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Lessons learned from 30-years of operation of the Caernarvon Freshwater Diversion, Louisiana USA

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ABSTRACT

Wetland loss is a worldwide issue with estimates of loss ranging from 50% to 71% in the 20th century. Louisiana's coastal zone lost approximately 4,830 km^2, or 25% of the land area between 1932 and 2016 due to a variety of natural and anthropogenic forces that both erode and prevent the growth or maintenance of existing land. Freshwater diversions were constructed along the Mississippi River to convey freshwater, nutrients, and sediment from the Mississippi River to Louisiana's coastal basins to combat saltwater intrusion, nourish the marshes, and stimulate fisheries. The Caernarvon Freshwater Diversion (CFD) was authorized by the Flood Control Acts of 1928 and 1965, the 1974 Water Resources Development Act, and a 1984 Environmental Impact Statement, with construction completed and operations started in 1991. The CFD has been largely successful from the standpoint of the project's authorized goals. Early on in the project, the CFD helped combat saltwater intrusion in a 2,730 km^2 basin and re-established the gradient from fresh to salt marsh, by creating conditions favorable to fresh marsh species. Although not a specific project goal, the CFD also built more than 700 acres of new emergent wetland between 1991 and 2016. By critically assessing 30 years of CFD governance, operations, monitoring, and adaptive management, lessons learned are developed that provide valuable information for making the operations and governance of current and future diversions more effective, transparent, adaptive, and trusted by the basin communities. Louisiana's Coastal Master Plan pivots to the use of river diversions to focus on land building and large-scale ecosystem restoration by mimicking natural processes that originally built the Louisiana deltaic landscape, rather than the more common small-scale restoration that has occurred over the past decades. However, large-scale restoration projects, by their nature, impact a wide variety of stakeholders and tend to cross political boundaries. Lessons learned from the CDF highlight the need for flexibility in the long-term and specificity in the short term in governing the operations of a large-scale coastal project. Recommendations developed for modernizing project implementation into the future given changing estuaries and climate will help increase effective implementation of larger-capacity river sediment diversions and other ecosystem-scale projects. It is time for big and bold action to restore south Louisiana and other coastal environments worldwide, and critical to success is using results from numerous past studies, applying lessons learned from existing projects like the CFD, and projections of future conditions.

1. Introduction

The coastal area of Louisiana has suffered high rates of land loss due to a variety of natural and anthropogenic forces that both erode and prevent the growth or maintenance of existing land (Walker et al., 1987; Wells and Coleman 1987; Boesch et al., 1994; Edmonds et al., 2023). Louisiana's coastal zone lost approximately 4,830 km^2, or 25% of the land area between 1932 and 2016 (Couvillion et al., 2017). Louisiana's land loss, coupled with the construction of oil, gas, and navigation canals that slice across hydrologic basins, exacerbates saltwater intrusion issues already present due to the high rates of relative sea-level rise experienced in coastal Louisiana (Penland and Ramsey 1990; Salinas

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et al., 1986; DeLaune et al., 1994; DeLaune et al., 1994; Doyle et al., 2010; Williams 2013; Hunter et al., 2016; Lane et al., 2016; Keogh and Tornqvist 2019). Saltwater intrusion can kill fresh and intermediate marsh vegetation, increasing the rates of erosion as plants that were holding soil together die. Saltwater intrusion drives fresh to saline habitat conversion, where fresh-adapted species of vegetation and animals cannot survive and are displaced over time as the aerial extent of fresh habitat decreases. While the land loss rates in Louisiana are high, wetland loss is a worldwide issue with estimates of loss ranging from 50% to 71% in the 20th century and degradation of some of the remaining wetlands (Gardner et al., 2015; Li et al., 2018). These losses are estimated to result in over US$20 trillion annually in ecosystem services (Gardner et al., 2015). Further losses are predicted with rising sea-levels and landward migration not fully able to compensate for seaward losses (IPCC 2022, Osland et al., 2022). Not only restoring the wetlands and other habitats in coastal Louisiana, but also the processes (e.g., input of riverine flows into estuarine wetlands) that maintain those habitats is a pressing issue, given the causes of land loss described above and climate change predictions for sea-level rise (IPCC 2022).

River diversions have been used for ecosystem restoration in many places in the world, mostly to combat saltwater intrusion (Ward et al., 2002; Das et al., 2012), restore flood plain hydrology (Fink and Mitsch 2007; Decker et al., 2008; Aishan et al., 2015; Wang et al., 2018), and restore natural features after alteration for industrial use (Scruton et al., 1998; Flatley and Markham 2021). In Louisiana, river diversions have been constructed for flood control of the Mississippi River (e.g. Bonnet Carre Spillway, Morganza Spillway), and to convey mostly freshwater, but also nutrients, and sediment from the Mississippi River to the coastal basins to combat saltwater intrusion, nourish the marshes, and stimulate fisheries. These diversions were not intended to build land, and were constructed 1) to limit sediment capture by drawing water near the surface of the river where there is less sediment (Allison and Meselhe 2010) and 2) locating them in the river where natural deposition is low (e.g. on the outside of bends (Allison et al., 2014)). The result was that the freshwater diversions mostly diverted silts and clays from river wash load, but very little sand. While discussed for decades (CWPPRA 1993, Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority, 1999), Louisiana is now on the brink of constructing river diversions for land building and ecosystem restoration (CPRA 2017, 2023). Sediment diversions are being designed to target sands transported by the river by having the intake located lower in the water column and sited over natural sand bars. In the past there has been construction of uncontrolled sediment diversions, such as the West Bay Sediment Diversion, where a channel is dredged to divert river water with no control structure to manage flow amount and duration. To date, there are no large-scale, controlled sediment diversions (with a structure in place that controls flow amount and duration) present on the landscape. However, the Mid-Barataria Sediment Diversion Project was recently permitted for construction and operation by USACE in 2022, and the State of Louisiana is currently pursing a similar permit for the Mid-Breton Sediment Diversion Project, both of which would be constructed within the next decade (CPRA 2017, 2023). Both projects are intent on reconnecting the Mississippi River to the Deltaic Plain to nourish swamps and marshes and building land.

The Caernarvon Freshwater Diversion (CFD) was authorized by the Flood Control Acts of 1928 and 1965, the 1974 Water Resources Development Act (USACE 1984), and construction was completed in 1990. This paper describes the CFD's location on the landscape, and historical and current governance, operations, and monitoring to illustrate limitations experienced in the current CFD management and operation. This paper addresses what lessons can be learned from synthesizing information about governance, operations, monitoring, and adaptive management from 30 years of operating the CFD. These lessons learned provide valuable information for the implementation and management of future diversions and may make operations more effective, transparent, adaptive, and trusted by the basin communities. The knowledge gained can be applied to the management of other large-scale projects that cross political boundaries and touch numerous stakeholder groups.

2. Caernarvon diversion setting

2.1. Caernarvon diversion location and specifications

The CFD is located on the east bank of the Mississippi River, in Plaquemines Parish at approximately RM 81.5 above head of passes (AHP) (Fig. 1). Project objectives for the CFD include: 1) enhance emergent marsh vegetation growth, 2) reduce marsh loss, and 3) increase productivity of significant commercial and recreational fish and wildlife (USACE 1991). These objectives were based on the purported benefits of the diversion outlined in the EIS. The CFD was the first controlled freshwater diversion constructed for restoration purposes, and began operation in 1991. The diversion structure includes five 4.6 m × 4.6 m box culverts with five vertical lift gates. The structure operates via gravity flow when the gates are open and discharge is controlled by adjusting gate height. The maximum flow capacity is 227 m^3/s. Freshwater Diversion operations are generally triggered and controlled by salinity conditions in the basin (explained in further detail in Section 3.2), as well as consideration for various fish and wildlife harvest seasons, coastal flood advisories, and emergencies in the Mississippi River.

How the water flows from any diversion, including the distribution routes, determines where within the receiving area the diversion operations have an effect. The diversion discharges into the northern end of the Breton Basin. The discharge flows into an outfall canal and then splits between Big Mar, a failed agricultural impoundment (western route, grey in Fig. 2), and Bayou Mandeville (eastern route, black dashed in Fig. 2). The amount of water that splits between the two routes varies with discharge, water level, and wind, and has changed over time as Big Mar has filled in with sediment from the diversion (Cable et al., 2007; Huang et al., 2011). Along the eastern route, the discharge proceeds to Lake Lery, then into Bayou Terre Aux Boeufs. Along the western route, the water proceeds through Big Mar into Delacroix Canal. Some of the water that enters this canal flows into Bayou Mandeville, but some proceeds west in Manuel's Canal. At CFD discharges above approximately 125 m^3/s, sheet flow across the marsh surface is induced near the diversion, in contrast to the flow being primarily channelized at lower discharges (Day et al., 2003; Cable et al., 2007; Snedden et al., 2007).

2.2. Basin conditions

Breton Basin is approximately 2,730 km^2, and is bounded on the west by the Mississippi River, on the north by the Verret Levee (Fig. 2), and on the east by the Mississippi River Gulf Outlet (MRGO) (Fig. 1). It is open to the Gulf of Mexico on the southern end and to Chandeleur Sound to the northeast. Breton Basin experienced 426 km^2 of wetland loss, or 38% of the wetlands from 1932 to 2016, and is the basin with the second-highest percentage loss in Louisiana (Couvillion et al., 2017). Breton Basin suffered approximately 245 km^2 of land loss due to direct or near-direct landfalls of two hurricanes in 2005 and 2008 (Potter and Amer 2020), with most of this loss attributable to Hurricanes Katrina and Rita in 2005 (Couvillion et al., 2017).

