Technical Support Document:
Historical Review of Nueces Bay (Segment 2482) Zinc Total Maximum Daily Load Effectiveness Monitoring

Including Nueces River Tidal (Segment 2101) and Corpus Christi Inner Harbor (Segment 2484)

Prepared for:

Texas Commission on Environmental Quality

TCEQ

Prepared by:

Center for Coastal Studies
Texas A&M University-Corpus Christi

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Corpus Christi Inner Harbor (Segment 2484)

Prepared for:

Texas Commission on Environmental Quality
Jim Neece, TMDL Project Manager
MC-203
P.O. Box 13087
Austin, TX 78711-3087
Ph. 512.239.1524
E-mail: jim.neece@tceq.texas.gov

Prepared by:

Center for Coastal Studies
Erin M. Hill and Brien A. Nicolau

Texas A&M University-Corpus Christi
Center for Coastal Studies
6300 Ocean Drive NRC 3200
Christi Corpus Christi, Texas 78412
Ph. 361.825.5791 or 361.825.5807
E-mail: erin.hill@tamucc.edu or brien.nicolau@tamuccc.edu

EXECUTIVE SUMMARY

This document provides a historical data review and assessment of the Total Maximum Daily Load (TMDL) model established for elevated zinc in oyster tissue concentrations in Nueces Bay and the effectiveness monitoring of the data collected under the subsequent Implementation Plan (I-Plan) developed.

Historically, the American Smelting and Refining Company processed several billion tons of high-grade zinc ore from 1942 to 1985 and discharged this effluent to the Corpus Christi Inner Harbor and Nueces Bay. Based on risk assessment analysis conducted by the Texas Department of Health (now Department of State Health Services, DSHS), the regulatory authority over fish and shellfish advisories and closures in Texas waters, the conclusion in 1995 was that:

> *"The consumption of oysters from Nueces Bay may result in deleterious effects on the digestive (acute effects) and hematologic systems (intermediate and chronic effects) and that the consumption of oysters from Nueces Bay is not recommended."*

As elevated zinc in oyster tissue concentrations continued to exceed the DSHS Health-based Assessment Comparison value of 700 mg/kg, Nueces Bay was placed on TCEQ's 1998 303(d) of impaired waters for not supporting the oyster waters use criteria. This listing, and the environmental concern of local citizens involved with newly created Corpus Christi Bay National Estuary Program, prompted the TCEQ TMDL Program to contract for the development of a zinc loading model and establishing an intensive sampling program (2004-2006) in Nueces Bay to allocate the allowable zinc load in Nueces Bay. The TMDL was adopted by the TCEQ Commission on November 1, 2006 and approved by the U.S. Environmental Protection Agency on December 15, 2006.

As required, an Implementation Plan was then developed to provide an adaptive management approach that includes regulatory and non-regulatory activities that can be implemented to hopefully achieve the water quality goals. TCEQ approved the Implementation Plan designed for Nueces Bay on October 24, 2007.

Based on TMDL recommendations, strategies developed in the Implementation Plan addressed zinc in oyster tissue as a legacy pollutant. Zinc attenuation in oyster tissues was to be tracked through a targeted data collection effort (2010-2014) to determine if the designated uses were being met, and to track zinc loadings to Nueces Bay and the effect these loadings have on water and sediment quality and ultimately in oyster tissue. The expectation was that the maintenance of zinc levels in water at or near current levels would ultimately lead to zinc in oyster tissue being reduced over time through attenuation.

Nueces Bay – Segment 2482 is a shallow secondary bay approximately 75 km^2 in size with an average depth of 2.3 m. Oyster reefs or beds scattered throughout Nueces Bay are made up of the American oyster (*Crassostrea virginica).*

Numerous ecosystem services are provided by naturally occurring oyster reefs including food and habitat for many animals such as fish, crabs, and birds. Hard reef structures also provide for shoreline stabilization and by reducing wave energy and subsequent erosion.

However, perhaps the most important ecosystem service provided is that of water filtration. Oyster reefs are natural filtration systems that filter plankton, silt, and contaminants from the water and one oyster can filter up to 50 gallons of water in one day. This efficacy in filtering water, demonstrate the role oysters play in maintaining good water quality. It is also the reason that some bays, like Nueces Bay, are closed to the harvest of oysters due to high contaminant levels sequestered in oyster tissue.

Data collected under the TMDL and I-Plan showed a poor correlation to zinc in oyster tissue concentrations as total zinc in water rarely exceeded the criteria and sediment concentrations in Nueces Bay were never exceeded. However, zinc in oyster tissue collected from Nueces Bay, to satisfy Management Measure 1 *"Document Natural Attenuation"* of the I-Plan showed concentration levels of individual zinc in oyster tissue samples from Nueces Bay remained highly variable, ranging from 231 mg/kg to 3340 mg/kg, with 76% of the samples taken from 2010 through 2014 still exceeding the HAC value of 700 mg/kg.

This suggests that the zinc WQ criteria (29 µg/l) developed in the TMDL and defined as Management Measure 2, *"Adjust the Water Quality Criteria"* in the I-Plan may be too high and as stated in the I-Plan Review Strategy, "If attenuation does not result in acceptable levels of zinc in oyster tissue, the plan will be revised to evaluate and address other potential sources identified in the TMDL".

While zinc in oyster tissue levels were high, attenuation appeared to be occurring as some individual station concentrations decreased in the first four years of I-Plan sampling. However, in the fifth-year concentration levels started increasing again and then then sampling stopped. To track attenuation over time requires taking the long view. Environmental contaminant problems are seldom solved, let alone remediated, in the short term.

Because of this poor correlation, the authors suggest reevaluating the zinc WQ criteria (29 µg/l) and investigating the role of Nueces Bay sediments more closely. The 2012 case study described in Section 6 revealed how unconsolidated and easily disturbed Nueces Bay sediments can be and identified that a legacy layer of zinc in sediment does exist in some areas. Disturbance of these sediments does provide a zinc load to the bay that ultimately may be contributing to zinc in oyster tissue contamination.

We believe sampling should not have stopped after five years and that continued sampling of oyster tissue, water, and sediment should continue but should be enhanced to include additional sampling parameters since zinc in water and sediment values, as presently sampled, show no concern. A long-term program like NOAAs Mussel Watch needs to be in place to adequately document if attenuation of zinc in oyster tissue continues over time as suggested in the I-Plan. In addition, new approaches must be considered to better understand the oysters in Nueces Bay and the interactions occurring.

More importantly, new sampling approaches should be implemented that include analyzing suspended particulate organic matter in the water column and sediment surface organic matter, which is an important and substantial part of oyster diets. Valuable data gained by investigating the sediment more closely may show that the sediment contaminant screening level (410 mg/kg) is also not proper to support the oyster water use.

To summarize, extended sampling time and new approaches are needed to fully comprehend and answer such possible questions as:

- Are the oysters slowly responding, but simply need more time?
- What is the actual contribution of suspended particulate organic matter (SPOM) in the water column and sediment surface organic matter (SSOM)?
- Is the subsurface sediment more important than the surface sediment?
- Are there suspected hotspots we haven't found? Do we need more cores such as done in the CBBEP "Nueces Bay Zinc in Sediment Profile Assessment" project?
- Are there hidden sources? Nueces Bay has one of the highest densities of oil wells and pipe lines in Texas. Is the sacrificial coating of zinc applied to galvanized oil field equipment a factor?

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ACRONYMS AND ABBREVIATIONS

CCIA	Corpus Christi International Airport
CCS	Center for Coastal Studies
CFR	Code of Federal Regulations
cfs	Cubic Feet Per Second
DO	Dissolved Oxygen
DSHS	Texas Department of State Health Services
DWL	Dry Weather Load
GIS	Geographic Information System
GPS	Global Positioning System
HAC	Health Assessment Criteria
LA	Load Allocation
mL	Milliliter
MOS	Margin of Safety
NCDC	National Climate Data Center
NAS-CC	Naval Air Station-Corpus Christi
NEXRAD	Next Generation Radar
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NPS	Nonpoint Sources
NRCS	National Resource Conservation Service
SPOM	Suspended Particulate Organic Matter
SSOM	Sediment Surface Organic Matter
SWQS	Surface Water Quality Standards
TAMU-CC	Texas A&M University-Corpus Christi
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Load
TPDES	Texas Pollution Discharge Elimination System
USEPA	U.S. Environmental Protection Agency
WLA	Waste Load Allocation
WQ	Water Quality
SWQM	Surface Water Quality Monitoring
WWTF	Wastewater Treatment Facility

1.0 INTRODUCTION AND BACKGROUND

1.1 Clean Water Act History

The Clean Water Act (CWA) was passed into law by the United States Congress in 1972 for the protection of surface water in the United States. The Act was initially legislated in 1948 under the name Federal Water Pollution Control Act which was restructured and expanded in 1972. It wasn't until 1977 through several amendments that the Act received its official name the "Clean Water Act". The goal of the CWA is to establish regulatory and non-regulatory standards that reduce pollutants entering our nation's waterways. The Act outlines why states and territories need to develop surface water quality standards to ensure the health and safety of the public, along with the goal of restoring and sustaining the chemical, physical, and biological integrity of US surface water to support "the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water." (https://www.cfpub.epa.gov/watertrain/pdf/modules/IntrotoCWA.pdf).

Since the conception of the CWA, many regulatory improvements have been made to the Act that are enforceable and punishable by the law, and if not followed, typically results in large monetary fines. Two main improvements have been: "(1) water quality protection rules based on establishing enforceable standards that apply to the chemical physical, or biological condition of surface water bodies; and (2) protection measures based on treatment technology requirements for facilities that discharge effluent, pollutants, wastes, or other substances into water bodies." (https://cfpub.epa.gov/watertrain/pdf/modules/IntrotoCWA.pdf).

1.2 Total Maximum Daily Load Program Background

Under the CWA, each state is required to evaluate their waters to assess attainment of their waterbodies designated uses as described in their surface water quality standards. If water quality standards are not met for a state's waterbody, the state is required to create a 303(d) list of impaired waters describing their water bodies and the water quality parameter that does not support its designated use. When a waterbody is listed on a 303(d) list, the state in which this waterbody is located is required by the CWA to initiate a Total Maximum Daily Load (TMDL) for the impaired water body. The purpose of a TMDL is to determine the maximum amount or load of a pollutant that a water body can receive while still supporting its designated uses. The end goal of a TMDL is to identify the allowable load of all potential causing sources to attain and restore water quality standards.

In Texas, these standards are detailed in the Texas Administrative Code, Title 30, Chapter 307. The Texas Surface Water Quality Standards (SWQS) deal primarily with the concentration limits of anthropogenic pollutants that may be allowed in the state's water bodies. The Texas Commission on Environmental Quality (TCEQ) is responsible for the identification and restoration of all surface waters of the state of Texas that do not meet the SWQS. As part of this responsibility, the TCEQ establishes TMDLs for all impaired waters in the state of Texas. The TCEQ also works with local stakeholders to develop TMDL Implementation Plans to address excess pollutant loadings in the impaired water bodies identified listed on the 303(d) list.

The TMDL process is funded by the Texas Legislature who appropriates funds to the TCEQ and the Texas State Soil and Water Conservation Board. Both agencies support the development of the TMDL, but TCEQ is ultimately responsible for the adoption of the TMDL and final approval from EPA. The TMDL program fulfills the requirements of Section 303(d) of the Clean Water Act. However, funding for implementation of the TMDL is often from local governments or privately owned facilities that discharge water to the impaired waterbody.

1.3 History of the Development of One TMDL for Zinc in Oyster Tissue in Nueces Bay

Oyster reefs and their importance in Nueces Bay have long been overlooked. As key habitat, oyster reefs add valuable complexity to the function of the Nueces Estuary as a nursery ground for economically and recreationally important fish and bird species, habitat for passerby migratory species, shoreline stabilization, structure to slow wave action that is currently eroding the delta face, and a filter for contaminants including excess nutrients, suspended sediments, and harmful algal blooms (Volety et al. 2009; Beck et al. 2011). In addition, oyster reefs provide habitat for the only native estuarine turtle, the Texas Diamondback Terrapin which has a documented population in the Nueces River and Nueces Bay (Baxter 2015).

Globally, 85% of oyster reefs have been lost, making them one of the most significantly impacted habitats needing successful management strategies to balance the pressures challenging oyster reefs worldwide (Nature Conservancy 2016; www. nature.org). Water quality degradation in the United States has negatively affected oysters and with decreased oyster populations comes a decrease in water filtration provided by the species. Because Nueces Bay is much different in nature compared to Chesapeake Bay and other East Coast areas, due to lack of freshwater inflow and common hypersaline conditions, more information on the oyster reef ecosystem roles and life history is needed from Nueces Bay oysters.
http://chesapeakebay.noaa.gov/oysters/oyster-reefs

A large 108 acre hydrometallurgical complex Encycle Texas, Inc., a subsidiary of the American Smelting and Refining Company (ASARCO), was found responsible for disposing excessive amounts of zinc into Nueces Bay (TCEQ 2011). The facility processed several billion tons of high-grade zinc ore at this site from 1942 to 1985; discharging effluent to the Corpus Christi Inner Harbor and Nueces Bay (Barrera et al. 1985; Armstrong and Ward 1998).

From 1988 to 2002 ASARCO/ENCYLE used the site as a waste management facility; treating inorganic hazardous and non-hazardous materials used for recycling, reclamation, and volume reduction. ASARCO/ENCYCLE was located along the northern side of the Corpus Christi Inner Harbor with McBride Lane and Valero Refining to the east and Dona Drive on the south. Dona Park is located near the former ASARCO/ENCYCLE facility along with several industrial plants and refineries that make up Corpus Christi's industrial complex.

The following information is based on a Texas Department of Health (now Department of State Health Services or DSHS) inter-office memorandum (January 1995):

> *In March, 1994, the Texas Natural Resource Conservation Commission, presented results of an initial soil sampling effort for the Dona Park neighborhood in Corpus Christi. The results indicated that soil in the Dona Park neighborhood was contaminated with lead, cadmium, and zinc. They attributed this contamination to a former ASARCO site. The ASARCO site, which is currently owned by Encycle, is immediately north of the Dona Park neighborhood, south of the Turning Basin adjacent to Nueces Bay. Numerous refinery and chemical operations are within the immediate geographical area of the former ASARCO site. These include Coastal, Champlin, Southwestern, Valero, Koch, Javelina, and Citgo refineries as well as the American Chrome and Chemical Co. Subsequent sampling (June, 1994) by Dames & Moore (contractors for ASARCO) confirmed the presence of cadmium, zinc, and lead in surficial soil in Dona Park.*
>
> *Residents of Dona Park have numerous health complaints which they attribute to the contamination from the former ASARCO site as well as from releases from nearby refinery stacks and large piles of coke along the canal, north of Encycle. During a Texas Department of Health (TDH) investigation of citizen health complaints, citizens had raised concerns about the safety of eating fish and shellfish taken from the Nueces Bay area. Apparently, there were reports of releases into the bay. In response to this concern and the potential bioavailability of certain metals to seafood, the TDH Bureau of Epidemiology asked the Division of Seafood Safety to collect fish and shellfish samples from Nueces Bay (NB) and the Turning Basin (TB) area.*
>
> *A total of 20 fish samples (NB,14; TB,6), 3 crab samples (NB,1; TB,2), and 2 oyster samples (NB) were collected and analyzed for metals, pesticides, PCBs, and semi-volatile organic chemicals. With few exceptions zinc, mercury, copper, and arsenic were found at low levels in all 20 fish sampled (arsenic was reported below the detection limit in speckled trout; n=2). Arsenic, copper, mercury, and zinc were found at low levels in crab. Arsenic, cadmium, and copper were found at low levels in oysters; however, zinc was found at an average level of 2,389 mg/kg. All other chemicals were found to be below the detection limits.*

Based on risk assessment analysis at the time the conclusion was that:

> *"The consumption of oysters from Nueces Bay may result in deleterious effects on the digestive (acute effects) and hematologic systems (intermediate and chronic effects) and that the consumption of oysters from Nueces Bay is not recommended."*

Subsequent analysis continued to show water quality impairments in Nueces Bay based on elevated zinc in oyster tissue concentrations. As the state of Texas' water quality criteria for zinc in oyster tissue uses the DSHS Health-based Assessment Comparison (HAC) value of <700 mg/kg zinc in oyster tissue, continued high concentrations resulted in placing Nueces Bay-Segment 2482, on TCEQ's 1998 303(d) of impaired waters for not supporting the oyster waters use criteria.

The development of the *Coastal Bend Bays Plan*, or *Bays Plan* in 1998 fueled the environmental concern for public consumption of oysters harvested from Nueces Bay. This four-year coastal bend community based planning effort was driven by the Coastal Bend Bays & Estuary Program, formally Corpus Christi Bay National Estuary Program and Port Industries of Corpus Christi. This process involved stakeholder representatives from different interest groups in the coastal bend (e.g. industry, agriculture, recreation, shrimping, municipal, scientist, etc.) coming together and identifying environmental issues of concern in our local bays and estuaries. The threat to public health from consuming oysters from Nueces Bay was identified as a priority issue in the *Bays Plan* (TCEQ 2006).

The DSHS continued evaluating seafood tissue from species of fish and shellfish from Nueces Bay and sampled again in 2002 and 2005 for seven metals, arsenic, cadmium, copper, lead, total mercury, selenium, and zinc, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and polychlorinated biphenyls (PCBs: Aroclors 1016, 1221, 1224, 1232, 1248, 1254, and 1260) (TDSHS 2003, TDSHS 2005) and still found zinc levels higher than the Health-based Assessment Comparison value of 700 mg/kg. For the 2002 sampling period, mean concentrations of all samples collected was 1005 mg/kg while 2005 mean concentrations were 886 mg/kg. Nueces Bay has been monitored since 1980, and from 1980-2005 overall mean concentration of zinc in oyster tissue was 1,087 mg/kg (n=49) (TCEQ 2006).

