BUILDING LAND IN COASTAL LOUISIANA

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

Supplemental Information

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HYDRODYNAMICS OF THE RIVER

Pulsed Flows

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. Occasionally the river floods at an atypical time of year, as it did in August 2015 and the magnitude of the flood peak in January 2016. Changes in the timing and number of river flood pulses with climate change will need to be monitored and taken into account with any operation plan.

River Discharge

River discharge has multiple factors that could affect operations including river flow, stage, velocity and trajectory of the river flow (rising/falling limbs of the flood event). For most recent modeling and planning purposes, the trigger to open or close a diversion is based solely on the amount of river discharge. The 2012 Coastal Master Plan (CPRA 2012) used triggers of 200,000 cfs for small diversions and 600,000 cfs to operate at full capacity for larger diversions. The Hydrodynamic and Delta Management Study is using a trigger of 600,000 cfs in the river to test operations of individual and collective diversions. At 600,000 cfs, sand resuspension potential increases resulting in significant suspended sand loads in the water column (Allison et al. 2012). However, starting operations at a lower river discharge could increase the transport of silt and clays, specifically on the rising limb which typically only lasts two to three weeks. For example, high flows on the Missouri River can deliver higher suspended sediment loads relative to water discharge (Allison et al. 2012).

Sand is an essential building block for land, but silt and clay are essential in sustaining any existing and newly created wetlands. 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. The opening point for a diversion should be based on maintaining a designated residual flow in the river, the head differential between the river and the receiving basin, and the suspended sediment load in both the river and the diversion channel. Under ideal conditions, the ratio of sediment to water in the diversion channel should be equal to or greater than the sediment to water ratio in the river. In cases where that is not possible, the sediment to water ratio should be maximized.

Designating a minimal residual flow, or discharge remaining in the river after the last diversion, is essential to continue to provide for navigation and community/industry needs, (e.g., to prevent saltwater wedge intrusion.) The salt wedge is known to travel 80 miles upriver with a flow of 260,000 cfs at Head of Passes (Galler and Allison 2010, Georgiou 2016). At this flow, navigation is impeded and drinking water supplies are threatened. At 400,000 cfs, the salt wedge is stabilized at River Mile 30 (Georgiou 2016). A minimum river discharge (residual flow at the Head of Passes) of 300,000 cfs (approximately 400,000 cfs at River Mile 30) should be maintained at all times when operating one or more diversions for navigation and community/industry use. However, extreme salinity spikes in the receiving basin during droughts could stress or kill freshwater marsh vegetation, if established over time, exacerbating erosion and thus offsetting land building. In such cases, the flexibility to allow even minimal flows could be instrumental in preventing unnecessary losses.

Also, operation strategies should not allow diversion operations at 400,000 cfs if the river flow is rising from an extended low flow period in which the saltwater wedge has moved upstream to ensure that the salt wedge retreats prior to operation (at least to River Mile 30). Once diversions are constructed, there is also a concern that the diversion intake and sediment transport potential would be affected by saltwater dynamics during low river flow. The diversion structure itself would need to withstand exposure to seawater.

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. 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 (see Figure 5, Main Report). If the threshold is lowered to 500,000 cfs, there is a 100% occurrence of one winter peak, a 79% occurrence of 2 winter peaks and a 61% occurrence of 3 or more winter peaks. It is important to note that peaks between 500,000 cfs and 600,000 cfs are typically short-lived, lasting less than one week (McCorquodale in prep).

Maximizing Diversion Efficiency

For the Mississippi River, hysteresis means that the flow and sediment load in the river is not only dependent on what is happening at the present time, but also what has happened in the past. For instance, the river can have the exact same flow rate (for example 550,000 cfs), but carry vastly different amounts of sediment depending if the river is rising (more sediment) or falling (less sediment). On rising limb, sediment load increases, but may exhaust the readily available sand. Concentrations of fine sediment tend to be higher on the rising limb of the first flood of the water year. Sand concentrations are sensitive to the upstream supply and the available in situ sand (Allison et al. 2012, McCorquodale in prep).

During the falling limb of a flood peak, sediment availability is typically limited (particularly sand). Thus, the rising limb of a flood event is transport limited and the falling limb is supply limited. Closing or reducing the flow of a diversion on the falling limb of the flood while discharge in the river is still relatively high would increase sediment transport potential in the river. Since a disproportionate amount of shoaling occurs on the falling limb, this operational strategy could help preserve stream power in the river and reduce the amount of shoaling that occurs in the river as a result of operating the diversion. A reduced flow may need to be maintained in the diversion channel to prevent the establishment of sandbars in the 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.

Operation triggers should focus on the rising limb and peak of the flood event to optimize sediment transport into the diversion channel. Operation strategies should consider closing on the falling limb to increase sediment transport potential in the river. 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 28 days in advance of the flood event, thus making a trigger based on the rising of the river easier to predict and manage. 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. Additional sediment monitors in the river would increase the capability to predict the sediment pulse.

In years with multiple flood peaks, the first flood will tend to have a higher concentrations of sand, silt and clay than later floods. Each additional peak will have less and less sediment available. Sand loads can also be significantly reduced in the year following a major flood (Allison et al. 2012). Diversions should be operated on the rising limb and peak of the first flood event of the water year. A combination of flow and sediment load should be used to determine if the diversion should be operated on the rising limb and peak of subsequent flood events. This factor will become more important as additional diversions are constructed and brought online to share the resources of the river.

Sediment Availability

Sediment availability will also vary annually. Sediment availability is affected not just by the sediment load coming down the river, but by the actions we take systematically on the river to restore the coast. For instance, an opened diversion or a dredged marsh creation project can leave a topographic depression in the river bed that will need to be filled over time, thus removing sediment that would otherwise be available for downstream diversions. In some instances when river and basin conditions are not ideal, it may be more sustainable to only operate a diversion every other year in order to allow the sand bar to rebuild and provide a large sediment source to capture during the next opening. Sediment capture and transport through the structure, conveyance channel and into the basin are important to consider in the siting, engineering and design of a sediment diversion, to ensure the most efficient and effective use of river sand transport when the diversion is operated. Operational strategies should focus on the most efficient periods for land building which are largely governed by the sediment load that can be captured and moved through the structure.

Other Factors

Velocity and currents in the river were not found to be essential drivers of operational strategies. Modeling has suggested that the impacts of diversions on recirculation within the river are limited to a zone near the diversion intake and generally do not produce adverse effects in the shipping lane (Meselhe et al. 2012). The Delft3D model shows slightly lower velocities in the shipping lane and higher velocities over the lateral bar near the diversion.

The CMP also recommended an 8% base flow for large diversions when river discharge is between 200,000 cfs and 600,000 cfs. The purpose of the base flow is to maintain established estuarine habitats year-round. From a river perspective, base flows are not an effective means to transport sediment and may result in siltation of the diversion or river channel from silts and clays as well as facilitate the movement upstream of the saltwater wedge; but minimal flows (about 5,000 cfs) may be appropriate during drought years to prevent salt water intrusion from killing newly created fresh marshes.

HYDRODYNAMICS IN THE BASIN

The deltaic landscape, such as in Barataria Basin, is a highly frictional system in which the tidal signal dissipates quickly. However low-frequency water level variations caused by frontal and tropical disturbances propagate with little attenuation (Das et al. 2010). Seasonal winds and weather patterns are also an important control on annual sea-level fluctuations (Kolker et al. 2012). In theory, these basins should be outwelling systems which export material in a gradient fashion. However even a small diversion can change the flushing potential in an estuary and become the dominant influence as far as salinity and freshwater residence times are concerned. Another influence on hydrodynamics in the basin is the highly variable atmospheric and offshore conditions, resulting from local wind and buoyancy forcing (Wang and Justic 2009). The net precipitation (rainfall minus evapotranspiration) is another important hydrological driver in the Barataria Basin.

Channel Development

The components of delta development were discussed and include crevasse and channel evolution, progradation, aggradation, subsidence, transgression and reworking (Roberts and Carney 1997). Wetlands in active and relict delta lobes often function very differently (Reed 2002) and progradation and aggradation can occur at different times in the lifespan of the delta (Paola et al. 2011, Roberts and Carney 1997). Sediment diversions should be designed to mimic the active portion of the delta cycle and maximize progradation to achieve a living, as opposed to a dying delta cutoff from the sediment input from the river. A sediment diversion would shift the functioning of the receiving basin wetlands from the current state of tidally-dominated wetlands to river-dominated coastal wetlands.

There are many constructed examples of freshwater and sediment diversions (e.g., West Bay, Wax Lake, Caernarvon, Davis Pond) that help us to understand the effects of a sediment diversion. One key difference is that the two major existing sediment diversions (Wax Lake and West Bay) empty into relatively deep to shallow open water bodies whereas the Mid-Barataria Sediment Diversion will empty into an area mixed with fragmented, degraded and weak marshes and shallow, open water before reaching Barataria Bay (similar to Caernarvon and Davis Pond Freshwater Diversions). Although the basin has a network of natural and man-made channels, none of the existing channels in the vicinity of the Mid-Barataria Sediment Diversion are sized appropriately to handle 75,000 cfs of water flowing into the basin. For the Mid-Barataria Sediment Diversion, it is estimated to take 5 to 10 years for the distributary channel network to develop to handle 75,000 cfs (McCorquodale 03/14/16). It is unlikely that the diversion could open on Day 1 at full capacity (75,000 cfs) without causing excessive flooding of marshes and potentially increasing the flood risk on adjacent communities (Grand Bayou, Lafitte). Very rapid opening can create a surge in the distributaries near the outfall of the diversion which could endanger waterway users and could cause excess scour. Access to these areas may need to be restricted during initial operations. The distributary network could potentially include some slight expansion of the tidal passes and increase in the tidal prism that could be offset by the increases in wetlands within the basin over time. After a natural distributary network is developed, the structure could be opened and closed to full capacity with a ramping period of approximately 3 days, depending on the specific engineering and design of the structure.

Residence Time

Residence time can have a large impact on water quality variables such as salinity, hypoxia and algal blooms. With higher magnitude discharges from diversions, residence time of water decreases dramatically. For example, a discharge of 10,594 cfs (300 m^3/s) into Barataria Basin would have a residence time of 33 days, whereas a discharge of 105,944 cfs (3,000 m^3/s) would have a residence time of 3.3 days (Das et al. 2010). Thus, key water quality constituents, such as nutrients, are moved from the nearfield (in basin) to the far field (coastal Gulf of Mexico) and are exported into Gulf waters as diversion discharges increase in size.

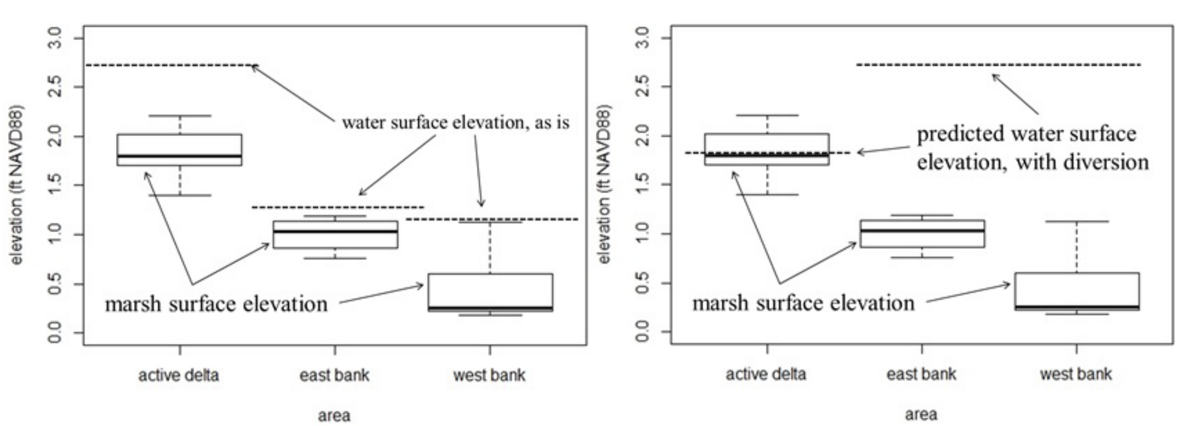
Tracer experiments have demonstrated a huge spatial variability in residence times throughout the basin depending on hydrologic connectivity, geographic location (flanking sides versus center of the basin) and habitat type (marsh, open water, channels, etc.). Lagrangian particle movement study in Breton Sound indicated that there is more displacement of particles when the diversion is open and residence time increases by 50% when the diversion is closed (Huang et al. 2011). Operation plans should include estuarine flux measurements and/or modeling to understand the spatial variability of residence times in the basin under various operation strategies.

Water Levels

Water levels are highly variable and can be influenced by diversion operations, tides, winds and the stage of the Gulf of Mexico. Typical seasonal winds alone can influence water levels by ± 1 ft (0.3 m) (southerly winds increase ~1 ft and northerly winds decrease ~1 ft), with much greater rises occurring during tropical cyclones (Gaweesh 2016, Georgiou 2016). Diversion of river water is expected to raise water levels by even greater amounts within several miles of the structure (Figure 10), but high resolution bathymetric data and hydrodynamic modeling are needed to predict the true extent. Water levels should be monitored closely in any Operation Plan, along with climatic and offshore conditions, to reduce the likelihood of unintended effects to vegetation, wetland health, water quality or flood risk to adjacent communities.

In many of these areas, vegetation already is flood stressed and additional research, modeling and monitoring are needed to determine how many acres of preexisting marshes will be negatively affected by the new, higher water levels (Figure 10). 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 (i.e., Grand Bayou), that would need to be understood and, if found to exist, accounted for in the operational plan or mitigation plan.

Figure 10: Marsh elevation and water elevation data from CRMS sites in the active deltaic marshes in the Bird's Foot delta and in inactive deltaic marshes further upstream on the east and west banks of the Mississippi River. The upper figure shows existing water levels; the lower figure shows hypothetical results of diversion operation on water levels hypothesized to increase at inactive deltaic sites as well as hypothesized to decrease at active delta sites.



