of the results will be difficult. However, such monitoring would provide some indication of project performance and impact.

The WVA operates under the assumptions that optimal conditions for a coastal wetland can be characterized, and that any existing or predicted condition can be compared to that optimum to provide an index of wetland quality. The quality component of a wetland is estimated or expressed through the use of a mathematical model developed specifically for each wetland type. Each model consists of 1) a set of variables that are considered important in characterizing the particular wetland type, 2) a suitability index graph for each variable, which defines the assumed relationship between wetland quality and the variable, and 3) a mathematical formula that combines the quality value (habitat suitability index or HSI) for each variable into a single value for overall wetland quality.

The variables chosen to describe wetland quality in each of the marsh types are

- V₁ - Percent of wetland covered by persistent emergent vegetation;
- V₂ - Percent of open water area dominated by aquatic vegetation;
- V₃ - Marsh edge and interspersion;
- V₄ - Water duration in relation to marsh surface;
- V₅ - Open water depth in relation to marsh surface;
- V₆ - Mean high salinity during the growing season; and
- V₇ - Aquatic organism access.

Predictions are then made as to how these model variables will change through time under two scenarios: with the proposed project in place and without the proposed project. A numerical representation of habitat quantity and quality is derived and compared between the two scenarios. Net benefits attributable to the project can then be compared to the net benefits from other projects in order to rank all proposed projects.

In most instances, variables measured in the monitoring program will provide data that can be used in the WVA models. Post-project WVA analyses utilizing these data can be compared with the results of WVA scores derived during priority project rankings in order to verify or refine the WVA. Such comparisons should not be used to judge project success or failure in achieving goals.

The monitoring work group recognizes the WVA as a planning tool and is therefore looking beyond the WVA in terms of monitoring variables. However, the WVA process can provide invaluable baseline information that may aid in the development of project-specific monitoring plans and/or the selection of appropriate control areas.

IV. APPROACH

The monitoring work group developed a broad-based, standardized approach for monitoring different variables. Each technical expert was asked to assemble a subgroup in order to

- 1) identify variables
- 2) develop a standard method or protocol for measuring each variable;
- 3) develop options for accurately and reliably measuring that variable over time;
- 4) develop options for accurately and reliably measuring that variable over space;
- 5) determine how the protocol, time, or space sampling might differ for each of the nine types of projects;
- 6) address a plan for statistical review;
- 7) address quality assurances;

I. TITLE: WATER QUALITY MONITORING IN COASTAL LOUISIANA

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IV. INTRODUCTION

The charge to the water quality monitoring subgroup was to develop a protocol documenting the approach the monitoring work group should use in establishing a water quality monitoring design. This design will provide data for the assessment of the different types of restoration projects on area water quality, and yet be consistent enough to allow for comparison of data between projects. The monitoring design must consider possible water quality effects on waters receiving discharge from restoration projects. The subgroup also felt that the protocol should be flexible in design to allow for successful monitoring of the many different types of restoration projects that will likely be attempted. It should be emphasized that many of the topics addressed by the water quality subgroup are directly related to the charges assigned to the hydrology, vegetative, and soil and sediment subgroups. Our subgroup recognizes the potential of fecal bacterial contamination by some CWPPRA projects; however, active monitoring programs by the Louisiana Departments of Health and Hospitals and Environmental Quality already address this issue. Frequency and intensity of collection of data for monitoring water quality are directly related to or influenced by the needs of these other subgroups.

V. GENERAL DISCUSSION

Pre-project Selection Considerations

The first recommendations of the water quality subgroup are that prior to actual selection of projects, the CWPPRA Planning and Evaluation Subcommittee must consider and perform the following tasks for each possible project:

Table 3. Recommended prioritization of water quality variables for CWPPRA.

Project type	Salinity/ temperature	Physical, dissolved oxygen, pH, specific conductance	Nutrients, nitrogen, phosphorus	Trace metals	Synthetic organic compounds	Soil/suspended sediment			
						Nutrients	Trace metals	Synthetic organics	Size fraction analyses
Freshwater introduction and diversion	1 ^a	2	2	4,2 ^b	4,2	4,2	4,2	4,2	3,N
Sediment diversion	4	4	3	4	4	2	3	3	2,N
Marsh management	1	2	2	4,2	4,2	3	4	4	4,N
Hydrologic restoration	1	2	2	2,4	2,4	3	4	4	4,N
Beneficial use of dredged material	4	4	4,1	4,1	4,1	2	3,1	3,1	2,N
Shoreline protection	4	4	4	4	4	4	4	4	N
Barrier island restoration	4	4	4,1	4,1	4,1	2	3,1	3,1	2,N
Vegetative plantings	1	3	3	4	4	2	3,2	3,2	3,N
Sediment and nutrient trapping	3	3	1	4,1	4,1	2	3,2	3,2	3,N

^aPriorities:

- 1 = Primary objective
- 2 = Secondary objective
- 3 = Tertiary objective - long term evaluation
- 4 = Lower priority - long term evaluation
- N = As needed, unique to a specific project

^bFor columns that have two numbers listed, the first number indicates the priority of that variable(s) for projects where information for tasks 1-6 are available. The second number indicates the priority of the monitoring task for projects lacking information for tasks 1-6.

Grouping of variables	Instrument	Cost	Frequency of record	Environment
Other physical measurements-pH, dissolved oxygen, specific conductance, ORP (oxidation reduction potential), turbidity	Data collection platform	\$20k instrumentation, \$2-4k installation ^a , \$6-8k maintenance	5-30 min	Highly variable, tidal areas
	Fixed recorder paper punch or digital recorder	\$4-8 maintenance	5-30 min	Highly variable, tidal areas
	Non-fixed data sonde (Hydrolab)	\$4-6k	5 min-2 hr	Highly variable, tidal situations, remote areas

^aInstallation cost if platform and transmitter are already installed.

These methods need quality control and assurance information in the form of duplicate samples, calibration checks, standards, and field checks. Dissolved oxygen probes may need frequent servicing during certain seasons to prevent biofouling.

Grouping of variables	Instrument	Cost	Frequency of record	Environment
Nutrients: total and dissolved nitrogen spp, phosphorus spp, (ortho P, NH ₄ , NO ₂ , NO ₃ , Organic)	Fixed sampler requires chilling to 4°C	\$20k instrumentation, \$10-35k including analysis	1 hr - daily	Highly variable, tidal situations
	Fixed probes for NH ₄ , NO ₃	\$8-20k instrumentation, \$2-3k installation ^a , \$3-4k maintenance, including analysis	5-15 min	Highly variable, tidal situations, nutrient-sensitive areas
	Daily observer	\$8k-collection and analysis	Daily	Stable areas

^aInstallation cost if platform and transmitter already installed.

Costs of monitoring can be greatly decreased by employing gas chromatograph-flame ionization scans for those compounds extractable with methylene chloride, and by using portable gas chromatographs for volatile organic compounds and immuno-assay kits for triazine herbicides. Confirmation of detections by any of these methods must be performed by using quantitative gas percent recoveries for the compounds analyzed.

Grouping of variables	Instrument	Cost	Frequency of record	Environment
Soils/sediment nutrients	Instantaneous, includes collection and analysis	\$200	NA	NA

All samples should be chilled to 4°C immediately upon collection. Samples should be analyzed according to accepted methods. Quality control and assurance information need to be collected including duplicate analyses and laboratory standard and blank information.

Grouping of variables	Instrument	Cost	Frequency of record	Environment
Soils/sediment trace metals	Instantaneous, includes collection and analysis	\$400-1,400*	NA	NA

* Cost is per sample. Cost of sample analysis is dependent upon the number and kinds of elements requested and the amount of ancillary data (TOC, grain size, surface area, etc.) needed.