After Nueces Bay was listed on the 1998 Texas Water Quality Inventory and Clean Water Act 303(d) list of impaired waters for not meeting oyster water use criteria, the TCEQ TMDL Program, along with the Texas General Land Office Coastal Management Program, funded two projects: 1) develop a Geographic Information System (GIS) zinc loading model and 2) develop a sampling program for zinc in oyster tissue from Nueces Bay (Nicolau and Hill 2013).

Mrini et al. (2003) developed the GIS zinc loading model which identified all potential zinc sources that could enter Nueces Bay. Ultimately, the model identified the Central Power & Light, Nueces Bay Power Station (currently Talen Energy, Nueces Bay Energy Center) water discharge into Nueces Bay as the main contributor to elevated zinc into Nueces Bay, since the station's water intake for its once-through cooling system was pulled from the Corpus Christi Inner Harbor (Segment 2484) (Mrini et al. 2003; Nicolau and Hill 2013).

The model results were achieved by delineating the Nueces Bay Watershed boundary and specifying all potential inflow sources to the bay that may contribute to the overall loading to the watershed system. The model used all known point and nonpoint sources of potential zinc loads and source flow values to Nueces Bay. Nonpoint sources of zinc included: surface runoff typically from stormwater and atmospheric deposition. Point sources included industrial and municipal dischargers to the bay, Inner Harbor via CP&L, and Lake Corpus Christi pass-through to Nueces Bay via Nueces River (Mrini et al. 2003). These five (5) point and nonpoint source data were put into a Continuously Stirred Tank Reactor model to replicate total zinc levels in Nueces Bay.

Based on zinc in water and zinc in air data, Mrini et al. (2003) model identified the Inner Harbor water via CP&L as the main source of zinc to Nueces Bay contributing 66% of the load compared to surface runoff (5%), atmospheric deposition (23%), permitted dischargers (1%) and Lake Corpus Christi (5%) (Mrini et al. 2003; Nicolau and Hill 2013). The model also identified the largest contributor to inflow into Nueces Bay was CP&L providing 79% of total flow, followed by Nueces River (12%), land surface runoff (9%), and municipal discharges (0.2%) (Mrini et al. 2003). For more detail about the zinc loading model for Nueces Bay see Mrini et al. (2003).

Prior to Nueces Bay listing on the 303(d) list, there was no TCEQ criteria for zinc to assess water quality in oyster waters. The Mrini et al. (2003) study, was used in developing the TMDL for oyster tissue in Nueces Bay. In addition, TCEQ initiated a sampling program conducted by the Center for Coastal Studies (CCS) at Texas A&M University-Corpus Christi (TAMU-CC) to collect new zinc concentration data, with four sampling events conducted between June 2004 – May 2005 (Nicolau and Nuñez 2005b) and from four sampling events that took place from September 2005 – July 2006 (Nicolau 2006b). Results also assisted in development of the current TMDL to allocate the allowable zinc load in Nueces Bay (TCEQ 2006). The TMDL, *One Total Maximum Daily Load (TMDL) for Zinc in Oyster Tissue in Nueces Bay* was adopted by the TCEQ Commission on November 1, 2006 and approved by the U.S. Environmental Protection Agency (USEPA) on December 15, 2006.

1.4 History of the Implementation Plan for One TMDL for Zinc in Oyster Tissue in Nueces Bay

As a management tool, TCEQ assists and funds the development of an Implementation Plan (I-Plan) for all TMDLs. An I-Plan provides an adaptive management approach that involves stakeholder input to develop a plan that includes regulatory and non-regulatory activities that can be implemented within the impaired waterbody or watershed that will hopefully achieve the water quality goals. TCEQ approved the I-Plan designed for Nueces Bay, Segment 2482 on October 24, 2007.

As stated in the *Implementation Plan for One Total Maximum Daily Load (TMDL) for Zinc in Oyster Tissue in Nueces Bay* (TCEQ 2007) the ultimate goals are to:

- *"Ensure levels of zinc in oyster tissue attenuate to levels below the health assessment comparison value (HAC) of 700 mg/kg that supports the oyster water use in Nueces Bay (DSHS 2006)."*

- *"Adopt a criterion for zinc in water that is more appropriate and protective of human health via the pathway of ingestion of oysters. Zinc concentrations in the surface water of Nueces Bay are below the current criterion; however, zinc resulting from legacy sources exists in oyster tissue at levels that could result in adverse health effects from regular or long-term consumption (DSHS 2006). For this reason, a revised criterion for total zinc of 29 µg/L (ppb) was calculated to ensure the protection of human health."*

Since the TMDL indicated no existing discharges would exceed the proposed revised zinc criterion there were no requirements to control known zinc sources through load reductions. Therefore, the I-Plan strategies would address zinc in oyster tissue as a legacy pollutant. Based on the revised criterion, zinc attenuation in oyster tissues was to be tracked through a targeted data collection effort by the CCS at TAMU-CC referred to as the *Nueces Bay Zinc TMDL Implementation and Effectiveness Monitoring Project*.

Project objectives were to conduct sampling in Nueces Bay (Segment 2482), the Corpus Christi Inner Harbor (Segment 2484), and the Nueces River tidal (Segment 2101) to track water, sediment, and oyster tissue zinc levels (Figure 1). Sampling for this project occurred in 2008, and 2010 through 2014 with two sampling events conducted per year. No sampling occurred in 2009 due lack of funding available for the project.

The goal was to provide TCEQ with sufficient data to address the zinc questions in Nueces Bay, (1) to determine if the designated uses were being met, and (2) to track zinc loadings to Nueces Bay (i.e. TMDL implementation) and the effect these loadings have on water and sediment quality and ultimately in oyster tissue. The expectation of the TMDL and the I-Plan was that the maintenance of zinc levels in water at or near current levels would ultimately lead to zinc in oyster tissue being reduced over time through attenuation.

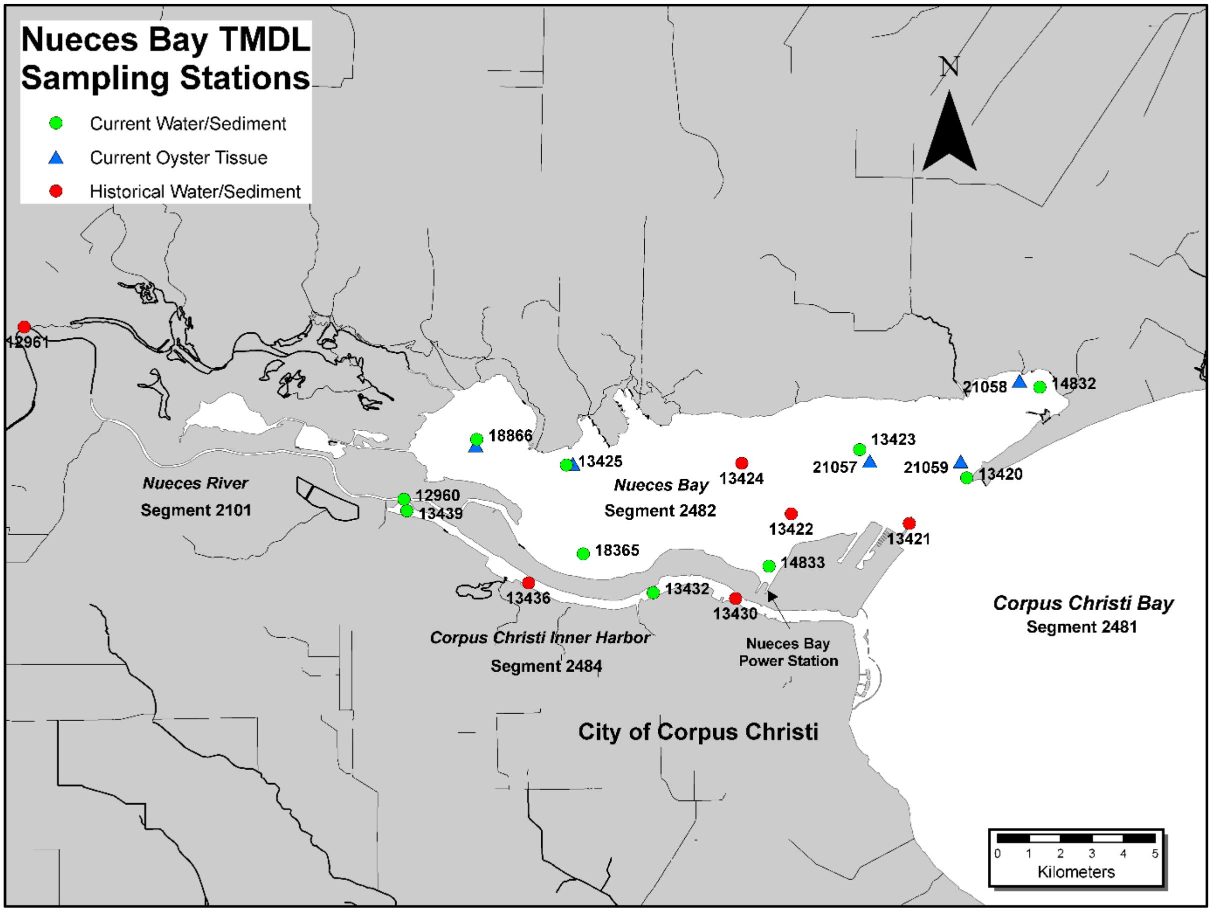

Figure 1. TCEQ Nueces Bay TMDL and Implementation Plan Sampling Stations, 2005-2014.

2.0 SITE DESCRIPTION

2.1 Nueces River Watershed

The Nueces River Watershed covers 4.3 million hectares with 5 ecoregions; the Edwards Plateau, Southern Texas Plains, East Central Texas Plains, Western Gulf Coastal Plains, and the Texas Blackland Prairies (Griffith and Omernik 2009; Hill et al. 2011). Rivers and streams that flow into the Nueces River originate from seeps and springs in the Edwards Plateau and include: Frio, Sabinal, Leona, and Atascosa rivers, and the Seco, Hondo, and San Miguel creeks (Figure 2) (Henley and Rauschuber 1981).

From 1934 to 2009 flow into the Edwards aquifer, from streams and creeks crossing the Balcones Fault Zone, contributed approximately 885 x 106 m^3 yr^{-1} (717,481 acre-ft yr^{-1}) and varies from year to year based on precipitation (Eckhardt 2011). The Nueces is the only river that regularly maintains some surface flow beyond the recharge zone. In lower Nueces River, rainfall provides much of surface flow for the Nueces and its tributaries (Hill et al. 2011).

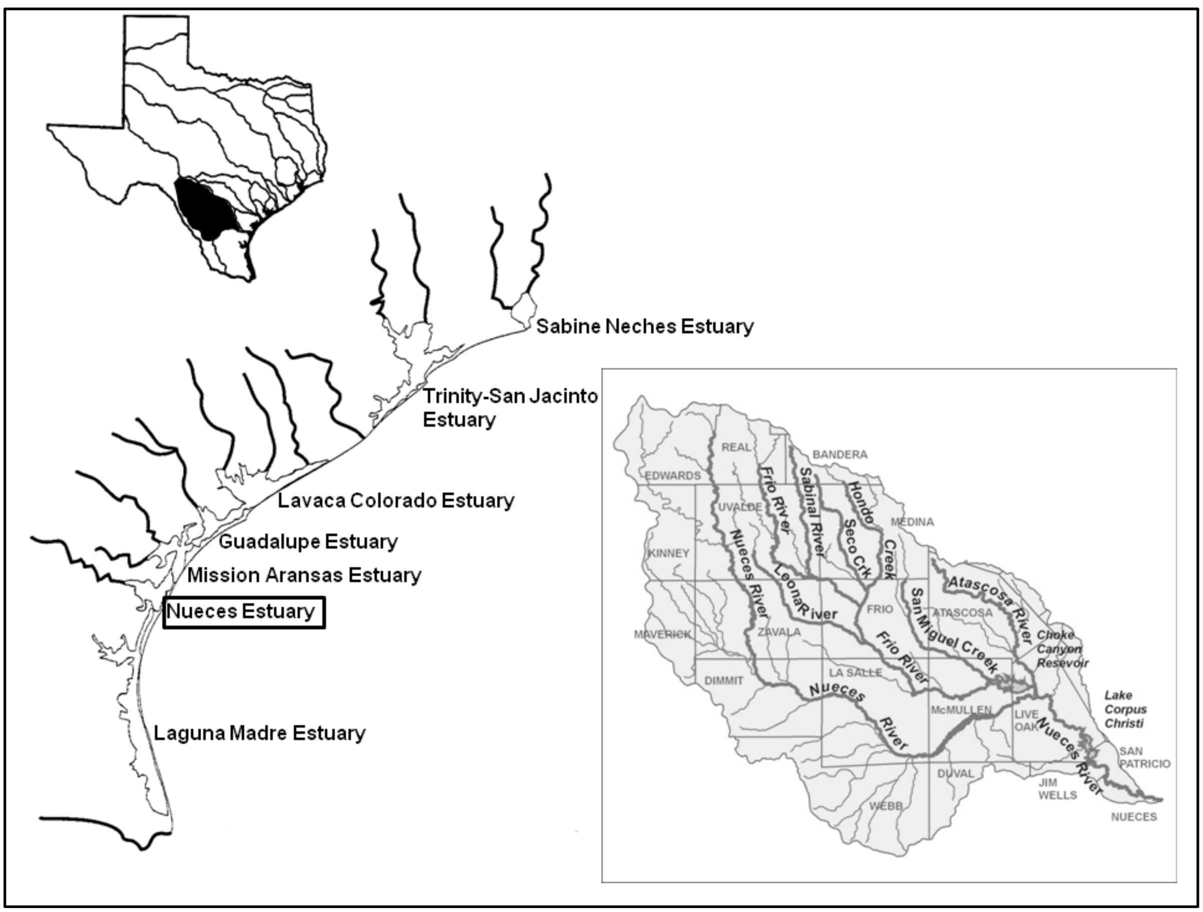

Figure 2. Nueces River Watershed and Texas' estuaries (Hill et al. 2011).

2.2 Nueces River

Two segments of the Nueces River are described in this section, Nueces River Below Lake Corpus Christi - Segment 2102 and Nueces River Tidal - Segment 2101. The Nueces River, Segment 2102, extends 35.0 miles and includes the river from below Lake Corpus Christi to the Calallen Saltwater Diversion Dam. The Nueces River Tidal, Segment 2101, is 12.0 miles in length and begins at the Calallen Saltwater Diversion Dam 1.7 km (1.1 miles) upstream of US77/IH37 in Nueces/San Patricio County and extends to the confluence with Nueces Bay (http://www.tceq.state.tx.us/assets/public/compliance/monops/water/02twqmar/basin21.pdf).

The Nueces River provides water for urban, agriculture, and industry use for the City of Corpus Christi and surrounding region (Anderson 1960). The Nueces River begins in Real County at an elevation of ~ 730 m (TPWD 1974; Benke and Cushing 2005). The Nueces River flows for ~ 507 km in a southeasterly direction, flowing over the Calallen Diversion Dam before emptying into Nueces Bay (TPWD 1974). The Calallen Diversion Dam was the first impoundment on the lower Nueces River tidal segment and was constructed in 1898 for surface water storage (Norwine et al. 2005; Hill et al. 2011). As Corpus Christi and the surrounding area increased in population and economic growth two main reservoir impoundments have been built on the Nueces River; Choke Canyon and Lake Corpus Christi.

The first dam built that held a large volume of water was La Fruta Dam in 1929 (rebuilt in 1935). La Fruta Dam created the Lovenskiold Reservoir located approximately 56 km upstream of the Calallen Dam. Lovenskiold Reservoir had an approximate storage capacity of 68 x 106 m^3 (55,000 acre-ft) (Cunningham 1999). In 1958, the La Fruta Dam was replaced with the Wesley Seale Dam creating Lake Corpus Christi with an increased storage capacity of 317 x 106 m^3 (257,260 acre-ft). The most recent impoundment constructed in 1982 was Choke Canyon Reservoir. Choke Canyon Reservoir is located 80 km upstream of Lake Corpus Christi on the Frio River with a storage capacity of 857 x 106 m^3 (695,271 acre-ft) (Coastal Bend Regional Water Planning Group, 2009).

Historical data (1940–2000) show Nueces River reservoir operations have reduced freshwater inundation frequencies to the Nueces Delta from 2.3 flood events to 1.2 events annually (BOR 2000). This prompted the Bureau of Reclamation (BOR) to fund a demonstration project to divert freshwater into the delta interior with the use of an overflow channel on the Nueces River (BOR 2000; Palmer et al. 2002). The Nueces Overflow Channel is located east of Interstate Highway 37 and was built in 1995. The Nueces Overflow Channel lowered the flood river stage height from 1.64 m above sea level to sea level increasing the probability for freshwater inflows to the upper delta (BOR 2000; Palmer et al. 2002).