SEDIMENT

Channel Development and Sediment Transport

Delta channels are the key to conveying water and sediment through the delta (Shaw and Mohrig 2014). Flow will favor existing channels. If those channels are undersized, then the area will experience backwater flooding with impacts on hydrology and sediment transport (i.e., Davis Pond). If the channels are oversized, then there is complete channelized flow and sediment is moved away from the area of interest to build land. An example of this is Mardi Gras Pass where channelization reduces direct deposition on the marsh surface at most flow regimes (Lopez et al. 2014). Orientation of the channel network is also important. Under sustained diversion flows the distributary system will adjust to equilibrium or regime dimensions which are a function of the discharge and the sediment load (Lacey 1929, Cao and Knight 2002).

Velocity in the conveyance channel is one of the most important factors for moving sediment. In general, the velocity in the channel must be over 6.6 ft/sec (2 m/sec) to convey sand in suspension (Hjulstrom curve) and prevent deposition. The maximum velocity in existing channels is less than 6.6 ft/sec (McCorquodale 03/14/16); however, the maximum velocity in the main stem of the Mississippi River is approximately 6.6 ft/sec. Cubit's Gap subdelta data show that velocities in a crevasse network maintain the ability to transport sand up to 6 km from the entrance to the marsh complex during high flow, indicating that efficient sediment transport networks in diversion-like settings (Esposito et al. 2013). The typical velocities expected in a diversion conveyance channel may be sediment limited and may have the capacity to carry more sand; therefore sediment transport could be enhanced by pumping sand from a shoaling area into the conveyance channel. By pumping sediment into the conveyance channel, it can increase efficiency of the sediment diversion and reduce constraints on the river side concerning when to operate the structure. For instance, operations could be increased when the sediment load in the river is lower by supplementing with dredge sediment. There was some concern from the WG about clogging the distributary channel. Sedimentation in the channel will occur as the diversion is being closed; however this sediment can be scoured out with the next opening as long as the operations account for any consolidation. Operation plans should evaluate periodic supplemental dredging to increase the efficiency of the sediment diversion in transporting sediments into the basin.

Sediment Retention

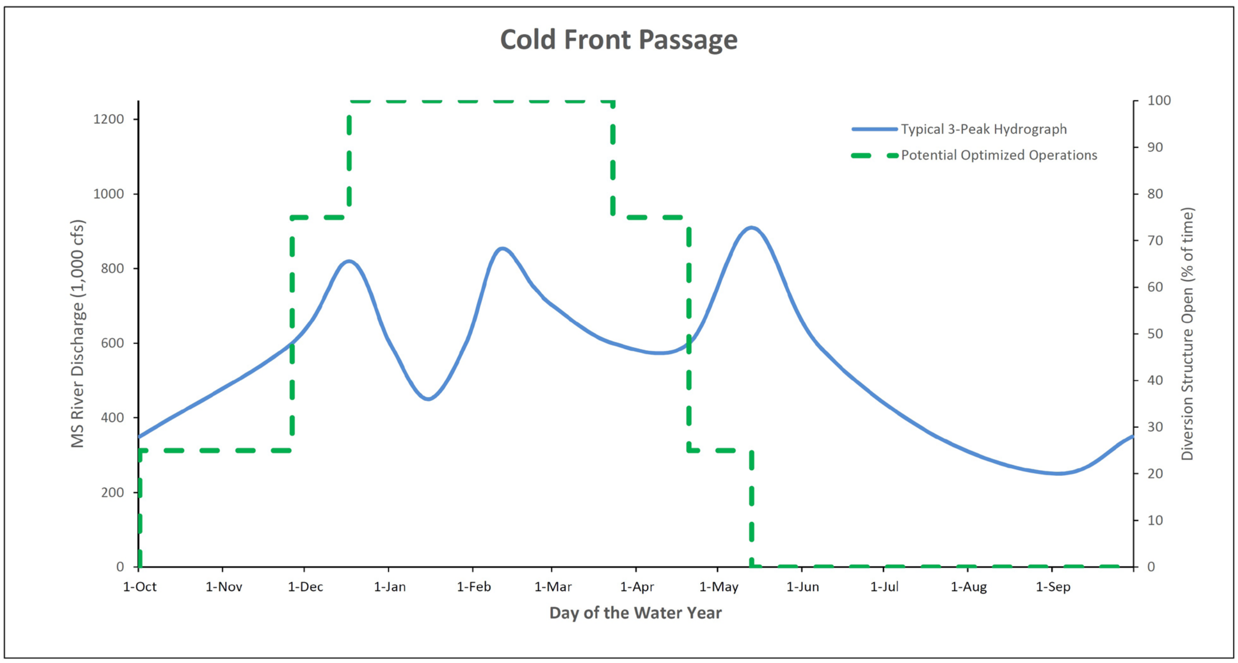
The ability of a diversion to build and sustain land is largely dependent on its sediment retention rate. There are multiple examples of varying retention rates, based on basin geology.

- The crevasse at Caernarvon during the 1927 flood retained an estimated 55% of the total diverted sediment over 3 months which led to accumulation of up to 5 meters in some areas (Day et al. 2016).
- The Bonnet Carré Spillway retains 100% of the sands, but only 10% of the fine sediments that are discharged into the receiving area (Meselhe et al. 2016).
- The Atchafalaya Bay retention can vary from 10% to 22% of total sediment, which is consistent with the percentage of sand in the river at flood stage (Rosen and Xu 2015).

The studies above all establish different boundaries in which the retention rate is calculated (e.g., the shelf break, the bay boundary, basin/watershed boundary). A key variable in understanding the retention rate of a sediment diversion is clearly defining the area of interest. If the key interest is building land near the outfall, a localized area of interest would be established which would have a lower retention rate. If interested in more regional effects of a diversion, a larger area of interest can be established which would have a higher retention rate.

The goals of sediment diversions, as described in the 2012 Coastal Master Plan, are not just to build new land but to sustain and prevent loss of existing land. There are three sediment transport regimes that sustain existing wetlands: river-dominated processes (diversion open), storm/cold front processes (diversion closed/reworking) and tidal action. For the Mid-Barataria Sediment Diversion, the outfall area is a relatively low energy environment where sediment deposition is less likely to be reworked by storms and cold fronts. However, fine sediments that are carried further into the basin will be deposited in Barataria Bay, a higher energy open water system, where the passage of storms and cold fronts can resuspend and move the sediments onto the wetland surface (Carle et al. 2015, Freeman et al. 2015) (Figure 11). Note that this wetland maintenance process depends greatly upon wave energy, which is believed to sustain the elevation of existing and constructed wetlands. The remainder of the suspended sediments will be transported to the Gulf of Mexico through the inlets and passes of the barrier islands.

Figure 11: A conceptualized diversion operations to optimize the use of cold fronts to resuspend and deposit sediment onto the marsh surface.



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 the Barataria Bay. Management should set a targeted sediment retention rate that maximizes retention based on basin geology and diversion location (a suggested target retention of 75% of the sediment discharge within the Barataria Basin).

Fine-grained sediments are more effective at reaching and benefiting the degrading interior wetland and should be considered valuable as such. Fine sediment deposited in open water are only mobile for a short time period

(1-3 months) before they will consolidate, and current studies are underway to understand the time limitations. There is great potential in operating diversions to supply fine sediments to the bay bottom during the time period that cold fronts are most prevalent (Carle et al. 2015, Freeman et al. 2015). Cold fronts tend to occur from October through early May, although they tend to get weaker and less frequent past mid-March. Discharges could be optimized to most likely coincide with cold front passage through statistical analysis. If a diversion was operated just prior to a cold front passage it could maximize sediment resuspension onto the wetland surface, while also moving some sediment in suspension offshore as the cold front passes.

Sediment retention is a large reason there is a multi-decadal time lag between crevasse opening and emergent land (Wells and Coleman 1987) in addition to the depth of the accommodation space in the open water bodies. Landscape features can be designed to accelerate the land-building process by increasing the sediment retention rate in a specific area. Examples such as sediment retention and enhancement devices (SREDs) can be designed and placed at various points in the receiving basin to promote sedimentation, or could be natural or man-made features on the landscape that are utilized for the same purpose. These do not have to be located directly in the flow path, but could be designed to mimic a natural delta formation. Ultimately, the design of SREDs should focus on reducing fetch to create quiescent conditions in the basin that enhance sediment deposition and accumulation. These features could also be used to direct water flows, such as "training" levees to direct channel flow or ridges to move water away from a community. It is important to recognize that trapping sediments in the upper basin will reduce the quantity of sediment available to be deposited in the bay bottom and reworked to help sustain wetlands along the Barataria Bay. This trade-off should be evaluated when making decisions about how and where to build sediment retention features. CPRA should develop an outfall management plan with targets, various adaptation strategies 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. SREDs may also influence how sediment and salinity may influence the distribution of faunal species in the lower basin.

Seasonal sedimentation in wetlands actively receiving river water can range from ~1-4 cm over the course of a flood event, with higher values measured in very large systems or marsh regions located directly adjacent to the channel (Esposito et al. 2013, Kolker et al. 2012, Kolker et al. 2014). These rates are high enough to match or sometimes exceed rates of local relative sea level rise, indicating that diversions have a strong chance of building and/or sustaining land even in the face of climate change.

Retention of cohesive sediments is less understood but could influence the morphology of river deltas. Retention rates can be linked to salinity regimes through the flocculation of sediments. At this time, there are limited measurements for settling velocities based on the extent of the flocculation and how it changes in time and space in a highly dynamic system (Galler and Allison 2008, Kolker et al. 2014, Bianchi et al. 2007, Land et al. 2012, McAnally et al. 2007).

Sediment-Water Ratio

The WG also discussed concerns with the use of sediment-water ratios (SWR) in the modeling. The ratio is also very sensitive to location and will vary greatly if a diversion is mining a nearby river bar. The SWR is an indicator of the efficiency of the diversion in capturing the available sediment load in the river. Capturing sand is important to riverside issues, such as shoaling, but is not the only essential sediment size class for building and sustaining the coastal ecosystem. Sand can contribute to the construction of new land, but fine sediments are also important for building new land and may be even more important for maintaining existing land and providing far-field benefits. Although previous studies have found that Wax Lake and Atchafalaya deltaic wetlands are made up of up to 70% sand, other work indicates that 10 to 50% may be more typical of deltaic wetlands (DeLaune et al. 2013). Johnson et al. (1985) shows an overall weighted average of 49.3% sand on the Atchafalaya delta areas with emergent vegetation and 42% sand in the mudflats with submerged aquatic vegetation (SAVs). Reliance on the SWR for sand in modeling efforts does not capture the importance of the total suspended sediment load in the river. In addition, the same flow can have drastically different concentrations of sands or suspended fines, so the same sediment water ratio could have drastically different loads.

WATER QUALITY

Salinity

Freshwater discharge from a sediment diversion will have a large effect on salinity throughout most of the mid- and lower Barataria Basin during the time that the diversion is operated. When diversions are inactive and estuarine recovery has taken place, there is very little difference in the salinity levels throughout the basin, even at year 50 meaning that the freshening is temporary (CPRA 2012). Climatic conditions, such as precipitation, and offshore conditions can also affect salinity levels in the basin at any given point. Freshwater plumes will likely have only minor offshore effects as the water exits the basin and enters into the coastal currents and longshore drift.

During the operation of the Mid-Barataria Sediment Diversion, the basin gradually freshens over a week until it expands its influence from the eastern/central portion of the basin to the barrier islands. The term freshening does not mean that all areas of the basin are at 0 ppt, but that there is some mixing of freshwater throughout the basin. For instance, after operating for more than 1 month at full capacity, salinities inside the barrier islands range from 0.3 to 5 ppt with western side of the basin having the higher salinities (Meselhe et al. 2016). Once the diversion is closed, estuarine gradient recovery can happen quickly within 2 to 4 weeks depending on the specific basin and Gulf conditions at the time the diversion is closed (Meselhe et al. 2013). For example in the Barataria Basin, the operations of Davis Pond and the siphons as well as the GIWW flow and rainfall will impact the recovery time. If these freshwater diversions are not operated during the recovery period, 50% recovery of the normal salinity gradient is achieved in 1 to 2 weeks in Barataria Bay, 2 to 3 weeks northeast of Grand Isle and 3 to 4 weeks in Little Lake (Meselhe et al. 2016, Das et al. 2012).

In terms of water quality, salinity can cause changes in phytoplankton species composition, promote flocculation of clay particles, and varying water column stratification associated with hypoxia. There is no optimal operation for salinity as an independent parameter, but salinity is a significantly important variable in its effect on other parameters of the estuary. Salinity can affect the occurrence, distribution and abundance of wetland vegetation, invasive species and fish and wildlife species, as well as predator abundance (e.g. the snail, Stramonita haemastoma, preying upon oysters).

Temperature

Barataria Bay, as part of the northern Gulf of Mexico region, is a subtropical to temperate climate with mild winters. Twilley et al. (2001), state the "Gulf of Mexico, Caribbean Sea, and Atlantic Ocean substantially influence the region's climate. Occasionally, however, these mild winters are punctuated by cold air masses reaching far south from the northern Pacific or the Arctic, bringing low temperatures and freezing conditions. Summers in the region tend to be hot and humid." The Barataria Basin's water temperature is not only influenced by regional climate, but also significantly influenced from up-basin land runoff from precipitation, and at times from the Davis Pond Freshwater Diversion, maximum flow 10,600 cfs, and smaller siphons located below Davis Pond. The Basin is also influenced down-basin by water discharge from the Mississippi River into the Gulf of Mexico and re-entering through the barrier island tidal passes (Swenson and Turner 1998).

River water is colder than estuarine waters in the winter and spring seasons. Under extremely short residence times associated with peak diversion flows, the water temperature of incoming river water may not have enough time to reach ambient temperature as it flows through the estuary which could affect phytoplankton growth and other biogeochemical rates (White et al. 2009). However, some water entering into shallow marshes in the Wax Lake Outlet have been shown to warm quickly (Twilley et al. 2016). In addition, recent research indicates that the Mississippi River's annual water temperature has increased (0.9C/decade), resulting in a positive effect on vegetation biomass and the length of the growing season (White and Visser 2016).

