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# Collaborative Environmental Approach for Development of the Lower Laguna Madre Estuary Program Strategic Plan in South Texas

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**ABSTRACT.** The National Estuary Program (NEP) is a promising eco-system based approach to improve the water quality and ecological integrity of estuaries of national importance in the United States. Due to population growth and concomitant development pressure in South Texas, the future of the Lower Laguna Madre (LLM) without an estuary program is problematic. The development of a management plan for the LLM will enable the region to develop local solutions to local problems. The fundamental purpose of this research was to develop a strategic plan for the foundation of the Laguna Madre Estuary Program of the Gulf Coast of Texas. The comprehensive plan provided local communities with information to restore water quality, conversing habitat, and protecting coastal resources along the Gulf coast. The strategic plan was organized along the lines of the NEP program focused on the three most important foundational elements to establish a NEP for the LLM. The three primary Thrust Areas are as follows: (1) the national significance of the Laguna Madre estuary system, (2) the needs and goals for a proposed program, and finally (3) the plan for the sustainability and support to operate and maintain such a NEP. The outcomes of the strategic plan can be used as a model by the decision-makers to promote community resilience and establish integrated local water quality and ecosystem management plans for their respective communities and jurisdictions. Ultimately, the main objective of this project is to assess the ability to integrate science and public policy development for the common good.

*Keywords:* coastal zone management, Gulf of Mexico, National Estuary Program, governance, environmental planning, program development, South Texas

## 1. Introduction

Over half the United States population lives in coastal areas, including along the shores of estuaries (NOAA, 2013). Estuaries can be defined as a partially enclosed water body formed by the amalgamation of a river or stream and the ocean when there is a mixing between the saltwater from the ocean and the freshwater from rivers or streams (Bricker, 2007). Since it is located in the transition zone between fresh and saltwater, the estuary ecosystem provides a highly productive environment (Taylor et al., 2018). Estuarine habitats are places where thousands of species of birds, mammals, fish, and other wildlife live, feed, and reproduce. Several species of fish and shrimp are dependent upon estuaries in some stages of their life cycle (Beck et al., 2009; Abrantes et al., 2015).

Because of their great products, the economy of many coastal areas is based primarily on the commercial and recreational activities in the estuary environment. It is also important for other commercial activities, including marine transportation, oil and gas production, and business and residential development. Consequently, estuary regions are subjected to substantial physical modification and pollution, which has deleterious effects on living resources and the habitat of the estuary system (Barbier et al., 2011; Bugica et al., 2020). This degradation can lead to a decline in estuary ecosystem services, such as fishery production, which also has an economic cost (Taylor et al., 2018). Due to the diverse anthropogenic activities, estuaries are probably under the greatest threat of all ecosystems globally (Branch, 1999).

In the United States, there are more than 100 estuarine systems along the coast that are considered a source of important economic and ecological resources. Modeled after the U.S. Environmental Protection Agency's (USEPA) Great Lakes and Chesapeake Bay programs, the National Estuary Program (NEP) was designed to protect and restore the water quality and ecological integrity of the estuaries of national significance (Martin, 2014; DeAngelis et al., 2020). As called for in Section 320 of the Clean Water Act, the NEPs conduct long-term planning and management to address the complex factors that contribute to the deterioration of estuaries, such as increasing development along the

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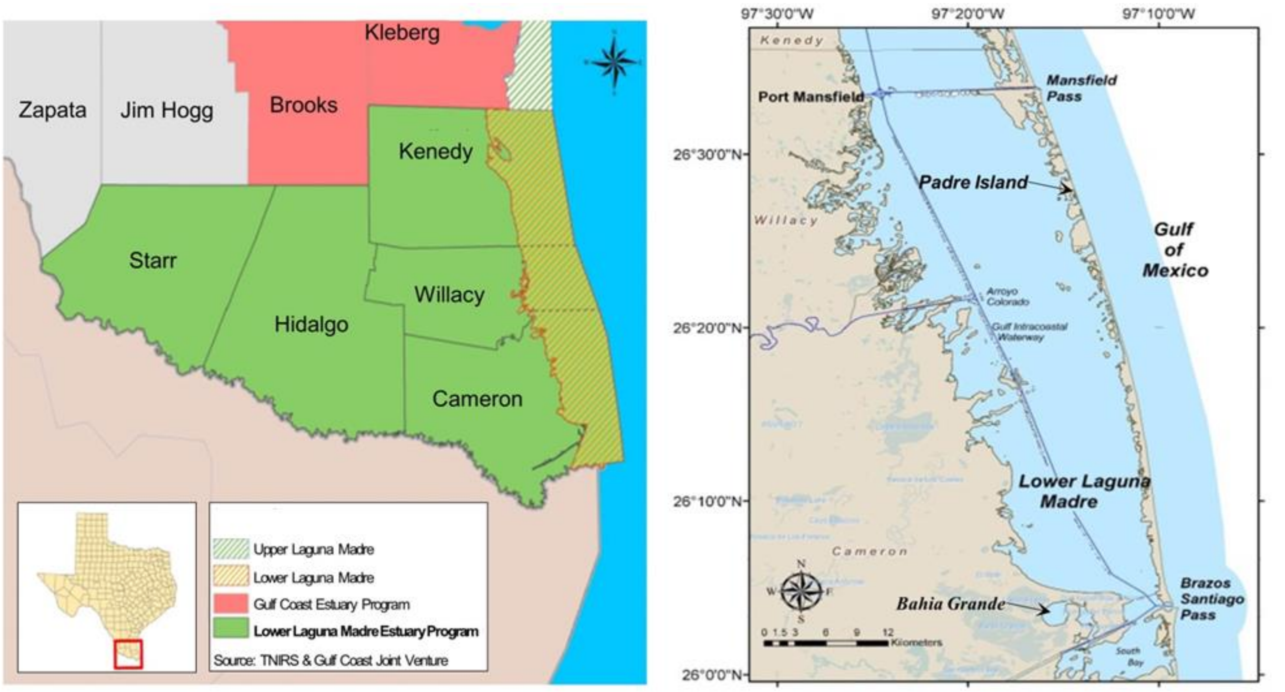


**Figure 1.** The geographic region of the Lower Laguna Madre Estuary Program (left), location of the Lower Laguna Madre in relation to the Gulf of Mexico.

coast (Greening et al., 2018). The EPA periodically calls for nominations into the NEP from state governors. If an estuary faces significant risks to its ecological integrity, contributes substantially to commercial activities, and meets several other criteria that indicate it would benefit greatly from comprehensive planing and management, the EPA may include it in the program. Any NEP should take a community-based watershed approach that can be adapted for a variety of environmental management situations, including both coastal and non-coastal watershed initiatives.