While Breton Sound Basin has been largely cut-off from riverine inflow due to the construction of flood control levees, inflow has recently increased in the lower basin due to the formation of new river crevasses and the enlargement of existing ones. There are various uncontrolled freshwater inputs into Breton Basin down-river from the CFD and the end of the flood control levees (just north of Mardi Gras Pass) that influence the basin (Fig. 1). Some of these freshwater inflows developed well after the CFD was planned and implemented through the formation of new inflows or the enlarging of existing ones. These inflows

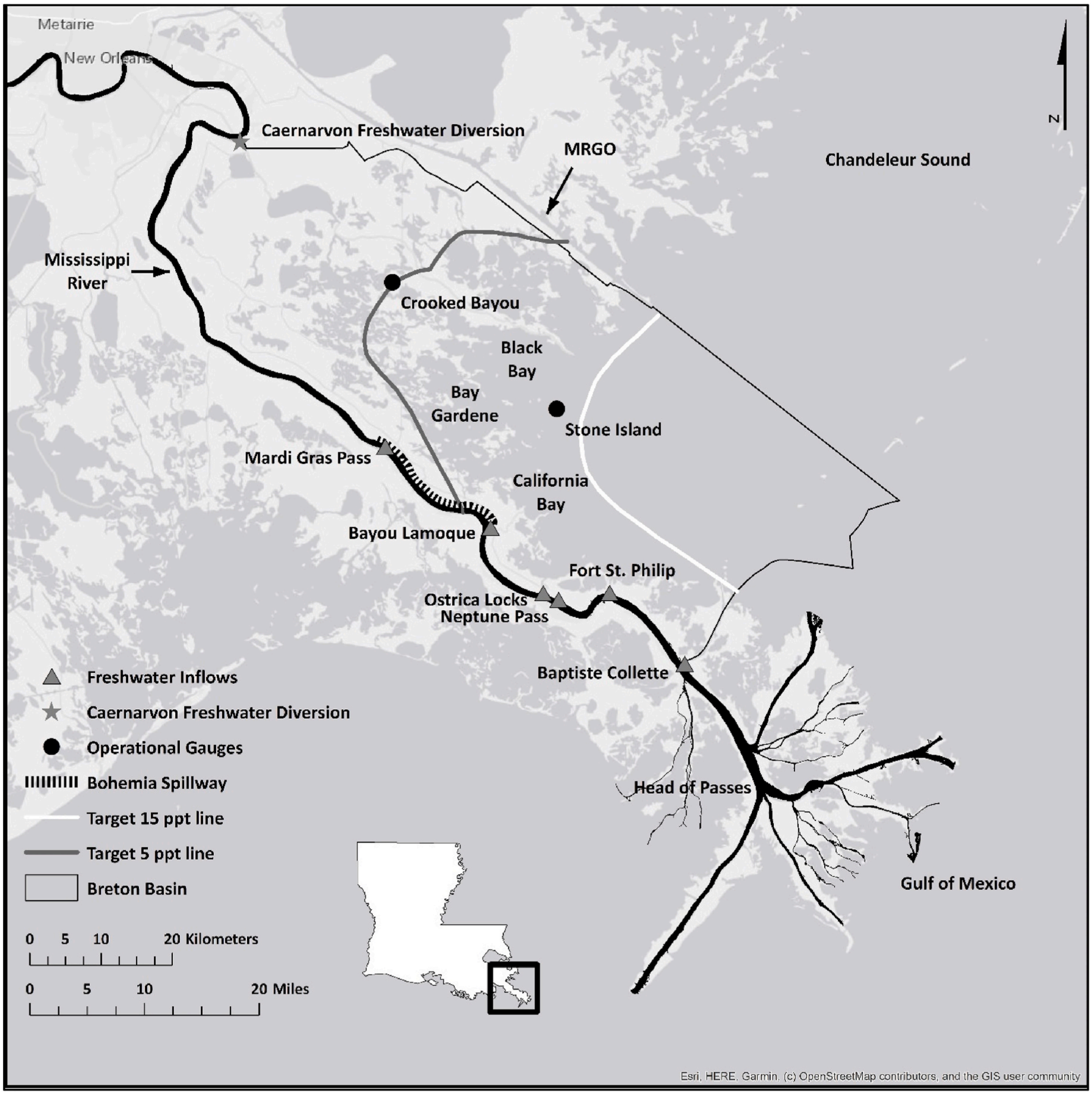

Fig. 1. Breton Basin with major freshwater inflow locations besides Caernarvon Freshwater Diversion, diversion project operational gauges, and target isohalines. Major freshwater inflows include the Bohemia Spillway, Mardi Gras Pass, Ostrica Locks, Neptune Pass, Fort St. Philip and Baptiste Collette. There are numerous unnamed smaller inflows along the East Bank of the Mississippi River where there is no levee (south from the northern end of the Bohemia Spillway).

can be major drivers in the basin and impact CFD operations over time (described below) by decreasing basin salinity at key points in the basin used as triggers for Project operations. The Bohemia Spillway is a 19-km stretch where the levees were degraded in 1926 to relieve flood waters during Mississippi River floods, by releasing water from the river, decreasing pressure on the river levees and reducing the risk for overtopping. Freshwater discharges through this stretch into the basin when the river stage at this section is above 1.7 m (Lopez et al., 2013). During the 2011 flood, 850 to 1,400 m^3/s was observed discharging through the whole of the Bohemia Spillway by Lopez et al. (2013). Within the Bohemia Spillway is a crevasse termed Mardi Gras Pass, which formed in 2012 at RM 44 AHP (Lopez et al., 2014a). It has enlarged over time, although the crevasse dimensions and discharge capacity of Mardi Gras Pass may be stabilizing (Songy et al., 2021). The crevasse currently has a maximum discharge capacity of approximately 800 m^3/s at river flood stage.

Bayou Lamoque (Fig. 1) discharges a maximum of approximately 99 m^3/s when the river is in flood stage (Connor et al., 2020). Below Bayou Lamoque, there are a few named freshwater inflows with no discharge capacity information. These include the Ostrica Locks and Neptune Pass. Neptune Pass has enlarged considerably since 2016, such that the USACE is taking steps to limit the flow of water through the pass to levels similar to before the expansion began. The Fort St. Philip (FSP) crevasse (Fig. 1) developed during the 1973 Mississippi River Flood. Before the 2016 flood, FSP maximum discharge was approximately 1,700 m^3/s during river flood stage (Connor et al., 2020). During the 2016 Mississippi River flood, the FSP crevasse enlarged and now discharges approximately 5,380 m^3/s at flood stage (Connor et al., 2020). Baptiste Collette (Fig. 1) has a maximum discharge of approximately 3,400 m^3/s at peak river stage (Connor et al., 2020). The FSP crevasse and Baptiste Collette discharge freshwater into the lower portions of Breton Sound, but in both cases this water can be pushed into the Breton Basin during south and southeast winds and incoming tides. Between Bayou Lamoque and Baptiste Collette, there are also numerous smaller, un-named inflows that also discharge into Breton Sound. On the East Bank of the Mississippi River, the levees end at the top of the Bohemia Spillway, and below this point the river inflows into the Breton Basin are dynamic, changing with flood seasons by expanding or contracting. The result of

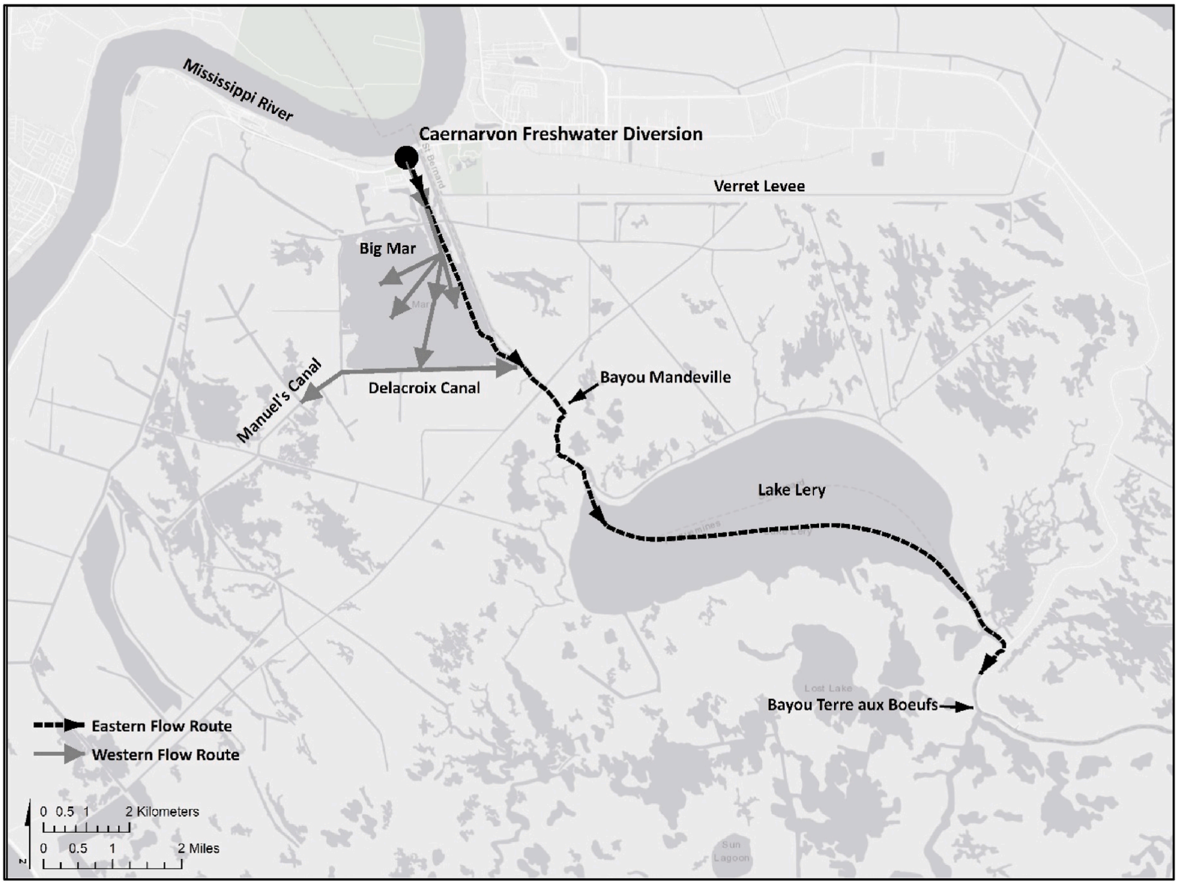

Fig. 2. Major flow paths from the Caernarvon Freshwater Diversion into upper Breton Basin.

the development of Mardi Gras Pass and the enlargement of FSP and other outlets is that there are substantial freshwater inputs higher in the Breton Basin over the last decade than there were when the CFD was authorized and constructed. This has contributed to reduced CFD operations over the life of the project, which will be detailed in Section 3.2.