The Allison Wastewater Treatment Plant is one of four permitted discharges and the only municipal wastewater permitted outfall on the tidal segment of the

Nueces River (Table 1; Figure 3). The plant was built in 1966 with an initial treatment capacity of 2.0 MGD. Over the years, the plant has been expanded twice and is now permitted to treat 5.0 MGD. This plant services 5,600 acres from the Calallen, TX and Tuloso, TX areas with 18% of its flow coming from a meat packing plant. The Allison Wastewater Treatment Plant Outfall 002 is in the Nueces Delta, adjacent to the Nueces River and water was discharged during a demonstration project that evaluated the use of treated wastewater as a freshwater source (Hill et al. 2011). The non-tidal segment of the Nueces River, which is above the saltwater barrier dam has one no-discharge permit but the entity at times will discharge in to the Nueces River after heavy rain events (Table 2).
(http://www.cctexas.com/government/wastewater/facilities/allison/index)

Table 1. Permitted discharges to Nueces River Tidal, Segment 2101. Information from Nueces River Authority Nueces 2010 Basin Highlights Report, San Antonio-Nueces Coastal Basin, Nueces River Basin, Nueces-Rio Grande Coastal Basin.

Permit	Entity	GPD	Description
WQ0000531-000	Flint Hill Resources Limited Partnership (LP)	n/a	Via ditch, Outfalls 005, 008, and 010
WQ0001255-000	Lon C Hill	1,098,000 0	Via Outfall 001, Outfall 002 intermittent and flow variable. (Re-issued)
WQ0010401-006	City of Corpus Christi Allison Plant	5,000,000	Via Outfalls 001 directly to Nueces River Tidal and Outfall 002 via South Lake to Nueces Bay
WQ0013644-001	San Patricio County MUD No. 1	75,000	Via unnamed ditch to Hondo Creek to Nueces River Tidal

Table 2. Permitted discharges to Nueces River Non-Tidal, Segment 2102. Information from Nueces River Authority Nueces 2010 Basin Highlights Report, San Antonio-Nueces Coastal Basin, Nueces River Basin, Nueces-Rio Grande Coastal Basin.

Permit	Entity	GPD	Description
WQ0002027-000	Wright Materials, Inc.	n/a	This is a no-discharge permit, but there is occasional discharge after heavy rains

Figure 3. Image of permitted TCEQ outfalls in the Nueces River, Nueces Bay, and Corpus Christi Inner Harbor (TCEQ 2016).

2.3 Nueces River Delta

The Nueces River flows into Nueces Bay creating the Nueces Delta and Nueces Estuary (Figure 3). The Nueces River is the only flow the Nueces Delta receives but is typically bypassed due to the river's flow pattern as it meanders along the southern edge of the delta. The delta only receives natural river flow during periods of flooding or from scheduled Rincon Bayou Pump Station releases (Hill et al. 2011; Hill et al. 2015).

Hypersaline conditions in the Nueces Delta frequently occur from the combination of reduced river inflows, low and variable precipitation, and high evaporation rates (Hill 2011; Hill 2015). The resulting negative ecological effects from high salinity (>35 ppt) pushed the state of Texas to develop inflow criteria for freshwater inflows for the Nueces Estuary in 1990 (reviewed in Montagna et al. 2009). US Geological Survey data from 1941–1974 showed mean annual inflow to the Nueces Delta prior to construction of the 2 dams was 774 x 10^6 m^3 yr^{-1} (627,492 acre-ft yr^{-1}) (Henley and Rauschuber 1981; Hill et al. 2011). The current 2001 Agreed Order requires the Nueces Estuary to receive no less than 186 x 10^6 m^3 yr^{-1} (151,000 acre-ft yr^{-1}) of river inflow per year. This mandate represents a 76% decrease in past annual (1941–1974) inflows into the Nueces Estuary.

2.4 Nueces Bay

Nueces Bay – Segment 2482 is a shallow secondary bay approximately 75 km^2 in size with an average depth of 2.3 m. The Corpus Christi Inner Harbor runs parallel along the bay's southern edge along with industrial facilities that includes oil refineries, chemical plants, a power plant, and a railway system. On the northern shoreline of Nueces Bay is the city of Portland. The city of Portland has residential homes along the shore, large areas of agriculture land, and the Papalote Creek Wind Farm consisting of 196 turbines built in 2009. Because of the bay's shallow nature, it is typically turbid from sediment resuspension caused by wind and wave action, from past and present human activities including dredging, and the installation and maintenance of oil and gas wells, pipelines, and electric utility power lines that are in Nueces Bay. Five entities are permitted to discharge to Nueces Bay (Table 3).

Table 3. Permitted discharges to Nueces Bay, Segment 2482. Information from Nueces River Authority Nueces 2010 Basin Highlights Report, San Antonio-Nueces Coastal Basin, Nueces River Basin, Nueces-Rio Grande Coastal Basin.

Permit	Entity	GPD	Description
WQ0001244-000	Nueces Bay WLE LP	500,000,000	Once through cooling water and previously monitored effluent
WQ0010237-002	City of Odem	475,000	Via drainage ditch to Rincon Bayou to Nueces Bay
WQ0010401-006	City of Corpus Christi Allison Plant	2,000,000	Via outfalls 001 (Nueces River Tidal) and outfall 002
WQ0010478-001	City of Portland WWTP	2,500,000	Via drainage ditch to Nueces Bay
WQ0011096-001	Sublight Enterprises, Inc. (Portland Inn)	9,000	None Given

Since the early 1900's, Nueces Bay has been extensively explored for oil and gas which has resulted in a high number of oil wells and pipelines in the bay (D'Unger et al. 1996). Nueces Bay bottom sediments are unconsolidated and easily disturbed (Hill et al. 2014) and both past, and current, oil and gas activities result in disturbances which can release buried contaminants (e.g. zinc) into the water column. Figure 4 shows the extent of oil and gas activities in Nueces Bay.

Mrini (2003) gave a detailed description of land use practices in the Nueces Bay Watershed, which are ultimately determining factors when identifying potential sources of pollutants. Mrini (2003) determined land use in the Nueces Bay watershed by these categories: (1) planted and cultivated 53%, (2) water 10%,

(3) forested upland 10%, (4) shrubland 10%, (5) wetlands 9%, (6) herbaceous upland 4%, (7) developed areas 3%, and (8) barren 1%.

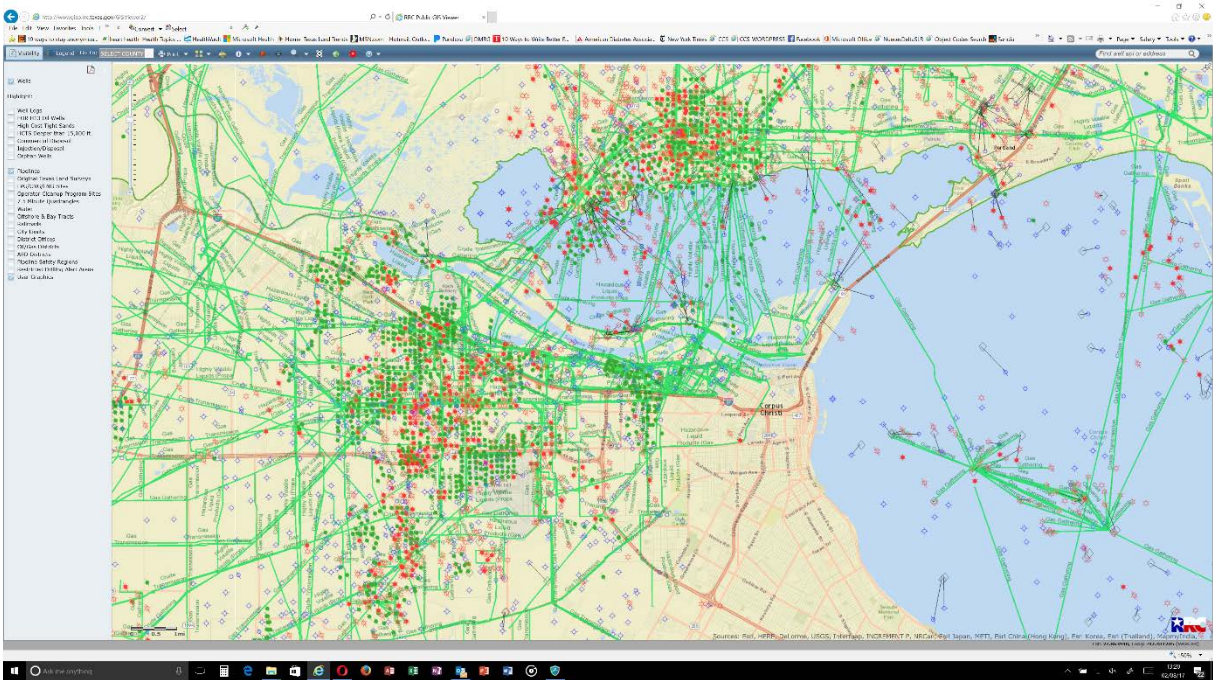

Figure 4. Railroad Commission of Texas GIS Public Viewer depiction of oil wells and pipelines (abandon and active) that are currently in Nueces Bay.

Oyster reefs or beds scattered throughout Nueces Bay are made up of the American oyster (*Crassostrea virginica*). Oyster reefs in Nueces Bay are most dense in the western back part of the bay and the northern portion of the bay near Portland, Texas. These reefs provide habitat and structure for recreational and commercially important fish and shellfish, benthic invertebrates, and help stabilize bottom sediments and break wave energy to prevent shoreline erosion. Reefs in Nueces Bay are prone to crash and boom cycles in productivity and survival that are freshwater influenced by 1) huge freshwater inflow events that overbank the Nueces River and inundate the Nueces Delta resulting in a large sediment load to Nueces Bay that bury the reefs and suffocate the oysters, 2) hypersalinity (>35 ppt) conditions in Nueces Bay from lack of freshwater inflow that may inhibit reproduction. However, contrary to text book descriptions that oysters prefer and thrive in 10-20 ppt, Nueces Bay oysters of market size have been collected in >40 ppt (personal observation).

Oyster reefs were once very abundant in Nueces Bay but due to extensive shell dredging in the 1930s and 1940s many of the reefs have disappeared or have significantly been reduced in size. In many coastal areas, dredged oyster shell was used for building material and used as street pavement (Doran 1965). Historically, in the mid 1800's a large oyster reef that crossed the mouth of Nueces Bay and was used as a bridge between Corpus Christi and Portland. The exact amount of shell removed from Nueces Bay is not known but records show in the 20th century alone, 24 million cubic yards of oyster shell was removed from Nueces Bay. Regulatory initiatives in the 1950s and 1960s finally eliminated the practice of damaging the living reefs and adjacent bottoms and ended shell dredging in the 1970s. (www.epa.gov/sites/production/files/2015-09/documents/stateofthebaypart2.pdf)

2.5 Corpus Christi Inner Harbor

Historical information in this section is summarized from the Port of Corpus Christi History Highlights Website (http://www.portofcc.com) which gives an extensive historical background to the founding of the Corpus Christi Inner Harbor.

The initial idea began in 1920 when the U.S. Congress authorized the Corps of Engineers to conduct a feasibility study to find the best location to build an inner harbor that would connect to a dredged channel beginning at the Port Aransas jetties and crossing Corpus Christi Bay (Figure 5). The study took in account other city options that included Rockport, Aransas Pass, and Port Aransas. Corpus Christi was selected in 1921 because of two main advantages it had over the other cities: (1) the city sits on a 39-40 ft. bluff which is the highest tidal point between Miami, Florida and Veracruz, Mexico and (2) the city also was serving three railroads unlike the other city options (http://www.portofcc.com).

The feasibility study selecting Corpus Christi as home to the inner harbor, compounded many new developments in city government and on October 31, 1922 the Port of Corpus Christi was established and the development of the Navigation District following. The final authorization from U.S. Congress to construct a 25 foot by 200 feet wide dredged channel connecting Corpus Christi to Port Aransas jetties was given to the Corps of Engineers in 1923. The final construction of the channel and Inner Harbor was on September 14-15, 1926 (http://www.portofcc.com). From that date forward, the Port of Corpus Christi has grown to one of the top 6 largest ports in the United States. From a regulatory position, the Corpus Christi Inner Harbor is classified as Segment 2484 and is monitored by TCEQ Region 14. Based on the 2016 Basin Highlight Report, the Corpus Christi Inner Harbor has concerns for elevated nitrates and ammonia levels in surface water (NRA, 2016). Currently, TCEQ Region 14 Field Office samples two stations in the Inner Harbor: (1) 13439 in Viola Turning Basin and (2) 13432 near Navigation Boulevard.

The current structure of the Corpus Christi Inner Harbor is described as an 8.6-mile-long channel with an area of 0.7 sq. miles that begins in Corpus Christi Bay at the U.S. Highway 181 Harbor Bridge and extends to the Viola Turning Basin (Figure 6). Beginning in 1978, the Corpus Christi Inner Harbor was deepened to 49 feet and the dredged material was placed on an adjacent upland site (Smith et al, 1987). Over 70 industrial permitted outfalls, and one (1) municipal outfall are discharged into the Corpus Christi Inner Harbor (See Figure 3). In 2011, six wind turbines were installed and projected to provide over 30 million kilowatt-hours of clean energy annually.

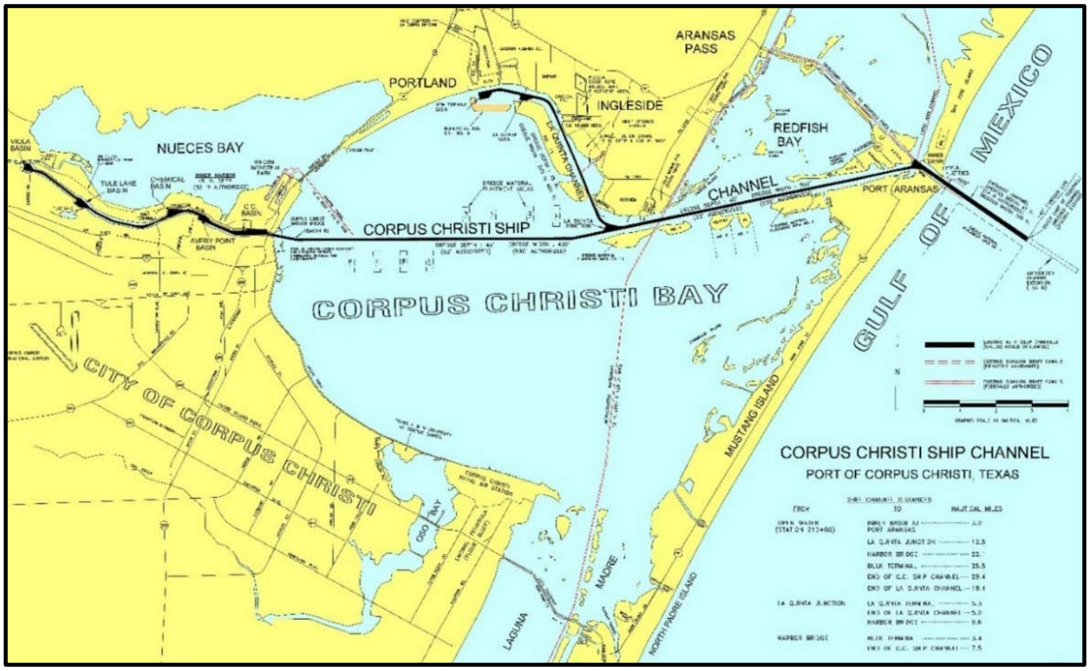

Figure 5. Map of Corpus Christi Ship Channel (www.portofcc.com).

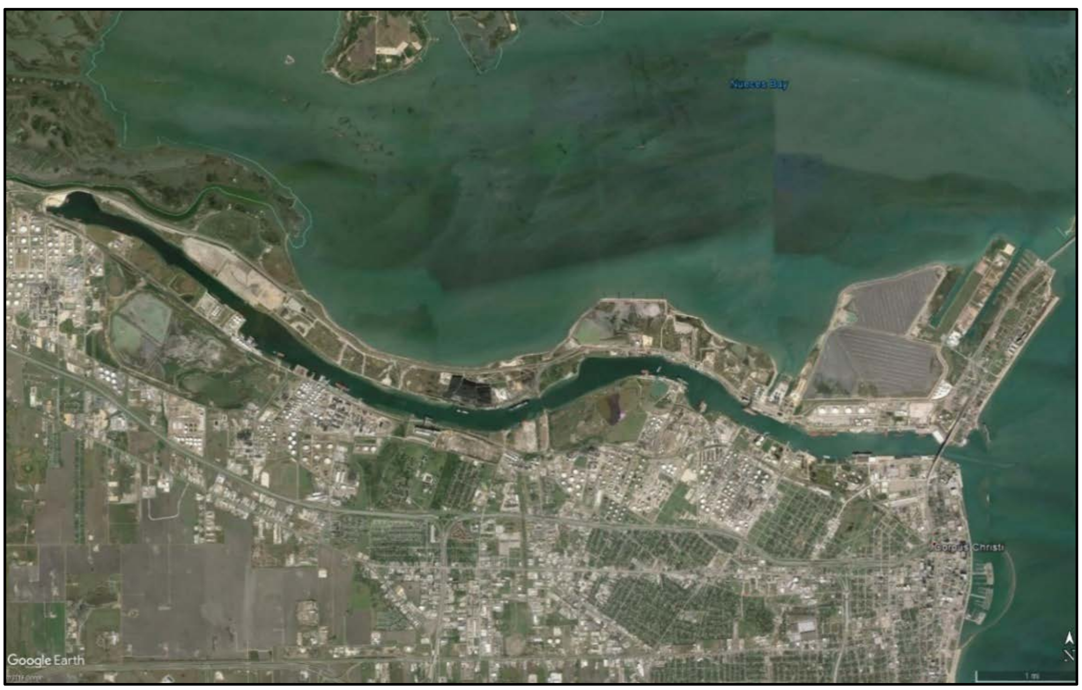

Figure 6. Image of Corpus Christi Inner Harbor (Retrieved 08.15.2016).

