Alternative Methods to Add Freshwater to the Nueces Delta

TWDB Contract #1600012016

by
David Buzan, Freese and Nichols, Inc.
Ernest To, Alan Plummer and Associates, Inc.

PURSUANT TO HOUSE BILL 1 AS APPROVED BY THE 84TH TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHOR(S) AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

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August 31, 2017

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1 Executive Summary

To meet requirements of a Texas Water Development Board grant, 13 experts familiar with the Nueces Delta and Nueces Estuary were interviewed during 2016 and 2017 to identify ways to add more water to the Delta. The interviews, combined with literature review, identified 14 potential ways to add more water and four alternatives which would enhance ecological condition by modifying ways water is currently added to the Delta.

Estimated cost per acre-foot of water and amount of water potentially added to the Delta was calculated for each alternative (Table 1). Additional considerations including possible effects on source waterbodies and the Delta, along with regulatory concerns and estimated time to complete implementation of the alternative were evaluated. The lowest cost alternative would provide treated wastewater from the Allison wastewater treatment plan. Implementation of this alternative is limited by the wastewater permit requirement that any discharge to the Delta meet a 4 mg/L ammonia-nitrogen concentration. Cost estimates of these alternatives will change when more intensive, up-to-date, analyses are applied.

Special Condition 5.B. referred to as the agreed order of water rights permit, Certificate of Adjudication No. 21-3214, requires Corpus Christi to pass through the Lake Corpus Christi/Choke Canyon reservoir system up to 151,000 acre-feet of water per year to the Nueces Estuary through a combination of spills, releases, and return flows to maintain ecological health and productivity of the estuary. Some alternatives could be implemented without affecting the agreed order while others would require its modification. Administrative and legal costs associated with change of the agreed order might be relatively expensive and time-consuming.

The ecological benefits of alternatives were qualitatively compared based on the ability of the alternative to provide (Table 2):

- Continuous versus intermittent flow,
- Freshwater rather than brackish or saline water,
- 5 acre-feet per day or more,
- Sediment in addition to water,
- Water to areas of the Delta other than Rincon Bayou, and
- Implementation with low versus high requirements for infrastructure and ongoing operations and maintenance.

Alternatives qualitatively assigned the most checks may provide the most ecological benefit to the Delta.

TABLE 1. Possible Alternatives to Add Water to the Nueces Delta.

Alternative	Estimated Cost per acre-foot	Volume Added (acre-feet per day)	May Require Agreed Order Amendment
Allison Wastewater Treatment Plant	$38	6 (continuous)	No
Sand/Gravel/Caliche Mine Ponds	$100	Unknown	No
Hondo Creek Realignment	$72–190	6 – 16 (continuous)	No
Nueces River Tidal Diversions	$129–202	6 (continuous) – 640 (high flow periods)	No
Industrial Wastewater	$134	92 (continuous)	No
Deep-Water Wells in Nueces Delta	$159–302	49 (continuous)	No
Evaporation Control	$180–642	Unknown	Yes
Off-Channel Storage/Aquifer Storage and Recovery	$225–409	85 (continuous, off-channel reservoir) 2–77 (continuous, aquifer storage and recovery)	Maybe
Brackish Seepage above Calallen Dam	$330–458	2 (continuous)	Maybe
Lake Corpus Christi Pipeline	$376	69 (continuous)	Yes
Mary Rhodes Pipeline	$624	5.8 (continuous)	No
Treated Wastewater from Portland to Aransas Pass	$744	39 (continuous)	No
Nueces Bay Additions	$855	6 (continuous)	No
Odem Wastewater Treatment Plan	$1,700	0.4 (continuous)	No
Pollywog Pond	Unknown	Unknown, less than 0.46	No

TABLE 2. Qualitative Comparison of Ecological Benefits of Proposed Alternatives.

Alternative	Flow, Continuous	Freshwater	Volume (≥ 5 acre-feet/day)	Sediment Added	Delivery Location	Energy required
Allison Wastewater Treatment Plant	√	√			√	√
Sand/Gravel/Caliche Mine Ponds		√		√	√	√
Hondo Creek Realignment	√	√	√			√
Nueces River Tidal Diversions	√		√		√	
Industrial Wastewater	√	√	√		√	
Deep-Water Wells in Nueces Delta			√		√	
Evaporation Control	√	√	√			√
Off-Channel Storage/Aquifer Storage and Recovery		√	√		√	
Brackish Seepage above Calallen Dam			√			
Lake Corpus Christi Pipeline		√		√		
Mary Rhodes Pipeline	√	√	√		√	
Treated Wastewater from Portland to Aransas Pass	√	√	√		√	
Nueces Bay Additions			√		√	
Odem Wastewater Treatment Plan	√	√			√	√
Pollywog Pond		√		√	√	√

2 Introduction

The Nueces Basin and Bay Area Stakeholder Committee (BBASC) recommended the Texas Water Development Board (TWDB) fund an exploration of ways to add more water to the Nueces Delta. The project's broad objective was to identify ways to add more water to the Delta to protect and enhance its ecological condition. This report provides information gathered from October 2016 through June 2017 under TWDB Contract No. 1600012016 by the Freese and Nichols, Inc. team (Freese and Nichols, Inc., Alan Plummer and Associates, Inc. and AmaTerra Environmental Inc.) to achieve that objective. This report does not include in-depth feasibility study of ecological benefits and financial costs of any alternative.

The utility of this report is its identification of potential alternatives, some of which have been evaluated in water plans for Region N. It provides stakeholders a general idea of factors involved in implementing alternatives. The BBASC or its members may use this information to focus future in-depth feasibility analysis.

Three principles, identified by regional experts interviewed for this study, guided this project:

- The Nueces Delta ecosystem existing prior to 1958 when Wesley Seale Dam was completed on the Nueces River cannot be replicated. Regardless, addition of water to the Delta should be maximized to the extent possible.
- Water should be added in locations, volumes, and frequencies, which provide the greatest ecological benefit for the cost of providing the water. Addition of relatively small volumes of water has had positive physical, chemical, and biological effects in the Delta.
- The Delta is part of the Nueces River tidal, Rincon Bayou, and Nueces Bay system. Addition of water to the Delta should be considered in the context of the ecological relationship between the bay and river. Preferred alternatives will be those which provide water to the Delta and improve, or at least do not degrade, ecological health of Rincon Bayou, Nueces Bay, or the Nueces River tidal.

3 Background

Prior to reservoir construction, the Nueces River flooded the Delta about three times each year (Nueces BBEST, 2011). In 1877 the upper Nueces Delta was considered "…a boggy area filled with pools of low-salinity brackish water." (Nueces BBEST, 2011). Since reservoir construction, the river floods the Delta about once every three years. As a result, freshwater inflow and sediment loading to the Delta have diminished over the past 30 years. Large areas of the Delta are frequently dry and become hypersaline, negatively impacting Delta vegetation, habitat and wildlife. Reduced sediment loading contributes to recession of the Delta face, lowered elevations and expansion of open water areas in the lower Delta. These open areas may flood on high tide and become hypersaline as water evaporates.

Municipal and industrial need for water has increased around Corpus Christi over the past 100 years. As demand for water increased, freshwater flow to the Delta, Nueces River tidal, and Nueces Bay has diminished.

To balance human needs for water with protection of the Nueces Estuary, controlled releases of water to the Nueces Delta are managed by an agreed order, Special Condition 5.B., of the water rights permit, Certificate of Adjudication No. 21-3214 issued by the Texas Commission on Environmental Quality's (TCEQ) predecessor agency, the Texas Natural Resource Conservation Commission. The certificate holders—City of Corpus Christi, the Nueces River Authority, and City of Three Rivers—manage freshwater releases to the Delta under the agreed order issued April 5, 2001. The City of Corpus Christi manages the reservoir system as stated in the agreed order.

The agreed order requires Corpus Christi to pass through the reservoir system up to 151,000 acre-feet of water per year to the Nueces Estuary through a combination of spills, releases, and return flows to maintain ecological health and productivity of the estuary. Freshwater inflow targets in the agreed order, designed to maintain ecological health of the estuary, depend primarily on the amount of water stored in the reservoir system (Choke Canyon Reservoir and Lake Corpus Christi) (Table 3).

Pass-through releases from the reservoir system to meet target inflows may be reduced under specific salinity conditions described in the agreed order or when there is inflow to the bay and Delta not resulting from spills from Lake Corpus Christi or pass-through releases. Corpus Christi and Nueces Estuary stakeholders including municipal, industrial, and agricultural water suppliers, scientific researchers, representatives of state and federal regulatory agencies, and non-governmental organizations have collaborated for over 30 years in balancing human and ecological needs for water in this semi-arid region. Considerable information on relationships between ecological health and freshwater inflows in Nueces Delta and the bay has been generated to support this balancing effort.

TABLE 3. Target Inflows to Nueces Bay and Nueces Delta in acre-feet.

Month	Reservoir System Capacity (≥70%)	Reservoir System Capacity (≥40% and <70%)	Reservoir System Capacity (≥30% and <40%)	Reservoir System Capacity (<30%)
January	2,500	2,500	1,200	0
February	2,500	2,500	1,200	0
March	3,500	3,500	1,200	0
April	3,500	3,500	1,200	0
May	25,500	23,500	1,200	0
June	25,500	23,000	1,200	0
July	6,500	4,500	1,200	0
August	6,500	5,000	1,200	0
September	28,500	11,500	1,200	0
October	20,000	9,000	1,200	0
November	9,000	4,000	1,200	0
December	4,500	4,500	1,200	0
Total	**138,000**	**97,000**	**14,400**	**0**

4 Study Area

Nueces Delta is in San Patricio County, Texas, and borders the north shore of the tidal reach of the Nueces River (Figure 1). The Nueces River tidal and the Delta drain into Nueces Bay. Rincon Bayou is the primary channel draining the Delta into the bay. The portion of the Delta upstream of the Union Pacific Railroad bridge and north of Rincon Bayou drains into Rincon Bayou. The portion of the Delta upstream of the Union Pacific Railroad bridge and south of Rincon Bayou drains into South Lake which also empties directly into Nueces Bay.

Substantial portions of West Lake (sometimes referred to as Goose Lake) and South Lake are dry much of the time and these dry areas can experience hypersalinity. Hypersalinity in this report represents salinities greater than 35 practical salinity units (PSU). These areas are in the upper Delta which is generally considered the area west of the Union Pacific Railroad. Because of this area’s distance from regular tidal inundation, it may experience the most direct effects from freshwater addition.

The area east of the Union Pacific Railroad is generally considered the lower Delta. Although portions of the lower Delta may experience high salinities, much of this area is regularly inundated by tides with salinities like those in Nueces Bay.

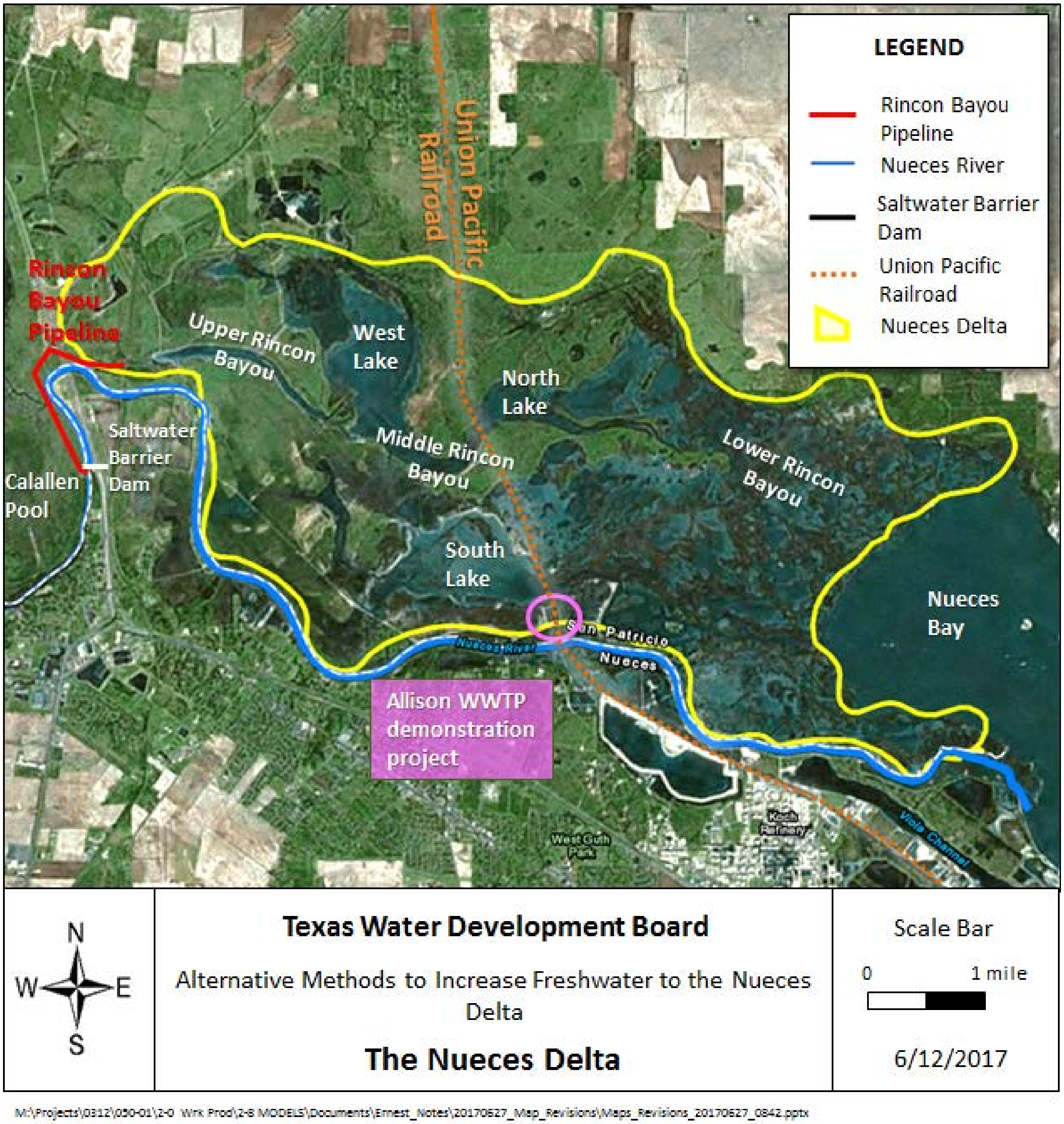

Figure 1. **Nueces Delta Study Area.**

5 Ecological Effects of Adding Water

The addition of fresh or low salinity water can ecologically benefit the Nueces Delta. Benefits depend on water quality (nutrients, salinity, sediments and presence of potentially toxic substances), volume, frequency, and location at which the water is added.

Continuous flow in Rincon Bayou and maintenance of salinities below 25 PSU in the Delta are important to its ecological health (Dodson et al., 2016; Montagna et al., 2016a; Montagna et al., 2016b).

Montagna et al. (2016b) recommended pass-through flows pumped to Rincon Bayou to maintain:

- salinity between 1 and 15 PSU;
- water depth between 0.2–0.7 foot (0.05–0.2 meter); and
- continuous flows of 29–48 acre-feet/day.

These flow rates are equivalent to 870–1,440 acre-feet per 30 days (10,600–17,500 acre-feet per year).

Dodson et al. (2016) recommended "regular inundation events" which would combine flows in Rincon Bayou with diversions from Rincon Bayou to the South Lake area. Inundation events would cover a substantial area that is usually dry to a depth of greater than or equal to 1 centimeter with water less than 25 PSU for one tidal cycle (approximately 6.2 hours) each day for at least 30 days. This approach would benefit up to 370 acres of Delta at pass-through inflows of 1,200 acre-feet per month and 610 acres of Delta at pass-through inflows of 3,000 acre-feet per month. Spring and early summer would be preferred seasons for these inundation events.

Dodson et al. (2016) also recommended diverting treated effluent from the town of Odem's municipal wastewater treatment plant to the Delta. Although the projected volume is relatively small, 153 acre-feet for 2015 (Nueces River Authority (NRA), 2016), they concluded it would create positive ecological benefits if discharged to an appropriate wetland location.

Forbes et al. (2008) recommended ways to apply treated wastewater to the Delta to achieve different ecosystem management goals:

- <u>To maintain endemic plant communities, discharges should mimic natural wet-dry cycles</u>. Their recommendation included alternating wastewater discharges between two or more areas so one area would be wet while another would dry out. This alternation between wet and dry would mimic a natural cycle of pulsed flows.
- <u>To increase plant productivity, maintain a continuous discharge to the same location</u>. Growth may decline over time requiring the addition of wastewater to be temporarily stopped and restarted to stimulate growth.

The Nueces BBEST (2011) identified two indicator species in the Delta, which can be used to guide addition of water.

- *Spartina alterniflora* protects recreationally, economically and ecologically important species of fish and shellfish. Juvenile Redfish, Spotted Seatrout, and Blue Crabs utilize the margins of *Spartina* marsh for shelter from predators and for food. Birds, like Clapper Rails, feed and nest in the marsh, while egrets and herons feed in the marsh and along its edge. There is relatively little *Spartina* marsh along the Texas coast south of Nueces

Delta. Research in the Delta indicates *Spartina* health declines when porewater salinities exceed 25 PSU. A flow of 30.8 acre-feet per day (924 acre-feet over a 30-day period) in Rincon Bayou was estimated necessary to keep porewater salinity along Rincon Bayou below 25 PSU.

- Benthic macroinvertebrates like polychaetes and amphipods play important ecological roles, aerating sediments, mobilizing nutrients, and creating biomass which feeds a variety of fish and shellfish from detritus. Several studies conducted in Rincon Bayou since 1990 show upper Rincon Bayou salinities from 16–19 PSU are preferable for benthic macroinvertebrates.

6 Methods

Recommendations to increase the amount of water to the Nueces Delta were obtained in two steps:

- expert interviews, and
- data collection and information review.

Interviews were conducted with thirteen experts experienced with the Nueces Delta along with Kathy Alexander, who provided advice on water rights and interbasin transfer regulations (Table 4).

TABLE 4. Experts Interviewed for the Project.

Name	Affiliation	Interview Date
Alexander, Kathy	TCEQ	March 17, 2017
Allen, Ray	Coastal Bend Bays and Estuaries Program	November 3, 2016
Dodson, James	Private consultant	March 21, 2017
Dunton, Ken	University of Texas Marine Science Institute	January 30, 2017
Francis, Larijai	City of Corpus Christi	January 10, 2017
Freund, Rocky	Nueces River Authority	January 10, 2017
Hodges, Ben	University of Texas at Austin	December 16, 2016
Montagna, Paul	Harte Research Institute	January 30, 2017
Moulton, Bruce	Private consultant	November 18, 2016
Ramos, Esteban	City of Corpus Christi	January 10, 2017 and May 19, 2017
Shockley, Cory	HDR	November 1, 2016
Smith, Tony	Carollo Engineers	November 18, 2016
Tunnell, Jace	Mission-Aransas National Estuarine Research Reserve	December 1, 2016
Ward, George	University of Texas at Austin	December 16, 2016

Each expert was asked if he/she had ideas about ways more water could be added to the Nueces Delta. We discussed each idea and asked each expert to comment on ideas suggested by other experts.

After expert interviews, we gathered information from existing literature and data sources to help evaluate each idea for adding water to the Delta. Considerable information was derived from regional water plans developed for Region N.

Categories of information included in analyses were:

Costs: The cost per acre-foot of water added to the Delta is estimated whenever possible. Estimated costs to construct and operate alternatives have been generated for some versions of some of these alternatives during the regional water planning process. Costs for some alternatives were not available. When possible, we attempted to find costs for similar projects in the same water planning region, Region N, and the sources of those costs are cited in the report. Costs were based on best professional judgment of the authors when other sources could not be identified.

Source: The surface water body or groundwater aquifer which would be the source of water is identified.

Amount: The amount of water which could be added to the Delta is estimated. Volumes have been estimated for some versions of these alternatives during the regional planning process. Volume estimates are not readily available for some alternatives and in some cases are based on best professional judgment. Some alternatives could provide steady flows or variable flows while other alternatives would only provide increased volumes of flow during high flows or when there was an ecological need to add water. Actual amounts of water provided would vary with the ability of the source to provide water, ecological needs, and costs.

Point(s) of addition: The area of the Delta to which water would be added is identified.

Effects of removing and Effects of adding water: In most cases, ecological effects of adding water are described in Section 4, “Effects of Adding Water.” Those ecological effects are not repeated for each alternative for which they are appropriate. These two sections attempt to capture general expected ecological effects and possible human concerns of taking water from the source as well as adding water to the Delta if effects differ from those described in Section 4.