3. Diversion governance and operations

3.1. Governance

Project governance provides direction and defines decision-making procedures and metrics guiding project operations and maintenance. It also enables the project team to deliver on requirements and creates a forum for issue resolution to occur in a timely manner. Project governance sets out the rules for how a project is operated, how decisions in relation to project operations and maintenance will be made, and the process for how stakeholder and public feedback is incorporated in to decision-making procedures. Faulty or outdated governance structures can hinder project performance and erode public trust in project implementors. The CFD is operated and maintained as part of a cost-share partnership between the CPRA and U. S. Army Corps of Engineers (USACE). Operation decisions in real-time (when to open and close the diversion) are made by the CPRA; however, there is guidance from multiple sources that informs operational decisions. The Water Control Plan (USACE 1991) provides limits to operations. For example, the plan caps the maximum discharge at 227 m^3/s, and dictates that the diversion must be closed for chemical spills in the Mississippi River and approaching storms, and that water must always flow from the river into the basin (reverse flows are not allowed). The Water Control Plan also describes the formation and function of the Caernarvon Interagency Advisory Committee (CIAC) and the Technical Working Group (TWG) which provide feedback on the annual operation plan that governs day to day operations. The Water Control Plan lays out the structure in which to determine operations but does not prescribe day-to-day operations outside of the broad limits described above. The CIAC has representation from various state and federal resource agencies, commercial and recreational fisheries, landowners, and other relevant stakeholders (USACE 1991). The CIAC is in place to express concerns, assess impacts of prior operations, receive recommendations from the TWG, and decide/vote on an operation plan for the following year, which will guide the day to day operational decisions made by the CPRA. The TWG is made up of state agencies and the USACE and is in place to resolve technical problems, assess monitoring data, and make recommendations to the CIAC.

On an annual basis, the governance typically proceeds as follows:

1) CPRA develops a draft operations plan outlining any proposed changes from the previous year and prepares a presentation summarizing the monitoring data from the previous year;
2) CPRA convenes a meeting with the TWG in the Fall, where the TWG comments on proposed changes and comes to an agreement on what should move forward to the CIAC;
3) CPRA convenes a meeting of the CIAC in December when the committee and the public receives presentations on the monitoring data from the previous year, the proposed operations plan for the following year, and any other items that CPRA is putting up for vote (voting items could include changes to monitoring gauges, changes to by-laws, votes to instate a new member, etc.); and
4) The CIAC votes on items, including the operations plan, which passes with a simple majority vote.

Once the operations plan is approved, it is the guiding document for diversion operations for the following year. At every CIAC meeting there is also an opportunity for the public to express concerns, support, or ask questions about diversion operations.

3.2. Historic operations

The CFD began operating in August of 1991, and the operations plan, as established by the project governance, targeted the maintenance of a 15 ppt isohaline from December through May and a 5 ppt isohaline from June through November (Fig. 1). The 15 ppt line was described in the 1984 EIS and is based on studies and observations that determined the ideal salinity conditions for oyster survival and growth. The designation of the 15 ppt line aimed to re-establish the salinity conditions prior to 1950, before saltwater intrusion was pervasive in the basin (USACE 1970; Chatry et al., 1983). The 5 ppt line was also described in the 1984 EIS and was established to promote fresh and intermediate marsh at the head of the estuary, habitats which support greater wildlife production and were disappearing because of saltwater intrusion (Palmisano 1973). Both of these lines are meant to be an average annual target, meaning the average conditions over the year at those two lines would be 5 ppt and 15 ppt, recognizing that there is fluctuation throughout the year. The goal of these targets is to maintain saltier conditions during the summer and fall in Breton Sound (by having the target line 5 ppt line up basin), which is important for oyster spawning (Chatry et al., 1983; La Peyre et al. 2013, 2016) and a fresher winter (as a result of more diversion operation by targeting the 15 ppt line down basin), when lower salinities are of less concern for many organisms that are either somewhat dormant or are not present in the upper and mid-estuary at that time of year (Patillo et al., 1995; Visser and Sandy 2009; Vanderkooy et al., 2012; Snedden et al., 2015; Peyronnin et al., 2017). The salinity that controls operations is based on two gauges (Fig. 1). When targeting the 15 ppt isohaline, the gauge USGS 073745275 (Black Bay near Stone Island near Pointe-A-La-Hache, LA; Stone Island henceforth) is used for operations. When targeting the 5 ppt isohaline, the gauge USGS 073745257 (Crooked Bayou Northwest of Lake Cuatro Caballo near Delacroix; Crooked Bayou henceforth) is used for operations. Other gauges nearby are consulted for supplemental information and to provide redundancy during gauge outages.

The operation plans have changed over time, but can, in general, be divided into three eras. The different eras represent different attempts to maintain the desired 5 and 15 ppt lines in response to changing basin conditions. From inception through 1997, operations targeted a monthly mean salinity at three stations in Black Bay, California Bay, and Bay Gardene (Fig. 1, Table 1). The monthly salinity targets fluctuated throughout the year, with the highest in August through November and the lowest in January, February, and December. The goal of these salinity targets was to result in an average annual salinity of 5 ppt and 15 ppt at two lines described above and shown in Fig. 1.

From 1998 through 2012, operations were based on discharge ranges

Table 1
The 1993 Caernarvon Freshwater Diversion operation plan from the 1991–1997 era of operations that targeted monthly salinity. The salinity target was based on the average of three stations in three different bays also known as the Caernarvon Target Zone (footnote 2), unless otherwise noted.

1993 Operational Plan		
Month	Salinity (ppt)[1]	Discharge (m^3)
January	>5 ppt & > 3 ppt	257 [2]
February	>5 ppt & > 3 ppt	257 [2]
March	<11.0 ppt	20 min & up to 257 for salinity modification
April	<8.0 ppt	20 min & up to 257 for salinity modification
May	<9.0 ppt	20 min & up to 257 for salinity modification
June	<11.0 ppt	20 min & up to 257 for salinity modification
July	<12.5 ppt	20 min & up to 257 for salinity modification
August	<15.7 ppt	20 min & up to 257 for salinity modification
September	<17.0 ppt	20 min & up to 257 for salinity modification
October	<16.8 ppt	20 min & up to 257 for salinity modification
November	<16.1 ppt	20 min & up to 257 for salinity modification
December	>5 ppt & > 3 ppt	257 [2]

[1] All salinities are in reference to the Caernarvon Target Zone.
[2] 257 m^3 will be discharged if the 3 station salinity average (N. California Bay, Bay Gardene, and Black Bay) > 5 ppt & Salinity is > 3 ppt at the Bay Gardene station.

Table 2
Examples of three operation plans from the 1998–2012 discharge range era. Operation plans are shown for 2003, 2007, and 2012.

	Flow Range (m3/s) [1]		
Month	2003 Operation Plan	2007 Operation Plan[3,6]	2012 Operation Plan[3,6]
January	85–113[2]	Pulses up to 212 and 20 days allowed, otherwise 0–184[8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[8]
February	85–113[2]	Pulses up to 212 and 20 days allowed, otherwise 0–184[8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[8]
March		Pulses up to 212 and 20 days allowed, otherwise 0–184[8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[8]
April	14–113[7]	Pulses up to 212 and 20 days allowed, otherwise 0–184[8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[8]
May	14–113[4]	Pulses up to 212 and 20 days allowed, otherwise 0–184[5,8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[5,8]
June	28–113[4]	Pulses up to 212 and 20 days allowed, otherwise 0–184[5,8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[5,8]
July	28–57[6]	0–184	0–227
August	28–576	0–184	0–227
September	28–57[6]	0–184	0–227
October	28–57[6]	0–184	0–227
November	28–57[6]	0–184	0–227
December	71; 159 During Duck Season Split[2]	May pulse up to 212 and 20 days, otherwise 0–184[8]	Pulses up to 227 and 20 days allowed, otherwise 0–227[8]

[1] Notwithstanding these flow range targets, operational procedures relating to emergencies, closure of the structure or reduction of flow to reduce the threat of coastal flooding or high water levels reflected by monitoring and operational procedures pertaining to low Mississippi River stage or drought conditions shall all remain in effect. The 2003 plan also included the following note: The structure will be closed if the water level measured by a real-time gauge at the southeast corner of Big Mar reads above 3.1 NGVD.
[2] Salinity at Bay Gardene will be monitored to stay above 3 ppt.
[3] Salinity at Bay Gardene will be monitored to stay above 3 ppt as a 4 week moving average.
[4] For oyster production, the salinities at the Bay Gardene station will be monitored during these months. The structure will be operated at the lower discharge levels. If the Bay Gardene station moves to 9 ppt based on a two-week average, Caernarvon discharge will be increased, but will not exceed 4,000 cfs, to decrease the average to 9 ppt. Water levels gauges will be added to certain sites and monitored.
[5] For oyster production, if the salinity at the Bay Gardene station rises above 9 ppt, based on a 4 week moving average, Caernarvon discharge will be increased, but will not exceed 184 m^3 (in 2007 plan), or 227 m^3 (in 2012 plan), to decrease the average to 8–9 ppt.
[6] Seek to maintain annual average 5 ppt line, based on a yearly average, and monitor salinities as to promote enhancement of oyster production in the public seed grounds and to achieve other stated benefits of the project, up to 57 m^3 (for 2003 plan), up to 184 m^3 (for 2007 plan), or up to 227 m^3 (for 2012 plan).
[7] Seek to maintain annual average 5 ppt line, based on a yearly average, and monitor salinities as to promote enhancement of oyster production in the public seed grounds and to achieve other stated benefits of the project, up to 113 m^3 (for 2003 plan).
[8] May modify timing of pulse based on waterfowl or fisheries concerns. Every effort will be made to pulse during river rise for sediment delivery for marsh recovery. Pulses during frontal passage may be done at the discretion of the structure coordinator. The length of the pulse may be at the discretion of the structure coordinator and depend on salinity conditions.

(Table 2 for examples). The plan was changed by vote of the CAIC committee to allow more flexibility and magnitude in operations, as the previous methods proved was somewhat restrictive because the salinity targets in Table 1 were achieved with minimal operation. The monthly discharge ranges were dictated by fishing seasons, hunting seasons, and biology. These ranges changed over the years, and there was a tendency for the maximum part of the range to increase over time (from monthly maxima of 57–113 m^3 in 2003 to 257 m^3 in 2012). There were also many caveats (listed at the bottom of Table 2) associated with the allowable discharge ranges.

Since 2013, operations were changed, by vote of the CIAC, to use a range of salinity at the operational gauges (i.e. the Stone Island and Crooked Bayou gauges). Basin stakeholders had expressed concern about the lack of transparency in operational decisions using previous operations plans. This new plan provided an easy-to-follow graph that would show when operations were allowed (Fig. 3). The long-term monthly mean salinity data for each operational gauge (over a running average of approximately 10 years; i.e., bringing in new data every year and removing the oldest data) ± one standard deviation was graphed to establish a range of salinity. If the 14-day moving average at the target gauge (depending on time of year) was within that range, the diversion could be operated (Fig. 3). In practice, the diversion usually was not operated unless the 14-day average was above the mean of the range, to avoid the need for constant operation adjustments or opening and closing of the diversion as the salinity fluctuated around the minimum. Waiting for the salinity to be above the mean allows for more steady and prolonged operation. In 2018, CPRA instituted a 14 m^3/s baseflow, as outlined in the EA, to maintain consistent fresh conditions near the diversion (top of the estuary). Other operational constraints included consulting with the Louisiana Department of Wildlife and Fisheries (LDWF) in March to accommodate brown shrimp post-larvae moving into the basin and in May–June and September–October for oyster reproduction.