The EPA has accepted 28 estuaries into the NEP since 1987, and all of these NEPs have completed their management plans. Based on the EPA's latest guidance (2007) on conforming watershed- and community-based estuary programs, the process will compass four phases: establishing a governance structure, linking good science and sound management, developing a management plan, and implementing the management plan. Since each estuary case is geographically and ecologically different, each program adopts a different approach that suits its own needs to facilitate coastal restoration and recovery. At the same time, each program uses a common principle and general framework that gives a degree of consistency (Tuler et al., 2002). Developing the vision of setting restoration goals for recovery is entirely different depending on the environmental issues for each estuary area (DeAngelis et al., 2020). For example, water quality deterioration in the Chesapeake Bay led to a rapid decline in several important habitats, especially oysters with estimated economic losses of more than $4 billion over the past three decades. Therefore, the Chesapeake Bay Program set up a quantifiable goal that focused on large-scale restoration to produce a significant improvement in the oyster population (Kennedy et al., 2011). On the other hand, urban development activities negatively impacted seagrass beds in Tampa Bay, Florida. Eighty-one percent of seagrass's areal extent was lost by the early 1980s in the subtropical estuary. In 1998, the Tampa Bay Estuary Program recovery effort revolved around improving water quality goals in order to promote seagrass recovery (Greening and Janicki, 2006). The estuarine ecosystem is highly complex and dynamic, which creates uncertain conditions that are extremely changing for the design and management of the governance system. Each estuary project differs with respect to ecosystem characteristics, jurisdictional complexity, and diverse causes of ecological impairments. To improve water quality and enhance living resources, NEPs address many of the problems that result from development stresses through a comprehensive planning process (Imperial and Hennessey, 1996). However, this plan may foster changes in existing regulations and the development of new approaches to protecting the estuarine resources (Bowden, 1996).

Along the Gulf of Mexico, there are seven NEPs located in the following states: Texas, Louisiana, Alabama, and Florida (Greening et al., 2018). The Laguna Madre is located on the Texas coast, and it is the largest estuary and the southernmost. The Laguna Madre is one of only five hypersaline lagoons in the world (Tunnell et al., 2001). The Laguna Madre has two parts: the Upper Laguna Madre (ULM) and the Lower Laguna Madre (LLM). The ULM is part of the area covered by the Coastal Bend Bays and Estuaries Program (CBBEP) and is a component of the NEP. The CBBEP joined the NEP in 1994 and since then no other estuary has been assigned the category of being of national significance. The main objective of the CBBEP is to conserve and manage the Coastal Bend Bays of South Texas. However, the LLM is not currently part of the NEP despite the fact that the area has experienced rapid economic and population growth in the past 30 years. The proximity of Cameron County to the coast makes it vulnerable to inundation due to the low elevation which ranges from sea level to 18 m (60 ft), in addition to the potential impacts of sea rise concern (Brown et al., 1977; Lange et al., 2018). With population growth and concomitant development pressure in South Texas, the future of the LLM without an estuary program is problematic.

The objective of this study is to illustrate the collaborative environmental approach for the development of a strategic plan for the Lower Laguna Madre Estuary Program (LLMEP). The article describes the strategy, structure, and process to provide science-based restoration and management support that is organized along the lines of the NEP program. The strategic plan will be used to establish a framework of fundamental information and critical ideas to serve as a basis to found the LLMEP of the Gulf Coast of Texas. The LLMEP used the NEP as a model for the development of a comprehensive plan for the enhancement of the water quality and coastal resources at the LLM. This perspective will help to assess the management of the environmental issues of the LLM as well as a model for future estuarine initiatives. The development of a management plan for the LLM will enable the region to develop local solutions to local problems.

## 2. The Lower Laguna Madre Estuary

### 2.1. LLM Major Features

The Lower Laguna Madre (LLM) encompasses 59 miles of Texas coastline. Besides the lagoon, the LLM includes unique natural systems, such as Padre Island, South Bay, and the Bahia Grande. This shallow subtropical lagoon is bordered on the east by a barrier island, Padre Island, the longest barrier island in the world. The elevation of Padre Island is slightly above the sea level averaging 1.5 ~ 3.0 m, except for the large sand dune with an elevation of 6.1 ~ 9.1 m (Lange et al., 2018). The Bahia Grande is considered one of the largest marine restoration projects in the U.S., and it includes five counties (Cameron, Willacy, Hidalgo, Kenedy, and Starr). Furthermore, Bahia Grande comprises the watershed that contributes freshwater to the LLM, and it is included in the program area (Figure 1).

The Laguna Madre is the largest coastal embayment along the Texas coast with a surface area of more than 1,658 km$^2$ at mean sea level (Table 1) (Tanyeri-Abur et al., 1998). The western shore of the lagoon consists mostly of sparsely populated and undeveloped semi-arid coastal prairie and rangeland of the Texas mainland. The LLM is a shallow bar-built negative estuary. Sources of freshwater and nutrient inflow come from precipitation, direct mainland runoff, the Arroyo Colorado, the North Floodway, Raymondville Drain, Hidalgo/Willacy Main Drain, and the city of Brownsville. Brazos-Santiago Pass, located at the southern terminus of the LLM, is a natural tidal pass that was deepened for ship traffic and armored with jetties, while Port Mansfield Pass, 60 km to the north, is a smaller man-made pass used for recreational boat traffic completed by 1962.

