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Economic assessment of rapid land-building technologies for coastal restoration

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ECONOMIC ASSESSMENT OF RAPID LAND-BUILDING TECHNOLOGIES FOR COASTAL RESTORATION

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ABSTRACT

In the wake of recent hurricanes, coastal managers in Louisiana have begun integrating infrastructure protection and habitat restoration. Concurrent with this change, emphasis has been placed on marsh creation (MC) techniques that rely on mechanical dredges and sediment conveyance pipelines to rapidly build new land. The costs and benefits of this approach are increasingly compared to more natural and slower methods using fresh water diversions (FWD), yet such comparisons are not typically inclusive of time and risk considerations.

Data for more than 300 coastal wetland restoration projects were evaluated for the statistical development of generic acreage trajectories and restoration cost models. These models were incorporated into a benefit-cost construct and sensitivity analyses were conducted to examine the relative importance of specific project attributes related to time, distance, project scale, discount rate, and site-specific land loss rates. Benefit uncertainty was addressed through incorporation of climatological and political risk within an expected valuation framework. Case studies were examined for MC and FWD projects under hypothetical acreage targets and locations.

As expected, project period and scale were found to be inversely correlated with unit cost ($/acre). Likewise, discount rate, distance from source material to project site, and specific sub-costs associated with dredge mobilization were positively related to unit cost. The degree of these effects, however, differed greatly between the two generic models. The most pronounced finding is that the relatively slow rate of restoration from FWD projects negatively affects project feasibility. Furthermore, the incorporation of project-specific types of risk (hurricane impacts and social constraints) was found to compound the problems associated with slower performing projects.

Perhaps most importantly, simulations for both FWD and MC projects indicated that required break-even annual benefits were considerably larger than actual benefits reported as accounting from similar projects in the non-market ecosystem valuation literature. This finding suggests the need for a reevaluation of current spending to ensure the most cost-effective combination of attributes in project selection. The decision framework provided here allows restoration managers to increase efficiency in the allocation of limited funding for coastal restoration.

CHAPTER 1. INTRODUCTION

1.1 General Background

Louisiana’s coastal wetlands are of tremendous economic, ecological, cultural and recreational value to residents of the state. Moreover, the coastal wetlands of south Louisiana are one of the most important, productive ecosystems in the United States. In 2006, over 2 million residents -more than 47% of the state’s population according to U.S. Census estimates- lived in Louisiana’s coastal parishes (U.S. Census Bureau, 2007). The coastal zone covers approximately 14,913 square miles, of which 6,737 square miles is water and 8,176 square miles land (LOSCO, 2005).

Louisiana has lost more than 2,100 square miles of coastal wetlands since the 1930’s partly due to natural forces, such as sea level rise, subsidence, erosion, saltwater intrusion, tropical storm and hurricane impacts, but also due to human activities such as dredged canals, man-made levees and development (Barras *et al*., 2003; Dunbar *et al*., 1992; LaCPRA 2007). In addition, there are other factors including upstream dams and soil conservation practices which have modified the movement of freshwater, suspended sediment, and made the coastal ecosystem more susceptible to saltwater intrusion (Caffey *et al*., 2003). Human disturbance has had a massive impact on the balance of wetland growth and decline. In the past 100 years, Louisiana has lost 20% of its wetlands, representing an acceleration of 10 times the natural rate (CPRA 2000). Within the last 50 years, land loss rates have exceeded 40 square miles per year, and in the 1990’s the rate has been estimated to be between 25 and 35 square miles each year. Thus, the rate of coastal land loss in Louisiana has reached where it represents 80% of the coastal wetland loss in the entire continental United States. Louisiana will lose an additional 800,000 acres of wetland by the year 2040 without significant action (Desmond, 2005). To find solutions to the coastal land loss problem, many measures have been evaluated, including controlled and uncontrolled sediment diversions, placement of dredged material, fresh water diversions, and regulation of wetland alteration.

1.2 Methods for Restoration

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) projects primarily focus on restoration and protection of fragile wetlands. Restoration projects are grouped as vegetative, structural and hydrologic projects. Vegetative projects use appropriate plants to trap sediment in vulnerable areas. To create new wetlands or protect existing wetlands, structural projects use materials, including dredged material or rocks, for shoreline protection and barrier island restoration. Hydrologic projects restore more natural flow and salinity patterns and include freshwater/sediment diversion, sediment and nutrient trapping, outfall management, marsh management, and hydrological restoration. According to the description of project types from the Office of Coastal Protection and Restoration (OCPR), a brief introduction of each technique is given below.

Dredged material/marsh creation (MC) projects use dredged sediments from regular maintenance of navigation channels and access canals, or use sediments dredged specifically to create new marsh. Barrier island (BI) projects integrate different techniques to protect and restore Louisiana's barrier island chain, such as the placement of dredged material to increase the height and width of the coastal islands, and use vegetative planting and sand-trapping fences to hold sediments together and stabilize sand dunes on barrier island beaches. Shoreline protection (SP) projects use various techniques to decrease shoreline erosion, such as rock berms, segmented breakwaters, and wave-dampening fences. Freshwater diversion (FWD) projects are usually located along major rivers and use gates or siphons to control the volume of water into coastal marshes.

Vegetative planting (VI) projects are often used in combination with shoreline protection, barrier island restoration, sediment trapping, and marsh creation techniques. This type of restoration uses the planting native wetland plants to stabilize and hold sediments together to establish new wetland.

Hydrologic restoration (HR) projects address wetland damaging problems associated with human-induced hydrological changes. These projects use locks or gates on major navigation channels, the blocking of dredged canals, or the cutting of gaps in levee banks. Sediment & nutrient trapping (SNT) projects use the construction of complex patters of earthen terraces to slow water flow and help the buildup of sediments in open areas of water.

Marsh management (MM) projects involve controlling water level and salinity in order to improve vegetation and wildlife habitat in an impounded marsh area. Outfall management (OM) projects use a variety of techniques to regulate the flow of freshwater diversion to ensure that water and sediment reach needed areas and maximize the benefit of projects. These projects utilize water structures and management regimes to assist in optimizing the distribution of fresh water to nourish coastal wetlands. Sediment diversion projects involve cutting gaps into river levees in an uncontrolled manner, allowing sediment-loaded water to flow into shallow open water areas and imitate natural land-building processes to create new marsh.

1.3 Efficiency in Restoration

Selection of the appropriate technology is important for making efficient decisions concerning wetland restoration. Technology selection is partly determined by the location of the wetland to be restored. Freshwater diversions must be located along major rivers. Dredged material/marsh creation usually use dredged materials that are available from regular maintenance of navigation channels and canals. Vegetative planting involves planting native wetland vegetation to stabilize and hold sediments together, often used in combination with other technologies in most locations. Sediment and nutrient trapping projects involve the construction of intricate pattern of terraces in open-water areas to reduce wind-wave erosion. However, terraces can subside rapidly, so they can only be constructed in areas with sufficient soils, such as in the coastal bays of the southwest. Outfall management is designed to maximize the benefit of larger river diversion projects, and this optimize the distribution of fresh water given existing constraints (e.g. fisheries displacement, landowner flooding, etc.).

Because sediment diversion projects involve opening the river levees in an uncontrolled manner, this technology is typically reserved for those areas which are located on major rivers well-below populated areas. A review of projects from CWPPRA shows that most projects use at least two technologies to improve and restore wetlands. The use of different technologies can create different cost-efficacies for these projects. Thus, it is important to develop a standard method to evaluate the efficacy of coastal restoration across project types.

Benefit-cost analysis is a useful technique to value environmental and wetland projects by comparing the economic benefits with the economic costs. Benefits and costs are usually expressed in money terms and on a common basis in terms of their present value (PV). The standard economic criterion for justifying a project is that the benefits exceed the costs over the life of the project. Benefit-cost analysis is most useful as a starting point from which to begin evaluation of a project (Perman et al., 2003).

The Benefits-Cost Ratio (BCR) is calculated as the sum of the present value of project benefits divided by the sum of the present value of project costs over a particular time period and using a specific discount rate, shown in equation 1.1.

$$BCR = \frac{Total\ Benefits}{Total\ Costs} = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+R)^t}}{\sum_{t=1}^{T} \frac{C_t}{(1+R)^t}} \qquad \text{(Eq. 1.1)}$$

where B_t is value of the benefits at time t and C_t is the cost at time t, (benefits and costs are both measured in dollars), R is the discount rate and t is year. If the BCR is equal to or exceeds one, then the project represent a net benefit increase (Mishan and Euston Quah 2009).

Although benefit-cost analysis can be useful, there are some difficulties in its application. First, it requires that monetary values be assigned to all benefits and all costs. There are, however, many environmental benefits and costs which are cannot be easily quantified, so it is often difficult to use BCA for examining environmental restoration projects. Another issue is that the results can be very sensitive to the choice of the discount rate. Making benefit-cost analysis can be very controversial when widely accepted discount rate does not exist.

Cost-efficacy analysis (CEA) can be used to value environmental and wetland projects as an alternative to BCA. CEA is different from cost-benefit analysis in that it uses a non-monetary unit to value the benefit. While CEA is operationally more applicable for wetland restoration projects, the benefits must still be quantified. The CEA is usually expressed in terms of a ratio where the numerator is the total present value of project costs measured in dollars and the denominator is the total benefits of project measured in some form of standardized units, shown in equation 1.2:

$$CE = \frac{Total\ Costs}{Total\ Benefits} = \frac{\sum_{t=1}^{T} \frac{C_t}{(1+R)^t}}{Total\ Benefits} \qquad \text{(Eq. 1.2)}$$

where *CE* is cost effectiveness. Total costs can be derived from existing cost data by adding the appropriately discounted total capital and operating/maintenance costs (Mishan and Euston Quah 2009).

In order to better employ CEA, wetland benefits must be clearly categorized and standardized; however, it is usually hard to measure them since there are numerous ways to measure the value of wetlands. Economists would employ any number of market and non-market valuation techniques, yet most wetland assessment procedures have been developed by biophysical scientists. The technique developed specifically for CWPPRA is known as the Wetland Value Assessment or "WVA Method' (Bartoldus 1999a).

The Wetland Value Assessment (WVA) technique utilizes a community ecology approach to determine wetland benefits of proposed projects, where the benefits expressed in Average Annual Habitat Units (AAHUs). The WVA can be used to measure restoration benefits on several habitat types along the Louisiana coast. Community models include fresh marsh, intermediate marsh, brackish marsh, saline marsh, fresh swamp, barrier islands, and barrier headlands. Each model employs a number of specifically weighted variables of habitat quantity and quality and these variables are used to develop model scores using a Habitat Suitability Index (HSI). The net benefits of a proposed project are determined by predicting future habitat conditions under two scenarios– future without project and future with project, with benefits expressed as Habitat Units (HU) over the life of the project. These are then annualized to produce Average Annual Habitat Units. The results of the WVA can be combined with cost data to determine the effectiveness of proposed project in terms of average annual cost per AAHU.

Aust (2006) indicated that WVA is the current method for evaluating the benefits of CWPPRA projects because it can standardize project comparisons and allow for prioritization by cost-efficiency and facilitate selection of projects. However, the research also found that in recent years the program appeared to be favoring projects that were less efficient on an AAHU basis. A preference for rapid land-building projects - those relying primarily on the mechanical recovery and placement of sediments - had become a significant driver of project selection during the 1999-2004 program period, despite the fact that such projects are relatively inefficient on a $/AAHU basis.

1.4 Shifting the Focus

Hurricanes Katrina and Rita hit the southeastern and southwestern part of Louisiana on August 29 and September 23, 2005, respectively. They were unparalleled in recent history and resulted in massive property damage and human fatalities. Katrina caused $81 billion and Rita caused $11.3 billion in total estimated property damage (National Hurricane Center, 2007). At least 1,800 people lost their lives in the storms and their aftermath. Over 80% of New Orleans was under water by the time Katrina passed, and over 700,000 homes were destroyed along the Louisiana, Mississippi, and Alabama coasts. Katrina and Rita also had a profound impact on the environment. The storm surge caused substantial beach erosion, in some cases completely submerging coastal areas. The US Geological Survey has estimated that 217 square miles of land were transformed to water by Katrina and Rita (LaCPRA 2007), an amount that represents 42 percent of what was predicted to occur over a 50-year period from 2000 to 2050 before Hurricanes Katrina and Rita (USGS, 2006).

In the wake of Hurricanes Katrina and Rita, state and federal agencies began seeking ways to integrate the previously separate objectives of hurricane protection and coastal restoration (Petrolia and Kim 2010, Petrolia *et al*., 2011). Moreover, Hurricanes Katrina and Rita changed the policy focus from slow-moving wetland restorations focused on ecological services toward more immediate, human-focused issues such as hurricane protection. Additionally, state managers have realized that coastal land loss occurs at a much greater rate than was originally estimated prior to the storms when environmental benefits (AAHU) were the primary focus (Petrolia *et al*., 2009). Because time has become more critical, many citizens and scientists have begun supporting quantity over quality in order to keep the remaining wetlands in place. Thus, policy emphasis has begun to shift increasingly towards the integration of coastal protection with coastal restoration. This integration introduces a new benefits construct – which in many cases is simply to build land as rapidly as possible. The term "rapid land-building"(RLB) as used here refers to those technologies with the potential for creating or restoring substantial amounts of wetland acreage within a very short time frame compared to other methods. Examples of RLB include pumping sediments, pipeline sediment conveyance, and beneficial issue of dredge spoil.

1.5 Problem Statement

Louisiana coastal communities have shifted their focus to preserving remaining coastal wetlands and are paying more attention to rapid wetland restoration projects after the losses of Hurricanes Katrina and Rita (Petrolia et al., 2011). Previous economic analyses have focused on the qualitative benefits (i.e. $/AAHU) of coastal restoration spending. However, a new benefit construct, which in many cases is simply to build land as rapidly as possible (i.e. $/acre), is now emerging. For wetland restoration, freshwater diversions (FWD) and rapid land building technologies are the two main restoration options. Freshwater diversions mimic nature's way to build new land. Also, this technology results in high quality and sustainable land and is an excellent option for protecting existing marshes. Although this technique helps protect and sustain existing wetlands, it could take decades or centuries for new lands to be built up. In contrast, RLB technologies can build land quickly and gain earlier benefits which may mean less project risk over time. When time and risk are accounted for, rapid land building projects may be more cost-effective than freshwater diversions.

It is still unclear, however, if the benefits of the more natural, freshwater diversion method outweigh the risks of waiting for the land to be restored. Also, it is not clear if the risk reduction by moving benefits up in time outweigh the higher costs and loss of natural wetland functions. Furthermore, available sediments and project distance are two of several variables that must be considered when comparing the two technologies. Only a comprehensive economic assessments of these technologies can provide the information to remove these uncertainties from the decision making process of coastal restoration managers.

1.6 Objectives

The main objective of this study is to develop a comparative economic assessment of rapid land-building (RLB) technologies and freshwater diversions (FWD) (existing and proposed) for coastal restoration. The specific objectives include:

1. Develop generic models of coastal restoration project trajectories and cost by technology;
2. Conduct sensitivity analyses with varying values for coastal wetlands, discount rates and risk; and
3. Perform case-studies to illustrate tradeoffs between coastal restoration technologies.

1.7 Data and Methods

Benefit trajectory and cost data for objective 1 were collected from coastal restoration project cost estimates from surveys, bids, and actual project expenditures. The main source of data came from actual coastal restoration projects constructed and proposed under CWPPRA. Additional cost data were obtained from project proposals and bids submitted to the Louisiana Department of Natural Resources (LaDNR) and Louisiana Office of Coastal Protection and Restoration (OCPR) under the Water Resources Development Act (WRDA), the Coastal Impact Assistance Program (CIAP), and the Louisiana Coastal Area (LCA) Restoration Program. To a lesser extent, direct communications with coastal engineering firms were used to provide additional costs and benefits data. Data were aggregated into like categories and multiple regression analysis employed to develop generic models of costs and benefits by technology. Cost for delivery of physical quantities of wetland restoration material (i.e. $/acre) were estimated as a function of several variables, including mobilization/demobilization costs, distance, dredging quantity, containment, shaping, and vegetation. Generic cost models were constructed for FWD and RLB projects.

Benefit data for objective 2 were obtained from two sources; market prices for coastal wetland acreage and non-market, ecological service values ($/acre) from existing literature. The wetland valuation literature employs a wide range of non-market techniques to place dollar estimates on coastal wetland functions and values (e.g. habitat, water quality, storm surge reduction). A compilation of these estimates were used to quantity annual service values. Using a benefits-transfer approach, these estimates were used to inform simulations where benefits need to be expressed in dollar terms. Cost and benefit estimates were incorporated into a NPV framework, with varying levels of risk (i.e. storm landfall probabilities, project scales, and technology efficacy data) and variable discount rates. Gamma discounting has been shown to be better than static (constant) discount rates, which can underestimate the value of ecosystem restoration that takes many years to deliver (Weitzman, 1994-2001).

The basic model uses a net present value (NPV) approach that incorporates hurricane risk (Klotzbach and Gray, 2009), scale of the restoration project (CWPPRA 1992-2008), and varying assumptions on technology efficacy for FWD and RLB projects. The net present value is the current value of all project net benefits at a particular discount rate. Net benefits are simply the sum of benefits minus costs. The basic formula for NPV is given by equation 1.3:

$$NPV = \sum_{t=1}^{T} \frac{B_t - C_t}{(1+R)^t} = \sum_{t=1}^{T} \frac{B_t}{(1+R)^t} - \sum_{t=1}^{T} \frac{C_t}{(1+R)^t} \qquad \text{(Eq. 1.3)}$$

where B_t is the sum of benefit at time t, C_t is the sum of cost at time t, R is the discount rate and t is the year. If the NPV is greater than zero, then the project might be a good candidate for implementation (Perman et al., 2003). Given that projects costs usually known and can be generically modeled, the benefit-value per acre can be solved with a positive NPV. Petrolia et al. (2009) developed simulations of hurricane risk-adjusted NPV for CWPPRA projects and compared the results of similar time and risk assumptions with FWD and RLB projects over 20-50 years periods. These simulations provide the basis for an expanded model, where risk was more fully quantified based on existing literature.

Once the model framework was in place, simulations (Objective 3) were conducted based on actual proposed restoration scenarios in coastal Louisiana. Such simulations can be used to inform policy decisions. One example of such an application is the Third Delta Conveyance Channel Feasibility alternatives developed in 2005 (CH2M-Hill 2006). That analysis compared the cost/acre of a large-scale FWD project against the cost/acre for three RLB project alternatives. This case-study approach was successful in informing public policy about the relative disadvantages of large scale FWD. Expansion of these types of comparisons in a risk-adjusted framework provides addition information for future spending of coastal restoration dollars. The core issue between FWD and RLB projects is: will the risk reduction gained by moving benefits up in time with RLB marsh creation projects outweigh the higher costs of land built by slower, FWD marsh creation projects?

1.8 Rationale

Given the increasing debate whether RLB or FWD project are more appropriate, additional economic research is needed. RLB projects are often dismissed for being too expensive and less sustainable than other types of coastal restoration methods. On the other hand, FWD projects are often dismissed as being too slow and ineffectual for short term needs. This debate comes at a time when coastal restoration costs are increasing dramatically. The CWPPRA program has allocated more than $1.5 billion for projects constructed and operation since in 1990. In 1998, the COAST 2050 report estimated that an additional $14 billion was needed to address Louisiana's land loss problem. In 2002, the LCA Plan requested that $14 billion, but only $1.9 billion was authorized in 2004 through the WRDA. Furthermore, attempts to get federal royalties from petroleum activities off the state's outer continental shelf (OCS) were unsuccessful until 2005, when a one-time payment of $540 million was allocated to Louisiana under the CIAP. In 2007, the Gulf of Mexico Energy Security Act (GOMESA) approved more OCS revenue, and it is now projected that the state will receive $210 million annually through 2017 and $650 million after 2017. Despite these increases, the CPRA recently estimated that $100 billion would be needed to fully integrate coastal restoration and protection (Graves 2009). Given current sources of projected funding, that means that Louisiana will have only 13% of the funds needed to accomplish its coastal wetland restoration goals.

Based on that information, it is important that large-scale spending needs be allocated to obtain the greatest benefits for the limited funding available. Thus, more information is needed to guide program planning and to assess different wetland restoration techniques on an economic basis.

This thesis research will establish generic cost and benefit functions for RLB and FWD projects as a function of variables such as technology, distance, sediment source, depreciation, risk and time for rapid land-building and freshwater diversion projects. Based on this information, and an examination of project-specific constraints, information will be generated in the total economic and environmental costs and benefits of competing project alternatives. Incorporation of time and uncertainty consideration will help to better understand the feasibility of rapid land-building projects compared to more traditional methods, such as freshwater diversion projects. Results from this research will be helpful to costal restoration programs, such as CWPPRA, CIAP, LCA, WRDA, CPRA, and GOMESA.

CHAPTER 2. DESCRIPTIVE DATA

2.1 Introduction

In order to develop a comprehensive economic comparison of rapid land-building (RLB) technologies and freshwater diversions (FWD) (existing and proposed) for coastal restoration, it is necessary to understand the general costs and benefits of these projects. As mentioned in Chapter 1, there are three potential sources of information for project costs and benefits: 1) authorized coastal restoration projects, 2) bids for coastal restoration projects; and 3) surveys. Given the sensitivity of this information, it is unlikely that surveys of project contractors would yield reliable information. For this reason, the focus here will be on authorized project data and pending projected data (e.g. bid data).[1] Thus, wetland restoration project data for this portion of the study are collected from numerous sources, including data on authorized and bidded projects from the Office of Coastal Protection and Restoration (OCPR), CWPPRA priority project list appendices for years 1991-2009, and CWPPRA ecological review reports and project fact sheets.

Between 1991 and 2009, a total of 341 restoration projects were authorized under programs such as CWPPRA, Coastal Impact Assistance Program (CIAP), Federal Emergency Management Agency (FEMA), Hurricane Storm Damage Risk Reduction System (HSDRRS), Louisiana Coastal Area (LCA), the State of Louisiana (STATE), and Water Resources Development Act (WRDA). Table 2.1 lists the number of the projects under these programs. A majority of the projects (52%) are sponsored by the CWPPRA program, which to date has initiated 178 coastal wetlands restoration projects. State projects, at 23%, are the second most frequent project type, and are usually low cost vegetative planting projects. The remaining

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[1] Bids are competitive offers from commercial contractors for wetland restoration projects. In all cases, projects bids are in response to state and federal solicitations that include detailed project expectations. If accepted, bids are legally binding.

projects are sponsored by the CIAP program (77%), WRDA (4.5%), FEMA (4.5%), LCA (4%), HSDRRS (2%) and other programs (3%).

Table 2.1 Louisiana Coastal Restoration Programs and Projects 1991-2009

Programs	Project Number (n=341)	Percentage (%)
CWPPRA	178	52%
STATE	75	23%
CIAP	26	8%
WRDA	16	5%
FEMA	16	5%
LCA	14	4%
OTHERS	10	3%
HSDRRS	6	2%

2.1.1 CWPPRA Project Data

Since the majority of projects are funded by CWPPRA, this program provides the most readily available data. This study will focus primarily on coastal restoration projects authorized and proposed under the CWPPRA program from 1991 to 2009, with project data from additional restoration programs included as appropriate. Specific project details are collected from aggregated and individual CWPPRA project reports. Of the 178 initiated projects under CWPPRA, 124 projects are authorized, 29 projects have been de-authorized, 4 projects have been transferred and 21 are considered demonstration projects. Table 2.2 shows the average cost per unit for the following measures of restoration: AAHU, enhancement acres, acres protected, and total net acre.[2] Average costs are reported for the 124 authorized projects initiated by CWPPRA. All cost-effectiveness measures are adjusted by the civil works construction cost index (CWCCIS) and expressed in terms of 2009 dollars (USACE 2010). Projects are organized

[2] Enhancement acres represent the acres of rehabilitation or reestablishment from a degraded wetland area or the acres of modification from an existing wetland area as a result of a wetland restoration project. Acres protected represent the acres of emergent marsh protected from loss as a result of a wetland restoration project.

Table 2.2 Average Cost for CWPPRA Authorized Projects (n=124)

Type	Obs.	$/AAHU	$/Acre (Enhancement)	$/Acre (Protection)	$/Net Acre			
					μ	σ	Min.	Max.
BI	13	220,080	550,411	1,003,791	289,686	435,947	3,196	1,682,585
MC	23	178,310	335,688	2,496,170	100,795	76,063	4,555	342,593
SP	30	179,639	40,670	86,970	65,717	70,793	500	253,202
FWD/SD	15	67,934	73,486	154,159	37,619	46,877	1,561	182,001
HR	31	39,609	8,216	80,212	31,939	41,165	682	183,144
OM	3	37,021	1,962	36,841	18,391	19,040	5,356	40,241
SNT/TR	4	48,634	48,471	79,054	14,775	13,649	1,258	32,839
MM	2	18,276	2,625	10,827	7,727	3,072	5,555	9,900
HC	1	32,066	N/A	6,414	6,414	N/A	6,414	6,414
VP	2	8,156	19,527	27,176	5,649	118	5,520	5,778

Legend(CWPPRA Project Types)

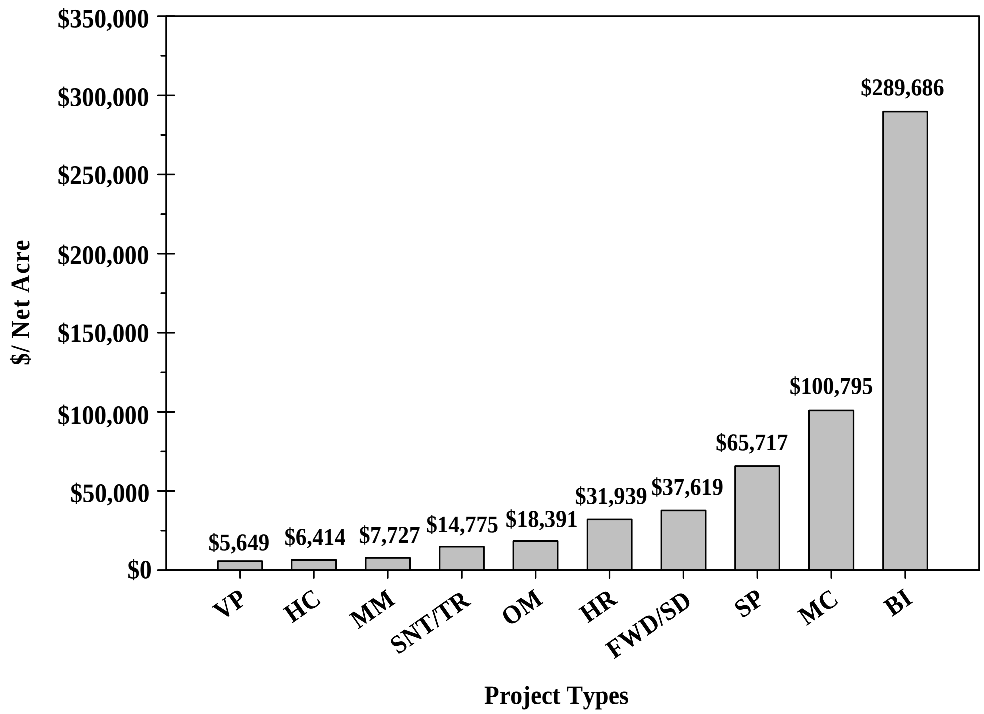
BI	Barrier Island Restoration
MC	Marsh Creation
SP	Shoreline Protection
FWD/SD	Freshwater Diversion/ Sediment Diversion
HR	Hydrologic Restoration
OM	Outfall Management
SNT/TR	Sediment and Nutrient Trapping/ Terracing Restoration
MM	Marsh Management
HC	Herbivory Control
VP	Vegetation Planting

by dominant type of technology used in the restoration.[3] The average cost per net acre for all projects ranges from a low of $5,649/acre to a high of $289,686/acre. This large range is due to vast differences in project technology, location, and size. At the upper bound of this range are barrier island (BI) restoration projects, with an average cost per net acre of $289,686 (Figure 2.1). These projects are very expensive because of their remoteness (i.e. distance from shore), higher transportation and labor costs, and their vulnerability to high-energy waves. In fact, barrier island projects are currently 2.9 times the average cost of the next highest project type, marsh creation (MC) ($100,795). Additional project types that have a high average cost include shoreline protection (SP) ($65,717) and freshwater diversion projects (FWD) ($37,619). These four project types account for more than 65 percent of all CWPPRA projects selected and more than 83 percent of the budgeted program spending from 1991-2009.

Figure 2.2 depicts the geographic location of these four project types. Note that two of these types (MC and SP) are dispersed equally across the coast. The other two, however, are restricted to being offshore (BI) or at the end of major rivers (FWD). Despite these location differences, there are occasions when two or more of these methods are considered as restoration alternatives for the same location. A common example of this option can be found at coastal locations where both MC and FWD are possible. But, of these four methods, only three have the potential for significant land-building. Shoreline protection projects are designed primarily for maintaining and protecting existing shorelines. Figure 2.3 depicts the frequency of selection for the three most expensive methods of land-building (MC, BI, and FWD) and shows an increasing trend towards the use of MC projects. Approximately 61% of the projects authorized during the 2005 to 2009 time period under CWPPRA were marsh creation projects. This represents a more

[3] While it is typical for some projects to utilize more than one restoration method, the categorization here is by the dominant type of technology.

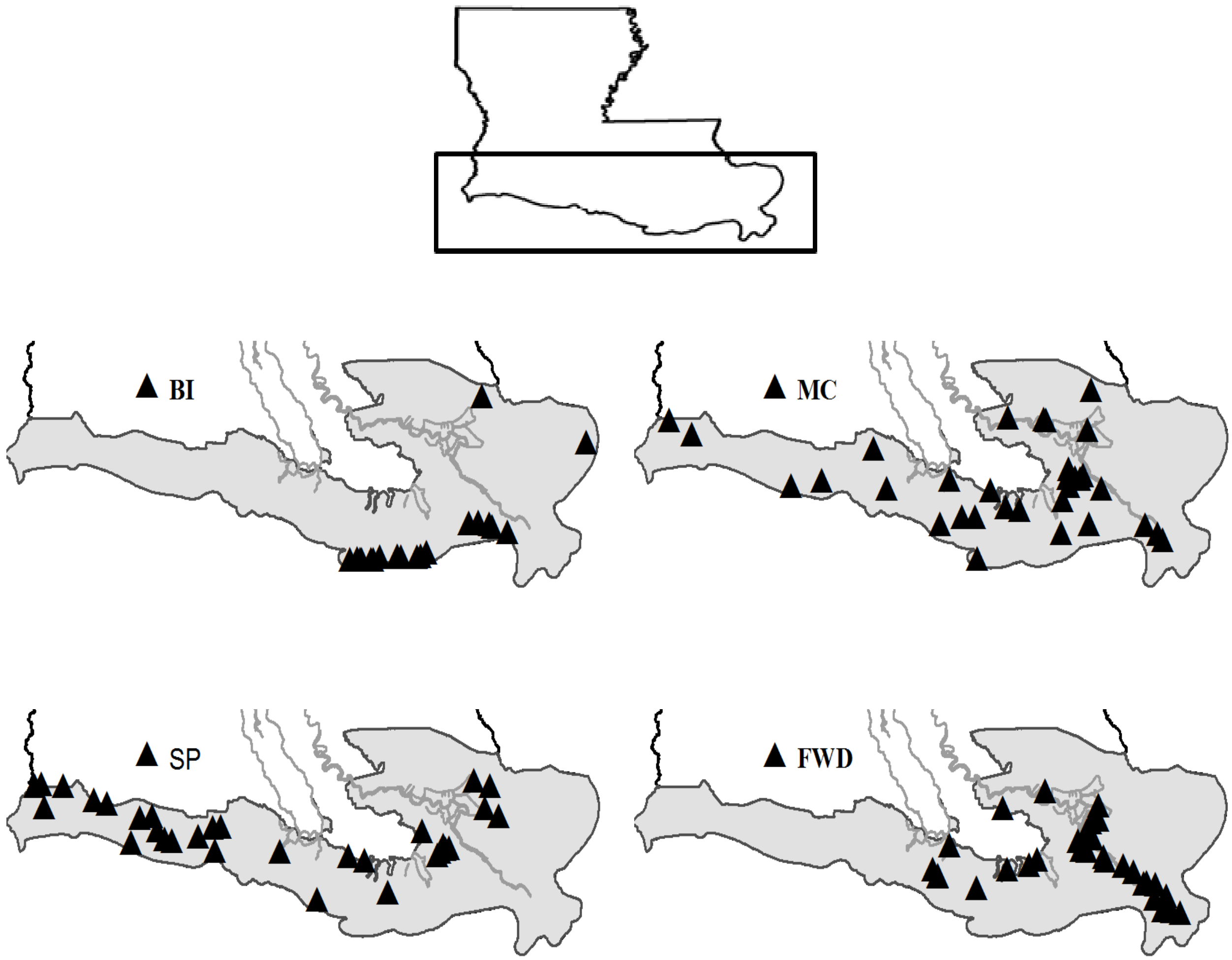
than doubling of the selection of these types of projects during the previous period of 2000-2004. This increase is consistent with recent policy changes in the wake of Hurricane Katrina and the growing public demand for projects that restore coastal land within a shorter time frame (Petrolia *et al*., 2011). Similar reasons are likely behind a decline in the frequency of freshwater diversion project selection – which have accounted for only 11% of the projects selected under CWPPRA in recent years.



Legend(CWPPRA Project Types):

BI	Barrier Island Restoration
MC	Marsh Creation
SP	Shoreline Protection
FWD/SD	Freshwater Diversion/ Sediment Diversion
HR	Hydrologic Restoration
OM	Outfall Management
SNT/TR	Sediment and Nutrient Trapping/ Terracing Restoration
MM	Marsh Management
HC	Herbivory Control
VP	Vegetation Planting

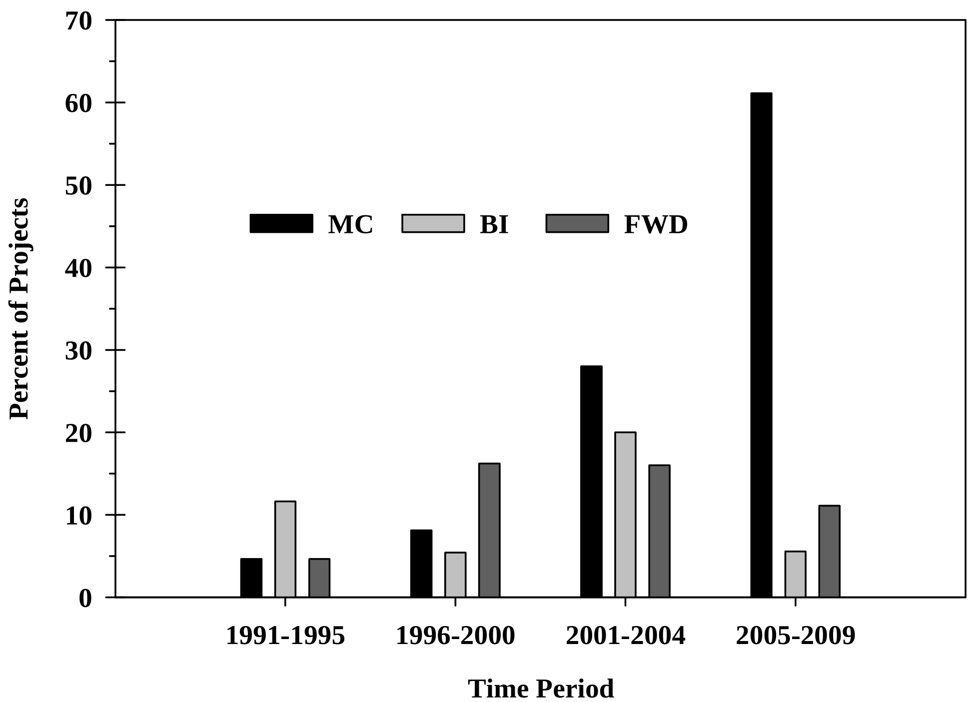
Figure 2.1 Average costs of net acre for CWPPRA projects by type, 1991-2009 (n=124)



Legend(CWPPRA Project Types)

BI	Barrier Island Restoration
MC	Marsh Creation
SP	Shoreline Protection
FWD	Freshwater Diversion/ Sediment Diversion

Figure 2.2 Geographic locations of four selected restoration methods in Louisiana (CWPPRA project data 1991-2009)



Legend(CWPPRA Project Types)
BI Barrier Island Restoration
MC Marsh Creation
FWD Freshwater Diversion/ Sediment Diversion

Figure 2.3 Selection of land-building restoration projects by period (CWPPRA project data, n=51)

2.2 Data for Analysis

In order to develop a comprehensive comparison of the costs and benefits of RLB and FWD projects, it is necessary to identify all available data for these types of projects.[4] The following sections provide a listing of this data for authorized and proposed projects.

2.2.1 Project Data: Marsh Creation

Tables 2.3 and 2.4 depict the cost of MC projects from CWPPRA and Bid data. The costs per net acre are reported for 23 authorized MC projects. An additional 46 bids for MC

[4] From this point forward, the reference to rapid land building projects (RLB) will be limited to two methods: marsh creation (MC) and barrier island (BI).

projects are also available. As legally-binding offers, these bids include much of the same detailed information on costs and benefits. Bids were collected from the Louisiana Office of Coastal Protection and Restoration (OCPR) for projects authorized between 1998 and 2004 and adjusted by the CWCCIS in terms of 2009 dollars. Table 2.4 shows the bids for marsh creation projects under CWPPRA and STATE programs. Each project contains up to five bids by the same or different construction companies. Data are presented by project for the following: Priority Project List (PPL), Bid, Total Bid Cost (TBC), and total millions Cubic Yards of Sediment (CYD) estimated.[5]

2.2.2 Project Data: Barrier Island

Table 2.5 describes the authorized BI projects and their attributes under CWPPRA between 1991 and 2009. Data are presented by project for the following: project priority list (PPL), fully funded cost (FFC), net acres, total AAHUs, dollar per net acre, dollar per AAHU, and total cubic yards of sediment required. The fully funded costs of each project were adjusted by the civil works construction cost index (CWCCIS) and expressed in terms of 2009 dollars (USACE 2010). The costs per net acre are reported for 13 authorized BI projects.

An additional 39 bids for BI projects were also available. Bids were collected from the Louisiana Office of Coastal Protection and Restoration (OCPR) for projects authorized between 1991 and 2001 and adjusted by the CWCCIS in terms of 2009 dollars. Table 2.6 shows these bids for BI island projects authorized under the CWPPRA program. Each project contains up to seven bids by the same or different wetland restoration contractors.

[5] Total Bid Cost (TBC) is only the costs associated with project construction. This estimate differs from the Fully Funded Costs (FFC) which includes planning, design, operation, monitoring and maintenance in addition to construction.

Table 2.3 Authorized MC Projects and Attributes, CWPPRA 1991-2009 (n=23)[6]

Number	Project Name	PPL	FFC($)	Net Acres	$/Net Acre	AAHU	$/AAHU	Total cyds
ME-31	Freshwater Bayou Marsh Creation	19	25,523,755	279	91,483	108	236,331	640,000
PO-75	Labranche East Marsh Creation	19	32,323,291	715	45,207	339	95,349	N/A
TE-72	Lost Lake Marsh Creation	19	22,943,866	749	30,633	281	81,651	N/A
BA-68	Grand Liard Marsh Restoration	18	30,797,529	286	107,684	158	194,921	3,900,000
BA-47	West Pointe a la Hache Marsh Creation	17	16,842,940	203	82,970	126	133,674	N/A
BA-48	Bayou Dupont Marsh and Ridge Creation	17	22,573,372	187	120,713	121	186,557	N/A
PO-34	Alligator Bend Marsh Restoration	16	32,736,490	127	257,768	56	584,580	2,988,700
TE-51	Madison Bay Marsh Creation and Terracing	16	35,432,419	372	95,248	242	146,415	N/A
TE-52	West Belle Pass Barrier Restoration	16	46,271,351	305	151,709	203	227,938	2,774,000
BA-42	Lake Hermitage Marsh Creation	15	43,957,905	447	98,340	211	208,331	5,526,440
MR-15	Venice Ponds Marsh Creation and Crevasses	15	10,391,951	511	20,336	153	67,921	1,666,800
TV-21	East Marsh Island Marsh Creation	14	28,333,932	169	134,284	106	267,301	2,382,974
PO-33	Goose Point/Pointe Platte Marsh Creation	13	21,049,245	436	48,278	297	70,873	3,977,270
BA-39	Bayou Dupont Sediment Delivery System	12	37,120,258	326	113,866	159	233,461	5,200,000
BA-36	Dredging on the Barataria Basin Landbridge	11	22,118,619	242	91,399	135	163,842	6,845,696
BA-37	Little Lake Shoreline Protection	11	41,106,558	713	57,653	349	117,929	4,828,865
TE-46	West Lake Boudreaux Restoration	11	27,344,085	277	98,715	129	211,970	1,255,980
TE-48	Raccoon Island Marsh Creation	11	24,324,092	71	342,593	64	380,064	1,036,728
TE-44	North Lake Mechant Landbridge Restoration	10	55,128,127	604	91,272	367	150,213	4,000,000
TV-19	Weeks Bay Marsh Creation	9	43,415,799	278	156,172	N/A	N/A	N/A
CS-28	Sabine Refuge Marsh Creation	8	44,592,375	993	44,907	386	115,524	4,666,200
BA-19	Barataria Bay Waterway Restoration	1	2,027,007	445	4,555	151	13,424	1,740,000
PO-17	Bayou LaBranche Wetland Creation	1	6,598,171	203	32,503	191	34,545	2,851,133

[6] Authorized MC projects and their attributes under CWPPRA (1991 and 2009) are presented by project for the following: Priority Project List (PPL), Fully Funded Cost (FFC), Net Acre, Dollar per Net Acre ($/Net Acre), Average Annual Habitat Unit (AAHU), Dollar per AAHU ($/AAHU), and total Cubic Yards of Sediment (CYD) required. The fully funded costs of each project are adjusted by the civil works construction cost index (CWCCIS) and expressed in terms of 2009 dollars (USACE 2010).