Over the 30 years of the CFD operations, some patterns and changes have emerged. Mean discharge from August of 1991 (start of operations) through 2020 was 34 ± 40 m^3/s (Fig. 4). The year with the highest discharge was 2010 at 87 ± 94 m^3/s. This year was abnormal as all of the diversions along the coast were opened to full capacity from April 23 through August 14 to combat impacts from the Deepwater Horizon Oil Spill (DHNRDA Trustees 2016). The year with the highest mean discharge outside of this abnormal event was 2007 at 79 ± 50 m^3/s. The year with the lowest mean discharge was 2016 at 3.3 ± 1.8 m^3/s. Over the 30 years of operation, average monthly diversion discharge was highest in February (64 ± 66 m^3/s), January (60 ± 55 m^3/s), and March (48 ± 61 m^3/s); and lowest in October (14.6 ± 25 m^3/s) and September (15.6 ± 22 m^3/s). Mean discharge varied by meteorological season (winter = Dec. through Feb.; spring = Mar. through May, etc.) with the highest discharge occurring in winter (54 ± 58 m^3/s) and spring (39 ± 57 m^3/s). The lowest discharge was in the fall (17.2 ± 24 m^3/s) and the summer (25.7 ± 40 m^3/s). If 2010 is removed from the calculation of means, due to the abnormally high summer discharge, mean discharge for the summer falls to 21 ± 23 m^3/s (lower mean, but much lower standard deviation). Discharge also varied by the three discharge eras described above. The 1998–2012 era, when operations were dictated by discharge ranges, had the highest monthly-average discharge (48 ± 55 m^3/s; Fig. 4). The most recent 2013-present era where discharges were adjusted to target a salinity range showed the lowest average discharge (14.6 ± 22 m^3/s). The era targeting monthly salinity had an intermediate discharge (29 ± 49 m^3/s). These differences between the eras

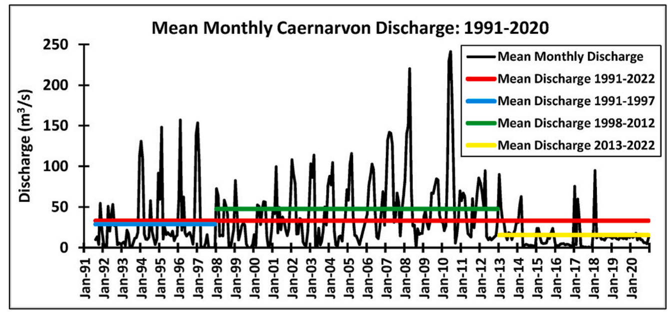

Fig. 4. Monthly-average discharge at the Caernarvon Freshwater Diversion from 1992 to 2020 (black line). Also shown are the overall 1992–2020 mean monthly-average discharge (red line, mean = 34.2 m^2/s) and mean monthly-average discharge for the three eras described in the text. The mean discharge for the 1992–1997 era (blue line) was 28.9 m^2/s, for the 1998–2012 era (green line) was 47.6 m^2/s, and for the 2013–2020 era (yellow line) was 14.6 m^2/s.

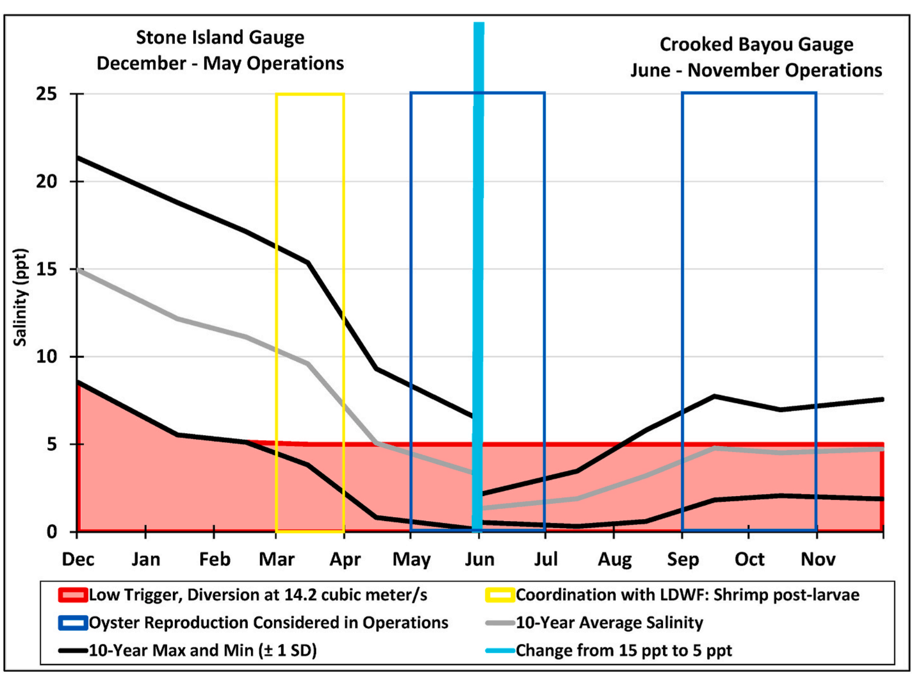

Fig. 3. Example of the operation plan from the current salinity-range era (2013–2020). Ten-year average (+1 standard deviation) salinities from the Stone Island Gauge (USGS site 073745275) from December through May, and the Crooked Bayou Gauge (USGS site 073745257) from June through November are graphed. The Caernarvon Freshwater Diversion structure may be operated when the 14-day moving average salinity is within or above the range shown. Operations will be decreased to the 14.2 m^3/s minimum if the moving average drops below the low trigger. Periods that trigger species-specific consultations between CPRA and LDWF are shown in yellow and blue.

could be skewed by a variety of factors. The basin salinity regime has changed over time, becoming fresher, which has substantially limited operations in the most recent era. In a dynamic basin over 30 years, operations have not only been impacted by operation plans and methodology, but also by a changing basin, including changing freshwater inflows, land acreage, and coastal restoration (described in more detail below).

3.3. Diversion influence region

The effects of diversion operations on the Breton Basin differ depending on flow magnitude and duration. Region of influence is defined as the area of the basin where a certain environmental factor (salinity, nutrients, sediment, or temperature) is above or below typical background (baseline conditions without project operation) conditions. The influence region of diversion projects in general, references the distance into the basin, radiating from the diversion structure, which the environmental factor reaches. The freshening effect of the diversion reaches further into the basin under any given flow than the nutrient, sediment, or temperature influence region. Larger and longer operations will have a farther reaching impact on salinity than smaller and/or shorter pulses. Large pulses (above 184 m^3/s) lasting a month or longer resulted in a maximum diversion influence of approximately 30 km radius into Breton Basin (Cable et al., 2007). The diversion influence was much larger during the abnormal flows from 2010 (DHNRDA Trustees 2016), when the diversion was operated at maximum capacity for over three months in the summer. Historically, high flows of longer than a month would freshen most of the upper and mid basin, with an approximately 2-week lag before salinity decreased in the lower basin, and with a rapid salinity recovery of less than a month when operations ceased (Day et al., 2009a). Nutrients have the next largest influence region after salinity.

Nutrient concentrations were greatly reduced within 20 km of the diversion, with removal occurring primarily via denitrification, assimilation by flora and fauna, burial, and nitrogen reduction (Lane et al. 1999, 2004). Suspended sediment had the next largest influence region. The extent of sediment deposition under flows described above was 10 km into the basin, although the majority occurred within 6 km (Cable et al., 2007; Day et al., 2009a). Diversion flows need to be above approximately 100 m^3/s to induce overland flow which increases rates of sediment deposition on the marsh platform near the diversion (Snedden et al., 2007; Day et al., 2009a). The amount of discharge, sediment concentrations in the Mississippi River at the time of flow, and days of operation all influence the rate and extent of sediment deposition into the basin. Water temperature generally equilibrated within 10 km of the diversion (Day et al., 2003).

In summation, the CFD influence region is primarily the upper Breton Basin unless there are high flows for extended time (>1 month), which is uncommon for normal operations. Sediments have the smallest influence area (<10 km), nutrients have an intermediate influence area (<20 km) and the freshwater has the highest influence area (<30 km). These influence regions will vary with discharge magnitude and length, wind direction, tidal influence, etc. The influence regions listed above can be considered the maximum under high flows for greater than one month, which could be considered the maximum operation under the current operation regime. Under less operation, these influence regions will shrink. Within the upper Breton Basin, the addition of freshwater, nutrients, and sediment by the CFD supports food webs, enhances nekton nursery habitat, increases the occurrence of SAV, and stimulates plant growth (Wissel and Fry 2005; Wissel et al., 2005; Delaune et al., 2008; Day et al., 2009a).

Breton Basin has freshened over time due to increased freshwater flow from new and enlarged outlets and recent years (2016–2020) of prolonged high Mississippi River stages, which has in turn led to reduced CFD operations. As discussed in the basin description section, the main new freshwater influences include Mardi Gras Pass (MGP) and Ft. St. Philip (FSP). The effect of these river outlets, is the freshening of Breton Basin rapidly when the river begins to rise, freshening some areas year-round. The freshening resulted in conditions at the operational gauges that were often too fresh to trigger CFD operation. The actual 5 ppt isohaline is often down basin or sea-ward of the target 5 ppt isohaline (Fig. 5), and in 2019 the area of the basin analyzed was below 5 ppt for the entire year. These changes have resulted in minimal CFD operation since 2013 (Fig. 4). Therefore, upper Breton Basin is not receiving the river water containing fresh, oxygenated water with nutrients and sediment that help nourish nearby marshes, build new land, stimulate the food web, and provide habitat. In most years, the river water coming into the basin from the lower river does not reach the upper basin, and as a result, the basin is now effectively cut off from the river that built it. The basin that existed in the 1970's and 1980's, when the CFD was planned and designed, has changed substantially over the last 30 years. Due to substantial land loss, changing river flow patterns and river outlets, and climate change, the basin is unlikely to return to those historic conditions. Therefore, it is time to revisit the operations plan again to ensure that upper basin marshes are nourished.