3.0 Closing of Nueces Bay for Oyster Consumption and Harvesting, DSHS Zinc in Oyster Tissue Assessment

3.1 American Oyster (*Crassostrea virginica*)

To better understand why oysters have the ability to accumulate metals, an understanding of their physiology, biology, and effectiveness for filtering out pollutants from water is necessary.

Numerous ecosystem services are provided by naturally occurring oyster reefs including food and habitat for many animals such as fish, crabs, and birds. Hard reef structures also provide for shoreline stabilization and by reducing wave energy and subsequent erosion. However, perhaps the most important ecosystem service provided is that of water filtration (Beck et al. 2011). Oyster reefs are natural filtration systems that filter plankton, silt, and contaminants from the water and one oyster can filter up to 50 gallons of water in one day. This efficacy in filtering water, and the role oysters play in maintaining good water quality, are also reasons that some bays, like Nueces Bay, are closed to the harvest of oysters due to high contaminant levels sequestered in oyster tissue.(http://galvbay.org/how-we-protect-the-bay/on-the-ground/oyster-conservation/) (http://tpwd.texas.gov/fishboat/fish/didyouknow/oysterarticle.phtml).

Beck et al. (2011) states water quality affects oyster health, but not as much as it affects human health. Oysters can tolerate and often thrive in conditions well beyond the point human health concerns become an issue. In this particular case, zinc in oyster tissue concentrations are elevated in Nueces Bay and effect human health. But it is unknown what concentration of zinc may cause death to oyster reefs in Nueces Bay.

The eastern oyster spawns from late spring to early fall with the female releasing more than 100 million eggs each season with 1% settling and reaching the next stage of maturity (Cake and Cordes 1983). Oysters are protandric, meaning in their first year they spawn as males and as they continue to mature and develop energy reserves they switch and spawn as females. The oyster body has two calcareous valves joined together by a hinge. The right valve is flat and the left valve is cuplike, the oyster typically rests on the bay bottom on its flat or right valve (Galtsoff 1964). The valve or shell length can reach up to 8 inches (20 cm).
(http://tpwd.texas.gov/huntwild/wild/species/easternoyster/).

The American oyster has been a commercially important species since the mid-19th century. Middens, or archaeological shell heaps, found in the Texas Coastal Bend also indicate oysters were an important food source for Native Americans. Annually the Gulf of Mexico produces more than 500 million pounds of oysters, with Texas commercial landings in 2000 exceeding 6.1 million pounds of meat, with a monetary value over $11.1 million. Oysters in Texas are harvested from public reefs (22,760 acres) and private oyster leases (2,321 acres).

Approximately 90% of the public reef areas harvested for oysters are found in Galveston, Matagorda, and San Antonio Bay systems with all oyster leases taking place in Galveston Bay (TPWD.Texas.gov). However, as previously stated, no harvesting of oysters occurs in Nueces Bay due to zinc contamination.

3.2 Zinc in Oyster Tissue DSHS Assessment Data

The DSHS is the regulatory authority over fish and shellfish advisories and closures in Texas waters, not the TCEQ. Shellfish are defined as oyster, clams, and mussels which are filter feeders and are often consumed raw. Their filter feeding ability allows oysters to also filter contaminants (e.g. zinc) out of the water which bioaccumulates in the oyster's tissue. The health risks to humans associated with consuming oysters with high levels of zinc include, both acute and chronic effects. Acute negative effects include nausea, lack of appetite, abdominal cramps, diarrhea, vomiting, and headaches. Chronic effects include copper deficiencies, anemia, immune system deficiencies, and reduced high-density lipoproteins levels.
(https://www.dshs.texas.gov/seafood/)

Because oysters are often eaten raw, the DSHS developed the Seafood and Aquatic Life program to protect the health of those who consume oysters. The Seafood and Aquatic Life Group, a part of DSHS, is responsible for the collection and monitoring of oyster, crab, and finfish tissue. The Seafood and Aquatic Life Group also designates molluscan shellfish harvesting areas, certification of shellfish shipments, licensing of crab meat processors, approval of imported crab meat, and fish and shellfish consumption advisories and bans in the State of Texas public waters.

The DSHS HAC value for zinc in oyster tissue is <700 mg/kg. When zinc in tissue exceeds 700 mg/kg, the DSHS issues an advisory warning the public of potential toxic human health effects that may occur if oysters are consumed.

When advisories are issued, the waterbody receives a violation from TCEQ for not meeting the TCEQ Texas SWQS. The TCEQ identifies and lists the waterbody by their segment number for the contaminant and includes all connected water segments that may also be affected. TCEQ used the DSHS oyster data from Nueces Bay to list this waterbody on the Texas 303(d) list of impaired waters in 1998. Along with oysters, finfish and crabs are also collected and analyzed for contaminants.

This data assessment and review for Nueces Bay focuses on DSHS zinc in oyster tissue data that closed Nueces Bay waters to oyster harvesting and placement on the Texas 303(d) list resulting in a TMDL.

3.3 DSHS Oyster Tissue Assessment in Texas Bays

The Texas Department of Health (now DSHS) originally began sampling oyster tissue from Texas oyster harvesting waters in 1968, for Nueces Bay sampling dates to 1980 (Table 4). The number of oyster samples collected from each bay varies and is sparse due to limited funds the department receives. Typically, DSHS only samples oyster tissue as a reactionary response to a spill, occurrence of an algae bloom, or other impaired water quality factors to protect human health.

Oysters collected by DSHS since 1968, and analyzed for contaminants from Texas public waters are of legal-size (3 inches or greater) required by the State of Texas regulations to harvest for consumption. The DSHS collects oysters from several sites within the harvestable waterbody to characterize the spatial distribution of contaminants. Nueces Bay considerably exceeded the HAC value of 700 mg/kg with Sabine Lake having the next highest zinc levels but below 700 mg/kg based on the DSHS 1968-2005 dataset (Figure 7).

Table 4. **Texas Department of State Health oyster tissue historical sampling information: water body name, number of oyster tissue samples analyzed, and data date range.**

Water Body	No. Samples	Date Range
Sabine Lake	5	1980-1981
Trinity Bay	4	1972-1990
East Galveston Bay	3	1970-1984
Galveston Bay	144	1968-2000
West Galveston Bay	36	1969-1990
Chocolate Bayou	6	1975-1983
Bastrop Bay	1	1983
Freeport Area	4	1979-1982
Christmas Bay	2	1982-1983
East Matagorda Bay	6	1982-1983
Tres Palacios Bay	6	1982-1983
Carancahua Lake	21	1974-1979
Powderhorn Lake	3	1981-1984
Espiritu Santo Bay	9	1982-1984
San Antonio Bay	13	1981-1985
Mesquite Bay	8	1982-1983
Copano Bay	5	1982-1984
Aransas Bay	10	1982-1984
Nueces Bay	49	1980-2005
Corpus Christi Bay	2	1984
Laguna Madre	4	1984
South Bay	9	1981-1984

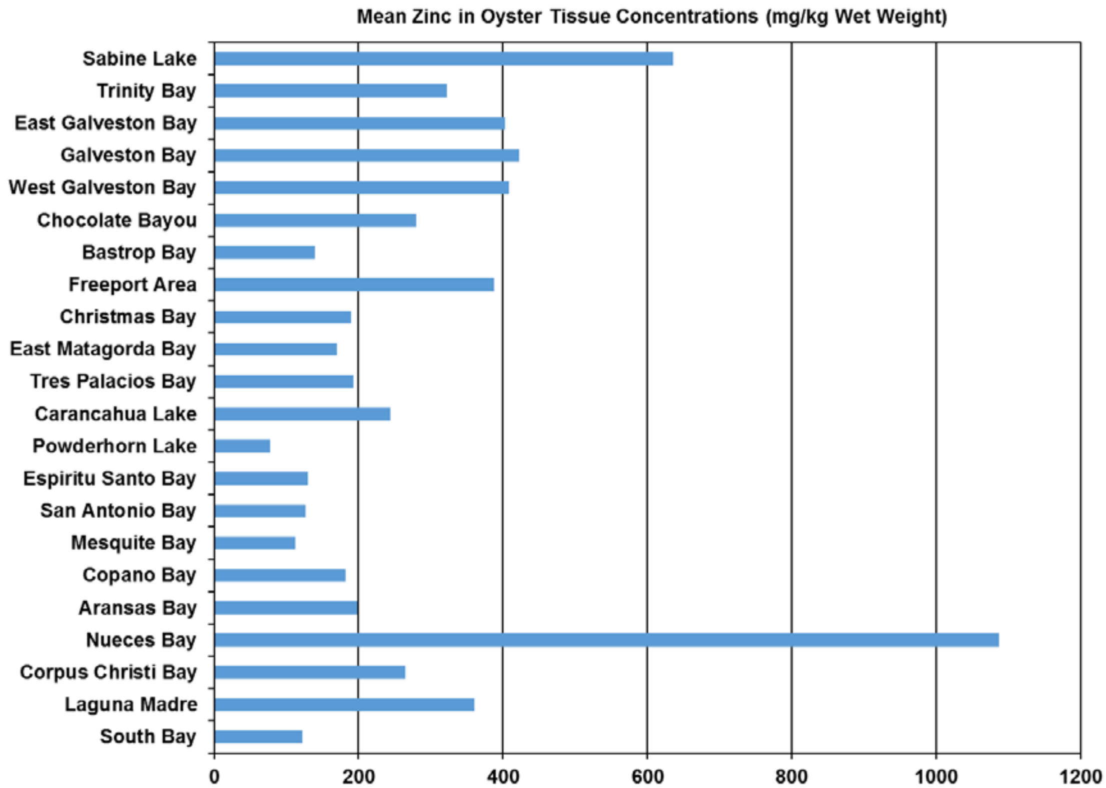

Figure 7. Texas DSHS Mean Zinc concentrations in Oyster tissue from Texas Bays, 1968-2005.

3.4 Oyster Tissue Assessment in Nueces Bay

Oyster tissue collected and analyzed in Nueces Bay by DSHS in 1994 contained elevated zinc levels ranging from 2294-2483 mg/kg with a mean concentration of 2389 mg/kg (Figure 8 and Table 5). This effort by DSHS in 1994 was in response to residents of Dona Park concerned about eating seafood from Nueces Bay because of contaminated soils were found in their neighborhood that was related to the ASARCO zinc smelting site. The zinc in oyster tissue levels in Nueces Bay were well above the 700 mg/kg HAC value prompting DSHS to close Nueces Bay for oyster harvesting and TCEQ classifying Nueces Bay as “impaired” and placing it on the 1998 303(d) list (Mrini 2003).

Prior to the DSHS 1994 oyster sampling, zinc in oyster tissue concentrations were well above the 700 mg/kg HAC value (Figure 8 and Table 5). Background levels of zinc in oyster tissue prior to 1994 indicate zinc pollution in Nueces Bay had started before 1980 but DSHS did not react to high levels of zinc found in oyster tissue in 1980, 1982, 1983, or in 1984. It wasn’t until the 1994 ASARCO complaint and contaminated soils were found in Dona Park neighborhood that the DSHS closed oyster harvesting in Nueces Bay. The DSHS resampled in 2002 (TDSHS 200s) and 2005 (TSDHS 2005) and zinc in oyster tissue remained above the 700 mg/kg HAC value with high variability between individual samples and mean concentrations of 1005 mg/kg and 886 mg/kg (Figure 8 and Table 5), respectively and Nueces Bay remains closed for oyster harvesting to this day.

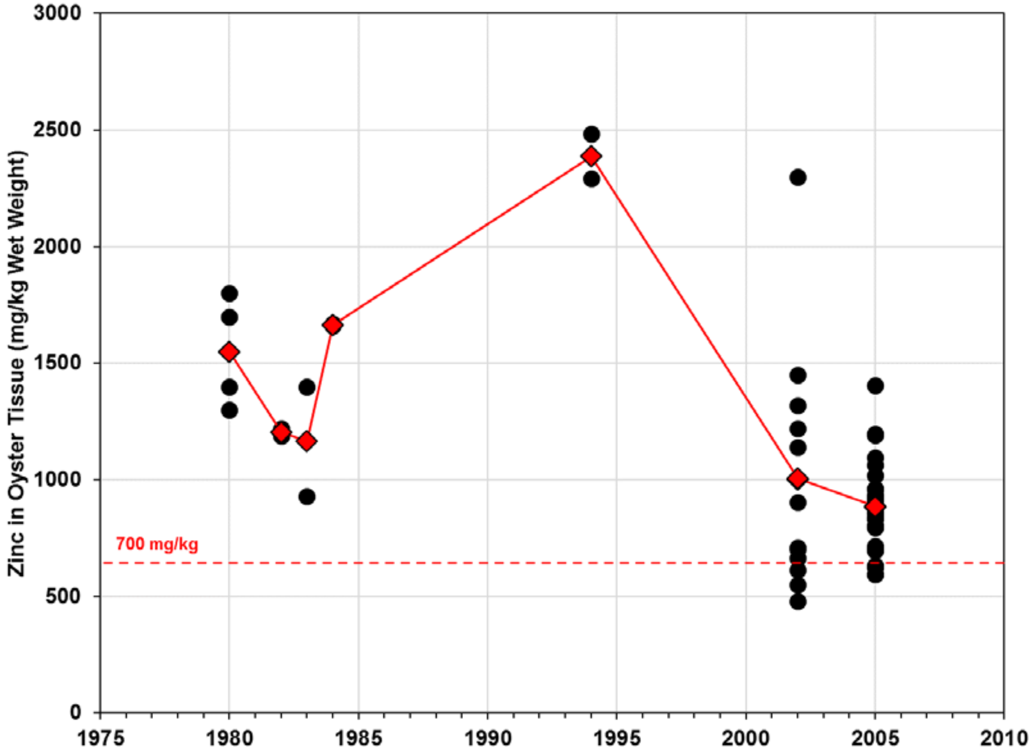

Figure 8. Texas DSHS Zinc in Oyster Data from Nueces Bay, 1980-2005. Black dots represent individual sample concentrations, red diamonds represent mean value of all sample concentrations above HAC criteria for that year, and red dashed line represents HAC criteria.

Table 5. Texas DSHS oyster tissue historical sampling information for Nueces Bay.

Station	Date	No. Samples	Zinc Concentration Range (mg/kg)	Zinc Concentration Mean (mg/kg)
Mid-Nueces Bay	1980	4	1300-1800	1550
Mid-Nueces Bay	1982	2	1190-1220	1205
Mid Nueces Bay	1983	2	930-1400	1165
Mid-Nueces Bay	1984	2	1660-1670	1665
Gum Hollow Mid-Nueces Bay (South Shore)	1994	2	2294-2483	2389
Nueces Bay Causeway (n=7) Nueces Bay Power Station (n=5)	2002	12	479-2300	1005
Nueces Bay Causeway (n=8) Gum Hollow (n=6) Power Lines (n=5) White Point (n=6)	2005	25	623-1405	886

3.5 Zinc in Oyster Tissue Data from Nueces Bay Aside from DSHS Assessment Data

Existing literature regarding studies where zinc in tissue was sampled in Nueces Bay is limited. However, several studies aside from DSHS data were identified. In reviewing historical literature, Jensen and Bowman (1977) provides information about zinc in oyster tissue being collected from two stations in Nueces Bay. Both sites were above the 700 mg/kg HAC value with Nueces Bay Station 3 located along powerlines-south at 1800 mg/kg and Nueces Bay Station 4 located along powerlines-north at 1100 mg/kg.

Barrera et al. (1995) reported in the U.S. Fish & Wildlife Service 1988-1989 study, elevated levels of zinc in oyster tissue from the Corpus Christi Inner Harbor and Nueces Bay. Mean zinc in oyster tissue from the Corpus Christi Inner Harbor was 11,600 mg/kg dry weight (approx. 1,798 mg/kg wet weight) and in Nueces Bay (Whites Point, Mouth of Nueces River, Causeway) was 6006 mg/kg (approx. 931 mg/kg wet weight) with a range of 5196 to 7180 mg/kg dry weight (approx. 805 to 1,113 mg/kg wet weight).

4.0 One TMDL for Zinc in Oyster Tissue in Nueces Bay

4.1 Launching of the TMDL for Zinc in Oyster Tissue - Coastal Bend Bays Plan or Bays Plan

As previously summarized, the TMDL for zinc in oyster tissue in Nueces Bay was fueled by the 1998 community based planning effort by the Corpus Christi Bay National Estuary Program, now the Coastal Bend Bays & Estuary Program. This four-year process, engaged numerous people representing the diverse stakeholder interest groups that make up the coastal community to developed the *Coastal Bend Bays Plan* or *Bays Plan* that identified environmental issues of concern for our local bays and estuaries (CBBEP 1998).

The stakeholder groups invested more than 35,000 hours in the Bays Plan development and consisted of local representatives from industry, commercial shrimping, agriculture, ranching, recreational activities, environmental organization, municipal and county governments, scientists, and federal and state agencies. The *Bays Plan* clearly identified the public health threat from consuming oysters from Nueces Bay due to high zinc concentrations found by DSHS in 1994 as a priority. The attention the *Bays Plan* gave to the zinc in oyster tissue concern, spurred TCEQ to initiate a TMDL in 2002 to address the environmental issue of zinc in oyster tissue contamination in Nueces Bay.

In addition to community awareness motivating TCEQ to address the zinc in oyster tissue issue, as previously stated, DSHS performed quantitative risk characterization studies in 2002 (TDSHS 2003) and 2005 (TDSHS 2005) and still found elevated levels of zinc in oyster tissue in Nueces Bay. The DSHS collected oyster tissue from two sites in 2002, one located near the Nueces Bay Causeway and the other site near the Nueces Bay Power Station. The average zinc in oyster tissue from the Nueces Bay Causeway site was 661 mg/kg (n=7) and from the

Nueces Bay Power Station site 1,486 mg/kg (n=5) and ranged from 479-2300 mg/kg with a mean concentration of 1005 mg/kg (see Figure 8 and Table 5).