Table 2.4 Projected MC Projects and Attributes, 1998-2004 (n=46)

Number	Project Name	PPL	Bid	TBC($)	Total MM cyds
TV-21	East Marsh Island Marsh Creation Project	14	3	26,991,137	2.82
TV-21	East Marsh Island Marsh Creation Project	14	2	19,640,463	2.82
TV-21	East Marsh Island Marsh Creation Project	14	1	16,199,401	2.82
PO-33	Goose Point/Pointe Platte Marsh Creation	13	4	21,887,914	3.01
PO-33	Goose Point/Pointe Platte Marsh Creation	13	3	18,240,170	3.01
PO-33	Goose Point/Pointe Platte Marsh Creation	13	2	17,661,557	3.01
PO-33	Goose Point/Pointe Platte Marsh Creation	13	1	16,649,047	3.01
BA-39	Mississippi River Sediment Delivery System - Bayou Dupont	12	2	31,605,120	2.34
BA-39	Mississippi River Sediment Delivery System - Bayou Dupont	12	1	28,148,184	2.34
BA-36	Dedicated Dredging on the Barataria Basin Landbridge	11	3	46,035,945	6.50
BA-36	Dedicated Dredging on the Barataria Basin Landbridge	11	2	37,235,600	6.50
BA-36	Dedicated Dredging on the Barataria Basin Landbridge	11	1	36,990,153	6.50
TE-44	North Lake Mechant Landbridge Restoration	10	4	61,442,194	4.97
TE-44	North Lake Mechant Landbridge Restoration	10	3	55,776,722	4.97
TE-44	North Lake Mechant Landbridge Restoration	10	2	45,833,353	4.97
TE-44	North Lake Mechant Landbridge Restoration	10	1	43,654,494	4.97
CS-28-2 & 3	Sabine Refuge Marsh Creation, Cycles 2 & 3	8	3	34,278,786	4.04
CS-28-2 & 3	Sabine Refuge Marsh Creation, Cycles 2 & 3	8	2	26,191,271	4.04
CS-28-2 & 3	Sabine Refuge Marsh Creation, Cycles 2 & 3	8	1	20,824,592	4.04
CS-28-3	Sabine Refuge Marsh Creation, Cycle 3	8	1	22,203,378	5.33
CS-28-1	Sabine Refuge Marsh Creation, Cycle 1	8	1	11,342,798	2.52
4351-BRM	Brown Marsh Small Dredge Demo Project	N/A	5	769,604	0.07
4351-BRM	Brown Marsh Small Dredge Demo Project	N/A	4	748,081	0.07
4351-BRM	Brown Marsh Small Dredge Demo Project	N/A	3	564,945	0.07
4351-BRM	Brown Marsh Small Dredge Demo Project	N/A	2	420,742	0.07
4351-BRM	Brown Marsh Small Dredge Demo Project	N/A	1	353,013	0.07

Table 2.4 continued

LA-01b	Dedicated Dredging Program-Bayou Dupont	N/A	5	1,812,541	0.41
LA-01b	Dedicated Dredging Program-Bayou Dupont	N/A	4	1,844,674	0.41
LA-01b	Dedicated Dredging Program-Bayou Dupont	N/A	3	1,725,979	0.41
LA-01b	Dedicated Dredging Program-Bayou Dupont	N/A	2	1,428,090	0.41
LA-01b	Dedicated Dredging Program-Bayou Dupont	N/A	1	1,441,006	0.41
LA-01c	Dedicated Dredge Program - Pass A Loutre	N/A	3	3,273,113	0.39
LA-01c	Dedicated Dredge Program - Pass A Loutre	N/A	2	1,821,474	0.39
LA-01c	Dedicated Dredge Program - Pass A Loutre	N/A	1	1,926,253	0.39
LA-01d	Dedicated Dredging-Terrebonne Parish School Board	N/A	3	3,390,167	0.30
LA-01d	Dedicated Dredging-Terrebonne Parish School Board	N/A	2	2,296,069	0.30
LA-01d	Dedicated Dredging-Terrebonne Parish School Board	N/A	1	1,593,580	0.30
LA-01e	Dedicated Dredging-Grand Bayou Blue	N/A	5	3,824,896	0.30
LA-01e	Dedicated Dredging-Grand Bayou Blue	N/A	4	3,285,078	0.30
LA-01e	Dedicated Dredging-Grand Bayou Blue	N/A	3	3,264,121	0.30
LA-01e	Dedicated Dredging-Grand Bayou Blue	N/A	2	2,999,070	0.30
LA-01e	Dedicated Dredging-Grand Bayou Blue	N/A	1	2,648,174	0.30
LA-01f	Dedicated Dredging-Point Au Fer	N/A	4	6,531,028	0.30
LA-01f	Dedicated Dredging-Point Au Fer	N/A	3	5,333,542	0.30
LA-01f	Dedicated Dredging-Point Au Fer	N/A	2	4,773,636	0.30
LA-01f	Dedicated Dredging-Point Au Fer	N/A	1	3,570,233	0.30

Legend(CWPPRA Project Types)

PPL	Priority Project List
TBC	Total Bid Cost
CYD	Cubic Yards of Sediment

Table 2.5 Barrier Island Projects and Attributes, CWPPRA 1991-2009 (n=13)

Number	Project Name	PPL	FFC($)	Net acres	$/net acre	AAHU	$/AAHU	Total cyds
BA-76	Cheniere Ronquille Barrier Island Restoration	19	43,828,285	234	187,300	190	230,675	3,000,000
BA-40	Riverine Sand Mining/Scofield Island Restoration	14	54,814,331	234	234,249	229	239,364	2,415,620
TE-50	Whiskey Island Backbarrier Marsh Creation	13	40,345,509	272	148,329	292	138,170	2,026,000
BA-35	Pass Chaland to Grand Bayou Restoration	11	61,354,800	263	233,288	208	294,975	2,561,767
BA-38	Barataria Barrier Island Complex Project	11	107,657,656	334	322,328	287	375,114	4,010,000
TE-47	Ship Shoal: Whiskey West Flank Restoration	11	86,214,651	195	442,126	269	320,501	4,000,000
TE-37	New Cut Dune and Marsh Restoration	9	19,026,123	102	186,531	43	442,468	844,540
TE-40	Timbalier Island Dune and Marsh Creation	9	25,290,391	273	92,639	124	203,955	3,600,000
TE-30	East Timbalier Island Restoration II	4	12,158,165	215	56,550	140	86,844	1,677,815
TE-25	East Timbalier Island Restoration I	3	6,113,799	1,913	3,196	319	19,166	949,300
TE-27	Whiskey Island Restoration	3	11,677,372	1,239	9,425	549	21,270	2,500,000
TE-24	Isles Dernieres Restoration Trinity Island	2	18,242,876	109	167,366	120	152,024	3,371,616
TE-20	Isles Dernieres Restoration East Island	1	15,143,267	9	1,682,585	45	336,517	3,935,000

Table 2.6 Projected BI Projects and Attributes, 1991-2001 (n=39)

Number	Project Name	PPL	Bid	TBC($)	Total MM cyds
BA-38	Chaland Headland Restoration Project	11	2	38,803,753	2.74
BA-38	Chaland Headland Restoration Project	11	1	21,709,335	2.74
BA-35	Pass Chaland to Grand Bayou Pass Barrier Shoreline Restoration	11	2	60,360,966	2.87
BA-35	Pass Chaland to Grand Bayou Pass Barrier Shoreline Restoration	11	1	48,485,715	2.87
TE-40	Timbalier Island Dune and Marsh Creation	9	3	21,583,569	4.60
TE-40	Timbalier Island Dune and Marsh Creation	9	2	17,274,221	4.60
TE-40	Timbalier Island Dune and Marsh Creation	9	1A	15,612,402	4.60
TE-40	Timbalier Island Dune and Marsh Creation	9	1	19,330,569	4.60
TE-37	New Cut Dune and Marsh Restoration	9	3A	7,296,349	0.97
TE-37	New Cut Dune and Marsh Restoration	9	3	18,568,706	0.83
TE-37	New Cut Dune and Marsh Restoration	9	2A	11,968,828	0.97
TE-37	New Cut Dune and Marsh Restoration	9	2	13,974,437	0.83
TE-37	New Cut Dune and Marsh Restoration	9	1	14,348,387	0.86
TE-11 & TE-37	New Cut Dune/Marsh Restoration	9	2	13,293,136	2.13
TE-11 & TE-37	New Cut Dune/Marsh Restoration	9	1	11,719,052	2.13
TE-30	East Timbalier Island Sediment Restoration, Phase 2	4	1	8,459,477	1.69
TE-25 & TE-30	East Timbalier Island Restoration	3,4	4	18,660,815	2.27
TE-25 & TE-30	East Timbalier Island Restoration	3,4	3	16,582,385	2.27
TE-25 & TE-30	East Timbalier Island Restoration	3,4	2	15,818,068	2.27
TE-25 & TE-30	East Timbalier Island Restoration	3,4	1	13,354,440	2.27
TE-27	Whiskey Island Restoration	3	5	13,378,248	3.00
TE-27	Whiskey Island Restoration	3	4	11,063,956	3.00
TE-27	Whiskey Island Restoration	3	3	11,059,237	3.00
TE-27	Whiskey Island Restoration	3	2	10,394,502	3.00
TE-27	Whiskey Island Restoration	3	1	10,067,477	2.85
TE-25	East Timbalier Island Sediment Restoration, Phase 1	3	1	6,151,759	3.00

Table 2.6 continued

TE-20 & TE-24	Isles Dernieres Restoration (Phase 1-Trinity Island)	1,2	4	19,025,122	4.85
TE-20 & TE-24	Isles Dernieres Restoration (Phase 1-Trinity Island)	1,2	3	18,539,547	4.85
TE-20 & TE-24	Isles Dernieres Restoration (Phase 1-Trinity Island)	1,2	2A	1,691,258	4.85
TE-20 & TE-24	Isles Dernieres Restoration (Phase 1-Trinity Island)	1,2	2	16,224,982	4.85
TE-20 & TE-24	Isles Dernieres Restoration (Phase 1-Trinity Island)	1,2	1A	18,238,179	4.85
TE-20 & TE-24	Isles Dernieres Restoration (Phase 1-Trinity Island)	1,2	1	16,545,100	4.85
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	4A	15,898,514	3.60
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	4	15,898,514	3.60
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	3	13,456,045	3.60
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	2A	14,614,119	3.60
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	2	11,981,806	3.60
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	1A	10,924,476	3.60
TE-20 & TE-24	Isles Dernieres Restoration (Phase 0-East Island)	1,2	1	11,660,966	3.60

Legend(CWPPRA Project Types)

PPL	Priority Project List
TBC	Total Bid Cost
CYD	Cubic Yards of Sediment

2.2.3 Project Data: Freshwater Diversion

Table 2.7 shows the authorized FWD projects and their attributes under CWPPRA between 1991 and 2009. The fully funded costs of each project are adjusted by the civil works construction cost index (CWCCIS) and expressed in terms of 2009 dollars (USACE 2010). The costs per net acre are reported for the 15 FWD projects authorized by CWPPRA since 1991. Compared to MC projects which have recently dominated project selection under CWPPRA (61% of all projects authorized since 2005), FWD projects have comprised less than 15% of selected projects in the last 5 years.

At the time of this study, no bid data were available from CWPPRA for FWD projects. While CWPPRA provides funding for the majority of restoration projects in coastal Louisiana, some of the larger scale FWD projects are beyond the scope of CWPPRA budget constraints. Additional funding for FWD projects began in 1998 when the state of Louisiana and federal partners sponsored the Coast 2050 visioning process. Recognizing a more aggressive effort was needed, 77 ecosystem restoration strategies were identified at an estimated cost of $14 billion (Louisiana Coastal Wetland Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority 1998). In 2001, funding for FWD projects identified in the Coast 2050 plan was sought via the Louisiana Coastal Area (LCA) Louisiana-Ecosystem Restoration Study (LCA 2004). The LCA program would help Louisiana to design and build the large-scale FWD projects needed to protect and restore coastal resources. Such projects are typically funded through the Water Resources Development Act (WRDA), the congressional legislation that authorizes the U.S. Army Corps of Engineers (Corps) to deal with various aspects of water resources, including flood control, navigation, ecosystem restoration and stream bank erosion prevention projects. The first WRDA was passed in 1974, and subsequent versions of the

Table 2.7 Freshwater Diversion Projects and Attributes, CWPPRA 1991-2009 (n=15)[7]

Number	Project Name	PPL	FFC($)	Net Acres	$/Net Acre	AAHU	$/AAHU	Avg. cfs
BS-18	Bertrandville Siphon	18	22,151,631	1,613	13,733	965	22,955	2,000
CS-49	Cameron-Creole Freshwater Introduction	18	12,545,415	473	26,523	524	23,942	N/A
BS-15	Bohemia Mississippi River Reintroduction	17	7,226,847	637	11,345	989	7,307	10,000
BS-12	White Ditch Diversion Restoration	14	18,267,729	189	96,655	107	170,726	500
MR-14	Spanish Pass Diversion	13	17,488,762	433	40,390	79	221,377	7,000
TE-49	Avoca Island Diversion and Land Building	12	26,026,210	143	182,001	132	197,168	1,000
PO-29	River Reintroduction into Maurepas Swamp	11	231,730,462	5,438	42,613	8,486	27,307	1,500
BS-10	Delta Building Diversion North of Fort St. Phillip	10	9,396,627	501	18,756	157	59,851	2,500
BA-34	Mississippi River Reintroduction Into Northwest Barataria	10	20,899,000	941	22,209	781	26,759	800
MR-13	Benneys Bay Diversion	10	42,848,824	5,706	7,509	1,426	30,048	50,000
TE-39	South Lake de Cade Freshwater Introduction	9	7,552,982	202	37,391	60	125,883	N/A
TE-32a	North Lake Boudreaux Basin Freshwater Introduction and Hydrologic Management	6	31,138,632	603	51,640	422	73,788	3,750
MR-09	Delta Wide Crevasses	6	7,192,332	2,386	3,014	927	7,759	N/A
MR-06	Channel Armor Gap Crevasse	3	1,460,758	936	1,561	234	6,243	2,500
MR-03	West Bay Sediment Diversion	1	87,902,656	9,831	8,941	4,912	17,895	19,188

[7] Data are presented by project for the following: Priority Project List (PPL), Fully Funded Cost (FFC), Net Acre, Dollar per Net Acre ($/Net Acre), Average Annual Habitat Unit (AAHU), Dollar per AAHU ($/AAHU), and Average Water Flow Rate which is measured by cubic feet per second (CFS).

Act was authorized in 1976, 1986, 1988, 1990, 1992, 1996, 1999, 2000, and 2007. Title VII of WRDA 2007 focuses on addressing hurricane damage, storm protection and ecosystem restoration projects outlined in the LCA report of 2004. The entire ACT authorizes $23 billion in projects nationwide, with $1 billion for wetland restoration projects in Louisiana (Heikkila et al., 2008).

Prior to 1974, the U.S. Congress authorized the Corps' flood control and navigation projects primarily under the Flood Control Act (FCA), enacted by Congress in response to costly floods. Large-scale FWD projects authorized under this Act include Caernarvon and Davis Pond authorized in 1965. These structures were subsequently modified by the WRDAs of 1974, 1986 and 1996. The WRDA 2007 would re-authorize/modify the operation of the Davis Pond and Caernarvon Freshwater and set the average flow rate of each of these two structures at 5000 cfs. The current rates of each of these two freshwater diversion projects are less than 2000 cfs. An additional six freshwater diversion projects are proposed, including a medium scale diversions at White's Ditch and Myrtle Grove (35,000 cfs) and small-scale diversions at Convent/Blind River (1,500 cfs), Bayou Lafourche, Amite River, and Hope Canal (2,000 cfs) (LCA 2004). As shown in Table 2.8, the larger scale diversion projects (including all LCA projects) have been authorized under the FCA/WRDA program.

2.3 Summary

A review of coastal restoration project data for Louisiana identified 341 projects under 7 major programs. Of these programs, the largest contributor of projects and detailed project information is the CWPPRA program. An evaluation of 124 CWPPRA projects constructed from 1991-2009 shows that the most expensive three options for land-building are MC, BI, and FWD projects. Detailed information for these three projects types is limited and highly variable.

Table 2.8 WRDA Freshwater Diversion Projects (n=9)

Program(s)	Project Number	Project Name	Authorized Date	Net Acres	Avg.(cfs)	FFC($)
FCA/WRDA	BS-08	Caernarvon Freshwater Diversion	1965	N/A	1,835	$42,892,021
FCA/WRDA	BA-01	Davis Pond Freshwater Diversion	1965	N/A	1,000	$163,027,094
WRDA	BS-19	Modification of Caernarvon Diversion	2007	N/A	5,000[8]	$24,840,000
WRDA	BA-72	Modification of Davis Pond Diversion	2007	N/A	5,000	$77,040,000
WRDA	BS-20	Medium Diversion at White's Ditch	2007	N/A	35,000[9]	$334,800,000
WRDA	BA-71	Medium Diversion with Dedicated Dredging at Myrtle Grove	2007	N/A	2,500-15,000	$278,300,000
WRDA	PO-67	Small Diversion at Hope Canal	2007	N/A	2,000[10]	$150,000,000
WRDA	PO-68	Small Diversion at Convent/Blind River	2007	N/A	1,500	$128,529,843
WRDA	BA-70	Small Bayou Lafourche Reintroduction	2007	N/A	4,000	$133,500,000

[8] Caernarvon and Davis Pond have maximum design capacities of 8,000 and 10,600 cfs, respectively. The structures have only been operating at 1000-2000 average cfs due primarily to social and political constraints. The reauthorization of these structures would increase the average flow rate of each structure to 5,000 cfs in an attempt to increase marsh nourishment and stimulate land building.

[9] Maximum flow rate.

[10] Diversions proposed for Hope Canal and Blind River are for salinity control and nutrient delivery only and not for land-building purposes.

Additionally, some values are absent due to incomplete reporting and some may subsequently change over time due to social, political, and financial constraints or as new information becomes available.

From the CWPPRA program data are available for 23 MC projects, 13 BI projects, and 15 FWD projects. An additional 85 project bids for CWPPRA and State projects are also available, but these bids are limited only to RLB projects. Given the large-scale and high costs of FWD projects, data must be collected from other programs. The LCA and WRDA initiatives contain 9 additional FWD projects for which costs and benefits have been estimated. Despite these limitations, these projects represent the best available historic data for informing future investments in coastal restoration. To date, this baseline information has provided the basis for more than $1 billion in coastal restoration spending in Louisiana alone. The challenge is to determine if the data can be used to develop representative models of how the benefits and costs of these projects accrue.

CHAPTER 3. GENERIC BENEFIT MODELS

3.1 Introduction

In order to develop a comprehensive economic comparison of RLB technologies and FWD (existing and proposed) for coastal restoration, it is necessary to estimate and build generic models that describe the way that these projects restore land over time. The rate and shape of land gain, referred to as the restoration trajectory, is needed so that the elements of costs, benefits, time and risk can be used in the economic analysis. Data for authorized CWPPRA projects (n=51) described in Chapter 2 provide the basis for the development of generic benefit models. Restoration trajectories in the following section are developed by using information generated by the technical review within the CWPPRA committee.[11] Under the program, net acres are predicted for each project under two scenarios - future with-project and future without-project. These predictions can be made on a yearly basis, but are more commonly provided at only a few intervals during the 20-year project life.

3.2 Generic Benefit Model: Marsh Creation

Data for MC benefits were obtained from technical review documents for 23 projects (Table 2.3). After examining inter-period acreage projections for these projects, the six most representative MC projects were chosen for development of the generic benefits model.[12] Figure 3.1 depicts restoration trajectories for the six typical MC projects. As evident from these curves, expected marsh creation usually follow a sigmoid trajectory in which net acres are static or decreasing in year 1, followed by a rapid accrual of acreage in years 2-5. Most of the land gained in the first 5 years is due to rapid placement of sediment from either a dredge or dredge

[11] Technical review includes WVA assessments, project appendices, and ecological reviews.
[12] Only a portion of the MC projects had inter-period acreage projection data available. After removal of outliers, six MC projects were chosen for development of the generic model.

pipeline. From year 5 to 20, net acreages are either constant or slightly decreasing as new land settles (reduction in elevation) or is eroded.[13]

Figure 3.2 shows the aggregated trajectories of these projects during the 20 year projected life time, which reinforces the sigmoidal trend. Three projects (BA-36, BA-42, and TV-21) initially have negative net acres in the first year due to channel and containment dike construction. All of the projects, however, quickly achieve the proposed net acres within the first 5 years of construction. The second set of curves in Figure 3.2 includes each project's pre-construction period for engineering and design. During this period of engineering and design, no project construction occurs, and thus no benefits accrue. Other factors that can add to this "lag period" include delays due to funding and political and social constraints. An average curve can be estimated for these 6 projects (based on percentage of project completion) to produce the generic construction trajectory for marsh creation projects. Project construction under the generic trajectory is delayed by 4 years when the average lag period for these projects is incorporated.

Figure 3.3 depicts the percentage completion of project construction curves and equations for the generic trajectories without and with engineering design lag, respectively. These generic trajectories are depicted here as being stable after construction without consideration for erosion or subsidence.[14] Using sigmoid function with three parameters, the estimated equations based on these data are:

$$T_{MC} = \frac{1}{(1 + EXP(-(t - 0.96)/0.08))} \qquad \text{(Eq. 3.1)}$$

$$T_{MC-L} = \frac{1}{(1 + EXP(-(t - 5.98)/0.043))} \qquad \text{(Eq. 3.2)}$$

[13] While project benefits can accrue beyond 20 years, these projections are limited to the 20-year project cycle typically used in CWPPRA.
[14] Erosion and accrual rates will be incorporated in the expanded net present value model in Chapter 4.

where T_{MC} is percentage completion of project trajectory, $T_{MC\text{-}L}$ is percentage completion of project with engineering lag trajectory, and t is time period expressed in years with R^2=0.90 and R^2=0.93, for the generic and lagged model, respectively.

Compared to freshwater diversions, land-building in marsh creation projects is relatively rapid, and the estimated sediments input are primarily a function of net acres accrued. A total of eight typical marsh creation projects were chosen from Table 3.4 to illustrate the functional relationship between total sediments and net acres. Figure 3.4 depicts this relationship for marsh creation projects for net acres accrued, expressed as:

$$S_{MC} = -10.03 + 2.50 * LN(A) \qquad \text{(Eq. 3.3)}$$

where S_{MC} are the estimated sediments input expressed in million cubic yards(MM cuyds) and A are benefits expressed in net acres (R^2 = 0.88).

3.3 Generic Benefit Model: Barrier Island

Data for BI benefits was obtained from technical review documents for 13 projects (Table 2.5). After examining inter-period acreage projections for these projects, six most representative BI projects were chosen for development of the generic benefits model. Figure 3.5 depicts trajectories for the six typical BI projects chosen to illustrate the general trend of how net acres accrue during the 20-yeart lifespan.

Figure 3.6 shows the individual and aggregate trajectories of these projects. Similar to MC projects, BI projects initially follow a general sigmoidal trend in which net acres are mechanically restored over a short time period, and then are either constant or slowly decreasing. However, because of the capacity for long-shore currents to build land on barrier islands, some

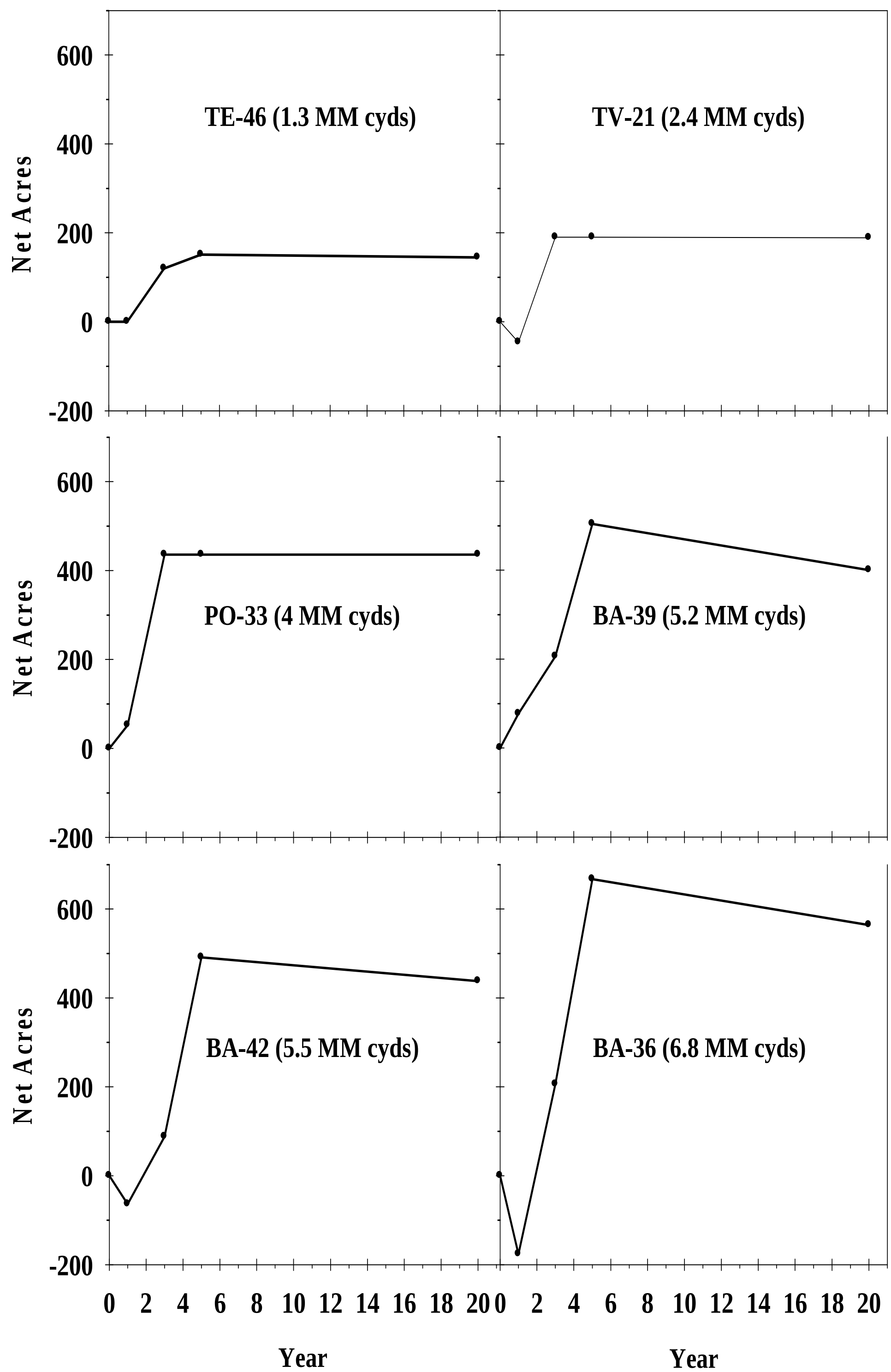


Figure 3.1 Six net acre trajectories by marsh creation technology under CWPPRA (n=6)

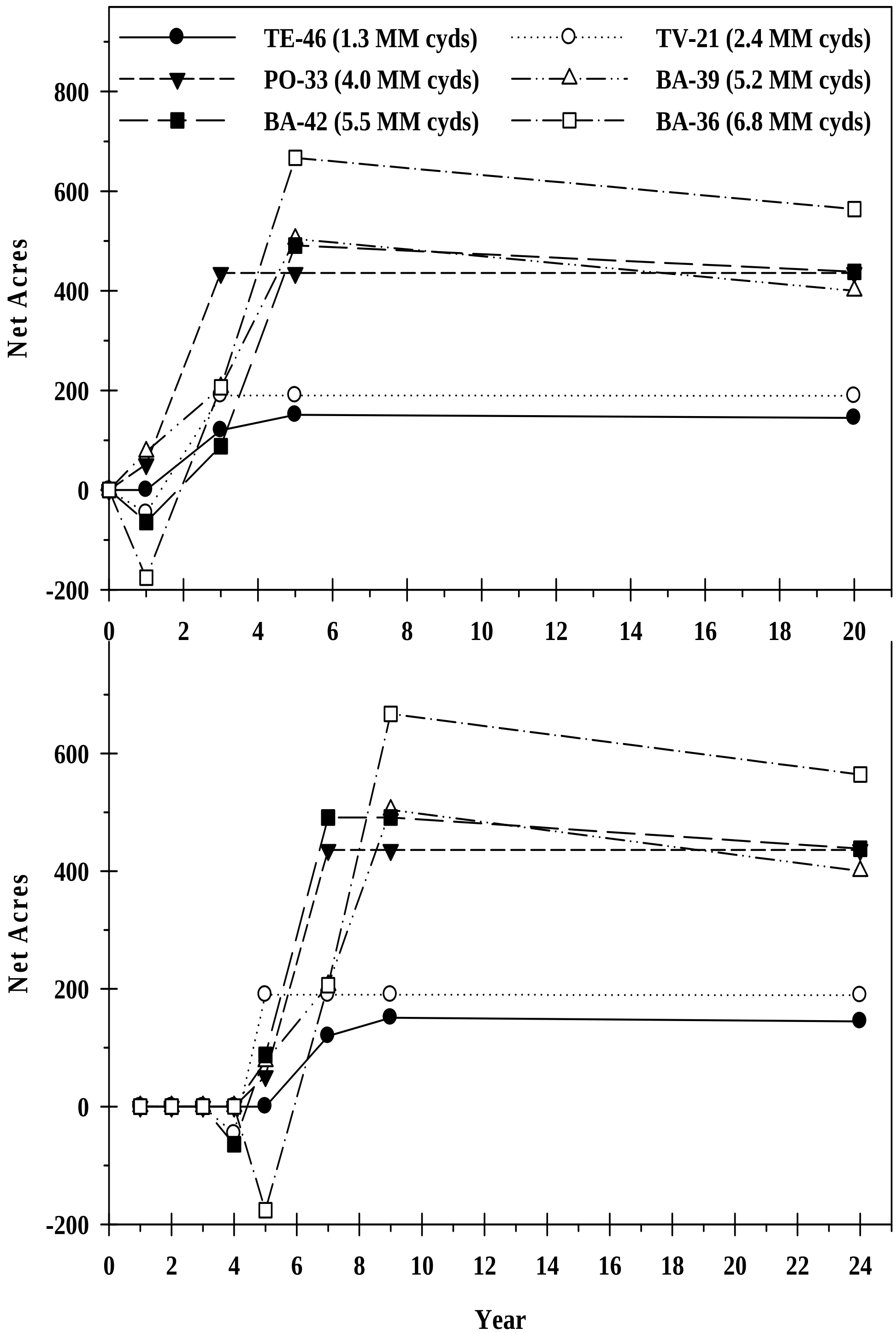


Figure 3.2 Marsh creation projects trajectories without and with engineering design consideration for the trend of net acres under CWPPRA (n=6)

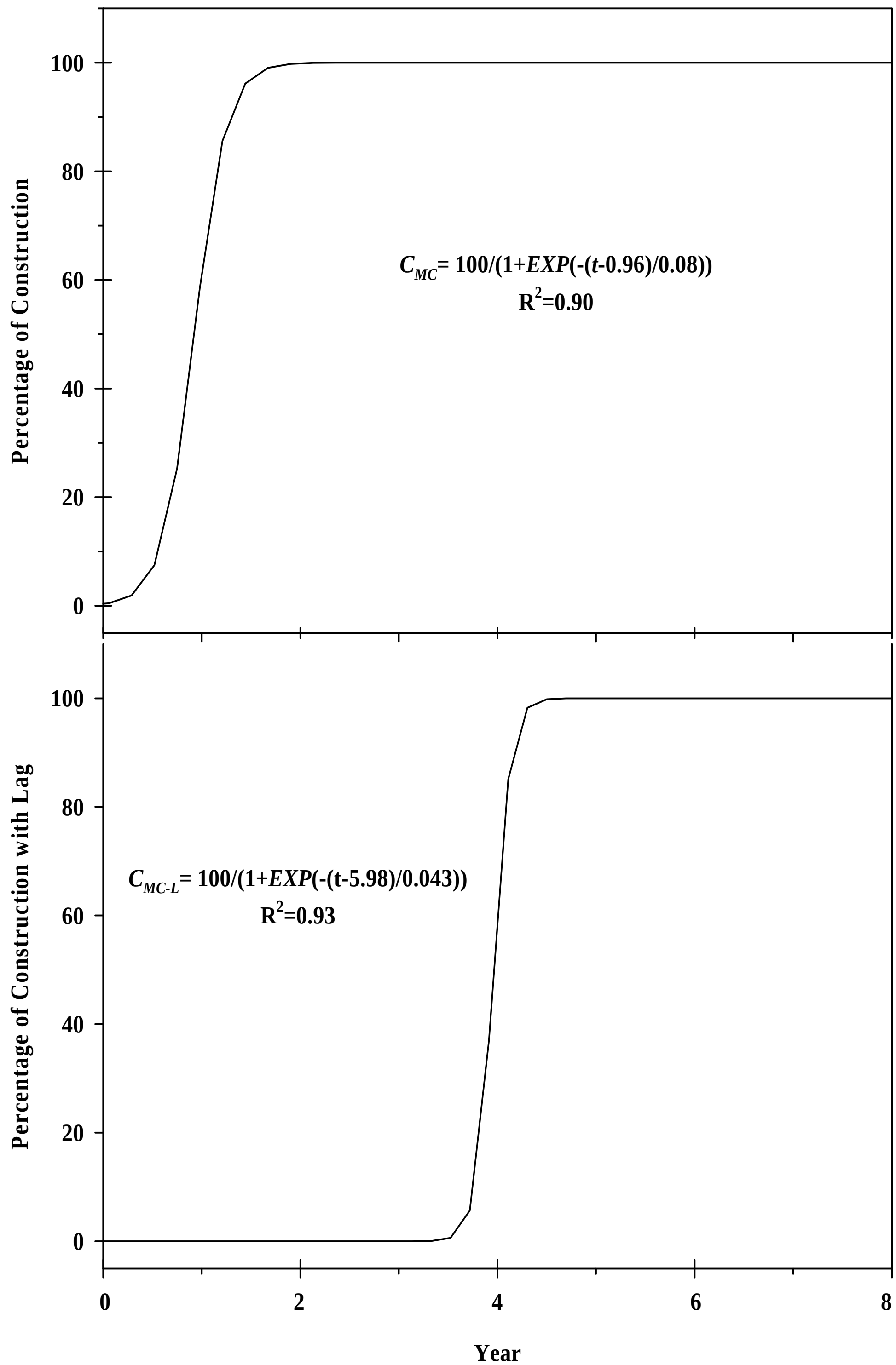


Figure 3.3 Marsh creation projects percent completion curves without and with engineering design consideration

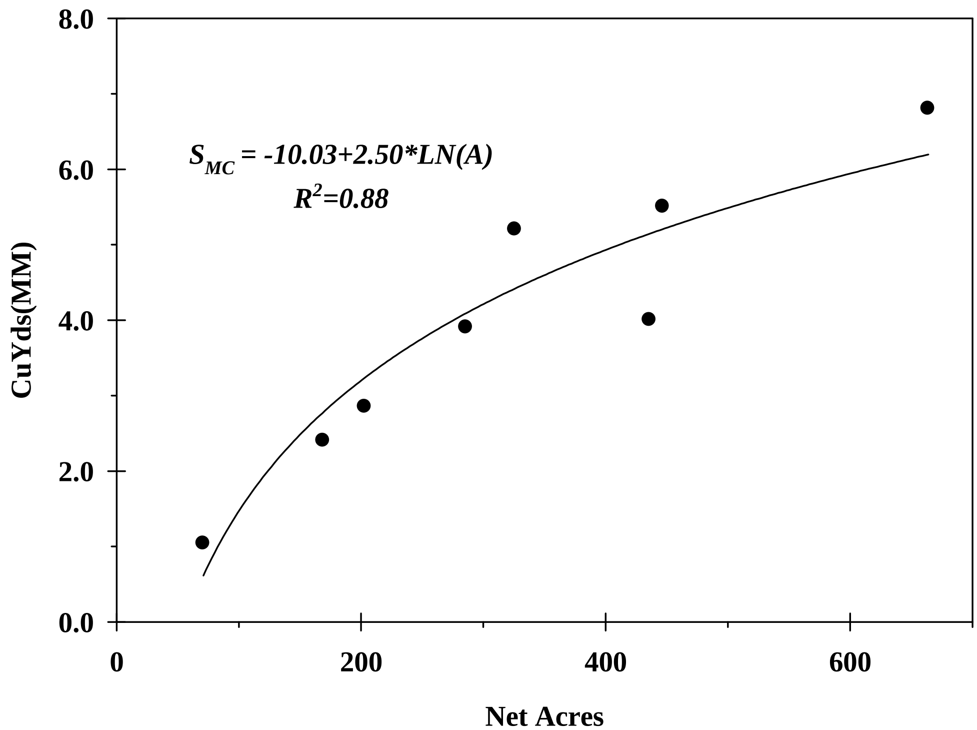


Figure 3.4 Estimated sediment requirements for marsh creation technology under CWPPRA (n=8)

of the CWPPRA models have restoration trajectories that predict gradual increases in land beyond initial construction – usually after year 10. Modeling this trajectory is difficult because of the dynamics of these systems, and also because of the extreme variability between projects. The second set of curves in Figure 3.6 includes each project's pre-construction period for engineering and design. During the engineering and design stages, similar to marsh creation projects, no net acres accrue. Meanwhile, funding and social constraints can be added to this stage to delay the net acres accumulated.

Based on percentage of project completion, a global curve was estimated for these 6 projects to illustrate the generic construction trajectory for barrier island projects. Similar to marsh creation project, project construction is delayed by an average of 4 years when the average lag period for these projects is incorporated into the generic trajectory. Figure 3.7 depicts the percentage completion of project construction curves and equations for this generic trajectory without and with engineering design lag. As with marsh creation projects, the generic trajectories depicted here are held stable after construction without consideration for long-shore sediment transportation, erosion or subsidence. The equations for these generic curves are:

$$T_{BI} = \frac{1}{(1 + EXP(-(t - 0.89)/0.0654))} \quad \text{(Eq. 3.4)}$$

$$T_{BI-L} = \frac{1}{(1 + EXP(-(t - 4.89)/0.0654))} \quad \text{(Eq. 3.5)}$$

where T_{BI} is percentage completion of project trajectory, T_{BI-L} is percentage completion of project with engineering lag trajectory, and t is time period expressed in years with R^2=0.98 and R^2=0.99, for the generic and lagged model, respectively.

A total eight barrier island projects were chosen from Table 3.8 to illustrate the functional relationship between total sediments and net acres accrued. Figure 2.10 depicts this relationship of various sediment delivery rates for barrier island projects for land accrual, expressed as:

$$S_{BI} = -10.38 + 2.37 * LN(A) \qquad \text{(Eq. 3.6)}$$

where S_{BI} are the estimated sediments input expressed in million cubic yards(MM cuyds) , and A are benefits expressed in net acres ($R^2 = 0.67$).

3.4 Generic Benefit Model: Freshwater Diversion

Given the small number of projections, only a few projects are available for examining restoration trajectories of FWD projects under CWPPRA. Figure 3.9 depicts restoration trajectories for six typical freshwater diversion projects that exemplify the general trend of how net acres accrue during the 20-year life time of these projects. FWD projects are expected to follow a linear trajectory, in which net acreage is assumed to increase at a slow, constant rate over the 20-year project life time. Beyond 20 years, CWPPRA provides no data on the expected accrual of project acreage. For many of these projects, CWPPRA scientists provide only two points, a beginning and ending acreage. A few of the project reviews assume a linear interpolation applying a constant rate of land accrual.

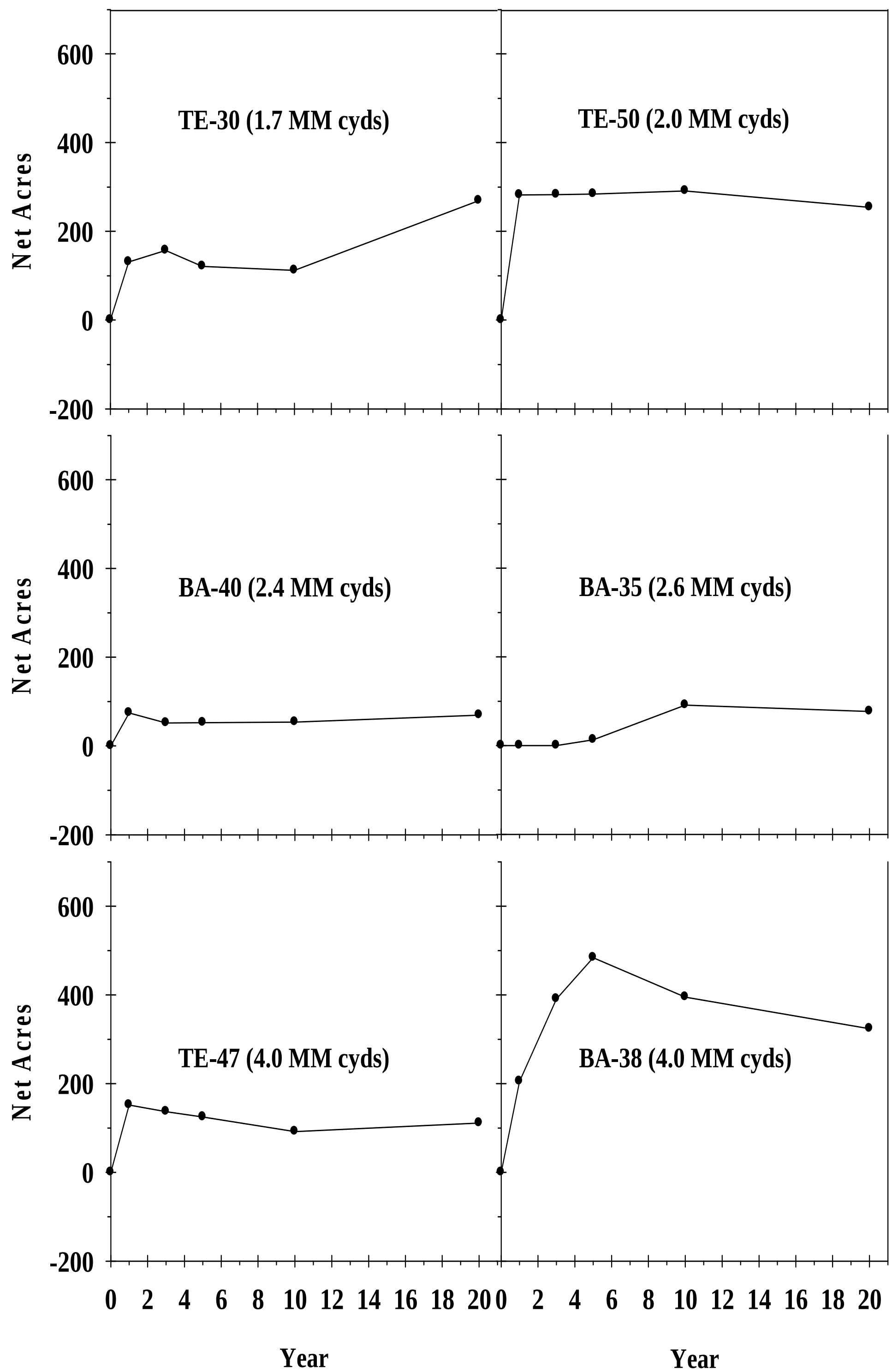


Figure 3.5 Six net acre trajectories by barrier island technology under CWPPRA (n=6)

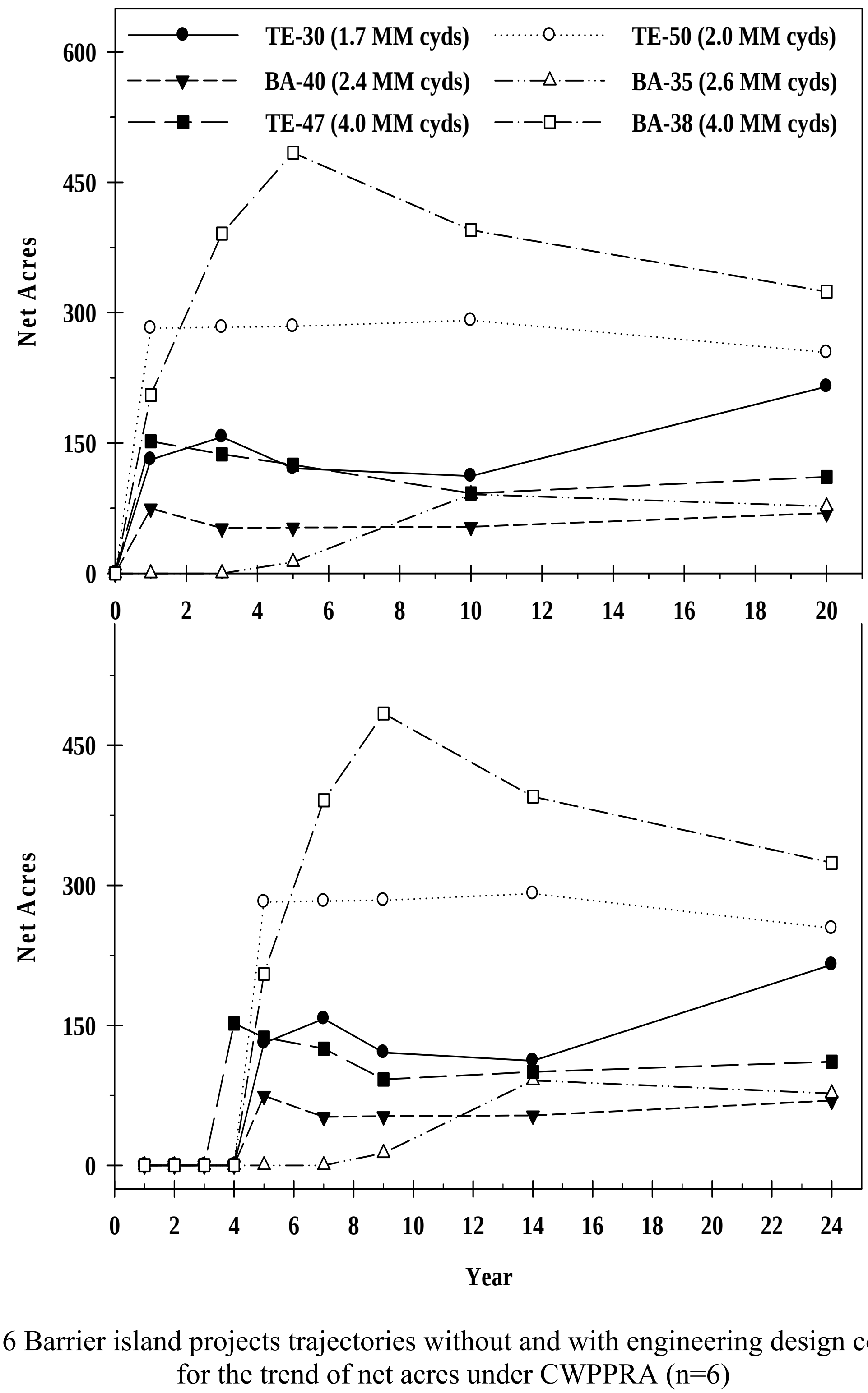


Figure 3.6 Barrier island projects trajectories without and with engineering design consideration for the trend of net acres under CWPPRA (n=6)

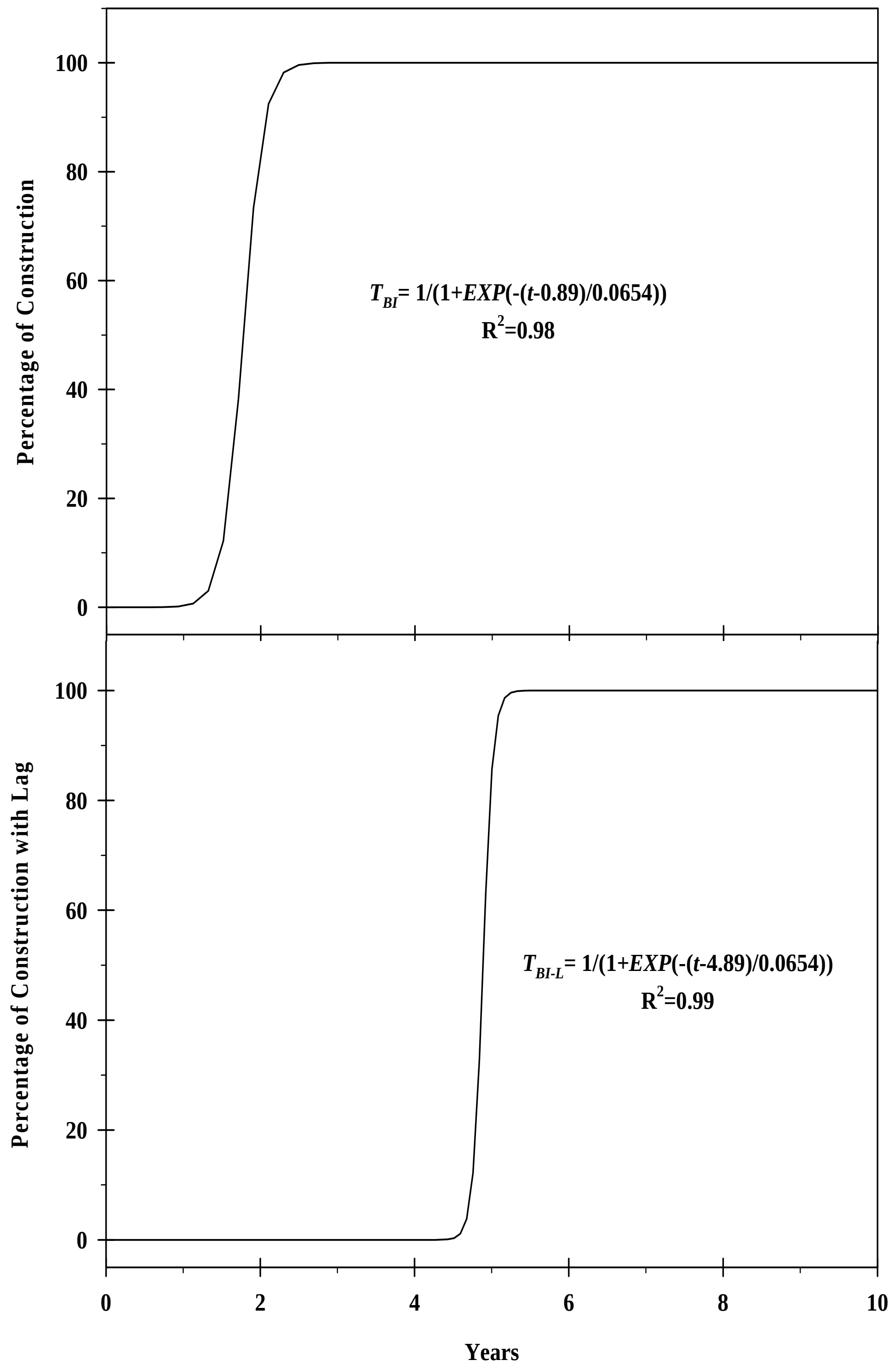


Figure 3.7 Barrier island projects percent completion curves without and with engineering design consideration

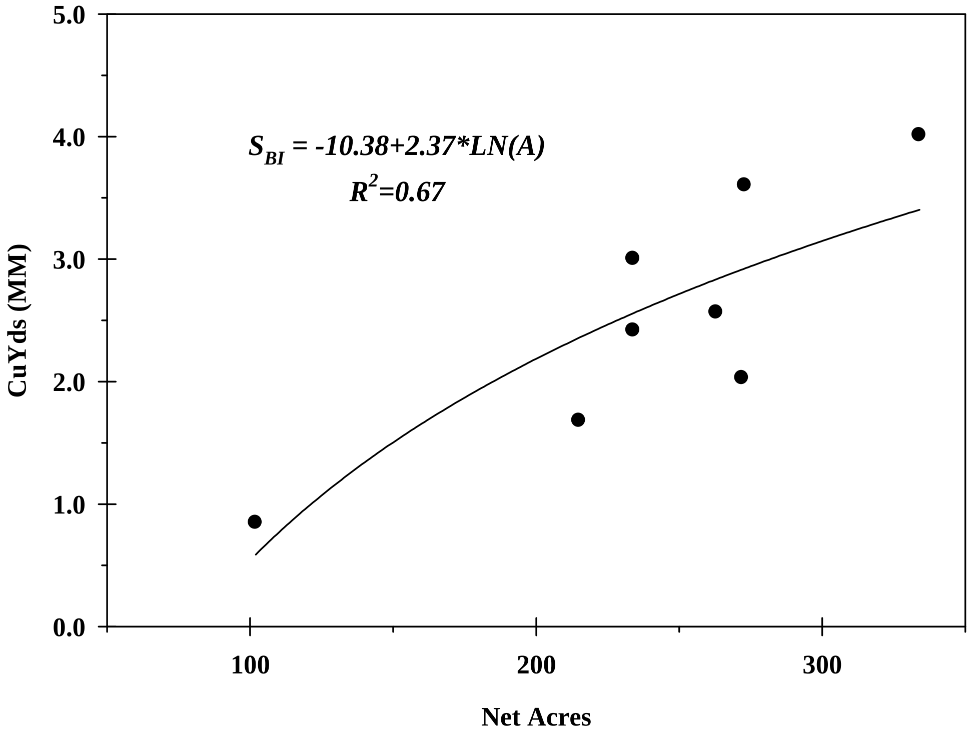


Figure 3.8 Estimated sediments rate by barrier island projects technology under CWPPRA (n=8)

Figure 3.10 shows the aggregated trajectories for six typical freshwater diversion projects which follow a gradually land increase after the completion of project structure.[15] The second set of curves in Figure 3.10 shows these trajectories under engineering and design consideration. Similar to marsh creation and barrier island projects, no benefits accrue during this lag stage. Project construction under the generic trajectory is delayed by an average of 7 years when the average lag period for these projects is incorporated.[16] Figure 3.11 depicts the generic trajectories and equations for these FWD projects. It is important to note that the generic trajectory here is cumulative percentage of net acre accrual. Given that these projects take an average of 2 years to construct, the actual lag period is 9 years before any acreage begins to accrue. The graphics depicted in Figure 3.11 represent this trajectory without and with engineering design lag, respectively. With erosion and natural land accrual rates held constant, these generic trajectories depict a gradual and stable rate of benefit increase after construction. The constant land accrual rate is depicted by the simple regression lines, and the equations for these generic curves are given by:

$$T_{FWD} = -0.0029 + 0.0501 * t \qquad \text{(Eq. 3.7)}$$

$$T_{FWD-L} = -0.1394 + 0.0375 * t \qquad \text{(Eq. 3.8)}$$

[15] It should be noted that completion of project construction here does not immediately produce acreage benefits as with RLB projects. In this situation, construction refers to completion of the project structure (i.e. siphons, gates, culverts, etc.)