3.4. Basin monitoring

The purpose of the CFD project's monitoring program was to determine project impacts and to guide diversion operations. The monitoring program set up for the project included robust sampling three years prior to diversion operation and four years post-construction. The intent of this section is not to analyze the 30 years of CFD project monitoring data, rather it is to describe the types of monitoring that have occurred and assess how the results of the monitoring have contributed to operational changes. The original monitoring plan (USACE 1986) indicated that monitoring would be reduced after the four-year robust sampling period but did not detail the means and methods of subsequent monitoring, only that the results of the robust monitoring should inform what parameters needed continued monitoring. The robust monitoring plan included pre- and post-diversion assessments of marsh vegetation species changes, wildlife populations (including muskrat, alligators, waterfowl), fish and shellfish populations (including oysters, shrimp, blue crab, and finfish), contaminants in finfish and shellfish, fishery harvest (landings), water and sediment quality (including salinity, dissolved oxygen, pH, nutrients, suspended solids, trace metals, temperature and turbidity), and data collection to support hydrologic modelling (USACE, 1986). The results of the robust pre – and post-construction monitoring can be found in a series of reports (USACE & LDWF 1992, USACE 1993, 1994, 1995a, b, Conzelmann et al., 1996, USACE & LDWF 1998).

Monitoring of the CFD project area, in various forms, has continued for the 26 years after the intense four year post-construction monitoring described above (Fig. 6). The monitoring can be split into three major categories: project-specific monitoring paid for by the project, programmatic monitoring conducted by the CPRA or partner agencies and contractors (e.g., the Coastwide Reference Monitoring System), and academic research studies to further the science on river diversions.

Currently, the majority of the monitoring paid for by the project is of water quality and fisheries. Water quality (salinity, temperature, conductivity) is measured at six continuous, real-time gauges, one of which is in the CFD outfall canal and also measures water velocity and discharge (Fig. 6). There have also been nine continuous, but not real-time, water quality data recorders deployed at various times throughout the project life; however, only one of these gauges remains while the others have been removed because they became redundant with other data collection programs. The data from these gauges and other analysis has shown that when the diversion is operated for an extended period of time (over 1 month) and at a high discharge (near maximum), basin salinities are impacted, the basin is freshened, especially the northern end, and the diversion does combat saltwater intrusion (Day et al., 2003; Snedden et al., 2015). CPRA has contracted

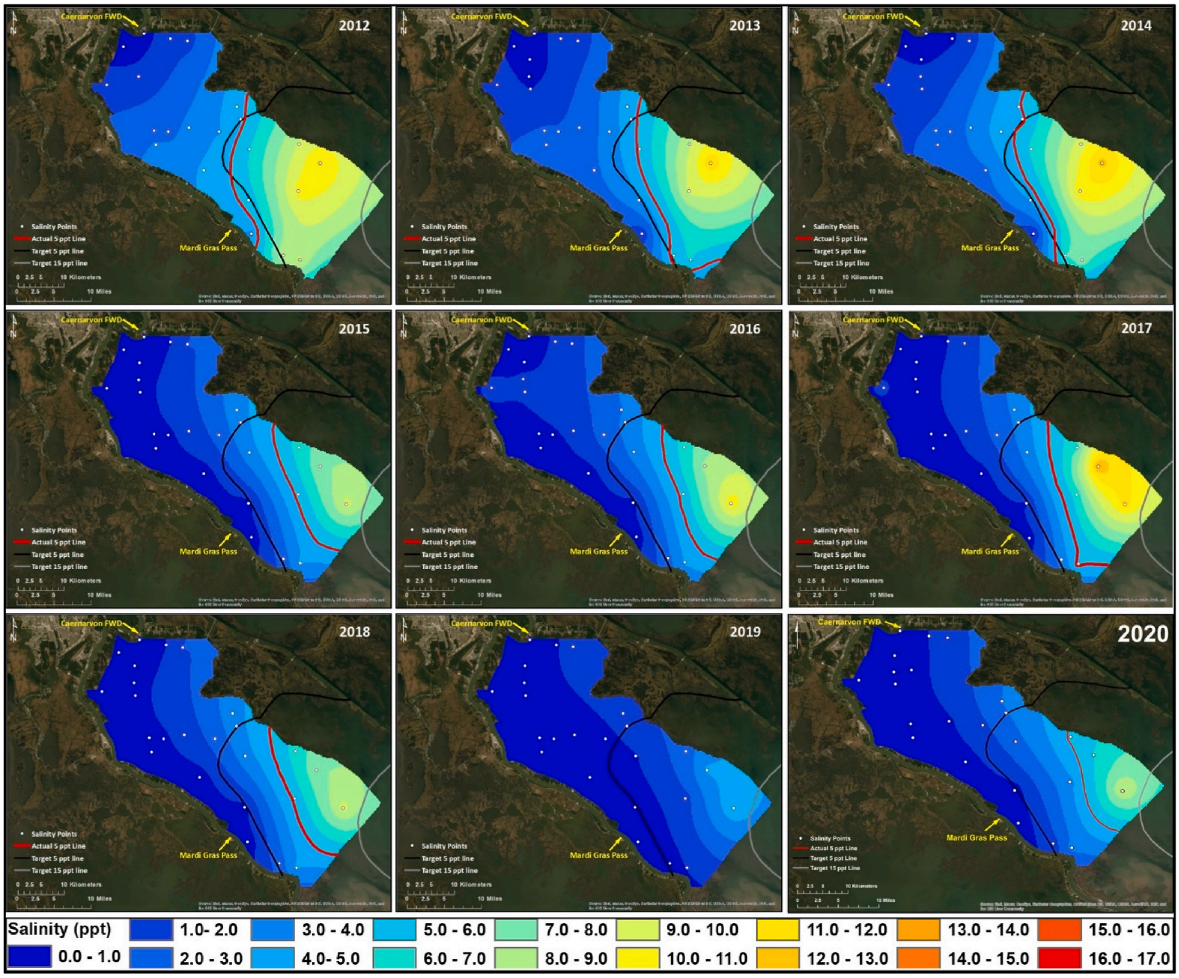

Fig. 5. Surface salinity interpolation in a portion of Breton Basin from 2012 through 2020. The white dots are salinity stations that were used in the interpolation. The black line is the target 5 ppt isohaline and the red line is the actual 5 ppt isohaline for the year. In 2019, no part of the analysis area was above 5 ppt on average in the year.

LDWF for supplemental fisheries monitoring. The LDWF Fisheries Independent Monitoring Program (FIMP) has been in place in some form since the 1960's, although some sampling techniques and locations have been added over time. CPRA pays for supplemental samples in Breton Basin of certain gear types to analyze the impact of the diversion on basin fisheries (Fig. 6). The collection of these data has resulted in two comprehensive fishery analyses of basin fisheries (Sable and Villarrubia 2011; Sable et al., 2020). CPRA also occasionally orders land:water analysis for a region within 10 km of the diversion to estimate land-building rates in the outfall area. Although land building is not a project goal (marsh nourishment is), it is evident that it is occurring, especially in Big Mar, where from 2002 to 2016 over 700 acres of new emergent wetlands were built.

The Coastwide Reference Monitoring System (CRMS) is a series of monitoring stations (approximately 390) in coastal Louisiana that measure a variety of environmental parameters following the same protocol at all stations (Steyer et al., 2003). This program is funded primarily by the Coastal Wetlands Planning, Protection, and Restoration Act and CPRA, with supplemental funding from NRDA, and is administered through a partnership with USGS and CPRA. There are 20 CRMS stations in the Breton Basin that were installed between 2006 and 2008 (Fig. 6). The data collected at the CRMS stations include surface water quality (salinity and temperature collected continuously), sediment pore water quality (salinity, temperature, collected at two depths, 6 to 8 times a year), water level (continuous), percent cover of herbaceous species (annually), tree growth rates (at swamp CRMS stations, triennially), wetland accretion rates (feldspar, annually), wetland elevation (sediment elevation tables, annually), and analysis of land:water in a 1 km^2 survey area around the station (triennially). These data are informative of site conditions in their own right, but also inform a variety of indices to assess marsh and swamp health across the coast. Since the data are publicly available, it is also used by many researchers not affiliated with the CPRA. While not installed from the beginning of the CFD project (because they are not project specific research stations and the CRMS program was not established until 2006), the CRMS stations provide important ecological data that aids in detecting changes over time due to the CFD and other influences in the basin.

The CFD receiving area has been the focus of numerous studies that investigated the impacts of the diversion on a variety of parameters, and to inform the modelling and planning of future sediment diversions in southeast Louisiana. Fisheries studies have been conducted on nekton assemblages (Piazza and La Peyre 2011; de Mutsert and Cowan 2012; de Mutsert et al., 2012; Rose et al., 2014), brown (*Farfantepenaeus aztecus*) and white (*Litopenaeus setiferus*) shrimp (Rozas et al., 2005; Rozas and Minello 2011; Adamack et al., 2012; Doerr et al., 2016), oysters (La Peyre et al. 2009, 2016; Wang et al., 2017), and general food web impacts (Wissel and Fry 2005; Piazza and La Peyre 2012; Riekenberg et al., 2015). In general, due to the ephemeral nature of diversion operations, and the multitude of other factors that have impacted the basin (tide, storms, winds, rainfall, river discharge), it has been difficult to tease out specific impacts from the diversion in the basin, especially on fish and wildlife populations as a whole. Ascertaining specific and lasting