Samples need to be chilled at the time of collection. Holding times are less critical; however, possibility for sample contamination is much greater. Analyses should be done according to accepted methods. This grouping of variables needs quality control and assurance information in the form of duplicate samples, and spikes and blanks from the laboratory.

Table 4. Sampling frequency and priority of variables.

Project type	Salinity/ temperature	Physical, dissolved oxygen, pH, specific conductance	Nutrients, nitrogen, phosphorus	Trace metals	Synthetic organic compounds	Soil/suspended sediment			
						Nutrients	Trace metals	Synthetic organics	Size fraction analyses
Freshwater introduction and diversion	R ^a	R2 ^b	I2N	I4,2N	I4,2N	I4,2	I4,2N	I4,2N	I3N
Sediment diversion	4N	4N	I3N	I4,2N	I4,2N	I2N	I3N	I3N	I2N
Marsh management	R	R2N	I2N	I4,2N	I4,2N	I3N	I4N	I4N	I4N
Hydrologic restoration	R	R2N	I2N	I2,4N	I2,4N	I3N	I4N	I4N	I4N
Beneficial use of dredged material	I4	I4	I4,1N	I4,1N	I4,1N	I2N	I3,1N	I3,1N	I2N
Shoreline protection	I4N	I4N	I4N	I4N	I4N	I4N	I4N	I4N	N
Barrier island restoration	I4N	I4N	I4N	I4N	I4N	I2N	I3N	I3N	I2
Vegetative plantings	I1	I3N	I3	I4	I4	I2	I3,2	I3,2	I3
Sediment and nutrient trapping	I3	I3	I1	I4,1	I4,1	I2	I3,2	I3,2	I3

^aFrequency of collection

I = Instantaneous

R = Realtime

^bPriorities:

1 = Primary objective

2 = Secondary objective

3 = Tertiary objective - long term evaluation

4 = Lower priority - long term evaluation

N = As needed, unique to a specific project

These kinds of projects are not expected to have any impacts on water quality; however, specific projects may require chemical samples from water and sediments before and after the project is completed.

Barrier Islands

These kinds of projects are not expected to have any impacts on water quality; however, specific projects may require chemical samples from water and sediments before and after the project is completed.

Vegetative Plantings

The water quality monitoring subgroup recommends that an initial synoptic sampling of the project area be completed (unless recent historical data exists) prior to initiation of the project. Sampling, especially soil and sediments, is recommended if problems are observed in the growth of the targeted plant species. Areas receiving agricultural runoff, especially herbicides, may need seasonally targeted sampling to determine factors effecting the success of the project.

Sediment and Nutrient Trapping

The water quality monitoring subgroup recommends that an initial synoptic sampling of the project area be completed (unless recent historical data exists) prior to initiation of the project. Additional yearly samples may be required to determine the effectiveness of an individual project. It should be noted that only those compounds identified during the initial synoptic sampling need to be reanalyzed.

VII. HISTORICAL DATA

Inventory of Existing Data

Maps and an inventory of current and historical U.S. Geological Survey (USGS) chemical and monitoring sites are on file with the monitoring work group. Nutrients, trace metals, pesticides, PCB's, and major ions in water and nutrients, trace metals, pesticides, and PCB's in sediments have been collected at most of the sites plotted on the map. Many of the current sites have suspended sediment and discharge collected on routine basis. Volatile organic compounds (VOCs), triazine herbicides, and semi-volatile priority pollutant data have not been collected at any USGS sites with the exception of the Mississippi, Calcasieu, and Mermentau Rivers.

A listing of the Louisiana Department of Environmental Quality (LDEQ) water quality stations also is on file with the monitoring work group. The LDEQ does not analyze for synthetic organic compounds on a routine basis at any of their sites with the exception of VOC's on the Mississippi River. The LDEQ does have synthetic organic compound data for the Calcasieu River system.

A listing of all stations in the U.S. Environmental Protection Agency STORET system also is on file with the monitoring work group. A total of 2,922 stations are listed for the Louisiana coast and inland to Interstate 10.

I. TITLE: HYDROLOGIC MONITORING IN COASTAL LOUISIANA

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IV. INTRODUCTION

The primary purpose of hydrologic monitoring is to collect data required for the scientific evaluation of completed projects. In this evaluation, the success of a completed project will be measured by the number of acres of wetlands saved or created. This effort is intended by all involved—Federal, State, and local governments and private citizens alike—to be successful and have a positive, lasting effect in coastal Louisiana and to either preserve or create a measurable impact on our marshes and coastline. To measure the degree to which these activities and projects are being successful, physical variables must be quantified in the beginning, during construction, after completion, and for posterity. These variables will define the problem, define human impact, measure progress, suggest midcourse changes, improve design and performance of future projects, and ultimately justify our efforts and direction.

indicators of hydrologic conditions in a wetland, of seasonal flooding, and of extreme events such as floods and hurricanes. They are indicators of tidal exchanges and sea-level change. Water-level data are important in interpreting aerial photography and converting bathymetric and topographic data to a sediment deposition, subaqueous delta development, and scour. Bathymetry can also provide valuable information on water depths, location of channels and crevasses, and overall marsh bottom configuration that will affect different hydrologic measurement and management practices.

Topography

Topography can be used in conjunction with aerial photography in quantifying increases and decreases in wetland areas and barrier islands. The elevation of the ground in a wetland affects the type of vegetation present and the depth and duration of water. Topography can be used to measure sediment deposition, subaerial deltaic development, and subsidence. Topography can also provide valuable information on channel obstructions, natural and artificial banks and levees, and points of ingress and egress.

Salinity

It is important to quantify the salinity in a project area because of its influence on wetland habitat. Wetland habitats are characterized by salinity levels, i.e., fresh marsh and saline marsh. Saltwater intrusion is a major cause of loss of freshwater wetland habitat in areas such as the Mississippi River delta because of its adverse impact on freshwater vegetation. Project types such as marsh management, freshwater diversion, and hydrologic restoration are geared toward regulation of salinity levels in a project area to reduce wetland loss.

The main body of information on this variable can be found in the report on water quality monitoring.

Discharge, Velocity, and Direction

Discharge, velocity, and direction data are important in defining circulation patterns and tidal characteristics within a project area. Circulation affects the presence and variability of nutrients in a wetland; estuarine organisms; and turbidity, salinity, and other water quality variables. Water exchange is an important variable in the quality of cypress-tupelo swamps. Discharge can be correlated with suspended sediment to quantify the amount of sediment available for deposition. Discharge measurements can be used to "rate" a structure to determine the volume of flow entering or exiting a water control structure, such as freshwater diversion or hydrologic restoration structures given certain headwater and tailwater conditions. Velocity and direction data can assist refuge managers in determining when to open or close a structure and for how long.

independent auxiliary datum references used to verify or reestablish the gauge datum. All gauges should be periodically checked by running levels or GPS and by using the reference marks to maintain a fixed datum.

A common datum for all the gauges in the coastal zone would be beneficial. A common datum allows for the comparison of data within the project area and throughout the coastal zone. However, this may prove to be cost prohibitive or infeasible. Reference marks may use a common datum such as NGVD but will contain different adjustments to the datum.

