TM 2.2-Relevant Environmental Studies
Candidate Intake and Discharge Locations

Variable Salinity Desalination Demonstration Project
City of Corpus Christi, Texas

10 July 2015

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Introduction

Desalination of seawater is an import and increasingly common way for cities, industry, and nations to satisfy human needs and demands for freshwater. The desalination process has a long history in the Middle East and Mediterranean, but it now has expanding capacities that can be found in the United States, Europe, and Australia (Lattemann et al. 2010, Roberts et al. 2010). Consequently, there is an increasing global interest in understanding the environmental impacts of desalination plants, particularly including their intakes and discharges on coastal and marine environments. The purpose of this report is to examine the relevant environmental literature in the Corpus Christi Bay area to determine the potential environmental impacts of siting a desalination plant along the shores of this bay system.

Although there are known environmental impacts caused by desalination plants, it is important for cities and regions to consider them, since freshwater produced by these plants can augment or partially replace natural waters from rivers and reservoirs. Since Corpus Christi is geographically located along the Texas coastline where evaporation generally equals precipitation (Tunnell et al. 1996), there will be a continued and increasing need for more water than is available from natural surface freshwater sources. Research has already shown over the past 20 years or so that there is not sufficient freshwater inflow into the Nueces-Corpus Christi estuary to maintain its proper ecological functioning (Nueces BBEST 2011). Environmental flows in rivers in the region are likewise already low or stressed by not having enough water. Augmenting freshwater needs in the region by a desalination plant could benefit the natural environment by leaving freshwater to flow in rivers to the estuaries.

The primary negative environmental concerns of desalination plants include water intake facilities that cause impingement (entrapment of marine life on intake screens) and entrainment (passage of smaller aquatic organisms into the plant) of marine species, discharge of brine concentrate and chemicals into receiving waters, site selection and associated construction impacts, and increased emissions of greenhouse gases and other air pollutants (Lattemann et al 2010). The greatest environmental and ecological impacts have occurred around older multi-stage flash (MSF) plants discharging their brine concentrate into water bodies with little flushing. These discharge scenarios, primarily in the Middle East, can lead to substantial increases in salinity and temperature, and the accumulation of metals, hydrocarbons, and toxic anti-fouling compounds into receiving waters. The planned Corpus Christi demonstration plant, as well as the potential full-scale one, will use reverse osmosis, rather than this older technology, and therefore require specific consideration for this locality and its environment.

With increased functionality and efficiency in membrane technology, the City of Corpus Christi has chosen the desalination process-of-choice today, the Seawater Reverse Osmosis (SWRO) plant. Below and following is an overview of the Corpus Christi Bay ecosystem and nearshore Gulf of Mexico environment, regarding the physical setting, biota and habitats of the area, and species of concern (threatened or endangered), and then a close up look at the pertinent species in general, particular habitats, and specific species of concern at the three chosen potential sites for intakes and discharges for the desalination demonstration plant (Corpus Christi Inner Harbor, La Quinta Channel, and offshore [discharge only of offshore site]).

The Corpus Christi Bay Ecosystem

Two of the three potential areas chosen (Corpus Christi Inner Harbor and La Quinta Channel) for intakes and discharges for the Corpus Christi Variable Salinity Desalination Demonstration Plant Project are within Corpus Christi Bay. Therefore, understanding the environmental setting, biota, habitats, and species of concern (threatened or endangered) is important for narrowing the selection of several final sites to the single chosen one.

In 1994, the new Corpus Christi Bay National Estuary Program (CCBNEP; now Coastal Bend Bays and Estuaries Program, CBBEP) recognized that the living resources of the Texas Coastal Bend are “unique and valuable resources which require protection” (CCBNEP 1994). Corpus Christi Bay is one of three estuarine systems within the 12-county Coastal Bend, and it was determined during the first year of this newly-designated National Estuary Program that all living resources should be characterized. This one-year evaluation of all available literature and data resulted in a four-volume set comprised of 1,442 pages entitled *Current Status and Historical Trends of the Estuarine Living Resources within the Corpus Christi Bay National Estuary Program Study Area*:

1. All living resources – Tunnell et al. 1996a (CCBNEP-06A)
2. Avian resources – Chaney et al. 1996 (CCBNEP-06B)
3. Summary – Tunnell et al. 1996b (CCBNEP-06C)
4. Checklist of species – Tunnell and Alvarado 1996 (CCBNEP-06D)

Although many more reports have been published by the CCBNEP and CBBEP, as well as many scientific journal articles, none are as comprehensive or inclusive as these regarding all of the natural environments of the area, so they will be used primarily to characterize the Corpus Christi Bay ecosystem. In short, these four volumes list and discuss 3,178 species, 8 major habitats, 49 protected species, and 1 introduced species. The information below is primarily from the *Living Resources* reports noted above, so they will not be repeatedly cited over and over again, but selected, pertinent literature to the desalination project from within these volumes will be cited below, as well as more recent papers covering the topics of concern.

