November 20, 2020
AS-192

Source Characterization of Dioxin Loads in the Houston Ship Channel and Upper Galveston Bay

Segments 0901, 1001, 1005, 1006, 1007, 2421, 2425, 2426, 2427, 2428, 2429, 2430, 2436, and 2438

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Distributed by the
Total Maximum Daily Load Team
Planning and Implementation Section
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087

Houston Ship Channel Dioxin project reports are
available on the TCEQ website at:
<www.tceq.texas.gov/waterquality/tmdl/26-hscdioxin.html>

The preparation of this report was financed in part through grants from
the United States Environmental Protection Agency.

This source characterization report is based on
the following project reports prepared by
the University of Houston and Parsons Water & Infrastructure Inc.

Data Report
"Total Maximum Daily Loads for Dioxin in the Houston Ship Channel:
Quarterly Report No. 3, Work Order No. 582-6-70860-02," July 2006.

Modeling Report
"Total Maximum Daily Loads for Dioxin in the Houston Ship Channel:
Modeling Report/Quarterly Report No. 3, Work Order 582-6-70860-18,"
October 2008.

Load Allocation Report
"Total Maximum Daily Loads for Dioxin in the Houston Ship Channel:
Load Allocation Document – Revision 4, Contract No. 582-6-70860, Work Order
No. 582-6-70860-18", October 2008.

Contents

Figures

Tables

Abbreviations / Definitions

2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin, also known as 2,3,7,8-tetrachlorodibenzodioxin
2,3,7,8-TCDF	2,3,7,8-tetrachlorodibenzofuran
AU	assessment unit
congener	any member of a very closely related group of molecules, e.g., 2,3,7,8-tetrachlorodibenzo-p-dioxin and 1,2,3,7,8-pentachlorodibenzo-p-dioxin are both dioxin congeners
d	day
dioxin	(a) collective term for the 17 toxic polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran congeners (b) collective term for all 210 polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofuran congeners
DSHS	Texas Department of State Health Services
EPA	Environmental Protection Agency
g	gram
H-GAC	Houston-Galveston Area Council
HSC	Houston Ship Channel
HSC/SJR	HSC portion of the San Jacinto River, from Galveston Bay to the I-10 bridge
HSC/BB	HSC portion of Buffalo Bayou, from the confluence with the HSC/SJR to the Turning Basin
kg	kilogram (one thousand grams = 10^{3} gram)
km	kilometer
L	liter
lbs	pounds
legacy sources	substances that are banned or severely restricted but remain in the environment
LA	load allocation = loads from unregulated storm water, atmospheric deposition, transport from upstream, and sediment
mg	milligram (one thousandth gram = 10^{-3} gram)
MS4	municipal separate storm sewer system
ng	nanogram (one billionth gram = 10^{-9} gram)
ng/kg	nanogram per kilogram = 1 ppt
ng-TEQ/d	load in nanogram TEQ per day
ng-TEQ_6/d	load in nanogram TEQ_6 per day
ng-TEQ/kg	solid concentration in nanogram TEQ per kilogram of tissue or sediment = 1 ppt
PCDD	polychlorinated dibenzo-p-dioxin (all dioxin congeners)
PCDF	polychlorinated dibenzo-furan (all furan congeners)
pg	picogram (one trillionth gram = 10^{-12} gram)
pg-TEQ/L	liquid concentration in picogram TEQ per liter of water = 1 ppt
pg-TEQ_6/L	liquid concentration in picogram TEQ_6 per liter of water = 1 ppt

pg/L	picogram per liter, approximately 1 grain of salt in 20 Olympic swimming pools = 1 ppt
ppm	parts per million (10^{-6})
ppb	parts per billion (10^{-9})
ppt	parts per trillion (10^{-12}) for solids, 1 ppt = ng/kg for liquids, 1 ppt = pg/L)
PS	point source
RMA	Resource Management Associates
RMA2 WES	a two-dimensional hydrodynamic model written by RMA for the US Army Waterways Experiment Station
ROD	Record of Decision
SIC	Standard Industrial Classification
SCS	Soil Conservation Service (former name of the U.S. Natural Resource Conservation Service)
SJR	San Jacinto River
SJRWP	San Jacinto River Waste Pits
mi^2	square miles
SWQM	Surface Water Quality Monitoring
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TEF	toxic equivalency factor
TEQ	toxic equivalence (toxicity-weighted sum of all congeners)
TEQ_6	toxic equivalence (toxicity-weighted sum of the six congeners that dominate the total dioxin TEQ)
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TWC	Texas Water Code
TSWQS	Texas Surface Water Quality Standards
WASP	Water Quality Analysis Simulation Program, a dynamic multi-dimensional, EPA-supported water quality model
WES	Waterways Experiment Station, now the U.S. Army Engineer Research Development Center
WQ	water quality
WWTF	wastewater treatment facility
µg	microgram (one millionth gram = 10^{-6} gram)

Source Characterization of Dioxin Loads in the Houston Ship Channel and Upper Galveston Bay

Executive Summary

This document provides historic information on hydrodynamic, water quality, and mass balance modeling which was the basis for evaluating dioxin concentrations in the Houston Ship Channel (HSC) and upper Galveston Bay to characterize the nature, extent, and potential sources of dioxin contamination in the HSC and upper Galveston Bay.

The HSC is part of the San Jacinto River (SJR) Basin located in southeast Texas and drains into Galveston Bay. The watershed encompasses most of Harris County and the greater Houston area occupies most of the watershed.

In September 1990, the Texas Department of State Health Services (DSHS) (formerly known as the Texas Department of Health), issued the first of a series of fish consumption advisories for the HSC and upper Galveston Bay due to dioxin. The DSHS issues seafood consumption advisories when tests on fish and shellfish indicate there is an increased risk to human health from the presence of toxic pollutants.

Dioxins are formed as unintentional trace by-products of industrial and chemical production processes and by incomplete combustion. Dioxins are extremely persistent, degrade slowly in the environment, and can cause skin rashes, liver damage, weight loss, reproductive damage, and an increased risk of cancer (DSHS, 2010).

These DSHS advisories prompted inclusion of the HSC and upper Galveston Bay on the Texas 303(d) List, first in the 1996 Texas Water Quality Inventory (Table 2) and subsequently still listed for dioxin in edible tissue.

Fourteen segments were identified as impaired on the Texas 303(d) list for dioxin in edible fish tissue: segments 0901, 1001, 1005, 1006, 1007, 2421, 2425, 2426, 2427, 2428, 2429, 2430, 2436, and 2438. In response to these listings, the Texas Commission on Environmental Quality (TCEQ) and its predecessor agency, the Texas Natural Resource Conservation Commission (TNRCC) conducted a study to determine the potential sources of dioxin contamination.

Samples of water, sediment, air, watershed runoff, fish tissue, and crab tissue were analyzed to support this study of dioxin in the HSC and upper Galveston Bay. The sampling results were used to analyze the extent of the impairments and to identify and quantify external sources of dioxin to the HSC and upper

Galveston Bay. Data the TCEQ analyzed, from the assessment period of July 31, 2002 through December 2, 2004, showed dioxin concentrations in water above the 2000 surface water quality criterion in 86% of the samples.

The interaction of sediment with dioxin in water can be complex and variable. While highly polluted sediment releases dioxin into the water, less polluted sediment may adsorb dioxin. Sediment loads cannot be measured directly, so they were estimated using a mass balance model. The model analyses for this study coupled a two-dimensional hydrodynamic model with a two-dimensional water quality model to predict the response of the HSC and upper Galveston Bay to various loading scenarios and determine the contribution of sediment dioxin loads to water. Model results were subsequently summarized to determine the average daily mass balance in the system and the sediment load.

The modeling and data analysis indicated the largest source of dioxin in these segments was legacy-pollutant contamination of bottom sediment (86% of the total load). Legacy pollutant is a collective term used to describe substances that are banned or severely restricted by the U. S. Environmental Protection Agency (EPA), but remain in the environment. Because of their slow rate of decomposition, these substances frequently remain at elevated levels in the environment for many years. Gradual declines in environmental legacy pollutant concentrations occur because of natural attenuation processes.

The Texas Surface Water Quality Standards (TSWQS) include numeric criteria for maximum acceptable concentrations of specific toxic compounds to protect human health. The study timeline, shown in Table 1, indicates the 2000 TSWQS were in effect at the time of this study. The 2000 human health saltwater criterion for dioxins and dibenzofurans in water was 0.0933 picograms per liter (pg-TEQ/L). However, in the 2014 TSWQS, the criterion was revised to 0.0797 pg-TEQ/L; this criterion remains in effect in the current TSWQS. The results of the modeling conducted as part of this study concluded that legacy dioxin contamination in sediments is the largest source of dioxin in the affected water bodies and that, unless these sources are addressed, dioxin concentrations in fish tissue may not be reduced to acceptable levels in the foreseeable future.

Table 1. Study Timeline

Event	Date Range
TSWQS Criterion	2000
Intensive Sampling Period	7/2002 – 8/2005
Modeling Period	7/2002 – 4/2005
TSWQS Criterion Revised	2014

The change in dioxin criterion does not affect this conclusion, as the modeling shows mitigation of legacy sediment sources will also result in average water concentration, and associated fish and crab tissue concentrations, that are below the current criterion. Therefore, all future references to the applicable TSWQS criterion for dioxin and dibenzofurans is based on the 2000 TSWQS human health criterion for saltwater which was in effect during the data analysis and modeling phases of this project.

Loads from legacy sediment (86% of the total load) dominated most of the upper SJR, Buffalo Bayou, and the lower SJR (segments 1001, 1007 and 1005). Current discharge loads include point source (permitted) wastewater and stormwater outfalls and nonpoint (unregulated) sources such as runoff, direct atmospheric deposition, and upstream sources. Current discharge loads were small (14% of total load) when compared to legacy-pollutant contaminated sediment loads.

The San Jacinto River Waste Pits (SJRWP) superfund site is on the National Priorities List and has been identified as a source of dioxin in the study area. The site consists of two sets of impoundments, or pits, built in the mid-1960s for the disposal of solid and liquid pulp and paper mill wastes, and the surrounding areas containing sediments and soils impacted by waste materials disposed in the impoundments. In 2011 a temporary armored cap was constructed over the northern impoundments to prevent direct contact with the paper mill waste material and to prevent further releases to the San Jacinto River until a permanent remedy is implemented. On September 28, 2016, the EPA released its proposed plan to clean up waste materials at the site. Additionally, on October 11, 2017 EPA issued the Record of Decision (ROD) which requires excavation of the waste material. The remedial design for the site is underway and implementation of the remedy is expected to occur in 2022. The EPA is the lead agency for addressing the site and cleaning up the contamination.

The combined load from ongoing sources other than legacy sediment was not sufficient to cause impairments in water quality. The dioxin impairments were driven by the legacy sediment load. Impairments would not have occurred in the absence of sediment load. A typical Total Maximum Daily Load (TMDL) is designed to limit ongoing loads from wastewater and stormwater-related sources. However, in this case, the impairment is driven by legacy loads, so a TMDL would not likely restore the water quality.

Introduction

The HSC is part of the SJR Basin located in southeast Texas and drains into Galveston Bay. The watershed encompasses most of Harris County, and the greater Houston area occupies most of the watershed. In September 1990, the DSHS issued the first of a series of fish consumption advisories (catfish and blue crab) for the upper Galveston Bay and the HSC due to dioxin. The DSHS issues seafood consumption advisories when tests on fish and shellfish indicate there is an increased risk to human health from the presence of toxic pollutants.

Dioxins are formed as unintentional trace by-products of industrial and chemical production processes and by incomplete combustion. Dioxins are extremely persistent, degrade slowly in the environment, and can cause skin rashes, liver damage, weight loss, reproductive damage, and an increased risk of cancer (DSHS, 2010).

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards to restore the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired streams, reservoirs, lakes, bays, and estuaries (water bodies).

These DSHS advisories prompted inclusion of the HSC and upper Galveston Bay on the Texas 303(d) List, first in the 1996 Texas Water Quality Inventory and subsequently from 1998 through 2014. The section 303(d) priority ranking assigned to these segments has been High (or Category 5a) since 2000. Category 5a indicates that the water body does not meet applicable water quality standards or is threatened for one or more designated uses by one or more pollutants and that a TMDL is under way, scheduled, or will be scheduled.

The objective of this study is to identify and characterize the sources of fish and shell fish tissue consumption use impairments caused by dioxin in the HSC and upper Galveston Bay. This report provides historic information on hydrodynamic, water quality, and mass balance modeling which was the basis for evaluating dioxin concentrations in the HSC and upper Galveston Bay.

This report addresses “dioxin”, which is the collective name for a family of 210 closely related polychlorodibenzo-p-dioxin and polychlorinated dibenzofuran molecules called congeners, 17 of which are highly toxic. Since six congeners accounted for most of the toxicity in the HSC, only those six were used in the modeling.

Problem Definition

The HSC and upper Galveston Bay are currently on the Texas 303(d) list and have DSHS fish advisories for dioxin. Dioxin can cause cancer in humans (USEPA 2000a) and health problems at low doses. Exposure and bioaccumulation of dioxin have been documented to have the following health effects: reproductive problems, behavioral abnormalities, and alterations in immune functions. Dioxin-like compounds have also been proven to accumulate in biological tissues, particularly in animals. The major route of human exposure is through the food chain.

The current advisory for Galveston Bay, ADV-50 (2013), recommends restricted consumption of all species of catfish, spotted trout, and blue crab in upper Galveston Bay. In addition, it recommends restricted consumption of all species of catfish in lower Galveston Bay and contiguous waters (Trinity Bay, East Bay, West Bay, and Chocolate Bay). The current advisory for the HSC, ADV-55 (amended and signed March 27, 2019), bans the consumption of all species of fish and blue crab in the HSC, including the SJR between the Lake Houston Dam and all contiguous waters north of the Fred Hartman Bridge.

Study Area

As shown in Figure 1, the study area (outlined in black) covered large portions of the HSC and Galveston Bay. It included Buffalo Bayou from downtown Houston to the SJR, the SJR from the Lake Houston dam to Galveston Bay, adjacent side bays, and the upper portion of Galveston Bay located north and west of a line from Eagle Point to Smith Point to Houston Point.

The study area initially included all or portions of 13 impaired segments (0901, 1001, 1005, 1006, 1007, 2421, 2426, 2427, 2428, 2429, 2430, 2436, and 2438). In addition, Segment 2425 was only included in the modeling conducted during the study as a boundary condition because it was unimpaired at that time (Table 2). In 2010, it became impaired and was added to the 303(d) List for a combined total of 14 impaired segments discussed in this report. In addition, non-impaired Segment 1013 was used throughout the analysis and modeling, and three non-impaired segments (1014, 1016, and 1017) were used in the preliminary analysis but not the modeling.

The analysis conducted on segments 1014, 1016 and 1017 provided upstream boundary loadings for the model domain. Assessment units (AUs) 1006_05, 1006_07, and 2421_03 became impaired after the modeling was completed and are not included in the discussion. AU 1005_01 is unique in that it consists of both a section of the SJR and the oxbow named Old River. Because they are hydrologically different, it was modeled as two separate AUs (or sub-AUs): 1005_01_OR and 1005_01_SJR.

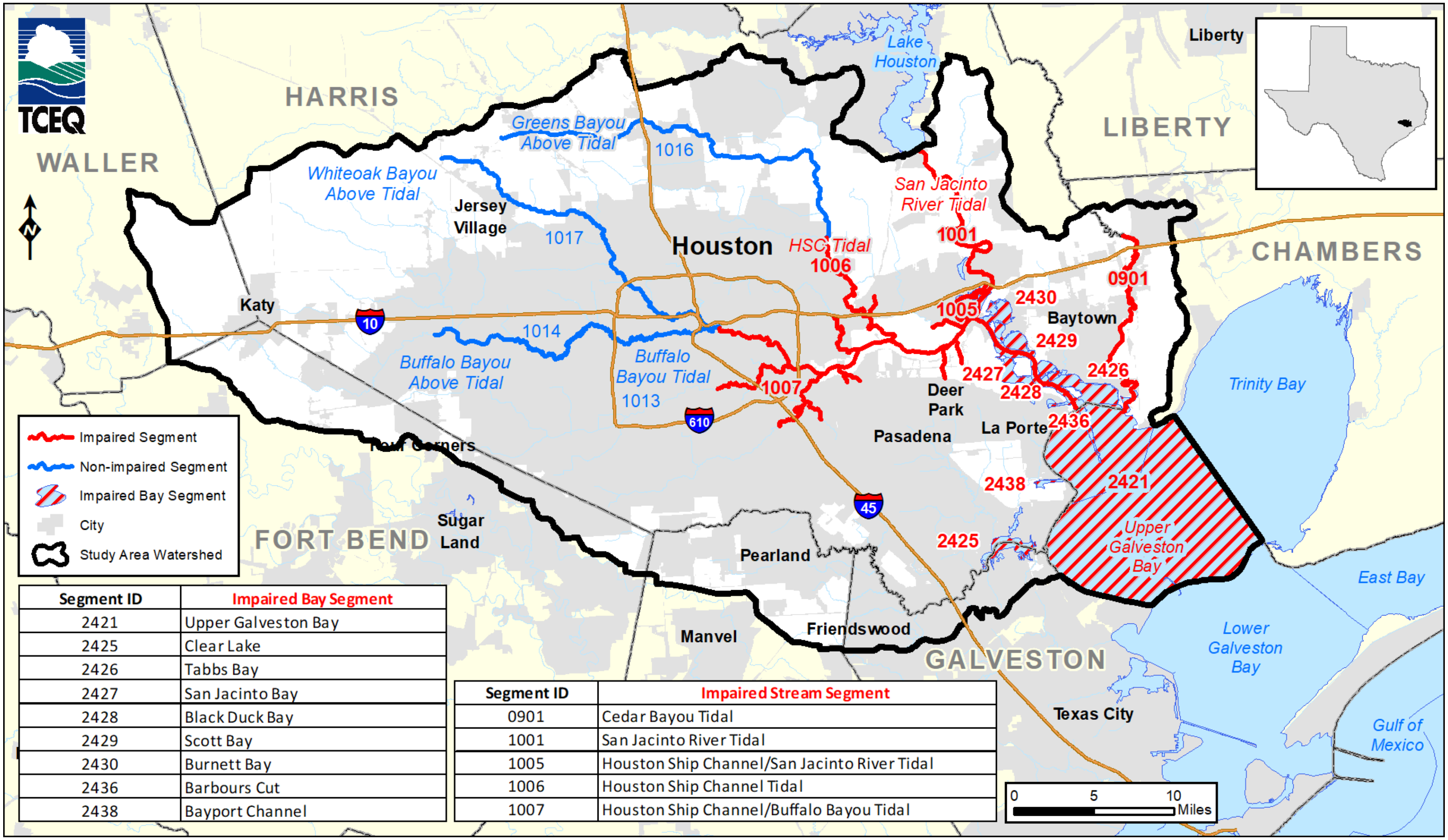
Table 2. Study Area Segments and First Year on 303(d) List

Segment Number	Segment Name	First Year Listed
0901	Cedar Bayou Tidal	2002
1001	San Jacinto River Tidal	2000
1005	Houston Ship Channel / San Jacinto River Tidal	1996
1006	Houston Ship Channel Tidal	1996
1007	Houston Ship Channel Tidal / Buffalo Bayou Tidal	1996
2421	Upper Galveston Bay	1996
2425	Clear Lake	2010
2426	Tabbs Bay	1996
2427	San Jacinto Bay	1996
2428	Black Duck Bay	1998
2429	Scott Bay	1998
2430	Burnett Bay	1998
2436	Barbour's Cut	1998
2438	Bayport Channel	2000

Dioxin Observations

The TCEQ's sampling of water, sediment, air, watershed runoff, and fish and crab tissue occurred from July 31, 2002 through August 30, 2005. This effort yielded a total of 149 in-stream water samples, 210 sediment samples, 186 catfish tissue samples, 155 crab tissue samples, and 64 air samples, for a total of 764 samples. These samples were used to assess the dioxin impairment, to quantify external loads to the system, and to parameterize and calibrate fate and transport models. A detailed summary of sampling procedures and results was included in the Data Summary Report (University of Houston and Parsons 2006). Table 3 summarizes data for dioxin in water, sediment, and tissue for surface water quality monitoring (SWQM) stations used for modeling purposes. The SWQM stations are shown in Figure 2. The data shows 98% of the fish samples and 96% of the crab samples exceeded the health-based criterion of 0.47 nanograms per kilogram (ng/kg) established by the DSHS. The most contaminated segments were the SJR Tidal (1001), HSC/SJR Tidal (1005), HSC Tidal (1006), and HSC/Buffalo Bayou Tidal (1007).