The costs to establish a datum for a water-level gauge has not been included in the cost of the gauge presented in this report. Costs will vary depending on the location of the gauge. A baseline of levels has been established by the U.S. Army Corps of Engineers (USACE) along the Mississippi River into Southwest Pass. Levels have also been run for the Lower Atchafalaya River. To tie into these baselines may be expensive; the cost of the Mississippi River levels was \$40,000 for 20 miles of levels. GPS has been used in the Lake Verret-Atchafalaya area very successfully. The field work and post processing costs were approximately \$26,000. More than 10 gauge datums were verified with the GPS method; the cost per gauge is therefore reasonable. In using GPS, consideration should be given to grouping gauges in a geographical area to reduce costs.

Ongoing Programs

The USACE has a gauging program to evaluate the effectiveness of their projects. The gauges are located predominantly along rivers, channels, and bayous. The networks, type of gauge, and parameters measured were designed for projects such as navigation, flood control, and water supply. Because many of the gauges are continuous recording or realtime, they can provide valuable information for the CWPPRA projects in the vicinity. Use of USACE gauges can minimize the cost of the CWPPRA monitoring program.

The USACE also installs gauges for data collection during the design phase of their projects. Although the data collection is short term and often uses an arbitrary datum, it can provide information on pre-project conditions in the coastal zone.

The USACE and U.S. Geological Survey (USGS) have a cooperative stream-gauging program with many gauges in the coastal zone. Again, the gauges are located predominantly along rivers, channels, and bayous and were installed mainly for flood control purposes.

The USGS and the Louisiana Department of Natural Resources have a cooperative program to monitor state wetland restoration projects in the coastal zone. The collection of stage, precipitation, salinity, wind speed and direction, and velocity data are primarily in realtime.

The U.S. Fish and Wildlife Service has installed some gauges in several of their refuge areas to monitor water levels, salinity, and tidal characteristics. The gauges collect realtime data.

Precipitation should be recorded continuously by using the same recording periods as the National Weather Service. Hourly incremental precipitation data can be determined from the data collected. Monthly and annual totals can be computed from the data with adjustments for periods of high intensity.

The uses for which the precipitation data are intended should determine network density. A relatively sparse network of stations would suffice for determining annual averages over large areas. In general, sampling errors, in terms of depth, tend to increase with increasing areal mean precipitation and decrease with increasing network density, duration of precipitation, and size of area. Average errors tend to be greater for summer than for winter precipitation because of the greater spatial variability. The minimum density of precipitation network recommended for general hydrometeorological purposes for flat regions of tropical zones is 230-350 mi² per station.

For lower priority projects, records from nearby precipitation stations may be sufficient. Gauges should be added, if necessary, to achieve a good spatial density. The cost to purchase and install a recording rain gauge is approximately \$1,400 with maintenance costs around \$1,000. Tipping bucket gauges can also be installed at existing realtime stage recording sites; the cost to purchase and install this equipment is approximately \$800 for the gauge and \$1,000 to install. Maintenance costs should be no more than \$500 per year but will include some analysis of the data for quality control.

Evaporation

The pan is the most widely used evaporation instrument. The operation of a pan station is relatively inexpensive and should provide good estimates of annual evaporation. Water levels in the pan are measured, and the evaporation, in inches, is computed as the difference between observed levels, adjusted for any precipitation recorded. Three types of exposures are employed for pan installation: sunken, floating, and surface. Burying the pan tends to eliminate boundary effects such as radiation on the side walls and heat exchange between the atmosphere and the pan, but causes observational problems.

In the coastal zone, there are currently no evaporation pans from which evaporation rates can be determined. For projects where precipitation and evaporation are high priorities, one evaporation pan should be installed in the hydrologic basin along with a precipitation gauge for continuous data collection and realtime transmission. Purchase costs will be approximately \$800 for the pan. Installation and maintenance costs will be included in the cost of the precipitation gauge.

Evaporation should be recorded continuously by using the same recording periods as the National Weather Service. Annual, seasonal, and monthly evaporation rates can be determined from the data collected. One evaporation pan per hydrologic basin should be sufficient spatial density.

Wind Speed and Direction

Wind speed is measured with anemometers. Both cup and propeller anemometers are commonly used. A wind vane measures the direction from which the wind is blowing. Surface winds are generally reported in miles per hour, meters per second, or knots. Surface wind directions are generally reported in degrees to the nearest 10 degrees.

Water Level

Stage is a measure of water-level surface in a body of water. Stage can be measured discretely or continuously over a period of time. Depending on the measurement device, accuracy limitations will range from 0.01 to 0.1 ft.

Stage measurements can be made by using several different devices. A staff gauge is the simplest of stage measurement devices. Water-level measurements are made by visual inspection of a vertical graduated staff. Water-level measurements can also be measured with a continuous stage recorder. The water levels are determined by using a tape-float system or pressure transducer. Readings are recorded on a regular time interval on digital recorders, graphic recorders, or electronic data recorders. Electronic data recorders are devices such as basic data recorders where the stage values are stored in memory and downloaded into a computer during field inspections or into data collection platforms that transmit the data via satellite, radio, or telephone on a realtime basis.

Stage recorders can be temporary or built to last over a long period of time and under various environmental and climatological conditions. Cost can range from \$200 for a staff gauge to \$20,000 for some data collection platforms. Some of this equipment can be rented.

Where cost is not a major issue and where water-level data are a high priority variable data collection platforms are recommended as the standard protocol. Data collection platforms have a high equipment and installation cost for the stage recorders but reduce the cost of collecting other variables such as water temperature, dissolved oxygen, and precipitation because the equipment that measures the other variables can also use the data collection platform. Data collection platforms reduce maintenance costs; maintenance personnel can see when a gauge is not functioning properly and can perform maintenance on a less frequent basis than without the data collection platform. Because maintenance is performed immediately rather than on a scheduled basis, periods of bad or missing data are reduced. Equipment costs will be \$5,000 and installation costs \$3,000. Maintenance costs will range from \$3,000 to \$6,000 per year (\$5,000 will be used for estimating purposes), including analysis of the data for quality control.

The measurement of stage over time can be from one reading at a site to whatever interval is required, such as daily, hourly, or less over a determined period.

Measurement of stage at one location can be compared to other water levels within a certain range of the gauge in common hydrologic areas. Spatial distribution of water level gauges will depend on the project type and the hydrologic characteristics of the project area.

At many project areas, existing stage recorders or realtime data collection platforms in the vicinity will suffice. At some locations, an observer may be hired to daily record stage from a staff gauge; a paid observer usually receives about \$365 per year. Purchase and installation of the staff gauge would be about \$1,100, with annual maintenance costs about \$500 per year. Some sites can be monitored continuously for a short time, i.e., 30 to 180 days to determine the relationship of stage at the project to a nearby permanent location. Other sites can have a staff gauge installed, which would be read during the site visits. Purchase and installation would be approximately \$1,100. These protocols are best suited for projects where collection of water-level data is a low priority.

as colloid. Suspended sediment is expressed in parts per million (ppm) or milligrams of dry sediment per liter of water sediment mixture (mg/L). Suspended sediment samples can be collected in several ways. In moving water, samples can be collected by using a number of different types of point samplers. Samples are collected at different points in a vertical profile and combined for analysis or analyzed individually. Suspended sediment samples can be collected in low velocities with wide-mouth samplers. Suspended sediment samples can also be collected by using a pump system to collect the sample. Automatic samplers are also available to provide unattended sampling at the frequency desired. Sediment sample costs will vary depending on the number of samples taken. A typical sampling program would cost about \$1,800 for data collection and lab analysis of around 20 stations on small channels. A DH59 sampler costs about \$500. Additional information is provided in the water quality monitoring subgroup report.

Where sediment sampling is a high priority, channel measurements taken with a point sampler should be made or an automatic sampler should be installed. Channel measurements generally require a discharge or velocity measurement for correlation. Automatic samplers require implementation of a good quality control system that includes routine visits for maintenance. The frequency of measurements will be project and site dependent. Sampling should be performed a minimum of six times per year. Sampling could be done during the site visits.

