Total Maximum Daily Loads for Dioxins

in the Houston Ship Channel

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UNIT SYMBOLS, ABBREVIATIONS, AND CONVERSIONS

Symbol or abbreviation	Text	**Unit Equivalence**	**Unit Type**
^{o}C	degrees celcius		temperature
kg	kilograms	10^{3} grams	mass
g	grams	454 grams ~ 1 pound	mass
mg	milligrams	10^{-3} grams	mass
µg	micrograms	10^{-6} grams	mass
ng	nanograms	10^{-9} grams	mass
pg	picograms	10^{-12} grams	mass
fg	femtograms	10^{-15} grams	mass
L	liter	3.78 liters ~ 1 gallon	volume
mL	milliliter	10^{-3} liters	volume
mBq	millibecquerel	27 microcuries (mCi)	radioactivity
µg/L	micrograms per liter	~10^{-9}, or 1 ppb	mass/volume concentration
ng/L	nanograms per liter	~10^{-12}, or 1 ppt	mass/volume concentration
pg/L	picograms per liter	~10^{-15}, or 1 ppq	mass/volume concentration
ng/kg	nanograms per kilogram	=10^{-12}, or 1 ppt	mass/mass concentration
mg/g	milligrams per gram	10^{-3}	mass/mass concentrations
g/cm^2	gram per square centimeter		cumulative mass
mBq/g	millibecquerel per gram		radioactivity
ppm	parts per million	10^{-6}	unitless concentration
ppb	parts per billion	10^{-9}	unitless concentration
ppt	parts per trillion	10^{-12}	unitless concentration
ppq	parts per quadrillion	10^{-15}	unitless concentration

EXECUTIVE SUMMARY

This document is the Final Report for Work Order No. 582-0-80121-07 issued by the Texas Commission on Environmental Quality (TCEQ) for the Total Maximum Daily Loads for Dioxin in the Houston Ship Channel. This report summarizes the activities and results of the project for the period September 1, 2003 to August 31, 2005.

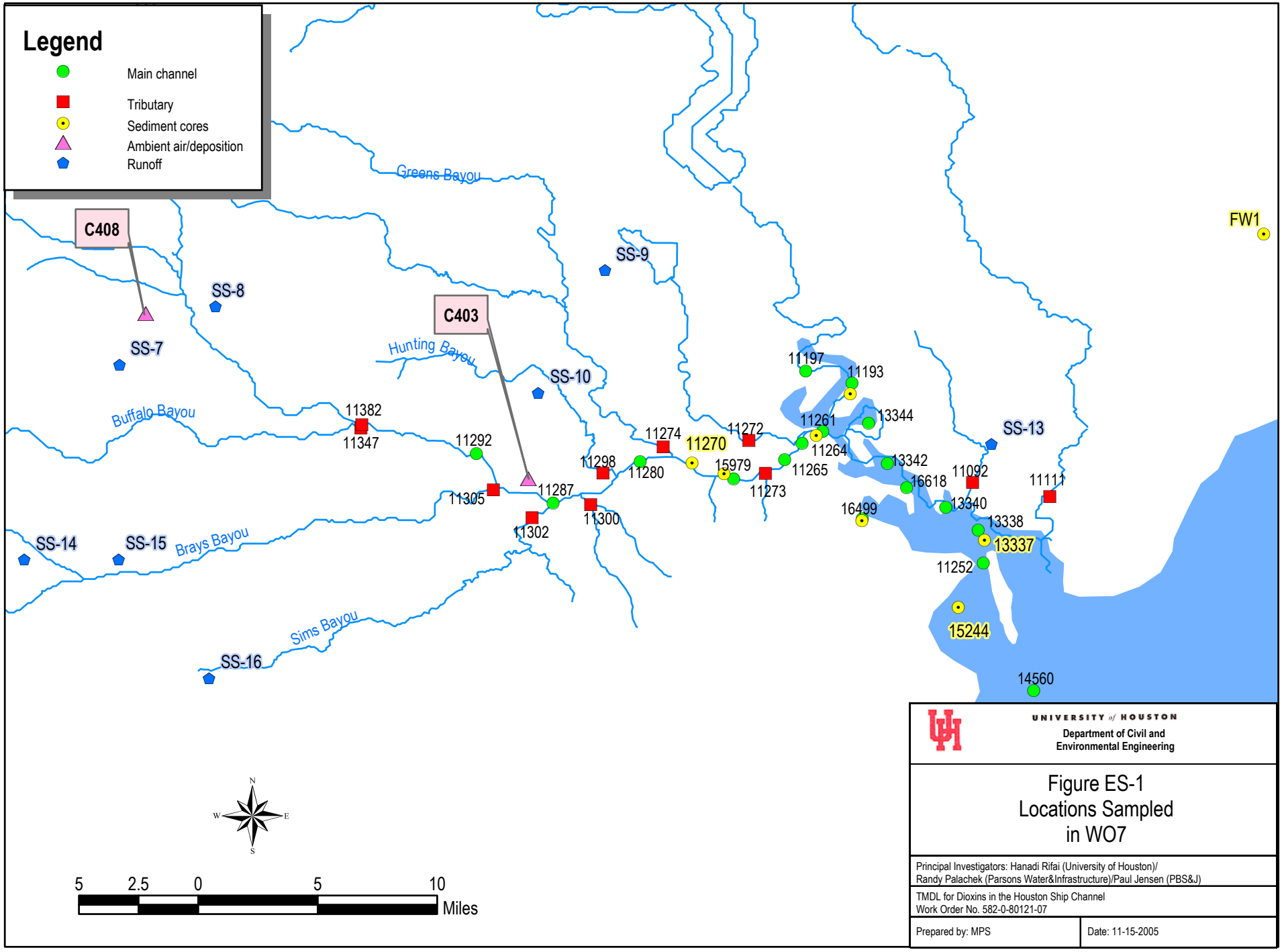
Polychlorinated dibenzo-*p*-dioxins and dibenzofurans (dioxin) are extremely persistent in the environment, and can affect human health at low concentrations. As a result of dioxin found in seafood organism tissue, a seafood consumption advisory for catfish and blue crabs was issued by the Texas Department of Health in September 1990 for the upper portion of Galveston Bay and the Houston Ship Channel (HSC). The HSC system was subsequently placed on the §303(d) list and a TMDL study was initiated by the TCEQ. Segments placed on the §303(d) list include the San Jacinto River Tidal (Segment 1001), Houston Ship Channel (Segments 1005, 1006, 1007), Tabbs Bay (Segment 2426), San Jacinto Bay (Segment 2427), Black Duck Bay (Segment 2428), Scott Bay (Segment 2429), Burnett Bay (Segment 2430), and Barbours Cut (Segment 2436). In addition, Upper Galveston Bay (Segment 2421), Segment 2438 (Bayport Channel), and Segment 901 (Cedar Bayou Tidal) were included in the §303(d) list and are part of this TMDL study, even though they are not part of the HSC system.

The overall purpose of this project is to develop a TMDL for dioxin in the Houston Ship Channel System, including upper Galveston Bay, and a plan for managing dioxins to correct existing water quality impairments and maintain good water quality in the future. The project also includes an assessment of existing PCB levels in the channel to determine the scope and nature of PCB impairment.

MONITORING AND DATA COLLECTION

The monitoring and data collection task encompassed two main subtasks: (*i*) monitoring and data collection to assess current levels of dioxins in the HSC, and (*ii*) sampling to evaluate sources of dioxins to the HSC system. Water, sediment and tissue were sampled during four "major" sampling events during the reporting period (Spring 2004, Summer 2004, Fall 2004, and Summer 2005). In addition, continuous air/deposition, sediment core, and runoff sampling were conducted. Figure ES-1 shows the sampling locations.

Monitoring conducted as part of Work Order 7 yielded a total of 71 in-stream water samples, 98 sediment samples, 53 catfish tissue samples, 47 crab tissue samples, 106 sediment core samples, 8 runoff samples, 41 soil samples, 18 ambient air samples, 13 dry deposition samples, 3 wet deposition samples, 2 bulk deposition samples, and 21 particulate air samples.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Sediment cores
Ambient air/deposition
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Greens Bayou
Hunting Bayou
Buffalo Bayou
Brays Bayou
Sims Bayou
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C403
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SS-8
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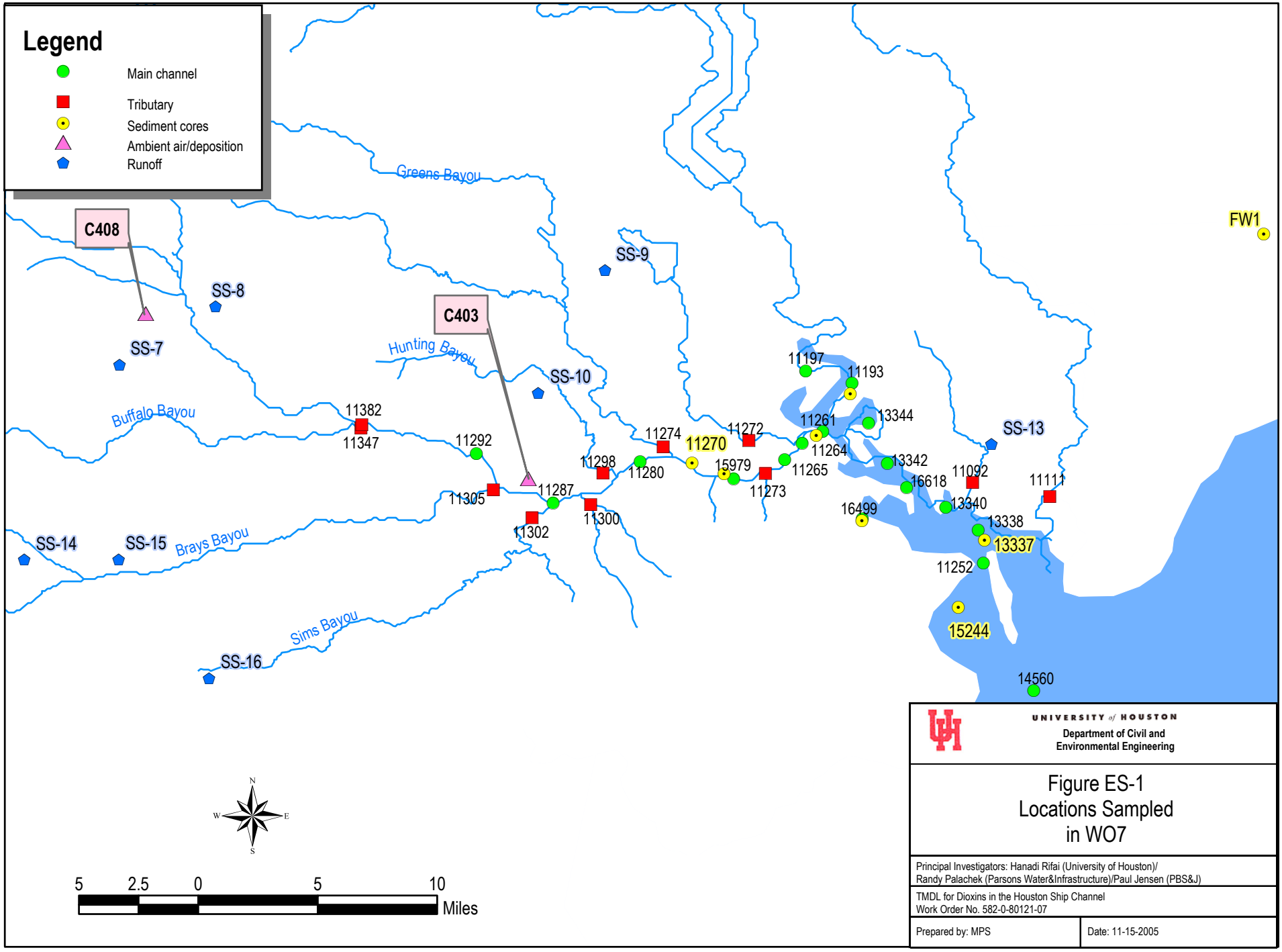
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure ES-1
Locations Sampled in WO7
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07
Prepared by: MPS
Date: 11-15-2005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UNIVERSITY of HOUSTON
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Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)
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Assessment of Current Levels of Dioxins in the HSC

Water, sediment, catfish, and crab were sampled at 17 in-channel locations to determine the levels of dioxins in the HSC. Tissue was also sampled at 11 tributary locations to aid in the development of bioaccumulation factors. In addition, eight sediment cores were collected to complete geochronology and dioxin analyses. Overall, measurable levels of dioxins were found in most of the samples collected in WO7. Table ES-1 provides a summary of the measured levels of 2378-TCDD (the most toxic congener) and of Total TEQ by sampling event and media. The observed dioxin concentrations were generally high as indicated by the high percent of exceedances of the health-based standards shown in Table ES-1.

Table ES-1 Summary of Dioxin Concentrations by Media

Media	Event	2378-TCDD		Total TEQ		
		Range	Average	Range	Average	Percent Exceeding[a]
Water (pg/L)	Spring 2004	<0.03-1.1	0.329	0.089-1.252	0.409	94% *(17)*
	Fall 2004	<0.026-0.603	0.238	0.075-0.877	0.34	94% *(17)*
Sediment[b] (ng/kg)	Spring 2004	0.64-330	25.97	0.92-451.4	42.70	-
	Summer 2004	<4.3-60	14.19	8.06-55.1	22.57	-
	Fall 2004	<0.36-650	47.51	0.49-846.3	68.80	-
Catfish (ng/kg)	Spring 2004	<0.11-21	5.09	0.19-19.6	5.68	96% *(28)*
	Fall 2004	0.63-26	9.01	0.93-27.2	9.39	100% *(17)*
Crab (ng/kg)	Spring 2004	<0.18-6.20	2.57	0.37-8.61	3.32	96% *(26)*
	Fall 2004	0.86-12	5.83	1.32-12.08	6.93	100% *(17)*
Sediment cores (ng/kg)	-	<0.16-190	12.66	0.27-238.99	18.20	-

[a] Percent of samples that exceed either the WQS (0.0933 pg/L) or the TDH screening value (0.47 ng/kg). The numbers in parentheses correspond to the number of samples collected for each event.
[b] Results for the Summer 2005 event are not available as of this writing.

In-channel sampling showed that OCDD is the major contributor to the total dioxin concentration (the sum of the seventeen 2378-substituted congeners) in water, sediment, and catfish samples from the HSC, while 2378-TCDF is the major contributor in crab samples. However, 2378-TCDD is the major contributor to total TEQ in all cases with average contributions of 47%, 49%, 80%, and 68% for water, sediment, catfish, and crab samples, respectively.

Results from deep and shallow water samples collected simultaneously (Summer 2004 event) showed that deep concentrations were generally higher than shallow concentrations, with average deep/shallow ratios of up to 1.69 and 1.54 for locations 11193 and 15979, respectively

(maximum ratios were 2.85 and 2.67, respectively). An analysis of fugacity ratios suggested a lack of equilibrium at the suspended-dissolved and sediment-dissolved interfaces for most of the congeners. Data indicate that 2378-TCDD is close to equilibrium between the bottom sediments and the dissolved phase (deep) at location 15979, whereas a bottom sediment–> dissolved flux is expected at location 11193. For almost all the remaining congeners, ratios lower than 1 were measured for the dissolved-suspended interface indicating flux of dioxins from the dissolved phase to the suspended phase. For the bottom sediment-dissolved interface, on the other hand, ratios greater than 1 were measured for some PCDFs and ratios lower than 1 for the higher chlorinated PCDDs.

High-resolution sediment sampling was conducted in Summer 2004 to pinpoint the location of unidentified major sources near stations 15979 and 11193. While dioxin results for samples collected along segments 1006 and 1007 did not show a marked "high-spot," both 2378-TCDD and TEQ levels at a station 1 km upstream of location 11193 were significantly higher than those observed at the remaining locations in segment 1001, which might suggest the presence of an unidentified source of 2378-TCDD. This finding prompted additional high-resolution sediment sampling at the bend in San Jacinto River during Summer 2005.

Geochronology analyses performed on 7 sediment cores yielded sedimentation rates between 0.14±0.08 and 113.10±87.08 cm/yr. The longest time coverage of the sediment cores was about 150 years. Vertical distribution of dioxin concentrations in the collected cores versus the estimated year of deposition showed surprisingly that the oldest interval concentrations appeared to be as high or slightly higher than those measured in the surface intervals. This could indicate the presence of other sources prior to the construction of the HSC.

Assessment of Major Sources of Dioxins in the HSC

To aid in the assessment of major sources of dioxin to the HSC, water samples were collected at the mouths of 11 major tributaries, ambient air and deposition sampling was conducted at two locations, and stormwater runoff was sampled at 8 locations. A summary of the dioxin results for sampling conducted under this task is presented in Table ES-2.

Results from the ambient air samples showed that 2378-TCDD was mainly present in the vapor phase with little to no presence in the particle phase. The major contributors to total TEQ in ambient air were found to be 23478-PeCDF (32%) and 12378-PeCDD (23%). The congener 2378-TCDD contributed up to 20% of the total TEQ in ambient air. Regarding dry deposition, none of the lower chlorinated congeners were detected. The higher chlorinated congeners, 1234678-HpCDD, OCDD, 1234678-HpCDF, and OCDF were consistently detected.

Table ES-2 Summary of Dioxin Results for Source Assessment

Media	Event	2378-TCDD		Total TEQ		
		Range	Average	Range	Average	Percent Exceeding[a]
Water-tributaries (pg/L)	Spring 2004	<0.005-0.603	0.136	0.044-1.824	0.389	82% *(11)*
	Fall 2004	<0.015-0.427	0.082	0.069-1.43	0.332	73% *(11)*
Ambient air (fg/m^3)	All	<0.6-1.6	1.0	6.0-21.0	13.7	-
Wet deposition ($pg/m^2/day$)	All	<0.4-<4.0	-	9.9-14.4	[b]	-
Dry deposition ($pg/m^2/day$)	All	<0.2-<2	-	1.33-3.58	2.42	-
Runoff (pg/L)	-	<0.006-<0.81	-	0.019-0.491	0.255	88% *(8)*

[a] Percent of samples that exceed the WQS (0.0933 pg/L). The numbers in parentheses correspond to the number of samples collected for each event.
[b] Only two samples were collected.

The wet deposition dioxin profiles were dominated by the higher chlorinated congeners (hexas to octas) but lower chlorinated compounds were also detected. It is noted that 2378-TCDF, a compound existing predominantly in the vapor phase, was detected in rain at a concentration of 99 fg/L. These results show that rain, while intermittent, is an important process that removes dioxins from the atmosphere.

Dioxin concentrations measured in runoff were at or below the levels measured in the in-stream water of the HSC. The dissolved and suspended dioxin profiles in runoff samples were dominated by the higher chlorinated congeners OCDD, 1234678-HpCDD, and OCDF. 2378-TCDD was detected only in the suspended phase (1- and 40-μm filters). It was noted that approximately between 78 and 96% of the total dioxin mass in runoff was associated with the particulate phase. This characteristic is similar to the distribution of the dioxin congeners in the particle and gas phases in the ambient air, where over 70% of the total dioxin mass detected was bound to atmospheric particles. A comparison between the 1- and 40-μm suspended phase samples showed that with a few exceptions, the total mass was mainly bound to fine particles (<1 μm). Particles in the size range <2.5 μm are known to be the result of anthropogenic activities such as diesel-fueled vehicle emissions.

SITE-SPECIFIC BIOACCUMULATION FACTORS AND WATER QUALITY TARGETS

Measurements of dioxin concentrations in various media allowed the determination of site-specific partitioning relationships. These partitioning relationships are important not only to develop the model to support load allocations, but also to establish an appropriate water quality target for the TMDL, to allow for economical long-term monitoring of continuing progress toward the water quality target, and to facilitate implementation of the TMDL through water quality permitting. A summary of bioaccumulation factors (BAFs) and biota-to sediment accumulation factors (BSAFs) for congeners contributing more than 2% to the total TEQ in tissue is provided in Table ES-3. It is noted that the site-specific BAFs are in all cases significantly higher that the average bioconcentration factor (BCF) of 5,000 L/kg used by the state of Texas in the calculation of the dioxin WQS.

Table ES-3 Summary of Site-specific BAFs and BSAFs

Congener	BAF	BSAF
2378-TCDD	154,882	0.0089
12378-PeCDD	60,256	0.0033
2378-TCDF	29,512	0.0034
23478-PeCDF	39,811	0.0027

For each congener, the higher of the catfish and crab factors was selected.

The estimation of congener-specific bioaccumulation factors (BAFs) using all the sampling data from this project yielded water quality targets for 2378-TCDD and TEQ of 0.011 and 0.070 pg/L, respectively (see Table ES-4 for a summary of congener-specific targets). The calculated target for dioxin TEQ in water is approximately 75% of the state water quality criterion of 0.0933 pg/L. Sediment quality targets calculated using site-specific BSAFs were estimated to be 43 and 115 ng/kg-oc for 2378-TCDD and TEQ, respectively. A comparison of sampling data to the estimated water quality targets showed exceedance rates greater than 90%. It appeared that an 85-90% reduction in concentrations, or one order of magnitude would be required for the water quality targets to be met.

Table ES-4 Summary of Site-Specific Water Quality Targets in Various Media

Congener	Water – Dissolved pg/L	Water - Total pg/L	Sediment ng/kg-OC
2378-TCDD	0.0024	0.011	43
12378-PeCDD	0.0007	0.016	13
2378-TCDF	0.0207	0.087	182
23478-PeCDF	0.0015	0.010	23
Total TEQ	0.0081	0.070	115

For each congener, the lower target for the two species (catfish or crab) was selected.

DATA ANALYSIS

Spatial Trends

Longitudinal profiles of TEQ concentrations along the HSC were fairly consistent for all the events conducted in both Work Order 4 (WO4) and WO7: the water concentrations start relatively low, they then increase until reaching the highest dioxin concentration and then concentrations decrease downstream towards Galveston Bay. For all the events, the profiles showed peak TEQ concentrations in segment 1006 (at location 15979) and most of the side bays and tributaries are at or above the levels observed in the main channel at the confluence segments. In addition, the dioxin concentration at station 11193 in the San Jacinto River (segment 1001) was higher than those measured at the confluence with the main channel and higher than that measured at station 15979. The only discrepancy was observed in the Fall 2004 profile which presented an additional "peak" in segment 1005.

Similarly, longitudinal profiles for sediment samples collected in WO7 showed that organic carbon (OC)-normalized TEQ concentrations started low and increased to a peak at station 11280 (segment 1007), then they showed a dramatic drop at station 15979 (segment 1006), in segment 1006 concentrations maintained a general increasing trend up to station 16618 (segment 1005) to finally decrease towards Galveston Bay. Dioxin concentrations were lower for most of the locations upstream and downstream of station 11280. Sediment TEQ concentration for station 11193 in segment 1001 was the only exception, with a concentration almost as high as that measured at station 11280. Concentrations in side bays were, in general, higher than those measured at the receiving main channel. The concentrations measured in WO4 showed similar behavior but the peak was observed at station 15979 in segment 1006.

Catfish and crabs exhibited relatively "flat" profiles with in-stream levels greater than those for side bays. The Fall 2004 profile, however, showed a significant peak at Morgan's Point (11252) for both catfish and crab.

Temporal Trends

Dioxin concentrations at the locations sampled during five sampling events conducted for WO4 and WO7 of this project (Summer 2002, Fall 2002, Spring 2003, Spring 2004, and Fall 2004[*]) were analyzed using the Mann-Kendall test to evaluate possible trends over time for all media. Results from this test showed that furans were decreasing more over the sampling period than dioxins. In addition, thirteen of the 23 significantly increasing series corresponded to dioxins. Sediment concentrations at station 11280 showed a significant upward trend, mainly because the concentrations measured in 2004 were dramatically higher than the ones measured in WO4. Of the 24 series showing significant decrease over time, all but one, 2378-TCDD sampled at station 11252, are furan congeners. When congeners showing no trend were taken into account, the overall trend of all data at all stations appeared to be downward. OCDD was the only congener that appeared to be holding steady with a slight increase at most sampling stations and sampling media.

Seasonal Trends

In general, average congener profiles for the different media/season for the stations that were sampled during each event did not change substantially from one season to another. Exceptions to note are 2378-TCDD and 2378-TCDF in catfish and crab samples, whose averages showed a considerable increase in Fall 2004. This increase, however, may be related to the fact that lipid contents for the Fall 2004 samples were consistently higher than those measured at the remaining events.

To further analyze if dioxin patterns changed with season, the ratio of the Σ PCDDs to the Σ PCDFs was analyzed for all the sampled media. Overall, the PCDD contribution is higher for most of the samples, with average ΣPCDD/ΣPCDF ratios of 24.9, 24.2, 2.2, and 1.2 for water, sediment, catfish, and crab, respectively. For sediment samples, the concentration patterns seem equivalent, with slightly different ΣPCDD/ΣPCDF average ratios for the different events. Water and tissue data, on the other hand, exhibited different ratios for the various sampling events, especially catfish for which the slope of the best-fit line for data collected in the Summer was much greater than the ones for the other four events.

Comparison of Dioxin Data Among the Three Sampled Media

In terms of TEQ, station 11273 (Patrick Bayou) was the most contaminated location in this study, with the highest average TEQ in water, and the second highest in sediment and crab. Among the stations located in the main channel and Upper Galveston Bay, station 15979 shows high contamination, with the third highest average TEQ concentration in sediment and water and the second highest average concentration in catfish. Other dioxin "hot spots" were located at

[*] Summer 2004 and 2005 results were not included in the temporal trends because they were localized events in segments 1001/1006/1007 and, thus, most of the stations were sampled only once.

stations 11280 and 13344. Station 11193 in segment 1001 exhibited the second highest average TEQ in water and the fourth highest TEQ in sediment.

In terms of 2378-TCDD, the two most contaminated locations were 11193 and 15979, with average concentrations in water and sediment among the three highest. Stations 11273 and 11265 were additional "hot spots."

MODEL DEVELOPMENT

Development of a preliminary mass-balance of dioxins in the HSC was completed using the MEGA-TX model (a modification of the QUAL-TX model completed for this project) to ensure that all the sources and process had been identified. In addition, a steady-state WASP model of the HSC was developed and a 1-month transient WASP simulation is underway. Major sources in the conceptual model for dioxins in the HSC include wet/dry air deposition, direct discharges, tributary input, sediment resuspension, land runoff, and discharges from groundwater. Major sinks include biodegradation, sediment burial, sediment removal by dredging, volatilization, groundwater outflow, hydrolysis, and photolysis.

A screening quantification of relative source importance conducted using the MEGA-TX model for the HSC showed that known sources (point sources and storm runoff) accounted only for 5% and 26% of the total 2378-TCDD and TEQ load in the HSC, respectively. In an attempt to calibrate the model, a source of $5x10^6$ ng/day for TEQ and $3.5x10^6$ ng/day for 2378-TCDD (assuming no flow associated with such a source) was input to the model to match the measured concentration at station 15979 in Summer 2002.This would suggest "possible unidentified/ unquantified sources" in the vicinity of this sampling station. Similarly, an additional source would have to be entered in the vicinity of station 11193 to match the peak observed at that location. Possible unquantified sources include road runoff, groundwater leachate, dredged material leachate, and localized contaminated sediments (e.g. old waste pit in san Jacinto River at I-10, currently under investigation). It is also noted that resuspension in general is likely to have been underestimated due to the fact that MEGA-TX has no mechanism for increasing the water column concentration from a bed load pool (due to scour or desorption). This may account for some of the difference between observed and modeled concentrations along the channel.

A simplified steady-state WASP model for 2378-TCDD in the HSC was also completed in WO7. No calibration was attempted for the simplified model. Instead, the focus was on determining which variables had most impact on model results. Thus, scenarios were run assuming different conditions to determine the change in the output concentrations. Results indicated that TSS concentrations are most sensitive to settling/resuspension (benthic exchange) and dispersion processes as well as point and non-point source loadings. Concentrations of 2378-TCDD in water showed sensitivity to most of the parameters, with the greatest variation in model results corresponding to changes in the dispersion and benthic exchange coefficients. Total 2378-TCDD concentrations in water did not show sensitivity to either pore processes or

decay.

A detailed transient WASP model for 2378-TCDD in the HSC is underway to estimate contributions from sediment resuspension, direct deposition, and additional sources. The hydrodynamics are being run using DYNHYD5. The hydraulic model is currently being refined and calibrated. The DYNHYD output was linked to the WASP model and the benthic segments were added to complete water quality simulations. The water quality model is under development.

PCB ASSESSMENT

Results from the 1999 Health Assessment conducted by the Texas Department of Health (TDH) in the HSC and Upper Galveston bay showed the presence of PCBs (Aroclor 1260) in 3 out of 12 finfish samples from the Lynchburg Ferry and the San Jacinto River. Based on the results from the 1999 studies, it was recommended by the TDH to extend the existing advisory for the HSC to include all species of finfish due to the presence of pesticides and PCBs in concentrations that exceed health-based comparison values. The scope for the dioxin project was, subsequently, expanded to include a preliminary assessment of PCB concentrations in all media in the channel and leverage the costs involved in dioxin sample collection. Unlike the TDH study, the dioxin TMDL project quantified both the 209 PCB congeners and the Aroclors in all media and results were presented in the Final Report for WO4.

Analysis of PCB and Aroclor data gathered in this project led to the following conclusions:

- When evaluating congener-specific results, water concentrations showed a Tier-1 primary concern in segments 1006 and 1007; additional PCB congener in water samples are required to determine use support in segments 1006 and 1007. In contrast, when looking at Aroclor data, none of the segments showed a concern.
- Tissue data collected in this project confirms a concern of PCBs in catfish in segments 1001, 1006, and 1007 when evaluating congener data; whereas Aroclor data shows a concern in segment 1001 only.
- Congener-specific PCB data in catfish also showed potential concerns for stations located in the tidal portions of Sims Bayou, Vince Bayou, Patrick Bayou, Buffalo Bayou, and Whiteoak Bayou. These water bodies are also included in the Draft 2004 Texas §303(d) List.

The above-mentioned conclusions indicate a need to evaluate both the Aroclor and congener specific data to determine if §303(d) listings and future TMDL projects are warranted. In addition, since the water quality standard and the TDH screening values are based on Aroclors and not on PCB congeners, a methodology to compare PCB data and to establish criteria to assess use support is needed. More investigation is warranted to address the new food consumption advisory for trout.

CHAPTER 1

INTRODUCTION

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDF) and polychlorinated biphenyls (PCBs) are halogenated aromatic compounds that have been widely found in the environment. The PCDDs include 75 congeners and PCDFs include 135 different congeners. Only 7 out of the 75 PCDD congeners and 10 of the 135 PCDF congeners have been identified as having dioxin-like toxicity. There are 209 PCB congeners, of which 13 are identified as having dioxin-like toxicity. These dioxin-like compounds are highly toxic and persistent environmental contaminants and, consequently, have received a great deal of attention by environmental regulators and researchers.

Dioxin (the term used to refer to dioxin-like compounds) presents a likely cancer hazard to humans (U. S. Environmental Protection Agency, 2000a) and can cause health problems even at extremely low doses. Reproductive problems, behavioral abnormalities, and alterations in immune functions are among the health effects caused by exposure to dioxin. Because dioxin-like compounds have been proven to bioaccumulate in biological tissues, particularly in animals, the major route of human exposure is through the food chain. Thus, several food advisories have been issued across the United States to prevent people from consuming unhealthful doses of these compounds.

1.1 PROBLEM STATEMENT

Section §303(d) of the Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards and develop a list of such waters known as the §303(d) list. For each listed water body that does not meet a standard, states must develop a total maximum daily load (TMDL) for each pollutant that has been identified as contributing to the impairment of water quality in that water body. The Texas Commission of Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas. The ultimate goal of these TMDLs is to restore the quality of the impaired water bodies such that water quality standards are met.

A seafood consumption advisory for catfish and blue crabs in the upper portion of Galveston Bay and the Houston Ship Channel (HSC) was issued by the Texas Department of Health in September of 1990 as a result of dioxin found in fish and crab tissue. The HSC system was subsequently placed on the §303(d) list and a TMDL study was initiated by the TCEQ. Segments placed on the §303(d) list include the San Jacinto River Tidal (Segment 1001), Houston Ship Channel (Segments 1005, 1006, 1007), Tabbs Bay (Segment 2426), San Jacinto Bay (Segment 2427), Black Duck Bay (Segment 2428), Scott Bay (Segment 2429), Burnett Bay (Segment 2430), and Barbours Cut (Segment 2436). In addition, Upper Galveston Bay (Segment 2421), Segment 2438 (Bayport Channel), and Segment 901 (Cedar Bayou Tidal) were included in the §303(d) list and are part of this TMDL study, even though they are not part of the HSC system. The overall purpose of this project is to develop a TMDL for dioxin in the Houston Ship Channel System, including upper Galveston Bay, and a plan for managing dioxins to

correct existing water quality impairments and maintain good water quality in the future. The project also includes an assessment of existing PCB levels in the channel to determine the scope and nature of PCB impairment.

1.2 PROJECT DESCRIPTION

The dioxin TMDL study has been divided into several phases to ensure a cost-effective, flexible and logical project development.

Phases I and II have been completed and final reports submitted to TCEQ. Phase I was aimed at assessing current conditions and identifying the deficiencies in dioxin data in the HSC. Phase I resulted in the development of a work plan for Phases II and III of the project. Two work orders were completed for Phase I. Work Order 1 encompassed an assessment of current dioxin levels and trends in the Project area, an assessment of major sources and fate and transport of dioxin in the environment, and development of a work plan and cost estimate for Phases II and III of the TMDL. The scope of work also included participation in the stakeholder process for the dioxin TMDL. The second work order (TNRCC Work Order No. 582-0-80121-03) was aimed at incorporating recent information that became available from EPA and other State agencies into the project workplan.

Phase II of the TMDL study (TNRCC Work Order No. 582-0-80121-04) included the following tasks: 1) identification of water quality targets; 2) monitoring and data collection in the Houston Ship Channel (for dioxins and PCBs); 3) modeling the fate and transport of dioxin in the Houston Ship Channel; 4) participation in the stakeholder process; and 5) developing load allocation scenarios.

Phase III of the TMDL study is currently underway (TCEQ Work Order No. 582-0-80121-07). Work Order 7 incorporates data evaluation, additional data collection, system-wide modeling, and load assessments. There are seven main tasks to be completed in WO7:

1. Project administration;
2. Development of a Quality Assurance Project Plan (QAPP) for additional data collection;
3. Conducting dioxin monitoring and data collection in the Houston Ship Channel area;
4. Incorporating collected data into dioxin TMDL models developed in WO4;
5. Participation in stakeholder involvement with the dioxin TMDL project;
6. TMDL allocations; and
7. Evaluation of PCB data gathered to date and assessment of the need for a PCB TMDL.

1.3 DESCRIPTION OF THE REPORT

This document constitutes the Final Report for Work Order No. 582-0-80121-07 (Contract Number 582-0-80121) of the Dioxin TMDL Project and summarizes the activities undertaken by the University of Houston, in conjunction with Parsons and PBS&J during the period September 1, 2003 to August 31, 2005.

This report compiles the seven quarterly reports submitted to TCEQ in compliance with the Work Order and adds the activities completed during the last quarter of the project. The topics in the report are organized according to the tasks specified in Work Order 582-0-80121-07.

The approved Quality Assurance Project Plan (QAPP) for the sampling activities conducted for this project and its approved amendments are addressed in Chapter 2 and

Appendix A of this report. Chapter 2 also presents a description of the quality control activities conducted and lists the quality control issues encountered throughout the project.

Chapter 3 describes the monitoring and data collection activities conducted to assess current levels of dioxins in the HSC and to evaluate sources of dioxins to the HSC system. Along with the description of sampling activities, a summary of analytical results is presented in Chapter 3. Chapter 3 also includes an update of the section describing the collection of sediment data to support modeling that had been previously included in the Final Report for WO4. The update incorporates sediment data collected in the Houston Ship Channel in recent years.

Chapter 4 presents the development of site-specific values for water quality targets for this TMDL project. A quantification of site-specific bioaccumulation factors (BAFs) and biota-to-sediment accumulation factors (BSAFs) is also detailed in Chapter 4. In addition, Chapter 4 presents analyses of the entire dioxin dataset to evaluate spatial, temporal, and seasonal trends.

Modeling activities are summarized in Chapter 5. Data in Chapter 5 describe the methods and technical approaches followed to set up a QUAL-TX, a simplified WASP, and a transient WASP model for dioxins in the HSC system.

A list of activities completed in support of stakeholder activities during WO7 is presented in Chapter 6. This chapter also includes copies of the presentations given by members of the project team at stakeholder meetings.

An assessment of the PCB data gathered in WO4 along with recommendations for TMDL needs is included in Chapter 7. Finally, Chapter 8 presents a summary and conclusions of project activities completed under Work Order No. 7.

CHAPTER 2

QUALITY ASSURANCE PROJECT PLAN

The goal of this task is to develop a plan for additional data collection that met the needs for the TMDL. The quality assurance project plan was prepared based on the proposed monitoring activities outlined in task 3 of the work plan for Work Order 7. A first draft of the Quality Assurance Project Plan for data collection was submitted to TCEQ on September 19, 2003. Comments from TCEQ on the first draft were received and addressed prior to November 11, 2003. The revised QAPP was approved by TCEQ and submitted to EPA on December 9, 2003. EPA approved and signed the QAPP on January 24, 2004. An annual update compiling the original QAPP and the approved amendments was submitted to TCEQ on January 24, 2005. The annual update was approved by TCEQ on March 9, 2005 and by EPA on April 22, 2005.

2.1 AMENDMENTS TO THE APPROVED QAPP

Two amendments to the approved QAPP and one amendment to the Annual Update were developed and submitted to TCEQ. The first amendment added high-resolution sediment sampling in segments 1001 and 1006 aimed at identifying the possible causes of elevated dioxin levels in those segments. The second amendment included additional dioxin runoff data collection and evaluation of a surrogate estimation method for dioxins in runoff. The amendment also extended the sampling time for air sampling and increased the deposition sampler surface area to minimize non-detects. Amendment No. 1 was approved on July 1, 2004 and Amendment No. 2 was approved on August 19, 2004.

In addition to compiling the original QAPP and approved Amendments, the annual update submitted on January 2005 included flow measurements using and Acoustic Doppler Profilers (ADP) to support modeling activities. Finally, an Amendment to the annual update was submitted on July 11, 2005. This final Amendment added more high-resolution sediment sampling in segments 1001, 1006, and 1007 to characterize sediment "hot spots" within the project area and support the search for unknown sources of dioxins. This Amendment was approved on July 12, 2005 through a non-substantive change request.

Appendix A of this report includes the Annual Update as well as the final Amendment.

2.2 QUALITY CONTROL ACTIVITIES

The quality assurance/quality control (QA/QC) tasks that were conducted during Work Order 7 included monitoring/coordinating sample deliveries to the laboratories, verifying laboratory compliance with the QAPP, and verification of data packages. There were no noncompliant issues encountered in the shipping and receiving of the samples collected in Fall and Summer 2004. All samples were received by the laboratories without incident and were within the temperature range specified in the QAPP. In Spring 2004, there were two instances in which the sample IDs were mislabeled in the chain-of-custody (COC). The water sample collected on 3/12/04 was labeled 11342 instead of 13342. The water sample collected on 4/2/04 was mistakenly labeled as 11302, the correct ID is 11287. In both cases, the station IDs were corrected in the database. In Summer 2005, two sediment sample containers broke during shipment (Sites 10 and 12). New samples were collected at those two sites and submitted to the laboratories for analysis.

There were no non-compliance issues encountered in the data verification conducted for dioxin samples collected in 2004 and 2005.

Due to the complexity of the dioxin/furan analysis, many different data qualifiers (flags) are used by the various laboratories. Standardization of these flags was necessary to allow for accurate and consistent qualification of the data. The flags that have been assigned to the data by the project team are given in Table 2.1.

Table 2.1 Standardized Flags Assigned to Data

Flag	Description
B	Blank contamination (result is less than twenty times the amount found in the associated blank).
U	Target analyte is not detected above the method detection level (MDL) in the sample.
J	Result is between the method detection limit (MDL) and the reporting level (RL) or the value is to be considered an estimate due to quality control issues involved in the analysis.
UJ	Analyte was not detected but the result is an estimate due to non compliant QC.
R	Sample result is to be rejected and is considered unusable.

These flags are consistent with those given in the USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review dated February 1994.

The analyses of all the samples have been in compliance with the QAPP. There have been a few instances when the reporting levels have been elevated because they were either based on the signal to noise ratio of each sample injection or due to matrix interferences. When

interferences have caused a higher than normal reporting level, the laboratories have reported the analyte as non-detect and the reporting level as the maximum estimated possible concentration that could be in the sample based on the peak area of the interference. This practice is recommended in the original EPA method. Method blanks have also been reported with detectable amounts of target analytes. Several method blanks have been reported with detectable amounts of target analytes. However, all of the concentrations reported in the method blank were within the acceptable criteria given in the QAPP for blanks and all data were considered usable.

All reviewed analytical data for dioxins/furans complies with the QA/QC requirements outlined in the QAPP. The QA/QC requirements outlined in the QAPP include: holding times, method blanks, initial calibration curves, ambient water reporting limits (AWRL) verification, laboratory control sample (LCS), field duplicates, matrix spikes/matrix spike duplicates, laboratory duplicates, continuing calibration samples, surrogates, and internal standards. In the sample results reviewed, no data were rejected. The percent data verification completed for each laboratory per matrix for the different sampling events is summarized in Table 2.2.

There was a non-compliant issue with the samples analyzed by NWDLS consisting of the exceedance of holding times for a group of samples as described in Section 2.3.2 below.

Table 2.2 Percentage Data Packages Reviewed

Laboratory	Media	# samples collected	Results reviewed
Spring 2004			
PSC/Maxxam Analytical	Water	30	100%
PSC/Maxxam Analytical	Catfish	37	100%
PSC/Maxxam Analytical	Crab	29	100%
Pace Analytical	Sediment	21	100%
Summer 2004			
PSC/Maxxam Analytical	Water	7	100%
Pace Analytical	Sediment	21	100%
Fall 2004			
PSC/Maxxam Analytical	Water	28	100%
PSC/Maxxam Analytical	Catfish	19	100%
PSC/Maxxam Analytical	Crab	19	100%
Pace Analytical	Sediment	19	100%
Pace Analytical	Sediment cores	102	94%[a]
Runoff (Fall 2004 to Summer 2005)			
PSC/Maxxam Analytical	Water	24 (8 sites)	88%[b]
Pace Analytical	Sediment/soil	41	95%[b]
Air (Fall 2003 to Summer 2005)			
Alta	Ambient air	18	94%[c]
Alta	Particle size	21	100%
Alta	Dry deposition	13	92%[c]
PSC/Maxxam Analytical	Wet deposition	3	67%[c]
PSC/Maxxam Analytical	Bulk deposition	2	50%[c]

[a]Six additional core samples (deepest for each core) were submitted for analysis in August 2005. Results have not been received.
[b]Results for the last runoff sample have not been received from the laboratory.
[c]The last sample is being collected (June to December 2005)

2.3 QC ISSUES

2.3.1 Wet Deposition Sample Mishandling

The XAD-2 column resin column that collected wet deposition at site C-408 (Lang Road) and delivered to PSC Analytical Services on April 23, 2004 was not handled appropriately. As a consequence the sample was unusable. The Project QAO requested a Corrective Action Report from the laboratory including: (1) a statement of what occurred, (2) an explanation of what caused the problem(s), and (3) an explanation of corrective measures taken to ensure the error would not re-occur. PSC Analytical Services is preparing the report.

2.3.2 Holding Times

When verifying the data packages received from NWDLS, it was noticed that the holding times for total dissolved solids (TDS) and Volatile Solids analyses were exceeded in a number of occasions by 2-3 days (holding time as per the QAPP is 7 days for both analyses). Data for TDS or volatile solids are not used in the dioxin data analysis, but per the QAPP, the project team is required to analyze for those parameters and report data to TRACS. The number of samples that exceeded the holding time is listed in parenthesis:

- TDS: Spring 04 (2), Summer 04 (2), Fall 04 (15)
- Volatile Solids: Spring 04 (9), Fall 04 (9).

Results for samples that exceeded the holding time were not reported to TRACS.

2.3.3 Wet Deposition Sample Duration

The wet deposition sample was intended to be collected and analyzed as a six-month composite sample using two co-located samplers. Sample collection proceeded as planned, the columns were changed three times for each sampler for a total of 6 XAD-resin samples to be combined. However, because all the columns were spiked prior to deployment as indicated in the method, it was not possible to combine all six of them for a single analysis because the amount of spike will overwhelm the GC unit and increase the detection limits. Thus, only the first pair of co-located XAD-2 columns deployed in the field (i.e. a 2 month-sample) were combined and analyzed for dioxins. The remaining columns are being combined and analyzed in pairs. A second field effort to collect a six-month wet deposition sample was initiated in early June 2005 and is currently on-going.

2.3.4 Field Duplicates

A field duplicate is defined as a split sample (or measurement) from the same location, collected in immediate succession (after homogenization), using identical techniques. Field duplicates were collected at a frequency of 7.1 % or higher[1].

Table 2.3a summarizes the relative percent deviation of the field duplicates (FRPD) for dioxin samples collected during Spring 2004. As can be observed, the average FRPDs for dioxins are 17, 30, 9, 39, and 49% for dissolved, suspended sediment, bottom sediment, catfish, and crab,

[1]Field duplicate frequency required as per QAPP is 5% or higher.

Table 2.3a Percent Deviation of the Field Duplicates collected in Spring 2004

Matrix	Dioxins[a] (%)			Total TEQ (%)		
	min	max	mean[b]	min	max	mean[b]
Dissolved	0	49	17 ± 4	6	36	16 ± 42
Suspended	0	65	30 ± 7	6	57	33 ± 64
Sediment	0	37	9 ± 3	3	4	4 ± 6
Catfish	4	103	39 ± 12	22	73	42 ± 67
Crab	5	144	49 ± 15	3	12	41 ± 89

[a] Percent deviation was calculated for each of the 17 dioxin-like congeners, only detected concentrations were used.
[b] Mean ± Confidence interval (α=0.05)
A complete table with all the FRPD calculations by sample is included in Appendix A.

respectively, when the comparison is based on each individual congener. When the comparison is based on total TEQ, the average FRPDs were 16, 33, 4, 42, and 41%, for dissolved, suspended sediment, bottom sediment, catfish, and crab, respectively.

Table 2.3b includes the relative percent deviation of the field duplicates (FRPD) for dioxin samples collected during Summer 2004. As can be observed, the average FRPDs for dioxins are 7, 3, and 98% for dissolved, suspended sediment, and bottom sediment, respectively, when the comparison is based on each individual congener. When the comparison is based on total TEQ, the average FRPDs were 3, 2, and 71%, for dissolved, suspended sediment, and bottom sediment, respectively. The high percent deviation observed in bottom sediment duplicates is due to samples collected at location 11193 that probably were not adequately homogenized.

Table 2.3b Percent Deviation of the Field Duplicates collected in Summer 2004

Matrix	Dioxins[a] (%)			Total TEQ (%)		
	min	max	mean[b]	min	max	mean[b]
Dissolved	0	20	7 ± 5	na[c]	na[c]	3[c]
Suspended	0	9	3 ± 2	na[c]	na[c]	2[c]
Sediment	0	161	99 ± 26	7	135	71 ± 125

[a] Percent deviation was calculated for each of the 17 dioxin-like congeners, only detected concentrations were used.
[b] Mean ± Confidence interval (α=0.05)
[c] Only 1 duplicate was collected. The mean value corresponds to the measured FRPD for the collected duplicate.
A complete table with all the FRPD calculations by sample is included in Appendix A.

Table 2.3c includes the relative percent deviation of the field duplicates (FRPD) for dioxin samples collected during Fall 2004. As can be observed, the average FRPDs for dioxins are 9, 6, 11, 23, and 39% for dissolved, suspended sediment, bottom sediment, catfish, and crab, respectively, when the comparison is based on each individual congener. When the comparison is based on total TEQ, the average FRPDs were 21, 5, 8, 9, and 53%, for dissolved, suspended sediment, bottom sediment, catfish, and crab, respectively.

The approved QAPP requires the FRPD be 50% or less. Thus, water, sediment, and catfish field duplicates that exceeded the criteria were flagged as estimates.

The relative percent deviation criterion was met for all field duplicates for conventional analyses in water. The 50% FRPD criterion for conventional analyses was met for most sediment field duplicates with the exception of four values for grain size analysis that were flagged as estimates and were not reported to TRACS.

Table 2.3c Percent Deviation of the Field Duplicates collected in Fall 2004

Matrix	Dioxins[a] (%)			Total TEQ (%)		
	min	max	mean[b]	min	max	mean[b]
Dissolved	1	20	9 ± 5	5	37	21 ± 0.3
Suspended	1	21	6 ± 3	0	10	5 ± 0.1
Sediment	0	30	11 ± 3	2	14	8 ± 0.1
Catfish	7	74	23 ± 7	8	10	9 ± 0.1
Crab	5	120	39 ± 11	49	57	53 ± 0.1

[a] Percent deviation was calculated for each of the 17 dioxin-like congeners, only detected concentrations were used.
[b] Mean ± Confidence interval (α=0.05)
A complete table with all the FRPD calculations by sample is included in Appendix A.

It is noted that the duplicates for crab samples collected in Spring 2004 were prepared using different individuals than the parent sample (i.e. two complete sets of crabs were collected at the same location and time). Therefore, these field duplicates are not actually a measure of the precision of the sampling and analytical methods but rather a measure of the variation in the chemical composition among individuals.

2.3.5 Laboratory Duplicates

There was a set of sediment samples for which the % RPD for laboratory duplicates was 11.4%. As per the approved QAPP, the % RPD for total organic carbon (TOC) in sediment should not exceed 10%. However, the 10% value is too low as indicated by the % RPD for TOC in water (20%). Furthermore, the Surface Water Quality Monitoring (SWQM) QAPP has a 30% RPD criterion for TOC in sediment as indicated by the TCEQ Project Management and QC Section. Therefore, it was considered that the TOC results for the aforementioned set of sediment

samples were valid, met the QC criterion, and could be both reported to TRACS and used for dioxin data analyses.

CHAPTER 3

MONITORING AND DATA COLLECTION

The monitoring and data collection task encompasses two main subtasks: (i) monitoring and data collection to assess current levels of dioxins in the HSC, and (ii) sampling to evaluate sources of dioxins to the HSC system. This chapter summarizes the sampling activities conducted between September 1, 2003 and August 31, 2005. In addition, the chapter includes a summary of the sampling results and presents an analysis of the gathered data. Four "major" sampling events were completed in support of this task. The first event (Spring 2004) was conducted between March 9 and May 8, 2004. The second sampling event (Summer 2004) was initiated on August 2, 2004 and was completed on August 31, 2004. Sampling for the third sampling event (Fall 2004) was conducted between October 19 and December 2, 2004. Finally, the fourth sampling event (Summer 2005) was completed between August 15 and August 30, 2005. In addition to the major sampling events, continuous air/deposition sampling was conducted between December 2003 and August 2005; sediment core sampling was conducted between May 21, 2004 and February 17, 2005; and runoff sampling was conducted between December 16, 2004 and July 14, 2005.

Monitoring conducted as part of Work Order 7 yielded a total of 71 in-stream water samples, 98 sediment samples, 53 catfish tissue samples, 47 crab tissue samples, 106 sediment core samples, 8 runoff samples, 41 soil samples, 18 ambient air samples, 13 dry deposition samples, 3 wet deposition samples, 2 bulk deposition samples, and 21 particulate air samples.

A description of the methods and technical approach undertaken to accomplish the sampling tasks is presented below. All the sampling and analysis procedures employed for this task followed those specified in the approved QAPP.

3.1 DESCRIPTION OF SAMPLING ACTIVITIES

3.1.1 Assessment of Current Levels and Trends of Dioxins in the Houston Ship Channel

The main purpose of this task is to confirm the severity, spatial and temporal extent of the current impairment and to determine whether water quality is improving or deteriorating for each segment listed. The goals include: (i) using the data results to verify whether dioxin concentrations are above the criteria and where, and/or how much dioxin levels must decline to meet the criteria, (ii) identifying historical increases and declines in dioxin levels that may be related to changes in sources over time, and (iii) characterizing other segments/waterbodies, such as side bays, where dioxin levels have not been previously measured.

During the Spring 2004 sampling event, 17 in-stream sites were sampled for ambient water, 18 sites for sediments, and 28 sites for catfish and crab tissue. For the Summer 2004 sampling event, 15 in-channel locations were sampled for sediments, and 4 locations for ambient water (in two of them water was sampled at 2 different depths). In addition, sediment was sampled in a transect at location 15979 to assess the difference in dioxins levels between the center of the channel and the banks. During the Fall 2004 sampling event, 17 in-stream locations were sampled for ambient water and sediments, and 28 locations for catfish and crab tissue. Finally, during the Summer 2005 sampling event, 40 sediment samples and 1 sediment core were collected. Additionally, 8 sediment cores were collected for geochronological and dioxin

analyses during WO7. Table 3.1 includes a summary of the total number of samples collected for WO7.

Samples were shipped to the laboratories to be analyzed for dioxins (EPA method 1613B) and conventional parameters. The following sections present a summary of sampling sites, media, and sampling procedures.

3.1.1.1 In-channel Water Sampling

Water sampling was conducted using the high-volume technique to allow for detection of concentrations below the reporting limit for the analytical method (10 pg/L for 2378-TCDD). Using this technique allows concentrating dioxins from large volumes of water to obtain measurable quantities. The high-volume system uses a stainless steel column packed with hydrophobic polymeric resin beads through which large volumes of water can be passed. Since dioxins are very hydrophobic, they rapidly sorb onto the resin, making it possible to completely collect the dissolved dioxins from the sampled water. Later, in the laboratory, the dioxins are recovered from the resin by extraction with a nonpolar organic solvent. Dioxins associated with suspended particulate matter were collected on a fiber glass filter, which was also extracted later in the laboratory.

For this TMDL, the project team used a commercially-available Infiltrex 300 high-volume sampling system manufactured and sold by Axys Environmental Systems of Sydney, British Columbia.

Table 3.1 Number of Samples Collected in for Current Levels and Trend Analysis

Matrix	Spring 2004			Summer 2004			Fall 2004			Summer 2005		
	# sites	QC samples[a]	total # samples	# sites	QC samples[a]	total # samples	# sites	QC samples[a]	total # samples	# sites	QC samples[a]	total # samples
In-channel water - *XAD Column*	17	3	20	2, 2(2)[b]	2	8	17	3	20			
- *Filter*	17	3	20	2, 2(2)[b]	2	8	17	3	20			
Sediment	18	6	24	15,1(5)[c]	4	24	17	3	20	32	8	40
Tissue - *Catfish*	28	4	32	0	0	0	17	4	21			
- *Crab*	26	2	28	0	0	0	17	2	19			
Sediment core	2 (11)[d]	2	24	2 (11)[d]	2	24	4 (11)[d]	4	48	5(1),1(5)[d]		10

[a] Field duplicates, field blanks and recovery columns specified in the QAPP.
[b] 2 sites were sampled at 2 depths (surface and bottom).
[c] Sediment samples were collected along a transect (5 samples) at one location.
[d] Numbers in parentheses correspond to the number of core sections analyzed for dioxins.

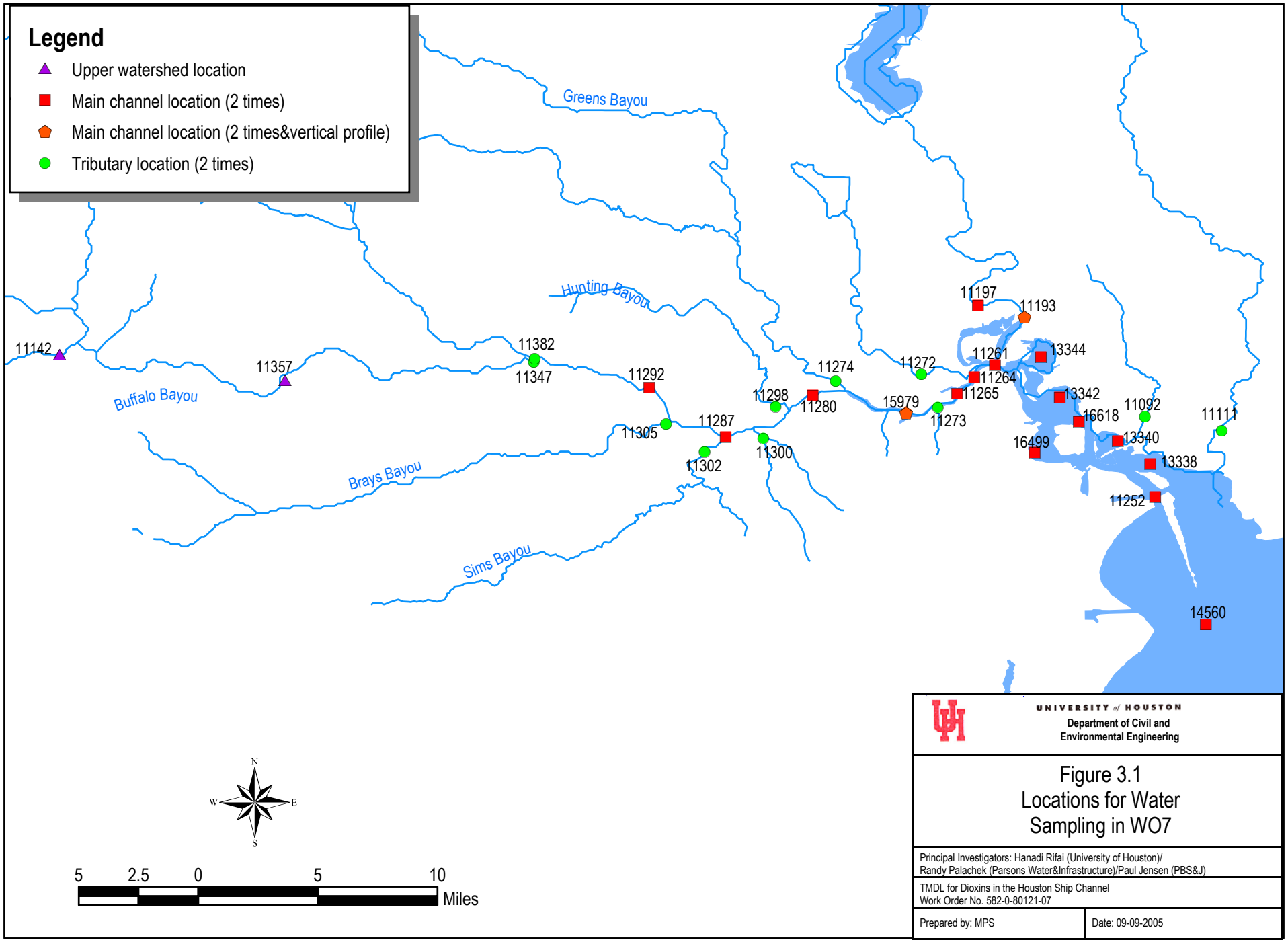
Water sampling was conducted following the guidelines set forth in the QAPP for the dioxin project. A pumping rate of about 1.6 L/min was selected for this project based on the manufacturer's recommendations to avoid incomplete capture of the dissolved analytes by the resin trap (breakthrough). The target volume of water was 700 L, which allows reporting limits as low as 0.014 pg/L for 2378-TCDD. This target volume was achieved for all but one sample. The exception was station 11357 (Buffalo Bayou at San Felipe Rd) for which the pumping rate could not be maintained above 1 L/min due to the high solids content that constantly plugged the pre-filter; after 8 hours of pumping only 326 L were processed.

A total of 19 locations in the main channel were sampled for ambient water. Fifteen locations were sampled twice (Spring and Fall 2004), two locations were sampled three times (Spring, Summer, and Fall 2004), and 2 locations were sampled once (Summer 2004) to determine dioxin levels in water (dissolved and suspended). Figure 3.1 shows the locations of the sampled sites. Table 3.2 includes a description of the sampled sites as well as the sampled volume for each station.

In addition to measuring dioxin concentrations at each location, grab water samples were collected to be analyzed for TSS (total suspended solids), TDS (total dissolved solids), DOC (dissolved organic carbon content), and TOC (total organic carbon content). Field probe parameters (i.e., pH, temperature, dissolved oxygen, conductivity, and salinity) were measured using a YSI sonde (6920 or 600-XLM).

3.1.1.2 Sediment Sampling

Sediment samples were collected using a stainless steel Ponar dredge. Prior to collection at each sample site, the dredge, stainless steel spoon, and polyethylene or stainless steel


Legend
Upper watershed location
Main channel location (2 times)
Main channel location (2 times&vertical profile)
Tributary location (2 times)
Greens Bayou
Hunting Bayou
Buffalo Bayou
Brays Bayou
Sims Bayou
11142
11357
11382
11347
11292
11305
11287
11302
11298
11300
11280
11274
11272
15979
11273
11265
11264
11261
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5 2.5 0 5 10
Miles
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 3.1
Locations for Water Sampling in WO7
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07
Prepared by: MPS
Date: 09-09-2005

Table 3.2 Summary of Water, Sediment, and Tissue Sampling in WO7

Station ID	Site Description	Segment	Spring 2004						Summer 2004			Fall 2004						Summer 2005
			Water		Sediment	Catish		Crab	Water		Sediment	Water		Sediment	Catish		Crab	Sediment
			Date	Volume (L)		Date	Species		Date	Volume (L)		Date	Volume (L)		Date	Species		
11111	Cedar Bayou Tidal at Roseland Park Boatramp, 400 meters upstream of Spur 55	901	4/27/2004	707		4/27/2004		4/27/2004				11/4/2004	702					
11193	San Jacinto River Tidal IH 10 Bridge East of Channelview	1001	3/23/2004	700/702 (dup)	3/24/2004	3/23/2004		3/23/2004	8/3/2004	723(sh)/678(de)[d]	8/11/2004 (dup)	11/3/2004	705/720(dup)	11/4/2004	10/28/2004	Hardhead	10/28/2004	
18389	San Jacinto River Tidal at CM15										8/11/2004							
18388	San Jacinto River Tidal at CM21										8/2/2004							
11197	San Jacinto River Tidal at Missouri-Pacific RR Bridge		3/24/2004	702	3/24/2004	3/24/2004 (dup)		3/23/2004			8/11/2004 (dup)	10/29/2004	703	11/9/2004	10/28/2004	Hardhead	10/28/2004	
18390	San Jacinto River Tidal, 1 km downstream of IH10	1005									8/11/2004							
11252	Houston Ship Channel at CM 91, Morgan's Point		3/10/2004	709	3/11/2004	3/9/2004		3/9/2004				11/19/2004	704	11/8/2004	11/3/2004	Hardhead	10/26/2004	
11261	Houston Ship Channel San Jacinto River at Lynchburg Ferry		3/25/2004	712	3/24/2004	3/24/2004		3/23/2004				10/28/2004	708	11/9/2004	10/27/2004	Hardhead	10/26/2004	
16618	Houston Ship Channel/San Jacinto River West of Exxon Docks and North of Alexander Island		3/17/2004	712	3/19/2004	3/18/2004		3/18/2004				11/15/2004	701	11/9/2004	11/3/2004	Hardhead	11/2/2004	
11271	Houston Ship Channel at confluence with Greens Bayou	1006									8/2/2004							
11270	Houston Ship Channel at CM 150										8/2/2004							
18391	0.8 km downstream of station 11270										8/2/2004							
11269	Houston Ship Channel at Beltway 8										8/2/2004							
15980	Houston Ship Channel at Shell outfall 008										8/2/2004							
15979	Houston Ship Channel at Shell Barge Cut, 0.9 mi. downstream of Beltway 8		3/31/2004	701/701 (dup)	4/2/2004[c]	3/31/2004		3/31/2004	8/5/2004	661(sh)/659(de)[d]	8/2/2004[c]	10/25/2004	712/708(dup)	11/4/2004	10/26/2004	Hardhead	10/21/2004	08/16/2005
11268	Houston Ship Channel at Channel Marker 142										8/11/2004							08/16/2005
11267	Houston Ship Channel at Patrick Bayou Confluence (Cargill-North and Diamond Shamrock-South) below CM 139										8/11/2004							08/16/2005
11264	Houston Ship Channel at San Jacinto Park, West of Battleship Texas		3/25/2004	701	3/24/2004	4/2/2004 (dup)		3/23/2004				10/27/2004	706	11/4/2004	10/26/2004	Hardhead	10/21/2004	
11265	Houston Ship Channel at CM 136		3/30/2004	702	4/1/2004	4/2/2004		3/30/2004				10/26/2004	703	11/4/2004	10/26/2004	Hardhead	10/21/2004	
11272	Carpenter Bayou Tidal at South Sheldon Rd in Channelview		4/13/2004	706		4/15/2004		4/15/2004				11/22/2004	701					
11273	Patrick Bayou Tidal immediately upstream of bridge leading to Occidental Chemical Intake Station on Houston Sship Channel		4/29/2004	702		4/21/2004		4/21/2004 (dup)				12/1/2004	701					
11274	Greens Bayou Tidal at Mechling Barge Lines in Houston		4/21/2004	710	5/8/2004	4/1/2004		4/20/2004				11/23/2004	720[b]					
11280	Houston Ship Channel/Buffalo Bayou at Armco Steel Corporation Intake Screens	1007	4/1/2004	706	4/1/2004	4/2/2004		4/1/2004			8/10/2004	10/21/2004	701	11/4/2004	10/21/2004	Hardhead	10/20/2004	8/16/2005[f]
18392	Houston Ship Channel/Buffalo Bayou, 830m upstream of Greens Bayou										8/10/2004							08/16/2005
11287	Houston Ship Channel/Buffalo Bayou at Confluence with Sim's Bayou		4/2/2004	701	4/2/2004 (dup)	4/2/2004		4/1/2004				10/20/2004	704[a]	11/4/2004	10/28/2004	Blue	10/19/2004	
11292	Houston Ship Channel/Buffalo Bayou in middle of Turning Basin		4/9/2004	707	4/2/2004 (dup)	4/3/2004		4/3/2004				10/19/2004	705	11/4/2004	10/20/2004	Channel	10/20/2004	
11298	Hunting Bayou tidal at Federal Road bridge in Houston		4/20/2004	702				4/20/2004 (dup)				11/12/2004	707					
11300	Vince Bayou at North Richey St. in Pasadena, TX		4/8/2004	702		4/21/2004		4/16/2004				11/29/2004	708					
11302	Sims Bayou at Lawndale Ave. in Houston		4/16/2004	734		4/15/2004		4/14/2004				11/10/2004	702					
11305	Brays Bayou at Broadway Blvd. south of Houston		4/15/2004	708				4/22/2004				11/11/2004	702					
11347	Buffalo Bayou Tidal at Main St. in Houston	1013	4/22/2004	703/705 (dup)								10/22/2004	701					
11382	Whiteoak Bayou at North Main Street in Houston		4/23/2004	707		4/20/2004						11/8/2004	704					
11142	Buffalo Bayou at Barker Dam	1014							8/19/2004	707/707 (dup)								
11357	Buffalo Bayou at San Felipe St.								8/31/2004	326								
14560	Upper Galveston Bay at HSC Marker 75	2421	3/11/2004	702	3/11/2004	3/9/2004		3/9/2004				11/9/2004	703	11/4/2004	11/3/2004	Hardhead	11/4/2004	
11092	Goose Creek at Market St. in Baytown	2426	4/28/2004	707[a]		4/27/2004		4/30/2004				11/30/2004	702					
13338	Tabbs Bay Midway Between Goose Creek and Upper Hog Island		3/18/2004	701	3/19/2004	3/18/2004		3/17/2004				11/18/2004	709	11/8/2004	11/5/2004	Hardhead	11/2/2004	
16499	San Jacinto Bay 200 yds SW of CM25 (98GB007)	2427	3/16/2004	706	3/19/2004	3/18/2004		3/17/2004				11/16/2004	686	11/9/2004	10/29/2004	Hardhead	11/8/2004	
13340	Black Duck Bay at mid-bay	2428	3/9/2004	705	3/11/2004	3/9/2004		3/9/2004				11/17/2004	702	11/9/2004	11/5/2004	Hardhead	11/3/2004	
13342	Scott Bay at Mid-Bay	2429	3/12/2004	702	3/11/2004	3/9/2004		3/9/2004				12/2/2004	712	11/9/2004	10/29/2004	Hardhead	10/28/2004	
13344	Burnett Bay at Mid-Bay	2430	3/19/2004	703	3/19/2004	3/18/2004		3/18/2004				11/5/2004	700	11/8/2004	10/28/2004	Hardhead	10/22/2004	
New sites 1 through 21	250 m grid at San Jacinto River just North of the I-10 bridge	1001																08/15/2005-08/30/2005
New sites 25, 26, 27	Locations upstream and downstream of 15979	1006																08/16/2005-08/17/2005
New sites 22, 23, 24	LOcations upstream and downstream of 11280	1007																08/16/2005

[a] A recovery column was collected

[b] Sampling was attemped at this location but it was not possible to catch crabs to complete a sample

[c] A second sediment sample was collected during Spring 2004 on a different date from the first sample

[d] sh=shallow, de=deep

[e] Five sediment samples along a transect were also collected at this station

[f] Five sediment samples from a core were also collected at this station

dup = duplicate

samples highlighted in gray indicate tributary

tray/mixing bowl were rinsed with deionized water, then ambient water. Samples were collected and deposited into a stainless bowl. A minimum of three grab samples were composited using the top 5 centimeters of sediment, mixed thoroughly with a clean stainless steel spoon, and deposited into a labeled, pre-cleaned amber glass jar with a Teflon seal. A separate sample of the same mixture was prepared for solids and TOC analysis. Multiple grab samples from the dredged channel and both banks at a given stream location were collected and composited into a single sample. Sampling procedures and handling followed the requirements specified in the QAPP for the project.

Sediment samples were collected at a total of 17 locations in the Ship Channel, San Jacinto River, Upper Galveston Bay, and side bays during Spring and Fall 2004 (Figure 3.2). One location was sampled once during the Spring 2004 event. During Summer 2004, 15 locations in segments 1001, 1005, and 1006 were sampled to obtain detailed concentration profiles and 1 location was sampled along a transect to measure differences in concentrations across the width of the channel (Figure 3.3). High-resolution sampling conducted in Summer 2005 included 32 locations shown in Figures 3.4 and 3.5. Table 3.2 includes a description of the sampled sites.

Standard field parameters (DO, pH, temperature, conductivity, and salinity) were measured at the time of sample collection using a YSI sonde (6920 or 600XLM).

3.1.1.3 Tissue Sampling

Tissue was sampled along with water and sediment to obtain data on bioaccumulation and/or transport of dioxin. For this sampling component, fish fillets and edible crab portions were collected, processed, and analyzed.

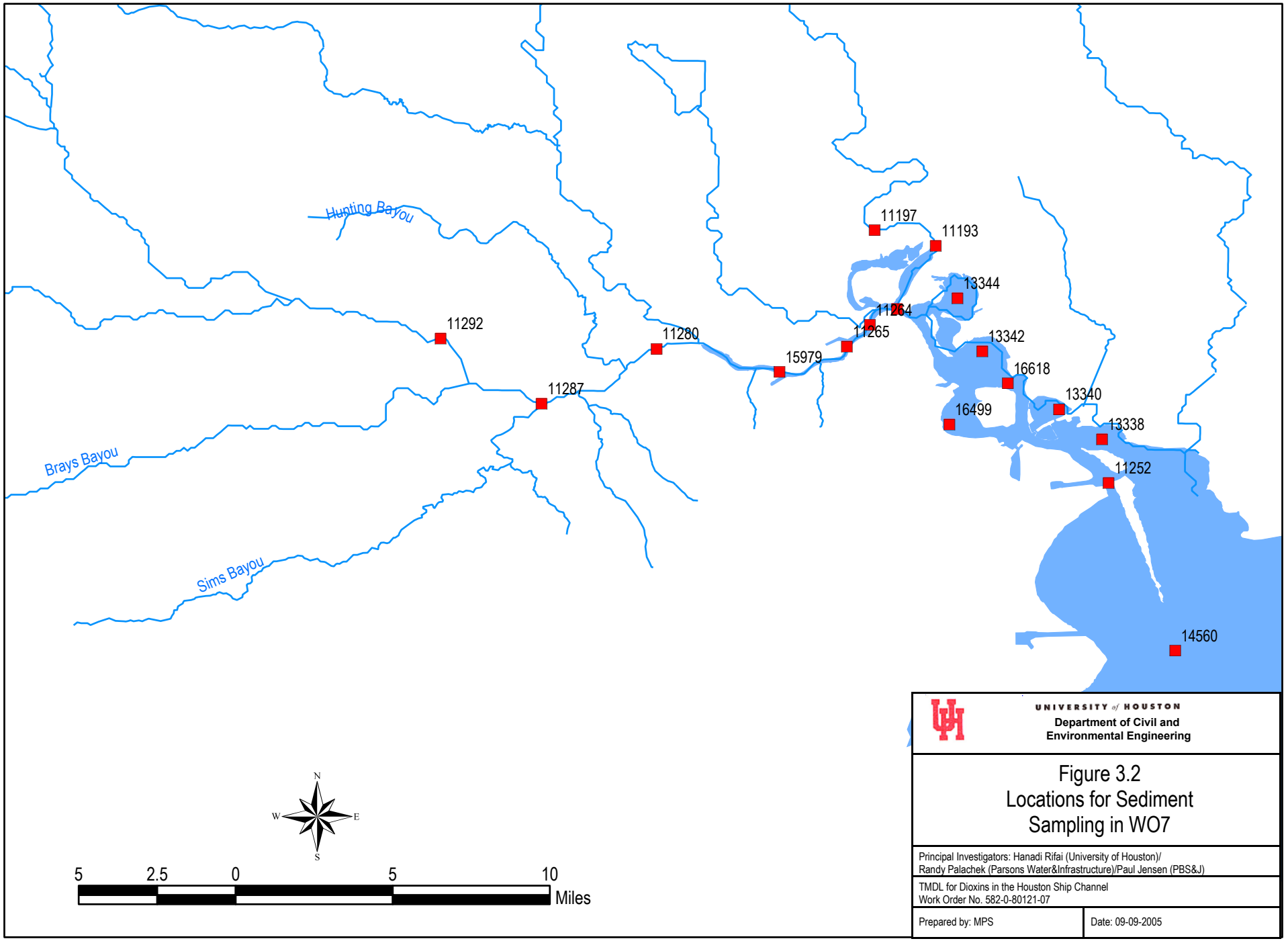

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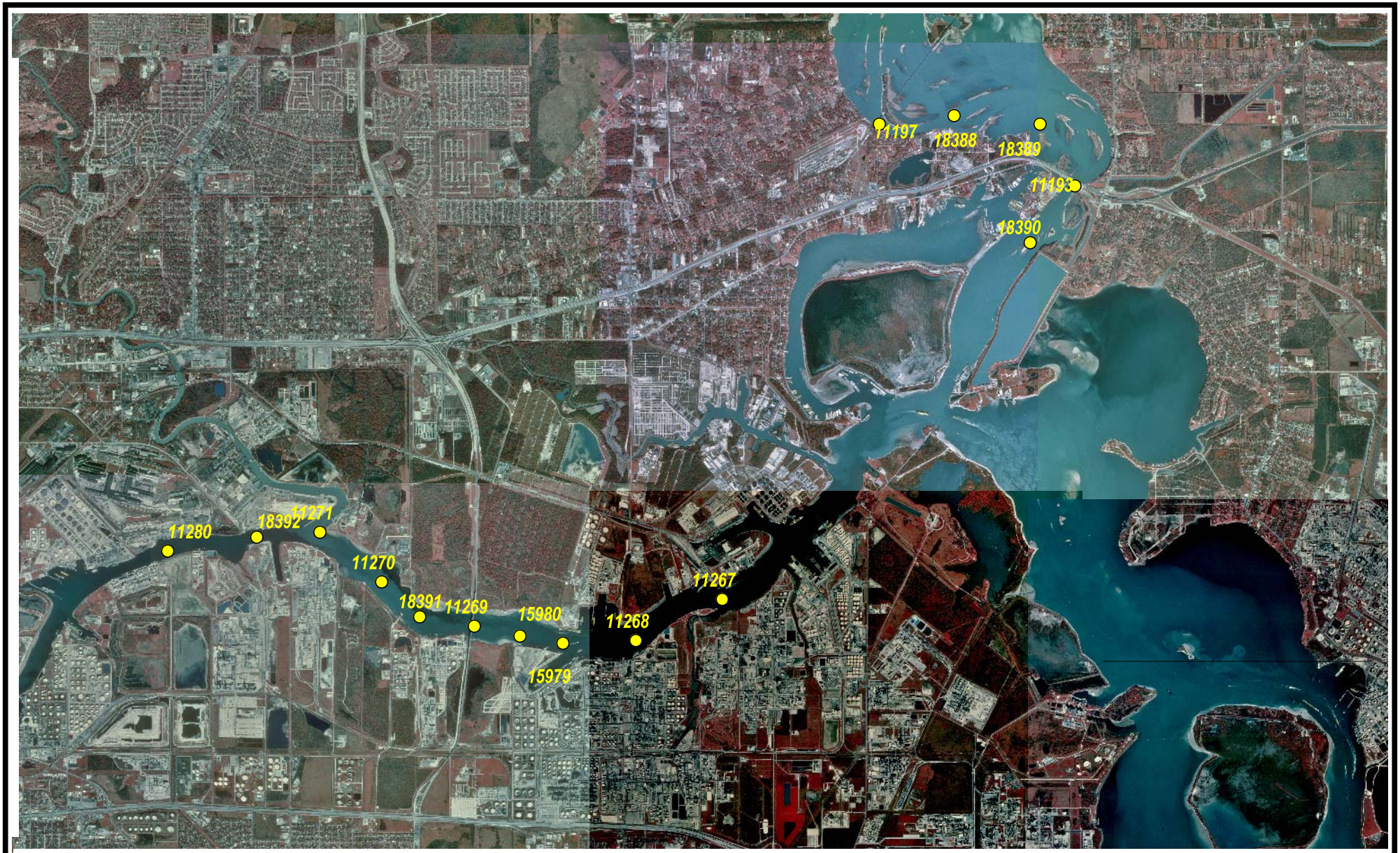
Figure 3.2
Locations for Sediment Sampling in WO7

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

Prepared by: MPS

Date: 09-09-2005



N
W E
S
2 0 2 4 Kilometers

Legend

Sampling location

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Figure 3.3
Sediment Locations Sampled in Summer 2004

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Water&Infrastructure)/ Paul Jensen (PBS&J)

TMDL for Dioxin in the Houston Ship Channel

Prepared by: MPS | Date: 11-12-2004

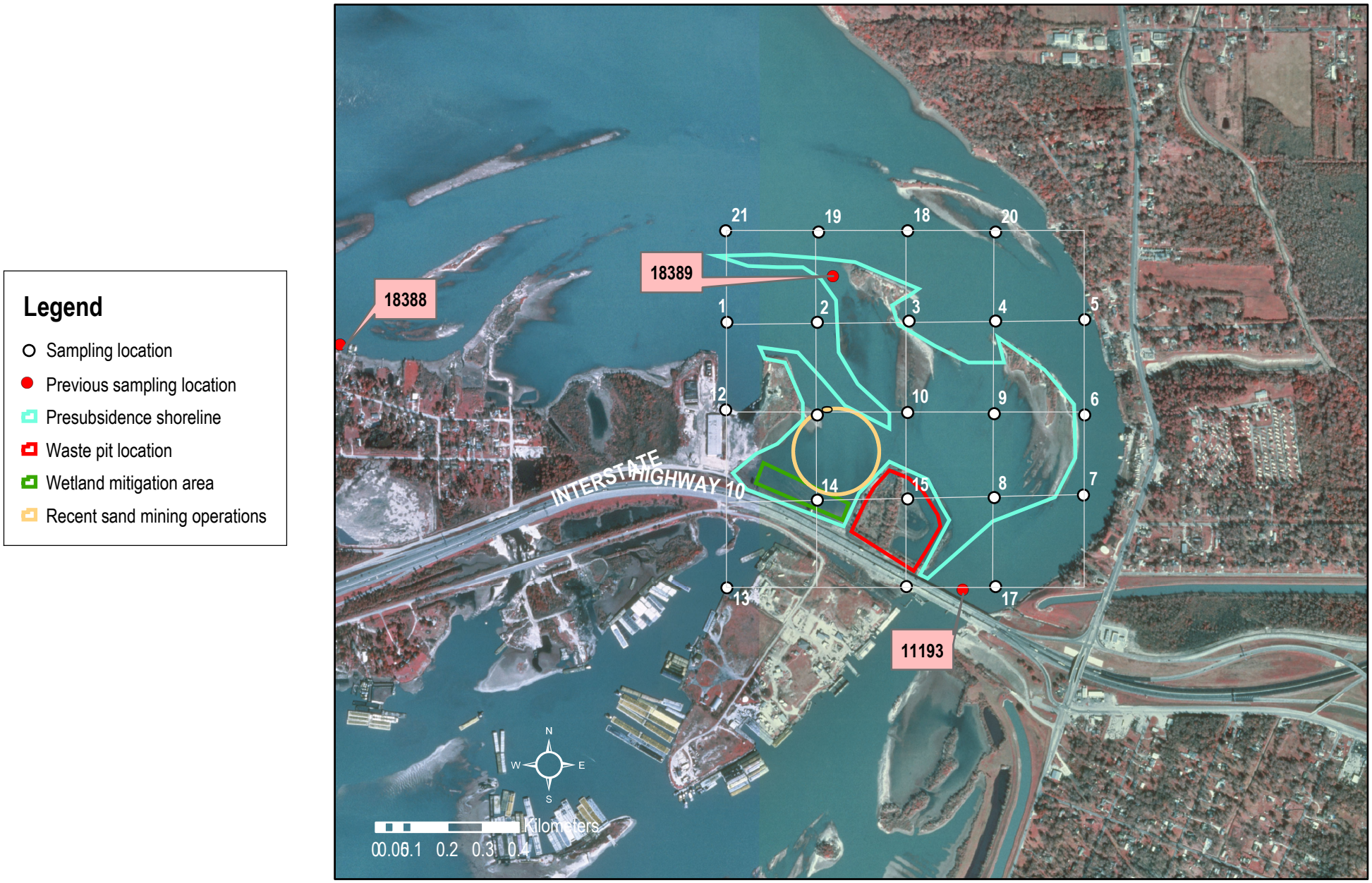


Figure 3.4 Sampled Locations in the San Jacinto River in Summer 2005

Figure 3.5a Sampled Locations in Segment 1007 in Summer 2005

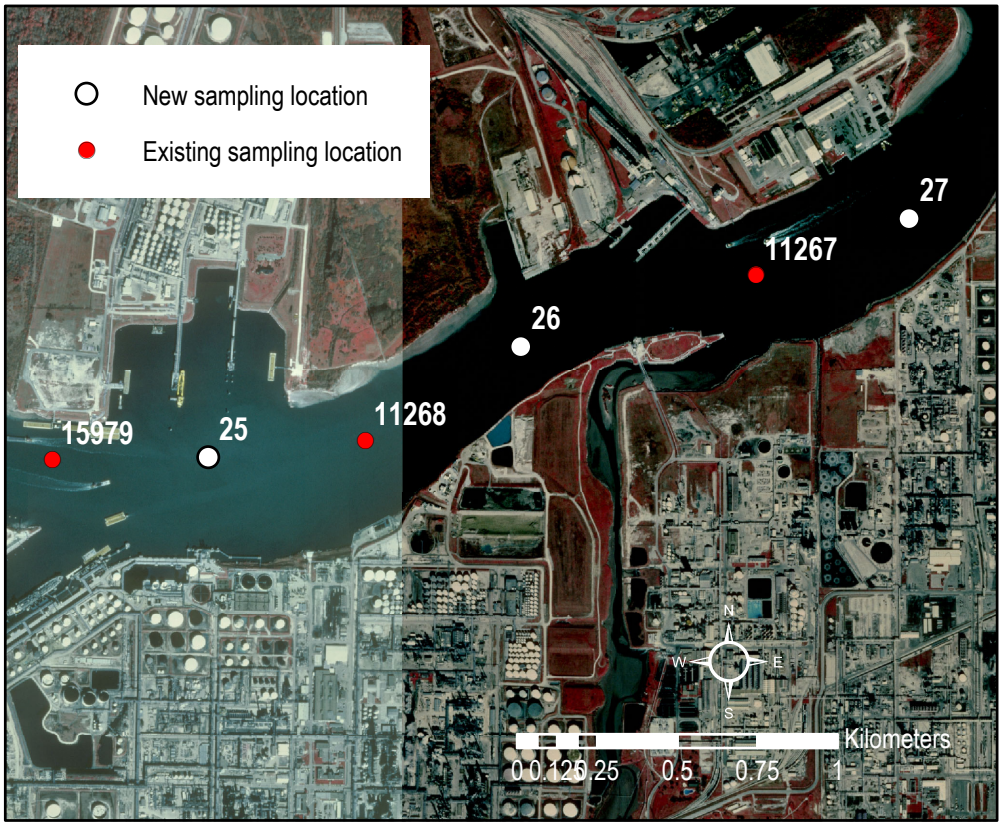


Figure 3.5b Sampled Locations in Segment 1006 in Summer 2005

Species that were sampled included hardhead catfish (*Arius felis*), blue catfish (*Ictalurus furcatus*), and blue crabs (*Callinectes sapidus*). Sample size for fish and crabs was approximately 100 g. All tissue sample collections were conducted using procedures that are consistent with those documented in the *TCEQ Surface Water Quality Monitoring Procedures Manual* (TCEQ, 2003) and according to the QAPP for this project.

Gill nets or a fishing line with bait (shrimp or chicken) were used to catch sufficient catfish to obtain 100 grams of muscle tissue. A minimum of three catfish were collected from each selected sample site to give a representative sample. A total length of 300 mm was targeted for collection for catfish. After each station collection, fish were separated, placed into a plastic bag, and placed into a cooler with ice. Once all fish samples were collected, the sampled fish were taken to the U of H field office, measured, weighed, and processed. Collected fish were filleted with a clean stainless steel knife, packed in clean foil with the dull side facing the tissue and placed into individual Ziploc® bags. Fillets were taken from the left side of the fish and, in most cases, the right side was used as a duplicate sample. All Ziploc® bags were labeled and frozen. All fish samples were packed in dry ice for shipment to the analytical laboratory. The fish tissue samples of a single species collected at a single station were composited into a single sample for analysis.

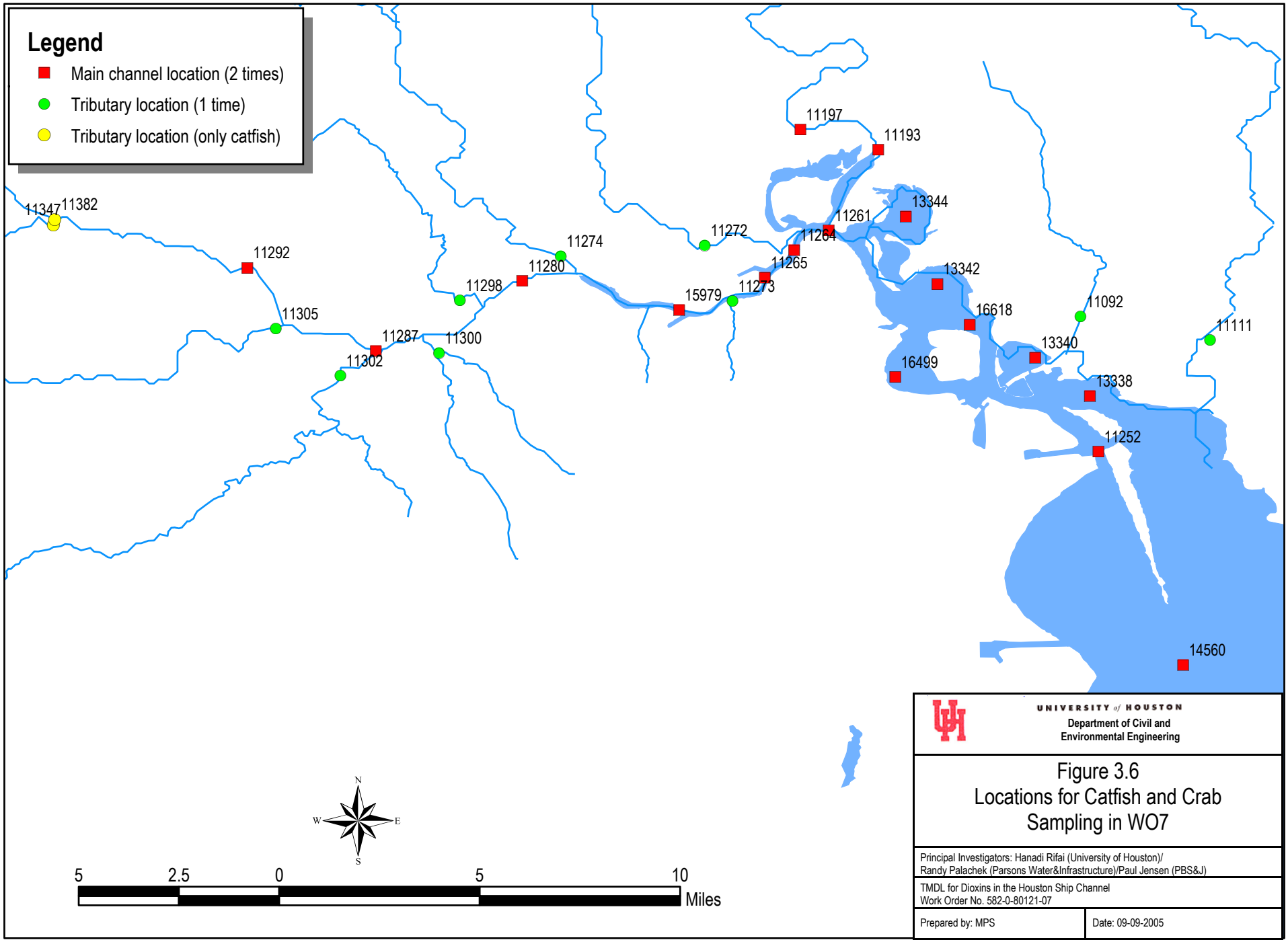
Crab tissue was harvested from blue crabs using standard plastic coated wire mesh crab traps. A minimum of three blue crabs, and typically five, were collected from each selected sample site to give a representative sample. Blue crabs with a carapace width of 125 mm and greater were targeted. Caught crabs were measured and weighed, and their edible tissue was

separated, composited, wrapped in aluminum foil, placed in a labeled Ziploc® bag, and frozen prior to shipment to the laboratory.

Preparation of tissue samples was performed in a clean working area at the U of H field office. Prior to sample preparation for each sampled site, all equipment including plastic cutting boards, stainless steel knives, scales, etc. were cleaned with distilled water, acetone, distilled water rinse, and allowed to air dry. Samples were prepared on polypropylene cutting boards that had been covered in aluminum foil with the dull side of the foil exposed. This foil was replaced after each sample was processed.

Tissue samples were packed on dry ice and shipped to the laboratory via overnight courier. Samples remained frozen until the laboratory confirmed that samples could be shipped, received and processed in the required time frame. The field teams retained a sample sized aliquot of the right side fillets of most fish samples (except the duplicate samples), and a portion of the crab tissue was kept frozen at the University of Houston field office until results were obtained and confirmed.

During WO7, 17 locations were sampled for catfish tissue twice and 11 locations were sampled once (Figure 3.6 and Table 3.2). Similarly, crab samples were collected two times from 17 locations and once from 9 locations. The locations sampled for crabs are shown in Table 3.2 and Figure 3.6. It is noted that there were two sites (stations 11347-Buffalo Bayou and 11382-Whiteoak Bayou) where no crabs were found during Spring 2004. This explains the discrepancy in the total number of sites sampled for crab tissue between the QAPP (28) and Table 3.1 of this report (26). Tables 3.3 and 3.4 present a summary of species, weight, and length of individuals composited to make catfish and crab samples, respectively.


Legend
Main channel location (2 times)
Tributary location (1 time)
Tributary location (only catfish)
11347
11382
11292
11305
11287
11302
11300
11298
11280
11274
11272
15979
11273
11265
11264
11261
11197
11193
13344
13342
16618
16499
13340
13338
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Miles
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 3.6
Locations for Catfish and Crab Sampling in WO7
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07
Prepared by: MPS
Date: 09-09-2005

Table 3.3 Catfish Tissue Samples Collected from HSC & Upper Galveston Bay

				Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Average	
Station	Date	Time	Species	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)
Spring 2004																	
11252	3/9/2004	5:40	hardhead	13.875	411	12.5	277	12.75	276							13.0	321.3
13342	03/09/04	7:30	hardhead	16.3	763.0	14.3	399.0	15.5	638.0							15.3	600.0
13340	03/09/04	5:30	hardhead	14	370	14.5	359	16.5	600	16	562	14	360			15.0	450.2
14560	03/09/04	6:15	hardhead	14.25	581	12.875	279	13.25	292							13.5	384.0
11193	03/23/04	16:00	blue	14	365	12.5	264	14.25	441	13.5	310					13.6	345.0
11261	03/24/04	11:30	hardhead	12.5	316	16.25	572	15	496	14.25	386	13	311			14.2	416.2
11264-D	04/02/04	8:10	hardhead	14.75	537	15.5	699	16.5	660	14.5	465	14.3	422			15.1	556.6
16499	03/18/04	9:50	hardhead	13.5	317	13.7	380	15	465							14.1	387.3
16618	03/18/04	10:30	hardhead	14.75	475	16	590	15.75	616	15	616	15	450	14.25	400	15.1	524.5
13344	03/18/04	12:00	hardhead	16.5	675	12.5	315	15.5	553	15.5	512					15.0	513.8
13338	03/18/04	9:00	hardhead	13	326	14.75	448	15.75	570	15.25	524	14.5	457			14.7	465.0
11197	03/24/04	8:15	blue	13.75	290	14.75	432	13.75	335	14.5	358	14.6	400			14.3	363.0
11280	04/02/04	13:30	hardhead	13.25	374	112.25	235	12.5	279							46.0	296.0
15979	03/31/04	12:00	hardhead	12.5	274	14.5	461	14	477							13.7	404.0
11287	04/02/04	9:00	blue	13.25	329	16.5	612	15.25	511							15.0	484.0
11265	04/02/04	15:00	hardhead	12.25	213	12.9	268	12.5	253	12.75	263	12.9	321			12.7	263.6
11305	04/15/04	9:50	blue	13.25	244	20.5	#NAME?	16.5	647							16.8	#NAME?
11272-A	04/15/04	14:00	blue	13	297	13.5	410	13.5	353	12.75	262					13.2	330.5
11272-B	04/15/04	14:00	blue	17.25	769	20.5	1264	23	1940							20.3	1324.3
11292	04/03/04	11:00	blue	13.5	288	15.25	494	15	422							14.6	401.3
11092	04/27/04	14:50	blue	16.75	615	14.25	412	14.25	330	15.75	491					15.3	462.0
11300	04/21/04	10:30	blue	26	#NAME?	12.50	293.00	13.80	327.00							17.4	#NAME?
11347	04/22/04	9:56	blue	15	499.00	13.25	332.00	14.75	414.00	13.50	325.00					14.1	392.5
11382	04/20/04	11:50	channel	14.5	459.00	13.50	329.00	13.00	285.00	13.50	295.00					13.6	342.0
11302-A	04/15/04	9:20	blue	14.5	368.00	12.50	295.00	9.80	92.00							12.3	251.7
11302-B	04/15/04	9:20	blue	25	1956.00	26.00	3175.15									25.5	2565.6
11298	04/22/04	13:45	blue	12.25	263.00	14.25	361.00	21.50	#NAME?							16.0	#NAME?
11274	04/21/04	13:00	blue	18	877.00	14.00	341.00	22.75	#NAME?	24.50	#NAME?					19.8	#NAME?
11273	04/21/04	13:50	hardhead	14	443.00	12.50	383.00	14.20	526.00	12.20	328.00	13.10	371.00			13.2	410.2
11111	04/27/04	13:30	blue	13.5	306.00	11.88	181.00	14.20	348.00							13.2	278.3
Fall 2004																	
11292	10/20/2004	12:00	Channel	12.8	368	16.1	654	12.6	302							13.8	441.3
11280	10/21/2004	09:30	Hardhead	12.1	276	12.5	294	12.5	290	12.8	264					12.5	281.0
11264	10/26/2004	15:07	Hardhead	15.5	520	12.8	414	12.7	268	12.5	298	13.4	431			13.4	386.2
15979	10/26/2004	12:12	Hardhead	16.0	747	14.6	625	17.1	623	16.3	628	15.5	625			15.9	649.6
11265*	10/26/2004	10:20	Hardhead	15.2	693	13.7	456	14.8	546	15.7	562	14.2	479			14.7	547.2
11261	10/27/2004	09:22	Hardhead	15.5	580	14.8	557	15.4	506	15.9	810	16.7	965			15.7	683.6
13344	10/28/2004	14:12	Hardhead	15.2	427	16.4	790	14.8	465	16.3	620	14.8	393			15.5	539.0
11197	10/28/2004	11:40	Hardhead	18.4	1036	15.5	681	14.3	359	12.2	270					15.1	586.5
11287	10/28/2004	09:00	Blue	14.2	360	14.4	336	15.6	570							14.7	422.0
11193*	10/28/2004	10:52	Hardhead	13.8	363	13.2	308	13.4	353	13.7	361	12.6	263			13.3	329.6
16499	10/29/2004	09:20	Hardhead	15.5	505	14.8	444	16.3	544	14.9	433					15.4	481.5
13342	10/29/2004	08:40	Hardhead	16.7	598	15.5	478	16.9	642	16.5	568	17.8	598			16.7	576.8
16618	11/03/2004	12:05	Hardhead	16.2	728	16.6	717	15.0	599	15.9	664	17.6	852			16.3	712.0
14560	11/03/2004	08:30	Hardhead	16.2	612	13.1	312	15.4	440	17.9	777	16.9	810			15.9	590.2
11252	11/03/2004	10:10	Hardhead	15.2	608	14.0	374	13.4	252	16.1	748	14.6	474			14.7	491.2
13338	11/05/2004	09:20	Hardhead	13.3	374	13.2	229	14.0	394	14.5	574	15.0	555			14.0	425.2
13340	11/05/2004	10:01	Hardhead	16.2	681	16.0	683	12.4	244	16.7	691					15.3	574.8

* Duplicate taken from right side of sample.

Table 3.4 Blue Crab Tissue Samples Collected from HSC & Upper Galveston Bay

			Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7	
Station	Date	Time	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)	Length (in)	Weight (g)
11252	3/9/2004	5:40	2.75	23	4.375	60	5.875	163								
13342	03/09/04	7:30	6.8	199.0	6.8	246.0	6.9	205.0	7.3	324.0	7.3	258.0				
13340	03/09/04	5:30	5.25	108	6.25	209	5.75	104	6.25	159	5	108				
14560	03/09/04	6:15	3.5	40	7	297	6.7	176								
11193	03/23/04	13:10	6.25	232	7	238	5.625	122								
11261	03/19/04	10:00	6.125	173	5.75	127	5.75	138	5	90						
11264	03/23/04	15:00	5.75	110	5.125	112	5.25	114	4.5	83	4.25	55				
16499	03/17/04	15:30	5.375	138	5.25	91	5.375	133	6.875	190						
16618	03/18/04	10:00	7.125	332	6.25	187	6.875	249								
11261	03/23/04	14:30	6.25	217	6.625	228	6	180	6.25	164	6	165				
13344	03/18/04	12:00	7.125	281	7.375	289	6.5	233	5.375	122						
13338	03/17/04	9:00	5.875	169	5	96	5.75	124	5.5	155	5.25	101				
11197	03/23/04	13:45	5.75	128	5.875	115	4.5	66	4	51						
11280	04/01/04	12:40	6.5	224	6.125	148	6.25	193	5.375	139	6	130	5.5	104		
15979	03/31/04	16:30	7	296	5.75	178	6.875	178	6.25	168	6	165	6	173		
11287	04/01/04	13:00	6.875	275	6.25	169	6	152	6.75	222	6	169				
11265	03/30/04	12:00	6.625	155	5.75	143	6.5	171	5.125	101						
11305	04/22/04	12:35	5.8	114	4.5	82	6	129	5.5	79	5.6	136	5.1	100	5	108
11272	04/13/04	14:00	4	50	4.25	47	4.5	73	4.5	74	4.3	61				
11292	04/03/04	11:00	4.25	55	4.2	55	4.3	70	3.9	43	4.25	52	4.3	58		
11092	04/30/04	8:30	5.75	170	5.8	149	6.25	233	5.5	133						
11300	04/16/04	8:40	6.2	153.09	5.75	147.42	6.00	130.41	5.20	116.23	4.75	76.54	5.20	96.39		
11302	04/14/04	12:00	5.5	133.24	4.50	85.05	5.20	113.40	5.50	121.90	5.20	85.05				
11298-D	04/20/04	14:15	5.9	73.71	5.50	113.40	6.50	130.41	6.30	147.42	5.30	99.22	6.00	116.23		
11298	04/20/04	14:15	5.25	124.74	5.20	121.90	5.90	167.26	5.25	113.40	5.50	110.56	5.75	104.89		
11274	04/20/04	15:10	5.25	93.55	4.30	56.70	4.90	70.87	4.50	56.70	4.25	31.18	4.00	53.86		
11273-D	04/21/04	13:50	7.3	292.00	7.50	283.50	7.00	260.82	6.75	226.80	7.00	221.13	6.25	232.47		
11273	04/21/04	13:50	7.5	334.52	7.25	243.81	7.25	229.63	6.80	229.63	6.50	187.11	6.25	204.12		
11111	04/27/04	13:30	5.8	155.92	5.20	153.09	6.00	155.92	5.30	136.08	6.30	170.10	5.10	113.40		
Fall 2004																
11287	10/19/2004	14:20	5.5	98	6.1	231	6.5	237	5.7	166	5.6	163				
11280	10/20/2004	13:30	6.5	234	6.1	175	6.5	255	6.0	260	6.1	163				
11292	10/20/2004	12:33	6.0	149	6.1	161	6.8	241	6.3	183	6.5	201	5.1	155	5.5	156
11264	10/21/2004	10:40	5.6	147	5.4	152	6.4	288	6.0	153						
15979*	10/21/2004	10:20	6.2	192	6.5	182	6.4	189	6.8	199	6.8	269	5.7	158		
11265	10/21/2004	10:30	6.3	253	6.9	266	6.7	204	6.5	220	6.4	195				
13344	10/21/2004	11:20	6.6	182	7.4	156	6.2	117	5.1	86	7.2	183				
11252	10/26/2004	17:23	7.0	301	5.7	97	7.2	334	6.5	131	5.8	114	7.2	242		
11261	10/26/2004	16:30	6.0	203	6.5	222	6.7	208	7.0	326	7.0	385				
13342	10/28/2004	14:48	7.3	263	6.2	182	7.4	178	7.1	190	7.0	192				
11193*	10/27/2004	10:04	7.1	277	7.3	289	6.9	174	7.3	252	7.0	190				
11197	10/28/2004	11:40	8.0	336	7.1	181	7.5	326	7.2	246	7.2	265				
13340	11/03/2004	13:34	6.2	183	5.9	173	6.2	166	6.8	248	6.9	289	6.4	187		
16618	11/02/2004	17:00	6.6	161	5.8	137	6.5	199	6.6	227	6.3	149	7.1	414		
16499	11/08/2004	14:50	6.4	204	6.3	216	7.1	249	6.0	161						
14560	11/04/2004	08:15	6.4	227	6.6	213	6.0	192	6.2	200	7.2	312	5.5	147		
13338	11/02/2004	14:15	6.5	171	7.1	213	7.0	170								

* Duplicate taken from right side of sample.

3.1.1.4 Sediment Core Sampling

The ability to collect sediment cores that are adequate to address the objectives of the project has been challenging, considering the heavily impacted and commercially active nature of the Houston Ship Channel (HSC), upper Galveston Bay and the lower San Jacinto River, where this research is focused. Numerous field trips were necessitated to acquire usable cores: 5/21/04 - Reconnaissance trip: project team visited all of the prospective field sites to determine where it may be best to attempt coring.

6/16/04 - Sampling trip 1: Five aqueous sampling sites were visited and a total of 15 cores were collected. Of these, the core collected at station 11261 was appropriate to begin processing for analytical work.

8/4/04 - Sampling trip 2: Five aqueous sampling sites were visited and a total of 10 cores were collected. Of these, the core collected at station 15244 was appropriate to begin processing for analytical work.

8/30/04 - Sampling trip 3: Five aqueous sampling sites were visited and a total of 6 cores were collected. Of these, cores collected at stations 11193 and 15979 were chosen to begin processing for analytical work.

10/18/04 – Sampling trip 4: Three sampling sites were visited and a total of 3 cores were collected. Of these, station 11270 was chosen for processing.

11/8/04 – Sampling trip 5: Two sampling sites were visited and a total of 6 cores were collected. Of these, none were deemed satisfactory for processing by UH researchers.

12/10/04 – Sampling trip 6: Two forested wetland sites within the lower reaches of the Trinity River floodplain were visited and a total of 4 cores were collected. Of these, station FW1 was chosen for processing.

2/17/05 – Sampling trip 7: Six sites were visited and three were sampled. Out of that a total of 11 cores were collected, cores from stations 16499 and 13337 were chosen for processing.

All sub-aqueous cores have been collected by divers. The 6" diameter PVC core sleeves were driven into the sediments to refusal, capped and stored upright for transportation to the laboratory where they were immediately processed. Replicate x-ray trays were collected in the same fashion at each station to allow for preliminary examination of the stratigraphy at each site, in an effort to process only those cores that may yield useful results. Each selected core was then sectioned at 1cm intervals using a sterilized spatula to avoid cross-contamination. Sediment aliquots for dioxin determination were stored in amber bottles at 4^{o}C until delivery to the laboratory. Figure 3.7 shows the locations of the collected sediment cores.

3.1.2 Assessment of Major Sources, Transport and Fate of Dioxins in the Houston Ship Channel

The objective of this task is to assess the relative importance of the potential sources of dioxin in the HSC and its transport and fate in the environment. This task addresses tributary water sampling, air deposition (dry and wet) measurements, and stormwater runoff sampling.

During WO7, 11 locations at the mouths of major tributaries were sampled using high-volume units twice (Spring and Fall 2004). Ambient air and dry deposition sampling was

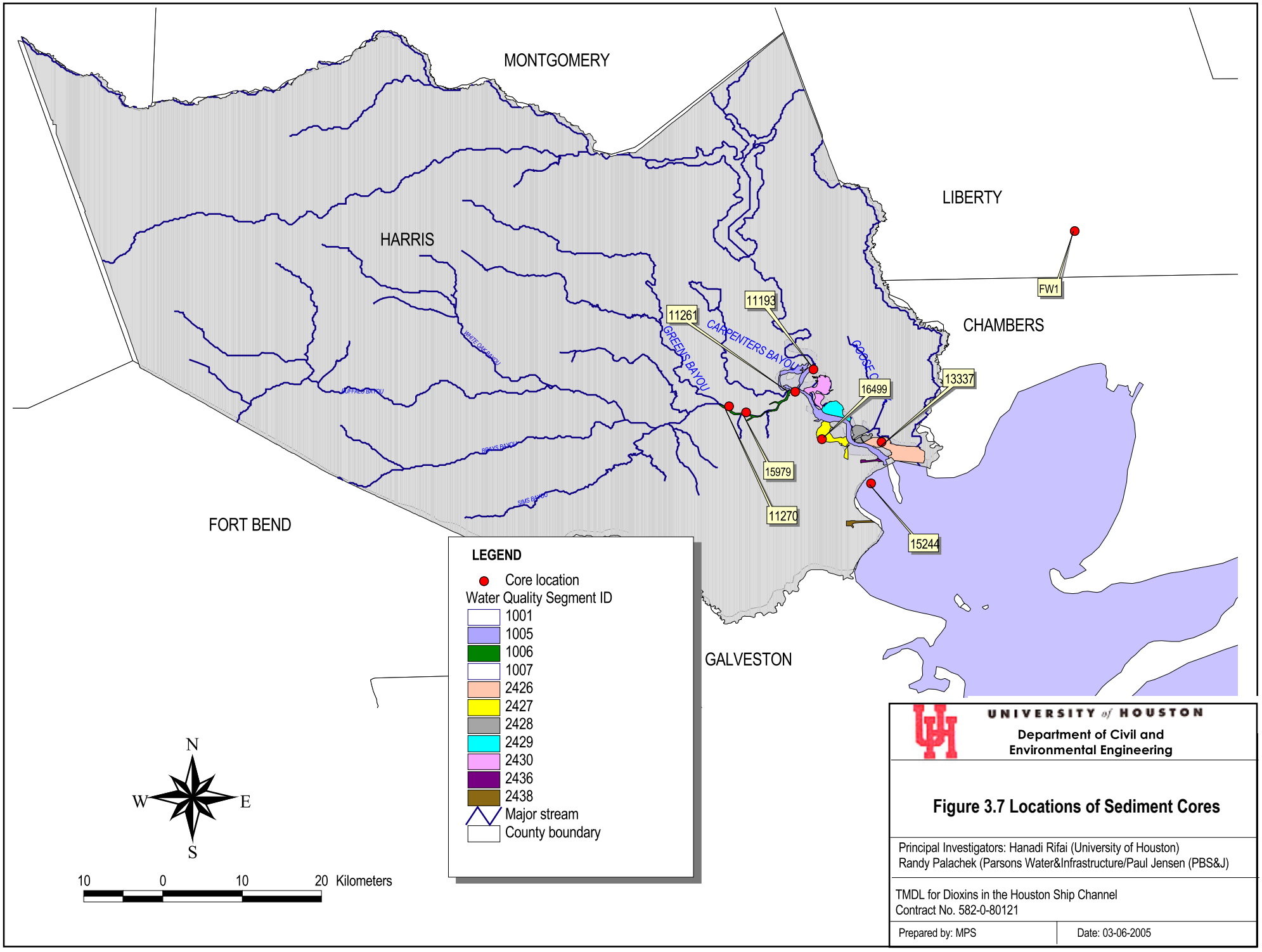

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Figure 3.7 Locations of Sediment Cores

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TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 03-06-2005

conducted at two locations 4 times and at 1 location 4 times, respectively. Wet deposition was sampled at one location three times and bulk deposition twice. In addition, eight locations were sampled for stormwater runoff. Table 3.5 includes a summary of the total number of samples collected in WO7 for assessing major sources of dioxin to the HSC.

A description of the sampling locations, media, frequency, and sampling methodology is presented in the following sections.

3.1.2.1 Water Sampling

In-stream water samples were collected at the confluences of the tributaries with the main system to assess dioxin levels that are coming from the tributary or are "background" concentrations. During Spring and Fall 2004, a total of 11 sites were sampled for water using the high-volume technique (Figure 3.1 and Table 3.2). Sample collection followed the procedure described in section 3.1.1.1 of this report and was consistent with the requirements specified in the QAPP for the project.

3.1.2.2 Air Sampling

During WO7, ambient air concentrations of dioxins and furans were monitored intermittently between December 2003 and August 2005 at two sampling locations: Clinton Drive (C403) and Lang Road (C408) (Figure 3.8). Due to the ultra trace levels of dioxins in the air, monthly and bi-monthly sampling events were planned to obtain enough sample volume for dioxin analysis.

Wet and dry deposition was concurrently measured at Clinton Dr and Lang Road from December 2003 to April 2004 and at Clinton Dr from September 2004 to February 2005 and from June to December 2005 (ongoing sampling). Likewise bulk deposition was measured at

Table 3.5 Number of Samples Collected in Support of Sources and Transport Assessment

Matrix	Winter-Spring 2004			Summer-Fall 2004			Winter-Spring-Summer 2005		
	# sites	QC samples[a]	total # samples	# sites	QC samples[a]	total # samples	# sites	QC samples[a]	total # samples
Water from tributaries - *XAD Column*	11	2	13	11	0	11			
- *Filter*	11	1	12	11	0	11			
Air - *Ambient*	2(*4*)[c]	3(*2*)[c,d]	14	1(*2*)[c]	0	2	1(*2*)[c,e]	0	2
- *Particulate(by size)*	2(6)[f]	1(*2*)[c]	14	1(6)[f]	1	7			
- *Dry Deposition*	2(*3*),1(*1*)[c]	1(*2*)[c]	9	1(*2*)[c]	0	2	1(*2*)[c,e]	0	2
- *Wet Deposition*	1(*1*)[c]	0	1	1(*1*)[c]	0	1	1(*1*)[c,e]	0	1
- *Bulk Deposition*				1(*1*)[c]	0	1	1(*1*)[c,e]	0	1
Runoff - *XAD Column*				1	0	1	7	0	7
- *Filter*[g]				1(*2*)[g]	0	2	7(*2*)[g]	0	14
- *Soil*				1(*1*)[c]	0	1	7(*1*)[c]	0	7
- *Sediment*				1(*6*)[h]	0	6	7(*5*)[h]	0	35

[a] Field duplicates, field blanks and recovery columns specified in the QAPP
[b] Including samples collected in previous quarter
[c] Number in parentheses and italics indicates sampling frequency
[d] QC samples (duplicates at both sites plus a blank) were collected only for the two first sampling events
[e] The last sample is being collected (June 2005 to December 2005)
[f] Number is parentheses and italics indicate number of particle-size stages
[g] 1-µm and 40-µm were analyzed separately, number in parenthesis indicate number of filters per site
[h] Number in parentheses and italics indicate number of land use types sampled per site

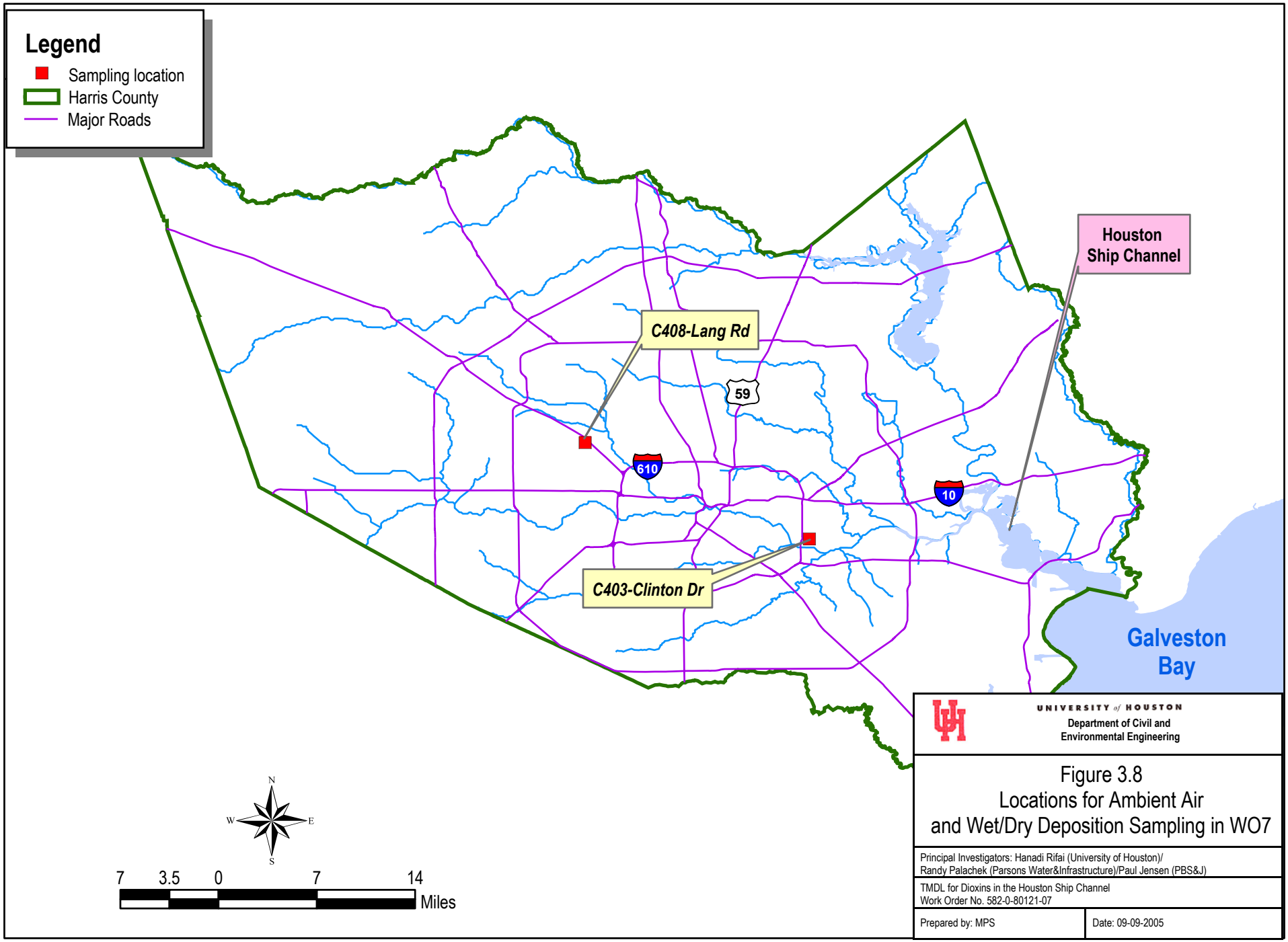

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Figure 3.8
Locations for Ambient Air and Wet/Dry Deposition Sampling in WO7

Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

Prepared by: MPS

Date: 09-09-2005

Clinton Dr. twice (including an ongoing event). In addition to ambient air, the distribution of dioxins by particle size was sampled at Clinton Dr. three times. Samples were sent to the selected laboratories to be analyzed for dioxins using EPA method TO-9A (ambient air, particulate size, and dry deposition) and EPA 1613B (wet and bulk deposition).

Ambient air samples were collected using high-volume samplers designed to collect both vapor and particle bound phases. In these samplers, air is first drawn through a quartz micro-fiber filter (QFF) where atmospheric particles of >0.1 μm in diameter are trapped. Air then passes through a polyurethane foam plug (PUF) used to remove the vapors from the air stream. Quartz filters were replaced on a weekly-basis to avoid significant pressure drops through the system. So, for example, at the end of a monthly event, a sample consisting of 4 QFF filters and 1 PUF were shipped to the laboratory for dioxin analysis. The airflow rate was calibrated to 0.25 m^3/min prior to initiation of the sampling event. At this flow rate, a minimum of 6000 m^3 of air was processed during the sampling period. The sampler motors were replaced every 500 hours of operation to avoid motor malfunctions that might cause loss of sample. QFFs were baked at 400°C for 5 hours and dried in a clean atmosphere prior to use. Likewise, the PUF adsorbent plugs were subjected to a 16-hour Soxhlet extraction with acetone at approximately 4 cycles per hour to ensure cleanliness. The PUF plugs are then air dried in a clean atmosphere, placed in glass cartridges, and spiked with $^{37}Cl_4$-2378-TCDD. The PUF plugs are wrapped in aluminum foil for protection from light prior to their use in the field.

Wet/Dry deposition samples were collected using modified automated precipitation collectors. Because these samplers were originally designed to collect only rain samples for wet deposition, they have been modified to include dry deposition sample collection. The modified

sampler consists of two separate compartments where rainwater (wet event) and falling particles (dry event) are collected. The sampler is equipped with a rain sensor and a controller. The controller records the time corresponding to the total and dry events. The dry deposition compartment consists of an inverted translucent glass fiber Frisbee with a sharp edge (<10°) mounted on a mechanical actuator. The edge design minimizes abrupt interruptions of the wind path that might affect the deposition process. The face of the Frisbee exposed to the ambient air is covered with a one-foot diameter disk of Velcro brand loop material to collect the falling particles. When raining, the sampler is designed to automatically retract the dry deposition Frisbee, cover it with a lid, and expose the rain collector compartment. During dry periods, the rain collector is covered and the dry deposition disk is exposed to the environment. The rain collector compartment consists of an aluminum funnel with an area of 0.212 m^2 and a depth of 0.46 m. This funnel is connected to a XAD-2 resin column, wrapped in aluminum foil, where dioxins/furans are removed from the rainwater stream. To avoid losses and/or potential degradation of the sample, the dry deposition Velcro brand loop sampling material was replaced on a weekly basis.

The bulk (wet + dry) deposition sampler is an open-aluminum funnel with an area of 0.372 m^2. Similarly to the wet/dry deposition units, the funnel is connected to a XAD-2 resin column wrapped in aluminum foil. The columns are regularly replaced with fresh ones. The used columns are wrapped in aluminum foil and then stored at 4°C in darkness. At the end of the sampling event, the columns are composited and analyzed for dioxins and furans.

Particle size distribution of associated dioxins and total organic carbon (TOC) samples (in ambient air) were collected using two high-volume total suspended particle (TSP) pumping

systems equipped with five-stage cascade impactors. Aerosol particles were separated into six size fractions on glass- and quartz-fiber filters according to the following equivalent cutoff diameters: first stage >7.2 μm, second stage 7.2-3 μm, third stage 3.0-1.5 μm, fourth stage 1.5-0.95 μm, fifth stage 0.95-0.49 μm and backup filter <0.49 μm. Slotted glass and quartz-fiber filters (SQFF) were used as collection substrates. Similarly to QFFs used in the collection of ambient air samples of dioxins, the filters were baked at 400°C for 5 hours and dried in a clean atmosphere prior to use. The cascade impactors were adjusted to run at a flow rate of 1.13 m^3/min. The samplers were programmed to run 6 days/week, 4weeks/month. On the seventh day, the filters were replaced to avoid significant pressure drops. Similarly to ambient air samplers, the motors were replaced every 500 hours of operation to avoid motor malfunctions that might cause loss of sample.

3.1.2.3 Runoff Sampling

For storm water sampling, ten tentative sites were selected from 25 Harris County Flood Control District (HCFCD) candidate drainage ditches. All sites have the following characteristics:

- No dry weather flow;
- Channelized (or pipe) cross section with easy to establish stage-discharge relationship;
- Safe and adequate access (e.g., roadway overpass that is amenable to lane closure or other off-road parking and working areas);
- More than 50% of the drainage area with the same land use/land cover;
- More than 50% of the drainage area with the same soil type; and
- Close to air sampling sites.

All sites were visited prior to sampling to ascertain access, identify safety issues, and to deploy stage markings for later use. During WO7, eight locations (Figure 3.9) were sampled for stormwater runoff using a high-volume unit (Infiltrex 300). Sampling typically proceeded in the following manner:

First, using radar images and weather reports, a sampling team mobilized to a preselected sampling site in advance of the storm. Upon arrival at the sampling site, the booster pump and discharge line were placed in the stream and sampling was initiated using the high-volume equipment that was located in a suitable location on the bank. The gear pump on the Infiltrex drew from the stainless steel reservoir while the booster pump continuously pumped runoff water from the channel. This arrangement was required due to the low suction lift capability of the Infiltrex unit gear pump. The team continued sampling until the desired sample size (i.e. 700 L) was achieved. The standard high-volume equipment was supplemented with extractable 40 micron pre-filters installed before the standard 1 micron filters to extend filter run times under heavy solids loading and minimize primary filter changes. All filters and pre-filters used during the processing of a sample were collected for dioxin analysis.

During sample volume collection, grab samples were collected every 15 minutes. Equal amounts of all samples (250 mL) were combined into one large container and stored on ice. The composited volume was used to obtain sub-samples for total suspended solids, total dissolved solids, total organic carbon, and dissolved organic carbon . Water level and flow measurements were recorded during the event as well.

In addition, up to five surface soil and one drainage ditch sediment samples were collected from within each of the eight runoff sampling drainage areas, generating a total of forty-one

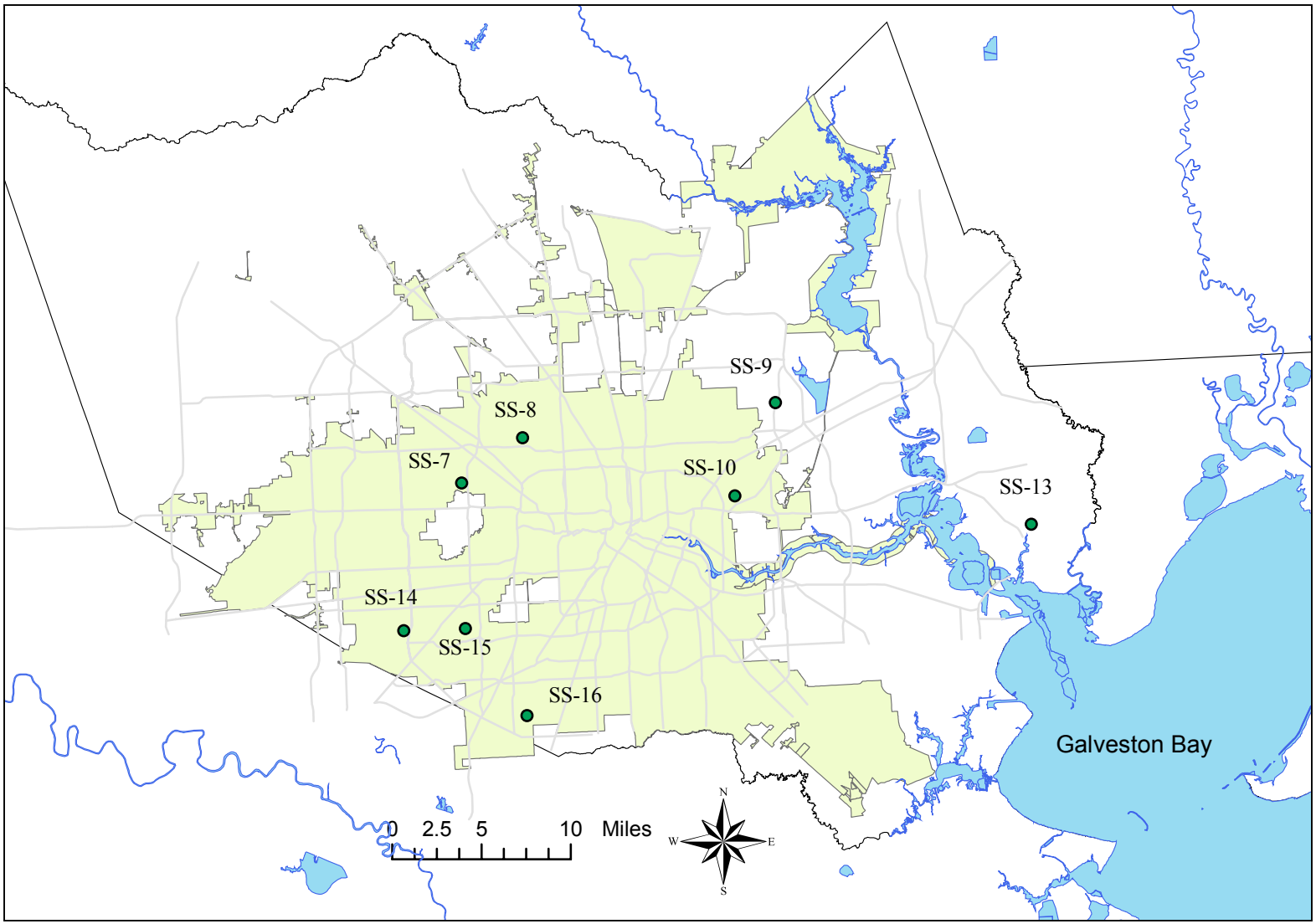

Figure 3.9 Runoff Monitoring Sites

samples. Each of the five samples within the runoff sampling drainage areas was collected from different land use categories (for example, near highways or residential areas) to have a good representation of the area. The samples were analyzed for dioxins, organic content, and particle size distribution. The dioxin concentrations observed in each of the sampling land use category will then be used as indicative of the concentrations elsewhere in the drainage area with the same land uses. Average concentrations in soil will be used along with the TSS event mean concentrations to develop a surrogate runoff load estimation method.

Figure 3.10 shows the Harris County Office of Emergency Management (OEM) rain gauges with the recorded rainfall amounts 24 hours prior to sampling. Figure 3.11 shows the amount of rain recorded prior to, during, and after the sampling event, along with the stream flow for each sampled location.

Sampling at location SS-10 (located in east Houston on an unnamed tributary to Hunting Bayou) was undertaken on December 16, 2004. A total of 707 L of stormwater runoff were processed at SS-10. Sampling at location SS-13, located in Baytown on an unnamed tributary to Goose Creek, was conducted on January 13, 2005. Total volume pumped at SS-13 was 709 L. Sampling at station SS-9, located in northeast Houston on an unnamed tributary to Greens Bayou, was undertaken on February 7, 2005. A total of 698 L of water were pumped at SS-9. Sampling at station SS-15, located in west Houston on an unnamed tributary to Brays Bayou, was conducted on February 24, 2005. The total volume sampled at SS-15 was 700 L. Sampling at SS-14 (located in east Houston on an unnamed tributary to Brays Bayou) was undertaken on March 2, 2005. A total volume of 700 L was processed at SS-14. Station SS-16, located in southwest Houston on an unnamed tributary to Sims Bayou, was sampled on March 16, 2005. A total of 700 L of water

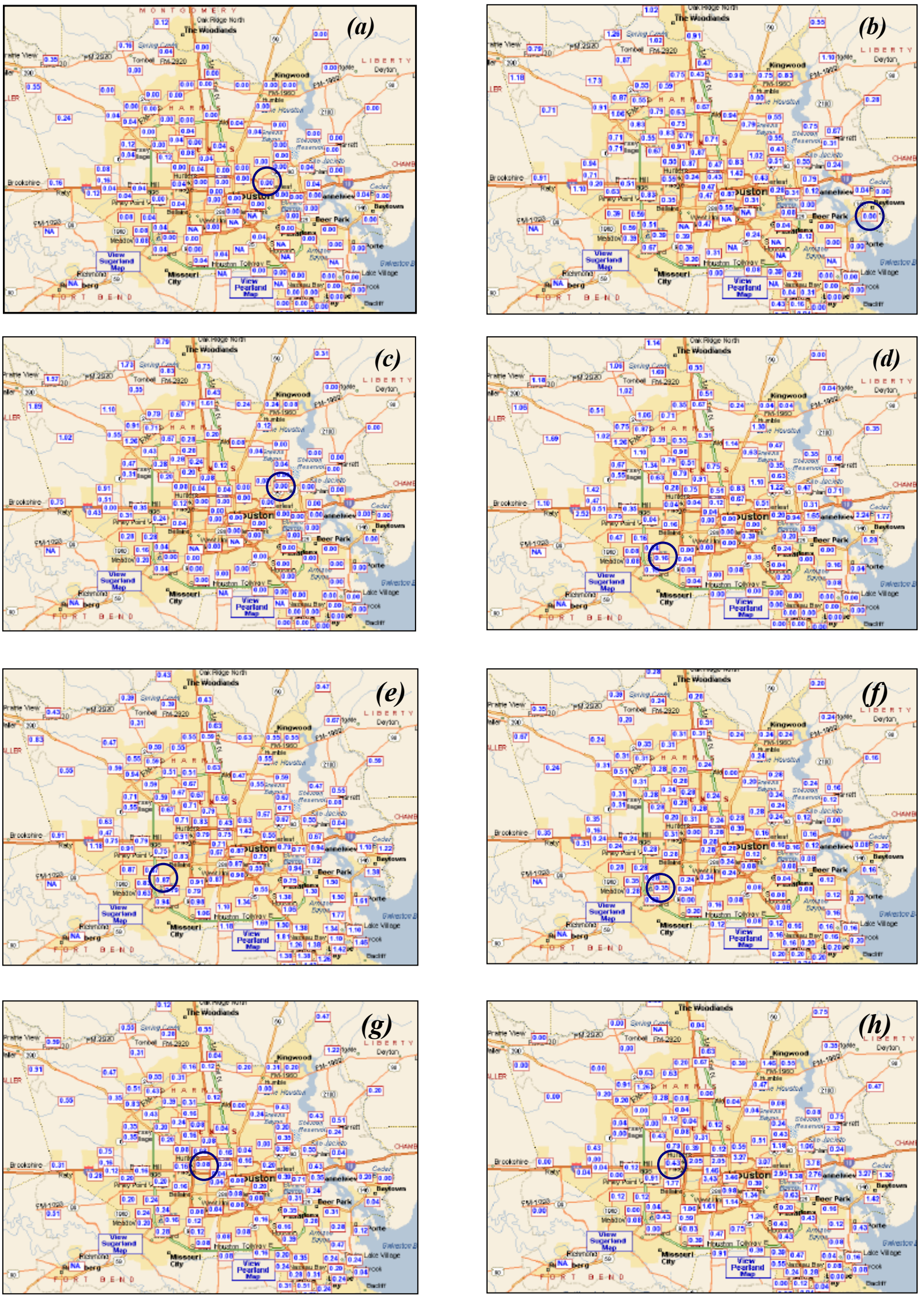

Figure 3.10 Rainfall Totals for 24-hour Period Prior to Beginning of Sampling from HCOEM
(a) Location SS-10 (b) Location SS-13 (c) Location SS-9 (d) Location SS-15 (e) Location SS-14 (f) Location SS-16 (g) Location SS-8 (h) Location SS-7

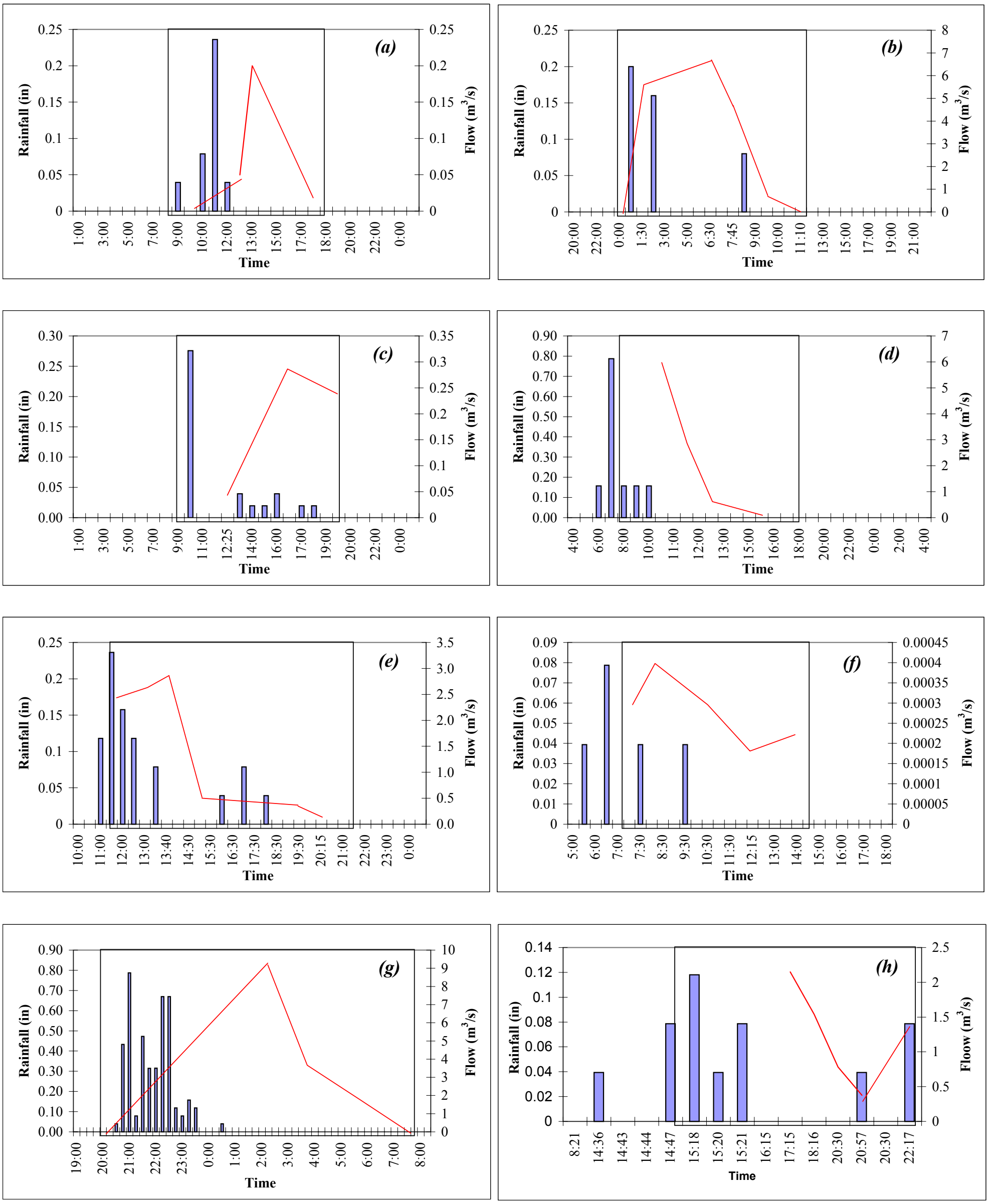

Figure 3.11 Rainfall Hyetographs and Flow During Runoff Events

(a) Sample Station SS-10 (HCOEM Gage 0830) - 16 December 2004
(b) Sample Station SS-13 (HCOEM Gage 1520) - 13 January 2005
(c) Sample Station SS-9 (HCOEM Gage 1620) - 7 February 2005
(d) Sample Station SS-15 (HCOEM Gage 0460) - 24 February 2005
(e) Sample Station SS-14 (HCOEM Gage 0475) - 3 March 2005
(f) Sample Station SS-16 (HCOEM Gage 0380) - 16 March 2005
(g) Sample Station SS-8 (HCOEM Gage 0535) - 29 May 2005
(h) Sample Station SS-7 (HCOEM Gage 2250) - 14 July 2005

were pumped through the Infiltrex unit at SS-16. Station SS-8, located in northwest Houston on an unnamed tributary to White Oak Bayou, was sampled on May 29-30, 2005. Total sample volume at SS-8 was 708 L. Sampling at station SS-7, located in west Houston on Buttermilk Creek, a tributary to Spring Branch, was undertaken on July 14, 2005. A total of 617 L of stormwater runoff were collected at SS-7.

3.1.3 Gather Information to Support Modeling

Flow measurements were conducted using an acoustic doppler profiler on a line towed boat configuration (RiverCat®) to provide data for model development. Flows and velocities were measured across transects in the HSC and major tributaries between 6 and 8 times each. Measurements were conducted at 15 locations (shown in Figure 3.12) following the standard operating procedure (SOP) included in the approved QAPP. Measured flows were used to establish a relationship between flow and the change in tide height. These relationships can be used to predict flow at any time from the change in tide height.

Flow calibration of the model requires flow data from several in-stream locations as well as from major tributaries. The flow at any point was assumed to be equal to the sum of tributary inflows, wastewater discharges, tidally-driven water movements, and runoff to the system downstream of tributary flow gages. Other minor factors affecting flow include groundwater gain and loss, water withdrawals, evaporation, and direct rainfall. Using the tide/flow relationships and tide height data, together with tributary inflow data from USGS gages, and runoff estimates from the HSPF model, it would be possible to predict and model flow over long time periods (days, months, or years) at intervals as short as six minutes. The tidally-driven currents are expected to

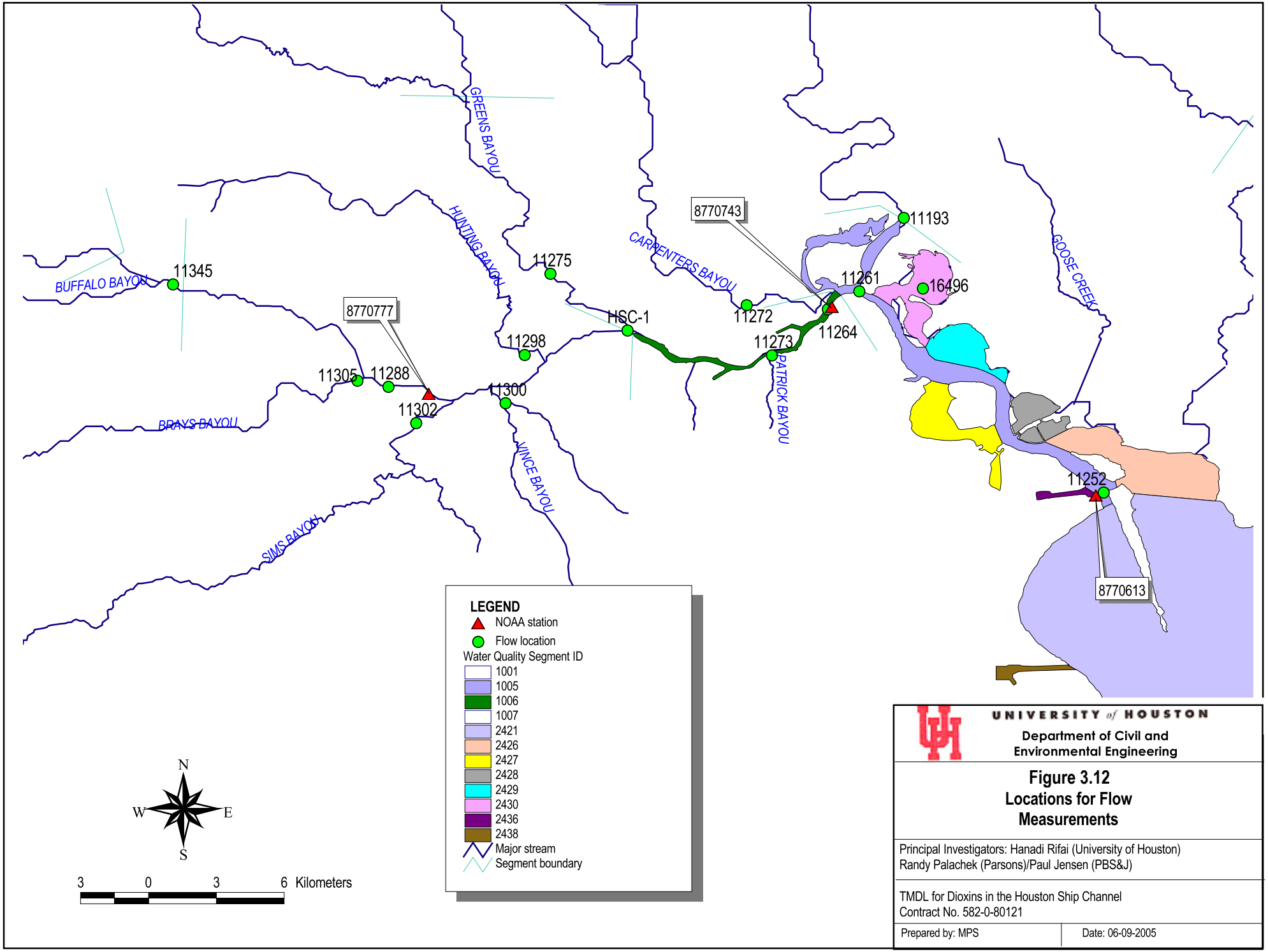

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Figure 3.12
Locations for Flow Measurements

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TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 06-09-2005

be the dominant flows, and understanding the relationship between flow and tide cycle is key to predicting flows.

Up to seven simultaneous flow/tide height measurements were performed at each of the locations in Figure 3.5 to develop the required relationships between flow and tide height. Each time flow was measured, a minimum of 4 different flow readings was collected to assure data of adequate quality. In addition, flow measurements were collected under a variety of tidal conditions, including rising and falling tides. The timing of the measurements was also important. Measurements were made at flood, ebb, and slack tide conditions to the extent possible. Also, because the relationships could be weakened if tributary inflows change substantially during the period in which flow measurements were made, the flow measurements were performed in dry weather conditions. Table 3.6 lists the locations at which sampling was conducted as well as the measured parameters.

3.2 SAMPLING RESULTS

This section provides a summary of data collected as part of Work Order 7. The data include field water parameters (dissolved oxygen, pH, salinity, and water temperature), physical characteristics of water and sediment samples, and dioxin levels for the collected samples.

To date, 100% of the results for dioxin for Spring, Summer, and Fall 2004, and Spring 2005 samples have been received and verified, while dioxins results for the Summer 2005 samples have not been received as of this writing.

Table 3.6 Summary of Locations for Flow Measurements

Station ID	Station Description	Segment	Waterbody		Data from other Agencies		
				Parameters Measured[a]	Agency	Station Description	Parameters Retrieved[a]
11193	San Jacinto River Tidal IH 10 Bridge East of Channelview	1001	Houston Ship Channel	Q, V, D, T, C, S			
11252	Houston Ship Channel at CM 91, Morgan's Point	1005	Houston Ship Channel	Q, V, T, C, S	NOAA CO-OPS[b]	8770613 - HSC at Morgan's Point	GH
11261	Houston Ship Channel San Jacinto River at Lynchburg Ferry	1005	Houston Ship Channel	Q, V, T, C, S	NOAA CO-OPS[b]	8770743 - HSC at Battleship Texas Park[c]	GH
11264	Houston Ship Channel at San Jacinto Park, West of Battleship	1006	Houston Ship Channel	Q, V, T, C, S	NOAA CO-OPS[b]	8770743 - HSC at Battleship Texas Park	GH
HSC-1	Houston Ship Channel at segment 1006/1007 boundary, just upstream of confluence with Greens Bayou	1006/1007	Houston Ship Channel	Q, V, D, T, C, S			
11288	Houston Ship Channel/Buffalo Bayou at IH610	1007	Houston Ship Channel	Q, V, T, C, S	NOAA CO-OPS[b]	8770777 - HSC at Manchester	GH
11272	Carpenter Bayou Tidal at South Sheldon Rd in Channelview	1006	Carpenter Bayou	Q, V, D, T, C, S			
11273	Patrick Bayou Tidal immediately upstream of bridge leading to Occidental Chemical Intake Station	1006	Patrick Bayou	Q, V, D, T, C, S			
11298	Hunting Bayou tidal at Federal Road bridge in Houston	1007	Hunting Bayou	Q, V, D, T, C, S			
11300	Vince Bayou at North Richey St. in Pasadena, TX	1007	Vince Bayou	Q, V, D, T, C, S			
11302	Sims Bayou at Lawndale Ave. in Houston	1007	Sims Bayou	Q, V, D, T, C, S			
11305	Brays Bayou at Broadway Blvd. south of Houston	1007	Brays Bayou	Q, V, D, T, C, S			
11345	Buffalo Bayou Tidal at Mckee St.	1013	Buffalo Bayou	Q, V, D, T, C, S			
11275	Greens Bayou Tidal at I-10 Bridge	1006	Greens Bayou	Q, V, D, T, C, S			
16496	Burnet Bay 1.5mi east of North Lynchburg Ferry Landing, 1.2mi NE of HSC24	2426	Burnet Bay	Q, V, D, T, C, S			

[a] Q = flow, V = stream velocity, D = water depth, T = water temperature, C = conductivity, S = salinity, GH = gage height

[b] National Oceanic and Atmospheric Administration, Center for Operational Oceanographic Products and Services

[c] The NOAA station located in Battleship Texas will be used for this site as the NOAA Lynchburg Ferry station is inactive

3.2.1 Assessment of Current Levels and Trends of Dioxins in the Houston Ship Channel

3.2.1.1 In-stream Water Quality Sampling

Table 3.7 provides a summary of field parameters measured during in-channel water sampling activities and Table 3.8 presents the results of the physical properties of water-column samples analyzed by North Water District Laboratory Services (NWDLS). Vertical profiles of field parameters are shown in Figure 3.13. Data in Figure 3.13 indicate that, in general, stations in the main channel exhibited thermal and/or salinity stratification, while stations in the side bays showed little change in temperature and salinity with depth. This is relevant for bottom sediment-water partitioning calculations.

A summary of dioxin/furan concentrations in water samples collected in WO7 and the resulting Texas-TEQ levels is provided in Table 3.9. It is noted that PSC Analytical reported dissolved (XAD-2 resin) and suspended (filter) levels on a mass basis (in picograms), thus, dissolved and suspended concentrations were calculated by dividing those results by the sampled volume and adding them up to obtain the total concentration in water presented in Table 3.9. Maps illustrating total TEQ concentrations in water for the Spring and Fall 2004 sampling events are shown in Figure 3.14. Overall, dioxin concentrations in water for Spring 2004 varied between 0.089 and 1.252 pg TEQ/L with an average value of 0.409 pg TEQ/L. Dioxin concentrations in water samples collected in Fall 2004 varied between 0.075 and 0.877 pg TE/L with an average value of 0.34 pg TEQ/L. It is noted that dioxin levels in water exceeded the water quality standard (0.0933 pg TEQ/L) at 94% of the locations sampled in Spring 2004 and 94% of the locations sampled in Fall 2004. The highest TEQ levels in the Spring samples were measured at stations

Table 3.7 Field Measurements during Water Sampling Activities

Station ID	Date	Time	Depth (m)	Temperature (°C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity (°/oo)
Spring 2004								
13340	03/09/2004	09:52	0.4	18.7	NA	11.9	8.6	NA
			0.6	18.7	NA	11.6	8.5	NA
			1.1	18.1	NA	8.1	8.3	NA
		15:25	0.4	20.1	NA	13.7	8.5	NA
			0.6	20.1	NA	13.7	8.6	NA
			1.1	20.1	NA	13.7	8.6	NA
11252	03/10/2004	11:15	0.5	18.1	14300	8.1	5.7	9.7
			1.5	17.8	14800	7.9	6.1	10.1
			2.5	17.7	15300	8.0	6.4	10.6
			4.0	17.6	15400	8.0	6.5	10.7
		16:50	0.5	18.0	15200	8.3	6.1	10.4
			2.0	17.7	15300	8.3	6.5	10.6
			3.5	17.6	15400	8.4	6.7	10.7
			5.0	17.5	15100	2.2	6.7	10.4
14560	03/11/2004	09:03	0.4	17.2	16800	8.6	5.4	11.8
			1.6	17.2	16800	8.6	6.1	11.8
			3.0	17.2	16900	8.5	6.0	11.8
		15:35	0.4	19.4	15200	11.8	7.2	10.1
			1.6	18.6	16500	11.3	7.6	11.2
			2.9	17.4	17400	9.2	7.5	12.2
13342	03/12/2004	10:36	0.3	17.9	NA	8.8	6.4	NA
			0.8	17.8	NA	8.7	6.3	NA
			1.8	17.9	NA	8.5	6.0	NA
		15:52	0.3	18.5	NA	8.7	7.3	NA
			0.8	18.5	NA	8.7	7.3	NA
			1.8	18.4	NA	8.7	7.2	NA
16499	03/16/2004	08:45	0.3	18.5	8320	8.4	8.3	5.4
			1.3	18.5	8350	7.8	8.1	5.4
			2.3	18.5	8710	7.9	8.2	5.7
		14:55	0.3	22.6	8000	8.6	7.8	4.7
			1.0	20.1	8280	8.3	7.8	5.1
			1.6	19.1	8120	8.1	7.7	5.2
			2.3	18.8	8280	8.0	7.7	5.3
			3.3	18.6	9060	7.7	7.7	5.8
16618	03/17/2004	09:00	0.3	18.9	9780	8.2	8.2	6.3
			1.0	18.9	9740	8.2	8.1	6.3
			1.6	18.9	9750	8.1	8.1	6.3
		15:20	0.4	20.1	10200	8.8	8.1	6.5
			1.0	19.8	10400	8.5	8.0	6.6
			1.7	19.2	11200	8.2	8.0	7.2
			2.1	18.9	11900	7.6	7.9	7.7
13338	03/18/2004	10:02	0.3	21.9	10400	9.5	8.3	6.3
			1.0	21.8	10300	9.3	8.2	6.3
			1.2	21.7	10200	4.4	8.1	6.2
		14:10	0.3	23.3	10700	11.3	8.2	6.3
			1.0	23.3	10700	11.1	8.3	6.3
			1.2	23.0	10300	3.6	8.1	6.1
13344	03/19/2004	09:35	0.3	21.9	7270	9.0	8.6	4.3
			1.2	21.8	7280	8.9	8.5	4.3
		14:21	0.1	22.3	7460	7.0	5.8	4.4
			0.6	22.3	7460	6.7	4.7	4.4
			1.3	22.3	7460	6.9	5.0	4.4

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (°C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity (°/₀₀)
11193	03/23/2004	09:12	0.4	20.3	3890	NA	8.4	2.3
			2.7	20.3	5050	NA	8.0	2.9
			5.0	20.3	5440	NA	8.1	3.2
		15:40	0.4	21.3	4710	NA	7.6	2.7
			2.5	21.1	5000	NA	7.6	2.9
			5.1	21.0	5390	NA	7.6	3.3
11197	03/24/2004	08:32	0.3	20.3	380	8.5	8.6	0.2
11261	03/25/2004	11:20	0.3	20.1	8900	8.4	8.1	5.5
			1.5	20.1	NA	8.0	NA	NA
			2.0	20.1	9310	7.6	7.9	5.9
		15:15	0.3	20.3	9910	8.1	8.0	6.2
			1.0	20.3	9920	8.1	8.0	6.2
			2.0	20.3	9900	7.7	8.1	6.2
11264	03/26/2004	07:30	0.4	20.3	7480	8.1	6.7	4.6
			4.0	20.3	8440	7.3	7.0	5.2
			8.1	20.2	8660	7.0	7.0	5.4
			11.3	20.3	8720	3.7	6.5	5.4
		13:51	0.3	20.7	8340	8.0	7.2	5.1
			4.0	20.6	8520	8.1	7.3	5.2
			8.1	20.4	8890	7.7	7.3	5.5
			11.3	20.3	8970	7.2	7.3	5.6
11265	03/30/2004	08:58	0.4	21.2	8080	7.2	6.8	4.9
			1.2	21.2	8120	7.0	7.0	4.9
			2.0	21.2	8160	7.0	6.9	4.9
		15:25	0.4	21.5	8080	7.1	6.8	4.8
			1.1	21.5	8090	7.1	6.9	4.9
			2.3	21.3	8200	7.0	6.9	4.9
15979	03/31/2004	09:34	0.4	21.1	6790	6.1	6.7	4.1
			1.5	21.1	6860	5.9	7.0	4.1
			3.6	21.1	7130	5.9	6.9	4.3
		15:45	0.4	22.8	7070	6.8	7.1	4.1
			1.5	22.0	7260	6.3	7.1	4.3
			3.1	21.6	8150	6.1	7.2	4.9
11280	04/01/2004	09:30	0.3	21.7	5660	5.5	6.8	3.3
			2.5	21.5	5690	5.2	6.9	3.3
			5.0	21.5	5780	5.1	7.0	3.4
			6.8	21.5	6160	5.0	6.9	3.6
		15:30	0.3	23.4	5490	6.5	7.7	3.1
			2.5	22.1	5610	5.1	7.5	3.2
			5.0	21.9	5690	4.7	7.4	3.3
			6.3	21.7	5880	3.3	7.4	3.4
11287	04/02/2004	10:30	0.2	22.5	3410	6.9	6.8	1.9
			4.0	21.8	4260	3.3	7.0	2.4
			8.8	21.7	4590	1.2	6.8	2.6
		13:00	0.3	23.5	3460	8.4	7.5	1.9
			5.0	21.8	4210	4.3	7.3	2.4
			9.0	21.7	5040	0.9	6.9	2.9
11300	04/08/2004	08:45	0.4	21.1	830	2.9	6.4	0.4
			0.6	21.0	1180	1.6	6.8	0.6
			1.5	21.0	2700	0.8	6.5	1.5
		14:45	0.4	21.8	2480	2.0	6.9	1.4
			0.7	21.8	2890	1.3	7.0	1.6
			1.5	21.5	3030	1.3	6.9	1.7

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
11292	04/09/2004	10:30	0.3	22.2	1530	2.9	7.8	0.8
			2.3	21.8	3090	0.4	7.3	1.7
			4.5	21.8	3800	0.6	7.3	2.1
		16:50	0.2	26.5	1840	4.3	7.6	0.9
			2.3	22.0	2850	0.4	7.3	1.6
			4.8	21.9	3830	0.9	7.3	2.2
11272	04/13/2004	09:18	0.4	15.9	450	10.1	6.1	0.3
			1.1	15.9	450	10.3	6.8	0.3
			1.8	16.0	470	2.9	6.4	0.3
		16:15	0.4	19.0	510	9.9	5.6	0.3
			1.1	18.4	490	9.5	5.9	0.3
			1.3	18.4	510	8.2	6.2	0.3
11305	04/15/2004	10:47	0.3	20.7	600	7.8	6.2	0.3
			3.0	18.8	480	6.3	7.3	0.3
			5.7	18.2	510	8.1	7.0	0.3
11302	04/16/2004	10:00	0.3	20.5	840	5.4	8.0	0.5
			1.0	20.1	820	5.1	8.1	0.5
			2.0	20.1	810	4.9	8.1	0.4
			3.0	19.6	1170	3.6	8.0	0.6
			5.0	19.5	2230	0.4	7.4	1.3
		15:06	0.3	23.3	820	7.3	8.0	0.4
			1.0	23.0	810	6.4	8.0	0.4
			2.0	20.7	910	5.9	8.1	0.5
			3.0	20.3	1290	4.1	8.0	0.8
			5.0	19.6	2280	2.0	7.8	1.3
11298	04/20/2004	10:20	0.4	21.3	4330	6.1	7.6	2.5
			2.0	20.9	5680	5.4	7.4	3.4
			4.0	20.8	5120	0.9	6.7	3.0
		15:27	0.4	22.4	4180	6.7	7.0	2.3
			2.0	22.1	4360	6.4	NA	2.5
			4.0	21.5	5400	6.0	NA	3.2
11274	04/21/2004	10:45	1.0	21.4	2340	6.0	7.4	1.3
			2.0	21.4	2670	5.6	7.3	1.5
			3.0	21.1	4330	5.4	7.3	2.5
			4.0	21.2	3800	1.0	6.9	2.2
		15:30	1.0	22.1	2810	7.4	7.8	1.6
			2.0	21.6	3320	6.0	7.6	1.9
			3.0	21.3	3430	4.2	7.5	1.9
			3.5	21.4	3450	3.1	7.4	2.0
11347	04/22/2004	08:50	0.4	23.2	870	6.7	7.4	0.4
		15:25	0.4	25.1	890	7.5	7.4	0.4
11382	04/23/2004	11:31	0.3	25.2	10800	8.3	7.5	6.1
		15:30	0.3	25.5	11200	10.6	8.3	6.3
11111	04/27/2004	08:50	0.4	24.4	13200	8.9	6.6	7.7
		16:30	0.4	24.3	14800	8.0	7.2	8.7
11092	04/28/2004	10:32	0.5	24.5	3520	NA	NA	1.9
			1.5	24.1	5030	NA	NA	2.8
			3.5	24.6	6230	NA	NA	3.4
		16:06	0.5	25.1	7390	NA	NA	4.1
			1.5	25.0	8390	NA	NA	4.7
			3.5	25.0	8440	NA	NA	4.7
11273	04/29/2004	10:03	0.3	23.3	10100	7.9	8.0	5.9
			1.0	23.3	10100	7.9	7.9	5.9
		16:52	0.2	24.3	9910	7.4	8.1	5.7
			1.3	23.9	9810	6.3	8.0	5.7

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
Summer 2004								
11193	08/03/2004	15:20	0.9	33.9	14700	7.6	7.9	7.3
			3.0	31.9	18700	5.2	7.6	9.6
			4.6	31.3	21400	4.2	7.6	11.2
			6.4	31.3	22200	4.1	7.6	11.7
		18:10	0.9	34.8	13200	11.4	8.6	6.2
			3.0	32.1	17900	5.4	7.6	9.1
			4.6	31.3	21400	3.9	7.5	11.2
			7.6	31.3	22500	3.5	7.5	11.9
15979	08/05/2004	09:00	0.3	30.9	NA	2.7	7.3	NA
			1.5	30.8	NA	2.5	7.3	NA
			3.0	30.9	NA	2.6	7.3	NA
			4.6	31.0	NA	2.3	7.3	NA
			6.1	31.1	NA	2.3	7.3	NA
			7.6	31.1	NA	2.3	7.3	NA
			9.1	31.1	NA	2.1	7.4	NA
		13:29	0.3	32.0	NA	3.9	7.4	NA
			4.6	31.1	NA	2.4	7.3	NA
			9.1	31.2	NA	2.2	7.3	NA
		15:40	0.3	32.4	NA	5.2	7.5	NA
			4.6	31.2	NA	2.6	7.3	NA
			9.1	31.2	NA	2.4	7.3	NA
11142	08/19/2004	10:26	0.3	26.4	720	6.6	7.9	0.4
		16:10	0.3	28.3	730	7.6	8.3	0.4
11357	08/31/2004	17:53	0.3	28.6	NA	NA	NA	NA
Fall 2004								
11292	10/19/2004	12:40	0.3	27.3	11300	NA	7.2	6.1
			0.9	27.3	11400	NA	7.2	6.2
			1.5	26.7	11700	NA	7.1	6.3
			3.0	26.3	16400	NA	7.1	9.3
			4.6	26.2	18000	NA	7.1	10.4
		15:40	0.3	27.8	9360	NA	7.3	4.9
			0.9	27.8	9470	NA	7.3	5.0
			1.5	27.7	10100	NA	7.2	5.4
			3.0	26.4	16600	NA	7.1	9.4
			4.3	26.3	17300	NA	7.1	9.8
11287	10/20/2004	09:15	0.3	26.8	13600	NA	6.7	7.8
			0.9	26.3	17700	NA	6.8	10.5
			1.8	26.2	17700	NA	6.9	10.4
			2.7	26.2	17900	NA	6.9	10.6
			4.6	26.1	18500	NA	7.0	11.0
		16:00	0.3	26.9	16300	NA	7.3	9.2
			0.9	27.2	16900	NA	7.2	10.0
			1.5	26.6	17500	NA	7.2	10.3
			2.7	26.4	18100	NA	7.2	10.7
			4.6	26.2	18700	NA	NA	11.1
11280	10/21/2004	08:30	0.5	26.2	18500	NA	6.1	11.0
			0.8	26.2	18500	NA	6.3	11.0
			1.1	26.2	18600	NA	6.5	11.0
			1.6	26.2	18600	NA	6.6	11.0
			2.5	26.2	18600	NA	6.8	11.0
		13:36	0.2	27.5	18600	NA	7.3	11.0
			1.1	26.8	18700	NA	7.3	11.1
			1.5	26.4	18700	NA	7.3	11.0
			2.2	26.4	18700	NA	7.3	11.1
			3.5	26.3	18700	NA	7.3	11.2

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
11347	10/22/2004	08:12	0.3	28.3	780	6.3	6.5	0.4
		08:14	1.5	27.9	800	5.2	7.0	0.4
		08:15	1.0	28.2	780	5.9	7.3	0.4
		14:55	0.3	28.3	780	4.5	7.6	0.4
		15:00	0.5	28.2	780	4.3	7.4	0.4
15979	10/25/2004	09:00	0.3	26.3	15800	3.9	6.8	9.2
			0.9	26.2	15900	4.1	6.9	9.3
			1.5	26.4	16800	3.3	7.0	9.8
			2.7	26.7	19800	3.7	7.0	11.8
			4.0	26.7	20300	3.5	7.0	12.0
			4.9	26.7	20700	3.5	7.1	12.4
		15:38	0.3	27.8	16000	5.3	7.4	9.3
			0.9	27.5	16000	5.4	7.4	9.3
			1.5	27.6	16200	4.8	7.4	9.4
			2.7	27.1	17300	4.0	7.3	10.1
			3.4	26.9	13700	1.1	7.3	7.9
11265	10/26/2004	09:00	0.3	26.5	18000	3.3	7.0	10.6
			0.6	26.5	18100	3.3	7.2	10.6
			0.9	26.5	18100	3.3	7.2	10.7
		15:35	0.3	27.0	17700	3.4	7.4	10.4
			0.6	27.0	17700	3.4	7.4	10.4
			0.9	27.0	17700	3.4	7.4	10.4
11264	10/27/2004	10:06	7.7	26.7	NA	NA	NA	NA
			3.8	26.4	NA	NA	NA	NA
			0.6	26.6	NA	NA	NA	NA
		15:55	0.4	27.0	NA	NA	NA	NA
			3.0	26.9	NA	NA	NA	NA
			6.4	26.8	NA	NA	NA	NA
11261	10/28/2004	08:20	0.3	26.6	20400	3.4	7.0	12.2
			1.5	26.5	20400	3.2	7.2	12.2
			3.0	26.4	20500	3.2	7.3	12.2
			4.6	26.5	20600	3.2	7.4	12.2
			6.1	26.5	20600	3.2	7.4	12.3
		14:28	0.3	26.9	19600	3.5	7.6	11.6
			1.5	26.9	19700	3.5	7.6	11.7
			3.0	26.9	19700	3.5	7.6	11.7
			3.6	26.9	19700	3.5	7.6	11.7
11197	10/29/2004	09:09	0.3	26.2	15100	5.7	8.0	8.8
			1.4	29.9	17200	5.4	7.8	10.0
			2.4	26.9	18600	5.2	7.7	11.0
			3.4	26.9	18900	5.0	7.7	11.2
			4.3	26.9	19300	4.8	7.7	11.5
		15:44	0.3	26.9	15500	8.0	8.1	8.0
			1.3	26.9	15500	7.4	8.1	8.7
			2.3	26.9	15700	7.4	8.0	8.8
			3.3	26.9	15400	7.4	8.0	8.9
			4.2	26.9	16300	6.6	7.8	9.7
11193	11/03/2004	08:30	0.1	21.9	12400	4.3	7.0	7.1
			1.5	22.3	13800	4.2	7.3	8.0
			3.0	22.3	14000	4.0	7.4	8.1
			4.6	22.3	14100	4.1	7.5	8.2
			5.3	22.3	14100	3.8	7.5	8.2
		14:47	0.3	21.9	12000	4.5	7.5	6.8
			1.5	21.8	12000	4.3	7.5	6.9
			3.0	21.8	12100	4.1	7.5	6.9
			4.6	21.8	12100	4.1	7.5	6.9
			6.1	21.8	12100	4.1	7.5	6.9

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
11111	11/04/2004	08:32	0.4	19.4	13000	7.5	5.7	7.5
			0.7	19.5	11600	5.1	6.5	6.7
		16:21	0.4	21.0	8440	1.4	7.2	4.7
			0.9	20.7	9330	4.8	7.5	5.2
			1.0	20.8	9270	5.4	7.5	5.2
13344	11/05/2004	08:35	0.6	19.6	NA	NA	NA	NA
			0.9	19.6	NA	NA	NA	NA
			1.6	19.9	NA	NA	NA	NA
			2.4	20.7	NA	NA	NA	NA
		16:28	0.3	20.1	NA	NA	NA	NA
			1.0	20.1	NA	NA	NA	NA
			1.5	20.8	NA	NA	NA	NA
			2.3	21.2	NA	NA	NA	NA
11382	11/08/2004	09:20	0.3	20.3	740	2.7	7.2	0.4
			0.9	20.3	750	2.7	7.3	0.4
			1.8	20.3	750	2.7	7.4	0.4
		15:40	0.3	21.2	750	0.8	7.5	0.4
			0.9	21.2	750	0.8	7.6	0.4
			1.5	20.9	750	0.8	7.5	0.4
14560	11/09/2004	09:00	0.3	20.9	NA	8.3	6.9	NA
			0.9	20.9	NA	8.3	7.4	NA
			1.8	20.9	NA	8.2	7.7	NA
			2.7	21.4	NA	7.6	8.0	NA
			3.4	21.4	NA	7.6	8.0	NA
		15:35	0.3	21.6	NA	10.3	8.3	NA
			0.9	21.5	NA	9.9	8.3	NA
			1.8	21.5	NA	9.3	8.2	NA
			2.7	21.3	NA	8.0	8.1	NA
			3.4	21.3	NA	7.8	8.1	NA
11302	11/10/2004	08:56	0.5	20.9	NA	1.8	7.4	NA
			1.6	22.0	NA	1.0	7.2	NA
			3.2	22.0	NA	0.8	7.2	NA
			5.0	22.1	NA	0.8	7.1	NA
		15:50	0.5	22.7	NA	0.4	7.5	NA
			1.6	21.9	NA	0.2	7.3	NA
			3.1	22.0	NA	0.1	7.2	NA
			4.7	22.1	NA	0.1	7.2	NA
11305	11/11/2004	09:30	0.3	22.5	NA	NA	7.8	NA
			1.1	22.5	NA	NA	7.7	NA
			1.7	22.3	NA	NA	7.3	NA
			2.8	22.2	NA	NA	7.3	NA
			4.2	22.2	NA	NA	7.3	NA
		15:06	0.3	23.0	NA	NA	7.7	NA
			1.1	22.8	NA	NA	7.6	NA
			1.7	22.5	NA	NA	7.3	NA
			2.8	22.3	NA	NA	7.2	NA
			3.2	22.3	NA	NA	7.2	NA
11298	11/12/2004	08:25	0.3	21.3	17900	NA	6.5	10.6
			0.6	21.8	20300	NA	7.0	12.1
			1.1	21.7	20400	NA	7.1	12.2
			1.5	21.5	20600	NA	6.7	12.4
		15:05	0.3	20.2	10500	NA	7.3	7.3
			0.6	21.5	19600	NA	7.3	11.7
			0.9	21.8	19600	NA	7.3	11.7
			1.2	21.9	19900	NA	7.3	11.9

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
16618	11/15/2004	08:09	0.3	18.1	32000	1.3	8.0	20.0
			0.9	18.1	32000	1.1	7.9	20.0
			1.5	18.2	32900	1.1	7.9	20.7
		15:11	0.3	18.7	30200	2.2	7.9	18.8
			0.9	18.7	30200	2.5	7.9	18.8
			1.2	18.6	30300	2.5	7.9	18.8
16499	11/16/2004	09:00	0.3	18.4	30600	NA	7.8	18.8
			0.9	18.4	30300	NA	7.8	18.8
			2.1	18.4	30400	NA	7.8	19.0
			3.0	18.4	30600	NA	7.8	19.1
			4.3	18.4	30800	NA	7.8	19.2
		15:55	0.3	19.2	30400	NA	7.9	18.9
			0.9	19.1	30400	NA	7.9	18.9
			2.1	18.9	31600	NA	7.9	19.7
			3.0	18.9	31700	NA	7.9	19.8
			4.3	18.9	32000	NA	7.8	20.0
13340	11/17/2004	08:26	0.6	18.8	NA	6.9	7.6	NA
			1.1	18.8	NA	6.9	7.9	NA
			1.7	18.8	NA	7.0	8.0	NA
			2.1	19.0	NA	6.0	8.0	NA
			2.3	19.1	NA	1.3	7.9	NA
		13:47	0.6	19.1	NA	7.9	8.2	NA
			1.2	19.1	NA	7.7	8.2	NA
			1.8	19.1	NA	7.8	8.2	NA
			2.3	19.1	NA	4.8	8.2	NA
13338	11/18/2004	10:20	0.3	20.0	37400	4.1	7.7	26.6
			0.9	20.0	37600	3.9	7.7	26.7
			1.4	20.0	37800	3.9	7.7	26.7
		13:40	0.6	20.3	33000	4.1	7.7	23.0
			1.2	20.3	33000	4.0	7.7	23.0
11252	11/19/2004	08:15	0.2	19.6	NA	NA	NA	NA
			0.9	19.6	NA	NA	NA	NA
			1.9	19.9	NA	NA	NA	NA
			2.8	20.0	NA	NA	NA	NA
		15:32	0.2	20.1	NA	NA	NA	NA
			0.9	20.1	NA	NA	NA	NA
			1.9	20.0	NA	NA	NA	NA
			2.6	20.0	NA	NA	NA	NA
11272	11/22/2004	08:54	0.3	19.9	1910	4.4	7.0	1.0
			0.9	19.9	2040	4.4	7.1	1.0
			1.5	19.9	2330	4.4	7.1	1.2
			2.1	19.8	2390	4.4	7.2	1.2
			2.7	19.8	2420	4.4	7.2	1.3
		15:44	0.3	20.6	1400	3.9	7.6	0.7
			0.9	20.6	1380	3.9	7.6	0.7
			1.5	20.6	1410	3.9	7.6	0.7
			2.1	20.6	1440	3.9	7.6	0.7
			2.7	20.6	1430	3.9	7.6	0.7

Table 3.7 Field Measurements during Water Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (°C)	Specific Conductance (μ S/cm)	DO (mg/L)	pH (SU)	Salinity (°/₀₀)
11274	11/23/2004	10:55	0.2	19.7	NA	NA	8.0	NA
			1.8	19.6	NA	NA	8.0	NA
			3.7	19.6	NA	NA	8.0	NA
		16:20	0.3	20.0	NA	NA	7.8	NA
			1.6	20.0	NA	NA	7.8	NA
			3.5	20.0	NA	NA	7.9	NA
	11/24/2004	09:10	0.3	20.7	210	6.4	7.5	0.1
			1.2	20.6	210	6.4	7.5	0.1
			2.2	20.5	220	2.0	7.1	0.1
			2.8	20.6	220	2.8	6.9	0.1
		12:27	0.7	20.8	210	6.4	7.7	0.1
			1.6	20.5	220	6.3	7.7	0.1
			2.5	20.8	220	4.5	7.7	0.1
11300	11/29/2004	07:40	0.3	19.4	640	4.0	6.3	0.3
			0.9	19.3	680	4.1	6.1	0.3
			1.5	19.3	710	4.5	5.8	0.4
		15:28	0.3	20.1	630	2.8	7.4	0.3
			0.6	20.1	650	2.6	7.4	0.3
			1.2	19.9	660	2.7	7.4	0.3
11092	11/30/2004	08:51	0.3	18.2	1240	NA	7.0	0.6
			0.8	18.2	1510	NA	7.3	0.8
			1.7	18.2	1520	NA	7.3	0.8
			2.7	18.2	1630	NA	7.1	0.8
			3.9	18.3	1730	NA	7.0	0.9
11273	12/01/2004	08:35	0.3	15.2	6160	NA	6.6	3.4
			0.6	15.5	6770	NA	6.7	3.7
			0.9	15.6	6760	NA	6.8	3.7
		15:59	0.3	18.6	8530	NA	7.7	4.8
			0.6	18.6	8020	NA	7.6	4.5
13342	12/02/2004	08:35	0.3	17.3	9230	0.1	6.9	6.1
			1.0	17.3	9230	0.2	6.8	6.2
			2.1	17.3	9380	0.3	6.7	6.3
		15:08	0.3	17.1	9090	<0.1	7.5	6.1
			0.6	17.1	9090	<0.1	7.5	6.1
			1.2	17.2	9060	<0.1	7.5	6.1

NA = not available

Tributary

Failed post-calibration criteria. Value considered an estimate. Data not reported to TRACS

Table 3.8 Physical Characteristics of Water Samples

Station ID	Date	Time	TSS (mg/L)	TDS (mg/L)	TOC (mg/L)	DOC (mg/L)	POC (mg/L)[a]
Spring 2004							
13340	03/09/2004	15:15	32	5316	29.4	24.2	
11252	03/10/2004	16:35	15	8858	25.8	21.5	
14560	03/11/2004	15:35	25	8777	24.0	21.1	
13342	03/12/2004	16:15	17	4876	24.2	21.5	
16499	03/16/2004	14:50	9	4154	28.3	25.8	
16618	03/17/2004	15:10	14	5752	29.4	25.6	
13338	03/18/2004	13:30	59	6153	27.0	24.6	
13344	03/19/2004	14:00	9	3948	25.6	24.2	
11193	03/23/2004	15:20	20	2503	22.2	20.9	
11193-dup	03/23/2004	15:20	19	2505	23.0	20.8	
11197	03/24/2004	15:10	21	366	15.8	13.7	
11261	03/25/2004	15:10	25	5472	34.0	26.2	
11264	03/26/2004	13:37	22	4557	26.2	24.3	
11265	03/30/2004	15:25	34	4051	25.4	23.6	
15979	03/31/2004	15:30	36	3611	20.8	20.4	
15979-dup	03/31/2004	15:30	35	3586	21.4	20.7	
11280	04/01/2004	15:16	15	2805	20.9	20.0	
11287	04/02/2004	15:42	24	1766	21.6	19.4	
11300	04/08/2004	14:30	16	717	18.2	18.0	
11292	04/09/2004	16:00	21	678	16.8	16.2	
11272	04/13/2004	16:15	87	238	15.3	13.4	
11305	04/15/2004	16:20	15	341	10.7	9.9	
11302	04/16/2004	14:45	17	223	15.8	15.1	
11298	04/20/2004	15:40	23	2637	14.9	12.8	
11274	04/21/2004	15:15	30	2596	16.2	13.8	
11347	04/22/2004	15:10	27	461	11.0	10.4	
11347-dup	04/22/2004	15:10	29	462	11.7	10.8	
11382	04/23/2004	15:30	19	560	11.2	10.1	
11111	04/27/2004	16:08	39	9280	27.8	20.2	
11092	04/28/2004	16:10	66	4020	24.4	20.8	
11273	04/29/2004	16:30	23	5760	23.6	14.7	
Summer 2004							
11193-sh	08/03/2004	12:50	16	9996	38.5	38.0	
11193-de	08/03/2004	13:40	22	12491	28.7	26.4	
11193-sh	08/03/2004	18:00	7	6676	29.8	26.6	
11193-de	08/03/2004	18:00	31	12676	26.8	25.8	
15979-sh	08/05/2004	09:31	35	12554	29.3	27.2	
15979-de	08/05/2004	09:31	36	14141	29.0	28.2	
15979-sh	08/05/2004	15:00	27	12566	32.4	30.4	
15979-de	08/05/2004	15:00	97	14016	71.6	40.0	
11142	08/19/2004	10:00	92	461	9.0	8.2	
11142	08/19/2004	16:10	83	457	9.3	8.1	
11357	08/31/2004	10:30	142	272	10.2	9.3	
11357	08/31/2004	18:00	68.4	273	9.9	9.4	

Table 3.8 Physical Characteristics of Water Samples - Cont'd

Station ID	Date	Time	TSS (mg/L)	TDS (mg/L)	TOC (mg/L)	DOC (mg/L)	POC (mg/L)[a]
Fall 2004							
11292	10/19/2004	[b]	5.0	6869	6.36	6.02	29.10
11287	10/20/2004	[b]	4.5	8248	7.75	7.44	23.00
11280	10/21/2004	[b]	4.5	12638	5.55	5.38	21.30
11347	10/22/2004	[b]	40.5	476	5.84	5.75	7.89
15979	10/25/2004	[b]	8.0	9862	6.20	5.81	18.60
15979-dup	10/25/2004	[b]	9.5	9540	5.80	5.75	17.50
11265	10/26/2004	[b]	15.5	13304	5.87	5.68	20.10
11264	10/27/2004	[b]	11.0	14217	5.80	5.54	15.40
11261	10/28/2004	[b]	12.0	14624	5.66	5.66	16.20
11197	10/29/2004	[b]	4.0	10143	7.76	7.36	22.50
11193	11/03/2004	[b]	6.0	8016	7.50	7.35	13.40
11193-dup	11/03/2004	[b]	8.8	8358	7.41	7.38	10.70
11111	11/04/2004	[b]	33.6	6802	6.84	6.62	4.00
13344	11/05/2004	[b]	4.8	8716	6.39	6.35	12.40
11382	11/08/2004	[b]	15.0	434	6.80	6.80	12.10
14560	11/09/2004	[b]	14.5	19607	4.37	4.13	7.20
11302	11/10/2004	[b]	8.5	2617	9.54	9.31	10.70
11305	11/11/2004	[b]	11.5	1828	6.02	5.75	7.70
11298	11/12/2004	[b]	5.0	6022	6.86	6.79	16.30
16618	11/15/2004	[b]	11.5	18407	4.50	4.46	5.52
16499	11/16/2004	[b]	9.5	19389	4.41	4.38	5.03
13340	11/17/2004	[b]	8.5	18953	4.60	4.41	16.10
13338	11/18/2004	[b]	26.5	13033	5.00	4.96	5.03
11252	11/19/2004	[b]	13.0	8149	5.67	5.51	7.47
11272	11/22/2004	[b]	50.0	1419	11.70	10.70	3.54
11274	11/23/2004	[b]	266.0	151	8.70	7.59	2.36
11274	11/24/2004	[b]	124.0	162	11.70	10.40	2.76
11300	11/29/2004	[b]	5.5	355	7.21	7.18	22.70
11092	11/30/2004	[b]	74.0	547	12.90	12.80	4.93
11273	12/01/2004	[b]	33.0	3842	6.75	6.68	<1
13342	12/02/2004	[b]	9.5	4354	7.42	7.27	9.48

[a] POC was analyzed to aid in partitioning calculations but was not reported to TRACS

[b] Sample was a composite of equal-size grabs (300 mL) collected every hour throughout the duration of sampling

dup = duplicate sh=shallow de=deep

Tributary

Sample exceeded holding time (7 days). Value considered an estimate. Data not reported to TRACS

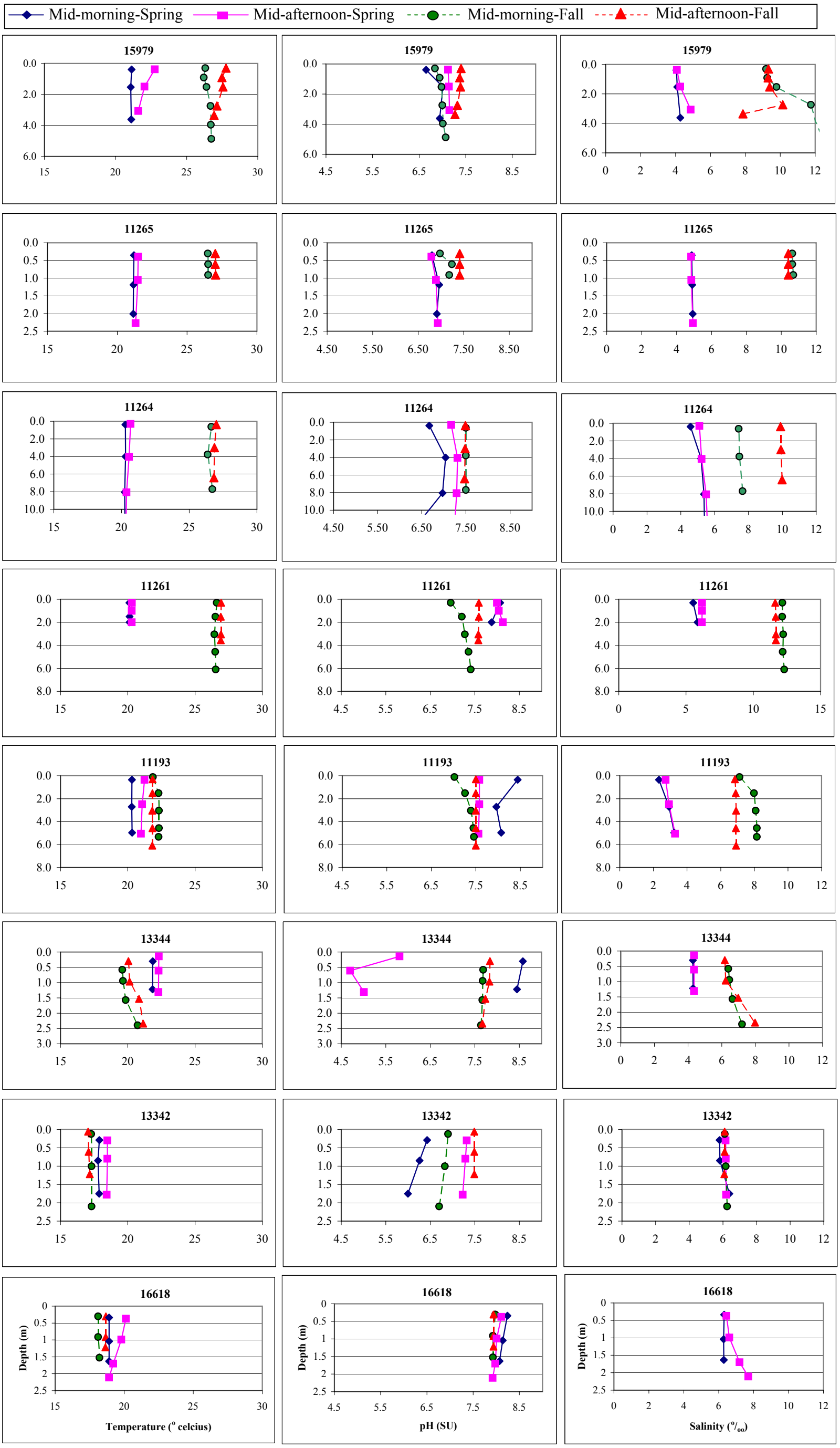


Figure 3.13 Vertical profiles of field parameters (in-stream)

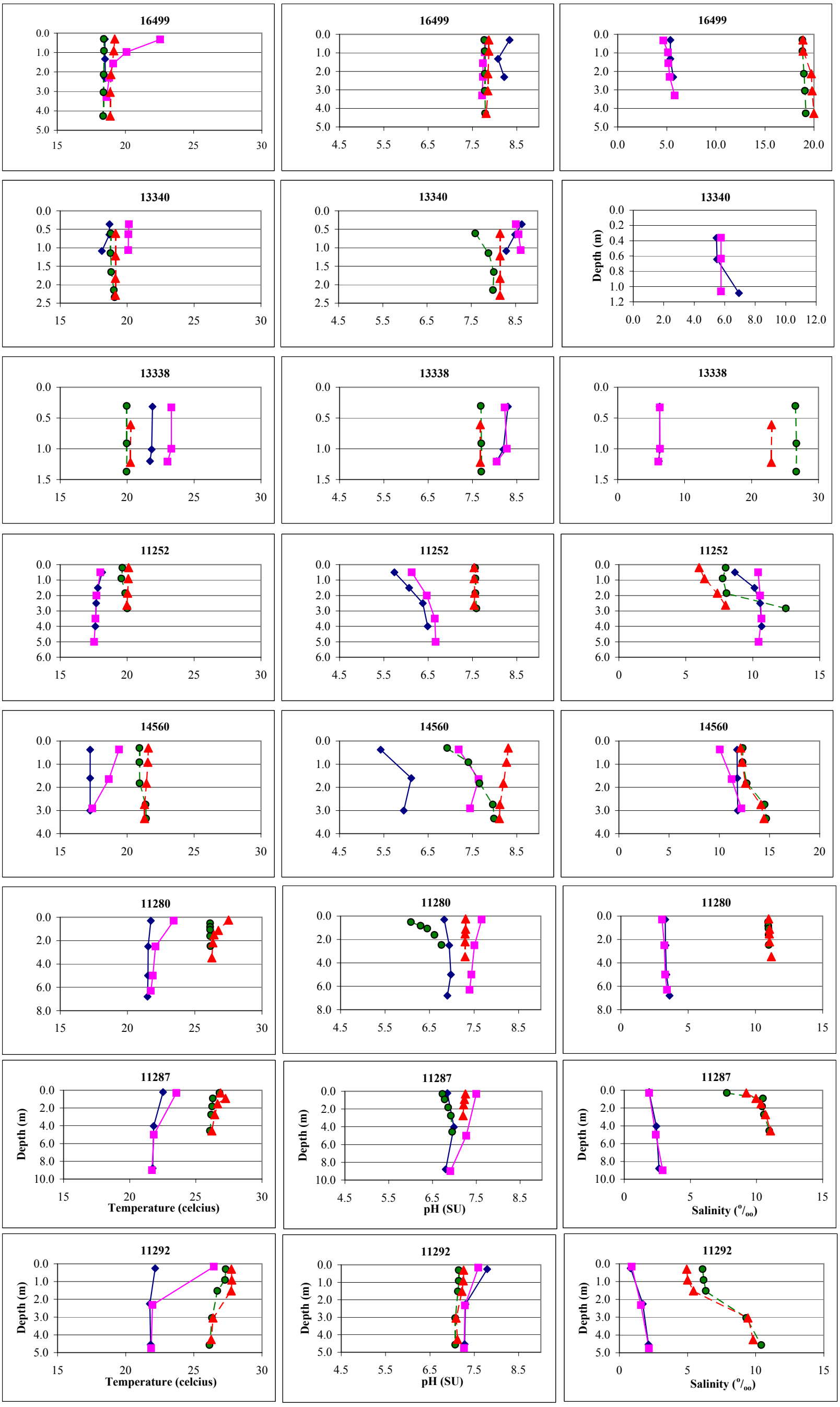


Figure 3.13 Vertical profiles of field parameters (in-stream) - Continued

Table 3.9 Total Dioxin Concentrations in Water (pg/L)

Station ID	Date	Volume (L)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Average TEQ[a]
Spring 2004																					
13340	03/09/2004	705	< 0.0440	0.0129	0.0299	0.0553	0.0965	2.0000	57.7305	0.1220	0.0142	0.0217	< 0.0278	< 0.0163	0.0150	< 0.0045	< 0.2638	< 0.0197	0.9787	0.0893	0.0893
11252	03/10/2004	709	< 0.0677	0.0175	0.0385	0.0804	0.1523	3.0606	112.8350	0.1834	0.0188	0.0199	0.0358	0.0188	0.0147	< 0.0071	< 0.3004	< 0.0261	1.5515	0.1274	0.1274
14560	03/11/2004	702	< 0.0513	0.0208	0.0570	0.1083	0.2436	4.4587	142.4501	0.1296	0.0160	0.0199	0.0407	0.0229	0.0194	< 0.0077	< 0.3504	< 0.0298	1.5427	0.1272	0.1272
13342	03/12/2004	702	0.1681	0.0175	0.0422	0.0840	0.1368	3.3476	118.3761	0.4416	0.0255	0.0281	< 0.0588	< 0.0268	0.0204	< 0.0080	< 0.4416	< 0.0370	2.8917	0.2728	0.2728
16499	03/16/2004	706	< 0.1941	0.0201	0.0401	0.0737	0.1374	3.1161	117.5637	0.5099	0.0288	0.0248	0.0659	0.0262	0.0197	0.0059	< 0.4660	< 0.0326	3.0737	0.2662	0.2662
16618	03/17/2004	712	0.1952	0.0202	0.0382	0.0787	0.1306	3.1882	139.0449	0.5056	0.0337	0.0251	0.0640	0.0289	0.0219	< 0.0052	< 0.4185	< 0.0407	3.2022	0.3068	0.3068
13338	03/18/2004	701	< 0.2168	< 0.0347	0.1013	0.1797	0.4023	6.8188	206.8474	0.5392	0.0350	< 0.0277	0.0932	0.0456	0.0268	< 0.0076	< 0.6990	< 0.0585	4.0514	0.3596	0.3596
13344	03/19/2004	704	< 0.0909	0.0089	< 0.0216	0.0423	0.0847	1.9176	62.7841	0.2401	0.0143	0.0156	0.0330	< 0.0143	0.0118	< 0.0055	< 0.2401	< 0.0214	1.4361	0.1309	0.1309
11193	03/23/2004	700	1.1000	< 0.0279	0.0410	0.0929	0.1486	4.0857	181.4286	3.2857	0.1033	0.0836	0.2214	0.0644	0.0230	< 0.0101	< 0.5171	0.0526	2.7857	1.5475	1.2524
11193-dup	03/23/2004	702	0.6781	0.0185	0.0283	0.0598	0.0926	2.5499	106.8376	2.0228	0.0641	0.0510	0.1410	0.0447	0.0168	< 0.0080	< 0.3205	< 0.0340	1.7379	0.9573	
11197	03/24/2004	702	< 0.0477	< 0.0124	0.0303	0.0684	0.0969	3.1481	148.1481	0.1453	0.0137	0.0135	0.0246	< 0.0470	0.0114	< 0.0081	< 0.2350	< 0.0221	0.6211	0.0957	0.0957
11261	03/25/2004	712	0.3722	0.0215	0.0448	0.0997	0.1601	3.9888	148.8764	1.0112	0.0435	0.0406	0.1070	0.0417	0.0247	< 0.0083	< 0.6096	0.0476	4.8876	0.5548	0.5548
11264	03/26/2004	701	0.4394	< 0.0207	0.0395	0.0927	0.1441	3.5663	129.8146	1.2268	0.0506	0.0425	0.1155	0.0439	0.0230	< 0.0090	< 0.5949	0.0502	5.4066	0.6413	0.6413
11265	03/30/2004	702	0.4288	0.0283	0.0527	0.1154	0.1838	4.4587	155.2707	1.1966	0.0687	0.0541	0.1624	0.0615	0.0312	0.0090	< 0.9630	< 0.0688	11.1111	0.6547	0.6547
15979	03/31/2004	701	0.8417	0.0338	0.0588	0.1669	0.1912	5.4636	169.7575	2.3110	0.0799	0.0785	0.2397	0.0813	0.0484	< 0.0104	< 1.6120	< 0.1013	17.5464	1.2124	1.1782
15979-dup	03/31/2004	701	0.7989	< 0.0342	0.0603	0.1612	0.1669	5.0785	158.3452	2.1398	0.0785	0.0785	0.2126	< 0.0813	0.0452	< 0.0103	< 1.3124	< 0.0873	12.9672	1.1441	
11280	04/01/2004	706	0.4108	0.0239	0.0374	0.1020	0.1034	3.2436	68.4136	1.1756	0.0657	0.0567	0.1643	< 0.0643	0.0330	0.0082	< 0.6983	< 0.0525	2.4646	0.6227	0.6227
11287	04/02/2004	703	< 0.0711	< 0.0186	< 0.0349	0.0916	0.0900	2.7738	36.4154	0.2304	< 0.0193	0.0260	0.0597	< 0.0351	0.0272	< 0.0073	< 0.6543	< 0.0387	1.6615	0.1416	0.1416
11292	04/09/2004	708	< 0.0297	0.0275	0.0492	0.1299	0.1370	4.1808	64.8305	0.2062	0.0246	0.0508	0.0763	< 0.0537	0.0438	< 0.0103	< 0.7486	< 0.0387	1.4831	0.1324	0.1324
Summer 2004																					
11193-de	08/03/2004	678	1.6077	< 0.0413	0.0624	0.1475	0.2507	5.8260	162.2419	5.5752	0.1503	0.1069	0.2743	0.0883	0.0320	< 0.0114	0.7006	< 0.0416	7.0944	2.3318	2.3318
11193-sh	08/03/2004	723	0.9986	< 0.0243	0.0372	0.0730	0.1268	3.4163	119.2254	3.4163	< 0.0920	0.0802	0.2102	< 0.0542	< 0.0196	< 0.0077	< 0.3582	< 0.0397	2.4896	1.4482	1.4482
15979-de	08/05/2004	659	0.9105	0.0569	0.1024	0.1775	0.3187	4.7344	91.0470	2.3976	< 0.0812	0.0653	0.1517	0.0534	0.0328	< 0.0118	< 0.8346	< 0.0640	8.8012	1.2993	1.2993
15979-sh	08/05/2004	661	0.5204	< 0.0257	< 0.0384	0.0968	0.1289	3.1316	65.8094	1.4221	< 0.0525	0.0578	0.1183	< 0.0452	< 0.0322	< 0.0092	0.6278	< 0.0384	5.1225	0.7512	0.7512
11142	08/18/2004	707	< 0.0106	< 0.0228	< 0.0371	< 0.0880	0.1150	3.0410	93.0693	0.0383	< 0.0136	< 0.0137	0.0215	< 0.0197	< 0.0273	< 0.0146	< 0.4342	< 0.0252	0.7624	0.0550	0.0551
11142-dup	08/18/2004	707	< 0.0093	< 0.0192	< 0.0378	< 0.0921	0.1141	3.0410	92.9279	0.0348	< 0.0163	0.0147	0.0218	< 0.0199	< 0.0262	< 0.0141	< 0.3762	< 0.0221	0.7793	0.0552	
11357	08/31/2004	326	< 0.0178	< 0.0322	< 0.0531	< 0.1080	0.1393	3.4908	66.3804	< 0.0491	< 0.0193	< 0.0199	< 0.0322	< 0.0334	< 0.0380	< 0.0156	0.4794	< 0.0242	1.0294	0.0722	0.0745
11357-dup	08/31/2004	326	< 0.0172	< 0.0291	< 0.0466	< 0.1077	< 0.1291	3.1963	66.4417	< 0.0485	< 0.0221	< 0.0184	< 0.0313	< 0.0371	< 0.0374	< 0.0169	0.4773	< 0.0316	1.0040	0.0768	
Fall 2004																					
11292	10/19/2004	705	< 0.0255	< 0.0397	< 0.0383	< 0.0851	< 0.0750	2.0000	29.6170	0.2298	< 0.0411	< 0.0525	< 0.0559	< 0.0999	< 0.0356	< 0.0369	< 0.3670	< 0.0325	0.8695	0.1004	0.1004
11287	10/20/2004	704	< 0.0838	< 0.0246	< 0.0293	< 0.0604	< 0.0631	1.7372	28.6364	0.2770	< 0.0384	< 0.0351	< 0.0501	< 0.0558	< 0.0253	< 0.0261	< 0.3824	< 0.0364	1.4119	0.1351	0.1351
11280	10/21/2004	701	0.3566	< 0.0237	< 0.0359	< 0.0743	< 0.0854	1.9971	47.2183	1.0699	< 0.0670	< 0.0514	< 0.0917	< 0.0803	< 0.0300	< 0.0341	< 0.4151	< 0.0452	4.0942	0.5263	0.5263
15979	10/25/2004	712	0.6025	< 0.0247	< 0.0331	< 0.1045	< 0.1129	2.9368	58.2865	1.8961	< 0.0823	< 0.0756	0.1788	< 0.2107	< 0.0539	< 0.0295	< 1.6096	< 0.0854	20.2949	0.9002	0.8708
15979-dup	10/25/2004	708	0.5621	< 0.0328	< 0.0692	< 0.1243	< 0.1370	2.8390	55.9322	1.8503	< 0.1017	< 0.0791	< 0.1552	< 0.2117	< 0.0579	< 0.0551	< 1.4986	< 0.1299	20.4520	0.8415	
11265	10/26/2004	703	0.3215	< 0.0336	< 0.0351	< 0.0829	< 0.1233	2.4609	58.7482	0.9246	< 0.0795	< 0.0578	0.1593	< 0.1437	0.0475	< 0.0293	< 0.8663	< 0.1108	14.7937	0.5030	0.5030
11264	10/27/2004	706	0.3513	< 0.0572	< 0.0618	< 0.1252	< 0.1521	2.7620	72.3796	0.9490	< 0.1119	< 0.0977	< 0.2323	< 0.1742	0.0663	< 0.0538	< 1.4178	0.1841	25.1133	0.5582	0.5582
11261	10/28/2004	708	0.6031	< 0.0308	< 0.0516	0.1134	< 0.1879	4.0395	106.7797	1.6525	< 0.0989	< 0.0658	0.1893	< 0.1653	0.0410	< 0.0243	< 1.1709	< 0.1144	22.7401	0.8774	0.8774
11197	10/29/2004	703	< 0.0967	< 0.0206	< 0.0427	< 0.0597	< 0.0853	< 1.6188	83.6984	0.2532	< 0.0388	< 0.0347	< 0.0459	< 0.0474	< 0.0283	< 0.0307	< 0.2475	< 0.0541	1.7553	0.1555	0.1555
11193	11/03/2004	705	< 0.2142	< 0.0211	< 0.0482	< 0.0837	< 0.1163	2.5404	128.2270	0.6582	< 0.0610	< 0.0496	< 0.0715	< 0.0949	< 0.0257	< 0.0200	< 0.3603	< 0.0624	3.5603	0.3277	0.3372
11193-dup	11/03/2004	720	0.2319	< 0.0251	< 0.0360	< 0.0693	< 0.1025	2.6528	126.6667	0.6639	< 0.0458	< 0.0333	< 0.0608	< 0.0874	< 0.0226	< 0.0250	< 0.3556	< 0.0431	3.6389	0.3468	
13344	11/05/2004	700	< 0.2243	< 0.0951	< 0.1809	< 0.1809	< 0.1806	2.6714	82.2857	0.6429	< 0.1414	< 0.1257	< 0.1339	< 0.1316	< 0.1457	< 0.1669	< 0.4543	< 0.2516	4.8000	0.3703	0.3703
14560	11/09/2004	703	< 0.0417	< 0.0183	< 0.0428	0.0972	0.2105	3.1863	81.3656	0.1380	< 0.0253	< 0.0201	< 0.0398	< 0.0324	< 0.0174	< 0.0114	< 0.2333	< 0.0277	1.4097	0.0948	0.0948
16618	11/15/2004	701	< 0.1398	< 0.0205	< 0.0344	< 0.0586	< 0.1424	2.7104	73.6091	0.3894	< 0.0267	< 0.0314	< 0.0526	< 0.0298	< 0.0201	< 0.0228	< 0.2910	< 0.0352	3.3096	0.2112	0.2112
16499	11/16/2004	703	< 0.1735	< 0.0228	< 0.0313	< 0.0752	< 0.1078	2.5889	76.1024	0.4694	< 0.0351	< 0.0324	< 0.0548	< 0.0277	< 0.0188	< 0.0205	< 0.3997	< 0.0553	3.7980	0.2474	0.2474
13340	11/17/2004	702	< 0.0393	< 0.0137	< 0.0330	< 0.0501	< 0.0897	1.5969	44.6581	0.1140	< 0.0188	< 0.0170	< 0.0256	< 0.0161	< 0.0147	< 0.0134	< 0.1936	< 0.0353	0.9160	0.0752	0.0752
13338	11/18/2004	709	< 0.2525	< 0.0265	0.0673	0.1347	< 0.2172	5.0212	150.6347	0.8039	< 0.0522	< 0.0450	0.1016	< 0.0621	< 0.0288	< 0.0226	< 0.6841	< 0.0901	8.6178	0.3979	0.3979
11252	11/19/2004	704	0.0881	< 0.0207	< 0.0175	< 0.0398	0.0682	1.6903	73.8636	0.2543	< 0.0230	< 0.0209	0.0243	< 0.0195	< 0.0182	< 0.0206	< 0.1776	< 0.0273	1.2642	0.1413	0.1413
13342	12/02/2004	712	0.1124	< 0.0249	< 0.0324	< 0.0348	< 0.0560	1.4888	71.0674	0.3301	< 0.0341	< 0.0298	< 0.0251	< 0.0534	< 0.0288	< 0.0308	< 0.2008	< 0.0504	2.9073	0.1757	0.1757

[a] Average of duplicate samples, otherwise concentration of a single sample

dup = duplicate de= deep sh=shallow

Values reported to the detection limit

If either the dissolved or suspended concentration was non-detect, the total concentration in water was reported here as less than the sum of the detected concentration and the MDL for the non-detected phase. If a congener was non-detected in both phases, the total concentration in water was reported as less than the sum of the MDL for both phases

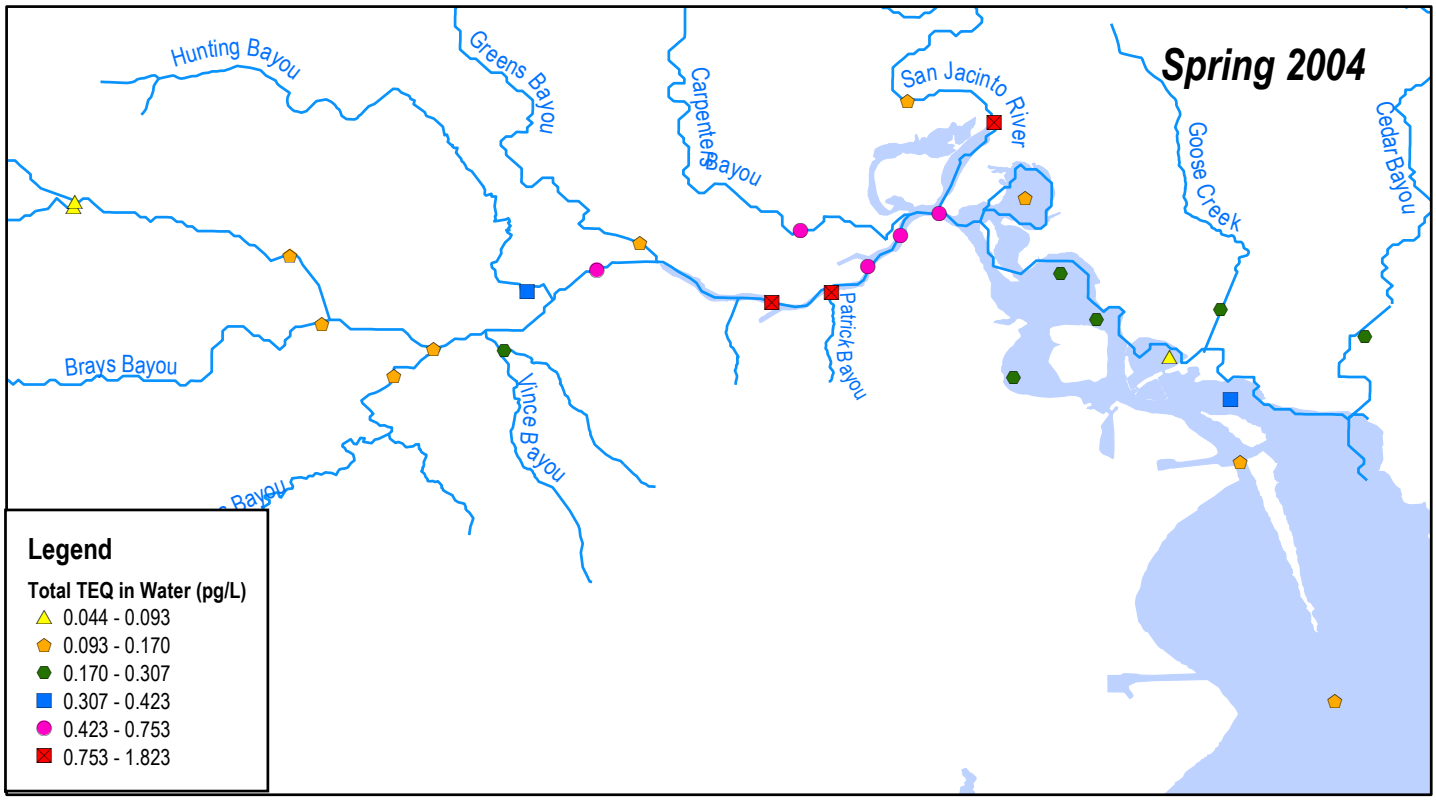
Total TEQ was calculated as the sum of the dissolved TEQ plus the suspended TEQ. Non-detects were assumed to be 1/2 detection limit

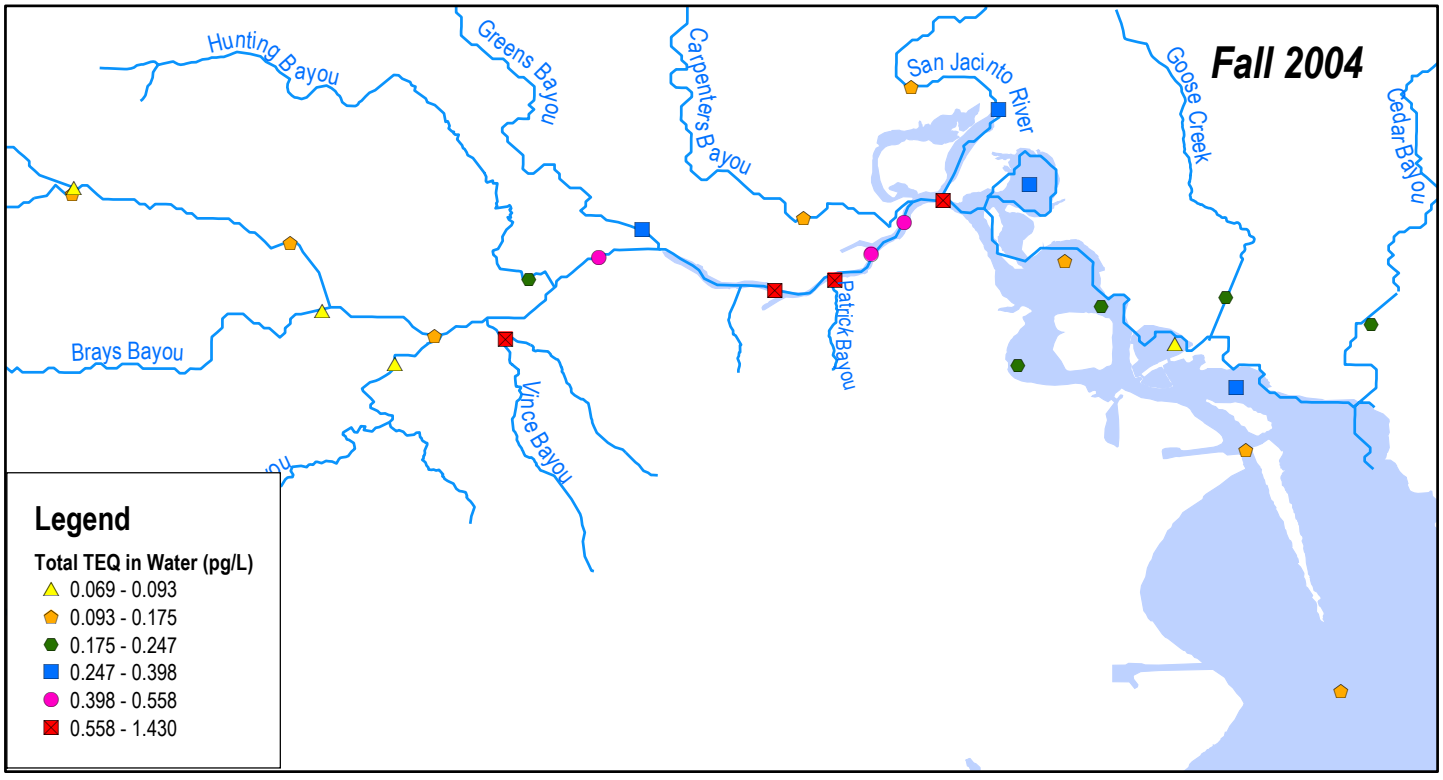
Value for one or both phases is between the detection and the reporting limits

Value for one or both phases is an estimate due to blank contamination (concentration < 20 times lowest concentration)

Value for one or both phases is an estimate due to QC issues (interference, signal to noise ratio)

Exceeds the Texas WQS (0.0933 pg/L)





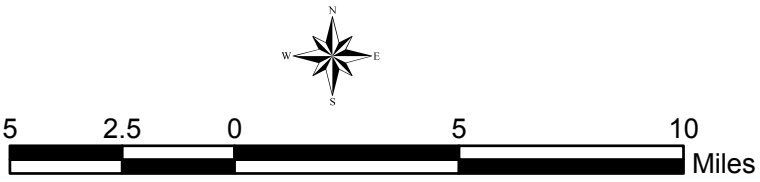


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Figure 3.14
Total TEQ Concentrations in Water

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TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

Prepared by: MPS

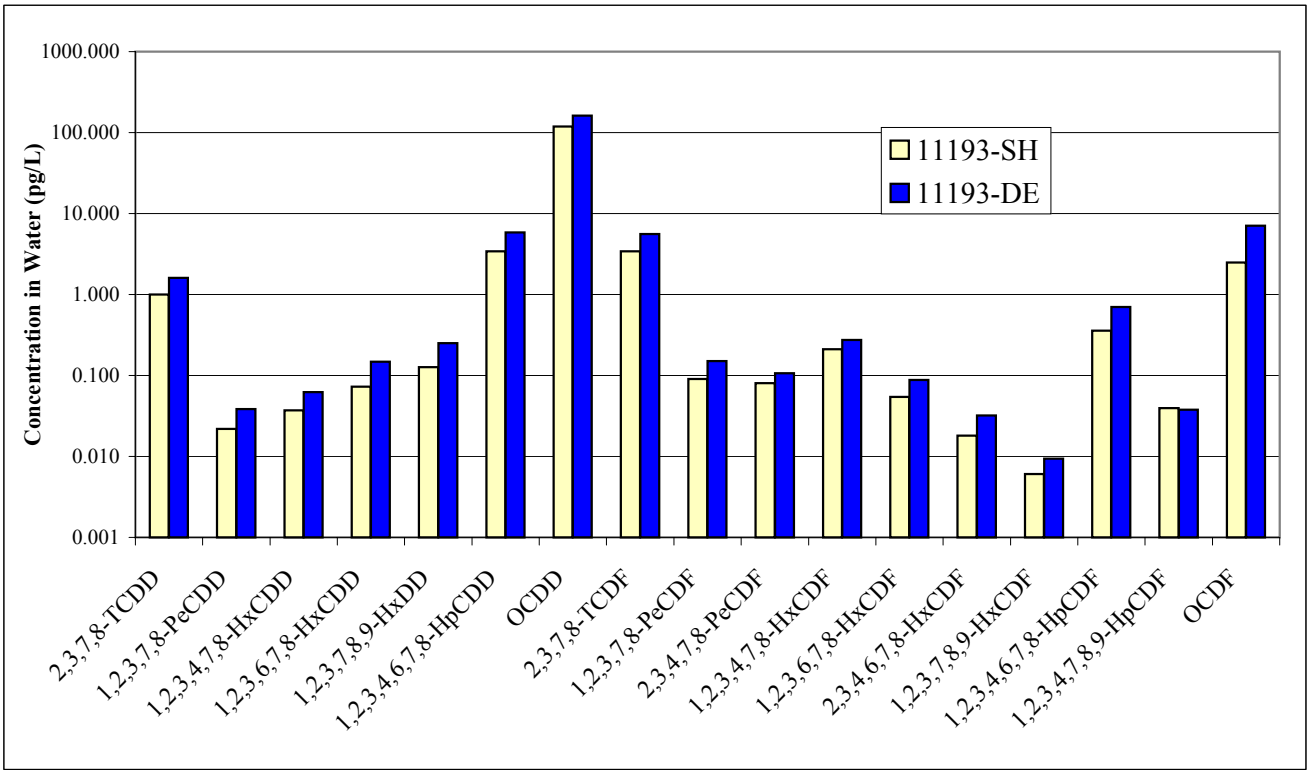
Date: 09-09-2005

11193 (segment 1001) and 15979 (segment 1006), while the highest TEQ concentrations in Fall samples were measured at stations 11261 (segment 1005) and 15979 (segment 1006).

Analysis of dioxin data in bottom sediments and water column collected in 2002-2003 indicated "disequilibrium" between these two media. However, it is noted that the collected data correspond to shallow water and there is the possibility of thermal and salinity-driven stratification in the channel. To address whether or not dioxin concentrations in the HSC are at equilibrium between bottom sediments and the water column, the project team gathered samples to develop vertical profiles of dioxins at two locations (Figure 3.1) during the Summer 2004. Dioxin concentrations for the vertical profiles are included in Table 3.9. A graphical comparison between shallow and deep dioxin concentrations is presented in Figure 3.15. As can be seen in Figure 3.15, deep concentrations were generally higher than shallow concentrations, with average deep/shallow ratios of up to 1.69 and 1.54 for locations 11193 and 15979, respectively (maximum ratios were 2.85 and 2.67, respectively). The only exceptions were 1234789-HpCDF at station 11193 and 123789-HxCDF at station 15979 for which the shallow concentrations were higher than those measured in the deep samples.

To investigate if dioxins are at equilibrium at the local scale among different phases in the HSC, fugacity calculations were completed for the different 2378-PCDD/Fs for the two locations sampled in Summer 2004. Fugacity is the tendency of a compound to "escape" from one phase to another (Mackay, 1991) and is linearly related to concentration by

$$C=Z^{*}f \qquad (3.1)$$



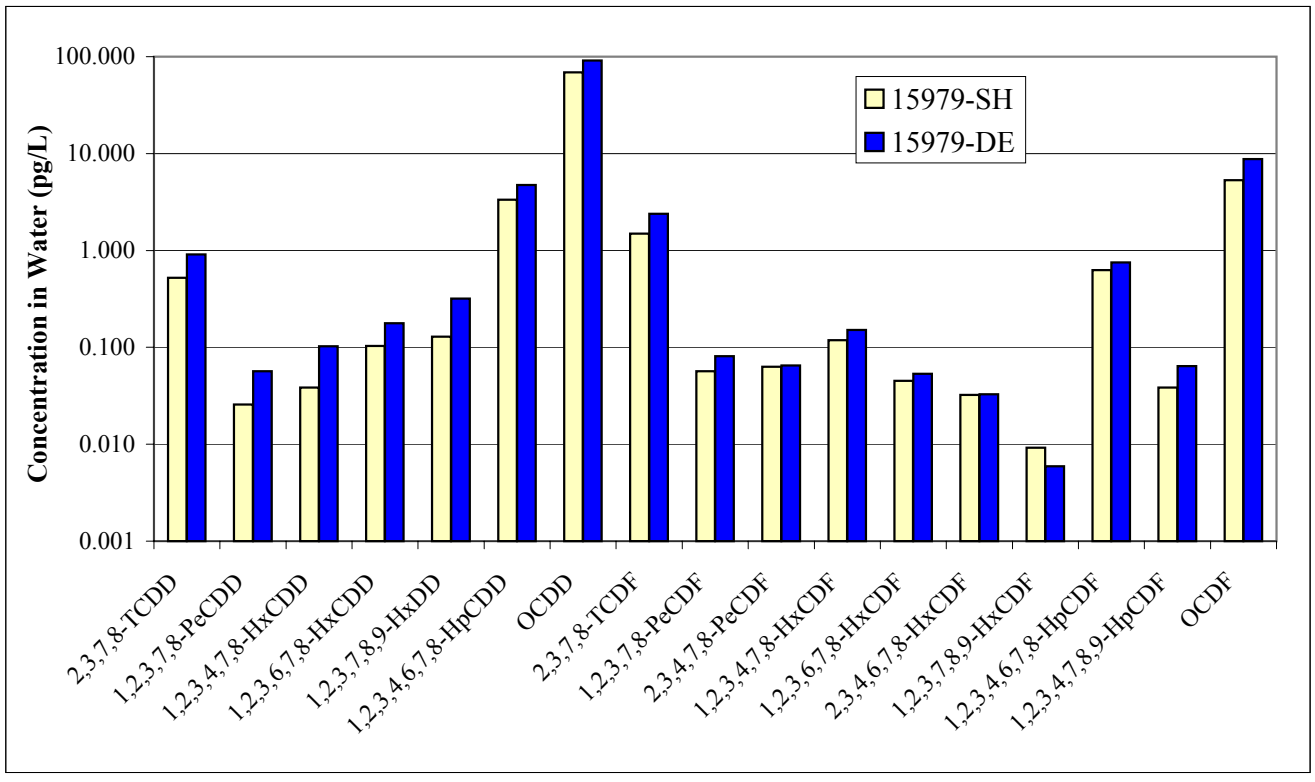


Figure 3.15 Comparison of Dioxin Concentrations in Shallow and Deep Water Samples

where C is the concentration of a chemical in a given phase, Z is the fugacity capacity [mol/m^{3}Pa], and f is fugacity [Pa]. The fugacity capacity can be calculated using the following equations (Mackay, 1991):

$$\text{Water:} \quad Z = \frac{1}{H} \quad \text{or} \quad Z = \frac{C^S}{P^S} \tag{3.2}$$

$$\text{Solid Sorbent:} \quad Z = \frac{K_P \rho_S}{H} \quad \text{or} \quad Z = \frac{K_{oc} f_{oc} \rho_S}{H} \tag{3.3}$$

where H is the Henry's law constant [Pa m^3/mol], C_s is the aqueous solubility [mol/m^3], P_s is the vapor pressure [Pa], K_p is the partitioning coefficient [L/kg], K_{oc} is the organic carbon-normalized partitioning coefficient [L/kg-oc], f_{oc} is the fraction organic carbon [uniteless], and ρ_s is density [kg/L].

Equilibrium organic carbon partitioning coefficients (K_{oc}) were calculated using a linear model with 95% confidence limits developed by Seth et al. (1999):

$$\log K_{oc} = 1.03 \log K_{ow} - 0.61 \tag{3.4}$$

Using Equation (3.4), measured individual concentrations, and the estimated fugacity capacities, it is possible to estimate congener-specific fugacities (f) for each of the collected samples. The tendency for a specific compound to partition from one phase to another can be evaluated by the ratio of its fugacities in the two respective phases. The fugacity ratios between the suspended and dissolved phases (f_{sus}/f_w) and between bottom sediments and dissolved phase (f_{sed}/f_w) equal 1 at equilibrium.

Figures 3.16a and b show the suspended/dissolved and sediment/dissolved fugacity ratios for selected 2378-substituted PCDD/Fs, respectively. There is a lack of equilibrium at the suspended-dissolved and sediment-dissolved interfaces for most of the congeners as indicated by

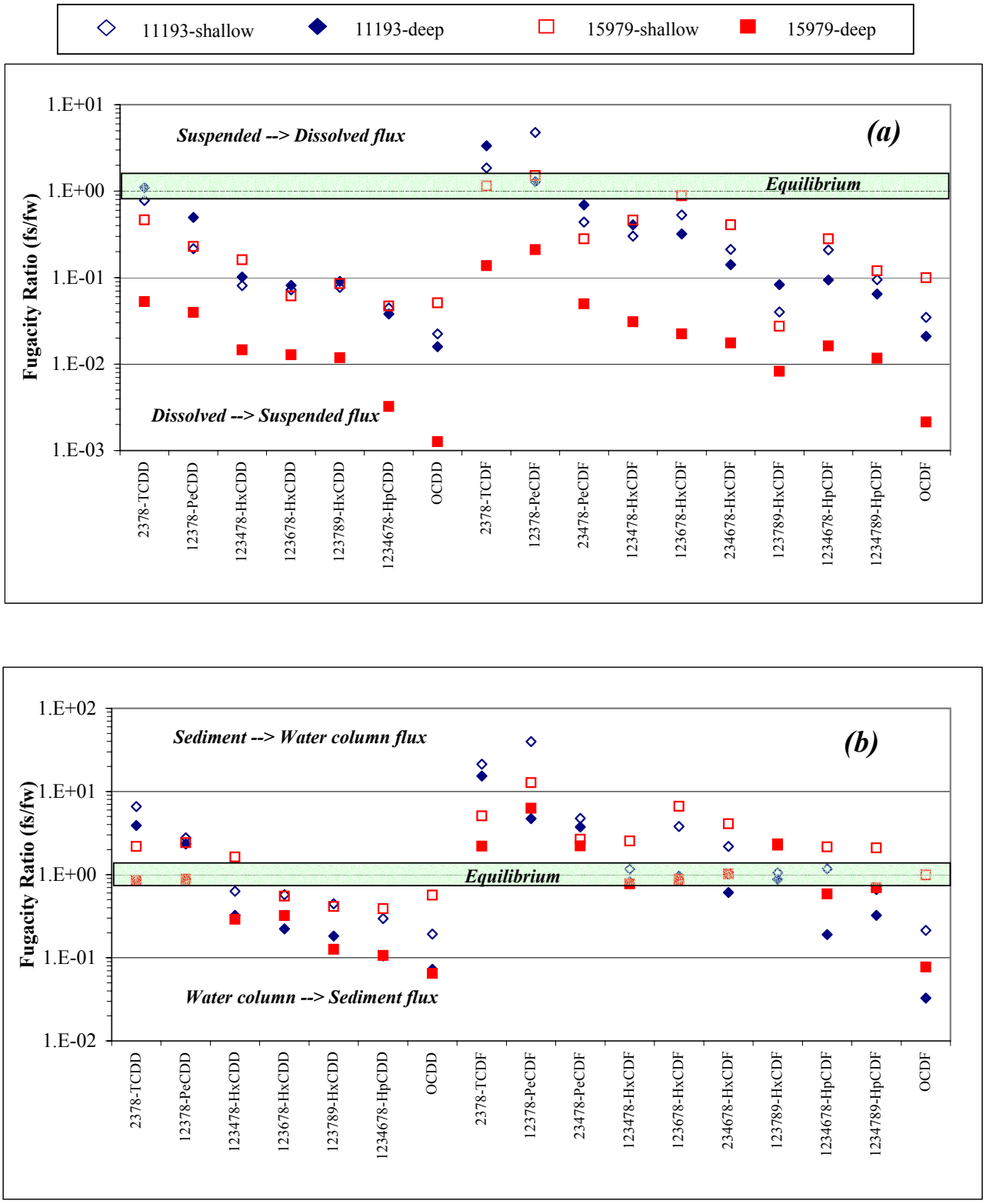


Figure 3.16 Fugacity Ratios
(a) Suspended Sediment/Dissolved (b) Bottom Sediment/Dissolved

the large range of fugacity ratios depicted in Figure 3.16. An f_s/f_w ratio greater than 1 indicates that the organic compound has a tendency to move from the particulate phase to the dissolved phase, while an f_s/f_w ratio smaller than 1 indicates a tendency of the compound to move from the dissolved to the particulate phase. Using shallow water data, fugacity ratios for the 2378-substituted dioxins varied from 0.02 to 4.77 with an average of 0.47 for the suspended-dissolved interface and from 0.19 to 39.7 with an average of 4.03 for the bottom sediment-dissolved interface. Similarly, dioxin data in deep water samples yielded fugacity ratios varying from 0.001 to 3.35 with an average of 0.26 for the dissolved-suspended interface and from 0.03 to 15.35 with an average of 1.60 for the bottom sediment-dissolved interface.

Data in Figures 3.16a suggest that 2378-TCDD is close to equilibrium at location 11193, while a dissolved–> particulate flux is expected at location 15979 as indicated by f_s/f_w ratios lower than 1. Data in Figure 3.16b indicate that 2378-TCDD is close to equilibrium between the bottom sediments and the dissolved phase (deep) at location 15979, whereas a bottom sediment–> dissolved flux is expected at location 11193. For almost all the remaining congeners, ratios lower than 1 were measured for the dissolved-suspended interface. The only exceptions were 2378-TCDF and 12378-PeCDF. For the bottom sediment-dissolved interface (Figure 3.16b), on the other hand, ratios greater than 1 were measured for some PCDFs and ratios lower than 1 for the higher chlorinated PCDDs. In addition, as can be seen in Figure 3.16b, 12378-PeCDD, 123478-HxCDF, 123678-HxCDF, 234678-HxCDF, 1234678-HpCDF,and 1234789-HpCDF are close to equilibrium between the bottom sediments and dissolved (deep) phases.

During Summer 2004, two additional locations in the upper watershed were sampled to obtain boundary dioxin data for calibration purposes (Stations 11142 and 11357 in Figure 3.1).

Table 3.9 presents a summary of dioxin/furan concentrations and the resulting Texas-TEQ levels for the samples collected in the upper watershed. Calculated Texas-TEQ levels were 0.055 pg/L and 0.074 pg/L for locations 11142 (Buffalo Bayou at Barker Dam) and 11357 (Buffalo Bayou at San Felipe), respectively. It is noted that dioxin levels in both locations were below the Texas WQS of 0.0933 pg/L.

A database of water sampling results reported by PSC/ Maxxam Analytical Laboratory is included in Appendix B1.

3.2.1.2 In-channel Sediment Sampling

Table 3.10 presents water column parameters obtained during the sediment sampling effort and Table 3.11 summarizes the results of the physical properties of sediment samples analyzed by NWDLS.

A summary of dioxin levels in sediment and their corresponding Texas-TEQs are presented in Table 3.12. Maps illustrating total TEQ concentrations in sediment for the Spring and Fall 2004 sampling events are shown in Figure 3.17. For the Spring 2004, dioxin levels in sediment varied from 0.92 to 451.4 ng TEQ/kg-dry wt. (dry weight), with an average value of 42.7 ng TEQ/kg-dry wt. Organic carbon (OC)-normalized levels ranged from 183.7 to 24,008 ng TEQ/kg-oc, with a mean value of 2,701 ng TEQ/kg-oc. TEQ. It is noted that the data are influenced by three relatively high values. A better estimate of central tendency, in this case, is probably the median which is equal to 1,048 ng TEQ/kg-oc. Likewise, TEQ concentrations in sediments collected in Fall 2004 varied ranged from 0.5 to 846.3 ng/kg-dry wt., with an average value of 68.8 ng/kg-dry wt. Organic carbon-normalized levels ranged from 247.1 to 30,551 ng/kg-oc, with a median value of 1,433 ng/kg-oc. The highest TEQ levels in the Spring samples

Table 3.10 Field Measurements during Sediment Sampling Activities

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Conductivity (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
Spring 2004								
13338	03/19/2004	8:10	0.3	22.4	12200	7.1	7.0	7.7
			1.2	22.4	12100	7.6	6.9	7.3
16499	03/19/2004	8:30	0.3	21.2	11100	7.8	5.5	6.8
			1.2	21.1	11300	7.8	5.4	7.0
16618	03/19/2004	9:04	0.3	20.4	10200	7.6	6.5	6.4
			1.2	20.2	10000	8.2	6.6	6.3
13344	03/19/2004	9:35	0.3	21.9	7270	9.0	8.6	4.3
			1.2	21.8	7280	8.9	8.5	4.3
11197	03/24/2004	9:40	0.3	20.3	380	8.5	8.6	0.2
			2.0	20.3	390	8.4	8.1	0.2
			4.1	20.2	390	8.2	7.9	0.2
11193	03/24/2004	10:20	0.3	20.3	4120	8.3	7.5	2.5
			4.9	20.3	4430	8.0	7.5	2.6
			9.8	20.3	4700	7.9	7.5	2.9
11261	03/24/2004	11:30	0.3	20.2	9940	7.7	7.5	6.2
			6.1	20.2	10700	7.6	7.5	6.7
			10.7	20.2	11300	7.2	7.5	7.1
11264	03/24/2004	14:00	0.3	20.2	10400	7.2	7.6	6.4
			4.9	20.3	10500	6.6	7.5	6.6
			10.7	20.3	11000	6.3	7.5	6.9
11292	04/02/2004	11:00	0.3	24.0	1650	5.2	6.8	0.9
			4.6	22.0	3320	1.7	6.7	1.9
			10.1	21.5	3800	0.5	6.8	2.2
11287	04/02/2004	12:50	0.3	23.5	3460	8.4	7.5	1.9
			4.6	21.8	4210	4.3	7.3	2.4
			8.2	21.7	5040	0.9	6.9	2.9
15979	04/02/2004	14:00	0.3	22.2	6910	6.3	7.4	4.0
			4.6	21.9	7530	6.0	7.4	4.5
			7.0	21.7	8780	2.1	7.1	5.3
11274	04/20/2004	15:17	0.3	21.2	2150	4.8	7.4	1.2
			1.2	21.2	2220	4.4	7.4	1.2
11305	04/15/2004	10:49	0.3	20.7	600	7.8	6.2	0.3
			3.0	18.8	480	6.3	7.3	0.3
			5.7	18.2	570	8.1	7.0	0.3
11300	04/15/2004	12:00	3.4	19.3	1310	2.9	7.2	0.7
			1.5	19.3	1120	2.9	7.2	0.6
			0.3	20.4	630	3.5	7.3	0.3
Summer 2004								
18388	08/02/2004	17:40	0.3	34.3	9790	10.7	8.0	4.5
			1.8	31.5	16900	6.8	7.5	8.7
11280	08/11/2004	8:02	0.3	30.6	15500	NA	7.2	9.0

Table 3.10 Field Measurements during Sediment Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Conductivity (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
			12.2	30.8	19100	NA	7.3	11.2
18392	08/11/2004	8:08	0.3	30.5	15900	NA	7.2	9.2
			11.6	30.8	18700	NA	7.4	12.2
11271	08/11/2004	8:14	0.3	30.4	15800	NA	7.3	9.2
			10.3	30.8	21300	NA	7.4	12.6
11270	08/11/2004	8:17	0.3	30.4	16400	NA	7.3	9.5
			10.4	30.9	21100	NA	7.4	12.1
18391	08/11/2004	8:20	0.3	30.4	15800	NA	7.3	9.6
			11.3	30.9	20900	NA	7.4	12.4
11269	08/11/2004	8:24	0.3	30.2	16700	NA	7.3	9.7
			8.8	30.8	21300	NA	7.4	12.7
15980	08/11/2004	8:30	0.3	30.5	17500	NA	7.3	10.2
			10.1	30.8	21700	NA	7.4	13.0
15979	08/11/2004	8:51	0.3	30.5	19800	NA	7.3	10.4
			0.3	30.6	18800	NA	7.4	11.1
11269	08/11/2004	8:24	9.4	30.8	21600	NA	7.4	12.9
			11.3	30.8	22400	NA	7.4	13.4
11268	08/11/2004	9:02	0.4	30.6	20000	NA	7.3	10.7
			11.6	30.7	26200	NA	7.5	14.2
11267	08/11/2004	9:29	0.3	30.5	20500	NA	7.4	10.5
			11.6	30.7	23200	NA	7.5	13.9
11197	08/11/2004	10:52	0.3	31.2	12900	NA	8.0	6.5
			6.0	30.8	18100	NA	7.5	9.5
18389	08/11/2004	11:47	0.4	31.3	15400	NA	7.9	7.8
			4.1	30.7	21100	NA	7.5	10.4
11193	08/11/2004	12:09	0.3	31.8	14500	NA	8.1	7.4
			8.7	30.7	22200	NA	7.5	11.6
18390	08/11/2004	13:01	0.3	31.0	19200	NA	7.7	10.1
			3.2	30.7	21700	NA	7.6	11.5
Fall 2004								
14560	11/04/2004	08:15	0.3	21.2	26800	4.0	8.0	15.4
			6.1	21.5	17400	2.3	8.0	9.8
			10.7	21.8	29200	4.4	8.0	16.8
11292	11/04/2004	10:30	0.3	20.6	380	9.3	7.6	<0.1
			4.6	20.2	300	9.1	7.8	<0.1
			9.1	22.4	8500	3.1	7.4	4.4
11287	11/04/2004	12:00	0.3	20.2	580	7.7	7.6	<0.1
			5.5	21.7	5170	4.7	7.4	2.4
			11.9	23.6	16900	3.8	7.4	9.5
11280	11/04/2004	12:35	0.3	21.2	3180	4.1	7.6	1.2
			5.2	22.3	9130	3.8	7.7	4.8
			10.4	23.8	24400	3.9	7.7	14.0
			0.3	21.4	5350	4.0	7.6	2.5

Table 3.10 Field Measurements during Sediment Sampling Activities - Cont'd

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Conductivity (μ S/cm)	DO (mg/L)	pH (SU)	Salinity ($^{o}/_{oo}$)
15979	11/04/2004	13:35	6.1	22.6	13800	3.8	7.7	7.6
			12.5	24.0	27700	3.7	7.8	16.0
11265	11/04/2004	14:21	0.3	21.9	9040	4.2	7.7	4.7
			6.1	22.6	15600	4.0	7.7	8.7
			12.2	23.8	26800	4.0	7.8	15.4
11264	11/04/2004	14:50	0.3	22.2	9630	4.0	7.7	5.1
			6.1	22.5	15300	3.8	7.7	8.5
			12.2	23.5	27600	3.7	7.8	15.9
11193	11/04/2004	16:05	0.3	21.0	8750	4.9	7.7	4.6
			3.5	21.0	8810	4.9	7.7	4.6
			7.0	20.9	9210	4.8	7.6	4.9
13340	11/09/2004	08:40	0.3	20.0	20800	7.6	8.4	11.8
			0.9	20.0	20900	7.5	8.4	11.8
			1.3	20.0	20900	7.3	8.4	11.9
11261	11/09/2004	09:41	0.3	20.9	18200	4.3	7.6	10.3
			5.0	21.4	21700	3.9	7.6	12.4
			10.1	21.4	27800	3.2	7.7	16.0
11197	11/09/2004	10:20	0.3	20.5	6440	4.8	7.2	3.2
			2.4	20.8	8700	4.1	7.8	4.5
			4.6	21.4	14000	3.8	7.6	7.7
13344	11/09/2004	11:17	0.3	20.7	16800	3.9	7.7	9.4
			0.9	20.7	16800	3.7	7.6	9.4
			1.8	21.7	20400	2.6	7.4	11.6
13342	11/09/2004	11:31	0.3	21.0	17400	4.1	7.7	9.8
			0.8	20.9	17600	3.8	7.6	9.9
			1.2	20.9	18400	3.7	7.6	10.4
16618	11/09/2004	11:52	0.3	21.1	21100	4.0	7.7	12.0
			5.3	21.2	24600	3.9	7.7	14.1
			10.7	21.3	28800	4.0	7.7	16.6
16499	11/09/2004	12:20	0.3	21.9	19800	3.0	7.6	11.2
			0.8	21.5	19900	2.8	7.6	11.3
			1.9	21.2	20000	2.3	7.6	11.3
11252	11/09/2004	12:50	0.4	21.3	25000	3.2	7.8	14.3
			6.2	21.3	28500	2.9	7.8	16.4
			12.4	21.2	31600	2.8	7.9	18.3
13338	11/09/2004	13:15	0.3	21.5	24400	2.6	7.7	14.0
			0.9	21.7	24500	2.6	7.7	14.0

Calculated from conductivity-salinity regression using data collected during water sampling activities

N/A not available

Table 3.11 Physical Characteristics of Sediment Samples

Station ID	Date	Moisture (%)	Total Solids (%)	TOC (%)	Volatile Solids (%)
Spring 2004					
14560	03/11/2004	32.9	67.1	NA	1.78
11252	03/11/2004	42.9	57.1	NA	2.9
13342	03/11/2004	72.8	27.2	NA	7.83
13340	03/11/2004	68.4	31.6	NA	6.62
13338	03/19/2004	60.0	40	1.52	4.48
13344	03/19/2004	79.2	20.8	1.77	8.13
16618	03/19/2004	39.0	61	0.59	2.01
16499	03/19/2004	59.2	40.8	1.21	4.69
11197	03/24/2004	31.8	68.2	0.48	1.54
11193	03/24/2004	67.9	32.1	1.66	6.1
11261	03/24/2004	30.9	69.1	0.49	1.74
11264	03/24/2004	34.3	65.7	0.99	NA
11280	04/01/2004	50.1	49.9	1.88	NA
11265	04/01/2004	55.5	44.5	1.39	NA
11287	04/02/2004	50.4	49.6	1.7	NA
11287-dup	04/02/2004	51.0	49	1.68	NA
11292	04/02/2004	63.5	36.5	2.69	NA
11292-dup	04/02/2004	62.9	37.1	2.88	NA
15979	04/02/2004	28.5	71.5	1.26	NA
11274	05/18/2004	47.6	52.4	1.5	NA
15979	05/18/2004	57.7	42.3	1.77	NA
Summer 2004					
11280	08/10/2004	60.8	39.2	2.12	7.37
18392	08/10/2004	57.4	42.6	1.84	6.73
11271	08/10/2004	44.8	55.2	1.20	5.26
11270	08/10/2004	54.2	45.8	1.66	6.00
18391	08/10/2004	52.2	47.8	1.50	5.60
11269	08/10/2004	52.5	47.5	1.21	5.16
15980	08/10/2004	53.8	46.2	1.45	5.32
15979	08/10/2004	52.3	47.7	1.36	5.05
15979-TransA	08/10/2004	61.2	38.8	1.53	6.73
15979-TransB	08/10/2004	49.9	50.1	1.16	5.14
15979-TransC	08/10/2004	41.9	58.1	1.11	3.49
15979-TransD	08/10/2004	54.4	45.6	1.50	5.66
15979-TransE	08/11/2004	41.0	59.0	1.60	3.60
11268	08/11/2004	59.9	40.1	1.38	6.16

Table 3.11 Physical Characteristics of Sediment Samples - Cont'd

Station ID	Date	Moisture (%)	Total Solids (%)	TOC (%)	Volatile Solids (%)
11267	08/11/2004	65.4	34.6	1.87	7.09
11197	08/11/2004	68.8	31.2	1.40	5.49
11197-dup	08/11/2004	67.9	32.1	1.17	5.65
18388	08/11/2004	51.9	48.1	0.90	3.85
18389	08/11/2004	34.5	65.5	0.43	2.11
11193	08/11/2004	61.1	38.9	1.09	4.59
11193-dup	08/11/2004	60.4	39.6	1.52	5.26
18390	08/11/2004	33.5	66.5	0.56	2.41
Fall 2004					
14560	11/04/2004	20.9	79.1	0.20	0.53
11292	11/04/2004	61.0	39.0	2.97	6.94
11287	11/04/2004	67.7	32.3	3.65	6.32
11280	11/04/2004	59.2	40.8	2.77	5.58
15979	11/04/2004	61.8	38.2	1.69	4.27
11265	11/04/2004	61.1	38.9	1.37	4.40
11264	11/04/2004	59.6	40.4	1.17	3.75
11193	11/04/2004	42.4	57.6	0.81	2.00
11193-dup	11/04/2004	43.5	56.5	0.81	1.96
13344	11/08/2004	72.0	28.0	1.66	NA
13344-dup	11/08/2004	72.6	27.4	1.66	NA
13338	11/08/2004	56.3	43.7	0.94	NA
11252	11/08/2004	54.8	45.2	0.98	NA
13340	11/09/2004	67.9	32.1	1.63	NA
11261	11/09/2004	52.5	47.5	1.07	NA
11197	11/09/2004	50.2	49.8	0.83	NA
13342	11/09/2004	71.1	28.9	1.31	NA
16618	11/09/2004	57.5	42.5	1.02	NA
16499	11/09/2004	55.3	44.7	1.15	NA

NA= not available. Exceeded holding time. Sample rejected.

Table 3.12 Total Dioxin Concentrations in Sediment (ng/kg-dry wt)

Station ID	Date	TOC (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Total TEQ in OC	Average TEQ[a]	Average TEQ in OC[a]
Spring 2004																							
11252	03/11/2004	0.68	2.60	0.92	< 1.00	1.90	2.60	69.00	1400.00	6.90	0.53	< 0.52	1.50	0.39	0.38	0.29	< 4.80	< 0.53	44.00	4.66	685.66	4.66	685.66
14560	03/11/2004	0.50	< 0.75	< 0.36	< 0.42	0.68	0.75	26.00	470.00	< 0.82	0.21	0.27	0.48	0.34	< 0.19	< 0.23	3.00	< 0.58	19.00	0.92	183.70	0.92	183.70
13340	03/11/2004	2.04	4.00	< 1.00	3.30	5.60	7.60	220.00	4500.00	9.30	< 0.92	< 1.40	< 3.40	1.80	1.50	0.53	25.00	1.90	100.00	7.76	380.20	7.76	380.20
13342	03/11/2004	1.81	17.00	< 1.60	2.60	5.60	6.30	190.00	4500.00	43.00	3.10	3.10	< 6.60	2.50	2.20	0.86	27.00	3.10	220.00	25.74	1422.15	25.74	1422.15
13338	03/19/2004	1.52	8.90	0.93	1.90	3.40	3.70	93.00	2000.00	29.00	1.50	1.30	< 4.60	1.90	0.98	0.50	9.60	1.20	88.00	14.46	951.18	14.46	951.18
13344	03/19/2004	1.77	11.00	1.10	2.10	4.50	4.90	150.00	4800.00	28.00	2.50	2.60	< 6.10	1.70	2.00	1.20	22.00	< 2.30	170.00	17.72	1001.13	17.72	1001.13
16499	03/19/2004	1.21	29.00	2.20	2.90	9.60	6.30	160.00	2700.00	55.00	2.70	2.50	7.40	3.40	2.00	0.75	29.00	3.90	210.00	40.22	3323.97	40.22	3323.97
16618	03/19/2004	0.59	3.30	< 0.57	1.10	1.70	2.00	58.00	1400.00	7.30	0.55	0.51	1.30	0.48	0.38	0.28	6.40	1.00	53.00	5.18	877.80	5.18	877.80
11193	03/24/2004	1.66	61.00	2.30	< 2.10	< 3.60	5.50	160.00	5200.00	230.00	6.60	6.20	11.00	3.60	2.20	1.70	19.00	2.80	160.00	91.27	5497.89	91.27	5497.89
11197	03/24/2004	0.48	5.90	0.72	< 0.61	1.70	< 1.40	67.00	2600.00	16.00	< 0.64	0.98	< 1.40	0.62	0.56	0.37	6.00	0.64	39.00	8.86	1846.15	8.86	1846.15
11261	03/24/2004	0.49	5.50	0.45	0.73	1.40	1.30	36.00	1000.00	17.00	0.81	0.73	1.20	0.32	0.42	0.33	4.90	0.68	83.00	8.40	1714.39	8.40	1714.39
11264	03/24/2004	0.99	10.00	0.93	1.30	3.40	1.80	84.00	1700.00	39.00	16.00	10.00	10.00	2.30	1.80	1.80	32.00	3.50	610.00	22.41	2263.13	22.41	2263.13
11265	04/01/2004	1.39	15.00	1.40	2.60	6.60	4.60	180.00	4100.00	40.00	6.90	6.70	< 16.00	5.60	4.10	4.90	100.00	14.00	2100.00	27.04	1944.96	27.04	1944.96
11280	04/01/2004	1.88	330.00	6.80	9.70	28.00	15.00	720.00	9000.00	810.00	22.00	39.00	40.00	26.00	42.00	2.90	160.00	15.00	740.00	451.36	24008.51	451.36	24008.51
11287	04/02/2004	1.70	8.50	2.00	3.30	8.40	5.30	260.00	3500.00	22.00	2.10	3.20	5.80	2.70	3.50	1.40	46.00	3.90	150.00	16.45	967.35	16.11	953.32
11287-dup	04/02/2004	1.68	8.60	< 1.60	3.10	7.20	4.80	220.00	3000.00	25.00	2.10	2.90	< 8.30	2.90	3.40	1.70	46.00	4.40	150.00	15.78	939.29		
11292	04/02/2004	2.88	0.93	2.30	3.30	8.10	5.70	270.00	3900.00	3.00	1.20	2.60	< 6.20	2.50	4.00	1.50	42.00	3.10	120.00	6.56	227.78	6.46	232.01
11292-dup	04/02/2004	2.69	0.64	2.40	3.30	8.90	6.30	270.00	3900.00	2.70	1.10	2.70	2.50	2.70	3.60	1.10	41.00	3.20	120.00	6.36	236.25		
11274	05/18/2004	1.50	1.30	0.76	1.10	2.10	2.20	83.00	220.00	4.20	0.57	1.10	1.50	0.96	0.98	0.38	10.00	0.92	26.00	3.60	240.03	3.60	240.03
15979-A	04/02/2004	1.26	9.80	0.67	0.76	< 1.50	1.20	50.00	1100.00	26.00	1.20	1.30	2.00	0.92	0.84	1.00	24.00	3.60	510.00	14.19	1126.35	16.52	1095.77
15979-B	05/18/2004	1.77	12.00	1.40	1.70	4.30	3.60	130.00	380.00	32.00	1.80	2.30	3.30	1.80	1.70	0.74	26.00	2.80	54.00	18.85	1065.20		
Summer 2004																							
18388	08/02/2004	0.90	10.00	0.87	1.60	4.10	3.60	140.00	4800.00	28.00	2.00	1.60	2.70	1.40	1.40	0.63	14.00	2.50	140.00	15.68	1742.00	15.68	1742.00
11269	08/10/2004	1.21	8.50	1.30	1.30	3.10	3.00	93.00	3100.00	20.00	1.30	1.60	1.70	1.60	1.20	0.60	15.00	2.00	170.00	13.27	1096.28	13.27	1096.28
18391	08/10/2004	1.50	< 4.30	< 3.90	< 4.40	< 3.50	< 3.40	110.00	3700.00	30.00	< 3.70	< 2.80	< 3.60	< 2.30	< 2.60	< 3.20	23.00	< 3.20	170.00	8.07	537.83	8.07	537.83
11270	08/10/2004	1.66	6.20	1.30	2.00	5.10	4.00	160.00	6600.00	16.00	1.80	2.60	< 0.18	2.40	2.00	0.97	28.00	2.80	130.00	11.50	692.53	11.50	692.53
11271	08/10/2004	1.20	5.30	< 0.39	1.40	3.10	2.80	98.00	4700.00	13.00	1.20	1.80	2.10	1.50	1.50	0.66	16.00	1.70	82.00	8.96	746.96	8.96	746.96
18392	08/10/2004	1.84	18.00	2.10	2.90	6.70	5.20	200.00	5200.00	50.00	< 0.33	4.30	5.70	3.20	3.20	1.50	34.00	4.20	220.00	29.05	1578.71	29.05	1578.71
11280	08/10/2004	2.12	25.00	3.00	3.60	9.60	6.50	310.00	6200.00	63.00	6.70	6.80	12.00	6.50	5.10	2.60	50.00	4.70	230.00	41.13	1939.86	41.13	1939.86
15979	08/10/2004	1.36	12.00	1.30	2.10	4.60	3.50	150.00	4400.00	29.00	2.40	2.60	3.80	2.00	1.80	1.40	29.00	3.80	310.00	18.89	1388.97	18.89	1388.97
15980	08/10/2004	1.45	12.00	1.70	2.30	5.80	4.30	160.00	5000.00	30.00	2.60	3.30	8.10	3.10	2.30	1.50	32.00	4.20	360.00	20.37	1404.83	20.37	1404.83
15979-transA	08/10/2004	1.53	4.80	0.65	1.20	2.50	2.10	71.00	2100.00	12.00	1.00	1.60	2.00	1.20	1.10	0.50	12.00	1.70	110.00	8.24	538.24	8.24	538.24
15979-transB	08/10/2004	1.16	12.00	1.20	1.90	5.00	3.70	150.00	4200.00	30.00	2.60	2.90	< 0.42	2.30	2.10	1.40	27.00	3.80	290.00	18.84	1624.22	18.84	1624.22
15979-transC	08/10/2004	1.11	11.00	0.85	1.60	3.90	3.20	110.00	3100.00	35.00	3.50	3.00	< 1.10	2.00	1.80	1.10	25.00	4.50	360.00	18.02	1622.97	18.02	1622.97
15979-transD	08/10/2004	1.50	11.00	1.20	1.70	4.30	3.10	110.00	2900.00	27.00	2.40	2.80	< 0.32	1.90	1.90	1.10	23.00	2.10	210.00	17.24	1149.07	17.24	1149.07
15979-transE	08/10/2004	1.60	10.00	< 2.90	< 2.80	< 2.50	< 2.90	74.00	2800.00	30.00	< 2.20	< 2.30	< 1.80	< 2.30	< 2.60	< 2.10	< 3.10	< 2.50	660.00	15.21	950.31	15.21	950.31
18390	08/11/2004	0.56	8.00	0.49	0.62	1.10	1.40	39.00	1500.00	26.00	0.82	0.71	< 0.25	0.61	< 0.35	< 0.33	4.60	< 0.82	36.00	11.66	2082.23	11.66	2082.23
11193	08/11/2004	1.52	11.00	0.46	0.45	0.89	1.10	31.00	1400.00	55.00	1.00	1.40	0.70	0.49	0.32	< 0.21	2.70	< 0.38	17.00	17.89	1176.68	55.13	4825.95
11193-dup	08/11/2004	1.09	60.00	1.90	2.00	4.00	5.20	170.00	7800.00	260.00	6.00	5.70	6.40	2.90	1.30	1.00	15.00	2.20	120.00	92.38	8475.23		
18389	08/11/2004	0.43	11.00	0.60	0.76	1.60	1.70	59.00	2100.00	33.00	< 0.20	1.20	1.80	0.77	0.55	0.36	5.60	0.68	56.00	15.96	3711.40	15.96	3711.40
11197	08/11/2004	1.17	17.00	1.50	2.30	4.90	5.50	190.00	7300.00	53.00	2.60	2.40	4.50	2.90	1.40	0.89	15.00	2.10	100.00	26.62	2275.13	25.76	2027.03
11197-dup	08/11/2004	1.40	17.00	< 3.90	< 4.30	< 3.30	< 3.00	190.00	6800.00	52.00	< 2.80	< 2.50	< 2.60	< 2.30	< 2.80	< 2.40	11.00	< 3.40	110.00	24.91	1778.93		
11268	08/11/2004	1.38	22.00	< 3.30	< 4.20	< 2.90	< 3.50	190.00	4900.00	51.00	5.10	3.90	< 2.40	< 2.30	< 2.70	< 2.50	52.00	< 3.70	800.00	31.16	2257.61	31.16	2257.61
11267	08/11/2004	1.87	16.00	1.90	3.70	8.30	6.40	230.00	5700.00	< 0.24	20.00	14.00	29.00	5.60	7.00	10.00	270.00	30.00	6500.00	31.96	1709.20	31.96	1709.20

Table 3.12 Total Dioxin Concentrations in Sediment (ng/kg-dry wt) - Cont'd

Station ID	Date	TOC (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Total TEQ in OC	Average TEQ[a]	Average TEQ in OC[a]
Fall 2004																							
11193	11/04/2004	0.81	27.00	0.62	0.73	1.90	2.20	71.00	2300.00	100.00	2.60	2.50	3.40	0.96	0.53	0.39	8.00	0.92	110.00	39.70	4919.58	42.73	5287.66
11193-dup	11/04/2004	0.81	31.00	0.84	0.70	1.50	1.90	57.00	2000.00	120.00	2.50	2.60	3.20	1.10	0.60	< 0.20	8.10	1.00	100.00	45.76	5655.75		
11252	11/08/2004	0.98	1.40	1.00	1.60	2.90	4.10	96.00	2000.00	3.10	0.31	0.52	0.72	< 0.32	0.41	< 0.45	5.30	< 0.38	27.00	3.50	357.20	3.50	357.20
11264	11/04/2004	1.17	11.00	1.00	1.30	3.00	3.30	100.00	2600.00	28.00	2.10	2.00	3.10	1.10	1.20	0.67	13.00	2.10	190.00	16.77	1433.50	16.77	1433.50
11265	11/04/2004	1.37	17.00	1.20	1.80	3.70	3.90	110.00	2700.00	42.00	2.40	< 0.29	4.30	1.40	1.60	0.95	20.00	2.80	370.00	23.76	1734.12	23.76	1734.12
11280	11/04/2004	2.77	650.00	13.00	9.20	30.00	16.00	680.00	9500.00	1600.00	27.00	34.00	30.00	12.00	12.00	5.10	130.00	15.00	760.00	846.28	30551.62	846.28	30551.62
11287	11/04/2004	3.65	10.00	1.80	3.50	8.00	5.80	230.00	3800.00	27.00	2.40	3.70	3.70	3.40	3.80	1.00	44.00	3.90	140.00	18.49	506.58	18.49	506.58
11292	11/04/2004	2.97	1.20	2.00	3.40	9.10	5.80	250.00	3800.00	4.90	1.10	2.90	6.50	2.70	3.50	0.96	44.00	3.50	120.00	7.39	248.86	7.39	248.86
14560	11/04/2004	0.20	< 0.36	< 0.35	< 0.36	< 0.29	0.48	11.00	220.00	0.37	< 0.21	< 0.23	< 0.21	< 0.23	< 0.25	< 0.24	0.48	< 0.25	2.10	0.49	247.13	0.49	247.13
15979	11/04/2004	1.69	12.00	1.40	2.00	5.00	4.00	150.00	5100.00	29.00	2.00	2.70	4.00	2.00	2.30	0.93	26.00	2.60	210.00	19.07	1128.58	19.07	1128.58
13338	11/08/2004	0.94	5.00	< 0.33	2.40	4.30	5.60	150.00	3900.00	14.00	0.89	1.20	2.20	0.97	0.79	< 0.62	18.00	1.60	95.00	8.78	932.48	8.78	932.48
13344	11/08/2004	1.66	15.00	1.70	3.20	6.70	6.40	240.00	6900.00	38.00	2.90	3.20	5.30	2.50	2.40	1.50	35.00	3.80	290.00	24.20	1457.53	23.98	1444.58
13344-dup	11/08/2004	1.66	15.00	1.90	2.90	5.80	6.30	210.00	6300.00	36.00	2.90	3.20	4.00	1.90	2.40	1.40	32.00	3.30	250.00	23.77	1431.63		
16499	11/09/2004	1.15	56.00	5.70	5.50	28.00	18.00	360.00	5100.00	110.00	4.00	4.40	< 0.18	3.90	3.80	1.60	64.00	5.70	360.00	78.34	6812.09	78.34	6812.09
16618	11/09/2004	1.02	12.00	0.84	1.70	3.50	4.50	110.00	3500.00	31.00	1.20	1.30	< 0.17	0.87	0.76	0.41	12.00	1.30	150.00	17.41	1707.11	17.41	1707.11
11197	11/09/2004	1.66	8.80	0.69	1.10	2.70	2.90	100.00	3800.00	26.00	1.10	1.20	2.00	0.71	0.82	< 0.27	9.20	1.10	72.00	13.44	809.43	13.44	809.43
11261	11/09/2004	1.07	12.00	0.63	1.30	2.40	3.10	79.00	2000.00	36.00	1.30	1.50	2.50	0.70	0.83	0.62	11.00	1.50	170.00	17.88	1670.56	17.88	1670.56
13340	11/09/2004	1.63	2.90	1.20	1.70	3.90	4.30	120.00	2400.00	7.40	0.96	1.40	1.30	1.10	1.00	0.46	12.00	1.30	49.00	6.36	390.43	6.36	390.43
13342	11/09/2004	1.31	15.00	1.40	3.30	7.10	7.80	220.00	7900.00	49.00	2.90	3.10	3.10	2.50	2.10	1.00	33.00	3.60	300.00	24.99	1907.25	24.99	1907.25

[a] Average of duplicate samples, otherwise concentration of a single sample

dup = duplicate

trans=transect

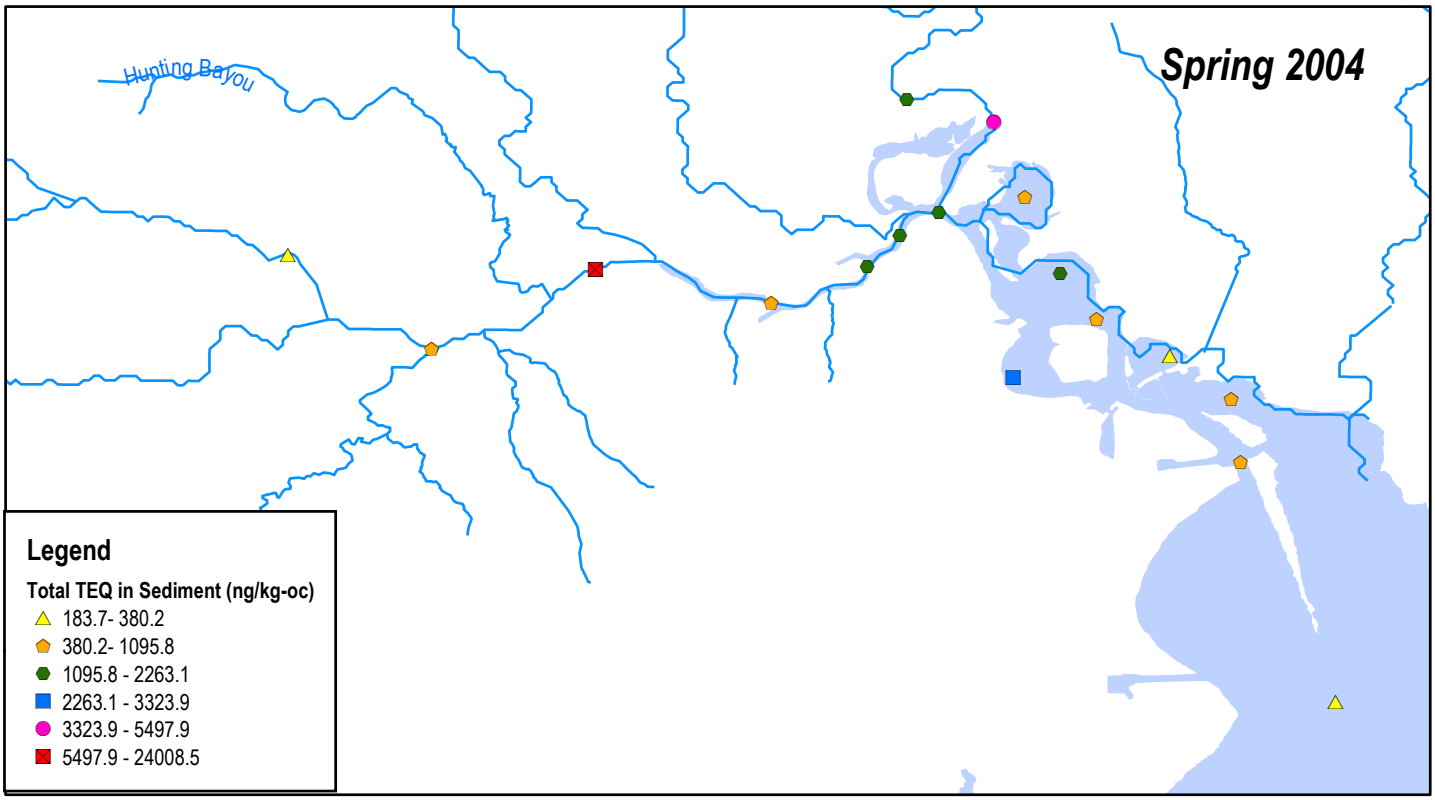
Values reported to the Detection Limit

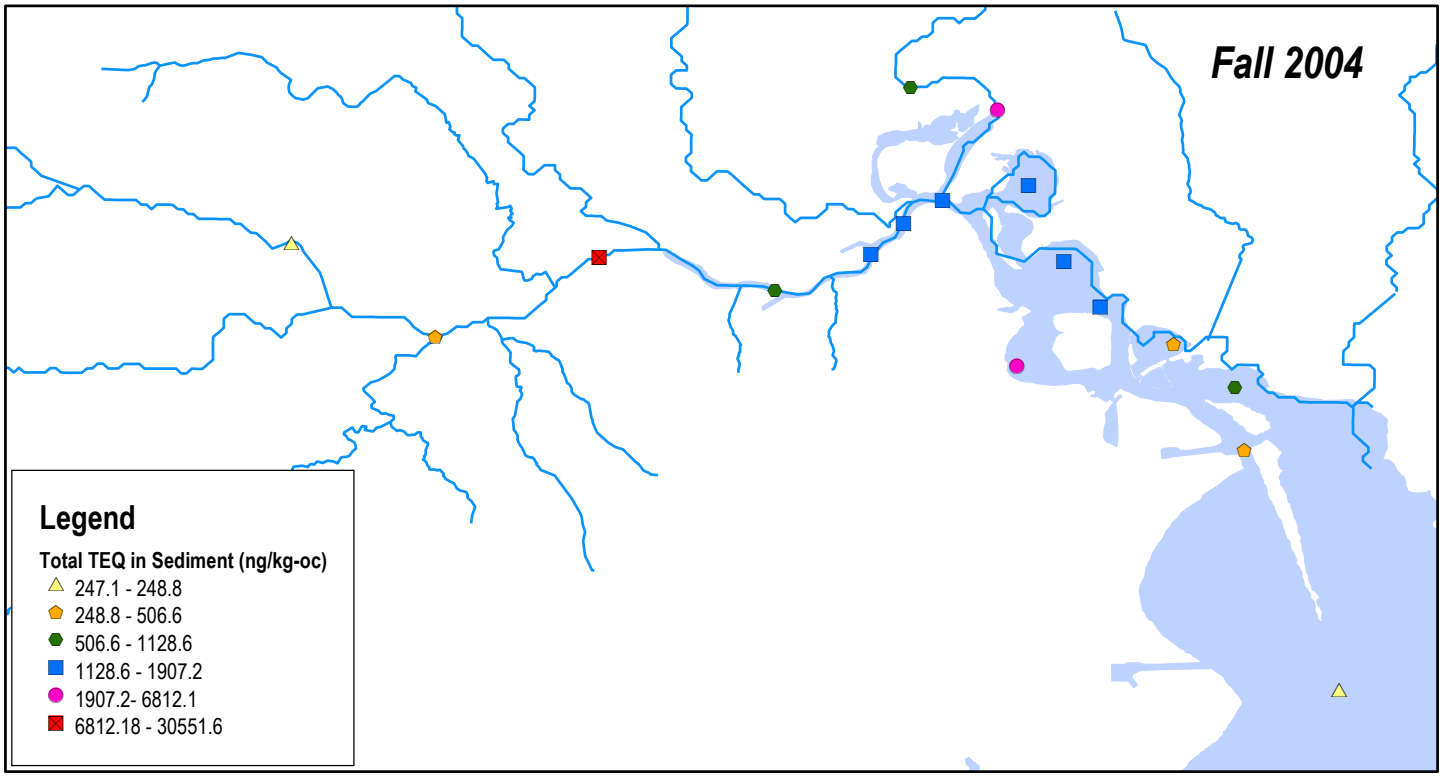
Non-detects assumed as 1/2 MDL for TEQ calculations

Value between the detection and the reporting limits

Value is an estimate due to blank contamination (concentration < 20 times lowest concentration)

Value is an estimate due to QC issues (interference, signal to noise ratio)





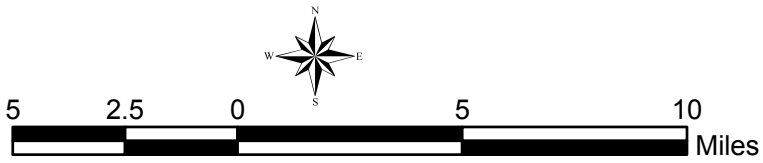


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Figure 3.17
Organic-carbon Normalized
TEQ Concentrations in Sediment

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

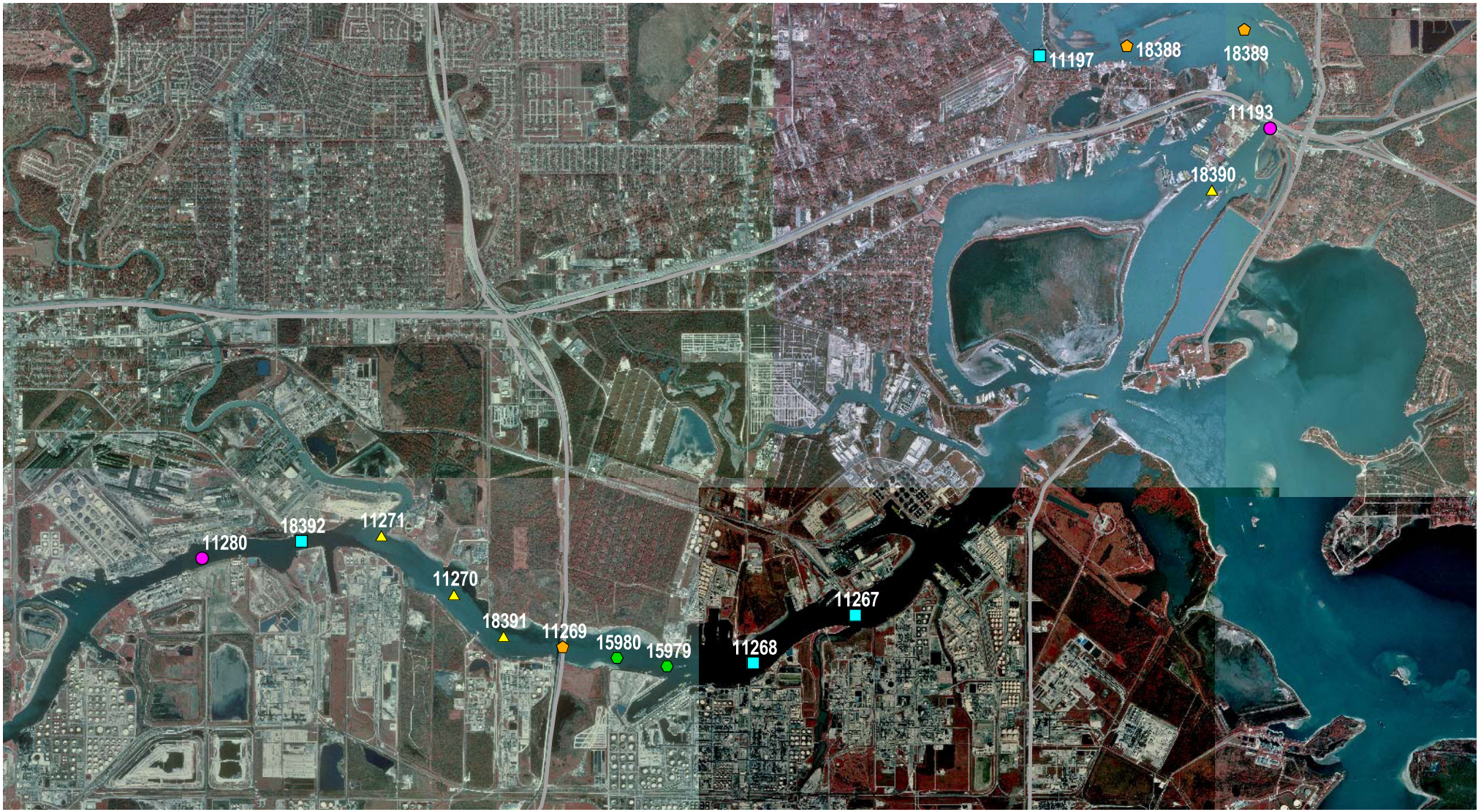
Prepared by: MPS

Date: 09-09-2005

were measured at locations 11280 (segment 1007) and 11193 (segment 1001), whereas the highest TEQ concentrations in Fall samples were measured at locations 11280 (segment 1007) and 16499 (segment 2427).