[16] Freshwater diversions projects have historically had a longer average lag period because social constraints tend to be greater for these projects (e.g. land rights acquisition, fisheries implications, salinity changes, etc.). The lag period of the CWPPRA-funded freshwater diversion projects listed in Table 2.5 ranges from 1 to 13 years.

where T_{FWD} is percentage of net acres accrued trajectory, $T_{FWD\text{-}L}$ is percentage of net acres accrued with engineering lag trajectory, and t is time period expressed in years with R^2=0.99 and R^2=0.90, for the generic and lagged model, respectively.

This generic model of freshwater diversions under CWPPRA provides a basis for future simulations on the estimated water flow rate. While land-building is generally slower using these projects, the flow-rate is a function of overall scale of net acreage. A total of seven typical freshwater diversion projects were chosen from Table 2.5 to illustrate the functional relationship between water flow rate and net acres accrued. Figure 3.12 depicts the functional relationship of various flow rates for land accrual, expressed in cubic feet per second and the equation is given by:

$$F_{FWD} = 1302.86 - 5849.80 * LN(A) \qquad \text{(Eq. 3.9)}$$

where F_{FWD} is flow rate expressed in cubic feet per second (CFS), and A is benefits expressed in net acres (R^2 = 0.60).

3.5 Other Freshwater Diversion Benefit Models

Given the relative scarcity and simplicity of CWPPRA benefit projections for FWD projects, it is important to identify additional restoration programs and examine alternative methods for projecting the benefits of these types of projects.

3.5.1 Crevasse Model

One FWD benefit projection model that has experienced a high level of use in coastal restoration efforts is the “crevasse model” (Banks 2002). Crevasses connecting the river and shallow estuarine sites help the restoration and creation of marsh areas. The creation of crevasses

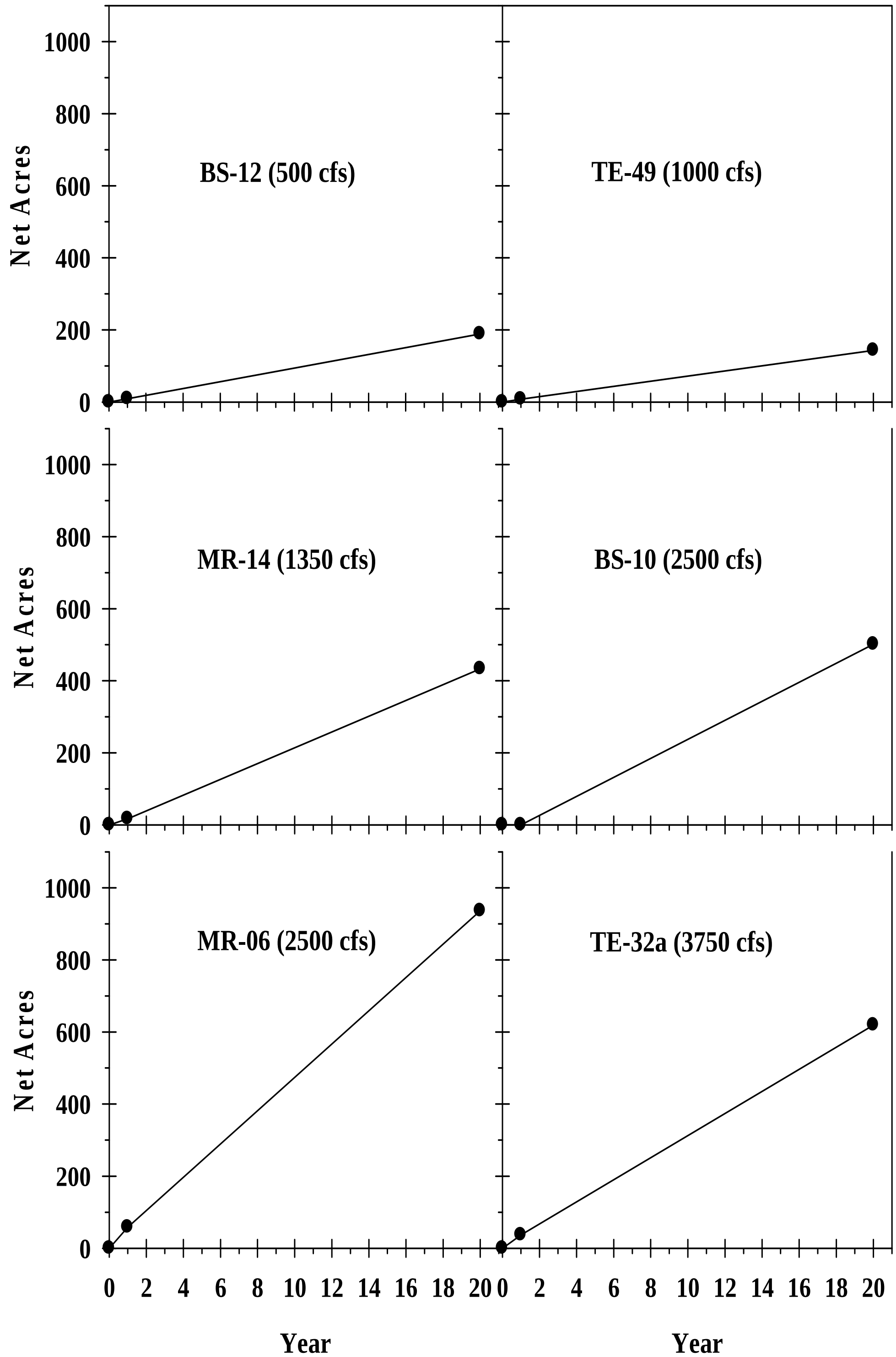


Figure 3.9 Six net acre trajectories by freshwater diversion technology under CWPPRA (n=6)

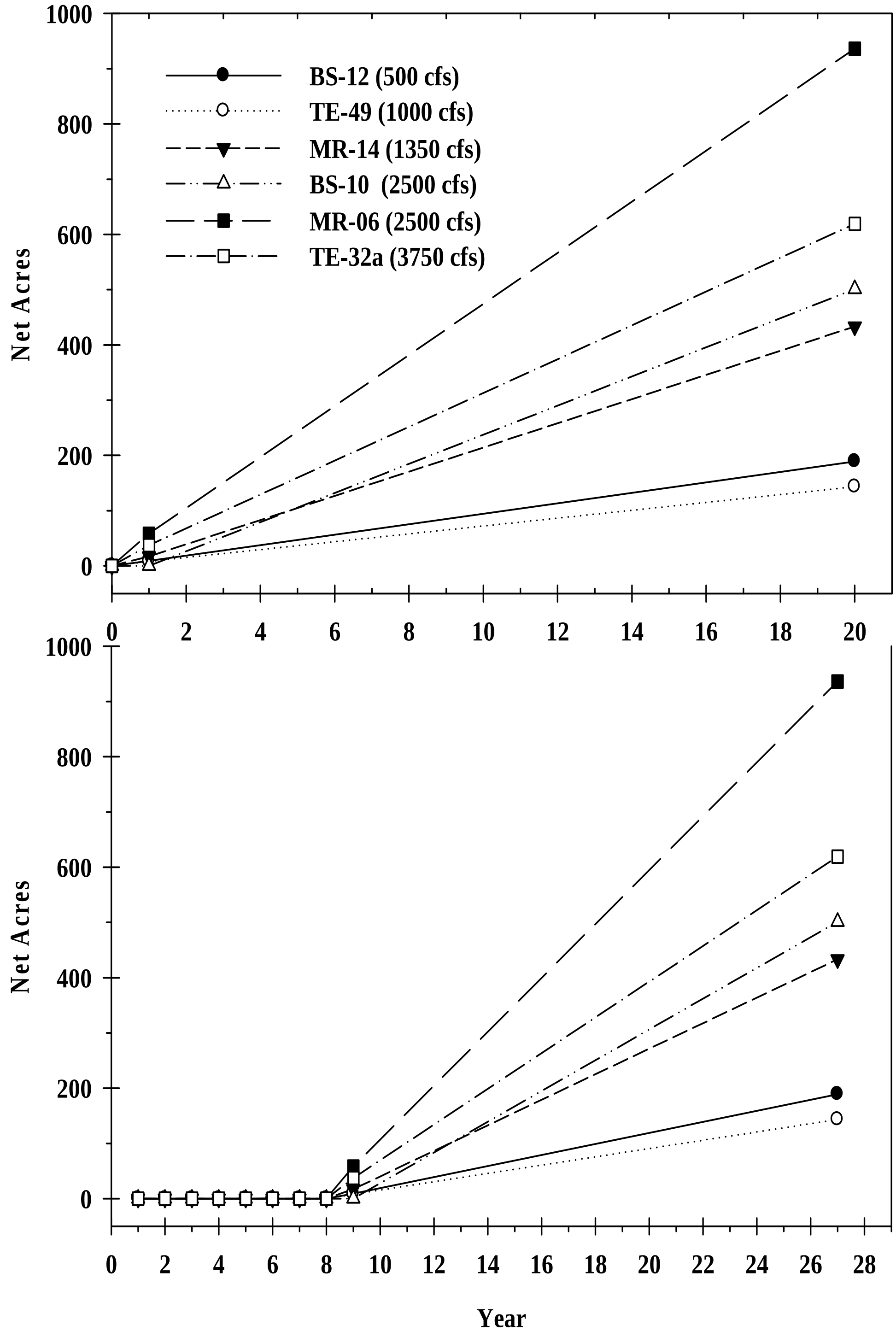


Figure 310 Freshwater diversion projects trajectories and regression line for the trend of net acres under CWPPRA (n=6)

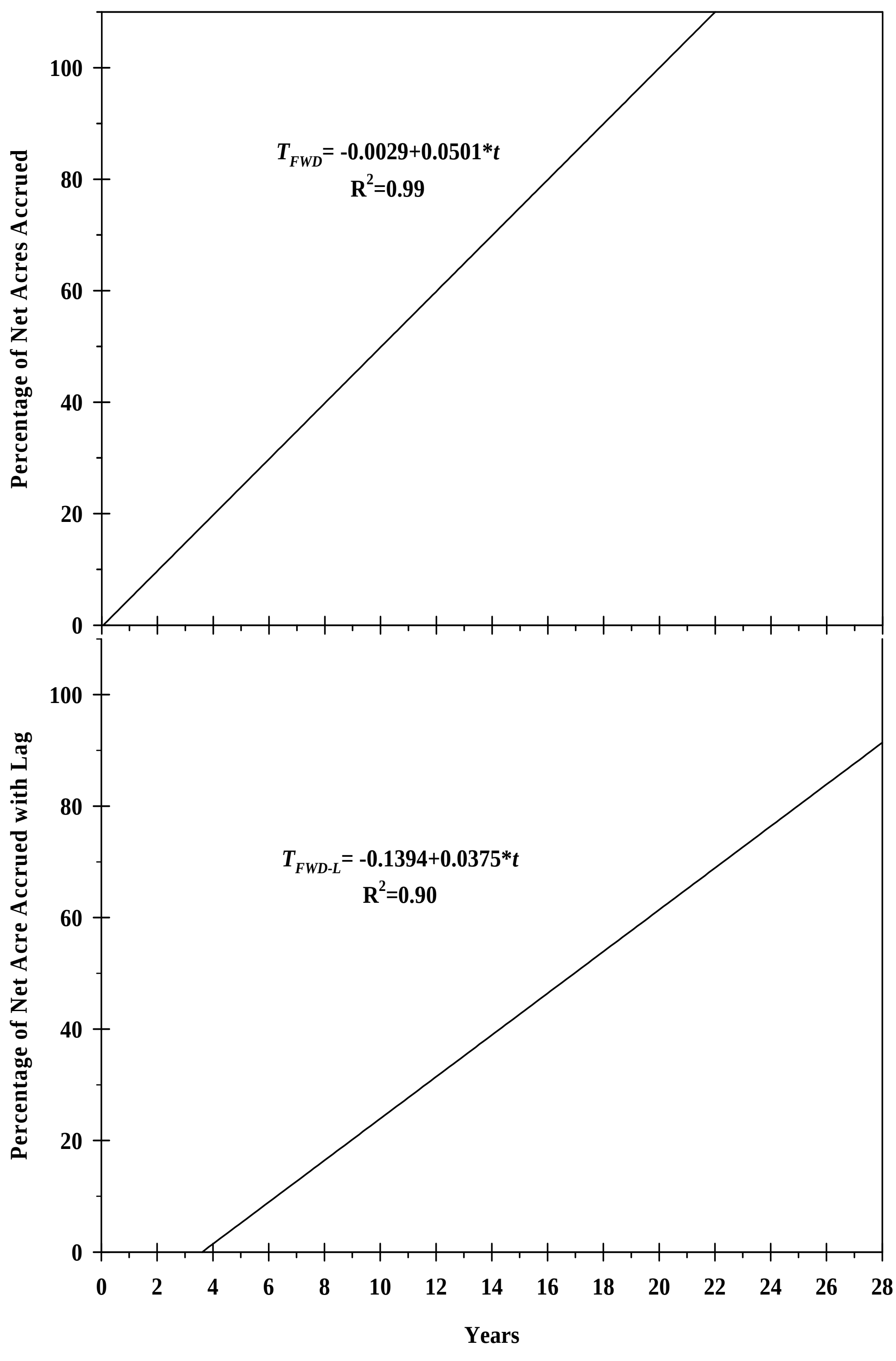


Figure 3.11 Fresh water diversion projects percentage of net acre accrued curve without and with engineering design consideration

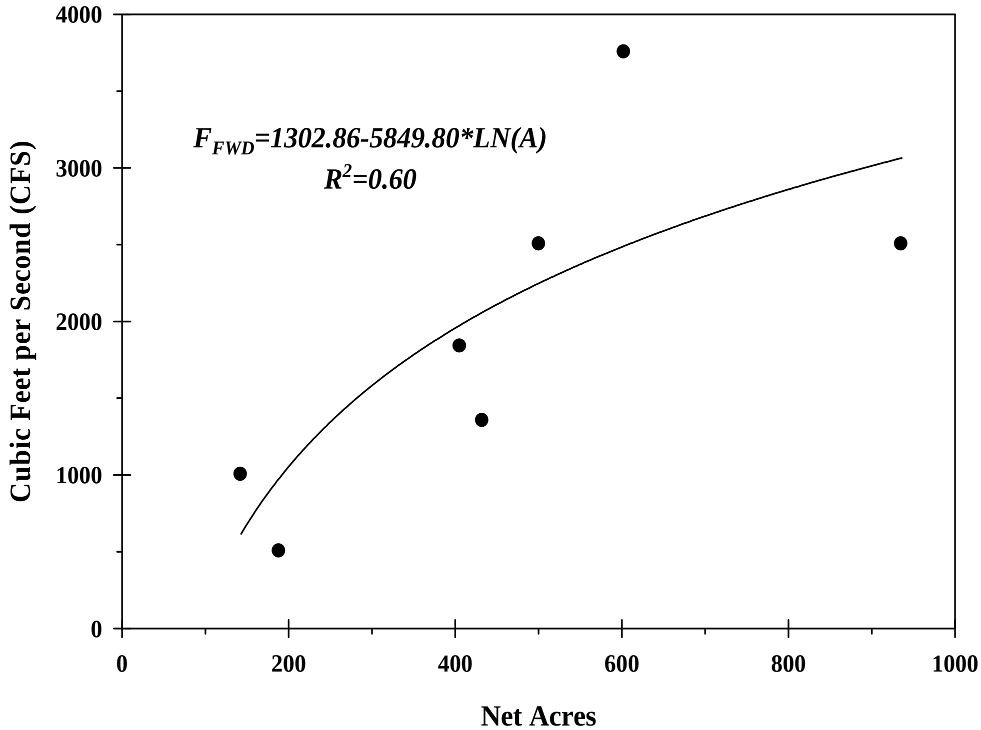


Figure 3.12 Water flow rate by freshwater diversion technology under CWPPRA (n=7)

not only helps to rebuild the desired site but also helps to mimic natural paths in a river with modified hydrology. According to Banks (2002), "the most successful crevasse is one that discharges from a large pass into a large, open-ended receiving basin that allows water to flow efficiently through the system." To predict the growth rate of land building, the author employed a multiple linear regression analysis to explore the relationship between the selected parameters and growth rate. The model is given by:

$$G = 3.097 - 1.299 * PO + 0.002 * PW - 0.324 * CA + 0.039 * CCSA + 0.004 * RA \qquad \text{(Eq. 3.10)}$$

where: *G* refers to the growth rate of land building. PO stands for parent order, which is a descriptive variable used to denote the source and scale of the incoming water source. Where the Mississippi and Atchafalaya Rivers are examples of a primary (PO=1), and distributaries are numbered 2, 3, and 4 based on size and scale. PW is parent channel width, CA is crevasse age, CCSA is crevasse cross-sectional area, and RA is receiving area (Banks 2002).

3.5.2 N-SED Model

Unlike the project described above, most large-scale FWD projects use controlled structures[17] and thus can't be modeled as a natural flow crevasse. For these projects, an alternative model has been developed. Boustany (2007) developed a model for FWD projects that incorporates a "mass balance"[18] approach to estimate project benefits. Under the N-SED1 model (i.e. short for Nutrient-Sediment model #1), land building is a function of flow rate, nutrients and sediments. Within these three module components there are 21 sub-variables and sub-functions that govern the way that benefits (net acres) accrue under a given combination of assumptions. Given the

[17] Controlled structures are those diversions that use a valve or a gate to control the flow of water.
[18] The "mass balance" approach here refers to a numerical method of projecting the output of net land as a function of specific inputs of associated with freshwater, nutrients, and sediments into a specific project area.

model's biophysical complexity, the sub-functions are not provided here, although components of the model are listed in Table 3.1.

Table 3.1 N-SED1 Land Building Model

Variables	**Parameters**
Flow Rate (cfs)	User-Specified
Number of days	Calculated
Acre-ft of water	Calculated
Volume of water (L)	Calculated
Nutrients	
Productivity Rate (gdw m^{-2} y^{-1})	User-Specified
% Retention	User-Specified
% N/P	User-Specified
g m^{-2} NP	Calculated
kg/acres NP (Required)	Calculated
NP Concentration (net)	User-Specified
Total NP (kg) (Available)	Calculated
Nutrient Potential Acres	Calculated
Land Loss Rate	User-Specified
Nutrient Acres	Calculated
Sediments	
TSS Concentration (mg/l)	User-Specified
Bulk Density (g cm^{-3})	User-Specified
% Retention	User-Specified
Average Depth (ft)	User-Specified
TSS (g) (Available)	Calculated
Sediment Potential Acres (acre-ft y^{-1})	Calculated
Sediment Acres	Calculated
TY1 Acres (Gross Annual Acres)	Calculated
TY50 Acres	Calculated
TY100 Acres	Calculated
Area (acres)	User-Specified
Annual Land Loss Rate	User-Specified
Annual Land Loss	Calculated
Adjusted Annual Net Acres	Calculated
Adjusted Land Change Rate	Calculated
Area Sustained (zero loss rate)	Calculated

According to Boustany (2010), the flow rate is specified and based on particular combinations of descriptors, including project goal, location, and scale. The number of days at a particular flow rate is used to determine the volume of source water. Nutrient benefits are based on total nitrogen and phosphorus concentration in the source water, nutrients required for plants based upon annual growth rates, and the percentage of nutrients retained in the system. Sediment benefits are based upon total amount of suspended solids in the source water, bulk density of marsh in the project area, average depth, and retention of these materials introduced. Nutrient benefits and sediment benefits are combined together and used to adjust the overall land loss rate.

3.5.3 Extant Flood Control Structures

Finally, benefits of FWD projects can also be projected by using existing flood control projects (FCP) such as the Bonnet Carre Spillway on Lake Pontchartrain and the Morganza Spillway in east central Louisiana. The largest existing FCP is the Old River Control Structure, commissioned in 1954. This structure has received 30 percent of the Mississippi River's annual average flow rate (495,000 cfs) since the project was completed in 1963 (CWPPRA 2000). Sedimentation rates in the Atchafalaya Basin and the deltas forming at Wax Lake and Atchafalaya Bay provide evidence of the power of a large scale diversion to build new land. According to CWPPRA, the lower Atchafalaya Delta and Wax Lake delta currently have a total of 16,000 acres of subaerial land.[19] Given the land building that is occurring from sediments and nutrients via the Atchafalaya River, the region is expected to have an additional 67,000 acres in the year 2050, a growth rate of 1,275 acres per year. This rate is for net acreage of coastal land, and does not reflect the submarine infilling of sediments into deeper water bodies.

[19] The term subaerial is mainly used in geology to describe structures that existing, occurring, or formed in the open air or on the earth's surface, not under water or underground.

3.6 Summary

Developing generic benefit models of coastal restoration projects is constrained by two major factors: 1) there are relatively few programs that sponsor such projects from which benefits can be estimated in a standardized way; and 2) variation within comparable project types is often very large. An evaluation of 124 CWPPRA projects provided data for 23 marsh creation projects, 13 barrier island projects, and 15 freshwater diversion projects. While apparently the least expensive of these three methods, FWD projects require a relatively long time to restore or create new land. The constant, linear accrual rate of FWD projects is in stark contrast to the rapid, mechanical construction of net acres achieved under marsh creation and barrier island projects – which by comparison, are three to eight times more expensive to construct, respectively. This wide range of physical scales produces difficulties in the production of generic restoration trajectories. Alternative models for estimating FWD benefits have recently become available for large-scale, WRDA sponsored projects. The crevasse model is one example; however, the N-SED1 model has been used more for the technical review of FWD projects. In addition to the generic benefits models derived here, the crevasse and N-SED1 model can also be used in the cost-benefit simulations.

The fit of generic restoration trajectories is general given the limited data. These three project types represent the extreme ends of the restoration natural-to-artificial continuum from less expensive to more expensive, from slow to rapid. From the standpoint of time, the MC technology is almost four times faster than FWD technology. From the viewpoint of cost, the average cost per net acre for MC technology ($100,795) is 2.68 times higher than that of freshwater diversion technology ($37,619). While descriptive statistics on project costs were identified in Chapter 2, specific drivers of these costs have not been estimated. Similar to benefit trajectories, generic cost models by technology are needed for benefit-cost simulations. Such models would reflect the cost of establishing physical quantities of wetland restoration ($/net acre) as a function of location, time and scale variables (e.g. dredging quantity and volume of flow).

CHAPTER 4. GENERIC COST MODELS

4.1 Introduction

In Chapter 3, projects authorized under CWPPRA were used to develop generic trajectories of coastal restoration benefits. Additional projects authorized under WRDA were also considered, along with alternative benefit projection models. This chapter is concerned with understanding the costs associated with those trajectories. Specifically, how have costs for marsh creation (MC), barrier island (BI), and freshwater diversion (FWD) projects been calculated in the past, and how are those costs determined today. The relevant questions are: What have been the historic drivers of project costs? What are the present drivers of project cost? How can these drivers be used to build generic cost models for these three methods?

To better examine the effectiveness of RLB and FWD restoration projects, some generic understanding of project costs is necessary. Aust (2006) developed cost models of CWPPRA projects on a dollar per AAHU basis. Comparison assessments developed using CWPPRA data on a dollar per net acre basis will provide information on the differences between quality (AAHU) and quantity (net acres) as drivers of project efficiency. Additionally, bid data from recent and pending projects can be used to estimate the major cost components of construction. Bids are legal contracts, which contain detailed project information. Indeed, all authorized wetland restoration projects funded by state or federal agencies have been based on contract bids. All generic cost models are developed by building on the descriptive data for project costs outlined in Chapter 2 (Tables 2.1 - 2.8).

Generic cost functions for each project type were developed using regression analysis. Potential drivers of costs were selected as independent variables and obtained from the following sources: past and current cost projections, project bids, and project alternatives; project operation, maintenance, and monitoring reports; fact sheets, monitoring plans, completion reports, ecological reviews, PPL appendices, and personal communication with CWPPRA project managers (CWPPRA 2010; Browning 2010).

Regression models were constructed to determine the relationship between dependent and independent variables by fitting a linear equation to observed data. The basic regression model is given by:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n \qquad \text{(Eq. 4.1)}$$

where *Y* is the dependent variable, *X* is a series of independent variables. The parameter β_0 is the intercept and parameters β_1, β_2 … β_n are the regression coefficients (Abraham and Ledolter 2005). The following sections use multiple regression techniques to estimate the cost models for MC, BI, and FWD projects.

4.2 Potential Variables

The following section defines the dependent and independent variables for regression models to determine past and present drivers of project costs and project materials. Separate models are estimated for each of the three wetland restoration types being investigated (MC, BI and FWD), and in some cases, specific variables are used as dependent or independent variables, depending on the modeling objective. All variables were identified through consultation with coastal scientists and restoration project managers. A list of the dependent and independent variables utilized is provided below and in Table 4.1.

4.2.1 Dependent Variables (Cost Models)

- **Dollars per Net Acre ($/Net Acre)**: For CWPPRA authorized projects, dollars per net acre is used to measure program efficiency. This measure divides the fully funded costs of a project by the total net acres (NA) created, restored, and enhanced during the 20 years project life.

- **Construction Cost (CC_M and CC_B)**: For authorized and bidded CWPPRA projects, the total construction costs (CC) refers to the total costs for completing the built portion of the restoration project. For MC and BI projects, this includes all project-specific structures. CC is limited to construction of the project structure only. On average, CC comprises approximately 85% of total costs for CWPPRA projects (M=marsh creation, B=barrier island).

- **Total Cost (FWD) (TC_F)**: This is the total cost estimate for completion of all tasks associated with construction of a freshwater diversion project. It is generally compose of three types of costs**;** **e**ngineering and design, construction costs, and operation and monitoring (F=freshwater diversion).[20]

4.2.2 Dependent Variables (Materials Models)

- **Dredged Material (Cubic Yards of Sediment CYD_M and CYD_B)**: In this research, the physical materials were considered dependent variables associate with acreage created, project elevation and depth for MC and BI projects.

- **Average Flow rate (AFR_F)**: Similar to RLB project, the physical materials, cubic feet per second (CFS) or average flow rate (AFR_F), was considered as a dependent variable associated with acreage accrued, project boundary area for FWD projects.

4.2.3 Independent Variables (Cost Models)

- **Priority Project List (PPL)**: The PPL is a term developed by CWPPRA that describes the annually produced list of high priority restoration projects. Since the CWPPRA program was enacted in 1990, there have been 19 PPLs. This list, referred to as the "Priority Project List" or "PPL", includes only those projects that have been authorized for funding in a given year. For example, PPL 1 means the project was approved in 1991 and PPL 2 means this project was approved in 1992. Over time, project costs have increased dramatically. Previous research has shown that a positive relationship exists between costs and time (PPL). Aust (2006) theorized that this might occur if the easy projects were completed in earlier years, with an increasing number of large and complex projects appearing in recent years. Program managers have also pointed out that apparent

[20] The total costs (TC) refers to the fully funded cost (FFC) of a RLB or FWD project in this research. The typical planning horizon for CWPPRA projects is 20 years.

increases in cost over time may be driven by more comprehensive cost accounting (Roy 2005).

- **Project Boundary Area (PBA)**: PBA refers to the total benefited area (includes acres enhanced) determined by the CWPPRA Environmental Work Group during the Wetland Value Assessment (WVA) process. The relationship between project boundary and costs is unknown.

- **Average Annual Habitat Units (AAHU):** AAHU as determined by the CWPPRA Environmental Work Group, represent a numerical integration of variables focused on habitat quality within a given area at a given point in time. AAHU represent the average number of habitat units within any given year over the project life for a given area. Aust (2006) found that project costs per unit generally decrease with AAHU increase, this indict potential economies of scale.

- **Dredged Material (CYD)**: For RLB project, dredged material measured in cubic yards (CYD), comprises a substantial portion of total construction costs. The expected relationship between costs and sediments is positive. The more sediment needed, the higher the costs are expected to be.

- **Distance (DIST)**: For RLB project, DIST is the distance in miles from sediment borrows site(s) to the marsh creation site(s). Data for this variable were collected from project fact sheets, scaled project maps, or from project managers. In general, the longer the distance, the higher the costs (i.e. positive relationship between cost and distance).

- **Mobilization (MOB)**: Overhead expenditures include a wide range of costs, for RLB projects one of the largest overhead costs is the transporting of large-scale dredge equipment to and from the project site. Mobilization and demobilization costs (MOB) include the installation and removal of all on-site support facilities needed for the project. So, this variable is expected to have a positive relationship with costs.

- **Dredge Size (DS)**: Most RLB projects use bucket dredge or a cutter-head dredge. For projects that pump dredged sediment from remote borrow sites, the dredge size diameter and initial pipeline diameter ranges from 24 inches to 36 inches. The expected relationship between dredge size (DS) and costs is unknown and depends on the operational efficiency of the particular dredge being used.

- **Payment Type (PYT)**: For RLB project, contractors usually receive payment in one of two ways – they are either paid by the cut or by the fill. If they are paid by cut, the compensation is based on the amount of sediments removed from the borrow site. If they are paid by fill, the compensation is based on the average filling elevation of the target project site. In this case, PYT is a binary variable. In general, payment by fill is the most costly for contractors because of sediment settlement and sediment losses from the project area.

- **Pumps (BP)**: For RLB project, booster pumps (BP) can help transport sediments needed for land building restoration. The number of booster pumps needed depends on the distance from sediment borrow site to marsh creation site. Usually every 5 miles one booster pump is needed to assistant in the movement of sediment slurry through the pipeline. The expected relationship is positive between the costs and the number of booster pump.

- **Average Flow rate (AFR)**: For FWD project, water flow rate is usually measured in cubic feet per second (CFS). Water flow rate can be measured regularly or measured over time in different seasons. Because these rates vary, an average annual flow rate is used to quantify this parameter. The higher the average annual flow rate, the more sediment and nutrition input provided. Average flow rate is expected have positive relationship with project costs.

- **Diversion Control (CON)**: For FWD project, control of flow rate is accomplished by gates, culverts, siphons, constructed channels, weirs, and natural crevasses. There are basically two ways to manage these projects - one is the manual control of water discharge over a certain time horizon, and the other involves uncontrolled discharges which allow the water to flow naturally to nourish the target area. In generally, controlled freshwater diversion projects have higher costs compared to uncontrolled FWD projects (which, in general, have lower operation and monitoring cost).

- **Containment Dikes (CD):** For RLB project, containment dikes or small levees are often constructed to maintain sediment slurry. The expected effect on cost is positive.

- **Access Dredging (AD)**: For RLB and FWD project, access dredging is often required to get heavy equipment on location or to provide a conduit for the distribution of sediment and nutrients. The expected effect on cost is positive.

4.2.4 Independent Variables (Materials Models)

- **Net Acres (NA):** This measure is total net acres for a project. It includes acres of emergent marsh protected, created, and restored. The relationship between net acres and costs is expected to be positive.

- **Average Elevation (AVE)**: For RLB project, elevation is the project site elevation above sea level, using the standard North American Vertical Datum 1988 (NAVD88). Although different elevation targets can be reported within each project, a summary or average elevation estimate is provided for most projects.

- **Average Depth (AEP)**: For RLB projects, depth is the project site depth below sea level, using the standard North American Vertical Datum 1988 (NAVD88). Although different depths can be reported within the initial boundary for each project, a summary or average depth is provided by consultation with CWPPRA project engineers. The relationship between average depth and costs is expected to be positive.

- **Target Thickness (THK)** For RLB project, target thickness is the difference between average elevation and average depth. Although thickness measures may vary across a project boundary, the target thickness is a summary or average for the entire project estimated by CWPPRA project engineers. The relationship between thickness and costs is expected to be positive. In combination with target acreage, this variable is expected to be a significant driver of the quantity of sediments (CYD) required for a RLB project.

Table 4.1 Variable Descriptions and Expected Signs

Variable Abbreviation	Variable Description	
Dependent Variables		
\$/Net Acre	Dollars per Net Acre	
CC_M and CC_B	Total Construction Costs for MC and BI Projects	
TC_F	Total Costs for FWD projects	
CYD_M and CYD_B	Dredged Material for MC and BI Projects	
AFR_F	Average Flow rate for FWD projects	
Independent Variables		Expected Sign
PPL	Project Priority List (Year)	+
PBA	Project Boundary Area	unknown
AAHU	Average Annual Habitat Units	-
CYD	Cubic Yard of Sediments	+
DIST	Average Sediment Transport Distance	+
MOB	Mobilization and demobilization	+
DS	Dredge Size (diameter in inches)	unknown
PYT	Payment Type (Cut=0, Fill=1)	-
BP	Number of Booster Pumps	+
AFR	Average Annual Water Flow Rate (CFS)	+
CON	Diversion Control (Natural Flow=0, Manual Control=1)	+
CD	Containment Dikes	+
AD	Access Dredging	+
NA	Net Acres	+
AVE	Average Project Elevation	+
ADP	Average Depth	+
THK	Target Thickness	+

4.3 Generic Cost Models: Marsh Creation

4.3.1 Historic Drivers of MC Cost

A total of 23 authorized MC projects from CWPPRA (1990-2009) were examined for development of a generic cost model. Twelve of these projects have been completed and 11 are under construction or in the engineering or design stages. Nine variables were selected to construct a conceptual cost relationship:

$$\$/NA_M = f(PPL, CYD, PBA, DIST, MOB, DS, PYT, BP, AAHU) \qquad \text{(Eq. 4.2)}$$

where $\$/NA_M$ is the cost for an MC project expressed in dollars per net acre and *PPL, CYD, PBA, DIST, MOB, DS, PYT, BP*, and *AAHU* are independent variables (Table 4.1). The assumption is that MC project costs have a linear relationship with these independent variables.

Due to data gaps, 12 of the 23 MC projects contained data for all nine independent variables. Data for the model were imported and analyzed into statistical programs SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.2.

Table 4.2 Parameter Estimate 1: March Creation Costs - $\$/NA_M$

N=12
R-square = 0.98

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation[21]
Intercept	-131942	61460	-2.15	0.16	0
PPL	-11148	3600.35	-3.10	0.09	20.98
CYD	-3426.67	2859.56	-1.20	0.35	3.46
PBA	9.04	1.86	4.86	0.04	3.16
DIST	3958.57	3237.73	1.22	0.35	6.10
MOB	0.02	0.01	1.42	0.29	27.09
DS	14076	3470.14	4.06	0.06	13.60
PYT	20041	8928.53	2.24	0.15	2.60
BP	-65002	18580	-3.50	0.07	12.32
AAHU	-172.50	48.40	-3.56	0.07	3.32

[21] Variance inflation factors are a measure of the multicollinearity in a regression design matrix. A VIF value is greater than 10 is an indication of potential multicollinearity problems.

This result shows that independent variables, PPL, PBA, DS, BP, and AAHU are appearing to account for the ability to predict the cost of marsh creation projects at significance of level $\alpha < 0.10$. Pearson correlation analysis (Appendix A) and the high value of variance inflation factor (VIF) indicate that two or more independent variables in this regression model are highly correlated, also known as multicollinearity.[22] Since multicollinearity can adversely affect the results of regression analysis, it is important to remove the highest correlated variables from this model in order to obtain better and more intuitive results.

Table 4.3 Parameter Estimate 2: Marsh Creation Costs - $\$/NA_M$

N=12
R-square = 0.96

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	-98306	65518	-1.50	0.23	0
PPL	-6370.46	1456.99	-4.37	0.02	2.57
CYD	-695.88	2441.25	-0.29	0.79	1.89
PBA	9.37	2.13468	4.39	0.02	3.12
DIST	7095.31	2730.30	2.60	0.08	3.25
DS	10397	2660.71	3.91	0.03	5.98
PYT	13750	8952.10646	1.54	0.2221	1.95844
BP	-43540	12432	-3.50	0.0394	4.13137
AAHU	-206.29001	48.67690	-4.24	0.0241	2.51130

By removing the variable MOB, the VIF values were greatly reduced (Table 4.3). This result shows that the dependent variable cost ($/net acre) can be predicted from a linear combination of the independent variables PPL, PBA, DIST, DS, BP and AAHU under significance level $\alpha < 0.10$. In this regression model, annual increases in time (PPL) let to a cost

[22] Multicollinearity refers to a situation that two or more explanatory variables are highly linearly related in a multiple regression model. When two variables are highly correlated, they are basically measuring the same phenomenon or convey the same information.

decrease of $6,370.46/net acre for marsh creation (with PBA, DIST, DS, BP and AAHU held constant). This finding is the opposite of what Aust (2006) found for the effects of time on the cost for all project types combines.[23] A unit increase in the number of booster pumps (BP) results in decreased costs of $43,540/net acre. This result also is the opposite of what was expected. Even more confounding is that the variable CYD, expected to be highly important, does not emerge as a significant driver. This result is likely due to the limited number of useable observations and the huge cost variations between and within MC projects authorized under CWPPRA during the past 20 years.

4.3.2 Present Drivers of MC Cost

An alternative cost model can be constructed using more current data (2000-2009) from project bids in which total construction costs (CC) is the dependent variable. A total of 34 MC project bids were examined to develop an alternative generic cost model for MC projects. Due to data limitations, this more simplified, bid-based model is conceptualized with five variables that account for 93 percent of average construction costs. The conceptual cost relationship is given by:

$$CC_M = f(CYD, MOB, DIST, AD) \qquad \text{(Eq. 4.3)}$$

where CC_M is the total construction costs for a MC project expressed in dollars based on bidded project data and *CYD, MOB, DIST*, and *AD* are independent variables (Table 4.1). The assumption is that the *CC* of MC project has a linear relationship with *CYD, MOB, DIST*, and *AD*

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[23] Aust (2006) did not develop cost models for specific project types; rather the analysis was for all project types combined.

variables. Data for the MC construction costs model were imported and analyzed in statistical programs SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.4.

Table 4.4 Parameter Estimate 3: Marsh Creation Construction Costs - CC_M

N=34
R-square = 0.94

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	-1507336	1676901	-0.90	0.3761	0
CYD	2486867	688322	3.61	0.0011	3.15583
MOB	2.73887	0.90917	3.01	0.0053	3.69121
DIST	2379910	1084981	2.19	0.0364	2.59813
AD	15.10992	2.73958	5.52	<.0001	3.28683

From the statistical analysis results, variables, CYD, MOB, DIST and AD were significant drivers of the costs for MC projects (α=0.10 R^2=0.93). Based on the statistical analyses, the linear regression model for future MC projects bids is given by:

$$CC_M = -1507336 + 2486867 * CYD + 2.74 * MOB + 2379910 * DIST + 15.11 * AD \qquad \text{(Eq. 4.4)}$$

In this regression model, the CC_M increase \$2,486,867 when the average dredged material increases one million cubic yard (with MOB, DIST, and AD held constant). The construction costs increase \$2.74 when the MOB increase one dollar (with CYD, DIST, and AD held constant). The construction costs increase \$2,379,910 when the distance from the sediment borrow site to marsh creation site increases one mile (with CYD, MOB, and AD held constant). The construction costs increase \$15.11 when the AD cost increase one dollar (with CYD, MOB, and DIST held constant).

In addition to the CC_M model, it is helpful to develop a physical materials model in order to account for additional factors that influence the total quantity of sediments needed to build an MC project. While Figure 3.4 describes this as a simple function of acreage, additional variables can be used to refine the relationship. A conceptual model is that the *CYD* of MC project is a function of *NA, AVE, DEP*, and *THK*. Due to the data limitations, there are only a few *DEP* and *THK* data available. The conceptual model for the sediment required in a MC project was simplified and is given by:

$$CYD_M = f(NA, AVE) \qquad \text{(Eq. 4.5)}$$

where CYD_M is the total sediments required for an MC project expressed in millions of cubic yards and *NA* and *AVE* are independent variables (Table 4.1). The assumption is that the *CYD* of MC project has a linear relationship with *NA* and *AVE* variables. The MC sediments model were imported and analyzed in SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.5.

Table 4.5 Parameter Estimate 4: Marsh Materials Model - CYD_M

N=16
R-square = 0.59

	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	4.50205	1.94679	2.31	0.0378	0
NA	0.00544	0.00188	2.90	0.0123	1.09499
AVE	-1.30727	0.59703	-2.19	0.0474	1.09499

Results indicate that NA and AVE were significant drivers of the sediments required for MC projects (α=0.10 R^2=0.59). Results from Pearson correlation coefficients analysis indicated that these two variables were not correlated in this model (Table.4.6). Normality test shows that data set was well-modeled by a normal distribution (Appendix B).

Table 4.6 Pearson Correlation Coefficients 1: MC - CYD_M

Prob > |r| under H0: Rho=0		
	NET	AVE
NET	1.00000	-0.29453 0.2681
AVE	-0.29453 0.2681	1.00000

Based on the statistical analyses, the linear regression model is given by:

$$CYD_M = 4.5 + 0.0054 * NA - 1.31 * AVE \quad \text{(Eq. 4.6)}$$

In this regression model, the CYD increase 0.0054 million cubic yard when the net acre increase one acre (with AVE held constant). The CYD decreases 1.31million cubic yards when the AVE increases one foot (with NA held constant). CYD increase 0.0054 million cubic yard when net acre increase by one implies a 3.4 of AVE. This value is close to the average AVE of the data, which ranges from 2 to 4 with an average 2.7.

4.4 Generic Cost Models: Barrier Islands

4.4.1 Historic Cost Models for BI Project

A total of 13 authorized CWWPRA BI projects were examined for development of a generic cost model in which dollar per net acre was the dependent variable. Nine of these projects have been completed and 4 are under construction or engineering and design stage. Descriptive analysis (Table 2.2) and previous research (Aust 2006) indicate that BI projects are relatively high cost projects compared to MC projects. The higher costs for barrier island projects are likely due to remoteness and their location in high energy, offshore environments. Likewise, in this model, dollars per net acre is expected to be a function of year approved, quantity of dredged material, project area, elevation, distance, overhead costs, payment type, and average annual habitat units. Dredge size and number of booster pumps were not included in this model due to insufficient data.