Groundwater

Probably the easiest technique to measure groundwater is to install a shallow piezometer at the same time soil cores are initially taken. The piezometer would be slotted PVC and would need some type of fine-gravel pack to minimize siltation, an upper casing, and a protective cap. Height of groundwater could be measured by using a simple ruler from the top of the casing during site visits, or any other data collection event.

Piezometers to monitor groundwater are relatively inexpensive; they cost a few hundred dollars each. Piezometer monitoring could be done during site visits or when personnel are in the field for other monitoring.

Piezometers can probably be installed at a cost of a \$200 to \$400 each. Actual monitoring costs will be minimal since the monitoring will occur during other visits to the project area and take only a few minutes. Data collation and analysis will also be minimal. Estimated costs are \$5 for collection and \$10 for collation, quality control, and analysis per piezometer.

Soil Salinity

Soil salinities can be measured by extracting interstitial water from a surface sediment sample by centrifuge. In many cases, freezing and defrosting a segment of sediment will disrupt sediment particle structure and allow settling. Separation of interstitial water can then be measured by a conductivity probe. Titration is accurate, but time consuming and therefore expensive in terms of labor. A refractometer is quick and inexpensive, but measurements are only accurate to approximately 1 ppt.

Soil salinities change slowly, and variation will be dampened compared to variation in salinity of the overlying water, which will change with tidal cycle as well as wind direction, seasonal changes to freshwater input, and climatic cycles. Thus soil salinities can be measured monthly for projects that

Table 6. Monitoring matrix by priority^a for hydrologic monitoring projects.

Project type	Precip.	Evap.	Wind speed direction	Water level	Bathymetry	Topography	Salinity	Discharge	Suspended sediment	Ground water	Soil salinity	Annual cost ^b
Freshwater diversion	1	3	1	1	3	3	1	1	1	4	4	\$39,200
Sediment diversion	3	3	3	1	1	1	3	1	1	4	4	\$46,200
Marsh management	1	3	1-3	1	2	2	1	2	3	4	2-3	\$23,600
Hydrologic restoration	1	3	2-3	1	2	2	1	2	3	4	2-3	\$24,100
Dredged material	4	4	4	3	1	1	4	4	4	4	1	\$10,500
Shoreline protection	4	4	2 ^c	3 ^d	1	1	4	3	4	4	4	\$6,000
Barrier island restoration	4	4	2 ^c	3 ^d	1	1	4	3	4	4	4	\$11,000
Vegetative plantings	2	3	4	2-3	3	3	1	4	3	4	2-3	\$8,000
Sediment and nutrient trapping	4	4	3	2-3	1	2	3	4	2-3	4	2-3	\$33,100

^aKey:

- 1 = Primary objective
- 2 = Secondary objective
- 3 = Tertiary objective (long term evaluation)
- 4 = Lowest objective (long term evaluation)

^bEstimates include average annual equipment maintenance cost for one gauging station.

^cWind vectors may have a higher priority if needed to hindcast wave height and period.

^dA directional wave gauge to determine the forces and littoral transport may have a high priority in determining failures.

**CWPPRA PROJECTS ON SOIL DEVELOPMENT, SUBSIDENCE, AND
MARSH ACCRETION**

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processes (involving the accumulation of both organic and inorganic material) must occur or the marshes will be gradually submerged and the vegetation subjected to waterlogging. In addition, an important aspect of marsh creation is the development of soil properties. The newly created marsh soil must attain adequate hydrologic function to prevent waterlogging and/or the accumulation of toxics while providing the necessary nutrients for vegetative growth.

In those projects that aim to stimulate accretionary processes or recreate natural marsh development processes, e.g., sediment diversions, monitoring of marsh vertical accretion and changing soil properties is essential to assessing the success of the project. On the basis of this assessment of the need for monitoring of soil development and accretionary processes in a variety of types of project, the proposed CWPPRA projects can be classified as follows:

Class A. Those that aim to create new marsh by artificial means (e.g., use of dredged spoil) but do not manipulate marsh processes, and where subsequent accretion and soil development are essential for the longevity of the project.

Class B. Those in which the manipulation of accretionary processes is a minor or secondary aim of the project, but where indirect affects on accretion and changes in soil type might occur (e.g., freshwater diversion, marsh management).

Class C. Those that specifically aim to enhance accretionary processes in existing marsh or to create new viable marsh by the manipulation of existing processes (e.g., sediment diversion, crevasse splays).

In addition, the variables to be measured during monitoring have been ranked according to project type and their importance in assessing project goals.

V. GENERAL DISCUSSION

Rationale of Variables

The marsh soil is a result of the cumulative effect of marsh building processes that include the production, transport, and decomposition of organic matter and net influx of inorganic sediments. Depending upon the rate of soil development or marsh accretion, the soil can represent the cumulative impacts of these processes over years or decades. Consequently, monitoring changes in soil variables after project implementation can provide two types of information regarding the success of CWPPRA restoration projects:

- (1) documentation of changes in soil composition, stability, structure or development that occur as a direct or indirect result of the project.

Variables:

- Organic matter
- Bulk density
- Water content
- Grain size
- Soil redox
- Soil nutrients
- Soil contaminants (trace metals, synthetic organics, etc.)

Table 7. Monitoring matrix.

	Class	Accretion	Subsidence	Organic matter	Bulk density	Water content	Grain size	Soil redox	Erosion/creation large scale (mapping)	Erosion/creation small scale
Freshwater diversion	B ^a	2, 1a ^{bc}	2	1	1	1	3	2	3	N/A
Sediment diversion	C	1	1	1	1	1	1	2	1	N/A
Marsh Management	B	1	2	1	1	1	4	1	3	N/A
Dredged material	A	1	2	1	1	1	3	2	N/A	1D, 4M ^d
Barrier island restoration	A	1	3	3	3	3	2	4	N/A	1
Shoreline protection	B	2, 3c	4	3	3	3	3c	4	N/A	1
Vegetative plantings	B	2	4	2	2	2	3	2	N/A	1
Sediment and nutrient trapping	C	1	1 Basin	1	1	1	2	3	N/A	1
Hydrologic restoration	B	1	2	2	2	2	3, 2d	2	3	2 e

^aA - Create new marsh by artificial means, not manipulate processes.

B - Manipulation of soil processes is a minor aim of project but impact on soil occurs.

C - Project aims to enhance accretionary processes or create new marsh using natural processes.

^b1 - Primary objective

2 - Secondary objective

3 - Tertiary objective - long term evaluation

4 - Lowest priority - long term evaluation

^aa - depending on the scale of monitoring for vegetative vigor/growth

b - higher priority of no previous information on soil quality available

c - higher priority if marsh creation is expected

d - if riverine sediment transport paths are affected

e - small scale monitoring required if marsh creation is expected

^dD - importance at design stage

M - importance for monitoring

Basin - basin scale subsidence information only

- * Control and project areas should be comparable in their vegetation (within marsh habitat), hydrology, and proximity to sediment sources. The amount of acceptable variability varies according to the number of control areas selected (see Experimental Design section).
- * Control and project areas should be comparable in the thickness of the marsh soil. This provides the substrate for marsh growth and is the zone where changes resulting from project implementation will be identified. Previous studies by the U.S. Soil Conservation Service and Louisiana Geological Survey have noted some variations in the depth to the "clay horizon." In order to make effective comparisons between control and project areas, variations in the thickness of marsh soil must be examined before sampling sites are selected.

