BUILDING LAND IN COASTAL LOUISIANA

Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs

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Supplemental Information available online at **www.MississippiRiverDelta.org/DiversionOpsReport**

ACKNOWLEDGEMENTS

We would like to thank the core members of the Sediment Diversion Operations Expert Working Group which include Rex Caffey, James H. Cowan Jr., Dubravko Justic, Alex Kolker, Shirley Laska, Alex McCorquodale, Earl Melancon Jr., James Andrew Nyman, Robert Twilley, Jenneke Visser, John White and James Wilkins. We would also like to thank Andrew Barron, Sam Bentley, Matt Bethel, Martin Bourgeois, Jim Boyd, Steve Cochran, Brady Couvillion, Mark Davis, John Day Jr., Henrietta DeGroot, JoAnne DeRouen, Ioannis Georgiou, Sean Graham, Scott Hemmerling, Duncan Kemp, Megan LaPeyre, Chunyan Li, Doug Meffert, Irv Mendelssohn, Ehab Meselhe, Corey Miller, David Muth, Ronnie Paille, Kristina Peterson, Rosina Phillipe, Kimberly Reyher, Lawrence Rozas, Shaye Sable, Leonard Shabman, Greg Snedden, Thomas Soniat, Christopher Swarzenski, Scott Duke Sylvester, Jim Tripp, David Walther, Andrew Wilson, Carol Wilson, Maura Wood, Kehui Xu and Tracy Yandle who were guests that contributed their vital expertise to the working group. Their contributions to the working group meetings do not represent and should not be seen as an endorsement of the contents of this report. This work was led by Environmental Defense Fund (Natalie Peyronnin) and the Restore the Mississippi River Delta Coalition (Alisha Renfro, John Lopez, Estelle Robichaux and Rachel Rhode) and funded and made possible by the Walton Family Foundation.

Suggested Citation:

Peyronnin, N., R. Caffey, J.H. Cowan Jr., J. Dubravko, A. Kolker, S. Laska, A. McCorquodale, E. Melancon Jr., J.A. Nyman, R. Twilley, J. Visser, J. White and J. Wilkins. 2016. Building Land in Coastal Louisiana: Expert Recommendations for Operating a Successful Sediment Diversion that Balances Ecosystem and Community Needs. www.MississippiRiverDelta.org/DiversionOpsReport

RESTORE
THE MISSISSIPPI RIVER DELTA

Introduction

Figure 1: Historic network of distributaries, channels and sub-deltas of the Mississippi River (modified from Fisk 1947)

Historically, the Mississippi River entered into the Gulf of Mexico through multiple distributary networks of channels and sub-deltas throughout the southeastern and south-central coast of Louisiana.

The influence of freshwater, sediment and nutrients was spread over a vast area of wetlands based on the natural rise and fall of the river. As the river crested, flood waters overflowed the banks (natural levees) of the river and its distributaries and deposited sediment throughout coastal Louisiana. In addition, breaches which formed by erosion through the natural levee during overbank floods, called crevasses, would occur at various locations. Crevasses occurred regularly under natural conditions, but their frequency increased after Europeans settled the natural levees. Settlers began building artificial levees to protect communities and cleared farmland from the spring flood beginning in the 1720s. As many as 20 crevasses would occur annually during the eighteenth, nineteenth and early twentieth centuries, depending on the river flood cycles, as early Europeans began to build disconnected and inadequate artificial levee systems. The uneven construction and maintenance of the levee system raised river flood heights resulting in frequent levee failures (Kesel 2003).

Levee construction along the lower Mississippi River and its distributaries following settlement and land clearing for agriculture was largely complete by the mid-nineteenth century. However, a comprehensive federally managed system of levees from Cairo, Illinois to Venice, Louisiana was not completed until after the flood of 1927. In response to that devastating event, Congress authorized the Mississippi River and Tributaries (MR&T) Program to be constructed and managed by the U.S. Army Corps of Engineers (USACE). This action ended any breaches or overtopping that had previously occurred during flood events and ultimately ended any of the natural functioning and flooding of the Mississippi River, severing the river from its floodplain. Current levee management practices on the river have resulted in almost all of the land-building benefits of the Mississippi River being concentrated in two outlets of the river - at the Birdsfoot Delta and the Atchafalaya Delta complex - leading to a collapse of expansive deltaic wetland complexes (Craig et al. 1979, Boesch et al. 1994, Kesel 1989). This resulting condition was not unforeseen. Engineer E.L. Corthell (1897) wrote in a National Geographic article entitled "The Delta of the Mississippi River" from December 1897:

> *No doubt the great benefit to the present and two or three following generations accruing from a complete system of absolutely protective levees, excluding the flood waters entirely from the great areas of the lower delta country, far outweighs the disadvantages to future generations from subsidence of the Gulf delta lands below the level of the sea and their gradual abandonment due to this cause.*

Sediment diversions are one of the most underutilized ecosystem restoration tools that the State of Louisiana has to combat land loss and climate change impacts, such as sea level rise. A diversion is a structure of gates built into the levee system that allows river water, sediment and nutrients to flow into the degraded wetlands, mimicking the natural cycle of spring flooding, crevassing and distributary sub-delta formation. Diversions are anticipated to provide significant benefits to the deltaic complex, including the fish and wildlife that depend upon it and the estuarine complex it sustains, and in turn improve the overall health of the Gulf and forestall the gradual abandonment of areas of the coast to the Gulf of Mexico (Kim et al. 2007, Gagliano et al. 1970, Gagliano et al. 1973, Gagliano and Day 1973, Paola et al. 2011).

Sediment diversions have been proposed as a foundational solution to the coastal land loss issue for decades. The first reports of coastal land loss from the 1970s made recommendations for the construction of diversions and sub-deltas (Gagliano et al. 1970, Tripp and Herz 1987). In 1990, the Coastal Wetland Planning, Protection and Restoration Act (CWPPRA), authored by the State of Louisiana and the USACE, included as one of five objectives "To plan and evaluate alternative long-range projects (with complex socio-economic interactions) designed to provide widespread and continuing long-term benefits to vegetated wetlands (e.g., large-scale freshwater and sediment diversions)." Coast 2050, Louisiana Coastal Area (LCA) Study and the 2007 and 2012 Coastal Master Plans all include large-scale sediment diversions as a keystone for coastal sustainability (CPRA 2007, CPRA 2012, LCWCRTF 1998, Twilley et al. 2008). Two key mid-basin diversions, Myrtle Grove (Mid-Barataria Sediment Diversion) and White's Ditch (Mid-Breton Sediment Diversion) were authorized by Congress in 2007 WRDA Title VII.

Not only does Louisiana have a long history of recognizing that utilizing the land-building capacity of the river with diversions is the key to sustaining functional coastal wetlands, the state has also identified numerous user groups and uncertainties that need to be addressed. The 1993 CWPPRA Restoration Plan stated that "studies [on future sediment diversion projects] must determine the upper limit to the amount of water and sediment which can be diverted from the Mississippi River system without significantly affecting navigation channel maintenance, municipal and industrial water supplies, and other aspects of human activity, such as commercial and recreational fishing." Currently, the State of Louisiana is tackling engineering and design challenges concerning the size, location and type of structure, as well as modeling questions such as anticipated ecological, social and natural resource outcomes. However, in many ways, these engineering and design decisions about the construction of a diversion structure are not nearly as significant to the ecosystem and stakeholders as decisions about how the structure will be operated initially and over time.

SIMPLIFIED OPERATION STRATEGIES FOR PLANNING PURPOSES

One approach for determining the optimal size, location and type of diversion structure is to standardize and simplify the diversion operation strategy to provide consistency to the analysis, reduce computational costs and allow easy comparison between alternatives during the planning, engineering and design phases. By standardizing the operation strategy, the Louisiana Coastal Protection and Restoration Authority (CPRA) and USACE can better determine the cause and effect of changes in outcomes across multiple alternative locations, sizes or structure types. For instance, operations could be held constant while the location of the structure along the river is modified. Holding this "standardized operation strategy" constant while other factors are varied provides the consistency needed to determine which location is optimal for sediment capture and land building.

In past and ongoing planning efforts, CPRA has adopted a simplified operation based on the flow of the river. For the 2012 Coastal Master Plan, the standardized operation strategy for a 50,000 cubic feet per second (cfs) sediment diversion was defined as:

- Operated at full capacity (50,000 cfs) when the flow of the Mississippi River exceeds 600,000 cfs,
- Operation at 8% of the river discharge with the flow of the Mississippi River ranges from 600,000 cfs to 200,000 cfs, and
- No operations when the flow of the Mississippi River is below 200,000 cfs (CPRA 2012).