Given these description and expectation, BI project costs could be determined by 7 different variables. The conceptual cost relationship for BI projects is given by:

$$\$/NA_B = f(PPL, CYD, PBA, DIST, MOB, PYT, AAHU) \qquad \text{(Eq. 4.7)}$$

where $\$/NA_B$ is the costs for a BI project expressed in dollars per net acre based on fully funded cost for authorized BI projects and *PPL, CYD, PBA, DIST, MOB, PYT,* and *AAHU* are independent variables (Table 4.1). The assumption is that project costs have a linear relationship with these independent variables.

Similar to MC cost model analysis, Pearson correlation analysis (Appendix C) and the high value of VIF indicate that model runs for BI projects produced problems with multicollinearity. A recombination of the variables (removal of PYT) yielded 11 authorized BI projects that contained data for the remaining 6 independent variables. Data for the model were imported and analyzed in SigmaPlot 11.0 and SAS 9.1. The resulting analysis is presented in Table 4.7.

As indicated in the initial model runs with MC projects, the results with authorized BI project data were confounding. Specifically, the materials variable (CYD) was found to be insignificant. This result is once again likely due to the limited number of useable observations

Table 4.7 Parameter Estimate 5: Barrier Island Costs - $\$/NA_B$

N=11

R-square = 0.91

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	102360	274360	0.37	0.7280	0
PPL	-43673	22592	-1.93	0.1254	2.62461
CYD	29608	56848	0.52	0.6300	1.62235
PBA	-0.10706	6.66540	-0.02	0.9880	2.07200
DIST	-15596	29981	-0.52	0.6304	2.81887
MOB	0.29311	0.05034	5.82	0.0043	1.40192
AAHU	-512.99320	455.10950	-1.13	0.3227	1.19559

and the huge cost variations between and within BI projects authorized under CWPPRA during the past 20 years.

4.4.2 Present Cost Models for BI Project

An alternative cost model can be constructed using project bid data in which total construction costs (CC) is the dependent variable. A total of 39 BI project bids were examined to develop an alternative generic cost model for BI projects. In this model, cost is expected to be a function of CYD, MOB and DIST. The conceptual cost relationship is given by:

$$CC_B = f(CYD, MOB, DIST) \qquad \text{(Eq. 4.8)}$$

where CC_B is the total construction costs for a BI project expressed in dollar based on bidded project data, and *CYD, MOB* and *DIST* are independent variables (Table 4.1). The assumption is that CC of BI project have a linear relationship with *CYD, MOB* and *DIST* variables. Data for the

BI construction costs model was imported and analyzed in SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.8.

Table 4.8 Parameter Estimate 6: Barrier Island Construction Costs - CC_B

N=39

R-square = 0.71

	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	-10100291	4428163	-2.28	0.0288	0
CYD	3910489	1002575	3.90	0.0004	1.71326
MOB	4.18020	0.63399	6.59	<.0001	1.33729
DIST	1349345	463073	2.91	0.0062	2.11973

This model shows that independent variables, CYD, MOB, and DIST, were significant predictors of total construction cost at ten percent significance level (α=0.10 R^2=0.72). Based on these results, the construction cost model for future BI projects is given by:

$$CC_B = -10100291 + 3910489 * CYD + 4.18 * MOB + 1349345 * DIST \qquad \text{(Eq. 4.9)}$$

In this regression model, the CC_B increase \$3,910,489 when the average dredged material increases one million cubic yards (with MOB and DIST held constant), the construction costs increase \$4.18 when the MOB increase one dollar (with CYD and DIST held constant), and the construction costs increase \$1,349,345 when the distance from sediments borrow site to project fill site increase one mile (with CYD and MOB held constant).

In addition to the CC_B model, it is helpful to develop a physical materials model in order to account for additional factors that influence the total quantity of sediments needed to build a BI project. While Figure 3.8 describes this a simple function of acreage, additional variables can be used to refine the relationship. A conceptual model is that the *CYD* of BI project is a function of *NA, AVE, DEP*, and *THK*. Likewise, due to the data limitations, there are only a few *DEP* and *THK* data available. The conceptual model for the sediment required in a BI project was simplified and is given by:

$$CYD_B = f(NA, AVE) \qquad \text{(Eq. 4.10)}$$

where CYD_B is the total sediments required for a BI project expressed in million cubic yard. *NA* and *AVE* are independent variables (Table 4.1). The assumption is that the *CYD* of BI project has a linear relationship with *NA, AVE, DEP*, and *THK* variables. Data for the BI sediments model were imported and analyzed in SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.9.

Table 4.9 Parameter Estimate 7: Barrier Island Materials Model - CYD_B

N=6
R-square = 0.79

	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	0.00167	1.93911	0.00	0.9994	0
NA	0.01267	0.00422	3.00	0.0576	1.12719
AVE	-0.27226	0.56727	-0.48	0.6641	1.12719

From the statistical results, variables, NA was found to be a significant drivers of the sediments required for MC projects (α=0.10 R^2=0.79). The variable AVE did not significantly add to the ability of the equation to predict the sediments required. Results from Pearson correlation coefficients analysis indicated that these two variables were not correlated in this model (Table.4.10). Normality test shows that data set was well-modeled by a normal distribution (Appendix D).

Table 4.10 Pearson Correlation Coefficients 2: BI - CYD_B

Prob > |r| under H0: Rho=0		
	NET	AVE
NET	1.00000	-0.33591 0.5151
AVE	-0.33591 0.5151	1.00000

Based on the statistical analyses, the linear regression model is given by:

$$CYD_B = 0.01267 * NA \qquad \text{(Eq. 4.11)}$$

In this regression model, the CYD increase 0.01267 million cubic yard when the net acre increase one acre.

4.5 Generic Cost Models: Freshwater Diversions

4.5.1 Historic and Present Drivers of FWD Cost

A total of 15 FWD projects were examined for development of a generic cost model in which dollar per net acre was the dependent variable. Water diversion and sediment diversion restoration projects were combined in the dataset. Three of these projects have been completed and 12 are under construction or in the engineering and design stage. In this model, dollars per net acre is expected to be a function of year approved, water flow rate, project boundary area, diversion types (controlled or uncontrolled), and average annual habitat units. Thus, the hypothesized cost relationship is given by:

$$\$/NA_F = f(PPL, AFR, PBA, CON, AAHU) \qquad \text{(Eq. 4.12)}$$

where *$/NA_F$* is the costs for a FWD project expressed in dollar per net acre and *PPL, AFR, PBA, CON,* and *AAHU* are independent variables. The assumption is that project costs have a linear relationship with these independent variables.

Thirteen of the 15 FWD projects contained data for all 5 independent variables. Data for the model were imported and analyzed in SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.11.

Table 4.11 Parameter Estimate 8: Fresh Water Diversion Costs - $\$/NA_F$

N=13
R-square = 0.17

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	46812	48752	0.96	0.3689	0
PPL	129.98567	4525.43148	0.03	0.9779	1.99078
AFR	-0.99443	1.49943	-0.66	0.5284	1.47973
PBA	2.35955	3.79495	0.62	0.5538	5.01669
CON	-30008	46949	-0.64	0.5431	1.93906
AAHU	-11.15195	15.18187	-0.73	0.4865	4.80145

From the statistical analysis results, none of the independent variables were found to be significant drivers of the costs for FWD projects (α=0.10). Similar to MC and BI projects, this result could be due to the sparse amount of observations available (n=13), or the long period of time between projects included in the model (20 years). Moreover, as seen with the MC and BI projects, the huge variation in project costs over time makes it extremely difficult to develop a representative cost model for FWD projects on dollar per unit cost basis.

Because there are currently no formal bid data available for FWD projects under CWPPRA, an alternative cost model for FWD projects was developed using fully funded cost (FFC) estimates as the dependent variable. Unlike RLB projects, restoration project materials (sediments and nutrients) for FWD projects are not delivered by dredge or pipeline conveyance, but instead are delivered via river water. Thus, the size and capacity of a FWD – as expressed by average annual flow rate (AFR) - could have some influence on total project costs. Moreover, another variable that could influence a project's fully funded cost include is whether or not the structure is controlled by gates or valves or is free flowing/uncontrolled (CON). Eight authorized CWPPRA FWD projects were used to develop a generic cost model for FWD projects. In this model, costs are expected to be a function of AFR and CON. Project costs could be determined by these two variables alone, with a conceptual relationship given by:

$$TC_F = f(AFR, CON) \qquad \text{(Eq. 4.13)}$$

where TC_F is the total cost for a FWD project expressed in dollar based on authorized project data and AFR and CON are independent variables. The assumption is that project costs have a linear relationship with these two independent variables. Results from Pearson correlation coefficients analysis and normality test indicated that these two variables were not correlated in this model and the data set was well-modeled by a normal distribution (Appendix E). Data for the model were imported and analyzed in SigmaPlot 11.0 and SAS 9.1. The resulting analysis is contained in Table 4.12.

Table 4.12 Parameter Estimate 9: Freshwater Diversion Fully Funded Costs - TC_F

N=8
R-square = 0.86

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	6024854	2825933	2.13	0.0862	0
CFS	521.52627	126.43960	4.12	0.0091	1.05815
CON	10894218	3984605	2.73	0.0411	1.05815

This model shows that independent variables, CFS and CON, were significantly related to FFC at the ten percent significance level (α=0.10 R^2=0.86). Based on the statistical analyses, the linear regression model for FWD projects is given by:

$$TC_F = 6024854 + 521.53 * CFS + 10894218 * CON \qquad \text{(Eq. 4.14)}$$

In this regression model, CON is equal to one if the diversion uses manual control and CON is equal to zero if the diversion use natural flow. The costs increase \$521.53 when the average water flow rate increases one cubic foot per second. There is \$10,894,218 more cost for manual control projects comparing to natural flow diversion structure during the project life time. In addition to the TC_F cost model, it is helpful to develop a physical materials model in order to account for additional factors that influence the average flow rate (CFS) needed for a particular FWD project. Figure 3.12 describes this simple function,

$$CFS_F = 130286 - 5849.80 * LN(NA) \qquad \text{(Eq. 4.15)}$$

where the flow rate of a diversion is related to targeted net acreage (NA) (R^2=.60). As with RLB projects, additional variables can be incorporated to refine the materials function, but those variables are not readily available from CWWPRA program data. Some of these project-specific variables can be incorporated through the use of external models, such as N-SED (Table 3.1) for case studies where specific project conditions are known.

4.6 Summary

Generic cost models of coastal restoration projects are very difficult to construct based on the authorized projects data alone. If analysis is constrained to authorized projects, there are only

12 MC projects, 11 BI projects, and 12 FWD projects in which sufficient data exists for multiple independent variables. Moreover, regression analyses of authorized project data often yielded counterintuitive results, with obvious problems in the hypothesized significance and sign of primary variables. These problems may be due to the large amount of changes that have occurred in the cost and benefit estimation process over the last 20 years of coastal restoration under CWPPRA. Recall that Aust (2006) focused on the cost-efficacy of habitat restoration ($/AAHU), while this analysis focuses on the efficiency of land building. Prior to 2005, the AAHU benefit model of CWPPRA was rapidly evolving, but land building did not become a major policy objective until after the hurricanes of 2005. Because project benefits have constantly evolved, it is often difficult to observe a significant relationship with spending.

Through the use of project bid data, generic cost models can be more easily constructed for MC and BI projects. As legally-binding offers, these bids include much of the same detailed information on costs and benefits. Using total construction costs (TCC) as the dependent variable, and analyzing a total of 85 RLB project bids, simplified, but representative, cost models were developed for MC and BI projects. In addition, the development of refined materials models for each of these RLB methods provides the flexibility to vary project conditions in future cost-benefit simulations.

While no current bid data from CWPPRA were available for FWD projects, a suitable model for estimating FFC was derived as a function of three variables. Additional refinement of flow rate requirements (CFS) can be obtained from exogenous variables generated by extant models of FWD benefits (e.g. N-SED model).

Based on the generic benefit and cost models for MC, BI, and FWD projects developed in Chapters 3 and 4, a conceptual benefit-cost model can be established to conduct the economic comparison of RLB and FWD technologies. As discussed in Chapter 1, the basic conceptual model will be net present value. Thus, the results derived from this research can be used to focus on generic simulations or case studies of actual or proposed restoration project alternatives. Before simulations and case studies can be conducted, synthesis of the basic NPV model is needed.

CHAPTER 5. BENEFIT-COST ANALYSIS

5.1 Introduction

As discussed in Chapter 1, benefit-cost analysis (BCA) is a common and useful means to examine environmental and wetland projects. BCA provides economic insight and involves comparison of the long-term economic benefits and costs. This technique can help decision makers to evaluate project alternatives that offer the greatest benefits to the community by comparing the economic benefits with economic costs. Several variations on the basic benefit-cost analysis can be used to compare the benefits and costs of a proposal project, which include benefit cost ratio (BCR), internal rate of return (IRR), and net present value (NPV) (Hanley and Spash, 1993).

The BCR is the ratio of discounted benefits divided by the discounted costs:

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+R)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+R)^t}} \qquad \text{(Eq. 5.1)}$$

where B_t is the benefit in time t and C_t is the cost in time t (benefits and costs are both measured in dollars). *R* is the discount rate. If the BCR is equal to or exceeds one, then the project is expected to yield a net welfare gain, and thus a good candidate for acceptance.

5.2 The Mechanism of NPV

Net present value (NPV) is the value of all projected net benefits in today's dollar terms. Projected net benefits are simply the sum of benefits minus costs in each time period under a specific discount rate. In Chapter 1, Equation 1.3 shows the basic mechanics of NPV. The equation is given by:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+R)^t} = \sum_{t=0}^{T} \frac{B_t}{(1+R)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+R)^t} \qquad \text{(Eq. 5.2)}$$

where B_t is the sum of benefit in time t, C_t is the sum of cost in time t, R is the discount rate and t is the year.

The NPV approach calculates the present value of a series of different future costs and benefits. In the NPV function, costs and benefits of a project need to be identified with the same units and appropriate discount rates should be taken into account. Then the NPV can be calculated to make comparison between or among alternatives. If the NPV is greater than zero, then the project is generally considered to be a good candidate for implementation (Perman et al., 2003). If there are two potential projects, the one with higher NPV would typically be chosen. The major factors affecting present value are the time and the discount (interest) rate. The change in the discount (interest) rate would have a significant effect on net present value analysis.

Generic cost models for marsh creation (MC), barrier island (BI), and freshwater diversion (FWD) projects have been developed in Chapter 4 and all project cost expressed in dollar basis. To apply NPV models for wetland restoration alternatives, the costs and benefits of a project must have the same units. Therefore, full utilization of NPV required that benefits, in addition to cost, be expressed in common units. To be consistent with actual policy decisions, this research uses dollars as the basic unit.

As described in Chapters 1 and 2, the CWPPRA program standardized benefits into common units known as annual average habitat units (AAHU). Aust (2006) examined the cost efficacy of different projects on a $/AAHU basis. Instead of a quality-of-benefit examination, this research standardizes output on a quantity-of-benefit basis, such as net acres. Likewise, in Chapter 3 generic benefit trajectories for marsh creation (MC), barrier island (BI), and freshwater diversion (FWD) projects have been developed and the benefits are expressed on a net acre (quantity) basis. Additional refinements include incorporating land loss and land accretion rates, incorporating method-specific time lags, and selecting appropriate discount rates. The following sections discuss these challenges in regards to their impact on the NPV model for evaluating wetland restoration projects.

5.3 Region-Specific Landscape Changes

In Chapter 3, wetland restoration benefit trajectories are developed. For rapid land-building projects (MC and BI), all desired net acres are obtained during project construction. For freshwater diversions, net acres accrue slowly after the project structure is completed. During or beyond project life time, land loss or erosion is a constant force. As introduced in Chapter 1, there are many forms of natural and human disturbance that contribute to coastal land loss.

Land loss rates have been determined and projected for each of the four Coast 2050 planning regions for the 1990-2050 period (LaDNR 1998). Table 5.1 describes the land loss rates for different habitat types in these regions. On a habitat scale, the projected average annual loss rates range from a low of 0.03% to a high of 0.70% for all regions. For the entire Louisiana coast, the projected average annual loss rates for Regions 1, 2, 3, and 4 are 0.30%, 0.32%, 0.28%, and 0.22%, respectively, for the period 1990 to 2050. Differences in land loss rates among these individual regions are caused by subsidence, sea level rise, storm induced erosion, channelization and dredging of waterways (LaDNR 1998). These average annual land loss rates provide a habitat-specific and regional-specific way to introduce erosion into the NPV model. In some cases, accretion rates might exceed erosion; however, the average accretion rates of 0.7 to

Table 5.1 Existing and Projected Habitat Types in Each Coast 2050 Region

	Fresh marsh acres	Intermediate marsh acres	Brackish marsh acres	Saline marsh acres	Total marsh acres
Region 1					
Acreage in 1990	34,700	27,700	110,900	79,700	253,000
Projected acreage in 2050	30,100	16,000	99,900	61,400	204,000
Net acres lost by 2050*	4,600	11,700	11,000	18,300	45,600
Percent 1990 marsh lost	13%	42%	10%	23%	18%
Average Annual Loss Rate (1990-2050)	0.22%	0.70%	0.17%	0.38%	0.30%
Region 2					
Acreage in 1990	220,100	73,000	214,500	151,100	658,700
Projected acreage in 2050	194,250	61,900	174,900	102,100	533,150
Net acres lost by 2050*	25,850	11,100	39,600	49,000	125,550
Percent 1990 marsh lost	12%	15%	18%	32%	19%
Average Annual Loss Rate (1990-2050)	0.20%	0.25%	0.30%	0.53%	0.32%
Region 3					
Acreage in 1990	298,300	92,700	240,700	140,200	771,900
Projected acreage in 2050	292,330	69,100	184,800	94,900	641,130
Net acres lost by 2050*	5,970	23,600	55,900	45,300	130,770
Percent 1990 marsh lost	2%	25%	23%	32%	17%
Average Annual Loss Rate (1990-2050)	0.03%	0.42%	0.38%	0.53%	0.28%
Region 4					
Acreage in 1990	354,600	171,700	198,600	33,200	758,100
Projected acreage in 2050	317,070	151,070	160,200	32,250	660,590
Net acres lost by 2050*	37,530	20,630	38,400	950	97,510
Percent 1990 marsh lost	11%	12%	19%	3%	13%
Average Annual Loss Rate (1990-2050)	0.18%	0.20%	0.32%	0.05%	0.22%

*includes acres preserved by Breaux Act Priority Lists 1-6 and Caernarvon and Davis Pond Diversions.
Source from Coast 2050: Toward a Sustainable Coastal Louisiana

0.8 cm/yr across the Louisiana coastal region are not sufficient to keep up with current sea level rise rate, which measured to be 1.0 cm/yr in most regions (DeLaune et al. 1992). For BI projects, land accretion from long shore sediment transport is an important factor in shoreline change.

Longshore sediment is mainly driven by waves that arrive at the shoreline at an angle. Longshore sediment transport direction and rate is a function of the angle of wave approach, wave strength and the time between consecutive waves (Hart et al., 2008). The sediments that accumulate through this natural force can result in net acreage gains for barrier islands. There are many investigations about the shoreline rate change along the Louisiana coast, especially on Chandeleur Island. Williams et al. (1992) provided the most comprehensive analysis of gulf and bayside shoreline change (1853 to 1989). The shoreline rate change varies greatly from south to the north of Chandeleur Island. McBride et al (1993) found that the average rate of gulf shoreline change for the entire island is -6.5 m/yr for the 134 years record, while the bayside change rate is 2.9 m/yr during the same period. On average, the accretion rate is around 0.8% for barrier islands in Louisiana. Choosing an appropriate accretion rate; however, requires consideration of region-specific land loss and accretion rates in combination. The interaction of erosion and accretion forces will affect the net acreage accrual rate for BI projects. If the land loss rate is less than the accretion rate, net acreage is increasing. If the land loss rate is equal to the accretion rate, the net acreage is constant. If the land loss rate is greater the accretion rate, net acreage is declining.

5.4 Time Lag

The amount of time required between project authorization and final structure completion is referred to as the construction time lag. During this period, engineering and design (E&D) studies are carried out and social constraints are addressed, but there are no benefits accruing. As detailed in Chapter 3, MC and BI projects authorized under CWPPRA have taken an average E&D period of 4 years, with a range from a low of 1 year to a high of 12 years. However, the time lag for FWD projects averages 7 years, and ranges from a low of less than 1 year to a high of 11 years.[24] The actual construction time required for project structures is approximately 2 years for RLB projects and 2 years for FWD projects (Table 5.2). After construction, gradual erosion causes all benefits (net acres) to slowly decline for MC and BI projects, unless offset by accretion. However, FWD project benefits (net acres) continue to slowly increase after completion of the project structure and could feasibly continue well after the 20-year project life, unless offset by erosion.

Table 5.2 Average Project Design and Construction Period under CWPPRA Program (n=105)

Type	Avg. Design Period(Years)	Range Low	Range High	Obs.	Avg. Construction Period(Years)	Range Low	Range High	Obs.
MC	4	2	12	14	2	<1 Year	7	19
BI	4	1	6	8	2	<1 Year	7	10
FWD/SD	7	<1 Year	11	14	2	<1 Year	6	13

5.5 Discount Rate

For the NPV model, it is necessary to convert all costs and benefits into present value expressed in monetary terms. However, the costs and benefits occur in every time period of project life (20 years) for all wetland restoration projects under CWPPRA. So the questions are, How is this time effect taken into account? and How can costs and benefits be compared when they occur in different time periods? In theory, it is not difficult to solve these problems. Comparison can be made between the costs and benefits when they are discounted. In equation 5.3, the present value of benefit (PVB) and present value of cost (PVC) received in time t with discount rate R ($0 \le R \le 1.0$). A higher discount rate means a greater preference for things now rather than later (Hanley and Spash, 1993). The lower discount rate reflects simply a less intense

[24] Refers to CWPPRA authorized FWD projects only. For FWD projects built by other programs, the lag can be considerably longer. The Caernarvon and Davis Pond FWD projects each had construction lags of 30 and 40 years, respectively due to various constraints.

preference for the present and does and does not reflect a preference for the future over the present (Uyar 1993).The rationale is simple. For example, one dollar invested now at an interest rate of 10% in ten years will have grown to $\$1*(1+10\%)^{10}$, which is \$2.59. This means that \$2.59 in ten years is worth the same as \$1 now.

Although discounting is the most appropriate method for accumulating costs and benefits over time, it is sometimes politically difficult to identify a consensus discount rate when assessing a project with a long time horizon. If using common discount rates between 4% and 10%, the costs or benefits in a very long time horizon often have little impact on NPV (Holland et al., 2010). At a discount rate of 10%, one dollar to be received in 100 years is worth less than one cent. At discount rates 0%, one dollar benefit to be received in 100 years is worth exactly one dollar.

It has been long debated how to select the correct discount rate for an environmental projects when applying BCA analysis. In fact, there is no agreement on a single discount rate used by environmental economists. Using zero discount rate means that benefits today are the same with benefits received in the future from now. Conversely, a 100% high discount rate means all future actions are meaningless. Most economists agree that positive discount rates should be used when using BCA methods to evaluate environmental projects. The reasons for applying a positive discount rate are: positive rates of inflation diminish the purchasing power of dollars over time, dollars can be invested today, earning a positive rate of return, future benefits might not ever be realized because of the existence of uncertainty, and humans are generally impatient and prefer instant gratification rather than waiting for long-term benefits (NOAA 2000). However, some non-economists would argue that negative discount rate, or at least zero discount rate should be used in BCA models. The assumption that there will always be growth in the long term, a basis for positive discount rates, doesn't necessarily always hold. It is entirely possible that the human race could overexploit and exhaust the natural resources necessary for growth. The economy could start at some point to decay or be precipitated to a crash all at once because of some disaster or a war. When global recession and decline occur, a negative or zero discount rate should be taken into account (Environmental Economics 2005). Weitzman (2001) conducted a survey to determine discount rate from the opinions of 2,160 economists. He points out that even if every individual believes in a constant discount rate, the wide spread opinion on discount rates means that a declining rate should be used in any benefit-cost analysis for long-term environmental projects. For these reasons, this research will use a variety of discount rates and evaluate their impact on NPV results using sensitivity analysis. Another way is to use a time-declining rate of discount, which might begin at 4%-10% value and decline slowly over time (Holland et al., 2010, Weitzman 2001).

5.6 Integrated NPV Models

As stated in Chapter 1, the main objective of this study is to develop a comprehensive economic assessment of rapid land-building (RLB) technologies and freshwater diversions (FWD) (existing and proposed) for coastal restoration. The benefits trajectories and associated costs functions defined in Chapters 2, 3 and 4 can be integrated into a basic NPV analysis (Eq. 5.2) for these various restoration methods over a given time period. In the following sections, three general models for NPV are constructed by integrating previously described benefit and costs variables and functions for MC, BI, and FWD projects.

5.6.1 NPV Model: Marsh Creation

From equation 5.2, we define benefits in period t for MC projects by the function:

$$B_t(MC) = NA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_m) - 0.96)}{0.08} \right)} \right] * (1 - E)^{t - lag_m} * (ESV_m) \qquad \text{(Eq. 5.3)}$$

where t is the number of years (ranging from 1 to 20 for CWPPRA projects). $B_t (MC)$ is the total annual benefits (in \$) of a MC project in year t. *NA* is a user specified variable referring to the desired net acreage gain from the project over a given time period. The bracketed expression [Eq 3.1] is the percentage of project construction for a MC project completed in year t. The time lag_m is the engineering and design (E&D) phase for MC projects, which is also a user specified variable in this model. The capital letter E stands for a geographically-specific land loss rate obtained from Table 5.2, such that $(1\text{-}E)^{t\text{-}lag_m}$ is the proportion of land remaining at time t.

The acronym ESV_M stands for the annual non-market, ecosystem values for each acre restored. By isolating this value, we can solve for the break-even level of ESV_M that would be needed for a BCR of 1.0, or greater:

$$ESV_M = \frac{B_t(MC)}{NA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_m) - 0.96)}{0.08} \right)} \right] * (1 - E)^{t - lag_m}} \qquad \text{(Eq. 5.4)}$$

To obtain the PVB, a discount rate is introduced into the model and the equation is given by:

$$PVB(MC) = \sum_{t=1}^{20} B_t(MC) * \frac{1}{(1 + R)^t} \qquad \text{(Eq. 5.5)}$$

where the t stands for a given year from 1 to 20. *PVB(MC)* is the total discounted benefits (in $) of a marsh creation project during the project life R is the discount rate.

The associated costs of engineering and design $C_t\,(ED_M)$ and operation and maintenance $C_t\,(OM_M)$ typically account for 10% and 5%, respectively of total project costs under CWPPRA. Although specific data for these two costs is unavailable, they can be derived algebraically as a function of construction costs $C_t\,(CC_M)$, which accounts on average for 85% of CWPPRA costs for MC projects. In turn construction costs are estimated from regression analysis of cost factors for MC projects under CWPPRA (see Chapter 4 Eq.4.4). In this model, *CYD* is an independent variable representing the number of cubic yards of sediment (in millions), and *MOB, DIST,* and *AD* are user specified variables representing mobilization and demobilization costs ($), average sediment transport distance in miles, and access dredging/channel costs ($), respectively. The corresponding cost in period t for MC projects is given by the function:

$$TC_t(MC) = C_t(ED_M(CC_M)) + C_t(OM_M(CC_M)) + C_t(CC_M) \qquad \text{(Eq. 5.6)}$$

where:

$$C_t(ED_M) = 0.12 * C_t(CC_M) \qquad \text{(Eq. 5.6.1)}$$

$$C_t(OM_M) = 0.06 * Ct(CCM) \qquad \text{(Eq. 5.6.2)}$$

$$C_t(CC_M) = -1507336 + 2486867 * CYD + 2.74 * MOB + 2379910 * DIST + 15.11 * AD \qquad \text{(Eq. 5.6.3)}$$

By substituting Eq.5.6.1, Eq.5.6.2 and Eq.5.6.3 into Eq.5.6, the following model is obtained:

$$
\begin{aligned}
TC_t(MC) &= C_t(CC_M) + 0.12 * C_t(CC_M) + 0.06 * C_t(CC_M) \\
&= C_t(CC_M) * (1 + 0.12 + 0.06) \\
&= 1.18 * C_t(CC_M)
\end{aligned}
\qquad \text{(Eq. 5.7)}
$$

where $TC_t\,(MC)$ is the total annual costs of a MC project in year t, $C_t\,(ED_M)$ is the engineering and design costs of a MC project in year t, $C_t\,(OM_M)$ is the operation and maintenance costs of a MC project in year t, $C_t\,(CC_M)$ is the construction costs of a MC project in year t.

The sub equation (5.6.3.1) for CYD is derived from representative MC projects described in Chapter 4 (see Eq.4.5) and rewritten here as:

$$
\overline{CYD}_M = 4.5 + 0.0054 * NA - 1.31 * AVE \qquad \text{(Eq. 5.6.3.1)}
$$

where the $\overline{CYD}_M$ is a function of NA (net acreage desired) and the AVE (average project elevation) and the NA and AVE are user specified variables.

Combining Eq.5.7 with Eq. 5.6.3 yields:

$$
\begin{aligned}
TC_t(MC) &= 1.18 * C_t(CC_M) \\
&= 1.18 * [-1507336 + 2486867 * CYD + 2.74 * MOB + 2379910 * DIST + 15.11 * AD]
\end{aligned}
\qquad \text{(Eq. 5.8)}
$$

Therefore, the PVC function for MC projects can be expressed as:

$$
PVC(MC) = \sum_{t=1}^{20} \left(C_t(ED_M(CC_M)) + C_t(OM_M(CC_M)) + C_t(CC_M)\right) * \frac{1}{(1+R)^t} \qquad \text{(Eq. 5.9)}
$$

where t stands for the number of year of a project and range from 1 to 20. *PVC(MC)* is the total discounted costs (in $) of a MC project during the project life. $C_t(MC)$ is the total annual costs of a MC project in year t. R is the discount rate.

5.6.2 NPV Model: Barrier Islands

Benefits in period t for BI project are given by the function:

$$B_t(BI) = NA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_b) - 0.89)}{0.0654} \right)} \right] * (1 + A)^{t - lag_b} * ESV \qquad \text{(Eq. 5.10)}$$

where the t stands for the number of years (ranging from 1 to 20 for CWPPRA projects). $B_t(BI)$ is the total annual benefits (in $) of a BI project in year t. *NA* is a user specified variable referring to the desired net acreage gain from the project over a given time period. The bracketed expression [Eq 3.4] is the percentage of project construction for a BI project completed in year t. The time lag_b is the engineering and design (E&D) phase for BI projects, which is also a user specified variable in this model. The capital A is a derived variable referring to net accretion rate for BI projects in coastal Louisiana.

The sub function for net accretion rate (A) is given by:

$$A = L - E \qquad \text{(Eq. 5.10.1)}$$

where the capital L is a user specified variable and stands for long shore sediment transport rate in coastal Louisiana. The capital letter E stands for a location-specific land loss rate obtained from Table 5.2.

The acronym ESV_b stands for the annual non-market, ecosystem values for each acre restored. By isolating this value, we can solve for the break-even level of ESV_b that would be needed for a BCR of 1.0, or greater:

$$ESV_B = \frac{B_t(BI)}{NA * \left[\dfrac{1}{1 + EXP\left(\dfrac{-\left(\left(t - lag_b\right) - 0.89\right)}{0.0654} \right)} \right] * (1 + A)^{t - lag_b}} \qquad \text{(Eq. 5.11)}$$

To obtain the PVB, a discount rate is introduced into the model and the equation is given by:

$$PVB(BI) = \sum_{t=1}^{20} B_t(BI) * \frac{1}{(1+R)^t} \qquad \text{(Eq. 5.12)}$$

where the t stands for a given year from 1 to 20. *PVB(BI)* is the total discounted benefits (in \$) of a barrier island project during the project life and R is the discount rate.

The associated costs of engineering and design $C_t\ (ED_B)$ and operation and maintenance $C_t\ (OM_B)$ typically account for 10% and 5%, respectively of total project costs under CWPPRA. Although specific data for these two costs is unavailable, they can be derived algebraically as a function of construction costs $C_t\ (CC_B)$, which accounts on average for 85% of CWPPRA costs for BI projects. In turn construction costs are estimated from regression analysis of cost factors for BI projects under CWPPRA (see Chapter 4 Eq.4.9). In this model, *CYD* is an independent variable representing the number of cubic yards of sediment (in millions). *MOB* and *DIST* are user specified variables representing mobilization and demobilization costs ($) and average sediment transport distance in miles, respectively. The corresponding cost in period t for BI projects is given by the function:

$$TC_t(BI) = C_t(ED_B(CC_B)) + C_t(OM_B(CC_B)) + C_t(CC_B) \qquad \text{(Eq. 5.13)}$$

Where

$$C_t(ED_B) = 0.12 * C_t(CC_B) \qquad \text{(Eq. 5.13.1)}$$

$$C_t(OM_B) = 0.06 * C_t(CC_B) \qquad \text{(Eq. 5.13.2)}$$

$$C_t(CC_B) = -10100291 + 3910489 * CYD + 4.18 * MOB + 134934 * DIST \qquad \text{(Eq. 5.13.3)}$$

By substituting Eq.5.12.1, Eq.5.12.2 and Eq.5.12.3 into Eq.5.12, the following model is obtained:

$$\begin{aligned} TC_t(BI) &= C_t(CC_B) + 0.12 * C_t(CC_B) + 0.06 * C_t(CC_B) \\ &= C_t(CC_B) * [1 + 0.12 + 0.6] \\ &= 1.18 * C_t(CC_B) \end{aligned} \qquad \text{(Eq. 5.14)}$$

Combining 5.14 with 5.13.3 yields:

$$\begin{aligned} TC_t(BI) &= 1.18 * C_t(CC_B) \\ &= 1.18 * [-10100291 + 3910489 * CYD + 4.18 * MOB + 1349345 * DIST] \end{aligned} \qquad \text{(Eq. 5.15)}$$

where $TC_t\,(BC)$ is the total annual costs of a BC project in year t, $C_t\,(ED_B)$ is the engineering and design costs of a BI project in year t, $C_t\,(OM_B)$ is the operation and maintenance costs of a BI project in year t, $C_t\,(CC_B)$ is the construction costs of a BI project in year t.

The sub equation (5.12.3.1) for *CYD* is derived from representative BI projects described in Chapter 4 (see Eq.4.11) and rewritten here as:

$$\overline{CYD}_B = 0.01627 * NA \qquad \text{(Eq. 5.13.3.1)}$$

where the $\overline{CYD}_B$ is a function of *NA* (net acreage desired) and the *NA* is a user specified variable.

Therefore, the PVC function for BI projects can be expressed as:

$$PVC(BI) = \sum_{t=1}^{20} \left(C_t(ED_B) + C_t(OM_B) + C_t(CC_B) \right) * \frac{1}{(1+R)^t} \qquad \text{(Eq. 5.16)}$$

where *t* stands for the number of year of a project and range from 1 to 20. *PVC(BI)* is the total discounted costs (in $) of a BI project during the project life. $C_t(BI)$ is the total annual costs of a BI project in year t. *R* is the discount rate.

5.6.3 NPV Model: Freshwater Diversions

The benefits function of the basic NPV model for FWD projects is given by:

$$B_t(FWD) = NA * \left[-0.0029 + 0.0501 * \left(t - lag_f \right) \right] * (1-E)^{t-lag_f} * ESV \qquad \text{(Eq. 5.17)}$$

where the *t* stands for the number of years (ranging from 1 to 20 for CWPPRA projects). B_t *(FWD)* is the total annual benefits (in $) of a FWD project in year *t. NA* is a user specified variable referring to the desired net acreage gain from the project over a given time period. Unlike MC and BI projects, the bracketed expression [Eq 3.7] is the percentage of net acres accrued for a FWD project in year *t.* The time lag_f is the engineering and design (E&D) phase for FWD projects, which is also a user specified variable in this model.

The acronym ESV_f stands for the annual non-market, ecosystem values for each acre restored. By isolating this value, we can solve for the break-even level of ESV_f that would be needed for a BCR of 1.0, or greater:

$$ESV_F = \frac{B_t(FWD)}{NA * \left[-0.0029 + 0.0501 * \left(t - lag_f\right)\right] * (1-E)^{t-lag_f}} \quad \text{(Eq. 5.18)}$$

To obtain the PVB, a discount rate is introduced into the model and the equation is given by:

$$PB(FWD) = \sum_{t=1}^{20} B_t(FWD) * \frac{1}{(1+R)^t} \quad \text{(Eq. 5.19)}$$

where the t stands for a given year from 1 to 20. *PVB(FWD)* is the total discounted benefits (in $) of a freshwater diversion project during the project life and *D(t)* is the discount factor in year t and R is the discount rate.

The associated costs of engineering and design $C_t\,(ED_F)$, construction costs $C_t\,(CC_F)$, and operation and maintenance $C_t\,(OM_F)$ typically account for 10%, 85%, and 5%, respectively of total project costs under CWPPRA. These three cost categories can be derived algebraically as a function of CWPPRA costs for FWD projects. The corresponding cost function of the basic NPV model for FWD projects is given by:

$$TC_t(FWD) = C_t(ED_F) + C_t(CC_F) + C_t(OM_F) \quad \text{(Eq. 5.20)}$$

where $TC_t\,(FWD)$ is the total annual costs of a FWD project in year t, $C_t\,(ED_F)$ is the engineering and design costs of a FWD project in year t, $C_t\,(CC_F)$ is the construction costs of a FWD project in year t, $C_t\,(OM_F)$ is the operation and maintenance costs of a FWD project in year t. The sub functions for individual cost categories are given by:

$$C_t(ED_F) = 0.10 * C_t(FWD) \qquad \text{(Eq. 5.20.1)}$$

$$C_t(CC_F) = 0.85 * C_t(FWD) \qquad \text{(Eq. 5.20.2)}$$

$$C_t(OM_F) = 0.05 * C_t(FWD) \qquad \text{(Eq. 5.20.3)}$$

The total costs for a FWD project are estimated from regression analysis using CWPPRA data (see Chapter 4 Eq.4.14) and given by:

$$C_t(FWD) = 6024854 + 521.53 * AFR + 10894218 * CON \qquad \text{(Eq. 5.21)}$$

where AFR and CON are derived variables and stand for average annual water flow rate (cubic feet per second, cfs), diversion types (controlled=0 and uncontrolled=1) respectively. The sub equation (5.20.4.1) for AFR is derived from representative FWD projects described in Chapter 4 (see Eq.4.15) and rewritten here as:

$$\overline{AFR}_F = 1302.86 - 5849.80 * LN(NA) \qquad \text{(Eq. 5.21.1)}$$

where the AFR_F is a function of NA (net acreage desired) and the NA is a user specified variable.

Therefore, the PVC function for FWD projects can be expressed as:

$$PC(FWD) = \sum_{t=1}^{20} \left(C_t(ED_F) + C_t(C_F) + C_t(OM_F) \right) * \frac{1}{(1+R)^t} \qquad \text{(Eq. 5.22)}$$

where *t* stands for the number of year of a project and range from 1 to 20. *PVC(FWD)* is the total discounted costs (in $) of a FWD project during the project life. $C_t(FWD)$ is the total annual costs of a FWD project in year t. *D(t)* is the discount factor and *R* is the discount rate.

5.7 Summary

A NPV model for comparing coastal restoration projects has been developed using representative benefit trajectories and generic cost models. Additional refinements have been incorporated to capture geographically-specific land loss and land accretion rates, method-specific time lags, and accounting for the time value of benefits and costs over many years. All these factors have an effect on the output of BCA calculations.

This basic model framework provides a template for the economic assessment of three coastal wetland restoration methods, MC, BI, and FWD projects. Once all simulation or case study variables have been set, the model can readily conduct comparisons of project alternatives. As currently expressed, the model can be used to derive the level of annual level of break-even ESV benefits that must be obtained for project costs to be covered. These dollar-based estimates can be compared to existing ecosystem values from the literature in order to assess the feasibility of a given simulation or case study example.

CHAPTER 6. BREAK-EVEN SIMULATIONS

6.1 Introduction

In Chapter 5, net present value (NPV) models have been integrated for rapid land-building (RLB) and freshwater diversion (FWD) projects to develop a process for comparing the economic outcomes of wetland restoration alternatives. It is difficult, however, to place a value on the functional benefits of a restored coastal wetland. Such benefits are typically not traded in markets. The challenge here is to determine how these wetland values should be taken into account and how to express quantity-based benefits (net acres) in monetary terms (dollars). This chapter provides a brief summary of non-market valuation methods and develops a series of simulated required break-even ecosystem values (ESV) for RLB and FWD projects under different assumptions.

6.2 Valuing Coastal Wetlands

Wetlands provide not only food and habitat for fish and wildlife but also a number of economic services and goods to humans. The economic services of wetlands are derived from their ecological and physical functions. These services include flood control, water quality maintenance, soil erosion prevention, and recreation opportunities (EPA 2006). More specifically, coastal wetlands provide estuarine habitat and protection of human infrastructure from storm and tidal surge. These provisions are tremendously valuable to all coastal communities. However, measuring the value of these coastal wetland functions is not always easy. In theory, benefits from wetlands would be measured either through market-based methods or non-monetary, numerically-based methods. In practice, there is a wide array of market and non-market methods, which have been used to assess the different values of wetlands. The following section will provide a brief overview of these methods.

6.2.1 Non-Market Based Methods

Ecosystem services are not usually captured directly by per acre market prices for coastal wetlands. Non market valuation techniques are required to measure these service benefits for coastal restoration projects. Because there is lack of a clearly defined market, these methods typically rely on surveys and secondary data to acquire the direct and indirect information needed to value these environmental benefits. A brief look at non-market based methods (below) includes the hedonic method, travel cost method, contingent valuation, energy analysis, and benefits transfer.

- **Hedonic Method (HM):** The hedonic price method is technique that determines coastal resource value as a function of environmental quality. It can be used to estimate the impact of certain amenities (e.g. wildlife, recreation, aesthetics) or inconveniences (e.g. water, air, or noise pollution), on the price of a house or other property. By comparing the market value of two properties, the implicit price of that characteristic can be obtained by estimating people's willingness to pay for environmental quality (Lipton 1995).

- **Travel Cost Method (TC):** The travel cost method is used to determine the recreation value of a coastal resource by the expenditures of visitors. This method quantifies the total value of a wetland site by calculating the trip-related market-based expenditures; including food, hotel, transportation costs, entrance fees, and opportunity cost of travel time (White 1998).

- **Contingent Valuation (CV):** This is a purely non-market-based technique that measures the value people place on non-market goods or services by asking them questions directly. The examiners set up a hypothetical scenario market and query a random population to estimate how much people would be willing to pay for the improvement or how much compensation people would be willing to accept for the decline in environmental quality. Contingent valuation methods are a useful when no market-based alternative exists for valuing ecosystem services. Based on survey responses, examiners estimate the mean and median willingness to pay for an environmental improvement or willingness to accept compensation for a decline in environmental quality (Carson et al., 2001).

6.2.2 Non-Monetary Based Methods

- **Energy Analysis (EA):** This approach looks at the relationships within natural systems that lead to the production (supply) of natural services, rather than human demand for natural system products (Costanza and Farber 1984). It uses the total amount of energy captured by natural ecosystems in primary production as an estimate of their potential to produce economically useful products such as fish and wildlife. The critical link in using energy analysis for nonmarket valuation is the relationship between the energy embodied in the system and its economic value, and this relationship is controversial (Costanza 1980 and 1984, Daly 1981, Huettner 1982). Even with this uncertainty, energy analysis is frequently used by ecologists to estimate the economic value of natural systems.

- **Benefits Transfer (BT):** The benefit transfer method is used to estimate economic values for ecosystem services by transferring available economic information from one place and time to make inferences about the economic value of environmental goods and services at another place and time (Wilson and Hoen, 2006). Thus, the basic goal of benefit transfer is to estimate benefits for one context by adapting an estimate of benefits from some other context. Benefit transfer is often used when it is too expensive and/or there is too little time available to conduct an original valuation study and it can only be as accurate as the initial study.

- **Meta-Analysis (MA):** Meta-analysis use formal and informal statistical methods collecting information to combine the results of several studies that address related research purposes. Glass (1976) first used the term meta-analyses to refer to the statistical analysis of a large collection of analysis results for the purpose of integrating the findings. Cooper and Hedges (1994) describe meta-analysis as a set of methods to synthesize empirical research. The main advantage of meta-analysis is providing a rigorous statistical synthesis of literature that cannot be achieved by using qualitative analysis (Woodward and Wui 2001).

6.3 Coastal Wetland Values

Understanding the annual economic contributions of ecosystem services from coastal wetlands can provide useful information for NPV analyses. Although there are many ecosystem services existing in coastal wetlands; reduction of storm surge, habitat provision, and water quality improvement are the three most often studied. These services are considered to be primary nonmarket value drivers of coastal restoration project benefits. Conducting a nonmarket valuation study for each project-specific NPV simulation would be beyond the scope of this study. Instead, this research compares derived ESV benefit estimates to existing research on the non-market value of coastal wetlands for storm surge attenuation and habitat and water quality provision.

There is limited literature on coastal wetland valuation of ecosystem services and the range of these estimates is very large. Costanza (2008) provides the most recent estimates for storm protection value. He estimated the value of coastal wetlands for storm surge attenuation ranging from $101/acre/year to $20,648/acre/year in 2007 dollars, with a mean of $3,336/acre/year and median of $1,308/acre/year. By using meta-analysis approach, Kazmierczak (2001) provided mean, median, lower and upper bound estimates of the value of wetlands for habitat/species protection, hunting and fishing, and water quality. These estimates, expressed in year 2000 dollars, ranged from a low of $1.05/acre/year for outdoor recreation to a high of $5,673.80 water quality provision. Farber (1996) provided per acre values of wetlands for fisheries production in coastal Louisiana. He estimated values ranging from $36.93 per acre to $51.52 per acre in 1990 dollars. Woodward and Wui (2001) estimated additional values for these services and for other services including bird watching, flood absorption, and recreational hunting and fishing. Table 6.1 lists coastal wetland valuation studies with examples to illustrate a range of estimation methods and non-market service values.

6.4 Simulations

6.4.1 Break-Even Simulations

The generic benefit and cost models were incorporated into a net present valuation construct (Eq.1.3) and given by developed within Microsoft Excel 2010. From this construct, a "ecosystem services break-even analysis" can be conducted by setting the B:C ratio (Eq.1.1) equal to 1.0 and solving for the average annual value per acre that equates project benefits and costs over the period.

