AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

An Economic Assessment of Competing Technologies for Coastal Restoration

[1]Hua Wang, [2]Rex H. Caffey, and [3]Daniel R. Petrolia

[1]Graduate Research Assistant
Center for Natural Resource Economics & Policy
Department of Agricultural Economics
Louisiana State University
hwang23@tigers.lsu.edu

[2]Professor,
Center for Natural Resource Economics & Policy
Department of Agricultural Economics
Louisiana State University Agricultural Center
Louisiana Sea Grant College Program
rcaffey@agcenter.lsu.edu

[3]Assistant Professor
Department of Agricultural Economics
Mississippi State University
petrolia@agecon.msstate.edu

Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Birmingham, AL, February 4-7, 2012

Copyright 2012 by Hua Wang, Rex H. Caffey, and Daniel R. Petrolia. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided this copyright notice appears on all such copies.

Background

In the wake of Hurricane Katrina, the Louisiana Coastal Protection and Restoration Authority (CPRA) was established in an attempt to integrate programs for habitat restoration and infrastructure protection. The Authority has begun aligning the state's coastal spending to reflect increasing public interest in the aggressive restoration of surface acreage. Concurrent with this change, there has been increased public interest on rapid land building (RLB) techniques that rely on mechanical dredges and sediment conveyance pipelines for marsh creation. To some degree, this more aggressive approach to restoration is indicative of the recognition that time is a major limiting factor in addressing land loss in coastal Louisiana.

Given increasing support for aggressive restoration, the costs and benefits of RLB projects are increasingly compared to the more "natural" method of fresh water/sediment diversions (DIV). Such cost-benefit comparisons are central to the ideological and economic debate over which restoration technique provides the most sustainable and cost-effective provision of ecological services. Petrolia et al. (2009) explored measures of cost-effectiveness for land building technologies, focusing primarily on the sediment dredging costs associated with increases in project acreage. This research extends that analysis by incorporating time and risk considerations into cost-benefit comparisons of RLB and DIV projects for wetland restoration in Louisiana.

Objectives, Data, and Methods

The overall goal of this study was to develop a comparative assessment of RLB and DIV methods for coastal land-building. Specific objectives included: 1) estimating generic models of costs and benefits by technology; 2) conducting sensitivity analyses with varying degrees of risk; and, 3) performing case-studies to illustrate economic tradeoffs between and within technologies.

For objective one, 20 years of federal restoration program data were collected for more than 146 authorized projects and projects bids submitted the Coastal Wetland Planning Protection and Restoration Act (CWPPRA), the Coastal Impact Assistance Program (CIAP), and the Louisiana Coastal Area (LCA) Comprehensive Ecosystem Study. Projected acreage data were used to construct generic restoration trajectories by technology and generic cost models were constructed via regression analysis using technology-specific cost estimates for marsh creation projects (MC, n=69) and diversions (DIV_1, n=25). Additionally, an exogenous model of diversion benefits (DIV_2) was utilized to capture a wider suite of nutrient and sediment contributions at specific flow rates (Boustany 2010).

For objectives two and three, generic models were incorporated into a net present valuation framework and sensitivity analyses were conducted to examine the relative importance of specific project attributes. Average parameters were used to develop baseline benefit-cost (B:C) projections and simulations were conducted by allowing a single, user-specified parameter to vary across its known range and solving for the break-even ecosystem service value ($/acre/year) in which the B:C ratio was equal to 1.0. Risk assessments were conducted using an expected valuation framework incorporating data on hurricane landfall probability and measures of social constraints specific to diversions. Case study simulations were developed for lower and upper estuary locations to capture project and site-specific opportunities and constraints (Wang 2011).

Generic Benefit Models

Data for the development of a RLB benefit trajectory were obtained from technical review documents containing inter-period acreage projections over a 20 year project life time. Figure 1 depicts an average restoration trajectory derived from six typical MC projects. After a project is authorized, the generic trajectory is delayed by an average of four years, during which engineering and design considerations are finalized. During this period, 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.

As evident from these curves, marsh creation projects usually follow a sigmoid trajectory, in which net acres accrue rapidly between years 4-6 and slowly decline afterwards, due to erosion. Some projects initially have negative net acres prior to year four, due to wetlands lost in channel and containment dike construction. All of the projects, however, achieve the proposed net acres within 2 years' time period due to rapid placement of sediment from either a dredge or dredge pipeline. Afterwards, net acreages are either constant or slightly decreasing as new land settles (reduction in elevation) or is eroded. A global curve can be estimated for these projects (based on percentage of project completion) to produce the generic construction trajectory for marsh creation projects. Using regression techniques, an estimated trajectory based on these data is developed in which T_{MC} is percentage completion of project trajectory and t is time period expressed in years (R^2=0.90):

$$T_{MC} = \frac{1}{(1 + EXP(-(t - 0.96)/0.08))} \tag{1}$$

Data for the development of a diversion benefit trajectory were obtained from technical review documents containing inter-period acreage projections over a 20 year project life time. Figure 2 depicts an average restoration trajectory derived from six typical DIV_1 projects. After a project is authorized the generic trajectory is delayed by an average of seven years, during which engineering and design considerations are finalized. The extended lag period for diversions is typically attributable to social constraints, given the wider range of property affected by these projects.