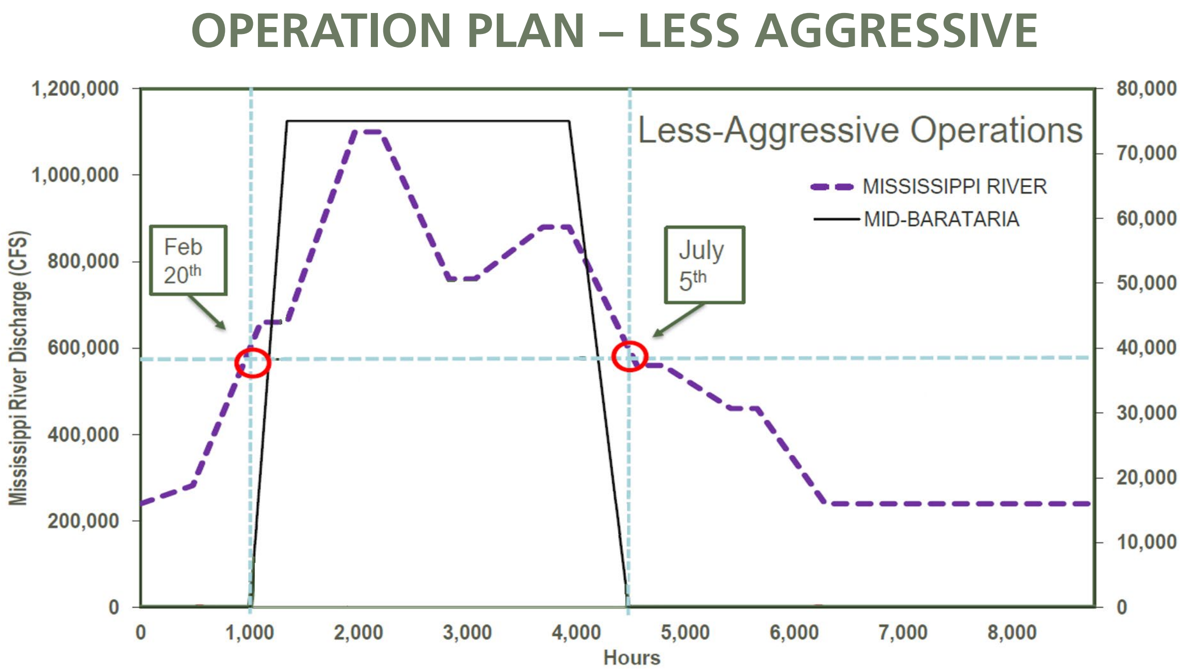
The master plan analysis utilized a 20-year hydrograph record (1990-2009) and repeated it over a 50-year planning horizon. This operation strategy resulted in a diversion that, in the first 20 years, was open at full capacity (flow = 50,000 cfs) 21% of the time. This timing may seem reasonable to take advantage of peaks in river flows. However, by operating at 8% of the river flow for maintenance, it resulted in the diversion operating at flow rate greater than 10,000 cfs 73% of the time and the diversion was completely shut off (flow = 0 cfs) for only 2 months in the 20-year period (Table 1). To put this in perspective, at the average annual discharge of the Mississippi River (590,000 cfs) from 2008 to 2010 (Allison et al. 2012), the diversion would have a discharge over 47,000 cfs. For a lower river discharge of 400,000 cfs, the diversion would be operated at 32,000 cfs. This operation strategy provides a consistent basis for comparison essential to planning efforts but does not provide a realistic or optimized operation strategy, over-estimates effects to communities and fish and wildlife species, and will likely result in detrimental impacts to the wetlands that are not currently accounted for in the modeling approach.

Table 1: Monthly average diversion flow in cubic feet per second (cfs) based on daily average flow from the Mississippi River between 1990 and 2009 utilized in the 2012 Coastal Master Plan modeling (CPRA 2012).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1990	32,836	50,000	50,000	50,000	50,000	50,000	42,870	28,415	24,189	24,312	24,088	34,813
1991	50,000	50,000	50,000	50,000	50,000	48,808	29,626	18,857	17,691	8,888	28,616	47,419
1992	47,739	34,684	48,834	42,373	36,599	32,512	31,734	38,668	23,157	19,515	27,827	49,605
1993	50,000	48,831	50,000	50,000	50,000	50,000	50,000	50,000	42,347	45,215	37,275	49,337
1994	39,006	50,000	50,000	50,000	50,000	33,931	31,179	22,970	14,968	16,614	25,699	40,266
1995	35,574	42,140	47,985	39,795	50,000	50,000	44,637	31,574	19,731	18,810	23,976	23,301
1996	29,721	45,167	42,369	46,408	50,000	50,000	37,329	31,561	21,405	26,170	41,115	50,000
1997	47,130	50,000	50,000	50,000	49,455	49,701	39,409	23,360	16,867	16,524	20,381	25,636
1998	45,899	49,334	50,000	50,000	50,000	46,784	47,837	31,311	16,517	22,895	30,187	32,175
1999	41,040	50,000	49,605	50,000	50,000	45,840	41,123	22,204	2,160	0	0	16,343
2000	12,088	7,454	39,334	46,427	31,554	33,744	39,401	20,183	4,461	3,786	15,275	25,915
2001	28,147	43,574	50,000	50,000	40,797	49,205	31,120	22,222	15,227	19,677	19,091	46,986
2002	38,689	48,606	40,356	50,000	50,000	49,149	27,406	18,973	13,240	25,639	28,651	31,267
2003	40,575	30,383	50,000	40,688	45,383	49,429	35,406	28,103	24,768	20,297	23,469	40,552
2004	45,326	47,321	48,294	43,949	47,419	49,557	44,387	25,548	27,016	27,332	42,224	50,000
2005	50,000	50,000	45,773	47,517	34,498	29,192	23,471	4,947	15,877	8,307	4,285	15,892
2006	20,797	38,849	33,915	34,200	38,498	24,080	18,426	1,613	4,792	24,526	33,392	32,036
2007	48,919	40,814	44,317	49,661	49,004	32,072	38,532	24,005	22,749	6,844	16,733	30,354
2008	38,405	42,229	50,000	50,000	50,000	50,000	47,814	33,554	36,747	26,795	18,203	26,237
2009	45,773	38,246	44,854	50,000	50,000	50,000	36,934	31,835	26,293	44,299	50,000	49,925

The standardized operation strategy has been modified slightly for the Mississippi River Hydrodynamics and Delta Management Study conducted by the USACE and CPRA. The maintenance flow rate at 8% of the river flow is no longer being utilized. The operation of the diversions depends only on a Mississippi River flow rate threshold of 600,000 cfs. Using an average hydrograph over 50 years, the diversion is opened when the river is over 600,000 cfs and the diversion is closed when the river falls below 600,000 cfs. By using an average hydrograph over 50 years, the period for which the river is above 600,000 cfs extends from February 20th to July 5th, and the Mid-Barataria Sediment Diversion, when modeled with all diversions in the 2012 Coastal Master Plan, would be open for almost that entire period (Figure 2, modified from Meselhe et al. 2015). This representative river flow has never been documented to occur on the Mississippi River, thus making an unrealistic modeling approach for operational planning. Although this standardized operation strategy facilitates an easy comparison of different alternatives, it would likely result in unacceptable impacts to vegetation, wetland health, water levels, water quality and fish and wildlife species.

Figure 2: Hydrograph of the river and operation of the Mid-Barataria Sediment Diversion as modeled in the Mississippi River Hydrodynamic and Delta Management Study using a less aggressive operation plan. (Other diversions included in the operation plan are not shown here). (modified from Meselhe et al. 2015).



To acquire approval for the permits needed to start construction, CPRA will need to provide an Operation and Adaptive Management Plan that defines how, when and why the diversion structure will be opened and closed; what factors will be considered; what monitoring is required; what governance and decision-making structures will be used to oversee these decisions; and what role stakeholders will play in the decision-making process. Defining the operation plan, and the strategies to be included in it, is an iterative process that will need to incorporate modeling, data collection and analysis, best professional judgment from experts in their field and input from stakeholders, people directly and indirectly affected and the public. This report provides recommendations on strategies to consider, research and monitoring to be conducted and steps to engage all relevant stakeholders, including local communities and businesses, in the development of an operation plan. ***This document is intended to start a dialogue that can improve and advance operation strategies moving forward.***

Methodology

An interdisciplinary group of experts was formed to explore, discuss, debate and document the complex physical, ecological, economic and social issues related to operating a sediment diversion. The Sediment Diversion Operations Expert Working Group (WG), formed in September 2015, includes 12 core members (Table 2) that provide insight and recommendations on the various topics identified in Table 3. Additionally, a total of 42 guest experts, selected by the core members, participated in a portion of each meeting to provide their input and recommendations on topics of relevance to their fields of expertise. The guest experts included individuals who are extremely knowledgeable in their field and provided reliable insights into the Mississippi River Delta and the surrounding environment. Most of the guest experts and core members have on-the-ground extensive understanding of the Louisiana coast and Barataria Basin, the site of the proposed case study.

Table 2: Core members of the Sediment Diversion Expert Working Group including expertise and affiliation.

Name	Title	Expertise	Affiliation
Dr. Rex Caffey	Professor and Director, Center for Natural Resource Economics & Policy	Natural Resource Economics	Louisiana State University
Dr. James Cowan Jr.	Professor	Fisheries	Louisiana State University
Dr. Dubravko Justic	Professor	Oceanography	Louisiana State University
Dr. Alex Kolker	Associate Professor	Sedimentology	LUMCON/Tulane
Dr. Shirley Laska	Professor	Social Sciences	University of New Orleans
Dr. Alex McCorquodale	Professor	Hydrodynamics	University of New Orleans
Dr. Earl Melancon Jr.	Professor Emeritus/Sea Grant Scholar	Oysters/Coastal Shellfish	Nicholls State University/ Louisiana State University
Dr. John Andrew Nyman	Professor	Wildlife and Fisheries	Louisiana State University
Dr. Robert Twilley	Executive Director, Louisiana Sea Grant College Program	Estuarine Ecology	Louisiana State University
Dr. Jenneke M. Visser	Associate Professor and Associate Director, Institute for Coastal and Water Research	Vegetation	University of Louisiana at Lafayette
Dr. John White	Professor	Biogeochemistry	Louisiana State University
James Wilkins, J.D.	Professor, Louisiana Sea Grant College Program and Director, Sea Grant Law & Policy Program	Law/Policy	Louisiana State University

Over an eight-month period (September 2015 to April 2016), the WG met once per month to discuss a specific topic(s) of importance to diversion operations (Table 3). The core members provided consistent analysis among topics and discussions, while the guest experts provided detailed information on the specific topic being discussed. The meetings included background presentations on the topic by core members, a facilitated discussion between guest experts and core members and analysis and evaluation of recommendations by core members. With each topic, the team discussed the state of knowledge, data gaps, triggers for modifying management actions, monitoring needs and how the issue could be affected by various operation schemes. The process considered each of the key topics and their specific parameters as the only objective with no other constraints to determine the optimal operation strategy of a diversion to maximize each parameter (i.e., What operation strategy would maximize land building if that was the only objective with no other constraints? What operation strategy would maximize shrimp production if that was the only objective with no other constraints? What operation strategy would maximize vegetation health as the only objective?). After each topic and its specific parameters were discussed, the WG identified both consistencies and incongruities in the operations strategies. Lastly, the WG discussed legal issues, governance structures and stakeholder involvement.