Regulations: This section attempts to capture possible regulatory requirements but should not be considered a complete list, particularly since regulatory requirements continue to change.

Time: For most alternatives, the amount of time it would take to conduct feasibility studies, satisfy regulatory requirements, and implement an alternative to the extent water is being added to the Delta, is not known. Timing will vary depending on funding available, regulations, and public involvement. Unless otherwise specified with a literature citation, the amount of time it would take for an alternative to add water is based on best professional judgment.

7 Alternatives

Two projects have been implemented which provide freshwater to the Nueces Delta. These projects do not increase the amount of water provided to Nueces Bay over amounts required by the agreed order. They increase the amount of water provided as pass-through releases moving through the Delta instead of being transported by the Nueces River tidal to the bay.

1. The Nueces Overflow Channel was constructed in 1995 as part of a study called the Rincon Bayou Demonstration Project to divert more flood flow from the Nueces River to Rincon Bayou and through the Delta. Prior to the project, high river flows moved down the tidal river and bypassed the Delta (Bureau of Reclamation, 2000). Rincon Bayou almost immediately experienced positive effects of lower salinity, experiencing increases in benthic and planktonic algal production and abundance, biomass, and diversity of benthic macroinvertebrates. The diversion channel was closed after completion of the initial project in 2000 and reopened in 2001. At times, some high tides pushed water upstream in Rincon Bayou into the Nueces Overflow Channel, all the way to the Nueces River tidal. The maximum annual amount authorized for diversion through the Nueces Overflow Channel is 8,000 acre-feet.

2. The Rincon Bayou pump station and pipeline began operating in 2007 (Lloyd, 2016), pumping water from the Nueces River upstream of Calallen Dam to Rincon Bayou about 0.4 river mile downstream of the connection of the Nueces Overflow Channel with the Nueces River tidal (Figure 2). After implementation of this project, a water control structure was installed on Rincon Bayou upstream of the discharge to prevent water flowing upstream towards the Nueces River tidal instead of downstream through the Delta. This structure, which must be opened and closed manually, must be opened to allow water entering the Nueces Overflow Channel flow into Rincon Bayou.

   Most pass-through releases up to 3,000 acre-feet per month are now pumped through the Rincon Bayou pipeline.

   The pump station includes three pumps. Flow capacity is 124 acre-feet per day with one pump, 203 acre-feet per day with two pumps, and 265 acre-feet per day with three pumps. The pumps can meet pass-through release requirements of the agreed order targets in many months.

Fourteen alternatives are summarized in this report which may add more water to the Delta and four alternatives are reviewed which would enhance ecological health in the Delta by changing ways water is added to the Delta or modifying ways that current additions of water move through the Delta.

Figure 2. Rincon Bayou Diversion. View towards upstream with discharge point on the right and water control structure upstream. January 30, 2017.

7.1 Alternative 1: Nueces River Tidal Diversions

Water would be moved from the Nueces River tidal to the Delta by one or more of three approaches (Figure 3) in this strategy.

- Structures, whether permanent weirs or inflatable dams, in the Nueces River tidal would raise water levels during high flows in the river above the left (north) bank, forcing water to flow from the river into the Delta. These structures would provide water to the Delta resulting from rainfall events over the watershed downstream of Lake Corpus Christi and from spills from Lake Corpus Christi which in the past flowed down the Nueces River tidal.
- Lower the left bank of the river to allow water at high flows (which are below flood flows) to move from the river onto the Delta.
- Install pumps on the river to pump river water to the Delta.

Weirs or inflatable dams could be placed in locations to maximize ecological benefits of diversions. The left river bank in certain areas could be lowered to facilitate flow out of the river into different areas of the Delta during high flow (Dodson et al., 2016). Historical accounts indicate the left river bank may have been raised to protect farmland on the Delta from flooding.

Analysis

Cost: Place a structure in the Nueces River tidal to force flow over the bank into the Delta (without pumps or pipes) combined with lowering the left bank of the Nueces River tidal:

$149 per acre-foot over 20 years (assuming one hard dam, 4,100 feet of bank lowered, causing 5,000 more acre-feet to flood into the Delta each year)

$129 per acre-foot over 20 years ((assuming one inflatable dam, 4,100 feet of bank lowered, causing 5,000 more acre-feet to flood into the Delta each year)

- Hard dam (1): $5 million to complete project, $420,000 annual operating (estimated from cost of building local balancing storage reservoir for Nueces County WCID #3, i.e. cost of dam without pumps or pipes) (Coastal Bend Regional Water Planning Group (CBRWPG), 2015).
- Inflatable dam (1): $3 million (estimated from cost of inflatable dams for projects in the Delta) (Dodson et al., 2016)
- Lowering bank of Nueces River tidal: $1.5 million (estimated from cost of constructing 4,100 feet of 100-foot wide channel in the Delta) (Dodson et al., 2016)

Install a pump on the river: **$202 per acre-foot over 20 years.** $3.2 million to complete project, $290,000 annual operating (estimated from cost for local balancing storage reservoir for Nueces County WCID #3) (CBRWPG, 2015).

Source: Nueces River tidal

Amount: Cost is variable depending on the number of dams, pumps, and reach (s) of river bank lowered. For example:

- One 10-million gallon per day (MGD) pump or five 2-MGD, pumps could divert 29 acre-feet per day of continuous flow for an undetermined time. Pumps could be turned off when naturally high flows were entering the Delta or during wet seasons when hypersaline conditions are less likely to develop.

- Ex. 640 acre-feet per day during high flow events. The Nueces River at the Calallen U.S. Geological Survey (USGS) gage (8211500) recorded flows ranging from 490–2,040 acre-feet per day and totaling 19,000 acre-feet over the two-week period from October 25 to November 7, 2013. The Rincon Bayou USGS gage (08211503) did not record downstream flows during the same period indicating all the flow went down the Nueces River tidal. If half the flow could have been diverted from the tidal river into Rincon Bayou or the Delta, the Delta could have received over 9,000 acre-feet during the two-week flow event.

Designs would ensure raised water level would not flood private property and residences along the right bank (south shore) of the river.

Source location: Locations of structures and pumps or lowered river bank would be based on cost-effectiveness of construction and ecological benefit of moving the water to the Delta in different locations.

Delta location: South Lake basin upstream of the Union Pacific Railroad or downstream of the Union Pacific Railroad along the south side of the Delta

Effects of removing water: Reduced amounts of freshwater would be expected to reach Nueces Bay due to loss of water to evaporation, transpiration and seepage into the ground as water crossed the Delta on its way to the bay.

A potential issue is the use of the tidal reach of the river by Diamondback Terrapins which migrate up the river and use it as a lower salinity refuge when salinities are rising in the marsh. This is particularly the case near the Allison Wastewater Treatment Plant (WWTP) discharge into the river. Turtles have been observed concentrating near the discharge (Ray Allen, personal communication).

Removing water from the river may decrease its rate of water exchange with the bay, potentially increasing salinities due to evaporation, lowering dissolved oxygen, and allowing more algal blooms to occur in the tidal reach of the river.

Effects of adding water: See Section 5.

Regulations: TCEQ water rights permits with interbasin transfer authorizations may be required to force water over the shore or pump water from the river.

USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Use Lease may be required to modify the shore and install dams and infrastructure.

Other factors to consider: Recreational boaters and anglers may be concerned about possible effects of structures on their access to the Nueces River. Residents along the river would be expected to express concern about possible flooding of their property. Pumps and intakes may be exposed to flooding during tropical storms, hurricanes and significant rainfall runoff events.

Time: Hard dam (one): Eight years
Inflatable dam (one): Five years
Lowering bank of Nueces River tidal: 1.5 years
Installing pump: 2.5 years

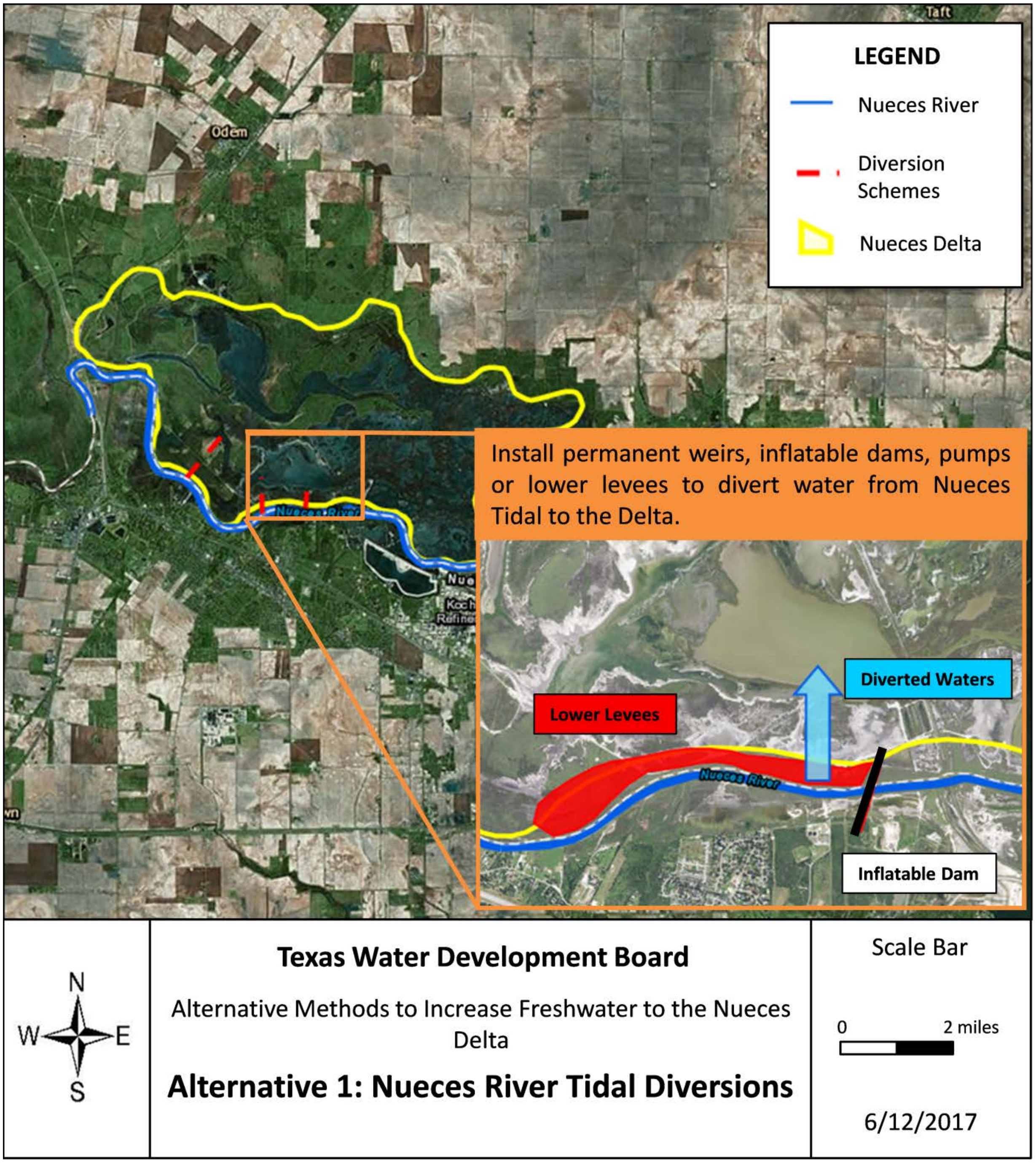

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Figure 3. Nueces River Tidal Diversions.

7.2 Alternative 2: Nueces Bay/Corpus Christi Inner Harbor Additions

Water could be pumped from Nueces Bay or the Corpus Christi Inner Harbor to the Delta (Figure 4). This approach would be implemented during drought when salinities exceeding 35 PSU begin to develop in the Delta and there are few or no sources of fresh or brackish water flow to the Delta. The principle behind this alternative is that it would be helpful to add saline water to the Delta if it could prevent or minimize development of hypersaline conditions.

Analysis

Cost: **$855 per acre-foot over 20 years.** (This assumes a cost of $3.7 million to install 6.1-acre-foot/day pump station and 7 miles of 10-inch diameter pipeline from Nueces Bay or the Viola Turning Basin of the Corpus Christi Inner Harbor to Upper Rincon Bayou. This also assumes it would only be used during dry spells, about 25 percent of the time, when there would be no pass-through releases to the Delta and salinities in Rincon Bayou would start to exceed 35 PSU.)

Source: Nueces Bay and/or Corpus Christi Inner Harbor

Amount: 6.1 acre-feet per day when salinities at the Nueces Delta 2 salinity monitoring site (042, NUDE2) exceed 35 PSU.

Source location: Nueces Bay near the shore of the Nueces Delta or the Corpus Christi Harbor Viola Turning Basin shore

Delta location: Upper Rincon Bayou above the confluence with West Lake

Effects of removing water: A potential impact associated with pumping water from the bay may be entrainment of larval fish and shrimp near the intake. Many would survive but some mortality would occur. Pumping during winter should have less impact on larval organisms while pumping during April and May (Tolan and Newstead, 2004) would be expected to have the greatest impact. Pumping from near the Delta face or within the Delta would be expected to have greater entrainment effects than from the open water of the bay or Corpus Christi Inner Harbor.

One potential issue with this approach is that salinities in the upper end of Nueces Bay (SALT03 salinity data (Conrad Blucher Institute (CBI), 2017)) and the surface of the Inner Harbor (TCEQ, 2017) appear to exceed 35 PSU approximately 25 percent of the time. When salinities in Rincon Bayou reach 35 PSU or higher, salinities in the bay and Inner Harbor may also exceed 35 PSU. A continuous flow with salinity ranging from 40–45 PSU may be preferable to an extended period of salinities exceeding 70 PSU in Rincon Bayou.

Salinity data were analyzed from continuous monitoring stations in Nueces Bay (SALT03, 074) and Rincon Bayou (NUDE2, 042) over the period from August 1, 2013 through July 30, 2017 (CBI, 2017). At times when Nueces Bay salinities (SALT03) equaled or exceeded 35 PSU during this period, Rincon Bayou salinities (NUDE2) averaged 22 PSU and ranged from 0.4 to 49.4 PSU. Conversely at times during 2014 when salinities in Rincon Bayou were consistently above 40 PSU and reached 49 PSU, salinities in Nueces Bay averaged 37 PSU.

Effects of adding water: Continuous flow with salinity of 35 PSU or less with water from Nueces Bay or the Corpus Christi Inner Harbor may prevent hypersaline conditions developing in Rincon Bayou. Salinity data from the Nueces Delta 2 salinity monitoring site has reached 96 PSU, and salinities at this monitoring location can exceed 35 PSU when there are no pass-through releases to Rincon Bayou. A possible additional benefit of pumping from the bay would be movement of sediment in the frequently turbid Nueces Bay water to the upper end of the Delta.

Regulations: USACE Section 404 permit, TCEQ 401 water quality certification, TCEQ water rights permit, and Texas General Land Office State Land Use Lease may be required to install the pump station and pipeline.

Other factors to consider: Pumps and intakes may be exposed to flooding during tropical storms and hurricanes. Pipes may cross private lands, requiring coordination with private landowners. The cost-effectiveness of this alternative may be limited about the amount of time when hypersalinity is developing in the Delta and bay salinities are at 35 PSU or less.

Time: Three years

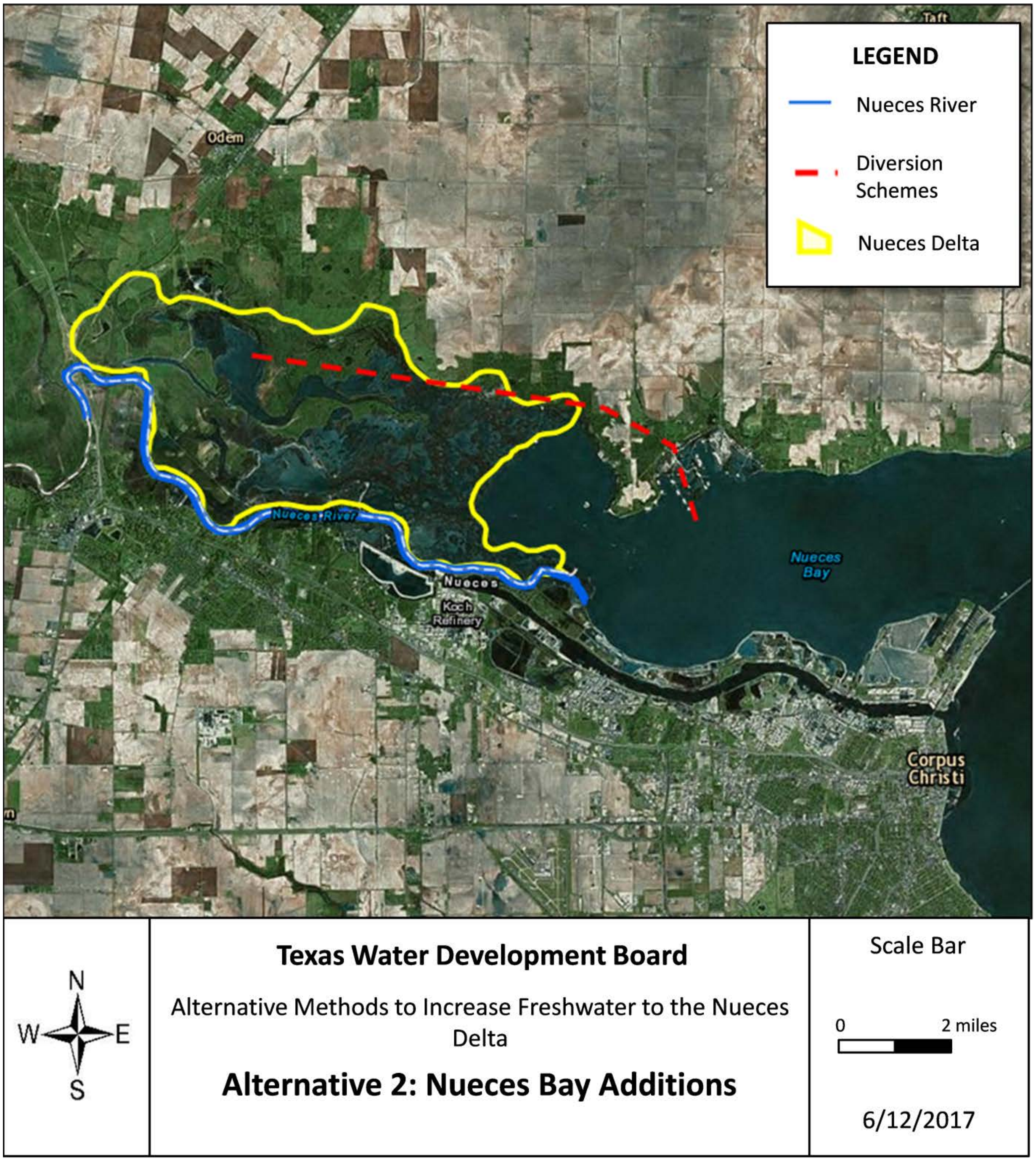

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Figure 4. Addition of Water from Nueces Bay or the Corpus Christi Inner Harbor.

7.3 Alternative 3: Hondo Creek Realignment

Hondo Creek flows into the left bank of the Nueces River tidal downstream of Calallen Dam about 0.4 river mile upstream of the I-37 bridge (Figure 5). Its watershed covers about 10 square miles immediately west of I-37 and north of the Nueces River. This alternative would realign the lower reaches of Hondo Creek's channel so it flows directly into Rincon Bayou. Hondo Creek is spring-fed (Rocky Freund, 2017, personal communication). Hondo Creek flow is not gaged so it is not known exactly how much water it may provide. The watershed floods when the Nueces River floods out of its banks and retains water for some time after flood events have passed.

Analysis

Cost: $190 per acre-foot over 20 years for 2,200 acre-feet per year.

$72 per acre-foot over 20 years for 5,800 acre-feet per year.

Estimates are based on costs to excavate 76,270 cubic yards at $20 per cubic yard from a 1.5-mile channel, 65 feet wide and 4 feet deep. A total cost estimate of $8.3 million includes $2.2 million to build and $6.1 million for 20 years of operation and maintenance.

Flow estimates do not include flood flows channeled into the Delta from Hondo Creek during overbanking floods.

Source: Hondo Creek and Hondo Creek watershed

Amount: According to National Hydrography Dataset (NHD)Plus, the average flow of this ungauged watershed is estimated to be between 6 and 16 acre-feet per day (180–480 acre-feet per 30 days or 2,200–5,800 acre-feet per year). This would be continuous flow. Data should be collected to confirm actual flow rates in Hondo Creek. Actual continuous flows substantially lower than those estimated by the National Hydrography Dataset would cause a proportionally large increase in costs per acre-foot of water provided.