The validity of the comparisons made between project and control areas will depend upon the number of replicate samples that are taken. The project and control areas should be divided into marsh habitats and at least five replicate sample sites selected randomly within the areas. For instance, if the project area includes both brackish and saline marsh habitats and the study is to consider only back marsh locations, then five brackish-backmarsh-control, five brackish-backmarsh-project, five saline-backmarsh-control, and five saline-backmarsh-project sampling sites should be selected. It is necessary to ensure that control and project areas are comparable. If the project area is large, then sample size should be increased. It is essential that sampling sites are not chosen for logistic reasons but to represent the marsh area being studied. Boardwalks may be necessary to prevent unnecessary disturbance in areas where frequent access is necessary. In all cases, sampling on all areas should be conducted during as short a period as possible to prevent the confounding effects of unpredictable extreme events.

Marsh accretion and soil development are mediated by marsh hydrology and vegetative growth. If monitoring is to be conducted regarding hydrology and vegetation, the understanding of marsh function and the impact of the project will be greatly enhanced by coordination of sampling sites and frequencies. Indeed, the monitoring of marsh-water levels and vegetation productivity (aboveground and belowground), in particular, will enhance the understanding of project impacts gained from the monitoring of marsh accretion and soil development. Consequently, the overall monitoring strategy should allow for coordination between monitoring protocols. Preferably, the same agency or contractor should be responsible for these aspects of the monitoring, or a mechanism for cooperation should be established.

Sampling Design

The sampling matrix (Table 8) shows three strategies for sampling the different types of projects according to the frequency of sampling. The basic monitoring is for Class A projects; more detailed monitoring is proposed for Class B projects; and Class C projects require the most intensive monitoring as soils and sediments are included in the primary objectives of the projects. In addition, for projects where no control sites are available, pre-project monitoring of certain variables is proposed to provide baseline data. These are believed to be the minimum requirements necessary to meet the mandate of CWPPRA for scientific evaluation of project success.

Methods

Soil properties - organic matter content, dry bulk density, water content, grain size

Core samples should be taken from the marsh for the evaluation of these variables.¹ The technique used for coring the marsh is important because inappropriate techniques can cause compaction of marsh sediments and particularly inaccurate measurements of dry bulk density and water content. The best method, which works in all marsh habitats (saline through fresh) and with minimum disturbance to the marsh surface, is cryogenic coring. This involves the freezing of the marsh onto a copper tube and the extraction of a small diameter (5 cm) core without compaction (Knaus and Cahoon 1990). The cores can be sliced into 1 cm or larger segments while still frozen. This method is more field intensive than other methods involving coring devices, but the frozen cores allow easier laboratory analysis for bulk density than other standard practices (e.g., Procedure 4A in U.S. Department of Agriculture, Soil Conservation Service 1984). Alternative coring methods usually involve some compaction of sediments, which can be critical in the evaluation of soil bulk density. A large-diameter (15 cm) core tube can be used to minimize compaction but it usually has to be dug from the substrate causing considerable disturbance. Such disturbance is not appropriate in areas that are being monitored, i.e., where repeated sampling is required. The core segments should be weighed while wet and then oven dried before reweighing. The difference in weights indicates the water content of the soil and the weight of the dried segment which, when standardized for the segment volume, provides the dry bulk density. Organic matter content can be similarly determined by loss to ignition at 375°C for 16 h in a laboratory muffle furnace (or see Procedure 8F in U.S. Department of Agriculture, Soil Conservation Service 1984). Size determination of the ashed sediment samples by using a combination of sieving and pipette/Coulter Analyzer techniques will provide soil grain size data.

Cost per sample ² :	Organic matter content	\$100
	Dry bulk density	\$100
	Water content	\$50
	Grain size	\$100

Accretion (Feldspar)

Feldspar marker horizons should be established at each sampling site. Areas should be at least 50 cm x 50 cm and the layer of feldspar should be at least 3 mm thick. The increment of soil deposited and accumulated above marker horizons should be monitored seasonally. The cryogenic coring technique should be used to sample the surface soil layers at randomly selected locations and the increment of accumulation measured to 0.5 mm. Alternative techniques for sampling feldspar marker horizons,

¹ The depth to which these variables are measured within the soil and the number of samples taken from each core (e.g., 5 cm, 10 cm, 15 cm, etc.) will depend upon the nature of the project, but will be consistent between sampling within the project and control areas.

² Costs are very approximate and depend upon who is conducting the sampling and sample processing. Estimates were made based upon one agency or contractor conducting the monitoring and taking samples for all analyses during the same field trips. Project access costs (for example, if an airboat is required) could increase costs. Estimates were based on \$100 per day for boat access to project areas. For airboats this would increase to \$450.

rise above the ground because it is free to move. Nests of three extensometers completed at different depths can be used to determine the amount of shallow compaction (or subsidence) and how it is vertically distributed.

Cost per vibrocore: \$2,000
Cost per extensometer: \$14,000

Subsidence - project scale

Tide gauges established within each project (by the hydrology group) should be tied into the existing regional network of long-term gauges. Analysis of annual trends in tide-gauge data for long-term stations should be continued, with additional establishment of GPS benchmarks and extensometers (see above) at each project, which are tied to the basin-scale network.

Costs: See above.

Soil redox potential

Soil redox potential should be measured *in situ* at 5-cm intervals below the marsh surface by using brightened platinum electrodes (Mendelssohn and McKee 1988). The depth to which measurements need to be made will depend on the particular project but should be at least 20 cm to coincide with samples taken for chemical analyses.

Cost of profile measurement: \$75

Marsh erosion and creation - large scale

The methodologies and costs for this type of monitoring fall under the auspices of the habitat mapping group. Those types of projects that require this evaluation are indicated in Table 1, and we defer to the recommendations of the habitat mapping group regarding the acquisition of these data.

Marsh erosion and creation - small scale

Small-scale changes in the position of the marsh edge can be determined by one of two techniques:

- (1) Repeated surveys of marker stakes (standard beach survey technique).
- (2) Repeated measures of the position of the marsh margin in relation to a fixed point within the marsh (Letzsch and Frey 1980).

Which technique is most appropriate will depend upon the individual projects, substrate conditions, and the rate of expected erosion and progradation. The survey technique provides information on marsh morphology and is more accurate but requires experienced personnel for surveying. The Letzsch and Frey technique requires the insertion of posts at fixed positions in relation to each other and the original marsh edge. Subsequent measurements are made with a tape measure and do not require experienced personnel. Costs vary accordingly.

Cost of measurement: \$150-\$300

**I. TITLE: VEGETATIVE HEALTH MONITORING ON CWPPRA PROJECTS
IN COASTAL LOUISIANA**

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IV. INTRODUCTION

The vegetative health monitoring subgroup of the CWPPRA Monitoring Work Group was tasked to develop vegetative protocols and analyses required to determine the degree of success of the various types of projects built under the CWPPRA. The act specifically asks for the development of projects that significantly contribute to the long-term restoration or protection of the physical, chemical, and biological integrity of coastal vegetated wetlands. The major goal of protection projects is to slow or reverse coastal erosion rates, while the major goals of restoration projects are to preserve, enhance, and/or promote the growth of emergent and submergent vegetation. These goals will be evaluated through the determination of acres of wetlands saved or created. Vegetative health monitoring allows us to determine to what degree the predicted response is occurring other than by the mere presence or absence of vegetative communities.

VI. METHODOLOGY

This section defines those variables chosen to monitor vegetative health. A recommended protocol for quantitative sampling of each of the variables is identified, with a discussion of its advantages and ~~and communities are present. It requires compiling a list of all species~~ represents the community. Although this type of survey indicates what new species occur and existing species disappear with time, it cannot indicate change in vegetational importance unless a measure of abundance or dominance is provided. Therefore, it is recommended that species composition and relative abundance be measured at the same time by using the protocols discussed under relative abundance.