Table 3: WG meetings, dates and topics discussed to develop recommendations in this report.

Meeting Topic	Date	Parameters
River Hydrology and Sediment Loads	9/16/15	River flow, stage, velocity, trajectory, sediment concentrations, discharge, sediment transport and budget, sediment-water ratios (SWR), atmospheric conditions, climate change
Basin Geology and Land-Building	10/16/15	Delta development (channel evolution, progradation, aggradation, subsidence), seasonal sedimentation, sediment transport, diversion discharge, velocity, sediment retention, cold fronts, turbidity, topography, bathymetry, soil salinity, substrate, erodibility, shear stress/strength
Water Quality	11/20/15	Hydrodynamics, residence time, discharge, salinity, temperature, nutrients (flux, load), hypoxia, phytoplankton production, harmful algal blooms, sediment, turbidity, flocculation, disease, pathogens, hormones, pharmaceuticals, cold fronts
Wetland Health	12/14/15	Habitat types, estuarine salinity gradients, saltwater intrusion, elevation, vegetation, salinity, invasive vegetation species, sediment input, sediment quality, sediment composition, bulk density, nutrient loading rates, vegetative biomass, nitrogen availability, phosphorus, sulfates/sulfides, temperature, respiration rates, duration of flooding, growing season
Fish and Wildlife Species	1/13/16	Trophic productivity, salinity, species composition, dietary ranges, niche breadth, predator-prey relationships, species distribution, estuarine salinity gradients, habitat quality, species abundance, nutrients, water depth, sediment input, fish productivity, eutrophication, fishing practices, fish life cycles, habitat value, community composition, fishing pressure, mortality, life cycle and habitat needs of various species
Communities, User Groups, and Socio-Economic Effects	2/17/16	River flow, stage, distributary width, discharge, flood risk, subsidence, sea level rise, storm seasons, tides, salinity, turbidity, temperature, storm surge, channelization, winds, velocity, elevation, transition costs, compensation, sack and seed oyster fisheries, private and public leases, oyster cultch, shrimp production, blue crab stock, social behavior, politics, community adaptation
Operation Strategies	3/14/16	Sediment discharge, peak floods, cold fronts, vegetation stress/loss, growing seasons, sediment retention rates, river flow, velocity, active adaptive management, saltwater intrusion, biological spawning seasons, species productivity, fisheries, indicator species, productivity impacts, economic value, salinity, sediment regimes, vegetation, nitrates, nutrient reduction
Governance, Legal, and Stakeholder Involvement	4/13/16	Property rights, negligence, eminent domain, inverse condemnation, oyster leases acquisition and compensation programs, oyster lease dynamics, flow capacity, salinity, flow easements, land trusts, public ownership, conservation easements, advisory groups, frontloading, insurance, decision-making framework, insurance, transparency, trust, role of stakeholders, agencies and public officials

CASE STUDY: MID-BARATARIA SEDIMENT DIVERSION

The Mid-Barataria Sediment Diversion project was used as a case study for this report, although it was noted that existing and future planned diversions in each hydrologic basin should be considered. For this case study, Davis Pond, Caernarvon and the Lower Barataria Basin Diversion would be included in some scenarios discussed.

Figure 3: Location of the Mid-Barataria Sediment Diversion, a structure to deliver freshwater, sediment and nutrients into Barataria Basin.

The Mid-Barataria Sediment Diversion is a river sediment diversion being designed to strategically reintroduce sediment and freshwater inputs into mid-Barataria Basin. The proposed project location is on the west bank of the Mississippi River just north of Myrtle Grove, at river mile 60.7 (Figure 3). Current designs for this project are based on peak flow of 75,000 cfs and include a gated structure between the river and bay sides, a 300-foot bottom width channel, a pump station and highway and railroad modifications. The Mid-Barataria Sediment Diversion has a long history in restoration planning in coastal Louisiana. One of the earliest mentions of a freshwater and land-building diversion at Myrtle Grove can be found in a 1973 report published by Louisiana State University's former Center for Wetland Resources (Gagliano et al. 1973). The Coast 2050 report recommended a delta-building diversion at Myrtle Grove (LCWCRTF 1998), and the Water Resources Development Act of 2007 authorized the Louisiana Coastal Area Ecosystem Restoration Program, which included a medium-diversion at Myrtle Grove with dedicated dredging (USACE 2004). The project was selected for implementation in the 2012 Coastal Master Plan (CPRA 2012) and is currently in the engineering and design phase.

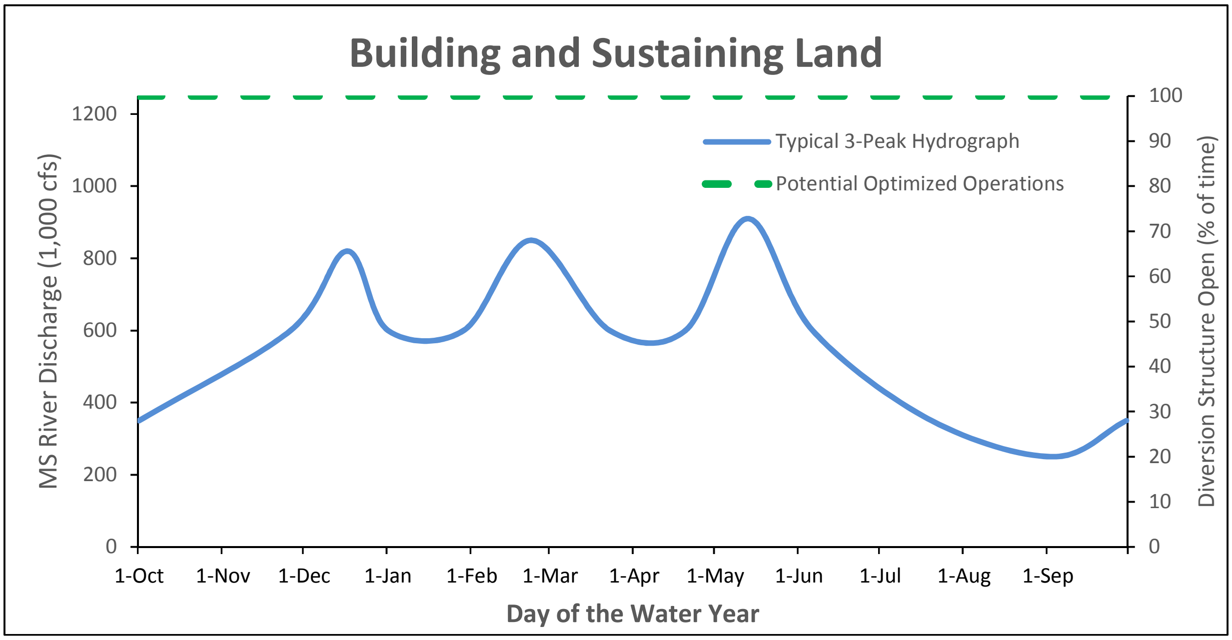
Recommendations

GOALS AND OBJECTIVES

Defining clear goals and measurable objectives for a sediment diversion project is critical to making appropriate operation decisions and determining the success of the project over time. The goals and objectives of the Mid-Barataria Sediment Diversion should fit under one or more of the five objectives of the Coastal Master Plan (storm surge protection, natural processes, coastal habitats, cultural heritage and working coast). The WG believes it is possible for a single sediment diversion project to contribute to all five of the state's master plan objectives. Setting the goals and objectives can be challenging and should include input from a wide range of entities, including local governments, other state and federal agencies, scientists and engineers and key affected stakeholders.

Building and sustaining land should always remain as the primary goal of operating a sediment diversion, but other primary or secondary objectives should also be developed that are specific and measurable. The WG agreed that land building is not a limiting or constraining factor to operation strategies. If land building were the primary and only goal, without any other constraints or considerations, the operation strategy could be to open the diversion structure nearly year-round and focus on delivering the maximum quantity of sediment possible to the receiving basin (Figure 4). Every minute the diversion is open is additional sediment that is delivered to the system, and modifications in discharges would only be used to move sediment through the system (e.g., open wide to blow out accumulated sediment), limit scour at initial operations and maximize vegetation health. Operating a sediment diversion for only a land-building goal provides a good baseline and can demonstrate the benefits and consequences of incorporating additional objectives or constraints.

Figure 4: Conceptual optimization of sediment diversion operations for building and sustaining land only with no other constraints overlaid on the common three peak hydrograph typology. Graphic notes when diversion could potentially be opened, not that it would be anticipated to be open the entire timeframe.



OPERATION PLANS

Future conditions of coastal Louisiana are highly uncertain due to the dynamics of riverine and marine processes, vulnerability of the delta to extreme tropical events, climate change and ongoing human reliance on the natural resources and ecosystem services of the coast. Managing such a complex system in which natural and socio-economic systems are highly integrated is inherently difficult. Sediment diversions are a unique restoration tool that can be modified and adapted over time based on the changing operations/ outcome conditions experienced and best available science. To facilitate the adaptive implementation of sediment diversions, ***operation plans should be living documents*** that are updated a minimum of every 5 years or as conditions warrant (e.g., a hurricane or unforeseen event occurs). Initial operation plans may be designed for individual diversions, but should quickly move toward an active adaptively managed operation plan for each hydrologic basin that incorporates all diversions within the basin. Operation plans should also take into account diversions and flood control structures in other basins that are utilizing the same river source and a sediment budget to ensure efficient and strategic use of the river's resources. System-based operation plans, including biennial operations that take into account all diversions in the coastal zone, should be explored as additional sediment diversions are constructed. Once multiple large diversions are constructed and sharing the same resources, there will be advantages and disadvantages to operating every diversion annually versus alternating diversions over multiple years.