As evident from these curves, diversion projects follow a linear trajectory, in which net acreage is assumed to increase at a slow, constant rate over the project life time. It is important to note that the generic trajectory here is a cumulative percentage of net acre accrual. With erosion and natural land accrual rates held constant, these generic trajectories depict a gradual and stable rate of benefit increase after construction of the project structure. This rate is depicted by an estimated trajectory in which T_{DIV} is percentage of net acres accrued and t is time period expressed in years (R^2=0.99)

$$T_{DIV} = -0.0029 + 0.0501 * t \tag{2}$$

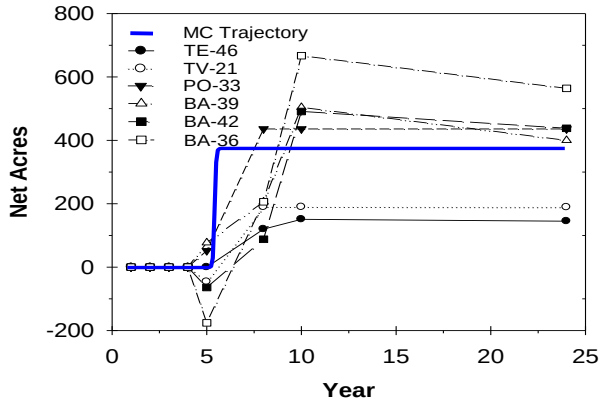

Figure 1. Marsh creation benefit trajectories

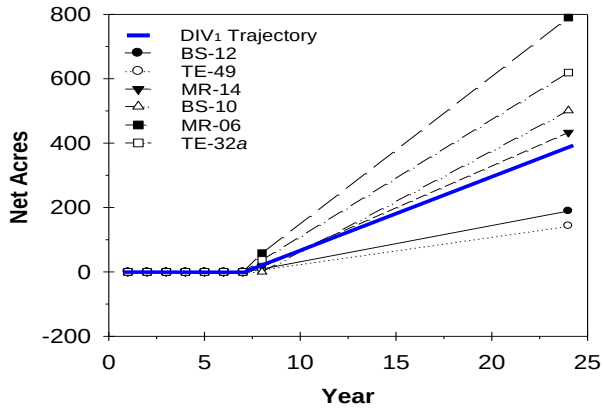

Figure 2. Diversion benefit trajectories

Generic Cost Models

A total of 34 MC project bids were examined to develop a 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 assumption is that the construction costs (CC_{MC}) of marsh creation projects has a linear relationship with cubic yards dredged material **(***CYD)*, the costs of mobilization and demobilization of dredging equipment (*MOB)*, sediment delivery distance (*DIST)*, and access dredging costs **(***AD)*. Data for the MC construction cost model were imported and analyzed into statistical programs SAS 9.1. The resulting analysis is contained in Table 1.

Table 1. Parameter Estimates : CC_{MC}

N=34
R-square = 0.94 Adj R-sqr = 0.92

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	2.74	0.91	3.01	0.0053	3.69121
DIST	2379910	1084981	2.19	0.0364	2.59813
AD	15.11	2.74	5.52	<.0001	3.28683

Variables, CYD, MOB, DIST and AD, were found to be 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:

$$CC_{MC} = -1507336 + 2486867 * CYD + 2.74 * MOB + 2379910 * DIST + 15.11 * AD \qquad (3)$$

Developing a comprable generic cost model for diversion projects is confounded by two limitations. First, there are very few of these projcts available (either constructed or pending) from which to develop cost projections. Secondly, the cost estimates for diversion projects are less specified, which limits the chgaracterization of their ccosts. Because detailed construction costs are were not available at the time of this research, the generic model was developed using the total (fully-funded) cost (TC) estimates as the dependent variable.

Restoration project materials (sediments and nutrients) for DIV projects are not delivered by dredge or pipeline conveyance, but instead are delivered via river water. Thus, the size and capacity of a diversion – as expressed by average annual flow rate (CFS) – is expected to 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 DIV projects were available for the development of a generic cost model for DIV projects. Data for the model were imported and analyzed into statistical programs SAS 9.1. The resulting analysis is contained in Table 2.