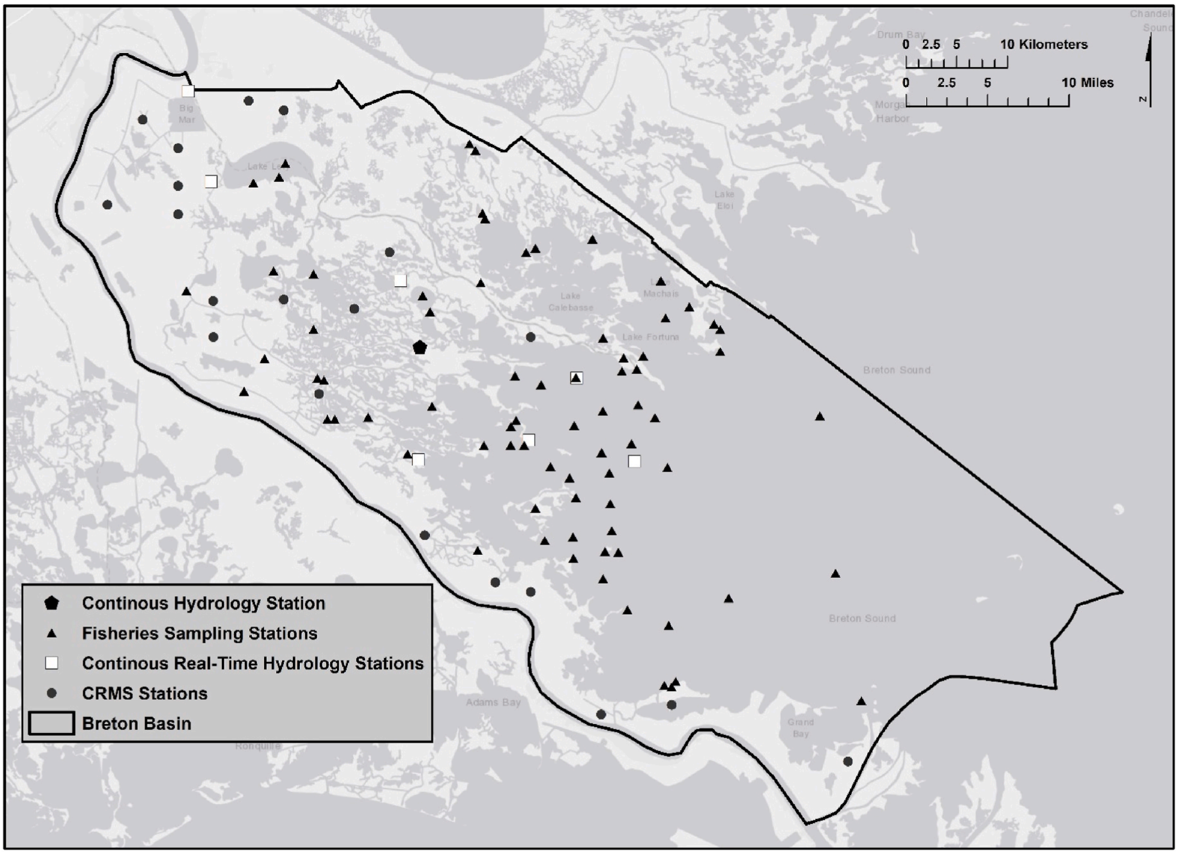

Fig. 6. Location of monitoring stations in the Breton Basin.

impacts on fisheries populations has been unsuccessful due to the factors described above, the inherent noisy nature of fisheries data, and the lack of dense sampling sites close to the diversion (Sable and Villarrubia 2011; Sable et al., 2020). However, increased species diversity was detected in the area under the influence of the diversion because it provides a fresh habitat that was not available in eastern half of the basin (de Mutsert and Cowan 2012). The diversion also flooded the marsh near the outfall, providing increased marsh habitat accessibility for small species (Piazza and La Peyre 2011). Finally, in general, the river diversion provided increased food web support for the basin by enhancing productivity at the northern end of the basin, which eventually is transported down basin via trophic interactions (Wissel and Fry 2005; Wissel et al., 2005; Piazza and La Peyre 2012).

The potential for CFD to contribute to eutrophication and algal blooms in the open estuary of Breton Sound prompted numerous studies of nutrients loads under varying flow regimes and the rate and pathways of uptake in the basin (Lane et al. 1999, 2004; DeLaune et al., 2005a; VanZomeren et al. 2012, 2013; Zhang et al., 2012; Lundberg et al., 2014; Day et al., 2018; Poormahdi et al., 2018). These studies generally found either neutral (no negative impacts) or positive effects from the nutrient addition (biomass increase), but did not find evidence of eutrophication caused by the diversion. Some studies found that most nutrients were assimilated in the upper basin and thus little to none was exported down basin (Lane et al. 1999, 2004; DeLaune et al., 2005a; Lundberg et al., 2014). The receiving area includes shallow lakes and ponds that become well mixed at low wind speeds. Therefore, residence times in these shallow waters are low, especially during high discharges, when nutrient loading would be highest, which helps to prevent stratification and eutrophication (Swenson et al., 2006; Lane et al., 2007; Huang et al., 2011).

Over time, land building was observed in the CFD outfall area, which prompted studies on sediment delivery, accretion, erodibility, and aerial extent of new land (DeLaune et al., 2003; Snedden et al., 2007; Moerschbaecher 2008; Lo et al., 2014; Lopez et al., 2014b; Xu et al., 2016; Poormahdi et al., 2018; Sha et al., 2018; Turner et al., 2019). The nutrients entering the basin, as well as the potential for prolonged marsh inundation during diversion operations, prompted studies on the impact of the diversion on specific plant species as well as general patterns of above ground and below ground biomass with distance from the diversion (DeLaune et al., 2005b; Moerschbaecher 2008; Day et al. 2009b, 2013; Snedden et al., 2015). Lastly, there have also been numerous studies that investigated the impact area under a variety of flow regimes (varying discharge and duration), to assess the actual impact of the diversion on the basin (Day et al. 2003, 2009a; Cable et al., 2007; Delaune et al., 2008; Huang et al., 2011). While this is not a comprehensive reporting of all of the studies conducted around the CFD, it gives an indication of the type of research being conducted and the importance of the area for scientific study.

While the extensive monitoring described above has aided in ascertaining the impact and benefits of the diversion on a variety of environmental factors, it has not had a significant impact on operations. The study that showed discharge above 125 m^3/s induced over land flow (Snedden et al., 2007) has inspired higher and shorter pulses, when operation is possible. However, the current operation restrictions discussed above, makes it difficult to alter operations in response to monitoring results.

4. Lessons learned and suggestions for future diversion projects

While this section will focus on improvements that can be made to future diversion projects, based on lessons learned from the CFD, it is important to note that the CFD has been largely successful from the standpoint of the Project's authorized goals. Early on in the project, the CFD did help combat saltwater intrusion and re-established the gradient from fresh to salt marsh (Fig. 7), by creating conditions favorable to fresh marsh species at the northern end of Breton Basin. Prior to the diversion, the basin was mostly brackish and salt marsh with a small area of intermediate marsh and no fresh marsh (Fig. 7) (Chabreck and Linscombe, 1988, 1997; Visser et al., 1998; Sasser et al. 2008, 2014; Nyman et al., 2022). Additionally, although not a project goal, the CFD has built land in Big Mar (over 700 acres as of 2016), which has developed into black willow (*Salix nigra*) forest in some locations, and is solid enough to support a swamp tree planting program (Hillmann et al., 2020), and to remain intact through numerous hurricanes (Hurricane Isaac, 2012; Hurricane Zeta, 2020; Hurricane Ida, 2021). The CFD was the first project of its kind in Louisiana; that is, a large-scale, ecosystem restoration project that impacts multiple user groups. Project management has been challenged due to shifts in the natural, public opinion, scientific, legal, and political environments over time. Because of these challenges, there have been many lessons learned and ideas to improve future project implementation, which are outlined below.

4.1. Governance

4.1.1. Committee structure for stakeholder feedback leads to frustration

The structure for stakeholder feedback via membership on the CIAC is not the most effective route for stakeholder engagement. While stakeholders do have the opportunity to provide feedback and voice concerns, those that are opposed to the project have often felt unheard and marginalized. The difficulty arises with projects of this scale, which have impacts that cross multiple political boundaries (parishes) and differentially affect a large swath of user groups. Some of the stakeholders on the CIAC do not want the diversion operated at all, making it difficult to discuss operations, both past and present, as not operating the project at all is not a feasible option from the state's perspective. Therefore stakeholders that oppose any operation are never satisfied because the desire of no operation will never be implemented. In contrast, there are also stakeholders that are frustrated with the lack of operation and question why the diversion is not operated more. Given the large swath of stakeholders that are influenced by large-scale restoration projects, such as the CFD, it will always be difficult, if not

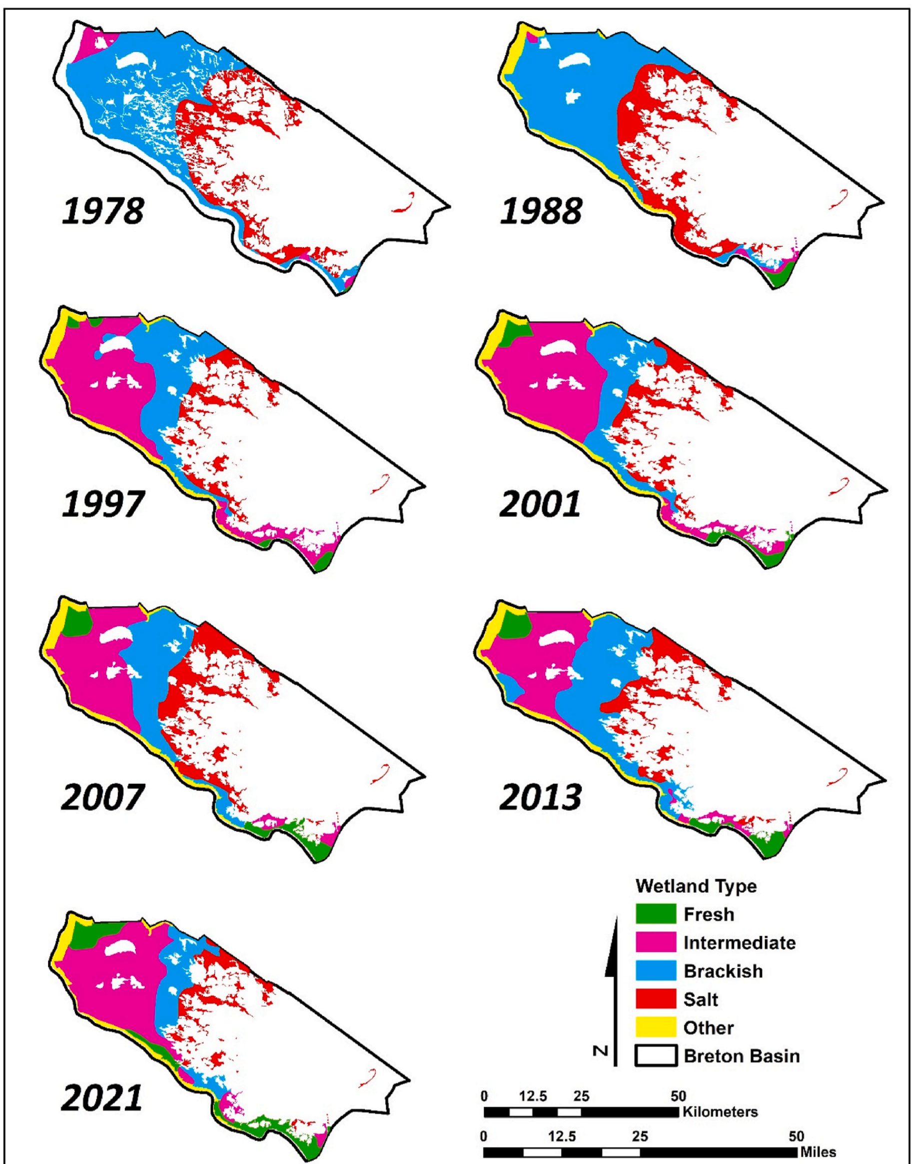

Fig. 7. Location of fresh, intermediate, brackish, and salt marsh over time in the Breton Basin. Before Caernarvon Freshwater Diversion operations there was no fresh marsh in the upper basin (1978, 1988). Shortly after operation began in 1991, there was a small area of fresh marsh (1997). Over time, the area of fresh and intermediate marsh has expanded in the upper Breton Basin.

impossible, to reach a stakeholder consensus on project implementation (Ko et al., 2017).