Physical Setting

Within the Texas Coastal Bend the Nueces Estuary (or Nueces-Corpus Christi bays ecosystem) is located between the northern Mission-Aransas Estuary that is brackish and sub-humid, with salt marshes, oyster reefs, and fringing sea grass beds, and the southern Laguna Madre that is hypersaline and semi-arid, with vast expanses of shallow water and dense sea grass beds and extensive wind-tidal flats. The Nueces-Corpus Christi bays ecosystem lies between these two sparsely populated areas to the north and south, and it supports the second largest human population on the Texas coast. In addition, Corpus Christi is known to sit on the boundary where precipitation is higher to the north and evaporation is higher to the south.

Nueces Bay is the smaller bay where the Nueces River flows into in the upper western end along the south side of the Nueces Delta. It is a very shallow bay, averaging only about 3 feet, and with a muddy bottom. However, in past decades before the middle of last century when large volumes of freshwater flowed into the bay and salinities were much lower, oyster reefs abounded within the bay. Today, with little freshwater inflows, salinities are too high to support extensive oyster reefs, and the estuary is sometimes referred to as a reverse estuary where salinity is higher in the upper bay than the lower bay. For these reasons, it is important that we do not plan any desal project locations along the shores or within Nueces Bay. In addition, the City of Corpus Christi has an Agreed Order with the Texas Commission on Environmental Quality to manage their reservoir system by releasing freshwater into Nueces Bay in order to maintain biological productivity.

Corpus Christi Bay is much larger than Nueces Bay (115 square miles vs 29) and it is deeper, with an almost level bottom averaging about 10 feet in depth. The bay is micro-tidal and subject to strong meteorological forcing, and like other South Texas bays, it is characterized by broad climate variations that alternate between wet and dry cycles. Corpus Christi Bay is bordered by the urban environment and drainages of the City of Corpus Christi to the south, the towns of Portland and Ingleside, along with heavy industry on the north shore, and Mustang Island, a barrier island along the Gulf of Mexico to the east. The Corpus Christi Ship Channel extends across Corpus Christi Bay at a depth of 45 feet, and the La Quinta Channel hugs the north shore of the bay at 45 feet. The latter has recently been extended to accommodate a large container dock and facility, as well as a turning basin at the end of the channel, and it is dredged to 40 feet.

Ecologically, Corpus Christi Bay is a typical mid-coast Texas bay, primarily composed of open-bay bottom habitat dominated by soft mud (Armstrong 1987). Special habitats of interest include salt marshes, sea grass beds, and oyster reefs, but most of these are located on the back side of Mustang Island in low energy areas protected from the strong and consistent southeast winds that dominate the area.

Marine and Coastal Species

There is a total of 3,178 species recorded for the Texas Coastal Bend (Tunnell and Alvarado 1996), and this includes 836 species of plants and 2,342 species of animals. Most of the animals are invertebrates, and those are dominated by the arthropods (shrimp, crabs, etc.), annelids (segmented marine worms), and mollusks (seashells such as bivalves, snails, squid, etc.). There are 924 species of vertebrates, including 234 species of fish, 30 amphibians, 87 reptiles, 494 birds, and 79 mammals (Tunnell et al. 1996a). These groups are not broken out by bay system within the report, although their distribution is noted within the checklist (Tunnell and Alvarado 1996).

Habitats

There are 8 distinct and selected habitats covered in the *Living Resources* report (open bay, oyster reef, hard substrate, seagrass meadow, coastal marsh, tidal flat, barrier island, and Gulf beach). The open bay habitat is the most relevant for the desalination demonstration project, but the oyster reef, hard substrate, seagrass meadow, and tidal flat could be affected also, particularly at the La Quinta location, and if the offshore site is chosen for discharge, the barrier island and Gulf beach habitats could be impacted.

Open bay habitat – The open bay habitat is defined as the nonvegetated, soft-bottom portion of the subtidal estuarine environment. Open bay habitat is the most common and wide-spread habitat within Corpus Christi Bay. Limitations, such as depth, turbidity, wave action, and salinity preclude submerged, and restrict shoreline vegetation, as well as oyster reefs, in most places within the bay, except on the backside of Mustang Island.

Primary production is dominated by phytoplankton in the open bay habitat (Armstrong 1987). Zooplankton, the primary consumers in the open bay, is the energy transfer link between the phytoplankton and the higher trophic levels of fish and shellfish. *Acartia tonsa*, a calanoid copepod, is the dominant zooplankter in Corpus Christi Bay (Holland et al. 1975). Like phytoplankton, zooplankton abundance and community composition is temporally dynamic and exhibits daily and seasonal fluctuations.

The abundance and community composition of benthic macrofauna have received considerable attention in Corpus Christi Bay (Holland et al. 1975, Calnan et al 1983, Flint and Younk 1983, Martin and Montagna 1995, Montagna and Ritter 2006). Capitellid and spionid polychaetes are ubiquitous and often dominate benthic assemblages, while bivalves, primarily dwarf surf clam, are the dominant mollusk, and amphipods the dominant crustaceans. Over time, macroinfaunal abundance in Corpus Christi Bay is greatest during winters and springs (Armstrong 1987).