Dioxin results of high-resolution sediment sampling, conducted in Summer 2004 to pinpoint the location of unidentified major sources near stations 15979 and 11193, are included in Table 3.12. Total TEQ concentrations varied between 8.07 and 92.38 ng/kg-dry wt. with an average of 22.57 ng/kg-dry wt. Figure 3.18 shows the distribution of Texas TEQ in sediment samples and Figure 3.19 shows profiles of oc-normalized 2378-TCDD and TEQ concentrations at the 15 sampling locations. The highest organic-carbon normalized TEQ concentrations were observed at stations 11268 and 18389 for segments 1006 and 1001, respectively. Both 2378-TCDD and TEQ levels at station 18389 (~1 km upstream of station 11193) are significantly higher than those observed at the remaining locations in segment 1001, which might suggest the presence of an identified source of 2378-TCDD. This finding prompted additional high-resolution sediment sampling at the bend in San Jacinto River (1001) as discussed in Section 3.1.1.2. In the main channel results suggest additional unidentified sources might be present in the vicinity of 11280 and between 11269 and 11267.

The high-resolution data from Summer 2004 were analyzed using Principal Component and Cluster Analysis Techniques to determine if the fingerprints for the various locations were different (Figure 3.20). As shown in Figure 3.20, almost all the locations exhibited similar fingerprints, the only exception is station 11267 that seems to form its own cluster (relatively high concentrations of 1234678-HpCDF and OCDF), thus suggesting a different source from the other stations.



N
W E
S

1 0 1 2 Kilometers

LEGEND
TEQ Concentration (ng/kg-dry wt.)
- 8.068 - 11.661
- 11.661 - 15.959
- 15.959 - 20.37
- 20.37 - 31.962
- 31.962 - 55.133

UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering

Figure 3.18
Dioxin Concentrations in High-resolution Sediment Samples

Principal Investigators: Hanadi Rifai (University of Houston)
Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 12-07-2004

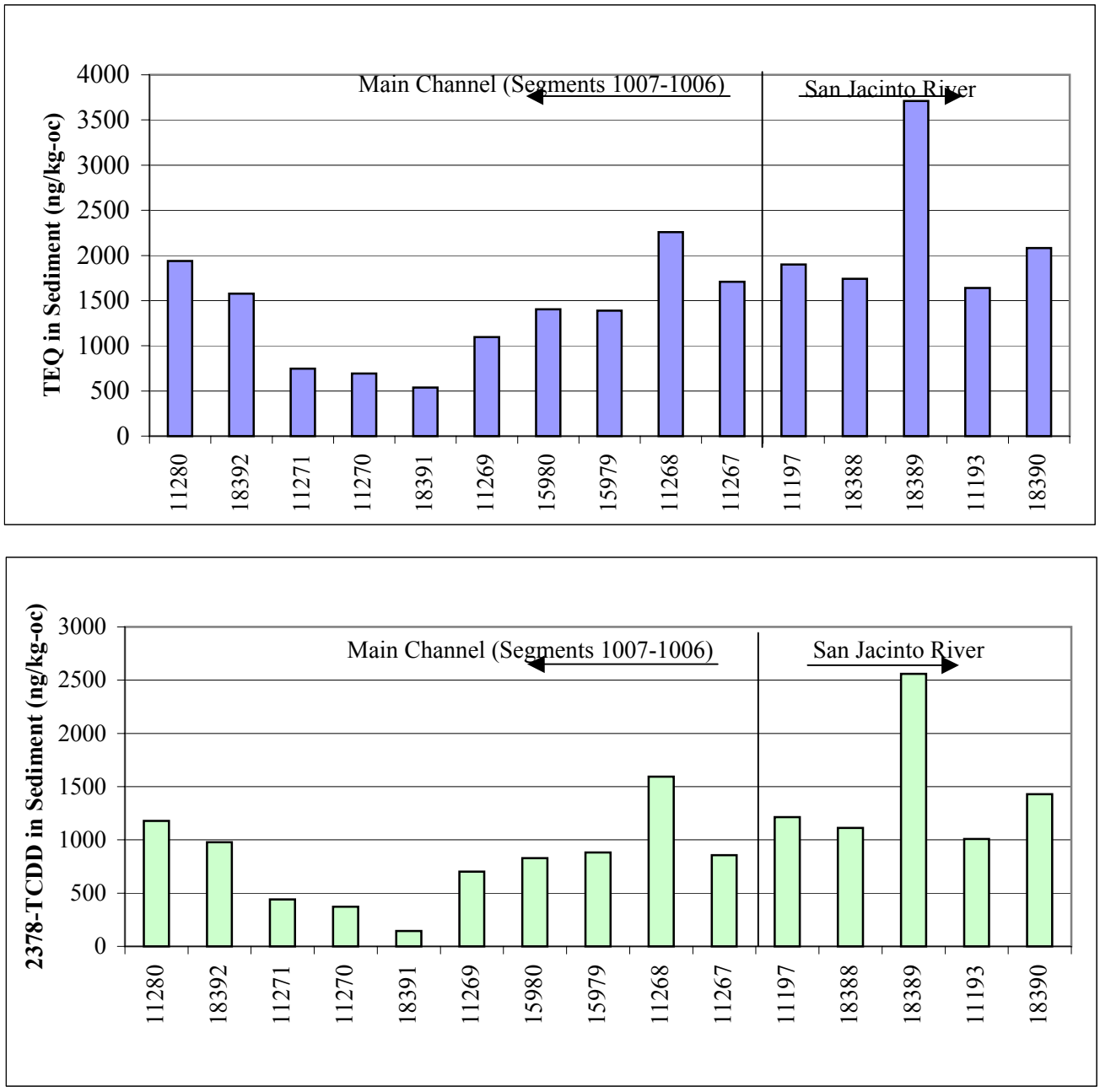
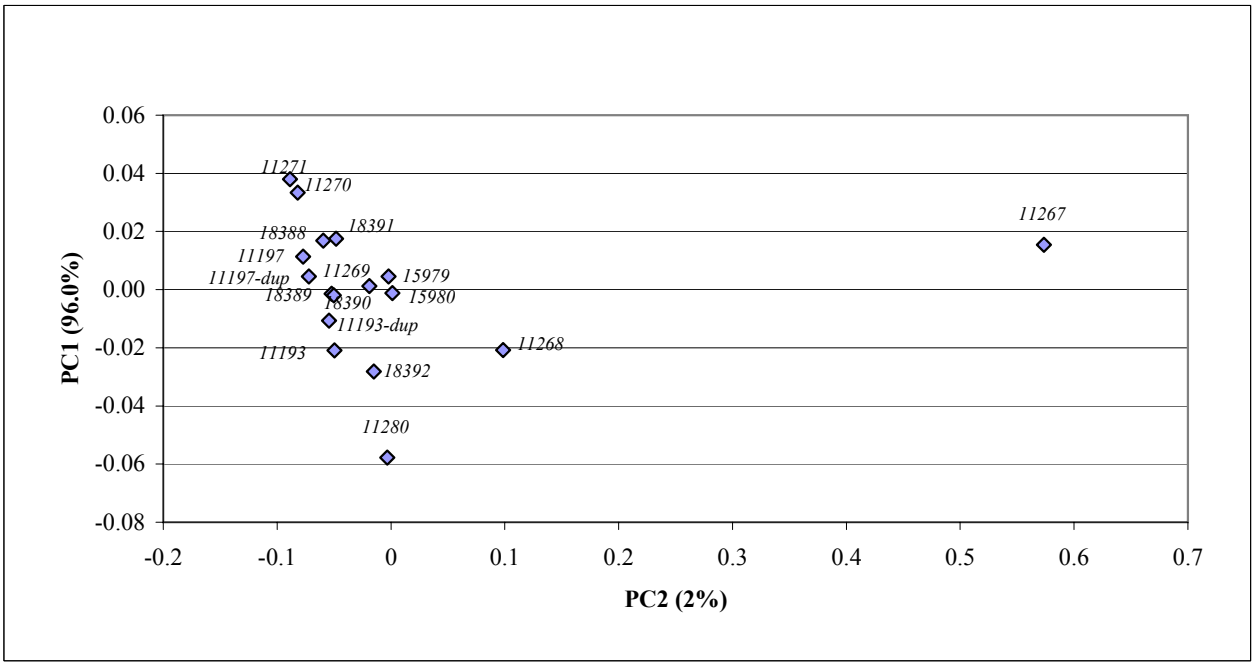


Figure 3.19 Organic-carbon Normalized Concentrations from High-Resolution Sediment Sampling



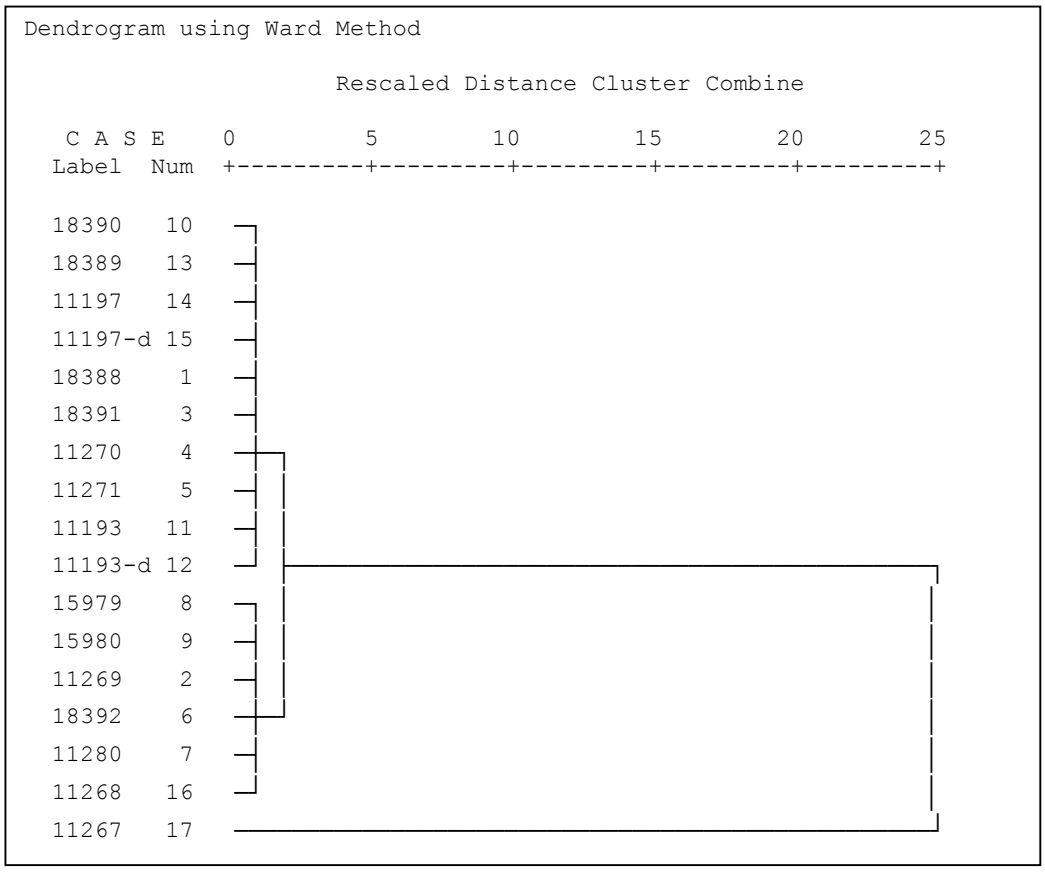


Figure 3.20 Principal Component and Cluster Analysis Results for the High-resolution Sediment Samples

In addition to high-resolution sediment sampling, five samples along a transect at location 15979 were collected during the Summer 2004 to evaluate the difference in dioxin concentrations between the dredged channel and the channel banks. Concentrations of dioxins along the transect are presented in Table 3.12 and depicted in Figure 3.21. Data show that the concentrations in the main channel are higher than those measured at the banks.

Results from the sediment sampling conducted during Summer 2005 are not available as of this writing and will be discussed in the next quarterly report.

A database of sediment results reported by Pace Analytical Laboratory is included in Appendix B1.

3.2.1.3 Tissue Sampling

A summary of dioxin levels in catfish and crab samples and their corresponding TEQs are presented in Tables 3.13 and 3.14, respectively. Total TEQ concentrations in tissue are mapped in Figures 3.22 and 3.23 for catfish and crab, respectively. Spring 2004 tissue samples varied from 0.19 to 19.64 ng TEQ/kg-wet wt. for catfish and from 0.37 to 8.61 ng TEQ/kg-wet wt. for crabs, with average values of 5.68 and 3.32 ng TEQ/kg-wet wt., respectively. Similarly, TEQ concentrations in Fall 2004 ranged from 0.93 to 27.4 ng/kg-wet wt. for catfish, and from 1.32 to 12.08 ng/kg-wet wt. for crabs, with respective average values of 9.39 and 6.93 ng/kg-wet wt. Lipid-normalized concentrations[2] in catfish and crabs showed average values of 11.39 and 6.82 ng TEQ/kg-wet wt. in Spring 2004, and 13.1 and 16.19 ng TEQ/kg-wet wt. in Fall 2004.

[2] Fish samples normalized to 3% lipids and crab samples to 2% lipids.

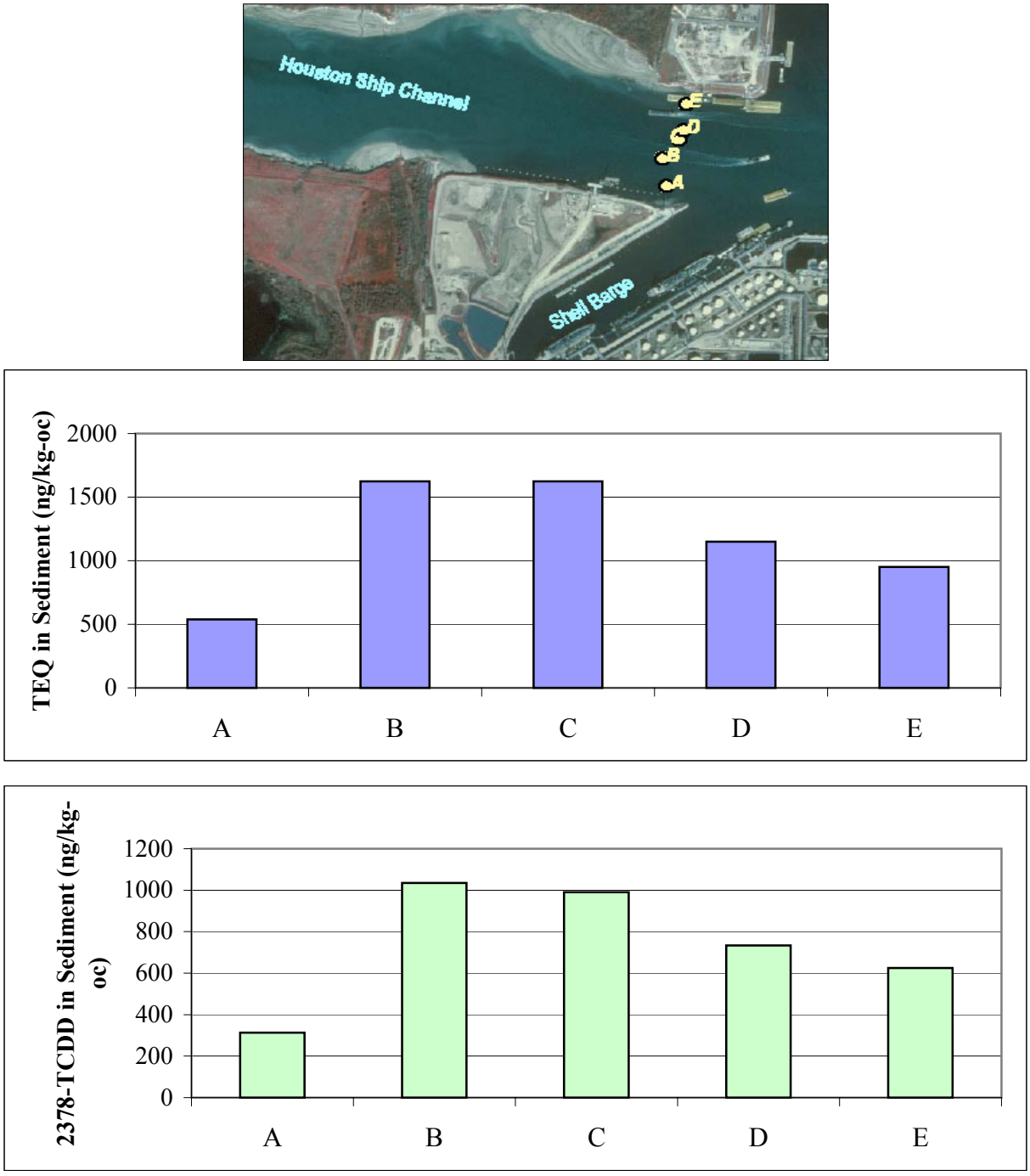


Figure 3.21 Dioxin Concentrations along Transect at Station 15979

Table 3.13 Total Dioxin Concentrations in Catfish (ng/kg-wet wt.)

Station ID	Date	Lipid Content (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Lipid-normalized TEQ[a]	Average TEQ[b]	Average Lipid-normalized TEQ[a,b]
Spring 2004																							
14560	03/09/2004	1.20	4.20	0.33	0.23	0.96	0.38	1.40	5.30	0.19	< 0.10	0.45	< 0.10	< 0.11	< 0.10	0.13	0.20	0.16	0.68	4.80	11.99	4.80	11.99
13342	03/09/2004	2.10	4.60	0.24	< 0.12	0.56	0.27	1.20	7.10	1.10	0.21	0.46	0.22	< 0.29	0.15	< 0.11	< 0.59	< 0.16	6.40	5.22	7.45	5.22	7.45
13340	03/09/2004	1.20	1.10	0.19	0.12	0.43	0.18	1.10	5.70	0.16	< 0.10	0.19	< 0.10	< 0.11	< 0.11	< 0.11	0.18	< 0.12	0.78	1.40	3.51	1.40	3.51
11252	03/09/2004	0.80	1.90	0.16	< 0.10	0.37	0.15	1.10	6.90	0.15	< 0.11	0.20	< 0.09	< 0.10	< 0.10	< 0.10	0.23	< 0.11	0.84	2.17	8.15	2.17	8.15
13338	03/18/2004	1.60	3.90	0.38	0.22	0.72	0.29	1.40	5.10	0.19	0.16	0.45	< 0.10	< 0.39	< 0.09	< 0.08	< 0.24	< 0.18	0.52	4.50	8.43	4.50	8.43
16499	03/18/2004	1.00	3.90	0.24	0.12	0.42	0.14	0.82	4.90	0.20	0.14	0.32	< 0.12	< 0.44	0.09	< 0.09	< 0.24	< 0.18	0.50	4.32	12.95	4.32	12.95
16618	03/18/2004	0.80	3.00	0.22	< 0.28	0.57	< 0.30	1.10	7.20	0.20	0.13	0.29	< 0.09	< 0.09	< 0.10	< 0.09	< 0.41	< 0.41	0.64	3.39	12.70	3.39	12.70
13344	03/18/2004	3.60	11.00	0.51	0.37	1.30	0.47	2.80	10.00	2.60	0.21	0.80	< 0.09	< 0.10	0.11	< 0.09	< 0.41	< 0.44	0.66	12.16	10.14	12.16	10.14
11193	03/23/2004	2.40	4.60	0.29	< 0.14	0.40	0.23	1.50	7.00	0.29	0.13	0.37	0.12	0.10	0.11	0.09	< 0.35	< 0.18	0.91	5.08	6.35	5.08	6.35
11197	03/24/2004	0.70	1.60	0.17	< 0.10	0.29	< 0.14	0.88	5.70	0.27	< 0.09	< 0.22	0.07	< 0.29	0.08	< 0.06	< 0.23	< 0.12	2.80	1.84	7.90	2.18	9.34
11197-dup	03/24/2004	0.70	2.10	0.21	0.17	0.57	0.20	1.30	6.30	0.42	0.11	0.27	0.09	< 0.20	0.10	< 0.08	< 0.25	< 0.16	0.89	2.51	10.78		
11261	03/24/2004	1.20	4.20	0.25	0.14	0.40	0.14	1.30	6.80	0.21	< 0.11	< 0.33	< 0.07	< 0.43	< 0.07	< 0.07	< 0.71	< 0.13	10.00	4.53	11.33	4.53	11.33
15979	03/31/2004	2.20	13.00	0.46	0.20	0.97	0.29	1.50	5.80	0.48	< 0.11	0.71	< 0.09	< 0.11	< 0.10	< 0.10	< 0.26	< 0.14	0.61	13.80	18.82	13.80	18.82
11264	04/02/2004	1.80	7.90	0.38	< 0.18	0.57	< 0.20	1.40	8.50	0.41	< 0.21	0.59	< 0.17	< 0.18	< 0.19	< 0.18	0.31	< 0.29	0.79	8.54	14.24	7.69	12.82
11264-dup	04/02/2004	1.80	6.40	< 0.33	< 0.19	0.55	< 0.21	1.20	6.20	0.25	< 0.19	0.45	< 0.16	< 0.17	< 0.17	< 0.17	< 0.28	< 0.30	0.73	6.85	11.41		
11280	04/02/2004	1.90	12.00	0.45	< 0.19	0.76	0.25	1.80	7.80	0.44	< 0.23	0.80	< 0.15	< 0.17	< 0.17	< 0.16	0.42	< 0.29	3.30	12.82	20.24	12.82	20.24
11265	04/02/2004	1.30	6.00	0.32	< 0.17	0.55	0.25	1.40	5.90	< 0.25	< 0.23	0.53	< 0.19	< 0.21	< 0.21	< 0.20	< 0.26	< 0.22	0.68	6.57	15.17	6.57	15.17
11287	04/02/2004	1.40	1.90	< 0.35	< 0.36	< 0.42	< 0.37	1.30	6.70	< 0.18	< 0.30	0.40	< 0.32	< 0.33	< 0.35	< 0.33	< 0.31	< 0.33	< 0.93	2.33	4.99	2.33	4.99
11292	04/03/2004	1.30	2.10	0.37	0.28	0.48	0.27	0.96	5.30	0.17	< 0.17	< 0.49	0.23	< 0.15	< 0.21	< 0.14	< 0.29	< 0.15	0.72	2.58	5.95	2.58	5.95
11302-A	04/15/2004	0.80	2.30	< 0.36	< 0.30	0.41	< 0.30	1.20	6.50	0.27	< 0.29	0.43	< 0.30	< 0.31	< 0.33	< 0.31	0.27	< 0.26	0.88	2.77	10.40	12.85	25.42
11302-B	04/15/2004	1.70	21.00	1.50	0.43	1.60	0.53	1.70	7.30	0.50	0.21	1.50	0.34	0.29	0.33	< 0.10	< 0.55	< 0.38	1.00	22.92	40.44		
11272-A	04/15/2004	0.40	3.00	< 0.51	< 0.58	< 0.62	< 0.53	2.30	8.40	0.30	< 0.59	< 0.57	< 0.42	0.53	< 0.32	< 0.45	< 0.89	< 0.86	2.60	3.51	26.35	2.13	14.70
11272-A-dup	04/15/2004	0.40	1.20	0.26	< 0.16	0.31	0.19	1.20	5.80	0.16	0.20	0.33	0.19	0.19	0.16	0.11	0.41	0.16	2.60	1.64	12.33		
11272-B	04/15/2004	0.50	1.30	0.21	< 0.14	0.29	0.18	0.79	5.10	0.12	0.19	0.27	0.17	0.20	0.18	< 0.15	0.28	0.14	0.66	1.68	10.07		
11305	04/15/2004	1.10	2.90	0.23	< 0.09	0.23	< 0.10	0.59	2.50	< 0.10	< 0.11	0.30	< 0.10	< 0.11	< 0.11	< 0.11	< 0.17	< 0.10	< 0.34	3.23	8.80	3.23	8.80
11298	04/20/2004	2.00	12.00	0.56	0.17	0.77	0.26	1.20	4.20	0.92	< 0.11	0.70	0.12	< 0.11	< 0.11	< 0.11	< 0.22	< 0.12	0.41	12.87	19.31	12.87	19.31
11382	04/20/2004	0.80	< 0.79	< 0.57	< 0.73	< 0.86	< 0.74	< 1.10	7.10	< 0.34	< 0.52	< 0.50	< 0.65	< 0.68	< 0.72	< 0.69	0.78	< 0.78	1.30	0.95	3.55	0.95	3.55
11300	04/21/2004	3.90	18.00	1.10	0.38	1.30	< 0.45	2.20	7.60	0.59	0.34	1.40	0.25	0.55	0.34	< 0.17	< 0.58	< 0.28	1.20	19.64	15.11	19.64	15.11
11274	04/21/2004	0.60	6.70	0.58	< 0.36	0.62	< 0.36	1.40	6.20	0.46	< 0.42	0.90	< 0.20	0.25	< 0.23	< 0.22	0.59	< 0.44	3.30	7.65	38.26	7.65	38.26
11273	04/21/2004	1.60	2.40	0.29	0.26	< 0.28	< 0.24	< 0.98	5.80	< 0.15	< 0.23	0.36	< 0.20	0.22	< 0.22	< 0.21	< 0.25	< 0.23	1.00	2.84	5.33	2.84	5.33
11347	04/22/2004	0.60	< 0.11	< 0.11	< 0.10	< 0.11	< 0.10	0.46	2.50	< 0.11	< 0.10	0.13	< 0.10	< 0.11	< 0.11	< 0.11	< 0.13	< 0.11	0.32	0.19	0.96	0.19	0.96
11111	04/27/2004	0.50	< 0.36	< 0.61	< 0.65	< 0.77	< 0.66	< 1.00	6.70	< 0.43	< 0.25	< 0.24	< 0.45	< 0.47	< 0.50	< 0.47	< 0.47	< 0.51	1.30	0.62	3.71	0.62	3.71
11092	04/27/2004	0.60	0.44	< 0.20	< 0.25	< 0.30	< 0.26	0.99	5.50	< 0.19	< 0.30	< 0.29	< 0.24	< 0.25	< 0.27	< 0.26	< 0.24	< 0.26	< 0.82	0.67	3.36	0.67	3.36
Fall 2004																							
14560	10/03/2004	1.10	0.96	< 0.17	< 0.22	0.32	< 0.24	0.51	0.99	0.30	< 0.20	< 0.20	< 0.19	< 0.18	< 0.21	< 0.26	< 0.19	< 0.24	< 0.26	1.18	3.23	1.18	3.23
11252	10/03/2004	2.60	26.00	0.58	< 0.28	1.90	0.45	2.20	3.70	0.95	< 0.29	1.10	< 0.21	< 0.20	< 0.24	< 0.34	< 0.27	< 0.34	0.73	27.24	31.43	27.24	31.43
16618	10/03/2004	0.90	3.20	< 0.21	< 0.27	< 0.29	< 0.28	0.55	1.40	0.35	< 0.21	< 0.22	< 0.24	< 0.22	< 0.26	< 0.42	< 0.24	< 0.35	< 0.31	3.45	11.49	3.45	11.49
13338	10/04/2004	0.90	1.50	< 0.28	< 0.36	< 0.40	< 0.38	0.60	0.99	< 0.40	< 0.36	< 0.37	< 0.20	< 0.18	< 0.22	< 0.30	< 0.29	< 0.34	< 0.39	1.79	5.98	1.79	5.98
13340	10/05/2004	0.60	0.63	< 0.30	< 0.34	< 0.38	< 0.36	< 0.47	< 1.00	< 0.34	< 0.33	< 0.35	< 0.28	< 0.26	< 0.31	< 0.41	< 0.28	< 0.33	< 0.69	0.93	4.67	0.93	4.67
11292	10/20/2004	1.90	0.64	0.31	0.25	< 0.44	< 0.24	0.65	1.10	0.26	< 0.16	0.60	0.27	0.24	0.21	0.17	< 0.33	< 0.16	0.42	1.27	2.01	1.27	2.01
11280	10/21/2004	2.80	18.00	0.46	0.33	0.99	0.38	1.50	4.10	1.50	0.34	0.99	0.41	< 0.22	0.24	< 0.21	< 0.29	0.19	0.45	19.15	20.52	19.15	20.52
11265	10/26/2004	2.60	8.80	0.33	0.24	0.55	0.22	0.67	1.50	0.59	< 0.16	0.48	< 0.25	0.18	0.22	< 0.12	< 0.22	< 0.12	0.35	9.43	10.88	9.92	11.68
11265-dup	10/26/2004	2.50	9.70	0.41	< 0.27	0.59	0.32	0.87	1.70	0.50	0.26	0.54	< 0.25	< 0.23	0.28	< 0.22	< 0.33	0.28	0.76	10.41	12.49		
15979	10/26/2004	1.70	7.00	0.27	0.25	0.48	< 0.21	0.64	1.30	0.65	< 0.19	0.47	0.18	0.19	0.18	< 0.11	< 0.23	< 0.16	< 0.46	7.58	13.38	7.58	13.38
11264	10/26/2004	2.80	13.00	0.36	< 0.24	0.65	< 0.27	0.88	1.70	0.94	0.19	0.66	0.23	0.18	< 0.21	0.11	< 0.29	0.16	2.20	13.77	14.75	13.77	14.75
11261	10/27/2004	3.70	14.00	< 0.51	< 0.31	1.10	0.42	1.30	2.50	0.74	< 0.13	0.67	< 0.37	0.22	0.23	< 0.11	< 0.22	< 0.15	< 0.51	14.78	11.98	14.78	11.98
11287	10/28/2004	1.80	4.40	0.42	< 0.30	0.80	0.34	1.20	1.90	0.45	0.21	0.57	0.28	< 0.22	< 0.29	0.20	< 0.37	0.22	2.20	5.15	8.59	5.15	8.59
11193	10/28/2004	3.50	14.00	0.50	0.41	0.86	0.38	1.30	3.60	1.00	< 0.11	0.75	< 0.30	0.19	< 0.20	< 0.17	< 0.28	< 0.19	0.61	14.95	12.81	14.34	14.04
11193-dup	10/28/2004	2.70	13.00	0.35	0.34	< 0.67	0.29	1.00	2.40	0.77	0.19	0.66	< 0.24	0.22	< 0.18	0.13	< 0.25	< 0.16	0.50	13.74	15.27		
11197	10/28/2004	4.00	14.00	0.50	0.45	1.30	0.43	1.70	3.80	0.76	0.19	0.82	< 0.36	0.18	0.22	< 0.12	< 0.31	< 0.17	< 0.44	15.03	11.27	15.03	11.27
13344	10/28/2004	1.20	5.00	0.15	< 0.13	0.43	< 0.17	0.77	1.40	0.68	< 0.12	0.31	< 0.09	< 0.08	< 0.09	< 0.12	< 0.11	< 0.14	0.32	5.38	13.44	5.38	13.44
13342	10/29/2004	2.10	13.00	0.47	0.29	1.00	0.37	1.30	2.60	0.30	< 0.12	0.61	< 0.24	< 0.18	0.21	0.12	< 0.25	< 0.11	0.64	13.79	19.70	13.79	19.70
16499	10/29/2004	0.60	4.40	0.28	< 0.26	0.50	0.22	0.58	1.30	< 0.13	0.11	0.38	0.20	0.20	0.21	< 0.11	< 0.25	< 0.15	0.42	4.89	24.47	4.89	24.47

[a] Catfish tissue normalized to 3% lipids

[b] Average of duplicate samples, otherwise concentration of a single sample

dup = duplicate

Values reported to the Detection Limit

Non-detects assumed as 1/2 MDL for TEQ calculations

Value between the detection and the reporting limits

Value is an estimate due to blank contamination (concentration < 20 times lowest concentration)

Value is an estimate due to QC issues (interference, signal to noise ratio)

Tributary

Exceeds the Texas Health Standard (0.47 ng/kg)

Table 3.14 Total Dioxin Concentrations in Crabs (ng/kg-wet wt.)

Station ID	Date	Lipid Content (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Lipid-normalized TEQ[a]	Average TEQ[b]	Average Lipid-normalized TEQ[a,b]
Spring 2004																							
13340	03/09/2004	1.50	0.97	0.36	< 0.36	0.46	< 0.55	1.10	6.10	2.00	0.33	0.48	0.32	0.38	0.40	0.58	0.58	0.59	1.40	1.87	2.49	1.87	2.49
11252	03/09/2004	1.10	1.40	< 0.33	< 0.33	< 0.38	0.48	0.92	7.10	3.20	< 0.37	< 0.37	< 0.30	< 0.33	< 0.34	< 0.58	0.50	0.51	1.20	2.07	3.76	2.07	3.76
14560	03/09/2004	1.10	1.50	< 0.20	< 0.20	< 0.23	< 0.21	< 0.61	6.50	2.20	< 0.22	0.25	< 0.16	< 0.19	< 0.19	< 0.18	< 0.29	< 0.24	0.75	1.97	3.58	1.97	3.58
13342	03/09/2004	0.90	4.40	0.29	< 0.15	< 0.28	0.25	0.77	10.00	9.80	0.32	0.51	0.21	0.21	< 0.16	< 0.15	< 0.37	< 0.17	0.72	5.90	13.11	5.90	13.11
13338	03/17/2004	1.20	0.66	< 0.19	< 0.29	< 0.32	< 0.29	0.68	6.40	1.60	0.41	0.40	< 0.34	0.37	< 0.19	< 0.18	1.00	< 0.28	10.00	1.21	2.01	1.21	2.01
16499	03/17/2004	1.30	2.90	0.15	< 0.14	0.22	0.17	0.78	8.20	5.80	0.26	0.32	< 0.18	< 0.22	0.13	< 0.09	< 0.35	< 0.10	0.73	3.81	5.86	3.81	5.86
16618	03/18/2004	1.10	5.90	0.34	< 0.22	0.26	0.27	1.20	12.00	8.20	0.33	0.46	< 0.18	< 0.23	0.09	< 0.09	< 0.50	< 0.33	0.67	7.23	13.15	7.23	13.15
13344	03/18/2004	0.80	3.80	0.20	< 0.25	< 0.30	< 0.27	0.82	8.10	8.20	0.25	0.38	0.20	0.17	< 0.10	< 0.10	0.43	< 0.42	0.59	5.01	12.53	5.01	12.53
11193	03/23/2004	1.00	2.70	0.18	< 0.12	< 0.14	0.19	0.92	10.00	3.70	0.18	0.25	< 0.12	< 0.12	< 0.07	< 0.07	0.25	< 0.26	0.53	3.35	6.69	3.35	6.69
11197	03/23/2004	1.20	1.40	0.17	0.15	0.30	0.24	1.10	9.50	3.50	0.16	0.27	< 0.11	< 0.18	< 0.10	< 0.09	< 0.24	< 0.12	0.45	2.07	3.45	2.07	3.45
11264	03/23/2004	1.30	2.20	0.17	< 0.13	0.23	< 0.19	1.10	9.00	4.10	0.26	0.26	< 0.17	< 0.18	0.10	< 0.08	< 0.36	< 0.18	0.60	2.91	4.47	2.91	4.47
11261	03/23/2004	1.20	2.30	< 0.22	< 0.14	0.25	0.18	1.10	9.90	6.80	0.18	0.26	0.16	< 0.11	< 0.11	< 0.11	< 0.25	< 0.18	0.58	3.26	5.43	3.26	5.43
11265	03/30/2004	0.90	2.20	< 0.19	< 0.15	0.21	< 0.16	0.73	6.70	4.60	0.18	0.24	0.13	< 0.12	< 0.12	< 0.12	< 0.25	< 0.17	0.59	2.90	6.45	2.90	6.45
15979	03/31/2004	0.90	5.00	0.22	< 0.14	0.19	< 0.15	0.74	6.40	8.40	0.26	0.38	< 0.17	< 0.11	< 0.11	< 0.11	< 0.31	< 0.19	1.90	6.21	13.80	6.21	13.80
11280	04/01/2004	0.80	5.10	0.35	< 0.14	0.26	0.22	1.10	8.40	8.90	0.31	0.41	0.20	0.16	< 0.14	< 0.14	< 0.64	< 0.16	7.60	6.49	16.23	6.49	16.23
11287	04/01/2004	0.80	4.50	0.30	< 0.18	< 0.21	< 0.19	1.10	7.00	8.20	0.30	0.43	< 0.18	< 0.20	< 0.20	< 0.19	< 0.39	< 0.30	1.00	5.77	14.42	5.77	14.42
11292	04/03/2004	1.30	< 0.43	< 0.50	< 0.49	< 0.62	< 0.50	1.40	7.20	1.20	< 0.36	0.58	< 0.43	< 0.43	< 0.46	< 0.43	0.59	0.47	1.10	0.93	1.43	0.93	1.43
11272	04/15/2004	0.60	0.99	< 0.59	< 0.64	< 0.75	< 0.65	1.50	9.20	1.20	< 0.44	< 0.43	< 0.41	< 0.43	< 0.46	< 0.43	0.53	< 0.43	1.10	1.56	5.22	1.56	5.22
11302	04/16/2004	0.80	1.30	< 0.44	< 0.32	0.47	< 0.33	1.60	6.80	1.90	< 0.49	< 0.47	< 0.35	< 0.37	< 0.39	< 0.37	0.58	< 0.38	0.81	1.88	4.71	1.88	4.71
11300	04/16/2004	0.80	0.85	< 0.85	< 0.33	< 0.29	< 0.30	< 0.79	1.20	4.40	0.58	< 0.56	0.39	< 0.32	< 0.31	< 0.28	< 0.31	1.20	5.90	1.80	4.51	1.80	4.51
11298	04/20/2004	1.20	1.90	0.37	< 0.22	0.30	< 0.23	0.99	6.30	4.60	< 0.35	0.41	0.32	0.22	< 0.21	< 0.20	< 0.31	< 0.20	< 0.61	2.89	4.81	4.43	7.38
11298-dup[c]	04/20/2004	1.20	4.30	0.41	0.32	< 0.43	0.38	1.60	14.00	9.70	0.40	0.58	0.38	< 0.29	0.24	0.17	0.47	< 0.25	0.78	5.97	9.95		
11274	04/20/2004	0.90	1.30	0.40	0.25	< 0.28	0.19	1.20	11.00	2.90	0.28	0.39	0.27	< 0.22	0.13	0.16	0.34	< 0.26	0.91	2.12	4.72	2.12	4.72
11273	04/21/2004	1.60	5.90	0.46	< 0.28	0.41	0.31	1.30	7.60	11.00	1.50	1.10	0.95	0.42	< 0.29	< 0.27	0.80	< 0.20	2.90	8.11	10.13	8.61	11.58
11273-dup[c]	04/21/2004	1.40	6.20	0.81	0.48	0.64	0.62	2.00	12.00	12.00	1.70	1.40	1.40	0.83	0.71	0.55	2.60	0.70	18.00	9.11	13.02		
11305	04/22/2004	0.60	1.20	< 0.37	< 0.41	< 0.48	< 0.42	1.10	6.40	2.30	< 0.55	< 0.54	< 0.38	< 0.39	< 0.42	< 0.40	0.38	< 0.27	0.86	1.82	6.05	1.82	6.05
11111	04/27/2004	0.50	0.46	< 0.22	< 0.22	< 0.26	< 0.22	0.96	6.60	0.65	< 0.17	0.28	0.23	0.24	< 0.14	< 0.14	< 0.29	< 0.20	0.96	0.82	3.28	0.82	3.28
11092	04/30/2004	0.80	< 0.18	< 0.23	< 0.29	< 0.34	< 0.29	1.20	11.00	0.40	< 0.33	< 0.33	< 0.21	< 0.22	< 0.24	< 0.23	0.36	< 0.24	0.78	0.37	0.92	0.37	0.92
Fall 2004																							
13338	10/02/2004	0.70	2.00	< 0.14	< 0.11	< 0.16	< 0.11	4.20	62.00	3.50	< 0.10	0.13	< 0.16	< 0.08	< 0.10	< 0.14	< 0.83	< 0.30	3.70	2.50	7.13	2.50	7.13
16618	10/02/2004	0.60	5.10	< 0.32	< 0.20	< 0.20	< 0.20	0.44	1.80	11.00	< 0.30	0.37	< 0.13	< 0.12	< 0.15	< 0.18	< 0.19	< 0.24	0.47	6.53	21.77	6.53	21.77
13340	10/03/2004	0.80	0.86	< 0.27	< 0.23	< 0.26	< 0.24	0.42	1.30	1.90	< 0.40	< 0.44	< 0.20	< 0.19	< 0.23	< 0.31	< 0.22	< 0.27	< 0.44	1.32	3.30	1.32	3.30
14560	10/04/2004	0.70	1.00	< 0.45	< 0.25	< 0.27	< 0.26	0.34	1.20	1.70	< 0.42	< 0.44	< 0.25	< 0.23	< 0.27	< 0.40	< 0.23	< 0.26	< 0.36	1.50	4.28	1.50	4.28
13342	10/05/2004	0.60	8.90	< 0.26	< 0.16	< 0.18	< 0.17	0.47	3.80	19.00	< 0.33	0.46	< 0.15	< 0.14	< 0.17	< 0.22	0.22	< 0.15	3.00	11.16	37.21	11.16	37.21
16499	10/08/2004	0.90	3.80	< 0.23	< 0.12	0.21	< 0.16	0.41	1.70	7.60	< 0.28	< 0.26	< 0.29	< 0.26	< 0.31	< 0.39	< 0.19	< 0.25	0.34	4.79	10.64	4.79	10.64
11287	10/19/2004	0.80	5.90	0.36	0.32	< 0.45	< 0.35	0.80	2.20	9.50	0.58	< 0.65	< 0.40	0.31	< 0.31	0.29	< 0.46	0.27	0.81	7.39	18.47	7.39	18.47
11292	10/20/2004	0.90	0.86	< 0.44	0.20	3.10	< 0.33	1.10	2.10	1.90	0.75	0.86	0.84	0.37	0.33	0.13	0.52	< 0.12	0.36	2.14	4.76	2.14	4.76
11280	10/20/2004	0.70	8.70	0.35	0.24	< 0.29	< 0.22	0.51	3.30	12.00	0.57	0.68	0.43	0.21	< 0.22	0.14	< 0.32	0.17	0.44	10.58	30.23	10.58	30.23
15979	10/21/2004	0.80	12.00	0.31	0.25	0.35	< 0.23	0.54	1.90	17.00	0.56	0.66	0.40	0.22	0.19	0.15	< 0.32	0.16	0.35	14.38	35.95	11.20	27.99
15979-dup	10/21/2004	0.80	6.60	0.23	0.19	0.26	< 0.19	0.40	1.60	9.40	0.42	0.41	0.32	0.21	0.17	< 0.12	0.41	0.21	1.40	8.01	20.03		
11265	10/21/2004	0.70	5.40	< 0.20	0.19	0.28	< 0.15	0.39	1.90	8.10	0.26	< 0.32	0.24	0.19	0.22	< 0.13	< 0.24	< 0.18	0.24	6.48	18.51	6.48	18.51
11264	10/21/2004	1.00	5.70	0.17	< 0.14	0.21	0.19	< 0.40	1.40	9.60	0.32	0.39	0.28	0.18	< 0.17	0.11	0.31	0.15	0.27	7.07	14.14	7.07	14.14
13344	10/21/2004	0.90	3.40	0.15	0.20	0.23	< 0.13	0.45	2.40	5.80	0.21	0.33	< 0.19	< 0.16	0.17	< 0.11	0.28	< 0.11	0.27	4.32	9.60	4.32	9.60
11252	10/26/2004	1.50	9.50	0.34	< 0.32	0.56	0.43	0.81	2.30	19.00	0.42	0.61	0.26	< 0.23	< 0.21	0.16	0.33	0.17	0.58	12.08	16.10	12.08	16.10
11261	10/26/2004	1.10	7.30	0.37	0.30	0.44	< 0.33	< 0.56	2.00	13.00	0.38	0.56	0.34	0.26	0.26	0.28	< 0.32	< 0.18	0.59	9.29	16.89	9.29	16.89
11193	10/27/2004	1.10	6.60	0.12	< 0.12	0.21	0.23	0.84	5.20	17.00	< 0.20	0.39	0.16	0.11	0.13	< 0.13	0.28	< 0.18	0.93	8.66	15.74	11.49	20.90
11193-dup	10/27/2004	1.10	11.00	0.14	< 0.10	0.23	0.18	0.61	3.30	29.00	0.43	0.54	< 0.11	< 0.09	< 0.11	< 0.14	< 0.17	< 0.12	0.51	14.33	26.05		
11197	10/28/2004	1.20	6.20	0.18	< 0.12	0.60	0.26	0.80	3.70	14.00	0.26	0.40	0.19	< 0.10	< 0.12	< 0.14	< 0.20	< 0.11	0.39	8.03	13.39	8.03	13.39

[a] Crab tissue normalized to 2% lipids

[b] Average of duplicate samples, otherwise concentration of a single sample

[c] The duplicate sample is an additional set of crabs

dup = duplicate

Values reported to the Detection Limit

Non-detects assumed as 1/2 MDL for TEQ calculations

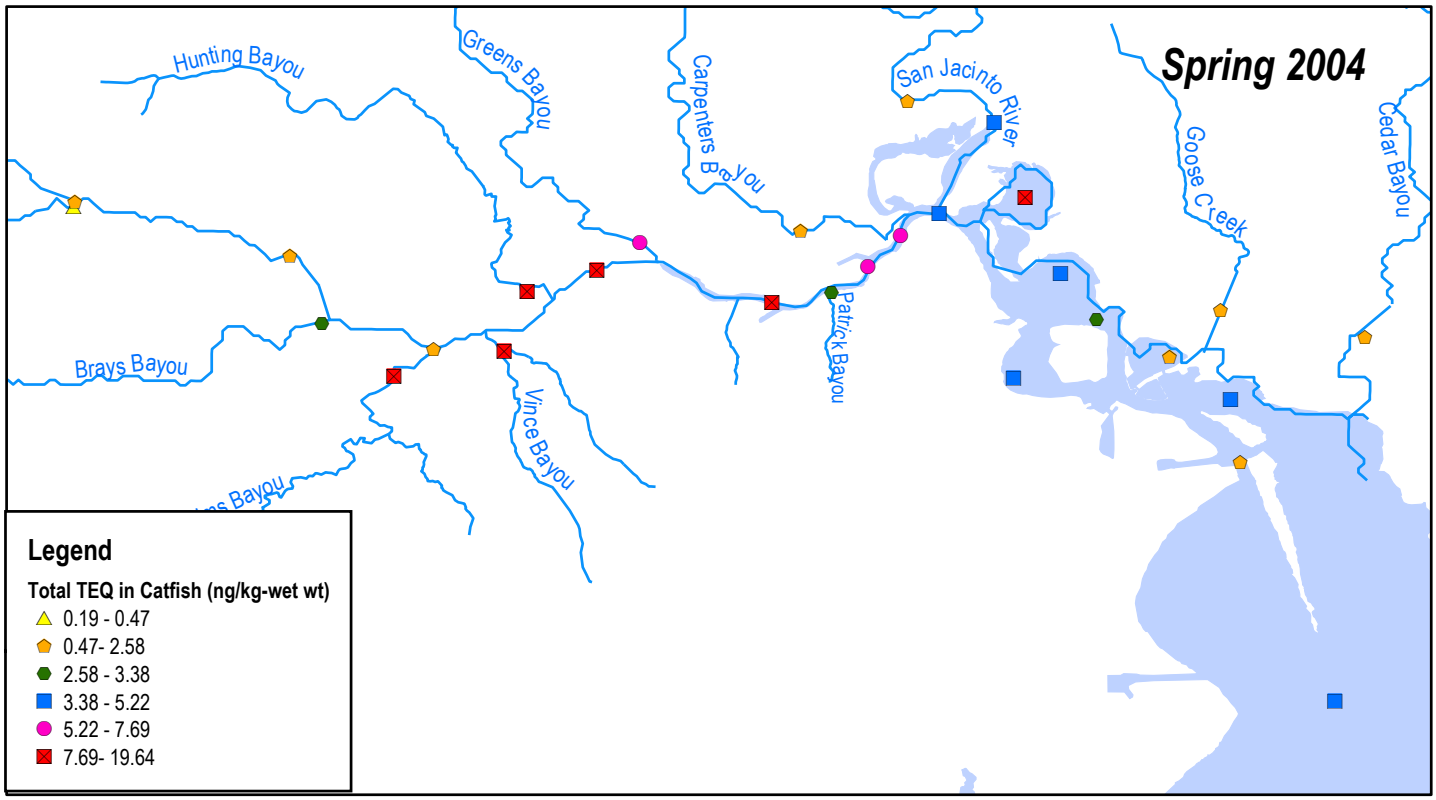
Value between the detection and the reporting limits

Value is an estimate due to blank contamination (concentration < 20 times lowest concentration)

Value is an estimate due to QC issues (interference, signal to noise ratio)

Tributary

Exceeds the Texas Health Standard (0.47 ng/kg)



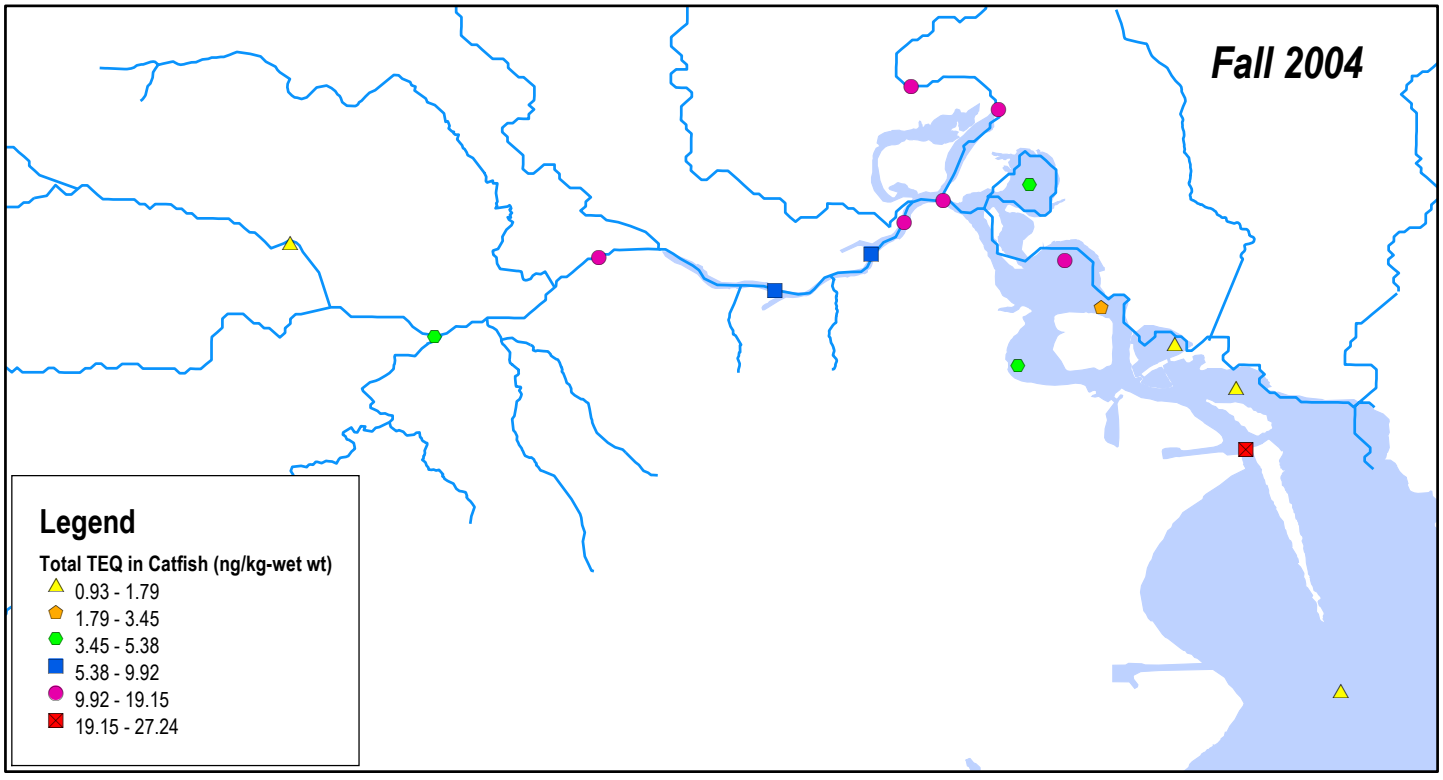


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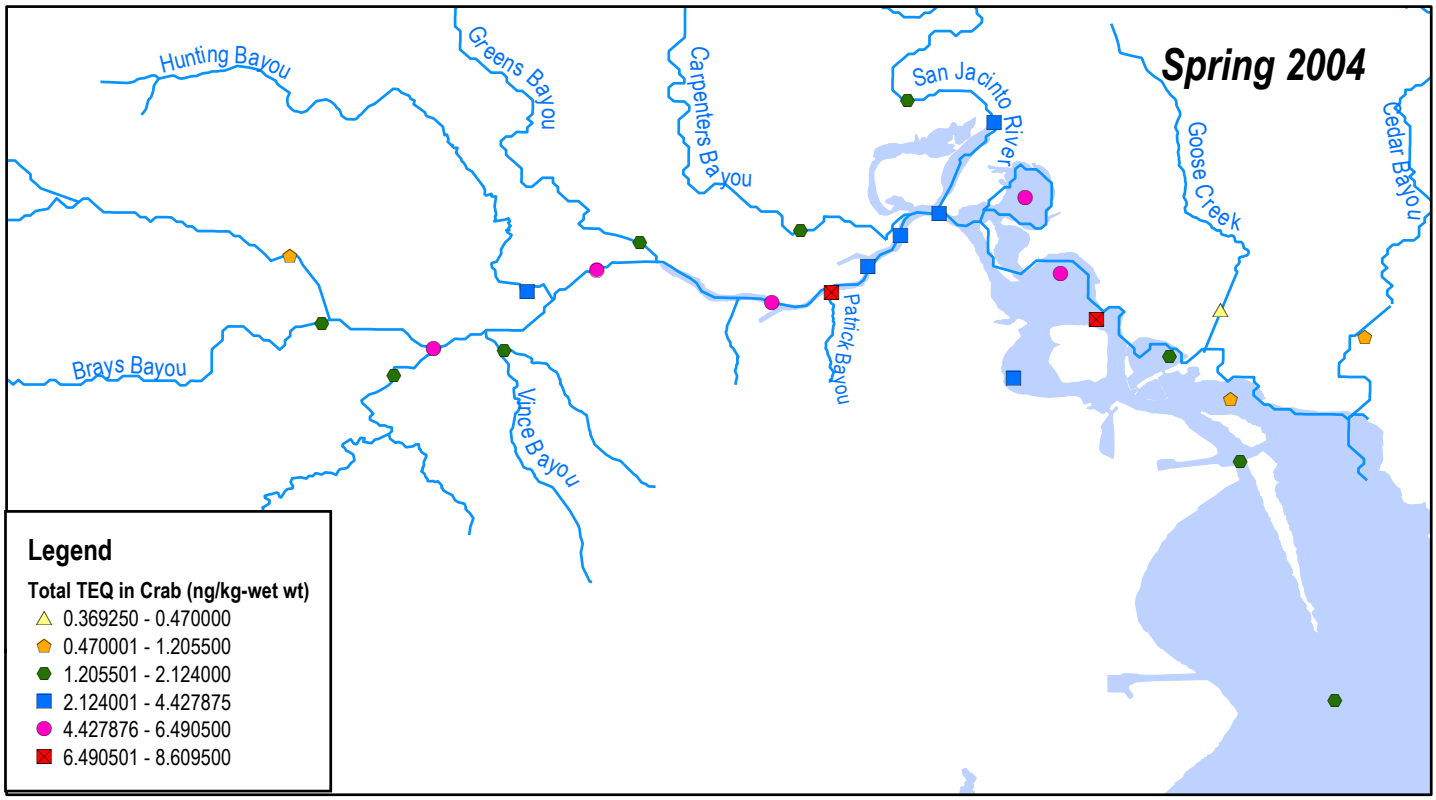
Figure 3.22
TEQ Concentrations in Catfish

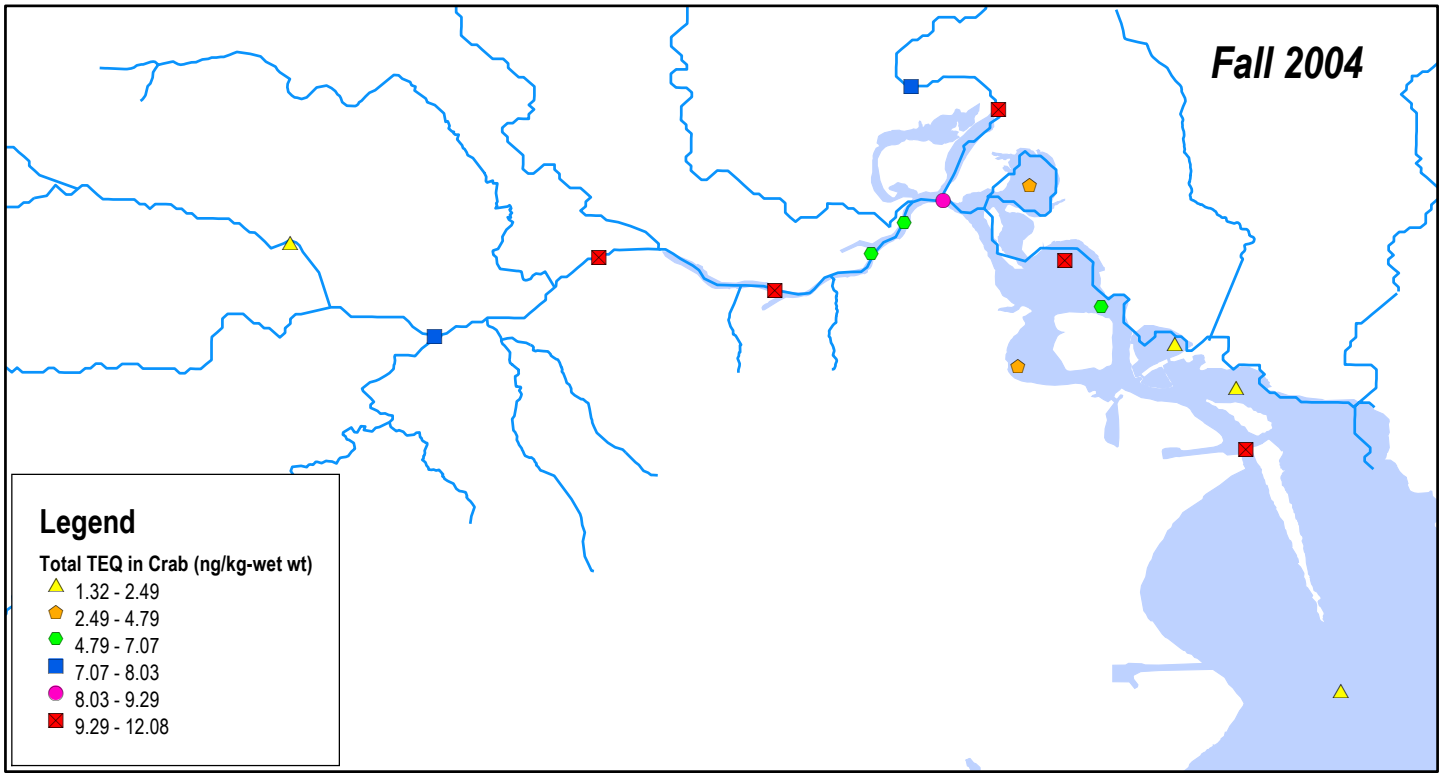
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

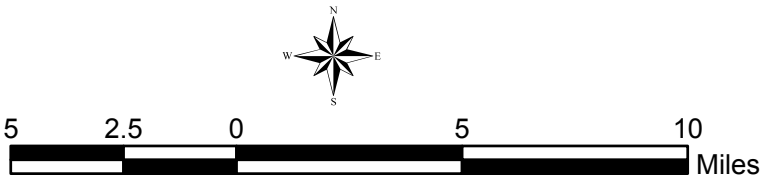
TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

Prepared by: MPS

Date: 09-09-2005







UNIVERSITY of HOUSTON

Department of Civil and Environmental Engineering

Figure 3.23
TEQ Concentrations in Crabs

Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

Prepared by: MPS

Date: 09-09-2005

The health-based standard of 0.47 ng TEQ/kg (derived from the Texas WQS) was exceeded in 96% of the Spring 2004 samples (for both catfish and crabs) and in all tissue samples collected in Fall 2004. In Spring 2004, locations 11300 (Vince Bayou) and 15979 (segment 1006) showed the highest dioxin catfish concentrations, while locations 11273 (Patrick Bayou) and 16618 (segment 1005) presented the highest dioxin concentrations in crabs. The highest dioxin concentrations in tissue collected in Fall 2004 were found at locations 11252 (segment 1005) and 11280 (segment 1007) for catfish, and 11193 (segment 1001) and 11252 (segment 1005) for crabs. It is noted that tissue was not sampled in tributaries during Fall 2004.

A database with results from tissue samples reported by PSC Philip Analytical Laboratory is provided in Appendix B1.

3.2.1.4 Sediment Core Sampling

Physical and Geochonological Analyses. This section presents the results for the eight cores selected for sediment dating analysis. It is noted that:

- Unsupported or excess ^{210}Pb ($^{210}Pb_{xs}$) is derived from atmospheric fallout and is the constituent of interest in terms of modeling sediment accumulation. Supported ^{210}Pb is that fraction of the isotope derived by the in situ radioactive decay of its progenitor, ^{226}Ra. The determination of $^{210}Pb_{xs}$ is outlined in more detail in subsequent sections.
- Cumulative mass depth is used here and is a mass based assessment of depth, as opposed to cm or some other one dimensional unit. Mass depth = [(1 – porosity) * density * interval thickness], where the density is assumed = 2.5 g cm^{-3} and the typical interval thickness = 1 cm. Cumulative mass depth is the summation of mass depth over the interval of interest.

- Reported concentrations of ^{239,240}Pu have been corrected to account for a small, above background anomaly, most likely resulting from slight contamination of an acid bath. The concentrations of ^{239,240}Pu in samples where no ^{137}Cs was found have been combined as an average value (0.022 $\pm$ 0.009 mBq/g), which was then subtracted from all reported values of ^{239,240}Pu.

Station 11261

Summary physical and radiochemical data for this station are shown in Tables 3.15a and b. X-radiograph and the core grain size distribution are shown in Figure C-1 and listed in Table C-1 of Appendix C. The core grain size distribution is shown in Figure 3.24 and listed in Table 3.15a. For this and all stations, $^{210}Pb_{xs}$ is defined as total ^{210}Pb – deepest ^{210}Pb values in the core, where equilibrium is assumed between ^{210}Pb and its progenitor, ^{226}Ra (Walsh and Nittrouer 2003, Kim and Rejmankova 2002, Craft and Richardson 1993, Binford 1990). Here, the mean ^{210}Pb value over the depth interval of 23 – 48 cm was used as the supported value (10.93 $\pm$ 1.00 mBq g^{-1}). Deep penetration of ^{7}Be to 20 cm (Figure 3.25) could be interpreted as either deep mixing or rapid sedimentation. The absence of a distinct ^{137}Cs peak (Table 3.13b), the layered structure of POC and porosity (Table 3.15a, Figure 3.26) and the close correlation of ^{7}Be activity concentrations with POC concentrations (Figure 3.27) are all consistent with rapid sedimentation, and inconsistent with deep mixing. This station appears to have experienced recent and very rapid sedimentation. The very low concentrations of ^{239,240}Pu also support rapid and recent sedimentation here (Table 3.15b).

Sediment accumulation rates using both ^{7}Be and $^{210}Pb_{xs}$ have been determined using the constant flux-constant sedimentation (CF-CS) model (Yeager *et al.* 2004), where sedimentation

Table 3.15a Physical data for station 11261

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	0.47	0.81	3.80 + 0.01	45.8	39.9	14.3
2	1.28	0.68	3.40 + 0.01	50.1	37.4	12.5
3	2.34	0.58	4.40 + 0.01	43.4	40.3	16.3
4	3.42	0.57	3.85 + 0.01	52.9	33.3	13.8
5	4.55	0.55	3.00 + 0.01	60.5	29.1	10.5
6	5.87	0.47	2.15*	64.6	26.6	8.8
7	7.35	0.41	3.60 + 0.01	52.2	33.8	14
8	8.45	0.56	6.17 + 0.04	32.3	45.1	22.6
9	9.6	0.54	4.00 + 0.02	51.3	32.7	16
10	11.17	0.37	2.35 + 0.01	50.4	39.4	10.3
11	12.75	0.37	2.53 + 0.01	65.6	26.6	7.8
12	14.17	0.43	3.28 + 0.02	57.8	31.3	10.8
13	15.48	0.48	3.50 + 0.02	54.3	30.4	15.4
14	16.64	0.54	3.83 + 0.02	52.4	32.3	15.3
15	17.89	0.5	4.00 + 0.02	53.5	32.9	13.7
16	19.39	0.4	3.40 + 0.02	44.5	40.3	15.2
17	20.7	0.48	3.35 + 0.02	43.8	38	18.2
18	22.08	0.45	3.80 + 0.02	50.4	34.9	14.8
19	23.82	0.31	2.80 + 0.01	56.9	30.4	12.7
20	25.41	0.36	3.10 + 0.02	60.2	28.8	11
21	26.95	0.38	4.13 + 0.02	56.7	29.9	13.3
22	28.63	0.33	3.50 + 0.02	56.9	30.6	12.5
23	30.12	0.4	3.30 + 0.01	56.9	31.6	11.5
24	31.75	0.35	2.80 + 0.01	61.5	29.8	8.6
25	33.25	0.4	2.70*	65.8	26	8.2
26	34.78	0.39	2.60*	64.9	26	9.1
27	36.34	0.38	2.43*	71.5	21.4	7.2
28	37.92	0.37	2.83*	69.4	22.8	7.8
29	39.5	0.37	2.98 + 0.01	68.1	24.3	7.6
30	41.12	0.35	4.25 + 0.01	63.5	26.9	9.6
31	42.56	0.43	--	--	--	--
32	43.99	0.43	--	--	--	--
33	45.44	0.42	--	--	--	--
34	46.99	0.38	--	--	--	--
35	48.37	0.45	--	--	--	--
36	49.68	0.47	--	--	--	--
37	51.3	0.35	--	--	--	--
38	52.93	0.35	--	--	--	--
39	54.5	0.37	--	--	--	--
40	55.95	0.42	--	--	--	--
41	57.26	0.47	--	--	--	--
42	58.45	0.53	--	--	--	--
43	59.67	0.51	--	--	--	--
44	60.86	0.53	--	--	--	--
45	61.98	0.55	--	--	--	--
46	62.83	0.66	--	--	--	--
47	64.23	0.44	--	--	--	--
48	65.65	0.43	--	--	--	--

*denotes an error of < 0.01

Table 3.15b Radiochemical data for station 11261

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	$^{210}Pb_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	139.49 + 9.86	0.94 + 0.10	15.16 + 1.07	4.23 + 1.46	0
2	131.42 + 16.12	1.23 + 0.12	15.46 + 1.15	4.53 + 1.52	--
3	158.51 + 9.86	1.10 + 0.10	16.07 + 1.10	5.14 + 1.48	0
4	133.46 + 8.09	0.56 + 0.05	12.84 + 0.92	1.91 + 1.36	--
5	106.96 + 6.94	0.76 + 0.08	9.70 + 0.72	0	0
6	98.27 + 8.83	0.70 + 0.06	8.56 + 0.61	0	--
7	153.60 + 9.32	1.24 + 0.15	13.61 + 0.99	2.68 + 1.40	0
8	234.34 + 16.85	2.20 + 0.22	19.08 + 1.32	8.15 + 1.65	--
9	166.72 + 10.80	1.33 + 0.20	13.44 + 1.03	2.51 + 1.43	0.016 + 0.003
10	127.89 + 11.18	0	8.08 + 0.54	0	--
11	117.74 + 8.98	0	10.42 + 0.81	0	0
12	144.85 + 9.17	1.24 + 0.11	12.19 + 0.90	1.26 + 1.34	--
13	171.15 + 10.33	0.57 + 0.06	15.01 + 1.06	4.08 + 1.46	0
14	140.39 + 9.42	1.37 + 0.26	13.97 + 0.95	3.04 + 1.38	--
15	160.29 + 7.45	0	14.06 + 0.98	3.13 + 1.40	0
16	166.25 + 10.13	0.75 + 0.13	13.39 + 0.99	2.46 + 1.40	--
17	175.23 + 10.95	--	14.60 + 0.99	3.67 + 1.40	0.008 + 0.001
18	154.64 + 9.58	--	13.24 + 0.94	2.31 + 1.37	--
19	132.57 + 9.14	--	10.58 + 0.79	0	0.007 + 0.002
20	114.17 + 8.75	--	9.44 + 0.66	0	--
21	4.26 + 0.62	--	8.82 + 0.64	0	0
22	0	--	9.35 + 0.71	0	--
23	0	--	8.72 + 0.65	0	0.008 + 0.001
24	--	--	7.34 + 0.59	0	--
25	--	--	6.71 + 0.58	0	0
26	--	--	6.14 + 0.51	0	--
27	--	--	5.87 + 0.57	0	0
28	--	--	8.18 + 0.64	0	--
29	--	--	8.06 + 0.59	0	--
30	--	--	11.09 + 0.59	0	0
31	--	--	14.66 + 1.45	3.73 + 1.76	--
32	--	--	14.37 + 1.46	3.44 + 1.77	--
33	--	--	15.68 + 1.60	4.75 + 1.89	--
34	--	--	11.23 + 0.91	0	--
35	--	--	9.93 + 0.90	0	--
36	--	--	11.11 + 1.05	0	--
37	--	--	12.12 + 0.96	1.19 + 1.39	--
38	--	--	9.05 + 1.07	0	--
39	--	--	11.94 + 1.19	1.01 + 1.55	--
40	--	--	11.30 + 1.03	0	--
41	--	--	14.18 + 1.17	3.25 + 1.54	--
42	--	--	11.49 + 1.30	0	--
43	--	--	14.57 + 1.35	3.64 + 1.68	--
44	--	--	12.99 + 1.13	2.06 + 1.51	--
45	--	--	15.68 + 1.25	4.75 + 1.60	--
46	--	--	13.61 + 1.15	2.68 + 1.52	--
47	--	--	8.34 + 0.83	0	--
48	--	--	9.82 + 0.85	0	--

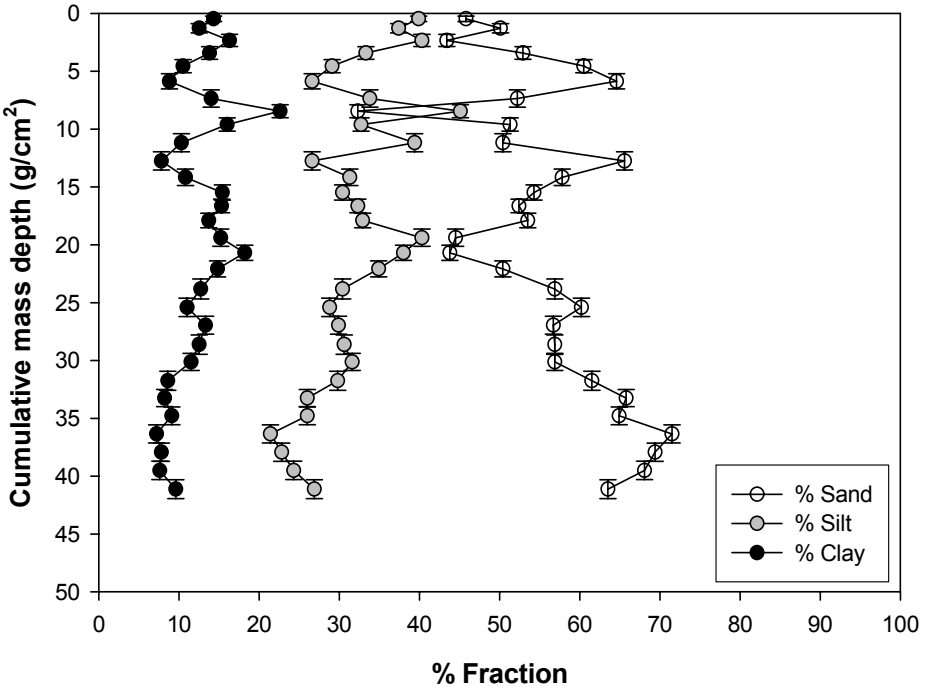


Figure 3.24 Grain size distribution for core sediment at station 11261

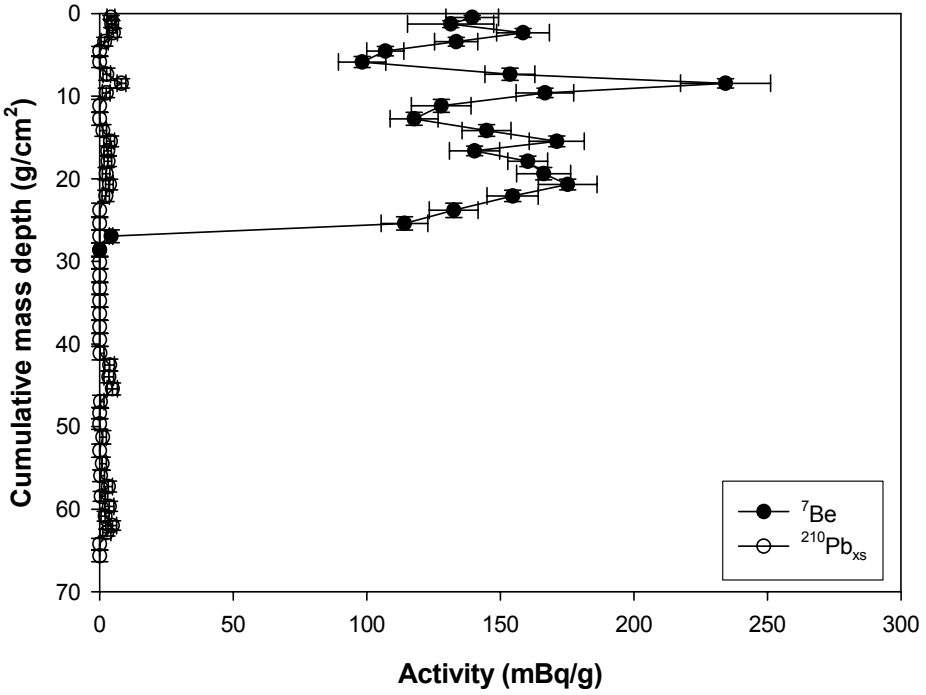


Figure 3.25 $^{210}Pb_{xs}$ and ^{7}Be data for station 11261

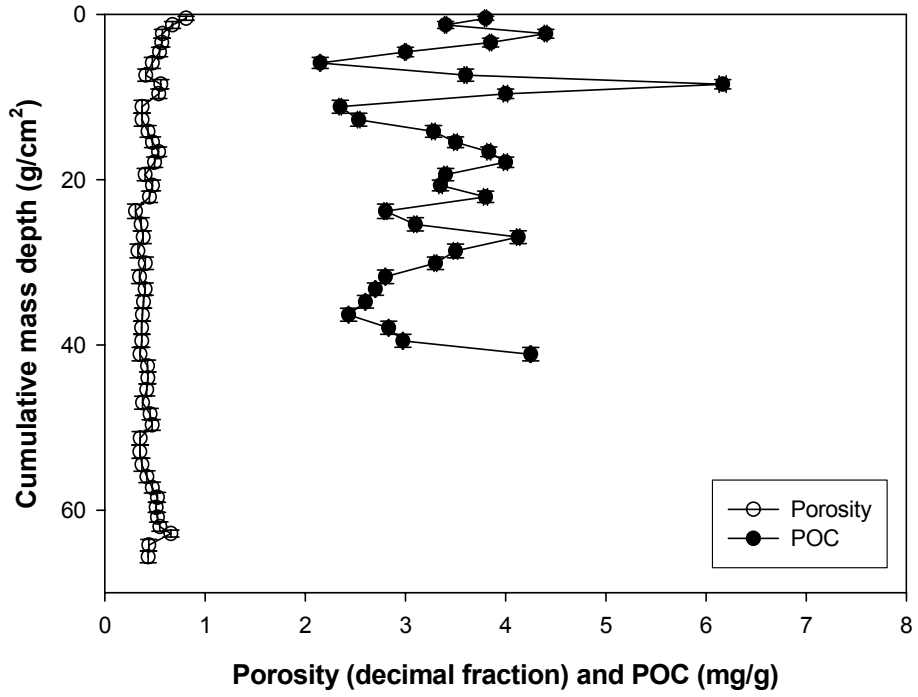


Figure 3.26 Porosity and POC data for station 11261

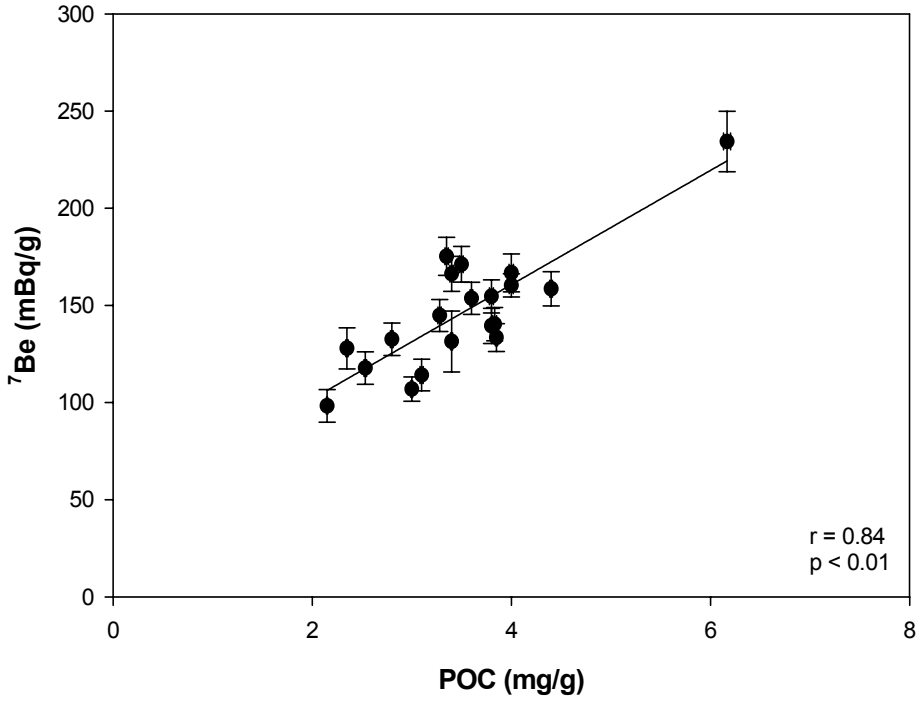


Figure 3.27 POC vs. ^{7}Be for station 11261

rates can be calculated assuming steady state conditions and at relatively constant porosity, using:

$$[I(z)] = [I(0)]^{-\alpha z} \tag{3.5a}$$

$$\alpha = \frac{\lambda}{S} \tag{3.5b}$$

where [*I(z)*] and [*I(0)*] represent ^{7}Be or $^{210}Pb_{xs}$ concentration at depth *z* and at the sediment-water interface, respectively; *S* = sediment accumulation rate (g cm^{-2} yr.$^{-1}$) and λ = decay constant of each isotope (^{210}Pb = 0.031 yr.$^{-1}$ and ^{7}Be = 4.75 yr.$^{-1}$). Figures 3.28 and 3.29 show the semi-log plots of each isotope over depth, from which sediment accumulation rates were derived. The time frame over which each isotope is valid in terms of modeling sedimentation rates is equal to approximately seven times its half-life, so ^{7}Be represents a one year time frame while $^{210}Pb_{xs}$ represents over one hundred years. Sediment accumulation rates for this station were determined to be 143.94 ± 109.39 g cm^{-2} yr.$^{-1}$ (or 113.10 ± 87.08 cm yr.$^{-1}$) in the upper 20 cm (0 – 26.95 g cm^{-2}) via ^{7}Be and beneath this depth to be 2.82 ± 1.30 g cm^{-2} yr.$^{-1}$ (or 1.94 ± 0.89 cm yr.$^{-1}$) via $^{210}Pb_{xs}$. It thus appears that the upper 20 cm was deposited over a ≈ 2.5-month time frame, considering the half-life of ^{7}Be (53 d). Sedimentation below 26.95 g cm^{-2} was determined by applying a weighted average technique, where the average log $^{210}Pb_{xs}$ for the upper region (0 - 26.95 g cm^{-2}) was used as the first point of the plot.

The chronology of the sediment profile is represented in Figure 3.30. As previously discussed, the upper 20 cm (0 – 26.95 g cm^{-2}) was deposited over several months, based on ^{7}Be data. This upper region chronology was determined by applying the constant flux model (CF)

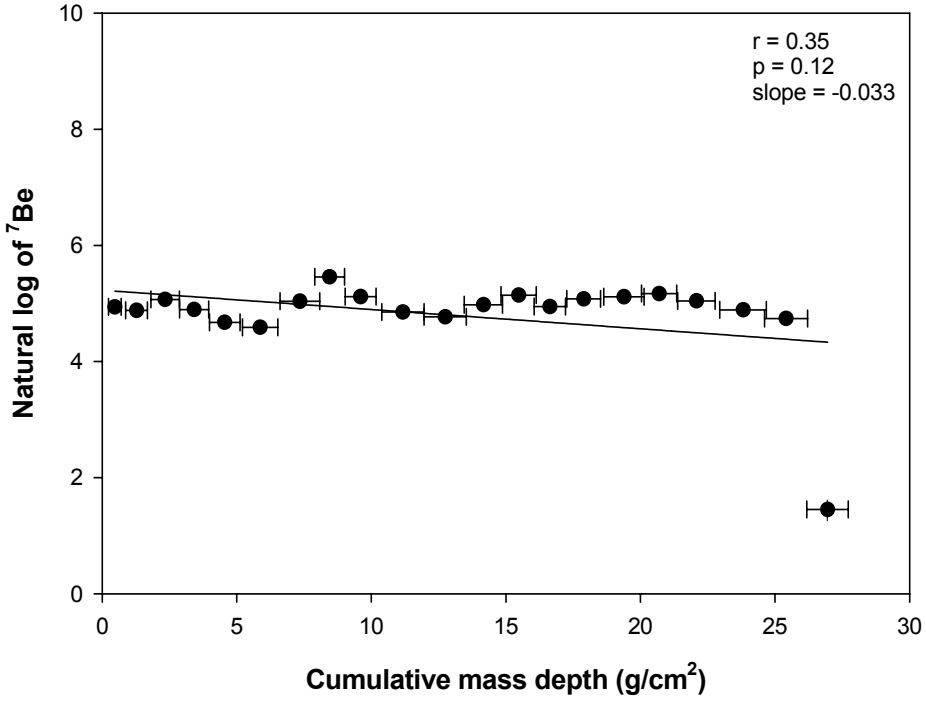


Figure 3.28 ^{7}Be modeling data for station 11261

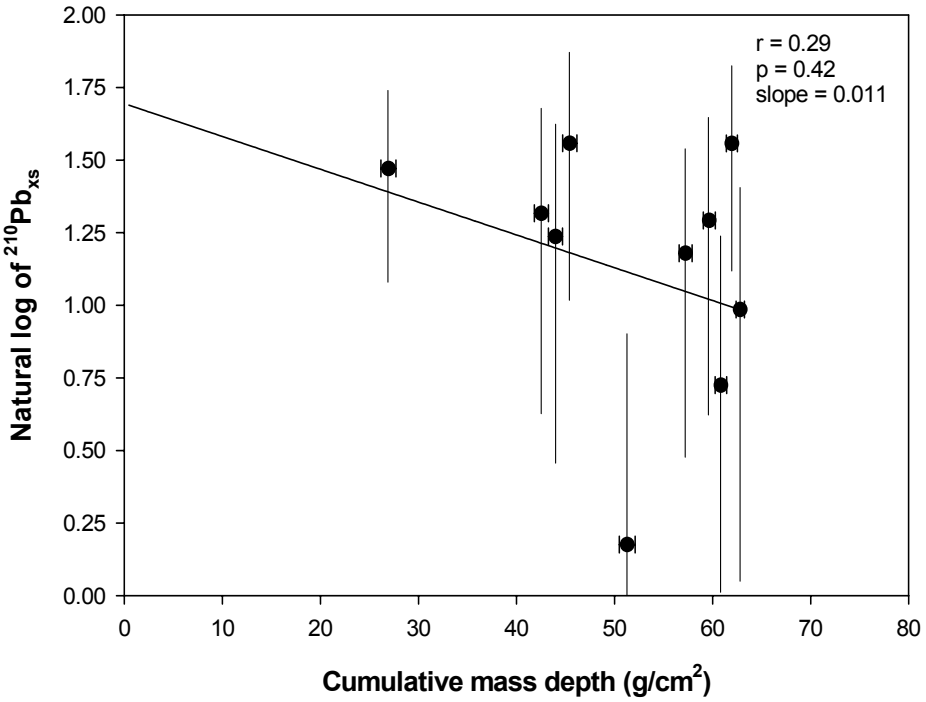


Figure 3.29 $^{210}Pb_{xs}$ modeling data for station 11261

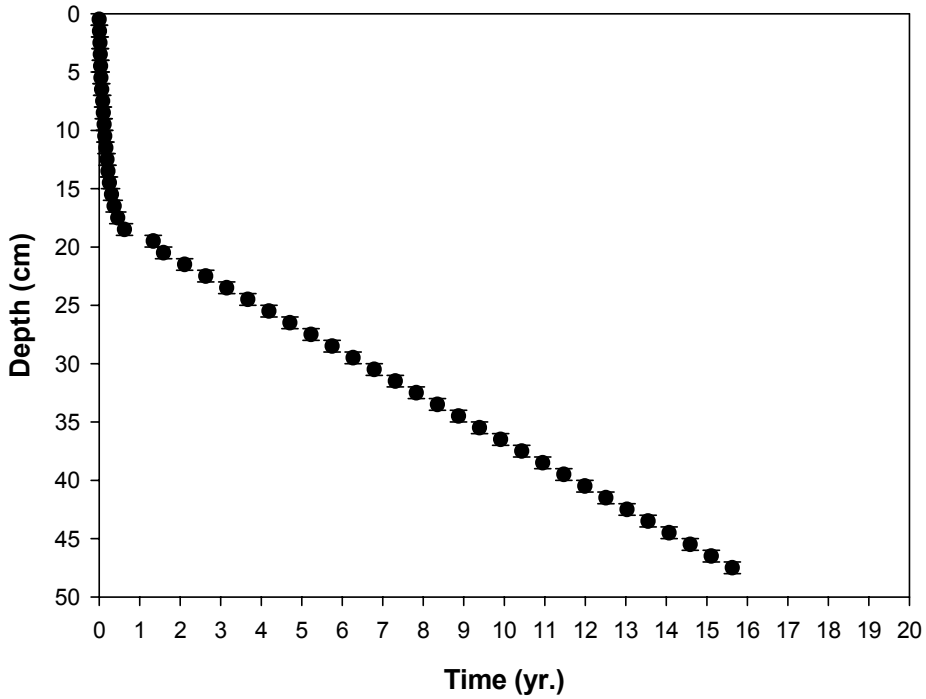


Figure 3.30 ^{7}Be and $^{210}Pb_{xs}$ based chronologic profile for station 11261

(Robbins 1978, Appleby and Oldfield 1978), which is defined as:

$$t = -\frac{1}{\lambda}\ln\left[1 - \frac{\Sigma(m))}{\Sigma(\infty)}\right] \qquad (3.6)$$

where t = time (yr.), λ = ^{7}Be decay constant (4.75 yr.$^{-1}$), $\Sigma(m) = \int_0^m A(u)du = \int_0^t F_7 e^{-\lambda t}dt$, $\Sigma(\infty)$ = F_7/λ and F_7 = ^{7}Be flux (mBq cm^{-2} yr.$^{-1}$). Since $^{210}Pb_{xs}$ data at this station is sporadic, the CF model is not applicable for sediment below 20 cm. The chronology below this depth is determined by applying the longer term $^{210}Pb_{xs}$ based sedimentation rate.

Station 15244

Summary physical and radiochemical data for this station are listed in Tables 3.16a and b. X-radiograph and the core grain size distribution are shown in Figure C-2 and listed in Table C-1 of Appendix C. The grain size distribution for the core is shown in Figure 3.31 and summarized in Table 3.16a. The mean ^{210}Pb value over the depth interval of 6 – 30 cm was used as the supported value (23.05 $\pm$ 1.73 mBq g^{-1}). This station shows nearly ideal profiles for ^{7}Be and $^{210}Pb_{xs}$ (Figure 3.32), indicating that mixing over the short term is constrained to the very upper section of the sediment profile (< 3 cm) at most, and that the profile represents over 100 years of deposition. This interpretation is supported by porosity and POC data (Figure 3.33), that indicate little mixing at depth and a stable, accumulating sedimentary setting.

Sediment accumulation rates using $^{210}Pb_{xs}$ have been determined using the CF-CS model, as previously described. Figure 3.34 shows the semi-log plot of $^{210}Pb_{xs}$ over depth, from which a sediment accumulation rate was derived. Sediment accumulation at this station based on $^{210}Pb_{xs}$ is 0.24 $\pm$ 0.10 g cm^{-2} yr.$^{-1}$ (or 0.31 $\pm$ 0.13 cm yr.$^{-1}$). Sediment accumulation rates have also been

Table 3.16a Physical data for station 15244

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	0.7	0.72	7.13 + 0.03	10.1	45.4	44.5
2	1.05	0.86	7.20 + 0.03	7	36.3	56.7
3	1.59	0.78	5.50 + 0.02	11.4	44.6	44
4	2.23	0.75	3.85 + 0.01	16.5	52.4	31.1
5	2.96	0.71	4.80 + 0.02	15.7	44.4	39.9
6	3.85	0.64	4.03 + 0.02	16.4	51.4	32.3
7	4.84	0.6	3.87 + 0.02	16.3	53.3	30.4
8	5.54	0.72	3.70 + 0.01	19.7	50.9	29.4
9	6.11	0.77	4.70 + 0.02	15.7	51	33.3
10	6.89	0.69	3.80 + 0.01	15.3	48.6	36.1
11	7.57	0.73	4.53 + 0.02	13.8	45	41.2
12	8.31	0.71	4.10 + 0.02	6.9	59.8	33.4
13	9.04	0.71	5.05 + 0.03	18.2	48	33.8
14	9.79	0.7	4.60 + 0.03	16.5	49.2	34.4
15	10.35	0.78	4.40 + 0.03	15.5	51.8	32.8
16	11.06	0.71	4.65 + 0.03	14.3	49	36.7
17	11.79	0.71	4.65 + 0.03	14.8	46.8	38.4
18	12.86	0.57	4.00 + 0.02	18.5	51.3	30.2
19	13.61	0.7	3.95 + 0.01	16.8	53.7	29.5
20	14.39	0.69	4.27 + 0.01	16.4	50.4	33.2
21	14.96	0.77	4.60 + 0.01	15.8	53.2	31
22	15.87	0.64	4.20 + 0.01	14.2	56.7	29.1
23	16.62	0.7	4.50 + 0.01	12.7	53.3	34
24	17.41	0.69	4.00 + 0.01	15.3	58.1	26.7
25	18.18	0.69	4.20 + 0.01	16.7	48.3	35
26	18.92	0.71	4.80 + 0.02	13.9	48.1	38
27	19.69	0.69	4.65 + 0.01	14.6	47.9	37.5
28	20.35	0.74	4.80 + 0.02	14.1	47.4	38.5
29	21.53	0.53	3.90 + 0.01	16.8	55.6	27.5
30	22.21	0.73	4.55 + 0.01	16.2	49.4	34.5

Table 3.16b Radiochemical data for station 15244

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	$^{210}Pb_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	49.34 + 3.10	2.65 + 0.24	33.17 + 2.50	10.12 + 3.04	0.064 + 0.007
2	18.56 + 1.44	3.45 + 0.33	37.28 + 2.77	14.22 + 3.27	0.039 + 0.005
3	1.22 + 0.45	1.90 + 0.23	30.74 + 2.43	7.68 + 2.98	0.042 + 0.005
4	0	1.33 + 0.14	26.68 + 1.95	3.62 + 2.61	0.022 + 0.003
5	--	1.21 + 0.12	26.09 + 1.97	3.04 + 2.62	0.035 + 0.004
6	--	2.11 + 0.22	24.50 + 1.75	1.45 + 2.46	0.041 + 0.007
7	--	1.06 + 0.10	24.58 + 1.79	1.53 + 2.49	0.032 + 0.003
8	--	1.64 + 0.19	22.50 + 1.50	0	0.018 + 0.002
9	--	1.69 + 0.16	21.86 + 1.65	0	0.030 + 0.003
10	--	2.40 + 0.25	25.62 + 1.99	2.56 + 2.64	--
11	--	3.12 + 0.27	25.40 + 1.93	2.35 + 2.59	0.055 + 0.006
12	--	2.07 + 0.22	27.00 + 1.97	3.94 + 2.62	0.032 + 0.004
13	--	1.64 + 0.14	25.77 + 1.71	2.72 + 2.43	0.046 + 0.004
14	--	2.61 + 0.24	24.19 + 1.90	1.13 + 2.57	0.029 + 0.004
15	--	1.80 + 0.15	25.68 + 2.02	2.63 + 2.66	0.045 + 0.006
16	--	2.29 + 0.21	22.61 + 1.78	0	--
17	--	2.28 + 0.25	24.49 + 1.85	1.44 + 2.53	0.037 + 0.006
18	--	1.26 + 0.12	22.09 + 1.67	0	--
19	--	0	21.20 + 1.42	0	--
20	--	0	21.55 + 1.68	0	0.021 + 0.002
21	--	--	24.47 + 1.94	1.41 + 2.60	--
22	--	--	21.15 + 1.53	0	--
23	--	--	22.83 + 1.83	0	--
24	--	--	21.41 + 1.51	0	--
25	--	--	19.56 + 1.39	0	--
26	--	--	23.28 + 1.71	0.23 + 2.43	--
27	--	--	23.43 + 1.63	0.38 + 2.38	--
28	--	--	21.83 + 1.64	0	--
29	--	--	18.96 + 1.32	0	--
30	--	--	20.39 + 2.14	0	--

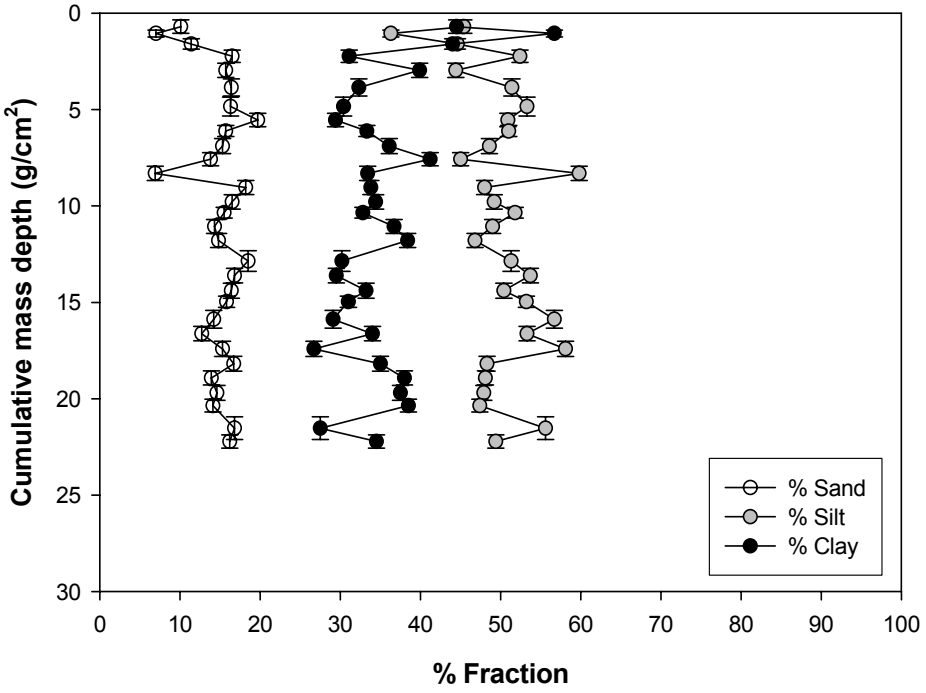


Figure 3.31 Grain size distribution for core sediment at station 15244

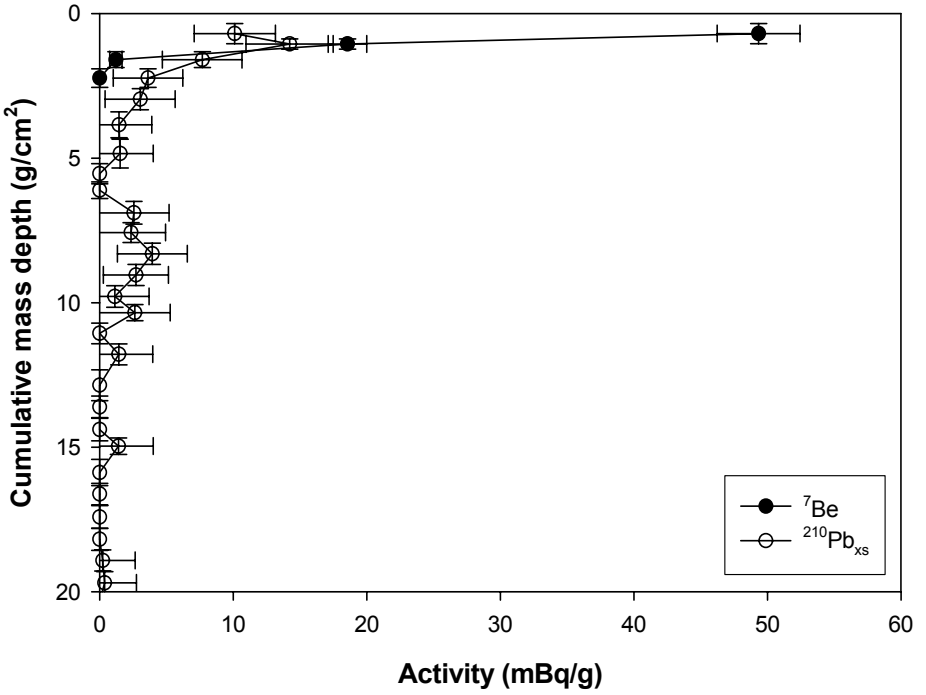


Figure 3.32 $^{210}Pb_{xs}$ and ^{7}Be data for station 15244

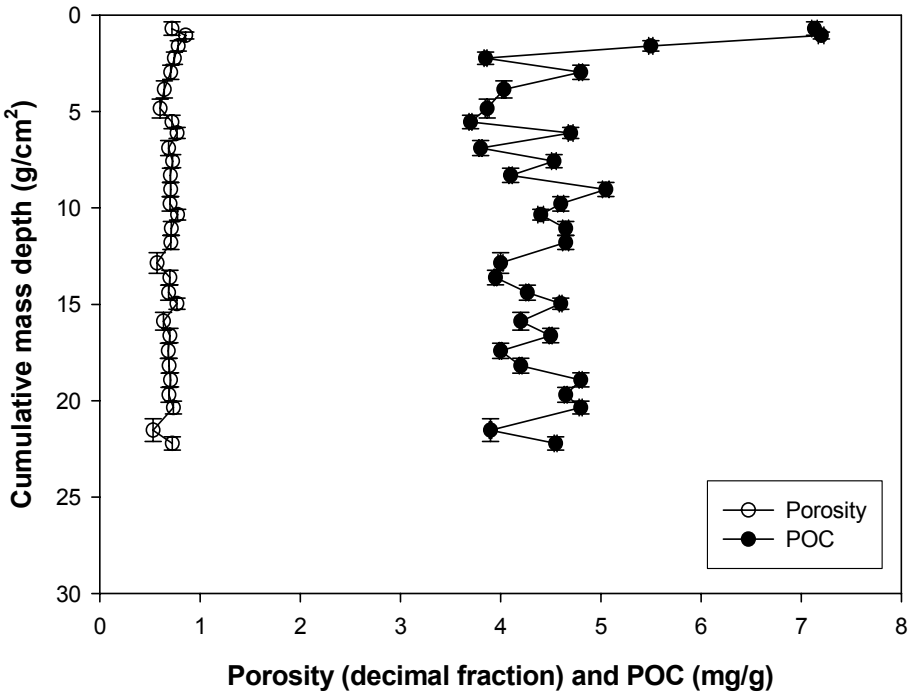


Figure 3.33 Porosity and POC data for station 15244

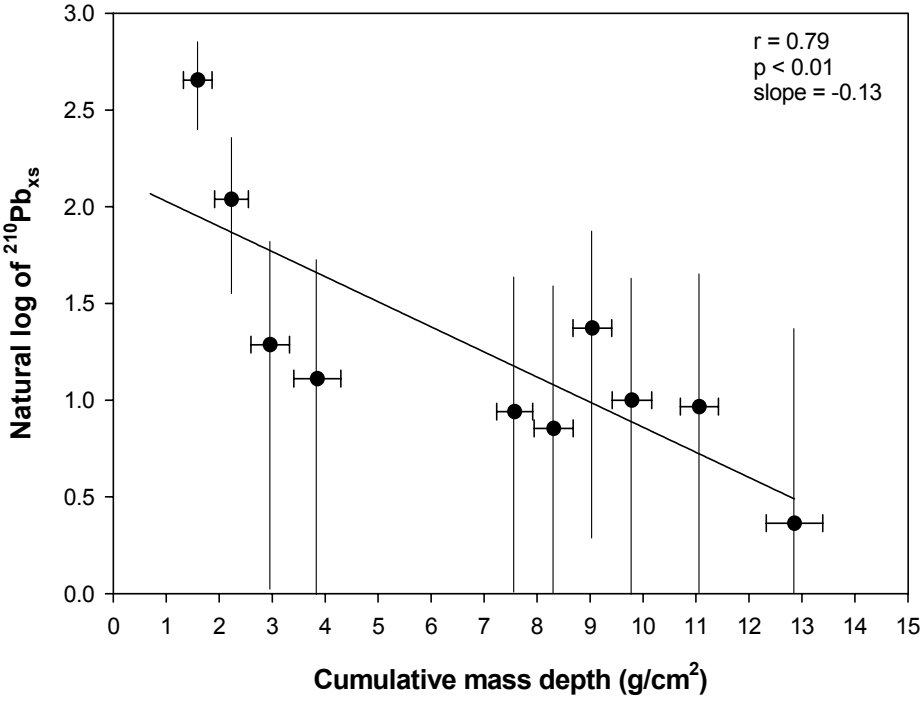


Figure 3.34 $^{210}Pb_{xs}$ modeling data for station 15244

determined using ^{137}Cs (Table 3.16b) by:

$$S = \frac{D_{pk}}{T} \tag{3.7}$$

where S = sediment accumulation rate (g cm^{-2} yr. $^{-1}$), D_{pk} = mass depth (g cm^{-2}) at which the ^{137}Cs maxima occurs (1963) and T = time (yr.). This model is based on the assumption of limited vertical mobility of cesium in sediments (Huntley *et al.* 1995, Winkels *et al.* 1998, Valero-Garces *et al.* 1999). Sediment accumulation rates at this station based on ^{137}Cs are 0.26 $\pm$ 0.03 g cm^{-2} yr.$^{-1}$ (or 0.27 $\pm$ 0.05 cm yr^{-1}), are very close to those determined using ^{210}Pb$_{xs}$ (Figure 3.35). This rate is further supported by ^{239,240}Pu data, whose temporal input function and particle reactive nature allow for the same approach as for ^{137}Cs. Sediment accumulation rates at this station based on ^{239,240}Pu are 0.18 $\pm$ 0.01 g cm^{-2} yr.$^{-1}$ (or 0.26 $\pm$ 0.03 cm yr^{-1}) (Figure 3.36).

The chronology of the sediment profile is represented in Figure 3.37 and was determined using ^{210}Pb$_{xs}$ data and the constant flux (CF) model, as previously discussed.

Station 11193

Summary physical and radiochemical data for station 11193 are listed in Tables 3.17a and b. X-radiograph and the grain size distribution for the core are shown in Figure C-3 and listed in Table C-2 of Appendix C. The grain size distribution for this core is shown in Figure 3.38 and summarized in Table 3.17a. ^{7}Be data (Table 3.17b, Figure 3.39) suggest that short term mixing is confined to the very surface layer of sediment here (0 – 2 cm). For this station, the mean ^{210}Pb value over the depth interval of 30 – 40 cm was used as the supported value (8.34 $\pm$ 0.78 mBq g^{-1}), ^{210}Pb$_{xs}$ is shown in Figure 3.39. The interpretation of limited mixing is supported by porosity and POC data (Figure 3.40).

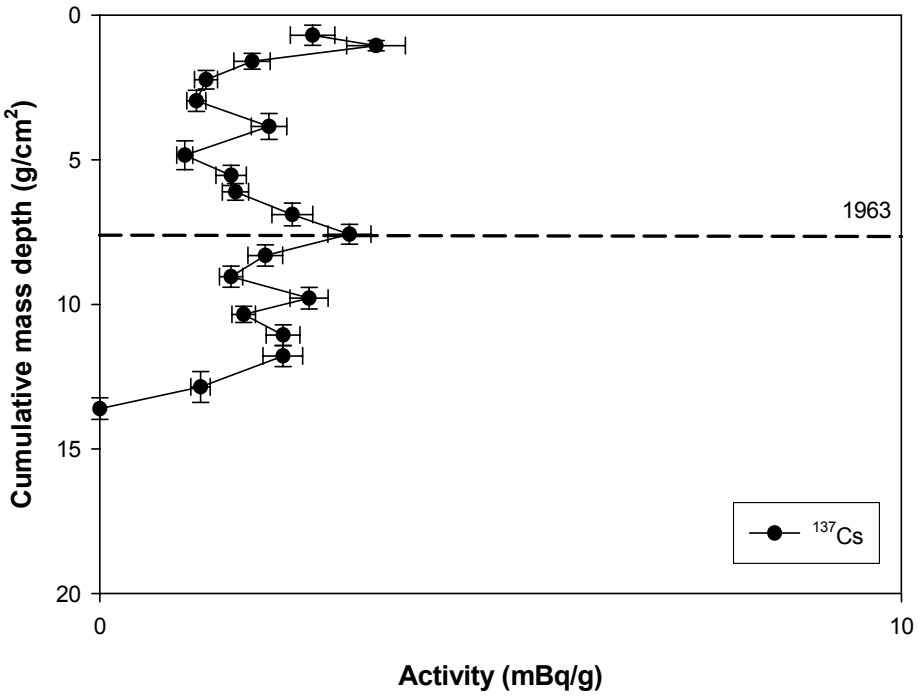


Figure 3.35 ^{137}Cs data for station 15244

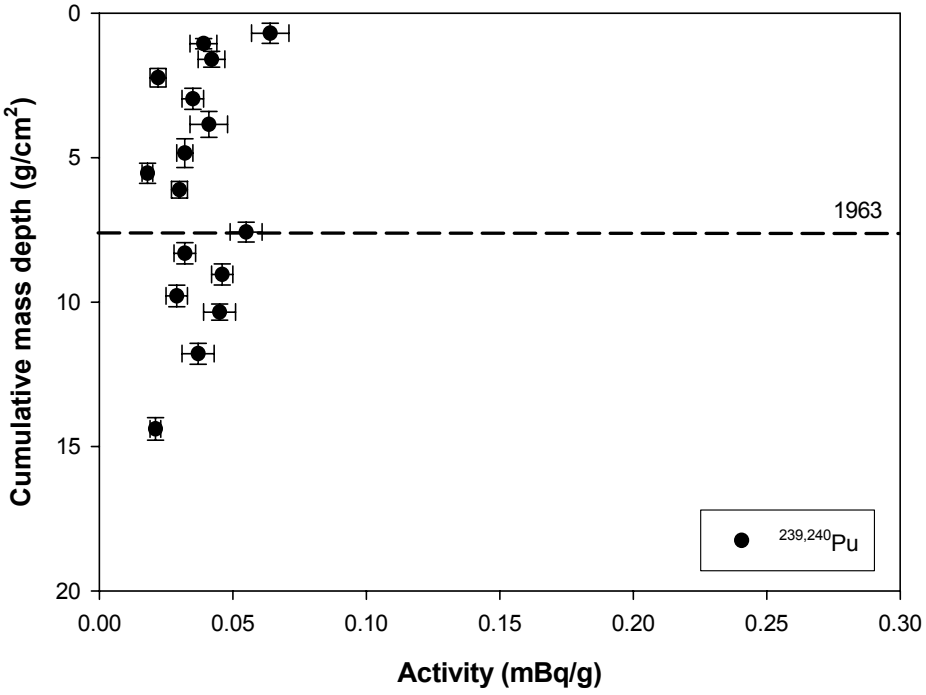


Figure 3.36 ^{239,240}Pu data for station 15244

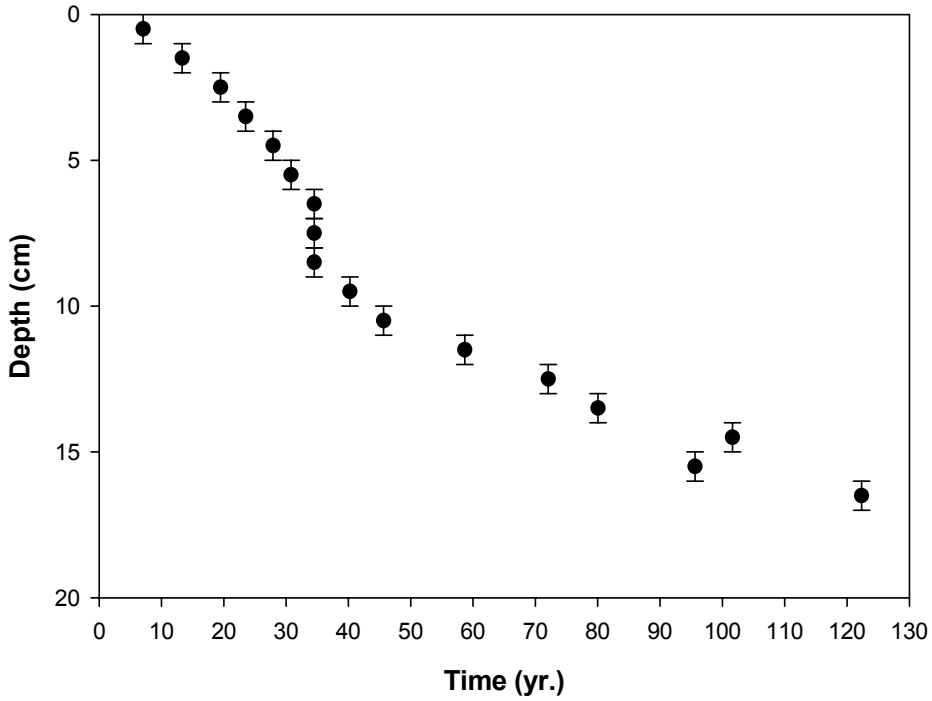


Figure 3.37 $^{210}Pb_{xs}$ based chronologic profile for station 15244

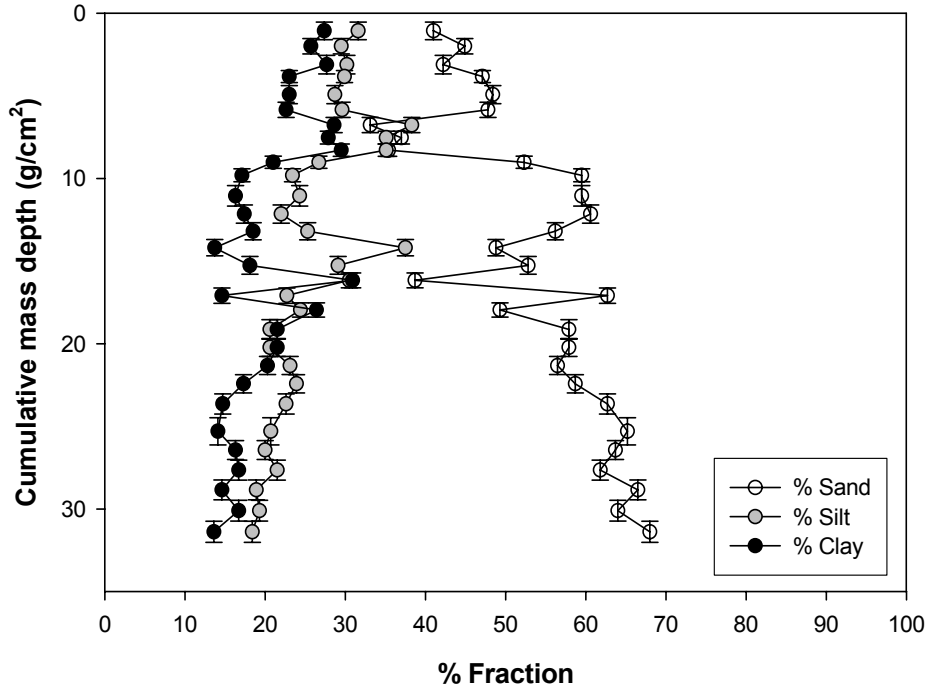


Figure 3.38 Grain size distribution for core sediment at station 11193

Table 3.17a Physical data for station 11193

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	1.07	0.57	4.70 + 0.02	41	31.6	27.4
2	1.2	0.63	4.23 + 0.02	44.9	29.5	25.7
3	3.11	0.55	4.13 + 0.02	42.2	30.2	27.7
4	3.84	0.71	4.15 + 0.02	47.1	29.9	23
5	4.93	0.56	3.20 + 0.01	48.4	28.7	23
6	5.85	0.63	4.45 + 0.03	47.8	29.6	22.6
7	6.77	0.63	4.65 + 0.03	33.1	38.3	28.6
8	7.53	0.69	4.37 + 0.03	37	35.1	27.9
9	8.29	0.7	4.53 + 0.03	35.4	35.1	29.5
10	9.02	0.71	3.60 + 0.03	52.3	26.7	21
11	9.81	0.68	3.70 + 0.03	59.5	23.4	17.1
12	11.06	0.5	2.75 + 0.02	59.5	24.3	16.3
13	12.15	0.56	2.80 + 0.02	60.6	22	17.4
14	13.2	0.58	3.30 + 0.02	56.2	25.3	18.5
15	14.19	0.6	3.10 + 0.02	48.8	37.5	13.7
16	15.26	0.57	3.90 + 0.03	52.8	29.1	18.1
17	16.16	0.64	3.45 + 0.03	38.7	30.5	30.9
18	17.09	0.63	4.45 + 0.03	62.7	22.7	14.6
19	17.96	0.65	3.95 + 0.03	49.3	24.4	26.4
20	19.14	0.53	3.43 + 0.03	57.9	20.6	21.5
21	20.23	0.56	2.85 + 0.03	57.9	20.6	21.5
22	21.32	0.56	3.25 + 0.03	56.5	23.1	20.3
23	22.42	0.56	3.25 + 0.03	58.7	23.9	17.3
24	23.64	0.51	3.33 + 0.03	62.7	22.6	14.7
25	25.3	0.34	2.30 + 0.02	65.2	20.7	14.1
26	26.44	0.55	3.15 + 0.03	63.7	20	16.3
27	27.65	0.52	2.65 + 0.02	61.8	21.5	16.7
28	28.85	0.52	3.13 + 0.03	66.5	18.9	14.6
29	30.11	0.5	2.85 + 0.03	64	19.3	16.7
30	31.39	0.49	2.83 + 0.03	68	18.4	13.6
31	32.73	0.47	--	--	--	--
32	34.17	0.42	--	--	--	--
33	35.29	0.55	--	--	--	--
34	36.66	0.45	--	--	--	--
35	38.01	0.46	--	--	--	--
36	39.45	0.42	--	--	--	--
37	40.73	0.49	--	--	--	--
38	42.04	0.47	--	--	--	--
39	43.12	0.57	--	--	--	--
40	44.63	0.39	--	--	--	--

Table 3.17b Radiochemical data for station 11193

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	^{210}Pb$_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	18.62 + 1.09	1.14 + 0.12	21.15 + 1.64	12.81 + 1.82	0.034 + 0.005
2	0	1.32 + 0.15	15.86 + 1.17	7.52 + 1.41	0.013 + 0.003
3	--	0.99 + 0.10	17.20 + 1.28	8.86 + 1.50	0.017 + 0.002
4	--	0.83 + 0.10	15.58 + 1.10	7.24 + 1.35	0.016 + 0.003
5	--	0.91 + 0.07	15.63 + 1.25	7.29 + 1.47	0.013 + 0.003
6	--	1.03 + 0.10	16.73 + 1.27	8.39 + 1.49	0.022 + 0.003
7	--	2.01 + 0.22	17.47 + 1.25	9.13 + 1.47	0.015 + 0.003
8	--	1.50 + 0.18	16.61 + 1.85	8.27 + 1.91	--
9	--	3.46 + 0.42	19.66 + 1.44	11.32 + 1.64	0.023 + 0.003
10	--	0.95 + 0.11	17.25 + 1.22	8.91 + 1.45	0.016 + 0.002
11	--	0	11.65 + 1.42	3.31 + 1.62	0.019 + 0.002
12	--	--	9.90 + 0.85	1.56 + 1.16	--
13	--	--	9.57 + 0.96	1.23 + 1.24	0
14	--	--	10.34 + 0.78	2.00 + 1.11	--
15	--	--	9.49 + 0.84	1.15 + 1.15	0.005 + 0.001
16	--	--	12.27 + 1.74	3.93 + 1.27	--
17	--	--	11.75 + 0.91	3.41 + 1.20	0.005 + 0.001
18	--	--	13.08 + 0.98	4.74 + 1.25	--
19	--	--	11.22 + 1.15	2.88 + 1.39	0.006 + 0.001
20	--	--	11.88 + 0.88	3.54 + 1.18	--
21	--	--	10.65 + 1.10	2.31 + 1.35	0.005 + 0.001
22	--	--	14.84 + 1.09	6.50 + 1.34	--
23	--	--	14.34 + 1.37	6.00 + 1.58	--
24	--	--	13.10 + 0.98	4.76 + 1.25	--
25	--	--	14.43 + 1.09	6.09 + 1.34	--
26	--	--	13.14 + 1.02	4.80 + 1.29	--
27	--	--	12.45 + 1.17	4.11 + 1.41	--
28	--	--	13.86 + 1.18	5.52 + 1.42	--
29	--	--	14.96 + 1.14	6.62 + 1.38	--
30	--	--	13.78 + 1.04	5.44 + 1.30	0.007 + 0.001
31	--	--	10.10 + 0.97	--	--
32	--	--	8.48 + 0.77	--	--
33	--	--	8.44 + 0.79	--	--
34	--	--	8.38 + 0.84	--	--
35	--	--	7.76 + 0.83	--	--
36	--	--	6.73 + 0.66	--	--
37	--	--	6.33 + 0.62	--	--
38	--	--	7.14 + 0.76	--	--
39	--	--	6.13 + 0.63	--	--
40	--	--	8.50 + 0.71	--	--

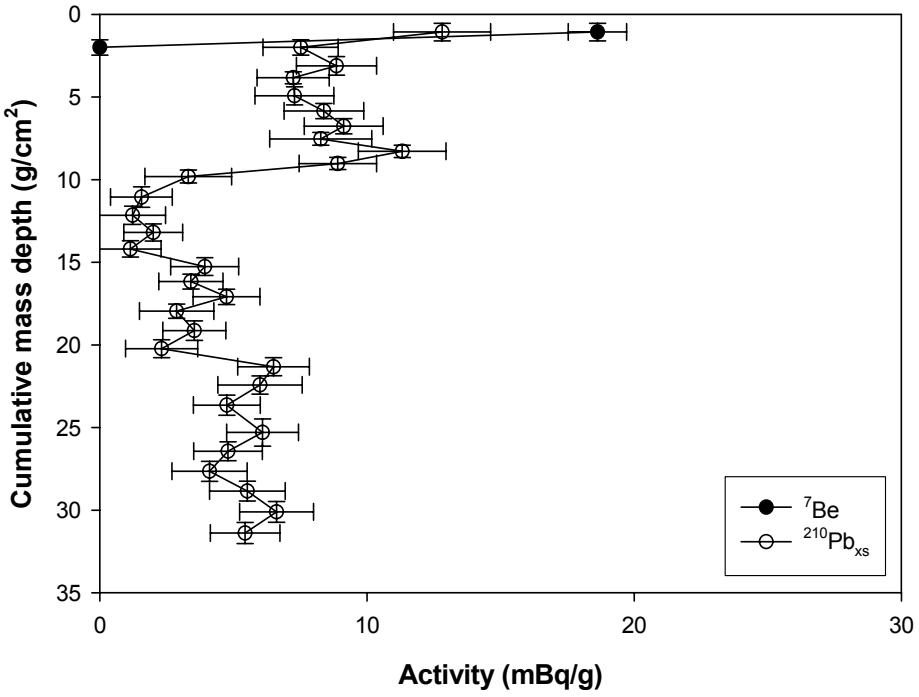


Figure 3.39 $^{210}Pb_{xs}$ and ^{7}Be data for station 11193

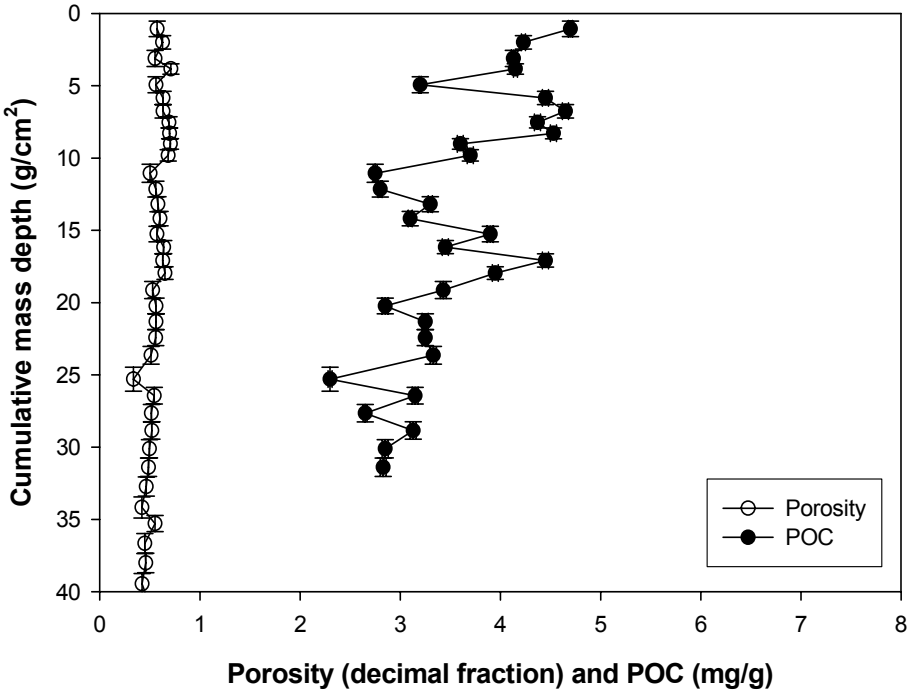


Figure 3.40 Porosity and POC data for station 11193

Sediment accumulation rates using $^{210}Pb_{xs}$ have been determined using the CF-CS model, as previously described. Figure 3.41 shows the semi-log plot of $^{210}Pb_{xs}$ over depth, from which a sediment accumulation rate was derived. Only the upper section of the profile was modeled, as the lower portion of the profile does not show exponential decline (see Figure 3.39), likely due to mixing or very rapid sedimentation that occurred in the past, prior to the upper most, exponential portion's deposition. Sediment accumulation at this station based on $^{210}Pb_{xs}$ is 0.18 $\pm$ 0.09 g cm^{-2} $yr.^{-1}$ (or 0.21 $\pm$ 0.11 cm $yr.^{-1}$). Sediment accumulation rates have been determined using ^{137}Cs as described previously (Figure 3.42), 0.20 $\pm$ 0.02 g cm^{-2} $yr.^{-1}$ (or 0.21 $\pm$ 0.02 cm yr^{-1}), very close to those determined using $^{210}Pb_{xs}$ (Figure 3.41).

The extrapolated chronology of the sediment profile is represented in Figure 3.43 and was determined using $^{210}Pb_{xs}$ data and the constant flux (CF) model, as previously discussed.

Station 15979

Summary physical and radiochemical data for station 15979 are presented in Tables 3.18a and b. X-radiograph and the core grain size distribution are shown in Figure C-4 and listed in Table C-2 of Appendix C. The grain size distribution for this core is shown in Figure 3.44 and summarized in Table 3.18a. ^{7}Be (Table 3.18b, Figure 3.45) data suggest that short term mixing is confined to the near surface (0 – 2 cm). For this station, the mean ^{210}Pb value over the depth interval of 28 – 35 cm was used as the supported value (6.69 $\pm$ 0.66 mBq/g), $^{210}Pb_{xs}$ is shown in Figure 3.45. The possibility of longer term, episodic mixing or rapid sedimentation is indicated by the grain size distribution (increased sand composition with depth, Figure 3.44) and irregular $^{210}Pb_{xs}$ and POC profiles (Figures 3.45 and 3.46, respectively).

The use of $^{210}Pb_{xs}$ to determine sediment accumulation rates for this core is not

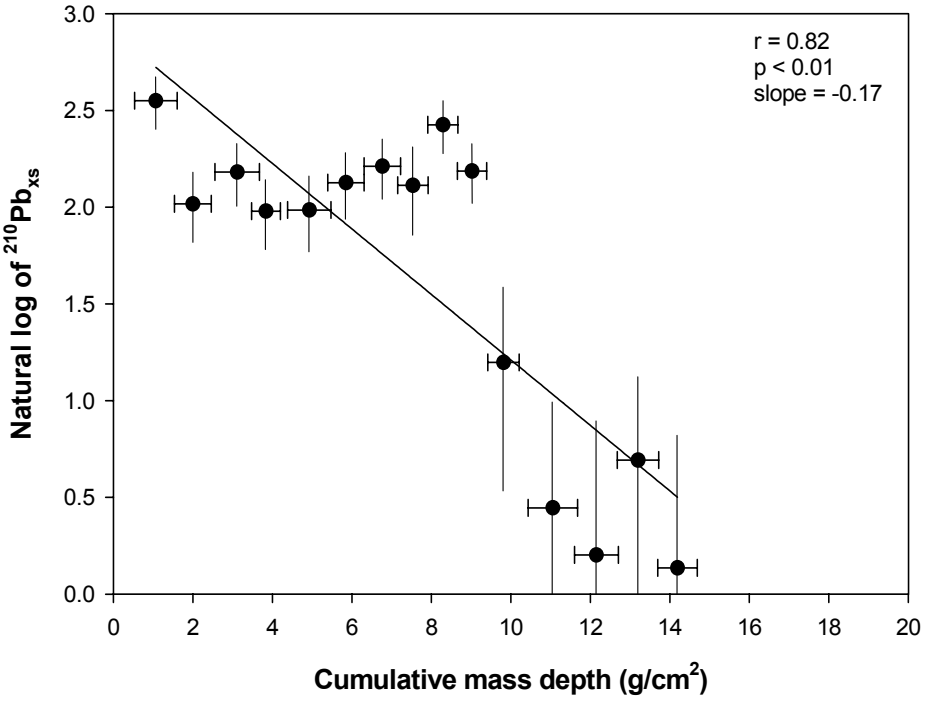


Figure 3.41 $^{210}Pb_{xs}$ modeling data for station 11193

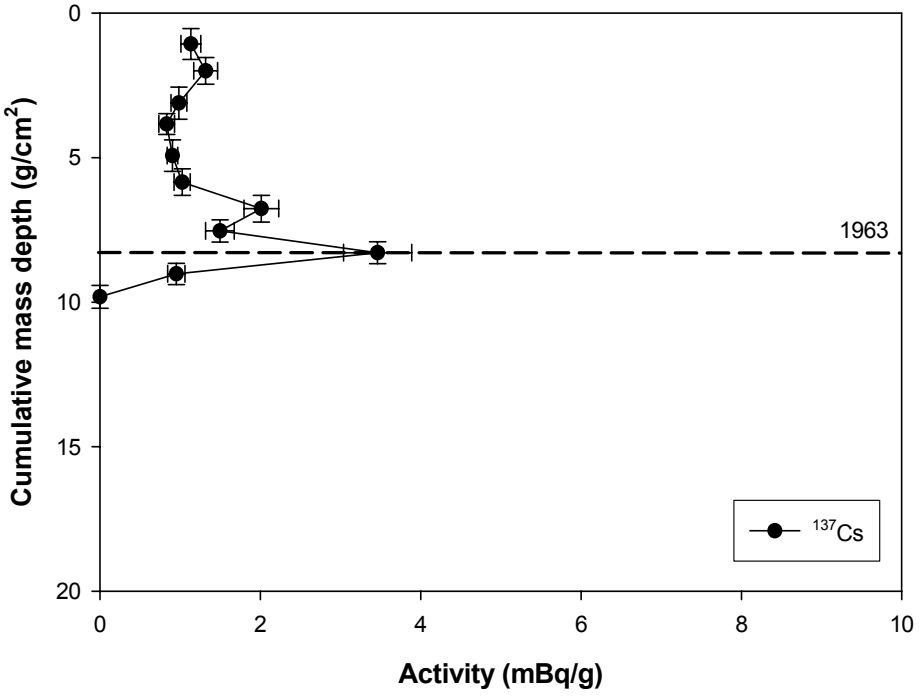


Figure 3.42 ^{137}Cs data for station 11193

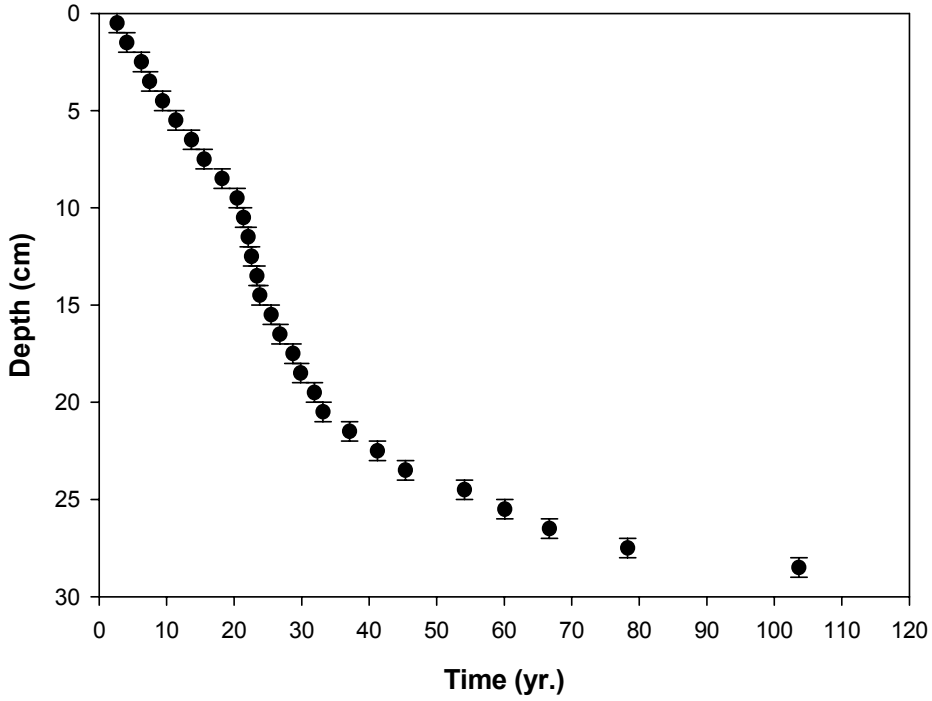


Figure 3.43 $^{210}Pb_{xs}$ based chronologic profile for station 11193

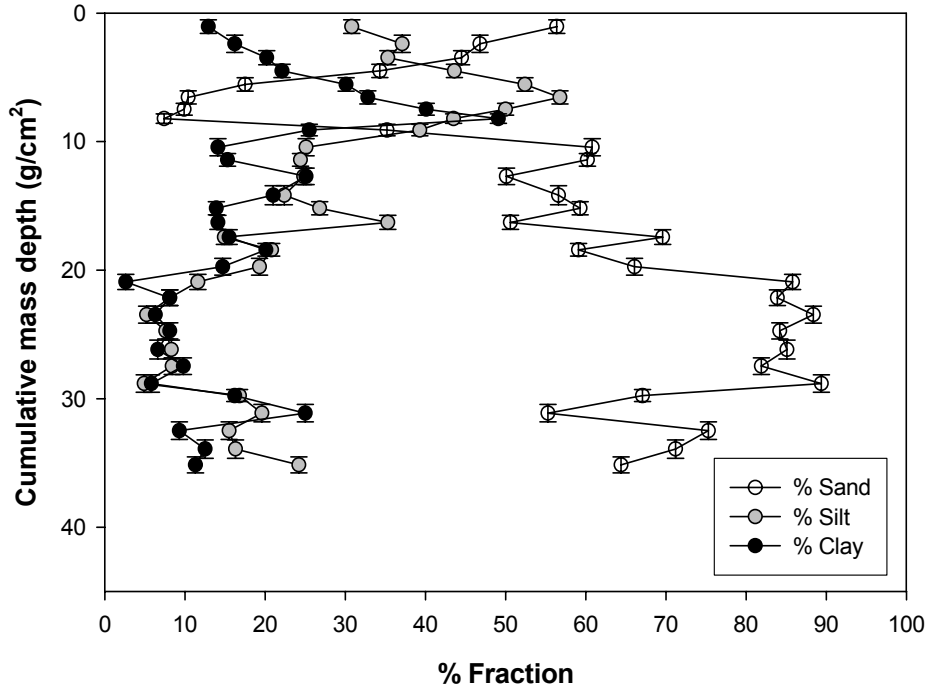


Figure 3.44 Grain size distribution for core sediment at station 15979

Table 3.18a Physical data for station 15979

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	1.05	0.58	2.95 + 0.01	56.4	30.8	12.9
2	2.38	0.47	2.25 + 0.01	46.8	37.1	16.2
3	3.47	0.57	4.85 + 0.01	44.5	35.3	20.2
4	4.49	0.59	4.23 + 0.01	34.3	43.6	22.1
5	5.55	0.58	5.80 + 0.01	17.5	52.4	30.1
6	6.56	0.6	6.63 + 0.02	10.4	56.8	32.8
7	7.48	0.63	6.30 + 0.02	9.9	50	40.1
8	8.207	0.71	11.80 + 0.03	7.4	43.5	49.1
9	9.1	0.64	5.70 + 0.01	35.2	39.3	25.5
10	10.44	0.46	2.30 + 0.01	60.8	25.1	14.1
11	11.42	0.61	2.15 + 0.01	60.2	24.4	15.3
12	12.7	0.49	2.35 + 0.01	50.1	24.8	25.1
13	14.17	0.41	2.23 + 0.01	56.6	22.4	21
14	15.18	0.59	2.55 + 0.01	59.3	26.8	13.9
15	16.28	0.56	2.45 + 0.01	50.6	35.3	14.1
16	17.42	0.54	3.55 + 0.01	69.6	14.9	15.5
17	18.41	0.6	4.13 + 0.02	59.1	20.8	20.1
18	19.73	0.48	3.23 + 0.01	66.1	19.3	14.7
19	20.91	0.53	2.17 + 0.01	85.8	11.6	2.6
20	22.14	0.51	1.80*	83.9	8.1	8.1
21	23.46	0.47	1.40*	88.4	5.2	6.3
22	24.72	0.5	1.13*	84.2	7.6	8.1
23	26.17	0.42	1.10*	85.1	8.3	6.6
24	27.46	0.48	0.93*	81.9	8.4	9.8
25	28.82	0.46	1.47*	89.4	4.9	5.8
26	29.75	0.63	2.77*	67.1	16.8	16.2
27	31.12	0.46	2.57*	55.3	19.6	25
28	32.49	0.45	2.00*	75.3	15.5	9.3
29	33.91	0.43	1.50*	71.2	16.3	12.5
30	35.14	0.51	1.17*	64.4	24.2	11.3
31	36.52	0.45	--	--	--	--
32	38.16	0.34	--	--	--	--
33	39.41	0.5	--	--	--	--
34	40.72	0.48	--	--	--	--
35	41.9	0.53	--	--	--	--

*denotes an error of < 0.01

Table 3.18b Radiochemical data for station 15979

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	$^{210}Pb_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	8.22 + 0.72	0	12.11 + 0.91	4.33 + 1.18	0
2	0	0	9.61 + 0.67	1.84 + 1.00	0
3	--	1.04 + 0.12	16.25 + 1.15	8.48 + 1.37	0.043 + 0.015
4	--	0.94 + 0.10	17.44 + 1.33	9.66 + 1.53	--
5	--	0.43 + 0.06	23.37 + 1.55	15.59 + 1.72	0
6	--	--	28.50 + 2.02	20.73 + 2.15	--
7	--	--	27.39 + 2.16	19.61 + 2.29	--
8	--	3.58 + 0.37	46.56 + 3.84	38.79 + 3.91	0.047 + 0.009
9	--	--	28.84 + 2.17	21.06 + 2.30	--
10	--	0	8.98 + 0.65	1.20 + 0.99	--
11	--	--	9.33 + 0.68	1.55 + 1.01	0.006 + 0.002
12	--	--	9.55 + 0.92	1.77 + 1.19	--
13	--	0	7.91 + 0.76	0	--
14	--	--	7.77 + 0.75	0	0.005 + 0.003
15	--	--	10.55 + 0.77	2.77 + 1.07	--
16	--	0	13.65 + 1.48	5.87 + 1.66	--
17	--	--	12.99 + 1.24	5.22 + 1.45	0
18	--	--	8.48 + 0.96	0	--
19	--	--	7.53 + 0.57	0	--
20	--	--	5.51 + 0.52	0	--
21	--	--	6.31 + 0.55	0	--
22	--	--	6.31 + 0.51	0	--
23	--	0	4.20 + 0.32	0	--
24	--	--	4.62 + 0.39	0	--
25	--	--	7.08 + 0.55	0	--
26	--	0	20.61 + 1.61	12.84 + 1.77	0
27	--	--	15.81 + 1.09	8.03 + 1.32	--
28	--	--	8.24 + 0.64	0.46 + 0.98	--
29	--	--	5.33 + 0.55	0	--
30	--	--	9.09 + 0.85	--	--
31	--	--	4.74 + 0.55	--	--
32	--	--	5.90 + 0.65	--	--
33	--	0	4.71 + 0.60	--	--
34	--	--	5.93 + 0.58	--	--
35	--	--	9.55 + 0.86	--	--

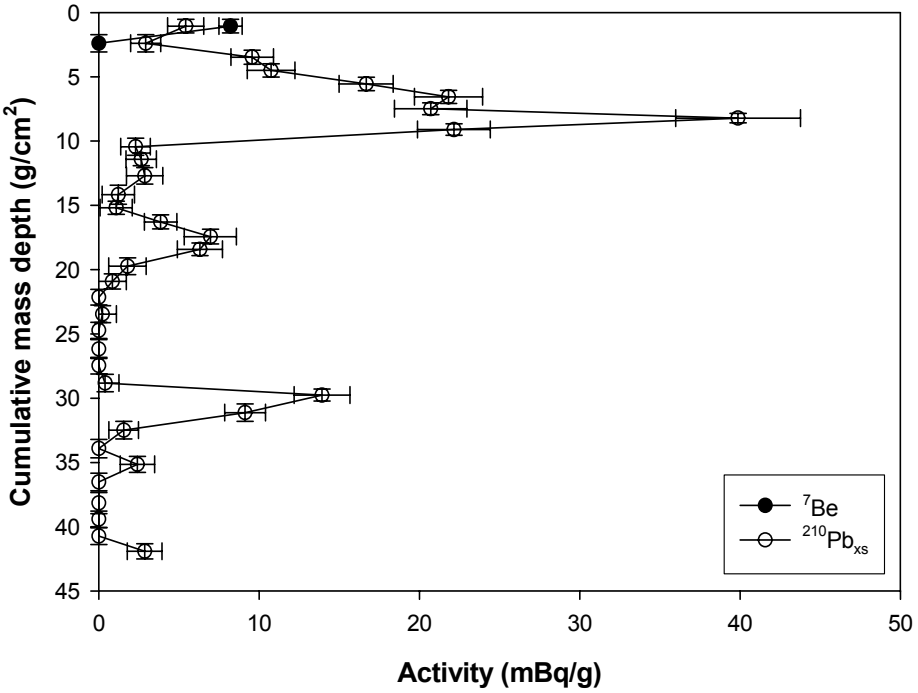


Figure 3.45 $^{210}Pb_{xs}$ and ^{7}Be data for station 15979

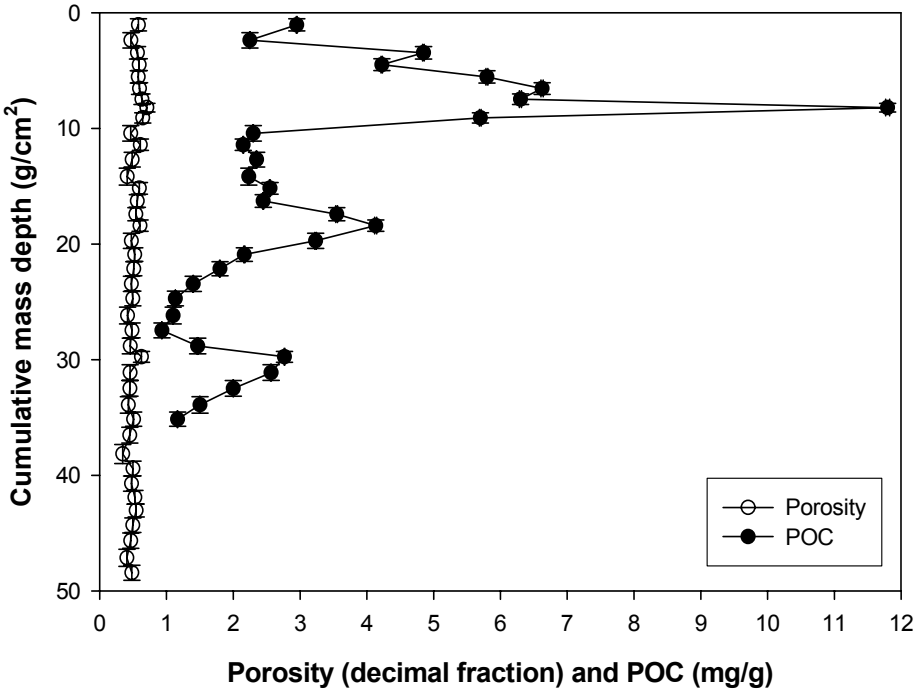


Figure 3.46 Porosity and POC data for station 15979

appropriate, since the distribution of ^{137}Cs suggests that sediment beneath 10.43 g cm^{-2} (10 cm, Table 3.18b) is older than 1953 (year when appreciable ^{137}Cs was detected at the earth's surface) or is comprised of older sediment which has been mixed into the profile. An average rate of sediment accumulation has been determined using ^{137}Cs based on this premise, 0.20 ± 0.03 g cm^{-2} $yr.^{-1}$ (or 0.18 ± 0.02 cm yr^{-1}).

The extrapolated chronology of the sediment profile is represented in Figure 3.47 and was determined based on the average sedimentation rate as determined using ^{137}Cs.

Station 11270

Summary physical and radiochemical data for station 11270 are presented in Tables 3.19a and b. X-radiograph and the core grain size distribution are shown in Figure C-5 and listed in Table C-3 of Appendix C. The grain size distribution for this core is shown in Figure 3.48 and summarized in Table 3.19a; note the dominance of the sand fraction in the near surface, indicative of a recent depositional event. The absence of ^{7}Be (Table 3.19b) suggests a mixed setting where "old" sediment (relative to the half life of ^{7}Be) has been deposited over the last few years. For this station, the mean ^{210}Pb value over the depth interval of 38 – 43 cm was used as the supported value (5.95 + 0.54 mBq/g); $^{210}Pb_{xs}$ is shown in Figure 3.49. The $^{210}Pb_{xs}$ profile is also indicative of mixing or rapid sedimentation. The presence of high quantities of $^{210}Pb_{xs}$ deep in the profile suggests the possibility that the sediment profile has been affected by high energy depositional events. Episodic deposition events are also indicated by other evidence, including high $^{210}Pb_{xs}$ values at depth and an irregular profile for POC (Figure 3.50) as well as a chaotic ^{137}Cs profile (Table 3.19b, Figure 3.51) and very low values for $^{239,240}Pu$ (Table 3.19b).

A rigorous determination of sedimentation rates derived from any of the isotopes

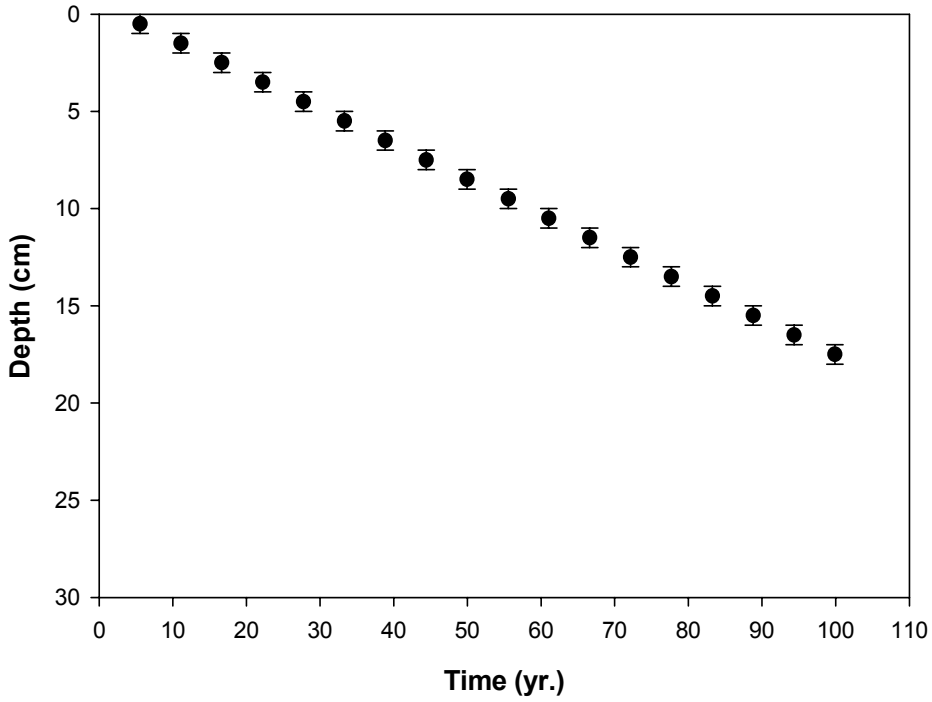


Figure 3.47 $^{210}Pb_{xs}$ based chronologic profile for station 15979

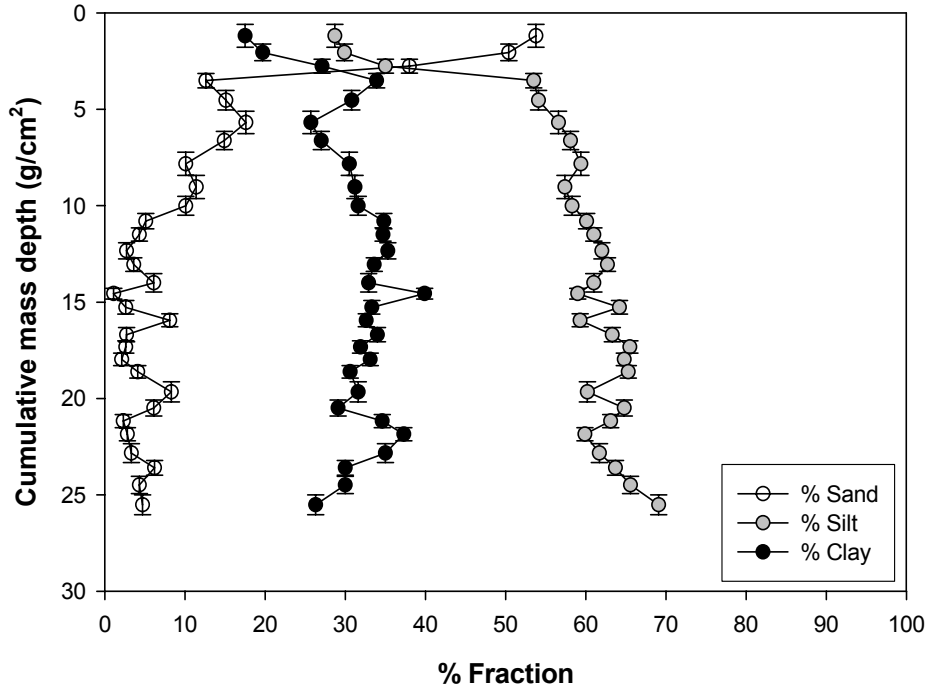


Figure 3.48 Grain size distribution for core sediment at station 11270

Table 3.19a Physical data for station 11270

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	1.18	0.53	5.27 + 0.02	53.8	28.7	17.5
2	2.05	0.65	5.70 + 0.02	50.4	29.9	19.7
3	2.77	0.71	9.33 + 0.03	38	35	27.1
4	3.51	0.7	6.60 + 0.02	12.6	53.5	33.9
5	4.53	0.59	5.85 + 0.02	15.1	54.1	30.8
6	5.68	0.54	5.35 + 0.02	17.6	56.6	25.7
7	6.62	0.63	3.95 + 0.01	14.9	58.1	27
8	7.83	0.52	3.15 + 0.01	10.1	59.4	30.5
9	9.03	0.52	4.15 + 0.01	11.4	57.4	31.2
10	10.01	0.61	3.53 + 0.01	10.1	58.3	31.6
11	10.8	0.68	4.65 + 0.01	5.1	60.1	34.8
12	11.5	0.72	4.90 + 0.01	4.3	61	34.7
13	12.34	0.66	7.25 + 0.01	2.7	62	35.3
14	13.05	0.71	6.15 + 0.01	3.6	62.7	33.6
15	14	0.62	5.10 + 0.01	6.1	61	32.9
16	14.56	0.78	6.90 + 0.03	1.1	59	39.9
17	15.27	0.72	8.00 + 0.03	2.6	64.2	33.3
18	15.94	0.73	6.35 + 0.03	8.1	59.3	32.6
19	16.69	0.7	6.40 + 0.03	2.7	63.3	34
20	17.33	0.75	7.30 + 0.03	2.6	65.5	31.9
21	17.97	0.74	8.70 + 0.04	2.1	64.8	33.1
22	18.61	0.74	6.75 + 0.03	4.1	65.3	30.6
23	19.66	0.58	6.10 + 0.03	8.3	60.2	31.6
24	20.49	0.67	9.05 + 0.04	6.1	64.8	29.1
25	21.17	0.73	11.40 + 0.06	2.3	63.1	34.6
26	21.86	0.73	10.35 + 0.05	2.8	59.9	37.3
27	22.83	0.61	7.85 + 0.04	3.3	61.7	35
28	23.6	0.69	8.18 + 0.04	6.2	63.7	30
29	24.49	0.64	9.77 + 0.05	4.3	65.6	30
30	25.52	0.59	7.10 + 0.03	4.7	69.1	26.3
31	26.31	0.68	--	--	--	--
32	27.06	0.7	--	--	--	--
33	27.74	0.73	--	--	--	--
34	28.38	0.74	--	--	--	--
35	29.08	0.72	--	--	--	--
36	29.78	0.72	--	--	--	--
37	30.64	0.66	--	--	--	--
38	31.89	0.5	--	--	--	--
39	33.15	0.5	--	--	--	--
40	34.37	0.51	--	--	--	--
41	36.01	0.34	--	--	--	--
42	37.61	0.36	--	--	--	--
43	38.52	0.64	--	--	--	--

*denotes an error of < 0.01

Table 3.19b Radiochemical data for station 11270

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	$^{210}Pb_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	0	1.36 + 0.12	12.65 + 1.35	6.70 + 1.45	0
2	--	1.29 + 0.12	19.07 + 1.91	13.13 + 1.99	--
3	--	2.21 + 0.24	17.14 + 1.60	11.20 + 1.69	--
4	--	4.22 + 0.48	25.24 + 1.70	19.30 + 1.78	--
5	0	1.54 + 0.13	15.43 + 1.60	9.49 + 1.69	0.013 + 0.002
6	--	2.39 + 0.29	18.40 + 1.89	12.45 + 1.97	--
7	--	2.33 + 0.23	18.02 + 1.76	12.07 + 1.84	--
8	--	1.59 + 0.59	14.05 + 1.48	8.11 + 1.58	--
9	--	2.25 + 0.22	10.87 + 1.26	4.92 + 1.37	--
10	0	2.77 + 0.32	14.63 + 1.46	8.69 + 1.56	0.039 + 0.009
11	--	3.04 + 0.30	19.25 + 2.26	13.30 + 2.32	--
12	--	2.16 + 0.21	23.98 + 1.64	18.03 + 1.73	--
13	--	3.02 + 0.34	22.03 + 2.39	16.09 + 2.45	--
14	--	--	19.08 + 2.08	13.13 + 2.15	--
15	--	--	19.65 + 1.54	13.70 + 1.63	0.014 + 0.002
16	--	--	26.04 + 2.49	20.09 + 2.55	--
17	--	--	25.22 + 1.71	19.27 + 1.79	--
18	--	--	19.70 + 1.31	13.76 + 1.42	--
19	--	--	17.74 + 2.07	11.80 + 2.14	--
20	--	--	24.00 + 1.81	18.06 + 1.89	--
21	--	--	22.21 + 2.32	16.27 + 2.38	--
22	--	--	19.57 + 1.94	13.63 + 2.01	--
23	--	--	19.90 + 1.67	13.95 + 1.76	--
24	--	--	21.62 + 2.48	15.68 + 2.54	--
25	--	--	18.25 + 1.41	12.31 + 1.51	--
26	--	--	19.09 + 2.04	13.14 + 2.11	--
27	--	--	16.42 + 1.56	10.47 + 1.66	--
28	--	--	21.68 + 2.15	15.73 + 2.22	--
29	--	--	22.50 + 2.31	16.56 + 2.37	--
30	--	--	15.79 + 1.49	9.84 + 1.59	--
31	--	--	22.20 + 2.29	16.25 + 2.35	--
32	--	--	13.09 + 1.28	7.15 + 1.39	--
33	--	--	33.57 + 3.15	23.27 + 2.89	--
34	--	--	10.35 + 1.11	4.40 + 1.24	--
35	--	--	31.72 + 2.75	25.77 + 2.80	--
36	--	--	13.32 + 1.05	7.38 + 1.18	--
37	--	--	16.28 + 1.08	10.33 + 1.21	--
38	--	--	6.24 + 0.54	0.29 + 0.77	--
39	--	--	6.53 + 0.60	0.58 + 0.81	--
40	--	--	4.68 + 0.38	0	--
41	--	--	5.62 + 0.52	0	--
42	--	--	5.71 + 0.51	0	--
43	--	--	6.90 + 0.69	0.95 + 0.88	--

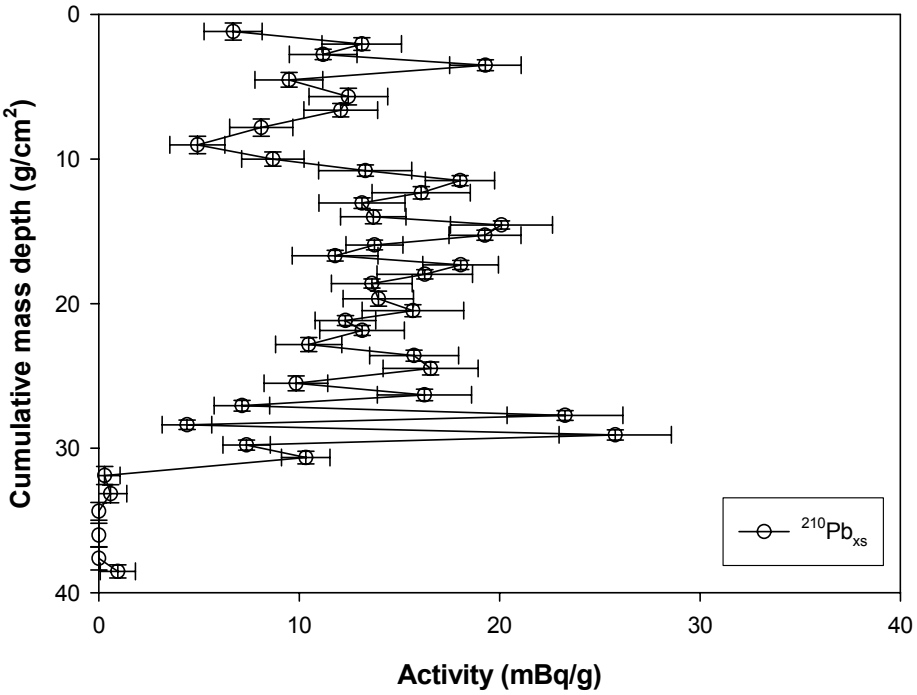


Figure 3.49 $^{210}Pb_{xs}$ data for station 11270

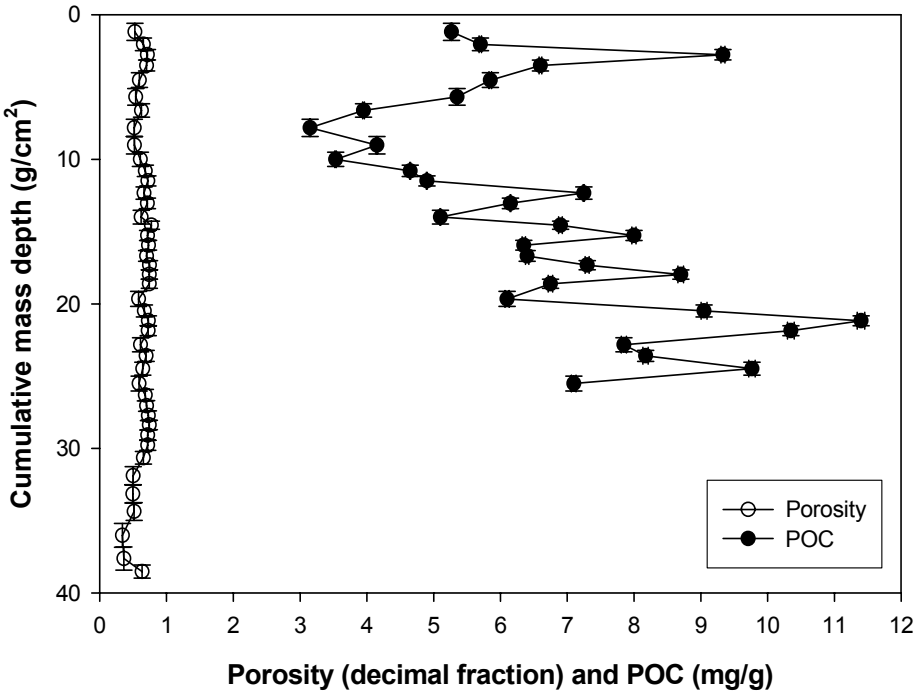


Figure 3.50 Porosity and POC data for station 11270

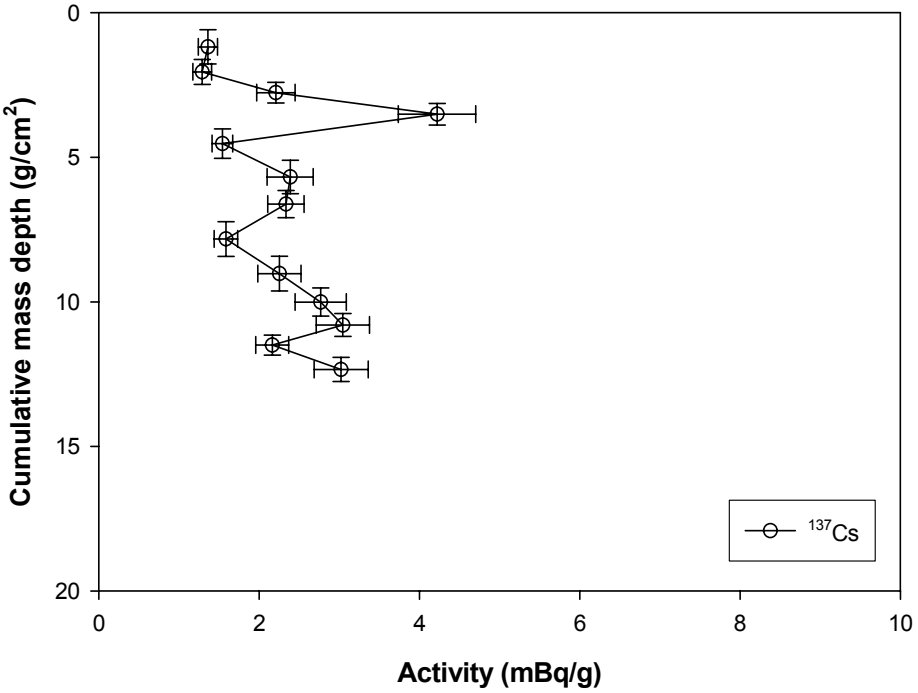


Figure 3.51 ^{137}Cs data for station 11270

quantified herein is impossible for this station, as is a chronological determination. However, the ^{137}Cs data (Figure 3.51) indicate that the interval over which appreciable ^{137}Cs is found at least 13 g cm^{-2}, deposited in less than 50 years, suggesting at least 0.65 g cm^{-2} yr^{-1} of equivalent continuous sediment accumulation. It must be emphasized that lateral transport events are typical in this system, as evidenced by the number of sites visited and cores collected that showed evidence of either mixing or strong depositional and/or erosional events.

Station FW1

A wetland core was selected and identified as an essential component of the research, in that such a core, if collected from a stable area nearby but not in the HSC system could provide background (atmospheric input) data for dioxins. The data from the core, combined with chronological information from radionuclide studies would significantly contribute to the overall project objectives (in particular the "legacy" issue). Summary physical and radiochemical data for station FW1 are presented in Tables 3.20a and b. X-radiograph and the core grain size distribution are shown in Figure C-6 of Appendix C and listed in Table 3.20a. The grain size distribution for the core is shown in Figure 3.52 and summarized in Table 3.20a. The mean ^{210}Pb value over the depth interval of 20 – 41 cm was used as the supported value (9.50 $\pm$ 0.92 mBq g^{-1}). This station shows nearly ideal profiles for ^{7}Be and $^{210}Pb_{xs}$ (Figure 3.53), indicating that mixing over the short term is constrained to the very upper section of the sediment profile (< 2 cm) at most. This interpretation is supported by porosity and POC data (Figure 3.54) that indicate little mixing at depth and a stable sedimentary setting. Of note is the high concentration of POC in the near surface, an expected scenario in a forested wetland.

Sediment accumulation rates using $^{210}Pb_{xs}$ have been determined using the CF-CS model,

Table 3.20a Physical data for station FW1

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	0.73	0.71	67.58 + 0.24	39	36.9	24.1
2	1.39	0.74	43.55 + 0.16	42.7	36.7	20.7
3	2.31	0.63	24.25 + 0.09	44.5	35.7	19.8
4	3.77	0.42	21.90 + 0.08	48.2	39.7	12.1
5	5.87	0.16	8.75 + 0.03	47.7	37.8	14.5
6	7.34	0.41	5.00 + 0.02	44.5	35.5	20
7	8.71	0.45	8.70 + 0.03	36	33.3	30.8
8	10.02	0.47	4.50 + 0.02	42.9	36.9	20.2
9	11.86	0.27	4.40 + 0.02	50.4	35.4	14.2
10	13.44	0.37	5.00 + 0.02	50.2	38.5	11.3
11	14.92	0.41	5.38 + 0.02	52	38.1	9.9
12	16.03	0.56	4.40 + 0.02	52.1	38.1	9.8
13	17.37	0.47	4.33 + 0.02	51.6	39.2	9.2
14	18.85	0.41	3.67 + 0.02	52.7	37.5	9.8
15	20.79	0.22	4.25 + 0.02	54.4	36.8	8.8
16	22.33	0.38	3.50 + 0.02	53.5	37.5	8.9
17	23.89	0.38	3.85 + 0.02	52.4	38.5	9.1
18	25.43	0.38	3.50 + 0.02	53.3	36.9	9.8
19	26.69	0.5	4.55 + 0.02	51.7	40.6	7.7
20	28.14	0.42	3.50 + 0.02	53.6	36.5	9.9
21	29.68	0.39	3.90 + 0.01	52.3	39	8.7
22	31.16	0.41	4.05 + 0.01	54.2	38.2	7.6
23	32.62	0.42	3.65 + 0.01	53.9	39.2	6.9
24	34.04	0.43	3.47 + 0.01	54.2	37.7	8
25	35.29	0.5	3.30 + 0.01	52.2	39.2	8.6
26	37.05	0.3	4.00 + 0.01	53.7	37.8	8.5
27	38.4	0.46	3.55 + 0.01	52.9	38.5	8.6
28	39.77	0.45	3.40 + 0.01	51.8	38.8	9.4
29	41.48	0.32	3.55 + 0.01	54.1	38.7	7.2
30	43.3	0.28	3.05 + 0.01	58.6	31.9	9.5
31	45.18	0.25	--	--	--	--
32	46.66	0.41	--	--	--	--
33	48.38	0.31	--	--	--	--
34	50.27	0.24	--	--	--	--
35	51.84	0.37	--	--	--	--
36	53.54	0.32	--	--	--	--
37	55.11	0.37	--	--	--	--
38	57.04	0.23	--	--	--	--
39	58.62	0.37	--	--	--	--
40	60.39	0.29	--	--	--	--
41	62.07	0.33	--	--	--	--

*denotes an error of < 0.01

Table 3.20b Radiochemical data for station FW1

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	^{210}Pb$_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	19.52 + 1.60	14.98 + 1.50	82.94 + 5.18	73.44 + 1.16	0.394 + 0.054
2	6.68 + 0.61	17.07 + 1.59	70.46 + 5.04	60.96 + 1.18	0.427 + 0.053
3	0	17.46 + 1.90	58.95 + 5.68	49.45 + 1.12	0.364 + 0.044
4	0	25.99 + 1.77	50.65 + 4.00	41.15 + 1.01	0.302 + 0.032
5	0	18.38 + 1.52	38.43 + 2.92	28.93 + 0.93	0.318 + 0.046
6	0	28.92 + 3.04	20.45 + 1.82	10.95 + 1.01	0.227 + 0.030
7	0	6.67 + 0.60	17.61 + 1.43	8.11 + 1.02	--
8	0	4.85 + 0.35	18.21 + 1.62	8.71 + 1.03	--
9	0	4.60 + 0.43	14.45 + 1.25	4.94 + 0.96	--
10	0	2.61 + 0.22	11.53 + 0.91	2.03 + 0.99	--
11	--	2.01 + 0.20	13.93 + 1.45	4.43 + 1.00	--
12	--	2.02 + 0.23	12.80 + 1.42	3.30 + 1.07	--
13	--	1.79 + 0.18	11.79 + 1.08	2.29 + 1.03	--
14	--	0	12.28 + 1.00	2.78 + 1.01	--
15	--	--	12.60 + 1.24	3.10 + 0.95	--
16	--	--	11.29 + 0.95	1.79 + 1.00	--
17	--	--	9.92 + 1.00	0.42 + 0.99	--
18	--	--	12.52 + 1.28	3.02 + 1.00	--
19	--	--	11.65 + 1.07	2.15 + 1.04	--
20	--	--	10.99 + 1.06	1.49 + 1.01	--
21	--	--	11.90 + 1.14	2.40 + 1.00	--
22	--	--	13.92 + 1.44	4.42 + 1.01	--
23	--	--	11.06 + 1.22	1.56 + 1.01	--
24	--	--	11.66 + 1.21	2.16 + 1.01	--
25	--	--	10.21 + 0.84	0.71 + 1.05	--
26	--	--	11.69 + 1.11	2.19 + 0.97	--
27	--	--	11.94 + 1.11	2.44 + 1.03	--
28	--	--	11.81 + 1.10	2.31 + 1.02	--
29	--	--	12.04 + 1.05	2.54 + 0.97	--
30	--	--	11.08 + 1.12	1.58 + 0.96	--
31	--	--	8.11 + 0.73	--	--
32	--	--	8.20 + 0.74	--	--
33	--	--	7.19 + 0.82	--	--
34	--	--	6.02 + 0.57	--	--
35	--	--	6.08 + 0.55	--	--
36	--	--	7.06 + 0.74	--	--
37	--	--	8.60 + 0.86	--	--
38	--	--	9.72 + 0.89	--	--
39	--	--	5.23 + 0.49	--	--
40	--	--	4.89 + 0.44	--	--
41	--	--	9.60 + 0.97	--	--

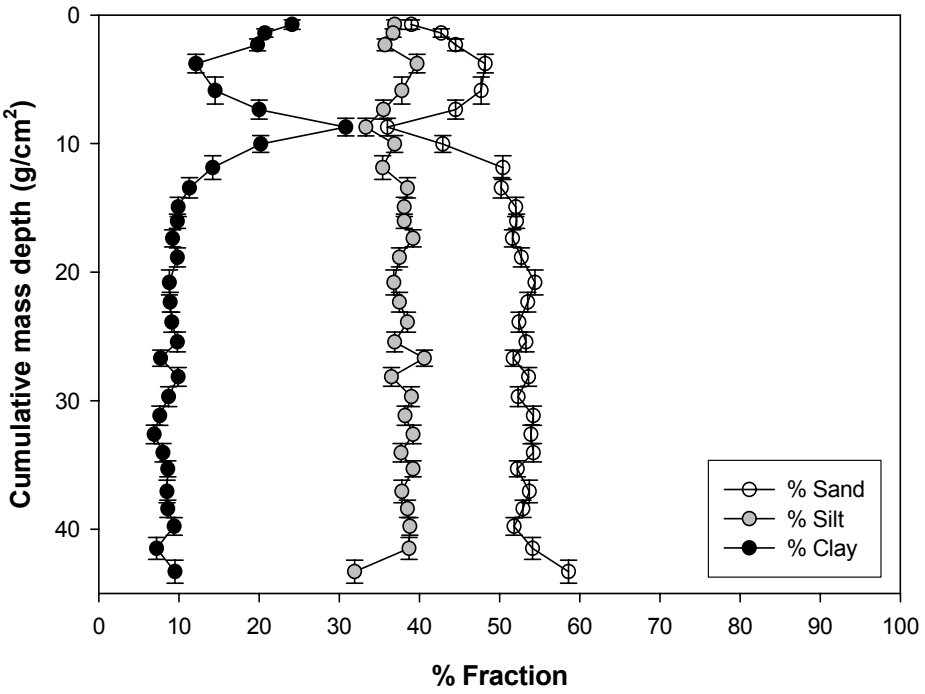


Figure 3.52 Grain size distribution for core sediment at station FW1

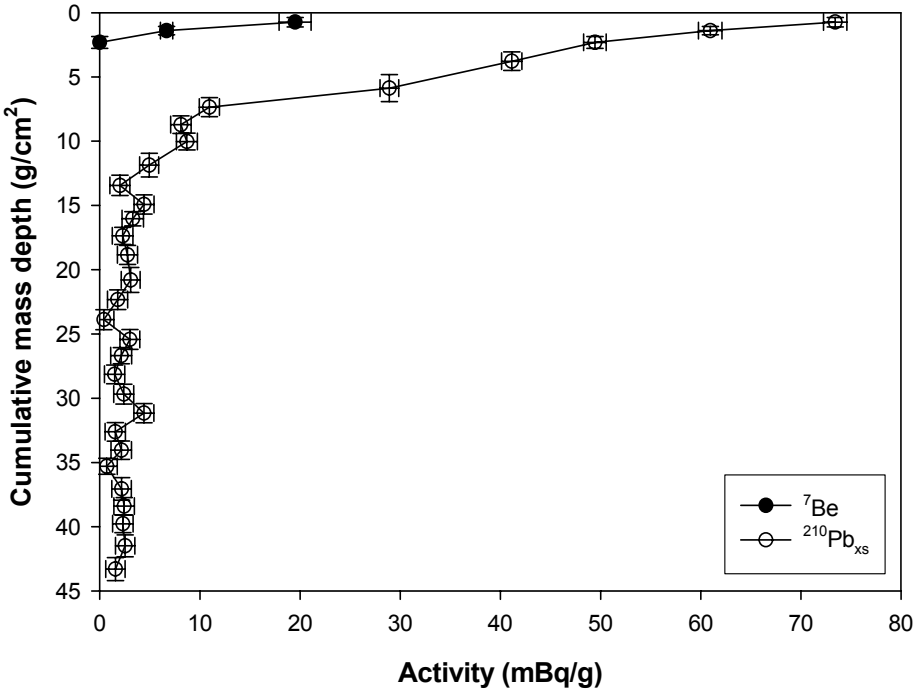


Figure 3.53 $^{210}Pb_{xs}$ and ^{7}Be data for station FW1

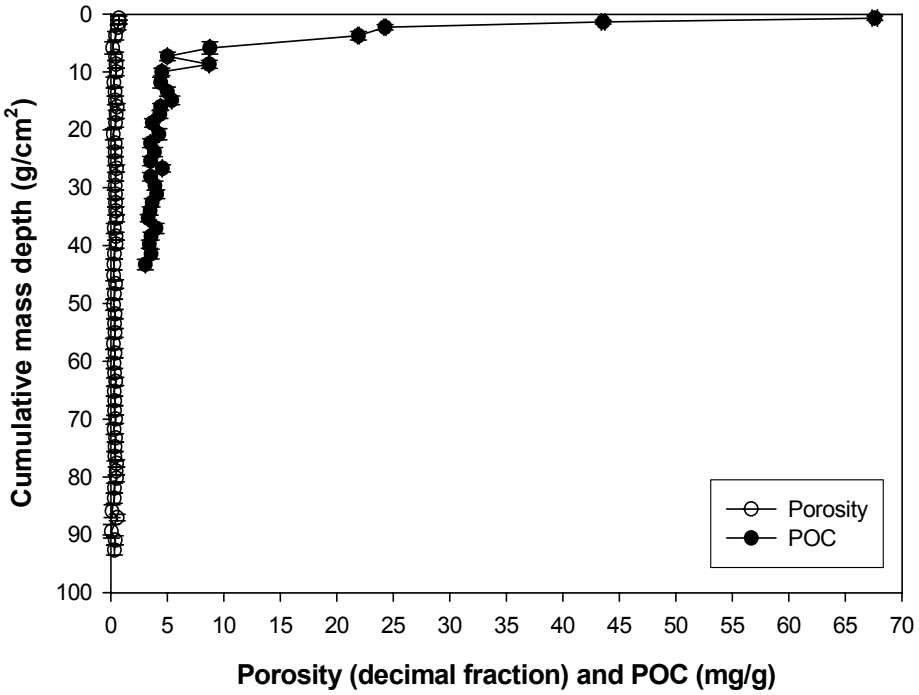


Figure 3.54 Porosity and POC data for station FW1

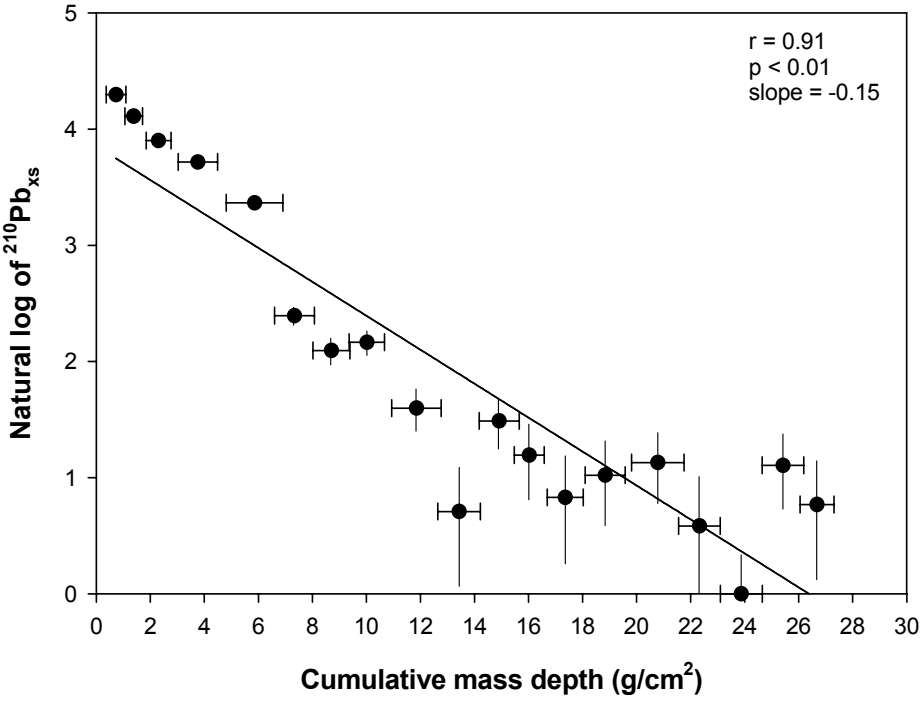


Figure 3.55 $^{210}Pb_{xs}$ modeling data for station FW1

as previously described. Figure 3.55 shows the semi-log plot of $^{210}Pb_{xs}$ over depth, from which a sediment accumulation rate was derived. Only the upper portion of the profile was modeled (0 – 19 cm), as it is representative of the exponential decay of $^{210}Pb_{xs}$ here. Sediment accumulation at this station based on $^{210}Pb_{xs}$ is 0.21 $\pm$ 0.12 g cm^{-2} yr.$^{-1}$ (or 0.14 $\pm$ 0.08 cm yr.$^{-1}$). Sediment accumulation rates have been determined using ^{137}Cs as previously discussed. The sediment accumulation rate at this station based on ^{137}Cs is 0.18 $\pm$ 0.04 g cm^{-2} yr.$^{-1}$ (or 0.13 $\pm$ 0.03 cm yr^{-1}), very close to that determined using $^{210}Pb_{xs}$ (Figure 3.56). Of note here is the double peak in the ^{137}Cs profile. In addition to the expected peak corresponding to maximum global fallout of ^{137}Cs in 1963, a second, smaller but distinct peak is present and corresponds to the Chernobyl accident which occurred in the former Soviet Union in 1986, further testament to the very stable setting at this core. Using this peak as an additional chronologic marker yields a sediment accumulation rate of 0.21 + 0.08 g cm^{-2} yr.$^{-1}$ (or 0.19 $\pm$ 0.05 cm yr^{-1}).

The chronology of the sediment profile is represented in Figure 3.57 and was determined using $^{210}Pb_{xs}$ data and the constant flux (CF) model, as previously discussed.

Station 16499

Summary physical and radiochemical data for station 16499 are presented in Tables 3.21a and b. X-radiograph and the core grain size distribution are shown in Figure C-7 and listed in Table C-3 of Appendix C. The grain size distribution for this core is shown in Figure 3.58 and summarized in Table 3.21a. The mean ^{210}Pb value over the depth interval of 39 – 41 cm was used as the supported value (8.64 $\pm$ 0.91 mBq g^{-1}). Profiles of ^{7}Be and $^{210}Pb_{xs}$ (Figure 3.59) suggest a very recent, stable sedimentary setting, overlying what appears to be a previously mixed or rapidly deposited profile, as evidenced by the homogenized $^{210}Pb_{xs}$ data after approximately 4 cm

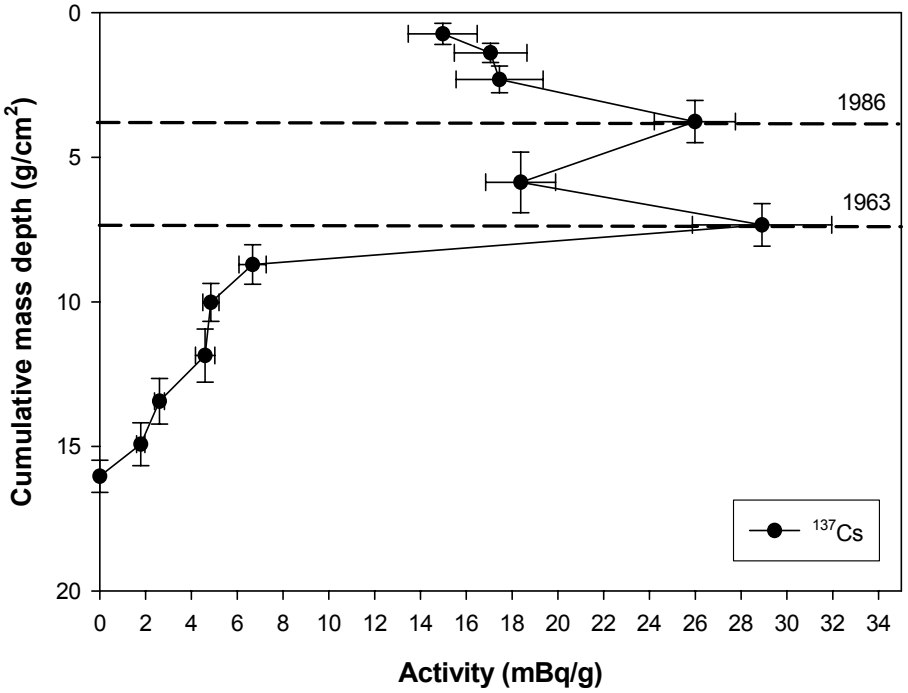


Figure 3.56 ^{137}Cs data for station FW1

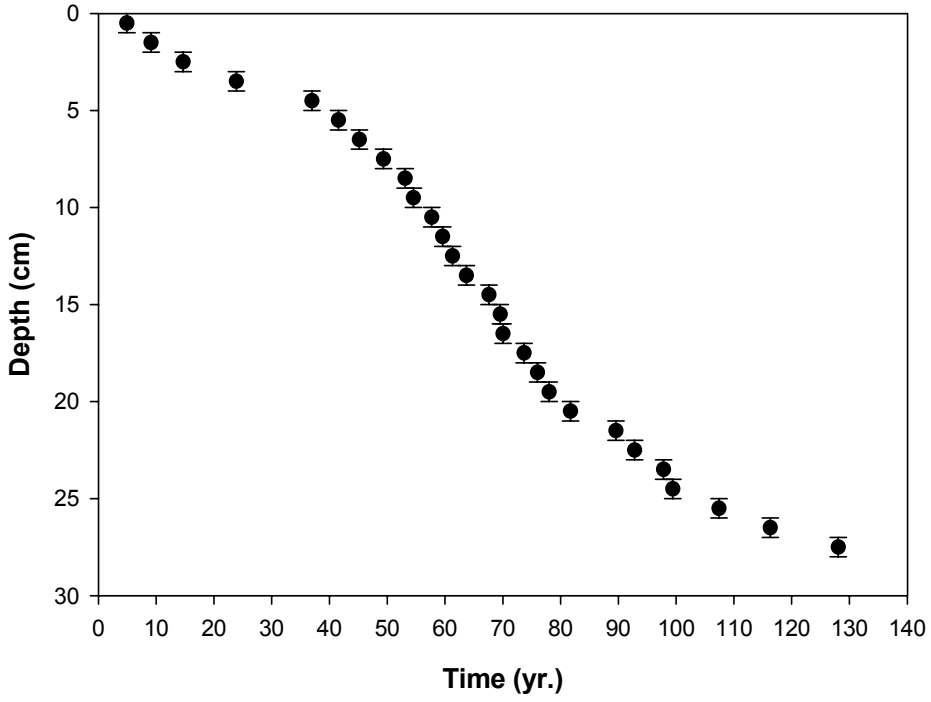


Figure 3.57 $^{210}Pb_{xs}$ based chronologic profile for station FW1

Table 3.21a Physical data for station 16499

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	0.46	0.82	11.75 + 0.06	19.7	42.5	37.8
2	1	0.78	10.03 + 0.05	19.5	59.6	20.9
3	1.62	0.75	8.13 + 0.04	32.5	20.5	47
4	2.16	0.78	5.85 + 0.03	43.1	33.9	23
5	2.83	0.73	7.25 + 0.04	44.9	32.8	22.2
6	3.66	0.67	5.65 + 0.03	43.4	33.3	23.3
7	4.37	0.72	7.27 + 0.04	45.5	30.4	24.1
8	5.26	0.65	6.58 + 0.04	42.3	32.5	25.2
9	5.91	0.74	10.07 + 0.05	35.2	35.4	29.4
10	6.37	0.82	8.40 + 0.05	28.1	17.3	54.6
11	6.89	0.79	11.34 + 0.08	21.6	44.3	34.1
12	7.5	0.76	12.05 + 0.09	15.9	46.9	37.2
13	8.12	0.75	10.72 + 0.08	23.5	34.9	41.5
14	8.69	0.78	7.20 + 0.05	27.8	34.4	37.7
15	9.1	0.83	7.78 + 0.06	16.6	16.3	67.1
16	9.76	0.73	7.60 + 0.06	29.8	35.6	34.6
17	10.31	0.78	2.95 + 0.02	38.1	31.3	30.7
18	10.8	0.81	5.60 + 0.04	31.4	33.9	34.7
19	11.28	0.81	9.45 + 0.07	11.5	39.4	49.1
20	11.68	0.84	12.17 + 0.09	7.3	41.8	50.8
21	12.08	0.84	12.45 + 0.07	10.3	41.5	48.2
22	12.45	0.85	11.05 + 0.06	8.6	40.5	50.9
23	13.02	0.77	4.70 + 0.03	10.6	25.5	63.8
24	13.65	0.75	13.95 + 0.08	13.9	49.9	36.2
25	14.15	0.8	12.30 + 0.07	15.2	43.7	41.1
26	14.64	0.8	11.30 + 0.06	12.6	41.4	46
27	15.06	0.84	14.65 + 0.08	12.1	38.3	49.6
28	15.48	0.83	14.00 + 0.08	9.2	39.5	51.3
29	15.88	0.84	14.50 + 0.08	10.6	37.8	51.6
30	16.31	0.82	16.88 + 0.09	13.9	38.2	47.8
31	16.75	0.83	--	--	--	--
32	17.18	0.83	--	--	--	--
33	17.73	0.78	--	--	--	--
34	18.21	0.81	--	--	--	--
35	18.78	0.77	--	--	--	--
36	19.22	0.82	--	--	--	--
37	19.61	0.85	--	--	--	--
38	20.18	0.77	--	--	--	--
39	20.82	0.74	--	--	--	--
40	21.36	0.78	--	--	--	--
41	22.11	0.7	--	--	--	--

*denotes an error of < 0.01

Table 3.21b Radiochemical data for station 16499

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	^{210}Pb$_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	21.48 + 1.36	2.22 + 0.22	48.61 + 4.77	39.97 + 4.86	--
2	8.16 + 0.58	1.76 + 0.16	47.67 + 4.29	39.03 + 4.39	--
3	0	0.92 + 0.08	23.08 + 2.49	14.44 + 2.65	--
4	0	0.96 + 0.11	24.69 + 1.87	16.05 + 2.08	--
5	0	1.67 + 0.18	21.69 + 1.92	13.05 + 2.12	--
6	0	1.73 + 0.17	21.32 + 1.55	12.68 + 1.80	--
7	0	1.45 + 0.17	23.20 + 1.64	14.56 + 1.88	--
8	--	--	23.29 + 2.11	14.65 + 2.30	--
9	--	--	19.72 + 1.72	11.08 + 1.95	--
10	--	--	25.79 + 1.80	17.15 + 2.02	--
11	--	2.24 + 0.26	20.48 + 1.47	11.85 + 1.73	--
12	--	--	26.96 + 2.36	18.32 + 2.53	--
13	--	--	25.43 + 2.42	16.79 + 2.59	--
14	--	--	24.25 + 2.28	15.61 + 2.45	--
15	--	--	28.85 + 2.56	20.22 + 2.72	--
16	--	--	22.47 + 2.40	13.83 + 2.57	--
17	--	--	19.88 + 1.54	11.24 + 1.79	--
18	--	--	22.41 + 1.99	13.77 + 2.19	--
19	--	--	26.50 + 1.87	17.86 + 2.08	--
20	--	4.73 + 0.54	38.57 + 3.21	29.93 + 3.34	--
21	--	--	27.54 + 2.50	18.91 + 2.66	--
22	--	--	28.93 + 2.26	20.29 + 2.44	--
23	--	--	16.97 + 1.45	8.33 + 1.71	--
24	--	--	21.43 + 2.29	12.79 + 2.47	--
25	--	--	32.44 + 3.21	23.81 + 3.34	--
26	--	--	24.35 + 2.35	15.71 + 2.52	--
27	--	--	30.53 + 3.08	21.89 + 3.21	--
28	--	--	22.34 + 2.17	13.70 + 2.36	--
29	--	3.59 + 0.39	23.17 + 2.03	14.54 + 2.23	--
30	--	--	30.07 + 2.33	21.43 + 2.50	--
31	--	--	28.44 + 2.14	19.80 + 2.33	--
32	--	--	27.90 + 1.93	19.27 + 2.14	--
33	--	--	25.67 + 1.82	17.04 + 2.04	--
34	--	--	21.12 + 1.60	12.48 + 1.84	--
35	--	--	24.88 + 2.17	16.24 + 2.36	--
36	--	--	12.83 + 1.06	4.20 + 1.40	--
37	--	--	25.12 + 2.07	16.48 + 2.27	--
38	--	--	22.48 + 2.15	13.84 + 2.33	--
39	--	--	4.60 + 0.43	0	--
40	--	--	9.35 + 0.97	0.71 + 1.34	--
41	--	--	11.96 + 1.33	3.32 + 1.62	--

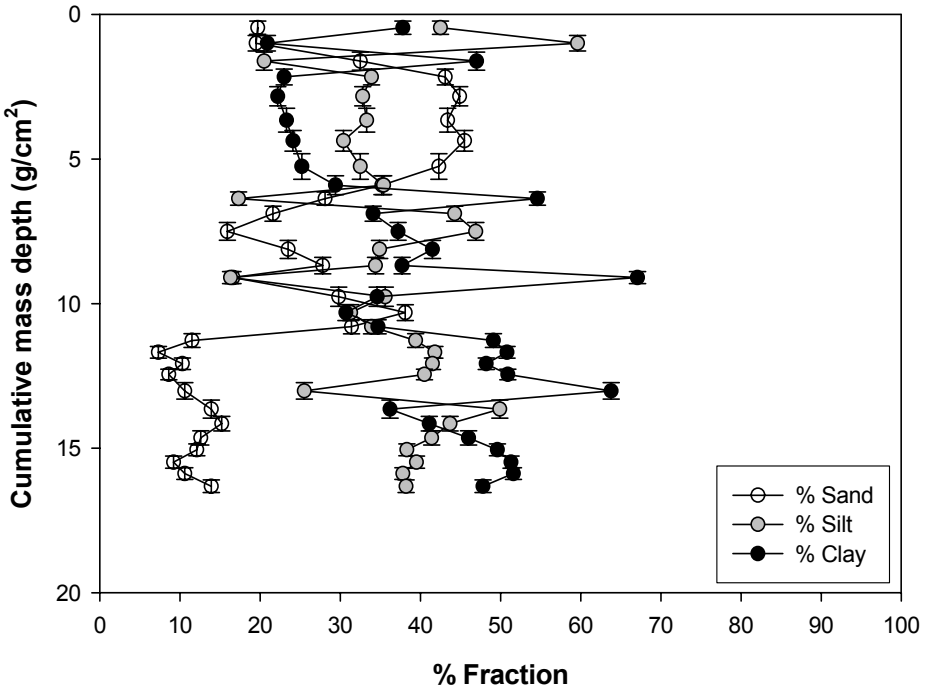


Figure 3.58 Grain size distribution for core sediment at station 16499

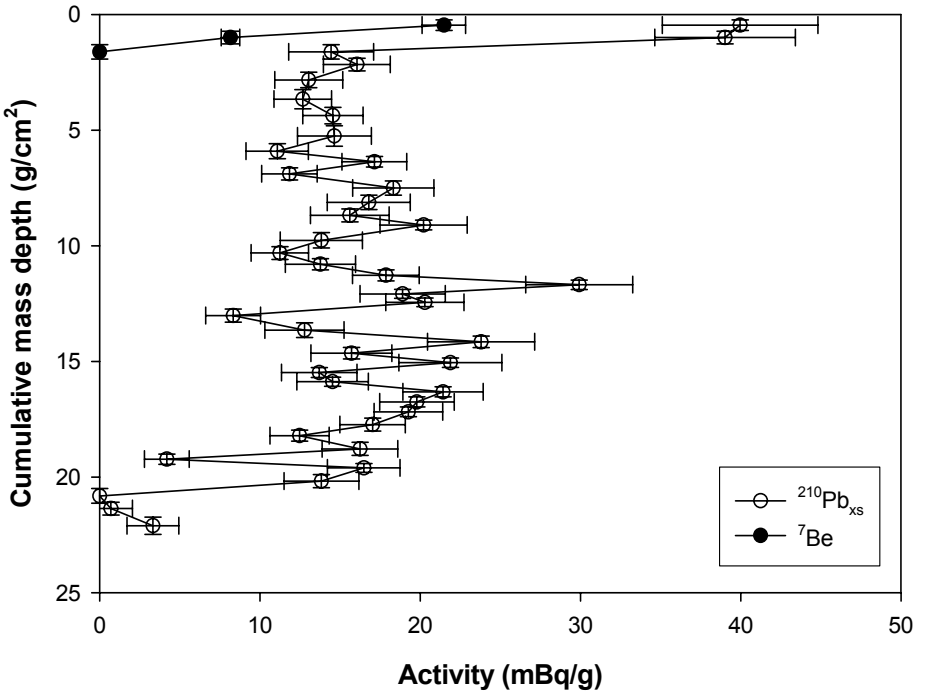


Figure 3.59 $^{210}Pb_{xs}$ and ^{7}Be data for station 16499

depth. This interpretation is supported by POC data (Figure 3.60) that indicate a stable sedimentary setting at the near surface only.

The use of $^{210}Pb_{xs}$ to determine sediment accumulation rates for this core is not appropriate due to the homogenized nature of the $^{210}Pb_{xs}$ profile and the persistence of appreciable ^{137}Cs with depth (29 cm, Table 3.21b). As such, an average rate can be obtained as was done for station 15979, using the lowest occurrence of ^{137}Cs as representative of 1953 (year which appreciable ^{137}Cs was detected at the earth's surface). An average rate of sediment accumulation of 0.31 $\pm$ 0.01 g cm^{-2} $yr.^{-1}$ (or 0.56 $\pm$ 0.02 cm yr^{-1}) has been determined using ^{137}Cs based on this premise.

The extrapolated chronology of the sediment profile is represented in Figure 3.61 and was determined based on the average sedimentation rate as determined using ^{137}Cs.

Station 13337

Summary physical and radiochemical data for station 13337 are presented in Tables 3.22a and b. X-radiograph and the core grain size distribution are shown in Figure C-8 and listed in Table C-4 of Appendix C. The grain size distribution for this core is shown in Figure 3.62 and summarized in Table 3.22a. The mean ^{210}Pb value over the depth interval of 38 – 44 cm was used as the supported value (29.67 $\pm$ 2.73 mBq g^{-1}). This station shows a nearly ideal profile for ^{7}Be, indicating very little mixing at the surface in the short term and a steadily declining $^{210}Pb_{xs}$ profile with depth (Figure 3.63). This interpretation is supported by porosity and POC data (Figure 3.64) that indicate little mixing at the near surface and in general, a gradual decline in concentrations of POC moving down section.

Sediment accumulation rates using $^{210}Pb_{xs}$ have been determined using the CF-CS model, described previously. Figure 3.65 shows the semi-log plot of $^{210}Pb_{xs}$ over depth, from which a

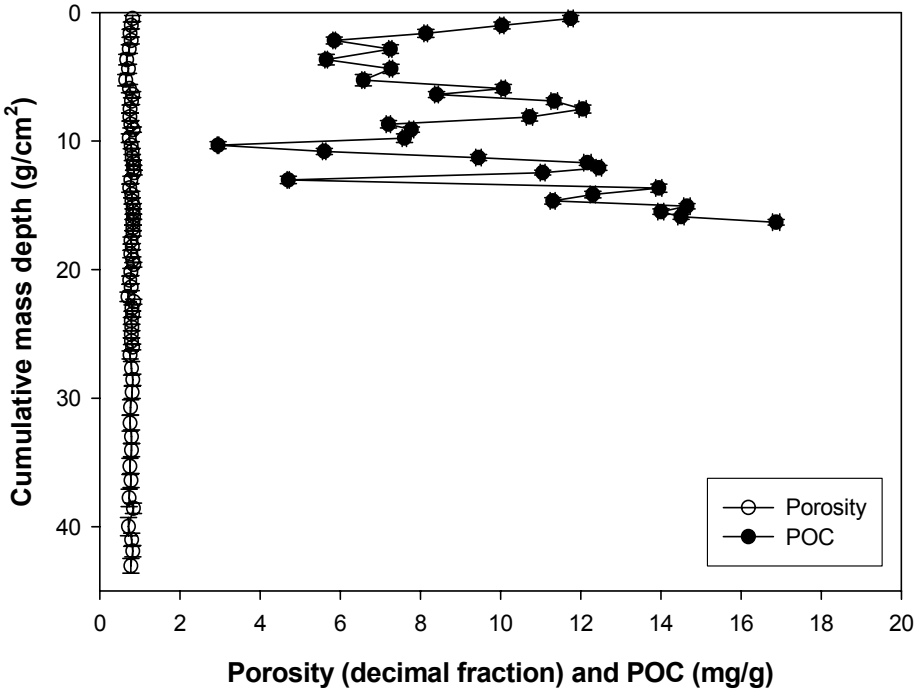


Figure 3.60 Porosity and POC data for station 16499

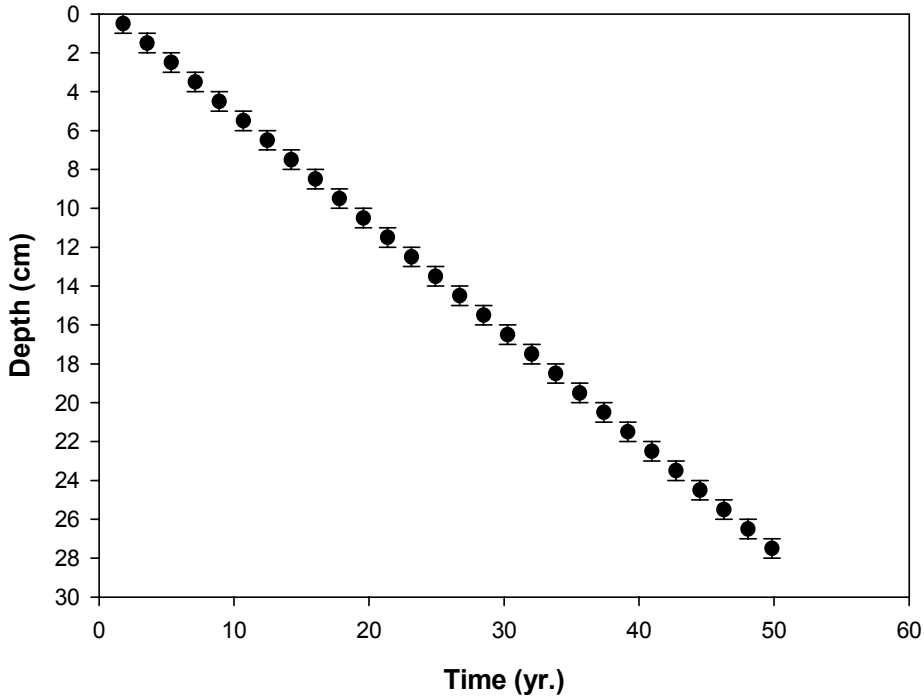


Figure 3.61 $^{210}Pb_{xs}$ based chronologic profile for station 16449

Table 3.22a Physical data for station 13337

Depth (cm)	Cumulative mass depth (g/cm2)	Porosity (decimal fraction)	POC (mg/g)	% Sand	% Silt	% Clay
1	0.78	0.69	11.30 + 0.06	0.6	35	64.4
2	1.1	0.88	11.15 + 0.06	1.2	34.8	64
3	1.46	0.85	9.95 + 0.05	3.1	36.5	60.4
4	1.94	0.81	9.50 + 0.05	3.6	37.1	59.3
5	2.33	0.84	9.75 + 0.05	2.7	39.4	57.9
6	2.75	0.83	9.40 + 0.05	3.4	40.3	56.3
7	3.27	0.79	8.45 + 0.05	4.9	39.3	55.8
8	3.69	0.83	8.75 + 0.05	3.6	41.6	54.8
9	4.17	0.81	8.55 + 0.05	3.2	41.1	55.7
10	4.67	0.8	9.60 + 0.05	3.5	41.8	54.7
11	5.2	0.79	9.85 + 0.06	3.9	39.9	56.2
12	5.68	0.81	9.75 + 0.06	3	37.9	59.1
13	6.17	0.8	8.75 + 0.05	3.6	38.1	58.3
14	6.54	0.85	9.15 + 0.06	2.1	37.4	60.5
15	7.03	0.81	9.45 + 0.05	1	33.1	65.9
16	7.48	0.82	9.65 + 0.06	1.8	37.1	61
17	7.88	0.84	9.55 + 0.05	0.4	36.1	63.4
18	8.33	0.82	9.40 + 0.05	2.7	31.6	65.7
19	8.76	0.83	9.75 + 0.06	0.5	39.1	60.4
20	9.39	0.75	8.05 + 0.05	1.1	46.1	52.8
21	9.95	0.77	8.75 + 0.05	1.7	38.8	59.5
22	10.41	0.82	9.15 + 0.05	3.9	39.8	56.4
23	10.87	0.82	10.15 + 0.06	1.5	32.7	65.8
24	11.39	0.79	9.15 + 0.05	2.8	36.9	60.3
25	11.82	0.83	8.55 + 0.05	3.6	34.1	62.3
26	12.25	0.83	8.80 + 0.05	2.6	31.7	65.7
27	12.77	0.79	8.90 + 0.05	4.4	35.2	60.4
28	13.32	0.78	8.65 + 0.05	6.3	36.7	57
29	13.79	0.82	9.65 + 0.06	6.9	35.8	57.4
30	14.3	0.8	8.75 + 0.05	6.2	38.4	55.3
31	14.85	0.78	--	--	--	--
32	15.25	0.84	--	--	--	--
33	15.69	0.82	--	--	--	--
34	16.1	0.84	--	--	--	--
35	16.58	0.81	--	--	--	--
36	17.11	0.79	--	--	--	--
37	17.59	0.81	--	--	--	--
38	18.02	0.83	--	--	--	--
39	18.54	0.79	--	--	--	--
40	19.1	0.77	--	--	--	--
41	19.52	0.83	--	--	--	--
42	19.94	0.84	--	--	--	--
43	20.33	0.84	--	--	--	--
44	20.84	0.8	--	--	--	--

*denotes an error of < 0.01

Table 3.22b Radiochemical data for station 13337

Depth (cm)	^{7}Be (mBq/g)	^{137}Cs (mBq/g)	Total ^{210}Pb (mBq/g)	^{210}Pb$_{xs}$ (mBq/g)	^{239,240}Pu (mBq/g)
1	60.87 + 2.73	4.50 + 0.38	53.24 + 4.23	23.57 + 5.03	--
2	44.94 + 2.88	4.25 + 0.44	54.01 + 4.28	24.34 + 5.08	--
3	14.33 + 0.72	3.71 + 0.37	48.99 + 3.98	19.32 + 4.82	--
4	0	2.97 + 0.31	52.90 + 3.65	23.23 + 4.56	--
5	0	3.39 + 0.37	50.28 + 3.50	20.61 + 4.43	--
6	0	4.13 + 0.39	49.21 + 5.17	19.54 + 5.84	--
7	--	3.47 + 0.31	47.55 + 3.15	17.88 + 4.17	--
8	--	3.53 + 0.38	43.67 + 3.23	14.00 + 4.23	--
9	--	--	38.87 + 3.78	9.20 + 4.66	--
10	--	3.41 + 0.33	43.71 + 3.30	14.04 + 4.28	--
11	--	--	44.47 + 3.74	14.80 + 4.63	--
12	--	--	43.22 + 4.14	13.54 + 4.96	--
13	--	--	41.73 + 3.14	12.05 + 4.16	--
14	--	--	47.88 + 4.38	18.21 + 5.16	--
15	--	5.55 + 0.61	52.87 + 4.61	23.20 + 5.35	--
16	--	--	48.21 + 4.04	18.53 + 4.88	--
17	--	--	37.48 + 2.93	7.81 + 4.00	--
18	--	--	47.75 + 4.51	18.08 + 5.27	--
19	--	--	39.06 + 2.91	9.39 + 3.99	--
20	--	5.06 + 0.59	33.55 + 2.83	3.88 + 3.93	--
21	--	--	43.14 + 3.99	13.47 + 4.84	--
22	--	--	38.51 + 3.33	8.84 + 4.30	--
23	--	--	42.50 + 3.80	12.83 + 4.68	--
24	--	--	47.31 + 4.59	17.63 + 5.34	--
25	--	3.33 + 0.40	35.81 + 2.69	6.14 + 3.83	--
26	--	--	36.51 + 3.50	6.84 + 4.44	--
27	--	--	42.01 + 3.52	12.34 + 4.45	--
28	--	--	33.54 + 2.82	3.87 + 3.92	--
29	--	--	35.38 + 2.92	5.71 + 3.99	--
30	--	6.08 + 0.60	37.30 + 3.00	7.63 + 4.05	--
31	--	--	32.37 + 2.82	2.70 + 3.92	--
32	--	--	32.70 + 2.85	3.03 + 3.94	--
33	--	--	36.46 + 3.40	6.78 + 4.36	--
34	--	--	34.29 + 3.00	4.62 + 4.05	--
35	--	--	37.70 + 3.13	8.03 + 4.15	--
36	--	--	32.68 + 2.73	3.01 + 3.86	--
37	--	--	30.84 + 2.65	1.17 + 3.80	--
38	--	--	27.16 + 2.43	--	--
39	--	--	29.03 + 3.03	--	--
40	--	5.59 + 0.67	29.07 + 3.20	--	--
41	--	--	27.33 + 2.30	--	--
42	--	--	33.24 + 2.85	--	--
43	--	--	31.46 + 3.10	--	--
44	--	--	30.41 + 2.18	--	--

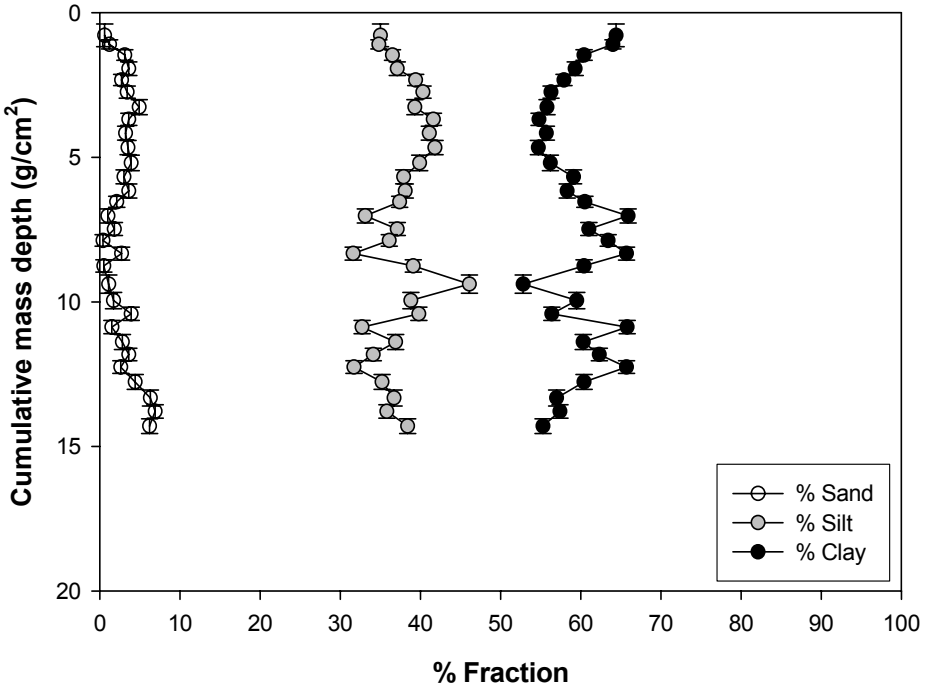


Figure 3.62 Grain size distribution for core sediment at station 13337

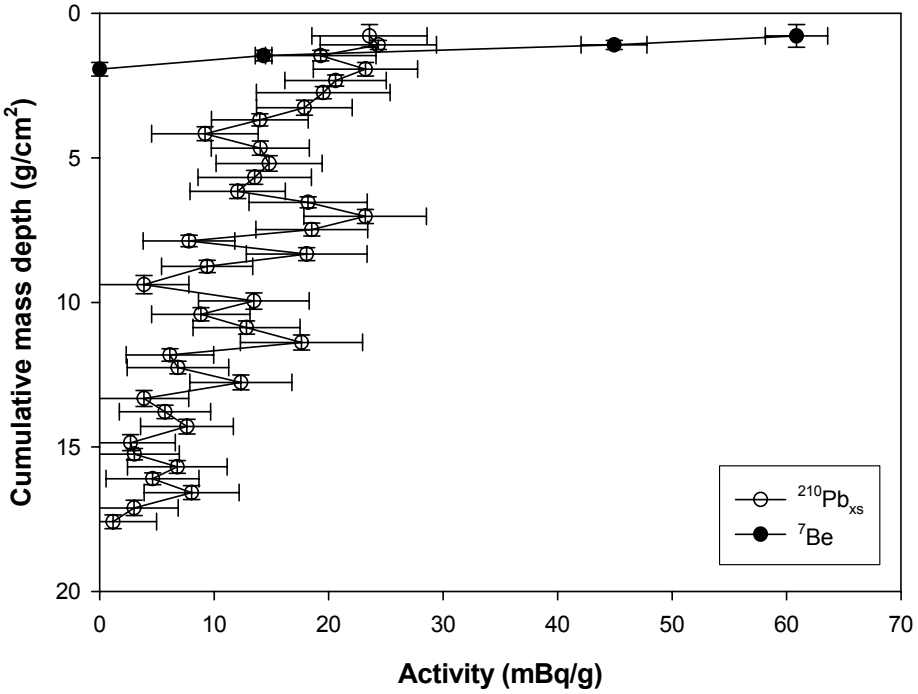


Figure 3.63 $^{210}Pb_{xs}$ and ^{7}Be data for station 13337

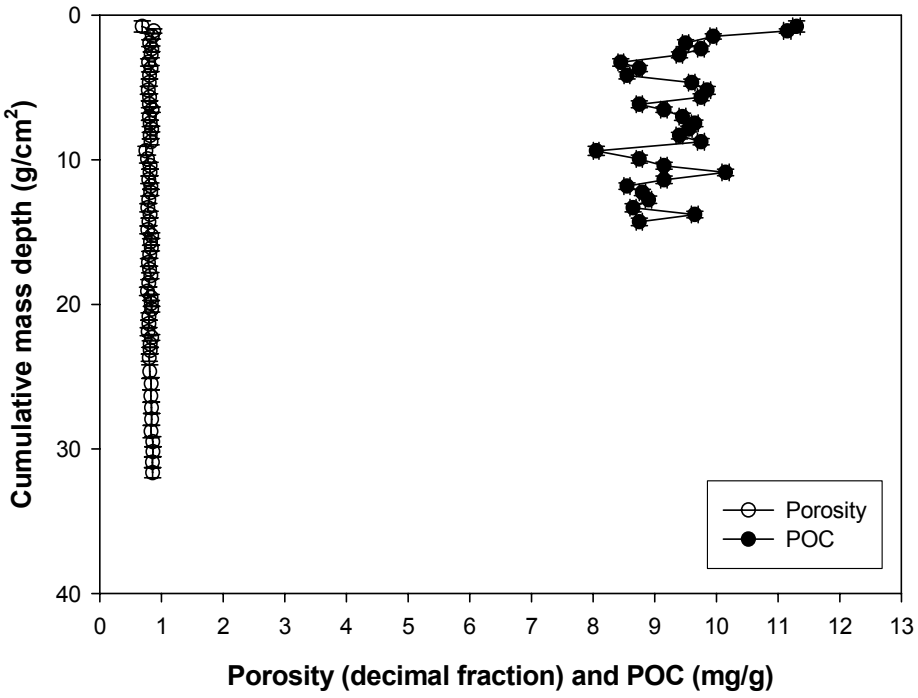


Figure 3.64 Porosity and POC data for station 13337

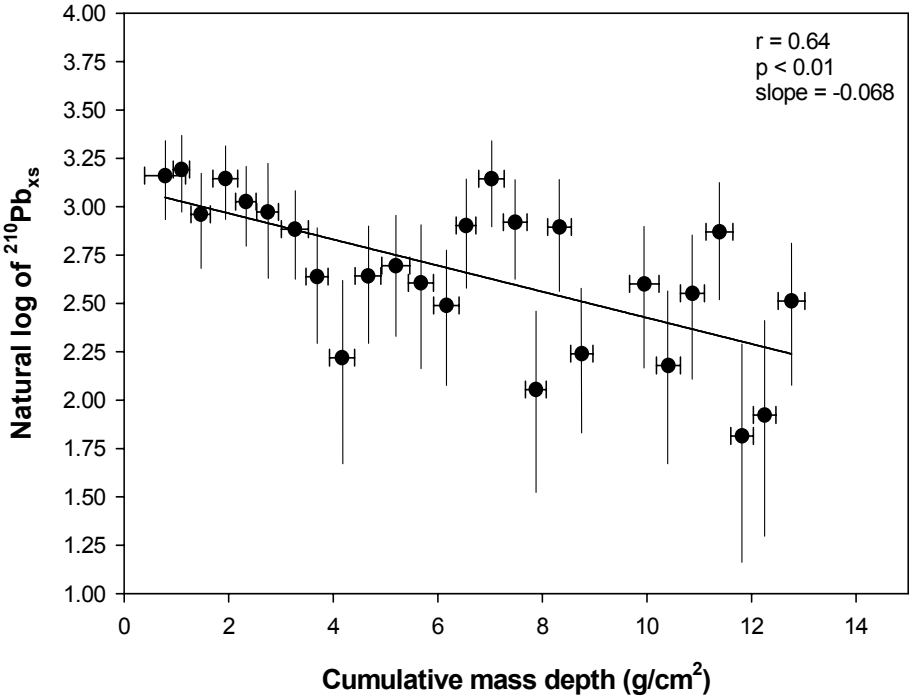


Figure 3.65 $^{210}Pb_{xs}$ modeling data for station 13337

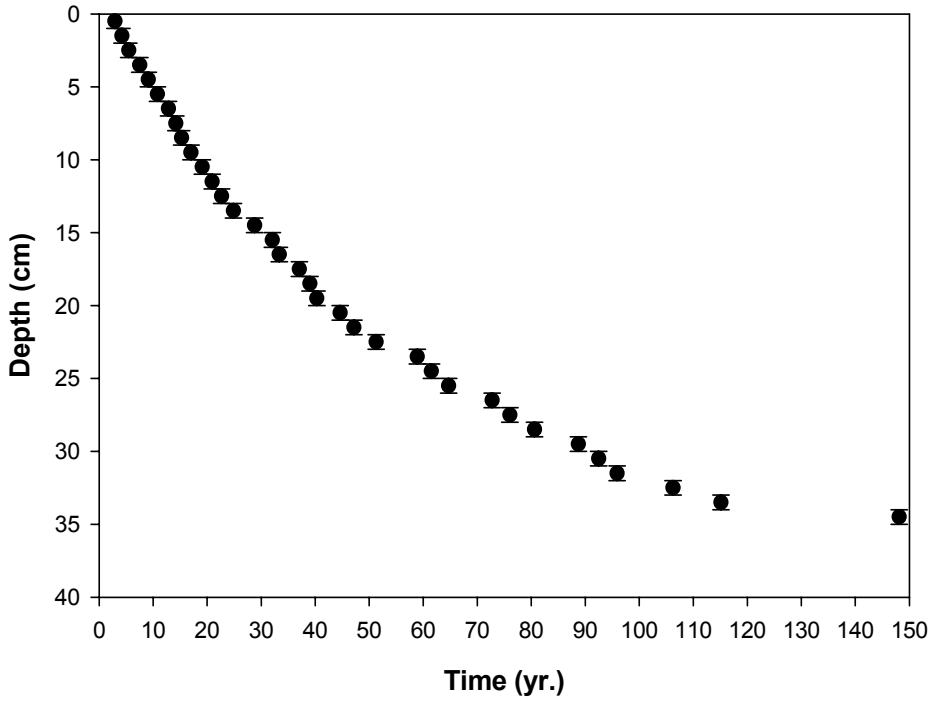


Figure 3.66 $^{210}Pb_{xs}$ based chronologic profile for station 13337

sediment accumulation rate was derived. Sediment accumulation at this station based on $^{210}Pb_{xs}$ is 0.46 $\pm$ 0.14 g cm^{-2} $yr.^{-1}$ (or 0.97 $\pm$ 0.30 cm $yr.^{-1}$). While additional data will refine the ^{137}Cs approach, taking the deepest significant ^{137}Cs point (40 cm, Table 3.22b) as 1953 yields an average sediment accumulation rate that is close to that determined via $^{210}Pb_{xs}$, i.e., 0.37 $\pm$ 0.01 g cm^{-2} $yr.^{-1}$ (or 0.77 $\pm$ 0.02 cm $yr.^{-1}$).

The chronology of the sediment profile is represented in Figure 3.66 and was determined using $^{210}Pb_{xs}$ data and the constant flux (CF) model, as previously discussed.

A summary of accumulation rates for the eight sediment cores is presented in Table 3.23. Data indicate that core 11261 presented the highest sedimentation rate, while the wetland location (FW1) exhibited the lowest sedimentation rate. Cores 15979 and 11270 exhibited high mixing, whereas the remaining cores presented mixing limited to the upper sections.

Table 3.23 Summary of Sediment Accumulation Rates

Core	Accumulation Rate (cm/yr)	Comments
11261	113.10 ± 87.08	Recent and rapid sedimentation
15244	0.31 ± 0.13	Stable, shallow mixing
11193	0.21 ± 0.11	Limited mixing
15979	0.18 ± 0.02	Episodic mixing
11270	Could not be calculated	High mixing
FW1	0.14 ± 0.08	Stable, shallow mixing
16499	0.56 ± 0.02	Stable, shallow mixing
13337	0.97 ± 0.30	Stable, shallow mixing

Dioxin Analyses. Dioxin results for eight sediment cores are included in Table 3.24. Overall, total TEQ concentrations varied from 0.27 to 238.9 ng/kg-dry wt. Average TEQ concentrations for cores 11261, 15244, 11193, 15979, 11270, FW1A, 13337, and 16499 were 6.32, 5.03, 12.77,

Table 3.24 Total Dioxin Concentrations in Sediment Cores (ng/kg-dry wt.)

Station ID	Date	Interval (cm)	POC (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Total TEQ in OC	Average TEQ[a]	Average TEQ in OC[a]
11261	06/16/2004	1	3.8	2.70	0.28	0.34	0.66	0.99	23.00	540.00	7.10	< 0.45	0.48	0.79	< 0.35	0.36	< 0.36	4.60	0.76	76.00	4.15	109.23	4.15	109.23
		3	4.4	3.70	< 0.41	0.47	0.94	0.86	28.00	710.00	9.70	< 0.47	0.75	0.93	0.80	0.58	< 0.38	7.40	< 0.38	170.00	5.64	128.10	5.64	128.10
		6	2.2	3.90	< 0.36	0.55	< 1.20	1.20	35.00	720.00	11.00	0.72	1.00	1.30	1.00	< 0.74	< 0.49	8.70	< 0.95	150.00	6.15	286.16	6.15	286.16
		7	3.6	7.00	0.54	0.79	2.00	1.50	54.00	1100.00	20.00	1.40	1.70	2.50	1.70	< 0.95	0.72	17.00	1.70	270.00	11.16	309.96	11.16	309.96
		8	6.2	10.00	0.95	0.85	2.80	1.80	71.00	1400.00	28.00	1.30	2.40	3.30	2.10	< 1.30	1.10	19.00	2.40	310.00	15.80	256.22	15.80	256.22
		11	2.5	< 2.70	0.37	< 0.43	1.00	0.65	20.00	390.00	7.60	0.72	0.75	< 1.00	0.60	0.53	0.44	5.00	< 0.59	78.00	3.10	122.35	3.10	122.35
		13	3.5	4.10	< 0.23	< 0.52	1.00	0.92	29.00	600.00	13.00	0.79	0.77	0.98	0.85	< 0.54	< 0.30	6.30	1.00	94.00	6.33	180.71	6.33	180.71
		17	3.4	2.80	< 0.36	< 0.43	0.78	0.91	23.00	450.00	7.20	< 0.39	0.52	0.96	< 0.60	< 0.45	< 0.48	6.50	1.10	79.00	4.24	126.65	4.24	126.65
		20	3.1	2.70	< 0.32	< 0.50	0.79	< 0.65	21.00	420.00	6.30	0.43	0.41	0.82	0.75	< 0.33	< 0.35	5.40	0.61	79.00	3.96	127.87	3.96	127.87
		30	4.3	2.00	< 0.18	< 0.23	0.45	0.33	15.00	310.00	5.30	0.23	0.36	0.46	0.33	0.32	< 0.21	4.20	0.42	45.00	2.98	70.06	3.22	75.69
		30-dup	4.3	2.30	0.18	0.23	0.56	0.41	18.00	380.00	5.20	0.22	0.47	0.70	0.53	0.47	< 0.21	5.20	< 0.45	59.00	3.46	81.33		
		40	NA	3.90	0.30	0.41	0.93	0.72	27.00	580.00	8.70	0.52	0.66	0.92	1.00	0.57	0.31	7.50	< 0.81	88.00	5.76	NA	5.76	NA
15244	08/04/2004	1	7.1	3.30	1.70	< 1.80	3.60	5.30	130.00	3200.00	8.00	< 0.93	1.10	< 1.50	< 1.10	< 1.30	< 1.20	10.00	< 1.50	59.00	6.76	94.74	6.76	94.74
		2/3	6.4	4.60	1.50	< 2.30	4.60	6.20	170.00	3700.00	12.00	1.20	1.50	2.70	1.80	1.60	0.91	16.00	< 1.50	66.00	9.26	145.76	9.26	145.76
		4	3.9	4.50	< 1.50	< 1.50	4.30	7.10	170.00	3700.00	12.00	2.00	< 2.50	< 3.50	< 1.80	2.10	< 1.10	21.00	3.20	74.00	8.55	221.95	8.55	221.95
		5	4.8	2.30	1.20	1.40	2.40	3.50	89.00	2000.00	6.00	< 0.51	0.72	< 1.50	0.70	0.82	< 0.31	9.00	< 0.40	42.00	4.85	100.94	4.85	100.94
		6	4.0	3.00	0.98	1.20	2.50	3.40	78.00	1700.00	7.20	0.69	0.85	1.40	0.88	0.70	0.33	8.60	1.40	42.00	5.71	141.58	5.71	141.58
		10	3.8	2.30	0.79	1.10	2.50	3.10	97.00	2300.00	5.60	0.64	< 0.65	1.50	0.96	0.94	< 0.40	10.00	1.40	46.00	4.48	117.88	4.48	117.88
		15	4.4	1.60	0.50	0.85	1.80	2.20	59.00	1300.00	3.60	0.35	0.49	0.81	< 0.51	< 0.57	< 0.23	5.20	< 0.52	33.00	3.10	70.55	3.10	70.55
		20/21	4.4	0.84	0.53	1.10	2.00	2.40	64.00	210.00	2.90	0.38	< 0.43	0.69	0.58	0.64	< 0.22	6.30	0.75	15.00	2.27	51.28	2.19	49.38
		20/21-dup	4.4	1.00	0.54	0.70	1.10	1.90	49.00	160.00	2.10	< 0.33	< 0.33	0.58	0.49	0.46	< 0.23	4.60	0.70	6.00	2.11	47.49		
		30	4.6	1.90	< 0.85	1.60	2.60	3.60	87.00	1900.00	3.90	< 0.57	< 0.59	< 0.97	< 0.85	0.89	< 0.31	9.20	1.40	61.00	3.64	79.99	3.64	79.99
		40	NA	1.10	< 0.28	< 0.42	< 0.67	0.83	22.00	450.00	2.30	0.28	< 0.27	0.53	0.45	< 0.29	< 0.22	3.60	0.53	35.00	1.74	NA	1.74	NA
11193	08/30/2004	1	4.7	16.00	0.87	0.96	1.90	2.30	72.00	2600.00	40.00	1.50	1.60	< 3.40	1.20	0.63	< 0.39	8.90	1.40	86.00	22.20	472.31	22.20	472.31
		2	4.2	12.00	0.73	1.30	2.60	2.20	83.00	3000.00	34.00	1.40	1.40	< 3.60	1.30	< 0.28	0.76	9.10	1.50	66.00	17.55	414.45	17.55	414.45
		3	4.1	6.40	< 0.43	0.48	1.10	< 1.00	34.00	1100.00	16.00	< 0.61	< 0.65	1.40	0.57	< 0.46	< 0.21	4.60	0.76	39.00	8.72	211.06	8.72	211.06
		4	4.2	10.00	0.81	< 1.10	2.90	2.20	99.00	2900.00	28.00	1.30	1.30	< 2.70	0.86	0.78	0.38	9.90	1.20	63.00	14.82	357.16	14.82	357.16
		5	3.2	6.00	< 0.40	0.81	< 1.20	0.98	40.00	1000.00	17.00	< 0.69	0.76	1.40	0.59	0.42	0.32	5.10	0.75	41.00	8.71	272.16	8.71	272.16
		8	4.4	9.40	0.78	1.60	2.50	3.30	99.00	2500.00	23.00	1.00	1.20	< 2.20	0.94	0.86	< 0.39	11.00	1.80	68.00	13.79	315.79	13.79	315.79
		10	3.6	10.00	0.83	1.10	2.60	2.30	90.00	2600.00	24.00	2.60	1.80	< 6.20	2.20	1.20	1.10	11.00	2.00	84.00	15.21	422.36	15.21	422.36
		15	3.1	5.10	0.45	< 0.42	< 1.10	< 1.20	50.00	1300.00	12.00	0.61	0.70	1.20	< 0.44	0.45	0.48	4.50	< 0.55	34.00	7.28	234.73	7.28	234.73
		20	3.4	6.80	< 0.35	0.83	1.40	< 1.60	49.00	1400.00	17.00	0.89	0.88	1.60	0.77	0.58	0.44	7.20	1.20	59.00	9.71	282.93	9.71	282.93
		30/31	2.8	5.90	< 0.50	0.90	1.80	1.60	48.00	960.00	14.00	0.69	0.70	1.40	0.77	0.67	0.60	5.60	1.10	41.00	8.58	302.95	8.75	308.84
		30/31-dup	2.8	6.20	0.49	0.85	1.50	1.70	51.00	1400.00	15.00	0.70	0.67	< 1.40	0.98	< 0.31	< 0.28	6.60	< 0.43	51.00	8.92	314.74		
		40	NA	11.00	0.46	< 0.42	0.88	< 0.82	22.00	680.00	18.00	< 0.62	0.76	0.89	0.50	0.45	0.29	4.50	0.51	63.00	13.79	NA	13.79	NA
15979	08/30/2004	1	3.0	1.40	< 0.17	< 0.22	< 0.31	0.33	4.40	98.00	3.80	0.28	0.31	0.28	0.28	0.37	0.32	2.60	0.79	54.00	2.18	73.76	2.18	73.76
		2	2.3	1.20	< 0.18	< 0.22	0.27	< 0.19	4.40	76.00	3.60	0.20	0.24	0.43	< 0.22	< 0.25	< 0.20	1.80	< 0.30	37.00	1.86	82.62	1.86	82.62
		3	4.9	1.30	< 0.18	< 0.23	< 0.26	< 0.20	6.90	97.00	3.30	< 0.20	< 0.23	0.25	< 0.23	< 0.25	< 0.21	1.40	0.28	24.00	1.83	37.76	1.83	37.76
		6	6.6	13.00	0.80	1.60	4.20	2.50	120.00	1900.00	34.00	4.00	3.20	9.10	3.40	1.10	0.94	23.00	2.90	120.00	20.88	315.23	20.88	315.23
		7	6.3	10.00	0.82	1.10	3.40	< 1.70	70.00	1300.00	28.00	3.40	3.00	4.60	2.60	1.60	0.85	20.00	2.50	99.00	16.38	260.00	16.38	260.00
		8	11.8	15.00	1.80	2.60	6.30	4.70	140.00	4100.00	43.00	2.40	4.60	7.60	3.20	1.90	1.50	31.00	4.00	200.00	25.40	215.25	25.40	215.25
		10	2.3	3.20	0.24	< 0.46	0.82	0.55	15.00	380.00	9.20	< 0.49	< 0.47	0.96	0.41	0.43	0.29	6.20	0.96	130.00	4.74	206.03	4.74	206.03
		25	1.5	1.20	< 0.18	< 0.23	0.22	0.26	4.10	79.00	3.00	< 0.20	< 0.23	0.28	< 0.23	< 0.26	< 0.21	3.10	< 0.41	58.00	1.73	117.95	1.73	117.95
		26	2.8	1.10	< 0.18	< 0.23	0.26	< 0.20	2.60	48.00	2.80	< 0.20	< 0.23	< 0.18	< 0.23	< 0.26	< 0.21	1.70	< 0.21	33.00	1.58	57.07	1.58	57.07
		30/31	1.2	3.70	< 0.18	< 0.23	0.44	< 0.28	9.80	140.00	9.20	0.24	0.23	0.61	0.36	0.40	0.30	6.00	1.50	140.00	5.03	431.01	9.38	803.94
		30/31-dup	1.2	10.00	0.24	0.25	1.20	0.69	21.00	360.00	26.00	0.70	0.90	0.87	0.75	0.88	0.61	24.00	4.20	900.00	13.73	1176.86		
		40	NA	13.00	0.35	0.43	1.50	0.82	24.00	340.00	34.00	0.96	1.20	1.40	0.89	0.87	0.81	22.00	3.70	770.00	17.90	NA	17.90	NA

Table 3.24 Total Dioxin Concentrations in Sediment Cores (ng/kg-dry wt.) - Cont'd

Station ID	Date	Interval (cm)	POC (%)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	1,2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Total TEQ in OC	Average TEQ[a]	Average TEQ in OC[a]
11270	10/18/2004	2	5.7	1.60	< 0.29	< 0.27	0.34	0.20	4.30	110.00	3.90	0.26	0.37	< 0.41	0.18	0.22	0.20	< 0.93	< 0.26	6.00	2.41	42.25	2.41	42.25
		4	6.6	26.00	1.40	1.80	6.30	3.50	150.00	2800.00	57.00	2.80	3.00	5.10	2.70	2.10	1.00	32.00	3.80	140.00	36.29	549.85	36.29	549.85
		8	3.2	48.00	< 0.70	< 0.53	1.90	< 0.95	36.00	1000.00	96.00	2.00	2.10	< 3.10	0.82	0.97	< 0.35	8.50	1.00	32.00	59.54	1890.17	59.54	1890.17
		12	4.9	190.00	2.30	1.70	5.80	3.60	120.00	2700.00	420.00	4.40	6.20	7.40	2.50	2.50	1.30	30.00	2.90	130.00	238.95	4876.53	238.95	4876.53
		16	6.9	100.00	1.80	2.30	5.50	2.50	100.00	1700.00	230.00	2.80	5.00	5.90	< 1.60	1.90	0.84	20.00	2.90	98.00	128.51	1862.52	128.51	1862.52
		20	7.3	96.00	2.10	2.90	11.00	5.70	220.00	4300.00	230.00	6.30	7.30	14.00	4.20	4.50	2.00	53.00	5.80	240.00	128.45	1759.52	128.45	1759.52
		24	9.1	59.00	1.60	2.00	8.00	4.40	130.00	2100.00	140.00	4.40	6.60	12.00	2.70	< 2.30	1.50	34.00	4.40	130.00	80.50	889.45	80.50	889.45
		28	8.2	120.00	< 3.10	5.10	21.00	10.00	420.00	6700.00	330.00	< 25.00	17.00	30.00	9.90	3.80	6.20	110.00	12.00	410.00	171.50	2097.86	171.50	2097.86
		32	NA	85.00	4.60	8.70	34.00	15.00	690.00	9700.00	250.00	< 36.00	25.00	35.00	14.00	5.40	4.40	160.00	15.00	800.00	137.35	NA	137.35	NA
		37	NA	89.00	1.60	1.40	6.00	2.90	110.00	3100.00	180.00	3.90	4.20	6.50	2.40	2.40	1.20	24.00	2.80	110.00	112.38	NA	112.38	NA
		40/41	NA	1.50	< 0.41	< 0.28	< 0.36	< 0.37	1.90	110.00	3.50	< 0.23	< 0.20	< 0.16	< 0.18	< 0.22	< 0.16	< 0.28	< 0.32	< 0.48	2.09	NA	1.55	NA
		40/41-dup	NA	< 1.00	< 0.29	< 0.27	< 0.28	< 0.18	1.40	100.00	2.80	0.18	0.16	< 0.20	< 0.15	< 0.21	< 0.15	< 0.21	< 0.21	0.95	1.01	NA		
		43	NA	3.20	< 0.29	0.41	< 0.31	< 0.52	4.40	490.00	6.00	< 0.23	< 0.28	0.44	0.36	0.46	0.52	0.69	0.55	2.00	4.21	NA	4.21	NA
FW1A	12/10/2004	1	67.6	< 0.24	0.75	1.50	2.40	2.20	59.00	1000.00	1.20	0.60	0.92	< 0.97	0.89	1.10	0.37	11.00	0.85	18.00	2.00	2.96	2.00	2.96
		2	43.6	< 0.16	< 0.33	0.64	< 0.95	1.00	21.00	410.00	< 0.30	0.29	< 0.33	0.47	0.42	0.51	0.26	3.20	0.51	5.00	0.65	1.50	0.65	1.50
		3	24.3	< 0.19	0.31	< 0.57	0.63	0.75	17.00	420.00	0.26	0.20	0.25	0.38	0.25	0.32	< 0.21	2.40	0.23	3.70	0.68	2.82	0.68	2.82
		4	21.9	< 0.17	< 0.18	0.40	0.68	1.20	12.00	360.00	< 0.24	< 0.20	0.23	0.36	0.24	0.28	< 0.21	2.10	0.20	3.60	0.59	2.69	0.59	2.69
		5	8.8	< 0.16	< 0.20	< 0.23	0.46	0.35	8.20	180.00	< 0.24	< 0.20	< 0.23	< 0.18	< 0.23	< 0.26	< 0.21	1.60	< 0.20	1.90	0.34	3.90	0.34	3.90
		6	5.0	< 0.16	< 0.18	< 0.23	0.36	< 0.24	5.90	120.00	< 0.24	< 0.20	< 0.23	0.27	< 0.23	< 0.26	< 0.21	1.30	0.31	1.60	0.32	6.42	0.32	6.42
		8	4.5	< 0.16	< 0.18	< 0.23	< 0.18	< 0.27	4.50	190.00	< 0.24	< 0.20	< 0.23	< 0.18	< 0.23	< 0.26	< 0.21	0.56	< 0.20	< 0.78	0.28	6.17	0.28	6.17
		10	5.0	< 0.16	< 0.19	0.42	0.33	< 0.35	12.00	500.00	< 0.23	< 0.20	< 0.22	0.22	< 0.22	< 0.25	< 0.21	0.93	< 0.20	< 0.77	0.35	6.95	0.35	6.95
		20/21	3.7	< 0.28	< 0.22	< 0.23	< 0.18	0.22	3.10	95.00	< 0.24	0.20	0.23	< 0.18	< 0.23	< 0.26	< 0.21	< 0.30	< 0.20	< 0.78	0.42	11.31	0.37	9.97
		20/21-dup	3.7	< 0.22	< 0.23	< 0.23	< 0.21	< 0.20	2.00	63.00	< 0.27	< 0.20	< 0.23	< 0.18	< 0.23	< 0.26	< 0.21	< 0.31	< 0.20	< 0.79	0.32	8.64		
		30	3.1	< 0.16	< 0.18	< 0.22	< 0.18	< 0.19	0.77	18.00	< 0.23	< 0.19	< 0.22	< 0.18	< 0.22	< 0.25	< 0.20	< 0.30	0.24	< 0.77	0.27	8.80	0.27	8.80
		40	NA	< 0.16	< 0.23	0.23	< 0.18	0.30	2.80	140.00	< 0.26	< 0.25	< 0.23	< 0.18	< 0.23	< 0.26	< 0.21	< 0.31	< 0.20	< 0.78	0.32	NA	0.32	NA
13337	02/17/2005	1	11.3	4.60	1.40	2.80	5.10	6.10	140.00	4300.00	14.00	1.40	1.40	2.90	< 1.30	< 1.40	< 0.47	14.00	1.70	91.00	9.32	82.46	9.32	82.46
		2	11.2	1.70	0.57	1.00	1.60	2.00	46.00	1400.00	5.10	< 0.51	< 0.52	< 1.10	0.67	0.55	0.23	5.20	0.63	35.00	3.30	29.58	3.30	29.58
		3	10.0	4.90	1.80	3.10	5.40	6.60	140.00	4700.00	15.00	1.60	1.50	2.40	1.70	1.40	< 0.59	15.00	1.70	100.00	10.22	102.71	10.22	102.71
		4	9.5	4.90	1.60	2.90	5.30	5.70	110.00	2800.00	14.00	1.40	1.50	1.80	1.30	1.50	< 0.92	12.00	1.20	64.00	9.82	103.33	9.82	103.33
		5	9.8	4.80	1.60	2.30	3.60	3.80	79.00	2100.00	16.00	1.20	1.30	1.70	1.00	1.10	< 0.44	8.80	0.98	49.00	9.28	95.20	9.28	95.20
		10/11	9.7	3.70	1.50	2.90	4.90	6.70	140.00	3600.00	11.00	1.10	1.40	< 2.20	1.50	1.70	< 0.65	17.00	< 1.30	98.00	8.22	84.50	7.01	72.11
		10/11-dup	9.7	3.00	0.87	1.10	2.10	2.20	43.00	1000.00	11.00	0.71	1.00	0.92	< 0.67	< 0.59	0.43	5.20	< 0.74	28.00	5.81	59.73		
		15	9.5	3.80	1.20	2.00	3.40	3.90	75.00	1600.00	11.00	< 1.00	1.50	1.30	1.50	1.40	< 0.45	8.40	1.50	52.00	7.65	80.93	7.65	80.93
		20	8.1	3.80	0.94	1.10	< 1.90	2.00	40.00	880.00	11.00	0.78	1.50	1.10	0.71	0.76	< 0.41	5.10	< 0.81	33.00	6.84	84.99	6.84	84.99
		25	8.6	3.30	< 1.20	2.10	4.30	5.10	100.00	2300.00	9.10	< 1.20	1.40	1.90	1.50	1.20	< 0.49	13.00	1.60	80.00	6.87	80.40	6.87	80.40
		30	8.8	7.80	1.20	2.00	3.40	3.50	73.00	1400.00	20.00	1.60	1.90	1.90	1.40	1.20	0.40	10.00	1.60	86.00	12.81	146.40	12.81	146.40
		35	NA	8.20	1.30	< 0.97	2.40	2.20	46.00	900.00	24.00	< 4.20	1.80	1.70	0.69	1.00	0.70	8.00	1.40	63.00	13.17	NA	13.17	NA
		39/40	NA	7.30	0.98	2.20	5.00	4.00	120.00	2200.00	30.00	< 3.20	3.50	3.60	2.10	1.20	< 0.77	19.00	3.20	170.00	14.47	NA	14.47	NA
16499	02/17/2005	1/2	10.9	9.20	< 1.40	4.20	9.30	7.10	250.00	5400.00	24.00	1.90	2.00	2.70	1.60	1.60	0.96	34.00	< 2.40	210.00	15.79	144.98	15.79	144.98
		3	8.1	2.10	< 0.46	0.66	2.00	1.50	41.00	710.00	5.30	0.53	0.56	< 1.00	0.56	0.61	0.41	8.60	0.77	44.00	3.68	45.19	3.68	45.19
		5	7.3	0.48	< 0.30	< 0.29	< 0.47	< 0.44	5.50	88.00	1.20	0.35	0.36	< 0.47	0.45	< 0.40	< 0.30	1.50	< 0.47	5.60	1.04	14.29	1.04	14.29
		10	8.4	2.30	0.41	0.36	< 1.30	< 0.90	22.00	430.00	4.90	0.51	0.53	0.81	< 0.45	0.53	0.27	4.40	0.57	25.00	3.62	43.04	3.62	43.04
		15	7.8	9.70	1.50	2.50	6.90	5.30	120.00	2700.00	20.00	1.80	2.10	3.50	2.30	2.00	0.76	24.00	3.00	140.00	15.92	204.71	15.92	204.71
		19/20	10.8	7.90	< 2.10	< 2.90	8.30	6.70	120.00	1900.00	19.00	< 1.40	2.30	3.00	2.10	1.80	< 0.72	18.00	3.30	77.00	13.88	128.43	13.95	129.05
		19/20-dup	10.8	8.40	1.30	1.60	5.90	4.70	99.00	2400.00	17.00	1.80	2.10	3.70	2.40	2.20	0.75	22.00	3.00	110.00	14.02	129.67		
		25	12.3	10.00	1.60	2.70	6.70	5.60	110.00	2100.00	23.00	2.00	2.30	< 3.90	2.50	2.10	< 0.84	25.00	3.20	120.00	16.55	134.53	16.55	134.53
		30	16.9	14.00	1.90	2.10	8.60	6.00	120.00	2400.00	30.00	2.30	3.20	4.80	2.60	2.50	1.10	33.00	4.40	210.00	22.44	132.95	22.44	132.95
		35	NA	16.00	1.20	1.20	3.90	2.70	42.00	570.00	34.00	1.60	2.10	2.30	1.30	1.20	0.61	9.00	1.50	79.00	22.45	NA	22.45	NA
		40	NA	9.40	1.70	1.80	< 6.20	9.40	96.00	2200.00	21.00	< 1.80	2.10	2.70	2.20	< 1.70	1.20	19.00	2.20	160.00	15.57	NA	15.57	NA
		49/50	NA	< 0.88	1.30	1.50	3.70	< 0.52	67.00	1000.00	16.00	< 0.87	1.80	5.50	2.10	1.40	1.10	27.00	4.70	330.00	5.17	NA	5.17	NA

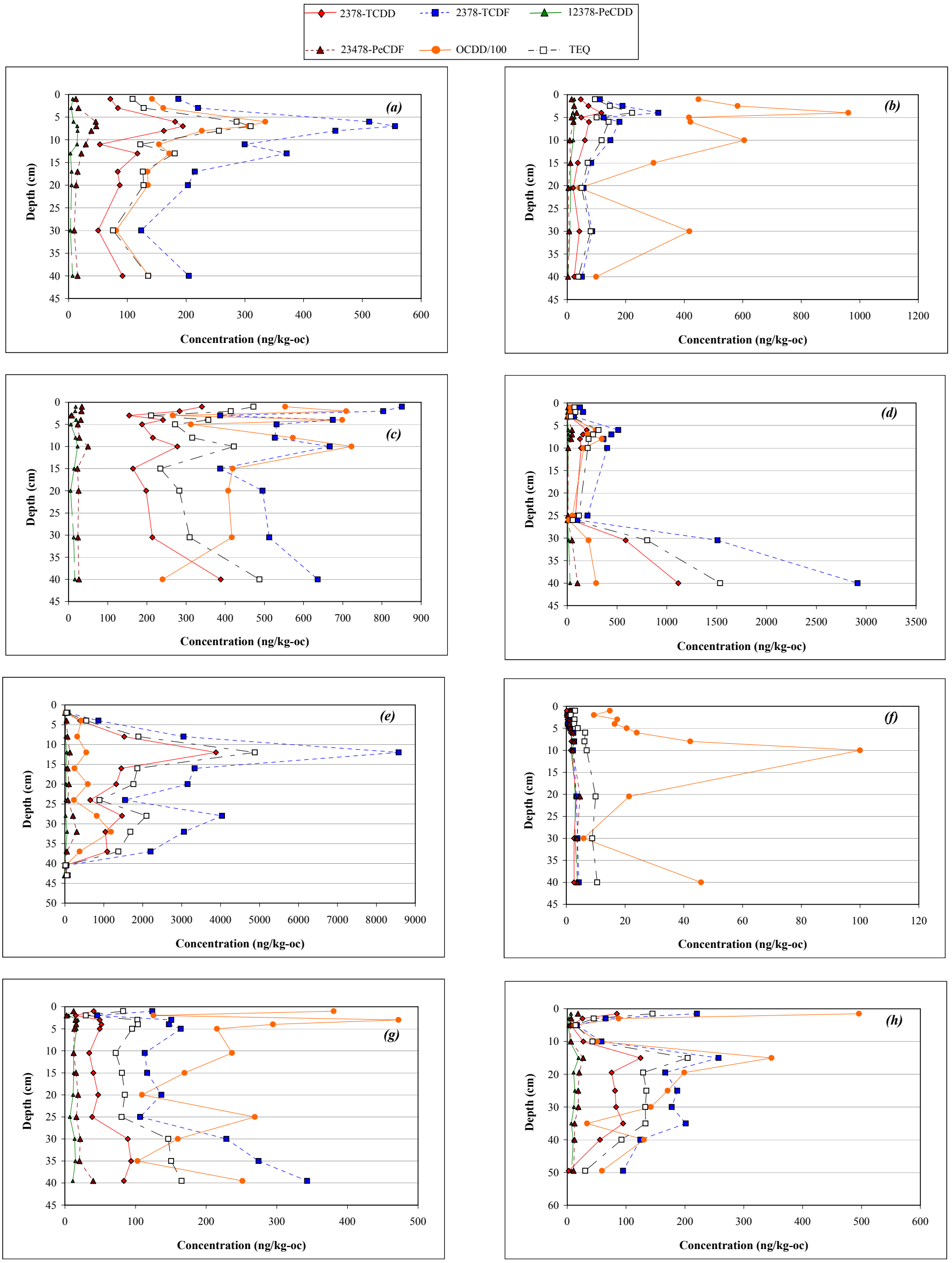
Provisional data. Do not reference or cite.

9.44, 91.80, 0.56, 9.23, and 12.38 ng/kg-dry wt., respectively. As expected, the "cleanest" core was that collected from a wetland (FW1A), while the most contaminated core was retrieved from location 11270.

Figure 3.67 shows vertical profiles of selected organic carbon-normalized 2378-substituted congeners and TEQ for all eight cores. It can be seen in Figures 3.67a, d, and e that all the congeners follow the same pattern for cores 11261, 15979, and 11270, with significant peaks at the 8-cm, 7-cm, and 12-cm depth intervals, respectively. These cores are also characterized by a relatively high presence of 2378-TCDF when compared to the other congeners (except OCDD). It is noted that core 11270 exhibited the highest concentrations (up to 15 times its counterparts for the remaining cores). Likewise, cores 15244, 11193, 13337, and 16499 showed similar fairly consistent pattern among the selected congeners (Figures 3.67b, c, g, and h), with significant peaks for all the congeners but OCDD in the top 5 cm of the cores and a second peak in the intervals around 20-cm. 12378-PeCDD and 23478-PeCDF in this group of cores exhibited very "flat" profiles, with concentrations significantly lower than those for the other congeners. Concentrations for core FW1A (Figure 3.67f) showed no significant peaks, with the exception of OCDD that showed a peak at the 10-cm interval. The profiles at FW1A exhibited a slight increase with depth. It is also noted that this core showed the lowest concentrations with most of the congeners below the detection limit.