Source location: The new channel might cut off the existing channel about 1,000–2,000 feet upstream of Hondo Creek's confluence with the Nueces River tidal.

Effects of removing water: Freshwater, nutrients and sediment loading typically entering the Nueces River tidal from Hondo Creek would flow into Rincon Bayou. It would be difficult to predict the effects of removing this water from the Nueces River tidal under normal to low flow conditions. Salinity may increase in the Nueces River tidal. The delta of the Nueces River tidal where it enters Nueces Bay would lose sediment loading from the Hondo Creek watershed as that sediment is moved into Rincon Bayou.

Effects of adding water: This may create continuous flow into Rincon Bayou which would maintain ecologically favorable salinities when there would not be pass-through releases through the Rincon Bayou diversion. It would also add nutrients and sediment directly to the Nueces Delta instead of the river. Nutrient and sediment contributions from the Hondo Creek watershed would be expected to be relatively small. It may also extend the period of elevated flows into the upper Delta after flooding in the basin downstream of Lake Corpus Christi as floodwaters drain from the watershed. The period of freshwater runoff following flooding which flows into the Nueces Delta from Hondo Creek would be extended an unknown amount of time, possibly days or weeks.

Regulations: TCEQ water rights permits with interbasin transfer authorizations may be required to divert water from Hondo Creek to Rincon Bayou from the river. USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Use Lease may be required to create the new channel.

Other factors to consider: Key factors in consideration of this alternative are landowner(s) cooperation and effects of land modification associated with rerouting.

Time: Five years

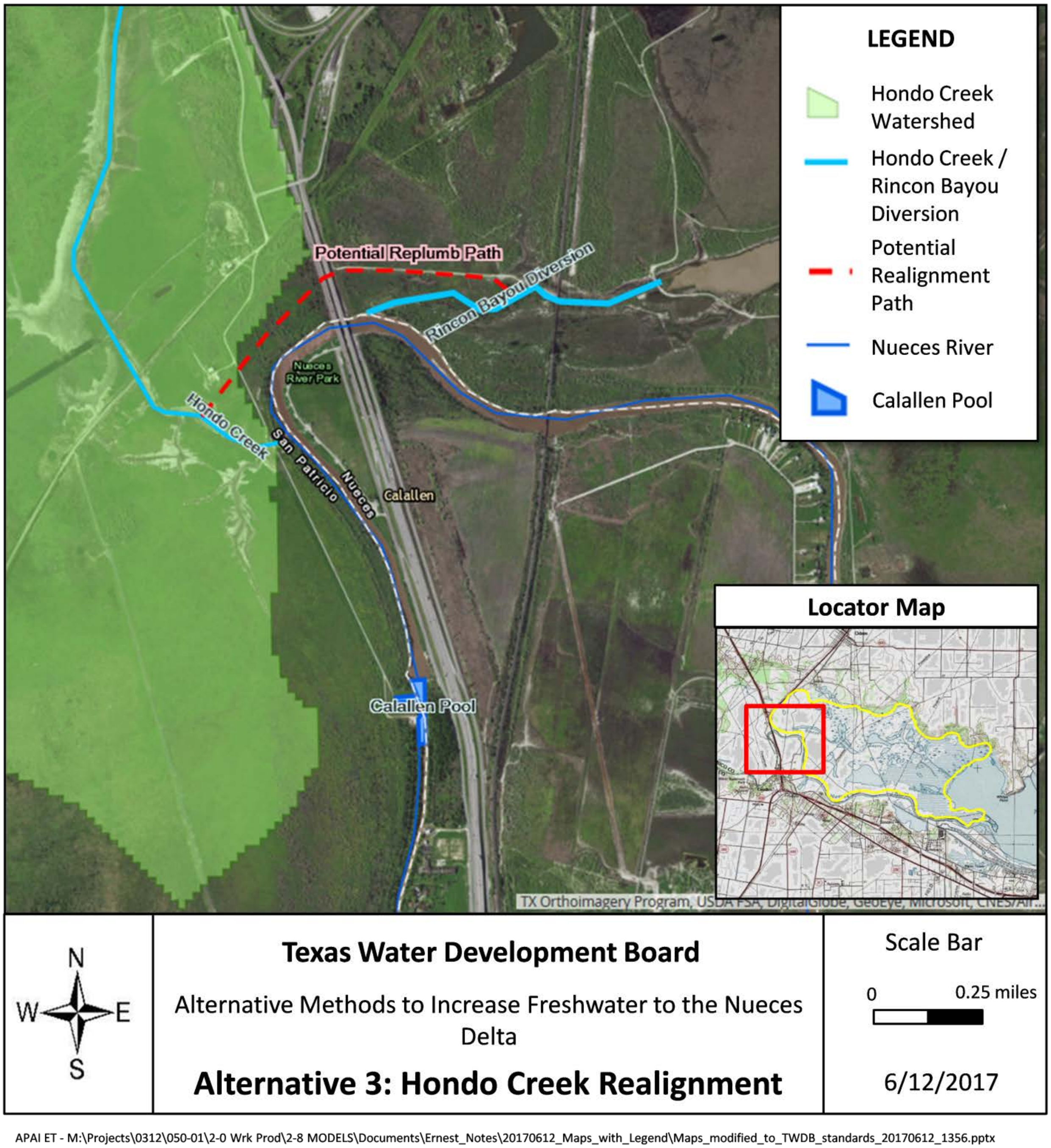

Figure 5. Hondo Creek Realignment.

7.4 Alternative 4: Deep-Water Wells in Nueces Delta

One to several deep-water wells (perhaps greater than 1,000 feet in depth) could be installed at selected points in or near the Nueces Delta to pump brackish groundwater (Figure 6). Operation of these wells might occur when conditions are dry and there are no pass-through releases. Application of well water only to help prevent hypersaline conditions from developing would minimize potential impacts caused by continuous groundwater withdrawal.

An advantage of this alternative may be its capability to function partially as aquifer storage and recovery. When freshwater inflow to the Delta is high, these wells may be able to inject high flows and floodwaters into the aquifer for future use.

One concern would be placement of wells so they would not be flooded when the Delta episodically floods. A variation of this alternative would be construction of a brackish water well field outside the Delta. There are areas near the Delta with adequate elevation to avoid flooding. Costs would be higher in this case because of the need to move water to the Delta from the well field.

Analysis

Cost: **$159-$302 per acre-foot** (CBRWPG, 2015). $6,700,000 per year for 18,000 acre-feet per year (CBRWPG, 2009). Development of a single well may cost $1,685,000 (CBRWPG, 2015). Another study for a confidential client suggested cost to install six wells providing a total of 1,600 acre-feet per month at peak operation may reach $14 million. A feasibility study of deep wells providing water may cost approximately $3.5 million and would include drilling one test well designed to be an operating well in the eventual well field.

Source: Gulf Coast Aquifer

Amount: Ex. 18,000 acre-feet per year from the Gulf Coast Aquifer in Bee County (CBRWPG, 2009)

Total modeled available groundwater for San Patricio County Groundwater Conservation District (19,013 acre-feet per year) (San Patricio County Groundwater Conservation District (SPCGCD), 2017) and the Corpus Christi Aquifer Storage and Recovery Conservation District (2,526 acre-feet per year) will be 21,539 acre-feet per year in 2020 (Corpus Christi Aquifer Storage and Recovery Conservation District (CCASRCD), 2014).

Whether wells provide continuous flow or only during dry conditions without pass-through releases will depend on operating costs, effects on groundwater, and desired ecological outcomes.

Delta location: One or more locations would be selected in the upper and lower portions of the Delta, which would be considered important for preventing development of hypersaline conditions.

Effects of removing water: Concerns include potential land subsidence and faulting. Providing 18,000 acre-feet per year was estimated to drawdown the groundwater level of the Gulf Coast Aquifer in Bee County by 50 feet which was within criteria at the time (CBRWPG, 2009). Since many small streams are intermittent in Bee County, aquifer drawdown was expected to have minimal effect on base flow in Bee County streams. Withdrawal of Gulf Coast Aquifer water in the Nueces Delta should not affect base flow in any streams.

Effects of adding water: Total dissolved solids concentrations of test wells ranged from 671–1,120 mg/L (CBRWPG, 2009). Some groundwater wells could be strategically located and operated nearly continuously within the Delta so they discharge directly to desirable locations for wetland development. Other wells could be in areas where discharges would prevent development of hypersaline conditions. Well water with total dissolved solids concentrations approaching 20,000 mg/L may be acceptable for these purposes. Testing would be necessary to show there would not be toxicity or impairment caused by the ionic composition of the groundwater.

Regulations: Permitting requirements of the Corpus Christi Aquifer Storage and Recovery Conservation District which covers most of the southern two-thirds of the Delta and the San Patricio County Groundwater Conservation District covering the northern portions of the Delta would have to be met. A TCEQ water rights permit may be required. The TCEQ may require treatment of water injected into the aquifer which would increase the cost of this alternative. If treatment is required, the additional cost would vary with the quality of the water being treated.

USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Use Lease may be required to install the well infrastructure and pipelines.

Other factors to consider: Well-heads would need protection from flooding if placed in or near the Delta. Members of the public with private wells in the vicinity would be expected to express concerns about possible impacts of groundwater withdrawal on their private well production and water quality.

Time: Five years

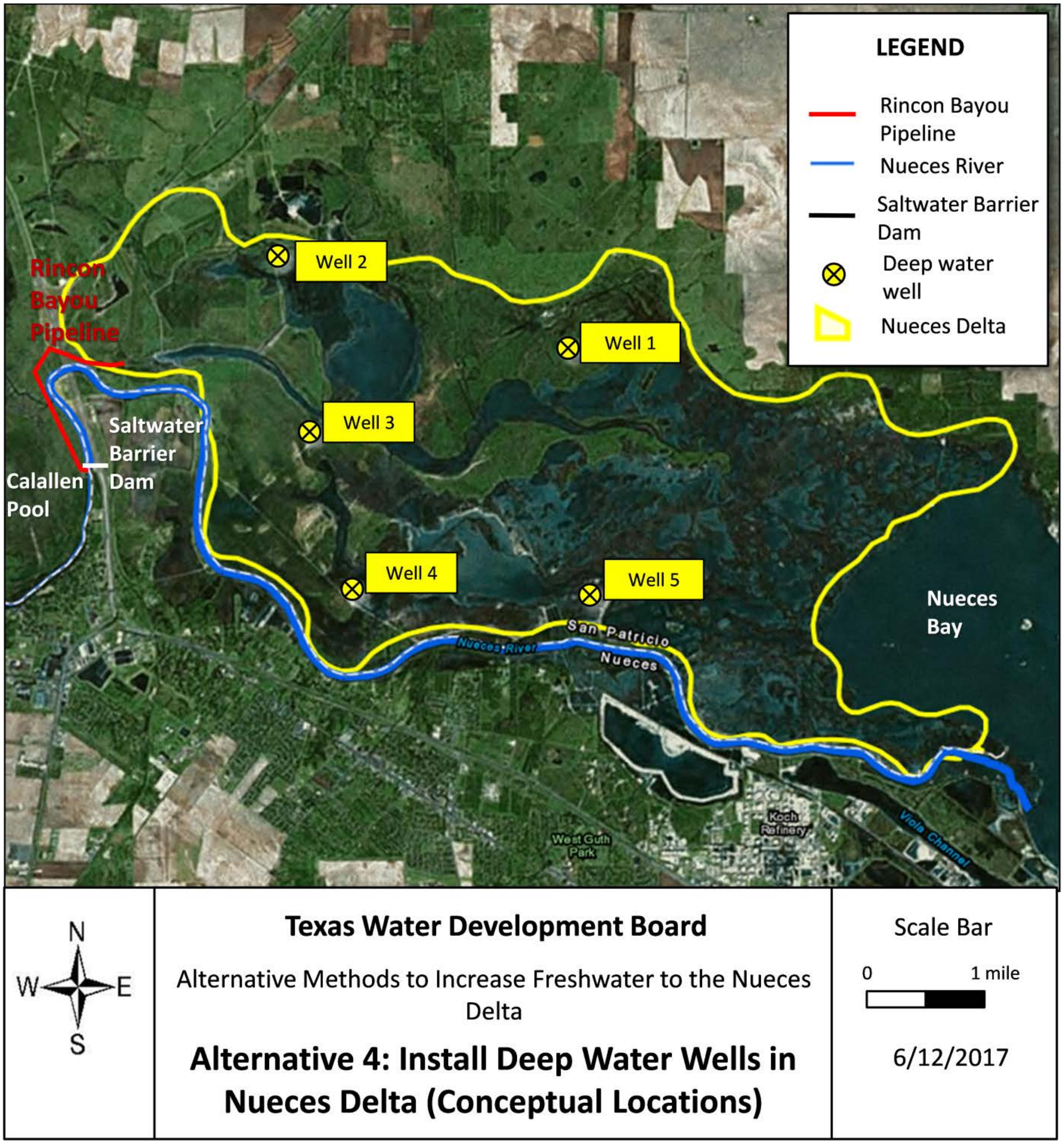

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Figure 6. Deep-Water Wells in Nueces Delta.

7.5 Alternative 5: Sand/Gravel/Caliche Mine Ponds

Sand/gravel/caliche mine ponds on private property north of West Lake have held water from 1961 to present based on review of Google Earth aerial photography (Figure 7). Source of water in the ponds is unknown but may be primarily shallow groundwater. The landowners have not been interested in selling the property in the past. Although they have not wanted to sell the property, selling water from the ponds may provide additional income which may appeal to them. A potential advantage to this alternative is movement of water to the Delta could occur via gravity flow. Addition of water might be accomplished with little new infrastructure and energy to transport water to the Delta.

The ponds could also provide a small off-channel reservoir location. Pond levees could be raised, ponds could be connected or deepened, and stormwater could potentially be moved from Peters Swale which transports rainfall runoff to Chiltipin Creek.

Analysis

Cost: Ex. $100 per acre-foot. The price would be negotiated with the seller but could be lower or higher than this amount but should not exceed $326 per acre-foot (cost of City of Corpus Christi untreated water).

Source: Sand/gravel/caliche mine ponds on private property north of West Lake and south of Odem

Amount: Unknown. The area covered by ponds is 94 surface acres (estimated from January 2, 2017 aerial photo available on Google Earth). If the source of water for the ponds is shallow groundwater, the quantity available to the Delta will depend on groundwater flow rates into the ponds in wet and dry periods. The ponds may be able to sustain a relatively small continuous flow or they might be used to provide episodic flushing flows. The amount of water available will also be influenced by evaporation rates on the ponds.

Delta location: West Lake

Effects of removing water: Discharge of water should not be allowed to interfere with private use of the water. Ponds provide habitat for waterfowl and the landowner leases the property for waterfowl hunting. Mining may still occur with pond water used to wash mined material.

Effects of adding water: It appears water may already drain from channels, both man-made and natural, from the ponds to the north side of West Lake. If mining continues, it may be possible to time water releases with times when suspended solids are high so more sediment can be moved to the Delta.

Regulations: USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Use Lease may be required to install any infrastructure like drains or gates necessary to facilitate controlled release of water from the ponds.

If discharge of water from the ponds affects groundwater conditions, the San Patricio County Groundwater Conservation District may have some regulatory authority. A TCEQ water rights permit may be required.

Other factors to consider: The private landowner(s) would be expected to express concern about use of water in the ponds and how it might impact their economic interests and quality of water in the ponds.

Time: Four years

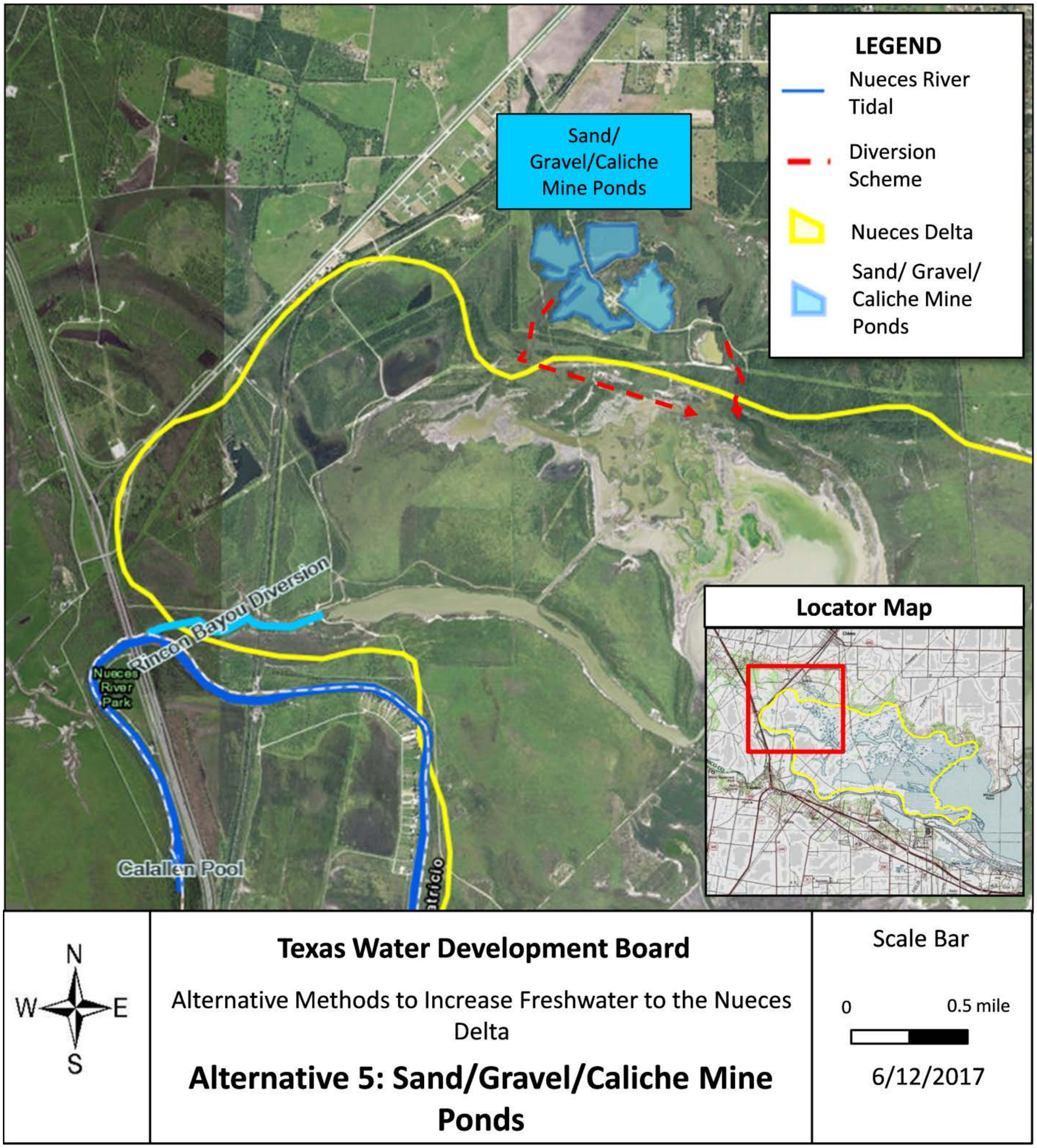

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Figure 7. Sand/Gravel/Caliche Mine Ponds.

7.6 Alternative 6: Allison Wastewater Treatment Plant

Treated wastewater has been discharged from the Allison WWTP (TCEQ wastewater discharge permit WQ0010401006) in the past to South Lake (Figures 8 and 9). The facility's wastewater discharge permit allows a daily average discharge of 6 acre-feet per day (2 MGD) to be discharged to the Delta. The City of Corpus Christi receives return flow credits each month for the treated wastewater discharged from the Allison Wastewater Treatment Plant.

This permitted discharge took place from 1998 through 2010 with intensive monitoring conducted of the discharge's effects in the Delta from 1998–2002 (Alexander and Dunton, 2006). Positive ecological effects of the discharge into the Delta included habitat creation for birds. Discharge stopped when the U. S. Environmental Protection Agency (EPA) and TCEQ required discharges to the Delta to meet a daily average of 4 mg/l ammonia-nitrogen limit due to EPA's concern with possible toxicity of ammonia discharged to the Delta.

Corpus Christi would have to pay increased treatment costs to reduce ammonia-nitrogen to 4 mg/L for the discharge to the Delta to resume. It has been more cost-effective for the city to discharge all of Allison's WWTP treated effluent to the Nueces River tidal. Considerable effort by stakeholders has been exerted to convince EPA and TCEQ that the ecological benefits of discharging the treated effluent with an ammonia-nitrogen limit of 12 mg/L (the limit allowed for discharge to the Nueces River tidal) outweigh concerns about potential toxic effects (Dodson et al., 2016).