There are eight major habitats associated with the LLM: seagrass, jettied tidal inlets, oyster reefs, mangroves, salt marsh, wind-tidal flats, dredge material islands, and open bay bottom. The dominant and critical habitat for the LLM is seagrass. Seagrass meadows are very productive while simultaneously providing habitat and nursery for marine animals like blue crabs, shrimp, and redfish (Beck et al., 2009). They also improve water quality, stabilize sediment, and provide a massive amount of surface area for epiphytes, i.e., organisms that live on the seagrass leaves (Poor et al., 2001). Wind-tidal flats are barren-looking sand/mud flats that border the LLM (820 km$^2$), mostly on the eastern shore. They are irregularly flooded due to a combination of astronomical, storm, and wind tides. Between periods of inundation, the flats dry out. During that process, salinity of the water sitting on the flats can become very high (> 100) due to evaporation. Despite the harshness of the flats, they are very productive. There are two jettied tidal inlets for the LLM-Brazos-Santiago Pass and Port Mansfield Pass. The jetties provide a hard substrate habitat for species that would not normally be present in the region. Oyster reefs, created largely by the eastern oysters, provide a hard substrate for a wide variety of sessile (attached) organisms and protective habitat. Mangroves and salt marshes occur along the edges of the lagoon, but mangroves are much more abundant. Mangroves provide substrate and protective habitat for intertidal organisms. Fish are an essential and economically important (recreational and commercial) component of the Lower Laguna Madre ecosystem. One hundred thirty-one fish species have been collected in the LLM. There are five fish species of concern either threatened or endangered in the lagoon (Campbell, 2003).

The LLM area has been an important economic driver for South Texas as its commercial and sport fishing industries have grown; agricultural activities have expanded through citrus and vegetable growing; oil and gas development upstream has fostered infrastructure growth in pipelines and liquefied natural gas (LNG) terminals, and eco-tourism has expanded. The ports of Brownsville and Harlingen are busy commercial centers for the region. Three proposed new LNG plants have been proposed near the Brownsville Ship Channel. The oil/gas industry has been expanding due to increased drilling and pipeline construction associated with the expansion of the Eagle Ford Shale gas and oil strata in South Texas. A new SpaceX facility is also being conceptualized in Cameron County. All of these new projects will stress water and land resources in the Lower Laguna Madre region.

### 2.2. LLM Unique Aspects

Some of the unique aspects of the LLM include hypersalinity, international border location on migratory paths for waterfowl, other birds, and other features. The LLM is one of the most favorable nesting habitats for the endangered species at South Padre Island and other southern shorelines in Tamaulipas, Mexico. In the South Texas estuaries, salt concentrations are relatively high because they are situated in arid or semi-arid areas' regions with high evaporative losses. In a semi-arid area, evaporation processes are routinely greater than precipitation recharge, leading to high salt concentrations (Tunnell et al., 2001). The Laguna Madre Estuary (LLE) is a unique hypersaline lagoon (saltier than the ocean). It is among a handful that exists worldwide. One of the contributing factors for the Laguna's salinity is the shallow depth. The water in the LLM may be saltier than in the ULM, with an average salinity of about 45 ppm, but it is an important habitat of abundant snook, tarpon, jackfish, and mackerel (Patoski, 2008). The Laguna Madre is fairly shallow. It has an average depth of about 0.76 m (2.5 ft) and a maximum of 1.5 m (5 ft) of depth and covers 2.5 $km^2$ (609 $mi^2$) (Mitchell, 1992).

**Table 1.** Characteristics of the Lower Laguna Madre

| | |
|---|---|
| Dimensions | Length 91 km: (57 mi)<br>Average width: 8 km (5 mi)<br>Surface area: MLW 727 $km^2$ (281 $mi^2$) and MHW 1364 $km^2$ (527 $mi^2$)<br>Average depth: 1.4 m (4.6 ft) |
| Major Habitat | Seagrass: turtle grass (*Thalassia testudinum*), manatee grass (*Syringodium filiforme*), and shoal grass (*Halodule wrightii*)<br>Jettied tidal inlets: Brazos-Santiago Pass and Port Mansfield Pass<br>Oyster reefs: eastern oyster (*Crassostrea virginica*)<br>Salt marshes: cordgrass (*Spartina alterniflora*)<br>Mangroves: black mangrove (*Avicennia germinans*)<br>Wind-tidal flats<br>Fish: 131 different species |
| Unique Aspects | Hypersalinity: only such waterbody in the US<br>Shallow depth: maximum 1.5 m<br>Subtropical climate: hot and humid most of the year<br>International border location: South Texas and Northern Mexico |

Another important aspect that makes LLM a unique estuary is the climatic conditions in the Gulf of Mexico that are known to be subtropical, with rainfall ranging from 635 to 965 mm (25 ~ 38 inches) annually. The strategic location of the LLM near the international border has served to promote and extend many commercial activities along the border. One example is the shrimping industry in Port Isabel, located in the area of the LLM. This industry has served as a gateway not only to South Texas but also to northern Mexico. Additionally, Port Isabel is further supported by commercial fishing, tourism, and the petroleum industry.

## 3. Methods for the Development of the LLMEP Strategic Plan

The focus of any estuary program that seeks national designation by the US Congress should be founded on the following principles: 1) protect and restore estuaries by developing and implementing comprehensive conservation and management plan (CCMP) and 2) enhance economic development and quality of life across the estuary's watershed. In addition, NEP has to foster consensus on difficult issues by establishing effective governance structures and conducting vigorous education and outreach by involving the public. Also, NEP can obtain significant funding by leveraging scarce resources and establishing credibility by using science to inform decision-making and sustaining their efforts by measuring and communicating results. The governance structure of a stakeholder-based organization provides the platform for collaborative decision-making and reflects the community's concerns and the unique problems and characteristics of the watershed. Most programs target five general constituencies as key members of the governance structure: elected and appointed policymaking officials from all governmental levels; environmental managers from federal, state, regional, and local agencies; local scientific and academic communities; private citizens; and representatives from public and user interest groups: businesses, industries, and community and environmental organizations.

The Management Conference should ensure the program accommodates a forum for open discussion, cooperation, and compromise that results in consensus, interested parties, and stakeholders' groups that are free to join the discussion/development of the program. In addition, the leadership, regardless of its host agency, must work to demonstrate that it is committed to the entire range of stakeholders. In order to achieve this last goal, autonomy must be given by the host organization to the management conference to build support for future participation and leverage funding of the program. If the NEP nomination is accepted, EPA and the state governor select the management conference to carry out the program.