Temperature is the most fundamental and primary environmental parameter that influences life and its biophysical processes. Biophysical processes, such as enzyme activity, respiration, reproduction, transpiration and muscle activity, are governed by temperature (Reddy and DeLaune 2008). All life forms can be broadly categorized into two types based on ability to respond to environmental temperature, namely, endotherm or ectotherm. Endotherms, exclusively birds and mammals, use body metabolism to generate body heat and maintain their temperature above ambient temperature. Ectotherms, all plants and most animals, do not use body metabolism to generate body heat and have a body temperature similar to ambient environmental temperature. Therefore, understanding how temperature, and specifically water temperature for aquatic species, influences their ability to metabolize becomes essential for understanding how they exist within a habitat. It also becomes essential to understand that an organism's metabolism is key to understanding how it will adjust or cope to changing osmotic conditions, (i.e., changing salinity, during a diversion's outflow.)

A typical example of how water temperature changes through the seasons is shown in Figure 12 for St. Mary's Point. St. Mary's Point is located mid-basin at the confluence of major bayou and navigation channels empting up-basin waters and where it is readily influenced by Mississippi River discharge entering through the tidal passes from down-basin. Water temperature steadily increases in March from a winter low to a summer high (Figure 12). Water temperature is more variable during winter and spring than in summer during June-August (Figure 12). As temperature increases in the spring, an ectotherm's metabolism increases and therefore its potential sensitivity to salinity changes increases.

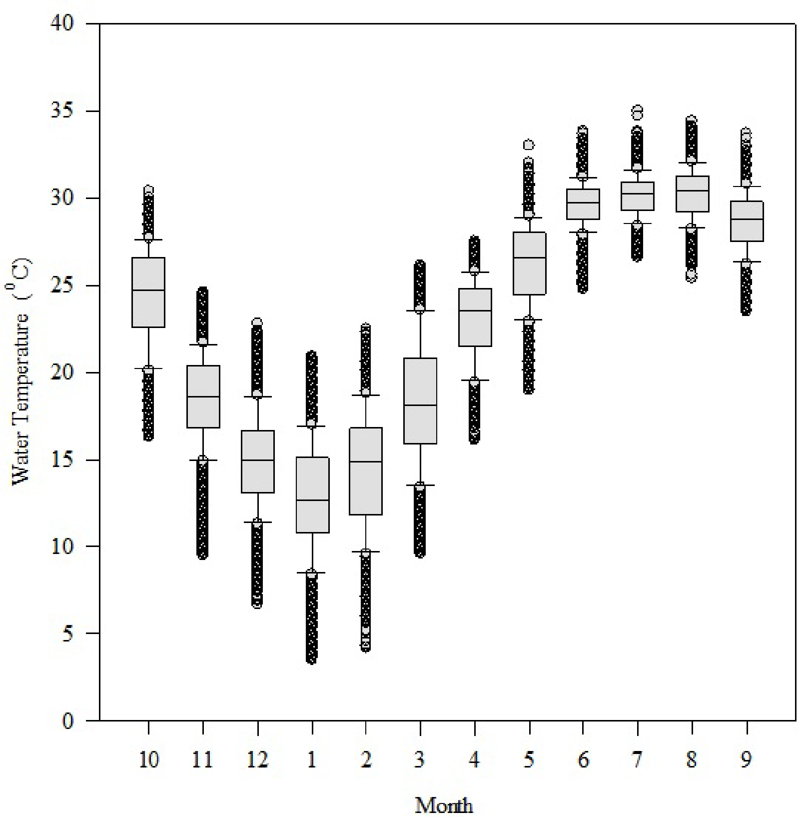


Figure 12: Water Temperature at St. Mary's Point Barataria Bay 2007-2015. Data represents hourly Median, 25% and 75% Quartiles, and Range for USGS station 07380251 Barataria Bay N. of Grand Isle, LA.

Nutrients

Nutrient concentrations, specifically nitrogen, in the river have stabilized and have yet to indicate a decrease from watershed agricultural nutrient reduction efforts. The nutrient flux (concentration x flow) has a similar pattern to sediment loads and this coupling indicates that maximizing a diversion for sediment capture will also increase the nutrient load captured by the diversion (Justic et al. 2005, Allison et al. 2012), although the reverse is not necessarily true – maximizing for nutrient load capture does not maximize sediment capture. In other words, it is not possible to have a sediment-efficient diversion that captures a low volume of nitrogen. The peak in nitrate flux coincides with the spring flood; however, the peak in nitrate concentration normally lags several months behind the first spring flood (Justic et al. 2003). Other nutrients, such as phosphorous and silicon, exhibit different relationships (Justic et al. 2005). Thus, varying discharge inflows have the potential to alter nutrient ratios entering the basin. In general, the bioavailable phosphorus concentrations of the Mississippi River are low compared to the bioavailable nitrogen pool (Roy et al. 2013).

When sediment diversions are constructed, significant changes are likely in how nitrogen is processed by the system. Presently, a small percent of nutrients is being imported into Barataria Basin from the Gulf of Mexico and around a quarter of the nutrients are being exported into deep Gulf waters from the Birdsfoot Delta. With diversions, Barataria Basin could become a source of nitrogen for the coastal Gulf of Mexico and the amount exported into deep Gulf waters from the Birdsfoot Delta could decrease (Das et al. 2011, Das et al. 2012, Wang and Justic 2009).

As mentioned, residence time can also have a great effect on the levels of nitrate exported from the basin. Long residence times (~30 days) will result in very little export as most all of the nutrients will be consumed or processed within the estuary proper. Larger diversions will reduce the residence time and increase nutrient export to the Gulf of Mexico. For instance, based on studies conducted in different estuarine systems around the world, a residence time of 3 days could mean that up to 70% of the nitrogen may ultimately be exported (Dettmann 2011, Lane et al. 2004, Perez et al. 2011). Phosphorus, on the other hand, tends to sorb to sediments and is therefore more likely to accumulate in the basin regardless of residence time (Roy et al. 2012). A host of physical and biological factors can impact the nitrogen cycle, which is fairly complex due to the number of oxidation-reduction reactions. While the 1997 opening of the Bonnet Carré Spillway was followed by a harmful algal bloom later in the summer, the 2008 and 2011 spillway openings were not (Roy et al. 2013, Dortch et al. 1999, Dortch et al. 2001, McCorquodale et al. 2009, Turner et al. 2002).

Salinity can affect nutrient levels in the basin by affecting the ability of plants to uptake the nutrients. Most wetland plants (except mangroves), if salt stressed, cannot efficiently take advantage of nutrients. Lowering the salinity removes it as a limiting factor and increases the capacity of plants to uptake nutrients from the discharge waters. Building the marshes and shell (oyster or clam) reefs in optimal locations can increase the nutrient uptake and limit the export of nutrients.

Hypoxia

The hypoxic zone in the Gulf of Mexico - known as the dead zone - has grown in size since 1993. The areal extent of the summertime hypoxia varies in size and pattern of occurrence (spatially and temporally) based on annual climatic conditions, short-term meteorological forcings, and riverine freshwater and nutrient inputs. The hypoxic zone is an offshore phenomenon that has little interaction with the estuary. Large diversions could locally change the patterns of hypoxia occurrence/severity, but is unlikely to significantly affect the size of the hypoxic zone. If the goal of the diversion is to reduce nitrate amounts offshore, thus reducing the size of the dead zone, then the diversion should be operated year-round at a lower discharge rate. This strategy would likely lead to increased denitrification and nitrate uptake within the estuary proper, especially during the warm part of the year.

Inshore hypoxia is not anticipated to become a large problem as the shallow waters of the basin are generally well-mixed. However, hypoxia may develop locally in deeper channels in response to increased stratification resulting from freshwater inflow or salinity intrusions.

Phytoplankton and Harmful Algal Blooms

It is expected that a high discharge from a diversion would increase flushing and decrease phytoplankton biomass in the area influenced by the diversion. The turbidity and velocity of water limits the production of algal blooms (Bargu et al. 2011). However, once the diversion is closed, phytoplankton biomass could increase rapidly as nutrient-laden water becomes stagnant (Bargu et al. 2011). Salinity can also affect phytoplankton by causing a shift in phytoplankton species composition, although this shift in community composition is not necessarily considered detrimental.

Sediment

The main effect of suspended sediments on water quality is through turbidity and flocculation. Salinity and physical mixing controls when and how flocculation occurs, thus when fine-grained sediment deposition occurs. Only minor flocculation occurs at salinities less than around 0.5 (Note: new salinity standard, psu, has no units), and thus the entire basin could become very turbid under those conditions. At salinities of 1 to 2, there is rapid flocculation and settling to the seabed.

Disease, Pathogens, Hormones and Pharmaceuticals

Diseases, pathogens, hormones and pharmaceuticals can not only have potentially negative effects on the ecosystem, but on human communities and users of the ecosystem. Some materials contain microbeads which are also difficult to break down in an appropriate manner and when they do breakdown, they release whatever chemicals are inside of them. Inorganics such as mercury can potentially create problems in anaerobic soils and lower trophic levels, as well as lead to bioaccumulation in higher trophic levels. There is also on-going work by US Geological Society (USGS) and others on the concentrations and effects of herbicides such as atrazine. Environmental Protection Agency (EPA) and the Department of Health and Hospitals (DHH) have guidelines on standards for designated use of water bodies and water quality parameters. EPA also lists and monitors impaired waterways. The working group acknowledged that the expertise in the room was not best suited to understand, discuss and address all the issues related to this topic and future discussion on this topic may need to include an environmental toxicologist.

WETLAND HEALTH

Habitat Types

Habitat types and the delineation of habitat types on the landscape are largely dictated by changes in the estuarine salinity gradients. General habitat types (from freshest to most saline) include forested wetlands/swamps, freshwater marsh, intermediate marsh, brackish marsh, saline marsh and mangroves. Vegetation change has been documented along the coast from 1968 to 2013 (Chabreck 1972, Sasser et al. 2014). In most areas of the Louisiana coast, habitat types have become more saline, and more saltwater tolerant vegetation is moving in-basin especially in the last decade (Sasser et al. 2014). Even areas that are influenced by the river, such as portions of Point au Fer Island, have become more saline. In other areas, such as the Bohemia Spillway, the influence of the river has maintained brackish marsh near the river that would have otherwise become saline. Intermediate and brackish marsh currently exists near the Mid-Barataria Sediment Diversion site. In Barataria, even with diversion flow at 50,000 to 75,000 cfs, a strong estuarine habitat gradient will be maintained with saline marsh near the Gulf of Mexico. Salinity gradients can be restored in approximately 2 to 4 weeks after the closure of the diversion operating at full capacity (McCorquodale personal communication). The estuarine recovery will progress from the barrier islands to the diversion site. The diversion operations are unlikely to change large areas into freshwater marsh, but could increase the occurrence of SAVs in open water areas and steepen the slope of the salinity gradient (compressing the extent of brackish marsh) (Visser et al. 2013). Management should not design operations to achieve specific habitats in specific locations, but allow the habitats to self-organize.

Maintenance flows (smaller discharges that occur year-round) have been proposed in the past, and were modeled in the 2012 Coastal Master Plan. The purpose of maintenance flows is to prevent saltwater damage to freshwater vegetation established in the outfall area when the diversion is closed allowing more saline waters from the Gulf to move into the outfall area. Another purpose could be to prevent wetland areas of higher elevation, especially those created by the diversion over time, from experiencing extended dry periods when the diversion is not operating. This depends on the amount of precipitation that is experienced in the basin throughout the rest of the year. Climate change, specifically sea level rise, with subsidence could also increase saltwater intrusion in the future and lead to the need for additional maintenance flows in the future.

Maintenance flows are not the most efficient means of capturing sediment, but should be considered under an adaptive management plan for specific ecosystem conditions (e.g., vegetation stress, oyster predation, nesting wildlife) in the basin. 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.

Vegetation

Within each habitat type, there are a variety of species that have different requirements to establish and grow. It is important to understand the environmental requirements of the species that currently exist in the outfall of the diversion, as well as any species that is likely to establish with diversion operations. Flowing water over marsh is a lot less stressful (because of water oxygen content) to vegetation than stagnant water over a marsh. Therefore, some experimental data with stagnant flooding conditions may overestimate the flooding impact. Field data that study flooding stress, like marsh organ studies, provide a more realistic estimate (Snedden et al. 2015). In general, fresh and intermediate marsh species are less sensitive to flooding than brackish and saline marsh species (Visser and Sandy 2009). In general, the plant community that is established is based on average salinity and plant species survival is based on peak salinity.

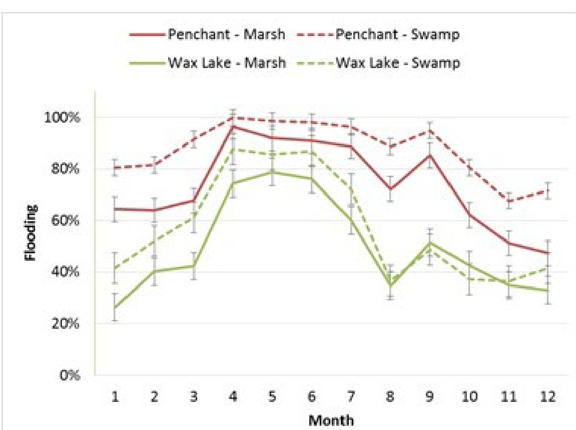
There is a perception that the vegetative community will be able to handle and respond positively and quickly to any changes in salinity caused by diversion operation. However, there tends to be a lot of inertia in plant community dynamics. Prior to Hurricane Katrina, Spartina patens dominated the outfall area of the Caernarvon Diversion for over 15 years of operations. After a large storm surge disturbance, the vegetative community is now made up of very little S. patens. There is an assumption that freshening the existing marsh in the outfall area will cause a fairly immediate shift in community types. However, 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. Established species generally are not killed by reducing salinity, in addition propagules for freshwater species may be limited or absent when diversions enter into brackish or saline marsh areas.