Table 2. Parameter Estimate : TC_{DIV}

N=8
R-square = 0.86 Adj R-sqr = 0.80

Variable	Parameter Estimate	Standard Error	t Value	Pr > |t|	Variance Inflation
Intercept	-1507336	1676901	-0.90	0.3761	0
CFS	522	126	4.12	0.0091	1.05815
CON	10894218	3984605	2.73	0.0411	1.05815

Given the limited data, this basic model shows that independent variables, CFS and CON, are significant predictors of total project costs[1] at ten percent significance level (α=0.10 R^2=0.86). Based on the statistical analyses, the linear regression model for DIV projects is given by:

$$TC_{DIV} = 6024854 + 522 * CFS + 10894218 * CON \tag{4}$$

Break-Even Simulations

The generic benefit and cost models were incorporated into a net present valuation construct developed within Microsoft Excel 2010. Net present value (NPV) is the current value of all project net benefits at a particular discount rate, expressed as the sum of discounted benefits minus discounted costs. The basic formula for NPV is given by:

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+R)^t} = \sum_{t=0}^{T} \frac{B_t}{(1+R)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+R)^t} \tag{5}$$

[1] It is important to note that project costs data for diversions accounted only for estimates of engineering and design, construction, and operation and maintenance. Such estimates include no accounting for public accommodations (compensation) which are expected to be significant at higher flow rates.

Where t is the year, 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. While the cost function for MC projects has already been expressed in dollars (equation 3), the associated benefit function can be also expressed in dollars through the expression:

$$B_t(MC) = TA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_M) - 0.96)}{0.08} \right)} \right] * (1 - E)^{t - lag_M} * (ESV_M) * \frac{1}{(1 + R)^t} \tag{6}$$

where t is the number of years (ranging from 1 to 50). $B_t(MC)$ is the total present annual benefits (in $) of a MC project in year t. TA is target acreage, a user specified variable referring to the desired net acreage gain from the project over a given time period. The bracketed expression is the percentage of project construction for a MC project completed in year t (eq. 1). The variable lag_M is the engineering and design phase time lag for MC projects, a user specified variable in the model. The variable E is a geographically-specific land loss rate, such that $(1-E)^{t-lag_M}$ is the proportion of land remaining at time t. Finally, ESV_M is the annual non-market, ecosystem value for each acre restored. By isolating this variable, we can solve for the break-even value of ESV_M that would be needed for a B:C ratio equal to 1.0.

$$ESV_M = \frac{B_t(MC) * (1 + R)^t}{TA * \left[\frac{1}{1 + EXP\left(\frac{-((t - lag_M) - 0.96)}{0.08} \right)} \right] * (1 - E)^{t - lag_M}} \tag{7}$$

Likewise, the associated benefits function in period t for DIV_1 projects can be also expressed in dollars through the function:

$$B_t(DIV_1) = TA * [-0.0029 + 0.0501 * (t - lag_D)] * (1 - E)^{t - lag_D} * ESV_{D1} * \frac{1}{(1 + R)^t} \tag{8}$$

where the t stands for the number of years (ranging from 1 to 50). $B_t(DIV_1)$ is the total present annual benefits (in $) of a DIV_1 project in year t. TA is target acreage over a given time period. The bracketed expression is the percentage of net acres accrued for a diversion project in year t. The variable lag_D is the engineering and design phase time lag for DIV_1 projects. The variable E is a geographically-specific land loss rate, such that $(1-E)^{t-lag_D}$ is the proportion of land remaining at time t. Finally, ESV_{D1} is the annual non-market, ecosystem value for each acre restored. By isolating this variable, we can solve for the break-even value of ESV_{D1} that would be needed for a B:C ratio equal to 1.0.

$$ESV_{D1} = \frac{B_t(DIV_1) * (1+R)^t}{TA * [-0.0029 + 0.0501 * (t - lag_D)] * (1-E)^{t-lag_D}} \tag{9}$$

For comparison purposes, an exogenous diversion benefits model (DIV_2) was also used in the analysis. This alternative, mass-balance-based model contains 21 user-defined and derived parameters that characterize nutrient and sediment dynamics in the outfall area of a freshwater or sediment diversion project. Boustany (2010) provides additional details on the construction and application of this nutrient-sediment "N-SED" model. For this analysis, all N-SED parameters are held constant and only water flow rate (CFS) is modified to obtain a specific target acreage.

Thus, the benefits in period *t* for from the N-SED model (DIV_2) are given by the function:

$$B_t(DIV_2) = (8.69 * CFS - 7944) * [-0.0029 + 0.0501 * (t - lag_D)] * ESV_{D2} * \frac{1}{(1+R)^t} \tag{10}$$

where the *t* stands for the number of years (ranging from 1 to 50). $B_t(DIV_2)$ is the total present annual benefits (in $) of a DIV_2 project in year *t*. Target acreage is defined via the exogenous model as a function of average flow rate (*CFS*) over a given time period. The bracketed expression is the percentage of net acres accrued for a diversion project in year *t*. The variable lag_D is the engineering and design phase time lag for DIV_2 projects. Unlike the DIV_1, acreage benefits in DIV_2 have already been internally accounted for through the N-SED model. The time lag_D is the engineering and design phase for DIV_2 projects and ESV_{D2} is the annual non-market, ecosystem values for each acre restored. By isolating this value, we can solve for the break-even level of ESV_{D2} that would be needed for a B:C ratio equal to 1.0.