All Management Conferences establish several core committees to carry out their work. These generally include a policy and management committee and advisory committees for technical and citizen input. Some EPs also have committees dealing with finance and local government. A director and program staff coordinate these committees and are accountable to the Management Conference. The EP director and staff are also responsible for facilitating the development of the management plan, supporting its implementations, and producing documents, such as annual budgets and work plans. The LLMEP hosted and housed in Cameron County (via a Cameron County Commissioners Court Resolution) and administratively supported by Research, Applied Technology, Education and Services, Inc. Rio Grande Valley (RATES/RGV) is structured as shown in Figure 2.

The project council is the core group that ensures that the day-to-day work of the committees is completed. This group is responsible for the nuts and bolts of the planning and implementation process. In the LLMEP, the project council representatives include mid-level managers and elected officials from local governments, technical staff from RATES/RGV, and representatives from local institutions of higher education. The LLMEP daily operations are facilitated by RATES/RGV staff, and the LLMEP team is advised by Cameron County staff, workgroups, and other committees. The Council defines and ranks the problems of the watershed, develops management strategies,

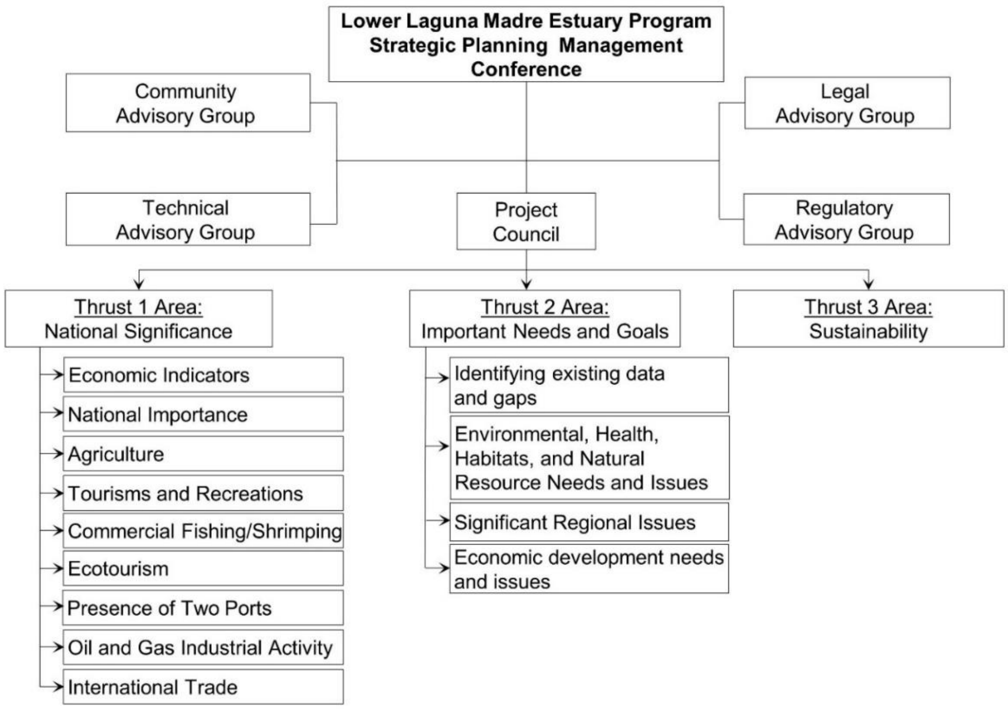


**Figure 2.** Institutional structure of the strategic plan Management Conference.

and oversees the development of the Strategic Plan and its components. The Project Council activities typically occur under the general guidance and direction of the Regulatory and Legal workgroup.

Technical Advisory Committee: Although the program is fundamentally a management program rather than a basic research program, the importance of obtaining sound scientific information cannot be overstated. Stakeholders and those responsible for implementing recommended management strategies need actions that are based on firm scientific findings. Technical Advisory Committee members represent a balance of scientific disciplines that address the key issues of the LLM watershed. They may be noted local experts, nationally recognized scientists, or resource management agency personnel. Members of the Technical Advisory Committee were selected with advice from the Management Committee; local, state, and federal agencies; and regional scientists.

Community advisory group: Since the establishment of the LLMEP directly impacts local jurisdictions and requires the support and commitment of local government agencies, to ensure that local governments are part of the decision-making process, this workgroup was formed so that local government representatives can assist the program by providing practical advice on local planning needs, issues, and existing projects. They also provide political analyses that are needed for effective decision-making and implementation. In the LLMEP, the core membership is comprised of members of the LRGV Total Pollution Discharge Elimination System (TPDES) Stormwater Taskforce, established in 1998, which has been addressing, regulatory and water quality issues under the "regional approach" paradigm. The Task Force is comprised of 23 local governments sharing one regional stormwater management plan. The LLMEP became a State of Texas nonprofit 5013(c) organization in 2019. LLMEP and RATES/RGV, a 5013(c) organization too, entered into a Memorandum of Agreement in 2019 where RATES/RGV would facilitate and provide administrative, fiscal, and technical support to LLMEP.

The Strategic Plan Management Conference for the LLMEP conducted several workshops to identify the environmental problems throughout the area by collecting and analyzing relevant data. The project team formed a partnership to develop a strategic plan to establish LLMEP. The Strategic Plan includes tools, techniques, and information to assist coastal and LLM watershed communities better understand water quality, ecosystem health, and resilience vulnerabilities in their region. The resulting Strategic Plan now consists of three topic thrusts under the following headings: (1) National significance designation, (2) Important needs and goals for an LLM Estuary Program, and (3) Critical resource identification and planning for the implementation and sustainability of an LLMEP. Each topic thrust was subdivided into subtopics and further divided into specific areas of interest. Each area of interest was assessed and critical issues for that topic thrust were identified, and each critical issue consisted of a goal, objective, and action items (Appendix A).