Table 6.1 Non-Market Values for Coastal Wetlands

Author(s)	Published and $ Year	Ecosystem Services	Method	Wetland Value($/acre/year)			
				Mean	Median	Min	Max
Costanza	2008/2007	Hurricane protection	RC	3,336	1,308	101	20,648
Kazmierczak	2001/2000	Habitat Species Protection	MA-All	249	253	169	403
Kazmierczak	2001/2000	Hunting and Fishing	MA	114	10	1.05	664
Kazmierczak	2001/2000	Water Quality	MA	825	211	2.85	5,674
Bergstrom et al.,	1990/1990	Recreation	TC-CV	NA	NA	91	91
Farber	1996/1990	Fisheries production	BT	NA	NA	37	52
Woodward and Wui	2001/1990	Flood	MA–CV	393	NA	89	1,747
Woodward and Wui	2001/1990	Recreation Fishing	MA–CV	357	NA	95	1,342
Woodward and Wui	2001/1990	Commercial Fishing	MA–CV	778	NA	108	5,618
Woodward and Wui	2001/1990	Waterfowl hunting	MA–CV	70	NA	25	197
Woodward and Wui	2001/1990	Birding	MA–CV	1,212	NA	528	2,782
Woodward and Wui	2001/1990	Amenity	MA–CV	3	NA	1	14
Woodward and Wui	2001/1990	Habitat	MA–CV	306	NA	95	306
Woodward and Wui	2001/1990	Storm	MA–CV	237	NA	11	5,142

Legend

BT	Benefit Transfer
CV	Contingent Valuation
EA	Energy Analysis
HM	Hedonic Method
MA	Meta Analysis
RC	Replacement Cost
TC	Travel Cost Method

$$BCR = \frac{Total\ Benefits}{Total\ Costs} = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+R)^t}}{\sum_{t=1}^{T} \frac{C_t}{(1+R)^t}} = 1.0 \qquad \text{(Eq. 6.1)}$$

The cost and benefit function for MC projects have already been expressed in equation 5.8 and equation 5.5. By rewriting equation 5.8 and equation 5.5 and solving for the break-even ESV yields:

$$ESV_M = \sum_{t=1}^{T} \frac{TC\,(MC)}{TA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_m) - 0.96)}{0.08}\right)}\right] * (1 - E)^{t - lag_m}} \qquad \text{(Eq. 6.2)}$$

Also, the cost and benefit function for BI projects have already been expressed in equation 5.15 and equation 5.21. By rewriting equation 5.15 and equation 5.12 and solving for the break-even ESV yields:

$$ESV_B = \sum_{t=1}^{T} \frac{TC(BI)}{TA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_b) - 0.96)}{0.08}\right)}\right] * (1 - E)^{t - lag_b}} \qquad \text{(Eq. 6.3)}$$

Likewise, the associated cost and benefit function in period *T* for FWD projects have already been expressed in equation 5.21 and equation 5.19. By rewriting equation 5.21 and equation 5.19 and solving for the break-even ESV yields:

$$ESV_F = \sum_{t=1}^{T} \frac{TC(FWD)}{TA * [-0.0029 + 0.0501 * (t - lag_f)] * (1 - E)^{t - lag_f}} \qquad \text{(Eq. 6.4)}$$

6.4.2 The Profile of NPV Models

This section takes up NPV simulations under different assumptions for two RLB models and 2 FWD models. As shown in Table 6.2, a total of 47 components, which include 22 user-specified parameters and 25 derived parameters, were introduced into the mathematical NPV model developed in Chapter 5 using MS Excel software. For each control parameter, ranges were obtained from project data and related literature. Ranges were set up from a low to high with a mean value for user-specified variables. Derived parameters were produced from regression models and mathematical results after the user-specified parameter were inputted to the models. For a view of the four spreadsheet models, see Appendix F.

To calculate the required break-even ecosystem services value (ESV) for RLB and FWD projects, non-market values of wetland are needed. As mentioned before, due to the limited literature on coastal wetland valuation of ecosystem services and the scope of this research, this study used three non-market values (storm surge attenuation and habitat and water quality provision) from the existing literature as “starting values.” By initially incorporating these starter values into the NPV model in MS Excel and setting the cost-benefit ratio equal to one, the required break-even ESV (annual $/year) can be calculated through the MS-Excel analytical tool “SOLVER”. For the following simulations, no market values for coastal wetlands are incorporated. The assessments focus only on the annual ESV benefits that would be required to generate a positive cost-benefit result.

Table 6.2 NPV Model

Components	Parameters
Time period (year)	User-Specified
Desired Acreage	User-Specified
Elevation*	User-Specified
Depth*	User-Specified
Discount rate	User-Specified
Water Flow Rate- FWD 2 (Boustany)	User-Specified
Mob/Demob($)	User-Specified
Distance (Miles)	User-Specified
Access Dredging/Channel ($)	User-Specified
E&D Lag (MC)	User-Specified
E&D Lag (BI)	User-Specified
E&D Lag (FWD)	User-Specified
Projected Construction Costs	User-Specified
Projected E&D cost	User-Specified
Projected O&M cost	User-Specified
Market Value of Land ($/acre)*	User-Specified
Hurricane probability (Klotzbach and Gray 2010)	User-Specified
Starting Ecosystem Value (Habitat) $/acre/year	User-Specified
Starting Ecosystem Value (Water Quality) $/acre/year	User-Specified
Starting Ecosystem Value (Storm Surge Protection) $/acre/year	User-Specified
Region-Specific Land Loss Rate (Coast 2050)	User-Specified
Longshore Sediment Transport rate BI projects only	User-Specified
Net Accretion Rate for BI	Derived
Starting Ecosystem Value - Aggregate ($/acre/year)	Derived
Total Sediments-MC (cuyds MM, Eq. 3.3)	Derived
Total Sediments-BI (cuyds MM, Eq. 3.6)	Derived
Water Flow Rate- FWD 1(cfs, Eq. 3.9)	Derived
Construction Cost-MC (Eq. 4.4)	Derived
E&D cost-MC	Derived
O&M cost-MC	Derived
Total Fully Funded Cost-MC	Derived
Construction Cost-BI (Eq. 4.9)	Derived
E&D cost-BI	Derived
O&M cost-BI	Derived
Total Fully Funded Cost-BI	Derived
Construction Cost-FWD1	Derived
E&D cost-FWD 1	Derived
O&M cost-FWD1	Derived
Total Fully Funded Cost-FWD1(Eq. 4.14)	Derived
E&D cost-FWD 2	Derived

Table 6.2 continued

O&M cost-FWD2	Derived
Total Fully Funded Cost-FWD2(Eq. 4.14)	Derived
Annual Break-Even Benefits-MC ($/acre/year)	Derived
Annual Break-Even Benefits-BI ($/acre/year)	Derived
Annual Break-Even Benefits-FWD1 ($/acre/year)	Derived
Annual Break-Even Benefits-FWD2 ($/acre/year)	Derived

*Elevation, depth, and market value of land ($/acre), are not used in the current simulation models due to the insufficient data. They are shown here as potential variables for future research.

6.4.3 Baseline Simulations

For comparison purposes, a baseline simulation is required before simulations can be conducted under different scenarios. Table 6.3 lists 22 user-specified variables and values. Based on historical wetland restoration project data and related literature, values for each user-specified variable are shown for the relevant range and mean. The set values shown here are used for the baseline simulation. From this chapter and hereafter, benefit for FWD projects are divided to two types: FWD1 and FWD2. The FWD1 benefits model is derived from the freshwater diversion project data under CWPPRA program. The FWD2 benefits are derived from the N-SED model (Boustany 2010). A description of each baseline set parameter follows.

Project life time ranges from a low 20 years to a high 50 years with a mean 20 years. Because most of CWPPRA projects are 20 years life time, the base set value for project life time was set at 20 years. For RLB and FWD project, the desired acreages range from 300 acres to 10,000 acres with a mean 1000 acres. The set value for this variable is 1000 acres. As mentioned in a previous section, elevation, depth, and market value of land ($/acre), are not used in the current simulation models. Elevation and depth range from 1.5 to 3.5 with a mean 2.44 and 2.5 to 5.5 with a mean 3.78 by using the North American Vertical Datum of 1988 (NAVD 88) standard, respectively. This research does not collect data for the market value of land, due to the insignificance of this value in the scope of costal restoration cost-benefit analyses. Discount rates were set to range from 0 to 0.15 with a mean 0.04 (Holland et al., 2010, Weitzman 2001). Water flow rate for FWD2 was set up to 1,029 cubic feet per second based on the desired acreage (1000 acre) and input from N-SED model. Mobilization and demobilization (MOB) costs range from a low $110,000 to high $4,000,000, the mean value $1,000,000 is used as the set value in the baseline simulation for RLB projects. Sediment delivery distance ranges from a low 1 mile to a high 50 miles (projected) with a mean 4 miles for RLB projects. For MC projects, access dredging (AD) costs range from 0 to $2,000,000 with the mean $600,000. The average engineer and design period are 4 and 7 years for RLB and FWD projects, respectively. Projected construction costs (CC), E&D costs, and O&M costs were set up to 85%, 15%, and 5% based on the CWPPRA project data, respectively. Hurricane probabilities are not incorporated in the baseline simulation and will be discussed in the following chapter. The average starting ecosystem value (habitat, water quality, and storm surge protection) were set at $249/ acre/year, $825/ acre/year, and $3,336/ acre/year (Costanza 2008, Kazmierczak 2001). The region-specific land loss rate ranges from 0.03% to 0.7% per year (see Table 5.1 for fresh, intermediate, brackish, and saline marshes). A set value of 0.35% per year is used in the base simulation because it is more indicative of the loss rates in brackish and saline marshes. Long-shore sediment transport rate ranged from 0 to 1% per year and was set at zero for BI projects in the baseline simulation. These set values were used for developing the baseline scenario.

Figure 6.1 shows that the highest fully funded project cost (FFC) for the base simulation is the marsh creation project model. At $44,000,000, this method is 1.3 times the FFC of the next highest project type, barrier islands ($33,000,000). Freshwater diversion projects also have a high average FFC, including FWD1 at $26,000,000 and FWD2 projects at $17,000,000. While these FFC estimates are based on a 1000 acre simulation, the freshwater diversion projects do not achieve this level of acreage within the set time period of 20 years. Thus, the cost comparison changes when the actual per unit cost of restored acreage is considered. Figure 6.2 depicts the baseline simulation result of the break-even ESV that would be required for benefits to equal cost in each of these of the four project models. Note that freshwater diversion projects (FWD1 and FWD2) have the highest and the next highest projected costs, with required break-even ESV values at $8,291/acre/year and $5,449/acre/year, respectively. While more expensive on a FFC basis, the other two models (MC and BI) are more cost efficient, with required break-even ESV are at $4,010/acre/year and $2,907/acre/year, respectively.

6.4.4 Simulations under Different Assumptions

Ten different simulations were developed in which a single, user-specified parameter is allowed to vary across its known range, and all other parameters are held constant at the baseline set level described in section 6.4.2. In each simulation the effect of these parameter variations are incorporated into the specified NPV model to determine the required break-even ESV ($/acre/year) for each of the four model types.

- **Scenario 1: Changes in Project Life-Span**

Project life time is allowed to range from 5 years to 50 years at a 5 year interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.4 provides results of this simulation and required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. For all project types, benefits are increasing over time at various rates according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

Table 6.3 User-Specified Value in Baseline simulation NPV Model

User-Specified	Set Value	Range		
		Low	High	Mean
Time period (year)	20	20	50	20
Desired Acreage	1,000	300	10,000	1000
Elevation	2	1.5	3.5	2.44
Depth	4	2.5	5.5	3.78
Discount rate	0.04	0	0.15	0.04
Water Flow Rate- FWD 2 (Boustany 2010)	1,029			1,029
Mob/Demob($)	$1,000,000	$110,000	$4,000,000	$1,000,000
Distance (Miles)	4.00	1	50	4
Access Dredging/Channel ($)	$600,000	$0	$2,000,000	$600,000
E&D Lag (MC)	4	2	7	4
E&D Lag (BI)	4	1	6	4
E&D Lag (FWD)	7	1	30	7
Projected Construction Costs	85%	50%	90%	85%
Projected E&D cost	15%	5%	30%	15%
Projected O&M cost	5%	1%	20%	5%
Market Value of Land ($/acre)	$0			
Hurricane probability (Klotzbach and Gray 2010)	23%	0%	100%	23%
Starting Ecosystem Value (Habitat) $/acre/year	$249	$169	$403	$249
Starting Ecosystem Value (Water Quality) $/acre/year	$825	$3	$5,674	$825
Starting Ecosystem Value (Storm Surge Protection) $/acre/year	$3,336	$101	$20,648	$3,336
Region-Specific Land Loss Rate (Coast 2050)	0.30%	0.03%	0.7%	0.33%
Longshore Sediment Transport rate BI projects only	0	0	0.01	0.008

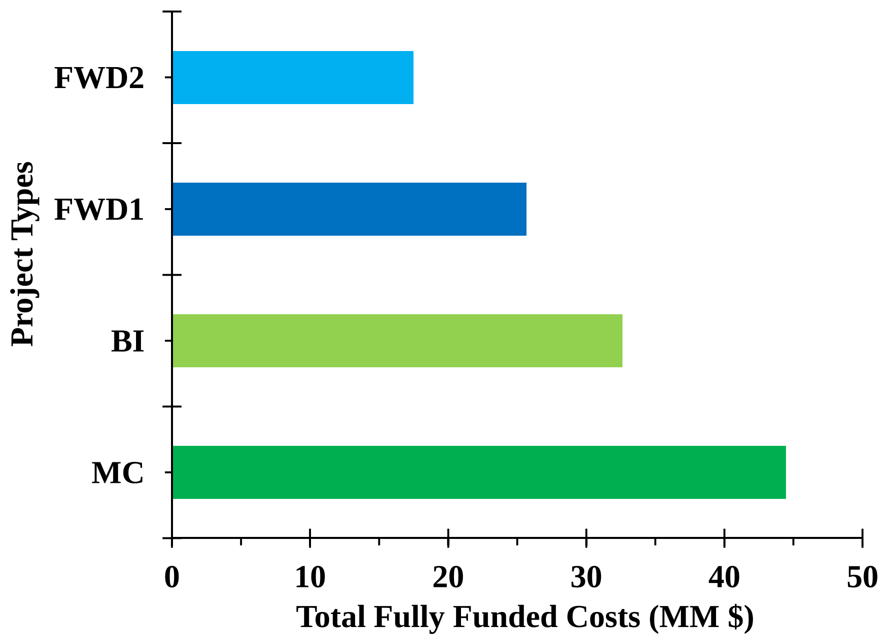


Figure 6.1 Total fully funded costs for RLB and FWD projects

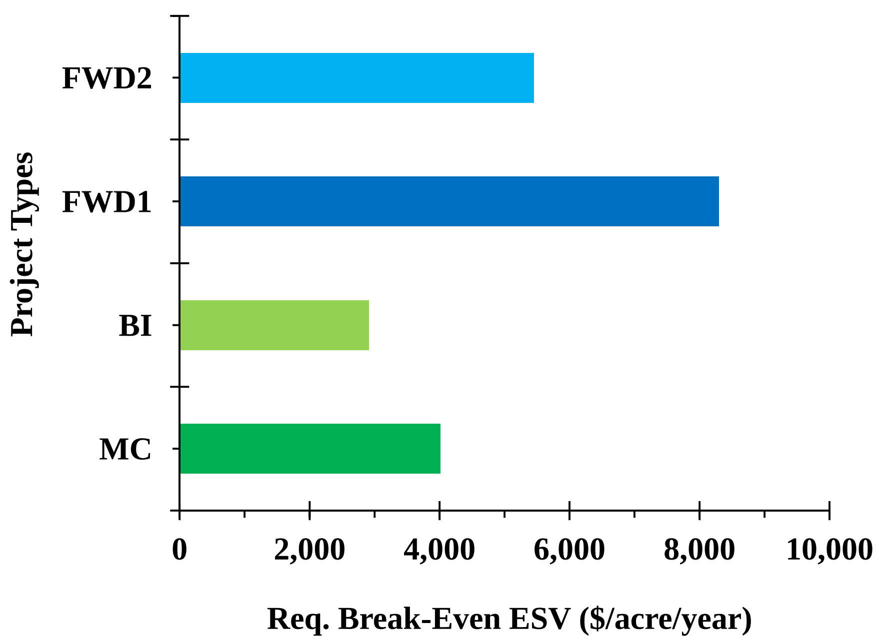


Figure 6.2 Required break-even ESV for RLB and FWD projects

Not surprisingly, the greatest reduction in break-even ESVs comes with freshwater diversion projects (-98%). As more and more benefits accrue with longer project time periods, the FWD1 and FWD2 models eventually converge on the per-unit efficiency of the MC and BI models – somewhere between years 25-35. Figure 6.3 shows these relationships graphically. For all project types, the required break-even ESVs decrease quickly during first 10 years and then decrease more slowly there afterward. The required break-even ESVs are comparatively large for freshwater diversion projects during the typical 20-year life of CWPPRA projects. While diversion-based models eventually converge with the RLB model over time, the simulation shows the importance of time in the cost-benefit decision model.

- **Scenario2: Changes in Desired Acreage**

Project scale (net acreage) is allowed to range from 300 to 10,000 acres at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.5 provides the results of this simulation and the required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. For all project

Table 6.4 Effects of Time on BEV for RLB and FWD Projects

Variable	Time Period	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	10	$9,266	$6,556	$98,462	$62,449
	15	$5,400	$3,888	$18,457	$11,988
	20	$4,010	$2,907	$8,291	$5,449
	25	$3,337	$2,426	$5,011	$3,324
	30	$2,927	$2,132	$3,521	$2,353
	35	$2,661	$1,941	$2,709	$1,823
	40	$2,477	$1,808	$2,214	$1,499
	45	$2,345	$1,713	$1,888	$1,286
	50	$2,247	$1,642	$1,661	$1,138
% Change		-76%	-75%	-98%	-98%

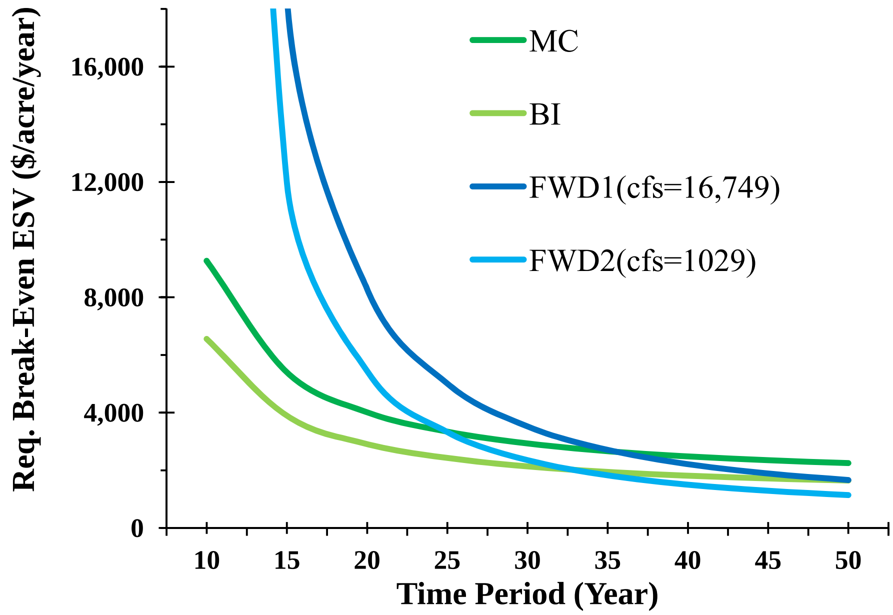


Figure 6.3 Effects of time on BEV for RLB and FWD projects

types, benefits are increasing (ESV's are decreasing) with increasing project scale, according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

It is well known that the more net acres restored, the more benefits accumulated from a given wetland restoration project. For this simulation, the percent change in ESVs for all project types is very large (-91% to -96%) across the set range, indicting economies of scale for project size. However, with the time period set at the CWPPRA baseline level (20 years), the benefits obtained from FWD projects are far less than those of RLB projects at almost all project scales. As seen in Figure 6.4, the FWD2 model only falls below the efficiency of MC projects at high levels of projected acreage (~5,000 acres). The FWD1 model also converges, but at a much slower rate and at the 10,000 acre scale it continues to be more than twice per unit cost of RLB projects. This simulation depicts the importance of project scale on the benefit-cost relationship

Table 6.5 Effects of Scale (Acreage) on BEV for RLB and FWD Projects

Variable	Desired Acreage	MC	BI	FWD1 (cfs=1,296~46,303)	FWD2 (cfs=925~2,064)
Range	300	$10,722	$5,577	$18,955	$15,071
	500	$7,107	$4,393	$13,583	$10,901
	800	$4,829	$3,347	$9,760	$6,811
	1,000	$4,010	$2,906	$8,291	$5,449
	1,500	$2,852	$2,215	$6,112	$3,640
	2,000	$2,234	$1,808	$4,895	$2,734
	3,000	$1,578	$1,344	$3,556	$1,829
	4,000	$1,231	$1,082	$2,822	$1,377
	5,000	$1,014	$911	$2,355	$1,105
	10,000	$553	$527	$1,327	$562
% Change		-95%	-91%	-93%	-96%

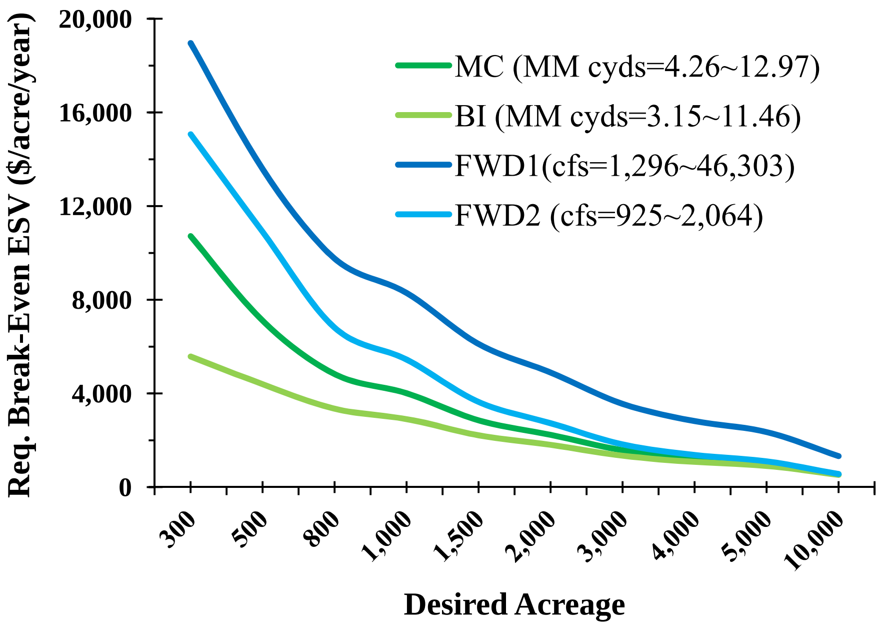


Figure 6.4 Effects of scale on BEV for RLB and FWD projects

of coastal restoration projects in Louisiana. Generally speaking, as project scales increases, differences in methodological efficiency decrease, especially for projects of 5000 acres or greater.

- **Scenario3: Changes in Discount Rate**

Discount rate (%) is allowed to range from 0 to 15% at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.6 provides the results of this simulation and the required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. For all project types, the required break-even ESVs are increasing with increasing discount rates, according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

Table 6.6 depicts the required break-even ESV increase for both of RLB and FWD projects with an increasing discount rate. For this simulation, the percent change in ESVs for all project types is very large (138% to 185%) across the set range, indicting the substantial effect of discounting on project cost and benefits. The required break-even ESVs at the highest discount rate (15%) are more than two times higher than the required break-even ESVs with no discount rate applied (0%). Figure 6.5 shows these effects graphically, with a divergence in model efficiencies for increasing discount rates. As evident from these curves, a higher discount rate usually means a higher time costs, thus the application of any type of project benefit discounting will compound the problems associated with slower restoration methods. To a very large degree, the selection of an appropriate discount rate will have a major impact on the cost-benefit decision analysis for coastal restoration.

Table 6.6 Effects of Discount Rate on BEV for RLB and FWD Projects

Variable	Discount Rate	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	0%	$3,047	$2,203	$6,121	$4,030
	1%	$3,274	$2,369	$6,615	$4,353
	2%	$3,511	$2,542	$7,140	$4,697
	3%	$3,756	$2,721	$7,699	$5,062
	4%	$4,010	$2,906	$8,291	$5,449
	5%	$4,273	$3,098	$8,919	$5,859
	6%	$4,543	$3,295	$9,583	$6,293
	8%	$5,105	$3,704	$11,027	$7,235
	10%	$5,694	$4,133	$12,635	$8,282
	15%	$7,266	$5,272	$17,448	$11,410
% Change		138%	139%	185%	183%

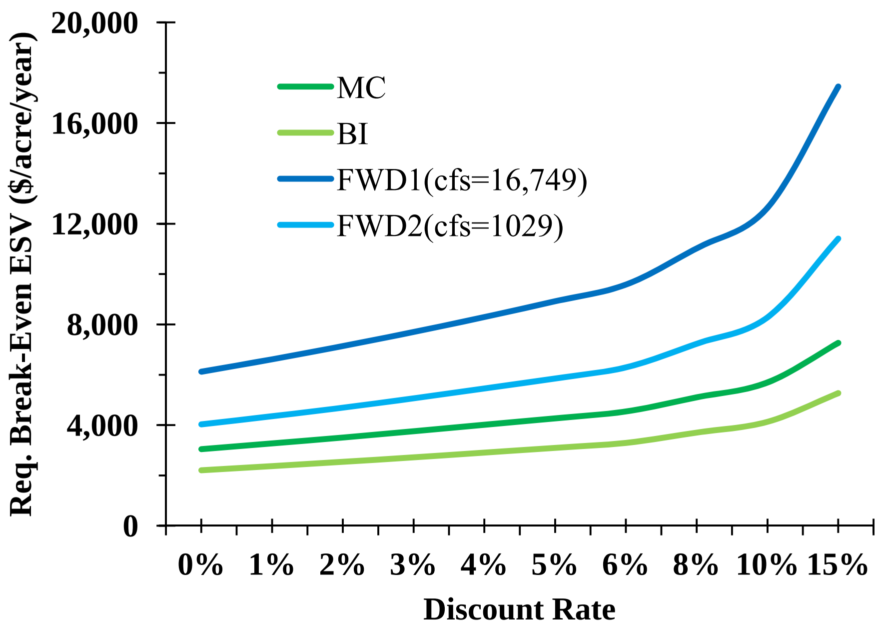


Figure 6.5 Effects of discount rate on BEV for RLB and FWD projects

- **Scenario 4: Changes in Mobilization and Demobilization Costs**

Mobilization and demobilization costs are allowed to range from \$110,000 to \$4,000,000 at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.7 provides results of this simulation and required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. The percentages are zero for both FWD1 and FWD2 models because there are no MOB costs reported on budgets for FWD projects. For RLB project types, ESV break-even costs are increasing with increases in MOB costs according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

For this simulation, the percent change in ESVs caused by increases in MOB across the known range result in 30% and 68% increases in break-even costs of MC and BI projects, respectively. The effect of MOB is most pronounced with BI projects, where the required break-even ESV at the highest MOB costs (\$4,000,000) is almost two times higher than at the lowest MOB cost (\$110,000) for BI project. Figure 6.6 shows these effects graphically. The required break-even ESVs are constant for FWD projects and are increasing, and slightly converging for the RLB projects. This simulation indicates that as a single project cost variable, MOB has a substantial effect on RLB project costs, but it is more sensitive for BI projects due to their relatively lower starting value.

- **Scenario 5: Changes in Distance**

Distances are allowed to range from 1 to 50 miles at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.8 provides results of this simulation and required break-even ESVs at each interval for all four project types.

Table 6.7 Effects of Mobilization/Demobilization Costs on BEV for RLB and FWD Projects

Variable	Mob	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	$110,000	$3,752	$2,516	$8,291	$5,449
	$300,000	$3,807	$2,600	$8,291	$5,449
	$600,000	$3,894	$2,731	$8,291	$5,449
	$800,000	$3,952	$2,819	$8,291	$5,449
	$1,000,000	$4,010	$2,906	$8,291	$5,449
	$1,500,000	$4,156	$3,126	$8,291	$5,449
	$2,000,000	$4,301	$3,345	$8,291	$5,449
	$2,500,000	$4,447	$3,564	$8,291	$5,449
	$3,000,000	$4,592	$3,784	$8,291	$5,449
	$4,000,000	$4,883	$4,222	$8,291	$5,449
% Change		30%	68%	0%	0%

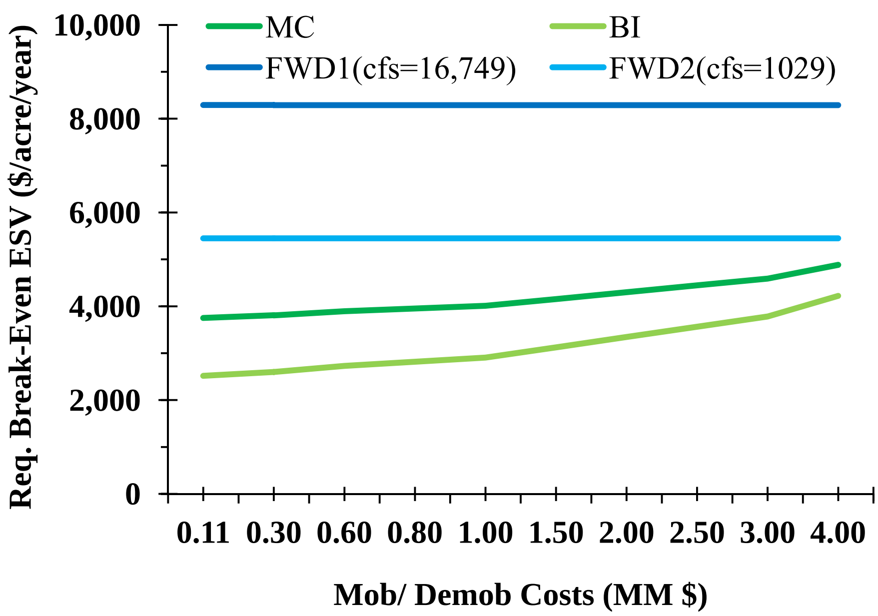


Figure 6.6 Effects of mobilization/demobilization costs on BEV for RLB and FWD projects

The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. These percentages are zero for both FWD1 and FWD2 models because sediments delivery distances do not affect FWD projects. For RLB project types, ESV break-even costs are increasing with increases in distance according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

Table 6.8 depicts the required break-even ESV for RLB projects at increasing distances. For this simulation, the percent increase in ESVs for RLB project types is very large (280%-381%) across the set range, indicting the substantial effect of distance on project cost and benefits. The required break-even ESVs at the longest distance (50 miles) are more than three times higher than the required break-even ESVs at the nearest distance (1 mile) for RLB projects. Figure 6.7 shows these effects graphically. The required break-even ESVs remain constant for FWD projects and with a divergence in model efficiencies for increasing distance for RLB projects. For RLB project types, the required break-even ESVs increase slowly from 1 to 10 miles and then increase more quickly there afterward. To a large degree, the proximity of the sediment borrow site has a major impact on the cost-benefit decision analysis for RLB projects, with costs per unit increasing rapidly beyond 10 miles.

- **Scenario 6: Changes in Access Dredging Costs**

Access dredging costs are allowed to range from \$0 to \$2,000,000 at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.9 provides results of this simulation and required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. The percentages are

Table 6.8 Effects of Distance on BEV for RLB and FWD Projects

Variable	Distance (Miles)	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	1	\$3,252	\$2,482	\$8,291	\$5,449
	2	\$3,505	\$2,623	\$8,291	\$5,449
	3	\$3,758	\$2,765	\$8,291	\$5,449
	4	\$4,010	\$2,906	\$8,291	\$5,449
	6	\$4,516	\$3,190	\$8,291	\$5,449
	8	\$5,021	\$3,473	\$8,291	\$5,449
	10	\$5,527	\$3,756	\$8,291	\$5,449
	20	\$8,054	\$5,172	\$8,291	\$5,449
	30	\$10,581	\$6,587	\$8,291	\$5,449
	50	\$15,635	\$9,419	\$8,291	\$5,449
% Change		381%	280%	0%	0%

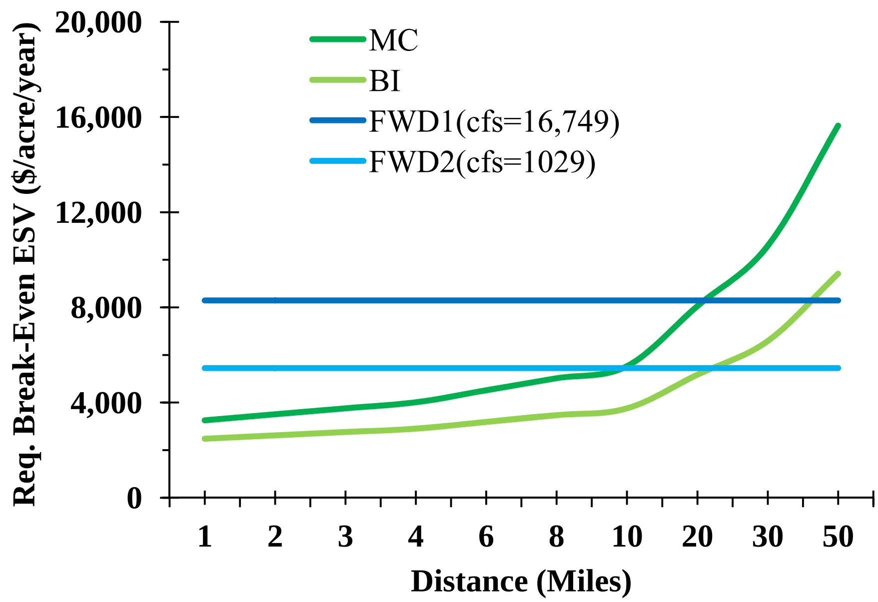


Figure 6.7 Effects of distance on BEV for RLB and FWD projects

zero for BI, FWD1 and FWD2 models because AD costs are not usually reported in cost estimates in these models. For MC project types, the required break-even ESV is increasing with increases in AD costs, according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

For this simulation, the percent change in required ESVs for MC project types is very large (105%) across the set range. The required break-even ESV at the highest AD costs ($2,000,000) is more than two times higher than the required break-even ESV with no AD costs applied ($0) for MC project. Figure 6.8 shows these effects graphically, the required break-even ESVs remain constant for BI and FWD projects and increase quickly for MC projects. This simulation indicates the significant relationship of AD costs in the MC cost model.

- **Scenario 7: Changes in Land Loss Rate**

Land loss rate (%) is allowed to range from 0.03% to 0.7% per year at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.10 provides the results of this simulation and the required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. For all project types, the required break-even ESVs are increasing with increasing land loss rates, according to the benefit and cost models established in Chapters 3 and 4.

Table 6.10 depicts the required break-even ESV increase for both of RLB and FWD projects with an increasing land loss rate. For this simulation, the percent increase in ESVs for all project types is small (5%-6%) across the set range, indicting the relatively weak effect of land loss on project cost and benefits.

Table 6.9 Effects of Access Dredging on BEV for RLB and FWD Projects

Variable	AD	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	$0	$3,048	$2,906	$8,291	$5,449
	$200,000	$3,369	$2,906	$8,291	$5,449
	$400,000	$3,690	$2,906	$8,291	$5,449
	$600,000	$4,010	$2,906	$8,291	$5,449
	$800,000	$4,331	$2,906	$8,291	$5,449
	$1,000,000	$4,652	$2,906	$8,291	$5,449
	$1,200,000	$4,973	$2,906	$8,291	$5,449
	$1,400,000	$5,294	$2,906	$8,291	$5,449
	$1,600,000	$5,615	$2,906	$8,291	$5,449
	$2,000,000	$6,257	$2,906	$8,291	$5,449
% Change		105%	0%	0%	0%

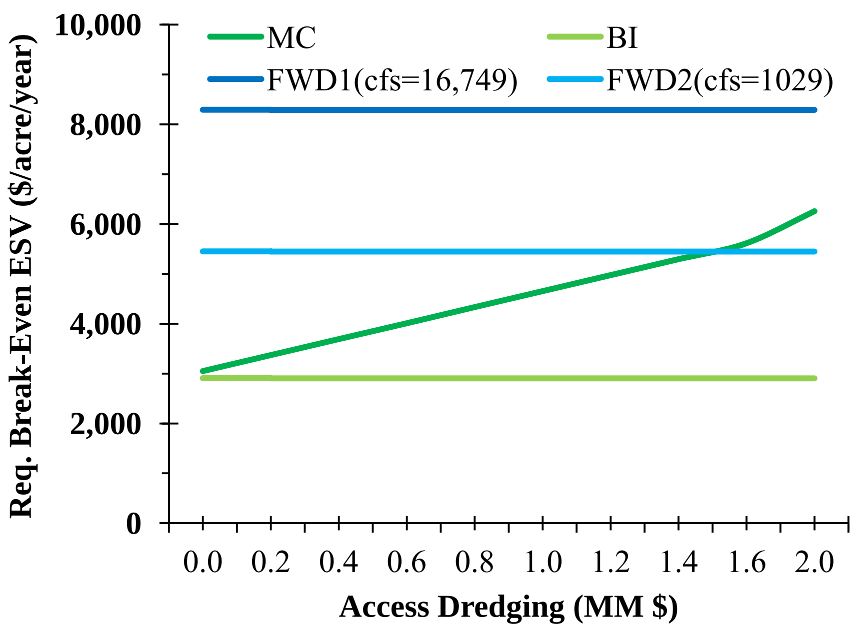


Figure 6.8 Effects of access dredging on BEV for RLB and FWD projects

The required break-even ESVs at the highest land loss rate (0.7%) are only slightly higher than the required break-even ESVs at eh lowest land loss rate (0.03%). Figure 6.9 shows these effects graphically, with gradual reductions in efficiencies at increasing land loss rates. It is surprised that with an increasing land loss rate, there is only a small impact on the on the cost-benefit decision analysis for coastal restoration. Nevertheless, this simulation is based on a 20 year period and currently assumes no natural disaster or human disruption.

- **Scenario 8: Changes in Long-Shore Sedimentation**

Long-shore sediment transport rate (%) is allowed to range from 0 to 1% per year at an increasing interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.11 provides results of this simulation and required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. The percentages do not change for MC, FWD1 and FWD2 models because the long-shore sediment accretion process only occurs for BI project. For BI projects, benefits can actually slightly increasing above the set, 1000 acre level as the long-shore sediment transport rates exceeds the average rate of erosion. These relationships are based on the benefit and cost models established in Chapters 3 and 4 and currently assume no natural disaster or human disruption.

For this simulation, the percent change in ESVs for BI project types is very small (-7%) across the set range. The required break-even ESV with no long-shore transport rate applied (0%) is on slightly higher than the required break-even ESV at the highest long-shore transport rate (1%) for BI projects. Figure 6.10 shows these effects graphically, the required break-even ESVs remaining constant for MC and both FWD projects, and decrease slowly for BI projects as the rate of long-shore transport rate increasing across its known range. This simulation indicates

Table 6.10 Effects of Land Loss Rate on BEV for RLB and FWD Projects

Variable	Land Loss Rate	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	0.03%	$3,926	$2,846	$8,100	$5,325
	0.05%	$3,932	$2,851	$8,114	$5,334
	0.17%	$3,970	$2,877	$8,199	$5,389
	0.20%	$3,979	$2,884	$8,220	$5,403
	0.22%	$3,985	$2,889	$8,234	$5,412
	0.25%	$3,995	$2,895	$8,255	$5,426
	0.30%	$4,010	$2,906	$8,291	$5,449
	0.42%	$4,048	$2,934	$8,377	$5,506
	0.53%	$4,083	$2,958	$8,457	$5,558
	0.70%	$4,138	$2,997	$8,581	$5,639
% Change		5%	5%	6%	6%

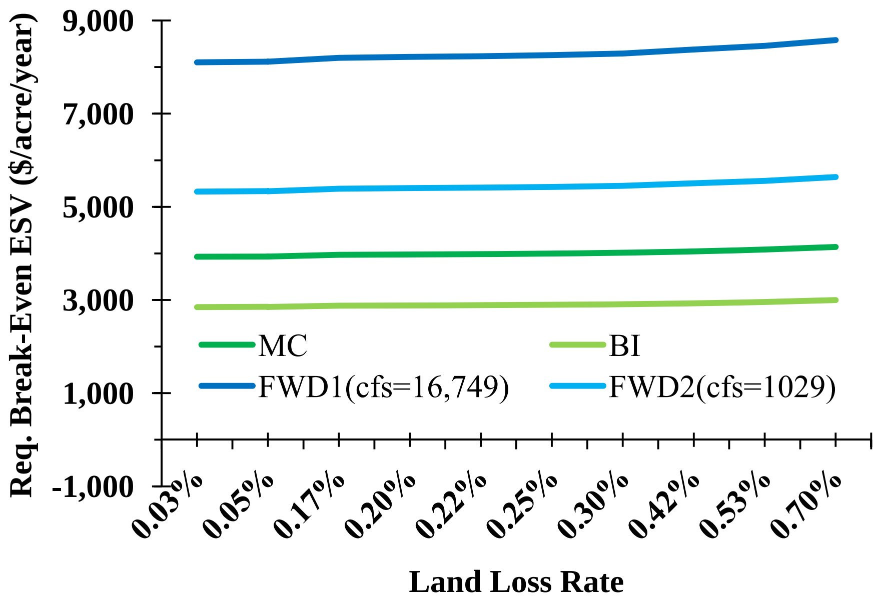


Figure 6.9 Effects of land loss rate on BEV for RLB and FWD projects

that for BI projects, long-shore transport can help to maintain or slightly increase benefits (i.e. reduce cost), as long as it exceeds the average rate of erosion.

- **Scenario 9: Changes in Lag time for RLB and FWD Models**

Project lag time is allowed to range from 1 to 10 years at a 1 year interval, with all other set parameters held constant at the baseline level described in section 6.4.2. Table 6.12 provides the results of this simulation and the required break-even ESVs at each interval for all four project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. For all project types, the required break-even ESVs are increasing with increasing lag times, according to the benefit and cost models established in Chapters 3 and 4. These simulations currently assume no natural disaster or human disruption.

Table 6.12 depicts the required break-even ESV increase for both of RLB and FWD projects with an increasing time lag. For this simulation, the percent reduction in ESVs is large (66%-68%) for RLB projects and very large (138%-185%) for FWD projects across this particular range of lag times. The required break-even ESVs at the longest time lag (10 years) are more than 1.6 and 2.7times higher than the required break-even ESVs at the shortest time lag (1year) for RLB and FWD projects, respectively. Figure 6.11 shows these effects graphically, with a divergence in model efficiencies for increasing time lag. Note that at beyond year 4 the required break-even ESV for FWD2 begins to exceed the required break-even ESV for MC. As evident from these curves, longer delays in construction are more problematic for FWD projects because they are comparatively much slower in generating benefits.

- **Scenario 10: Changes in Lag Time Between FWD1 and FWD2**

The effects of lag-time are important to simulate further, because FWD projects are often

Table 6.11 Effects of Long-Shore Sedimentation on BEV for RLB and FWD Projects

Variable	Long-Shore Trans Rate	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	0%	$4,010	$2,906	$8,291	$5,449
	0.2%	$4,010	$2,862	$8,291	$5,449
	0.3%	$4,010	$2,840	$8,291	$5,449
	0.4%	$4,010	$2,862	$8,291	$5,449
	0.5%	$4,010	$2,884	$8,291	$5,449
	0.6%	$4,010	$2,774	$8,291	$5,449
	0.7%	$4,010	$2,753	$8,291	$5,449
	0.8%	$4,010	$2,731	$8,291	$5,449
	0.9%	$4,010	$2,710	$8,291	$5,449
	1.0%	$4,010	$2,689	$8,291	$5,449
% Change		0%	-7%	0%	0%

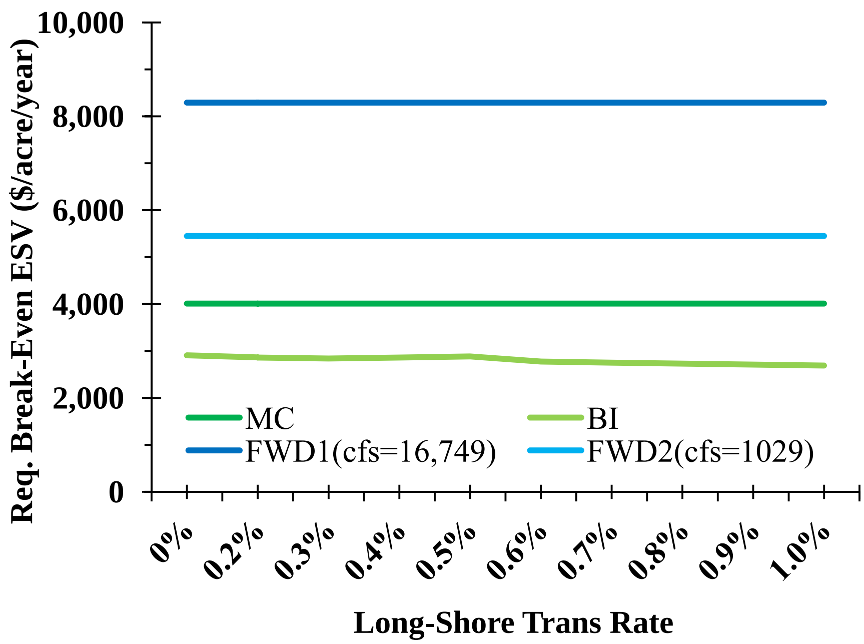


Figure 6.10 Effects of Lang-shore sediment transport rate on BEV for RLB and FWD projects

very controversial and can be delayed for many years due to public concerns over flooding and changes in salinity (see section 5.4). Outside of CWPPRA, the time lag time for FWD has been as high as 30 to 40 years between authorization and construction for projects like Caernarvon and Davis Pond. In this simulation, project lag is allowed to vary for FWD projects only and ranged from 1 to 20 years at a set interval, with other set parameters held constant at the baseline level described in section 6.4.2. Table 6.13 provides the results of this simulation and the required break-even ESVs at each interval for FWD project types. The percentages at the bottom of the table (% Change) depict the overall change in the starting and ending ESVs across the simulated range. For FWD project types, the required break-even ESVs increases dramatically over the set range, according to the benefit and cost models established in Chapters 3 and 4.