While dioxin is a mixture of chemically related compounds, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) is considered the most toxic dioxin congener and the major contributor to total toxicity of dioxin in all the media sampled. In most locations, 2,3,7,8-TCDD was used as a tracer to indicate source locations. Figure 3 shows the 2,3,7,8-TCDD dioxin concentration in water in the HSC and the lower SJR, which connects to Galveston Bay. Concentrations were low in Galveston Bay, but increased in the lower SJR approaching the confluence with the HSC. The increase continued to a maximum in the Buffalo Bayou section of the HSC, and then declined near the turning basin. 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF), another major contributor to the total toxicity of dioxin in the sampled media, was used as a tracer in the upper SJR (Segment 1001).



Segment ID	Impaired Bay Segment
2421	Upper Galveston Bay
2425	Clear Lake
2426	Tabbs Bay
2427	San Jacinto Bay
2428	Black Duck Bay
2429	Scott Bay
2430	Burnett Bay
2436	Barbours Cut
2438	Bayport Channel

Segment ID	Impaired Stream Segment
0901	Cedar Bayou Tidal
1001	San Jacinto River Tidal
1005	Houston Ship Channel/San Jacinto River Tidal
1006	Houston Ship Channel Tidal
1007	Houston Ship Channel/Buffalo Bayou Tidal

Figure 1. Houston Ship Channel Watershed

Table 3. Summary of Dioxin Data – July 2002- August 2005

Segment	Station ID	Water [a] Average (pg-TEQ/L [d])	Sediment [b] Average (ng-TEQ/kg [d])	Catfish [c] Average (ng-TEQ/kg [d])	Crab [c] Average (ng-TEQ/kg [d])
0901 Cedar Bayou Tidal	11111	0.247	5.5	**2.3**	**1.0**
1001 San Jacinto River Tidal	11193	1.345	74.1	**9.6**	**6.3**
	11197	0.126	18.5	**6.5**	**5.1**
	11200	0.062	0.6	**1.5**	**1.0**
	16622	0.078	1.6	**2.4**	**0.9**
	18388	NS [e]	15.7	NS [e]	NS [e]
	18389	NS [e]	16.0	NS [e]	NS [e]
1005 Houston Ship Channel / San Jacinto River Tidal	11252	0.182	4.3	**8.7**	**3.7**
	11258	NS [e]	2.5	**6.8**	**5.7**
	11261	0.535	11.0	**10.1**	**4.8**
	16618	0.301	22.1	**5.9**	**9.8**
	18390	NS [e]	11.7	NS [e]	NS [e]
1006 Houston Ship Channel Tidal	11264	0.495	19.2	**9.6**	**4.6**
	11265	0.579	25.4	**8.8**	**4.7**
	11267	NS [e]	39.0	NS [e]	NS [e]
	11268	NS [e]	41.6	NS [e]	NS [e]
	11269	NS [e]	13.3	NS [e]	NS [e]
	11270	0.374	15.8	**10.2**	**5.9**
	11271	NS [e]	9.0	NS [e]	NS [e]
	11272	0.439	7.8	**2.0**	**1.3**
	11273	1.627	158.5	**7.4**	**7.3**
	11274	0.257	4.3	**5.3**	**2.5**
	15979	1.083	101.9	**11.2**	**7.1**
	15980	NS [e]	20.4	NS [e]	NS [e]
	18391	NS [e]	8.1	NS [e]	NS [e]
1007 Houston Ship Channel Tidal/Buffalo Bayou Tidal	11280	0.407	188.9	**11.1**	**6.5**
	11287	0.119	11.7	**5.0**	**6.5**
	11292	0.097	16.9	**2.9**	**1.7**
	11298	0.315	16.3	**5.5**	**5.1**
	11300	0.517	92.6	**29.9**	**3.2**
	11302	0.120	4.8	**7.1**	**2.0**
	11305	0.087	2.7	**3.9**	**2.5**
	18392	NS [e]	22.0	NS [e]	NS [e]

Segment	Station ID	Water [a] Average (pg-TEQ/L [d])	Sediment [b] Average (ng-TEQ/kg [d])	Catfish [c] Average (ng-TEQ/kg [d])	Crab [c] Average (ng-TEQ/kg [d])
2421 Upper Galveston Bay	13309	0.161	1.2	**2.7**	**1.7**
	14560	0.138	2.8	**5.5**	**2.1**
	15464	0.109	0.6	**1.9**	0.4
	15908	0.164	1.1	**4.2**	**0.7**
	16213	0.173	1.7	**2.6**	**0.7**
2426 Tabbs Bay	11092	0.213	7.5	**0.7**	**0.6**
	13336	0.494	4.8	**2.0**	**1.9**
	13337	0.320	14.5	**6.8**	**1.9**
	13338	0.527	16.1	**4.9**	**2.2**
	13341	0.113	5.3	**3.5**	**2.5**
2427 San Jacinto Bay	13339	0.413	12.0	**8.0**	**6.8**
	16499	0.505	39.8	**6.0**	**4.3**
2428 Black Duck Bay	13340	0.106	7.5	**2.2**	**1.4**
2429 Scott Bay	13342	0.307	24.4	**8.1**	**6.0**
	17971	0.299	19.5	**6.0**	**5.8**
2430 Burnett Bay	13343	0.272	3.7	**8.1**	**4.3**
	13344	0.272	24.1	**8.6**	**4.7**
	16496	0.343	30.6	**9.4**	**4.5**
2436 Barbour's Cut	13355	0.596	0.8	**3.7**	**1.7**
	17970	NS [e]	1.6	**3.4**	**3.1**
2438 Bayport Channel	13363	0.254	0.9	**1.7**	**0.6**
	13589	0.074	0.9	**1.2**	**1.0**

[a] The 2000 Texas Water Quality Standard was 0.0933 pg-TEQ/L. Shading indicates it was exceeded.
[b] A sediment standard has not been defined because sediment can release or adsorb dioxin, depending on conditions.
[c] DSHS health based 0.47 ng/kg tissue standard. Values in **red bold** indicate the DHS standard was exceeded.
[d] The units pg-TEQ/L are used for solids dissolved in liquids (dioxin in water), but ng-TEQ/kg is used for solids mixed with solids (dioxin in tissue, and dioxin in sediment). They are approximately equal and both are commonly referred to as ppt.
[e] NS = not sampled

Figure 4 shows the 2,3,7,8-TCDF concentration in water in the upper SJR, beginning at its confluence with the HSC. At the time of this study, before construction of the SJRWP temporary armored cap, the 2,3,7,8-TCDF concentration was already high at the confluence and continued to increase in the upstream direction, reaching a maximum near the SJRWP, before declining as it approaches Lake Houston (Figure 4).

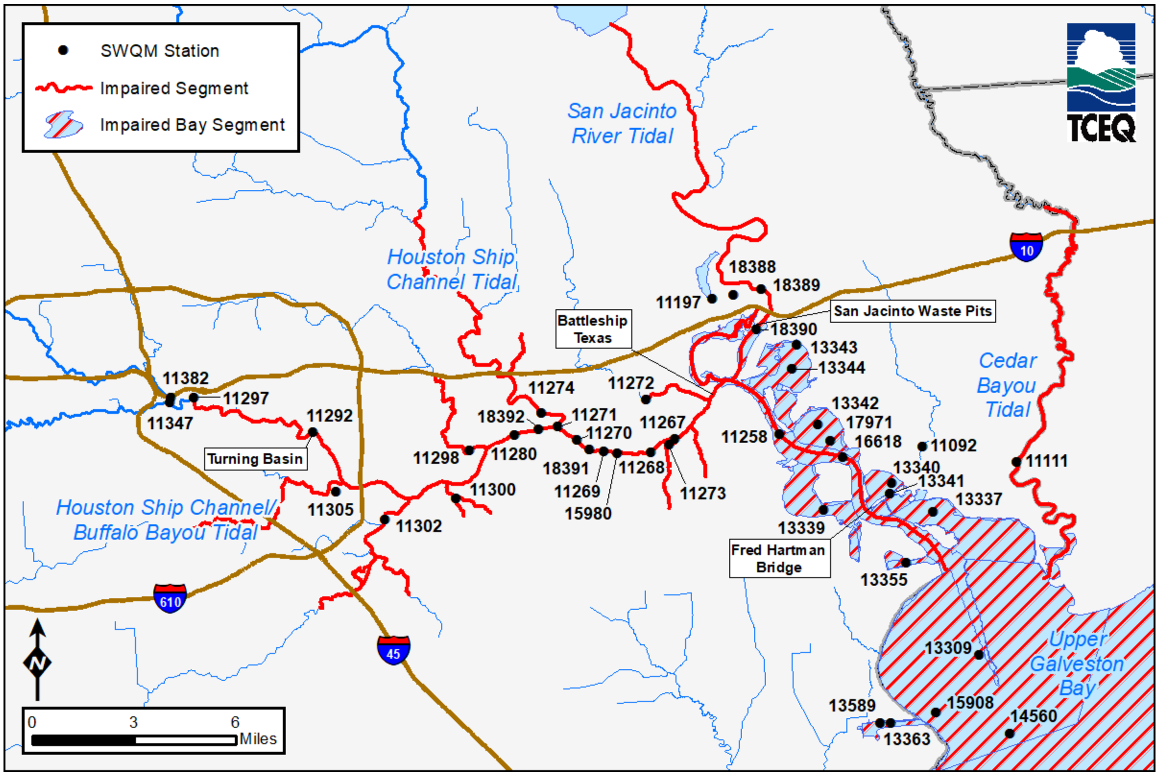


Figure 2. SWQM Sampling Station Locations Used for Modeling in the Study

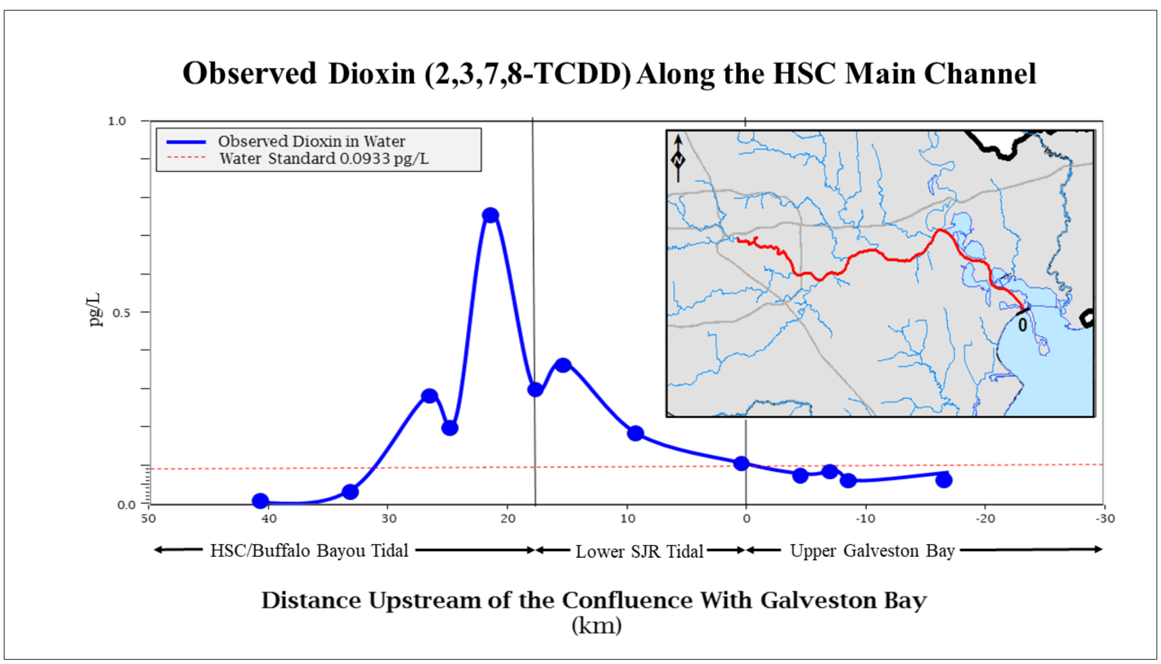


Figure 3. Observed Dioxin (2,3,7,8-TCDD) Concentration in Water in the Houston Ship Channel

* The figure above illustrates the 2000 human health saltwater criterion for dioxins and represents the time period before construction of the SJRWP temporary armored cap. In 2014, the TSWQS criterion for dioxins was revised and it remains in effect.

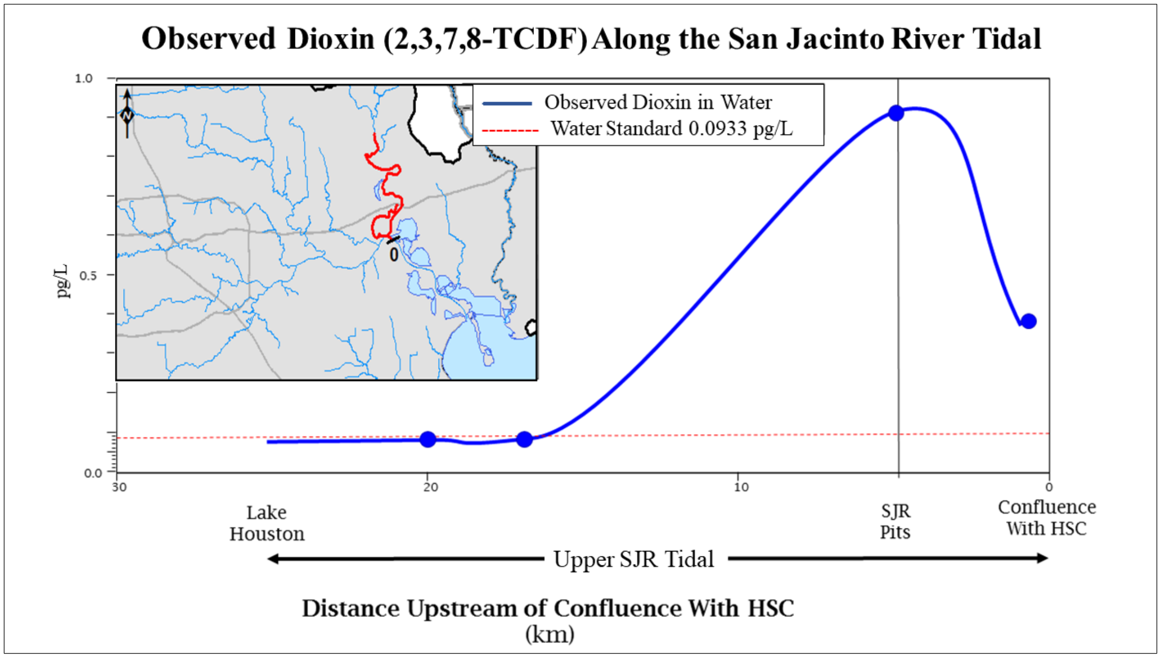


Figure 4. Observed Dioxin (2,3,7,8-TCDF) Concentration in Water in the Upper San Jacinto River

* The figure above illustrates the 2000 human health saltwater criterion for dioxins and represents the time period before construction of the SJRWP temporary armored cap. In 2014, the TSWQS criterion for dioxins was revised and it remains in effect.

Watershed Overview

The HSC is part of the SJR Basin and is located in southeast Texas adjacent to the City of Houston and Galveston Bay. This watershed spans approximately 1,387 square miles and encompasses most of Harris County and parts of Fort Bend, Waller, and Galveston counties. The greater Houston area occupies most of the study area watershed.

The climate of the region is subtropical humid, with very hot and humid summers and mild winters [US Army Corps of Engineers (USACE) 1985]. The average daytime temperature in the summer is 93 degrees Fahrenheit while the average daytime temperature in the winter is between 36-61 degrees Fahrenheit. Rainfall during the summer months is dominated by subtropical convection, winter months by frontal storms, and fall and spring months by combinations of the two (Burian 2005). Annual average precipitation is about 50 inches. Significant snowfall is rare, but traces of snow are recorded during many winters. The relative humidity in the area is high, with the annual average ranging from 60% to 87%.

Land uses in the HSC watershed were varied and have a significant industrial component. Most of the industrial development was located in the eastern part of the watershed where the HSC serves as an access link for ocean-going vessels and provides large quantities of industrial cooling water. Historically, urban development has taken place primarily in the central and southern portion of the watershed. Expansion of urban development has also taken place in the northern and western areas of the watershed. Table 4 and Figure 5 show the land use distribution for the contributing watershed associated with the HSC.

The land use data were taken from LandSat 8 data classified by the Houston-Galveston Area Council (H-GAC, 2011). The primary 2011 land use category within the study area was developed land (59%). The second most prominent land use category was farm and ranch, which encompassed 15% of the watershed.