Operation plans should embody the concept of active adaptive management (Walters 1986), which is an approach that places ***learning as a priority management function***. As such, project/system goals and objectives, normal and emergency operation strategies, project outcomes and indicators of success/failure, cumulative impacts, uncertainties, maintenance, monitoring plans and a governance structure with decision-making framework all become part of the main management function—learning. The overall long-term strategy(s) of the operation plan could then be modified in response to what has been learned during initial operations.

Operation strategies should be first developed based on average basin, offshore and atmospheric conditions. Once strategies are developed and tested for average conditions, modifications to those strategies can be explored based on more extreme conditions, such as excessive precipitation and drought or elevated stage in the Gulf of Mexico. The WG recommendations are based only on average basin, offshore and atmospheric conditions.

Defining annual operation strategies clearly will aid in transparency, communication and expectation management. Annual operation strategies should utilize the overall strategies in the operation plan and supplement with a prediction of river and basin conditions, the outcomes of the previous year's operations and other conditions.

Initial Operations –

There are multiple geological, hydrodynamic, ecological and social concerns that need to be understood and considered when developing an initial operation plan. In general, initial operations (Years 0 to 10) will need different operational considerations than later year operations, as the basin matures and adjusts to the new normal condition. ***Initial operation plans should include more monitoring and flexibility to modify operations as the conditions in the basin change and adjust rapidly.*** Updates to initial operation plans may need to occur more frequently based on integrated and near real-time operations-monitoring feedback loops.

A significant hydrodynamic effect in the river is not anticipated based solely on how the timing or process for opening the diversion is modified (i.e., whether the diversion is opened fully to 75,000 cfs in less than one day or gradually opened over a series of days, months or years). However, initial operation plans should take into account the hydrodynamics on the basin side. There are many constructed examples of freshwater and sediment diversions (e.g., West Bay, Wax Lake, Caernarvon, Davis Pond, Bonnet Carré Spillway) that help us to understand the effects of a sediment diversion. One key difference with the two existing sediment diversion examples (West Bay and Wax Lake) is that they have channels that connect them to relatively deep to shallow, open water bodies whereas the Mid-Barataria Sediment Diversion will empty into an area mixed with broken marsh and shallow, open water before reaching Barataria Bay. Although the basin has an existing network of natural and man-made channels, it does not currently have a distributary channel system that effectively moves 75,000 cfs of water and sediment through the basin. For the Mid-Barataria Sediment Diversion, it will take an estimated 5 to 10 years for the distributary channel network to develop to handle 75,000 cfs (McCorquodale 03/14/16). Very rapid opening can create a surge in the distributaries which could endanger waterway users and could cause excess scour (Wellner et al. 2005, Wright 1977). Operations should ramp up to 75,000 cfs over time to facilitate the development of the network.

The diversion will be flowing into already fragmented, degraded and weak marshes, similar to the Caernarvon and Davis Pond Freshwater Diversions. In many of these areas, vegetation is already flood stressed and additional research, modeling and monitoring are needed to determine how many acres of preexisting marshes may be negatively affected by the new, higher water levels (Snedden and Steyer 2013, Snedden et al. 2015). There is also the potential for an initial increase in flood risk for adjacent communities, and a likely one for those living within the marsh (e.g., Grand Bayou, Lafitte), that would need to be understood and, if found to exist, accounted for in the operation or mitigation plan.

From a geological perspective, initial operations could result in rapid erosion of areas of deteriorating marsh near the channel outfall, which is largely dependent on the velocity of discharge from the diversion. The discharge from a diversion is most commonly modeled as a turbulent jet plume that experiences the frictional effects of the bay bottom, because of the expected velocities based on water volume (Wright 1977). As a result, there may be a zone of scouring where the jet plume enters the basin (Wellner et al. 2005, Wright 1977), which can play an important role in the evolution of a crevasse (i.e., West Bay and Fort St. Philips) (Yuill et al. 2016). It is important to understand how the basin geology will respond to the initial opening of the diversion. Scour will occur in the channel and the immediate outfall area. However, those sediments will most likely be deposited in wetlands and bay bottoms further south in the basin. Efforts should be made to anticipate this erosion and limit it to areas of the developing channel network through gradual operation strategies or the engineering and design of the structure itself.

Wetland loss could also occur from preexisting vegetation loss due to increased flood stress. This wetland loss will occur within a few years but will be minor relative to diversion-induced land building that will occur over several decades after the diversion begins operating. To reduce unnecessary vegetation stress and/or wetland loss, it is important to focus operations on the non-growing season for the first 2 to 3 years before operating during the growing season to allow vegetation to adapt to the new conditions. Similar to vegetation, fish and wildlife species can suffer from an initial shock of changing conditions. Initial operations should occur gradually to ensure fish and wildlife species, as well as the habitats they depend on, can self-organize around the new normal conditions.

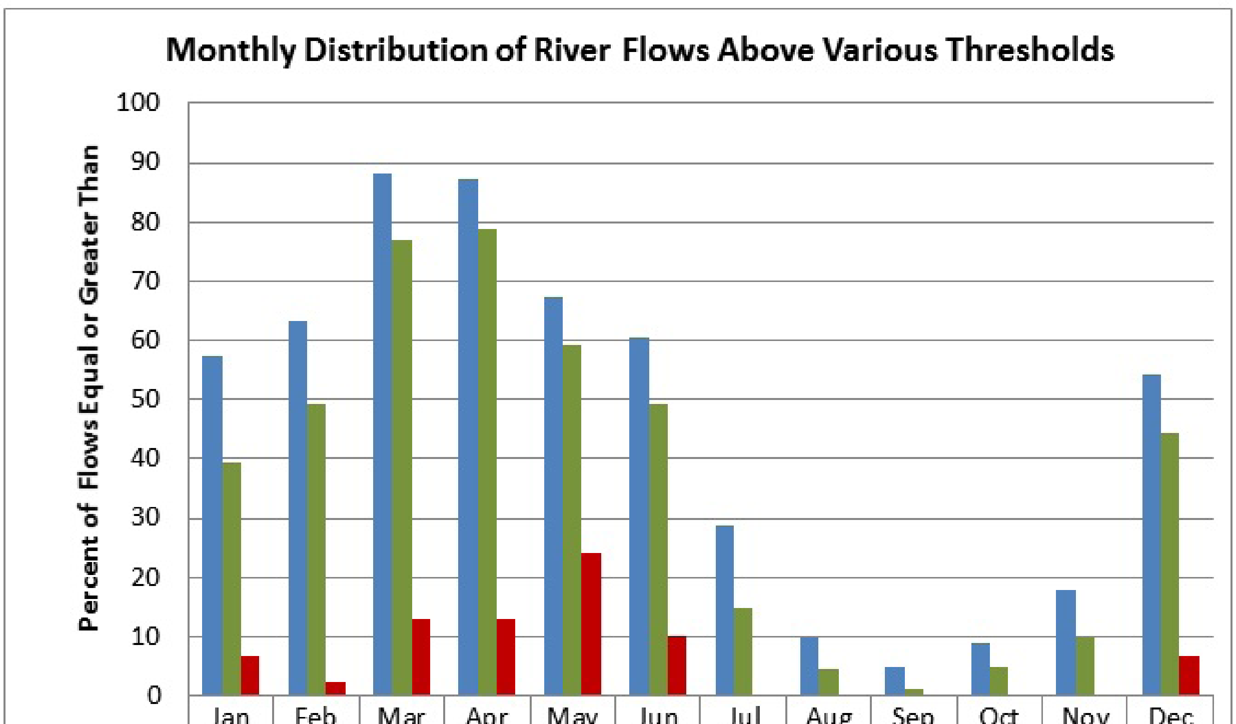
Operation plan development should model and research various ***strategies for initial, gradual openings*** based on seasonality and over numerous years to ***facilitate the development of the distributary network and allow the ecosystem to adjust and self-organize*** around the new normal conditions.

OPERATION STRATEGIES

Hydrodynamics of the River –

The Mississippi River Delta does not function naturally as a result of river management decisions that have created an artificial landscape dominated by a primarily deteriorating delta. It is not feasible to return the system to a completely natural state. Therefore, sediment diversions are an engineering solution that can return some areas into a man-made replication of a natural state. A commonly accepted operation strategy for sediment diversions is to mimic the natural functioning of the river and its floodplain. Operation strategies should focus on using ***pulsed operations based on the natural flood cycles of the Mississippi River***, which typically occur from late winter to early summer, but could extend from early winter to late summer. As much as possible, management should allow the ecosystem, vegetation and species to self-organize around these pulses of freshwater, sediment and nutrients.