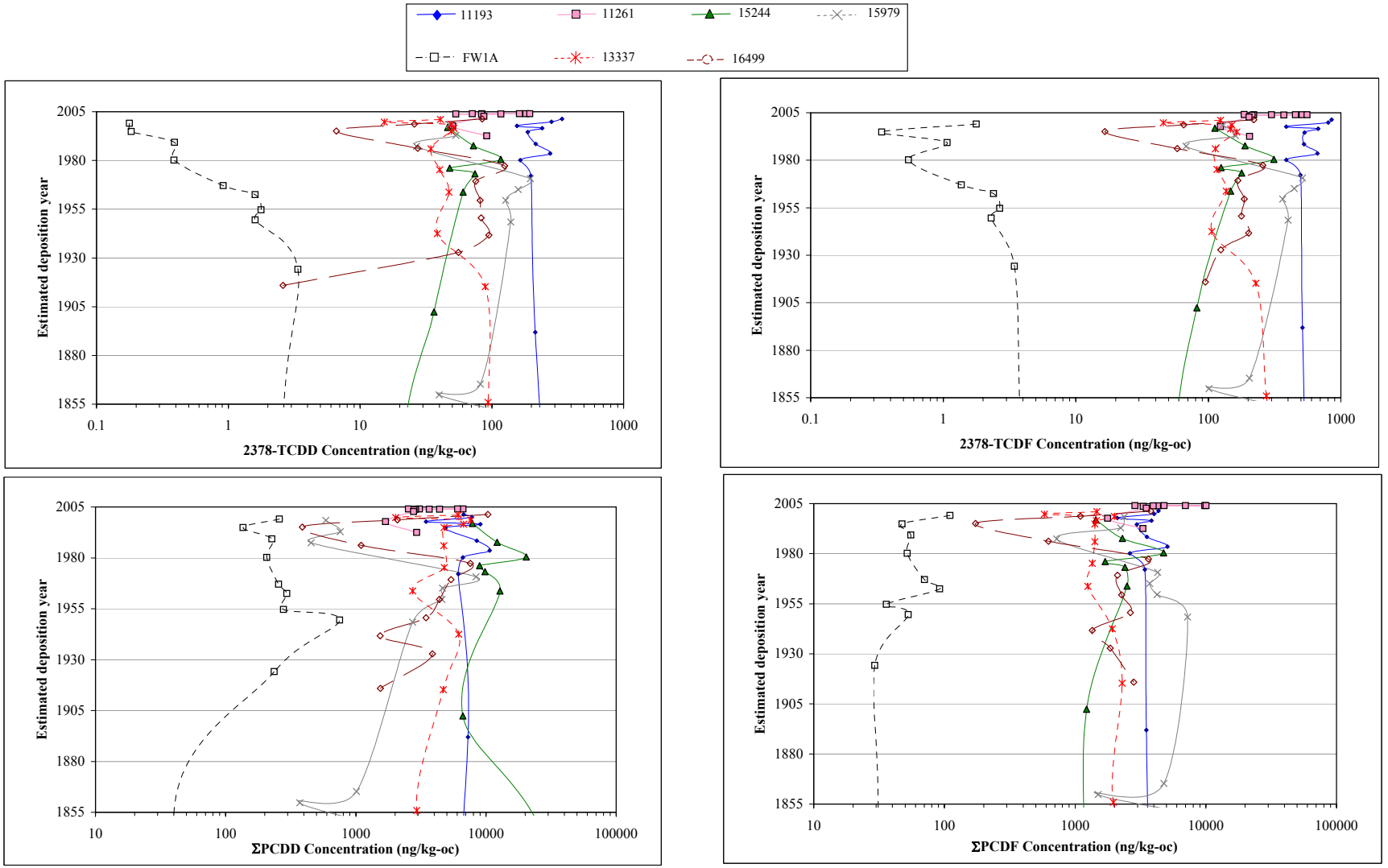
Figure 3.68 presents the vertical distribution of 2378-TCDD, 2378-TCDF, ΣPCDD and ΣPCDF concentrations in seven of the collected cores[3] versus the estimated year of deposition (derived from $^{210}Pb_{xs}$ and ^{137}Cs profiles). The longest time coverage of the sediment cores was

[3] Estimation of age was not possible for core 11270 due to mixing.



Lines are drawn to facilitate visualization and do not imply continuity
Non-detects assumed as 1/2MDL
If TOC was not measured for a given interval, the concentration of the closest measured interval was assumed

Figure 3.67 Dioxin Concentrations in Sediment Cores
(a) 11261 (b) 15244 (c) 11193 (d) 15979 (e) 11270 (f) FW1A (g) 13337 (h) 16499



Lines are drawn to facilitate visualization and do not imply continuity
Non-detects assumed as 1/2MDL
If TOC was not measured for a given interval, the concentration of the closest measured interval was assumed

Figure 3.68 Chronologies of Dioxin Concentrations
(a) 2378-TCDD (b) 2378-TCDF (c) ΣPCDD (d) ΣPCDF

about 150 years (sample 13337-35cm). It is noted that geochronology analyses for the deepest intervals were not undertaken, but when the age vs. depth curves were extrapolated coverages of up to 800 years were estimated. Data in Figure 3.68 show that surprisingly the oldest interval concentrations appear to be as high or slightly higher than those measured in the surface intervals. This could indicate the presence of other sources prior to the construction of the HSC (1909).

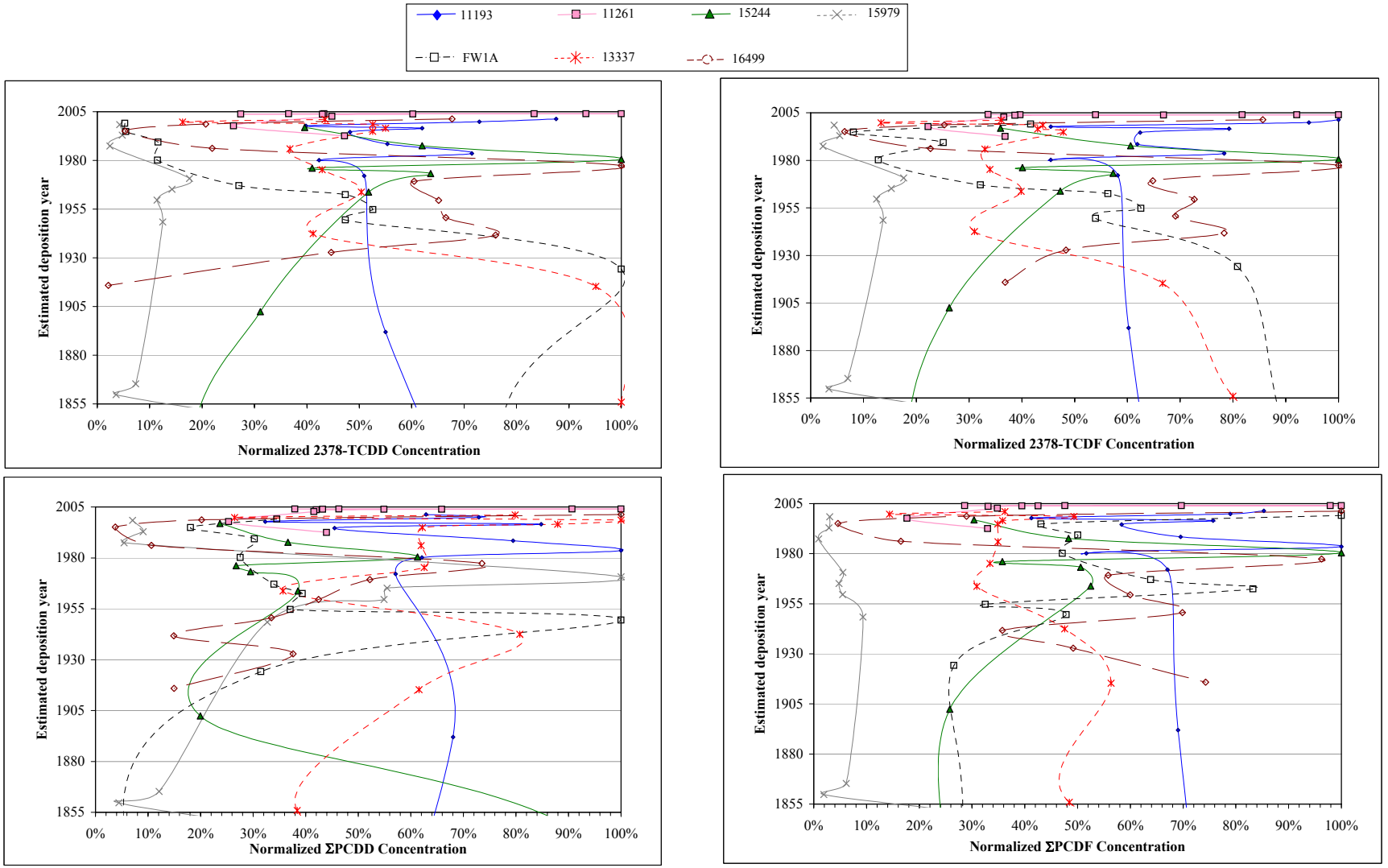
Figure 3.69 shows vertical distribution of selected compounds normalized to the maximum (=100%). It can be seen in Figure 3.69 that the maximum concentration of 2378-TCDD and 2378-TCDF was located in the oldest (deepest) sediment layers for cores 11193, 13337, and 15979. Additional samples at greater depths are being analyzed for dioxins to confirm this observation.

A database of dioxin results for the sediment cores as reported by Pace Analytical is included in Appendix B2.

3.2.2 Assessment of Major Sources, Transport and Fate of Dioxins in the Houston Ship Channel

3.2.2.1 Water Sampling

Results from field and conventional parameters for water samples collected in the main tributaries are included in Tables 3.7 and 3.8, respectively. Vertical profiles of temperature, pH, and salinity are shown in Figure 3.70. Salinity data in Figure 3.70 indicate that the profiles for most stations are similar, reflecting nearly freshwater at the surface and an increase in salinity with depth. The exceptions are stations 11272 (Carpenter Bayou), 11300 (Vince Bayou), 11347



Lines are drawn to facilitate visualization and do not imply continuity
Non-detects assumed as 1/2MDL

Figure 3.69 Chronologies of Dioxin Concentrations Normalized to Maximum Concentrations
(a) 2378-TCDD (b) 2378-TCDF (c) ΣPCDD (d) ΣPCDF

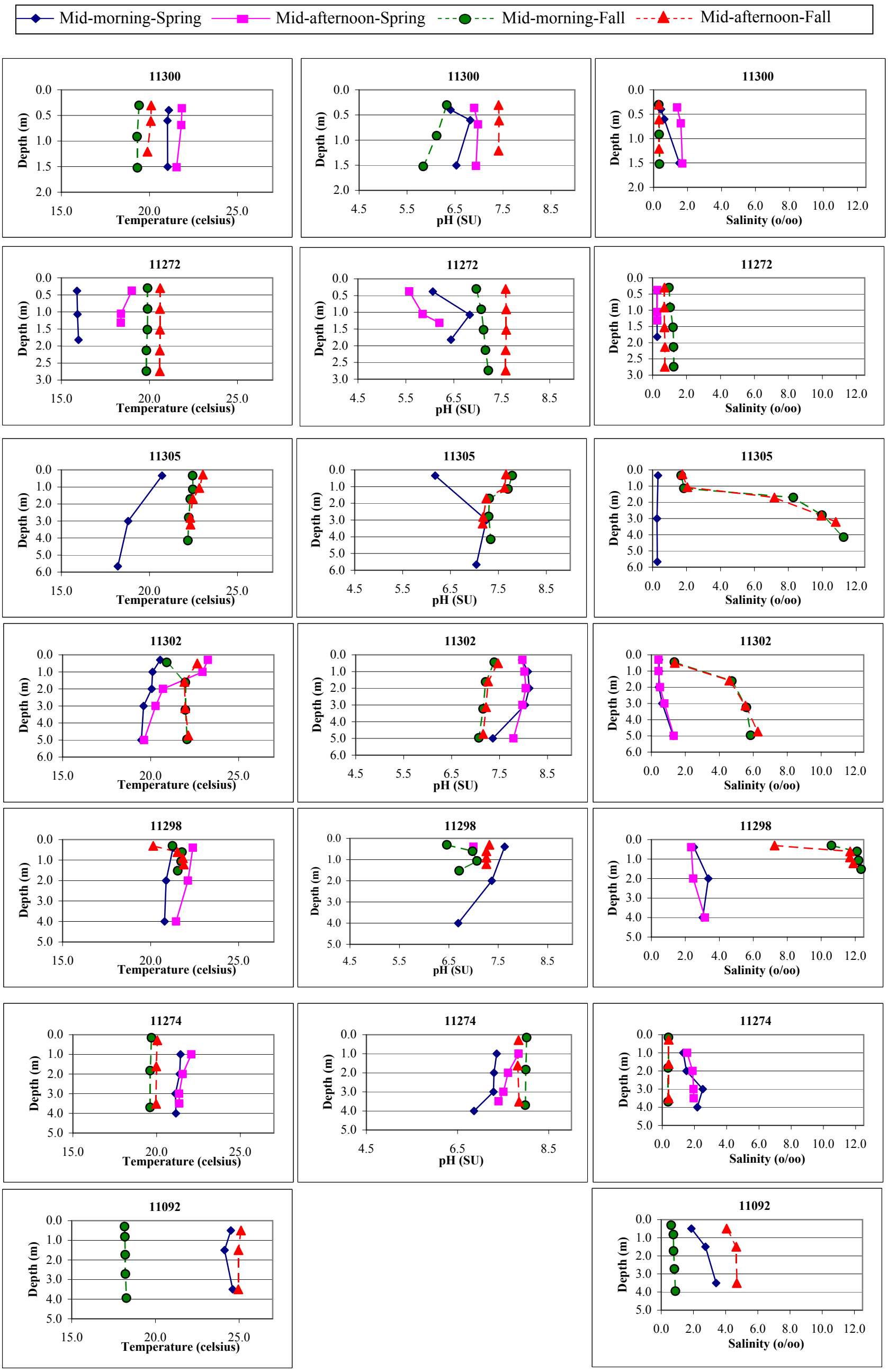


Figure 3.70 Vertical profiles of field parameters (tributaries)

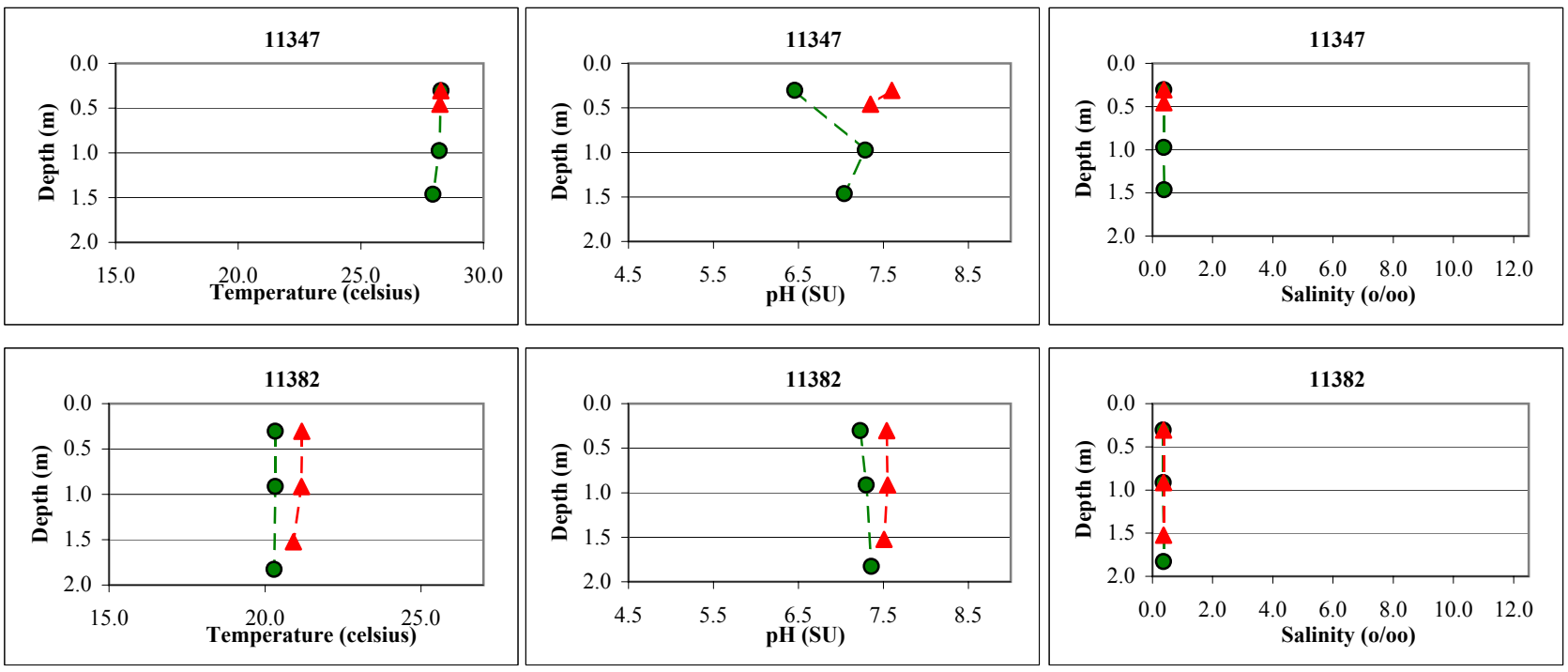


Figure 3.70 Vertical profiles of field parameters (tributaries) - Continued

(Buffalo Bayou) and 11382 (Whiteoak Bayou), where the salinity profile is more uniform, with concentrations close to 0 $^{o}/_{oo}$.

Dioxin results from the water samples collected at main tributaries are included in Table 3.25. Total TEQ concentrations in water from tributaries are mapped in Figure 3.14. Dioxin levels in water samples collected at the mouth of 11 tributaries during Spring 2004 varied from 0.044 to 1.824 pg TEQ/L, while the Fall 2004 concentrations varied from 0.069 to 1.430 pg TEQ/L. The average concentrations were 0.389 pg TEQ/L for Spring 2004 and 0.332 pg TEQ/L for Fall 2004. These averages are very similar to those calculated for in-channel samples (0.409 and 0.340 pg TEQ/L for the Spring and Fall 2004, respectively). Location 11273 (Patrick Bayou) exhibited the highest dioxin levels for both Spring and Fall 2004. Nine of the 11 (82%) tributary locations exceeded the Texas water quality standard (0.0933 pg/L) in Spring 2004, while eight of them (73%) exceeded the standard in Fall 2004. Location 11382 (Whiteoak Bayou) was the only one that did not exceed the WQ standard in both samples.

3.2.2.2 Air Sampling

Ambient Air Concentrations

The total ambient air dioxin concentrations along with the concentrations of the 17 individual 2378-substituted congeners at the two air monitoring stations measured as part of WO7 are presented in Table 3.26. Total ambient air dioxin concentrations measured in WO7 ranged from 668 to 1,518 fg/m^3 at Clinton Drive (C403), and from 486 to 1,559 fg/m^3 at Lang Road (C408). Average dioxin concentrations at Clinton Drive for the Dec/03-Apr/04 and Sep/04-Feb/05 periods (mean±standard deviation) were 1159 ± 342, and 1083 ± 387 fg/m^3, respectively. Similarly, the average total ambient air concentration measured at Lang Road during the Dec/03-

Table 3.25 Total Dioxin Concentrations in Water from Tributaries (pg/L)

Station ID	Date	Tributary	Volume (L)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ	Average TEQ[a]
Spring 2004																						
11300	04/08/2004	Vince Bayou	700	< 0.0596	< 0.0284	0.0363	0.0951	0.1049	2.5000	29.0000	0.3300	0.1871	0.0851	0.4471	0.1311	0.0456	< 0.0111	< 0.6114	< 0.0680	0.9257	0.2370	0.237
11298	04/20/2004	Hunting Bayou	703	0.2475	< 0.0256	0.0546	0.1536	0.1579	5.1209	93.8834	0.7966	< 0.0464	0.0546	0.0939	< 0.0640	0.0403	< 0.0065	< 0.8435	0.0451	1.6358	0.4232	0.423
11274	04/21/2004	Greens Bayou	710	< 0.0732	0.0206	0.0379	0.1042	0.1155	3.8873	214.0845	0.3211	0.0283	0.0394	0.0817	< 0.0859	0.0239	< 0.0056	< 0.4268	< 0.0320	1.1690	0.1603	0.160
11347	04/22/2004	Buffalo bayou	703	< 0.0115	0.0284	0.0324	0.3841	0.1536	8.2504	69.7013	0.0555	0.0176	0.0248	0.0415	< 0.0498	0.0326	< 0.0088	< 0.5064	< 0.0257	0.7653	0.1072	0.091
11347-dup	04/22/2004	Buffalo Bayou	705	< 0.0105	0.0218	0.0250	0.2426	0.1021	5.9574	52.4823	0.0553	< 0.0121	< 0.0196	0.0360	0.0213	0.0233	< 0.0054	< 0.3716	0.0180	0.5830	0.0743	
11382	04/23/2004	Whiteoak Bayou	707	< 0.0050	< 0.0129	0.0181	0.0533	0.0512	1.7115	26.1669	0.0636	< 0.0095	0.0219	0.0243	< 0.0216	0.0140	< 0.0050	< 0.2772	< 0.0182	0.6917	0.0439	0.044
11272	04/13/2004	Carpenters Bayou	706	0.4207	0.0694	0.1445	0.3414	0.4207	11.7564	548.1586	1.0340	0.1275	0.0878	0.3244	< 0.1586	0.0754	0.0177	< 1.5581	< 0.1076	9.3768	0.7536	0.754
11305	04/15/2004	Brays Bayou	708	< 0.0167	0.0274	0.0500	0.1116	0.1257	3.1921	39.8305	0.1059	0.0267	0.0410	0.0597	< 0.1653	0.0379	< 0.0092	< 0.5551	< 0.0312	0.9011	0.1021	0.102
11302	04/16/2004	Sims Bayou	734	< 0.0341	0.0450	0.0845	0.2030	0.1757	4.9183	45.7766	0.1580	0.0463	0.0599	0.0940	0.0627	0.0790	0.0399	< 1.1308	< 0.0967	2.4114	0.1703	0.170
11111	04/27/2004	Cedar Bayou	708	< 0.0975	0.0397	0.1186	0.1963	0.4181	8.2203	224.5763	0.2684	0.0381	0.0323	0.0691	< 0.0480	0.0284	< 0.0114	< 0.5692	< 0.0359	2.2175	0.2406	0.241
11092	04/28/2004	Goose Creek	707	< 0.0519	0.0554	0.1405	0.2928	0.4102	10.1414	301.2730	0.1669	0.0444	0.0505	0.1277	< 0.0764	0.0699	< 0.0119	< 1.5120	< 0.0751	3.8331	0.2306	0.231
11273	04/29/2004	Patrick Bayou	702	< 0.6026	< 0.0984	< 0.1866	0.5470	0.5584	15.6553	216.5242	3.1624	1.9088	0.8732	3.2336	< 0.9544	0.4843	0.6325	< 21.1538	1.5057	478.6325	1.8235	1.824
Fall 2004																						
11347	10/22/2004	Buffalo Bayou	701	< 0.0251	< 0.0294	< 0.0454	0.1268	0.1284	3.8088	77.4608	0.0999	< 0.0471	< 0.0428	< 0.0628	< 0.2197	< 0.0579	< 0.0318	< 0.7618	< 0.0285	1.8973	0.0951	0.095
11111	11/04/2004	Cedar Bayou	702	< 0.0726	< 0.0641	< 0.1439	0.2279	< 0.4103	8.7607	316.2393	0.2279	< 0.0670	< 0.0598	< 0.0897	< 0.1311	< 0.0541	< 0.0484	< 0.6410	< 0.0912	2.5214	0.2323	0.232
11382	11/08/2004	Whiteoak Bayou	704	< 0.0337	< 0.0334	< 0.0405	< 0.0817	< 0.0984	2.8551	75.4261	< 0.0653	< 0.0440	< 0.0412	< 0.0253	< 0.1477	< 0.0334	< 0.0303	< 0.4574	< 0.0322	1.4432	0.0745	0.074
11302	11/10/2004	Sims Bayou	702	< 0.0150	< 0.0221	< 0.0321	0.0880	0.0812	2.8362	45.3276	< 0.1225	< 0.0236	< 0.0272	< 0.0379	< 0.0922	< 0.0298	< 0.0157	< 0.6453	< 0.0178	1.7422	0.0695	0.069
11305	11/11/2004	Brays Bayou	702	< 0.0178	< 0.0142	0.0283	0.0806	< 0.0620	2.8063	44.0171	0.1026	< 0.0328	< 0.0389	< 0.0544	< 0.2194	< 0.0322	< 0.0175	< 0.5043	< 0.0353	1.1011	0.0727	0.073
11298	11/12/2004	Hunting Bayou	707	< 0.0934	< 0.0212	0.0521	0.1260	0.1372	4.2207	99.1513	0.3904	< 0.0474	< 0.0508	0.1007	< 0.1491	< 0.0373	< 0.0264	< 0.7001	< 0.0666	2.0141	0.2058	0.206
11272	11/22/2004	Carpenters Bayou	701	< 0.0442	< 0.0310	< 0.0613	< 0.1041	< 0.1526	4.7361	469.3295	0.1255	< 0.0399	< 0.0442	< 0.0606	< 0.1441	< 0.0321	< 0.0184	< 0.4322	< 0.0185	2.0399	0.1236	0.124
11274	11/24/2004	Greens Bayou	720	< 0.0681	< 0.0529	0.1335	0.3403	0.4069	14.6250	1305.5556	0.4597	< 0.0981	0.1164	0.3006	< 0.5306	< 0.1006	< 0.0363	< 1.8458	< 0.3514	6.0514	0.3545	0.354
11300	11/29/2004	Vince Bayou	708	< 0.0763	< 0.0268	< 0.0510	0.1271	< 0.1256	4.2655	66.3842	1.1723	1.2147	< 0.3828	2.5226	0.7218	< 0.0905	< 0.0547	< 1.3008	< 0.3404	2.0494	0.7975	0.798
11092	11/30/2004	Goose Creek	702	< 0.0265	0.0429	< 0.1293	< 0.2688	0.3276	9.3020	351.1396	0.1154	< 0.0490	< 0.0410	< 0.1115	< 0.2721	0.0652	< 0.0132	< 1.3704	< 0.0761	3.0584	0.1953	0.195
11273	12/01/2004	Patrick Bayou	701	0.4265	< 0.0670	< 0.1241	0.3281	0.3666	10.9130	208.2739	2.0685	1.2553	0.5193	2.0542	< 2.2539	0.3324	0.3081	< 19.9287	1.4180	637.6605	1.4304	1.430

[a] Average of duplicate samples, otherwise concentration of a single sample

dup = duplicate

Values reported to the Detection Limit

Non-detects assumed as 1/2 MDL for TEQ calculations

Value between the detection and the reporting limits

Value is an estimate due to blank contamination (concentration < 20 times lowest concentration)

Value is an estimate due to QC issues (interference, signal to noise ratio)

Tributary

Exceeds the Texas WQS (0.0933 pg/L)

Table 3.26 Dioxin Concentrations in Ambient Air (fg/m^3)

Congener	Clinton Drive (C403)							Lang Road (C408)			
	Dec/03-Jan/04	Jan/04-Feb/04	Feb/04-Mar/04	Mar/04-Apr/04	Sep/04-Oct/04	Nov/04-Dec/04	Jan/05-Feb/05	Dec/03-Jan/04	Jan/04-Feb/04	Feb/04-Mar/04	Mar/04-Apr/04
2,3,7,8-TCDD	1	1	1.6	<1.0	0.9	1.1	0.6	1.2	<1.0	<0.6	<1.0
1,2,3,7,8-PeCDD	4	8	9	3	<4	5	3	6	6	3	2
1,2,3,4,7,8-HxCDD	7	11	10	3	4	8	5	10	9	5	2
1,2,3,6,7,8-HxCDD	13	18	17	6	9	18	10	19	16	9	5
1,2,3,7,8,9-HxCDD	13	12	16	5	8	18	10	19	16	8	5
1,2,3,4,6,7,8-HpCDD	213	278	250	98	125	269	154	291	223	104	71
OCDD	803	949	914	451	519	1022	600	1024	815	382	300
2,3,7,8-TCDF	4	8	5	2	4	4	4	5	3	4	2
1,2,3,7,8-PeCDF	4	9	7	2	3	5	5	6	4	4	2
2,3,4,7,8-PeCDF	7	11	10	3	3	9	8	12	7	8	3
1,2,3,4,7,8-HxCDF	9	11	12	5	5	11	11	14	5	10	6
1,2,3,6,7,8-HxCDF	8	7	9	5	5	10	8	12	6	7	4
2,3,4,6,7,8-HxCDF	10	7	9	8	6	16	14	18	7	13	7
1,2,3,7,8,9-HxCDF	4	8	3	2	1	5	4	6	3	4	2
1,2,3,4,6,7,8-HpCDF	37	23	32	32	28	55	46	60	39	43	32
1,2,3,4,7,8,9-HpCDF	7	8	<4	5	<4	6	6	9	6	*2*	4
OCDF	38	35	76	37	54	56	62	47	36	37	38
Σ(PCDDs + PCDFs)[a]	1182	1404	1383	668	779	1518	951	1559	1202	643	486
ΣTEQ[a]	14	19	20	7	8	17	13	21	14	12	6
Average Temp (°C)	13.2	11.7	19.3	21.9	25.9	16.1	15.3	12.3	11.2	19.1	21.3

1 fg = 10^{-15} g.

[a] Non-detected assumed equal to ½ MDL for calculations.

Apr/04 sampling periods was 972 ± 497 fg/m^3.

The higher chlorinated congeners such as 1234678-HpCDD, 1234678-HpCDF, OCDF, and especially OCDD were consistently found at both sites as the congeners making the major contribution to the total ambient air dioxin concentration. In most of the cases, the contribution of OCDD was found to be >50% at all stations during the period sampled (see Figure 3.71). Concentrations for OCDD of up to 1,024 fg/m^3 were measured in the Houston area at the Lang Road site in the January/04 event. In contrast, 2378-TCDD had a very low contribution to the total dioxin concentration during the sampled period. A maximum concentration of 1.6 fg/m^3 was detected for this congener at the Clinton Drive site (this site is located in the industrial area and near major highways) in the February-March/04 event.

In terms of ΣTEQ concentrations, values were found fluctuating from 7 to 20 fg/m^3 at Clinton Drive and from 6 to 21 fg /m^3 at Lang Road. The congeners 12378-PeCDD and 23478-PeCDF were consistently found to be the major contributors to the ΣTexas-TEQ concentration. Contributions of up to 23 and 22% were observed for 12378-PeCDD at Clinton Drive and Lang Road, respectively. Similarly, contributions of up to 31 and 33% were found for 23478-PeCDF at the same sites, respectively. Finally, 2378-TCDD contributions to the total TEQ were up to 15 and 20%, for the aforementioned sites, respectively.

Particle Size Distribution of Associated Dioxins

Bi-monthly particle size data of associated dioxins samples were collected from September 2004 to February 2005 at Clinton Drive (C403). Three sampling events were completed: September/04-October/04, November/04-December/04, and Janaury/04-February/05. The airborne particles were separated into the following size ranges: >7.2, 7.2-3.0, 3.0-1.5, 1.5-

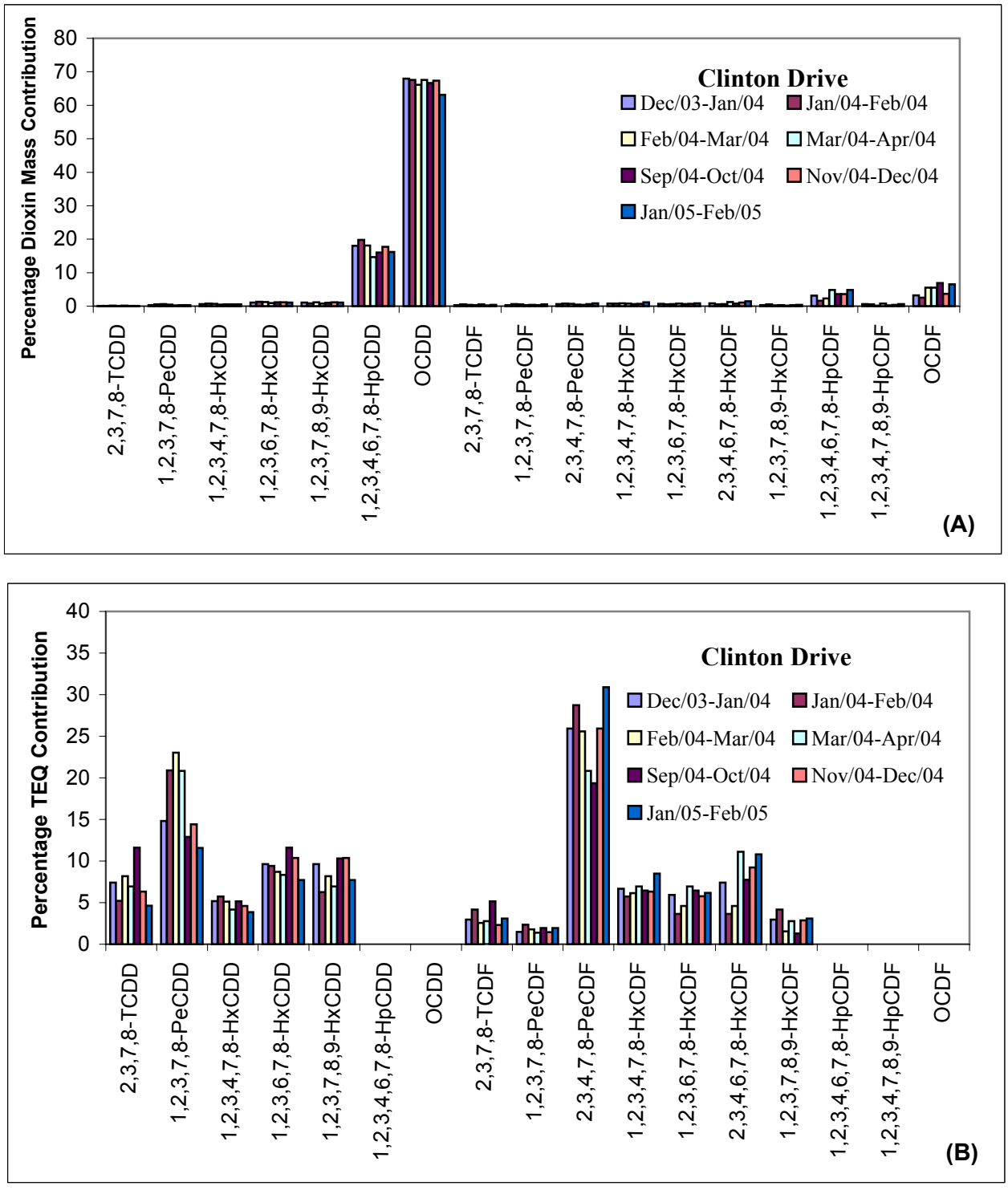


Figure 3.71 Ambient Air Profiles of Dioxins and Furans (Clinton Drive)
(A) Dioxin mass concentration (B) TEQ concentration.

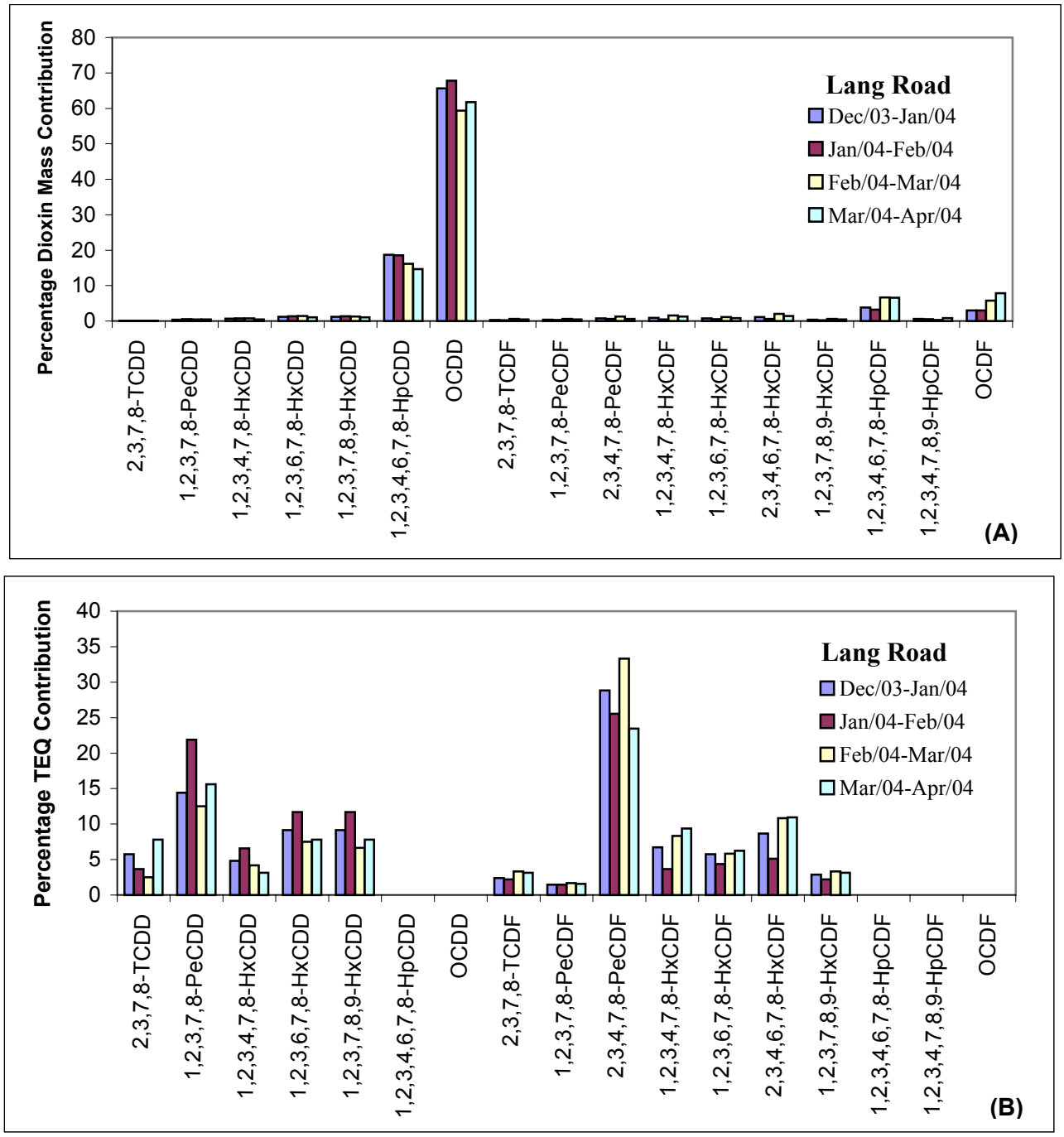


Figure 3.71 Ambient Air Profiles of Dioxins and Furans (Lang Road) - Continued
(A) Dioxin mass concentration; (B) TEQ concentration

0.95, 0.95-0.49, <0.49 μm in aerodynamic diameter (d_{ae}) as mentioned previously.

The concentrations (fg/m^3) of individual dioxin and furan congeners, and organic and elemental carbon determined in the different particle size ranges are summarized in Table 3.27. The concentrations of the higher chlorinated congeners were significantly higher than those of the less chlorinated congeners at all stages. OCDD was the most prominent congener for the full size range analyzed in this study. Lower chlorinated congeners were found associated with the smallest fraction of particles (i.e., 0.95-0.49 and <0.49 μm). Fine particles (d_{ae} < 2.5 μm) are known to be produced predominantly from gas-to-particle conversion and from incomplete combustion (anthropogenic sources such as diesel fueled vehicles). The congener 2378-TCDD was primarily found bound to particles with d_{ae} <0.49 μm in November/04-December/04 and January/05-February/05 events at concentrations of 0.2 and 0.1 fg/m^3, respectively.

The total dioxin particle-phase concentration was found to be mostly associated to the range sizes 0.95-0.49 and <0.49 μm in the three events. In fact, the combined contributions of these two stages to the total dioxin particle-phase concentrations observed in the three consecutive events were 84, 94, and 90%, respectively.

From the particle size ranges analyzed in this study, particles with d_{ae} >7.2 μm were characterized by having the highest deposition velocities. At this particle size range, OCDD, 1234678-HpCDD, 1234678-HpCDF, and OCDF were consistently found dominating the dioxin mass profile. In fact, more than 98% of the total dioxin mass detected at this specific size range (>7.2 μm) was attributed to these four congeners.

Total TEQ data in Table 3.27 indicated that the highest concentrations were observed in the particle sizes rich in lower chlorinated congeners (0.95-0.49 and <0.49 μm). Concentrations

Table 3.27 Concentrations of PCDD/PCDFs with respect to Particle Size (fg/m^3) at Clinton Drive

Congener	September-October 2004						November-December 2004						January-February 2005					
	>7.2 µm	7.2-3.0 µm	3.0-1.5 µm	1.5-0.95 µm	0.95-0.49 µm	<0.49 µm	>7.2 µm	7.2-3.0 µm	3.0-1.5 µm	1.5-0.95 µm	0.95-0.49 µm	<0.49 µm	>7.2 µm	7.2-3.0 µm	3.0-1.5 µm	1.5-0.95 µm	0.95-0.49 µm	<0.49 µm
2,3,7,8-TCDD	<0.06	<0.04	<0.04	<0.04	<0.04	<0.06	<0.02	<0.02	<0.02	<0.02	0.09	0.2	<0.04	<0.02	<0.02	<0.02	<0.06	0.1
1,2,3,7,8-PeCDD	<0.2	<0.04	<0.04	<0.04	0.2	<0.6	0.1	<0.02	<0.02	0.03	0.7	2	<0.06	<0.02	<0.02	0.03	<0.4	<1
1,2,3,4,7,8-HxCDD	0.1	<0.04	<0.1	<0.1	0.6	1	0.1	<0.06	<0.04	0.07	1	6	0.1	<0.02	<0.04	<0.04	1	3
1,2,3,6,7,8-HxCDD	0.3	<0.04	<0.1	<0.1	2	3	0.3	0.1	0.1	0.16	2	12	0.2	<0.02	0.04	0.1	2	6
1,2,3,7,8,9-HxCDD	<0.2	<0.04	<0.1	<0.1	2	3	0.3	0.1	<0.06	0.13	3	13	0.2	<0.02	0.04	0.1	2	7
1,2,3,4,6,7,8-HpCDD	8	0.6	0.7	1	26	56	6	0.8	1	2	34	225	7	0.4	0.5	1	28	117
OCDD	62	3	3	5	99	285	51	3	3	8	114	848	59	2	2	5	101	452
2,3,7,8-TCDF	<0.08	<0.1	<0.06	<0.06	0.07	0.2	<0.2	<0.02	<0.04	<0.02	0.2	0.6	<0.2	<0.02	<0.02	<0.02	0.2	0.5
1,2,3,7,8-PeCDF	<0.06	<0.2	<0.06	<0.1	<0.1	0.3	<0.2	<0.04	<0.04	0.02	0.4	1	0.1	<0.04	<0.02	0.03	0.5	1
2,3,4,7,8-PeCDF	0.1	<0.04	<0.06	<0.06	0.2	0.6	0.1	<0.04	<0.04	0.05	1	3	0.1	<0.04	<0.02	0.04	1	3
1,2,3,4,7,8-HxCDF	<0.2	<0.02	<0.02	<0.02	0.5	1	0.1	0.03	0.04	0.07	2	6	0.2	0.03	0.03	0.1	2	6
1,2,3,6,7,8-HxCDF	<0.2	<0.02	<0.02	<0.02	0.5	1	0.1	0.03	0.04	0.08	1	6	0.1	<0.02	0.04	0.1	2	4
2,3,4,6,7,8-HxCDF	<0.2	<0.02	0.02	0.03	1	2	0.2	0.1	0.1	0.13	3	11	0.2	0.03	0.04	0.1	3	9
1,2,3,7,8,9-HxCDF	<0.02	<0.02	<0.04	<0.02	0.3	0.6	0.1	<0.02	<0.02	0.04	1	3	0.1	<0.02	<0.02	0.04	1	3
1,2,3,4,6,7,8-HpCDF	1	0.1	0.1	0.2	5	11	1	0.2	0.2	0.45	9	44	1	0.1	0.15	0.4	12	31
1,2,3,4,7,8,9-HpCDF	<0.2	<0.02	<0.04	<0.04	0.7	2	<0.2	<0.02	<0.02	0.1	1	6	<0.2	<0.02	<0.02	<0.04	<1	4
OCDF	15	0.5	<0.2	0.6	9	24	4	0.2	0.3	0.53	8	45	8	0.2	0.24	0.53	15	38
Σ(PCDD+PCDF)[a]	87	5	4	7	147	391	64	5	5	12	181	1232	77	3	3	8	171	685
ΣTexas-TEQ[a]	0.2	0.06	0.07	0.05	0.9	1.7	0.2	0.07	0.06	0.1	2.3	8.5	0.21	0.04	0.04	0.1	2	5.8
Total Organic Carbon-TOC (µg/m^3)	1.19	0.05	0.06	0.09	0.32	4.8	0.41	0.02	0.04	0.06	0.24	4.1	0.62	0.03	0.03	0.06	0.6	3.3
Elemental Carbon-EC (µg/m^3)	0.14	0.005	0.01	0.01	0.03	0.93	0.04	0.002	0.003	0.005	0.02	1.1	0.05	0.002	0.002	0.003	0.07	0.98
Total Carbon-TC (µg/m^3)	1.33	0.055	0.07	0.1	0.35	5.73	0.45	0.022	0.043	0.065	0.26	5.2	0.67	0.032	0.032	0.063	0.67	4.28
Particle Concentration (µg/m^3)	23.2	3	2.1	1.8	8.1	28.7	15.1	1.5	1.3	1.3	4	23.1	20.1	3.2	2	1.7	4.6	31.5

[a] Non-detects assumed equal to ½ MDL for calculations.

fluctuating from 0.9 to 2.5 fg ΣTexas-TEQ/m^3 and from 1.7 and 8.5 fg ΣTexas-TEQ/m^3 were observed for these two particle sizes, respectively. A combined contribution of these two particle sizes of >87% to the ΣTexas-TEQ was found (see Figure 3.72).

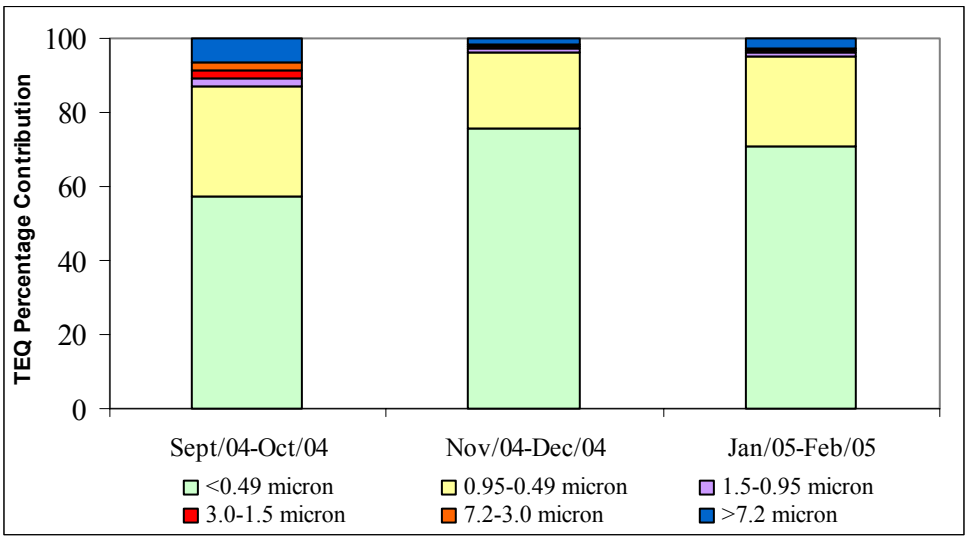


Figure 3.72 ΣTexas-TEQ Distribution by Particle Size

Total organic carbon (TOC), elemental carbon (EC), and total carbon (TC) concentrations are also summarized in Table 3.27. Significant concentrations of OC and EC were consistently found in particles with sizes >7.2 μm, 0.95-0.49 μm, and <0.49 μm. EC, a characteristic constituent of fine particles and diesel emissions (soot), was consistently and predominantly found in particles <0.49μm.

Dry and Wet Deposition

First Dry and Wet Deposition Experiment

Monthly dry deposition samples were concurrently collected at Clinton Drive and Lang Road from December 2003 to April 2004 in four different sampling events: December/03-

January/04, January/04-February/04, February/04-March/04, and March/04-April/04. Results of this experiment are summarized in Table 3.28. Total dry deposition was observed to fluctuate from 305 to 376 and from 95 to 155 pg/m^2/day at Clinton Drive and Lang Road, respectively. A *t*-test was conducted to establish if there was any statistical significant difference in the dry deposition process between these two sites. The test, carried out at an α=0.05 significance level, demonstrated the existence of spatial variability of the dry deposition.

None of the lower chlorinated congeners were found in the dry deposition sample. In contrast, the higher chlorinated congeners, 1234678-HpCDD, 1234678-HpCDF, OCDF and especially OCDD were found to dominate the dry deposition profile. A contribution of up to 88% of the total dry deposition flux was attributed to OCDD, followed by 1234678-HpCDD with 10% (Figure 3.73). This result is in agreement with those obtained from the particle size distribution of associated dioxin samples where the stage containing the largest particles (>7.2 μm) was dominated by the higher chlorinated congener (in particular OCDD). Particles in this range (coarse mode particles) are generated mostly by mechanical processes such as grinding, wind, or erosion.

Results for the wet deposition sample collected (December/03-April/04) at Clinton Dr are listed in Table 3.29. A total wet deposition flux of 2,873 pg/m^2/day was measured at that specific location. In the case of wet deposition, 123478-HxCDF, 123678-HxCDD, 1234678-HpCDD, OCDD, 2378-TCDF, 123478-HxCDF, 123678-HxCDF, 234678-HxCDF, OCDF were detected in rain. OCDD, as seen in dry deposition, was the most prominent congener with a contribution of 81% to the total wet deposition flux (Figure 3.74). It is noted that 2378-TCDF, a compound existing predominantly in the vapor phase, was detected in rain at a concentration of 99 fg/L.

Table 3.28 Dry Deposition fluxes (pg/m^2/day) at Clinton Drive and Lang Road sites (December 2003-April 2004)

Congener	Clinton Drive				Lang Road		
	Dec/03-Jan/04	Jan/04-Feb/04	Feb/04-Mar/04	Mar/04-Apr/04	Dec/03-Jan/04	Feb/04-Mar/04	Mar/04-Apr/04
2,3,7,8-TCDD	<1	<2	<1	<2	<2	<1	<2
1,2,3,7,8-PeCDD	<2	<3	<2	<2	<3	<2	<2
1,2,3,4,7,8-HxCDD	<4	<4	<3	<4	<4	<3	<2
1,2,3,6,7,8-HxCDD	<4	<4	<3	<4	<4	<3	<4
1,2,3,7,8,9-HxCDD	<4	<4	<3	<4	<4	<3	<4
1,2,3,4,6,7,8-HpCDD	31	35	34	32	14	15	8
OCDD	241	289	280	306	89	124	68
2,3,7,8-TCDF	<1	<1	<2	<1	<3	<1	<1
1,2,3,7,8-PeCDF	<2	<1	<2	<2	<3	<2	<2
2,3,4,7,8-PeCDF	<2	<2	<2	<2	<3	<2	<2
1,2,3,4,7,8-HxCDF	<1	<2	<1	<1	<1	<1	<1
1,2,3,6,7,8-HxCDF	<1	<2	<1	<1	<1	<1	<1
2,3,4,6,7,8-HxCDF	<1	<2	<1	<1	<1	<1	<1
1,2,3,7,8,9-HxCDF	<1	<3	<2	<1	<2	<1	<1
1,2,3,4,6,7,8-HpCDF	5	6	7	7	<3	3.2	<5
1,2,3,4,7,8,9-HpCDF	<1	<2	<1	<2	<1	<1	<1
OCDF	14	18	24	17	5.8	2	3.6
TEQ[a]	2.36	3.38	2.35	2.90	3.58	2.25	2.80
Σ(PCDD+PCDF)	305	365	356	376	126	155	95

[a] Non-detects assumed as 1/2 MDL for TEQ calculations

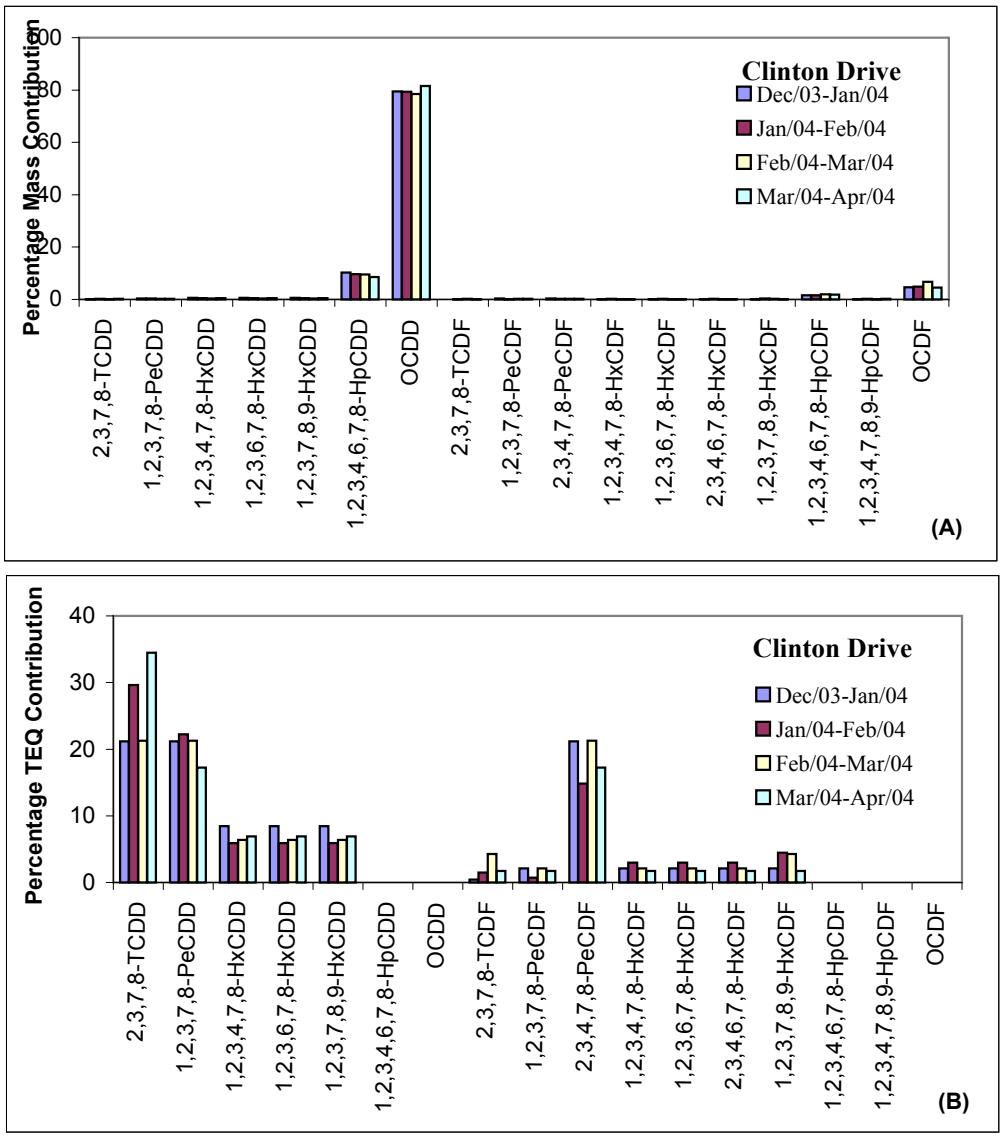


Figure 3.73 Dry Deposition Profiles at Clinton Drive and Lang Road Sites (First Dry and Wet Deposition Experiment): (A) Mass Contribution, (B) TEQ Contribution

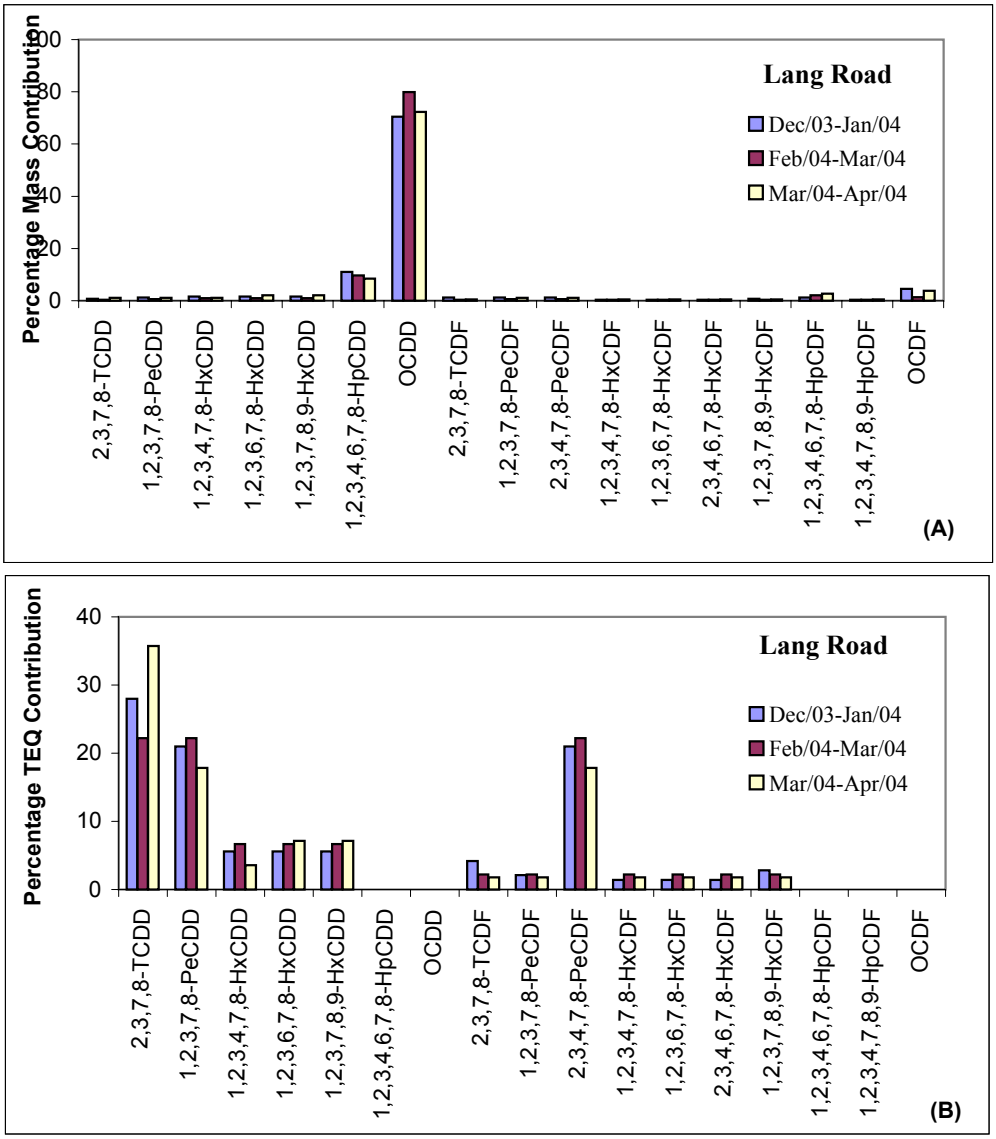


Figure 3.73 Dry Deposition Profiles at Clinton Drive and Lang Road Sites (First Dry and Wet Deposition Experiment): (A) Mass Contribution, (B) TEQ Contribution - Cont'd

Table 3.29 Wet Deposition Flux (pg/m^2/day) at Clinton Drive (December 2003-April 2004)

Congener	Rainwater Concentration (fg/L)	Wet Deposition Flux (pg/m^2/day)[a]
2,3,7,8-TCDD	<46	<4
1,2,3,7,8-PeCDD	<98	<8
1,2,3,4,7,8-HxCDD	99	9
1,2,3,6,7,8-HxCDD	153	14
1,2,3,7,8,9-HxCDD	<206	<18
1,2,3,4,6,7,8-HpCDD	3678	329
OCDD	26018	2329
2,3,7,8-TCDF	99	9
1,2,3,7,8-PeCDF	<134	<12
2,3,4,7,8-PeCDF	<126	<12
1,2,3,4,7,8-HxCDF	135	12
1,2,3,6,7,8-HxCDF	90	8
2,3,4,6,7,8-HxCDF	75	7
1,2,3,7,8,9-HxCDF	<58	<6
1,2,3,4,6,7,8-HpCDF	<592	<52
1,2,3,4,7,8,9-HpCDF	<78	<8
OCDF	1077	96
TEQ[b]	160.7	14.4
Σ(PCDD+PCDF)		2873

[a] Number of days with rain during sampling period is 5.96

[b] Non-detects assumed as 1/2 MDL for TEQ calculations

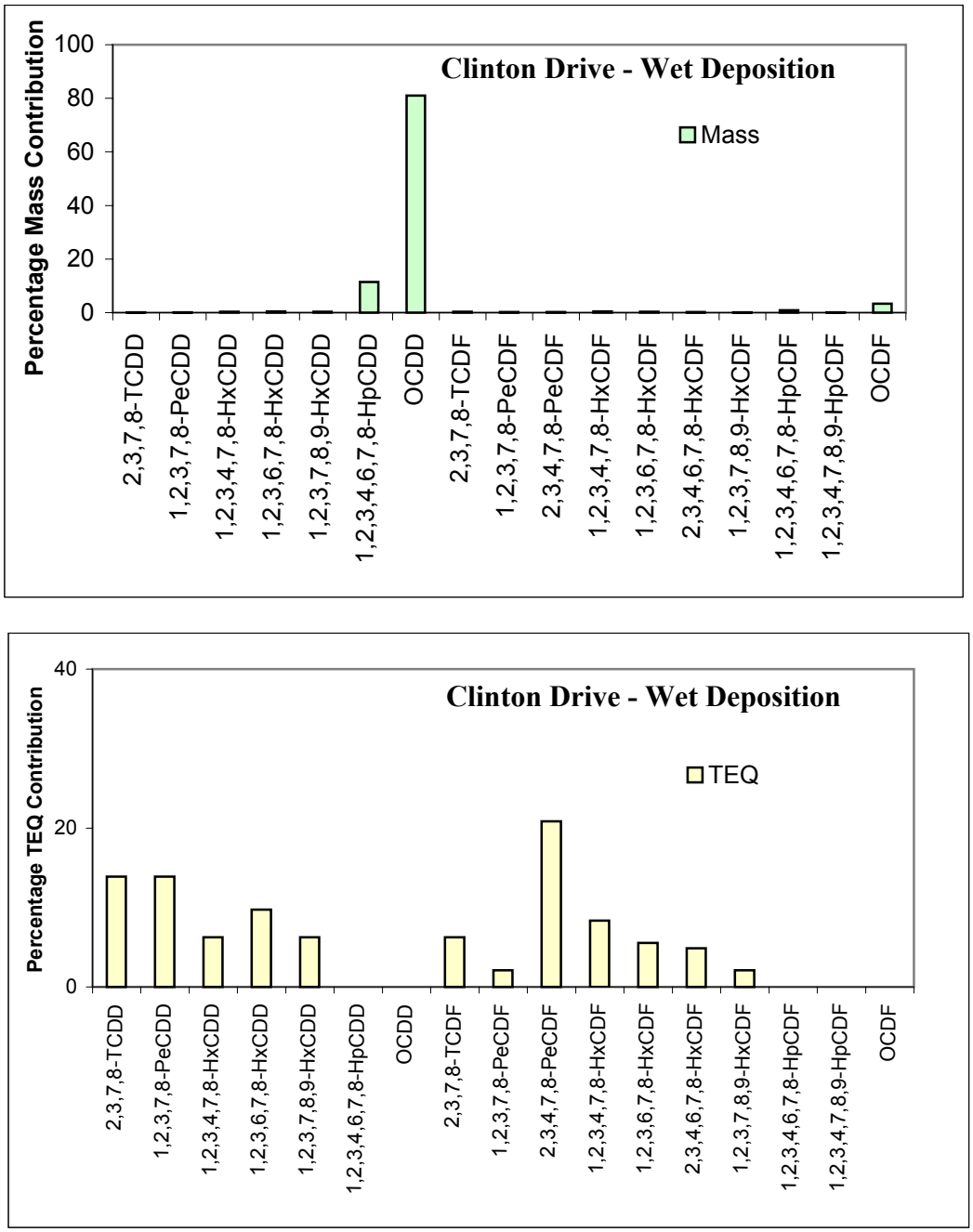


Figure 3.74 Wet Deposition Profile at Clinton Drive (First Dry and Wet Deposition Experiment)

These results show that rain, while intermittent, is an important process that removes dioxins from the atmosphere.

The individual contributions of the observed wet and dry deposition fluxes of dioxins were combined to obtain a total deposition flux for the Houston area. To do this, the wet deposition flux was adjusted by accounting for the fraction of time during the sampling period with rain and the remaining fraction of time was used to adjust the dry deposition flux. This weighting allowed totaling the individual contributions of both deposition processes. An analysis of rain data at the monitoring station for the period sample revealed that precipitation of 0.01" or more occurred approximately 7% of the time. Therefore, a total deposition flux of 527 $pg/m^2/day$ was estimated for the Houston area. This value translated to a Texas-TEQ flux of 0.41 $pg/m^2/day$.

Second Dry and Wet Deposition Experiment

Although dioxins and furans were detected in the dry and wet deposition samples in the first experiment, a number of congeners were not detected especially in the dry deposition. Therefore, a second experiment was undertaken from September/04 to February/05. In this case, co-located samplers were installed at Clinton Drive to increase the collection area. Similarly, bi-monthly sampling events were designed with the purpose of increasing the amount of sample to minimize non-detects. Thus, dioxin samples were collected in three bi-monthly events: September/04-October/04, November/04-December/04, and January/05-February/05.

Results of the second dry and wet deposition experiment are summarized in Table 3.30. For the dry deposition samples, the higher chlorinated congeners, 1234678-HpCDD, OCDD, 1234678-HpCDF, and OCDF were consistently detected. In the case of the wet deposition sample, more congeners were detected in comparison with the first deposition experiment. The

Table 3.30 Dry and Wet Deposition Fluxes (pg/m^2/day) at Clinton Drive (September 2004-February 2005)

Congener	Dry			Wet[a]
	Sep/04-Oct/04	Nov/04-Dec/04	Jan/05-Feb/05	Sep/04-Feb/05
2,3,7,8-TCDD	<1	<0.2	<0.2	<0.4
1,2,3,7,8-PeCDD	<1	<2	<0.4	<0.6
1,2,3,4,7,8-HxCDD	<2	<2	<2	8
1,2,3,6,7,8-HxCDD	<1	2	2	12
1,2,3,7,8,9-HxCDD	<2	<4	<4	16
1,2,3,4,6,7,8-HpCDD	80	52	66	300
OCDD	751	395	597	2290
2,3,7,8-TCDF	<2	<1	<1	5
1,2,3,7,8-PeCDF	<1	<1	<1	4
2,3,4,7,8-PeCDF	<1	<1	<1	5
1,2,3,4,7,8-HxCDF	<0.2	<1	<2	13
1,2,3,6,7,8-HxCDF	<2	<1	<2	9
2,3,4,6,7,8-HxCDF	<1	<2	<2	5
1,2,3,7,8,9-HxCDF	<0.4	<0.6	<0.1	<1
1,2,3,4,6,7,8-HpCDF	12	7	9	26
1,2,3,4,7,8,9-HpCDF	<0.6	<0.2	<1	5
OCDF	58	20	33	112
TEQ[b]	1.56	1.66	1.33	9.90
Σ(PCDD+PCDF)	908	484	715	2811

[a] Number of days with rain during sampling period is 6.85

[b] Non-detects assumed as 1/2 MDL for TEQ calculations

congeners 2378-TCDD, 12378-PeCDD, and 123789-HxCDF were still missing from wet deposition. In both dry/wet deposition, OCDD followed by 1234678-HpCDD were, once again, identified as the major contributors to the total wet and dry deposition fluxes (Figure 3.75).

Similarly to the first wet and dry deposition experiment, the contributions of the wet and dry deposition fluxes of the second experiment were combined to obtain a total deposition flux. In this case, 4% of the total time sampled showed precipitation of 0.01 inches or more. A total deposition flux of 787 pg/m^2/day was estimated for the Houston area. This value translated to a Texas-TEQ flux of 0.50 pg/m^2/day.

Bulk Deposition

The combined contribution (bulk) of deposition of dioxins in the Houston area was studied concurrently with the second dry and wet deposition experiment (September/04-February/05) at the Clinton Drive site. The fluxes for the detected congeners are summarized in Table 3.31.

Table 3.31 Bulk Deposition Fluxes of Dioxins (pg/m^2/day)

Congener	Bulk Deposition Flux
2,3,7,8-TCDD	<0.1
1,2,3,7,8-PeCDD	0.3
1,2,3,4,7,8-HxCDD	0.6
1,2,3,6,7,8-HxCDD	0.8
1,2,3,7,8,9-HxCDD	1
1,2,3,4,6,7,8-HpCDD	27
OCDD	207
2,3,7,8-TCDF	0.6
1,2,3,7,8-PeCDF	0.2
2,3,4,7,8-PeCDF	0.2
1,2,3,4,7,8-HxCDF	0.6
1,2,3,6,7,8-HxCDF	0.6
2,3,4,6,7,8-HxCDF	0.3
1,2,3,7,8,9-HxCDF	<0.04
1,2,3,4,6,7,8-HpCDF	4.0
1,2,3,4,7,8,9-HpCDF	0.2
OCDF	11
Σ(PCDD+PCDF)	255

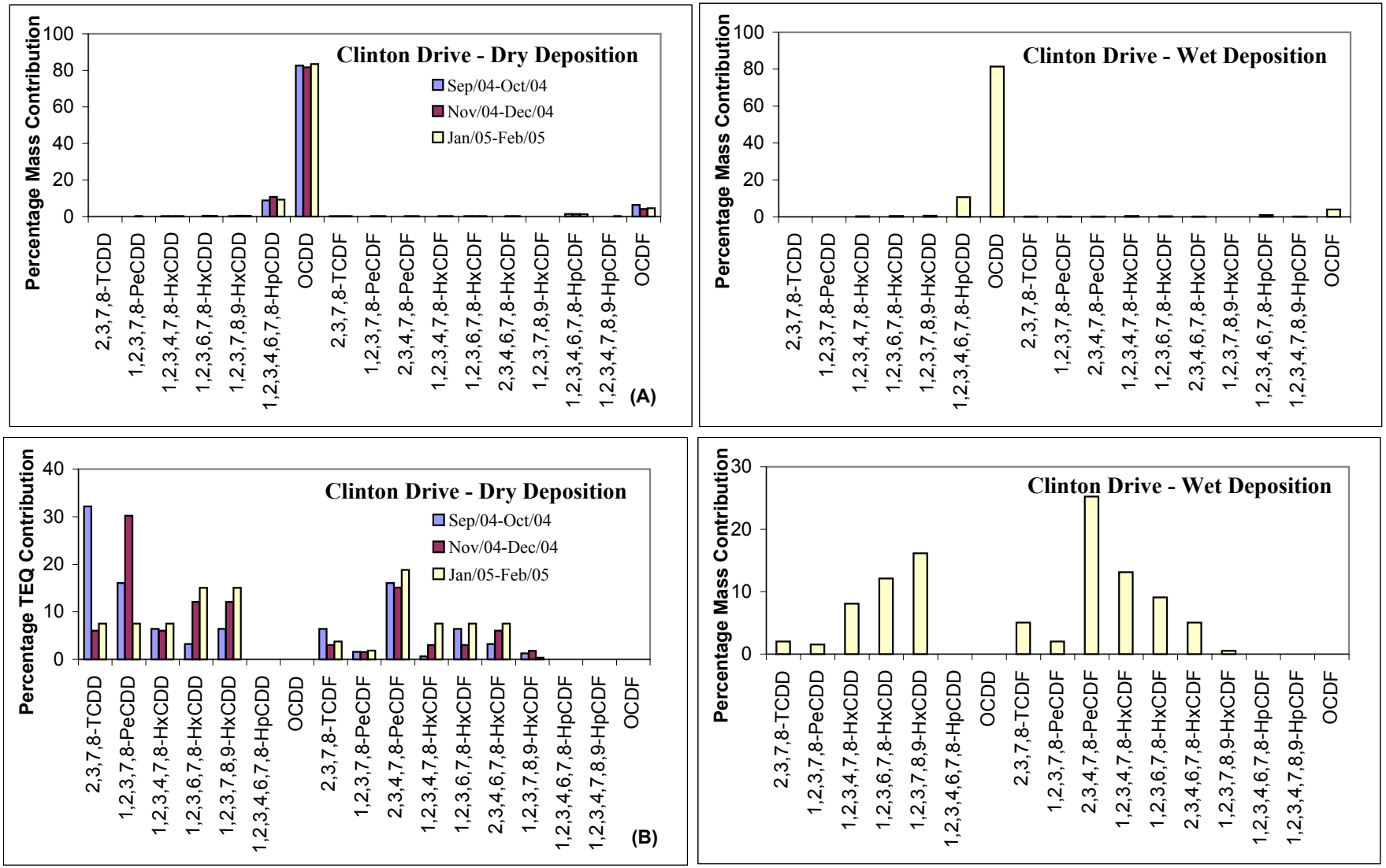


Figure 3.75 Wet and Dry Deposition at Clinton Drive Site (Second Dry and Wet Deposition Experiment): (A) Mass Contribution (B) TEQ Contribution.

Table 3.32 Field Measurements during Runoff Sampling Activities

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Conductivity (μ S/cm)	Salinity ($^{o}/_{oo}$)	pH (SU)	Flow (m^3/s)	DO (mg/L)	Sample Volume (L)	Antecedant Dry Period[a] (day)	Total Rainfall[a] (in)
SS-10	12/16/2004	9:35						0.003		707	10	0.39
		10:41	0.05	9.51	612	0.30	7.16					
		12:15						0.05				
		13:00	0.43	10.07	1116		7.48	0.20	0.67			
		14:00	0.61	10.61	582	0.28	7.65					
		15:00	0.59	11.66	467		7.62		0.66			
		17:00	0.48	11.42	374		7.59		0.64			
		17:30						0.02				
		19:08	0.36	11.31	349	0.17	7.69					
SS-13	01/13/2005	01:00						0.08				
		01:30						5.66				
		02:10	0.91	NA	NA	NA	NA		NA			
		6:35						6.70				
		7:45						4.83				
		9:20						0.91				
		11:10						0.26		709	8	1.22
SS-9	02/07/2005	12:25						0.05		697	2	0.04
		12:45	0.07	16.40	341	0.16	5.59		4.65			
		16:40						0.29				
		19:15						0.24				
		20:05	0.49	16.18	314	0.14	6.42		2.25			
SS-15	02/24/2005	10:30						6.07		674	11	1.42
		11:30						3.00				
		12:30	1.02	NA	NA	NA	NA	0.73	NA			
		15:30						0.21				
SS-14	03/02/2005	11:30						2.49		700	3	0.87
		13:00						2.67				
		13:40						2.91				
		15:00						0.61				
		17:00	0.14	14.19	162		7.73		18.51			
		19:00	0.18	14.26	186		7.67		18.72			
		19:30						0.46				
		20:15						0.26				
		21:00	0.14	14.22	205		7.60		17.98			
		23:00	0.11	14.11	237		7.58		16.98			

Table 3.32 Field Measurements during Runoff Sampling Activities

Station ID	Date	Time	Depth (m)	Temperature (^{o}C)	Conductivity (μ S/cm)	Salinity ($^{o}/_{oo}$)	pH (SU)	Flow (m^3/s)	DO (mg/L)	Sample Volume (L)	Antecedant Dry Period[a] (day)	Total Rainfall[a] (in)
SS-16	03/16/2005	07:15	0.16	13.35	864	0.43	8.00	0.0003		700	9	0.2
		08:00						0.0004				
		10:30						0.0003				
		12:15						0.0002				
		14:00						0.0002				
		14:49	0.13	16.39	714	0.35	8.22					
SS-8	05/29/2005	20:00	0.18	28.38	573		14.00	0.006	3.90	708	21	4.37
		22:00	0.42	23.12	217		14.00		6.66			
		00:00	0.50	22.58	77		14.00		6.27			
		02:00	0.46	22.29	81		14.00		5.71			
		02:16						9.37				
		03:40						3.94				
		04:00	0.56	22.28	96		14.00		5.02			
		05:40						2.03				
		06:00	1.02	22.26	107		14.00		4.33			
		07:40						0.43				
		08:00	1.20	22.25	120		14.00		3.55			
SS-7	07/14/2005	15:30	0.04	26.91	99	0.05	8.58		4.78	617		
		16:15	0.05	27.07	60	0.03	8.21	2.15	5.25			
		17:15						1.54				
		17:30	0.21	27.43	94	0.04	7.79		4.49			
		18:15	0.08	27.46	100	0.05	7.71	0.78	4.25			
		19:15	0.07	27.39	122	0.06	7.67		3.88			
		20:00	0.05	27.33	133	0.06	7.63		3.85			
		20:30						0.37				
		21:00	0.05	27.30	174	0.08	7.69		3.91			
		21:45	0.07	27.26	150	0.07	7.81		4.00			
		22:00						1.41				
		22:15	0.1	27.30	175	0.08	7.72		4.12			
		22:45	0.15	27.39	188	0.09	7.97		4.09			

NA= not available due to a failure of the YSI recording device

[a] Using data from the closest HCOEM rain gage

2378-TCDD and 123789-HxCDF were the only two congeners not detected in the bulk deposition sample. The profile was found to be dominated by the higher chlorinated congeners (Figure 3.76). A total bulk deposition flux of 255 pg/m^2/day was measured at Clinton Drive. This flux translated to 0.71 pg TEQ/m^2/day.

Load calculations from dry, wet, and bulk deposition will be presented in Chapter 4. A database of air sampling results is included in Appendix B3.

3.2.2.3 Runoff Sampling

Stormwater Runoff Samples

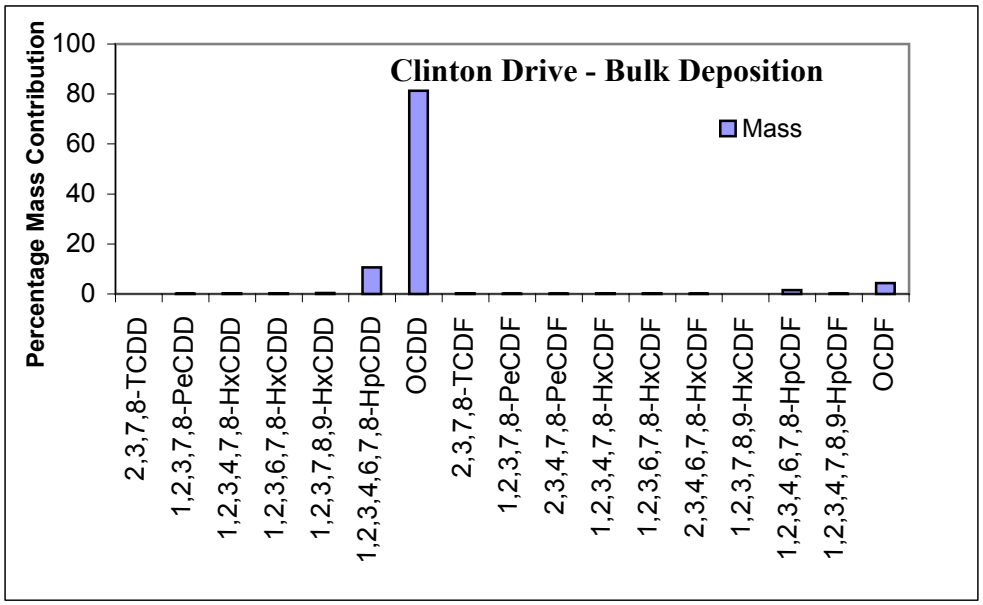
Table 3.32 provides a summary of field parameters measured during runoff sampling activities. Table 3.33 presents a summary of physical characteristics of storm water samples collected as of this writing. A summary of physical characteristics of soil/sediment samples collected during runoff sampling is included in Table 3.34.

Table 3.33 Physical Characteristics of Runoff Samples

Sampling Site	Date	TSS (mg/L)	TDS (mg/L)	TOC (mg/L)	DOC (mg/L)
SS-10	12/16/2004	66	NA	10.9	10.4
SS-13	01/13/2005	70.4	276	9.12	8.04
SS-9	02/07/2005	39.2	288	16.8	16.2
SS-15	02/24/2005	74.8	NA	9.19	9.04
SS-16	03/16/2005	<4.0	391	8.79	8.54
SS-14	03/22/2005	122	214	8.1	7.22
SS-8	05/29/2005	244	145	8.56	8.48
SS-7	07/14/2005	27.6	97	8.64	8.15

NA= Not available, sample volume not sufficient for analysis

Results for dioxins in Houston urban runoff samples in both dissolved and suspended (1 and 40 μm) phases collected at different locations are summarized in Table 3.35. Total TEQ



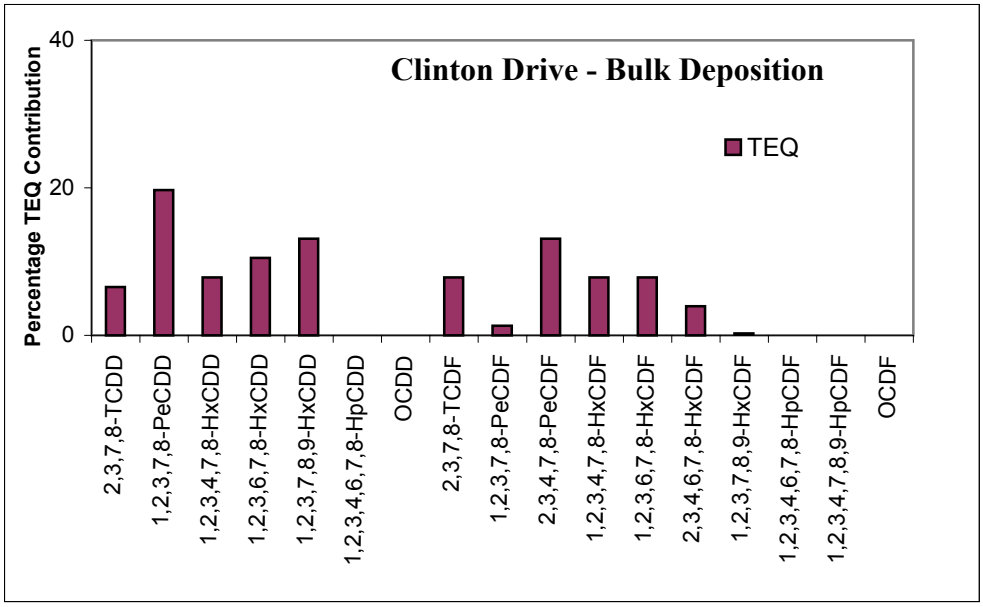


Figure 3.76 Bulk Deposition Profile

Table 3.34 Physical Characteristics of Soil/Sediment Samples collected during Runoff Sampling

Station ID	Date	Type	Solids Content %	TOC %	Gravel %	Coarse Sand %	Medium Sand %	Fine Sand %	Silt %	Clay %	Silt and Clay %
SS-10	12/16/2004	Residential	72.0	2.68	0.00	0.00	0.00	0.00	40.60	59.40	
		Urban	81.0	3.62	10.13	10.82	18.91	42.40	[a]	[a]	17.74
		Grass	74.6	3.59	0.00	0.00	7.01	31.38	40.90	20.71	
		Forest	56.4	3.77	0.00	0.00	0.00	0.00	50.94	49.06	
		Transitional	84.4	0.77	0.00	0.00	40.92	39.98	8.70	10.40	
		Sediment	53.8	3.42	0.00	0.00	0.00	0.00	33.01	66.99	
SS-13	01/13/2005	Woodland	67.6	3.24	0.00	0.00	0.00	0.00	44.08	55.92	
		Grass	76.6	3.99	0.00	0.00	0.00	27.70	48.94	23.37	
		Transitional	74.2	2.53	0.00	0.00	0.00	0.00	43.28	56.72	
		Urban/Road	75.2	2.06	0.00	0.00	0.00	0.00	40.51	59.49	
		Sediment	72.7	3.94	26.18	21.11	21.41	16.90	[a]	[a]	14.39
SS-9	01/27/2005	Forest	72.3	1.49	0.00	0.00	7.30	40.98	42.87	8.86	
		Grass	80.1	2.05	0.00	0.13	14.06	73.10	[a]	[a]	12.72
		Transitional	95.5	1.78	0.00	0.38	16.69	57.85	[a]	[a]	25.07
		Urban	98.9	5.66	21.53	17.30	21.65	31.09	[a]	[a]	8.43
		Residential	90.9	0.90	0.00	0.19	17.67	61.80	[a]	[a]	20.35
		Sediment	61.8	0.44	0.00	0.00	0.02	61.92	32.20	5.86	
SS-15[b]	02/24/2005	Urban/Residential	72.9	5.09	0.00	0.00	5.24	48.99	39.66	6.11	
		Urban	85.3	1.89	0.00	0.00	3.90	50.44	34.36	11.30	
		Grass	73.1	3.61	0	0	6.1	34.75	40.48	18.67	
		Forest	72.9	5.70	0	0	5.96	29.42	49.52	15.11	
		Transitional	79.7	1.77	0	0	5.52	37.84	48.89	7.74	
SS-14	03/02/2005	Sediment	63.4	0.92	0	0	0.02	33.48	55.54	10.96	
		Residential	77.9	2.84	0	0	2.55	43.14	48.01	6.29	
		Urban	70.7	2.70	0	0	2.61	38.62	47.64	11.13	
		Grass	68.9	2.56	0	0	5.51	36.3	46.7	11.48	
		Forest	66.5	4.24	0	0	2.96	37.51	43.01	16.53	
		Transitional	73.3	1.34	0	0	0.28	35.25	51.45	13.03	
SS-16	03/15/2005	Forest	76.6	3.56	0	0	0	38.69	52.45	8.86	
		Grass	74.2	4.24	3.43	13.37	38.13	27.71	[a]	[a]	17.35
		Urban	93.8	3.45	0	0	5.8	39.86	47.3	7.04	
		Urban/Residential	79.5	3.92	0	0	0	0	69.93	30.07	
		Transitional	83.0	1.88	0	0	5.05	42.64	43.94	8.37	
		Sediment	73.7	0.94	0	0	0.1	81.35	14.03	4.52	
SS-8	05/29/2005	Forest	82.2	1.82	0	0	0.6	25.6	59.6	14.3	
		Grass	80.9	2.62	0	0.2	1.4	18.2	63.70	16.50	
		Urban/Residential	80.9	1.90	0	0.1	2.7	24.7	58.70	13.8	
		Transitional	77.2	2.00	0	0	3.4	34.0	51.1	11.50	
		Sediment	81.5	1.78	0	0	5.3	39.0	42.8	13.0	
SS-7	07/14/2005	Urban/Residential	83.4	1.43	0	0.1	2.4	20.9	62.4	14.1	
		Sediment	79.9	1.75	34.6	25.4	15.4	14.9	7.8	2.0	

[a] Dry sieve data do not differentiate silt/clay fractions

[b] Sediment was not collected at this site because the ditch is concrete-lined

Table 3.35 Total Dioxin Concentrations in Runoff (pg/L)

Station ID	Date	Volume (L)	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ
Dissolved																				
SS-10	12/16/2004	707	< 0.0030	< 0.0071	0.0091	0.0170	0.0198	0.4243	5.3748	0.0311	0.0066	0.0120	0.0184	0.0102	0.0098	< 0.0021	< 0.0948	< 0.0058	0.1259	0.021
SS-13	01/13/2005	709	< 0.0039	0.0141	0.0381	0.0621	0.0677	3.5261	26.7983	0.0076	< 0.0032	0.0048	0.0103	0.0038	0.0071	< 0.0017	< 0.2257	< 0.0127	0.9591	0.031
SS-9	02/07/2005	698	< 0.0029	0.0119	0.0201	0.0301	0.0473	1.5759	108.8825	< 0.0158	0.0040	0.0046	0.0057	0.0544	0.0029	< 0.0019	< 0.0258	< 0.0023	0.0372	0.027
SS-15	02/24/2005	700	< 0.0016	< 0.0050	0.0053	0.0131	0.0127	0.3571	4.0000	< 0.0157	0.0024	0.0056	0.0077	0.0083	0.0044	< 0.0019	< 0.0529	< 0.0046	0.1343	0.011
SS-14	03/02/2005	700	< 0.0016	0.0054	0.0057	0.0157	0.0143	0.4000	3.7143	0.0200	0.0030	0.0071	0.0091	0.0067	0.0053	< 0.0019	< 0.0429	< 0.0039	0.0814	0.015
SS-16	03/16/2005	700	< 0.0017	< 0.0021	0.0019	0.0037	0.0040	0.0671	0.6429	< 0.0114	< 0.0017	0.0040	0.0036	0.0034	0.0020	< 0.0017	< 0.0123	< 0.0019	0.0271	0.006
SS-8	05/29/2005	708	< 0.0045	0.0083	0.0121	0.0367	0.0297	1.1017	15.5367	0.0381	0.0051	0.0133	0.0169	0.0198	0.0099	< 0.0023	< 0.0989	0.0097	0.1977	0.030
SS-7	07/14/2005	617	< 0.0194	< 0.0152	< 0.0088	0.0178	< 0.0160	0.4052	5.1864	0.0276	< 0.0194	< 0.0178	0.0178	< 0.0243	0.0128	< 0.0094	< 0.0405	0.0152	0.0827	0.029
Suspended-1 µm																				
SS-10	12/16/2004	707	0.0109	0.0453	0.0750	0.1697	0.1980	4.1018	55.1627	< 0.1697	0.0509	0.0820	0.2405	0.1132	0.1117	< 0.0059	< 1.1174	< 0.0622	1.6973	0.177
SS-13	01/13/2005	709	0.0096	0.0832	0.2398	0.4090	0.4513	22.5670	211.5656	0.0131	0.0103	0.0085	0.0465	< 0.0037	0.0254	< 0.0047	< 1.6925	< 0.0606	7.8984	0.175
SS-9	02/07/2005	698	0.0049	0.0358	0.0974	0.1576	0.2865	9.5989	902.5788	< 0.0172	0.0066	0.0085	0.0330	0.0186	0.0133	0.0039	< 0.1433	0.0095	0.3295	0.089
SS-15	02/24/2005	700	0.0070	0.0229	0.0286	0.0714	0.0929	2.0000	22.8571	0.0314	0.0087	0.0143	0.0400	0.0414	0.0243	< 0.0019	< 0.3714	0.0186	1.0143	0.059
SS-14	03/02/2005	700	0.0066	0.0329	0.0529	0.1329	0.1714	4.0000	44.2857	0.0500	0.0171	0.0214	0.0786	0.0700	0.0429	< 0.0037	0.6571	0.0400	1.4000	0.095
SS-16	03/16/2005	700	< 0.0023	0.0026	0.0033	0.0070	0.0073	0.1571	1.4286	0.0070	< 0.0024	0.0033	0.0070	0.0069	0.0039	< 0.0024	< 0.0343	< 0.0027	0.0814	0.008
SS-8	05/29/2005	708	0.0047	0.0339	0.0664	0.1836	0.1836	5.6497	137.0056	0.0664	0.0212	0.0325	0.1144	0.1017	0.0621	0.0038	< 1.0028	0.0579	2.2599	0.117
SS-7	07/14/2005	617	< 0.0259	0.0454	0.0810	0.1783	0.1783	5.3485	66.4506	0.0583	0.0227	0.0227	0.0972	0.3890	0.0697	< 0.0151	1.2480	0.0632	2.5932	0.154
Suspended-40 µm																				
SS-10	12/16/2004	707	< 0.0062	0.0297	< 0.0438	0.1047	0.1301	2.6874	35.3607	0.1103	0.0339	0.0552	0.1556	0.0721	0.0736	< 0.0042	< 0.7921	< 0.0438	1.1174	0.114
SS-13	01/13/2005	709	0.0103	0.0776	0.2398	0.4090	0.4372	21.1566	211.5656	0.0116	0.0093	< 0.0062	0.0381	< 0.0031	0.0226	< 0.0039	< 1.6925	< 0.0564	8.3216	0.167
SS-9	02/07/2005	698	0.0037	0.0287	0.0731	0.1160	0.2149	7.4499	702.0057	0.0129	0.0044	0.0060	0.0215	0.0112	0.0089	0.0027	< 0.1032	< 0.1032	0.2436	0.067
SS-15	02/24/2005	700	0.0091	0.0271	0.0343	0.0814	0.1143	2.2857	25.7143	0.0357	0.0104	0.0157	0.0671	0.0586	0.0314	< 0.0019	< 0.4714	< 0.0243	1.1143	0.073
SS-14	03/02/2005	700	0.0053	0.0314	0.0500	0.1286	0.1429	3.8571	40.0000	< 0.0486	0.0143	0.0214	0.0771	0.0914	0.0429	0.0027	< 0.6143	< 0.0386	1.3857	0.088
SS-16	03/16/2005	700	< 0.0021	< 0.0021	< 0.0021	0.0034	0.0043	0.0786	0.8000	< 0.0034	< 0.0020	0.0023	0.0034	0.0033	< 0.0020	< 0.0020	< 0.0186	< 0.0033	0.0400	0.005
SS-8	05/29/2005	708	0.0102	0.0508	0.0989	0.2542	0.2684	7.9096	197.7401	0.0960	0.0297	0.0438	0.1695	0.1384	0.0862	0.0066	1.3842	0.0791	3.1073	0.171
SS-7	07/14/2005	617	0.0357	0.1118	0.1507	0.3241	0.3566	9.7245	124.7974	0.1102	0.0340	0.0389	0.1621	0.7293	0.1021	< 0.0340	2.2690	0.1118	5.3485	0.308
Total																				
SS-10	12/16/2004	707	< 0.0201	< 0.0820	< 0.1279	0.2914	0.3479	7.2136	95.8982	< 0.3112	0.0915	0.1492	0.4144	0.1955	0.1950	< 0.0123	< 2.0042	< 0.1119	2.9406	0.312
SS-13	01/13/2005	709	< 0.0238	0.1749	0.5176	0.8801	0.9563	47.2496	449.9295	0.0323	< 0.0228	< 0.0195	0.0949	< 0.0106	0.0550	< 0.0103	< 3.6107	< 0.1298	17.1791	0.373
SS-9	02/07/2005	698	< 0.0115	0.0764	0.1905	0.3037	0.5487	18.6246	1713.4670	< 0.0458	0.0150	0.0191	0.0602	0.0842	0.0251	< 0.0085	< 0.2722	< 0.1149	0.6103	0.183
SS-15	02/24/2005	700	< 0.0177	< 0.0550	0.0681	0.1660	0.2199	4.6429	52.5714	< 0.0829	0.0216	0.0356	0.1149	0.1083	0.0601	< 0.0056	< 0.8957	< 0.0474	2.2629	0.144
SS-14	03/02/2005	700	< 0.0134	0.0697	0.1086	0.2771	0.3286	8.2571	88.0000	< 0.1186	0.0344	0.0500	0.1649	0.1681	0.0910	< 0.0083	< 1.3143	< 0.0824	2.8671	0.198
SS-16	03/16/2005	700	< 0.0061	< 0.0069	< 0.0073	0.0141	0.0156	0.3029	2.8714	< 0.0219	< 0.0061	0.0096	0.0140	0.0136	< 0.0079	< 0.0061	< 0.0651	< 0.0079	0.1486	0.019
SS-8	05/29/2005	708	< 0.0194	0.0931	0.1774	0.4746	0.4816	14.6610	350.2825	0.2006	0.0559	0.0895	0.3008	0.2599	0.1582	< 0.0127	< 2.4859	0.1468	5.5650	0.318
SS-7	07/14/2005	617	< 0.0810	< 0.1724	< 0.2405	0.5203	< 0.5509	15.4781	196.4344	0.1961	< 0.0762	< 0.0794	0.2771	< 1.1426	0.1846	< 0.0585	< 3.5575	0.1903	8.0243	0.491

Provisional data. Do not reference or cite.

Values reported to the Detection Limit

Non-detects assumed as 1/2 MDL for TEQ calculations

If either the dissolved or suspended concentration was non-detect, the total concentration in water was reported here as less than the sum of the detected concentration and the MDL for the non-detected phase. If a congener was non-detected in both phases, the total concentration in water was reported as less than the sum of the MDL for both phases

Exceeds the Texas WQS (0.0933 pg/L)

concentrations varied between 0.019 and 0.491 pg/L, with an average of 0.255 pg/L. Seven of the eight samples (88%) exceeded the Texas WQS of 0.0933 pg/L. It is noted that the concentrations measured in runoff were at or below the levels measured in the in-stream water of the HSC.

The profiles in both phases (dissolved and suspended) were dominated by the higher chlorinated congeners OCDD, 1234678-HpCDD, and OCDF. Particularly for OCDD, this congener contributed over 82% of the total dioxin mass that was observed in both phases (dissolved and suspended) at all monitoring sites. The congener 2378-TCDD was detected only in the 1- and 40-μm suspended phases with average contributions of (mean±std) 0.018 ± 0.021 and 0.024 ± 0.040 % to the total dioxin mass, respectively. Dioxin profiles for the dissolved and suspended (1 μm and 40 μm) phases are illustrated in Figures 3.77 to 3.79.

The general distribution of the total dioxin mass between the dissolved and suspended phases is depicted in Figure 3.80. It is noted that approximately between 78 and 96% of the total dioxin mass was associated with the particulate phase (1 and 40 μm). This characteristic is similar to the distribution of the dioxin congeners in the particle and gas phases in the ambient air where over 70% of the total dioxin mass was detected bound to atmospheric particles. A comparison between the 1- and 40 μm suspended-phase samples showed that with the exception of sites SS-15 and SS-8, the total dioxin mass was mainly bound to fine particles (<1 μm). Particles in the size range (<2.5 μm) are known to be the result of anthropogenic activities such as diesel-fueled vehicle emissions.

Similar to the distribution of the total dioxin mass between the suspended and dissolved phases, the TEQ distribution is illustrated in Figure 3.81. On average, approximately 80% of the total TEQ (suspended + dissolved) was found associated with particulate matter. 12378-PeCDD,

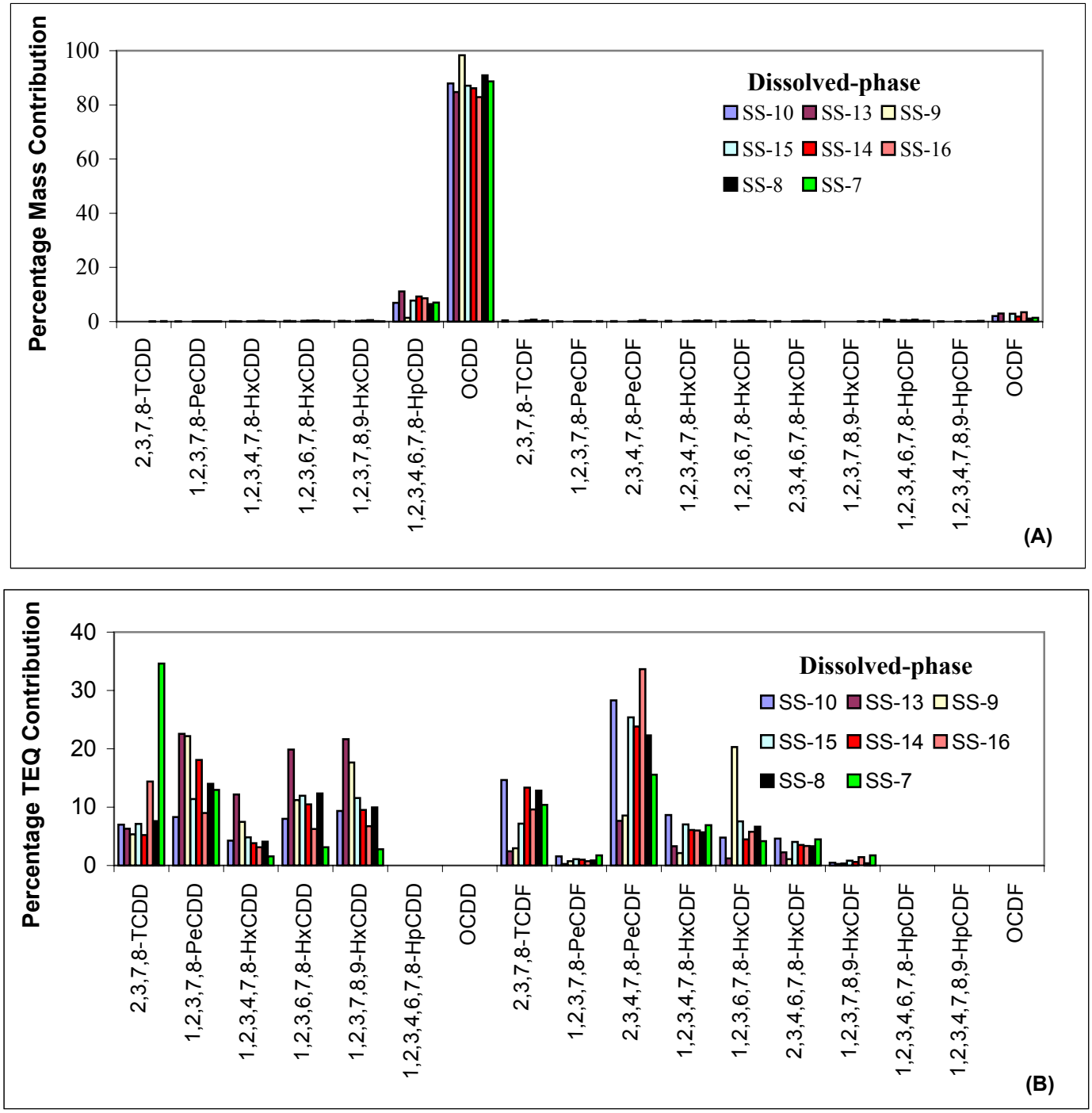


Figure 3.77 Dissolved-Phase Profile of Dioxins: (A) Mass; (B) TEQ.

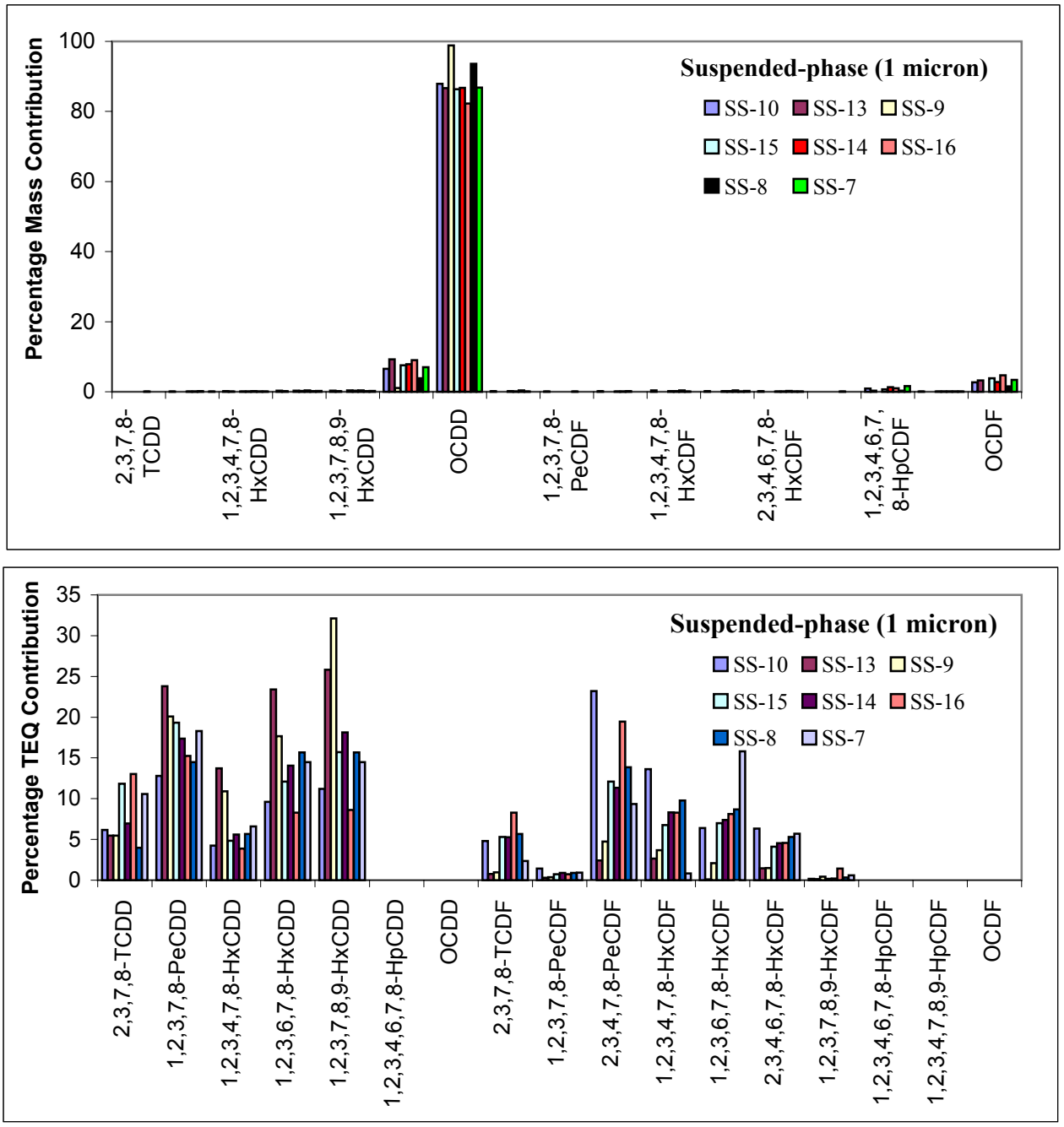
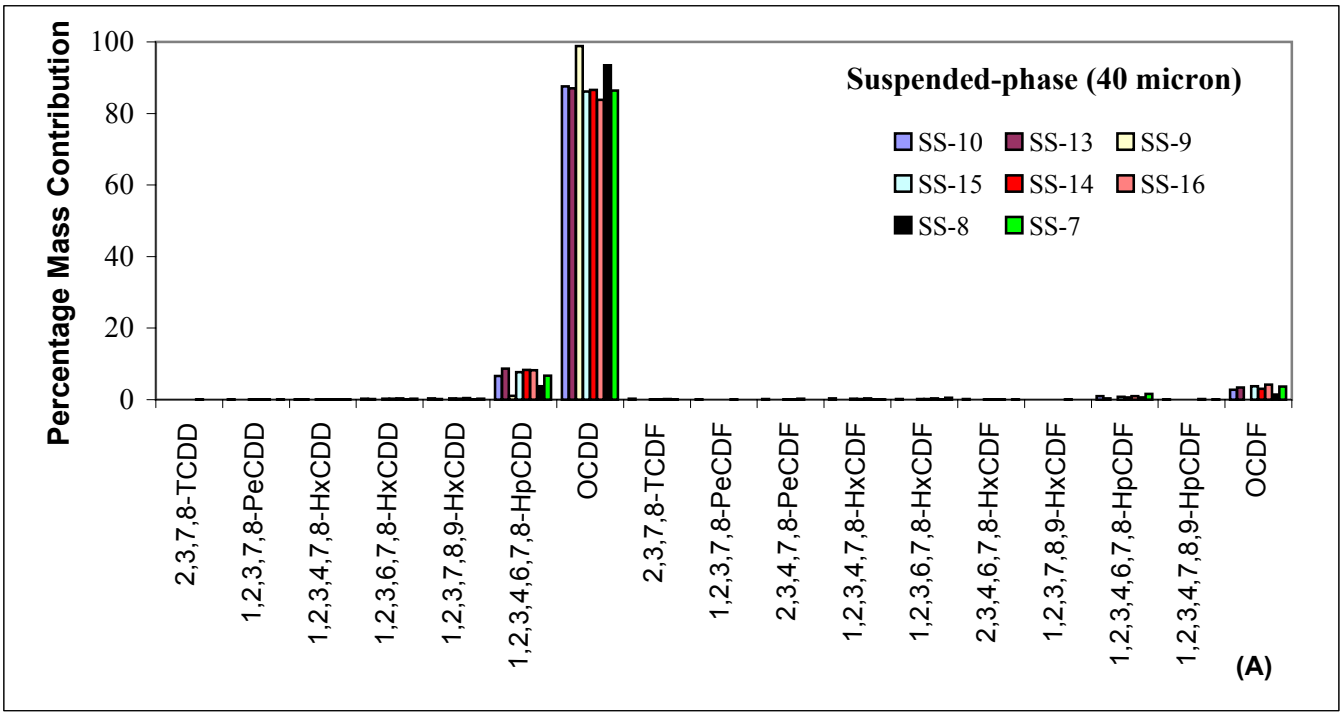


Figure 3.78 Suspended-Phase (1 micron) Profile of Dioxins: (A) Mass; (B) TEQ.



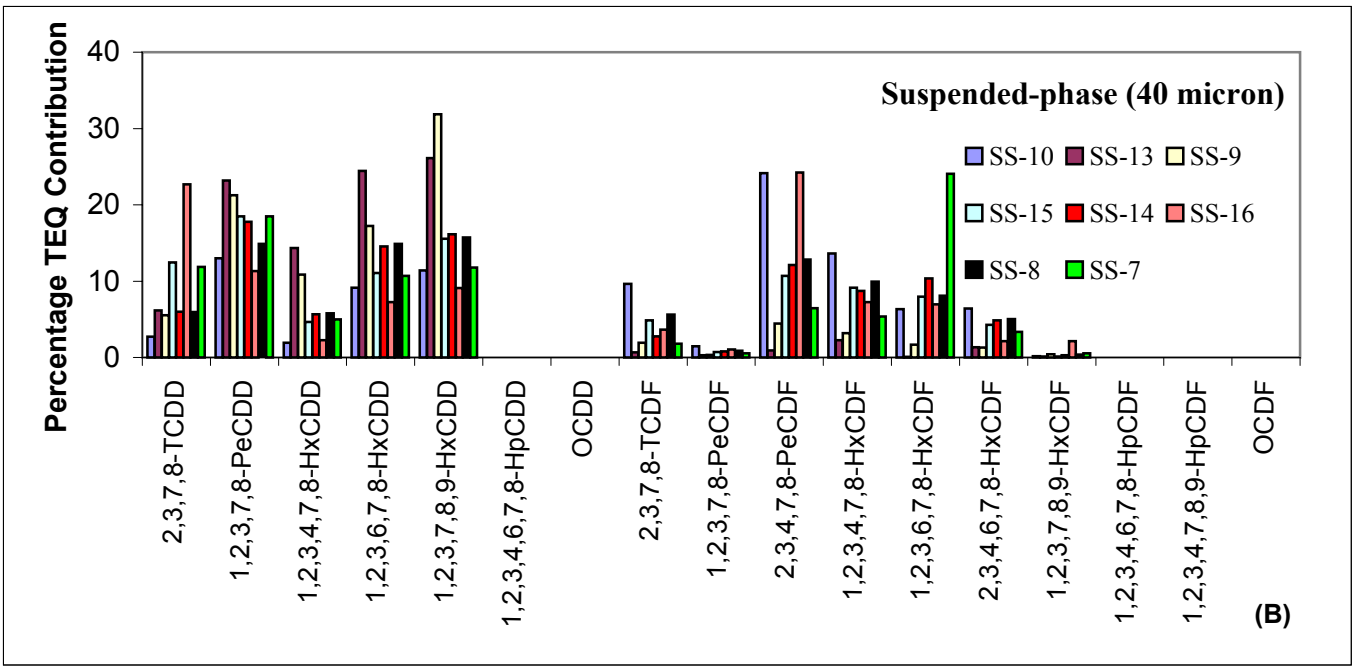


Figure 3.79 Suspended-Phase (40 micron) Profile of Dioxins: (A) Mass; (B) TEQ.

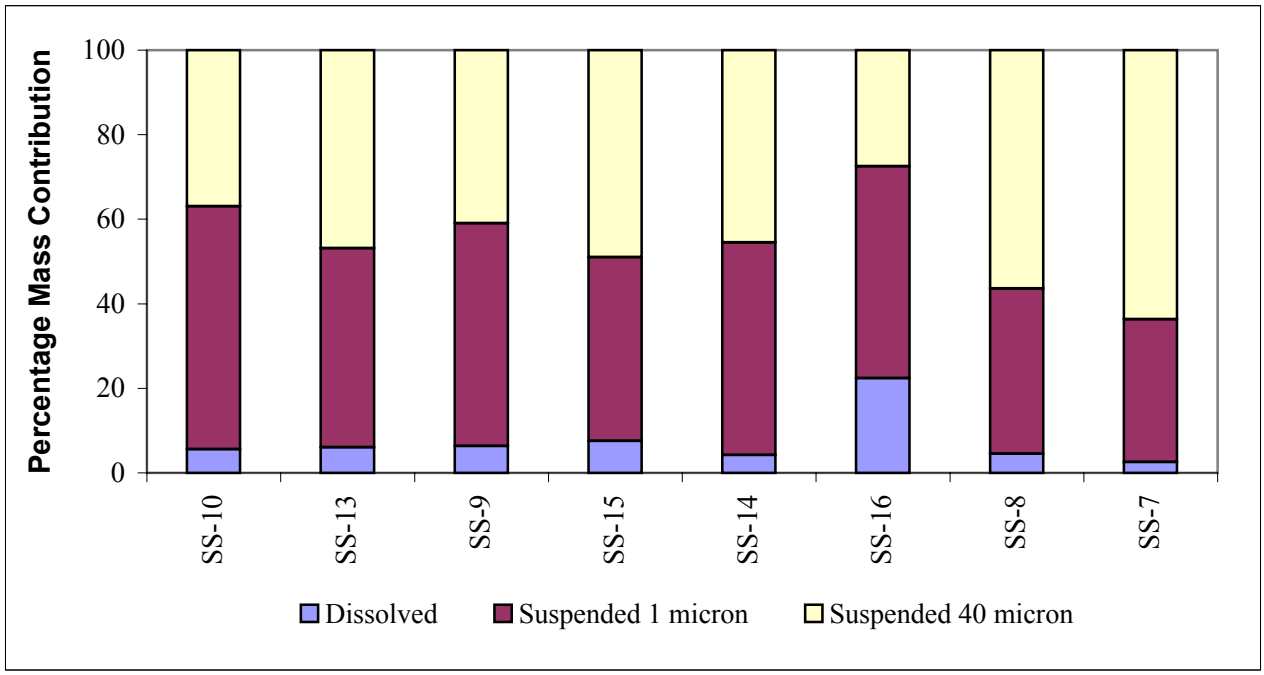


Figure 3.80 Distribution of Total Dioxin Mass in Houston Urban Runoff

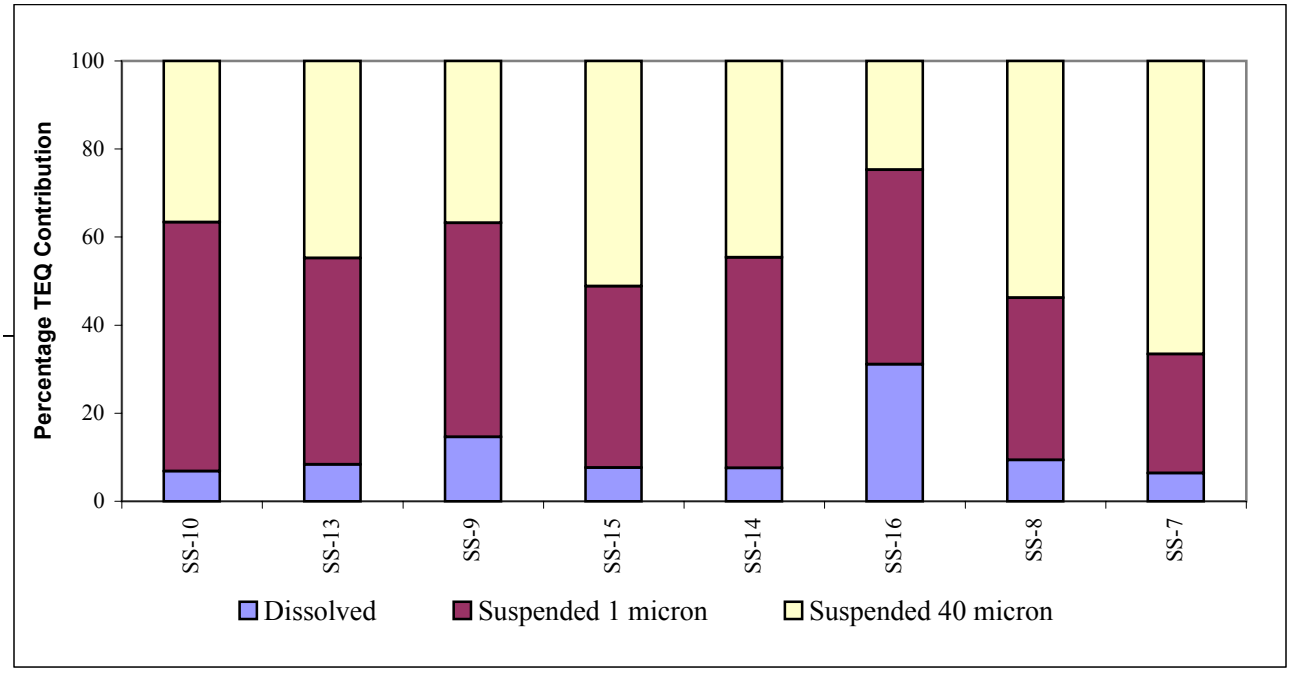


Figure 3.81 Distribution of TEQ in Houston Urban Runoff

123789-HxCDD, and 23478-PeCDF were found as the major contributors to the total TEQ in the dissolved and suspended phases. The combined average contributions of these three congeners to the TEQs in the dissolved, and 1- and 40-mm suspended phases were 48.8 ± 2.2, 48.2 ± 4.7, and 47.9 ± 4.9 %, respectively. Likewise, 2378-TCDD was found contributing respectively an average of 7.6 ± 3.1, 7.6 ± 3.5, and 8.8 ± 6.8 % to the total TEQ.

Soil/sediment Samples

One sediment sample and up to five soil samples were collected from the drainage area of each of the runoff sites. The soil samples were representative of different land uses: forest, grass, urban, transitional, and residential. Transitional soil refers to a sample collected from a boundary between two defined land uses. Tables 3.36 and 3.37 provide a summary of the dioxin results obtained for sediment samples that were collected during runoff conditions and prior to runoff sampling in September-October/2004. As shown in Tables 3.36 and 3.37, sediment concentrations ranged from 0.27 (SS-16) to 2.75 ng TEQ/kg-dry wt (SS-10) under runoff conditions, and from 0.35 (SS-16) to 4.28 (SS-9) ng TEQ/kg-dry wt. for samples collected prior to runoff. Total TEQ concentrations for sediment samples collected during runoff conditions were additionally normalized by TOC content. Concentrations fluctuating from 18.4 (SS-8) to 261 (SS-9) ng TEQ/kg-oc were determined. It was noted that while 2378-TCDD was found below the detection limit in the set of sediment samples collected during runoff conditions, this same congener was detected in only one of the soil samples collected prior to runoff sampling (i.e., SS-9) (Table 3.37) at a concentration of 0.33 ng/kg-dry wt. This concentration of 2378-TCDD represented a contribution of ~8% to the total TEQ.

The individual contribution of each congener to the total dioxin sediment dioxin mass

Table 3.36 Dioxins in Houston Urban Sediment during Runoff Conditions (ng/kg-dry wt.)

Congener	SS-10	SS-13	SS-9	SS-14	SS-16	SS-8	SS-7
2,3,7,8-TCDD	<0.54	<0.16	<0.16	<0.16	<0.16	<0.16	<0.17
1,2,3,7,8-PeCDD	<1.20	<0.42	0.57	0.69	<0.18	<0.18	0.66
1,2,3,4,7,8-HxCDD	1.6	1	1.2	1.1	<0.23	<0.23	1.1
1,2,3,6,7,8-HxCDD	4.4	2.4	2.2	2.3	<0.18	0.32	8
1,2,3,7,8,9-HxCDD	3.6	2	2.7	2	<0.2	0.25	5.2
1,2,3,4,6,7,8-HpCDD	85	58	110	53	2.6	9.8	310
OCDD	1000	670	4800	800	30	560	3900
2,3,7,8-TCDF	1.4	<0.24	<0.24	0.5	<0.23	<0.24	0.38
1,2,3,7,8-PeCDF	<1.00	<0.2	<0.2	0.3	<0.20	<0.2	<0.25
2,3,4,7,8-PeCDF	1.2	<0.23	<0.23	0.41	<0.23	<0.23	0.4
1,2,3,4,7,8-HxCDF	1.1	<0.6	0.42	0.8	<0.18	0.24	1.6
1,2,3,6,7,8-HxCDF	0.8	<0.99	0.26	<0.23	<0.23	<0.23	<7.2
2,3,4,6,7,8-HxCDF	2.1	<1.3	0.3	<0.26	<0.25	<0.26	<0.93
1,2,3,7,8,9-HxCDF	<1.10	<0.21	<0.21	<0.21	<0.21	<0.21	0.38
1,2,3,4,6,7,8-HpCDF	15	<18	2.4	9.3	0.54	1.4	<6.1
1,2,3,4,7,8,9-HpCDF	<3.50	<0.96	0.24	0.93	<0.20	<0.20	6.5
OCDF	34	21	5.2	23	1.5	3.3	400
Σ(PCDD+PCDF)[a]	1153.87	766.06	4926.01	894.76	35.98	576.38	4642
Total TEQ[a]	2.75	0.95	1.16	1.35	0.27	0.33	2.69
TOC %	3.42	3.94	0.444	0.916	0.936	1.78	1.75
Total OC-TEQ[a, b]	80.41	25.88	260.81	147.38	29.17	18.37	153.93
Date	12/16/2004	01/13/2005	02/07/2005	03/02/2005	03/16/2005	05/29/2005	07/14/2005

[a] Non-detects assumed as 1/2 MDL for calculations

[b] Normalized by TOC content (concentrations in ng/kg-oc)

Sediment was not collected at SS-15 because the ditch is concrete-lined

Table 3.37 Dioxins in Houston Urban Sediment Prior to Runoff Sampling (ng/kg-dry wt.)

Congener	SS-5	SS-14	SS-15	SS-16	SS-108	SS-7	SS-8	SS-9	SS-10A	SS-13	SS-10B
2,3,7,8-TCDD	<0.54	<0.89	<2.50	<0.18	<0.22	<0.47	<0.47	0.33	<0.37	<0.39	<2.50
1,2,3,7,8-PeCDD	<0.35	<1.40	<4.60	<0.28	<0.37	0.55	<0.31	2.6	<0.29	1	<4.60
1,2,3,4,7,8-HxCDD	<0.41	<2	<4.20	<0.42	0.6	0.62	<0.42	4.7	<0.41	2	<4.20
1,2,3,6,7,8-HxCDD	0.58	<1.10	<2.40	0.29	1.6	1.6	0.8	7.5	0.27	4.4	<2.40
1,2,3,7,8,9-HxCDD	0.76	<1.60	<3.30	0.34	<0.33	0.93	0.59	12	<0.32	2.9	<3.30
1,2,3,4,6,7,8-HpCDD	11	20	77	5.9	36	47	11	390	4.2	130	77
OCDD	240	560	840	61	480	840	150	31000	47	1900	840
2,3,7,8-TCDF	<0.23	<1.1	<3.20	<0.23	0.44	0.43	<0.23	0.26	<0.23	<0.24	<3.20
1,2,3,7,8-PeCDF	<0.23	<0.80	<1.70	<0.16	<0.18	<0.17	<0.17	<0.33	<0.16	0.35	<1.70
2,3,4,7,8-PeCDF	<0.14	<0.71	<2.10	<0.15	0.36	0.7	<0.18	<0.19	<0.14	<0.29	<2.10
1,2,3,4,7,8-HxCDF	<0.35	<1.20	<3	<0.25	0.56	<0.32	<0.35	<0.25	<0.25	0.96	<3
1,2,3,6,7,8-HxCDF	<0.32	<1.60	<3.50	<0.32	<0.32	<0.33	<0.38	0.44	<0.32	0.74	<3.50
2,3,4,6,7,8-HxCDF	0.21	<0.89	<1.90	<0.18	0.39	0.8	0.39	0.41	<0.18	0.97	<1.90
1,2,3,7,8,9-HxCDF	<0.22	<1.10	<2.30	<0.22	0.69	0.24	<0.28	0.47	<0.22	<0.25	<2.30
1,2,3,4,6,7,8-HpCDF	1.7	2.3	<3.00	1	4.3	6.2	2.2	3.6	0.82	18	<3
1,2,3,4,7,8,9-HpCDF	<0.28	<1.4	<2.80	<0.28	<0.28	0.6	<0.36	<0.28	<0.28	1.1	<2.80
OCDF	4	4.3	30	2.2	15	22	3.2	13	1.5	58	30
Σ(PCDD+PCDF)[a]	259.79	594.5	967.25	72.07	540.79	922.32	169.76	31435.84	55.38	2121.01	967.25
ΣTexas-TEQ[a]	0.63	1.52	4.16	0.35	0.85	1.36	0.62	4.28	0.42	2.01	4.16
Date	09/30/2004	09/30/2004	09/30/2004	09/30/2004	09/30/2004	10/01/2004	10/01/2004	10/01/2004	10/01/2004	10/01/2004	10/01/2004

[a] Non-detects assumed as 1/2 MDL for calculations

concentration both during runoff sampling and prior to runoff sampling is depicted in Figure 3.82. The higher chlorinated congeners were found to be the major contributors to the total dioxin mass concentration. The combined contribution of 1234678-HpCDD, OCDD, 1234678-HpCDF, and OCDF to the total dioxin sediment dioxin mass concentration at all of the sites was found to be >95%. Similarly, 2378-TCDD was found to contribute with <0.3% to the total dioxin mass concentration. The profiles shown in Figure 3.82 resemble the profiles found for dioxins in ambient air; mainly, the higher chlorinated congeners were the most abundant congeners.

Tables 3.38 and 3.39 summarize the dioxin concentrations obtained for different types of soil (forest, grass, residential, urban, and transitional) in samples collected during runoff conditions and prior to runoff sampling, respectively. Concentrations of 0.82±0.80, 1.18±1.34, 1.19±0.93, 0.92±0.37, and 2.73±5.67 ng TEQ/kg-dry wt. were measured for the aforementioned types of soil, respectively. The congener 2378-TCDD was detected only in the following soils and sites: Grass (SS-8), Residential (SS-16), Urban (SS-15), and Transitional (SS-16), at concentrations of 0.94, 0.51, 0.19, and 0.51 ng/kg-dry wt., respectively. Profiles for each type of soil are illustrated in Figures 3.83 through 3.87. Similar to runoff and sediment samples, the profiles were dominated by the higher chlorinated congeners, especially OCDD.

A database of storm water sampling results reported by PSC Philips Analytical Laboratory and of the soil/sediment results reported by Pace Analytical is included in Appendix B4.

3.2.3 Flow Measurements in Support of Modeling Activities

As mentioned in Section 3.1.3, flow measurements were collected at least once per day during the course of a 1-week period using the RiverCat. Each time flow was measured, a minimum of 4 different flow readings was collected to assure data of adequate quality. In

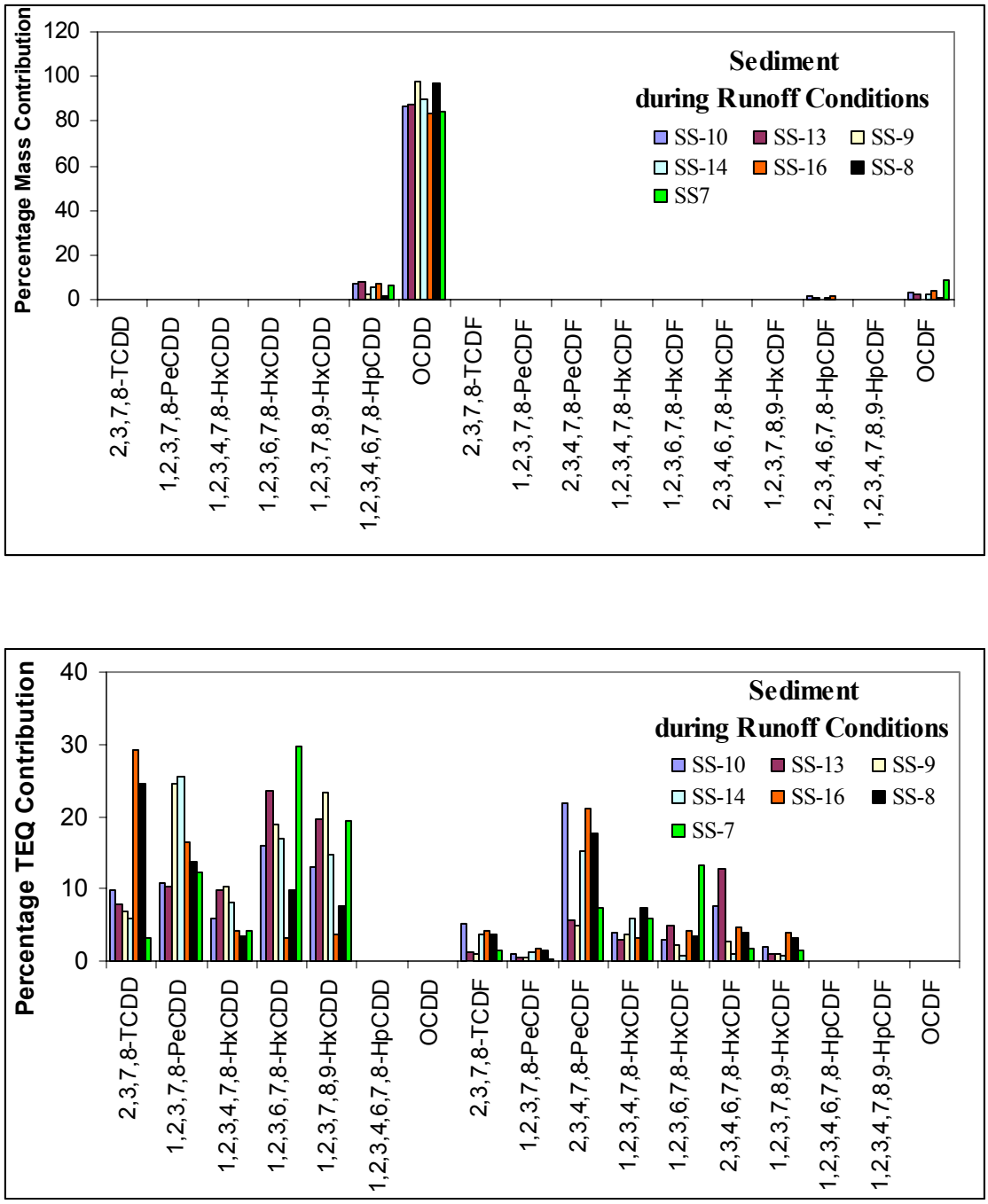


Figure 3.82 Fraction Contribution of Dioxins in Houston Sediment during Runoff and Dry Conditions

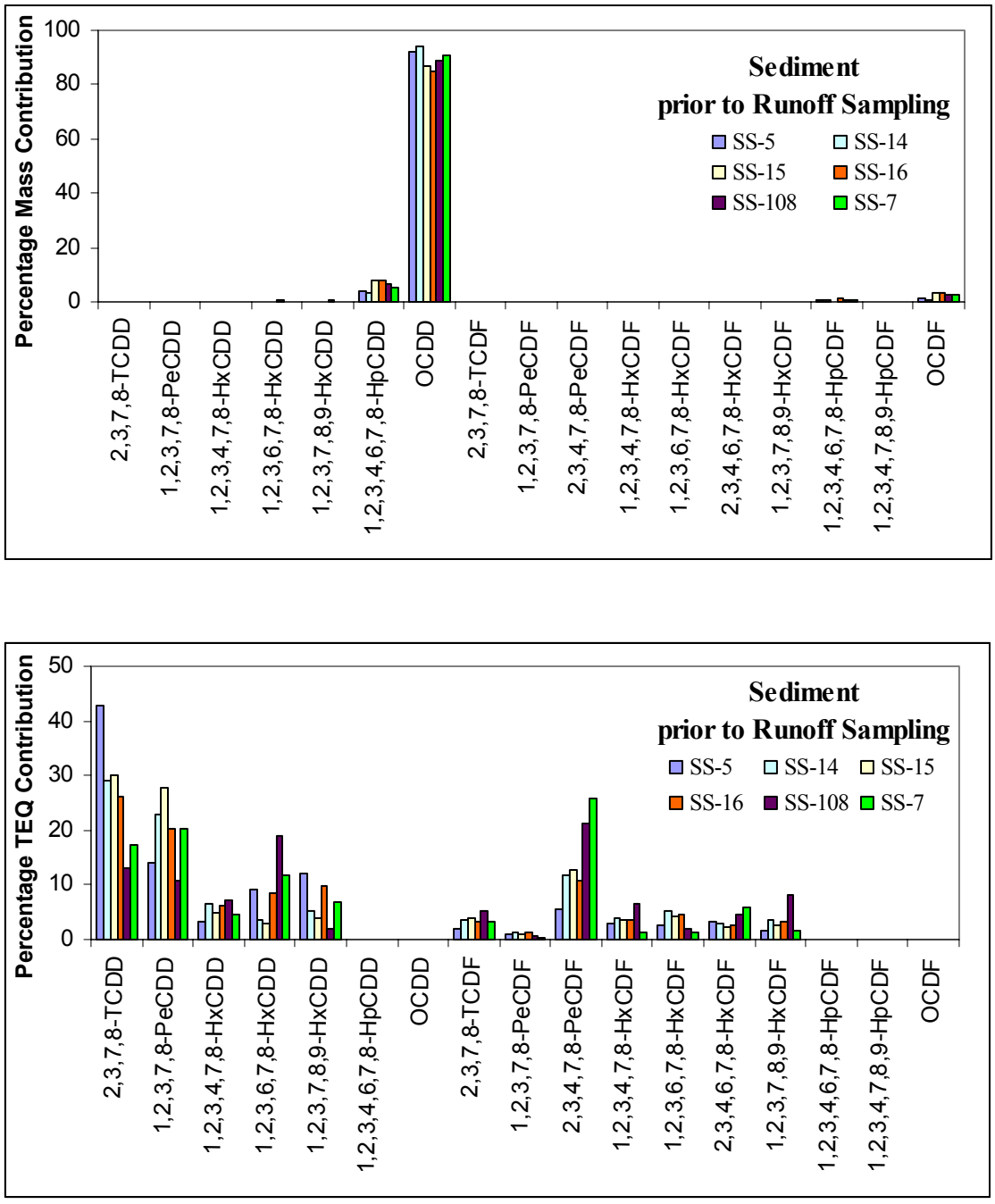


Figure 3.82 Fraction Contribution of Dioxins in Houston Sediment during Runoff and Dry Conditions – Cont'd

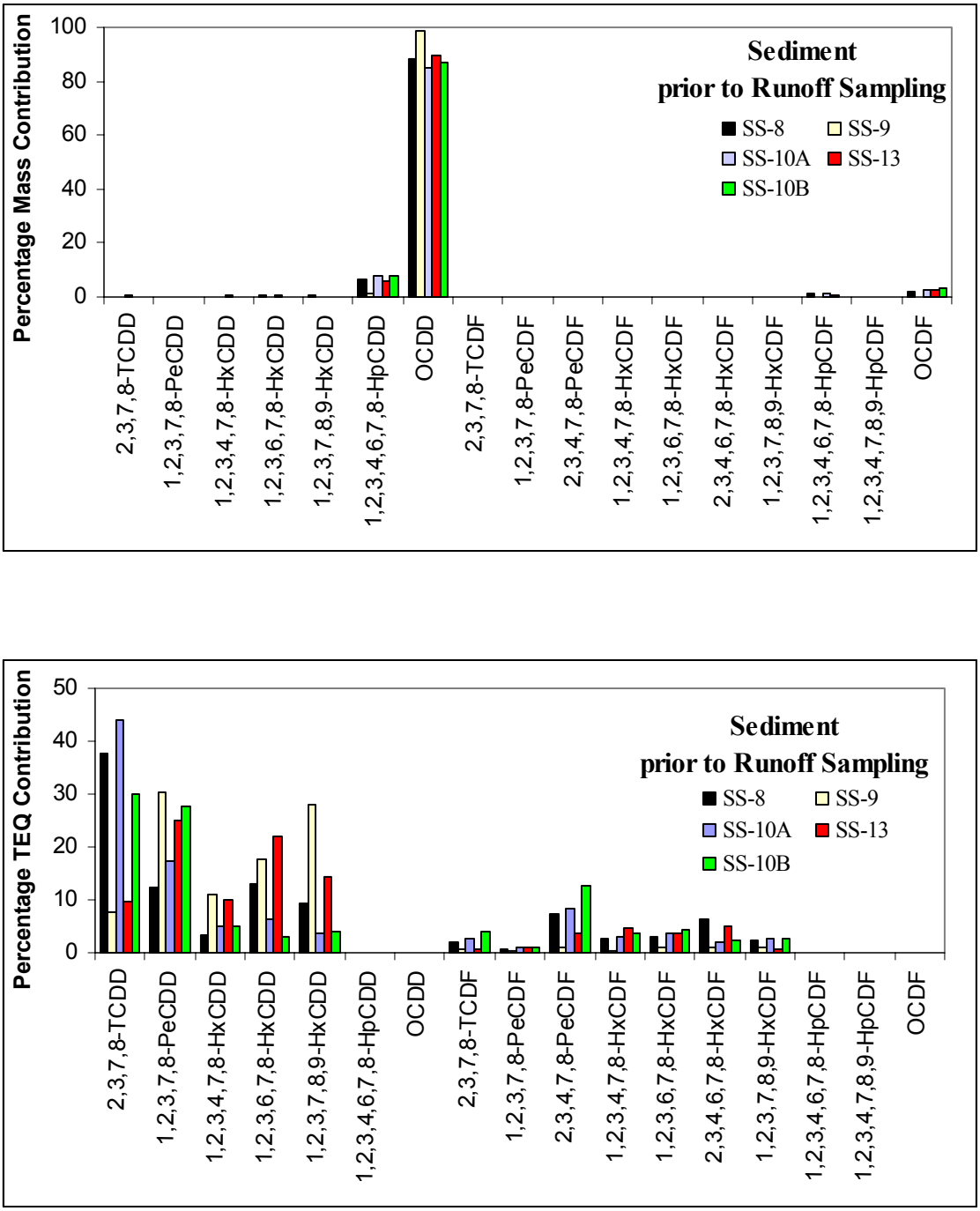


Figure 3.82 Fraction Contribution of Dioxins in Houston Sediment during Runoff and Dry Conditions – Cont'd

Table 3.38 Dioxins in Houston Soil collected during Runoff Conditions (ng/kg-dry wt.)

Congener	Forest							Grass							Residential						
	SS-10	SS-13	SS-9	SS-15	SS-14	SS-16	SS-8	SS-10	SS-13	SS-9	SS-15	SS-14	SS-16	SS-8	SS-10	SS-9	SS-15	SS-14	SS-16	SS-8	SS-7
2,3,7,8-TCDD	<0.17	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.16	<0.23	<0.16	<0.15	<0.16	<0.16	0.94	<0.16	<0.16	<0.21	<0.16	0.51	<0.16	<0.14
1,2,3,7,8-PeCDD	<0.19	0.18	0.51	<0.18	<0.18	<0.18	3.2	0.22	<0.33	<0.18	0.53	<0.18	<0.18	0.83	<0.18	0.53	1.2	0.29	0.32	0.23	0.33
1,2,3,4,7,8-HxCDD	<0.24	0.23	1.6	0.27	<0.23	0.31	6.5	0.28	<0.94	0.97	0.78	<0.23	<0.22	1.9	0.25	1.3	<0.22	0.47	<0.23	<0.23	0.42
1,2,3,6,7,8-HxCDD	0.32	0.31	2.1	0.74	<0.18	1.1	62	0.57	2.3	1	2.7	0.66	0.28	6	<0.18	1.7	4.2	1	0.98	0.49	2.8
1,2,3,7,8,9-HxCDD	<0.21	0.38	2.5	<0.2	<0.2	0.6	14	0.52	1.2	1.4	1.6	0.45	<0.20	2.9	<0.19	2.2	4.7	0.67	0.79	0.3	1.1
1,2,3,4,6,7,8-HpCDD	9.2	8.8	100	16	4.9	29	830	10	88	49	56	14	9.2	230	6.8	81	100	20	20	12	61
OCDD	2700	360	4700	150	43	610	6600	100	1300	3400	620	200	83	2300	140	4300	1200	210	200	110	550
2,3,7,8-TCDF	<0.25	0.24	<0.24	<0.24	<0.24	<0.23	0.62	0.25	<0.40	<0.24	0.58	<0.24	<0.23	3.7	<0.23	<0.24	0.78	<0.23	2	<0.24	0.22
1,2,3,7,8-PeCDF	<0.21	<0.2	<0.2	0.68	<0.2	<0.23	2.4	<0.19	<0.52	<0.20	<0.21	<0.20	<0.20	1	<0.19	<0.20	0.37	0.25	0.92	<0.2	0.21
2,3,4,7,8-PeCDF	<0.24	<0.23	<0.23	0.45	<0.23	0.36	5.7	<0.22	<0.45	<0.23	0.72	<0.23	<0.22	1.2	<0.22	<0.23	1.1	0.36	0.71	<0.23	0.35
1,2,3,4,7,8-HxCDF	<0.19	0.18	0.36	0.77	0.2	0.67	6	0.38	<0.54	0.33	<0.17	0.28	0.24	<0.18	<0.18	0.41	2.4	0.57	2.1	0.28	0.52
1,2,3,6,7,8-HxCDF	<0.24	<0.23	0.25	0.53	<0.23	0.34	5.5	<0.31	<0.84	<0.23	0.84	<0.23	<0.22	2.7	<0.22	<0.23	1.9	0.41	0.68	<0.23	0.59
2,3,4,6,7,8-HxCDF	<0.27	<0.26	0.35	0.72	<0.26	0.57	9.8	<0.25	<0.25	0.28	1.5	0.26	<0.25	3.1	<0.25	<0.26	2.1	0.52	0.65	<0.25	0.37
1,2,3,7,8,9-HxCDF	<0.22	<0.21	<0.21	<0.21	<0.21	0.23	4.9	<0.20	<0.23	<0.21	<0.20	<0.21	<0.20	0.45	<0.20	<0.21	0.61	<0.21	0.33	<0.21	<0.14
1,2,3,4,6,7,8-HpCDF	<0.33	0.57	7.4	7.5	2	8.3	110	1.7	7	2.9	24	3.8	2.3	42	0.97	2.8	29	4.6	5.2	2.4	<4.9
1,2,3,4,7,8,9-HpCDF	<0.21	<0.36	0.41	0.57	0.28	<0.2	5.5	<0.40	<0.39	0.2	1.4	<0.42	0.21	3.1	<0.22	<0.20	1.8	0.49	0.59	<0.20	<0.49
OCDF	0.91	2.5	24	18	5.2	26	250	3.8	25	7.9	81	10	5.2	92	2.7	7.5	56	10	10	4.3	10
Σ(PCDD+PCDF)[a]	2711.915	374.215	4840	196.725	56.74	678.08	7916.2	118.59	1426.06	3464.71	792.02	230.5	101.47	2691.91	151.93	4398.31	1406.38	249.93	245.9	130.98	630.75
Total TEQ[a]	0.31075	0.4015	1.136	0.7195	0.285	0.70425	15.582	0.49	0.83	0.62	1.52	0.4	0.3	4.09	0.28	1.02	2.95	0.8	1.84	0.42	1.03
TOC %	0.773	2.53	1.78	1.77	1.34	1.88	2	3.59	3.99	2.05	3.61	2.56	4.24	2.62	2.68	0.898	5.09	2.84	3.92	1.9	1.43
Total OC-TEQ[a,b]	40.2005175	15.86957	63.820225	40.649718	21.26866	37.460106	779.1	13.59	20.88	30.22	42.21	15.55	7.15	156.07	10.53	113.08	58.03	28.29	46.82	22.24	31.06
Date	12/16/2004	1/13/2005	1/27/2005	2/24/2005	3/2/2005	3/15/2005	5/29/2005	12/16/2004	1/13/2005	1/27/2005	2/24/2005	3/2/2005	3/15/2005	5/29/2005	12/16/2004	1/27/2005	2/24/2005	3/2/2005	3/15/2005	5/29/2005	7/14/2005

Congener	Urban						Transitional						
	SS-10	SS-13	SS-9	SS-15	SS-14	SS-16	SS-10	SS-13	SS-9	SS-15	SS-14	SS-16	SS-8
2,3,7,8-TCDD	<0.24	<0.22	<0.16	0.19	<0.16	<0.16	<0.16	<0.16	<0.16	<0.21	<0.16	0.51	<0.16
1,2,3,7,8-PeCDD	<0.30	0.37	0.68	<0.20	<0.18	<0.18	<0.18	0.18	0.53	1.2	0.29	0.32	0.23
1,2,3,4,7,8-HxCDD	<1	0.79	<0.23	1.2	<0.23	0.7	0.25	0.23	1.3	<0.22	0.47	<0.23	<0.23
1,2,3,6,7,8-HxCDD	1.7	1.2	<0.18	2.2	0.35	2.9	<0.18	0.31	1.7	4.2	1	0.98	0.49
1,2,3,7,8,9-HxCDD	2.5	1.5	2.3	2.4	<0.20	1.6	<0.19	0.38	2.2	4.7	0.67	0.79	0.3
1,2,3,4,6,7,8-HpCDD	45	33	64	43	7.8	82	6.8	8.8	81	100	20	20	12
OCDD	720	840	2400	420	88	880	140	360	4300	1200	210	200	110
2,3,7,8-TCDF	0.7	<0.30	<0.24	0.3	<0.24	0.24	<0.23	0.24	<0.24	0.78	<0.23	2	<0.24
1,2,3,7,8-PeCDF	<0.53	<0.19	<0.20	0.29	<0.2	0.26	<0.19	<0.2	<0.20	0.37	0.25	0.92	<0.2
2,3,4,7,8-PeCDF	0.49	<0.22	<0.23	0.44	<0.23	0.36	<0.22	<0.23	<0.23	1.1	0.36	0.71	<0.23
1,2,3,4,7,8-HxCDF	<0.34	0.19	0.31	0.94	0.3	0.89	<0.18	0.18	0.41	2.4	0.57	2.1	0.28
1,2,3,6,7,8-HxCDF	<0.37	0.35	<0.23	0.65	<0.23	0.44	<0.22	<0.23	<0.23	1.9	0.41	0.68	<0.23
2,3,4,6,7,8-HxCDF	0.76	0.28	<0.26	1.1	<0.26	0.79	<0.25	<0.26	<0.26	2.1	0.52	0.65	<0.25
1,2,3,7,8,9-HxCDF	<0.39	<0.20	<0.21	0.24	<0.21	0.25	<0.20	<0.21	<0.21	0.61	<0.21	0.33	<0.21
1,2,3,4,6,7,8-HpCDF	6.2	3.3	2.9	9.3	1.9	12	0.97	0.57	2.8	29	4.6	5.2	2.4
1,2,3,4,7,8,9-HpCDF	<1.20	0.5	<0.42	0.63	0.3	1.2	<0.22	<0.36	<0.20	1.8	0.49	0.59	<0.20
OCDF	15	9	7.2	18	4.1	36	2.7	2.5	7.5	56	10	10	4.3
Σ(PCDD+PCDF)[a]	794.54	891.05	2478.57	500.98	103.82	1019.8	151.93	374.22	4398.31	1406.38	249.93	245.9	130.98
Total TEQ[a]	1.12	0.81	0.811	1.38	0.321	1.09	0.28	0.4	1.02	2.95	0.8	1.84	0.42
TOC %	3.62	2.06	5.66	1.89	2.7	3.45	0.773	2.53	1.78	1.77	1.34	1.88	2
Total OC-TEQ[a,b]	39.36	14.33	72.88	11.89	31.86	31.06	40.2	15.87	63.82	40.65	21.27	37.46	779.1
Date	12/16/2004	1/12/2005	1/27/2005	2/27/2005	3/2/2005	3/15/2005	12/16/2004	1/12/2005	1/27/2005	2/24/2005	3/2/2005	3/15/2005	5/29/2005

Table 3.39 Dioxins in Houston Soil Prior to Runoff Sampling (ng/kg-dry wt.)

Congener	SS-5	SS-14A	SS-14B	SS-15A	SS-15B	SS-16	SS-108	SS-7	SS-8	SS-9	SS-10	SS-13A	SS-13B
2,3,7,8-TCDD	<0.33	<0.22	<0.28	<2.30	<2.70	<0.32	<0.31	<0.28	<0.32	<0.29	0.4	<0.39	<0.39
1,2,3,7,8-PeCDD	<0.29	<0.27	<0.30	<2.80	<2.80	1	0.38	<0.29	1.2	0.81	<0.28	<0.31	1.6
1,2,3,4,7,8-HxCDD	<0.43	<0.41	<0.42	<4.20	<4.20	2	0.56	0.86	2.6	1.8	<0.42	1.1	3.9
1,2,3,6,7,8-HxCDD	0.39	<0.23	<0.24	9	5.4	8.5	1.3	1.6	7.8	3.3	<0.23	2.5	5.3
1,2,3,7,8,9-HxCDD	0.44	0.66	0.91	13	9.2	3.1	1.1	<0.34	3.6	<0.31	1.3	1.6	4.2
1,2,3,4,6,7,8-HpCDD	3.8	18	29	210	160	280	27	38	240	120	10	100	200
OCDD	110	270	440	2500	1900	2800	230	990	7700	12000	100	2800	2400
2,3,7,8-TCDF	<0.24	<0.23	<0.24	<2.50	2.7	0.3	0.32	0.25	<0.24	<0.22	<0.23	<0.36	<0.23
1,2,3,7,8-PeCDF	<0.18	<0.16	<0.22	<1.80	<1.70	0.44	<0.20	<0.17	0.4	<0.18	<0.17	<0.20	0.47
2,3,4,7,8-PeCDF	<0.15	<0.14	<0.21	<1.60	<2.30	0.63	0.41	<0.15	<0.15	0.17	0.15	1.1	<0.18
1,2,3,4,7,8-HxCDF	<0.26	<0.31	<0.26	2.6	<2.50	11	0.95	0.81	1.3	<0.34	<0.25	0.83	1.9
1,2,3,6,7,8-HxCDF	<0.33	<0.31	<0.32	<3.20	<3.20	1.8	0.51	<0.33	0.98	<0.30	<0.32	0.52	<0.32
2,3,4,6,7,8-HxCDF	<0.19	0.2	<0.19	<1.90	3.6	2.3	0.57	0.76	1.1	0.46	<0.18	1	1.5
1,2,3,7,8,9-HxCDF	<0.23	<0.22	<0.23	<2.30	<2.30	0.96	0.5	<0.23	<0.23	<0.21	<0.22	<0.22	0.48
1,2,3,4,6,7,8-HpCDF	<0.20	2.3	3.7	30	35	72	5.5	8	59	7.6	0.72	12	22
1,2,3,4,7,8,9-HpCDF	<0.29	<0.27	<0.51	<2.80	3.2	9	<0.65	<0.29	2.2	0.5	<0.28	1.2	2.1
OCDF	1	6	11	70	51	360	11	17	280	27	2	44	67
Σ(PCDD+PCDF)[a]	117.19	298.35	486.32	2847.3	2180.95	3553.19	280.68	1057.82	8300.65	12162.57	115.56	2966.59	2711.01
Total TEQ[a]	0.45	0.39	0.46	5.46	5.37	3.99	1.14	0.73	2.58	1.26	0.77	1.61	2.82
Date	9/30/2004	9/30/2004	9/30/2004	9/30/2004	9/30/2004	9/30/2004	9/30/2004	10/1/2004	10/1/2004	10/1/2004	10/1/2004	10/1/2004	10/1/2004

[a] Non-detects assumed as 1/2 MDL for calculations

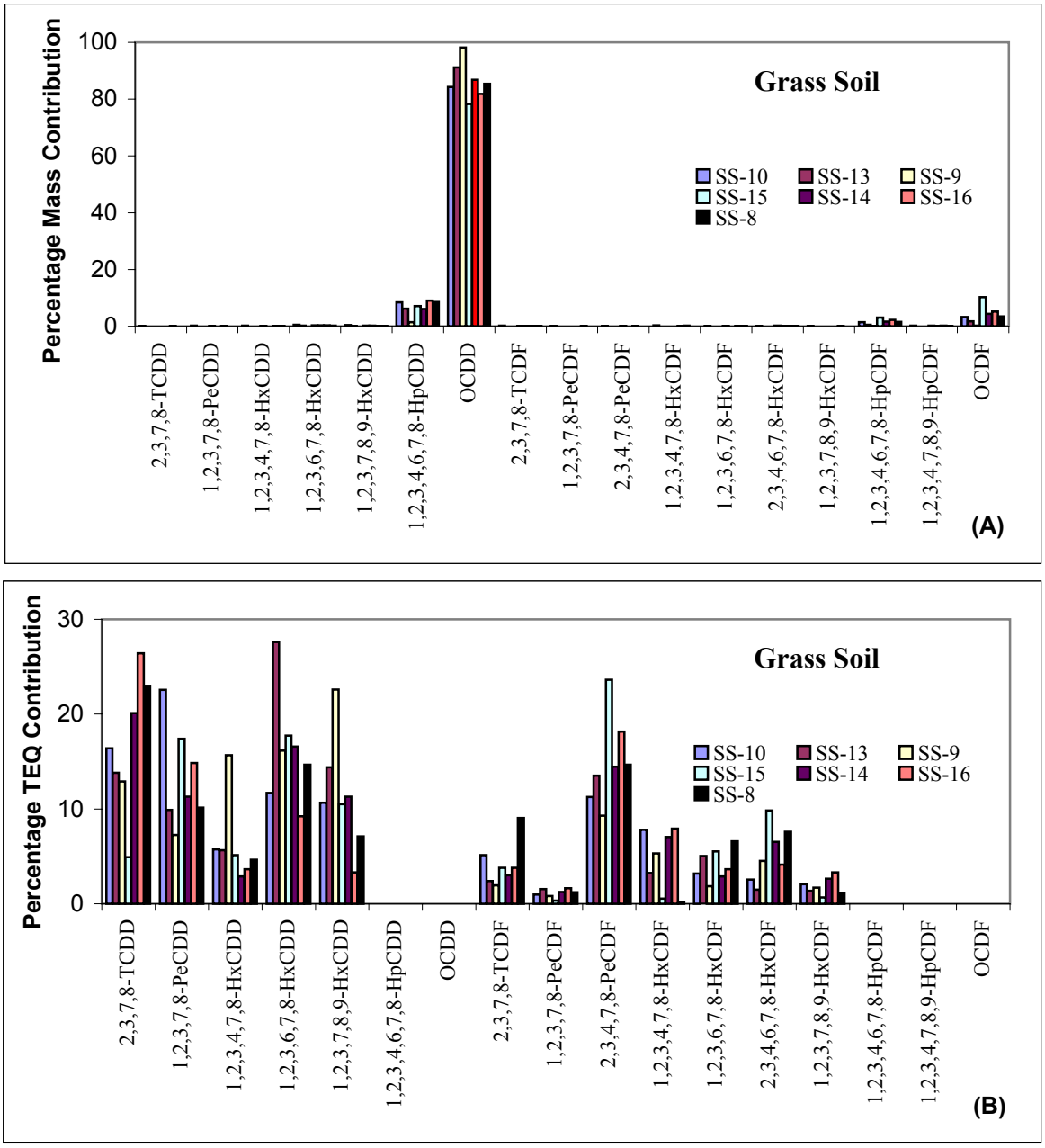


Figure 3.83 Percentage Contribution of Dioxins in Houston Grass Soil during Runoff Conditions: (A) Mass Contribution, (B) TEQ Contribution.

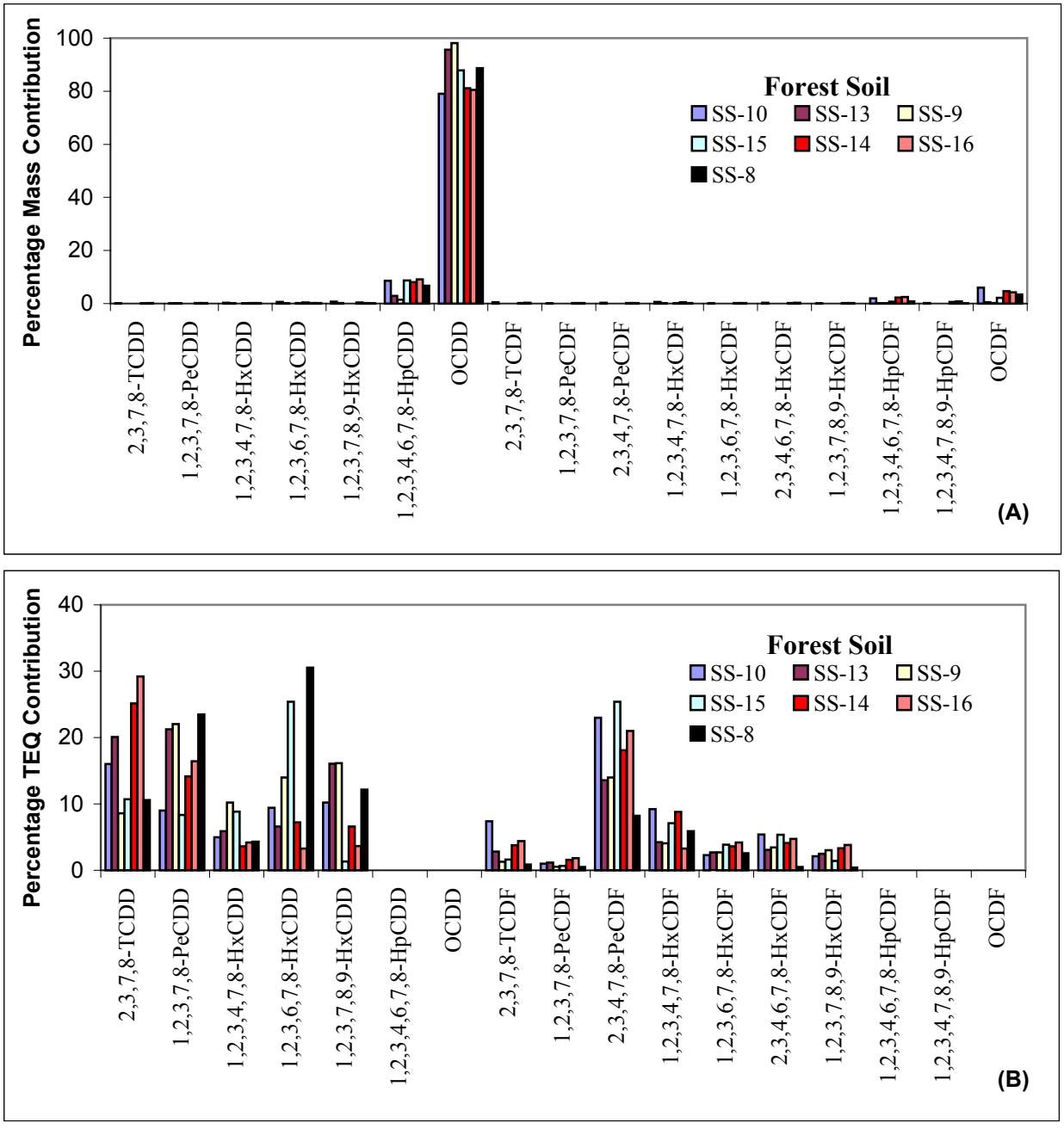


Figure 3.84 Percentage Contribution of Dioxins in Houston Forest Soil during Runoff Conditions: (A) Mass Contribution, (B) TEQ Contribution.

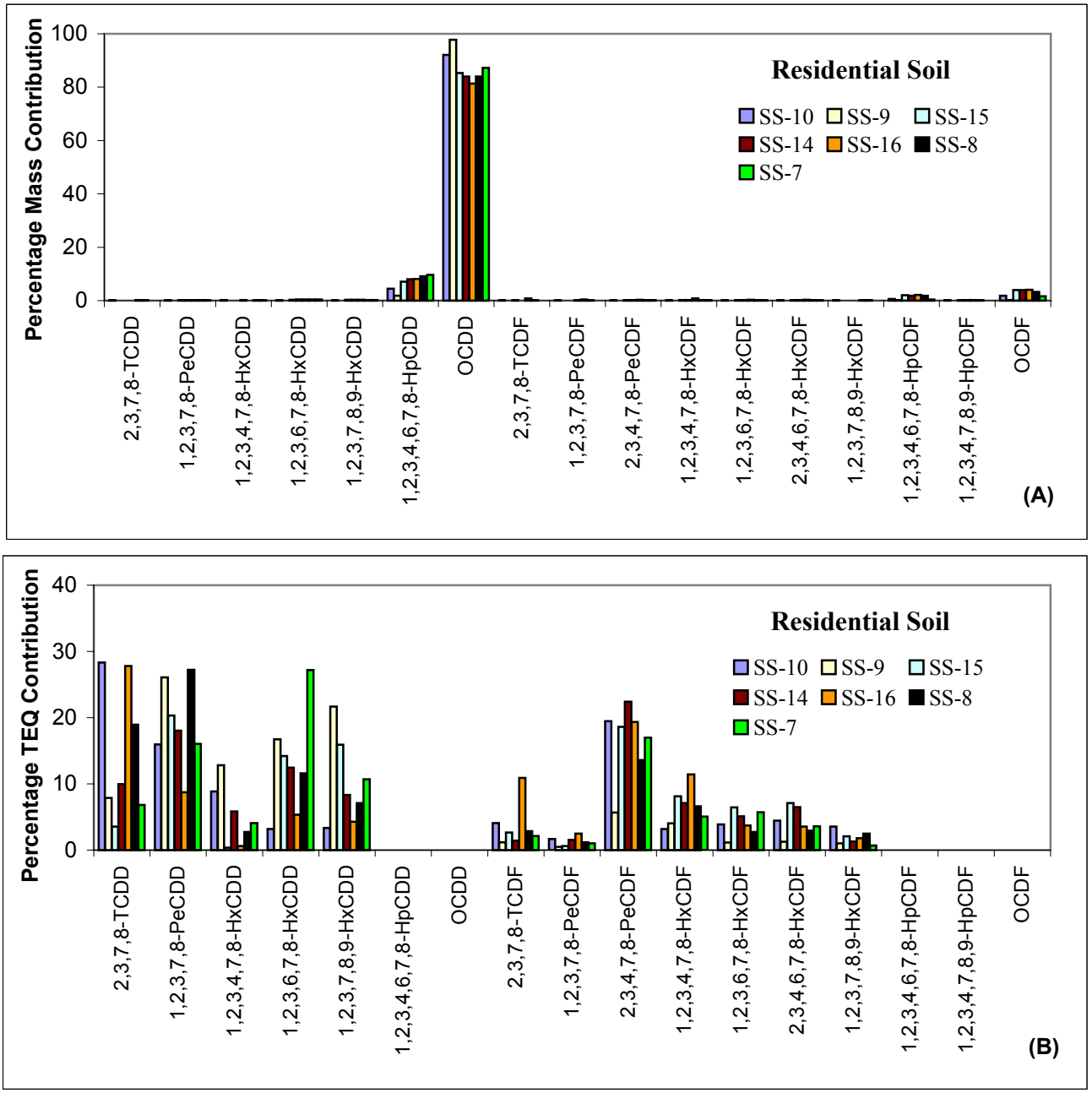


Figure 3.85 Percentage Contribution of Dioxins in Houston Residential Soil during Runoff Conditions: (A) Mass Contribution, (B) TEQ Contribution.

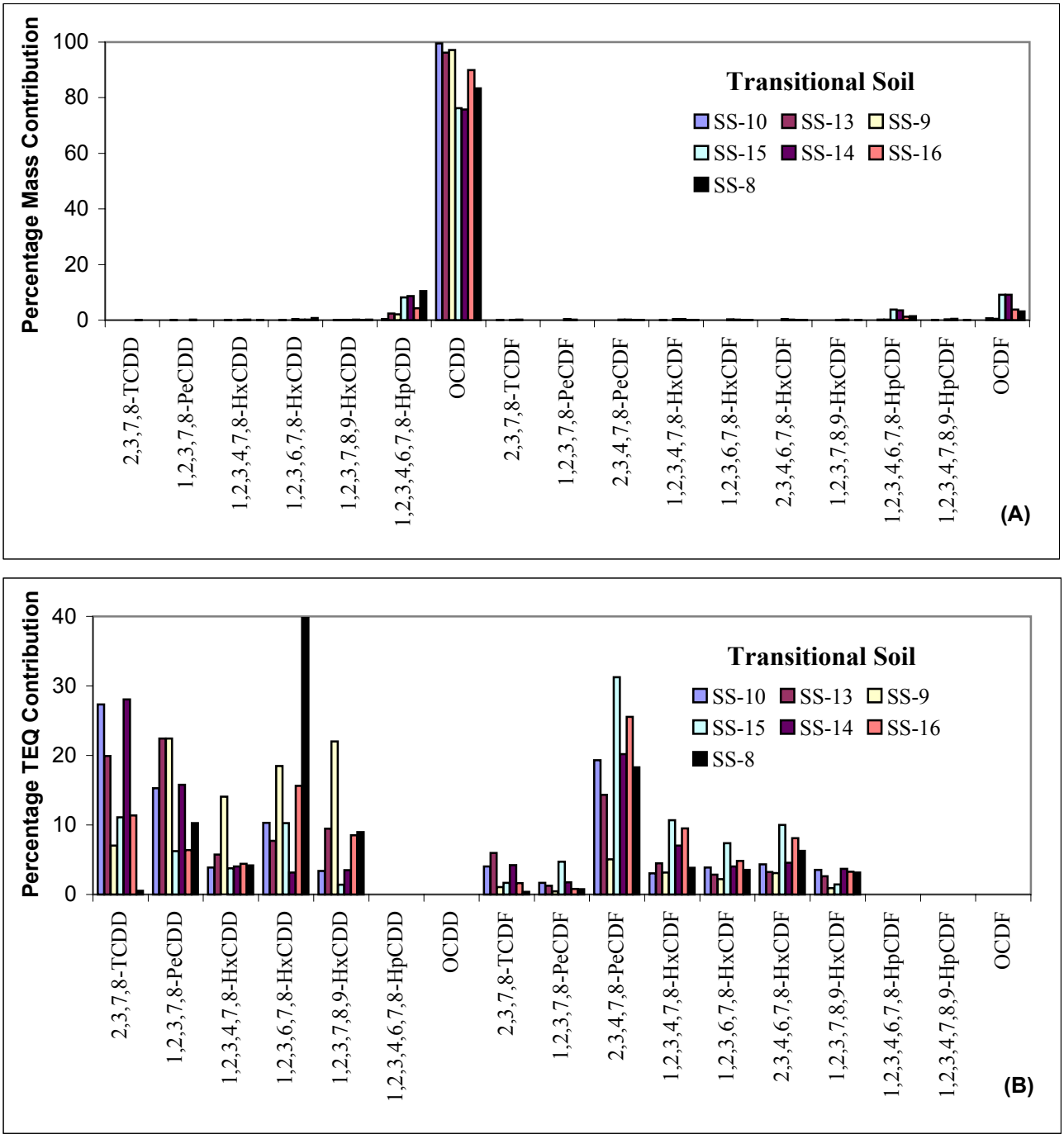


Figure 3.86 Percentage Contribution of Dioxins in Houston Transitional Soil during Runoff Conditions: (A) Mass Contribution, (B) TEQ Contribution.

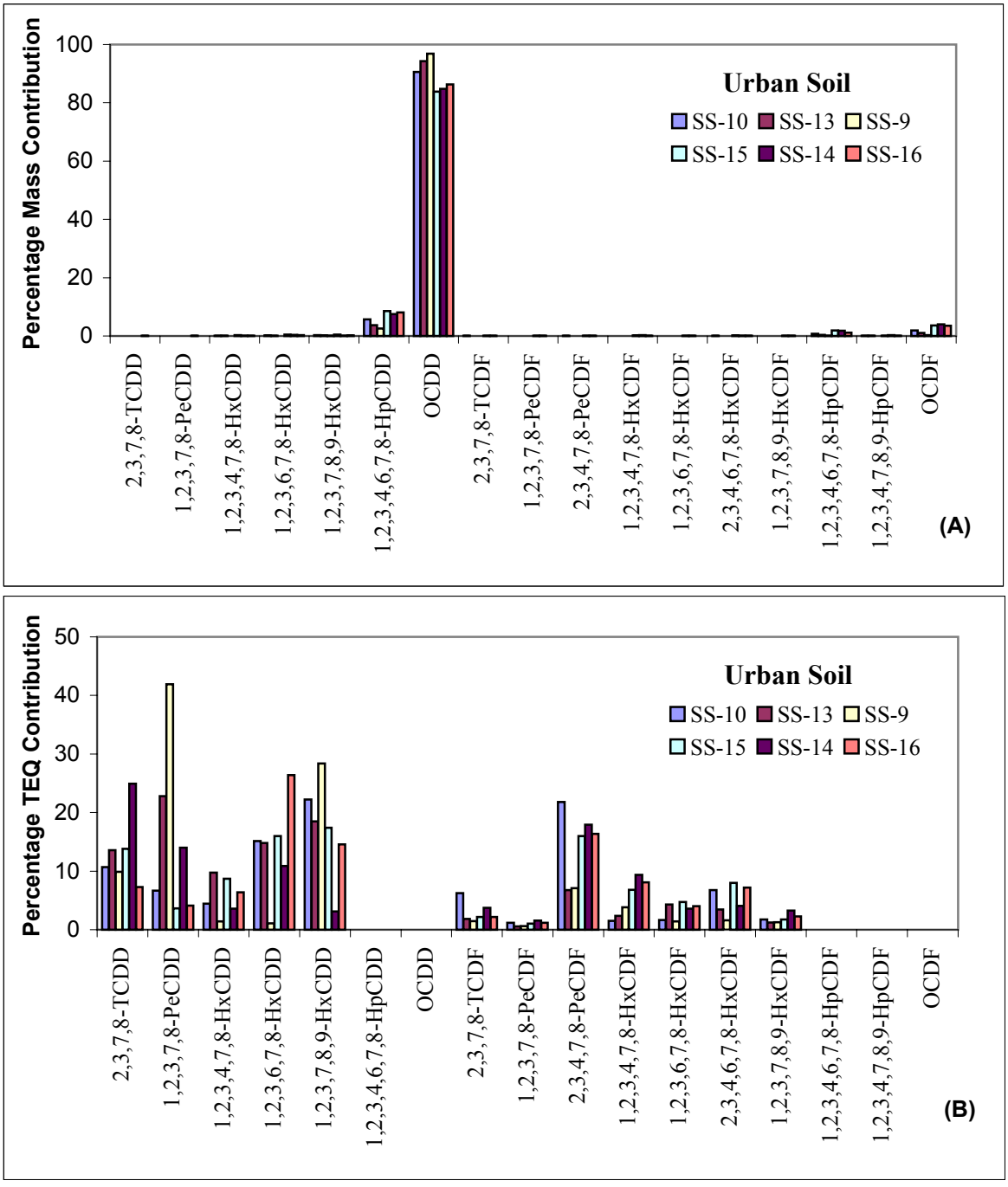


Figure 3.87 Percentage Contribution of Dioxins in Houston Urban Soil during Runoff Conditions: (A) Mass Contribution, (B) TEQ Contribution.

addition, flow measurements were collected under a variety of tidal conditions, including rising and falling tides. Tide elevation data were collected with either a YSI probe or downloaded from the NOAA website. The YSI tide elevation data were recorded at 5 minute intervals and the NOAA data were reported at 6 minute intervals over the 1-week period. These data were then transformed into either 15-minute or 18-minute time intervals to simulate the change in tide elevations. The tide elevation data were broken down into several periods (15, 30, 45, 60, 75, 90 minute, etc.). This was done, for example, by subtracting the tide elevation at 15 minutes from the tide elevation at 0 minutes, etc.

Since several flow measurements were taken during one sampling period, the flows were averaged together after being viewed and checked for quality in the SonTek RiverSurveyor Software V4.30. The average flows for each sampling period are shown in Table 3.40. The time shown in Table 3.40 corresponds to the average time of the day that the flow measurements were taken.

Data from each flow event were matched to the corresponding tidal elevation data. A linear regression was performed using the data analysis package in Excel to find the best relationship between measured flow and the change in tidal elevation. The regression results (R^2, intercept and X1 variable) for each flow sampling location are shown in Table 3.41. These data were then used to form an equation to predict the flow at a change in tide elevation as follows:

$$Q = a + b * dt(T) \quad (3.8)$$

where Q = Predicted Flow (m^3/s), a = Y-Intercept (m^3/s), b = X- variable (m^2/s), and $dt(T)$ = the change in tidal elevation for a given time period T (m).

The predicted flows were then plotted at each sampling location along with the measured and average flows (Figure 3.88). The figures show that the predicted flows are in good agreement

Table 3.40 Average Flows for Each Event

Station ID	Date	Time	Flow (m^3/s)
11193	03/29/05	13:11	77.37
11193	03/30/05	10:16	-331.04
11193	03/31/05	11:57	-380.05
11193	04/01/05	10:16	192.79
11193	04/04/05	8:00	189.05
11193	04/04/05	10:56	214.26
11193	4/5/2005	10:05	222.67
11252	03/29/05	9:09	-1553.73
11252	03/30/05	14:42	253.81
11252	03/31/05	8:16	-828.15
11252	03/31/05	17:23	-149.64
11252	04/04/05	15:17	-985.81
11252	04/05/05	14:23	-483.20
11261	03/29/05	16:57	4.28
11261	03/30/05	8:29	-886.33
11261	03/31/05	13:19	-438.18
11261	04/01/05	8:02	870.65
11261	04/04/05	12:03	106.15
11261	04/05/05	9:06	573.34
11264	03/29/05	15:44	166.85
11264	03/30/05	9:19	430.03
11264	03/31/05	14:41	32.14
11264	04/04/05	9:33	188.68
11264	04/05/05	8:09	271.99
11264	04/05/05	12:51	-29.54
11272	04/19/05	11:35	3.10
11272	04/19/05	13:21	-4.50
11272	04/19/05	15:24	-2.78
11272	04/19/05	17:43	-8.67
11272	04/20/05	9:06	1.64
11272	04/20/05	12:25	5.75
11275	03/22/05	12:45	46.19
11275	03/23/05	11:29	13.78
11275	03/23/05	18:16	-10.08
11275	03/24/05	12:53	6.58
11275	03/24/05	17:57	-2.21
11275	03/25/05	11:21	14.88

Table 3.40 Average Flows for Each Event - Cont'd

Station ID	Date	Time	Flow (m^3/s)
11288	04/06/05	12:53	-19.43
11288	04/06/05	18:00	-63.84
11288	04/07/05	11:25	50.54
11288	04/07/05	14:40	25.23
11288	04/07/05	16:38	-24.28
11288	04/08/05	14:51	20.91
11298	03/22/05	16:34	-1.94
11298	03/23/05	8:21	0.40
11298	03/23/05	15:48	-4.97
11298	03/24/05	10:59	5.22
11298	03/24/05	17:02	-3.80
11298	03/25/05	8:58	-0.34
11300	03/22/05	9:37	3.69
11300	03/23/05	14:18	-1.91
11300	03/24/05	8:10	-0.15
11300	03/24/05	16:00	-4.32
11300	03/25/05	6:47	-1.48
11300	03/25/05	15:07	0.89
11302	03/22/05	18:04	-8.86
11302	03/23/05	13:18	0.59
11302	03/24/05	9:41	20.64
11302	03/24/05	15:10	-16.88
11302	03/25/05	7:52	-6.46
11302	03/25/05	13:55	14.24
11305	04/06/05	11:53	12.20
11305	04/06/05	17:17	-9.18
11305	04/07/05	10:24	3.01
11305	04/07/05	15:36	4.16
11305	04/08/05	9:38	0.41
11305	04/08/05	15:53	-2.68
11345	04/19/05	10:22	4.87
11345	04/19/05	12:28	11.51
11345	04/19/05	14:24	-6.50
11345	04/19/05	16:28	-1.70
11345	04/20/05	7:53	4.80
11345	04/20/05	11:21	6.96

Table 3.40 Average Flows for Each Event-Cont'd

Station ID	Date	Time	Flow (m^3/s)
16496	03/29/05	11:23	-60.40
16496	03/30/05	12:30	-108.45
16496	03/30/05	17:23	21.90
16496	04/01/05	12:48	-89.96
16496	04/04/05	13:09	-63.24
16496	04/05/05	11:23	84.76
HSC-1	04/06/05	14:34	105.12
HSC-1	04/07/05	8:56	171.23
HSC-1	04/07/05	12:45	163.31
HSC-1	04/07/05	17:51	-63.02
HSC-1	04/08/05	13:20	259.98
HSC-1	04/08/05	17:19	4.36

Flows were not used in regression.

Table 3.41 Regression Results

Station ID	R^2	Y-Intercept	X-Variable	Time Interval (minutes)
11193	0.98686	95.26	-3970.10	60
11252	0.974	149.01	-12180.58	90
11261	0.93576	0	-9004.46	72
11264	0.89648	37.07	-6010.38	36
HSC-1	0.95489	52.58	-2083.63	60
11288	0.95968	0	-424.11	108
11272	0.86976	0	-65.04	105
11298	0.90086	0	-24.29	90
11300	0.91434	0	-78.64	45
11302	0.70311	0	-316.88	30
11305	0.89462	0	-81.17	60
11345	0.92922	0.93	-97.17	45
11275	0.95515	2.90	-96.97	75
16496	0.75744	15.05	-2205.11	60

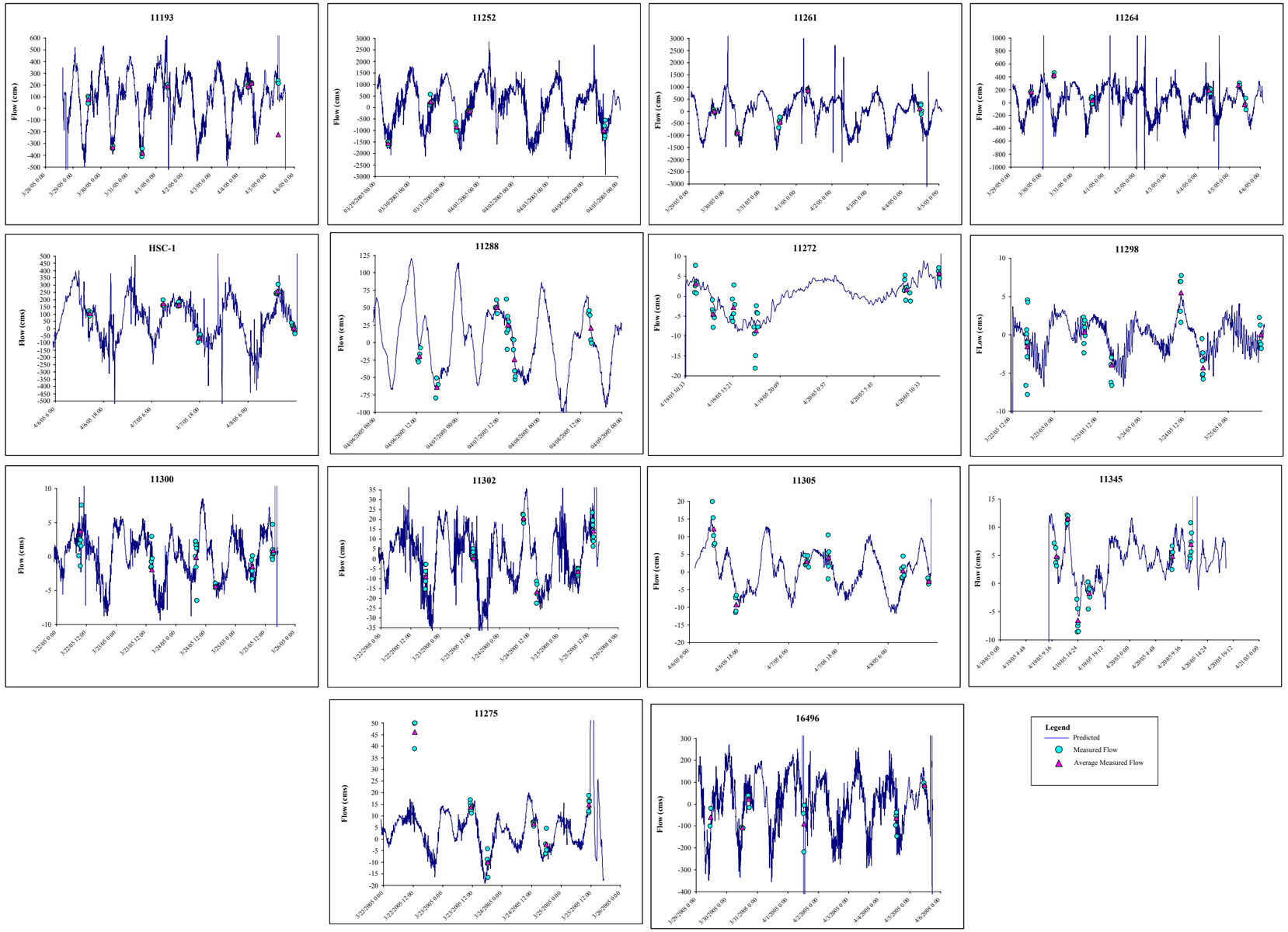


Figure 3.88 Measured and Predicted Flow in the HSC

with the measured and average flows.

Since the RiverCat requires at least 3 feet of water to measure a representative flow reading, the data from sampling location 11273 was not processed due to the shallow water levels during sampling times (flows not included in Figure 3.88).

A summary of the regression outputs for each of the stations is included in Appendix D.

3.3 COLLECTION OF SEDIMENT DATA TO SUPPORT MODELING ACTIVITIES

While data on the sources of dioxins and furans are limited, it is expected that a substantial portion of the inputs to the Houston Ship Channel (HSC) is associated with particulate matter in runoff flows. This analysis provides estimates of the annual runoff loads of Total Suspended Solids (TSS) and Volatile SS (VSS) from tributaries to the HSC. These loads may be significant sources of dioxins to the HSC. Also included in this section is an analysis of sediment accumulation and removal from the HSC. In the analysis the loads removed from the HSC through dredging are calculated and compared with source estimates.

3.3.1 Background

Sediment loads to the channel have been studied in the past and measurements continue to be made. For example, the US Army Corps of Engineers (1987) analyzed sediment loads as part of its studies for improving the channel. Estimates were made by the Corps to determine the changes in sediment accumulation as a result of making the channel deeper and wider. As part of a major wastewater study for the City of Houston (1988), Pate and Espey, Huston & Associates (EH&A) analyzed sediment sources and removal from the HSC. The 1988 study of sources employed data from Winslow and Associates (1986) as well as the Corps and other sources. The 1988 study calculated the TSS and VSS loads by two methods. One was based on tributary

sampling data and the other was based on estimates of individual components such as load per unit area for various land use types.

Loads to the HSC in metric tons per year, from the area including Greens Bayou and above were:

	TSS	VSS
Tributary sampling method	318,500	55,500
Individual Component method	142,700	45,590

The load by the tributary method for the watershed from Greens Bayou to Morgan's Point

was	90,950	15,860
thus,		
Total tributary method	409,450	71,360
Total Individual component method	233,650	61,450

As can be seen, the tributary method gives higher loads than the individual component method.

This same City of Houston (1988) study also reviewed the Corps dredging records and found that on average the solids removal from Morgan's Point and up was 431,000 metric tons per year. That is roughly equal to the 409,450 tons per year obtained using the tributary sampling method estimate. However, there are a number of points considering the distribution of TSS and VSS sources that were considered in the 1988 analysis. Accordingly, the relevant portions of this analysis are included with this document as Appendix E.

In addition to the above mentioned resources, the Galveston Bay National Estuary Program commissioned a study to estimate nonpoint source loads to Galveston Bay (Newell et al., 1992). The study assembled event mean concentration (EMC) values for a variety of parameters,

including TSS. Defined as the total constituent mass divided by the total runoff volume, the EMC is a parameter used to represent the flow-weighted average concentration of a given parameter during a storm event. It is usually measured by analyzing flow weighted composite samples of runoff. VSS EMC information was not included in the GBNEP report. Table 3.42 presents the TSS EMC values used in the GBNEP analysis:

Table 3.42 EMC TSS Values for Various Land Uses

Land Use Category	TSS EMC (mg/L)	Land Use Category	TSS EMC (mg/L)
High Density Urban	166	Forest	39
Residential	100	Wetlands	39
Agricultural	201	Water	0
Open/Pasture	70	Barren	2200

Source: Newell et al., 1992

Using the above EMC values, land use coverages obtained from a LANDSAT image obtained in November 1990, and runoff volume estimates using the Soil Conservation Service (SCS) curve number method, three pollutant loading rates were determined for sub-watersheds defined in the study. Loading rates were determined for an "average" precipitation year, a wet year, and an individual average size storm. The estimated loads to the Houston Ship Channel are presented in Table 3.43. The study estimated average TSS load of 217,000 metric tons per year, somewhat lower but in the same range as calculated in the 1988 City of Houston study.

The *Storm Water Joint Task Force* (JTF), which is made up of the City of Houston, Harris County, Harris County Flood Control District, and TxDOT presently conducts storm water runoff sampling to obtain EMC values for a variety of parameters including TSS. The JTF members are

Table 3.43 TSS Loads to the Houston Ship Channel from Newell et al. (1992)

Watershed	Area (sq. miles)	Average Precipitation Year		Wet Precipitation Year		Individual Storm	
		Runoff Volume (thousand acre-feet)	TSS Load (mt)	Runoff Volume (thousand acre-feet)	TSS Load (mt)	Runoff Volume (thousand acre-feet)	TSS Load (mt)
Barker Reservoir	122	71	32,000	105	47,000	19	7,400
Addicks	134	82	22,000	120	31,000	20	5,100
White Oak Bayou	110	128	24,000	181	34,000	20	3,500
Buffalo Bayou	105	116	22,000	167	31,000	19	3,400
Subtotal at Turning Basin	471	397	100,000	573	143,000	78	19,400
Brays Bayou	127	147	29,000	226	43,000	23	4,400
Sims Bayou	93	91	16,000	159	27,000	15	2,500
Greens Bayou	209	184	30,000	268	43,000	33	5,000
Subtotal at Greens Bayou confluence	900	819	175,000	1226	256,000	149	31,300
San Jacinto River	68	65	8,000	96	12,000	10	1,300
Ship Channel	166	198	34,000	310	53,000	29	4,800
TOTAL	1134	1082	217,000	1632	321,000	188	37,400

Table 3.44 Summary of TSS EMC Data from Storm Water Management Joint Task Force (mg/L)

Agency	Sample site	Number of EMCs	Maximum	Minimun	Mean	Standard deviation
City of Houston	11th Street	18	459	10	98	120
City of Houston	Briar Forest	7	565	22	236	229
City of Houston	Lazybrook	18	128	5	31	30
City of Houston	Memorial City	12	60	5	23	17
City of Houston	Tanglewilde	20	380	6	75	84
City of Houston	Willowbrook	8	82	15	31	22
Harris County	Bayport	11	704	21	226	220
Harris County	Commercial	6	34	2	12	11
Harris County	Cypress Station	11	244	17	98	68
Harris County	Industrial	6	250	20	82	87
Harris County	Multi-Family	6	332	14	101	126
Harris County	Overbluff	14	185	16	95	64
Harris County	Single-Family	6	1340	122	647	503
Harris County	Steeplechase	13	104	14	53	31
Harris County	Undeveloped	6	496	32	211	184
TxDOT	TxDOT 59	11	440	18	161	151
TxDOT	TxDOT 610	11	1700	26	266	496
OVERALL AVERAGE		11	441	21	144	144

joint permittees who have a federally issued municipal separate storm sewer system (MS4) National Pollutant Discharge Elimination System (NPDES) storm water permit. The permit has required the JTF to monitor total suspended solids (TSS) on a quarterly basis since 1998. The TMDL project team has requested all TSS EMC data from the JTF along with drainage area boundaries and sampling sites. Table 3.44 presents a summary of the TSS EMC information. There is considerable variation with the means of the EMC values as would be expected from runoff data. Means of TSS EMC range between 12 mg/L and 647 mg/L. The overall average runoff event EMC value is 144 mg/L, which is within the range of EMC values used in Newell et al. (1992).

3.3.2 New Sediment Source Calculations

Since these earlier studies were performed, there has been considerable new data collected and some changes in the watershed. To produce updated information, the basic procedure was to analyze the relationship between bayou flow and TSS-VSS concentrations at available flow gages. The resulting relationships were used to estimate loads from the entire watershed, including the ungaged areas.

The USGS stream flow gages employed are shown on Figure 3.89. These gages recorded hourly flow observations for the period October 1991 to September 2003, although there are periods with missing data at some gages. Samples for TSS and VSS were collected by several agencies in close proximity to the gaging stations. In rare cases, samples were collected by the USGS at the gage itself, but more often, samples were collected by either the TCEQ or one of the City of Houston agencies at stations at or nearby the flow gaging station. To obtain the best

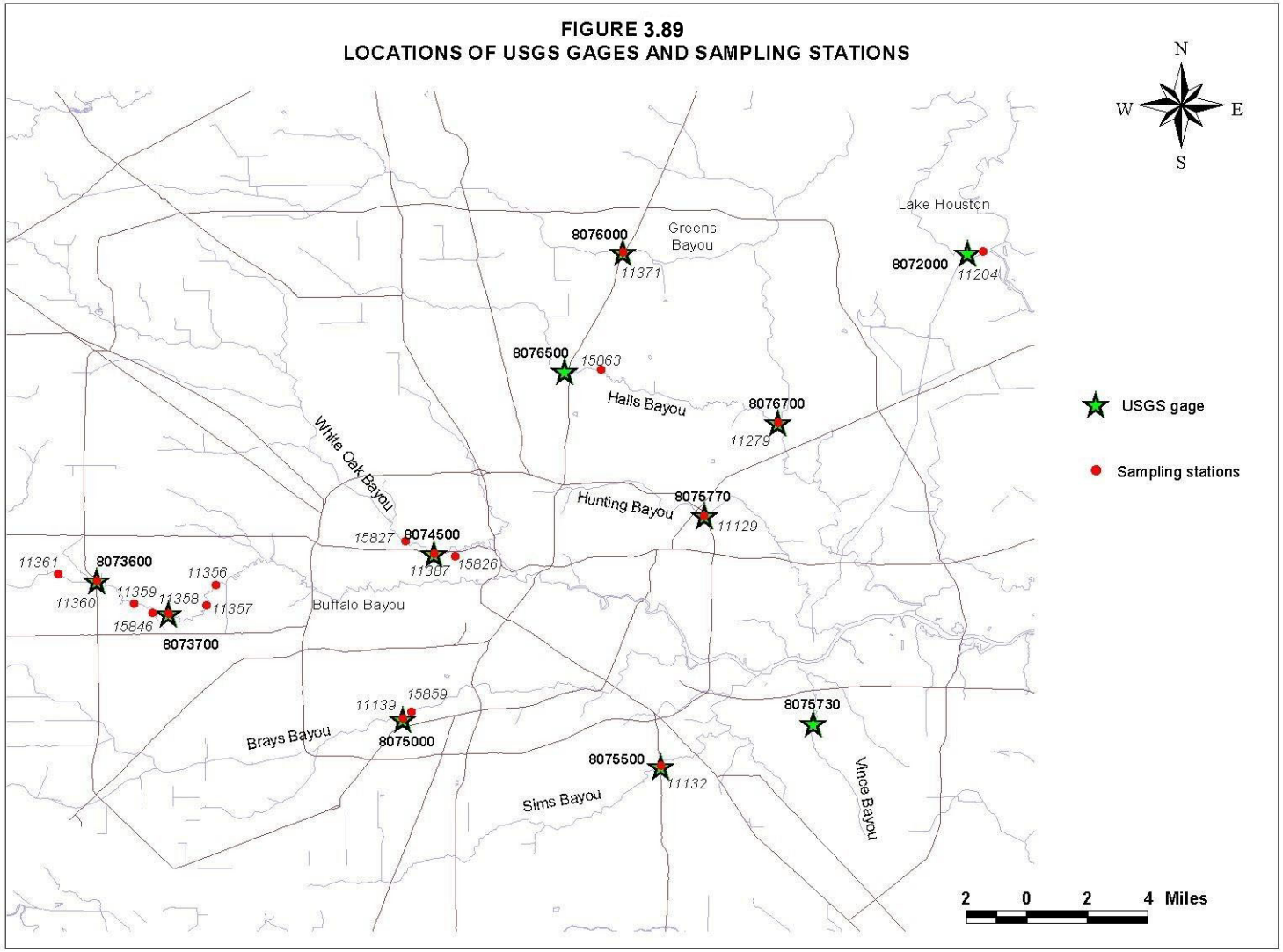


FIGURE 3.89
LOCATIONS OF USGS GAGES AND SAMPLING STATIONS
N
W
E
S
Lake Houston
Greens Bayou
8076000
11371
8072000
11204
8076500
15863
Halls Bayou
8076700
11279
White Oak Bayou
Hunting Bayou
8075770
11129
15827
8074500
11387
15826
11361
8073600
11356
11359
11358
11360
11357
15846
8073700
Buffalo Bayou
11139
15859
8075000
Brays Bayou
8075730
8075500
11132
Sims Bayou
Vince Bayou
USGS gage
Sampling stations
2 0 2 4 Miles

relationship with flow, regressions were produced using all available data at stations in close proximity to the flow measurements. The adjacent stations are also shown in Figure 3.89.

Figures 3.90a-e show the regressions of log flow against TSS. The regressions that have slopes that are significantly different from zero at the 95% confidence level are labeled as significant. Note that all of the plots show a great deal of scatter, reflecting grab sample data where the limited number of higher flow observations are subject to major uncertainties including whether the sample is a first-flush or a trailing limb observation. Even with a low r^2 and excessive scatter, the data indicate a relationship between flow and TSS. Even though most of the stations have a significant correlation between TSS and flow, several factors must be kept in mind. One is that the low flow end of the flow distribution for most stations is maintained by wastewater flow. Another is that the Buffalo Bayou stations are affected at higher flows by Barker and Addicks Reservoirs that allow settling of TSS so that it is not uncommon for the highest flow observations to have some of the lowest TSS concentrations. Other stations that do not show a relationship are Sims Bayou at Telephone Road (possible tidal influence) and Lake Houston (flow from spillway rating curve but concentrations obtained from Lake near dam). All the remaining gages exhibit statistically significant albeit noisy relations.

A similar but even noisier pattern is shown with the log flow versus VSS observations in Figure 3.91a-d. In general, there tend to be fewer VSS observations than TSS, and there also seems to be somewhat more variability in the data. Because these VSS data are limited, a tabulation was made of the paired TSS and VSS observations. Overall it was found that VSS averaged 27% of the TSS values, and this was used in the calculations that follow.

FIGURE 3.90a
RELATIONSHIP BETWEEN TSS AND FLOW

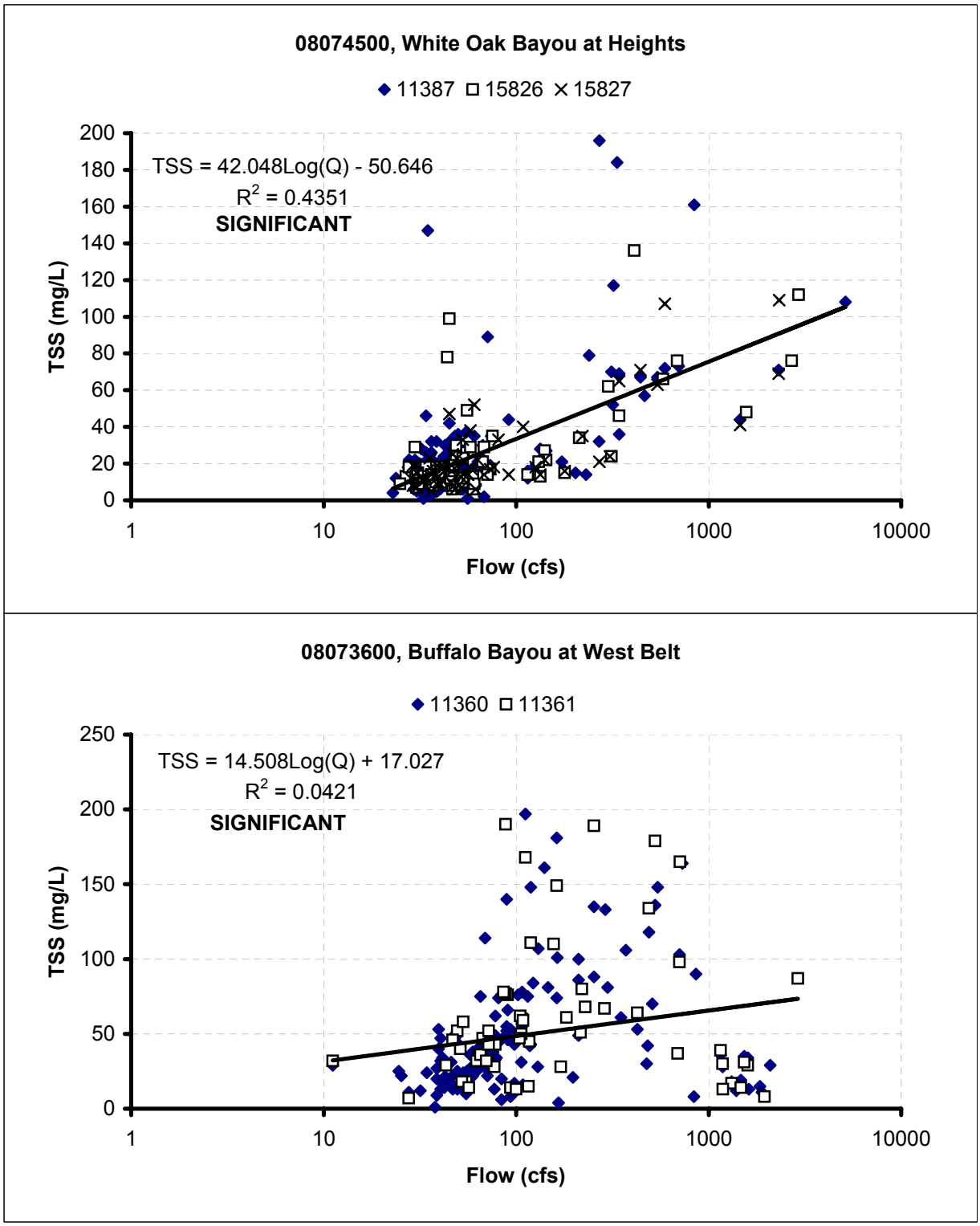


FIGURE 3.90b
RELATIONSHIP BETWEEN TSS AND FLOW

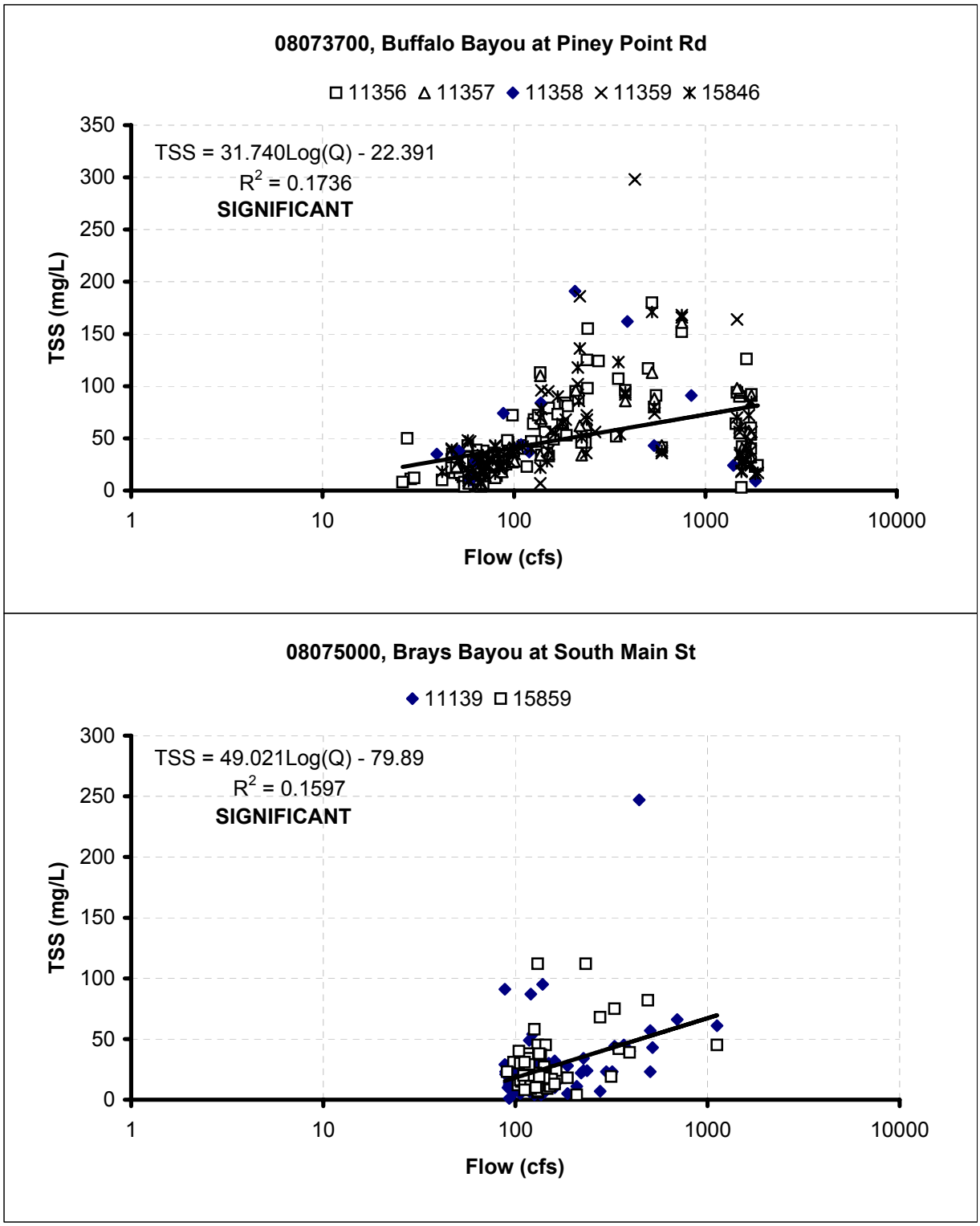


FIGURE 3.90c
RELATIONSHIP BETWEEN TSS AND FLOW

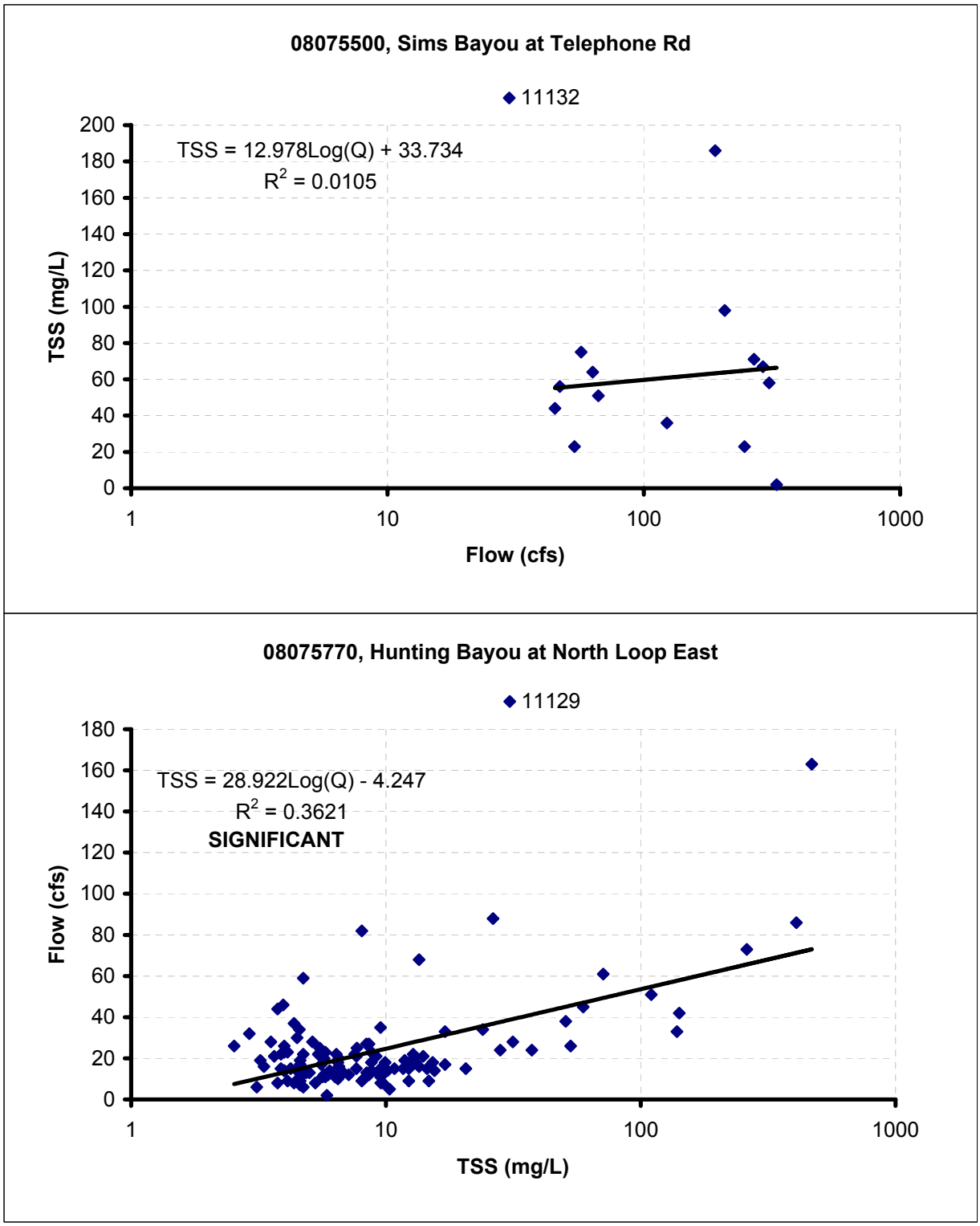


FIGURE 3.90d
RELATIONSHIP BETWEEN TSS AND FLOW

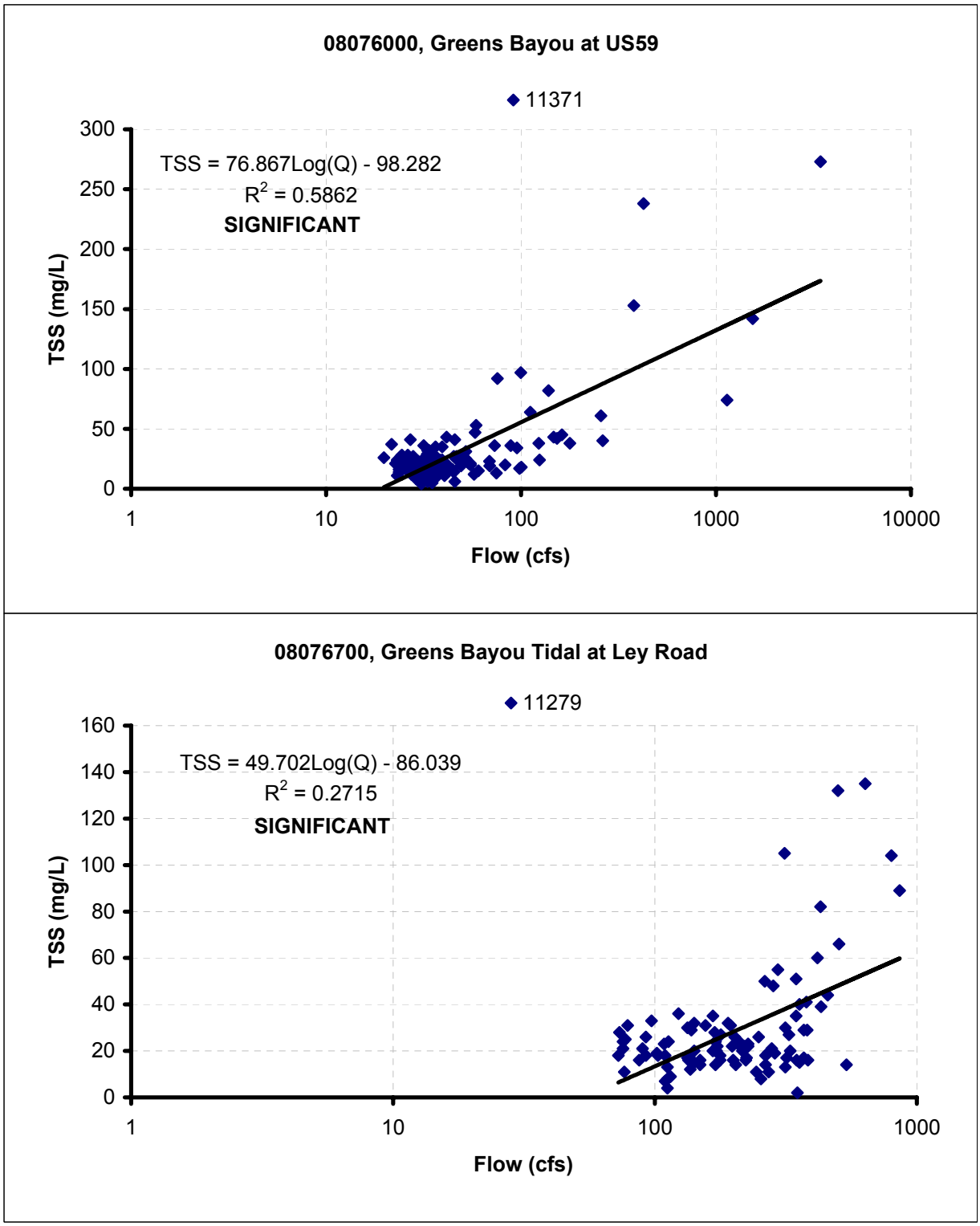


FIGURE 3.90e
RELATIONSHIP BETWEEN TSS AND FLOW

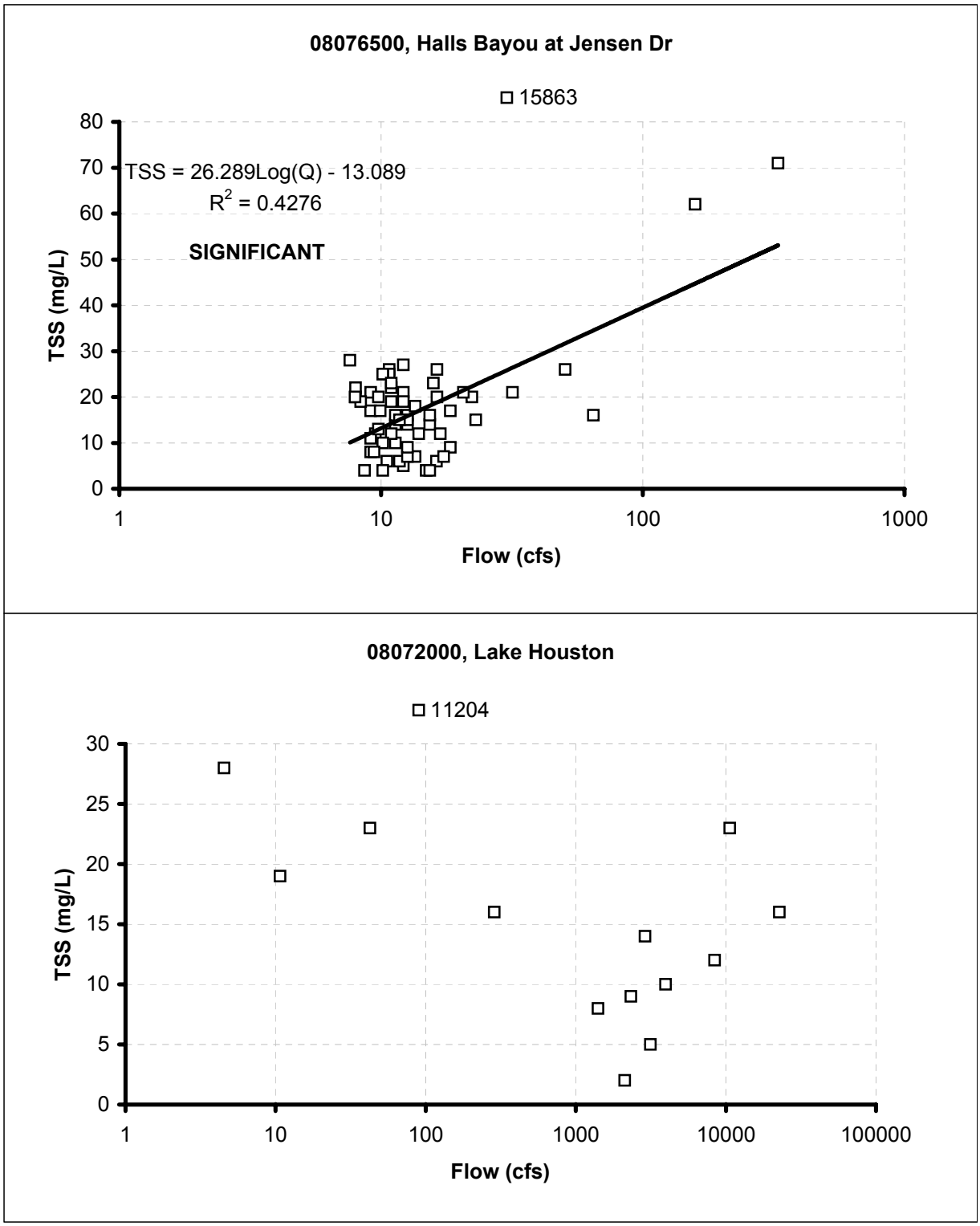


FIGURE 3.91a
RELATIONSHIP BETWEEN VSS AND FLOW

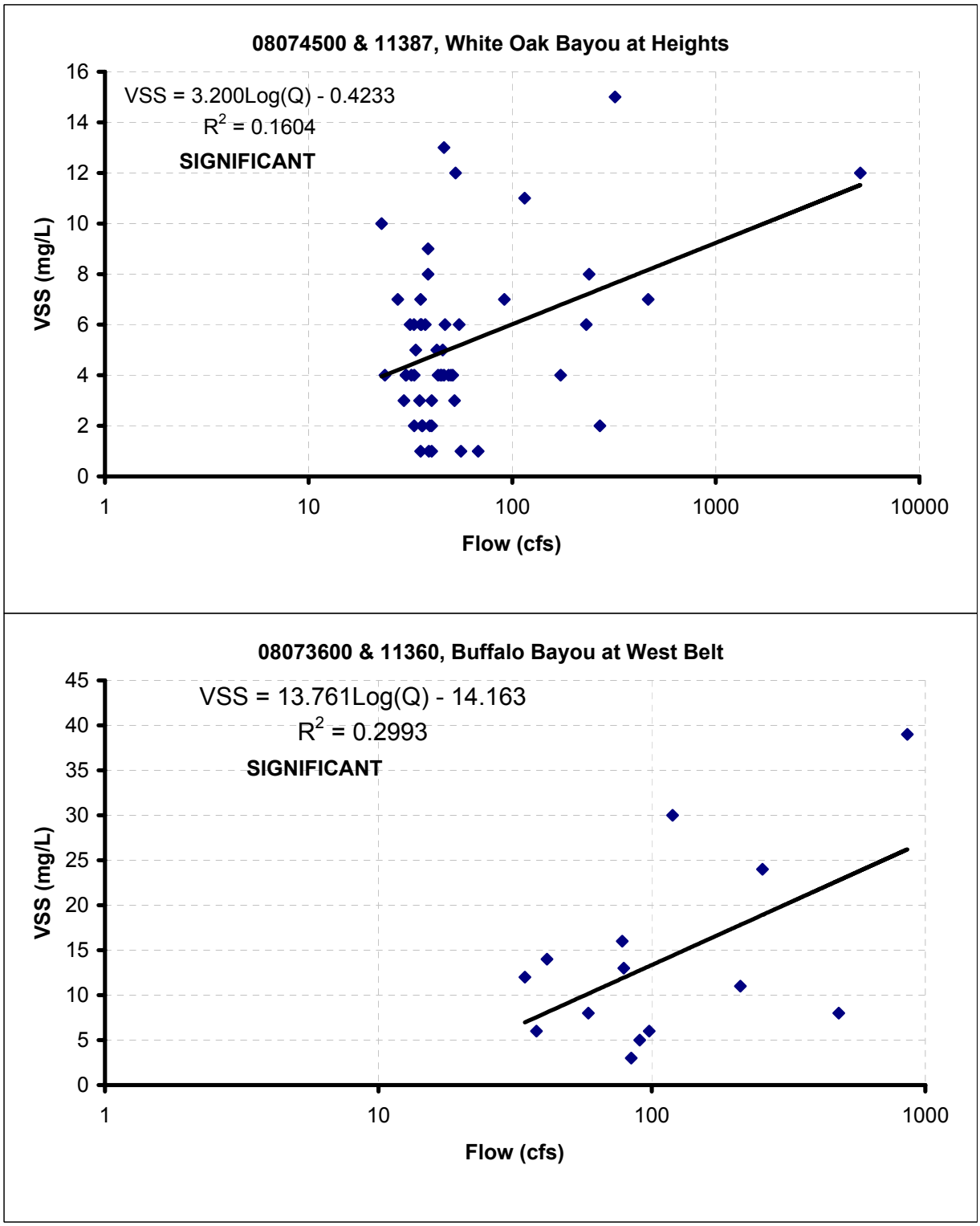


FIGURE 3.91b
RELATIONSHIP BETWEEN VSS AND FLOW

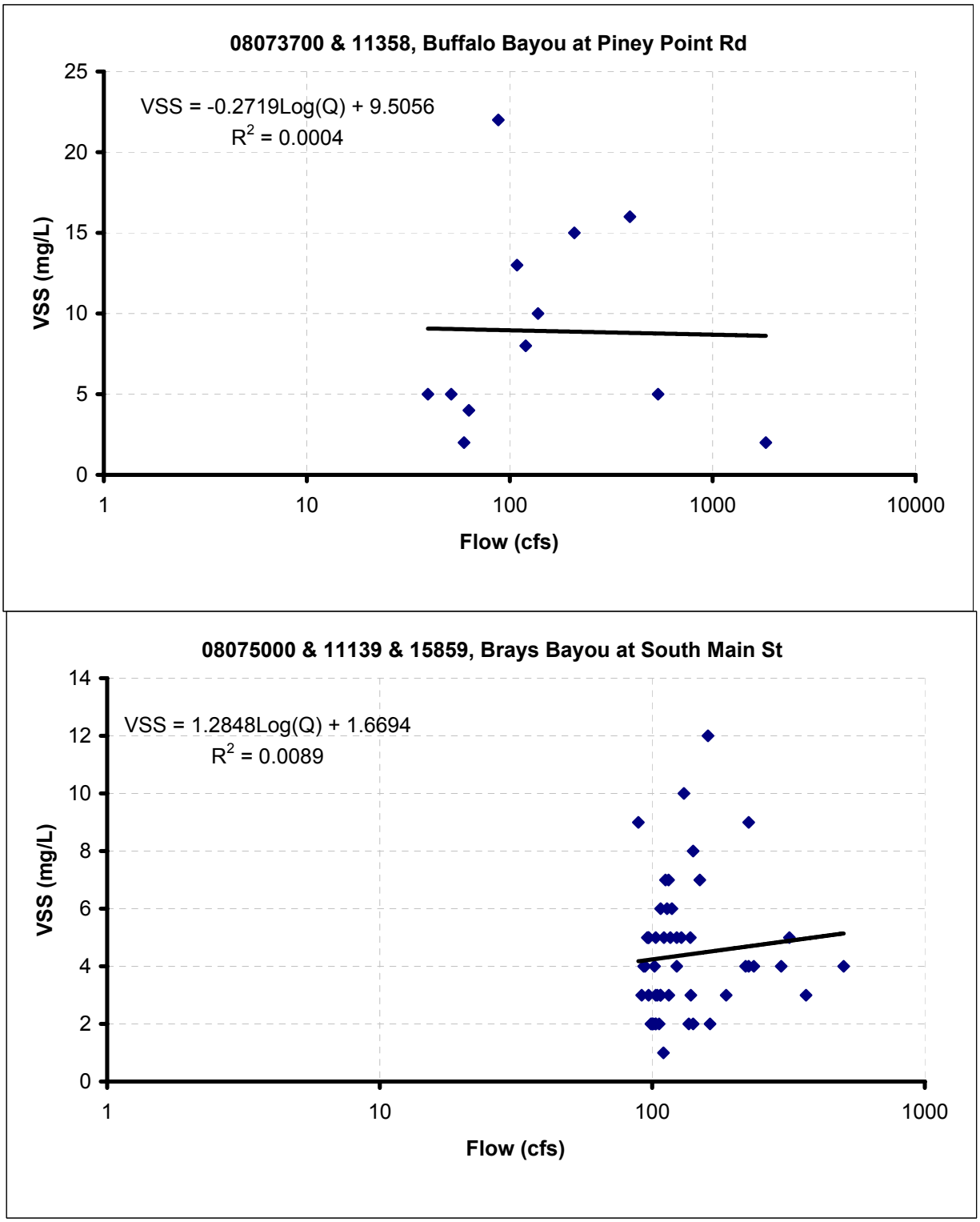


FIGURE 3.91c
RELATIONSHIP BETWEEN VSS AND FLOW

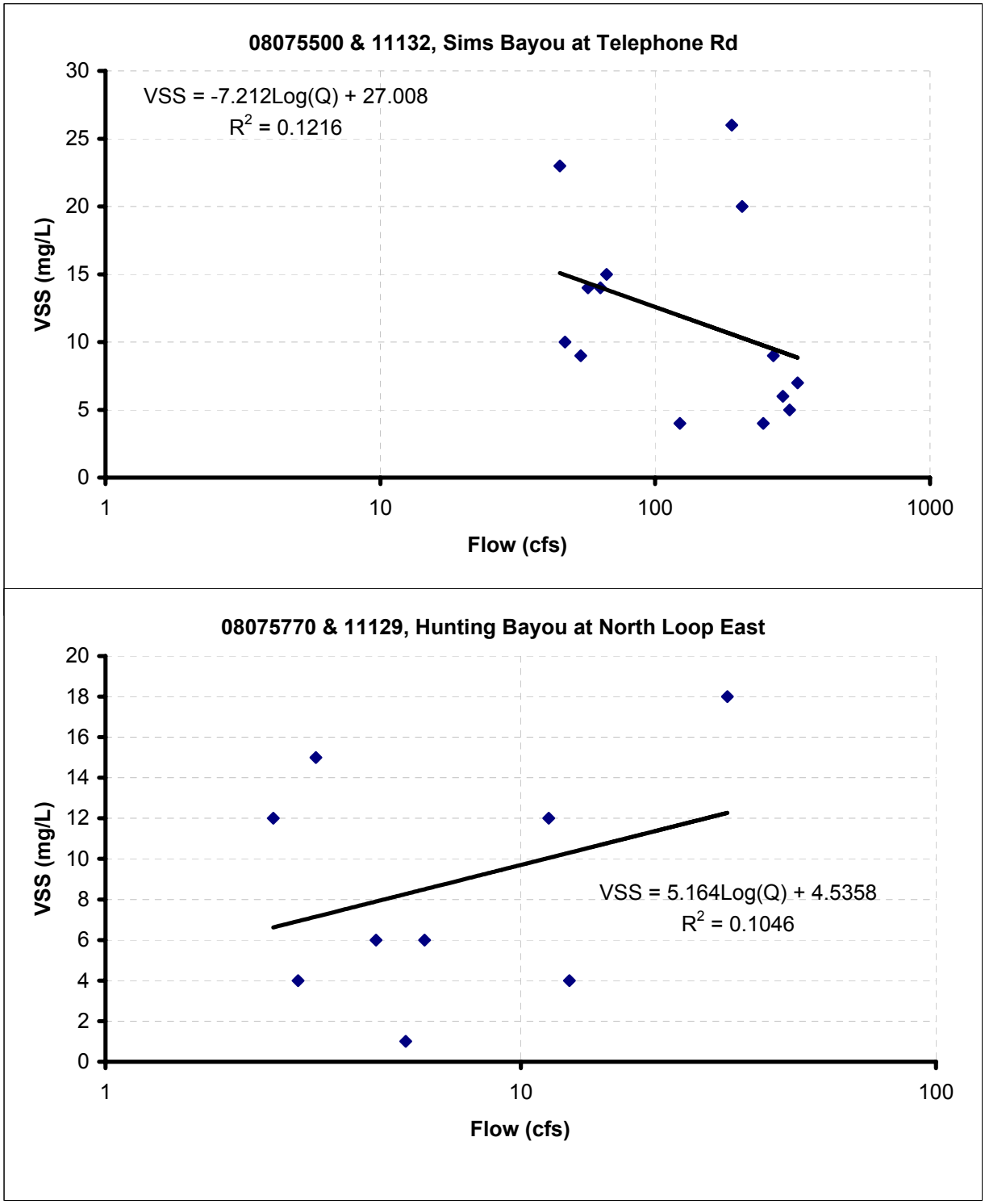
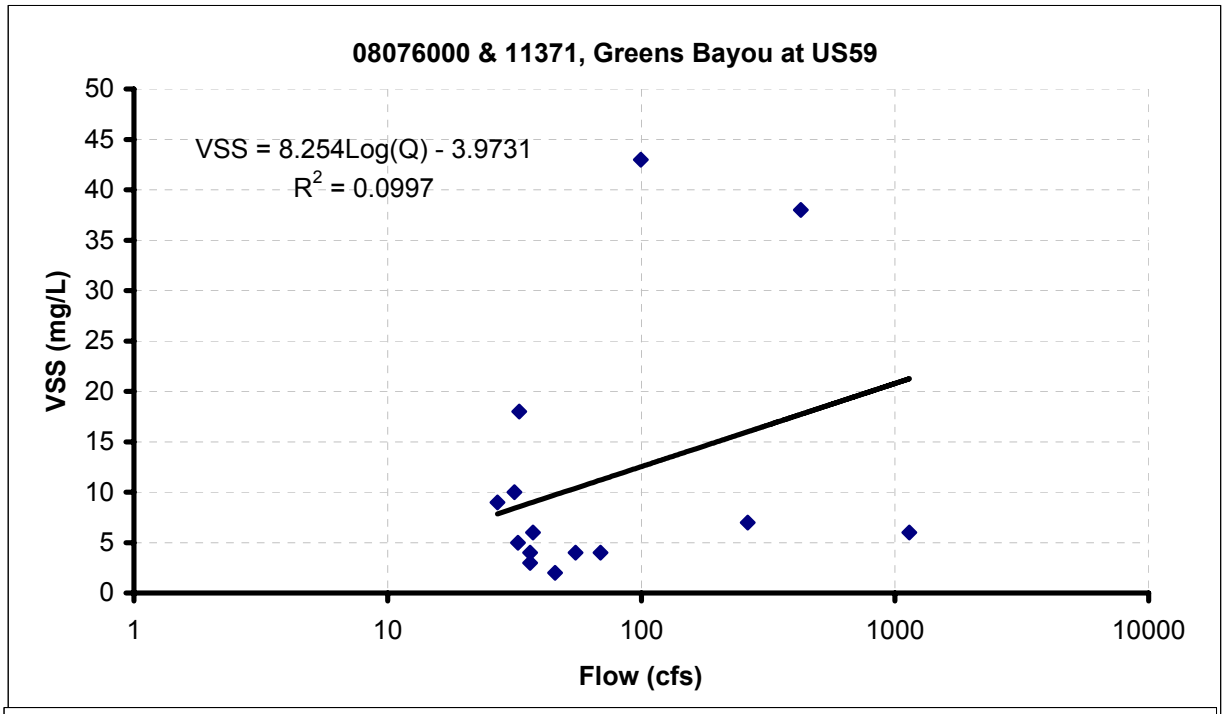
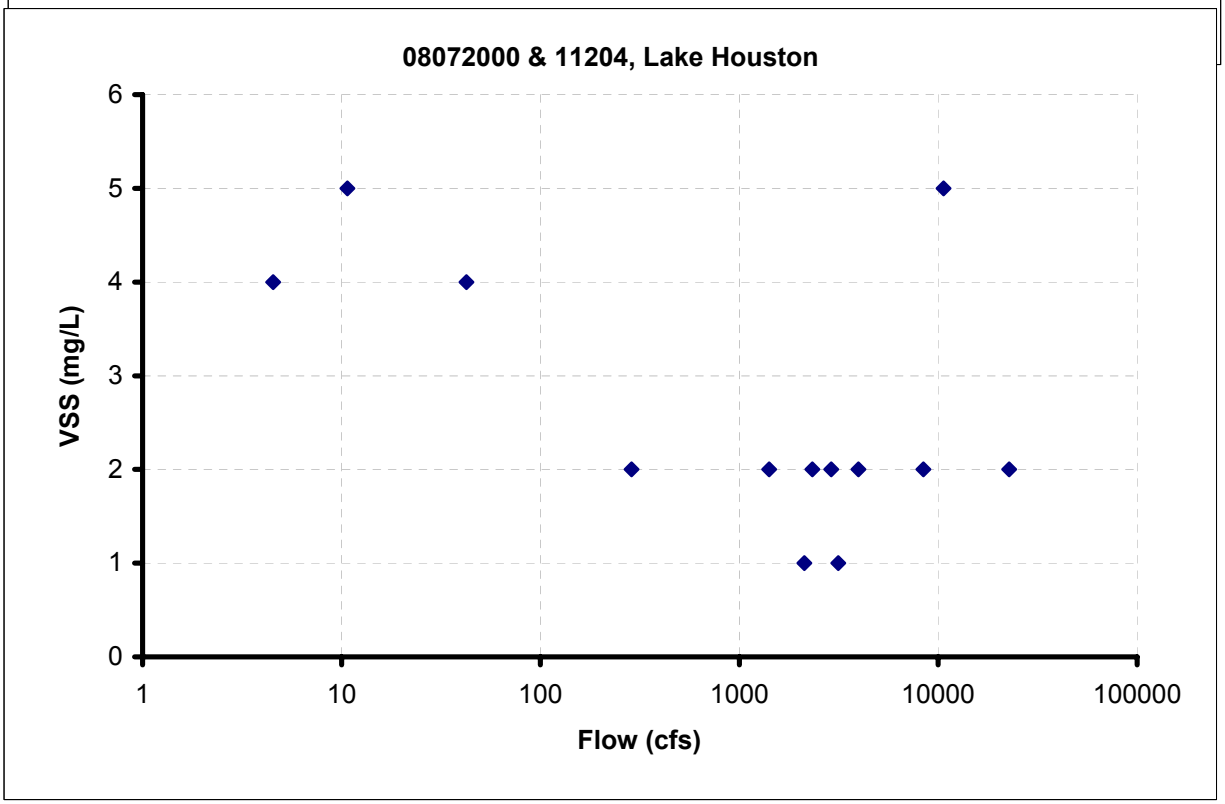


FIGURE 3.91d
RELATIONSHIP BETWEEN VSS AND FLOW





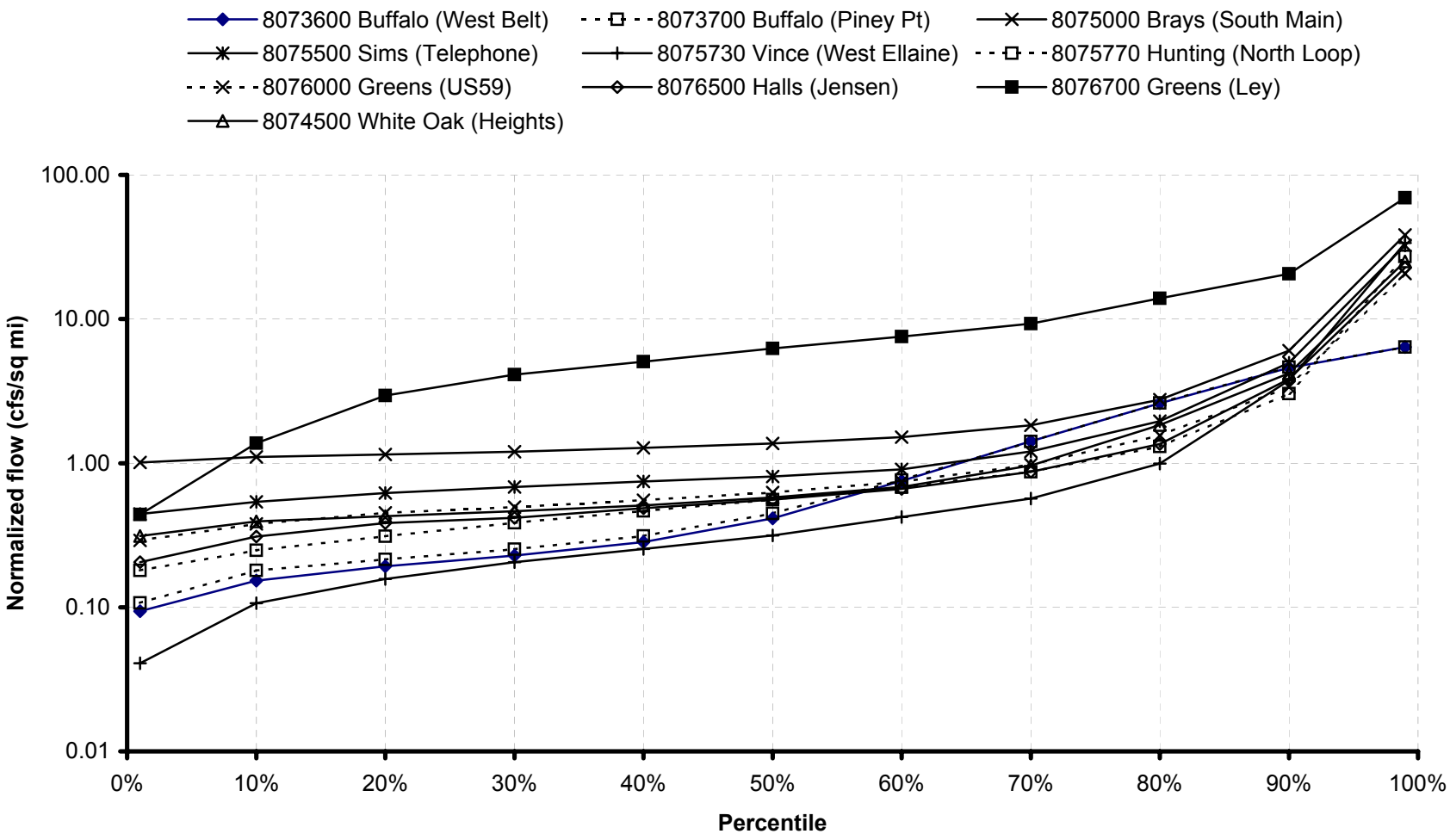
The illustrated regression relationships while useful do not capture some key points. For example, it is typical in a runoff event for the first part of the hydrograph to exhibit higher concentrations associated with runoff, while the declining limb of the hydrograph typically exhibits lower concentrations. This basic relationship is ignored in the correlation approach. However, to take that into account would require the development of a more sophisticated runoff model.

To calculate the overall TSS and VSS loads to the HSC, a multi-step analysis was performed. The first step was the regressions with hourly flow described above. These regressions provided a means to estimate the sediment load from flow data.

Next, the flow distributions for each of the gages were produced to examine the effects of different watershed characteristics. Figure 3.92 shows the flow distributions from all of the gages considered, after normalizing by the watershed area of each gage. The first point to be noted from this figure is that gages that are tidally influenced only report results when the flows are high enough to remove the tidal effect. In this case, the flow distributions are offset upward. This is the case with Greens Bayou at Ley Road that shows markedly higher flows per unit area than the other bayous. Another point is that the low flow values for many of the streams are affected by wastewater discharges and never get below set values. This is the case to varying degrees with most of the bayous, with Brays Bayou being the most affected. The only bayou that appears to show no upstream wastewater discharge effect is Vince Bayou.

The flow gage and concentration measurements exist for only part of the HSC watershed. To calculate the TSS and VSS loads for the entire HSC, a common procedure is needed. The modeling was developed as follows:

FIGURE 3.92
DISTRIBUTIONS OF FLOW NORMALIZED W.R.T. DRAINAGE AREA



First, since the goal was to analyze TSS and VSS loads and the point source flows contributed little in the way of these parameters and are monitored separately, it was deemed appropriate to use the Vince Bayou unit flow distribution, as it appears to be the one that is least affected by point source discharges.

Second, the average slope of the significant TSS regression line for the non-Buffalo Bayou streams was used. The stations on Buffalo Bayou have statistically significant but flatter slopes that reflect the reservoir effect in a part of their watersheds. For this analysis the decision was made to represent the area of the gages below the reservoirs in the same way as other areas, and the reservoirs themselves with a different approach described below. Figure 3.93 shows all the regressions for TSS plotted versus a normalized flow (flow/watershed area). It can be seen that the slope of the TSS-log Q relation is generally similar for most of the streams, and somewhat lower for the Buffalo Bayou stations that are affected by the upstream flood reservoirs. The dashed line shown is the average slope of the regressions for the stations without upstream flow regulation (excluding Buffalo Bayou stations) and the Greens Bayou at Ley which has tidal effects.

Annual average TSS and VSS loads for locations along the channel were then calculated and presented in Table 3.45. These were done using the watershed areas of each of the major tributaries, the unit flow distribution without point sources obtained from the Vince Bayou gage refined to one percentile intervals at the high flow end, and the average concentration-flow regression (dashed line in Figure 3.93). The inputs from Lake Houston were taken from the 1988 study, which were in turn taken from a 1982 publication by Baca, Bedient and Olson (Baca et. al., 1982). The Barker and Addicks reservoir watersheds were average inputs based on this Lake

FIGURE 3.93
REGRESSION LINES OF TSS AGAINST NORMALIZED FLOW

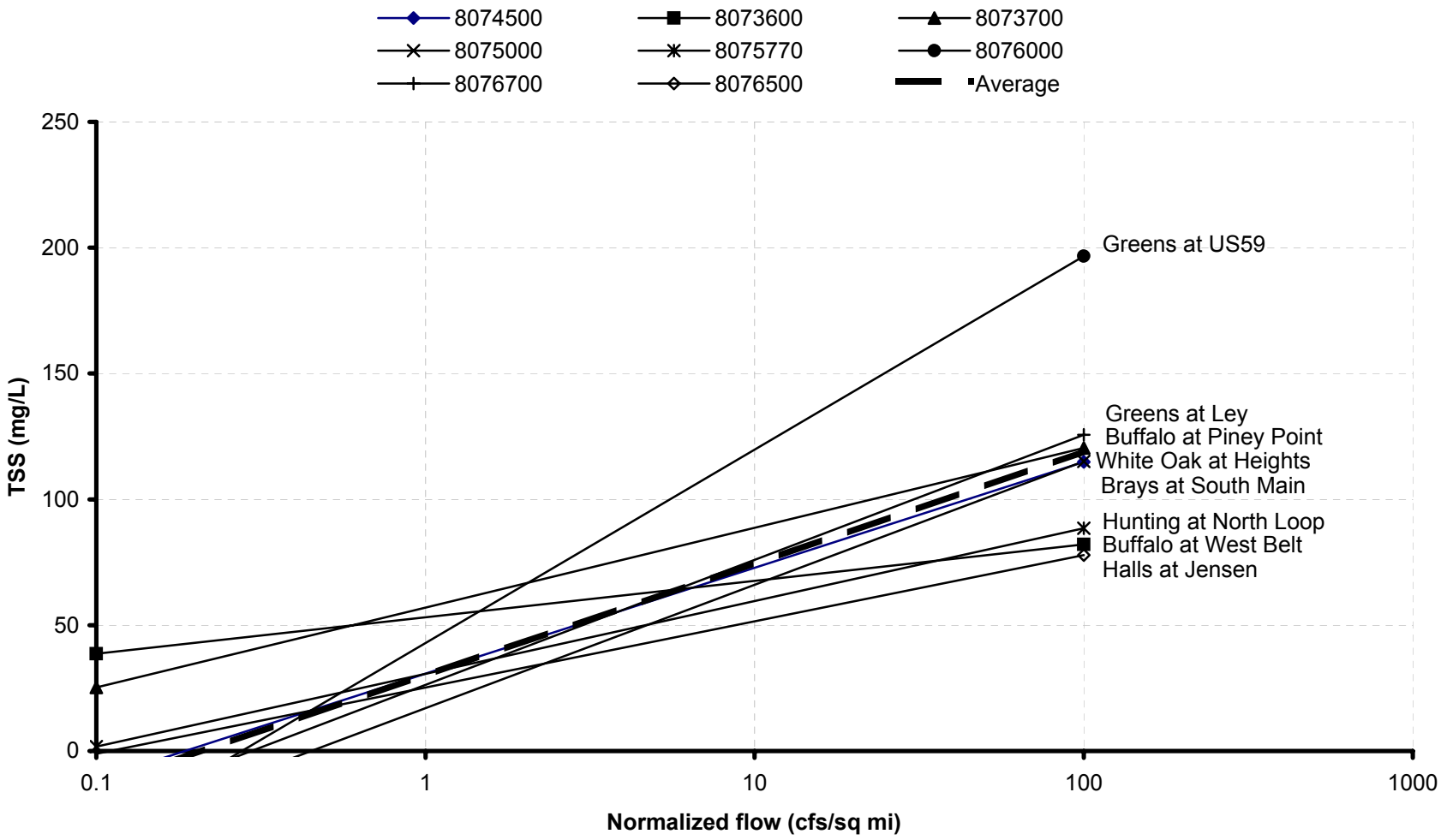


Table 3.45 Estimated Annual TSS and VSS Loads to the Houston Ship Channel

Location	Channel Km	Incremental drainage area (sq mi)	Cumulative drainage area (sq mi)	Annual TSS runoff load (mt)	Annual VSS runoff load (mt)		Annual TSS point source load (mt)	Annual VSS point source load (mt)	Annual total TSS load (mt)	Annual total VSS load (mt)
Barker & Addicks		264	264	3,395	917					
At Turning Basin	40.0	215	479	37,808	10,208	Turning				
Confluence with Brays	37.0	127	606	58,135	15,696	Basin				
Confluence with Sims	33.5	93	699	73,021	19,716	to				
Confluence with Hunting	28.5	48	747	80,703	21,790	Greens				
Confluence with Greens	25.5	208	955	113,996	30,779	Bayou	5,302	3,181	119,298	33,960
Confluence with Carpenters	17.0	59	1014	123,439	33,329	Greens				
Confluence with San Jacint	15.0	65	1079	170,207	45,956	Bayou to				
Morgan's Point	0.0	76	1155	182,371	49,240	Morgan's Pt	2,324	1,394	70,699	19,856
Total Load							7,626	4,576	189,997	53,816

Notes:

1. TSS loading rate is 160 mt/sq mile for HSC watershed, excluding Barker & Addicks Reservoirs and area upstream of Lake Houston.
   The loading rate of 160 mt/sq mile is calculated from the unit flow distribution of the Vince Bayou gauge and the average concentration-flow regression, TSS = 44.63xLog(flow in cfs/sq mile) + 30.
2. VSS load is estimated as 0.27 of TSS load.
3. TSS load from Lake Houston spill = 80 million lbs/year (36,364 mt/yr), drainage area = 2828 sq miles.
   From: A Design and Operating Strategy for the City of Houston's Wastewater Facilities and Operations, Vol. 4, 1988, Pate Engineers, Inc & Espey, Huston & Asso., Inc. citing Baca et al, 1982.
4. TSS load from Barker & Addicks Reservoirs based on load per unit drainage area of TSS load of Lake Houston spill.
5. Point source loads estimated from discharge flow and TSS conc of 10 mg/L and VSS conc of 6 mg/L. From 9/98 to 8/99 self-reported data, average flow to HSC up to Greens Bayou is 383.2 MGD, and flow to HSC between Greens Bayou and Morgan's Point is 167.9 MGD.

Houston rate. This is probably an underestimate because the settling time in these flood control reservoirs is much less than that of Lake Houston.

Also included in Table 3.45 is an estimate of the point source TSS and VSS loads. This estimate is conservative as the actual concentrations tend to be lower than those assumed. The annual average TSS load shown in Table 3.45, 189,997 metric tons/year, is somewhat lower than those computed in the 1988 study (233,650 - 409,450 mt/year) or the 1992 Galveston Bay NPS study, 217,000 mt/year. Given the inherent noise in runoff data, the limited amount of data actually available, and differences in calculation methodology, the differences are to be expected. It is also possible the sediment loads themselves may have reduced over time as the rate of development in the area has slowed from the extreme pace of the 1960s and 70s, and erosion control has become more of a priority in construction work. The changes over time are also addressed in the section dealing with dredging loads. Another factor to consider is the calculation procedures. In August 2000, the USGS published an analysis of over 3,200 paired TSS and suspended sediment concentration (SSC) data and concluded that SSC is a more reliable measure of solid phase material in natural waters than TSS. This finding was based upon the following observations (Grey, et. al., 2000):

SSC is determined from the entire water sample whereas TSS is determined from a sub-sample collected in inconsistent and unrepresentative ways from the original sample. This introduces significant errors and frequently yields underestimates of solids content;

- SSC values tend to be larger than their paired TSS values as the percentage of sand-size material exceeds about a quarter of the mass of sediment in the sample,

- TSS values for paired samples tend to be more equal for samples with finer solids (< 0.062 μm);
- the tendency for SSC values to exceed their paired TSS values has important ramifications for computations of suspended solid-phase discharges; those computed using TSS data will often underestimate solid-phase discharges. This is particularly true for sites when the percentages of sand-size material in the water samples exceed about a third of the total and where concentrations and percentages of sand-size material in transport increase with flow;

Review of the literature indicates that the TSS method originated as an analytical method for wastewater, presumably for samples collected after a settling step at a wastewater treatment facility. The results of this evaluation do not support use of the TSS method to produce reliable concentrations of solid-phase material in natural-water samples. The TSS method is being misapplied to samples from natural water.

In fact, Grey et al., (2000) state:

"The TSS method, which was originally designed for analyses of wastewater samples, is shown to be fundamentally unreliable for the analysis of natural-water samples. In contrast, the SSC method produces relatively reliable results for samples of natural water, regardless of the amount or percentage of sand-size material in the samples. SSC and TSS data collected from natural water are not comparable and should not be used interchangeably. The accuracy and comparability of suspended solid-phase concentrations of the Nation's natural waters would be greatly enhanced if all these data were produced by the SSC analytical method."

The USGS findings strongly suggest that the use of historical TSS will under-predict the true sediment load to the HSC. The degree of under-prediction appears to depend upon the fraction of particles in the load of sand or larger size. As the soils in the study area have a high silt and clay content, with relatively little sand, the error in using TSS data may not be extreme but still needs to be considered. The dioxin TMDL QAPP calls for the use of SSC to characterize the sediment in runoff events. These data will be reviewed to further refine our estimates of sediment load to the HSC.

3.3.3 Sediment Accumulation and Removal

Dredging records of the Galveston District, US Army Corps of Engineers, were retrieved and analyzed to establish the long-term pattern of sediment accumulation and removal. This section describes the data and analysis methods. The dredging records are an especially valuable data source for sediment loads as they reflect the great bulk of sediment that enters the system, concentrated into a small place. While the channel bottom is a small part of the total drainage area, it is by far the deepest and most conducive to settling. Areas to the side of the channel such as the side bays are not dredged and have exhibited no significant sediment accumulation.

The Houston Ship Channel (HSC) is a federal navigation project, and the Corps is charged with the responsibility to maintain the channel at its authorized depth for safe navigation. To do this, the Corps makes regular hydrographic surveys to track the situation. As sediments accumulate and depths are decreased, the Corps dredges the appropriate reaches and places the material in designated areas. The amount of material actually removed down to the specified dredging depth can be estimated using the difference between before dredging and after dredging

(BD and AD) surveys. Records of these surveys, and the in situ material removed from the HSC bottom, are the basis for this analysis.

Figure 3.94 shows the channel distances in kilometers from Morgan's Point, and the major landmarks in the HSC. Figure 3.95 illustrates the dredging reaches and the years when maintenance dredging contracts were completed. The period 1968 through 2003 was used. The 40 ft project depth by 400 ft width over most of the channel was completed in 1964, and work on the 45 ft x 530 ft project began at the end of the 90s, but has been excluded from the analysis. Only contracts marked as maintenance dredging were employed in the analysis. Each dot in Figure 3.95 is an end point to a reach. Between each dot a volume of material was removed during the specified year.

The first step in the analysis was to compute an accumulation rate for a channel reach between two successive dredging operations. This was done by dividing the volume of material removed in dredging a reach by the channel bottom area of the reach, to get an overall average depth of sediment removed in feet. The calculated value was then divided by the time between dredging to get a rate for the reach in feet per year. The volume of material accumulated between the two operations is the sum of the over-dredged volume of the first operation and the prescribed volume of the second operation. This accounts for differences in overdredging amounts from one cycle to the next. There is some inaccuracy in the accumulation rate because the dates of the historical dredging contracts are only recorded to the year. Figure 3.96 shows the individual rate calculations over the period of record along the channel from Morgan's Point to the most upstream Turning Basin. Each value is plotted at the center of the reach, and further identified by the decade in which the work was performed. The values for the 70s include some dredging

FIGURE 3.94
MAP OF HOUSTON SHIP CHANNEL

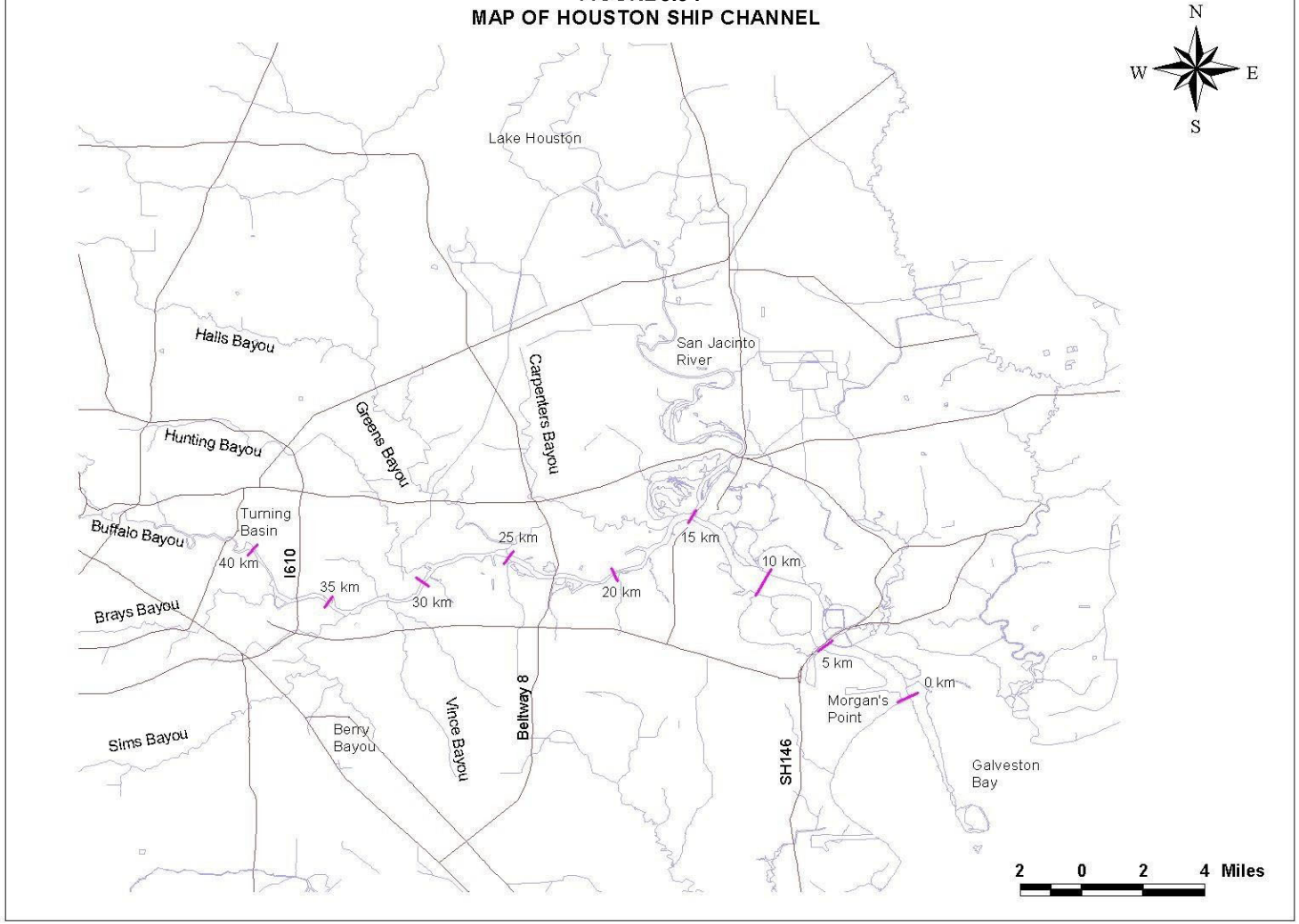


FIGURE 3.95
MAINTENANCE DREDGING CONTRACT REACHES AND PERIODS

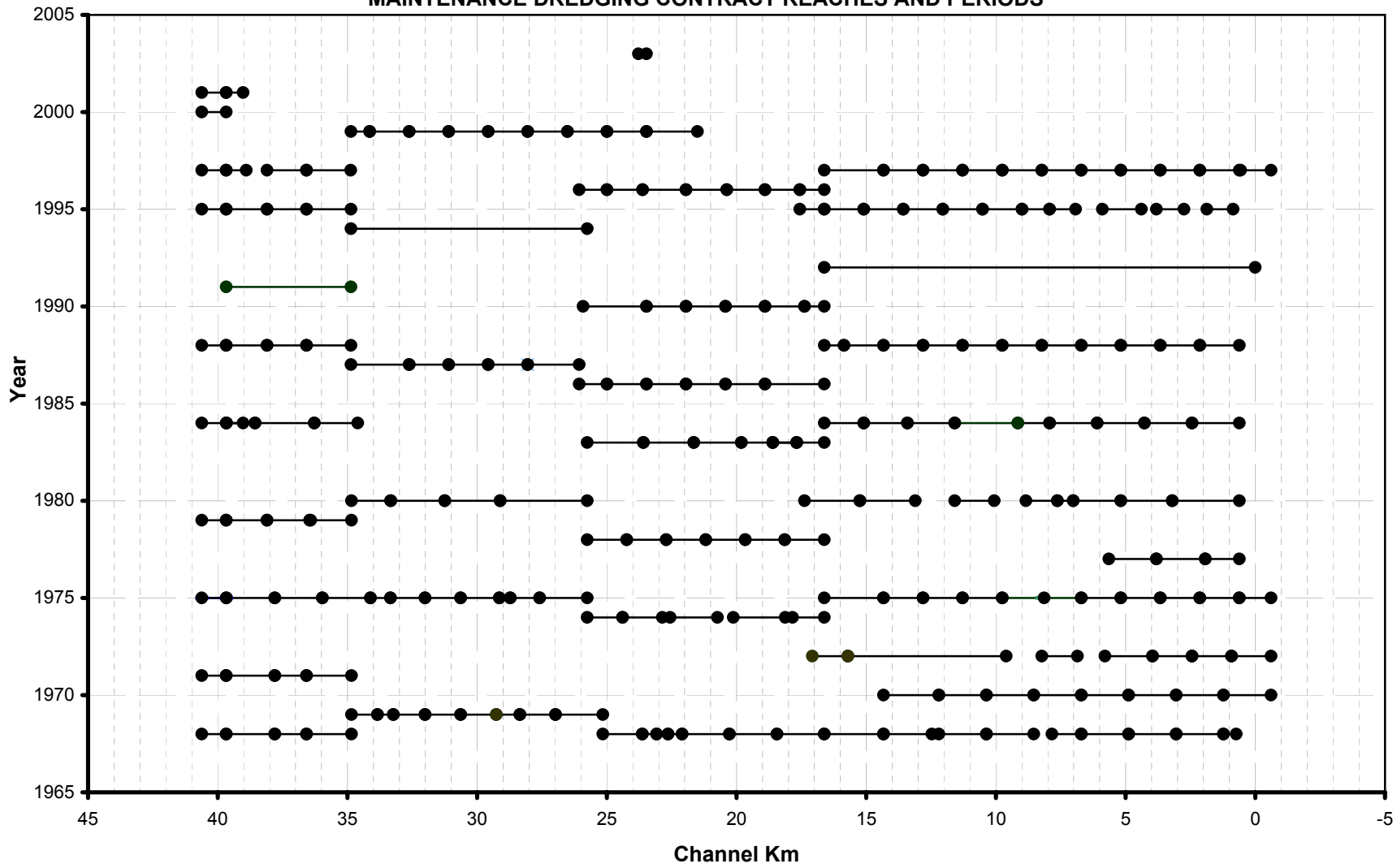
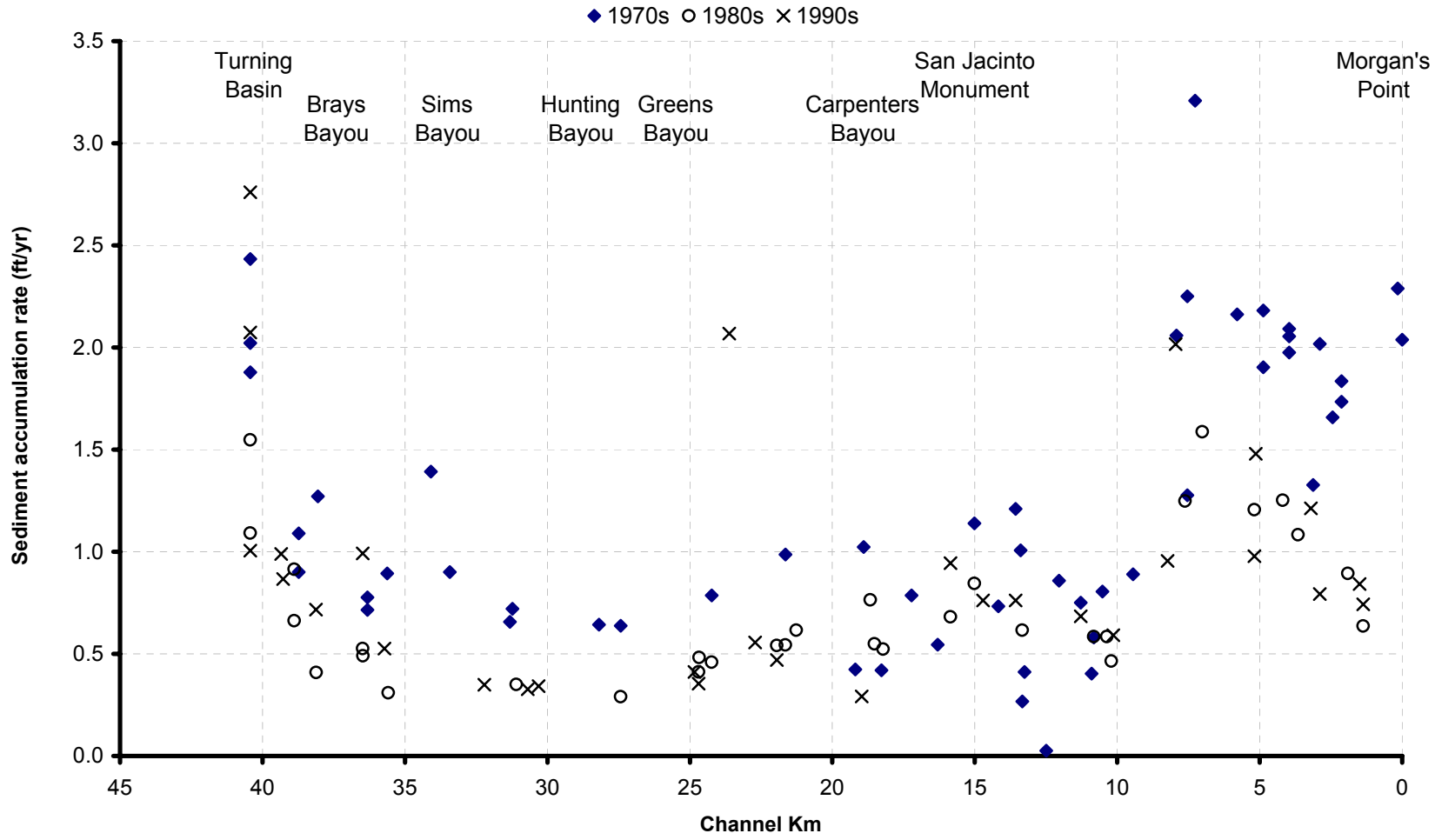


FIGURE 3.96
SEDIMENT ACCUMULATION RATES IN THE HOUSTON SHIP CHANNEL

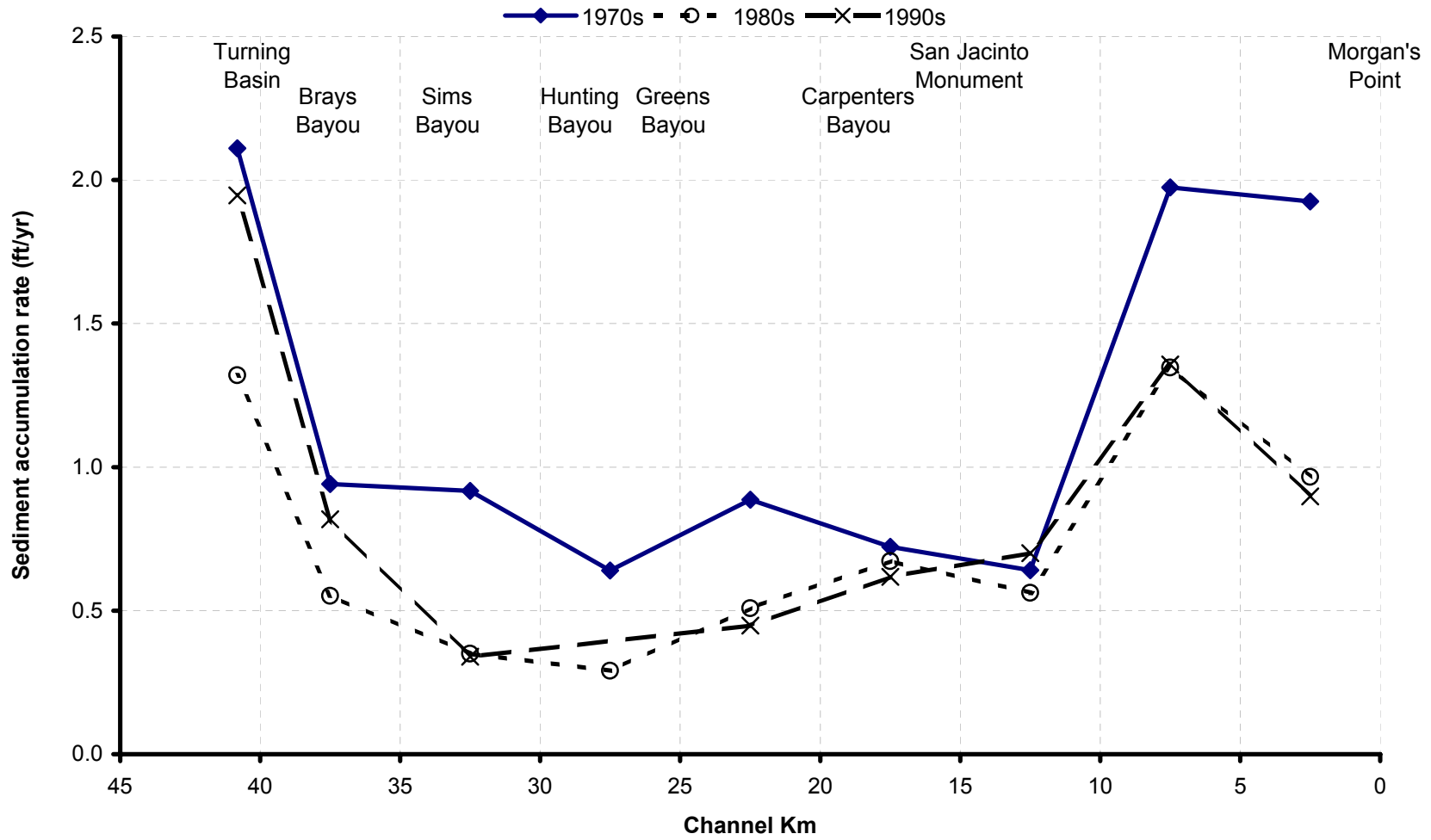


performed in the late 60s while the values for the 90s include some dredging performed in the early 00s.