Table 6.13 depicts the required break-even ESV increase for both of FWD1 and FWD2 projects with an increasing time lag. For this simulation, the percent reduction in ESVs for RLB is huge (7139%-7737%) for FWD projects across the set range, indicting the tremendously high degree of influence that time lag has on both project cost and benefits. The required break-even ESVs at the longest time lag (20 years) are more than 70 times higher than the required break-even ESVs at the shortest time lag (1year) FWD projects. Figure 6.12 shows these effects graphically, with sharp increases beyond 10 years. For example, in a 20 year lag, no benefits have accrued, yet planning and engineering expenditures (overhead) have already been made - usually within the in the first few years. In this scenario, break-even ESVs tends to infinity with ever-increasing time lags and at a minimum would far exceed the ranges reported for ESVs in the non-market valuation literature.

Table 6.12 Effects of Lag Time on BEV for RLB and FWD Projects

Variable	Time Lag	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	1	$3,521	$2,558	$4,537	$3,014
	2	$3,665	$2,660	$4,930	$3,270
	3	$3,827	$2,776	$5,389	$3,568
	4	$4,010	$2,906	$5,929	$3,919
	5	$4,219	$3,055	$6,762	$4,336
	6	$4,459	$3,225	$7,522	$4,838
	7	$4,738	$3,423	$8,291	$5,449
	8	$5,065	$3,654	$9,462	$6,206
	9	$5,454	$3,928	$10,940	$7,160
	10	$5,925	$4,258	$12,844	$8,387
% Change		68%	66%	183%	178%

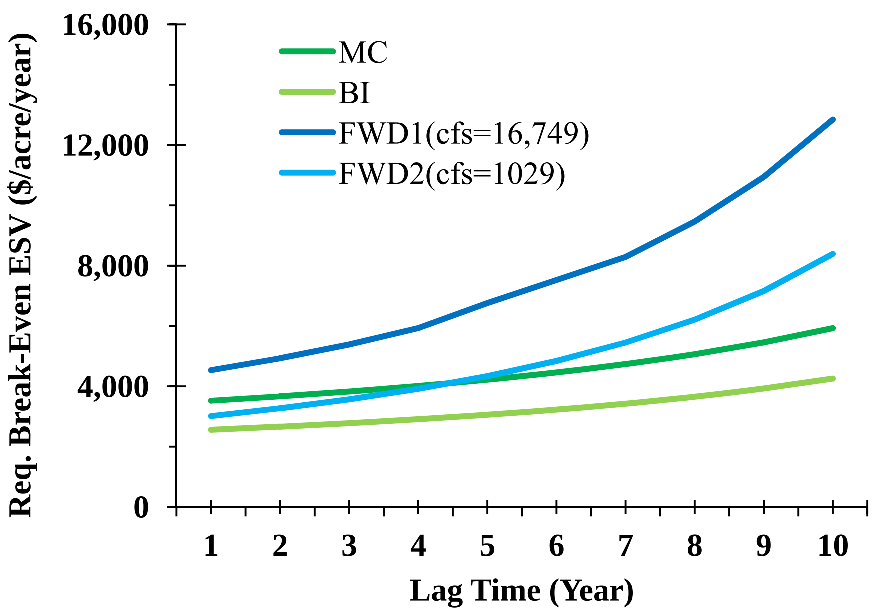


Figure 6.11 Effects of lag time on BEV for RLB and FWD projects

Table 6.13 Effects of Time on BEV for FWD Projects

Variable	Time Lag (FWD 1~20)	MC	BI	FWD1 (cfs=16,749)	FWD2 (cfs=1029)
Range	1	$4,010	$2,906	$4,537	$3,014
	3	$4,010	$2,906	$5,389	$3,568
	5	$4,010	$2,906	$6,762	$4,336
	7	$4,010	$2,906	$8,291	$5,449
	9	$4,010	$2,906	$10,940	$7,160
	10	$4,010	$2,906	$12,844	$8,387
	13	$4,010	$2,906	$23,662	$15,322
	16	$4,010	$2,906	$62,437	$39,894
	19	$4,010	$2,906	$355,548	$218,187
	20	$4,010	$2,906	$355,548	$218,187
% Change		0%	0%	7737%	7139%

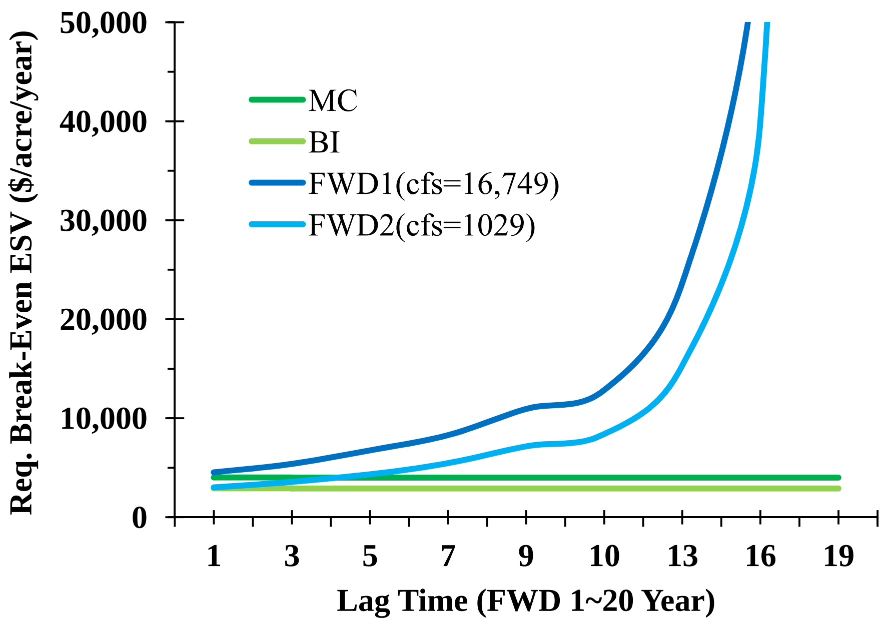


Figure 6.12 Effects of lag time on BEV for FWD projects

6.5 Summary

In this chapter, methods and estimates for the non-market, ecosystem service values (ESV) of wetlands have been discussed and identified. Starting values for estimates were incorporated into a mathematical NPV model along with 22 other user-specified set values to develop baseline cost-benefit simulations for two RLB models (MC and BI) and two freshwater diversion models (FWD1 and FWD2. Simulations against this baseline were conducted by allowing a single, user-specified parameter to vary across its known range and generating the required break-even ESV ($/acre/year) for each simulation. In the vast majority of these simulations, the required ESV is considerably higher than the range of values reported in the non-market valuation literature.

As found in chapters 3, 4, and 5, project life time, scale, discount rate, and time lag have a major impact on the cost-benefit decision analysis for coastal restoration. The MOB costs were founded more sensitive for BI projects than MC projects. For a RLB project, the distance between sediments borrow site and project site will have a major impact on the cost-benefit decision analysis. The cost of AD is not an important fact for BI and FWD projects, but it is significant on MC projects cost and benefits analysis. The long-shore transport rate has a very small effect on BI projects cost and benefits only. Finally, time lag was found to have a very import impact on the cost-benefit decision analysis for all models, especially FWD projects.

Surprisingly, the rate of land loss had only a small impact the cost-benefit relationship for RLB and FWD projects. This indicates that average land loss rates are usually too small to affect the costs and benefits of a wetland restoration project; however, these simulations assume no natural disaster or human disruption. Therefore, uncertainty should be considered and the probabilities of hurricane occurrence should be incorporated into the NPV models. Once the probabilities of hurricane landfall have been identified and incorporated into these models, a more reliable result will be obtained from these simulations. The following chapter will introduce and explore this uncertainty.

CHAPTER 7 INCORPORATING UNCERTAINTY

7.1 Introduction

So far in this study, net present value (NPV) analysis has primarily focused on conditions in which the user-controlled set values affecting the simulated outcomes have been assumed to be known with certainty. In most cases, however, comparisons of wetland restoration alternatives using the NPV method are developed with a consideration of uncertainty. This can be accomplished through a variety of climatological, political, and ecological factors that influence project costs and benefits.

7.2 Risk and Uncertainty

While the terms "risk" and "uncertainty" are often used interchangeably, the terms have many different definitions and applications and there is no single consistent method for their incorporation into decision-making. Knight (1921) introduced the definitional difference between risk and uncertainty by pointing out that risk has an unknown outcome, but the likelihood distribution of that outcome can be calculated. In contrast, "uncertainty" refers to the case in which the likelihood distribution of an outcome cannot be expressed in terms of mathematical probability. Hubbard (2007, 2009) defines risk as a state of uncertainty where some possible outcomes have an undesired effect or significant loss. And Jones (2006) defines risk as the probable frequency and magnitude of future loss. In economic terms, this can refer to a decline in income due to losses resulting from a natural hazard.

Many uncertainties are faced when deciding to fund a restoration project. In regards to hurricanes, managers need information on the frequency and impact of these storms on coastal restoration projects. Specific questions include: What is the statistical probability of a major hurricane making landfall in the project area?; How would such a storm affect the benefits and costs of the project?; and, How can this risk and impact be incorporated into the NPV analysis of the project? Political constraints might delay a wetland restoration project, cut the project budget, or constrain its operation. Ecological factors might also impose risk by constraining optimal plant growth or through changes in water quality. Without incorporating these risks, comparisons based on NPV methods might provide misleading results. This section primarily explores hurricane risk, how to incorporate that risk into the NPV method, and the impacts of hurricanes on a given project type and location. This information is used to revisit the estimates of required break-even ecosystem services value (ESV) for RLB and FWD projects under the situation of hurricane landfall. Meanwhile, political and ecological risks are discussed.

7.3 Hurricane Risk

From a climatological perspective, risk can be expressed as the likelihood of hurricane landfall, which would alter the benefits and costs of a wetland restoration project. The probability of a hurricane in any given year would range from 0 to 1 (0% to 100%) during the project life period. For the purpose of NPV analysis, however, probabilities are rarely based strictly on historical information. The adjusted currently available information is taken into account and referred to as subjective probabilities of hurricane landfall. Once the probabilities of hurricane landfall have been characterized and quantified, this information may be introduced into NPV analysis. Klotzbach and Gray (2011) report that the annual probabilities of major storm (i.e. Category 3 or greater) making landfall in Louisiana are 12% and 20% for climatological and current-year probabilities, respectively. In their research, these storms are defined in two categories: hurricanes (75mph $\leq$ winds <115) and intense hurricane (major hurricane winds $\geq$115 mph). To simplify the analysis of major hurricane landfall risk, this study adopts the current-year probability and assumes that this probability is the same each year during the project life time. Meanwhile, this research assumes that there are two different situations that will be denoted as Risk1 and Risk2. Risk1 refers to a hurricane impact (percent acreage loss) for the project that is static or averaged over the life of the project. Risk2 refer to a percent acreage loss that varies annually according to the degree of project completion.

Table 7.1 depicts the probabilities of hurricane landfall in five coastal states: Texas, Louisiana, Mississippi, Alabama, and Florida. The annual probability of hurricane landfall ranges from a low of 11% to a high 51% and a low of 18% to a high 72% for climatological and current-year probability, respectively. The annual probability of from a major hurricane ranges from a low of 3% to a high 21% and a low of 5% to a high 35% for climatological and current-year probability, respectively. Table 7.2 depicts the probabilities of hurricane landfall for 18 coastal parishes in Louisiana. The range of probability of 1 or more hurricanes making landfall in the parish are from a low 1% to a high 10% and the range of probability of 1 or more major hurricanes making landfall in the parish are from a low 1% to a high 5%.

7.3.1 NPV Models with Hurricane Risk

The basic framework for incorporating risk to be used in this study will be Expected Value (EV) analysis. This process involves identifying the probability of specific outcomes and incorporating that probability into the NPV process. Holland (2010) describes this incorporation as:

$$
\begin{aligned}
E[NB] &= \sum_{t=1}^{T} (B_t - C_t) * P_t \\
&= (B_1 - C_1)P_1 + (B_2 - C_2)P_2 + \ldots + (B_t - C_t)P_t
\end{aligned}
\quad \text{(Eq. 7.1)}
$$

Table 7.1 Probabilities of Hurricane Landfall in Five Coastal States

State	Climatological Probability		Current-Year Probability	
	H	MH	H	MH
Texas	33%	12%	51%	20%
Louisiana	30%	12%	48%	20%
Mississippi	11%	4%	18%	8%
Alabama	16%	3%	26%	5%
Florida	51%	21%	72%	35%

Source from United States Landfall Probability Webpage by Philip Klotzbach and William Gray (2011)

Table 7.2 Probabilities of Hurricane Landfall at Coastal Parishes in Louisiana

Parish	Probability of 1 or More Hurricanes Making Landfall in the Parish	Probability of 1 or More Intense Hurricanes Making Landfall in the Parish
Cameron	7%	2%
Vermilion	3%	1%
Calcasieu	4%	1%
Iberia	4%	2%
St. Mary	5%	2%
St. Martin	4%	2%
Terrebonne	10%	5%
Lafourche	4%	2%
Assumption	3%	1%
St. John the Baptist	1%	1%
St. Charles	3%	1%
Ascension	3%	1%
Livingston	2%	2%
Tangipahoa	1%	1%
Jefferson	2%	2%
Plaquemines	5%	4%
St. Bernard	5%	4%
Orleans	4%	3%
St. Tammany	5%	4%

Source from United States Landfall Probability Webpage by Philip Klotzbach and William Gray (2011) where *E[NB]* is the expected net benefits of a given project. The *t* stands for a given year within a particular time period *T*. B_t and C_t represent discounted benefits and costs of a wetland restoration project, respectively, in the year *t*, and P_t is the probability of a risk contingency *i* occurring in the year *t*. The sum of probabilities is equal to 1.

7.3.1.1 Hurricane Risk 1 Scenario

This study utilizes the basic EV model to incorporate the probability of a major hurricane (P_t) and its simulated effects on the acreage (B_t) of a given restoration project. Table 7.3 depicts a simulated percent acreage loss with a major hurricane under the *Risk 1* scenario. In this situation, the percentage of land loss (X_H) is assumed to be constant across time, with static impacts occurring during the project life time. The annual probability (P_1) of major storm hitting the coast of Louisiana is 20 percent and the inverse probability of no major storm is 80 percent ($1-P_1$) (Klotzbach and Gray 2011).

Table 7.3 Percent Acreage Loss fixed with a Major Hurricane (Risk1)

Variables	Percentage	Description
P_1	20%	Annual probability of major storm
$P_2=1-P_1$	80%	Annual probability of no major storm
X_H	25%	Static land loss with a major hurricane

Under this scenario, the benefits of a wetland restoration project under situation of *Risk1* are given by the function:

$$E[V_1] = \sum_{t=1}^{20} \left[P_1 * \left(NA_t * (1 - X_H) \right) + P_2 * NA_t \right] * ESV * \frac{1}{(1+R)^t} \qquad \text{(Eq. 7.2)}$$

where $E[V_1]$ is the expected benefits of the wetland restoration project. The *t* stands for the number of years (ranging from 1 to 20 for CWPPRA projects). The P_1 is the annual probability of major storm and $P_2 = (1\text{-}P_1)$, which stands for the annual probability of no major storm. NA_t is a user specified variable referring to the desired net acreage gain from the project in year *t*. X_H stands for the percent acreage loss expected with a major hurricane. The acronym *ESV* stands for the annual non-market, ecosystem values for each acre restored. *R* is the discount rate.

7.3.1.2 Hurricane Risk 2 Scenario

Table 7.4 depicts the simulated percent acreage loss with a major hurricane under the *Risk 2* scenario. In this situation, X_H is allowed to vary per year as a function of the percent completion of a given wetland restoration project. The annual probability of a major storm (coast-wide) is set at 20 percent and the annual probability of no major storm is 80 percent (Klotzbach and Gray 2011). To capture an element of resiliency/vulnerability, a sliding scale is introduced in which the simulated percent acreage loss is higher/lower for projects that are less/more completed. For example, an 80% reduction in acreage might occur from an major hurricane if the given project's percent completion was less than or equal to 20% in time period *t*; The percent acreage loss is set at 60% for a major hurricane if completion is less than 40% in time period *t*. The percent acreage loss is set at 40% if project is less than or equal to 60% complete in time period *t*. And finally, the percent acreage loss is set at 20% if project is than or equal to 80% complete in time period *t*.

Table 7.4 Percent Acreage Loss Varies with a Major Hurricane (Risk2)

Variables	Percentage	Description
P_1	20%	Annual probability of major storm
P_2=1-P_1	80%	Annual probability of no major storm
Simulated Impacts		
X_{H1}	80%	If project completion≤20%
X_{H2}	60%	If project completion≤40%
X_{H3}	40%	If project completion≤60%
X_{H4}	20%	If project completion≤80%

Benefits for wetland restoration project under situation of *Risk2* scenario are given by the function:

$$E[V_2] = \sum_{t=1}^{20} \left[P_1 * \left(NA_t * \left(1 - X_{HN} \right) \right) + P_2 * NA_t \right] * ESV * \frac{1}{\left(1 + R \right)^t} \qquad \text{(Eq. 7.3)}$$

where $E[V_2]$ is the expected benefits of the wetland restoration project. The t stands for the number of years (ranging from 1 to 20 for CWPPRA projects). The P_1 is the annual probability of major storm and $P_2 = (1-P_1)$, which stands for the annual probability of no major storm. NA_t is a user specified variable referring to the desired net acreage gain from the project in year t. X_{HN} (N=1, 2, 3, 4) stands for the percent acreage loss with a major hurricane and varies per year as a function of percent completion of a given wetland restoration project. The acronym *ESV* stands for the annual non-market, ecosystem values for each acre restored. R is the discount rate.

7.3.2 Depicting Hurricane Risk Impacts on Wetland Restoration Projects

After examining and incorporating hurricane risk for these projects, benefits were re-calculated based on NPV models. Figure 7.3 depicts effects of erosion and simulated hurricane risk on net acres for RLB and FWD projects. As described in Chapter 3, with an average four year delay of project construction, MC projects follow a sigmoid trajectory. Net acres are static in year 4, followed by a rapid accrual of acreage in years 4-6, with most of the land gain occurring in years 5 and 6. From year 6 to year 20, net acreage is either constant or slightly decreasing (because of erosion) given a no hurricane scenario. Under hurricane scenarios of Risk 1 (constant impacts) and Risk 2 (scaled impacts), MC projects would still follow a sigmoid trajectory but with reduced levels of benefits. Projected benefits (net acres) would be the least under the Risk 1 scenario because of the constant (equal) probability of land loss across the project life time. Conversely, the benefits under the Risk 2 scenario would be slightly higher because of the varying probability of land loss due to the scaled impact related to project completion. Likewise, with an average four years delay of project construction, BI projects initially follow a similar sigmoidal trend. Net acres are mechanically restored over a short time period, and then are either constant or slowly decreasing under in the absence of hurricanes. Under hurricane Risk 1and Risk 2 scenarios, BI projects follow the same general sigmoid trends as the MC projects and benefits (net acre) are the lowest under Risk 1 scenario.

Figure 7.1 also depicts the effects of erosion and simulated hurricane risk on net acre accrual for FWD 1 and FWD2 projects. As described in Chapter 3, the average FWD project has an average seven year lag prior to construction and benefits follow a linear trajectory. Net acreages increase at a slow, constant rate over a 20-year time span in a no hurricane scenario. Unlike with MC and BI projects, hurricane-based acreage reductions for FWD projects are assumed to be greater in the Risk 2 scenario because of the slow rate of benefit accrual with FWD projects. This effect is partially evident in the documented impacts to the Caernarvon freshwater diversion project, which was heavily impacted by Hurricane Katrina in 2005. The effects of Katrina on Caernarvon have greatly expanded the range of thinking about coastal restoration options under hurricane risk (Zinn 2007).

7.4 Refining Risk Assumptions

While the landfall probabilities of a major hurricane are easily extracted from climatological studies, the degree of impact from these storms on a coastal restoration project is less predictable. At a minimum, the impact is expected to be a function of scale, location, and project type. How big a project is, its proximity to the coast, and whether it is a FWD or RLB project are all factors that have an influence on hurricane vulnerability. Additionally, other forms of risk to coastal restoration projects exist – such social and mechanical constraints.

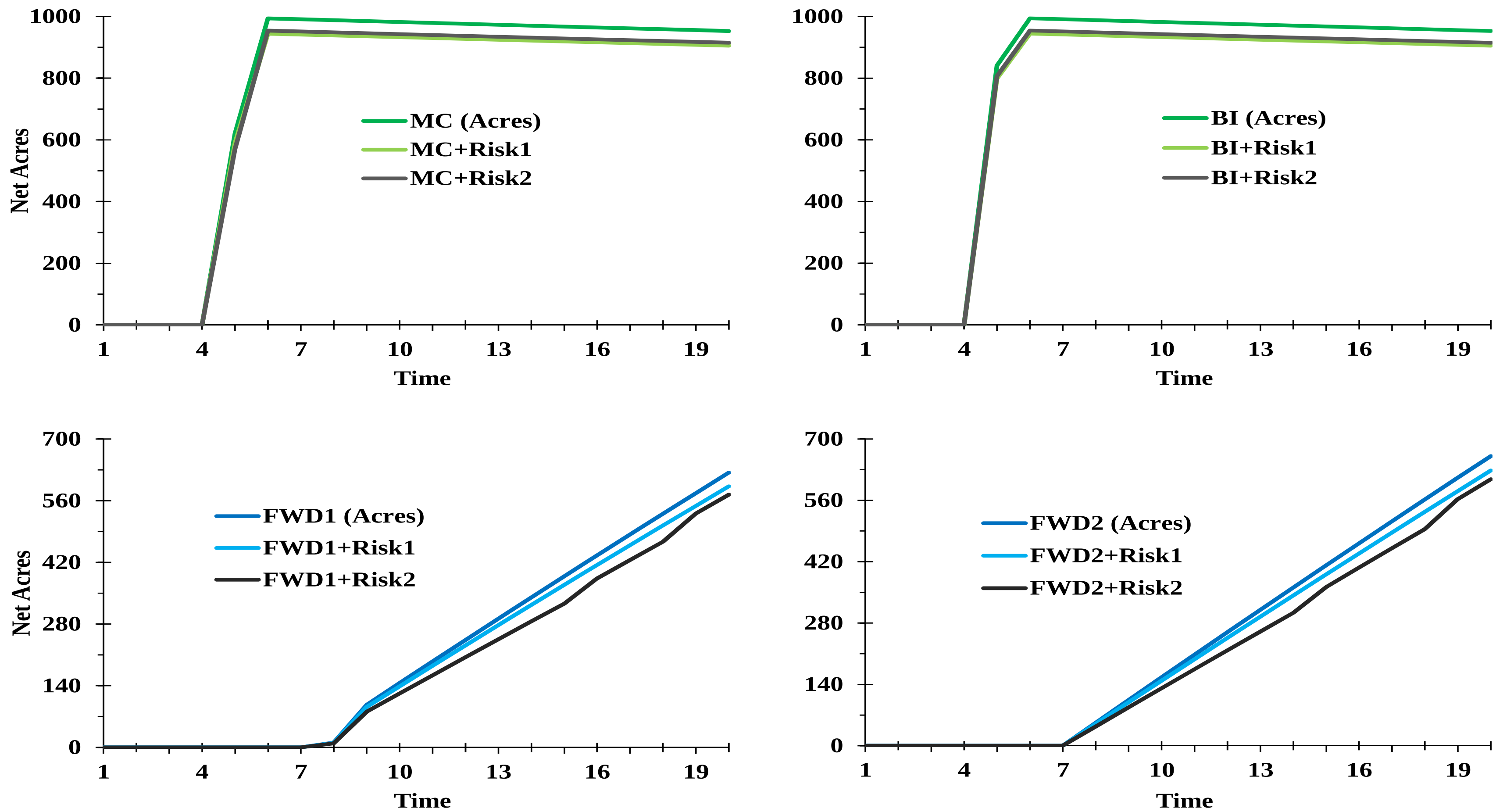


Figure 7.1 Effects of erosion and risk on net acres for RLB and FWD project

7.4.1 Scaling Hurricane Impacts

On August 29, 2005 Hurricane Katrina struck the northern Gulf Coast as a category 4 storm with 140 mph winds and caused adverse effects on the wetlands being created at the Caernarvon Freshwater Diversion restoration project. Salinities and water levels were dramatically impacted by the storm with devastating effects on the marshes in Breton Sound. Just three weeks later, on September 24, 2005 Hurricane Rita made landfall near Sabine Pass at the Louisiana-Texas border as a category 3 storm with 120-140 mph winds. The storm impacted the Holly Beach Sand Management Project, a RLB project completed in 2002.

These two projects can be used to demonstrate a process through which the impacts of hurricanes to restoration projects can be further refined. In order to scale the effect of hurricane impacts on these two typical projects, a land change analysis was undertaken through the use of Geographic Information Systems (GIS) lab of the Department of Agricultural Economics at Louisiana State University. The degree of acreage effect at Caernarvon and Holly Beach can be estimated using pre- and post-storm imagery. Project specific impacts (i.e. adjusting X_H under the Risk2 scenario) were refined for these two storms and two projects using Earth Resource Data Analysis System (ERDAS) software (version 10.1). Digital Orthoimagery Quarter Quadrangles (DOQQ) images from pre- and post-landfall of Hurricanes Katrina and Rita acquired from the U.S.Geological Survey (USGS).

Table 7.5 depicts that the calculated project area of the Caernarvon Freshwater Diversion outfall area in Breton Sound, comprising approximately 690,759 acres, of which 443,340 acres are classified as water and 247,419 acres were classified as land in 2005 before Hurricane Katrina. The water area increased to 481,893 acres and the land area decreased to 208,866 acres in 2006 after Hurricane Katrina. An approximately 38,553 acres of coastal land was converted to open water, which represents a 15 percent land change in the wake of Hurricane Katrina. Figure 7.2 shows the land change before and after the storm. This loss is somewhat comparable to estimates from the published literature on the effects of Katrina and the Caernarvon Freshwater Diversion project. O'Brien and Matrinez (2008) estimated a 35,839 acre loss, which equates to a 14% reduction in surface acreage to the wetlands of the Caernarvon outfall area in Breton Sound. Likewise, Zinn (2007) and USACE (2007) estimated acreage losses of 25,000 and 25,983, equating to a 10 percent and 11 percent loss, respectively.

Table 7.6 depicts the calculated project area of the Holly Beach Sand Management project, comprised of approximately 10,850 acres, of which 1,494 acres were classified as water area and 9,356 acres were classified as land area in 2005 prior to Hurricane Rita. The water area increased to 1,701 acres and the land area decreased to 9,149 acres in 2006 after Hurricane Rita. An approximately 207 acres land was converted to open water, which equates to a 2.2 percent land change after Hurricane Rita. Figure 7.3 shows the land change before and after this Hurricane. Only human-made features remained after this storm and the mean horizontal shoreline change was -58.7 ft along the 1.5 mile stretch of the project (Stockdon et al., 2007). These two examples demonstrate how the impacts of a major hurricane landfall can be scaled using actual project data. In these cases, a major hurricane landfall results is an approximately ten percent to an approximately fifteen percent land convert to open water for RLB and FWD project, respectively. Additional factors that affect vulnerability and degree of impact in include project location. The more inland a project is located, the lower the degree of vulnerability. This assumption could also be tested by case study analysis using the same project type in different locations.

Table 7.5 Caernarvon Freshwater Diversion Project Land Change Pre and Post Hurricane Katrina

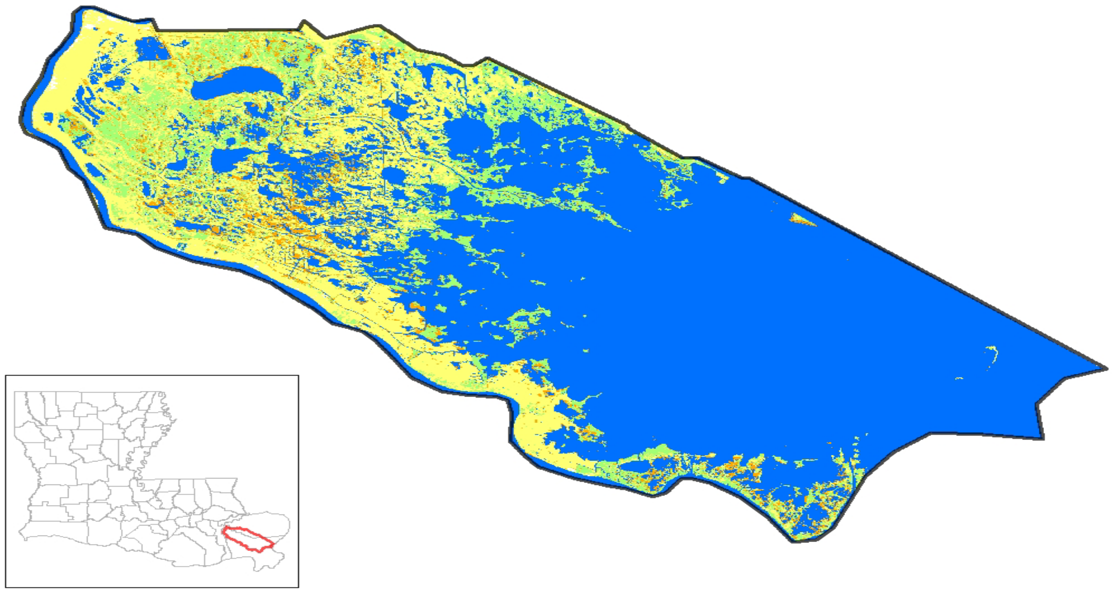
	2005 (March-April)	2006 (June)
Total Area (acre)	690,759	690,759
Water Acreage	443,340	481,893
Land Acreage	247,419	208,866
Land Loss after Hurricane Katrina (acre)		38,553
Percentage of Land Loss		15%

Table 7.6 Holly Beach Sand Management Project Land Change Pre and Post Hurricane Rita

	2005 (April)	2006 (June)
Total Area (acre)	10,850	10,850
Water Acreage	1,494	1,701
Land Acreage	9,356	9,149
Land Loss after Hurricane Rita (acre)		207
Percentage of Land Loss		2.2%

7.4.2 Adjusting for Political Risk

From a social perspective, risk can also be expressed as the likelihood of political constraints, which would alter the benefits and costs of a wetland restoration project. The probability of political constraints is not typically calculated, as with hurricane frequencies, and it must be estimated based using case-specific historical information. As discussed in Chapters 2 and 3, project construction is, on average, delayed by four years and seven years for RLB and FWD projects, respectively. Some of this lag is due to political and social constraints. These lag effects were incorporated and simulated into the NPV model in chapters 5 and 6. For FWD projects, however, project operation can also be fraught with social constraints. The following two cases illustrate particular constraints associated with FWD projects.



2005

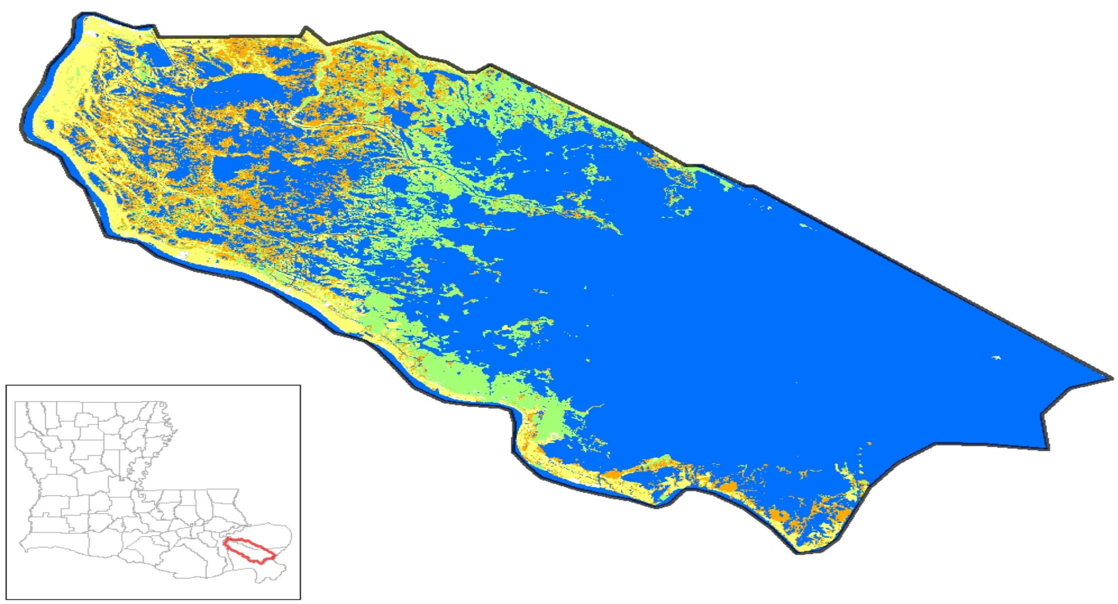


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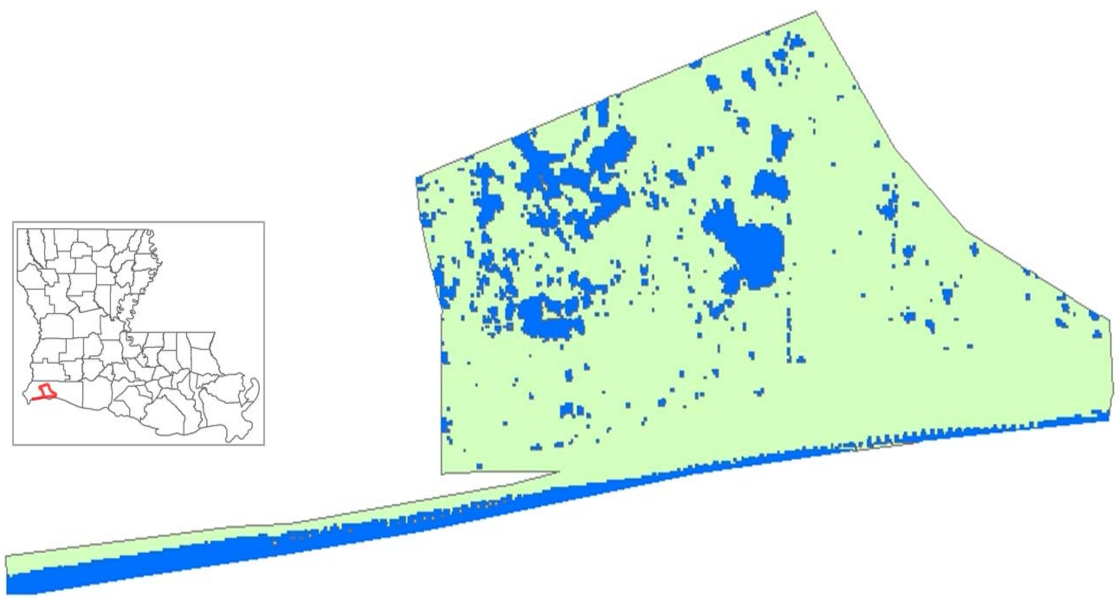
Figure 7.2 Classified Image of Caernarvon Freshwater Diversion Project Pre-Post Hurricane Katrina

2005



2006

Figure 7.3 Landsat Image of Holly Beach Sand Management Project Pre-Post Hurricane Rita

The Caernarvon Freshwater Diversion Project was authorized by the U.S. Congress under the Flood Control Act of 1965 and the Water Resources Development Act of 1974, 1986, and 1996. The project was constructed between 1988 and 1991 and began operations in August 1991. From initial project authorization to construction, this project had a lag of 26 years. The structure is designed to divert up to 8,000 cubic feet per second (cfs) of freshwater from the Mississippi river into the marshes and bays of the Breton Sound estuary. Since opening, flow rates for the Caernarvon project have been curtailed by a number of constraints related primarily to short-term fisheries impacts (Caffey and Schexnayder 2003). Soon after opening 1991, oyster fishermen argued that this diversion project damaged many of the oyster beds and filed law suit against the state. This law suit led to $2.3 billion in judgments that threatened the ability to conduct future wetland restoration projects in Louisiana. To deal with these problems and combat the high rate of coastal wetlands loss in Louisiana, the 2003 Louisiana legislature passed three constitutional amendments through referendum, which were intended to remove these constraints and increase the state's capacity for coastal wetland restoration. These amendments limited the state's liability to compensate property damage caused by coastal restoration projects. The value of operational losses was limited to the fair market value of affected property (Caffey and Schexnayder 2003). In addition to the oyster industry, a number of other stakeholders have requested reduced flow rates for the Caernarvon structure. Shrimp fishermen, crab harvesters, land owners, recreational fishermen and hunters, and navigation interests have all served on the interagency advisory committees that controls the structures flow rate.

Due to all of these constraints, the 14 year (1991-2005) average operational discharge for the project has been relatively low. Although the structure has been opened to 6,500 cfs for short term periods during a "pulsing" study conducted by Louisiana State University, the long-term average discharge of Caernarvon has been only 23% (1,840 cfs) of its designed capacity (OCPR 2006). Table 7.7 depicts the annual flow rate and percent maximum capacity of this project from 2001 to 2010 water year.[25] Even with the amendments passed in 2003, the discharge of the Caernarvon project remains constrained by social and political factors. The flow rates range from a low of 1,325 cfs to a high of 3,160 cfs with an average flow rate at 1,969 cfs. The percent capacity ranges from 17 to 40 with a mean 25 percent. These records are partial[26] evidence of the social constraints to using freshwater diversions for coastal restoration in Louisiana. As can be seen in Figure 7.4, Caernarvon's yearly discharge has been fairly consistent from 2001 to 2005. This structure has not exceeded 50% of the maximum capacity (8,000 cfs) during this period. The 10-year (2001-2010) average discharge is 1,969 cfs, which is only 25 percent of the designed capacity.

The Davis Pond Freshwater Diversion project was authorized by the U. S. Congress in 1965 and the Water Resources Development Act of 1974, 1986 and 1996. It was constructed between 1997 and 2002 and began operations in July 2002. From project authorization to structure completion, this project had construction lag of 38 years. This project is designed to re-introduce up to 10,600 cfs of freshwater from Mississippi River into the Barataria estuary. Most of the operations during October 2003 to September 2004 were minimum discharges or discharges for testing. Even with the maximum capacity of 10,600 cfs, the structure was closed 58% of the time and limited the flow rate at certain time of the year due to engineering problems and political and social opposition (OCPR 2005).

[25] The term U.S.Geological Survey "water year" in reports that deal with surface-water supply is defined as the 12-month period October 1, for any given year through September 30, of the following year. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months (USGS).
[26] Other constraints include mechanical and seasonal limits because of low rivers stages.

Table 7.7 Caernarvon Freshwater Diversion Annual Flow Rate (2001-2010)

Water Year	Annual Flow Rate (cfs)	Percentage of Max Capacity (8,000 cfs)
2001	1,511	19%
2002	1,471	18%
2003	1,325	17%
2004	1,467	18%
2005	1,594	20%
2006	1,967	25%
2007	2,935	37%
2008	2,709	34%
2009	1,554	19%
2010	3,160	40%
Average	1,969	25%

Source: the U.S.Geological Survey (USGS).
National Water Information System: Web Interface

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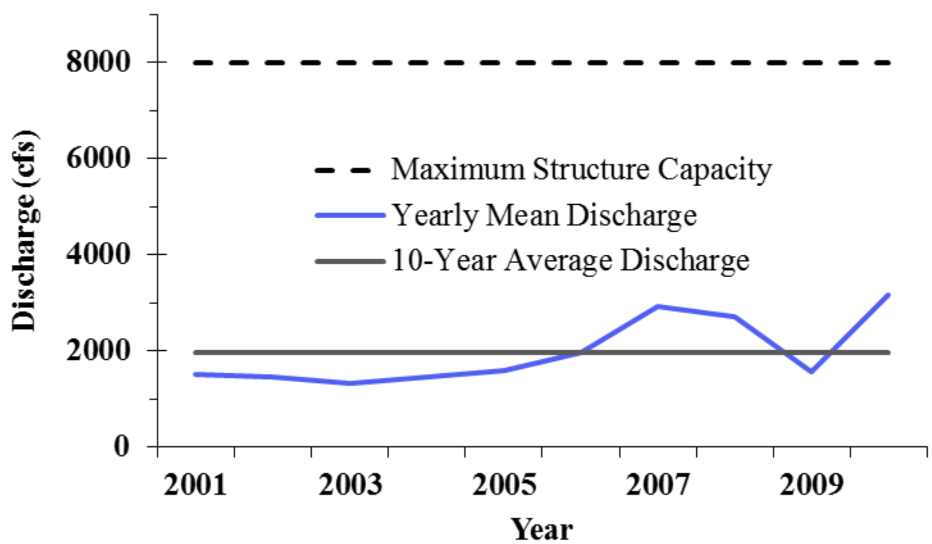

Figure 7.4 Yearly Mean Discharge at Caernarvon Freshwater Diversion

Table 7.8 depicts the annual flow rate and percent maximum capacity of Davis Pond project from 2003 to 2010 water year. Likewise, even with the 2003 constitutional amendments, the discharge rate of this project has also constrained by social and political factors. The flow rates range from a low of 683 cfs to a high of 3,873 cfs with an average flow rate at 2,143 cfs.

The percent capacity ranges from 6 to 36 with a mean 22 percent. As can be seen in Figure 7.4, Davis Pond yearly discharge were relative lower in the year 2003, 2004 and 2005 after operation and has not exceeded 10% of the maximum capacity. Davis Pond discharge for the 8- year (2003-2010) time period averaged 2,143 cfs, which is only 22 percent of the maximum capacity. These records and graph are also partially indicative of the social constraints to freshwater diversion projects in coastal Louisiana.

Table 7.8 Davis Pond Freshwater Diversion Annual Flow Rate (2003-2010)

Water Year	Annual Flow Rate (cfs)	Percentage of Max Capacity (10,600 cfs)
2003	833	8%
2004	683	6%
2005	821	8%
2006	3,101	29%
2007	2,207	21%
2008	3,551	34%
2009	3,802	36%
2010	3,873	36%
Average	2,143	22%

Source: U.S.Geological Survey (USGS).
National Water Information System: Web Interface

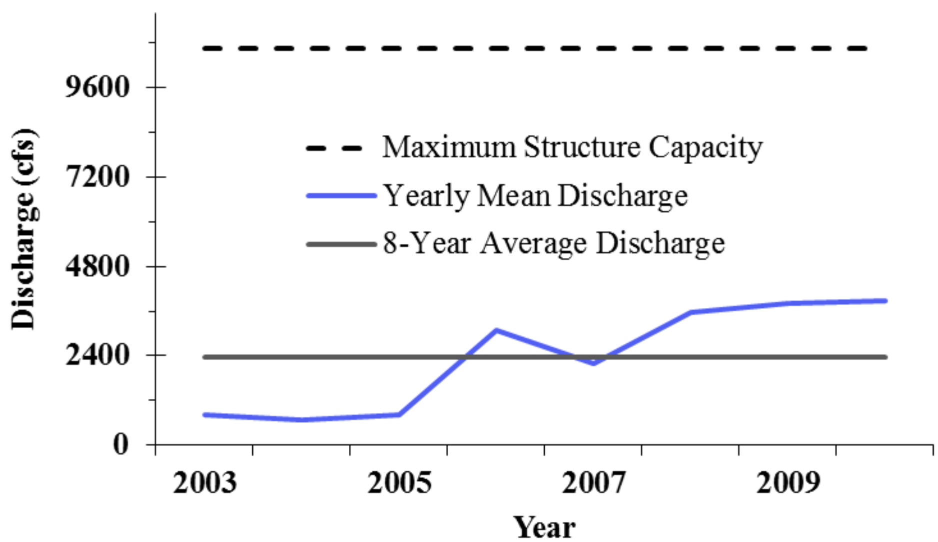

Figure 7.5 Yearly Mean Discharge at Davis Pond Freshwater Diversion

Unlike the expected valuation construct used for hurricane scenarios (Risk 1 and Risk 2), the incorporation of social constraints to FWD operations is represented here through a simple numerical factor. Drawing from the benefit model of FWD-based wetland restoration (Eq. 5.17), the factor is applied as:

$$B_t(FWD) = \sum_{t=1}^{20} \left(NA * \left[-0.0029 + 0.051 * \left(t - lag_f \right) \right] * \left(1 - E \right)^{t - lag_f} * ESV_f \right) * X_S * \frac{1}{\left(1 + R \right)^t} \qquad \text{(Eq. 7.4)}$$

where the X_S is a user-defined social constraints for FWD operation ranging from 0 to 100 percent.

Figure 7.6 depicts the simulated effects of political risk on net acre accrual for FWD 1 and FWD2 projects. Using a simulated social constraint to operations "Risk 3" scenario, the average FWD project has an average seven year lag prior to construction, social constraint (Xs) is set to 23 percent of the designed capacity of the structure, and benefits still follow a linear trajectory but with much higher reduced levels of benefits. Net acreages increase at a slower, constant rate over the 20-year life time.

7.5 Summary

Although risk assumptions are often hidden in economic comparisons, all coastal wetland restoration projects face direct and indirect sources of uncertainty and risk as to the benefits they provide. In this chapter, risk are discussed and incorporated into the NPV process. Hurricane risk was considered in two different situations - static and dynamic. Under static hurricane risk (X_H, Risk1), the percentage of hurricane-driven land loss was assumed to occur at a constant rate across project life time. Under the dynamic hurricane risk scenario (X_H, Risk2); however, the percentage of hurricane-driven land loss varied each time interval as a function of scale (i.e.