Figure 5: Potential monthly distributions of river discharges over various thresholds for operations. (Note: Legend is in 1,000s cfs).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
>= 500k	57.38	63.32	88.05	87.06	67.28	60.35	28.69	9.894	4.947	8.904	17.81	54.41
>= 600k	39.44	49.31	76.92	78.89	59.17	49.31	14.79	4.438	0.986	4.931	9.861	44.38
>= 1000k	6.857	2.5	12.86	12.86	24	10.29	0	0	0	0	0	6.857

Operation plans should be developed based on the water year, defined as October 1st through September 30th of the next year. The Mississippi River can experience one or more flood peaks in any given year and those peaks often begin in the winter. Occasionally the river floods at an atypical time of year, as it did in August 2015 and January 2016. In the last 56 years (1960-2016), winter flood peaks (defined as over 600,000 cfs) from November through February have occurred 82% of the time (McCorquodale in prep). There is a 41% occurrence rate of 2 winter peaks in a year and a 14% occurrence rate of 3 or more winter peaks in a year. Exceeding 600,000 cfs has a 40% chance of happening in January and a 50% chance of happening in February and increases to 57% and 63% if a threshold of 500,000 cfs is utilized (Figure 5). When lowering the operation threshold to 500,000 cfs, the occurrence of winter peaks increases to 100% although some peaks may be short-lived (less than one week) (McCorquodale in prep).

Winter Operations –

There are some ***clear advantages to focusing operations, both initially and long-term, on winter peaks*** that occur from November to February. In general, there are fewer concerns when considering prolonged operations in the winter than in the spring and summer. Advantages of operating during winter flood peaks, specifically in the initial operations, include:

- The first peak of the water year tends to carry the greatest concentration of sand, silt and clay.
- The highest suspended sediment concentrations occur from November to February even though the highest sediment loads don't occur until March (McCorquodale in prep).
- Silts and clays that are initially deposited on bay and canal bottoms can be resuspended and deposited on the marsh surface by cold front passages prior to consolidation (Reed 1989, Roberts et al. 1989, Carle et al. 2015, Freeman et al. 2015). If a diversion were operated just prior to a cold front passage (most prevalent from November to March) it could maximize sediment resuspension and transfer onto the wetland surface.
- Cold fronts can also push nutrient-laden water onto the marsh surface and increase the denitrification potential of the basin, which is lowest in the winter.
- The sea surface elevation of the Gulf of Mexico is lowest in the winter, which can help move water out of the basin thereby reducing residence times and reducing the risk of elevated water levels for extended periods of time.
- Operating during the non-growing season (winter to early spring) will reduce vegetation stress and loss and allow prolonged and continuous flooding while plants are in a dormant state. This is especially important during the initial operations.
- Reduce and eliminate impacts to most commercial and recreational fish and wildlife species, including a reduced mortality rate in oysters, due to the species' ability to adapt to low salinity conditions when water temperatures are lower. This also can be especially important during the initial operations.
- Estuarine gradient recovery (which occurs over 2-4 weeks after the diversion is closed) can facilitate the mating of blue crabs in the spring and their larval recruitment during summer, and brown shrimp (late winter/early spring) and white shrimp (late spring/summer) postlarvae immigration into the estuary.

Spring and Early Summer Operations –

Although there is a lot of potential to optimize operations with winter peak flows, to achieve the primary goal of maximizing land building and sustaining potential, operation plans must also ***take full advantage of spring and early summer flood peaks***, especially in years where no winter peak occurs. Spring and summer flood peaks are generally higher in magnitude and carry a higher total sediment load than winter peaks.

Operations during the spring and summer are more complex and require a more intricate operation strategy. Some of the key considerations for operation planning include:

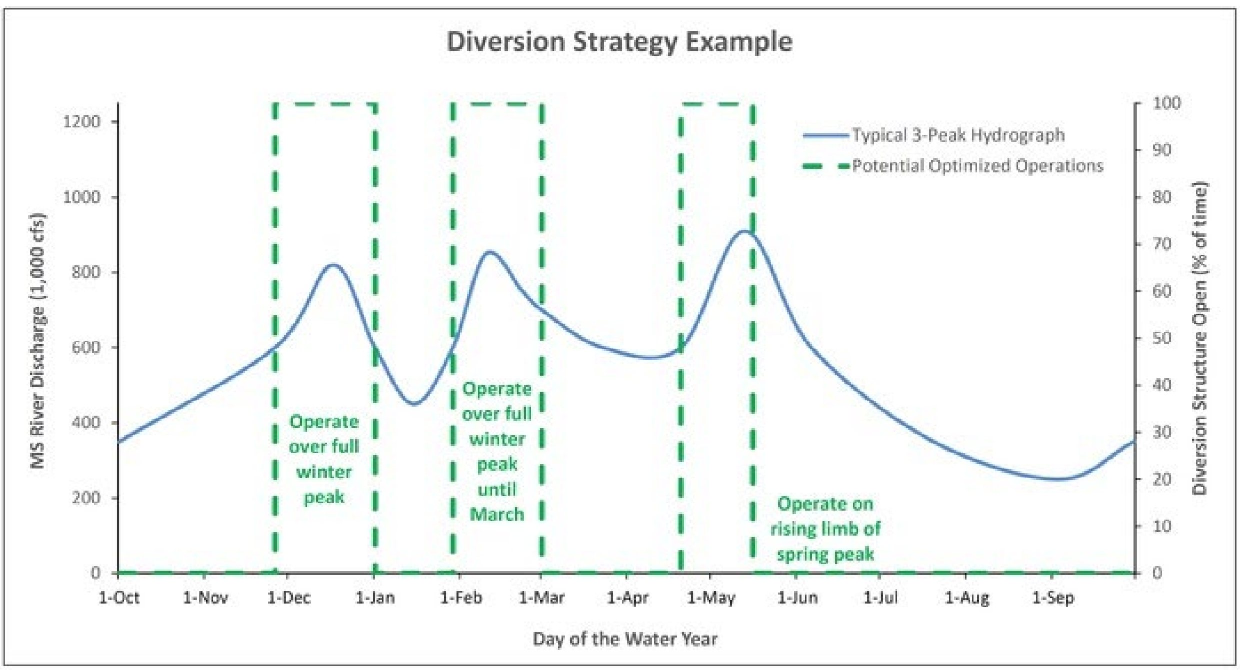
- Any operations during the growing season should include adequate dry periods to allow vegetation to recover from flood stress. Flood durations at the beginning of the growing season (April-May) should be monitored closely as this is a vital period for plant growth.
- Understanding residence times and water distribution in the basin can lead to operations that improve water quality, especially since denitrification rates are highest in the warmer months and the concentration of nutrients in the river typically peaks during or after the spring floods (Roblin 2008).
- While maintaining a focus on land building/sustaining, operations should minimize net negative effects to indicator species, as a representative subset of the overall biological community. Operation plans should include modeling, research and monitoring to predict, quantify, mitigate and communicate any potential negative impacts that may occur.
  - American alligators, once established, nest from mid-May to early September (Platt et al. 1995).
  - Blue crab mate in March through May and spawn primarily from August to September, although some spawning occurs in spring (Guillory et al. 2001).
  - Oyster's first spawn and recruitment occurs in late spring/early summer (Hayes and Menzel 1981).
  - Brown shrimp postlarvae recruit to the basin in March through May (Global Trust 2011).
  - In addition, consideration should be given to peak calving season of the bay, sound, estuary bottlenose dolphins, thought to occur during warmer spring and summer months, in coordination with National Oceanic and Atmospheric Administration (NOAA) and US Fish and Wildlife Service (USFWS) (Wells et al. 1987, Miller et al. 2013, Henderson 2004).

Sediment Capture –

The amount of sediment carried by the river can vary based on whether the flood peak is rising (more sediment) or falling (less sediment), and also on whether the flood peak is the first peak (higher sediment concentration, especially fines) of the water year. The sediment spike tends to occur over a narrower timeframe than the rising limb of the flood waters. Operation triggers should ***focus on the rising limb***

and peak of the flood event to optimize sediment transport in relation to the amount of water carried into the diversion channel. Operating on the rising limb would result in approximately 56% of the water diverted and 72% of the sediment diverted compared to operating on both the rising and falling limbs of the hydrograph (McCorquodale in prep). Predictions of river discharge are made available by NOAA and United States Geological Survey (USGS) 28 days in advance of the flood event (http://water.weather.gov/ahps/forecasts.php), thus making a trigger based on the rising of the river easier to predict and manage. NOAA and National Weather Service (NWS) also develops predictions of weekly, 8 to 14 day, monthly and longer precipitation forecasts (http://www.weather.gov/forecastmaps). Additional predictive capabilities should be explored, including the ability to predict longer-term flood patterns based on a combination of environmental conditions and statistical analysis similar to the hurricane season predictions.

Figure 6 - One potential operation strategy focused on effectively using river hydrology and capturing sediment from the river, while balancing the needs of the ecosystem. The graph demonstrates how a three-peak hydrograph typology can be used to develop operation strategies. Notice the diversion operates throughout the winter flood, most of the late winter flood peak (closing by March to allow estuarine recovery) and closes after the peak of the spring flood, focusing on the rising limb to capture the most sediment and reduce the effect to the ecosystem. Note: Although the diversion is depicted as open 100% or completely closed, each opening could happen gradually over time.