Table 4. Land Use Composition 2011

Category	Area in Square Miles (mi^2)	Percent Contribution
Developed	818	59%
Farm and Ranch	208	15%
Wetland	111	8%
Forest	125	9%
Water	125	9%

Endpoint Identification

The standards for water quality are defined in the TSWQS which are located in 30 Texas Administrative Code (TAC), Chapter 307 (TCEQ 2018). The Texas Water Code (TWC) §26.023 states the TCEQ will set water quality standards by rule. The specific uses as assigned by the TSWQS to the 14 impaired segments addressed in this report are primary contact recreation (PCR) and noncontact recreation, navigation, industrial water supply, oyster waters, and aquatic life; however, not all of these segments are designated to support all of these uses (Table 5). All of the impaired segments are considered to have sustainable fisheries.

Toxic Equivalency Factors

The term “dioxins” is defined as a family of 210 polychlorinated molecules, called congeners, derived from the parent molecule dibenzo-p-dioxin or from a similar parent molecule, dibenzofuran. Because congener toxicity varies widely, a toxic equivalency factor (TEF) is assigned to each congener and is used to calculate a toxicity weighted average called toxic equivalent (TEQ). 2,3,7,8-TCDD is considered by experts to be the most toxic of the dioxin congeners; TEFs have been developed for several other well studied congeners that have also been found to have toxic effects. TEFs are provided in Table A-1 in Appendix A of the 2000 TSWQS. Texas has defined TEFs for the 12 most toxic congeners.

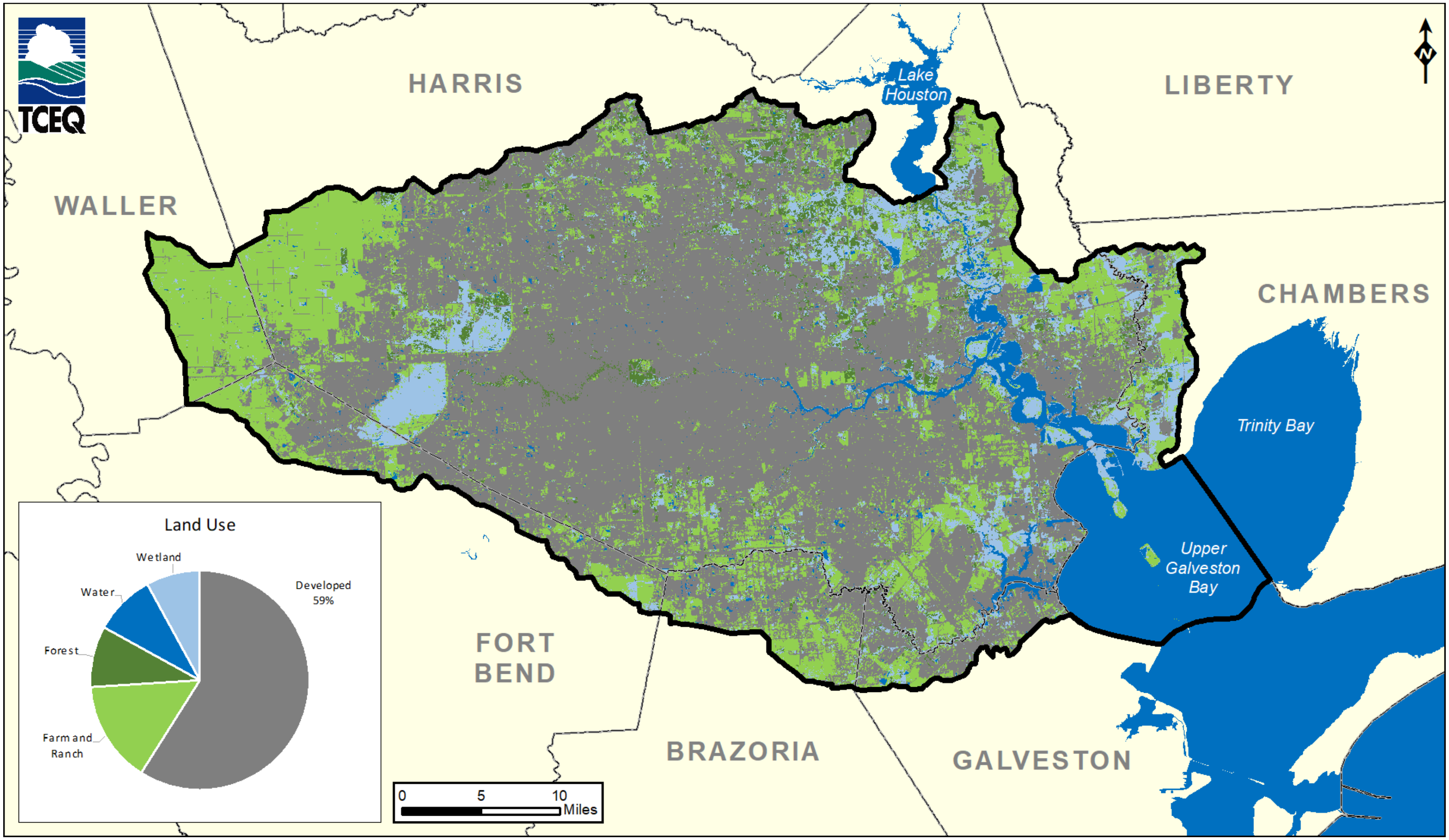


Figure 5. Houston Ship Channel Watershed Land Use 2011

Table 5. Designated Uses for the Segments Included in this Report

Segment Number	Segment Name	Designated Uses
0901	Cedar Bayou Tidal	PCR 1 High Aquatic Life Uses
1001	San Jacinto River Tidal	PCR 1 High Aquatic Life Uses
1005	Houston Ship Channel / San Jacinto River Tidal	Noncontact Recreation High Aquatic Life Uses
1006	Houston Ship Channel Tidal	Navigation Industrial Water Supply
1007	Houston Ship Channel Tidal / Buffalo Bayou Tidal	Navigation Industrial Water Supply
2421	Upper Galveston Bay	PCR 1 Oyster Water High Aquatic Life Uses
2425	Clear Lake	PCR 1 High Aquatic Life Uses
2426	Tabbs Bay	PCR 1 High Aquatic Life Uses
2427	San Jacinto Bay	PCR 1 High Aquatic Life Uses
2428	Black Duck Bay	PCR 1 High Aquatic Life Uses
2429	Scott Bay	PCR 1 High Aquatic Life Uses
2430	Burnett Bay	PCR 1 High Aquatic Life Uses
2436	Barbour's Cut	PCR 1 High Aquatic Life Uses
2438	Bayport Channel	Noncontact Recreation High Aquatic Life Uses

(30 Texas Administrative Code, Chapter 307 [TCEQ 2018])

Water Quality Standard

The TSWQS (§307.6) establishes numerical criteria for specific toxic substances. The 2000 TSWQS included a human health water quality criterion for dioxins based on saltwater fish consumption. Data collected during the study sampling period, July 31, 2002 through December 2, 2004, showed that the dioxin levels in water from the HSC and upper Galveston Bay were above the 2000 standard in approximately 86% of the samples.

At the time of this modeling, the 2000 TSWQS were in effect, and the dioxin criterion was based on information used to calculate the EPA's nationally recommended dioxin criterion. Using EPA's recommended cancer potency factor and bioconcentration factor, the TCEQ calculated a surface water quality criterion of 0.0933 pg-TEQ/L (Saltwater Fish Only) when measuring all dioxin congeners.

However, in order to reduce computational effort, only the six most toxic congeners (2,3,7,8-TCDD, 1,2,3,7,8-PeCDD, 1,2,3,6,7,8-HxCDD, 2,3,7,8-TCDF, 2,3,4,7,8-PeCDF, and 123678-HxCDF) were modeled. After adjustment, it was determined that the surface water quality criterion of 0.0933 pg-TEQ/L was equivalent to 0.0776 pg-TEQ_6/L (83.2% of the surface water quality criterion) for comparison to the six modeled congeners.

Source Analysis

Pollutants may come from several sources, both point and nonpoint. Point source pollutants come from sources regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) Program. Industrial and municipal wastewater treatment facilities (WWTF) and stormwater discharges from industries, construction, and the separate storm sewer systems of cities are point sources of pollution. Nonpoint source pollution originates from multiple locations and is not regulated by permit under the TPDES Program.

The TCEQ received delegation of the National Pollutant Discharge Elimination System program from the EPA on September 14, 1998. The TCEQ is authorized to implement the TPDES Program, which is the program that regulates discharges of pollutants to surface waters. The TPDES program covers all permitting, inspection, public assistance, and enforcement regulatory processes associated with waste discharges into or adjacent to waters of the state. This includes discharges of waste from industry and municipal treatment works and discharges of storm water associated with industrial activities, construction sites, and municipal separate storm sewer systems (MS4s).

Dioxins can reach receiving water bodies through point source discharges of wastewater effluent, diffuse nonpoint sources such as runoff, and direct deposition from airborne emissions. Historically, a major dioxin source in the HSC was the use of chlorine to bleach wood pulp used to manufacture paper. Considerable reductions in dioxin point source discharges have resulted from state and federal permitting programs, from the use of substitute bleaching agents, and from pulp and paper plant shutdowns. Gillespie (1994) reported a 92% reduction in national dioxin generation from 1988 to 1993. However, in the HSC, the total amount of dioxin in fish and shellfish remains high, indicating continued loading from legacy sources, primarily contaminated bottom sediment.

Point Sources

All segments in the watershed have TPDES-permitted point sources, which include industrial WWTFs, domestic WWTFs, and stormwater MS4s.

WWTFs

At the time of this study there were more than 360 permitted WWTFs discharging to the HSC including 236 outfalls discharging to tributaries, ranging from small municipalities to very large industrial facilities. Only three of these permitted facilities have effluent limits or monitoring requirements for dioxins.

Dioxin in effluent data from non-stormwater point sources were gathered as part of this project during the spring of 2003 and were used to calculate daily loadings (University of Houston and Parsons 2006). In instances when the point source effluent was not sampled and the Standard Industrial Classification (SIC) was among those identified as potential dioxin dischargers, the concentration of a given congener in effluent was assumed equal to the average concentration of the congener in effluent from sampled HSC facilities with the same SIC code. If the SIC was not among industries identified as potential dioxin dischargers, the dioxin concentration was assumed to be equal to zero.

This analysis included all permitted continuous discharges except once-through cooling water systems. Once-through cooling water systems utilize water to circulate through pipes to absorb heat. Cooling water discharges do not significantly alter intake concentrations and are not expected to affect the water quality of receiving waters.

A summary of the point source data by AU is included in Table 6 and Table 7. Table 6 shows discharges into tributaries upstream of the modeling domain, but which drain into it. Because these discharges are outside the modeling domain, they appear as tributary loads for the AU they enter. The subtotal of these loads from the six modeled congeners was 145,571 ng-TEQ_6/d and the corresponding total load for all congeners was 174,966 ng-TEQ/d.

Table 7 shows discharges directly into the modeling domain, which appear as point source loads for the AU they enter. The subtotal of the loads from the six modeled congeners was 812,458 ng-TEQ_6/d, and the corresponding total load for all congeners was 976,512 ng-TEQ/d.

Some AUs are listed in both Table 6 and Table 7. For example, 16 permits discharge into tributaries that drain into Cedar Bayou 0901_01, and are listed in Table 6. In addition, one permit discharges directly into 0901_01, and is listed in Table 7.

Table 6. Permitted Wastewater Loads Discharged into Tributaries [a]

Tributaries of Water Body	Tributaries of AU	Permits	Average Flow [b] (MGD)	2,3,7,8-TCDD [c] (ng-TEQ/d)	1,2,3,7,8-PeCDD [c] (ng-TEQ/d)	1,2,3,6,7,8-HxCDD [c] (ng-TEQ/d)	2,3,7,8-TCDF [c] (ng-TEQ/d)	2,3,4,7,8-PeCDF [c] (ng-TEQ/d)	1,2,3,6,7,8-HxCDF [c] (ng-TEQ/d)	Subtotal of 6 Congeners [d] ($ng\text{-}TEQ_6/d$)	Total of All Congeners [e] (ng-TEQ/d)
Cedar Bayou	0901_01	16	16	1,835	1,761	2,073	5,278	2,904	3,614	17,465	20,992
Carpenters Bayou	1006_02	5	5	444	828	343	880	607	830	3,932	4,726
Greens Bayou Tidal	1006_03	3	1	76	171	93	277	107	93	817	982
Sims Bayou	1007_02	12	29	2,576	4,642	2,639	5,194	2,564	3,511	21,126	25,392
Hunting Bayou	1007_03	3	3	409	997	794	1,189	391	962	4,742	5,700
Brays Bayou	1007_04	23	68	5,904	7,434	5,249	8,327	4,794	3,203	34,911	41,960
Buffalo Bayou	1013 [f]	97	46	4,737	9,343	4,330	13,110	5,403	2,840	39,763	47,792
Greens Bayou	1016	75	22	2,404	5,382	2,527	7,847	2,943	1,614	22,717	27,304
Whiteoak Bayou	1017 [f]	1	0	-	-	-	-	-	-	0	0
Tabbs Bay	2426_01	1	0	10	23	11	34	13	7	98	118
Total	NA	236	190	18,395	30,581	18,059	42,136	19,726	16,674	145,571	174,966

[a] These are discharges into tributaries which drain into the modeling domain
[b] From daily flow monitoring
[c] From Average Flow and typical speciation
[d] Sum of the 6 congeners listed
[e] Subtotal of 6 congeners / 83.2%
[f] Segment discharges to 1013, which was in the model domain, but not on the 303(d) List.

Table 7. Permitted Wastewater Loads Discharging Directly into Modeled Water Bodies

Modeled Water Body [a]	Modeled AU	Per-mits	Average Flow [b] (MGD)	2,3,7,8-TCDD [c] (ng-TEQ/d)	1,2,3,7,8-PeCDD [c] (ng-TEQ/d)	1,2,3,6,7,8-HxCDD [c] (ng-TEQ/d)	2,3,7,8-TCDF [c] (ng-TEQ/d)	2,3,4,7,8-PeCDF [c] (ng-TEQ/d)	1,2,3,6,7,8-HxCDF [c] (ng-TEQ/d)	Subtotal of 6 Congeners [d] ($ng\text{-}TEQ_6/d$)	Total of All Congeners [e] (ng-TEQ/d)
Cedar Bayou	0901_01	1	0.03	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0	0
San Jacinto River	1001_01	14	7	1,886	2,019	2,079	9,896	2,060	803	18,743	22,528
	1001_02	4	4	681	419	519	1,274	837	1,200	4,930	5,925
	1005_01-SJR	3	1	135	106	463	1,392	1,721	5,811	9,628	11,572
Old River	1005_01-OR	4	2	210	415	254	708	306	371	2,264	2,721
Houston Ship Channel	1005_04	1	1	1,930	894	894	4,670	1,590	887	10,865	13,059
	1006_01	7	32	6,511	6,432	12,076	28,340	25,669	87,860	166,888	200,587
	1006_02	28	18	3,702	3,603	7,035	11,220	11,071	17,444	54,075	64,994
Greens Bayou Tidal	1006_03	7	6	563	918	414	3,706	1,543	891	8,035	9,657
Houston Ship Channel / Buffalo Bayou	1007_01	18	124	15,638	36,051	40,200	271,794	79,347	33,069	476,099	572,234
Sims Bayou Tidal	1007_02	7	34	1,459	3,536	3,587	5,064	3,978	1,838	19,462	23,392
Hunting Bayou Tidal	1007_03	2	1	76	169	80	247	93	52	717	862
Brays Bayou Tidal	1007_04	1	0.4	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0	0
Vince Bayou Tidal	1007_05	1	8	894	1,560	1,050	1,810	1,310	951	7,575	9,105
Buffalo Bayou Tidal	1007_07	1	0.01	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0	0
Upper Galveston Bay	2421_01	1	3	341	765	361	1,120	419	233	3,239	3,893
	2421_02	5	3	290	649	306	948	356	198	2,747	3,302
Tabbs Bay	2426_01	3	4	355	362	651	2,161	849	576	4,954	5,954
San Jacinto Bay	2427_01	7	3	610	293	1,333	2,394	693	477	5,800	6,971
Scott Bay	2429_01	1	0.3	46	26	102	355	211	403	1,143	1,374
Barbours Cut	2436_01	2	0.3	39	41	42	92	45	95	354	425
Bayport Channel	2438_01	1	11	1,070	1,240	1,780	3,840	2,050	4,960	14,940	17,957
Burnett Bay	2430_01	1	0.03	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0 [f]	0	0
Total	NA	120	263	36,436	59,498	73,226	351,031	134,148	158,119	812,458	976,512

[a] Water bodies without any permitted discharges are not shown.
[b] From daily flow monitoring
[c] From average flow and typical speciation
[d] Sum of the 6 congeners listed
[e] Subtotal of 6 congeners / 83.2%
[f] No WWTFs discharge dioxin.

TPDES Regulated Stormwater

When evaluating wasteload allocations and load allocations, stormwater discharges fell into two categories:

1) Permitted stormwater, which is any stormwater originating from a TPDES-permitted discharge; and
2) Unregulated stormwater, which is any stormwater originating from any area not covered by a TPDES permit.

A significant portion of the project watershed (approximately 60%) was regulated under the stormwater discharge permit WQ0004685000 jointly held by Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation (Houston MS4 Permit). The jurisdictional boundary of the Houston MS4 permit was derived from the 2000 EPA Urbanized Area map, which was the latest map available at the time of the modeling. (EPA 2000c).

There was no monitoring data available from Houston MS4 permits to characterize dioxin concentrations or loads from regulated stormwater discharged to receiving waters in the HSC watershed, so they were estimated. Table 8 lists the percentage of each watershed covered under the Houston MS4 permit.

As stated in the modeling report (University of Houston and Parsons 2008a), runoff volumes were estimated using the Soil Conservation Service (SCS) Runoff Curve Number method (Natural Resource Conservation Service (NRCS), 1986). Wet weather loadings were then computed using the dioxin concentrations in runoff measured in 2003 and 2005 as part of this project (Data Report, University of Houston and Parsons 2006).

The resulting TEQ daily loads by AU are summarized in Table 9 for discharges into tributaries and in Table 10 for discharges directly into modeled water bodies. The estimated loads were further split into loads from the MS4 permit area and nonpoint loads using the percent of each watershed covered by the MS4 permit. The estimated MS4 stormwater load discharged to the tributaries was 1,085,945 ng-TEQ/d, while the MS4 stormwater load discharged directly to the modeled AUs was 130,466 ng-TEQ/d.