The highest accumulation rates occur at both ends of the channel. There also appears to be a difference in accumulation rates by decade. To further explore this, Figure 3.97 shows the average rate for each 5 kilometers of channel for each decade in the dredging record. In averaging, the exceptionally high value at about 24 km in the 90s group was excluded. This value was calculated with 2003 data (see Figure 3.95) of a short reach that may not be representative. From this it appears that in most areas the accumulation rates were markedly higher in the 1970s than in either the 80s or 90s. The reasons for this difference are not clear, but a possible reason may be higher growth rates in the metropolitan areas in the 60s and 70s compared to the last two decades in the twentieth century. With more growth and development there would be greater exposed soil for erosion during rains. Because of the apparent difference, the analysis for present and future conditions will use the data from the 80s and 90s, and not the higher rate data from the 70s.

The higher sediment accumulation rates in the upper channel may be due to the fact that the most upstream Turning Basin, being a relatively wide spot that receives drainage from a substantial portion of the basin, is a natural sediment accumulation point. It has been referred to as the stormwater settling basin for Houston. Further down the HSC the dredging contracts cover a longer reach of channel relative to the drainage area so the accumulation rate is lower. The reasoning for the upper channel high rates do not apply to the high accumulation rates in the lower channel, as these areas have a much smaller drainage area and thus much less input from runoff. This higher rate may be due to a combination of local erosion and resuspension of

FIGURE 3.97
AVERAGE SEDIMENT ACCUMULATION RATES BY DECADES



sediments from the smaller side bays in this reach, and the effect of sediments suspended by wind waves in Galveston Bay that are carried into the confined and sheltered waters of the upper channel during flood tides.

The dredged volume in cubic yards was converted to a mass of solids that can be compared with the tributary loads. Table 3.46 is a summary of sediment data collected in early August 2002 and late May 2003 at a number of stations in the HSC. The left part of the table contains the data for each station, and the right part groups data by channel reach. The upper channel sediments tend to have a higher organic content and a lower bulk density than the lower channel stations. These parameters are reflected in the solids removal calculations in Table 3.47. The basic procedure is to get the total and volatile solids considering the higher organic content and lower bulk density of the upper channel sediments.

As solids, both mineral and organic, settle into the HSC, there is a process of decay in which organic matter is mineralized anaerobically. In 1988 this was estimated at about 4,000 metric tons from Morgan's Point up. See Appendix E, Table 5.2.2-4, for calculation methods.

3.3.4 Solids Balance

In comparing the sediment source in Table 3.45 and the sediment removed in Table 3.47, in the channel down to Morgan’s Point there is considerably more material removed than supplied. This is shown in Table 3.48. However, the amount of solids input to the upper channel is much closer to that removed in dredging when compared to the lower channel. There are several factors that contribute to this difference. In the lower channel, there is a relatively small drainage area to contribute sediment, but large dredging volumes. One of the sources of the lower channel sediment accumulation is likely to be the contribution of Galveston Bay sediments

Table 3.46 Sediment Data from 2002 and 2003 Intensive Surveys

Station ID	Channel Km	2002 Data					2003 Data				Channel reach	Density [2]	% solids [2]	VSS [2]
		Density (kg/l)	Volatile solids (mg/kg wet wt)	% solids	%moisture	VSS % dry wt	Density [1] (kg/l)	% solids	%moisture	VSS % dry wt		(kg/l)		% dry wt
11292	40	1.3	21,700	36.4%	63.6%	5.96%	1.5	49.7%	50.3%	6.33%	Turning Basin	1.4	43.1%	6.15%
11288	36.1	1.3	23,300	39.9%	60.1%	5.84%	1.6	60.8%	39.2%	3.72%	39.7 to 35 km	1.4	50.4%	4.78%
11287	33.5	1.3	15,300	36.4%	63.6%	4.20%	1.3	38.2%	61.8%	5.97%	35 to 30 km	1.3	37.3%	5.09%
11281	28.5	1.2	19,800	33.9%	66.1%	5.84%	1.3	38.0%	62.0%	5.91%				
11271	25.5	1.4	16,600	47.6%	52.4%	3.49%	1.5	56.2%	43.8%	2.58%	30 to 25 km	1.4	43.9%	4.45%
11269	22.6	1.6	11,100	52.2%	47.8%	2.13%	1.4	43.3%	56.7%	4.39%	25 to 20 km	1.5	47.8%	3.26%
11265	18.1	1.3	13,400	45.6%	54.4%	2.94%	1.2	29.6%	70.4%	5.05%				
11263	15.8	1.3	13,300	39.8%	60.2%	3.34%	1.3	40.1%	59.9%	3.69%	20 to 15 km	1.3	38.8%	3.76%
11260	13	1.6	8,000	64.8%	35.2%	1.23%	1.8	75.9%	24.1%	0.88%				
11258	11.5	1.4	12,600	41.2%	58.8%	3.06%	1.4	42.4%	57.6%	2.75%	15 to 10 km	1.5	56.1%	1.98%
11257	8.6	1.4	11,900	39.6%	60.4%	3.01%								
11254	7						1.6	64.5%	35.5%	1.77%	10 to 5 km	1.5	52.1%	2.39%
11252	0	1.2	14,000	30.7%	69.3%	4.56%	1.4	43.5%	56.5%	2.93%	5 to 0 km	1.3	37.1%	3.75%
13308	-6.4	1.3	11,600	32.6%	67.5%	3.56%								

Source: PBS&J-TCEQ Channel Intensive Surveys, Aug 5-7, 2002 and May 20-22, 2003.

[1] Density data not available in 2003. Estimated from regression line between 2002 % solids and density.

[2] Average of 2002 and 2003 data.

Table 3.47 Estimated Annual Volume and Mass of Solids Accumulation in Houston Ship Channel

Channel reach	Average sediment accumulation rate [1] (ft/yr)	Bottom area [2] (sq ft)	Volume of sediment removed (cu ft/yr)	Sed values from IS: Average % solids	Sed values from IS: VSS (% dry wt)	Sed values from IS: Density (kg/l)	Solids removed (mt/yr)	Organic conc. (gm/l)	Organics removed (mt/yr)
Turning Basin	1.70	1,465,200	2,484,555	43.1%	6.15%	1.4	41,669	36.4	2,561
39.7 to 35 km	0.67	4,921,260	3,311,295	50.4%	4.78%	1.4	68,109	34.7	3,255
35 to 30 km	0.34	4,921,260	1,683,896	37.3%	5.09%	1.3	23,236	24.8	1,182
30 to 25 km	0.29	4,921,260	1,430,823	43.9%	4.45%	1.4	24,205	26.6	1,078
	Turning Basin to Greens Bayou		8,910,569				157,220		8,077
25 to 20 km	0.48	5,409,777	2,621,569	47.8%	3.26%	1.5	52,717	23.1	1,718
20 to 15 km	0.66	6,561,680	4,309,406	38.8%	3.76%	1.3	60,863	18.7	2,285
15 to 10 km	0.63	6,561,680	4,141,571	56.1%	1.98%	1.5	100,795	17.0	1,996
10 to 5 km	1.35	6,561,680	8,877,102	52.1%	2.39%	1.5	198,214	18.8	4,732
5 to 0 km	0.93	6,561,680	6,114,802	37.1%	3.75%	1.3	82,767	17.9	3,100
	Greens Bayou to Morgan's Point		26,064,450				495,355		13,832
		TOTAL	34,975,018				652,575		21,908

[1] Average of rates in 80s and 90s.

[2] Bottom width is 400 ft up to 21.5 km and 300 ft beyond that.

[3] Solids removed = Volume of sediment removed x Density x Average % solids x 0.02832

Organic conc = Density x Average % solids x VSS % dry weight x 1000

Organics removed = Organic conc x Volume of sediment removed x 2.832 x 10^{-5}

Last numbers in the above equations are units conversion factors.

Table 3.48 Sediment and Organic Balances

	Channel reach		Total
	Turning Basin to Greens Bayou	**Greens Bayou to Morgan's Point**	
Sediment			
TSS Sources (mt/yr)[a]	119,298	70,699	180,997
TSS Sinks (mt/yr)[b]	157,220	495,355	652,575
Balance	(37,922)	(424,656)	(462,577)
Source % of Sink	76%	14%	29%
Organics			
VSS Sources (mt/yr)[1]	33,960	19,856	53,816
VSS Sinks (mt/yr)[2]	10,267	15,840	26,106
Balance	23,694	4,016	27,710
Source % of Sink	331%	125%	206%

[a] Sources as calculated in Table 3.45
[b] Sinks as calculated in Table 3.47. VSS Sinks include organics in-situ decay, values from 1988 Study.

suspended by wind waves that are carried above Morgan's Point during flood tides and can settle in the more protected waters. Another source in this reach is erosion of the shorelines, particularly on the shallow side bays. Moreover, some of the material in larger rain events from the upper channel watershed would be carried into the lower channel before settling.

Another dimension that may be playing a role is the difference between TSS and SSC. The data do not exist that would allow quantification of this difference, but it would not be surprising to find that an analysis that captures the larger particles more completely would indicate a substantially higher runoff load. This would tend to make the sources and sinks in closer agreement.

With the organic load, VSS source and sink, the calculated sources exceed the amount removed by a substantial margin. One possible reason is that the estimate of organic decay in the sediments is low. While the runoff solids average 27% VSS, the channel sediments have only about 3% of the dry weight as volatile material. A higher estimate of biological decay of organic matter would bring the source and sink values closer together.

CHAPTER 4

DATA ANALYSIS

4.1 SITE-SPECIFIC BIOACCUMULATION FACTORS AND WATER QUALITY TARGETS

4.1.1 Development of Site-specific Bioaccumulation Factors

The BAF is defined by the USEPA (2003) as the ratio (in liters per kilogram of tissue) of the concentration of a chemical in the tissue of an aquatic organism to its concentration in water, in situations where both the organism and its food are exposed and the ratio does not change substantially over time. As is typical, in this project only the dissolved concentration in water, rather than the total water concentration (including the chemical associated with suspended particulate and colloidal material), was used in calculating the BAF.

$$BAF = \frac{C_{tissue}}{C_{water,diss}} \tag{4.1}$$

Because BAFs have been shown to vary in direct proportion to the lipid content of the tissue (USEPA 2003), the lipid-normalized tissue concentration is often used in lieu of the total tissue concentration in calculating a BAF. These BAFs are called lipid-normalized BAFs or BAF_l

$$BAF_l = \frac{C_{tissue} / F_{lipid}}{C_{water,diss}} \tag{4.2}$$

where F_{lipid} is the lipid fraction of the tissue by weight.

BAFs for catfish and crabs were calculated for each of the paired water and tissue samples collected in the spring, summer, and fall seasons from 2002 through 2004. Each fish or crab sample was a composite tissue sample from 3 to 5 animals. Because lipid normalization increased the variability in the BAF relationships, and the lipid measurement method used was imprecise, all BAFs were based on whole tissue concentrations and were not lipid-normalized. An effort was made to collect the fish, crab, and water samples from a given station on the same day. However, in practice this proved difficult and the samples from various media for a station were often collected several days apart.

BAFs[4] for PCDD/F congeners measured in 111 catfish and water samples from the HSC system are shown in Figure 4.1, and those measured in 106 blue crab and water samples are shown in Figure 4.2. BAFs varied widely both among and between congeners. The individual log BAF patterns are similar between catfish and crabs, indicating the importance of chemical properties in controlling BAFs. However, on average the BAFs for crabs were lower than those in fish for most congeners. For the dioxin congeners, a systematic decline in BAF with increasing hydrophobicity (as indicated by size and chlorination) was evident, which is consistent with independent observations that for very hydrophobic chemicals such as the larger PCDD/Fs, dietary uptake efficiencies decline with increasing hydrophobicity (Opperhuizen and Sijm 1990; Gobas et al. 1988). This pattern was not evident to the same extent in the furan congeners.

More importantly, and for a given congener, the log BAFs vary over a wide range. Possible factors accounting for the variability include seasonality, spatial factors, tissue properties

[4] BAFs were calculated as the ratio of the tissue concentration to the dissolved concentration for each individual data point.

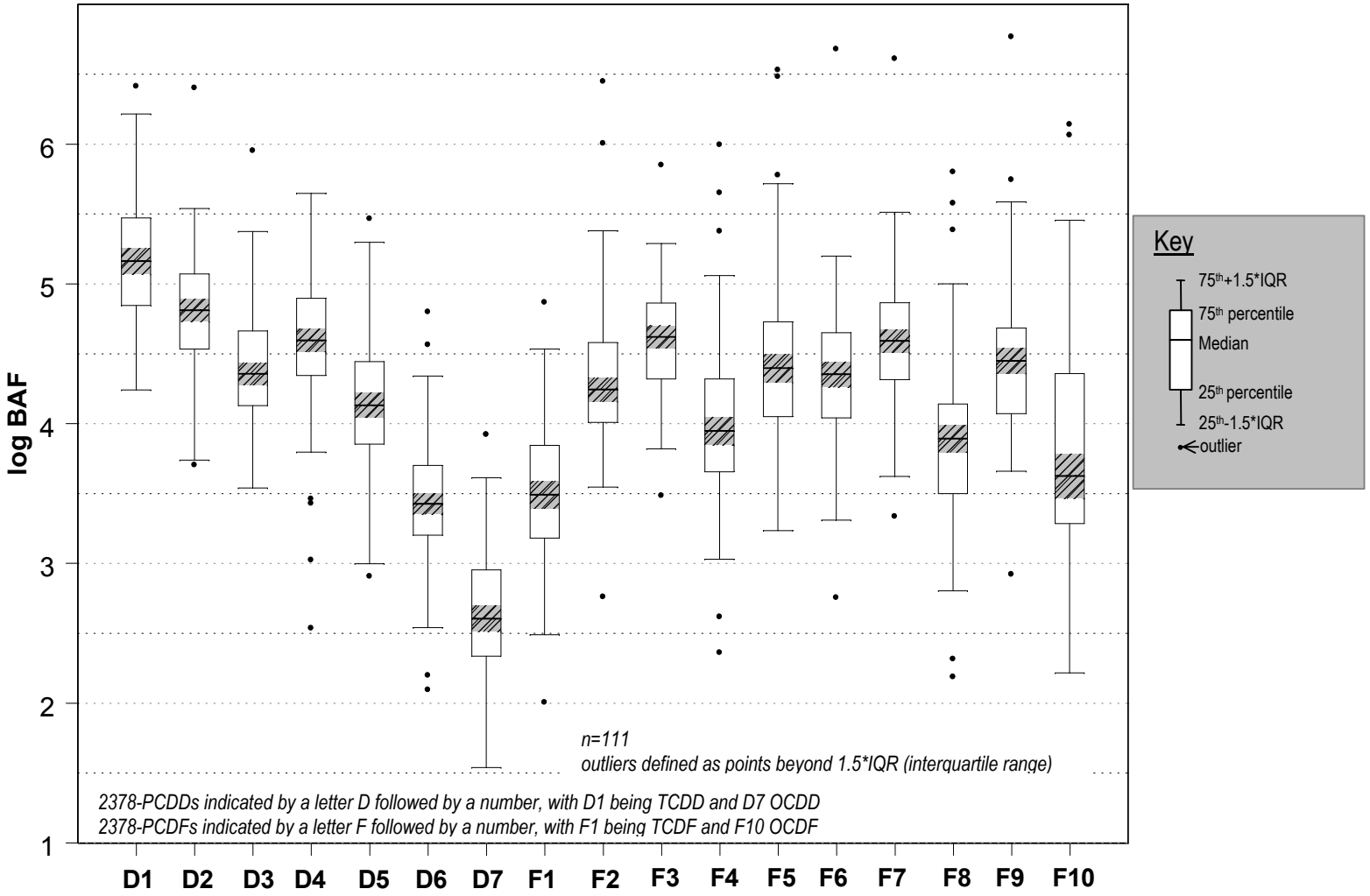


Figure 4.1 Distribution of Individual log BAFs for Catfish from the HSC

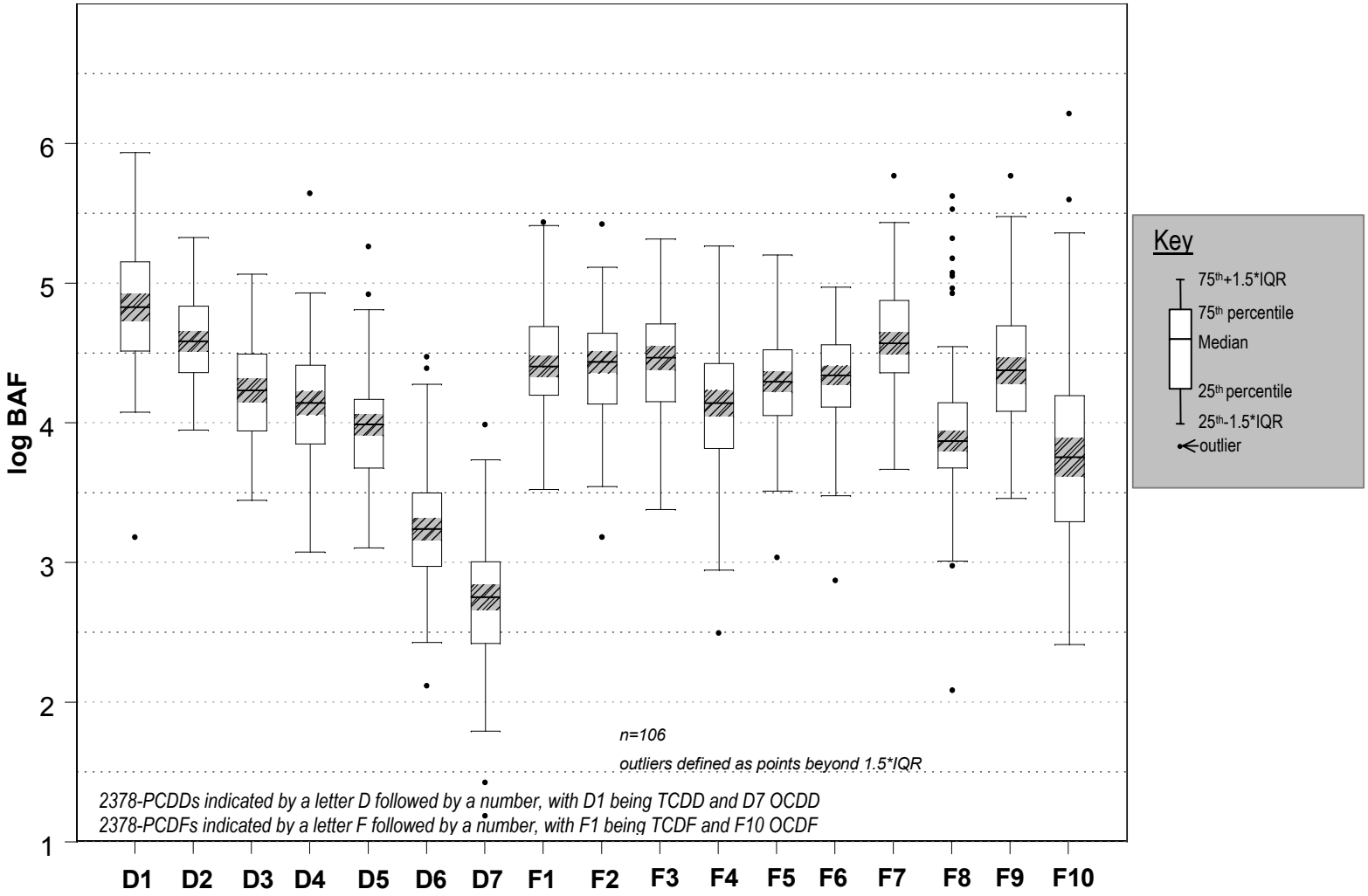


Figure 4.2 Distribution of Individual log BAFs for Crabs from the HSC

(species, size, lipid content, etc), water properties (salinity, temperature, TOC, etc), and random error due to the fact that many of the reported values were non-detects or between the detection limit and the reporting limit (Non-detects were assumed equal to half of the detection limit). Preliminary non-parametric correlations between tissue concentrations of 2378-TCDD and a number of explanatory variables are summarized in Table 4.1. Overall, there are few significant correlations between 2378-TCDD concentrations and other factors. For example, concentrations in catfish and crabs are correlated to the lipid content but the correlation coefficients are not very large. Table 4.2 summarizes correlation coefficients between log BAF for 2378-TCDD and some explanatory variables. It can be seen in Table 4.2 that while tissue lipid content did not explain a significant amount of variation in the tissue concentrations, BAFs did exhibit a small but statistically significant relationship with a measure of the "fatness" of the fish: the average weight to length ratio. Seasonal variations in BAF were not statistically significant. While the catfish species sampled included some gafftopsail catfish, blue catfish, channel catfish and black bullheads among the hardhead catfish, there was no significant variation in BAF among species.

In general, BAFs measured at less contaminated sites with low PCDD/F concentrations tended to be higher than those from sites with high water concentrations (Figure 4.3). This may be explained by the fact that fish are exposed to PCDD/F concentrations that vary over several orders of magnitude. Spatial variation in PCDD/F concentrations spans several orders of magnitude in the HSC system. Fish and crabs are of course mobile, and most leave the system for deeper waters between late November and March (USFWS 1983). Also, fish and crabs accumulate PCDD/Fs from direct exposure to PCDD/Fs in sediments and water, and from their diet of multiple prey species residing in those media. Tissue concentrations are expected to be substantially less dynamic than the concentrations in other media, resulting in a relative

Table 4.1 Spearman Correlation Coefficients for Concentrations of 2378-TCDD in Tissue and some Explanatory Variables

		% lipid	Median weight	Median length	Weight/ length ratio	Temperature	Conductivity	DO	pH	Salinity	TSS	TOC	DOC	TDS	POC
2378-TCDD in catfish	Spearman's rho[1]	**0.525**	-0.028	-0.141	-0.002	-0.113	-0.032	0.011	*-0.267*	0.133	*-0.265*	-0.132	-0.034	-0.181	-0.105
	Sig. (2-tailed)	0.000	0.766	0.139	0.983	0.356	0.793	0.932	0.026	0.277	0.017	0.241	0.764	0.106	0.352
	N	112	112	112	112	69	69	69	69	69	81	81	81	81	81
2378-TCDD in catfish-lipid	Spearman's rho[1]	-0.149	0.068	-0.074	0.100	0.148	0.011	-0.065	-0.067	0.105	*-0.259*	-0.054	0.028	-0.122	0.076
	Sig. (2-tailed)	0.118	0.475	0.439	0.296	0.226	0.931	0.598	0.583	0.389	0.020	0.633	0.801	0.277	0.501
	N	112	112	112	112	69	69	69	69	69	81	81	81	81	81
2378-TCDD in crab	Spearman's rho[1]	**0.326**	**0.414**	**0.407**	**0.406**	-0.026	**-0.348**	0.002	-0.224	0.005	*-0.244*	-0.059	0.038	*-0.236*	0.031
	Sig. (2-tailed)	0.001	0.000	0.000	0.000	0.836	0.004	0.984	0.067	0.965	0.027	0.599	0.732	0.032	0.779
	N	108	108	108	108	68	68	68	68	68	82	82	82	82	82
2378-TCDD in crab-lipid	Spearman's rho[1]	-0.141	**0.462**	**0.398**	**0.466**	-0.060	*-0.268*	-0.033	-0.170	0.067	**-0.289**	0.103	0.140	*-0.240*	0.077
	Sig. (2-tailed)	0.147	0.000	0.000	0.000	0.630	0.027	0.786	0.166	0.585	0.008	0.355	0.209	0.030	0.492
	N	108	108	108	108	68	68	68	68	68	82	82	82	82	82

[1]A nonparametric version of the Pearson correlation coefficient, based on the ranks of the data rather than the actual values. It is appropriate for ordinal data, or for interval data that do not satisfy the normality assumption.

Values of the coefficient range from -1 to +1. The sign of the coefficient indicates the direction of the relationship, and its absolute value indicates the strength, with larger absolute values indicating stronger relationships.

Spearman coefficients in bold indicate that the correlation is significant at the 0.01 level (2-tailed).

Spearman coefficients in italics indicate that the correlation is significant at the 0.05 level (2-tailed).

Table 4.2 Pearson Correlation Coefficients for log BAF of 2378-TCDD and some Explanatory Variables

		% lipid	Median weight	Median length	Weight/ length ratio
2378-TCDD log BAF in catfish	Pearson correlation	**0.276**	0.059	**0.310**	**0.319**
	Sig. (2-tailed)	0.003	0.544	0.001	0.001
	N	111	109	109	109
2378-TCDD log BAF in crab	Pearson correlation	0.117	**0.269**	*0.195*	0.136
	Sig. (2-tailed)	0.229	0.006	0.048	0.168
	N	106	104	104	104

Pearson coefficients in bold indicate that the correlation is significant at the 0.01 level (2-tailed).
Pearson coefficients in italics indicate that the correlation is significant at the 0.05 level (2-tailed).

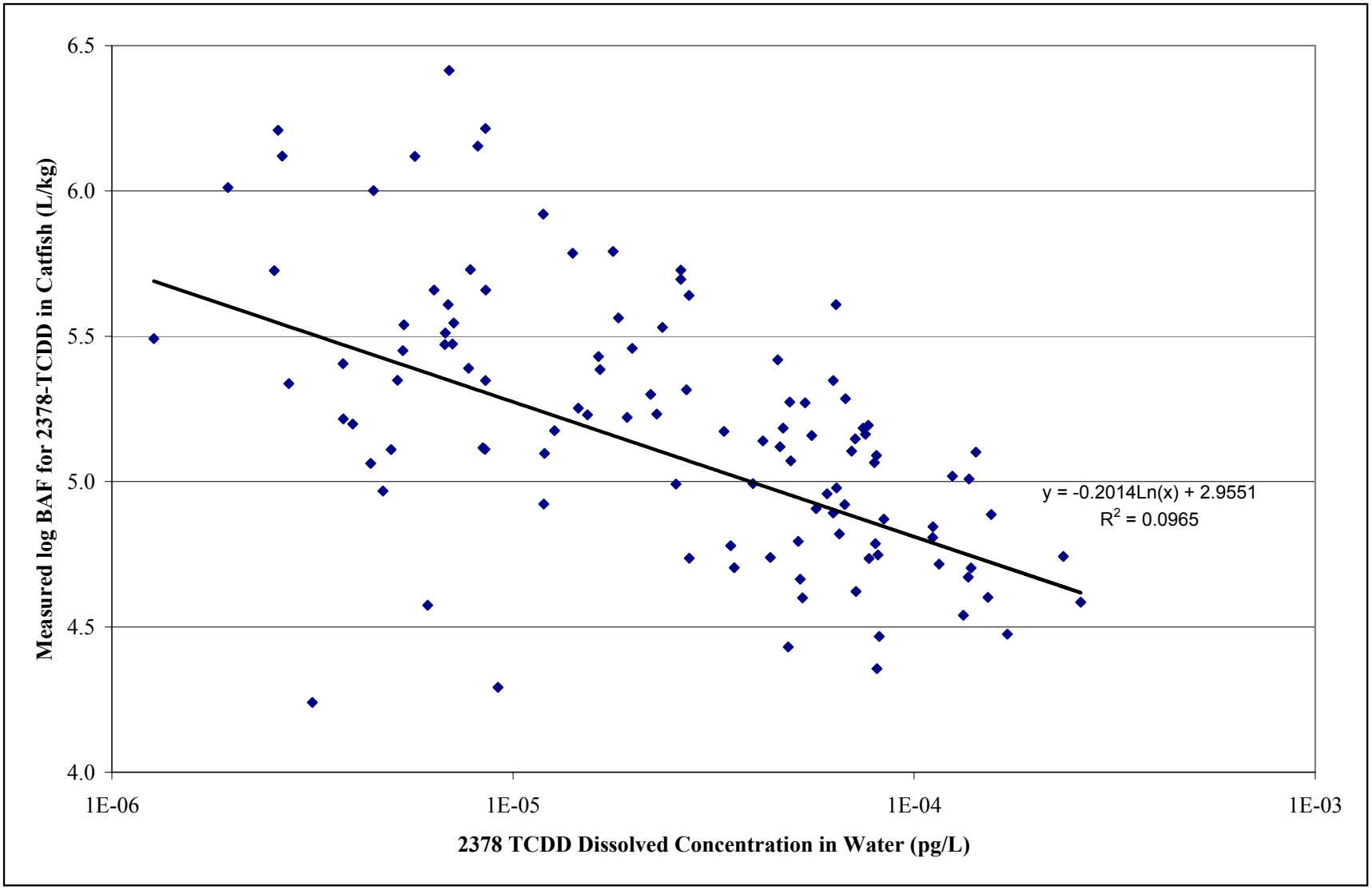


Figure 4.3 Variation in Catfish BAF with Dissolved Concentration in Water

"flattening" of the tissue:water concentration ratio and the observed decline in BAF with increasing dissolved concentration.

The next section describes the detailed methodology for estimating BAFs for the 17 congeners.

4.1.1.1 Estimation of BAF for 2378-TCDD

As a first step, regressions of 2378-TCDD concentrations in tissue and water were completed in order to establish the most appropriate regression model for estimating BAFs for the remaining congeners. Since dioxins and furans are members of a class of chemical compounds known as nonpolar hydrophobic organic compounds (HOCs), they partition preferentially into lipid matter. It is often found that the variability of BAFs or BCFs between species and individuals for HOCs is reduced if they are first normalized by the tissue lipid content (USEPA, 1995). The lipid-normalized bioaccumulation factor (BAF_l) is defined by Equation (4.2).

Combining Equations (4.1) and (4.2), the concentration of an HOC in tissue of biota can be predicted using:

$$C_b = BAF_i * F_i * C_w \qquad (4.3)$$

The USEPA (1995) advises that BAFs and BCFs (bioconcentration factors) for organic compounds should be calculated from lipid-normalized tissue concentrations and dissolved concentrations in water.

BAFs are also typically adjusted to correct for chemical bioavailability. The water concentration of a chemical includes portions associated with suspended and colloidal particles and dissolved organic matter, as well as portions truly dissolved in water. However, only the freely dissolved concentration is bioavailable for uptake across gill membranes or external body

surfaces (USEPA, 1995). It is likely that the dissolved data collected using the high-volume sampling technique correspond to the freely dissolved concentrations, as the colloidal fraction most probably passes through the XAD-2 resin.

In order to determine the strongest partitioning relationship for the HSC data (the USEPA (1995) suggest using either freely dissolved or total water concentrations), an analysis of correlation between the different measurements in water and tissue was performed and is included in Table 4.3. As indicated in Table 4.3, the strongest partitioning relationship was observed between measured 2378-TCDD in not lipid-normalized tissue and the dissolved concentrations. Thus, BAFs were calculated using regressions between tissue and dissolved concentrations.

Dissolved water concentrations and catfish data for 2378-TCDD were analyzed using different regression methods to determine the best-fit BAF. In general, linear regression is

Table 4.3 Pearson Correlation Coefficients between Water and Catfish Concentrations of 2378-TCDD

		2378-TCDD dissolved	2378-TCDD in water-total
2378-TCDD in catfish	Pearson coefficient	**0.434**	0.188
	Sig. (2-tailed)	0.000	0.087
	N	84	84
2378-TCDD in catfish-lipid	Pearson coefficient	*0.244*	**0.349**
	Sig. (2-tailed)	0.026	0.001
	N	84	84

Pearson coefficients in bold indicate that the correlation is significant at the 0.01 level (2-tailed).
Pearson coefficients in italics indicate that the correlation is significant at the 0.05 level (2-tailed).
Shading indicates the strongest correlation.

preferred because it would yield a BAF directly from the slope. However, since the HSC data do not meet the assumptions of constant variance and normality of the residuals for the Ordinary

Least Square Method (OLS), and because there are outliers due to the various reasons cited earlier, alternative robust linear regression models were investigated. These alternative methods for regression include Robust Least Trimmed Squares (LTS)[5], Robust MM Regression, and Iterative Weighted Least Squares (WLS)[6]. Robust methods help to control the disproportionate influence of outliers that could well be legitimate data points (Helsel and Hirsch, 2002). In addition, a curve representing the average log BAF from individual measurements was also included in the analysis.

Figures 4.4 and 4.5 present the HSC 2378-TCDD data as well as the best-fit lines derived using the previously mentioned methods. A summary of the test statistics for each of the regression models for both catfish and crabs is included in Table 4.4. Two non-linear regressions (power and polynomial as indicated in Figures 4.4 and 4.5 and Table 4.4) were also evaluated for comparison purposes. As can be seen in Figures 4.4 and 4.5, there was a lot of variance in the relationships. It is noted that a simple linear BAF regression between tissue concentrations and dissolved concentrations does not work well to explain the data collected in the Houston Ship Channel. The linear BAFs have low r^2 and F values and high standard errors. The polynomial and power (log-transformed data) models seem to better represent the data but they have the disadvantage that a BAF cannot be directly derived from the equations. This might suggest the need for developing a multivariate regression model or it might indicate that the congener-specific BAF approach cannot be used for the HSC.

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[5] See Appendix F for a brief description of the used robust regression methods.

[6] Other methods such as Reduced Major Axis (also known as Geometric Mean Regression) and Least Median of Squares were also considered. However, results are not included due to the difficulty in obtaining test statistics to compare with the other methods employed in this analysis.

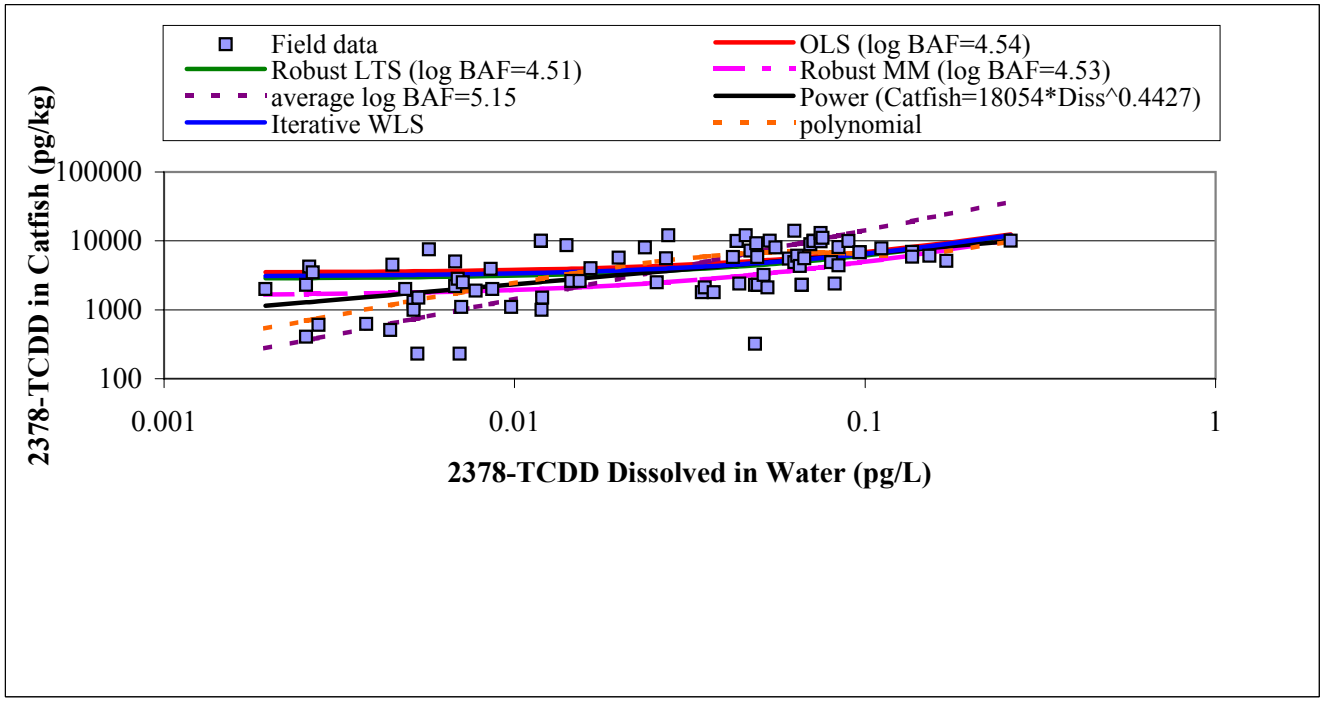


Figure 4.4 Partitioning of 2378-TCDD between Catfish and Dissolved Phase in the HSC

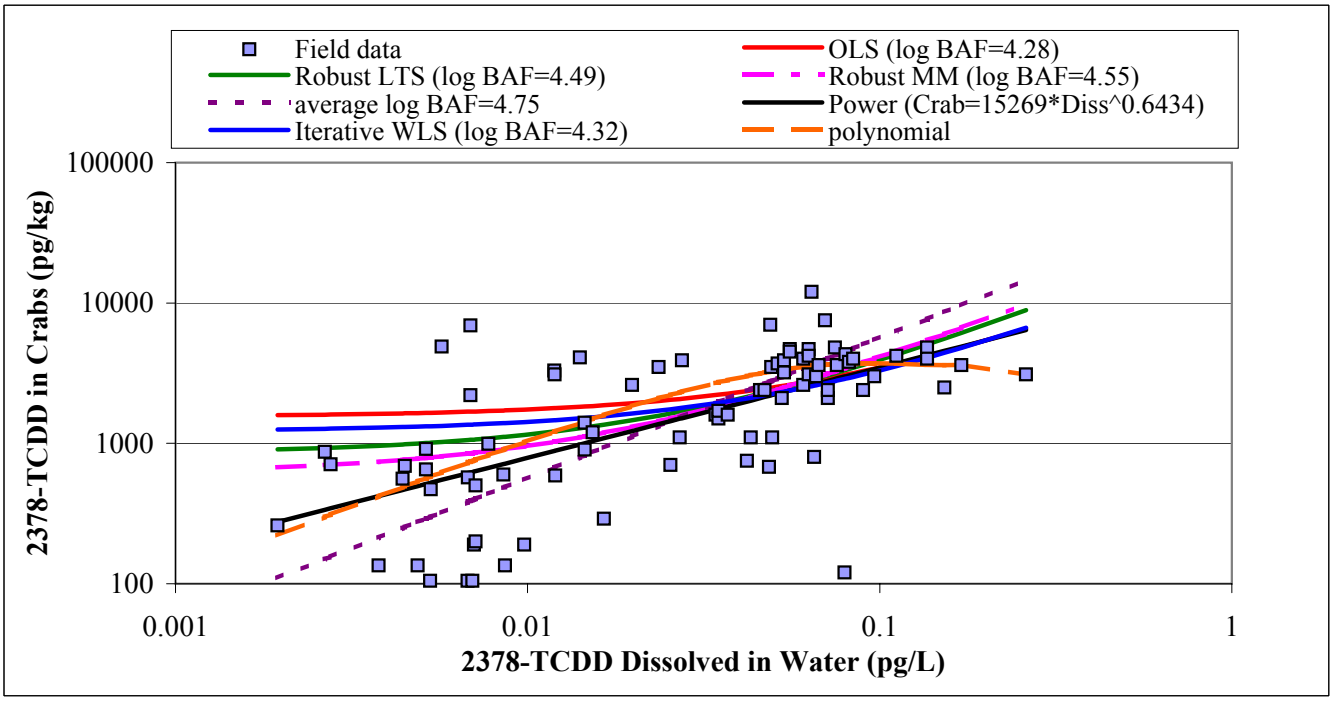


Figure 4.5 Partitioning of 2378-TCDD between Crabs and Dissolved Phase in the HSC

Table 4.4 Summary of Regression Statistics and Parameters for Tissue-Water Relationships

Catfish

Model	F-statistic	p-value	Residual SE	b0			b1 (BAF in linear regressions)			b2			b3		
				Value	SE	t-value[a]	Value	SE	t-value[a]	Value	SE	t-value[(a)]	Value	SE	t-value[a]
OLS	18.982	0.000038	3233.280	3442.86652	502.21325	6.855388	34617.64	7945.602	4.35683						
Robust LTS	22.678	8.68E-06	2820.080	3133.919	442.533	7.08	33154.95	6962.162	4.762						
Robust MM	9.51	0.00861	2527.180	1604.75	468.8	3.423	33642.7	6913.294	4.867						
Iterative WLS	26.0646	2.10E-06	2670.800	3032.742	434.41	6.981	34840.53	6824.318	5.105						
Polynomial			3184.840	-3.49E+07	2.37E+07	-1.472	2.03E+07	1.06E+07	1.915	-3.86E+06	1.37E+06	-2.81943	2.82E+05	5.07E+04	5.553
Power	38.553	2.08E-08	2.228	18054	1.3197996	35.321	0.4427	0.0712	6.209						

Crabs

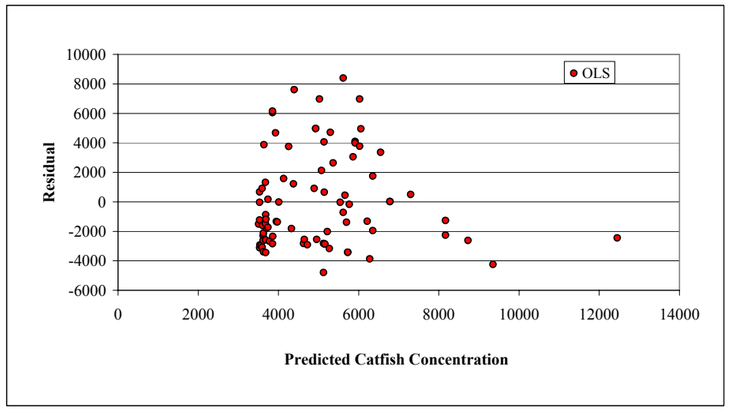
Model	F-statistic	p-value	Residual SE	b0			b1 (BSAF in linear regressions)			b2			b3		
				Value	SE	t-value[a]	Value	SE	t-value[a]	Value	SE	t-value[(a)]	Value	SE	t-value[a]
OLS	15.9251	0.00015	1923.760	1551.086	303.779	5.106	19228.16	4818.324	3.991						
Robust LTS	57.24	9.89E-11	1154.000	964.31	199.339	4.837	26680.2	3526.449	7.566						
Robust MM	4.46	0.107	1036.950	606.473	320.854	1.89	35391.22	6062.389	5.838						
Iterative WLS	33.85	1.25E-07	1318.000	1214.18	219.757	5.525	20943.91	3599.663	5.818						
Polynomial			1821.890	-9.76E+06	1.38E+07	-0.707	5.93E+06	6.20E+06	0.957	-1.28E+06	8.02E+05	-1.601	1.16E+05	2.95E+04	3.931
Power	53.29	1.98E-10	8.515	15269.00	2.183	28.401	0.6434	0.0881	7.300						

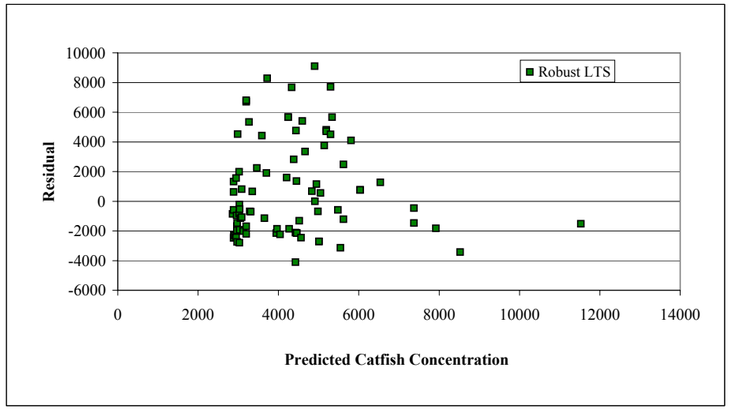
[a] If |t-value|>2, the linear relationship is statistically significant atα=0.05.

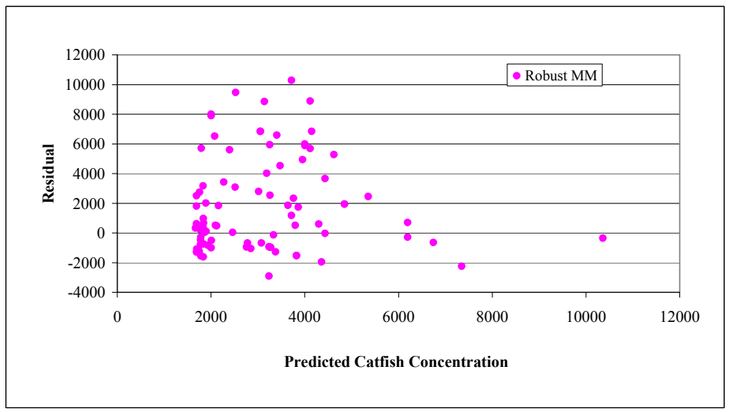
It is noted that non-detects were assumed to be equal to half of the detection limit. Because the detection limits were variable, this should not have introduced a large bias towards a single value. It is noted, however, that those values have high uncertainty associated with them. The BAF regressions for 2378-TCDD presented earlier were compared to those completed assuming non-detects as zeros but no significant differences were evident and the relationships were not stronger.

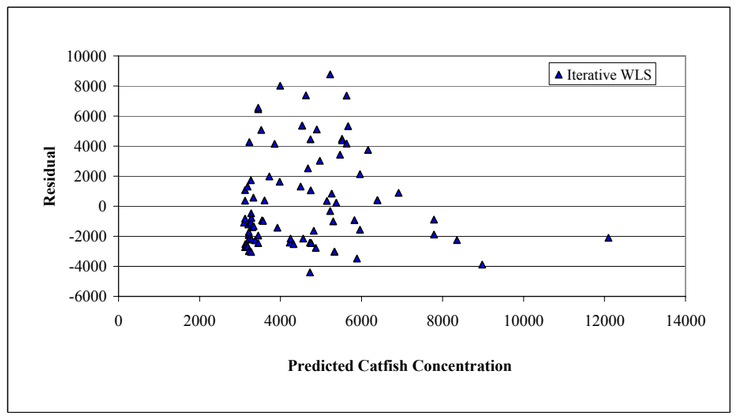
To aid in selecting the linear regression method that would be used to estimate BAFs for all the 2378-substituted congeners, residuals versus fit plots for the different models were prepared and visually inspected (Figures 4.6 and 4.7 for catfish and crabs, respectively). The residuals present some clustering but, in general, they were distributed randomly in both directions. At the higher end of the predicted values, there were a few outliers that produced curvature. This confirmed the need for using a robust regression method. Figures 4.8 and 4.9 present histograms plotted along the probability mass function for a normal distribution for each set of residuals. As expected, the residuals of log-transformed data (power regression) are normally distributed. However, due to difficulties in calculating BAFs from non-linear regressions, the robust LTS regression was selected as the model to use for bioaccumulation factor estimation. As suggested by the data in Figures 4.8 and 4.9, residuals from the robust LTS had the distribution that differs the least from a normal distribution among all the linear methods.

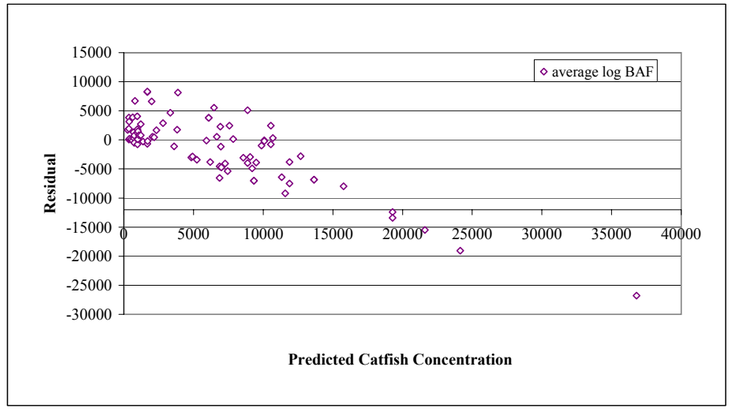
The last step followed prior to completing regressions for all the congeners was to examine the plots of catfish residuals versus other explanatory variables. This helped in determining if other variables could have been included in a multiple regression model to explain the noise in the data. Figure 4.10 shows scatterplots of residuals versus sampling date, catfish

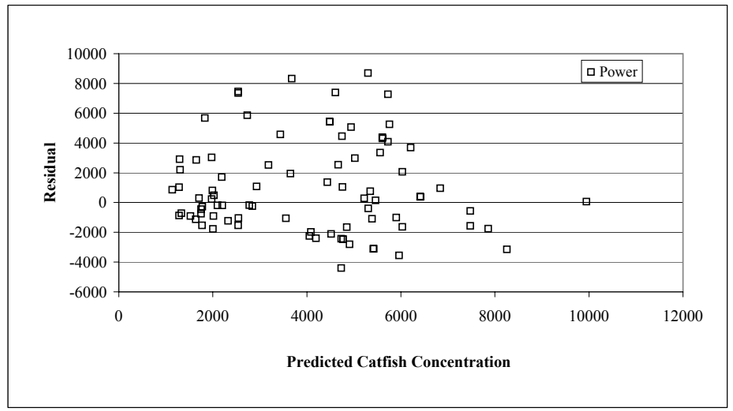












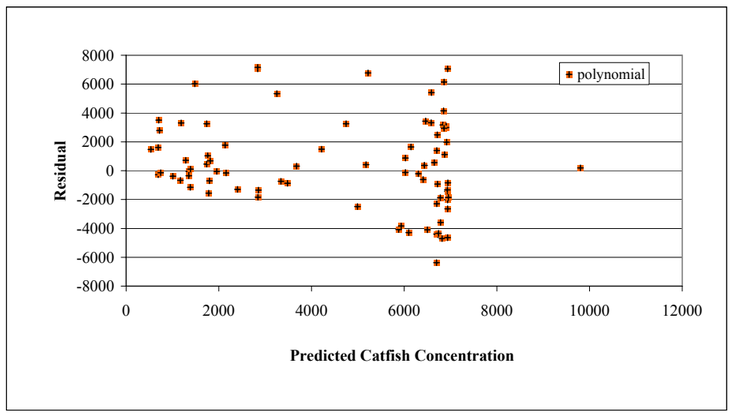
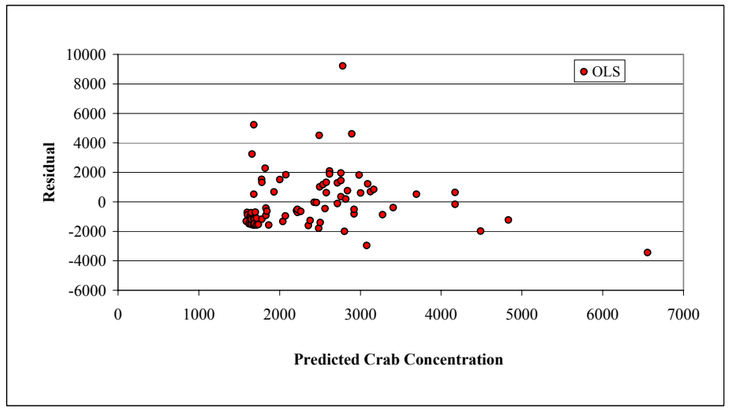
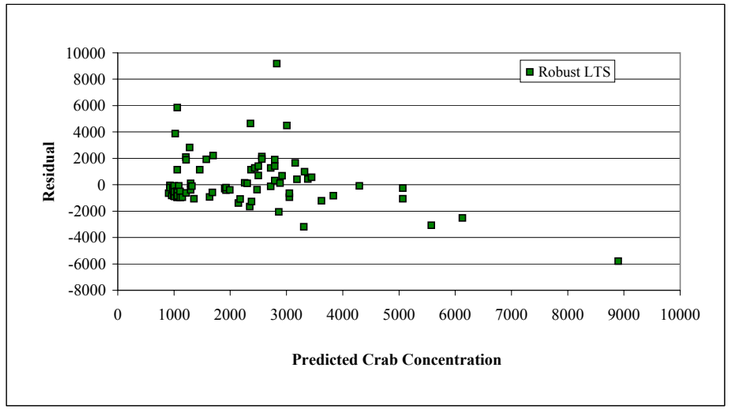
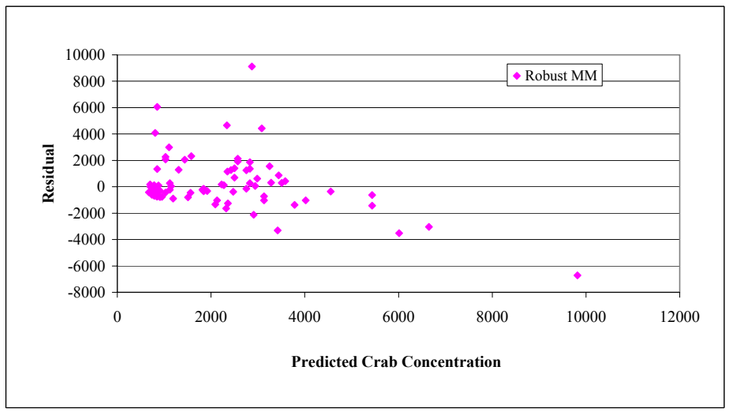
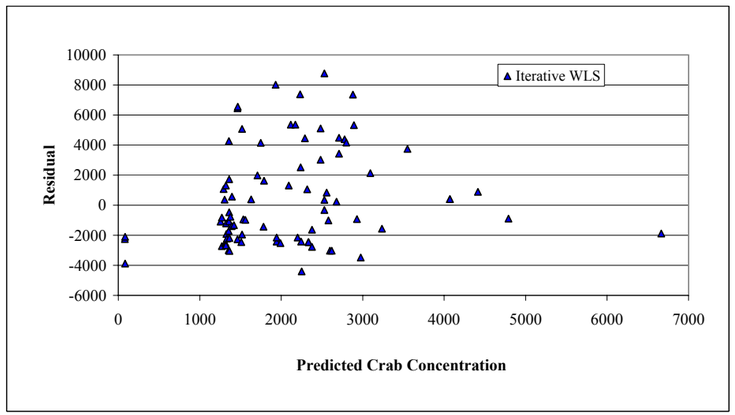


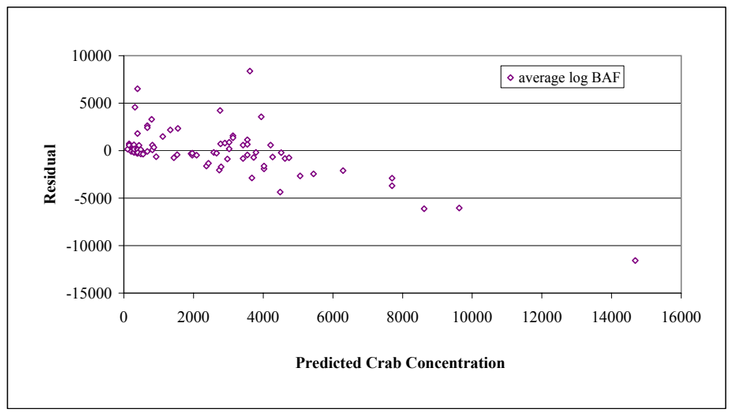
Figure 4.6 Residuals vs Fit Plots for Regressions between Catfish and Dissolved 2378-TCDD Concentrations

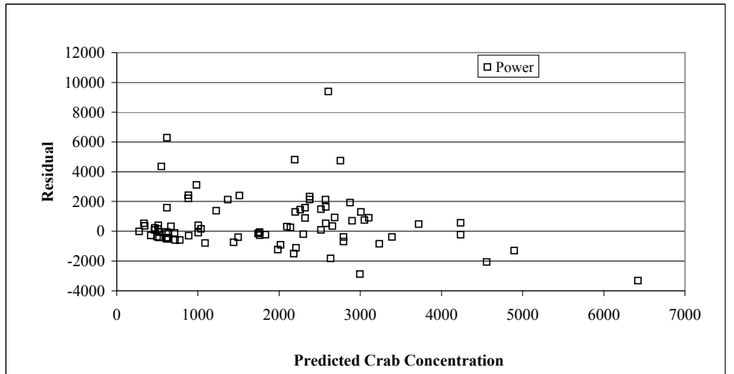












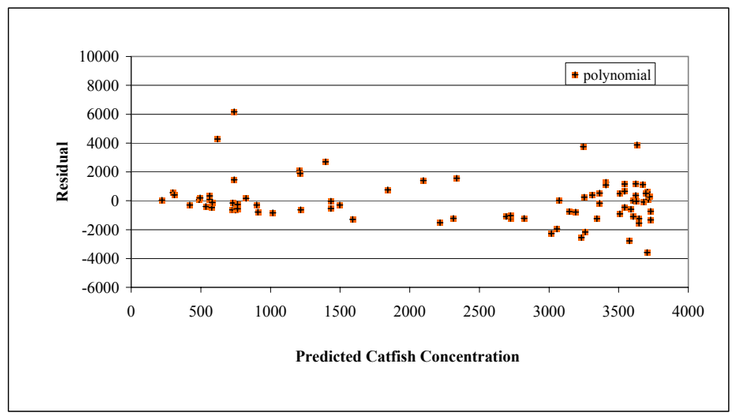
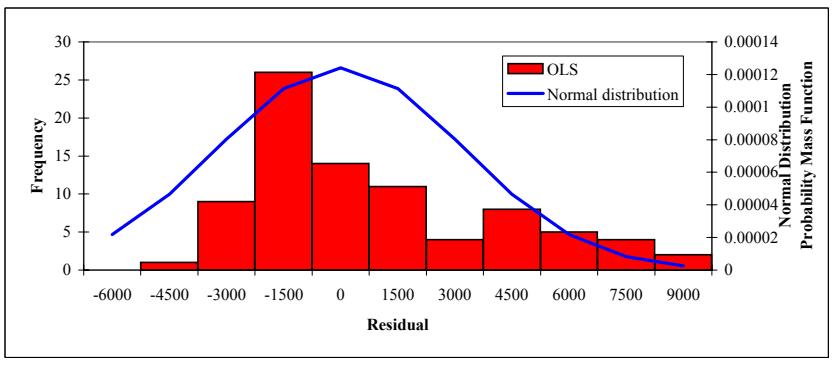
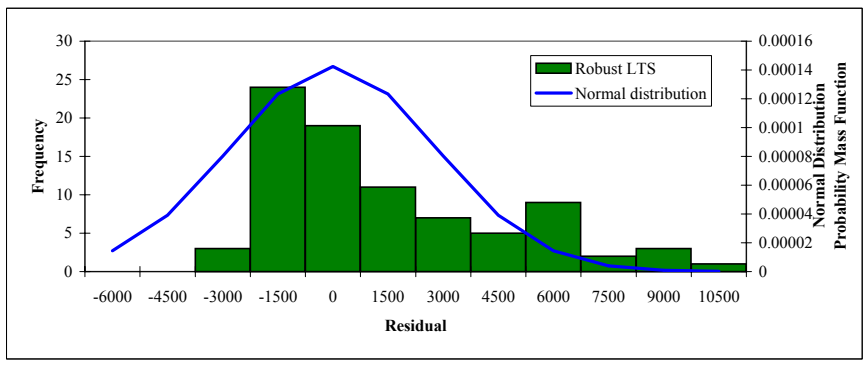
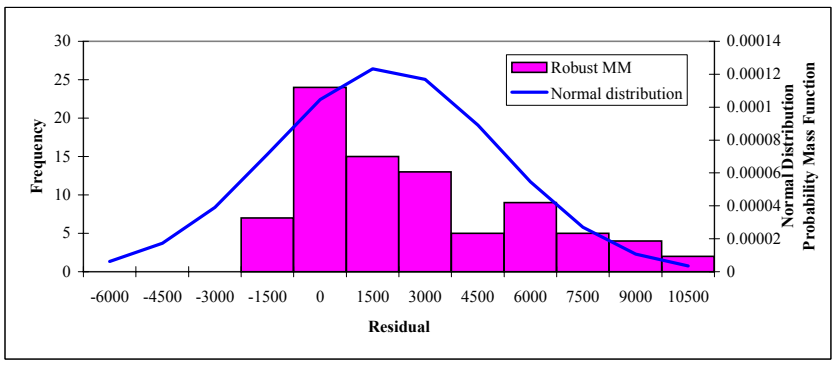
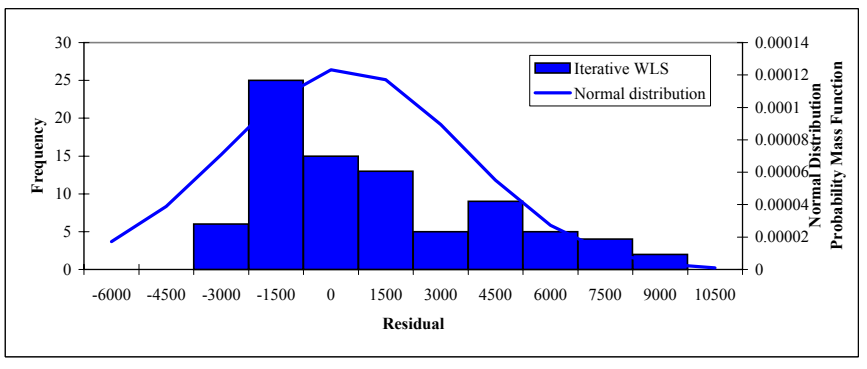


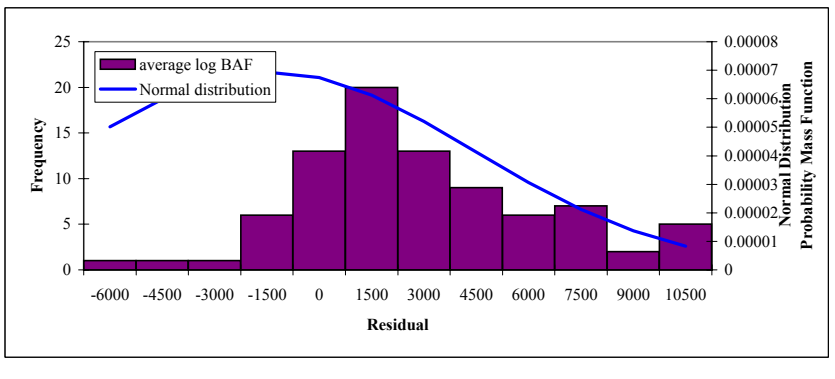
Figure 4.7 Residuals vs Fit Plots for Regressions between Crab and Dissolved 2378-TCDD Concentrations

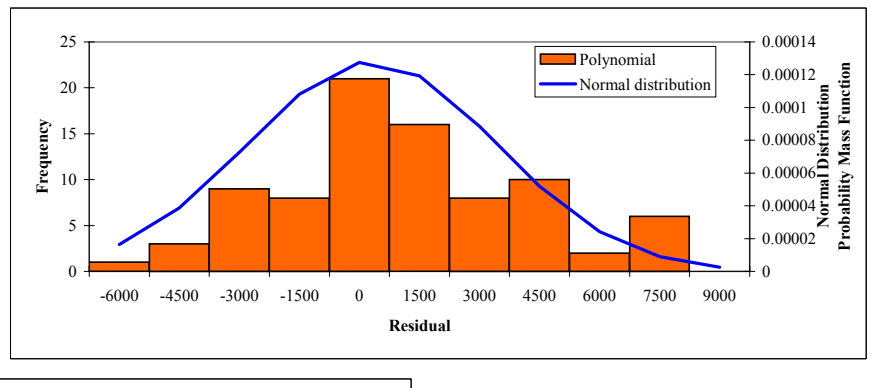












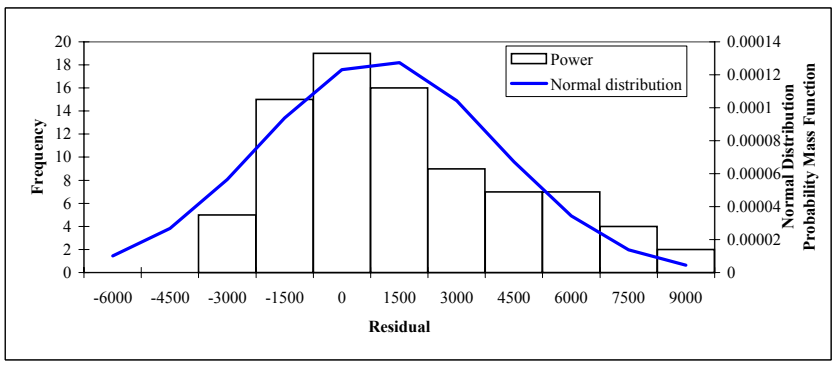
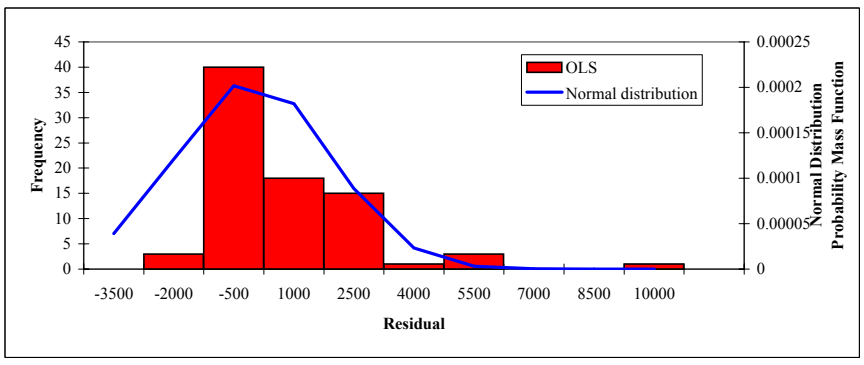
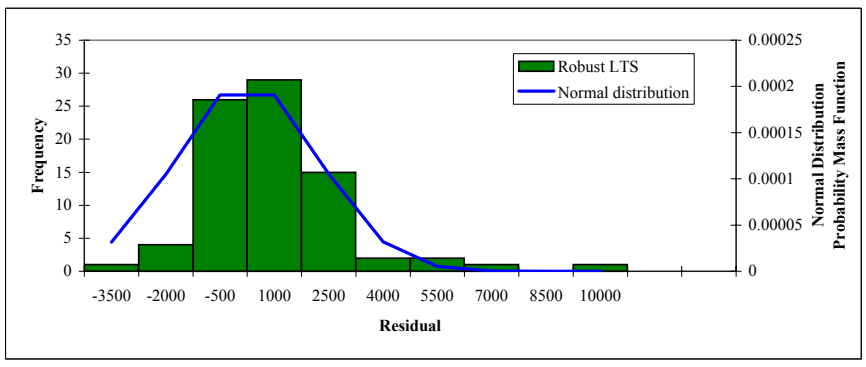
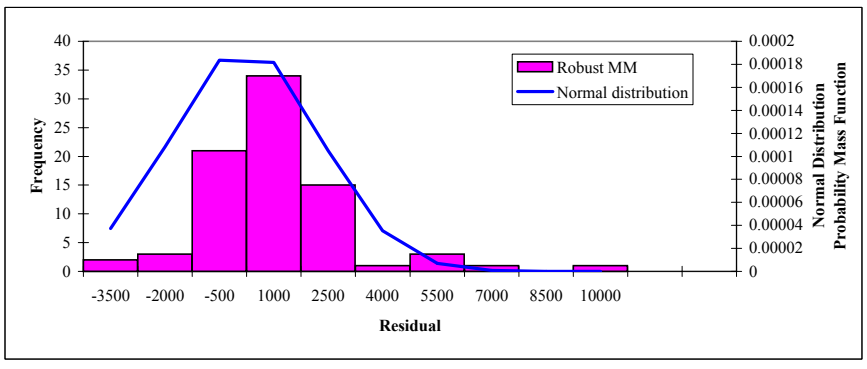
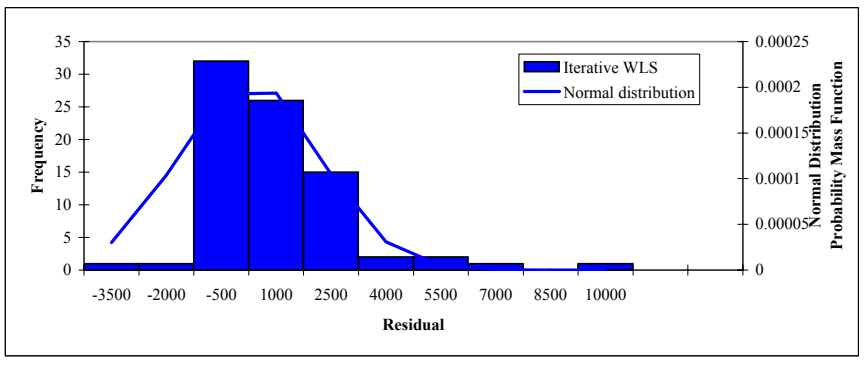


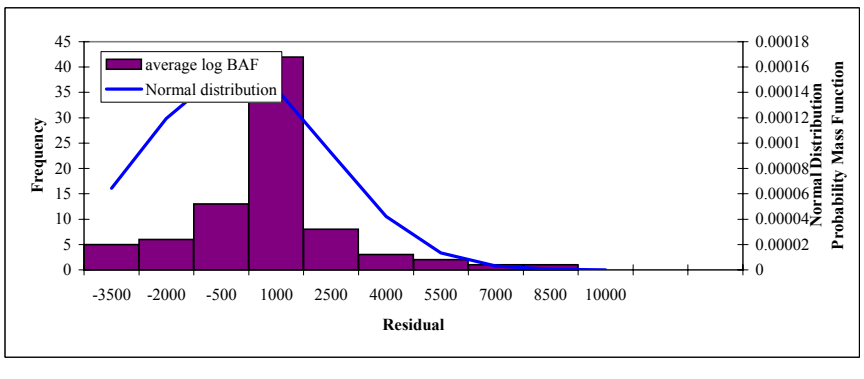
Figure 4.8 Histograms of Residuals for Regressions of Catfish and Dissolved Concentrations of 2378-TCDD

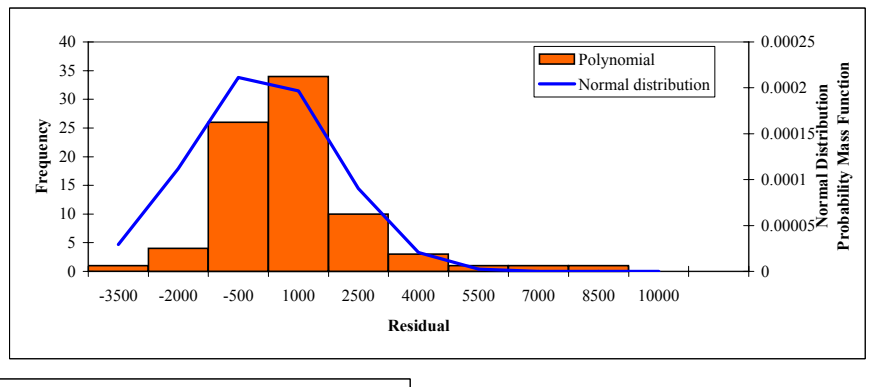












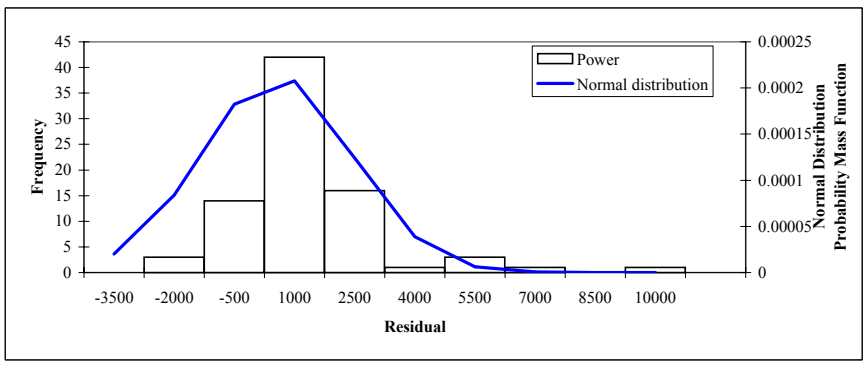
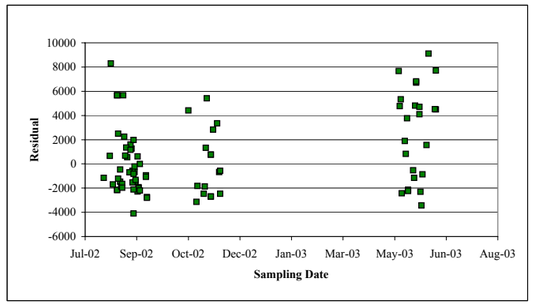
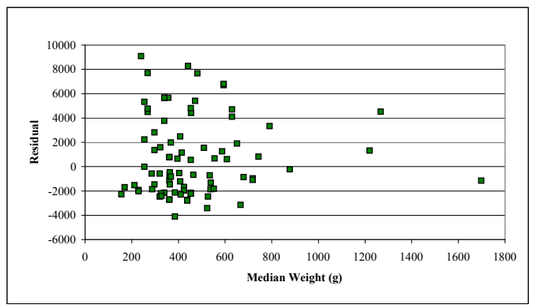
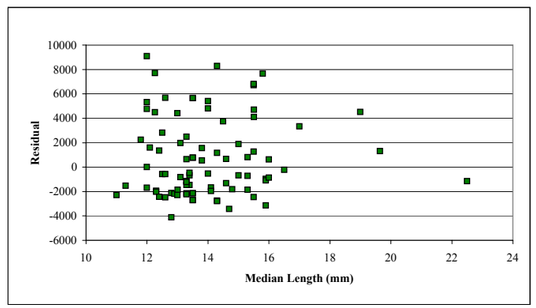
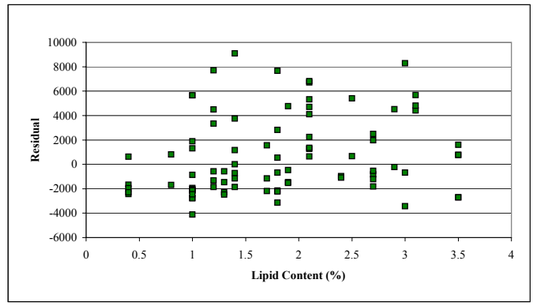


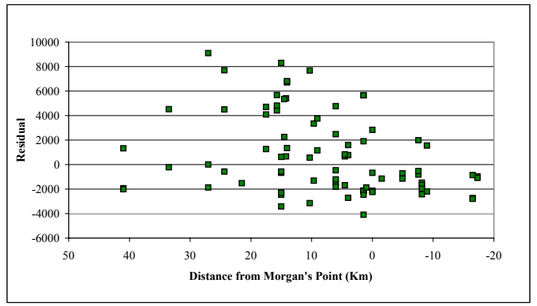
Figure 4.9 Histograms of Residuals for Regressions of Crab and Dissolved Concentrations of 2378-TCDD

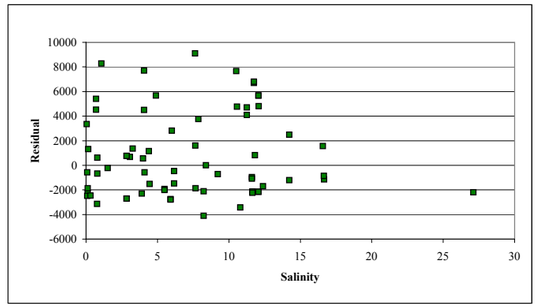


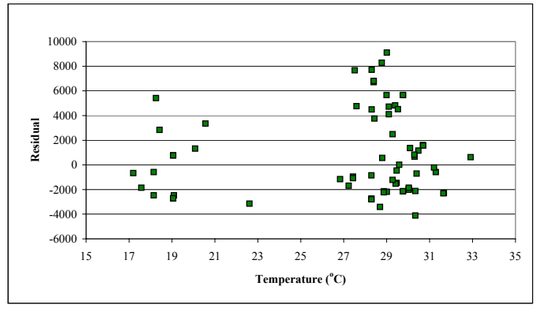


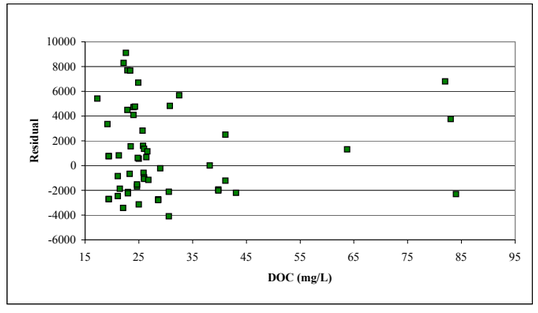


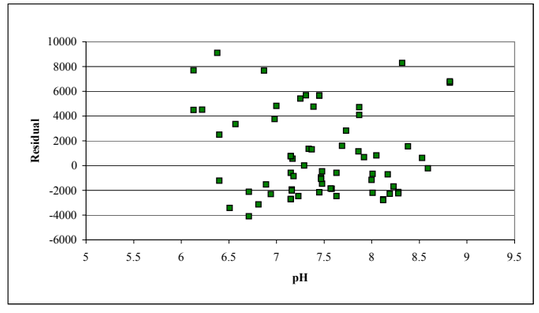


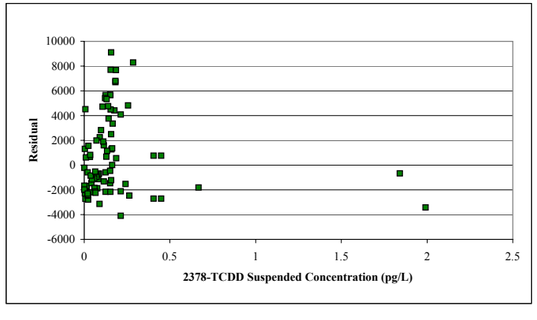


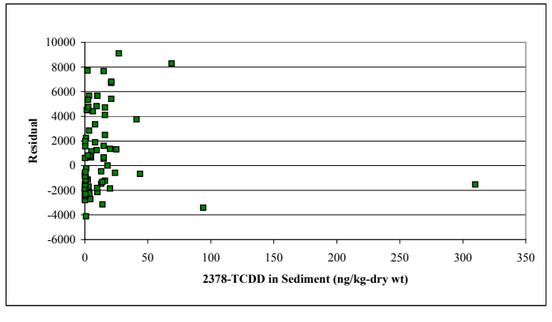












NOTE: Only residuals from Robust LTS regression are plotted

Figure 4.10 Residuals from Catfish BAF Regressions Plotted by Additional Explanatory Variables

characteristics (weight, length, and lipid content), sampling location (distance from Morgan's Point), water properties (salinity, temperature, DOC, and pH), and suspended and bottom sediment 2378-TCDD concentrations. In addition, Figure 4.11 presents boxplots of the residuals by two categorical explanatory variables: fish species and water quality segment. In both cases, the goal was to identify a pattern that would pinpoint a variable affecting the relationship between catfish and dissolved concentrations. No obvious trend was inferred from the scatterplots in Figure 4.10. The residuals seem to be randomly distributed without being affected by seasonality or any other explanatory variable. The boxplots in Figure 4.11 indicate that the magnitude of the residuals is similar for the different segments, although segment 2421 seems to present slightly lower residuals. Regarding fish species, residuals from hardhead catfish appear to be considerably higher than those from blue catfish. However, sample sizes are very different which complicates comparison between the two datasets.

4.1.1.2 Estimation of BAF for All Congeners from Regressions

As mentioned earlier, because the dioxin congeners have a wide range of bioaccumulation potentials, it was considered necessary to estimate BAFs for each compound. As mentioned in the previous section, the robust LTS regression method was selected to fit the dioxin data in the HSC. While a non-linear model could represent the data more accurately, it would fail to provide a direct estimate of the bioaccumulation potential.

The following guidelines were used for BAF estimation:

1. The BAF was derived from linear regression between tissue concentrations and dissolved concentrations measured at the same location and approximately at the same time.
2. An effort was made to analyze all the data using the same regression method. However, if

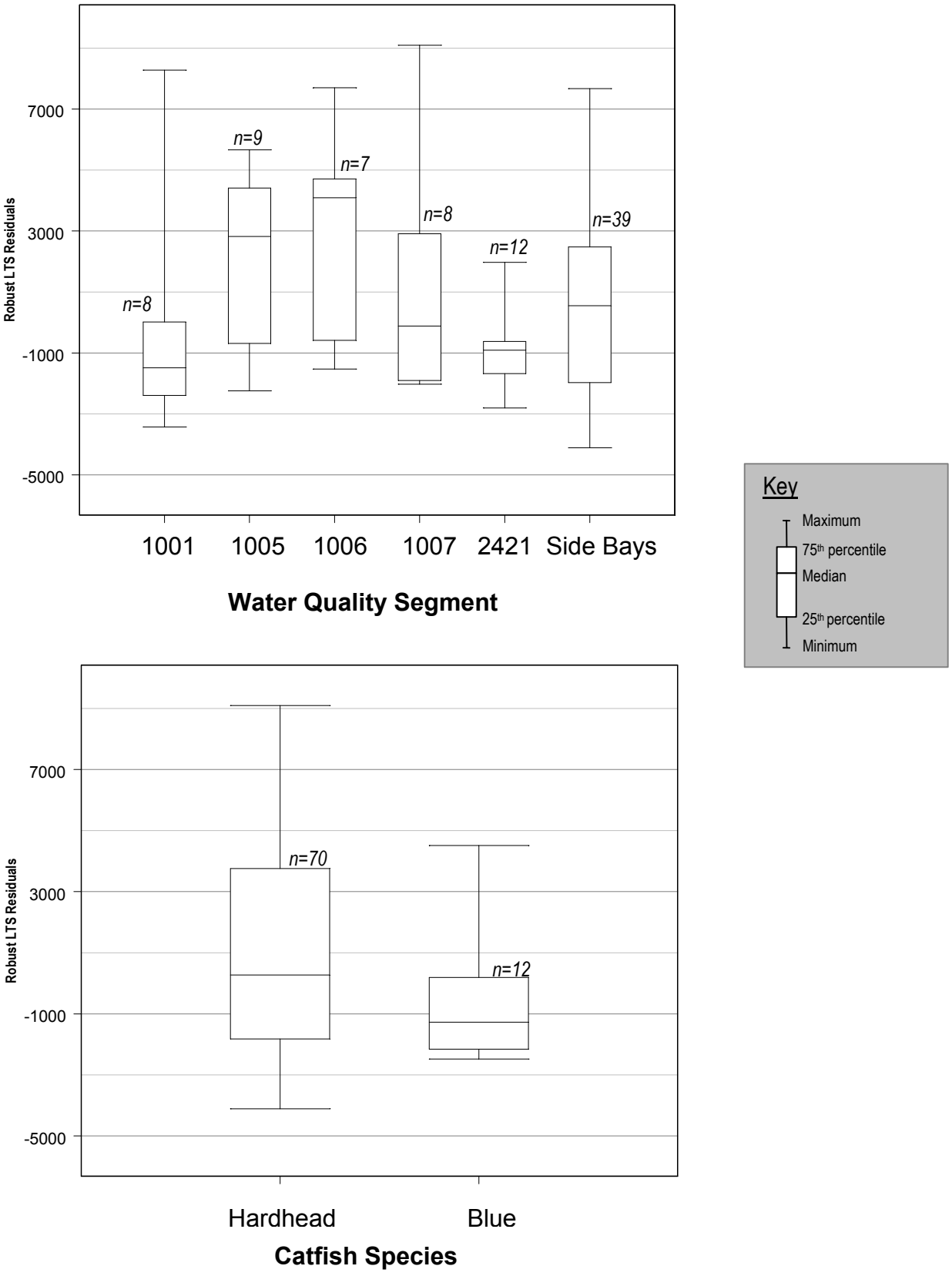


Figure 4.11 Distribution of Residuals from Catfish BAF Regressions by Categorical Variables

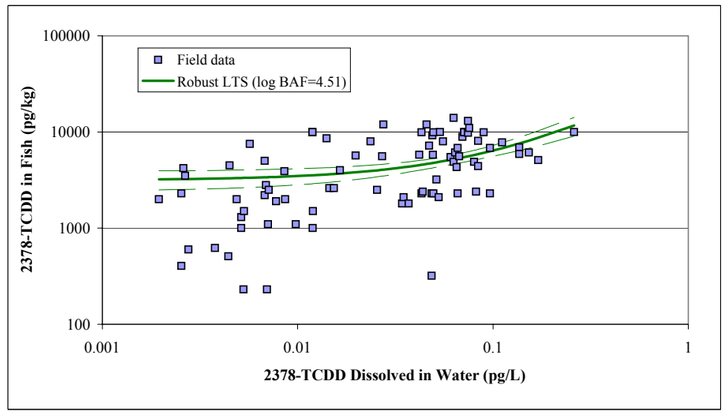
the BAF for a particular congener could not be derived using the LTS regression (i.e., the slope was not statistically significant or it was negative), the regression was performed using the WLS method.

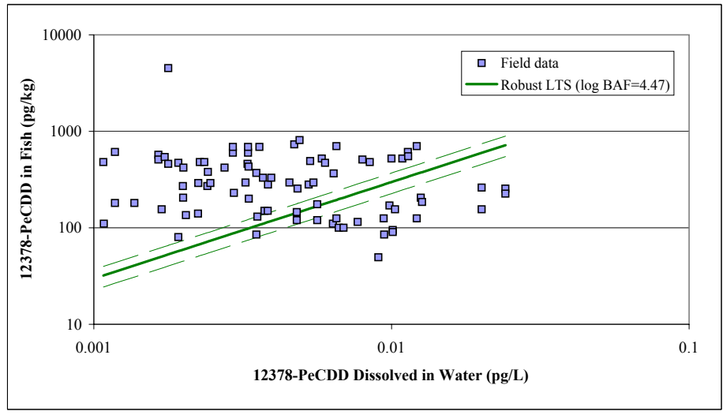
3. All the test statistics and confidence intervals were calculated for a 95% confidence level (α=0.05).

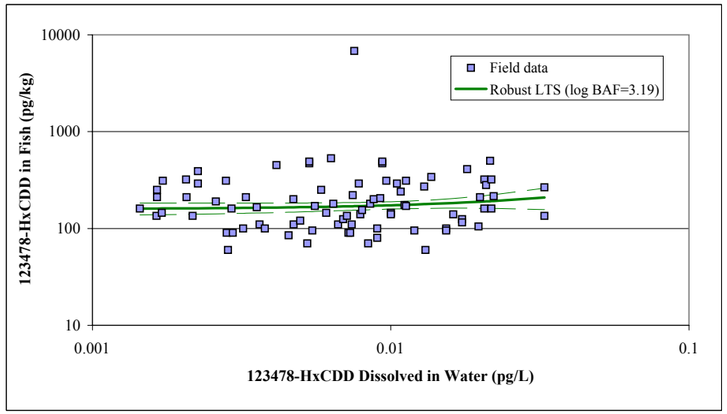
Figures 4.12 and 4.13 present the best-fit lines along with the confidence intervals for dioxins in catfish and crabs, respectively. The relevant test statistics are summarized in Table 4.5. Estimated BAFs vary from 38±20 to 32617±13925 for catfish and from 15±41 to 26680±7030 for crabs. Bioaccumulation factors varied within 2 orders of magnitude among the different congeners and were generally higher for catfish than for crabs. This may be the result of higher lipid content in fish than in crabs. It is noted that for some congeners the relationships were not statistically significant at the 95% confidence level (e.g., 123478-HxCDD in catfish, *p*-value =0.23) and, thus, the uncertainty in the estimated bioaccumulation factors for these compounds is high. An attempt was made to fit the field data for those congeners using all the above-mentioned methods, but in all cases the regressions were weak.

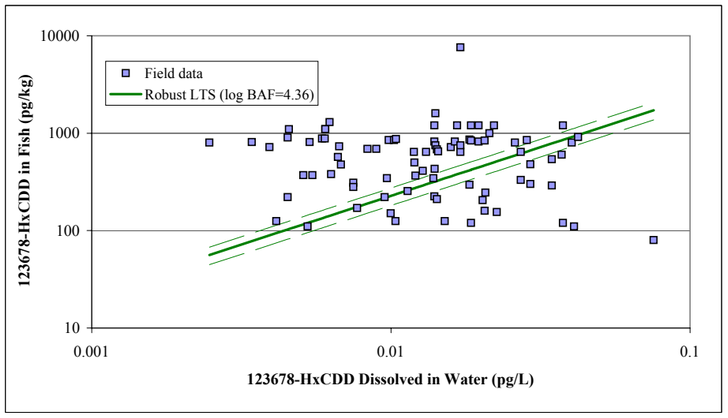
It is important to point out that the best-fit regression yielded negative slopes for congeners 123478-HxCDF, 234678-HxCDF, 123789-HxCDF, 1234678-HpCDF, and OCDF for catfish data and 123678-HxCDD, 123789-HxCDD, 23478-PeCDF, 123478-HxCDF, 123478-HpCDF, and OCDF for crab data. These negative slopes could be interpreted as a lack of bioaccumulation of the particular congeners in the sampled species or as the need for a more appropriate non-linear model.

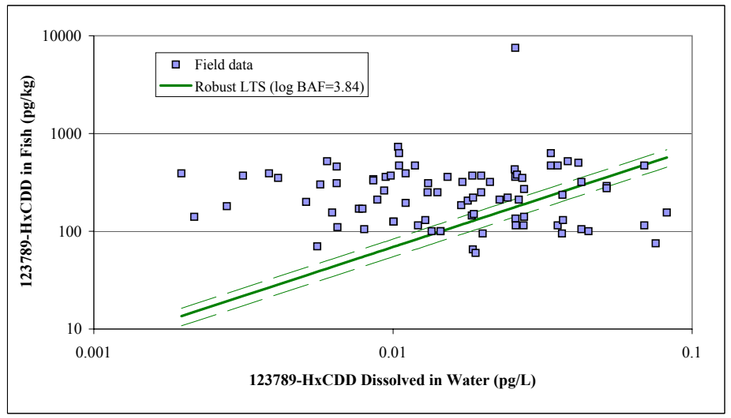
It is noted that BAFs are equilibrium concepts. Aquatic animals are not infinite sinks for chemicals. As they take up chemicals, they also eliminate them via urine, feces, biochemical

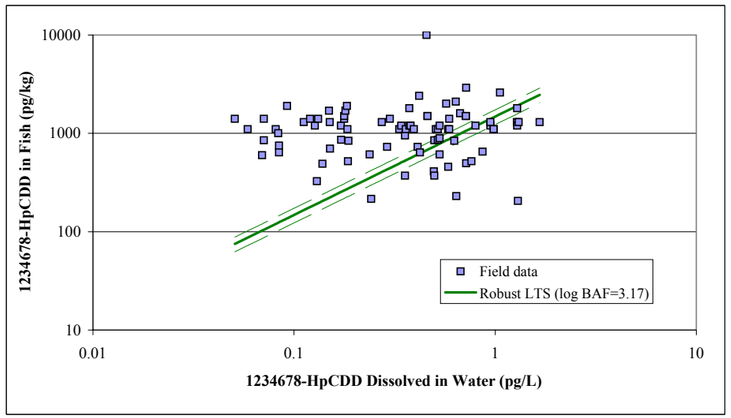


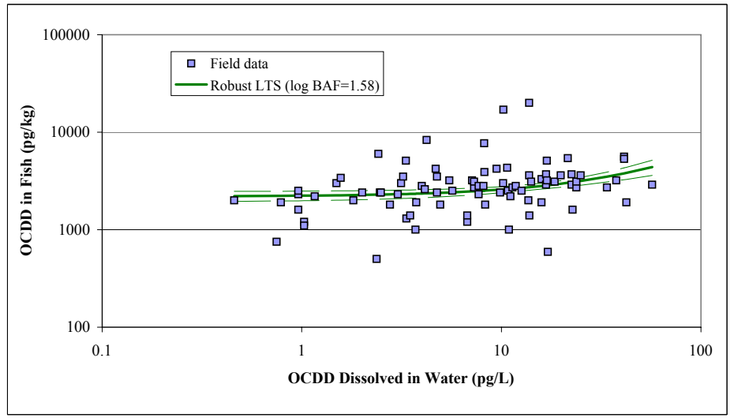






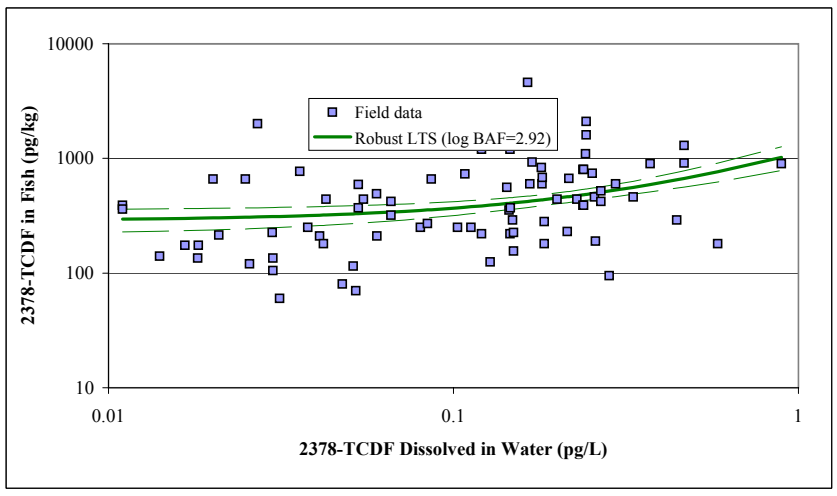


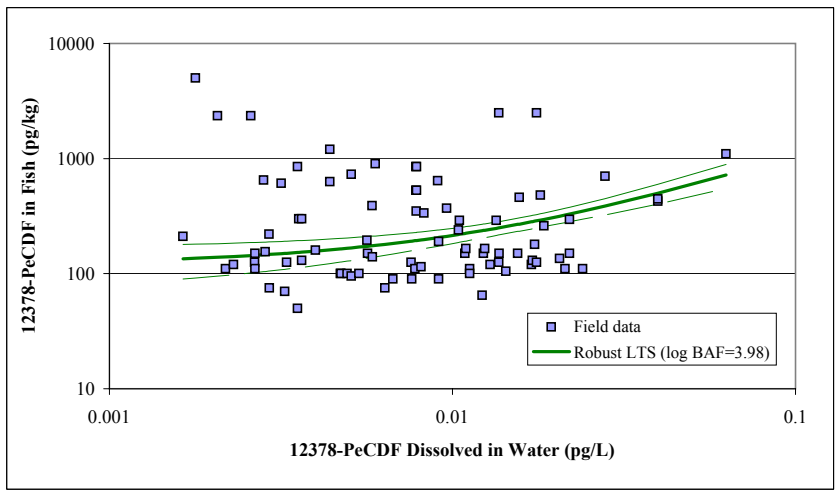


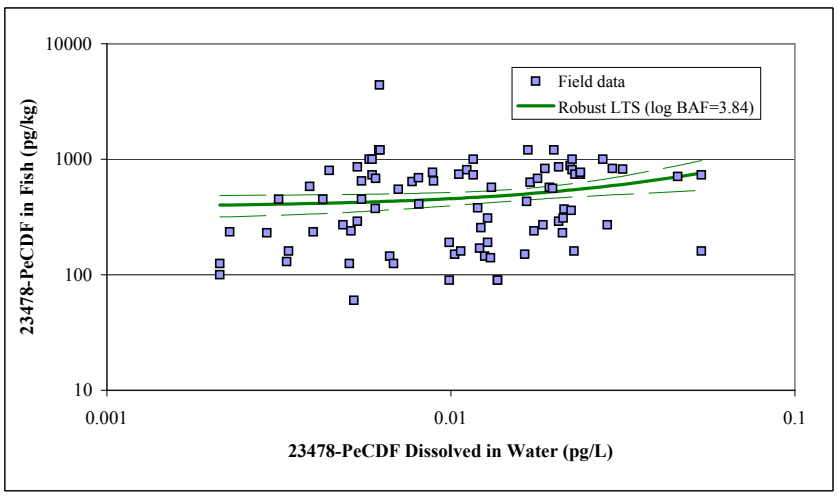


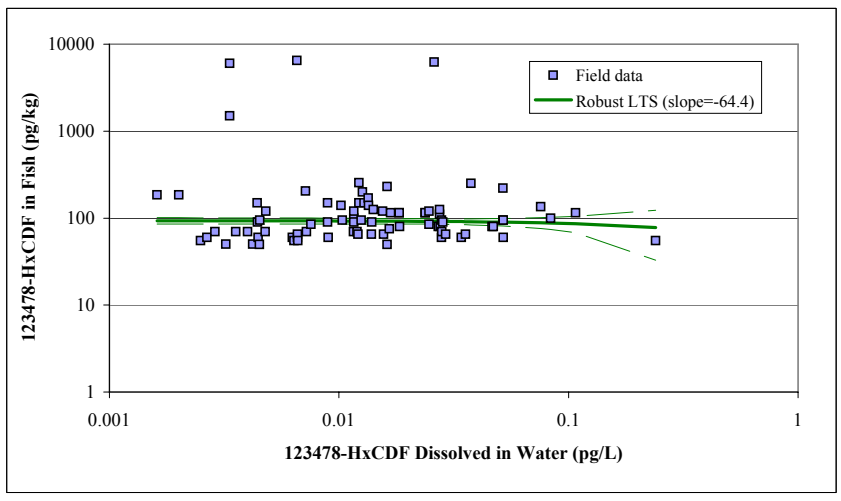
Dashed lines correspond to the 95% confidence intervals

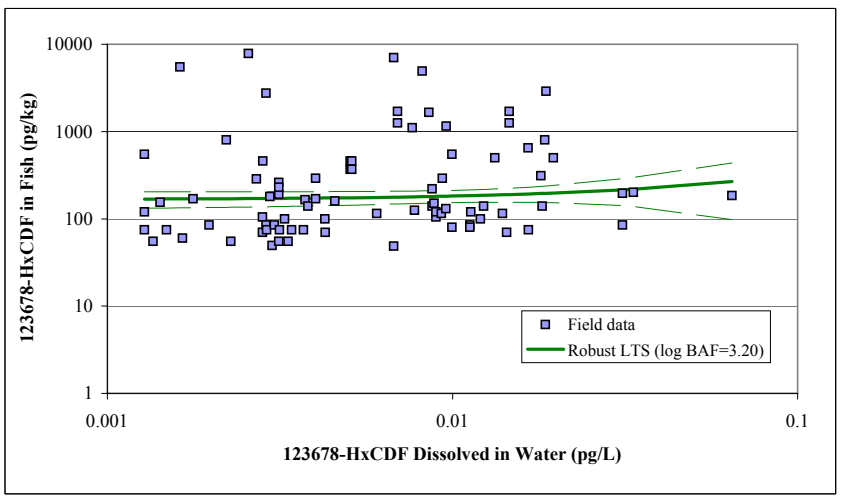
Figure 4.12a Bioaccumulation Factors for Dioxins in Catfish from the HSC

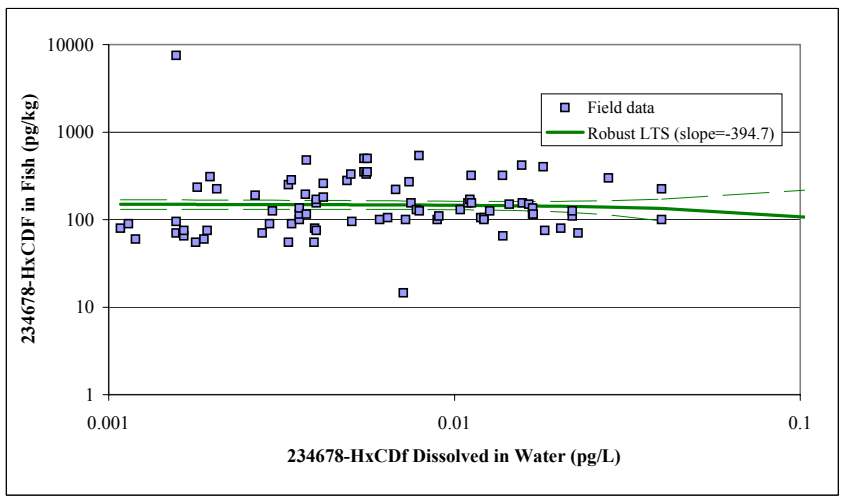


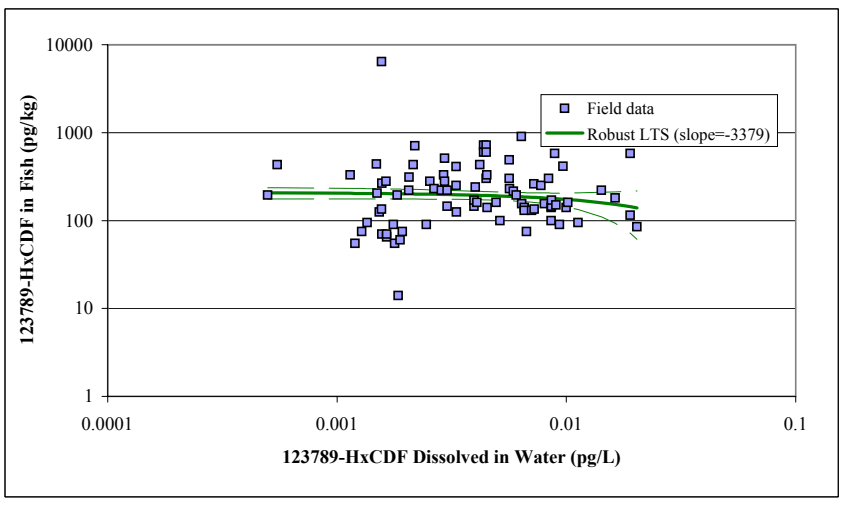


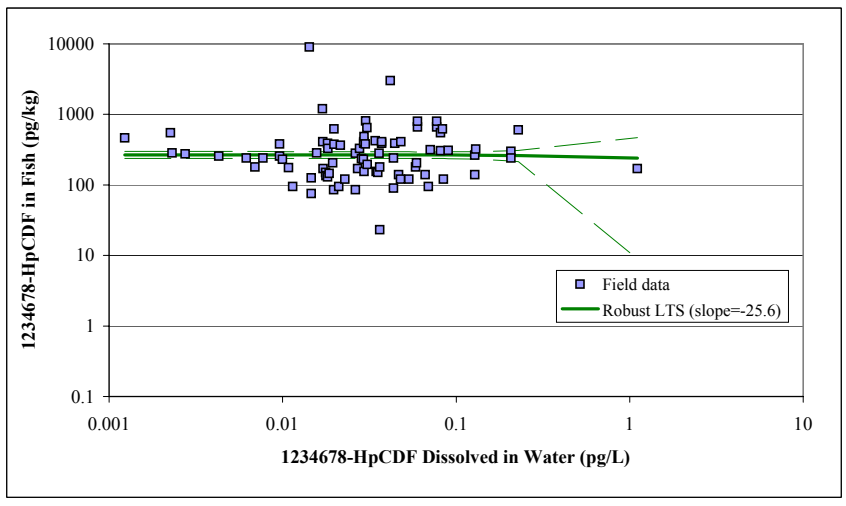


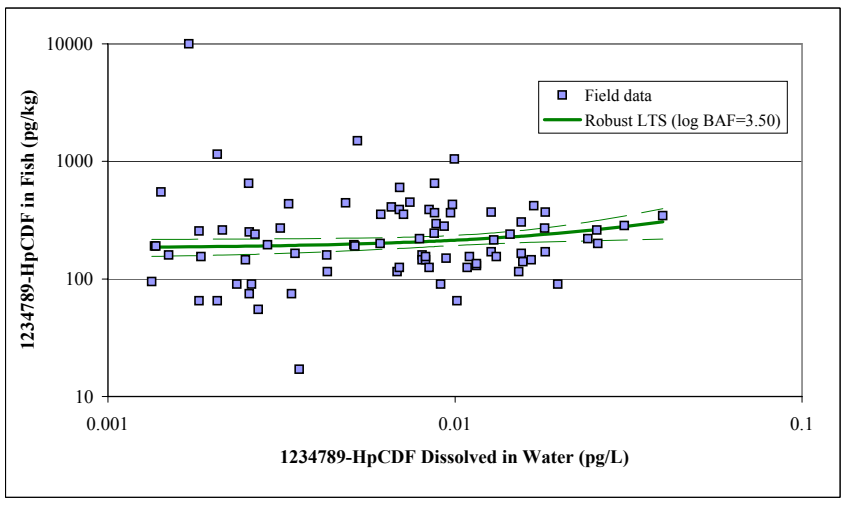


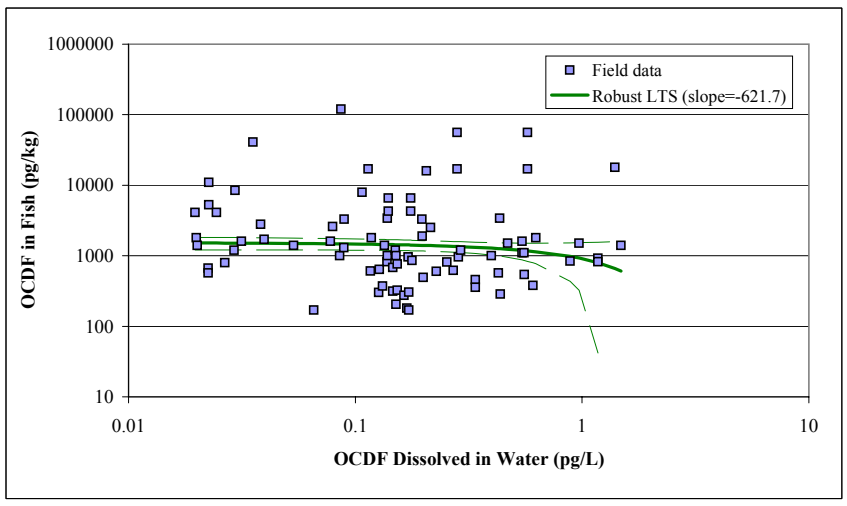






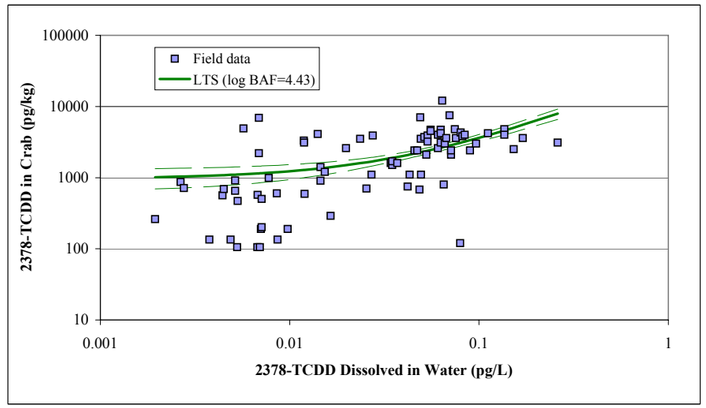


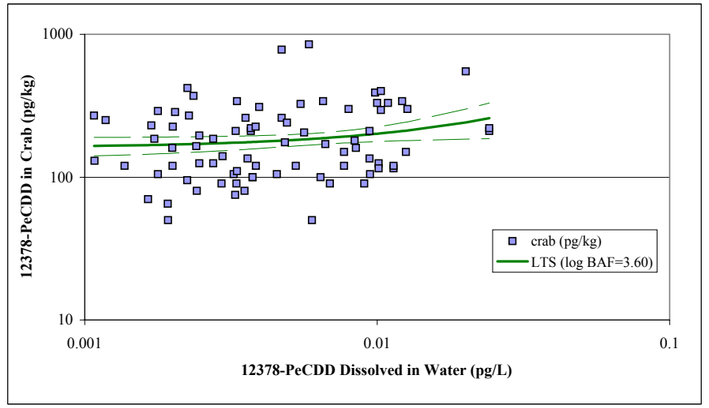


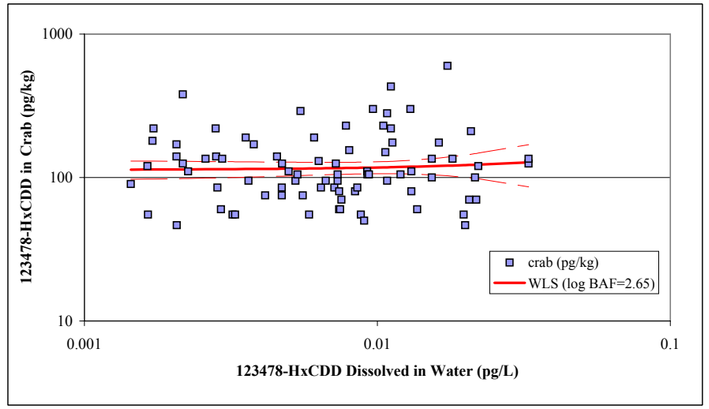


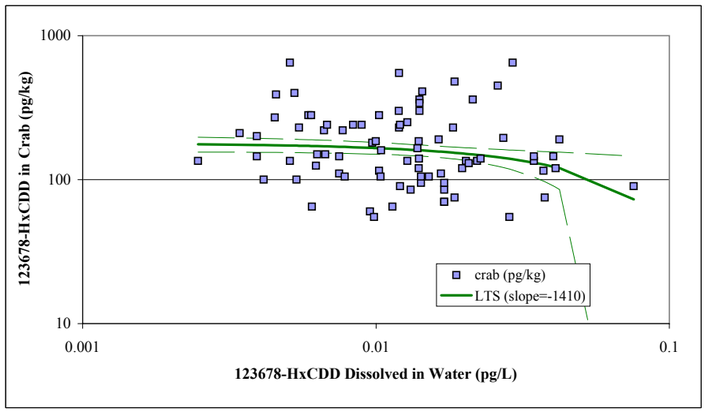
Dashed lines correspond to the 95% confidence intervals

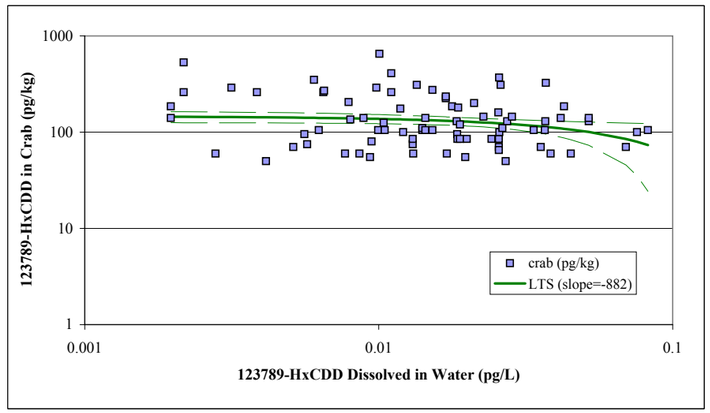
Figure 4.12b Bioaccumulation Factors for Furans in Catish from the HSC

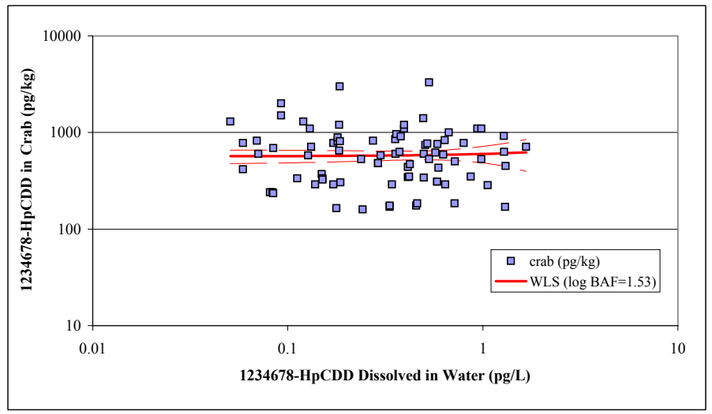


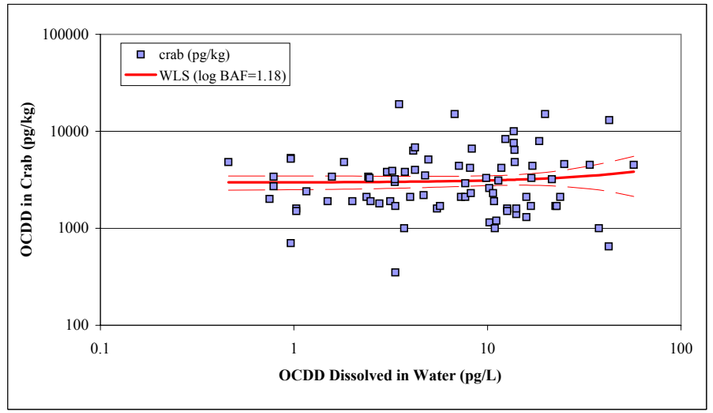






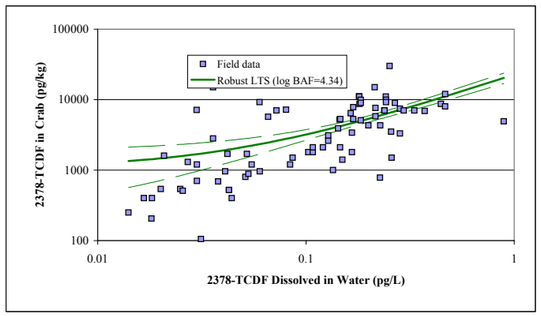


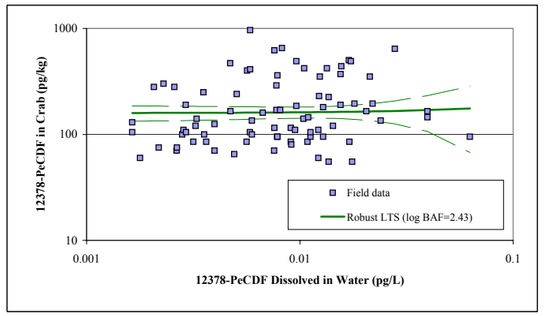


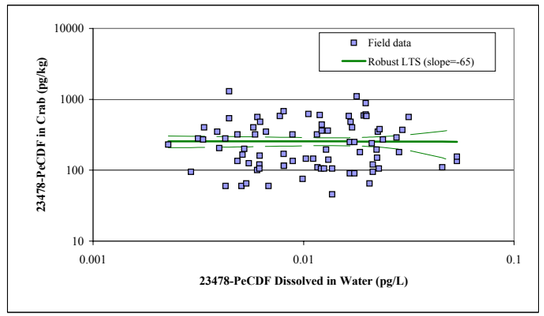


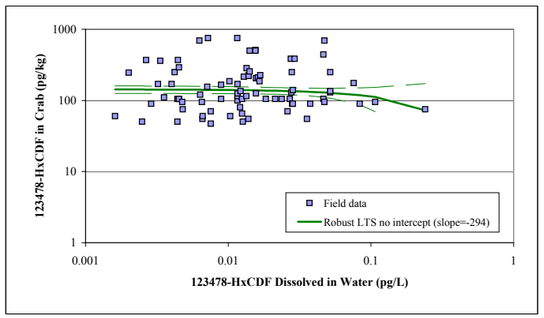
Dashed lines correspond to the 95% confidence intervals

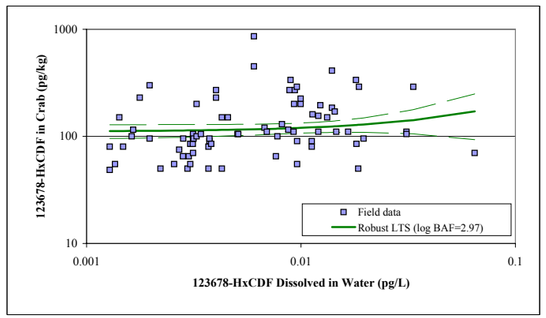
Figure 4.13a Bioaccumulation Factors for Dioxins in Crabs from the HSC

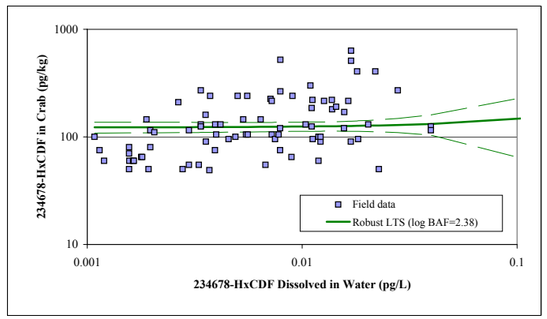


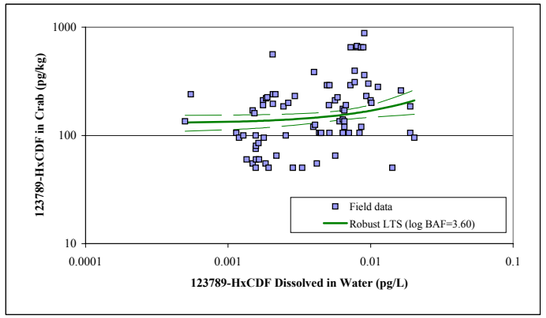


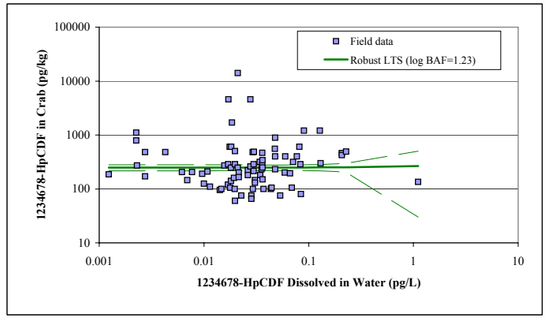


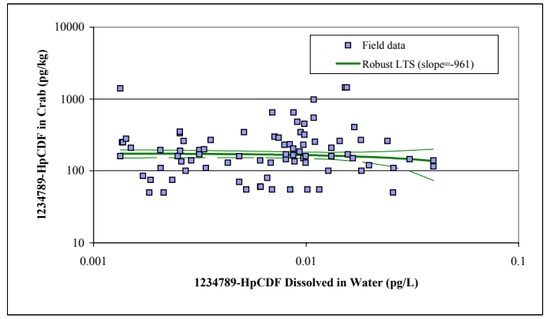


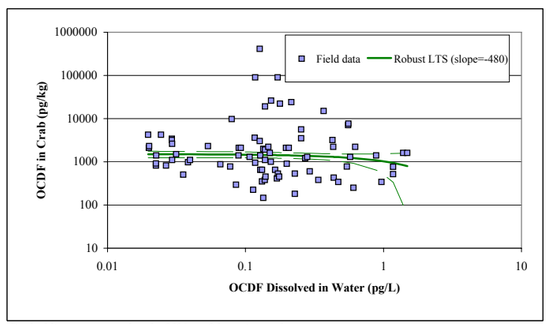












Dashed lines correspond to the 95% confidence intervals

Figure 4.13b Bioaccumulation Factors for Furans in Crabs from the HSC

Table 4.5a Estimated Bioaccumulation Factors for HSC Catfish

Congener	Method	Regression		Slope	
		SE	Significance F	Estimated BAF	*p* -value
2378-TCDD	Robust LTS	2833.2	21.744	32617±13925	1.267E-05
12378-PeCDD	Robust LTS	299.2	-47.208	29777±8567	9.824E-10
123478-HxCDD	Robust LTS	77.5	1.455	1538±2542	0.2317
123678-HxCDD	Robust LTS	512.0	-44.925	22712±5556	4.106E-12
123789-HxCDD	Robust LTS	208.3	-47.771	6900±1689	4.864E-12
1234678-HpCDD	Robust LTS	787.5	-54.057	1481±302	3.136E-15
OCDD	Robust LTS	985.7	15.079	38±20	0.0002
2378-TCDF	Robust LTS	245.8	18.760	825±380	4.716E-05
12378-PeCDF	Robust LTS	163.6	24.547	9601±3865	4.848E-06
23478-PeCDF	Robust LTS	302.2	4.639	6942±6415	0.0343
123478-HxCDF	Robust LTS	33.8	0.274	N/A[1]	0.6023
123678-HxCDF	Robust LTS	145.2	0.770	1571±3574	0.3834
234678-HxCDF	Robust LTS	85.1	0.343	N/A[1]	0.5601
123789-HxCDF	Robust LTS	105.0	1.292	N/A[1]	0.2594
1234678-HpCDF	Robust LTS	147.2	0.038	N/A[1]	0.8452
1234789-HpCDF	Robust LTS	109.3	3.378	3145±3411	0.0701
OCDF	Robust LTS	1167.0	1.712	N/A[1]	0.1951

[1] The slope of the best-fit regression is negativ

The relationship is not statistically significant

Table 4.5b Estimated Bioaccumulation Factors for HSC Crabs

Congener	Method	Regression		Slope	
		SE	Significance F	Estimated BAF	*p* -value
2378-TCDD	Robust LTS	1154.3	57.240	26680±7030	9.889E-11
12378-PeCDD	Robust LTS	89.9	3.090	4018±4554	0.0829
123478-HxCDD	Iterative WLS	86.4	-49.599	451±1861	3.799E-13
123678-HxCDD	Robust LTS	71.9	3.958	N/A[1]	0.0500
123789-HxCDD	Robust LTS	64.9	3.673	N/A[1]	0.0590
1234678-HpCDD	Iterative WLS	477.9	-44.104	34±203	3.18E-12
OCDD	Iterative WLS	2655.4	-47.999	15±41	4.768E-08
2378-TCDF	Robust LTS	2588.4	63.411	21655±5420	1.652E-11
12378-PeCDF	Robust LTS	99.9	0.049	268±2420	0.8261
23478-PeCDF	Robust LTS	169.8	0.001	N/A[1]	0.9719
123478-HxCDF	Robust LTS	74.9	1.169	N/A[1]	0.2833
123678-HxCDF	Robust LTS	67.7	1.267	927±1641	0.2639
234678-HxCDF	Robust LTS	63.3	0.223	239±1010	0.6384
123789-HxCDF	Robust LTS	76.6	3.766	3977±4087	0.0563
1234678-HpCDF	Robust LTS	150.0	0.016	17±267	0.9001
1234789-HpCDF	Robust LTS	83.8	0.642	N/A[1]	0.4256
OCDF	Robust LTS	1019.0	1.638	N/A[1]	0.2051

[1] The slope of the best-fit regression is negativ

The relationship is not statistically significant

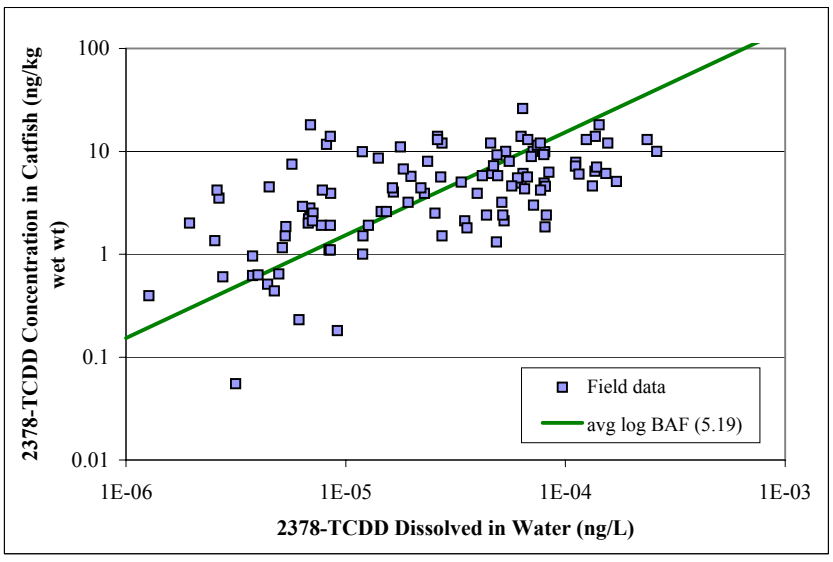
reactions (in some cases), and other mechanisms. Elimination processes are grouped in the term "depuration". When an animal is exposed to a new chemical, its BAF will increase until the chemical uptake rate is balanced by the chemical depuration rate. As a general rule, when the term BAF is used, it can be assumed to refer to the steady-state, equilibrium BAF. However, because the uptake and elimination rates for large animals, such as fish and crabs, are slow relative to the dynamically changing concentrations in water, it is expected that individual measured BAFs always incorporate some disequilibrium. This may help explain the high scatter observed in the data.

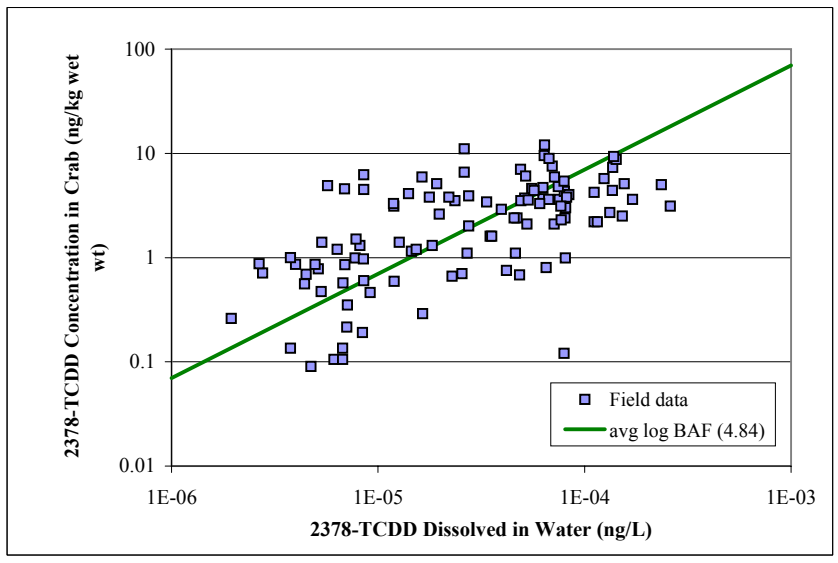
4.1.1.3 Determination of BAF using Measures of Central Tendency

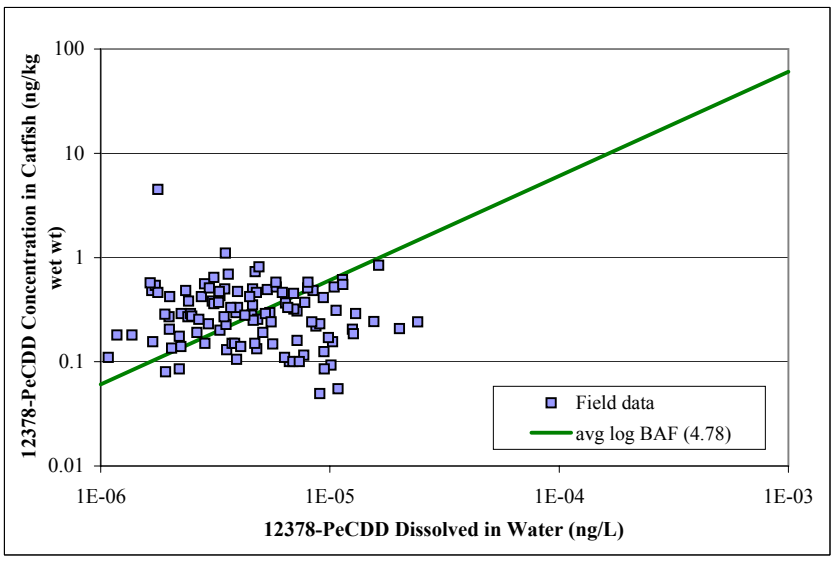
Since the linear regressions to estimate BAFs did not fit the observed data very well, an alternative approach was used. This approach uses measures of central tendency (i.e. mean or median) of the ratios of tissue concentrations to dissolved concentrations (Figures 4.1 and 4.2) rather than BAFs estimated from linear regressions. For tissue to water ratios, it was considered that the log BAF datasets followed a fairly normal distribution. Thus, the average log BAF is an appropriate measure of central tendency. Line fit plots for BAFs comparing fish and crabs for several important congeners are shown in Figure 4.14.

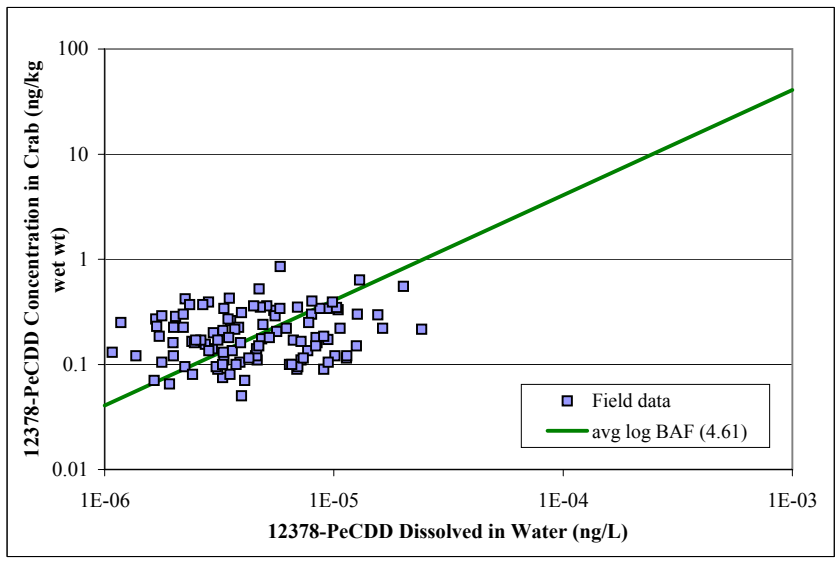
4.1.2 Development of Site-specific Biota-Sediment Accumulation Factors

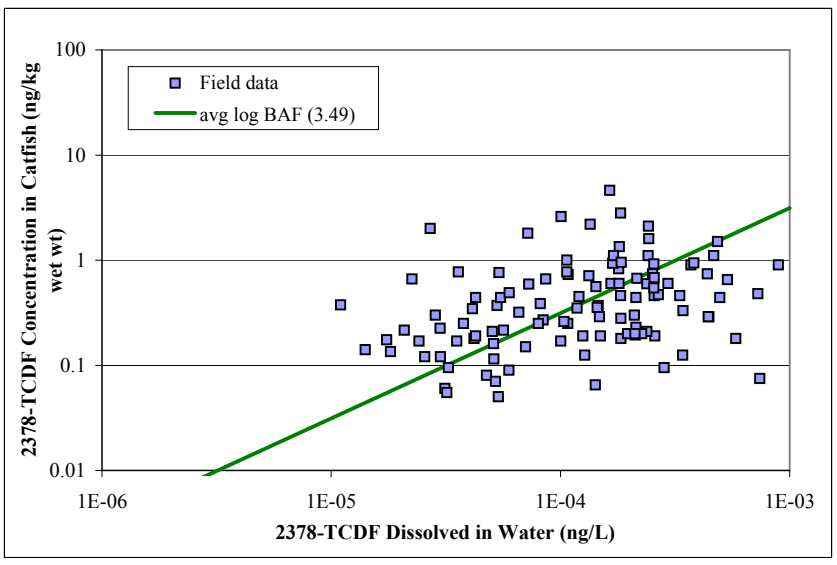
The BSAF is defined by the USEPA (2003) as the ratio (in kilograms of sediment organic carbon per kilogram of lipid) of the lipid-normalized concentration of a chemical in the tissue of an aquatic organism to its organic carbon-normalized concentration in surface sediment, in situations where the ratio does not change substantially over time, both the organism and its food

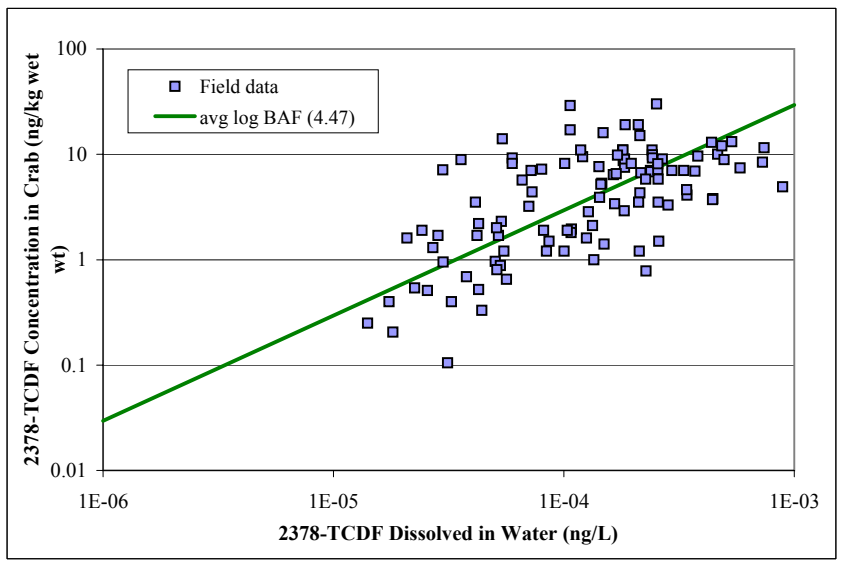


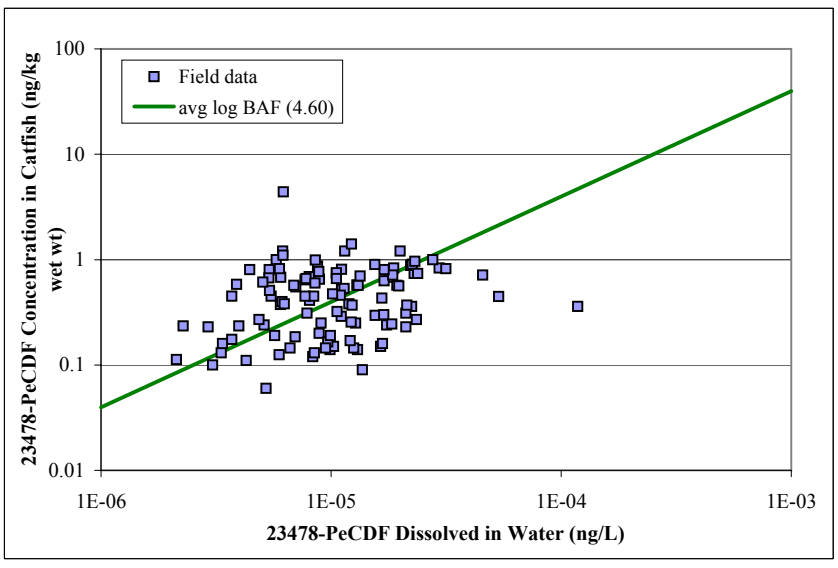












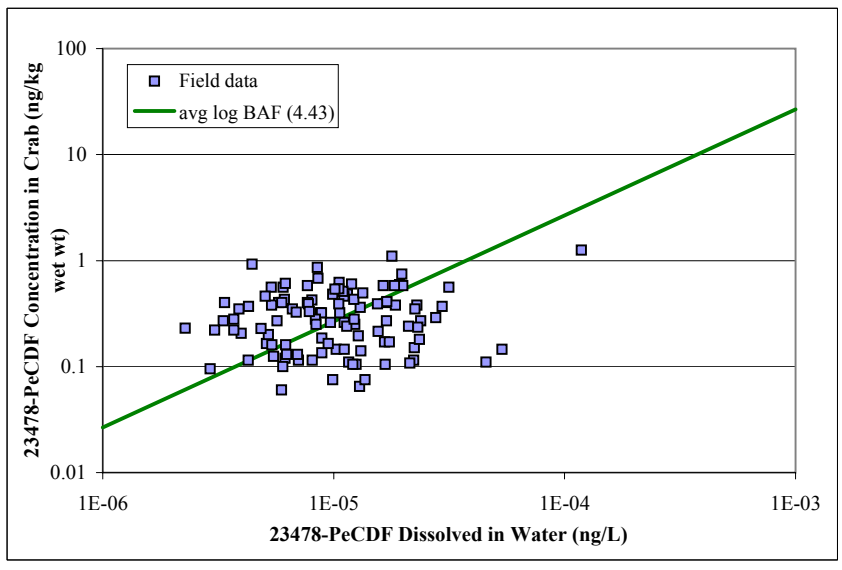


Figure 4.14 Line Fit Plots of BAF for Selected Congeners in Tissue from the HSC

are exposed, and the surface sediment is representative of average surface sediment in the vicinity of the organism.

$$BSAF = \frac{C_{tissue} / F_{lipid}}{C_{sed} / F_{oc}} \quad (4.4)$$

where F_{oc} is the organic carbon fraction of the sediment by weight.

BSAFs for catfish and crabs were calculated for each of the paired water, tissue, and sediment samples collected in the spring, summer, and fall seasons from 2002 through 2004. Because lipid normalization increased the variability in the BAF/BSAF relationships, and the lipid measurement method used was imprecise, all BSAFs were based on raw tissue concentrations and were not lipid-normalized.

BSAFs for PCDD/F congeners measured in 130 catfish and sediment samples from the HSC system are shown in Figure 4.15. BSAFs for PCDD/F congeners measured in 131 blue crab and sediment samples from the HSC system are shown in Figure 4.16. As with the calculated BAFs, these BSAFs are calculated from the bulk tissue concentration, and not normalized to the tissue lipid concentrations. BSAFs exhibited many of the same patterns as BAFs, which is expected as they are based on the same tissue concentrations.

4.1.2.1 Estimation of BSAF for 2378-TCDD

Based on measurements from the Houston Ship Channel system, it was observed that the tissue lipid normalizations decrease the strength of the relationship between tissue dioxin concentrations and organic carbon-normalized sediment dioxin concentrations. Thus, BSAF relationships were developed using whole tissue dioxin concentrations.

Regressions for catfish and sediment-organic carbon concentrations of 2378-TCDD were

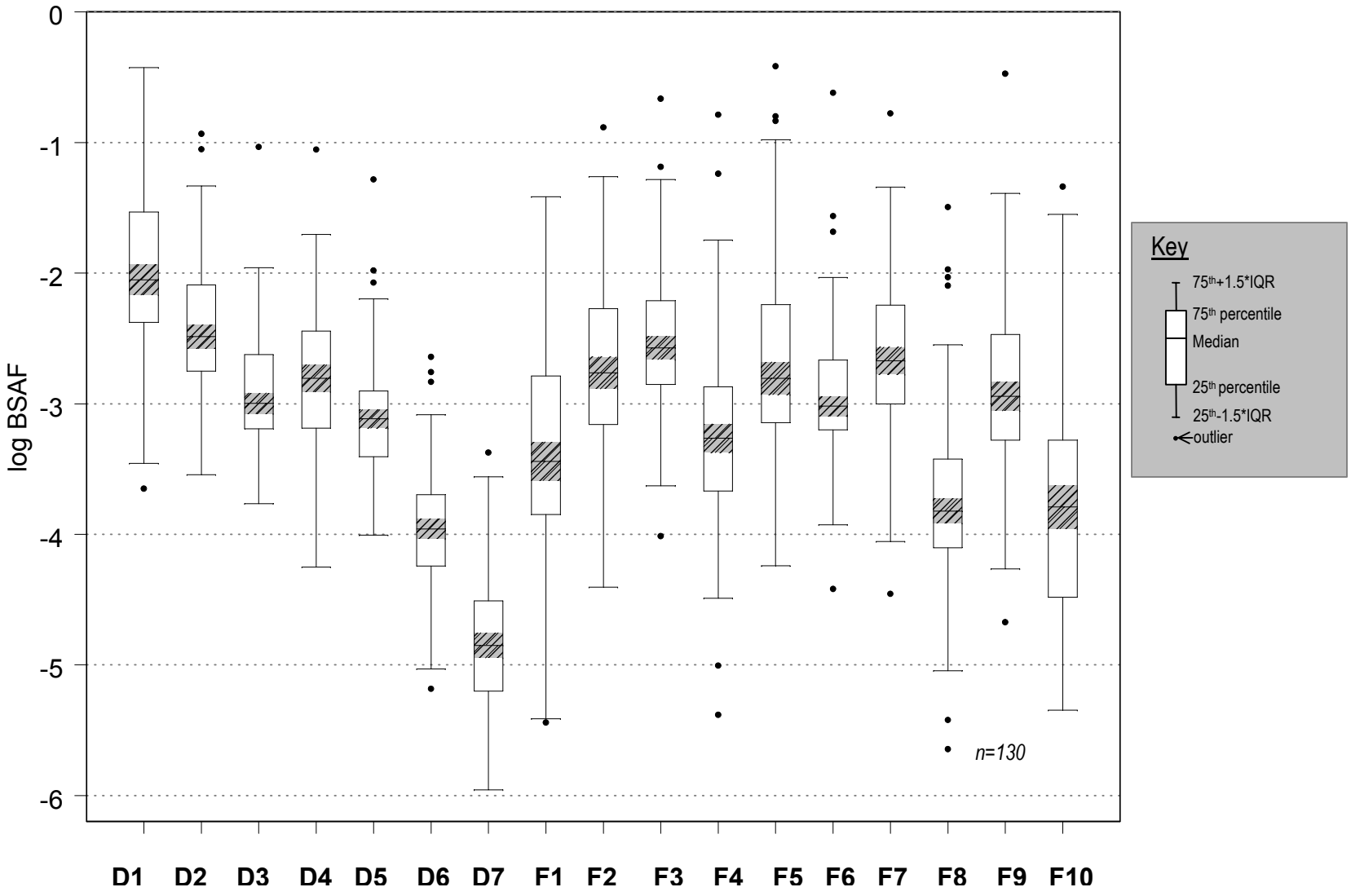


Figure 4.15 Distribution of Individual BSAFs for Catfish from the HSC

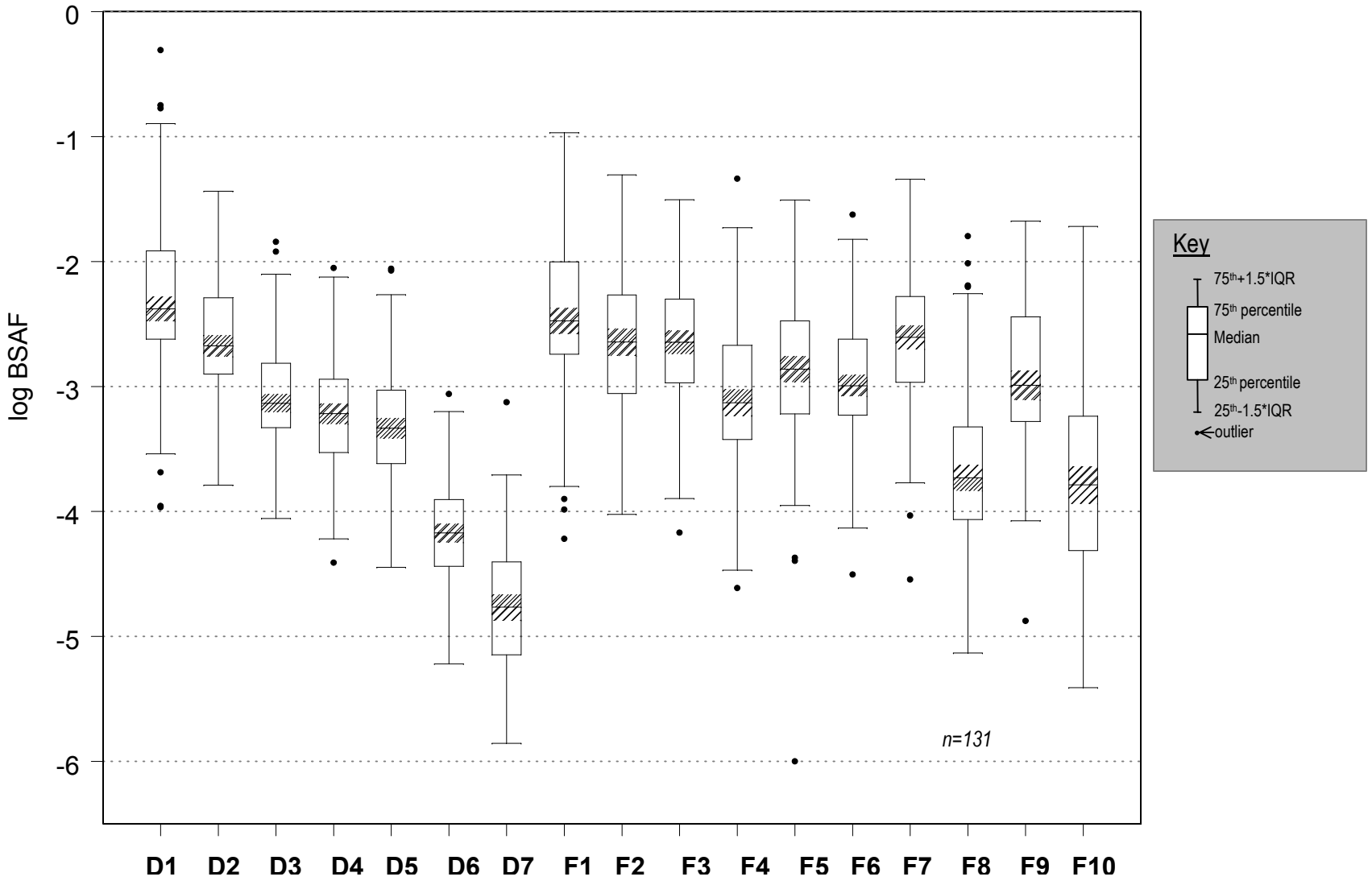


Figure 4.16 Distribution of Individual BSAFs for Crabs from the HSC

performed using the linear models employed to estimate BAFs. Again, two non-linear models (power and polynomial) were included for comparison purposes. Figure 4.17 shows the best-fit lines for the various regression methods and Table 4.6 summarizes the test statistics. Similar to what was observed with tissue-water relationships, linear models did not provide the best fit for the field data. However, they were preferred over the non-linear ones because a biota to sediment accumulation factor could be directly derived. Figure 4.18 presents residuals versus fit plots for the various models. Clustering of the residuals is more evident for the sediment data. However, for low to medium predicted concentrations, the residuals seem to be varying randomly around zero for most of the models. It is noted that all the models in this case (including the non-linear ones) exhibit tailing of the residuals. This is due to very high concentrations of 2378-TCDD in some of the sediment samples. The histograms for the residual datasets are presented in Figure 4.19. Data in Table 4.6 and Figures 4.18 and 4.19 suggest that the LTS model best describes the field data among the linear regressions and fairly meets the assumptions of normality of residuals and constant variance. Thus, this method was selected to estimate the BSAFs for the remaining congeners.

Prior to calculating BSAFs for the different dioxin and furan congeners, scatterplots of residuals versus several explanatory and categorical variables were examined to look for possible correlations (Figures 4.20 and 4.21). No evident patterns were observed in the data.

4.1.2.2 Estimation of BSAF for All Congeners

Biota to sediment accumulation factors were estimated using the robust LTS regression method and following the guidelines outlined in the BAF section. Plots of tissue concentrations of each congener versus the measured concentration in organic carbon-normalized sediment along

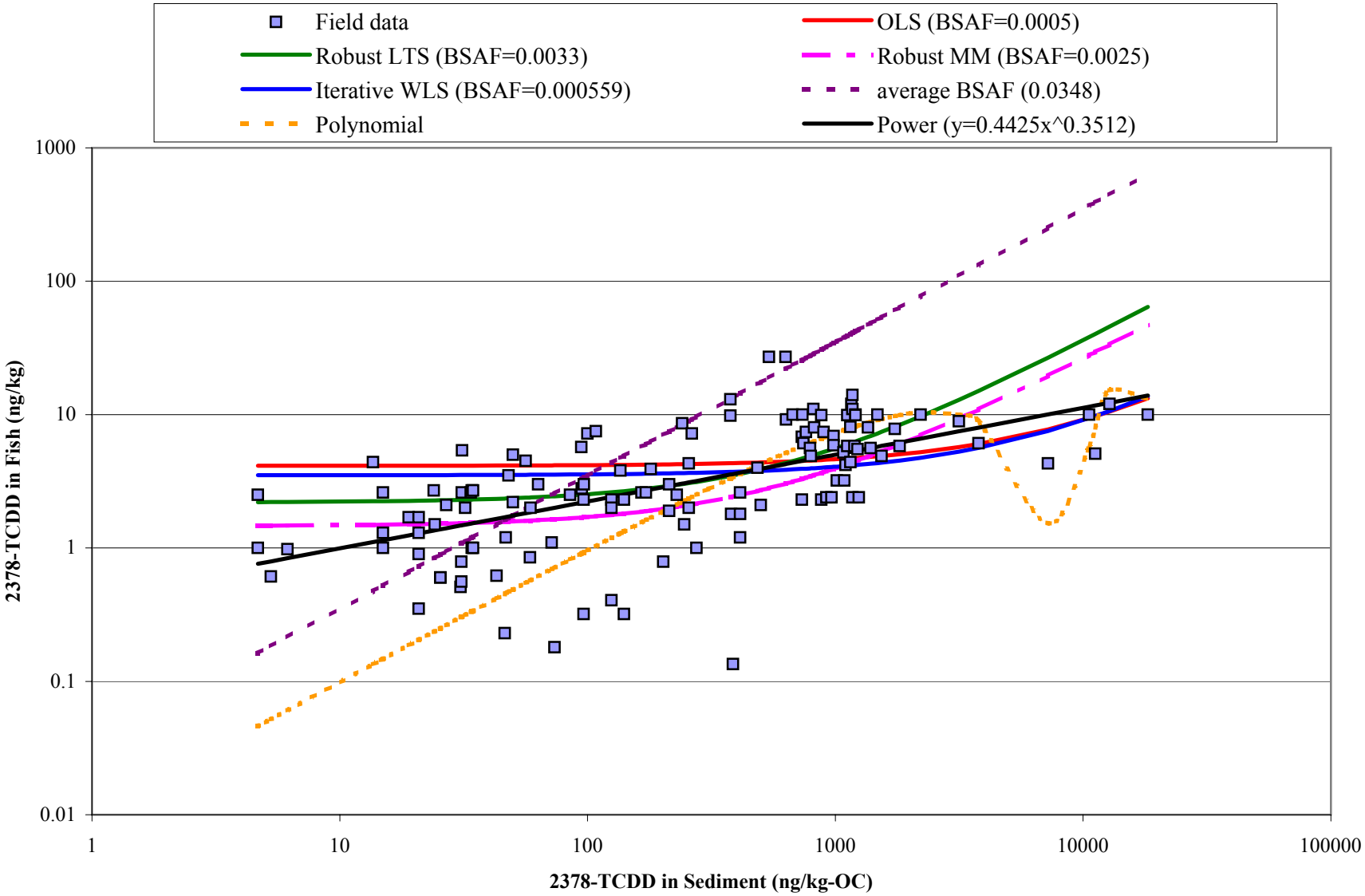
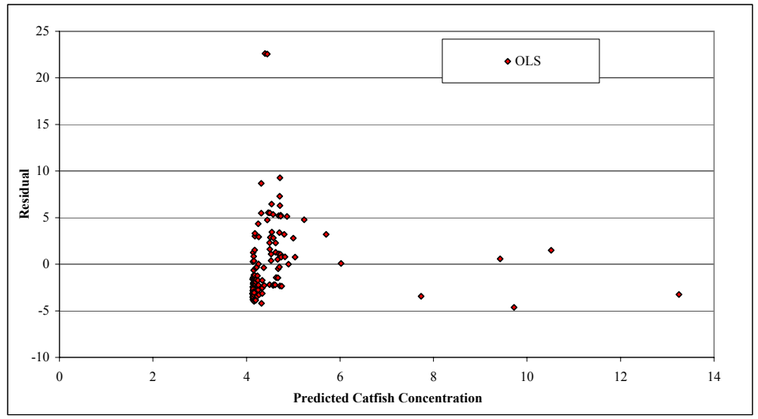


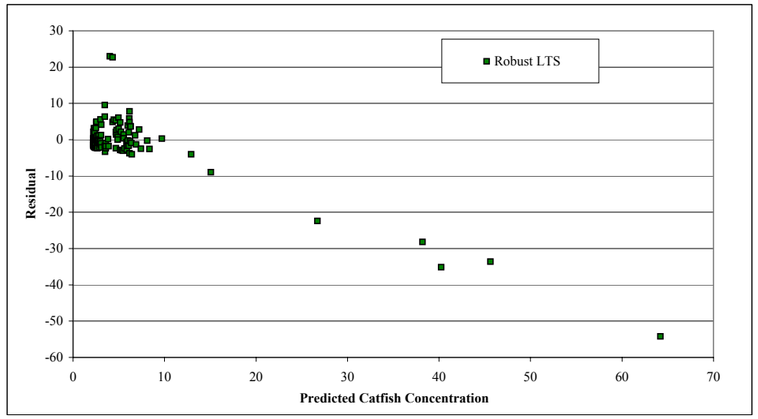
Figure 4.17 Partitioning of 2378-TCDD between Catfish and Carbon-normalized Sediment in the HSC

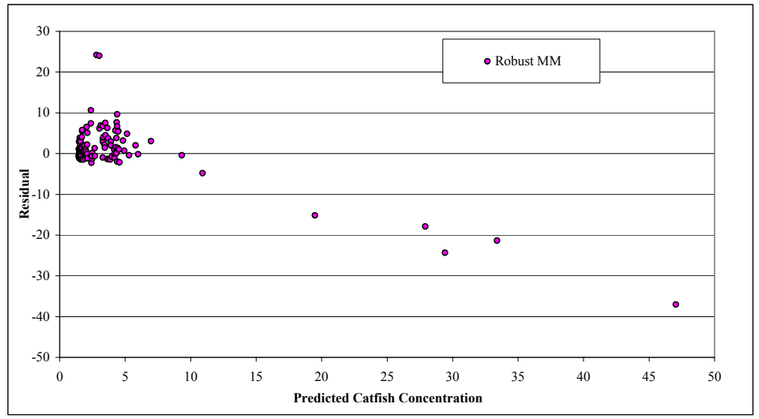
Table 4.6 Summary of Regression Statistics and Parameters for Catfish-Carbon Normalized Sediment Relationships

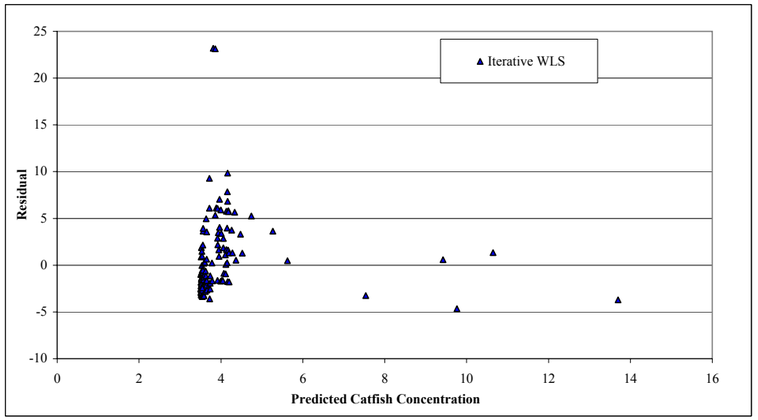
Model	F-statistic	p-value	Residual SE	b0			b1 (BSAF in linear regressions)			b2			b3		
				Value	SE	t-value[a]	Value	SE	t-value[a]	Value	SE	t-value[a]	Value	SE	t-value[a]
OLS	11.28	0.001037	4.242	4.1289	0.4037	10.2275	0.0005	0.0002	3.3585						
Robust LTS	90.56	1.11E-16	2.208	2.191	0.2674	8.1946	0.0034	0.0004	9.5165						
Robust MM	*11.1*	*0.0036*	2.061	1.4574	0.2371	6.147	0.0025	0.0004	7.2084						
Iterative WLS	27.67	6.10E-07	2.804	3.5067	0.2775	12.6376	0.0006	0.0001	5.2606						
Polynomial	7.13		4.024	-7.83E-15	1.61E-15	-4.86813	2.74E-10	5.01E-11	5.48E+00	-2.91E-06	4.23E-07	-6.90E+00	9.88E-03	8.41E-04	1.17E+01
Power			2.296	0.4425	0.1012	-3.49869	0.3512	0.0408	8.598						

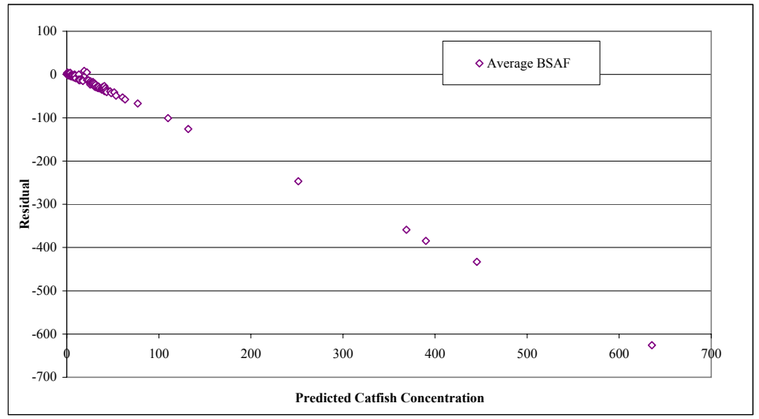
[a] If |t-value|>2, the linear relationship is statistically significant at α=0.05.

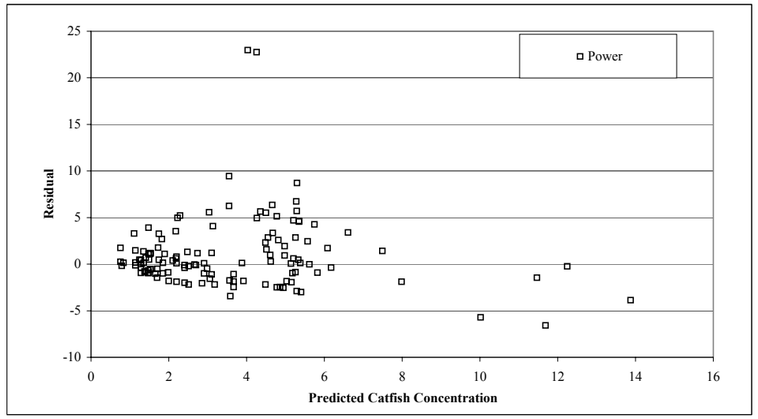












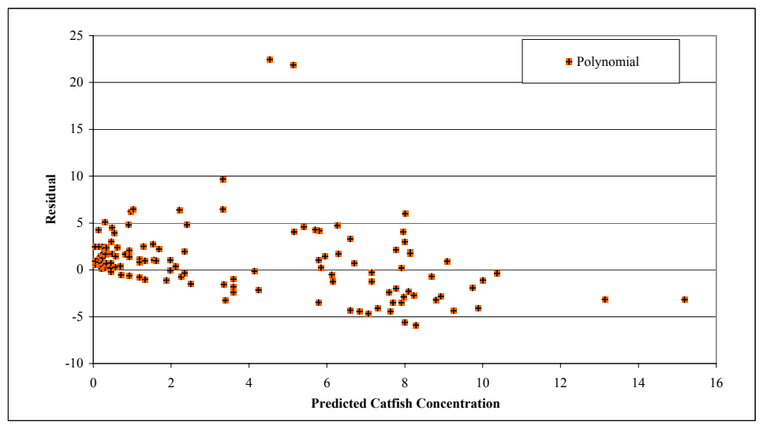
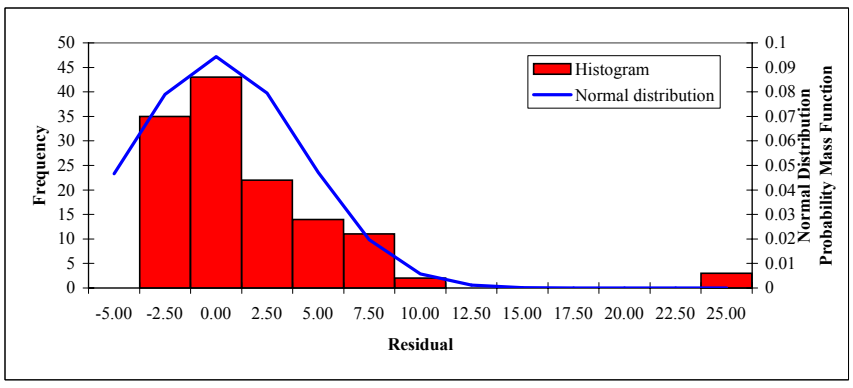
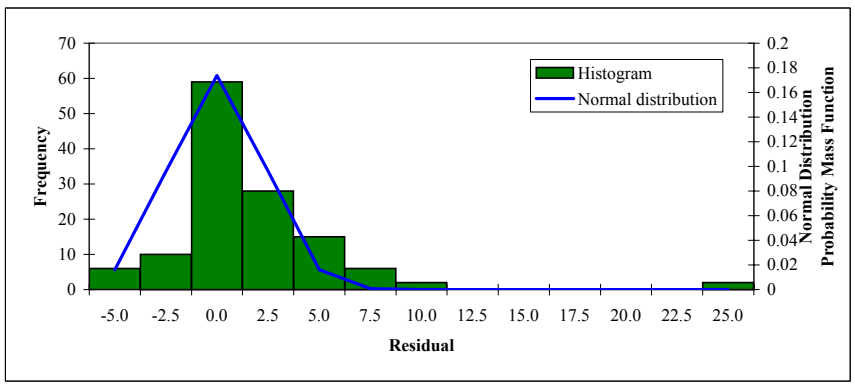
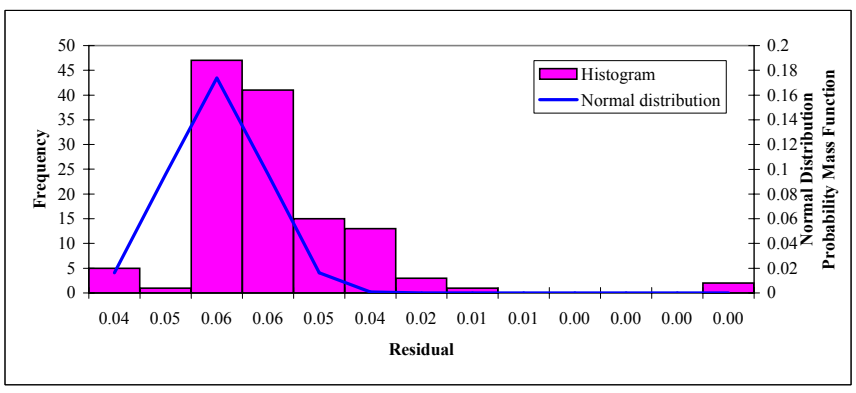
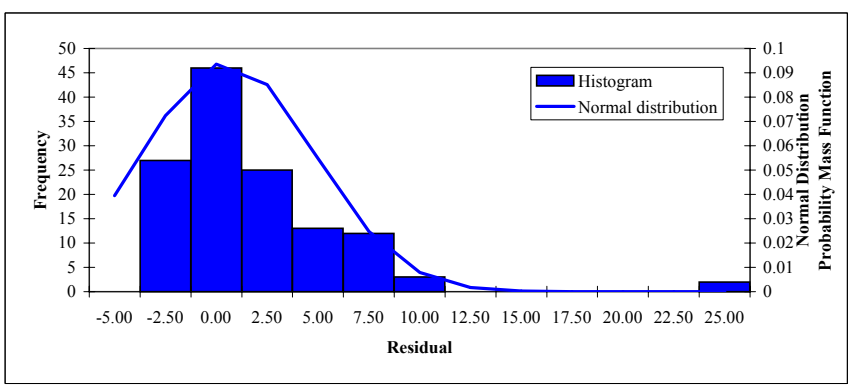


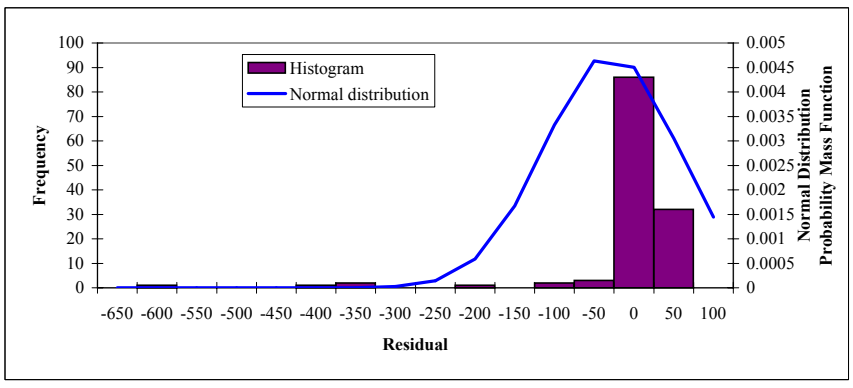
Figure 4.18 Residuals vs Fit Plots for Regressions between Catfish and Sediment-Organic Carbon 2378-TCDD Concentrations

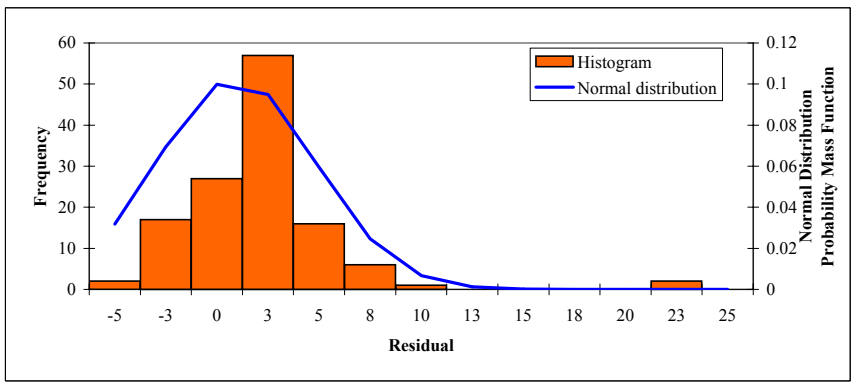












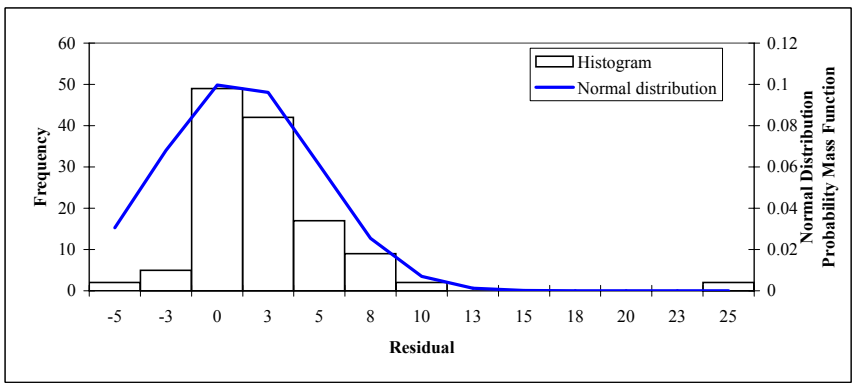
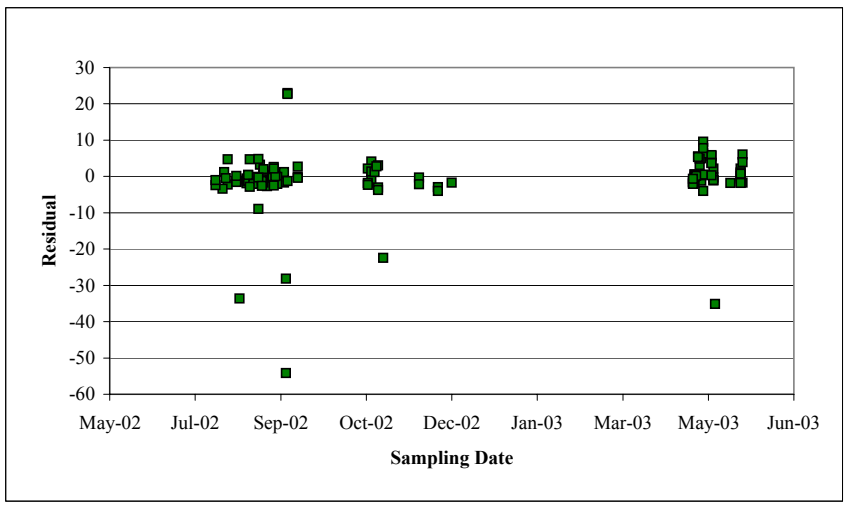
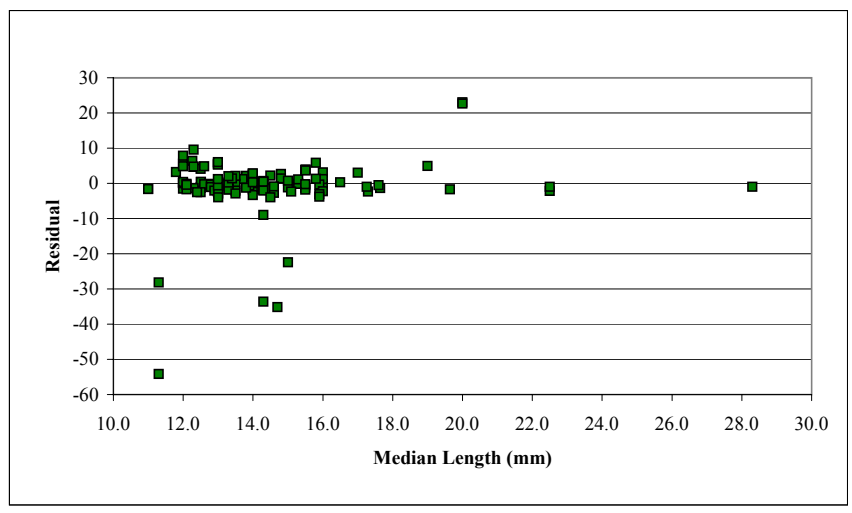
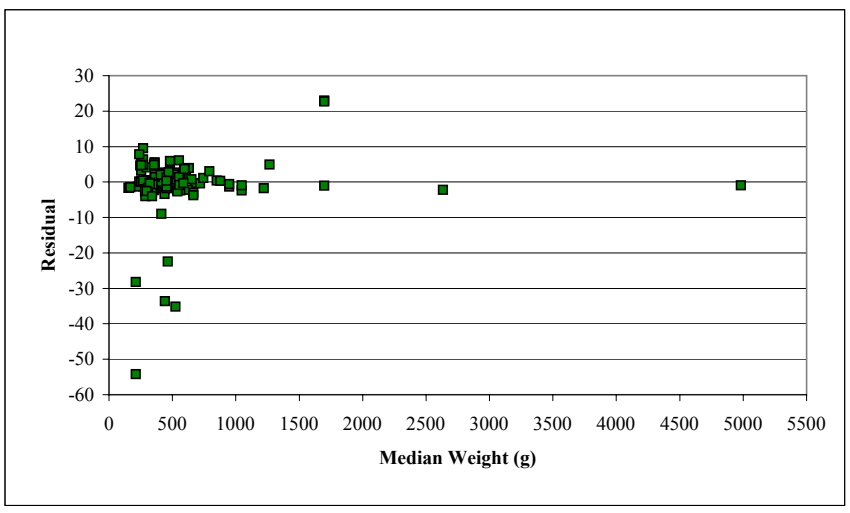
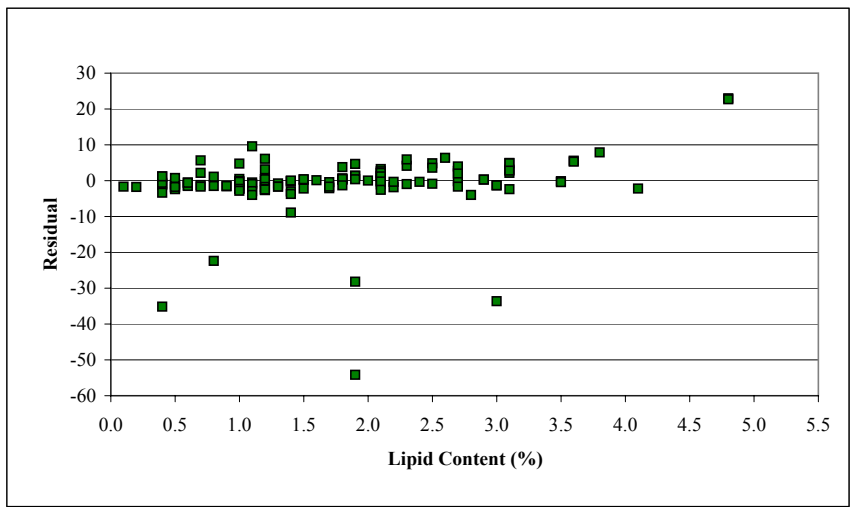


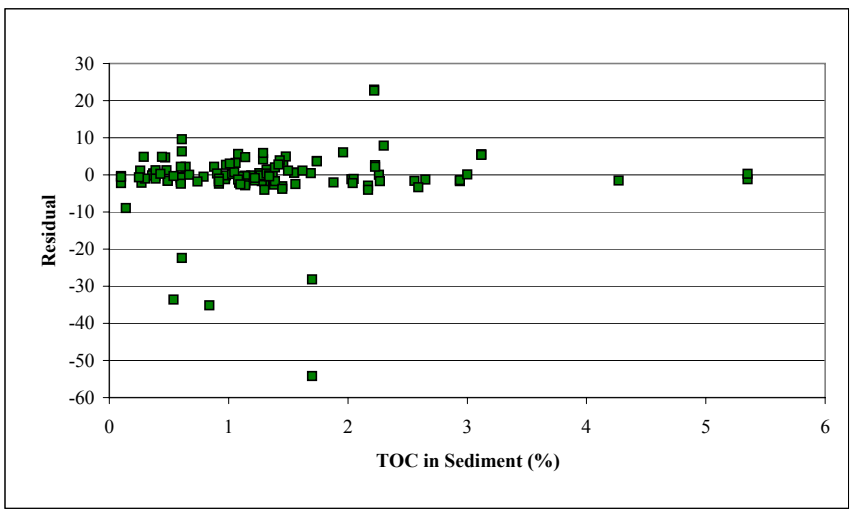
Figure 4.19 Histogram of Residuals for Regressions of Catfish and Sediment Concentrations of 2378-TCDD

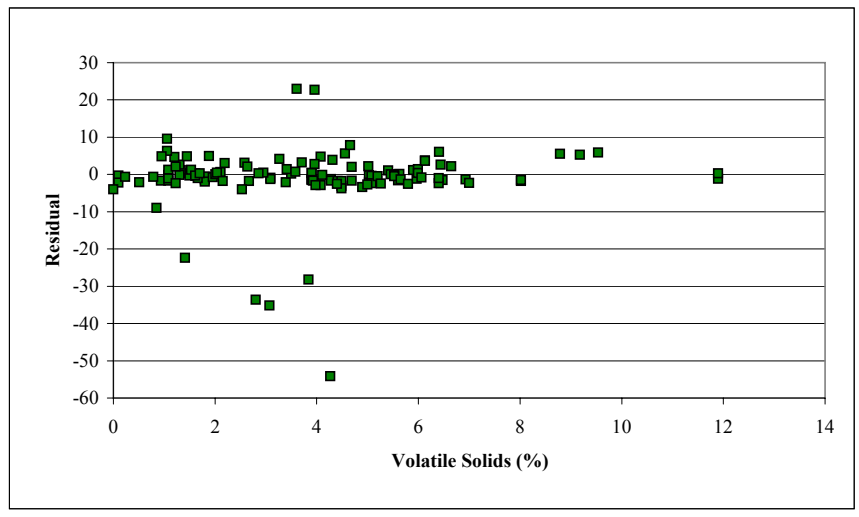












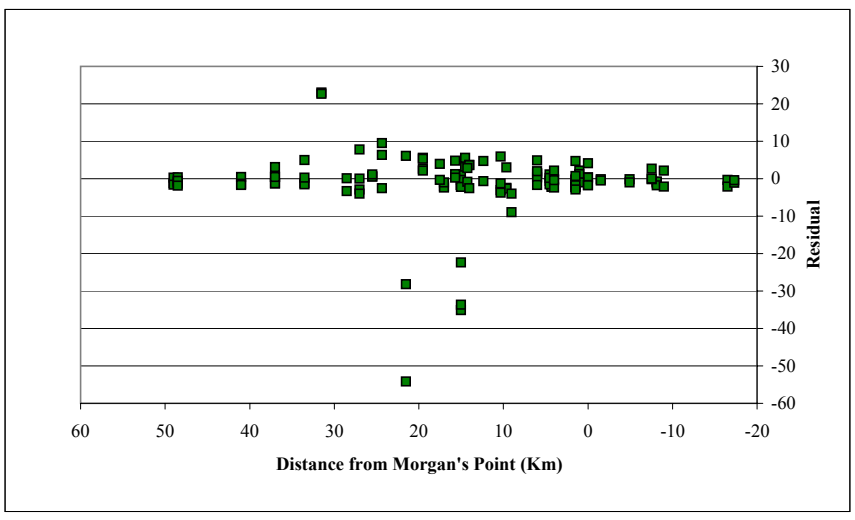


Figure 4.20 Residuals from Catfish BSAF Regressions Plotted by Additional Explanatory Variables

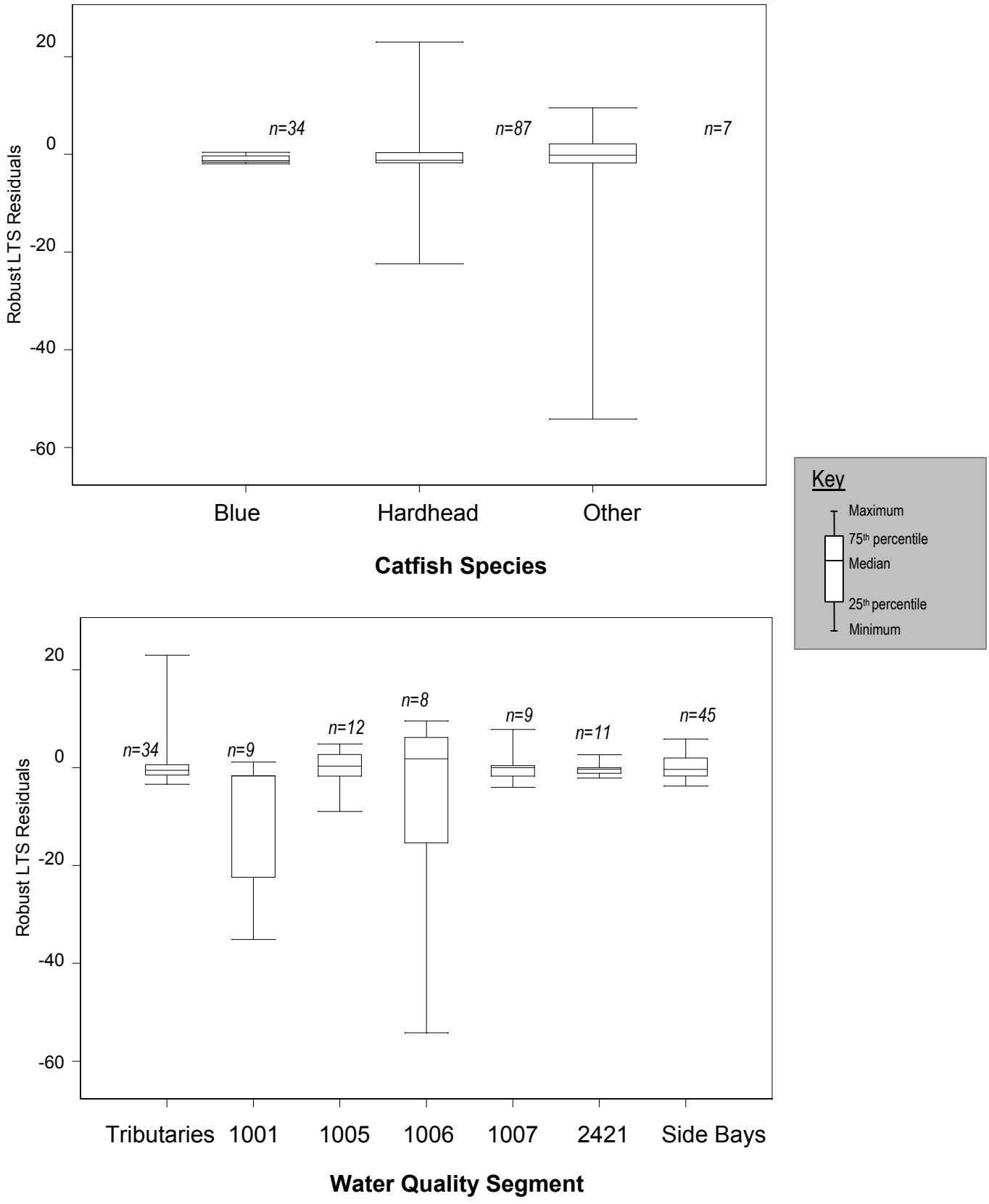


Figure 4.21 Distribution of Residuals from Catfish BSAF Regressions by Categorical Variables

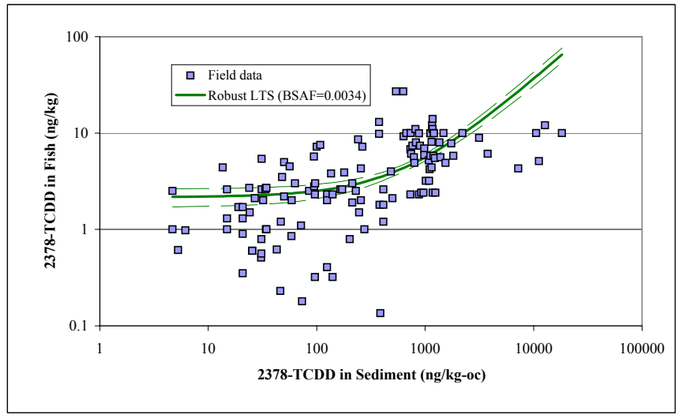
with the best-fit line and the confidence intervals are presented in Figures 4.22 and 4.23 for catfish and crabs, respectively. Table 4.7 summarizes the test statistics for each regression. Biota to sediment accumulation factors varied within 2 orders of magnitude among the different congeners and were generally higher for catfish than for crabs. This may be the result of higher lipid content in fish than in crabs. It is noted that for some congeners the relationships were not statistically significant at the 95% confidence level and, thus, the uncertainty in the estimated BSAFs for those compounds is high.

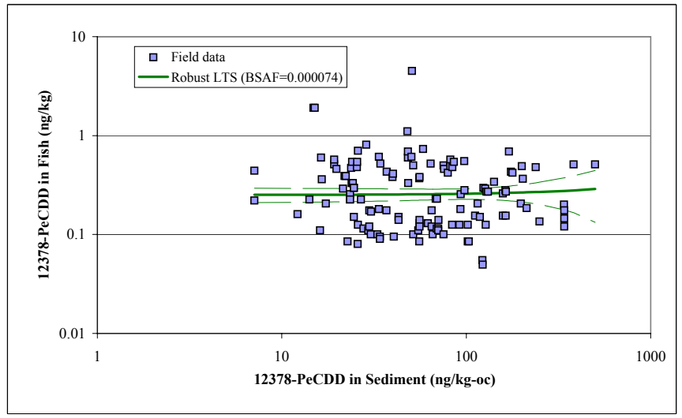
4.1.2.3 Determination of BSAF using Measures of Central Tendency

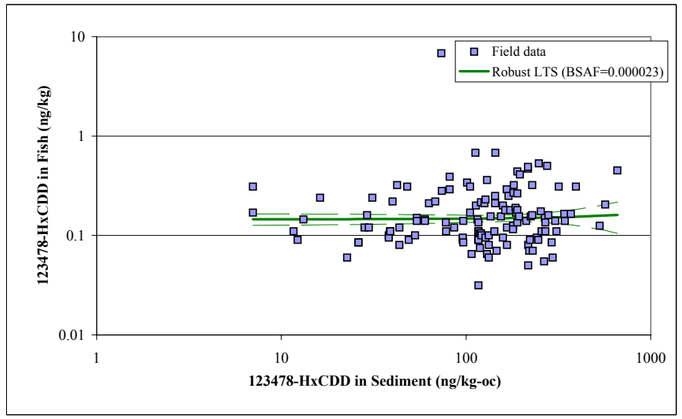
Similarly to the observations for BAFs, linear models did not fit BSAF relationships well. Thus, a measure of central tendency (i.e. mean or median) of the ratios of tissue concentrations to sediment concentrations (Figures 4.15 and 4.16) was used instead of BSAFs estimated from linear regressions. The tissue to organic carbon-sediment do not follow a normal distribution as indicated by large skeweness and kurtosis (up to 8 and 40, respectively). Thus, the median was selected as the most appropriate measure of central tendency. Figure 4.24 shows organic carbon-normalized sediment and tissue data and the BSAF fitting lines calculated for selected congeners in both catfish and crabs.

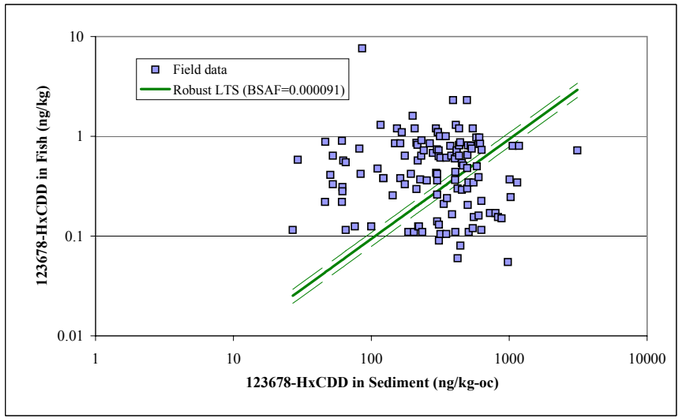
4.1.3 Combined Bioaccumulation and Biota to Sediment Accumulation Factors

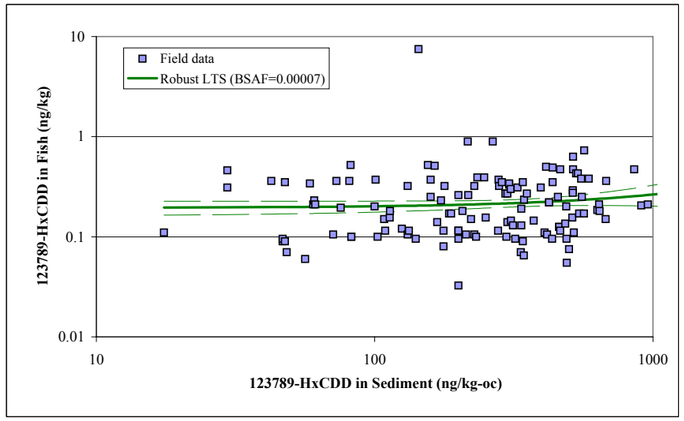
In theory, the estimated BAFs include the effects of all routes of chemical exposure in the aquatic ecosystem. Thus, they do not assume simple water-biota partitioning but are an overall expression of the bioaccumulation using the concentration of the chemical in the water column as a reference point (USEPA, 1995). However, this holds true only if the dissolved and bed sediment

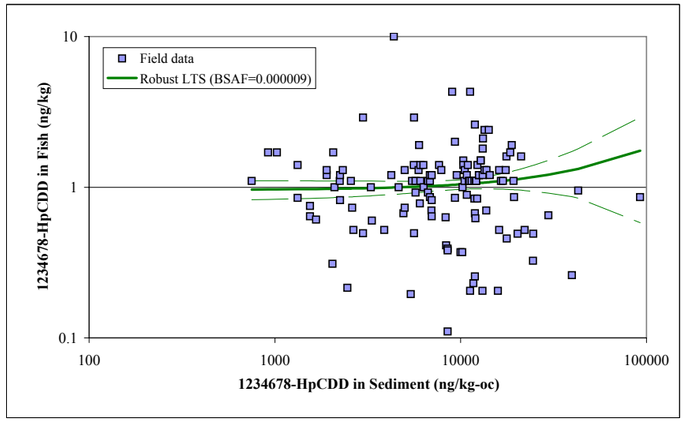


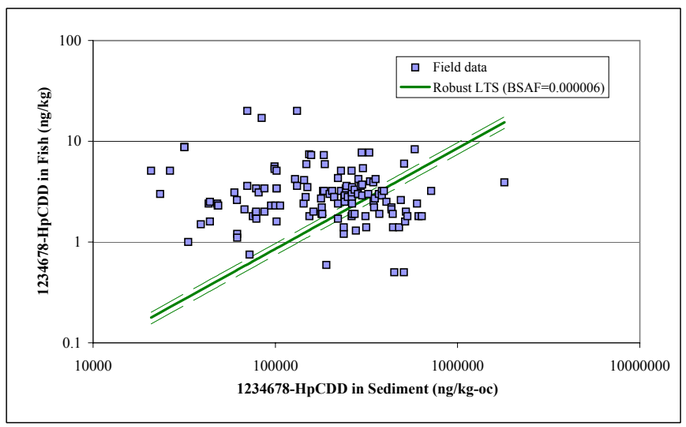






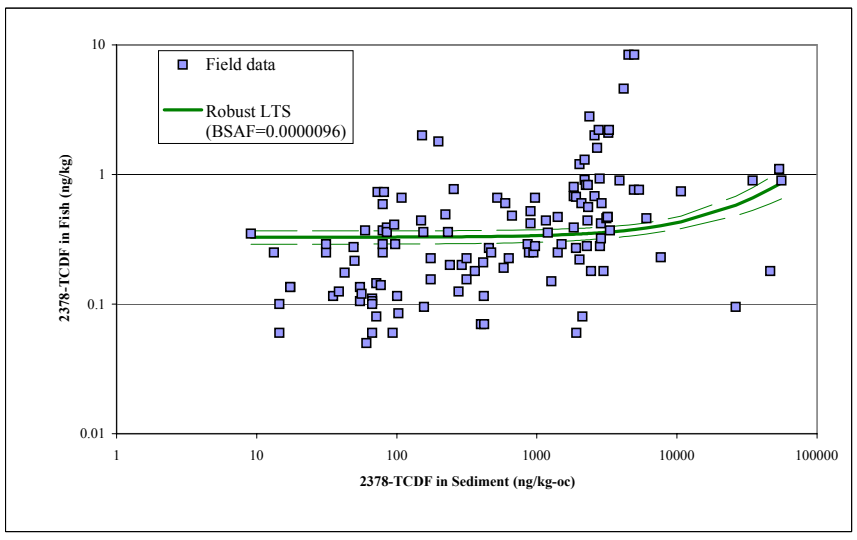


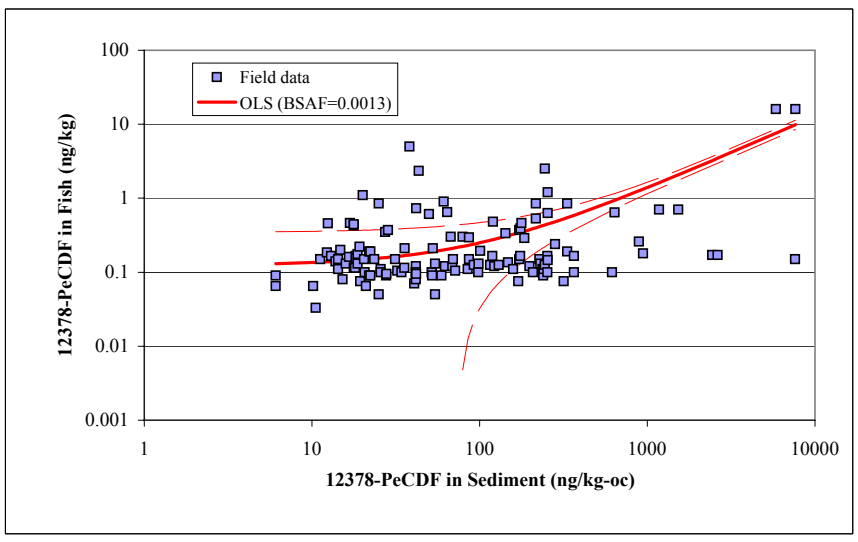


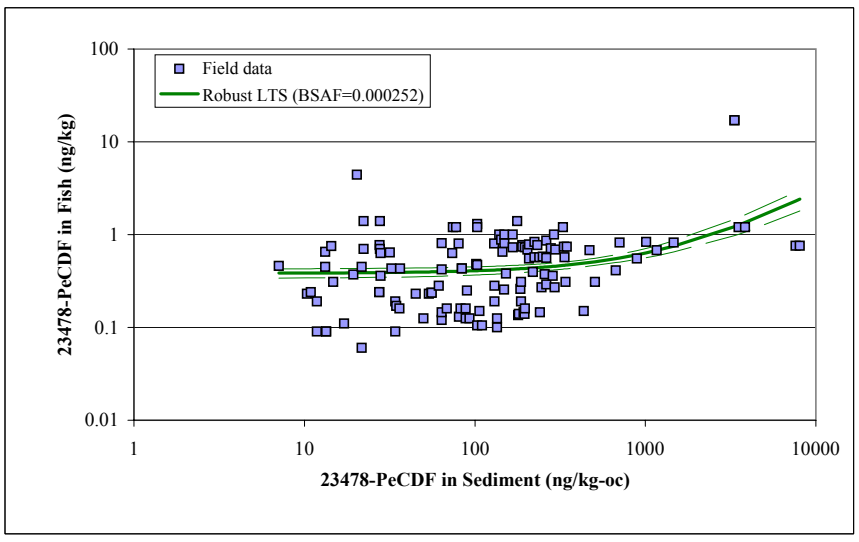


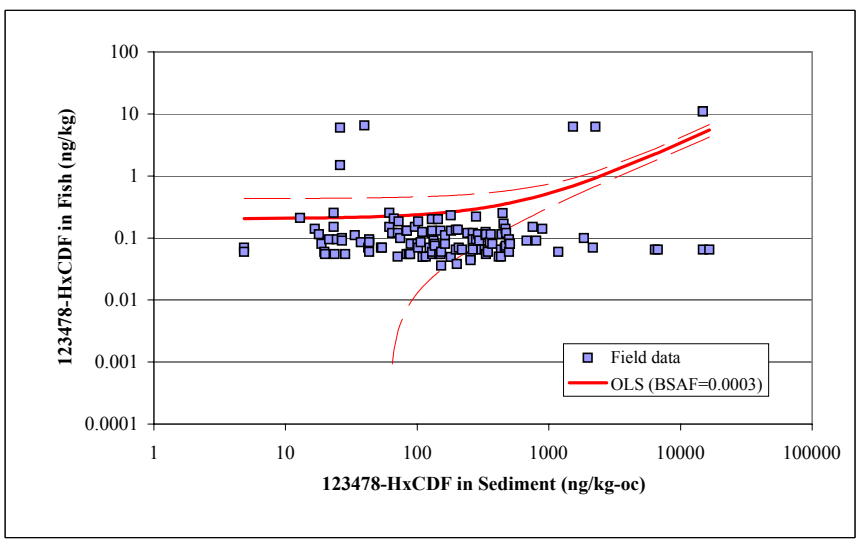
Dashed lines correspond to the 95% confidence intervals

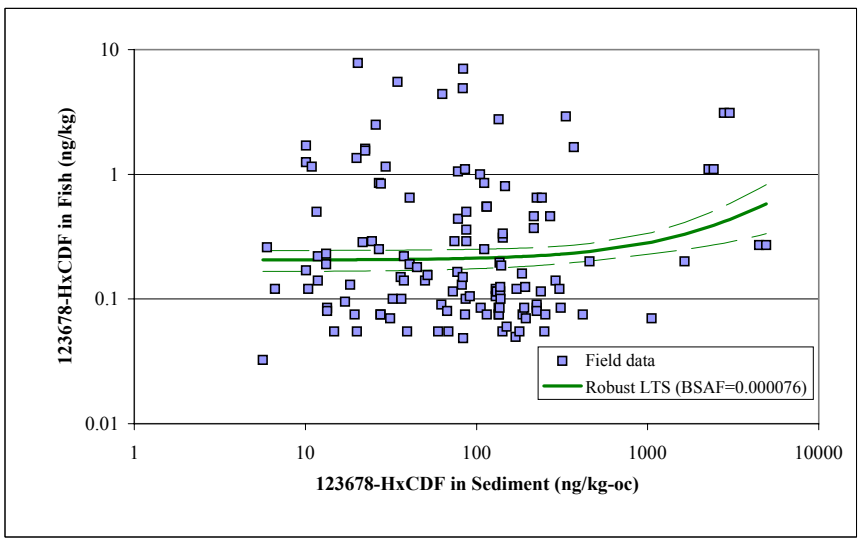
Figure 4.22a Biota to Sediment Accumulation Factors for Dioxins in Catfish from the HSC

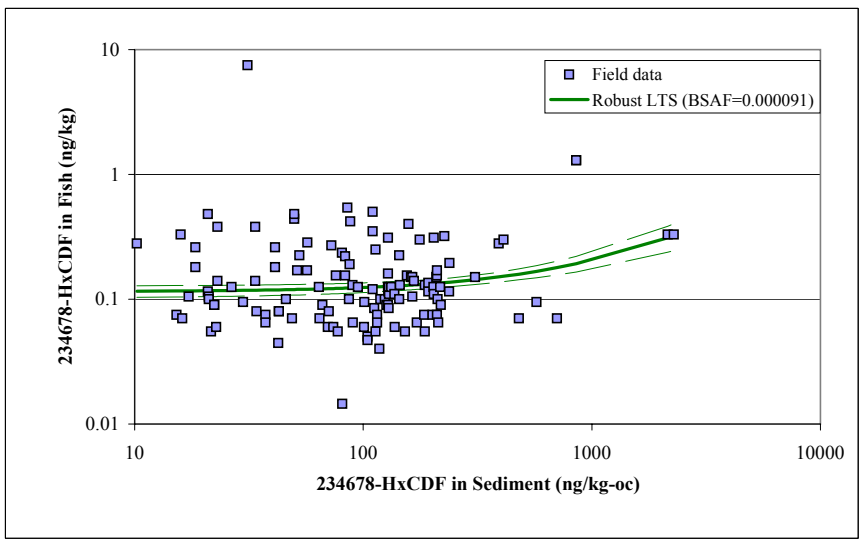


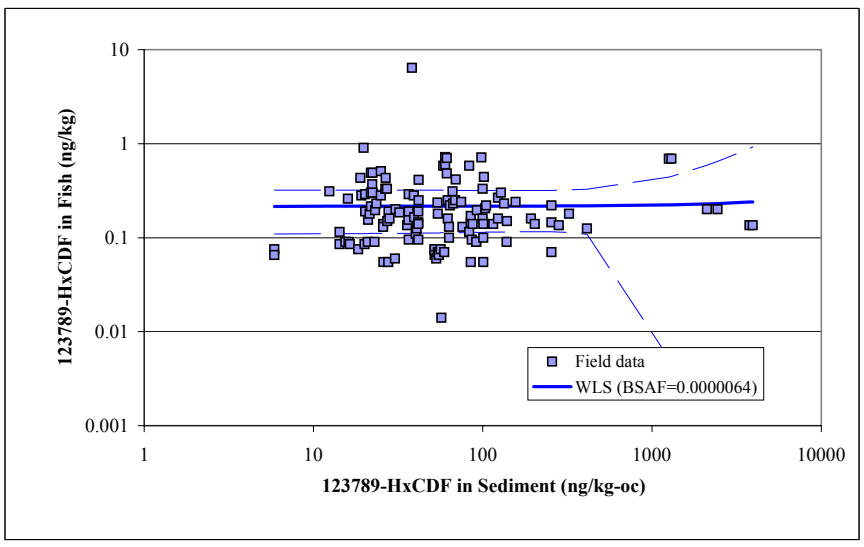


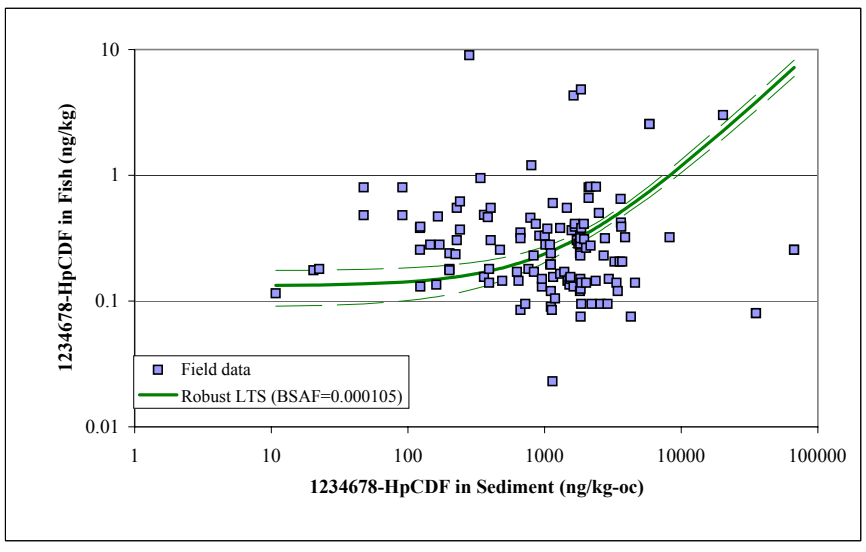


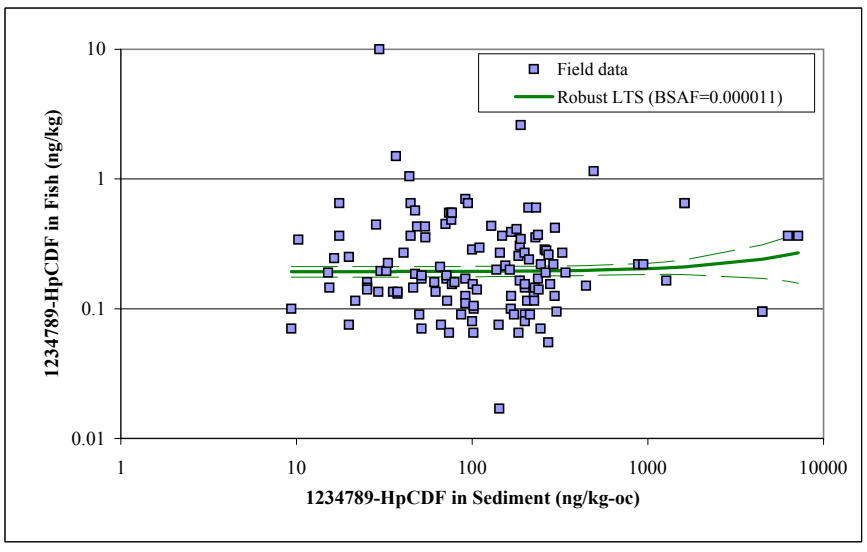


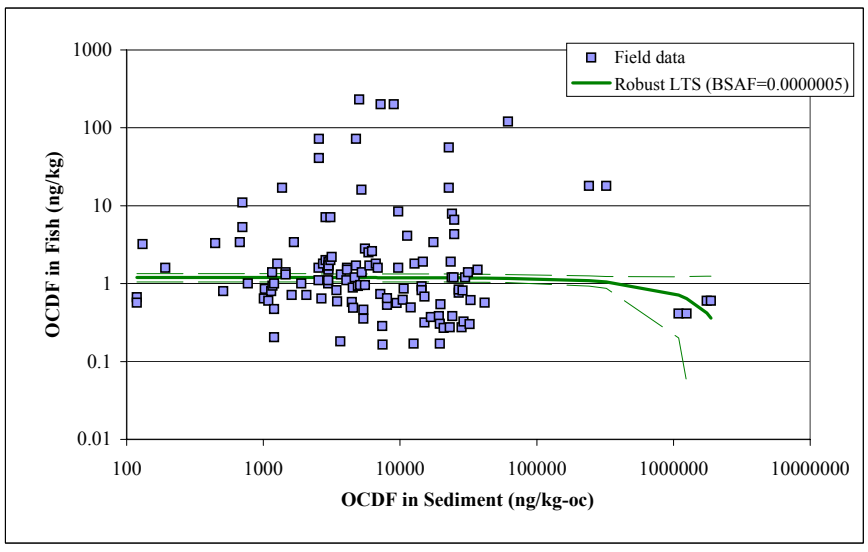






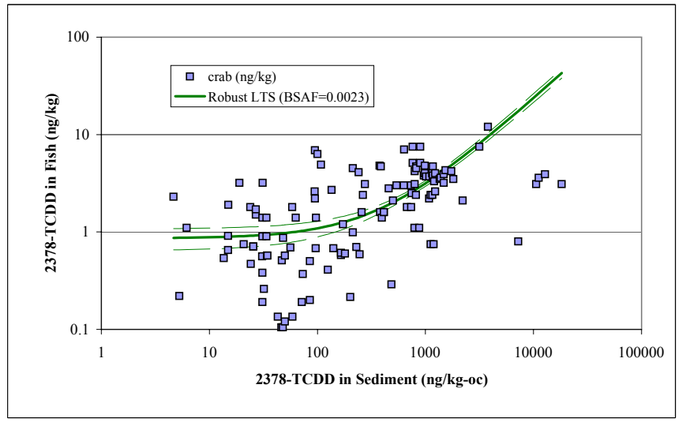


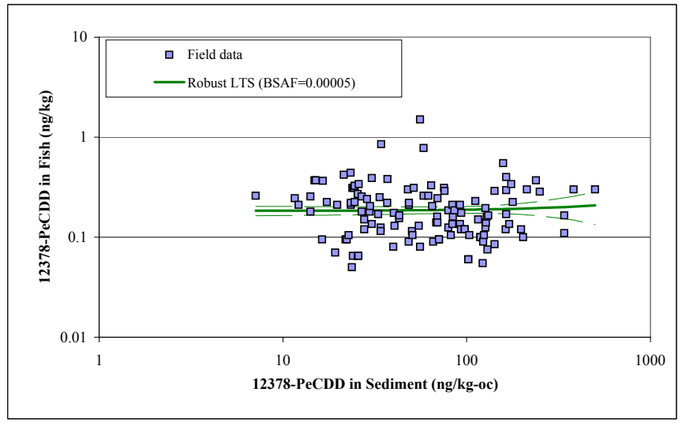


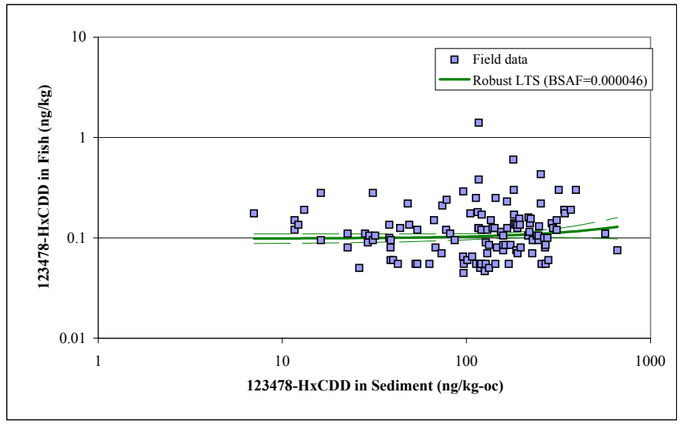


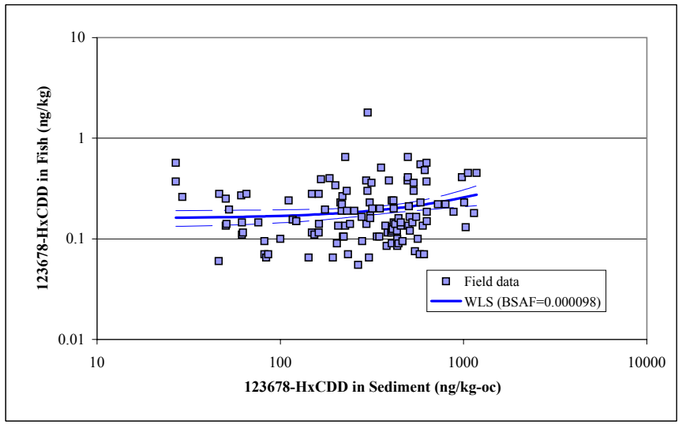
Dashed lines correspond to the 95% confidence intervals

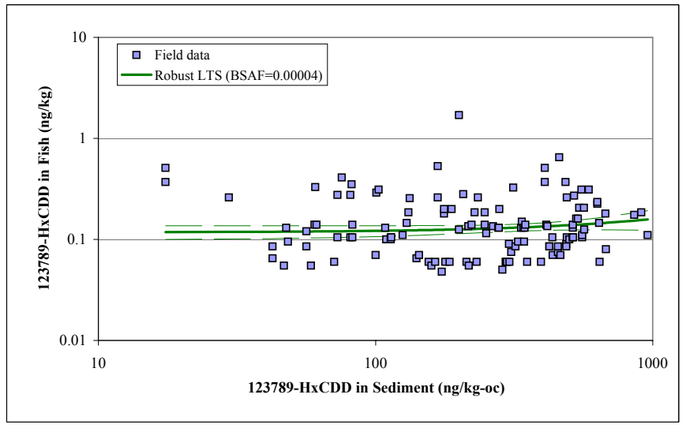
Figure 4.22b Biota to Sediment Accumulation Factors for Furans in Catfish from the HSC

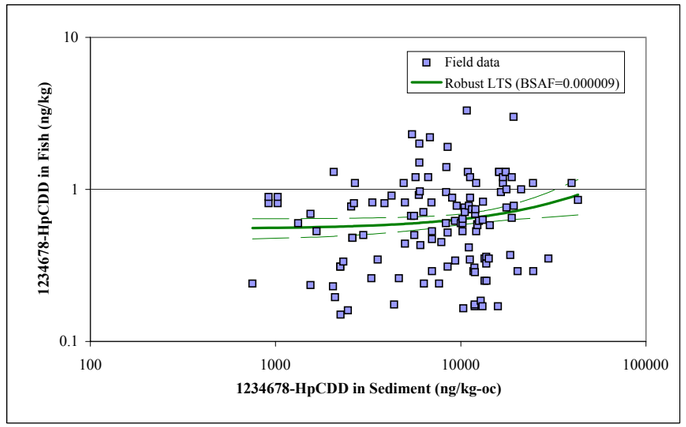












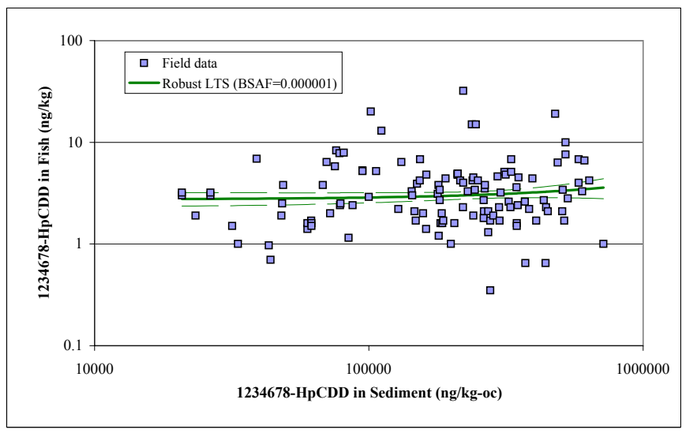
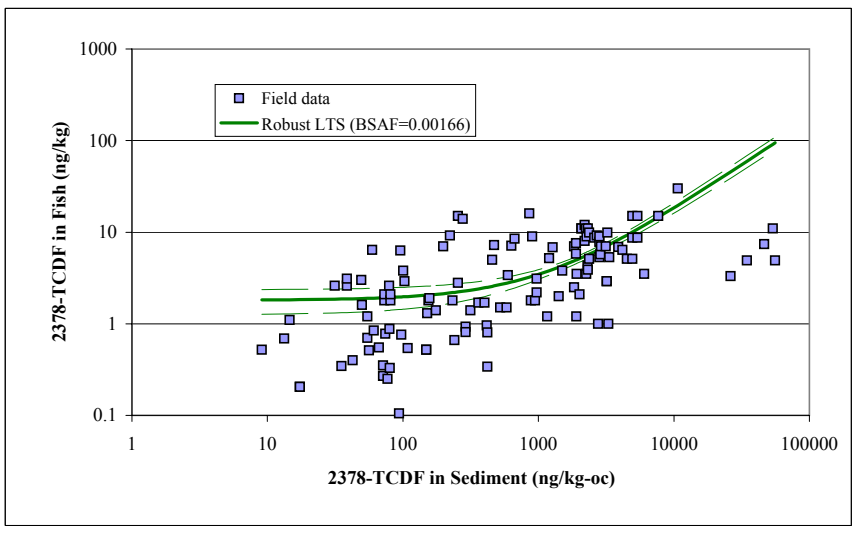
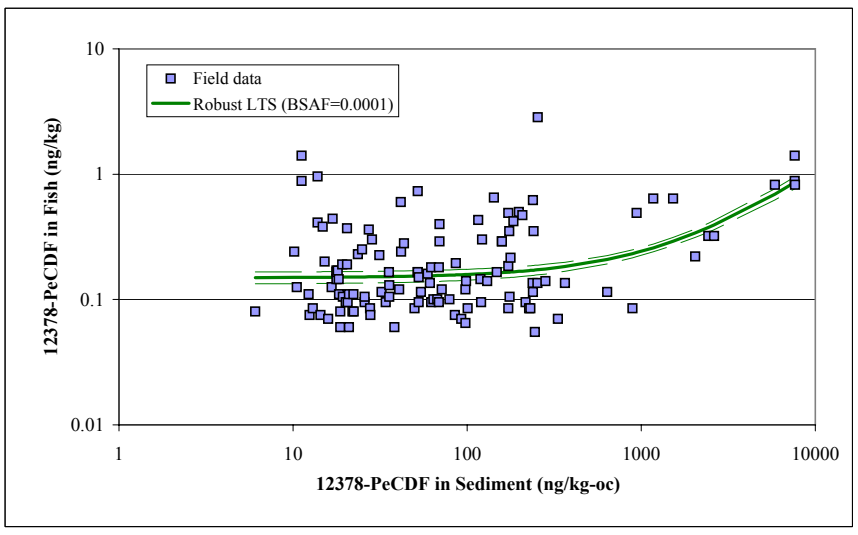
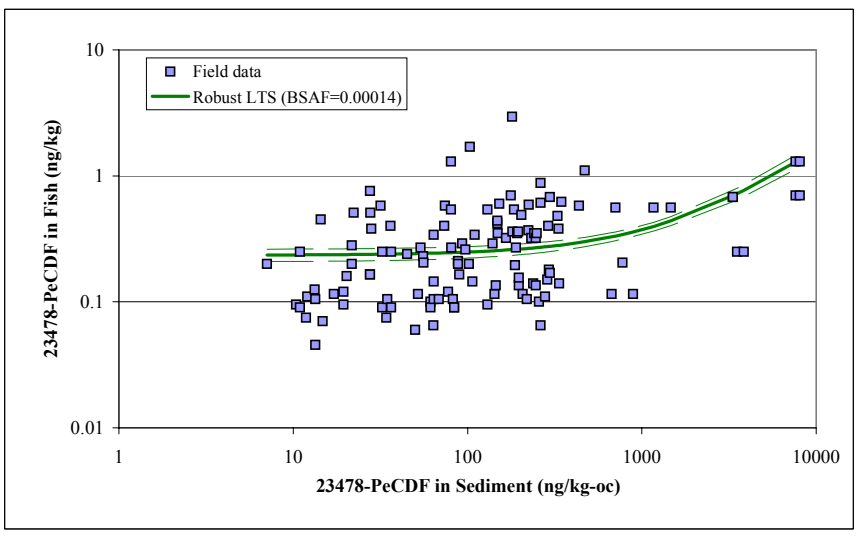
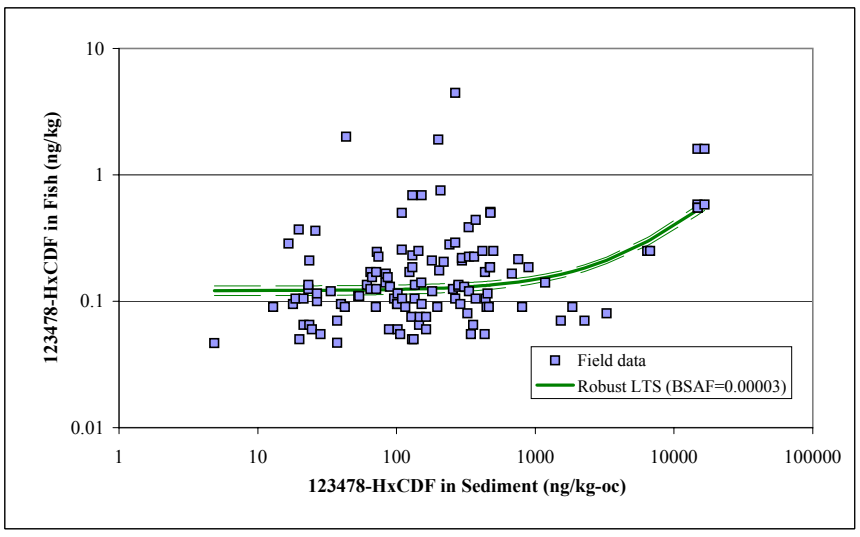


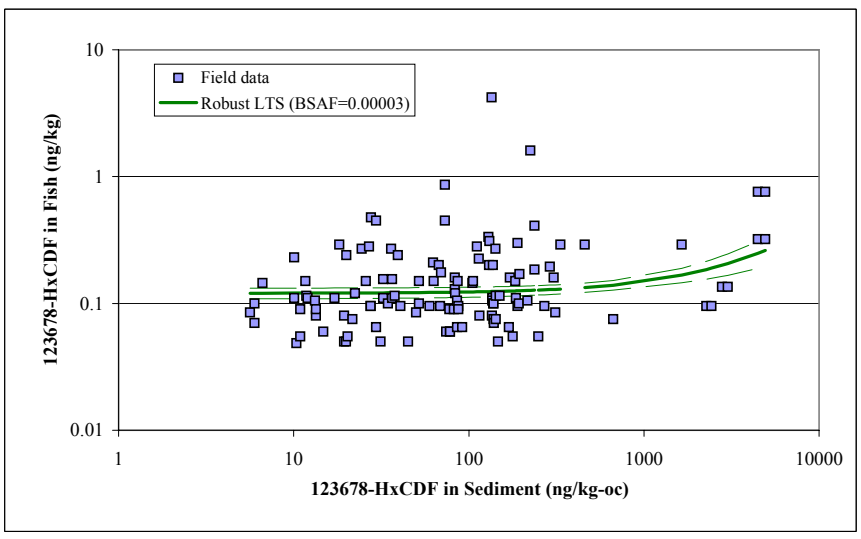
Figure 4.23a Biota to Sediment Accumulation Factors for Dioxins in Crabs from the HSC

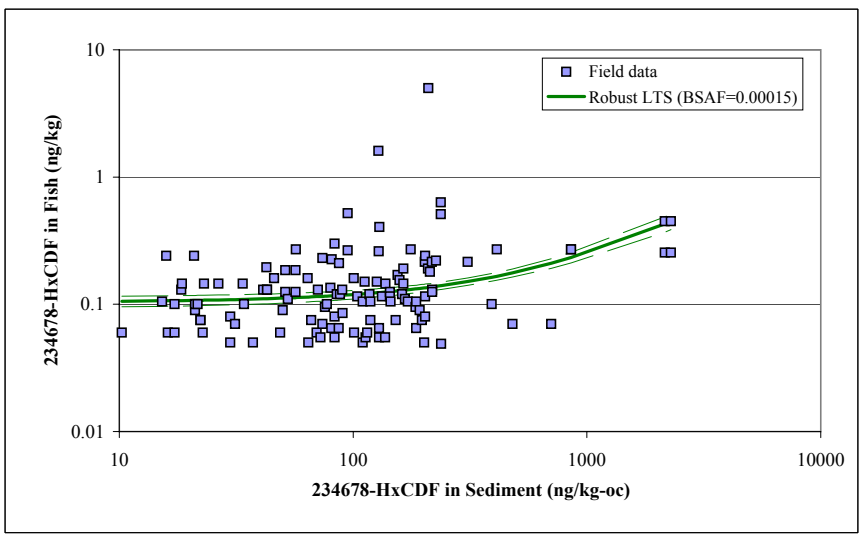


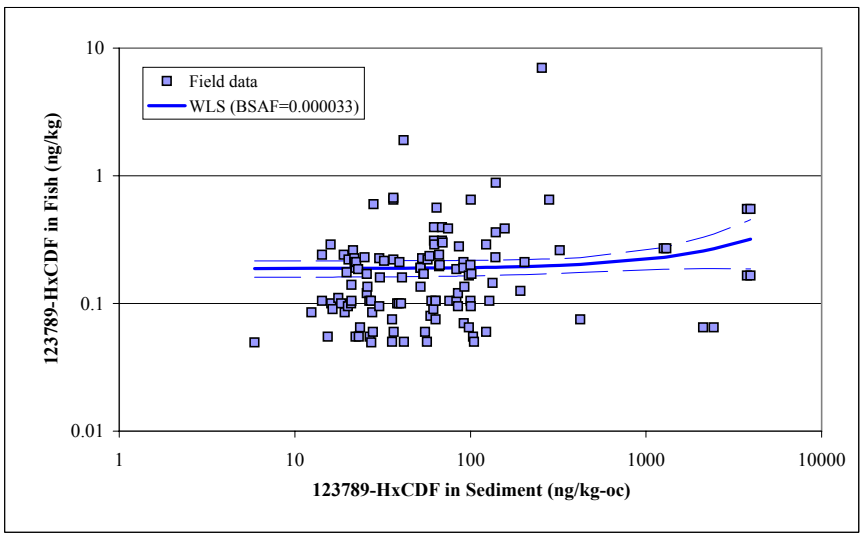


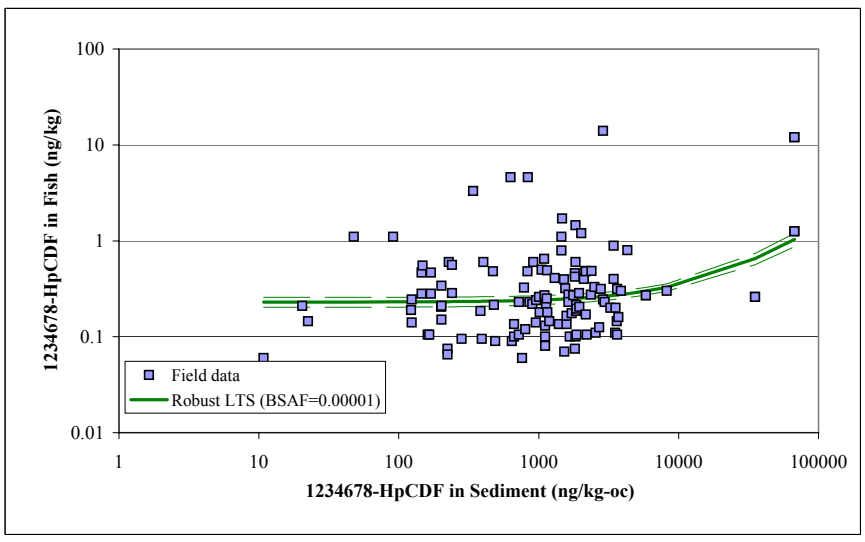


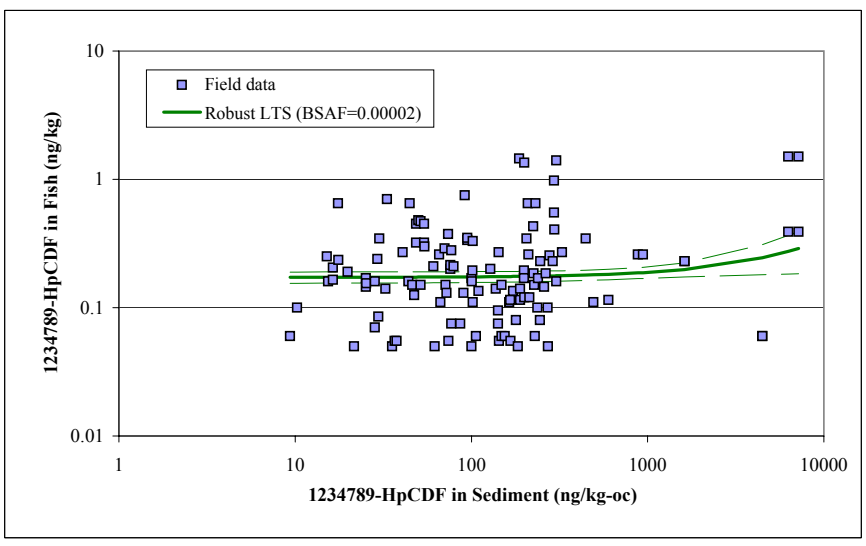












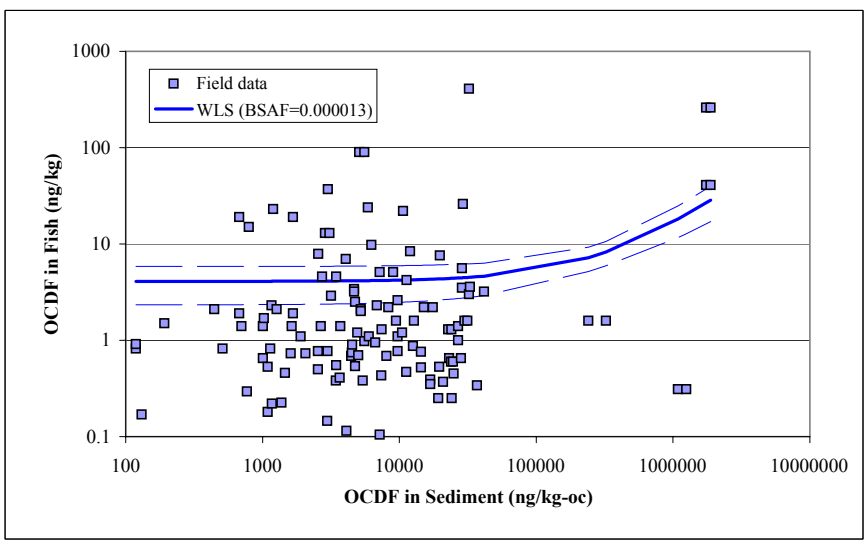


Figure 4.23b Biota to Sediment Accumulation Factors for Furans in Crabs from the HSC

Table 4.7a Estimated Biota to Sediment Accumulation Factors for HSC Catfish

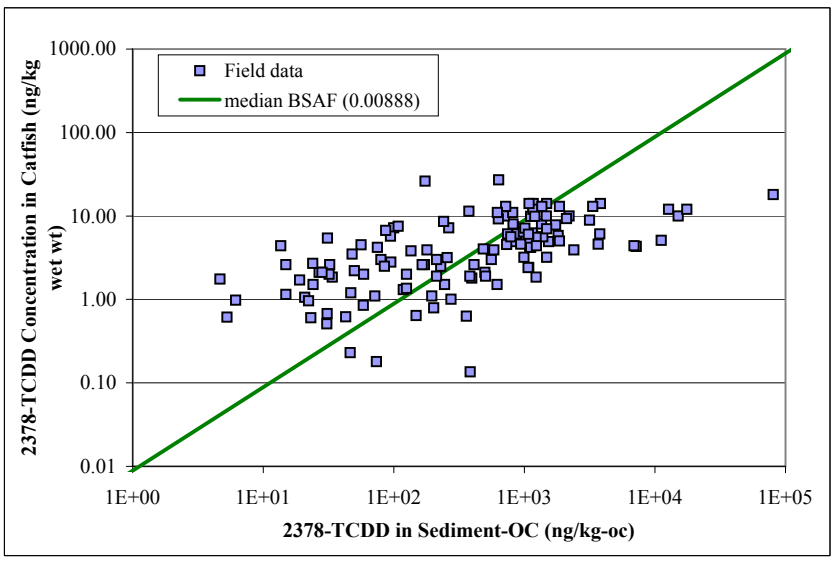
Congener	Method	Regression		Slope	
		SE	Significance F	Estimated BAF	*p*-value
2378-TCDD	Robust LTS	2.3	84.254	0.00345±0.00074	2.266E-15
12378-PeCDD	Robust LTS	0.2	0.008	0.00007±0.00036	0.9297
123478-HxCDD	Robust LTS	0.1	0.129	0.00002±0.00013	0.7203
123678-HxCDD	Robust LTS	0.4	-54.482	0.00094±0.00018	3.063E-18
123789-HxCDD	Robust LTS	0.1	1.791	0.00007±0.0001	0.1834
1234678-HpCDD	Robust LTS	0.5	1.024	0.00001±0.00002	0.3136
OCDD	Robust LTS	2.1	-81.882	0.00001±0	7.009E-18
2378-TCDF	Robust LTS	0.2	15.760	0.00001±0	0.0001
12378-PeCDF	OLS	1.5	120.906	0.00127±0.00023	3.947E-20
23478-PeCDF	Robust LTS	0.3	28.694	0.00025±0.00009	4.519E-07
123478-HxCDF	OLS	1.5	44.888	0.00032±0.00009	6.232E-10
123678-HxCDF	Robust LTS	0.2	5.864	0.00008±0.00006	0.0172
234678-HxCDF	Robust LTS	0.1	17.009	0.00009±0.00004	7.169E-05
123789-HxCDF	Iterative WLS	0.6	0.027	0.00001±0.00018	0.8688
1234678-HpCDF	Robust LTS	0.2	114.428	0.0001±0.00002	7.962E-19
1234789-HpCDF	Robust LTS	0.1	1.194	0.00001±0.00002	0.2769
OCDF	Robust LTS	1.5	-68.643	0.0000004±0.0000009	0.3497

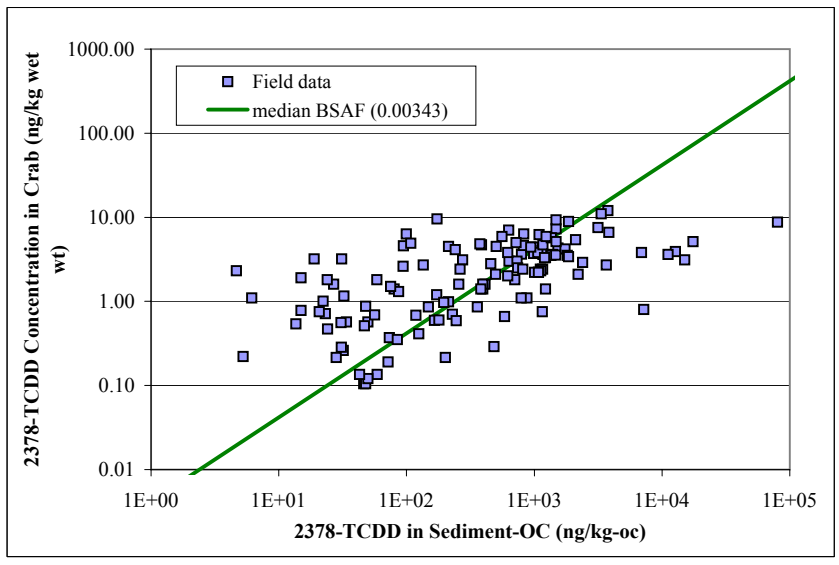
The relationship is not statistically significant

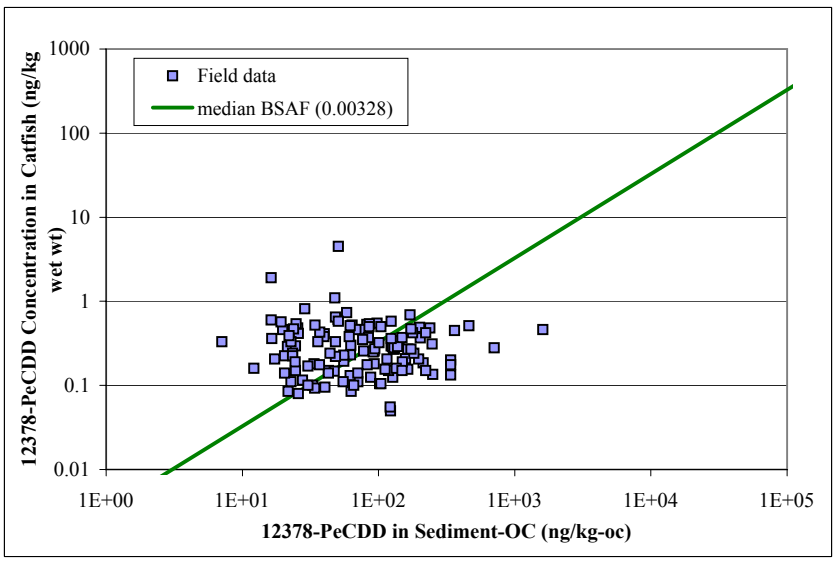
Table 4.7b Estimated Biota to Sediment Accumulation Factors for HSC Crabs

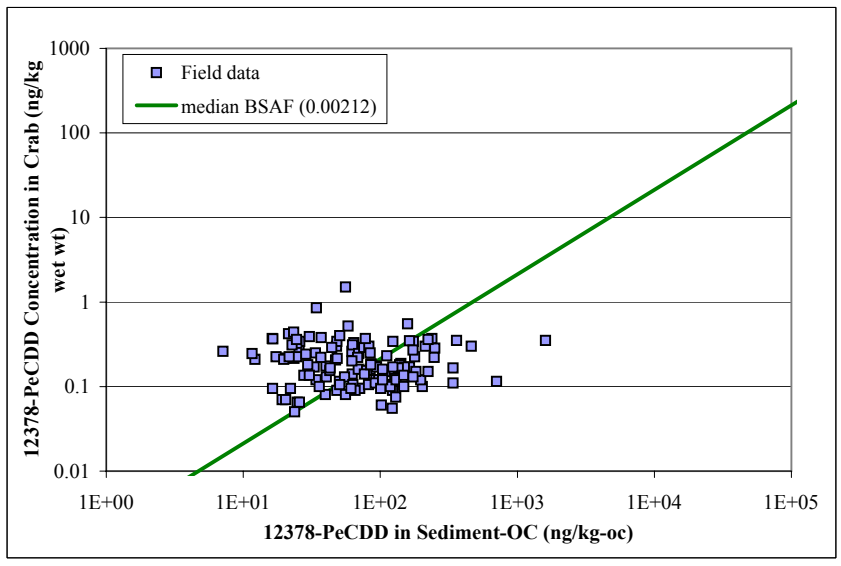
Congener	Method	Regression		Slope	
		SE	Significance F	Estimated BAF	*p*-value
2378-TCDD	Robust LTS	1.0	212.750	0.0023±0.00031	4.29E-27
12378-PeCDD	Robust LTS	0.1	0.220	0.00005±0.00021	0.6399
123478-HxCDD	Robust LTS	0.0	1.618	0.00005±0.00007	0.2061
123678-HxCDD	Iterative WLS	0.1	5.281	0.0001±0.00007	0.0233
123789-HxCDD	Robust LTS	0.1	1.875	0.00004±0.00006	0.1737
1234678-HpCDD	Robust LTS	0.3	4.003	0.00001±0.00001	0.0478
OCDD	Robust LTS	1.6	1.516	1.16E-06±1.87E-06	0.2208
2378-TCDF	Robust LTS	2.6	106.818	0.00166±0.00032	6.629E-18
12378-PeCDF	Robust LTS	0.1	144.845	0.00009±0.00002	1.504E-21
23478-PeCDF	Robust LTS	0.2	102.920	0.00014±0.00003	1.815E-17
123478-HxCDF	Robust LTS	0.1	179.169	0.00003±0	1.613E-24
123678-HxCDF	Robust LTS	0.1	11.470	0.00003±0.00002	0.0010
234678-HxCDF	Robust LTS	0.1	72.306	0.00015±0.00004	9.631E-14
123789-HxCDF	Iterative WLS	0.2	2.449	0.00003±0.00004	0.1202
1234678-HpCDF	Robust LTS	0.2	58.975	0.00001±0	8.369E-12
1234789-HpCDF	Robust LTS	0.1	3.148	0.00002±0.00002	0.0789
OCDF	Iterative WLS	11.2	11.970	0.00001±0.00001	0.0008

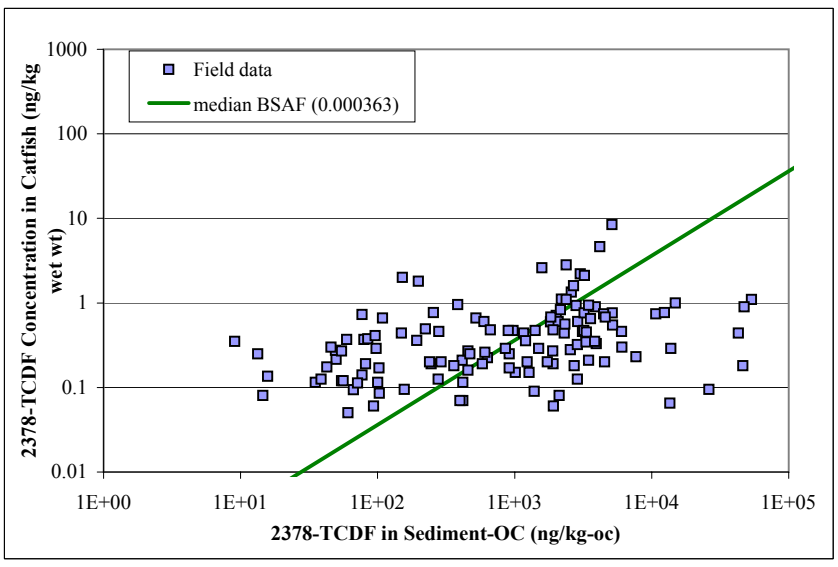
The relationship is not statistically significant

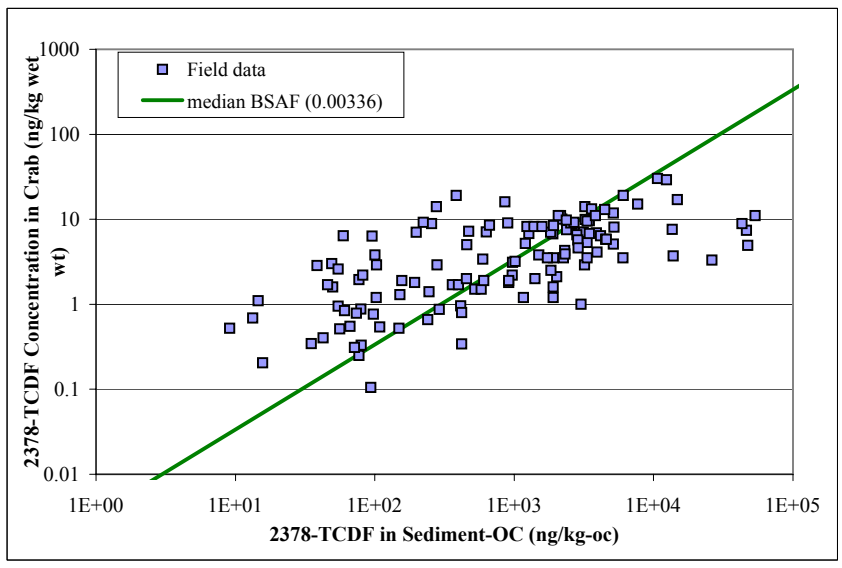


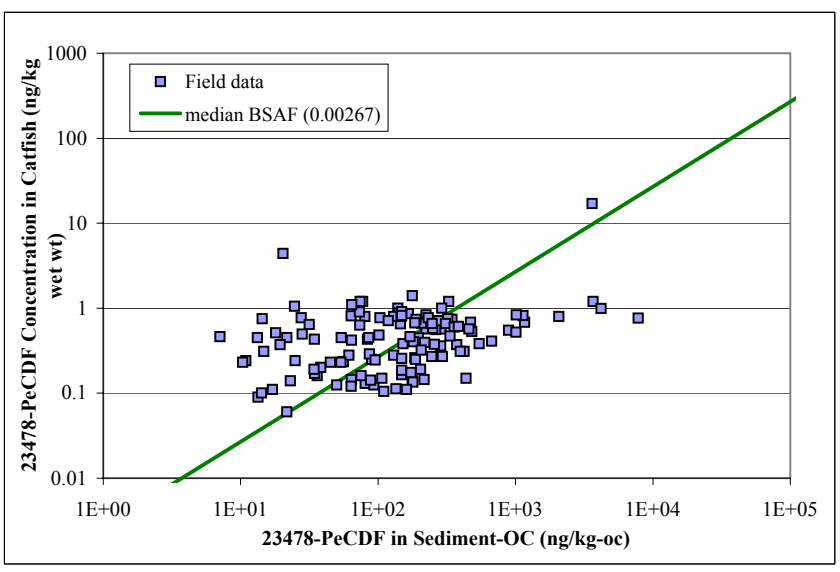












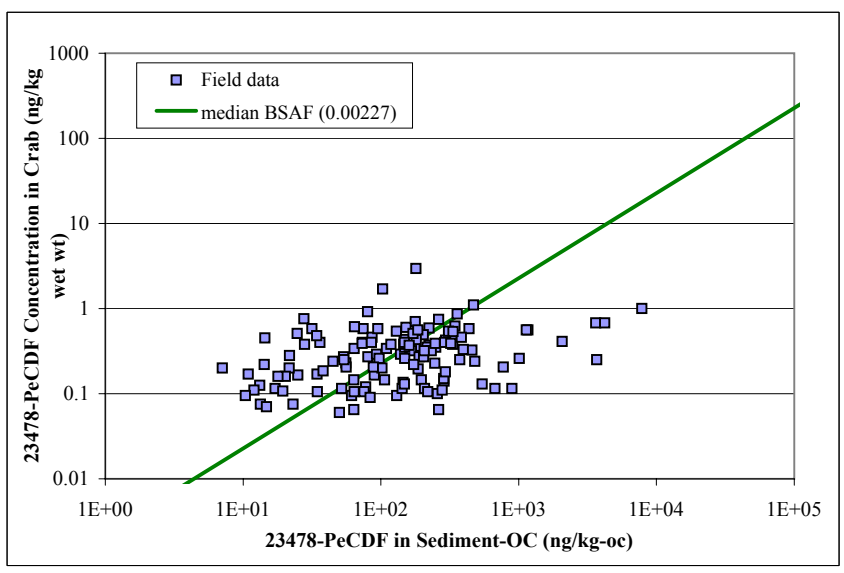


Figure 4.24 Line Fit Plots of BSAF for Selected Congeners in Tissue from the HSC

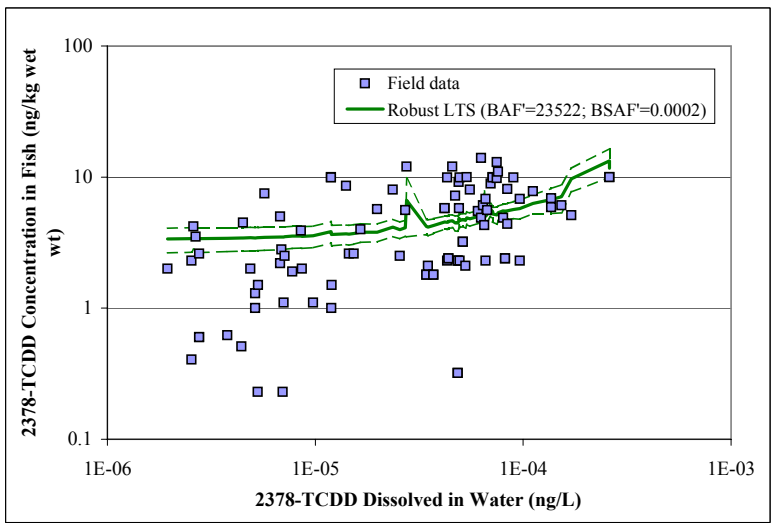
concentrations are at equilibrium, in which case sediment concentrations are related to the dissolved concentrations by an isotherm (linear or non-linear). For the HSC, it is unclear if the equilibrium assumption is valid, since the correlation between dissolved and bed sediment concentrations is rather poor.

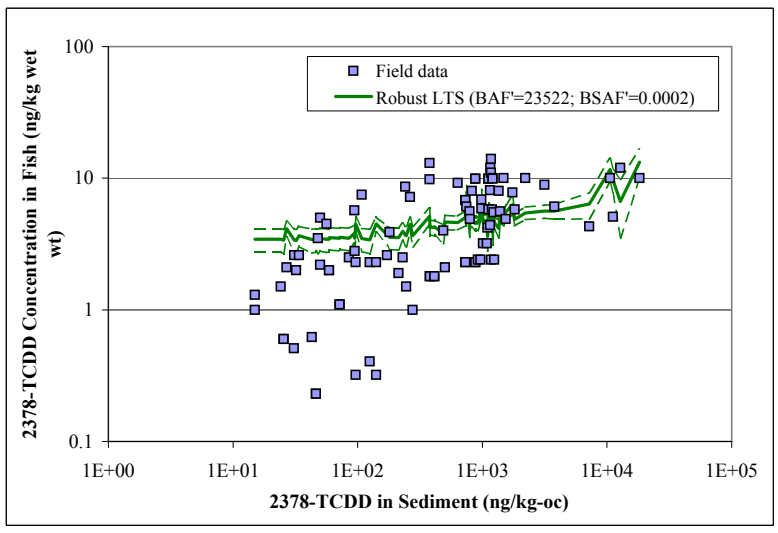
Estimating BAFs and BSAFs independently using water-tissue and sediment-tissue data, respectively may overestimate their values. Thus, an alternative method that uses a combination of the two factors was used to account for all routes of exposure and eliminate overlapping effects. This method consists of multiple linear regressions among dissolved, organic carbon-normalized sediment, and tissue concentrations. It is noted, however, that a multiple regression assumes that the independent variables (dissolved and organic carbon-normalized sediment) are not correlated and that assumption is not completely valid for the HSC. The best-fit line equations will be of the form:

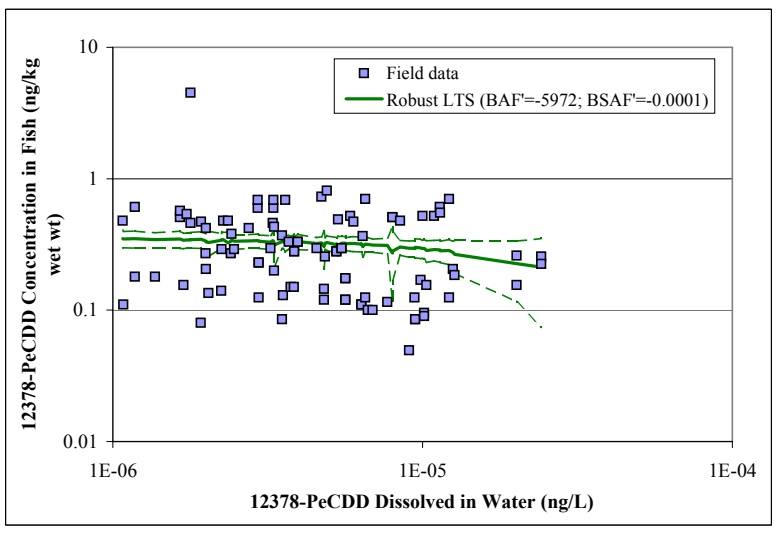
$$C_b = b0 + BAF' * C_{w,diss} + BSAF' * C_{soc} \quad (4.5)$$

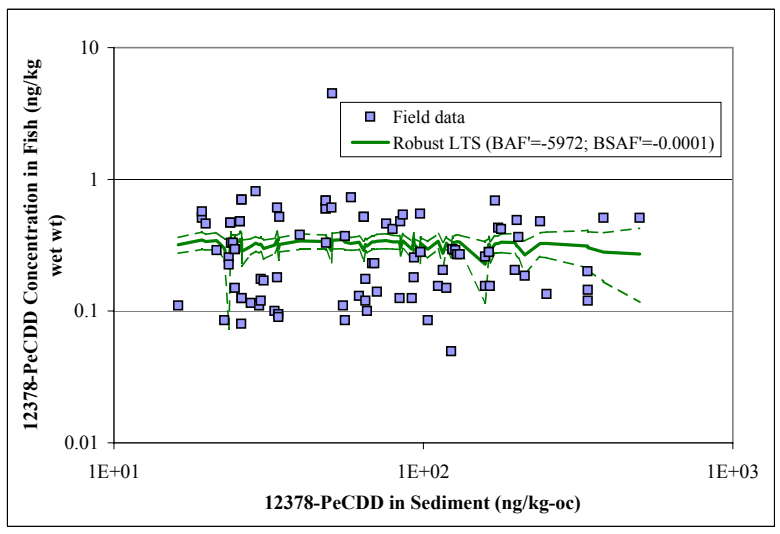
where *b0* is a coefficient and BAF' and BSAF' are the factors calculated using both water and sediment-oc data. A prime notation is used to differentiate between the independently calculated-factors and the combined factors. The robust LTS regression method was used to minimize the effect of outliers. Figures 4.25 and 4.26 show the results of the multiple regressions for the congeners that contribute more than 1.5% to the TEQ in catfish and crabs[7]. Table 4.8 summarizes the test statistics for each regression. The resulting BAF's were lower than their respective BAFs calculated in Section 4.1.1.2, with the exception of 123678-HxCDF in catfish. The estimated

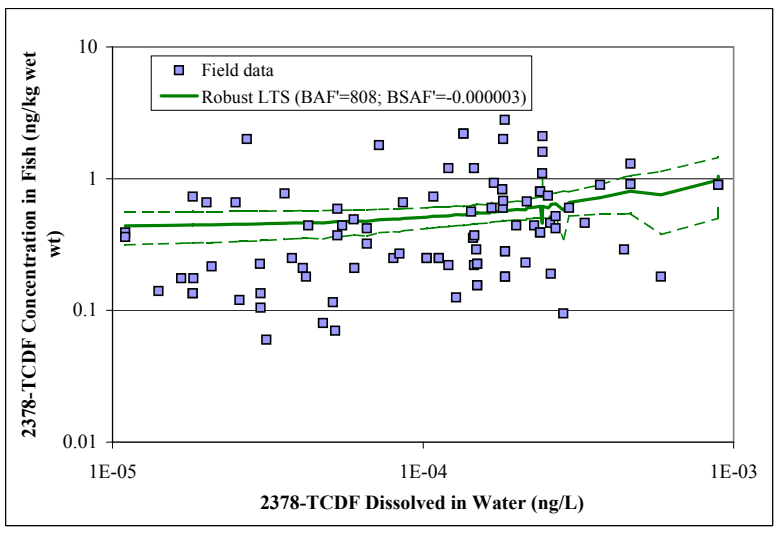
[7] 2378-TCDD, 12378-PeCDD, 2378-TCDF, 23478-PeCDF, and 123678-HxCDF for catfish and 2378-TCDD, 12378-PecDD, 2378-TCDF, and 23478-PeCDF for crabs.