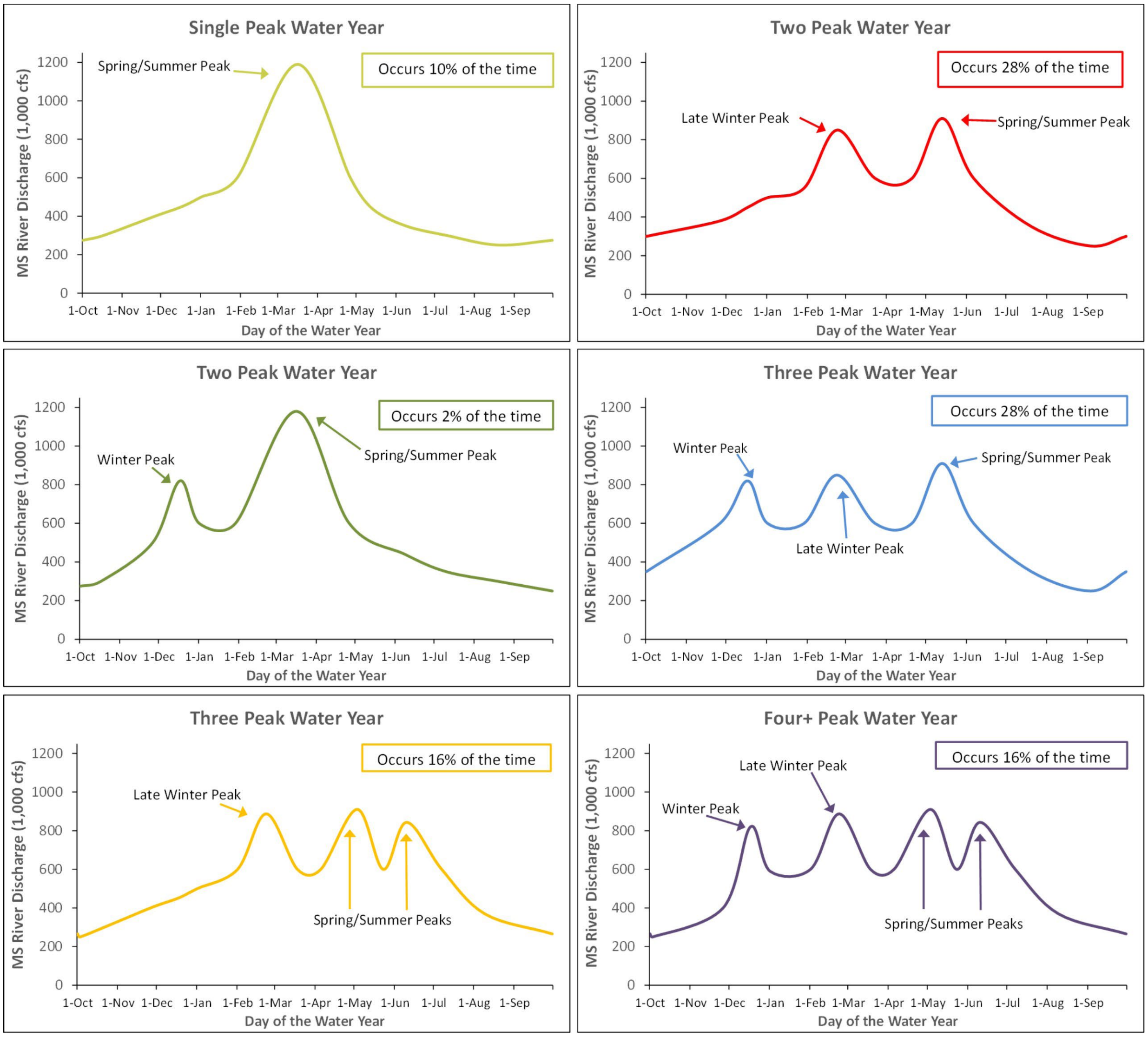


Operation strategies should consider ***closing or reducing flow on the falling limb*** to increase sediment transport potential in the river to minimize shoaling by increasing water flow in the river during the peak (McCorquodale in prep). A reduced flow may need to be maintained in the diversion channel to prevent the establishment of sandbars in the outfall channel. If sandbars do form in the outfall channel, the diversion would need to be operated for a short period to blow-out the sandbar prior to consolidation of the material in the channel. Diversions should be operated on the rising limb and peak, and potentially the entire peak, of the ***first flood event of the water year***. Measurement of a combination of flow and sediment load, plus ecosystem and community needs, should be used to determine if the diversion should be operated on the rising limb and peak of subsequent flood events (Figure 6). Additional sediment monitors in the river would increase the capability to predict the sediment pulse.

In natural flood cycles, the river water would remain in the river channel until it reached a high enough stage to overflow its banks (natural levees). Planning efforts have designated that threshold as 600,000 cfs for sediment diversions. However, this threshold is somewhat arbitrary and operation plans should ***maintain flexibility to operate a diversion when the river is below 600,000 cfs***, specifically to capture significant suspended sediment loads of silts and clays. For example, high flows on the Missouri River can deliver higher sediment loads relative to water discharge (Allison et al. 2012, Flynn et al. 1995). Suspended sediments are an essential input to sustaining the existing wetland landscape.

It is important to try to ***maintain a minimum residual flow of approximately 300,000 cfs*** in the river at Head of Passes (approximately 400,000 cfs at River Mile 30) to ensure continued navigation and community/industry use (low salt water intrusion). However, extreme salinity spikes in the receiving basin during droughts could stress or kill freshwater marsh vegetation (if established in the outfall area) (Flynn et al. 1995, Howard and Mendelssohn 1999, Howard and Mendelssohn 2000), exacerbating erosion and thus offsetting land building. In such cases, the flexibility to allow even minimal flows could be instrumental in preventing unnecessary losses.

Figure 7: Hydrograph typologies of the Mississippi River based on 56 years of river flows and the rate of occurrence (McCorquodale in prep).



Hydrograph Typologies –

The WG recommends utilizing ***hydrograph typologies to define, analyze and communicate operations strategies in the operation plan***. By understanding and communicating operating strategies using typical hydrographs, the public will have a better understanding of what operations are anticipated to occur in any given year. Hydrograph typologies were developed by McCorquodale (in prep) as part of this effort using the past 56 years of hydrographs on the Mississippi River. There are six main hydrograph typologies that occur regularly on the Mississippi River as depicted in Figure 7. These topologies show the mean of the observed peaks and their mean time of occurrence.

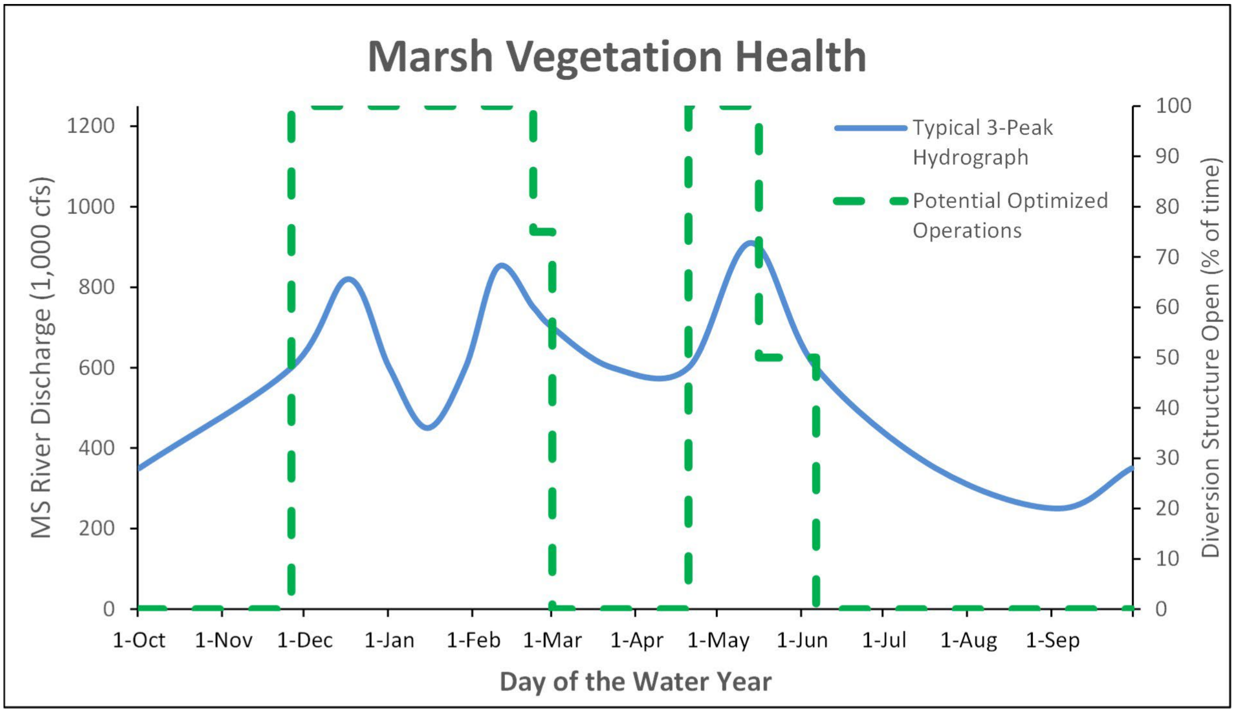
Sediment Retention –

On the basin side, operation plans should focus on maximizing sediment retention to maximize land built/sustained by the diversion. A ***sediment retention target area should be defined*** (Blum and Roberts 2009). For the Mid-Barataria Sediment Diversion, the area of interest is recommended to include all of Barataria Basin, with the southern boundary of the Barataria Basin barrier island chain, to capture the sediments that are deposited and reworked in Barataria Bay. Management should **set a targeted sediment retention rate** that maximizes retention based on basin geology and diversion location (a suggested minimum of 75% of the sediment discharge within the Barataria Basin). Some options for increasing sediment capture and sediment retention are: periodic supplemental dredging of river sediments and placement directly into the diversion channel; utilizing cold front resuspension; and developing an outfall management plan with targets; various adaptation strategies (such as sediment retention and enhancement devices (SREDs) or hydrologic modification of canals and spoil banks) to manage water flow and sediment retention; and cost estimates to provide flexibility to managing the basin geomorphology to meet the objectives of the project.

Vegetation –

Operation of a sediment diversion does not necessarily mean that large areas of Barataria Basin will turn into freshwater habitats. There is a perception that the vegetative community will be able to handle and respond positively and quickly to any changes in salinity caused by diversion operation. However, there tends to be a lot of inertia in plant community dynamics and the dynamics of vegetation shifts are more complex. There are examples in coastal Louisiana of vegetation being very responsive to shifts (Naomi Siphon) and others where vegetation has been very stagnant (Caernarvon Diversion). The exact response in Barataria Basin may be difficult to predict. Freshwater vegetation may establish over time in the immediate outfall area. However, the WG recommends ***maintaining as much intermediate and brackish marsh as possible*** to prevent episodic loss of freshwater vegetation that can occur with salinity spikes during droughts, or to ensure that wetlands are more resilient in the face of rising sea levels and an increase in daily salinities. As mentioned above, ***operating sediment diversions during the dormant season and limiting the operations during the growing season will also prevent vegetation loss and subsequent land loss*** (Figure 8).