Samples collected at multiple sites across Nueces Bay in the 2005 DSHS quantitative risk characterization study (TDSHS 2005) ranged from 623-1405 mg/kg and had a mean concentration of 886 mg/kg (see Figure 7 and Table 5) and the data clearly shows the majority of samples for both studies exceeding the HAC value of <700 mg/kg zinc in oyster tissue levels.

4.2 One TMDL for Zinc in Oyster Tissue in Nueces Bay

As stated earlier, the *Bays Plan* initiated TCEQ to begin a TMDL in 2002 to address the environmental issue of zinc in oyster tissue contamination in Nueces Bay (TCEQ 2006). The TMDL process for zinc in oyster tissue in Nueces Bay was driven by stakeholder involvement, in this case, two groups made up the stakeholders.

The CBBEP, formerly the Corpus Christi Bay National Estuary Program and the Port Industries of Corpus Christi (PICC). The CBBBEP represented: (1) public, (2) environmental groups, (3) municipalities, (4) industry, agriculture, (5) river authorities, and (6) state and federal agencies. The PICC represented (1) industry associated with Port of Corpus Christi. The stakeholder involvement is one component of the TMDL in addition to data collection and model development for estimating load allotments the waterbody can handle to keep in attainment with state water quality standards.

The *One Total Maximum Daily Load for Zinc in Oyster Tissue in Nueces Bay* was adopted by TCEQ on November 1, 2006 and approved by the U.S. Environmental Protection Agency on December 15, 2006. The TMDL developed the allowable zinc load for Nueces Bay to meet the TCEQ zinc in oyster tissue water quality standard criteria. The TMDL also estimated how much current zinc loads should be reduced to achieve zinc in oyster tissue standards that are not a risk to consumers defined by DSHS. The TMDL was prepared by the TMDL Section, Water Programs Division, Chief Engineer’s Office, TCEQ with support from (1) University of Texas, Center for Research in Water Resources at the University of Texas, Austin, (2) DSHS, Seafood and Aquatic Life Group, (3) Center for Coastal Studies, Texas A&M University Corpus Christi, (4) CBBEP, and (4) GLO.

4.3 Establishing the Zinc Water Quality Target for the TMDL

The TMDL water quality (WQ) target for total zinc of 29 µg/L was calculated using the bioconcentration factor (BCF) of 23,820 liters per kilogram (L/kg) and the DSHS HAC value of <700 mg/kg. The BCF was chosen by Mrini (2003) after conducting a literature review of water quality data from other waterbodies throughout the US. The bioconcentration factor is equal to the ratio of the concentration of zinc in oyster tissue to the concentration of total in zinc in water. Prior to the 29 µg/L water quality target value, there was no established zinc criterion for the protection of oyster water use in the State of Texas.

Total Zinc in Water Quality Target Equation:

"BCF = concentration of zinc in oyster tissue / concentration of total zinc in water

HAC 700 mg/kg = Concentration of zinc in oyster tissue

BCF 23,820 L/kg = HAC 700mg/kg/C

C = (700 mg/kg) (1 kg / 23,820 L)

C = .029 mg/L or 29 µg/L

Therefore, the calculated concentration of total zinc in water in Nueces Bay must be less than 29 µg/L to support the target HAC <700 mg/kg value DSHS uses for zinc in oyster tissue to ensure public safety for consumption or harvesting of oysters from Nueces Bay.

4.4 Sampling Data Used in TMDL Development

The TMDL used the Mrini (2003) zinc loading model for Nueces Bay and utilized new zinc data collected by the CCS at TAMU-CC using ultra clean sampling ("clean hands – dirty hands") and analysis methods as detailed in EPA Method 1669 *Sampling ambient water for trace metals at EPA water quality criteria levels* (USEPA 1999) and Albion Environmental, Inc. Standard Operating Procedures modified after EPA Method 1669.

Albion Environmental, Inc. located in College Station, Texas performed the analyses for (1) total zinc in water, and (2) dissolved zinc in water. To note, only total zinc in water data was used for the development of the TMDL because total zinc includes both dissolved and particulate zinc quantities. Whereas dissolved zinc in water only includes the amount dissolved in water. Therefore, dissolved zinc in water will not be discussed in this review. Zinc in sediment will be presented as additional pertinent information. Data presented in this review was pulled from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) of data submitted and approved by TCEQ and collected by the TCEQ Region 14 Field Office and CCS at TAMU-CC.

4.5 Total Zinc in Water Data

Zinc in water samples were collected under an approved TCEQ Quality Assurance Project Plan (QAPP) by CCS at TAMU-CC for trace metals using the latest methods for ultra clean sampling techniques which were not being used by TCEQ Region 14 during this time. This rigorous method prevents the possibility of contamination during field sampling, which methods prior to ultra "clean hands – dirty hands" techniques may not have prevented, creating inaccuracies in laboratory metals data results. Reducing the potential for contamination during field sample collection is essential since the primary sources of contamination come from airborne particulates and human contact with collection bottles.

(Nicolau and Nuñez 2004; Nicolau and Nuñez 2005a; Nicolau and Nuñez 2005b; Nicolau 2006a).

Zinc in water was sampled at 14 Sites in 2004: which included, eight (8) sites in Nueces Bay, two (2) sites in the Nueces River, and four (4) sites in the Corpus Christi Inner Harbor. Zinc in water was sampled at 15 sites in 2005 and 2006 (one site added mid-year in the northern part of Nueces Bay): nine (9) sites in Nueces Bay, two (2) in the Nueces River and four (4) sites in the Corpus Christi Inner Harbor.

Sampling in 2004 took place two times, June 2004 and September 2004, and in 2005 took place four times, January 2005, May 2005, September 2005, and December 2005. Sampling in 2006 took place twice, April 2006 and July 2006.The sampling design gave a spatial characterization of zinc in water from Nueces Bay and reviews the total zinc in water data used to calculate the TMDL for Nueces Bay by looking at total zinc in water data from Nueces Bay, Nueces River, and Corpus Christi Inner Harbor. Data from the April 2006 and July 2006 sampling was obtained too late to use in the development of the TMDL.

Total zinc in water collected from Nueces Bay in 2004 (n=16) ranged from 3.00 µg/L to 20.70 µg/L with a mean of 7.22 µg/L, in 2005 (n=32) ranged from 2.16 µg/L to 43.40 µg/L with a mean of 9.69 µg/L, and in 2006 (n=32) ranged from 1.78 µg/L to 46.10 µg/L with a mean of 13.61 µg/L (Figure 9). Three water samples from Nueces Bay exceeded the 29 µg/L zinc water quality target established in the TMDL, one total zinc in water data point from Nueces Bay in 2005 and two in 2006. Mean value for all three years combined (n=66) was 10.16 µg/L.

Total zinc in water collected from Nueces River in 2004 (n=4) ranged from 3.96 µg/L to 8.79 µg/L with a mean of 6.07 µg/L, in 2005 (n=8) ranged from 0.97 µg/L to 4.89 µg/L with a mean of 2.39 µg/L, and in 2006 ranged from 1.03 µg/L to 17.70 µg/L with a mean of 6.35 µg/L (Figure 10). Mean value for all three years combined (n=16) was 4.30 µg/L.

Total zinc in water collected from Corpus Christi Inner Harbor in 2004 (n=8) ranged from 3.68 µg/L to 11.70 µg/L with a mean of 7.33 µg/L, in 2005 (n=16) ranged from 3.86 µg/L to 23.40 µg/L with a mean of 9.23 µg/L, and in 2006 ranged from 4.66 µg/L to 20.50 µg/L with a mean of 11.50 µg/L (Figure 11). Mean value for all three years combined (n=32) was 9.32 µg/L.

Overall, total zinc in water data collected for the TMDL in Nueces Bay, is below the water quality target of 29 µg/L, and therefore under the assumptions of the TMDL, should not be contributing to zinc contamination in oyster tissue. While not under the same water quality target as Nueces Bay, the two other sources of water to Nueces Bay via the Nueces River and the Corpus Christi Inner Harbor also show levels well below the 29 µg/L water quality target value established by the TMDL.

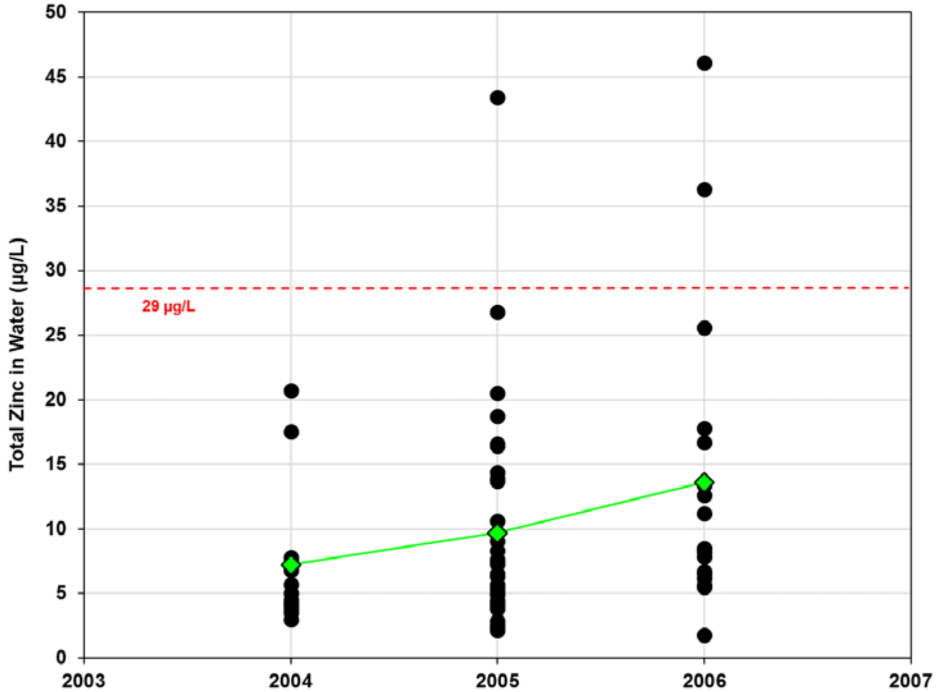

Figure 9. Total zinc in water (µg/L) from Nueces Bay-Segment 2482, 2004 - 2006. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below WQ criteria for that year, and red dashed line represents WQ criteria.

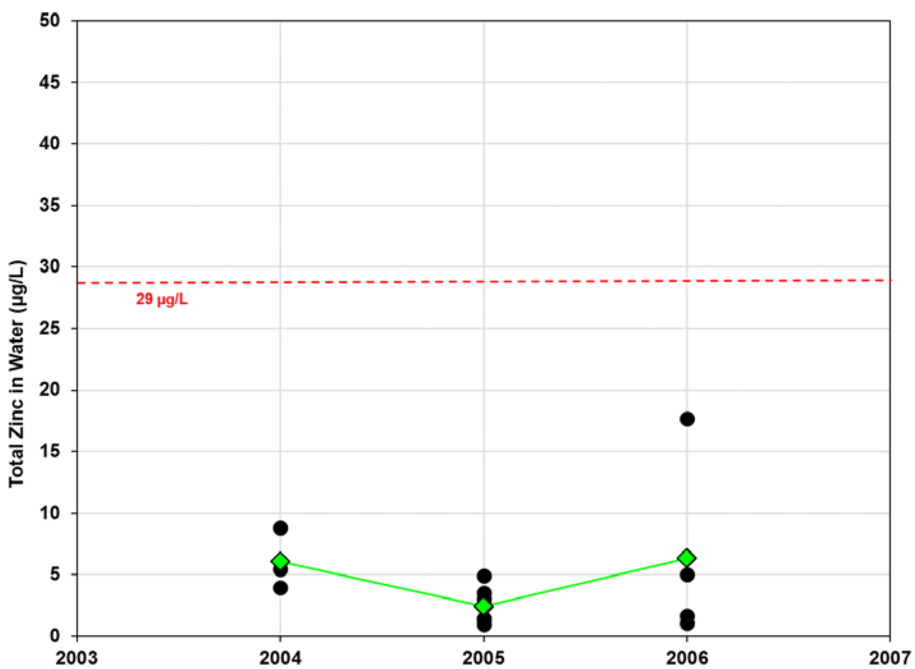

Figure 10. Total zinc in water (µg/L) from Nueces River-Segment 2101, 2004 - 2006. Black dots represent sample concentrations, green diamonds represent mean value of all sample concentrations below WQ criteria for that year, and red dashed line represents WQ criteria.

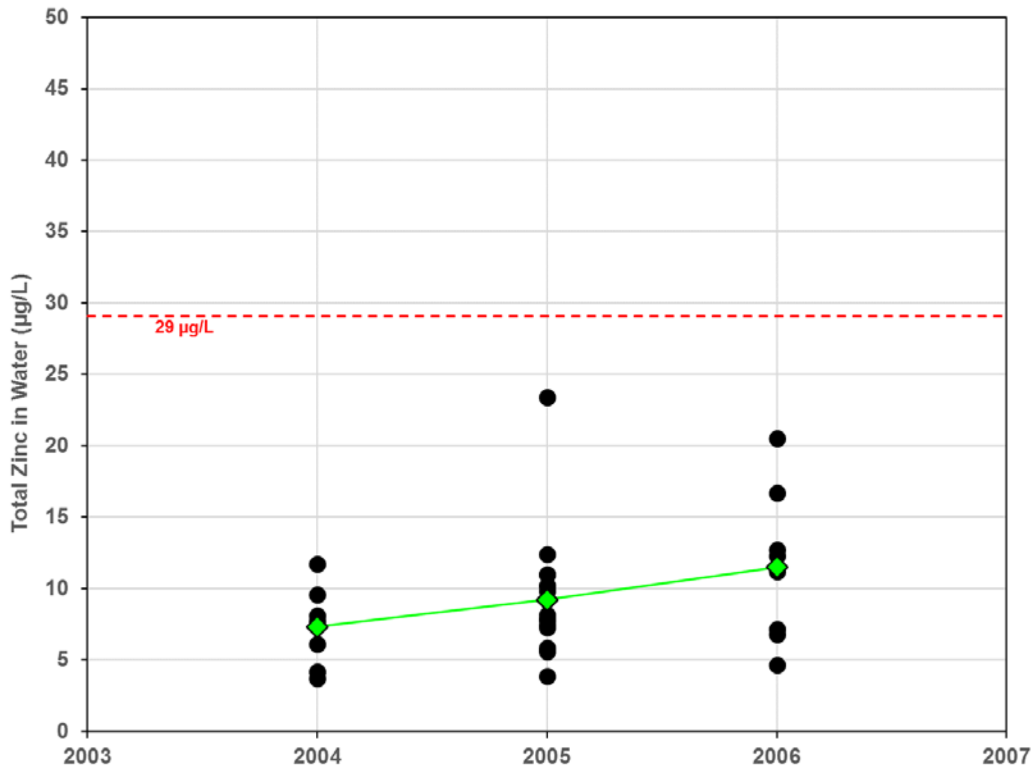

Figure 11. **Total zinc in water (µg/L) from the Corpus Christi Inner Harbor-Segment 2484, collected 2004 - 2006. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below WQ criteria for that year, and red dashed line represents WQ criteria.**

4.6 Zinc in Sediment Data

Zinc samples were also collected under an approved TCEQ QAPP. At each site, a modified 0.04 m^2 Van Veen sampler, was utilized be utilized to obtain multiple grab samples. The surficial sediment layer (2 to <5 cm) from a minimum of three grabs was collected by spatula or scoop and composited into a final sample to provide enough sediment for analysis. Sediment samples were collected by the CCS at TAMU-CC and analyzed by TestAmerica, Inc. Analyses included total zinc, total organic carbon (TOC), and sediment grain size (Nicolau and Nuñez 2004; Nicolau and Nuñez 2005a; Nicolau and Nuñez 2005b; Nicolau 2006a). One sediment sampling took place in September 2004, and two sampling events took place in May and September 2005.

The contaminant screening level used for zinc is 410 mg/kg, which is the Effects Range-Median (ER-M). The Effects Range-Median value of 410 mg/kg is the level above which contaminants in the sediment will probably have adverse effects on animals that live in that sediment. This ER-M, developed by Long et al. (1995), is the screening level used by the National Oceanic and Atmospheric Administration to identify potential impacts to coastal resources and habitats likely to be affected by hazardous wastes and do not constitute criteria or clean-up levels and do not represent official NOAA policy. These screening levels are used in

Texas and in many other parts of the world as the Sediment Quality Guideline of choice (Birch and Hogg 2011).

However, although useful, Birch and Hogg (2011) state that SQGs are not applicable to animals living in the water column as the guidance was developed with specificity to the benthic populations living in sediment and not to organisms like oysters, who live in the water column. Filtering feeding organisms by nature, remove particulates from the water column, which contains re-suspended sediment and organic material from the sediment, along with biological particulates such as phytoplankton, rather than consuming available food directly from the substrate (Birch and Hogg 2011). This distinction presents difficulty in relating tissue burden of filter feeders to sediment chemistry alone and the suggestion is that looking at the resuspendable bottom sediment fraction may prove more useful.

Analysis of Zinc in sediment data during TMDL development collected from Nueces Bay in 2004 (n=8) ranged from 13.20 mg/kg to 115.80 mg/kg, with a mean of 59 mg/kg, in 2005 (n=16) ranged from 8.00 mg/kg to 120.80 mg/kg, with a mean of 58 mg/kg, and in 2006 (n=9) ranged from 13.50 mg/kg to 88.40 mg/kg, with a mean of 45 mg/kg (Figure 12). Mean concentration of zinc in sediment for all three years combined (n=33) was 54.50 mg/kg.