$$ESV_{D2} = \frac{B_t(DIV_2) * (1+R)^t}{(8.69 * CFS - 7944) * [-0.0029 + 0.0501 * (t - lag_D)]} \tag{11}$$

Because of the comprehensive, mass-balance accounting inherent to the N-SED model, the flow rate required for DIV_2 at a specific target acreage is considerable lower than that required by the DIV_1 model. For example, given a 20-year project life and a target of 1,000 acres, the required flow rate from the DIV_2 model is 1029 CFS, while the required flow rate for the DIV_1 model is 16,749 CFS. While this difference is stark, the corresponding projected costs (equation 4) at these two flow rates are much closer: $17,455,181 and $25,645,301 for DIV_2 and DIV_1, respectively. The difference in these project costs estimates is expected to increase substantially at higher flow rates when social costs are incorporated (e.g. land acquisition and fisheries impact compensation).

Sensitivity Analysis

Average parameters were set for user-specified model variables to construct baseline projections of project benefits and project costs. Sensitivity analyses were developed by allowing a single parameter to vary across its known range, holding all other parameters constant at the baseline level[2]. In each simulation the effect of these parameter variations is incorporated into the specified NPV model to determine the required average annual break-even ESV ($/acre/year) required for a B:C of 1.0. Figure 3 shows the effects of these break-even simulations for changes in time, project scale, discount rate, and pumping distance on the MC, DIV_1, and DIV_2 models.

For project life-span simulations, the required ESV decreases quickly during first 10 years for all project types and then more slowly afterwards. The MC model is the least-cost alternative prior to year 25, after which it intersects the DIV_2 model. In each case the required break-even ESVs are comparatively large for diversion projects during the typical 20-year life period. While diversion-based models eventually converge with the MC model over time, the simulation shows the importance of time in the cost-benefit decision model.

For project scale simulations, the MC model provides the least-cost alternative for projects less than ~5,000 acres, and afterwards converges with DIV_2. The DIV_1 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 MC projects. This simulation depicts the importance of project scale on the benefit-cost relationship of coastal restoration in Louisiana. Generally speaking, as project scales increases, differences in methodological efficiency decrease, especially for projects of 5000 acres or greater.

For discount rate simulations, a higher discount rate usually means a higher time costs. Thus, the application of any type of project discounting will compound the problems associated with slower restoration methods. As expected, the selection of an appropriate discount rate has a major impact on the cost-benefit relationships. However, even at a discount rate of zero, the slow rate of restoration of the diversion method produces a higher break even cost of restoration for the baseline time period. As indicated in the time scale simulation, this dynamic is expected to change beyond 25 years.

For pumping distance simulations, the required break-even ESV remains constant for diversion projects and increases with distance for the MC model. To a large degree, the proximity of the sediment borrow site has a major impact on the cost-benefit analysis of MC projects. An eventual convergence of the MC cost curve with the diversion cost curves occurs at distances of 10 and 20 miles for DIV_2 and DIV_1 models, respectively.

One notable finding of this break-even analysis is that the annual restoration costs for the baseline period is considerably higher (in the majority of simulations) than the annual ecosystem services values reported in the non-market valuation literature. Considering recent non-market values for storm surge, habitat and water quality, the aggregate annual service value of coastal wetlands is estimated at $4,410 (Costanza 2008; Kazmierczak 2001a,b). Assuming this level of ecosystem services, project costs are only justified in only a small number of simulations.

---

[2] Baseline values for NPV model parameters were set using either mean , median, or mode values for specific variables depending on guidance from existing literature, case history, or project location. Specific baseline parameters were set at: 1000 acres; 20 years; r=0.4; MOB=$1,000,000; DIST=4 miles; AD=$600,000; E=0.003, lag_M = 4 yrs, lag_D= 7 yrs.