Figure 8: Conceptualized operation strategy that optimizes vegetation health and minimizes loss of vegetation from prolonged and extensive flooding.



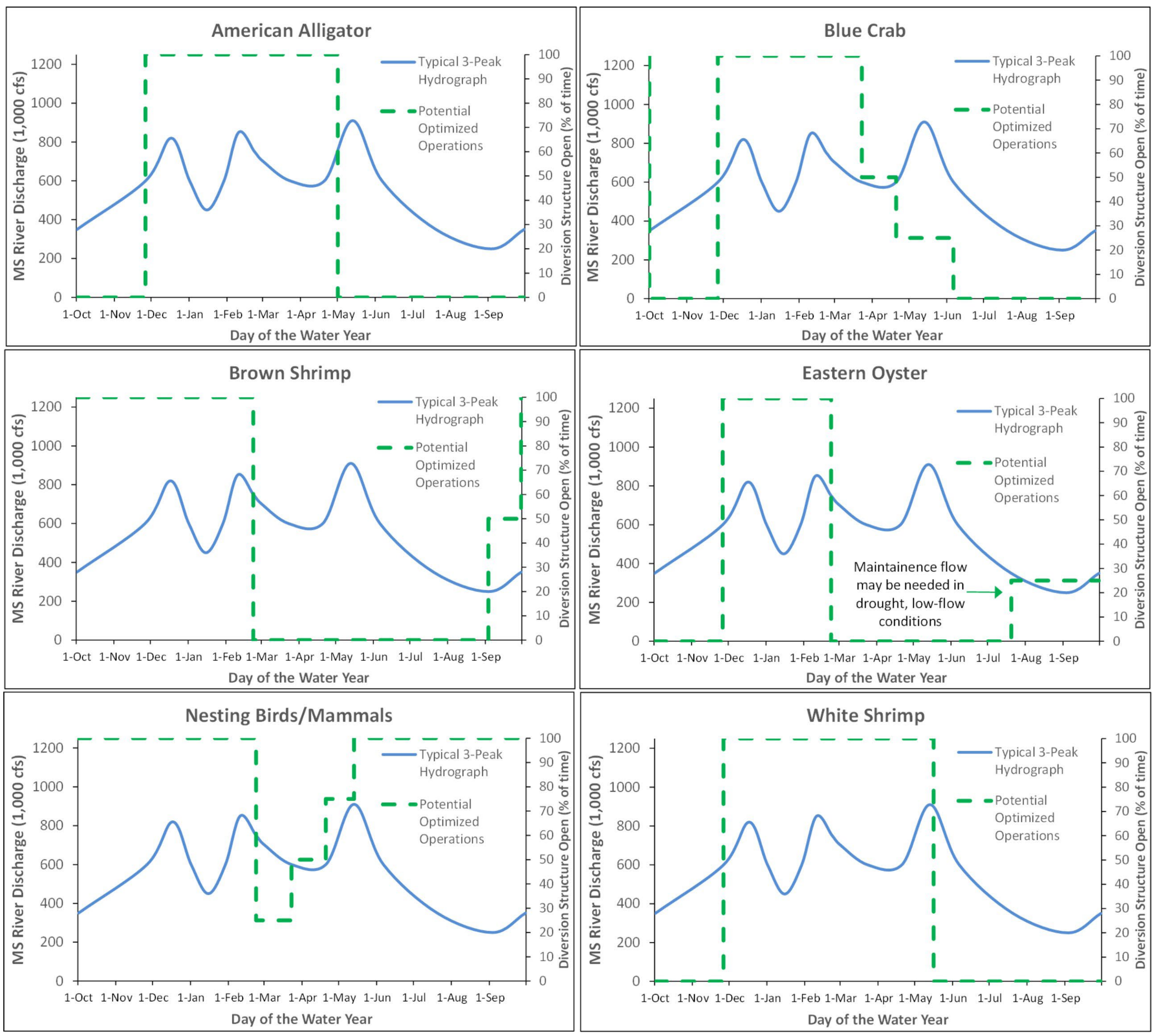
Fish and Wildlife –

From a holistic fish and wildlife population perspective, the WG recommended that operations ***focus on community structure and productivity*** rather than individual species. Some species are going to be affected detrimentally whether we act or not (CPRA 2012). Understanding the benefits and impacts of a sediment diversion on indicator species is important for transparency and expectation management. Predictions based on salinity, habitat responses and life history stages should be made to the best of our ability and monitoring should be incorporated, with a solid adaptive management plan, to understand and improve management over time.

In general, an objective of a sediment diversion should be to ***minimize net negative effects on indicator species, as a subset of the overall biological community, to the extent possible***, while keeping in mind that land building and sustaining is the primary goal. It is important to consider net effects as the decline in one valuable species could be offset by the increase in another valuable species. The operation plan should identify valuable or indicator species that include important commercial and recreational species, but should also include species of intrinsic value to the food web or the ecosystem.

Each species environmental requirements are different (see Supplemental Information), but by overlaying an operation optimized by species over the hydrograph typologies (Figure 9), operation plans can start to see commonalities and disparities in species needs with the overall primary goal of land building/sustaining. Although operation plans should not be developed to meet any species' specific needs, understanding the discrepancies of these operations will provide important information for the modeling, research and monitoring of potential detrimental effects and can inform discussions with people who may be affected on expectations of outcomes. In addition, gradual openings and closings, as well as maintenance flows could be important to reduce the shock of changing conditions, maintain habitats in newly established areas (i.e., newly established oyster leases in the southern portion of the basin due to salinity shifts or potential sedimentation of upper basin leases) and prevent establishment and then subsequent loss of nests (alligator, ducks, etc.) in low-lying areas.

Figure 9: Operations to "optimize" a specific species overlaid on one of the common three peak hydrograph typologies. Optimize means to leave at present-day status quo within the Barataria Basin. Note that just because the diversion could potentially be opened during a period of time, it is not anticipated to be opened the entire time period.



Louisiana has been gaining, and will continue to gain habitat coast-wide for more saline species for the next 50 years with and without action (CPRA 2012). In Barataria Basin, many of the species that may be positively affected by a diversion are also negatively affected by a future with no action, and vice versa. Although optimum diversion flow conditions may negate optimum conditions for many species, this does not potentially negate the possibilities for diversion flow that allows for a reduced presence of a group of species from current or future conditions, while maintaining economically harvestable levels. Other species could see an increase in harvestable levels (CPRA 2012). ***Modeling efforts and dialogue with commercial and recreational stakeholders that possess traditional ecological knowledge (TEK) are critical*** for scientists and resource managers to not only identify knowledge gaps in the life history of indicator species but also develop and inform operation plans that ***meet the primary goal of land building while balancing the needs of the ecosystem and communities***. These discussions should also inform the development of secondary objectives of the sediment diversion project.

Water Quality –

If reducing adverse impacts associated with nutrients both offshore and in the basin is an objective of the diversion, then the operation of the diversion should be done when both the sediment and nutrient loads in the river are high and shut down gradually to prevent nutrient-laden water from becoming stagnant, thus avoiding creating favorable conditions for algal bloom formation (Roy et al. 2016). A gradual shutdown (to 10-20% capacity) will allow some water flow through the system as residence times are gradually increased and nutrients are processed within the estuary. Algal primary production peaks immediately after river water shutoff in Lake Pontchartrain have been composed primarily of a non-toxic species of diatom, which are efficient in removing excess nutrients from the water column (Bargu et al. 2011, Roy et al. 2013).

Some of the channels and canals in the Barataria Basin allow nutrient-rich water to short-circuit the estuary and expel directly into the Gulf of Mexico. Strategically placed landscape features or potential re-plumbing of the hydrodynamic system could increase the amount of nitrogen that is consumed in the estuary. These nutrient retention and enhancement devices (NREDs) could increase the ability of the basin to act as a nutrient sink and potentially could be combined with SREDs to improve the sediment trapping and nutrient uptake efficiencies of the basin.

Maintenance Flows –

Maintenance flows are defined as low flows, typically of 10,000 cfs of less, that flow at times of the year that are not optimal for sediment transport, and therefore are not the most efficient means of capturing sediment. However, ***maintenance flows should be considered under an adaptive management plan for specific ecosystem conditions in the basin***, including the potential establishment of freshwater habitats at the outfall that could be damaged by saltwater intrusion, preventing an increase in oyster predation and disease (especially if sub-tidal oyster populations shift to the lower estuary) and preventing waterfowl and alligators from nesting in low-lying areas that will later be flooded during a flood peak. Maintenance flows are not presently anticipated to be needed on an annual basis; however, the effects of sea level rise may increase the utility of these flows in the future.

SOCIAL AND ECONOMICS

As the state moves forward with its thinking on developing and operating diversions, ***socio-economic effects, community resiliency and mitigation opportunities all need to be fully considered***. Some isolated socio-economic analysis has been conducted (e.g., fisheries implications of freshwater introductions (Caffey and Schexnayder 2002), role of cost efficacy in project selection, economic analysis of oyster lease dynamics (Keithly and Kazmmierczak 2007), cost-earnings survey of various fisheries, and economic evaluation of land loss in coastal Louisiana (Barnes et al. 2015)), but more research and stakeholder engagement needs to be done. CPRA is currently working on a basin-wide socio-economic analysis, and will need to carefully think through how to communicate to affected stakeholders and communities and engage in an informed stakeholder discussion.