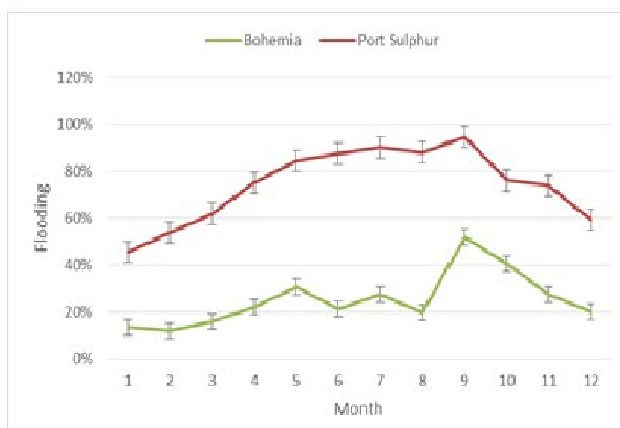
Invasive plants, especially submerged and floating aquatics, can aggressively take over native plant communities and clog waterways. It is not anticipated that invasive species will be a significant ecological problem for the Mid-Barataria Sediment Diversion. Both flow and salinity can be used to control the establishment of aquatic invasive species. It was noted that the establishment of SAVs in shallow open water will aid in trapping sediment.

Sediment Input

Marsh health is not just influenced on the quantity of sediment, but the quality. Wetland vegetation responds the best when established with fine-grained sediment. Sands and coarse-grained sediments are important for filling up open water areas but do not support the same biogeochemistry processes found in marshes established with fine-grained sediment, as fine grained sediments absorb nutrients and organic matter, and keep coastal soils moist. Created marsh from dredged material can take decades to function as a natural wetland (Craft et al. 2002, Moy and Levin 1991). Marsh vegetation does best when marshes are established on fine grain sediment and it is these materials that need to be deposited on the existing marsh surfaces (Stumpf 1983). Sand has a better geological value and fines have a better ecological value. The increased sediment input also has been shown to increase bulk density (Carpenter et al. 2007). Higher bulk densities have been correlated with higher aboveground biomass in species such as Spartina alterniflora (DeLaune et al. 1979). Sediment input will also raise the elevation of the marsh surface which can result in a decrease in the time the marsh is flooded. For example, the Wax Lake marshes and Bohemia marshes are flooded less than the Penchant marshes and Buras marshes, respectively (Figure 13).

Figure 13: Comparison of flooding between wetlands affected by diversion (green lines) and similar wetlands that are not (red lines).





Biogeochemistry

Nutrient loading will increase biomass to an optimal point, beyond which any additional nutrient input results in no additional increase in biomass in multiple species (Meselhe et al. 2015) or could result in a decrease in biomass, such as Spartina alterniflora, due to an increase in herbivory (Visser et al. 2006, Visser and Sasser 2009). There is a general positive effect when nutrient loading rates are lower than 10 g m^{-2} y^{-1} (Nyman 2014). The naturally occurring loading rate at the Caernarvon Diversion was found to be between 0 to 8 g m^{-2} y^{-1} (Hyfield et al. 2008). Negative effects of nutrients on plant roots were found in studies that added in additional nutrients above what occurs naturally in the ecosystem or the river (Nyman 2014). The availability of nitrogen also strongly influences the aboveground to belowground allocation ratio. Although the exact levels are species-specific, plants allocate more biomass to the roots with low levels of nitrogen. As nitrogen levels increase, more biomass is allocated to the shoots.

Nitrogen and phosphorous are not the only parameter in the river water that are important to wetland health. Sulfates and sulfides can be toxic to plants, especially freshwater plants that have not developed protections to the toxicity. Marshes are exposed to sulfates from river water but the exposure levels are much greater from saltwater (Goldhaber et al. 1983). The concentration of sulfate in seawater is much greater than the concentration in river water. Iron (specifically reduced iron) can react with sulfides to form insoluble ferrous sulfides (FeS), helping reduce the free hydrogen sulfide and, thus, the likelihood of sulfide toxicity. Climate change, specifically increased temperature, will also increase microbial respiration rates and problems found in warm sulfidic environments. Warmer environments lead to faster rates of sulfate reduction due to the increase in bacterial activity (Reddy and DeLaune 2008).

Timing and Duration of Flooding

In general, emergent vegetation is most sensitive to the percent of time flooded during the growing season. The growing season, which is controlled by day length and temperature, varies by species. In general, more saline species have longer growing seasons (February to November) versus fresher species (April to August for Sagittaria lancifolia or May to October for Phragmites australis) (Hopkinson et al. 1978). Plants are less likely to experience any stress from flooding during the non-growing season (November to March), even if flooded for 1 to 2 months. It is possible that opening the diversion in April could place some stress on the vegetation as this is a time of early growth and, therefore, the most vital stage. The growing season also effects the distribution between aboveground or belowground biomass. Aboveground biomass is highest in the summer and fall, whereas belowground biomass remains stable most of the year with a slight increase in the winter (Piazza et al. 2011). Climate change can increase the temperature which will extend the growing season and effect the distribution of some species (e.g. frost intolerant mangroves) (Pickens and Hester 2011, Osland et al. 2013).

Duration of flooding is one of the most important variables to vegetation health when planning diversion operations. Increased duration of flooding has been demonstrated to cause a decline in both aboveground and belowground biomass (Visser and Sandy 2009, Snedden et al. 2015). Sensitivity to flooding varies by species, for instance Spartina alterniflora is slightly sensitive to flooding where as Spartina patens is very sensitive to flooding losing almost all biomass when flooded over 60% of the time. Species also vary in their ability to withstand flooding by fresh water versus flooding by salt water. There is no effect of freshwater flooding on Panicum hemitomon, and a slight decline in Sagittaria lancifolia, with freshwater flooding, but both of these species die when flooded with brackish water (6 ppt) (Visser and Peterson 2015). Recent research by USGS has also indicated that wetlands in the Caernarvon Diversion outfall area have been experiencing extensive flood durations (60-80% of the time) during the growing season. These wetlands are stressed, thus a disturbance event can cause damage or change the vegetation composition (Snedden et al. 2015). To reduce vegetation stress and loss, diversions should operate during the non-growing season (winter to spring) as much as possible. This will allow prolonged and continuous flooding while plants are in a dormant state. 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. Healthy vegetation will aid in trapping sediment when the diversion is operational. Vegetation in the outfall area should be mapped and depending on the pre-existing species distributions, additional research or testing may be needed to understand the optimal flood duration and recovery period.

FISH & WILDLIFE POPULATIONS

Fish and wildlife species are incredibly diverse and abundant in Louisiana's coastal wetlands. The total value of all fisheries and wildlife enterprises to the Louisiana economy from 2010 to 2014 was $1.74 billion and account for 70-75% of the fisheries landings in the Gulf of Mexico (LSU AgCenter 2014, NMFS 2016, de Mutsert et al. 2008). Approximately 80% of the species in the Gulf of Mexico are estuarine dependent and rely on the vast coastal wetlands in Louisiana (Cowan et al. 2008). Between 2000 and 2004, 97% of Gulf of Mexico commercial and recreational landings (by weight) were estuarine dependent species (Lellis-Dibble et al. 2008).

There are two different aspects of fish and wildlife to consider. One is species populations (distribution and abundance) based on the life history and environmental requirements of the species themselves. The second is the people and industry that rely on the resource. In general, more is known and more studies have been completed on species of economic importance than species that are charismatic or important to the food web.

Productivity and the Food Web

In general, the productivity of the entire trophic system (wildlife and fish species) increases with the input of nutrients. However the changes in diversity of species is more variable with the input of freshwater. With lower salinities, wildlife species have larger dietary ranges and more niche breadth. However, for fish and shellfish species, the lowest species diversity occurs between 5 to 8 ppt (Levinton 1982). Diversions can also have a significant effect on predator-prey relationships important to the food web. Lowering salinities can restrict the distribution of large predator species, but can also shift the distribution of some species toward the Gulf and more predators in deeper waters. Diversions also increase the introduction and mobilization of organic matter; however, this response is not yet linked to a trophic response. Research should be conducted on the overall productivity and diversity of the system pre- and post-construction of a diversion to demonstrate the benefits of increased nutrients and changes that are anticipated due to increased sediment and freshwater on the overall food web.

Diversions could also affect growth rates of fish and shellfish species. Temperature, salinity and size can affect the rate of food consumption, assimilation and respiration in fishes. Fish and shellfish species do not have the ability to metabolically regulate their body temperature and therefore metabolize according to ambient water temperature. Often in cold water conditions, ≤ 20 °C (68 °F), species are metabolizing at a low rate and can tolerate extreme low salinity conditions.

Wildlife Habitat

Habitat types and the delineation and trends in vegetation are largely dictated by estuarine salinity gradients. The extent and quality of habitat types can be used to estimate the occurrence or abundance of wildlife species. The next 50 years without action will be similar to the last 50 years where Louisiana continues to lose low salinity habitat and gain extensive shallow water with higher salinities. This can result in tremendous loss of species that rely on low saline waters. Most effects of diversions on wildlife will be related to salinity (immediate and persistent) but water depth (immediate and for first few decades) and nutrients may also be important factors. With the input of sediment, water depth concerns are likely to diminish and stabilize over time.

Diversions will cause habitat change depending on the operations. These habitat changes will appear moderate when viewed coastwide but could be more intense when viewed locally. Wildlife communities will change based on this habitat switching. In the future, wildlife communities may also change because of new introduced species, range expansion of tropical species and changes in human harvest of predators/prey.

Fish and Shellfish Habitats

Despite over 60 years of research in estuarine ecosystems, there is little known about the direct relationship between wetland habitat types and fish biomass production. It is difficult to detect a signal of environmental change in fish productivity due to adaptions necessary for survival in highly variable estuarine environments. These species have been adapting to the ever-changing and dynamic delta for the last 15,000 years. This adaptation capacity is evident in the number of fish species that are known to be true estuarine residents (10s of species) compared to those that use the estuary as a nursery for a portion of their life cycle (100s of species). This is also true for many of Louisiana's most important commercially and recreationally harvested species, as well as most of the forage base on which the estuarine transients depend for food. In a review of all of the estuaries in Europe, Elliot and Hemingway (2002) concluded that among the 11 distinct habitat types found in estuaries, ranging from tidal fresh marshes to biogenic reefs, that estuarine soft bottoms had the highest Habitat Utilization index. This may be self-evident given that this habitat is always underwater and produces most of the food organisms consumed by juvenile fishes. Although changes in habitat quality can be masked by overharvest, there are growth differences between high quality habitat and low quality habitat.

As solid marsh, which provides minimal fish habitat, degrades, the area of marsh edge relative to open water has been considered essential to many of the life stages of estuarine dependent species (Baltz et al. 1993, Rozas and Zimmerman 2000). According to Browder et al. (1985, 1989) salt marsh habitat value for fish is maximized when the maximum extent of edge is reached after which additional loss decreases the habitat value for fish. In Barataria Basin, the most productive basin in the state from a fish standpoint, the extent of marsh edge to open water do not seem to be driving species abundance. Scientists determined that the maximum extent of marsh interface (i.e. edge) was achieved in 1985 (Lewis et al. 2016). However, species abundance and community composition have remained unchanged since 1966. Factors that may be more important in driving species abundance are fishing pressure, estuarine-like conditions on the shallow shelf (Cowan et al. 2008), shallow, open bays (Fry et al. 2008), and local adaptations at larger spatial and temporal scales.

Research of the fish population in the outfall of the Caernarvon Freshwater Diversion demonstrated a significant difference in conditions before and after the opening. The nursery function of the wetlands was improved with lower salinities, which led to a change in size distribution. It was also shown that some prey species abundance increased as the fresher water excluded large predators, thus changing some of the predator/prey relationships (de Mutsert et al. 2012).

From a holistic perspective of fish, operations should focus on community structure and productivity rather than individual species. Some species may be affected detrimentally whether we act or not, but probably not in the short term. It is likely that the distribution of estuarine species will change in response to changes in freshwater input, but it won't necessarily have an effect on biomass and production. 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 contrast to fish, there are known direct relationships between habitat types and biomass production for some shellfish species, especially as it relates to commercial harvest. For example, oyster habitat for the Barataria and Terrebonne estuaries has been delineated for wet and drought basin conditions (Melancon et al. 1998), white and brown shrimp habitat to predict annual harvests take into consideration water temperature and salinity for species' growth and for habitat acreage (Bourgeois et al. 2015), and habitat types have been incorporated into stock assessments for the blue crab (Bourgeois et al. 2014).

Specific Species Information

Understanding the positive and negative effects of a sediment diversion on indicator species is important for transparency and expectation management. In general, an objective of a sediment diversion should be to minimize net negative effects on indicator species to the extent possible, considering land building and sustaining as the primary goal. It is important to consider the net effect as the decline in one valuable species could be replaced by the increase in another valuable species. The Operation Plan should identify indicator species that include important commercial and recreational species, but should also include species of intrinsic value to the food web or the ecosystem. The information below focuses only on those with commercial or recreational value.

American Alligator

The American alligator (Alligator mississippiensis) was nearly extinct due to overharvest, but has been brought back and is now prolific due to a strong economic driver that led to sound management and harvest practices. The harvest of alligators has continued to increase from the 1970s to today, as has the number of alligator nests (Ryberg et al. 2002).

Although most of the adult alligator industry relies on farms, almost all eggs supplied to those farms are harvested from coastal marshes. Alligators can be negatively affected by water depths or stressed vegetation during the nesting season. Nest construction occurs from mid-May to mid-June, egg laying from mid-June to early July and hatching from mid-August to early September. Alligators do live a long time and are sexual mature when they reach six feet in length, which is largely dependent on the food source not age of the individual. Although elevated water levels can destroy nesting for the year, the loss of an age class does not have a detrimental effect to the population, and the next year can make up for a lost year (Platt et al. 1995).

The American alligator prefers fresh marshes and will cease feeding over 10 ppt. The current outfall area of the Mid-Barataria Sediment Diversion is mostly intermediate and brackish marsh, therefore the population of alligators currently in the receiving area is likely low. The elevated water levels that occur in the first 10 years may deter additional alligator nests; however, over time, the population is anticipated to grow as the diversion is operated. Alligators have been seen to congregate in very large numbers at the outfall channel of the diversion when it is operating to feed on fish coming through the water control structure.