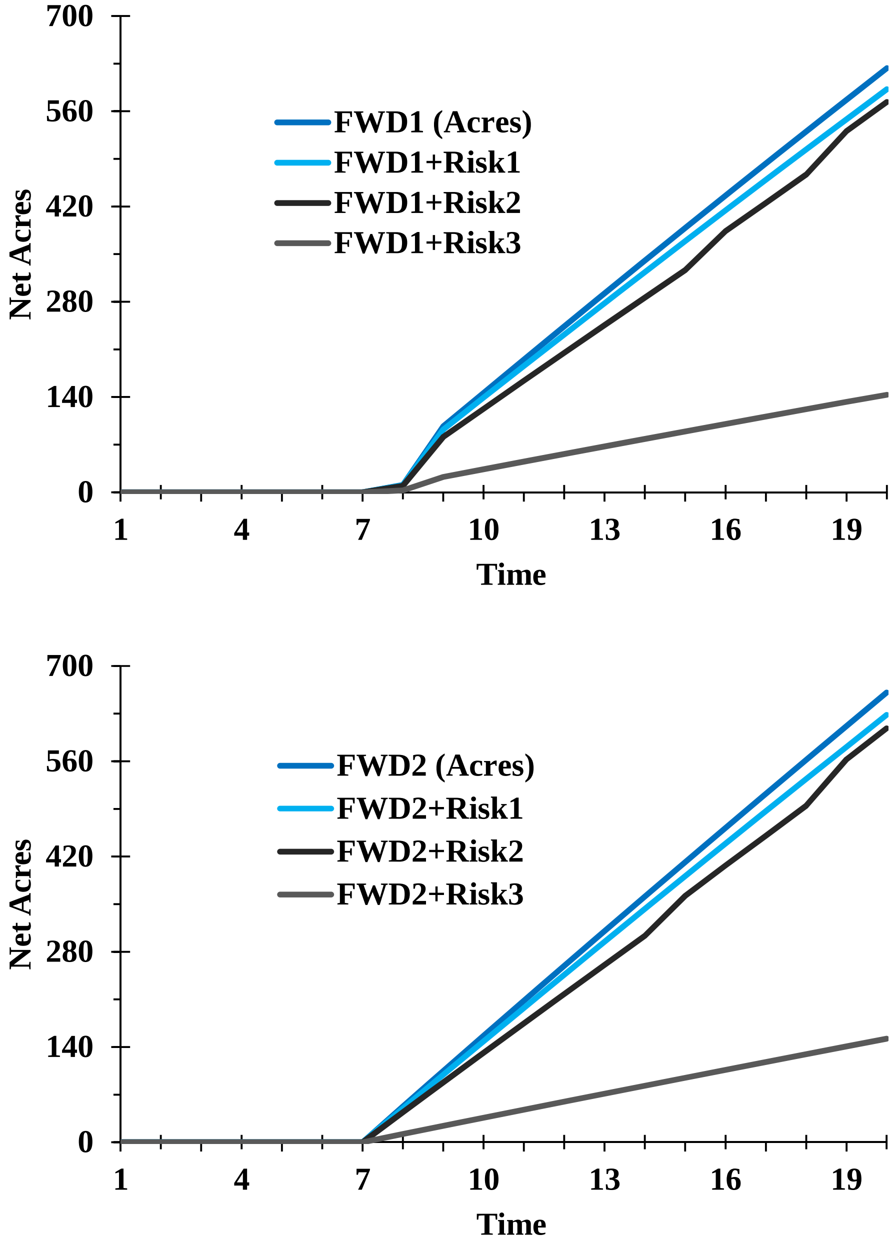

Figure 7.6 Effects of erosion and risk on net acres for FWD project

percent completion of the project). Hurricane risks were found to have the greatest impact on FWD projects due to their relatively slow rate of restoration. A method is described through which pre- and post-storm imagery can be used to determine actual project impacts and to adjust the user-defined X_H variable. A similar approach could be used to refine hurricane risk by project location.

Risks are compounded for FWD projects when political and social constraints are considered. Under a social risk scenario (X_S, Risk3), FWD project benefits are significantly curtailed, and by extension, costs per unit greatly increased. Data from two FWD projects – Caernarvon and Davis Pond – were used to estimate the potential operational constraints to flow rate driven by stakeholder opposition. If historical rates of flow constraint are used, approximately 80 percent of the FWD is unavailable for restoration purposes. Under this scenario, benefits are reduced to less than a third of those projected otherwise. While this may seem to represent a worse-case scenario, it is consistent with historical operations of FWD project in coastal Louisiana. These results show that incorporating risk into the BC analysis greatly changes the economic outcome and preference for coastal restoration alternatives.

CHAPTER 8 CASE STUDIES

8.1 Introduction

The previous chapter incorporated aspects of risk and uncertainty into generic NPV models developed for rapid land-building (RLB) and freshwater diversion (FWD) projects. This chapter uses that information to perform case-studies under different assumptions to illustrate tradeoffs between RLB and controlled FWD wetland restoration technologies.[27] For the purpose of simplifying the comparisons, these case studies utilize one RLB model (MC) and one FWD model (FWD2).

8.2 Assumptions of Case Studies

Two specific locations along the Mississippi River (an upper estuary site and a lower estuary site) were considered for the case study simulations. The Upper location is assumed to be along the western side of the Mississippi River between Myrtle Grove and Point a La Hache. The Lower location is along the western side of the Mississippi River between Boothville and Venice (Figure 8.1). In these comparisons, the MC scenarios are denoted as “M” and the FWD scenarios are denoted as “F” for the two estuary locations.

As descripted in Chapter 6 (Table 6.3), a total of 22 user-specified variables and values are available for the NPV simulation process. In this chapter, case studies for all projects and locations will use a sub-set of 14 user-specified variables that incorporate hurricane and social risk into the analytical framework. To further simplify the case-studies, six user-specified parameters will be modified to represent different scales (target acreage), time periods, and constraints unique to the case study locations. A general explanation of these parameters follows:

[27] As mentioned in Chapter 3(3.5.2), controlled structures are those diversions that use a valve or a gate to control the flow of water.

1) Project life time is set to 20 years and 50 years for both location case studies;

2) Target scales are assumed to be 1000 acres and 5000 acres;

3) Time lag times range from 4 to 10 years depending on project type and location;

4) Major hurricane probability ranges from 0.1 to 0.2 depending on location;

5) Land loss rate ranges from 0.3 to 0.6 depending on location;

6) Social constraints range from 0.25 to 0.80 depending on scale and locations.

Figure 8.1 Case studies project at upper and lower estuary locations

A qualitative description of the 16 case scenarios is provided in Table 8.1. Table 8.2 depicts 14 parameters for the eight scenarios at the upper estuary location with 6 variables adjusted to reflect project-specific conditions. The Upper M-1and Upper F-1 scenarios estimate the total benefits and costs based on a target of 1000 acres and a 20-year project life time. The Upper M-2 and Upper F-2 scenarios are for 1000 acres and a 50-year project life time. The Upper M-3 and Upper F-3 scenarios determine the total benefits and costs based on a 5000 acre target and a 20-year project life time. The Upper M-4 and Upper F-4 scenarios are based on the same target and a 50-year project life time. For these four Upper estuary scenarios, lag times are assumed to be 4 years for MC project and 10 years for FWD projects, probability of hurricane land fall is set to 10 percent, regional-specified land loss rate is assumed to be 0.3 percent per year, and capacity is set to 40 percent for small scale FWD project and 25 percent for large scale project, respectively. Finally, four different water flow rates were derived from the N-SED1 model (Boustany 2007) for the upper basin scenarios, including 1,029 cubic feet per second (cfs), 963 cfs, 1489 cfs, and 1161 cfs based on the desired acreage and project life time.

Table 8.3 depicts 14 parameters for the eight scenarios at the Lower estuary location with 6 variables adjusted to reflect project-specific conditions. The Lower M-1and Lower F-1 scenario estimate the total benefits and costs for two wetland restoration project types (MC and FWD2) based on 1000 target acres during a 20-year project life time. The Lower B-2and Lower F-2 scenarios are based on a 50-year project life time. The Lower M-3and Lower F-3 scenarios determine the total benefits and costs based on a 5000 target acre during a 20-year project life time. The Lower M-4and Lower F-4 scenarios are based on a 50-year project life time. For these four lower estuary scenarios, lag times are assumed to be 4 years for MC project and 7 years for FWD project, probability of hurricane land fall is set to 20 percent, regional-specified land loss

Table 8.1 Upper and Lower Estuary Case Study Scenarios - Qualitative Descriptions

Scenario	Description
Upper M-1	Upper estuary MC project, 20 years, 1000 acre target, low/no public opposition, lower hurricane risk, lower erosion, shorter lag time
Upper M-2	Upper estuary MC project, 50 years, 1000 acre target, low/no public opposition, lower hurricane risk, lower erosion, shorter lag time
Upper M-3	Upper estuary MC project, 20 years, 5000 acre target, low/no public opposition, lower hurricane risk, lower erosion, shorter lag time
Upper M-4	Upper estuary MC project, 50 years, 5000 acre target, low/no public opposition, lower hurricane risk, lower erosion, shorter lag time
Upper F-1	Upper estuary MC project, 20 years, 1000 acre target, medium/high public opposition, lower hurricane risk, lower erosion, longer lag time
Upper F-2	Upper estuary MC project, 50 years, 1000 acre target, medium/high public opposition, lower hurricane risk, erosion, longer lag time
Upper F-3	Upper estuary MC project, 20 years, 5000 acre target, high public opposition, lower hurricane risk, lower erosion, longer lag time
Upper F-4	Upper estuary MC project, 50 years, 5000 acre target, high public opposition, lower hurricane risk, lower erosion, longer lag time
Lower M-1	Lower estuary MC project, 20 years, 1000 acre target, low/no public opposition, higher hurricane risk, higher erosion, shorter lag time
Lower M-2	Lower estuary MC project, 50 years, 1000 acre target, low/no public opposition, higher hurricane risk, higher erosion, shorter lag time
Lower M-3	Lower estuary MC project, 20 years, 5000 acre target, low/no public opposition, higher hurricane risk, higher erosion, shorter lag time
Lower M-4	Lower estuary MC project, 50 years, 5000 acre target, low/no public opposition, higher hurricane risk, higher erosion, shorter lag time
Lower F-1	Lower estuary MC project, 20 years, 1000 acre target, medium public opposition, higher hurricane risk, higher erosion, longer lag time
Lower F-2	Lower estuary MC project, 50 years, 1000 acre target, medium public opposition, higher hurricane risk, higher erosion, longer lag time
Lower F-3	Lower estuary MC project, 20 years, 5000 acre target, medium/high public opposition, higher hurricane risk, higher erosion, longer lag time
Lower F-4	Lower estuary MC project, 50 years, 5000 acre target, medium/high public opposition, higher hurricane risk, higher erosion, longer lag time

Table 8.2 Case Study Parameters - Upper Estuary Scenarios

User-Specified	Set Values for MC and FWD2 Case Studies				Range		
	Upper M-1 Upper F-1 1000ac/20y	Upper M-2 Upper F-2 1000ac/50y	Upper M-3 Upper F-3 5000ac/20y	Upper M-4 Upper F-4 5000ac/50y	Low	High	Mean
Time period (year)	20	50	20	50	20	50	20
Desired Acreage	1,000	1,000	5,000	5,000	300	10,000	1000
Discount rate	0.04	0.04	0.04	0.04	0	0.15	0.04
Water Flow Rate- FWD 2 (Boustany 2010)	1,029	963	1,489	1161	0	35,000	1,029
Mob/Demob($)	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$110,000	$4,000,000	$1,000,000
Distance (Miles)	4.00	4.00	4.00	4.00	1	50	4
Access Dredging/Channel ($)	$600,000	$600,000	$600,000	$600,000	$0	$2,000,000	$600,000
E&D Lag (MC)	4	4	4	4	2	7	4
E&D Lag (FWD)	10	10	10	10	1	30	7
Projected Construction Costs	85%	85%	85%	85%	50%	90%	85%
Projected E&D cost	15%	15%	15%	15%	5%	30%	15%
Projected O&M cost	5%	5%	5%	5%	1%	20%	5%
Hurricane probability (Klotzbach and Gray 2010)	10%	10%	10%	10%	0%	100%	20%
Region-Specific Land Loss Rate (Coast 2050)	0.3%	0.3%	0.3%	0.3%	0.03%	0.7%	0.33%
Social Constraint to Diversion Operations (% of capacity)	40%	40%	25%	25%	0	100%	23%

Table 8.3 Case Study Parameters - Lower Estuary Scenarios

User-Specified	Set Values for MC and FWD2 Case Studies				Range		
	Lower M-1 Lower F-1 1000ac/20y	Lower M-2 Lower F-2 1000ac/50y	Lower M-3 Lower F-3 5000ac/20y	Lower M-4 Lower F-4 5000ac/50y	Low	High	Mean
Time period (year)	20	50	20	50	20	50	20
Desired Acreage	1,000	1,000	5,000	5,000	300	10,000	1000
Discount rate	0.04	0.04	0.04	0.04	0	0.15	0.04
Water Flow Rate- FWD 2 (Boustany 2010)	1,029	963	1,489	1161	0	35,000	1,029
Mob/Demob($)	$1,000,000	$1,000,000	$1,000,000	$1,000,000	$110,000	$4,000,000	$1,000,000
Distance (Miles)	4.00	4.00	4.00	4.00	1	50	4
Access Dredging/Channel ($)	$600,000	$600,000	$600,000	$600,000	$0	$2,000,000	$600,000
E&D Lag (MC)	4	4	4	4	2	7	4
E&D Lag (FWD)	7	7	7	7	1	30	7
Projected Construction Costs	85%	85%	85%	85%	50%	90%	85%
Projected E&D cost	15%	15%	15%	15%	5%	30%	15%
Projected O&M cost	5%	5%	5%	5%	1%	20%	5%
Hurricane probability (Klotzbach and Gray 2010)	20%	20%	20%	20%	0%	100%	20%
Region-Specific Land Loss Rate (Coast 2050)	0.6%	0.6%	0.6%	0.6%	0.03%	0.7%	0.33%
Social Constraint to Diversion Operations (% of capacity)	80%	80%	50%	50%	0	100%	50%

rate is assumed to be 0.6 percent per year, and the percent of capacity are set to 80 for small scale FWD project and 50 percent for large scale project, respectively. Finally, four different water flow rates were derived from the N-SED1 model (Boustany 2007) for the lower basin scenarios, including 1,029 cubic feet per second (cfs), 963 cfs, 1489 cfs, and 1161 cfs based on the desired acreage and project life time.

8.3 Depicting Acreage Effects

Figure 8.2 depicts the effects of scale, lag time, land loss rate, and risk on net acres for MC and FWD projects at Upper Estuary location under the assumptions for a target of 1000 and 5000 acres during a 20 and 50 year project life time. As evident in the graphics, the net acres from the MC project are far greater than the gained net acres from FWD project during the first several decades. As described in Chapter 3 and Chapter 7, net acreage follows a sigmoid trajectory for MC projects. With the four year lag time, acreage is not realized until year 4, and then most of the land is gained in years 4-6. After year 6, the land gradually decreases because of erosion and hurricane risk. In comparison, because of the 10 year lag time for FWD project in the upper estuary, net acres are zero until year 10, and then increase very slowly over the project life time following a linear trajectory. However, due to public opposition - which is greater in the upper estuary and also higher for large scale projects – the assumed flow rates of the FWD projects are constrained to 25 to 40 percent of their designed capacity. Because of this constraint, the trajectories for diversion projects (F1, F2, F3, and F4) produce less than 20% of the target acreage.

Figure 8.3 depicts the effects of location, scale, lag time, land loss rate, and risk on net acres for MC and FWD projects at Lower Estuary location with the same assumption: a target 1000 and 5000 acres and a 20 and 50 year project life time. The benefits also follow a sigmoid trajectory for MC project, with net acres at zero until 4, and then rapidly gained in years 4-6. After year 6, net acreage for MC projects is slightly decreasing (because of erosion and hurricane risk). For the FWD projects, net acreage is zero until year 7, and then increase at a slow, constant rate over project time period following a linear trajectory. In these simulations, the net acreage appears to converge on the MC projects beyond 50 years. These results demonstrate the potential for FWD projects in the absence of social constraints – where lower levels of public opposition and shorter time lags allow for higher flow rates.

8.4 Comparison of Case Studies

Sixteen case studies were conducted in which six user-specified parameters were modified to represent different scenarios at Upper and Lower estuary locations for MC and FWD projects. In each scenario, these modified parameters were incorporated into the specified NPV model to determine the net acres, total NPV benefits ($), total NPV costs ($), B-C ratio, and cost per unit ($/acre).

Table 8.4 and Table 8.5 provide the economic results of NPV simulations for the Upper and Lower estuary locations, respectively. In each table, five types of estimate are provided MC and FWD projects of 1000 and 5000 acre target scales and 20 and 50 year time periods. The additional parameters for these case simulations were previously described in Tables 8.2 and 8.3.

- **Acreage**

In all case simulations, the MC project acreage exceeds the acreage for FWD projects; however, for 50-year periods in the lower basin, the FWD project acreage is very close to converging on acreage of the MC projects. For both project types, neither achieves the target acreage during the specified time period. In the case of MC projects, three factors constrain the project's ability to reach the target benefit: lag time, erosion, and hurricane effects (X_{HN}).

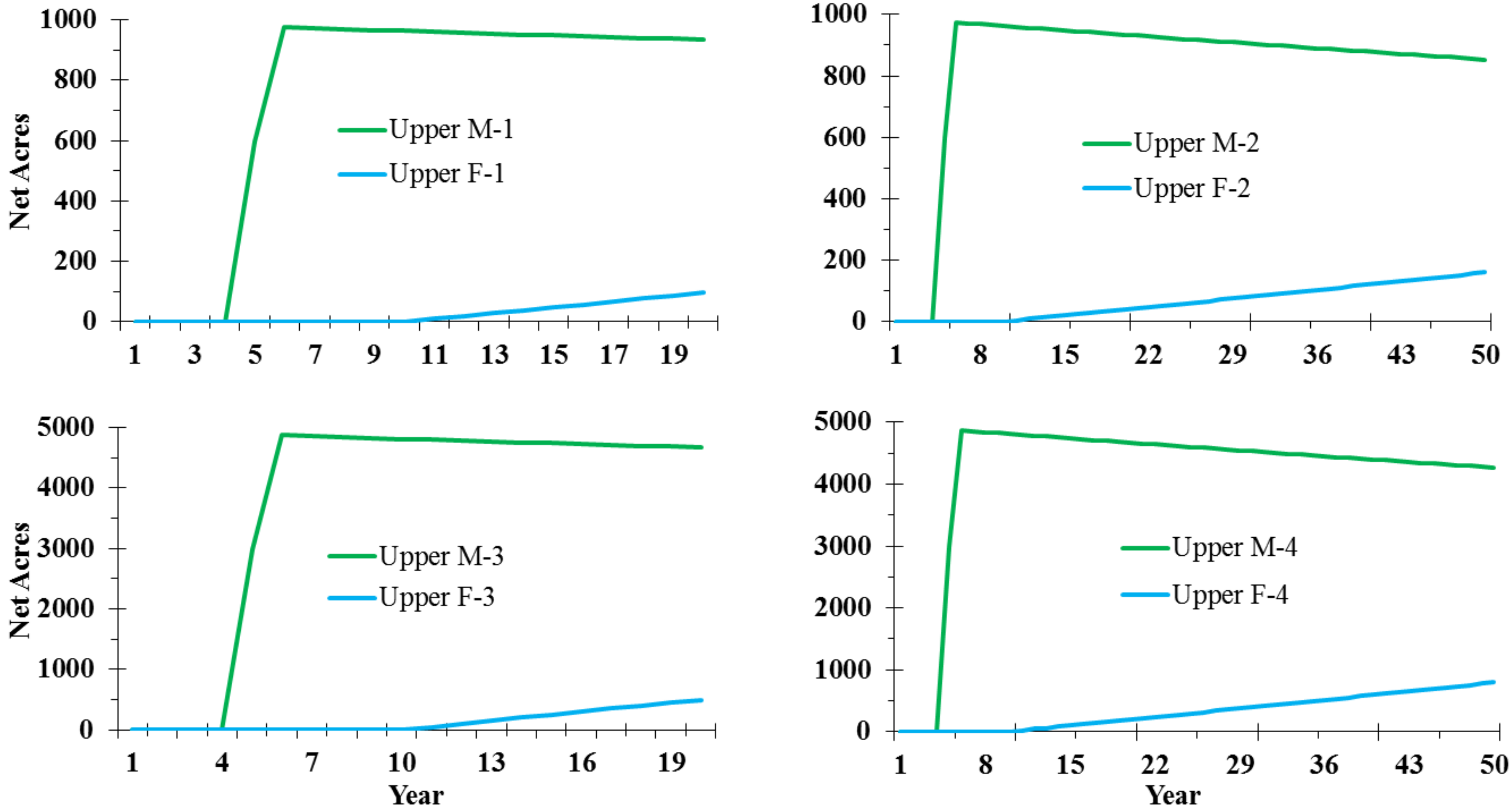

Figure 8.2 Effects of scale, and risk on net acres for RLB and FWD projects at upper estuary location

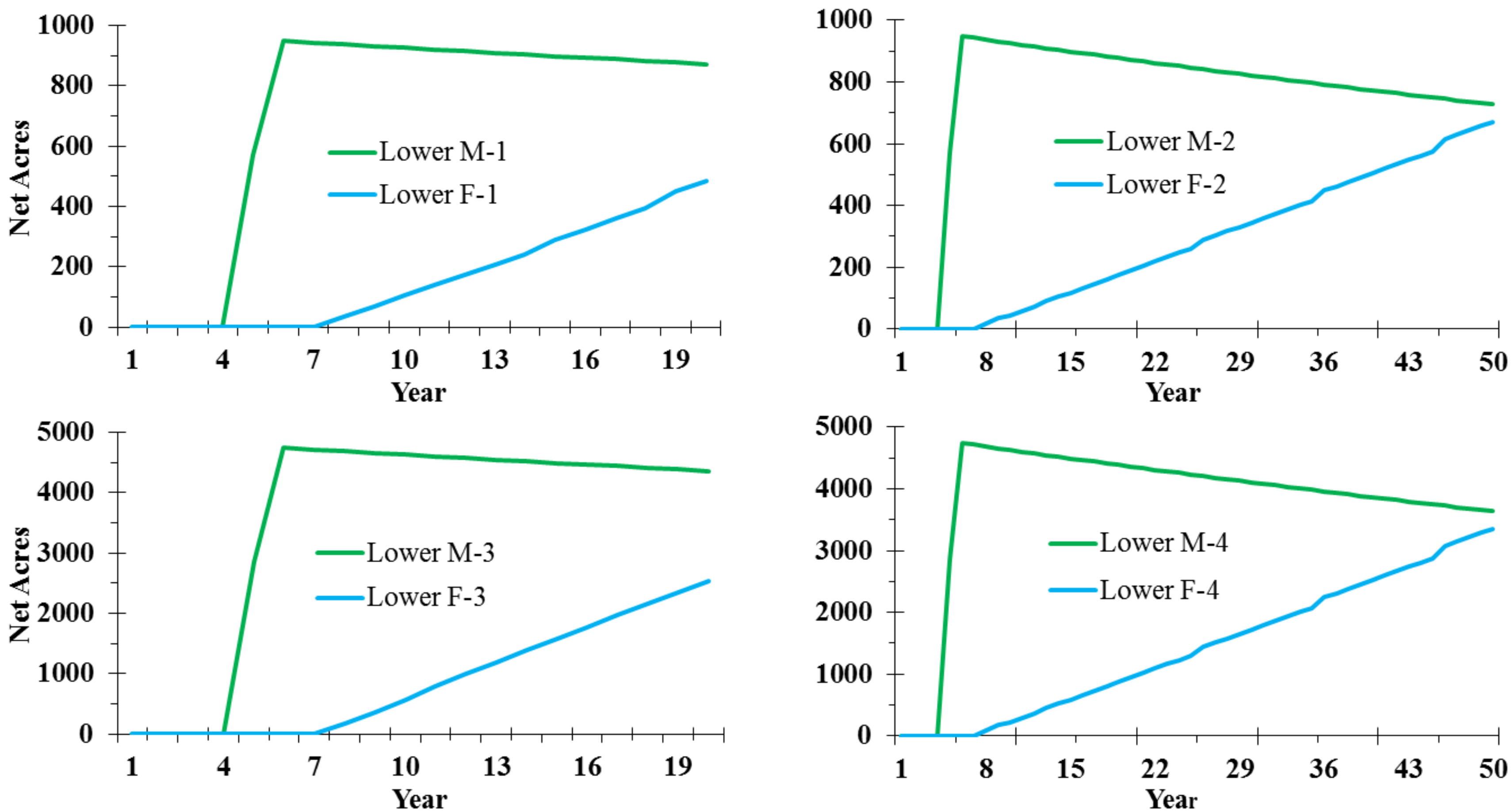

Figure 8.3 Effects of scale, and risk on net acres for RLB and FWD projects at lower estuary location

Because of these constraints MC projects achieve only 85 and 93 percent of the target acreage in the upper estuary; and only 87 and 73 percent of the target acreage in the lower estuary. In the case of FWD projects, four factors constrain the project's ability to reach the target benefit: lag time, erosion, hurricane effects (X_{HN}) , and social constraints (X_S). Because of these constraints FWD project benefits range from 12 to 32 percent of the target acreage in the upper estuary; and 30 to 87 percent of the target acreage in the lower estuary.

- **Costs**

One of the often cited arguments against RLB projects is their apparent high costs. In Tables 8.4 and 8.5 this argument can be seen. The costs for MC projects at similar scales, time periods, and locations ranges from 2.8 to nearly 4 times higher than the comparable costs of FWD projects designed for the same target acreage. While FWD projects do produce the lowest per unit cost for 50-year projects in the lower estuary, those simulations involved very low public opposition (i.e. flow constraints). For FWD projects to operate at higher capacity in the upper, populated basin; additional cost would likely be incurred – such as compensation for fisheries displacement and fair market value expropriation of private property. Pre-emptive compensation to diversion-affected parties would need to be estimated and added to the operational cost model for diversions. The estimation of such costs; however, are beyond the scope of this study.

- **Benefits**

Conversely, and as seen in the acreage data, the MC project benefits greatly exceed the performance of the FWD projects under the same scale, time, and location assumptions of these case studies. Given that benefits are assigned on an annual basis using three non-market, ecosystem valuation estimates (Table 6.2), the net benefits in dollars for MC projects ranges from 4 to 27 times higher than the comparable benefits of FWD projects designed for the same

Table 8.4 Cost and Benefit Output for Upper Estuary Scenarios

	MC				FWD			
	Upper M-1 1000ac/20y	Upper M-2 1000ac/50y	Upper M-3 5000ac/20y	Upper A-4 5000ac/50y	Upper F-1 1000ac/20y	Upper F-2 1000ac/50y	Upper F-3 5000ac/20y	Upper F-4 5000ac/50y
Net Acres	934	853	4670	4267	193	321	602	1003
NPV Costs ($)	37,798,400	37,423,575	47,801,529	47,327,509	12,035,230	11,830,916	12,082,695	11,900,929
NPV Benefits ($)	40,687,958	71,993,875	203,439,791	359,969,373	2,399,596	7,323,328	7,496,977	22,880,297
B-C Ratio	1.08	1.92	4.26	7.61	0.2	0.62	0.62	1.92
$/acre	40,469	43,873	10,236	11,092	62,359	36,856	20,071	11,865

Table 8.5 Cost and Benefit Output for Lower Estuary Scenarios

	MC				FWD			
	Lower M-1 1000ac/20y	Lower M-2 1000ac/50y	Lower M-3 5000ac/20y	Lower M-4 5000ac/50y	Lower F-1 1000ac/20y	Lower F-2 1000ac/50y	Lower F-3 5000ac/20y	Lower F-4 5000ac/50y
Net Acres	872	728	4359	3639	508	671	1520	2098
NPV Costs ($)	37,798,400	37,423,575	47,801,529	47,327,509	13,366,465	13,151,140	13,419,179	13,229,091
NPV Benefits ($)	38,885,396	67,044,229	194,426,982	335,221,144	8,161,172	16,722,894	24,271,476	52,247,394
B-C Ratio	1.03	1.79	4.07	7.08	0.61	1.27	1.81	3.95
$/acre	43,347	51,406	10,966	13,006	26,312	19,599	8,828	6,306

target acreages.

- **B-C Ratio and Unit Costs**

All B-C ratios are greater than 1.0 for the 8 MC case study projects, and exceed 1.0 in four of the 8 FWD case scenarios. The overall B-C ratio for MC projects ranges from a low of 1.03 to a high of 7.61. For FWD projects, B-C ratios range from 0.2 to 3.95. The least expensive (most efficient) projects in these case study comparisons are the large scale FWD projects in the lower estuary. These projects achieve a unit cost of $8,828 and $6,306 per acre for 20 year and 50 year trajectories, respectively. This finding is consistent with the recommendations of coastal restoration planners and diversion advocates who tend to dismiss RLB projects as overly expensive and unsustainable and who promote the use of large scale FWD projects on a long-term basis as the only sustainable solution for addressing Louisiana's coastal land loss crisis (Reed 2009). In reality, there are very few locations where such projects can be implemented without major opposition from fishermen, land owners, and other interests. Primarily because of social constraints, the use of FWD projects in the middle to upper estuary is much more problematic and less efficient. The unit cost of FWD projects in the upper estuary ranges from $11,865 to $62,359 – and in each of the four comparable scenarios, the MC projects have a lower cost per unit acre –ranging from $10,236 to $40,449.

8.5 Summary

This chapter incorporates all of the benefit and cost model calculations developed in Chapters 1-7 to perform preliminary case studies for MC and FWD projects in two hypothesized locations of coastal Louisiana. A total of 16 case studies scenarios were developed for upper and lower estuary locations based on varying target scales, time periods, lag times, erosion rates, hurricane risks, and social constraints. These case studies provide an example of how the time and risk-adjusted NPV models can provide useful information to decision-maker about the choice of restoration projects.

Two FWD projects were found to achieve the lowest unit cost per acre (highest efficiency), but only for lower estuary locations where public opposition is assumed to be much lower. For a large-scale FWD projects to be constructed and operated at full capacity in the middle to upper estuary, social costs would dramatically increase. This study addresses those cost through a mathematical constraint to diversion flow rate (X_S) – which is enumerated in a manner consistent with the public operation of these structures.

Given the limited number of locations where a large FWD can be located with minimum social opposition, and considering the tremendous rate of coastal land loss in Louisiana, there would appear to be a preference for those projects that build land rapidly and cost-efficiency at upper and middle estuary locations. Results indicate that even with a much higher total NPV costs, MC projects are more cost effective in the majority of the simulations.

An alternative simulation would include calculating the costs of pre-emptive compensation to diversion-affected parties and then adding those costs into the estimated cost model for diversions. While such compensation costs are beyond the scope of this study, these costs must be addressed formally by coastal restoration managers and planners if large-scale FWD projects are to be used in the middle to upper estuary.

CHAPTER 9. SUMMARY and CONCLUSIONS

9.1 Summary and Conclusions

Using natural or artificial ways of building wetlands to combat coastal land loss has long been debated in coastal Louisiana. In the wake of Hurricanes Katrina and Rita, the Louisiana Coastal Protection and Restoration Authority was (CPRA) was established in an attempt to integrate programs for habitat restoration and infrastructure protection. As a result, wetland restoration has begun shifting from ecosystem-focused to more human-focused issues. Coastal communities have expressed strong interest in the rapid land-building (RLB) techniques that rely on mechanical dredges and sediment conveyance pipelines to build new land, even though these projects have apparent high costs.

The costs and benefits of RLB methods are increasingly compared to the more traditional methods of fresh water and sediment diversions (FWD). Selecting an appropriate technology is very important to make wetland restoration more efficient. Previous economic analyses have focused on the qualitative benefits (dollars per habitat unit) of coastal restoration spending. This study focused on quantitative benefits (net acres) associated with project contributions and incorporated time and risk factors into benefit-cost (BC) models for RLB and FWD wetland restoration project types in Louisiana.

The overall objective was to develop a comprehensive economic assessment, and comparison of RLB and FWD for coastal restoration. The specific objectives were: (1) to estimate generic models of coastal restoration project trajectories and cost by technology; (2) to conduct sensitivity analyses with varying values of variables, and; (3) to perform case-studies to illustrate tradeoffs between/within coastal restoration technologies.

Data from a total of 341 projects were collected from numerous sources including 124 projects authorized by the Coastal Wetland Planning Protection and Restoration Act (CWPPRA). A total of 23 marsh creation (MC) projects, 13 barrier island (BI) projects, and 15 FWD projects were authorized by CWPPRA projects and available for use in the BC analyses. To supplement the available data, 85 RLB project bids and 9 additional FWD projects estimates were obtained from the Louisiana Coastal Areas (LCA) Ecosystem Restoration Program and the Water Resources Development Act (WRDA). Initial comparisons indicated that the most expensive, and most frequently used coastal land-building technologies are MC, BI, and FWD. Together, these three project types have accounted for more than 78% of CWPPRA projects authorized since 2005.

Generic benefit trajectories and cost models were constructed through the consideration of authorized project data and formal bids for MC projects (n=69), BI projects (n=52), and FWD projects (n=25). Using multiple regression analysis, benefit trajectories were constructed by examining the percent completion of target acreage goal by year. For RLB projects, these trajectories were sigmoidal in shape and for FWD projects these trajectories were constant and upward sloping. Because of the relatively small amount of FWD benefit data, an exogenous benefit model was incorporated (FWD2) into the analyses. The $NSED_1$ model is a nutrient and sediment-based mass-balance model developed by the Natural Resources Conservation Service (NRCS) and refined by the US Army Corps of Engineers (USACE) to examine the accretion potential of FWD projects.

For the comparative costs models, numerous independent variables were found to be significant drivers of the costs for MC projects (α=.10). Cubic yards of sediment (CYD), mobilization and demobilization costs (MOB), distance (DIST) and access dredging (AD) were positively correlated with the cost RLB projects. Likewise, the variables, cubic feet per second (CFS) and diversion control (CON), were found to be significant and positive predictors of the costs of FWD projects.

These benefit and cost models were incorporated into a net present valuation (NPV) framework and sensitivity analyses were conducted to examine the relative importance of specific attributes related to time, distance, project scale, discount rate, and site-specific land loss rates. Data for 22 project-specific attributes were used to develop baseline BC simulations for two RLB project types (MC and BI) and two freshwater diversion models (FWD1 and FWD2). Simulations against the baseline were conducted by allowing a single, user-specified parameter to vary across its known range and solving for the break-even cost ($/acre/year) in which the BC ratio was equal to 1.0.

As expected, project life time, scale, discount rate, and time lag have a major impact on the cost-benefit decision analysis for coastal restoration. Increases in project life time and project scale serve to decrease per unit costs where increases in discount rate and time lag were found to increase per unit cost. Additional factors, such as the mobilization of dredging equipment costs were found to be more sensitive for BI projects than MC projects. Dredging access costs and the distance between sediment borrow site and project site also had a major impact on the costs of RLB projects. The rate of long-shore sediment transport had a very small effect on BI projects cost and benefits only. Under the assumption with no hurricane and human disruption, the rate of land loss was found to have only a small impact the cost-benefit relationship for RLB and FWD projects.

Hurricane risks were examined using landfall probabilities unique to the Louisiana cost and modeled under an expected valuation framework. The scaling of hurricane impacts was demonstrated under two scenarios, constant and dynamic. Under static hurricane risk (X_H, Risk1), the percentage of hurricane-driven land loss was assumed to occur at a constant rate across project life time. Under the dynamic hurricane risk scenario (X_H, Risk2); however, the percentage of hurricane-driven land loss varied each time interval as a function of scale (i.e. percent completion of the project). Hurricane risks were found to have the greatest impact on FWD projects due to their relatively slow rate of restoration. A method is described through which pre- and post-storm imagery could be used to determine actual project impacts and to adjust the user-defined X_H variable. A similar approach could be used to refine hurricane risk by project location. When political and social constraints (X_S, Risk3) are considered; however, the benefits were significantly curtailed. Per unit costs were dramatically increased due to their relatively slow rate of restoration, and the incorporation of social risk into the BC analysis greatly changed the economic outcome and potential preference for coastal restoration alternatives.

Case studies for MC and FWD projects were conducted in two hypothesized locations of coastal Louisiana. A total of 16 case studies scenarios were developed for upper and lower estuary locations based on varying target scales, time periods, lag times, erosion rates, hurricane risks, and social constraints. Two FWD projects were found to achieve the lowest unit cost per acre (highest efficiency), but only for lower estuary locations where public opposition is assumed to be much lower. For any large-scale FWD projects to be constructed and operated at full capacity in the middle to upper estuary, social costs would increase. This study addresses those cost through a mathematical constraint to diversion flow rate (X_S) – which is enumerated in a manner consistent with the public operation of these structures. These case studies provide an example of how the time and risk-adjusted NPV models can provide useful information to decision-maker about the choice of restoration projects. Future simulations might also benefit from the use of declining (Gamma) discount rates applications that vary according to time and project scale.

The results from this research showed that while RLB projects are often characterized as being cost-prohibitive, when time and risk are considered these projects are much more competitive in comparison to more natural methods. Delays in construction (time lag) and the relatively slow rate of restoration proved to be major, negative factors on the feasibility of the FWD projects. Furthermore, the incorporation of project-specific types of risk was found to compound the problems associated with the slower performing, FWD projects. Perhaps more importantly, results indicated that the break-even annual costs in the vast majority of simulations were considerably higher than the range of annual benefits reported in the non-market, ecosystem valuation literature. This finding suggests the need for additional scrutiny to ensure the most feasible combination of project attributes. The generic cost and benefit functions established in this analysis provide a decision framework for the CPRA to utilize in the economic assessment of competing technologies for coastal wetland restoration. Results indicate that even with a much higher total NPV costs, MC projects are more cost effective in the majority of the simulations. Given the limited number of locations where a large FWD can be located with minimum social opposition, and considering the tremendous rate of coastal land loss in Louisiana, there would appear to be a preference for those projects that build land rapidly and cost-efficiency at upper and middle estuary locations. Simulations in this portion of the study showed that MC projects and FWD project are more comparable because BI projects are limited in where it can only be constructed on coastal islands.

9.2 Limitations and Refinements

- **Data Availability and Frontier Analysis**

Although every effort was made to obtain all available program data and variables for the models developed in this study, there was only a small amount of project data available be used to construct the cost and benefits models. Meanwhile, there is large degree of data variation within comparable project types and the lacking data for variables could be very important to the simulation model (e.g. estimating depth, elevation, and thickness). These data limitations; however, are not unique to this study. In reality, these are the only cost and benefit data available to the state for guiding the analysis and future allocation of potential billions in restoration spending. More benefit and cost data should be collected on current and proposed coastal wetland restoration projects. As additional projects come on-line (constructed) and additional bids are generated, these costs and benefit models should be refined. For RLB projects, attempts to model project thickness as a function of average depth of receiving area and elevation proved problematic. Moreover, attempts to model the effects of RLB payment type (on the cut versus on the fill) were plagued by insufficient data. Thus, a more detailed tracking of these measurements is needed for RLB projects. Meanwhile, an alternative analysis-frontier analysis, which estimates maxima or minima of a dependent variable given explanatory variables, could be used to determine the cost models.

- **Static Discount Rate and Gamma/Dynamic Discounting**

This research used the static discount rate in which the discount rate keep constant during the project life time. By comparison, dynamic discounting (a time-declining rate of discount) could be considered incorporating into NPV analysis. The time-declining discount rate is known as Gamma discount rate, which gave a declining discount rate schedule as a simple function of time (Weitzman 2010).

- **Sea Level Rise/Subsidence and Erosion Constant or Risk Function**

At many coastal sites, global sea level rise and/or subsidence are the main factors responsible for land loss. Douglas (1997) estimated that each year global sea level rises about 1.8 mm as a result of a worldwide increase in water volume. This value, however, is substantially less than the total rise in relative sea level recorded at many tide gauges (Emery and Aubrey, 1991). Scientists have concluded that the remaining amount of relative sea-level rise is caused by land subsidence. The relative sea level rise and/or subsidence accelerate coastal erosion (Morton 2003). This research used a constant annual land loss rate from the Coast2050 report. A dynamic land loss rate or risk function associated with sea level rise and/or subsidence could be considered and incorporate into NPV models.

- **Scale Limitations and Consideration of Massive-Scale Projects**

Case studies assumed two project scale scenarios: 1000 and 5000 target acreages. Massive-scale project simulations would be considered. An alternative, more comprehensive cost simulation for FWD would involve calculating the costs of pre-emptive compensation to diversion-affected parties and then adding those costs into the estimated cost model for diversions. While such compensation costs are beyond the scope of this study, these costs should be formally assessed by coastal restoration managers and planners in cases where large-scale FWD projects are being considered in the middle to upper regions of the estuary.

Independent Modeling and Integrated Benefit-Cost Analysis (BCA)

All comparison of freshwater diversion and rapid land-building are independent. The generic benefit and cost model based on independent project type. For FWD projects, the cost model utilized is simply a function of estimated average flow rate and the type of diversion (controlled or uncontrolled). The two benefit models used for diversions (FWD1 and FWD2) were vastly different in their estimated flow rates required for simulations of target acreage – with the required flow to meet target acreage for the former being as much as sixteen times the latter. Thus, while the FWD1 benefit model estimated in this study might prove too conservative, the FWD2 model - which was used for the case study simulations - could prove too liberal in the estimation of project benefits. This wide difference in benefit trajectories illustrates some of the scientific uncertainly associated with the efficacy of freshwater diversions. Addition analyses will be required to examine the case studies with some hybrid combination of the two benefit trajectories and their associated costs.

In reality, a more integrated wetland restoration scenario could involve the combination of a RLB project sustained by a FWD. This scenario is increasingly promoted as a compromise for the use of these approaches in restoring coastal Louisiana. The models developed in this study could easily be used for such a simulation.

- **Benefits Transfer and Site-Specific/Project-Specific Development of ESV Estimates**

Limited literature on coastal wetland valuation of ecosystem services and the wide range of these estimates is also problematic. This research used three primary non market values (e.g. storm surge attenuation, habitat protection, and water quality provision) from the existing literature as "starting values" to quantify the break-even simulations. Ecosystem values incorporated into this study via benefit-transfer, which might not always appropriate. Additional recently site-specific and project-specific estimates are required to refine the ecosystem services value.

- **Lack of Market Values and Addition of Annualized Market Values**

The market value of an acre wetland could be ranged from a few hundred dollars to a few million dollars per acre in different coastal areas. It can be measured through direct, observable market behavior to place monetary values on wetland. Additional annualized market value data are required to further refine the cost models and could be added into these cost functions using a high and a low value in the simulations to show the difference.

- **Scaling Risks and Impacts and Additional GIS Case Studies**

Finally, the degree of impact from a major hurricane land fall on a coastal restoration project can be measured using GIS analysis; however, the number of direct hits from major hurricanes is limited. This study demonstrated a dynamic impact scenario in which scale (size and percent completion) and project type can be used to adjust the risk from future storms. The impacts of social constraints, by comparison, are much more difficult to model. Increased time lag and operational flow constraints are common for FWD projects in coastal Louisiana. This study uses a very simple approach to constrain FWD benefits based on case-specific historical information.

9.3 Policy Recommendations

While project selection processes have traditionally relied on limited interval or end-of-stage cost comparisons, economic modeling based on a dynamic trajectory allows for more comprehensive accounting of a project's ecosystem services over time. Through this approach, decision-makers can examine highly detailed economic trade-offs between project type, scale, time, distance, risk, and location. The model developed by this study provides a novel construct for examining the efficiency of competing projects, and it could substantially improve the return on investment from millions in state and federal dollars slated for coastal restoration in Louisiana.

The primary finding of this research is that the relatively slow rate of restoration is a major, negative factor on the economic feasibility of diversion projects. Advocates for large-scale diversion projects will be encouraged to see that the economic comparisons from this study support their arguments in certain cases. In reality, however, there are very few locations in coastal Louisiana where large-scale diversions can be built without major public impacts (i.e. the lower Mississippi River below Venice and the lower Atchafalaya River below Morgan City). Because other locations in the middle to upper estuary along Mississippi River and Atchafalaya River are populated, policy evaluation of diversion projects in these areas requires the addition of pre-emptive compensation and/or relocation costs and various other forms of impact payments. Without considering these social costs, any economic comparison of diversions in the middle to upper estuary are largely incomplete.

Rapid land building projects, by comparison, have much higher initial cost, but restore land very rapidly, which is assumed to be very important to combat rapid land loss in coastal Louisiana. Otherwise, the long-term sustainability of these marsh creation projects is problematical because of sea level rise and erosion. The most important finding from the majority of case study is that the required break-even value ($/acre/year) is well above the publication of non-market value. This finding suggests that wetland restoration planners need to revisit spending practices to ensure the most effective combination of project attributes to ensure that public dollars are spent efficiently, and produce higher benefits for coastal Louisiana.