Figure 8. Allison Wastewater Treatment Plant Discharge Demonstration Site (January 30, 2017).

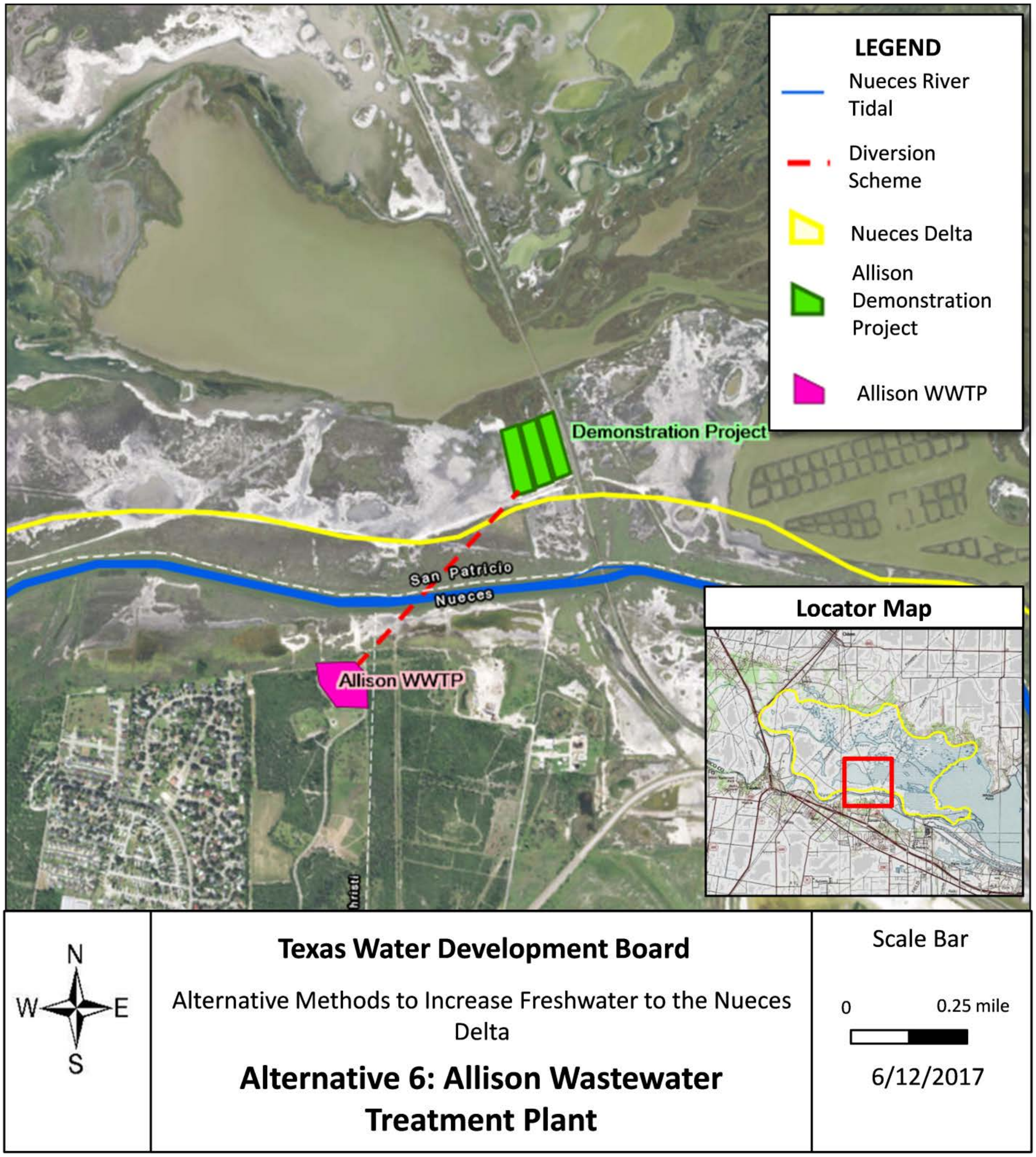

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Figure 9. Alternative 6: Allison Wastewater Treatment Plant.

One possible option to move much of the Allison treated wastewater to the Delta without having to meet the 4-mg/L ammonia-nitrogen limit would involve placing an intake in the river near the WWTP discharge and pumping water from the river near the discharge into the Delta. Pumping would remain a transfer from one "water of the U.S." to another and potentially avoid the more stringent wastewater permitting requirements.

The Region N water plan (CBRWPG, 2015) evaluated the possibility of diverting effluent from the Broadway and Greenwood wastewater treatment plants to the Allison wastewater treatment plant and moving the treated effluent to Rincon Bayou. Three scenarios were considered: 12 acre-feet per day from Allison, 28 acre-feet from Allison and Broadway, and 61 acre-feet per day from Allison, Broadway and Greenwood. The cost of providing treated effluent to Rincon Bayou for these scenarios ranged from $4 to $563 per acre-foot. Corpus Christi's city council considered consolidation of several existing wastewater treatment plants but voted at their June 13, 2017 meeting not to proceed with consolidation.

Options which might allow the discharge to the Delta to resume without the cost of more stringent treatment include:

- Amending the permit to move Outfall 002 to the downstream end of the Allison Demonstration Project in South Lake (Figure 10). Flow could enter one of the three constructed basins and pass through all three basins before being discharged to South Lake. This suggested option would require wastewater to travel nearly 0.5 mile through the treatment cells, possibly tripling retention time and biological uptake of ammonia-nitrogen before discharge. In the current configuration, each of three basins has an individual discharge to South Lake.
- Commingling the effluent with another source of water (ex. deep-well groundwater in the Delta) so ammonia-nitrogen is diluted below 4 mg/L as a daily average.

Analysis

Cost: $38 per acre-foot using existing infrastructure but not including treatment costs to supply effluent meeting the permit requirement of a daily average of 4-mg/L ammonia-nitrogen ($84,000 operating cost per year to move water to the Delta, 6 acre-feet per day for 365 days) (CBRWPG, 2010)

If water was pumped from the river near the wastewater treatment plant's discharge, the estimated cost would be: **$202 per acre-foot over 20 years.** ($3.2 million to complete project, $290,000 annual operating (estimated from cost for local balancing storage reservoir for Nueces County WCID #3)) (CBRWPG, 2015).

If the effluent is commingled with water from a deep groundwater well, the cost of providing water may range from **$197–$340 per acre-foot ($38 per acre-foot cost of moving effluent from the treatment plant added to the $159–$302 per acre-foot estimated to develop deep ground water wells)** (CBRWPG, 2015).

Source: City of Corpus Christi Allison Wastewater Treatment Plant treated effluent

Amount: Six acre-feet per day from Allison WWTP Outfall 002 as continuous flow. The total permitted discharge from the WWTP is 15 acre-feet per day (5.0 MGD from outfalls 001 and 002). Outfall 001 discharges to the Nueces River tidal. The actual daily discharge from the

WWTP was 8.3 acre-feet per day (2.7 MGD) in 2015 and was entirely from Outfall 001 to the river.

Delta location: South Lake upstream of the Union Pacific Railroad bridge

Effects of removing water: Reducing effluent discharge to the river reduces nutrient loading and potential for algal blooms and development of hypoxic conditions in the Nueces River tidal. These conditions have caused fish kills prior to the discharge's diversion in 1998 to the Delta (Texas Parks and Wildlife Department, 2017).

Figure 10. Possible change in location for Allison WWTP Outfall 002.

This alternative removes a freshwater source to the Nueces River tidal. Anecdotal information suggests Diamondback Terrapins may congregate at the wastewater plant discharge when salinities are high because it is the sole source of freshwater to the river under those conditions (Ray Allen, personal communication).

Effects of adding water: Positive effects of the Allison wastewater discharge to the South Lake area showed (Dunton and Hill, 2006):

- Plants grew, covering bare ground and plant diversity increased,
- Increased use of the area by shorebirds, and
- Nitrogen taken up as water moved through the demonstration site.

Regulations: The WWTP permit from TCEQ already allows discharge of up to 6 acre-feet per day of effluent with a daily average ammonia-nitrogen concentration of 4-mg/L to the Delta. Corpus Christi could evaluate modifying its discharge permit to allow all its effluent discharged to the Delta. The facility's estimated flow by 2045 would be 12.3 acre-feet per day (4.0 MGD). TCEQ water rights permit may be required.

Other factors to consider: Potential considerations which threaten the option of renewing the discharge to the Delta include:

- Cost of treating wastewater to meet a daily average concentration of 4-mg/L ammonia-nitrogen.
- Age and poor condition of the facility which is causing the city to consider options of moving the wastewater treated by the Allison facility to a new wastewater treatment facility referred to as the "North" plant in the city's wastewater management plan (Stantec Consulting, 2016).
- Interest in selling effluent to industries to satisfy industrial demand. For example, Flint Hills has expressed interest in purchasing treated effluent from this facility.

Time: No additional time is required for permitting however substantial time and funds would be needed to modify the treatment system to meet the 4-mg/L ammonia-nitrogen limit requirement to allow discharge to the Delta. The cost of maintaining and operating this facility makes it economically challenging to consider spending money to treat waste to a more stringent level of treatment than currently required. The estimated cost of repairing and rehabilitating the facility is estimated at $17 million over the next 10 years (Stantec Consulting, 2016).

7.7 Alternative 7: Off-Channel Storage/Aquifer Storage and Recovery

This alternative would create an off-channel reservoir or aquifer storage and recovery field to scalp high or flood flows from the Nueces River or Lake Corpus Christi and store them until needed in the Delta (Figure 11). Projects of the sizes described here and intended to augment current municipal and industrial raw water supplies would not be feasible solely for providing additional water to the Delta. Sharing costs for these projects by entities interested in providing more water to the Delta may be one way of increasing flows to the Delta.

Regional water planning explored the feasibility of constructing an off-channel reservoir near the headwaters of Lake Corpus Christi to capture flood flows expected to spill from Lake Corpus Christi (CBRWPG, 2009). At certain reservoir water elevations, water would be pumped from Lake Corpus Christi to the off-channel reservoir. The project estimated 31,392 acre-feet of firm yield could be made available for water supply for $323 million (September 2008 prices) and operated for $12.8 million per year (September 2008 prices). Unit cost of untreated water would be $409 per acre-foot. Evaluation of off-channel storage would consider effects of evaporative losses on the cost-effectiveness of the storage system. Evaporation controls described in Alternative 12 may be used to reduce evaporation rates in off-channel reservoirs.

The Corpus Christi Aquifer Storage & Recovery Conservation District, located in portions of Aransas, Kleberg, Nueces and San Patricio counties and encompassing most of the Nueces Delta was formed in 2005 (CCASRCD, 2014) and is dedicated to,

> “...developing and maintaining an aquifer storage and recovery program, providing the most efficient use of groundwater resources to supplement existing supplies, while controlling and preventing waste of groundwater.”

The district issues permits to drill wells for water use and aquifer storage.

It may be possible to combine aquifer storage with Alternative 4, Deep-Water Wells in the Delta. Using deep-water wells in the Delta, water could be stored in aquifers below the Delta when it was flooding and the same wells could be used to pump stored aquifer water into the Delta under dry conditions.

An alternative not explored in depth here would be to combine off-channel storage with the sand/gravel/caliche mine ponds on private property. It may be possible to increase the volume of the ponds by raising levees and expanding their surface area so they contain more water. It may also be possible to capture a portion of flood waters draining into Peters Swale which drains stormwater from Odem to Chiltipin Creek.

Small scale aquifer storage and recovery projects adjacent to the Delta and which provide relatively brackish water may be more feasible from a cost perspective.

Analysis

Cost: **$409 per acre-foot for off-channel storage:** $323 million (September 2008 prices) for design, permitting, engineering and construction with $13 million (September 2008 prices) for annual operating costs (CBRWPG, 2009).

$225 per acre-foot for aquifer storage and recovery: $36.8 million (2016 prices) (including feasibility study, design, permitting and construction) and $1 million (2016 prices) for annual operating costs for up to 3,150 acre-feet per month for four months of the year.

Source: Off-channel reservoir: Lake Corpus Christi or Nueces River downstream of Lake Corpus Christi

Aquifer storage and recovery: Evangeline Aquifer north of Sinton and the Mary Rhodes pipeline, between Skidmore on the west and Refugio on the east

Amount: Off-channel storage: 31,000 acre-feet (CBRWPG, 2010) providing continuous flows or pulsed releases. Pulsed releases up to 1,400 acre-feet per day (750 cubic feet per second at the USGS gage on the Nueces River at Bluntzer) could be combined with alternatives to divert flow into the Delta from the Nueces River tidal.

Aquifer storage and recovery: 707–28,155 acre-feet per year providing continuous flows or seasonal flows, particularly during dry conditions (CBRWPG, 2015).

Delta location: Water could be diverted to Rincon Bayou through the Nueces Overflow Channel or to the southern portion of the Delta by diversions along the Nueces River tidal.

Effects of removing water: Off-channel reservoir (CBRWPG, 2009):

- Reduction in volume of flood flows and sediment loading into Lake Corpus Christi or the Nueces River downstream of Corpus Christi;
- Low impacts to wetlands, primarily riparian zone, associated with constructing the intake structure;
- Low impacts to terrestrial and wetland habitat associated with construction of a pipeline from Lake Corpus Christi or the Nueces River to the off-channel reservoir;
- Impacts to terrestrial and wetland habitat associated with inundation and construction of the off-channel reservoir; and
- Reduction of flood flows, sediments and nutrients to Rincon Bayou, Nueces River tidal, and Nueces Bay.

Aquifer storage and recovery:

- Reduction in volume of flood flows and sediment loading into Lake Corpus Christi, the Nueces River downstream of Corpus Christi, Nueces River tidal or the Nueces Delta.

Effects of adding water: See Section 5

Regulations: Off-channel reservoir (CBRWPG, 2009):

- TCEQ Water Right and Storage permit including interbasin authorization
- USACE Sections 10 and 404 permits for construction of the reservoir and pipelines
- Texas General Land Office Sand and Gravel Removal permit
- Texas General Land Office Easement for use of state-owned land
- Coastal Management Plan review and approval
- Texas Parks and Wildlife Department Sand and Gravel Individual Permit for stream crossings
- Approval by the State Historical Preservation Officer

Aquifer storage and recovery:

- Requirements of controlling groundwater management district, and

- The TCEQ may require treatment of water injected into the aquifer which would increase the cost of this alternative. If treatment is required, the additional cost would vary with the quality of the water being treated.

Other factors to consider: Either approach would require considerable negotiation with private landowners of locations where these facilities may be constructed.

Time: 10–18 years for off-channel reservoir including 4 years for construction alone (CBRWPG, 2009).

Eight years for aquifer storage and recovery.

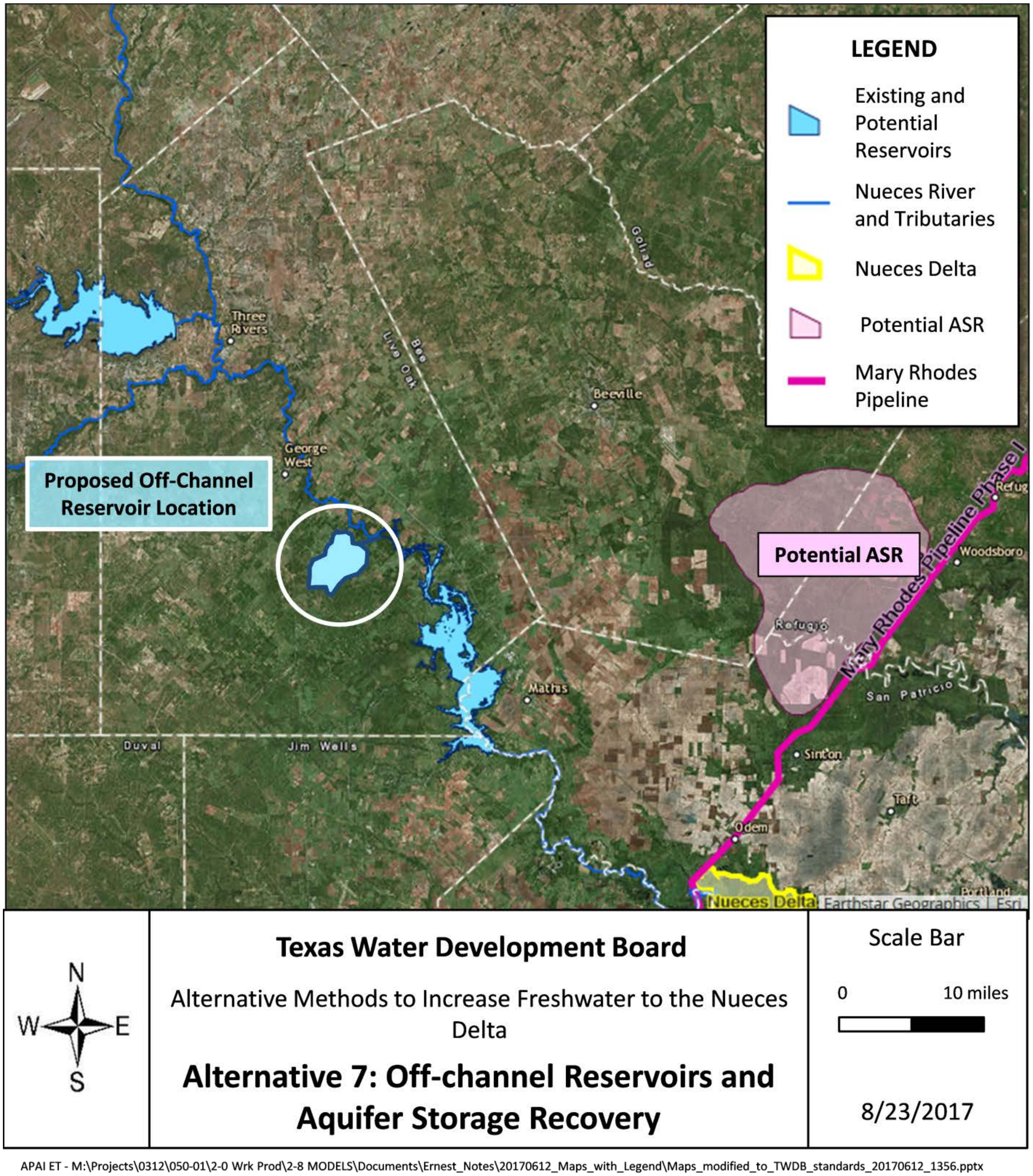

Figure 11. Off-channel Reservoirs/Aquifer Storage and Recovery.

7.8 Alternative 8: Industrial Wastewater

Wastewater discharges to the Corpus Christi Inner Harbor would be collected and routed to the Nueces Delta (Table 5) (Figure 12). In 2015 there were eight industrial and one municipal permitted wastewater treatment facilities discharging a total of 33,754 acre-feet to the Corpus Christi Inner Harbor (NRA, 2016).

There was previous discussion with industries regarding this concept about 15 years ago (Rocky Freund and Ray Allen, personal communication). At that time industries expressed concern about potential liability if constituents in their effluents were perceived to negatively impact the Delta. One approach to addressing concern about effluent constituents may be to focus on collection and transport of stormwater runoff from industrial facilities to the Delta instead of treated wastewater. There has not been recent discussion with industries about discharging treated wastewater into the Delta.

TABLE 5. Wastewater Discharges to the Corpus Christi Inner Harbor in 2015.

Permittee	Permit #	Outfall #	Acre-feet discharged in 2015
American Chrome and Chemicals	WQ0000349	001	7,348
Flint Hills Resources	WQ0000457	001, 011	1,295
Valero Refining-East Plant	WQ0000457	001	1,761
Citgo Refining and Chemicals	WQ0000467	001, 002, 003, 004, 005, 006, 007	7,712
Flint Hills Resources	WQ0000531	001,003, 004, 006, 0011	5,381
Valero Refining Texas LP	WQ0001909	003, 005, 007	3,260
Equistar Chemicals LP	WQ0002075	001	1,187
BTB Refining	WQ0002720	001	4.70
John Bludworth Shipyard	WQ0004889	001, 002	616
City of Corpus Christi Broadway Wastewater Treatment Plant*	WQ0010401	001	5,188
Total acre-feet in 2015			**33,754**

*City of Corpus Christi Broadway wastewater treatment plant is a municipal wastewater treatment facility which discharges to the Corpus Christi Inner Harbor. If a collector system were created which captured industrial wastewater return flows it may be possible to include the Broadway WWTP effluent.