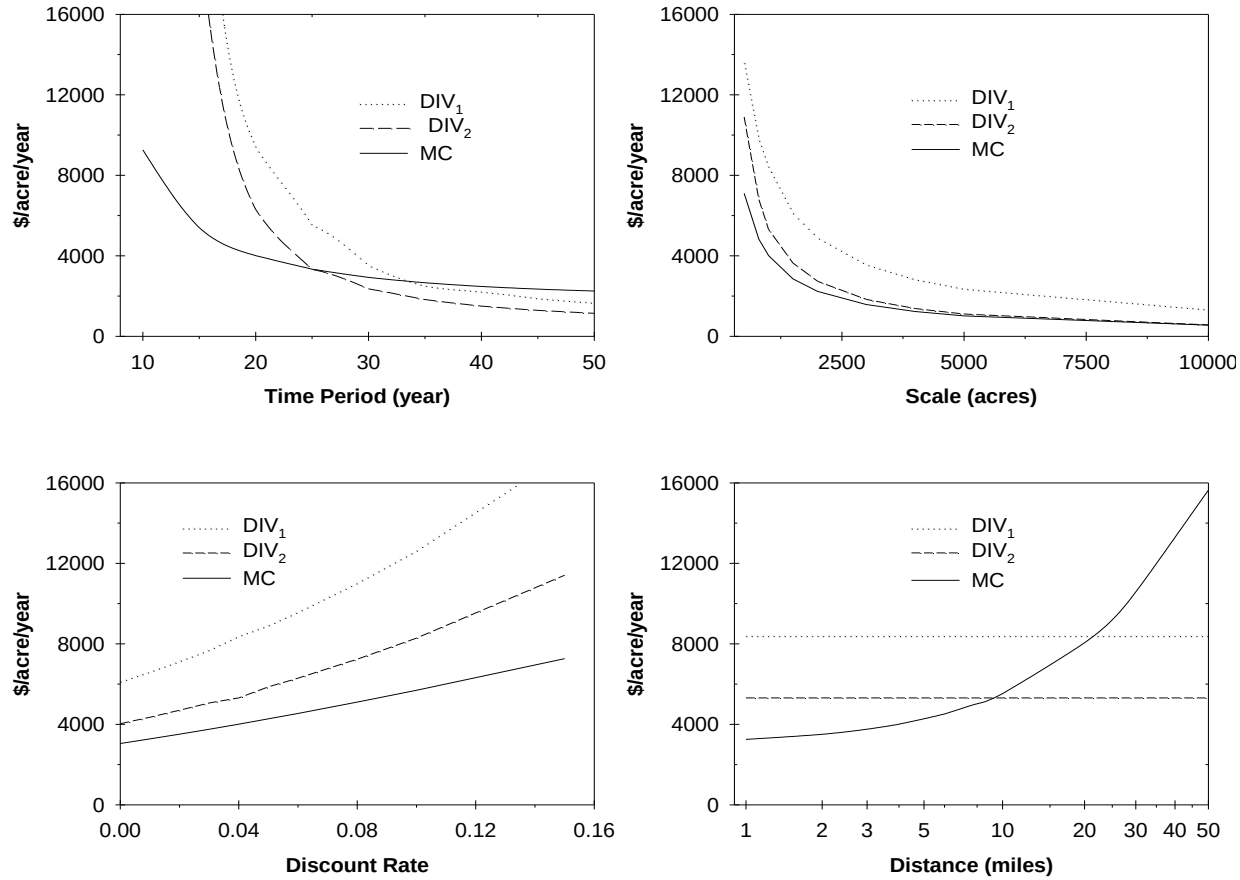

Figure 3. Effects of time, scale, discount rate, and distance on the break-even costs of marsh creation and diversion projects for coastal restoration.

Incorporating Risk

Thus far, break-even simulations have only utilized discount rates to reflect risk and uncertainty. A more specified approach can be accomplished through consideration of a variety of climatological and societal factors that influence project costs and benefits.

Hurricane Impacts

For example, using hurricane landfall probability data from Klotzach and Gray (2011), an expected valuation approach can be used to adjust the benefits of marsh creation and diversion projects given by the function:

$$E[V] = \sum_{t=1}^{20} \left[P_1 * \left(TA_t * \left(1 - X_{HN}\right)\right) + P_2 * TA_t \right] * ESV * \frac{1}{(1+R)^t} \tag{12}$$

where $E[V]$ is the expected benefits of the wetland restoration project. The t stands for the number of years (ranging from 1 to 50). The P_1 is the annual probability of major storm[3] and $P_2 = (1-P_1)$, which stands for the annual probability of no major storm.

While landfall probabilities are relatively easy to calculate, the corresponding impacts of major hurricanes on coastal restoration projects are more difficult to gauge. Wang (2011) describes a conceptual approach in which project type and scale of completion (%) are expected to be associated with resilience. Projected acreage loss from a hurricane ($X_{H\%}$) ranges from 20 percent to 80 percent, depending on project type, location, and percentage of project completion.

Social Constraints of Diversions

Risk can also be expressed as the likelihood of social constraints, which would alter the benefits and costs of a wetland restoration project. The probability of social opposition to a project is not easily calculated, as with hurricane frequencies, and it must be estimated based using case-specific information. For diversion projects, project operation is often fraught with controversy over the effects of potential or actual salinity changes. These concerns can increase the lag time between authorization and construction and result in substantial reductions to flow rate. The following example illustrates these social constraints associated with two diversion projects.

The Caernarvon Freshwater Diversion Project and the Davis Pond Freshwater Diversion Project were authorized by the U.S. Congress under the Flood Control Act of 1965. Construction of these projects was completed in 1991 and 2002, respectively. The structures are designed to divert up freshwater from the Mississippi river into the marshes and bays of the Louisiana estuary. Maximum flow rates are 8,000 cfs at Caernarvon and 10,800 cfs at Davis Pond.

Since construction, flow rates for both structures gave been curtailed by a complaints related primarily to short-term fisheries impacts. Soon after opening 1991, oyster fishermen argued that freshwater from the Caernarvon diversion had damaged many of their oyster beds. They filed a law suit against the state that eventually resulted in $2.3 billion in preliminary judgments on behalf of the oyster industry. This litigation severely curtailed the flow rate of the structure and threatened the ability to of the state to conduct future wetland restoration projects (Caffey and Schexnayder 2003).