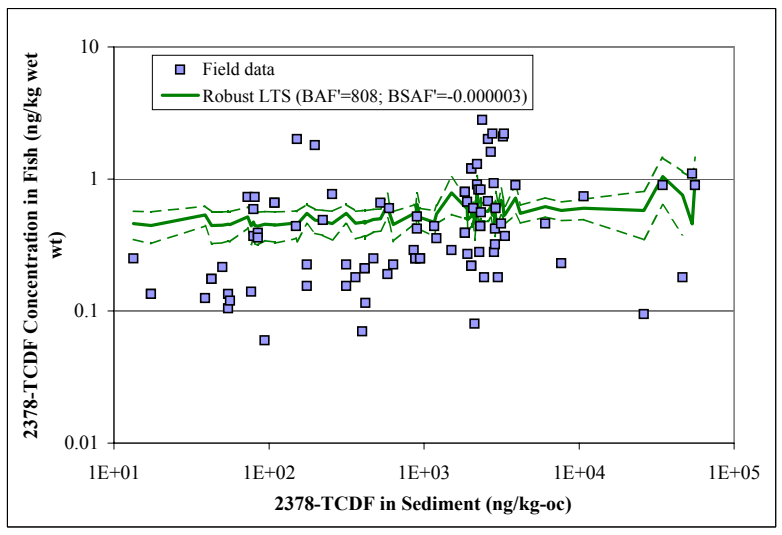


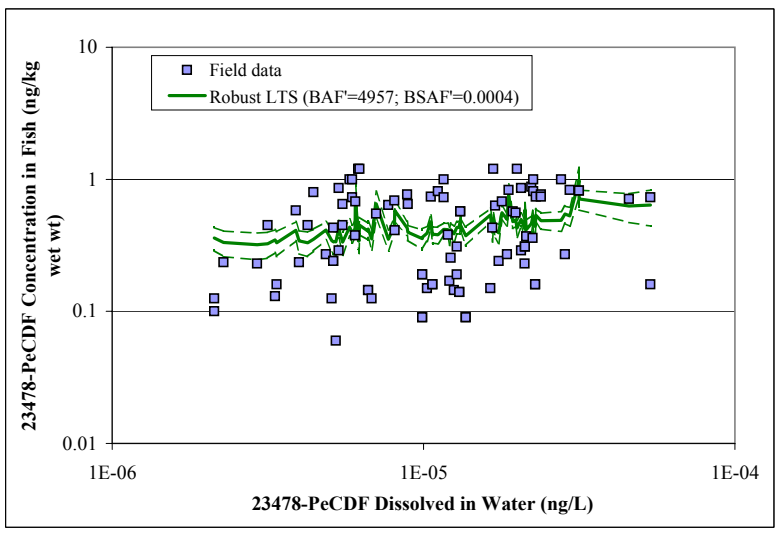


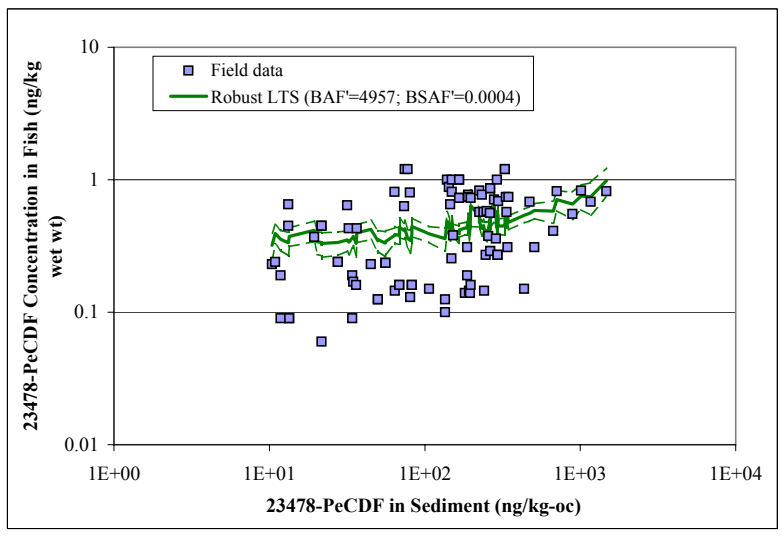


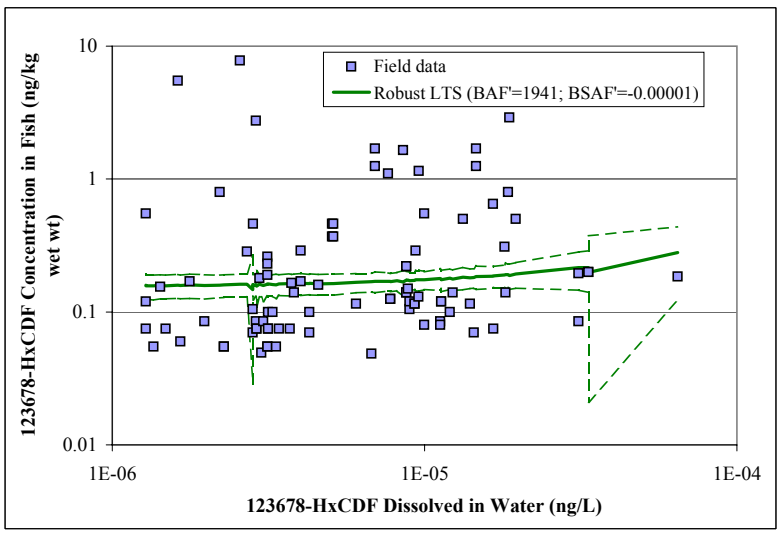


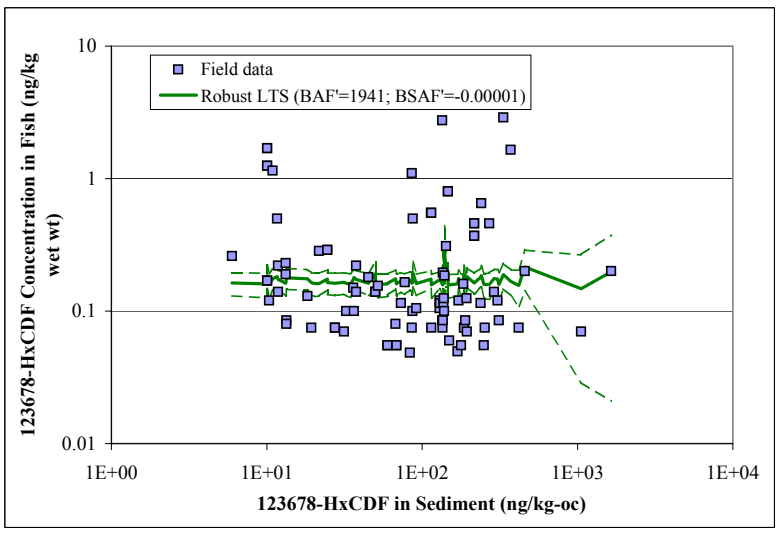






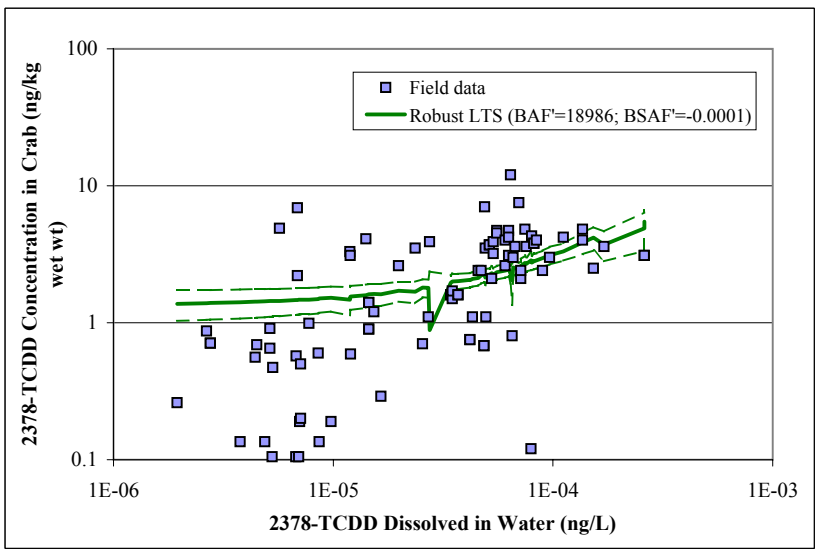


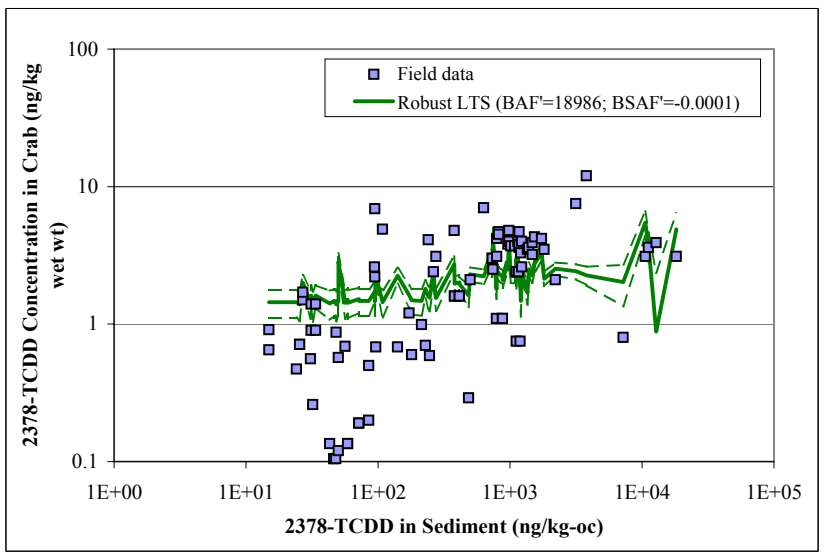


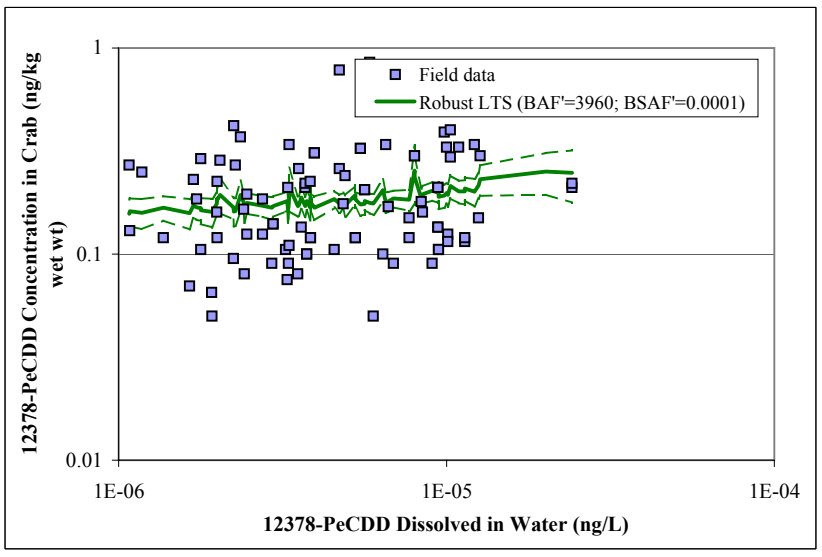


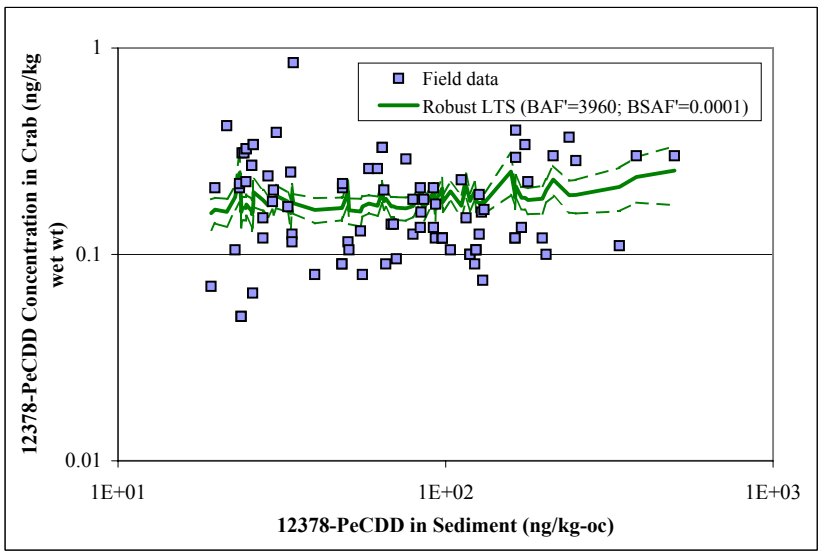
Dashed lines correspond to the 95% confidence intervals

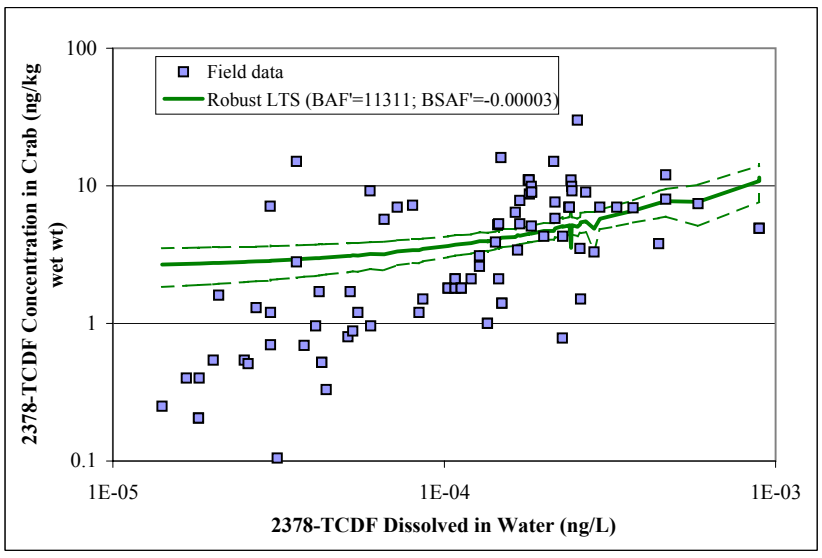
Figure 4.25 Line Fit Plots of Multiple Regressions for Selected Congeners in Catfish from the HSC

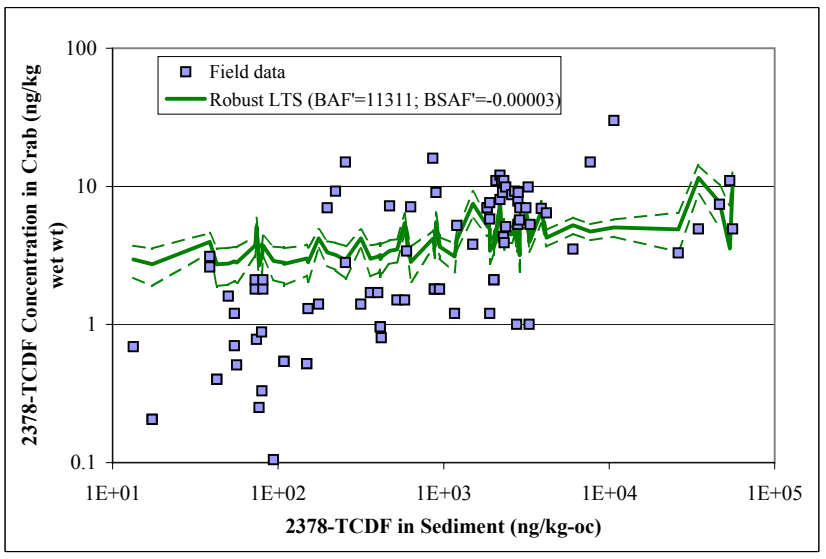


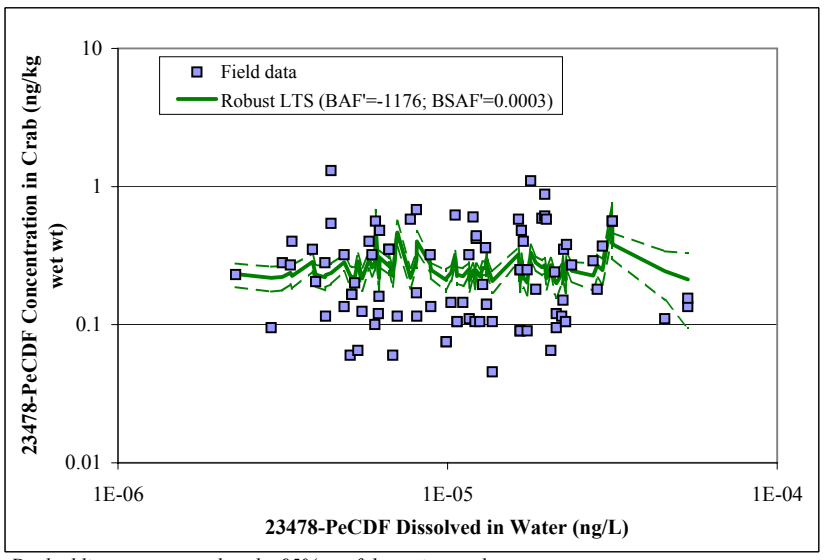


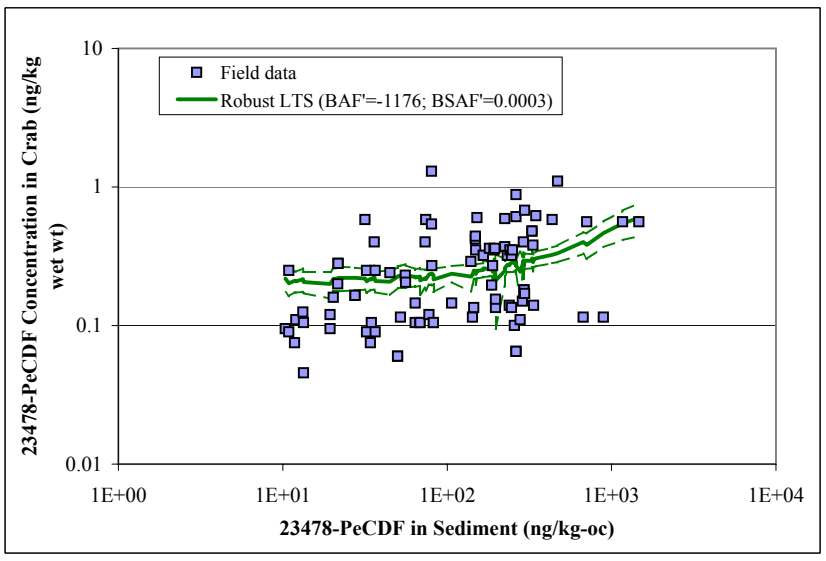












Dashed lines correspond to the 95% confidence intervals

Figure 4.26 Line Fit Plots of Multiple Regressions for Selected Congeners in Crabs from the HSC

Table 4.8a Estimated Combined Bioaccumulation and Biota to Sediment Accumulation Factors for HSC Catfish

Congener	Method	Regression		b0		b1		b2	
		SE	Significance F	Intercept	*p* -value	Estimated BAF'	*p* -value	Estimated BSAF'	*p* -value
2378-TCDD	Robust LTS	3.1	12.460	3.316	5.3E-11	23522±17355	0.0084	0.00021±0.0003	0.1705
12378-PeCDD	Robust LTS	0.2	1.018	0.359	5.3E-15	N/A[1]	0.1707	N/A[1]	0.7261
2378-TCDF	Robust LTS	0.5	2.194	0.430	2.6E-07	808±891	0.0748	N/A[1]	0.6597
23478-PeCDF	Robust LTS	0.3	7.740	0.302	4.1E-08	4957±5640	0.0842	0.00036±0.00023	0.0033
123678-HxCDF	Robust LTS	0.1	0.680	0.157	3.1E-10	1941±3336	0.2501	N/A[1]	0.8478

[1] The slope of the best-fit regression is negative

The relationship is not statistically significant

Table 4.8b Estimated Combined Bioaccumulation and Biota to Sediment Accumulation Factors for HSC Crabs

Congener	Method	Regression		b0		b1		b2	
		SE	Significance F	Intercept	*p* -value	Estimated BAF'	*p* -value	Estimated BSAF'	*p* -value
2378-TCDD	Robust LTS	1.4	14.030	1.342	9.9E-09	18986±8276	9.9912E-09	N/A[1]	0.2855
12378-PeCDD	Robust LTS	0.1	2.281	0.149	3.9E-11	3960±4417	0.0782	0.00015±0.00023	0.2055
2378-TCDF	Robust LTS	3.3	9.993	2.523	9.3E-06	11311±6621	0.0004	N/A[1]	0.5070
23478-PeCDF	Robust LTS	0.2	7.270	0.219	3.3E-10	N/A[1]	0.4982	0.00028±0.00015	0.0003

[1] The slope of the best-fit regression is negative

The relationship is not statistically significant

BSAF's for catfish were lower than the BSAF calculated in Section 4.1.2.2, while BSAF's for 12378-PeCDD and 23478-PeCDF in crabs were higher than their respective BSAFs. Note that in some cases, the best-fit line coefficients were negative (e.g., 12378-PeCDD in catfish). This was interpreted as a lack of bioaccumulation of the congener in biota from the HSC.

4.1.4 Texas Statewide Water Quality Criterion

Texas Surface Water Quality Standards (30 TAC §307.1-307.7) include a human health water quality criterion for dioxins/furans of 9.33×10^{-8} µg/L water (0.0933 pg/L), based on saltwater fish consumption. This criterion is based on 2378-tetrachloro-dibenzo-*p*-dioxin (TCDD) equivalent concentrations (TEQs) for the following congeners that are the toxic forms regulated by the Texas Commission on Environmental Quality (TCEQ):

Table 4.9 Toxicity Equivalent Factors (TEFs)

Congener/Isomer	TEF
2,3,7,8 TCDD	1
1,2,3,7,8 PeCDD	0.5
2,3,7,8 HxCDDs	0.1
2,3,7,8 TCDF	0.1
1,2,3,7,8 PeCDF	0.05
2,3,4,7,8 PeCDF	0.5
2,3,7,8 HxCDFs	0.1

The dioxins/furans human health water quality criterion was calculated by the TCEQ from the following equation and risk-based assumptions:

$$(RL \times BW) / (CSF \times CR \times BAF) \quad (4.6)$$

where: RL = risk level = 10^{-5} or 1 in 100,000

BW = adult body weight = 70 kg

CSF = cancer slope factor = 10^5 kg-day/mg

CR = consumption rate of fish/shellfish = 0.015 kg/day

BAF = bioaccumulation factor for dioxins = 5000 L/kg

The human health criterion for dioxins in water is then:

(10^{-5} x70 kg)/(10^5 kg-day/mg x 0.015 kg/day x 5000 L/kg) = ***$9.33x10^{-11}$ mg/L****, or* ***0.0933 pg/L***

This criterion applies to the total dioxin concentration in water, including the suspended particulate plus dissolved fractions.

As stated previously, TMDLs are required for water bodies not meeting water quality standards. It is worth noting that the water bodies addressed by this project were not found to exceed this water quality standard, but instead were not expected to meet the water quality standard because high levels of dioxins were found in fish and crab tissue by the Texas Department of Health. Results of water sampling undertaken in this project, however, confirm that the water quality standard is indeed not met in many of the water bodies.

There are several inherent problems with using this human health water quality criterion as a water quality target for a TMDL. First, it is difficult to measure 0.0933 picograms per liter in ambient water, and it requires complex and expensive sampling equipment. Thus, it is difficult and expensive to evaluate compliance with this criterion. Also, some assumptions used to derive this water-based criterion, such as the BAF, are questionable. The applicability of the BAF of 5,000 L/kg used by the TCEQ in calculating this criterion was not known, and the USEPA recommends determination of site-specific field-measured bioaccumulation relationships

(Sections 4.1.1 and 4.1.2). Thus, a waterbody meeting the TCEQ human health water quality criterion for dioxins/furans in water does not necessarily guarantee that fish and shellfish tissue concentration levels will be safe for human consumption.

The primary advantage of using a water concentration as the water quality target for the TMDL is that it is facilitates calculations of loadings and permit limits. Water quality targets based on tissue or sediment concentrations offer other advantages. For example, it is easier and less expensive to sample and analyze concentrations in tissue and sediment to evaluate compliance.

The following sections are focused on using the data from this project for developing a WQ target that is based on a site-specific bioaccumulation factor as well as a sediment-based WQ target.

4.1.5 Tissue Residue Criterion

The fish or shellfish tissue residue criterion (TRC) is the target concentration in tissue considered acceptable for saltwater fish consumption and is calculated using the following equation and the TCEQ risk management assumptions:

$$TRC = RL \times BW / CSF \times CR \qquad (4.7)$$

Note that Equation (4.7) is identical to Equation (4.6) except that it leaves out the BAF, which translates the tissue concentration to a water concentration. Thus, the target concentration for dioxins (TEQ) in fish or crab tissue based on TCEQ assumptions is:

$(10^{-5} \times 70\ kg)/(10^{5}\ kg\text{-}day/mg \times 0.015\ kg/day) = 4.7 \times 10^{-7}\ mg/kg = 0.47\ ng/kg$

4.1.6 Water Quality Target Calculations for Dissolved PCDD/Fs in Water

The water quality targets for dissolved PCDD/Fs can be calculated from the TRC and the BAF from the following relationship:

$$C_{w,d} = \frac{TRC}{BAF} \tag{4.8}$$

While the tissue residue criterion is based on TEQ, a composite measure of toxic contributions from twelve dioxin and furan congeners, each of the congeners contributing to the dioxin TEQ has different physical and chemical properties and different bioaccumulation potentials. Given that the BAFs of the various congeners vary so widely, use of a composite BAF for dioxin TEQ seemed inappropriate. Thus, water quality targets for each of the major congeners contributing to the total equivalent concentration are desirable. However, no formal guidelines exist on developing targets for mixtures of compounds that contribute to an exceedance of a WQ criterion.

The fraction of the total TEQ attributable to a given congener f_i^{TEQ} can be calculated as:

$$f_i^{TEQ} = \frac{C_i * BAF_i * TEF_i}{\sum_{i=1}^{17} C_i * BAF_i * TEF_i} \tag{4.9}$$

Then the water quality target for a given congener can be calculated as:

$$C_{w,d} = \frac{TRC * f_i^{TEQ}}{BAF_i * TEF_i} \tag{4.10}$$

In this way, each congener was assigned a water quality target concentration that corresponded to their average fraction of the total TEQ in catfish and crab tissue in the system[8].

[8] For instance, if 2378-TCDD had contributed, on average, 80% of the TEQ in catfish, and 23478-PeCDD had

These congener-specific targets calculated for all congeners were summed to calculate the water quality target for dioxin TEQ. Note that only the targets for congeners contributing, on average, more than 2% of the TEQ (2378-TCDD, 12378-PeCDD, 2378-TCDF, 23478-PeCDF) were used to calculate exceedance rates in Section 4.1.9 below.

Site-specific water quality targets for dissolved PCDD/Fs in the HSC system calculated from the measured BAFs using Equation (4.10) and the average log BAF (Section 4.1.1.3) for all the data collected for this TMDL project are shown in Table 4.10. Because log BAFs exhibited a normal distribution, the average log BAF for each congener measured in the HSC system was used. The calculated water quality targets were lower for catfish than crabs for most congeners, and the lower target for the two species was selected as the overall water quality target. Typically, 2378-TCDD comprised half or more of the TEQ in all media. The water quality target for dissolved 2378-TCDD was calculated to be 0.0024 pg/L. The water quality target for dioxin TEQ dissolved in water was calculated to be 0.0081 pg/L. The 95% confidence limits for the average BAF also were calculated and used to identify the 95% confidence limits around the water quality target.

4.1.7 Water Quality Target Calculations for PCDD/Fs in Water

Since BAFs were calculated from dissolved concentrations, it is necessary to estimate partitioning relationships to calculate targets that would apply to total water concentrations (dissolved + suspended). Aquatic sediments take up PCDD/Fs just as aquatic animals do, and PCDD/Fs associated with suspended sediments typically exceed those dissolved in a given water sample. Partitioning between the suspended and dissolved phases can be quantitatively

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contributed 20%, the WQ target for 2378-TCDD would be calculated from a catfish TEQ of 0.47 * 80% = 0.376 ng/kg TEQ_{tcdd}, or 0.376 ng/kg TCDD, and the WQ target for 23478-PeCDD would be 0.47 * 20% = 0.094 ng/kg TEQ_{tcdd}, or 0.188 ng/kg PeCDD (TEF=0.5).

Table 4.10a Summary of BAFs and the Resulting Water Quality Targets for Catfish in the HSC

Congener	Texas TEF	log BAF (L/kg)			Average contribution to TEQ[a]	Water Quality Target - Diss (pg/L)			Dissolved-Suspended Isotherm		Water Quality Target - Total (pg/L)		
		BAF	LCL95	UCL95		Value using avg log BAF	LCL95	UCL95	log k	1/n	Value using avg log BAF	LCL95	UCL95
2378-TCDD	1	5.19	5.10	5.27	80.3%	0.0024	0.0020	0.0030	5.16	1.001	0.011	0.010	0.014
12378-PeCDD	0.5	4.78	4.70	4.86	4.5%	0.0007	0.0006	0.0008	2.96	0.057	0.016	0.016	0.017
123478-HxCDD	0.1	4.40	4.32	4.48	0.6%	0.0011	0.0009	0.0013	3.34	0.076	0.035	0.035	0.036
123678-HxCDD	0.1	4.57	4.49	4.66	1.4%	0.0018	0.0014	0.0021	3.54	-0.004	0.094	0.094	0.094
123789-HxCDD	0.1	4.15	4.06	4.24	0.8%	0.0026	0.0021	0.0032	3.58	0.000	0.101	0.101	0.102
1234678-HpCDD		3.46	3.38	3.55	0.0%				5.12	-0.071			
OCDD		2.63	2.55	2.72	0.0%				6.50	0.109			
2378-TCDF	0.1	3.49	3.41	3.58	2.1%	0.0319	0.0260	0.0384	5.08	1.065	0.112	0.090	0.136
12378-PeCDF	0.05	4.34	4.24	4.43	0.4%	0.0017	0.0014	0.0022	4.74	0.786	0.011	0.010	0.014
23478-PeCDF	0.5	4.60	4.53	4.67	6.5%	0.0015	0.0013	0.0018	4.38	0.662	0.010	0.009	0.011
123478-HxCDF	0.1	4.01	3.90	4.11	0.6%	0.0029	0.0023	0.0037	4.21	0.372	0.051	0.047	0.057
123678-HxCDF	0.1	4.45	4.34	4.55	1.4%	0.0023	0.0019	0.0030	4.00	0.377	0.029	0.026	0.032
234678-HxCDF	0.1	4.35	4.26	4.44	0.6%	0.0013	0.0010	0.0016	3.73	0.308	0.019	0.018	0.021
123789-HxCDF	0.1	4.62	4.54	4.70	0.7%	0.0008	0.0007	0.0010	4.81	0.932	0.003	0.003	0.004
1234678-HpCDF		3.89	3.78	3.99	0.0%				4.57	0.270			
1234789-HpCDF		4.44	4.35	4.53	0.0%				4.19	0.480			
OCDF		3.77	3.62	3.91	0.0%				5.52	0.646			
Σ TEQ$_{\text{major congeners in catfish}}$					93.4%	0.0067	0.0056	0.0082			0.036	0.031	0.042
Total TEQ[b]						0.0081	0.0067	0.0099			0.070	0.064	0.077

[a] Average contribution of each congener to TEQ in catfish

[b] Σ TEQ$_{\text{all congeners}}$ (Σ Target$_i$*TEF$_i$)

Water quality targets in blue indicate values for congeners contributing less than 2% to the total TEQ

LCL95 = lower confidence level (α=0.05)

UCL95 = upper confidence level (α=0.05)

Bioaccumulation factors were calculated using data for all the events conducted during this TMDL study

Table 4.10b Summary of BAFs and the Resulting Water Quality Targets for Crabs in the HSC

Congener	Texas TEF	log BAF (L/kg)			Average contribution to TEQ[a]	Water Quality Target - Diss (pg/L)			Dissolved-Suspended Isotherm		Water Quality Target - Total (pg/L)		
		BAF	LCL95	UCL95		Value using avg log BAF	LCL95	UCL95	log k	1/n	Value using avg log BAF	LCL95	UCL95
2378-TCDD	1	4.84	4.76	4.93	68.0%	0.0046	0.0038	0.0056	4.91	0.867	0.025	0.020	0.029
12378-PeCDD	0.5	4.61	4.55	4.67	5.3%	0.0012	0.0011	0.0014	2.69	-0.038	0.018	0.017	0.018
123478-HxCDD	0.1	4.24	4.17	4.31	0.7%	0.0019	0.0016	0.0022	3.26	0.073	0.032	0.031	0.033
123678-HxCDD	0.1	4.17	4.09	4.25	1.1%	0.0035	0.0029	0.0042	3.37	-0.043	0.081	0.081	0.081
123789-HxCDD	0.1	3.97	3.89	4.05	0.9%	0.0045	0.0038	0.0054	3.75	0.049	0.116	0.114	0.118
1234678-HpCDD		3.27	3.19	3.36	0.0%				5.10	0.013			
OCDD		2.72	2.62	2.81	0.0%				6.37	0.183			
2378-TCDF	0.1	4.47	4.39	4.55	13.0%	0.0207	0.0172	0.0249	4.85	0.860	0.087	0.087	0.087
12378-PeCDF	0.05	4.39	4.32	4.46	0.5%	0.0019	0.0016	0.0022	3.92	0.435	0.016	0.015	0.018
23478-PeCDF	0.5	4.43	4.35	4.50	6.8%	0.0024	0.0020	0.0029	3.94	0.481	0.015	0.015	0.015
123478-HxCDF	0.1	4.13	4.03	4.22	1.0%	0.0035	0.0028	0.0044	3.93	0.266	0.053	0.050	0.057
123678-HxCDF	0.1	4.29	4.22	4.37	0.8%	0.0019	0.0016	0.0023	3.64	0.273	0.023	0.021	0.024
234678-HxCDF	0.1	4.32	4.25	4.38	0.8%	0.0018	0.0016	0.0021	3.54	0.254	0.020	0.019	0.021
123789-HxCDF	0.1	4.59	4.52	4.66	1.1%	0.0013	0.0011	0.0016	4.32	0.764	0.005	0.004	0.005
1234678-HpCDF		3.95	3.85	4.05	0.0%				4.41	0.175			
1234789-HpCDF		4.39	4.31	4.48	0.0%				3.62	0.266			
OCDF		3.82	3.68	3.96	0.0%				5.35	0.546			
Σ TEQ$_{\text{major congeners in crabs}}$					93.1%	0.0085	0.0070	0.0102			0.049	0.045	0.054
Total TEQ[b]						0.0104	0.0086	0.0125			0.083	0.078	0.089

[a] Average contribution of each congener to TEQ in crab

[b] Σ TEQ$_{\text{all congeners}}$ (Σ Target$_i$*TEF$_i$)

Water quality targets in blue indicate values for congeners contributing less than 2% to the total TEQ

LCL95 = lower confidence level (α=0.05)

UCL95 = upper confidence level (α=0.05)

Bioaccumulation factors were calculated using data for all the events conducted during this TMDL study

characterized by the linear partitioning coefficient (K_p) or by the partitioning constants derived either from the Freundlich or Langmuir sorption equations (Mansour 1993).

The partition coefficient, K_p, describes the ratio of a chemical's concentration in sediment and water at steady-state equilibrium conditions.

$$C_s = K_p * C_{w,d} \tag{4.11}$$

where C_s is the concentration of the chemical in the solid phase, in pg/kg, and $C_{w,d}$ is the dissolved concentration in water, in pg/L. It was noted, however, that the linear partitioning coefficient did not fit the observed HSC data for many congeners (Figure 4.27). Thus, log-transformed data were used to estimate suspended-dissolved partitioning. This is equivalent to using the Freundlich isotherm:

$$C_s = K * C_{w,d}^{1/n} \tag{4.12}$$

where K is the adsorption constant and $1/n$ is another constant providing a rough estimate of the intensity of adsorption (Mansour 1993). The linear partitioning approach is equivalent to the Freundlich isotherm with an exponent ($1/n$) of 1. Congener-specific partitioning constants for the HSC are summarized in Table 4.11.

Water quality targets for total water concentrations (dissolved + suspended) were calculated assuming the average measured suspended particulate matter concentration in the HSC system of 26 mg/L and Equation (4.13):

$$C_{w,total} = C_{w,d} + K * C_{w,d}^{1/n} * [SPM] \tag{4.13}$$

where $C_{w,total}$ is the water quality target concentration for whole water samples, $C_{w,d}$ is the water quality target for dissolved concentrations in water, and [SPM] is the concentration of suspended particulate matter. Site-specific water quality targets for PCDD/Fs in water samples from the

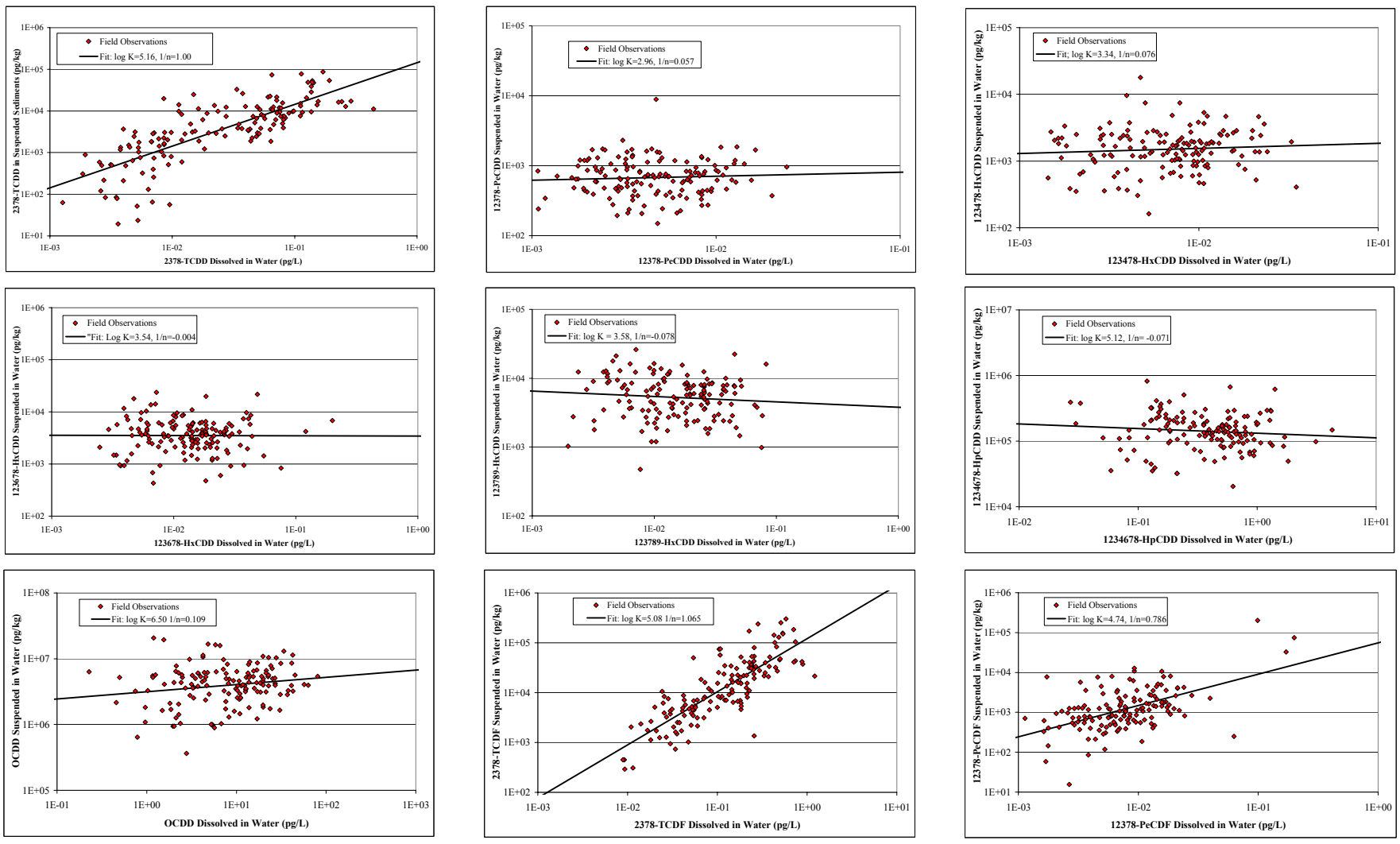


Figure 4.27 Partitioning of Dioxins between Suspended and Dissolved Phases

Table 4.11 Summary of Suspended-Dissolved Partitioning

Congener	r^2	F-statistic	p-value	log K			1/n		
				Value	SE	t-value[a]	Value	SE	t-value[a]
2378-TCDD	0.614	231.99	5.82E-32	5.16	0.11	45.32	1.001	0.07	15.23
12378-PeCDD	0.003	0.50	4.82E-01	2.96	0.19	15.53	0.057	0.08	0.70
123478-HxCDD	0.006	0.84	3.61E-01	3.34	0.18	18.26	0.076	0.08	0.92
123678-HxCDD	0.000	0.00	9.57E-01	3.54	0.16	22.81	-0.004	0.08	-0.05
123789-HxCDD	0.008	1.23	2.69E-01	3.58	0.13	27.22	-0.078	0.07	-1.11
1234678-HpCDD	0.010	1.53	2.18E-01	5.12	0.03	151.38	-0.071	0.06	-1.24
OCDD	0.031	4.63	3.30E-02	6.50	0.05	127.45	0.109	0.05	2.15
2378-TCDF	0.674	301.64	2.42E-37	5.08	0.07	77.55	1.065	0.06	17.37
12378-PeCDF	0.288	58.99	2.11E-12	4.74	0.22	21.61	0.786	0.10	7.68
23478-PeCDF	0.190	34.34	2.95E-08	4.38	0.23	19.09	0.662	0.11	5.86
123478-HxCDF	0.119	19.73	1.75E-05	4.21	0.17	25.08	0.372	0.08	4.44
123678-HxCDF	0.095	15.26	1.43E-04	4.00	0.22	18.53	0.377	0.10	3.91
234678-HxCDF	0.085	13.58	3.22E-04	3.73	0.19	19.41	0.308	0.08	3.68
123789-HxCDF	0.376	87.87	1.23E-16	4.81	0.25	19.29	0.932	0.10	9.37
1234678-HpCDF	0.071	11.14	1.07E-03	4.57	0.13	35.19	0.270	0.08	3.34
1234789-HpCDF	0.133	22.47	5.01E-06	4.19	0.23	18.25	0.480	0.10	4.74
OCDF	0.387	92.00	3.37E-17	5.52	0.06	87.61	0.646	0.07	9.59

[a] If |t-value|>2, the linear relationship is statistically significant at a=0.05.

The relationship is not statistically significant

SE = standard error

Partitioning coefficients were calculated using all the data collected under this TMDL project

HSC system are shown in Table 4.10. The water quality target for 2378-TCDD in water was calculated to be 0.011 pg/L, and the water quality target for dioxin TEQ in water was calculated to be 0.070 pg/L. These targets are several times higher than for dissolved concentrations, indicating that a large portion of the total dioxin is associated with the suspended particulate phase in water. This calculated target for dioxin TEQ in water is approximately 75% of the state water quality criterion of 0.093 pg/L.

4.1.8 Water Quality Target Calculations for PCDD/Fs in Sediments

The water quality target concentration in sediment can be calculated using the following equation:

$$C_{sed,oc} = \frac{TRC}{BSAF} \tag{4.14}$$

The water quality targets for individual congeners contributing to the composite TEQ concentration can be calculated as:

$$C_{sed,oc} = \frac{TRC * f_i^{TEQ}}{BSAF_i * TEF_i} \tag{4.15}$$

Site-specific sediment quality targets for PCDD/Fs in the HSC system calculated from the measured BSAFs using Equation (4.15) and the entire database collected for this TMDL project are shown in Table 4.12. For BSAFs, which exhibited non-normality, the median BSAF was selected as the most appropriate measure of the typical BSAF for each congener. Also note that this target is based on the organic carbon-normalized sediment concentration, calculated as the bulk sediment concentration divided by its organic carbon content. The calculated targets were lower for fish than crabs for most congeners, and the lower target for the two species was selected as the overall water quality target. Typically, 2378-TCDD comprised half or more of the TEQ

Table 4.12a Summary of BSAFs and the Resulting Water Quality Targets for Catfish in the HSC

Congener	Texas TEF	BSAF			Average contribution to TEQ[b]	Sediment-based Quality Target (ng/kg-oc)		
		Median BSAF	LCL95[a]	UCL95[a]		Value using median BSAF	LCL95	UCL95
2378-TCDD	1	8.88E-03	6.29E-03	1.23E-02	80.3%	43	31	60
12378-PeCDD	0.5	3.28E-03	2.71E-03	4.68E-03	4.5%	13	9	16
123478-HxCDD	0.1	1.01E-03	8.30E-04	1.41E-03	0.6%	28	20	34
123678-HxCDD	0.1	1.57E-03	1.25E-03	1.81E-03	1.4%	42	36	53
123789-HxCDD	0.1	7.70E-04	5.60E-04	9.50E-04	0.8%	48	39	66
1234678-HpCDD		1.10E-04	1.00E-04	1.30E-04	0.0%			
OCDD		1.40E-05	1.10E-05	1.80E-05	0.0%			
2378-TCDF	0.1	3.63E-04	2.74E-04	5.21E-04	2.1%	272	189	360
12378-PeCDF	0.05	1.72E-03	1.35E-03	2.40E-03	0.4%	22	16	28
23478-PeCDF	0.5	2.67E-03	2.22E-03	3.90E-03	6.5%	23	16	28
123478-HxCDF	0.1	5.44E-04	3.73E-04	6.23E-04	0.6%	54	47	79
123678-HxCDF	0.1	1.57E-03	1.00E-03	2.34E-03	1.4%	42	28	66
234678-HxCDF	0.1	9.60E-04	8.20E-04	1.23E-03	0.6%	30	23	35
123789-HxCDF	0.1	2.14E-03	1.80E-03	3.59E-03	0.7%	16	10	19
1234678-HpCDF		1.51E-04	1.27E-04	1.90E-04	0.0%			
1234789-HpCDF		1.14E-03	8.68E-04	1.54E-03	0.0%			
OCDF		1.62E-04	8.38E-05	2.33E-04	0.0%			
Σ $TEQ_{major\ congeners\ in\ catfish}$					93.4%	88	62	118
Total TEQ_{soc}[c]						115	83	154

[a] LCL95 = lower confidence level (α=0.05)
UCL95 = upper confidence level (α=0.05)

[b] Average contribution of each congener to TEQ in catfish

[c] Σ $TEQ_{all\ congeners}$ (Σ $Target_i$*TEF_i)

Sediment-based quality targets in blue indicate values for congeners contributing less than 2% to the total TEQ

Biota-to-sediment accumulation factors were calculated using data for all the events conducted during this TMDL study

Table 4.12b Summary of BSAFs and the Resulting Water Quality Targets for Crabs in the HSC

Congener	Texas TEF	BSAF			Average contribution to TEQ[b]	Sediment-based Quality Target (ng/kg-oc)		
		Median BSAF	LCL95[a]	UCL95[a]		Value using median BSAF	LCL95	UCL95
2378-TCDD	1	4.18E-03	3.43E-03	5.60E-03	68.0%	76	57	93
12378-PeCDD	0.5	2.12E-03	1.82E-03	3.22E-03	5.3%	24	15	27
123478-HxCDD	0.1	7.36E-04	5.90E-04	8.88E-04	0.7%	45	37	56
123678-HxCDD	0.1	6.07E-04	4.55E-04	7.80E-04	1.1%	85	66	114
123789-HxCDD	0.1	4.65E-04	3.64E-04	5.96E-04	0.9%	91	71	116
1234678-HpCDD		6.75E-05	5.90E-05	7.98E-05	0.0%			
OCDD		1.72E-05	1.29E-05	2.27E-05	0.0%			
2378-TCDF	0.1	3.36E-03	2.84E-03	4.35E-03	13.0%	182	140	215
12378-PeCDF	0.05	2.27E-03	1.87E-03	2.94E-03	0.5%	21	16	25
23478-PeCDF	0.5	2.27E-03	1.61E-03	2.84E-03	6.8%	28	23	40
123478-HxCDF	0.1	7.44E-04	6.18E-04	1.06E-03	1.0%	63	44	76
123678-HxCDF	0.1	1.38E-03	8.74E-04	1.73E-03	0.8%	27	22	43
234678-HxCDF	0.1	1.02E-03	8.37E-04	1.34E-03	0.8%	37	28	45
123789-HxCDF	0.1	2.49E-03	1.75E-03	3.28E-03	1.1%	21	16	30
1234678-HpCDF		1.86E-04	1.25E-04	2.31E-04	0.0%			
1234789-HpCDF		1.03E-03	7.71E-04	1.70E-03	0.0%			
OCDF		1.64E-04	1.10E-04	1.97E-04	0.0%			
Σ $TEQ_{major\ congeners\ in\ crabs}$					93.1%	120	90	148
Total TEQ_{soc}[c]						158	119	197

[a] LCL95 = lower confidence level (α=0.05)
UCL95 = upper confidence level (α=0.05)

[b] Average contribution of each congener to TEQ in crabs

[c] Σ $TEQ_{all\ congeners}$ (Σ $Target_i$*TEF_i)

Sediment-based quality targets in blue indicate values for congeners contributing less than 2% to the total TEQ

Biota-to-sediment accumulation factors were calculated using data for all the events conducted during this TMDL study

in all media. The sediment quality target for 2378-TCDD was calculated to be 43 ng/kg oc. The water quality target for dioxin TEQ in sediments was calculated to be 115 ng/kg oc. The 95% confidence limits for the average BSAF also were calculated and used to identify the 95% confidence limits around the water quality target.

4.1.9 Observed Target Exceedance Rates

The water quality targets are summarized in Table 4.13 below.

Table 4.13 Summary of Site-Specific Water Quality Targets in Various Media

Congener	Water – Dissolved pg/L	Water - Total pg/L	Sediment ng/kg-OC
2378-TCDD	0.0024	0.011	43
12378-PeCDD	0.0007	0.016	13
2378-TCDF	0.0207	0.087	182
23478-PeCDF	0.0015	0.010	23
Total TEQ	0.0081	0.070	115

For each congener, the lower target for the two species (catfish or crab) was selected.

Water and sediment data collected in Phases II and III of the project were compared to the estimated media-specific water quality targets to evaluate the current state of impairment of the HSC system, and the concentration reductions required to meet the water quality targets. Table 4.14 summarizes the percent target exceedances by congener for both water and sediment samples. Water quality targets are exceeded in most samples for most congeners, and overall exceedance rates are currently greater than 90%. Note that for many congeners, these exceedance rates may be high, as the exceedance status for nonquantifiable measurements could not be compared to the targets unless the quantitation limit was less than the target. The percent reductions in ambient dioxin levels required to meet the water quality targets in various media are shown in Table 4.15. Overall, it appears that an 85-90% reduction in concentrations, or one order of magnitude, will be required for the water quality targets to be met.

Table 4.14 Summary of Exceedances of the Estimated Water Quality Targets

Congener	Dissolved Water Samples[a]	Total Water Samples[a]	Sediment Samples[a]
Number of samples	*148*	*148*	*173*
2378-TCDD	96% (84)	83% (93)	84% (167)
12378-PeCDD	100% (64)	39% (127)	95% (86)
2378-TCDF	93% (147)	89% (148)	76% (174)
23478-PeCDF	100% (93)	91% (95)	88% (154)
Total TEQ	100% (148)	91% (148)	93% (174)

[a]Value in parentheses represents the number of samples that could be used for determination of target exceedance because either the concentrations were quantifiable or, if the concentrations were not quantifiable, the quantitation limits were below the water quality target

Table 4.15 Median Measured Congener Concentrations and Percent Reductions Required To Meet Water Quality Targets by Media

Congener	Dissolved Water Samples		Total Water Samples		Sediment Samples	
Number of samples	*148*		*148*		*173*	
	Median Concentration	% Reduction	Median Concentration	% Reduction	Median Concentration	% Reduction
2378-TCDD	0.027	91%	0.106	90%	621	93%
12378-PeCDD	0.0043	84%	0.016	0%	75	83%
2378-TCDF	0.13	84%	0.40	78%	1,582	88%
23478-PeCDF	0.0095	84%	0.030	67%	147	84%
Total TEQ	0.066	88%	0.23	69%	1,065	89%

4.2 SPATIAL TRENDS

4.2.1 Longitudinal Profiles

A summary of average TEQ concentrations in water, sediment, and tissue by segment is presented in Tables 4.16a and b for TEQ and 23478-TCDD, respectively. It can be observed in Table 4.16a that for the Summer 2002 samples, segment 1006 exhibited the highest average concentrations of dioxins in sediment, while segment 2430 showed the highest average concentration in water, segment 1007 showed the highest average concentration in catfish, and segment 1005 showed the highest average TEQ for crabs. Similarly, for the Fall 2002 samples, segment 1006 exhibited the highest average TEQ in water, segment 1007 showed the highest dioxin average in sediment, segment 2430 in catfish, and segment 2429 in crabs. It is also noted that the average dioxin concentrations in water and sediment measured in the Fall 2002 samples were for the most part higher than the ones measured in Summer 2002 by factors up to 7.1. Average TEQ concentrations in catfish and crab for Fall 2002 are higher than their counterparts for the Summer event only in 50% of the cases with ratios up to 1.8 and 2.2, respectively. It is noted, however, that during Fall 2002 samples were collected at fewer locations than during Summer 2002 and, thus, results from this comparison may not be conclusive.

Results from the Spring 2003 samples indicate that the highest average TEQ concentrations in water and sediment were found in segment 1001, while segments 2429 and 2427 showed the highest average TEQ concentration in catfish and crab, respectively. For the Spring 2004 event, the highest average TEQ concentrations were calculated for segment 1006 in water, for segment 1007 in sediment, for segment 2430 in catfish, and for segment 2429 in crab. It

Table 4.16a Summary of Average TEQ Concentrations by Segment

Segment	Water										Sediment									
	Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004		Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004	
	# of Samples	Average TEQ (pg/L)	# of Samples	Average TEQ (pg/L)	# of Samples	Average TEQ (pg/L)	# of Samples	Average TEQ (pg/L)	# of Samples	Average TEQ (pg/L)	# of Samples	Average TEQ (ng/kg dry wt.)	# of Samples	Average TEQ (ng/kg dry wt.)	# of Samples	Average TEQ (ng/kg dry wt.)	# of Samples	Average TEQ (ng/kg dry wt.)	# of Samples	Average TEQ (ng/kg dry wt.)
901	1[a]	0.267	ns	-	ns	-	1[a]	0.241	1[a]	0.232	1[a]	5.462	ns	-	1[a]	5.544	ns	-	ns	-
1001	3	0.194	2	1.369	2	1.597	2	0.674	3	0.794	3	34.801	2	32.228	2	70.768	2	50.063	4	34.265
1005	3	0.319	2	0.271	3	0.356	3	0.330	3	0.410	4	3.642	2	8.734	4	20.529	3	6.081	3	12.928
1006	3	0.528	1	1.633	2	0.399	6	0.869	7	0.695	6	97.993	ns	-	6	33.054	4	17.391	10	19.288
1007	3	0.166	2	0.143	2	0.232	7	0.261	7	0.272	7	26.316	2	52.121	7	17.461	3	157.977	4	228.322
1013	ns	-	ns	-	ns	-	2	0.067	2	0.085	2	2.555	ns	-	2	1.812	ns	-	ns	-
1014	ns	-	ns	-	ns	-	ns	-	2	0.065	ns	-	ns	-	ns	-	ns	-	ns	-
2421	5	0.146	2	0.148	4	0.138	1[a]	0.127	1[a]	0.095	5	2.653	1[a]	0.554	5	1.144	1[a]	0.919	1[a]	0.494
2426	3	0.376	2	0.642	1[a]	0.294	2	0.295	2	0.297	4	13.043	2	8.268	2	9.780	1[a]	14.458	1[a]	8.784
2427	2	0.440	1[a]	1.140	1[a]	0.313	1[a]	0.266	1[a]	0.247	2	22.173	1[a]	15.978	1[a]	4.222	1[a]	40.220	1[a]	78.339
2428	2	0.125	1[a]	0.127	1[a]	0.108	1[a]	0.089	1[a]	0.075	2	8.623	1[a]	9.906	2	3.524	1[a]	7.756	1[a]	6.364
2429	2	0.349	2	0.306	1[a]	0.374	1[a]	0.273	1[a]	0.176	2	23.338	2	18.645	1[a]	23.663	1[a]	25.741	6	17.566
2430	3	0.603	1[a]	0.271	2	0.320	1[a]	0.131	1[a]	0.370	3	19.068	1[a]	30.960	2	17.524	1[a]	17.720	1[a]	23.980
2436	1[a]	0.223	1[a]	0.968	ns	-	ns	-	ns	-	2	0.781	1[a]	2.529	1[a]	0.681	ns	-	ns	-
2438	2	0.091	1[a]	0.401	1[a]	0.074	ns	-	ns	-	2	0.644	1[a]	1.206	1[a]	1.065	ns	-	ns	-

Segment	Catfish										Crab									
	Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004		Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004	
	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)	# of Samples	Average TEQ (ng/kg wet wt.)
901	1[a]	3.144	ns	-	1[a]	3.159	1[a]	0.619	ns	-	1[a]	1.132	ns	-	1[a]	0.926	1[a]	0.820	ns	-
1001	3	6.023	2	3.337	2	3.289	2	3.628	2	14.686	3	2.609	1[a]	1.361	2	2.438	2	2.708	2	9.763
1005	4	7.440	2	8.605	4	7.098	3	3.364	3	15.155	4	7.665	2	3.669	4	4.283	3	4.186	3	9.298
1006	6	6.748	ns	-	6	8.406	6	6.807	3	10.422	6	4.906	ns	-	6	2.716	6	4.054	3	8.248
1007	7	8.082	2	3.861	6	6.458	7	9.473	3	8.525	7	3.645	ns	-	7	4.449	7	3.302	3	6.704
1013	2	1.288	ns	-	2	3.079	2	0.569	ns	-	2	2.132	ns	-	2	2.657	ns	-	ns	-
1014	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-
2421	5	2.542	ns	-	5	5.047	1[a]	4.797	1[a]	1.185	5	1.579	1[a]	0.322	5	0.903	1[a]	1.969	1[a]	1.500
2426	4	3.919	2	4.239	2	3.625	2	2.585	1[a]	1.794	4	1.197	2	3.399	2	1.346	2	0.787	1[a]	2.495
2427	2	6.890	1[a]	7.175	1[a]	9.900	1[a]	4.317	1[a]	4.894	2	5.649	1[a]	3.108	1[a]	9.167	1[a]	3.812	1[a]	4.787
2428	2	3.480	ns	-	2	3.254	1[a]	1.403	1[a]	0.935	2	0.883	1[a]	1.973	2	2.597	1[a]	1.866	1[a]	1.321
2429	2	4.898	2	5.510	1[a]	12.791	1[a]	5.217	1[a]	13.793	2	5.126	2	5.533	1[a]	3.139	1[a]	5.900	1[a]	11.163
2430	3	6.441	1[a]	10.521	2	10.316	1[a]	12.164	1[a]	5.378	3	4.460	1[a]	4.551	2	4.544	1[a]	5.010	1[a]	4.320
2436	2	2.226	1[a]	4.109	1[a]	4.805	ns	-	ns	-	2	3.099	1[a]	2.097	1[a]	0.795	ns	-	ns	-
2438	2	1.527	ns	-	1[a]	0.793	ns	-	ns	-	2	0.919	1[a]	0.449	1[a]	0.743	ns	-	ns	-

[a] The value presented corresponds to the result for the single sample for that segment

ns = not sampled

Table 4.16b Summary of Average 2,3,7,8 - TCDD Concentrations by Segment

Segment	Water										Sediment									
	Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004		Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004	
	# of Samples	Average TCDD (pg/L)	# of Samples	Average TCDD (pg/L)	# of Samples	Average TCDD (pg/L)	# of Samples	Average TCDD (pg/L)	# of Samples	Average TCDD (pg/L)	# of Samples	Average TCDD (ng/kg dry wt.)	# of Samples	Average TCDD (ng/kg dry wt.)	# of Samples	Average TCDD (ng/kg dry wt.)	# of Samples	Average TCDD (ng/kg dry wt.)	# of Samples	Average TCDD (ng/kg dry wt.)
901	1[a]	0.108	ns	-	ns	-	1[a]	0.088	1[a]	0.064	1[a]	2.50	ns	-	1[a]	2.10	ns	-	ns	-
1001	3	0.111	2	0.965	2	1.093	2	0.466	3	0.536	3	23.08	2	22.06	2	47.28	2	33.45	4	22.58
1005	3	0.176	2	0.173	3	0.214	3	0.207	3	0.271	4	2.32	2	4.95	4	14.21	3	3.80	3	8.47
1006	3	0.326	1	1.231	2	0.235	6	0.411	7	0.357	6	50.48	ns	-	6	10.22	4	9.30	10	12.01
1007	3	0.084	2	0.055	2	0.116	7	0.119	7	0.257	7	6.39	2	24.25	7	7.34	3	113.11	4	171.55
1013	ns	-	ns	-	ns	-	2	0.004	2	0.013	2	0.13	ns	-	2	0.19	ns	-	ns	-
1014	ns	-	ns	-	ns	-	ns	-	2	0.009	ns	-	ns	-	ns	-	ns	-	ns	-
2421	5	0.064	2	0.076	4	0.049	1[a]	0.043	1[a]	0.017	5	1.00	1[a]	0.12	5	0.53	1[a]	0.38	1[a]	0.18
2426	3	0.202	2	0.413	1[a]	0.140	2	0.121	2	0.021	4	7.09	2	4.05	2	4.61	1[a]	8.90	1[a]	5.00
2427	2	0.265	1[a]	0.819	1[a]	0.188	1[a]	0.047	1[a]	0.125	2	14.50	1[a]	9.90	1[a]	2.80	1[a]	29.00	1[a]	56.00
2428	2	0.039	1[a]	0.059	1[a]	0.044	1[a]	0.154	1[a]	0.151	2	4.00	1[a]	5.70	2	1.41	1[a]	4.00	1[a]	2.90
2429	2	0.210	2	0.197	1[a]	0.231	1[a]	0.035	1[a]	0.035	2	14.75	2	11.90	1[a]	15.00	1[a]	17.00	6	10.69
2430	3	0.172	1[a]	0.222	2	0.170	1[a]	0.168	1[a]	0.112	3	12.00	1[a]	21.00	2	11.80	1[a]	11.00	1[a]	15.00
2436	1[a]	0.112	1[a]	0.176	ns	-	ns	-	ns	0.191	2	0.24	1[a]	1.00	1[a]	0.12	ns	-	ns	-
2438	2	0.027	1[a]	0.636	1[a]	0.195	ns	-	ns	-	2	0.15	1[a]	0.54	1[a]	0.40	ns	-	ns	-

Segment	Catfish										Crab									
	Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004		Summer 2002		Fall 2002		Spring 2003		Spring 2004		Fall 2004	
	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)	# of Samples	Average TCDD (ng/kg wet wt.)
901	1[a]	2.500	ns	-	1[a]	2.600	1[a]	0.180	ns	-	1[a]	0.700	ns	-	1[a]	0.595	1[a]	0.460	ns	-
1001	3	5.367	2	2.884	2	2.860	2	3.225	2	13.750	3	1.827	1[a]	0.800	2	1.868	2	2.050	2	7.500
1005	4	6.725	2	7.600	4	3.708	3	3.033	3	14.400	4	5.763	2	2.950	4	3.350	3	3.200	3	7.300
1006	6	6.225	ns	-	6	7.099	6	6.181	3	9.750	6	3.700	ns	-	6	2.169	6	2.957	3	6.800
1007	7	5.538	2	3.300	6	7.519	7	8.650	3	7.680	7	2.537	ns	-	7	3.386	7	2.324	3	5.153
1013	2	0.836	ns	-	2	2.175	2	0.225	ns	-	2	0.485	ns	-	2	2.100	ns	-	ns	-
1014	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-	ns	-
2421	5	2.118	ns	-	5	2.330	1[a]	4.200	1[a]	0.960	5	1.022	1[a]	0.105	5	0.560	1[a]	1.500	1[a]	1.000
2426	4	3.348	2	3.325	2	3.138	2	2.170	1[a]	1.500	4	0.725	2	2.550	2	0.693	2	0.375	1[a]	2.000
2427	2	6.325	1[a]	6.100	1[a]	5.884	1[a]	3.900	1[a]	4.400	2	4.200	1[a]	2.500	1[a]	7.000	1[a]	2.900	1[a]	3.800
2428	2	2.750	ns	-	2	2.950	1[a]	1.100	1[a]	0.630	2	0.440	1[a]	1.400	2	0.505	1[a]	4.400	1[a]	0.860
2429	2	4.400	2	5.200	1[a]	8.350	1[a]	4.600	1[a]	13.000	2	3.650	2	4.200	1[a]	2.400	1[a]	4.400	1[a]	8.900
2430	3	5.667	1[a]	10.000	2	9.275	1[a]	11.000	1[a]	5.000	3	3.133	1[a]	3.550	2	3.700	1[a]	3.800	1[a]	3.400
2436	2	1.900	1[a]	3.150	1[a]	4.400	ns	-	ns	-	2	2.400	1[a]	1.600	1[a]	0.540	ns	-	ns	-
2438	2	1.325	ns	-	1[a]	0.510	ns	-	ns	-	2	0.625	1[a]	0.120	1[a]	0.560	ns	-	ns	-

[a] The value presented corresponds to the result for the single sample for that segment

ns = not sampled

is noted, however, that the highest catfish and crab average TEQs for the Spring 2004 event correspond to a single sample collected in the mentioned segments. Finally, the highest average TEQ concentrations in water, sediment, catfish, and crab measured in fall 2004 were calculated for segments 1001, 1007, 1005, and 1001, respectively.

Data in Table 4.16b indicate that the maximum average 2378-TCDD concentration in water was measured in the Fall 2002 in segment 1006, while the maximum average in sediment was measured in Fall 2004 in segment 1007. The maximum average 2378-TCDD concentrations for catfish and crabs were measured in Fall 2004 in segments 1005 and 1001, respectively.

Figure 4.28 shows concentration profiles along the main channel for total water dioxin concentrations measured in 2004 (WO7) compared to those measured in 2002-2003 (WO4). These data provide an indication of spatial patterns. As can be seen in Figure 4.28, the longitudinal profile was fairly consistent for all events: the water concentrations start low, they then increase until reaching the highest dioxin concentration and then concentrations decrease downstream. For all the events the profiles show peak TEQ concentrations in segment 1006 (at station 15979) and most of the side bays and tributaries at or above the levels observed in the main channel at the confluence segments. In addition, the dioxin concentration at station 11193 in the San Jacinto River (segment 1001) is higher than those measured at the confluence with the main channel and higher than that measured at station 15979. The only discrepancy was observed in the Fall 2004 profile which presented an additional "peak" in segment 1005.

Figure 4.29 depicts concentration profiles along the HSC for sediment samples collected in WO4 and WO7. Figure 4.29 shows similar profiles for the Spring and Fall 2004 samples: OC normalized TEQ concentrations start low and increase to a peak at station 11280 (segment 1007),

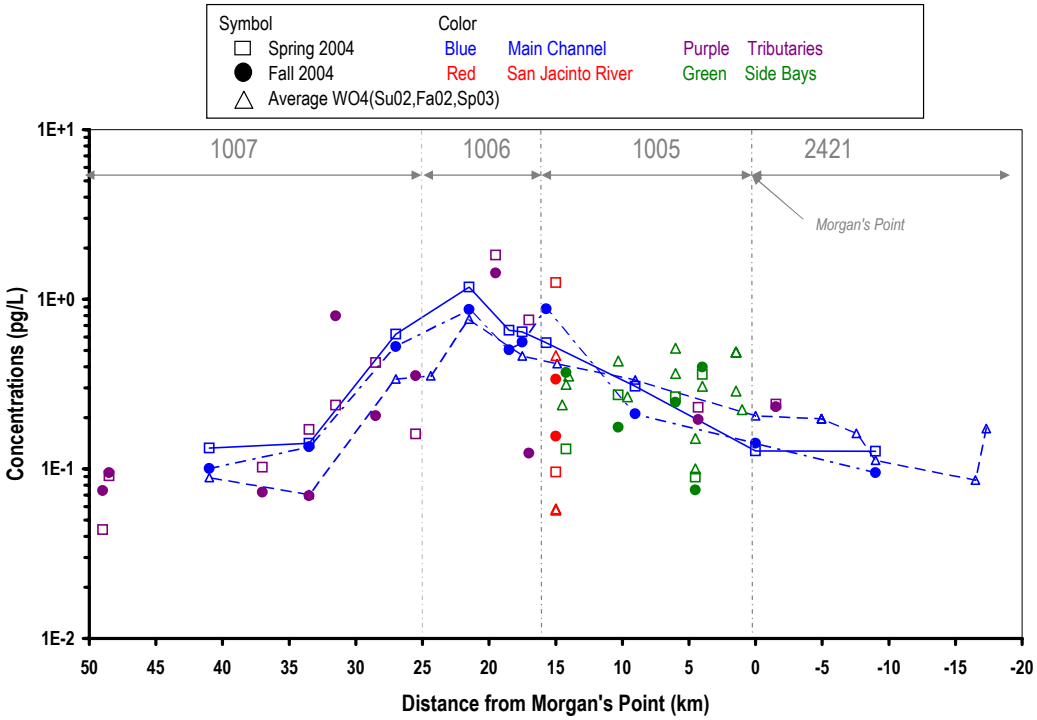


Figure 4.28 Total Water TEQ Concentration Profiles

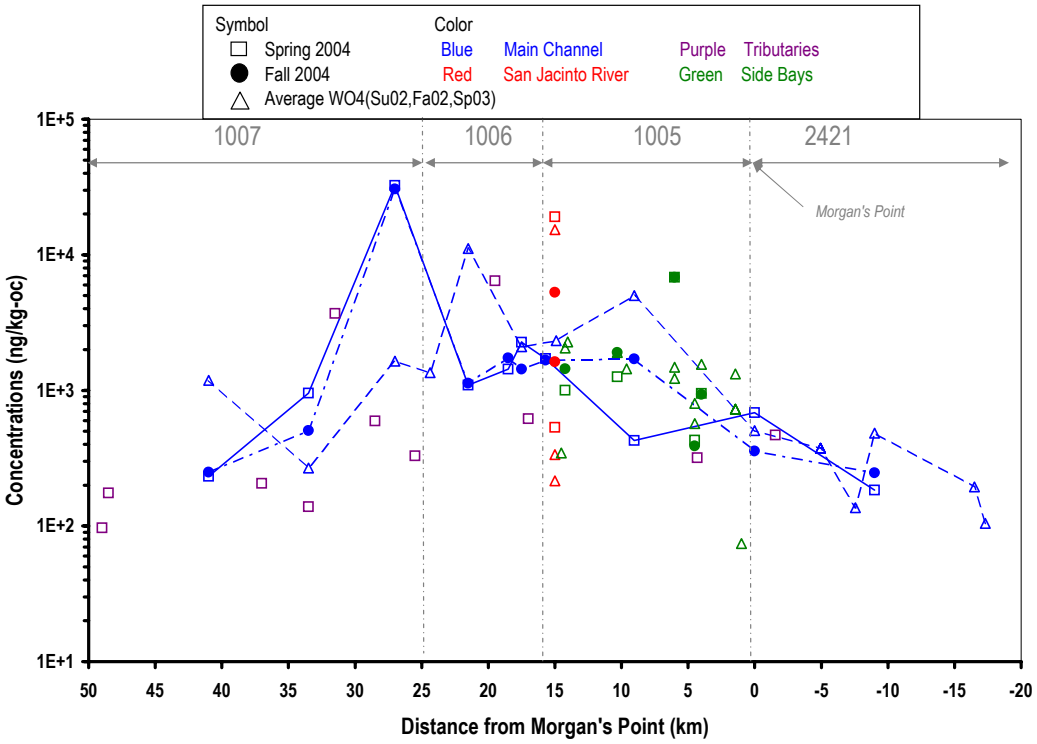


Figure 4.29 Total Organic-carbon Normalized Sediment TEQ Profiles

then they show a dramatic drop at station 15979 (segment 1006), in segment 1006 concentrations maintain a general increasing trend up to station 16618 (segment 1005) to finally decrease towards Galveston Bay. Dioxin concentrations were lower for most of the locations (upstream and downstream of station 11280). Sediment TEQ concentration for station 11193 in the San Jacinto River (segment 1001) was the only exception, with a concentration almost as high as that measured at station 11280. Concentrations in side bays were, in general, higher than those measured at the receiving main channel. The concentrations measured in WO4 showed similar behavior but the peak was at station 15979 in segment 1006.

Figures 4.30 and 4.31 present concentration profiles along the HSC for catfish and crab samples, respectively. Catfish and crabs exhibited relatively "flat" profiles with in-stream levels that are greater than those for side bays. The Fall 2004 profile, however, showed a significant peak at Morgan's Point (11252) for both catfish and crab.

4.2.2 Multivariate Analysis

In order to test for spatial variability within the PCDD/F data set collected, two different classes of analysis technique were employed: Principle Component Analysis (PCA), and clustering analyses. Background information on PCA and cluster analysis is included in Appendix F. The data sets for summer, fall, and spring did not include all the same sampling points. Therefore, only the summer dataset was used as it contains the most complete set of sampling points. A map with the locations sampled during Summer 2002 is included in Appendix F. There were eight sub-sets of data within the summer dataset: sediment, air, and suspended/dissolved concentrations for water, runoff, and effluent.

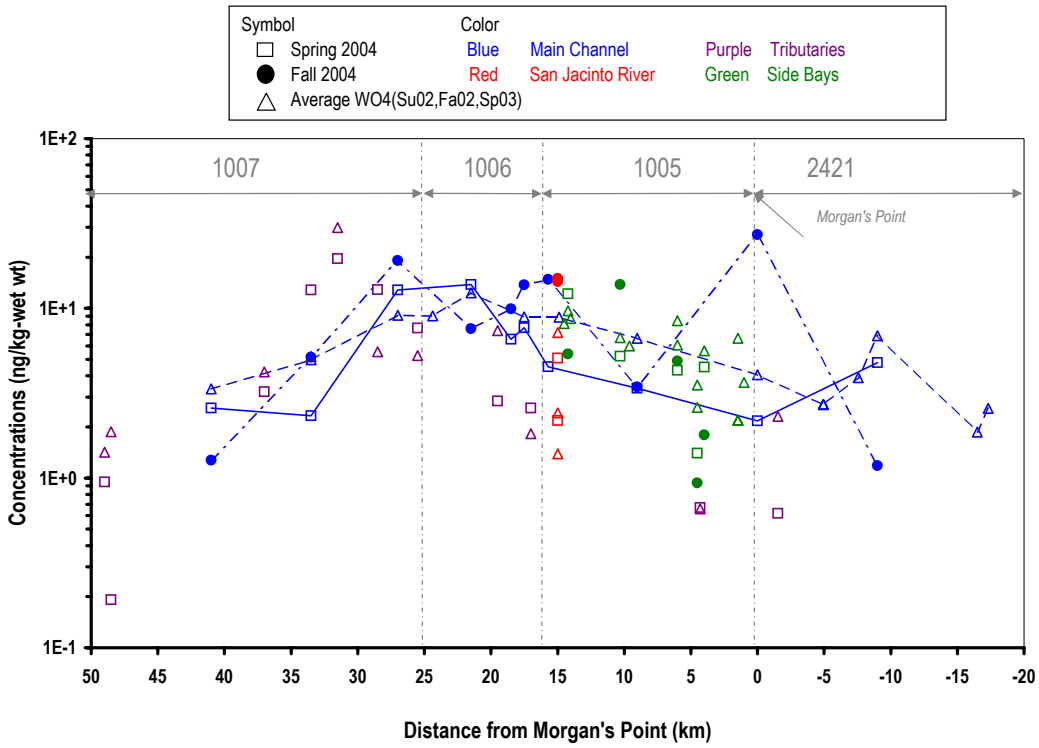


Figure 4.30 Total Catfish TEQ Concentration Profiles

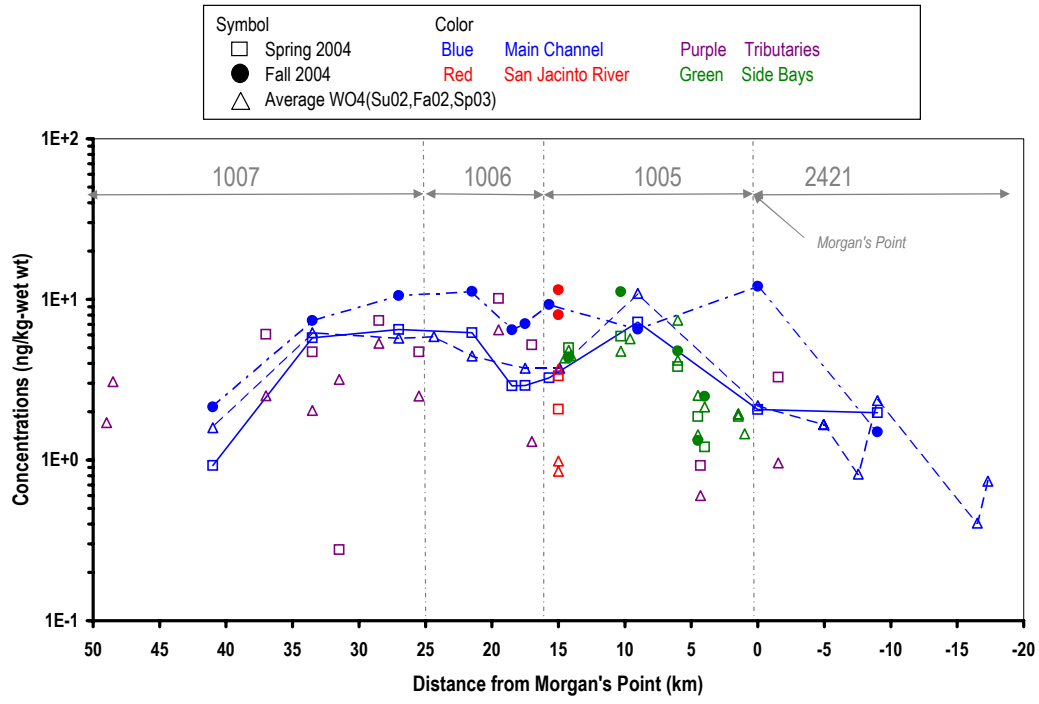


Figure 4.31 Total Crab TEQ Concentration Profiles

In order to complete these analyses, the homologue profile and/or the 17 dioxin-like congener profile of the samples was compared. The profiles, or fingerprints, are the basis for the spatial variability testing that is presented below.

4.2.2.1 Methodology

In order to normalize the data prior to PCA and cluster analysis, the PCDD/F totals from each homologue group were divided by the sum total of all PCDD/Fs for that sampling point. To view the 17 dioxin-like congener profiles, two different methods were tested and compared. In the first method, the individual congener concentrations were divided by the total homologue group for that congener. OCDD and OCDF were divided by the sum total of PCDD and PCDF, respectively (Gotz and Lauer, 2003). This method would show the spatial relationship of toxic congeners as compared to the homologue groups. In the second method, the individual congener concentrations were divided by the sum total of the seventeen 2378-substituted congeners. This method would give a spatial pattern of the 17 congeners with respect to each other.

Regarding non-detects, for the Principle Components Analysis and Cluster Analysis, the same procedure was followed when deciding which data points to include in the analysis. Initially, a procedure was developed which would include most of the data, but excluded data with non-detects. In this method, homologue groups missing greater than 25% of the data due to non-detects were excluded from the analysis, and individual sampling stations missing data were excluded case-wise. Other methods for data inclusion have been presented in the literature, and include assuming non-detects (ND) as half the detection limit, or substituting a zero for the ND.

As a first step, PCA for sediment samples was completed in order to establish the most appropriate approach for determining the profiles and working with non-detects. Figure 4.32

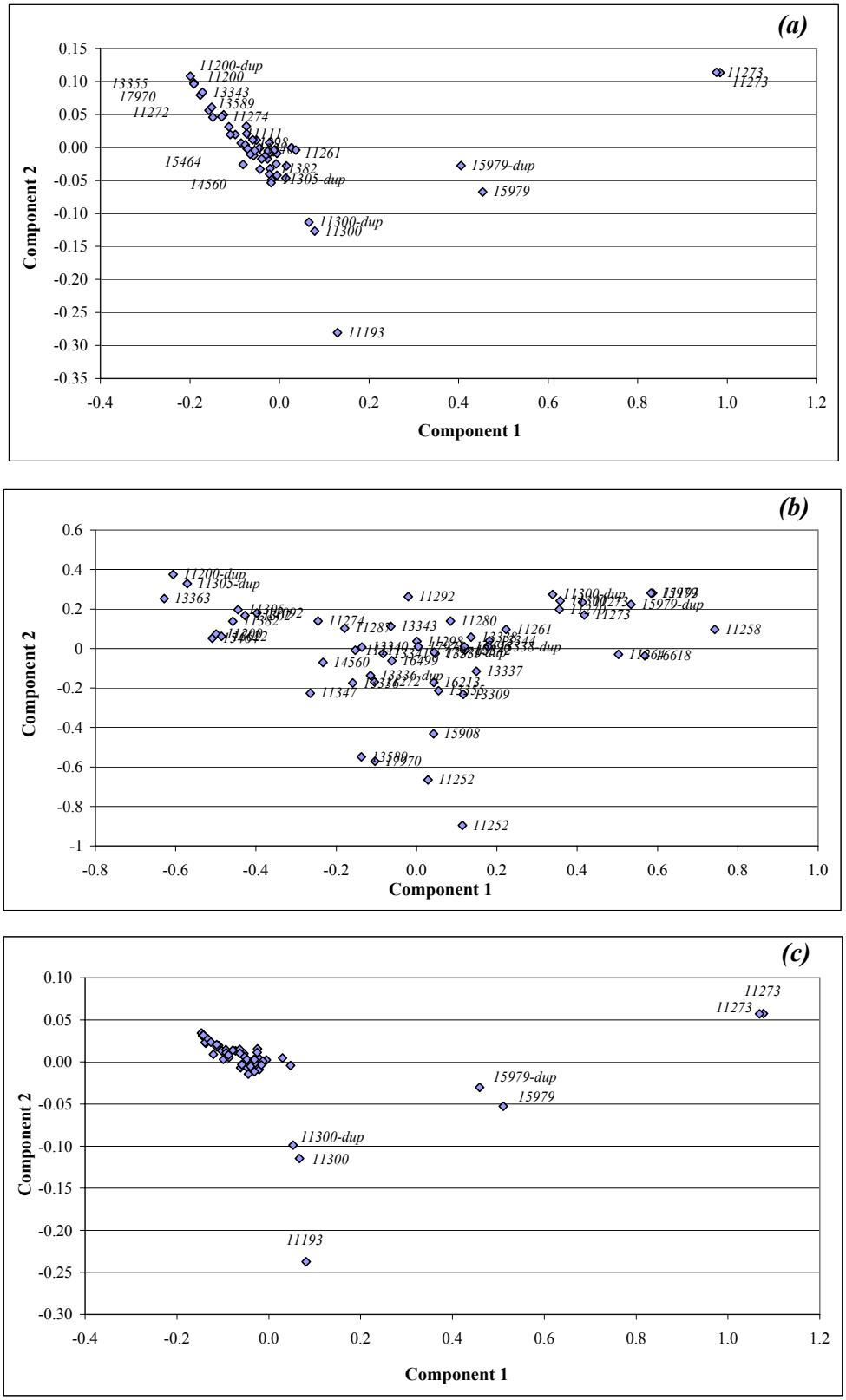


Figure 4.32 Different Schemes for Normalizing Profiles of Sediment Data

(a) Homologue Profiles Normalized by Σ PCDD/F (b) Congener Profiles Normalized by Homologue Group Concentrations
(c) Congener Profiles Normalized by Σ 17 congeners

shows the three different schemes for normalizing profiles discussed earlier. Figure 4.32a shows a biplot of sediment data using homologue profiles, this scheme is appropriate for analyzing data because it considers all the congeners present in the samples, not only the dioxin-like congeners. Figures 4.32b and c show biplots of sediment data using congener profiles for the 17 dioxin-like compounds. For analysis of congener profiles, the second normalization method (Figure 4.32c) was considered more applicable to this study than the one presented in Figure 4.32b because the question of interest is the spatial pattern of the 17 congeners with respect to each other. Also, the pattern found for the toxic congeners normalized by the sum of the 17 congeners (Figure 4.32c) resembled the spatial patterns for homologue groups (Figure 4.32a). This may allow for interchangeability between homologue groups and dioxin-like congener analysis. For this study, however, only the homologue groups were used in subsequent analyses.

Figure 4.33 shows biplots of PCA results using three different methods for dealing with non-detects. In the first method (Figure 4.33a), non-detects were excluded from the database. However, it was decided that this method excluded too much data. Figure 4.33b shows the results when non-detects are substituted by half of the detection limit. For this study, it was decided that including ND at ½ the detection limit might lead to unreliable results because of two reasons. First, the detection limit was not the same for all samples, and second the inclusion of these points would result in a different homologue profile. Because the profile is what is compared between samples, it was decided that a substitution of a zero for ND was the best method (Figure 4.33c). This resulted in the ability to include all data in the analysis, and did not change the profile of homologue concentrations.

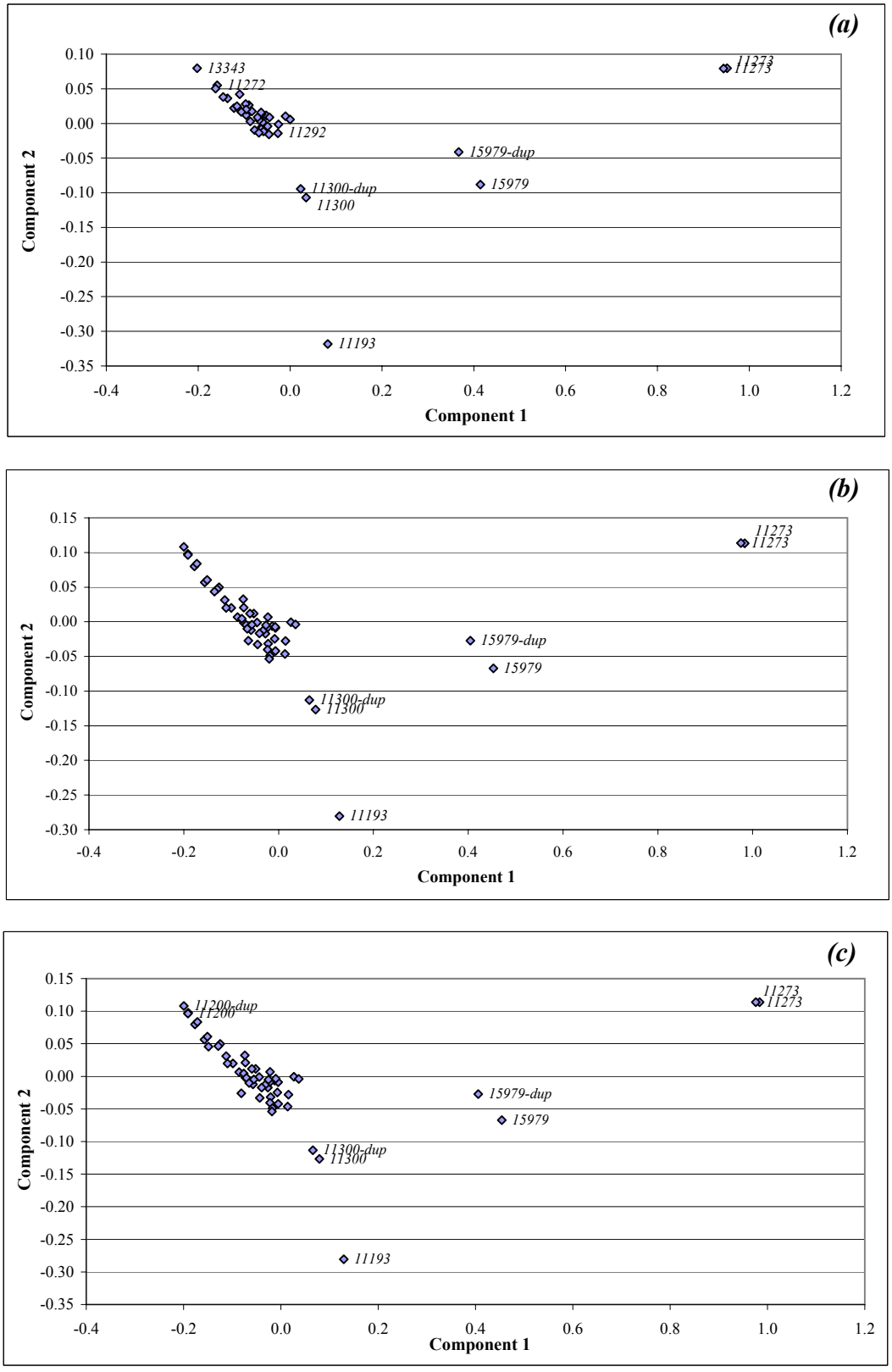


Figure 4.33 Different Methods for Treating Non-detects

(a) Non-detects excluded (b) Non-detects equal 1/2 MDL (c) Non-detects equal to zero

Based on the previous analyses, PCA and cluster analysis testing for the remaining media were completed using homologue profiles normalized by the total dioxin concentration (Σ PCDD/PCDF) and assuming non-detects as zeros.

The first step in completing a PCA is creating a covariance matrix. SPLUS statistical package was used for this and all other aspects of PCA testing. Covariance is the default SPLUS choice, and it was chosen instead of a correlation matrix because the data were all of the same type and had previously been normalized. The scores of the loadings generated from the creation of components were utilized to generate scatter plots. Principle Components one and two were graphed together to look for possible patterns, or clusters. As a way to further validate or explain clustering in the PCA, cluster analysis was employed to explore the relationships within clusters.

Several different types of cluster analyses were examined for this project. It is important to note that cluster analysis utilizes a dissimilarity matrix, while the PCA algorithm generates a similarity matrix. Four major types of cluster analysis were explored: k-means, partitioning around mediods (pam), fuzzy, and agglomerative hierarchical. With k-means, pam, and fuzzy methods, the analysis was carried out in SPLUS. Background information on the different cluster analysis techniques is included in Appendix F.

When considering the PCDD/F data from the Houston Ship Channel, all three cluster analysis methods (fuzzy, k-means , and pam) were utilized and the results compared. For these three clustering techniques, the number of clusters must be chosen (see Appendix F for details on how this was accomplished). It was found that the k-means method was not very effective and so it was discarded. Using pam and fuzzy analysis gave different cluster memberships, and no

apparent pattern was evident, indicating that a more robust method was needed in order to generate results.

Agglomerative Hierarchical Clustering (AHC) was selected as another alternative, since the number of clusters is not pre-chosen in order to run the analysis. SPSS was also used to complete this analysis. The method begins with all the data points in their own cluster, and then combines the points with the next point least dissimilar, or more similar, until there is one large group. Ward's method was chosen as the measure of similarity between points in a cluster. This method was chosen as it gives the same amount of variance within clusters. It also assumes that the clusters are spherical in hyperspace. This may not be true, but it seems reasonable to look for clusters which have the same variance within them when looking at this data. It would be difficult to interpret the cluster results if the clusters had different amounts of variation within them.

The output from the AHC method is a clustering tree. This is a graph that looks something like a family tree. This visual aid makes it easy to interpret the clustering results. It is possible to see how much the sample points vary from each other, or how much the clusters differ from each other based on the height of the dividing branch. One downfall of this method is that if a point is miss-classified in the first cluster step, it continues to be placed in that cluster throughout the analysis. It is important to be discerning when analyzing the results.

4.2.2.2 Results

As mentioned in the previous section, principle components analysis and cluster analysis were employed to discover the spatial patterns (if any) of PCDD/Fs in the different media in the Houston Ship Channel. The results of these analyses are presented below.

Dissolved Data

Figure 4.34 shows that most of the sampling stations for dissolved water homologue profiles are clustered in the bottom right-hand corner. The clustering is not tight, however. Looking at Figure 4.35, the hierarchical cluster analysis output shows that there is only one station outlier, which is 13340. This means that although station 11287 also looks like an outlier, it is actually part of a cluster which is not much different from the other points in the analysis.

Suspended Sediment Data

The patterns of suspended sediment PCDD/F homologue profiles do not seem to be distinct. It appears that the points are spread out somewhat randomly on the scatter plot of PCA scores (Figure 4.36). Looking at Figure 4.37, the hierarchical cluster output, shows that although stations 15464, 11200, 13343, and 16622 appear to be closely related they are somewhat spread out on the PCA scatter plot. This means that the results are not a tight, true cluster.

Bottom Sediment

Sediment was the medium studied most thoroughly, as the properties of PCDD/Fs indicate that dioxins would be more likely to attach to particles. Sediment also tends to move less over time, and so would be a better indicator of homologue fingerprints throughout the HSC area than a medium that is constantly in motion. It was hoped that a clear pattern of side bays and main channel would be found. This was not the case.

However, it was found that there are some stations which clearly do not have the same homologue pattern as the rest of the stations. Figure 4.38 shows these stations to be 11273, 15979, 11193, and 11300. This analysis is borne out by the cluster analysis output (Figure 4.39), which shows 11273 and 15979 as a distinct group. Although station 11193 and 11300 appear to

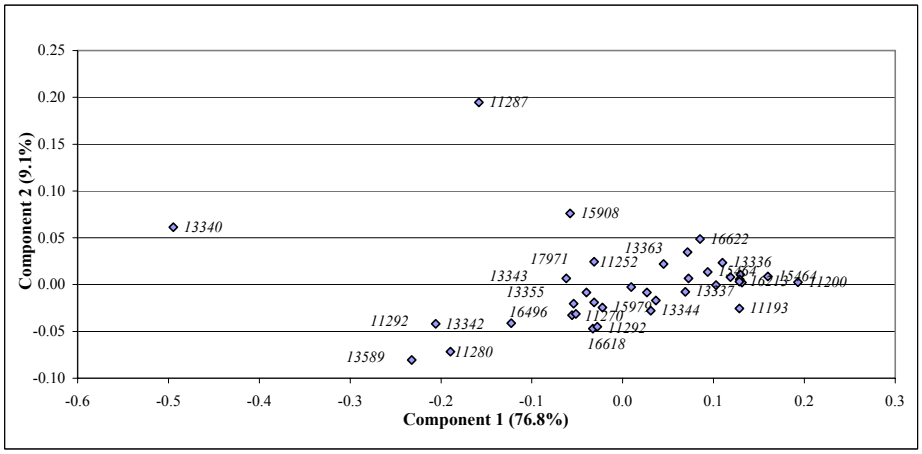


Figure 4.34 PCA Analysis for Dissolved Concentrations

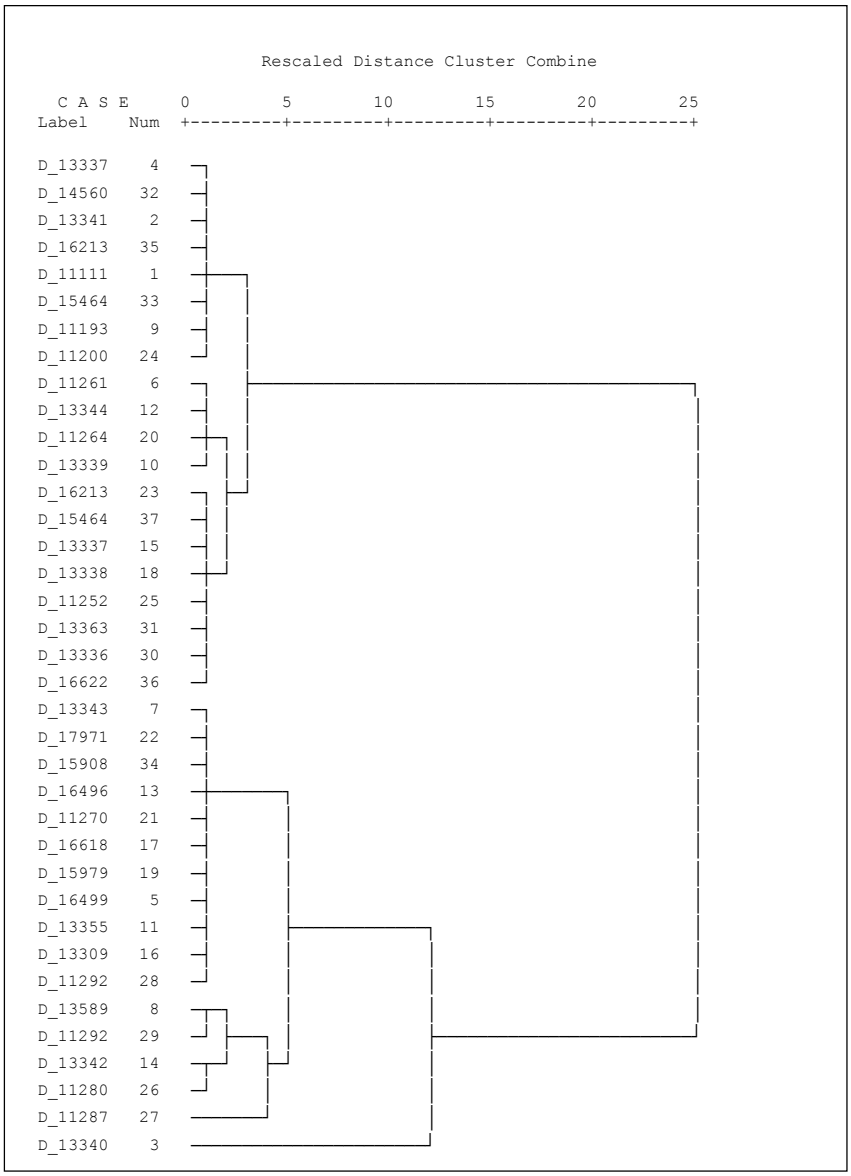


Figure 4.35 Dissolved Concentrations Dendogram using Ward Method

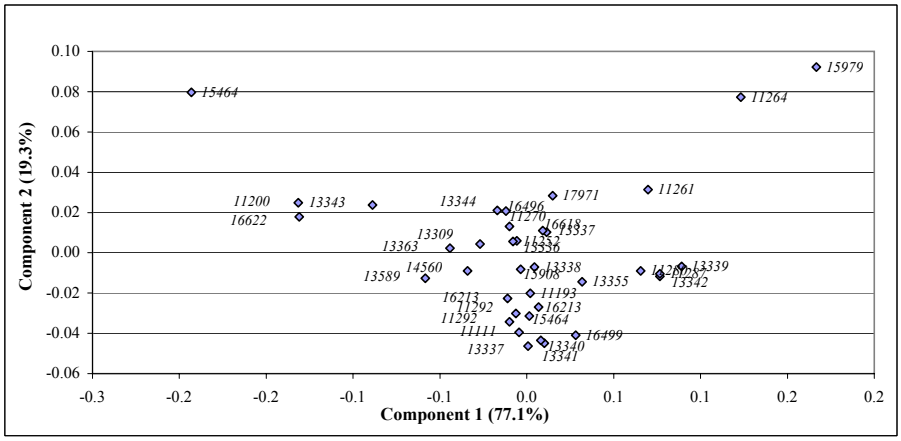


Figure 4.36 PCA Analysis for Suspended Sediment Concentrations

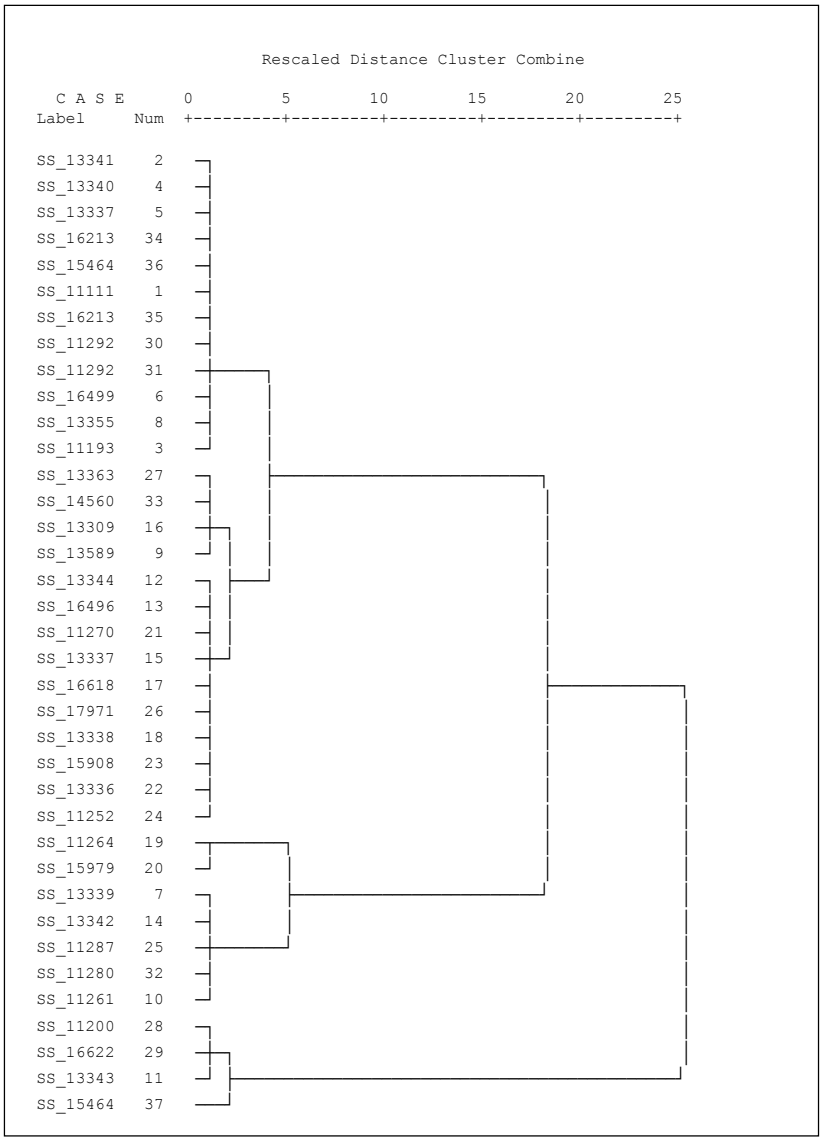


Figure 4.37 Suspended Concentrations Dendogram using Ward Method

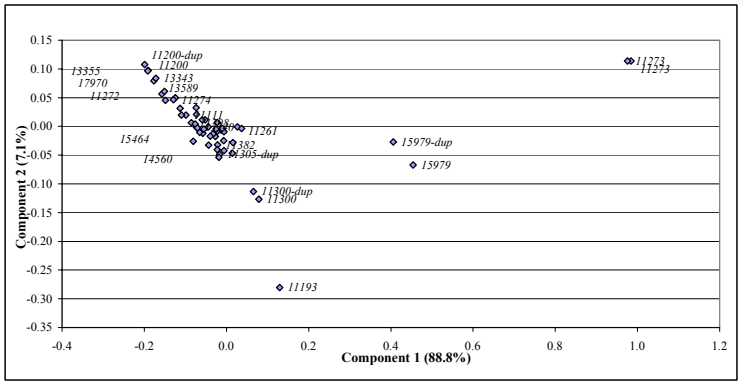


Figure 4.38 PCA Analysis for Sediment Concentrations

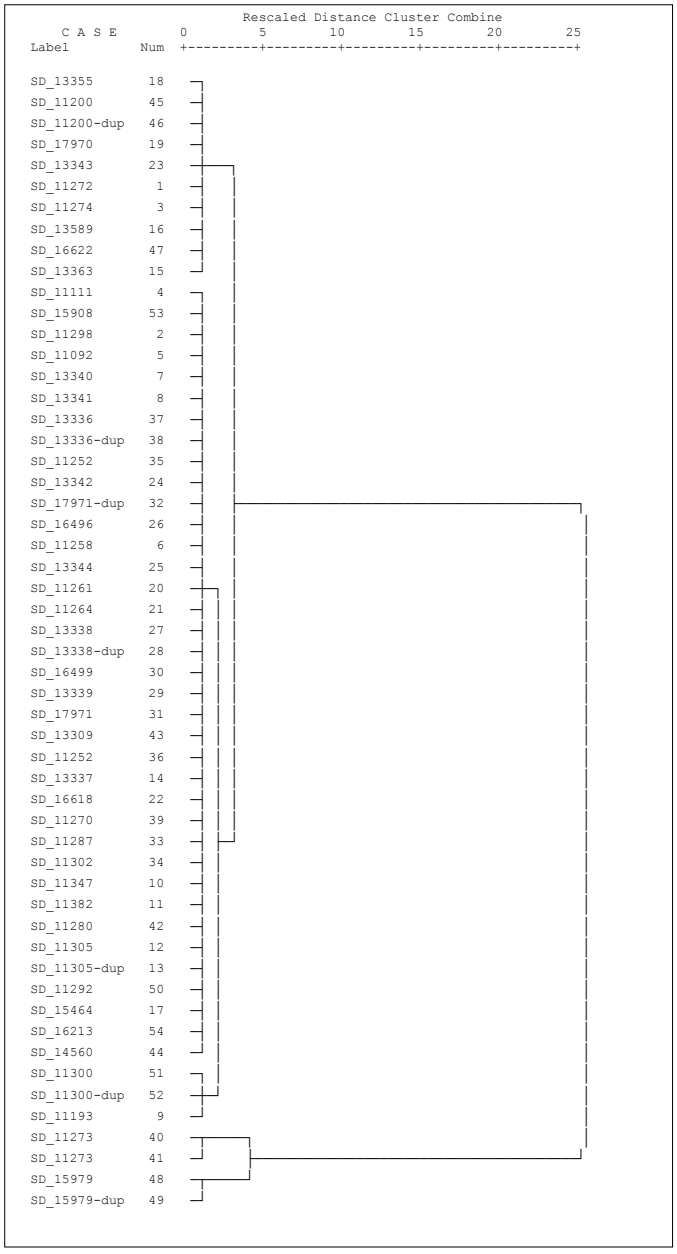


Figure 4.39 Bottom Sediment Concentrations Dendogram using Ward Method

be a separate group in the PCA scores scatter plot (Figure 4.39), the cluster analysis shows that while the stations are somewhat different from the other stations, they are not highly dissimilar. This statement can be made based on the height of clustering branch declaring the two stations a separate cluster.

The homologue fingerprints for the stations 11273 and 15979 show much higher percentages of the furan homologue groups, which differs somewhat from the majority of stations that exhibit higher levels of dioxin homologue groups in their fingerprints. The homogeneity found between and among the stations is most likely due to the abundance of different sources for dioxin, and the re-suspension of sediment which would tend to create a pattern remaining consistent up and down the channel.

Effluent

Effluent is divided into two groups, as the PCDD/Fs were analyzed as either dissolved or sorbed to suspended solids within the effluent. Figure 4.40, which is a scatter plot of the PCA scores for a combined test of suspended and dissolved effluent, shows that while there is some overlapping of homologue patterns, most of the dissolved effluent is in the lower right hand corner, and most of the suspended effluent is in the bottom left. The outliers of 46, 34, and 40 suspended effluent show the same pattern that they have when included with the sediment and suspended solids analysis. The cluster analysis, Figure 4.41, shows that three samples, along with 80 dissolved effluent samples do in fact constitute a separate cluster. This is to be expected, because the different physical properties of the 10 homologue groups lead to different homologue profiles in different media.

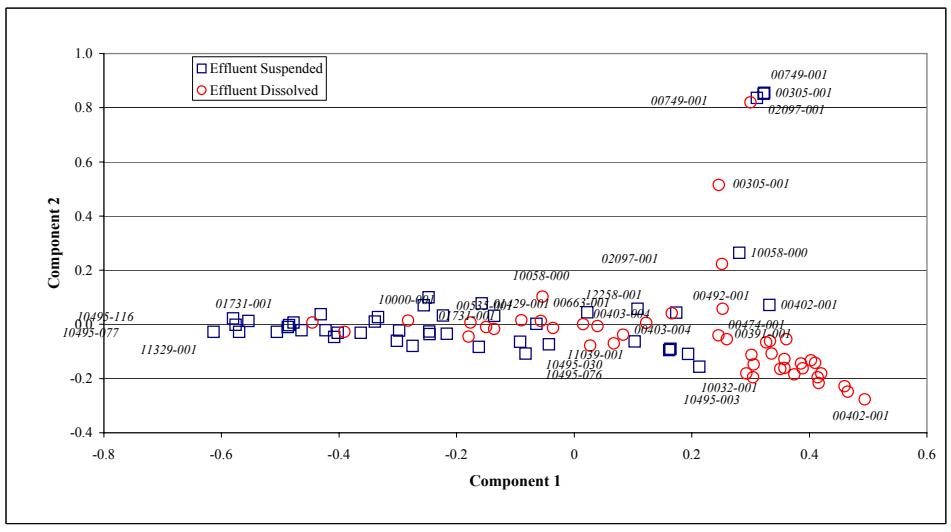


Figure 4.40 PCA Analysis for Effluent Concentrations

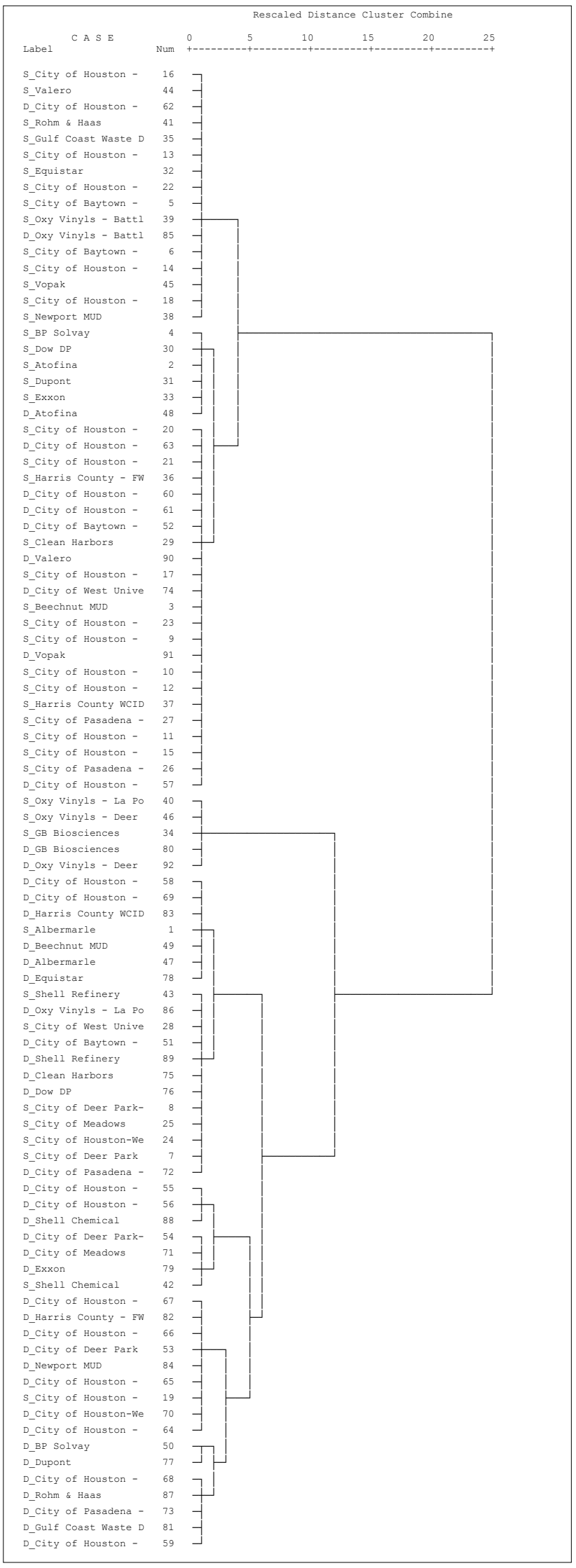


Figure 4.41 Total Effluent Concentrations Dendogram using Ward Method

An individual analysis of dissolved and suspended effluent was also completed. Dissolved effluent did not exhibit strong clusters in the PCA analysis (Figure 4.42), but did show strong clustering with the hierarchical cluster analysis (Figure 4.43). This means that the clusters should be interpreted with some caution.

Suspended effluent (Figure 4.44) does indicate one distinct cluster, again numbers 34, 40, and 46 and a less distinct cluster of 1,7,8,19,24,25,28, 42, and 43. This supports the analysis that the three samples (34, 40, and 46) do in fact form a cluster. That is most likely due to the high percentages of furans in the homologue patterns for those. The hierarchical cluster analysis is presented in Figure 4.45.

Runoff

A map showing the locations sampled for runoff is included in Appendix F. Runoff was divided up in a way similar to effluent samples. An analysis of suspended and dissolved runoff together shows that the homologue profile of the two groups is very different. Figure 4.46 illustrates this, as the dissolved runoff samples are in their own cluster in the bottom center of the PCA scores scatter plot. This is further supported by the clustering in the hierarchical cluster analysis, Figure 4.47, which shows the dissolved runoff samples in their own cluster. The majority of the remaining samples are shown in Figure 4.46 on the middle right side, which constitutes the suspended cluster.

There are four samples which are located in the top left hand corner of Figure 4.46, and these four constitute their own cluster. This analysis is, again, supported by Figure 4.47, the hierarchical cluster analysis. This analysis shows that Samples SS-9 and SS-8 are separated from the rest of the suspended and dissolved samples. It is interesting that the dissolved and suspended

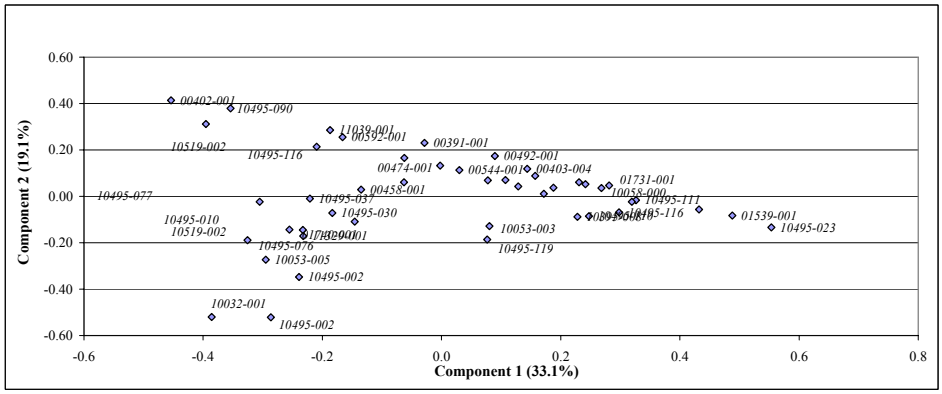


Figure 4.42 PCA Analysis for Dissolved Effluent Concentrations

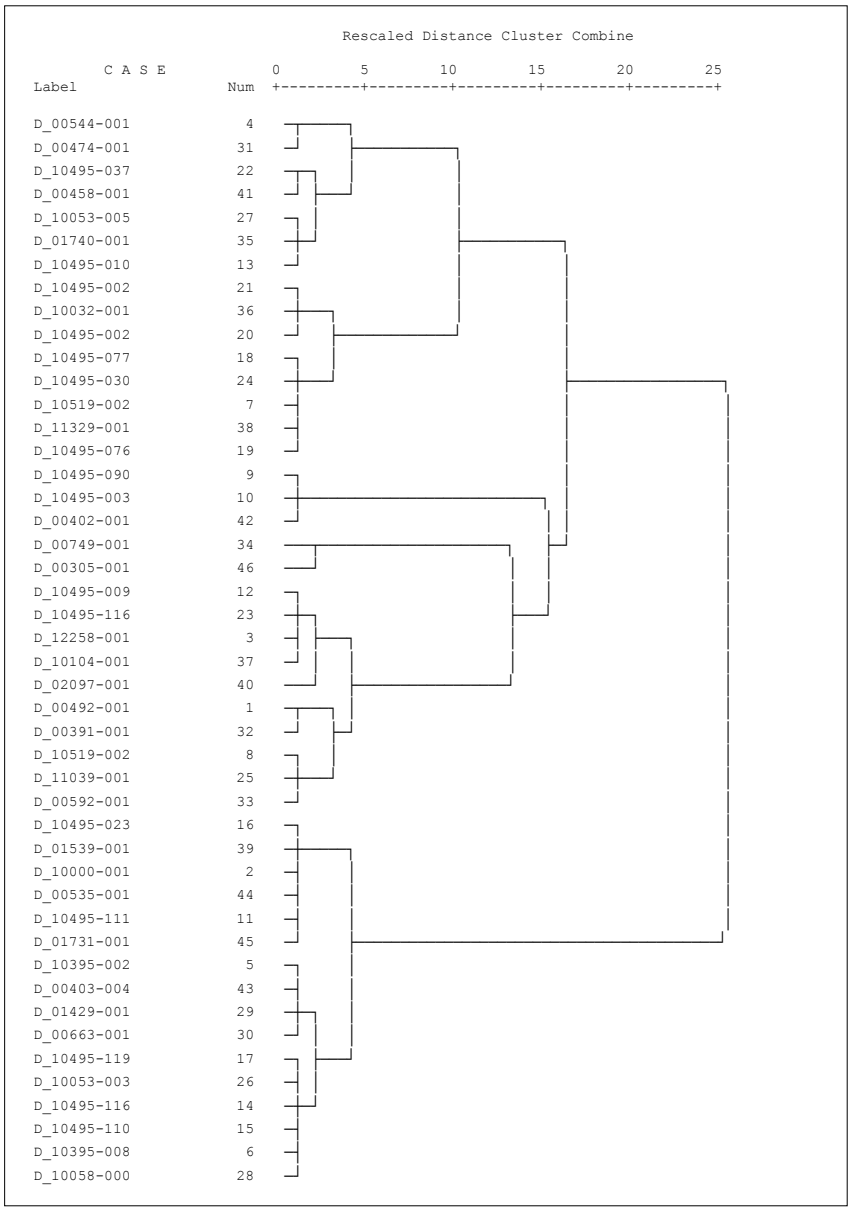


Figure 4.43 Dissolved Effluent Concentrations Dendogram using Ward Method

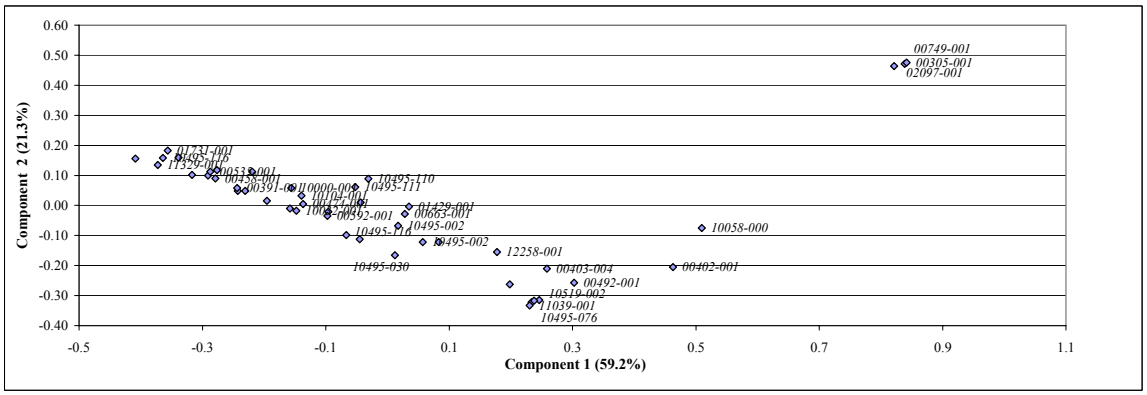


Figure 4.44 PCA Analysis for Suspended Effluent Concentrations

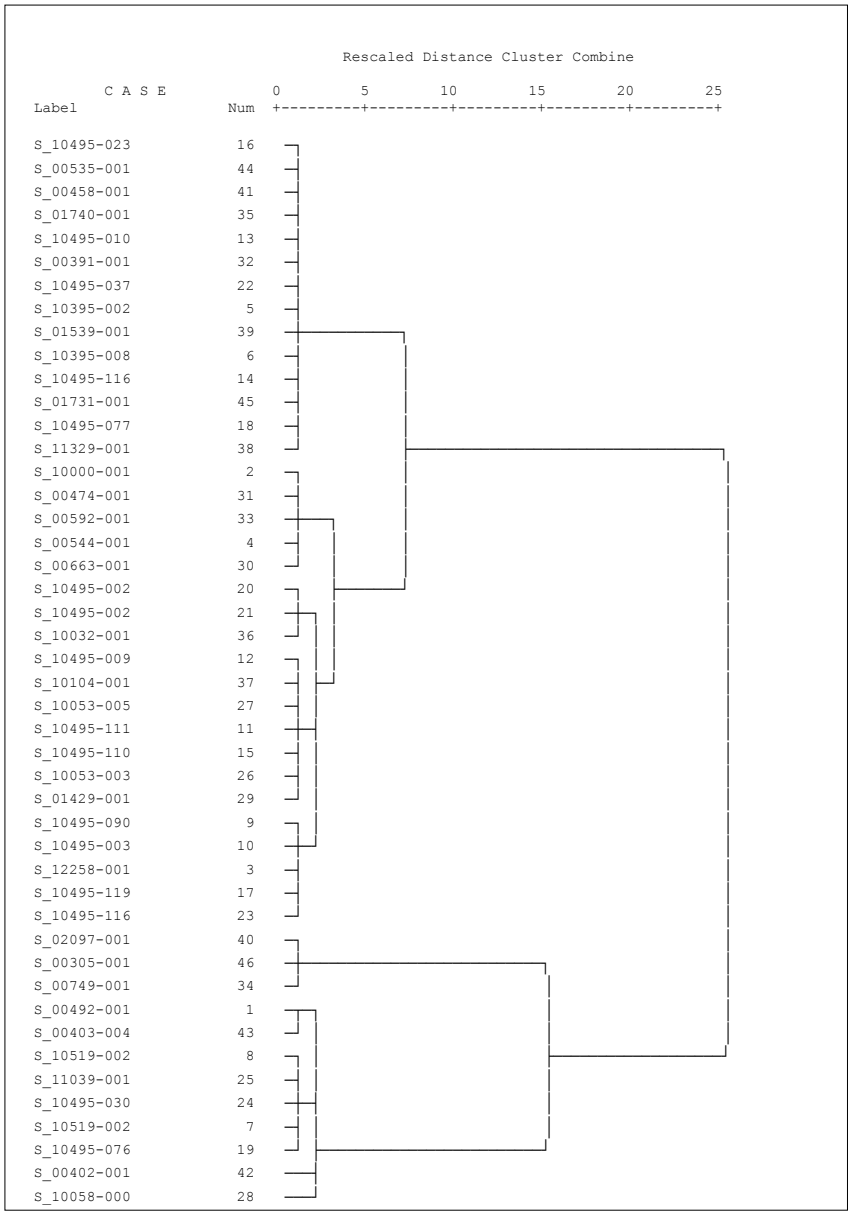


Figure 4.45 Suspended Effluent Concentrations Dendogram using Ward Method

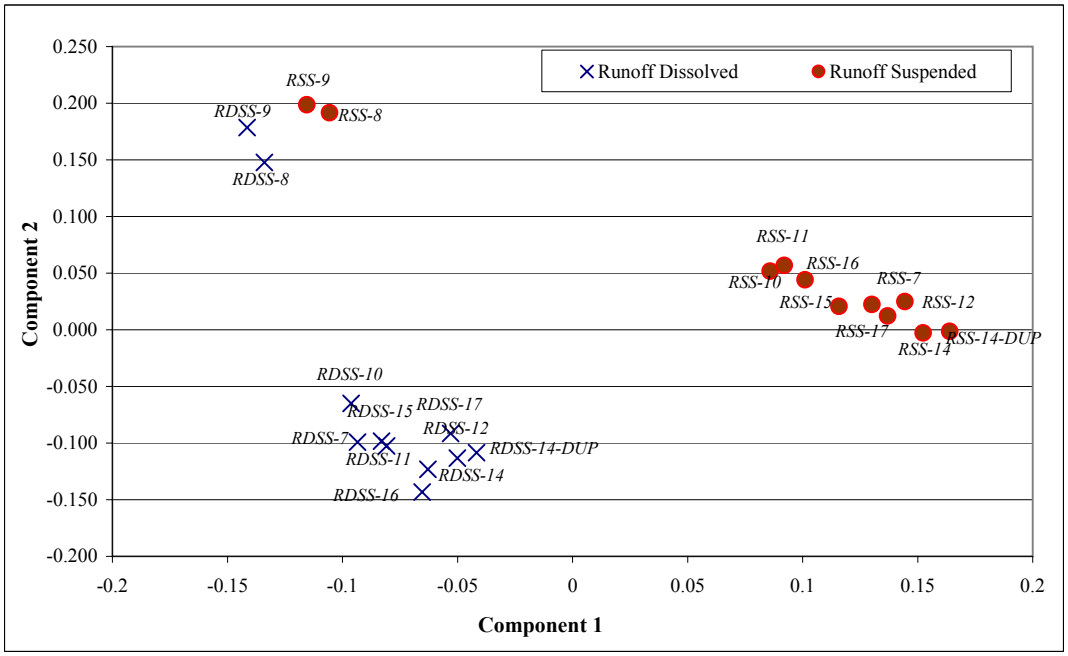


Figure 4.46 PCA Analysis for Runoff Concentrations

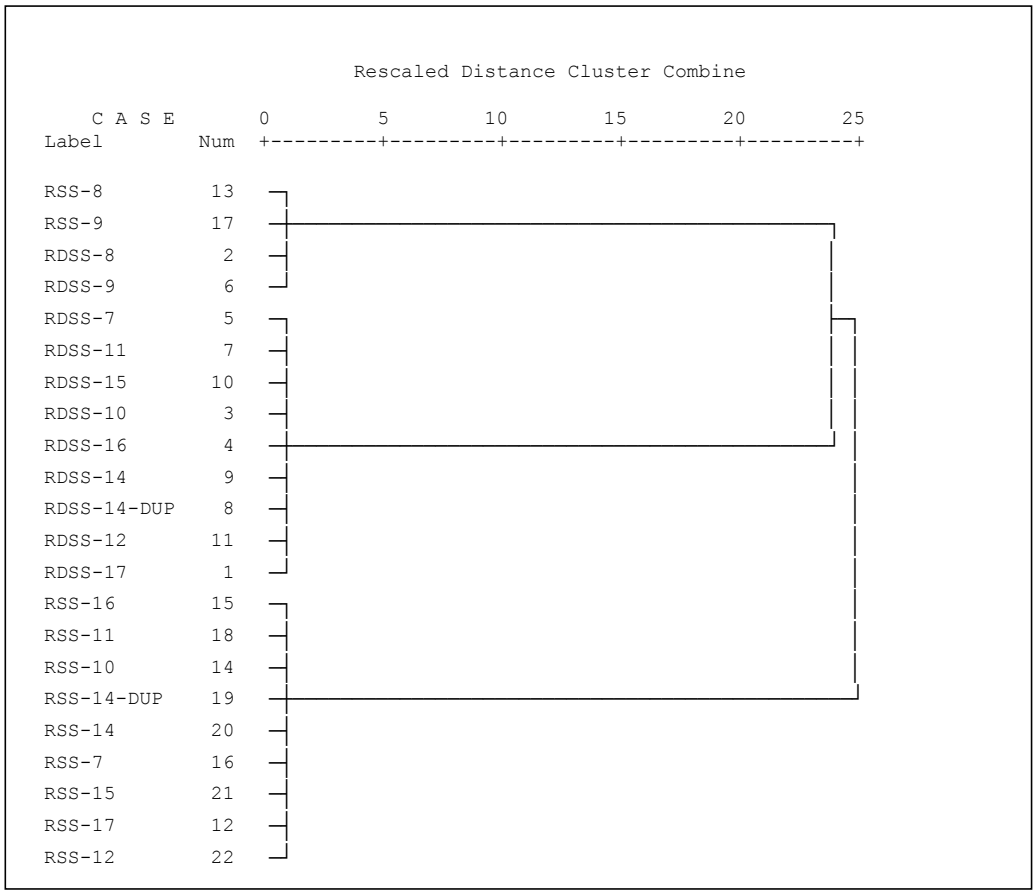


Figure 4.47 Runoff Concentrations Dendogram using Ward Method

samples for stations SS-8 and SS-9 are clustered together when the rest of the samples from other stations are split between the suspended and dissolved clusters. According to Figure 4.47, the dissolved runoff samples are more like the other suspended solids samples than SS-9 and SS-8. Figure 4-48 shows fingerprints for suspended concentrations at samples SS-8 and SS-9 along with sample SS-17 for comparison. It can be seen that samples SS-8 and SS-9 differ from other samples in that almost 100% of the dioxin concentration is due to OCDD, while for other samples (e.g SS-17), OCDD comprises about 70% of the total dioxin concentrations and there is a significant contribution of the higher chlorinated furans.

The dissolved and suspended runoff samples were also analyzed separately, and when examined in this manner there are actually two clusters in the dissolved runoff samples. This is observed at in the PCA scores scatter plot, Figure 4.49, and confirmed with Figure 4.50, the hierarchical cluster analysis. Figure 4.50 shows that there is a high degree of dissimilarity between the cluster of SS-8/SS-9 and the rest of the samples.

The suspended runoff analysis also shows that stations SS-8 and SS-9 form their own cluster much different than the rest of the samples. This is illustrated in the PCA scatterplot in Figure 4.51 and confirmed with Figure 4.52, the cluster analysis.

Air

A map showing the locations sampled for air is included in Appendix F. Air is an interesting media to analyze for PCDD/F homologue profile patterns. The data for this analysis consist of three samples for each of five stations for the months of June, July, and August of 2002. Furthermore, the samples at stations C403 and C408 were divided into PUF and filter concentrations. This gives 27 total variables to input into the analysis. These three months were selected because the data for the other media were from Summer 2002 as well. As before, a

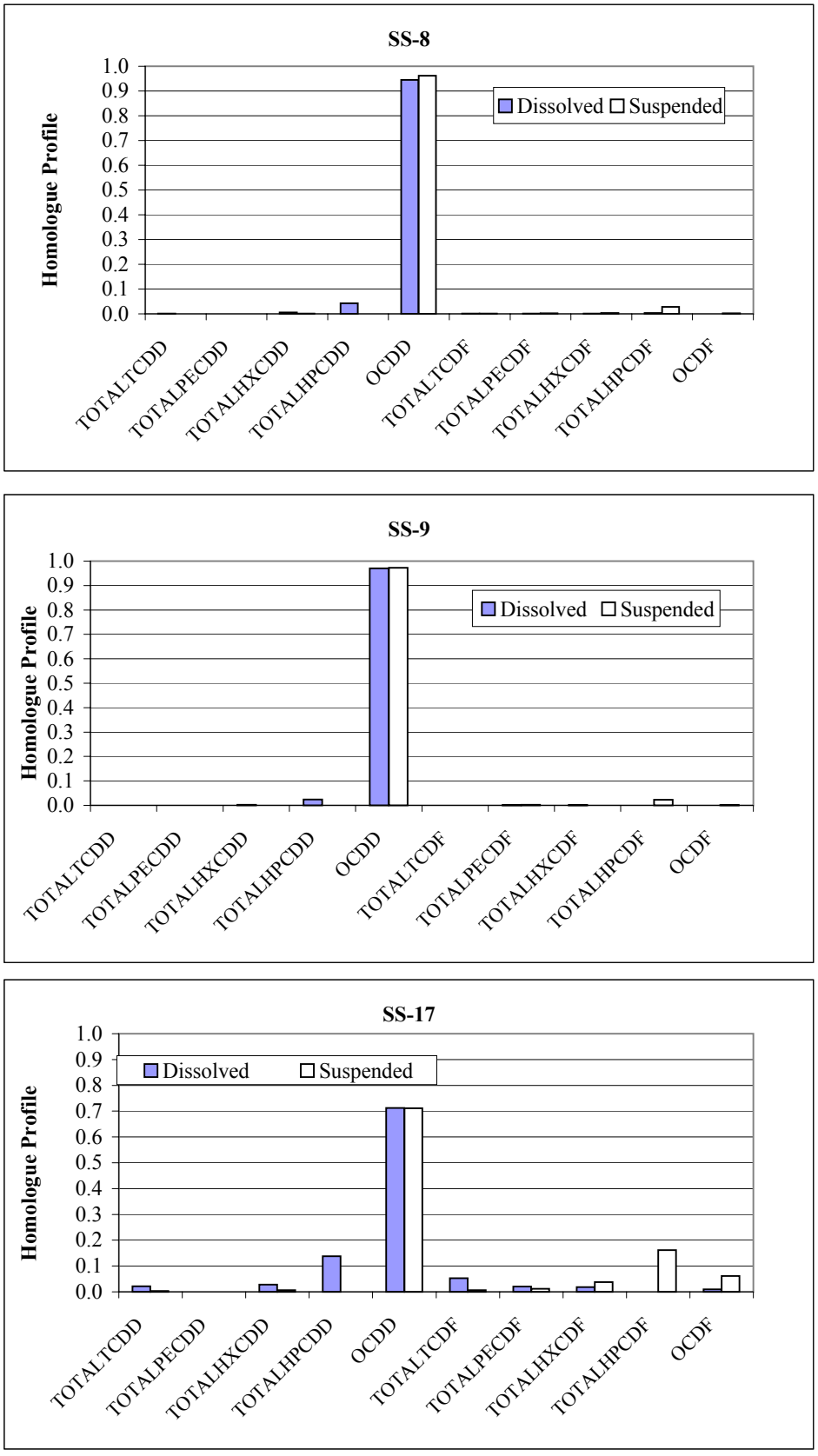


Figure 4.48 Fingerprints of Suspended Runoff Concentrations for Selected Stations

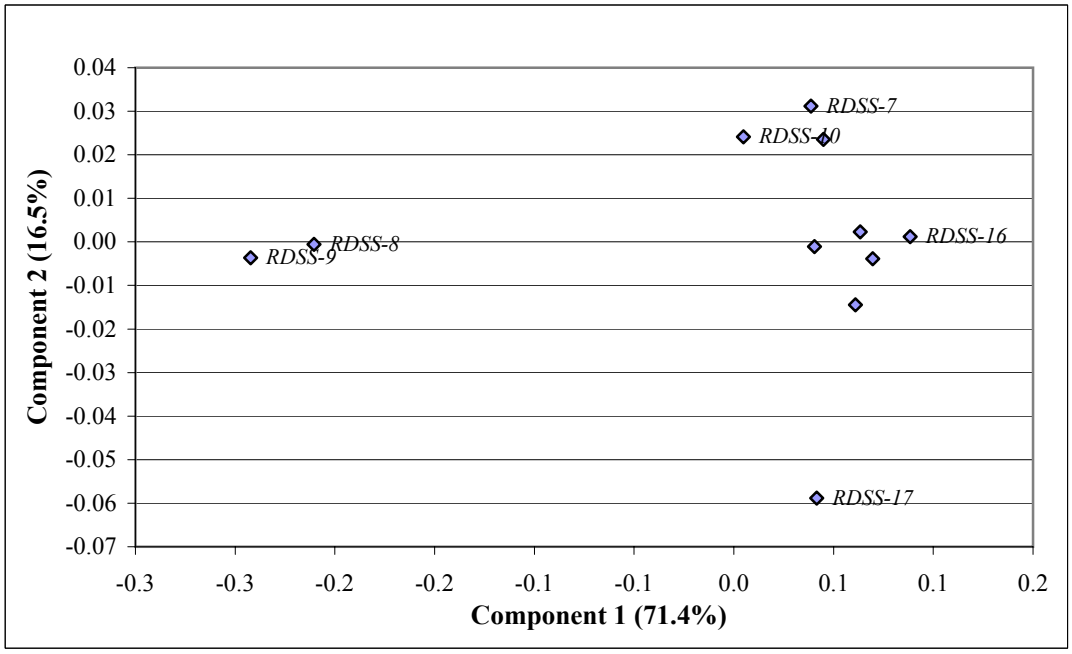


Figure 4.49 PCA Analysis for Dissolved Runoff Concentrations

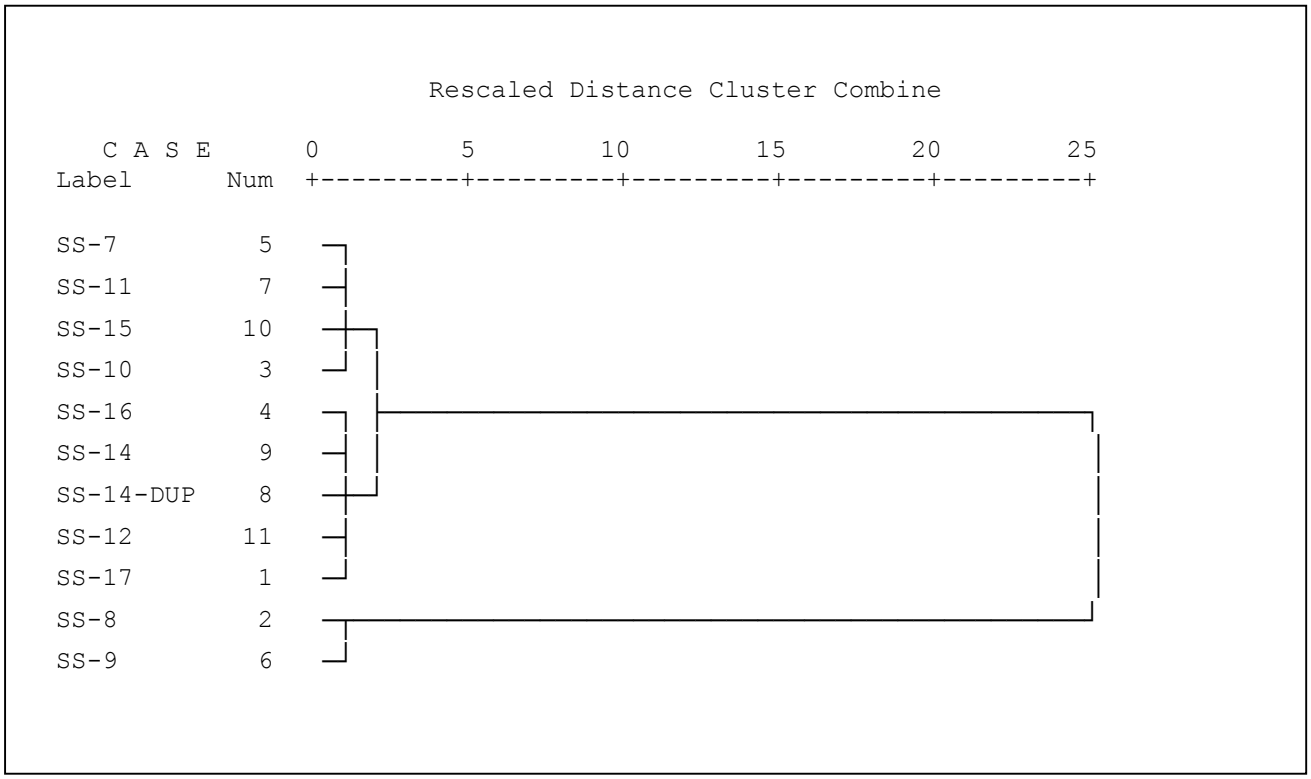


Figure 4.50 Dissolved Runoff Concentrations Dendogram using Ward Method

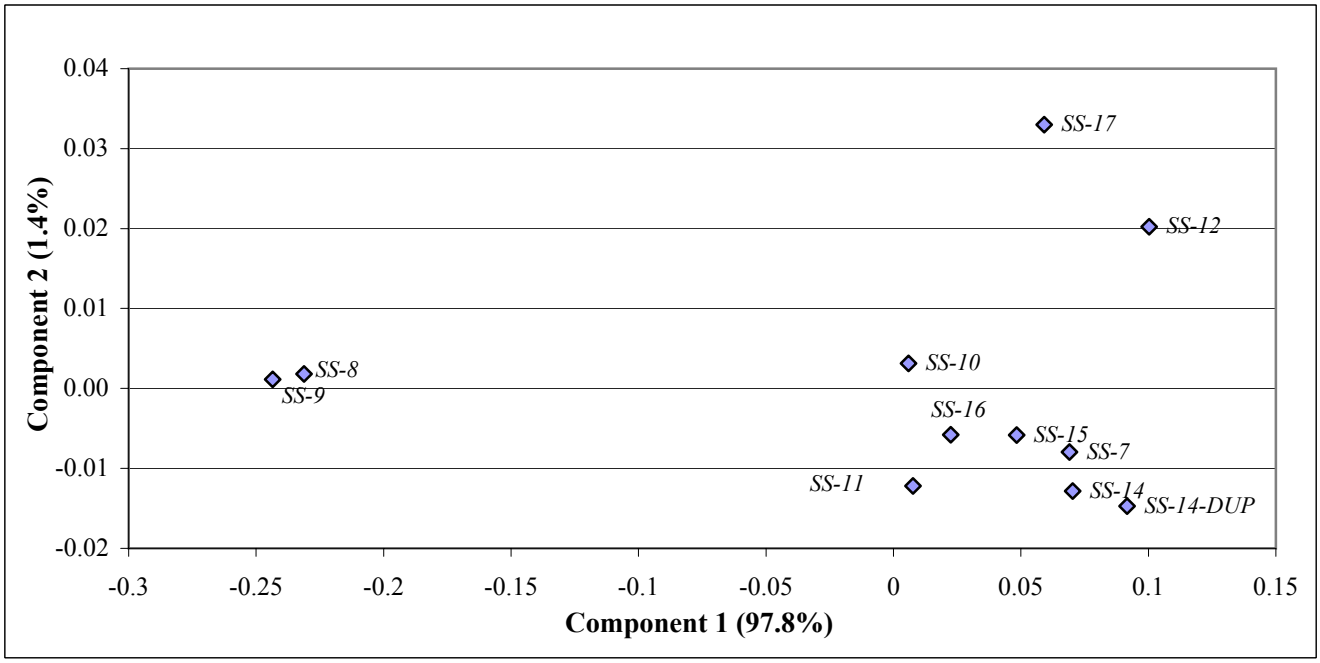


Figure 4.51 PCA Analysis for Suspended Runoff Concentrations

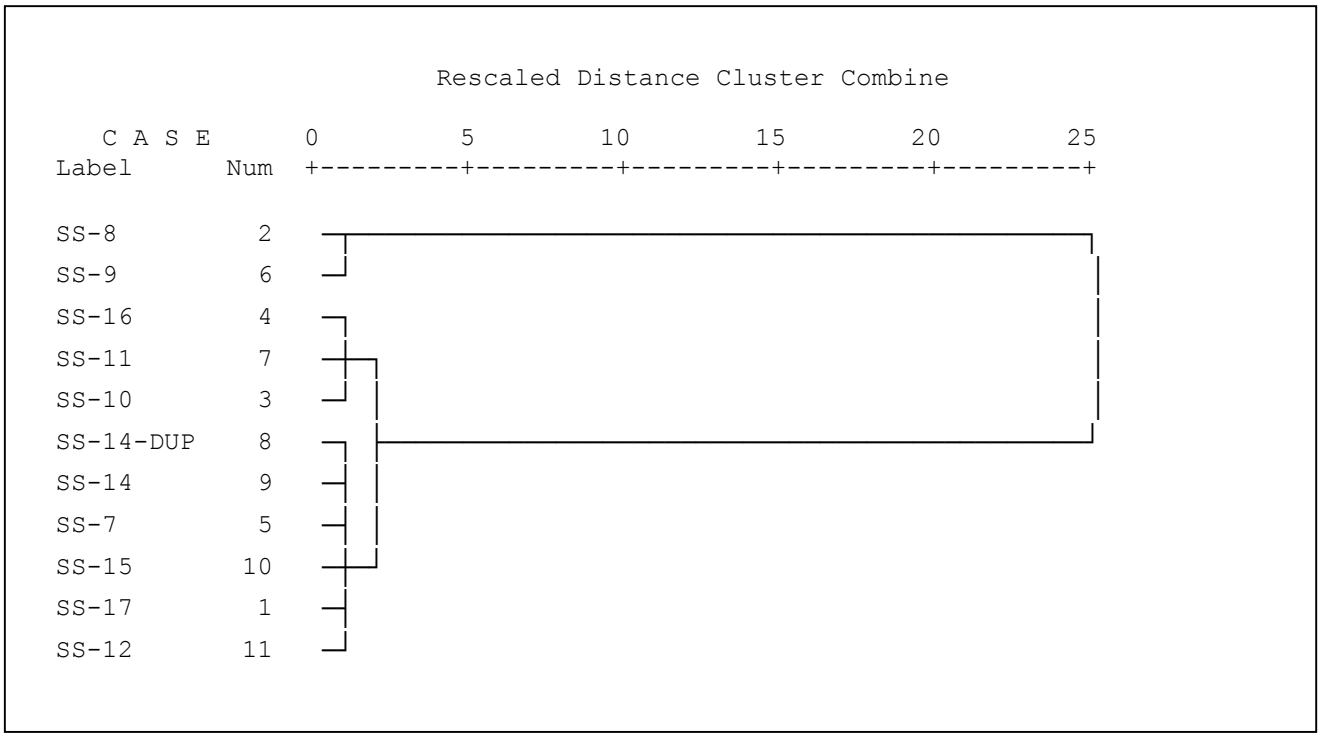


Figure 4.52 Suspended Runoff Concentrations Dendogram using Ward Method

PCA was completed along with a hierarchical cluster analysis. The PCA scatter plot of scores, Figure 4.53, seems to show that C603_JUNE is an outlier when compared to the other samples. This is supported when the hierarchical cluster analysis is considered, and it shows that the homologue fingerprint for C603_June has a very high percentage of OCDF. Figure 4.54 shows the fingerprint of this sample. It is also possible to see the other clusters in the air PCA scatter plot of scores. The PUF samples show a very different homologue distribution from the other samples. This is illustrated in Figure 4.55, the hierarchical cluster analysis, which shows that the PUF samples are quite different from the rest of the samples. The homologue fingerprint for all samples in this cluster is shown in Figure 4.56. These samples are all low in heavy homologues. This is most likely because of the high vapor pressure of the lighter PCDD/Fs compared to the more highly chlorinated homologues. It is more likely to find these homologue groups in the vapor phase than sorbed to particulate matter because of their high vapor pressure. This would also account for the different clusters found using both PCA and hierarchical cluster analysis.

4.3 TEMPORAL TRENDS

4.3.1 Historical versus Current Data

No historical in-stream water data for dioxin were available for comparison with the data obtained in this project. Therefore, this analysis of temporal trends only includes sediment and tissue data.

Dioxin concentrations in sediments from samples collected in Work Orders No. 4 and No. 7 were compared to data gathered by others in 1993 and 1994 (see University of Houston, 2001 for a summary of historical data) and 2001 (PBS&J and Parsons, 2001). It is noted, however, that differences in sampling and analytical methods used in the 1993-1994 study may limit the

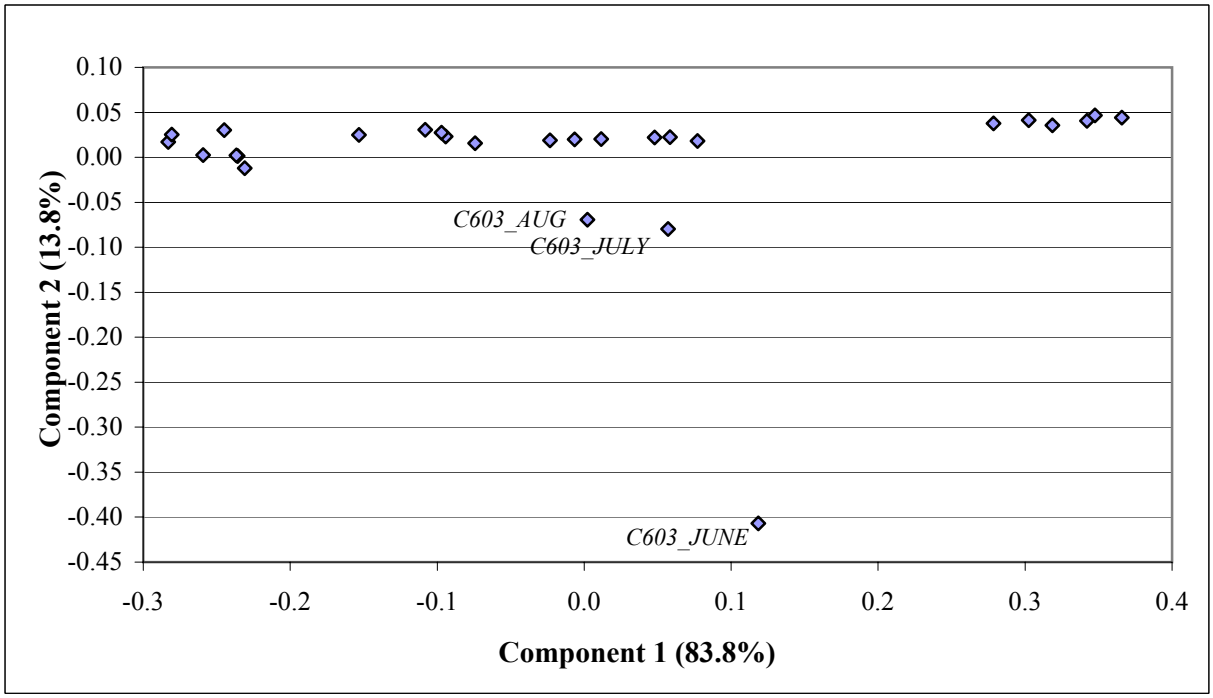


Figure 4.53 PCA Analysis for Ambient Air Concentrations

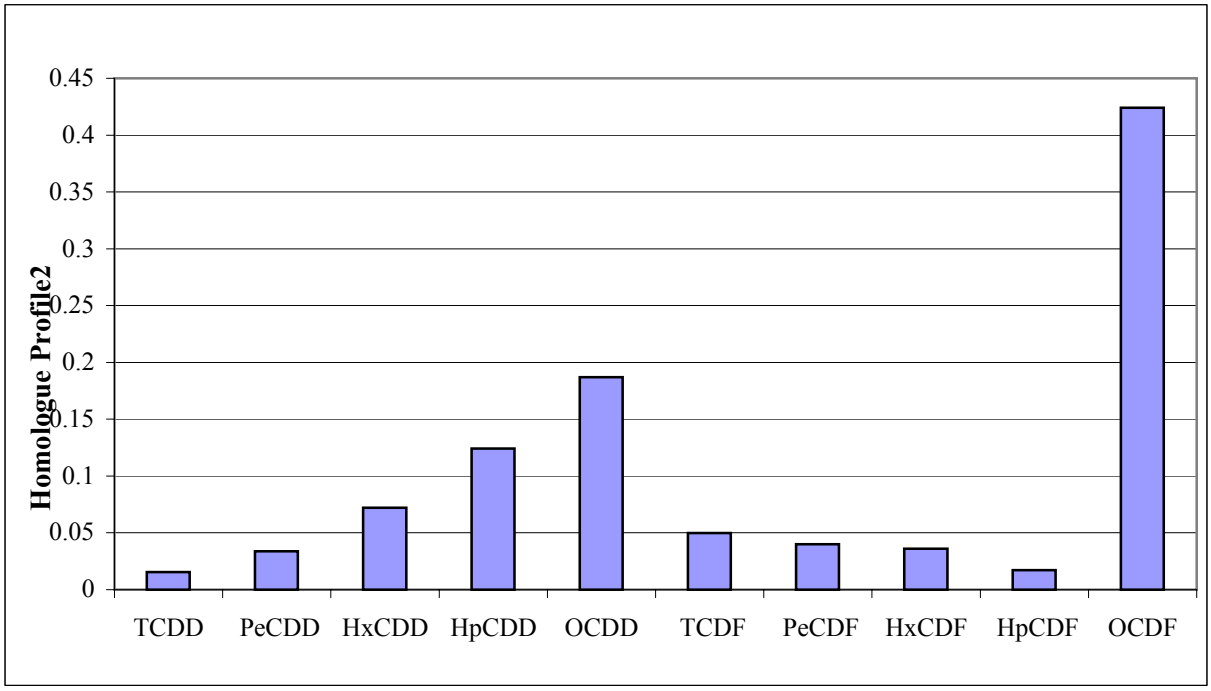


Figure 4.54 Homologue Profile for Sample C603-June

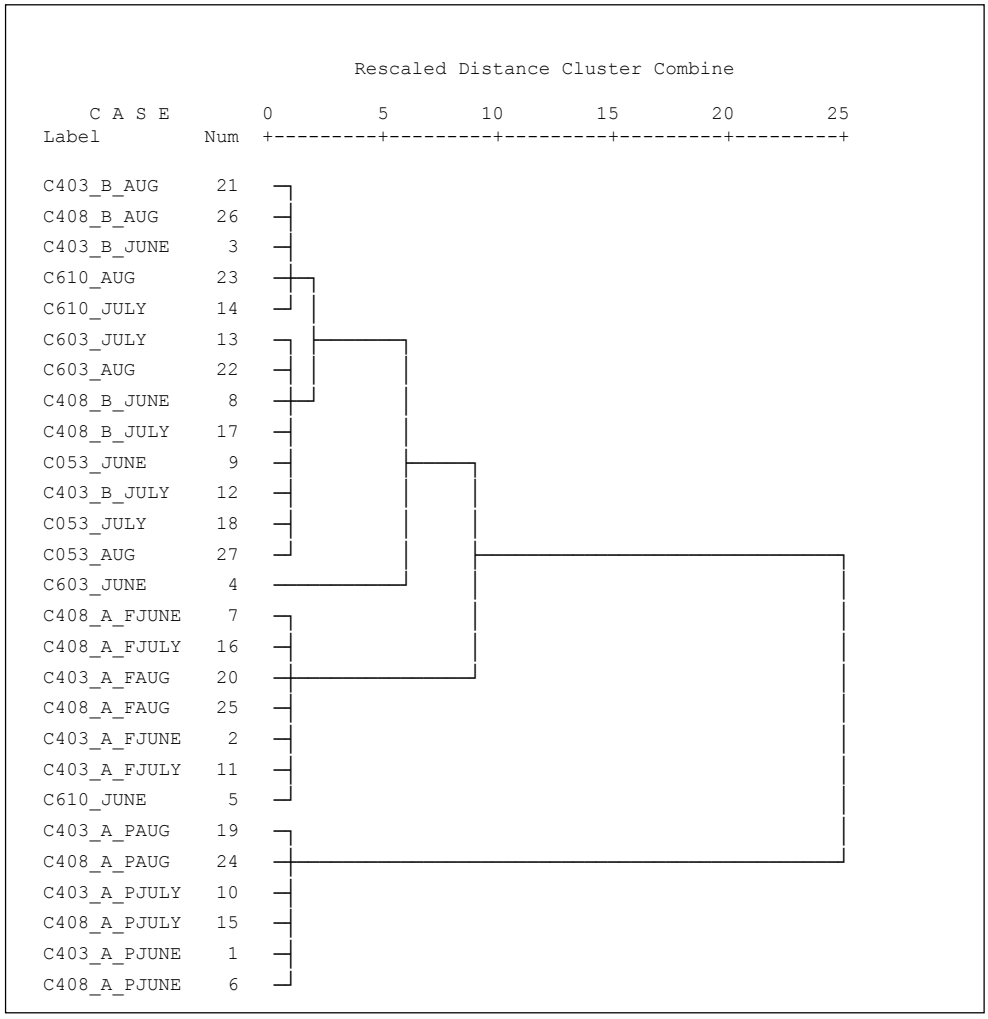


Figure 4.55 Summer Ambient Air Concentrations Dendogram using Ward Method

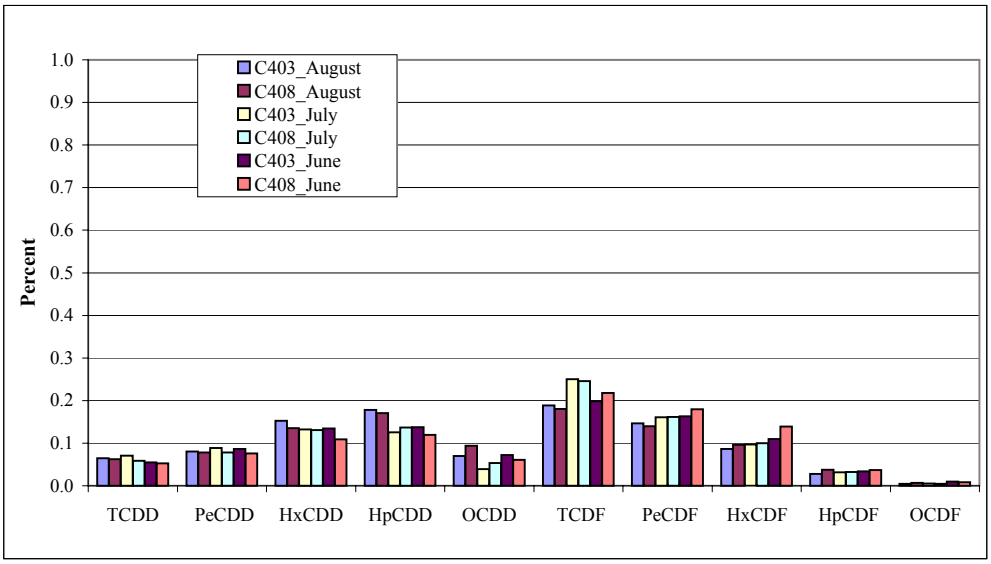


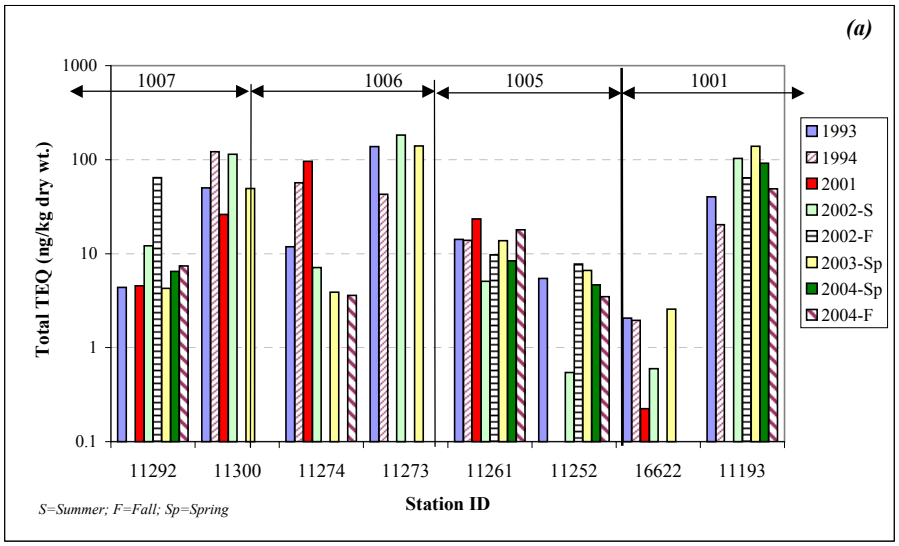
Figure 4.56 Homologue Profiles of Air Vapor (PUF) Concentrations

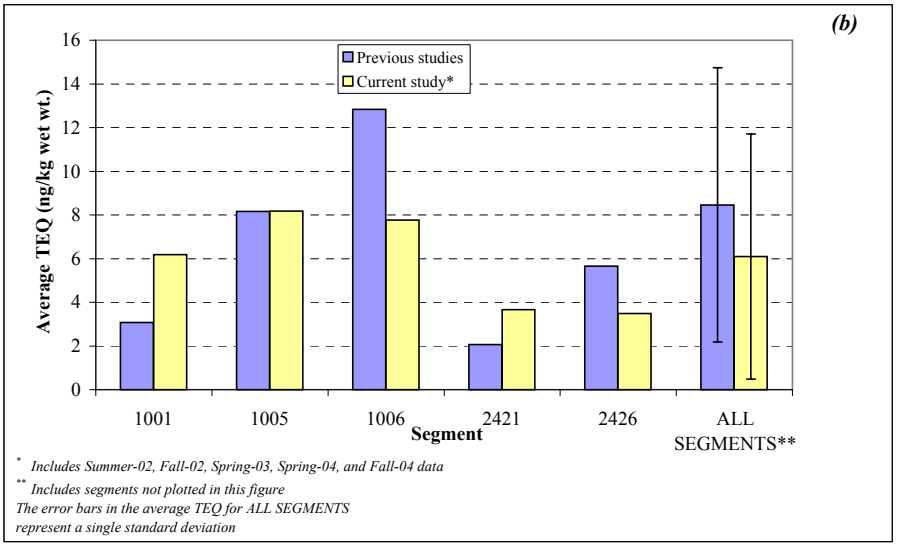
results of such comparison. The average TEQ concentration in sediment from previous studies (1993-2001) was 27.05 ng/kg dry wt., while the average TEQs measured in this study are 25.23, 18.70, 17.58, 42.70, and 68.80 ng/kg dry wt. for Summer-02, Fall-02, Spring-03, Spring-04, and Fall-04, respectively.

Figure 4.57a shows a comparison of total TEQ concentrations in sediment from previous studies and data from this study at selected stations. Overall, current sediment TEQs in segments 1006 and 1001 (San Jacinto River) were higher than the values measured in previous studies, whereas they were lower in segments 1007 and 1005.

A comparison of the levels of dioxins in tissue samples to historical data was also conducted. Table 4.17 presents a summary of tissue data from previous studies by segment and Table 4.18 shows the average total toxicity equivalent of the tissue samples segregated by species for each of the segments in the study area for both previous and current studies. The TEQ was calculated for historical data using the Texas TEF. The data in these tables are not normalized for lipid content of the sample as information on percent lipids was not available for all the historical data gathered. Table 4.18 shows that overall the concentrations measured in 2002, 2003, and 2004 are similar to those observed during the Summer 2001 sampling and higher than the ones observed prior to 1996 for most cases (especially catfish).

Figures 4.57b and c show average TEQs in catfish and crab for a number of segments in the study area. It can be seen from Figure 4.57b that average TEQ concentrations in catfish measured in the current study are higher than those measured previously for segments 1001 and 2421, but not for segment 1005, 1006, or 2426. The mean of the total TEQ (using data for the





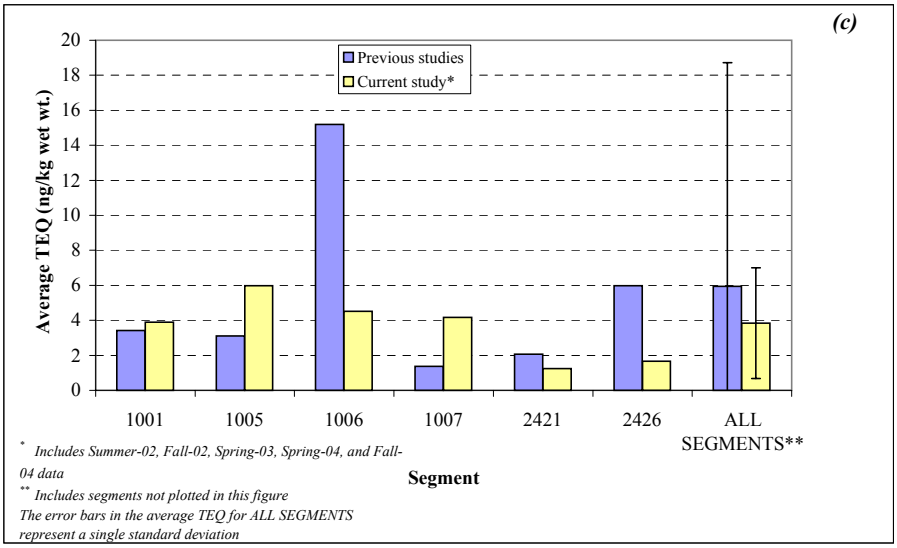


Figure 4.57 Comparison of Past and Current TEQ Levels
(a) Sediment (b) Catfish (c) Crab

Table 4.17 Summary of Total TEQ in HSC Tissue between 1989-2001

	Catfish	Crab	Fish[a]	Oyster	Total
# samples	43	43	32	16	134
Minimum (ng/kg wet wt.)	0.65	0.50	0.06	0.30	0.06
Maximum (ng/kg wet wt.)	22.46	63.38	7.84	8.72	63.38
Average (ng/kg wet wt.)	8.40	5.89	1.84	3.92	5.49
Standard deviation (ng/kg wet wt.)	6.21	12.63	1.85	3.06	8.41
Median (ng/kg wet wt.)	6.54	3.31	1.09	3.46	3.27

[a] all species other than catfish, including: spotted seatrout, southern flounder, Atlantic croaker, red drum, black drum
Non-detects assumed as 1/2 MDL

Table 4.18 Average Texas TEQ for Tissue Samples for All Segments (ng/kg wet wt.)

Segment	Year	Data	Catfish	Crab	Fish	Oyster	Total
	1993	Average TEQ	1.67	2.71			2.19
		# of Samples	*2*	*2*			*4*
	2001	Average TEQ	4.47	4.11			4.29
		# of Samples	*2*	*2*			*4*
	Summer 2002	Average TEQ	6.02	2.61			4.32
		# of Samples	*3*	*3*			*6*
1001 - San Jacinto River Tidal	Fall 2002	Average TEQ	3.34	1.36			2.68
		# of Samples	*2*	*1*			*3*
	Spring 2003	*Average TEQ*	3.29	2.44			2.86
		# of Samples	*2*	*2*			*4*
	Spring 2004	*Average TEQ*	3.63	2.71			3.17
		# of Samples	*2*	*2*			*4*
	Fall 2004	*Average TEQ*	*14.69*	*9.76*			12.22
		# of Samples	*2*	*2*			*4*
1001 Average TEQ			*5.35*	*3.76*			*4.58*
1001 # of Samples			*15*	*14*			*29*
	1989	Average TEQ	14.77		0.19	7.66	8.79
		# of Samples	*2*		*1*	*3*	*6*
	1990	Average TEQ		3.63	0.33		1.98
		# of Samples		*2*	*2*		*4*
	1993	Average TEQ	3.28	4.20			3.65
		# of Samples	*3*	*2*			*5*
	1994	Average TEQ				3.68	3.68
		# of Samples				*1*	*1*
	1996	Average TEQ		1.42	1.63	3.28	1.88
		# of Samples		*5*	*2*	*2*	*9*
1005 - Houston Ship Channel/San Jacinto River Tidal	2001	Average TEQ	8.87	5.70			7.29
		# of Samples	*2*	*2*			*4*
	Summer 2002	Average TEQ	7.44	7.67			7.55
		# of Samples	*4*	*4*			*8*
	Fall 2002	Average TEQ	8.61	3.67			6.14
		# of Samples	*2*	*2*			*4*
	Spring 2003	*Average TEQ*	7.10	4.28			5.69
		# of Samples	*4*	*4*			*8*
	Spring 2004	*Average TEQ*	3.36	4.19			3.77
		# of Samples	*3*	*3*			*6*
	Fall 2004	*Average TEQ*	15.15	9.30			12.23
		# of Samples	*3*	*3*			*6*
1005 Average TEQ			*8.18*	*4.81*	*0.82*	*5.54*	*5.82*
# of Samples			*23*	*27*	*5*	*6*	*61*
	1989	Average TEQ	3.13	61.80			32.46
		# of Samples	*2*	*2*			*4*
	1990	Average TEQ	7.65	3.53	0.93	8.21	5.59
1006 - Houston Ship Channel Tidal		*# of Samples*	*3*	*1*	*2*	*2*	*8*
	1993	Average TEQ		2.26	5.18		3.23
		# of Samples		*2*	*1*		*3*
	1996	Average TEQ	11.20	4.06	3.32		5.48
		# of Samples	*2*	*5*	*2*		*9*

Table 4.18 Average Texas TEQ for Tissue Samples for All Segments (ng/kg wet wt.)- Cont'd

Segment	Year	Data	Catfish	Crab	Fish	Oyster	Total
	Summer 2002	Average TEQ	6.75	4.91			5.83
		# of Samples	*6*	*6*			*12*
	Fall 2002	Average TEQ					
		# of Samples					
1006 - Houston Ship	Spring 2003	*Average TEQ*	8.41	2.72			5.56
Channel Tidal		*# of Samples*	*6*	*6*			*12*
	Spring 2004	*Average TEQ*	6.81	4.05			5.43
		# of Samples	*6*	*6*			*12*
	Fall 2004	*Average TEQ*	*10.42*	*8.247833*			9.34
		# of Samples	*3*	*3*			*6*
1006 Average TEQ			*7.67*	*7.96*	*2.73*	*8.21*	*7.45*
# of Samples			*28*	*31*	*5*	*2*	*66*
1006 Average TEQ without 1989 crabs			*7.67*	*7.96*	*2.73*	*8.21*	*7.45*
# of Samples without 1989 crabs			*28*	*31*	*5*	*2*	*66*
	2001	Average TEQ		2.76			2.76
		# of Samples		2			*2*
	Summer 2002	Average TEQ	8.08	3.65			5.86
		# of Samples	*7*	*7*			*14*
	Fall 2002	Average TEQ	3.86				3.86
1007 - Houston Ship		*# of Samples*	*2*				*2*
Channel	Spring 2003	*Average TEQ*	6.46	4.45			5.38
		# of Samples	*6*	*7*			*13*
	Spring 2004	*Average TEQ*	9.47	3.30			6.39
		# of Samples	*7*	*7*			*14*
	Fall 2004	*Average TEQ*	*8.52*	*6.70*			7.61
		# of Samples	*3*	*3*			*6*
1007 Average TEQ			*7.80*	*4.05*			5.89
1007 # of Samples			*25*	*26*			*51*
	Summer 2002	Average TEQ	1.29	2.13			1.71
		# of Samples	*2*	*2*			*4*
	Spring 2003	*Average TEQ*	3.08	2.66			2.87
1013 - Buffalo Bayou		*# of Samples*	*2*	*2*			*4*
Tidal	Spring 2004	*Average TEQ*	0.57				0.57
		# of Samples	*2*				*2*
	Fall 2004	*Average TEQ*					
		# of Samples					
1013 Average TEQ			*1.65*	*2.39*			1.95
1013 # of Samples			*6*	*4*			*10*
	1990	Average TEQ			0.39	2.10	1.53
		# of Samples			*1*	*2*	*3*
	1994	Average TEQ		1.84			1.84
		# of Samples		*3*			*3*
	1996	Average TEQ				3.46	3.46
		# of Samples				*2*	*2*
	2001	Average TEQ	2.06	2.18			2.12
		# of Samples	*6*	*6*			*12*
2421 - Upper Galveston	Summer 2002	Average TEQ	2.54	1.58			2.06
Bay		*# of Samples*	*5*	*5*			*10*
	Fall 2002	Average TEQ		0.32			0.32
		# of Samples		*1*			*1*
	Spring 2003	*Average TEQ*	5.05	0.90			2.98
		# of Samples	*5*	*5*			*10*
	Spring 2004	*Average TEQ*	4.80	1.97			3.38
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*	*1.18*	*1.50*			1.34
		# of Samples	*1*	*1*			*2*
2421 Average TEQ			*3.13*	*1.58*	*0.39*	*2.78*	*2.28*
# of Samples			*18*	*22*	*1*	*4*	*45*

Table 4.18 Average Texas TEQ for Tissue Samples for All Segments (ng/kg wet wt.)- Cont'd

Segment	Year	Data	Catfish	Crab	Fish	Oyster	Total
	1996	Average TEQ	6.98		0.50		2.12
		# of Samples	*1*		*3*		*4*
	2001	Average TEQ	4.34	5.99			5.16
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	3.92	1.20			2.56
		# of Samples	*4*	*4*			*8*
2426 - Tabbs Bay	Fall 2002	Average TEQ	4.24	3.40			3.82
		# of Samples	*2*	*2*			*4*
	Spring 2003	*Average TEQ*	3.63	1.35			2.49
		# of Samples	*2*	*2*			*4*
	Spring 2004	*Average TEQ*	2.58	0.79			1.69
		# of Samples	*2*	*2*			*4*
	Fall 2004	*Average TEQ*	*1.79*	*2.50*			2.14
		# of Samples	*1*	*1*			*2*
2426 Average TEQ			*3.82*	*2.03*	*0.50*		*2.70*
# of Samples			*13*	*12*	*3*		*28*
	2001	Average TEQ	8.65	4.77			6.71
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	6.89	5.65			6.27
		# of Samples	*2*	*2*			*4*
	Fall 2002	Average TEQ	7.18	3.11			5.14
		# of Samples	*1*	*1*			*2*
2427 - San Jacinto Bay	Spring 2003	*Average TEQ*	9.90	9.17			9.53
		# of Samples	*1*	*1*			*2*
	Spring 2004	*Average TEQ*	4.32	3.81			4.06
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*	*4.89*	*4.79*			4.84
		# of Samples	*1*	*1*			*2*
2427 Average TEQ			*6.96*	*5.28*			6.12
2427 # of Samples			*7*	*7*			*14*
	2001	Average TEQ	2.66	1.09			1.87
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	3.48	0.88			2.18
		# of Samples	*2*	*2*			*4*
	Fall 2002	Average TEQ		1.97			1.97
		# of Samples		*1*			*1*
2428 - Black Duck Bay	Spring 2003	*Average TEQ*	3.25	2.60			2.93
		# of Samples	*2*	*2*			*4*
	Spring 2004	*Average TEQ*	1.40	1.87			1.63
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*	*0.93*	*1.32*			1.13
		# of Samples	*1*	*1*			*2*
2428 Average TEQ			*2.64*	*1.89*			2.26
2428 # of Samples			*7*	*7*			*14*
	2001	Average TEQ	17.11	5.50			11.30
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	4.90	5.13			5.01
		# of Samples	*2*	*2*			*4*
	Fall 2002	Average TEQ	5.51	5.53			5.52
		# of Samples	*2*	*2*			*4*
2429 - Scott Bay	Spring 2003	*Average TEQ*	12.79	3.14			7.97
		# of Samples	*1*	*1*			*2*
	Spring 2004	*Average TEQ*	5.22	5.90			5.56
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*	*13.79*	*11.16*			12.48
		# of Samples	*1*	*1*			*2*
2429 Average TEQ			*8.72*	*5.88*			*7.30*
2429 # of Samples			*8*	*8*			*16*

Table 4.18 Average Texas TEQ for Tissue Samples for All Segments (ng/kg wet wt.)- Cont'd

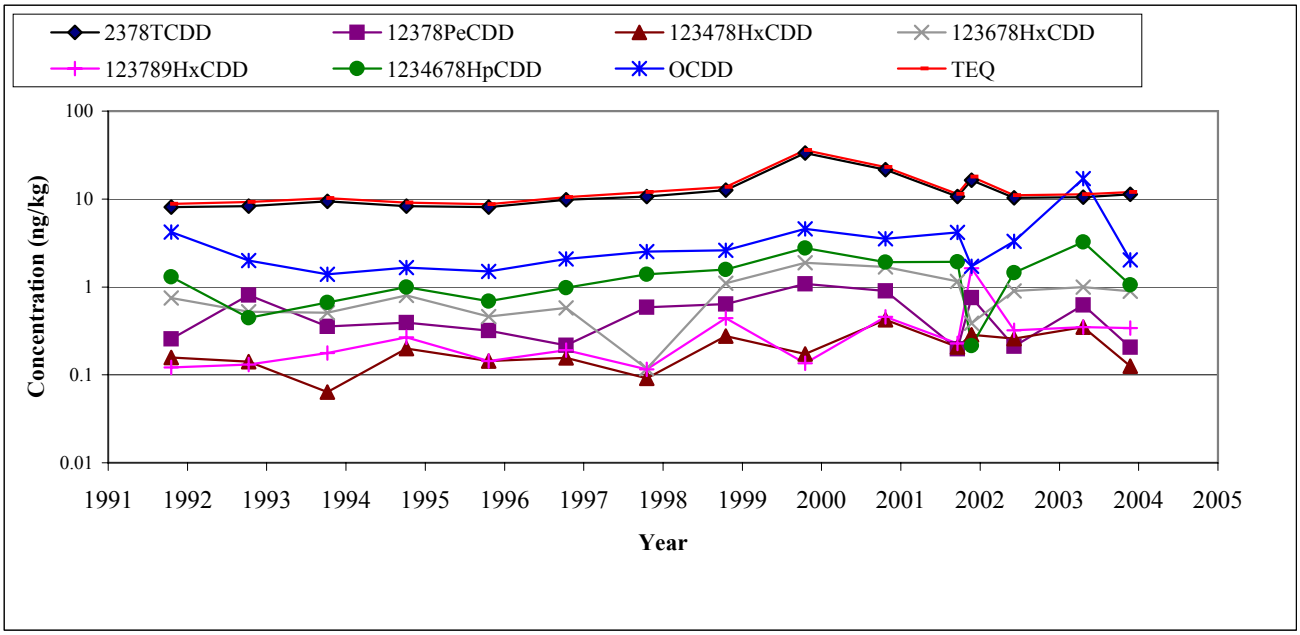
Segment	Year	Data	Catfish	Crab	Fish	Oyster	Total
2430 - Burnett Bay	2001	Average TEQ	6.53	4.34			5.43
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	6.44	4.46			5.45
		# of Samples	*3*	*3*			*6*
	Fall 2002	Average TEQ	10.52	4.55			7.54
		# of Samples	*1*	*1*			*2*
	Spring 2003	*Average TEQ*	10.32	4.54			7.43
		# of Samples	*2*	*2*			*4*
	Spring 2004	*Average TEQ*	12.16	5.01			8.59
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*	*5.38*	*4.32*			4.85
		# of Samples	*1*	*1*			*2*
2430 Average TEQ			*8.28*	*4.52*			6.40
2430 # of Samples			*9*	*9*			*18*
2436 - Barbours Cut	2001	Average TEQ	8.84	4.72			6.78
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	2.23	3.10			2.66
		# of Samples	*2*	*2*			*4*
	Fall 2002	Average TEQ	4.11	2.10			3.10
		# of Samples	*1*	*1*			*2*
	Spring 2003	*Average TEQ*	4.81	0.80			2.80
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*					
		# of Samples					
2436 Average TEQ			*4.44*	*2.76*			*3.60*
2436 # of Samples			*5*	*5*			*10*
2438 Bayport Channel	2001	Average TEQ	*5.48*	*1.81*			3.65
		# of Samples	*1*	*1*			*2*
	Summer 2002	Average TEQ	1.53	0.92			1.22
		# of Samples	*2*	*2*			*4*
	Fall 2002	Average TEQ		0.45			0.45
		# of Samples		*1*			*1*
	Spring 2003	*Average TEQ*	0.79	0.74			0.77
		# of Samples	*1*	*1*			*2*
	Fall 2004	*Average TEQ*					
		# of Samples					
2438 Average TEQ			*2.33*	*0.97*			*1.57*
2438 # of Samples			*4*	*5*			*9*

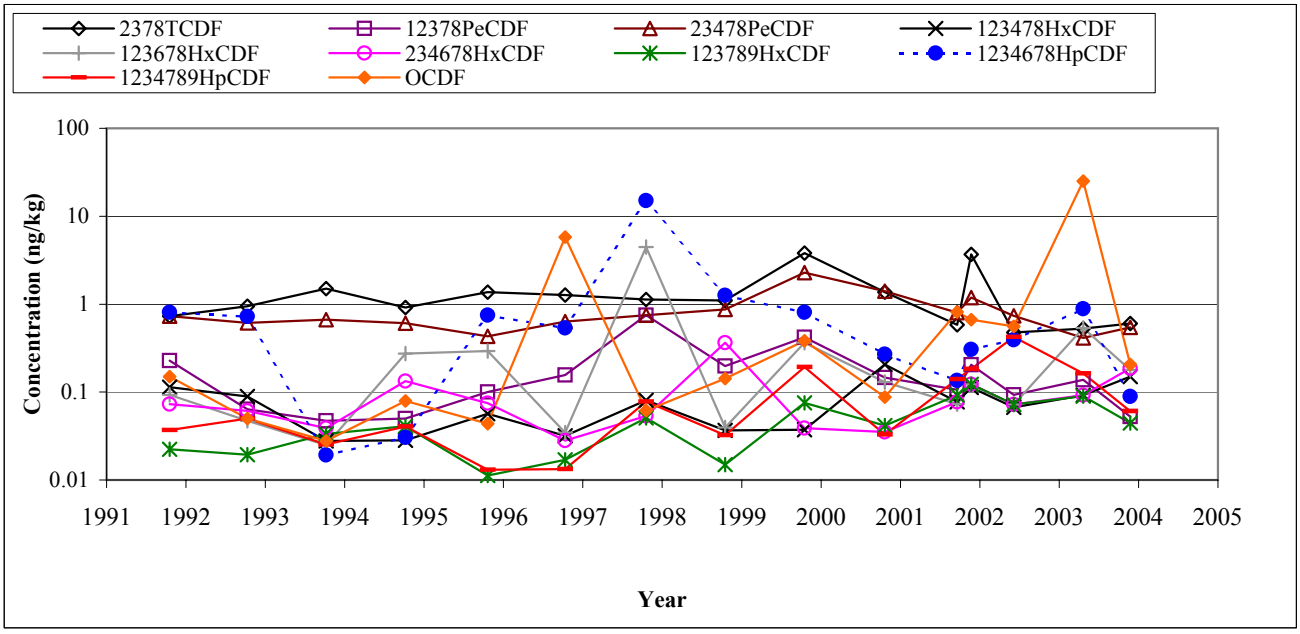
Notes:

- When only 1 sample was available for a segment, the TEQ for that single sample was included rather than the average TEQ
- TEQs for the stations that had duplicate samples collected were included in the calculations as the average of the two samples

stations measured both in previous studies and in this study) was found to be 8.46 and 6.10 ng/kg wet wt. for the previous and current studies, respectively. Overall, total TEQ concentrations from previous studies were significantly higher than their counterparts from this study (p-value=0.04). Similar observations were made for crabs (Figure 4.57c). The average TEQ in crabs from previous studies is 5.94 ng/kg-wet wt., while the average TEQ in crabs from this study is 3.84 ng/kg wet wt. The two TEQ datasets, however, were not found to be significantly different (p-value=0.29) when compared using the t-test.

In another analysis, the temporal trends for each of the dioxin congeners in catfish at a location near the San Jacinto Monument (station 11261) were evaluated (Figure 4.58). This analysis was conducted using the data collected from 1992 to 2001 by the GCWDA/Donohue facilities and includes results from Summer 2002, fall 2002, Spring 2003, Spring 2004, and fall 2004. Overall, PCDDs were higher than PCDFs with 2378-TCDD showing the highest levels throughout the entire period. It can be seen from Figure 4.58 that the PCDD lines remain relatively parallel from 1992 to 2002, with the exception of that for 123678-HxCDD, for which the 1997 measurement did not follow the trend. Conversely, the PCDF lines did not follow the same trends, especially those for congeners 12378-PeCDF, 123678-HxCDF, 234678-HxCDF, 1234678-HpCDF and OCDF, which differ substantially from the remaining curves after 1995. This may suggest a change in dioxin sources around 1995. Data in Figure 4.58 also indicate that, in general, there has been little change in congener concentrations with time. Linear regressions for each of the curves showed that, for most of the congeners the slope of the best-fit line was not significantly different from zero. The only exceptions were the congeners 12378-PeCDD, 123789-HxCDF, and 1234789-HpCDF, which exhibited a slightly increasing trend over time (p-





Data from GCWDA/Donohue Study (1992-2001) and this study (2002, 2003, and 2004)
Data normalized to 3% lipid content

Figure 4.58 Time Series of Dioxin Concentrations in Catfish at Location 11261

values between 0.005 and 0.04 and r^2 between 0.31 and 0.46). Results from a Mann-Kendall test for this data set confirmed the results from the linear regressions. The total TEQ showed no significant trend with time (*p*-value=0.16).

4.3.2 Time Trends of Current Data

Concentrations at the locations sampled during all five sampling events (Summer 2002, Fall 2002, Spring 2003, Spring 2004, and Fall 2004) of this project were analyzed using the Mann-Kendall test to evaluate possible trends over time. The Mann-Kendall test was selected because it allows for analysis of non-normally distributed data. The test was completed for all congeners at the selected stations for all media. The result was considered significant if the value associated with a given Mann-Kendall statistic (S) was less than the alpha value of 0.05. This would only occur for a value of S greater than 7. A summary of the procedure to compute S values is included in Appendix F.

Table 4.19 presents a summary of the data trends. Each data "series" is comprised of five data points that correspond to the measurements during each of the sampling events. Because the concentrations were ordered chronologically, the results are showing trends over time. The values in the table are the resultant probability given by the S-value derived from the critical values table presented in Appendix F. Only at a value less than 0.05 would a trend be considered significant. In Table 4.19, the values highlighted in orange indicate a significant upward trend in the concentrations of that congener over the five-sample time period. Values highlighted in light blue show a significant downward trend in concentrations of that congener for the sampling period. The value 0.592 is highlighted in white and indicates that there is no trend over time.

Table 4.19 Values Probability Results for Mann-Kendall Test for Trend

Media Station	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	Total TEQ
sed11193	0.242	0.242	0.117	0.080	0.117	0.117	0.080	0.242	0.408	0.242	0.408	0.408	0.408	0.408	0.080	0.592	0.117	0.242
sed11252	0.592	0.592	0.408	0.592	0.408	0.408	0.592	0.592	0.408	0.592	0.325	0.408	0.242	0.592	0.592	0.325	0.408	0.408
sed11261	0.117	0.117	0.180	0.117	0.242	0.242	0.117	0.042	0.242	0.180	0.242	0.592	0.117	0.035	0.408	0.242	0.242	0.117
sed11280	0.028	0.024	0.117	0.042	0.042	0.117	0.042	0.028	0.117	0.180	0.117	0.117	0.408	0.028	0.117	0.080	0.042	0.028
sed11292	0.408	0.592	0.408	0.408	0.242	0.242	0.242	0.408	0.242	0.117	0.592	0.242	0.242	0.242	0.408	0.117	0.080	0.408
sed11340	0.408	0.242	0.408	0.408	0.242	0.500	0.242	0.592	0.242	0.180	0.117	0.592	0.592	0.242	0.500	0.325	0.242	0.242
sed13342	0.500	0.325	0.242	0.408	0.592	0.408	0.242	0.117	0.325	0.500	0.408	0.080	0.180	0.117	0.592	0.080	0.408	0.408
susp11193	0.408	0.408	0.042	0.117	0.117	0.042	0.042	0.408	0.408	0.592	0.592	0.592	0.408	0.242	0.592	0.117	0.042	0.408
susp11252	0.042	0.242	0.592	0.408	0.117	0.242	0.242	0.042	0.042	0.042	0.042	0.117	0.042	0.242	0.042	0.042	0.042	0.042
susp11261	0.028	0.408	0.242	0.117	0.042	0.117	0.117	0.042	0.408	0.242	0.242	0.408	0.592	0.592	0.592	0.242	0.242	0.042
susp11280	0.242	0.242	0.592	0.242	0.117	0.592	0.408	0.242	0.117	0.242	0.408	0.117	0.117	0.408	0.242	0.592	0.042	0.242
susp13342	0.117	0.408	0.117	0.242	0.242	0.117	0.242	0.117	0.117	0.117	0.117	0.042	0.117	0.117	0.042	0.042	0.117	0.117
susp14560	0.117	0.242	0.117	0.117	0.117	0.242	0.592	0.408	0.408	0.408	0.408	0.592	0.592	0.242	0.117	0.242	0.592	0.408
dis11193	0.592	0.592	0.242	0.408	0.592	0.408	0.592	0.592	0.408	0.117	0.042	0.592	0.242	0.408	0.408	0.408	0.242	0.592
dis11252	0.408	0.592	0.242	0.042	0.042	0.117	0.117	0.592	0.592	0.408	0.592	0.592	0.117	0.117	0.592	0.408	0.117	0.408
dis11261	0.117	0.408	0.408	0.592	0.408	0.592	0.408	0.408	0.408	0.408	0.592	0.408	0.592	0.242	0.408	0.408	0.408	0.408
dis11280	0.242	0.242	0.408	0.408	0.242	0.408	0.242	0.117	0.592	0.592	0.592	0.242	0.242	0.242	0.242	0.592	0.117	0.117
dis13342	0.592	0.117	0.117	0.408	0.242	0.242	0.242	0.408	0.117	0.242	0.117	0.408	0.117	0.117	0.408	0.408	0.408	0.408
dis14560	0.117	0.592	0.408	0.408	0.242	0.592	0.592	0.408	0.242	0.592	0.408	0.592	0.242	0.242	0.242	0.242	0.408	0.242
cat11193	0.408	0.592	0.592	0.592	0.408	0.408	0.592	0.408	0.117	0.592	0.242	0.592	0.325	0.242	0.042	0.042	0.042	0.408
cat11252	0.408	0.408	0.117	0.592	0.408	0.408	0.592	0.408	0.408	0.592	0.242	0.325	0.242	0.242	0.117	0.408	0.028	0.592
cat11261	0.592	0.080	0.242	0.408	0.242	0.325	0.592	0.592	0.042	0.242	0.592	0.117	0.592	0.117	0.592	0.242	0.408	0.592
cat11280	0.408	0.592	0.592	0.592	0.242	0.180	0.242	0.242	0.592	0.592	0.242	0.592	0.325	0.242	0.042	0.117	0.042	0.408
cat11292	0.242	0.117	0.408	0.117	0.242	0.242	0.408	0.242	0.042	0.242	0.180	0.592	0.592	0.242	0.325	0.042	0.117	0.242
cat13342	0.242	0.117	0.408	0.117	0.042	0.408	0.500	0.408	0.408	0.242	0.242	0.408	0.117	0.500	0.408	0.080	0.592	0.242
crab11193	0.408	0.592	0.080	0.408	0.080	0.592	0.408	0.408	0.592	0.500	0.500	0.242	0.117	0.117	0.592	0.117	0.408	0.408
crab11252	0.242	0.408	0.408	0.408	0.408	0.408	0.592	0.242	0.242	0.242	0.242	0.408	0.408	0.242	0.592	0.592	0.242	0.117
crab11261	0.592	0.408	0.408	0.035	0.242	0.408	0.592	0.408	242.000	0.592	0.242	0.408	0.592	0.325	0.408	0.180	0.242	0.592
crab13340	0.408	0.408	0.408	0.242	0.408	0.592	0.592	0.592	0.242	0.408	0.408	0.408	0.242	0.242	0.500	0.242	0.242	0.592
crab13342	0.117	0.408	0.242	0.242	0.408	0.408	0.242	0.408	0.325	0.117	0.408	0.408	0.242	0.242	0.408	0.028	0.242	0.117

significant downward trend
downward trend
no trend
upward trend
significant upward trend

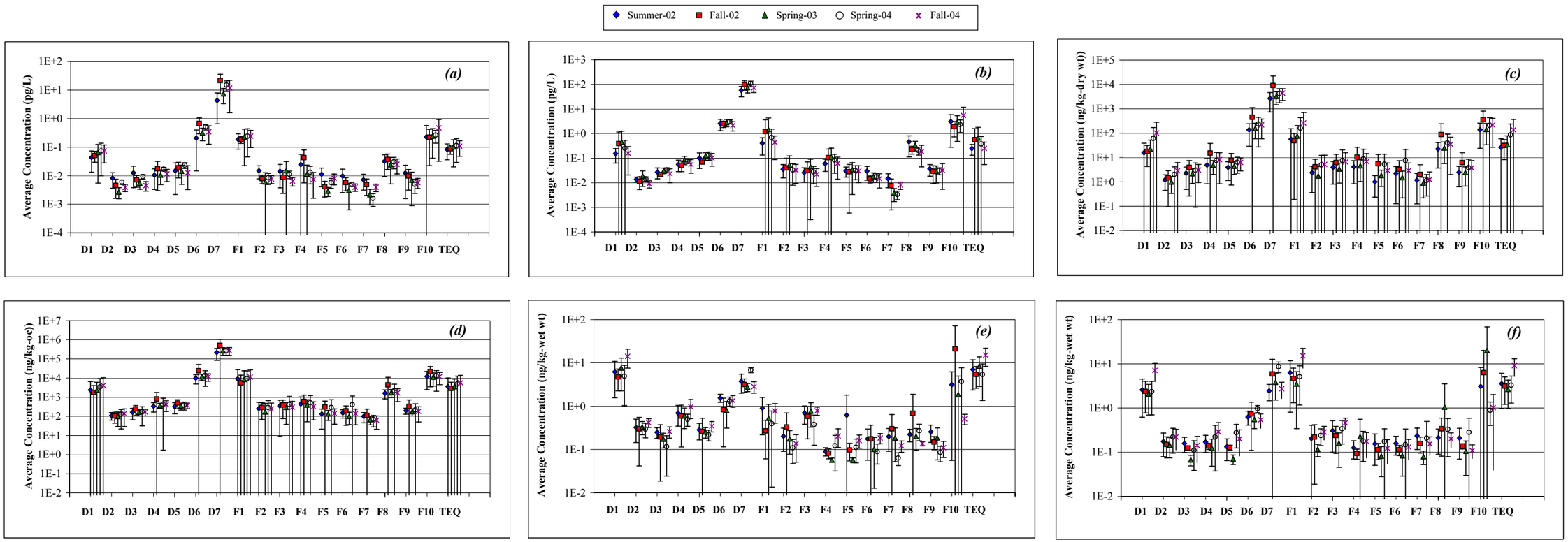
probabilities considered significant if the value is less than the alpha of 0.05
sed = bottom sediment
susp = suspended sediment
diss = dissolved
cat = catfish

Values in yellow indicate a general (non-significant) upward trend, and values highlighted in light green indicate a general downward trend in concentrations over time.

It appears that furans are decreasing more over the sampling period than dioxins. A majority of the green highlighted cells are on the furan half of the table. Also, all but one of the blue highlighted cells are on the furan side of the table. This is an interesting finding. In addition, thirteen of the 23 significantly increasing congeners were dioxins. At sediment station 11280, the TEQ is showing a significant upward trend, mainly because the concentrations measured in 2004 are dramatically higher than the ones measured in the previous events. Of the 24 congeners showing significant decrease over time, all but one, 2378-TCDD sampled at sediment station 11252, are furan congeners. When congeners showing no trend, (S=0) are taken into account, the overall trend of all data at all stations appears to be downward. OCDD is the only congener which appears to be holding steady with a slight increase at most sampling stations and sampling media.

4.4 SEASONAL TRENDS

Seasonal trends in data collected in this project were also analyzed. Figure 4.59 shows the average congener profiles for the different media/season for the stations that were sampled during each event. In general, the profiles did not change significantly from one season to another. Exceptions to note are 2378-TCDD and 2378-TCDF in fish and crab samples, whose averages showed a considerable increase in Fall 2004. To evaluate changes with season, data sets 1 (Summer-02), 2 (Fall-02), 3 (Spring-03), 4 (Spring-04), and 5 (Fall-04) for selected compounds (i.e., 2378-TCDD, OCCD, 2378-TCDF, 123678-HxCDF, OCDF, and TEQ) were compared to



Error bars correspond to the 95% confidence intervals
2378-PCDDs indicated by a letter D followed by a number, with D1 being TCDD and D7 OCDD
2378-PCDFs indicated by a letter F followed by a number, with F1 being TCDF and F10 OCDF

Figure 4.59 Seasonal Variation of Dioxins in the Houston Ship Channel
(a) Dissolved (b) Suspended (c) Sediment (d) Sediment-oc (e) Catfish (f) Crab

each other using a Wilconox Signed Rank test[9]. The goal was to find if there was a significant difference between any data sets. Dataset one was compared to five, four, three, and two. Dataset two was also compared to datasets three, four, and five, dataset three was compared to four and five, and dataset four was compared to five. This resulted in a comparison between all datasets. This test was performed purely to discover differences, if any, between data of different time periods. A trend analysis was performed to check for differences over time and the results of that analysis were presented in the previous section.

An examination of the results for all five media considered in this analysis show some surprising similarities. As shown in Table 4.20, in all media except sediment, the test results show that there is a significant difference between sampling events one and four, three and four, and five and four for OCDD.

Overall, most of the differences in the congener concentrations between time periods occur with OCDD. This congener occurs in concentrations much higher than the other congeners, in part due to its chemical characteristics and in part due to sources of OCDD. A more complete analysis of the differences occurring in each media is presented below. All results are summarized in Table 4.20.

Dissolved

Using the Wilconox Signed Rank test, there are significant differences in OCDD concentrations between time periods 1-2, 2-3, 3-4, and 1-4. OCDD is generally the most common congener found in the environment, and it is not surprising to find differing

[9] Non-parametric alternative to the paired *t*-test that uses both sign and magnitude to determine differences between samples.

Table 4.20 Results of Wilconox Test for Seasonality

Congener	Compared Events[1]	Dissolved		Suspended		Sediment		Sediment-OC		Catfish		Catfish - % Lipid		Crab		Crab - % Lipid	
		Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
2378-TCDD	2-1	-0.524	0.600	-0.314	0.753	-1.183	0.237	-0.338	0.735	-0.524	0.600	-0.734	0.463	-0.405	0.686	-0.674	0.500
	3-2	-0.524	0.600	-1.572	0.116	-0.423	0.672	-0.676	0.499	-0.943	0.345	-1.782	0.075	-0.680	0.496	-0.271	0.786
	4-3	-0.314	0.753	-0.314	0.753	-0.169	0.866	-0.507	0.612	-1.992	0.046	-1.153	0.249	-0.542	0.588	0.944	0.345
	3-1	-0.135	0.893	-0.105	0.917	-1.572	0.116	-0.169	0.866	-0.524	0.600	-1.992	0.046	-0.944	0.345	-0.405	0.686
	4-1	-0.314	0.753	-0.943	0.345	-1.014	0.310	-0.507	0.612	-0.631	0.528	-0.314	0.753	-0.405	0.686	-0.944	0.345
	4-2	-0.943	0.345	-0.105	0.917	-0.169	0.866	-1.014	0.310	-0.105	0.917	-0.524	0.600	-0.135	0.893	-1.483	0.138
	5-1	-1.153	0.249	-0.524	0.600	-0.524	0.600	-0.507	0.612	-1.992	0.046	-1.572	0.116	-2.023	0.043	-2.023	0.043
	5-2	-0.524	0.600	-0.314	0.753	-0.507	0.612	-1.014	0.310	-1.992	0.046	-0.943	0.345	-1.753	0.080	-1.483	0.138
	5-3	-0.734	0.463	-0.524	0.600	-0.524	0.600	-0.845	0.398	-1.787	0.074	-0.314	0.753	-2.032	0.042	-2.023	0.043
	5-4	-0.105	0.917	-1.153	0.249	-0.169	0.866	-0.169	0.866	-1.992	0.046	-1.572	0.116	-1.753	0.080	-2.023	0.043
OCDD	2-1	-1.992	0.046	-1.572	0.116	-2.197	0.028	-1.521	0.128	-0.524	0.600	-0.314	0.753	-1.214	0.225	-1.483	0.138
	3-2	-1.992	0.046	-1.363	0.173	-1.472	0.141	-0.507	0.612	-0.946	0.344	-0.314	0.753	-0.944	0.345	-0.135	0.893
	4-3	-2.201	0.028	-1.992	0.046	-1.101	0.271	-0.169	0.866	-2.201	0.028	-1.153	0.249	-2.023	0.043	-0.674	0.500
	3-1	-1.572	0.116	-0.734	0.463	-1.101	0.271	-0.507	0.612	-1.363	0.173	-0.105	0.917	-1.753	0.080	-1.753	0.800
	4-1	-2.201	0.028	-2.201	0.028	-1.521	0.128	-0.338	0.735	-2.201	0.028	-2.201	0.028	-2.023	0.043	-2.023	0.043
	4-2	-0.734	0.463	-0.524	0.600	-0.254	0.799	-0.845	0.398	-2.201	0.028	-1.782	0.075	-0.944	0.345	-0.405	0.686
	5-1	-1.153	0.249	-0.524	0.600	-1.859	0.063	-1.183	0.237	-1.153	0.249	-1.782	0.075	-0.135	0.893	-0.135	0.893
	5-2	-1.363	0.173	-0.943	0.345	-0.338	0.735	-0.676	0.499	0.000	1.000	-2.201	0.028	-0.944	0.345	-1.483	0.138
	5-3	-0.734	0.463	-0.105	0.917	-1.778	0.075	-0.169	0.866	-0.412	0.680	-1.363	0.173	-1.214	0.225	-1.214	0.225
	5-4	-0.734	0.463	-1.992	0.046	-0.338	0.735	-0.845	0.398	-2.201	0.028	-2.201	0.028	-2.032	0.042	-2.023	0.043
2378-TCDF	2-1	-0.105	0.917	-0.105	0.917	-1.183	0.237	-0.507	0.612	-2.207	0.027	-2.201	0.028	-0.944	0.345	-0.674	0.500
	3-2	-0.524	0.600	-1.363	0.173	-0.169	0.866	-0.338	0.735	-1.153	0.249	-1.992	0.046	-0.944	0.345	-0.944	0.345
	4-3	-0.105	0.917	-0.314	0.753	-0.338	0.735	-0.507	0.612	-0.314	0.753	-0.734	0.463	-0.944	0.345	-0.135	0.893
	3-1	-0.314	0.753	-0.105	0.917	-1.183	0.237	-0.169	0.866	-1.153	0.249	-0.734	0.463	-2.023	0.043	-1.483	0.138
	4-1	-0.314	0.753	-1.153	0.249	-0.676	0.499	-0.169	0.866	-2.201	0.028	-2.201	0.028	-0.135	0.893	-1.214	0.225
	4-2	-0.524	0.600	-0.105	0.917	-0.845	0.398	-0.507	0.612	-0.734	0.463	-1.153	0.249	-1.219	0.223	-2.023	0.043
	5-1	-0.734	0.463	-0.105	0.917	-0.845	0.398	-0.676	0.499	-0.314	0.753	-1.363	0.173	-2.023	0.043	-2.023	0.043
	5-2	-0.734	0.463	-0.314	0.753	0.000	1.000	-0.338	0.735	-2.201	0.028	-1.782	0.075	-1.753	0.080	-1.175	0.080
	5-3	-0.943	0.345	-0.314	0.753	-0.845	0.398	0.000	1.000	-1.363	0.173	-0.734	0.463	-2.023	0.043	-2.023	0.043
	5-4	-0.314	0.753	-0.943	0.345	-0.676	0.499	-0.169	0.866	-1.261	0.207	-0.943	0.345	-1.753	0.080	-2.023	0.043
123678-HxCDF	2-1	-1.178	0.075	-0.943	0.345	-1.690	0.091	-0.507	0.612	-1.153	0.249	-0.943	0.345	-0.674	0.500	-0.135	0.893
	3-2	-0.734	0.463	-2.201	0.028	-1.521	0.128	-1.690	0.091	-1.992	0.046	-0.314	0.753	-1.753	0.080	-0.674	0.500
	4-3	-2.201	0.028	-0.314	0.753	-1.873	0.061	-0.338	0.735	-1.992	0.046	-0.314	0.753	-2.032	0.042	-0.135	0.893
	4-1	-1.572	0.116	-0.105	0.917	-2.028	0.043	-0.338	0.735	-1.153	0.249	-0.734	0.463	-0.135	0.893	-0.674	0.500
	3-1	-2.201	0.028	-0.734	0.463	-1.183	0.237	0.000	1.000	-2.201	0.028	-1.572	0.116	-1.214	0.225	-0.135	0.893
	4-2	-1.153	0.249	-0.734	0.463	-0.338	0.735	-1.014	0.310	-1.153	0.249	-0.524	0.600	-1.214	0.225	-0.674	0.500
	5-1	-1.572	0.116	-0.105	0.917	-0.845	0.398	-0.676	0.799	-0.944	0.345	-1.363	0.173	-0.405	0.686	-0.674	0.500
	5-2	-1.782	0.075	-0.105	0.917	-0.508	0.611	-1.183	0.237	-1.261	0.207	-0.524	0.600	-0.135	0.893	-1.483	0.138
	5-3	-2.201	0.028	-0.524	0.600	-0.423	0.672	-0.507	0.612	-2.207	0.027	-0.105	0.917	-0.944	0.345	-0.135	0.893
	5-4	-1.214	0.225	-0.943	0.345	-1.363	0.173	-1.352	0.176	-1.363	0.173	-0.524	0.600	-0.674	0.500	-0.405	0.686

Table 4.20 Results of Wilconox Test for Seasonality - Cont'd

Congener	Compared Events[1]	Dissolved		Suspended		Sediment		Sediment-OC		Catfish		Catfish - % Lipid		Crab		Crab - % Lipid	
		Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)	Z	Asymp. Sig. (2-tailed)
OCDF	2-1	-0.734	0.463	-1.572	0.116	-2.366	0.018	-1.690	0.091	-0.734	0.463	-0.105	0.917	-0.405	0.686	-0.674	0.500
	3-2	-0.105	0.917	-1.992	0.046	-2.366	0.018	-1.859	0.063	-0.943	0.345	-0.105	0.917	-0.405	0.686	-0.405	0.686
	4-3	-0.105	0.917	-0.943	0.345	-0.338	0.735	-0.169	0.866	-0.734	0.463	-0.105	0.917	-1.214	0.225	-1.214	0.225
	3-1	-0.314	0.753	-0.734	0.463	-0.931	0.352	-0.507	0.612	-1.156	0.248	-0.524	0.600	-0.944	0.345	-0.944	0.345
	4-1	-0.943	0.345	-0.943	0.345	-0.676	0.499	-0.338	0.735	-0.105	0.917	-0.314	0.753	-1.483	0.138	-2.023	0.043
	4-2	-0.734	0.463	-1.782	0.075	-0.507	0.612	-0.845	0.398	-0.314	0.753	-0.314	0.753	-1.214	0.225	-1.483	0.138
	5-1	-1.992	0.046	-0.734	0.463	-0.845	0.398	-0.338	0.735	-2.201	0.028	-2.201	0.028	-0.944	0.345	-0.944	0.345
	5-2	-0.734	0.463	-1.363	0.173	-0.507	0.612	-1.014	0.310	-1.782	0.075	-1.992	0.046	-0.944	0.345	-0.944	0.345
	5-3	-1.153	0.249	-1.153	0.249	-0.676	0.499	-0.338	0.735	-1.572	0.116	-1.992	0.046	-0.944	0.345	-0.944	0.345
	5-4	-0.524	0.600	-0.943	0.345	-0.524	0.600	-1.352	0.176	-2.201	0.028	-2.201	0.028	-0.135	0.893	-0.135	0.893
TEQ	2-1	-0.734	0.463	-0.105	0.917	-1.183	0.237	-0.338	0.735	-0.943	0.345	-0.734	0.463	-0.135	0.893	-0.674	0.500
	3-2	-0.314	0.753	-1.572	0.116	-0.169	0.866	-0.507	0.612	-0.943	0.345	-1.992	0.046	-0.674	0.500	-0.674	0.500
	4-3	-0.105	0.917	-0.314	0.753	-0.169	0.866	-1.183	0.237	-2.201	0.028	-1.153	0.249	-0.944	0.345	-0.944	0.345
	3-1	-0.105	0.917	-0.105	0.917	-1.183	0.237	-0.169	0.866	-0.524	0.600	-1.572	0.116	-1.483	0.138	-0.135	0.893
	4-1	-0.314	0.753	-1.153	0.249	-0.507	0.612	-0.507	0.612	-1.153	0.249	-0.105	0.917	-0.405	0.686	-0.944	0.345
	4-2	-0.943	0.345	-0.105	0.917	0.000	1.000	-1.014	0.310	-0.105	0.917	-0.524	0.600	-0.135	0.893	-1.753	0.080
	5-1	-0.943	0.345	-0.524	0.600	-0.338	0.735	-0.676	0.499	-1.992	0.046	-1.572	0.116	-2.023	0.043	-2.203	0.043
	5-2	-0.314	0.753	-0.314	0.753	-0.338	0.735	-0.845	0.398	-1.992	0.046	-0.943	0.345	-1.753	0.080	-1.483	0.138
	5-3	-0.734	0.463	-0.314	0.753	-0.507	0.612	-0.676	0.499	-1.782	0.075	-0.105	0.917	-2.023	0.043	-2.023	0.043
	5-4	-0.105	0.917	-1.153	0.249	0.000	1.000	-0.169	0.866	-1.992	0.046	-1.572	0.116	-1.753	0.080	-2.023	0.043

[1] 1=Summer 2002, 2=Fall 2002, 3=Spring 2003, 4=Spring 2004, 5=Fall 2004

Comparisons significant at the 0.05 alpha level

concentrations of this congener different at different time periods. Unless there is a constant source of OCDD, expected levels of this congener in the dissolved phase of water would be expected to be different depending on such factors as temperature, humidity, UV strength, etc., since OCDD is enriched in atmospheric particulate deposition and also possibly created in the atmosphere.

Suspended

Again, concentrations in a media such as water are expected to vary widely based on the source of the contamination, and environmental factors such as temperature, turbidity of the water, and sunlight. In this case, there are significant differences in the concentrations of OCDD between time periods 1-4, 3-4, and 4-5. There is also a significant difference between sampling events 2-3 for OCDF.

Sediment

Analysis of sediment data using the Wilconox test showed that there is a significant difference in OCDD concentrations between time periods one and two. There are also differences in OCDF concentrations between periods 1-2, and 2-3. Sediment was the media that presented the least variability among seasons, in fact no differences were found for any of the congeners in organic-carbon normalized sediment concentrations.

Catfish

There is a surprising amount of concentration differences in catfish. The congener 2378-TCDD is significantly different in concentration between time periods 3-4, 5-1, 5-2, and 5-4 (based on positive ranks), and the test results for 2378-TCDF show a significant difference from periods 1-2, 1-4, and 5-2. OCDD is, again, significantly different between time periods 1-4, 2-4,

3-4, and 5-4. The total TEQ results, which should follow the 2378-TCDD results closely, also show a difference between time periods 3-4, 5-1, 5-2, and 5-4. This was somewhat surprising because concentrations in catfish would be expected to remain somewhat constant over time. However, different fish of different size and sex were collected for each sampling event. This could explain the significant differences for 2378-TCDD, OCDD, 2378-TCDF and total TEQ for the different sampling events. Lipid content may play an important role in the differences found as indicated by much fewer differences found in the lipid-normalized sets. To further evaluate the role of lipid content and size (expressed as the weight/length ratio) on the measured dioxin concentrations, their relationship was plotted in Figure 4.60. The 2378-TCDD curve seems to mimic the lipid content curve, specially at stations 11261, 11280, and 11292. The relationship with fish size is less marked but present.

Crab

The results of the Wilconox Signed Ranks test for this medium show that there are significant differences in concentration of OCDD between time periods 1-4, 3-4, and 5-4. Concentrations of 2378-TCDF are also significantly different between time periods 1-3, 5-1, and 5-3. Looking back at the Mann Kendall test for trends over time (Section 4.3.2), OCDD showed no significant upward or downward trend at any station for crabs. However, when using the Wilconox test to look for differences between sampling events, differences between events are found. One of the sampling events (Fall 2002) had much higher concentrations of OCDD than the other times, but a significant difference of concentration between two sampling events cannot be interpreted as a significant trend upward or downward. There is so much variability in the concentrations that the results of paired testing should be interpreted with caution. Again, the

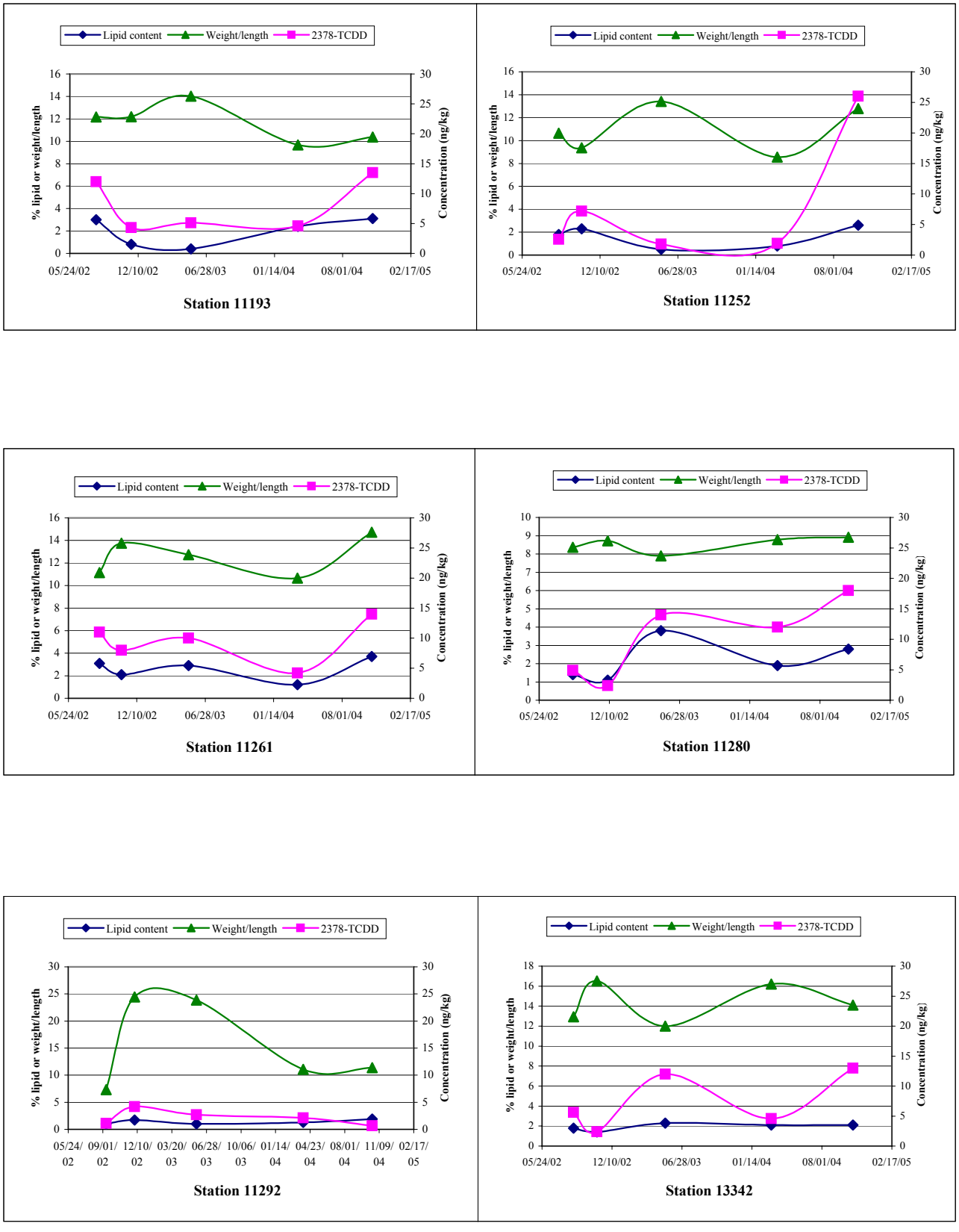


Figure 4.60 Relationship between Lipid Content/Fish Size and 2378-TCDD Concentrations

relationship of lipid content and crab size with the measured 2378-TCDD concentrations was evaluated (Figure 4.61). The relationships seem much weaker than those observed for catfish, especially for the weight/length ratio.

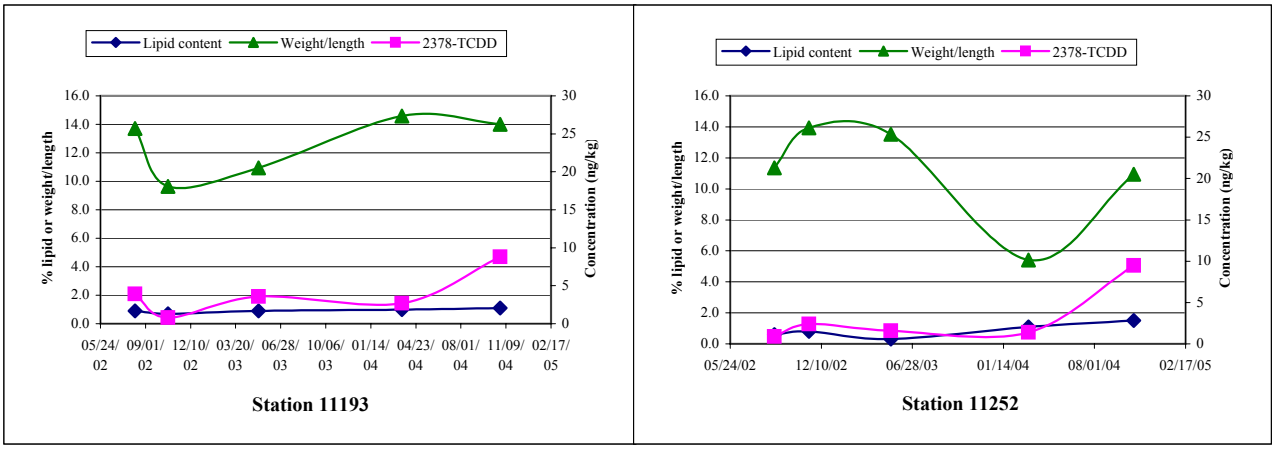
To further analyze if dioxin patterns changed with season, the relationship between the sum of PCDDs and PCDFs[10] was plotted for all the sampled media (Figure 4.62). Overall, the PCDD contribution is higher for most of the samples, with average ΣPCDD/ΣPCDF ratios of 24.9, 24.2, 2.2, and 1.2 for water, sediment, catfish, and crab, respectively. Data in Figure 4.62 indicate that for sediment samples, the concentration patterns seem equivalent, with slightly different ΣPCDD/ΣPCDF average ratios. Water and tissue data, on the other hand, exhibited different ratios for the various sampling events, especially catfish for which the slope of the best-fit line for data collected in the Summer was much greater than the ones for the other four events.

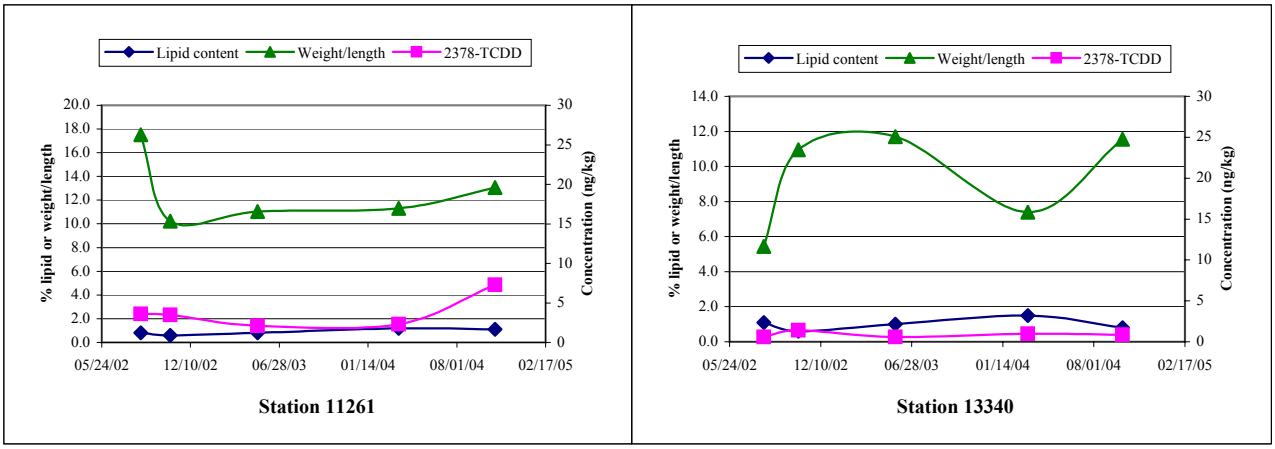
4.5 COMPARISON OF DIOXIN DATA AMONG THE THREE SAMPLED MEDIA

4.5.1 All data

Tables 4.21a and b summarize the average TEQ and 2378-TCDD concentrations measured in this study[11], respectively. In terms of TEQ, station 11273 (Patrick Bayou) was the most contaminated location in this study, with the highest average TEQ in water, and the second highest in sediment and crab. Among the stations located in the main channel and Upper Galveston Bay, station 15979 shows large contamination, with the third highest average TEQ

[10] This ratio includes both dioxin-like and non dioxin-like PCDDs and PCDFs. All the samples collected were included in this calculation.
[11] TEQ calculated as the average of the available Summer-02, Fall-02, Spring-03, Spring-04, and Fall-04 concentrations at each location.





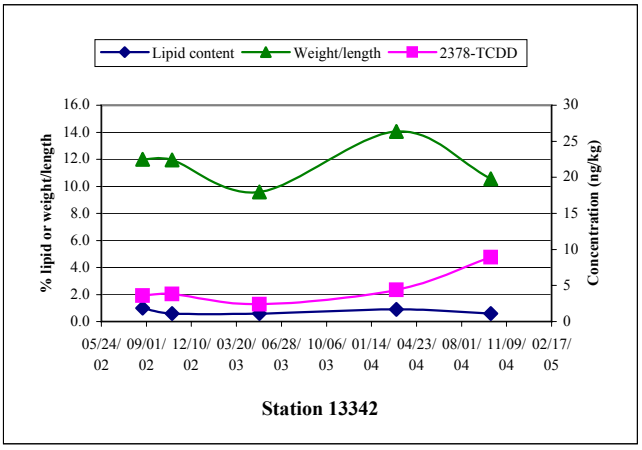


Figure 4.61 Relationship between Lipid Content/Crab Size and 2378-TCDD Concentrations

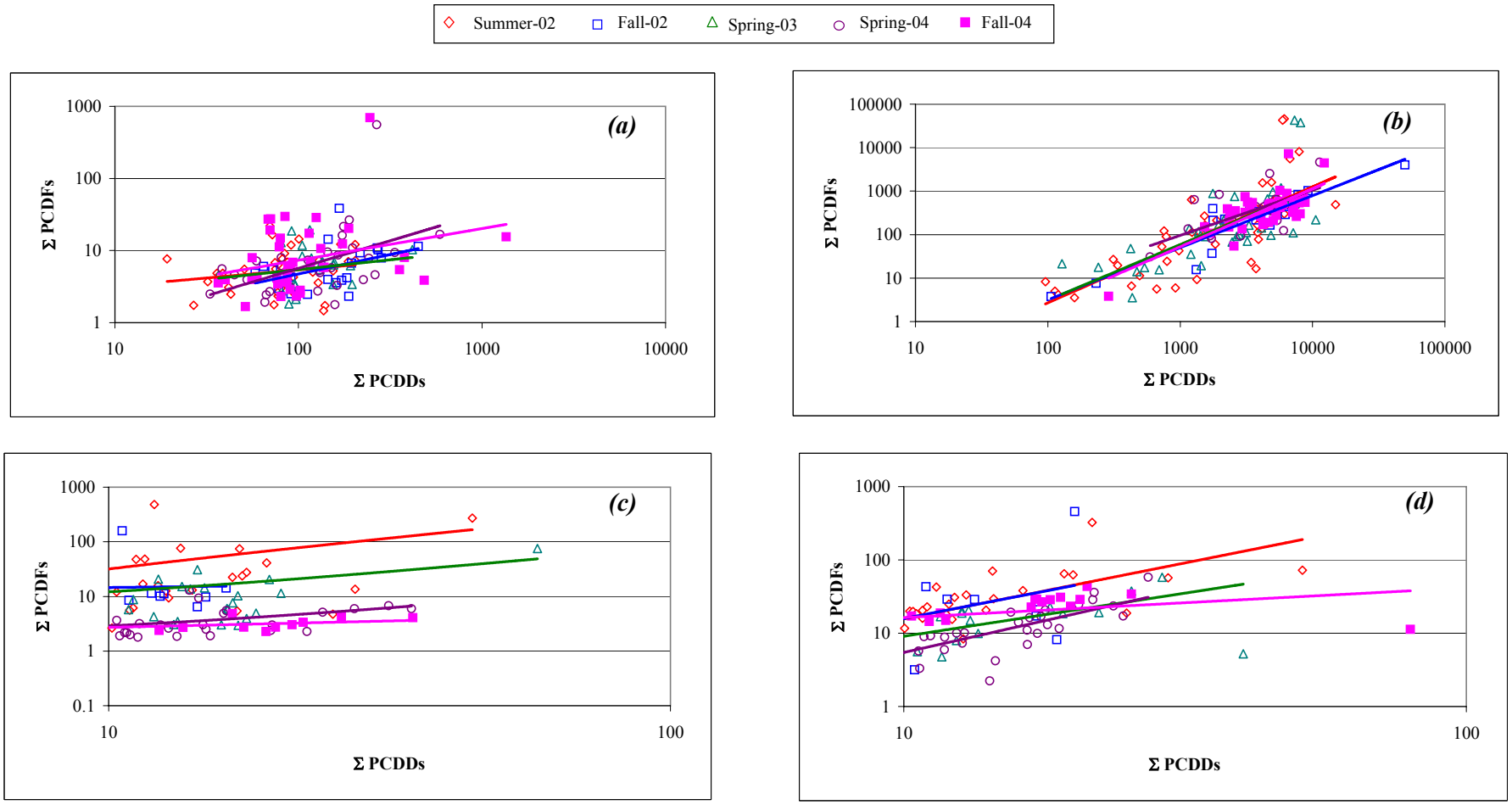


Figure 4.62 Relationship between PCDDs and PCDFs for the Various Sampling Events
(a) Water (b) Sediment (c) Catfish (d) Crab

Table 4.21a Average TEQ Concentrations by Media

Station ID	Site Description	Segment	Water		Sediment		Catfish		Crab	
			average[a] **(pg/L)**	**ranking**[b]	**average**[a] (ng/kg dry wt.)	**ranking**[b]	**average**[a] (ng/kg wet wt.)	**ranking**[b]	**average**[a] (ng/kg wet wt.)	**ranking**[b]
11111	Cedar Bayou Tidal at Roseland Park Boatramp	901	0.247	26	5.503	37	2.307	38	0.960	40
11193	San Jacinto River Tidal IH 10 Bridge East of Channelview	1001	1.619	2	82.535	4	8.623	11	5.242	12
11197	San Jacinto River Tidal at Missouri-Pacific RR Bridge	1001	0.126	33	16.020	20	8.603	12	5.051	13
11200	San Jacinto River Tidal at US 90 Bridge East of Sheldon	1001	0.062	45	0.570	56	1.825	42	0.986	39
16622	San Jacinto River Tidal at Banana Bend Road at end of pavem	1001	0.078	42	1.585	49	2.423	37	0.853	42
18388	San Jacinto River Tidal at CM21	1001			15.678	23				
18389	San Jacinto River Tidal at CM15	1001			15.959	21				
11252	Houston Ship Channel at CM 91, Morgan's Point	1005	0.181	28	4.621	41	8.694	10	4.156	21
11258	Houston Ship Channel at CM 120	1005			2.464	46	5.993	20	5.683	9
11261	Houston Ship Channel San Jacinto River at Lynchburg Ferry	1005	0.535	6	10.969	29	8.897	8	4.844	14
16618	HSC/San Jacinto River West of Exxon Docks and North of Al	1005	0.301	20	22.075	14	5.300	23	9.804	1
18390	San Jacinto River Tidal, 1 km downstream of IH10	1005			11.661	28				
11264	Houston Ship Channel at at San Jacinto Park, West of Battlesh	1006	0.517	8	19.154	16	10.127	5	4.567	17
11265	Houston Ship Channel at CM 136	1006	0.579	5	25.396	11	9.917	6	4.692	15
11267	Houston Ship Channel at Patrick Bayou Confluence (Cargill-N	1006			31.962	7				
11268	Houston Ship Channel at Channel Marker 142	1006			31.155	8				
11269	Houston Ship Channel at Beltway 8	1006			13.265	26				
11270	Houston Ship Channel at CM 150	1006	0.374	15	15.776	22	9.714	7	5.875	8
11271	Houston Ship Channel at confluence with Greens Bayou	1006			8.964	31				
11272	Carpenter Bayou Tidal at South Sheldon Rd in Channelview	1006	0.439	12	8.154	32	1.825	43	1.305	38
11273	Patrick Bayou Tidal at Oxychem Bridge	1006	1.627	1	158.458	2	7.379	17	7.306	2
11274	Greens Bayou Tidal at Mechling Barge Lines in Houston	1006	0.257	24	4.649	40	5.266	25	2.508	27
15979	Houston Ship Channel at Shell Barge Cut, 0.9 mi. downstream	1006	1.094	3	100.272	3	11.151	2	6.133	6
15980	Houston Ship Channel at Shell outfall 008	1006			20.370	15				
18391	0.8 km downstream of station 11270	1006			8.068	33				
11280	HSC/Buffalo Bayou at Armco Steel Corporation Intake Screer	1007	0.407	14	241.561	1	11.107	3	6.954	3
11287	Houston Ship Channel/Buffalo Bayou at Confluence with Sim	1007	0.119	35	10.554	30	5.023	27	6.499	5
11292	Houston Ship Channel/Buffalo Bayou in middle of Turning Ba	1007	0.099	39	18.959	17	2.940	34	1.727	33
11298	Hunting Bayou tidal at Federal Road bridge	1007	0.315	18	16.332	19	10.504	4	5.328	11
11300	Vince Bayou at North Richey St. in Pasadena, TX	1007	0.517	7	81.808	5	29.863	1	3.174	22
11302	Sims Bayou at Lawndale Ave. in Houston	1007	0.120	34	4.768	39	5.197	26	2.037	30
11305	Brays Bayou at Broadway Blvd. south of Houston	1007	0.087	41	2.848	44	4.222	29	2.518	26
18392	Houston Ship Channel/Buffalo Bayou, 830m upstream of Gree	1007			29.048	10				
11347	Buffalo Bayou Tidal at Main St.	1013	0.093	40	1.256	50	1.871	41	3.075	24
11382	Whiteoak Bayou at North Main Street	1013	0.059	46	3.112	43	1.419	45	1.714	34
11142	Buffalo Bayou at Barker Dam	1014	0.055	47						
11357	Buffalo Bayou at San Felipe St.	1014	0.074	43						
13309	Upper Galveston Bay at HSC CM 83/84	2421	0.161	31	1.224	51	2.504	36	1.665	36
14560	Upper Galveston Bay at HSC Marker 75	2421	0.129	32	2.814	45	5.456	21	2.135	29
15464	Upper Galveston Bay Near Shore, 0.2 km south of Clear Creek	2421	0.117	36	0.562	57	5.391	22	0.405	47
15908	Upper Galveston Bay at 96GB013, 0.5 mi. Ene of mouth of Ba	2421	0.164	30	1.082	52	3.901	30	0.816	43
16213	Upper Galveston Bay at 97GB019, 5.25mi north of the HL&P	2421	0.173	29	1.687	47	2.570	35	0.739	44
11092	Goose Creek at Market St. in Baytown	2426	0.213	27	7.547	34	0.657	47	0.600	46
13336	Tabbs Bay at CM #14 in Barge Channel Between The HSC an	2426	0.494	10	5.836	36	2.196	39	1.939	31
13337	Tabbs Bay Mid-Bay at Ruined Bridge	2426	0.320	17	14.513	24	6.667	18	1.871	32
13338	Tabbs Bay Midway Between Goose Creek and Upper Hog Isla	2426	0.462	11	13.929	25	4.668	28	2.232	28
13339	San Jacinto Bay at Buoy 15	2427	0.413	13	11.984	27	7.997	15	6.842	4
16499	San Jacinto Bay 200 yds SW of CM25 (98GB007)	2427	0.505	9	39.784	6	5.268	24	4.332	19
13340	Black Duck Bay at Mid-Bay	2428	0.106	38	7.536	35	2.186	40	1.414	37
13341	Black Duck Bay at SH 146 Bridge	2428	0.113	37	5.320	38	3.531	32	2.525	25
13342	Scott Bay at Mid-Bay	2429	0.307	19	24.360	12	7.427	16	6.032	7
17971	Scott Bay at Location to be determined	2429	0.299	21	18.000	18	6.007	19	5.679	10
13343	Burnett Bay, 100 meters south of confluence with Spring Gully	2430	0.272	23	3.707	42	8.141	14	4.328	20
13344	Burnett Bay at Mid-Bay	2430	0.272	22	24.073	13	8.586	13	4.667	16
16496	Burnett Bay 1.5mi east of North Lynchburg Ferry Landing, 1.2	2430	0.343	16	30.603	9	8.697	9	4.454	18
13355	Barbours Cut mid-way between mouth And terminus	2436	0.596	4	0.764	55	3.651	31	1.676	35
17970	Barbours Cut at Location to be determined	2436			1.622	48	3.032	33	3.089	23
13363	Bayport Channel mid-way between mouth and terminus	2438	0.254	25	0.896	53	1.705	44	0.615	45
13589	Bayport Channel immediately before Turning Basin	2438	0.074	44	0.884	54	1.071	46	0.900	41

[a] Average of the samples collected in Summer 2002, Fall 2002, Spring 2003, Spring 2004, and Fall 2004.

[b] The lowest average ranking (i.e. 1) corresponds to the location with the highest average concentration

Highest 10 average concentrations

Lowest 10 average concentrations

Table 4.21b Average 2,3,7,8 - TCDD Concentrations by Media

Station ID	Site Description	Segment	Water		Sediment		Catfish		Crab	
			average[a] **(pg/L)**	**ranking**[b]	**average**[a] (ng/kg dry wt.)	**ranking**[b]	**average**[a] (ng/kg wet wt.)	**ranking**[b]	**average**[a] (ng/kg wet wt.)	**ranking**[b]
11111	Cedar Bayou Tidal at Roseland Park Boatramp	901	0.087	25	2.300	36	1.760	37	0.695	40
11193	San Jacinto River Tidal IH 10 Bridge East of Channelview	1001	1.132	1	55.417	3	7.900	9	4.499	11
11197	San Jacinto River Tidal at Missouri-Pacific RR Bridge	1001	0.065	29	10.567	20	7.925	8	3.800	14
11200	San Jacinto River Tidal at US 90 Bridge East of Sheldon	1001	0.015	42	0.125	56	1.318	43	0.710	39
16622	San Jacinto River Tidal at Banana Bend Road at end of pavem	1001	0.019	38	0.338	51	2.060	34	0.503	42
18388	San Jacinto River Tidal at CM21	1001			10.000	21				
18389	San Jacinto River Tidal at CM15	1001			11.000	18				
11252	Houston Ship Channel at CM 91, Morgan's Point	1005	0.098	24	2.234	37	7.900	10	3.312	20
11258	Houston Ship Channel at CM 120	1005			1.585	40	5.300	20	4.250	12
11261	Houston Ship Channel San Jacinto River at Lynchburg Ferry	1005	0.346	6	7.380	28	8.275	7	3.760	16
16618	HSC/San Jacinto River West of Exxon Docks and North of Al	1005	0.182	18	15.400	13	4.750	21	7.625	1
18390	San Jacinto River Tidal, 1 km downstream of IH10	1005			8.000	26				
11264	Houston Ship Channel at at San Jacinto Park, West of Battlesh	1006	0.325	8	11.600	16	9.463	4	3.625	17
11265	Houston Ship Channel at CM 136	1006	0.375	3	16.000	9	9.250	5	3.800	15
11267	Houston Ship Channel at Patrick Bayou Confluence (Cargill-N	1006			16.000	10				
11268	Houston Ship Channel at Channel Marker 142	1006			22.000	5				
11269	Houston Ship Channel at Beltway 8	1006			8.500	23				
11270	Houston Ship Channel at CM 150	1006	0.217	14	10.833	19	7.797	13	4.550	9
11271	Houston Ship Channel at confluence with Greens Bayou	1006			5.300	31				
11272	Carpenter Bayou Tidal at South Sheldon Rd in Channelview	1006	0.228	13	3.800	32	1.508	41	0.935	35
11273	Patrick Bayou Tidal at Oxychem Bridge	1006	0.364	5	20.250	7	6.600	17	5.300	5
11274	Greens Bayou Tidal at Mechling Barge Lines in Houston	1006	0.059	30	1.580	41	4.500	23	1.800	24
15979	Houston Ship Channel at Shell Barge Cut, 0.9 mi. downstream	1006	0.770	2	70.195	2	10.250	3	5.424	4
15980	Houston Ship Channel at Shell outfall 008	1006			12.000	15				
18391	0.8 km downstream of station 11270	1006			2.150	38				
11280	HSC/Buffalo Bayou at Armco Steel Corporation Intake Screen	1007	0.264	11	178.917	1	10.260	2	5.809	2
11287	Houston Ship Channel/Buffalo Bayou at Confluence with Sim	1007	0.038	34	5.363	30	4.150	25	5.452	3
11292	Houston Ship Channel/Buffalo Bayou in middle of Turning Ba	1007	0.017	41	5.858	29	2.148	33	0.766	38
11298	Hunting Bayou tidal at Federal Road bridge	1007	0.165	20	8.200	25	8.909	6	4.543	10
11300	Vince Bayou at North Richey St. in Pasadena, TX	1007	0.059	31	13.000	14	22.500	1	2.217	23
11302	Sims Bayou at Lawndale Ave. in Houston	1007	0.017	40	1.313	42	4.493	24	1.400	28
11305	Brays Bayou at Broadway Blvd. south of Houston	1007	0.009	46	0.444	49	3.383	27	1.657	25
18392	Houston Ship Channel/Buffalo Bayou, 830m upstream of Gree	1007			18.000	8				
11347	Buffalo Bayou Tidal at Main St.	1013	0.009	45	0.130	55	1.239	44	1.325	30
11382	Whiteoak Bayou at North Main Street	1013	0.010	44	0.193	54	0.918	45	1.260	31
11142	Buffalo Bayou at Barker Dam	1014	0.006	47						
11357	Buffalo Bayou at San Felipe St.	1014	0.011	43						
13309	Upper Galveston Bay at HSC CM 83/84	2421	0.075	27	0.630	46	2.025	35	1.095	34
14560	Upper Galveston Bay at HSC Marker 75	2421	0.052	33	0.979	44	2.665	31	1.573	27
15464	Upper Galveston Bay Near Shore, 0.2 km south of Clear Creek	2421	0.034	37	0.123	57	1.695	39	0.157	47
15908	Upper Galveston Bay at 96GB013, 0.5 mi. Ene of mouth of Ba	2421	0.076	26	0.530	48	3.050	29	0.593	41
16213	Upper Galveston Bay at 97GB019, 5.25mi north of the HL&P	2421	0.073	28	0.860	45	1.600	40	0.323	45
11092	Goose Creek at Market St. in Baytown	2426	0.036	35	1.205	43	0.432	47	0.330	44
13336	Tabbs Bay at CM #14 in Barge Channel Between The HSC an	2426	0.289	9	2.525	35	1.705	38	1.390	29
13337	Tabbs Bay Mid-Bay at Ruined Bridge	2426	0.170	19	9.150	22	5.850	18	1.100	33
13338	Tabbs Bay Midway Between Goose Creek and Upper Hog Isla	2426	0.271	10	8.450	24	3.938	26	1.603	26
13339	San Jacinto Bay at Buoy 15	2427	0.238	12	7.900	27	7.333	14	5.267	6
16499	San Jacinto Bay 200 yds SW of CM25 (98GB007)	2427	0.342	7	27.725	4	4.644	22	3.300	21
13340	Black Duck Bay at Mid-Bay	2428	0.035	36	3.660	33	1.783	36	0.884	36
13341	Black Duck Bay at SH 146 Bridge	2428	0.055	32	2.563	34	3.000	30	0.350	43
13342	Scott Bay at Mid-Bay	2429	0.188	17	15.500	11	6.790	16	4.620	8
17971	Scott Bay at Location to be determined	2429	0.194	16	11.400	17	5.600	19	4.880	7
13343	Burnett Bay, 100 meters south of confluence with Spring Gully	2430	0.128	23	1.800	39	7.150	15	3.350	19
13344	Burnett Bay at Mid-Bay	2430	0.158	22	15.500	12	7.875	11	3.841	13
16496	Burnett Bay 1.5mi east of North Lynchburg Ferry Landing, 1.2	2430	0.204	15	20.500	6	7.875	12	3.400	18
13355	Barbours Cut mid-way between mouth And terminus	2436	0.374	4	0.220	53	3.250	28	1.247	32
17970	Barbours Cut at Location to be determined	2436			0.575	47	2.425	32	2.400	22
13363	Bayport Channel mid-way between mouth and terminus	2438	0.163	21	0.343	50	1.500	42	0.295	46
13589	Bayport Channel immediately before Turning Basin	2438	0.017	39	0.273	52	0.830	46	0.809	37

[a] Average of the samples collected in Summer 2002, Fall 2002, Spring 2003, Spring 2004, and Fall 2004.

[b] The lowest average ranking (i.e. 1) corresponds to the location with the highest average concentration

Non-detects assumed equal to 1/2 MDL

Highest 10 average concentrations

Lowest 10 average concentrations

concentration in sediment and water and the second highest average concentration in catfish. Other dioxin "hot spots" were located at stations 11280 and 13344[12]. Station 11193 in the San Jacinto River (segment 1001) exhibited the second highest average TEQ in water and the fourth highest TEQ in sediment.

In terms of 2378-TCDD, the two most contaminated locations were 11193 and 15979, with average concentrations in water and sediment among the three highest. Stations 11273 and 11265 were additional “hot spots.”

4.5.2 Principal Component Analysis

As mentioned in a previous section, principal components analysis and cluster analysis were employed to analyze the spatial patterns (if any) of PCDD/Fs in the Houston Ship Channel. It was also thought that by considering various media together in one PCA, and then using hierarchical cluster analysis to confirm/deny clusters, it would be possible to see if the homologue profile patterns for one media could be correlated to those in another media.

<u>All Media Analyzed Together</u>

As was expected, the patterns of homologue profiles differ by media. This was anticipated because of the different partitioning properties of the different homologue groups. The heavier homologues (OCDD and OCDF) have lower vapor pressures and so tend to be found sorbed to particles. The lighter homologue groups, like TCDD and TCDF, have the highest vapor pressures and so tend to volatilize rather than be found sorbed to a particle. This means that homologue profiles, or fingerprints, at samples of different media will be different. This can be

[12] Hot spots defined as stations with average TEQs among the highest for 3 or more media.

readily seen by looking at Figure 4.63, which is a scatter plot of PCA for all the media together. The obvious outliers are station 11273 and facilities with water quality permits number 00749-001, 02097-001, and 00305-001. Another small group appears to include station 15979.

Dissolved Water, Dissolved Runoff, Dissolved Effluent, Air Vapor

Because the partitioning of PCDD/Fs is highly dependent upon vapor pressure, it was thought that perhaps the homologue profiles would be similar when comparing all of the dissolved media. Dissolved Water, dissolved runoff, dissolved effluent, and air vapor were analyzed together in one PCA, to establish common patterns among the different media. Figure 4.64 shows the scatter plot of the scores output from this analysis. Components one and two are graphed in terms of each other, since most of the variability is now explained by these two components. What the figure shows is that Dissolved Water, which is from the Houston Ship Channel, and Dissolved Effluent seem to be somewhat independent of each other. The dissolved runoff, however, is right in the middle of the dissolved water points. The air vapor fingerprints for stations C403 and C408, which are the only two air sampling stations in which air vapor and air particulate matter were separated, show that there is a relationship in the pattern of homologue groups with the effluent dissolved stations nearest but not with runoff or in-stream water. Although, looking at the cluster output, Figure 4.65, the cluster which includes the air homologue profiles does not differ much from the next cluster.

Suspended Water, Runoff, Effluent, Sediment

The same reasoning for dissolved PCDD/F patterns was the basis for this analysis. Because dioxins are hydrophobic, it could be possible to find similar patterns of homologue groups between media groups which contain suspended solids. One would expect dioxins to sorb

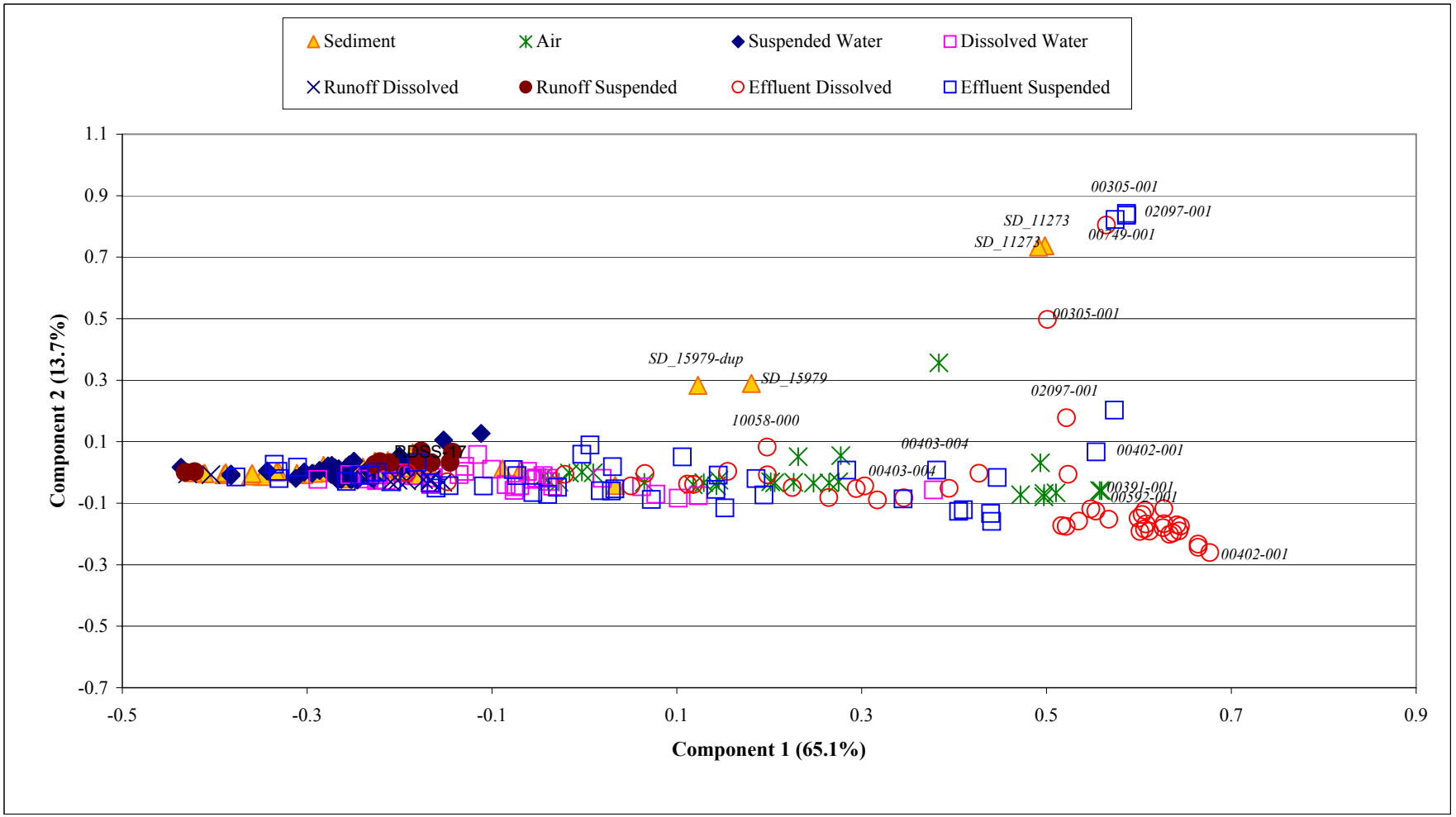


Figure 4.63 PCA Analysis for Concentrations in All Media

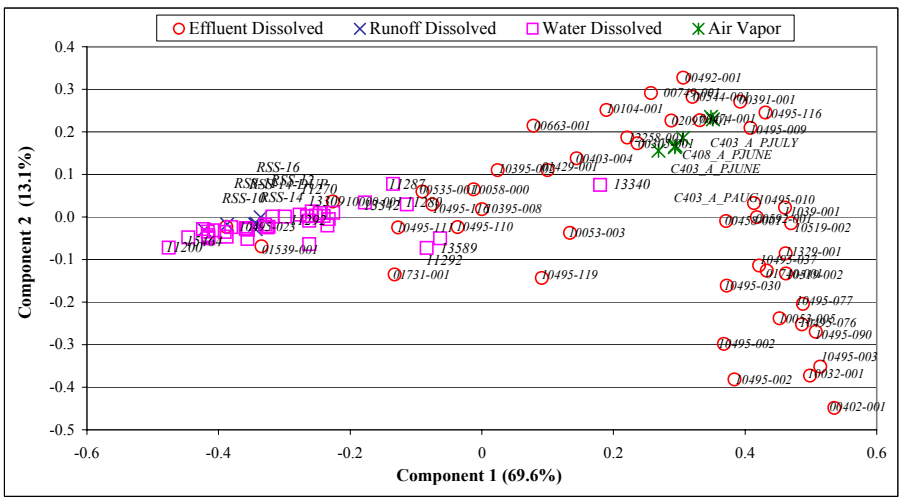


Figure 4.64 PCA Analysis for Dissolved and Air Vapor Concentrations

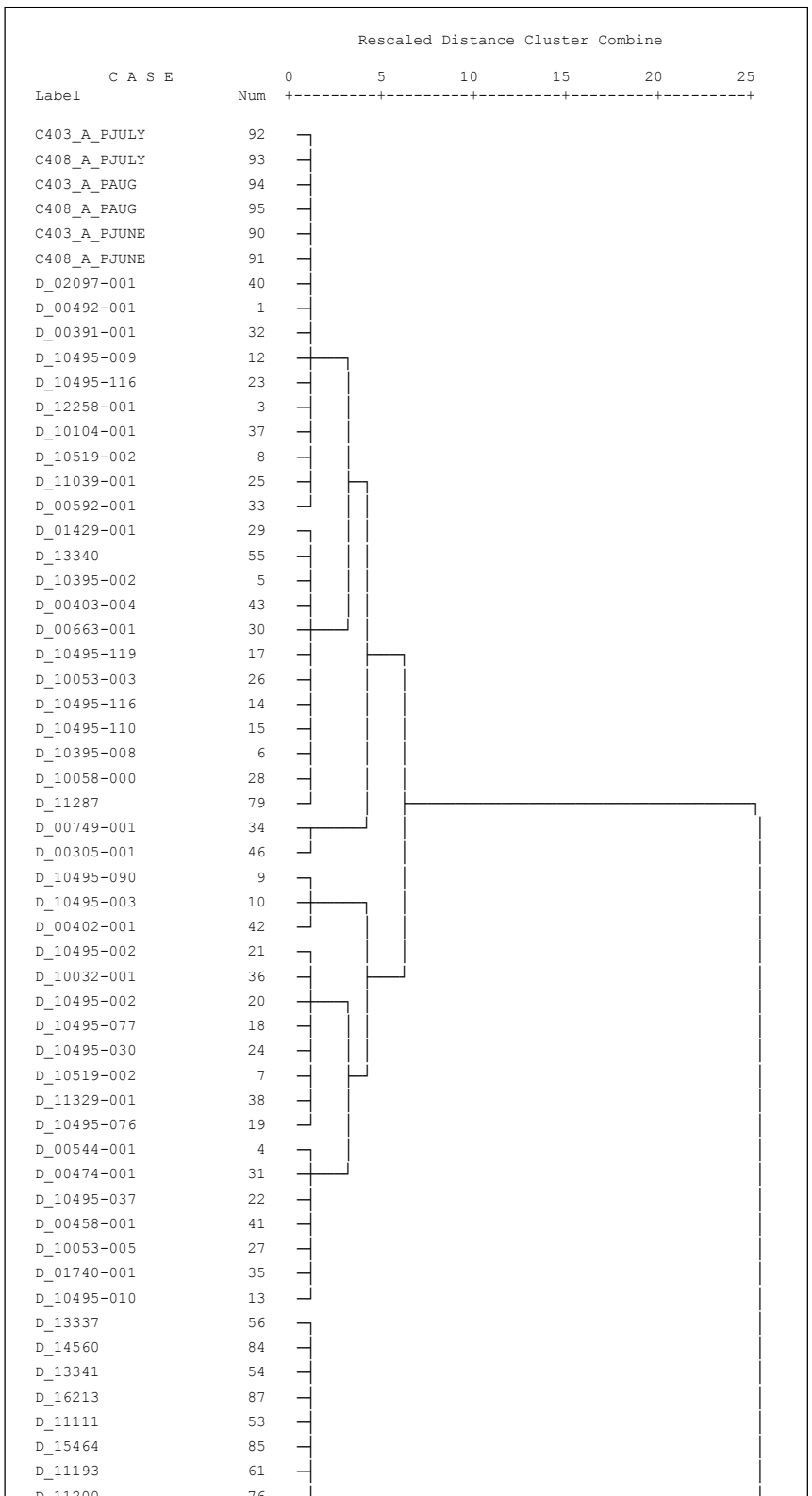


Figure 4.65 Dissolved Mixed Media Dendogram using Ward Method

to particles and thus might have different patterns than those in the dissolved phase. It can be seen in Figure 4.66 that the sediment sampling points seem to cluster together, all except for stations 15979 and 11273. Closely related to those stations are suspended effluent samples from three sources. This result is further supported by Figure 4.67, which is the hierarchical cluster analysis output for the same variables.

The Effluent Suspended samples seem to exhibit less clustering when compared to the Sediment stations. This is most likely because of the variability in homologue profiles from different sources. Once, however, the effluent becomes mixed with the waters of the HSC, the patterns would merge into one homologue profile which is what is shown in Figure 4.66. The Suspended Water samples show little variability in their profile, and are located overlapping the Runoff Suspended sample points. As mentioned before, this is most likely due to the mixing in the Ship Channel which would tend to homogenize the profiles into one fingerprint common to the Ship Channel. As far as the clustering of the sediment samples, it would be expected that the homologue profiles would be similar for most points in the HSC, due to yearly dredging, sediment-mixing effects of daily tide ebb-and-flow, ship/boat traffic wakes, and stormwater runoff pulses. The dredging would tend to re-suspend sediment particles and this re-suspension would cause a homogenous mixture downstream. The sediment data seem to reflect this. The stations with nearby sources of input are the only ones that are different from the rest.

4.6 ANALYSIS OF AIR DATA

Dioxins and furans in ambient air were monitored in monthly events at five different sampling locations between September 2002 and April 2004 and in bi-monthly events between December 2004 and April 2005 (see Final Report for WO4 and Chapter 3 of this report for results). The monitoring sites represent different levels of industrialization across the city (Figure

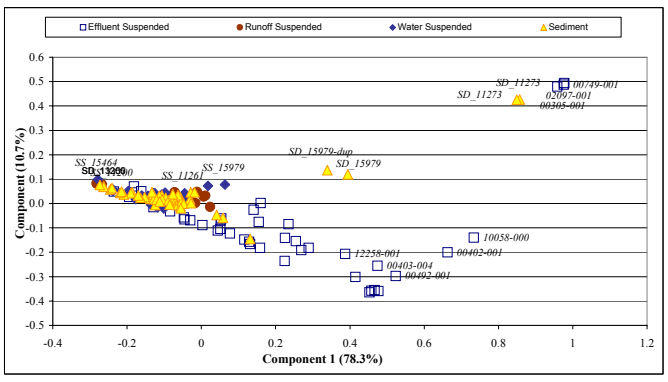


Figure 4.66 PCA Analysis for Suspended and Bottom Sediment Concentrations

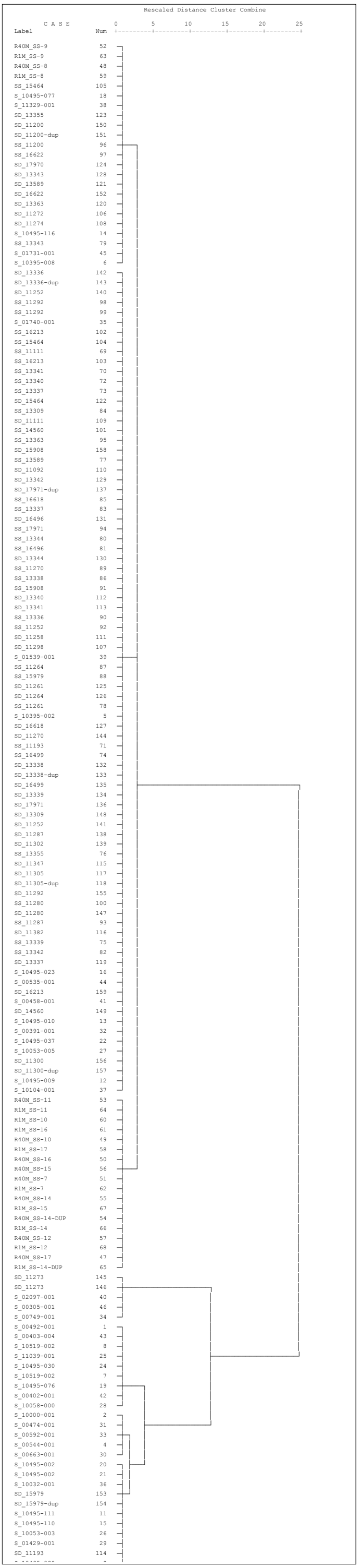


Figure 4.67 Suspended & Sediment Mixed Media Dendogram using Ward Method

4.68). The monitors at Clinton Drive (C403) and Haden Road (C603) are located in an industrial area, whereas Mont Belvieu (C610) is in a semi-rural area and Lang Road (C408) and Bayland Park (C53) are located in mostly residential areas. Co-located samplers were set up at C403 and C408 to determine V/P ratios.

Overall, the total ambient air dioxin concentrations were found ranging from 546 to 1,711 fg/m^3 at Clinton Drive (C403), from 269 to 2,427 fg/m^3 at Lang Road (C408), from 546 to 2,198 fg/m^3 at Haden Road, from 288 to 2,345 fg/m^3 at Mont Belvieu, and from 447 to 1,304 fg/m^3 at Bayland Park. It is worth noting that the two "industrial" sites had the highest minimum concentrations, but the highest maximum concentrations were at the "semi-rural" and one of the "mostly residential" sites.