Epibenthic and nektonic invertebrate communities in Corpus Christi Bay are dominated by economically important species, such as penaeid shrimp and portunid crabs. This community also includes a variety of other crustaceans (amphipods, crabs, grass shrimp), cndarians, ctenophores, and squid (Britton and Morton 1989). Jellyfish, especially the cabbage head, and ctenophores or comb jellies, which are seasonally very abundant, may be important in regulating zooplankton populations.

Fish are dominant constituents of the nektonic community in Corpus Christi Bay, and trawl surveys reveal dominance by Atlantic croaker, spot, anchovy, hardhead catfish, pinfish, sand seatrout, star drum, Gulf menhaden, striped mullet, and tidewater silversides. The most common recreational fish include spotted seatrout, red drum, black drum, croaker, southern flounder, and gafftopsail catfish (Tunnell et al. 1996a).

Nektonic communities in estuaries are generally structured in relation to species life histories, feeding strategies, and/or salinity gradients. Although there are no specific studies within Corpus Christi Bay concerning the effect of life histories or feeding strategies on nektonic community structure, there have been several within the Texas Coastal Bend that estimate salinity preferences of nekton (e.g. Hoese 1960, Hedgpeth 1967, Gunter 1961). In addition, a number of laboratory studies have attempted to determine salinity preferences or tolerances of Texas coast species (e.g. Zein-Eldin 1963, Zein-Eldin and Griffith 1969, Keiser and Aldrich 1976, Holt and Banks 1989, Wohlschlag 1977, Wohlschlag and Wakeman 1978, Longley 1994). Generally, mean salinities above 25 ppt have the potential to reduce densities and catch of white shrimp and Gulf menhaden. On the other hand, there were no relationships found between salinity and gill net catches of larger black drum, southern flounder, Gulf menhaden, striped mullet, red drum, or spotted seatrout by the Texas Parks and Wildlife Department.

The most comprehensive compilation of information that covers the distribution and abundance of all common fishes and invertebrates in Gulf of Mexico estuaries was completed by NOAA in the 1990s. As part of the NOAA Estuarine Living Marine Resources program, it lists 44 species in all of the 31 major estuarine systems of the northern Gulf of Mexico. Volume I or this two-volume set covers the distribution and abundance of all species, as well as their temporal occurrence of various life stages in each season of the year (Nelson et al. 1992), and Volume II covers the life history of all of these species, including salinity tolerance and habitat preference (Patillo et al. 1997).

Regarding other vertebrates in Corpus Christi Bay, there are no amphibians, and only rarely any reptiles, such as American alligators washed in during floods, diamond back terrapins which live around the Nueces Delta in adjacent Nueces Bay, and green sea turtles that occasionally come in from the Gulf. Birds are important consumers in open bay waters and along shorelines, but they are unlikely to be directly affected by desalination intakes or discharges. The only resident marine mammal of open bay areas is the Atlantic bottlenose dolphin, and estimates of their population for the Nueces-Corpus Christi bays system is about 300 (Armstrong 1987). Occasionally, a stray West Indian manatee passes through the area, staying only 2-3 days, but this occurs only about every 5-7 years.

Hard substrate habitat (except oyster reefs) – Hard substrate habitat within Corpus Christi Bay is composed of artificial, man-made structures, such as jetties, groins, breakwaters, riprap shorelines, and bulkheads along the shorelines, and offshore oil and gas platforms out in the bay. Although these are artificial habitats, they can contain a considerable diversity of marine life from various fleshy, macro algae, to invertebrates, such as limpets, other various snails, oysters and other bivalves, barnacles, and crabs, to fish who feed upon the invertebrates or other fish around the structures. This biota, often referred to as a fouling community, can be problematical for seawater intakes by causing clogging and requiring regular cleaning. Although considerable studies have been conducted on the jetties at Port Aransas in the Gulf of Mexico, none have been done specifically on these hard substrate habitats within Corpus Christi Bay.

Oyster Reefs – Oyster reefs are natural accumulations of shells, primarily Easter oyster (*Crassostrea virginica*) which form from generations of oyster shells growing in the same place.

They can be either intertidal or subtidal. Oyster shell and living oysters provide a hard substrate for settlement of a variety of sessile organisms, and they provide protective cover for a wide variety of mobile species. Oyster reefs are also known to provide important ecosystem services, including shoreline or bottom stabilization, filtration of large quantities of bay water (up to 50 gallons per day per oyster), high biodiversity, highly desirable human food, nursery ground habitat for selected species, and highly desirable habitat for certain recreational fish species. For all of these reasons they are an important habitat for protection and conservation, so management agencies discourage any construction or pollution that might impact them.

Although oyster reefs are more common to the north of Corpus Christi Bay in Aransas, Copano, and Mesquite bays, there are some shallow oyster beds on the back side of Mustang Island and oyster clusters on many artificial hard substrates around the bay and in some shoreline areas near Portland and Indian Point. There are no studies of the few oyster beds in Corpus Christi Bay, but intertidal reefs in Nueces Bay to the west and Redfish Bay to east revealed a biota of 116 species (Drumright 1989). Amphipods dominated, accounting for 63% of all organisms collected. Small gastropods were common herbivores, grazing on the algal film on oyster shells, and common filter feeders included bivalves, sponges, an anemone, gastropods, brozoans, tunicates, and polychaetes. Other polychaetes were dominant deposit feeders, and certain gastropods and crabs, notably stone crabs, were the dominant predators. Xanthid crabs and shrimp were common omnivorous detritivores on the reefs.