To deal with this opposition, the 2003 Louisiana legislature passed three constitutional amendments through public referendum, which were intended to remove the social constraints of diversions and increase the state's capacity for coastal wetland restoration. Under these amendments, the state liability is limited to fair market value compensation for any property damage caused by coastal restoration projects. The value of operational losses was limited to the fair market value of affected property. Yet, despite these amendments, the annual discharge of these two structures has been consistently below maximum capacity in recent years (Figure 4).

[3] Category 3 hurricane (or greater) on the Saffir-Simpson scale.

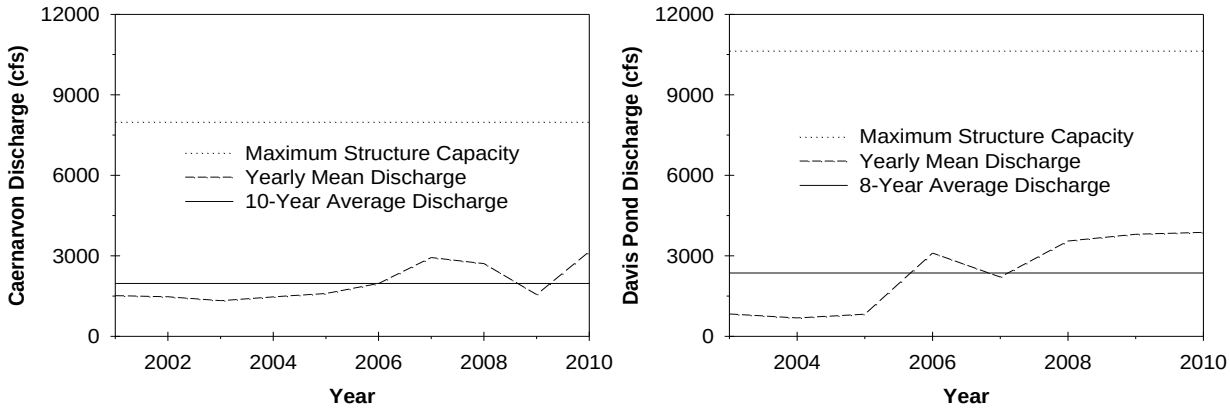

Figure 4. Yearly mean discharge of the Caernarvon and Davis Pond Diversion Projects

In the past decade, neither diversion structure has exceeded 50% of its maximum discharge capacity. The 10-year (2001-2010) average discharge for Caernarvon is 1,969 cfs, which is only 25 percent of the designed capacity. Likewise, 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 are also partially indicative of the social constraints to freshwater diversion projects in coastal Louisiana. In addition to the oyster industry, a number of other stakeholders have argued for reduced flow rates at these two structures. Shrimp fishermen, crab harvesters, land owners, recreational fishermen and hunters, and navigation interests are all represented on the interagency advisory committees that control the flow rates of these structures.

Unlike the expected valuation construct used for hurricane scenario, the incorporation of social constraints to DIV operations is represented here through a simple numerical scaling factor. Drawing from the benefit model of DIV-based wetland restoration, the factor is applied as:

$$B_t\left(DIV_1\right)=\sum_{t=1}^{20}\left(TA_t * \left[-0.0029+0.051*\left(t-lag_D\right)\right]*\left(1-E\right)^{t-lag_D} * ESV_{D1}\right)* X_S * \frac{1}{\left(1+R\right)^t} \qquad (13)$$

and

$$B_t\left(DIV_2\right)=\sum_{t=1}^{20}\left(\left(8.69*CFS-7944\right)*\left[-0.0029+0.051*\left(t-lag_D\right)\right]* ESV_{D2}\right)* X_S * \frac{1}{\left(1+R\right)^t} \qquad (14)$$

where the X_S is a user-defined social constraints for DIV operation (% of maximum capacity CFS) ranging from 20 percent to 80 percent.

Case Studies

By incorporating aspects of risk and uncertainty into the generic NPV models, case-studies can be used to illustrate tradeoffs between MC and DIV wetland restoration technologies. Assumptions for these case studies are described in Table 3. For the purpose of simplifying the comparisons, these case studies utilize MC model and one diversion model (DIV_2). In these comparisons, the MC scenarios are denoted as "M" and the DIV_2 scenarios are denoted as "D" for the two estuary locations.

Two specific locations along the Mississippi River (an *upper* estuary site and a *lower* estuary site) were considered for the case study simulations (Figure 5). 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 5).