Averaging, total ambient air dioxin concentrations for the first (Sep/02-Aug/03), second (Dec/03-Apr/04), and third (Sep/04-Feb/05) sampling periods (mean±standard deviation) of 879 ± 359, 1159 ± 342, and 1083 ± 387 fg/m^3 were observed at Clinton Drive. Similarly, average total ambient air concentrations for the first (Sep/02-Aug/03) and second (Dec/03-Apr/04) sampling periods of 1171 ± 647 and 972 ± 497 fg/m^3 were measured at Lang Road; average total concentrations of 1532 ± 552 and 667 ± 595 fg/m^3 occurred in the first sampling period (Sep/02-Aug/03) at Haden Road and Mont Belvieu, respectively. Finally, a concentration of 709 ± 319 was found at Bayland Park from March 2003 to August 2003.

The higher chlorinated congeners such as 1234678-HpCDD, 1234678-HpCDF, OCDF, and especially OCDD were consistently found at all sites as the congeners making the major contribution to the total ambient air dioxin concentration. In most of the cases, the contribution of OCDD was found to be >50% at all stations during the period sampled (see Figure 4.69). Concentrations for OCDD of up to 1718 fg/m^3 were measured in the Houston area at the Mont Belvieu site in the January/03 event. The congener 2378-TCDD made a very low contribution to

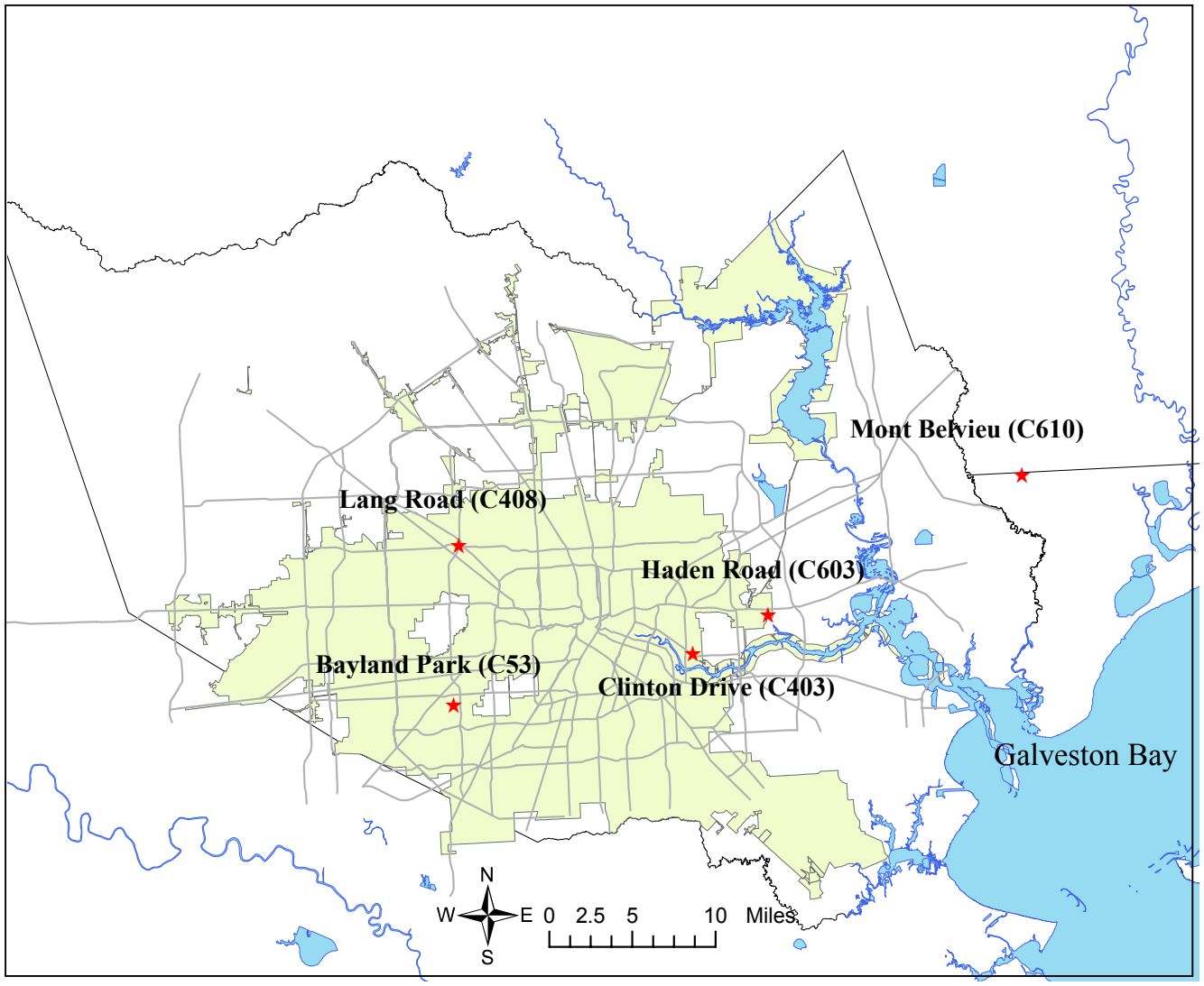


Figure 4.68 Air Monitoring Sites

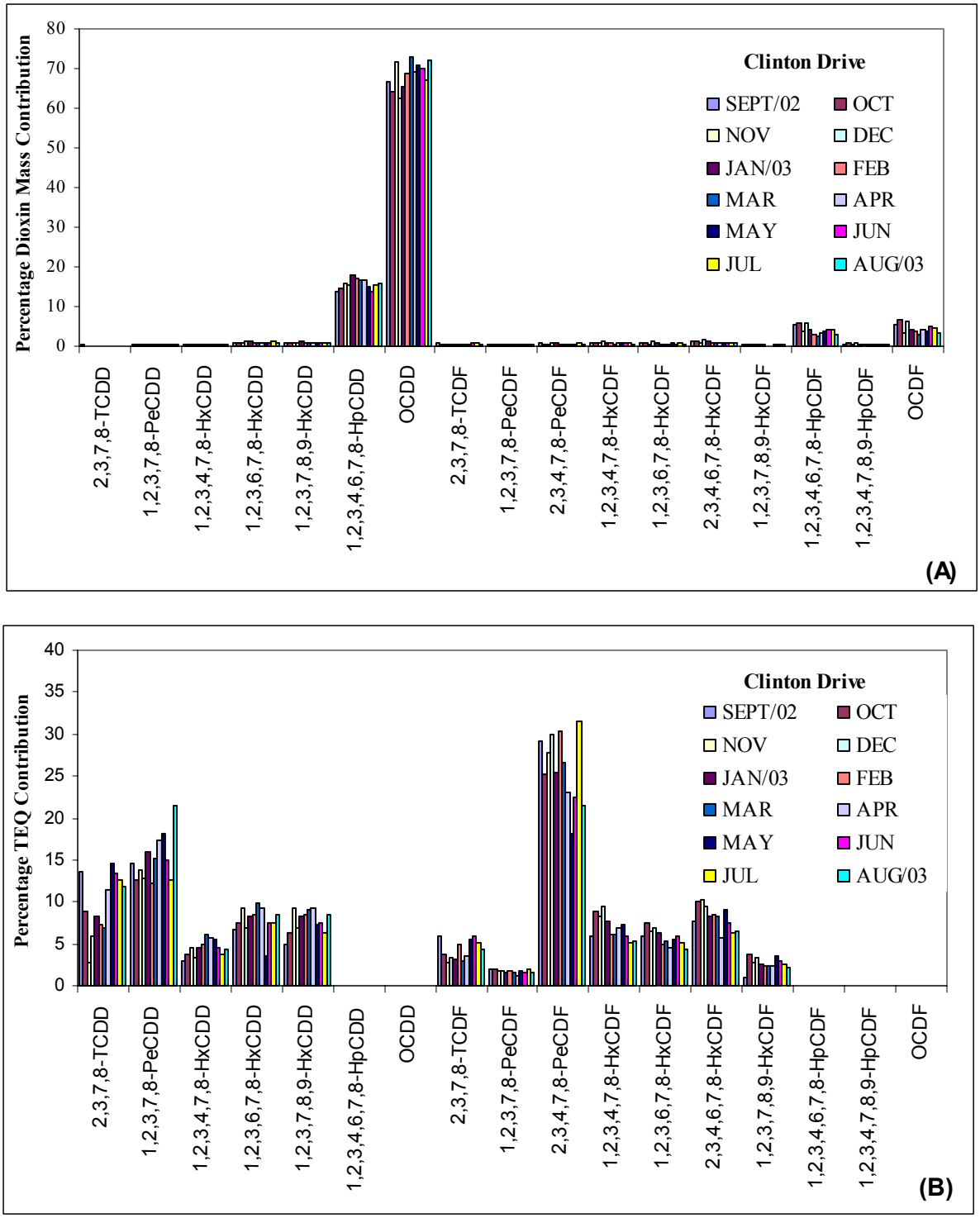
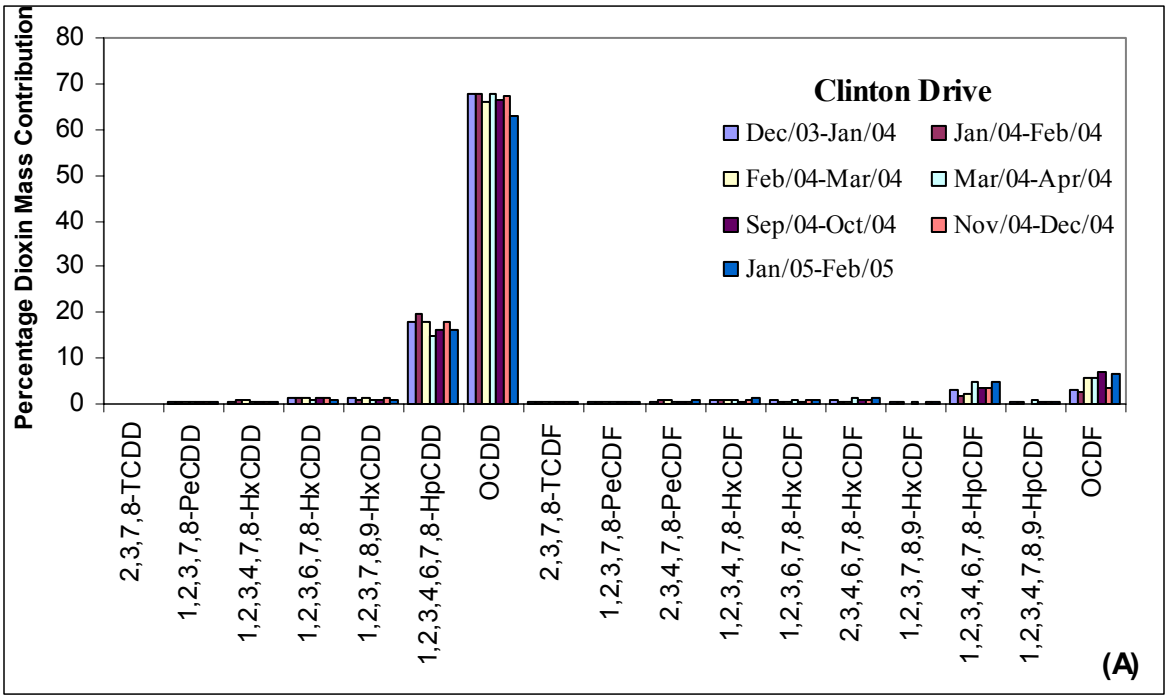


Figure 4.69 Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.



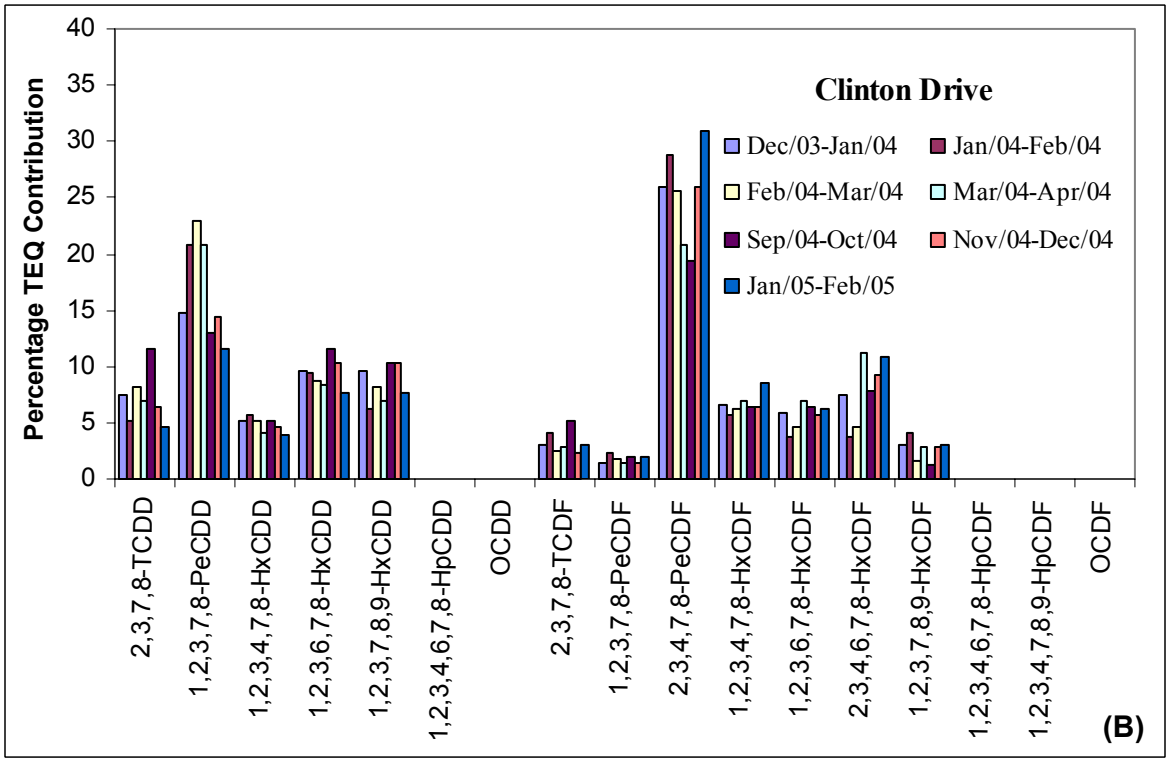


Figure 4.69 (Cont). Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.

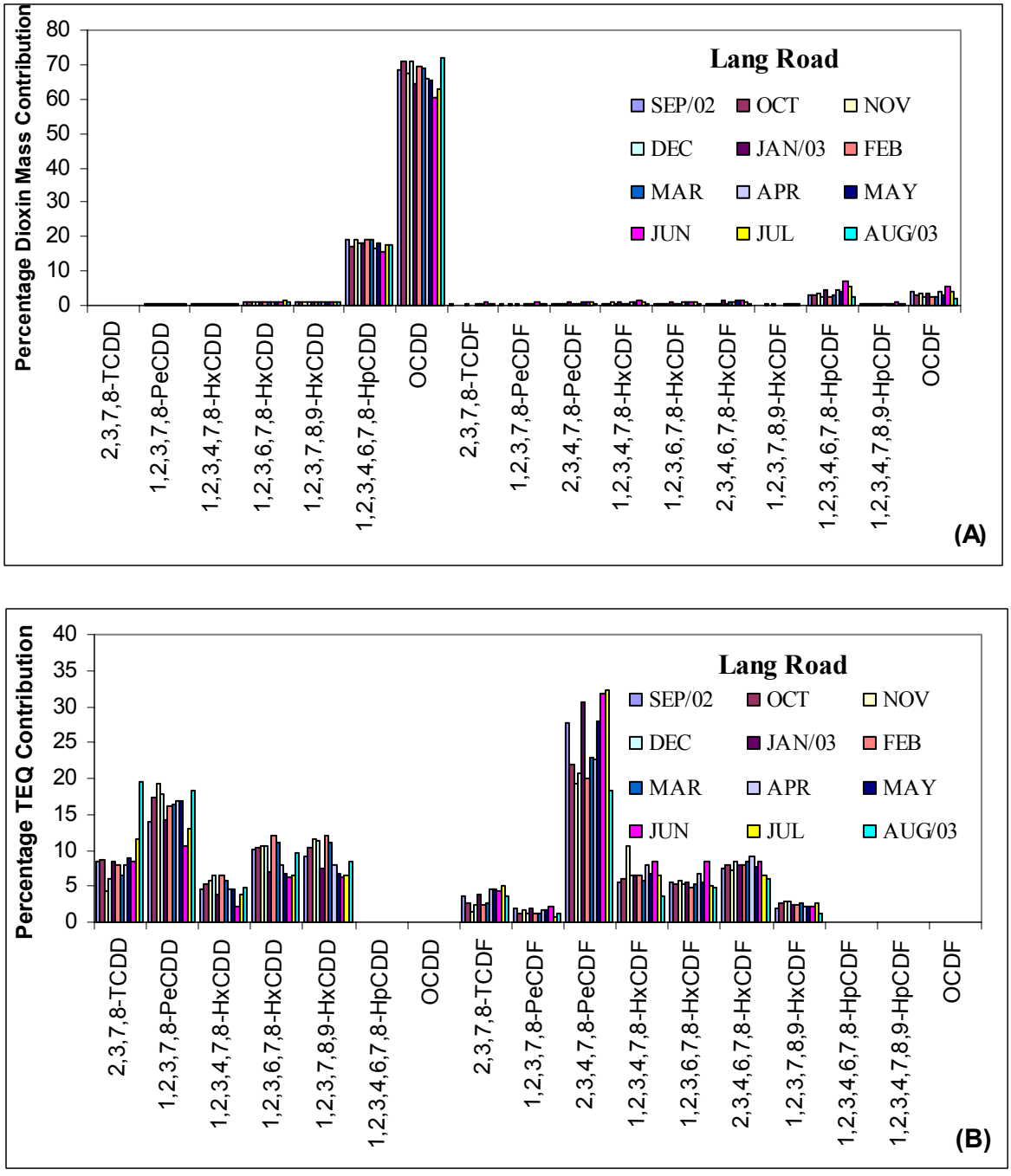


Figure 4.69 (Cont). Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.

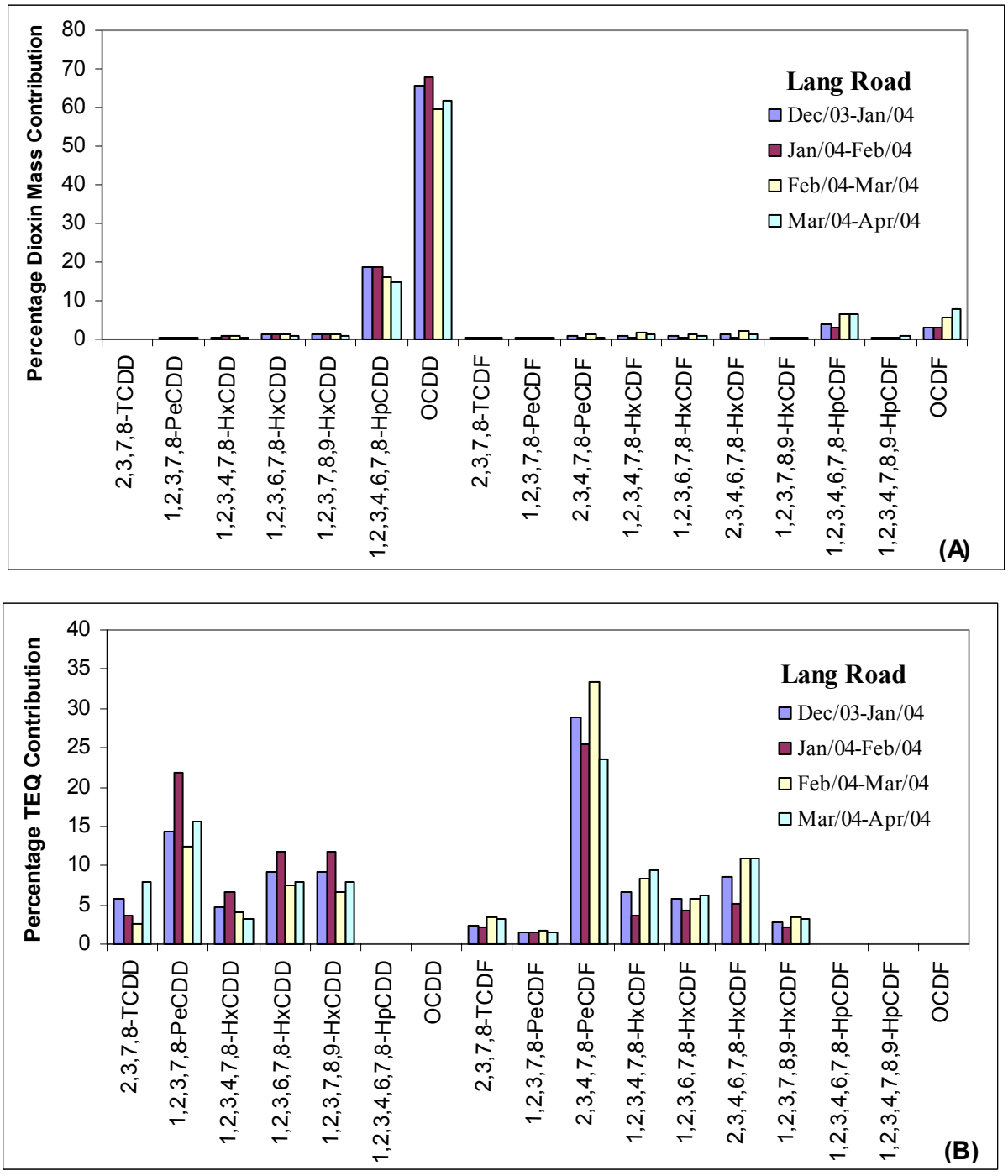


Figure 4.69 (Cont). Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.

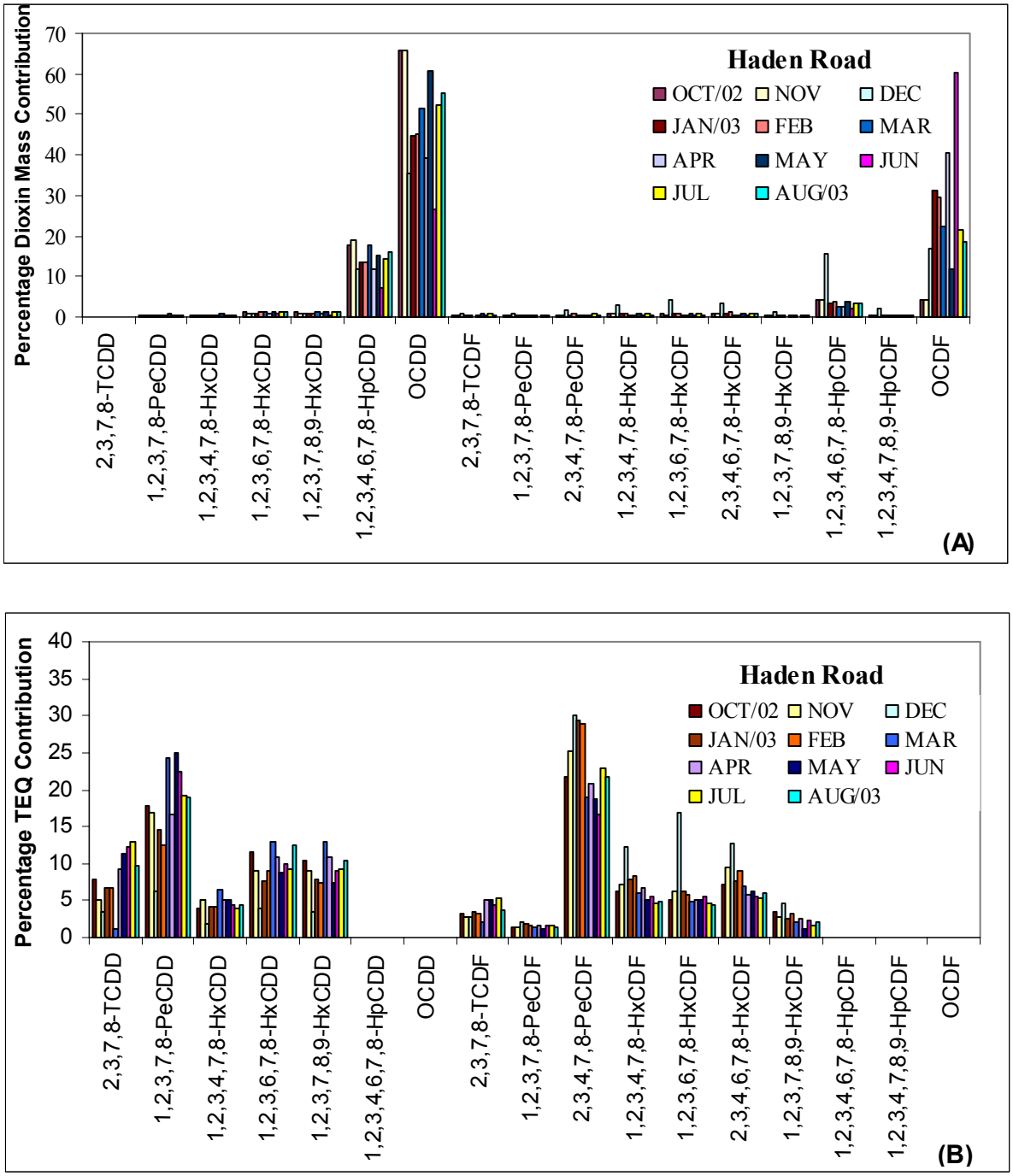


Figure 4.69 (Cont). Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.

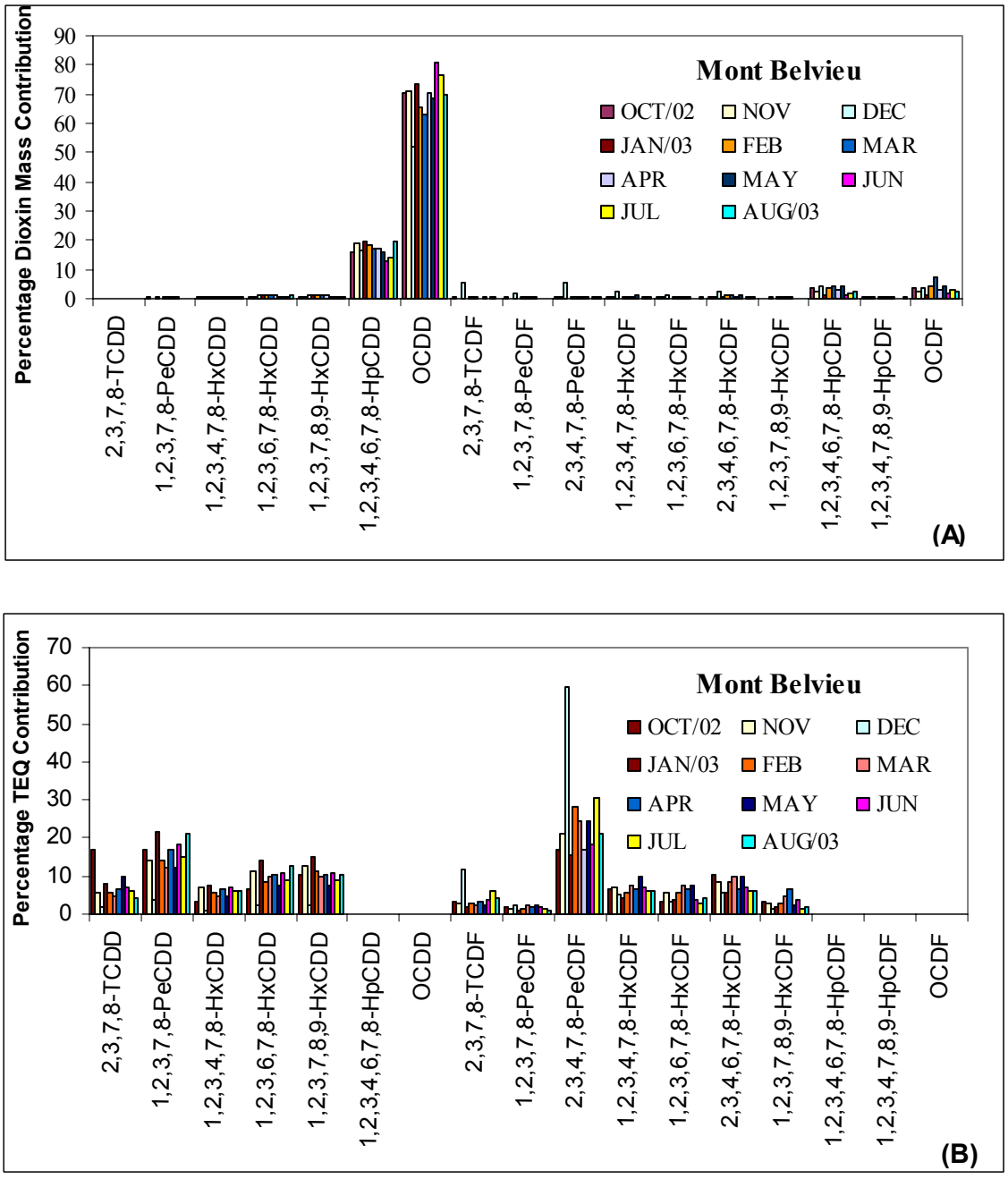


Figure 4.69 (Cont). Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.

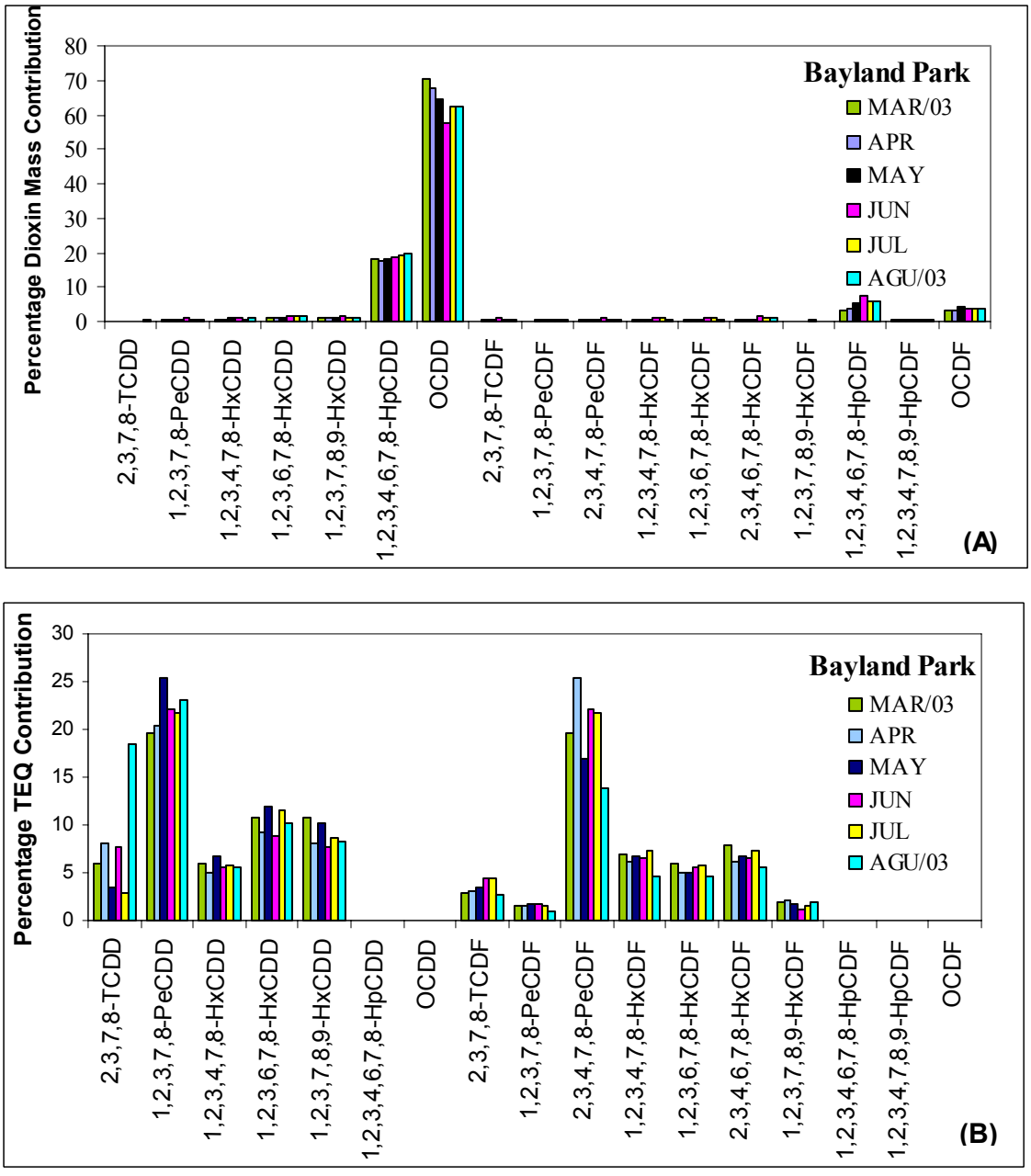


Figure 4.69 (Cont). Ambient Air Profiles of Dioxins and Furans in Houston, TX: (A) Mass, (B) TEQ Contribution.

the total dioxin concentration during the period sampled. A maximum concentration of 2 fg/m^3 was detected for this congener at the Haden Road site (the site in the industrial area) in the October/02 event.

In terms of ΣTexas-TEQ concentrations, values were found fluctuating from 6 to 20 fg Texas-TEQ/m^3 at Clinton Drive, from 5 to 21 fg Texas-TEQ/m^3 at Lang Road, from 8 to 48 fg Texas-TEQ/m^3 at Haden Road, from 3 to 28 fg Texas-TEQ/m^3 at Mont Belvieu, and from 6 to 11 fg Texas-TEQ/m^3 at Bayland Park. The congeners 1,2,3,7,8-PeCDD and 2,3,4,7,8-PeCDF were consistently found as the major contributors to the ΣTexas-TEQ concentration. Contributions of up to 23, 22, 25, 22, and 25 % were observed for 12378-PeCDD at Clinton Drive, Lang Road, Haden Road, Mont Belvieu, and Bayland Park, respectively. Similarly, contributions of up to 31, 33, 30, 60, and 25 % were found for 23478-PeCDF at the same sites, respectively. Finally, 2,3,7,8TCDD's contributions to the ΣTexas-TEQ of up to 15, 20, 13, 17, and 19 % were observed at the aforementioned sites, respectively.

4.6.1 Vapor-to-particle Partitioning

Tables 4.22 and 4.23 show the range in the percentage of the total concentration that was particle bound for individual congeners over the sampling period at Clinton Drive and Lang Road, respectively. A general gradation in partitioning behavior was observed from compounds found totally/almost exclusively in the vapor phase (e.g., 2378-TCDD), through those that had substantial concentrations in both phases (e.g., 123478-HxCDD), to those that were totally/almost exclusively found on particles (e.g., OCDD). Partitioning behavior is influenced by several factors, notably compound vapor pressure, temperature, level of chlorination, and nature of

Table 4.22 Particle-bound (P) and Vapor (V) Phase Concentrations (fg/m^3), and Particulate fraction (PF) of Dioxins and Furans at Clinton Drive

Congener	Oct/02			Jan/03			Feb/03			Mar/03			Apr/03			May/03			Jun/03			Jul/03		
	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF
2,3,7,8-TCDD	0.5	<0.8	-[b]	0.9	<0.6	-[b]	<0.4	<0.4	-[b]	0.8	<0.4	-[b]	0.7	<0.4	-[b]	0.6	<0.4	-[b]	0.9	<0.4	-[b]	0.8	<0.6	-[b]
1,2,3,7,8-PeCDD	1.1	0.5	0.34	<2.6	2.1	-[b]	1.8	1.3	0.42	2.5	1.4	0.36	2	1.2	0.38	1.6	0.4	0.21	1.8	<0.6	-[b]	2.2	<1.2	-[b]
1,2,3,4,7,8-HxCDD	0.9	1.7	0.66	1.7	5.8	0.78	1.6	3.6	0.69	3.3	4.9	0.6	2.3	2.7	0.55	1.6	1	0.38	1.5	1.4	0.47	1.4	1.3	0.49
1,2,3,6,7,8-HxCDD	1.7	3.1	0.64	2.5	10.3	0.8	2.4	6.4	0.72	4.9	9.4	0.66	3.9	4.1	0.51	3.2	2.1	0.39	2.7	2.7	0.5	3.1	2.9	0.49
1,2,3,7,8,9-HxCDD	1.3	3.5	0.73	1.9	10.6	0.85	2.2	7.2	0.77	4.1	9.7	0.7	3.2	5.2	0.62	2.5	2.4	0.49	2.1	2.5	0.54	2.3	3.2	0.58
1,2,3,4,6,7,8-HpCDD	6.3	84.8	0.93	4.4	213.5	0.98	6.1	151.3	0.96	19.2	282.5	0.94	30.5	114.2	0.79	23.4	58.8	0.72	17.7	65.8	0.79	18.7	61.6	0.77
OCDD	4.3	402	0.99	3	788	1	2.2	626.6	1	9	1286.3	0.99	28.5	587.2	0.95	29.3	360.5	0.92	25.6	393.7	0.94	16	316.7	0.95
2,3,7,8-TCDF	2.5	0.4	0.15	4.6	<0.8	-[b]	3.7	0.7	0.17	3.3	0.7	0.17	2.7	0.6	0.18	2.1	<0.4	-[b]	4.3	0.4	0.08	3.8	<0.8	-[b]
1,2,3,7,8-PeCDF	1.6	0.6	0.26	3.8	1.8	0.32	2.2	1.1	0.33	3.4	1.1	0.24	1.8	0.9	0.32	1.8	<1.4	-[b]	2	0.4	0.18	2.1	<1.2	-[b]
2,3,4,7,8-PeCDF	2.1	1.2	0.36	4.6	3.8	0.45	3.2	2.3	0.42	5.3	2	0.27	2.3	1.3	0.36	1.9	0.5	0.2	2.7	0.7	0.22	3.3	<1.2	-[b]
1,2,3,4,7,8-HxCDF	2.5	3.8	0.61	3.7	7.9	0.68	2.7	4	0.6	4.8	4.3	0.47	2.6	3.3	0.55	2.6	1.4	0.36	2.9	1.6	0.35	2.8	1.6	0.36
1,2,3,6,7,8-HxCDF	2.1	2.9	0.58	3.2	6.9	0.69	2.1	3.5	0.63	4.4	3.8	0.46	2.1	2.3	0.52	2.3	1.3	0.37	2.2	1.3	0.38	2.6	1.7	0.39
2,3,4,6,7,8-HxCDF	1.8	5.1	0.73	2.4	11.2	0.82	1.9	6.8	0.78	4.8	8	0.63	2	3.6	0.65	2.4	2.3	0.49	2.8	2.3	0.45	2.6	2.7	0.51
1,2,3,7,8,9-HxCDF	0.5	1.9	0.8	0.6	3	0.82	0.7	2	0.74	1.5	2.3	0.61	0.7	1.2	0.64	0.7	1.9	*0.74*	0.8	0.6	0.42	<0.6	<0.6	-[b]
1,2,3,4,6,7,8-HpCDF	4.6	32.6	0.88	2.6	48.2	0.95	2.7	25.4	0.9	9.1	38.8	0.81	6.5	21.2	0.77	7.2	13.3	0.65	9.5	15.4	0.62	7.9	13.4	0.63
1,2,3,4,7,8,9-HpCDF	<0.6	4.7	-[b]	<0.2	4.9	-[b]	<2.6	3.6	-[b]	<2.8	4.9	-[b]	<2.6	3	-[b]	0.5	<2.6	-[b]	0.8	1.8	0.68	<0.8	1.9	-[b]
OCDF	1.2	41.7	0.97	<1.0	52.5	-[b]	<5.2	30.8	-[b]	<5.4	50.2	-[b]	1.5	34.7	0.96	2.1	19.6	0.9	3.6	26.6	0.88	2.1	21.9	0.91
Σ(PCDDs + PCDFs)[a]	35.3	590.9	0.94	41.8	1171.2	0.97	39.6	876.8	0.96	84.5	1710.5	0.95	94.6	786.9	0.89	85.8	467.9	0.85	83.9	517.7	0.86	72.4	431.7	0.86
ΣTexas-TEQ[a]	3.5	3.5	0.5	6.1	9	0.59	4.5	5.5	0.55	8	6.3	0.44	4.9	3.8	0.44	4.2	1.9	0.32	5.2	2	0.28	5.5	2.3	0.3
Average Temp (°C)			19.3			10.6			12.3			17.4			21.3			26.3			27.7			27.9

Congener	Aug/03			Dec/03-Jan/04			Jan/04-Feb/04			Feb/04-Mar/04			Mar/04-Apr/04			Sep/04-Oct/04			Nov/04-Dec/04			Jan/05-Feb/05		
	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF
2,3,7,8-TCDD	1.3	<0.4	-[b]	0.7	<0.6	-[b]	0.9	<0.6	-[b]	1.3	<0.4	-[b]	<0.6	<0.4	-[b]	0.7	<0.4	-[b]	0.8	0.3	0.28	0.6	<0.2	-[b]
1,2,3,7,8-PeCDD	2.7	0.9	0.26	2	3.7	0.65	3.8	4.1	0.52	7.1	2	0.22	1.4	1.2	0.46	<2.2	<0.8	-[b]	2.1	3.2	0.6	<1.4	1.8	-[b]
1,2,3,4,7,8-HxCDD	2.2	2.4	0.52	1	8.6	0.9	5.2	5.6	0.52	4.8	4.9	0.51	<1.0	2.5	-[b]	2.1	2.2	0.51	1.2	7	0.85	0.8	4.5	0.85
1,2,3,6,7,8-HxCDD	4.3	4.2	0.49	2	16.6	0.9	7.9	9.6	0.55	7.8	9	0.54	1.5	4.7	0.77	3.8	4.9	0.56	2.3	15.4	0.87	1.3	8.3	0.86
1,2,3,7,8,9-HxCDD	3.5	4.7	0.57	1	15.1	0.92	3.1	8.8	0.74	6.1	9.9	0.62	<1.2	4.3	-[b]	2.9	5.4	0.65	1.7	16	0.9	1.2	9.2	0.88
1,2,3,4,6,7,8-HpCDD	32	135.2	0.81	3	291	0.99	3.9	273.7	0.99	20.8	229	0.92	7.7	90	0.92	20.4	104.6	0.84	5.3	264.1	0.98	3.2	150.4	0.98
OCDD	35.1	733.2	0.95	<2	990.7	-[b]	2.9	946.8	1	7.7	906.8	0.99	5.5	445.1	0.99	21.4	497.2	0.96	2.6	1019.2	1	1.8	598.4	1
2,3,7,8-TCDF	3.6	0.3	0.07	3	<1.2	-[b]	7.3	0.8	0.1	4.9	0.5	0.1	1.8	0.5	0.2	3.3	0.3	0.09	3.4	0.8	0.2	2.8	0.8	0.23
1,2,3,7,8-PeCDF	2.2	0.6	0.22	3	3	0.51	4.7	3.9	0.45	5.5	1.3	0.19	1.4	0.8	0.37	2.2	0.5	0.18	2.9	1.7	0.38	2.5	2	0.44
2,3,4,7,8-PeCDF	3.2	1.2	0.27	4	7.2	0.67	7.4	4.2	0.36	8.3	2.1	0.2	1.8	1.5	0.45	2.9	<0.8	-[b]	4.3	4.4	0.5	3.8	4.2	0.52
1,2,3,4,7,8-HxCDF	2.6	2.1	0.45	2	11.1	0.86	2.6	7	0.73	8.8	3.1	0.26	<2.2	4.3	-[b]	2.9	1.8	0.38	2.6	7.9	0.76	2.2	8.4	0.8
1,2,3,6,7,8-HxCDF	2.5	<1.8	-[b]	1	9.6	0.88	2	5.1	0.72	5.8	3.1	0.35	1.6	3.7	0.7	2.7	1.9	0.41	2.4	7.8	0.76	1.7	6.5	0.79
2,3,4,6,7,8-HxCDF	2.6	3.5	0.58	1	15.1	0.94	0.8	6.3	0.89	4.1	5	0.55	1.3	6.3	0.83	2.9	3	0.51	2	14	0.87	1.5	12.4	0.89
1,2,3,7,8,9-HxCDF	0.8	<1.2	-[b]	<0.4	5.6	-[b]	3.1	5.1	0.62	1.5	1.6	0.52	<0.4	1.7	-[b]	<0.6	1	-[b]	0.7	4.1	0.85	0.5	3.6	0.87
1,2,3,4,6,7,8-HpCDF	8.2	19.5	0.7	1	57	0.98	5.6	17.4	0.76	8.4	23.5	0.74	3.4	28.3	0.89	9.7	18.6	0.66	3.2	52.2	0.94	2.4	43.5	0.95
1,2,3,4,7,8,9-HpCDF	0.7	3.3	0.82	<0.2	9.2	-[b]	<0.6	7.9	-[b]	<0.6	<3.4	-[b]	<0.6	4.5	-[b]	<0.8	<2.4	-[b]	0.2	6	0.96	<0.2	6	-[b]
OCDF	2.2	30.7	0.93	<1.0	47.5	-[b]	<1.2	33.7	-[b]	<1.2	75	-[b]	<1.8	36.4	-[b]	2.6	51.8	0.95	0.4	55.6	0.99	0.4	62.1	0.99
Σ(PCDDs + PCDFs)[a]	109.7	943.5	0.9	26.5	1491.9	0.98	62.1	1340.3	0.96	103.8	1278.7	0.92	31.3	636	0.95	82.3	695.4	0.89	38.1	1479.7	0.97	27.5	922.2	0.97
ΣTexas-TEQ[a]	6.6	3.2	0.32	5	14.1	0.74	9.9	9.5	0.49	13.7	6	0.31	2.8	4.4	0.61	4.9	2.7	0.35	5.8	11.5	0.67	4.2	8.6	0.67
Average Temp (°C)			28			13.2			11.7			19.3			21.9			25.9			16.1			15.3

[a] non-detects assumed equal to ½ MDL for calculations

[b] not calculated (either of the phases below the detection limit).

Table 4.23 Particle-bound (P) and Vapor (V) Phase Concentrations (fg/m^3), and Particulate Fraction (PF) of Dioxins and Furans at Lang Road

Congener	Oct/02			Nov/02			Jan/03			Feb/03			Mar/03			Apr/03			May/03			Jun/03		
	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF
2,3,7,8-TCDD	0.9	<0.6	-[b]	0.4	<0.6	-[b]	1.2	<0.6	-[b]	0.8	<0.4	-[b]	0.8	<0.4	-[b]	0.6	<0.4	-[b]	0.7	<0.4	-[b]	0.5	<0.2	-[b]
1,2,3,7,8-PeCDD	2.4	1.4	0.37	2.1	4	0.65	3.7	2.3	0.39	2.5	1.8	0.41	4.6	1.1	0.19	2.3	<3.2	-[b]	1.9	<3.2	-[b]	1.2	<0.2	-[b]
1,2,3,4,7,8-HxCDD	2.1	4.2	0.66	1.6	9.3	0.85	2.1	6	0.74	2.4	5.5	0.7	5	3.5	0.41	2.4	1.6	0.4	2.4	0.9	0.28	1	0.6	0.37
1,2,3,6,7,8-HxCDD	3.6	7.8	0.69	3.3	16.9	0.84	3.4	11	0.76	4	9.2	0.7	9.7	6.6	0.41	4.1	3	0.42	4.4	1.8	0.29	2	1.3	0.39
1,2,3,7,8,9-HxCDD	3.1	9.1	0.75	2.4	18.4	0.88	2.7	12.1	0.82	3.3	10.4	0.76	9.1	8.1	0.47	3.4	3.4	0.5	3.6	2	0.36	<1.4	1.2	-[b]
1,2,3,4,6,7,8-HpCDD	18.7	213.2	0.92	6.2	427.3	0.99	7.3	219	0.97	11.9	236.8	0.95	45.5	275.1	0.86	30.1	84.4	0.74	45.4	51.3	0.53	13.5	30	0.69
OCDD	12.6	953.1	0.99	3.6	1500.1	1	4.8	812	0.99	4.9	918	0.99	17.7	1139.4	0.98	24.8	431.1	0.95	71.1	290.3	0.8	18.5	153.5	0.89
2,3,7,8-TCDF	2.5	0.5	0.15	2.9	0.7	0.2	7.3	1	0.13	2.5	0.7	0.21	3.5	0.3	0.09	3.2	0.5	0.14	3.2	0.6	0.16	2.6	<0.2	-[b]
1,2,3,7,8-PeCDF	2.3	0.9	0.29	4.5	1.6	0.27	5.8	2.3	0.28	2.3	1	0.31	3.7	0.7	0.17	2.7	<1.4	-[b]	2.3	0.7	0.24	2	0.3	0.13
2,3,4,7,8-PeCDF	2.9	1.6	0.36	5	3	0.37	7.1	5.1	0.42	2.8	2.3	0.45	5.6	1.5	0.21	3.5	1.2	0.26	2.5	1.2	0.32	2.5	0.5	0.18
1,2,3,4,7,8-HxCDF	3.4	3.7	0.52	11.7	9.5	0.45	4.3	9.4	0.68	2.5	4.5	0.64	7.1	3.3	0.32	4.4	2.5	0.37	3.3	2.2	0.4	3	1.2	0.28
1,2,3,6,7,8-HxCDF	2.7	3	0.53	5.7	6.3	0.52	3.6	7.7	0.68	2	3.8	0.66	5.6	2.9	0.34	3.8	2.1	0.35	2.9	2.1	0.42	2.6	0.8	0.24
2,3,4,6,7,8-HxCDF	2.4	6.3	0.73	4.1	11.4	0.73	2.7	13	0.83	1.6	7	0.82	7.4	6.9	0.48	4	4.1	0.51	3.1	5	0.61	2.9	1.7	0.37
1,2,3,7,8,9-HxCDF	0.8	2.2	0.74	1.9	4.1	0.68	0.7	3.8	0.84	0.6	2.3	0.78	2.2	1.9	0.47	1.2	1.3	0.52	0.9	<3.6	-[b]	0.8	0.7	0.46
1,2,3,4,6,7,8-HpCDF	6.5	34.7	0.84	8.7	69.2	0.89	3.6	51.6	0.93	2.9	29.3	0.91	15.4	36.2	0.7	11.3	21.4	0.65	9.6	12	0.55	9	9.9	0.53
1,2,3,4,7,8,9-HpCDF	<0.6	4.7	-[b]	0.8	11.3	0.93	<0.2	5.1	-[b]	<2.6	4.3	-[b]	<2.6	4.9	-[b]	0.7	3.3	0.83	<2.6	<2.6	-[b]	0.7	1.5	0.67
OCDF	1.4	41.9	0.97	0.6	80.8	0.99	<0.8	43.5	-[b]	<5.0	30	-[b]	1.7	44.6	0.96	1.9	24.9	0.93	3.2	14.6	0.82	2.5	13.9	0.85
Σ(PCDDs + PCDFs)[a]	68.6	1288.6	0.95	65.5	2174.2	0.97	60.8	1205.2	0.95	50.8	1267.1	0.96	145.9	1537.2	0.91	104.4	587.3	0.85	161.8	389.6	0.71	66	217.4	0.77
ΣTexas-TEQ[a]	5.7	5.5	0.49	7.5	11.5	0.6	9.6	10.5	0.52	5.5	6.6	0.55	11	4.9	0.31	6.3	3.5	0.36	5.4	3.3	0.38	4	1.2	0.23
Average Temp (°C)			18.6			14.9			10			10.5			16.9			20.9			26.1			27.3

Congener	Jul/03			Aug/03			Dec/03-Jan/04			Jan/04-Feb/04			Feb/04-Mar/04			Mar/04-Apr/04		
	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF	V	P	PF
2,3,7,8-TCDD	<0.6	<0.6	-[b]	1.6	<0.4	-[b]	<0.6	<0.6	-[b]	<0.6	<0.4	-[b]	<0.4	<0.2	-[b]	<0.6	<0.2	-[b]
1,2,3,7,8-PeCDD	1.5	0.7	0.31	2.2	1	0.31	2.2	3	0.57	3.4	1.4	0.29	2.2	<0.6	-[b]	1.2	0.7	0.35
1,2,3,4,7,8-HxCDD	1.9	<1.8	-[b]	1.7	2.5	0.59	1.6	7.5	0.83	1.9	5.1	0.73	2.3	2.2	0.49	<0.8	1.4	-[b]
1,2,3,6,7,8-HxCDD	3.6	2.6	0.43	3.4	4.2	0.55	2.7	13.9	0.84	3.4	10.4	0.75	4.2	4.9	0.54	1.9	3.5	0.65
1,2,3,7,8,9-HxCDD	2.7	2.9	0.51	2.5	4.8	0.66	1.9	13.1	0.87	2.9	11.3	0.79	3.2	4.4	0.57	1	3.5	0.77
1,2,3,4,6,7,8-HpCDD	21.2	59.3	0.74	28.5	117.4	0.8	5.8	244.1	0.98	6	207.4	0.97	14.9	89	0.86	7.7	62.9	0.89
OCDD	22.9	270.5	0.92	41.4	549	0.93	2.6	896.4	1	3.1	802.2	1	8	374.1	0.98	5.9	293.9	0.98
2,3,7,8-TCDF	3.4	<0.8	-[b]	2.6	<0.2	-[b]	4.2	1.3	0.24	2.5	0.5	0.16	3.7	0.5	0.11	2.1	<0.4	-[b]
1,2,3,7,8-PeCDF	2.4	<1.2	-[b]	1.9	0.3	0.15	3.6	2.1	0.37	2.1	1	0.33	3.4	<1.0	-[b]	1.5	0.7	0.32
2,3,4,7,8-PeCDF	3.6	<1.0	-[b]	2.6	0.6	0.17	4.9	5.4	0.53	3.3	2.1	0.38	6.1	1.9	0.24	1.9	1.4	0.42
1,2,3,4,7,8-HxCDF	3.2	2.1	0.4	2.5	1	0.29	2.7	8.1	0.75	2.4	4	0.63	6.6	3.6	0.35	2.4	3.3	0.58
1,2,3,6,7,8-HxCDF	2.8	2.1	0.43	2.7	1.1	0.29	2.3	7.3	0.76	2.1	3.9	0.65	5.2	<3.4	-[b]	1.7	2.7	0.61
2,3,4,6,7,8-HxCDF	2.9	3	0.51	2.9	2.2	0.43	1.4	10.6	0.89	<1.4	6.9	-[b]	6	6.9	0.53	1.7	5.4	0.76
1,2,3,7,8,9-HxCDF	<0.6	0.9	-[b]	0.7	0.8	0.53	<0.6	3.9	-[b]	<0.4	2.2	-[b]	1.9	2.2	0.54	<0.8	1.6	-[b]
1,2,3,4,6,7,8-HpCDF	8.9	15.4	0.63	9.4	11.2	0.54	2.3	41.8	0.95	2	26.8	0.93	11.9	30.8	0.72	5.2	26.7	0.84
1,2,3,4,7,8,9-HpCDF	<0.8	<1.8	-[b]	0.7	1.7	0.69	<0.4	8.1	-[b]	<0.4	4	-[b]	<0.6	2.1	-[b]	<0.8	4.1	-[b]
OCDF	1.8	17.6	0.91	3	16.6	0.85	<0.2	45.1	-[b]	<0.8	26	-[b]	<0.8	36.4	-[b]	<2.6	37	-[b]
Σ(PCDDs + PCDFs)[a]	83.8	380.7	0.82	110.3	714.7	0.87	39.1	1312	0.97	36.9	1115.4	0.97	80.5	561.6	0.87	37	449.2	0.92
ΣTexas-TEQ[a]	5.1	2.4	0.32	6	2.7	0.31	5.7	11.2	0.66	5.4	6.4	0.55	7.8	3.9	0.33	3.1	3.4	0.53
Average Temp (°C)			27.2			28.2			12.3			11.2			19.1			21.3

[a] ½ MDL taken for calculations

[b] not calculated (either of the phases below the detection limit).

particles.

Most of the total mass of the 2378-substituted congeners of dioxins and furans was extensively found bound to particles (see Tables 4.22 and 4.23). Total particulate fractions ranging from 0.85 to 0.98 and from 0.71 to 0.97 were detected at Clinton Drive and Lang Load, respectively. In terms of ΣTexas-TEQ particulate fractions, values fluctuating from 0.28 to 0.74 and from 0.23 to 0.66 were calculated at Clinton Drive and Lang Road, respectively.

Another finding from the collected data is that the dioxin congeners tend to be more associated with the particle phase than the furan congeners. This characteristic is due to differences in the vapor pressure (a temperature-dependent property) between these two groups of compounds (For example, an average particle fraction of 0.40 for 1,2,3,7,8-PeCDD versus 0.31 for 1,2,3,7,8-PeCDF at the Clinton Drive site - see Table 4.24).

The correlation between the mass fraction of each congener and the ΣTexas-TEQ bound to particles was assessed by linear regression (see Table 4.24). In general, the analysis showed a negative correlation of the particulate fraction with ambient temperature. This negative correlation means that the mass of a specific congener bound to particles increases as temperature decreases.

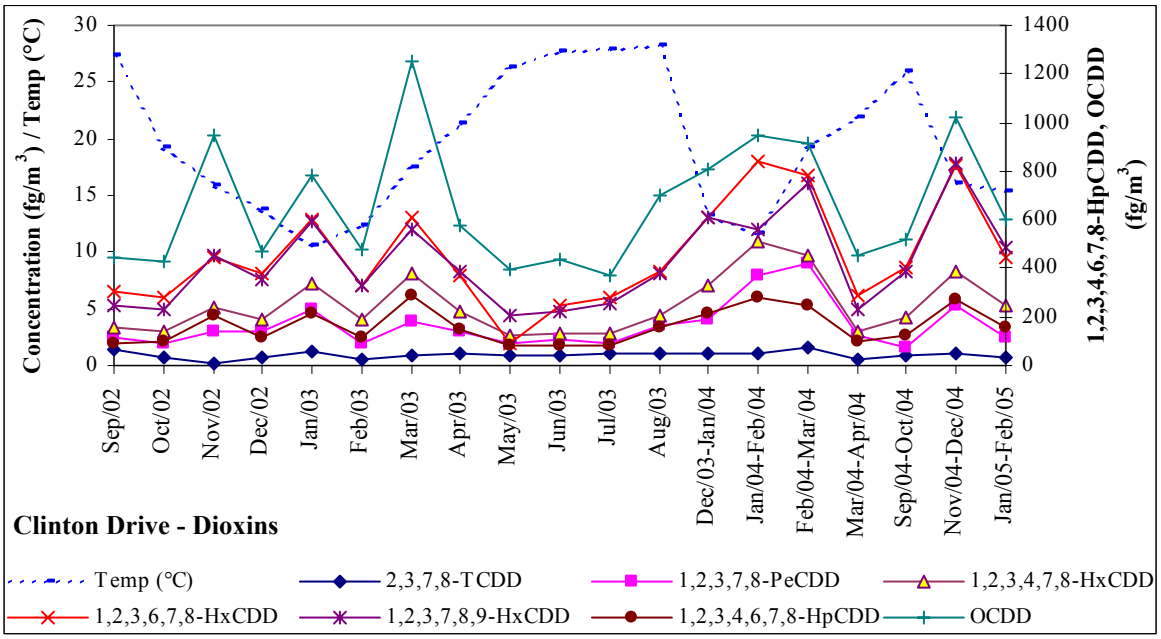
4.6.2 Temporal Trend

The temporal trend for each dioxin and furan congener at each location is illustrated in Figure 4.70a through e where the detected monthly/bi-monthly ambient air concentrations were plotted over time. The mean ambient temperature was also included in Figure 4.70. These plots suggest that there is dependence of the concentration over time due to level of chlorination, the

Table 4.24 Particulate Fraction (PF) versus Ambient Temperature Correlation Results

Congener	Clinton Dr				Lang Road			
	Slope	r^2	p-value	Mean PF	Slope	r^2	p- value	Mean PF
2,3,7,8-TCDD	-	-	-	0.28[a]	-	-	-	-
1,2,3,7,8-PeCDD	-0.0191	0.5	0.0155	0.4	-0.007	0.12	0.35	0.39
1,2,3,4,7,8-HxCDD	-0.0181	0.51	0.0028	0.62	-0.0198	0.44	0.0131	0.6
1,2,3,6,7,8-HxCDD	-0.0184	0.5	0.0023	0.64	-0.0209	0.58	0.0016	0.59
1,2,3,7,8,9-HxCDD	-0.182	0.7	0.0001	0.7	-0.0177	0.44	0.0137	0.67
1,2,3,4,6,7,8-HpCDD	-0.0133	0.8	2.9×10^{-6}	0.89	-0.0168	0.67	0.0003	0.85
OCDD	-0.0038	0.74	3.5×10^{-5}	0.98	-0.0065	0.56	0.0021	0.96
2,3,7,8-TCDF	-0.0052	0.28	0.0784	0.15	-0.0031	0.13	0.3134	0.16
1,2,3,7,8-PeCDF	-0.0127	0.48	0.0059	0.31	-0.0081	0.5	0.015	0.26
2,3,4,7,8-PeCDF	-0.015	0.41	0.0137	0.38	-0.0127	0.52	0.0053	0.33
1,2,3,4,7,8-HxCDF	-0.0228	0.59	0.0009	0.55	-0.0184	0.6	0.0011	0.48
1,2,3,6,7,8-HxCDF	-0.0224	0.57	0.0011	0.58	-0.0195	0.64	0.001	0.5
2,3,4,6,7,8-HxCDF	-0.0226	0.7	5.9×10^{-5}	0.7	-0.0209	0.62	0.0015	0.63
1,2,3,7,8,9-HxCDF	-0.0185	0.4	0.0123	0.69	-0.0173	0.6	0.0148	0.62
1,2,3,4,6,7,8-HpCDF	-0.0167	0.66	0.0001	0.8	-0.0221	0.84	4.4×10^{-6}	0.76
1,2,3,4,7,8,9-HpCDF	-0.0176	0.66	0.3474	0.82	-0.0195	0.97	0.0101	0.78
OCDF	-0.0068	0.73	0.0013	0.94	-0.0107	0.8	0.0028	0.91
ΣI-TEQ	-0.0174	0.61	0.0004	0.56	-0.0167	0.64	0.0006	0.52
ΣTexas-TEQ	-0.0188	0.58	0.0006	0.47	-0.0156	0.59	0.0015	0.44

[a] This value corresponds to the Nov/04-Dec/04 event where particle-bound concentration was detected.



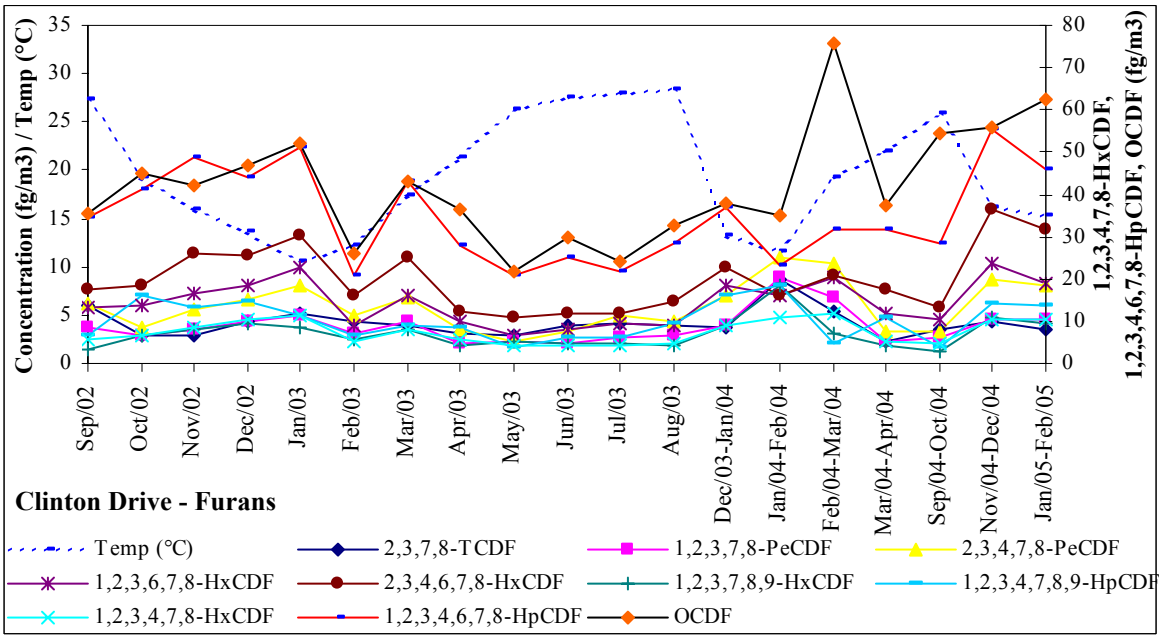
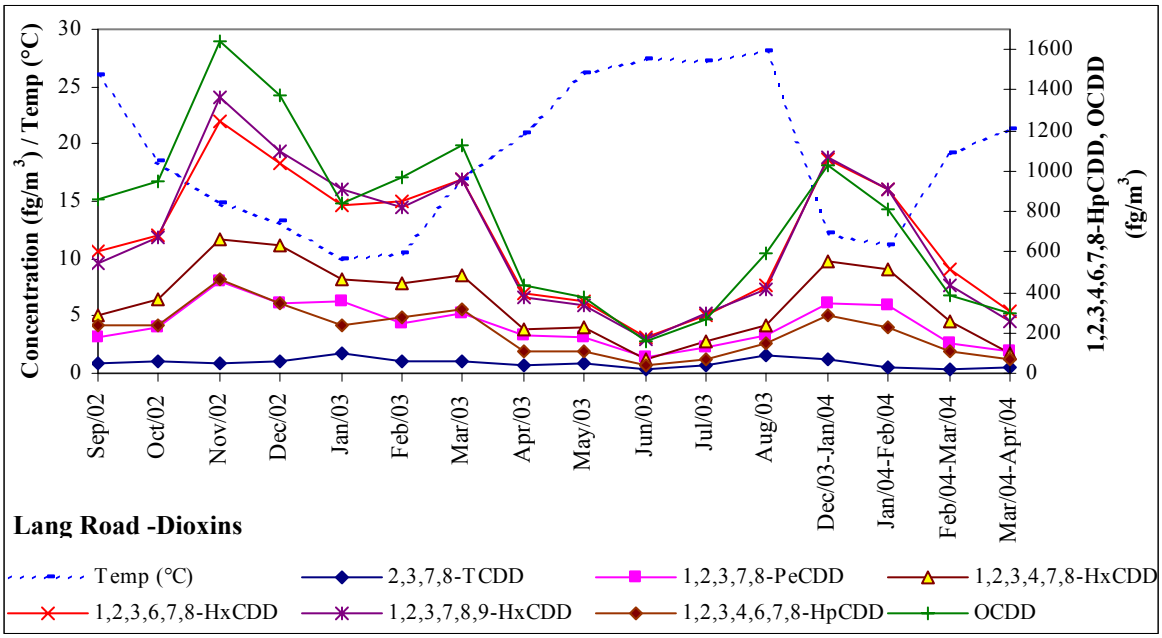


Figure 4.70a Monthly/Bi-Monthly Ambient Air Concentrations of Dioxins and Furan Congeners at *Clinton Drive* from September 2002 – February 2005.



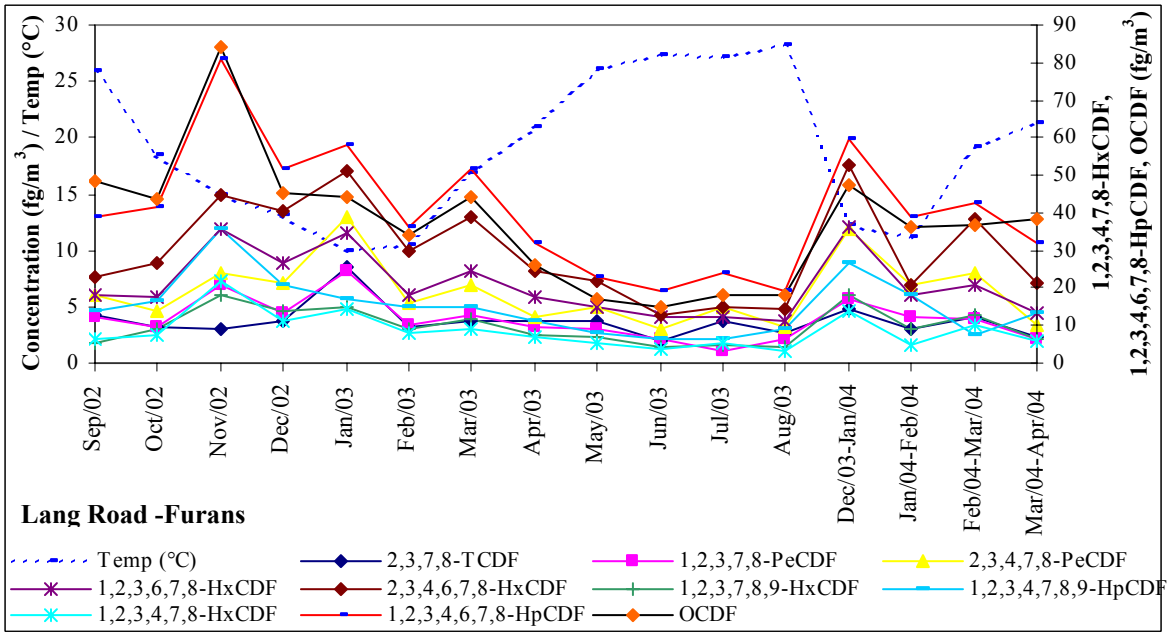
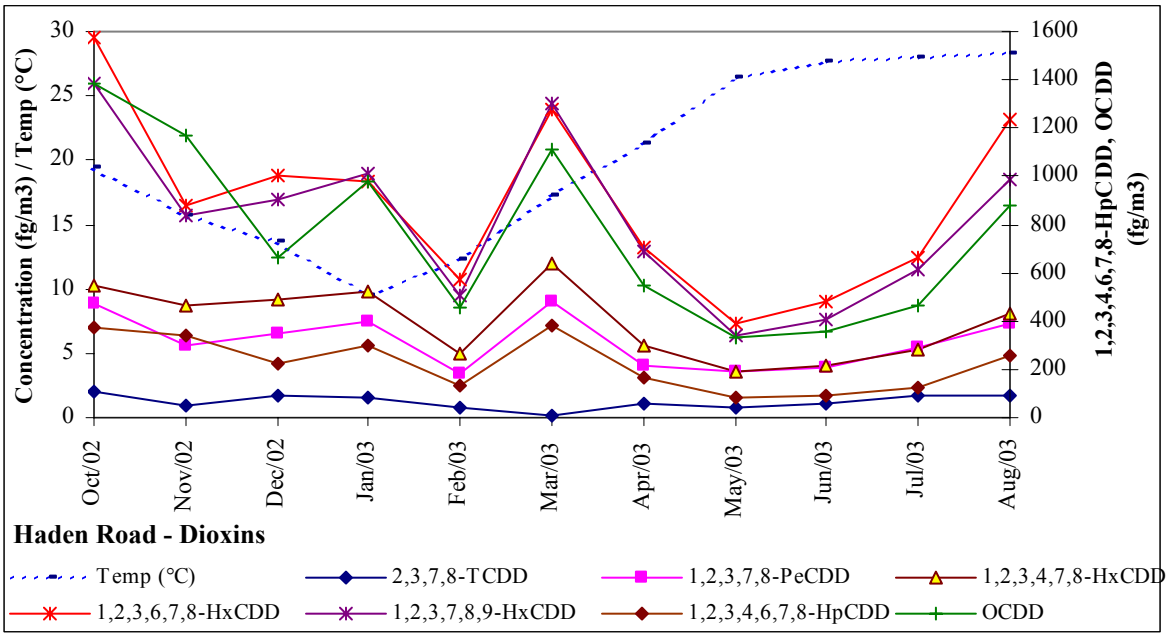


Figure 4.70b Monthly/Bi-Monthly Ambient Air Concentrations of Dioxins and Furan Congeners at *Lang Road* from September 2002 – April 2004.



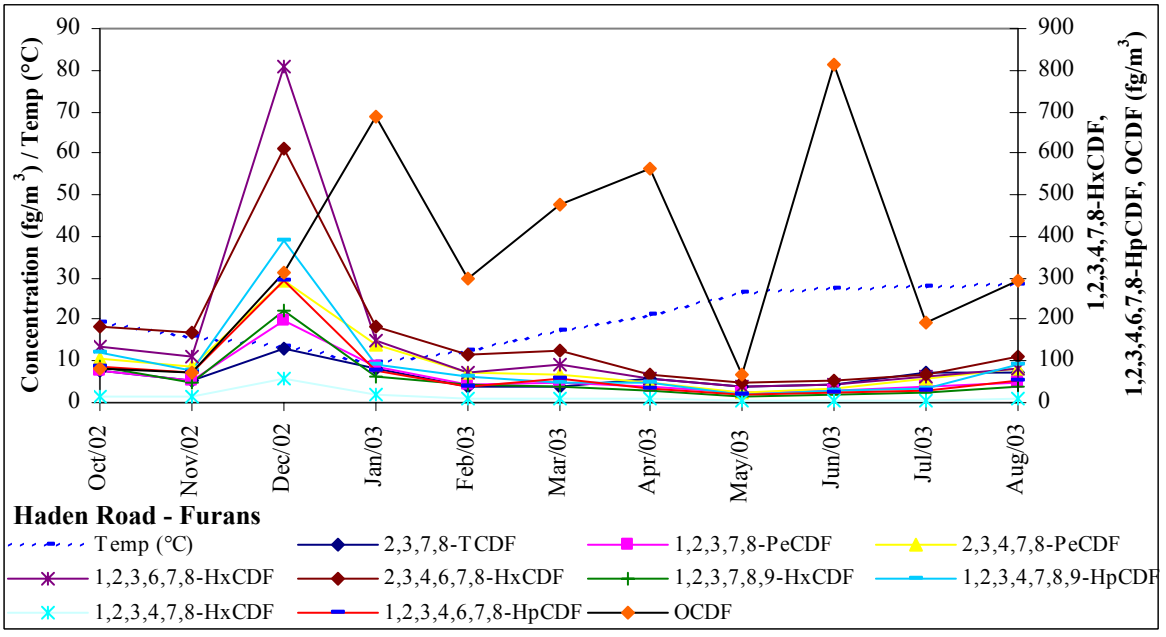


Figure 4.70c Monthly Ambient Air Concentrations of Dioxins and Furan Congeners at *Haden Road* from September 2002 – August 2003.

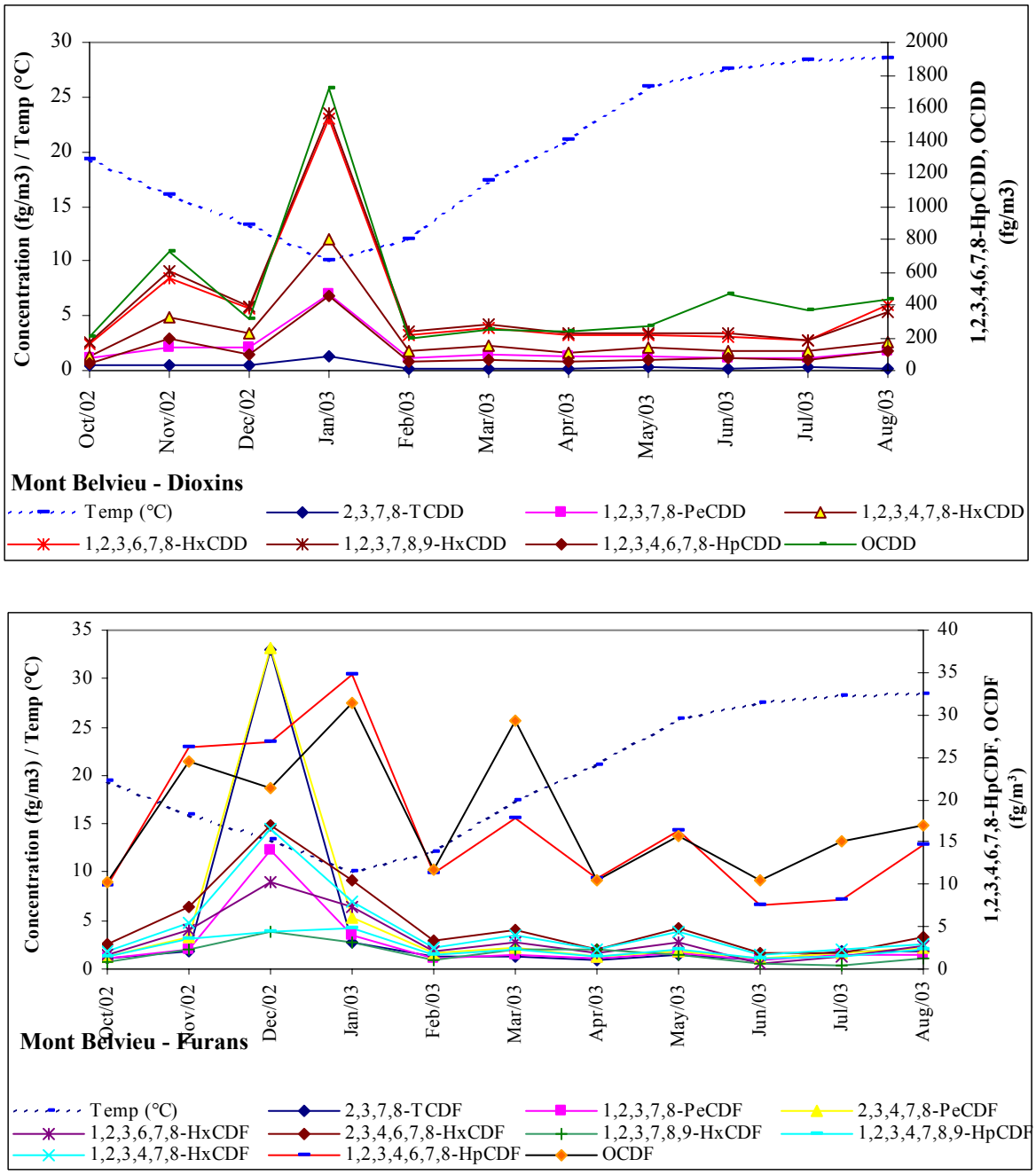
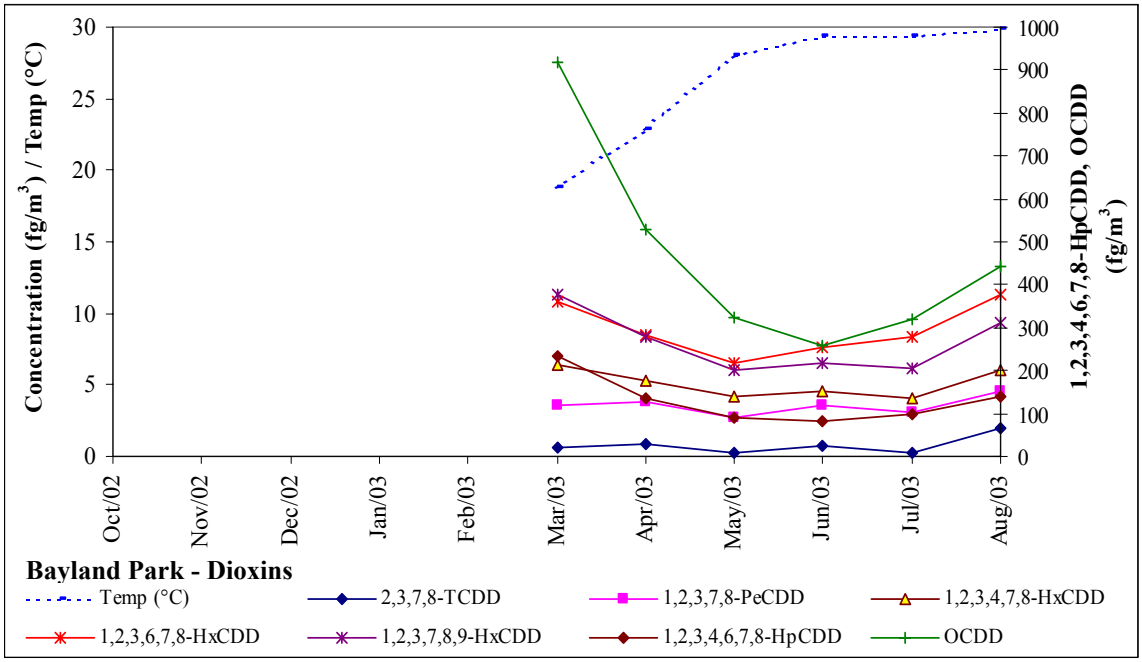


Figure 4.70d Monthly Ambient Air Concentrations of Dioxins and Furan Congeners at *Mont Belvieu* from September 2002 – August 2003.



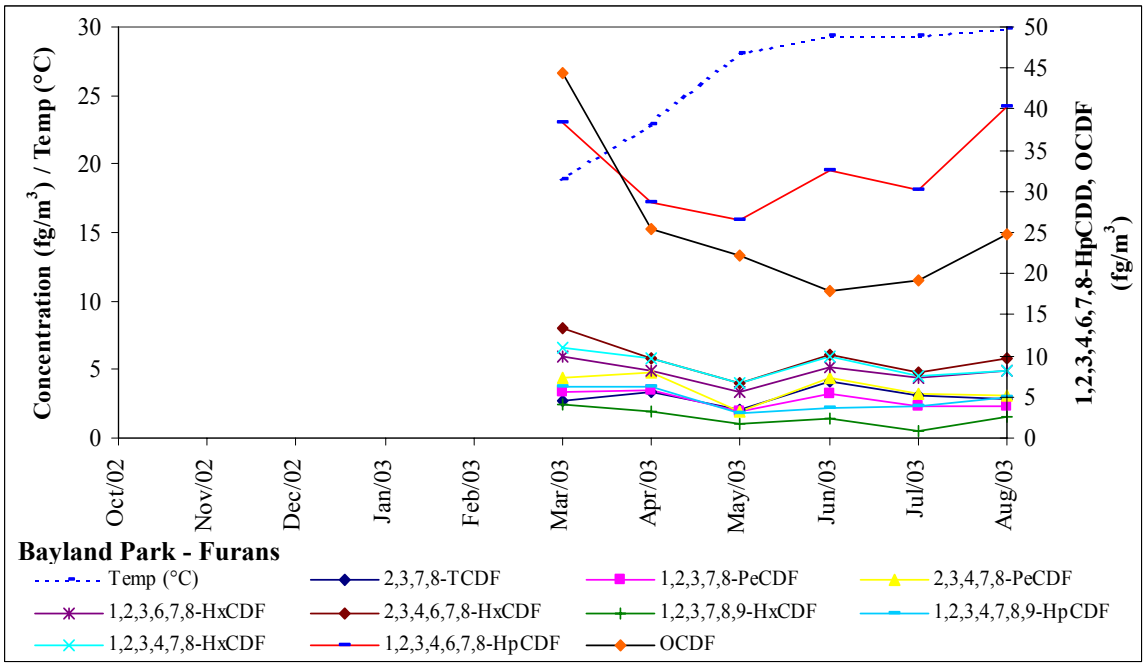


Figure 4.70e Monthly Ambient Air Concentrations of Dioxins and Furan Congeners at *Bayland Park* from March 2003 – August 2003.

type of congener (i.e., dioxin or furan) and, the time of year (i.e., ambient temperature). Dioxin and furan congeners tended to peak during the colder months (November – March). This seasonal behavior is likely due to seasonal sources of dioxins (e.g., combustion sources), atmospheric variations such as air mass movement patterns, temperature inversion conditions, and alteration of atmospheric removal processes such as chemical reactions occurring in the atmosphere and wet and dry deposition.

The variation of the ΣTexas-TEQ concentration over time (i.e., temperature) was statistically assessed using the Mann Kendall test for trend at Clinton Drive, Lang Road, Haden Road, and Mont Belvieu. Data collected over one year of sampling (September 2002 –August 2003) was analyzed for temporal trend. The data from Bayland Park was not included in the analysis because the sampling at this location was carried out for only 6 months (March 2003-August 2003), and therefore is not comparable. The test indicated a statistically significant trend (at $\alpha = 0.05$) of increasing ΣTexas-TEQ concentration with decreasing ambient temperature at the four monitoring locations.

4.6.3 Spatial Trends

The spatial variability among the data collected at the different air monitoring sites was analyzed using the *t*-test. Data obtained at Bayland Park (C53) was excluded from the analysis because the length of the sampling period (only six months) at this location does not make it comparable with the rest of the sites. Prior to the examination of the spatial variability, the coefficient of variation (CV) (the ratio between the standard deviation and the mean) at each site and congener was assessed to determine if the use of normal distribution parameters to estimate central tendency and variability was appropriate. The results of this analysis are summarized in

Table 4.25. In general, CV values less than 2 were obtained for all congeners at all sites, with the exception of 2,3,7,8-TCDF at Mont Belvieu site (C610). These results suggested that the use of normal distribution parameters was appropriate. The *p*-values of the pairs of monitoring sites were analyzed at an $\alpha = 0.05$ significance level and the results are also summarized in Table 4.25. In this analysis, the null hypothesis (H_O) of equal means ($\mu_x = \mu_y$) was tested against the alternative hypothesis (H_A) of difference of means ($\mu_x \neq \mu_y$). Overall, significant statistical spatial differences were observed among the congener, total ambient air, and ΣTexas-TEQ concentrations. For example, 2378-TCDD was found to fluctuate among the air monitoring pairs C403-C603, C403-C610, C408-C610, and C603-C610. Similarly, 1,2,3,7,8-PeCDD, one of the major contributors to the ΣTexas-TEQ concentrations was found to show significant statistical differences among the pairs C403-C603, C403-C610, C408-C603, C408-C610, and C603-C610. In contrast, no significant difference was observed for OCDD among the pairs of sites analyzed. Finally, ΣTexas-TEQ concentrations showed significant differences among the pairs C403-C603, C408-C603, C408-C610, and C603-C610. From these results, it is concluded that the Houston data exhibit spatial variability based on the observed differences between the sampled sites.

The overall spatial variability in the Houston data was further confirmed by applying the Kruskall-Wallis non-parametric comparison test on ΣTexas-TEQ concentrations at an $\alpha = 0.05$ level. This test also indicated that statistically different ΣTexas-TEQ concentrations exist among the four locations tested. These variations may be attributed to differences in air mass movement across the airshed and type of sources involved.

Table 4.25 Coefficient of Variation (CV) and *p* -value Results (September 2002 – August 2003)

Congener	Coefficient of Variation				Pairs of monitoring sites (*p* -values)					
	C403	C408	C603	C610	C403-C408	C403-C603	C403-C610	C408-C603	C408-C610	C603-C610
2,3,7,8-TCDD	0.34	0.37	0.44	0.84	0.4422	*0.0297*	*0.0015*	0.1061	*6.38E-05*	*0.0002*
1,2,3,7,8-PeCDD	0.34	0.49	0.35	0.98	0.1011	*0.0003*	*0.0142*	*0.0285*	*0.0037*	*8.63E-05*
1,2,3,4,7,8-HxCDD	0.39	0.54	0.37	0.94	0.0907	*0.0006*	0.1627	0.2041	*0.0226*	*0.0032*
1,2,3,6,7,8-HxCDD	0.4	0.51	0.42	1.03	0.06	*0.0007*	0.1877	*0.0459*	*0.0191*	*0.001*
1,2,3,7,8,9-HxCDD	0.39	0.55	0.42	1.02	0.0505	*0.001*	0.2706	0.1294	*0.0202*	*0.0026*
1,2,3,4,6,7,8-HpCDD	0.46	0.59	0.5	1.02	0.0783	*0.0068*	0.4318	0.7265	0.0661	*0.0427*
OCDD	0.44	0.57	0.48	0.94	0.2191	0.1606	0.2902	0.7598	0.1076	0.1099
2,3,7,8-TCDF	0.23	0.38	0.43	2.18	0.8683	*0.0081*	0.8273	*0.0107*	0.853	0.5107
1,2,3,7,8-PeCDF	0.3	0.55	0.8	1.32	0.525	0.0512	0.4355	0.108	0.2797	*0.0498*
2,3,4,7,8-PeCDF	0.35	0.46	0.79	1.91	0.3833	*0.049*	0.9731	0.1207	0.7244	0.2379
1,2,3,4,7,8-HxCDF	0.41	0.61	1.06	0.87	0.3143	0.0891	*0.0052*	0.2195	*0.0142*	*0.0424*
1,2,3,6,7,8-HxCDF	0.38	0.42	1.48	0.8	0.2354	0.1691	*0.0009*	0.2368	*0.0002*	0.0916
2,3,4,6,7,8-HxCDF	0.37	0.45	1	0.82	0.276	0.0996	*0.0045*	0.1842	*0.0006*	*0.0381*
1,2,3,7,8,9-HxCDF	0.36	0.55	1.04	0.64	0.3676	0.0895	*0.0003*	0.1345	*0.0029*	0.0526
1,2,3,4,6,7,8-HpCDF	0.33	0.47	1.07	0.53	0.3752	0.1139	*1.18E-05*	0.1737	*0.0003*	*0.0296*
1,2,3,4,7,8,9-HpCDF	0.43	0.52	1.11	0.54	0.2457	0.0968	*0.0027*	0.1817	*0.0016*	*0.0324*
OCDF	0.27	0.54	0.73	0.42	1.0000	*0.0207*	*2.16E-05*	*0.0025*	*0.0078*	*0.0003*
Σ(PCDDs + PCDFs)	0.41	0.55	0.36	0.89	0.1852	*0.0004*	0.2103	0.0565	0.0646	*0.0021*
ΣI-TEQ	0.31	0.43	0.56	0.97	0.1093	*0.0099*	0.1969	0.0535	*0.0097*	*0.008*
ΣTexas-TEQ	0.29	0.42	0.6	1.08	0.1571	*0.0131*	0.2401	*0.0499*	*0.0242*	*0.0117*

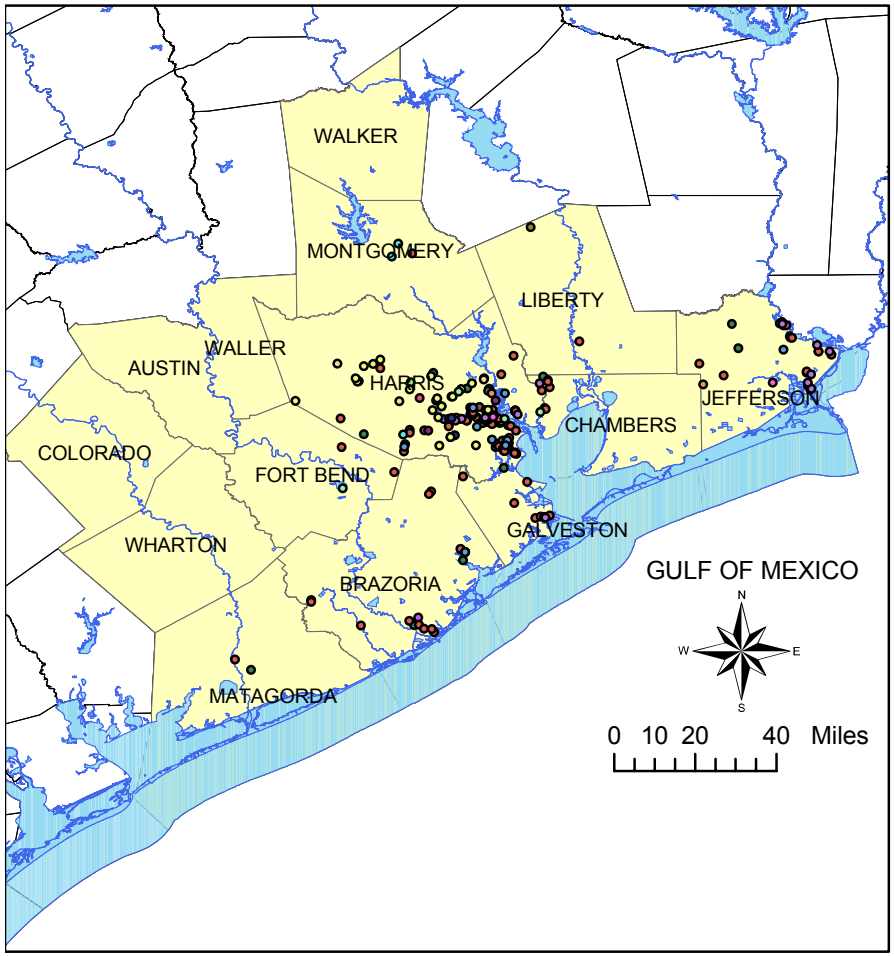
Values in italics correspond to *p* -values < α=0.05

4.6.4 Source Identification

The ambient air concentrations of dioxins were related to various emission sources of these compounds in order to explain the origin and contribution of these sources to the observed occurrence of these compounds in the Houston area. To identify the potential pollution sources, the ambient air concentrations were compared with (i) EPA's dioxin congener profile source database that contain the congener profiles of different sources of dioxin to the U.S. environment such as municipal, medical, and hazardous waste incineration, unleaded fuel combustion in vehicles, diesel fuel combustion in trucks among others, and (ii) EPA's Toxic Release Inventory Program (TRI) that contains information about the potential and confirmed sources of dioxins in Harris and surrounding counties. Figure 4.71 illustrates the potential sources of dioxins classified by SIC codes present in the area of study (e.g., industrial organic chemicals, petroleum refining, and pesticides and agricultural chemicals). Similarly, Figure 4.72 shows the potential and confirmed sources of dioxins for the year 2003 in the Harris and surrounding counties. A total of 35 industrial facilities out of 214 reported dioxin releases for the year 2003.

Historical air emission data of dioxins in Harris and surrounding counties from EPA's TRI program is depicted in Figure 4.73. As seen in Figure 4.73, a 53% decrease in air dioxin emissions occurred from 2000 to 2003, based on EPA's TRI program data.

Because the information from emission sources and receptors (ambient air) are expressed differently than data from this project, the data, prior to analysis, were normalized dividing the concentration of each 2378-substituted congener by the total sum of the 17 congeners at that specific sample (see Figure 4.69 for Houston profiles). The source profiles of the EPA's dioxin congener database are shown in Figure 4.74. This database includes profiles of municipal solid



- Asphalt paving mixtures and blocks (2951)
- Asphat felts and coatings (2952)
- Copper foundries (3366)
- Cyclic crudes and intermediates (2865)
- Electric services (4911)
- Electric services, gas & sanitary services (refuse systems) (4953)
- Industrial inorganic chemicals (2819)
- Industrial organic chemicals (2869)
- Metal coating & allied services (3479)
- Metal heat treating (3398)
- Metals barrels, drums, & pails (3411)
- Paper Mills (2621)
- Paperboard mills (2631)
- Pesticides and agricultural chemicals (2879)
- Petroleum Refining (2911)
- Pharmaceutical preparations (2834)
- Plastics, synthetics resins & nonvulcanized elastomers (2821)
- Sawmills & planing mills, general (2421)
- Soap & other detergents (2841)
- Steel pipes and tubes (3317)
- Wood Preserving (2491)

Figure 4.71 Potential Sources of Dioxins Classified by SIC Codes (Year 2003) (Source: EPA's Toxic Release Inventory Program-TRI).

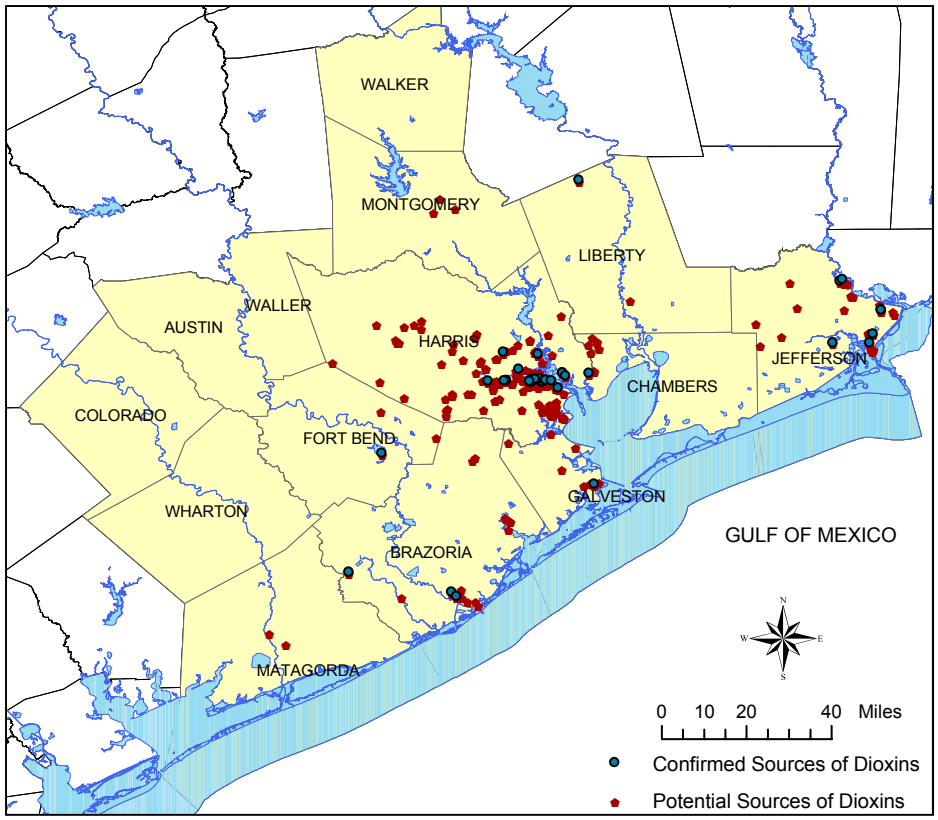


Figure 4.72 Potential and Confirmed Sources of Dioxins in Harris and Surrounding Counties (Year 2003) (Source: EPA's Toxic Release Inventory Program-TRI).

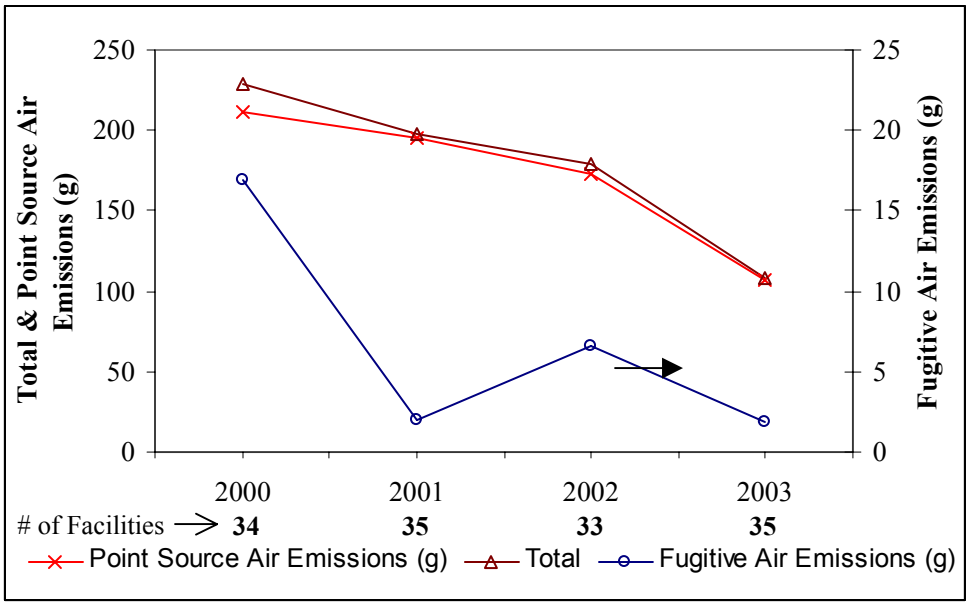


Figure 4.73 Historical Air Emissions of Dioxins in Harris and Surrounding Counties from Year 2000 to 2003 (Source: EPA's TRI Program).

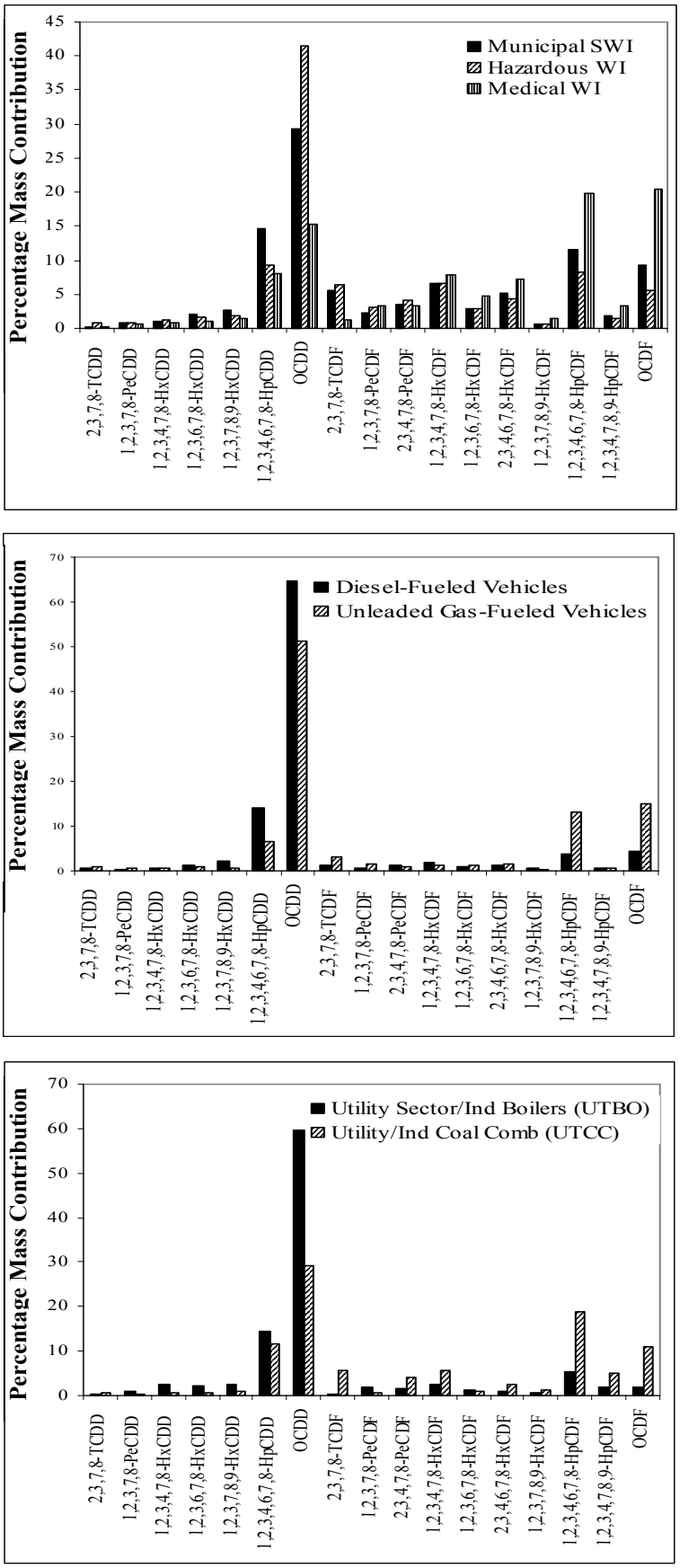


Figure 4.74 EPA's Dioxin Congener Profile Source Database.

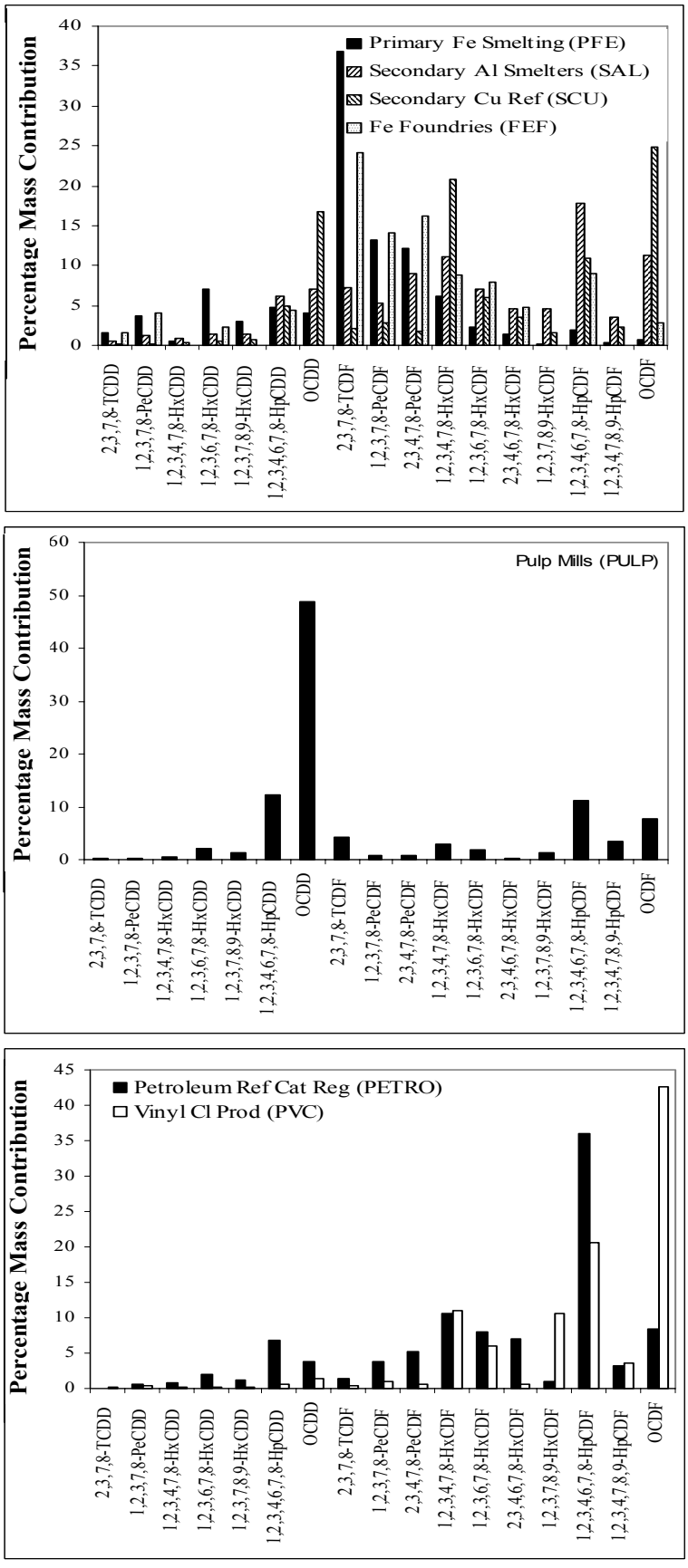


Figure 4.74 (Cont) EPA's Dioxin Congener Profile Source Database.

waste incineration (MSWI), medical waste incineration (MWI), hazardous waste incineration (HWI), combustion of wastewater sludge at bleach chemical pulp mills (PULP), utility sector and industrial boilers (UTBO), utilities and industrial coal combustion (UTCC), vinyl chloride production (PVC), diesel-fueled vehicles (DFV), unleaded gas-fueled vehicles (UFV), petroleum refining catalyst regeneration (PETRO), primary ferrous metal smelting (PFE), secondary aluminum smelters (SAL), secondary copper refinery (SCU), and ferrous foundries (FEF). Table 4.26 lists the confirmed sources of dioxins in the Houston area (year 2003) from the EPA's Toxic Release Inventory Program (TRI).

Principal Component Analysis (PCA) was applied to the air data similar to the analysis for the other media (using SPSS for Windows Version 10.0.5).

Ambient Air Concentration versus EPA's dioxin congener profile source database

Profiles of the ambient air concentrations of Houston and EPA's dioxin source database were compared in order to determine the degree of correlation between dioxin concentrations at different receptors sites and typical emission sources of these compounds.

Figure 4.75 shows the two-dimensional score plots for the five ambient air stations in Houston and the EPA's dioxin congener profile source database. As seen in Figure 4.75, the data sets with similarities in the profiles were closely located, while those with divergent signatures were found further apart. The score plots revealed that the ambient air stations Clinton Drive, Lang Road, Mont Belvieu, and Bayland Park were consistently found in closeness with DFV (Diesel-fueled vehicles) and UTBO (utility sector and industrial boilers) profiles. Similarly, the ambient air profiles were found moderately connected with UFV (unleaded-fueled vehicles), PULP (pulp mills), HWI (hazardous waste incineration), MSWI (municipal solid waste incineration), and UTCC (utilities and industrial coal combustion). The profiles of these emission

Table 4.26 Confirmed Sources of Dioxins in the Houston Area (year 2003) from the EPA's Toxic Release Inventory (TRI) Program

#	Facility	County	Latitude	Longitude	Fugitive Air Emissions (g)	Point Source Air Emission (g)	Surface Water Discharges (g)	Sic Code Description
1	ATOFINA PETROCHEMICALS INC, 1818 BATTLEGROUND RD, LA PORTE	Harris	29.718	-95.089	0	0.0146	0.0045	Plastics, synthetics resins & nonvulcanized elastomers (2821)
2	BP SOLVAY POLYETHYLENE N.A., 1230 BATTLEGROUND RD., DEER PARK	Harris	29.719	-95.086	0	0	197.8691	Plastics, synthetics resins & nonvulcanized elastomers (2821)
3	CLEAN HARBORS DEER PARK LP, 2027 BATTLEGROUND RD, DEER PARK	Harris	29.730	-95.096	0	0.06	.	Electric services, gas & sanitary services (refuse systems) (4953)
4	CROWN CENTRAL PETROLEUM CORP HOUSTON REFINERY, 111 RED BLUFF RD, PASADENA	Harris	29.724	-95.208	0	0.226124	.	Petroleum Refining (2911)
5	DEER PARK REFINING LTD PAR, 5900 HWY 225, DEER PARK	Harris	29.727	-95.124	0	0.1578	0.1519	Petroleum Refining (2911)
6	DUPONT LA PORTE PLANT, 12501 STRANG ROAD, LA PORTE	Harris	29.698	-95.033	0	0.0372	.	Industrial organic chemicals (2869)
7	EXXONMOBIL BAYTOWN CHEMICAL PLANT, 5000 BAYWAY DR, BAYTOWN	Harris	29.750	-95.018	0	0	.	Industrial organic chemicals (2869)
8	EXXONMOBIL CHEMICAL CO BAYTOWN OLEFINS PLANT, 3525 DECKER DR, BAYTOWN	Harris	29.750	-95.017	0	0.0000372	.	Industrial organic chemicals (2869)
9	EXXONMOBIL REFINING & SUPPLY BAYTOWN REFINERY, 2800 DECKER DR, BAYTOWN	Harris	29.739	-95.007	0	0	.	Petroleum Refining (2911)
10	GB BIOSCIENCES CORP, 2239 HADEN RD, HOUSTON	Harris	29.763	-95.167	1.77	5.22	0.0318	Pesticides and agricultural chemicals (2879)
11	GREENS BAYOU ELECTRIC GENERATING STATION, 12070 OLD BEAUMONT HWY, HOUSTON	Harris	29.821	-95.219	0	0.18	.	Electric services (4911)
12	LYONDELL CHEMICAL CO, 2502 SHELDON RD, CHANNELVIEW	Harris	29.814	-95.101	0	0.82	.	Cyclic crudes and intermediates (2865)
13	OXY VINYLS L.P DEER PARK VCM PLANT, 851 TIDAL RD, DEER PARK	Harris	29.718	-95.123	0	2.682	.	Industrial organic chemicals (2869)
14	OXY VINYLS LP LA PORTE VCM PLANT, 2400 MILLER CUTOFF RD, LA PORTE	Harris	29.725	-95.075	0	0.85	1.54	Industrial organic chemicals (2869)
15	OXY VINYLS LP LA PORTE VCM PLANT, 2400 MILLER CUTOFF RD, LA PORTE	Harris	29.725	-95.075	0	0	1.08	Industrial organic chemicals (2869)
16	OXY VINYLS LP DEER PARK C/A, 1000 TIDAL RD., DEER PARK	Harris	29.728	-95.111	0	0	4.22	Plastics, synthetics resins & nonvulcanized elastomers (2821)
17	OXY VINYLS LP DEER PARK C/A, 1000 TIDAL RD., DEER PARK	Harris	29.728	-95.111	0	0	.	Plastics, synthetics resins & nonvulcanized elastomers (2821)
18	PASADENA PAPER CO LP, N SHAVER AT WASHBURN TUNNE, PASADENA	Harris	29.723	-95.216	0	0	.	Paper Mills (2621)
19	RHODIA INC, 8615 MANCHESTER ST, HOUSTON	Harris	29.722	-95.272	0	0.166	.	Industrial inorganic chemicals (2819)
20	S R BERTRON ELECTRIC GENERATING STATION, 2018 MILLER CUTOFF RD, LA PORTE	Harris	29.723	-95.055	0	0.5	.	Electric services (4911)
21	SHELL CHEMICAL CO DEER PARK, 5900 HWY 225, DEER PARK	Harris	29.721	-95.129	0	0	0.9817	Industrial organic chemicals (2869)
22	EXXONMOBIL OIL BEAUMONT REFINERY, E END OF BURT ST, BEAUMONT	Jefferson	30.064	-94.070	0	2.09	.	Petroleum Refining (2911)
23	EXXONMOBIL OIL CORP DBA MOBIL CHEMICAL CO, 2775 GULF STATES RD, BEAUMONT	Jefferson	30.070	-94.062	0.05	0	.	Industrial organic chemicals (2869)
24	HUNTSMAN CORP C4/O&O FACILITIES, HWY 336 & HOGABOOM RD, PORT NECHES	Jefferson	29.965	-93.931	0	0.56	.	Industrial organic chemicals (2869)
25	HUNTSMAN CORP PO/MTBE PLANT, 2401 SPUR 136, PORT NECHES	Jefferson	29.965	-93.931	0	0.3	.	Industrial organic chemicals (2869)
26	MOTIVA ENTERPRISES LLC PORT ARTHUR REFINERY, 2100 HOUSTON AVE, PORT ARTHUR	Jefferson	29.883	-93.958	0.0000006	0.6	.	Petroleum Refining (2911)
27	ONYX ENVIRONMENTAL SERVICES LLC, HWY 73 W OF TAYLOR BAYOU, PORT ARTHUR	Jefferson	29.853	-94.095	0	0	.	Electric services, gas & sanitary services (refuse systems) (4953)
28	PREMCOR REFINING GROUP INC PORT ARTHUR REFINERY, 10801 S GULFWAY DR, PORT ARTHU	Jefferson	29.853	-93.970	0	0.09	.	Petroleum Refining (2911)
29	VALERO REFINING TEXAS L.P, 1301 LOOP 197 S, TEXAS CITY	Galveston	29.370	-94.909	0	0.2132	0	Petroleum Refining (2911)
30	CEDAR BAYOU ELECTRIC GENERATING STATION, 7705 W BAY RD, BAYTOWN	Chambers	29.748	-94.927	0	2.2	.	Electric services (4911)
31	GEORGIA-PACIFIC CORP., 12936 FM 787 W, CLEVELAND	Liberty	30.409	-94.962	0	0.2428	.	Sawmills & planing mills, general (2421)
32	BASF CORP, 602 COPPER RD, FREEPORT	Brazoria	29.001	-95.396	0	1.4	.	Industrial organic chemicals (2869)
33	CONOCOPHILLIPS CO SWEENY REFINERY COMPLEX, STATE HWY 35 AT FM 524, OLD OCEAN	Brazoria	29.069	-95.747	0	0.505	.	Industrial organic chemicals (2869)
34	DOW CHEMICAL CO FREEPORT FACILITY, 2301 N BRAZOSPORT BLVD BUILDING B-101, FREEPO	Brazoria	28.986	-95.379	0	85.39	318.5	Plastics, synthetics resins & nonvulcanized elastomers (2821)
35	W A PARISH ELECTRIC GENERATING STATION, 2500 Y U JONES RD, THOMPSONS	Ford Bend	29.475	-95.634	0	2.1	.	Electric services (4911)

Table 4.26 Confirmed Sources of Dioxins in the Houston Area (year 2003) from the EPA's Toxic Release Inventory (TRI) Program - Cont'd

#	Facility	Distribution of the 2,3,7,8-substituted congeners of dioxins (in percentage)																	
		2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF
1	ATOFINA PETROCHEMICALS INC, 1818 BATTLEGROUND RD, LA PORTE	2.73	4.92	3.62	3.38	3.38	6.7	24.59	5.14	8.39	3.57	4.6	2.49	2.51	1.99	8.57	2.66	10.76
2	BP SOLVAY POLYETHYLENE N.A., 1230 BATTLEGROUND RD., DEER PARK	0	0.07	0.2	0.26	0.39	9.65	78.09	0.25	0.14	0.11	0.45	0.23	0.15	0.07	2.79	0.26	6.89
3	CLEAN HARBORS DEER PARK LP, 2027 BATTLEGROUND RD, DEER PARK	2.1	3.5	3.8	3.8	3.5	4.4	25.3	6.3	3.2	3.4	4.8	4.6	4.8	5.5	8.6	2.8	9.6
4	CROWN CENTRAL PETROLEUM CORP HOUSTON REFINERY, 111 RED BLUFF RD, PASADENA	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
5	DEER PARK REFINING LTD PAR, 5900 HWY 225, DEER PARK	1.86	0.65	0.61	0.94	0.63	6.89	36.62	4.01	3.85	3.57	6.1	4.61	3.08	2.05	11.55	3.75	9.23
6	DUPONT LA PORTE PLANT, 12501 STRANG ROAD, LA PORTE	0.9	0.13	0.18	0.19	0.17	24.57	68.38	2.37	0.31	0.16	0.2	0.11	0.1	0.11	1.7	0.08	0.34
7	EXXONMOBIL BAYTOWN CHEMICAL PLANT, 5000 BAYWAY DR, BAYTOWN	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	EXXONMOBIL CHEMICAL CO BAYTOWN OLEFINS PLANT, 3525 DECKER DR, BAYTOWN	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
9	EXXONMOBIL REFINING & SUPPLY BAYTOWN REFINERY, 2800 DECKER DR, BAYTOWN	0.24	1.14	1.19	4	2.38	6.21	5.2	3.96	6.26	7.86	10.9	9.4	5.31	1.07	21.7	3.98	9.2
10	GB BIOSCIENCES CORP, 2239 HADEN RD, HOUSTON	0	0	0	0	0	0.01	0.21	0.07	0	0.12	0.27	0.06	0	0	0.27	0.12	98.87
11	GREENS BAYOU ELECTRIC GENERATING STATION, 12070 OLD BEAUMONT HWY, HOUSTON	1.51	3.04	3.99	1.87	3.04	3.66	5.56	1.47	1.97	1.93	1.61	0.91	1.33	1.81	57.99	4.46	3.85
12	LYONDELL CHEMICAL CO, 2502 SHELDON RD, CHANNELVIEW	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
13	OXY VINYLS L.P DEER PARK VCM PLANT, 851 TIDAL RD, DEER PARK	65.23	12.78	13.22	0.01	0.09	0.12	0.8	4.07	0.67	0.36	0.05	0.05	1.54	0.05	0	0.01	0.95
14	OXY VINYLS LP LA PORTE VCM PLANT, 2400 MILLER CUTOFF RD, LA PORTE	0.91	0.09	2.38	2.92	1.25	13.2	7.23	0.09	0.16	0.49	2.46	1.02	0.11	0.74	2.14	0.89	63.92
15	OXY VINYLS LP LA PORTE VCM PLANT, 2400 MILLER CUTOFF RD, LA PORTE	0.01	0.01	0.03	0.04	0.03	0.04	0.44	10.12	22.05	13.37	23.13	6.43	1.88	4.85	6.22	4.26	7.09
16	OXY VINYLS LP DEER PARK C/A, 1000 TIDAL RD., DEER PARK	0.31	0.41	0.37	0.28	0.33	2.27	60.12	1.86	3.37	0.86	5.71	1.12	0.23	0.22	2.31	0.61	19.62
17	OXY VINYLS LP DEER PARK C/A, 1000 TIDAL RD., DEER PARK	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
18	PASADENA PAPER CO LP, N SHAVER AT WASHBURN TUNNE, PASADENA	0.63	0	0	0	0	3.75	83.49	0.63	0	0	0	0	0	1.25	6.25	0.01	3.99
19	RHODIA INC, 8615 MANCHESTER ST, HOUSTON	6	12	6	6	7	14	0	5	5	7	16	6	5	1	1	3	0
20	S R BERTRON ELECTRIC GENERATING STATION, 2018 MILLER CUTOFF RD, LA PORTE	1.53	3.08	4.05	1.89	3.08	3.49	4.65	1.47	1.96	1.92	1.59	0.9	1.35	1.78	59.36	4.23	3.67
21	SHELL CHEMICAL CO DEER PARK, 5900 HWY 225, DEER PARK	0.1	0.28	0.2	0.21	0.22	2.21	12.53	0.12	0.11	0.38	1.52	1.72	1.53	0.6	20.08	3.78	54.41
22	EXXONMOBIL OIL BEAUMONT REFINERY, E END OF BURT ST, BEAUMONT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
23	EXXONMOBIL OIL CORP DBA MOBIL CHEMICAL CO, 2775 GULF STATES RD, BEAUMONT	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
24	HUNTSMAN CORP C4/O&O FACILITIES, HWY 336 & HOGABOOM RD, PORT NECHES	1	2	2	2	1	5	18	2	3	3	3	3	1	0	15.000	3	36
25	HUNTSMAN CORP PO/MTBE PLANT, 2401 SPUR 136, PORT NECHES	1	1	1	1	1	2	13	1	1	1	3	2	1	1	16.000	4	50
26	MOTIVA ENTERPRISES LLC PORT ARTHUR REFINERY, 2100 HOUSTON AVE, PORT ARTHUR	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
27	ONYX ENVIRONMENTAL SERVICES LLC, HWY 73 W OF TAYLOR BAYOU, PORT ARTHUR	0	0	0	0	0	0	1	59	10	15	6	3	1	0	4.000	0	1
28	PREMCOR REFINING GROUP INC PORT ARTHUR REFINERY, 10801 S GULFWAY DR, PORT ARTHU	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
29	VALERO REFINING TEXAS L.P, 1301 LOOP 197 S, TEXAS CITY	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
30	CEDAR BAYOU ELECTRIC GENERATING STATION, 7705 W BAY RD, BAYTOWN	1.55	3.13	4.11	1.91	3.13	3.31	3.71	1.47	1.95	1.91	1.56	0.9	1.38	1.74	60.76	3.99	3.49
31	GEORGIA-PACIFIC CORP., 12936 FM 787 W, CLEVELAND	0.06	0.1	0	0.43	0.53	11.55	63.17	8.53	2.35	1.63	1.14	0.77	0.96	2.24	2.98	1.17	2.39
32	BASF CORP, 602 COPPER RD, FREEPORT	3.39	0	0.08	0.08	0	0.44	7.39	0.09	0.23	0.16	1.15	0.63	0.37	0.21	16.59	2.3	66.89
33	CONOCOPHILLIPS CO SWEENY REFINERY COMPLEX, STATE HWY 35 AT FM 524, OLD OCEAN	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
34	DOW CHEMICAL CO FREEPORT FACILITY, 2301 N BRAZOSPORT BLVD BUILDING B-101, FREEPO	0.02	0.03	0.02	0	0.02	0.14	0.67	0.05	0.11	0.06	0.59	0	0.1	0.07	4.21	0.77	93.14
35	W A PARISH ELECTRIC GENERATING STATION, 2500 Y U JONES RD, THOMPSONS	0.83	0	0.45	0.47	0.45	7.49	55.7	4.49	0.88	1.58	3	1.26	3.85	1.46	6.11	0	11.98

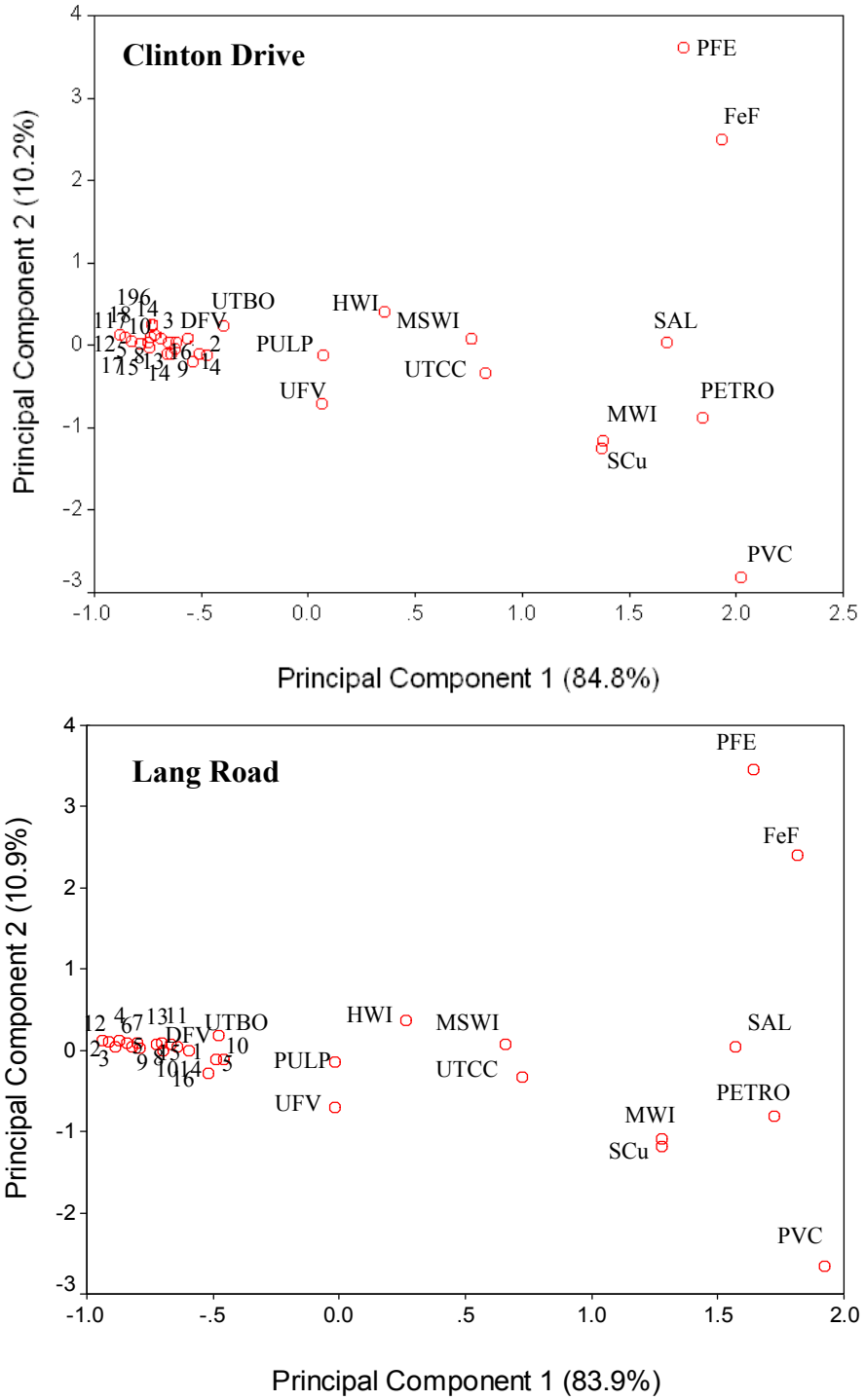


Figure 4.75 Score Plots from PCA When Comparing the Five Ambient Air Stations with the EPA's Dioxin Source Database. The Numbers in the Labels Correspond to the Sampling Events (1, Sept/02; 2, Oct/02; 3, Nov/02; 4, Dec/02; 5, Jan/03; 6, Feb/03, 7, Mar/03; 8, Apr/03; 9, May/03; 10, Jun/03; 11, Jul/03; 12, Aug/03; 13, Dec/03-Jan/04; 14, Jan/04-Feb/04; 15, Feb/04-Mar/04; 16, Mar/04-Apr/04; 17, Sep/04-Oct/04; 18, Nov/04-Dec/04; 19, Jan/05-Feb/05).

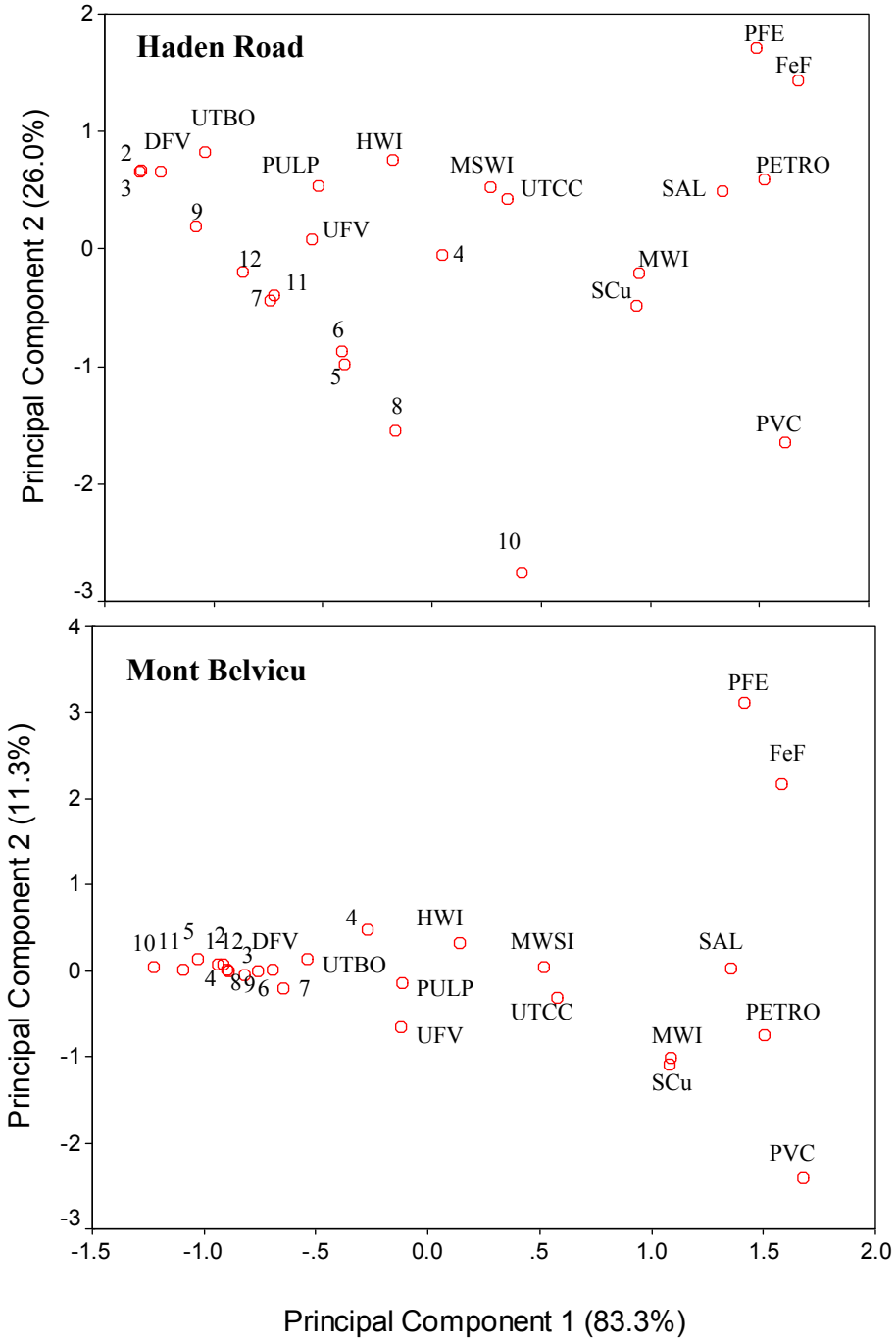


Figure 4.75 (Cont). Score Plots from PCA When Comparing the Five Ambient Air Stations with the EPA's Dioxin Source Database. The Numbers in the Labels Correspond to the Sampling Events (1, Sept/02; 2, Oct/02; 3, Nov/02; 4, Dec/02; 5, Jan/03; 6, Feb/03, 7, Mar/03; 8, Apr/03; 9, May/03; 10, Jun/03; 11, Jul/03; 12, Aug/03; 13, Dec/03-Jan/04; 14, Jan/04-Feb/04; 15, Feb/04-Mar/04; 16, Mar/04-Apr/04; 17, Sep/04-Oct/04; 18, Nov/04-Dec/04; 19, Jan/05-Feb/05).

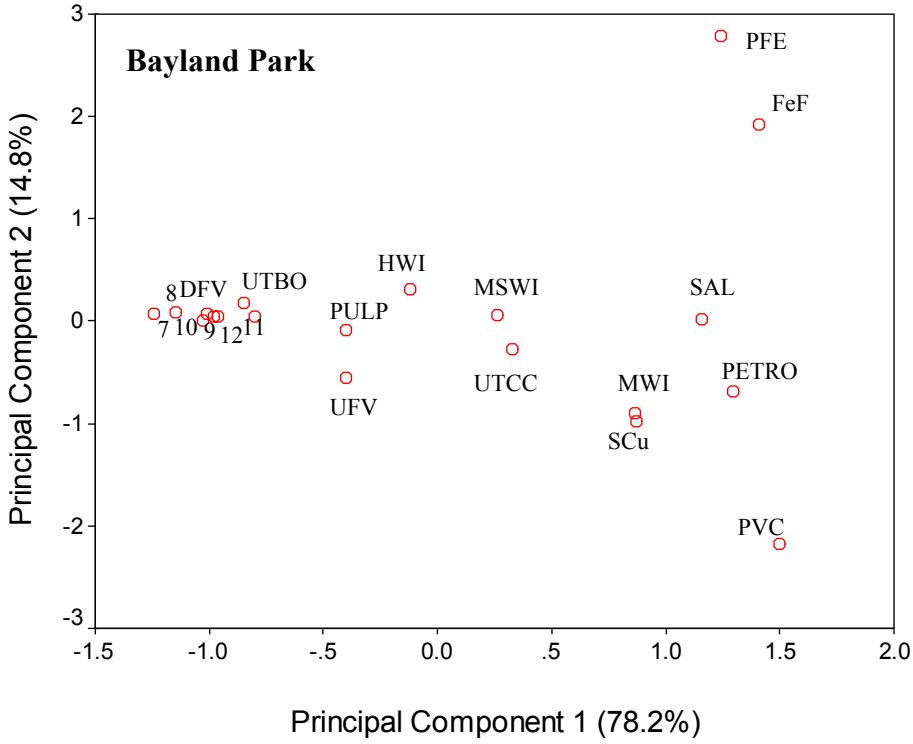


Figure 4.75 (Cont). Score Plots from PCA When Comparing the Five Ambient Air Stations with the EPA's Dioxin Source Database. The Numbers in the Labels Correspond to the Sampling Events (1, Sept/02; 2, Oct/02; 3, Nov/02; 4, Dec/02; 5, Jan/03; 6, Feb/03, 7, Mar/03; 8, Apr/03; 9, May/03; 10, Jun/03; 11, Jul/03; 12, Aug/03; 13, Dec/03-Jan/04; 14, Jan/04-Feb/04; 15, Feb/04-Mar/04; 16, Mar/04-Apr/04; 17, Sep/04-Oct/04; 18, Nov/04-Dec/04; 19, Jan/05-Feb/05).

sources are characterized by exhibiting considerable contributions of the higher chlorinated congeners (especially OCDD), similar to what is observed among the ambient air samples. No similarities were found between ambient air profiles and mineral smelting and refinery industries. The same cluster analysis was carried out using hierarchical cluster analysis (SPSS for Windows Version 10.0.5) and analogous results were obtained.

In contrast with these results, none of the ambient air profiles obtained at the Haden Road site seems to show any similarity with the EPA's dioxin congener source profiles with the exception of the events 2 (Oct/02), 3 (Nov/02), and 9 (May/03) that correlated with DFV (Diesel-fueled vehicles) and UTBO (utility sector and industrial boilers) profiles, and event 4 (Dec/03) that correlated with MSWI (municipal solid waste incineration) and UTCC (utilities and industrial coal combustion). These discrepancies among the Haden Road ambient air profiles may be attributed to higher levels of OCDF that are emitted in the proximity of the site. Ambient air profile contributions of up to 60% were observed for this congener (see Figure 4.69). This difference was explored comparing the Haden Road site with the confirmed sources of dioxins reported by EPA's TRI for Harris and surrounding counties as seen in the next section.

Ambient Air Concentration versus Confirmed Sources of Dioxins in Harris and Surroundings Counties

The dioxin ambient air profiles observed in Houston at the five different air-monitoring locations were also compared with confirmed sources of dioxins in the Houston area. The purpose of this analysis was to determine similarities, dissimilarities, and individual contributions to the dioxin pollution. The PCA analysis showed a consistent correlation at all of the air monitoring sites with emission sources # 2, 6, 16, 18, 31, and 35 listed in Table 4.26. These

emission sources are classified under the SIC code as sawmills and planing mills-2421 (#31), paper mills-2621 (#18), plastics, synthetic resins and nonvulcanized elastomers-2821 (#2, #16), industrial organic chemicals-2869 (#6), and electric services-4911 (#35). Figure 4.76 illustrates the clusters found at each air-monitoring site. In most of the cases, confirmed sources of dioxins in Houston are characterized by having a low contribution of 2378-TCDD as seen in the ambient air profiles. It is also noted that Haden Road (C603) seems to differ from the rest of the ambient air profiles with higher contributions of OCDF. This dissimilarity may be attributed to the fact that this site is located proximate to a pesticide plant (#10) where pesticides and agricultural chemicals are produced. As shown in Table 4.26, OCDF is a large component of dioxin emission for this type of industrial activitiy. Figure 4.76 shows that for the months where low concentrations of OCDF were detected, these months were located far apart from emission source #10. On the other hand, months with reported high concentrations of OCDF (April and June 2003) tend to be located in the vicinity of the emission source #10. However, it is important to note that despite these emissions, the profile observed at Haden Road tends to undergo a quick re-distribution when low OCDF concentrations are detected (see Figure 4.69 for Haden Road site) (e.g., October event) therefore showing the higher chlorinated congener (especially OCDD) making the major contribution to the profile. Identical results were obtained using hierarchical cluster analysis (SPSS for Windows Version 10.0.5).

4.6.5 Dry Deposition versus Ambient Air Concentrations

A *t*-test demonstrated the existence of spatial variability of the dry deposition (Chapter 3). This finding differs with the no spatial variability observed among the ambient air concentration samples collected at these two locations (see Table 4.25 pair C403-C408). These differences may

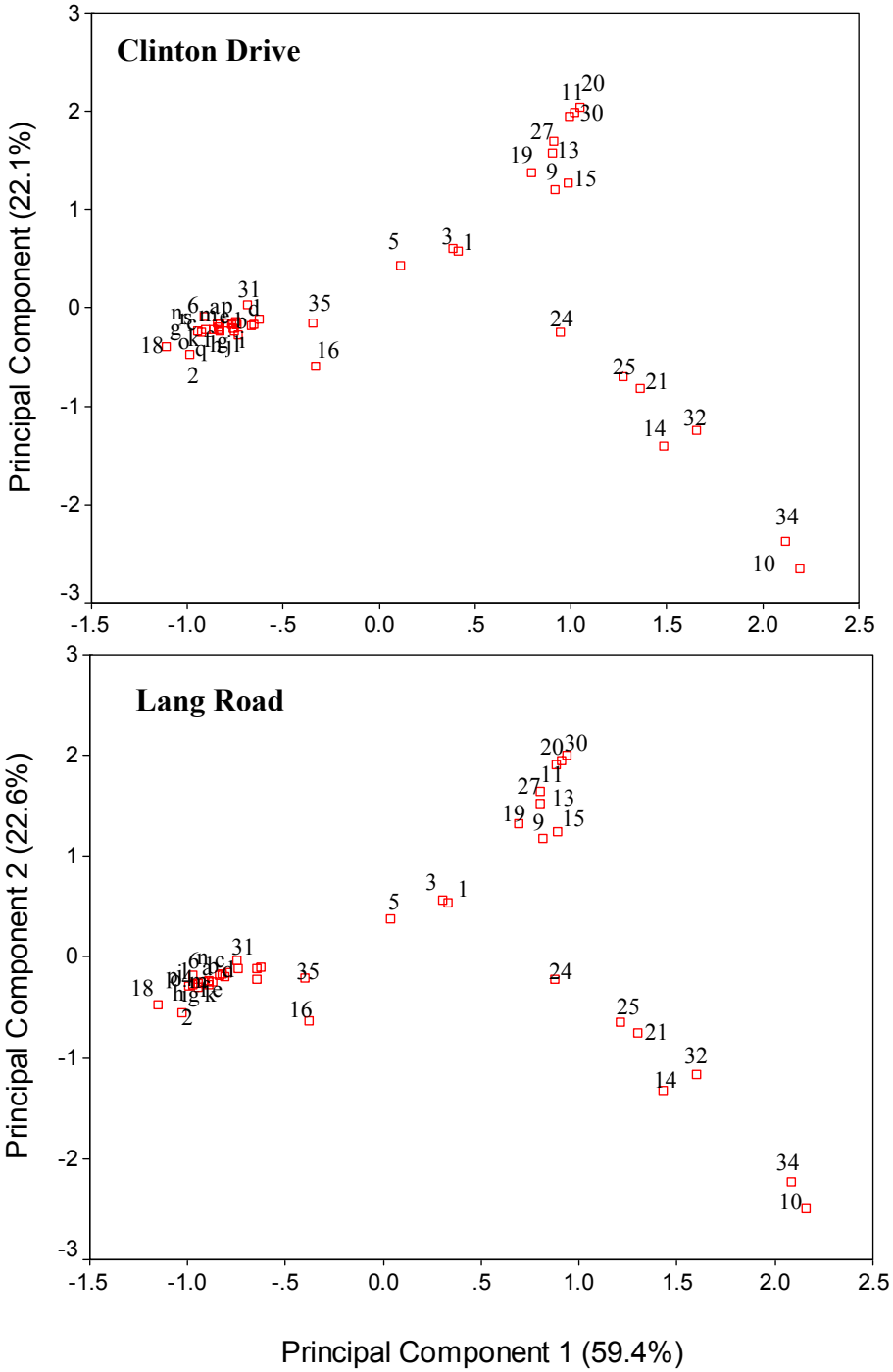


Figure 4.76 Score Plots from PCA When Comparing the Five Ambient Air Stations with the Confirmed Sources of Dioxins in Harris and Surroundings Counties from TRI (the Number Correspond to the Confirmed Sources Listed in Table 4.26; the Letters Correspond to the Ambient Air Sampling Events: a, Sept/02; b, Oct/02; c, Nov/02; d, Dec/02; e, Jan/03; f, Feb/03, g, Mar/03; h, Apr/03; i, May/03; j, Jun/03; k, Jul/03; l, Aug/03; m, Dec/03-Jan/04; n, Jan/04-Feb/04; o, Feb/04-Mar/04; p, Mar/04-Apr/04; q, Sep/04-Oct/04; r, Nov/04-Dec/04; s, Jan/05-Feb/05).

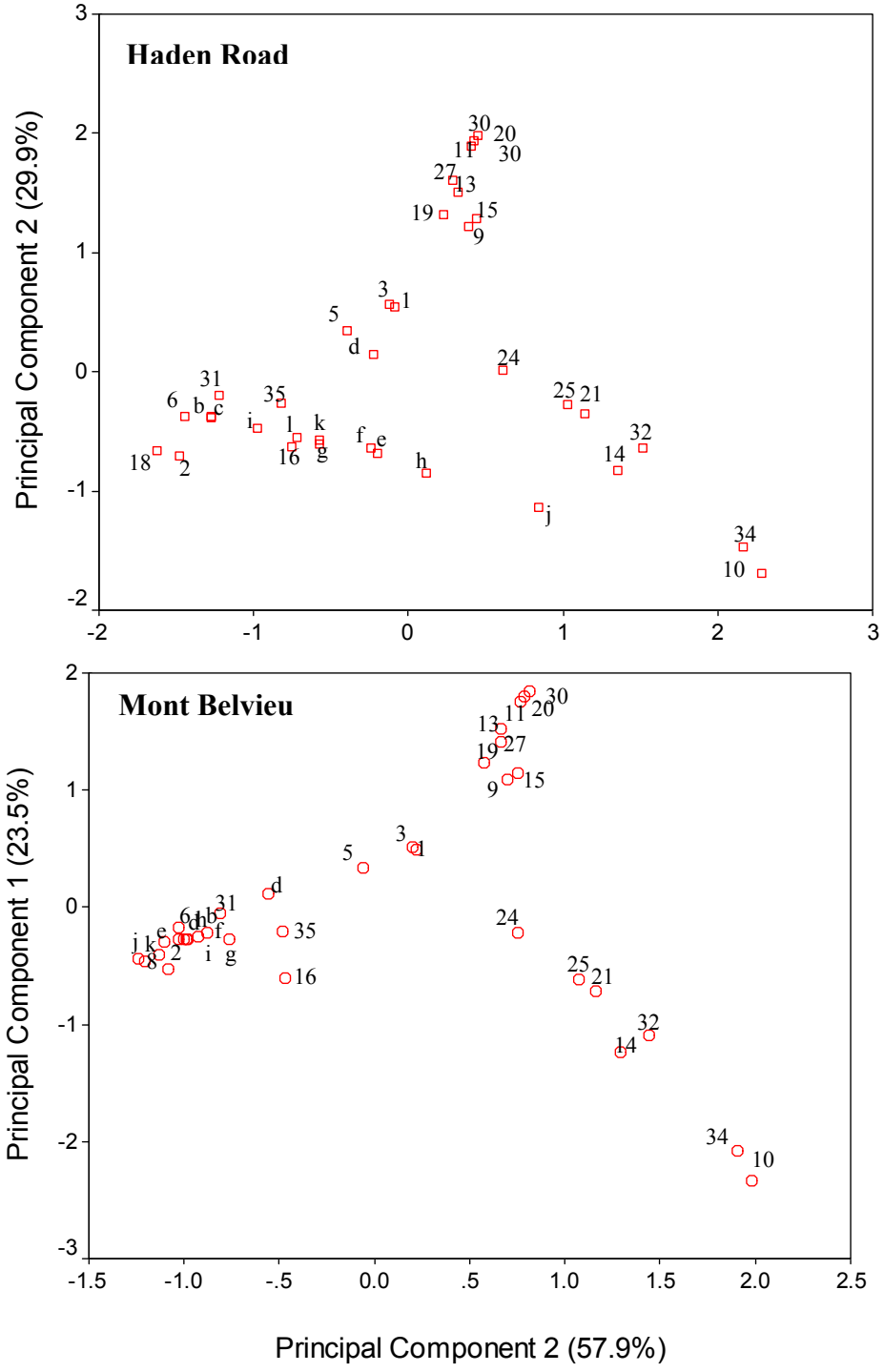


Figure 4.76 (Cont). Score Plots from PCA When Comparing the Five Ambient Air Stations with the Confirmed Sources of Dioxins in Harris and Surroundings Counties from TRI (the Number Correspond to the Confirmed Sources Listed in Table 4.26; the Letters Correspond to the Ambient Air Sampling Events: a, Sept/02; b, Oct/02; c, Nov/02; d, Dec/02; e, Jan/03; f, Feb/03, g, Mar/03; h, Apr/03; i, May/03; j, Jun/03; k, Jul/03; l, Aug/03; m, Dec/03-Jan/04; n, Jan/04-Feb/04; o, Feb/04-Mar/04; p, Mar/04-Apr/04; q, Sep/04-Oct/04; r, Nov/04-Dec/04; s, Jan/05-Feb/05).

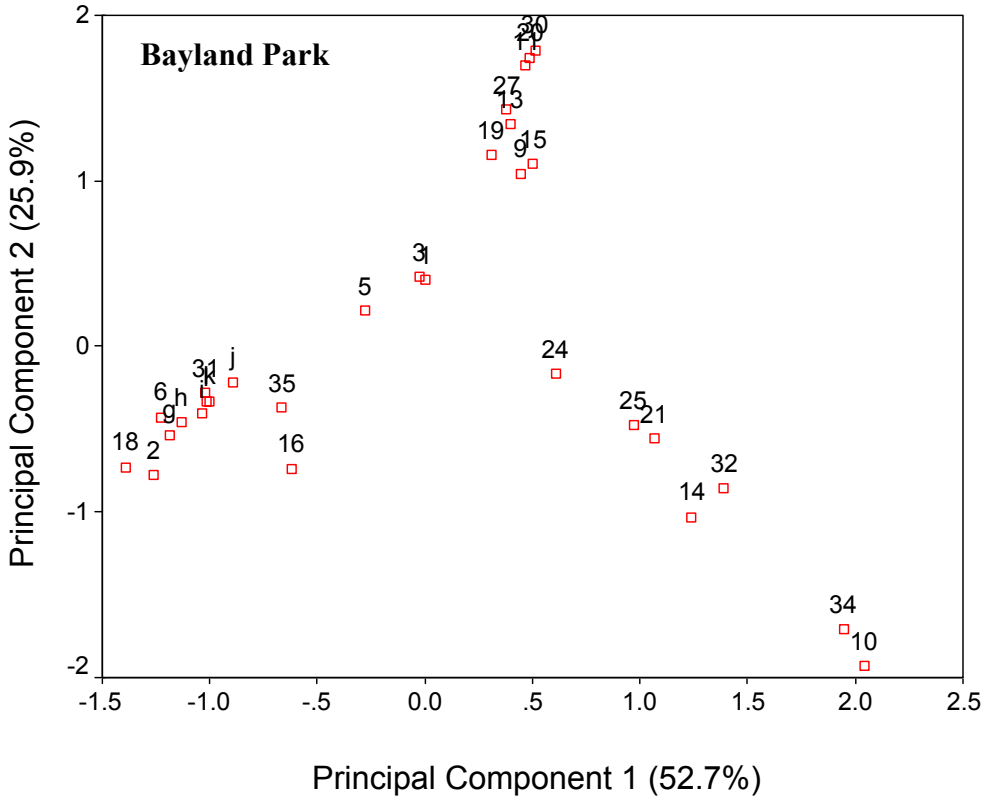


Figure 4.76 (Cont). Score Plots from PCA When Comparing the Five Ambient Air Stations with the Confirmed Sources of Dioxins in Harris and Surroundings Counties from TRI (the Number Correspond to the Confirmed Sources Listed in Table 4.26; the Letters Correspond to the Ambient Air Sampling Events: a, Sept/02; b, Oct/02; c, Nov/02; d, Dec/02; e, Jan/03; f, Feb/03, g, Mar/03; h, Apr/03; i, May/03; j, Jun/03; k, Jul/03; l, Aug/03; m, Dec/03-Jan/04; n, Jan/04-Feb/04; o, Feb/04-Mar/04; p, Mar/04-Apr/04; q, Sep/04-Oct/04; r, Nov/04-Dec/04; s, Jan/05-Feb/05).

be due to differences in the particle size distribution of associated dioxins, the existing meteorological conditions (e.g., wind speed and direction, atmospheric stability), and the type of sources.

The dry deposition fluxes for 1234678-HpCDD, OCDD, 1234678-HpCDF, and OCDF, obtained in the first and second deposition experiments (Results presented in Chapter 3), were correlated with their ambient air concentrations by linear regression. The r^2 values derived from this analysis are summarized in Table 4.27. In general, the results showed a poor correlation between the dry deposition fluxes and ambient air concentrations. This lack of correlation might be attributed to differences in the particle size distribution of associated dioxin congeners and the fact that dry deposition is governed by the size of the depositing particles. As discussed in Chapter 3, the particle size distribution samples demonstrated that most of the dioxin congener mass was concentrated in fine particles that exhibit low deposition.

Table 4.27 Dry Deposition Fluxes versus Ambient Air Concentration Results

Congener	r^2
1,2,3,4,6,7,8-HpCDD	0.15
OCDD	0.26
1,2,3,4,6,7,8-HpCDF	0.004
OCDF	0.13
Σ(PCDD+PCDF)	0.23

4.6.6 Analysis of Various Air Matrices

In order to evaluate possible similarities and/or difference among the different environmental matrices (particle and gas phases, and wet, dry and bulk deposition), PCA analysis

was applied. The results of the analysis are summarized in Figure 4.77 where three basic clusters of data can be distinguished. It is noted that the particle-phase profile more closely resembles the deposition profiles (dry, wet, and bulk) than the gas-phase profile. This evidences that deposition processes are governed by the fraction of dioxins that are bound to atmospheric particles. Moreover, the results also evidence that the deposition processes are influenced by the level of chlorination for the 2378-substituted congeners. Dioxins with higher levels of chlorination (e.g., 1234678-HpCDD) are removed more efficiently from the atmosphere. The same analysis was made using Hierarchical Cluster Analysis (SPSS for Windows Version 10.0.5). Similar and comparable results were obtained (Figure 4.78).

4.6.7 Deposition Loads

Using the dry/wet deposition fluxes measured at Clinton Dr., loads for the entire Houston Ship Channel watershed were calculated assuming constant fluxes across the watershed (Table 4.28). Direct deposition (sum of wet and dry loads from Table 4.28) of TEQ and 2378-TCDD to the channel surface was estimated to be 1.05×10^8 and 1.42×10^7 pg/yr, respectively when non-detects are set equal to half of the detection limit and 4.66×10^7 and 0 pg/yr, when non-detects are equal to zero. Similarly, when non-detects are assumed equal to half of the detection limit, total deposition over the entire watershed was estimated to be 5.80×10^9 and 7.84×10^8 pg/yr for TEQ and 2378-TCDD, respectively. While if non-detects are assumed equal to zero, total deposition over the entire watershed was estimated to be 2.57×10^9 and 0 pg/yr for TEQ and 2378-TCDD, respectively.

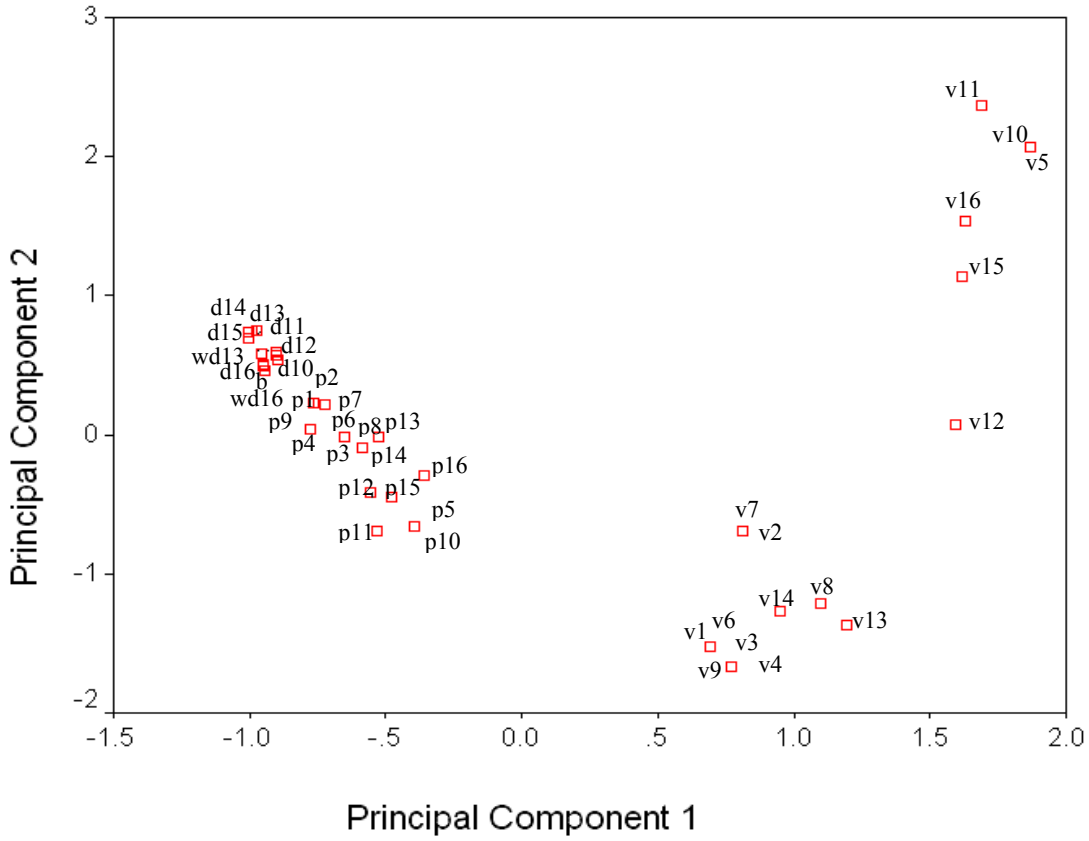


Figure 4.77 Score Plot from PCA When Comparing Particle-Bound (p) and Vapor (v) Concentrations, Wet (wd) and Dry (d) Deposition, Bulk (b) Deposition Profiles. The Numbers in the Labels Correspond to the Sampling Events (1, Oct/02; 2, Jan/03; 3,Feb/03, 4,Mar/03; 5, Apr/03; 6, May/03; 7, Jun/03; 8, Jul/03; 9, Aug/03; 10, Dec/03-Jan/04; 11, Jan/04-Feb/04; 12, Feb/04-Mar/04; 13, Mar/04-Apr/04; 14, Sep/04-Oct/04; 15, Nov/04-Dec/04; 16, Jan/05-Feb/05.

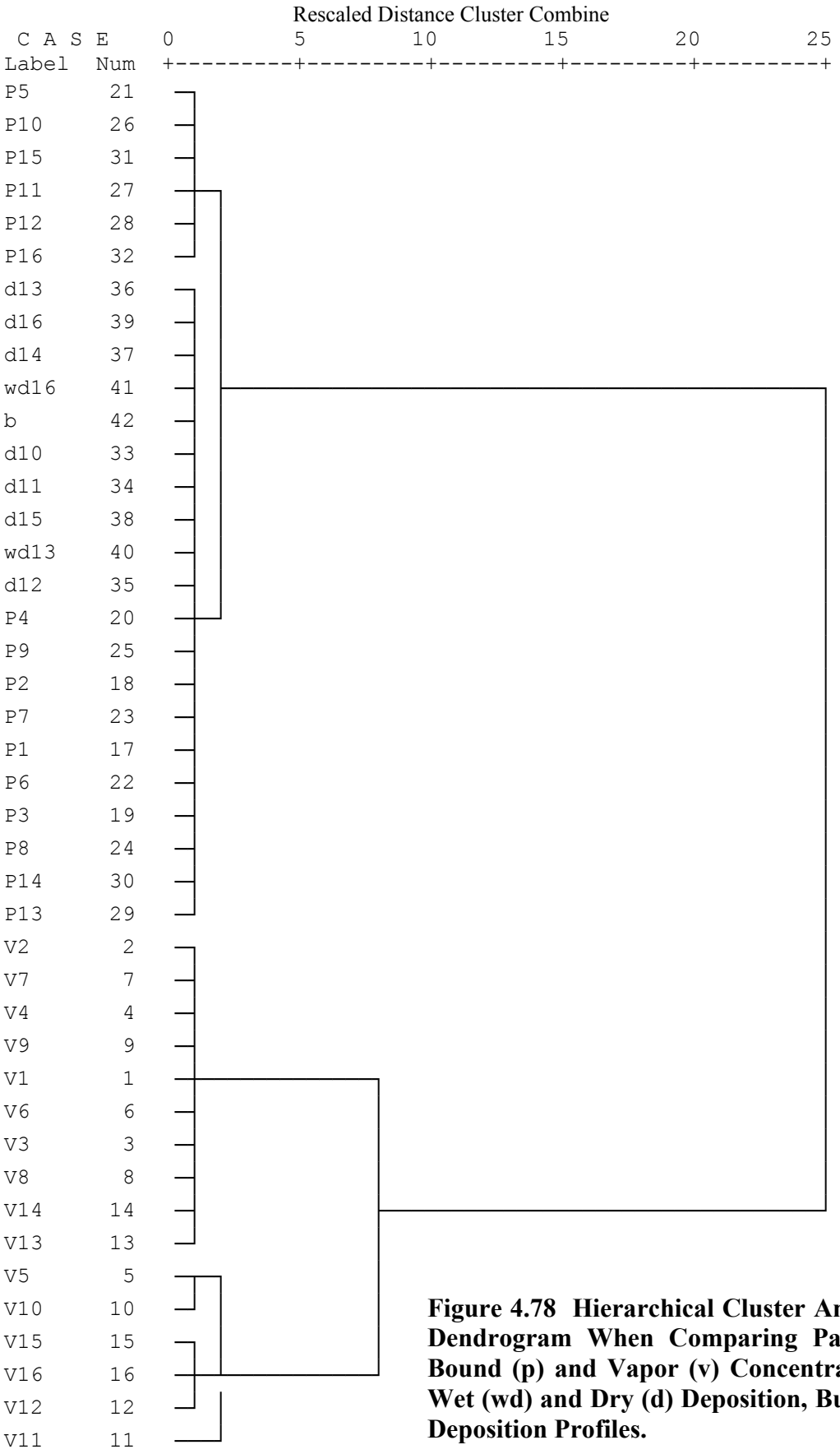


Figure 4.78 Hierarchical Cluster Analysis Dendrogram When Comparing Particle-Bound (p) and Vapor (v) Concentrations, Wet (wd) and Dry (d) Deposition, Bulk (b) Deposition Profiles.

Table 4.28 Deposition Loads

a. Directly to channel surface

Area	56,163,067	m2
	13,878	acres

CONGENER	TEF	ND = 1/2 MDL						ND = 0				
		Wet ($fg/m^2/day$)	Dry ($fg/m^2/day$)	Bulk ($fg/m^2/day$)	Wet load $(pg/yr)^a$	Dry load $(pg/yr)^b$	Bulk load (pg/yr)	Wet ($fg/m^2/day$)	Dry ($fg/m^2/day$)	Bulk ($fg/m^2/day$)	Wet load $(pg/yr)^a$	Dry load $(pg/yr)^b$
2378-TCDD	1	1.1	0.5	0.05	6.54E+06	7.69E+06	1.02E+06	0	0	0	0.00E+00	0.00E+00
12378-PeCDD	0.5	2.2	0.9	0.3	1.28E+07	1.29E+07	6.15E+06	0	0	0.3	0.00E+00	0.00E+00
123478-HxCDD	0.1	8.5	1.5	0.6	5.05E+07	2.18E+07	1.23E+07	8.5	0	0.6	5.05E+07	0.00E+00
123678-HxCDD	0.1	13.0	1.7	0.8	7.73E+07	2.50E+07	1.64E+07	13	0.6	0.8	7.73E+07	8.32E+06
123789-HxCDD	0.1	12.5	1.8	1	7.43E+07	2.60E+07	2.05E+07	8	0	1	4.76E+07	0.00E+00
1234678-HpCDD		314.5	47.1	27	1.87E+09	6.86E+08	5.53E+08	314.5	47.1	27	1.87E+09	6.86E+08
OCDD		2309.5	408.4	207	1.37E+10	5.94E+09	4.24E+09	2309.5	408.4	207	1.37E+10	5.94E+09
2378-TCDF	0.1	7.0	0.6	0.6	4.16E+07	9.36E+06	1.23E+07	7	0	0.6	4.16E+07	0.00E+00
12378-PeCDF	0.05	5.0	1.6	0.2	2.97E+07	2.39E+07	4.10E+06	2	0	0.2	1.19E+07	0.00E+00
23478-PeCDF	0.5	5.5	0.8	0.2	3.27E+07	1.14E+07	4.10E+06	2.5	0	0.2	1.49E+07	0.00E+00
123478-HxCDF	0.1	12.5	0.6	0.6	7.43E+07	8.52E+06	1.23E+07	12.5	0	0.6	7.43E+07	0.00E+00
123678-HxCDF	0.1	8.5	0.7	0.6	5.05E+07	1.04E+07	1.23E+07	8.5	0	0.6	5.05E+07	0.00E+00
234678-HxCDF	0.1	6.0	0.7	0.3	3.57E+07	1.04E+07	6.15E+06	6	0	0.3	3.57E+07	0.00E+00
123789-HxCDF	0.1	1.8	0.6	0.02	1.04E+07	9.36E+06	4.10E+05	0	0	0	0.00E+00	0.00E+00
1234678-HpCDF		26.0	7.6	4	1.55E+08	1.10E+08	8.20E+07	13	7.6	4	7.73E+07	1.10E+08
1234789-HpCDF		4.5	0.6	0.2	2.68E+07	8.11E+06	4.10E+06	2.5	0	0.2	1.49E+07	0.00E+00
OCDF		104.0	26.3	11	6.18E+08	3.83E+08	2.25E+08	104	26.3	11	6.18E+08	3.83E+08
TEQ		12.15	2.3	0.8	**7.22E+07**	**3.31E+07**	**1.56E+07**	7.7	0.06	0.71	**4.58E+07**	**8.32E+05**

[a] applied to 29% of the year

[b] applied to 71% of the year

b. Across entire watershed

Area:	3,092,000,000	m2
	764,048	acres

CONGENER	TEF	ND = 1/2 MDL						ND = 0				
		Wet ($fg/m^2/day$)	Dry ($fg/m^2/day$)	Bulk ($fg/m^2/day$)	Wet load $(pg/yr)^a$	Dry load $(pg/yr)^b$	Bulk load (pg/yr)	Wet (fg/m2/hr)	Dry (fg/m2/hr)		Wet load $(pg/yr)^a$	Dry load $(pg/yr)^b$
2378-TCDD	1	1.1	0.5	0.05	3.60E+08	4.24E+08		0	0	0	0.00E+00	0.00E+00
12378-PeCDD	0.5	2.2	0.9	0.3	7.04E+08	7.10E+08		0	0	0.3	0.00E+00	0.00E+00
123478-HxCDD	0.1	8.5	1.5	0.6	2.78E+09	1.20E+09		8.5	0	0.6	2.78E+09	0.00E+00
123678-HxCDD	0.1	13.0	1.7	0.8	4.25E+09	1.37E+09		13	0.6	0.8	4.25E+09	4.58E+08
123789-HxCDD	0.1	12.5	1.8	1	4.09E+09	1.43E+09		8	0	1	2.62E+09	0.00E+00
1234678-HpCDD	0	314.5	47.1	27	1.03E+11	3.78E+10		314.5	47.1	27	1.03E+11	3.78E+10
OCDD	0	2309.5	408.4	207	7.56E+11	3.27E+11		2309.5	408.4	207	7.56E+11	3.27E+11
2378-TCDF	0.1	7.0	0.6	0.6	2.29E+09	5.15E+08		7	0	0.6	2.29E+09	0.00E+00
12378-PeCDF	0.05	5.0	1.6	0.2	1.64E+09	1.32E+09		2	0	0.2	6.55E+08	0.00E+00
23478-PeCDF	0.5	5.5	0.8	0.2	1.80E+09	6.30E+08		2.5	0	0.2	8.18E+08	0.00E+00
123478-HxCDF	0.1	12.5	0.6	0.6	4.09E+09	4.69E+08		12.5	0	0.6	4.09E+09	0.00E+00
123678-HxCDF	0.1	8.5	0.7	0.6	2.78E+09	5.72E+08		8.5	0	0.6	2.78E+09	0.00E+00
234678-HxCDF	0.1	6.0	0.7	0.3	1.96E+09	5.72E+08		6	0	0.3	1.96E+09	0.00E+00
123789-HxCDF	0.1	1.8	0.6	0.02	5.73E+08	5.15E+08		0	0	0	0.00E+00	0.00E+00
1234678-HpCDF	0	26.0	7.6	4	8.51E+09	6.07E+09		13	7.6	4	4.25E+09	6.07E+09
1234789-HpCDF	0	4.5	0.6	0.2	1.47E+09	4.46E+08		2.5	0	0.2	8.18E+08	0.00E+00
OCDF	0	104.0	26.3	11	3.40E+10	2.11E+10		104	26.3	11	3.40E+10	2.11E+10
TEQ		12.15	2.3	0.8	**3.98E+09**	**1.82E+09**		7.7	0.06	0.71	**2.52E+09**	**4.58E+07**

[a] applied to 29% of the year

[b] applied to 71% of the year

4.7 ANALYSIS OF RUNOFF DATA

4.7.1 Runoff Concentrations versus Physical Properties

The observed TEQ concentrations in runoff were correlated with TSS, and TOC concentrations by linear regression (Figure 4.79, 4.80, and 4.81). Similarly, the ΣTexas-TEQ in the suspended phase was correlated with the ΣTexas-TEQ in the dissolved phase (Figure 4.82). The results showed that the ΣTexas-TEQ in the 40-μm suspended phase was better correlated with TSS than the 1-μm phase (r^2 of 0.4963 versus 0.0892). A weak correlation was obtained between the combined ΣTexas-TEQ (suspended + dissolved) and the TOC concentration. Finally, an r^2 of 0.7 was obtained when correlating the ΣTexas-TEQ observed in the suspended phase (1 and 40 μm) with that of the dissolved phase.

4.7.2 Runoff versus Soil/Sediment Profiles

Similarities and differences between the suspended-phase runoff and sediment profiles were evaluated by PCA and Hierarchical cluster analysis (Figure 4.83 and 4.84, respectively). Results obtained using these techniques were comparable. The results showed that, in general, the profiles for the 1- and 40-mm suspended phases are in proximity to the sediment profile at each site with the exception of site SS-8 that exhibited differences between the suspended and sediment profiles. It is also noted that the sites SS-9, SS-8 and SS-16 are each grouped in different clusters and separate from the remaining sites: SS-10, SS-13, SS-14, and SS-15. These dissimilarities among the sites may be attributed to the presence of different types of sources that have a specific impact at each site.

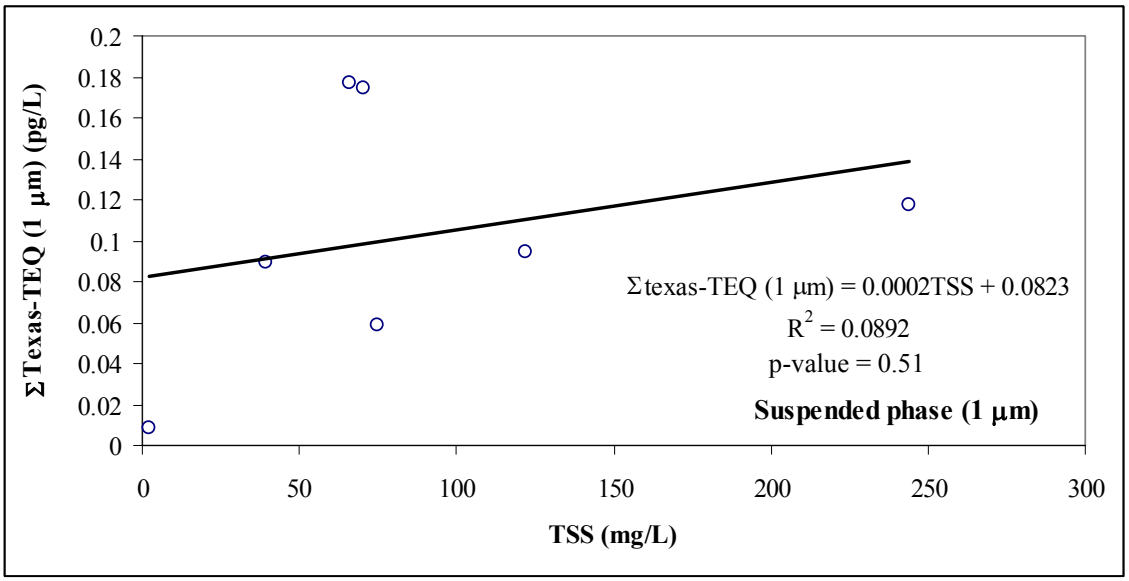


Figure 4.79 TEQ Concentration in the 1-µm Suspended Phase Versus TSS

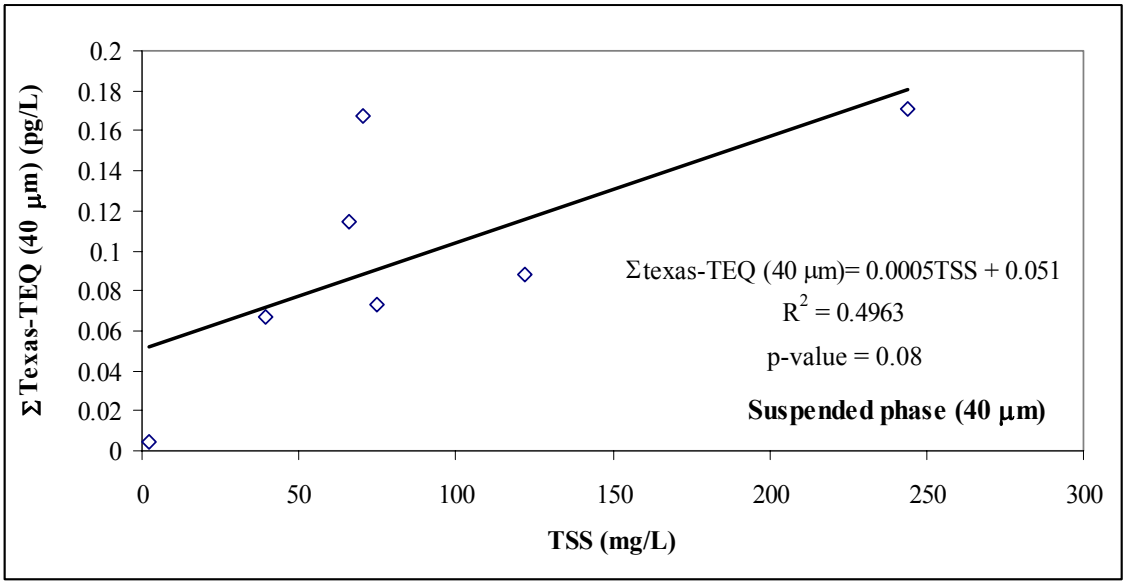


Figure 4.80 TEQ Concentration in the 40-µm Suspended Phase Versus TSS

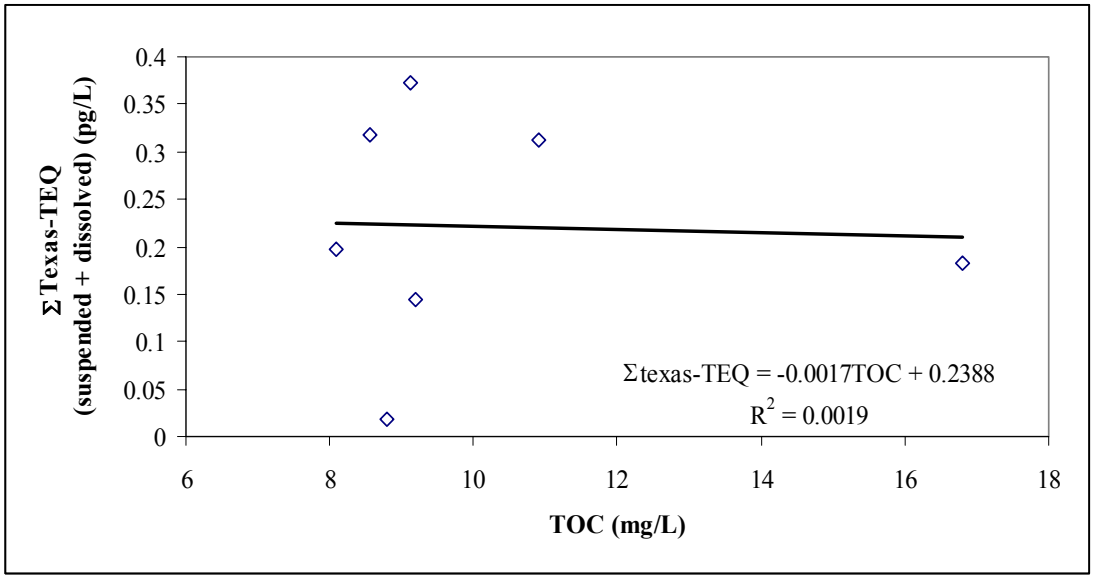


Figure 4.81 Combined TEQ Concentration Versus TOC

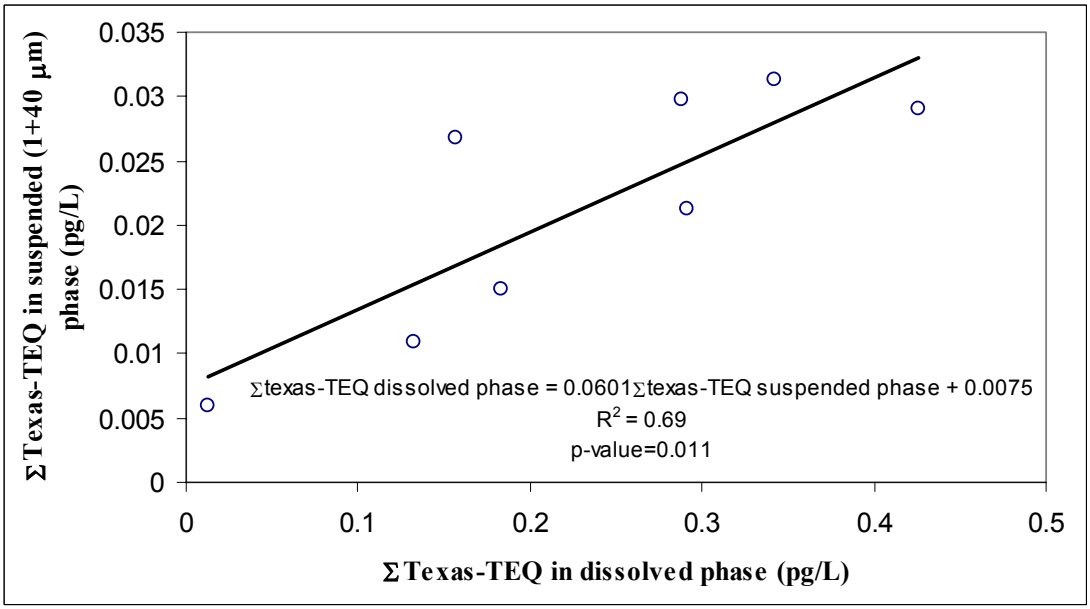


Figure 4.82 TEQ Dissolved-Phase Concentration Versus TEQ Suspended-Phase Concentration

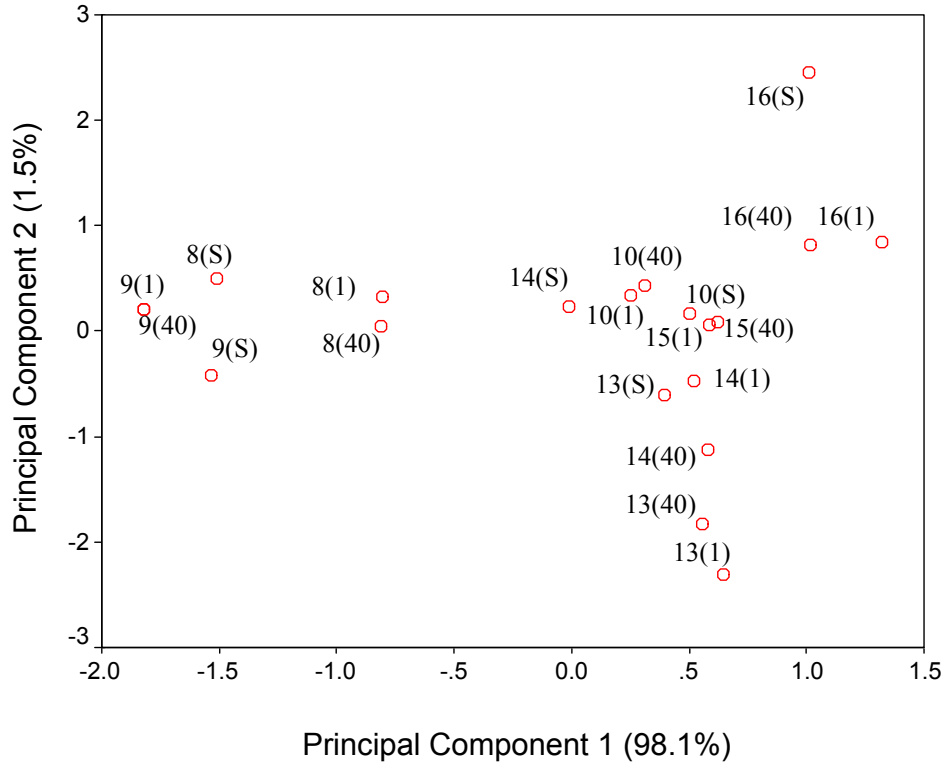


Figure 4.83 Score Plot from PCA When Comparing 1- and 40-µm Suspended Phases and Urban Sediment (During Runoff Conditions) Profiles. The Numbers in Figure Represent the Runoff Samples Sites; the Number/Letter in Parenthesis Correspond to Sampling Media (1, 1 µm; 40, 40 µm; S, sediment).

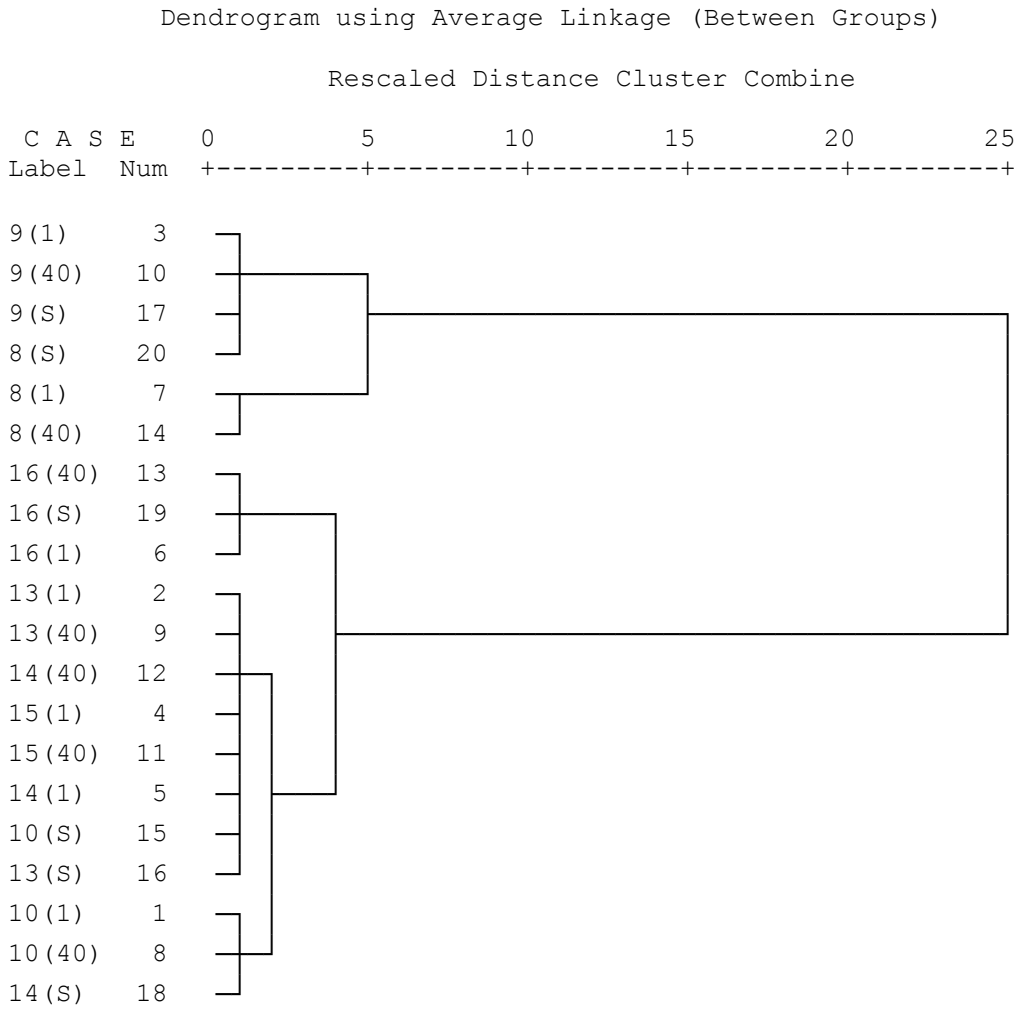


Figure 4.84 Hierarchical Cluster Analysis Dendrogram When Comparing 1- and 40-μm Suspended Phases and Urban Sediment (During Runoff Conditions) Profiles. The Numbers in Figure Represent the Runoff Samples Sites; the Number/Letter in Parenthesis Correspond to Sampling Media (1, 1 μm; 40, 40 μm; S, sediment).

CHAPTER 5

MODEL DEVELOPMENT

The goal of this task is to use models to elucidate the sources and major processes controlling observed levels of dioxins in the Houston Ship Channel and to identify the maximum permissible loading that would not impair water quality. Development of a preliminary mass-balance of dioxins in the HSC was completed using the MEGA-TX model (a modification of the QUAL-TX model completed for this project) to ensure that all the sources and process had been identified. In addition, a steady-state WASP model of the HSC was developed and a 1-month transient WASP simulation is underway. A conceptual model for dioxins in the HSC is provided in Figure 5.1. Major sources of dioxin to the channel include wet/dry air deposition, direct discharges, tributary input, sediment resuspension, land runoff, and discharges from groundwater. Major sinks include biodegradation, sediment burial, sediment removal by dredging, volatilization, groundwater outflow, hydrolysis, and photolysis (Figure 5.1).

5.1 MEGA-TX MODEL OF THE HOUSTON SHIP CHANNEL

5.1.1 Conceptual Model and Schematic

The MEGA-TX model was used to create a preliminary mass balance of TEQ and 2378-TCDD in the system. The simplified conceptual model representation of the physical system for MEGA-TX is presented in Figure 5.2a. The MEGA-TX model has the capability of incorporating point source discharges, nonpoint source runoff that includes dioxins from atmospheric deposition, and direct atmospheric deposition to the receiving water bodies. In addition the

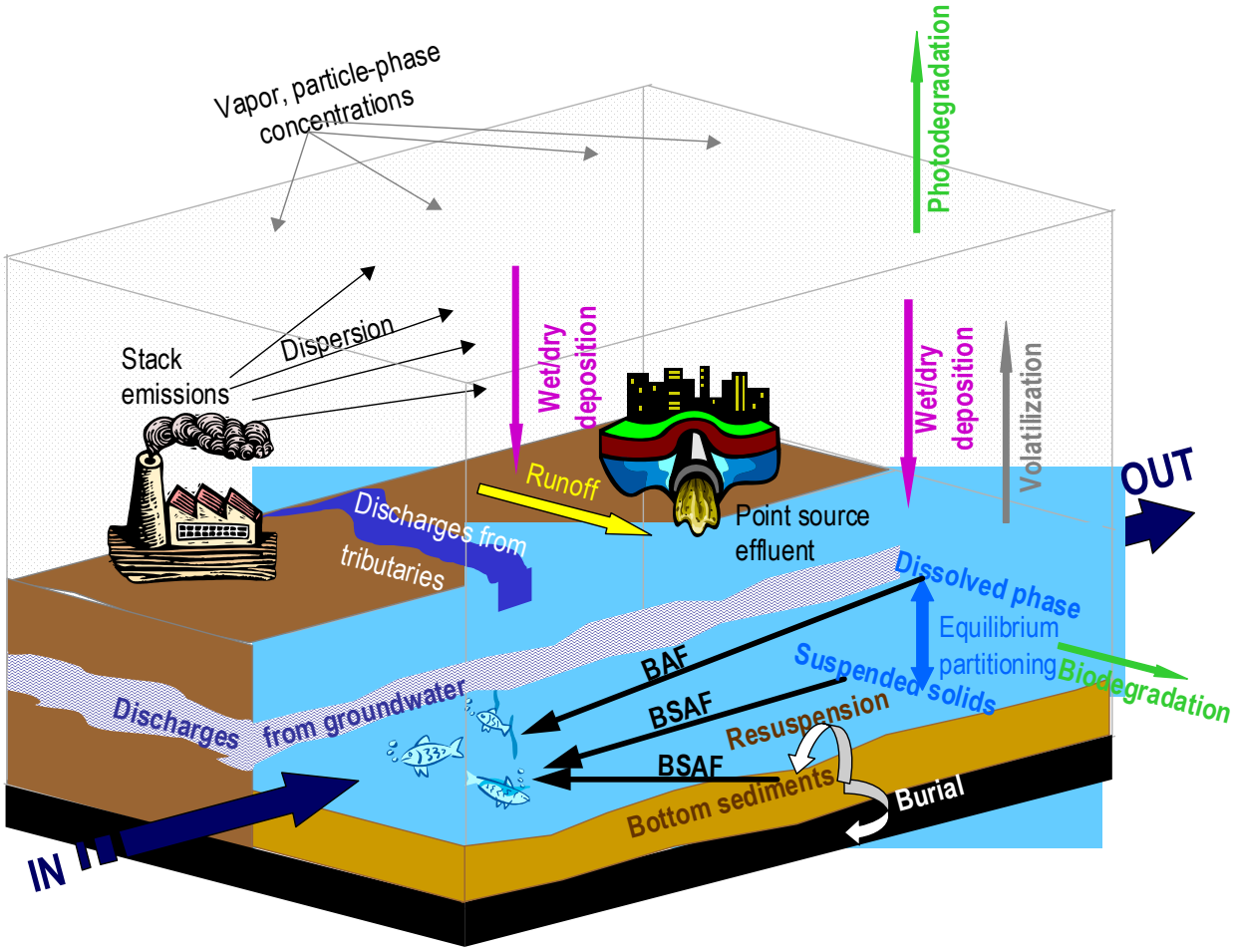


Figure 5.1 Conceptual Model for Dioxins in the HSC

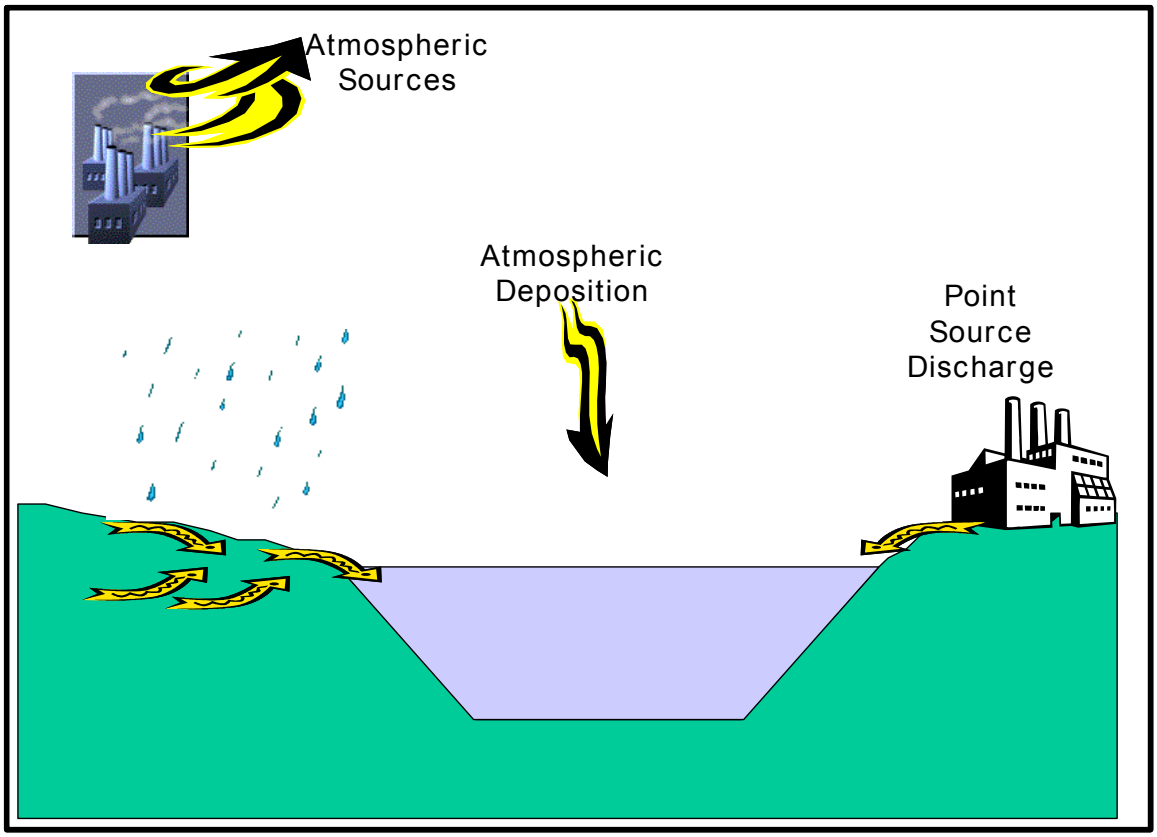


Figure 5.2a MEGA-TX Conceptual Source Schematic

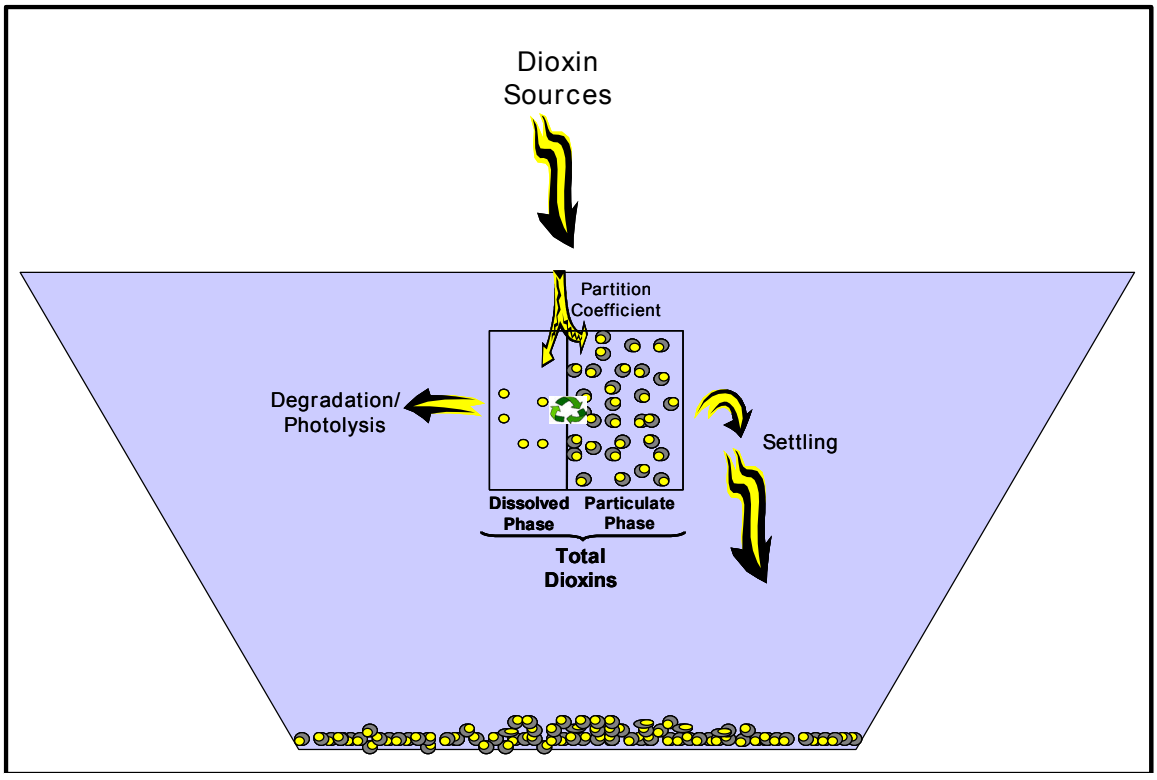


Figure 5.2b MEGA-TX Fate and Transport Schematic

model has the capability to simulate the transport and fate pathways and kinetics shown in Figure 5.2b. The MEGA-TX model also incorporates calibrated and accepted hydraulics for the receiving water bodies, and is easy to use and configure. It is noted that, because the mass balance was to be used as a preliminary, screening tool, only some of the dioxin sources/sinks identified in Figure 5.1 are included in the MEGA-TX model for dioxins in the HSC. Inclusion of all the processes will be completed using the WASP numerical model.

As a starting point, the same schematic that TCEQ employed for the recent nickel TMDL was used. The TCEQ nickel model schematic consists of a main model that encompasses the HSC system from the lower boundary at Morgans Point upstream to the approximate tidal limits of each of the tributaries and ten tributary models. The reasoning behind splitting the HSC system into eleven sub models lies in the historical limitations of the QUAL-TX model. The version of QUAL-TX currently in use by TCEQ is written in FORTRAN 77 and is dimensioned sufficiently to simulate the HSC main model on a typical PC.

A drawback resulting from splitting the HSC system into sub models is the effective blocking of dispersive transport from a downstream model to an upstream tributary model. The upstream tributary models are run first and their output is transferred to an intermediate file that is read as input by the downstream model at the appropriate location. Using this method, however, precludes any communication of dispersive or advective transport upstream from the lower model. The effect of this simplification is minimized by breaking the models at the approximate tidal limit where advective transport is theoretically downstream only and upstream dispersive transport is negligible.

Downstream to upstream dispersive transport was deemed of sufficient significance in the screening runs of QUAL-TX to justify modifying the model to eliminate the problem of interconnected sub-models. To provide this capability, some changes were made to the QUAL-TX code. The FORTRAN 77 code was updated to Fortran 95 and dynamic memory allocation was added. The new code is not constrained to a maximum size of model by static dimensioning, since it reads the input and dynamically allocates memory. The original QUAL-TX input decks for the TCEQ Nickel TMDL on the HSC were joined into a single model. The new model (MEGA-TX) is comprised of 481 model reaches that encompass 2100 individual calculational elements (Figure G-1 in Appendix G). The model has 172 headwater elements and a single lower boundary element to represent the main channel of the Houston Ship Channel/Buffalo Bayou and 171 tributaries.

In addition to being combined into a single model, the HSC nickel TMDL input decks were modified to simulate dioxin rather than nickel. In the dioxin TMDL HSC models, dioxin is modeled as a user-defined nonconservative parameter. Utilizing the MEGA-TX nonconservative parameter allows the inclusion of settling. Figure 5.3 is a schematic representation of the fate of dioxin in the MEGA-TX model.

5.1.2 Input Data

5.1.2.1 Hydraulic Model Input

The hydraulic and physical characteristics of each reach in the HSC model were obtained from the QUAL-TX model developed for the Nickel TMDL study (TNRCC, 2002). The upper boundaries are represented in the model by the headwaters. The lower boundary, on the other

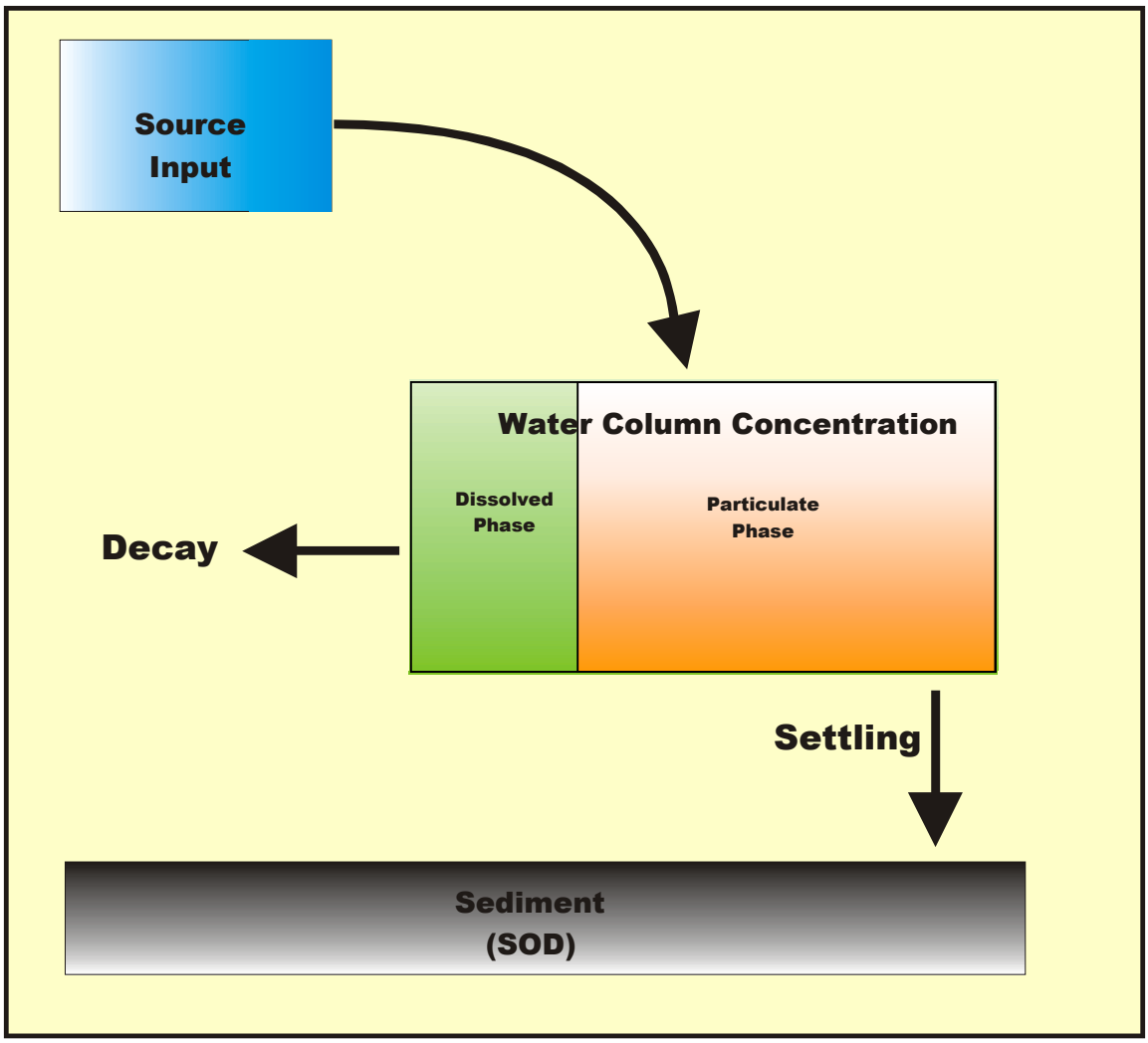


Figure 5.3 MEGA-TX Dioxin Schematic

hand, was set in Channel Marker 75 (Km -8.0, station 14560) in Galveston Bay, with water concentrations measured in Summer 2002: 0.1124 pg/L for TEQ and 0.0501 pg/L for 2378-TCDD.

5.1.2.2 Point Sources

Input from point sources is simulated in MEGA-TX by a steady state flow and a dioxin (TEQ or 2378-TCDD) concentration. The MEGA-TX input contains permitted flow values, as included in the TCEQ permittee database (as of May 2003). A second input deck with the average self-reporting flow for the period 1997-2002 was also prepared and run for comparison purposes. Dioxin concentrations from point sources (PS) gathered in this project during Spring 2003 were used as model input. For the point sources that were not sampled for effluent, one of the following three approaches was used to estimate a dioxin concentration:

1. If the PS was sampled for sludge, the concentration in effluent was extrapolated from a regression between the concentration in sludge and the concentration in effluent for the point sources sampled for both, as shown in Figure 5.4.
2. If the PS was not sampled for sludge or for effluent and the SIC was among those identified as potential dioxin dischargers, the dioxin concentration in effluent was assumed equal to the average dioxin concentration for effluent from facilities with the same SIC code. If no facilities with the SIC code of the PS were sampled, the dioxin concentration was assumed as the average dioxin concentration of all the sampled industrial outfalls.
3. If the PS was not sampled and the SIC code was not among those identified as potential sources of dioxins, the concentration was assumed zero.

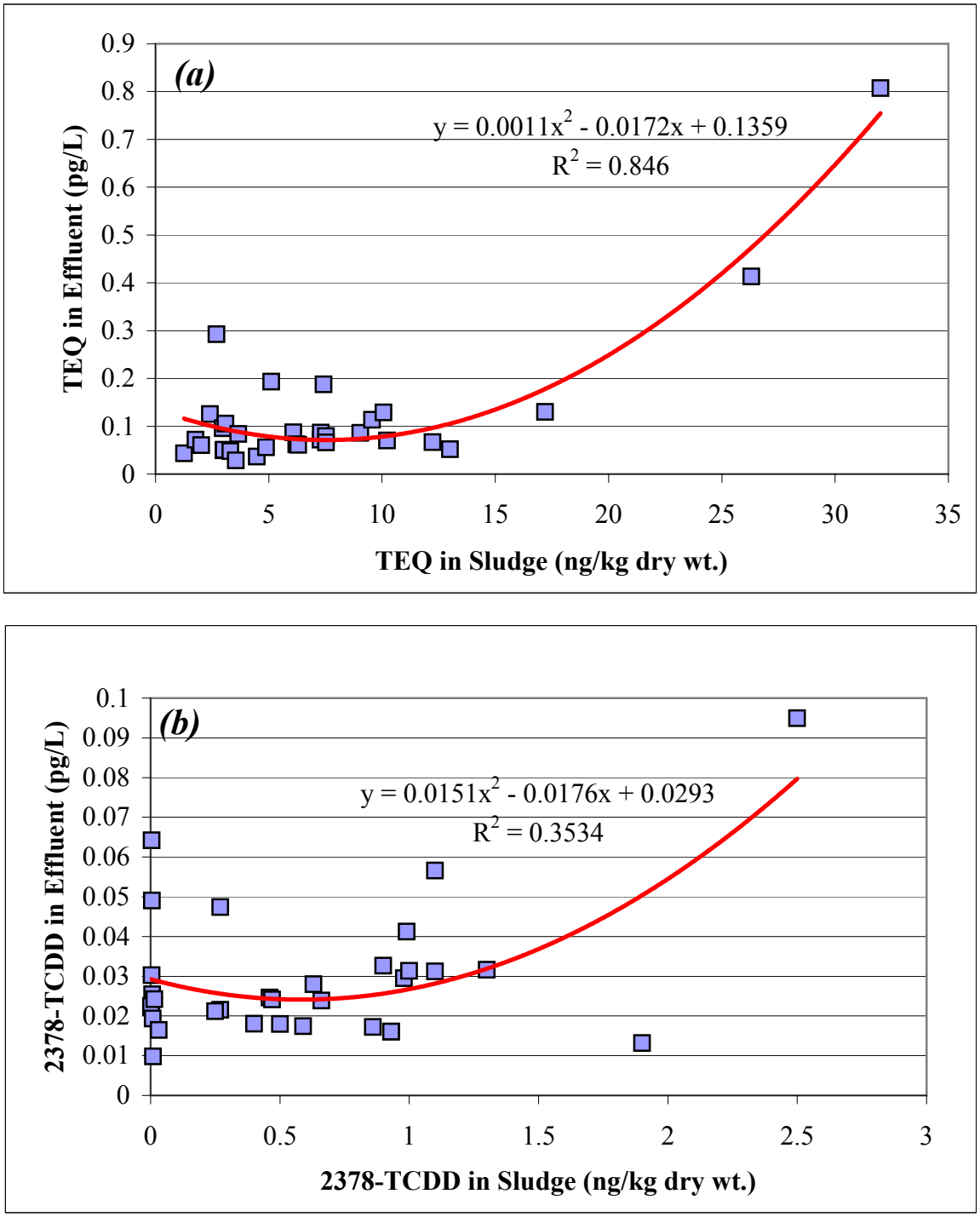


Figure 5.4 Relationship between Measured Dioxin Levels in Sludge and Effluent
(a) TEQ (b) 2378-TCDD

The point source concentrations are entered into the model in femtograms per liter (fg/L). Figures 5.5a and b show the distribution of PS in the HSC system and the magnitude of the TEQ and 2378-TCDD concentration entered into the model, respectively. Figures 5.6 and 5.7 summarize the distribution of point sources entered into the MEGA-TX model by segment using permitted and average self-reported flows, respectively. The total load from PS to the HSC system using permitted flows is estimated to be 5.98×10^5 ng/day for TEQ and 1.11×10^5 ng/day for 2378-TCDD, excluding any loads from the San Jacinto River above the Lake Houston Dam or from Galveston Bay. Similarly, the PS load to the HSC system using average self-reported flows is estimated to be 3.42×10^5 ng/day for TEQ and 5.71×10^4 ng/day for 2378-TCDD. Appendix G includes the input files.

5.1.2.3 Non-point Sources

Non-point source pollutant loads on a daily basis for the HSC watershed were calculated using land cover information, the dioxin concentrations in runoff measured in 2002/2003, and the recorded rainfall in 2002.

Subwatershed Delineation

The HSC watershed covers a total of 1,208 square miles within the San Jacinto River basin in Texas. In order to better simulate the fate and transport of dioxins, the model area was divided into a total of 355 subwatersheds . Subwatershed delineation was performed using ArcView 3.2 and CRWR-PrePro (a watershed delineation system developed by the Center for Research in Water Resources at the University of Texas at Austin). The delineation was based upon digital elevation (DEM) Arc/Info grids; an Rf3 stream network; and the reaches established for the HSC Nickel QUAL-TX model.

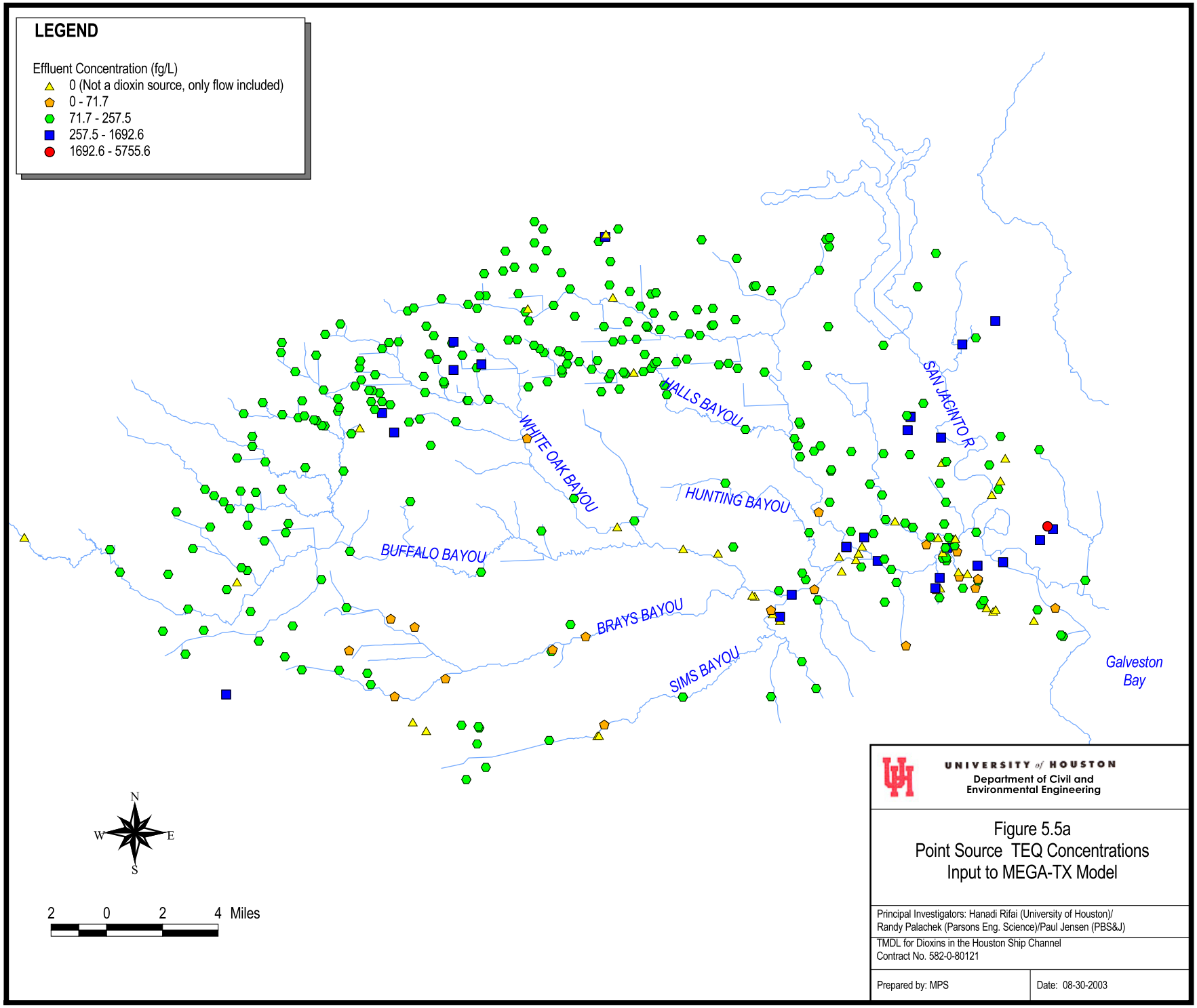


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Figure 5.5a
Point Source TEQ Concentrations
Input to MEGA-TX Model

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS

Date: 08-30-2003

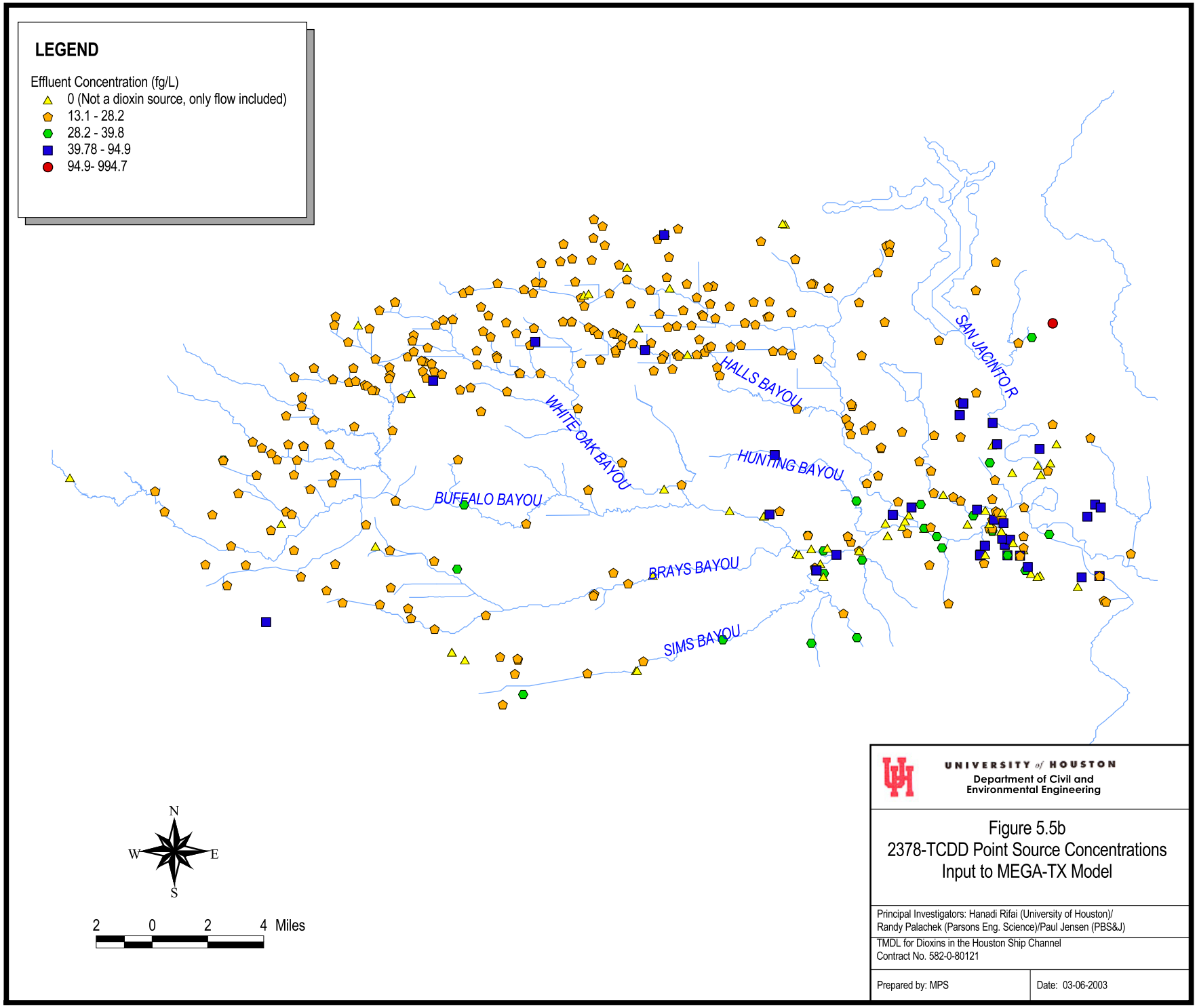

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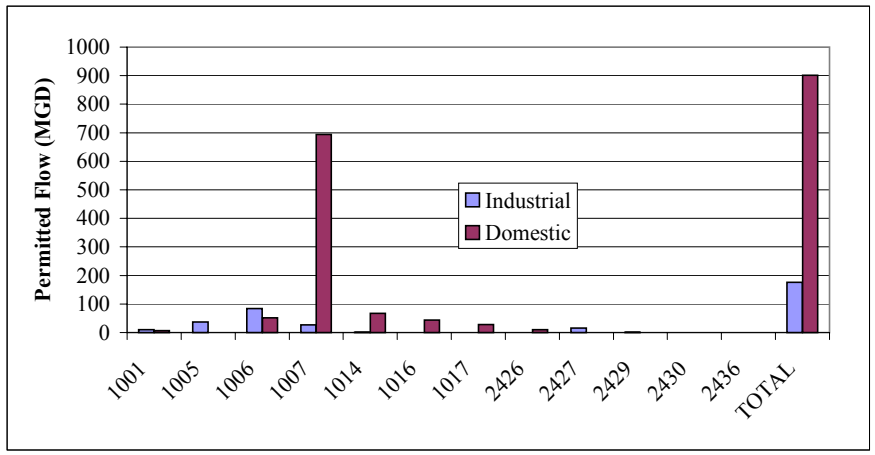
Figure 5.5b
2378-TCDD Point Source Concentrations Input to MEGA-TX Model

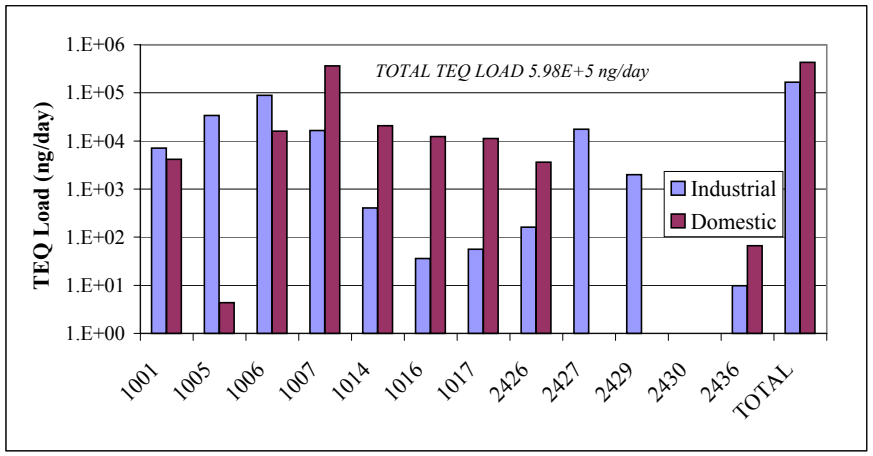
Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS

Date: 03-06-2003





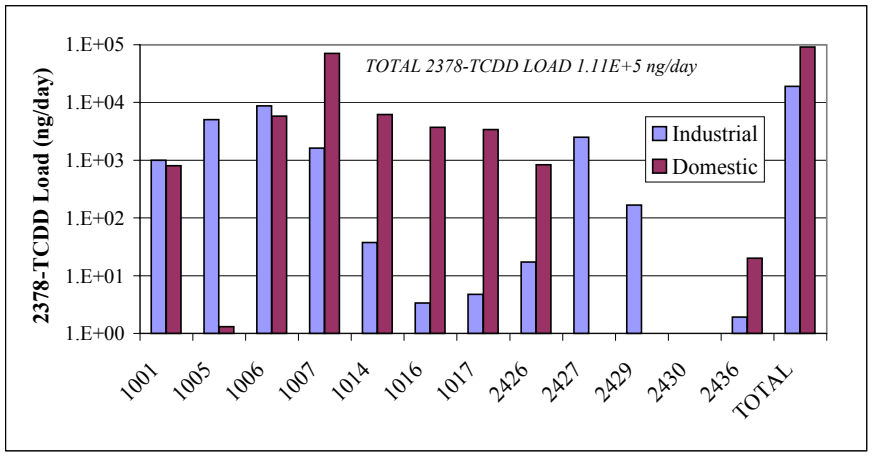


Figure 5.6 Point Source Flows and Loads by Segment using Permitted Flows

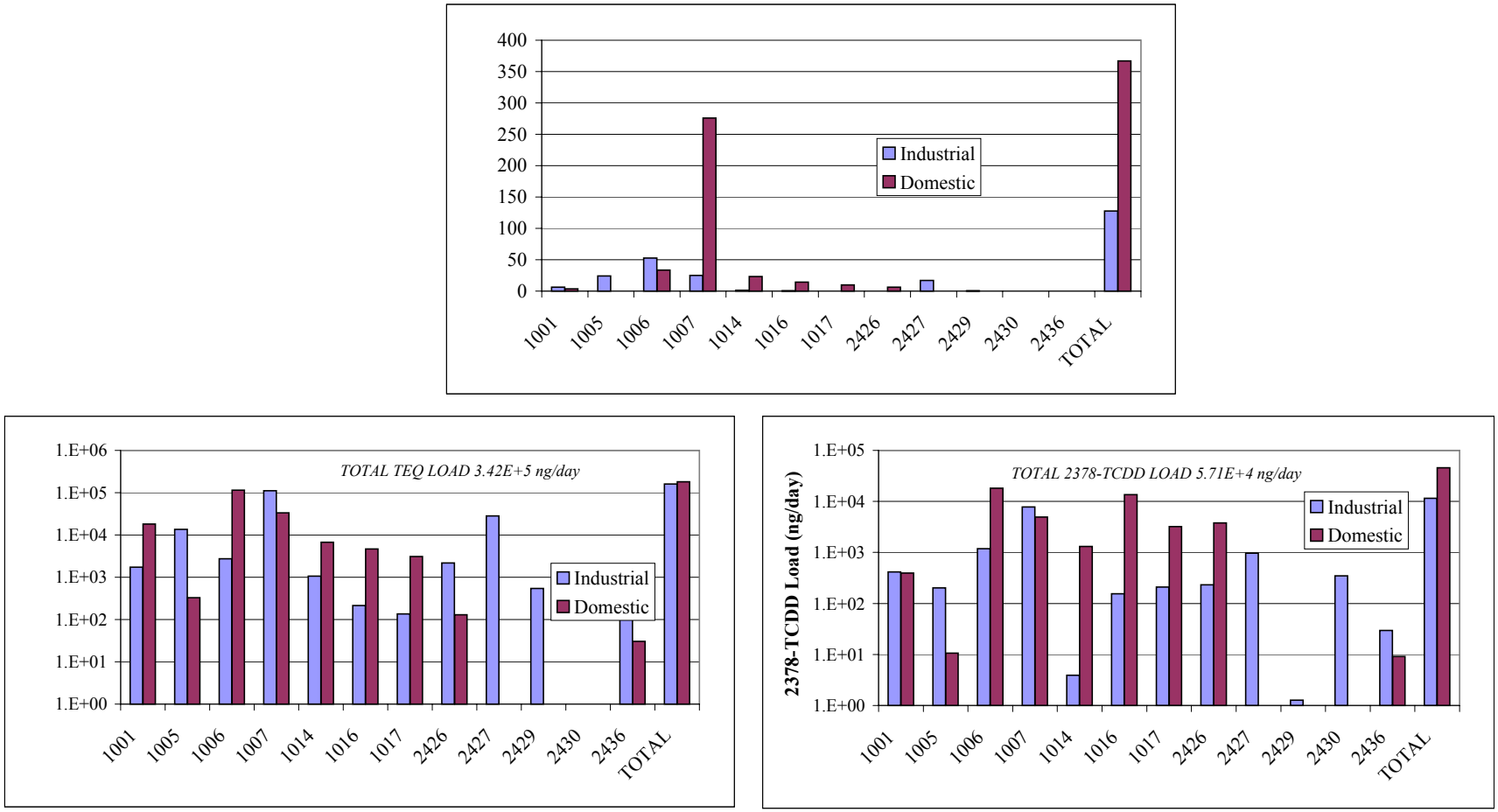


Figure 5.7 Point Source Flows and Loads by Segment using Average Self-reported Flows

DEMS used for delineation were obtained from BASINS 3, USGS DEM elevations grids (1:250,000 scale). The DEM grid data provided with BASINS 3.0 have 3 arc second cell (approximately 90 x 90 meter). DEM grids from Hydrologic Unit Codes 12030203, 12040101, 12040102, 12040103, 12040104, 12040202, 12040203, 12040204, 12040205 were merged together to form one large Grid. The BASINS Rf3 stream files were used for initial stream burn-in and outlets were added at the beginning of the model reaches, when necessary, in order to determine the drainage area for each reach. Figure 5.8 shows the resulting subwatershed delineation. It is important to note that this delineation differed from that used by the Harris County Flood Control District (HCFCD) because of the different methods used for watershed delineation.

Rainfall Data

Rainfall data from January 1, 2002 to December 31, 2002 were obtained from the Harris County Office of Emergency Management (OEM) webpage for the rain gages in the HSC watershed (Figure 5.9). These gages were selected based on the completeness of the rain data and the proximity of the rain gages to the subwatersheds. Average daily rainfall data were calculated as the total amount of rainfall for the year 2002 divided by 365 days. Each subwatershed was assigned the rainfall data from the closest gage.

Runoff Volume

The amount of runoff for each subwatershed was calculated using the SCS runoff curve number method (Natural Resource Conservation Service, 1986). The SCS Runoff Curve Number (CN) method is described in detail in NEH-4 (SCS 1985). The SCS runoff equation is:

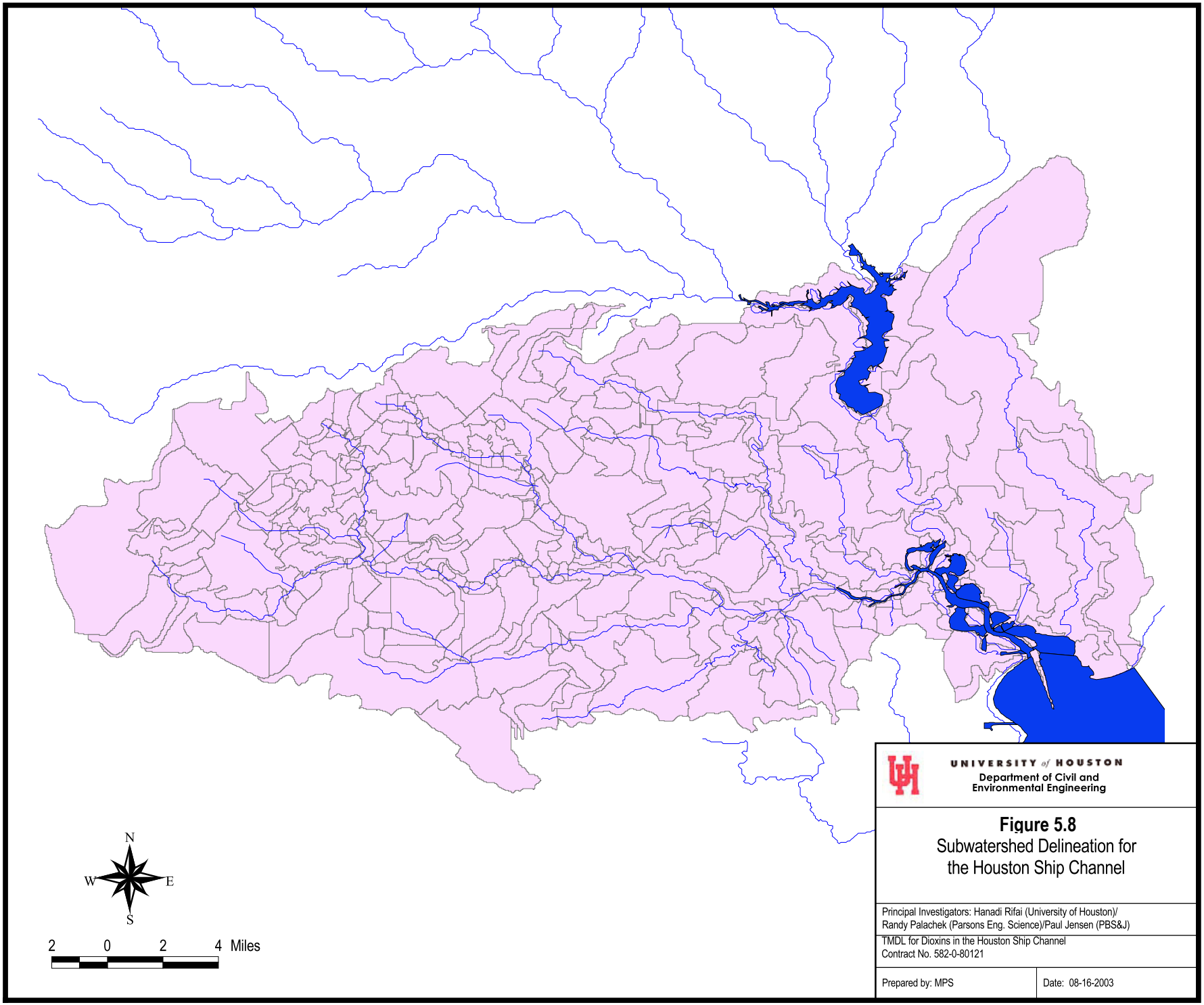


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Figure 5.8
Subwatershed Delineation for the Houston Ship Channel

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS

Date: 08-16-2003

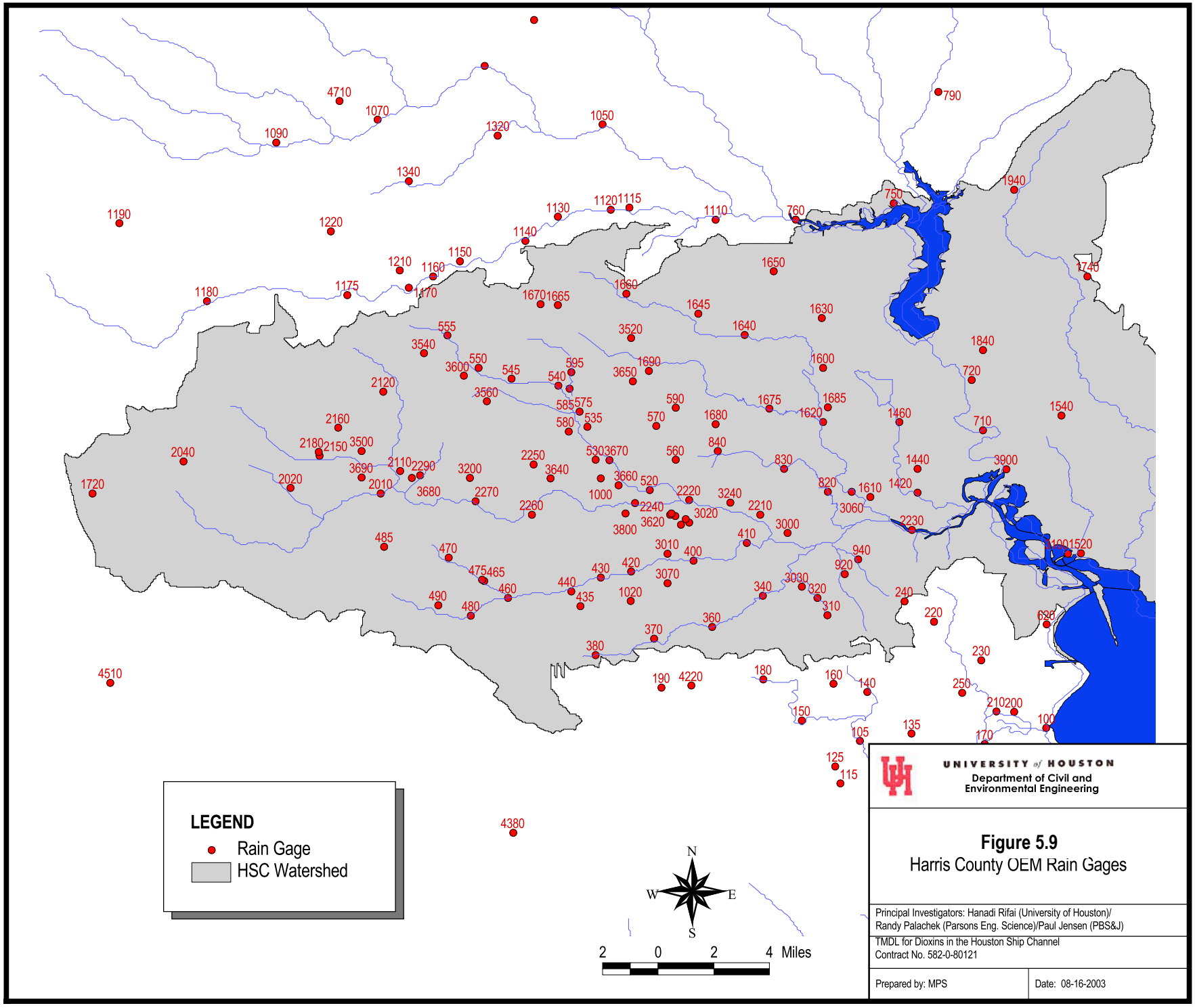
LEGEND
Rain Gage
HSC Watershed
N
W
E
S
2 0 2 4 Miles
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Figure 5.9
Harris County OEM Rain Gages
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-16-2003

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{5.1}$$

where Q = runoff (in);

P = rainfall (in);

S = potential maximum retention after runoff begins (in); and

I_a = initial abstraction (in).

Initial abstraction refers to all the losses before runoff begins and includes water intercepted by vegetation, infiltration, evaporation, and water retained in surface depressions. This parameter is very variable but is correlated to land cover and soil type (NRCS, 1986). The Natural Resource Conservation Service (1986) estimates Ia to be equal to

$$I_a = 0.2S \tag{5.2}$$

Substituting equation (5.2) into equation (5.1) gives a runoff estimate as a function of S and P:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{5.3}$$

Finally, S is related to the curve number (CN) by

$$S = \frac{1000}{CN} - 10 \tag{5.4}$$

CN values range from 0 to 100 and are based on land cover and soil group. For this runoff calculation, all subwatersheds were assumed to be in soil group D (silts and clays) that generally has low infiltration rates. Land coverage data developed by the HGAC in 2002 (HGAC, 2003) were used. The classification system for the HGAC dataset and their corresponding runoff curve numbers are included in Table 5.1.

Table 5.1 Runoff Curve Numbers for the HSC Watershed

Land Cover Code	Land Cover Description	CN[a]
1	Developed	96
2	Grass/Agriculture	89
3	Woodland	77
4	Open Water	0
5	Wetlands	30
6	Transitional/Bare	94

[a] Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986.

Non-point Source Loads

The total TEQ and 2378-TCDD concentrations in runoff measured in 2002/2003 in this project were used to calculate NPS loads for the different reaches in the MEGA-TX model. Because the drainage areas of the stormwater ditches sampled in Spring 2003 are not composed of a single land cover category, it was not possible to determine a dioxin concentration for each land cover type. Therefore, the available runoff dioxin data were assigned to the different subwatersheds based on proximity between the sampled stations and the specific watersheds. For each reach, the corresponding runoff TEQ concentration was multiplied by the drainage area to

calculate the NPS load. The resulting daily loads, normalized by subwatershed area are shown in Figures 5.10a and b for TEQ and 2378-TCDD, respectively. The calculated subwatershed concentrations ranged from 0.05 to 15.22 ng/acre/day for TEQ and from 0.006 to 0.27 ng/acre/day for 2378-TCDD. The total loads of NPS to the HSC system were estimated to be $1.17x10^6$ and $6.74x10^4$ ng/day for TEQ and 2378-TCDD, respectively. These estimates are based on the results from the 10 runoff samples gathered in 2202/2003. It is noted that direct dry-deposition to the HSC streams was not included in the NPS load calculation.

5.1.2.4 Decay and Settling Rates

Dioxin decay from the water column (biodegradation, volatilization, and photolysis) was assumed negligible and, thus, a first-order decay rate of zero was used in the model. Settling rates were assumed equal to the sediment net accumulation rates calculated using historical TSS data and dredging records from the Corps of Engineers (see Section 3.3). Table 5.2 summarizes the sediment accumulation rates in the Houston Ship Channel for the 1990's decade from Morgan's Point to the Turning Basin. Settling rates for the tributaries were assumed as the average of the available rates for the main channel. It is noted that these settling rates are probably overestimates, because they are based on sedimentation into the actual narrow deep channel, which is probably dominated in some reaches by sediment transport from tributaries, the undredged sides of the channel, and adjacent side bays.

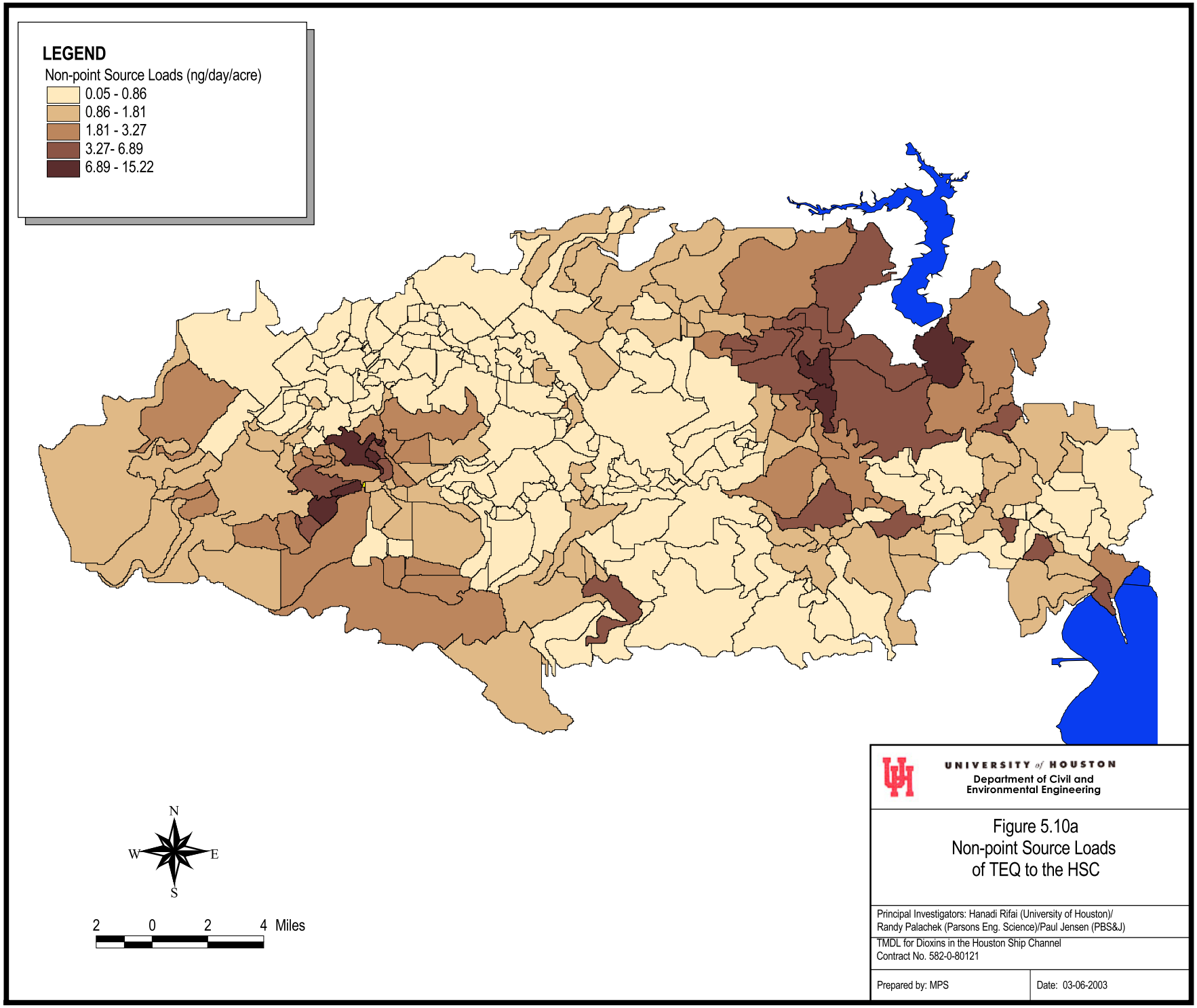
LEGEND
Non-point Source Loads (ng/day/acre)
0.05 - 0.86
0.86 - 1.81
1.81 - 3.27
3.27- 6.89
6.89 - 15.22
N
W
E
S
2 0 2 4 Miles
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Figure 5.10a
Non-point Source Loads
of TEQ to the HSC
Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 03-06-2003

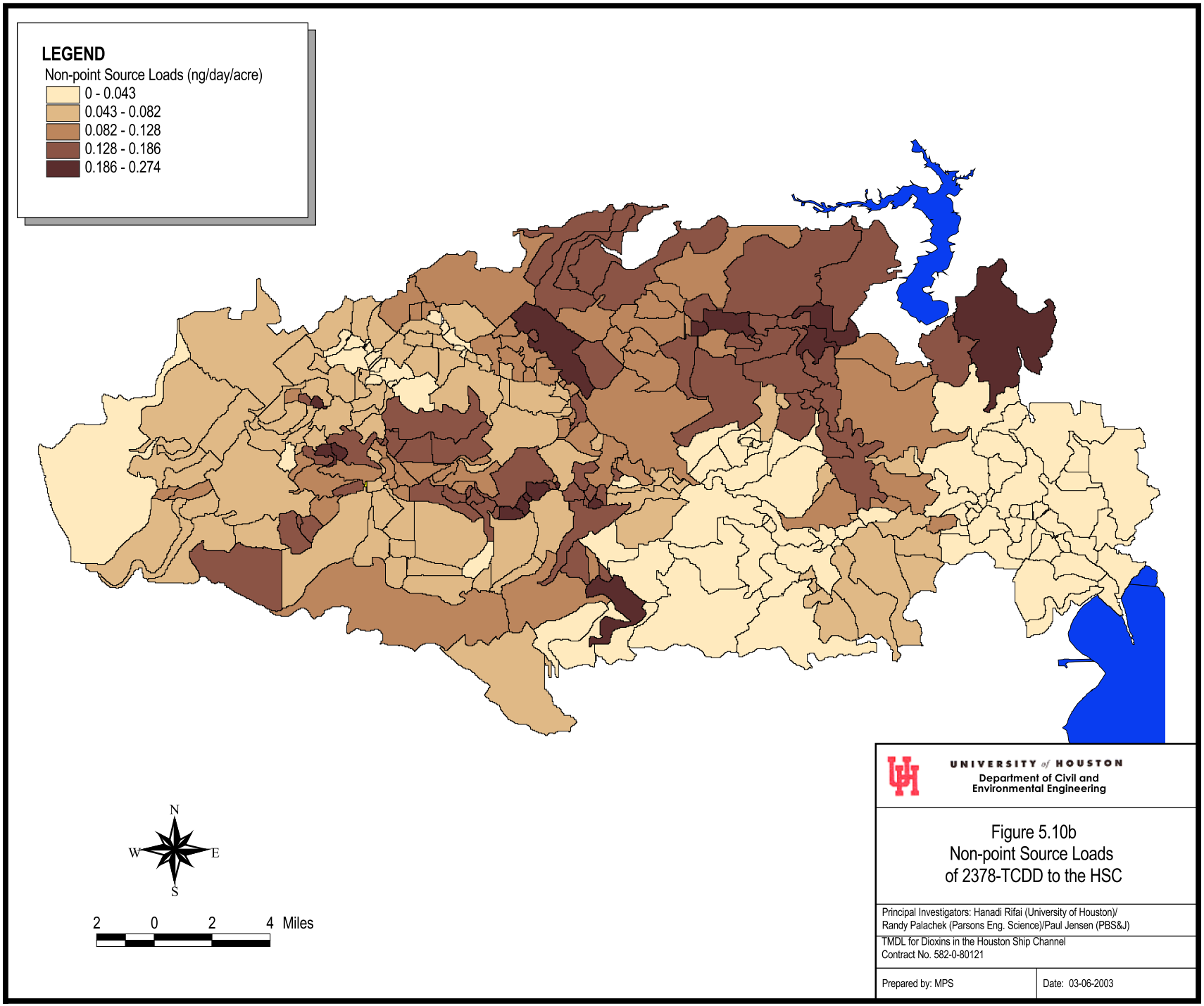

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Figure 5.10b
Non-point Source Loads
of 2378-TCDD to the HSC

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 03-06-2003

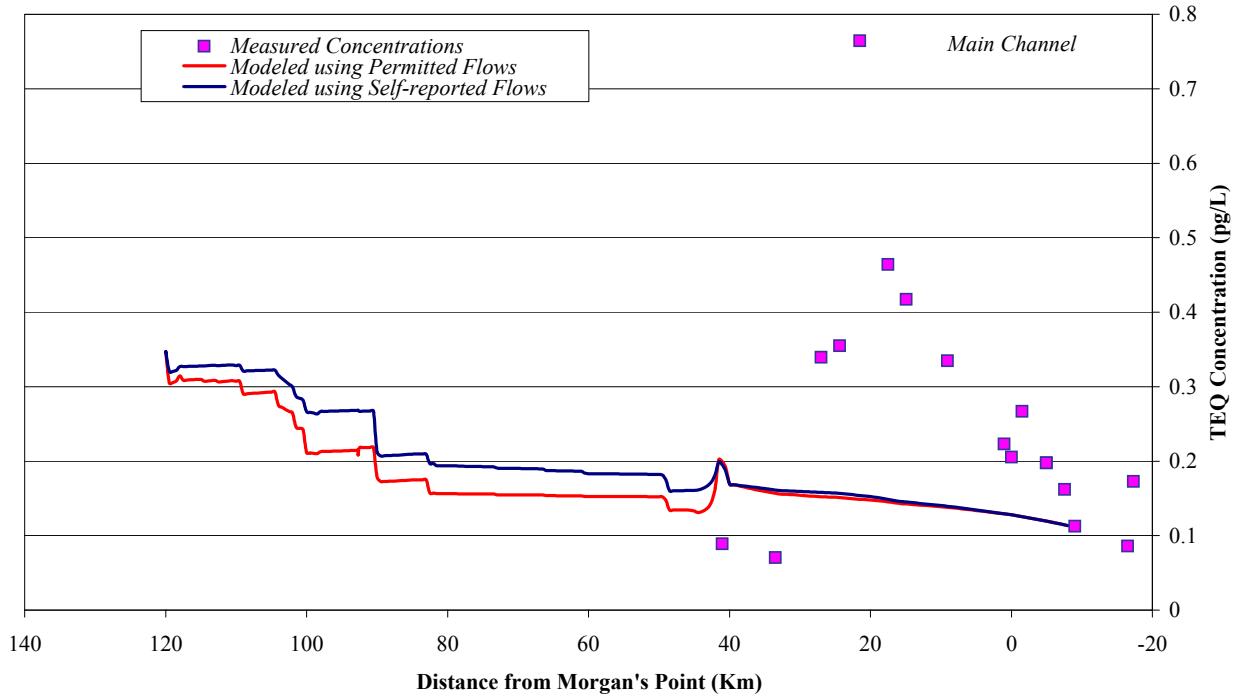
Table 5.2 Average Sediment Accumulation Rates

Channel Km	Sediment Accumulation Rate	
	(ft/yr)	(m/day)
2.5	0.897	0.0007
7.5	1.357	0.0011
12.5	0.699	0.0006
17.5	0.618	0.0005
22.5	0.413	0.0003
32.5	0.346	0.0003
37.5	0.745	0.0006
40.82	2.073	0.0017
Average for tributaries	0.893	0.0007

To track the fate of settled dioxin, the "Conversion to SOD" factor in the model is enabled and set to a value of 1.0. This option forces MEGA-TX to report the areal flux of dioxin to the sediments for each calculational element in the model.

5.1.3 Output Data

The total TEQ and 2378-TCDD water column concentration results from the runs of the MEGA-TX dioxin model are shown in Figures 5.11a and b, respectively, and the sediment flux results are shown in Figure 5.12. As can be seen, the modeled concentrations are lower than the measured ones in some reaches. Observed concentrations in the vicinity of stations 15979 and



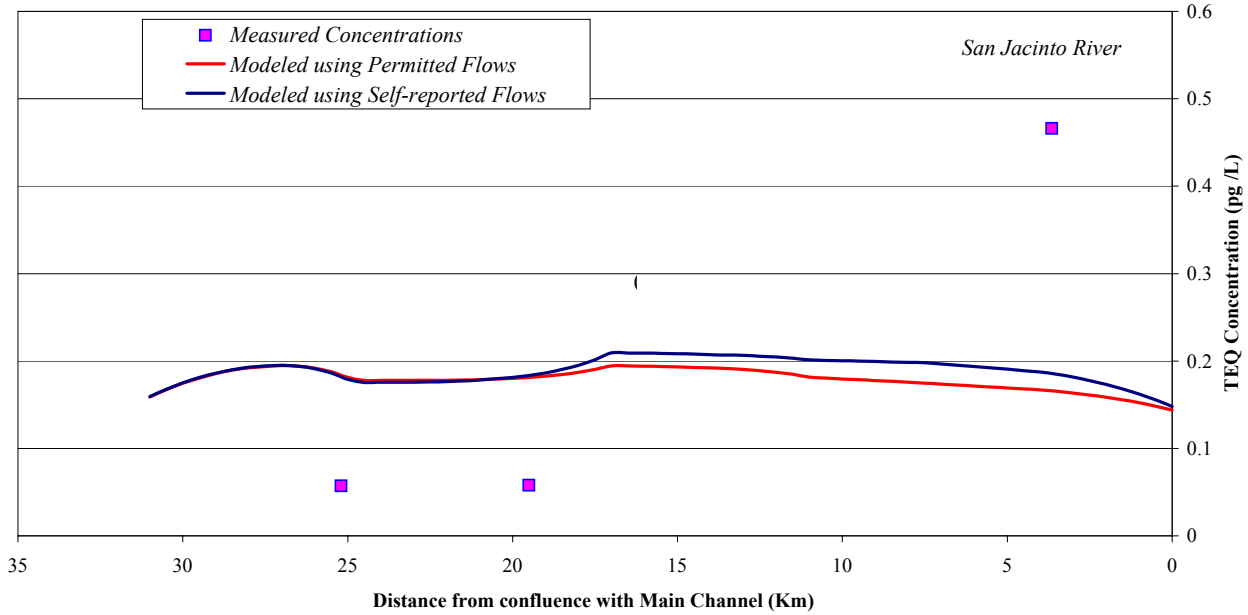
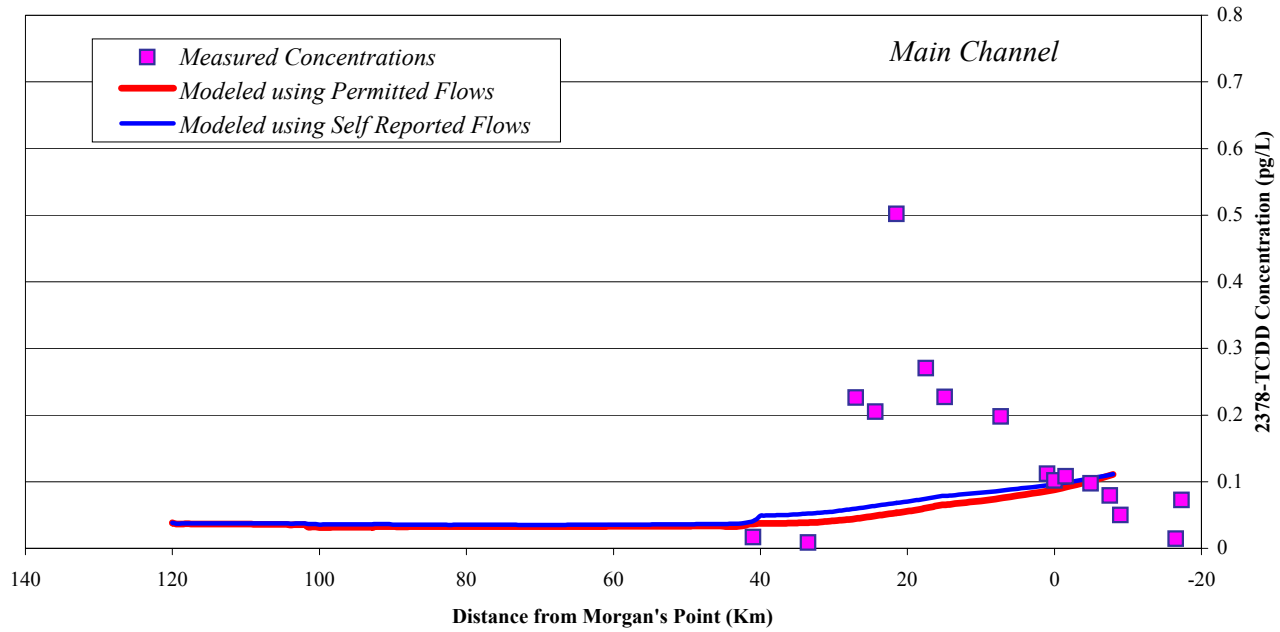


Figure 5.11a Total TEQ in Water Column



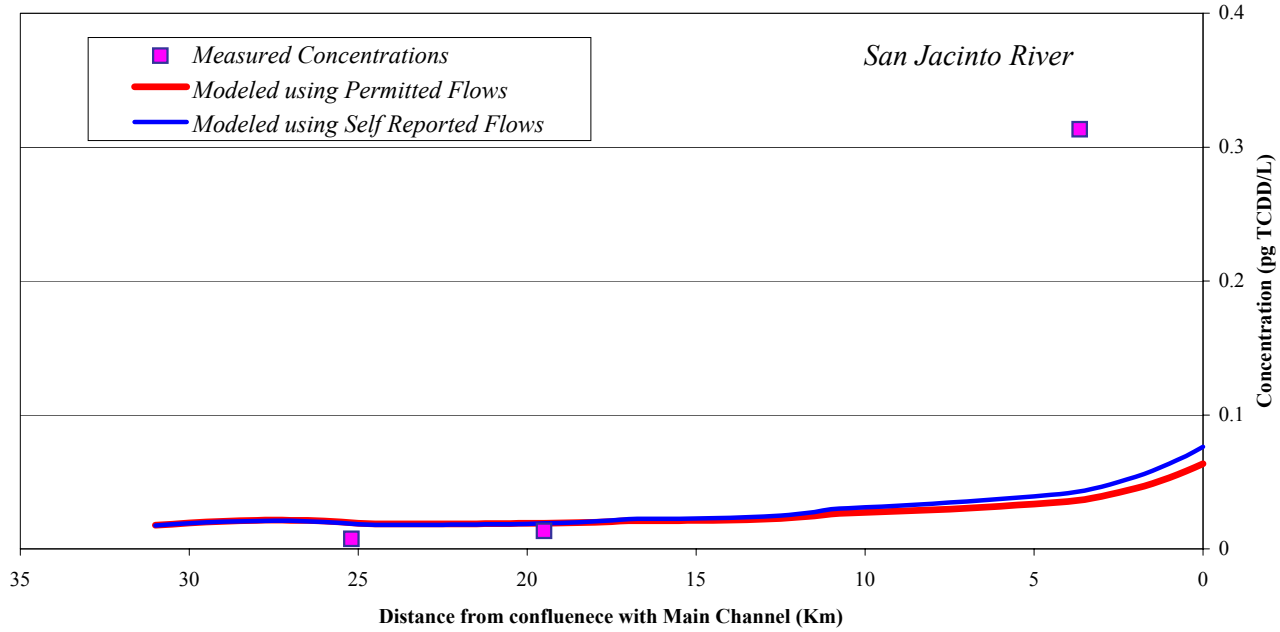
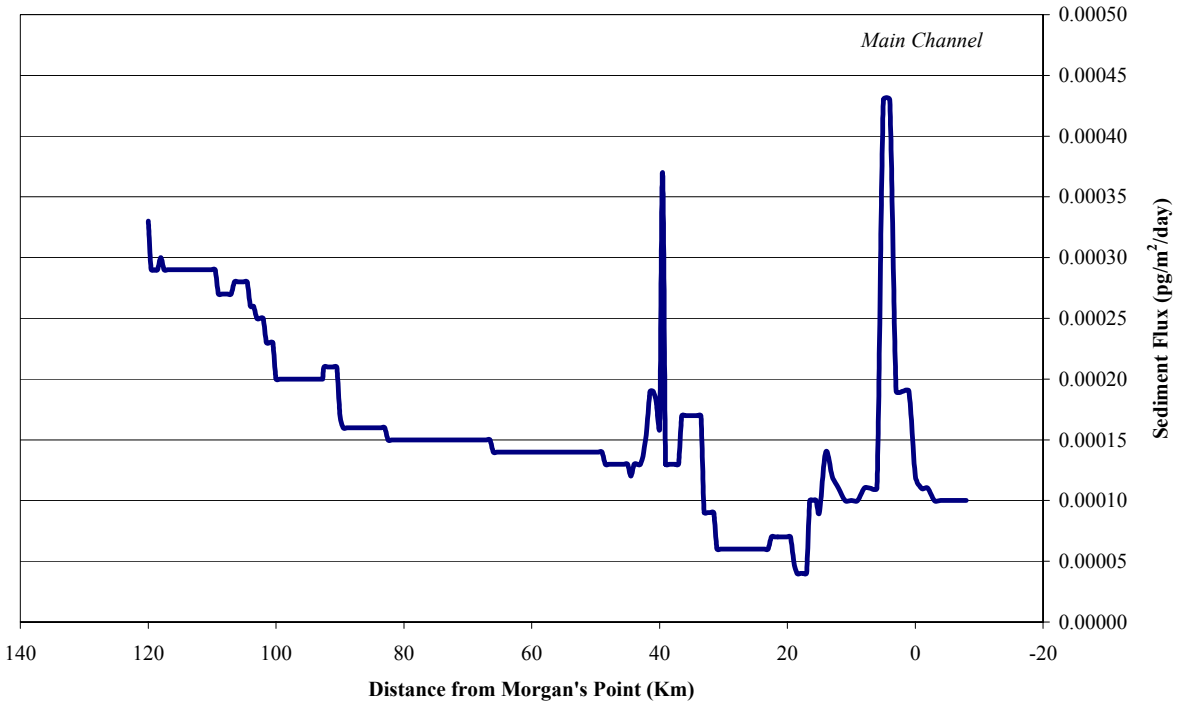


Figure 5.11b Total 2378-TCDD in Water Column



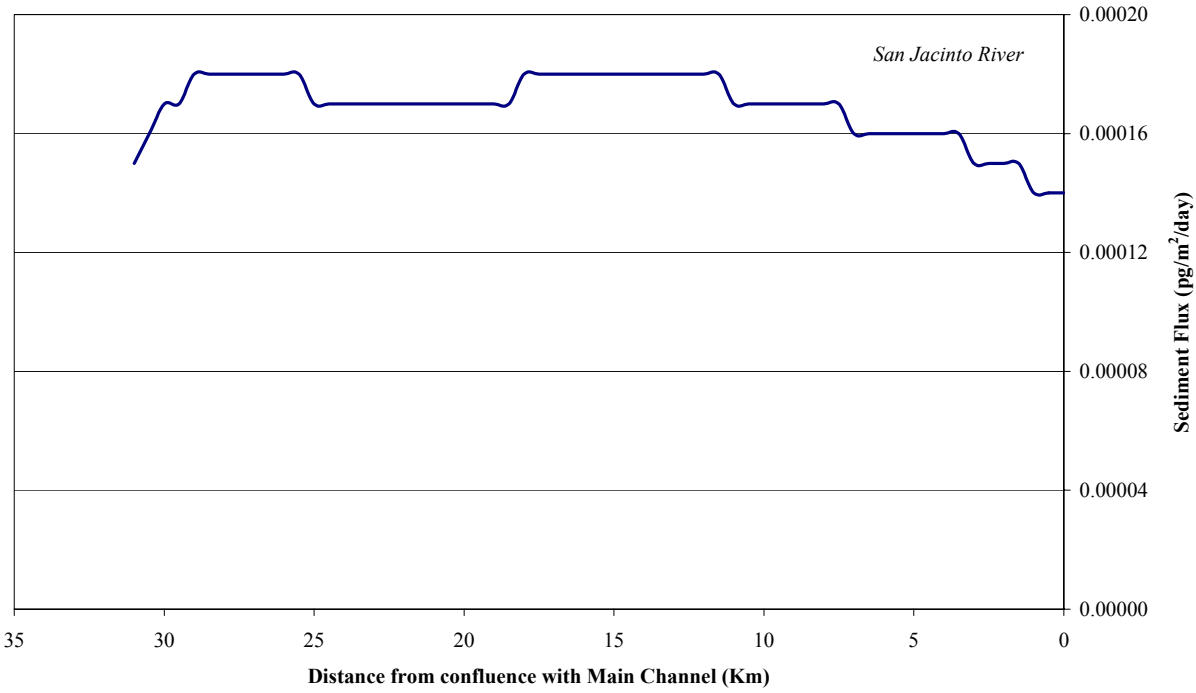
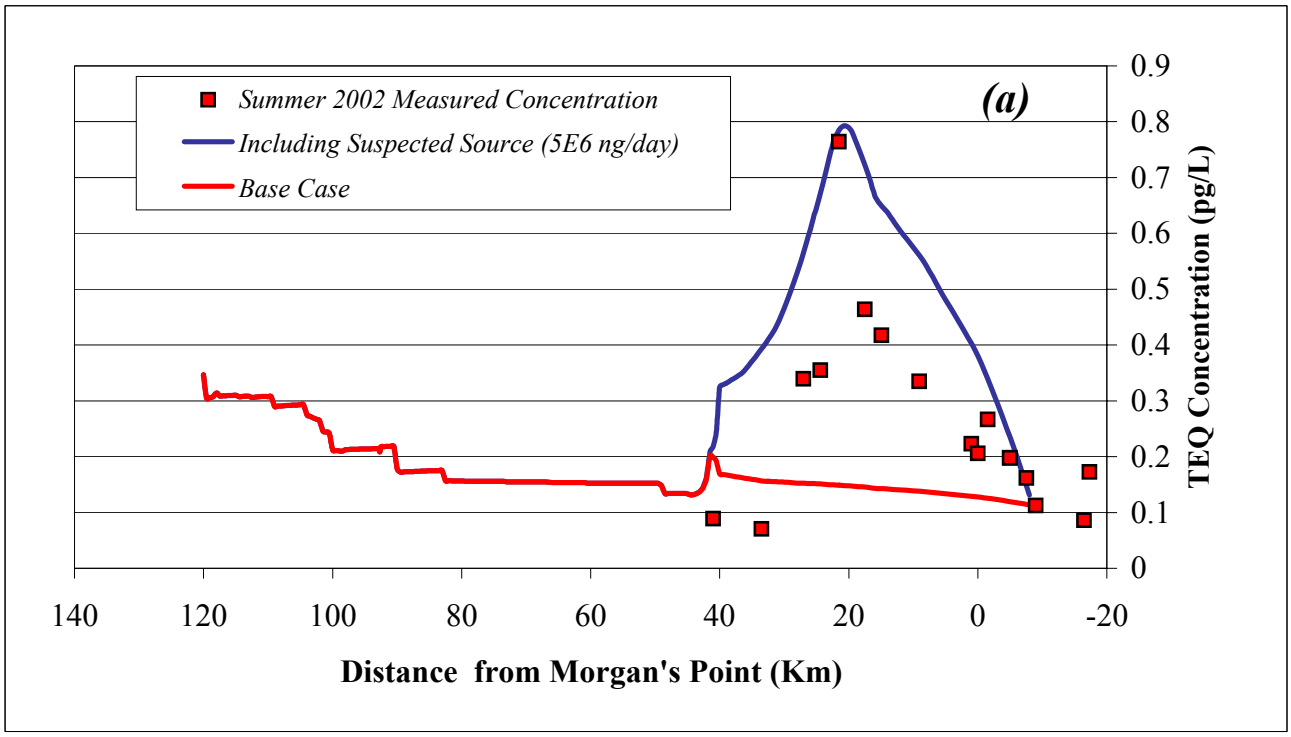


Figure 5.12 Dioxin Sediment Flux

11193 are elevated and could not be matched using data from known sources even when adjusting all model parameters. As a preliminary attempt to calibrate the model, a source of $5x10^6$ ng/day for TEQ and $3.5x10^6$ ng/day for 2378-TCDD (assuming no flow associated with such a source) was input to the model to match the measured concentration at station 15979 in Summer 2002 (Figure 5.13). This would suggest "possible unidentified/ unquantified sources" in the vicinity of this sampling station. Similarly, an additional source would have to be entered in the vicinity of station 11193 to match the peak observed at that location. Possible unquantified sources include road runoff, groundwater leachate, dredged material leachate, and localized contaminated sediments (e.g. old waste pit in san Jacinto River at I-10, currently under investigation). It is also noted that resuspension in general is likely to have been underestimated due to the fact that MEGA-TX has no mechanism for increasing the water column concentration from a bed load pool (due to scour or desorption). This may account for some of the difference between observed and modeled concentrations along the channel.