Fish collected in samples from oyster reefs in adjacent Nueces and Redfish bays were primarily juvenile and small adult age classes, however feeding activity by larger fish in and around the reefs was commonly observed (Drumright 1989). Common juvenile fish collected included pinfish, shepshead, and spot; Gulf toadfish, code goby, and naked goby were common adults. Gobies were the most numerous fish species collected. Oyster reefs are frequented by adult red drum which feed on invertebrates and fish on the reef, and black drum, Atlantic croaker, cownose rays, and spot, which feed on adult oyster or their spat.

Of the vertebrate groups, only selected birds frequented the intertidal oyster reefs in Nueces and Redfish bays, primarily as predators feeding on oysters or associated fauna during low tide (Drumright 1989). Of the 28 species observed, the most commonly observed were Laughing Gull, Willet, Great Blue Heron, Brown Pelican, and American Oystercatcher. Abundance of birds was greatest during winter.

Recent interest and studies on oysters in the Texas Coastal Bend have focused oyster response to flooding, nitrogen regulation, flood disturbance, and restoration of oyster reefs (Pollack et al. 2011, 2012, 2013, Palmer et al. 2015, George et al. 2015).

Seagrass Meadow Habitat – Seagrass meadows (or beds) are composed of aquatic vegetation that grows submerged in shallow seawater, and they are considered among the most productive coastal ecosystems. There are 5 species of seagrasses found in Corpus Christi Bay, including shoal grass (*Holodule wrightii*), widgeon grass (*Ruppia maritima*), turtle grass (*Thalassia testutinum*), manatee grass (*Syringodium filiforme*), and clover grass (*Halophila engelmannii*). Shoal grass is by far the most abundant at over 85% of seagrass cover, followed by widgeon grass and turtle grass with only very small amounts of manatee grass and clover grass (Pulich and White 1997).

Most seagrass habitat in Corpus Christi Bay is found on the backside of Mustang Island, but there is some also located in a narrow band in shallow waters along the north shoreline between Ingleside Point and Indian Point and around the large dredged material islands of La Quinta Channel. Some seagrass beds are single species and others are with mixed species, and some are dense stands, where it is difficult to see the substrate, and others are patchy with thinner stands of grass and varying degrees of bay bottom visible between the grasses.

Presence or absence of species, as well as zonation of species, is largely a function of substrate type or composition, wave energy, water depth (which relates to light penetration for photosynthesis), salinity tolerance, and successional stage. Seasonal peaks of biomass can be observed in all species with peak abundance and growth during April to early fall each year (Dunton 1990, 1994).

Seagrass bed habitat has a number of important ecosystem services, including high biodiversity, nursery ground, substrate stabilization, habitat for highly important and popular recreational fishes and therefore fishers. A diverse array of epibenthic, benthic, and epiphytic invertebrate macrofauna is associated with seagrass meadows in Corpus Christi Bay. Polychaete worms generally dominate the benthos around the roots and rhizomes, and mollusks, such as cerith snails, virgin nerites, dovesnails, cancellate venus clams, bay scallops and paper mussels are found among the grass blades.

Invertebrate nekton, such are shrimp and crabs, are diverse and abundant in seagrass beds, along with numerous small fish, such as sea horses, pipefish, silversides, and killifish. Slightly larger "bait fish", such as pinfish and anchovies, are also abundant and serve to attract larger predatory species like spotted seatrout, red drum, and southern flounder, which are targeted heavily by fisher people.

Recent interest and studies on seagrass beds in the Texas Coastal Bend have focused on seagrass use as fisheries habitat and as settlement and nursery grounds, as well as impacts from boat propeller scarring (Burfeind and Stunz 2006, 2007, Nanez-James et al. 2008, Reese et al. 2008, Froeschke et al. 2013.

Coastal Marsh Habitat – Coastal marshes are vegetated intertidal areas between upland and estuarine/marine ecosystems. The dominant type of low salt marsh in the Texas Coastal Bend is dominated by salt marsh cord grass (*Spartina alterniflora*). Within Corpus Christi Bay this kind of habitat is most common on the backside of Mustang Island and along the Indian Point Peninsula from Portland to the Corpus Christi Bay Causeway. A narrow band of this habitat is also found along the shoreline from Portland to the La Quinta Channel (White et al 1998).

Since Corpus Christi is at the borderline between semi-arid to the south and sub-humid to the north along the Texas coastline, the salt marsh cord grass habitat in the intertidal zone is not as common in Corpus Christi Bay as it is in the bays further north with more freshwater inflow. A variety of other mid-marsh and high marsh wetland plants are more common in the more arid, and higher saline, conditions around Corpus Christi Bay.

Coastal marsh habitat is one of the most productive of vegetated habitats in the marine environment, and they provide a number of important ecosystem services, such as shoreline stabilization, nursery grounds for many important recreational and commercial species (shrimp, crabs, fish), and filtration of water running off the land.