Table 8. Percentage of Permitted Stormwater (MS4) by Watershed

Watershed	Segment	Total Area [a] (mi^2)	Area Under MS4 Permit [a] (mi^2)	Area Under MS4 Permit [b] (%)
Cedar Bayou	901	199	14	7
San Jacinto River	1001	80	23	29
HSC / SJR Tidal & Old River	1005	40	12	30
Houston Ship Channel	1006	27	9	32
HSC / Buffalo Bayou Tidal	1007	17	10	62
Buffalo Bayou	1013/1014	369	177	48
Greens Bayou	1016	211	177	84
White Oak Bayou	1017	111	110	98
Brays Bayou	NA [c]	129	128	99
Carpenters Bayou	NA [c]	31	11	35
Goose Creek (flows into Tabbs Bay)	NA [c]	33	30	90
Hunting Bayou	NA [c]	31	26	85
Sims Bayou	NA [c]	94	94	100
Vince Bayou	NA [c]	15	15	100

[a] From GIS
[b] Area Under MS4 Permit / Total Area
[c] Unclassified segment

Table 9. Permitted Stormwater Runoff Loads Discharged into Tributaries[a]

Tributaries of Water Body	AU	Total Runoff Load [b] (ng-TEQ/d)	MS4 Permitted Runoff Load [c] (ng-TEQ/d)	Unpermitted Runoff Load [d] (ng-TEQ/d)
Cedar Bayou	0901_01	9,238	627	8,611
San Jacinto River	1001_01	1,761,962	507,187	1,254,775
Carpenters Bayou	1006_02	12,914	4,480	8,434
Greens Bayou	1006_03	119,118	99,949	19,169
Sims Bayou	1007_02	17,986	17,982	4
Hunting Bayou	1007_03	42,217	35,888	6,329
Brays Bayou	1007_04	156,747	155,635	1,112
Vince Bayou	1007_05	8,524	8,514	10
Buffalo Bayou [e]	1013_01	334,562	160,263	174,299
Whiteoak Bayou [e]	1017_01	82,199	80,949	1,250
Tabbs Bay [f]	2426_01	16,068	14,471	1,597
Total		2,561,535	1,085,945	1,475,590

[a] These are upstream discharges into tributaries which drain into the modeling domain
[b] Flow from SCS runoff curve method × measured typical dioxin concentrations
[c] Total Runoff load × Table 8 % Area Under MS4 Permit
[d] Total Runoff Load – MS4 Permitted Runoff load
[e] AU was part of the modeling domain, but it was not in the 303(d) List
[e] The watershed of Goose Creek drains into Tabbs Bay

Table 10. Permitted Stormwater Runoff Loads Discharged Directly into Modeled Water Bodies

Water Body	AU	Total Runoff Load [a] (ng-TEQ/d)	MS4 Permitted Runoff Load [b] (ng-TEQ/d)	Unpermitted Runoff Load [c] (ng-TEQ/d)
Cedar Bayou	0901_01	27,510	1,867	25,643
San Jacinto River	1001_01	41,194	11,858	29,336
	1001_02	2,613	752	1,861
Houston Ship Channel / San Jacinto River Tidal	1005_01 [d]	5,609	1,708	3,901
	1005_02	3,505	1,067	2,438
	1005_03	474	144	330
	1005_04	851	259	592
	1006_01	13,067	4,123	8,944
	1006_02	12,933	4,081	8,852
Greens Bayou Tidal	1006_03	24,102	20,224	3,878
Houston Ship Channel	1007_01	21,156	12,732	8,424
Sims Bayou Tidal	1007_02	14,609	14,606	3
Brays Bayou Tidal	1007_04	31,505	31,281	224
Vince Bayou Tidal	1007_05	4,465	4,459	6
Buffalo Bayou Tidal	1007_07	12,419	5,949	6,470
Upper Galveston Bay	2421_01	14,393	977	13,416
	2421_02	6,613	449	6,164
Clear Lake	2425_01	NA [e]	NA [e]	NA [e]
Tabbs Bay	2426_01	14,222	965	13,257
San Jacinto Bay	2427_01	9,380	0	9,380
Black Duck Bay	2428_01	1,190	81	1,109
Scott Bay	2429_01	5,761	391	5,370
Burnett Bay	2430_01	1,876	127	1,749
Barbours Cut	2436_01	769	53	716
Bayport Channel	2438_01	345	23	322
Total	NA	285,019	130,466	154,553

[a] Flow from SCS runoff curve method × measured typical dioxin concentrations
[b] Total TEQ load × percent of watershed covered by the MS4 permit
[c] Total Runoff Load – MS4 Permitted Runoff load
[d] 1005_01 = 1005_01_SJR + 1005_01_OR
[e] 2425 was only a boundary condition at the time of the modeling

Nonpoint Sources

Nonpoint source loads could enter the study area through distributed, unspecified locations. Nonpoint sources of dioxin could originate from stormwater runoff from areas not covered by an MS4 permit, air deposition, and contaminated sediments.

Stormwater Runoff

Estimated regulated and unpermitted stormwater loads are summarized in Table 9 and Table 10. The total estimated nonpoint TEQ loads discharged via runoff was 1,475,590 ng-TEQ/d to tributaries and 154,553 ng-TEQ/d directly to the modeled AUs.

Dry and Wet Air Deposition

Deposition loads were estimated using the dry/wet deposition fluxes measured in this project multiplied by the area of the different water quality segments (University of Houston and Parsons 2008a). Only direct deposition to the channel was addressed, since deposition to the watershed was ultimately carried to the channel via runoff. Therefore, deposition to the watershed was included in the wet weather load calculation. Table 11 presents a summary of deposition loads by AU. The TEQ load discharged to the system via dry/wet deposition was 602,373 ng-TEQ/d.

Sediment Sources

Sediment source loads are difficult to estimate because, under most conditions, dioxin slowly dissolves from sediment. However, under some conditions, sediment slowly adsorbs dioxin. Since these are very slow reactions and there are rapid tidal, wave, and storm driven movement of both the water and sediment, the system never reaches equilibrium.

While it was easy to measure the dioxin concentration in the sediment itself, that gave little indication of the dioxin load dissolved from or being adsorbed by the sediment. Therefore, the sediment load was derived from modeling, as described in the linkage analysis section.

Linkage Analysis

Establishing the potential relationship between instream water quality and the source of pollutant loadings is important in order to understand the causes of an impairment.

As shown in Figure 6, the modeling approach coupled a two-dimensional hydrodynamic model with a two-dimensional water quality model to estimate the instream total load.

Table 11. Direct Deposition Loads to Impaired AUs

Watershed [a]	AU	Channel Area [b] (km^2)	Total TEQ Load [c] (ng-TEQ/d)
Cedar Bayou	0901_01	0.3	586
San Jacinto River	1001_01	1.8	4,135
	1001_02	0.8	1,743
Houston Ship Channel / San Jacinto River Tidal	1005_01 [d]	1.7	3,995
	1005_02	3.5	8,086
	1005_03	0.9	2,196
	1005_04	1.8	4,022
	1006_01	1.4	3,256
	1006_02	1.8	4,071
Greens Bayou Tidal	1006_03	0.5	1,060
Houston Ship Channel	1007_01	3.3	7,644
Sims Bayou Tidal	1007_02	0.2	470
Brays Bayou Tidal	1007_04	0.4	873
Vince Bayou Tidal	1007_05	0.1	222
Buffalo Bayou Tidal	1007_07	0.4	348
Upper Galveston Bay	2421_01	93.7	224,163
	2421_02	80.3	192,105
	2421_03	36.9	88,277
Tabbs Bay	2426_01	10.4	23,757
San Jacinto Bay	2427_01	3.9	8,925
Black Duck Bay	2428_01	1.2	2,876
Scott Bay	2429_01	3.5	8,096
Burnett Bay	2430_01	4.6	10,564
Barbours Cut	2436_01	0.2	513
Bayport Channel	2438_01	0.2	390
Total	NA	253.8	602,373

[a] Non-impaired AUs not shown. Segment 2425 was not impaired until 2010, after modeling was conducted, therefore it is not included in this table
[b] From GIS database
[c] Channel Area × measured typical deposition rate
[d] 1005_01 = 1005_01_SJR + 1005_01_OR

The difference between the modeled instream total load and the sum of known loads (point, runoff, deposition, and tributaries) was assumed to be sediment load. A mass balance spreadsheet was used to estimate sediment load.

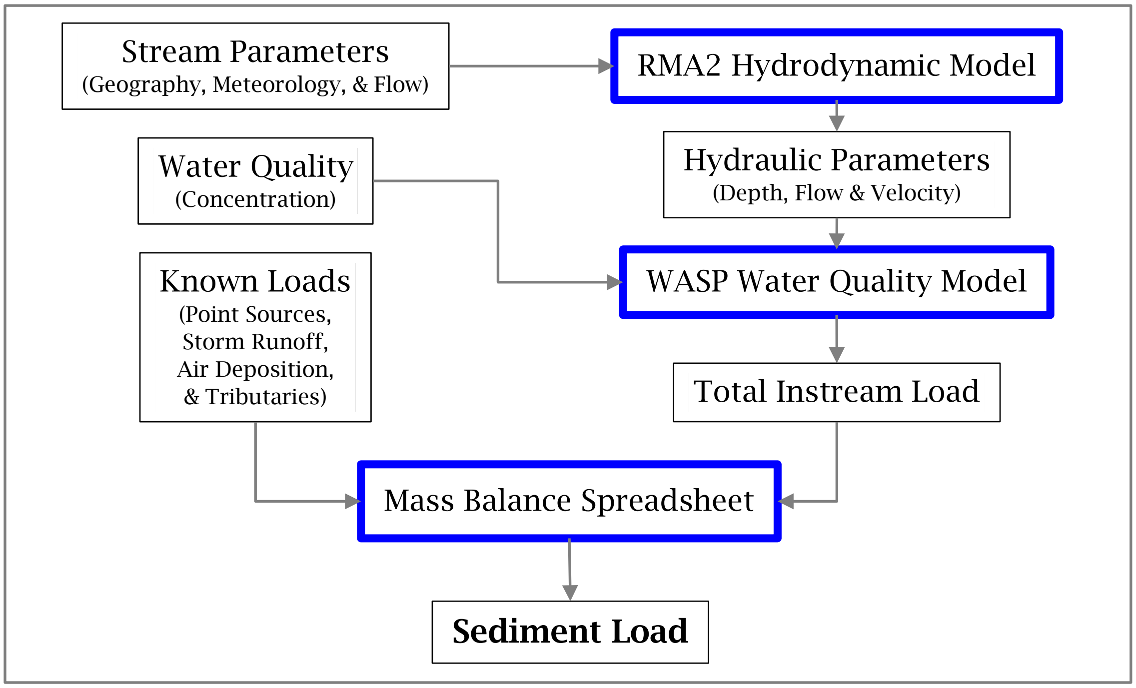


Figure 6. Modeling Process

The hydrodynamics of the HSC were modeled using the RMA2 WES 4.5 Program [U.S. Army Engineer Research Development Center (ERDC) 2005], while the U.S. EPA Water Quality Analysis Simulation Program (WASP7, Wool et. al. 2004) was used for the water quality portion of the model.

The mass balance spreadsheet was used to calibrate the model and to derive estimates of the effect of sediment-source dioxins on water column concentration, and is described in detail in Appendix B, Model Calibration. For mass balance calculations, the individual model segments were aggregated into AUs, then into mass balance segments, which may have contained multiple AUs.

The model was run for the period July 2002 to April 2005. Because the geographical distribution of congeners varied, separate models were developed for the six congeners that showed a contribution to the total TEQ that was higher than 1%. Details on the setup and calibration of the models can be found in the Final Modeling Report (University of Houston and Parsons 2008a).

Results for each of the six modeled congeners were then converted to TEQ using their TEFs (see Table A-1 in Appendix A). The sum of the TEQ for the six congeners was compared to the 2000 adjusted human health criterion of 0.0776 pg-TEQ_6/L (83.2% of 0.0933 pg-TEQ/L).

Model Analysis Strengths and Weaknesses

Strengths of the model analyses performed for this project included:

- A large amount of high-quality site-specific data representing all phases containing dioxin (dissolved, suspended solids, sediment, and tissue) and types of sources (air, runoff, and wastewater discharges) were collected and used for background analyses and modeling.
- Model dimensionality and hydrodynamics represented transport complexities inherent to tidal water bodies.
- The models were calibrated using site-specific data, and scenarios were compared to a conservative water quality standard.

Weaknesses of the model analyses included:

- Boundary conditions used in the model affected simulation results. Upstream boundary conditions were estimated to be high (e.g., non-detects were assumed to indicate half of the detection level) in order to be protectively conservative. However, these boundary conditions dominate the uppermost reaches and may cause an overestimation of loads in that area of the watershed.

Modeling Results

Source Types

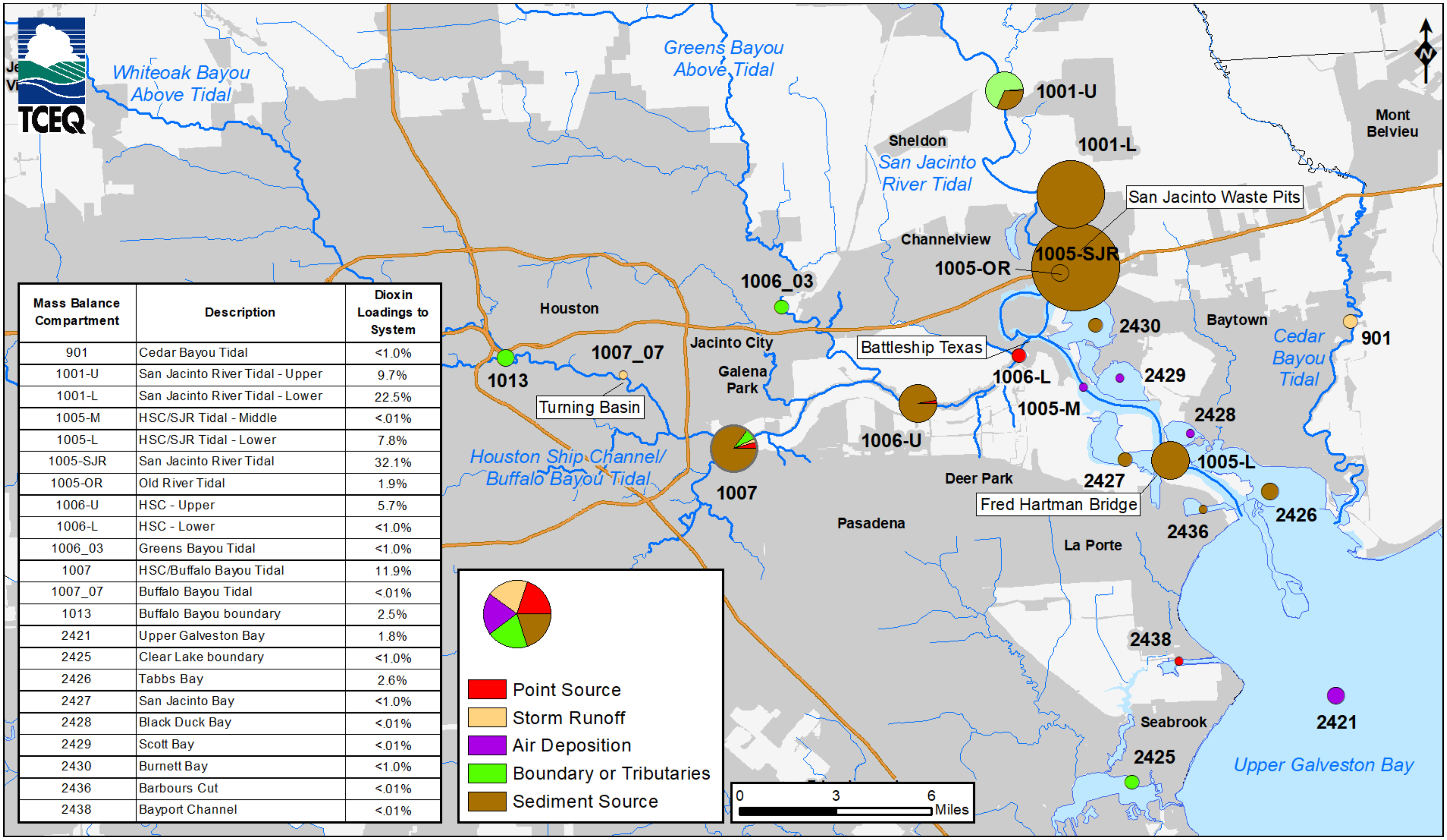
Table 12 summarizes the relative magnitude of various source types, which are illustrated in Figure 7. Each pie is located at the center of the mass balance compartment. The diameter of each pie represents the total load in that mass balance compartment. The slices of the pie are color coded with point source loads shown in red, stormwater loads in orange-tan, load from tributaries in green, direct deposition loads from the air in purple, and sediment source loads in brown. In several mass balance compartments, for example 1005-L, sediment was the largest dioxin source load and other source types were too small to see clearly. In some mass balance compartments, for example 1007_07, total dioxin loads were too small to even see the pie clearly.

The most notable feature of Figure 7 is that sediment loads (brown) dominated most mass balance compartments, and there was very little load from other sources in those mass balance compartments. Historically the largest sources were sediment loads near the SJRWP superfund site, located on the border between mass balance compartments 1001-L and 1005-SJR. A second area of high sediment load was along the HSC in 1006-U and 1007. A third area of high sediment load was 1005-L.