A preliminary mass balance using MEGA-TX results to date is presented in Table 5.3. It must be noted that the unknown/unquantified source (74% of the total TEQ load and 95% of the total 2378-TCDD load to the system) corresponds to that load that allowed matching the concentrations measured at station 15979 in Summer 2002. Concentrations at station 11193 were not matched using the MEGA-TX model.



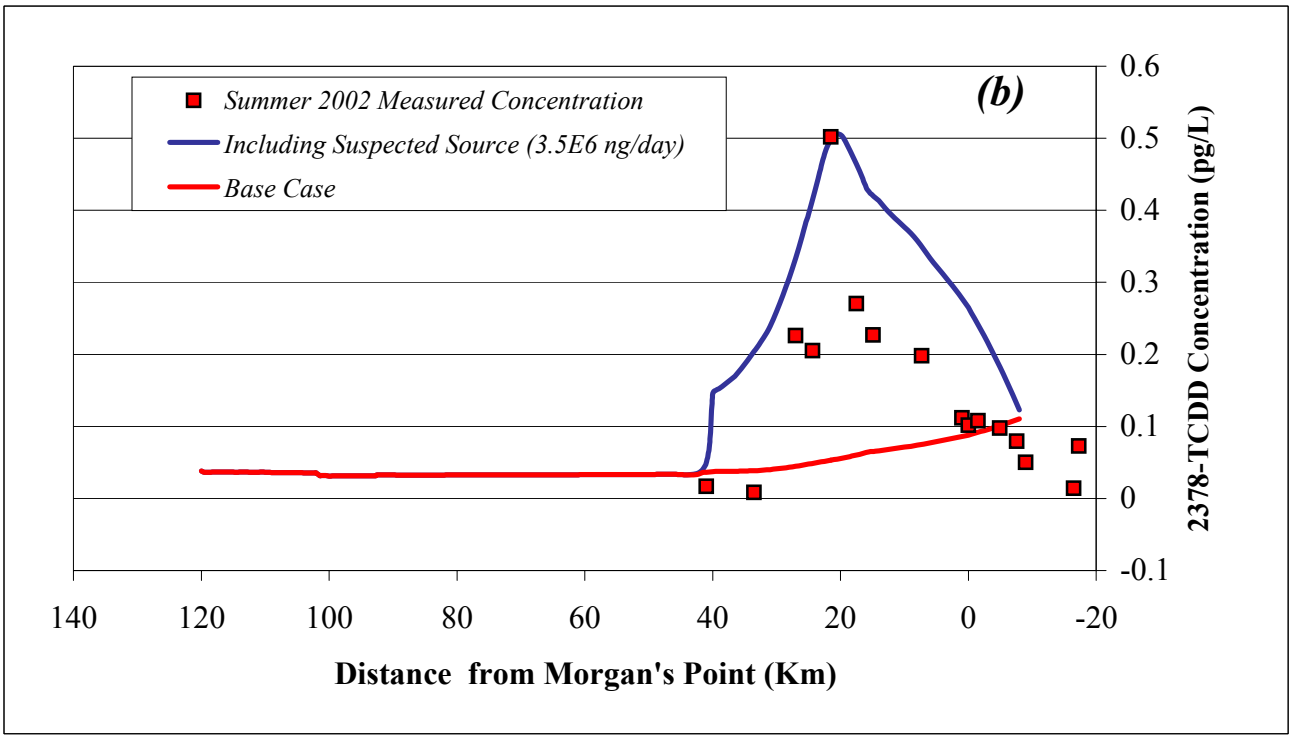


Figure 5.13 MEGA-TX Output Assuming Suspected Source in the Vicinity of Station 15979
(a) TEQ (b) 2378-TCDD

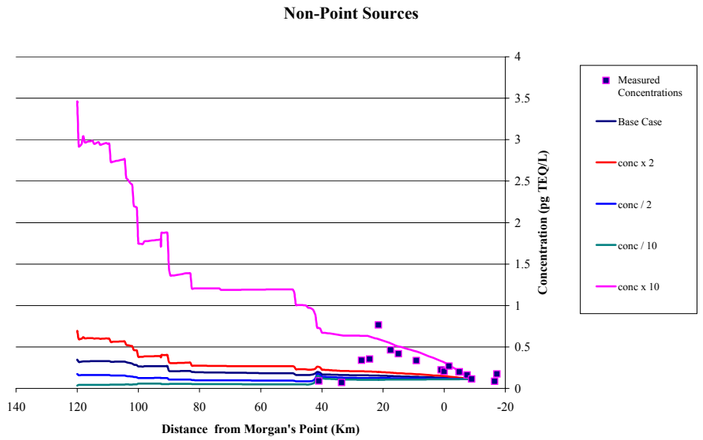
Table 5.3 Summary of Dioxin Loadings to the HSC

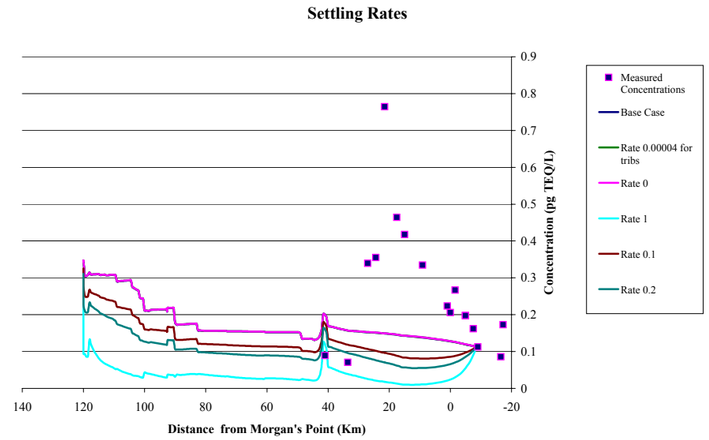
Source	TEQ		2378-TCDD	
	Load (ng/day)	**Contribution to Total Loading**	**Load (ng/day)**	**Contribution to Total Loading**
Permitted Point Sources	$5.98x10^5$	9%	$1.11x10^5$	3%
Stormwater Runoff	$1.17x10^6$	17%	$6.74x10^4$	2%
Unknown/unquantified	$5.00x10^6$	74%	$3.50x10^6$	95%
TOTAL	***$6.77x10^6$***		***$3.68x10^6$***	

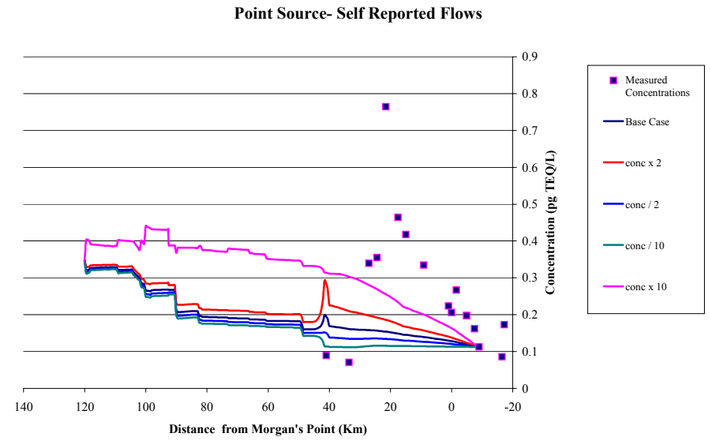
Note: The unknown source does not include the source necessary to match concentrations at station 11193. If that were done, the estimated % of unknown/unquantified load would be higher.

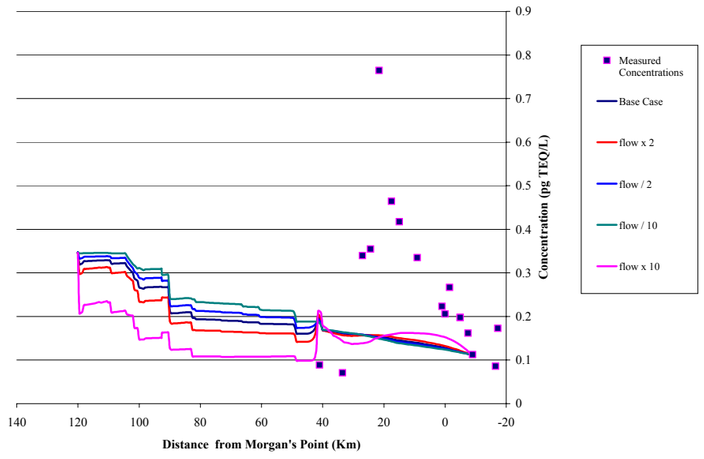
5.1.4 Sensitivity Analysis

Sensitivity analyses were conducted to examine the effect of changing the settling rate, runoff loadings, and permitted point source loadings on the overall concentration profile. For loadings, model parameters (flow and concentration) were varied individually by factors equal to 0.1, 0.5, 2, and 10. For settling rates, uniform rates of 0, 0.05, 0.1, 0.2, 1, and 2 m/day were input (Base case rates in m/day were summarized in Table 5.2). In addition, a model run assuming a settling rate of 0.00004 m/day for tributaries was completed. Results from the sensitivity analysis are presented in Figures 5.14 and 5.15 for the main channel and San Jacinto River, respectively. None of the adjusted parameters produced a concentration profile that matched the measured concentrations as discussed previously.









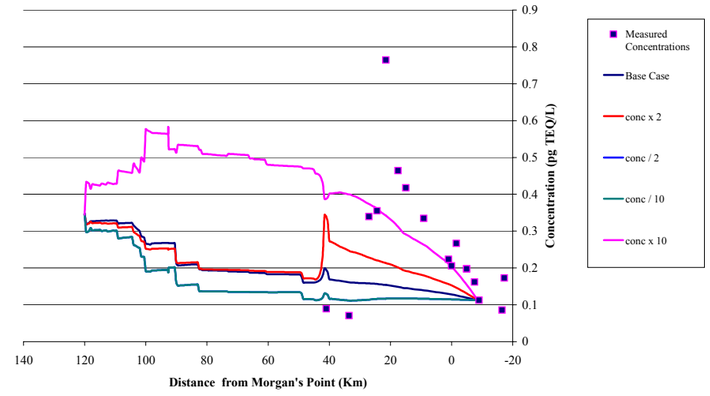
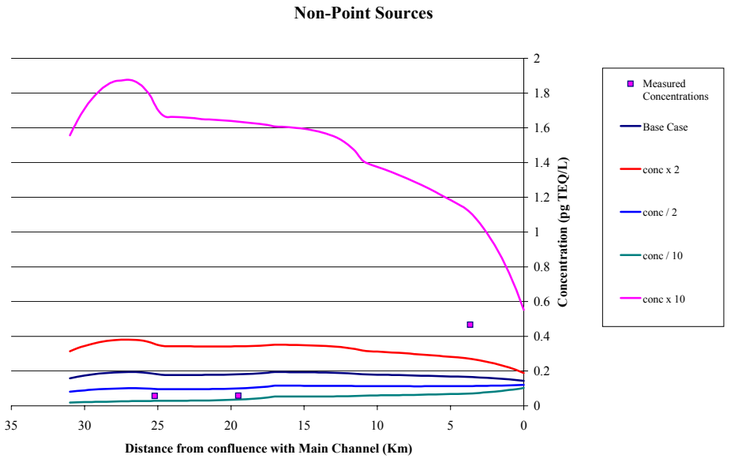
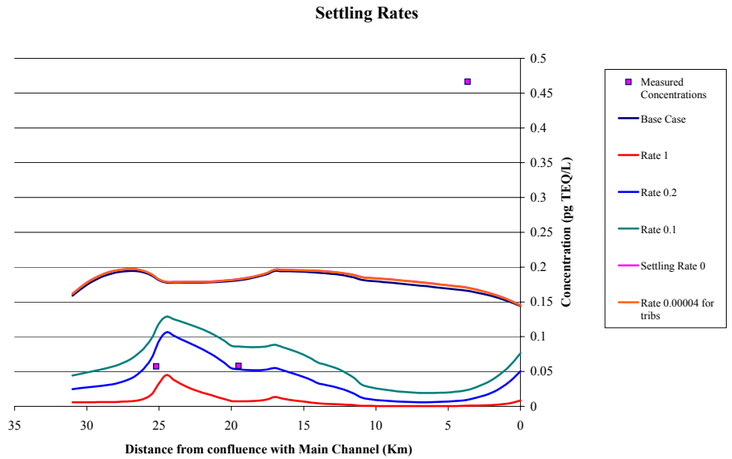
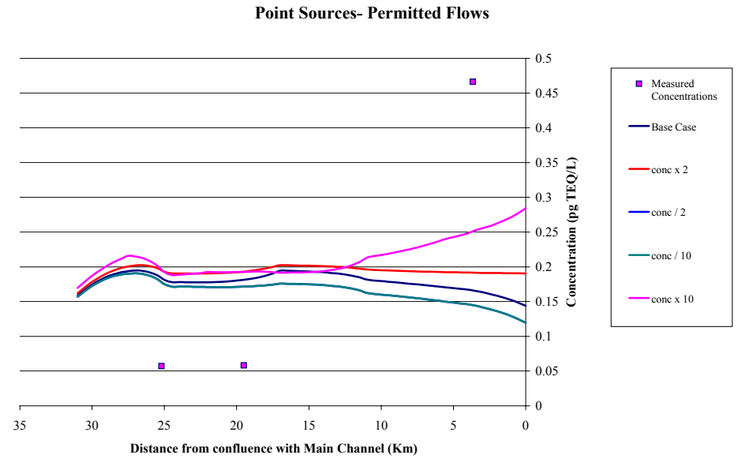
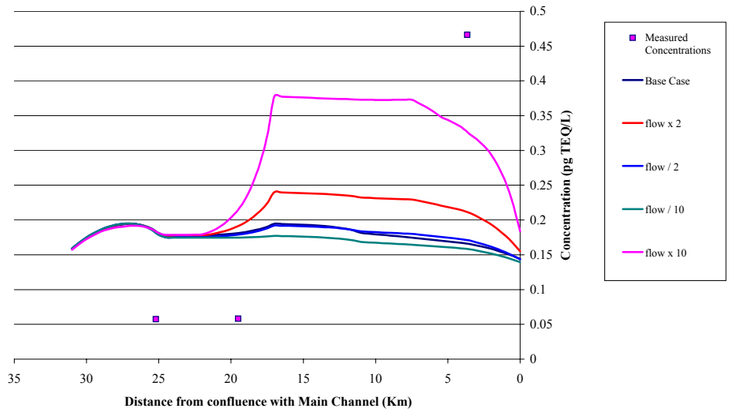


Figure 5.14 Results of Sensitivity Analysis - Main Channel









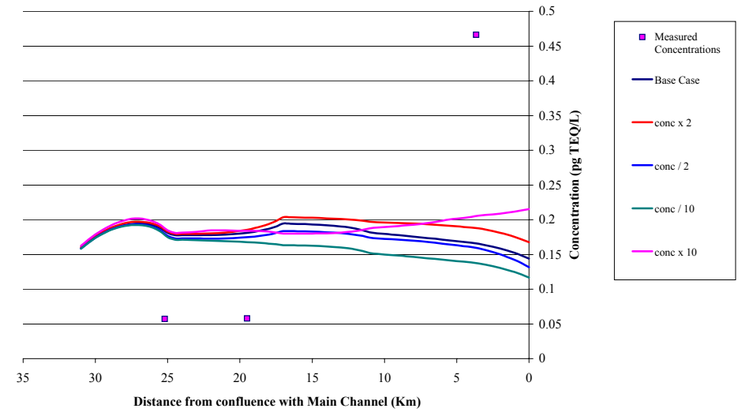


Figure 5.15 Results of Sensitivity Analysis - San Jacinto River

5.2 WASP SIMPLIFIED MODEL

The Water Quality Analysis Simulation Program (WASP) is a dynamic compartment model that can be used to simulate contaminant fate and transport in surface water. For this study WASP version 7.1 (Wool et al, 2004) is being used. The model consists of a main program, WASP7, and three subprograms: EUTRO5, TOXI5, and DYNHYD5. EUTRO5 is used to model BOD/DO eutrophication, TOXI5 is used to simulate toxic chemicals (tracers, organics, metals), and DYNHYD5 is used to simulate hydrodynamics.

WASP can be applied in 1-, 2-, or 3-D and can be linked to simulated hydrodynamics and sediment transport models. The model includes both the surface water column and the underlying benthic sediment layer. WASP simulates the varying processes of advection, dispersion, point and non-point mass loading, deposition/resuspension, and boundary exchange.

To model dioxin in the HSC, the TOXI5 model is used. TOXI5 can simulate up to six systems and 13 levels of complexity as summarized in Table 5.4. For the dioxin model, level 3 solids (simulated TSS), equilibrium level 3 (hydrophobic sorption), and kinetics 1 or 2 are needed. For this level of complexity, the equations used in the constituent mass balance are (for a 1-D system):

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left(-U_x AC + E_x A\frac{\partial C}{\partial x}\right) + A(S_L + S_B + S_K) \qquad (5.5a)$$

where C = concentration of the water quality constituent (mg/L)

t = time (days)

A = cross-sectional area (m^2)

U_x = longitudinal advective velocity (m/s)

Table 5.4 TOXI5 Systems and Levels of Complexity

System number	Name	Levels of Complexity				
		Solids			Kinetics	
		1,2	3	4	1-3	4
1	Chemical 1	x	x	x	x	x
2	Solid 1		x	x		
3	Solid 2			x		
4	Solid 3			x		
5	Chemical 2					x
6	Chemical 3					x

Complexity Level	Explanation
Solids 1	Descriptive solids concentration field
Solids 2	Descriptive solids concentration field with specific solids transport rates
Solids 3	Simulated total solids
Solids 4	Three simulated solids types
Equilibrium 1	Constant partitioning coefficient
Equilibrium 2	Spatially-variable partitioning coefficients
Equilibrium 3	Hydrophobic sorption
Equilibrium 4	Solids-dependent partitioning
Equilibrium 5	Sorption plus ionic speciation
Kinetic 1	Constant half-lives or rate constants
Kinetic 2	Spatially-variable rate constants
Kinetic 3	Second order rates
Kinetic 4	Transformation products

Source: WASP Manual (Ambrose et al., 1993)

E_x = longitudinal dispersion coefficient (m^2/s)

S_L = direct and diffuse loading rate (g/m^3-d)

S_B = boundary loading rate (g/m^3-d)

S_K = total kinetic transformation rate (g/m^3-d)

or

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(UC) + \frac{\partial}{\partial x}\left(E_x \frac{\partial C}{\partial x}\right) - \frac{C_S}{S} W_d + \frac{C_{s,b}}{S_b} W_e + S_B + S_K \qquad (5.5b)$$

where W_d = rate of sediment deposition (g/m^3-s)

W_e = scour rate of sediment (g/m^3-s)

C_s = constituent sorbed concentration in the water column (mg/L)

$C_{s,b}$= constituent sorbed concentration in the bottom sediment (mg/kg)

S = concentration of suspended sediment (mg/L)

S_b = sediment concentration in bottom sediment (mg/kg)

and

$$C_s = K_p S C_w \qquad (5.6a)$$

$$K_p = f_{oc} K_{oc} \qquad (5.6b)$$

where C_w is the concentration of dissolved constituent (mg/L), K_p is the linear partitioning coefficient, f_{oc} is the organic carbon mass fraction of suspended sediment (g/g), and K_{oc} is the organic-carbon partitioning coefficient of the constituent (L/kg).

A list of WASP input requirements for the dioxin model is included in Table 5.5.

Table 5.5 Data Requirements for the Dioxin WASP Model for the HSC

Data Group	Description	Source
A	**Model Identification and Simulation Control**	Basic simulation information including variables to simulate obtained from the statement of the problem
B	**Exchange Coefficients** Dispersion coefficient (water column and pore water) Cross-sectional area Characteristic length	 Calibration to a tracer or values from literature Channel data Channel data
C	**Volumes** Number of segments Type of segment (water column or benthic) Hydraulic geometry to derive depth and velocity as a function of flow	 Conceptual model for the channel Conceptual model Hydrodynamic model, rating curves from existing models for the site, or empirical coefficients for a given cross-section derived from Manning's equation
D	**Flows** - *Surface and Pore Water* Number of transport fields (up to six) Flow routing Flow time function - *Sediment Transport* Area for settling and resuspension Flow routing Velocity (settling or resuspension)	 Conceptual model Channel data Historical data (steady-state or dynamic), hydrodynamic linkage Channel data Channel data Sediment load study for the HSC, initial settling velocities estimated using Stoke's equation. Refine initial estimates with channel-specific calibration
E	**Boundary Concentrations** Concentrations for each system at segments that import, export, or exchange water with locations outside the network	 Channel data

Data Group	Description	Source
F	**Waste Loads**	
	Point source loadings	NPDES permit files, MEGA-TX model for the HSC, Spring 2003 effluent data, and regressions for non-measured outfalls
	Non-point source loadings	Estimated using GIS and spreadsheets models (steady-state) or simulated using runoff models such as HSPF (dynamic)
G	**Parameters**	
	Spatially variable characteristics of the water body that affect the particular processes being modeled.	
	Dissolved organic carbon concentration	Channel data
	Fraction organic carbon of solids	Channel data
	Total lumped first-order decay rate	Literature values
H	**Constants**	
	Organic carbon partitioning coefficient	Measured effective coefficients using data collected in this project (not needed if DOC and f_{oc} are input in Data Group G)
	First-order loss rate constant	Literature values
	Volatilization rate constant	Literature values or coefficients using data collected in this project
	Water column biodegradation rate	Literature values
	Benthic biodegradation rate	Literature values
	Photolysis rate	Literature values
I	**Kinetic Time Functions**	
	Not used in the dioxin model	
J	**Initial Conditions**	
	Concentration of each modeled system (dioxin and TSS) for each segment	Channel data

5.2.1 Conceptual Model

Two WASP implementations to simulate 2378-TCDD in the HSC are in progress. A simplified WASP model was setup using the 28 surface segments into which the entire channel

had been divided in a modeling study completed in 1971 (Espey et al., 1971). This segmentation had been used to setup a WASP5 model to simulate dissolved oxygen in the HSC (Benaman et al., 1996). The segmentation allowed the assumption of homogeneous hydrography. It is noted that since the geometry of the HSC has changed considerably between 1971 and present date, no attempt to calibrate the simplified model was undertaken. Similarly, the model was not used as a predictive model. The main goal of this simplified model was to determine data needs and to determine model sensitivity to the various input parameters. A more detailed, transient WASP model, still under development as discussed in Section 5.3, divides the HSC in more segments (55) with their corresponding underlying benthic segments.

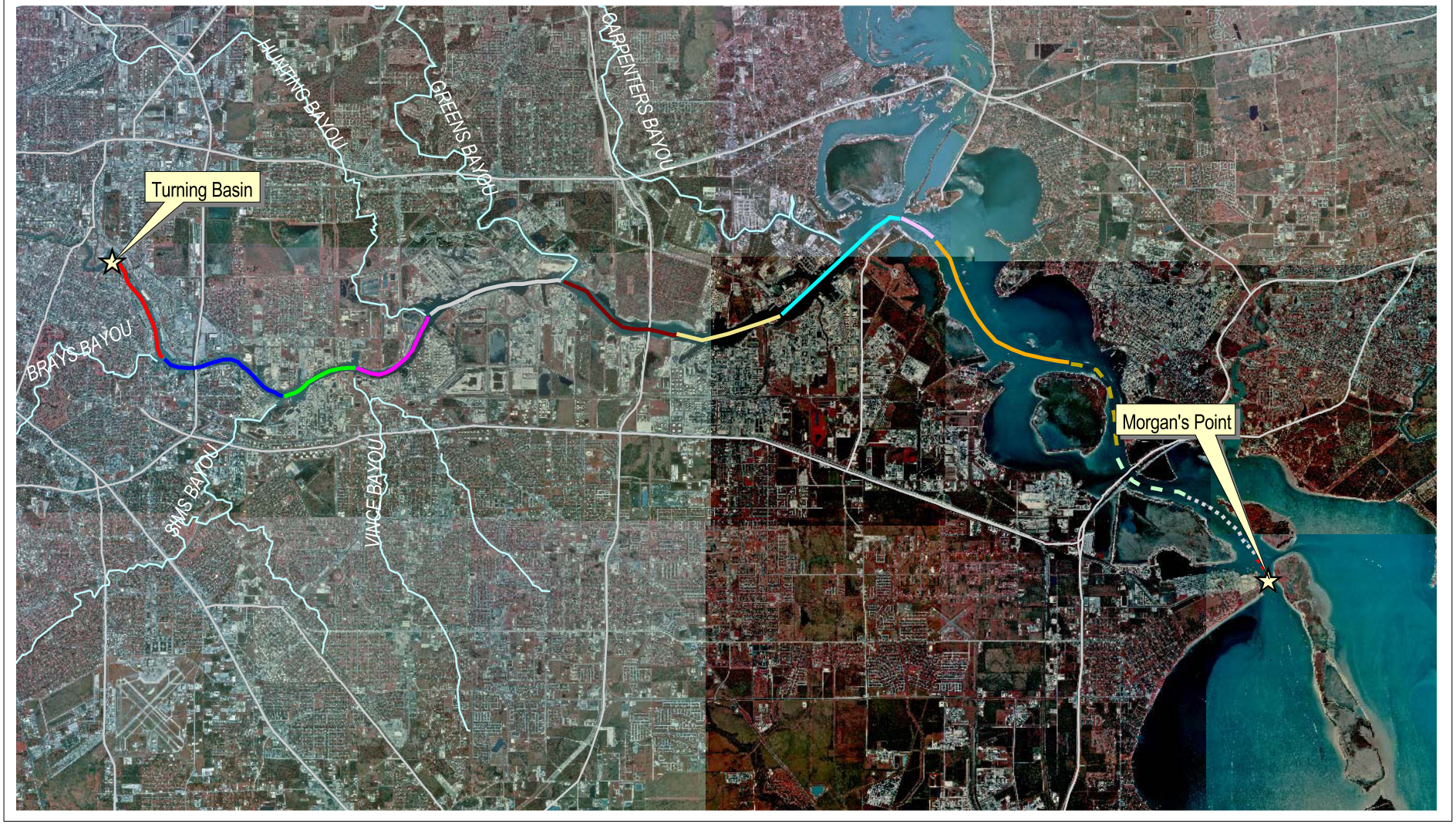
5.2.2 Channel Segmentation

In the simplified WASP model, the HSC (from the Turning Basin to Morgan's Point) was divided into 28 hydrographic segments. Fourteen segments correspond to the main channel (as shown in Figure 5.16) and the remaining fourteen are comprised by tributaries, side bays, Barbours Cut, and Galveston Bay. Figure 5.17 shows a detailed schematic of the original HSC model developed by Espey et al., 1971. As can be seen in Figures 5.16 and 5.17, segments were defined between major tributaries to allow the input of fresh water inflows.

5.2.3 Input Parameters

5.2.3.1 Hydraulic Model Input

The hydraulic and physical characteristics for each reach in the HSC model were obtained from the Tracor model developed for dissolved oxygen in the HSC (Espey et al., 1971). Table 5.6 summarizes the physical characteristics of the segments in the main channel. As can be seen in



N
W E
S

3 0 3 6 Kilometers

LEGEND

Model Segments
1
2
3
4
5
6
7
8
18
19
20
21
22
23

NOTE: tributaries, side bays, Barbours Cut, and Galveston Bay comprise 14 additional model segments.

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Figure 5.16
Segmentation for the Simplified Model

Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/ Paul Jensen (PBS&J)

TMDL for Dioxin in the Houston Ship Channel

Prepared by: MPS | Date: 10-04-2004

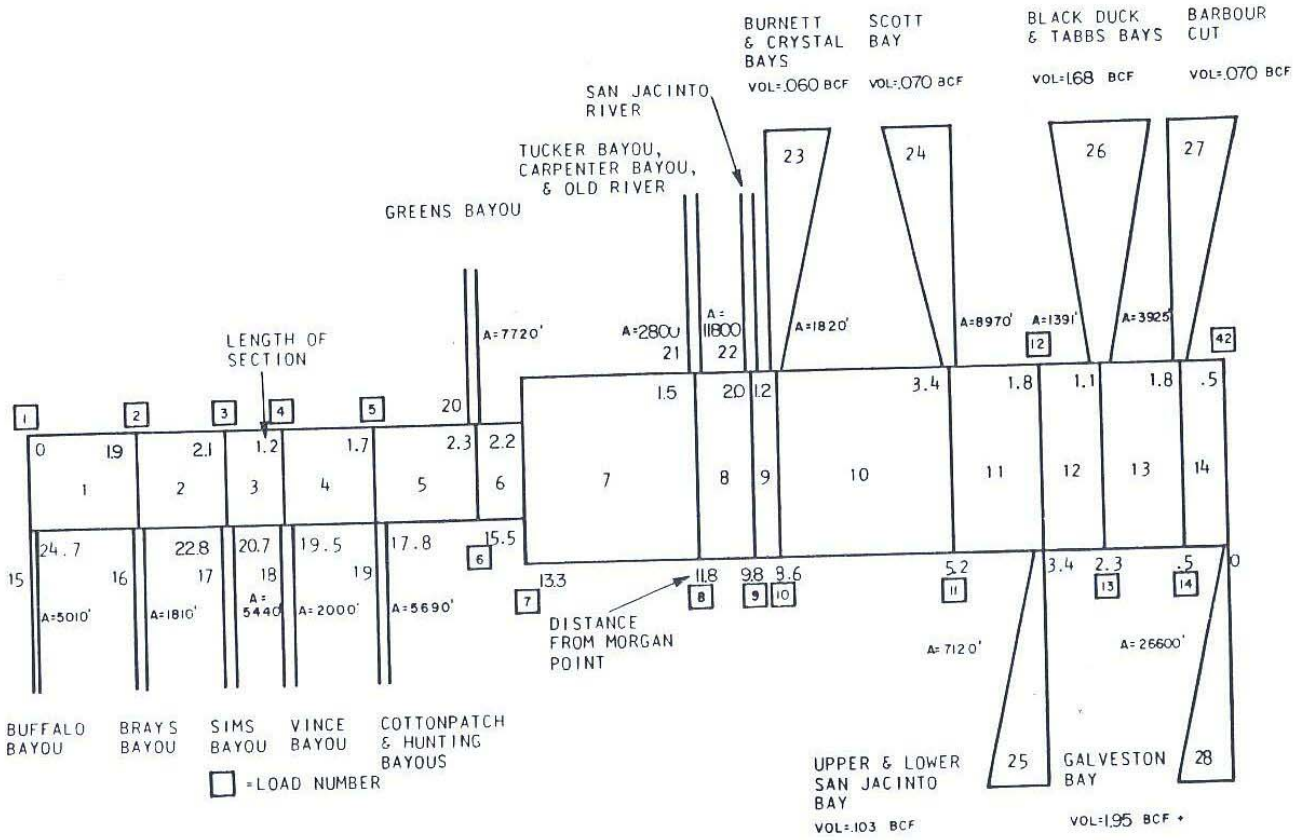


Figure 5.17 Schematic of Segmentation used in the Tracor Modeling Effort (Espey et al., 1971)

Table 5.6, the cross-sectional area in the Ship Channel was represented by Espey et al. (1971) as a series of two constant area sections. The upstream sections (Turning Basin to Shell Barge) have an average area of 1625.8 m^2, while the downstream sections (Shell Barge to Morgan's Point) have an average area of 2471.2 m^2. Table 5.3 also includes mean depth values measured in the Tracor Inc. modeling study.

The hydraulic coefficients that relate velocity and depth to flow as described in Equations (5.7) and (5.8) below were assumed to be those for rectangular channels [i.e., a=0.004, b=0.4, c=1.2, and d=0.6 (Ambrose et al., 1993)]. It is noted, however, that these coefficients are only important when calculating reaeration or volatilization and not for transport functions.

$$V = aQ^b \tag{5.7}$$

$$D = cQ^d \tag{5.8}$$

where V is the channel velocity (m/s), Q is channel flow (m^3/s), D is channel depth (m).

Dispersion coefficients were also obtained from the Tracor Inc. study. The study found that the magnitude of the dispersion coefficient varied with the magnitude of the net advective flow in the channel. The selected dispersion coefficients are presented in Table 5.6.

Segments that exchange water with locations outside the main network (tributaries, the lower downstream segment--Galveston Bay, and side bays) are represented in the model using boundaries segments. These boundary segments are included to account for inflows, outflows, and dispersive mixing. Table 5.7 includes the main characteristics for the boundary conditions.

The bottom sediment layer was simulated as a single benthic segment with a total length equal to the sum of lengths of the segments in the main channel. A depth of 10 cm was assumed for this benthic segment as shown in Table 5.7.

Table 5.6 Physical Characteristics of Main Channel Simplified Model Segments

Segment No.	Description	Type of segment	Length (m)	Area (m^2)	Depth (m)	Exchange coefficient (m^2/s)	Volume (m^3)	Surface area (m^2)	Flow (m^3/s)	Hydraulic Coefficients			
										a	b	c	d
1	Turning Basin to Brays Bayou	Surface	3040	1625.8	9.14	800.0	4.942E+06	5.405E+05	15.83	0.004	0.4	1.2	0.6
2	Brays Bayou to Sims Bayou	Surface	3360	1625.8	9.14	800.0	5.463E+06	5.974E+05	21.92	0.004	0.4	1.2	0.6
3	Sims Bayou to Vince Bayou	Surface	1920	1625.8	9.14	800.0	3.122E+06	3.414E+05	21.75	0.004	0.4	1.2	0.6
4	Vince Bayou to Hunting Bayou	Surface	2720	1625.8	6.10	800.0	4.422E+06	7.254E+05	24.13	0.004	0.4	1.2	0.6
5	Hunting Bayou to Greens Bayou	Surface	3680	1625.8	9.14	800.0	5.983E+06	6.543E+05	25.12	0.004	0.4	1.2	0.6
6	Greens Bayou to Shell Barge	Surface	3520	1625.8	6.10	800.0	5.723E+06	9.388E+05	28.49	0.004	0.4	1.2	0.6
7	Shell Barge To Carpenters Bayou	Surface	2400	2471.2	7.92	800.0	5.931E+06	7.484E+05	28.49	0.004	0.4	1.2	0.6
8	Carpenters Bay to San Jac River	Surface	3200	2471.2	7.92	800.0	7.908E+06	9.979E+05	29.48	0.004	0.4	1.2	0.6
18	Sn Jac River to Burnett Bay	Surface	1920	2471.2	7.01	1185.2	4.745E+06	6.768E+05	69.86	0.004	0.4	1.2	0.6
19	Burnett Bay to Scott Bay	Surface	5440	2471.2	6.10	1185.2	1.344E+07	2.205E+06	69.86	0.004	0.4	1.2	0.6
20	Scott Bay to San Jac Bay	Surface	2880	2471.2	4.88	1185.2	7.117E+06	1.459E+06	69.86	0.004	0.4	1.2	0.6
21	San Jac Bay to Tabbs Bay	Surface	1760	2471.2	4.88	1185.2	4.349E+06	8.918E+05	69.86	0.004	0.4	1.2	0.6
22	Tabbs Bay to Barbours Cut	Surface	2880	2471.2	4.88	1185.2	7.117E+06	1.459E+06	69.86	0.004	0.4	1.2	0.6
23	Barbours Cut toMorgan's Point	Surface	800	2471.2	4.88	1185.2	1.977E+06	4.054E+05	69.86	0.004	0.4	1.2	0.6

Source: Espey, et al., 1971

Table 5.7 Physical Characteristics of Boundary Segments for the Simplified Model

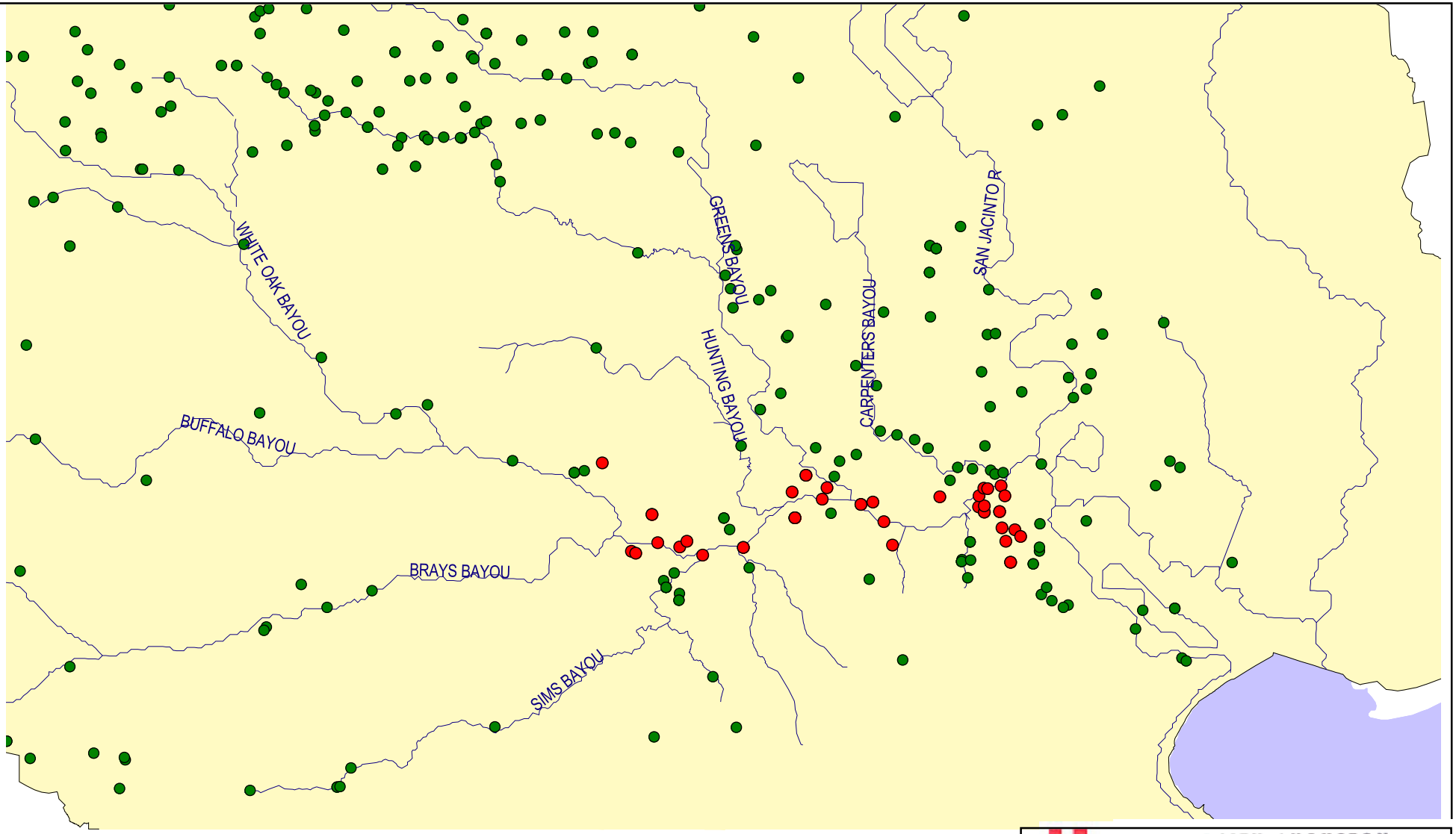
Segment No.	Description	Type of segment	Length (m)	Area (m^2)	Depth (m)	Exchange coefficient (m^2/sec)	Volume (m^3)	Surface area (m^2)	Flow (m^3/s)	Hydraulic Coefficients			
										a	b	c	d
9	Bottom sediment for the entire main channel	Benthic	39520	0.1	0.10	0.010	3.952E+03	1.264E+07		-	-	-	-
10	Buffalo Bayou	Surface	8000	465.4	9.14	118.5	3.724E+06	4.072E+05	15.83	0.004	0.4	1.2	0.6
12	Brays Bayou	Surface	3200	168.2	3.05	118.5	5.381E+05	1.765E+05	4.67	0.004	0.4	1.2	0.6
11	Sims Bayou	Surface	3200	505.4	4.88	118.5	1.617E+06	3.316E+05	1.25	0.004	0.4	1.2	0.6
13	Vince Bayou	Surface	3200	185.8	1.83	118.5	5.946E+05	3.251E+05	2.38	0.004	0.4	1.2	0.6
14	Hunting Bayou	Surface	3200	528.6	3.35	118.5	1.692E+06	5.045E+05	0.99	0.004	0.4	1.2	0.6
15	Greens/Halls Bayous	Surface	3200	717.2	10.06	118.5	2.295E+06	2.282E+05	3.37	0.004	0.4	1.2	0.6
16	Carpenters Bayou	Surface	3200	260.1	3.96	118.5	8.324E+05	2.101E+05	0.99	0.004	0.4	1.2	0.6
17	San Jacinto River	Surface	3200	1096.3	4.88	118.5	3.508E+06	7.193E+05	40.38	0.004	0.4	1.2	0.6
24	Burnett Bay	Surface	1600	169.1	0.61	118.5	2.705E+05	4.438E+05	0.03	0.004	0.4	1.2	0.6
25	Scott Bay	Surface	1600	833.3	0.91	118.5	1.333E+06	1.458E+06	0.03	0.004	0.4	1.2	0.6
26	San Jacinto Bay	Surface	1600	661.5	1.22	118.5	1.058E+06	8.681E+05	0.03	0.004	0.4	1.2	0.6
27	Tabbs Bay	Surface	1600	129.1	0.61	118.5	2.066E+05	3.389E+05	0.03	0.004	0.4	1.2	0.6
38	Barbours Cut	Surface	1600	364.6	6.10	118.5	5.834E+05	9.571E+04	0.03	0.004	0.4	1.2	0.6
39	Galveston Bay - downstream boundary	Surface	1600	2471.2	1.22	118.5	3.954E+06	3.243E+06	69.86	0.004	0.4	1.2	0.6

Source: Espey, et al., 1971

5.2.3.2 Point Sources

Input from point sources is simulated in WASP7 by a series of loading versus time values. It is important to note that mass entered as loads is not directly accompanied with inflow. This simplification is acceptable as long as the inflow associated with a loading is small compared with the water body flow. For the simplified model, point sources discharging directly to the main channel were aggregated by segment to determine total loads and flow. New segments were created in the advection section to account for the inflows and the respective loads were input in the loading section. For this model, only the outfalls discharging directly into the main channel segments were considered. This was to avoid duplication given that flows and concentrations for the boundary segments already include point sources discharging directly into the tributaries.

Figure 5.18 shows the distribution of point sources discharging to the main channel and Figure 5.19 shows the schematic of the "point source" segments. The WASP7 input contains permitted flow values, as included in the TCEQ permittee database (as of May 2003). Dioxin data from point sources (PS) gathered in this project during Spring 2003 were used to calculate load input. For the point sources that were not sampled for effluent and the SIC was among those identified as potential dioxin dischargers, the 2378-TCDD concentration in effluent was assumed equal to the average concentration for effluent from facilities with the same SIC code. If the SIC was not among the potential dioxin dischargers, the 2378-TCDD concentration was assumed equal to zero. The TSS loads from point sources were calculated using the average of the TSS self-reported data. A summary of the point source data for the model is included in Table 5.8. The total load of dioxins from PS discharging directly to the HSC system (not to the tributaries) calculated in this manner was estimated to be 2.90×10^{-8} kg/d.



N
W E
S

4 0 4 8 Kilometers

LEGEND

Point sources
- Discharge to main tributaries
- Discharge to main channel

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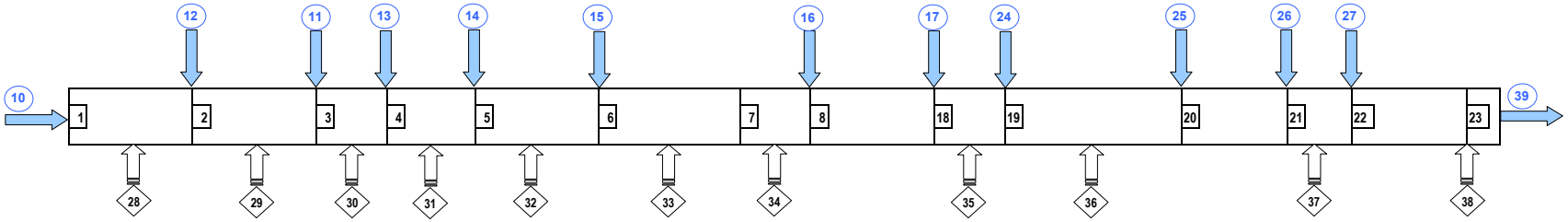
Figure 5.18
Point Sources in the Model Area

Principal Investigators: Hanadi Rifai (University of Houston)
Randy Palachek (Parsons)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 11-05-2004



LEGEND

- 1 — Main Channel Segment (Segment #)
- 10 — Boundary Segment (Segment #)
- 28 — Loading Segment (Segment #)

KEY

Segment No.	Description	Segment No.	Description
1-8;18-23	Main Channel	28	WWTPs to 1
10	Buffalo Bayou	29	WWTPs to 2
11	Sims Bayou	30	WWTPs to 3
12	Brays Bayou	31	WWTPs to 4
13	Vince Bayou	32	WWTPs to 5
14	Hunting Bayou	33	WWTPs to 6
15	Greens/Halls Bayous	34	WWTPs to 7
16	Carpenters Bayou	35	WWTPs to 18
17	SanJacinto River	36	WWTPs to 19
24	Burnett Bay	37	WWTPs to 21
25	Scott Bay	38	Barbours Cut
26	San Jacinto Bay	39	Downstream boundary-Galveston Bay
27	Tabbs Bay		

Figure 5.19 Schematic of Loading Segmentation

Table 5.8 Point Sources for Simplified Model

Segment	Total Flow (m^3/s)	2378-TCDD Load (kg/day)	TSS Load (kg/day)
1	3.94E-04	5.676E-13	8.87E-03
2	2.486	2.034E-09	1792
3	0.440	2.895E-09	310
4	1.424	5.072E-11	984
5	1.625	1.610E-09	1593
6	0.901	1.741E-09	623
7	1.114	1.326E-08	768
18	0.502	2.728E-09	347
19	0.112	1.416E-09	77
21	1.697	3.299E-09	1173

5.2.3.3 Non-point Sources

Non-point source pollutant loads on a daily basis for the HSC major watersheds were calculated using land cover information, the measured 2378-TCDD concentrations in runoff gathered in this project, and the amounts of rainfall in the year 2002.

Subwatershed Delineation

The watershed delineation completed recently by the HCFCD was used to determine drainage areas. Figure 5.20 shows the watersheds that correspond to the segments in the model.

Rainfall Data and Runoff Volume

See explanation presented in section 5.1.2.3 above.

Non-point Source Loads

The 2378-TCDD concentrations in runoff measured in this project were averaged and the mean value was used to calculate NPS loads of dioxins to the main subwatersheds. For each reach, the average runoff 2378-TCDD concentration (0.025 pg/L) was multiplied by the runoff volume to calculate the NPS load. For TSS, concentrations measured during runoff sampling were used to calculate solid loads. For the watershed with no sampling locations, the average of all the TSS measurements during runoff sampling was assumed (86 mg/L). Table 5.9 summarizes the loads from NPS. The total 2378-TCDD load from NPS to the HSC system is estimated to be 9.29×10^{-8} kg/d. This estimate is based on the results from the 10 runoff samples collected in 2002/2003. It is noted that direct dry-deposition to the HSC streams was not included in the NPS load calculation for the simplified model but will be incorporated in the detailed WASP model.

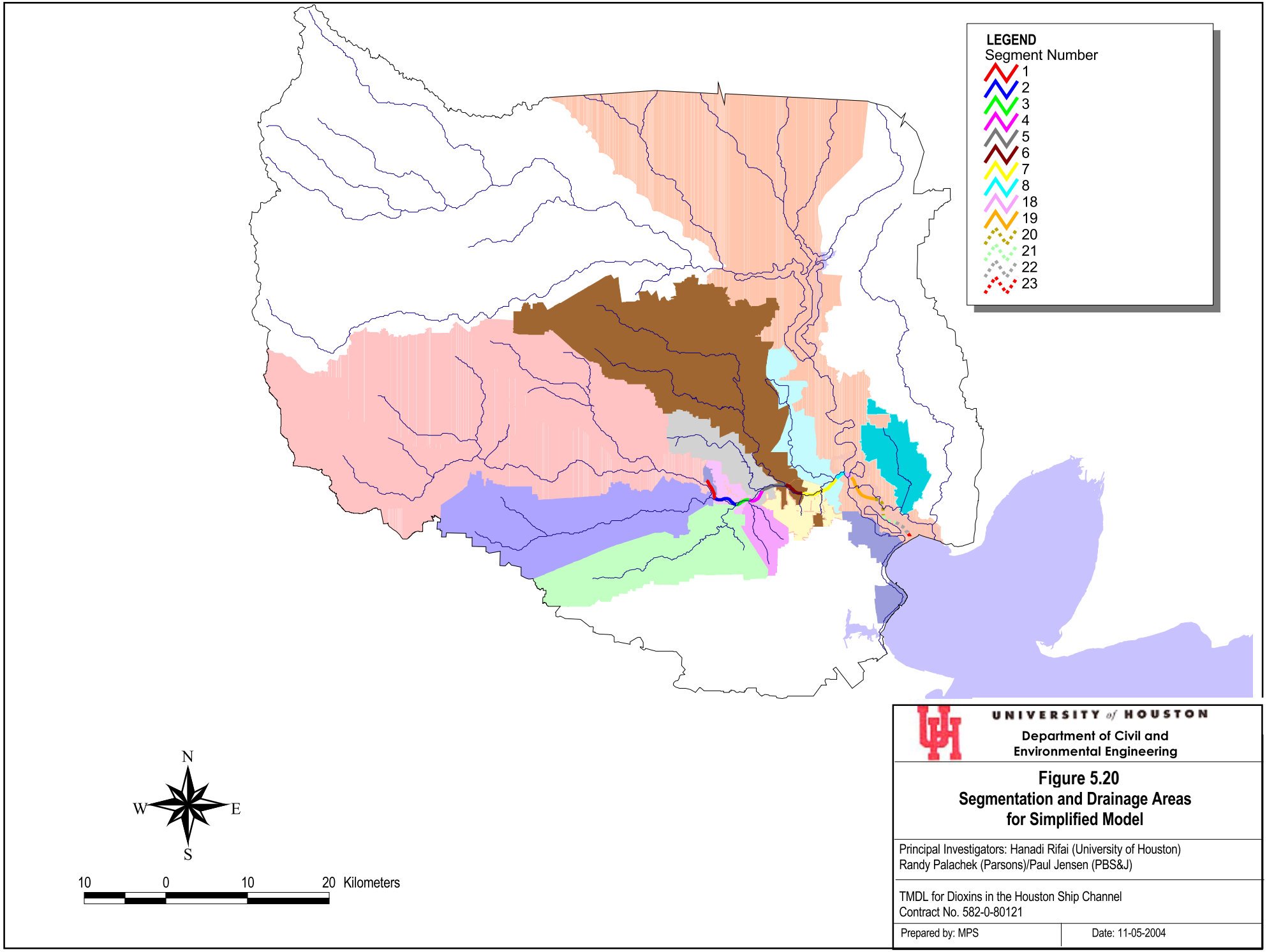


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Figure 5.20
Segmentation and Drainage Areas for Simplified Model

Principal Investigators: Hanadi Rifai (University of Houston)
Randy Palachek (Parsons)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 11-05-2004

Table 5.9 Non-point Sources for Simplified Model

Segment	Drainage Area (km^2)	Average daily rainfall (in)	TSS Concentration (mg/L)	2378-TCDD Load (kg/day)	TSS Load (kg/day)
1	1244	0.126	37.6	3.104E-08	46728
2	339	0.129	66.8	1.155E-08	30852
3	242	0.144	34.2	7.329E-09	10026
4	62	0.125	47.5	2.043E-09	3878
5	91	0.164	47.5	2.746E-09	5213
6	585	0.140	97.0	1.440E-08	55860
7	14	0.137	86.0	3.611E-10	1242
8	98	0.172	86.0	2.214E-09	7618
18	1125	0.177	86.0	1.795E-08	61735
22	85	0.175	48.3	2.147E-09	4151
23	50	0.137	86.0	1.157E-09	3980

5.2.3.4 Initial Concentrations and Boundary Concentrations

Concentrations of 2378-TCDD in water and TSS measured in Summer 2002 were used as initial concentrations. For the benthic segment (i.e., segment 9), the average 2378-TCDD concentration in sediment for the Summer 2002 data was assumed. Table 5.10 summarizes the initial and boundary concentrations.

In addition to chemical concentrations, the dissolved fractions must be specified for each segment at the beginning of the simulation. For dioxin, the dissolved fractions was set to 0.25. This fraction is internally recalculated by the model at each time step using partition coefficients and sediment concentrations.

5.2.3.5 Solid Transport Parameters

Sediment transport is a very important process in modeling dioxins because dioxins sorb strongly to sediment and thus undergo settling, scour, and sedimentation. In addition, sorption affects the transformation rates. The suspended sediment was simulated as a single solid class. The major processes affecting sediment distribution are advection and dispersion between the water column segments, and settling to and scour from the benthic segment.

Water Column Transport

Sediment and particulate dioxin in the water column may settle and deposit to the surficial benthic layer. Settling and scour rates in WASP7 are described by velocities and surface areas. Particulate transport velocities are multiplied by cross-sectional areas to obtain flow rates for solids and the particulate fractions of dioxins.

Table 5.10 Boundary and Initial Concentrations

Segment No.	Description	Boundary Concentration		Initial Concentration	
		2378-TCDD (mg/L)	TSS (mg/L)	2378-TCDD (mg/L)	TSS (mg/L)
1	Turning Basin to Brays Bayou			1.35E-11	22
3	Sims Bayou to Vince Bayou			8.5E-12	22
5	Hunting Bayou to Greens Bayou			2.259E-10	22
7	Patrick? To Carpenters Bayou			5.019E-10	22
8	Carpenters Bay to San Jac River			2.703E-10	22
18	Sn Jac River to Burnett Bay			2.269E-10	22
23	Barbours Cut toMorgan's Point			5.8E-11	22
9	Bottom sediment for the entire main channel			25[a]	$1x10^{6}$ [b]
10	Buffalo Bayou	3.99E-12	28		
12	Brays Bayou	3.66E-11	30		
11	Sims Bayou	1.70E-11	17		
13	Vince Bayou	8.33E-12	15		
14	Hunting Bayou	2.98E-11	16		
15	Greens/Halls Bayous	2.48E-10	23		
16	Carpenters Bayou	4.21E-10	87		
17	San Jacinto River	1.70E-10	19		
24	Burnett Bay	3.44E-10	22		
25	Scott Bay	2.1E-10	22		
26	San Jacinto Bay	2.65E-10	22		
27	Tabbs Bay	1.97E-10	22		
39	Galveston Bay - downstream boundary	5.8E-11	15		

[a] Concentration in ng/kg

[b] Solid content

Settling velocities should be set within the Stoke's range of velocities corresponding to the size distribution of suspended particles (Ambrose et al., 1993):

$$V_S = \frac{8.64g}{18\mu}(\rho_p - \rho_w)\cdot d_p{}^2 \qquad (5.9)$$

where V_s = Stokes velocity for particle with diameter d_p and density ρ_p (m/d)

g = acceleration of gravity = 981 cm/s^2

μ= absolute viscosity of water = 0.01(g/cm^3-s) at 20 ^{o}C

ρ_p = density of the solid (g/cm^3)

ρ_w = density of water =1.0 g/cm^3

d_p = particle diameter (mm)

Benthic exchange of sediment and particulate chemicals is driven by the net scour and deposition velocities. WASP calculates benthic exchange as:

$$W_{BS}=A_{ij}(w_R S_i - w_D S_j) \qquad (5.10)$$

where: W_{BS}= net sediment flux rate (g/d)

S = sediment concentration (g/m^3)

w_D= deposition velocity (m/d). The deposition velocity can be calculated as the product of the Stoke's settling velocity and the probability of deposition: $w_D = V_s\alpha_D$ (α_D is probability of deposition upon contact with the bed).

w_R= scour velocity (m/d)

A_{ij}= benthic surface area (m^2)

i = benthic segment

j = water segment

Grain size analyses of suspended particles have not been completed in this project, so it was assumed that the majority of the particles correspond to the size range for silt (0.0039-0.0625 mm). Thus, settling velocities should be within the range 0.716 and 183.9 m/day ($8.29x10^{-6}$ to 0.002 m/s). Initial settling velocities were assumed equal to 0.001 m/s for the main channel segments and 0.002 m/s for the side bays. Settling within the side bays was assumed higher as they are less affected by disturbances created from ship traffic.

There are no sediment studies in the HSC that allow determination of scour rates. These rates were assumed to be 2 orders of magnitude lower than the settling rates (i.e. $1x10^{-5}$ m/s). It is noted that there are no special process descriptions for solids transport in WASP7. Scour rates, for example, are not programmed as a function of water column shear stress. Consequently, the TOXI5 sediment model is considered descriptive and must be calibrated to site data (Ambrose et al., 1993)

Sediment Bed

The selected sediment bed option was constant bed volume, which allows sediment concentration to change. It is a simplified assumption. However, the detailed model will be refined using a variable bed volume option to allow for checking of balance of fluxes and also to model contaminant burial (provided that data are available on rates and mechanisms). The variable bed volume allows 2 benthic layers (upper uncompacted and lower more compacted layer).

Water Column-Sediment Bed Exchange

A dispersion coefficient of 0.01 m^2/s was assumed for the surface-benthic segment exchange (Table 5.7).

5.2.3.6 Parameters and Constants

In this model, the fraction organic carbon (f_{oc}) of the suspended sediments was the only parameter input to the model. Results of particulate organic carbon analyses for water samples were not available at the time of the simplified WASP model development (samples for POC analysis were collected in the Fall 2004 sampling event), thus, a value of 25% was assumed for all the surface segments. The f_{oc} for the benthic layer was assumed equal to the average of the fractions measured in sediments collected in Summer 2002 (2.5%).

For this model, two constants were input. The first one corresponds to the logarithm of the organic-carbon partitioning coefficient (K_{oc}), which was estimated to be 7.11 (University of Houston, 2004). For the simplified model, transformation processes (biodegradation, photolysis, and volatilization) were modeled as a lumped first-order decay rate. The second constant corresponds to the lumped decay rate, which was assumed to vary between $1x10^{-6}$ and $1x10^{-4}$ d^{-1}.

5.2.4 Model Runs

The base case for the simplified model was implemented with the following input parameters:

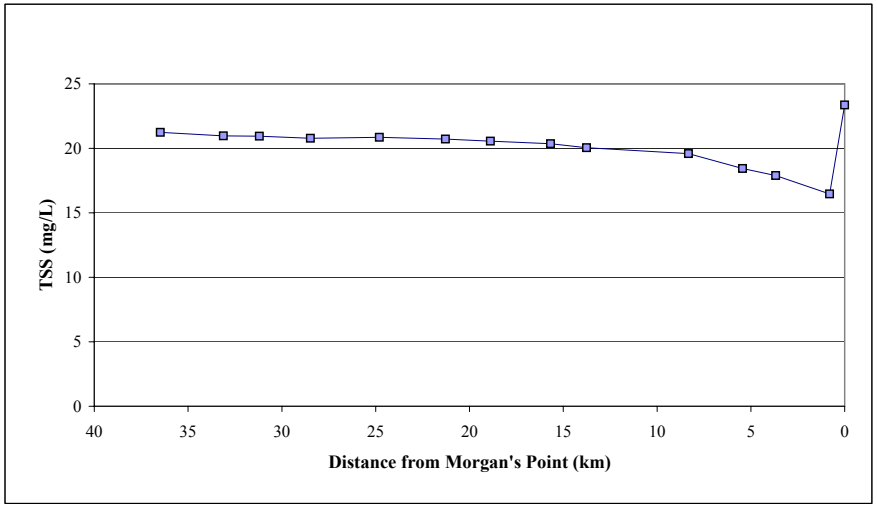
- Segment characteristics presented in section 5.2.3.1
- Point source flows and loads as summarized in section 5.2.3.2
- No non-point source loads
- Initial and boundary concentrations as described in section 5.2.3.4
- Settling and scour velocities as presented in section 5.2.3.5
- Linear hydrophobic sorption (log K_{oc}) and no decay processes.

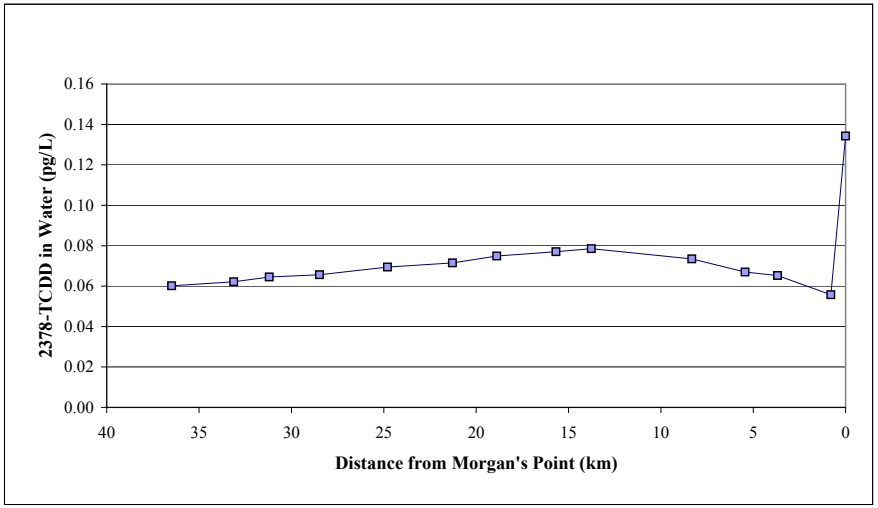
Figure 5.21 shows longitudinal profiles for TSS and 2378-TCDD modeled in the base case. As can be seen, TSS concentrations were relatively uniform along the main channel with values between 16 and 23 mg/L, and. 2378-TCDD concentrations in water varied between 0.06 and 0.13 pg/L. The input dataset for the base case run is included in Appendix H.

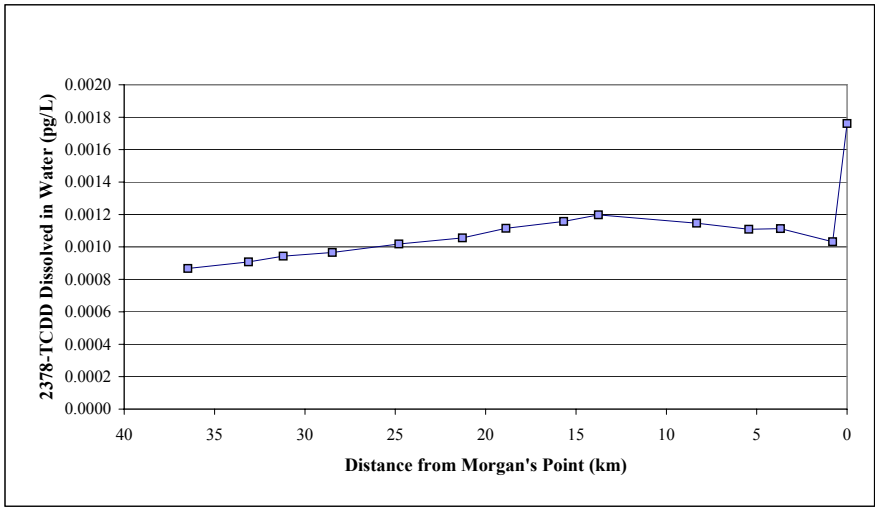
It is noted again that no calibration was attempted for the simplified model. Instead, the focus was on determining which variables had most impact on model results. Thus, scenarios were run assuming different conditions to determine the change in the output concentrations. The scenarios were divided into 8 main groups as summarized in Table 5.11.

Results from the model runs are presented in Figures 5.22a, b, c, and d for TSS, total 2378-TCDD in water, dissolved 2378-TCDD in water, and suspended 2378-TCDD in water, respectively.

Results indicate that TSS concentrations are most sensitive to settling/resuspension (benthic exchange) and dispersion processes as well as point and non-point source loadings (Figure 5.22a). Concentrations of 2378-TCDD in water showed sensitivity to most of the parameters (Figure 5.22b), with the greatest variation in model results corresponding to changes in the dispersion and benthic exchange coefficients. Total 2378-TCDD concentrations in water did not show sensitivity to either pore processes or decay.







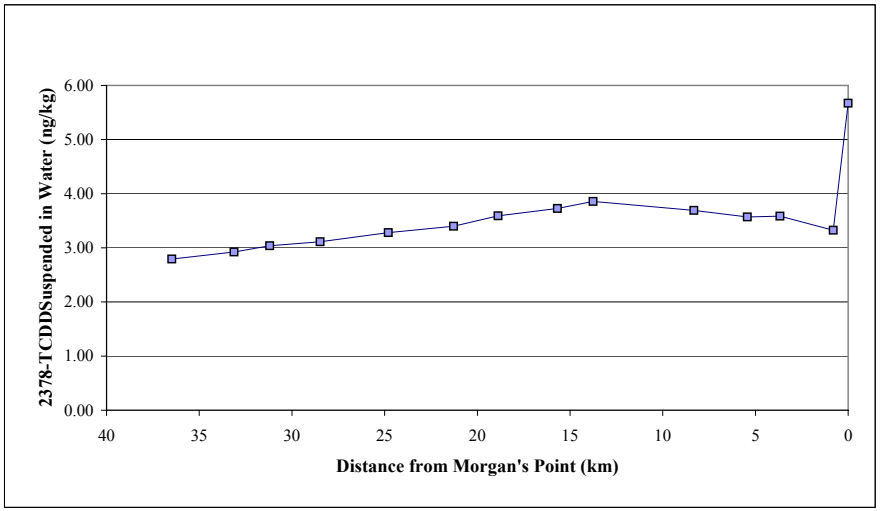
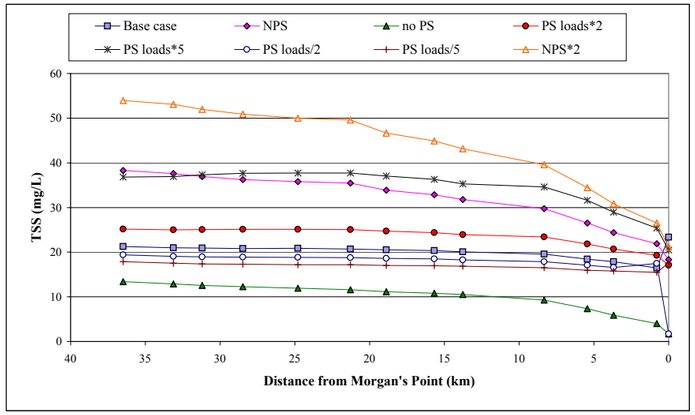
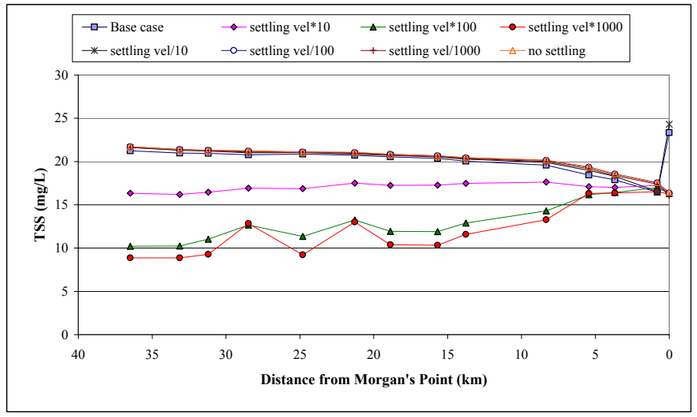


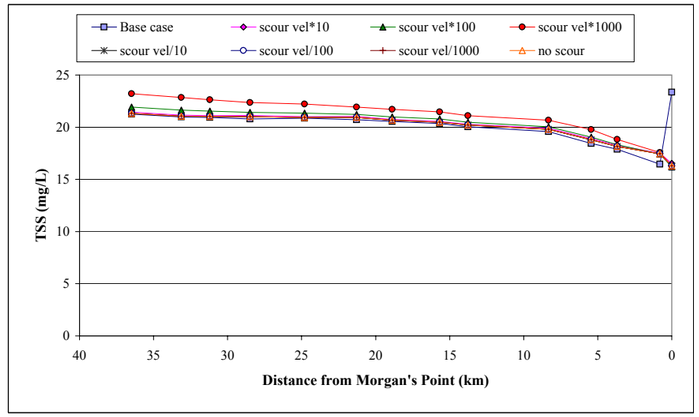
Figure 5.21 Model Results for the Base Case

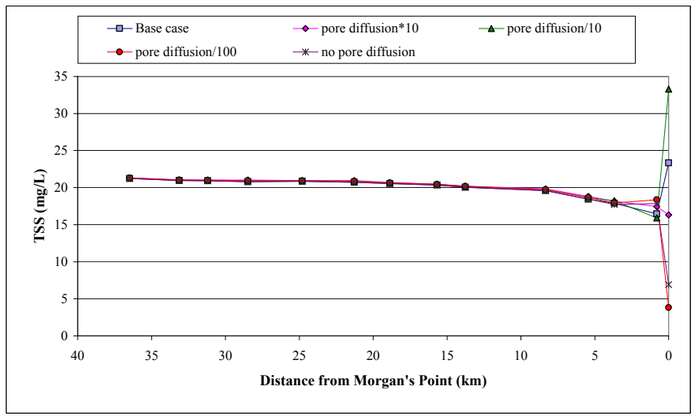
Table 5.11 Summary of Model Runs

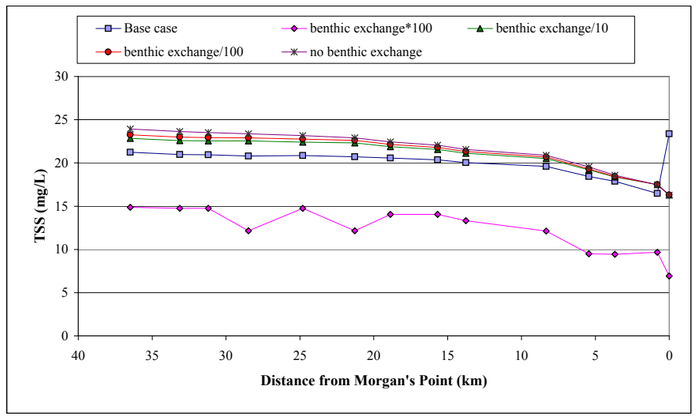
Run	Group	Description
Base Case	-	PS, no NPS, linear sorption, no decay
Case 1	Point and non-point sources	base case plus steady-state NPS
Case 2		no point sources
Case 47		base case plus steady-state NPS*2
Case 36		PS loads *2 (both dioxin and TSS)
Case 37		PS loads *5 (both dioxin and TSS)
Case 38		PS loads /2 (both dioxin and TSS)
Case 39		PS loads /5 (both dioxin and TSS)
Case 4	Sediment transport rates	settling velocity*10
Case 5		settling velocity*100
Case 6		settling velocity*1000
Case 8		settling /10
Case 9		settling /100
Case 10		settling /1000
Case 11		no setlling, only scour
Case 12		scour velocity*10
Case 13		scour velocity*100
Case 14		scour velocity*1000
Case 15		scour/10
Case 16		scour/100
Case 17		scour/1000
Case 18		no scour, only settling
Case 19	Pore water diffusion	pore water diffusion*10
Case 20		pore water diffusion/10
Case 21		pore water diffusion/100
Case 22		no pore water diffusion
Case 23	Surface water-benthic exchange	exchange with bed layer * 10
Case 24		exchange with bed layer * 100
Case 25		exchange with bed layer /10
Case 26		exchange with bed layer /100
Case 27		no exchange with bed layer
Case 28	Dispersion	dispersion *5 (surface segments)
Case 29		dispersion *10 (surface segments)
Case 30		dispersion /5 (surface segments)
Case 31		dispersion /10 (surface segments)
Case 32	Pore water exchange	pore water exchange*10
Case 33		pore water exchange*100
Case 34		pore water exchange/10
Case 35		pore water exchange/100
Case 40	Sorption	K_{oc}*10
Case 41		K_{oc}*100
Case 42		K_{oc}/10
Case 43		K_{oc}/100
Case 44	Decay	Decay rate 10^{-5}/day
Case 45		Decay rate 10^{-6}/day
Case 46		Decay rate 10^{-4}/day

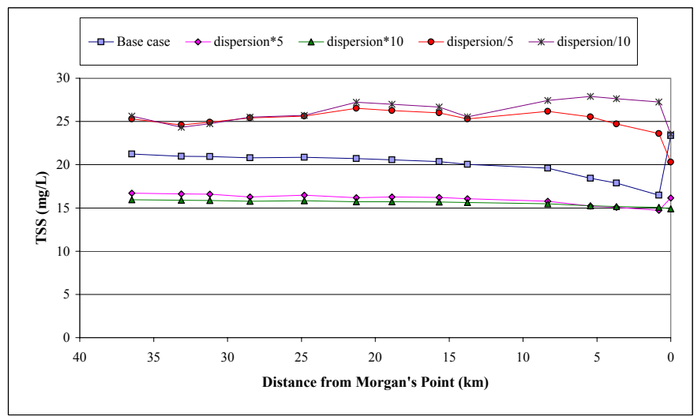












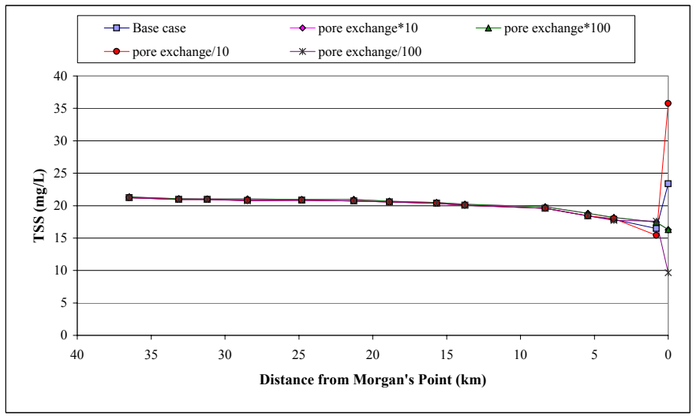
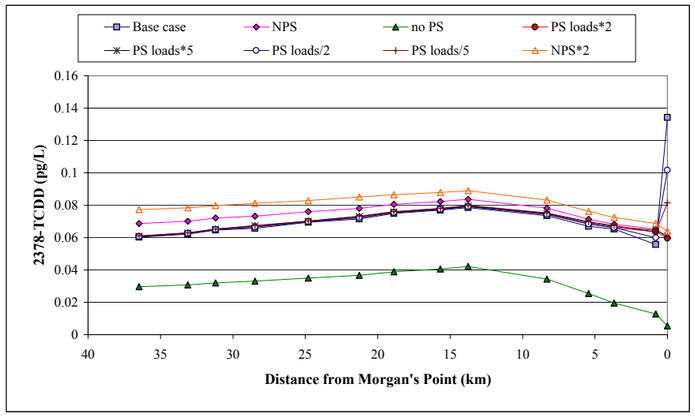
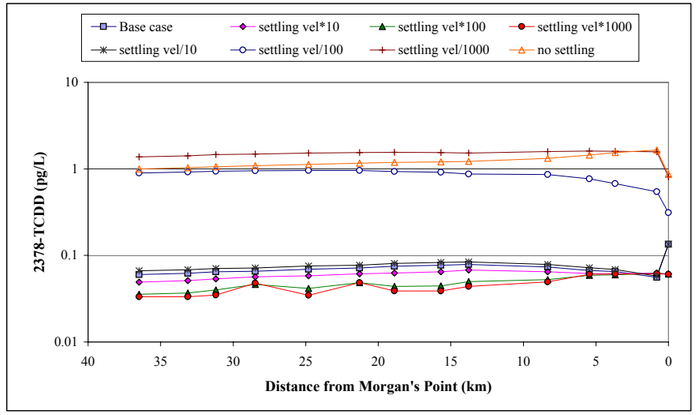
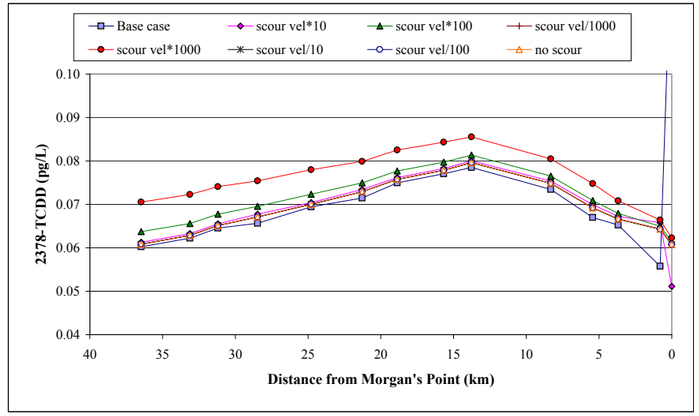
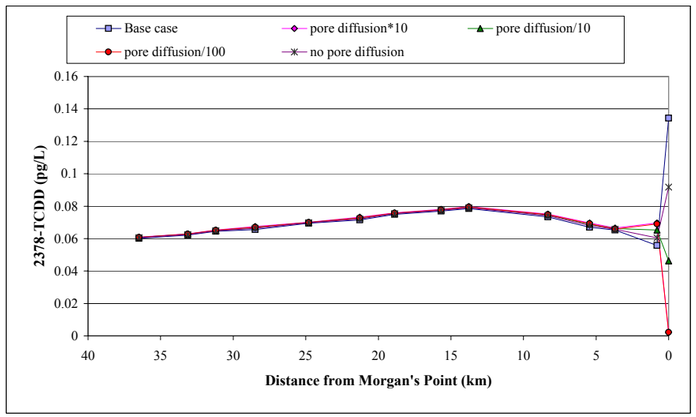


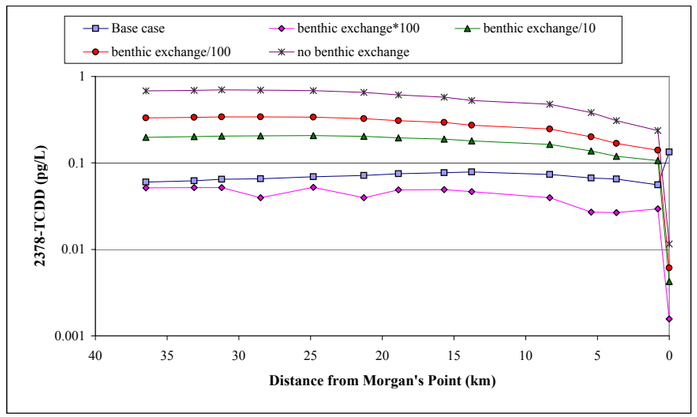
Figure 5.22a Summary of TSS Results

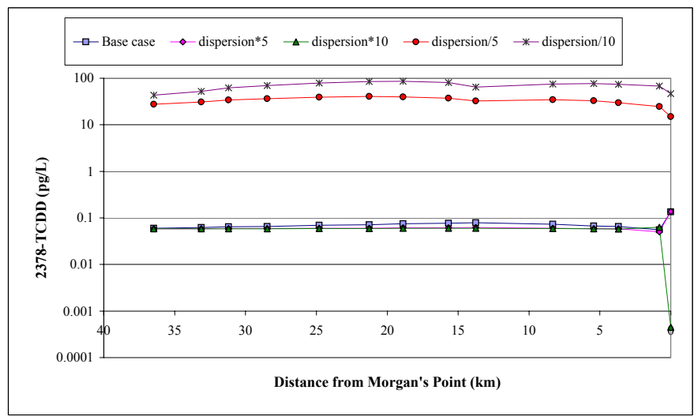


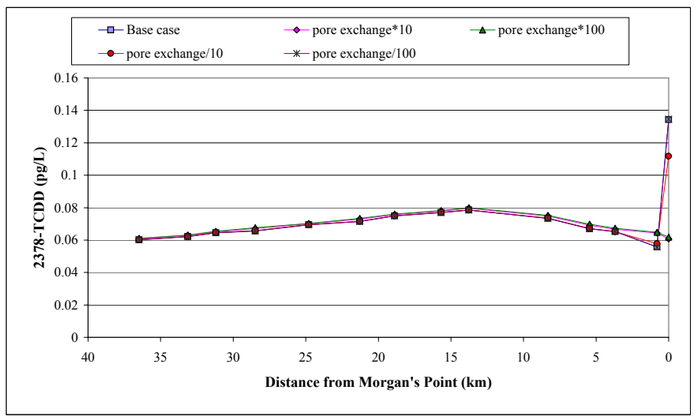


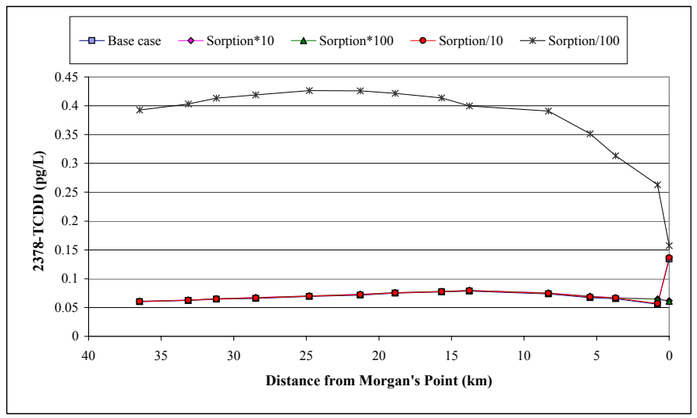












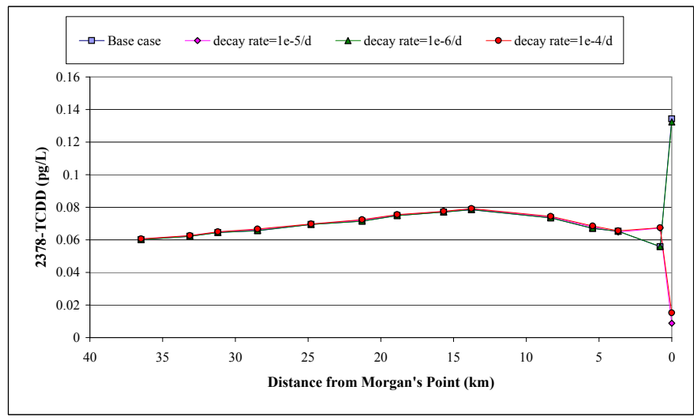
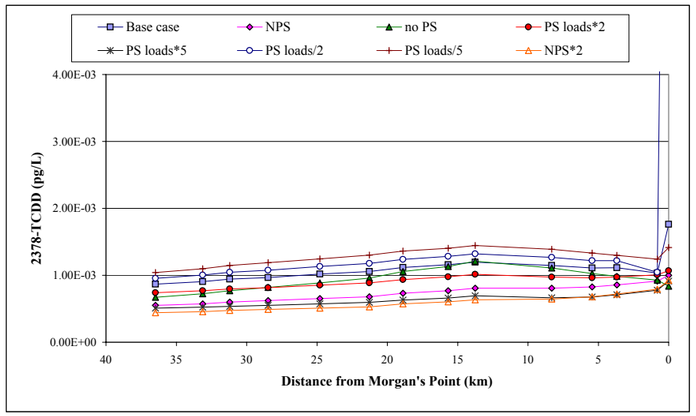
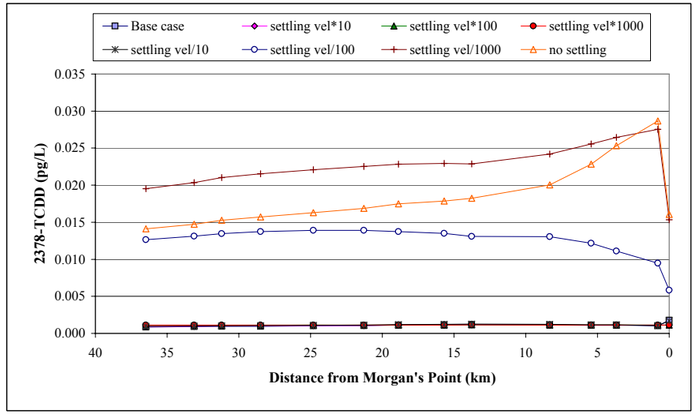
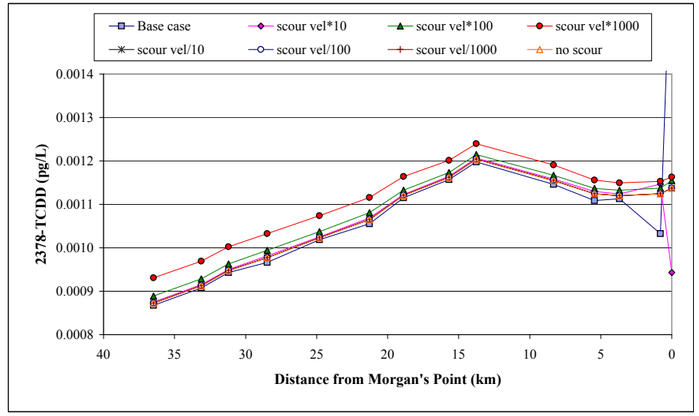
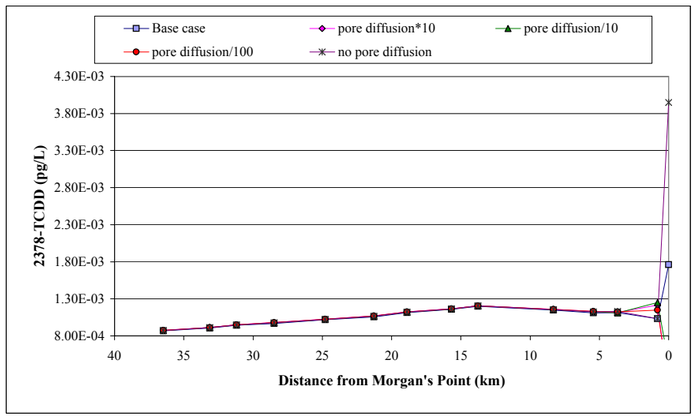


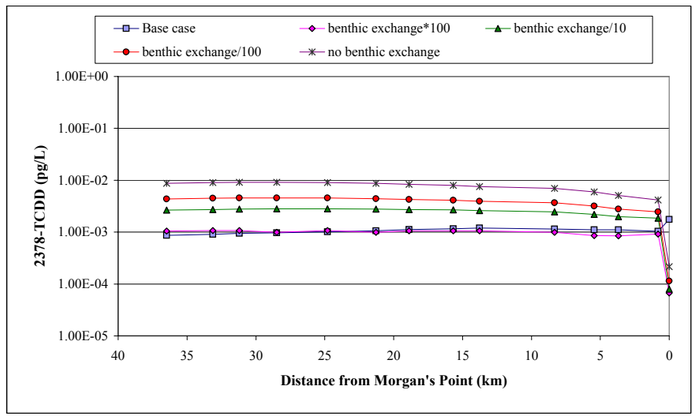
Figure 5.22b Summary of 2378-TCDD Concentrations in Water

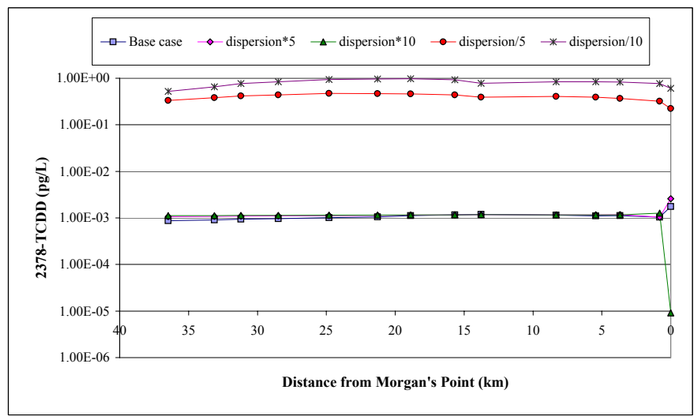


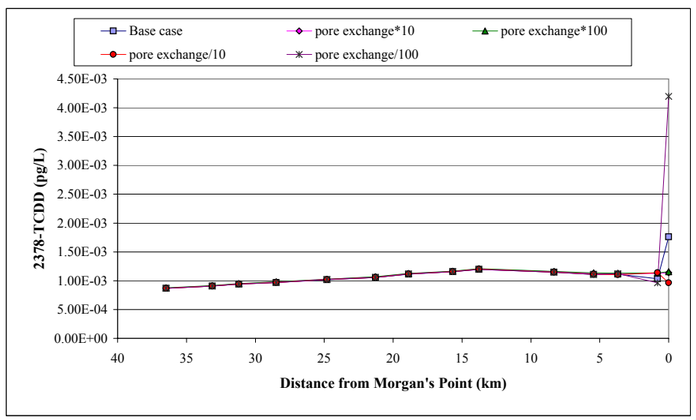


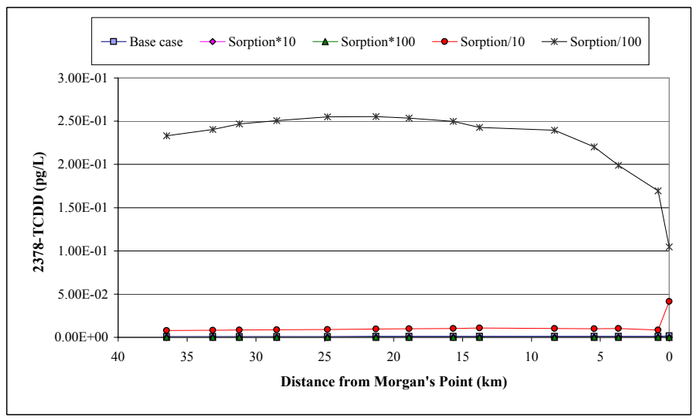












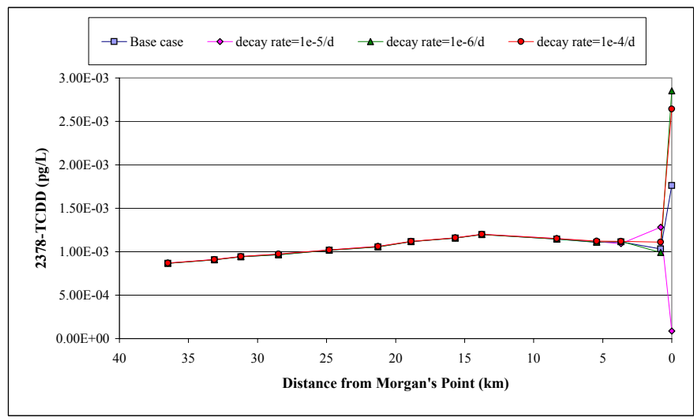
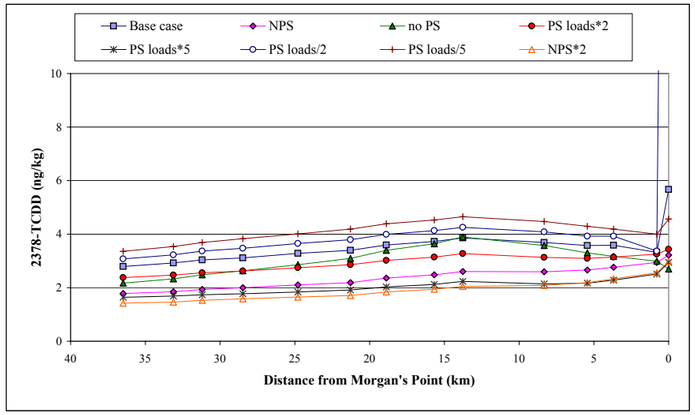
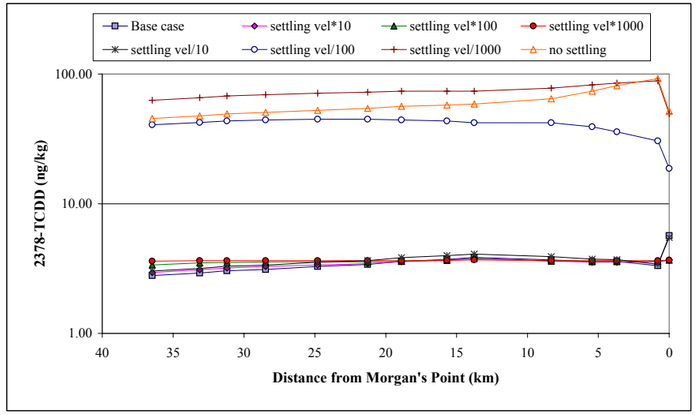
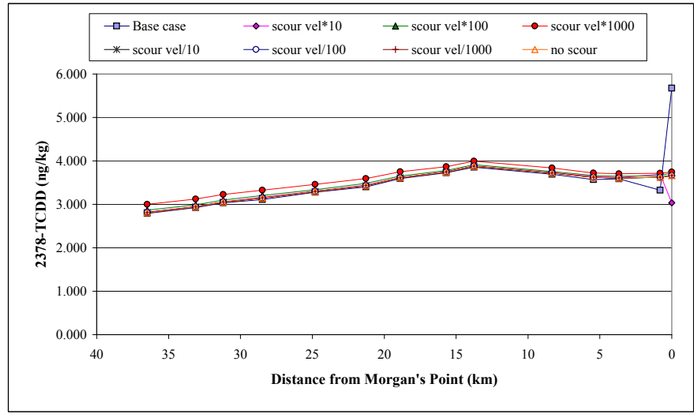
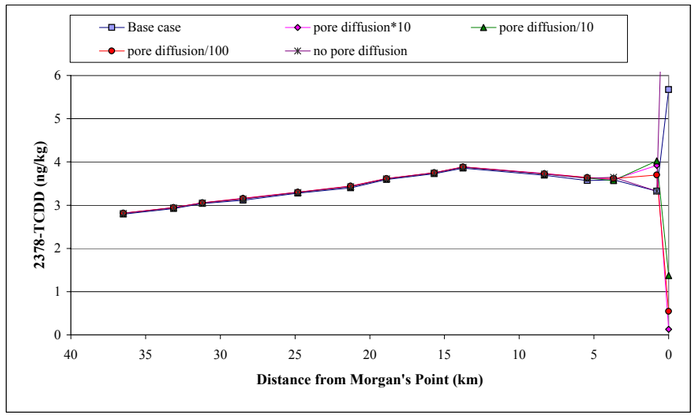


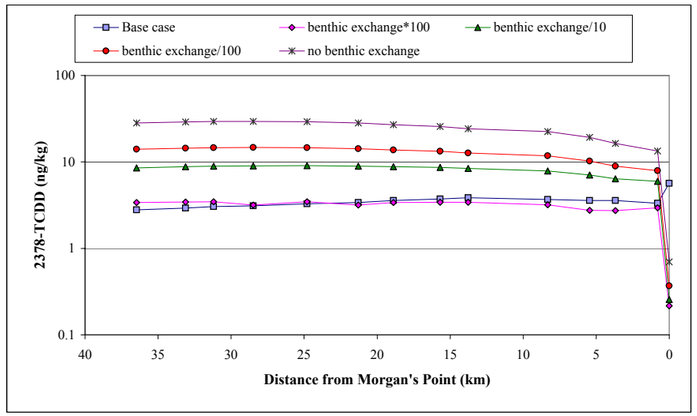
Figure 5.22c Summary of 2378-TCDD Dissolved Concentrations in Water

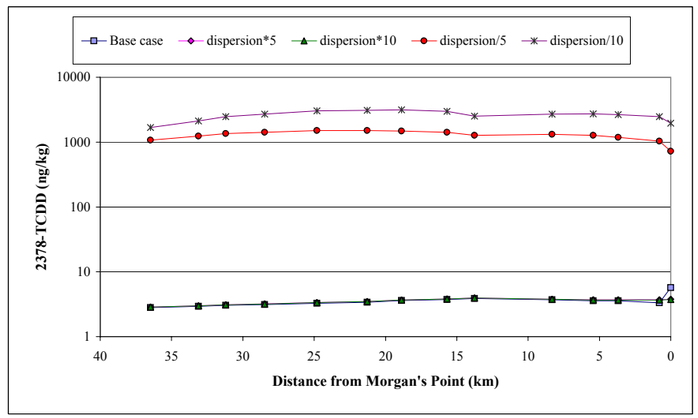


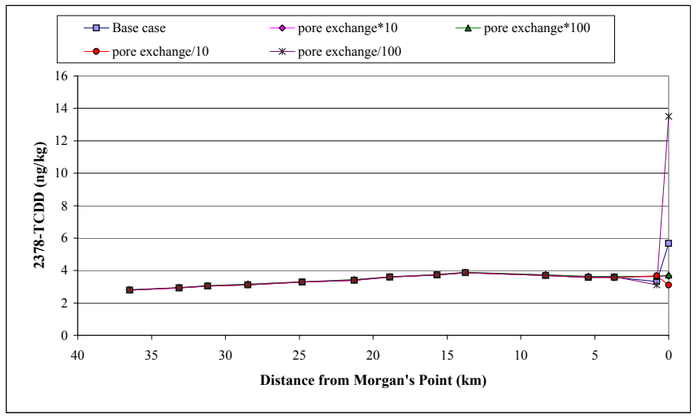


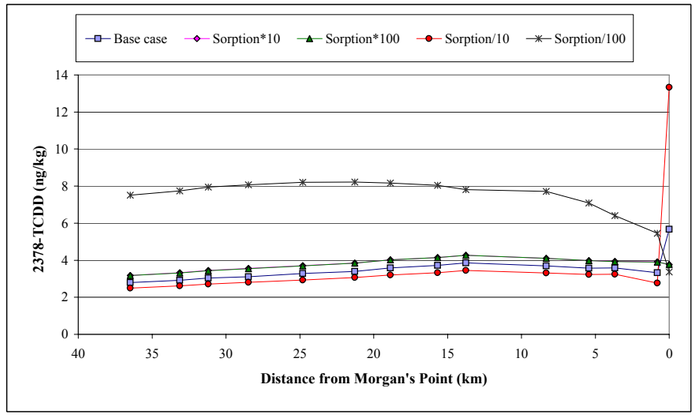












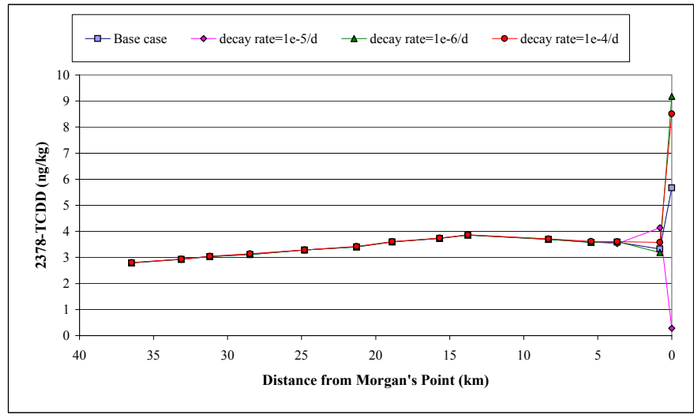


Figure 5.22d Summary of 2378-TCDD Suspended Concentrations in Water

5.3 WASP TRANSIENT MODEL

5.3.1 Channel Segmentation

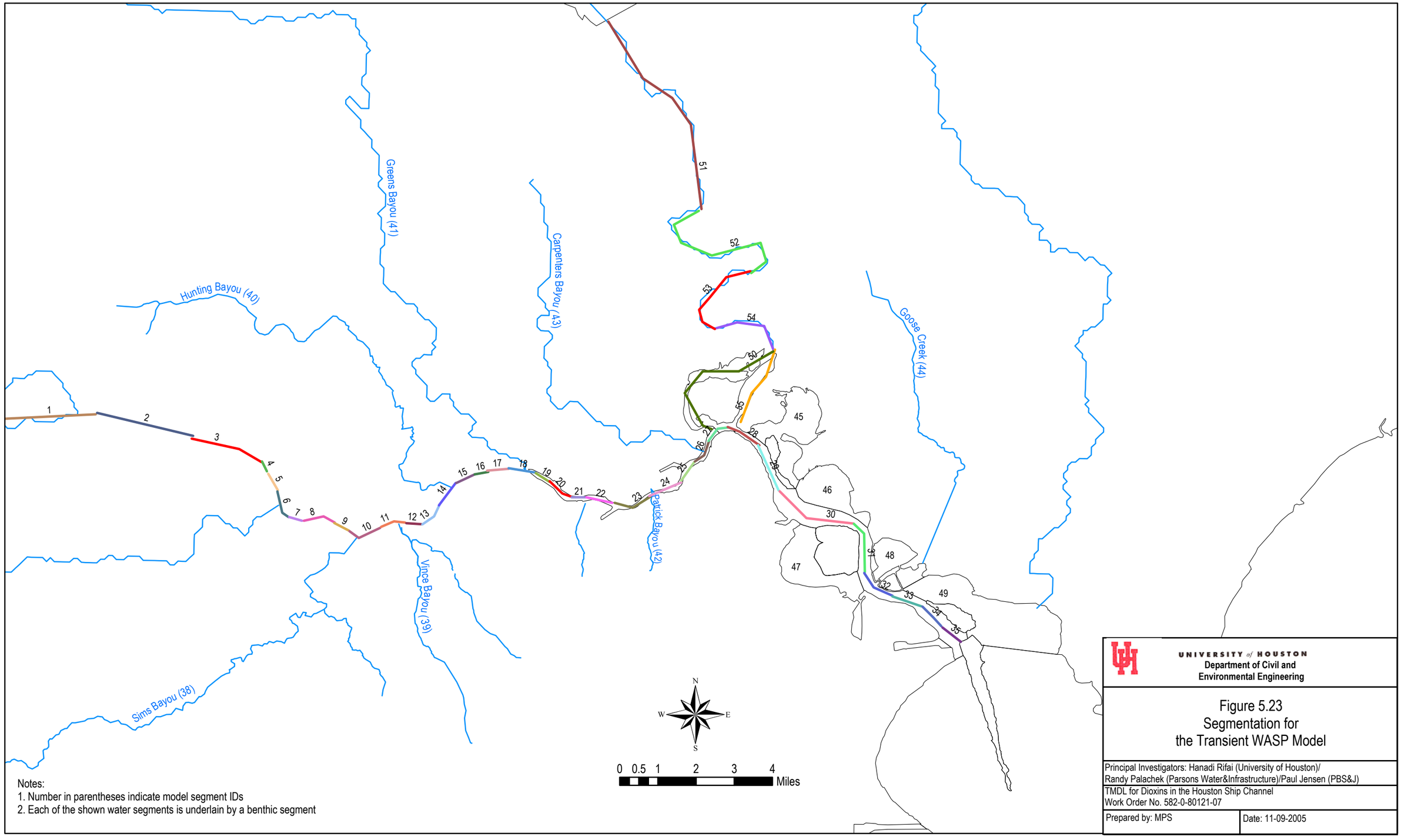
The latest watershed and subwatershed delineations were obtained from Harris County Flood Control District (HCFCD). The channel was divided into 55 water segments (including tributaries) with their corresponding underlying benthic segments (Figure 5.23). The tributary segments correspond to the section between the flow gage and the mouth of the stream.

5.3.2 Hydraulic Input

The Dynamic Estuary Model Hydrodynamics Program (DYNHYD5) was used to simulate the transient hydrodynamics. DYNHYD solves the one-dimensional equations of continuity and momentum for a branching or channel-junction computational network. The simulations are driven by variable upstream flows and downstream heads (Ambrose et al., 1993). The DYNHYD5 model was selected because of its relatively easy interface with WASP. However, the model has the following limitations:

- It can treat fairly complex branching flow patterns but it cannot handle stratified waterbodies
- DYNHYD only allows up to 5 variable inflows (inputs)
- The variable inflow only allows up to 100 breaks in the flow series

The following sections describe the input and output series for the HSC DYNHYD model.



Notes:
1. Number in parentheses indicate model segment IDs
2. Each of the shown water segments is underlain by a benthic segment

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Department of Civil and Environmental Engineering

Figure 5.23
Segmentation for
the Transient WASP Model

Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Work Order No. 582-0-80121-07

Prepared by: MPS

Date: 11-09-2005

5.3.2.1 Model Parameters

Simulation Period and Time Step

Because DYNHYD cannot handle more than 100 breaks in the flow series, the model was run for a 24-day period, with 6-hr time steps. The period of the simulation was from August 1, 2002 to August 24, 2002. This time period was selected because it corresponds to the period with the largest dioxin dataset.

Model Network

The model network corresponds to that shown in Figure 5.23, for a total of 56 nodes and 55 water segments (links).

Junction and Channel Data

Summaries of the initial conditions at each junction and channel are presented in Tables 5.12 and 5.13, respectively. To determine the different geometry parameters two sources of data were relied upon: (i) HSC cross-sections from the Center for Operational Oceanographic Products and Services, available on-line at http://www.co-ops.nos.noaa.gov/, and (ii) cross sections for major tributaries from the Tropical Storm Allison Recovery Project (TSARP).

Inflow Data

Hourly flow data for all the major tributaries was obtained from the USGS and averaged using 6-hour intervals. The major tributaries considered in the model, from downtown Houston to Morgan's Point, are listed in Table 5.14 below.

Table 5.12 Junction Parameters for DYNHYD Model

Junction ID	Surface Area (m^2)	Bottom Elevation (m)[a]	Channels entering Junction			
1	150472	-1.3	1			
2	329708	-4.4	1	2	36	
3	303023	-5.7	2	3		
4	50497	-11.6	3	4		
5	154923	-11.6	4	5		
6	173435	-11.6	5	6		
7	94263	-11.6	6	7	37	
8	259541	-11.6	7	8		
9	118540	-11.5	8	9		
10	349947	-11.4	9	10	38	
11	244483	-12.8	10	11		
12	131692	-12.7	11	12	39	
13	252347	-13.9	12	13		
14	248319	-13.8	13	14		
15	185670	-12.4	14	15	40	
16	113798	-12.3	15	16		
17	189825	-11.9	16	17		
18	251641	-12.2	17	18		
19	265945	-13.0	18	19	41	
20	469102	-13.2	19	20		
21	202121	-13.0	20	21		
22	439985	-13.8	21	22		
23	546573	-12.6	22	23		
24	508760	-13.7	23	24	42	
25	381278	-13.4	24	25		
26	488213	-14.1	25	26		
27	717951	-12.3	26	27	43	50
28	912187	-14.7	27	28	55	
29	612324	-14.3	28	29	45	
30	947611	-14.9	29	30	46	
31	620128	-14.9	30	31	47	
32	372077	-14.9	31	32	48	
33	421687	-14.9	32	33		
34	311597	-14.9	33	34	44	
35	231328	-14.9	34	35	49	
36	40927	-1.3	36			
37	385084	-3.2	37			
38	103013	-5.4	38			
39	86048	-3.1	39			
40	330960	-1.3	40			
41	1146445	-6.2	41			
42	4002006	-1.5	42			
43	255761.5	-2.5	43			
44	4124322	-2.0	44			
45	3332000	-2.0	45			
46	4301000	-2.0	46			
47	2745500	-2.0	47			
48	3145000	-2.0	48			
49	2720000	-2.0	49			
50	4440527	-11.1	50			
51	366687.1	-2.5	51			
52	720048.2	-3.7	51	52		
53	1837381.7	-5.0	52	53		
54	2287492.9	-11.2	53	54		
55	2411620.4	-7.0	28	55		
56	4779546	-13.6	35			

[a] Datum plane is mean sea level

Table 5.13 Channel Parameters for DYNHYD Model

Channel ID	Length (m)	Width (m)	Depth (m)	Direction (degrees)[a]
1	5655	18	1.3	85
2	5674	36	4.4	101
3	3041	81	5.7	108
4	386	119	11.6	146
5	1070	143	11.6	147
6	1151	147	11.6	155
7	611	155	11.6	98
8	1521	153	11.6	89
9	636	188	11.5	131
10	1641	185	11.4	73
11	1110	241	12.8	83
12	612	199	12.7	90
13	1159	232	13.9	45
14	1199	204	13.8	29
15	893	210	12.4	63
16	539	205	12.3	72
17	925	217	11.9	79
18	1159	194	12.2	92
19	740	241	13.0	123
20	1151	478	13.2	123
21	587	338	13.0	86
22	1231	351	13.8	94
23	1489	364	12.6	72
24	1416	370	13.7	62
25	1030	348	13.4	42
26	1062	392	14.1	24
27	1143	527	12.3	49
28	1829	480	14.7	116
29	2377	268	14.3	150
30	3658	247	14.9	110
31	2286	271	14.9	172
32	1372	271	14.9	123
33	1554	271	14.9	109
34	1189	271	14.9	134
35	914	253	14.9	139
36	2928	14	1.3	98
37	11972	32	3.2	98
38	813	127	5.4	98
39	3512	25	3.1	98
40	7057	47	1.3	98
41	19002	60	6.2	98
42	5063	836	1.5	98
43	4407	58	2.5	98
44	7890	836	0.9	98
45	2800	1400	2.0	98
46	2200	2300	2.0	98
47	3800	850	2.0	98
48	2000	1850	2.0	98
49	1600	2000	2.0	98
50	5063	836	2.0	98
51	3408	128.2	2.5	98
52	7063	87	3.7	98
53	8819	117	5.0	98
54	3330	300	11.2	98
55	3761	1074	7.0	98

[a] Angle measured from true north

Table 5.14 Major Tributaries and USGS Gages

Tributary	Station Description	USGS gage	Watershed Area (mi^2)	Parameters Measured	Long-term median flow (cfs)
San Jacinto River	San Jacinto River at Sheldon	08072050	2,879	GH	1.95
Buffalo Bayou	Buffalo Bayou at Shepherd	08074000	358	Q, GH	66
Whiteoak Bayou	Whiteoak Bayou at Heights	08074500	86.3	Q, GH	30
Greens Bayou	Greens Bayou at Ley Rd	08076700	182	Q, GH	260
Brays Bayou	Brays Bayou at Houston	08075000	94.9	Q, GH	76
Sims Bayou	Sims Bayou at Houston	08075500	63	Q, GH	35
Vince Bayou	Vince Bayou at Pasadena	08075730	8.26	Q, GH	1.70
Patrick Bayou	None	None	4.4		NA
Carpenters Bayou	None	None	25.8		NA
Hunting Bayou	Hunting Bayou at IH-610	08075770	16.1	Q, GH	7.30
Goose Creek	Goose Creek at Baytown	08067525	15.8	GH	NA

Q = flow, GH = gage height

Because DYNHYD does not allow more than five variable-flow input data series, the USGS data were combined as follows: (1) Buffalo Bayou, Whiteaok Bayou, and 69th St. WWTP entering the channel at segment 2, (2) Brays Bayou entering the channel at segment 37, (3) Sims Bayou entering the channel at segment 38, (4) Vince, Hunting, and Greens Bayous entering the channel at segment 41, and (5) San Jacinto River entering the channel at segment 52. The San Jacinto River flow series was developed using the USGS gage data and regressions made with the flow measurements collected as part of this project (Section 3.2.3). Figure 5.24 shows the flow series input to the model.

Seaward Boundary

As of this writing, the downstream boundary for the model is at Morgan's Point. Inclusion of a segment corresponding to Upper Galveston Bay is under consideration. Gage data for Morgan's Point was obtained from NOAA in 6-minute intervals and averaged to 1-hour intervals. Data for a single tidal cycle was then fitted (by the model) to the following regression:

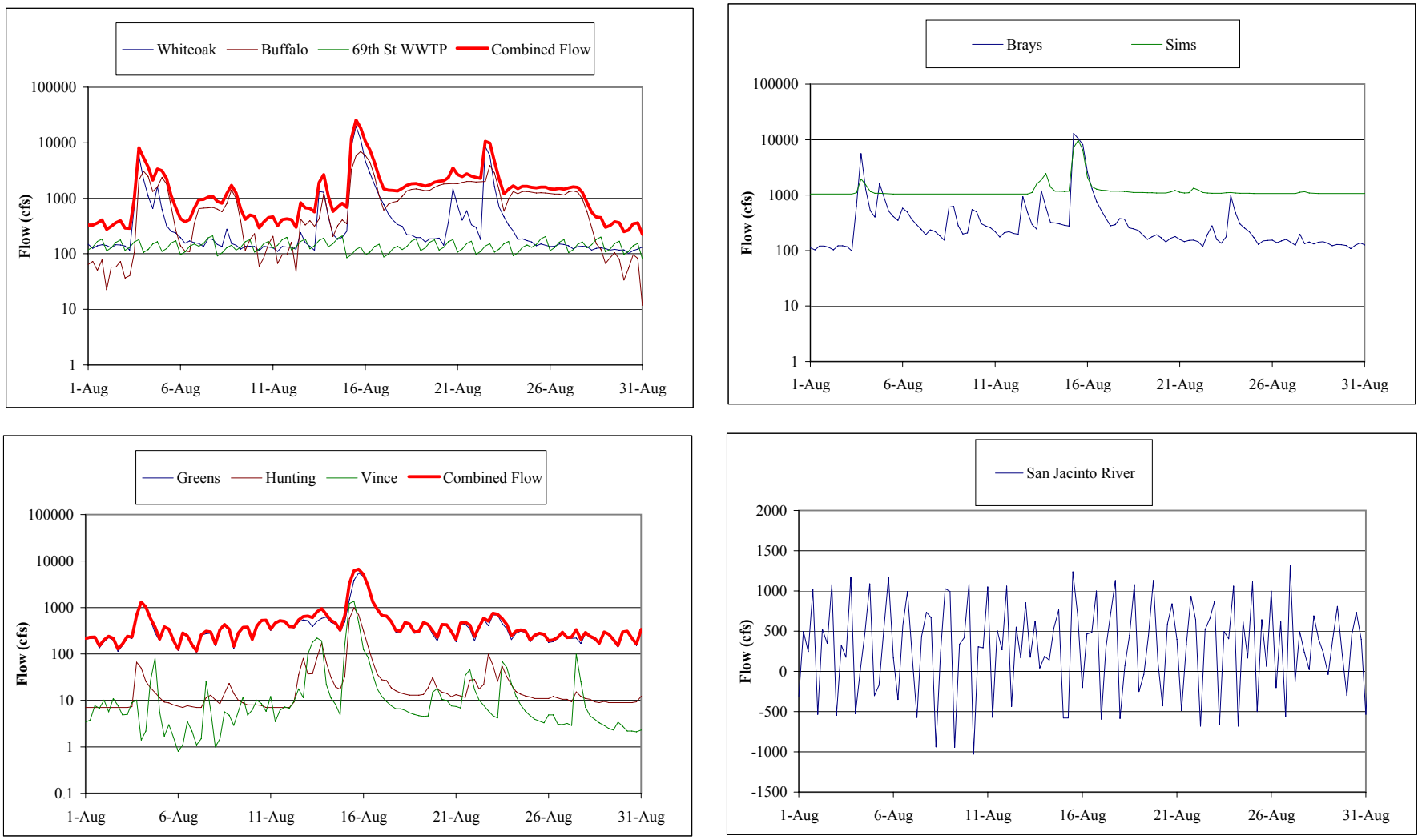


Figure 5.24 Flow Input Series for DYNHYD

$$H = A_1 + A_2 \sin(\omega t) + A_3 \sin(2\omega t) + A_4 \sin(3\omega t) + A_5 \cos(\omega t) + A_6 \cos(2\omega t) + A_7 \cos(3\omega t) \qquad (5.11)$$

where H is head (m), ω is tidal period (hr), and t is time (hr).

Figure 5.25 shows the tidal data input to DYNHYD (5-day period) and the resulting modeled gage heights for the simulation period (24 days) are depicted in Figure 5.26.

5.3.2.2 DYNHYD Output

Preliminary flow data series for a number of segments in the HSC as simulated by DYNHYD are presented in Figure 5.27. The hydraulic model is currently being refined and calibrated. An updated version of the model will be presented in the next quarterly report.

5.3.3 WASP Model Development

The output from DYNHYD was linked to the WASP model and the benthic segments were added to complete the water quality simulations. The WASP model is currently under development and its results will be discussed in the next quarterly report.

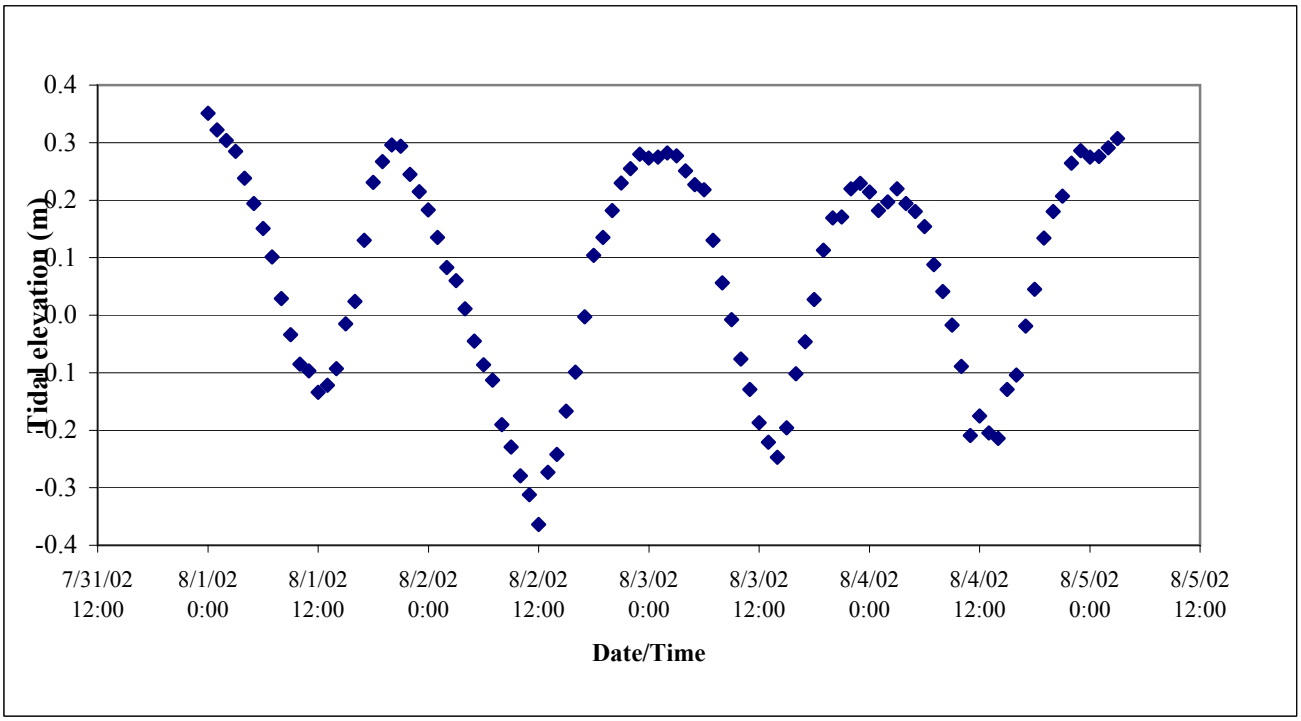


Figure 5.25 Input Tidal Data

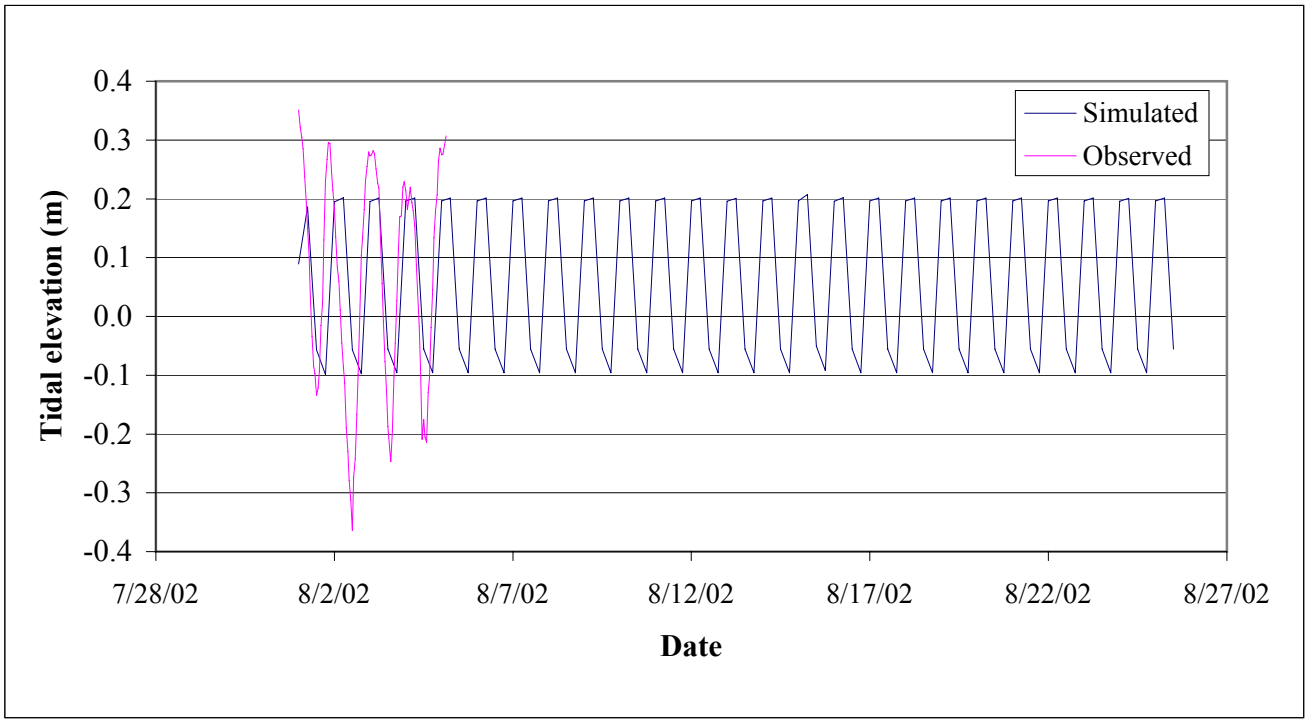
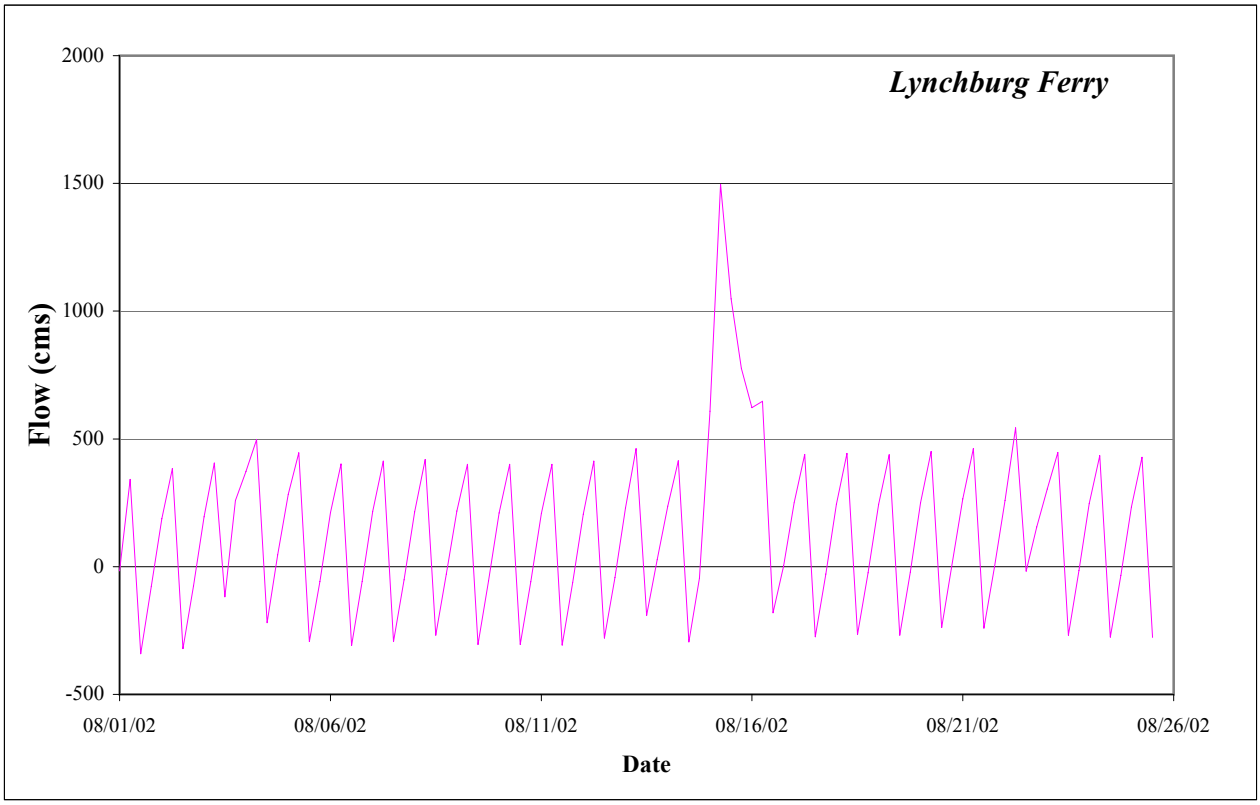


Figure 5.26 Tidal Data Simulated by DYNHYD



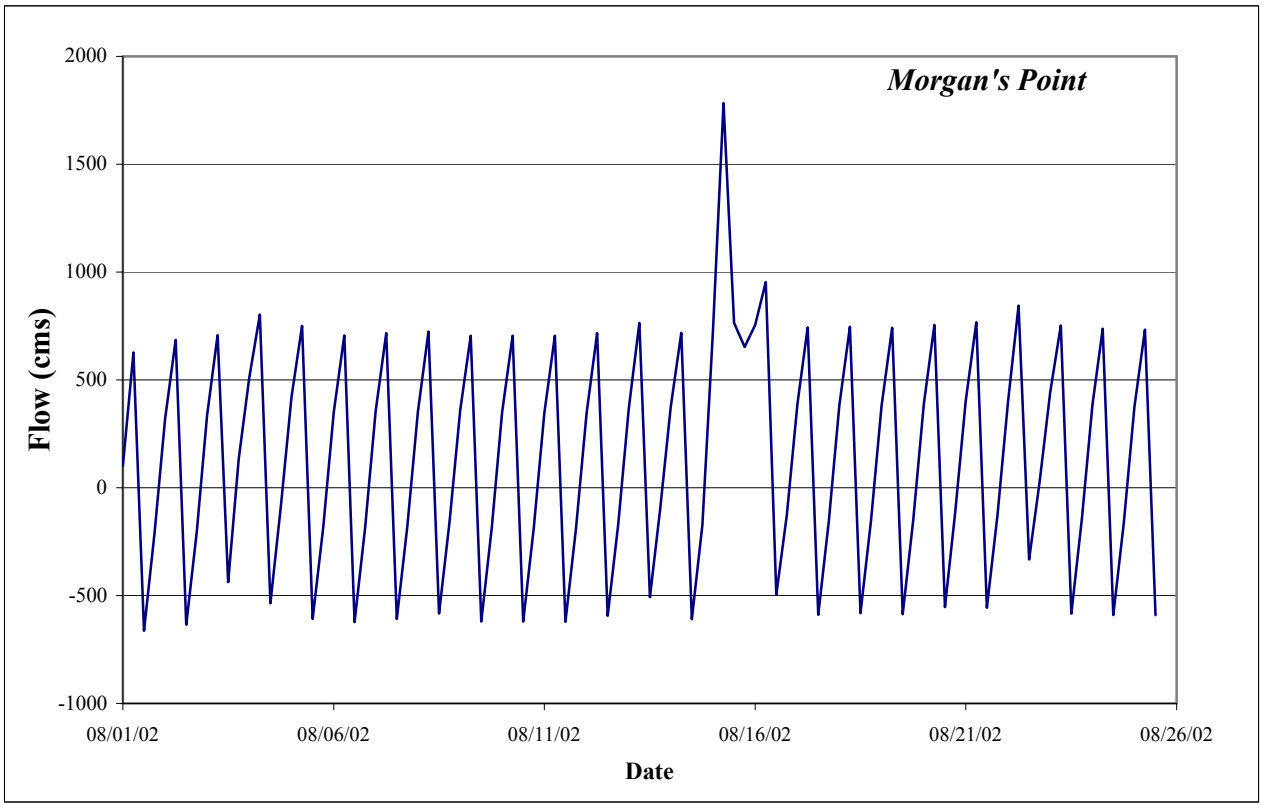


Figure 5.27 Modeled Flows

CHAPTER 6

STAKEHOLDER/PUBLIC EDUCATION AND INVOLVEMENT

6.1 SUMMARY OF SUPPORT ACTIVITIES

The project team supported the stakeholder process facilitated by the Houston Galveston Area Council (HGAC) and the Environmental Institute of Houston at UH Clear Lake. The following support tasks were undertaken:

- Development of informational materials summarizing the technical aspects of the project for electronic and paper distribution at stakeholder meetings. These materials included documents, maps, and the QAPP for this project;
- Preparation of web based project informational briefs;
- Participation in three stakeholder meetings (01/07/2004, 02/02/2005, and 08/31/2005);
- Participation in two technical meetings with members of the stakeholder group. The first one was held at the Port of Houston Authority main office on May 17, 2004 and the second took place at the University of Houston on May 24, 2004;
- Preparation of responses to questions and information requests from stakeholders and providing rationale for whether or not certain requests by stakeholders for refinement in technical analysis can or cannot be achieved. After the January 2004 stakeholder meeting, the project team received comments from Lial Tischler and from Oxy Vinyls. It is noted that these two documents present differing perspectives regarding calculating site-specific BAFs and BSAFs. In response to Lial Tischler's comments, congener-specific BAFs,

BSAFs, and BEFs were calculated using the USEPA (1995) guidance document and are discussed in Chapter 4 of this report. In addition, the project team prepared a document in response to comments received from Oxy Vinyls on February 16, 2004. The document, included in Appendix I of this report, was discussed during the May 24 technical meeting; and

- Preparation of data to be submitted to H-GAC for development of informational map and brochure on the project.
- On February 22, 2005, new information from the Texas Parks and Wildlife indicated the presence of a potential source in the San Jacinto River near the I-10 bridge. More research was completed to investigate this issue and as a result additional high-resolution sediment sampling was conducted in Summer 2005.

6.2 TECHNICAL PRESENTATIONS AT STAKEHOLDER MEETINGS

Copies of the technical presentations given at the stakeholder meetings are included in Appendix I. The QAPP and other related documents can be found on the web at http://www.hgac.cog.tx/intro/introtmdl.html.

6.3 PUBLIC OUTREACH

In addition to stakeholder presentations, the following technical presentations were given:

- "Development of a Dioxin TMDL for the Houston Ship Channel in Texas" at the *WEF 2003 TMDL National Conference* held in Chicago, IL on November 15-19, 2003;
- "Site-Specific Water Quality Targets for Fish Contaminants: Application of Sediment, Water, and Tissue Targets based on Measured Partitioning Relationships" at the *WEF*

2003 TMDL National Conference held in Chicago, IL on November 15-19, 2003;

- "Assessment of Particulate and Dissolved Dioxin Concentrations in Storm Water Runoff to Houston-area Waterways Using High Volume Sampling" at the *WEF 2003 TMDL National Conference* held in Chicago, IL on November 15-19, 2003;
- "TMDL for Dioxin in the Houston Ship Channel" at the *Haden Road Community Advisory Panel* on March 22, 2004;
- "TMDL for Dioxin in the Houston Ship Channel" at the *Board Meeting of the Galveston Bay Estuary Program* on April 22, 2004;
- "TMDL for Dioxin in the Houston Ship Channel" at the *Baytown Area Community Advisory Panel* on May 17, 2004; and
- "TMDL for Dioxin in the Houston Ship Channel" at the *GBNEP State of the Bay Conference* on January 25, 2005.

CHAPTER 7

PCB ASSESSMENT

In January and July 1999, the Texas Department of Health (TDH) collected twenty-four finfish[13] and eight composite blue crab samples from four sites in the Houston Ship Channel System to complete a Health Assessment. The locations included the Turning Basin, the Lynchburg Ferry/San Jacinto State Park, the San Jacinto River near I-10, and Tabbs Bay near Houston Point. Results from the 1999 Health Assessment showed the presence of PCBs (Aroclor 1260) in 3 out of 12 finfish samples from the Lynchburg Ferry and the San Jacinto River. The maximum and average concentrations for the samples above detection limits were 0.330 and 0.068 ng/g, respectively. Based on the results from the 1999 studies, it was recommended by the TDH to extend the existing advisory for the Houston Ship Channel to include all species of finfish due to the presence of pesticides and PCBs in concentrations that exceed health-based comparison values. The Health Assessment took into account potential cumulative noncancerous and carcinogenic health effects.

The scope for the dioxin project was, thus, expanded to include a preliminary assessment of PCB concentrations in all media in the channel and leverage the costs involved in dioxin sample collection. Unlike the TDH study, the dioxin TMDL project quantified both the 209 PCB congeners and the Aroclors in all media and results were presented in the Final Report for WO4. This chapter presents an analysis of the PCB data collected during the Summer 2002, Fall 2002,

and Spring 2003 sampling events to make recommendations regarding impairment and the need for initiating TMDL projects.

In February 2005, the Texas Department of Health issued a new advisory for the consumption of Speckled Trout from the HSC and Upper Galveston Bay.

7.1 PCB WATER QUALITY STANDARDS

Several national and state criteria and screening levels for PCBs in water and fish tissue exist. The state/federal Maximum Contaminant Level (MCL) for drinking water is 500 ng/L (ppt), while the human health water quality criteria based on uptake by fish consumption and water recommended by EPA is 0.17 ng/L (EPA, 1999).

The Texas Surface Water Quality Standards (§307.1-307.10) include human health water quality criteria for total PCBs (based on Aroclors) of 1.3 ng/L and 0.885 ng/L in freshwater and saltwater, respectively. These concentrations are lower than the MCL for drinking water due to the fact that the highest exposure potential of PCBs in waters is through the bioaccumulation potential and consumption of contaminated fish (Webster et al. 1998). Additionally, fresh and saltwater criteria differ because it is assumed that consumption rates are higher for saltwater species.

The Texas Department of Health based its health assessment of PCBs in the Houston Ship Channel (TDH, 2001) on a screening level of 47 ng-Aroclor/g-tissue. This screening value was derived from an EPA chronic oral reference dose (RfD) for Aroclor 1254 of 0.00002 mg/kg/day[14].

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[13] Seven hybrid bass, five smallmouth buffalo, three sheepshead, three red drum, one freshwater drum, two southern flounder, two common carp, and one blue catfish.

[14] This is the lower of the carcinogen and noncarcinogen comparison values. The comparison value using the EPA slope factor of 2 $(mg/kg/day)^{-1}$ to account for the carcinogen effects of PCBs was 270 ng/g. Assumptions: body

7.2 PCB ANALYTICAL QUANTIFICATION

PCBs may be quantified as individual congeners, as Aroclor equivalents, or as homologue groups (i.e. monochlorobiphenyl, dichlorobiphenyl, etc). Aroclors are identified as commercial mixtures of PCB congeners. Historically, the most common PCB analysis has been through Aroclor analysis (EPA Method 8082). However, the analysis of Aroclor may yield significant error in determining both total PCB and their total toxicity. This is because the Aroclor method assumes that the distribution of PCB congeners in environmental samples and parent Aroclor compounds is similar (U.S. EPA, 2000).

Cogliano (1998) found that bioaccumulated PCBs are more toxic and persistent than the original Aroclor mixtures. Thus, the U.S. EPA (2000) recommends analysis of homologue groups or PCB congeners. However, it acknowledges that all health-based assessments are based on Aroclors. EPA (2000) suggests summing 18 congeners to compare to total PCB or Aroclor-based screening values, as recommended by the National Oceanic and Atmospheric Administration (NOAA, 1989). The 18 congeners include PCB-8, PCB-18, PCB-28, PCB-44, PCB-52, PCB-66, PCB-77, PCB-101, PCB-105, PCB-118, PCB-126, PCB-128, PCB-138, PCB-153, PCB-169, PCB-170, PCB-180, and PCB-187.

7.3 SUMMARY OF PCB RESULTS IN THE HOUSTON SHIP CHANNEL

During the Summer 2002, concentrations of the 209 PCB congeners (EPA Method 1668A) were analyzed from 31 ambient water locations, 34 in-stream sediment locations, 45

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weight 70 kg, consumption rate 30 g/day, exposure period 30 yr (for carcinogens), and excess lifetime cancer risk of $1x10^{-4}$.

catfish and crab tissue locations, and 11 tributary sediment locations[15]. In addition, samples from 18 ambient water locations, 16 in-stream sediment locations, 13 locations for catfish tissue, and 13 locations for crab tissue were analyzed for PCBs (209 congeners) during Fall 2002. During the Spring of 2003, 4 water samples, 37 sediment samples, and 26 catfish samples were analyzed for the 209 PCB congeners. Table 7.1 includes a summary of the total number of samples collected during the three sampling events.

7.3.1 In-stream Water

Total concentrations of PCBs (calculated as the sum of the 18 NOAA congeners) in water (dissolved plus suspended fractions) for the three sampling events are summarized in Table 7.2. Figure 7.1 shows the distribution of total PCBs in water in the Houston Ship Channel System. Total Summer 2002 PCB concentrations ranged between 0.18 and 1.62 ng/L with a mean value of 0.56 ng/L for 31 stations, when non-detects were assumed equal to zero. Total PCB concentrations in Fall 2002 samples varied between 0.12 and 2.60 ng/L with an average of 0.68 ng/L for 18 locations. As can be seen in Table 7.2, only 5 out of the 31 (16%) locations sampled in Summer 2002 and 3 out of the 18 (17%) Fall 2002 locations exceeded the Texas Surface Water Quality Standard (WQS) for human health protection of 0.885 ng/L. In addition, the mean concentration is less than the WQS. The exceedances were observed at stations located in segments 1006, 1007, and 2427. During Spring 2003 PCBs in water were measured only for segments 1006 and 1007. Total PCB concentrations in Spring 2003 were between 0.96 and 1.8

[15] Water samples were collected using the high-volume technique, which yielded samples sizes between 268 and 731 L. Sediment samples were composites of 3 to 5 grab samples at each location. Tissue samples were obtained by compositing 3 to 5 individuals from a given location; only the edible portion was used in the sample composite.

Table 7.1 Total Number of PCB Samples

Matrix	Summer 2002			Fall 2002			Spring 2003		
	# sites	QC samples[a]	# samples	# sites	QC samples[a]	# samples	# sites	QC samples[a]	# samples
Water	31	2	33	18	2	20	4	1	5
Sediment									
- In-channel	34	6	40	16	1	17	26	1	27
- Tributaries	11	3	14	ns	ns	ns	11	2	13
Catfish									
- In-channel	34	6	40	13	4	17	18	1	19
- Tributaries	11	5	16	ns	ns	ns	8	2	10
Crab									
- In-channel	34	7	41	13	2	15	ns	ns	ns
- Tributaries	11	1	12	ns	ns	ns	ns	ns	ns

[a] Field duplicates
ns = not sampled

Table 7.2 Total PCB Concentrations in Water (ng/L)

Station ID	Date	Volume (L)	PCB 8	PCB 30/18	PCB 28/20	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 113/90/101	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 138/163/129	PCB 153/168	PCB 169	PCB 170	PCB 193/180	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Summer 2002																							
13343	08/20/2002	706	0.0051	0.0242	0.0361	0.0439	0.0595	0.0292	0.0034	0.0453	0.0105	0.0238	< 0.0003	0.0053	0.0357	0.0279	< 0.0001	0.0096	0.0174	0.0133	0.3906	0.3905	0.3905
13344	08/21/2002	709	< 0.0069	0.0271	0.0324	0.0969	0.1368	0.0472	0.0033	0.0733	0.0104	0.0228	< 0.0003	0.0048	0.0367	0.0310	< 0.0003	0.0072	0.0141	0.0120	0.5625	0.5613	0.5613
16496	08/22/2002	731	< 0.0082	0.0341	0.0315	0.0821	0.1081	0.0369	0.0038	0.0534	0.0118	0.0264	< 0.0003	0.0059	0.0397	0.0354	< 0.0003	0.0081	0.0161	0.0131	0.5135	0.5119	0.5119
13342	08/23/2002	509	0.0194	0.0477	0.0509	0.0974	0.1259	0.0373	0.0037	0.0747	0.0136	0.0403	< 0.0003	0.0067	0.0511	0.0511	< 0.0001	0.0106	0.0208	0.0181	0.6695	0.6693	0.6693
13337	08/24/2002	524	0.0202	0.0424	0.0443	0.0916	0.1164	0.0410	0.0036	0.0687	0.0145	0.0399	< 0.0003	0.0076	0.0553	0.0553	< 0.0003	0.0141	0.0248	0.0197	0.6598	0.6595	0.6595
13309	08/25/2002	532	0.0201	0.0303	0.0306	0.0545	0.0677	0.0289	0.0024	0.0545	0.0100	0.0252	< 0.0002	0.0048	0.0391	0.0427	< 0.0002	0.0084	0.0162	0.0154	0.4509	0.4508	0.4508
16618	08/26/2002	505	0.0174	0.0566	0.0554	0.0905	0.1164	0.0457	0.0044	0.0673	0.0147	0.0327	< 0.0002	0.0059	0.0455	0.0475	< 0.0001	0.0101	0.0188	0.0166	0.6459	0.6458	0.6458
13338	08/26/2002	544	0.0145	0.0368	0.0349	0.0717	0.0938	0.0379	0.0035	0.0662	0.0143	0.0369	< 0.0004	0.0086	0.0607	0.0588	< 0.0005	0.0142	0.0256	0.0222	0.6011	0.6006	0.6006
11264	08/27/2002	268	0.0247	0.1463	0.1392	0.2698	0.3108	0.1377	0.0125	0.1493	0.0381	0.0754	< 0.0007	0.0142	0.1045	0.0896	< 0.0004	0.0250	0.0560	0.0313	1.6247	1.6241	1.6241
15979	08/27/2002	522	0.0213	0.0971	0.0950	0.1759	0.2107	0.0715	0.0077	0.1073	0.0259	0.0536	< 0.0005	0.0126	0.0900	0.0747	< 0.0004	0.0222	0.0490	0.0274	1.1426	1.1422	1.1422
11270	08/28/2002	508	0.0224	0.1128	0.1157	0.2087	0.2480	0.0846	0.0089	0.1181	0.0325	0.0669	< 0.0005	0.0138	0.0984	0.0807	< 0.0004	0.0224	0.0508	0.0278	1.3132	1.3128	1.3128
15908	08/29/2002	503	0.0133	0.0199	0.0264	0.0501	0.0791	0.0203	0.0016	0.0402	0.0064	0.0181	< 0.0003	0.0038	0.0322	0.0332	< 0.0003	0.0066	0.0149	0.0107	0.3771	0.3768	0.3768
13336	08/29/2002	523	< 0.0069	0.0327	0.0424	< 0.0765	0.1128	0.0346	0.0033	0.0574	0.0117	0.0300	< 0.0004	0.0071	0.0518	0.0501	< 0.0003	0.0120	0.0260	0.0182	0.5446	0.5150	0.5150
11252	08/30/2002	703	0.0121	0.0259	0.0299	0.0637	0.0920	0.0245	0.0023	0.0384	0.0077	0.0188	< 0.0002	0.0038	0.0284	0.0282	< 0.0001	0.0062	0.0138	0.0101	0.4059	0.4057	0.4057
17971	08/31/2002	522	0.0121	0.0456	0.0492	0.0931	0.1374	0.0354	0.0037	0.0529	0.0113	0.0259	< 0.0004	0.0044	0.0370	0.0356	< 0.0003	0.0080	0.0167	0.0119	0.5804	0.5801	0.5801
13363	08/31/2002	560	< 0.0037	0.0152	0.0216	0.0350	0.0543	0.0163	0.0011	0.0334	0.0048	0.0145	< 0.0003	0.0028	0.0225	0.0248	< 0.0004	0.0046	0.0104	0.0086	0.2719	0.2696	0.2696
11200	09/02/2002	508	0.0091	0.0102	0.0122	0.0110	0.0122	0.0047	0.0004	0.0181	0.0035	0.0075	< 0.0003	0.0032	0.0240	0.0220	< 0.0002	0.0079	0.0213	0.0126	0.1803	0.1800	0.1800
16622	09/02/2002	529	< 0.0127	0.0195	0.0204	0.0195	0.0420	0.0093	0.0009	0.0236	0.0041	0.0093	< 0.0002	0.0023	0.0174	0.0155	< 0.0005	0.0054	0.0129	0.0087	0.2219	0.2198	0.2198
11292	09/03/2002	610	0.0170	0.0682	0.1098	0.0951	0.1066	0.0377	0.0041	0.0607	0.0182	0.0385	< 0.0005	0.0098	0.0770	0.0646	< 0.0003	0.0234	0.0485	0.0300	0.8098	0.8094	0.9489
11292-dup	09/03/2002	716	< 0.0190	0.1345	0.1480	0.1480	0.1592	0.0482	0.0059	0.0838	0.0216	0.0461	< 0.0005	0.0115	0.0894	0.0712	< 0.0001	0.0240	0.0490	0.0307	1.0896	1.0883	
11280	09/04/2002	501	< 0.0172	0.0828	0.1038	0.1651	0.2371	0.0547	0.0059	0.0918	0.0224	0.0499	< 0.0003	0.0098	0.0699	0.0539	< 0.0002	0.0172	0.0337	0.0246	1.0383	1.0364	1.0364
14560	09/04/2002	622	< 0.0058	0.0087	0.0130	0.0235	0.0341	0.0109	0.0007	0.0246	0.0037	0.0111	< 0.0002	0.0024	0.0186	0.0235	< 0.0002	0.0038	0.0072	0.0079	0.1989	0.1980	0.1980
13341	09/05/2002	509	< 0.0122	0.0187	0.0279	0.0395	0.0585	0.0193	0.0014	0.0432	0.0092	0.0253	< 0.0002	0.0061	0.0472	0.0424	< 0.0001	0.0120	0.0236	0.0196	0.4052	0.4039	0.4039
13339	09/06/2002	304	< 0.0148	0.0365	0.0497	0.0849	0.1138	0.0378	0.0042	0.0720	0.0171	0.0428	< 0.0004	0.0093	0.0734	0.0635	< 0.0002	0.0168	0.0329	0.0306	0.7004	0.7000	0.7000
13340	09/06/2002	367	< 0.0124	0.0175	0.0234	0.0338	0.0474	0.0166	0.0012	0.0398	0.0076	0.0221	< 0.0002	0.0050	0.0422	0.0373	< 0.0002	0.0092	0.0180	< 0.0036	0.3373	0.3370	0.3370
16213	09/10/2002	557	0.0124	0.0110	0.0151	0.0230	0.0293	0.0145	0.0011	0.0294	0.0055	0.0160	< 0.0002	0.0035	0.0307	0.0334	< 0.0002	0.0064	0.0133	0.0115	0.2561	0.2560	0.2560
13589	09/10/2002	512	0.0141	0.0125	0.0154	0.0195	0.0275	0.0104	0.0015	0.0248	0.0041	0.0117	< 0.0002	0.0022	0.0213	0.0227	< 0.0001	0.0040	0.0092	0.0078	0.2089	0.2088	0.2088
11193	09/11/2002	508	0.0531	0.0262	0.0346	0.0360	0.0630	0.0179	0.0017	0.0531	0.0150	0.0368	< 0.0001	0.0084	0.0539	0.0415	< 0.0001	0.0106	0.0203	0.0154	0.4876	0.4875	0.4875
15464	09/11/2002	318	< 0.0101	0.0116	0.0189	0.0201	0.0283	0.0126	0.0010	0.0267	0.0049	0.0138	< 0.0002	0.0028	0.0223	0.0252	< 0.0003	0.0053	0.0099	0.0099	0.2220	0.2200	0.2200
11261	09/12/2002	532	0.0141	0.0419	0.0568	0.1028	0.1276	0.0445	0.0047	0.0602	0.0160	0.0348	< 0.0003	0.0068	0.0461	0.0382	< 0.0001	0.0105	0.0197	0.0154	0.6402	0.6400	0.6400
11287	09/12/2002	508	0.0077	0.0317	0.0498	0.0537	0.0626	0.0191	0.0028	0.0400	0.0108	0.0226	0.0003	0.0065	0.0459	0.0360	< 0.0002	0.0114	0.0222	0.0157	0.4391	0.4391	0.4391
16499	09/13/2002	509	0.0086	0.0291	0.0344	0.0741	0.1055	0.0275	0.0031	0.0530	0.0108	0.0271	< 0.0003	0.0059	0.0464	0.0409	< 0.0001	0.0110	0.0218	0.0196	0.5190	0.5188	0.5183
16499-dup	09/13/2002	529	0.0091	0.0308	0.0365	0.0756	0.1021	0.0285	0.0030	0.0529	0.0108	0.0268	< 0.0002	0.0055	0.0463	0.0408	< 0.0001	0.0102	0.0198	0.0187	0.5178	0.5177	

Table 7.2 Total PCB Concentrations in Water (ng/L) - Cont'd

Station ID	Date	Volume (L)	PCB 8	PCB 30/18	PCB 28/20	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 113/90/101	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 138/163/129	PCB 153/168	PCB 169	PCB 170	PCB 193/180	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Fall 2002																							
11261	10/21/2002	422	0.0175	0.0429	0.0453	0.0995	0.1173	0.0377	0.0030	0.0382	0.0100	0.0258	< 0.0002	0.0047	0.0469	0.0419	< 0.0001	0.0065	0.0133	0.0107	0.5613	0.5611	0.5611
13341	10/24/2002	651	0.0060	0.0152	0.0209	0.0402	0.0482	0.0172	0.0014	0.0353	0.0061	0.0187	< 0.0002	0.0055	0.0584	0.0424	< 0.0002	0.0120	0.0252	0.0221	0.3751	0.3749	0.3749
13342	10/29/2002	712	0.0150	0.0725	0.0742	0.1053	0.1320	0.0479	0.0041	0.0618	0.0147	0.0344	0.0002	0.0070	0.0520	0.0421	< 0.0002	0.0108	0.0218	0.0176	0.7135	0.7134	0.7134
16499	10/30/2002	715	< 0.0170	0.1930	0.2154	0.3301	0.3455	0.1399	0.0080	0.1622	0.0340	0.0713	0.0004	0.0151	0.1189	0.0881	< 0.0001	0.0215	0.0400	0.0338	1.8341	1.8340	1.8340
13363	10/31/2002	727	0.0296	0.1076	0.1188	0.1513	0.1967	0.0624	0.0044	0.0605	0.0168	0.0362	< 0.0003	0.0061	0.0426	0.0316	< 0.0003	0.0074	0.0154	0.0133	0.9011	0.9009	0.9009
15979	11/01/2002	662	0.0826	0.3310	0.3580	0.3988	0.5181	0.1903	0.0136	0.1918	0.0468	0.1073	0.0005	0.0189	0.1360	0.0967	< 0.0003	0.0255	0.0491	0.0409	2.6061	2.6059	2.6059
13336	11/05/2002	570	0.0256	0.0542	0.0793	0.0860	0.0935	0.0467	0.0042	0.0526	< 0.0191	0.0386	< 0.0007	0.0070	0.0491	0.0404	< 0.0004	0.0158	0.0232	0.0156	0.6463	0.6407	0.6407
11280	11/06/2002	703	0.0523	0.0737	0.1127	0.0825	0.0896	0.0390	0.0044	0.0626	0.0218	0.0498	< 0.0010	0.0108	0.0811	0.0612	< 0.0012	0.0283	0.0418	0.0262	0.8388	0.8377	0.8377
11292	11/07/2002	722	0.0342	0.0479	0.0573	0.0542	0.0686	0.0229	< 0.0029	0.0429	0.0130	0.0291	< 0.0005	0.0089	0.0568	0.0429	< 0.0005	0.0169	0.0321	0.0233	0.5537	0.5525	0.5525
13344	11/08/2002	711	0.0115	0.0222	0.0322	0.0406	0.0489	0.0194	0.0016	0.0328	0.0080	0.0214	< 0.0002	0.0035	0.0267	0.0245	< 0.0002	0.0063	0.0097	0.0080	0.3177	0.3175	0.3175
13355	11/11/2002	498	0.0249	0.0325	0.0434	0.0456	0.0546	0.0217	0.0020	0.0450	< 0.0116	0.0267	< 0.0003	0.0058	0.0390	0.0349	< 0.0004	0.0139	0.0197	0.0133	0.4314	0.4275	0.4275
13338	11/12/2002	476	0.0475	0.0525	0.0624	0.0855	0.1113	0.0439	0.0034	0.0840	0.0197	0.0462	< 0.0006	0.0101	0.0714	0.0588	< 0.0007	0.0166	0.0313	0.0269	0.7723	0.7717	0.7717
14560	11/13/2002	703	0.0199	0.0245	0.0253	0.0344	0.0458	0.0158	< 0.0019	0.0286	0.0060	0.0149	< 0.0005	0.0030	0.0202	0.0185	< 0.0005	0.0046	0.0087	0.0077	0.2793	0.2778	0.2778
11252	11/14/2002	706	0.0174	0.0317	0.0351	0.0452	0.0557	0.0239	< 0.0017	0.0395	0.0067	0.0174	< 0.0004	0.0027	0.0225	0.0217	< 0.0005	0.0052	0.0101	0.0091	0.3457	0.3449	0.3296
11252-dup	11/14/2002	707	0.0163	0.0272	0.0294	0.0446	0.0569	0.0231	< 0.0023	0.0359	0.0061	0.0165	< 0.0003	0.0025	0.0182	0.0170	< 0.0005	0.0047	0.0088	0.0072	0.3158	0.3142	
17971	11/18/2002	708	0.0116	0.0407	0.0531	0.0689	0.0922	0.0410	0.0030	0.0404	0.0109	0.0271	< 0.0002	0.0045	0.0339	0.0297	< 0.0002	0.0075	0.0133	0.0110	0.4890	0.4888	0.4803
17971-dup	11/18/2002	711	0.0105	0.0406	0.0450	0.0727	0.0882	0.0345	< 0.0030	0.0457	0.0110	0.0248	< 0.0004	0.0048	0.0323	0.0284	< 0.0007	0.0072	0.0135	0.0105	0.4729	0.4719	
15464	11/19/2002	702	0.0083	0.0111	0.0138	0.0158	0.0222	0.0108	0.0007	0.0131	0.0030	0.0091	< 0.0002	0.0017	0.0124	0.0138	< 0.0002	0.0032	0.0057	0.0053	0.1501	0.1500	0.1500
11193	11/20/2002	709	0.0395	0.0312	0.0389	0.0377	0.0508	0.0186	0.0015	0.0339	0.0094	0.0264	< 0.0002	0.0042	0.0319	0.0250	< 0.0001	0.0055	0.0124	0.0093	0.3762	0.3761	0.3761
11200	11/21/2002	707	0.0122	0.0154	0.0191	0.0113	0.0137	0.0045	< 0.0004	0.0089	0.0021	0.0055	< 0.0002	0.0012	0.0091	0.0085	< 0.0001	0.0020	0.0050	0.0042	0.1232	0.1229	0.1229
Spring 2003																							
11264	06/02/2003	702	< 0.0214	0.1142	0.0876	0.2236	0.2835	0.0912	< 0.0048	0.1168	0.0211	0.0456	< 0.0023	0.0080	0.0570	0.0442	< 0.0010	0.0137	0.0239	0.0205	1.1760	1.1717	1.1398
11264-dup	06/02/2003	701	< 0.0190	0.1070	0.0827	0.2254	0.2568	0.0827	0.0056	0.1084	0.0197	0.0414	< 0.0022	0.0083	0.0571	0.0428	< 0.0011	0.0126	0.0227	0.0193	1.1113	1.1080	
11280	06/11/2003	700	< 0.0191	0.1089	0.1043	0.1571	0.1729	0.0504	0.0061	0.0786	0.0203	0.0457	< 0.0004	0.0091	0.0714	0.0586	< 0.0002	0.0150	0.0296	0.0204	0.9670	0.9658	0.9658
11287	06/17/2003	706	0.2732	0.1262	0.1418	0.1204	< 0.1119	0.0524	0.0081	0.1020	0.0382	0.0708	< 0.0009	0.0239	0.1700	0.1218	< 0.0004	0.0482	0.0836	0.0510	1.5442	1.5435	1.5435
11270	06/18/2003	702	0.0387	0.1477	0.1809	0.2821	0.3162	0.1182	0.0161	0.1524	0.0484	0.0983	< 0.0010	0.0209	0.1510	0.1111	< 0.0003	0.0308	0.0568	0.0409	1.8114	1.8110	1.8110

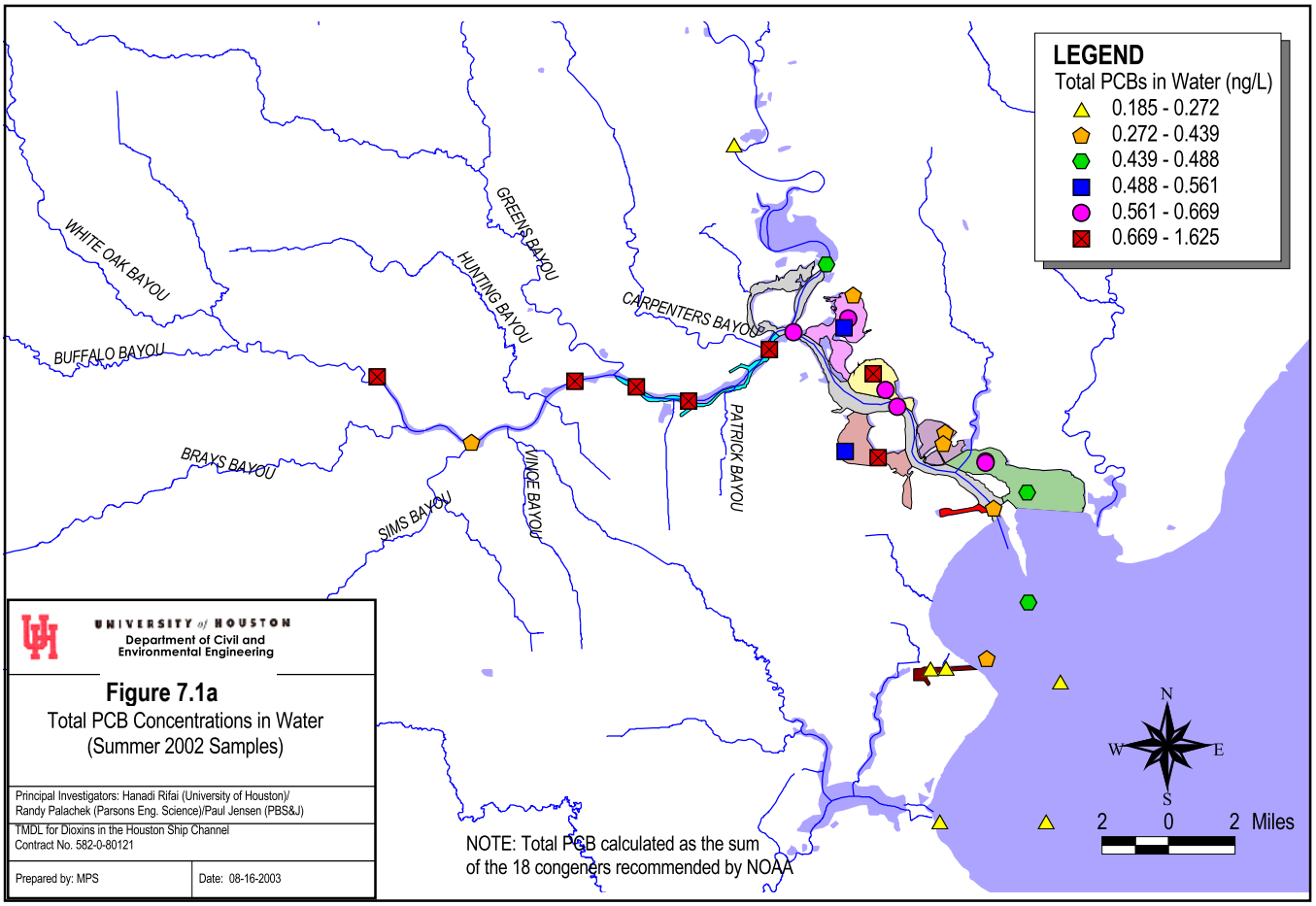
Total PCB concentration calculated as the sum of the 18 congeners recommended by NOAA
If either the dissolved or suspended concentration was non-detected, the total concentration in water is reported here as less than the sum of the detected concentration and the MDL for the non-detected phase. If a congener was non-detected in both phases, the total concentration in wat
is reported as less than the sum of the MDLs for both phases.

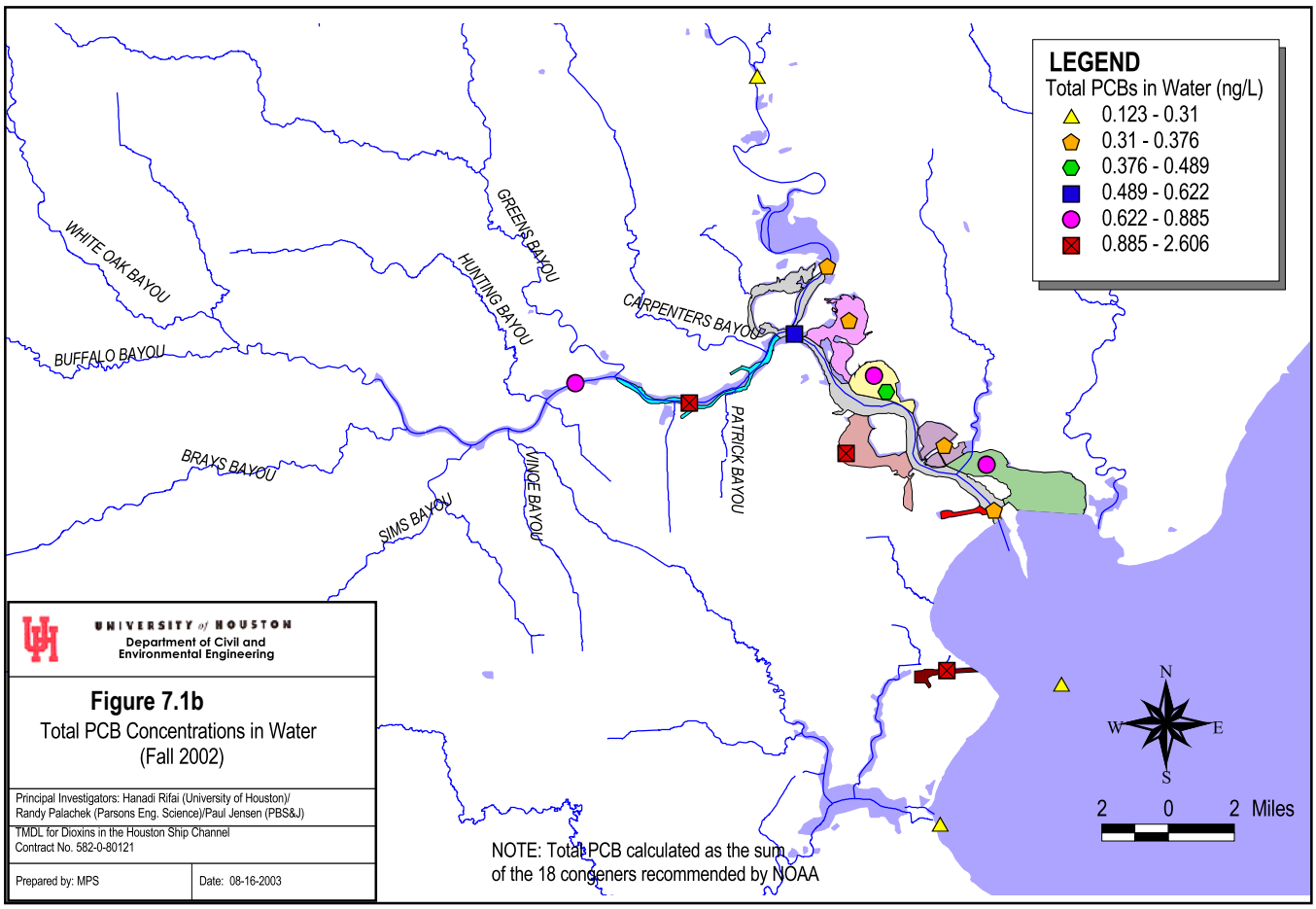
[a] Non-detects assumed to be 1/2 detection limit

[b] Non-detects assumed to be zero

[c] Average of duplicate samples, otherwise concentration of a single sample

Exceeds the WQS (0.885 ng/L)


LEGEND
Total PCBs in Water (ng/L)
0.185 - 0.272
0.272 - 0.439
0.439 - 0.488
0.488 - 0.561
0.561 - 0.669
0.669 - 1.625
WHITE OAK BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
BUFFALO BAYOU
PATRICK BAYOU
BRAYS BAYOU
VINCE BAYOU
SIMS BAYOU
N
W
E
S
2 0 2 Miles
NOTE: Total PCB calculated as the sum of the 18 congeners recommended by NOAA
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.1a
Total PCB Concentrations in Water
(Summer 2002 Samples)
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-16-2003


LEGEND
Total PCBs in Water (ng/L)
0.123 - 0.31
0.31 - 0.376
0.376 - 0.489
0.489 - 0.622
0.622 - 0.885
0.885 - 2.606
WHITE OAK BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
BUFFALO BAYOU
PATRICK BAYOU
BRAYS BAYOU
VINCE BAYOU
SIMS BAYOU
N
W
E
S
2 0 2 Miles
NOTE: Total PCB calculated as the sum of the 18 congeners recommended by NOAA
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.1b
Total PCB Concentrations in Water
(Fall 2002)
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-16-2003

ng/L with an average of 1.36 ng/L. The four stations sampled in Spring 2003 exceeded the Texas WQS for total PCBs.

Figure 7.2 shows the concentration distribution for the 18 NOAA congeners and total PCBs in dissolved and suspended phases for the three sampling events. The dissolved concentrations for the individual PCBs ranged from 0.00002 to 0.453 ng/L, while the suspended concentrations varied between 0.00002 and 0.114 ng/L. Overall, congener concentrations in dissolved water were greater than those in the suspended phase for the lower chlorinated PCBs with the exception of PCB-8. Average suspended/dissolved ratios for PCB-18 through PCB-101 vary between 0.34 and 0.85, while the average suspended/dissolved ratio for PCB-8 is 3.64 and for PCB-105 to PCB-187 it varies between 1.16 and 3.44. Concentrations of PCBs with the same number of chlorines are similar. On average, up to 50% of the dissolved total PCB concentration is attributable to congeners 28, 44, and 52. The total PCB concentration in suspended sediments, on the other hand, is distributed almost evenly among all but 2 congeners.

7.3.2 Sediment

PCB results from the in-channel sediment samples collected in Work Order No.4 are included in Table 7.3. Total PCB levels in Summer 2002 sediment samples varied between 56 and 1,445,307 ng/kg-dry wt. with a mean value of 61,366 ng/kg-dry wt. Similarly, Fall 2002 sediment samples exhibited total PCB concentrations between 76 and 1,117,233 ng/kg-dry wt. with a mean value of 82,986 ng/kg-dry wt. Total PCB concentrations in sediment samples collected in Spring 2003 ranged between 70 and 810,877 ng/kg-dry wt. with an average value of 40,537 ng/kg-dry wt. Figure 7.3 shows the distribution of total PCB concentrations along the HSC system for the different sampling events.

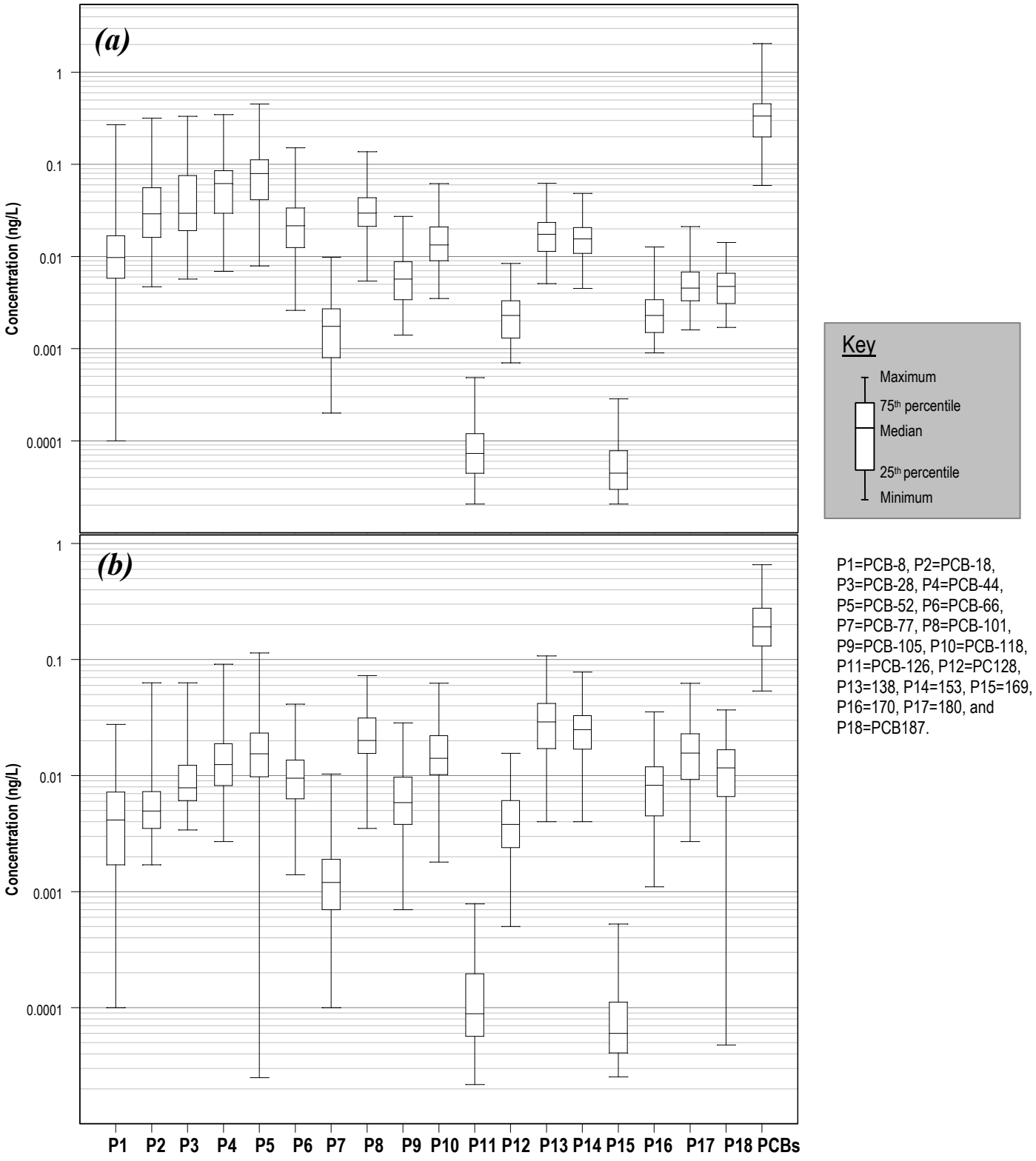


Figure 7.2 Distribution of Individual PCB Congeners in the Dissolved and Suspended Phases
(a) Dissolved (b) Suspended

Table 7.3 PCB Concentrations in Sediment (ng/kg-dry wt.)

Station ID	Date	PCB 8	PCB 30/18	PCB 28/20	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 113/90/101	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 138/163/129	PCB 153/168	PCB 169	PCB 170	PCB 193/180	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Summer 2002																						
11272	07/25/2002	87	78.6	190	241	247	238	< 48.1	227	88.6	223	< 48.1	< 48.1	283	257	< 48.1	92.2	213	132	2693.6	2597.4	2597.4
11298	07/29/2002	579	767	1780	2710	3200	1400	271	4550	1230	2800	< 47.3	880	6370	4440	< 47.3	2750	6130	4040	43944.3	43897.0	43897.0
11274	07/30/2002	9030	8670	22300	7580	7400	16800	2100	8570	5290	9890	139	2230	11600	7330	< 47.9	1590	3530	1700	125773.0	125749.0	125749.0
11111	07/31/2002	215	90.3	336	189	195	119	50	275	133	372	< 49.5	72.9	545	511	< 49.5	152	287	183	3774.7	3725.2	3725.2
11092	08/01/2002	578	711	1670	1110	1270	1080	122	1670	488	1330	< 98.7	318	1580	1490	< 98.7	485	1060	670	15730.7	15632.0	15632.0
11258	08/01/2002	< 48.8	< 48.8	72.4	57.2	64	< 48.8	< 48.8	56.3	< 48.8	< 48.8	< 48.8	< 48.8	51.4	< 48.8	< 48.8	< 48.8	< 48.8	< 48.8	618.5	301.3	301.3
13340	08/06/2002	< 49.9	121	< 49.9	< 49.9	< 49.9	< 49.9	< 49.9	1740	300	1060	< 49.9	239	1580	1410	< 49.9	575	1230	828	9282.6	9083.0	9083.0
13341	08/06/2002	127	122	339	536	702	< 49.5	53.9	1100	292	834	< 49.5	258	1800	1580	< 49.5	455	1040	522	9835.2	9760.9	9760.9
11193	08/08/2002	1090	75.7	259	326	585	283	< 49.6	934	369	976	< 49.6	217	1480	1060	< 49.6	321	663	322	9035.1	8960.7	8960.7
11347	08/12/2002	97.8	136	400	698	1070	775	157	6520	3940	8260	58.1	1590	9000	4940	< 49.9	1270	1970	910	41816.9	41791.9	41791.9
11382	08/12/2002	< 49.8	370	1130	1290	1550	809	178	2190	851	1600	< 49.8	569	3150	1970	< 49.8	858	1810	1010	19409.7	19335.0	19335.0
11305	08/13/2002	246	429	939	1740	1130	103	102	2200	559	1250	< 48.6	496	4630	3840	< 48.6	1980	4720	2100	26512.6	26464.0	27159.0
11305-dup	08/13/2002	315	490	1120	2090	1340	148	137	2370	679	1580	< 49.7	735	5700	4870	< 49.7	1460	3150	1670	27903.7	27854.0	
13337	08/14/2002	326	234	929	1050	1120	< 49.6	103	926	323	830	< 49.6	175	1210	1010	< 49.6	293	631	380	9614.4	9540.0	9540.0
13363	08/16/2002	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	< 49.1	56	< 49.1	< 49.1	< 49.1	473.4	56.0	56.0
13589	08/16/2002	< 50.5	< 50.5	88.7	93.6	121	77.2	< 50.5	< 50.5	< 50.5	< 50.5	< 50.5	< 50.5	165	126	< 50.5	< 50.5	< 50.5	< 50.5	974.5	671.5	671.5
15464	08/16/2002	< 49.6	< 49.6	69.9	55.2	56	54.6	< 49.6	< 49.6	< 49.6	< 49.6	< 49.6	< 49.6	54.7	52.2	< 49.6	< 49.6	< 49.6	< 49.6	640.2	342.6	342.6
17970	08/18/2002	< 48.6	< 48.6	88.7	57.9	69.4	69.3	< 48.6	69.1	< 48.6	63.6	< 48.6	< 48.6	102	95	< 48.6	< 48.6	< 48.6	< 48.6	858.0	615.0	615.0
13355	08/18/2002	< 45	< 45	88.7	50.7	60.3	65.6	< 45	86.4	< 45	72.5	< 45	< 45	130	106	< 45	< 45	< 45	< 45	885.2	660.2	660.2
11261	08/19/2002	92.7	112	238	390	433	278	< 49.6	460	123	283	< 49.6	92.5	708	715	< 49.6	238	571	404	5212.6	5138.2	5138.2
13343	08/20/2002	68.2	96.2	253	245	282	247	< 49.1	236	105	235	< 49.1	65.5	399	284	< 49.1	93.8	191	121	2995.4	2921.7	2921.7
11264	08/20/2002	646	921	1830	3170	3830	2370	257	4910	1890	4260	< 49	1090	6030	4080	< 49	892	1620	834	38679.0	38630.0	38630.0
16618	08/20/2002	550	229	352	469	669	317	< 43.9	677	186	564	< 43.9	84.2	601	468	< 43.9	153	319	194	5898.1	5832.2	5832.2
16496	08/21/2002	198	165	547	969	1140	949	107	1700	325	947	< 47.3	239	1550	1520	< 47.3	< 47.3	987	650	12064.0	11993.0	11993.0
11302	08/21/2002	875	766	1790	1090	1040	< 48.8	157	1170	564	1200	< 48.8	346	2570	1870	< 48.8	548	1220	606	15885.2	15812.0	15812.0
13338	08/21/2002	746	1100	1990	3500	3820	1700	233	3990	902	2370	< 48.3	501	3690	3370	< 48.3	910	1960	1380	32210.3	32162.0	33420.5
13338-dup	08/21/2002	845	1040	2110	3840	4090	3060	243	3910	940	2490	< 46.8	490	3580	3250	< 46.8	981	2190	1620	34725.8	34679.0	
13342	08/21/2002	197	221	632	1300	1510	773	122	2030	446	1170	< 48.7	245	1720	1500	< 48.7	620	1130	833	14497.7	14449.0	14449.0
13344	08/21/2002	212	202	608	845	969	939	128	1120	394	1040	< 48.7	252	1770	1570	< 48.7	399	693	585	11774.7	11726.0	11726.0
13339	08/22/2002	238	247	643	1230	1480	694	118	1880	410	1100	< 47.1	275	1920	1740	< 47.1	522	1170	1060	14774.1	14727.0	14727.0
16499	08/22/2002	304	315	783	1750	1960	1240	131	2340	524	1250	< 46.9	353	2840	2970	< 46.9	1060	2550	1870	22286.9	22240.0	22240.0
17971	08/24/2002	275	267	808	2270	1560	907	174	2600	643	1680	< 49.7	501	5270	5620	< 49.7	2630	5590	3260	34104.7	34055.0	35217.0
17971-dup	08/24/2002	208	263	862	2980	2250	1070	179	3220	652	1730	< 44.8	645	5860	6110	< 44.8	2220	4960	3170	36423.8	36379.0	
11287	08/26/2002	667	684	1380	1700	1730	880	154	2120	602	1400	< 49.2	382	2600	2110	< 49.2	763	1620	1120	19961.2	19912.0	19912.0
11252	08/27/2002	< 47.3	52.3	131	135	147	149	< 47.3	80	85	63.1	< 47.3	< 47.3	86	83	< 47.3	< 47.3	< 47.3	< 47.3	1200.6	1011.4	684.2
11252-dup	08/27/2002	< 48.9	< 48.9	91.3	71.2	77.2	60	< 48.9	57.3	< 48.9	< 48.9	< 48.9	< 48.9	< 48.9	< 48.9	< 48.9	< 48.9	< 48.9	< 48.9	674.9	357.0	
13336	08/27/2002	116	106	326	231	260	375	< 47.8	387	132	446	< 47.8	69.8	531	678	< 47.8	147	274	202	4352.5	4280.8	4324.2
13336-dup	08/27/2002	152	119	362	340	361	470	< 49.4	416	107	388	< 49.4	53.5	396	566	< 49.4	147	286	204	4441.6	4367.5	
11273	08/28/2002	20200	64300	124000	265000	306000	171000	17000	105000	45800	83700	423	12900	82600	63300	244	13800	25500	17400	1418167.0	1418167.0	1445307.7
11273-dup	08/28/2002	24700	61500	132000	264000	317000	161000	19000	140000	48800	80200	669	12600	81100	61300	79.3	16700	32300	19500	1472448.3	1472448.3	
11270	08/28/2002	2960	2560	6170	11200	10900	8660	458	10200	1540	6320	< 49	987	6770	6730	< 49	1210	2660	2040	81414.0	81365.0	81365.0
11280	08/29/2002	< 1490	2210	4830	8420	8220	4070	580	11000	2660	6950	< 97.7	1370	11500	10500	< 97.7	4950	11700	6600	96402.7	95560.0	95560.0
13309	08/30/2002	67.5	87.8	196	197	225	224	< 44.6	244	97.7	240	< 44.6	53.6	325	249	< 44.6	57.7	118	69.1	2518.3	2451.4	2451.4
14560	08/30/2002	132	157	378	450	460	496	< 46.5	531	186	487	< 46.5	124	879	800	< 46.5	226	477	306	6158.8	6089.0	6089.0
16622	09/03/2002	84.7	152	394	619	728	368	51.6	836	210	478	< 48.5	123	699	670	< 48.5	185	451	345	6442.8	6394.3	6394.3
11200	09/03/2002	< 45.6	< 45.6	88.9	46.6	53.1	58.3	< 45.6	50.2	< 45.6	46.9	< 45.6	< 45.6	78.1	62.3	< 45.6	< 45.6	< 45.6	< 45.6	712.4	484.4	419.8
11200-dup	09/03/2002	< 47.9	< 47.9	96.2	< 47.9	52.1	60	< 47.9	< 47.9	< 47.9	< 47.9	< 47.9	< 47.9	75.1	71.7	< 47.9	< 47.9	< 47.9	< 47.9	666.5	355.1	
15979	09/04/2002	11300	4310	6480	13300	21000	7710	956	21300	5330	14800	63.7	2900	22400	20000	< 46.8	4840	11300	6970	174983.1	174959.7	154092.0
15979-dup	09/04/2002	9060	3290	5240	10500	15800	5640	735	16900	3990	9020	59.2	2100	17600	15600	< 45.9	3640	8480	5570	133247.2	133224.2	
11292	09/05/2002	1010	2090	5020	8410	6320	3480	523	8120	2260	5530	54.5	1850	15400	14200	< 49.7	4750	10300	7270	96612.4	96587.5	96587.5
11300	09/05/2002	4900	4680	10300	17800	23300	10200	1960	43500	9750	25500	293	8190	55800	48500	57.8	9890	21800	15700	312120.8	312120.8	311932.3
11300-dup	09/05/2002	8170	6810	13700	20100	25600	10900	1880	39000	9480	24000	299	7750	53800	46300	54.7	9000	20000	14900	311743.7	311743.7	
15908	09/11/2002	< 46.9	53.5	126	127	< 46.9	74	< 46.9	151	< 46.9	83.9	< 46.9	< 46.9	81.1	88.3	< 46.9	< 46.9	47.5	51	1070.9	883.3	883.3
16213	09/11/2002	126	66.2	167	245	290	194	< 45.7	428	79.9	463	< 45.7	54.7	376	482	< 45.7	97.2	198	204	3539.6	3471.0	3471.0
Fall 2002																						
13338	10/22/2002	200	209	517	693	777	568	63.9	820	247	634	< 48.8	131	872	795	< 48.8	261	536	373	7745.7	7696.9	7696.9
13336	10/22/2002	154	174	448	656	746	513	58.9	845	236	613	< 47.5	139	988	907	< 47.5	299	626	421	7871.4	7823.9	7823.9
13340	10/23/2002	150	124	305	645	906	528	57.7	1670	301	1130	< 45.8	244	1780	1730	< 45.8	574	1150	915	12255.5	12209.7	12209.7
11252	10/24/2002	92.2	82.4	222	291	330	272	< 47.2	397	103	299	< 47.2	59.3	387	402	< 47.2	123	240	201	3571.7	3500.9	3500.9
17970	10/24/2002	56.6	65.3	157	159	204	146	< 48.7	215	49.8	167	< 48.7	< 48.7	156	143	< 48.7	< 48.7	63.9	49.7	1754.1	1632.3	1632.3

Table 7.3 PCB Concentrations in Sediment (ng/kg-dry wt.) - Cont'd

Station ID	Date	PCB 8	PCB 30/18	PCB 28/20	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 113/90/101	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 138/163/129	PCB 153/168	PCB 169	PCB 170	PCB 193/180	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
16499	10/24/2002	172	172	404	863	1090	566	84.5	1630	300	802	< 39.9	197	2400	2980	< 39.9	1010	2580	2040	17330.4	17290.5	17290.5
11261	10/26/2002	104	114	281	498	573	411	55.7	611	195	487	< 48	92.5	592	488	< 48	192	381	255	5378.2	5330.2	5330.2
13344	10/27/2002	217	232	655	1160	1280	1070	131	1550	369	1200	< 46.1	219	1430	1460	< 46.1	420	828	664	12931.1	12885.0	12885.0
17971	10/28/2002	307	289	657	1160	1230	848	95.5	1330	317	956	< 48.3	190	1420	1340	< 48.3	460	935	656	12238.8	12190.5	12190.5
13342	10/30/2002	213	220	641	1290	1460	943	129	1560	457	1170	< 46.6	261	1810	1560	< 46.6	510	991	786	14047.6	14001.0	14001.0
11193	10/31/2002	694	87.6	241	448	653	312	52.8	1330	285	696	< 49.7	217	1710	1770	< 49.7	528	1240	921	11235.1	11185.4	11185.4
13363	11/06/2002	< 49.5	< 49.5	100	92.4	120	79.8	< 49.5	129	< 49.5	72.8	< 49.5	< 49.5	82.4	84.6	< 49.5	< 49.5	< 49.5	< 49.5	1008.5	761.0	761.0
15464	11/06/2002	< 48.3	< 48.3	97.4	67.1	77	61.9	< 48.3	62.5	< 48.3	< 48.3	< 48.3	< 48.3	< 48.3	< 48.3	< 48.3	< 48.3	< 48.3	< 48.3	679.9	365.9	365.9
11200	11/21/2002	< 50	< 50	76.3	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50	501.3	76.3	76.3
11280	12/02/2002	107	2600	5050	7810	6480	4440	472	8480	2120	5490	< 49.9	1520	11700	11300	< 49.9	3750	9040	5300	85708.9	85659.0	103601.5
11280-dup	12/02/2002	2710	3630	6690	11600	9790	6120	641	13200	3230	8080	62.9	2040	14600	14100	< 48.5	5440	12300	7310	121568.2	121543.9	
11292	12/10/2002	20900	33800	49500	59700	81300	45600	4620	110000	24500	47900	431	20800	189000	167000	82.3	54800	133000	74300	1117233.3	1117233.3	1117233.3
Spring 2003																						
11092	04/30/2003	1030	894	1730	1360	1500	736	111	1230	374	956	< 46.5	231	1750	1410	< 46.5	288	628	< 46.5	14297.8	14228.0	14228.0
11258	04/30/2003	222	358	664	819	851	770	79	633	231	557	< 47.7	116	793	674	< 47.7	214	460	278	7766.7	7719.0	7719.0
11272	04/30/2003	< 248	< 248	593	786	881	620	< 248	899	274	688	< 248	< 496	1240	1040	< 248	276	580	383	9128.0	8260.0	8260.0
11274	05/01/2003	1710	2110	4780	4560	4920	3700	520	2930	1390	2820	< 49.2	560	3200	2150	< 49.2	630	1340	772	38141.2	38092.0	41617.5
11274-dup	05/01/2003	1550	2030	4870	6290	6440	4070	491	3750	1600	3350	< 49	706	4360	2970	< 49	599	1320	747	45192.0	45143.0	
11111	05/01/2003	136	111	279	266	309	203	< 47.6	296	72.6	221	< 47.6	< 95.2	353	383	< 47.6	78.2	149	114	3089.8	2970.8	2970.8
11302	05/01/2003	278	487	1150	1430	1460	969	< 239	1750	698	1500	< 239	499	3400	2600	< 239	831	1850	1050	20310.5	19952.0	19952.0
11298	05/02/2003	619	905	1710	2390	2770	1460	< 229	3830	1090	2380	< 229	815	5750	4210	< 229	1930	4240	2810	37252.5	36909.0	36909.0
11273	05/03/2003	11500	42000	80400	118000	134000	132000	11100	70000	23500	38200	539	7590	48600	39700	< 231	9990	20700	12200	800134.5	800019.0	810877.0
11273-dup	05/03/2003	11100	43300	79300	130000	144000	124000	11400	73000	23800	42400	615	8230	51500	40400	< 240	8990	18700	11000	821855.0	821735.0	
11305	05/04/2003	< 795	916	1350	2950	1530	948	< 244	2990	884	2050	< 244	900	6140	4750	< 244	1660	3700	2050	33581.5	32818.0	32818.0
11347	05/04/2003	< 239	310	593	601	695	518	< 239	945	522	1140	< 239	< 478	1720	1160	< 239	394	761	418	10494.0	9777.0	9777.0
13339	05/04/2003	100	78.7	207	231	275	190	< 49.9	328	95.2	250	< 49.9	< 99.9	424	363	< 49.9	98.6	210	161	3136.3	3011.5	3011.5
11287	05/05/2003	486	1010	1880	1390	1340	458	71.4	1100	388	927	< 47.4	337	2260	1810	< 47.4	473	1060	685	15722.8	15675.4	15675.4
11382	05/05/2003	< 235	521	1220	1330	1510	630	< 235	1100	502	938	< 235	< 471	1580	1050	< 235	349	699	397	12531.5	11826.0	11826.0
11270	05/06/2003	335	431	939	1480	1570	1060	127	1020	505	1050	< 49.5	187	1130	847	< 49.5	294	626	369	12019.5	11970.0	11970.0
11280	05/06/2003	1110	1540	3490	5840	6260	3650	507	9030	2600	6630	< 241	1930	12500	9790	< 241	3060	6370	3590	78138.0	77897.0	77897.0
11292	05/06/2003	673	1180	2480	4260	3070	1920	208	4130	1020	2530	65.5	761	5120	4710	< 47.5	1760	4050	2180	40141.3	40117.5	40812.3
16618	05/06/2003	1090	1040	1600	2360	2840	2510	256	4180	998	2670	< 238	723	6230	5700	< 238	2080	4670	2560	41745.0	41507.0	23751.5
11261	05/11/2003	282	149	368	577	703	158	55.9	645	229	563	< 46.4	122	750	639	< 46.4	188	374	193	6042.3	5995.9	5995.9
13342	05/11/2003	197	194	511	979	1150	742	110	1270	356	923	< 48.8	220	1390	1290	< 48.8	471	904	569	11324.8	11276.0	11276.0
13343	05/11/2003	84	97.2	274	359	428	297	< 48.7	382	126	299	< 48.7	< 97.4	484	431	< 48.7	129	248	173	3933.0	3811.2	3811.2
16496	05/11/2003	458	514	1230	2290	2480	1530	136	2100	626	1570	< 50.3	367	2430	2330	< 50.3	701	1510	833	21155.3	21105.0	21105.0
13309	05/12/2003	< 47.8	< 47.8	70.2	< 57.3	< 47.8	< 47.8	< 47.8	< 47.8	< 47.8	< 47.8	< 47.8	< 95.5	< 47.8	< 57.3	< 47.8	< 47.8	< 47.8	< 47.8	509.9	70.2	70.2
14560	05/12/2003	50.9	< 48.9	75	66.9	97.3	55.5	< 48.9	158	< 48.9	125	< 48.9	< 97.8	132	117	< 48.9	< 48.9	< 48.9	< 48.9	1122.1	877.6	877.6
15464	05/12/2003	65.2	56.1	122	87	93.5	98.6	< 50	74.7	< 50	58.6	< 50	< 100	65.8	75.5	< 50	< 50	< 50	< 50	1022.0	797.0	797.0
16213	05/12/2003	62.9	58.6	139	106	126	90.3	< 48.8	114	< 48.8	73	< 48.8	< 97.6	115	121	< 48.8	< 48.8	< 48.8	< 48.8	1225.4	1005.8	1005.8
11193	05/13/2003	3760	151	391	809	1930	261	< 47.8	3490	1360	3330	< 47.8	689	3470	2280	< 47.8	625	1060	421	24098.7	24027.0	24027.0
13589	05/22/2003	272	301	567	274	296	214	< 47.2	112	< 47.2	88.3	< 47.2	< 94.4	116	81.4	< 47.2	< 47.2	60.3	< 47.2	2570.8	2382.0	2382.0
11252	05/28/2003	104	86.2	190	238	255	222	< 49	276	83.5	228	< 49	< 98	272	258	< 49	85.9	171	105	2697.1	2574.6	2768.7
11252-dup	05/28/2003	159	104	237	270	290	260	< 48.1	281	91.8	248	< 48.1	< 96.2	313	291	< 48.1	87	204	127	3083.1	2962.8	
13337	05/28/2003	431	444	1130	1480	1470	1270	102	1300	380	971	< 50	233	1670	1590	< 50	396	843	480	14240.0	14190.0	14190.0
13340	05/28/2003	127	105	240	488	640	366	49.7	1100	225	847	< 45.4	182	1340	1290	< 45.4	494	1010	544	9093.1	9047.7	9047.7
13341	05/28/2003	48.3	< 48.3	69.1	< 58	54.3	< 48.3	< 48.3	62.8	< 48.3	< 48.3	< 48.3	< 96.7	154	127	< 48.3	63.5	141	82.1	1048.5	802.1	802.1
13355	05/28/2003	49.4	< 44.5	75.1	53.6	60	< 44.5	< 44.5	46.8	< 44.5	< 44.5	< 44.5	< 89	47.7	< 53.4	< 44.5	< 44.5	< 44.5	< 44.5	626.3	332.6	332.6
15908	05/28/2003	< 46.3	< 46.3	74.1	65.3	76.5	54.8	< 46.3	76.9	< 46.3	61.9	< 46.3	< 92.7	77.9	77.5	< 46.3	< 46.3	< 46.3	< 46.3	819.6	564.9	564.9
11264	05/29/2003	757	1280	2840	4660	5190	4050	338	3770	1170	2700	< 49	567	3570	3230	< 49	800	1760	1010	37741.0	37692.0	37692.0
11300	05/29/2003	3650	5550	8860	10100	13600	4660	1160	20300	5870	13400	203	4100	28400	25200	219	5250	11600	7250	169372.0	169372.0	169372.0
15979	05/29/2003	283	454	1110	1580	1750	1340	144	1780	552	1250	< 49.6	296	1940	1590	< 49.6	553	1180	639	16490.6	16441.0	16441.0
16622	05/29/2003	238	193	582	590	637	713	49.6	710	160	529	< 49.5	167	834	895	< 49.5	190	423	326	7286.1	7236.6	7236.6

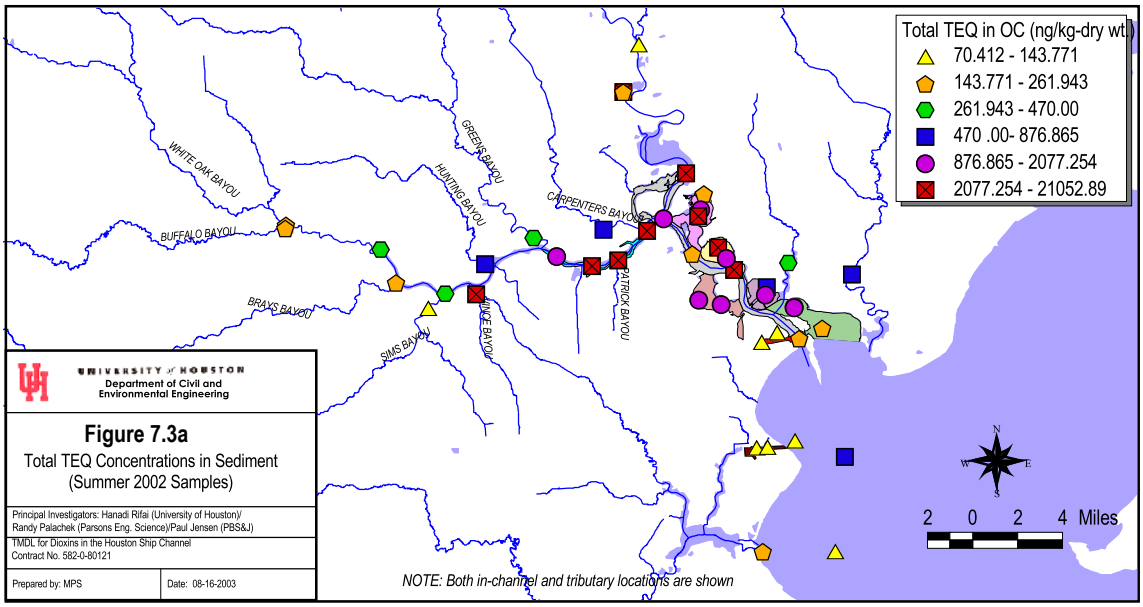
Total PCB concentration calculated as the sum of the 18 congeners recommended by NOAA
Values reported to the Method Reporting Limit

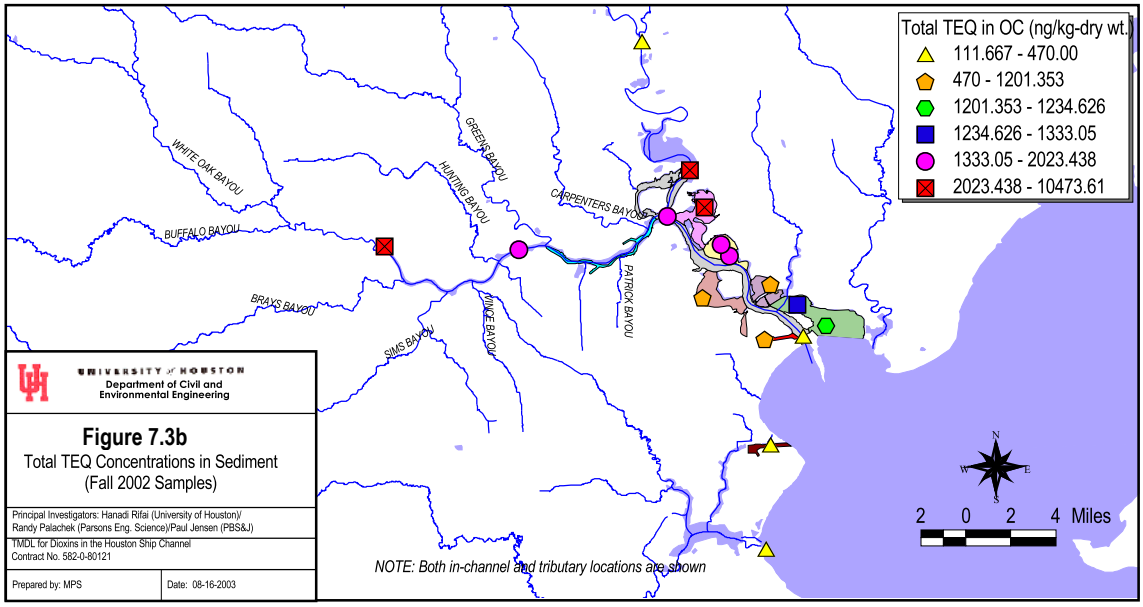
[a] Non-detects assumed to be 1/2 reporting limit

[b] Non-detects assumed to be zero

[c] Average of duplicate samples, otherwise concentration of a single sample

tributary


Total TEQ in OC (ng/kg-dry wt.)
70.412 - 143.771
143.771 - 261.943
261.943 - 470.00
470 .00- 876.865
876.865 - 2077.254
2077.254 - 21052.89
WHITE OAK BAYOU
BUFFALO BAYOU
BRAYS BAYOU
SIMS BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
PATRICK BAYOU
JUICE BAYOU
N
W
E
S
2 0 2 4 Miles
NOTE: Both in-channel and tributary locations are shown
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.3a
Total TEQ Concentrations in Sediment
(Summer 2002 Samples)
Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-16-2003


Total TEQ in OC (ng/kg-dry wt.)
111.667 - 470.00
470 - 1201.353
1201.353 - 1234.626
1234.626 - 1333.05
1333.05 - 2023.438
2023.438 - 10473.61
WHITE OAK BAYOU
BUFFALO BAYOU
BRAYS BAYOU
SIMS BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
PATRICK BAYOU
JUICE BAYOU
N
W
E
S
2 0 2 4 Miles
NOTE: Both in-channel and tributary locations are shown
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.3b
Total TEQ Concentrations in Sediment
(Fall 2002 Samples)
Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-16-2003

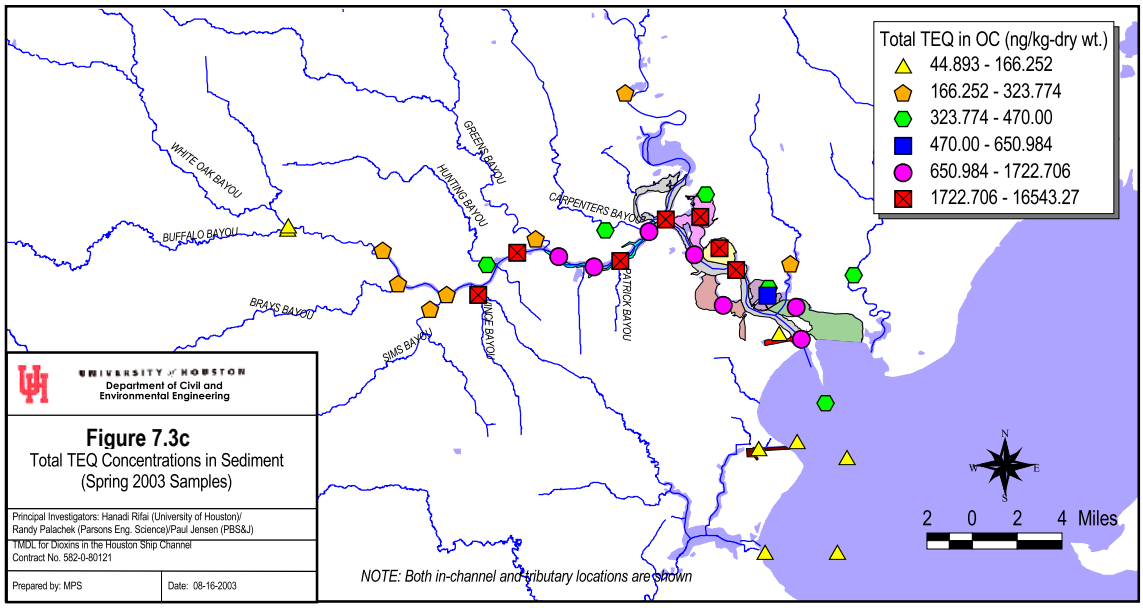

Total TEQ in OC (ng/kg-dry wt.)
44.893 - 166.252
166.252 - 323.774
323.774 - 470.00
470.00 - 650.984
650.984 - 1722.706
1722.706 - 16543.27
WHITE OAK BAYOU
BUFFALO BAYOU
BRAYS BAYOU
SIMS BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
PATRICK BAYOU
JUICE BAYOU
N
W
E
S
2 0 2 4 Miles
NOTE: Both in-channel and tributary locations are shown
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.3c
Total TEQ Concentrations in Sediment
(Spring 2003 Samples)
Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-16-2003

Figure 7.4 shows the concentration distribution for the 18 NOAA congeners and total PCBs in bottom sediments for the three sampling events. Sediment concentrations for the individual PCB congeners ranged from 20 to 317,000 ng/kg dry wt. The average contribution of individual congeners to total PCBs is below 10% for all the compounds with the exception of PCB-138 and PCB-153 that contribute on average 15 and 12%, respectively.

7.3.3 Tissue

PCB concentrations in catfish and crab tissue are included in Tables 7.4 and 7.5, respectively. Total PCB concentrations at the different locations sampled during Summer and Fall 2002 are mapped in Figures 7.5 and 7.6 for catfish and crab, respectively. Total PCB concentrations in catfish samples collected in Summer 2002 varied within the range 2.2- 866.1 ng/g wet wt. with an average value of 81.8 ng/g wet wt. Fall 2002 catfish samples showed concentrations between 36.2 and 115.9 ng/g wet wt. with an average of 64.4 ng/g wet wt. Finally, catfish samples collected during Spring 2003 exhibited concentrations between 8.0 and 303.8 ng/g wet wt. with an average of 104.2 ng/g wet wt. It was found that 59 out of 84 catfish samples (70%) exceeded the TDH Health Assessment Comparison Value (47 ng/g) using summed data of the 18 NOAA congeners.

Total PCB concentrations in crabs varied between 2.2 and 69.5 ng/g wet wt. in the Summer 2002 samples and between 1.9 and 20.2 ng/g wet wt. in Fall 2002 samples with respective averages of 18.2 and 10.9 ng/g wet wt. Only 1 out of 58 crab samples (3%) exceeded the TDH Health Assessment Comparison Value.

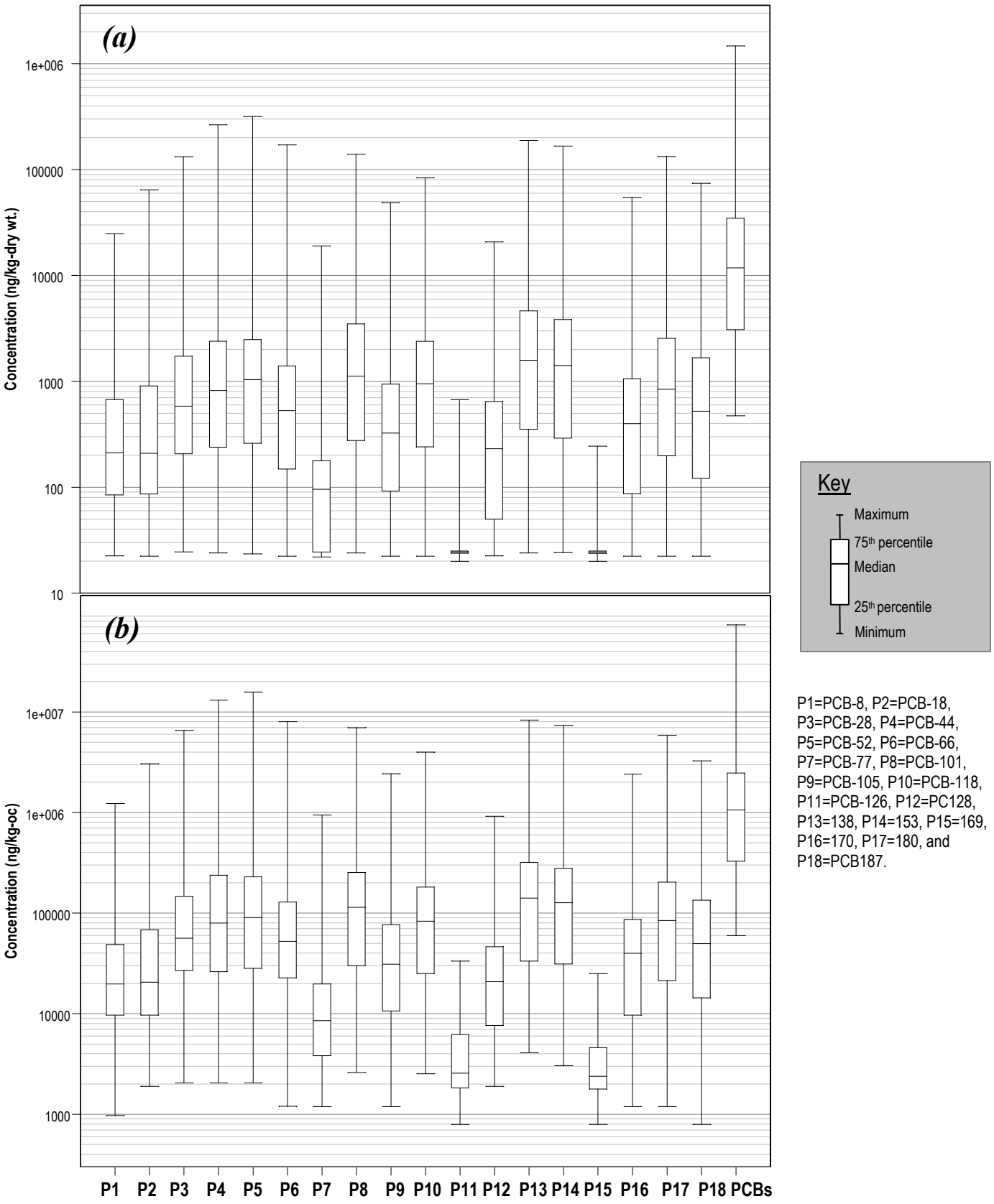


Figure 7.4 Distribution of Individual PCB Congeners in Bottom Sediment
(a) Not normalized (b) OC-normalized

Table 7.4 PCB Concentrations in Catfish Tissue (ng/g-wet wt.)

Station ID	Date	Lipid Content (%)	PCB 8	PCB 18/30	PCB 20/28	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 90/101/113	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 129/138/163	PCB 153/168	PCB 169	PCB 170	PCB 180/193	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Summer 2002																							
11272	07/26/2002	0.5	0.12	0.23	0.61	0.77	1.1	1.3	< 0.02	1.3	0.6	1.8	0.0067	0.31	2.1	2.4	< 0.0046	0.53	1.4	0.88	15.5	15.5	17.1
11272-dup	07/26/2002	0.5	0.14	0.25	0.7	0.88	1.2	1.6	< 0.023	1.6	0.74	2.1	< 0.0094	0.38	2.6	3.1	< 0.0042	0.67	1.7	1	18.7	18.7	
11274	07/30/2002	0.4	0.16	0.52	2.1	5.9	5	6.2	0.043	5.5	3.7	8.7	0.025	1.8	13	13	< 0.013	2.9	7.1	4.4	80.1	80.0	80.0
11111	08/01/2002	1.7	< 0.01	0.051	0.47	2.5	3.1	2.1	0.023	5.2	1.7	6.4	0.075	1.8	15	19	0.014	3	7	7.1	74.5	74.5	74.5
11258	08/01/2002	1.9	< 0.048	0.093	0.48	3.8	2.9	3.2	0.024	5.1	2.4	6.8	0.05	1.6	11	12	0.008	2.2	4.6	3.8	60.1	60.1	60.1
11092	08/02/2002	1.5	0.065	0.1	0.75	1.1	0.79	1.1	0.015	1.5	0.79	2.7	0.017	0.47	3.1	3.5	< 0.004	0.84	1.7	1.1	19.6	19.6	19.6
13340	08/07/2002	0.8	< 0.038	0.061	0.21	1.1	0.93	0.98	< 0.01	2.2	0.94	3.2	< 0.006	0.75	5.1	6.6	< 0.009	1.7	3.3	2.2	29.3	29.3	29.3
11193	08/09/2002	3.0	< 0.008	0.066	1.1	8.6	9.2	5.8	0.051	6.9	2.9	9.6	0.091	1.9	14	19	0.023	2.7	6.4	4.8	93.1	93.1	93.1
13341	08/09/2002	2.1	< 0.023	0.061	0.53	2.3	2.5	1.8	0.015	5.3	1.5	5.6	0.011	1.1	9.8	15	0.01	2.9	6.2	4.6	59.2	59.2	59.2
11382	08/11/2002	0.9	0.18	1.2	2.8	3.1	2.4	2.6	0.027	3.5	2.2	4.8	0.054	1.2	8.1	8.1	0.01	3.3	6.5	3.4	53.5	53.5	53.5
11305	08/13/2002	3.0	< 0.021	0.42	2.3	6.3	4.7	4.7	0.07	6.8	2.5	6.3	0.029	1.8	14	14	< 0.015	3.6	8.2	5.4	81.1	81.1	72.4
11305-dup	08/13/2002	1.2	0.089	0.4	1.8	4.3	3.2	2.8	0.045	4.5	1.9	5.2	0.023	1.4	13	13	< 0.008	3.1	5.3	3.7	63.8	63.8	
11347-1	08/13/2002	2.3	0.11	0.23	1.5	2.1	2	2.3	0.02	4.5	2.4	6.1	0.082	1.9	16	17	< 0.011	5.3	9.9	6	77.4	77.4	171.0
11347-2	08/13/2002	0.6	0.22	0.58	1.4	1.7	1.7	1.6	0.019	2.8	1.9	4	0.027	1.1	7.1	4.8	< 0.01	1.4	2.7	2.1	35.2	35.1	
11347-2-dup	08/13/2002	0.6	0.29	0.79	4	5.8	6.4	9.3	0.068	18	7.4	18	0.31	6.2	50	50	0.061	18	39	20	253.6	253.6	
11347-3	08/13/2002	2.2	0.35	0.88	6.1	10	8.5	16	0.13	17	13	30	0.4	9.4	65	58	0.06	20	40	23	317.8	317.8	
13337	08/14/2002	1.0	< 0.083	< 0.032	0.78	8	7.5	5.3	< 0.023	7.4	2.4	8.3	0.025	1.6	12	17	< 0.012	1.7	3.5	4.4	80.0	79.9	71.3
13337-dup	08/14/2002	1.0	< 0.012	0.015	0.4	4.7	3.7	3.7	< 0.017	4.7	1.9	6.4	0.013	1.5	11	14	< 0.01	2.1	4.7	3.9	62.7	62.7	
13589	08/17/2002	0.4	< 0.087	< 0.028	0.29	2.8	1.7	3	< 0.034	3.7	1.4	5	< 0.018	1.2	8.2	13	< 0.022	1.8	3.9	2.8	48.9	48.8	48.8
13589-dup	08/17/2002	0.4	< 0.08	< 0.034	0.31	2.6	2.5	2.5	< 0.022	3.2	1.1	3.5	< 0.053	0.9	6.7	10	< 0.008	1.4	2.8	2.8	40.4	40.3	35.0
13363	08/17/2002	1.3	< 0.004	0.006	0.18	1.2	0.99	1.3	0.008	2.3	0.92	3.3	0.009	0.74	5	8	< 0.004	1.2	2.7	1.9	29.8	29.8	
15464	08/18/2002	1.0	< 0.022	< 0.008	0.048	0.23	0.17	0.11	< 0.013	0.16	< 0.049	0.22	< 0.003	0.032	0.35	0.56	< 0.004	0.055	0.098	0.13	2.2	2.2	2.2
13355	08/18/2002	1.2	< 0.003	0.025	0.14	1.3	0.93	1.4	< 0.006	3	1.6	5.3	< 0.003	1.5	9.8	15	0.01	3.1	6.9	3.5	53.5	53.5	53.5
17970	08/18/2002	1.1	< 0.017	0.015	0.15	0.79	1	0.56	< 0.007	1.1	0.39	1.4	0.015	0.3	2.3	3	< 0.011	0.53	1.2	0.96	13.7	13.7	13.7
16618	08/19/2002	1.4	< 0.003	0.11	0.39	1.9	1.9	1.8	0.011	3.5	1.3	4	0.01	0.89	5.6	7.5	0.007	1.6	3.4	1.5	35.4	35.4	35.4
11264	08/20/2002	2.1	< 0.036	0.23	1.7	7.6	6.5	6.8	0.039	7.4	4.2	12	0.11	2.1	15	20	< 0.011	3.6	9.7	4.5	101.5	101.5	101.5
13343	08/20/2002	2.1	< 0.031	0.086	0.57	3.4	3.2	3.2	0.043	4.1	2.2	5.8	0.013	1.5	8.7	11	< 0.008	1.9	3.6	2.9	52.2	52.2	52.2
13344	08/21/2002	2.5	< 0.007	0.26	1.1	6.5	7.6	4.4	0.059	11	3.1	11	0.031	2	16	22	0.01	3	6.1	8.1	102.3	102.3	102.3
16496	08/21/2002	2.1	< 0.021	0.24	0.72	4	4.4	2.3	0.055	4.8	1.7	5	0.017	0.8	9.8	12	< 0.009	1.3	2.5	4	53.6	53.6	53.6
13342	08/22/2002	1.8	< 0.004	0.18	0.78	4.7	5	2.9	0.041	6.8	2.4	7.2	0.021	1.6	12	14	< 0.008	2.5	4.8	4.7	69.6	69.6	69.6
11261	08/23/2002	3.1	< 0.031	0.13	1.1	4.7	4.6	4	0.023	4.6	2.8	8	< 0.014	1.5	10	13	< 0.012	2.6	5.5	2.8	65.4	65.4	65.4
13338	08/23/2002	3.5	< 0.096	0.56	1.5	6.1	7.9	5	0.061	9.7	2.9	10	< 0.029	1.9	15	18	< 0.012	3	6.7	5.4	93.8	93.7	93.7
13339	08/23/2002	1.9	< 0.013	0.12	0.69	4.5	4	3.2	0.018	7.1	2.1	7.2	0.019	1.4	11	16	< 0.006	2.2	4.4	4.6	68.6	68.5	63.9
13339-dup	08/23/2002	1.9	< 0.01	0.1	0.59	3.5	3	2.7	0.023	6.1	1.7	6.2	0.019	1.4	10	14	< 0.008	1.8	3.1	5.1	59.3	59.3	
16499	08/23/2002	2.7	< 0.018	0.092	0.56	2.8	2.2	2	0.019	4	1.4	4.4	< 0.042	0.95	7.5	9.9	< 0.008	1.9	4.1	3.1	45.0	44.9	74.3
16499-dup	08/23/2002	2.7	< 0.005	0.17	1.1	5.5	5.2	4	0.043	9.8	2.9	9.4	0.03	2.3	19	26	< 0.02	3.1	7.1	8.1	103.8	103.7	
17971	08/24/2002	1.2	< 0.017	0.14	0.67	3.2	4.3	1.7	< 0.031	5.1	1.3	4.3	0.012	0.75	6.7	8.2	< 0.004	1.6	3.1	4.1	45.2	45.2	45.2
11287	08/25/2002	2.9	0.11	0.67	2.5	4.1	3	3	0.044	4	1.9	5.2	0.022	0.85	7.7	7.9	0.003	2	4.3	3.3	50.6	50.6	50.6
11252	08/26/2002	1.8	< 0.015	0.025	0.37	2.4	2.3	2	< 0.02	3.6	1.6	5.6	0.011	1.1	8.4	12	< 0.005	1.4	3.6	3.4	47.8	47.8	47.8
11302	08/26/2002	1.1	0.15	0.79	2.5	3.3	3	2.5	0.038	3.9	1.8	4.8	0.022	0.87	8.9	9.7	< 0.016	2.3	4.9	4.8	54.3	54.3	54.3
13336	08/27/2002	1.0	< 0.003	0.009	0.086	0.45	0.46	0.33	0.003	0.77	0.27	0.98	< 0.002	0.21	1.5	2.2	0.002	0.34	0.68	0.67	9.0	9.0	19.2
13336-dup	08/27/2002	1.0	< 0.029	< 0.017	0.23	1.5	1.4	1.4	< 0.017	2.5	1	3.7	< 0.014	0.64	4.9	7.4	< 0.014	0.96	1.9	1.9	29.5	29.4	
11270	08/28/2002	1.2	< 0.023	0.3	2.7	9.4	6.7	10	0.036	6.8	5.1	12	< 0.027	2.2	15	20	0.014	3.6	8.2	3	105.1	105.1	105.1
11280	08/28/2002	1.4	0.021	0.35	1.8	5.3	3.8	3	< 0.031	4.8	3.7	10	0.018	2.1	13	21	< 0.011	3.7	8.1	4.6	85.3	85.3	85.3
11298	08/29/2002	0.4	< 0.029	0.15	0.83	1.4	1.3	1.6	< 0.028	1.6	1.4	3.7	< 0.016	0.77	5.4	5.7	< 0.016	1.4	3.1	1.5	29.9	29.9	29.9
11273	08/30/2002	2.1	< 0.009	0.73	8.2	22	15	29	< 0.042	17	10	25	0.051	2.7	17	22	< 0.013	4.4	9.3	5.5	187.9	187.9	187.9
13309	08/30/2002	1.4	< 0.008	0.025	0.26	1.7	1.3	1.2	< 0.011	2.2	1.1	3.9	0.008	0.87	6.6	9.7	< 0.008	1.6	3.5	2.6	36.6	36.6	36.6
14560	08/30/2002	1.7	< 0.009	0.014	0.13	1.2	0.77	0.94	< 0.012	1.5	0.67	2.5	< 0.007	0.45	3.6	6.9	< 0.003	0.84	1.9	1.8	23.2	23.2	23.2
11200	09/03/2002	1.3	< 0.016	0.078	0.3	0.62	0.42	0.53	0.02	0.9	0.67	2.1	0.007	0.54	4.3	5	< 0.01	1.2	3	2.2	21.9	21.9	21.9
16622	09/04/2002	0.4	< 0.012	0.05	0.46	3.6	0.91	7.9	0.11	17	29	100	0.053	22	210	190	< 0.091	47	140	98	866.1	866.1	866.1
15979	09/05/2002	1.9	< 0.003	0.36	2.7	5.3	5.7	4.1	< 0.031	4.7	2.7	7.1	0.019	0.92	7.4	10	< 0.003	1.5	3.6	2.2	58.3	58.3	58.3
11300	09/06/2002	4.8	0.37	1.6	7.1	9	9.7	7.1	0.1	12	3.7	10	0.041	3.1	26	20	< 0.013	5.9	16	9.7	141.4	141.4	141.4
11292	09/11/2002	1.0	0.21	0.93	4.3	3.5	4.4	3.8	0.051	10	2.5	6.4	0.029	2.4	26	20	< 0.017	8	21	13	126.5	126.5	126.5
15908	09/11/2002	2.7	< 0.011	0.025	0.75	2.8	2.7	1.9	< 0.017	5.4	1.5	5.9	0.016	0.93	7.1	13	< 0.006	1.2	2.8	4	50.0	50.0	39.8
15908-dup	09/11/2002	2.7	< 0.012	0.009	0.22	1.5	1.4	1.2	< 0.016	2.4	0.85	3.1	0.007	0.58	4.5	8.5	< 0.007	0.96	2.2	2.2	29.6	29.6	
16213	09/11/2002	2.4	< 0.012	0.012	0.29	2.2	2.3	1.9	< 0.026	4.7	2	7.5	< 0.012	1.8	12	23	< 0.016	3.6	7.9	6.5	75.7	75.7	75.7

Table 7.4 PCB Concentrations in Catfish Tissue (ng/g-wet wt.) - Cont'd

Station ID	Date	Lipid Content (%)	PCB 8	PCB 18/30	PCB 20/28	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 90/101/113	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 129/138/163	PCB 153/168	PCB 169	PCB 170	PCB 180/193	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Fall 2002																							
13336	10/22/2002	1.2	< 0.003	0.042	0.73	3.8	3.1	3.3	< 0.021	5.1	3	8.4	0.11	1.5	11	14	0.014	2.5	5.3	2.4	64.3	64.3	64.3
13338	10/22/2002	3.1	< 0.004	0.024	0.32	2.7	2.2	2.1	< 0.015	5.6	2.6	9.1	0.011	1.9	13	19	0.012	2.7	5.2	3.6	70.1	70.1	72.5
13338-dup	10/22/2002	3.1	< 0.003	0.067	0.91	4.6	5.4	3.8	0.019	7.6	2.9	8.9	0.024	1.7	13	15	0.015	2.3	4.4	4.2	74.8	74.8	
11252	10/24/2002	2.3	< 0.003	0.065	0.72	4.3	5	3.1	0.013	7.5	2.6	7.5	0.02	1.5	11	13	0.012	2	3.8	3.2	65.3	65.3	65.3
16499	10/24/2002	1.9	< 0.004	0.04	0.3	2.3	1.9	1.5	< 0.016	3.2	1.5	4.7	0.018	0.93	7.8	11	0.009	2	4.4	2.8	44.4	44.4	44.4
17970	10/24/2002	2.1	< 0.006	0.04	0.76	3.4	4.2	2.4	< 0.022	6.4	1.5	4.7	0.014	1.3	9.8	12	< 0.008	2.1	4.5	4.3	57.4	57.4	66.5
17970-dup	10/24/2002	2.1	< 0.006	0.021	0.57	4	3.2	3	< 0.022	5.5	2.5	7.9	0.018	1.9	13	19	< 0.011	3	6.9	5.1	75.6	75.6	
11261	10/26/2002	2.1	< 0.01	0.056	0.65	5.1	4.3	4.5	< 0.01	7	3.3	11	0.021	1.9	14	18	< 0.02	3.5	9	4.6	86.9	86.9	86.9
13344	10/27/2002	3.1	< 0.007	0.069	0.72	4.4	4.1	3.5	< 0.026	6.1	2.6	8	0.018	1.6	11	15	< 0.017	2.6	6.2	4.2	70.1	70.1	70.1
13342	10/28/2002	1.4	< 0.009	0.044	0.37	1.9	1.7	1.7	< 0.023	3	1.5	4.4	0.013	0.94	6.7	8.8	< 0.007	1.4	3	2.3	37.8	37.8	37.8
17971	10/28/2002	3.1	< 0.011	0.053	0.75	4.5	3.4	4	< 0.029	5.5	3.4	11	0.026	2.1	17	23	< 0.018	3.4	8.6	5.6	92.4	92.3	92.3
11200-1	11/19/2002	2.2	< 0.059	0.12	0.51	0.83	1.3	1	< 0.009	1.7	0.47	1.4	0.005	0.31	2.4	2.7	< 0.013	0.48	1	1	15.3	15.2	47.7
11200-2	11/21/2002	4.1	0.13	0.51	1.4	3.1	3.6	2.3	0.068	3.3	1	3	< 0.016	0.73	6.1	7.2	< 0.03	1.5	2.8	3.1	39.9	39.8	
11200-2-dup	11/21/2002	4.1	< 0.097	0.17	2.9	4	2.6	5	0.061	5.1	3.2	8.9	0.033	1.8	14	18	< 0.023	4.6	11	6.8	88.2	88.2	
11193	11/20/2002	0.8	< 0.056	< 0.059	0.48	1.3	1.9	2.1	< 0.016	3.8	1.3	4.1	< 0.004	0.88	7	8	< 0.008	1.2	2.7	3.1	37.9	37.9	37.9
11292	12/02/2002	1.7	0.19	0.53	4.1	4.4	4.5	5.5	< 0.043	7.2	3.9	9.8	0.039	2.6	21	21	< 0.008	6.3	17	7.8	115.9	115.9	115.9
11280	12/05/2002	1.1	< 0.084	0.24	1.1	1.7	2.6	2.1	< 0.037	2.9	1.3	3.8	< 0.02	0.8	5.7	6.3	< 0.006	1.3	3.9	2.5	36.3	36.2	36.2
Spring 2003																							
11273	04/29/2003	3.6	0.035	1.3	4	14	8.6	19	0.039	10	9.3	21	0.034	2.6	16	20	< 0.025	3.4	8.4	3.8	141.5	141.5	141.5
11092	04/30/2003	0.7	0.06	0.046	0.21	0.26	0.23	0.37	< 0.012	0.55	0.28	0.99	< 0.0059	0.21	1.5	1.6	< 0.013	0.33	0.77	0.58	8.0	8.0	8.0
11092-dup	04/30/2003	0.9	0.06	0.047	0.34	0.35	0.24	0.46	< 0.0062	0.53	0.29	1	0.005	0.21	1.5	1.4	< 0.0029	0.32	0.72	0.57	8.0	8.0	
11272	04/30/2003	0.5	0.046	0.12	0.53	0.78	0.97	1.1	< 0.013	1.7	0.85	2.6	< 0.0078	0.55	4	4.5	< 0.013	1.1	3	2.1	24.0	23.9	23.9
11111	05/01/2003	2.1	< 0.02	0.021	0.32	1	0.96	0.93	< 0.017	2.1	0.75	2.8	< 0.024	0.56	3.8	5.2	< 0.0087	0.8	1.8	1.9	23.0	22.9	22.9
11274	05/01/2003	1.8	0.18	0.59	2.4	2.8	2.9	3.4	0.029	4	2.9	7.5	0.022	1.3	7.8	6.9	0.015	1.6	3.3	1.8	49.4	49.4	49.4
11298	05/01/2003	1.6	0.12	0.49	1.4	2.2	3.1	2.2	0.019	3.3	1.2	3.4	0.02	0.71	5.7	6.1	< 0.011	1.5	3.2	2.3	37.0	37.0	37.0
11302	05/01/2003	0.6	0.058	0.33	1.6	1.5	2.2	2.1	0.012	1.9	1.3	3.3	< 0.014	0.7	4.6	5	< 0.02	1.2	2.7	1.9	30.4	30.4	30.4
11347	05/02/2003	1.5	0.21	0.48	4	3.9	3.9	4.5	0.03	6.7	4.2	9.5	0.064	2.5	19	19	< 0.03	4.4	10	6.2	98.6	98.6	101.1
11382	05/02/2003	0.7	0.13	0.27	2.8	3.9	3.1	4.4	0.018	5.5	4.2	9.7	0.049	2.5	20	21	< 0.043	5.7	13	7.4	103.7	103.7	93.0
11382-dup	05/02/2003	1.5	0.14	0.3	2.7	3	3	3.4	0.023	4.8	3	7.3	0.04	2.1	16	16	< 0.0096	4.5	9.9	6.2	82.4	82.4	
11305	05/03/2003	1.2	0.15	0.56	2.6	5.3	4.5	5.2	0.03	8	4.3	9.9	0.06	2.9	25	25	< 0.045	7.3	16	9.1	125.9	125.9	125.9
13339	05/04/2003	2.5	0.023	0.39	1.4	8.1	6.7	7.2	0.035	14	5.1	15	0.048	2.7	19	26	< 0.033	4.1	8.1	8.5	126.4	126.4	126.4
11287	05/05/2003	3.1	0.15	0.74	3	5.8	7.5	5.8	0.044	10	4.2	9.2	0.071	2.7	23	23	< 0.029	5.7	13	6.1	120.0	120.0	120.0
16618	05/05/2003	2.8	< 0.0049	0.05	0.45	7.4	6.4	5.5	< 0.018	14	5.5	18	0.048	3.6	26	34	< 0.037	6.1	14	8.8	149.9	149.8	149.8
11270	05/06/2003	2.6	< 0.0075	0.27	1.3	9.8	9.8	7.2	< 0.0082	12	6	17	0.054	3.5	25	29	< 0.032	5	11	6.5	143.4	143.4	143.4
11280	05/06/2003	3.8	0.027	1.9	5.3	23	13	23	0.062	20	14	34	0.079	5.8	41	49	< 0.05	8.4	19	8.4	266.0	266.0	266.0
11261	05/10/2003	2.9	< 0.006	0.18	0.92	7.1	5.2	7	0.014	9.3	4.8	13	0.051	2.3	15	18	< 0.026	3.7	8.1	5.1	99.8	99.8	99.8
13342	05/11/2003	2.3	< 0.017	0.16	1.4	13	10	13	< 0.059	27	11	33	0.039	6.5	51	65	< 0.088	9.7	20	19	279.9	279.8	279.8
16496	05/11/2003	1.8	< 0.005	0.082	0.64	4	3.1	3.6	0.012	6.9	3	9.8	< 0.005	1.7	12	16	< 0.023	3.1	6.8	4.2	75.0	74.9	107.7
16496-dup	05/11/2003	2.5	< 0.0072	0.097	1.6	7.8	7.7	7.4	< 0.021	14	5.3	17	0.051	3.2	23	28	< 0.042	5.6	11	8.7	140.5	140.4	
13309	05/12/2003	1.1	< 0.021	0.11	0.28	2.7	3.3	2.4	< 0.018	10	2.1	8.5	< 0.01	2.2	18	27	< 0.036	4.3	10	8.1	99.0	99.0	99.0
11193	05/14/2003	0.4	< 0.0096	0.041	0.36	2.4	2.8	2.2	< 0.021	4.4	1.7	5.6	0.016	1.2	8.4	10	< 0.005	1.7	3.9	3.5	48.2	48.2	48.2
11264	05/15/2003	2.7	< 0.007	0.28	1.7	13	9.9	13	0.039	17	9.5	28	< 0.013	4.2	30	41	< 0.056	7.6	16	9.5	200.8	200.7	200.7
11252	05/16/2003	0.5	< 0.0094	< 0.0095	0.054	0.45	0.32	0.37	< 0.0036	0.74	0.32	1.1	< 0.01	0.26	1.7	2.4	< 0.0071	0.39	0.87	0.72	9.7	9.7	9.7
13589	05/16/2003	0.2	< 0.011	0.013	0.097	0.53	0.53	0.44	< 0.002	1.2	0.33	1.2	< 0.0096	0.29	2.1	2.8	< 0.0029	0.48	1.1	0.96	12.1	12.1	12.1
13355	05/28/2003	2.1	< 0.011	0.011	0.21	2.3	1.6	1.7	0.0061	3.7	1.8	6.5	0.012	1.2	10	14	< 0.012	2	4.8	2.4	52.3	52.2	52.2
15908	05/28/2003	2.0	< 0.0089	0.013	0.2	2.6	2.1	1.7	0.0067	4.4	1.8	7.1	0.011	1.4	11	17	< 0.015	2	4.5	2.5	58.3	58.3	58.3
11292	05/30/2003	1.0	0.12	0.45	4.1	7.8	9.3	8.7	0.021	20	9.1	19	0.12	7.1	65	65	< 0.084	20	45	23	303.9	303.8	303.8

Total PCB concentration calculated as the sum of the 18 congeners recommended by NOAA
Values reported to the Detection Limit

[a] Non-detects assumed to be 1/2 detection limit
[b] Non-detects assumed to be zero
[c] Average of duplicate samples, otherwise concentration of a single sample
exceeds TDH Screening Value (47 ng/g)
tributary

Table 7.5 PCB Concentrations in Crab Tissue (ng/g-wet wt.)

Station ID	Date	Lipid Content (%)	PCB 8	PCB 18/30	PCB 20/28	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 90/101/113	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 129/138/163	PCB 153/168	PCB 169	PCB 170	PCB 180/193	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Summer 2002																							
11272	07/26/2002	1.2	< 0.043	0.027	0.6	0.39	0.046	0.57	0.035	0.064	0.25	0.92	0.0049	0.095	0.7	1	< 0.0032	0.095	0.36	0.14	5.3	5.3	5.3
11298	07/29/2002	0.5	< 0.035	0.039	0.73	1.3	0.24	1.6	0.095	0.34	1.1	3.3	0.012	0.47	3.6	5	< 0.0038	0.61	2.3	1.1	21.9	21.8	21.8
11274	07/30/2002	0.6	0.062	0.032	2	1.8	0.38	2.6	0.2	0.68	1.6	3.2	0.012	0.39	2.8	2.8	< 0.0031	0.39	1.1	0.65	20.7	20.7	20.7
11111	07/31/2002	0.8	0.033	0.038	0.33	0.64	0.11	0.58	0.029	0.12	0.29	1.1	0.009	0.2	1.4	2.1	< 0.003	0.21	0.53	0.45	8.2	8.2	8.2
11258	08/01/2002	0.7	< 0.013	0.06	0.64	3.1	1.2	3.3	0.2	1.6	1.4	4.4	0.02	0.7	5.6	6.5	< 0.011	0.51	1.4	2	32.6	32.6	32.6
11092	08/02/2002	1.5	0.053	0.062	0.95	0.53	0.13	0.73	0.045	0.083	0.35	1.1	< 0.013	0.16	1.1	1.4	< 0.006	0.23	0.55	0.3	7.8	7.8	7.8
13340	08/07/2002	1.1	0.051	0.067	0.2	0.32	0.12	0.31	0.028	0.095	0.24	0.77	< 0.01	0.1	0.78	1	< 0.007	0.1	0.23	0.18	4.6	4.6	4.6
11193	08/09/2002	0.9	< 0.015	0.061	0.83	2.6	1.1	3.3	0.22	1.7	1.5	4.8	0.019	0.76	6.1	7.2	< 0.01	0.43	1.6	2.1	34.3	34.3	34.3
11347	08/12/2002	0.6	< 0.01	0.011	0.97	0.49	0.013	0.76	0.067	0.031	0.6	1.7	0.013	0.25	1.8	2	< 0.004	0.34	1.2	0.53	10.8	10.8	10.8
11382	08/13/2002	0.4	< 0.052	0.014	0.38	0.17	0.016	0.28	0.045	0.038	0.36	1	0.009	0.18	1.4	1.5	< 0.006	0.12	0.63	0.29	6.5	6.4	6.4
11305	08/14/2002	0.6	< 0.089	< 0.028	0.83	2.3	0.055	1.7	0.11	0.12	0.85	2.4	< 0.015	0.51	4.5	5.8	< 0.008	0.78	1.9	1.2	23.1	23.1	23.1
13337	08/14/2002	0.2	< 0.013	< 0.01	0.24	0.54	0.053	0.58	0.038	0.13	0.24	0.81	< 0.01	0.12	0.9	1.2	< 0.01	0.074	0.21	0.25	5.4	5.4	5.4
13341	08/16/2002	0.8	< 0.069	< 0.013	0.19	0.37	0.031	0.26	< 0.033	0.041	0.18	0.59	< 0.004	0.071	0.67	1	< 0.01	0.1	0.17	0.16	3.9	3.8	3.8
15464	08/17/2002	0.1	< 0.099	< 0.029	0.12	0.25	0.025	0.38	< 0.016	0.044	0.11	0.44	< 0.01	0.047	0.38	0.65	< 0.005	< 0.037	0.1	0.12	2.8	2.7	2.7
13363	08/17/2002	1.1	< 0.033	0.043	0.26	0.52	0.14	0.36	0.023	0.15	0.2	0.68	< 0.004	0.14	0.95	1.3	< 0.003	0.13	0.3	0.27	5.5	5.5	5.5
13589	08/17/2002	0.3	< 0.5	< 0.062	< 0.11	0.44	< 0.085	0.44	< 0.058	< 0.11	0.16	0.61	< 0.037	0.084	0.77	1.2	< 0.037	0.071	0.25	0.28	4.8	4.3	3.5
13589-dup	08/17/2002	0.3	< 0.077	< 0.02	0.079	0.28	0.033	0.25	< 0.01	0.044	0.08	0.33	< 0.01	0.056	0.42	0.71	< 0.008	0.056	0.14	0.13	2.7	2.6	
13355	08/18/2002	0.3	< 0.011	< 0.014	0.39	2	0.13	2	0.086	0.22	0.84	3.3	< 0.013	0.41	3.7	6.1	< 0.011	0.33	0.85	1.4	21.8	21.8	15.9
13355-dup	08/18/2002	0.3	< 0.1	< 0.025	0.21	0.82	0.11	0.92	0.036	0.2	0.35	1.4	< 0.007	0.21	1.7	2.8	< 0.01	0.12	0.38	0.71	10.0	10.0	
17970	08/18/2002	1.1	< 0.004	0.018	0.28	1.1	0.2	1.4	0.071	0.52	0.78	2.6	0.01	0.39	3.5	4.5	< 0.003	0.42	1.4	1.2	18.4	18.4	18.4
11261	08/20/2002	0.8	< 0.041	< 0.031	0.96	1.6	0.27	2	0.12	0.48	1.1	3.3	< 0.015	0.56	4.7	5.2	< 0.009	0.62	1.9	1.6	24.5	24.4	24.4
16618	08/20/2002	0.6	< 0.026	0.014	0.82	1.9	0.12	2.5	0.22	0.23	1.7	5.7	0.019	0.54	7	10	< 0.004	0.69	1.6	2.1	35.2	35.2	35.2
11264	08/20/2002	0.9	< 0.033	0.13	1.1	2.2	1.3	2.4	0.16	1.5	1.3	3.8	0.025	0.7	5.5	6.1	< 0.008	0.81	2.1	2.1	31.2	31.2	31.2
13338	08/23/2002	0.6	< 0.03	< 0.014	0.36	0.49	< 0.047	0.59	0.04	0.12	0.5	1.5	< 0.011	0.16	1.2	1.4	< 0.014	< 0.14	0.38	0.19	7.1	6.9	6.9
16499	08/23/2002	0.4	< 0.02	0.022	0.63	1.2	0.14	1.7	0.15	0.33	1.1	3.6	0.015	0.58	4.7	6.6	< 0.006	0.57	1.4	2	24.8	24.7	24.7
13344	08/23/2002	0.8	< 0.016	0.044	0.48	0.67	0.28	0.85	0.064	0.42	0.52	1.5	0.006	0.28	2.4	2.8	< 0.003	0.31	0.94	0.75	12.3	12.3	16.7
13344-dup	08/23/2002	0.8	0.011	0.078	0.65	1.2	0.67	2	0.18	0.97	0.95	2.8	0.012	0.41	4.1	3.7	< 0.007	0.5	1.3	1.5	21.0	21.0	
13342	08/24/2002	1.0	< 0.013	0.041	0.61	1.2	0.41	1.4	0.14	0.81	1.1	3	0.011	0.58	4.5	4.5	< 0.003	0.65	1.6	2.2	22.8	22.8	22.8
17971	08/24/2002	1.0	< 0.017	0.13	0.6	2	1.8	1.4	0.12	2.3	0.89	3.1	0.013	0.47	5.4	6.6	< 0.003	0.52	1.1	1.9	28.4	28.3	28.3
16496	08/24/2002	0.9	< 0.02	0.022	0.57	0.8	0.17	0.95	0.085	0.26	0.66	1.8	< 0.008	0.23	2.3	2.4	< 0.004	0.4	1	0.66	12.3	12.3	12.3
11287	08/25/2002	0.4	< 0.008	0.014	1.1	2.1	0.034	2.9	0.18	0.15	2.1	5.7	0.027	1.1	9	11	< 0.005	2.1	6.8	2.8	47.1	47.1	29.4
11287-dup	08/25/2002	0.7	< 0.039	0.017	0.68	0.73	0.021	0.67	0.073	0.04	0.56	1.5	< 0.006	0.25	2.4	2.7	< 0.01	0.36	1.2	0.58	11.8	11.8	
13339	08/25/2002	1.1	< 0.029	0.087	0.97	1.8	0.84	1.8	0.15	1	1.1	3.6	0.014	0.53	5.6	7.3	< 0.003	0.42	1.3	2.1	28.6	28.6	23.0
13339-dup	08/25/2002	1.1	< 0.02	0.031	0.75	1.4	0.31	1.8	0.11	0.51	1.1	3.3	0.011	0.26	2.7	3.1	< 0.002	0.25	0.7	1	17.3	17.3	
11302	08/26/2002	0.9	< 0.042	0.014	1.1	1.6	0.03	1.5	0.13	0.085	1.4	4	0.021	0.53	6.5	7.7	< 0.005	1	3.8	1.5	30.9	30.9	30.9
13336	08/27/2002	0.3	< 0.005	< 0.005	0.19	0.33	0.019	0.29	0.015	0.039	0.13	0.47	< 0.002	0.063	0.45	0.6	< 0.002	0.062	0.14	0.11	2.9	2.9	2.9
11270	08/28/2002	0.9	< 0.013	0.031	1.3	2.1	0.18	2.7	0.16	0.43	1.8	4.8	0.015	0.74	6.1	6.4	< 0.004	1.3	4.2	1.5	33.8	33.8	33.8
11273	08/28/2002	0.6	0.072	0.31	3.3	3	0.81	5.4	0.33	0.63	2.1	6.1	0.02	0.78	6.7	8.4	< 0.003	0.99	3.6	2	44.5	44.5	69.5
11273-dup	08/28/2002	0.6	0.17	0.83	10	7.2	2.9	19	1	2.5	6.3	15	0.049	1.1	8.8	9.8	< 0.002	1.5	5.3	3	94.5	94.4	
11280	08/28/2002	0.5	< 0.062	0.067	1.4	2.4	0.25	2.9	0.22	0.43	2.7	7.2	0.037	1.1	8.8	11	< 0.013	1.5	4.9	2.1	47.0	47.0	35.8
11280-dup	08/28/2002	0.6	< 0.004	0.03	0.92	1.5	0.087	1.3	0.08	0.16	1.3	3.6	0.015	0.55	4.6	5.9	0.003	0.82	2.5	1.3	24.7	24.7	
11252	08/29/2002	0.6	< 0.01	< 0.007	0.17	0.24	0.013	0.26	0.02	0.028	0.18	0.51	< 0.002	0.085	0.75	0.92	< 0.003	0.086	0.21	0.22	3.7	3.7	4.3
11252-dup	08/29/2002	0.6	< 0.008	< 0.007	0.16	0.36	0.038	0.38	0.025	0.066	0.22	0.79	< 0.003	0.11	0.86	1.2	< 0.003	0.11	0.29	0.27	4.9	4.9	
14560	08/30/2002	0.7	< 0.015	0.013	0.63	0.94	0.06	1.7	0.16	0.26	0.88	2.3	0.012	0.34	3	3.3	< 0.002	0.32	0.93	1	15.9	15.8	15.8
11200	09/02/2002	0.7	< 0.009	0.008	0.23	0.5	0.026	0.67	0.025	0.043	0.63	2	0.005	0.3	2.6	3.8	< 0.002	0.43	1.7	0.75	13.7	13.7	13.7
16622	09/02/2002	0.7	0.015	0.013	0.34	0.59	0.036	0.86	0.04	0.13	0.81	2.6	0.006	0.46	3.9	4.4	< 0.006	0.77	2.6	1.4	19.0	19.0	19.0
13343	09/04/2002	0.7	0.031	0.06	0.57	1.2	0.41	1.4	0.13	0.76	0.86	2.6	0.01	0.4	3.7	4.5	< 0.005	0.5	1	1.3	19.4	19.4	19.4
15979	09/05/2002	0.6	< 0.002	0.012	0.75	1.7	0.036	1.8	0.13	0.12	1.5	4.1	0.015	0.54	5	6.3	< 0.004	0.79	2.3	1.2	26.3	26.3	26.3
11300	09/09/2002	0.2	< 0.014	0.014	0.7	1.1	0.028	1.3	0.12	0.064	1.1	3.3	0.017	0.53	3.6	5.7	< 0.003	0.71	2	0.94	21.2	21.2	21.2
16213	09/10/2002	0.5	< 0.019	0.007	0.12	0.17	0.007	0.098	< 0.007	0.013	0.075	0.29	< 0.003	0.046	0.35	0.68	< 0.002	0.055	0.14	0.11	2.2	2.2	2.2
11292	09/11/2002	0.4	0.068	0.018	4.1	1.8	0.015	1.9	0.13	0.068	1.4	3.6	0.021	0.56	4.3	6.3	< 0.004	1	2.7	1.5	29.5	29.5	29.5
13309	09/11/2002	0.5	< 0.013	0.015	0.23	0.34	0.055	0.4	0.027	0.12	0.24	0.8	< 0.004	0.11	0.76	1.3	< 0.002	0.14	0.39	0.4	5.3	5.3	5.3
15908	09/11/2002	0.5	< 0.002	0.008	0.17	0.21	0.027	0.21	0.02	0.037	0.16	0.54	< 0.003	0.066	0.67	1.1	< 0.003	0.075	0.21	0.19	3.7	3.7	3.7

Table 7.5 PCB Concentrations in Crab Tissue (ng/g-wet wt.) - Cont'd

Station ID	Date	Lipid Content (%)	PCB 8	PCB 18/30	PCB 20/28	PCB 44/47/65	PCB 52	PCB 66	PCB 77	PCB 90/101/113	PCB 105	PCB 118	PCB 126	PCB 128/166	PCB 129/138/163	PCB 153/168	PCB 169	PCB 170	PCB 180/193	PCB 187	Total PCBs[a]	Total PCBs[b]	Average Total PCBs[b,c]
Fall 2002																							
11193	10/21/2002	0.7	0.045	0.011	0.37	0.54	0.07	0.65	0.04	0.09	0.41	1.3	0.005	0.18	1.3	1.7	0.016	0.25	0.86	0.38	8.2	8.2	8.2
13336	10/22/2002	1.1	< 0.012	0.011	0.26	0.45	0.056	0.59	0.047	0.2	0.43	1.4	< 0.003	0.23	1.7	1.9	< 0.003	0.18	0.41	0.55	8.4	8.4	8.4
13338	10/22/2002	0.8	0.015	0.015	0.65	1.1	0.03	1.5	0.13	0.17	0.97	2.8	0.013	0.35	3	3.8	< 0.003	0.38	1.1	1.1	17.1	17.1	17.1
13340	10/22/2002	0.6	0.072	0.025	0.14	0.26	0.022	0.3	0.011	0.088	0.18	0.67	0.008	0.054	0.52	0.68	0.012	0.093	0.21	0.2	3.5	3.5	3.5
16499	10/24/2002	0.8	< 0.079	< 0.009	0.56	0.84	0.015	1.1	0.059	0.046	0.64	1.8	< 0.008	0.32	2.3	3.5	< 0.003	0.37	0.94	0.81	13.3	13.3	13.3
17970	10/24/2002	0.6	< 0.011	0.009	0.28	0.58	0.05	0.7	0.043	0.16	0.4	1.3	< 0.005	0.22	1.8	2.2	< 0.002	0.19	0.49	0.55	9.0	9.0	9.0
11261	10/25/2002	0.6	< 0.064	0.012	0.32	0.92	0.053	< 0.74	0.055	0.1	0.5	1.7	< 0.005	0.25	1.8	2.5	< 0.004	0.24	0.78	0.61	10.2	9.8	9.8
13344	10/27/2002	0.6	< 0.031	< 0.01	0.4	1.3	0.083	1.2	0.082	0.13	0.78	2.5	0.012	0.33	2.9	4.1	< 0.004	0.34	1.3	1.1	16.6	16.6	20.2
13344-dup	11/14/2002	0.6	< 0.034	0.011	0.45	1.8	0.072	1.7	0.073	0.17	1.1	3.4	0.009	0.53	4.4	6.1	< 0.006	0.53	1.8	1.7	23.9	23.8	
13342	10/28/2002	0.6	< 0.009	0.012	0.45	0.98	0.063	1.3	0.11	0.32	0.86	2.5	0.014	0.42	3.6	4.4	< 0.004	0.46	1.2	1.2	17.9	17.9	17.9
17971	10/28/2002	0.4	< 0.011	0.014	0.69	1.1	0.062	1.4	0.12	0.25	0.83	2.5	0.011	0.36	2.7	3.1	0.005	0.32	0.72	0.94	15.1	15.1	16.6
17971-dup	10/28/2002	0.4	< 0.009	0.021	0.56	1.2	0.2	1.6	0.12	0.55	0.92	2.9	0.016	0.41	3.2	3.8	< 0.005	0.41	1	1.1	18.0	18.0	
11252	11/13/2002	0.8	< 0.055	< 0.011	< 0.39	0.83	0.021	1.1	0.052	0.11	0.62	2	< 0.006	0.29	2.1	3.1	< 0.005	0.3	0.79	0.83	12.4	12.1	12.1
15464	11/13/2002	0.8	< 0.051	0.011	0.088	0.12	< 0.009	0.15	< 0.013	< 0.013	0.12	0.37	< 0.003	0.043	0.28	0.51	< 0.004	0.042	0.09	0.074	1.9	1.9	1.9
13363	11/16/2002	0.5	< 0.058	< 0.008	0.13	0.2	0.024	0.23	< 0.014	0.052	0.15	0.47	< 0.005	0.064	0.51	0.83	< 0.003	0.06	0.16	0.19	3.1	3.1	3.1

Total PCB concentration calculated as the sum of the 18 congeners recommended by NOAA
Values reported to the Detection Limit

[a] Non-detects assumed to be 1/2 detection limit

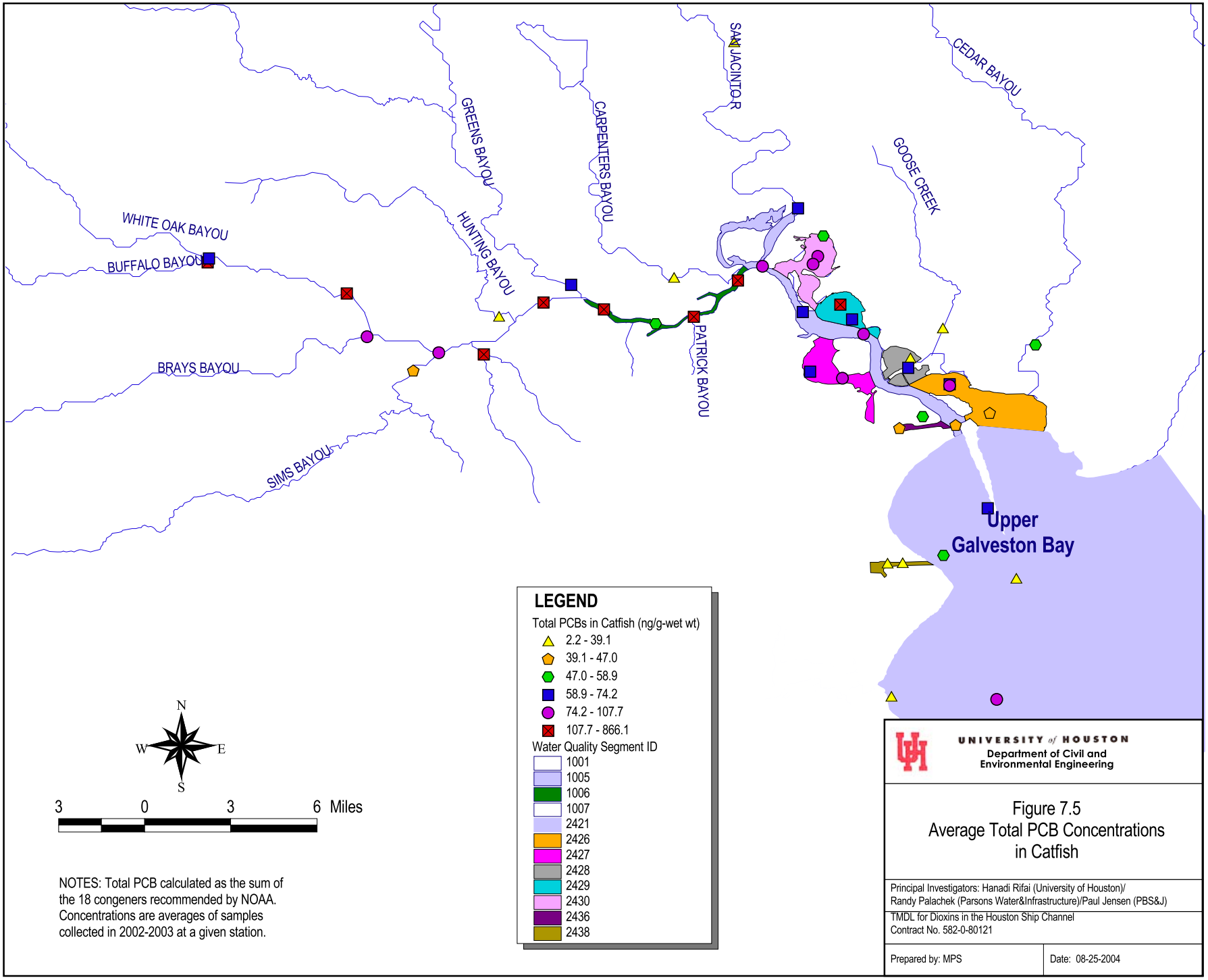
[b] Non-detects assumed to be zero

[c] Average of duplicate samples, otherwise concentration of a single sample

exceeds TDH Screening Value (47 ng/g)

tributary

Spring 2003 crab samples were not analyzed for PCBs


WHITE OAK BAYOU
BUFFALO BAYOU
BRAYS BAYOU
SIMS BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
SAN JACINTO R
PATRICK BAYOU
CEDAR BAYOU
GOOSE CREEK
Upper
Galveston Bay
LEGEND
Total PCBs in Catfish (ng/g-wet wt)
2.2 - 39.1
39.1 - 47.0
47.0 - 58.9
58.9 - 74.2
74.2 - 107.7
107.7 - 866.1
Water Quality Segment ID
1001
1005
1006
1007
2421
2426
2427
2428
2429
2430
2436
2438
N
W
E
S
3 0 3 6 Miles
NOTES: Total PCB calculated as the sum of the 18 congeners recommended by NOAA. Concentrations are averages of samples collected in 2002-2003 at a given station.
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.5
Average Total PCB Concentrations in Catfish
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-25-2004

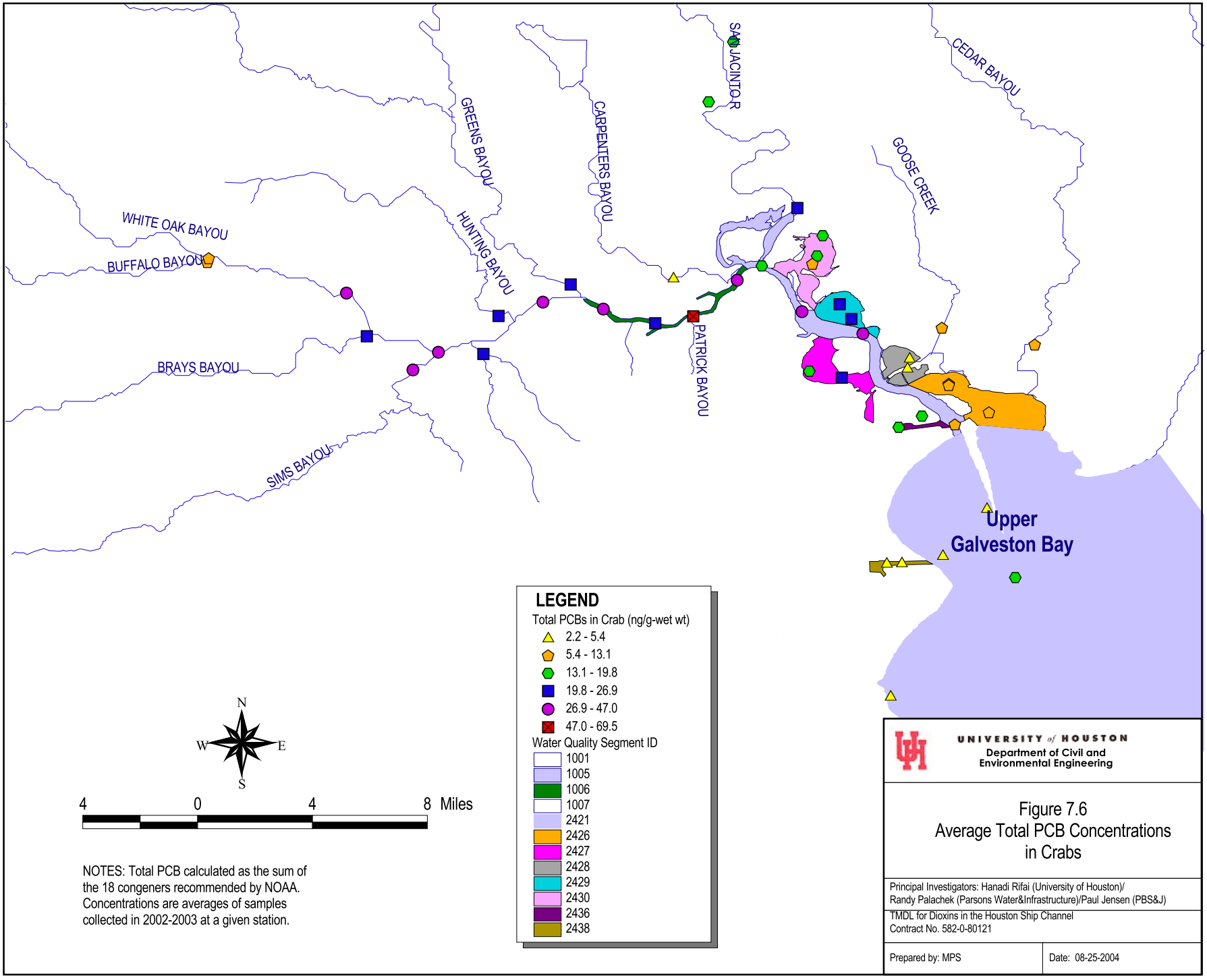

WHITE OAK BAYOU
BUFFALO BAYOU
BRAYS BAYOU
SIMS BAYOU
GREENS BAYOU
HUNTING BAYOU
CARPENTERS BAYOU
SAN JACINTO R
PATRICK BAYOU
CEDAR BAYOU
GOOSE CREEK
Upper
Galveston Bay
LEGEND
Total PCBs in Crab (ng/g-wet wt)
2.2 - 5.4
5.4 - 13.1
13.1 - 19.8
19.8 - 26.9
26.9 - 47.0
47.0 - 69.5
Water Quality Segment ID
1001
1005
1006
1007
2421
2426
2427
2428
2429
2430
2436
2438
N
W
E
S
4 0 4 8 Miles
NOTES: Total PCB calculated as the sum of the 18 congeners recommended by NOAA. Concentrations are averages of samples collected in 2002-2003 at a given station.
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 7.6
Average Total PCB Concentrations in Crabs
Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Water&Infrastructure)/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 08-25-2004

Figure 7.7 shows the concentration distribution for the 18 PCB congeners in catfish and crab samples. The concentrations for the individual PCBs ranged from 0.001 to 210 ng/g wet wt. for catfish and from 0.001 to 19 ng/g wet wt. for crabs. Most of the total PCB concentration in catfish can be attributed to PCB-138 and PCB-153 with average contributions of 20 and 21% to the total PCB sum, respectively. Similarly, the highest contributors to the total PCB concentration in crabs are also congeners PCB-138 and PCB-153, with average contributions of 18 and 23%, respectively. It is noted that congeners 138 and 153 are also the highest contributors to total PCB concentration in bottom sediments. PCB congeners 138 and 153 are not among the "dioxin-like" PCB congeners.