## 4. Outcomes and Discussions

### 4.1. National Significance of the LLM Estuary

Economic Indicators: By establishing the Lower Laguna Madre Estuary Program (LLMEP), the economic vitality and resilience of the LRGV, Texas, and subsequently the US, can be directly and positively affected. A study conducted in 1987 revealed that the Gulf of Mexico provided local economies with almost $760 million and $1.3 billion statewide for Texas (Quenzer, 1998). For example, the Nueces Estuary, Mission-Aransas Estuary, and Laguna Madre contribute approximately $1.87 billion annually to the Texas economy from recreational fishing activities. The estuary can provide food for a growing populartion, shelter for boats, homes, and ports, a place to live and recre-ate, marine transportation, creation of new industries & employment, energy production, and an opportunity to have physical, emotional, and personal wellbeing.

The quality of the LLM area and accessing the area will positively affect the indicators of the economic health of the estuary. Some stakeholders are willing to pay to protect the LLM estuary and its inhabitants due to its status as one of the largest hypersaline lagoons and underdeveloped barrier islands that houses the most diverse and abundant population of birds in Texas. The economic impact of the LLM is represented by money, jobs and taxes generated by specific business activities within the estuary in many ways, such as fisheries, seafood processing, seafood markets, tourism, boat dealers, eating and drinking places, hotel and lodging places, recreational vehicles parks and campgrounds, scenic water tours, sporting goods retailers, aquaria, deep sea freight transportation, marine passenger transportation, search and navigation equipment, new industries coming to the region, employment and wage, potential energy production, etc. The Nature Conservancy in 1998 designated the Upper Laguna Madre as a high-priority conservation area. Given the unique characteristics of the Laguna Madre, it is interesting to note that the Lower Laguna Madre was not included in the original designation of Estuaries of National Significance, which left unprotected a great extent of an area with unique characteristics (Tunnell et al., 2001).

National Importance: A genuine understanding of the benefits and values of these estuaries will provide enough information about what stands to be lost when this ecosystem is endangered (Koch et al., 2009). With its incessant supply of nutrients, sediments, and a salinity gradient associated with its union with saltwater from the ocean, estuaries are great sources of sustenance and habitat for a wide variety of shellfish species and other aquatic animals (Costanza and Folke, 1997; Barbier et al., 2011). In assigning value to estuaries, it is necessary to look at (1) their usefulness to local communities for a variety of products, such as raw materials and seafood, among others; (2) their importance as breeding habitats for aquatic life; (3) as "coastal storm barriers" to provide coastal protection to prevent periodic events, such as tsunamis, tropical storms, and coastal floods; and (4) their tourism, recreation, education, and research purposes (Barbier et al., 2011).

There is little public awareness of the international significance of the Laguna Madre ecosystem. This oversight is particularly due to its remoteness and protected status along over 70% of its shoreline by federal entities, including Padre Island National Seashore and Laguna Atascosa National Wildlife Refuge; the area also includes private lands that include the large King and Kennedy ranches. However, overall, the Laguna Madre char-acteristics make it unique as a natural treasure. In addition to being the most studied and most often referenced hypersaline lagoon in the world, the Laguna Madre is home to about 77% of the North American wintering population of redhead ducks; it provides shelter to many protected species, including piping and snowy plovers, reddish egrets, brown pelicans, peregrine falcons, and white-tail hawk; it provides the largest continuous expanse of suitable habitats in North America between the north-ern breeding grounds and more distant wintering grounds in South America and accounts for about 80% of all Texas sea-grass beds, which provide habitat to many extensive colonial waterbird rookeries. Further, it is one of the best places for recre-ational fishing for red drum, black drum and spotted sea trout in North America, and it is the most productive Texas bay fishery. It also has the most extensive wind tidal flats and clay dunes in North America. It is home to the only strain of high salinity adapted oysters in North America; it has the only serpulid worm reefs in Texas, and it has the only calcium carbonate (oolite) and gyp-sum crystal formation in Texas.

LLMEP can provide enough information about what stands to be lost when these ecosystems are endangered (Koch et al., 2009). In assigning value to estuaries, it is necessary to look at (1) their usefulness to local communities for a variety of products, such as raw materials and seafood; (2) their importance as breeding habitats for aquatic life; (3) as "coastal storm barriers" to provide coastal protection to mitigate periodic events, such as tsunamis, tropical storms, and coastal floods; and (4) their tourism, recreation, education, and research benefits (Barbier et al., 2011).

Agriculture: Production of Citrus crops in the LRGV, Arroyo Colorado, and Lower Laguna Madre watersheds is a major economic driver for the regional economy. The citrus industry was established early in the 20th century and is comprised of almost 27,000 acres across a three-County area in the LRGV, which produces more than 14 M cartons of citrus products each year valued at over $100 million. The medicinal qualities of the region made it a worldwide center of activity for the aloe industry, which was grown on 3,000 to 4,000 acres before and prompted growers to locate additional fields in Mexico.

Tourisms and Recreations: The Laguna Madre is protected by Padre Island National Seashore (PINS), which is the longest barrier (67.5 miles of the 130 miles) island in the world (Cambell and Joseph, 2020). There are areas under private or corporate ownership in the shorter sections that are located between the two county parks and the national seashore. The LLM Estuary has several popular water-based recreation destinations. It was ranked as the second-largest destination in terms of travel expenditures and employment in over the six major estuaries of Texas (Jones and Tanyeri-Abur, 2001). The LLM is one of the few places in Texas where travelers are able to find decent snorkeling from the beach. It was rated by Scuba Diving magazine as one of the top 100 snorkeling sites in 2010. The beach jetties provide homes to many types of fish normally found on reefs, including wrasse, trumpet fish, and triggerfish. However, recreational boaters with outboard propellers prompted propeller scarring in seagrass beds of the ULM, causing seagrass bed fragmentation and loss (Onuf, 2007).