Table 12. Mass Balance of Dioxin Loads in the HSC

Mass Balance Compartment			Point Sources	Storm Run-off	Air Deposition	Boundary or Tributaries [a]	Sediment Source	Sediment Sink
ID	Description	AUs [b]	(ng-TEQ$_6$/d)	(ng-TEQ$_6$/d)	(ng-TEQ$_6$/d)	(ng-TEQ$_6$/d)	(ng-TEQ$_6$/d)	(ng-TEQ$_6$/d)
San Jacinto River								
1001-U	San Jacinto River Tidal - Upper	1001_01	5,232	34,273	3,102	1,465,952	692,533	-
1001-L	San Jacinto River Tidal - Lower	1001_02	1,608	2,174	1,307	-	5,094,145	-
1005-SJR	San Jacinto River Tidal	1005_01-SJR	1,815	547	1,655	-	7,265,959	-
1005-OR	Old River Tidal	1005_01-OR [c]	704	4,120	1,342	-	422,815	-
HSC / Buffalo Bayou								
1006-U	HSC - Upper	1006_01	35,389	10,872	2,442	-	1,238,259	-
1006-L	HSC - Lower	1006_02	20,068	10,760	3,053	12,273	-	(856,767)
1006_03	Greens Bayou Tidal	1006_03	2,297	20,053	795	106,549	-	(69,515)
1007	HSC/Buffalo Bayou Tidal	1007_01 to 1007_05	117,062	71,713	6,906	210,005	2,281,801	-
1007_07	Buffalo Bayou Tidal	1007_07	-	10,333	261	-	-	(323,538)
1013	Buffalo Bayou boundary	NA [c]	-	-	-	375,221	185,330	-
San Jacinto River and Side Bays								
1005-M	HSC/SJR Tidal - Middle	1005_02	2,147	2,916	6,065	-	-	(7,328,308)
1005-L	HSC/SJR Tidal - Lower	1005_03 and 1005_04	3,817	1,103	4,663	-	1,757,573	-
2426	Tabbs Bay	2426_01	1,299	11,833	17,817	13,401	537,328	-
2427	San Jacinto Bay	2427_01	1,523	7,804	6,694	-	16,295	-
2429	Scott Bay	2429_01	251	4,793	6,072	-	-	(28,261)
2430	Burnett Bay	2430_01	-	1,561	7,923	-	24,510	-
Galveston Bay								
901	Cedar Bayou Tidal	0901_01	-	22,888	439	10,954	-	(10,916)
2421	Upper Galveston Bay	2421_01 to 2421_02	2,042	17,476	378,409	-	-	(3,599,272)
2428	Black Duck Bay	2428_01	-	990	2,157	-	-	(43,165)
2436	Barbours Cut	2436_01	105	640	385	-	1,123	-
2438	Bayport Channel	2438_01	3,773	287	292	-	-	(3,798)
2425	Clear Lake boundary	2425_01	-	-	-	51,173	-	(52,932)
Study Area Source Total (ng-TEQ$_6$/d)							**19,517,671**	
Study Area Source Total %							**86%**	

[a] Load from upstream freshwater reaches.
[b] AUs 1006_05 - 1006_07, and 2421_03 were added to the 303(d) List after modeling was completed and are not shown
[c] Non-impaired



Mass Balance Compartment	Description	Dioxin Loadings to System
901	Cedar Bayou Tidal	<1.0%
1001-U	San Jacinto River Tidal - Upper	9.7%
1001-L	San Jacinto River Tidal - Lower	22.5%
1005-M	HSC/SJR Tidal - Middle	<.01%
1005-L	HSC/SJR Tidal - Lower	7.8%
1005-SJR	San Jacinto River Tidal	32.1%
1005-OR	Old River Tidal	1.9%
1006-U	HSC - Upper	5.7%
1006-L	HSC - Lower	<1.0%
1006_03	Greens Bayou Tidal	<1.0%
1007	HSC/Buffalo Bayou Tidal	11.9%
1007_07	Buffalo Bayou Tidal	<.01%
1013	Buffalo Bayou boundary	2.5%
2421	Upper Galveston Bay	1.8%
2425	Clear Lake boundary	<1.0%
2426	Tabbs Bay	2.6%
2427	San Jacinto Bay	<1.0%
2428	Black Duck Bay	<.01%
2429	Scott Bay	<.01%
2430	Burnett Bay	<1.0%
2436	Barbours Cut	<.01%
2438	Bayport Channel	<.01%

Figure 7. Historic Dioxin Loading by Source Type

Pie slices represent the relative magnitude of dioxin source types, and the diameter represents the total dioxin load. In most mass balance compartments, sediment was the primary dioxin load and other source types may be too small to see clearly. In some mass balance compartments, total dioxin loads are too small to see the pie clearly.

Point sources (red) were small in 1007 and 1006-U, and almost nonexistent in other mass balance compartments. This indicates that permitted facilities are very small sources of dioxin compared to other sources in the modeled AUs.

The green color in 1001-U indicates a moderate load upstream of this compartment. Likewise, the green color in 1013 indicates a moderate load from upstream portions of Buffalo Bayou relative to other sources.

The purple color in 2421 indicates the major source was direct deposition of airborne dioxin into the water of upper Galveston Bay.

Orange/tan color represented direct inflow of uncontrolled stormwater, which was very small because almost all stormwater was managed by MS4s and included as a point source.

Sediment Behavior

Depending on conditions, sediment can release or adsorb dioxin, transferring it from areas of high dioxin concentration to areas of low dioxin concentration. In areas where there is a high concentration of dioxin in sediment, sediment may release dioxin into the water either by dissolution or suspension of sediment. In areas where there is a low dioxin concentration in sediment, sediment may adsorb dioxin from the water, or suspended sediment with higher dioxin concentration may settle.

Figure 8 shows the behavior of sediment on a color scale ranging from red to white to blue. Dark red indicates sediment was a major source, releasing as much as 7,000,000 ng-TEQ$_6$/d of dioxin into the water. White indicates sediment was neutral and did not release or adsorb significant amounts of dioxin. Dark blue indicates the sediment adsorbed as much as 7,000,000 ng-TEQ$_6$/d of waterborne dioxin transported from other compartments.

Sediment source loads clearly dominated red and light red areas. However, these source areas were separated by areas where sediment was neutral or sediment adsorption dominated. This suggests there are three separate and distinct source areas, which were identified in shades of red.

In the upper portion of the HSC/SJR, the SJRWP is located on the boundary between 1001-L and 1005-SJR. Prior to the construction of the temporary armored cap in 2011, it appeared to be the largest single source in the watershed. While tidal action appears to have distributed some dioxin upstream into 1001-L, the bulk was distributed downstream into 1005-SJR. But further downstream, in the middle portion of the HSC/SJR, sediment adsorption dominated 1005-M.

Downstream in the lowest portion of the HSC/SJR, sediment sources dominated 1005-L. This suggested that some of the 1005-L sediment loads were separate and distinct from the SJRWP and originated from a suspected weak source located in or near 1005-L.

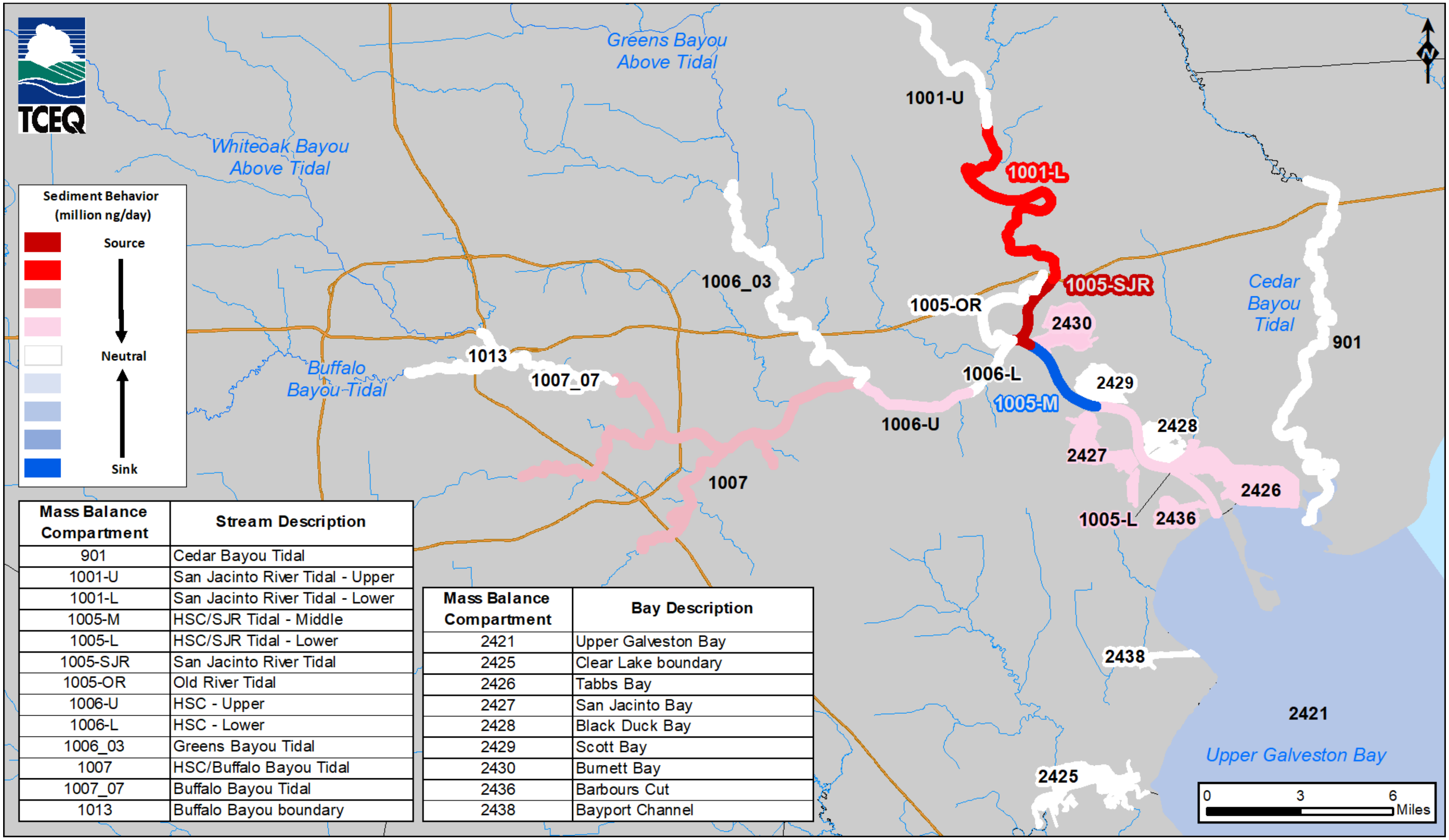
In the upper portion of the HSC/BB, compartments 1006-U and 1007 were dominated by sediment loads from unknown sources. But downstream, sediment was neutral in compartment 1006-L, suggesting those sediment loads were separate and distinct from the SJRWP, and originated from a suspected source located in or around mass balance compartment 1007.

Finally, in the upper portion of Galveston Bay, sediment adsorption dominated compartment 2421, indicating a net transfer of dioxin into Galveston Bay.

To summarize, as listed in Table 13 and shown in Figure 8, there were sediment source areas in the upper portion of the HSC/SJR, the upper portion of the HSC/BB, and the lower portion of the HSC/SJR. These source areas were separated by sink areas in the middle portion of the HSC/SJR, the lower portion of the HSC/BB, and the upper portion of Galveston Bay. Overall, sediment loads were the largest source, and a large portion of these were historically from the SJRWP, however sediment loads from other sources contributed as well. The nature and precise location of these suspected sources is unknown.

Table 13. Major Sediment Source and Sink Areas

Mass Balance Compartments	Description	Sediment Behavior
1001-L & 1005-SJR	Upper portion of the HSC/SJR	Source
1005-M	Middle portion of the HSC/SJR	Sink
1006-U & 1007	Upper portion of the HSC/BB	Source
1006-L	Lower portion of the HSC	Sink
1005-L	Lower portion of the HSC/SJR	Source
2421	Upper portion Galveston Bay	Sink



Mass Balance Compartment	Stream Description
901	Cedar Bayou Tidal
1001-U	San Jacinto River Tidal - Upper
1001-L	San Jacinto River Tidal - Lower
1005-M	HSC/SJR Tidal - Middle
1005-L	HSC/SJR Tidal - Lower
1005-SJR	San Jacinto River Tidal
1005-OR	Old River Tidal
1006-U	HSC - Upper
1006-L	HSC - Lower
1006_03	Greens Bayou Tidal
1007	HSC/Buffalo Bayou Tidal
1007_07	Buffalo Bayou Tidal
1013	Buffalo Bayou boundary

Mass Balance Compartment	Bay Description
2421	Upper Galveston Bay
2425	Clear Lake boundary
2426	Tabbs Bay
2427	San Jacinto Bay
2428	Black Duck Bay
2429	Scott Bay
2430	Burnett Bay
2436	Barbours Cut
2438	Bayport Channel

Figure 8. Sediment Source and Sink Areas

Shading from red to white to blue indicates sediment behavior, with red indicating compartments where dioxin is released from the sediment into the water. White indicates compartments where sediment is neutral and does not release or adsorb dioxin. Blue indicates compartments where sediment adsorbs dioxin from the water.

Water Concentration

The existing conditions scenario shows modeled concentrations in water. The results of this modeling are shown in Figure 9. The color codes indicate the dioxin concentration. Only the blue cell (60-Clear Creek - in the lower left portion of the computational grid) was below the criterion, and all other cells exceeded 0.0776 pg-TEQ_6/L. The largest concentrations were in the SJR near the SJRWP and the middle of Buffalo Bayou. The model was used to evaluate various loading scenarios, including sediment only, and no sediment scenarios. Because of different initial loadings, it was necessary to model each congener separately for each of the 13 scenarios for both the HSC and the SJR. A complete set of these scenarios was included in Appendix C. However, these scenarios are summarized in two charts discussed below, which illustrate the conclusion drawn from these scenarios.

Only 2,3,7,8-TCDD and 2,3,7,8-TCDF are discussed below because they dominated the total dioxin TEQ load, and their loads were sufficient to exceed 0.0776 pg-TEQ_6/L. Strictly speaking, 0.0776 pg-TEQ_6/L includes the sum of all congeners. However, 2,3,7,8-TCDD and 2,3,7,8-TCDF dominated the sum, so it was useful to compare them to 0.0776 pg-TEQ_6/L.

Figure 10 summarizes the modeling results along the HSC main channel from downtown Houston along Buffalo Bayou to its confluence with the SJR, and along the lower SJR to the entrance to Galveston Bay, then across Galveston Bay toward Dickinson. It shows the 2,3,7,8-TCDD concentration in water. Line (a) shows the existing conditions at the time of the modeling (2002-2005), which had a maximum concentration many times greater than 0.0776 pg-TEQ_6/L. Line (b) shows dioxin from sediment alone, which is almost indistinguishable from the existing conditions. Since the HSC main channel and the upper SJR are linked by tidal flow, the SJR probably contributed some load to this portion of the HSC. Line (c) shows there would be a minor reduction if there were not any sediment load from the upper SJR. As expected, line (d) shows the concentration would be greatly reduced if there was no load from the HSC main channel sediment. Finally, line (e) shows that if there was no sediment load from either the HSC main channel or the upper SJR, the concentration would be below 0.0776 pg-TEQ_6/L.

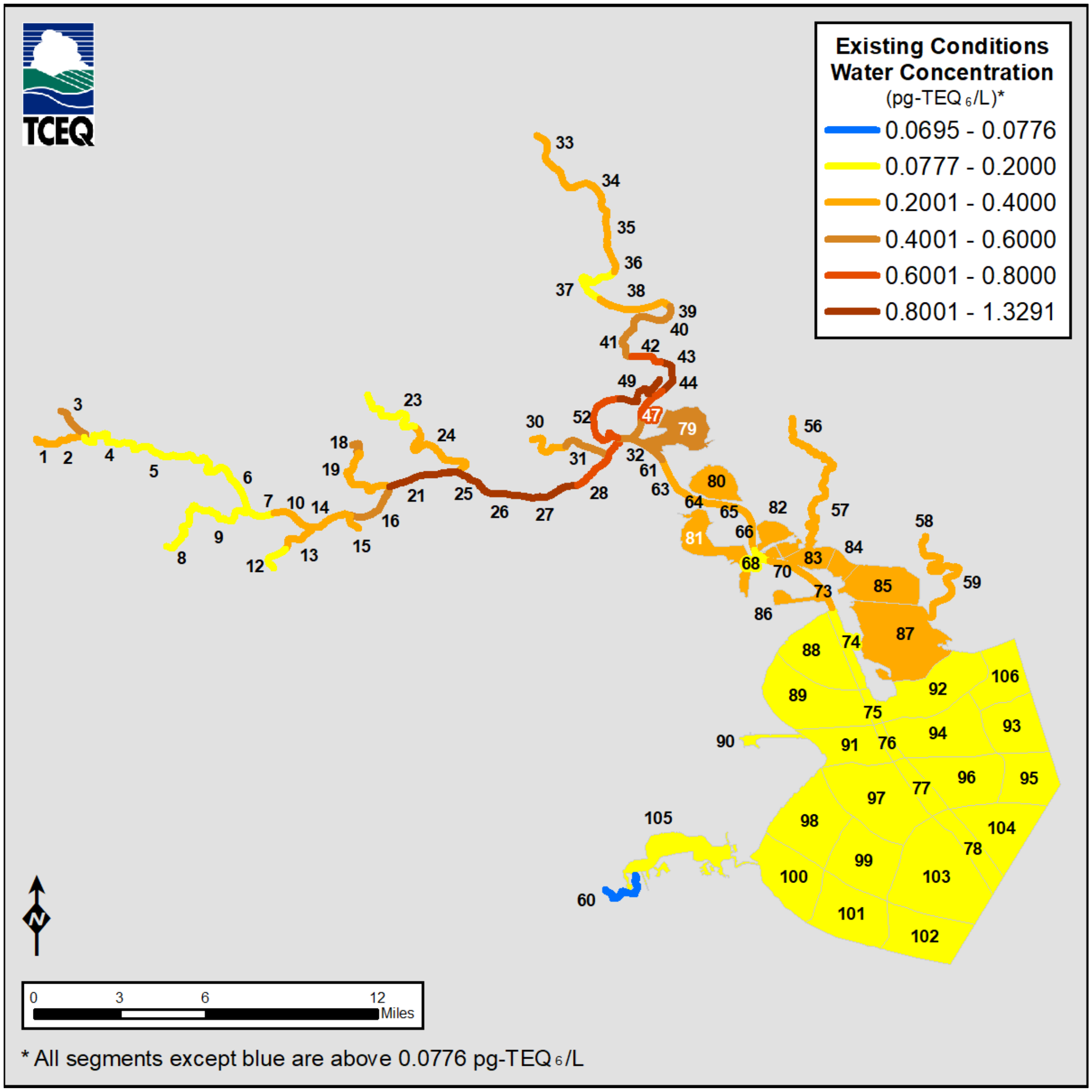


Figure 9. Modeled Dioxin in Water for the Existing Conditions

Note the color scale is different from Figure 13. Cell numbers shown are WASP segment numbers corresponding to Table 14.