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APPENDIX A: CORRELATION ANALYSIS FOR MC PROJECT BASED ON HISTORIC DATA

The CORR Procedure

Pearson Correlation Coefficients, N = 12 Prob > |r| under H0: Rho=0									
	PPL	**CYD**	**PBA**	**DIST**	**MOB**	**DS**	**PYT**	**BP**	**AAHU**
PPL	1.00000	-0.37325 0.2321	-0.01867 0.9541	0.41203 0.1832	0.81245 0.0013	0.41420 0.1807	-0.10650 0.7418	0.24185 0.4489	-0.08815 0.7853
CYD	-0.37325 0.2321	1.00000	-0.18345 0.5682	-0.31454 0.3194	-0.35525 0.2571	0.13159 0.6835	0.27352 0.3897	-0.05518 0.8648	0.21062 0.5111
PBA	-0.01867 0.9541	-0.18345 0.5682	1.00000	-0.37723 0.2267	-0.06105 0.8505	-0.64534 0.0234	-0.28575 0.3679	-0.37797 0.2257	0.58027 0.0479
DIST	0.41203 0.1832	-0.31454 0.3194	-0.37723 0.2267	1.00000	0.73836 0.0061	0.36876 0.2382	0.33099 0.2933	0.56758 0.0542	-0.58245 0.0469
MOB	0.81245 0.0013	-0.35525 0.2571	-0.06105 0.8505	0.73836 0.0061	1.00000	0.35123 0.2629	0.08814 0.7853	0.52181 0.0818	-0.31710 0.3152
DS	0.41420 0.1807	0.13159 0.6835	-0.64534 0.0234	0.36876 0.2382	0.35123 0.2629	1.00000	0.19127 0.5515	0.68584 0.0138	-0.39654 0.2019
PYT	-0.10650 0.7418	0.27352 0.3897	-0.28575 0.3679	0.33099 0.2933	0.08814 0.7853	0.19127 0.5515	1.00000	0.47809 0.1159	-0.04322 0.8939
BP	0.24185 0.4489	-0.05518 0.8648	-0.37797 0.2257	0.56758 0.0542	0.52181 0.0818	0.68584 0.0138	0.47809 0.1159	1.00000	-0.31896 0.3123
AAHU	-0.08815 0.7853	0.21062 0.5111	0.58027 0.0479	-0.58245 0.0469	-0.31710 0.3152	-0.39654 0.2019	-0.04322 0.8939	-0.31896 0.3123	1.00000

APPENDIX B: CORRELATION ANALYSIS AND NORMALITY TEST FOR MC PROJECT ON PHYSICAL MATERIAL MODEL

The CORR Procedure

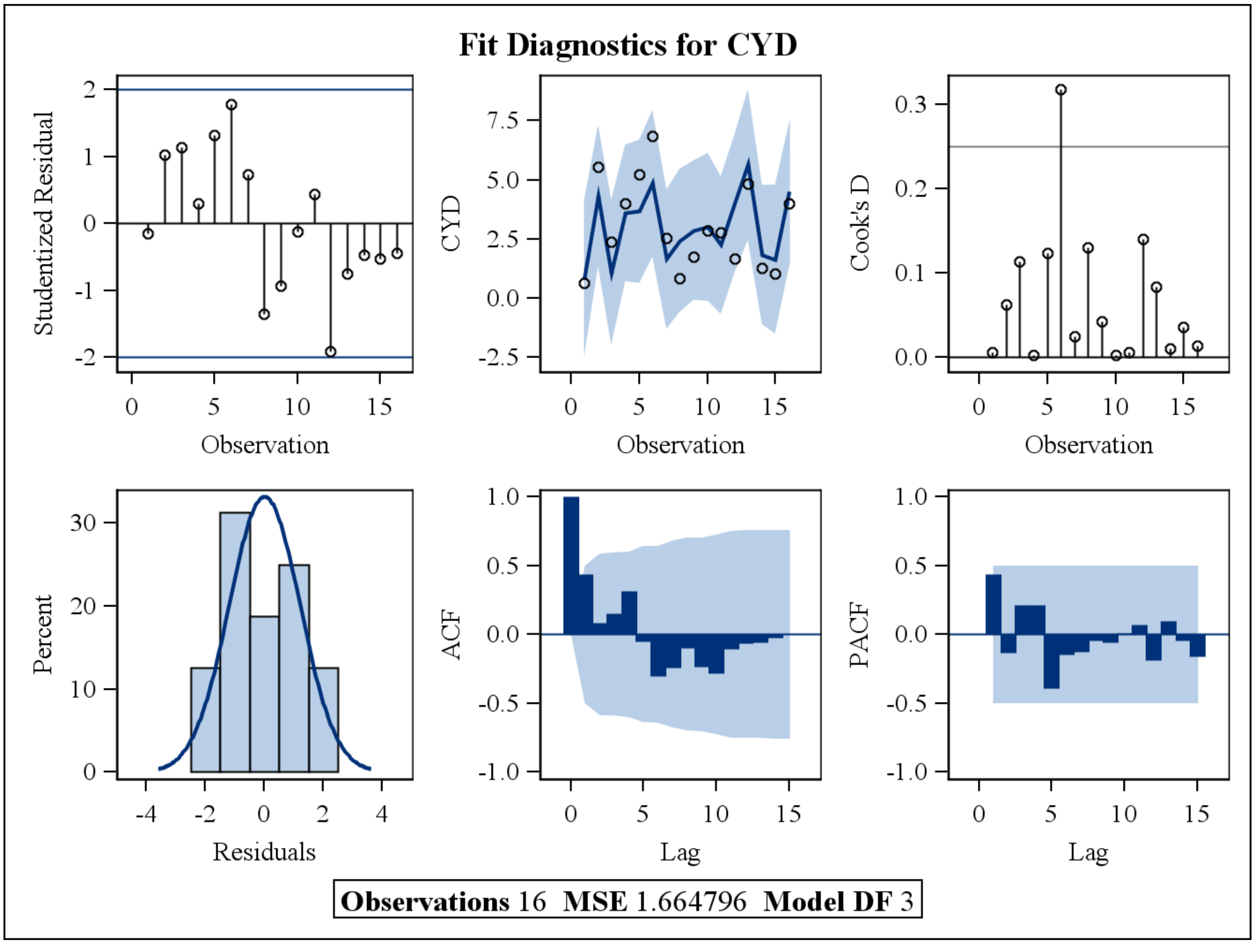
Pearson Correlation Coefficients, N = 16 Prob > |r| under H0: Rho=0		
	NET	**AVE**
NET	1.00000	-0.29453 0.2681
AVE	-0.29453 0.2681	1.00000

The AUTOREG Procedure

Ordinary Least Squares Estimates			
SSE	21.6423513	**DFE**	13
MSE	1.66480	**Root MSE**	1.29027
SBC	58.5568133	**AIC**	56.2390471
MAE	0.97895657	**AICC**	58.2390471
MAPE	47.1761888	**HQC**	56.3577358
Durbin-Watson	1.1084	**Regress R-Square**	0.5883
		Total R-Square	0.5883

Miscellaneous Statistics			
Statistic	**Value**	**Prob**	**Label**
Normal Test	0.3941	0.8212	Pr > ChiSq

Parameter Estimates					
Variable	**DF**	**Estimate**	**Standard Error**	**t Value**	**Approx Pr > |t|**
Intercept	1	4.5020	1.9468	2.31	0.0378
NET	1	0.005445	0.001876	2.90	0.0123
AVE	1	-1.3073	0.5970	-2.19	0.0474

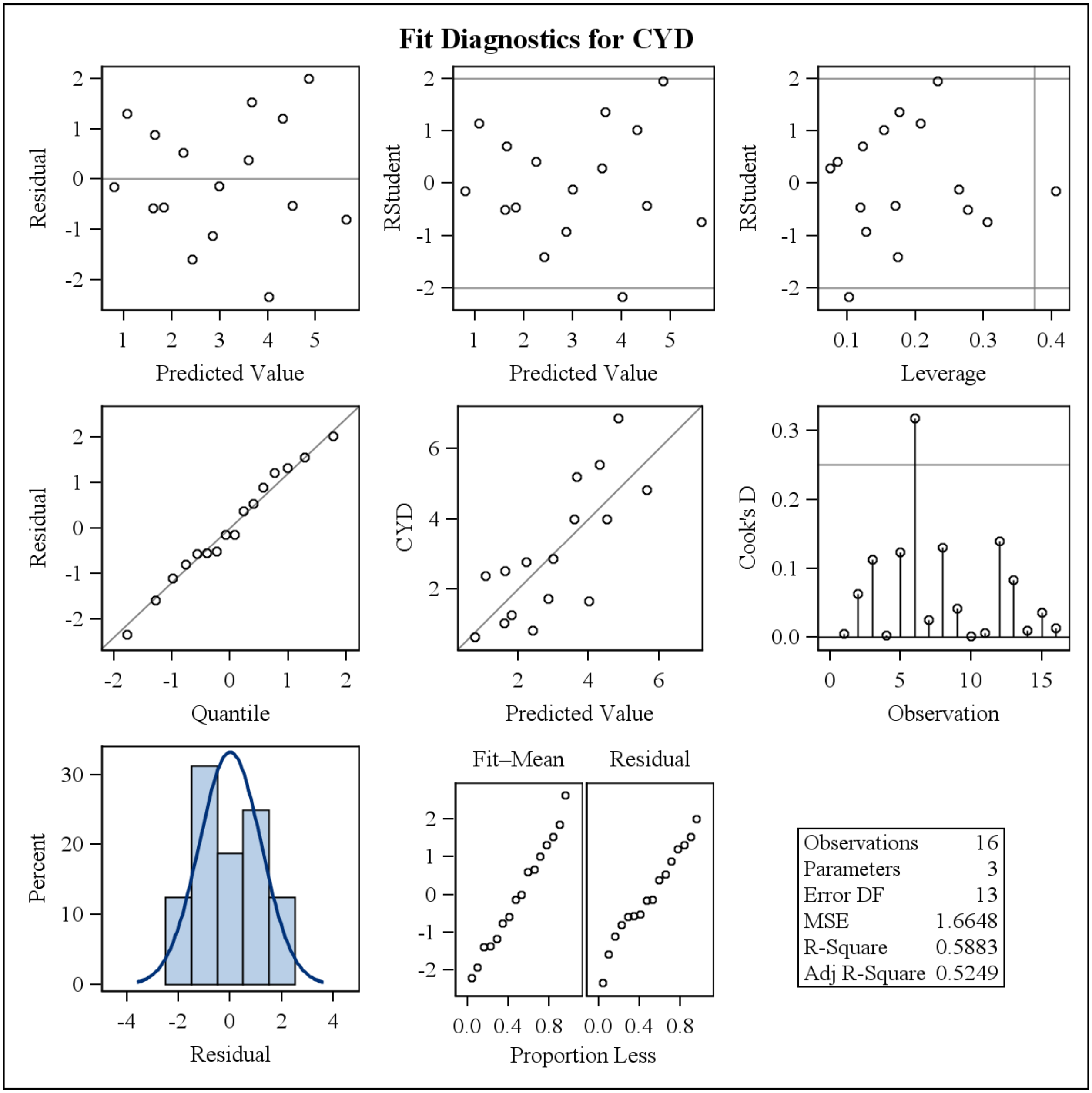


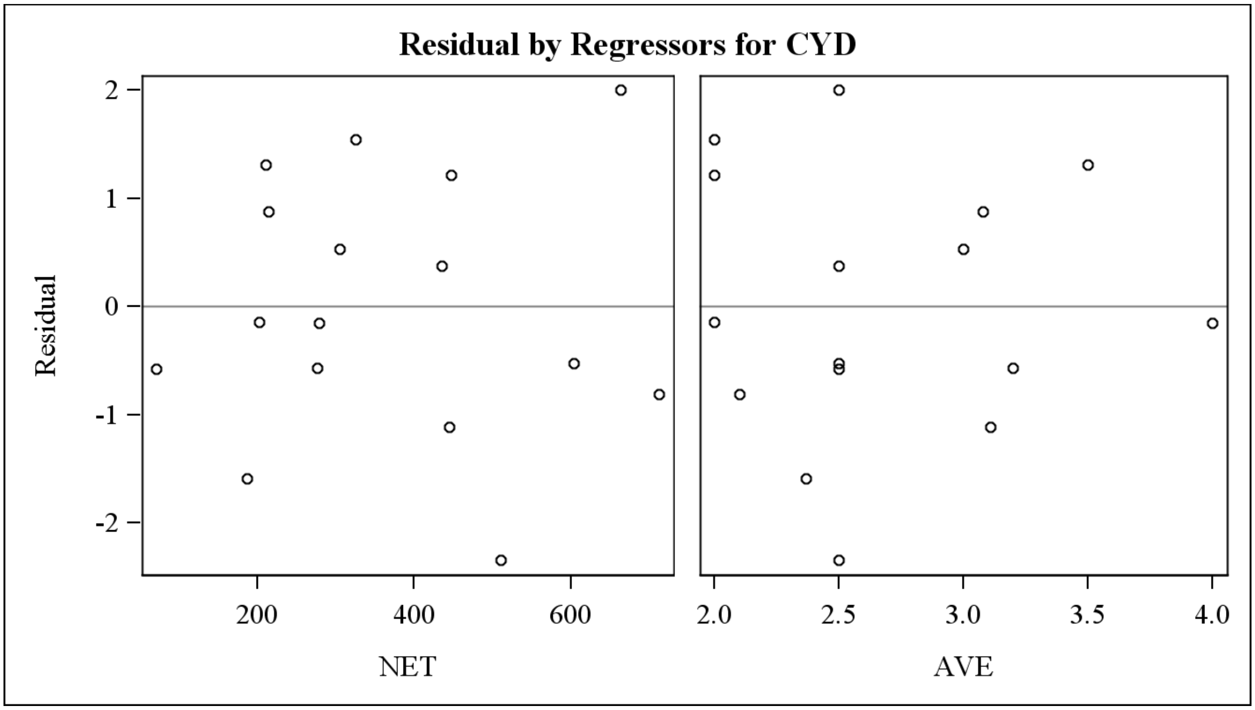
The REG Procedure

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	30.92424	15.46212	9.29	0.0031
Error	13	21.64235	1.66480		
Corrected Total	15	52.56659			

Root MSE	1.29027	**R-Square**	0.5883
Dependent Mean	3.00563	**Adj R-Sq**	0.5249
Coeff Var	42.92850		

Parameter Estimates							
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Tolerance	Variance Inflation
Intercept	1	4.50205	1.94679	2.31	0.0378	.	0
NET	1	0.00544	0.00188	2.90	0.0123	0.91325	1.09499
AVE	1	-1.30727	0.59703	-2.19	0.0474	0.91325	1.09499




Residual by Regressors for CYD
Residual
2
1
0
-1
-2
200
400
600
NET
2.0
2.5
3.0
3.5
4.0
AVE

The UNIVARIATE Procedure

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	**W**	0.979635	**Pr < W**	0.9606
Kolmogorov-Smirnov	**D**	0.109824	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.028258	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.173898	**Pr > A-Sq**	>0.2500

```
Stem Leaf          #  Boxplot
   2 0             1     |
   1 5             1     |
   1 23            2  +-----+
   0 59            2  |     |
   0 4             1  |  +  |
  -0 21            2  *-----*
  -0 8665          4  +-----+
  -1 1             1     |
  -1 6             1     |
  -2 3             1     |
    ----+----+----+----+
```

```
                Normal Probability Plot
 2.25+                              +*++
     |                          *+++
     |                       *+*++
 0.75+                       *+*++
     |                   ++*++
     |                 +++* *
-0.75+                 *+*+* *
     |            ++*+
     |          +++*
-2.25+        ++*+
      +----+----+----+----+----+----+----+----+----+----+
         -2      -1       0      +1      +2
```

APPENDIX C: CORRELATION ANALYSIS FOR BI PROJECT BASED ON HISTORIC DATA

The CORR Procedure

Pearson Correlation Coefficients, N = 11 Prob > |r| under H0: Rho=0							
	PPL	**CYD**	**PBA**	**DIST**	**MOB**	**PYT**	**AAHU**
PPL	1.00000	0.00396 0.9908	-0.36714 0.2667	0.76533 0.0061	0.25371 0.4516	0.86949 0.0005	0.05846 0.8644
CYD	0.00396 0.9908	1.00000	-0.54582 0.0824	-0.02875 0.9331	0.25671 0.4461	-0.12813 0.7073	-0.09084 0.7905
PBA	-0.36714 0.2667	-0.54582 0.0824	1.00000	-0.37239 0.2594	-0.41160 0.2085	-0.36734 0.2664	0.27576 0.4118
DIST	0.76533 0.0061	-0.02875 0.9331	-0.37239 0.2594	1.00000	0.39184 0.2333	0.86757 0.0005	-0.07432 0.8281
MOB	0.25371 0.4516	0.25671 0.4461	-0.41160 0.2085	0.39184 0.2333	1.00000	0.44888 0.1661	-0.26769 0.4261
PYT	0.86949 0.0005	-0.12813 0.7073	-0.36734 0.2664	0.86757 0.0005	0.44888 0.1661	1.00000	0.01286 0.9701
AAHU	0.05846 0.8644	-0.09084 0.7905	0.27576 0.4118	-0.07432 0.8281	-0.26769 0.4261	0.01286 0.9701	1.00000

APPENDIX D: CORRELATION ANALYSIS AND NORMALITY TEST FOR BI PROJECT ON PHYSICAL MATERIAL MODEL

The CORR Procedure

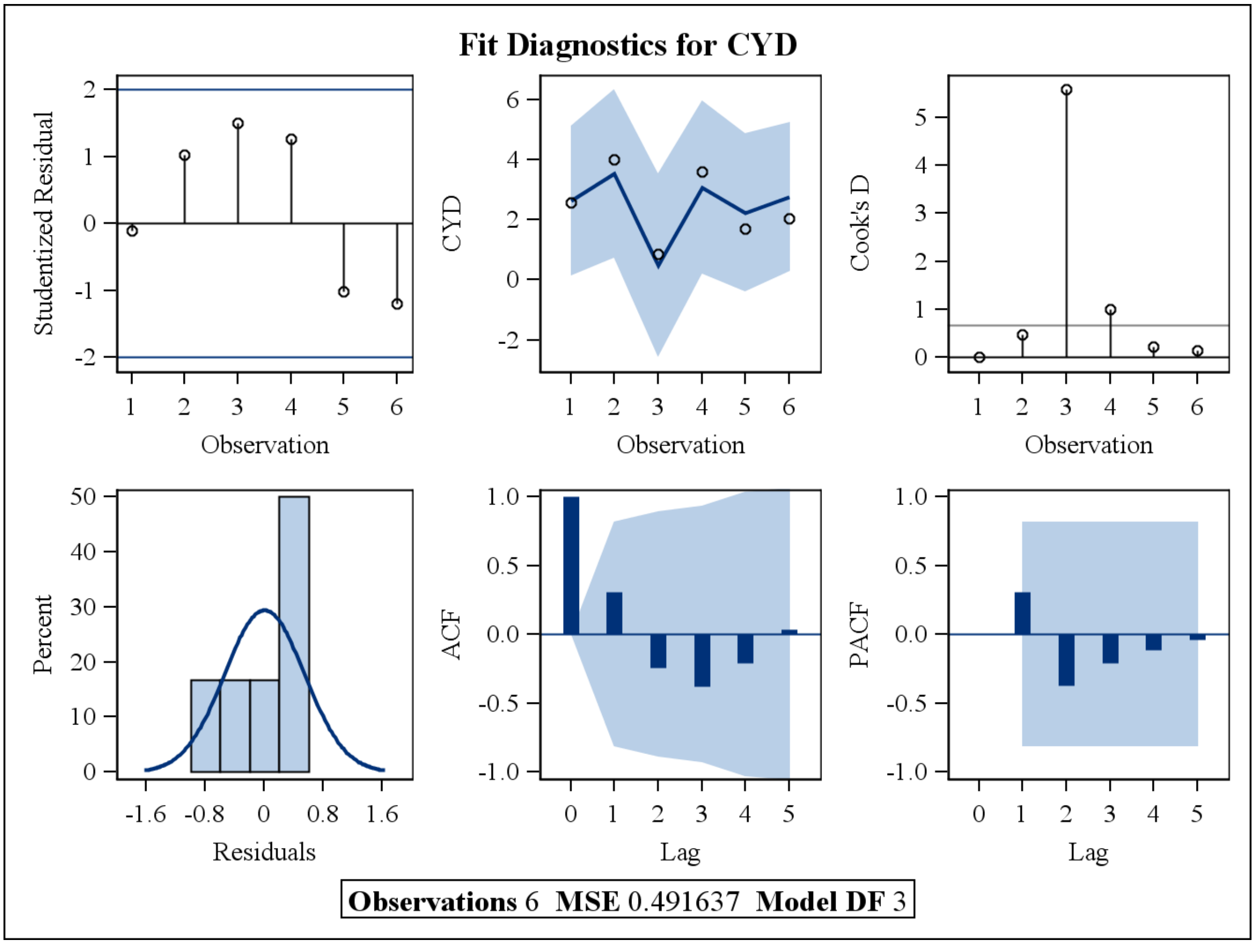
Pearson Correlation Coefficients, N = 6 Prob > |r| under H0: Rho=0		
	NET	**AVE**
NET	1.00000	-0.33591 0.5151
AVE	-0.33591 0.5151	1.00000

The AUTOREG Procedure

Ordinary Least Squares Estimates			
SSE	1.47491092	**DFE**	3
MSE	0.49164	**Root MSE**	0.70117
SBC	13.9835696	**AIC**	14.6082912
MAE	0.45127644	**AICC**	26.6082912
MAPE	23.5066878	**HQC**	12.1074797
Durbin-Watson	1.0212	**Regress R-Square**	0.7931
		Total R-Square	0.7931

Miscellaneous Statistics			
Statistic	**Value**	**Prob**	**Label**
Normal Test	0.7389	0.6911	Pr > ChiSq

Parameter Estimates					
Variable	**DF**	**Estimate**	**Standard Error**	**t Value**	**Approx Pr > |t|**
Intercept	1	0.001671	1.9391	0.00	0.9994
NET	1	0.0127	0.004222	3.00	0.0576
AVE	1	-0.2723	0.5673	-0.48	0.6641

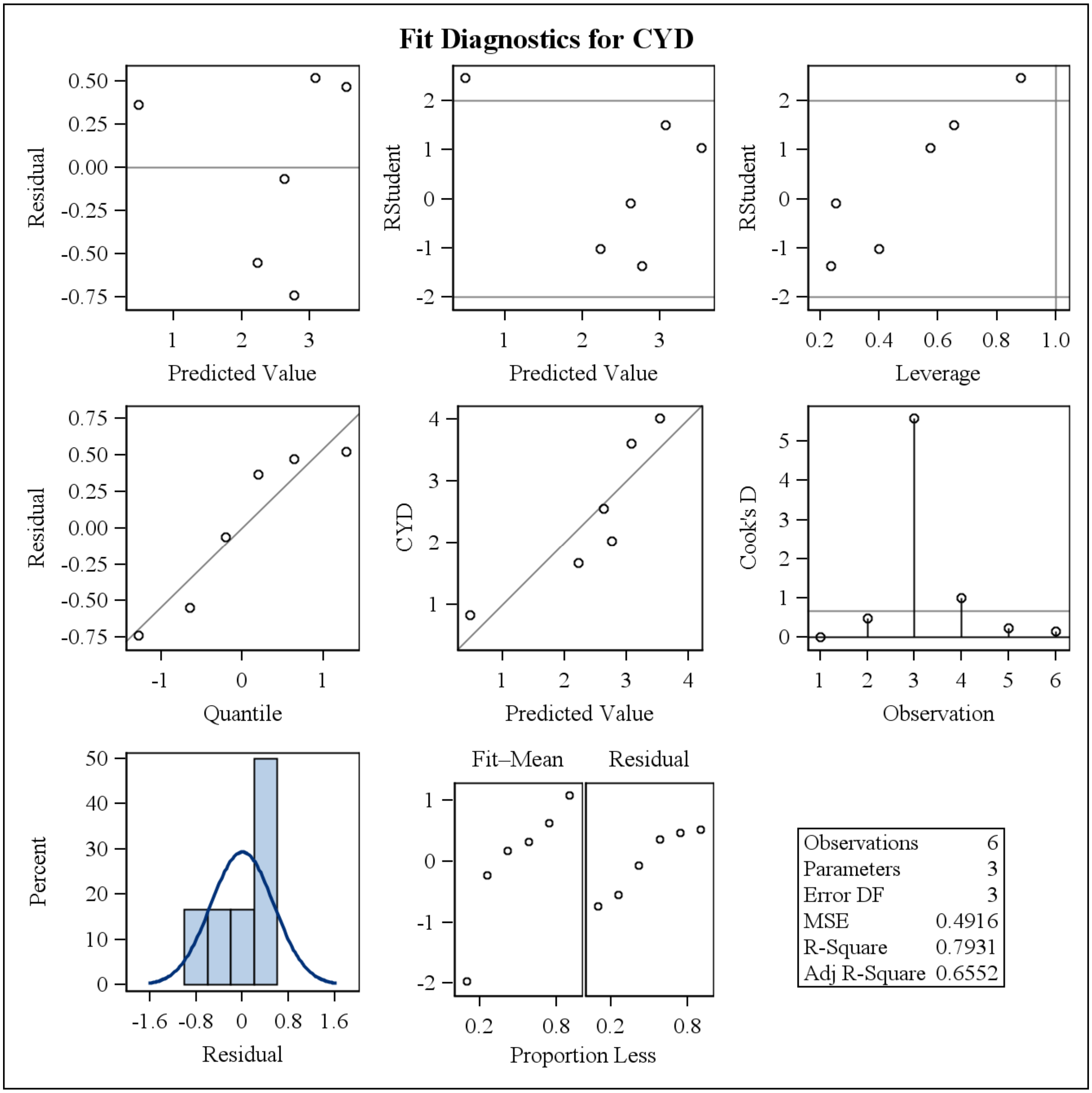


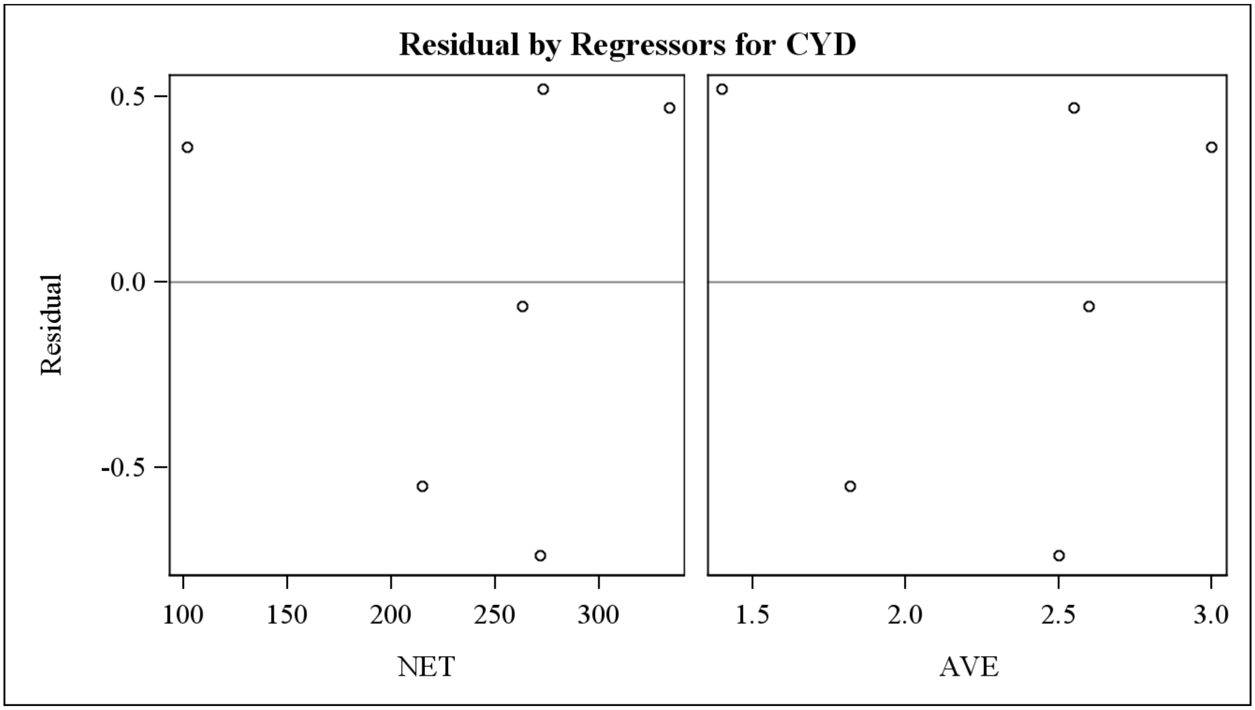
The REG Procedure

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5.65462	2.82731	5.75	0.0941
Error	3	1.47491	0.49164		
Corrected Total	5	7.12953			

Root MSE	0.70117	**R-Square**	0.7931
Dependent Mean	2.45333	**Adj R-Sq**	0.6552
Coeff Var	28.58023		

Parameter Estimates							
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**	**Tolerance**	**Variance Inflation**
Intercept	1	0.00167	1.93911	0.00	0.9994	.	0
NET	1	0.01267	0.00422	3.00	0.0576	0.88716	1.12719
AVE	1	-0.27226	0.56727	-0.48	0.6641	0.88716	1.12719




Residual by Regressors for CYD
Residual
0.5
0.0
-0.5
100
150
200
250
300
NET
1.5
2.0
2.5
3.0
AVE

The UNIVARIATE Procedure

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	**W**	0.870656	**Pr < W**	0.2288
Kolmogorov-Smirnov	**D**	0.247887	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.061706	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.388237	**Pr > A-Sq**	>0.2500

```
Stem Leaf                  #  Boxplot
   4 72                    2  +-----+
   2 6                     1  |     |
   0                          *--+--*
  -0 7                     1  |     |
  -2                          |     |
  -4 5                     1  +-----+
  -6 4                     1     |
     ----+----+----+----+
 Multiply Stem.Leaf by 10**-1
```

```
                Normal Probability Plot
  0.5+                         * ++++ *
     |                      * ++++
     |                     ++++
 -0.1+                     +*+
     |                  ++++
     |               ++++ *
 -0.7+              +*+
      +----+----+----+----+----+----+----+----+----+----+
          -2        -1         0        +1        +2
```

APPENDIX E: CORRELATION ANALYSIS AND NORMALITY TEST FOR FWD PROJECT ON TOTAL COST MODEL

The CORR Procedure

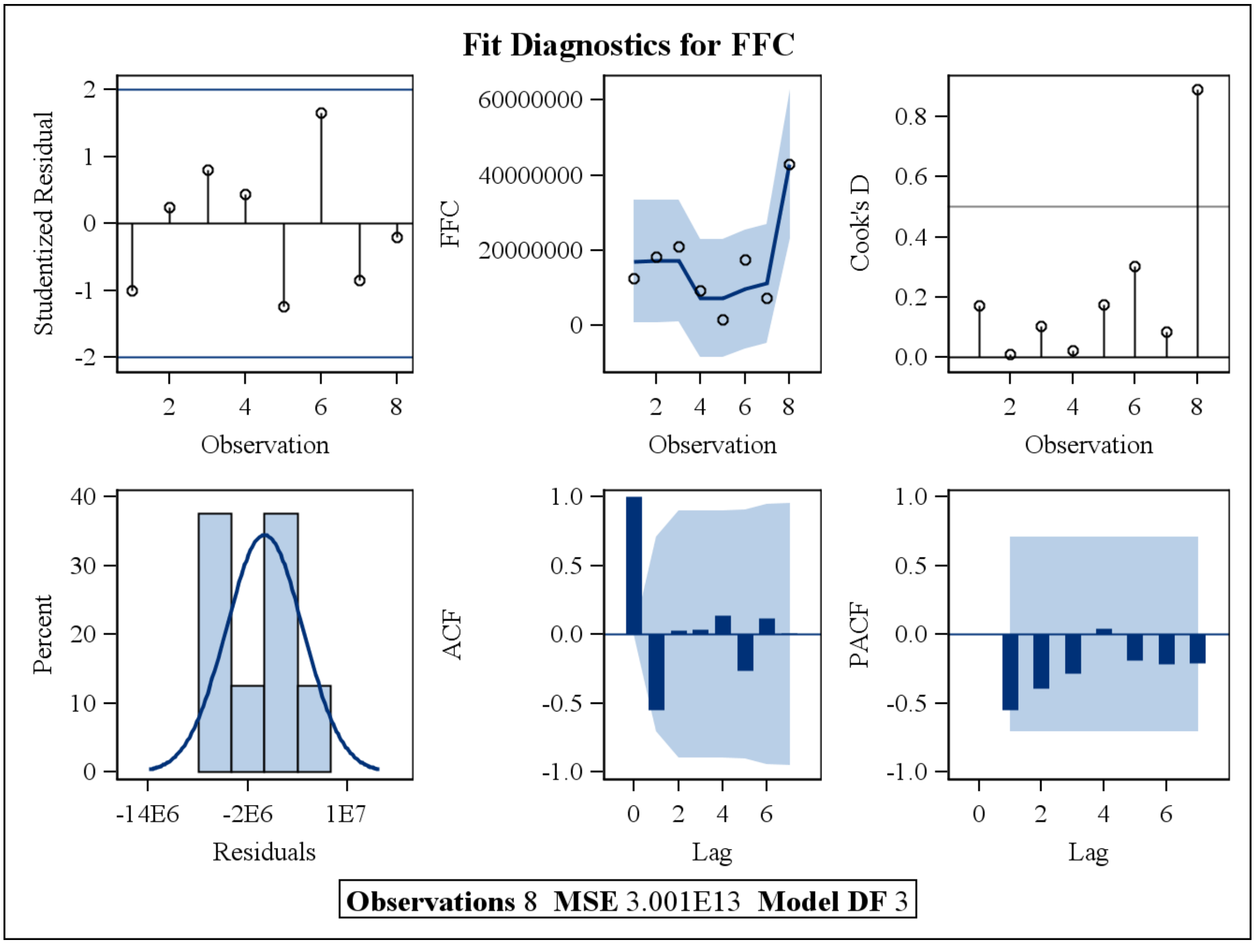
Pearson Correlation Coefficients, N = 8 Prob > |r| under H0: Rho=0		
	CFS	**CON**
CFS	1.00000	0.23442 0.5763
CON	0.23442 0.5763	1.00000

The AUTOREG Procedure

Ordinary Least Squares Estimates			
SSE	1.50046E14	**DFE**	5
MSE	3.00092E13	**Root MSE**	5478063
SBC	273.441507	**AIC**	273.203182
MAE	3632945.48	**AICC**	279.203182
MAPE	72.8956964	**HQC**	271.595778
Durbin-Watson	2.9631	**Regress R-Square**	0.8630
		Total R-Square	0.8630

Miscellaneous Statistics			
Statistic	**Value**	**Prob**	**Label**
Normal Test	0.3979	0.8196	Pr > ChiSq

Parameter Estimates					
Variable	**DF**	**Estimate**	**Standard Error**	**t Value**	**Approx Pr > |t|**
Intercept	1	6024854	2825933	2.13	0.0862
CFS	1	521.5263	126.4396	4.12	0.0091
CON	1	10894218	3984605	2.73	0.0411

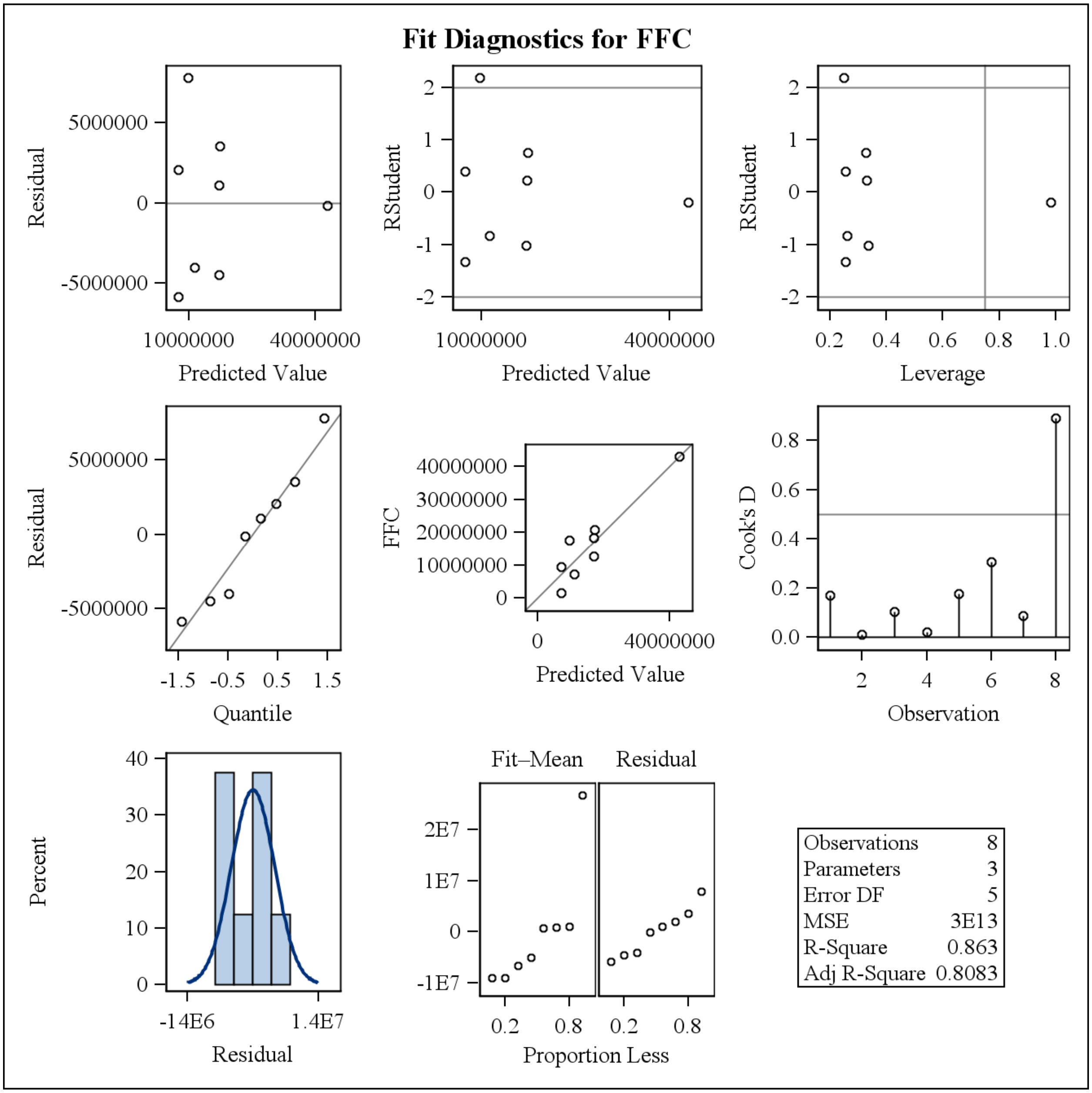


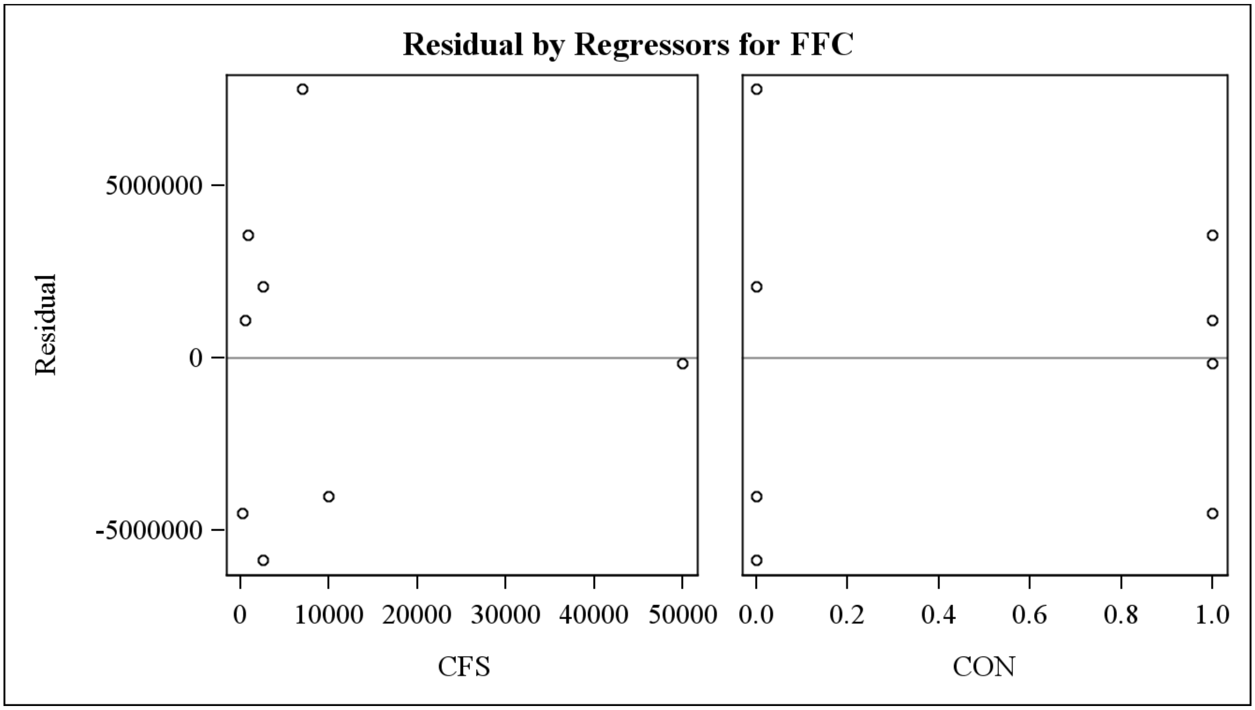
The REG Procedure

Analysis of Variance					
Source	**DF**	**Sum of Squares**	**Mean Square**	**F Value**	**Pr > F**
Model	2	9.454999E14	4.7275E14	15.75	0.0069
Error	5	1.500459E14	3.000918E13		
Corrected Total	7	1.095546E15			

Root MSE	5478063	**R-Square**	0.8630
Dependent Mean	16266745	**Adj R-Sq**	0.8083
Coeff Var	33.67645		

Parameter Estimates							
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	Tolerance	Variance Inflation
Intercept	1	6024854	2825933	2.13	0.0862	.	0
CFS	1	521.52627	126.43960	4.12	0.0091	0.94505	1.05815
CON	1	10894218	3984605	2.73	0.0411	0.94505	1.05815





Residual by Regressors for FFC
Residual
5000000
0
-5000000
0
10000
20000
30000
40000
50000
CFS
0.0
0.2
0.4
0.6
0.8
1.0
CON

The UNIVARIATE Procedure

Tests for Normality				
Test	**Statistic**		**p Value**	
Shapiro-Wilk	**W**	0.953967	**Pr < W**	0.7511
Kolmogorov-Smirnov	**D**	0.181983	**Pr > D**	>0.1500
Cramer-von Mises	**W-Sq**	0.031812	**Pr > W-Sq**	>0.2500
Anderson-Darling	**A-Sq**	0.222577	**Pr > A-Sq**	>0.2500

```
 Stem Leaf              #  Boxplot
    6 8                 1     |
    4                         |
    2 16                2  +-----+
    0 1                 1  *--+--*
   -0 1                 1  |     |
   -2                      |     |
   -4 950               3  +-----+
      ----+----+----+----+
 Multiply Stem.Leaf by 10**+6
```

```
                     Normal Probability Plot
 7000000+                               +*+++
        |                          ++++
        |                        *+++*
 1000000+                         ++*++
        |                  ++*+
        |                ++++
-5000000+           * +++*    *
         +----+----+----+----+----+----+----+----+----+----+
              -2        -1         0        +1        +2
```

APPENDIX F: NPV MODEL ASSUMPTIONS FOR MC, BI, AND FWD PROJECTS

Land Building Cost and Benefit Assumptions (MC, BI, and FWD)

	User Specified	Range		
	Derived	Low	High	Mean
Time period (yrs)	20	20	50	20
Desired Acreage	1,000	300	10,000	1000
Elevation	2	1.5	3.5	2.44
Depth	4	2.5	5.5	3.78
Discount rate	0.04	0	0.15	0.04
Water Flow Rate- FWD 2 (Boustany)	1,029			1000
Mob/Demob($)	$1,000,000	$110,000	$4,000,000	$1,000,000
Distance (Miles)	4.00	1	50	4
Access Dredging/Channel ($)	$600,000	$0	$2,000,000	$600,000
E&D Lag (MC)	4	2	7	4
E&D Lag (BI)	4	1	6	4
E&D Lag (FWD)	7	1	30	7
Projected Construction Costs	85%	50%	90%	85%
Projected E&D cost	10%	5%	30%	15%
Projected O&M cost	5%	1%	20%	5%
Market Value of Land ($/acre)	$0			
Hurricane probability (Klotzbach and Gray 2010)	20%	15%	30%	20%
Starting Ecosystem Value (Habitat) $/acre/year	$249	$169	$403	$249
Starting Ecosystem Value (Water Quality) $/acre/year	$825	$3	$5,674	$825
Starting Ecosystem Value (Storm Surge Protection) $/acre/year	$3,336	$101	$20,648	$3,336
Region-Specific Land Loss Rate (Coast 2050)	0.003	0.0003	0.007	0.003
Longshore Sediment Transport rate BI projects only	0	0	0.01	0.008
Net Accretion Rate for BI	-0.003	-0.0003	0.003	0.005
Starting Ecosystem Value - Aggregate ($/acre/year)	$4,410	$273	$26,725	$4,410
Total Sediments-MC (cuyds MM, Eq. 3.3)	7.22			
Total Sediments-BI (cuyds MM, Eq. 3.6)	6.00			
Water Flow Rate- FWD 1(cfs, Eq. 3.9)	16,749			
Construction Cost-MC (Eq. 4.4)	$37,767,448			
E&D cost-MC	$4,443,229			
O&M cost-MC	$2,221,615			
Total Fully Funded Cost-MC	$44,432,291			
Construction Cost-BI (Eq. 4.9)	$27,703,380			
E&D cost-BI	$3,259,221			
O&M cost-BI	$1,629,611			
Total Fully Funded Cost-BI	$32,592,212			

Table continued

Construction Cost-FWD1	$21,806,015		
E&D cost-FWD 1	$2,565,414		
O&M cost-FWD1	$1,282,707		
Total Fully Funded Cost-FWD1(Eq. 4.14)	$25,654,136		
Construction Cost-FWD2	$14,837,364		
E&D cost-FWD 2	$1,745,572		
O&M cost-FWD2	$872,786		
Total Fully Funded Cost-FWD2(Eq. 4.14)	$17,455,723	**Risk1**	**Risk2**
Annual Break-Even Benefits-MC ($/acre/year)	$420	$4,222	$4,187
Annual Break-Even Benefits-BI ($/acre/year)	$399	$3,059	$3,028
Annual Break-Even Benefits-FWD1 ($/acre/year)	$988	$8,727	$9,514
Annual Break-Even Benefits-FWD2 ($/acre/year)	$3,923	$5,736	$6,230
Percent Acreage Loss with a Major Hurricane(Fixed)	**0.25**		
Percent Acreage Loss with a Major Hurricane (%comp <=.2)	**0.8**		
Percent Acreage Loss with a Major Hurricane (%comp <=.4)	**0.6**		
Percent Acreage Loss with a Major Hurricane (%comp <=.6)	**0.4**		
Percent Acreage Loss with a Major Hurricane (%comp <=.8)	**0.2**		
Long-term Avg. Operational Constraint to diversions (%)	**0.23**	13%	23%

VITA

Hua Wang graduated from Xiangtan University in Hunan Province, China, in May 2002, where he received the title of Bachelor in Business Management. After the completion of this degree, he worked five years and came to Louisiana State University to pursue his master degree studying at the Department of Agricultural Economics in 2009 Spring. He is expecting to get the degree of Master of Science in Spring, 2012.