Commercial Fishing/Shrimping: The sportfishing industry in the LLM is estimated in value at about $180 million/year and supports about 1, 327 jobs (POI, 2017). The LLM serves as a key habitat for a wide variety of fish, such as speckled trout, sand trout, whiting, red drum (Redfish), black drum, tarpon, and mangrove snapper. The commercial fishing industry accounts for 25% of all finfish caught in Texas bay systems. In deep water, the fish of SPI and Port Mansfield include typical catches of Red Snapper, Kingfish, Tuna, Amberjack, Shark, Grouper, and a wide variety of deepwater species. Based on 1993 ~ 1995 average data, the Laguna Madre estuary is the second biggest commercial fishing employment source along the Texas Gulf Coast (Jones and Tanyeri-Abur, 2001). Port Isabel averaged a catch of 3,600,000 tons of shrimp annually, which accounted for 65% of the entire shrimp production of Texas.

Ecotourism: In the project area, there are nine principal estuarine habitats: open bays, hard substrates (i.e., jetties), oyster reefs, seagrass meadows, mangroves, coastal marshes, tidal flats, barrier islands, and Gulf beaches. Additional near coastal terrestrial habitats include coastal prairies, Lomas, and ranchland. All these habitats provide a home to more than 3,200 species of plants and animals. Laguna Madre (LM) is home to over 75% of the North American wintering population of redhead ducks (Onuf, 2007). It is home to the only strain of high-salinity-adapted oysters in North America. It has the only serpulid worm reefs in Texas and calcium carbonate (oolite) and gypsum crystal formations in Texas. With a continuous supply of nutriants, sediments, and a salinity gradient associated with its union with salt water from the ocean, estuaries are great sources of sustenance and habitat for a wide variety of shellfish species and other aquatic animals (Costanza and Folke, 1997; Barbier et al., 2011). The Laguna Atascosa National Wildlife Refuge is the largest protected area of natural habitat in the Lower Rio Grande Valley, and it is located in Cameron County. The Laguna Madre is also home to federally endangered species, such as Northern Aplomado Falcon, Ocelot (which is only found in Cameron and Willacy counties nationwide), Gulf Coast Jaguarundi, brown pelican, whooping crane, bald eagle, peregrine falcons, northern aplomado falcon, piping plover, snowy plover, least tern (inland breeding population), reddish egrets, brown pelicans, and white-tail hawks. The National Butterfly Center is located in Mission, TX, and is home to over 520 different bird species. The Santa Ana Wildlife Refuge is located along the banks of Rio Grande River in Hidalgo County. It serves as a habitat to 397 bird species and more than 300 butterfly species (FWS, 2014). The flora of the South Texas Sand Sheet includes about 54 taxa that are endemic to the state of Texas (Carr, 2019).

Presence of Two Ports: The Port of Isabel and the Port of Brownsville together represent the third largest-volume shrimp port in the nation, with average annual revenue of 57 million (POI, 2017). The Port of Brownsville is the only deep-water seaport directly on the U.S./Mexico border, located at the southernmost tip of Texas. It is the second-largest foreign trading zone in the US, and it is the largest land-owning public authority in the country. It provides employment with about 44,000 related jobs and about $3 billion in economic activity in the state. The Port of Corpus Christi is a major gateway to international and domestic maritime commerce and the 4th largest port in the United States in total tonnage, with a 36 mile, 47 foot (MLLW) deep channel. The port facilitated 61% of the 478 million barrels of crude oil exports in America in 2017 and exported $5.5 billion of crude oil to U.S. trading partners.

Oil and Gas Industrial Activity: The City of Corpus Christi has become the nation's leading oil exporter since the city was close to the source, and it was in good standing under federal clean-air regulations and also because the ship traffic in the city was low enough to take on a sudden influx of new tankers, as compared to Louisiana or Houston ports. In the first quarter of 2017, it exported 316,000 barrels a day, which is equivalent to the number of barrels exported by Beaumont, Port Arthur, and all Louisiana ports combined. Daily exports from Houston and Galveston are one-tenth of exports leaving from Corpus Christi. One of the regions that is greatly benefiting from the economic growth due to natural gas is the LRGV. The Rio Grande Liquefied Natural Gas (LNG) project is planning to have an investment of up to $20 billion for liquefaction plant and purification facility, with a capacity of 27 MTA (millions of tons per annum), and it will generate more than 3,000 permanent jobs in Cameron County. The project will also contribute $137 million in tax revenue to the County. In addition to creating high paying jobs, this project will also promote Science, Technology, Engineering, and Math (STEM) education. Exelon's Annova LNG project, at the Port of Brownsville, is expected to have a total capacity of 6.95 MTA and create 675 jobs during construction and 165 permanent jobs during operation. This project is projected to produce skilled worker opportunities with an average salary of $ 70,000 with benefits that will represent $110,000 in total compensation. The facility will also generate over $34 million in annual tax revenues. Being located in an international port, the project will help enhance the connectivity of Texas and the U.S. to the world. An LNG terminal in the Rio Grande is projected to contribute about $326 million per year to the county's gross production (Davison et al., 2015).

International Trade: This region is a nexus for international commerce with Mexico, contains several large and historic ranching operations, and is the center of natural resource-based tourism, including hunting, fishing, and natural history. The LLM Estuary region is unique due to the multibillion dollar trade volumes that cross the US-Mexico border. In 2015, Texas traded approximately 176.5 billion dollars of goods and services with Mexico, which is more than three times higher than its second-largest trading partner is China. In particular, the largest trading commodity between the Texas and Mexico border was comprised of machinery and electrical products, worth 39.2 billion dollars in 2015.

### 4.2. Needs and Goals

4.2.1. Identifying Existing Data and Gaps

There have been few studies in the LLM Estuary to characterize and model the indicators, which underscores the need to collect baseline conditions, such as water & air quality parameters, drainage maps, detailed topography, endangered species, and wetlands mapping. This section describes the status of existing data and the need for further data collection and improved modeling studies.