Analysis

Cost: $134 per acre-foot. (Estimate based on pipeline costs for Bee-San Patricio Well Field (Table 5D.8.2 in CBRWPG, 2015). Includes $16.1 million for 11 miles of 36-inch pipeline, annual operating costs of $1.6 million, and 33,754 acre-feet of industrial treated wastewater provided annually). This does not include the cost of individual industries amending their wastewater discharge permits for a different outfall location. The amount of water provided would probably be less than 33,754 acre-feet per year because it is unlikely all industries would participate.

Source: Industrial and municipal treated wastewater discharged to the Corpus Christi Inner Harbor

Amount: 33,754 acre-feet per year (NRA, 2016) provided continuously

Delta location: South Lake upstream of the Union Pacific Railroad bridge

Effects of removing water: Removing freshwater discharges from the Corpus Christi Inner Harbor may reduce vertical stratification in the Inner Harbor which can lead to hypoxic conditions developing in denser, higher salinity water near the bottom. Reduced loading of oxygen-demanding wastes to the Inner Harbor may also reduce hypoxia development.

Terrestrial ecosystem effects of infrastructure development would be expected to be relatively low because of the industrialized nature of most of the pipeline route.

Effects of adding water: Provision of 92 acre-feet per day to South Lake (2,774 acre-feet per month) would create a freshwater stream nearly equivalent to flow in Rincon Bayou when it is receiving 3,000 acre-feet per month. It might inundate most of the South Lake area most of the time, allowing considerable increase in permanently vegetated marsh. Marsh development may reduce aeolian erosion of sediments from the 230-acre South Lake basin, portions of which are frequently dry for extended periods of time. Creation of marsh may also trap inorganic sediment and add organic matter to the bottom, counteracting subsidence and sediment loss.

Regulations: Each participating industry would have to amend its TCEQ wastewater discharge permit to indicate a new outfall location. The TCEQ Surface Water Quality Standards indicate the Corpus Christi Inner Harbor, Water Quality Segment 2484, is assigned an intermediate aquatic life use (TCEQ, 2014). Water quality standards have not been established for the Nueces Delta. The TCEQ may reevaluate permit limits for some parameters like ammonia-nitrogen to ensure discharges to the Delta would protect aquatic life use in the Delta. A TCEQ water rights permit may be required.

USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Lease may be required to install the pipeline.

Other factors to consider: TCEQ's requirement for ammonia limitation for the Allison discharge to the Delta suggests the TCEQ may place more stringent discharge limits on industries wishing to discharge to the Delta to avoid toxicity. Wastewater treatment costs may be higher, limiting industries ability to participate.

Time: 12 years

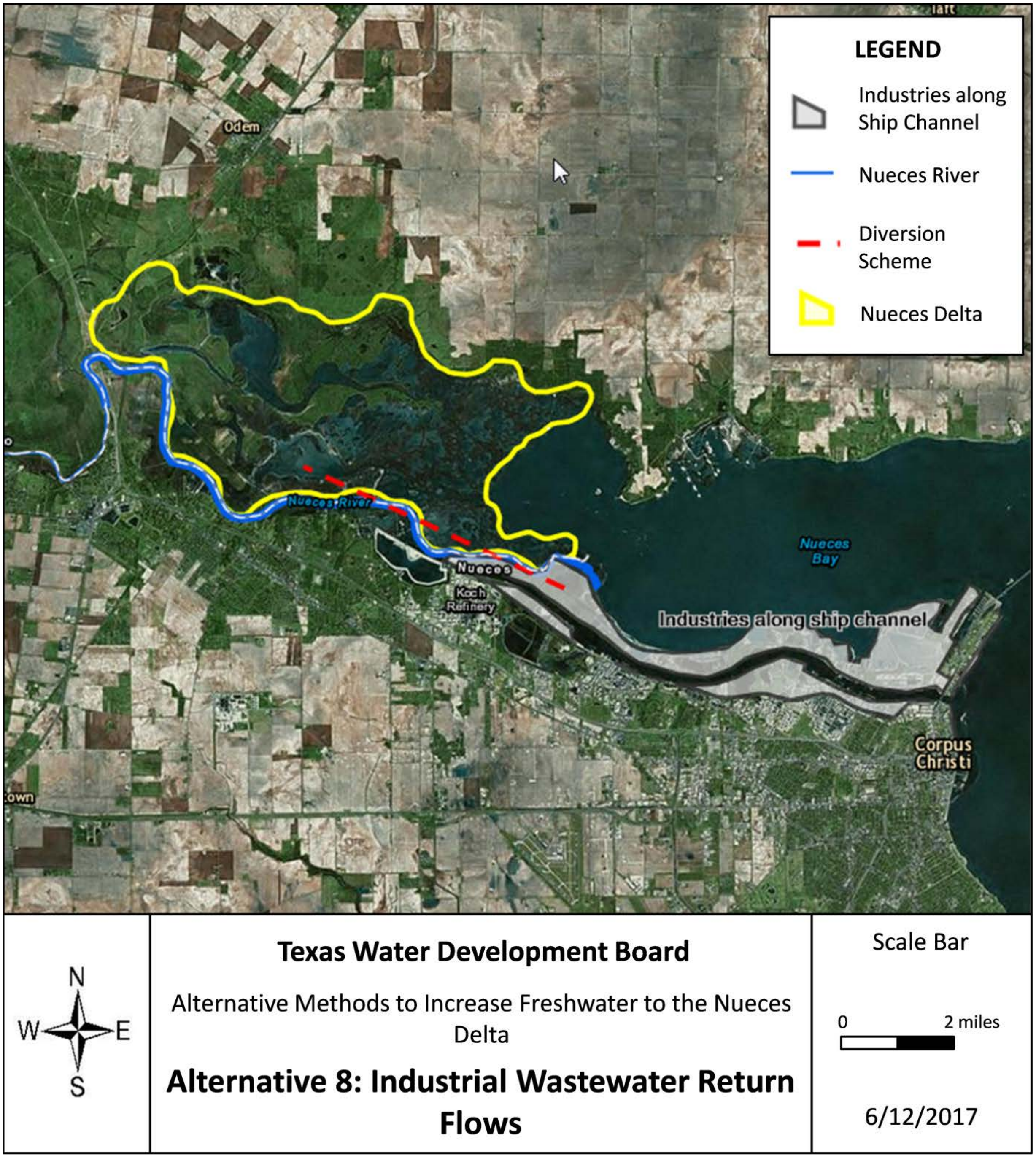

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Figure 12. Industrial Wastewater Return Flows.

7.9 Alternative 9: Brackish Seepage above Calallen Dam

Shallow brackish groundwater accumulates and seeps into the Nueces River upstream of Calallen Dam. According to the 2011 Coastal Bend Regional Water Plan – Phase 1 Study Report #4 – April 2009, this groundwater flow had a TDS concentration of 2,900 mg/L. Under extended low flow conditions, seepage of this brackish groundwater into the Nueces River above Calallen Dam can interfere with use of Nueces River water for water supply.

This alternative would capture this brackish groundwater with shallow wells along the river which intercept it before it reaches the river and then pump it to the Delta (Figure 13). Pumping the brackish, denser water, off the bottom of the river after it has seeped into the river is a second option. Whether using shallow groundwater wells or pumping from the bottom of the river, it may be possible to tie collected brackish water to existing infrastructure sending water to Rincon Bayou.

Although this water would come from the Nueces River above the Calallen Dam, it may not be considered a spill or pass-through release from Lake Corpus Christi. Its collection and discharge to Rincon Bayou may not be controlled by the agreed order.

Analysis

Cost: $330-458 per acre-foot based on $3,151,000 project costs and $287,000 operating and debt service costs each year for 20 years (CBRWPG, 2015). These costs are based on using a gravity siphon system which collects brackish water at the bottom of the Nueces River upstream of Calallen Dam upstream to Hazel Bazemore Park. This may be less expensive than drilling a field of shallow wells into the alluvium next to the river to intercept brackish groundwater flow.

Source: Shallow groundwater flowing into, or accumulating on the bottom of the Nueces River upstream of Calallen Dam

Amount: 627-869 acre-feet per year (CBRWPG, 2015). Estimated to average 16 acre-feet per day with a chloride concentration of 1,170 mg/L and a TDS concentration of 2,900 mg/L (CBRWPG, 2009). This source would not be continuous but may provide flow during dry weather.

Source location: In or adjacent to the Nueces River from Calallen Dam upstream about three river miles

Delta location: Rincon Bayou at, or near, the Rincon Bayou diversion

Effects of removing water: The infrastructure necessary to gather brackish water from the bottom of the Nueces River in this reach is expected to occupy "substantially" less than 1 acre of the river and riparian zone (CBRWPG, 2015). If water is pumped from the bottom of the river, larval and some young-of-the-year fish and shellfish may be entrained and pumped to Rincon Bayou. Removal of this brackish water from the river may eliminate treatment costs associated with treating it for municipal or industrial use.

Effects of adding water: This water is expected to have total dissolved solids concentrations less than 2.5 PSU. Provision of this water, particularly during summer and drought may help avoid hypersaline conditions developing in Rincon Bayou and the Delta.

Regulations: TCEQ water rights permits with interbasin transfer authorizations may be required to capture this water and pump it to Rincon Bayou.

USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Use Lease may be required for pipeline, pumps, and other infrastructure.

Drilling shallow groundwater wells to capture brackish groundwater would involve regulation by the San Patricio County Groundwater Conservation District.

Other factors to consider: Private landowners may control some of the property in this reach and would require coordination to place wells, pipes or other infrastructure on their property. If there are landowners with private wells, they may be concerned about possible impacts on the production and water quality of their wells. Any infrastructure placed along the river will need to be protected from episodic flooding.

Time: Six years

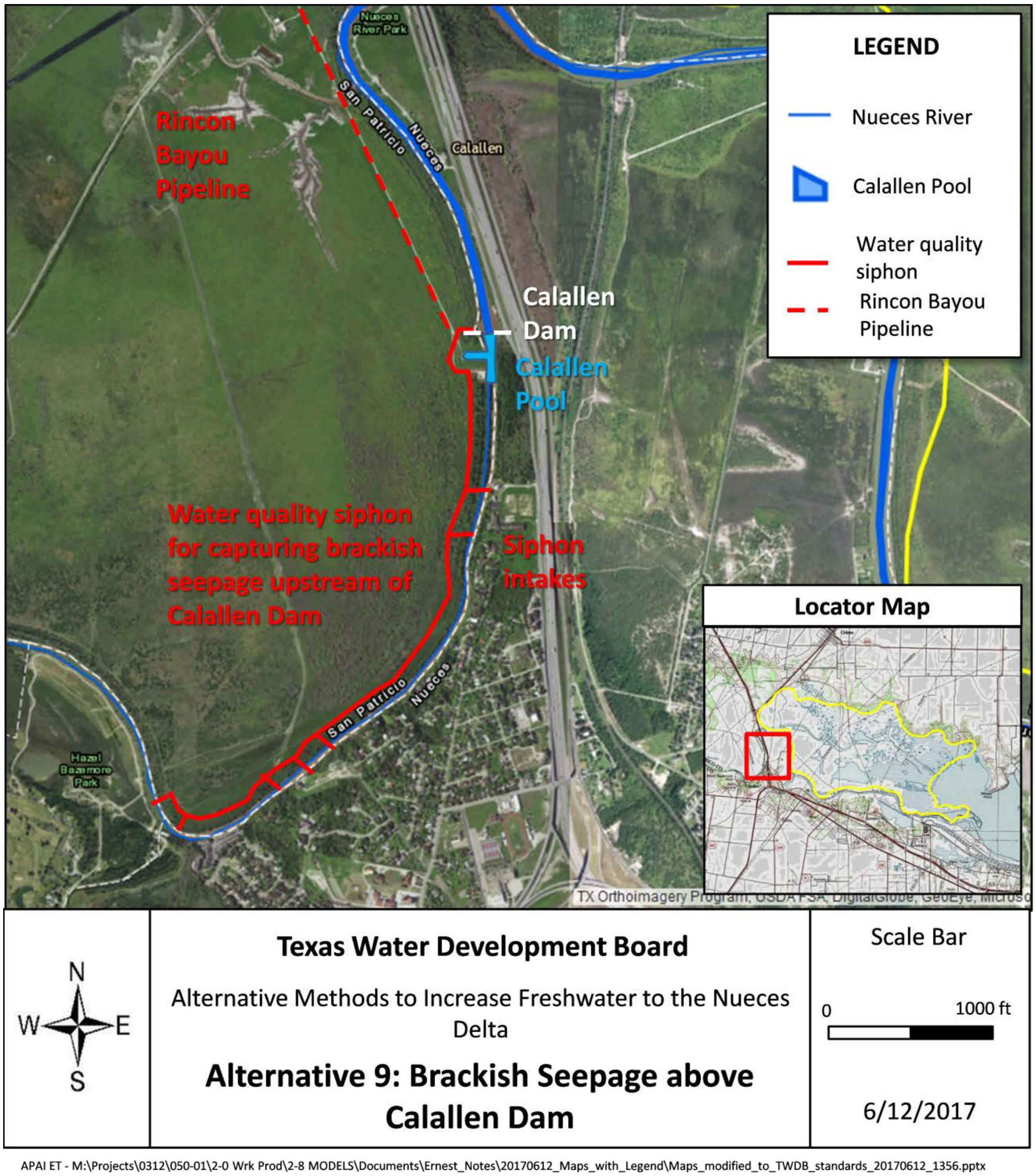

Figure 13. Overview of Brackish Seepage above Calallen Dam.

7.10 Alternative 10: Pollywog Pond

The Stevens Water Treatment Plant discharges sediment into Pollywog Pond, a series of ponds adjacent to the south shore of the Nueces River tidal (Figure 14). This site has a wastewater discharge permit (WQ0004934000) allowing disposal onsite of up to 6,400 tons dry weight per year of sludge from the water treatment plant. It may be possible to pump water or water and sediment from this facility to the Delta.

Although volumes from Pollywog Pond would be small they could help meet agreed order flow targets.

Analysis

Cost: Unknown

Source: Sediment and water from Stevens Water Treatment Plant

Amount: 0.46 acre-feet per day (0.15 MGD) and up to 6,400 tons of dry sediment per year. Quantities are too low to provide continuous flows. Episodic discharges would be expected to the Delta.

Delta location: Headwaters of South Lake

Effects of removing water: Pollywog Pond is a recreational bird-watching site (Coastal Bend Audubon Society, 2017). Whatever action taken, if any, should ensure bird and other wildlife use of the site is not significantly affected.

Removing water and sediment from the ponds may extend and maintain the capacity of the ponds to accept sludge.

Effects of adding water: Much of the sediment is Nueces River sediment transported to the water treatment plant and removed by settling and flocculation. A potential major positive effect of moving water and sediment is adding sediment to the Nueces Delta.

Regulations: This project would require a modification in the facility’s wastewater discharge permit which is currently a no-discharge permit.

TCEQ water rights permits with interbasin transfer authorizations may be required to move water into the Nueces Delta.

USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Use Lease may be required for construction and infrastructure needed for this project.

Other factors to consider: There may be some uncertainty whether this approach to sludge management will be continued by the city. Since Pollywog Pond has become a bird watching destination, there may be some concern about the effects of this alternative on bird watching in the area.

Time: This activity may be able to occur three to four times a year and be considered routine maintenance of the ponds. Maintenance activities that routinely remove sediment could pipe sediment to the Delta. Sand Wand Sediment Removal technology by Streamside, LLC is a system that could be used for this purpose.

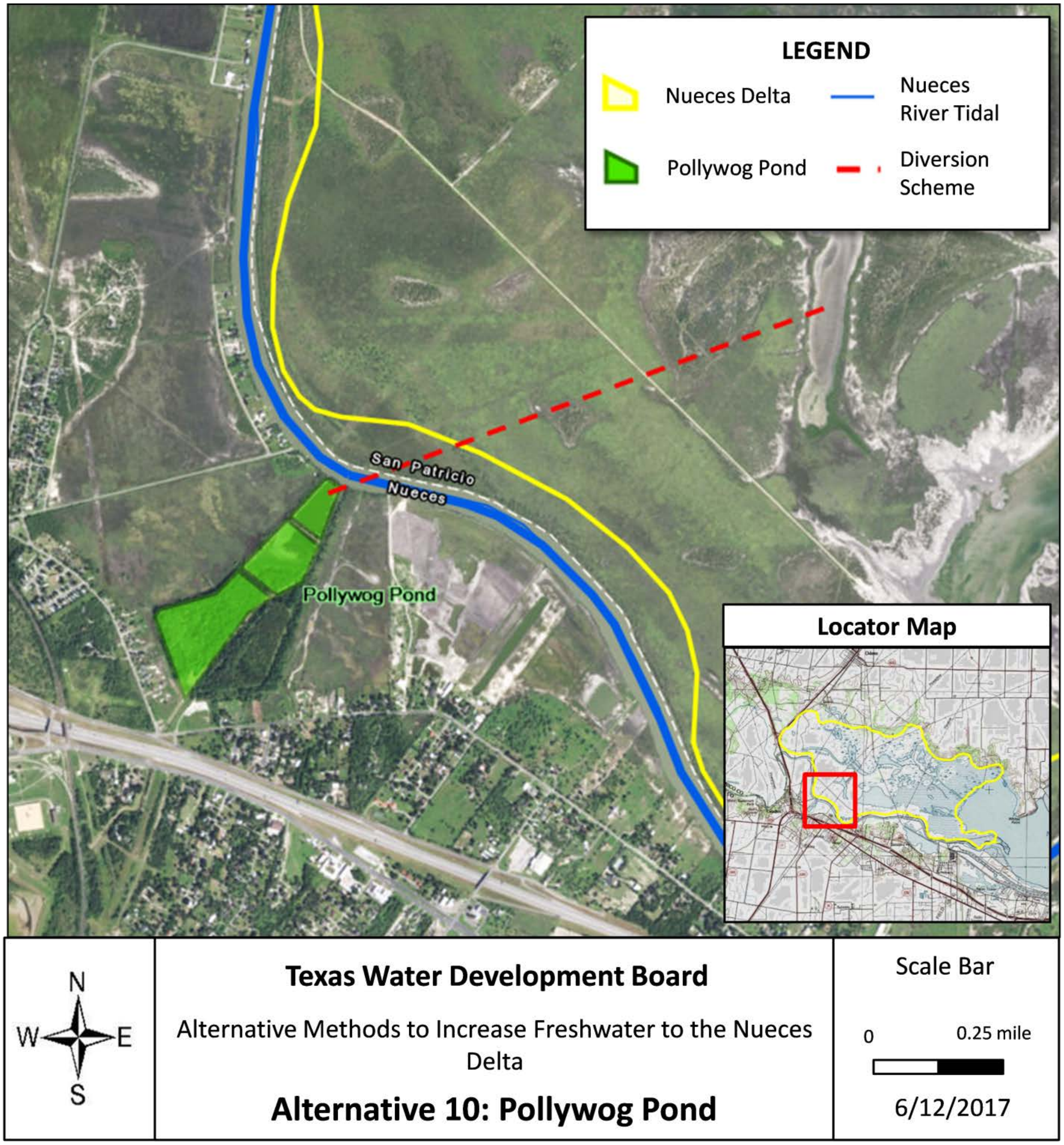

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Figure 14. Pollywog Pond.

7.11 Alternative 11: Mary Rhodes Pipeline

The Mary Rhodes pipeline can transport more water than it is currently carrying. When flows from Lake Texana and the Colorado River are in the pipeline, it should still have capacity for an additional 23,160 acre-feet per year of water (CBRWPG, 2010). This alternative would add treated municipal wastewater, river water and/or groundwater to the Mary Rhodes pipeline as it brings water from Lake Texana and the Colorado River to Corpus Christi. Added water would be discharged to the Delta as the pipeline crosses north of the Delta (Figure 15).

a. Sources of water along the pipeline route where water could be added to the pipeline would be identified. Ex. Groundwater well fields; interruptible water supply from the Guadalupe, San Antonio, Mission and Aransas rivers, and Tres Palacios Creek; and treated wastewater effluent from cities and industries along the pipeline route. These sources would intermingle in the pipeline with water from Lake Texana and the Colorado River and could not be kept separate. Precautions would be necessary to ensure undesired contaminants do not enter the pipeline with these sources of water.

b. Water would be discharged from the pipeline at one or more locations in the Delta rather than piped to the Stevens Water Treatment plant.