4.1.2. Stakeholder voting power leads to ineffective operations

The structure of the CIAC, where stakeholder representatives can vote on operations and other issues, makes it difficult to change project operation and implementation over time as monitoring data amasses, science advances, and basin conditions change. While the current state of science may suggest changing project implementation in one direction, stakeholders, who may not understand, trust, or agree with the science can resist change via voting power. This has proven to limit CFD operation above baseflow at times, maintaining a strict operation regime. This process is not the only aspect that limits CFD operations but is a contributing factor.

4.1.3. Mistrust and traditional ecological knowledge can lead to a misperception of operational needs and basin conditions

Many stakeholders spend a significant amount of time on the water or in the field while participating in their chosen vocation and therefore acquire significant amounts of traditional ecological knowledge (TEK). While considering this knowledge along with scientific data is important and can provide valuable observations and feedback about project impacts (Bethel et al., 2014), TEK is sometimes skewed when viewed through the narrow lens of a specific industry or fishery (Ko et al., 2017). The actual causes for change that stakeholders attribute to their observations can be either incorrect (attributed to something that is actually unrelated) or do not take into account a suite of causes (attributed to one factor when changes are actually attributable to a variety of factors).

4.1.4. Suggestions for governance change

Given the difficulty in incorporating the large variability of stakeholder feedback and the tendency for people to traditionally think along a narrow view point (industry specific, impacts to the individual), rather than on an ecosystem scale, a change in governance structure is suggested for future large-scale restoration projects. A governance structure using voting is not effective, as "majority rules" just leaves stakeholders who vote against implementation feeling unheard. Rather, there should be an opportunity for robust public or stakeholder feedback via a public meeting, convened before each new operation plan is developed (could be on an annual basis, could be less frequent), held in or near the communities where the project is implemented. These suggested changes were incorporated into the governance section for the Mid-Barataria Sediment Diversion EIS (USACE 2022). The agency in charge of the project will need to make a commitment to transparency. Data used to make project implementation decisions should be publicly available, and decision-making triggers presented in an easy accessible location (e.g. easy to find webpage or dashboard) and explained in a manner that is easy to understand (lacks scientific jargon). Transparency in operational decisions and justification for those decisions would help stakeholders to understand why the structure is opened or closed. While this would not eliminate opposition to projects (not necessarily the goal), it would eliminate the perception that decisions are made on a whim, behind closed doors and/or in an "ivory tower". Increased transparency with an opportunity for stakeholder and public feedback would help to reduce mistrust, and at a minimum, increase understanding even if it does not increase agreement.

4.2. Operations

Operations for the CFD should be altered based on new data, scientific investigations, a changing basin, and a changing climate. When the CFD was constructed, one of the main functions was to combat saltwater intrusion caused by land loss and canal dredging. This was successful in returning fresh marsh to the northern end of the basin. However, this main goal of the diversion is no longer relevant due to changing basin conditions. Lately, operations have been minimized by a changing operation plan and basin, and changes to the operational regime stifled due to overly restrictive operation triggers outlined in the founding documents.

4.2.1. Winter and early spring operations are recommended

The lower basin has changed and seems to be on a trajectory towards a fresher condition, which decreases the CFD operation thus starving the upper Breton Basin of the important connection to river nutrients and sediments, and preventing project goals from being met. Short, high-discharge, winter pulses, regardless of basin salinity, are recommended to achieve project goals. There is evidence that freshwater inputs into the estuary in winter and early spring (cold) months have less potential for negative impacts to habitat, fish, and wildlife, than the same flows experienced in warmer months closer to the peak of the growing season (Peyronnin et al., 2017). At low temperatures, oysters can tolerate low salinity conditions, due to decreased metabolism, for a longer time than if the same salinity was experienced under warmer temperatures (Patillo et al., 1995; Vanderkooy et al., 2012; Peyronnin et al., 2017). Elevated salinity is more important in summer months for oyster spawning (Chatry et al., 1983). Shrimp should not be affected by pulsed winter operations as shrimp post-larvae recruitment into the estuary occurs in March and April (Peyronnin et al., 2017). Marsh vegetation would be minimally impacted by pulsed winter operations because the plants are in a dormant state and less affected by prolonged inundation, which would cause mortality during the growing seasons (Visser and Sandy 2009; Sasser et al., 2014; Snedden et al., 2015; CPRA 2020). The maximum basin influence of CFD during short (2–3 weeks), high flow (near 227 m^3/s), pulses is between 20 km and 25 km down basin, where the influence of tides and wind become dominant (Cable et al., 2007; Huang et al., 2011). Also, if the basin is fresh from high Mississippi River flow, operating the CFD will not bestow any additional perceived negative impacts to the basin (i.e., there is little concern in over-freshening an already fresh condition).

For future diversions, where project goals emphasize land building and/or ecological benefits, winter and spring operations, as described above are still recommended, but not at the expense of project performance. For example, sediment diversions (USACE 2022) will be operated when sediment loads are elevated in the river, which may not always occur during the winter or spring time frame. However, sediment pulses tend to be highest during the first flood of the year, which generally occurs during the winter and spring, so project goals and recommended operation time could easily overlap (Allison et al., 2012; Peyronnin et al., 2017). Operations during the winter and spring could be prolonged to capture multiple sediment peaks, while operations in the summer and fall could be shorter pulses, lasting only as long as the sediment peak in the river. Often, the sediment will increase in the river during the rising limb of a flood event, and even if the river discharge remains high, the sediment concentration will decrease during the flood. Therefore, prolonged operation is not always needed to capture a sediment concentration peak in the river (Allison et al., 2014). River Diversions have the advantage of manual operation, which can be altered to existing conditions to maximize project performance while minimizing negative basin impacts.

4.2.2. Operational regime and triggers outlined in authorizing documents should maintain flexibility to accommodate future conditions

During project planning and design, the operational triggers should be developed in a manner that remain general, to make it easier to adapt to changing conditions in the basin. The current needs in the basin may not be the same throughout the 50-year (or longer) project life. When very specific triggers are incorporated into the founding documents (EIS, etc.), they can be difficult to change down the road, requiring a new Congressional authorization, an environmental assessment (EA), or a revised EIS, all of which can be expensive and time consuming to accomplish. If triggers are kept more general in founding documents, they can be narrowed to fit existing conditions for annual operation plan development under whatever governance structure is determined. This would allow flexibility to change triggers over time as basin needs and/or the project purpose changes, but specificity over shorter time scales in how the diversion will be operated. For example, the suggested operation change described in section 4.2.1 cannot be implemented for the CFD due to the founding documents coupled with a strict interpretation of those documents by the legal counsel of federal partners.

4.2.3. Transparency and simplicity in operational triggers is essential

Operations and operational triggers should be transparent to the public, and ideally, simple to understand. This could include explanations of why the diversion is not being operated when it could be, as well as current or real-time basin information. A dashboard, with all the factors under consideration displayed, and the status of each of those factors and how they are used to make operational decisions could be developed. An alert system for operation could also be set up, where subscribers receive a text message or email indicating that there is a planned opening or closing of the diversion. This would provide citizens time to remove equipment in the flow path (crab traps, trot lines).

4.2.4. Operational decisions should Be based on science and not politics

Transparency would aid in minimizing the insertion of politics in operational decisions. Operations should be determined by basin conditions and science-based decisions and not by the influence of a particular stakeholder group or local or regional politics. Politics have historically played a role in CFD operations, and have successfully shut down operations when angry constituents contacted their representatives, resulting in the issue being elevated to more powerful political positions. This occurs when the diversion is operating well within the operational guidelines set forth in the operation plan and founding documents. Ideally, operational decisions would be insulated from political opinions driven by outcry from those that experience or perceive a negative impact.

4.3. Basin monitoring

The monitoring associated with CFD was, in general, adequate and informative, including intense monitoring in the beginning that tapered off over time. A similar regime is recommended for future freshwater and sediment diversions, and has been incorporated into the monitoring plan in the EIS for the Mid-Barataria Sediment Diversion (USACE 2022; Appendix R). The parameters measured (water quality, fish and wildlife) were useful for understanding diversion impacts. However, some of this monitoring was from programs designed for other purposes, not specifically to understand diversion impacts, and therefore, improvement in monitoring regime for diversions would be useful.

4.3.1. Monitoring large-scale projects is essential to assess project performance

Comprehensive monitoring of large-scale restoration projects is important due to the large influence they have on basin dynamics. The purpose of proposed sediment and freshwater diversions is to have a large impact on the receiving basins. At the most basic level, these diversions are intended to mimic historic Mississippi River crevasses or overbank flooding where flow fluctuates with river stage, providing fresh, oxygenated water, nutrients and sediment to basin marshes. Monitoring will be important for these larger diversions to understand how the basin is changing, or in another sense, reverting back to some semblance of historic conditions. Achieving historic aerial extent of land is impossible and not the goal of these diversions, which is instead to re-establish the processes that built the wetlands in the first place.

4.3.2. Include long-term monitoring in the project budget during the planning phase

It is important to budget monitoring from the beginning of the project, as well as contingency for unknown scientific questions that may arise. While this seems like an obvious suggestion, monitoring can often be an afterthought and not fully funded for the life of the project. This is especially important for projects like river diversions since they have varying influence throughout the year and over time due to changing operations and changing basin conditions.

4.3.3. Real-time, publicly accessible water quality monitoring stations are important for transparency

Having some real-time water quality stations is important, to aid in the transparency discussed above; anyone in the public can go and check the data when they want, and since it is used to make operational decisions, they can gain an understanding of what is triggering changes in diversion operation. This has proven to be helpful with some CFD stakeholders.