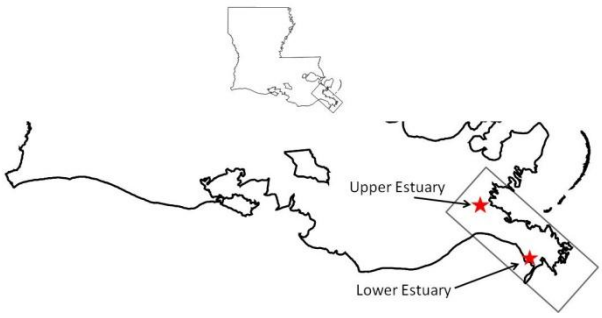

Figure 5. Location of upper and lower estuary case study locations in Plaquemines Parish Louisiana

Project life time is set to 20 years and 50 years for both location case studies. Target scales are assumed to be 1000 acres and 5000 acres. Time lag times range from 4 to 10 years depending on project type and location. Land loss rate ranges from 0.3 to 0.6 depending on location (LaDNR 1998). Major hurricane probability ranges from 0.1 to 0.2 depending on location (Klotzach and Gray 2011). Fresh water diversion type is controlled. Social constraints range from 0.25 to 0.80 depending on scale and locations.

Mobilization and demobilization cost and access dredging cost for MC project are assumed to be $1,000,000 and $600,000, respectively. The average pumping distance is assumed to be 4 miles. Construction, E&D, and O&M costs account for 85%, 10%, and 5% of total costs, respectively. The average starting ecosystem value (habitat, water quality, and storm surge protection) were set at $4,410/ acre/year (Costanza 2008, Kazmierczak 2001a,b).

Tables 4 and Table 5 provide the economic results of 16 NPV simulations for the *Upper* and *Lower* estuary locations, respectively. For each simulation, estimates are provided for projected acreage, net present costs and benefits, B:C ratio, and unit cost ($/acre).

Table 3. Case Study Assumptions

Variable	Description	Variable	Description
Project Types	MC and DIV_2 (Controlled)	Diversion Flow	0.25 to 0.80 of capacity
Location	Upper & Lower Estuary	Mob/Demob Cost	$1,000,000
Project life time	20 years and 50 years	Pumping Distance	4 miles
Target scales	1000 and 5000 acres	Access Dredging	$600,000
Time lag	4 to 10 years	Construction Costs	85%
Land loss rates	0.003 to 0.006 per year	E&D costs	10%
Hurricane probability	0.1 to 0.2, X_{HN}	O&M costs	5%
Discount rate	4%	Ecosystem service values	$4,410 per year

Table 4. Cost and Benefit Output for *Upper Estuary* Scenarios

	MC				DIV_2			
	Upper M-1 1000ac/20y	Upper M-2 1000ac/50y	Upper M-3 5000ac/20y	Upper A-4 5000ac/50y	Upper D-1 1000ac/20y	Upper D-2 1000ac/50y	Upper D-3 5000ac/20y	UpperD-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 5. Cost and Benefit Output for *Lower Estuary* Scenarios

	MC				DIV_2			
	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 D-2 1000ac/50y	Lower D-3 5000ac/20y	Lower D-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

Acreage

In all case simulations, the MC project acreage exceeded the acreage of DIV_2 projects. For 50-year periods in the lower basin; however, the DIV_2 project acreage is converging on acreage of the MC projects. Yet, neither project type achieves the target acreage during the specified time period. In the case of MC projects, three factors constrain target benefits: lag time, erosion, and hurricane effects (X_{HN}). 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. Four factors constrain DIV_2 target benefits: lag time, erosion, hurricane effects (X_{HN}), and social constraints (X_S). Because of these constraints DIV_2 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

An often cited argument against MC projects is their apparent high costs. Indeed, the costs for MC projects at similar scales, time periods, and locations ranged from 2.8 to nearly 4 times higher than the costs of DIV_2 projects designed for the same target acreage. While DIV_2 projects produce the lowest per unit cost for 50-year projects in the lower estuary, those simulations involve very low public opposition (i.e. low constraints to flow). For DIV_2 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

As with the acreage data, MC project benefits greatly exceed the performance of the DIV_2 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, the net benefits in dollars for MC projects ranges from 4 to 27 times higher than the comparable benefits of DIV_2 projects designed for the same target acreages and time periods.

B:C Ratio

All B-C ratios are greater than 1.0 for the eight MC case study projects, and exceed 1.0 in four of the eight DIV_2 case scenarios. The overall B-C ratio for MC projects ranges from a low of 1.03 to a high of 7.61. For DIV_2 projects, B-C ratios range from 0.2 to 3.95. The least expensive projects (per unit) in these case study comparisons are the large scale DIV_2 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 (Reed 2009). In reality; however, there are very few locations where large scale diversion projects can be implemented without major opposition from fishermen, land owners, and other interests. Because of these social constraints, the use of DIV_2 projects in the middle to upper estuary is more problematic. The unit cost of DIV_2 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.

Summary

Generally speaking, unit costs were found to decrease with increases in project time and scale, and increase at higher discount rates, regardless of restoration method. Additional factors, such as mobilization and demobilization of dredging equipment, access dredging costs, and the distance between sediment borrow site and project site, served to increase the unit costs of RLB projects. The primary finding; however, was that relatively slow rate of restoration was a major, negative factor on the economic feasibility of diversion projects.