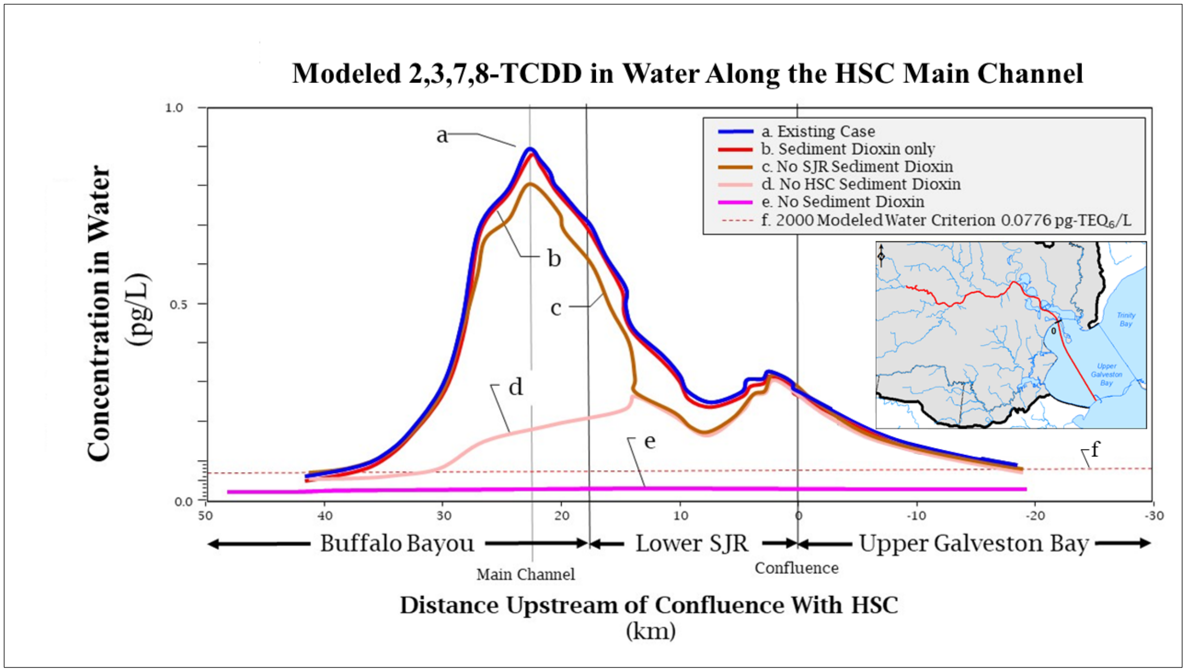


Figure 10. Modeled Dioxin in Water along the HSC Main Channel

Figure 11 is similar to Figure 10 except that it illustrates the modeled results for 2,3,7,8-TCDF, which is common in paper mill waste, in the upper SJR. Line (a) shows the existing conditions at the time of modeling, which had a maximum concentration many times greater than 0.0776 pg-TEQ_6/L shown by the dotted red line. Line (b) shows dioxin from sediment alone, which was almost indistinguishable from the existing conditions. Since there was only a small 2,3,7,8-TCDF load from the HSC main channel, line (c) shows the concentration would only be slightly reduced if there was no 2,3,7,8-TCDF load from HSC sediment.

However, line (d) shows there would be a major reduction if there was no load from the upper SJR. Finally, line (e) shows that if there was no sediment load from either the HSC or the upper SJR, the concentration would be below the criterion. Together, these charts demonstrate that legacy sediment contamination was the dominant source of dioxin and the most likely cause of the fish tissue impairment.

While Figure 10 shows maximums near kilometer (km) 2 and 23 in the HSC main channel and near the confluence with upper Galveston Bay, the peaks are broad indicating large sediment areas approximately 15 - 20 km long. This was in marked contrast to the narrow peak in 2,3,7,8-TCDF in the SJR, as shown in Figure 11. This difference in peak dioxin concentrations suggests that the 2,3,7,8-TCDD peak in the HSC main channel may have been the result of multiple historic sources.

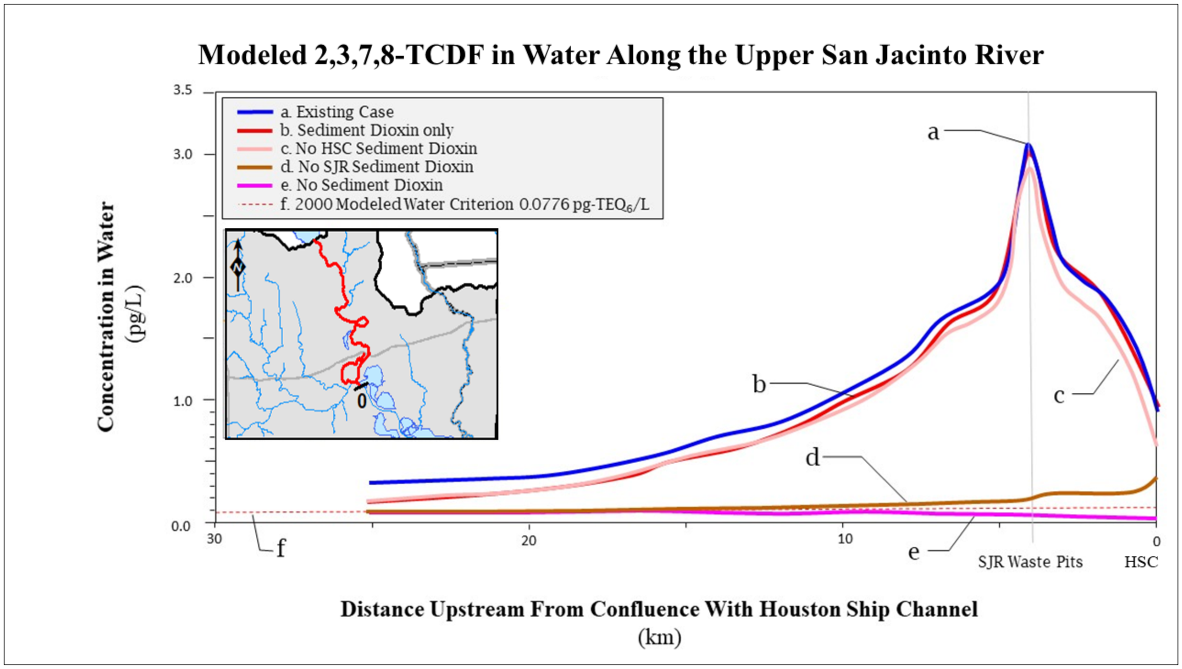


Figure 11. Modeled Dioxin in Water along the Upper San Jacinto River

No Legacy Sediment Load Scenario

A sensitivity test omitting all legacy sediment loads was modeled, and the average six-congener concentrations by WASP reach are included in Table 14. Figure 12 shows the spatial distribution of average TEQs. All areas except those shown in red on Figure 12 are below 0.0776 pg TEQ_6/L. All of red cells are headwater cells, so the levels may have been an artifact of overly conservative boundary conditions. Without sediment loads, 73% of the WASP reaches dropped below 0.0776 pg-TEQ_6/L and the overall average dropped from 0.3564 pg-TEQ_6/L to 0.0588 pg-TEQ_6/L, which was well below 0.0776 pg-TEQ_6/L and also below the current 2018 TSWQS criterion, even after adjustment to the six congener TEQ (0.0663 pg TEQ_6/L). As previously mentioned, the criterion in the 2018 WQS is 0.0797 pg-TEQ/L with an equivalent of 0.0663pg/L based on 6 modeled congeners (0.0797 x .0832), but this can also only be met with the mitigation of contaminated sediments since this is the largest source of dioxin contamination in the affected segments.

The individual summary tables for the six congeners were included in the Load Allocation Report (University of Houston and Parsons 2008b).

Legacy Sediment Impact

As indicated by the source load contributions, as well as the sediment only and no sediment load modeled scenarios, legacy sediment was the primary source of dioxin affecting the HSC water column and fish tissue.

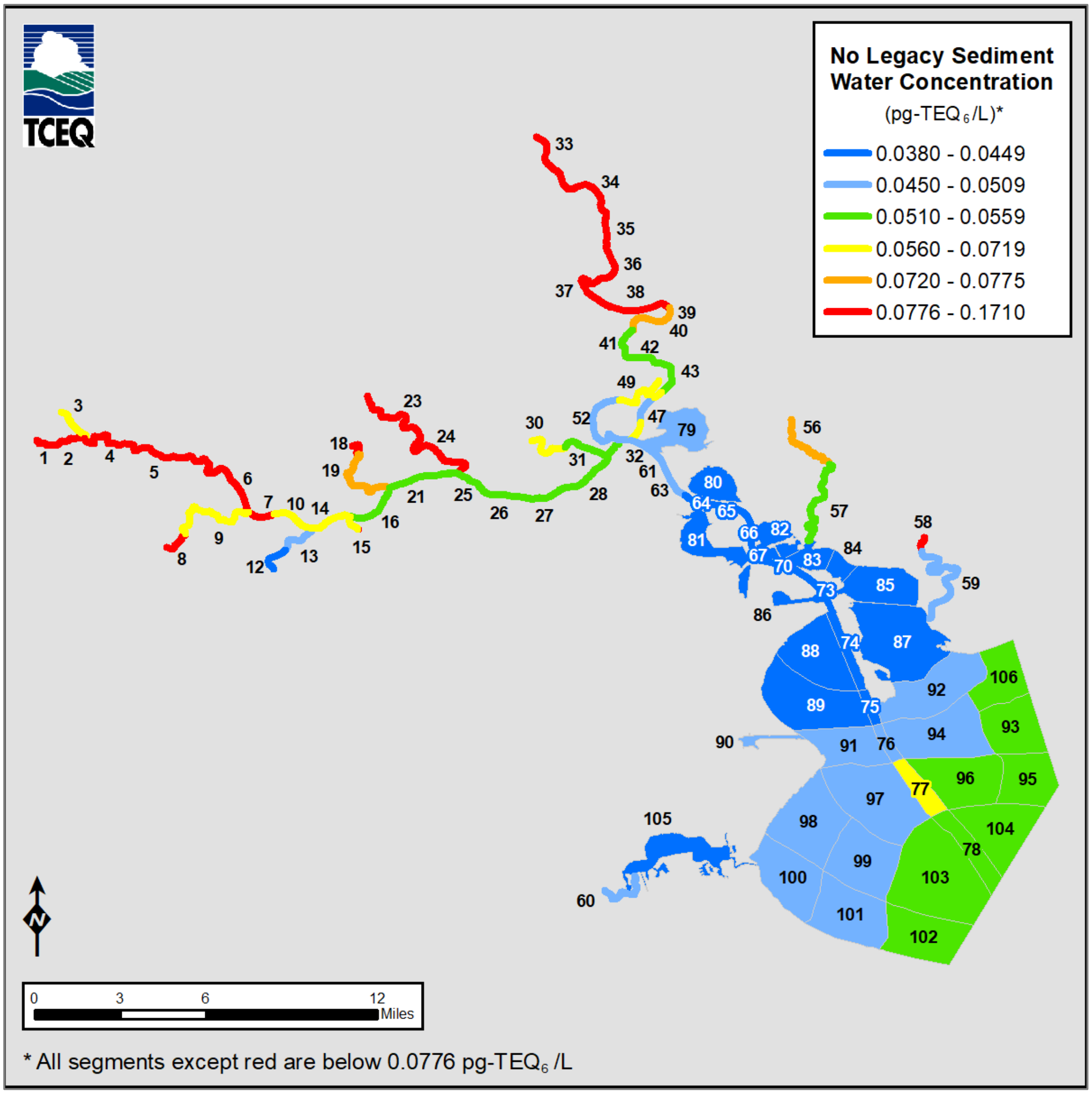


Figure 12. Modeled Dioxin in Water for No Legacy Sediment Scenario

Note the color scale is different from Figure 10. Cell numbers shown are WASP segment numbers corresponding to Table 14.

Data collection performed for this study revealed the presence of a deposit of paper mill sludge submerged in the upper SJR, which is frequently referred to as the SJRWP site. The submerged sludge deposit was a suspected source of dioxins. EPA added the site to the National Priority List of Superfund sites in 2008. EPA is the lead agency for addressing the site and cleaning up the contamination.

Table 14. Average TEQ_6 Concentrations from WASP Model Runs

Figure 10 and Figure 13 identify the WASP segment locations.

WASP Segment	Existing Conditions (pg-TEQ_6/L)	No Sediment Scenario (pg-TEQ_6/L)
1-Buffalo Bayou	0.2515	0.1710
2-Buffalo Bayou	0.2509	0.1226
3-Whiteoak Bayou	0.4927	0.0697
4-Ship Channel	0.1066	0.0983
5-Ship Channel	0.1025	0.0850
6-Ship Channel	0.1714	0.0906
7-Ship Channel	0.1816	0.0786
8-Brays Bayou	0.1837	0.0823
9-Brays Bayou	0.1550	0.0662
10-Ship Channel	0.2056	0.0710
11-Ship Channel	0.2453	0.0650
12-Sims Bayou	0.1476	0.0440
13-Sims Bayou	0.2847	0.0466
14-Ship Channel	0.3121	0.0564
15-Vince Bayou	0.2016	0.0670
16-Ship Channel	0.4197	0.0543
17-Ship Channel	0.5526	0.0522
18-Hunting Bayou	0.5464	0.1224
19-Hunting Bayou	0.3508	0.0756
20-Ship Channel	0.7945	0.0513
21-Ship Channel	0.8545	0.0514
22-Ship Channel at Greens	0.8830	0.0520
23-Greens Bayou	0.1569	0.0980
24-Greens Bayou	0.3445	0.0809
25-Ship Channel	0.9710	0.0532
26-Ship Channel	0.9769	0.0534
27-Ship Channel	0.8606	0.0532
28-Ship Channel	0.7665	0.0524
29-Ship Channel	0.7146	0.0515

WASP Segment	Existing Conditions (pg-TEQ_6/L)	No Sediment Scenario (pg-TEQ_6/L)
30-Carpenters Bayou	0.3494	0.0602
31-Carpenters Bayou	0.5311	0.0532
32-Ship Channel	0.6094	0.0511
33-San Jacinto River	0.2224	0.0967
34-San Jacinto River	0.2352	0.0905
35-San Jacinto River	0.2997	0.0875
36-San Jacinto River	0.2737	0.0851
37-San Jacinto River	0.1946	0.0823
38-San Jacinto River	0.3522	0.0785
39-San Jacinto River	0.4186	0.0753
40-San Jacinto River	0.4316	0.0723
41-San Jacinto River	0.5460	0.0696
42-San Jacinto River	0.7625	0.0665
43-San Jacinto River	0.9158	0.0636
44-San Jacinto River	1.3291	0.0617
45-San Jacinto River	0.9556	0.0572
46-San Jacinto River	0.7966	0.0531
47-San Jacinto River	0.6790	0.0488
48-San Jacinto River	0.3110	0.0494
49-Old River	0.9204	0.0559
50-Old River	0.8528	0.0523
51-Old River	0.7532	0.0502
52-Old River	0.6771	0.0493
53-Old River	0.5857	0.0500
54-Ship Channel at Lynchburg	0.5667	0.0513
55-Ship Channel	0.4916	0.0531
56-Goose Creek	0.2816	0.0734
57-Goose Creek	0.3057	0.0570
58-Cedar Bayou	0.2585	0.0897

WASP Segment	Existing Conditions ($pg\text{-}TEQ_6/L$)	No Sediment Scenario ($pg\text{-}TEQ_6/L$)
59-Cedar Bayou	0.2116	0.0462
60-Clear Creek	0.0695	0.0488
61-Ship Channel	0.4253	0.0493
62-Ship Channel	0.4236	0.0472
63-Ship Channel	0.3803	0.0452
64-Ship Channel	0.2703	0.0416
65-Ship Channel	0.2529	0.0406
66-Ship Channel	0.2582	0.0405
67-Ship Channel	0.2679	0.0404
68-Ship Channel	0.1686	0.0400
69-Ship Channel	0.1266	0.0401
70-Ship Channel	0.2899	0.0401
71-Ship Channel	0.2991	0.0403
72-Ship Channel	0.2691	0.0408
73-Ship Channel at Morgan's Point	0.2499	0.0412
74-Ship Channel	0.1255	0.0413
75-Ship Channel	0.1505	0.0438
76-Ship Channel	0.1188	0.0473
77-Ship Channel	0.0961	0.0510
78-Ship Channel d/s boundary	0.0787	0.0603
79-Burnett Bay	0.4230	0.0473
80-Scott Bay	0.2604	0.0406
81-San Jacinto Bay	0.3153	0.0388
82-Black Duck bay	0.2898	0.0393
83-Tabbs Bay	0.3525	0.0401
84-Tabbs Bay	0.3383	0.0407
85-Tabbs Bay	0.3220	0.0415
86-Barbours Cut	0.2534	0.0412
87-Galbay	0.2612	0.0422
88-Galbay	0.1769	0.0412
89-Galbay	0.1494	0.0431
90-Bayport Channel	0.1316	0.0462
91-Galbay	0.0866	0.0463
92-Galbay	0.1646	0.0471
93-Galbay	0.1285	0.0629
94-Galbay	0.1426	0.0500
95-Galbay	0.0860	0.0631
96-Galbay	0.0988	0.0532
97-Galbay	0.1040	0.0488
98-Galbay	0.1051	0.0457
99-Galbay	0.0956	0.0486
100-Galbay	0.0971	0.0446
101-Galbay	0.0909	0.0482
102-Galbay	0.0782	0.0576
103-Galbay	0.0803	0.0575
104-Galbay	0.0783	0.0634
105-Clear Lake	0.0941	0.0410
106-Galbay	0.1049	0.0600
107-Cedar Bayou	0.3049	0.0598
Average TEQ_6 (all reaches)	0.3564	0.0588

While the SJRWP was historically the largest and most well-known source of dioxin, other sediment sources of dioxin were suspected to exist. The number, precise location, composition, and origin of these suspected sediment sources remains unknown.

Regardless of its source, the dioxin appears to have been released in some areas and adsorbed in others. In general, it was released near the SJRWP and in Buffalo Bayou and then adsorbed or deposited along the SJR downstream of Lynchburg or in Galveston Bay.

The contaminated sediment throughout the HSC is a legacy of historical activities, including spills and previous improper disposal practices. In general, the total of ongoing sources (point sources, stormwater runoff, direct deposit of atmospheric dioxin and upstream tributaries) represents a small fraction of the load (14%) when compared to legacy sediment loads (86%) and are not sufficient to cause impairments of water quality in most cells. Since impairments are driven by sediment loads and would not occur in the absence of legacy sediment loads, they cannot be controlled by limiting the current ongoing maximum daily load of dioxin.

Current Status and Future Considerations

As previously mentioned, the EPA added the SJRWP site to the National Priority List of Superfund sites in 2008. The SJRWP site is one of EPA's highest priorities and the EPA's selected remedy to address contamination at the site was approved in 2017. The remedial design for the cleanup plan is currently being developed, and excavation of the waste material is projected to begin in the future.