4.3.4. Place baseline data in historic context and clearly define project goals

Much of the existing baseline data, especially fisheries data, were collected during a period of rapid (in some cases) ecosystem degradation. Therefore pre- and post-diversion monitoring should be conducted in the context of investigating changes in the basin and meeting project goals (land building for sediment diversions, ecosystem health for freshwater diversions) rather than using the data to assess whether conditions are similar to some point in time in the past, a baseline that ecologically should not be the goal, or is unachievable in modern times. In other words, historical conditions may not be a proper restoration goal. The CFD and other diversions can serve as an indication of what to expect, but given the larger scale of proposed projects, new expectations should be developed. Basins where diversions are occurring can be compared to basins where they do not exist, which would provide understanding in how these large scale restoration projects impact receiving basins.

4.3.5. Concentrate a high density of monitoring stations in areas of greatest project influence

A higher concentration of monitoring stations is recommended, especially for fisheries, in the immediate diversion influence area. Much of the fisheries monitoring is basin-wide (the FIMP program was designed with general fisheries management in mind), and it would be useful to have more sites in the area that is impacted the most by the diversion, to compare fish populations to areas that are not influenced and between operational and baseflow periods. While having fisheries sampling locations in the whole basin is useful, many of the current sampling stations would only be impacted if the CFD was operated at a high discharge for an extended period of time. One of the reasons why it has been difficult to come to any significant conclusions about CFD's impact or benefit on fisheries populations is because there are only a few sampling stations in the main diversion influence area (Sable and Villarrubia 2011; Sable et al., 2020). Similarly, the alligator and waterfowl data are collected for the management of those species, not to determine the impact of the diversion on those populations. A fish and wildlife monitoring program specifically designed to investigate diversion impacts on populations, where sampling began before diversion operation and continued for some time after, would help more accurately answer questions about how diversions impact these populations, instead of relying on data that are collected for other purposes. However, using these data from other programs results in substantial costs savings to the project.

4.3.6. Targeted species sampling

Along with more concentrated samples, potentially fewer fish species could be targeted. Some indicator species (freshwater vs estuarine vs saltwater) could be chosen and specific gear could be used that target those species, rather than general net types that target a variety of species. There is evidence that gear type can affect catch per unit effort and different gear types are useful for answering different, specific, fishery questions (Taylor et al., 2020). Targeting indicator species could decrease sampling costs and provide a condensed data set that could be more easily analyzed to assess diversion impacts to fish and wildlife populations.

4.3.7. Data sharing and consensus among management agencies

Consensus about diversion influence area under a variety of flow regimes among project management and fish and wildlife management agencies is essential. With the CFD, this consensus does not wholly exist and therefore causes conflict and concern among agencies when the agency in charge of the project wants to operate, while the agency in charge of fisheries management believes operation will impact a fishery. The operating agency could have confidence that the fishery would actually not be impacted given its location in the basin and planned operational regime. This has led to requests to limit operations when in fact, the concerned fishery would not have been impacted. It is important for agencies to collaborate and reach a consensus understanding of project impacts so that project goals and management goals of both agencies can all be achieved. Data, analysis, and conclusion sharing as well as periodic meetings to discuss project influence, basin changes, and fish and wildlife population changes would be useful to rectify this existing impasse.

5. Discussion

The governance, operation, and monitoring of CFD over the last 30 years provides many lessons that will be useful for future sediment and freshwater diversions, as well as large-scale projects that cross political boundaries and affect numerous stakeholders. However, it is important to note that there are important differences between the CFD and proposed diversions. The CFD was built to control salinity in the basin and nourish marshes but was not intended to build land or increase marsh elevation substantially. It was engineered in a manner that minimizes sediment capture by drawing water from the surface of the river, where there are lower concentrations and smaller-grained sediments and by its placement on a bend where there is high energy and less deposition. The CFD also has very specific salinity targets in the basin that determine operation. Future sediment diversions will actively trap sediment with the primary goal of building land and nourishing existing marshes. Future freshwater diversions will have larger ecosystem improvement or restoration goals in mind, which may include prevention of saltwater intrusion, but will have broader operational triggers. The delivery of freshwater, sediment, nutrients, and oxygenated water to the basin has broad ecosystem benefits. In general, future diversions will seek to mimic the flooding of the Mississippi River in timing and amount, with the goal of restoring processes that built the delta and created a rich ecosystem.

5.1. Incorporation of stakeholder input

One of the major lessons learned during governance of the CFD project has been that with the large-scale of diversion or restoration projects, there will be a wide variety of stakeholders that will run the spectrum from very supportive to very opposed to the project. The support or opposition, naturally, tends to be driven by the focus of user groups on their specific interest/use of the environment (how the project impacts the individual person or industry) rather than a holistic view of project impacts and benefits. Project opposition can be based on a short-term view of the project, focusing on immediate impacts and benefits and not potential future conditions. Most coastal restoration projects in Louisiana are developed with either a 20 year or 50 year planning horizon or project life, and therefore focus on maximizing benefits over the project life rather than short-term gains and losses. Stakeholder conflicts can also reduce the effectiveness of diversion projects, as seen with the CFD, where flow has been limited and operation plans have been difficult to adapt to accommodate changing conditions, because of local opposition. The representative of an industry on the committee may vote in a way that some or many participants in the same industry do not agree with. Future governance of diversions should focus on public input in the development of operation plans but eliminate the voting process. Public meetings can be held where anyone from any stakeholder group can have a voice and do not rely on being represented by one individual who may not actually speak the views of the entire industry. Also, in Louisiana, the major commercial and recreational fisheries have task forces (including shrimp, oyster, blue crab, and finfish) where issues can be discussed and the state can be called in to discuss or present findings. There is an adequate way to incorporate public feedback into project plans without impacting project effectiveness. Therefore, future large scale projects should focus on transparency in operation and implementation, receiving stakeholder feedback in a public venue, and provide clear, jargon-less communication of project plans.

5.2. Insights from three decades of project operations

CFD operations have changed over time with the CIAC input, on a trajectory towards more transparent and understandable operational triggers. These changes were based on stakeholder feedback. However, public mistrust established early in the project is difficult to overcome in future years. Communication about why operation is occurring at a specific time, proper lead time to warn citizens that operation will occur, and reporting about how operation impacted the basin are all important to establish public trust and allow time for basin users to prepare for and adapt to project implementation. Timing and magnitude of operations is an important consideration with the current science indicating that winter and early spring operation maximizes benefits and minimizes impacts (Peyronnin et al., 2017). However, with sediment diversions, operational decisions will depend on the river, which has varying flood and sediment concentration regimes from year to year (Peyronnin et al., 2017). It can be difficult to insert these subtleties into the public discourse where the conversation often centers on the diversion is on and at full capacity for extended periods, *or* it is closed. Actual operations are able to be varied in magnitude, length, and timing to achieve desired project performance metrics and minimize severe impacts. Large-scale projects such as river diversions will be most successful if flexibility is built in at the front end so that operations or project goals can adjust over time to changing basin conditions (both caused by and external to the project), changing climate, and advancing science. Flexibility in founding documents with specificity and transparency in regularly updated operation plans or project goals can maximize project success now and into the future. This combination of flexibility on longer time scales (project life) and specificity on shorter time scales (some regular cycle such as annually or quinquennially) would provide space for adaptability, while delivering regulation.

5.3. Addressing monitoring needs

Monitoring plans, where possible, should be developed and funded specifically for the project. However, with large-scale projects, monitoring the entire influence area with the same density as a smaller project, is logistically difficult and costly. Therefore, higher density monitoring should be focused closer to the project where there will be the greatest influence, statistical experimental design methods could be used to design a sampling regime that is suitable. Also, more thorough monitoring at the beginning of the project that tapers off over time was suitable for the CFD and should be applied to future projects. This will allow for cost saving over time as well as targeted data collection that will ascertain project influence and impacts while eliminating redundant or excessive data collection regimes, and achieve a similar understanding of basin dynamics as when more data were collected. Large-scale projects can take advantage of existing data collection efforts, but because those sampling regimes were designed for other purposes (e.g. population management, fish and/or hunting season management), it may be challenging to tease out project impacts from those data sets. Therefore, it is important to put data collection efforts in context with their purpose when analyzing the data to answer research questions for which the sampling regime was not developed. Real-time and other data, and reports should all be made publicly available to aid in transparency, public trust, agency consensus, and replication of analyses and conclusions by other scientists. Lastly, a lesson learned from the CFD that should be applied going forward is that there should be targeted meetings scheduled on a regular frequency where sister agencies can discuss and analyze the data to gain a consensus understanding of project influence region as well as project benefits and impacts from the perspective of all of the agencies' goals (e.g. project goals, fish and wildlife management goals, water quality and human health goals). This will help reduce conflict among agencies, and ensure that there is a cross-agency understanding of goals and responsibilities. In general, due to the ephemeral nature of diversion operations, and the multitude of other factors that have impacted the basin (tide, storms, winds, rainfall, river discharge), it has been difficult to tease out specific impacts from the diversion in the basin, especially on fish and wildlife populations.

5.4. *Restoration and mimicking of natural processes*

The purpose of future sediment diversions, or any large-scale project is to have a large-scale impact. The goal is to restore the processes that originally built the Louisiana delta. Restoring processes has the potential to restore a variety of habitats simultaneously rather than piece-meal restoration that has been occurring over the past decades. Marsh creation, through direct placement of dredge sediments, is a common technique used in Louisiana and has been effective, but is difficult and expensive to execute and maintain on a large-scale. Diversions and marsh creation are not mutually exclusive, marsh creation can be placed in the influence area of a diversion, and the diversion nourishes the marsh, prolonging the project life. This is a way to gain marsh quickly in the short term while maintaining it into the future, making marsh creation a better investment. Typical marsh creation (not under the influence of a diversions) continues to subside and experience other processes that cause land loss in Louisiana and will eventually disappear. Some habitats that are important but maybe somewhat ephemeral, such as submerged aquatic vegetation, are very difficult to directly restore, but restoring proper conditions and processes, may expand these types of communities. Using the lessons learned outlined in this document will help to increase the effectiveness in the implementation of these ecosystem-scale projects.

With large-scale restoration, which crosses political boundaries and multiple user groups, stakeholder conflict will be inevitable. If operations and adaptive management of large-scale projects are guided by science, and not politics, there is at least a common understanding of how and why decisions are made, even if not everyone agrees with them. Political pressure should not be a part of the monitoring, adaptive management, and operations process. It is time for big and bold action to restore south Louisiana, using results from numerous past studies, existing projects like the CFD, and predictions of future conditions. Progressively, the goals of modern restoration programs of any type have tended toward achieving comprehensive and systematic ecosystem restoration which will cause the issues raised in this manuscript to become more common. Large-scale ecosystem restoration will always be difficult as stakeholder numbers will be high and include industry, recreation, municipalities, and agencies. The solutions described here can set a project off on the right foot and avoid the pitfalls experienced with the Caernarvon Freshwater Diversion.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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