Even though the coastal marsh habitat is considered highly important along the Texas coast, none of them should be impacted directly by the proposed desalination demonstration plant locations under consideration, so no further detail will be presented here.

Tidal Flat Habitat – Tidal flat habitats are seemingly barren, relatively featureless sand, mud, or mixed sand and mud environments which lack any macrophytic vegetation. Like the salt marsh habitat, these tidal flats are mostly located on the backside of Mustang Island in Corpus Christi Bay, but there also some smaller shoreline flats located along the Indian Point Peninsula and Portland shoreline to the La Quinta Channel, as well as around the large dredged material islands of La Quinta Channel. The low, wider flats are often referred to as "wind-tidal flats" in the Coastal Bend area and southward, because they are generally inundated and exposed by wind tides, or meteorological tides, rather than astronomical tides (Withers and Tunnell 1998).

Variability in flooding frequency of these flats leads to hypersaline soils, which prevents the establishment of macrophytic vegetation. The major, primary producers on these flats are benthic micro-algae (blue-green algae), which form felt-like or leathery mats on the substrate. Most studies of wind-tidal flats in the region have been conducted in the Laguna Madre, where over 300 square miles of flats exist (Withers and Tunnell 1998).

When dry, these flats do not have much biological activity on them. However, when covered with shallow wind tides or when the flats are wet after the water has recently receded, small invertebrates are common to abundant. Tanaids, amphipods, and polychaetes can be abundant in the wettest portion of these blue-green algal flats, and insect larvae can be common in drier areas (Withers 1994). These organisms are generally most abundant during winter and early spring on the flats, the latter corresponding with high numbers of shorebirds during spring migration. Shorebirds are the most conspicuous vertebrate consumers on these tidal flats, and the Piping Plover and Snowy Plover, US Fish and Wildlife-designated endangered and threatened species, respectively, utilize both wet and dry tidal flats. Over 20 species of shorebirds have been recorded on the wind-tidal flats of Oso Bay on the south side of Corpus Christi Bay (Withers and Chapman 1993). When tidal flats are covered with water, herons and egrets, including the threatened Reddish Egret, can be common in this area, particularly during the summer and fall.

Barrier Island Habitat – Barrier islands are elongate geomorphic features that form barriers along coastlines and protect mainland areas, as well as bays, estuaries, and lagoons from the heavy seas and storms of the adjacent ocean, or ocean-like body of seawater. Mustang Island is the barrier island to the east of Corpus Christi Bay, and San Jose Island extends northward and Padre Island extends southward from Mustang.

Because of varying elevation, physical forces, and geomorphology, distinctive ecological zones occur parallel to the shoreline going east to west across Mustang, and other Texas barrier islands. Zones include the following habitat types: foreshore (or swash zone), backshore (from high tide to dune line), foredunes, vegetated flats with ponds and marshes, back island dunes or wind-tidal flats, and coastal marshes.

If an offshore discharge site is chosen for a desalination plant located somewhere on the land, all of the barrier island habitats listed above could be temporarily affected during construction of the pipeline. The main disturbance would be to the vegetated middle of the barrier island and the foredune ridge complex. Fortunately, Padre Island National Seashore has considerable experience with pipelines being laid across their property, and they have developed a number of conservation and restoration measures to minimize this kind of disturbance.

Morning glory and sea purslane are common pioneering plants on the backshore in front of the dunes, and sea oats and other grasses dominate the dune ridge, along with many perennials, such as croton, beach evening primrose, seaside heliotrope, etc. A mid- or tall-grass prairie climax community, dominated by seacoast bluestem and bushy bluestem, is common across the interior vegetated flats (Drawe et al. 1981 and Smith 2002). A variety of small fishes is found in the ephemeral ponds and borrow ditches on the barrier islands, and they are dominated by several small, hardy fish, such as sheepshead minnow, mosquitofish, and Gulf killifish. Several amphibians, such as leopard frogs, toads, and green treefrogs, as well as a variety of turtles, such as the red-eared slider and diamond back terrapin, are also found in these aquatic areas.

On the sandy, island soils keeled earless lizards are common in the dunes, while several snakes (e.g. king snakes, rattlesnakes, and garter snakes) are common in the vegetated flats. The State-listed threatened species found in vegetated areas include the Texas tortoise and Gulf saltmarsh snake. Although there are not many resident birds in the vegetated flats (American Kestrel, Harrier Hawk, Loggerhead Shrike, Northern Bobwhite Quail, various sparrows, etc.), neotropical migrants can be very diverse as they use the island as a fly-way each fall and spring. Although there are many kinds of small field mice and rats in the vegetated flats, the iconic small mammals on the barrier islands include the kangaroo rat, spotted ground squirrel, and the Texas pocket gopher. Larger mammals include the jack rabbits and coyotes.

Gulf Beach Habitat - The Gulf of Mexico beach habitat is the easternmost shoreline habitat with the Texas Coastal Bend, and it encompasses the foreshore and backshore of the beach, as well as the nearshore area, including the parallel bar and trough system out to the third sand bar. The Gulf beach on Mustang Island is composed of well-sorted fine to very fine sand, and it is considered as a moderate to high energy beach, depending on the season (Britton and Morton 1989).