While a TMDL is designed to limit ongoing loads from wastewater and stormwater-related sources, in this case the impairment is driven by legacy sediment loads such as dioxins, so a TMDL would not likely restore water quality.

There are currently other activities to address dioxins in this area. First, the seafood consumption advisories remain in place, and the TCEQ encourages everyone to follow the Texas Department of State Health Service's recommendations regarding fish consumption from this system for their safety. Second, the EPA has stringent dioxin-related technology-based effluent guidelines that reduce the potential for dioxins to be released from pulp and paper processes. And third, the TCEQ has helped fund fish tissue analysis for dioxins and other pollutants in the system and has an industrial discharge screening procedure in place for evaluating discharges that have the potential to discharge dioxins. In addition, sediment and water quality data continues to be collected by various entities and organizations to evaluate aquatic and biological conditions.

References

Burian, S. J., Shepherd, J.M. (2005). "Effect of Urbanization on the Diurnal Rainfall Pattern in Houston" Hydrological Processes. 19.5:1089-1103. March 2005.

DSHS (2010). Fish and Shellfish Consumption Advisory ADV-50. www.dshs.texas.gov/seafood/advisories-bans.aspx. Accessed March 2017.

DSHS (2013). Fish and Shellfish Consumption Advisory ADV-55. www.dshs.texas.gov/seafood/advisories-bans.aspx. Accessed March 2017.

DSHS (2019). Fish and Shellfish Consumption Advisory ADV-55 Modified in March 27, 2019. www.dshs.texas.gov/seafood/advisories-bans.aspx. Accessed April 2019.

Gillespie, W. J. (1994). "A Summary of Data Reflective of U. S. Pulp and Paper Industry Progress in Reducing the TCDD/TCDF Content of Effluents, Pulps and Wastewater Treatment Sludges." Organohalogen Compounds 20: 255-260.

H-GAC (Houston-Galveston Area Council) (2011). Classified LandSat 8 raster dataset "NOAA_Land_Cover_2011_22_Class" Retrieved January 2018 from ArcGIS Online.

Natural Resource Conservation Service-NRCS (1986). "Urban Hydrology for Small Watersheds." Technical Release 55. Conservation Engineering Division. June 1986.

University of Houston and Parsons (2005). Total Maximum Daily Loads for Dioxin in the Houston Ship Channel – Final Report, Work Order No. 582-0-80121-07. Prepared for the Texas Commission on Environmental Quality. Austin, TX, November 2005.

TNRCC (2000). Texas Administrative Code, Title 30, Environmental Quality, Part 1, Texas Commission on Environmental Quality, Chapter 307, Texas Water Quality Standards.

TCEQ (2014). Texas Administrative Code, Title 30, Environmental Quality, Part 1, Texas Commission on Environmental Quality, Chapter 307, Texas Water Quality Standards.

TCEQ (2018). Texas Administrative Code, Title 30, Environmental Quality, Part 1, Texas Commission on Environmental Quality, Chapter 307, Texas Water Quality Standards.

University of Houston and Parsons (2006). Total Maximum Daily Loads for Dioxin in the Houston Ship Channel – Quarterly Report No. 3, Work Order No. 582-6-70860-02. Prepared for the Texas Commission on Environmental Quality. Austin, TX, July 2006.

University of Houston and Parsons (2007). Total Maximum Daily Loads for Dioxin in the Houston Ship Channel – Final Report, Work Order No. 582-6-

70860-08. Prepared for the Texas Commission on Environmental Quality. Austin, TX, November 2007.

University of Houston and Parsons (2008a). Total Maximum Daily Loads for Dioxin in the Houston Ship Channel - Modeling Report/Quarterly Report No. 3 Revision 2, Work Order 582-6-70860-18. Prepared for the Texas Commission on Environmental Quality. Austin, TX, November 2008.

University of Houston and Parsons (2008b). Total Maximum Daily Loads for Dioxin in the Houston Ship Channel – Load Allocation Document Revision 4. Prepared for the Texas Commission on Environmental Quality. Austin, TX, November 2008.

U.S. Army Corps of Engineers-USACE (1985). Clear Creek Drainage Improvement Study. Bernard Johnson, Inc. August 1985.

US Army, Engineer Research and Development Center-ERDC (2005). User's Guide to RMA2 WES Version 4.5. Revised April 22, 2005.

USEPA (2000a). Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds. Volume 2: Sources of Dioxin-Like Compounds in the United States. Washington, D.C., Office of Research and Development.

USEPA (2000b). Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds. Volume 3: Properties, Environmental Levels, and Background Exposures. Washington, D.C., Office of Research and Development.

USEPA (2000c). Urbanized Area Maps for NPDES MS4 Phase II Stormwater Permits. www.epa.gov/npdes/urbanized-area-maps-npdes-ms4-phase-II-stormwater-permits, accessed 2/10/2017.

USEPA (2003). EPA Methodology Guidance, Volume 2. EPA-822-R-03-030. Washington, D.C., Office of Water

USEPA (2018). Site Status Update. San Jacinto River Waste Pits Superfund Site, Harris County, Texas. https://semspub.epa.gov/work/06/100009774.pdf Accessed August 2018

Wool, T.A., R.B. Ambrose, J.L. Martin, and E.A. Comer (2004). The water quality analysis simulation program (WASP) version 6.0: Draft User's Manual. Distributed by USEPA Region 4, Atlanta, Georgia.

Appendix A.
Toxic Equivalency Factors

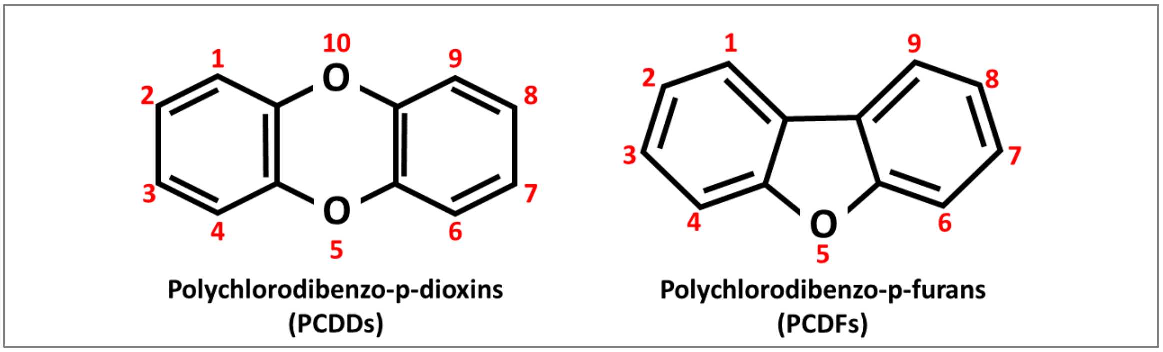


Figure A-1. Molecular Structure of Polychlorodibenzo-p-dioxins and Polychlorinated Dibenzofurans

Two or more chlorine atoms are substituted for hydrogen somewhere in positions 1-4, and two or more chlorine atoms are substituted somewhere in positions 6-9. Positions 5 and 10 are always oxygen.

Polychlorodibenzo-p-dioxins consist of two benzo rings linked by oxygen bridges, with two or more chlorine atoms substituted for hydrogen atoms in each benzo ring. Polychlorodibenzo-furans are a similar family of molecules, but each molecule only contains one oxygen bridge. Together, these form a family of 210 closely related molecules each of which is called a congener.

However, of the 210 congeners, only 12 congeners have high TEFs, and only six are present in significant quantity to contribute more than 1% of the toxic load:

- 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD)
- 1,2,3,7,8-pentachlorodibenzo-p-dioxin (1,2,3,7,8-PeCDD)
- 1,2,3,6,7,8-hexachlorodibenzo-p-dioxin (1,2,3,6,7,8-HxCDD)
- 2,3,7,8-tetrachlorodibenzofuran (2,3,7,8-TCDF)
- 2,3,4,7,8-pentachlorodibenzofuran (2,3,4,7,8-PeCDF)
- 1,2,3,6,7,8-hexachlorodibenzofuran (1,2,3,6,7,8-HxCDF)

Table A-1. Texas Toxic Equivalency Factors (TNRCC 2000)

Compound	Name	TEF
2,3,7,8-TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin	1
1,2,3,7,8-PeCDD	1,2,3,7,8-pentachlorodibenzo-p-dioxin	0.5
1,2,3,4,7,8-HxCDD	1,2,3,4,7,8-hexachlorodibenzo-p-dioxin	0.1
1,2,3,6,7,8-HxCDD	1,2,3,6,7,8-hexachlorodibenzo-p-dioxin	0.1
1,2,3,7,8,9-HxCDD	1,2,3,7,8,9-hexachlorodibenzo-p-dioxin	0.1
1,2,3,4,6,7,8-HpCDD	1,2,3,4,6,7,8-hexachlorodibenzo-p-dioxin	NA (0.01)
OCDD	octachlorodibenzo-p-dioxin	NA (0.0001)
2,3,7,8-TCDF	2,3,7,8-tetrachlorodibenzofuran	0.1
1,2,3,7,8-PeCDF	1,2,3,7,8-pentachlorodibenzofuran	0.05
2,3,4,7,8-PeCDF	2,3,4,7,8-pentachlorodibenzofuran	0.5
1,2,3,4,7,8-HxCDF	1,2,3,4,7,8-hexachlorodibenzofuran	0.1
1,2,3,6,7,8-HxCDF	1,2,3,6,7,8-hexachlorodibenzofuran	0.1
1,2,3,7,8,9-HxCDF	1,2,3,7,8,9-hexachlorodibenzofuran	0.1
2,3,4,6,7,8-HxCDF	2,3,4,6,7,8-hexachlorodibenzofuran	0.1
1,2,3,4,6,7,8-HpCDF	1,2,3,4,6,7,8-heptachlorodibenzofuran	NA (0.01)
1,2,3,4,7,8,9-HpCDF	1,2,3,4,7,8,9-heptachlorodibenzofuran	NA (0.01)
OCDF	octachlorodibenzofuran	NA (0.0001)

NA = not applicable, the Texas standards do not have a specified TEF for this congener. For reference, the number in parentheses corresponds to the TEF assigned in the 1998 World Health Organization scheme.

Appendix B.
Model Calibration

Mass balance Spreadsheet

The spreadsheet was used to calibrate the model and to derive estimates of the effect of sediment-source dioxins on water column concentration, which cannot be directly measured.

First, the model was calibrated with observations to determine the load in each mass balance compartment, and then all known loads were subtracted to obtain the sediment load. The spreadsheet provides estimates of sources of the six selected congeners to the HSC by mass balance compartment and compares them to modeled in-stream loads. The model system (RMA2 + WASP) integrates the basic dioxin conceptual equation across time and space, while incorporating transport and other physical phenomena that affect water quality. The summary spreadsheet organizes the model results into long-term averages. Stated as an illustrative "equation," the model predicts:

Equation 1

> Water quality = function of (flow, physical processes, point source load, runoff load, direct deposition load, upstream/downstream load, sediment load)

Or, in shorter form:

WQ = f(Q, PP, PS, RO, DD, U/S, Sed)

Where:

WQ = water quality
Q = flow (mass movement of water)
PP = physical processes (e.g., settling, resuspension, decay)
PS = point source loading
RO = watershed runoff loading
DD = atmospheric deposition directly onto water surfaces
U/S = upstream loading from headwaters or tributaries
Sed = sediment source loading of dioxin

In Equation 1, *Sed* represents the effect of sediment-source loading on predicted water column concentrations, which was the only loading source that could not be estimated from direct measurements. Running the model does require specification of the initial bed sediment concentrations; those were established based on field data and through the model calibration process.

The mass balance spreadsheet takes input from RMA2 and WASP7 and calculates loads for the entire simulation period in 30-minute time steps. The spreadsheet was structured to calculate fluxes of dioxin across each interface for a given mass balance compartment. Figure B-1 shows the conceptual model for a generic mass balance compartment.

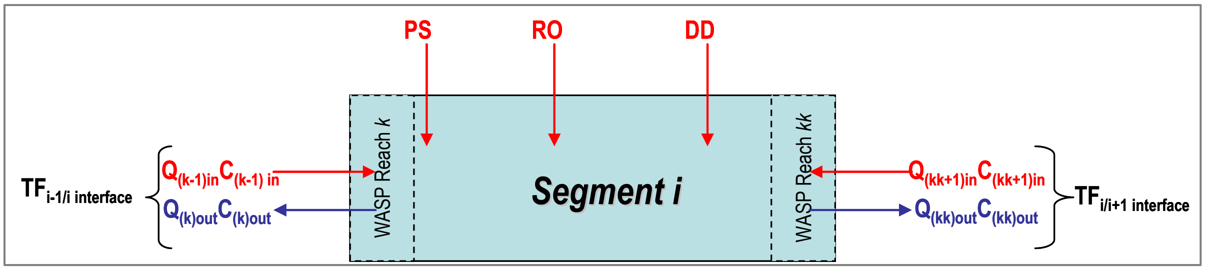


Figure B-1. Conceptual Model of the Mass Balance Spreadsheet

The conceptual basic equation for the spreadsheet summary of model results is:

Equation 2

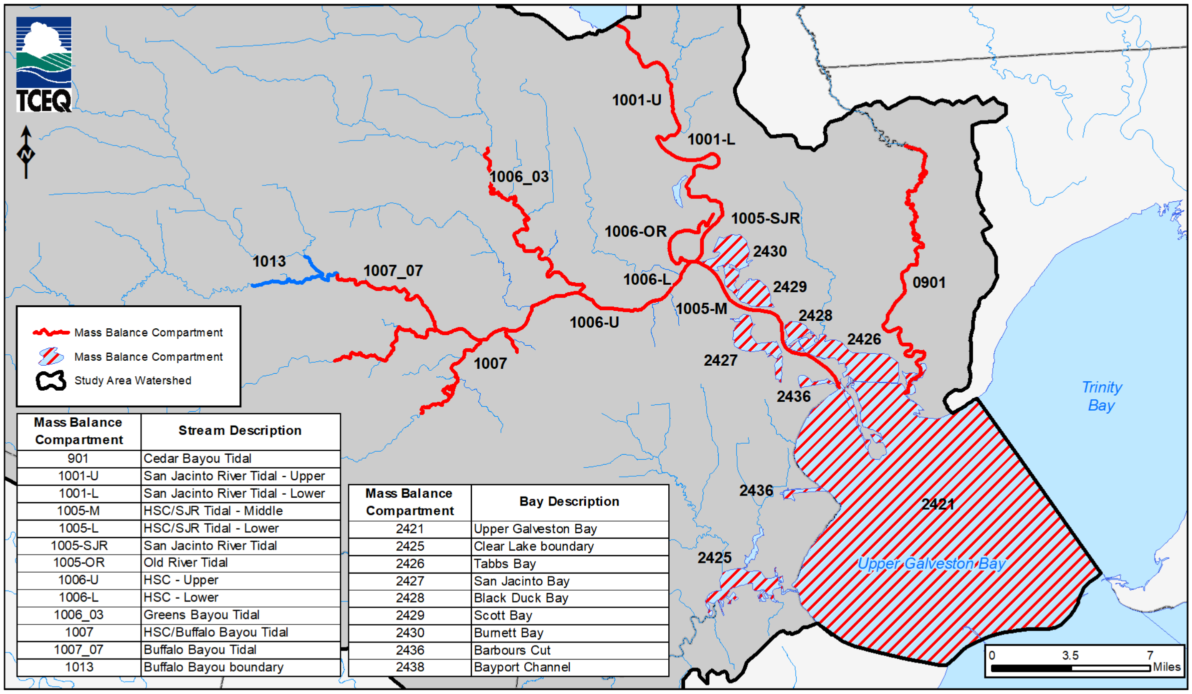
$$PS + RO + DD + U/S + \Sigma(Q_{in} * C_i) \pm dS = \text{net load} = \Sigma(Q_{out} * C_{average})$$

Where:

Q = flow (mass movement of water) in or out of model compartment
C = concentration of dioxin carried by flow
PS = point source loading directly to model compartment
RO = watershed runoff loading directly to model compartment
DD = atmospheric deposition directly onto model compartment surface
U/S = load from tributaries that join model at compartment
dS = net change in concentration (and thus load) within the model compartment
i = identifies model compartment (k and kk identify adjoining model compartments)

The mass balance spreadsheet predicts water quality as a function of loads, flows, transport, settling / resuspension, etc. In the “base case” model scenario, water quality in the form of “net load” was from observations. Loading from point sources, runoff, and direct deposition, plus flows, transport, and settling / resuspension, were predetermined based on project data as used for model calibration.

In the spreadsheet, the HSC was divided into 22 intercommunicated mass balance compartments as shown in Figure B-2. In some cases, the mass balance compartments correspond to more than one AU, so the estimated allocation was the overall load for that particular group of assessment units. A detailed description of the connections among mass balance compartments was presented in the modeling report (University of Houston and Parsons 2008a).



Mass Balance Compartment	Stream Description
901	Cedar Bayou Tidal
1001-U	San Jacinto River Tidal - Upper
1001-L	San Jacinto River Tidal - Lower
1005-M	HSC/SJR Tidal - Middle
1005-L	HSC/SJR Tidal - Lower
1005-SJR	San Jacinto River Tidal
1005-OR	Old River Tidal
1006-U	HSC - Upper
1006-L	HSC - Lower
1006_03	Greens Bayou Tidal
1007	HSC/Buffalo Bayou Tidal
1007_07	Buffalo Bayou Tidal
1013	Buffalo Bayou boundary

Mass Balance Compartment	Bay Description
2421	Upper Galveston Bay
2425	Clear Lake boundary
2426	Tabbs Bay
2427	San Jacinto Bay
2428	Black Duck Bay
2429	Scott Bay
2430	Burnett Bay
2436	Barbours Cut
2438	Bayport Channel

Figure B-2. Mass Balance Compartments

The water body known as Old River has not been formally assigned to an assessment unit. Formally, it is part of AU 1005_01, which consists of both a section of the San Jacinto River and Old River. Because they are hydrologically different, the San Jacinto River section is designated 1005-SJR, and the Old River is designated 1005-OR.

Compartment 1013 (Buffalo Bayou Tidal, which discharges to the HSC AU 1007_07) and compartment 2425 (Clear Lake, which discharges to Galveston Bay 2421) are part of the model domain, but they were not deemed impaired when these analyses were performed. However, the watershed and direct loading that entered and passed through those compartments in the model simulations will be accounted as external "headwater" or "upper boundary" gross loads in the allocations described hereafter.

For this study, "Gross Load" refers to the loadings that enter the mass balance compartment from any external source, before any loss or assimilation. "Net Load" refers to the load that exits the compartment in any direction. The concentration component of net load should be compared to 0.0776 pg TEQ_6/L.