Through unconstrained break-even analysis, MC projects were found to have consistently lower per unit costs, only exceeding diversion costs at time periods beyond 25 and 35 years, pumping distances of 10 and 20 miles, and target scales of 4,000 and 10,000 acres; compared to DIV_2 and DIV_1 models, respectively. These intersection points tend to increase substantially with the incorporation of method-specific and location-specific risks.

While the probability of hurricane impacts shifts economic feasibility marginally downward for both project types, social accommodations to flow rate were shown to be a major hindrance on the economic and ecologic performance of diversions. Even with social constraints set at half of historic levels, the 50-year acreage trajectory of diversions remains well below that of MC projects of similar target scale. In a series of 16 risk-adjusted case studies for Plaquemine Parish, MC projects had lower per unit costs in 75 percent of the simulations. Moreover, B:C ratios and ecosystem service flows (net present benefits) were found to be higher in all cases for MC projects - ranging from 9 to 27 times greater than diversions for the same target scale and time period (1000-5000 acres, 20-50 years).

While independent consideration of these two project types is necessary to isolate differences in economic and ecological performance, the two methods have been used in tandem for coastal restoration. Future research will focus on identifying the optimal economic combination of these methods given specific locations and constraints. Refinement of the generic benefit trajectory will likely be required for assessment of the large-scale diversions (>35,000 cfs) currently under consideration by CPRA. Likewise, the cost-accounting for such projects will need to be adjusted to include the associated costs of land acquisition and preemptive compensation.

Finally, and perhaps most importantly, the break-even annual costs in the majority of baseline simulations were found to be considerably higher than the range of annual benefits for coastal wetlands reported in the ecosystem valuation literature. This finding suggests the need for a reevaluation of restoration spending to ensure the most cost-effective combination of project attributes. The decision framework established in this study can help achieve that goal by improving the efficiency through which limited funding is allocated for coastal wetland restoration in Louisiana.

References

Boustany, R. (2010). “Estimating the Benefits of Freshwater Introduction into Coastal Wetland Ecosystems in Louisiana: Nutrient and Sediment Analyses”, Ecological Restoration, 28(2):160-174.

Caffey, R. H. and M. Schexnayder (2002). Fisheries Implications of Freshwater Reintroductions, Interpretive Topic Series on Coastal Wetland Restoration in Louisiana, Coastal Wetland Planning, Protection, and Restoration Act (eds.), National Sea Grant Library No. LSU-G-02-003, pp: 8.

Costanza, R., O. Perez-Maqueo, L.M. Martinez, P. Sutton, S.J. Anderson, and K. Mulder (2008). The Value of Coastal Wetlands for Hurricane Protection. Ambio, 37(4): 241-248.

Kazmierczak, Jr., Richard F. (2001)a. "Economic Linkages Between Coastal Wetlands and Water Quality: A Review of Value Estimates Reported in the Published Literature." Staff Paper 2001-02, Department of Agricultural Economics and Agribusiness, Louisiana State University, Baton Rouge, May 2001.

Kazmierczak, Jr., Richard F. (2001)b. "Economic Linkages Between Coastal Wetlands and Habitat/Species Protection: A Review of Value Estimates Reported in the Published Literature." Staff Paper 2001-04, Department of Agricultural Economics and Agribusiness, Louisiana State University, Baton Rouge, May 2001.

LaCPRA (Louisiana Coastal Protection and Restoration Authority) (2007). Louisiana's Comprehensive Master Plan for a Sustainable Coast, Executive Summary. http://dnr.louisiana.gov/crm/ocpr.asp

LaDNR (Louisiana Department of Natural Resources) (1998). Coast 2050: Toward a Sustainable Coastal Louisiana. http://www.coast2050.gov/products/docs/orig/2050report.pdf

National Hurricane Center (2007). November 2005 Atlantic Tropical Weather Summary. National Oceanic and Atmospheric Administration. http://www.nhc.noaa.gov/archive/2005/tws/MIATWSAT_nov_final.shtml

Petrolia, D. R., Tae-goun, K., Moore, R.G. and R.H. Caffey (2009) “A Cost Analysis of Rapid Land-Building Technologies for Coastal Restoration in Louisiana”, Southern Agricultural Economics Association 2009 Annual Meeting, January 31-February 3, 2009, Atlanta, Georgia. 15 p. http://purl.umn.edu/46844

Reed, D.J. (2009). A New Approach to River Management: Action for A Sustainable Coastal Landscape. Journal of Contemporary Water Research & Education, 141: 35-38.

USGS (U.S. Geological Survey) (2006). USGS Reports Latest Land Change Estimates for Louisiana Coast. http://landsat.gsfc.nasa.gov/pdf_archive/sci_0006.pdf

Wang, H. (2011) “An Economic Assessment of Rapid Land Building Technologies for Coastal Restoration in Louisiana”, Master’s Thesis, Louisiana State University, Defended on 11.21.11, (in review) estimated completion, February 2012.