The tidal regime of the Gulf beach on Mustang Island is micro-tidal with an average diurnal range of about 1.5 feet. Tidal frequencies on the Gulf beaches vary and may be: 1) diurnal, which is one high and one low tide per day (24 hours); 2) semi-diurnal, which is two highs and two lows per day; or 3) mixed, which includes one high and two lows or one low and two highs per day.

The three recognizes sub-habitats of the Gulf beach habitat are the supratidal backshore, the intertidal foreshore, and the subtidal bar and trough system. The backshore is dominated by ghost crabs and a few pioneering plants, like morning glory and sea purslane. Because of the unstable substrate of continual shifting sand, there are no fleshy algae or vascular plants living along the foreshore. It is dominated by infaunal invertebrates, dominated by coquina clams, mole crabs, haustoriid amphipods, and spionid polychaete worms. Haustoriid amphipods are generally the most abundant organisms in this high energy, unstable substrate zone. Densities of organisms living in this zone exhibit extreme highs and lows due to recruitment in fall and spring. Offshore, the lower energy, subtidal zone is characterized by higher species diversity and a shift from filter-feeding to predation and scavenging. Crabs, predatory gastropods and polychaetes, as well as echinoderms, such as sand dollars and star fish dominate (Shelton and Robertson 1981, Tunnell et al. 1981, Vega and Tunnell, 1987, Vega 1988).

Larvae and small juveniles of a few species comprise most (about 90%) of the fishes in the surf zone. The most abundant species include sardine, Atlantic croaker, anchovies, Atlantic thread herring, mullet, and Gulf menhaden. Abundances tend to be greatest during the summer and fall (Shaver 1984).

A few species of lizards and snakes are found on the backshore, including the keeled earless lizard, whip-tailed lizard, western diamond back rattlesnake and the massasauga. Both loggerhead sea turtle and Kemp's ridley, which is an endangered species, nest to the south on Padre Island and have been found on Mustang Island.

Shorebirds are the dominant vertebrates found on Gulf beaches, as it provides resting and foraging habitat for migrating, wintering, and resident species. Gulls and terns are abundant all year around, along with sandpipers and Sanderling. Gulf beaches are particularly important for endangered and threatened Piping and Snowy plovers, respectively, during fall migration, when tidal flats are flooded by seasonal high tides and unavailable. Peak abundances of most shorebirds coincides with spring and fall migration; abundances decline in late spring and early summer as the birds depart for northern breeding grounds (Chapman 1984, Chaney et al. 1993, Withers 2002).

The Offshore Ecosystem

Since the Corpus Christi Desal Demonstration Project is considering one potential offshore discharge site for brine, it is important to present an overview of that environment in general and the habitat and species present 2 miles offshore in approximately 40 feet of water. The nearshore environment of the Gulf of Mexico off the Texas Coastal Bend is characterized by a gently sloping, flat bottom continental shelf. The nearshore sandy bottom grades into a sandy mud bottom and then to a muddy bottom that extends to the shelf edge. Nearshore waters are highly variable in energy, ranging from low in the late summer-early fall to moderate in the spring and fall, except when winter fronts increase it to high energy, which is typical of the winter season. Nearshore waters can be quite turbid after fronts, during strong, sustained southeasterly winds (normal in the area), or during tropical storms or hurricanes. These same waters can be quite clear from July through September to early October when tropical waters move into the area from the south. Biologically, these waters are highly productive, being influenced by the nearby estuaries via passes or inlets through the barrier islands.

Two large-scale studies conducted in this offshore area have characterized the physical setting, species, and habitats, as well as ecological process. The first study was a three-year study during 1975-1977 and included 4 transects across the entire South Texas continental shelf from nearshore to the shelf edge (Flint and Rabalais 1981). The study was funded by the Department of Interior's Bureau of Land Management (later called the Minerals Management Service and now the Bureau of Ocean Energy Management) to set environmental baselines of the continental shelf before extensive oil and gas development in the area. This intensive, multidisciplinary study, the South Texas Outer Continental Shelf Project (STOCS), was led by the University of Texas Marine Science Institute in Port Aransas in partnership with Rice University and Texas A&M University. In parallel with this project the U.S. Geological Survey studied sediments and sediment geochemistry, and the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration investigated ichthyoplankton and commercial/recreational fishery species.

The second large study was part of a Texas, coast-wide study program funded by the State of Texas and conducted by the Bureau of Economic Geology (BEG) of the University of Texas during the 1980s. This program, coined the Submerged Lands of Texas Program, followed the highly successful and utilitarian BEG Environmental Geologic Atlas series (1972-1980), and it provided detailed information on the sediment, sediment geochemistry, benthic macroinvertebrates, and associated wetlands for all Texas bays, estuaries, and lagoons, as well as to a distance of 10 miles offshore into the Gulf of Mexico. One of the seven volumes with associated maps covers the Corpus Christi area (White et al. 1983).