The Louisiana coast has always been dynamic, with communities shifting their locations and people changing their livelihoods based on the variable loss of Louisiana's wetlands, saltwater intrusion, shifting fish and wildlife communities and storms. A better understanding of the history and baseline of social impacts would greatly inform the ability to predict how operations of a diversion may have future impacts in the context of this natural variability.

Among the questions, needs and opportunities that warrant further investigation:

- Clearly defining the spatial and temporal scale, including both short-term and long-term effects, that is appropriate to inform the decisions and provide consistency of analysis
- Incorporating TEK into monitoring plans
- Expanding disaster assessment models and conducting human adaptation studies
- Extrapolating biophysical modeling to understand socio-economic impacts on individual businesses and harvest sectors
- Providing multiple years of advance notice to oystermen and other fishers affected by salinity changes
- Understanding and communicating what the operation of a diversion could mean for redistribution of fish, shellfish and wildlife species and abundance
- Assessing impacts on subsistence fishers and on fishing access points
- Developing tools to help with fisheries transitions
- Understanding the positive and negative impacts of diversions on flood risk and community resiliency

Natural resources users, such as commercial fishers, hunters and recreational users, have long held economic and cultural significance in Louisiana (Davis 2010). They are experts who understand local conditions, and that traditional knowledge needs to be utilized. While the current level of modeling may provide proxies for predicting long-term socio-economic impacts, current methods are typically too broad in scope for estimating localized economic impacts.

Just as the Operations Working Group used the Mid-Barataria Sediment Diversion as a case study for various operational strategies, we encourage the state to similarly use Lafitte, a waterfront community just seven miles from the diversion site, as a case study for near term and long-term socio-economic impacts. In the near term, depending on how operations are ramped up and how distributary channels form to accommodate the flow from the diversion, water levels may increase slightly in the vicinity of Lafitte – perhaps less than a foot (McCorquodale 3/14/16). Without mitigation, even such small rises in water level could flood roads and properties in this low-lying community. However, over the next few decades, Lafitte will benefit from land building in the basin that can reduce long-term impacts from sea level rise and storms, that could be devastating to the community in a future without action.

As the state learns more about the impacts of different operational models and alternatives for diversions, it will be essential for that knowledge to be communicated to natural resource users and communities (including Lafitte) in a timely manner that allows for informed stakeholder input, participation and response. It will be important for the state to prioritize operational regimes that appropriately balance the urgency of stopping coastal land loss with the importance of minimizing and mitigating adverse socio-economic impacts, to the extent economically and scientifically feasible within the primary goal of land building.

GOVERNANCE AND STAKEHOLDERS

Clear governance of diversion operations is required to navigate the tension between scientifically oriented, regional or coast-wide goals and socio-economic interests on a sub-regional and individual level. The success of diversions in land building and stabilization of ecosystem functions depends on addressing socio-economic concerns to the extent that legal and political challenges do not compromise the coastal restoration goals of the projects. To that end, ***transparency on potential effects, two-way sharing of information and a genuine attempt to mitigate socio-economic impacts without compromising the effectiveness of the diversion, are crucial***. The state has the ultimate responsibility of setting the operating regime and should do so without letting political influences undermine the science. Once impacts to people are reasonably known the trade-offs can be assessed in light of long-term versus short-term interests and goals with heavy deference to restoration goals and finding ways to mitigate/compensate adverse effects.

Stakeholder participation in the process is limited by several factors including: the esoteric nature of scientific data techniques and principles to the general public, mistrust of government, lack of effective outreach skills, failure to address local input and self-serving agendas. CPRA should identify members of affected sectors who will truly represent their communities and develop relationships with them to create trust and develop acceptable solutions. However, operation strategies should not be modified based off of one interest group or individual. Negotiations with affected parties should focus on how to manage and deal with any predicted and unforeseen effects, not on how to operate the diversion. Effective education on the positive and negative effects of operations can help manage expectations and generate trust. ***Implementing this new behavior and building a transparent and inclusive decision-making structure for the Caernarvon and Davis Pond Freshwater Diversions now can become an example of how the sediment diversion decisions can be made in the future***.

The legal regime controlling diversion operations presents some challenges beginning with federal oversight under National Environmental Policy Act (NEPA) on adaptive management. Even though the state has taken legislative and judicial action to institute measures that provide some protection against government liability for damages to property, there are other federal and state constitutional issues that also need to be addressed. Takings and possible tort actions could still be viable and expose the state to significant liability.

Perhaps an even greater obstacle to effective diversion operations is political pressure from affected communities and individuals. Attempts have already been made to legislate less than optimum (for coastal restoration purposes) diversion operations to protect other interests and more attempts are likely to come. The operations of existing diversions have been continuously constrained by political pressure (Harrison 2014). It will be necessary to develop preemptive measures to mitigate and in some cases compensate for losses that result from diversion operations to avoid costly, long-term delays in achieving project goals. In this effort it is crucial that the state provides absolute transparency regarding expected impacts, a transparency that has so far been suboptimal.

MONITORING AND RESEARCH

The dynamic nature of the coast and the people and wildlife that depend on it, plus the complexity of outcomes from a sediment diversion, require the development of a robust and long-term monitoring program begun well in advance of the initial operations in order to have baseline data. This program should be able to determine the effectiveness of the restoration project in meeting its goals and objectives, understand the cause and effect of key outcomes in the basin and support an active adaptive management program. A short-term monitoring and research plan should also be developed to provide additional insights into the changes that occur due to the initial opening of the diversion and the first few years of operations, specifically to inform the design and operations of future diversions. Experts noted that monitoring programs at Caernarvon and Davis Pond diversions are woefully inadequate. It was also noted again that pre-construction/baseline monitoring that includes seasonal variability is just as important as post-construction monitoring. A good monitoring and research program in the river and the receiving basin is essential to observe conditions before, during and after operations and to measure project success, as well as far field effects. Monitoring should be sure to incorporate the entire influence area of the diversion, including the effect of the diversion on the Mississippi River discharge into the Gulf of Mexico, the nearshore environment of the basin in which the diversion is located as well as effects on adjacent basins through hydrologic connections (e.g., the Gulf Intracoastal Waterway (GIWW)). Specific monitoring and research recommendations are included in the Supplemental Information.

To support the monitoring program, a competitive research program should be funded to provide funding to answer key questions, topics of concern and address uncertainties related to all the various aspects of diversions including sociology, ecology, hydrology, geology, biology and economics including ones that have not yet been imagined. The Diversion Implementation Science Advisory Panel should be continued, or a new advisory panel formed, to support this effort.

Conclusions

Sediment diversions have long been identified as a keystone restoration project type needed in Louisiana to build new land and help maintain existing wetlands. Integrated into the levee system, these gated structures can be opened and closed to allow water, sediment and nutrients from the river to flow into open water and degraded wetlands, mimicking the natural system that existed before levees were built. Engineering, design and modeling is underway for two sediment diversion projects using a simplified diversion operation strategy based on river flow, but this simplified strategy is not operations for the real world. To make recommendations on sediment diversion operation strategies that take into account the complex physical, ecological, economic and social issues that exist in Louisiana, an interdisciplinary working group of experts was convened once per month over an eight month period.

The primary project goal of any sediment diversion project is to build and sustain land. The WG recommends that additional clear and measurable objectives be outlined and used as the starting point for developing an operation strategy, defining the project monitoring needs, and for a receiving basin management plan for measuring the success of the project over time. Due to the flexible nature of sediment diversion projects, the ongoing coastal restoration efforts and the dynamic nature of Louisiana's coast, diversion operations plans should be considered living documents that will need to be regularly updated and adapted to account for changing environmental conditions. For example, initial (years 0 to 10) operation considerations of the project will differ from later considerations in the project's lifespan to accommodate the development of the distributary channel network and allow the basin to adjust and self-organize around the new conditions.

While the goals and objectives of each project should be used to help develop its operation plan, there are some general operation strategies that need to be considered that maximize land building, but also taking into account other changes that may occur in the system. This includes changes that impact the people, communities and industries that rely on the natural environment. Economic evaluation of sediment diversion projects, both in the short term and long term, should be weighed when developing an operation strategy. It is also vital that there is absolute openness and effective communication to the public about what the operation plans of these projects are and what other changes to the system they may bring.

In general, the operation strategy of a sediment diversion should focus on pulsed opening based on the natural flood cycle of the Mississippi River and in particular the rising limb and peak of the river flood. Over the last 56 years, events with river discharge in excess of 600,000 cfs have occurred 82% of the time from November through February. Operation of a sediment diversion during the winter has some clear advantages. These advantages include the high concentration of sediment carried by the river in the first peak of the water year (October 1st through September 30th), the existing vegetation in the basin will be dormant and can tolerate prolonged flooding during this time, and this winter period coincides with times in the lifecycle for many recreational and commercial fish, shellfish and wildlife when they can tolerate lower salinities.

The winter high water peaks are important, but capitalizing on the spring and early summer river flood peaks is also necessary. River peaks in the spring and summer are generally of greater magnitude, carrying a greater total sediment load, but operation during this period may also entail a more intricate operation strategy that in the winter. For operation during warm months, the focus should be on building and sustaining land while also understanding and, when possible, minimizing net negative effects to indicator species, such as American alligators, oysters and shrimp.

The landscape of the Mississippi River Delta is ever-changing. Once the influence of the river's sediment, freshwater and nutrients spread over a vast wetland area, but today only a few outlets remain. A foundation of Louisiana's coastal restoration efforts, sediment diversion projects would put the river's resources back to work to build and sustain wetlands. The success of any sediment diversion project will depend on clear and honest communication with stakeholders, a well-thought out and adaptable operations plan and a robust and long-term monitoring program to evaluate project success.

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