Relative Abundance

Relative abundance provides an estimate of the number of individuals per species in a given sample area. It can be measured by cover estimates or stem counts, depending on whether the measurement needs to be relative or absolute. It is limited by the preciseness of measure, with the potential for introducing bias from one individual to the next. Therefore it is recommended that the same individual(s) conduct the monitoring every sampling trip, if at all possible.

The Braun-Blanquet method (Mueller-Dombois and Ellenberg 1974) should be used to identify species compositions and abundances. It requires compiling a species-area curve, which will determine the minimal sample area size. These samples should fulfill the following requirements: the cumulative plot area should be large enough to contain all species, and the habitat should be as uniform and representative as possible. The Braun-Blanquet Cover-Abundance Scale provides absolute values in relation to fixed plot sizes. Scale values that are chosen should not be deviated from for reasons of comparability.

The advantage of this method is that it is simple, comparable, and accepted by ecological investigators. It is also a semi-quantifiable approach that is less time and labor intensive than stem count methods. The disadvantages include subjectiveness in the cover estimates as well as decreasing accuracies with increasing plot sizes. Additionally, care must be taken in selecting the size, shape, and numbers of plots.

Ocular estimates and low-level aerial photography are qualitative techniques that could be used to measure relative abundances. Another quantitative technique that could be used is stem counts.

Aboveground Biomass

This variable provides a measure of growth, health, and vigor of plants by obtaining the weight of vegetation per unit area. The limitations of this measure include its difficulty in being used in large plots and in woody vegetation.

The cost estimate for each field visit to the project area is \$2,000. Aboveground biomass can be analyzed for \$10.00 per sample. These costs will vary depending on size and heterogeneity of the project area and mode of transportation (i.e., airboats).

Resources and project-specific goals will dictate what and how frequently vegetative health variables will be monitored. However, our recommendation is to use resources on habitat mapping first because it provides the baseline for monitoring habitat health.

The broad goals and methods of vegetative monitoring will be more specifically developed on the project level. Each project type may vary somewhat in methodology and frequency of sampling depending on the size and scope of the projects as well as on project-specific objectives.

VII. PROJECT TYPES REQUIRING MONITORING

The monitoring work group has identified nine types of projects for which vegetative health monitoring requirements are to be developed. The types of projects listed in Table 9 have been prioritized regarding their need for vegetative health monitoring. In addition, a determination of whether this monitoring should emphasize qualitative, quantitative, or mixed approaches is identified. Qualitative approaches are used on projects whose response is to create new marsh. These approaches are concerned with identifying the presence or absence of vegetation. Quantitative approaches are used on projects whose response is to shift community types. The emphasis is on determining how much of a difference there is between areas with and without project conditions. These approaches are not only concerned with identifying the presence or absence of vegetation, but also how the vegetation structurally and functionally responds to the projects. Mixed approaches may be used on projects that require some qualitative and some quantitative analyses.

Table 9. The nine types of projects for which vegetative health monitoring requirements are to be developed and their priorities.

Project type	Ranking	Monitoring emphasis
Freshwater diversion (FD)	1	quantitative
Sediment diversion (SD)	3	qualitative
Marsh management (MM)	1	quantitative
Hydrologic restoration (HR)	1	quantitative
Beneficial use of dredge material (DM)	3	qualitative
Shoreline protection (SP)	4	qualitative
Barrier island restoration (BI)	3	qualitative
Vegetative plantings (VP)	2	mixed
Sediment and nutrient trapping (S/NT)	2	mixed

The Coastal Restoration Division of the Louisiana Department of Natural Resources is in the second year of cooperative agreements with the State Soil and Water Conservation Committee and the Coastal Soil and Water Conservation Districts to implement over 50 vegetative restoration projects. Monitoring of these projects includes percent survival, number of new shoots, lateral spread, height, basal cover, vigor, seed head formation, insect damage, and herbivore damage. The herbivore monitoring in particular can provide some useful information.

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producing 500 wetland and upland habitat maps for coastal Louisiana, using infrared photography. Two hundred and twenty-three of these maps will be comparable to the previous mapping efforts of 1956 and 1978. In fact, many of the completed maps and the digital data available from them are being used in the planning process for the CWPPRA. Although this habitat mapping is providing data for basin-wide planning such as measuring wetland change, land loss, and marsh loss, the detail is insufficient for providing similar comparisons for each restoration project type. The regional mapping projects of NWRC and U.S. Army Corps of Engineers (USACE) are based upon 1:63,500 scale aerial photography or base maps; this scale precludes the ability to photointerpret and map consistently or economically those parcels of marsh or open water that are less than one acre in size. Consequently, studying the processes or documenting the change in the habitats in restoration project areas is difficult.

The objectives of habitat mapping are:

- * To provide a data base from which basin-wide wetland trends can be measured and to update the 1988 data base with 1993 thematic mapper data
- * To provide baseline maps for a historical time period for the vegetation within each of the restoration sites prior to the restoration project being implemented
- * To acquire aerial photography for each restoration site for successive years and provide that photography to other monitoring subgroups
- * To develop large-scale, detailed habitat maps (and assess the classification accuracy of these maps) for successive years that can be used by the other monitoring subgroups
- * To coordinate with the vegetative health subgroup in fieldwork, data collected, and maps generated
- * To assess the impacts or changes brought on by the restoration activity
- * To develop digital data for selected restoration projects on an as needed basis.

V. GENERAL DISCUSSION

Data Availability

Wetland and upland habitat maps and digital data are available from USFWS for the whole Louisiana coastal zone for 1956, 1978, and 1988 at a scale of 1:24,000.

The Louisiana Department of Natural Resources (LDNR) Coastal Management Division has classified satellite thematic mapper (TM) data for the whole coastal zone for winter 1984-85. Geocoded (Louisiana State Plane-South Zone) TM data are available for winter 1990-91 for the whole coastal zone. Partial January 1988 geocoded TM data are also available for the eastern half of the coastal zone.

The aerial photography should be collected by basin to avoid the changing water and vegetation conditions that can often vary from one basin to another.

The aerial photography should be collected each year for the first 3 years then every third year thereafter. However, this should be considered on a case by case basis after the first year because some of the projects may have changes that necessitate the acquisition of aerial photography more or less frequently than every third year.

3) **Historical**

Use the existing USFWS aerial photography from 1978 and enlarge to 1:24,000 scale, photointerpret the habitats, and map each unit to provide baseline data to measure changes against. For areas that are to be mapped at 1:24,000 scale, the 1988 USFWS habitat maps can be used as an additional time period since those data are readily available. For areas to be mapped at the 1:12,000 scale, the 1978 photography will be enlarged to 1:12,000 scale and photointerpreted. For areas to be mapped from present and future photography at 1:6,000, the 1978 photography cannot be enlarged to 1:6,000 and maintain sufficient clarity and resolution. Therefore these areas will be mapped at 1:12,000 for 1978.

Classification

The basic goal of the habitat mapping program is to provide a consistency of products through the use of the USFWS wetland classification system (Cowardin et al. 1979) and upland habitat delineation (as modified by Anderson et al. 1976).

1) **Basin level**

The 1993-94 TM imagery should be classified to Level I (modified by Perwitt Braud after Anderson et al. 1976) consisting of approximately 14 land cover categories following LDNR procedures used for the 1984-85 imagery.