Diversions will increase habitat quality and extent for American alligator. Initial operations (first 10 years) do not have to be as concerned with adversely affecting a relatively small population, but, over time, the population will grow in the outfall areas. Coastwide, the American alligator populations are still predicted to decrease over the next 50 years, even with areas of increasing population in the diversion outfall areas (CPRA 2012). Once a substantial population establishes, flooding should be minimized during the nesting season (mid-May to early September), although the loss of a single year of nesting will not be detrimental to the entire population.

Blue Crab

Barataria Basin has a substantial population of blue crabs (Callinectes sapidus) which accounted for 18% of the state harvest for the period 2000-2013 (Bourgeois et al. 2014). The life stages of the blue crab have specific salinity requirements. As an adult, the females move into lower salinities to mate, usually from March to May and then migrate out to higher salinities to spawn (Guillory and Elliot 2001). The blue crab egg must hatch in high salinity waters at the mouth of the estuaries and are carried offshore. The larvae return to the nearshore to develop into a juvenile which spends most of its time in seagrass, marsh or vegetated bottoms. Spawning in Barataria Basin typically occurs off of the barrier islands and lower estuary beginning in May but usually with a major peak from August to September. As female blue crabs are pushed further offshore, possibly from diversion operations, during their spawning period, there is the possibility of increasing predator mortality due to more open water with less habitat refuge. When outside the reproductive stages, adult blue crabs (especially males) function normally in freshwater environments.

Diversion operations should be most concerned with minimizing effects to mating females in March to May and during the peak spawning periods of August to September to the extent possible. Although no specific salinity range is noted in describing a blue crab's needs during mating, it is generally stated that they can mate in low-salinity habitats in the Gulf of Mexico (Bourgeois et al. 2014, Guillory and Elliot 2001). Assuring some degree of brackish water during the mating period may be crucial for the species.

A diversion could be operated in winter and early spring. Any estuarine recovery in May can also facilitate larval recruitment into Barataria Basin. Maintaining a salinity gradient during the late spring through summer can potentially enhance the fishery, as this is the typical habitat type for successful commercial harvests efforts (Jaworski 1972).

Bottlenose Dolphin

Bottlenose dolphins (Tursiops truncatus) are found in temperate and tropical waters worldwide and occupy a diverse array of habitats from shallow estuarine systems to deep oceanic waters. Dolphins are long-lived with life spans upwards of 20 to 30 years (Connor et al. 2000). They have a 12-month gestation period and the offspring generally remains with the mother for the first three years of its life (Wells et al. 1987). While calves can be born any time of year, studies of Bay, Sound and Estuary (BSE) dolphin populations in Sarasota Bay (Wells et al. 1987), Mississippi Sound (Miller et al. 2013) and others (Henderson 2004) suggest seasonal calving peaks in the GOM occur in the spring and summer months.

Salinity may play an important role in determining suitable dolphin habitat (Wilson et al. 1999). Although dolphins can tolerate low salinities for short periods of time, long-term, low salinities can cause ill-effects. The physiological stress of exposure to a salinity of 0 ppt for more than five to seven days may lead to severe health effects and even death. Health effects from low salinity waters can manifest as severe skin lesions (Simpson and Gardner 1972, Colbert et al. 1999) and disrupt the electrolyte balance in the blood (Andersen and Nielsen 1983). While the impact of skin lesions is not well-understood, these lesions may make dolphins more susceptible to infections or the absorption of chemicals and contaminants in the water (Mullin et al. 2015). The ill-effects of low salinity are intensified over longer periods of time and lower salinities (NMFS unpublished data).

Two recognized BSE dolphin stocks lie within the influence areas of the two planned mid-basin diversions, the Barataria Bay stock (B61) and the Mississippi River Delta stock (B30; Waring et al. 2015). While neither population has been extensively studied, research suggests that the bottlenose dolphin population is present year-round in Barataria Bay with recent satellite-linked tracking indicating little long-range movement out of the bay (Miller 2003; DWH MMIQT 2015). A study by Miller (2003) found dolphins in Barataria Bay present in a wide range of water temperatures (10.9-33.9°C), salinities (11.7-31.5), water depths (0.4-12.5 m), distance from the shore

(3-800 m) and turbidity levels (1.4-34.0 NTU). However, feeding activity was concentrated to a narrower range of water temperature (20-24°C), turbidity level (20-28 NTU), distance from shore (200-500m) and depth (4-6 m). Feeding activity was observed in channels and passes (Miller 2003). As part of the Deepwater Horizon Natural Resource Damage Assessment (NRDA), a dolphin satellite telemetry study in Barataria Bay was done, and tagged dolphins were observed at salinities ranging from 1.6 to 32.1, but, in general, dolphins were most often found in waters with salinities of 7.9 or higher (DWH MMIQT 2015).

Dolphins in Barataria Bay are not genetically homogenous (DWH MMIQT 2015) which may indicate that dolphins in this area are highly mobile and lack obvious barriers to their movement (Vollmer and Rosel 2013). While telemetry data indicates that dolphins remained in Barataria Bay over the course of the study (DWH MMIQT 2015), the lack of physical barriers, compared to those that are present in Lake Pontchartrain (Mullin et al. 2015), may allow this population to more easily move out of unfavorable reduced salinity conditions associated with diversion operations. The variation in ecological characteristics of different BSE dolphin stocks in the Gulf of Mexico suggests that specific and consistent monitoring of the Barataria and Mississippi River stocks is needed to understand and better manage these populations, both with and without the implementation of sediment diversion projects.

Eastern Oyster

Note: The working group discussed optimizing diversion operations to maintain oyster reefs in their current locations (status quo as depicted in Figure 9, Main Report). There was also discussion that focused on operations that would optimize oyster habitat in more consolidated and potentially productive locations further down-estuary in the basin. However, whether the focus is on oyster habitat to remain in its present basin locations or shifted further down-estuary with diversion operation, the biological and physiological needs of an oyster, as well as its habitat requirement to keep predators and disease at low levels, will not change.

Melancon et al. (1998) defined current zones of production for the eastern oyster (Crassostrea virginica) in Barataria and Terrebonne Basins, using the delineations dry zone, wet-dry zone, wet zone and high salinity zone. On the landscape today, the wet-dry zone or the “sweet spot” for oyster habitat includes areas that are directly adjacent to the nation’s largest river. This is not a natural condition and is only made possible by the river levees that were constructed to protect communities.

A review by Mackin and Hopkins (1961) will help to understand how today’s oyster habitats within the Barataria Basin (Melancon et al. 1998) compare to the Basin at the beginning of the 20th century. Mackin and Hopkins (1961), using historically published records and their own surveys from the late 1940s through the 1950s, state that by 1900 there was very limited natural subtidal oyster production in the lower portion of the Barataria estuary because of relatively high salinity, over fishing and the abundance of predators and disease. They found the majority of naturally producing subtidal oyster reefs in the mid portion of the bay and also referenced work by Moore (1899) that, by the 1890s, the reefs of Bastian Bay and Bay Jacque located near the western flank of the Mississippi River were used for bedding seed oysters for grow out and for later harvest up to two years, but not well-suited for natural recruitment. Proliferation of oyster leases into the middle and upper portions of the bay where the majority of natural subtidal oysters are presently located began in the late 1940s through the 1970s (Van Sickle et al. 1976).

In the 2012 Coastal Master Plan, oyster habitat is predicted to increase with or without restoration action coastwide and in Barataria Basin (Nyman et al. 2013, CPRA 2012). This is largely due to the continued loss of wetlands, continued saltwater intrusion, especially with sea level rise and increase in shallow, open water bodies. Evaluating the effects of a diversion in Breton Sound Basin, Soniat et al. (2013) predicted that the diversion would lead to a loss of oyster habitat in Breton Basin, but lead to an increase in suitable habitat in the Biloxi Marsh (if and only if the appropriate substrate was provided).

Oysters are sessile animals that rely on distinct salinity regimes. The ideal mean salinity from May to September for subtidal oysters is 10 to 20 ppt (Cake 1982) although 5 to 15 ppt is commonly used for an annual range. Salinity <8 ppt during larval stages and initial recruitment as a spat may hinder survival (Cake 1982). High salinity limitations (>20 ppt from spring to fall) are not a physiological response, but a predator and disease response. Extended low salinity (<5 ppt) during hot summer months (<25 Celsius) significantly and negatively affects oyster recruitment, survival and growth (LaPeyre et al. 2013, Rouhani and Oehrig 2015a, Rouhani and Oehrig 2015b).

When a reef dies, recruitment and recovery has to come from spawners elsewhere in the estuary, and there has to be a transport mechanism to allow the larval to recruit. Understanding estuarine water circulation patterns, especially during spring and fall spawning and recruitment times, is critical to understanding how reefs can become repopulated with oysters after a freshwater die off. Intertidal oyster reefs located further south in the basin away from low salinity events may provide spawn recruitment needed for reefs in the upper and middle basin. The southern bay distribution of intertidal reefs is also protected from predators and disease that are associated with high salinity habitats. Predation can be higher on flat, harvestable reefs as opposed to vertical, intertidal reefs. These spawner/recruitment reefs should be strategically sited in areas that have relatively stable salinities and currents to move larvae into the basin.

In Barataria Basin, most dips in salinity are due to precipitation as opposed to the operation of Davis Pond Freshwater Diversion (Habib et al. 2007, Swenson and Turner 1998). Occasionally, a flood with high mortality can benefit oyster populations and reef health. Oyster populations could potentially benefit from episodic flood events (approximately every 3-5 years) instead of annual flows. These occasional floods push out predators, reduce the occurrence of disease and provide shell for reefs to rebuild on (Dugas 1977). Oyster reefs can survive freshwater input in the winter months as long as the diversion operations cease by March (Melancon personal communication).

There is some uncertainty about if and at what rate oysters can develop their reproductive organs to be ready to spawn if the diversion is closed by March and considering the 2 to 4 weeks needed for salinity to rebound (although salinity rebound in the lower basin will be quicker than the upper basin). Oysters traditionally have two bimodal spawning peaks, spring (May-June) and fall (September-October), although some oysters are spawning through most months of the year except during winter. If the spring spawn and recruitment pulse is lost, the fall spawn and recruitment pulse may be adequate to establish new populations, but this needs more investigation. Maintenance flows may be needed in newly established oyster productivity areas lower in the basin to reduce predator pressure and the occurrence of disease.

Finfish

Some fish species have fairly stable age classes, while others are not stable, and populations tend to have strong and weak age classes due to a variety of environmental and human factors, including but not limited to predator-prey dynamics, growth, salinity, transport and harvest practices (May 1984). Operations for finfish productivity would best mimic the natural flood cycle. The frequency of winter flood events is anticipated to increase with climate change; however, by focusing on meta-populations over time, the seasonal timing should not be a tremendous factor. For some key species, like spotted seatrout (Cynoscion nebulosus), there would be very little effect as the males spend their winter in fresh water and the females tend to hunker down in deep navigation channels. In addition, in most species of finfish, juveniles are euryhaline and the salinity ranges tolerated narrow with age.

Mammals

Many of the mammals that live in coastal Louisiana are important to the fur-trapping industry. Many of these species, such as American mink (Neovison vison), river otter (Lontra canadensis) and nutria (Myocastor coypus), prefer fresh marshes. Muskrats (Ondatra zibethicus) prefer intermediate marshes. Diversions will increase habitat quality for most wetland mammals, including important fur-bearing species and invasive animals.

Increased nutrients, such as what would be delivered by a diversion, will increase the density of species like nutria, muskrat and feral hogs resulting in an increase in marsh damage (Visser et al. 2006, Ialegio and Nyman 2014). Management programs, like the nutria and wild hog control programs, have been fairly successful and may need to be expanded to address increased herbivory. In addition, the increase in alligator population expected at the diversion site will also aid in the control of the nutria population.

Migratory Birds

Louisiana's Coastal Zone supports about 300 regularly occurring species of native birds, including some of the highest densities and numbers of several coastal species of conservation concern of any state in the U.S., including brown pelican, sandwich tern, Wilson's plover and seaside sparrow. The region is also part of an important migratory flyway and supports some of the highest densities of migrating birds in the east. It is estimated that over 100 million songbirds of dozens of species stopover along Louisiana's coast in the spring after crossing the Gulf of Mexico – a 500-mile non-stop flight. Louisiana's coastal estuaries are also vitally important wintering areas for millions of waterfowl and geese, enjoyed by sportsmen and wildlife watchers alike. For these reasons, almost the entire area of Louisiana's Coastal Zone is included in one of 10 Important Bird Areas: Chandeleur Islands IBA, Active Delta (IBAs), Lake Pontchartrain IBA, West Pontchartrain-Maurepas Swamp IBA, Baratara-Terrabonne IBA, Isles Dernieres-Timbalier Islands IBA, Atchafalaya Delta IBA, Atchafalaya Basin IBA, Chenier Plain IBA and Coastal Prairie IBA.

According to the U.S. Fish and Wildlife Services' 2011 Report ("Birding in the U.S.: A Demographic and Economic Analysis: Addendum to the 2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation"), bird watching is one of the most popular outdoor recreational activities in the U.S., with 47 million people over the age of 16 self-identifying as bird watchers. About 18 million people in the U.S. travel to see birds, spending about $15 billion annually on trip-related expenses. Louisiana, with its unique culture and largely underutilized wildlife viewing opportunities, could promote diversions to provide new bird watching opportunities and attract some of these ecotourism dollars. Indeed, the Morganza Spillway and Bonnet Carré Spillway are already well known to local birders for providing exceptional bird watching opportunities (Gibbons et al. 2013, "A Birder's Guide to Louisiana"), in terms of the sheer numbers and diversity of birds, and for the potential for finding vagrants. The season and size of operations will affect the species composition, diversity and abundance of birds present on any given day, which will also depend on landscape context, but providing access to the area to birders will help reveal patterns in bird responses to changing water levels and shifting habitats.