There have been limited studies on water quality characterization or modeling in the LLM Estuary region. It is important to measure the streamflow volume and timings correctly for developing hydrologic models for the region. Previously, the TxBLEND model was implemented to simulate water circulation and salinity transport within the estuary system to capture long term trends in salinity gradients throughout the LLM (Schoenbaechler and Guthrie, 2011). However, the model failed to capture the short-term high-frequency variability in salinity. It was proposed that the development of 3-D hydrodynamic models will help to increase the capability and predictability of the TxBLEND model in capturing salinity changes (TWDB, 2019). The construction and operation of LNG and Space X will result in economic growth in Cameron County and communities in South Texas. Baseline data needs to be collected on water quality and air quality to determine the impacts of rapid urbanization and industry growth on human health and the environment. Given the flat topography of the LLM region, there is a need to collect high-resolution Digital Elevation Model (DEM) data to update the stream network in the LLM region (TWRI, 2018). Lack of detailed stream network and flat topography underscores the need to collect high-resolution DEM data and validate other elevations' datasets. The mapping of irrigation and drainage networks, the identification of existing coastal management and adaption programs, and enhanced wetlands delineation and mapping are all needed activities. More data is needed to monitor and estimate the baseline conditions of richness and biodiversity of federally endangered birds and wildlife species. Given the historic abundance of seagrass in the LLM and its role in determining the ecosystem health of the Laguna, it is critical to map seagrass distribution in the region (Onuf, 1994).

#### 4.2.2. Environmental, Health, Habitats, and Natural Resource Needs and Issues

Non-point source (NPS) pollution prevention and mitigation in both rural and urban and agricultural operations must be a priority for consideration by the proposed LLMEP. Due to the rapid urbanization, there is an increase in storm runoff, erosion, and sediment loadings in this region being washed into the streams (USGS, 2019). Excessive stormwater runoff from small colonies can create water impairment threats to the LLM with low dissolved oxygen, high bacteria level, and algal blooms, among others. Improved drainage, wastewater, and agricultural residual management can reduce the quantity of TSS, ortho-phosphate ($PO_4$), and phosphorus levels from urban and irrigation runoff in the Arroyo Colorado (Flores et al., 2017). There is a need to collect more water quality data to provide strong evidence to make water quality management decisions (Enciso et al., 2014). Process-based models are valuable in determining the locations of critical areas to develop and implement cost-effective non-point source pollution prevention programs (Moltz et al., 2011). Upcoming reclaimed water reuse "purple pipe" projects across the LRGV and may decrease flows in the Arroyo Colorado, increasing pollutant concentrations if not managed properly. Hurricane storm surge is also a threat to the region. Effective emergency disaster management plans and open evacuation routes will have to be considered during LLMEP development. An improved prediction of storm tide zones will give vital information on disaster prevention and countywide emergency disaster management. Flood control optimization for severe events should take into consideration in drainage planning, outflow bottlenecks, and storage. Most of the year, the LRGV remains under moderate drought conditions, which have expanded slightly in decades. With the implementation of drought contingency plans and management strategies, LLMEP can develop more resilience for future occurrences. Excessive groundwater pumping in coastal areas of the LLM Estuary system can result in salt-water intrusion issues in freshwater resources. There is a need to develop cost-effective technologies that can lower the costs of desalination and find alternative and cheaper methods to safely dispose of the brine in the Bahia Grande area or others in the LLM region. There is a need to minimize illegal dumping of wastes and spills in the Arroyo Colorado basin, remote areas, canals, and resacas throughout the LLM watershed by improved monitoring, data collection, and enhancement of awareness in the local society and by thorough enforcement of regulations. The LLMEP group must be prepared to work with municipalities and agencies to improve ecosystem health and help mitigate vector transmission of diseases such as the Zika virus where appropriate. Many studies show that the leakage of surface water to recharge groundwater and vice versa could vary significantly at various spatial and temporal scales (Sophocleous, 2002; Winter and Tartakovsky, 2002). Therefore, it is important to estimate and analyze surface watergroundwater interactions using modeling and data acquisition. Due to the Deepwater Horizon Oil spill, coastal and marine resources as well as natural habitats for wildlife and aquatic species can be severely impacted (Pallardy, 2010). Therefore, it is critical to estimate the impacts of an oil spill on these resources under LLMEP and restore the natural resources and habitats, especially in Gulf Coast areas. It is critical to monitor air and water quality in the LLM region to estimate and mitigate the potential impacts of rapid industrial growth on the environment and ecosystem services.

#### 4.2.3. Significant Regional Issues

Texas has some of the highest coastal erosion rates in the country; sixty-four percent of the Texas coast is eroding at an average erosion rate is 1.2 m (4.1 ft) per year. During erosion, loose rock, soil, and sand particles are moved from one location to another by water, vehicles, pedestrians, bulldozing construction work, grazing animals, or wind energy. Dune erosion may deplete the supply of sand available in inland areas for exchange during the hurricane and tropical storms (Patterson, 2005). Estimates of erosion and sedimentation rates are useful to land and water resource planners as a guide for land-conservation measures in areas where such measures are needed most. It is important to better understand the connections between species abundance and water availability in riparian ecosystems. There has been a decline in seagrasses in the LLM since 1967 and therefore, it is important to understand the factors that affect seagrass distributions in the region. New regulations or incentives are important to conserving seagrass ecosystems and reducing common threats to them (e.g., pollution, damage by boats) (Sheridan et al., 2003). Invasive plant species (e.g., guinea grass, buffelgrass, Brazilian pepper, hydrilla, water hyacinth, Resacas, Nutria, etc.) cause many problems in wildlife habitats by choking out native species, absorbing necessary water and/or competing for resources, destroying wetland vegetation, and plugging up drainage areas (McEver, 2005). Better management of invasive species is important through the minimization of the movement of weed-infested soil or gravel from all construction and maintenance activities. The preservation of the walking trail interconnections of parks and wildlife refuges within the estuary is important to protect and preserve the natural environment and provide visitors with opportunities to interact with their natural surroundings and the creatures living within them.