Zinc in sediment collected from the Nueces River in 2004 (n=2) ranged from 62.70 mg/kg to 485.00 mg/kg, with a mean of 274 mg/kg, in 2005 (n=4) ranged from 34.70 mg/kg to 136.20 mg/kg, with a mean of 53 mg/kg, and in 2006 (n=2) ranged from 41.60 mg/kg to 161.40 mg/kg, with a mean of 102 mg/kg (Figure 12). Mean concentration of zinc in sediment for all three years combined (n=8) was 125.50 mg/kg

Zinc in sediment collected from the Inner Harbor in 2004 (n=4) ranged from 63.40 mg/kg to 161.80 mg/kg, with a mean of 124 mg/kg, in 2005 (n=8) ranged from 51.10 mg/kg to 221.40 mg/kg, with a mean of 143 mg/kg, and in 2006 (n=4) ranged from 142.40 mg/kg to 202.00 mg/kg, with a mean of 181 mg/kg (Figure 14). Mean concentration of zinc in sediment for all three years combined (n=16) was 147.90 mg/kg

Zinc in sediment data from Nueces Bay was well below the ER-M value of 410 mg/kg and only one sample, collected from the Nueces River in 2004, exceeded the ER-M. Subsequently after the Nueces River sampling event, a car was pulled from the river near the site. Disposal and abandonment of cars and other zinc containing debris in the Nueces River are perhaps legacy sources of zinc contributing to the zinc in oyster tissue contamination in Nueces Bay but at this point remain unquantifiable.

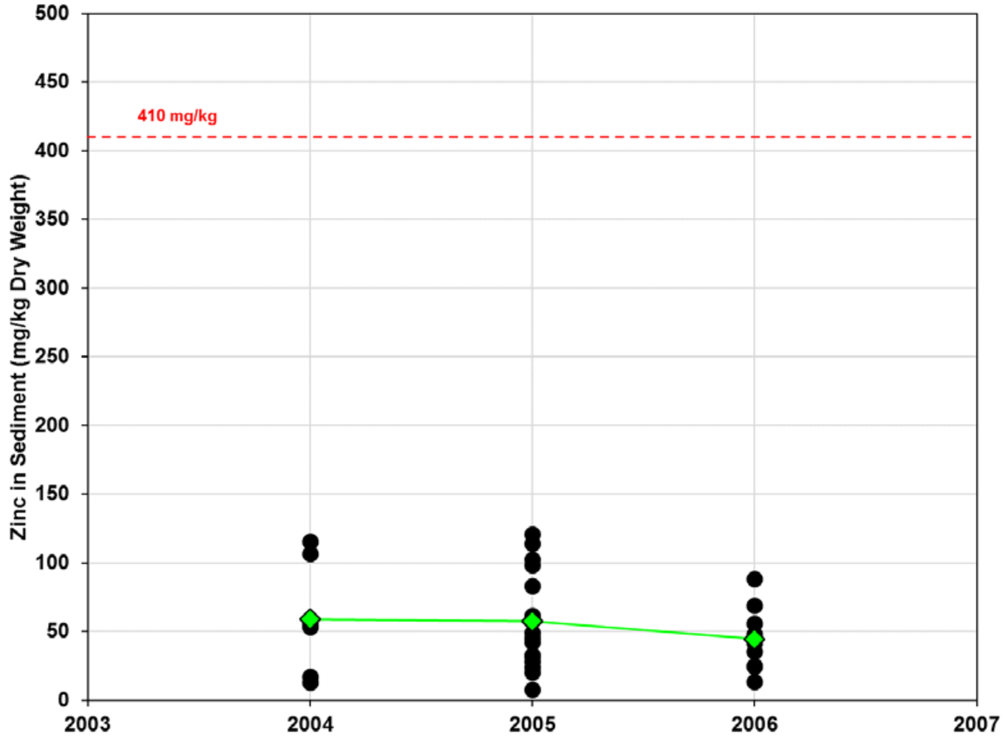

Figure 12. **Zinc in sediment (mg/kg) from Nueces Bay, collected 2004 - 2006. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below contaminant screening level for that year, and red dashed line represents contaminant screening level.**

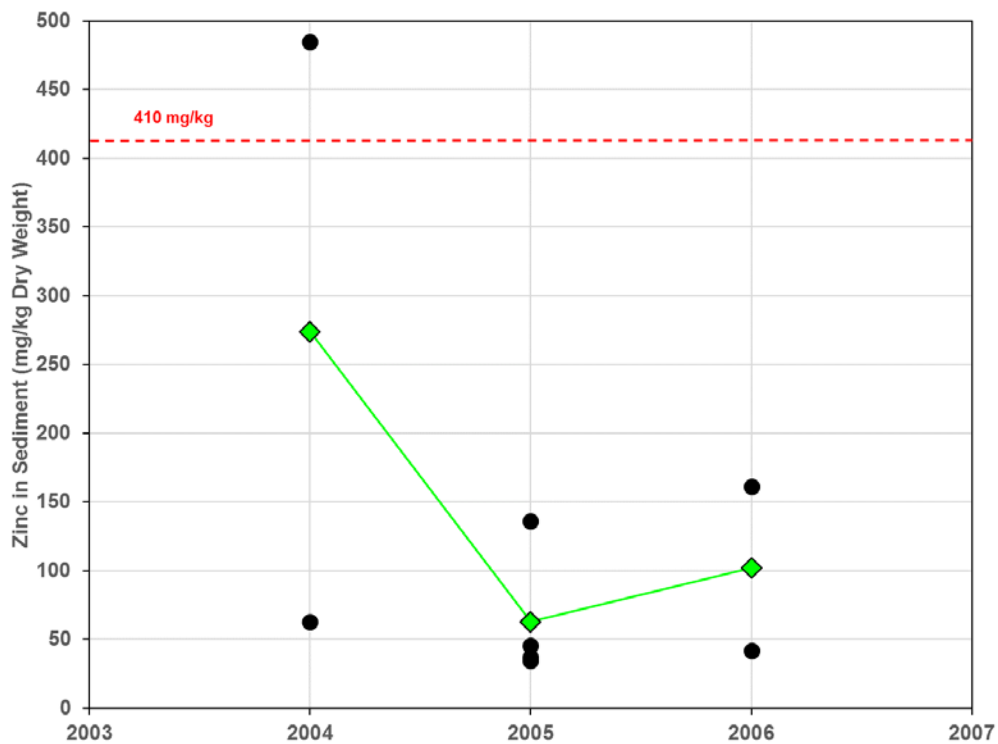

Figure 13. **Zinc in sediment (mg/kg) from Nueces River, collected 2004 - 2006. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below contaminant screening level for that year, and red dashed line represents contaminant screening level.**

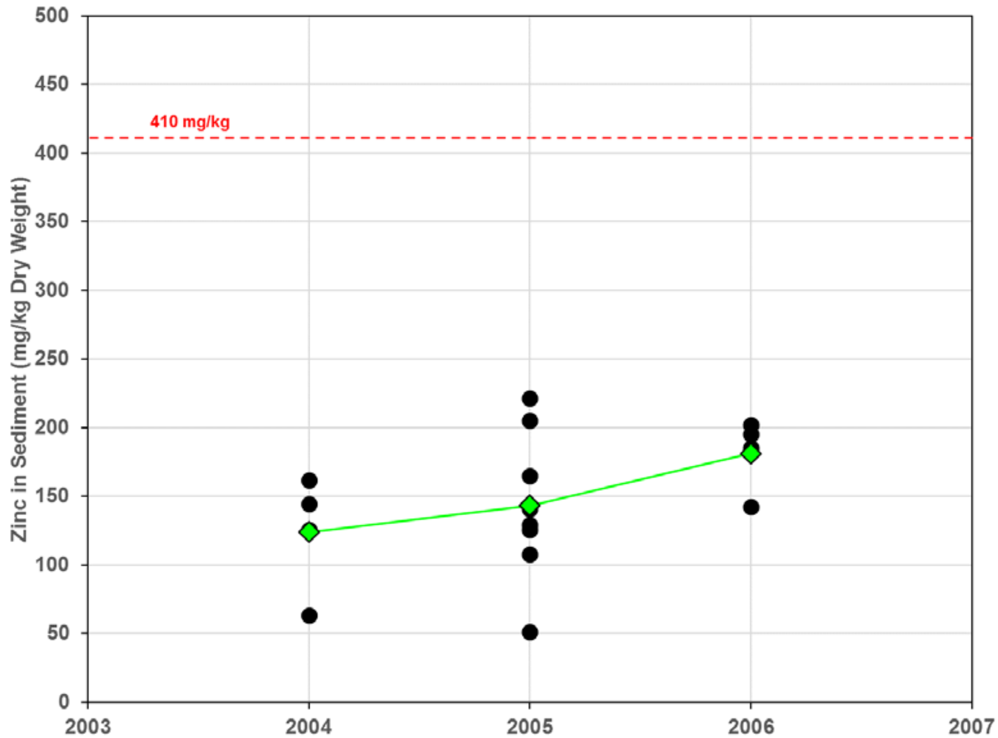

Figure 14. Zinc in sediment (mg/kg) from Corpus Christi Inner Harbor, collected 2004 – 2006. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below contaminant screening level for that year, and red dashed line represents contaminant screening level.

4.7 TMDL Findings

The TMDL calculations established 65.9 kg/d as the daily zinc load allowable to be discharged into Nueces Bay that is estimated to keep the bay compliant in meeting zinc in oyster tissue water quality standards and not exceed the 29 µg/L water quality target (TCEQ 2006).The *One TMDL for Zinc in Oyster Tissue in Nueces Bay* (TCEQ 2006) concluded that based on total zinc in water data used in the TMDL, Nueces Bay and the Corpus Christi Inner Harbor surface water does not represent a significant source of zinc since levels as concentrations were well below the target threshold of 29 µg/L. The TMDL makes a statement that if total zinc in water levels are maintained at the concentration observed in 2004 and 2005, oyster water use will be restored in Nueces Bay over time by attenuation.

The TMDL suggested sediments from Nueces Bay and Corpus Christi Inner Harbor contain a significant amount of zinc and could cause exceedances to the 29 µg/L criteria. The TMDL indicated that legacy zinc concentrations buried in the sediments from the historical outflow of ASARCO is the primary source of zinc contributing to oyster tissue contamination. The TMDL states sediment zinc concentrations should decline as long as large-scale sediment disturbances are minimized in the Inner Harbor. Overall, the TMDL states contamination is a legacy issue and zinc levels should decrease in oyster tissue through attenuation.

5.0 Implementation Plan (I-Plan) for Zinc in Oyster Tissue in Nueces Bay

5.1 Development of the I-Plan for One TMDL for Zinc in Oyster Tissue in Nueces Bay

The TMDL process includes the development of an I-Plan for the impaired water body detailing regulatory and non-regulatory management measures that may reduce the pollutant and restore TCEQ water quality standards. The I-Plan is developed by stakeholders of the community working together to improve water quality.

Zinc loadings into Nueces Bay were addressed in the *One TMDL for Zinc in Oyster Tissue in Nueces Bay* which specified that there were no existing discharges to the bay that would result in violation of the new proposed zinc criterion load of 65.9 kg/d and resulting water quality criterion of 29 µg/L. Therefore, the implementation strategies in the I-Plan addresses zinc contamination in oyster tissue as a legacy pollutant from past discharges to the bay. The I-Plan for the TMDL was approved by TCEQ October 24, 2007. The primary responsible party for restoring water quality to achieve oyster use status in Nueces Bay is the TCEQ.

Because zinc contamination in oyster tissue is being treated as legacy, the I-Plan includes measures that track zinc levels over time to determine if levels decline and if not, the I-Plan states TCEQ would reevaluate the TMDL and I-Plan. The I-Plan includes two Management Measures; Management Measure 1 is to "Document Natural Attenuation" of zinc and Management Measure 2 is "Adjust the Water Quality Criteria."

> *Management Measure 1, "Document Natural Attenuation", involves sampling several sites for oyster tissue, water, and sediment from Nueces Bay and Corpus Christi Inner Harbor. Also included in this measure was monitoring point source discharges into Nueces Bay, in particular the Nueces Bay Power Station. During the assessment period for zinc in oyster tissue in Nueces Bay, this power plant closed operation in 2003 but has since then repowered and has been in operation since 2010 with a discharge permit amount of 500 MGD.*
>
> *Management Measure 2, "Adjust the Water Quality Criteria" proposes the TMDL zinc target value for total zinc in water be changed to 29 µg/L. The 29 µg/L is better suited to protect human health and should therefore, be included in the 2008 water quality standards but specific to Nueces Bay only. The zinc criterion in water prior to 2008 was for dissolved zinc only and not total zinc with a criterion of: acute 92.7 µg/L and (2) chronic 84.7 µg/L. This request to change the criteria for Nueces Bay to total zinc in water to 29 µg/L was reviewed and facilitated through the triennial revisions to water quality standards, and subsequent approval by the Water Quality Standards Team at TCEQ in 2007.*

5.2 Effectiveness of the I-Plan for Zinc in Oyster Tissue in Nueces Bay

Implementing Management Measure 1 included sampling (1) water, (2) sediment, and (3) oyster tissue from several sites in Nueces Bay, Nueces River and Corpus Christi Inner Harbor to monitor levels of zinc and determine if concentrations were decreasing over time. Management Measure 2 was accomplished as part of the TMDL but would be evaluated as to its effectiveness after data collection under Management Measure 1 determined if zinc levels had decreased over time.

Sampling began in 2008 to monitor attenuation of zinc in oyster tissue. However, no oyster samples were collected in 2008 because no live market size oysters were found throughout the bay. Oyster tissue was not collected in 2009 due to lack of funds appropriated to the project. Water and sediment were collected from Nueces Bay, Nueces River, and Corpus Christi Inner Harbor. Oyster samples were only collected from Nueces Bay in 2010 through 2014.

5.3 Zinc in Oyster Data

Zinc in oyster tissue collected from Nueces Bay, to satisfy Management Measure 1 “Document Natural Attenuation” showed concentration levels of individual zinc in oyster tissue samples from Nueces Bay remained highly variable, ranging from 231 mg/kg to 3340 mg/kg, with 76% of the samples taken from 2010 through 2014 still exceeding the HAC value of 700 mg/kg (Figure 15). Mean concentrations for 2010 through 2014 were 2107 mg/kg, 1394, mg/kg, 1085 mg/kg, 915 mg/kg, and 1388 mg/kg, respectively (Figure 15).

When compared to the DSHS 1994 oyster data used for assessment and listing of Nueces Bay on the Texas 303 (d) list, zinc levels in some individual samples increased in 2010, 2011, and 2012 but decreased in 2013 and 2014 (Figure 15). Mean concentrations were lower than 1994 levels and higher than 2002 and 2005 concentrations in all but 2013.

Analysis of zinc in oyster tissue data for the five stations sampled for the Implementation Effectives Monitoring from 2010 through 2014 show just how variable samples were at individual stations (Figure 16). In addition, data showed high mean concentrations declining at Stations 18866, 13425, 21057 (See Figure 1 for station locations) for the first four years before spiking upward in 2014. Station 21058 in the northeastern portion of Nueces Bay declined sharply in 2011 and remained slightly above the 700 mg/kg HAC level and in 2013 was the only station to have a mean concentration below the HAC level. Station 21059 near the confluence of Nueces Bay and Corpus Christi bay also showed a steep decline in mean concentrations from 2010 to 2011 but then steadily rose in the following years (Figure 16).