The potential offshore site at 2 miles offshore from north Padre Island (Packery Channel area) is in about 40 feet of water with a bottom sediment composition of primarily sand (greater than 70% sand). The predominant macrofauna in this locality are mollusks and polychaetes with some amphipods. Nearest BEG benthic stations to this site show second highest to highest species diversity, according to their sampling. Pelagic biota on the Texas continental shelf is extremely high in annual phytoplankton productivity, and primary production in inner-shelf waters is bimodal annually with peaks in spring and fall (Flint and Rabalais 1981). There is a distinct and strong cross-shelf gradient of chlorophyll a concentrations with a peak inshore and a steep drop in the clear offshore waters.

The phytoplankton community is complex but rather consistent, generally being a reflection of the various water masses linked to varying environmental conditions. Zooplankton biomass and total density decrease with distance offshore, and the community is dominated in density by female copepods. It is not unusual to see estuarine species in nearshore samples, especially during the spring when riverine outflows may increase and push bay water and zooplankton into the nearshore zone of the Gulf via inlets or passes through the barrier islands.

Pelagic and demersal fish populations are mostly warm temperate (Carolinian Province) species, but there is a small component (increases in the summer) of tropical (Caribbean Province) species. The shallowest shelf zone where the discharge is potentially planned exhibits low species diversity throughout the year, but there are particularly high numbers of individuals of each species in winter and spring. This faunal association near shore dissipates during the late summer and early fall when shelf waters are the warmest.

Species of Concern (threatened and endangered)

Although approximately 56 species are listed by various state and federal agencies, as well as other organizations, within Nueces County as having some level of protection, less than 10 are estuarine-dependent or marine species (Texas Parks and Wildlife – Rare, Threatened, and Endangered Species of Texas website http://tpwd.texas.gov/gis/rtest/). Nueces County has 14 federally listed species and San Patricio has 11 (USFWS Corpus Christi Office, personal communication with Robyn Cobb and Mary Orms, 19 June 2015). Of the species listed by these two primary agencies, only the Reddish Egret, Snowy and Piping plovers, Red Knot, Texas pipefish, green sea turtle, bottlenose dolphin, and West Indian manatee have the potential of being impacted at the La Quinta proposed site, and only 4 sea turtles (Kemp's ridley, loggerhead, green, and leatherback) and the bottlenose dolphin have potential impact at the offshore discharge site. It is unlikely that any of the species would be affected at the Corpus Christi Inner Harbor sites.

Candidate Intake and Discharge Location Environments and Potential Impacts

Recent comprehensive, multi-year literature reviews agree and encourage utilizing sustainable techniques for intakes and discharges at desalination plants (Lattemann and Hopner 2008, Lattemann et al. 2010, Roberts et al. 2010, Voutchkov 2011, Darwish et al. 2013, Missimer et al. 2013a). Major projects should be investigated and mitigated by means of project- and location-specific environmental impact assessments, while the benefits and impacts of different water supply options should be balanced on the scale of regional management needs and alternative water supplies.

Coastal cities planning desalination plants that are located adjacent to deep water have an easier choice in placement of intakes and discharges, because nearby deep water is the best for both. In this situation, intake water is usually cleaner and clearer offshore, and will therefore take less treatment, and discharge brines will mix more rapidly and with less localized impact with the large volume of deep ocean water. However, when cities are geographically situated on a coastal plain, as is characteristic of the Texas coast, there is a critical balance between cost and environmental impact in deciding whether or not a project will be feasible.

Of these two key elements of a desalination plant project, intakes in shallow estuaries may be more cost effective and less environmentally damaging than discharges. Generally, a combination of variously meshed screens and intake velocity can be used to minimize the impingement of larger organisms, such as fish and turtles, while entrainment of smaller planktonic organisms, eggs, and larvae can be minimized by lower velocity intakes, subsurface intakes, or offshore intakes away from productive estuaries. Because of the highly productive waters in Texas being both inshore (within bays and estuaries) and in the near-offshore waters (Gulf of Mexico) for a considerable distance, this latter location may be problematic from a logistical/cost standpoint, because of the distance offshore. Locally, the Barney Davis Power

Plant has shown over several decades that Laguna Madre fisheries do not appear to have been damaged, as selected species in that area (e.g. black drum and spotted seatrout) have growing populations (J. Tolan, TPWD, personal communication), revealing that large (over 500 mgd) estuarine intakes are feasible and possible without extensive harm to the environment.

Beach well intakes or infiltration galleries are another highly desirable subsurface intake option because of the benefits of pre-filtration and lack of impingement and entrainment of marine life. For reverse osmosis desalination plants, these technologies can be less costly in the long-term, because the quality of raw water can be greatly improved in the beginning, reducing the need or use of costly chemicals and cleaning processes for the membranes (Missimer et al. 2013b). Key site-selection criteria include local geology and the volume of water needed (high volumes can be a problem, but multiple galleries are possible). These subsurface systems are not appropriate in the very silty/clayey, low-energy environments like Corpus Christi Bay, because of low or slow filtration qualities and cleaning difficulties. However, the sandy beaches in northeastern Florida have been evaluated and found appropriate, and those beaches are similar to local Gulf of Mexico beaches off Corpus Christi (Missimer et al. 2013b).