4.2.4. Economic Development Needs and Issues

Ecotourism needs to be focused more on LLMEP since it is important to build environmental and cultural awareness while providing a direct financial benefit for conservation. It is obvious that the positive and negative impacts of the new development plan (e.g., LNG projects) in this coastal/port area are serious issues for regional economic development and the environment. Smart Economic Development (SED) strategies need to be developed so that corresponding mitigation and restoration projects can be optimized to balance the impacts on the environment and human health with supporting businesses, workers, and quality of life. SED will help to create more jobs, encourage entrepreneurship, develop the workforce, and improve the quality of life (such as various transportation choices, artistic, cultural, and community resources, religious institutions, and medical, technical, and academic institutions, GI development, among others). Another important consideration of economic development is to estimate the effects of the second causeway on South Padre Island, Port Isabel, and the surrounding areas. Another example of infrastructure on economic growth is the renovation of Rio Hondo Bridge, which has lessened a serious transportation issue. In order to quantify the economic benefits from wildlife and nature reserves and birding centers within LLM Estuary, cost-benefit analyses need to be performed in terms of incorporating eco-tourism, recreation activities, and restoration projects.

### 4.3. Sustainability of the Estuary Program

The likelihood of success or sustainability of the proposed LLMEP will be based on the support and commitment of the regional and local stakeholders to achieve the goals of the program, including the achievement of a healthy coastal ecosystem. Federal and state agency collaboration will be important and influential, but the leadership and long term success will be most strongly dependent on the regional municipal and local communities and citizens. Public support for the LLMEP is essential and will be brought about through education programs, outreach, watershed protection planning group collaboration, higher education institutions in the region, and the LRGV Stormwater Task Force consisting of over 20 municipalities, cities, counties, irrigation districts, drainage districts, and agencies.

The local and regional support for the sustainability of the proposed LMEP is well established. The strategic plan for the LMEP will serve to help coalesce and integrate key items from the new and existing watershed protection plans, regional stormwater management plans, solid waste management plans, erosion control plans, and other critical guidance policies and protocols for the region. This plan can be formulated through three phases or stages as follows:

- Gather information, critical data, and guidance documents from the regional ecosystem and water quality-based plans already promulgated in the region including the Watershed Protection Plans for the Arroyo Colorado, the LLM/Brownsville Ship Channel, North Floodway, Hidalgo Main Drain and Raymondville Drain, the Cameron County Dune Protection and Erosion Control Plan, and others.
- Establish a publicly available regional data repository and cyberinfrastructure for the planned LMEP for ecological information and data warehousing and processing, quality assurance, and dissemination through program education and outreach activities.
- Develop updates to existing plans and develop new, coordinated, and coalesced planning guidelines, recom- mendations for policies, ecological and water quality for the new Program.

## 5. Summary

The Laguna Madre accounts for about 25% of the coastal region of Texas and is a shallow hypersaline lagoon, which is located on the western coast of the Gulf of Mexico. The principal goals for the LMEP will encompass the broad goals as itemized in the USEPA NEP goals for CCMPs. These goals include a focus on restoring water quality, restoring and conserving habitat, replenishing and protecting living coastal and marine resources, enhancing community resilience, and restoring and revitalizing the Gulf economy. There is little public awareness of the international significance of the Laguna Madre ecosystem, particularly due to its remoteness. Given the unique characteristics of the Laguna Madre, it is interesting to note that the LLM was not included in the original designation of Estuaries of National Significance, which left unprotected a great extent of the area which left unprotected a great extent of an area with unique characteristics.

The results of the study were organized according to the guidelines for the development of NEP. The resulting Strategic Plan now consists of three Topic Thrusts under the headings: (1) National significance designation, (2) Important needs and goals for an LLM Estuary Program, and (3) Critical resource identification and planning for the implementation and sustainability of an LLM NEP. Each Topic Thrust was subdivided into subtopics and further divided into specific areas of interest. The first Thrust highlighted the national significate of adding the LLM in the NEP. The LLM supports diverse species of fishes and invertebrates that are economically valuable to the region. The Laguna Madre and Lower Rio Grande Valley, located in the southernmost tip of Texas, along with the U.S. border with Mexico, has some of the fastest-growing communities in the U.S. This region produces important crops such as citrus, is a nexus for the international commerce with Mexico, contains several large and historic ranching operations, and is the center of natural resource-based tourism, including hunting, fishing, and natural history.

The second Thrust in the strategic plan identified the critical issues and concerns in the LLM estuary region that are important not only to promote conservation and sustainability of natural resources as well as ecosystems but also for the economic development of the region. The critical issues and needs are identified through the participation of local, state, and federal governments as well as interested entities (e.g., non-profit organizations and educational institutes). The third Thrust discussed the likelihood of success or sustainability of the proposed Laguna Madre Estuary Program. It can be based on the support and commitment of the regional and local stakeholders to achieve the goals of the Program, including the achievement of a healthy coastal ecosystem. Federal and state agency collaboration will be important and influential, but the leadership and long-term success will be most strongly dependent on the regional municipal and local communities and citizens.

Decision-makers will utilize the plan and municipal leaders to promote community resilience, disseminate information, and establish integrated local water quality and ecosystem management plans for their respective communities and jurisdictions. The project has identified pertinent data sources and compiled information on critical issues related to estuarine, coastal, agricultural, industrial, recreational, and inland resources in the LLM. The project also helped assess the findings, examine and prioritize critical area issues, ascertain the economic impact of the issue through cost analysis, and the development of objectives and action items to initiate the process. Additionally, the project located data gaps and expanded the collaborative team to include area stakeholders. To summarize some of the most critical issues to be addressed by the LMEP are the following as a starting point for the Management Committee to start initiatives for the Program:

- Limited freshwater inflows need characterization and protection, including the reduction of non-point source pollution with green infrastructure and innovation.
- Loss of wetlands and critical habitat needs to be addressed.
- Rapid oil and gas development for the emerging LNG industry needs evaluation and mitigation.
- Dredging of channels and spoil beneficial reuse is needed.
- Impacts of persistent brown tides need mitigation.
- Degradation of water quality in the estuaries and tributaries needs to be reversed.
- Sea turtle habitat protection and restoration must be a priority.
- Determining and mitigating cumulative impacts of new development and the maintenance of drainage and irrigation districts should be addressed.
- Protect and enhance birding habitat for whooping cranes, redhead duck, piping plover, and other shorebirds.
- The impacts of sea-level rise, beach and dune erosion and climate change on the Gulf Coast and LM must be assessed and planned for mitigation and adaptation.
- The balance between ecological protection and economic growth must be carefully considered and measured with innovative trend analyses for the LM.

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