Rangia Clams

Rangia clams (Rangia cuneata) do especially well with a river source and are an important part of the food web. Scientists have noted an explosion of clams near the outfall of the Caernarvon Diversion and Mardi Gras Pass. This indicates that with sediment diversions, reef restoration can expand beyond oyster reefs and explore the establishment of Rangia clam reefs in the upper basin near the outfall of the diversion.

Shrimp

Brown shrimp (Farfantepenaeus aztecus) and white shrimp (Litopenaeus setiferus) are collectively the largest fisheries in the state and most of the shrimp landings come from state waters, even though shrimp from federal waters are larger and have a higher value. Of the inshore harvest, Barataria Basin accounts for 44% of the brown shrimp and 31% of the white shrimp (Bourgeois et al. 2015). Shrimp are not only an important commercial species, but also an important player in the food web as a prey source.

Both brown and white shrimp spawn offshore. White shrimp spawn from April to August, although mostly in April and May, nearshore and along the shorelines out approximately 180 feet to deep water. Brown shrimp are spawning from September to November further offshore from 120 feet out to the continental shelf. Diversion operations are unlikely to affect shrimp spawning.

Brown shrimp migrate in mass from February to April to inshore waters as post-larvae and then spend March to June-July in the estuary as a juvenile. White shrimp migrate back to the estuary as post-larvae in June and then stay in the estuary as juveniles during July to December (Bourgeois et al. 2014). White shrimp seem to be more euryhaline and able to tolerate low salinities (Doerr et al. 2015).

Both brown and white shrimp are omnivores; however, white shrimp have a much broader diet than brown shrimp. Brown shrimp are partial to Polychaete worms and there is a large data gap in understanding how lower salinities will affect the food source for shrimp. In addition to diet, low salinity and low temperature can affect growth rates. For brown shrimp, growth is slow between 10 to 18 C, which is typically seen in February and March, and starts to increase in April. A modeled diversion operated in February and March had little effect on brown shrimp, but when operated in April and May had large, negative effects on production. Modeled diversions in April and May that drop the water temperature by 5 C or more could decrease juvenile brown shrimp production by 40 to 60% compared to a baseline, no diversion scenario (Adamack et al. 2012).

A key uncertainty with diversion operations is how it may affect the movement of post-larvae into the estuary during late winter to early spring. If the diversion is open, it could have an effect on local post-larvae recruitment and push post-larvae away from the estuary. However, the diversion could help move post-larvae into the estuary if estuarine recovery was timed with recruitment stages.

Over the past few decades, the relative abundance of brown to white shrimp has varied based on environmental conditions and fishing pressure. Historically, white shrimp and river shrimp were dominant, not brown shrimp. Potentially, diversion operations that are based on natural flood pulses could shift the relative abundance to more white shrimp than brown shrimp. Ecologically, brown and white shrimp fill the same niche with similar prey and predators, and there is no known ecological detriment to having a larger population of one variation over the other. However, white shrimp populations dominating the estuary could affect the timing of predator-prey interactions since brown shrimp are fall spawners.

For brown shrimp, operations could be reduced or cease by March to allow estuarine recovery while post-larvae are moving into the basin. For white shrimp, operations could function until June when post-larvae recruitment occurs. If the diversion operations are closed in time with larval migration, it will facilitate additional recruitment into Barataria Basin. Diversion operations could potentially increase the population of white shrimp and reduce the population of brown shrimp. Additional research is needed to confirm that there are minimal ecological consequences of this shift in dominant species and to determine the effect on the fisheries industry.

Waterfowl and other Water Birds

Waterfowl hunting leases had a gross farm value of $14 million in 2014. Gadwall (Anas strepera) habitat is predicted to be lost in the future without action in the 2012 Coastal Master Plan. However, that habitat would increase through implementation of the master plan, while the other waterfowl species modeled, green-winged teal (Anas carolinensis) and mottled duck (Anas fulvigula), are predicted to experience severe declines with or without the master plan (Nyman et al. 2013). Salinities less than 7 ppt will increase mottled duck breeding success, and operations that decrease overall salinities and increase the availability of SAVs will serve to benefit a diversity of dabbling ducks.

In general, waterfowl and other water birds will benefit from the low salinity, highly productive marshes created by the diversion. Diversions will lead to increased habitat quality, quantity and diversity, as well as increase submerged aquatic vegetation (SAVs) which provide a great habitat for dozens of species of waterfowl and wading birds. Because some water birds nest on or above the marsh surface or in low emergent vegetation in spring and summer, nesting seasons could be disrupted by rapid rising of water level elevations from opening of diversions. Most species would re-nest if water levels recede within the nesting season (roughly March to July), but even if not, other years without spring/summer flooding could offset losses from flooding years. Abrupt openings and closings of the diversion could be detrimental and confusing to waterfowl who may end up switching nesting sites multiple times in a year. Maintenance flows that keep low-lying areas wet during the nesting season will increase the nesting success potential as waterfowl will establish nests on higher elevations and not move into low-lying areas. Fall and winter operations would avoid the nesting season for most species, but may limit habitat availability in the short-term to species that depend on emergent marsh. These same species, however, would likely benefit in the long term by increases in the overall availability of marsh. Over years and decades of operation, sandbars and headlands that form would provide important nesting, foraging and loafing habitat for beach-nesting species, like terns, skimmers and shorebirds.

SOCIAL AND ECONOMIC ISSUES

Issues stemming from coastal land loss, climate change and coastal restoration and protection in Louisiana are fundamentally socio-economic challenges. Project development tends to favor the examination of biophysical processes far before the social science analysis is started. Social scientists need to be included as part of the project team from the start of the analysis, especially as many social and economic studies can require a longer timeframe than bio-physical planning efforts.

Socio-Economic Effects

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. There have been some isolated socioe-conomic analysis efforts, such as fisheries implications of freshwater introductions, role of cost efficacy in project selection, economic analysis of oyster lease dynamics, cost-earnings survey of various fisheries, trajectory economics on ecosystem services, and economic evaluation of land loss in coastal Louisiana. 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. A key to the socio-economic analysis is to clearly define the spatial and temporal scale that is appropriate to inform the decisions. This includes both short-term and long-term effects and requires spatial integration of biophysical and economic data, and incorporating traditional ecological knowledge (TEK) into monitoring plans (Bethel et al. 2014).

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 are appropriate to inform the decisions and provide consistency of analysis
- Incorporating traditional ecological knowledge (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 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 effects on subsistence fishers and on fishing access points
- Developing tools to help with oyster transitions
- Understanding the positive and negative effects of diversions on flood risk and community resiliency
- Promoting markets for harvestable species that are likely to increase with diversions
- Expanding ecotourism in diversion area

Some options to enhance the socio-economic analysis include expanding on disaster assessment methods, developing generic bio-economic models for simulating annual changes in net income, and conducting human adaptation studies. People are generally rooted in place, but mobility is a fundamental characteristic of living in a dynamic environment. The Louisiana coast has always been dynamic and communities have shifted locations and people have changed livelihoods based on the loss of Louisiana's coastal prairie and wetlands, saltwater intrusion, shifting fish and wildlife communities and storms. A better understanding of the history and baseline of social and economic effects would greatly inform the ability to predict how operations of a diversion may have future changes.

Natural Resource Dependent Communities

Fishers, hunters and people who use its wetlands for commercial and recreation activities, have long held economic and cultural significance in Louisiana. They are experts who understand local conditions, and that traditional understanding needs to be utilized. While the current level of modeling may provide proxies for predicting long-term socio-economic effects, current methods are typically too broad in scope for estimating localized economic effects. As the state learns more about the effects of different operational models and alternatives for diversions, it will be essential for that knowledge to be communicated to natural resource users and communities 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 effects, to the extent economically and scientifically feasible within the primary goal of land building.

Fish will likely adapt quickly, where as it is harder and takes longer for fishers and others to adapt. However, fishers need to be appreciated as experts and business owners. Biophysical modeling can help characterize management-driven changes to the distribution and productivity of specific fish assemblages, but an expanded analysis is required to examine the socio-economic effects of these changes on individual businesses and harvest sectors. Identifying a standard context is the principle challenge of such an expansion. While fisheries-independent and fisheries-dependent impact analyses are inexorably linked, they are often conducted on different scales. Louisiana's 2012 Coastal Master Plan, for instance, forecasted changes in ecosystems services (habitat potential) over relatively long periods (20 years, 50 years) and large geographic regions ("coast-wide" "basin-wide"). Such simulations may constitute long-term proxies of social welfare, but are typically too broad in scope for estimating localized, near-term economic effects (Caffey 2016).

Although the State of Louisiana subsidizes the oyster industry with cultch on public seed grounds, this source has become unreliable and many oyster farmers are moving toward investing in their own cultch. Investment in cultch is expensive ($60,000 - $100,000 per planting) and it typically takes 3 to 5 years to achieve a net return on the investment. Therefore, the farmer needs multiple years of advance notice of drastic changes to salinity that may affect their oyster productivity to properly plan their investments. If the farmers understand how the diversion will be operated, they can adapt to wet (open) and dry (closed) conditions and years, regardless of the basin and offshore conditions. In addition, developing tools to help with oyster lease transitions, such as an oyster lease relocation program, would ensure farmers are utilizing productive areas of the basin.

The operation of a diversion could mean a redistribution of fish, shellfish and wildlife species and abundance. For example, as discussed above, diversion operations that are based on natural flood pulses could potentially shift the relative abundance to more white shrimp than brown shrimp. Fish and shellfish species may shift into deeper water, requiring adaptation by fishers to those conditions. Alligator and waterfowl abundance in the outfall area is expected to increase dramatically.

Subsistence fishing is an important cultural aspect of coastal Louisiana, but is also an essential financial input into many "low-income" families. The effect of actions on subsistence fishing is hard to define by traditional research methods; however, using TEK can provide some understanding of the importance and potential positive and negative effects of diversion operations on subsistence fishing.

Access is another issue of concern. With the channel distributary system that would need to develop, there would be navigation access improvements, but with sedimentation and bar formation in other smaller canals and open water bodies, navigation access will be different than it is currently.

Access for ecotourists should also be expanded. One should consider partnering with local marinas to expand access for tourists, airboat operators, and recreational boaters, and canoe operators who want to see the diversion. This will provide alternative employment as fishery production fluctuates with the diversion-caused ecosystem changes.

Flood Risk to Communities

Sediment diversions can have both positive and negative effects on the flood risk of nearby communities. In addition, the source of the flood risk could be from the river flood and diversion operations, or from hurricane storm surges. Factors affecting flood risk include subsidence, sea level rise, peak diversion flow, years of operation, timing of peak flow, tidal effect, operation of other diversions, land building, elevation, frequency and intensity of hurricanes, and the cross-sectional areas of the tidal passes.

One major benefit of diversions is a reduction in river flood risk for the Greater New Orleans region and a contribution to the resilience of the MR&T flood control system. The diversions reduce flood stress on the levee system that protects New Orleans, which is one of the state's most economically important areas, has one of the state's largest and most treasured minority communities, and is a dense population center, the largest in the coastal zone. Modeling has indicated that diversions operating south of New Orleans can drop flood stage at the Carrollton river gauge by 1 to 4 feet. Operation of the Bonnet Carré Spillway would also be greatly reduced or eliminated.

Elevated water levels are expected in the immediate outfall area of the diversion where levees and revetments are expected to minimize any flood risk except for homes and camps within the marsh. Water level increases in the basin are expected to reach 1 to 2 feet at peak flow, after the distributary network has developed. Water levels finally level out to 0 approximately 26 miles south of the structure. These water level increases alone are not likely to increase flood risk for nearby communities within the levees. However, when coupled with a frontal passage, high tide or tropical event (in addition to future conditions such as sea level rise), it could increase the flood risk of communities such as Grand Bayou and Lafitte. For instance, consistent southerly winds could increase the water levels in the basin by one foot, whereas consistent northerly winds would result in a decrease of one foot. There is also slight overlap in the occurrence of river flood events and the tropical storm season. To date, a tropical storm has not hit the Louisiana coast at the same time as a flood on the Mississippi River; however, operations should be very cautious of any operations of a diversion past May 30. If water levels are elevated in the basin at the time of a tropical event and those waters are not able to drain into the Gulf of Mexico, the retention and attenuation capacity of the basin is greatly reduced and flood damages could increase dramatically.

It is also important to note that the distributary system will take time to develop. If the diversion was initially opened at full capacity, the flood risk would greatly increase. This is because the drainage system has not had time to develop and water would stack up at the outfall. A tropical wave today can move up the Barataria Basin all the way to Lake Cataoutche. Distributary systems could facilitate the movement of water up into the basin. The development of this drainage system could also cause the enlargement of the tidal passes and increase the overall tidal prism in Barataria Bay.

The timing of peak diversion flow should consider the stage height of the Gulf of Mexico (which is lowest in winter/spring), cold front passages (November to May) with wind-induced set up and set down, tropical storm season (June to November), and the tidal effect (spring tides are highest near winter and summer solstices).

The sediment diversion can reduce flood risk from tropical events by building and maintaining the coastal landscape and raising the elevation of land throughout the basin. The new distributary network will assist in the rapid retreat of storm surge and help drain large precipitation events that have been known to flood the upper basin. The effect of the increased volume of storm surge water moving into the basin is being researched.

GOVERNANCE AND LEGAL

Decision-Making Structure and Process

There are numerous entities that play a key role in the development and implementation of operation plans, including but not limited to: CPRA, USACE, other state agencies, other Federal agencies, local governments, elected officials, community leaders and members, the fishing industry, navigation industry, scientists (social and physical) and engineers, landowners, businesses and other interested parties. A formal structure of governance should be developed that identifies the roles and responsibilities of all the parties and the decision-making process. Although it is of the utmost importance for there to be a wide variety of voices that have a meaningful role in operation planning, ultimately, it is the responsibility of the state to ensure that the project goals and objectives are being met. Standing advisory councils should be formed to provide formal input and standing technical and scientific (including social sciences) committees should be formed to provide unbiased analysis of the monitoring data and recommend modifications to the operation plan or adaptive management strategies based on the ecological and social responses.