It is believed water transferred to the Delta in this manner would not be regulated under the agreed order. The agreed order manages releases and spills from the Lake Corpus Christi/Choke Canyon reservoir system which do not exceed inflows along with return flows and diversions to Nueces and Corpus Christi bays. Water described in this alternative would originate from other basins, not the Nueces River basin and would not be considered a spill or release from the reservoir system nor would it be considered a return flow or diversion of Nueces River water to the Delta.

Analysis

Cost: $624 per acre-foot (Assuming 5.8 acre-feet of water per day is transported via the pipeline for 20 years. Construction costs based on estimate for Odem WWTP diversion to the Delta (Dodson et al., 2016) including $1.6 million for construction and $184,000 annual operating, maintenance and interest costs for each of five facilities)

Sources:

- Potential sources include treated wastewater from towns like Refugio and Sinton which are near the pipeline.
    - Town of Placedo (permitted daily average discharge of 0.072 MGD, 0.22 acre-foot/day)
    - Town of Woodsboro (permitted daily average discharge of 0.25 MGD, 0.77 acre-foot/day; 2015 average daily discharge was 0.45 acre-foot/day (NRA, 2016))
    - Town of Refugio (permitted daily average discharge of 0.576 MGD, 1.8 acre-feet/day)
    - Town of Sinton (permitted daily average discharge of 0.80 MGD, 2.5 acre-feet/day; 2015 average daily discharge was 2.2 acre-feet/day (NRA, 2016))
    - Town of Taft (permitted daily average discharge of 0.9 MGD, 2.8 acre-feet/day; 2015 average daily discharge was 1.2 acre-feet/day (NRA, 2016))

- Possible purchase of interruptible water from the Lavaca, Guadalupe, San Antonio, Mission and/or Aransas rivers.
- Groundwater well fields.

Amount: Ex. 5.8 acre-feet per day (174 acre-feet per 30 days and 2,100 acre-feet per year) from the municipal wastewater treatment plants listed above as continuous flow

Delta location: Water would be released from the pipeline as it crosses Rincon Bayou or at strategically selected locations along the north side of the Delta.

Effects of removing water: There would be ecological effects of diverting treated wastewater from current receiving streams however there are not readily available data to quantify those effects. Receiving streams would probably return to a preexisting intermittent condition.

- Town of Placedo – discharges to unnamed ditch, to Ninemile Creek, to Placedo Creek to Lavaca Bay
- Town of Woodsboro – discharges to unnamed ditch to Willow Creek to Sous Creek to Mission River tidal
- Town of Refugio – discharges to Dry Creek to Mission River above tidal
- Town of Sinton – discharges to Chiltipin Creek to Aransas River tidal
- Town of Taft – discharges to Taft drainage ditch to mud flats to Copano Bay

Effects of adding water: See Section 5.

Regulations: Towns providing treated wastewater would require amended wastewater discharge permits from TCEQ to change the location of discharge. Permission for interbasin transfers would be required unless the sole water supply source of a town providing wastewater was groundwater. A TCEQ water rights permit may be required.

Other factors to be considered: Public concern would be expected if treated wastewater is transported in the pipeline with the city’s raw water supply. There may be concerns about contaminants entering the pipeline from the other sources and the potential costs of having to clean the pipeline if exposed to contamination.

Time: Eight years

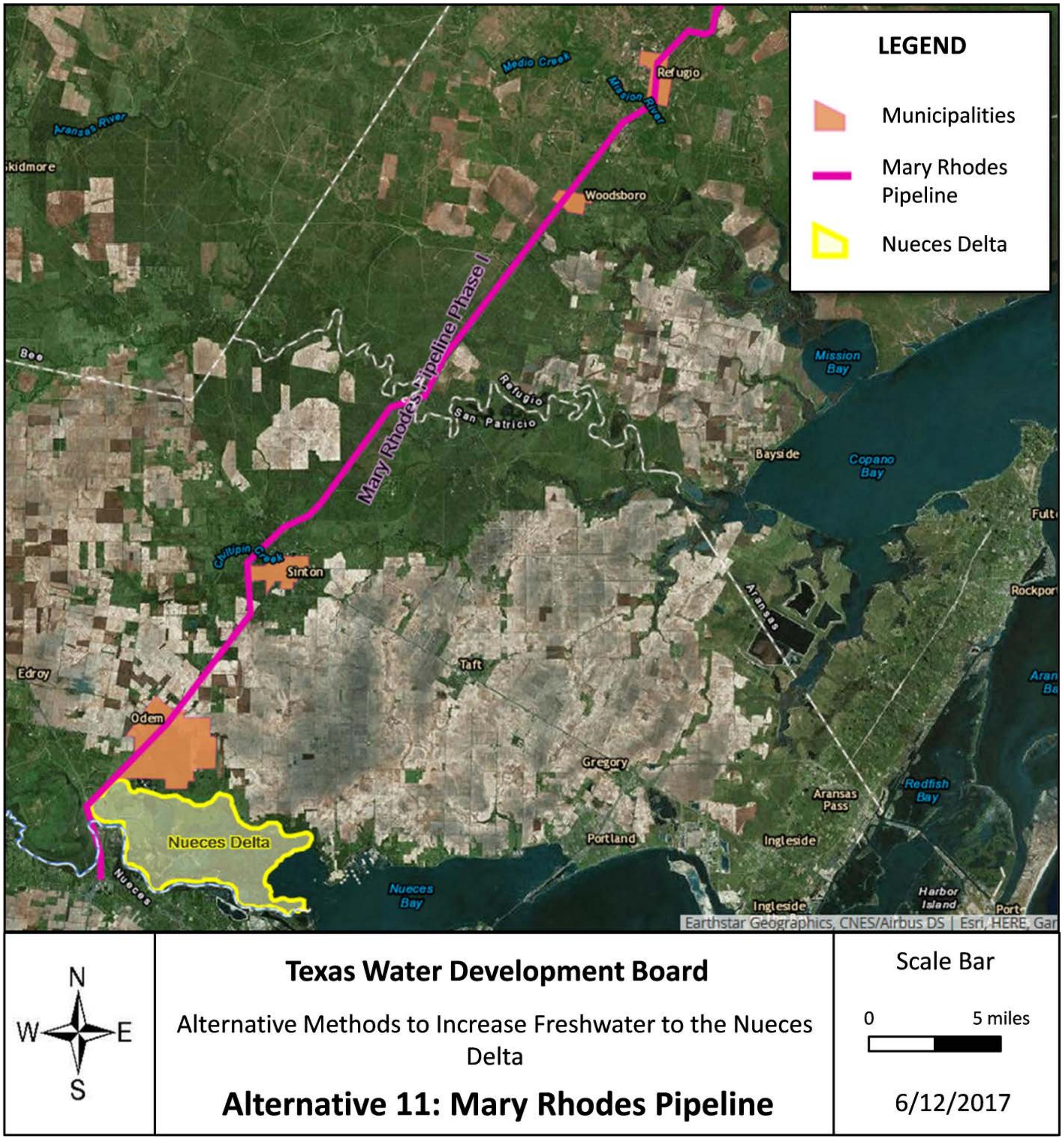

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Figure 15. Overview of Mary Rhodes Pipeline.

7.12 Alternative 12: Evaporation Control

Conservation measures to reduce water losses from evapotranspiration in Lake Corpus Christi and/or Choke Canyon Reservoir make up this alternative. Conserved water could be used for freshwater inflows to the Delta if the agreed order were modified to allow it. Responses to this alternative frequently raise questions about the inability to cover a substantial part of a reservoir like Lake Corpus Christi or Choke Canyon Reservoir. This alternative considers partial coverage of these reservoirs to balance water savings, costs and concerns of recreational users and residents. It would be appropriate to test variations of this alternative in a pilot project.

The amount of water in the Lake Corpus Christi/Choke Canyon Reservoir system lost to evaporation is approximately equal to the amount removed from the system for municipal and industrial use and pass-through releases to the estuary. An acre-foot of water evaporates from the reservoir system for every acre-foot passed through to the estuary.

> Ex. The agreed order requires a pass-through release of 1,000 acre-feet from Lake Corpus Christi one month to meet inflow targets. 2,000 acre-feet would be used from the reservoir to satisfy that pass-through release: 1,000 acre-feet to meet the pass-through release requirement and 1,000 acre-feet of reservoir water lost to evaporation.

Controlling water hyacinths to reduce evapotranspiration, adding thin surface layers of shade balls or other material to retard evaporation, piping from the headwaters of reservoirs, etc. may save water some of which could be considered for diversion to the Delta.

WaterSavr™ Technology utilizes a blend of calcium hydroxide, stearyl alcohol and cetyl alcohol to produce a monolayer reducing evaporation. It is a powder that spreads over the surface automatically by ionic repulsion. Treated water is considered potable and safe for aquatic life (McGuire Environmental Consultants, 2004). Strong winds can push the solution towards the shoreline and render it ineffective. WaterSavr™ has been applied to reservoirs, lakes, and ponds around the world where it has been shown to reduce evaporative loss by 16–35 percent (Flexible Solutions, 2010, Ikweiri et al., 2008). Analysis of its effectiveness at Wichita Fall's Lake Arrowhead in Texas showed a 15 percent reduction in evaporative loss (Wentzel and Solis, 2015). According to a news article from the TWDB report, the cost of treatment was "less than $180 per acre-foot of water conserved" (Bloom, 2015).

Floating or suspended covers like AquaCap, E-VapCap or SuperSpan systems last for about 10 years and reduce thermal energy penetrating the water body and wind action on the surface (Yao et al., 2010). These purport to reduce evaporation rates by 70–90 percent. Unit price ranges from $19 to $30 per square meter. Suspended covers are horizontal sail-like structures held over the reservoir by poles and cables. They can be made from impermeable plastic to porous screens. Floating covers rest on the water surface and do not usually cover the entire water body. Gaps provide space for the water to vaporize (Yao et al., 2010). Cost per acre-foot of water saved is estimated to range $368–$642 per acre-foot. Aquatic life and recreational activities may be affected with the implementation of these evaporative controls (Yao et al., 2010).

Shade Balls are black polyethylene balls 4 inches in diameter that float next to each other on the water's surface. They may reduce evaporation rates by about 75 percent. Because of their spherical shape, they conform to the dimensions of the reservoir (Shade Balls, 2017). The balls cost about $0.39 each and about $214,000 to cover an acre. Los Angeles, California, and other cities have used Shade Balls on several of their water supply reservoirs to reduce chemical treatment and evaporation loss during drought years (Howard, 2015). Shade Balls and floating evaporation suppressants may clog spillways and drainage pipes.

Water hyacinths are common on Lake Corpus Christi and the city pays for their periodic chemical control. Scientific literature indicates evapotranspiration rates with water hyacinths can be two to six times higher than evaporation rates of uncovered water (Brezny et al., 1973; Little, 1967). For example, if 4 acres of a reservoir loses 2 acre-feet per year to evaporation, the same area covered with water hyacinths may lose between 4–12 acre-feet per year to evaporation.

Analysis

Cost: $180 per acre-foot. WaterSavr™

$368 per acre-foot for floating covers to $642 per acre-foot for suspended covers.

Source: Reservoir water otherwise lost to evaporation and/or plant transpiration.

Amount: Volume of water protected depends on the reservoir area effectively covered. More water may be conserved during warmer months when evaporation and transpiration rates are higher.

Source location: Lake Corpus Christi, Choke Canyon Reservoir and Nueces River downstream of Lake Corpus Christi

Delta location: Rincon Bayou diversion

Effects of removing water: This approach allows pass-through flow requirements to be met using less water from the reservoir, therefore allowing more water to be retained in the reservoir longer and for more water to be available for municipal and industrial purposes. Recreational users and lake-side residents may appreciate this approach which may slow rates of water level change in the reservoir. Potentially slower rates of water level change may benefit nesting and shelter for important recreational species like Largemouth Bass, catfish and sunfish.

Effects of adding water: If there is the opportunity to modify the agreed order, this alternative may allow more water to be provided from the reservoir system for the Delta and bay.

Regulations: Coordination with TCEQ would be appropriate however it is not clear there would be any regulatory requirements.

Other factors to consider: Lake residents and recreational users may be concerned about the appearance of any evaporation control material placed over the water and possible interference of those materials with recreational use of the reservoir. There would also be some public concern expressed about potential contamination that may result as evaporation control materials degrade and enter the water.

Time: Two years to implement a pilot project

7.13 Alternative 13: Lake Corpus Christi Diversion

Alternative 13 involves providing some required pass-through releases from the headwaters of Lake Corpus Christi instead of from the Rincon Bayou diversion or flow over Calallen Dam. An intake with pump would be established on the left bank of the lake near its headwaters which would take turbid reservoir water and pump it to the Rincon Bayou diversion (Figure 16). Required pass-through releases up to 2,000 acre-feet per month could be made from this point rather than the Rincon Bayou pump station on the Nueces River above Calallen Dam. This would require a change in the agreed order since the proposed diversion point from Lake Corpus Christi to Rincon Bayou is not authorized.

Analysis

Cost: $376 per acre-foot. (Estimate based on pipeline costs for Bee-San Patricio Well Field (Table 5D.8.2 in CBRWPG, 2015). Includes $33.2 million for 69 acre-feet per day (22.6 MGD) pump, 27 miles of 36-inch pipeline, annual operating costs of $7.1 million, and maximum of 25,185 acre-feet of Lake Corpus Christi water provided annually).

Withdrawing water from the headwaters of Lake Corpus Christi and piping it directly to the Delta or Rincon Bayou requires less water to meet pass-through release requirements since there would be limited evaporative losses compared to passing the water through the reservoir and the Nueces River between the reservoir and the Calallen dam.

Source: Lake Corpus Christi

Amount: 69 acre-feet per day (25,185 acre-feet per year)

Source location: Headwaters of Lake Corpus Christi, Ex. Near west end of Live Oak County Road 350

Delta location: Rincon Bayou diversion

Effects of removing water: This approach allows pass-through flow requirements to be met using less water from the reservoir, therefore allowing more water to be retained in the reservoir longer and for more water to be provided for municipal and industrial purposes. Recreational users and lake-side residents may find appeal in this approach which may slow rates of water level change in the reservoir. Potentially slower rates of water level change may benefit nesting and shelter for important recreational species like Largemouth Bass, catfish, and sunfish.

This alternative would also pump typically more turbid, nutrient rich water from the headwaters, removing higher concentrations of sediment, phosphorus, and planktonic algae that would otherwise settle in the reservoir. For example (TCEQ, 2017):

- Secchi disk transparency at the station near the dam (station 12967) averaged 2 feet compared to 8 inches in the upper reservoir (station 17384)
- Total suspended solids averaged 14 mg/L at the station near the dam (station 12967) and 47 mg/L in the upper reservoir (station 17384)
- Total phosphorus at the station near the dam (station 12967) averaged 0.18 mg/L and 0.24 mg/L in the upper reservoir (station 17384)

This alternative may slightly benefit reservoir storage capacity by removing sediments which would otherwise settle in the reservoir.

Effects of adding water: This alternative would provide the same amount of water required by the agreed order but the water may have higher concentrations of sediment, nutrients, and algae which can benefit the Delta. Water coming from the Nueces River above Calallen Dam would be expected to have lower sediment concentrations under most flow conditions.

Regulations: USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Lease may be required to install the pump and pipeline. An amendment to the Certificate of Adjudication 21-2464 authorizing Lake Corpus Christi may be required by TCEQ.

Other factors to consider: Because this project would require a long pipeline, it would be expected to require considerable negotiation with private landowners. It may be difficult to balance the amount of water and sediment transported by the pipeline to ensure the pipeline does not become blocked with sediment at low points.

Time: 10 years

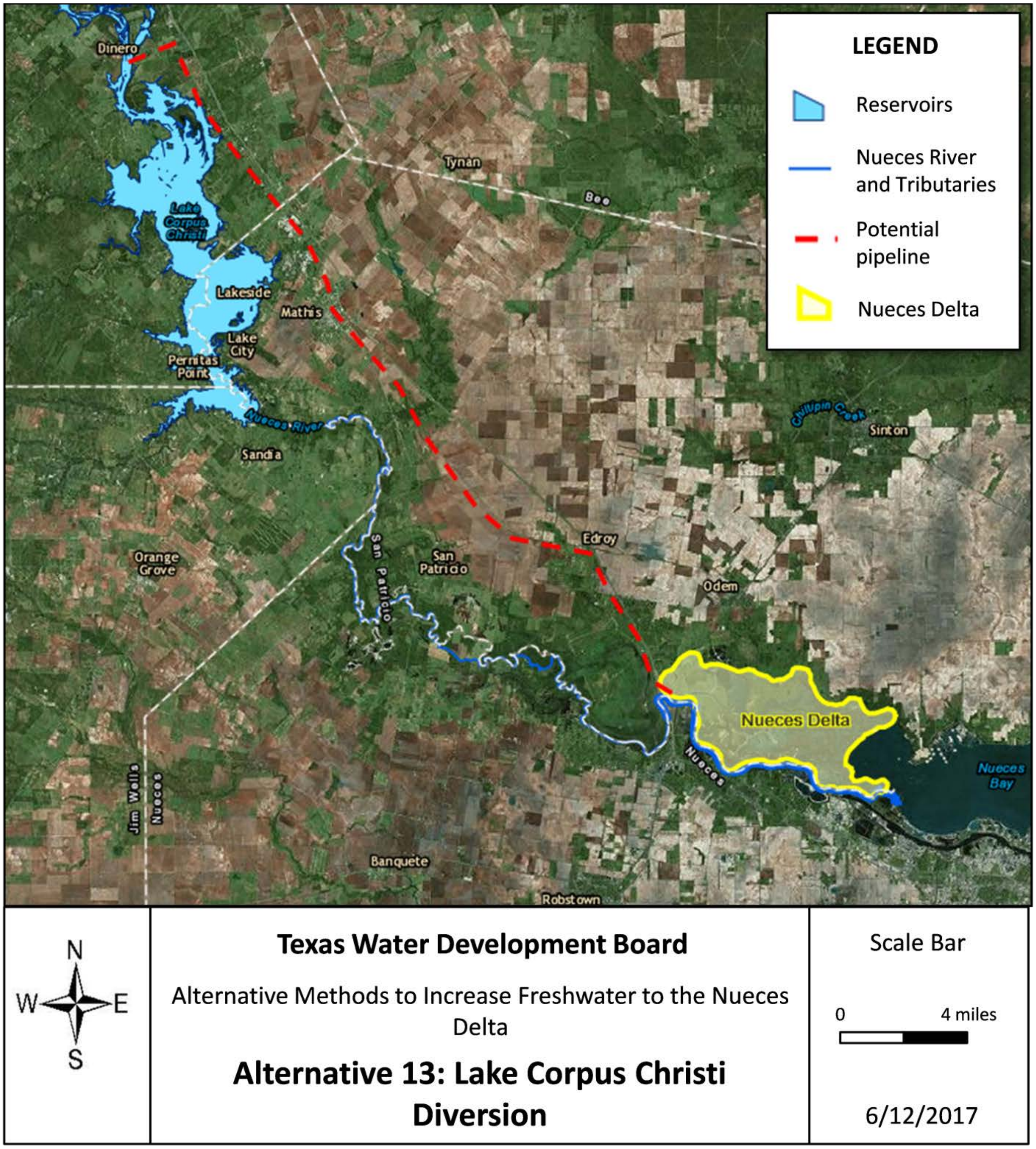

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Figure 16. Lake Corpus Christi Diversion.

7.14 Alternative 14: Treated Wastewater from Portland to Aransas Pass

Like Alternative 8, industrial and municipal treated wastewater would be collected from the Portland, Gregory, Ingleside and Aransas Pass area and routed to the Nueces Delta (Table 6) (Figure 17). In 2015 there were five industrial and five municipal permitted wastewater treatment facilities discharging a total of 14,355 acre-feet to Corpus Christi, Nueces and Redfish bays (NRA, 2016). Based on previous discussions with industries along the Inner Harbor, industries may express concern about potential liability if constituents in their effluents could be perceived to negatively impact the Delta.

TABLE 6. Wastewater Discharges to the Corpus Christi Inner Harbor in 2015.

Permittee	Permit #	Outfall #	Acre-feet discharged in 2015
Occidental Chemical Corporation	WQ0003083	000	1,437
E. I. DuPont De Nemours and Co.	WQ0001651	001 and 002	9,056
City of Gregory	WQ0010092	001	193
City of Ingleside	WQ0010422	001	867
City of Portland	WQ0010478	001	1,772
Sublight Enterprises, Inc.	WQ0011096	001	2
Gulf Marine Fabricators	WQ0012064	001	3
Gulf Marine Fabricators	WQ0003012	001	2
City of Aransas Pass	WQ0010521	001	1,023
Martin Operating Partnership, LP	WQ0012731	001	0.3
Total acre-feet in 2015			**14,355**

Analysis

Cost: $744 per acre-foot. (Estimate based on pipeline costs for Bee-San Patricio Well Field (Table 5D.8.2 in CBRWPG, 2015). Includes $27.4 million for 27 miles of 36-inch pipeline, annual operating costs of $2.0 million, and 14,335 acre-feet of treated wastewater provided annually). This does not include the cost of individual permittees amending their wastewater discharge permits for a different outfall location. The amount of water provided would probably be less than 14,355 acre-feet per year because it is unlikely all permittees would participate.