2) **Project specific**

Use the Cowardin et al. (1979) classification to the subclass level. As per the wishes of other monitoring subgroups, water regime, salinity, and species modifiers may be added to the mapping classification if sufficient fieldwork is funded and/or data from other monitoring subgroups are available. Additional modifiers, e.g., for flotant and managed areas may be added.

3) **Historical**

Use the Cowardin et al. (1979) classification for the historical mapping to the subclass level, with the use of water regime and special modifiers.

Products

- * **Aerial photographs**
- * **Final habitat maps**
- * **Digital data for selected restoration sites**
- * **Field notes**
- * **Classified TM data (including digital and hard copy products) for basin level mapping**
- * **Regional trend maps from basin-level mapping**

Dissemination

The products should be made available to researchers and monitoring groups, State and Federal agencies, parishes, and universities; however, all products should be made available to everyone. Reproduction of maps should be made simple. Photograph reproduction will be a problem of photography, maps, and digital data. One agency should be responsible for archiving and distribution of photography, maps, and digital data, but this will be costly.

Review

- 1) **Basin level**
Series of demonstrations for task force and subgroup chairs
- 2) **Project specific**
Internal review
Regional review
Draft map review - maps would be available to the public for comments from those interested in reviewing the maps. Schedule, though, may negate this if rushed for time.

Statistical Review

While there are no statistical criteria or standards for mapping, classification and positional accuracy will be assessed in order to estimate the overall accuracy of the data.

VI. METHODOLOGY

Basin-level Mapping

The wetland cover and trend work currently being completed for the CWPPRA task force is establishing historical regional trends on either a basin or coastwide basis. There is no need to repeat this process except to update the coastal trend data sets by including the 1988 habitat data set when completed.

Final habitat maps should be digitized for selected restoration projects. It may not be feasible to digitize each project for each year. The restoration projects to be digitized should be determined on reviewing the draft maps to evaluate the extent of change that has taken place. Digitization should be done using the Analytical Mapping System (AMS) on a UNIX workstation. The AMS digital data should be available in DLG-3 format for use on ArcInfo, Integraph, Infocad, etc. Deliverables will be the digital data on standard tape format and acreage summaries for each quad.

GIS should be used to analyze the digitized habitat maps for the purpose of developing wetland trend maps to identify areas of wetland loss and gain occurring within restoration plans over time. Digital data, wetland trend maps, and reporting data (landcover and wetland trend acreage tables) should be available for use on a cost reimbursable basis.

VII. PROJECT TYPES

Project Ranking

Because the mapping program is providing a supporting role, projects are not ranked by the habitat mapping subgroup but should follow the consensus ranking of the other subgroups to do the project-specific mapping.

Proposed Mapping Scale for Each Project Type

<u>Project</u>	<u>Acreage</u>	<u>Scale</u>
Fourchon	2,300 acres	1:12,000
Gulf Intracoastal waterway to Clovelly wetland	60,000 acres	1:24,000
Cameron-Creole watershed	64,000 acres	1:24,000
Bayou Sauvage National Wildlife Refuge	6,000 acres	1:12,000
Turtle Cove shoreline	1,000 acres	1:12,000
Sabine National Wildlife Refuge	13,000 acres	1:12,000
Vegetative plantings		
West Hackberry	> 100 acres	1:6,000
Dewitt-Rollover Gulf	< 100 acres	1:6,000
Falgout Canal shoreline	> 100 acres	1:6,000
Timbalier Island	> 100 acres	1:6,000
West Bay sediment diversion	9,800 acres	1:12,000
Barataria Bay waterway	1,000 acres	1:12,000
Lower Bayou LaCache	4,200 acres	1:12,000
LaBranche wetlands	300 acres	1:12,000
Cameron Prairie	640 acres	1:12,000
Vermilion River cutoff	200 acres	1:12,000
Eastern Isles Dernieres	100 acres	1:6,000
GIWW to U.S. 90	40,000 acres	1:24,000
Tiger Pass marsh	415 acres	1:12,000
Falgout Canal South wetland	220 acres	1:6,000
Lake Salvador shoreline	> 100 acres	1:6,000

VIII. PEER REVIEWERS

**Pat O'Neil
Melvin Fuhrmann
James Gosselink
Carol Clark
Nancy Powell
Paul Kemp
Edward Hickey
James Johnston
John Barras**

**U.S. Geological Survey
U.S. Fish and Wildlife Service
Louisiana State University
Louisiana Department of Natural Resources
U.S. Army Corps of Engineers
Coalition to Restore Coastal Louisiana
U.S. Soil Conservation Service
U.S. Fish and Wildlife Service
U.S. Fish and Wildlife Service**

addressed by the vegetative health monitoring subgroup.

The wildlife monitoring subgroup identified wildlife surveys conducted by the Louisiana Department of Wildlife and Fisheries (LDWF) and the U.S. Fish and Wildlife Service (USFWS) as having limited value for use in evaluating the success of specific coastal wetland creation and restoration projects. Both agencies collect annual records of waterfowl abundance and distribution within the Louisiana coastal zone, and the LDWF conducts inventories of fishery abundance and American alligator (*Alligator mississippiensis*) populations. The LDWF also periodically surveys colonial waterbird populations in Louisiana's coastal zone. The subgroup felt that some of these wildlife data bases, especially that for the alligator, may provide a valuable general index of the status and trends of wildlife populations across the Louisiana coast where wetland creation and restoration projects are underway. These data sets are, however, not considered to be adequate for use in evaluating the success of specific projects in achieving long-term wetland conservation.

VI. METHODOLOGY

The wildlife monitoring subgroup recommends that current and ongoing LDWF and USFWS surveys be used, where needed, as secondary data sets for examining correlations between wetland changes, wildlife abundance, and distribution problems. When used in conjunction with more quantitative monitoring data for water quality, vegetation, etc., these wildlife data bases may have value in confirming over a broad scale (i.e., entire Louisiana coast) what basin-specific monitoring data show for more localized areas.

Methodologies used by the LDWF and by the USFWS for wildlife surveys are either transect-based or are based on observations made on known wildlife concentration areas.

V. GENERAL DISCUSSION

Variables to be Measured

Ideally, impacts of CWPRA projects should be assessed by measuring fishery production from a project area. Realistically, however, the effort required to measure productivity is prohibitive, and measures of standing stock must be used as an indicator of fishery value in an area. Each project is likely to have a different assemblage of ecologically important species. These will include the following species of commercial, recreational, and food-chain importance: white shrimp, brown shrimp, grass shrimp, blue crab, stone crab, spotted seatrout, southern flounder, gulf menhaden, spot, Atlantic croaker, red drum, oysters, striped mullet, bay anchovy, and black drum. Other resident forage species may also be abundant, and certain freshwater species may be important in some projects. Most of these species can be sampled with similar gears and sampling designs. Because oysters are sedentary, however, different sampling techniques will be required for this species; monitoring for oysters can also include measures of recruitment, growth, and survival.

Juveniles and small adults (generally less than 100-mm total length [TL]) of the fishes and crustaceans should be targeted for sampling. Because the habitats being modified are usually nursery grounds for the young, juvenile stages are more abundant, making population sizes easier to estimate. Moreover, the best methods have been developed to quantitatively sample these small animals. Large juveniles and adults of these target species, if they are present in the area, will be extremely difficult to sample quantitatively. In addition, abundance measures for older juveniles and adults are subject to greater variances and may not reflect habitat value if populations are reduced by local fishing pressure.