With discharges the issues are multifold, including not only the higher salinity but also associated chemicals. In this case, the best solution is to be in the highest mixing volume possible, which is offshore. Biofouling agents, suspended solids, and scale deposits are typical components of a desalination membrane-type plant that is planned for Corpus Christi. Pre-dilution with waste water treatment plant water, power plant return flow water, or ground water are typical mitigation measures for reducing the salinity of the discharge stream. Multiport diffuser systems are a current state-of-the-art technique for mixing the concentrate in as small an area as possible to match ambient salinity of the surrounding water. This is the system planned for Corpus Christi. However, in smaller, contained areas, like within bays and ship channels where there is not adequate flushing, too large of a volume of concentrate will not mix, and it will eventually settle as a heavy seawater layer on the bottom and cause hypoxia or anoxia so that bottom-living organisms cannot survive.

A preliminary, or earlier, local study focusing on high salinity discharge water from the Barney Davis Power Plant into Oso Bay and subsequently into Corpus Christi Bay was used as a surrogate of a desalination plant discharge (Hodges 2006, 2010, and Hodges et al. 2011). This project clearly demonstrates how a hypersaline gravity plume, such as that resulting from a desalination discharge into the ocean, an estuary, or coastal embayment, may cause the development of hypoxic (low dissolved oxygen, DO) or anoxic (zero DO) regions that are detrimental to the environment. Parallel, but earlier, biological studies in the same southeastern region of Corpus Christi Bay revealed these hypoxic conditions as early as 1988 and their effect on benthic (bottom living) organisms, possibly related to the hypersaline outflow of Laguna Madre just east of the Hodges study site (Montagna and Kalke 1992, Ritter and Montagna 1999, Montagna and Ritter 2006, Montagna and Froeschke 2009, Montagna and Palmer 2012).

Most recently, Dr. Ben Hodges modeled the possible release of brine discharge from the Corpus Christi desalination project into the main ship channel in Corpus Christi Bay. His conclusion of this concept of putting the brine into the channel and expecting it to transit out into the open ocean waters of the Gulf of Mexico for dilution “does not appear to be practical”. The result of this action is likely to be "extended periods of hypoxia or anoxia in the ship channel" (Hodges 2015).

Engineering review by Mike Morrison of many of the more recent technical reports and publications has narrowed the best-available-technology for intakes and discharges for our local area on this project, suggesting that wedgewire screens for intake and multi-port diffuser discharge, respectively, are best (Morrison 2015). The HRI environmental team then examined specifically for biological impacts at the two general localities and multiple combinations of intakes and discharges in the vicinity of each, as well as the one potential offshore discharge site. Matrices prepared for each location show the pros and cons of these multiple combinations.

Below are summary comments specific to each of the potential locations for intakes and discharges related to the local species and habitat impacts, as well as protected species in the area, as noted earlier in this section (TM 2.2).

- **Corpus Christi Inner Harbor**
    - A properly designed and sited intake facility in the Inner Harbor would have minimal biological (species and habitat) impact, because it is already a highly disturbed and affected environment. Subsurface intakes cause the least mortality to resident biota, but the fine sediments and continual stirring up by passing ships may negate the use of this type of intake. Wedgewire screens are the next best option.
    - A discharge facility could be sited in the Inner Harbor with some potential biological impact for a small-scale demonstration desalination plant, but a full-scale plant should not discharge here, because it would cause hypoxia or anoxia in the channel, and possibly eventually out into Corpus Christi Bay.
    - The Inner Harbor has shoreline areas that could possibly support the protected bird species mentioned above, but it is unlikely that they would be there, and most Corpus Christi Bay shoreline near the harbor is bulkheaded and not appropriate habitat for them. The green sea turtle and the two marine mammals are unlikely to go into the Inner Harbor.

- **La Quinta Channel**
    - Since water quality is better in La Quinta Channel than the Inner Harbor, a water intake there would probably have more biological (species and habitat) impact.
    - A discharge facility could be sited in the La Quinta Channel with some potential biological impact for a small-scale demonstration desalination plant, but a full-scale plant at this location is least favorable, because it would cause hypoxia or anoxia in the channel, and possibly eventually out into Corpus Christi Bay.
    - Since the La Quinta Channel site has shoreline habitat areas, including tidal flats, salt marshes, and adjacent seagrass beds, those could potentially be used by the protected bird species and Texas pipefish mentioned above, and the waters of the channel have been known to have the green sea turtle, bottlenose dolphin, and manatee present in the past.
    - For the reasons noted here and above, the La Quinta Channel sites are undesirable due to possible higher impacts to native biota and habitats.

- **Offshore** (in Gulf of Mexico off Packery Channel area)
    - Subsurface intakes, which have no impingement or entrainment impacts, are the best option for offshore; the second best is the wedgewire screen intake.
    - Open water discharge into the Gulf of Mexico would be the best option for quickest dilution and least environmental impact.
    - Although the 4 sea turtles mentioned above and bottlenose dolphins live in the area, it is unlikely that they would be impacted by the outfall.

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