However, if new industries are established in the area, cost per acre-foot of water supplied may decrease.

Source: Industrial and municipal treated wastewater discharged to Corpus Christi, Nueces and Redfish bays

Amount: 14,355 acre-feet per year (NRA, 2016) provided continuously

Delta location: Rincon Bayou upstream of the Union Pacific Railroad bridge

Effects of removing water: Removing freshwater discharges from the bays may have localized effects on salinity regimes and nutrient loading in the bays. There is no indication these wastewater discharges are harming water quality in the receiving bays.

Terrestrial ecosystem effects of infrastructure development would be expected to be relatively low because of the developed and agricultural nature of most of the pipeline route.

Effects of adding water: Provision of 39 acre-feet per day to Rincon Bayou (1,170 acre-feet per month) would increase flows in the middle and lower reaches of Rincon Bayou and may flood some emergent marsh. Marsh development may reduce aeolian erosion of sediments.

Regulations: Each permittee would have to amend its TCEQ wastewater discharge permit to indicate a new outfall location. Water quality standards have not been established for the Nueces Delta so there is uncertainty if more stringent wastewater treatment limits would be required. TCEQ may reevaluate permit limits for some parameters like ammonia-nitrogen to ensure discharges to the Delta would protect aquatic life use in the Delta. A TCEQ water rights permit may be required.

USACE Section 404 permit, TCEQ 401 water quality certification, and Texas General Land Office State Land Lease may be required to install the pipeline.

Other factors to consider: The extended length of pipeline required for this alternative suggests it would require considerable negotiation with private landowners for pipeline right-of-way. TCEQ's requirement for ammonia limitation for the Allison discharge to the Delta suggests TCEQ may place more stringent discharge limits on other municipalities and industries wishing to discharge to the Delta to avoid toxicity. Wastewater treatment costs may be higher, limiting ability of municipalities and industries to participate.

Time: 12 years

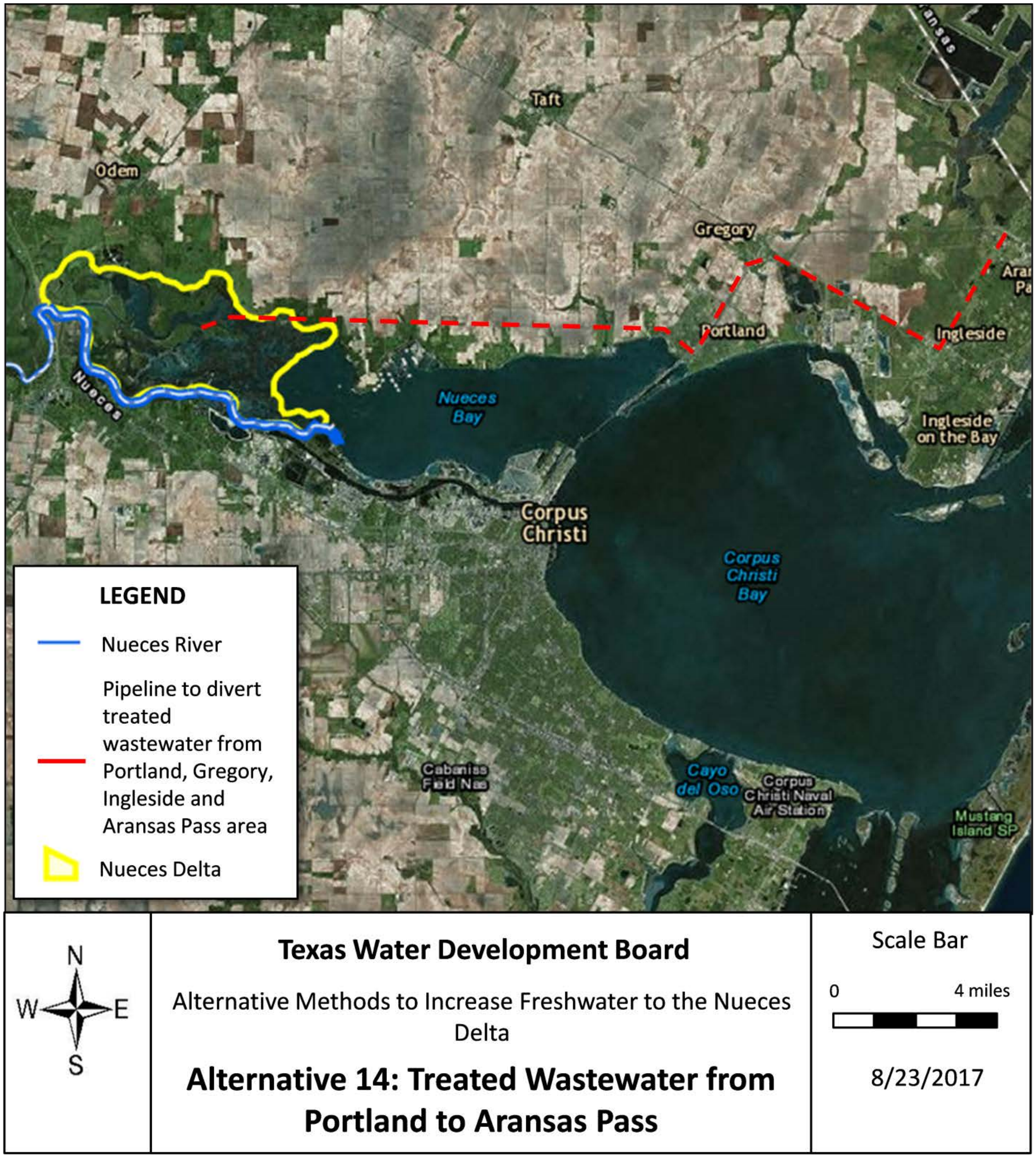

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Figure 17. Treated Wastewater from Portland to Aransas Pass.

7.15 Alternative 15: Rincon Bayou Continuous Flow

- Change monthly targets in the agreed order to seasonal targets (Shockley, 2014). Using seasonal targets (winter, spring and summer) instead of monthly targets can increase reservoir system safe yield and storage frequency. Increased ecological benefits can also be achieved by expanding opportunities to pass through inflows over a wider period (seasons of four months) compared to limiting pass-throughs to a monthly basis. Ecological needs may be met with lower total target inflows than those under the agreed order. The ecological effects on Nueces Bay have not been evaluated in this alternative however reduced inflow to Nueces Delta may be expected to increase either the frequency or extent of hypersalinity in the bay, particularly the west end of the bay near the Delta.
- Develop formal operating guidelines for providing required pass-through releases under the agreed order. Providing required pass-through flows in a more continuous flow regime to Rincon Bayou (Figure 18) is expected to enhance ecological benefits of the added water (Dodson et al., 2016; Montagna et al., 2016a; Montagna et al., 2016b). It may be possible to come closer to providing continuous flows if operating guidelines for providing pass-through flows are developed and implemented by the city. Operating guidelines would be developed to provide more continuous flows while meeting agreed order requirements and not impacting reservoir operations, capacity or yield. This would not be a change in the agreed order or the targets in the agreed order. It would be creation and formalization of guidelines to provide water according to the agreed order in a manner that maximizes ecological benefits.

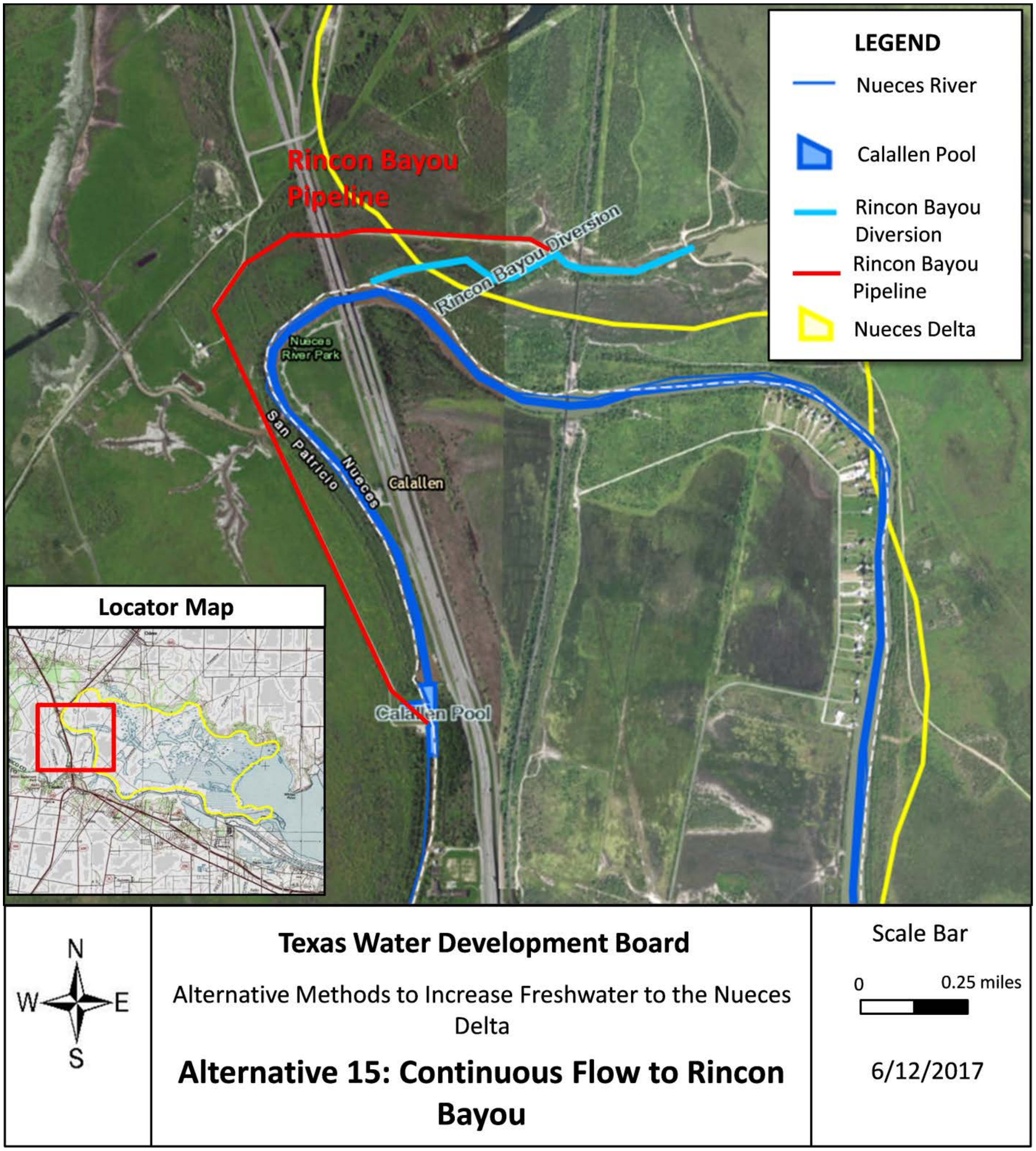

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Figure 18. Continuous Flow to Rincon Bayou.

7.16 Alternative 16: Delta Water Diversions

- Combine inflatable dams with constructed channels to divert water from Rincon Bayou to South Lake in the Delta (Dodson et al., 2016). This project suggested two diversions from Rincon Bayou, one on Middle Rincon Bayou (Figure 19) and the second on North Lake, where water would be diverted to South Lake (Figures 20–21). These diversions might increase the area of the Delta regularly inundated with water with salinity ranging from 20–25 PSU under certain conditions. Estimated cost to install the project would range from \$1.6–\$2.0 million with annual operating costs between \$210,000 and \$240,000.

- Shorten the connection between Upper Rincon Bayou and Middle Rincon Bayou (Montagna personal communication, 2017). There is a land constriction between Upper Rincon Bayou and Middle Rincon Bayou narrowing the channel from 300 feet wide in the upper portion to 30 feet just before it reopens into Middle Rincon Bayou. This constriction forces flow towards the northeast as channel width is constricted. This alternative would widen and straighten the channel and dredge it along the southeast orientation of Upper Rincon Bayou into Middle Rincon Bayou. This should facilitate flow between the two areas.

Figure 19. Middle Rincon Bayou. View from south shore towards north. (Photo taken January 30, 2017).

Figure 20. Proposed Diversion from Middle Rincon Bayou to South Lake. From Figure 3.1.1-4: Project #4 – Middle Rincon Bayou Diversion to South Lake Area (Dodson et al., 2016).

Figure 21. Proposed Diversion from North Lake to South Lake. From Figure 3.1.1-5: Project #5 – North Lake Diversion to South Lake System (Dodson et al., 2016).

7.17 Alternative 17: Union Pacific Railroad Open Areas

Two Union Pacific Railroad tracks cross the Delta from north to south, one just east of the Rincon Bayou diversion and the second across the middle of the Delta. The railroad track crossing the middle of the Delta spans 3.45 miles (Figures 22–23). There are three bridges under the tracks. The first, northern-most bridge, spans 0.19 miles of Rincon Bayou where it flows from Middle Rincon Bayou into North Lake. The second and third bridges span 0.04 mile and 0.16 mile, respectively, on the east side of South Lake. When the Delta floods with freshwater, flow towards Nueces Bay is forced between these three openings. Strategic creation of more openings under the railroad may allow more even flow and sediment transport across the lower Delta. This alternative would require coordination with Union Pacific Railroad. This reach of rail serves the industrial complex along the Corpus Christi Inner Harbor so any action affecting the railroad would imply possible impacts to area industries.

Figure 22. View of Union Pacific Railroad Crossing Near the Junction of Middle Rincon Bayou and North Lake. View toward north from south shore. Photo taken January 30, 2017.

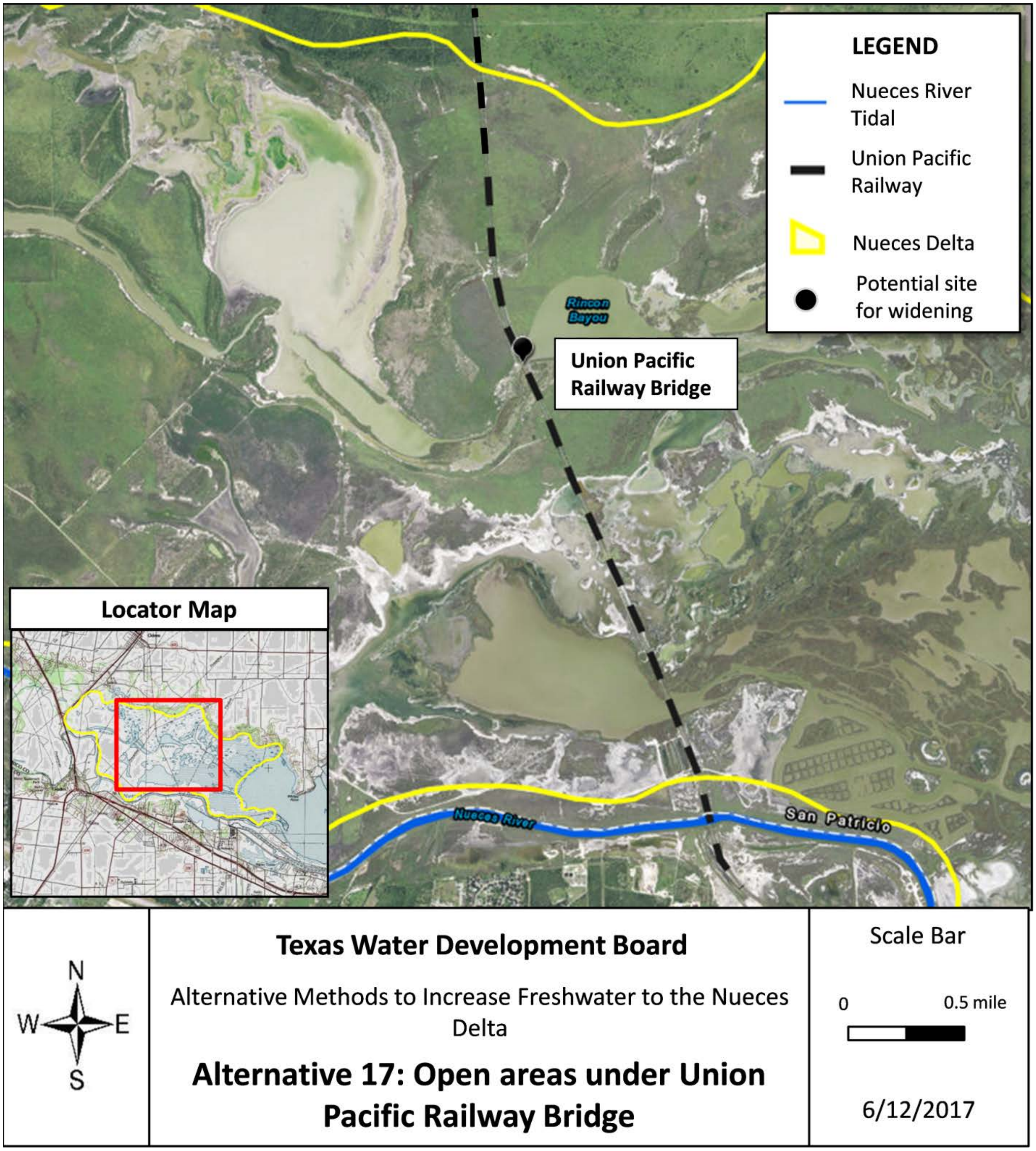

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Figure 23. Overview of Open Passage Under Railroad Tracks.

7.18 Alternative 18: Odem Wastewater Treatment Plant

The City of Odem discharges its treated municipal wastewater (Permit WQ0010237002) to a ditch adjacent to the west side of the Union Pacific Railroad crossing the middle of the Delta. During 2015, it discharged 153 acre-feet (NRA, 2016), about 0.4 acre-feet per day. The effluent evaporates and seeps into the ground 3,000 feet from the outfall and over 2,200 feet from the West Lake area of the Delta. Dodson et al. (2016) proposed capturing the discharge downstream of the outfall and conveying the discharge via pipeline to an ecologically desirable location in West Lake (Figure 24). They suggested ensuring the pipeline would have the capacity to capture some stormwater runoff and increasing volumes of effluent as population increases in Odem. Estimated cost for project installation was \$1.6 million with annual operating costs of \$184,000. If there were no change in effluent volume over 20 years, the estimated cost per acre-foot would be \$1,700.