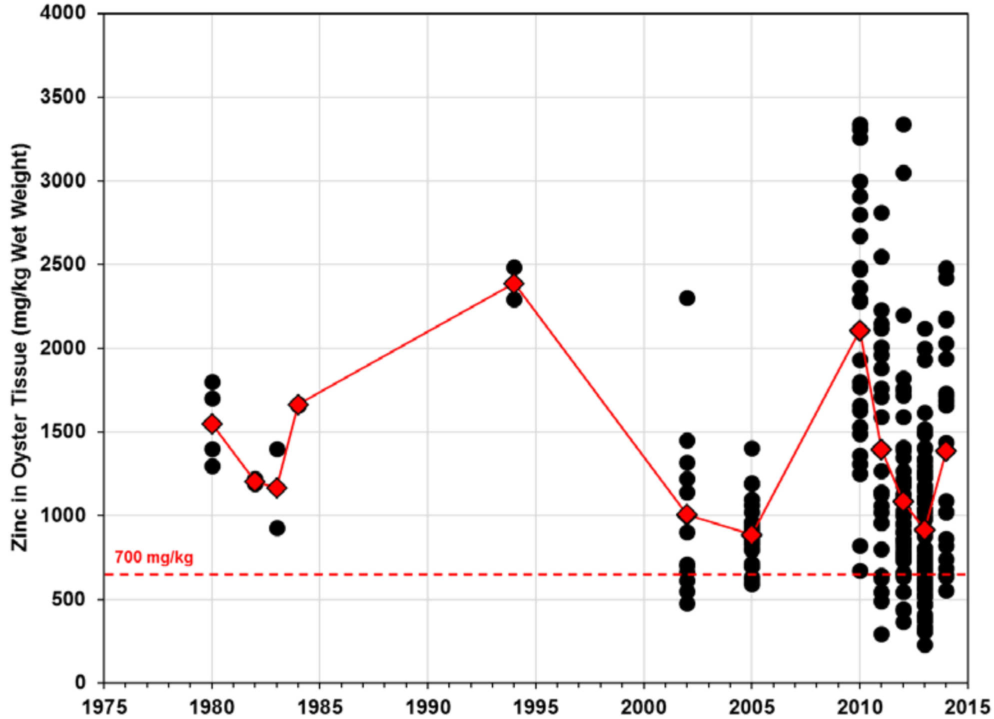

Figure 15. **Zinc in oyster tissue (mg/kg) from all sampling stations in Nueces Bay. DSHS Risk Assessment Data 1980-1982, 1994, 2002, and 2005, and TCEQ Implementation Plan Oyster sampling data 2008, and 2010-2014. Black dots represent sample concentrations, red diamonds represent mean value of all sample concentrations above HAC criteria for that year, and red dashed line represents HAC criteria.**

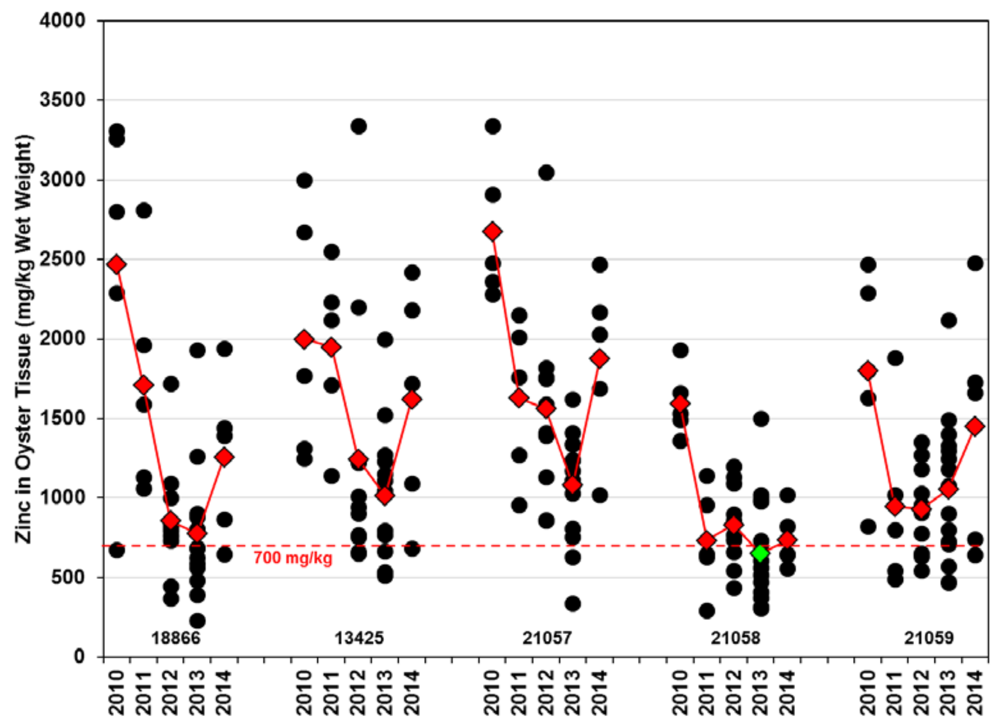

Figure 16. **Zinc in oyster tissue (mg/kg) from individual sampling stations in Nueces Bay. TCEQ Implementation Plan Data 2010-2014. Black dots represent individual sample concentrations, red and green diamonds represent mean value of all sample concentrations above or below HAC Criteria for that year, respectively, and red dashed line represents HAC criteria.**

5.4 Total Zinc in Water Data

Zinc in water data collected for the I-Plan Management Measure 1 was collected in 2008, and 2010 through 2014. No data was collected in 2009.

During the six years of zinc in water I-Plan sampling in Nueces Bay, 92% of the samples collected were <15.00 µg/L and the mean value for all six years combined (n=84) was 7.38 µg/L. Two data points for total zinc in water data were above the zinc target value of 29 µg/L from Nueces Bay (Figure 17). One exceedance in 2011 near Whites Point and one exceedance in 2013 near Gum Hollow which occurred on days when Nueces Bay was highly turbid.

No exceedances of the zinc target value of 29 µg/L were identified from the Nueces River (Figure 18) where mean concentrations of zinc in water for the six years combined (n=12) was 3.52 µg/L or in the or Corpus Christi Inner Harbor (Figure 19) where mean concentrations of zinc in water for the six years combined (n=24) was 10.78 µg/L.

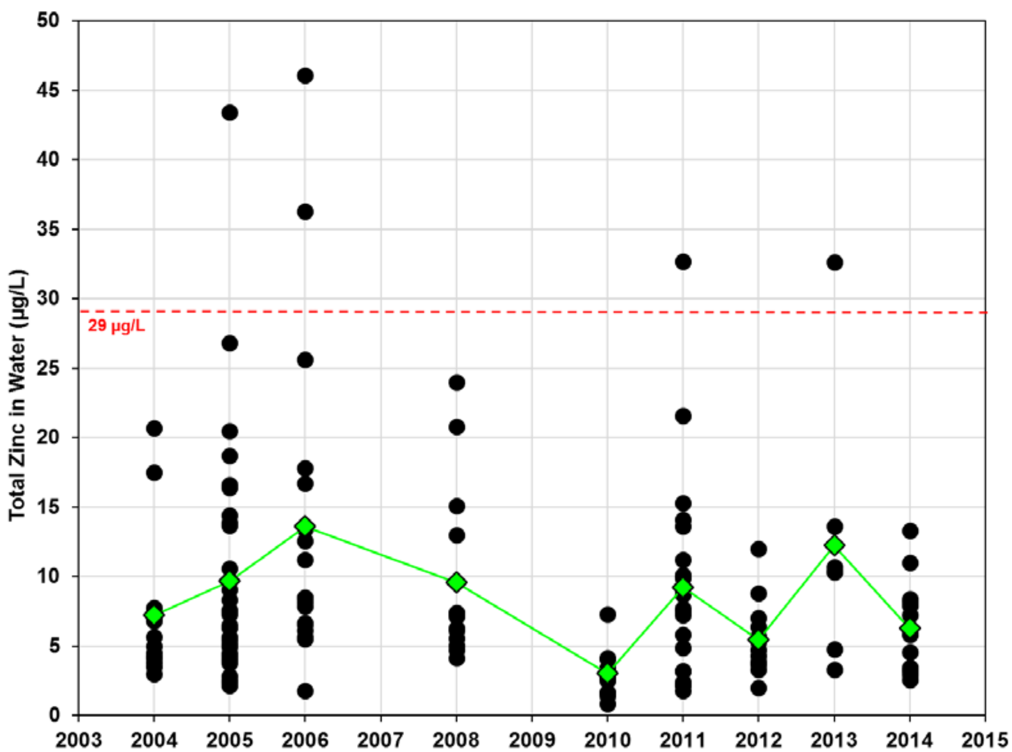

Figure 17. Total Zinc in Water from Nueces Bay. TCEQ TMDL Data 2004-2006 and TCEQ Implementation Plan Data 2008, and 2010-2014. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below the WQ criteria for that year, and red dashed line represents WQ criteria.

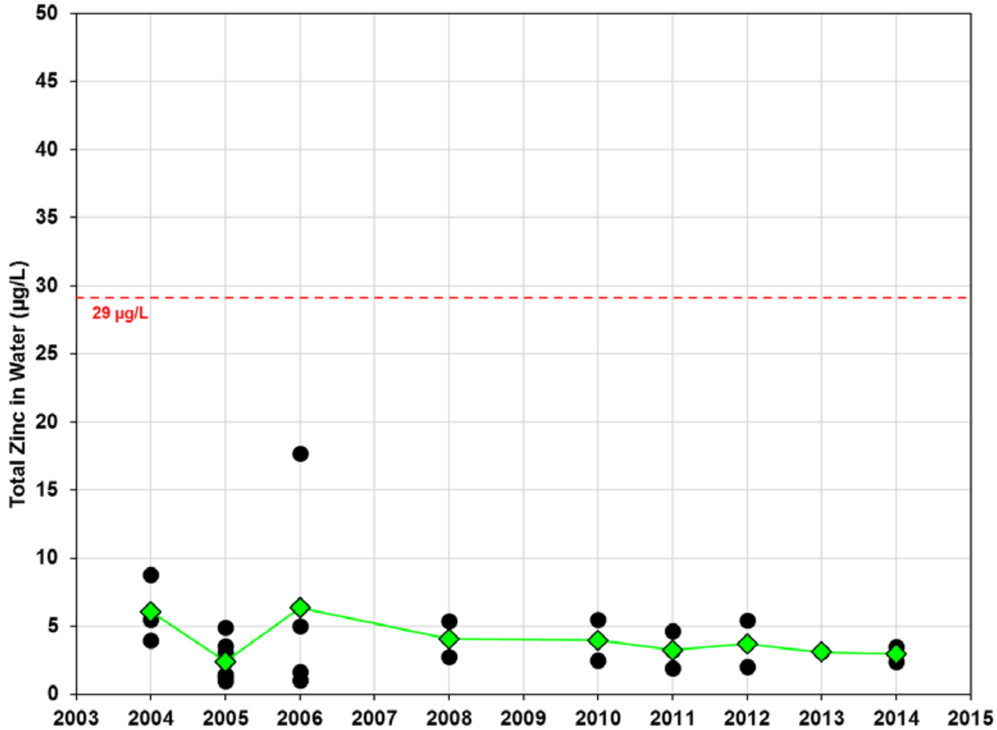

Figure 18. **Total Zinc in Water from the Nueces River. TCEQ TMDL Data 2004-2006 and TCEQ Implementation Plan Data 2008, and 2010-2014. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below WQ criteria for that year, and red dashed line represents WQ criteria.**

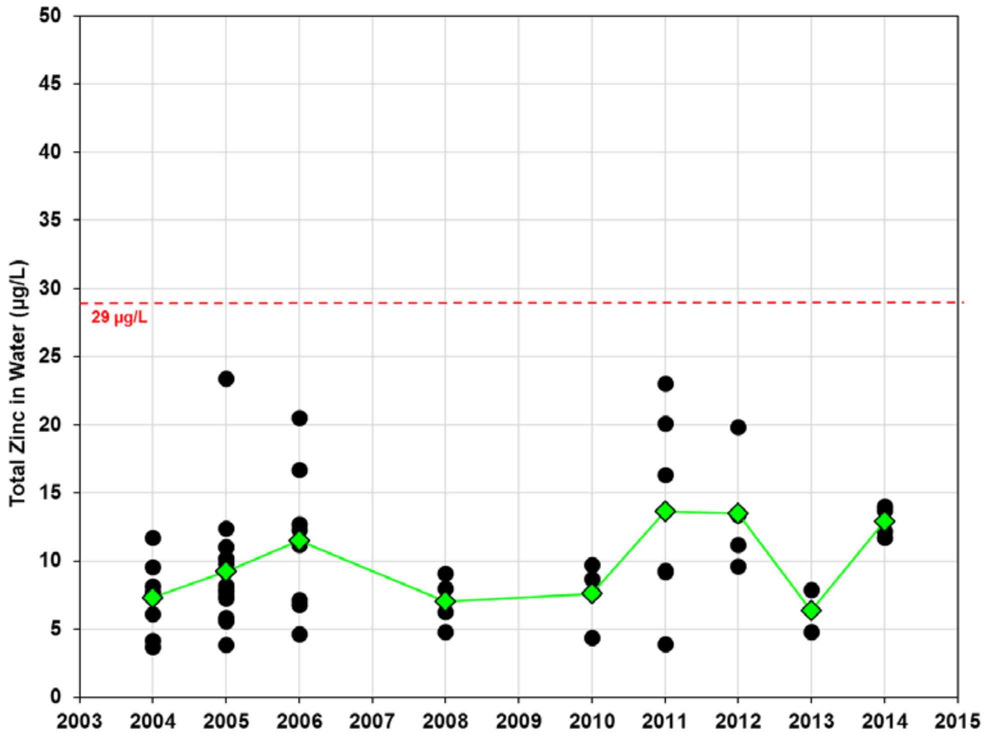

Figure 19. **Total Zinc in Water from the Corpus Christi Inner Harbor. TCEQ TMDL Data 2004-2006 and TCEQ Implementation Plan Data 2008, and 2010-2014. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below WQ criteria for that year, and red dashed line represents WQ criteria.**

5.5 Zinc in Sediment Data

For the I-Plan, zinc samples from the surficial sediment layer (2 to <5 cm) were collected in 2008, and 2010 through 2014. No data was collected in 2009.

During the six years of zinc in sediment I-Plan sampling in Nueces Bay the zinc in sediment data collected showed no exceedances of the 410 mg/kg ER-M screening value (Figure 20). Mean concentrations were below 50.00 mg/kg and the mean value for all six years combined (n=84) was 40.38 mg/kg.

Although concentrations were higher, no exceedances of the ER-M screening value were identified from the Nueces River (Figure 21) where mean concentrations of zinc in sediment for the six years combined (n=12) was 117.60 mg/kg or in the or Corpus Christi Inner Harbor (Figure 22) where mean concentrations of zinc in sediment for the six years combined (n=24) was 162.40 mg/kg.

Historically, the only sample that exceeded the ER-M 410 mg/kg was from the TMDL data collected in 2004 from the Nueces River. As mentioned earlier, this site in the Nueces River was located next to an abandoned car that was subsequently recovered from the river.

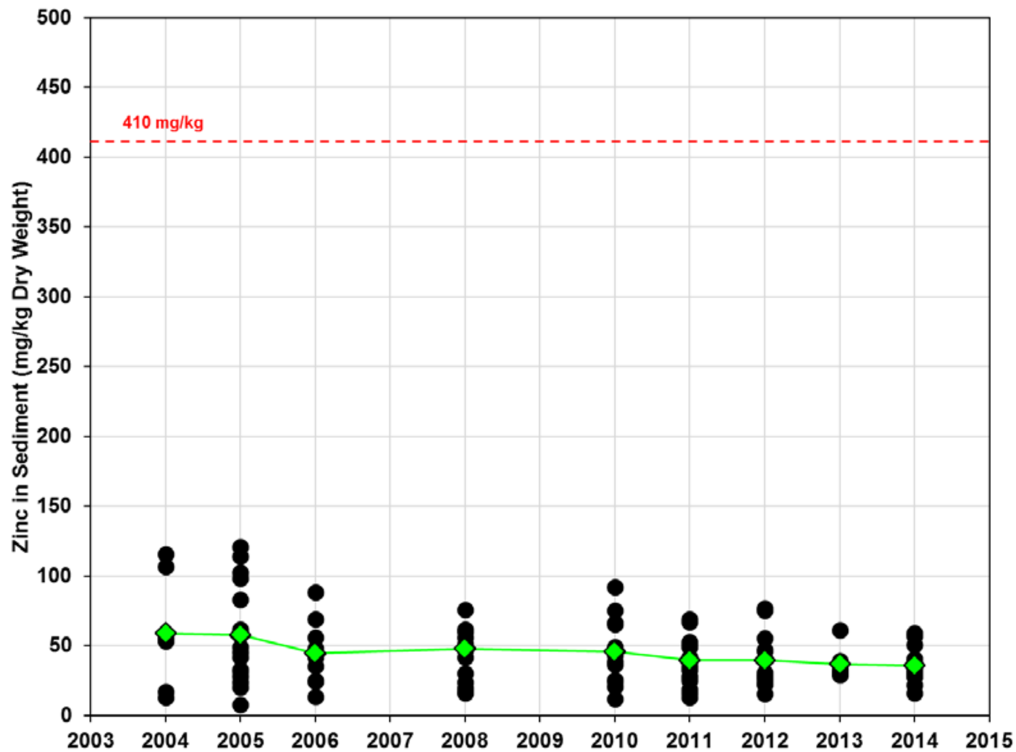

Figure 20. Zinc in Sediment from Nueces Bay. TCEQ TMDL Data 2004-2006 and TCEQ Implementation Plan Data 2008, and 2010-2014. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below the screening level for that year, and red dashed line represents contaminant screening level.

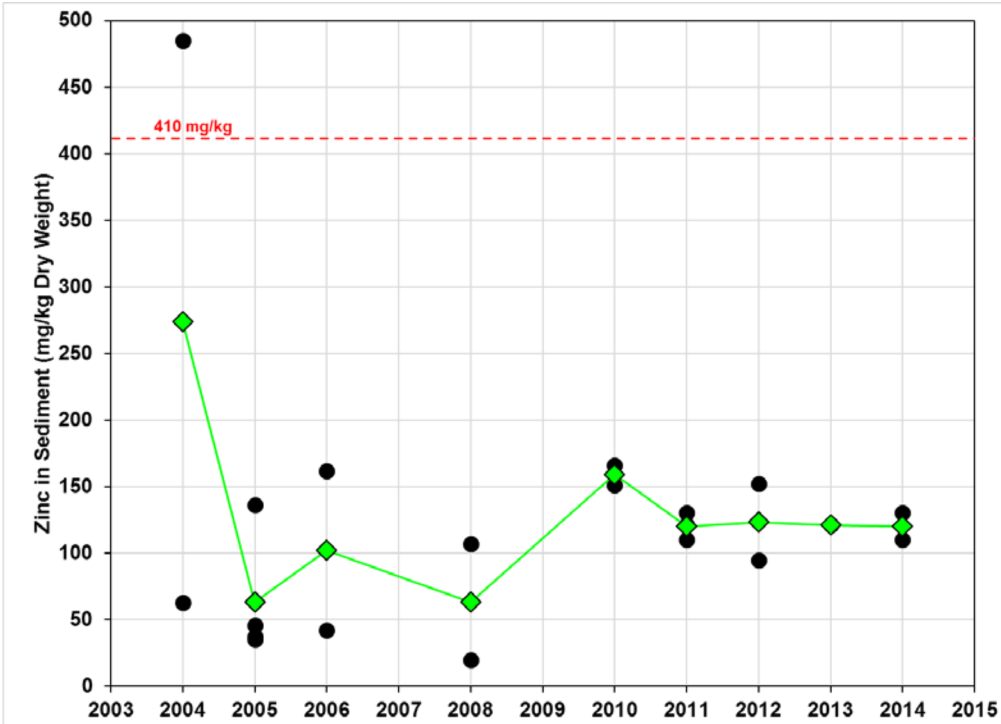

Figure 21. Zinc in Sediment from the Nueces River. TCEQ TMDL Data 2004-2006 and TCEQ Implementation Plan Data 2008, and 2010-2014. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below the screening level for that year, and red dashed line represents contaminant screening level.