In the governance of the structure, the first and most important step is setting the goals and objectives for the project. The primary goal has already been well-established – to build and sustain land. However, identifying the secondary goals and objectives is necessary to build appropriate operation strategies and should be developed with a wide array of input from entities additional to the State. With those goals and objectives in mind, the scientific analysis can develop a formula for operations independent from the socio-economic considerations and political pressures that can change rapidly. The formula can include provisions which identify triggers to closing the diversion or conditions that may lead to modification of the formula (i.e., when the goals of a freshwater diversion shifted from reducing saltwater intrusion to land building/sustaining). The next step is determining who is adversely affected by the operation formula and beginning negotiations with those parties. Negotiations should focus on the mitigation and transition solutions, not on the operation plans.

Active and Meaningful Participation of People Affected by Diversions

Success is dependent on a transparent and active process to engage people who may be affected by the diversion. CPRA should begin to identify individuals or businesses that will be directly adversely affected by the diversion and begin discussions now. Although not all of the affected entities will be known at this time, there are certainly individuals and businesses that will be affected by this project no matter what. Opening up ongoing, iterative conversations with these individuals and representatives now will build a relationship, identify mitigation and adaptation strategies and build an understanding of what will unfold that will streamline future project implementation. As more detailed information on operations is developed, additional people may be identified and added to the discussions. In addition, CPRA could consider doing a potential risk analysis that identifies which individuals or businesses could be affected and what is the likelihood of that effect.

There are multiple issues that deter the active and meaningful participation of people who could be affected in the process that occur in *all* of the interested parties, from government to elected officials to stakeholders with a vested interest to the general public. These issues include mistrust of each other, hidden personal agendas, misrepresentation of a group, misuse of science and modeling data, lack of understanding/level of knowledge, meeting fatigue, lack of two-way communication, refusal to acknowledge uncertainties or future conditions, close-mindedness and improper expectation management. Studies have shown that public participation is highest with medium-levels of trust and that very little public participation occurs when trust is at high or low levels (Yandle et al. 2011).

Engagement with one or two representatives of a stakeholder group can limit understanding of the full breadth of issues and concerns from that interest group. Often times, the individuals that attend town halls and public meetings are not representative of the community or stakeholder group as a whole. A recent study on TEK developed a new method for identifying a larger but manageable number of representatives that could be included in any given interest group. A large number of individuals are asked to nominate someone, besides themselves, that they would consider an expert on their issues and develop their lesson plan or key concerns/questions. Thus, the representatives are community-nominated for their ecosystem and fisheries expertise and respected by fellow harvesters (Bethel et al. 2014). In addition, building relationships in the communities being affected and having trusted agents in the field that are provided with the proper information, messaging and tools can increase meaningful engagement of interested parties.

Outreach

Education is critical to helping keep the public and interested parties informed about timescale and process for land building with a sediment diversion. For example, erosion is a part of the crevasse lifecycle. Erodibility is important to the development of channels and the delta complex. These processes may be alarming at first and give the impression that the sediment diversion is causing more harm than benefits, so visualizations and outreach materials should be developed to inform the public of what to expect from a sediment diversion, the processes for building and sustaining land, as well as erosion, and the other positive and negative effects of sediment diversions. Substantial efforts must be made to reach out to communities that are not typically engaged, such as low-income, urban and minority communities.

In addition, once the diversion is operational, outreach tools and technologies should be used to inform the public on when the diversion is operated and the current basin conditions. Online webinars, easy to understand real-time data websites and interactive apps that can be used in the field are all important tools to inform those who will be affected by the diversions.

Efforts should be made to expand ecotourism and environmental education in areas that are restored by the diversion.

Laws and Regulations

In order to acquire a permit for construction, CPRA and the USACE will need to complete a National Environmental Policy Act (NEPA) Environmental Impact Statement (EIS). The EIS will define the proposed action to be taken, evaluate alternatives, describe the affected environment and propose, but not require, mitigation actions that could lessen environmental and social adverse effects. It has been challenging for Federal agencies and others to build adaptive management components into the NEPA documentation. Where possible, the State and the USACE should work with the Council of Environmental Quality to help identify where flexibility can be built into the EIS to allow operations to respond to changing conditions and climate change, while also adhering to the law.

The actions by the State are being conducted as a necessary exercise of police power (public safety) and the state's actions would be scrutinized by the courts in tort action under the discretionary function immunity statutes that give considerable deference to state actions. The Avenal v. State (La. 2004) case against the state over damages from the Caernarvon Diversion relied on the hold harmless clauses in oyster leases to absolve the state of liability. The Louisiana Supreme Court also stated that the state's responsibilities under the public trust doctrine (La Const. art. IX Sec.1) could likely justify the state's actions in furtherance of coastal restoration independent of the indemnity clause, but it is unclear how far the police power exception can be extended to protect the state from liability for taking or damaging private property. The answer to that question will probably come on a case by case basis.

Fishing licenses, oyster leases and access to public resources are not considered private property rights. Individual Fishing Quotas (IFQs) are considered a property right, but have limited use in coastal Louisiana. Oyster culture on private water bottoms, commercial docks and private lands can all be considered private property rights that could be affected or damaged by flooding, sediment deposition or erosion and salinity changes from coastal restoration diversion projects. Approximately 80% of the coastal zone is privately owned. Flooding of private lands, even temporarily, would be considered a physical occupation of private property. Flowage easements are needed to regularly flood private property (Arkansas Game and Fish v. U.S.). Loss of business, from commercial marinas or docks, could be considered an economic tort but typically, for such a claim to be successful, would need to be accompanied by physical damage to the property which may be satisfied by damaging siltation, for instance, in areas near the outfall. Thus, potential legal challenges to diversion operations remain, though tempered to some extent by statutes and court decisions. Preemptive attention to legal issues is desirable to avoid long and costly delays to operations.

Current projections of diversion-based land reclamation and loss offset are dictated by an operational flow regime constrained only by river stage and structure capacity. Realizing this upper bound of restoration capacity would likely require that this regime be established in statute, similar to the legislation governing the state's existing flood control structures (Caffey 2016).

A non-exclusive list of existing laws that can protect the State's interest in coastal restoration:

- LA Const. art. 1§4(G) – "May place limitations on the extent of recovery" for coastal restoration takings.
- 49§214.6.5 – Limits amount of compensation to that allowed under the 5th Amendment.
- 49§214.6.10 – Holds harmless state & federal governments; requires hold harmless clauses in leases, permits, licenses.
- 9§2798.1 Discretionary Functions immunity.
- Acts N. 936 (1995) La. R.S. 9:214.5 – State to be held harmless for damages related to state leases, and all leases to include indemnity language.
- Acts No. 1304 La. R.S. 56:700.12 – Establishes Oyster Lease Damage Evaluation Board.
- Acts No. 1314 La. R.S. 56:432.1 – Creation of oyster lease relocation and compensation program (Amended 2000 and 2006).
- Acts No. 107 (2000) La. R.S. 56:427 – State to be held harmless for all coastal restoration projects; creation of "bobtail" leases subject to coastal restoration impacts under La. R.S. 56:482.1 (projected impact: 1-14 years) and 56:428.2 (known impact:1 year) (repealed 2006).
- Acts No. 583 La. R.S. 213.10 – Exercise of the State's "full police power" for coastal restoration efforts; Compensation for coastal restoration projects limited to U.S. 5th amendment levels; Venue for all actions related to oyster leases limited to 19th JDC in East Baton Rouge.
- Acts No. 425 La. R.S. 56:423, 425, 427.1 - Codifies limited nature of oyster lessee's property interest as defined by Avenal and requires State to report annually to oyster industry on status of coastal restoration projects; No issuance of inactive leases obtained in coastal restoration project areas absent permission of LDNR; Lessees may seek compensation for oyster leases acquired for coastal restoration projects.

- HCR No. 137 – "THEREFORE, BE IT RESOLVED that the Legislature of Louisiana does hereby urge and request the Department of Natural Resources to operate the Mississippi River freshwater diversions structures at as close to maximum capacity as is possible."

Transitions and Mitigation

In addition to the possible legal challenges to diversion operations, a potentially bigger hindrance is political roadblocks that are sure to arise when socio-economic effects are not addressed. For most public works initiatives, comprehensive project accounting includes some measure of the compensation costs required for acquiring private property and public easements. In the case of common public resources such as fisheries, and for river diversion projects in particular, direct compensation costs are seldom, if ever budgeted. Instead, economic concerns have historically been addressed through a multi-stakeholder advisory process that affords access to, and partial control of, diversion operations. This approach has at least partially contributed to the underutilization of existing diversions projects, Caernarvon and Davis Pond. Given the apparent lack of economic impact mitigation strategies in the current state master plan, it is likely that future diversions will continue being constrained by this approach and by stakeholder opposition over project-driven changes in hydrology and salinity (Caffey 2016).

As an alternative strategy, sediment diversion projects should incorporate preemptive mitigation, transition and compensation costs to the extent possible. Compensation should be utilized as a last resort for any adverse effect from the sediment diversions, as simple compensation will not preserve an industry or a culture/way of life. However, with the lack of other transitional or mitigation solutions, compensation would need to be considered. The ratio of state investments in mitigation/adaptation to compensation is a measure of successful diversion implementation. Mitigation/adaptation should be the primary use of state funds.

CPRA should begin to identify individuals or businesses that may be directly adversely affected by the diversion and begin discussions now. This suggestion echoes that of a multi-agency, interdisciplinary, 50-member working group convened in October 2015 to address the socio-economic and adaptive management challenges of diversions. Among the recommendations of that group was a call for near-term impact analyses to compliment the long-term economic assessments recently commissioned at the project level:

> *From a socio-economic perspective, the group collectively expressed support for development of program-level and project-level analyses that would provide timely and relevant socio-economic guidance on questions regarding diversion feasibility and project impact….(including) refining and expanding long-term, coast-wide socio-economic studies; commissioning parallel near-term analyses at the project and sector levels; examining critical legal questions related to private property rights and impact; and incorporating the input of federal and state partners in key permitting and management decisions related to construction and operation (Caffey et al. 2015).*

A new collaborative and iterative system of shared learning and problem solving needs to be developed and implemented to negotiate and deliberate effects and conflicts. A lesson from the Caernarvon Diversion was that the identification and resolution of adverse effects should be front-loaded as much as possible, although it is recognized that not all effects and all affected parties can be determined prior to project implementation. To address these unknown or unforeseen impacts, a program should be established to develop a toolkit of solutions and set up an administrative process to assess the validity of claims. There are successful examples of these types of administrative processes (i.e., malpractice lawsuits) and failed examples of this process (i.e., BP oil spill claims process).

The identification of affected fisheries businesses would be based on a number of factors related to target species, harvester location and mobility, and expected flow rates. Economic impact assessment would begin with detailed mapping of the current fisheries infrastructure in relation to the hydrologic footprint of a planned diversion. For firms and sectors in which sufficient data exist, market-based appraisal methods could be utilized to establish baseline economic valuations. Project-driven changes to these values would then be simulated using bio-economic methods in which net returns are subject to changes in water depth, isohalines and sediment deposition under average and maximum flow rates. Such projections would by necessity require distribution and productivity projections by species on a smaller scale (sub-basin grid) estimated over an annual or seasonal basis. The resulting subset of legitimately at-risk firms identified through this process would likely be greater than zero, yet considerably less than the dire predictions of diversion opponents. Once identified, numerous policies are available for mitigating economic impacts, including: one-time payments (buyouts), infrastructure relocation programs, transition assistance via low interest loans and professional retraining programs. For this process to work it will be necessary for the state and federal government to be completely transparent in their assessments, information gathering and outreach to the public. Such openness will create a much better atmosphere for negotiations than when people are unpleasantly surprised and feel they have been misled. And the involved governments must recognize the legitimacy of using government funds for these solutions rather than merely the traditional payment of claims (Laska et al. 2015).

The ultimate potential for realizing this process-driven approach to river management could be facilitated through the comprehensive accounting of, and preemptive mitigation of, legitimately affected firms in fisheries and other economic sectors. At a minimum, the direct costs of alternative compensation strategies should be compared to the indirect, opportunity costs resulting from stakeholder accommodations that currently characterize diversion operations and reduce their efficacy (Caffey et al. 2014).

MONITORING, RESEARCH & ADAPTIVE MANAGEMENT

Adaptive Management

Adaptive management uses a combination of active and passive learning – experimentation and monitoring, respectively – to answer questions and provide information about how ecosystems respond to management actions, such as restoration projects, as part of a science-based decision-making process. The primary driver behind adaptive management is to reduce uncertainty so decision makers, including managers, scientists and society, can make the best-informed decisions possible about natural resource issues, recognizing that they will never have perfect information nor eliminate all uncertainty.

Monitoring any restoration project is essential because it helps keep managers informed about short- and long-term trends in an ecosystem. Long-term monitoring, including the gathering of baseline data, is particularly important because ecosystems are complex, sensitive and often slow to change. Adaptive management with pre-construction monitoring facilitates the learning process that is imperative to a project with complex interactions and outcomes. Adaptive management embraces a scientific approach to reduce uncertainty around natural resource management actions by (1) identifying goals, objectives and appropriate actions, (2) implementing these actions, (3) monitoring and evaluating the system's response, and (4) using knowledge gained to inform future management decisions. In addition to explicit identification of goals and objectives and monitoring, other essential components of adaptive management include:

- Contingency planning – to systematically address potential challenges and identify actions to mitigate; may include developing a "what-if" chart of potential future impacts and benefits, along with a general framework for how to approach unanticipated challenges or responses. Potential challenges include but are not limited to changing coastal conditions, system response, legal/policy constraints and social acceptance that affects project implementation or operation.
- Measurement of progress – requires a structured approach to monitoring and reporting on key performance measures to ensure the project or management action is achieving its objectives; necessitates appropriate baseline monitoring. If the system does not respond as expected or if project goals and objectives are not being met, this information will be used in the adaptive learning feedback loop.
- Systematic use of new information – the core of the adaptive learning component of adaptive management; is part of a science-based process and thus a way to improve understanding of how different parts of the system, both environmental and social, are responding to project implementation. Synthesizing and incorporating new information and knowledge into the decision-making process for operations will improve analytical tools, design criteria and alternative options for future project development.