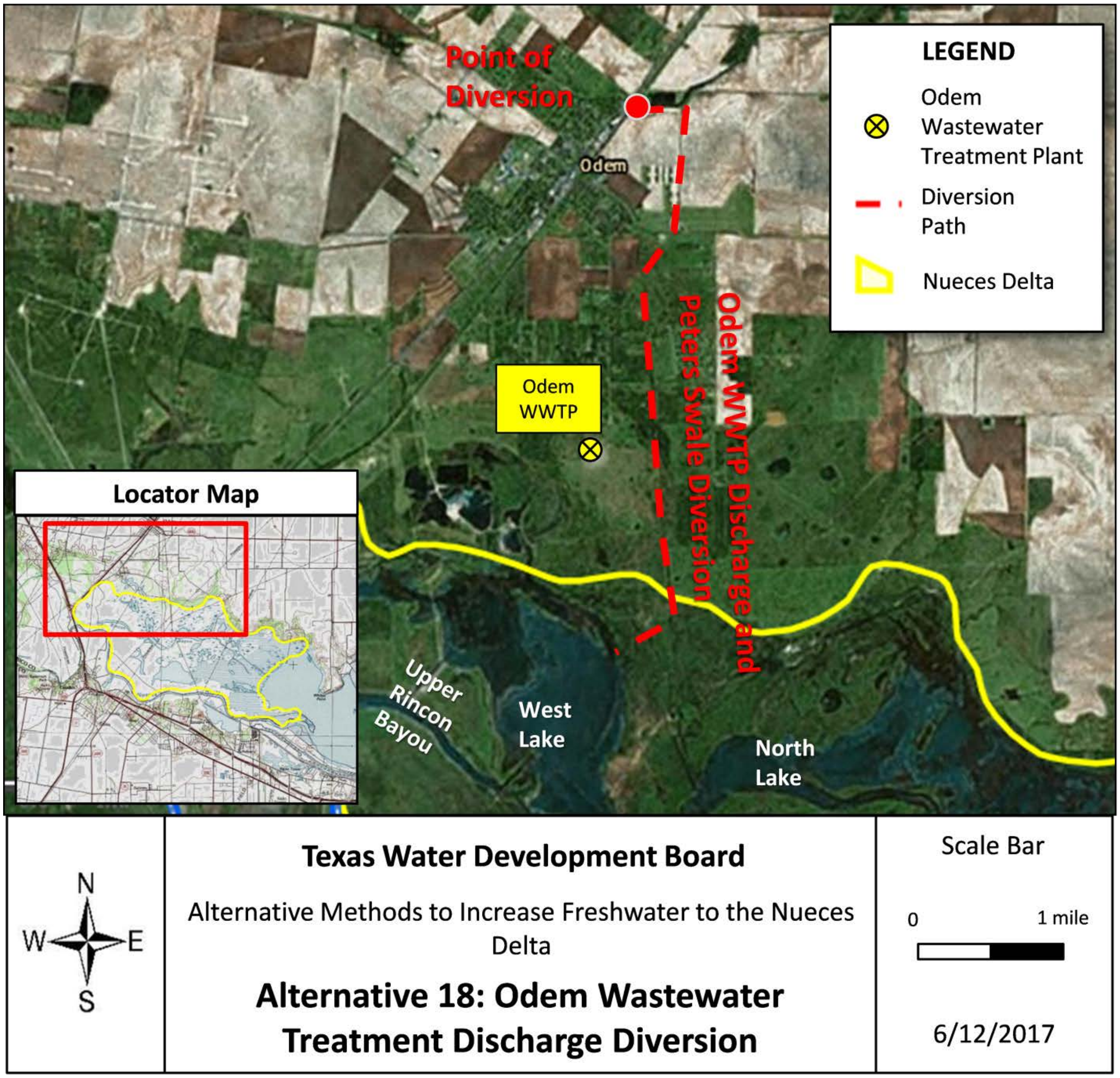

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Figure 24. Odem Wastewater Treatment Plant Discharge.

8 Summary

Thirteen experts familiar with the Nueces Delta and Nueces Estuary were interviewed during 2016 and 2017 to identify ways of adding more water to the Delta. Those interviews, combined with literature review, identified 15 potential ways for adding water and an additional four alternatives which would enhance ecological condition by modifying the ways water is currently added to the Delta. Estimated cost per acre-foot of water and amount of water potentially added to the Delta was generated for each alternative (Table 7). Although the table indicates volumes could be provided continuously, there may be costs and ecological advantages to providing these amounts in some other frequency than continuous flows.

The accurate cost of any alternative cannot be determined without an in-depth feasibility study fully exploring collaborative opportunities. For example, it may be possible to share the cost of construction of a pump station and pipeline from Lake Corpus Christi with other communities needing to operate pump stations on the lake.

Interest has grown in desalination of brackish and marine waters for municipal and industrial use along the Texas coast over the past 15 years. This study did not analyze how desalination may be used to add water of desirable salinity to the Nueces Delta however desalination should be considered as a possible source in the future.

A qualitative comparison of the ecological benefits of each of the alternative has been made (Table 8). A comprehensive analysis of the ecological benefits of each alternative are beyond the scope of this study. Factors considered in this qualitative analysis are listed below. The maximum qualitative rating an alternative may receive is six check marks.

- Continuous or intermittent flow. Continuous flow is considered more beneficial and a check mark is assigned for continuous flow.
- Salinity. A check mark is assigned if the source is freshwater rather than brackish or saline water.
- Volume. Greater volume is considered more positive than low volume and a check mark is assigned for alternatives providing five or more acre-feet per day.
- Sediment. Alternatives providing sediment in addition to water are considered more beneficial and a check mark is assigned for each one providing sediment.
- Location. Ability to deliver water to parts of the Delta other than to Rincon Bayou is considered more positive than providing more water to Rincon Bayou. A check mark is assigned to each alternative which can provide water to areas of the Delta other than directly to Rincon Bayou.
- Energy required for implementation, operation and maintenance. Alternatives requiring less infrastructure, operation and maintenance are considered more positive. Alternatives expected to have low energy requirements for implementation, operation and maintenance receive a check mark.

TABLE 7. Summary of Alternatives to Provide Additional Water to Nueces Delta.

Alternative	Estimated Cost per acre-foot	Volume Added (acre-feet per day)	May Require Agreed Order Amendment
Allison Wastewater Treatment Plant	$38	6 (continuous)	No
Sand/Gravel/Caliche Mine Ponds	$100	Unknown	No
Hondo Creek Realignment	$72–190	6–16 (continuous)	No
Nueces River Tidal Diversions	$129–202	6 (continuous) – 640 (high flow periods)	No
Industrial Wastewater	$134	92 (continuous)	No
Deep-Water Wells in Nueces Delta	$159–302	49 (continuous)	No
Evaporation Control	$180–642	Unknown	Yes
Off-Channel Storage/Aquifer Storage and Recovery	$225–409	85 (continuous, off-channel reservoir) 2–77 (continuous, aquifer storage and recovery)	Possible
Brackish Seepage above Calallen Dam	$330–458	2 (continuous)	Possible
Lake Corpus Christi Pipeline	$376	69 (continuous)	Yes
Mary Rhodes Pipeline	$624	5.8 (continuous)	No
Treated Wastewater from Portland to Aransas Pass	$744	39 (continuous)	No
Nueces Bay Additions	$855	6 (continuous)	No
Odem Wastewater Treatment Plan	$1,700	0.4 (continuous)	No
Pollywog Pond	Unknown	Unknown, less than 0.46	No

TABLE 8. Qualitative Comparison of Ecological Benefits of Proposed Alternatives.

Alternative	Flow, Continuous	Freshwater	Volume ($\geq$ 5 acre-feet/day)	Sediment Added	Delivery Location	Energy Required
Allison Wastewater Treatment Plant	√	√			√	√
Sand/Gravel/Caliche Mine Ponds		√		√	√	√
Hondo Creek Realignment	√	√	√			√
Nueces River Tidal Diversions	√		√		√	
Industrial Wastewater	√	√	√		√	
Deep-Water Wells in Nueces Delta			√		√	
Evaporation Control	√	√	√			√
Off-Channel Storage/Aquifer Storage and Recovery		√	√		√	
Brackish Seepage above Calallen Dam			√			
Lake Corpus Christi Pipeline		√		√		
Mary Rhodes Pipeline	√	√	√		√	
Treated Wastewater from Portland to Aransas Pass	√	√	√		√	
Nueces Bay Additions			√		√	
Odem Wastewater Treatment Plan	√	√			√	√
Pollywog Pond		√		√	√	√

The relatively low cost of transporting treated effluent from Allison WWTP suggests there is value in spending more time and money to find a solution allowing discharge to the Delta without further reduction in ammonia-nitrogen. Any effort to do so should focus on having all the effluent stream discharged to the Delta instead of the currently permitted 2 MGD.

There is a potential advantage to the City in pursuing rerouting wastewater discharges from the Corpus Christi Inner Harbor to the Delta. Section 1.d. of the agreed order states, "Any inflows, including measured wastewater effluent…which are intentionally diverted to the upper Nueces Delta region, shall be credited toward the total inflow amount delivered to Nueces Bay and/or the Nueces Delta." The treated wastewater discharges to the Inner Harbor total 33,754 acre-feet per year and any portion of them diverted to the Upper Delta could be credited to required releases from the reservoir system.

Implementation of any alternative will require permits issued by one or more agencies. In some circumstances water rights permits would be required or the agreed order would need to be amended. Permit requirements and amendments to the agreed order will depend on final project plans.

In their report evaluating modifications to water flow in the Delta, Dodson et al. (2016) concluded regarding the Odem WWTP discharge,

> "…diverting, on a regular basis, even the relatively small amount of effluent available from the Odem WWTP discharge into a suitable wetlands site within the West Lake area of the Nueces Delta would produce a net increase in the productivity and ecological value of the target wetlands."

Their statement is a reminder of the potential ecological value of continuing to investigate any alternative to add water to the Delta.

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APPENDIX:

TWDB Comments on Draft Report

Texas Water Development Board

P.O. Box 13231, 1700 N. Congress Ave.
Austin, TX 78711-3231, www.twdb.texas.gov
Phone (512) 463-7847, Fax (512) 475-2053

Mr. David Buzan
Project Manager
Freese and Nichols, Inc.
10431 Morado Circle, Suite 300
Austin, Texas 78759

RE: BBASC Contract with Freese and Nichols, Inc.; Contract No. 1600012016, Draft Report Comments Entitled "Alternative Methods to Add Freshwater to the Nueces Delta"

Dear Mr. Buzan:

Staff members of the Texas Water Development Board (TWDB) have completed a review of the draft report prepared under the above-referenced contract. ATTACHMENT 1 provides the comments resulting from this review. As stated in the TWDB contract, Freese and Nichols Inc. (F&N) will consider revising the final report in response to comments from the Executive Administrator and other reviewers. In addition, F&N will include a copy of the Executive Administrator's draft report comments in the Final Report.

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and six (6) bound double-sided copies. **Please further note, that in compliance with Texas Administrative Code Chapters 206 and 213 (related to Accessibility and Usability of State Web Sites), the digital copy of the final report must comply with the requirements and standards specified in statute. For more information, visit http://www.sos.state.tx.us/tac/index.shtml.** If you have any questions on accessibility, please contact David Carter with the Contract Administration Division at (512) 936-6079 or David.Carter@twdb.texas.gov.

F&N shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

Please feel free to contact Dr. Evan Turner of our Surface Water staff at 512-936-0820 or evan.turner@twdb.texas.gov if you have any questions or need any further information.

Sincerely,

Robert E. Mace, Ph.D., P.G.
Deputy Executive Administrator
Water Science and Conservation

Date: 8/14/12

Attachment

c w/o att.: Dr. Evan Turner, Surface Water

Attachment 1
Freese and Nichols, Inc.
"Alternative Methods to Add Freshwater to the Nueces Delta"
Contract No. 1600012016
TWDB Comments to Draft Report

REQUIRED CHANGES

General Draft Final Report Comments:

The goal of this study was to identify and evaluate alternative methods to add freshwater inflow to the Nueces Delta. The draft report successfully describes the benefits and challenges of thirteen alternatives for increasing the amount of water delivered to the Nueces Delta and four additional alternatives that would enhance ecological condition by modyifing the method in which water is added to and moves through the system. The report is well-organized and the map figures are helpful in viusalizing the alternatives. This study report adequately meets the tasks identified in the scope of work and will serve as an important strategy planning document for stakeholders.

1. Please add the following statement to the cover page of the final report:

   PURSUANT TO HOUSE BILL 1 AS APPROVED BY THE 84TH TEXAS LEGISLATURE, THIS STUDY REPORT WAS FUNDED FOR THE PURPOSE OF STUDYING ENVIRONMENTAL FLOW NEEDS FOR TEXAS RIVERS AND ESTUARIES AS PART OF THE ADAPTIVE MANAGEMENT PHASE OF THE SENATE BILL 3 PROCESS FOR ENVIRONMENTAL FLOWS ESTABLISHED BY THE 80TH TEXAS LEGISLATURE. THE VIEWS AND CONCLUSIONS EXPRESSED HEREIN ARE THOSE OF THE AUTHOR(S) AND DO NOT NECESSARILY REFLECT THE VIEWS OF THE TEXAS WATER DEVELOPMENT BOARD.

2. Please add the TWDB Contract #1600012016 to the front cover of the report.

3. Please proofread the report before submitting, looking for spelling and grammatical errors. Several areas of the report lack proper comma usage, omission of the definite article 'the' before nouns, and contain fragmented sentences. Please ensure the report adheres to the convention of spelling out numbers one through nine and writing numbers 10 and above in number form. The use of PSU (Practical Salinity Unit) in the report should be capitalized instead of lowercase.

Specific Draft Final Report Comments:

1. Pages vii, 1, 2, and 4: There is inconsistent spacing after section headings. Heading 1 and 2 (pages vii and 1) are different spacing than other sections (i.e.,

sections 3 and 4; pages 2 and 4). Please adjust the heading format to remain consistent throughout the report.

2. Page 1, Introduction: Replace references to the Nueces Estuary Advisory Council (NEAC) with the Nueces Basin and Bay Area Stakeholder Committee (BBASC). The Nueces BBASC recommended that the TWDB fund the study. Though membership in each committee overlaps, the NEAC is a separate, independent entity from the Nueces BBASC and is not responsible for providing recommendations to the TWDB concerning Senate Bill 3 work plan funding. Also, please provide a reference for the three guiding principles of the project (e.g., BBEST or BBASC reports, peer-reviewed literature, etc.). The bulleted list of project principles is written either with full sentence structure or as a shorthand list. Please correct the grammar of these paragraphs to create full sentences.

3. Page 2, Background, paragraph 3: Replace the word "permittee" with "certificate holders" and add "City of Three Rivers" to the certificate holders listed. The Nueces River Authority, City of Corpus Christi, and City of Three Rivers are the owners of Certificate of Adjudication No. 21-3214. The City of Corpus Christi is the managing entity of the reservoir system as stated in the Agreed Order.

4. Page 10, Alternatives, item 2: The description should also reflect that the maximum annual amount authorized for diversion in the Rincon Bayou project under Water Right Permit 5736 is 8,000 acre-feet per year.

5. Page 30, Alternative 7: Please correct the following statement, which should refer to Alternative 4: "*It may be possible to combine aquifer storage with Alternative 16, Deep-Water Wells in the Delta.*"

6. Page 42, Alternative 11: Please discuss in the 'Other Factors to be Considered' section that there is no way to keep the sources separate once in the pipeline.

7. Page 45, Alternative 12, paragraph 2: Please expand the statement: "*About half the water in LCC/CCR system is lost to evaporation and channel losses.*" For example, the reviewers suggest: "On average for any given year, about one half of total water use (municipal and industrial, pass-throughs, and evaporation) from the LCC/CCR system is via evaporation."

8. Page 47, Paragraph 1, last sentence: The reviewers suggest the last sentence in the description of Alternative 13 is incorrect. The proposed project may require an amendment to the underlying Certificate of Adjudication 21-2464 authorizing Lake Corpus Christi and subsequent changes to the Agreed Order depending on project specifics such as location of the diversion point, whether stored water is being diverted, inflows, etc.

9. Page 50, Alternative 14, bullet item 2: The reviewers suggest including "yield" along with operations and capacity not to be impacted by this alternative.

10. Page 57, Summary: The report includes an assessment of whether additional water rights permitting would be required; however, the need for amendments to the Agreed Order or additional water rights authorization will be dependent on final project plans. Please include a statement or paragraph reflecting this concept in the discussion section.

Figures and Tables Comments:

1. All Figures: The resolution of figure images appears to be below 300 dots per inch (dpi). Please include images at least 300 dpi for the final report as requested in Exhibit D of the TWDB contract.

2. All Tables: Font size in the tables appears to be lower than 12-point which reduces readability. Please use the same font size throughout the report (Times New Roman, 12pt).

3. Page vii, Table in Executive Summary: Please provide a table caption.

4. Page 13, Table 3; Page 31, Table 9; and Page 42, Table 14: In the 'Effects of adding water' column, Section 4 on Study Area is referenced. Please correct it to Section 5 on Ecological Effects of Adding Water.

5. Page 15, Table 4, Regulations: Please add, "TCEQ water rights permit may be required" to this section. A TCEQ water rights permit would be required to divert water from Nueces Bay or the Corpus Christi Inner Harbor.

6. Page 17, Table 5, Costs: Please remove the extra space in "76,270." Also, in the 'Effects of Removing Water' section: The landowner(s) cooperation and effects of land modification (rerouting) need to be taken into consideration for this alternative.

7. Page 18, Table 5, Effects of adding water: Please correct the misspelling of "Corpus Christi."

8. Page 20, Table 6, Regulations: Add, "TCEQ water rights permit may be required" to this section. A TCEQ water rights permit may be required to use the bed and banks of Nueces Delta/Rincon Bayou to transport groundwater.

9. Page 23, Table 7, Regulations: Add "TCEQ water rights permit may be required" to this section. If Peters Swale is determined to be a state watercourse, diversion of storm-water would require a water rights permit.

10. Page 29, Table 8, Regulations: Add, "TCEQ water rights permit may be required" to this section. If water is discharged from the WWTP to the river and

subsequently diverted as discussed on page 26 in the first paragraph under Figure 9, a water rights permit would be required by TCEQ.

11. Page 34, Table 11: Please avoid splitting tables between pages if possible. Move Table 11 to the next page so the table is not cut-off.

12. Page 35, Table 11, Regulations: Add, "TCEQ water rights permit may be required" to this section. A TCEQ water rights permit would be required to divert return flows from Corpus Christi Inner Harbor for indirect reuse.

13. Page 39, Figure 13: The text in red font is blurry and difficult to read. Please ensure all figures are clear and readable.

14. Page 43, Table 14, Regulations: Add, "TCEQ water rights permit may be required" to this section. In addition to the existing language addressing the need for an inter-basin transfer authorization relating to surface water based return flows, a TCEQ water rights permit would also be required if streamflow is diverted from a watercourse into the pipeline.

15. Page 48, Table 16, Regulations: Add, "An amendment to the Certificate of Adjudication 21-2464 authorizing Lake Corpus Christi may be required by TCEQ" to this section.

SUGGESTED CHANGES

Specific Draft Final Report Comments:

1. It would be helpful to include bookmarks for the section headers in the pdf document to better aid in navigation of the report.

2. Page 15, Alternative 2, Effects of Removing Water: The text states: "*...appear to exceed 35 psu approximately 25% of the time. When salinities in Rincon Bayou reach 35 psu or higher, salinities in the bay and Inner Harbor may also exceed 35 psu.*" Please include a statement about average salinity condition in Rincon Bayou when Nueces Bay is above 35 PSU. For example, "During the period when Nueces Bay is hypersaline, average salinities in Rincon Bayou is X, ranging from minimum Y to maximum Z."

3. Pages 20-22, Alternative 4: Aquifer storage and recovery may require additional regulations requiring the water to be treated (potentially to drinking water standards) before being injected into the aquifer. Consider discussing the additional standards and adjusting the project costs to reflect the treatment of the water for storage.

4. Pages 23-24, Alternative 5: This alternative includes the costs of purchasing water from a nearby landowner, but does not reflect the costs of transportation or loss. For example, some of the water will evaporate during transport and the reliance on gravity may alter the flow rate. Please reflect these caveats in the discussion.

5. Pages 25-29, Alternative 6: The City of Corpus Christi receives return flow credits each month for Allison WWTP and other discharge to Nueces Bay. Please include this in the discussion of the alternative. Also, consider discussing the estimated cost of pumping the river water from near the discharge point to the cells or diluting the water via a groundwater well.

6. Pages 30-32, Alternative 7: Please consider including discussion of the effects of evaporation on the off-channel reservoir. Also, consider including discussion of the regulations and costs of treating water before injection into an aquifer.

7. Pages 42-44, Alternative 11: Please expand on the discussion of water transferred to the delta that would not be regulated under the Agreed Order. The reviewers request justification as to why this water would not be counted toward pass-through targets. Also, the reviewers request the consideration of an alternative of piping industrial waste from Portland area using another pipeline to avoid contamination issues with the Mary Rhodes. Additionally, consider discussing the possibility of contamination of the pipeline.

Figures and Tables Comments:

1. Dealing with many large tables and figures is a challenge for readability as many of these tables span multiple pages. One suggestion is to always start a table or figure on a new page. Alternately, another suggestion regarding the tables is to remove them. Most of the tables include large paragraphs of text (less than 12-point font) and are used as a method for flow control instead of summarizing information. This tends to create large unused sections of white space in the table because of the text justification. The authors could instead remove most of the tables and place the text back in the body of the manuscript and make use of sub-headings within the section. The text can then be revised in full grammatical sentences. This would greatly add to the readability of the report findings.

2. Page 34, Alternative #8 and Table 10: Consider discussing whether discharges from marine seawater desalination plants is an alternative that could be considered in the future.

3. Page 57, Table 17 (also located in Executive Summary): Please consider expanding the simplified summary table to include the many other parameters evaluated in the study. An inflow alternative that may be cost-effective and provide a large volume of water could have other issues such as heavy regulation

or detrimental ecological effects but this is not easily summarized. One reviewer's suggestion is to categorize the information into rankings (e.g., 1 being cheapest per acre-foot, 1 being most ecologically beneficial, or 1 being least amount of regulatory challenges, etc.).