For the load analysis, the dS term in Equation 3 below was used to estimate the sediment loading effect. In the equation WQ = f(Q, PP, PS, RO, DD, U/S, Sed), all terms except Sed are "known" and the summary spreadsheet was used to determine sediment loading using the following.

Equation 3

$$dS = \Sigma(Q_{out} * C_{average}) - [PS + RO + DD + U/S + \Sigma(Q_{in} * C)]$$

When dS is positive, sediment resuspension or transport are net sources of dioxin entering the water column. When dS is negative, sediment is a net sink (water column dioxin adsorbs to the sediment).

Transported sediment that accumulates due to channel hydraulic factors may be seen as a source in this analysis, so the model compartments indicated to have sediment sources may not be the origin of the contaminated sediment. Because the channel is tidal and subject to back-and-forth flow, some transported load crossed and re-crossed model compartment lines and was “counted” more than once in summarizing the model. There was no discernible way to avoid that effect in the spreadsheet summaries, but the extent to which it happens makes the analysis more protective by overestimating sediment loading. The conclusion from the analytical mode of model use was that sediment was a significant source of dioxin loading that affects water column concentrations, and by extension affects tissue concentrations as well.

Individual flux spreadsheets were developed for the six congeners modeled in WASP and the results were included in the modeling report (University of Houston and Parsons 2008). However, given that the water quality standard for dioxins in Texas was in terms of TEQ and there are no standards defined for individual congeners, it was necessary to combine the values from the individual spreadsheets into a single TEQ_6 mass balance. This was accomplished by adding the columns from the various spreadsheets, weighted by the respective toxic equivalency factor (TEF). Table 12 presents the summary of the TEQ mass balance spreadsheet.

Calibration of Model

First, the model was calibrated to reproduce observations, then it was used to estimate sediment loads. The model analysis indicates that when the sediment loads are eliminated (i.e. point sources, runoff, and direct deposition are the only modeled sources of dioxin to the HSC and upper Galveston Bay), the concentration profiles for 2,3,7,8-TCDD, 2,3,7,8-TCDF, and 2,3,4,7,8-PeCDF changed substantially. The concentration profiles for 1,2,3,7,8-PeCDD and 1,2,3,6,7,8-HxCDD, on the other hand, were dominated by boundary conditions. The profile for 1,2,3,6,7,8-HxCDF showed the greatest change when all the external loads were removed (only sediment loads were kept).

The total sediment associated dioxin load into the system (sum of positive dS values) was calculated to be 19,517,671 ng-TEQ_6/d, which corresponds to 86% of the TEQ_6 load into the system. Settling caused 12,315,933 ng-TEQ_6/d (sum of negative dS values) of the sediment associated dioxin load to redeposit within the model realm during the simulation period. Therefore, 7,201,739 ng-TEQ_6/d (the total net sediment load) are transported between model compartments as sediment, as a daily average over the model period. Sediment transports about 69.7% of the average daily dioxin flux among the model compartments. The summary values cited in this paragraph correspond to the TEQ generated by the six major congeners.

A complete set of modeling sensitivity tests are shown in Appendix C and discussed in the modeling report (University of Houston and Parsons 2008a).

Appendix C.
Model Sensitivity Results by Congener

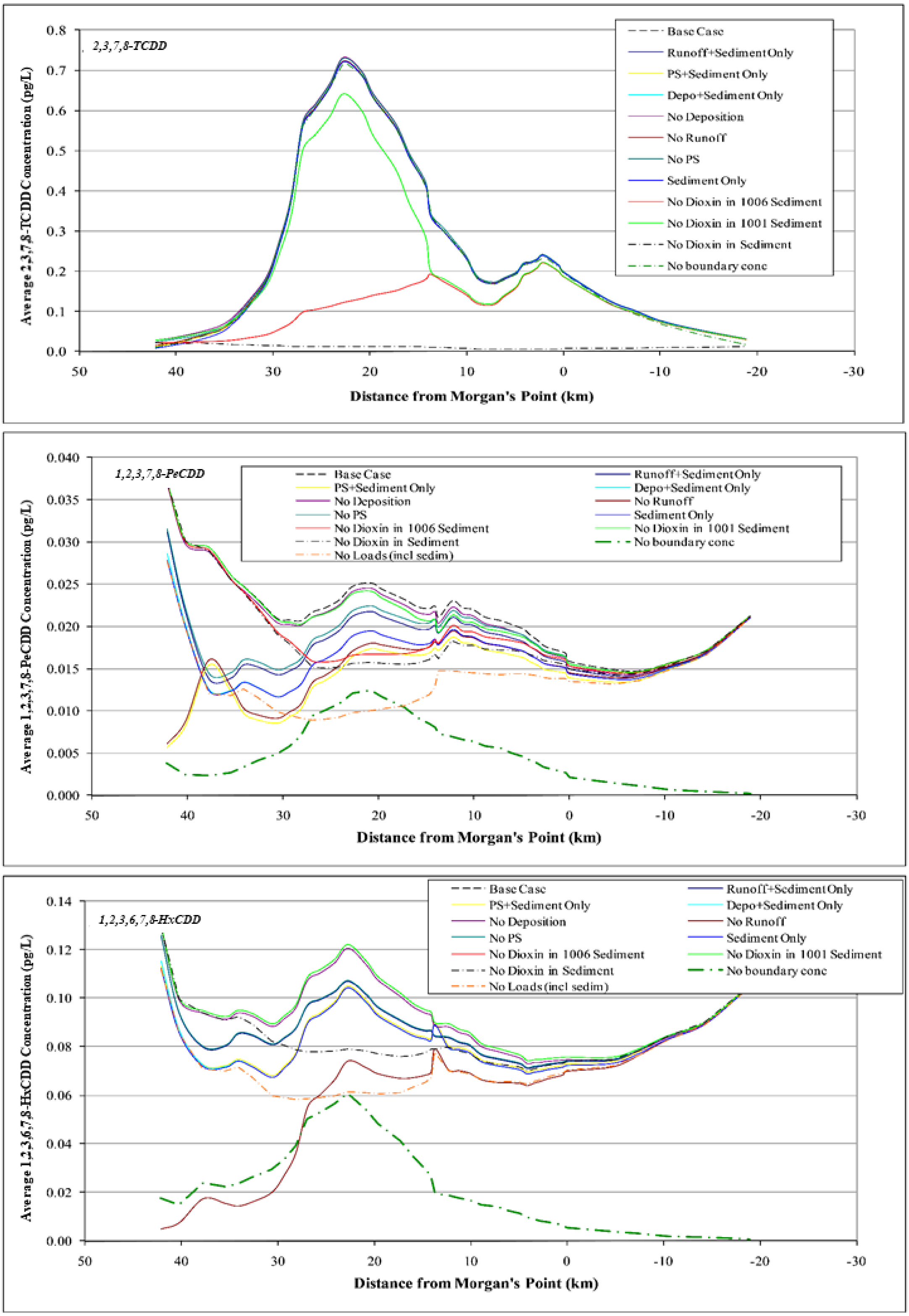


Figure C-1. HSC PCDD Sensitivity Runs by Congener

Note each graph is scaled differently

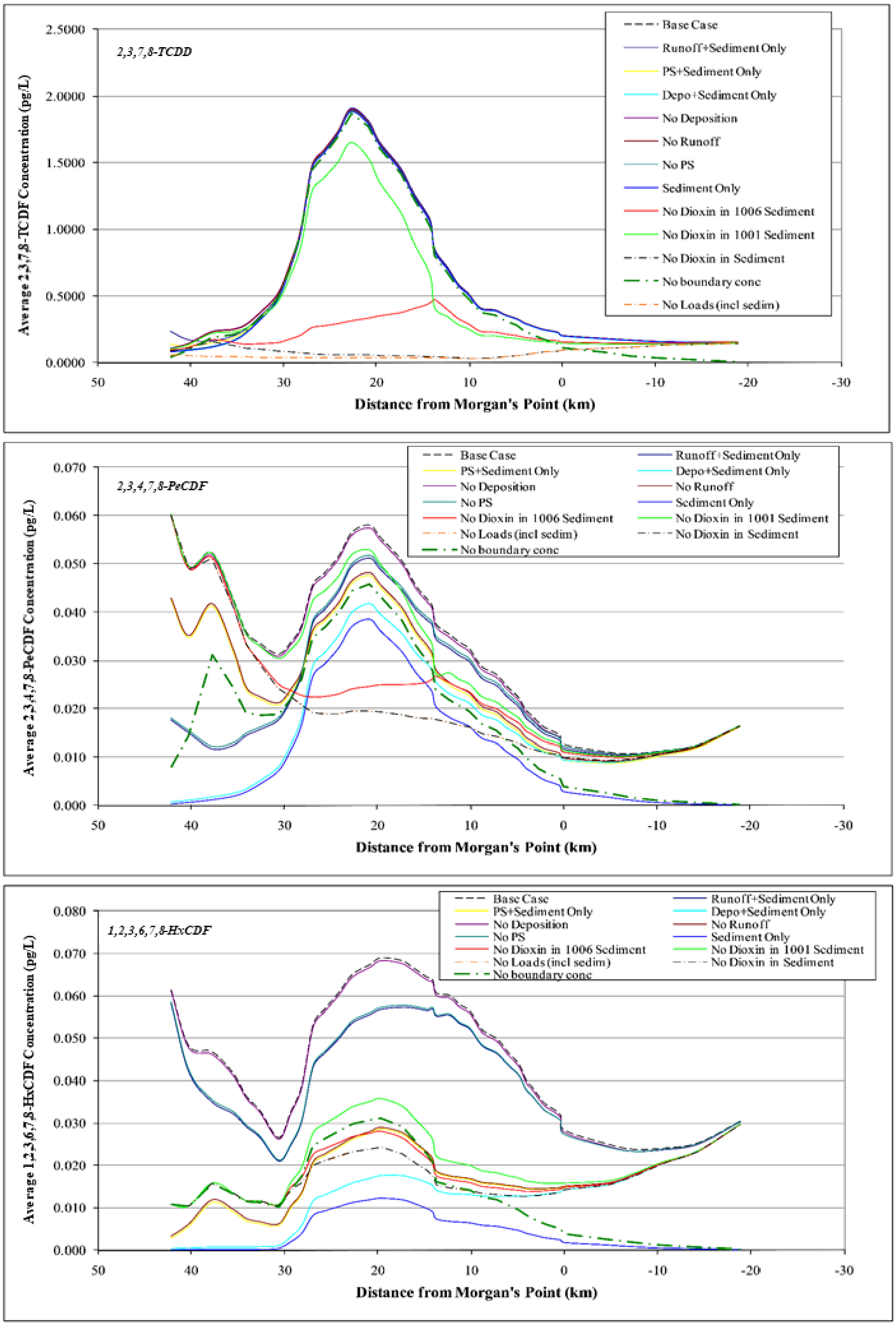


Figure C-2. HSC PCDF Sensitivity Runs by Congener

Note each graph is scaled differently.

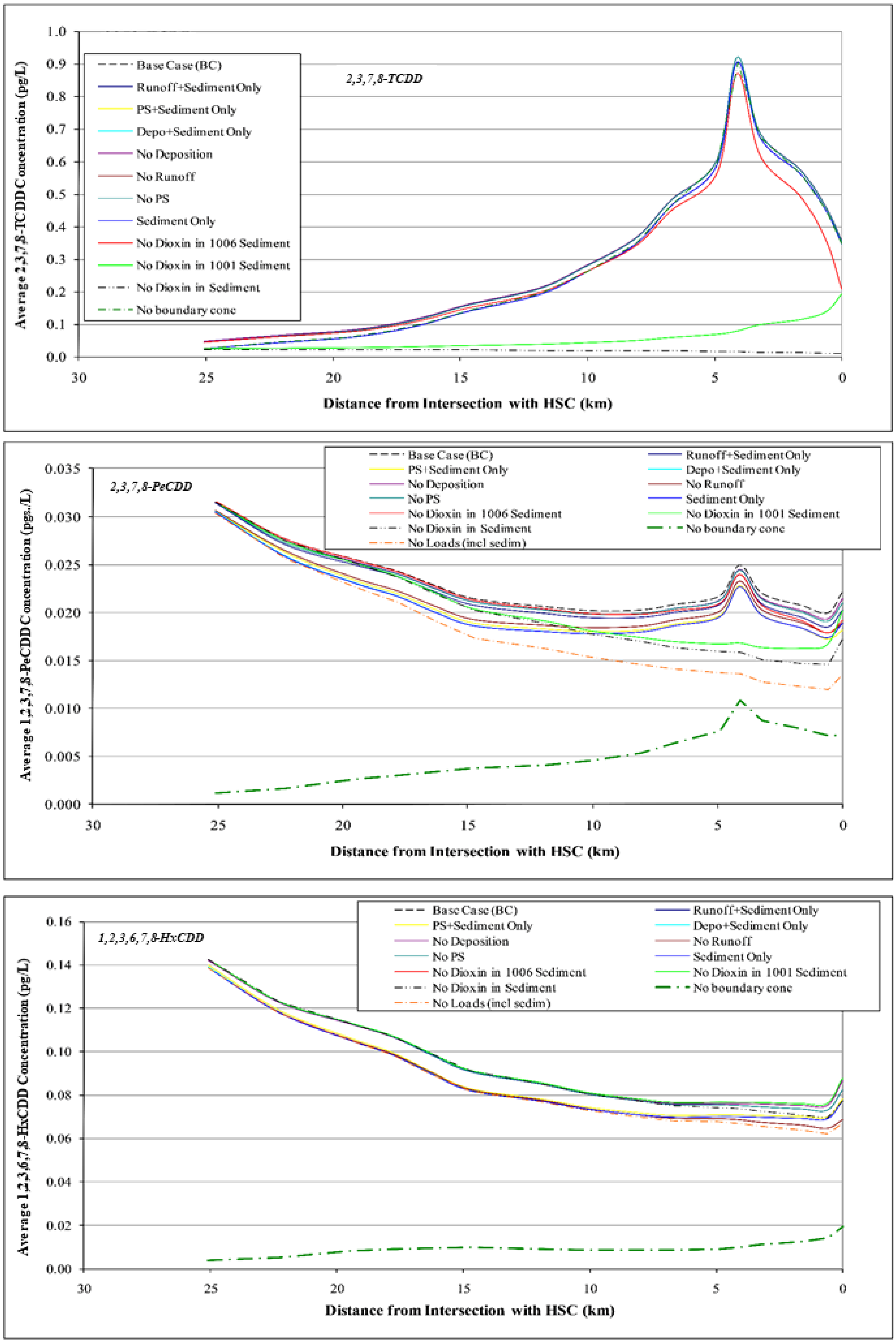


Figure C-3. SJR PCDD Sensitivity Runs by Congener

Note each graph is scaled differently.

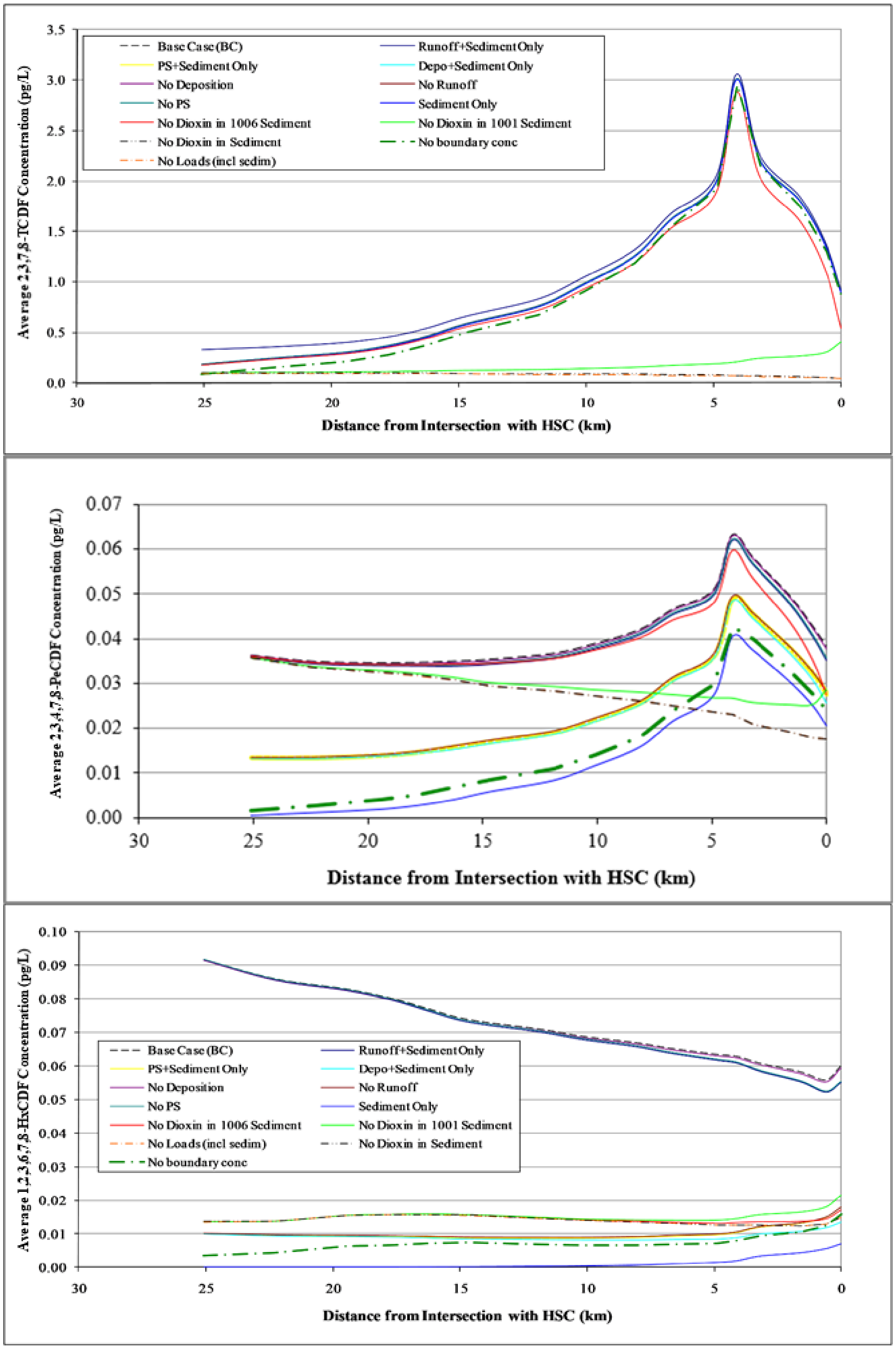


Figure C-4. SJR PCDF Sensitivity Runs by Congener

Note each graph is scaled differently.