Utilizing all of these elements, together, throughout the adaptive management process results in learning feedback loops. Adaptive management is an iterative process and, while new information is always used, exactly how this new information is used may differ. As new information is gathered and uncertainty around specific management actions reduced, operations or decision-making processes may be altered. However, if a particular knowledge gap has been addressed through experimentation it may become necessary or desirable to reassess the goals and objectives of a particular project or program. Even through passive learning, enough new information may be gathered after a long enough period that it becomes appropriate to revisit the original goals and objectives.

The construction and operation of a sediment diversion will result in an unprecedented amount of data and subsequent learning, both active and passive. From the moment the gates of a sediment diversion first open, we will be witnessing and learning about system change. It is clear that adaptive management will be a crucial component of operating a sediment diversion.

A workshop of experts developed some steps necessary to start the process (Caffey, et al. 2015):

1. Begin a multi-agency effort to develop a recommended framework for identifying adaptive management metrics and evaluating monitoring results to determine if the goals are being met.
2. Develop a draft adaptive management processes for model refinement and dispute resolution.
3. Review adaptive management protocols for other restoration plans and outline what data might be missing from the state's System-Wide Assessment and Monitoring Program.
4. Examine the range of National Environmental Policy Act compliance questions that will be needed and initiate responses to these questions.

It will be essential that a robust adaptive management plan, incorporating the elements described above, be developed so managers can be prepared to handle all this new information and maximize its use in both learning more about the system and future decision-making. Frameworks for decision-making about operations and for measuring project success should be established prior to construction, but with clear guidance as to when these processes should be reevaluated, since the needs of the system will likely change over the long term.

Monitoring and Research Plan

A good monitoring and research program in the receiving basin is essential to observing conditions before, during and after operations. Monitoring should be sure to incorporate the entire area of interest to understand both the near and far field effects of the diversion. One the key decision making tools for operations is a high resolution suite of models improved regularly by monitoring data that allow relatively accurate predictions of ecosystem and socio-economic responses to various operation strategies. The WG discussed some of the major data gaps related to the operation of diversions or research that would help inform management decisions. This list is in no way exhaustive. Although there were a lot of suggested monitoring needs, there was the acknowledgment that monitoring should focus on the most cost effective and efficient methods that provide the greatest amount of information.

Hydrodynamics of the River

- Improve modeling capabilities to ensure that all key components of the operation strategy are adequately captured (for instance, current models do not fully distinguish between the sediment dynamics of the rising and falling peaks). A robust model is needed to support annual management decisions about operations.
- Use the available river data to develop typologies of hydrographs to support planning and operation of a diversion. CPRA is using an average hydrograph in a Delft3D model to analyze and evaluate diversions. This does not provide a realistic scenario of river flow, as well as doesn't provide an understanding of the inter-annual variability that will be experienced during the

operation of a diversion. A typology of hydrographs to evaluate response of marshes and vegetation under representative years (high flow year, average flow, drought year, multiple peak years, early peak and late peaks). A typology could look for similarities in the 50 hydrographs being utilized in the Integrated Compartmental Model (ICM) for the 2017 Coastal Master Plan.

- Conduct research to understand how to merge the management of the navigation, flood protection and restoration programs.
- Conduct research to better understand the relationship and anticipated hydrologic conditions that could result from a hurricane and river flood happening simultaneously.
- Supplement the sediment-water ratios with a methodology that compares total sediment load to diversion flow versus total sediment load to river flow to better understand and, more importantly, communicate the total sediment load or average sediment load being captured by the diversion.
- To improve data available for modeling and operations, the following monitoring additions are recommended: (1) a permanent monitoring station at Venice for discharge and stage, (2) a permanent monitoring station next to each diversion outfall for discharge, stage and turbidity, (3) implement permanent or temporary monitoring stations in critical areas of the river that are experiencing significant changes in flow, sediment transport, etc., such as Fort St. Phillips, (4) multiple permanent monitoring stations for daily sediment load/turbidity in the river, up to Arkansas, with 10-20 field boat surveys per year to improve the ratings curve, (5) monitoring methods to measure grain size and concentration (LISST or acoustical backscatter sensor), (6) GPS monitoring network to monitor subsidence in the river and effect on the stage/discharge relationship, (7) monitor shoaling in the river with regular multi-beam surveys, including baseline surveys, directly at and downstream of the diversion and even further downstream to observe any far-field effects, (8) monitor navigation effects and boat safety around open and closed diversions with ship simulation models, GPS and engine monitoring on ships.

Hydrodynamics of the Basin

- Develop a tidal hydrograph that incorporates sea level rise. The hydrological connectivity for alluvial plains and how sediment and nutrients interact between the channel and emergent wetlands are fairly well understood. However, the hydrologic connectivity of the basin with tides, and specifically a diversion channel in Barataria Basin, is not as well understood and represented in our current models. The river has one hydrograph, but tides and sea-level hydrograph is just as important in moving sediment in and around the basin.
- Research to address uncertainties in marsh elevation relative to tidal amplitudes, including more ground-truthing of LIDAR data.
- Conduct additional research and modeling to quantify the benefit of utilizing cold front passages to resuspend sediment onto the marsh surface.
- Conduct estuarine flux measurements and/or modeling to understand the spatial variability of residence times in the basin under various operation strategies.
- Conduct a bathymetric survey of the open water areas in Barataria Basin.

Sediment and Land Building/Sustaining

- Conduct regular monitoring to capture sediment retention, acres of land sustained/maintained and acres of new land created by the sediment diversion.
- Establish monitoring stations through Coastwide Reference Monitoring System (CRMS) or System-Wide Assessment and Monitoring Program (SWAMP) to capture sediment movement into the marsh. Conduct annual transects from the channel into the marsh to collect bulk density, accretion, pore water, elevation, particle size, sediment profile, biomass, nitrate/sulfate/sulfide and soil shear strength. It is important to get lateral movement of sediment from the channel up onto the marsh surface. At this time, CRMS monitoring stations are not set up in a way to capture this specifically.
- Monitoring in the receiving basin related to basin geology and land-building should include turbidity (vertically stratified), topography, bathymetry, land change, sediment delivery (trajectory and accumulation), soil salinity, transportation and deposition of various size classes, in situ flocculation, sediment accumulation rates, etc.
- Prior to opening the diversion, a detailed analysis of the substrate in the receiving basin should be conducted to provide a baseline. Some parameters may be difficult to include but should be considered, such as shear stress/strength, erodibility of highly organic material and the heterogeneity properties of the marsh, which are all not adequately represented in the modeling.
- The erodibility of highly organic substrate is an important boundary condition with substantial uncertainty, yet there is no proven methodology to measure this parameter. Additional work is needed here.
- This should include shallow water multi-beam bathymetry, naturally-occurring radio isotope tracers, sub-bottom profilers and geotechnical properties. Sediment tracking should be conducted to understand how the sediment is being transported and deposited through the system.
- Since land-building is a longer-term process, it will be important to document how the diversion is sustaining and maintaining existing wetlands. Sedimentation should be measured, specifically sedimentation on existing marsh surfaces. This could be done through a variety of methods that measure trajectory and/or accumulation (surface elevation tables (SETs), acoustic sensors, radio isotopes, feldspar, fluorescent tracers, etc.). If multiple diversions are operating at once in a basin, colored tracers can be used to distinguish the effect of one diversion versus another. Other methods for evaluating land-building include LIDAR (aerial and boat-based), remote sensing (SAR), regular aerial imagery, side scan sonar, drone flights, turbidity measurements and denitrification enzyme mapping.
- Research into the design and application of sediment retention and enhancement devices (SREDs)

Water Quality

- In general, water quality data is biased to fair weather conditions, so, where possible, permanent or temporary stations, including nutrient sensors, should be deployed that can capture a wider range of conditions.
- Increase the offshore monitoring in coastal areas adjacent to major diversion sites, specifically focusing on salinity, nutrient concentrations and ratios, occurrence harmful algal blooms (HABs) and hypoxia.
- Monitor tidal passes to measure water, sediment and nutrient fluxes over diurnal tidal cycles, and also under different seasonal/climatic conditions. This monitoring, typically done by

shipboard measurements but could also be done with in-situ sensors such as mounted ADCPs, should be done before and after the construction of a diversion.

- Install a permanent monitoring station (or upgrade existing, such as Vicksburg) to capture nutrient loads up-river with ample travel time to consider in any operation management decision.
- Utilize CRMS stations, or anticipated SWAMP monitoring stations, to measure water quality in interior ponds and channels. Parameters to measure could include chlorophyll-a, nitrate, dissolved oxygen and turbidity. Conduct additional research to better understand how to minimize algal blooms or increase physical disturbance/dissipate blooms in problem areas (i.e., shock pulse from diversion).
- Monitor phosphorus concentrations and fluxes in bay sediments before and after diversion opening (baseline and then a year after).
- Consider opening the Bonnet Carré Spillway for one month during a hydrologically normal year to generate valuable data for better predicting water quality effects from future diversions.

Vegetation

- Conduct regular aerial surveys to monitor flood stress in vegetation, including surveys before during and after operations. Satellite or aerial surveys are essential to identifying flooding stress throughout a system. This would identify the signature in the landscape more so than monitoring stations. The same results could also be provided with the use of a drone during bi-weekly surveys; however, weather could prove to be problematic. Productivity studies, such as NVDI, can show any flood stress that may be occurring due to operations of a diversion.
- Baseline data should be collected on the distribution of various species, as well as the seed bank/propagule sources available, in the outfall area of the Mid-Barataria Sediment Diversion. This data should be mapped along with the species' growing seasons, environmental requirements and overlaid with predicted flood levels.
- Depending on the species, additional research or testing may be needed to understand the optimal flood duration and recovery period.
- Use available models, such as LaVegMod, to predict how vegetation will shift under various scenarios of water level and salinity changes.

Fish and Wildlife Species

- Research should be conducted on the overall productivity of the system pre- and post-construction of a diversion to demonstrate the benefits of increased nutrients, sediment and freshwater on the overall food web.
- Some wildlife and fish monitoring programs exist on the statewide basis to show overall trends, such as alligator nest counts, nutria nest counts, breeding bird surveys, colonial nesting bird surveys, avian beach surveys, waterfowl counts and fish independent monitoring. The state will need to increase these monitoring efforts in the area of interest to be able to evaluate changes due to a specific diversion project. Scale is a key factor in determining how you are impacting a particular species. A diversion may lead to a decline in a more saline species in the immediate outfall, or even within the basin of influence, however the population coastwide may be growing. Populations of many species are continuous and not isolated and effects in a basin may not be discrete. Thus, we are concerned with both abundance of the population, but also the distribution of the population. This may require the State to reassess and redo monitoring sampling plans with new sampling statistics.

- Habitat Suitability Index (HSI) modeling should include temperature effect, using time of year as a surrogate. The HSI or oyster modeling should incorporate positive effects that temperature and periodic freshwater can have on the population.
- Diversion operations could potentially increase the population of white shrimp and reduce the population of brown shrimp. Confirm with multiple experts that there are minimal ecological consequences of this shift in dominant species, and discuss socio-economic effects of this shift with fisheries representatives.
- Expand modeling capability to predict future ranges of oysters into dry zone, wet-dry zone, wet zone and high salinity zones with and without a diversion. Expand mapping of appropriate substrates for oyster development. In anticipation of shifting optimal oyster zones with diversion operations, plan development of habitats (i.e., cultch plantings) in areas that are going to be productive in the future to sustain the Barataria Basin oyster population.
- Consider the importance of conducting oyster monitoring not just on public ground but on private leases.
- Responses of some fish and wildlife populations are uncertain, and defining cause and effect can be very difficult. Some of the specific data gaps mentioned by the experts on food web dynamics and predator-prey relationships include:
    - Diets of oysters and their environmental requirements.
    - Monitoring top level predators, especially humans.
    - Fecundity of oysters by size class, how quickly can reproductive organs be developed.
    - Relationship of wetland health and quantity to fish productivity.
    - Predictions of overall productivity of the system considering carbon and nitrogen inputs.

Socio-economics

- Conduct near-term socio-economic impact assessment for key fisheries (e.g., oysters shrimp, finfish) as soon as possible. While long-term impact assessments are essential for project justification, near-term impact assessments are just as important because these assessments could have implications during the NEPA process. Such an assessment would take 1-2 years to complete.
- This assessment must include fishers (people) not just fishes (animals). It is essential to include fishers in these assessments because although some effects to fishes may be negligible over longer periods and across larger scales, there may be substantial impacts to fishers depending on their economic condition, location and mobility. Other social impacts to study include subsistence harvesting and reduction in the number of youth who know how to fish, shrimp or harvest oysters.
- Thorough analysis is needed to examine legal requirements for mitigation, compensation or transition support.

EMERGENCY OPERATIONS

There are scenarios, both foreseeable and unforeseeable, where the diversion would need to be operated under emergency conditions. A few examples were discussed:

- Diversion operations could contribute to the resilience of the MR&T flood control system. Modeling has indicated that diversions operating south of New Orleans can drop flood stage at Carrollton by 1 to 4 feet. Operation of the Bonnet Carré Spillway would be greatly reduced or eliminated. There is a potential to increase river discharge past that maximum 1.25 million cfs or to change the management at Old River Control Structure. Additional research is needed to understand how to merge the management of these two separate systems.
- A late flood in August 2015 reminded everyone that it is possible to have a river flood and a storm surge propagating up the river at the same time. Diversion structures could be operated to relieve surge levels on stressed levees. Additional research is needed to better understand the relationship and anticipated hydrologic conditions that could result from a hurricane and river flood happening simultaneously. The 2011 flood also extended into June, the beginning the hurricane season.
- Extreme rain events were discussed as a potential impact of climate change. There is not clear consensus on how more heavy rain events in the watershed will affect the discharge in the lower Mississippi River. These effects could be offset by other climatic changes in other parts of the watershed. The Mississippi River discharge records are one of the most stable, long-term records, with interesting variability but few changes in trends. The WG generally agreed that changes in river discharge were a lower priority until more definitive information is known.

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