The primary variables to be measured for juvenile fishes and crustaceans should be density (number of animals per area of bottom), size, and biomass. The number of species (species richness) collected within some standardized area should also be recorded. In certain instances, catch in standard gear (such as trawls and seines) may be measured rather than animal density. Catch per standard unit of effort can be useful in assessing relative abundance and species composition, but these data must be interpreted with caution because of the instability in catch efficiency (see Gear Selection).

Important Fishery Habitats

Different coastal habitats support different numbers and species of fishery organisms, and sampling efforts should be stratified within a project area by habitat. Examples of habitats include unvegetated sand or mud bottom, submerged aquatic vegetation, emergent vegetation, organic detrital bottom (coffee grounds), oyster reefs, and channels.

An assessment of relative area for each of these habitats will be necessary to determine sampling strata. Shallow unvegetated bottom is expected to be most common and must be sampled. Submerged aquatic vegetation and emergent shoreline vegetation are known to support high densities of juvenile fishery species and will also need to be sampled if present. Emergent vegetation may be omitted from the sampling program only if sampling can be conducted at low water levels (see section on water level). Sampling crustaceans will probably not be practical on bottoms with large amounts of organic detrital matter (coffee grounds) or on oyster reefs because quantitative sampling of these habitats is prohibitively labor and cost intensive. Combining solid-walled throw traps with the use of rotenone, however, could allow sampling of fishes in these habitats. Although deepwater channel habitats may be important for some animals, most juvenile fishery species are likely to be more abundant in shallow-water habitats. Shallow channels such as marsh creeks may be important habitats to sample.

emergent or submerged vegetation is present; thus comparisons among habitats are not possible. Trawls and seines can provide semi-quantitative (moderately stable catch efficiency) abundance samples of non-burrowing animals in nonvegetated habitats. These data can be useful in making comparisons among nonvegetated areas if environmental factors that affect catch efficiency (such as turbidity and bottom type) are examined as potential causes of bias.

Monitoring Costs

The fishery monitoring subgroup has attempted to address the problem of limited monitoring funds in several ways:

- 1) By restricting the types of projects that require fishery monitoring.
- 2) By emphasizing monitoring mainly of juvenile fishes and crustacea that occur in greater numbers and are more readily sampled.
- 3) By limiting assessment of impacts to more easily measured variables such as standing crop, size, and species richness rather than attempting to measure productivity. Productivity estimates (growth, survival, recruitment) are only recommended for oysters.
- 4) By limiting the recommended temporal replication of sampling efforts.

The following prioritized list (one being most important) of sampling procedures should be used to reduce sampling effort and cost:

1. Collect high quality samples to accurately measure animal density.
2. Select appropriate controls.
3. Collect sufficient sample numbers at any one time for rigorous hypothesis testing.
4. Sample all dominant habitats.
5. Collect samples during biologically different times of year (early spring, late spring, fall).
6. Collect samples in successive years following project implementation.
7. Collect samples every 2 months during a year.

Procedures 1-3 in this list are mandatory, and procedures 1-5 are probably necessary to provide a scientifically sound assessment of project impacts.

The projected cost of assessing impacts on fishery resources depends upon the size of the project areas, the number of important fishery habitats present, and the variability of the measured variables (this determines sample size). Following the procedures outlined in this document, a cost of approximately \$150-\$200 per throw-trap sample might be expected.

The Water Level Problem

The effect of water-level fluctuations must be considered in estimating the abundance of fishery organisms (see Figure 2). Most fishery species require water and are associated with the bottom in some manner. Changing of water levels at a site, either from tidal fluctuations, water-level control structures, or alterations in freshwater inflow can drastically alter density estimates of animals. As an example, the rising tide in many coastal areas can easily cause a two-fold difference in the amount of bottom area flooded in a

The most realistic picture of habitat use at a site would require sampling at all water levels in proportion to the time these water levels occur in the sampling area. This approach, however, would increase sample variances and result in unrealistic effort required to detect project impacts. The practical solution to this sampling problem is to sample both the control and project areas at similar water levels. Low-water sampling may be most desirable because it can eliminate the need to sample shoreline habitats (flooded vegetation) and will result in higher open-water densities. However, many locations are inaccessible at low tide except with air boats. In situations where water levels are being controlled as part of the project, sampling study and control areas at similar water levels should still be possible by carefully selecting sampling periods. If water level differences between project and control areas are persistent, all flooded habitats must be sampled, and differences in water levels and area flooded must be considered in interpreting the data.

Common Data

Availability of comprehensive water-quality data (temperature, salinity, dissolved oxygen, turbidity, water level) at the project and control areas will be essential in interpreting sampling results. These variables should also be measured every time a fishery sample is collected. In addition, estimates of coverage for different fishery habitats within project and control areas will be essential for fishery monitoring.

Ongoing Programs

The Marine Fisheries Division of the Louisiana Department of Wildlife and Fisheries monitors fishery species using a variety of equipment at stations in six coastal study areas of Louisiana. Samples are collected with plankton nets, 16-ft trawls, 6-ft trawls, seines, gill nets, and trammel nets. Oysters are sampled with Butler plates, a square-meter frame, and with an oyster dredge. The frequency of sampling and sampling locations are identified in a draft manual of their field procedures on file with the monitoring work group.

VI. METHODOLOGY

Sampling

Density of abundant juvenile and small adult fishes and crustaceans

- 1) Juveniles and small adults (generally less than 100-mm TL) should be targeted, and the density of animals per square meter of bottom area should be measured. In conjunction with this variable, the size of the organisms, the biomass of dominant species, and the number of species (species richness) collected within some standardized area should also be measured.
- 2) Throw traps similar to those described by Kushlan (1981) are recommended as sampling gear. The advantages are high catch efficiency in most shallow-water habitats; area sampled is fixed and known; easy and inexpensive to construct; easily deployed from an air boat; and recovery efficiency is measurable. The disadvantages are the area sampled is small, and large and highly motile organisms may avoid the sampler, especially in very clear water. A rough cost estimate that includes all overhead, personnel, and equipment costs would be approximately \$150-\$200 per sample.
- 3) Measuring density over time - density should optimally be measured every 2 months following project implementation. Minimally, samples should be collected in early spring, late spring, and fall.

- 4) Measurements over space - spatial coverage and number of samples will be determined by the number of sampling zones identified and the variance among samples. Sampling zones will be different for oysters than for fish and crustaceans.

Oyster settlement and early survival

- 1) The number of oyster spat settling and surviving on a defined area will be used as an indicator of recruitment success.
- 2) Butler plates will be deployed in conjunction with the Nestier trays.
- 3) Measurements over time - plates will be replaced quarterly when Nestier trays are surveyed, and the number of spat will be recorded in the laboratory.
- 4) Measurements over space - spatial coverage and number of samples will be the same as for Nestier trays.

VII. PROJECT TYPES REQUIRING MONITORING

All CWPPRA projects have the potential for positive or negative impacts on fishery resources. Decisions as to the types of projects that should be monitored, however, should be based on the likelihood of these impacts, the time frame of expected impacts, and the difficulty in assessment of impacts. Project types have been grouped into the following categories:

Projects that definitely require impact assessment:

- Hydrological restoration
- Freshwater diversion
- Marsh management

Projects that require limited assessment (selected projects):

- Sediment diversion
- Beneficial uses of dredged material (including terracing)
- Sediment and nutrient trapping

Projects where assessment is unlikely to provide valuable information:

- Vegetative plantings
- Barrier island restoration
- Shoreline protection

VIII. HISTORICAL DATA

The Louisiana Department of Wildlife and Fisheries (LDWF) collects fishery samples at numerous stations throughout coastal Louisiana. The Field Procedures Manual, on file with the monitoring work group, identifies station locations and summarizes the variables being estimated, frequency of collection, and gear types in use.