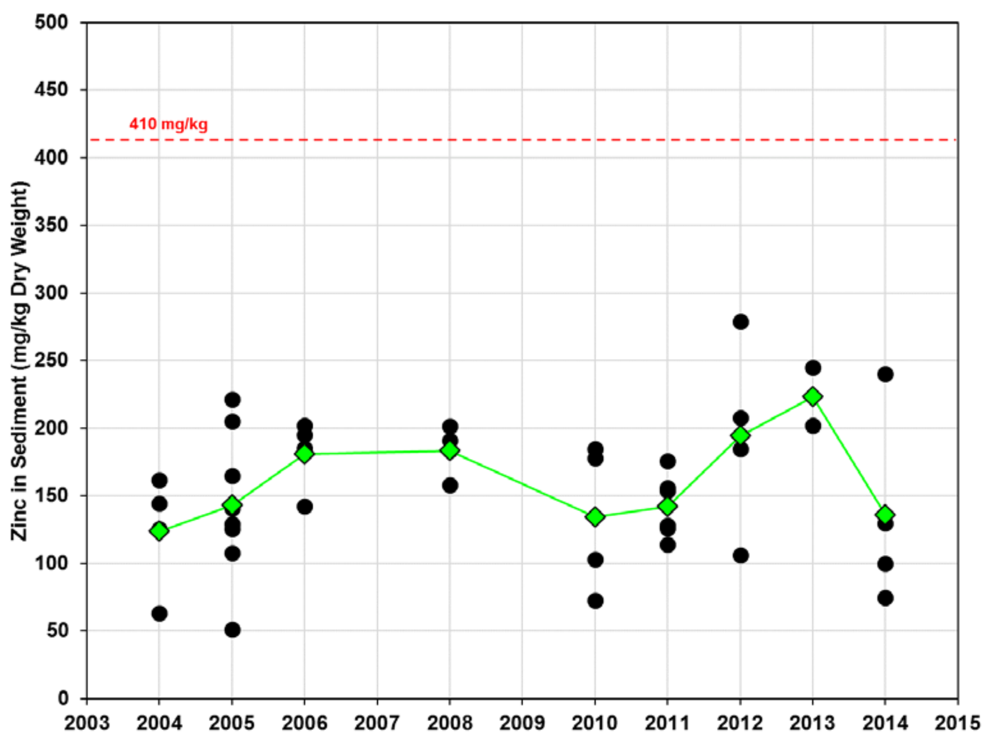

Figure 22. Zinc in Sediment from the Corpus Christi Inner Harbor. TCEQ TMDL Data 2004-2006 and TCEQ Implementation Plan Data 2008, and 2010-2014. Black dots represent individual sample concentrations, green diamonds represent mean value of all sample concentrations below the screening level for that year, and red dashed line represents contaminant screening level.

5.6 Zinc in Water and Sediment Data from Other Sources than the TMDL and I-Plan Data

Existing literature noting studies where zinc in water and zinc in sediment was sampled in Nueces Bay, Nueces River, and the Corpus Christi Inner Harbor is limited. However, several studies aside from the TMDL and I-Plan SWQM zinc in water and zinc in sediment data were identified.

In reviewing historical literature, Warshaw (1976) reported zinc in sediment from Nueces Bay ranged from 77.0 mg/kg – 230.0 mg/kg and in the Corpus Christi Inner Harbor ranged from 360 mg/kg - 4900 mg/kg. Warshaw (1976) also reported total zinc in water from Nueces Bay and the Corpus Christi Inner Harbor was <100 µg/L.

Jensen and Bowman (1977) reported zinc in sediment data in the Nueces River near the Allison Wastewater Treatment Plant to be 122.0 mg/kg and near the river mouth to be 103.0 mg/kg. Bowman and Jensen (1982) reported zinc in surface water from the Corpus Christi Inner Harbor was 720 µg/L and zinc in bottom water was 330 µg/L. In addition, zinc in sediment from the Corpus Christi Inner Harbor was 2100 mg/kg.

Barrera et al. (1995) reported zinc in sediment from the Corpus Christi Inner Harbor had a geometric mean of 179.5 ppm. The highest level of zinc from the Corpus Christi Inner Harbor was 645 ppm.

6.0 Is the Zinc in Oyster Tissue TMDL a Legacy Issue?

6.1 Case Study: Nueces Bay Zinc in Sediment Profile Assessment

In 2012, the CBBEP funded the *"Nueces Bay Zinc in Sediment Profile Assessment"* which indirectly addressed the legacy component of the TMDL and I-Plan for zinc in oyster tissue in Nueces Bay. This project: (1) identified a legacy layer of zinc in sediments in Nueces Bay and (2) determined zinc sediment concentrations detected in the surficial layer are likely legacy, but are also representative of the present zinc loading to Nueces Bay (Hill et al. 2014).

Nine (9) TCEQ stations were sampled under an approved QAPP in June 2013 (Figure 23). Sediment samples were collected from a pontoon boat using a hand-operated hammer/percussion coring system. Three to five cores measuring ~2 m in length were collected from each site. The cores were analyzed in 5 cm intervals for zinc by TestAmerica and included: (1) zinc in sediment, (2) total organic carbon, and (3) sediment grain size. Additional analyses were performed on sediment samples but are not included here, for detail see Hill et al. 2014.

The top 5 cm surficial layer, which in theory, represents current zinc load to Nueces Bay, did not show zinc concentrations above the 410 mg/kg ER-M value (Hill et al. 2014). Looking at the entire profile sediment data, there is a definite increasing trend in zinc below the surficial layer. One site (Station 21484) located in the historic ASARCO discharge point had a legacy layer of zinc with a concentration above the ER-M 410 mg/kg (Figure 24).

An interesting note in this study, was researchers summed total zinc in sediment down the entire length of cores to determine legacy zinc concentrations buried. For example, Station 21484 contains a total of 2576 mg/kg, Station 14833 totaled 2281 mg/kg, and Station 18619 had an extreme concentration of 3984 mg/kg, approximately 55% more than Station 21484 (Hill et al 2014).

Nueces Bay sediments are very unconsolidated and can easily be disturbed. The zinc legacy concentrations found in Nueces Bay could be easily resuspended during a storm event, major inflow event, or even during oil pipeline application, maintenance dredging, or any type of operation that disturbs the sediment. This data provides new information on zinc legacy concentrations in Nueces Bay. The zinc profile data provides potential buried zinc loads that could be re-released into Nueces Bay. Past data of this type did not exist and these data give a good baseline as to where high legacy concentrations are located. The profile data could be used as a management tool when industrial, commercial, or municipal operations include activities that disturb sediments in the bay and that may consequently, re-release buried zinc concentrations. The load is not from a pipe discharge permit but, disturbing sediments in Nueces Bay does provide a zinc load to the bay that ultimately may be contributing to zinc in oyster tissue contamination.

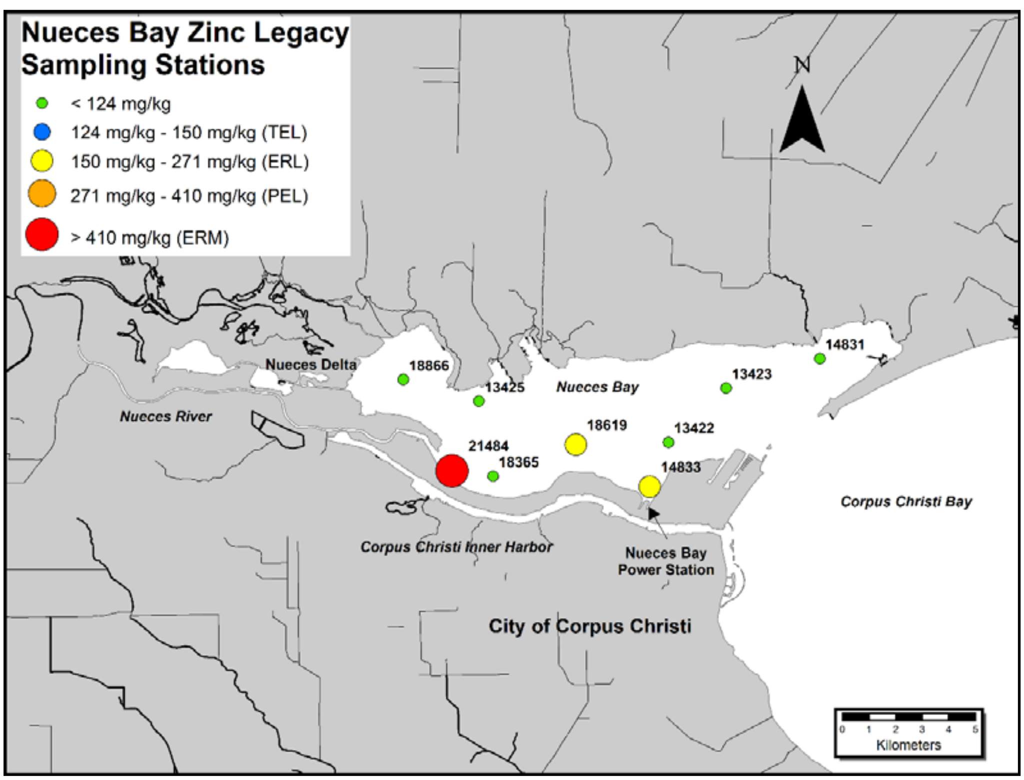

Figure 23. Maximum concentration of zinc in sediment (mg/kg) collected from Nueces Bay sediment profile assessment (Hill et al. 2014).

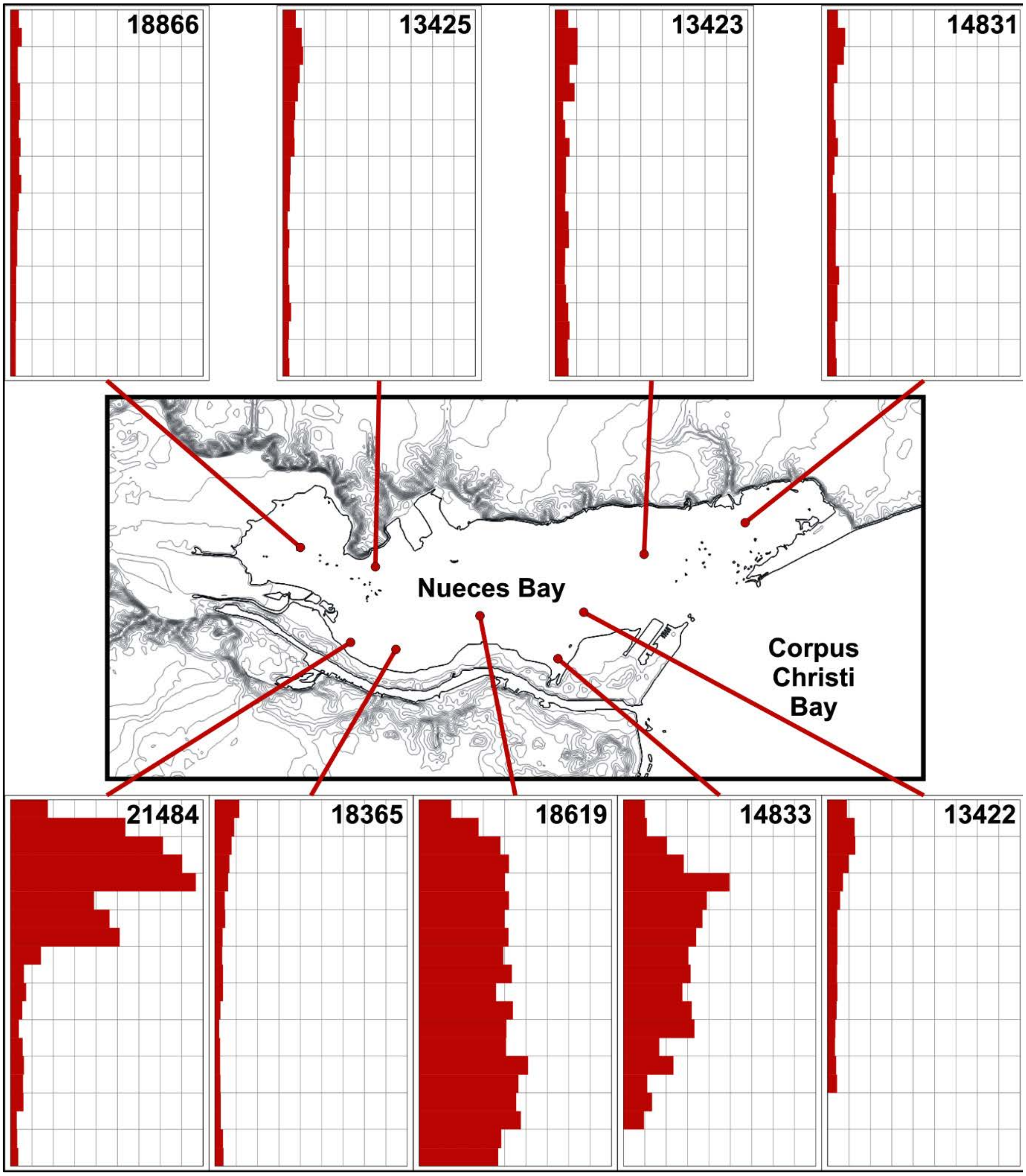

Figure 24. Zinc concentration profiles for Nueces Bay sediment cores from 0-100 cm depth. The horizontal scale for all nine plots is identical, and ranges from 0-450 mg/kg. The graticules mark increments of 10 cm in the vertical direction, and 50 mg/kg in the horizontal direction. The profiles have a blocky appearance because samples were analyzed in 5 cm stratigraphic intervals (Hill et al. 2014).

7.0 DISSCUSSION

Zinc in oyster tissue attenuation appeared to be decreasing at three stations in the first four years of the I-Plan sampling (see Figure 16), however, in the fifth-year zinc in tissue levels started increasing and then sampling stopped. To track attenuation over time requires taking the long view. Environmental contaminant problems are seldom solved, let alone remediated, in the short term.

We believe sampling should not have stopped after five years and that continued sampling of oyster tissue, water, and sediment should continue but should be enhanced to include additional sampling parameters since zinc in water and sediment values show no concern. A long-term program like NOAAs Mussel Watch needs to be in place to adequately document if attenuation of zinc in oyster tissue continues over time as suggested in the I-Plan. In addition, new approaches must be considered to better understand the oysters in Nueces Bay and the interactions occurring.

The data presented in this report shows oysters have a high variability in the amount of bio-accumulated zinc in tissue due to the species effectiveness for filtering out pollutants. Data indicated a poor correlation between zinc in water and zinc in sediment data, relative to the high levels of zinc occurring in oyster tissue sampled from Nueces Bay.

Because of this poor correlation, the authors suggest reevaluating the zinc WQ criteria (29 µg/l) and the high sediment contaminant screening level (410 mg/kg), as total zinc in water and sediment concentrations rarely exceeded the criteria developed, but oyster tissue often surpassed the 700 mg/kg HAC criteria for zinc in oyster tissue.

More importantly, new sampling approaches should be implemented and include SPOM in the water column and SSOM. The SSOM is an important and substantial part of oyster diets (Guo et al. 2001; Bloomberg et al. 2015).

To summarize, extended sampling time and new approaches are needed to fully comprehend and answer such possible questions as:

- Are the oysters slowly responding, but simply need more time?
- What is the actual contribution of SPOM and SSOM?
- Is the subsurface sediment more important than the surface sediment?
- Are there suspected hotspots we haven’t found? Do we need more cores such as done in the CBBEP “Nueces Bay Zinc in Sediment Profile Assessment” project?
- Are there hidden sources? Nueces Bay has one of the highest densities of oil wells and pipe lines in Texas. Is the sacrificial coating of zinc applied to galvanized oil field equipment a factor?

8.0 RECOMMONDATIONS

1. Reconvene I-Plan Stakeholders to update and begin discussion of where we are and where we go from here.

2. Reevaluate the total zinc criterion of 29 µg/L developed in the TMDL.

3. Continue monitoring zinc in sediment, water, and oyster tissue from Nueces Bay reefs but also;

    a. Conduct focused issue specific monitoring as needed to determine likely causes of the continued high tissue concentrations.

    b. Implement a new sampling approach be to include SPOM in the water column and sediment surface organic matter SSOM to mimic what the oysters are eating

4. The life cycle of oysters makes it difficult to know the age of the cohort that is being collected for analysis. Monitoring reproductive spawning events of oysters in Nueces Bay while sampling zinc in oyster tissue would help to define the age of oysters at time of sampling. This will also provide information on average growth rates in Nueces Bay.

5. Encourage projects that restore Nueces Bay existing extant oyster reefs to provide valuable ecosystem services such as increased water filtration capabilities that may facilitate cleaning up zinc legacy contamination.

6. Other finfish species that are consumed by humans should be tested for zinc in tissue to address the question if elevated levels of zinc are found higher up in the food chain or if the issue is strictly oysters.

7. Install signage warning public Nueces Bay is closed to oyster harvesting because of elevated zinc levels in their edible tissue.

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