7.4 ANALYSIS OF PCB DATA IN THE HOUSTON SHIP CHANNEL

7.4.1 BAF/BSAF Calculations

PCB data collected during WO4 were used to calculate congener-specific bioaccumulation factors (BAFs) and biota to sediment accumulation factors (BSAFs) for the entire Houston Ship Channel System. Two approaches for calculating BAFs were used. The first approach uses measures of central tendency (i.e. mean or median) of the ratios of tissue concentrations to dissolved concentrations and of the ratios of tissue concentrations to sediment concentrations. The second approach uses ratios of average concentrations for the different media (EPA, 2003).

Figure 7.8 shows dissolved and tissue dioxin data and BAF fitting lines for selected congeners using both approaches. Similarly, Figure 7.9 shows organic carbon-normalized sediment and tissue data and the BSAF fitting lines calculated using both approaches. The two approaches give similar results for BAFs, but not for BSAFs. As seen in Figure 7.9, the BSAFs

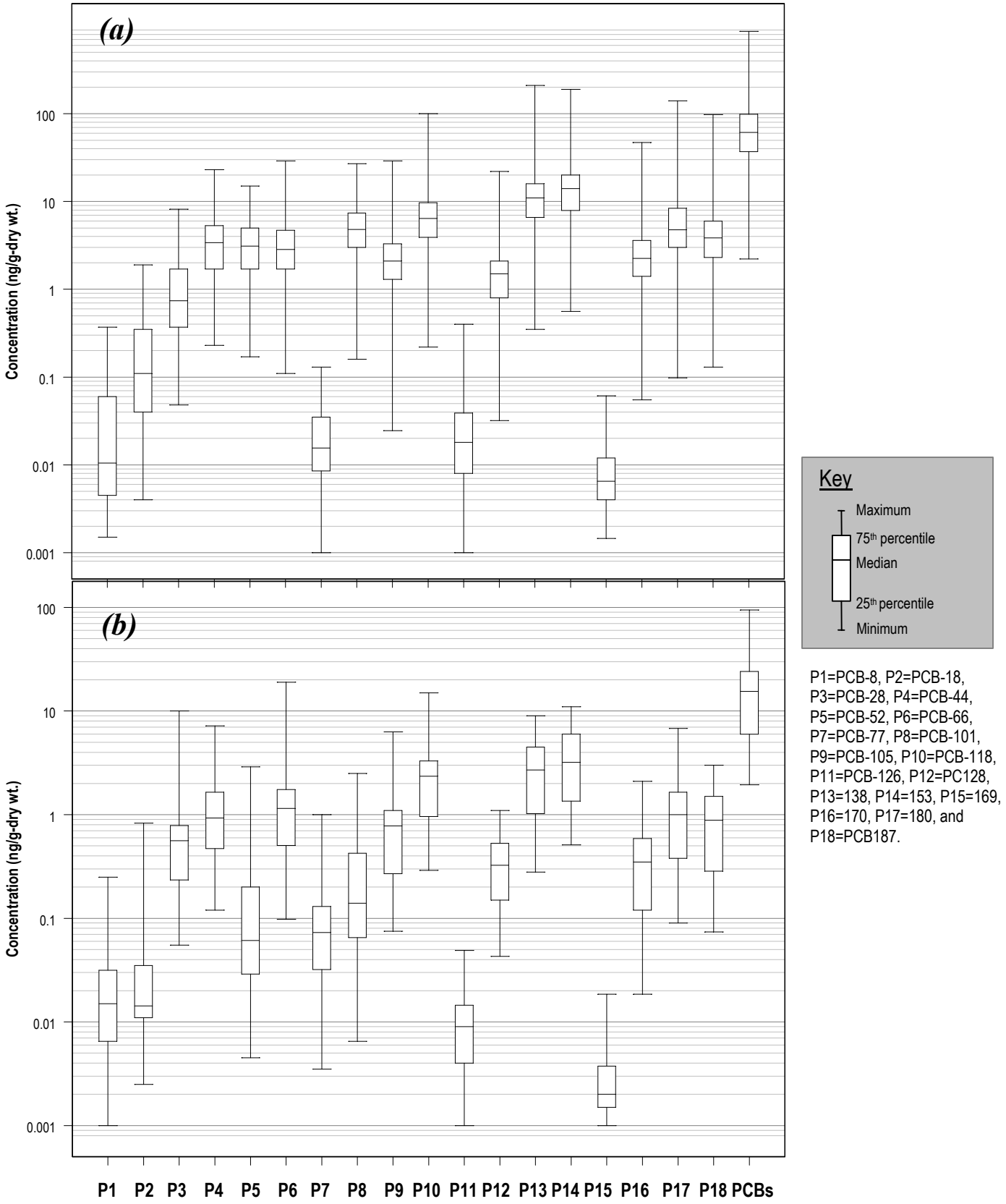
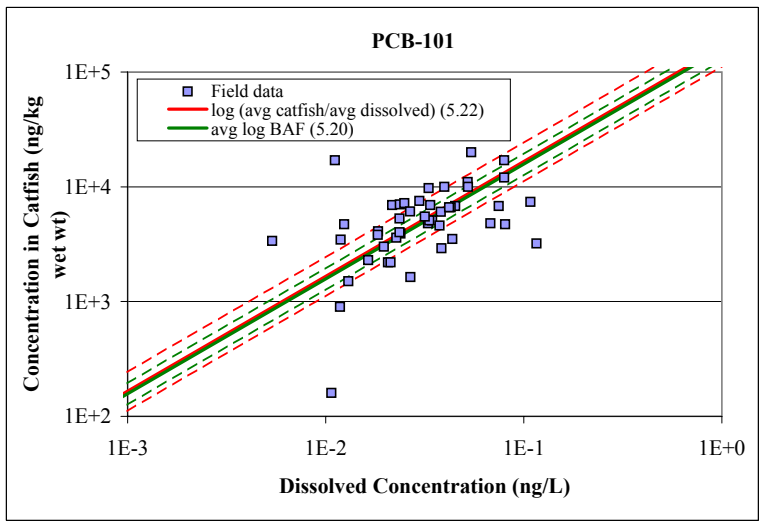
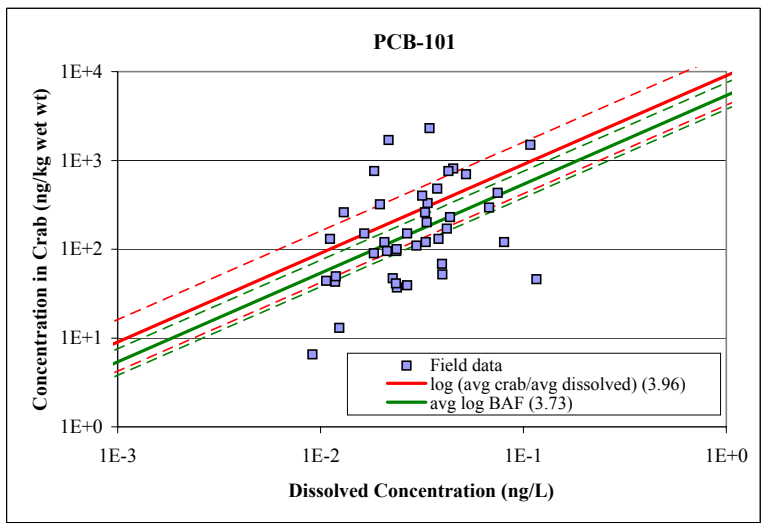
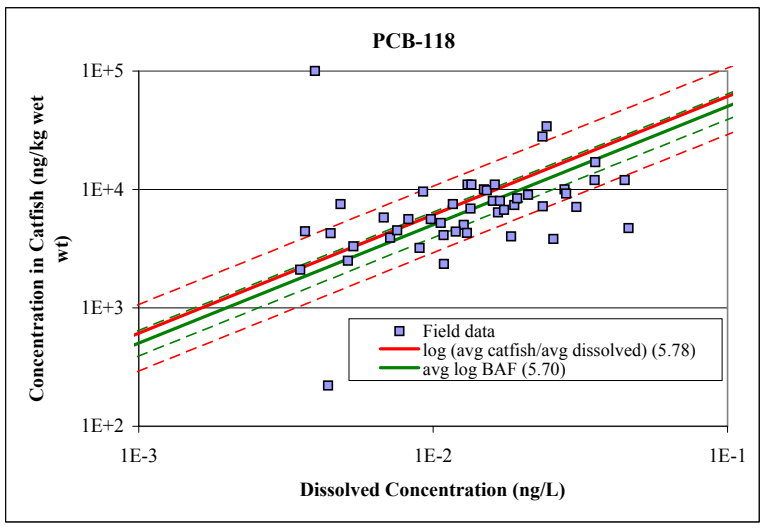
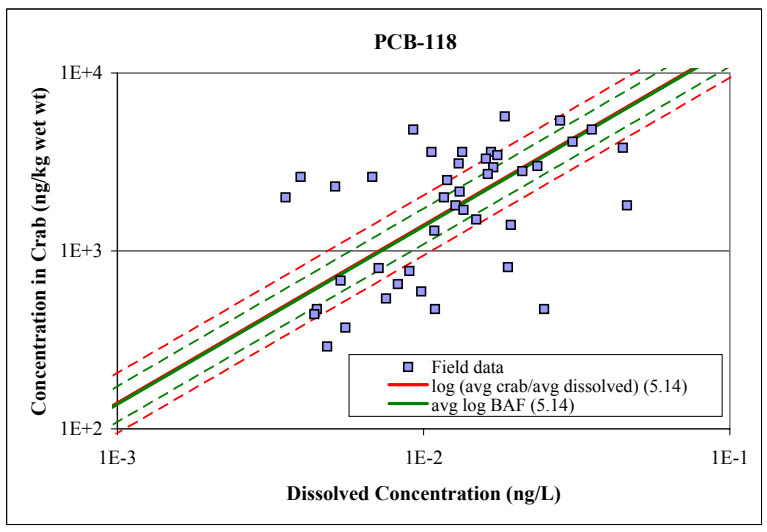


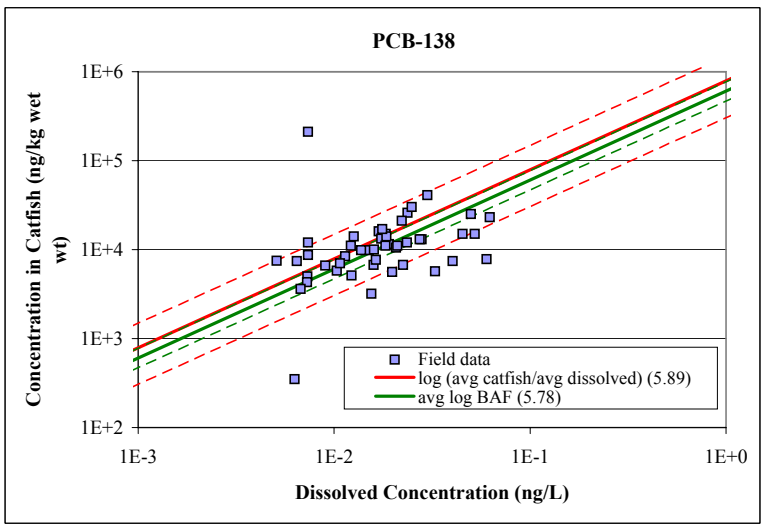
Figure 7.7 Distribution of Individual PCB Congeners in Tissue Samples
(a) Catfish (b) Crab

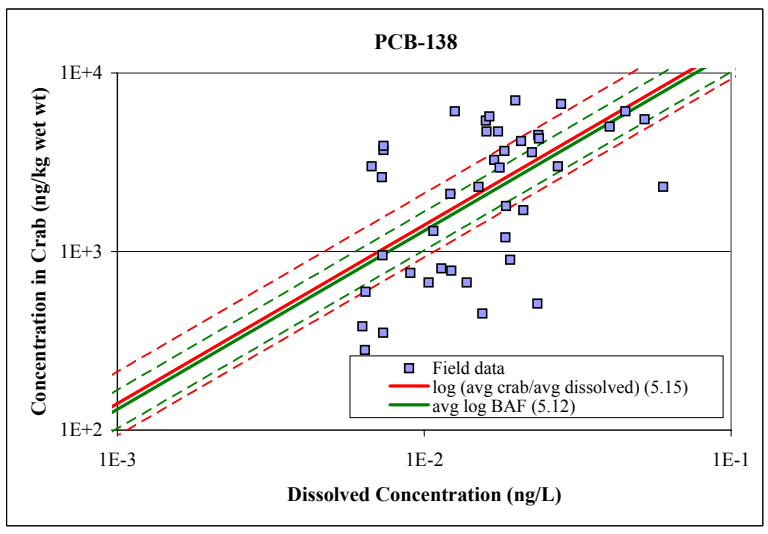


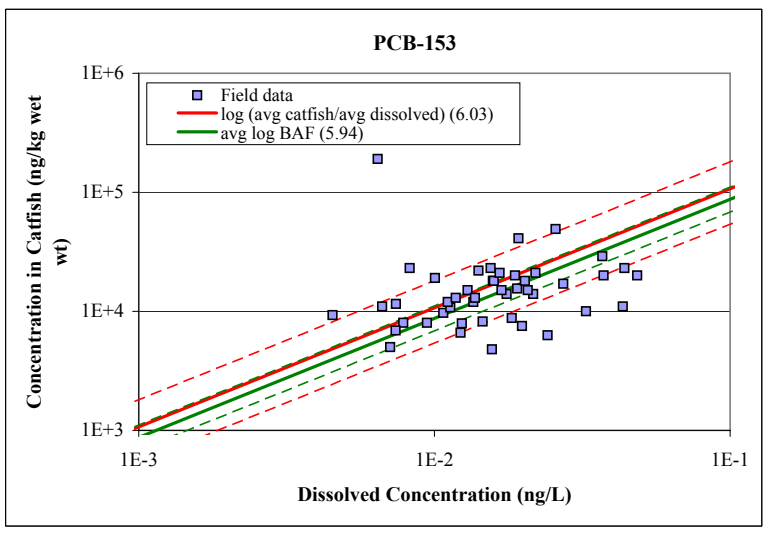


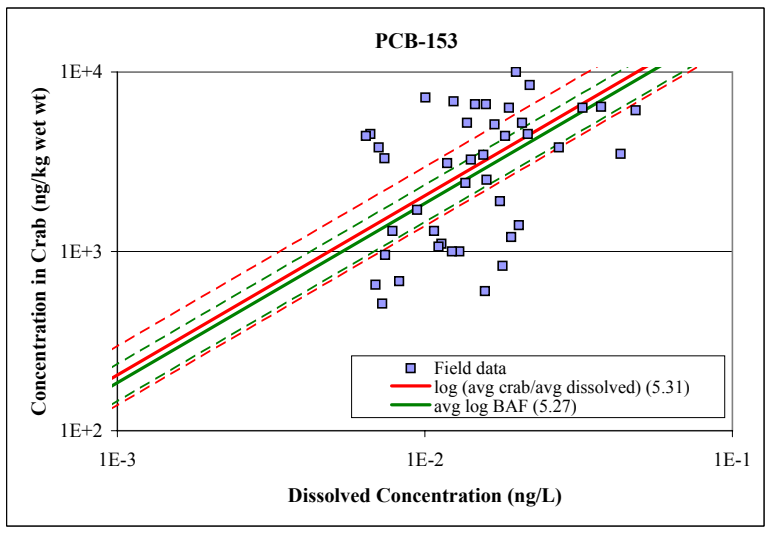


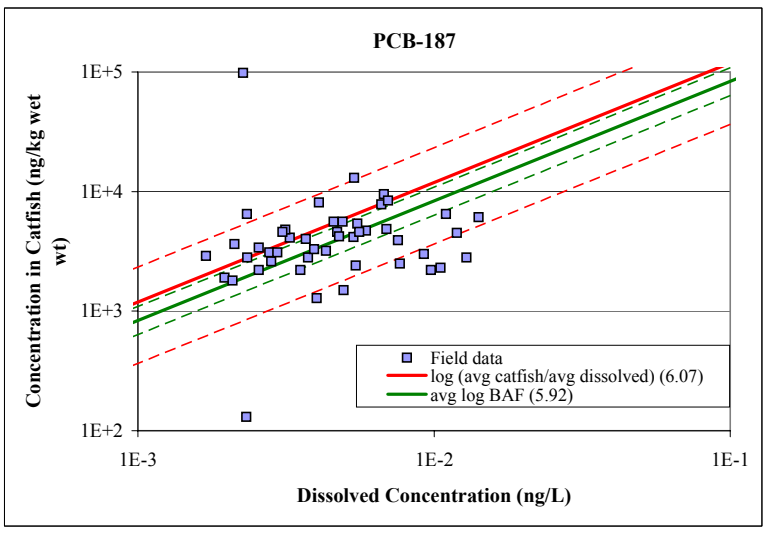


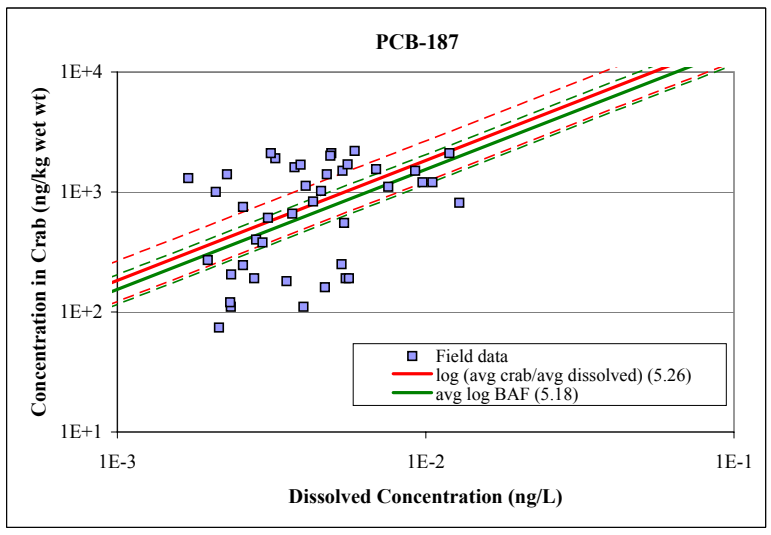






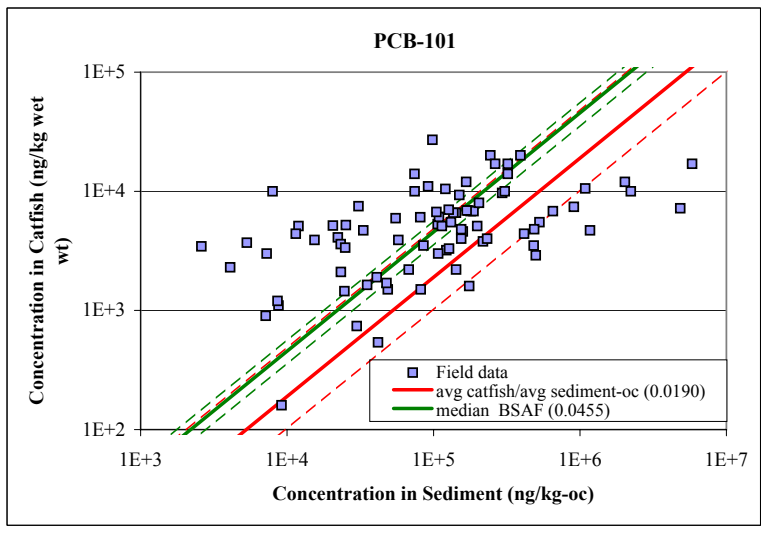


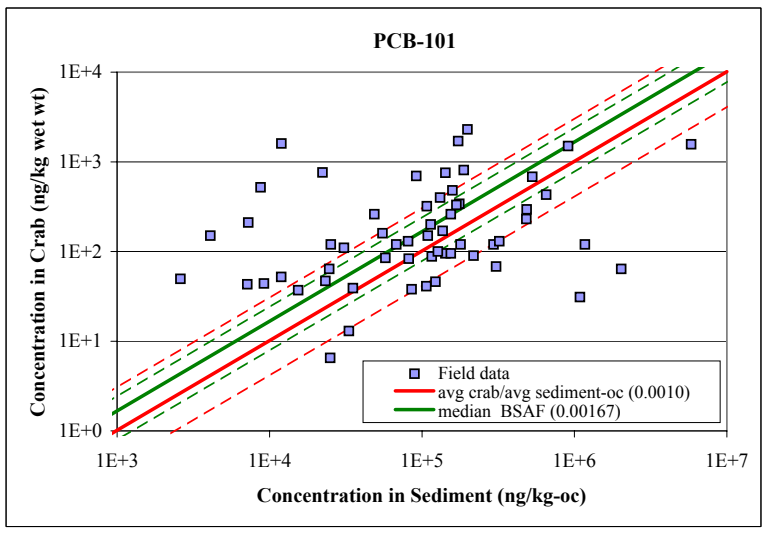


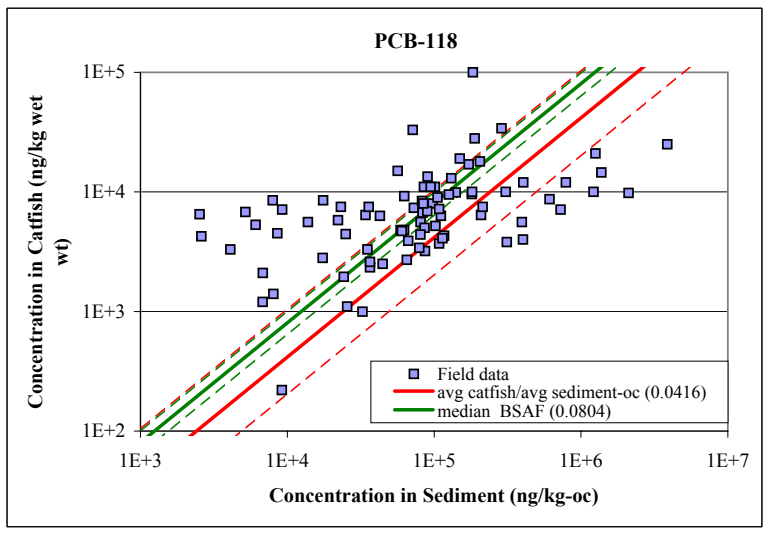


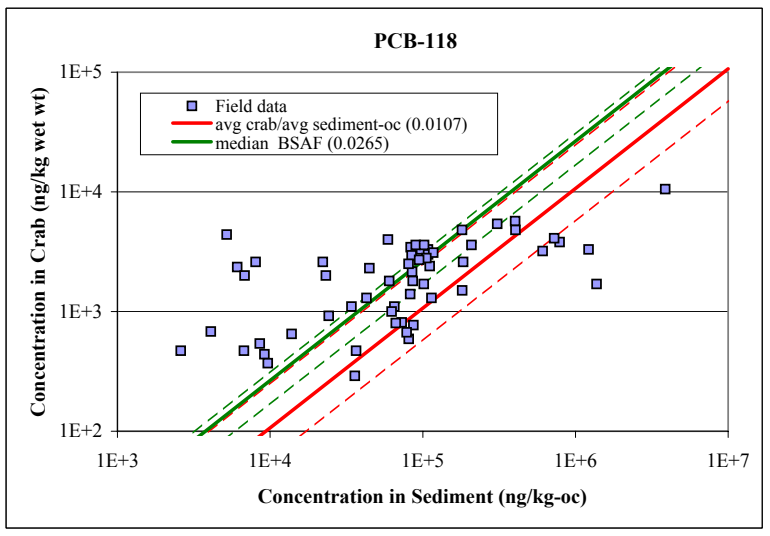
Green dashed lines correspond to the 95% confidence intervals of average slope
Red dashed lines correspond to ratios of confidence interval limits for average tissue and dissolved

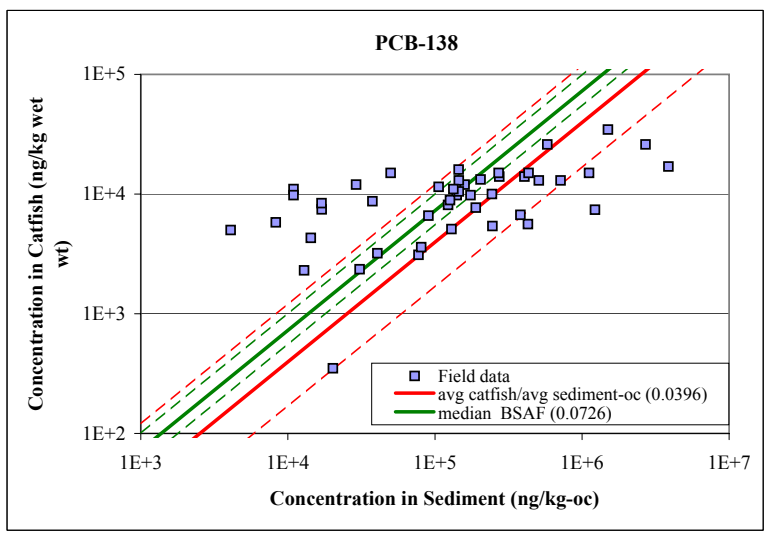
Figure 7.8 Line Fit Plots of BAF for Selected PCB Congeners in Tissue from the HSC

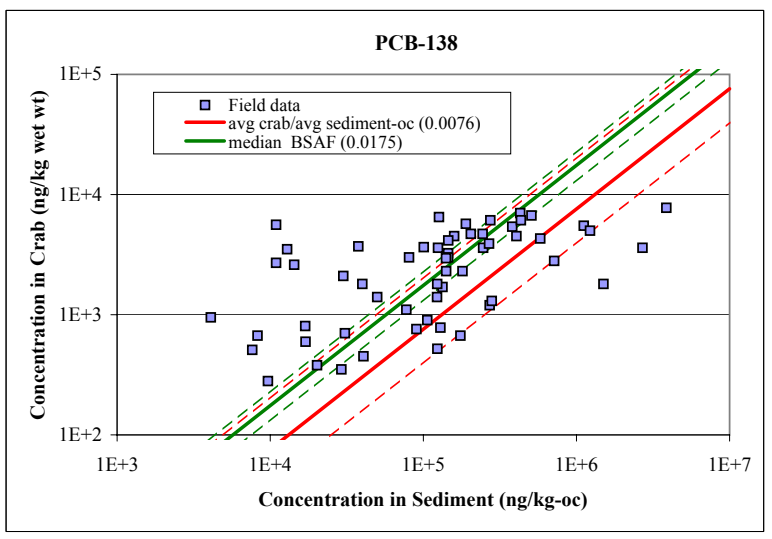


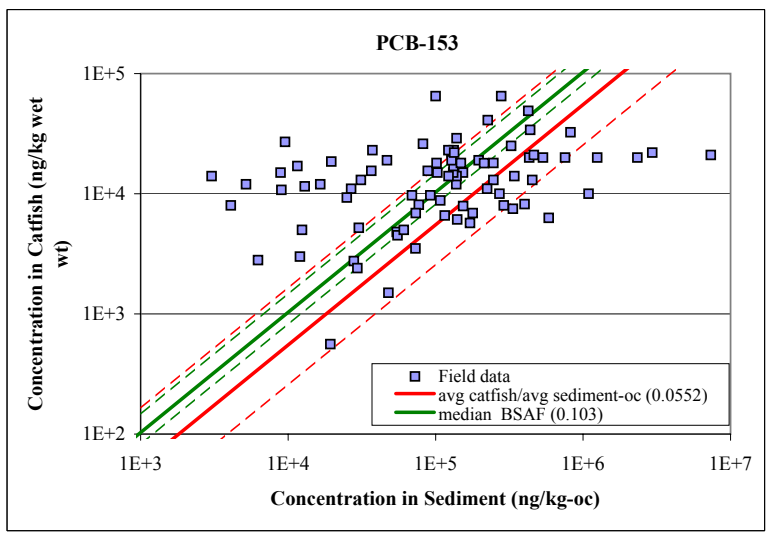


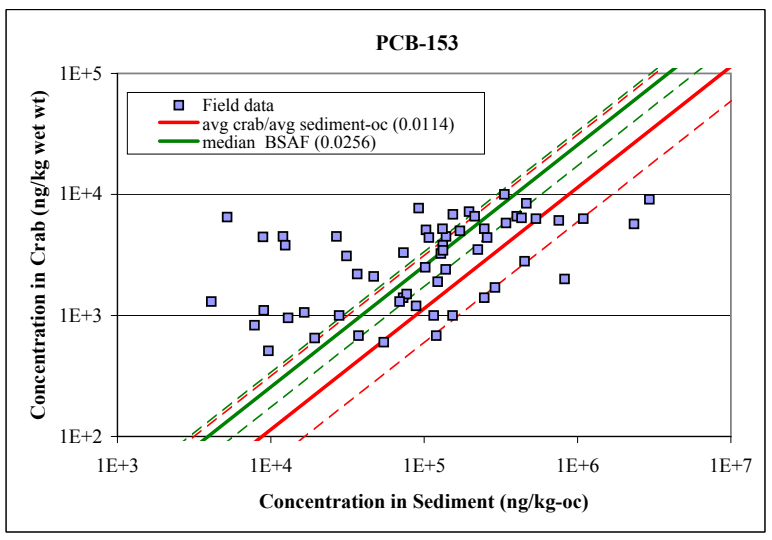


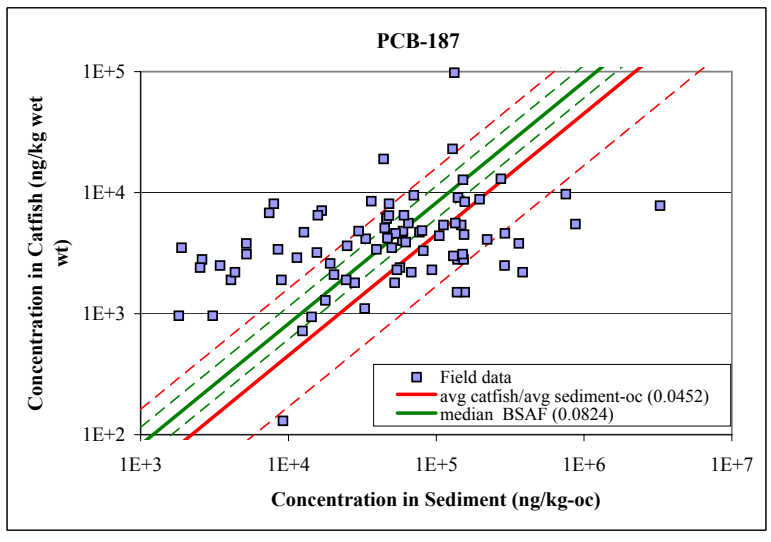


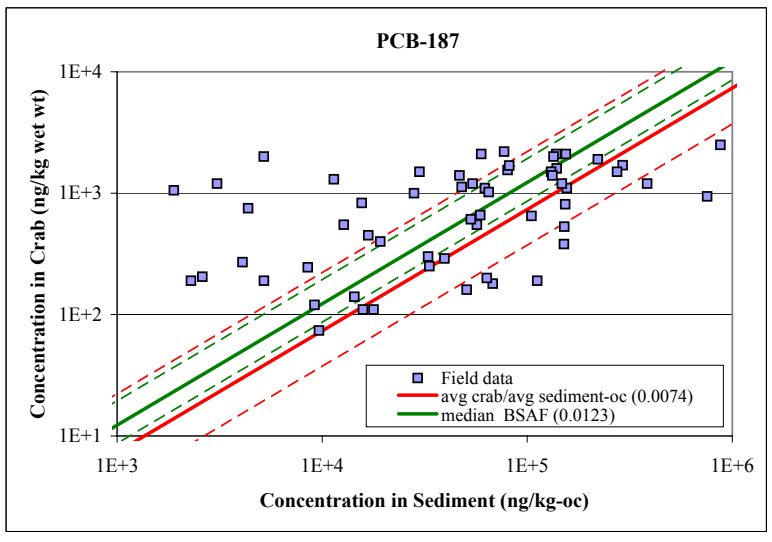












Green dashed lines correspond to the 95% confidence intervals of median slope
Red dashed lines correspond to ratios of confidence interval limits for average tissue and sediment-oc

Figure 7.9 Line Fit Plots of BSAF for Selected PCB Congeners in Tissue from the HSC

do not seem to fit the observed data very well, thus, a sediment-based water quality target was not calculated for PCBs.

Using the TDH screening value for PCBs (47 ng/g), a target concentration in water may be established using the following relationship:

$$WQ_{target,water} = TRC / BAF \quad (7.1)$$

Each of the congeners contributing to the total PCB concentrations has different physical and chemical properties and different bioaccumulation potentials. Using the estimated bioaccumulation factors, the PCB concentration in tissue (PCB_b) can be calculated using:

$$PCB_b = \Sigma (C_{diss})_i * BAF_i \quad (7.2)$$

Since the water quality criterion sets limits for the total equivalence of the mixture rather than the individual congeners and there are no guidelines to develop targets for mixtures of compounds that contribute to an exceedance of a WQ criterion, each congener was assigned a target concentration that corresponded to their associated fraction of the total PCB concentration that was observed historically (on average) in catfish and crab tissue in the system. This can be mathematically expressed as:

$$(C_{diss})_i = TRC * (PCB_b)_i / \Sigma PCB_b / BAF_i \quad (7.3)$$

Using the BAFs estimated from both approaches, and Equations (7.2) and (7.3), the target concentrations for individual congeners were calculated (Tables 7.6a and b).

These BAF ratios were calculated from dissolved water concentrations, so this target applies to the dissolved PCB concentration in water. Based on the average log BAFs for catfish, the water quality target for total PCB dissolved in water would be 0.335 ng/L. Based on the log of the ratio of the average catfish concentration to the average dissolved concentration, the water

Table 7.6a Summary of Average log BAFs, log BAFs from Average Concentrations, and the Resulting Water Quality Targets for PCBs in Catfish from the HSC

Congener	avg log BAF	log BAF[1]	Average contribution to ΣPCB[2]	Water Quality Target - Diss (ng/L)[3]		Dissolved-Suspended Isotherm[4]		Water Quality Target - Susp (ng/L)[5]		Water Quality Target - Total (ng/L)	
				Value using avg log BAF	Value using log BAF[1]	K	1/n	Value using avg log BAF	Value using log BAF[1]	Value using avg log BAF	Value using log BAF[1]
PCB 8	3.006	3.165	0.1%	0.0477	0.0331	5256	0.1426	0.0885	0.0840	0.1362	0.1171
PCB 18	3.471	3.670	0.4%	0.0579	0.0366	5338	0.0934	0.1063	0.1019	0.1642	0.1385
PCB 28	4.328	4.363	1.8%	0.0406	0.0375	14546	0.2441	0.1730	0.1696	0.2137	0.2071
PCB 44	4.810	4.774	5.5%	0.0401	0.0436	43820	0.5330	0.2052	0.2144	0.2453	0.2580
PCB 52	4.634	4.629	5.2%	0.0565	0.0572	33834	0.4650	0.2312	0.2326	0.2877	0.2899
PCB 66	5.142	5.139	5.0%	0.0170	0.0171	80758	0.6480	0.1497	0.1504	0.1666	0.1675
PCB 77	4.074	4.066	0.0%	0.0015	0.0015	193085	0.8434	0.0207	0.0210	0.0222	0.0225
PCB 101	5.197	5.219	8.0%	0.0238	0.0226	249868	0.8130	0.3112	0.2984	0.3350	0.3210
PCB105	5.584	5.659	3.5%	0.0043	0.0037	384909	0.8682	0.0889	0.0766	0.0932	0.0802
PCB 118	5.702	5.786	10.7%	0.0100	0.0082	296062	0.7820	0.2093	0.1800	0.2192	0.1882
PCB 126	5.330	5.421	0.0%	0.0001	0.0001	31677	0.6364	0.0021	0.0019	0.0022	0.0019
PCB 128	5.797	5.882	2.3%	0.0017	0.0014	905371	0.9522	0.0540	0.0449	0.0557	0.0462
PCB 138	5.782	5.896	17.0%	0.0132	0.0101	846901	0.9302	0.3927	0.3075	0.4058	0.3176
PCB 153	5.941	6.030	21.1%	0.0114	0.0093	866810	0.9437	0.3296	0.2720	0.3410	0.2813
PCB 169	5.124	5.176	0.0%	0.0001	0.0000	2618	0.3961	0.0014	0.0013	0.0014	0.0014
PCB 170	5.979	6.088	4.0%	0.0020	0.0015	507217	0.7554	0.1196	0.0988	0.1216	0.1004
PCB 180	6.023	6.192	8.9%	0.0040	0.0027	968877	0.8479	0.2319	0.1665	0.2358	0.1692
PCB 187	5.921	6.075	6.5%	0.0037	0.0026	1000000	0.9428	0.1310	0.0938	0.1347	0.0963
Σ PCBs				0.3353	0.2887			2.8464	2.5155	3.1818	2.8042

[1] BAF calculated as ratio of average catfish concentration to average dissolved concentration

[2] Average contribution of each congener to total PCB in catfish

[3] WQ_{target} calculated using equation (7.3)

[4] From Figure 7.10

[5] average TSS 26

Table 7.6b Summary of Average log BAFs, log BAFs from Average Concentrations, and the Resulting Water Quality Targets for PCBs in Crabs from the HSC

Congener	avg log BAF	log BAF[1]	Average contribution to ΣPCB[2]	Water Quality Target - Diss (pg/L)[3]		Dissolved-Suspended Isotherm[4]		Water Quality Target - Susp (pg/L)[5]		Water Quality Target - Total (pg/L)	
				Value using avg log BAF	Value using log BAF[1]	K	1/n	Value using avg log BAF	Value using log BAF[1]	Value using avg log BAF	Value using log BAF[1]
PCB 8	3.211	3.074	0.3%	0.0979	0.1342	5256	0.1426	0.0981	0.1026	0.1960	0.2368
PCB 18	2.779	2.758	0.2%	0.1862	0.1953	5338	0.0934	0.1186	0.1191	0.3048	0.3144
PCB 28	4.120	4.067	4.2%	0.1505	0.1700	14546	0.2441	0.2382	0.2454	0.3887	0.4154
PCB 44	4.197	4.121	6.8%	0.2040	0.2428	43820	0.5330	0.4883	0.5358	0.6922	0.7785
PCB 52	3.034	3.330	1.1%	0.4747	0.2403	33834	0.4650	0.6221	0.4533	1.0968	0.6936
PCB 66	4.637	4.608	7.9%	0.0857	0.0917	80758	0.6480	0.4274	0.4465	0.5131	0.5383
PCB 77	4.592	4.585	0.5%	0.0063	0.0064	193085	0.8434	0.0702	0.0710	0.0765	0.0774
PCB 101	3.731	3.956	1.8%	0.1550	0.0922	249868	0.8130	1.4269	0.9354	1.5818	1.0276
PCB105	5.037	5.025	4.8%	0.0206	0.0211	384909	0.8682	0.3435	0.3514	0.3640	0.3725
PCB 118	5.138	5.145	14.7%	0.0503	0.0494	296062	0.7820	0.7432	0.7330	0.7935	0.7825
PCB 126	4.977	4.979	0.1%	0.0003	0.0003	31677	0.6364	0.0051	0.0051	0.0055	0.0054
PCB 128	5.103	5.108	2.1%	0.0079	0.0078	905371	0.9522	0.2332	0.2304	0.2411	0.2382
PCB 138	5.116	5.150	17.5%	0.0630	0.0583	846901	0.9302	1.6817	1.5658	1.7446	1.6241
PCB 153	5.267	5.310	22.9%	0.0583	0.0528	866810	0.9437	1.5413	1.4047	1.5995	1.4575
PCB 169	4.705	4.723	0.0%	0.0004	0.0004	2618	0.3961	0.0030	0.0029	0.0033	0.0033
PCB 170	5.084	5.134	2.4%	0.0092	0.0082	507217	0.7554	0.3831	0.3517	0.3923	0.3599
PCB 180	5.224	5.306	7.0%	0.0195	0.0162	968877	0.8479	0.8955	0.7641	0.9151	0.7803
PCB 187	5.188	5.263	5.6%	0.0170	0.0143	1000000	0.9428	0.5573	0.4740	0.5742	0.4883
Σ PCBs				1.6067	1.4018			9.8764	8.7922	11.4831	10.1940

[1] BAF calculated as ratio of average crab concentration to average dissolved concentration

[2] Average contribution of each congener to total PCB in crab

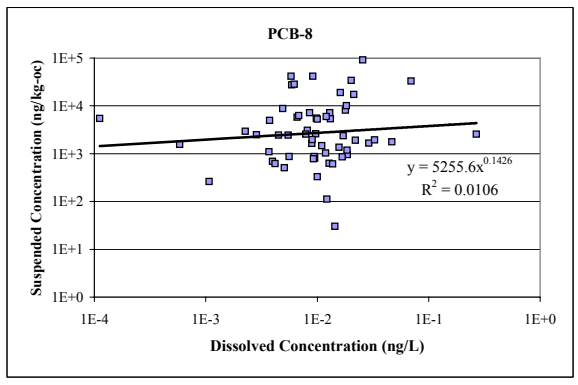
[3] WQ_{target} calculated using equation (7.3)

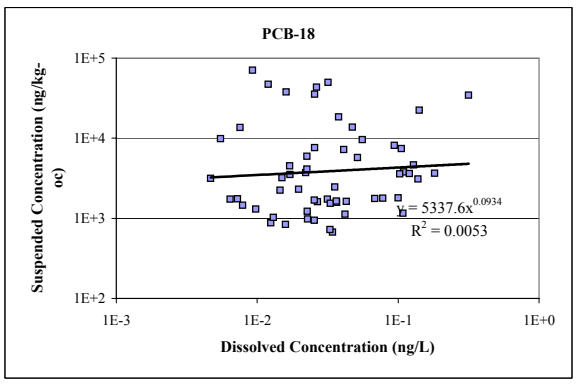
[4] From Figure 7.10

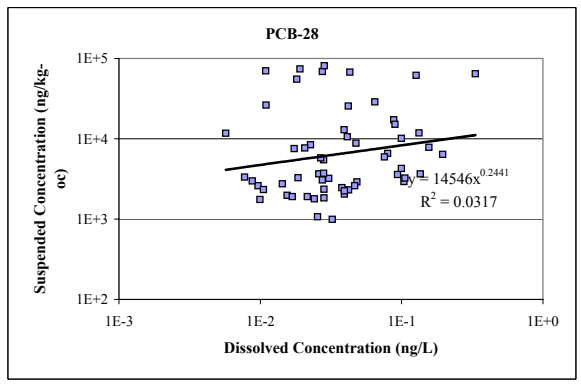
[5] average TSS 26

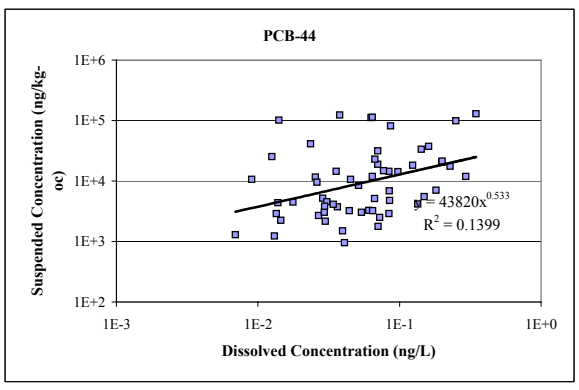
quality target for total PCBs dissolved in water would be 0.289 ng/L. Using dissolved-suspended partitioning relationships presented in Figure 7.10, the water quality target for total PCBs in water would be 3.182 and 2.804 ng/L for the first and second approach, respectively. These targets are higher than the Texas WQS of 0.885 ng/L for marine waters. Crab data yielded higher water quality targets with respective concentrations in whole water of 11.483 and 10.194 ng/L for the first and second approach.

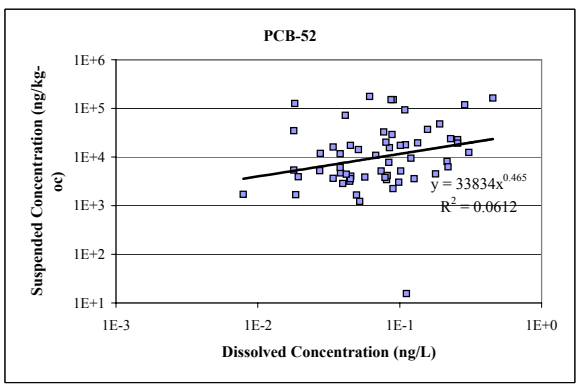
Water data collected in WO4 were compared to the estimated congener-specific targets derived using both approaches to evaluate the current state of impairment of the Houston Ship Channel. Table 7.7 summarizes the percent target exceedances by congener in the entire system. Data in Table 7.7 indicate that the water quality targets calculated using site-specific BAFs are not exceeded for most congeners. The congeners with most exceedances are PCB-44 and PCB-52 with 4 out of 58 samples exceeding the WQ target. The water quality target for total PCB is not exceeded in the HSC samples.

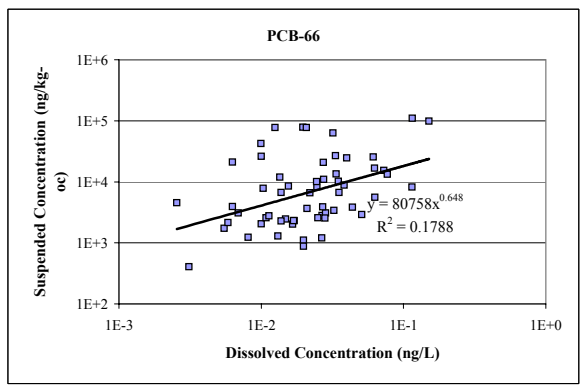


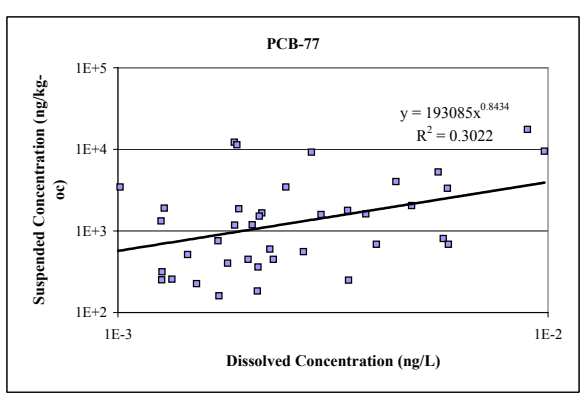


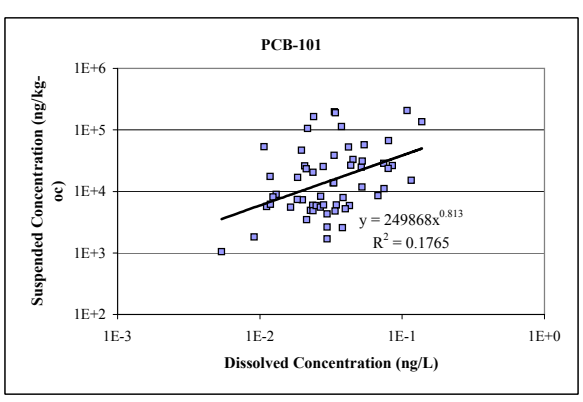


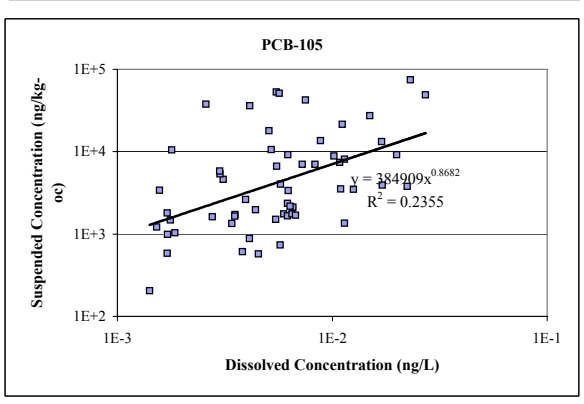


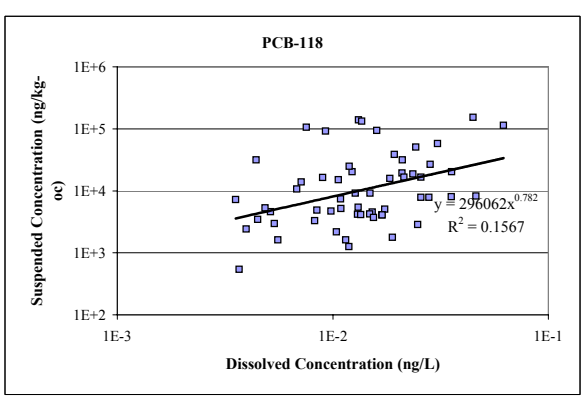


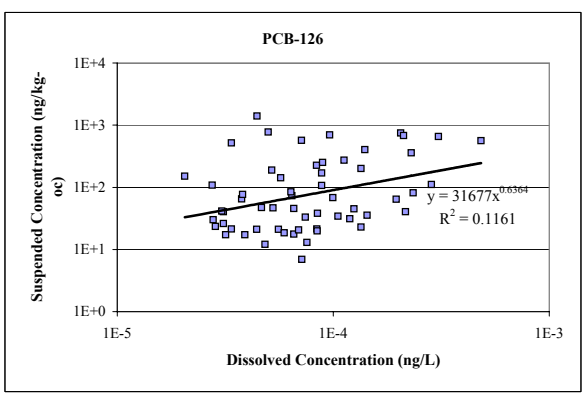


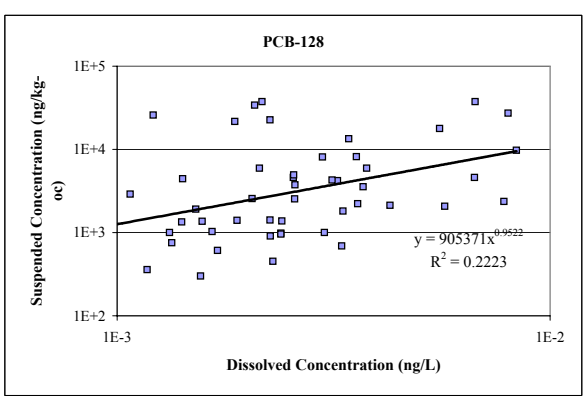


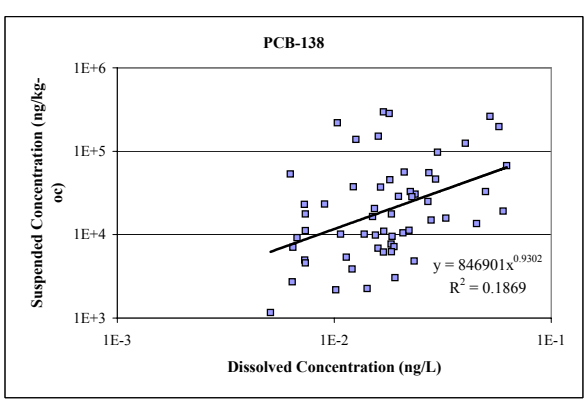


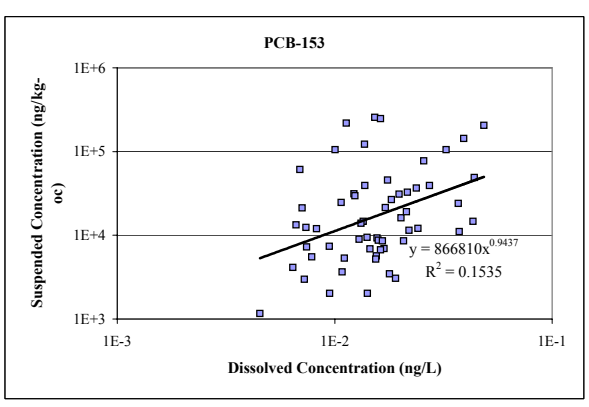


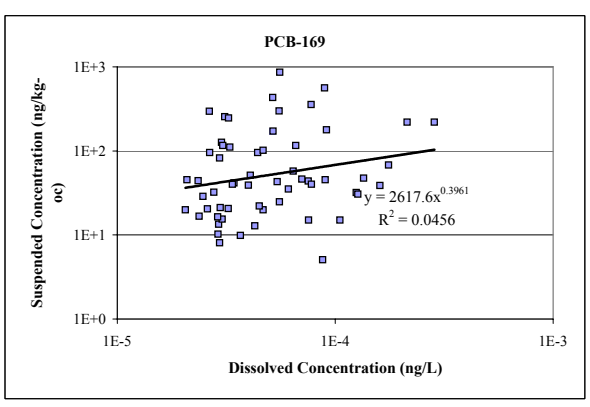


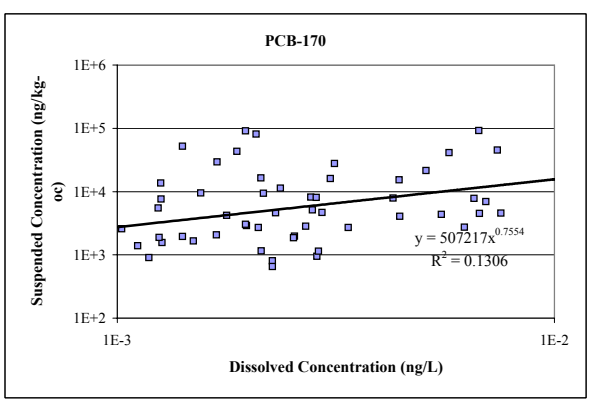


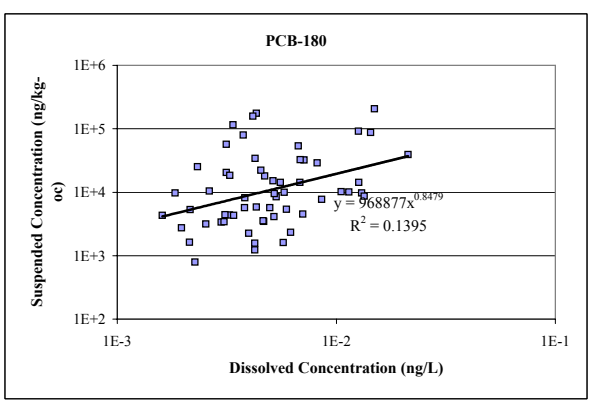












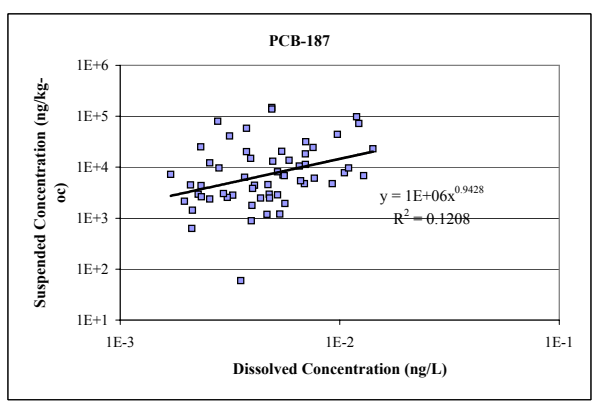


Figure 7.10 Partitioning of PCBs between Dissolved and Suspended Phases in the HSC

Table 7.7 Summary of Exceedances of the PCB Water Quality Criteria Estimated using Site-Specific BAFs

Congener	Using avg log BAF		Using log BAF[1]	
	# exceedances	%	% exceedances	%
PCB 8	1	1.7%	1	1.7%
PCB 18	2	3.4%	2	3.4%
PCB 28	2	3.4%	2	3.4%
PCB 44	4	6.9%	4	6.9%
PCB 52	4	6.9%	4	6.9%
PCB 66	1	1.7%	1	1.7%
PCB 77	0	0.0%	0	0.0%
PCB 101	0	0.0%	0	0.0%
PCB105	0	0.0%	0	0.0%
PCB 118	0	0.0%	0	0.0%
PCB 126	0	0.0%	0	0.0%
PCB 128	0	0.0%	0	0.0%
PCB 138	0	0.0%	0	0.0%
PCB 153	0	0.0%	0	0.0%
PCB 169	0	0.0%	0	0.0%
PCB 170	0	0.0%	0	0.0%
PCB 180	0	0.0%	0	0.0%
PCB 187	0	0.0%	0	0.0%
Σ PCBs	0	0.0%	0	0.0%

[1] BAF calculated as ratio of average catfish concentration to average dissolved concentration
samples=58

7.4.2 Spatial Trends

Figures 7.11, 7.12, 7.13, and 7.14 show total PCB concentration profiles along the main channel for water, sediment, catfish, and crabs, respectively; as well as the standard/screening values for the different environmental media. The total dioxin TEQ profiles are also shown for comparison. Figure 7.11 shows that average PCB concentrations in water start low (below the WQS) and they increase in segment 1006 to levels above the Texas WQS then start decreasing in the direction of Galveston Bay. A similar profile is obtained for average OC-normalized sediment concentrations (Figure 7.12), with the difference that the sediment profile exhibits a sudden decrease in concentration in station 11258 in segment 1005. Average OC-normalized sediment concentrations in the Side Bays are generally lower than those at the confluences with the main channel (Segment 1005).

Average catfish PCB concentrations exhibit a longitudinal profile that is fairly flat in the main channel prior to Galveston Bay (Figure 7.13). Most of the catfish concentrations exceed the TDH health-based screening level. Finally, average PCB concentrations in crab samples are somewhat stable in segments 1007, 1006 and beginning of 1005, with levels below the screening level (Figure 7.14). They then start decreasing towards Galveston Bay.

It is noted that for all the media, the PCB profiles mimic those for dioxin concentrations, confirming similar patterns for PCBs as for dioxins with one notable exception related to water PCB concentrations being below the standard in 1005 and 2421, whereas dioxin concentrations are not.

To further analyze spatial patterns, a Principal Component Analysis was completed for the Summer 2002 sediment dataset. The sediment dataset was selected because sediment

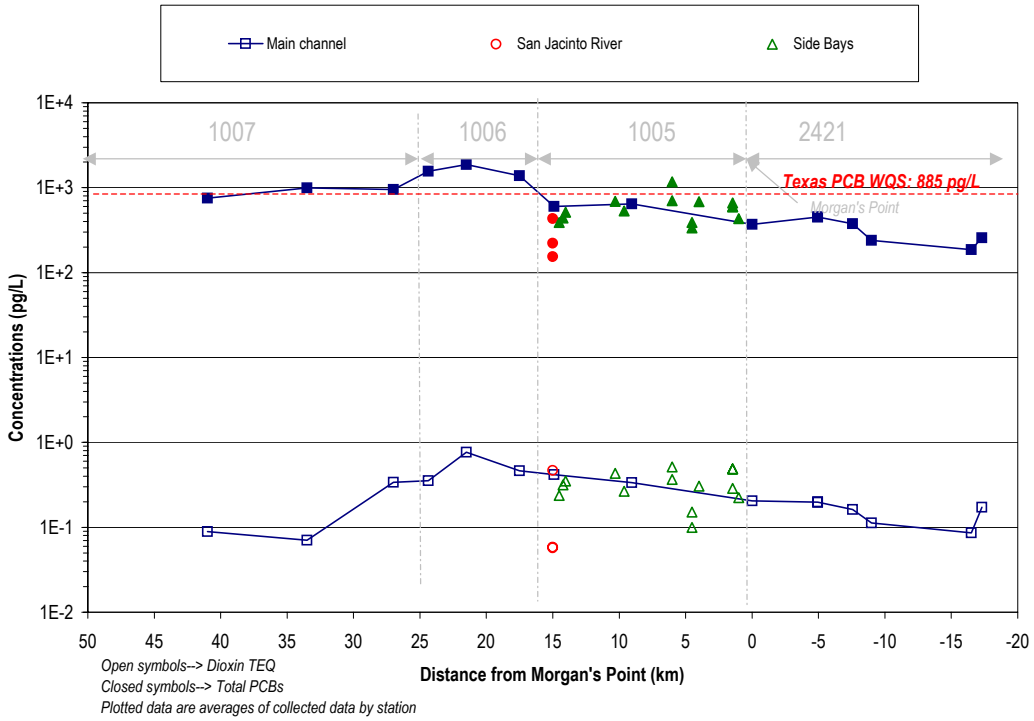


Figure 7.11 Total Water Dioxin and PCB Concentration Profiles in the HSC

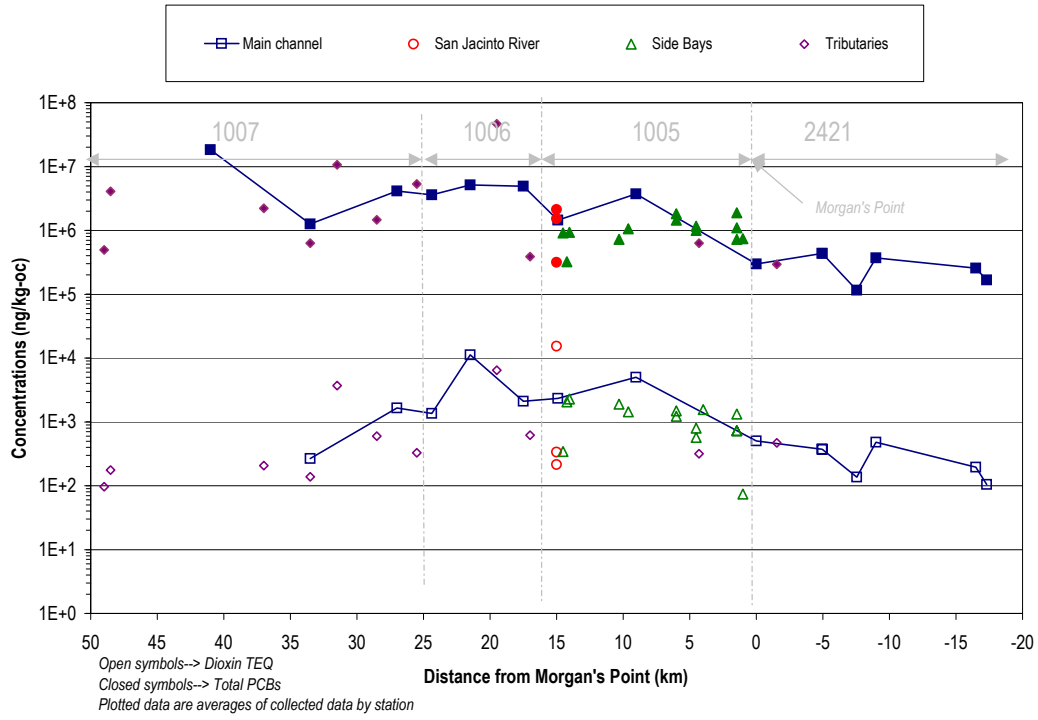


Figure 7.12 Total Organic Content-normalized Sediment Dioxin and PCB Concentration Profiles in the HSC

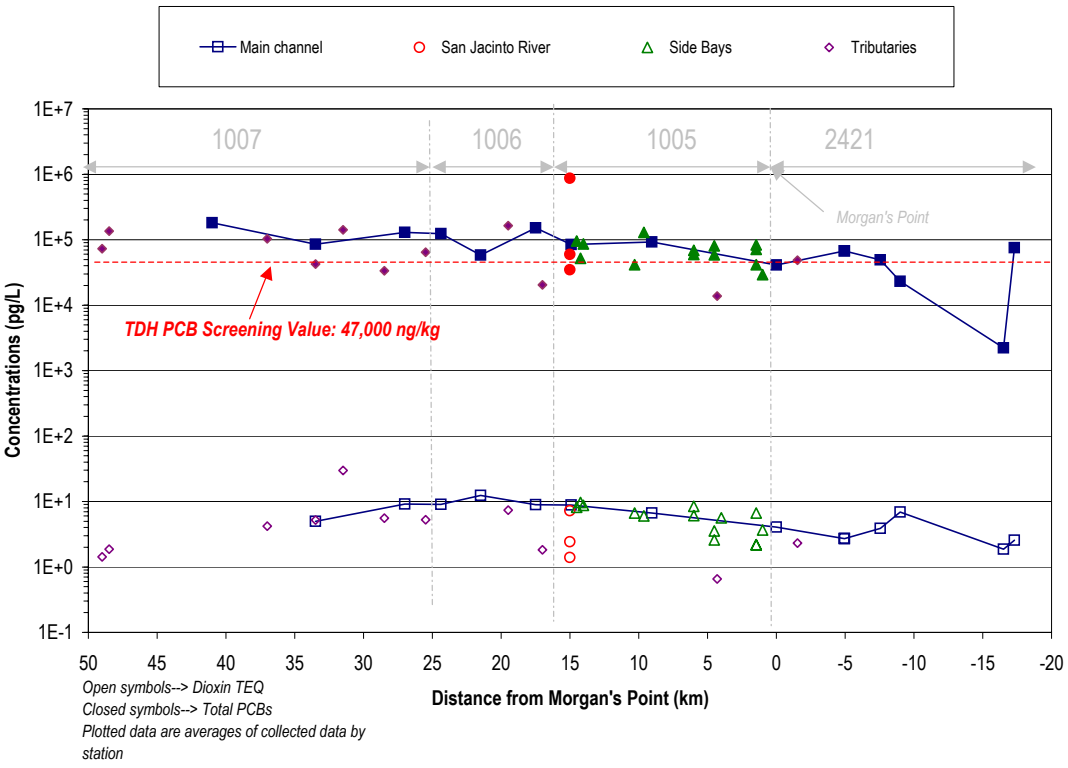


Figure 7.13 Total Catfish Dioxin and PCB Concentration Profiles in the HSC

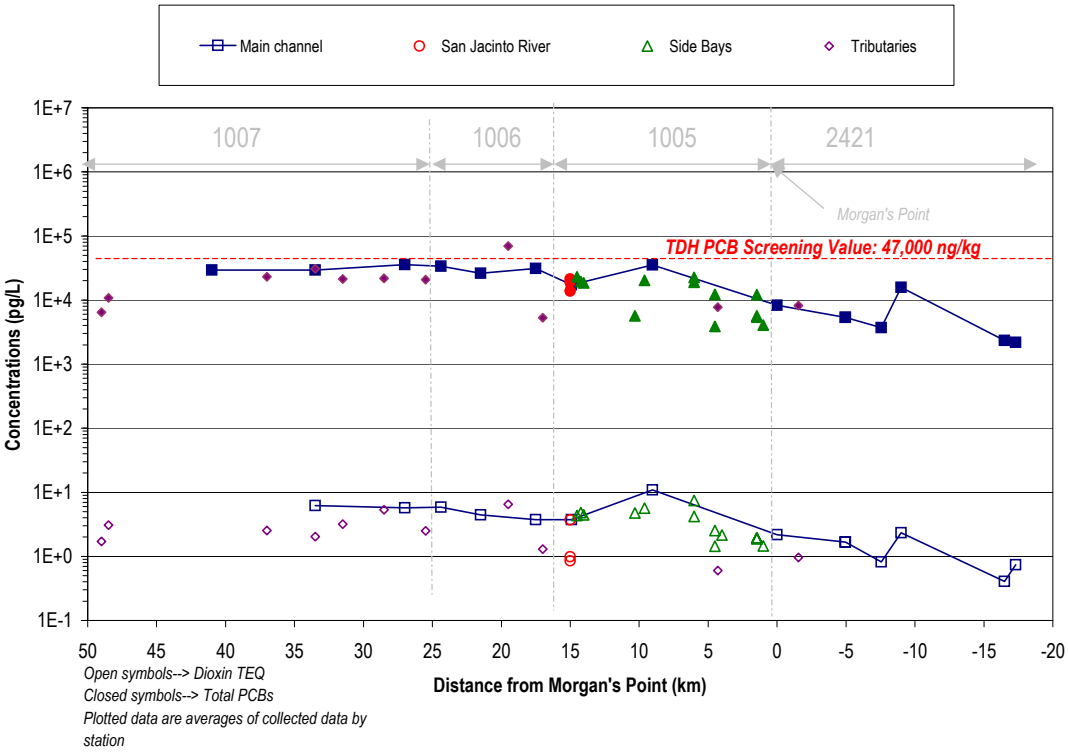


Figure 7.14 Total Crab Dioxin and PCB Concentration Profiles in the HSC

concentrations are expected to be more stable over time than concentrations in other media. Figure 7.15a shows the biplot of the PCA. It can be seen that Figure 7.15a does not represent a good PCA, since it takes 6 components to explain 88% of the variability. Figure 7.15b shows a plot of the three main components. Station 11273 is still an outlier when compared to the other stations, similar to what was observed for dioxin data. With the three components, only 44% of the variance could be explained. The cluster analysis tree (Figure 7.16) indicates that the relative outliers are 11273 and 11292. They do not appear as outliers in either scatter plot, but that is most likely because most of the variance is not explained in the first two or three components.

7.5 SUMMARY OF AROCLOR RESULTS IN THE HOUSTON SHIP CHANNEL

In addition to the 209 PCB congeners, Aroclor concentrations (EPA Method 8082) were also quantified in all the media. During the Summer 2002, Aroclors were analyzed from 18 ambient water locations (using the high-volume sampling technique), 28 in-stream sediment locations, 23 catfish tissue and 27 crab tissue locations, and 11 tributary sediment locations. In addition, during Fall 2002 samples from 18 ambient water locations, 16 in-stream sediment locations, 11 locations for catfish tissue, and 12 locations for crab tissue were analyzed for Aroclors. Table 7.8 includes a summary of the total number of samples collected during the Summer and Fall of 2002. Results of Aroclor analyses for Summer and Fall 2002 are presented in Tables 7.9 through 7.12. A summary of measured Aroclor concentrations for the different media is included in Tables 7.13a and b. Overall, the majority of the samples (>90%) showed

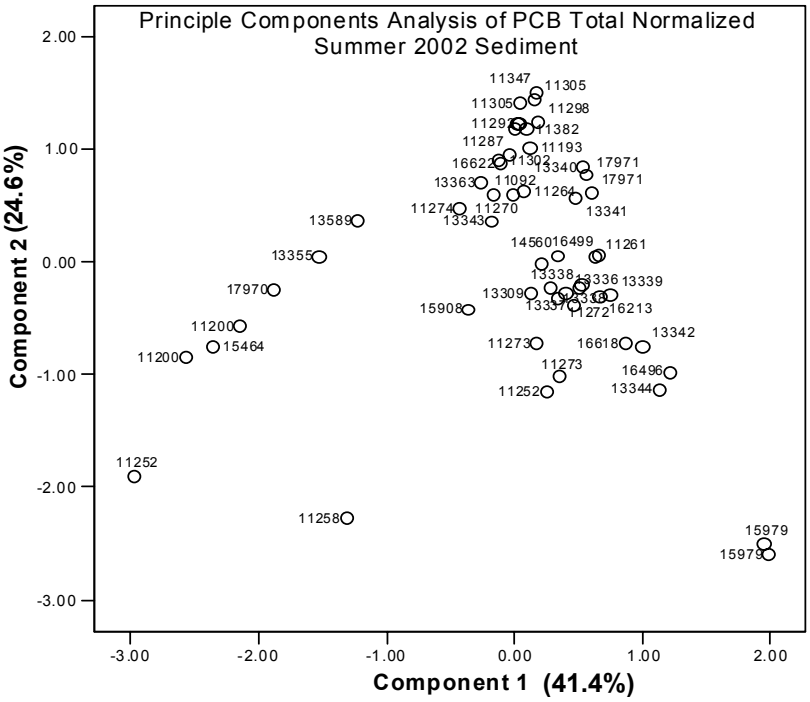


Figure 7.15a PCA of PCB Concentrations in Sediment

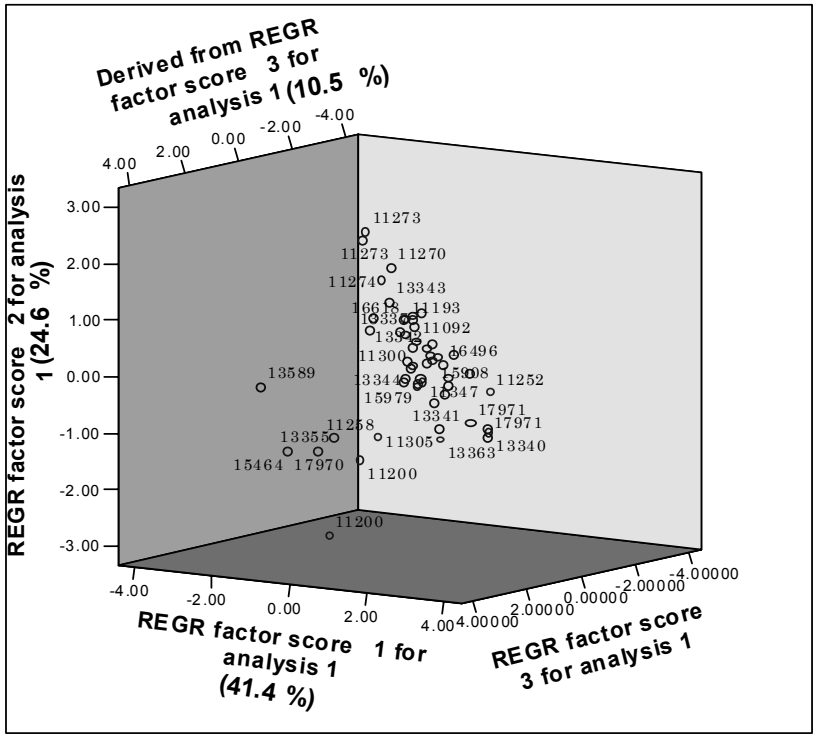


Figure 7.15b Scores for Three Main Components of PCBs in Sediment

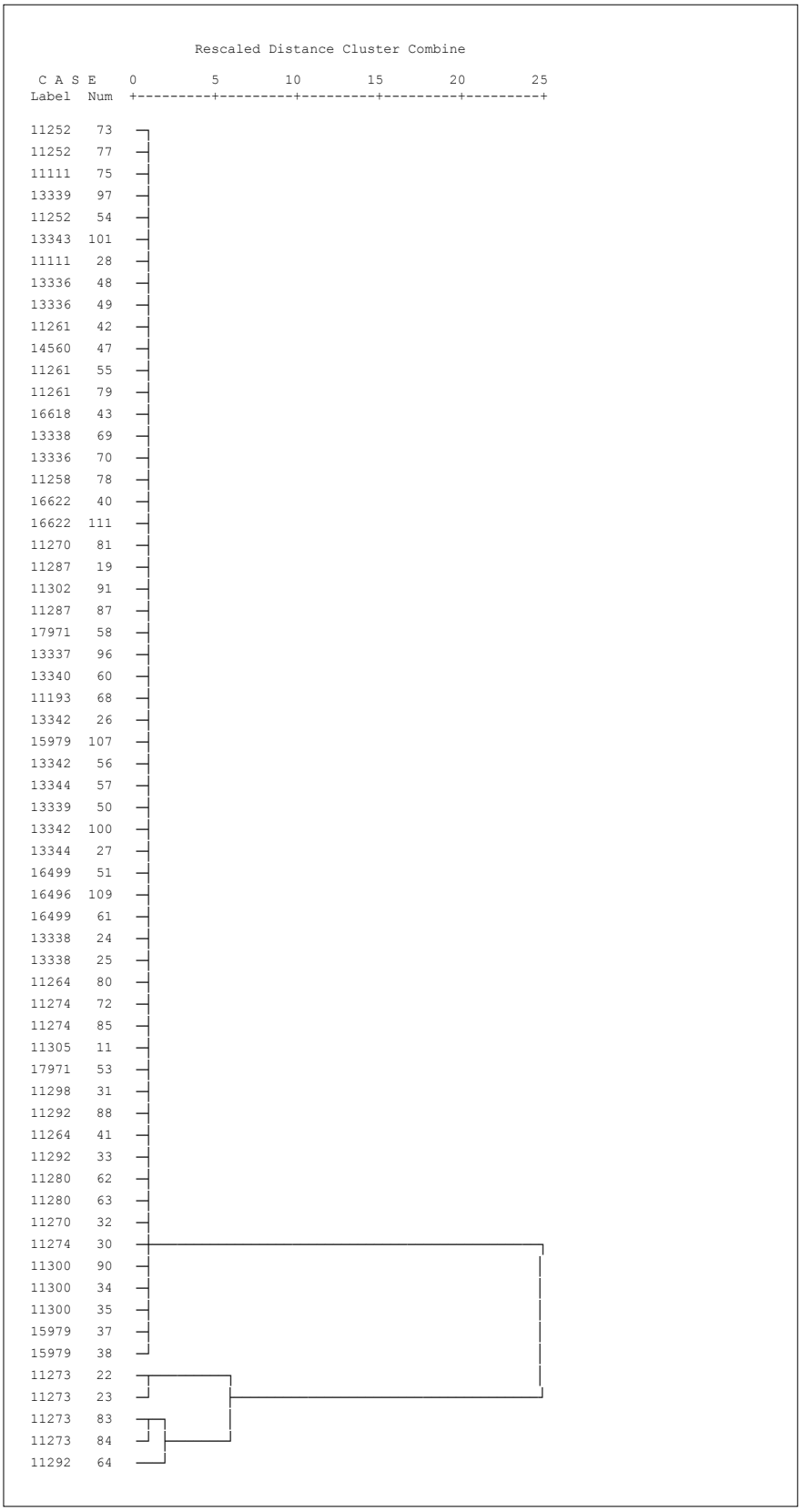


Figure 7.16 PCBs Sediment Dendrogram using Ward Method

Table 7.8 Total Number of Aroclor Samples

Matrix	Summer 2002			Fall 2002		
	# sites	QC samples[a]	# samples	# sites	QC samples[a]	# samples
Water	18	0	18	18	2	20
Sediment						
- In-channel	28	5	33	16	1	17
- Tributaries	11	3	14	ns	ns	ns
Catfish						
- In-channel	20	4	24	11	4	15
- Tributaries	3	0	3	ns	ns	ns
Crab						
- In-channel	23	4	27	13	2	15
- Tributaries	4	1	5	ns	ns	ns

[a] Field duplicates
ns = not sampled

Table 7.9 Aroclors in Water (ng/L)

Station ID	Date	Volume (L)	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260	Aroclor-1262	Aroclor-1268	Total Aroclors
Summer 2002												
11200	09/02/2002	508	< 0.433	< 0.276	< 0.433	< 0.984	< 1.614	< 1.102	< 0.630	< 0.630	< 0.315	< 1.614
11252	08/30/2002	703	< 0.686	< 0.398	< 0.626	< 1.422	< 2.361	< 1.607	< 0.910	< 0.910	< 0.455	< 2.361
11261	09/12/2002	532	< 0.423	< 0.263	< 0.414	< 0.940	< 1.541	< 1.053	< 0.602	< 0.602	< 0.301	< 1.541
11280	09/04/2002	501	< 0.436	< 0.190	< 0.263	< 0.543	< 0.860	< 0.597	< 0.838	< 0.363	< 0.184	< 1.337
11287	09/12/2002	508	< 0.433	< 0.276	< 0.433	< 0.984	< 1.614	< 1.102	< 0.630	< 0.630	< 0.315	< 1.614
11292	09/03/2002	610	< 1.028	< 0.689	< 1.082	< 2.500	< 4.016	< 2.738	< 1.541	< 1.541	< 0.787	< 4.016
13309	08/25/2002	532	< 0.258	< 0.094	< 0.083	< 0.083	< 0.079	< 0.071	< 0.305	< 0.083	< 0.045	< 0.310
13336	08/29/2002	523	< 0.427	< 0.268	< 0.421	< 0.956	< 1.568	< 1.071	< 0.612	< 0.612	< 0.306	< 1.568
13337	08/24/2002	524	< 0.259	< 0.181	< 0.252	< 0.519	< 0.823	< 0.571	< 0.347	< 0.347	< 0.176	< 0.830
13339	09/06/2002	579	< 0.407	< 0.207	< 0.266	< 0.508	< 0.781	< 0.725	< 0.352	< 0.352	< 0.180	< 0.950
13341	09/05/2002	509	< 0.433	< 0.187	< 0.259	< 0.534	< 0.847	< 0.587	< 0.509	< 0.358	< 0.181	< 1.000
13342	08/23/2002	509	< 1.081	< 0.688	< 1.081	< 2.456	< 4.047	< 2.711	< 1.591	< 1.591	< 0.786	< 4.047
13363	08/31/2002	560	< 0.609	< 0.375	< 0.589	< 1.339	< 2.161	< 1.482	< 0.857	< 0.857	< 0.429	< 2.161
13589	09/10/2002	512	< 3.439	< 3.418	< 5.371	< 12.207	< 19.727	< 13.672	< 7.813	< 7.813	< 3.906	< 19.727
14560	09/04/2002	622	< 0.252	< 0.153	< 0.212	< 0.437	< 0.693	< 0.481	< 0.362	< 0.293	< 0.148	< 0.764
15908	08/29/2002	503	< 0.654	< 0.417	< 0.656	< 1.491	< 2.406	< 1.650	< 0.954	< 0.954	< 0.477	< 2.406
16213	09/10/2002	557	< 0.414	< 0.251	< 0.395	< 0.898	< 1.472	< 1.005	< 0.575	< 0.575	< 0.287	< 1.472
16622	09/02/2002	524	< 0.636	< 0.401	< 0.630	< 1.431	< 2.309	< 1.584	< 0.916	< 0.916	< 0.458	< 2.309
Fall 2002												
11193	11/20/2002	709	< 0.183	< 0.212	< 0.183	< 0.183	< 0.183	< 0.155	< 0.183	< 0.183	< 0.102	< 0.212
11200	11/21/2002	707	< 1.909	< 2.016	< 2.016	< 1.909	< 1.909	< 1.909	< 1.485	< 1.485	< 0.318	< 2.016
11252	11/20/2002	706	< 0.425	< 0.425	< 0.637	< 0.637	< 0.850	< 0.850	< 0.850	< 0.850	< 0.319	< 0.850
11252-dup	11/14/2002	707	< 0.212	< 0.212	< 0.424	< 0.424	< 0.530	< 0.636	< 0.636	< 0.424	< 0.212	< 0.636
11261	10/21/2002	422	< 1.422	< 0.711	< 1.777	< 2.133	< 2.133	< 2.133	< 1.066	< 1.066	< 0.711	< 2.133
11280	11/06/2002	703	< 1.920	< 2.027	< 2.027	< 1.920	< 1.920	< 1.280	< 1.209	< 1.209	< 0.320	< 2.027
11292	11/07/2002	722	< 0.091	< 0.104	< 0.091	< 0.091	< 0.348	< 0.358	< 0.091	< 0.091	< 0.050	0.623
13336	11/05/2002	570	< 0.228	< 0.263	< 0.228	< 1.711	< 0.509	< 1.158	< 0.509	< 0.228	< 0.126	< 2.500
13338	11/12/2002	476	< 0.630	< 0.630	< 0.630	< 0.630	< 0.945	< 0.945	< 0.945	< 0.945	< 0.630	< 0.945
13341	10/24/2002	651	< 2.765	< 2.765	< 2.765	< 2.765	< 2.765	< 2.765	< 2.765	< 2.765	< 2.765	< 2.765
13342	10/29/2002	712	< 1.053	< 2.001	< 1.159	< 1.053	< 1.475	< 0.843	< 0.632	< 0.632	< 0.316	< 2.001
13344	11/08/2002	711	< 1.899	< 1.899	< 1.899	< 1.899	< 1.899	< 2.004	< 1.582	< 1.582	< 1.055	< 2.004
13355	11/11/2002	498	< 2.540	< 2.560	< 2.540	< 3.313	< 3.313	< 3.313	< 2.540	< 2.540	< 2.482	< 3.313
13363	10/31/2002	570	< 3.158	< 3.158	< 3.158	< 3.158	< 3.158	< 3.158	< 3.158	< 3.158	< 3.158	< 3.158
14560	11/13/2002	703	< 1.920	< 1.920	< 1.920	< 1.920	< 1.920	< 1.174	< 1.174	< 0.747	< 1.920	< 28.770
15464	11/19/2002	702	< 0.185	< 0.214	< 0.185	< 0.185	< 0.185	< 0.157	< 0.185	< 0.185	< 0.103	< 0.214
15979	11/01/2002	662	< 2.039	< 2.153	< 2.153	< 2.039	< 2.039	< 2.039	< 1.586	< 1.586	< 0.340	< 2.153
16499	10/30/2002	715	< 1.888	< 1.888	< 1.888	< 1.888	< 1.888	< 1.888	< 1.469	< 1.469	< 0.629	< 1.888
17971	11/18/2002	708	< 0.047	< 0.053	< 0.047	< 0.047	< 0.044	< 0.282	< 0.047	< 0.047	< 0.025	0.282
17971-dup	11/18/2002	711	< 0.211	< 0.211	< 0.211	< 0.211	< 0.422	< 0.422	< 0.422	< 0.422	< 0.211	< 0.422

Non-detects assumed as 1/2 MDL
Spring 2003 samples were not analyzed for Aroclors

Table 7.10 Aroclors in Sediment (ng/g-dry wt.)

Sample ID	Date	Aroclor 1016	Aroclor 1221	Aroclor 1232	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
Summer 2002								
11193	08/08/2002	< 44	< 44	< 44	< 44	< 44	< 44	< 44
11200	09/03/2002	< 43	< 43	< 43	< 43	< 43	< 43	< 43
11200-dup	09/03/2002	< 47	< 47	< 47	< 47	< 47	< 47	< 47
11252	08/27/2002	< 42	< 42	< 42	< 42	< 42	< 42	< 42
11252-dup	08/27/2002	< 43	< 43	< 43	< 43	< 43	< 43	< 43
11258	08/01/2002	< 40	< 40	< 40	< 40	< 40	< 40	< 40
11261	08/19/2002	< 43	< 43	< 43	< 43	< 43	< 43	< 43
11264	08/19/2002	< 49	< 49	< 49	< 49	< 49	< 49	< 49
11280	08/29/2002	< 96	< 96	< 96	< 96	< 96	120	< 96
11287	08/26/2002	< 50	< 50	< 50	< 50	< 50	< 50	< 50
13337	08/14/2002	< 1800	< 1800	< 1800	< 1800	< 1800	< 1800	< 1800
13309	08/30/2002	< 45	< 45	< 45	< 45	< 45	< 45	< 45
13336	08/27/2002	< 92	< 92	< 92	< 92	< 92	< 92	< 92
13336-dup	08/27/2002	< 84	< 84	< 84	< 84	< 84	< 84	< 84
13338	08/22/2002	< 87	< 87	< 87	< 87	< 87	< 87	< 87
13338-dup	08/22/2002	< 87	< 87	< 87	< 87	< 87	< 87	< 87
13339	08/22/2002	< 110	< 110	< 110	< 110	< 110	< 110	< 110
13340	08/06/2002	< 100	< 100	< 100	< 100	< 100	< 100	< 100
13341	08/06/2002	< 100	< 100	< 100	< 100	< 100	< 100	< 100
13342	08/21/2002	< 110	< 110	< 110	< 110	< 110	< 110	< 110
13343	08/20/2002	< 59	< 59	< 59	< 59	< 59	< 59	< 59
13344	08/21/2002	< 120	< 120	< 120	< 120	< 120	< 120	< 120
13355	08/18/2002	< 48	< 48	< 48	< 48	< 48	< 48	< 48
13363	08/16/2002	< 48	< 48	< 48	< 48	< 48	< 48	< 48
13589	08/16/2002	< 53	< 53	< 53	< 53	< 53	< 53	< 53
14560	08/30/2002	< 64	< 64	< 64	< 64	< 64	< 64	< 64
15464	08/16/2002	< 46	< 46	< 46	< 46	< 46	< 46	< 46
16496	08/21/2002	< 110	< 110	< 110	< 110	< 110	< 110	< 110
16499	08/22/2002	< 94	< 94	< 94	< 94	< 94	< 94	< 94
16618	08/19/2002	< 46	< 46	< 46	< 46	< 46	< 46	< 46
17971	08/24/2002	< 100	< 100	< 100	< 100	< 100	< 100	< 100
17971-dup	08/24/2002	< 89	< 89	< 89	< 89	< 89	< 89	< 89
17970	08/18/2002	< 47	< 47	< 47	< 47	< 47	< 47	< 47

Table 7.10 Aroclors in Sediment (ng/g-dry wt.) - Cont'd

Sample ID	Date	Aroclor 1016	Aroclor 1221	Aroclor 1232	Aroclor 1242	Aroclor 1248	Aroclor 1254	Aroclor 1260
11092	08/01/2002	< 100	< 100	< 100	< 100	< 100	< 100	< 100
11111	07/31/2002	< 95	< 95	< 95	< 95	< 95	< 95	< 95
11272	07/25/2002	< 120	< 120	< 120	< 120	< 120	< 120	< 120
11273	08/28/2002	< 71	< 71	< 71	< 71	1700	980	410
11273-dup	08/28/2002	< 79	< 79	< 79	< 79	2400	1200	470
11274	07/30/2002	< 61	< 61	< 61	< 61	310	230	< 61
11298	07/29/2002	< 84	< 84	< 84	< 84	< 84	< 84	< 84
11300	09/05/2002	< 61	61	< 61	61	61	61	61
11300-dup	09/05/2002	< 47	< 47	< 47	< 47	47	47	47
11302	08/26/2002	< 49	< 49	< 49	< 49	< 49	< 49	69
11305	08/13/2002	< 49	< 49	< 49	< 49	< 49	66	< 49
11305-dup	08/13/2002	< 51	< 51	< 51	< 51	< 51	< 51	< 51
11347	08/12/2002	< 44	< 44	< 44	< 44	< 44	< 44	91
11382	08/12/2002	< 49	< 49	< 49	< 49	< 49	< 49	120
Fall 2002								
11193	10/31/2002	< 53	< 53	< 53	< 53	< 53	< 53	< 53
11200	11/21/2002	< 40	< 40	< 40	< 40	< 40	< 40	< 40
11261	10/26/2002	< 55	< 55	< 55	< 55	< 55	< 55	< 55
11280	12/02/2002	< 88.3	< 88.3	< 88.3	< 88.3	< 88.3	< 88.3	< 88.3
11280-dup	12/02/2002	< 93	< 93	< 93	< 93	< 93	< 93	< 93
11292	12/10/2002	< 618	< 618	< 618	< 618	< 618	< 61.8	< 61.8
13336	10/22/2002	< 67.7	< 67.7	< 67.7	< 67.7	< 67.7	< 67.7	< 67.7
13338	10/22/2002	< 56.4	< 56.4	< 56.4	< 56.4	< 56.4	< 56.4	< 56.4
13342	10/28/2002	< 115	< 115	< 115	< 115	< 115	< 115	< 115
13363	11/06/2002	< 58.8	< 58.8	< 58.8	< 58.8	< 58.8	< 58.8	< 58.8
15464	11/06/2002	< 43.9	< 43.9	< 43.9	< 43.9	< 43.9	< 43.9	< 43.9
11252	10/24/2002	< 98.5	< 98.5	< 98.5	< 98.5	< 98.5	< 98.5	< 98.5
13340	10/23/2002	< 99.1	< 99.1	< 99.1	< 99.1	< 99.1	< 99.1	< 99.1
13344	10/27/2002	< 113	< 113	< 113	< 113	< 113	< 113	< 113
16499	10/24/2002	< 75	< 75	< 75	< 75	< 75	< 75	< 75
17971	10/28/2002	< 78.2	< 78.2	< 78.2	< 78.2	< 78.2	< 78.2	< 78.2
17970	10/24/2002	< 46.4	< 46.4	< 46.4	< 46.4	< 46.4	< 46.4	< 46.4

Values reported to the Method Reporting Limit

Tributary

Table 7.11 Aroclor in Catfish Tissue (ng/g-wet wt.)

Sample ID	Date	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260	Aroclor-1262	Aroclor-1268	Total Aroclors
Summer 2002											
11200	09/03/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
11252	08/26/2002	< 38	< 15	< 38	< 38	< 21	< 59	41	< 31	< 31	59
11261	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11270	08/28/2002	< 38	< 15	< 38	< 38	< 21	160	< 31	< 31	< 31	< 160
11273	08/30/2002	< 38	< 15	< 38	< 38	< 21	< 59	80	< 31	< 31	< 80
11280	08/28/2002	< 38	< 15	< 38	< 38	< 21	160	< 31	< 31	< 31	< 160
11287	08/25/2002	< 38	< 15	< 38	< 38	< 21	< 59	45	< 31	< 31	< 59
11298	08/29/2002	< 38	< 15	< 38	< 38	< 21	79	< 31	< 31	< 31	< 79
11302	08/26/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13309	08/30/2002	< 38	< 15	< 38	< 38	< 21	< 59	47	< 31	< 31	< 59
13336	08/27/2002	< 38	< 15	< 38	< 38	< 21	100	< 31	< 31	< 31	< 100
13336-dup	08/27/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13338	08/23/2002	< 38	< 15	< 38	< 38	< 21	61	< 31	< 31	< 31	< 59
13339	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	100	< 31	< 31	100
13339-dup	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	35	< 31	< 31	< 59
13342	08/22/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
13344	08/21/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
14560	08/30/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
15908	09/11/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
15908-dup	09/11/2002	< 38	< 15	< 38	< 38	< 21	120	< 31	< 31	< 31	< 120
15979	09/05/2002	< 38	< 15	< 38	< 38	< 21	78	< 31	< 31	< 31	78
16213	09/11/2002	< 38	< 15	< 38	< 38	< 21	95	< 31	< 31	< 31	< 95
16496	08/21/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
16499	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
16499-dup	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	190	< 31	< 31	< 190
16622	09/04/2002	< 38	< 15	< 38	< 38	< 21	< 59	480	< 31	< 31	480
17971	08/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 54	< 31	< 31	59

Table 7.11 Aroclor in Catfish Tissue (ng/g-wet wt.) - Cont'd

Sample ID	Date	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260	Aroclor-1262	Aroclor-1268	Total Aroclors
Fall 2002											
11193	11/20/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11200-1	11/19/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
11200-2	11/21/2002	< 38	< 15	< 38	< 38	< 21	67	< 31	< 31	< 31	67
11200-S	11/21/2002	< 38	< 15	< 38	< 38	< 21	69	< 31	< 31	< 31	69
11252	10/24/2002	< 38	< 15	< 38	< 38	< 21	59	< 31	< 31	< 31	59
11261	10/26/2002	< 38	< 15	< 38	< 38	< 21	180	< 31	< 31	< 31	< 180
13336	10/22/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13338	10/22/2002	< 38	< 15	< 38	< 38	< 21	59	< 31	< 31	< 31	< 59
13338-dup	10/22/2002	< 38	< 15	< 38	< 38	< 21	80	< 31	< 31	< 31	80
13342	10/28/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	59
13344	10/27/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
16499	10/24/2002	< 38	< 15	< 38	< 38	< 21	59	< 31	< 31	< 31	59
17971	10/28/2002	< 38	< 15	< 38	< 38	< 21	97	< 31	< 31	< 31	< 97
17970	10/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
17970-dup	10/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59

Values reported to the Detection Limit
Spring 2003 samples were not analyzed for Aroclors
Exceeds the TDH Comparison Value (47 ng/g)
Tributary

Table 7.12 Aroclors in Crab Tissue (ng/g-wet wt.)

Sample ID	Date	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260	Aroclor-1262	Aroclor-1268	Total Aroclors
Summer 2002											
11200	09/02/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11252	08/29/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11252-dup	08/29/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11273	08/28/2002	< 38	< 15	< 38	< 38	< 21	< 59	47	< 31	< 31	< 59
11273-dup	08/28/2002	< 38	< 15	< 38	< 38	< 21	< 59	41	< 31	< 31	< 59
11280	08/28/2002	< 38	< 15	< 38	< 38	< 21	66	< 31	< 31	< 31	< 66
11280-dup	08/28/2002	< 38	< 15	< 38	< 38	< 21	< 59	41	< 31	< 31	< 59
11287	08/25/2002	< 38	< 15	< 38	< 38	< 21	< 59	47	< 31	< 31	< 59
11287	08/25/2002	< 38	< 15	< 38	< 38	< 21	< 59	54	< 31	< 31	< 59
11292	09/11/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11300	09/09/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11302	08/26/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 55	< 31	< 31	59
11382	08/13/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13309	09/11/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13336	08/28/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13338	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13339	08/25/2002	< 38	< 15	< 38	< 38	< 21	< 59	35	< 31	< 31	59
13339-dup	08/25/2002	< 38	< 15	< 38	< 38	< 21	< 59	31	< 31	< 31	< 59
13341	08/16/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13342	08/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13343	09/04/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13344	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	36	< 31	< 31	< 59
13344-dup	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	61	< 31	< 31	< 61
14560	08/30/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
15908	09/11/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
15979	09/05/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
16213	09/10/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
16496	08/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 46	< 31	< 31	< 59
16499	08/23/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
16618	08/20/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
16622	09/02/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
17971	08/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 50	< 31	< 31	< 59

Table 7.12 Aroclors in Crab Tissue (ng/g-wet wt.) - Cont'd

Sample ID	Date	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260	Aroclor-1262	Aroclor-1268	Total Aroclors
Fall 2002											
11193	10/21/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11252	11/13/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
11261	10/25/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13336	10/22/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13338	10/22/2002	< 76	< 30	< 76	< 76	< 42	< 120	< 62	< 62	< 62	< 120
13340	10/22/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
16499	10/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13342	10/28/2002	< 76	< 30	< 76	< 76	< 42	< 120	< 62	< 62	< 62	< 120
13344	10/27/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13344-dup	11/14/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
13363	11/16/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
15464	11/13/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
17971	10/28/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59
17971-dup	10/28/2002	< 76	< 30	< 76	< 76	< 42	< 120	< 62	< 62	< 62	< 120
17970	10/24/2002	< 38	< 15	< 38	< 38	< 21	< 59	< 31	< 31	< 31	< 59

Values reported to the Detection Limit
Spring 2003 samples were not analyzed for Aroclors
Exceeds the TDH Comparison Value (47 ng/g)
tributary

Table 7.13a Aroclor Results for Summer 2002 Samples

Matrix/Units	Aroclor Mixture	#Detected/ # Sampled	Min	Max	Mean[a]
Water (ng/L)	All	0/18	ND	-	NC
Sediment (ng/g)	1016	0/47	ND	-	NC
	1221	1/47	ND	61	NC
	1232	0/47	ND	-	NC
	1242	1/47	ND	61	NC
	1248	5/47	ND	2400	1469
	1254	7/47	ND	1200	520
	1260	7/47	ND	470	230
Catfish (ng/g)	1016	0/27	ND	-	NC
	1221	0/27	ND	-	NC
	1232	0/27	ND	-	NC
	1242	0/27	ND	-	NC
	1248	0/27	ND	-	NC
	1254	8/27	ND	160	107
	1260	8/27	ND	480	127
	Total Aroclors	10/27	ND	480	119
Crab (ng/g)	1016	0/30	ND	-	NC
	1221	0/30	ND	-	NC
	1232	0/32	ND	-	NC
	1242	0/32	ND	-	NC
	1248	0/32	ND	-	NC
	1254	1/32	ND	66	NC
	1260	9/32	ND	61	44
	Total Aroclors	2/32	ND	59	59

[a] non-detects not included in calculation
ND=not detected; NC=not calculable
Detection limits included in Tables 7.9 to 7.12.

Table 7.13b Aroclor Results for Fall 2002 Samples

Matrix/Units	Aroclor Mixture	# Detected/# Sampled	Min	Max	Mean[a]
Water (ng/L)	All	0/20	ND	-	NC
Sediment (ng/g)	All	0/17	ND	-	NC
Catfish (ng/g)	1016	0/15	ND	-	NC
	1221	0/15	ND	-	NC
	1232	0/15	ND	-	NC
	1242	0/15	ND	-	NC
	1248	0/15	ND	-	NC
	1254	8/15	ND	180	84
	1260	0/15	ND	-	NC
	Total Aroclors	7/15	ND	80	64
Crab (ng/g)	All	0/14	ND	-	NC

[a] non-detects not included in calculation
ND=not detected; NC=not calculable
Detection limits included in Tables 7.9 to 7.12.

non-detectable levels during Summer 2002. All the Aroclors were below detection limits in water samples. In addition, Aroclor 1254 was at detectable levels in sediment from only 7 locations. Finally, the TDH Health Assessment comparison value (47 ng/g tissue) was exceeded in 32% of catfish samples and 6% of crab samples. The Fall 2002 samples showed similar low levels of Aroclors: water and sediment samples exhibited non-detectable levels for all the Aroclors, 6% of fish samples exceeded the TDH screening levels (only Aroclor 1254 was detected at 8 samples, all the other Aroclors were below detection levels), and none of the Aroclors were detected in crab samples.

7.6 USE SUPPORT AND RISK ASSESSMENT

In order to assess the current status of impairment of the HSC system by segment, total PCB concentrations calculated as the sum of the 18 NOAA congeners were compared to the

Texas human health water quality standard and screening criteria outlined in Section 7.2. When looking at the Aroclor analysis data, all water samples met the Texas WQS for total PCBs, and all but one were non-detects. A summary of results is presented in Table 7.14.

According to the *"Guidance for Assessing Texas Surface and Finished DrinkingWater Quality Data, 2004*" to assess water quality attainment a minimum of 10 samples are required, and samples are usually evaluated on a station by station basis. The Guidance, however, establishes that exceptions to the 10-sample rule can be made for streams or reaches of streams that are 25 miles or less in length and for estuarine waters, where water quality conditions are similar. For these water bodies or portions of water bodies, field measurements, constituents in water, sediment, and fish tissue collected at multiple sites may be aggregated to meet the 10-sample minimum requirement. Thus, data for all the locations within a given water quality segment were pooled. To determine the use (fish consumption) support of a water quality segment, the average of the collected samples was compared to the human health criteria (WQS for water). If the average exceeded the criterion and the number of samples was equal or greater than 10, the segment was considered not supporting. If the average exceeded the criterion and the number of samples was between 4 and 9, a Tier-1 primary concern was identified.

To assess the status of impairment of tissue data, catfish and crab data were evaluated using the TDH 1999 Health Assessment procedure. Tables 7.15a and b present estimates of the hazard index (HI)[16] and the cancer risk level for each tissue sample using the 18 PCB congeners and the Aroclors. In most cases (85%) using PCB congener data yields higher HI's and cancer

[16] Hazard Index (HI) is the sum of the ratios of single substance exposure levels over a specified time period to a reference dose for that substance derived from a similar exposure period. If the HI is greater than 1, there may be concern for potential noncancer effects (EPA, *Risk Assessment Guidance for Superfund (RAGS) Part A: Chapter 8: Risk Characterization,* http://www.epa.gov/superfund/programs/risk/ragsa/ch8.pdf).

Table 7.14 Exceedances in Houston Ship Channel PCB Assessment for 2002-2003 Period

Matrix	Segment	# Samples	# Exceedances	% > WQS or screening level	95% Confidence Interval of Samples > WQS[a]	Average Concentration[b]	Fish consumption use[c,d]
Water	1001	5	0	0.0%	2% - 30%	0.278	No concern
	1005	6	0	0.0%	2% - 27%	0.486	No concern
	1006	7	6	85.7%	42% - 95%	1.541	Tier 1 primary concern
	1007	8	4	50.0%	17% - 74%	0.910	Tier 1 primary concern
	2421	7	0	0.0%	1% - 25%	0.276	No concern
	2426	4	0	0.0%	2% - 34%	0.613	No concern
	2427	4	0	0.0%	2% - 34%	0.627	No concern
	2428	3	0	0.0%	3% - 38%	0.849	Not assessed, 3 or fewer samples
	2429	5	0	0.0%	2% - 30%	0.523	No concern
	2430	4	0	0.0%	2% - 34%	0.484	No concern
	2436	1	0	0.0%	-	na	Not assessed, 3 or fewer samples
	2438	3	1	33.3%	2% - 69%	0.461	Not assessed, 3 or fewer samples
Catfish	901	2	1	50.0%	3% - 80%	48.8	Not assessed
	1001	9	4	44.4%	15% - 69%	134.0	Not assessed
	1005	9	7	77.8%	40% - 91%	68.9	Not assessed
	1006	12	9	75.0%	43% - 89%	93.8	Not assessed
	1007	16	12	75.0%	47% - 88%	104.3	Not assessed
	1013	8	7	87.5%	47% - 96%	127.8	Not assessed
	2421	8	4	50.0%	17% - 74%	46.9	Not assessed
	2426	11	6	54.5%	25% - 75%	50.0	Not assessed
	2427	6	4	66.7%	24% - 86%	74.6	Not assessed
	2428	2	1	50.0%	3% - 80%	44.3	Not assessed
	2429	5	3	60.0%	17% - 83%	105.0	Not assessed
	2430	6	6	100.0%	52% - 99%	82.3	Not assessed
	2436	5	4	80.0%	30% - 93%	50.5	Not assessed
	2438	4	1	25.0%	1% - 60%	32.8	Not assessed
Crab	901	1	0	0%		na	Not assessed
	1001	6	0	0%	2% - 27%	12.5	Not assessed
	1005	7	0	0%	1% - 25%	17.6	Not assessed
	1006	7	1	14.3%	1% - 44%	36.6	Not assessed
	1007	9	2	22.2%	4% - 49%	28.6	Not assessed
	1013	2	0	0%	5% - 44%	8.6	Not assessed
	2421	6	0	0%	2% - 27%	5.3	Not assessed
	2426	6	0	0%	2% - 27%	8.1	Not assessed
	2427	4	0	0%	2% - 34%	21.0	Not assessed
	2428	3	0	0%	3% - 38%	4.0	Not assessed
	2429	5	0	0%	2% - 30%	20.4	Not assessed
	2430	6	0	0%	2% - 27%	17.6	Not assessed
	2436	4	0	0%	2% - 34%	14.8	Not assessed
	2438	4	0	0%	2% - 34%	4.0	Not assessed

[a] Nonparametric estimate of confidence limit (95%), where confidence intervals are described by the equation below

$$Limits = \frac{1}{n + Z^2_{1-\alpha/2}} * \left\{ (u - 0.5) + \frac{Z^2_{1-\alpha/2}}{2} \pm Z_{1-\alpha/2} * \left[(u - .5) - \frac{(u - 0.5)}{n} + \frac{Z^2_{1-\alpha/2}}{4} \right]^{1/2} \right\}$$

n = total # samples $\alpha = 0.05$

u = # of exceedances $Z = 1.96$

[b] Average concentrations in ng/L for water and in ng/g for tissue

[c] Assessment of use support using the TCEQ methodology is applicable only to water samples.

[d] Assessment of use support is based on average concentrations only. Data on exceedances are presented as reference only.

na = not applicable

Exceeds WQS (0.885 ng/L)

Exceeds health assessment comparison value (47 ng/g)

Table 7.15a Total PCBs and Health Effect Calculations for Catfish Samples

Station ID	Segment	Summer 2002						Fall 2002					
		From Congener Analysis			From Aroclor Analysis			From Congener Analysis			From Aroclor Analysis		
		Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]	Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]
11092	2426	19.6	0.21	8.42E-06									
11111	901	74.5	0.80	3.19E-05									
11193	1001	93.1	1.00	3.99E-05				37.9	0.41	1.62E-05	< 59	0	0
11200	1001	21.9	0.23	9.38E-06	< 59	0	0	15.2	0.16	6.53E-06	67	0.72	2.87E-05
11252	1005	47.8	0.51	2.05E-05	< 59	0	0	65.3	0.70	2.80E-05	59	0.63	2.53E-05
11258	1005	60.1	0.64	2.57E-05									
11261	1005	65.4	0.70	2.80E-05	< 59	0	0	86.9	0.93	3.73E-05	180	1.93	7.71E-05
11264	1006	101.5	1.09	4.35E-05									
11270	1006	105.1	1.13	4.50E-05	< 160	0	0						
11273	1006	187.9	2.01	8.05E-05	80	0.86	3.43E-05						
11280	1007	85.3	0.91	3.66E-05	160	1.71	6.86E-05	36.2	0.39	1.55E-05			
11287	1007	50.6	0.54	2.17E-05	< 59	0	0						
11292	1007	126.5	1.36	5.42E-05				115.9	1.24	4.97E-05			
11298	1007	29.9	0.32	1.28E-05	79	0.85	3.39E-05						
11300	1007	141.4	1.52	6.06E-05									
11302	1007	54.3	0.58	2.33E-05	< 59	0	0						
11305	1007	81.1	0.87	3.48E-05									
11347	1013	317.8	3.41	1.36E-04									
11382	1013	53.5	0.57	2.29E-05									
13309	2421	36.6	0.39	1.57E-05	< 59	0	0						
13336	2426	29.4	0.32	1.26E-05	100	1.07	4.29E-05	64.3	0.69	2.76E-05	< 59	0	0
13336-DUP	2426	9.0	0.10	3.84E-06	< 59	0	0						
13337	2426	62.7	0.67	2.69E-05									
13337-DUP	2426	79.9	0.86	3.42E-05									
13338	2426	93.7	1.00	4.02E-05	< 59	0	0	74.8	0.80	3.21E-05	59	0.63	2.53E-05
13338-DUP	2426							70.1	0.75	3.00E-05	80	0.86	3.43E-05
13339	2427	59.3	0.64	2.54E-05	100	1.07	4.29E-05						
13339-DUP	2427	68.5	0.73	2.94E-05	< 59	0	0						
13340	2428	29.3	0.31	1.25E-05									
13341	2428	59.2	0.63	2.54E-05									
13342	2429	69.6	0.75	2.98E-05	< 59	0	0	37.8	0.40	1.62E-05	< 59	0	0
13343	2430	52.2	0.56	2.24E-05									
13344	2430	102.3	1.10	4.38E-05	< 59	0	0	70.1	0.75	3.00E-05	< 59	0	0
13355	2436	53.5	0.57	2.29E-05									
13363	2438	29.8	0.32	1.28E-05									
13589	2438	40.3	0.43	1.73E-05									
13589-DUP	2438	48.8	0.52	2.09E-05									

Table 7.15a Total PCBs and Health Effect Calculations for Catfish Samples - Cont'd

Station ID	Segment	Summer 2002						Fall 2002					
		From Congener Analysis			From Aroclor Analysis			From Congener Analysis			From Aroclor Analysis		
		Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]	Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]
14560	2421	23.2	0.25	9.95E-06	< 59	0	0						
15464	2421	2.2	0.02	9.27E-07									
15908	2421	50.0	0.54	2.14E-05	< 59	0	0						
15908-DUP	2421	29.6	0.32	1.27E-05	120	1.29	5.14E-05						
15979	1006	58.3	0.62	2.50E-05	78	0.84	3.34E-05						
16213	2421	75.7	0.81	3.24E-05	95	1.02	4.07E-05						
16496	2430	53.6	0.57	2.30E-05	< 59	0	0						
16499	2427	44.9	0.48	1.93E-05	< 59	0	0	44.4		1.90E-05	< 59	0	0
16499-DUP	2427	103.7	1.11	4.45E-05	190	2.04	8.14E-05	13.3	0.14	5.70E-06	59	0.63	2.53E-05
16618	1005	35.4	0.38	1.52E-05									
16622	1001	866.1	9.28	3.71E-04	480	5.14	2.06E-04						
17971	2429	45.2	0.48	1.94E-05	< 59	0	0	92.3	0.99	3.96E-05	97	1.04	4.16E-05
17970	2436	13.7	0.15	5.88E-06				57.4	0.62	2.46E-05	< 59	0	0
17970-DUP	2436							75.6	0.81	3.24E-05	< 59	0	0

[a] Sum of 18 congeners recommended by NOAA

[b] HI=hazard index. EPA RfD = 0.00002 mg/kg-day. The RfD is based on Aroclor 1254 and should be applied to total PCBs (EPA, 2000)

[c] RL=carcinogen risk level. EPA CSF = 2 (mg/kg-day)^{1}. This Cancer Slope Factor is the upper-bound slope factor for food chain exposure (EPA, 2000)

Hazardous Index and Risk Calculations based on TCEQ assumptions: body weight 70 kg, consumption rate: 15 g/day, exposure period: 70 years

If compound was non-detected, both hazard index and risk level were assumed equal to zero

tributary

Hazard Index exceeds 1 and the sample presents a concern

2.00E-05 Cancer Risk exceeds $1x10^{-4}$ and the sample presents a concern

Table 7.15b Total PCBs and Health Effect Calculations for Crab Samples

Station ID	Segment	Summer 2002						Fall 2002					
		From Congener Analysis			From Aroclor Analysis			From Congener Analysis			From Aroclor Analysis		
		Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]	Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]
11092	2426	7.8	0.08	3.33E-06									
11111	901	8.2	0.09	3.50E-06									
11193	1001	34.3	0.37	1.47E-05				8.2	0.09	3.50E-06	< 59	0	0
11200	1001	13.7	0.15	5.88E-06	< 59	0	0	13.7	0.15	5.88E-06			
11252	1005	3.7	0.04	1.58E-06	< 59	0	0	12.4	0.13	5.30E-06	< 59	0	0
11252-DUP	1005	4.9	0.05	2.09E-06	< 59	0	0						
11258	1005	32.6	0.35	1.40E-05									
11261	1005	24.4	0.26	1.05E-05				10.2	0.11	4.39E-06	< 59	0	0
11264	1006	31.2	0.33	1.34E-05									
11270	1006	33.8	0.36	1.45E-05									
11273	1006	44.5	0.48	1.91E-05	< 59	0	0						
11273-DUP	1006	94.4	1.01	4.05E-05	< 59	0	0						
11280	1007	47.0	0.50	2.01E-05	< 59	0	0						
11280-DUP	1007	24.7	0.26	1.06E-05	66	0.71	2.83E-05						
11287	1007	47.1	0.50	2.02E-05	< 59	0	0						
11292	1007	29.5	0.32	1.26E-05	< 59	0	0						
11300	1007	21.2	0.23	9.10E-06	< 59	0	0						
11302	1007	30.9	0.33	1.32E-05	< 59	0	0						
11305	1007	23.1	0.25	9.88E-06									
11347	1013	10.8	0.12	4.62E-06									
11382	1013	6.4	0.07	2.76E-06	< 59	0	0						
13309	2421	5.3	0.06	2.28E-06	< 59	0	0						
13336	2426	2.9	0.03	1.25E-06	< 59	0	0	8.4	0.09	3.61E-06	< 59	0	0
13337	2426	5.4	0.06	2.31E-06									
13338	2426	6.9	0.07	2.97E-06				17.1	0.18	7.34E-06	< 120	0	0
13339	2427	17.3	0.19	7.43E-06	< 59	0	0						
13339-DUP	2427	28.6	0.31	1.23E-05	< 59	0	0						
13340	2428	4.6	0.05	1.97E-06				3.5	0.04	1.49E-06	< 59	0	0
13341	2428	3.8	0.04	1.64E-06	< 59	0	0						
13342	2429	22.8	0.24	9.75E-06	< 59	0	0	17.9	0.19	7.67E-06	< 120	0	0
13343	2430	19.4	0.21	8.33E-06	< 59	0	0						
13344	2430	21.0	0.23	9.01E-06	< 59	0	0	16.6	0.18	7.11E-06	< 59	0	0
13344-DUP	2430	12.3	0.13	5.28E-06	61	0.65	2.61E-05	23.9	0.26	1.02E-05	< 59	0	0
13355	2436	10.0	0.11	4.27E-06									
13355-DUP	2436	21.8	0.23	9.32E-06									
13363	2438	5.5	0.06	2.34E-06				3.1	0.03	1.33E-06	< 59	0	0

Table 7.15b Total PCBs and Health Effect Calculations for Crab Samples - Cont'd

Station ID	Segment	Summer 2002						Fall 2002					
		From Congener Analysis			From Aroclor Analysis			From Congener Analysis			From Aroclor Analysis		
		Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]	Total PCBs[a] (ng/g)	HI[b]	RL[c]	Total PCBs (ng/g)	HI[b]	RL[c]
13589	2438	2.6	0.03	1.12E-06									
13589-DUP	2438	4.3	0.05	1.85E-06									
14560	2421	15.8	0.17	6.79E-06	< 59	0	0						
15464	2421	2.7	0.03	1.14E-06				1.9	0.02	8.33E-07	< 59	0	0
15908	2421	3.7	0.04	1.58E-06	< 59	0	0						
15979	1006	26.3	0.28	1.13E-05	< 59	0	0						
16213	2421	2.2	0.02	9.26E-07	< 59	0	0						
16496	2430	12.3	0.13	5.27E-06	< 59	0	0						
16499	2427	24.7	0.27	1.06E-05	< 59	0	0	24.8	0.27	1.06E-05			
16618	1005	35.2	0.38	1.51E-05	< 59	0	0						
16622	1001	19.0	0.20	8.13E-06	< 59	0	0						
17971	2429	28.3	0.30	1.21E-05	< 59	0	0	15.1	0.16	6.48E-06	< 59	0	0
17971-DUP	2429							18.0	0.19	7.72E-06	< 120	0	0
17970	2436	18.4	0.20	7.88E-06				9.0	0.10	3.85E-06	< 59	0	0

[a] Sum of 18 congeners recommended by NOAA

[b] HI=hazard index. EPA RfD = 0.00002 mg/kg-day. The RfD is based on Aroclor 1254 and should be applied to total PCBs (EPA, 2000)

[c] RL=carcinogen risk level. EPA CSF = 2 (mg/kg-day)^{1}. This Cancer Slope Factor is the upper-bound slope factor for food chain exposure (EPA, 2000)

Hazardous Index and Risk Calculations based on TCEQ assumptions: body weight 70 kg, consumption rate: 15 g/day, exposure period: 70 years

If compound was non-detected, both hazard index and risk level were assumed equal to zero

tributary

Hazard Index exceeds 1 and the sample presents a concern

risks. Maximum Hazard Indices using 18 congeners are 9.28 and 1.01 for catfish and crab tissue, respectively. The Hazard Index exceeded 1 in 9 catfish samples (in segments 1001, 1006, 1007, 1013, 2430, and 2427) and 1 crab sample (in segment 1006), suggesting a potential risk from noncarcinogenic effects.

The maximum cancer risks from consuming catfish and blue crabs from the Houston Ship Channel, also calculated using 18 congeners, are 3.71×10^{-4} and 4.05×10^{-5}, respectively using all the data. The TDH recommends that consumption of seafood contaminated with carcinogenic compounds be limited to amounts that result in an estimated lifetime cancer risk of 1×10^{-4} (1 excess cancer risk in 10,000 people exposed through seafood). Thus, two catfish samples (one in segment 1001 and the other in segment 1013) present a potential risk from carcinogenic effects.

Based on the total PCB water data collected in this project using the 18 NOAA congeners, segments 1006 and 1007 present a *Tier-1 primary concern* for the fish consumption use due to 86% and 50% exceedances of the 0.885 ng/L Texas WQS, respectively. However, if one calculated a site-specific water quality target based on site-specific BSAFs, the water quality target would not be exceeded.

The Draft 2004 Texas §303(d) List includes Segments 1006 and 1007 as impaired due to high concentrations of PCBs in fish tissue. It also includes the section of segment 1001 between US Hwy 90 and IH 10 and the portion of segment 1005 between I-10 and Lynchburg Ferry Road. The listings, however, are based on PCB concentrations from Aroclor analyses. Based on data on the 18 NOAA PCB congeners in tissue collected in this project and the TDH risk assessment procedure, segments 1001, 1006, 1007, 1013, 2430, and 2427 present a potential concern.

7.7 RECOMMENDATIONS

Analysis of PCB and Aroclor data gathered in this project led to the following conclusions:

- When evaluating congener-specific results, water concentrations showed a *Tier-1 primary concern* in segments 1006 and 1007; additional PCB congener in water samples are required to determine use support in segments 1006 and 1007. In contrast, when looking at Aroclor data, none of the segments showed a concern.
- Tissue data collected in this project confirms a concern of PCBs in catfish in segments 1001, 1006, and 1007 when evaluating congener data; whereas Aroclor data shows a concern in segment 1001 only.
- Congener-specific PCB data in catfish also showed potential concerns for stations located in the tidal portions of Simms Bayou, Vince Bayou, Patrick Bayou, Buffalo Bayou, and Whiteoak Bayou. These water bodies are also included in the Draft 2004 Texas §303(d) List.

The above mentioned conclusions indicate a need to evaluate both the Aroclor and congener specific data to determine if §303(d) listings and future TMDL projects are warranted. In addition, since the water quality standard and the TDH screening values are based on Aroclors and not on PCB congeners, a methodology to compare PCB data and to establish criteria to assess use support is needed. More investigation is warranted to address the new food consumption advisory for trout.

CHAPTER 8

SUMMARY AND CONCLUSIONS

This report summarizes the activities conducted by the dioxin project team during the period September 1, 2003 to August 31, 2005. These activities are part of Phase III of the dioxin TMDL project.

During WO7, 30 locations (19 in-channel and 11 tributaries) were sampled for ambient water, 55 in-channel locations were sampled for sediment, 28 locations were sampled for catfish and crab tissue, 8 locations for sediment cores, 2 locations were sampled for air deposition/ambient air, and 8 locations were sampled for stormwater runoff. Analytical results for the Spring 2004, Summer 2004, Fall 2004, and Summer 2005 sampling events are discussed in this report.

Results from the dioxin analyses showed concentrations in water that exceed the Texas Surface Water Quality Standard (0.0933 pg/L) in 94% of the samples. In addition, the health-based standard of 0.47 ng TEQ/kg (derived from the Texas WQS) was exceeded in more than 96% of the catfish and crab samples.

Results from deep and shallow water samples collected simultaneously showed that deep concentrations were generally higher than shallow concentrations, with average deep/shallow ratios of up to 1.69 and 1.54 for locations 11193 and 15979, respectively (maximum ratios were 2.85 and 2.67, respectively). An analysis of fugacity ratios suggested a lack of equilibrium at the suspended-dissolved and sediment-dissolved interfaces for most of the congeners. Data indicate that 2378-TCDD is close to equilibrium between the bottom sediments and the dissolved phase

(deep) at location 15979, whereas a bottom sediment–> dissolved flux is expected at location 11193. For almost all the remaining congeners, ratios lower than 1 were measured for the dissolved-suspended interface indicating flux of dioxins from the dissolved phase to the suspended phase. For the bottom sediment-dissolved interface, on the other hand, ratios greater than 1 were measured for some PCDFs and ratios lower than 1 for the higher chlorinated PCDDs.

Geochronology analyses performed on 7 sediment cores yielded sedimentation rates between 0.14±0.08 and 113.10±87.08 cm/yr. The longest time coverage of the sediment cores was about 150 years. Vertical distribution of dioxin concentrations in the collected cores versus the estimated year of deposition showed surprisingly that the oldest interval concentrations appeared to be as high or slightly higher than those measured in the surface intervals. This could indicate the presence of other sources prior to the construction of the HSC.

Measurements of dioxin concentrations in various media allowed the determination of site-specific partitioning relationships. These partitioning relationships are important not only to develop the model to support load allocations, but also to establish an appropriate water quality target for the TMDL, to allow for economical long-term monitoring of continuing progress toward the water quality target, and to facilitate implementation of the TMDL through water quality permitting. An estimation of congener-specific bioaccumulation factors (BAFs) using all the sampling data from this project yielded water quality targets for 2378-TCDD and TEQ of 0.011 and 0.070 pg/L, respectively. The calculated target for dioxin TEQ in water is approximately 75% of the state water quality criterion of 0.093 pg/L. Sediment quality targets calculated using site-specific BSAFs were calculated to be 43 and 115 ng/kg-oc for 2378-TCDD and TEQ, respectively. A comparison of sampling data to the estimated water quality targets

showed exceedance rates greater than 90%. It appeared that an 85-90% reduction in concentrations, or one order of magnitude would be required for the water quality targets to be met.

An analysis of dioxin data collected in Phases II and III of this project showed that segment 1001 exhibited the highest average concentrations of dioxins in water, segment 1007 showed the highest overall average concentration in sediment, while segment 1006 showed the highest average concentration in catfish and segment 1005 showed the highest average TEQ for crabs.

OCDD is the major contributor to the total dioxin concentration (the sum of the 17 2378-substituted congeners) in water, sediment, and catfish samples from the HSC, while 2378-TCDF is the major contributor in crab samples. However, 2378-TCDD is the major contributor to total TEQ in all cases with average contributions of 47%, 49%, 80%, and 68% for water, sediment, catfish, and crab samples, respectively.

In addition to dioxin analyses, PCB levels in water, sediment and tissue samples were determined to assess the level of impairment of the HSC system. In general, concentrations of individual PCB congeners were low and the Texas Standard for total PCB in water was exceeded only in segments 1006 and 1007 when utilizing PCB congener data. The TDH health-based PCB tissue target level (47 ng/g) was exceeded in more than 60% of the fish samples but was exceeded in only 4% of the crab samples. Aroclor data revealed mainly non-detect values for all media.

A screening quantification of relative source importance conducted using a QUAL-TX model showed that known sources (point sources and storm runoff) accounted only for 5% and 26% of the total 2378-TCDD and TEQ load in the HSC, respectively. A detailed WASP model is

underway to estimate contributions from sediment resuspension, direct deposition, and additional sources.

REFERENCES

Ambrose, R.B., T.A. Wool, and J.L. Martin. 1993. "The Water Quality Analysis Simulation Program, WASP5." Environmental Research Laboratory, US Environmental Protection Agency, Athens, Georgia.

Appleby P.G. and Oldfield F., 1978. "The Calculation of Lead-210 Dates Assuming a Constant Rate of Supply of Unsupported ^{210}Pb to the Sediment." *Catena,* 5: 1-8.

Baca, E., P.B. Bedient and R. Olsen, 1982. "Urban Impacts of Water Supply Reservoir." *Journal of Environmental Engineering*, 108(EE1): 73-87.

Benamen, J., N.E. Armstrong, and D.R. Maidment. 1996. "Modeling of Dissolved Oxygen in the Houston Ship Channel using WASP5 and Geographic Information Systems." CRWR Online Report 96-2. Center for Research in Water Resources at the University of Texas, Austin, August 1996.

Binford, M.W., 1990. "Calculation and Uncertainty Analysis of ^{210}Pb Dates for PIRLA Project Lake Sediment Cores." *Journal of Paleolimnology,* 3: 253-267.

City of Houston, 1988. "Wastewater Strategy Study, Volume IV, Stream Model." Report prepared for City of Houston, Department of Public Works by Pate/EH&A Joint Venture.

Cogliano, J.V, 1998. "Assessing Cancer Risks from Environmental PCBs." *Environmental Health Perspectives*, 106 (6):317-323.

Craft, C.B. and Richardson, C.J., 1993. "Peat Accretion and N, P, and Organic Accumulation in Nutrient-enriched and Unenriched Everglades Peatlands." *Journal of Applied Ecology*. 3: 446-458.

Espey, W.H., A.J. Hays, Jr., W.D. Bergman, J.P. Buckner, R.J. Huston, and G.H. Ward, Jr., 1971. "Galveston Bay Project Water Quality Modeling and Data Management: Phase II Technical Report." Tracor, Inc, Austin, Texas.

Gobas, FAPC, DCG Muir, and D Mackay, 1988. "Dynamics of Dietary Bioaccumulation and Faecal Elimination of Hydrophobic Organic Chemicals in Fish." *Chemosphere*. 17(5): 943-962.

Gotz, R. And R. Lauer, 2003. "Analysis of Sources of Dioxin Contamination in Sediments and Soils Using Multivariate Statistical Methods and Neural Networks" *Environmental Science and Technology*, 37 (24): 5559-5565.

Grey, John R., Glysson, G. Douglas, Turcios, Lisa M., and Schwarz, Gregory E., 2000. "Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data." U.S. Geological Survey Water-Resources Investigations Report 00-4191.

Helsel, D.R. and R.M. Hirsch, 2002. "Statistical Methods in Water Resources. U.S. Geological Survey." Available at http://water.usgs.gov/pubs/twri/twri4a3/.

Houston-Galveston Area Council, 2003. "2002 Land Cover Image Processing and Accuracy Assessment Protocol." Prepared for Texas Commission on Environmental Quality - Texas Clean Rivers Program. Houston, TX, January 2003.

Huntley, S.L., Wenning, R.J., Su, S.H., Bonnevie, N.L., Paustenbach, D.J., 1995. "Geochronology and Sedimentology of the Lower Passaic River, New Jersey." *Estuaries,* 18 (2): 351-361.

Kim, J.G. and Rejmankova, E., 2002. "Recent History of Sediment Deposition in Marl and Sand based Marshes of Belize, Central America." *Catena*, 48(4): 267-291.

Mansour, M. (Ed), 1993. "Fate and Prediction of Environmental Chemicals in Soils, Plants, and Aquatic Systems." Lewis Publishers, Boca Raton, FL. 291 p.

McFarland, V.A., and J.U. Clarke, 1989. "Environmental Occurrence, Abundance, and Potential Toxicity of Polychlorinated Biphenyl Congeners: Considerations for a Congener-Specific Analysis." *Environmental Health Perspectives* 81:225-239.

Natural Resource Conservation Service, 1986. "Urban Hydrology for Small Watersheds." Technical Release 55. Conservation Engineering Division. June 1986.

Newell, C. J., Rifai, H. S., and Bedient, P. B., 1992. "Characterization of Non-Point Sources and Loadings to Galveston Bay." GBNEP-15, Prepared for the Galveston Bay National Estuary Program, Houston, TX.

NOAA (National Oceanic and Atmospheric Administration), 1989. "Standard Analytical Procedures of the NOAA National Analytical Facility." 2nd Edition.NOAA Tech. Mem. NMFS F/NWC-92, 1985-86. National Status and Trends Program, U.S. Department of Commerce, Rockville, MD.

Opperhuizen, A, and DTHM Sijm, 1990. "Bioaccumulation and Biotransformation of Polychlorinated Dibenzo-*p*-dioxins and Dibenzofurans in Fish." *Environmental Toxicology and Chemistry*, 9: 175-186.

PBS&J and Parsons Engineering, 2001. "Dioxin Sediment and Tissue Sampling in the Houston Ship Channel and Upper Galveston Bay." Prepared for Clean Rivers Program, Houston-Galveston Area Council, Houston, TX, September 2001.

Robbins, J. A., 1978. "Geochemical and Geophysical Applications of Radioactive Lead." In The Biogeochemistry of Lead in the Environment. J. Nriagu (Ed.), Elsevier, 285-393.

Soil Conservation Service, 1985. "National Engineering Handbook." Section 4-Hydrology (NEH-4).

Texas Commission on Environmental Quality, 2003. "Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data, 2004." Austin, TX, August , 2003.

Texas Department of Health, 2001. "Health Consultation - Houston Ship Channel and Tabbs Bay." Prepared by the Texas Department of Health under cooperative agreement with the Agency for Toxic Substances and Disease Registry. August 1, 2001.

Texas Natural Resources Conservation Commission, 2002. "Fourteen Total Maximum Daily Loads for Nickel in the Houston Ship Channel System." Prepared by the Strategic Assessment Division Water Permits and Resource Management Division. June 2002.

University of Houston, 2001. "Total Maximum Daily Load for Dioxins in the Houston Ship Channel – Final Report Work Order No. 1." Prepared for the Texas Natural Resources Conservation Commission. Houston, TX, June 2001.

University of Houston, 2004. "Total Maximum Daily Load for Dioxins in the Houston Ship Channel - Quarterly Report 2 Work Order No. 7." Prepared for the Texas Commission on Environmental Quality. Houston, TX, April 2004.

USACE (U.S. Army Corps of Engineers), 1987. "Final Feasibility Report and EIS, Galveston Bay Area Navigation Study." Volume 6. Appendix F, Plan Effects.

U.S. EPA, 1995. "Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors." EPA-820-B-95-005. Office of Water, Washington, DC.

U.S. EPA, 1999. "Polychlorinated Biphenyls (PCBs) Update: Impact on Fish Advisories." Fact Sheet, September 1999. EPA-823-F-99-019.

U.S. EPA, 2000. "Guidance for Assessing Contaminant Data for Use in Fish Advisories, Volume 1. Fish Sampling and Analysis." 3rd Edition.

U.S. EPA, 2003. "Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000). Technical Support Document. Volume 2: Development of National Bioaccumulation Factors." EPA-822-R-03-030, December 2003.

USFWS (United States Fish and Wildlife Service), 1983. "Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Gulf of Mexico): Sea Catfish and Gafftopsail Catfish." TR EL-82-4. October 1983.

Valero-Garces, B., Navas, A., Machin, J., Walling, D., 1999. "Sediment Sources and Siltation in Mountain Reservoirs: A Case Study from the Central Spanish Pyrenees." *Geomorphology*, 28: 23-41.

Walsh, J.P. and Nittrouer, C.A., 2003. "Contrasting Styles of Off-shelf Sediment Accumulation in New Guinea." *Marine Geology*, 196: 105-125.

Webster, C.F., Buchanan, T.A., Kirkpatrick, J. and Miranda R., 1998. "Polychlorinated Biphenyls in Donna Reservoir and Contiguous Waters - Results of Intensive Sediment, Water and Fish Sampling and Human Health Risk Assessment. Special Study Report No. AS-161." Field Operations Division, Texas Natural Resource Conservation Commission, Austin.

Winkels, H., Kroonenberg, S., Lychagin, M., Marin, G., Rusakov, G., Kasimov, N., 1998. "Geochronology of Priority Pollutants in Sedimentation Zones of the Volga and Danube Delta in Comparison with the Rhine Delta." *Applied Geochemistry*, 13(5): 581-591.

Winslow and Associates, Inc., 1986. "Houston Ship Channel Urban Runoff Nonpoint Source Study." Report prepared for TDWR.

Wool, T.A., R.B. Ambrose, J.L. Martin, and E.A. Corner, 2001. "Water Quality Analysis Simulation Program (WASP) Version 6.0 - User's Manual." U.S. Environmental Protection Agency Region 4.

Yeager, K.M., Santschi, P.H. and Rowe, G.T., 2004. "Sediment Accumulation and Radionuclide Inventories (^{239,240}Pu, ^{210}Pb and ^{234}Th) in the Northern Gulf of Mexico, as Influenced by Organic Matter and Macrofaunal Density." *Marine Chemistry*, 91: 1-14.

APPENDIX A - QUALITY ASSURANCE

Appendix A1 - Approved Annual Update to the Quality Assurance Project Plan and July 2005 Amendment (Electronic)

Appendix A2 - Field Duplicate Agreement for Dioxin Samples

Table A-1 Field Duplicate Agreement for Dioxin Concentrations - Spring 2004 event

a. Water Dissolved (concentrations in pg/L)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	03/23/2004	0.129		0.010	0.019	0.026	0.657	24.286	0.429	0.012	0.012	0.021	0.009	0.004			0.008	0.357	0.189
11193-Dup	03/23/2004	0.137	0.007	0.010	0.020	0.026	0.698	27.066	0.456	0.013	0.013	0.024	0.009	0.005			0.010	0.399	0.202
15979	03/31/2004	0.243	0.008	0.012	0.030	0.034	0.899	27.104	0.742	0.016	0.017	0.040	0.013	0.010				1.854	0.344
15979-Dup	03/31/2004	0.228		0.010	0.026	0.024	0.799	22.825	0.713	0.016	0.020	0.027		0.007				1.270	0.323
11347	04/22/2004		0.013	0.010	0.199	0.077	4.267	19.915	0.030	0.007	0.009	0.009		0.006				0.083	0.049
11347-Dup	04/22/2004		0.009	0.008	0.121	0.047	3.121	17.021	0.034	0.005	0.008	0.008	0.006	0.005			0.004	0.072	0.034
Percentage difference[b]																			
11193	03/23/2004	6.2%		2.7%	7.1%	0.3%	6.0%	10.8%	6.2%	7.8%	3.2%	12.2%	4.5%	17.4%			17.0%	11.0%	7.0%
15979	03/31/2004	6.1%		11.6%	15.4%	34.1%	11.8%	17.1%	3.9%	0.0%	15.4%	38.3%		37.9%				37.4%	6.5%
11347	04/22/2004		35.6%	19.6%	49.2%	48.5%	31.0%	15.7%	13.1%	28.2%	15.4%	14.1%		14.0%				13.1%	35.8%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**49.2%**	**OVERALL MEAN**		**16.8%**		**COUNT**	**38**		**CONFIDENCE**		**4.2%**	**TEQ AVERAGE**				**16.4%**

b. Water Suspended (concentrations in pg/L)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	03/23/2004	0.971	0.021	0.031	0.074	0.123	3.429	157.143	2.857	0.091	0.071	0.200	0.056	0.019			0.044	2.429	1.359
11193-Dup	03/23/2004	0.541	0.011	0.019	0.040	0.067	1.852	79.772	1.567	0.051	0.038	0.117	0.036	0.012	0.005			1.339	0.755
15979	03/31/2004	0.599	0.026	0.047	0.137	0.157	4.565	142.653	1.569	0.064	0.061	0.200	0.068	0.039	0.008		0.088	15.692	0.868
15979-Dup	03/31/2004	0.571	0.026	0.050	0.136	0.143	4.280	135.521	1.427	0.063	0.058	0.185	0.071	0.039	0.007		0.076	11.698	0.822
11347	04/22/2004		0.016	0.023	0.185	0.077	3.983	49.787	0.026	0.011	0.016	0.033	0.021	0.027				0.683	0.058
11347-Dup	04/22/2004		0.013	0.017	0.122	0.055	2.837	35.461	0.021			0.028	0.016	0.018			0.014	0.511	0.040
Percentage difference[b]																			
11193	03/23/2004	57%	62%	52%	60%	59%	60%	65%	58%	56%	60%	53%	44%	47%				58%	57%
15979	03/31/2004	5%	0%	6%	1%	10%	6%	5%	10%	2%	5%	7%	4%	0%	6%		16%	29%	6%
11347	04/22/2004		19%	29%	41%	33%	34%	34%	18%			14%	31%	38%				29%	37%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**65.3%**	**OVERALL MEAN**		**29.8%**		**COUNT**	**41**		**CONFIDENCE**		**6.9%**	**TEQ AVERAGE**				**33.1%**

c. Bottom Sediment (concentrations in ng/kg-dry wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11287	03/23/2004	8.50	2.00	3.30	8.40	5.30	260.00	3500.00	22.00	2.10	3.20	5.80	2.70	3.50	1.40	46.00	3.90	150.00	16.45
11287-Dup	03/23/2004	8.60		3.10	7.20	4.80	220.00	3000.00	25.00	2.10	2.90		2.90	3.40	1.70	46.00	4.40	150.00	15.78
11292	03/31/2004	0.93	2.30	3.30	8.10	5.70	270.00	3900.00	3.00	1.20	2.60		2.50	4.00	1.50	42.00	3.10	120.00	6.56
11292-Dup	03/31/2004	0.64	2.40	3.30	8.90	6.30	270.00	3900.00	2.70	1.10	2.70	2.50	2.70	3.60	1.10	41.00	3.20	120.00	6.36
Percentage difference[b]																			
11287	03/23/2004	1%		6%	15%	10%	17%	15%	13%	0%	10%		7%	3%	19%	0%	12%	0%	4%
11292	03/31/2004	37%	4%	0%	9%	10%	0%	0%	11%	9%	4%		8%	11%	31%	2%	3%	0%	3%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**36.9%**	**OVERALL MEAN**		**8.6%**		**COUNT**	**31**		**CONFIDENCE**		**3.1%**	**TEQ AVERAGE**				**3.7%**

d. Catfish Tissue (concentrations in ng/kg-wet wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11197	03/24/2004	1.60	0.17		0.29		0.88	5.70	0.27			0.07		0.08				2.80	1.84
11197-Dup	03/24/2004	2.10	0.21	0.17	0.57	0.20	1.30	6.30	0.42	0.11	0.27	0.09		0.10				0.89	2.51
11264	04/02/2004	7.90	0.38		0.57		1.40	8.50	0.41		0.59					0.31		0.79	8.54
11264-Dup	04/02/2004	6.40			0.55		1.20	6.20	0.25		0.45							0.73	6.85
11272-A	04/15/2004	3.00					2.30	8.40	0.30				0.53					2.60	3.51
11272-A-Dup	04/15/2004	1.20	0.26		0.31	0.19	1.20	5.80	0.16	0.20	0.33	0.19	0.19	0.16	0.11	0.41	0.16	2.60	1.64
Percentage difference[b]																			
11197-F	03/24/2004	27%	21%		65%		39%	10%	43%			31%		19%				104%	31%
11264-F	04/02/2004	21%			4%		15%	31%	48%		27%							8%	22%
11272 F-A	04/15/2004	86%					63%	37%	61%				94%					0%	73%
OVERALL MIN	**3.6%**	**OVERALL MA**	**103.5%**	**OVERALL ME**	**38.8%**	**COUNT**	**22**	**CONFIDENCE**	**12.2%**	**TEQ AVERAGE**	**41.8%**

e. Crab Tissue (concentrations in ng/kg-wet wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11298	04/20/2004	1.90	0.37		0.30		0.99	6.30	4.60		0.41	0.32	0.22						2.89
11298-Dup	04/20/2004	4.30	0.41	0.32		0.38	1.60	14.00	9.70	0.40	0.58	0.38		0.24	0.17	0.47		0.78	5.97
11273	04/21/2004	5.90	0.46		0.41	0.31	1.30	7.60	11.00	1.50	1.10	0.95	0.42			0.80		2.90	8.11
11273-Dup	04/21/2004	6.20	0.81	0.48	0.64	0.62	2.00	12.00	12.00	1.70	1.40	1.40	0.83	0.71	0.55	2.60	0.70	18.00	9.11
Percentage difference[b]																			
11298	04/20/2004	77%	10%				47%	76%	71%		34%	17%							70%
11273	04/21/2004	5%	55%		44%	67%	42%	45%	9%	13%	24%	38%	66%			106%		144%	12%
OVERALL MIN	**5.0%**	**OVERALL MAX**	**144.5%**	**OVERALL MEAN**	**49.5%**	**COUNT**	**20**	**CONFIDENCE**	**15.4%**	**TEQ AVERAGE**	**40.7%**

[a] Non-detects assumed to be equal to half of the detection limit for TEQ calculation

[b] Percentage difference calculated as [abs(t1-t2)/average(t1,t2)], only detected values were used

Table A-2 Field Duplicate Agreement for Dioxin Concentrations - Summer 2004 event

a. Water Dissolved (concentrations in pg/L)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11142	08/18/2004					0.010	0.212	5.375	0.011		0.004	0.003						0.041	0.018
11142-Dup	08/18/2004	0.005				0.009	0.212	5.233	0.009		0.004	0.003						0.044	0.019
Percentage difference[b]																			
11142	08/18/2004					8.6%	0.0%	2.7%	20.4%		3.5%	8.7%						6.7%	2.9%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**20.4%**	**OVERALL MEAN**		**7.2%**		**COUNT**	**7**	**CONFIDENCE**			**4.9%**	**TEQ AVERAGE**				**2.9%**

b. Water Suspended (concentrations in pg/L)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11142	08/18/2004		0.017	0.031	0.081	0.105	2.829	87.694	0.027			0.018	0.017	0.024	0.011	0.410		0.721	0.165
11142-Dup	08/18/2004			0.034	0.085	0.105	2.829	87.694	0.025	0.013	0.011	0.018	0.017	0.023	0.010			0.736	0.162
Percentage difference[b]																			
11142	08/18/2004			9%	5%	0%	0%	0%	5%			0%	0%	6%	7%			2%	2%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**8.7%**	**OVERALL MEAN**		**3.1%**		**COUNT**	**11**	**CONFIDENCE**			**2.0%**	**TEQ AVERAGE**				**1.8%**

c. Bottom Sediment (concentrations in ng/kg-dry wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	08/11/2004	11.00	0.46	0.45	0.89	1.10	31.00	1400.00	55.00	1.00	1.40	0.70	0.49	0.32		2.70		17.00	17.89
11193-dup	08/11/2004	60.00	1.90	2.00	4.00	5.20	170.00	7800.00	260.00	6.00	5.70	6.40	2.90	1.30	1.00	15.00	2.20	120.00	92.38
11197	08/11/2004	17.00	1.50	2.30	4.90	5.50	190.00	7300.00	53.00	2.60	2.40	4.50	2.90	1.40	0.89	15.00	2.10	100.00	26.62
11197-dup	08/11/2004	17.00					190.00	6800.00	52.00							11.00		110.00	24.91
Percentage difference[b]																			
11193	08/11/2004	138%	122%	127%	127%	130%	138%	139%	130%	143%	121%	161%	142%	121%		139%		150%	135%
11197	08/11/2004	0%					0%	7%	2%							31%		10%	7%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**160.6%**	**OVERALL MEAN**		**98.9%**		**COUNT**	**21**	**CONFIDENCE**			**25.6%**	**TEQ AVERAGE**				**70.9%**

[a] Non-detects assumed to be equal to half of the detection limit for TEQ calculation

[b] Percentage difference calculated as [abs(t1-t2)/average(t1,t2)], only detected values were used

Table A-3 Field Duplicate Agreement for Dioxin Concentrations - Fall 2004 event

a. Water Dissolved (concentrations in pg/L)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	11/03/2004						0.129	4.823	0.105									0.156	0.040
11193-dup	11/03/2004	0.038					0.153	5.833	0.108									0.167	0.058
15979	10/25/2004	0.139			0.006		0.128	2.107	0.534			0.010						0.632	0.200
15979-dup	10/25/2004	0.138					0.155	2.260	0.537									0.678	0.210
Percentage difference[b]																			
11193	11/03/2004						16.8%	19.0%	3.2%									6.6%	37.1%
15979	10/25/2004	0.5%					19.5%	7.0%	0.6%									7.0%	5.0%
OVERALL MIN	**0.5%**	**OVERALL MAX**		**19.5%**	**OVERALL MEAN**		**8.9%**		**COUNT**	**9**		**CONFIDENCE**		**5.0%**	**TEQ AVERAGE**				**21.1%**

b. Water Suspended (concentrations in pg/L)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	11/03/2004	0.184		0.028	0.064	0.096	2.411	123.404	0.553	0.033	0.024	0.064		0.017			0.035	3.404	0.288
11193-dup	11/03/2004	0.194		0.028	0.061	0.094	2.500	120.833	0.556	0.026		0.054						3.472	0.289
15979	10/25/2004	0.463				0.108	2.809	56.180	1.362	0.070	0.065	0.169	0.197	0.048				19.663	0.700
15979-dup	10/25/2004	0.424		0.041	0.096	0.110	2.684	53.672	1.314	0.069		0.141		0.042			0.106	19.774	0.631
Percentage difference[b]																			
11193	11/03/2004	5%		2%	4%	2%	4%	2%	0%	21%		16%						2%	0%
15979	10/25/2004	9%				2%	5%	5%	4%	1%		18%		12%				1%	10%
OVERALL MIN	**0.4%**	**OVERALL MAX**		**21.1%**	**OVERALL MEAN**		**6.0%**		**COUNT**	**19**		**CONFIDENCE**		**2.8%**	**TEQ AVERAGE**				**5.3%**

c. Bottom Sediment (concentrations in ng/kg-dry wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	11/04/2004	31.00	0.84	0.70	1.50	1.90	57.00	2000.00	120.00	2.50	2.60	3.20	1.10	0.60		8.10	1.00	100.00	45.76
11193-dup	11/04/2004	27.00	0.62	0.73	1.90	2.20	71.00	2300.00	100.00	2.60	2.50	3.40	0.96	0.53	0.39	8.00	0.92	110.00	39.70
13344	11/08/2004	15.00	1.70	3.20	6.70	6.40	240.00	6900.00	38.00	2.90	3.20	5.30	2.50	2.40	1.50	35.00	3.80	290.00	24.20
13344-dup	11/08/2004	15.00	1.90	2.90	5.80	6.30	210.00	6300.00	36.00	2.90	3.20	4.00	1.90	2.40	1.40	32.00	3.30	250.00	23.77
Percentage difference[b]																			
11193	11/04/2004	14%	30%	4%	24%	15%	22%	14%	18%	4%	4%	6%	14%	12%		1%	8%	10%	14%
13344	11/08/2004	0%	11%	10%	14%	2%	13%	9%	5%	0%	0%	28%	27%	0%	7%	9%	14%	15%	2%
OVERALL MIN	**0.0%**	**OVERALL MAX**		**30.1%**	**OVERALL MEAN**		**11.0%**		**COUNT**	**33**		**CONFIDENCE**		**2.8%**	**TEQ AVERAGE**				**8.0%**

d. Catfish Tissue (concentrations in ng/kg-wet wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11265	10/26/2004	8.80	0.33	0.24	0.55	0.22	0.67	1.50	0.59		0.48		0.18	0.22				0.35	9.43
11265-dup	10/26/2004	9.70	0.41		0.59	0.32	0.87	1.70	0.50	0.26	0.54			0.28			0.28	0.76	10.41
11193	10/28/2004	14.00	0.50	0.41	0.86	0.38	1.30	3.60	1.00		0.75		0.19					0.61	14.95
11193-dup	10/28/2004	13.00	0.35	0.34		0.29	1.00	2.40	0.77	0.19	0.66		0.22		0.13			0.50	13.74
Percentage difference[b]																			
11265	10/26/2004	10%	22%		7%	37%	26%	13%	17%		12%			24%				74%	10%
11193	10/28/2004	7%	35%	19%		27%	26%	40%	26%		13%		15%					20%	8%
OVERALL MIN	**7.0%**		**OVERALL MA**	**73.9%**		**OVERALL ME**	**23.4%**		**COUNT**	**20**		**CONFIDENCE**		**6.7%**		**TEQ AVERAGE**			**9.1%**

e. Crab Tissue (concentrations in ng/kg-wet wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
15979	10/21/2004	6.60	0.23	0.19	0.26		0.40	1.60	9.40	0.42	0.41	0.32	0.21	0.17		0.41	0.21	1.40	8.01
15979-dup	10/21/2004	12.00	0.31	0.25	0.35		0.54	1.90	17.00	0.56	0.66	0.40	0.22	0.19	0.15		0.16	0.35	14.38
11193	10/27/2004	11.00	0.14		0.23	0.18	0.61	3.30	29.00	0.43	0.54							0.51	14.33
11193-dup	10/27/2004	6.60	0.12		0.21	0.23	0.84	5.20	17.00		0.39	0.16	0.11	0.13		0.28		0.93	8.66
Percentage difference[b]																			
15979	10/21/2004	58%	30%	27%	30%		30%	17%	58%		47%	22%	5%	11%			27%	120%	57%
11193	10/27/2004	50%	15%		9%	24%	32%	45%	52%	100%	32%							58%	49%
OVERALL MIN	**4.7%**		**OVERALL MAX**	**120.0%**		**OVERALL MEAN**	**39.1%**		**COUNT**	**23**		**CONFIDENCE**		**11.3%**		**TEQ AVERAGE**			**53.1%**

f. Sediment Cores (concentrations in ng/kg-dry wt)

Station ID	Date	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxDD	1,2,3,4,6,7,8-HpCDD	OCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF	1,2,3,6,7,8-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,7,8,9-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF	OCDF	TEQ[a]
11193	11/04/2004	31.00	0.84	0.70	1.50	1.90	57.00	2000.00	120.00	2.50	2.60	3.20	1.10	0.60		8.10	1.00	100.00	45.76
11193-dup	11/04/2004	27.00	0.62	0.73	1.90	2.20	71.00	2300.00	100.00	2.60	2.50	3.40	0.96	0.53	0.39	8.00	0.92	110.00	39.70
13344	11/08/2004	15.00	1.70	3.20	6.70	6.40	240.00	6900.00	38.00	2.90	3.20	5.30	2.50	2.40	1.50	35.00	3.80	290.00	24.20
13344-dup	11/08/2004	15.00	1.90	2.90	5.80	6.30	210.00	6300.00	36.00	2.90	3.20	4.00	1.90	2.40	1.40	32.00	3.30	250.00	23.77
Percentage difference[b]																			
11193	11/04/2004	14%	30%	4%	24%	15%	22%	14%	18%	4%	4%	6%	14%	12%		1%	8%	10%	14%
13344	11/08/2004	0%	11%	10%	14%	2%	13%	9%	5%	0%	0%	28%	27%	0%	7%	9%	14%	15%	2%
OVERALL MIN	**0.0%**		**OVERALL MAX**	**30.1%**		**OVERALL MEAN**	**11.0%**		**COUNT**	**33**		**CONFIDENCE**		**2.8%**		**TEQ AVERAGE**			**8.0%**

[a] Non-detects assumed to be equal to half of the detection limit for TEQ calculation

[b] Percentage difference calculated as [abs(t1-t2)/average(t1,t2)], only detected values were used

APPENDIX B - DIOXIN LABORATORY RESULTS

Appendix B1 – Water, Sediment, and Tissue Results (File name: *DioxinWO7Data.mdb*)

Appendix B2 – Sediment Core Dioxin Results (File name: *SedimentCore.mdb*)

Appendix B3 – Air Results (File name: *Air Results.xls*)

Appendix B4 – Runoff Results (File name: *RunoffWO7.mdb*)

APPENDIX C - SEDIMENT CORE SUPPLEMENTAL DATA

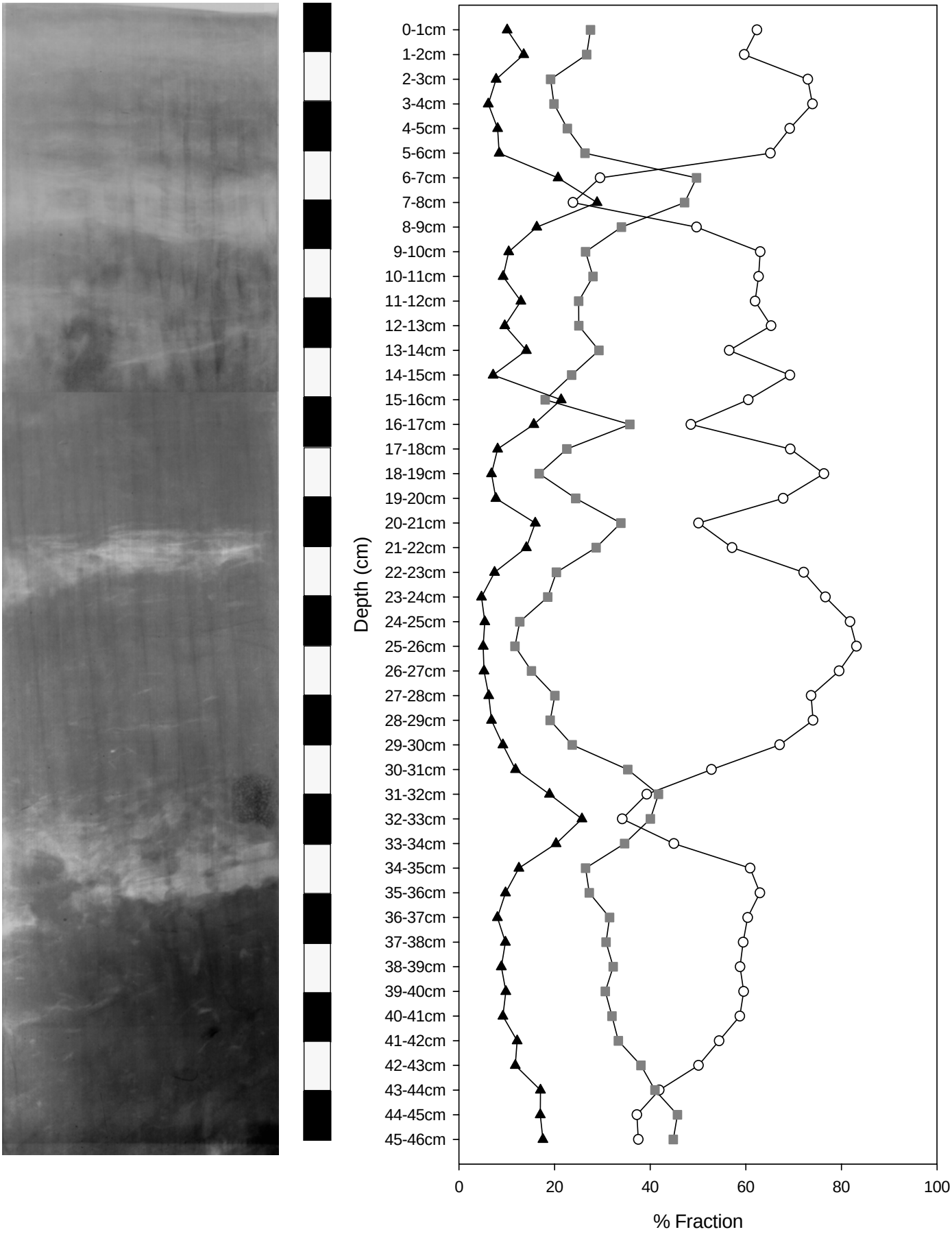


Figure C1: X-radiography and grain size distribution for 11261, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

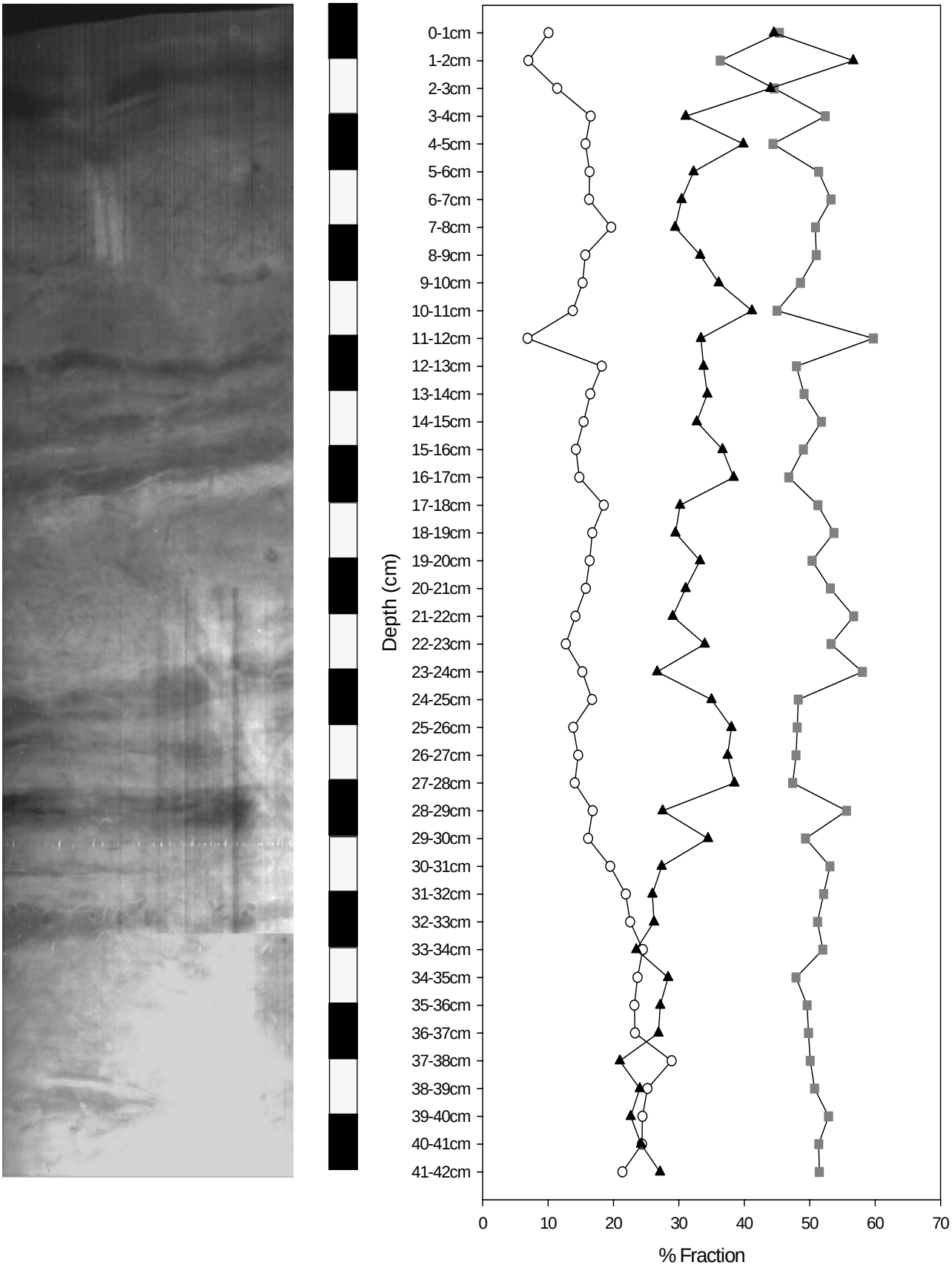


Figure C2: X-radiography and grain size distribution for 15244, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

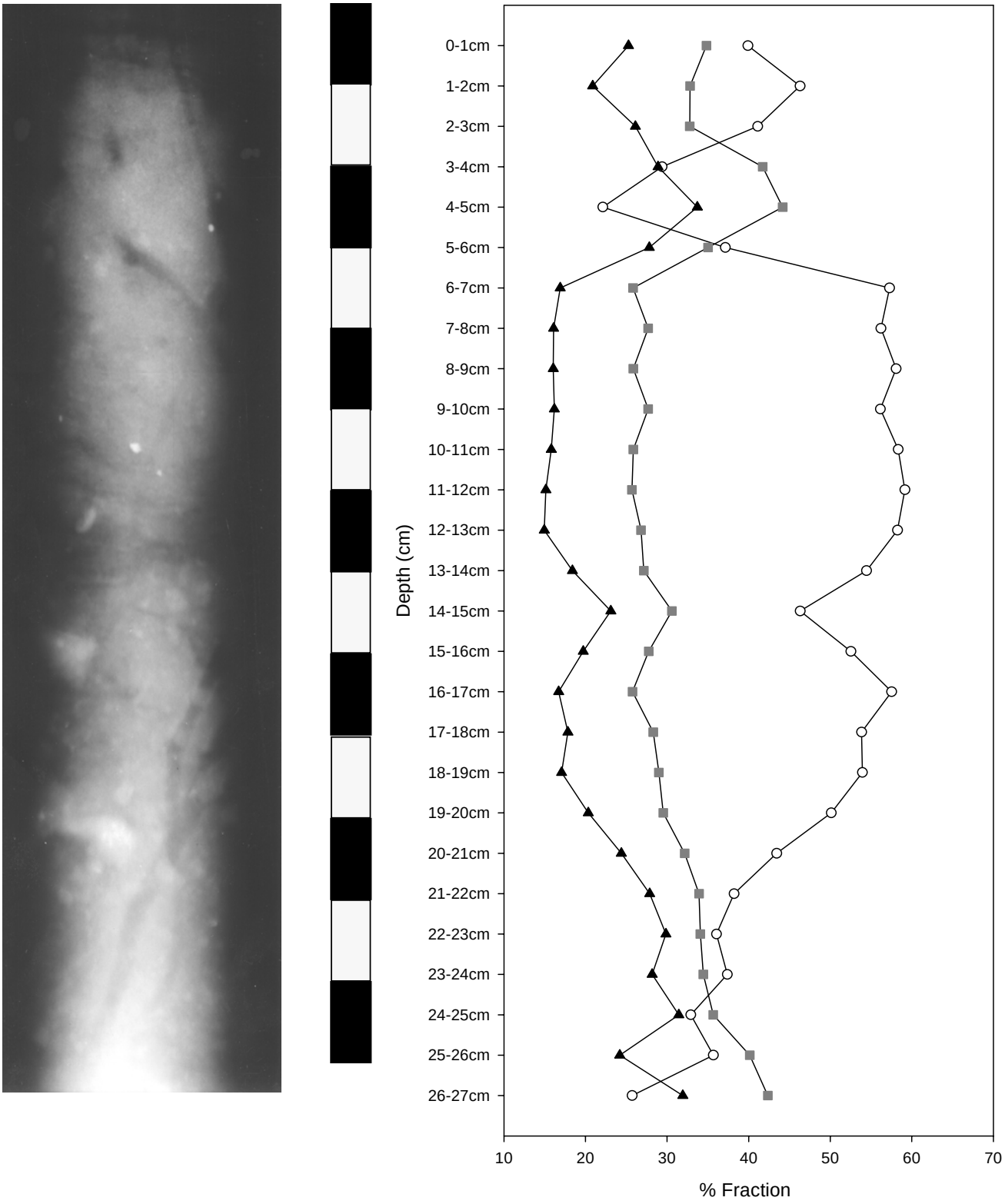


Figure C3: X-radiography and grain size distribution for 11193, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

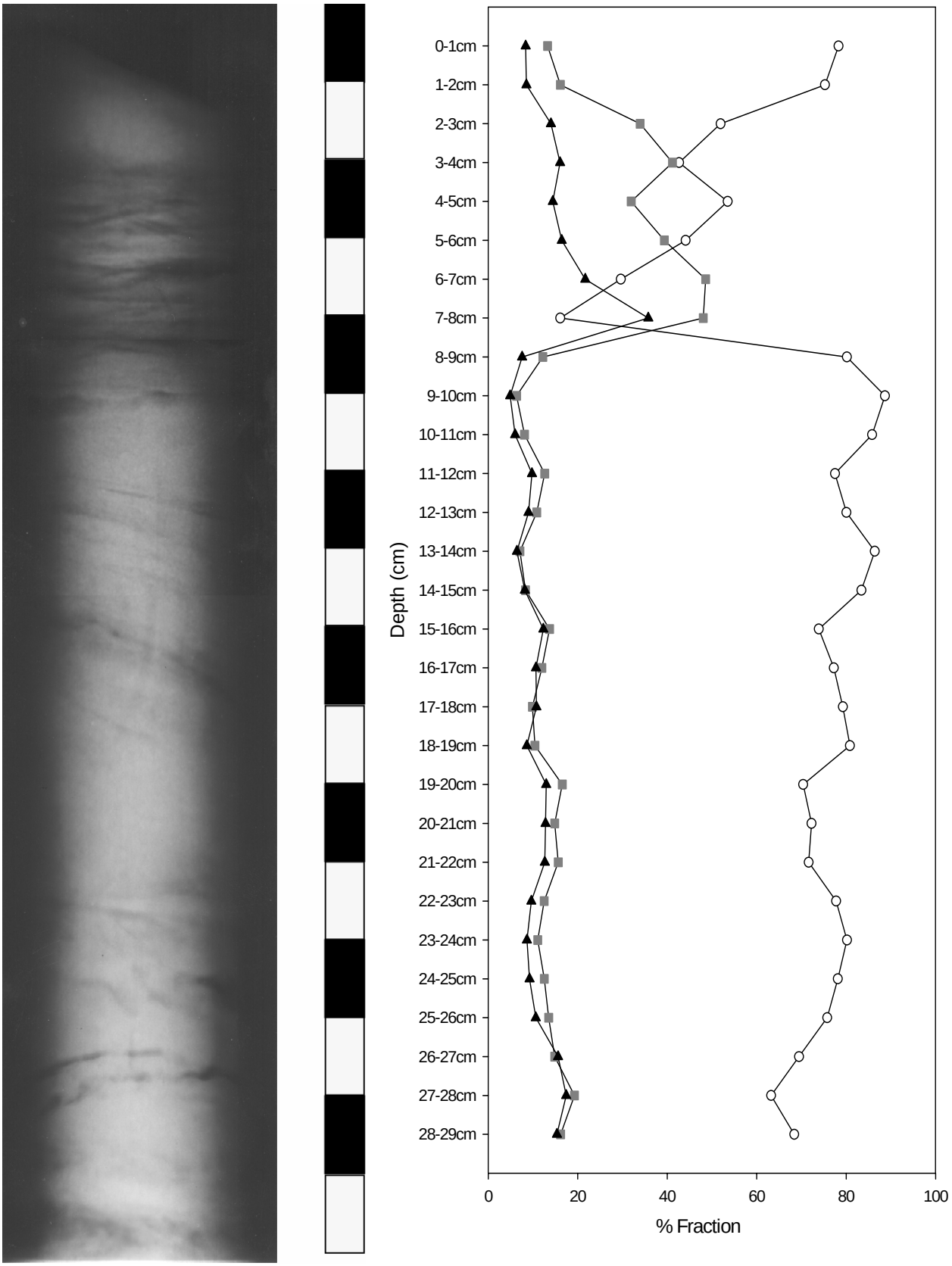


Figure C4: X-radiography and grain size distribution for 15979, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

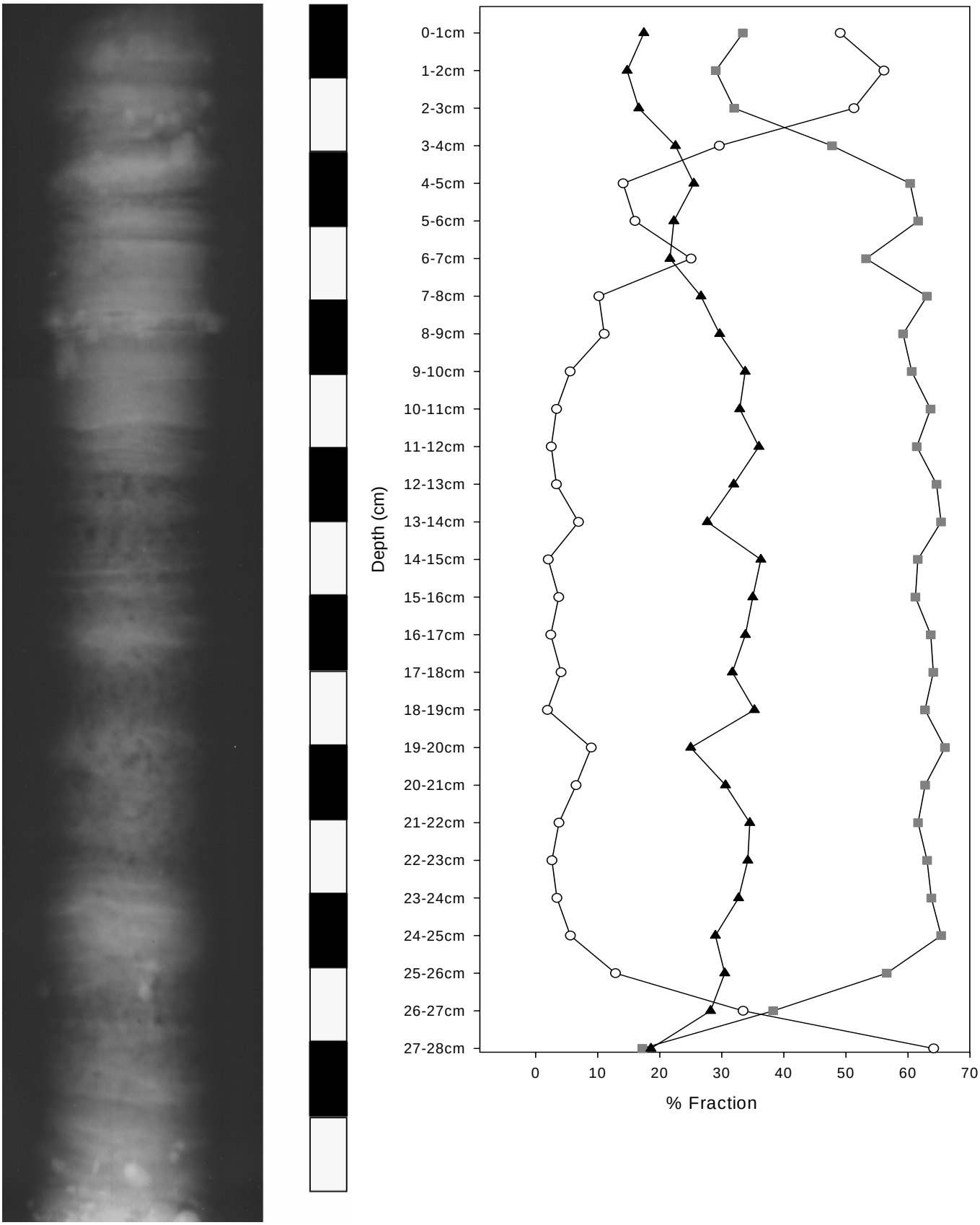


Figure C5: X-radiography and grain size distribution for 11270, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

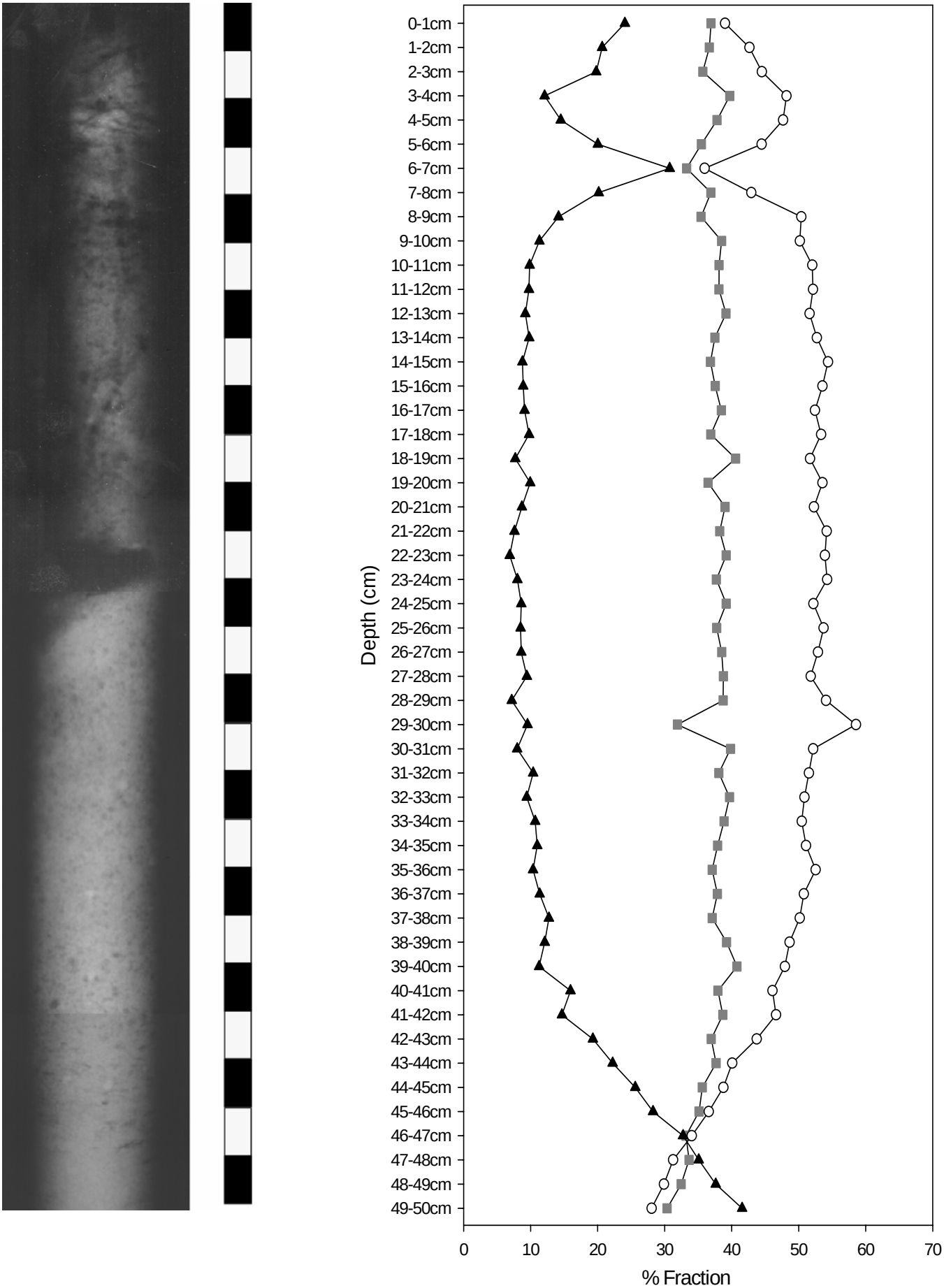


Figure C6: X-radiography and grain size distribution for FW1, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

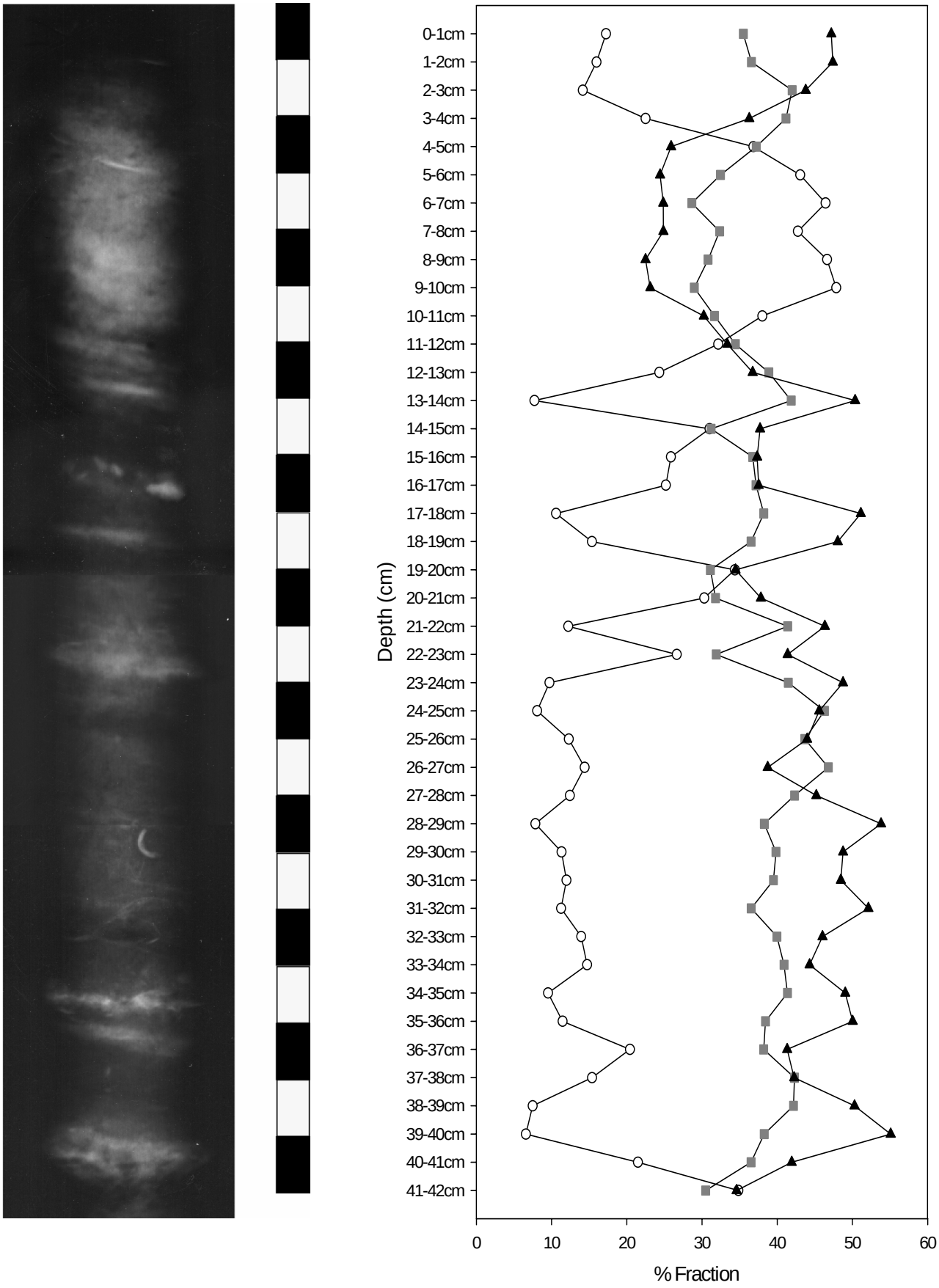


Figure C7: X-radiography and grain size distribution for 16499, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

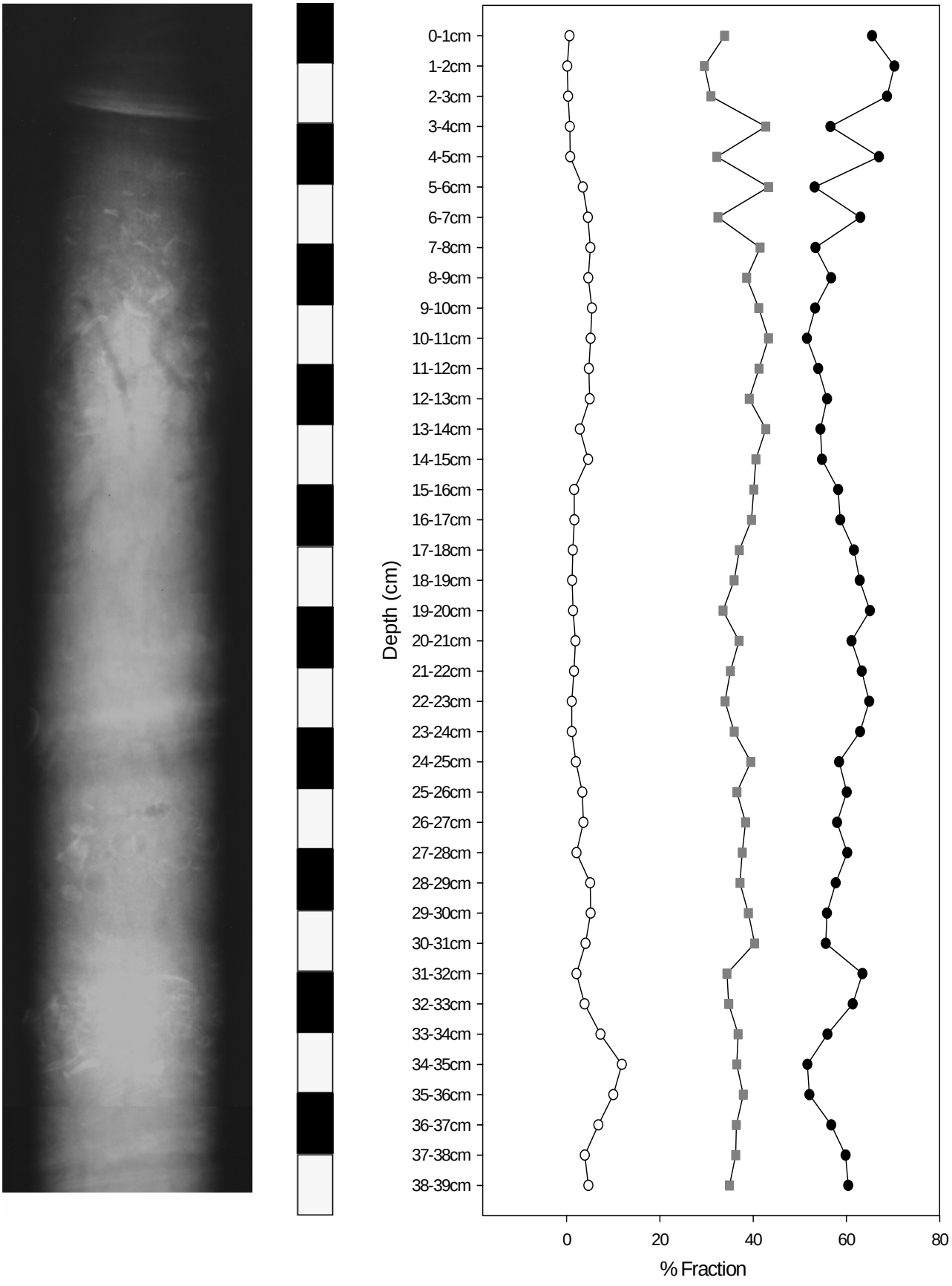


Figure C8: X-radiography and grain size distribution for 13337, open circles denote % sand, grey boxes denote % silt and solid triangles denote % clay.

Table C-1 Summary grain size data for stations 11261 and 15244 x-radiography sections.

(11261) Depth (cm)	% Sand	% Silt	% Clay	(15244) Depth (cm)	% Sand	% Silt	% Clay
1	62.3	27.6	10.1	1	11.2	41.2	47.6
2	59.7	26.7	13.6	2	9.9	38.7	51.4
3	73.0	19.2	7.8	3	11.5	46.5	42.0
4	74.0	19.9	6.1	4	15.4	46.6	38.0
5	69.2	22.7	8.1	5	18.0	49.3	32.7
6	65.2	26.4	8.4	6	18.4	49.8	31.8
7	29.5	49.7	20.7	7	19.1	48.8	32.1
8	23.9	47.2	28.9	8	18.3	51.9	29.8
9	49.7	34.0	16.3	9	17.0	48.5	34.5
10	63.1	26.5	10.4	10	14.8	49.5	35.6
11	62.7	28.1	9.3	11	15.1	52.8	32.2
12	62.0	25.1	13.0	12	13.2	46.3	40.6
13	65.3	25.1	9.6	13	16.1	48.0	35.9
14	56.6	29.3	14.1	14	17.1	47.4	35.5
15	69.3	23.6	7.2	15	13.3	44.8	41.9
16	60.5	18.1	21.4	16	20.1	49.9	30.0
17	48.5	35.8	15.7	17	19.5	50.3	30.2
18	69.3	22.6	8.1	18	14.9	49.4	35.8
19	76.4	16.8	6.8	19	15.6	47.2	37.3
20	67.8	24.4	7.7	20	17.7	49.7	32.6
21	50.1	33.9	16.0	21	20.1	54.8	25.1
22	57.1	28.7	14.1	22	18.4	53.5	28.2
23	72.1	20.4	7.5	23	16.8	50.0	33.2
24	76.7	18.6	4.7	24	17.4	51.1	31.4
25	81.8	12.7	5.4	25	19.0	48.8	32.1
26	83.2	11.7	5.1	26	20.0	48.8	31.2
27	79.5	15.2	5.3	27	17.5	45.8	36.7
28	73.7	20.1	6.2	28	20.8	49.2	30.0
29	74.1	19.1	6.8	29	22.0	49.7	28.3
30	67.1	23.7	9.2	30	20.3	47.3	32.4

Table C-2 Summary grain size data for stations 11193 and 15979 x-radiography sections.

(11193) Depth (cm)	% Sand	% Silt	% Clay	(15979) Depth (cm)	% Sand	% Silt	% Clay
1	39.9	34.8	25.3	1	78.3	13.3	8.4
2	46.3	32.8	20.9	2	75.3	16.1	8.5
3	41.1	32.8	26.1	3	52.0	34.0	14.0
4	29.4	41.7	28.9	4	42.7	41.2	16.1
5	22.1	44.2	33.7	5	53.6	32.0	14.5
6	37.1	35.0	27.8	6	44.1	39.4	16.5
7	57.3	25.8	16.9	7	29.7	48.6	21.7
8	56.2	27.7	16.1	8	16.1	48.1	35.8
9	58.1	25.9	16.1	9	80.2	12.2	7.6
10	56.1	27.7	16.2	10	88.7	6.4	4.9
11	58.3	25.9	15.8	11	85.8	8.1	6.0
12	59.2	25.7	15.1	12	77.5	12.6	9.8
13	58.2	26.8	14.9	13	80.1	10.9	9.0
14	54.5	27.2	18.4	14	86.4	7.1	6.4
15	46.3	30.6	23.1	15	83.4	8.4	8.2
16	52.5	27.8	19.7	16	73.9	13.7	12.3
17	57.5	25.8	16.7	17	77.3	12.0	10.7
18	53.8	28.3	17.8	18	79.3	9.9	10.8
19	53.9	29.0	17.1	19	80.9	10.5	8.6
20	50.1	29.5	20.3	20	70.4	16.6	13.0
21	43.4	32.2	24.4	21	72.3	14.9	12.8
22	38.2	33.9	27.9	22	71.7	15.7	12.7
23	36.1	34.1	29.9	23	77.8	12.5	9.7
24	37.4	34.4	28.2	24	80.2	11.1	8.7
25	32.9	35.7	31.4	25	78.2	12.6	9.3
26	35.7	40.1	24.2	26	75.8	13.6	10.6
27	25.7	42.3	31.9	27	69.5	14.9	15.6
28	--	--	--	28	63.3	19.3	17.4
29	--	--	--	29	68.4	16.2	15.4
30	--	--	--	30	--	--	--

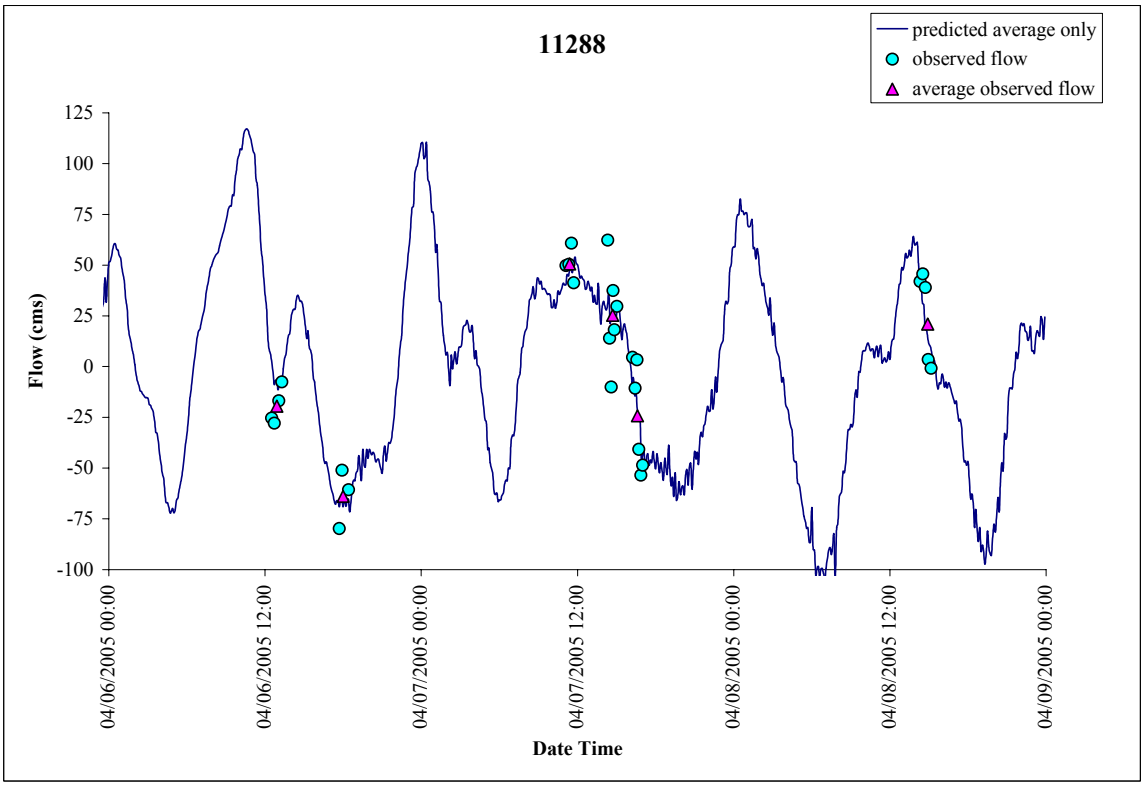
Table C-3 Summary grain size data for stations 11270 and 16499 x-radiography sections (FW1, se e report).

(11270) Depth (cm)	% Sand	% Silt	% Clay	(16499) Depth (cm)	% Sand	% Silt	% Clay
1	49.1	33.4	17.5	1	17.3	35.5	47.2
2	56.2	29.1	14.8	2	16.0	36.6	47.4
3	51.3	32.0	16.6	3	14.2	42.0	43.8
4	29.6	47.8	22.6	4	22.5	41.2	36.3
5	14.1	60.4	25.5	5	36.9	37.2	25.9
6	16.0	61.7	22.3	6	43.1	32.5	24.4
7	25.1	53.3	21.7	7	46.5	28.7	24.9
8	10.2	63.1	26.7	8	42.8	32.4	24.9
9	11.1	59.2	29.7	9	46.7	30.8	22.5
10	5.6	60.6	33.8	10	47.9	29.0	23.1
11	3.4	63.7	32.9	11	38.0	31.7	30.3
12	2.5	61.5	36.0	12	32.2	34.4	33.4
13	3.4	64.7	32.0	13	24.3	38.9	36.8
14	6.9	65.4	27.7	14	7.7	41.9	50.4
15	2.1	61.6	36.3	15	31.0	31.2	37.7
16	3.7	61.2	35.0	16	25.9	36.8	37.3
17	2.5	63.7	33.8	17	25.2	37.2	37.6
18	4.1	64.1	31.7	18	10.6	38.2	51.1
19	1.9	62.8	35.3	19	15.4	36.5	48.1
20	9.0	66.0	25.0	20	34.4	31.1	34.5
21	6.5	62.8	30.6	21	30.3	31.8	37.9
22	3.8	61.7	34.6	22	12.2	41.4	46.4
23	2.6	63.1	34.2	23	26.7	31.9	41.4
24	3.5	63.8	32.7	24	9.7	41.5	48.8
25	5.6	65.4	29.0	25	8.1	46.3	45.6
26	12.9	56.6	30.5	26	12.3	43.7	44.0
27	33.5	38.3	28.2	27	14.4	46.8	38.8
28	64.2	17.2	18.6	28	12.5	42.3	45.2
29	--	--	--	29	7.9	38.3	53.8
30	--	--	--	30	11.3	39.9	48.8

Table C-4 Summary grain size data for station 13337 x-radiography section.

(11270) Depth (cm)	% Sand	% Silt	% Clay
1	0.6	33.9	65.5
2	0.1	29.6	70.3
3	0.3	31.0	68.7
4	0.7	42.7	56.6
5	0.8	32.2	67.0
6	3.5	43.3	53.2
7	4.6	32.5	63.0
8	5.1	41.5	53.4
9	4.7	38.6	56.7
10	5.4	41.2	53.3
11	5.2	43.3	51.5
12	4.8	41.3	54.0
13	5.0	39.2	55.9
14	2.8	42.7	54.4
15	4.6	40.6	54.8
16	1.6	40.1	58.3
17	1.7	39.6	58.7
18	1.3	37.0	61.6
19	1.2	35.9	62.9
20	1.4	33.6	65.1
21	1.9	37.0	61.1
22	1.6	35.1	63.3
23	1.1	34.0	64.9
24	1.1	36.0	62.9
25	2.0	39.5	58.5
26	3.4	36.5	60.1
27	3.6	38.4	58.0
28	2.1	37.7	60.2
29	5.1	37.2	57.7
30	5.2	39.0	55.9

APPENDIX D – FLOW REGRESSIONS



Site	Date	Time	Total Q	Variation
11288	04/06/05	12:53	-19.43	-47%
11288	04/06/05	18:00	-63.84	-23%
11288	04/07/05	11:25	50.54	16%
11288	04/07/05	14:40	25.23	96%
11288	04/07/05	16:38	-24.28	-109%
11288	04/08/05	14:51	20.91	112%

SUMMARY OUTPUT

108

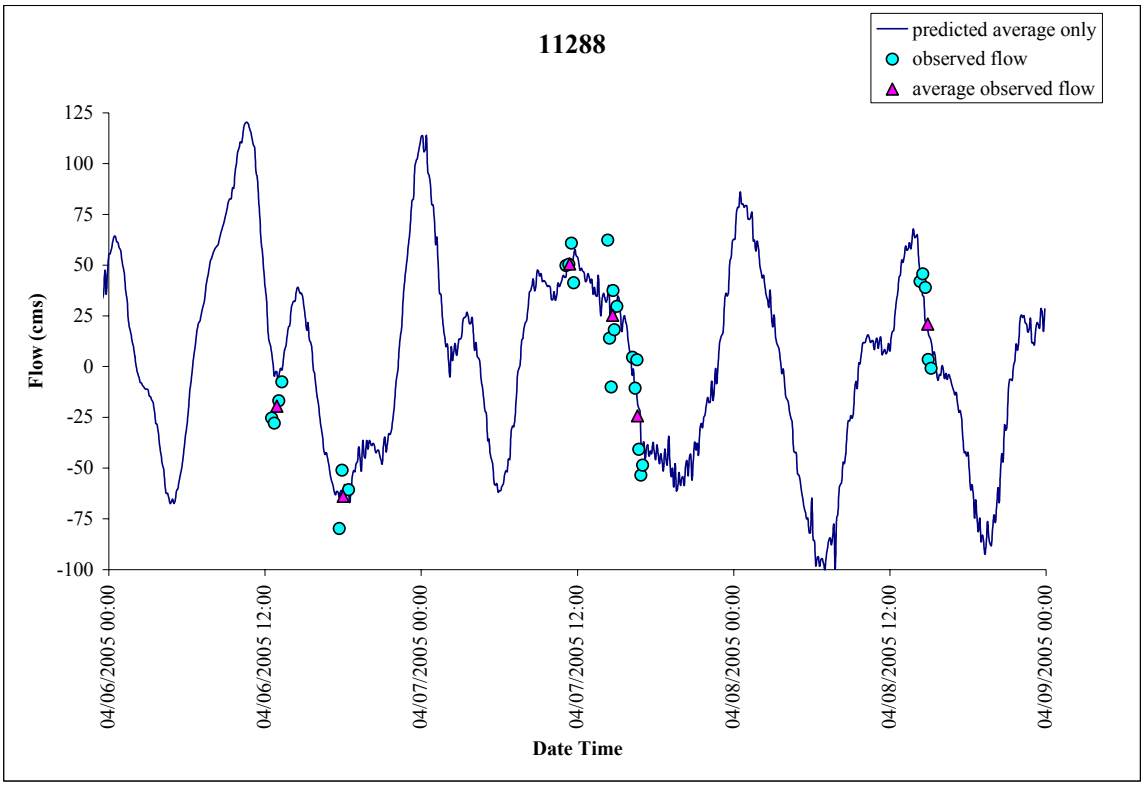
Regression Statistics	
Multiple R	0.985710447
R Square	0.971625086
Adjusted R Square	0.964531357
Standard Error	7.833253687
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8404.435196	8404.435196	136.9695879	0.000304828
Residual	4	245.4394533	61.35986333		
Total	5	8649.874649			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-4.15825965	3.204204277	-1.297751108	0.264151369	-13.05457536	4.738056056	-13.0545754	4.738056056
X Variable 1	-427.0713	36.49121408	-11.7034007	0.000304828	-528.387363	-325.7552378	-528.387363	-325.7552378

Set intercept to Zero



SUMMARY OUTPUT

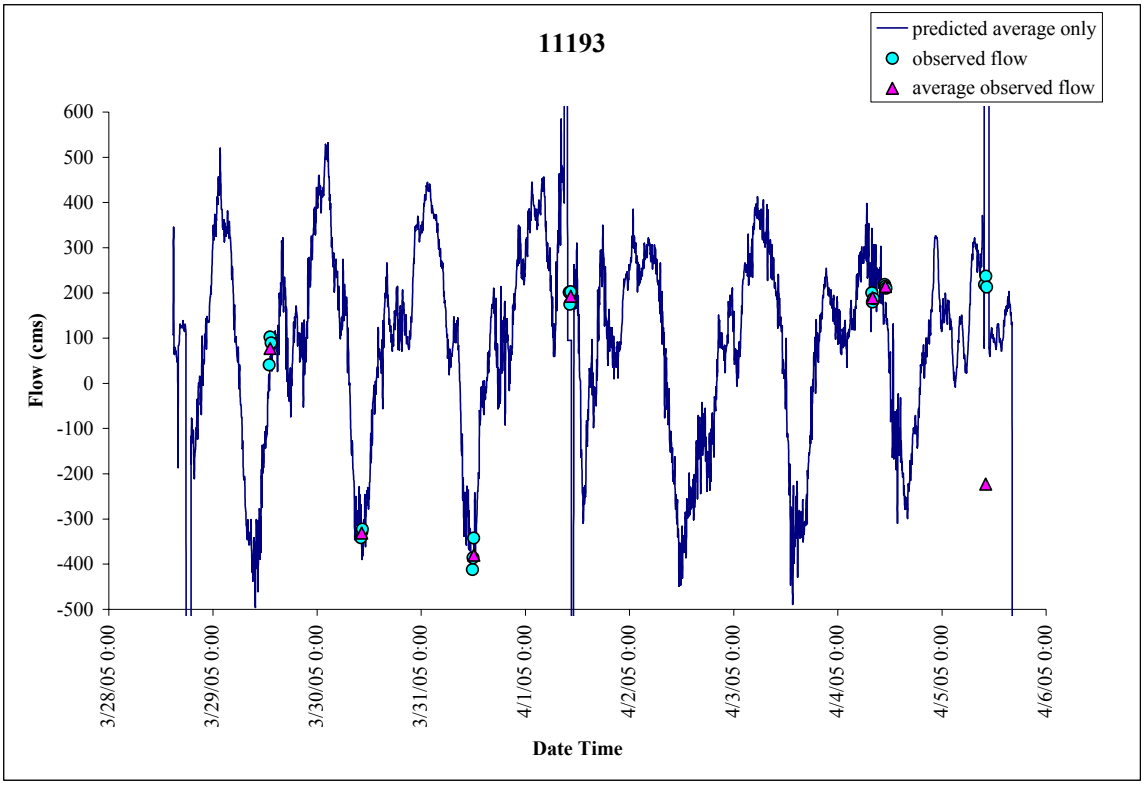
108

Regression Statistics	
Multiple R	0.979631628
R Square	0.959678126
Adjusted R Square	0.759678126
Standard Error	8.351995621
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	8301.095495	8301.095495	119.0021736	0.000400955
Residual	5	348.7791543	69.75583085		
Total	6	8649.874649			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-424.105031	38.83137328	-10.9217109	0.000111844	-523.924091	-324.285972	-523.924091	-324.285972



Site	Date	Time	Total Q	Variation
11193	03/29/05	13:11	77.37	42%
11193	03/30/05	10:16	-331.04	-3%
11193	03/31/05	11:57	-380.05	-9%
11193	04/01/05	10:16	192.79	8%
11193	04/04/05	8:00	189.05	5%
11193	04/04/05	10:56	214.26	2%
11193	4/5/2005	10:05	222.67	6%

Data points in red were not used for the regression

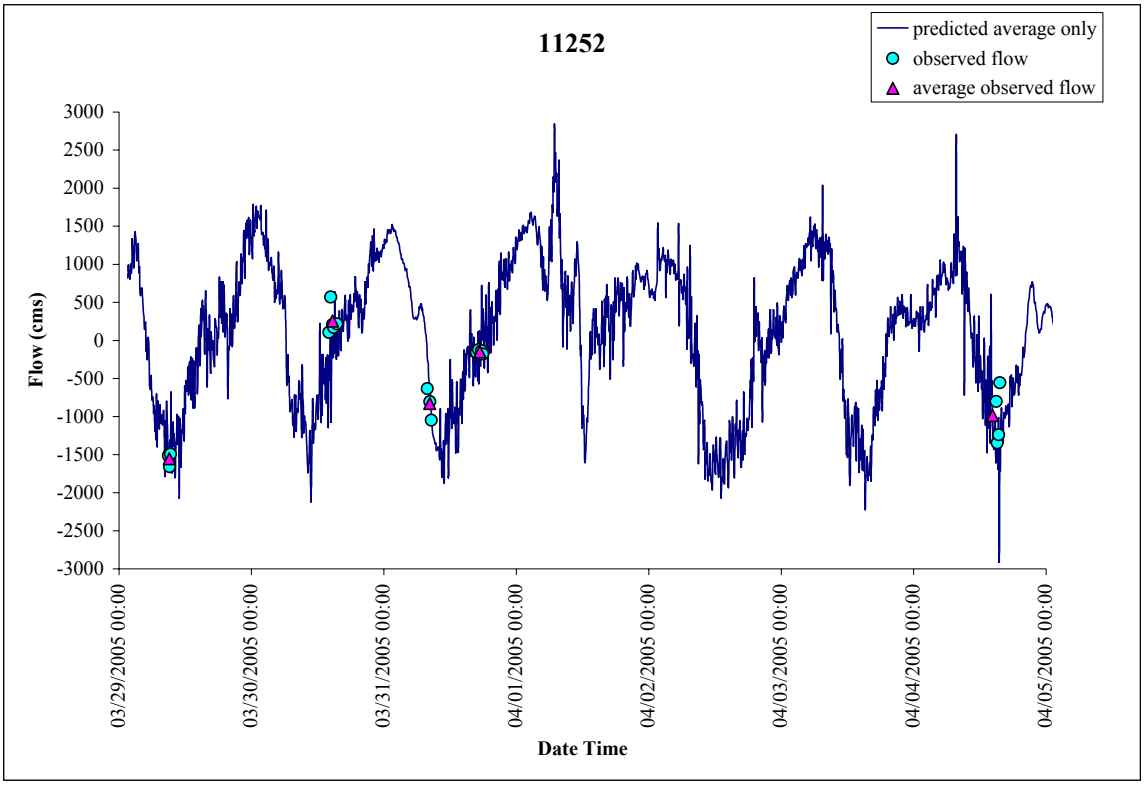
SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.993407158
R Square	0.986857782
Adjusted R Square	0.982477043
Standard Error	38.08182367
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	326695.1214	326695.1214	225.2719787	0.000641967
Residual	3	4350.675881	1450.225294		
Total	4	331045.7973			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	95.25561666	19.46069781	4.894768809	0.016314875	33.32293271	157.1883006	33.32293271	157.1883006
X Variable 1	-3970.09597	264.5132422	-15.00906322	0.000641967	-4811.895954	-3128.295994	-4811.89595	-3128.295994



Site	Date	Time	Total Q	Variation
11252	03/29/05	9:09	-1553.73	-6%
11252	03/30/05	14:42	253.81	71%
11252	03/31/05	8:16	-828.15	-25%
11252	03/31/05	17:23	-149.64	-17%
11252	04/04/05	15:17	-985.81	-38%
11252	04/05/05	14:23	-483.20	-68%

SUMMARY OUTPUT

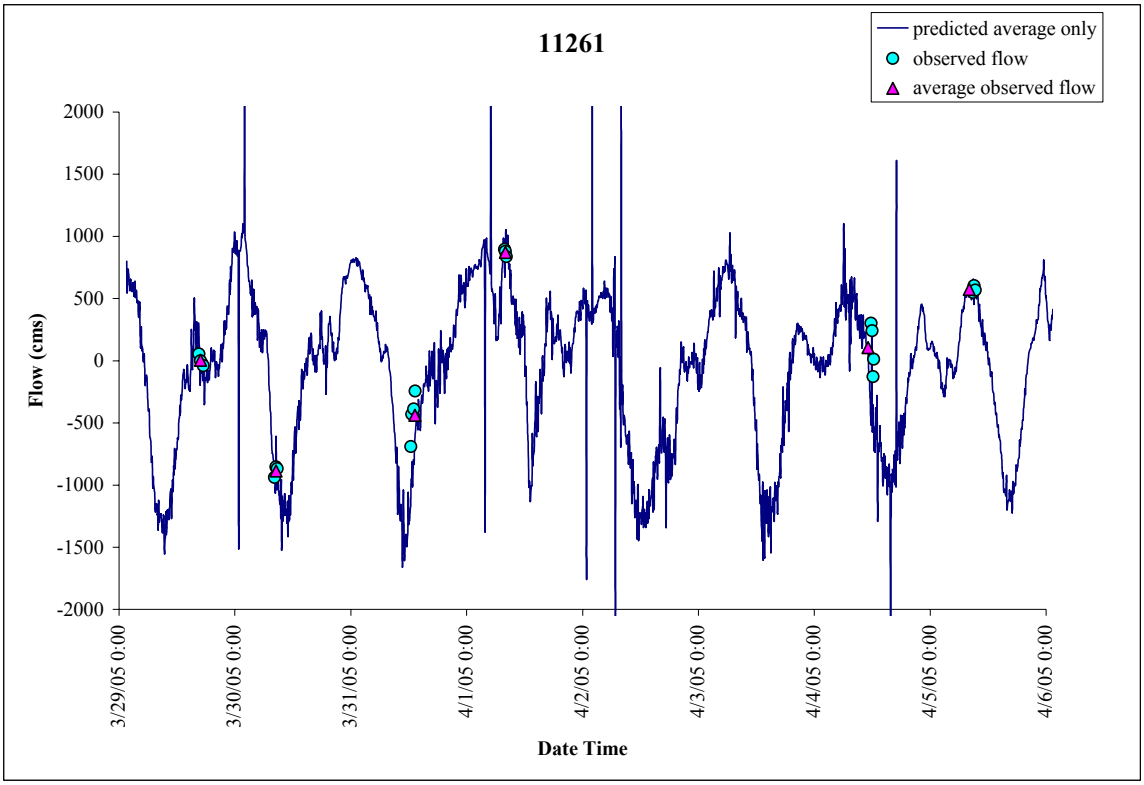
90 minute

Regression Statistics	
Multiple R	0.98691382
R Square	0.973998888
Adjusted R Square	0.96749861
Standard Error	115.5034523
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1999016.87	1999016.87	149.8395737	0.000255752
Residual	4	53364.18998	13341.0475		
Total	5	2052381.06			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	149.0135261	78.84236491	1.890018473	0.131747734	-69.88842541	367.9154776	-69.8884254	367.9154776
X Variable 1	-12180.5813	995.0725633	-12.24089759	0.000255752	-14943.35141	-9417.811269	-14943.3514	-9417.811269



Site	Date	Time	Total Q	Variation
11261	03/29/05	16:57	4.28	1100%
11261	03/30/05	8:29	-886.33	-5%
11261	03/31/05	13:19	-438.18	-43%
11261	04/01/05	8:02	870.65	4%
11261	04/04/05	12:03	106.15	188%
11261	04/05/05	9:06	573.34	5%

SUMMARY OUTPUT

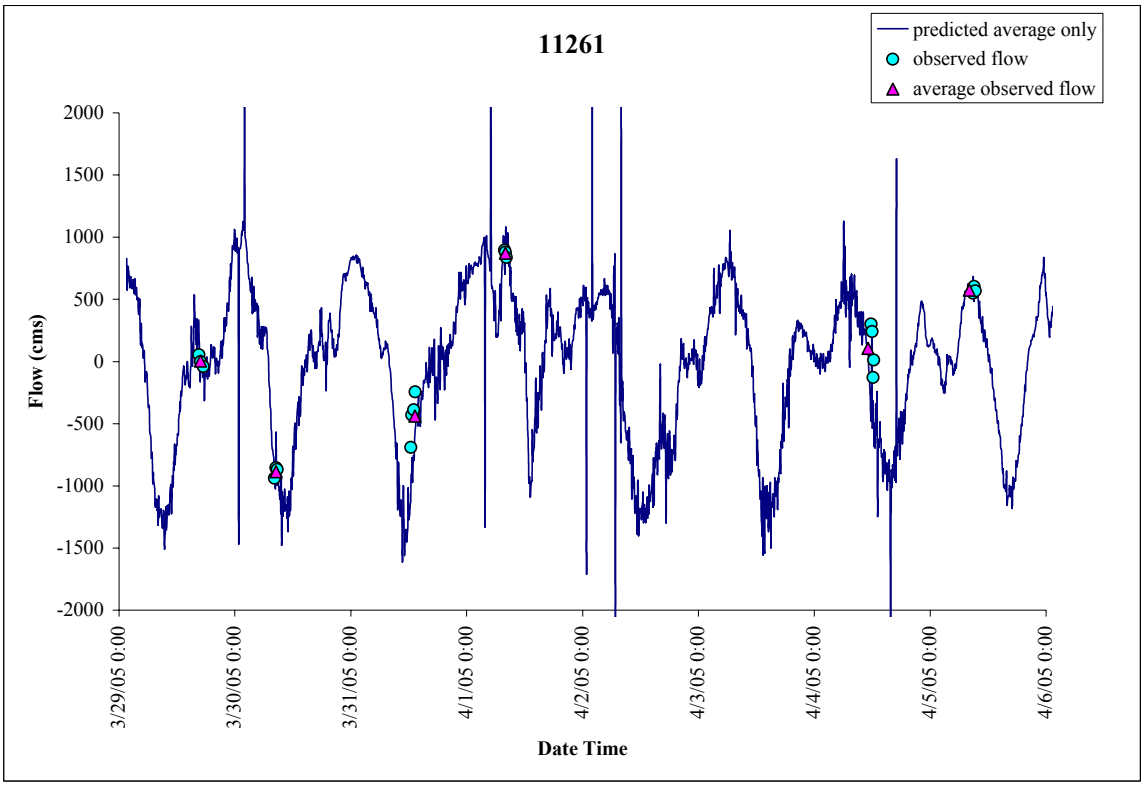
Regression Statistics	
Multiple R	0.969077427
R Square	0.93911106
Adjusted R Square	0.923888825
Standard Error	177.3739305
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1940966.823	1940966.823	61.69337542	0.001419524
Residual	4	125846.0449	31461.51122		
Total	5	2066812.868			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-34.2650405	72.99989155	-0.469384814	0.663237666	-236.9456519	168.4155708	-236.945652	168.4155708
X Variable 1	-9073.09743	1155.144483	-7.85451306	0.001419524	-12280.29931	-5865.895539	-12280.2993	-5865.895539

Set Intercept to Zero



SUMMARY OUTPUT

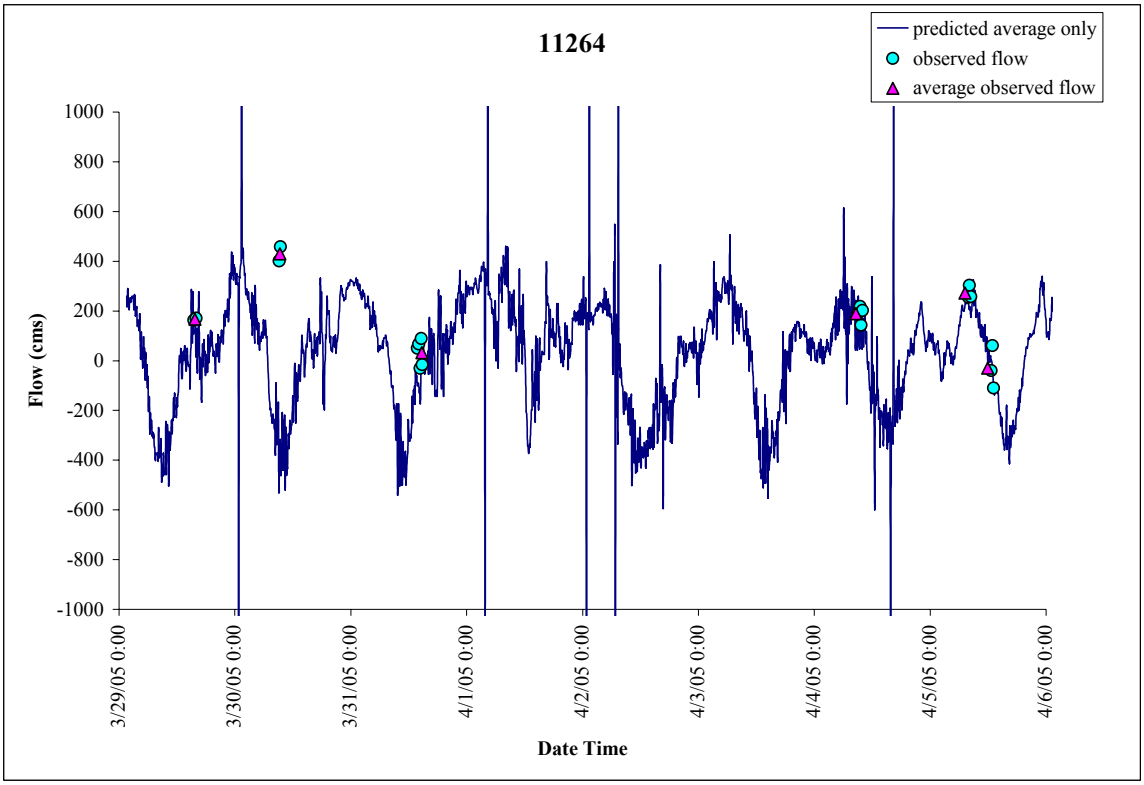
72

Regression Statistics	
Multiple R	0.967345473
R Square	0.935757265
Adjusted R Square	0.735757265
Standard Error	162.9587133
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1934035.157	1934035.157	72.82981228	0.001034639
Residual	5	132777.7112	26555.54225		
Total	6	2066812.868			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-9004.45867	1052.727711	-8.55345459	0.000359757	-11710.577	-6298.34036	-11710.577	-6298.34036



Site	Date	Time	Total Q	Variation
11264	03/29/05	15:44	166.85	3%
11264	03/30/05	9:19	430.03	9%
11264	03/31/05	14:41	32.14	163%
11264	04/04/05	9:33	188.68	17%
11264	04/05/05	8:09	271.99	10%
11264	04/05/05	12:51	-29.54	-291%

SUMMARY OUTPUT

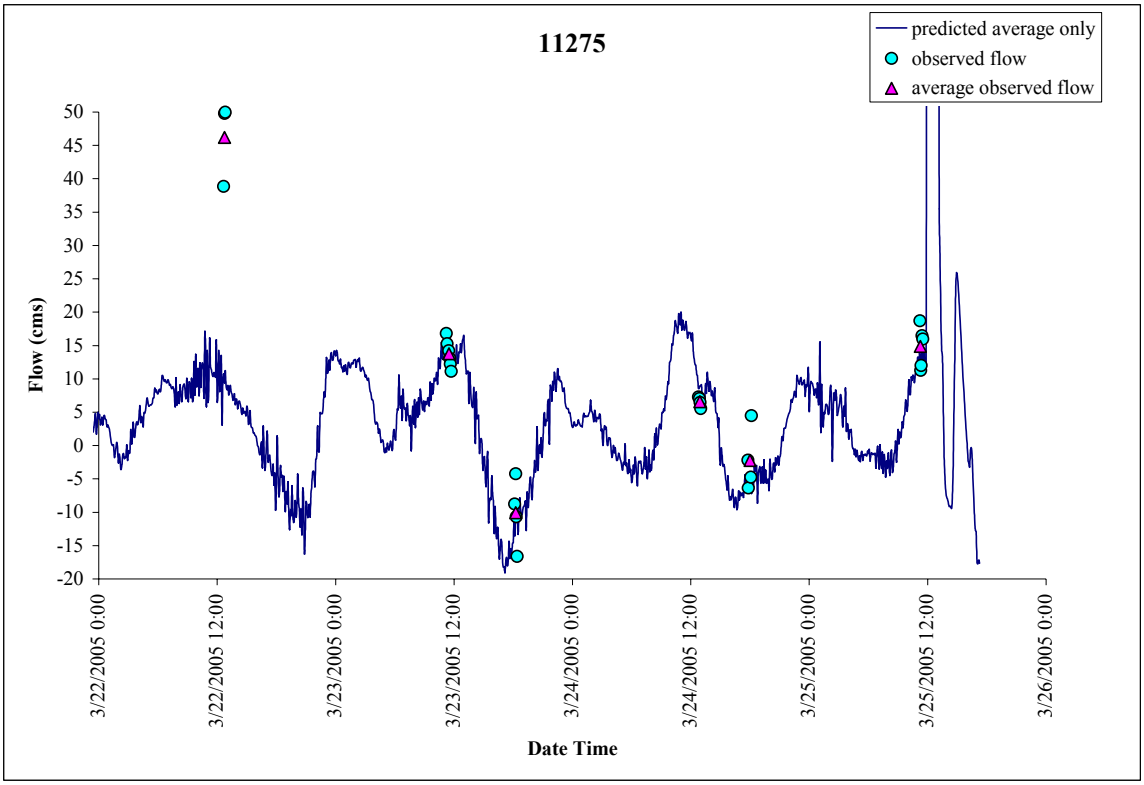
36

Regression Statistics	
Multiple R	0.946823638
R Square	0.896475002
Adjusted R Square	0.861966669
Standard Error	45.46959542
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	53710.15267	53710.15267	25.97850812	0.014602157
Residual	3	6202.452322	2067.484107		
Total	4	59912.60499			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	37.07055209	26.79710824	1.383378824	0.26051932	-48.20988603	122.3509902	-48.209886	122.3509902
X Variable 1	-6010.37981	1179.219938	-5.096911625	0.014602157	-9763.18747	-2257.572157	-9763.18747	-2257.572157



Site	Date	Time	Total Q	Variation
11275	03/22/05	12:45	46.19	14%
11275	03/23/05	11:29	13.78	15%
11275	03/23/05	18:16	-10.08	-51%
11275	03/24/05	12:53	6.58	12%
11275	03/24/05	17:57	-2.21	-217%
11275	03/25/05	11:21	14.88	21%

Data points in red were not used for the regression

SUMMARY OUTPUT

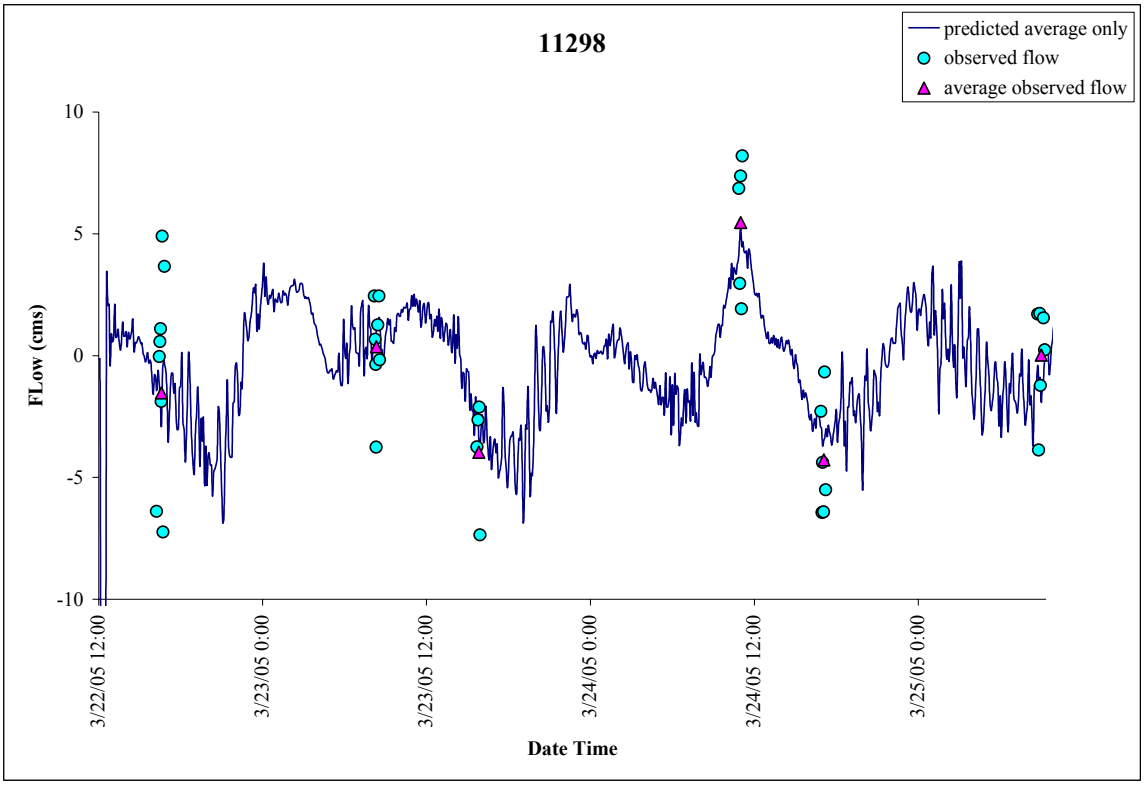
75

Regression Statistics	
Multiple R	0.977317437
R Square	0.955149373
Adjusted R Square	0.940199165
Standard Error	2.610042648
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	435.2304208	435.2304208	63.88869772	0.004086852
Residual	3	20.43696787	6.812322622		
Total	4	455.6673887			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.902546063	1.186181733	2.44696574	0.091927553	-0.872417153	6.677509279	-0.87241715	6.677509279
X Variable 1	-96.9723527	12.13209813	-7.993040581	0.004086852	-135.5821398	-58.36256561	-135.58214	-58.36256561



Site	Date	Time	Modified Total Q	Variation	Total Q	Variation
11298	03/22/05	16:34	-1.94	-2.50	-1.53	-3.16
11298	03/23/05	8:21	0.40	4.37	0.36	5.86
11298	03/23/05	15:48	-4.97	-0.35	-3.96	-0.60
11298	03/24/05	10:59	5.22	0.52	5.46	0.52
11298	03/24/05	17:02	-3.80	-0.54	-4.28	-0.55
11298	03/25/05	8:58	-0.34	-4.87	0.02	100.77

SUMMARY OUTPUT

90

Regression Statistics	
Multiple R	0.949966234
R Square	0.902435845
Adjusted R Square	0.878044806
Standard Error	1.263951449
Observations	6

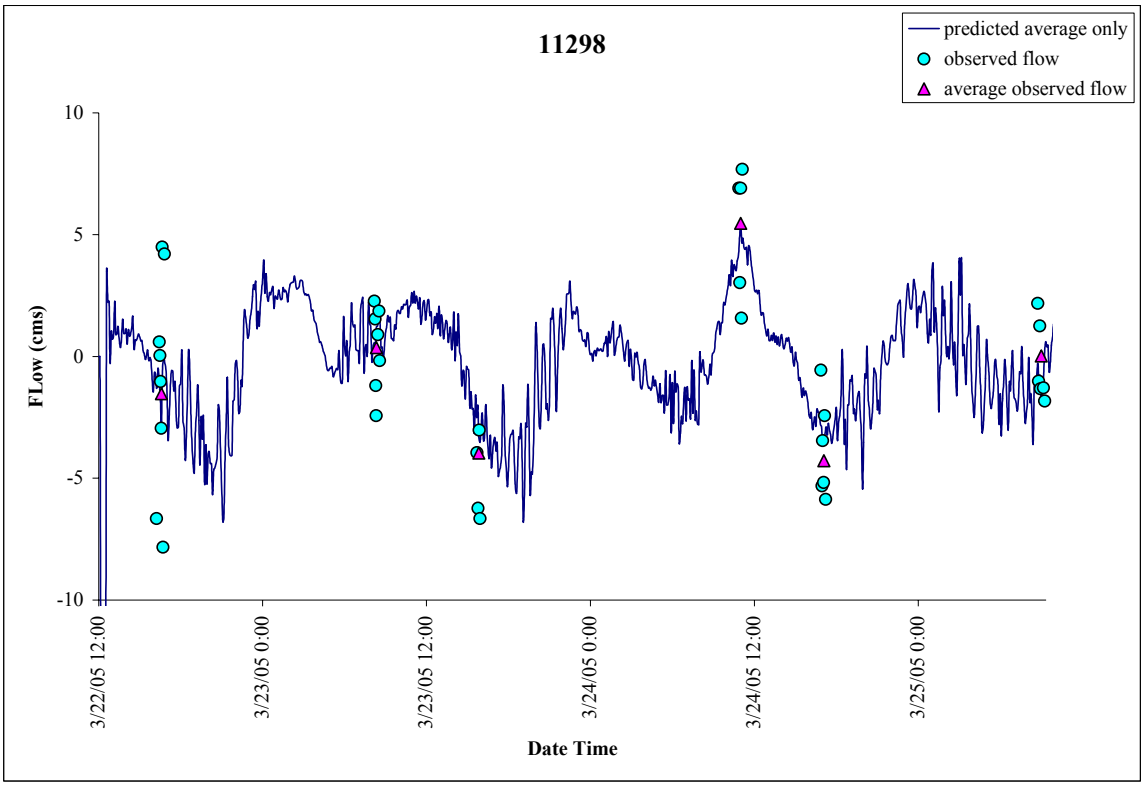
Red columns indicate that a modified Q was used for the regression (cut points off the profile, due to big turn in trajectory)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	59.10807626	59.10807626	36.9986639	0.00369244
Residual	4	6.390293057	1.597573264		
Total	5	65.49836932			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.13499441	0.531296328	-0.254084972	0.811956623	-1.610112557	1.340123731	-1.61011256	1.340123731
X Variable 1	-24.0539953	3.954523867	-6.082652703	0.00369244	-35.03353646	-13.07445411	-35.0335365	-13.07445411

Set Intercept to Zero



SUMMARY OUTPUT

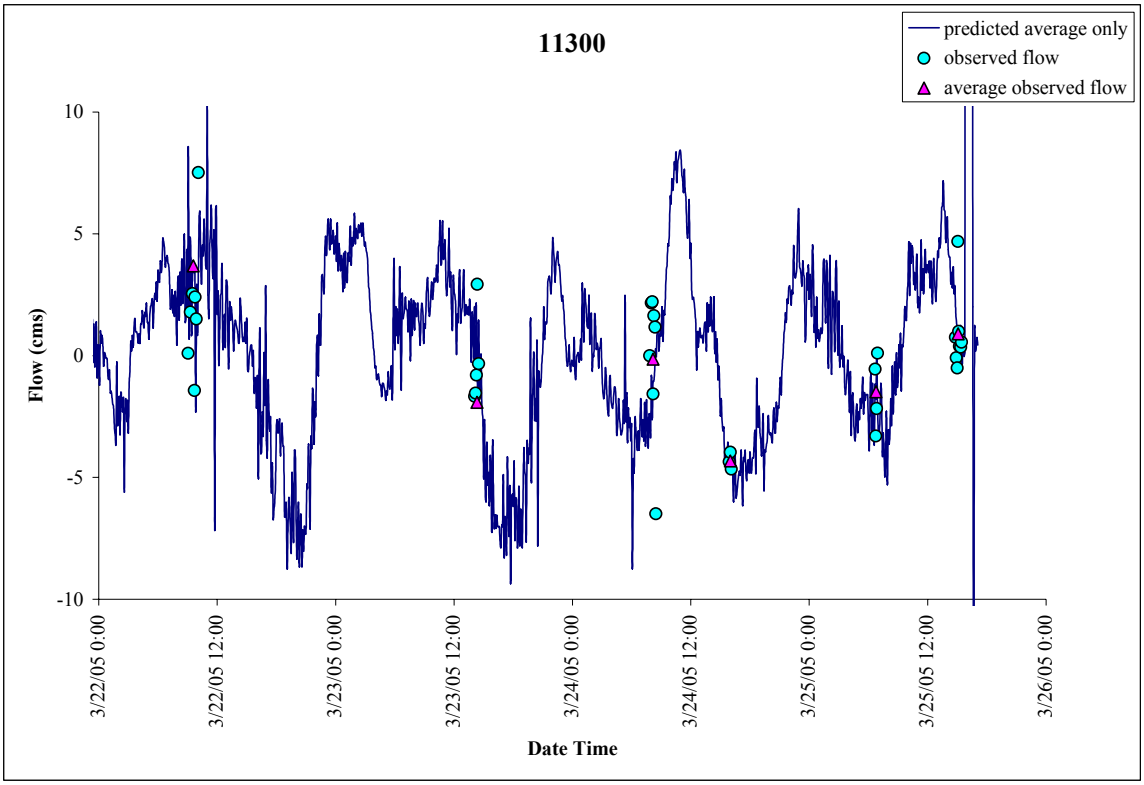
90

Regression Statistics	
Multiple R	0.949137071
R Square	0.90086118
Adjusted R Square	0.70086118
Standard Error	1.139599146
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	59.00493825	59.00493825	45.43433021	0.002524649
Residual	5	6.493431066	1.298686213		
Total	6	65.49836932			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-24.2933161	3.462851571	-7.01540786	0.000907517	-33.1948449	-15.3917873	-33.1948449	-15.3917873



Site	Date	Time	Total Q	Variation
11300	03/22/05	9:37	3.69	111%
11300	03/23/05	14:18	-1.91	-227%
11300	03/24/05	8:10	-0.15	-2333%
11300	03/24/05	16:00	-4.32	-8%
11300	03/25/05	6:47	-1.48	-104%
11300	03/25/05	15:07	0.89	180%

SUMMARY OUTPUT

45

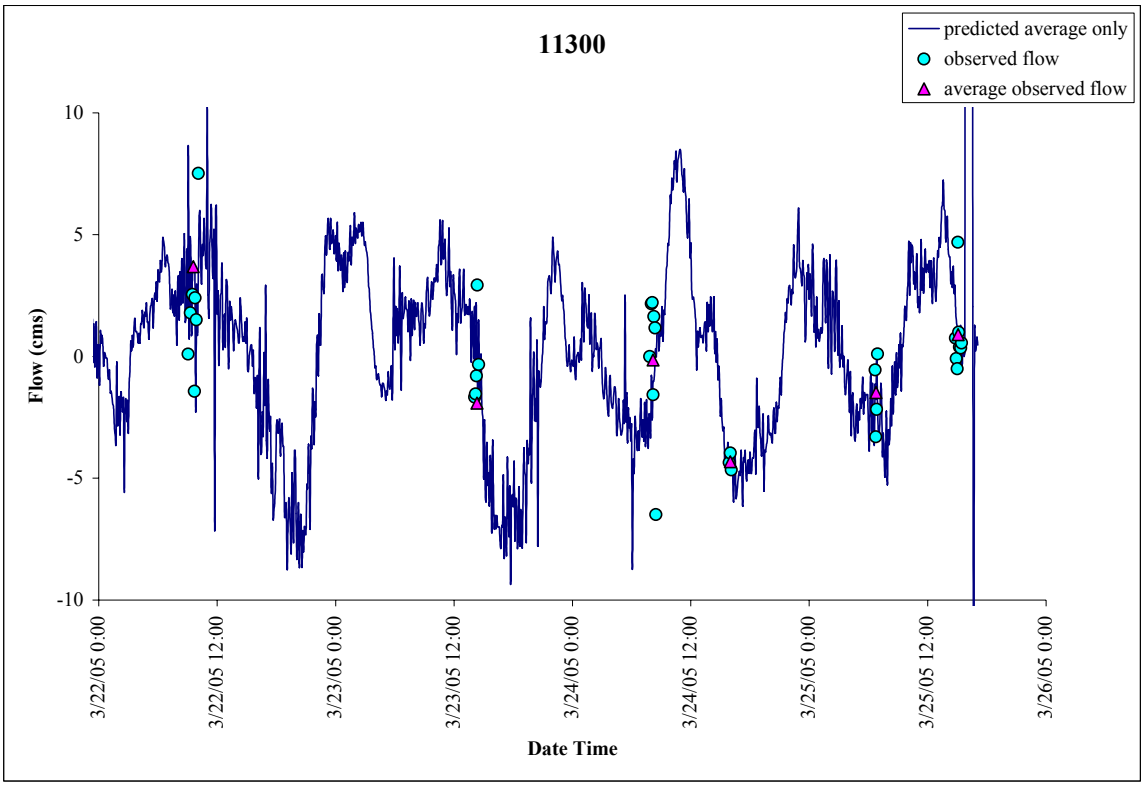
Regression Statistics	
Multiple R	0.956319325
R Square	0.914546652
Adjusted R Square	0.893183315
Standard Error	0.891577776
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	34.02947455	34.02947455	42.80916673	0.002820331
Residual	4	3.179643721	0.79491093		
Total	5	37.20911827			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.03663512	0.372223272	-0.098422429	0.926331772	-1.07009474	0.996824503	-1.07009474	0.996824503
X Variable 1	-78.3918208	11.98125647	-6.542871444	0.002820331	-111.6571906	-45.12645103	-111.657191	-45.12645103

Set Intercept to Zero



SUMMARY OUTPUT

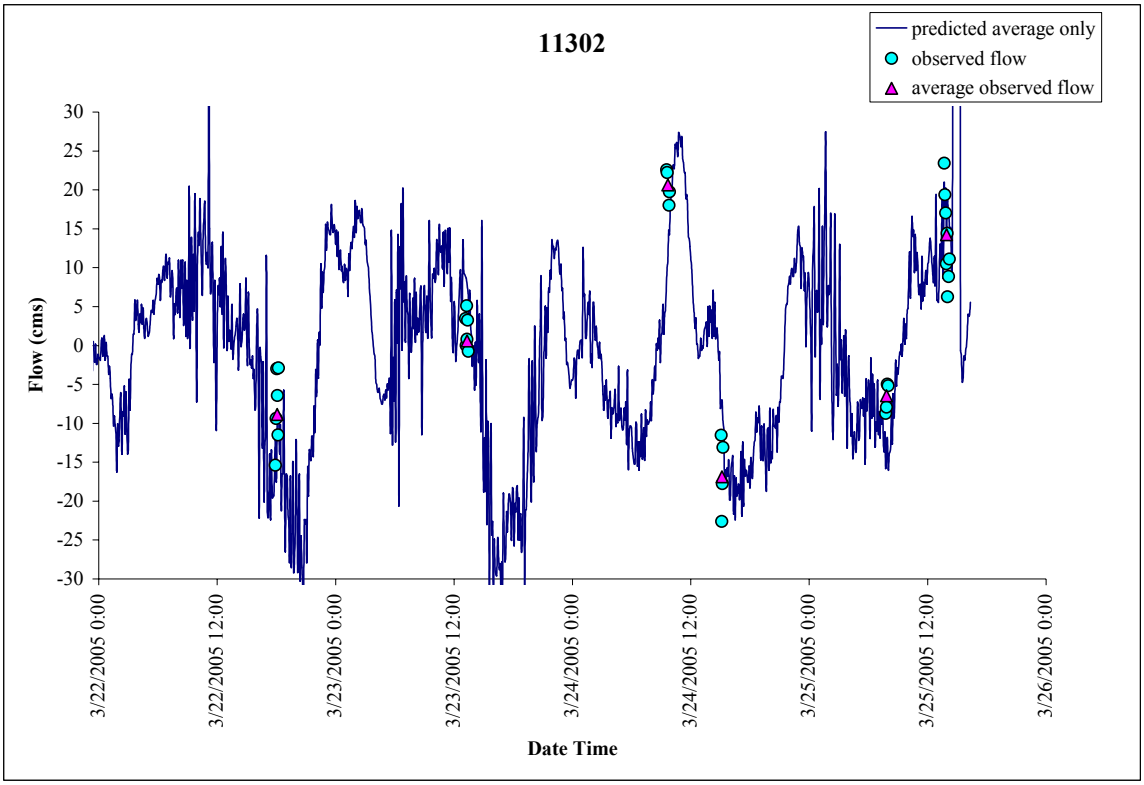
45

Regression Statistics	
Multiple R	0.95621112
R Square	0.914339706
Adjusted R Square	0.714339706
Standard Error	0.798416433
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	34.02177426	34.02177426	53.37010099	0.001867083
Residual	5	3.187344003	0.637468801		
Total	6	37.20911827			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-78.6385432	10.49186478	-7.49519222	0.000668242	-105.608696	-51.6683903	-105.608696	-51.6683903



Site	Date	Time	Modified Total Q	Variation	Total Q	Variation
11302	03/22/05	18:04	-8.86	-63%	-8.09	-61%
11302	03/23/05	13:18	0.59	520%	1.99	115%
11302	03/24/05	9:41	20.64	10%	-21.87	-11%
11302	03/24/05	15:10	-16.88	-17%	-16.25	-31%
11302	03/25/05	7:52	-6.46	-17%	-6.71	-28%
11302	03/25/05	13:55	14.24	50%	13.87	42%

Red columns indicate that a modified Q was used for the regression (cut points off the profile, due to big turn in trajectory)

SUMMARY OUTPUT

45

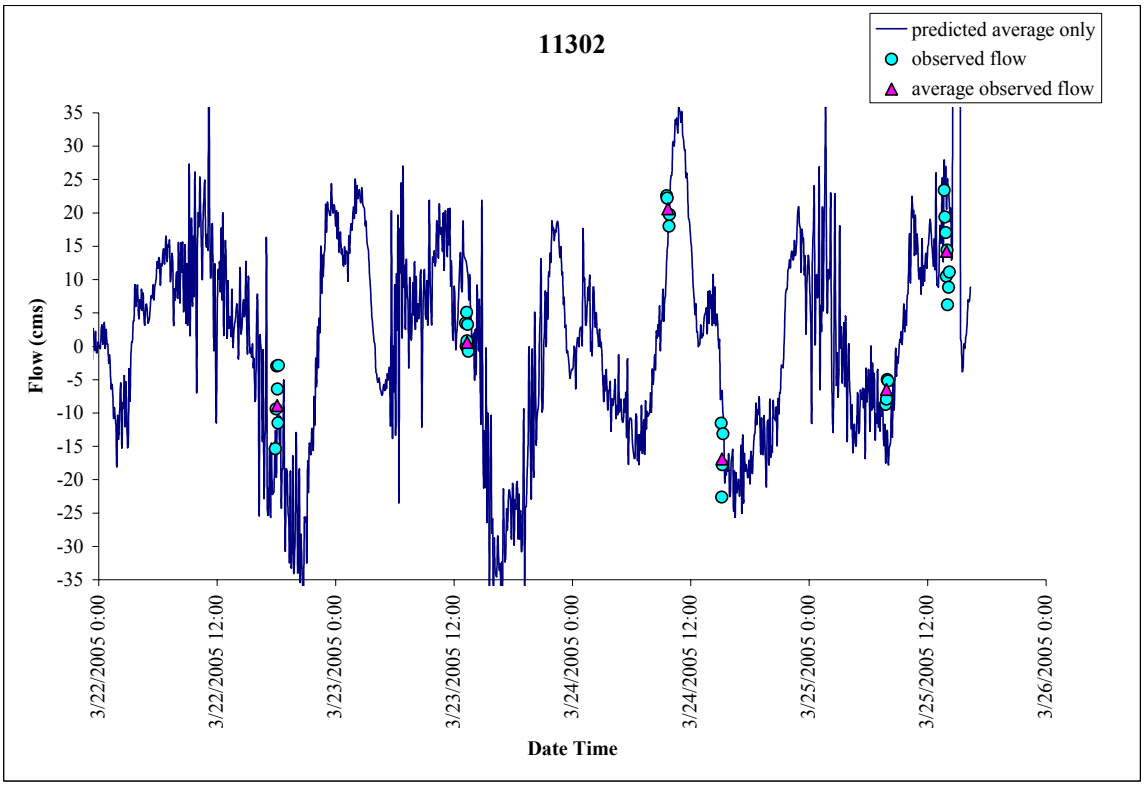
Regression Statistics	
Multiple R	0.845131894
R Square	0.714247917
Adjusted R Square	0.642809897
Standard Error	8.589376123
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	737.6372008	737.6372008	9.9981482	0.034119007
Residual	4	295.1095287	73.77738217		
Total	5	1032.746729			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-1.63660167	3.573771378	-0.457948061	0.670762929	-11.55900227	8.285798928	-11.5590023	8.285798928
X Variable 1	-256.547054	81.13481436	-3.161984851	0.034119007	-481.8138787	-31.28022915	-481.813879	-31.28022915

Set Intercept to Zero



SUMMARY OUTPUT

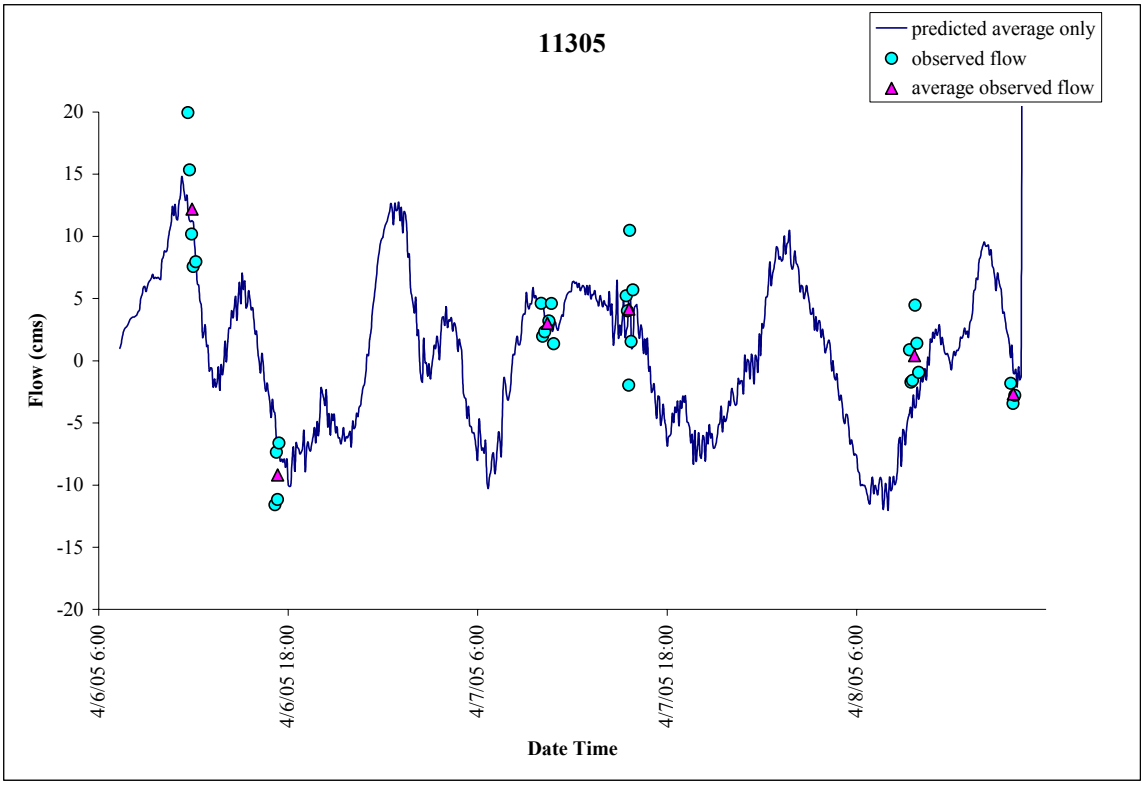
30

Regression Statistics	
Multiple R	0.838514444
R Square	0.703106472
Adjusted R Square	0.503106472
Standard Error	7.830910798
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	726.1309098	726.1309098	11.84105423	0.026267698
Residual	5	306.6158196	61.32316392		
Total	6	1032.746729			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-316.882934	91.97572653	-3.44528873	0.018330497	-553.31368	-80.4521885	-553.31368	-80.4521885



Site	Date	Time	Total Q	Variation
11305	04/06/05	11:53	12.20	44%
11305	04/06/05	17:17	-9.18	-28%
11305	04/07/05	10:24	3.01	46%
11305	04/07/05	15:36	4.16	101%
11305	04/08/05	9:38	0.41	574%
11305	04/08/05	15:53	-2.68	-30%

SUMMARY OUTPUT

60

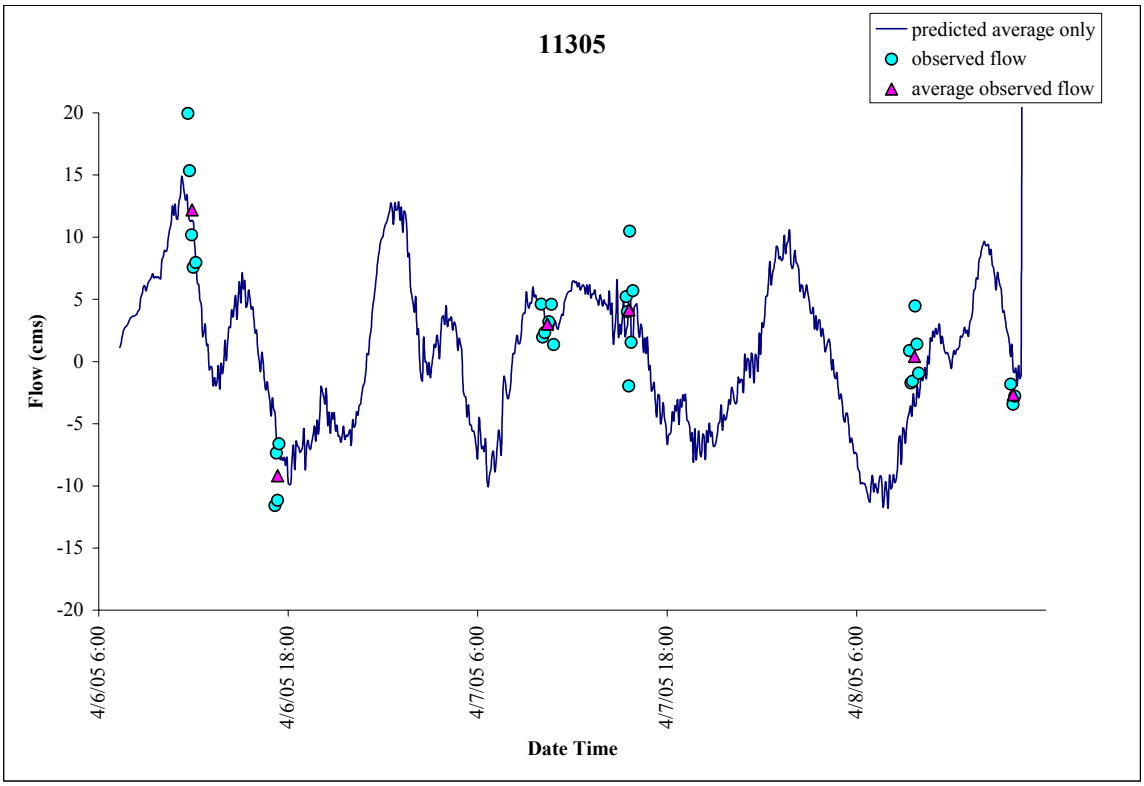
Regression Statistics	
Multiple R	0.946152346
R Square	0.895204262
Adjusted R Square	0.869005328
Standard Error	2.591868163
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	229.5431449	229.5431449	34.16949129	0.004271287
Residual	4	26.87112231	6.717780576		
Total	5	256.4142672			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.1621251	1.088131018	-0.148994097	0.888768239	-3.183267395	2.859017198	-3.18326739	2.859017198
X Variable 1	-81.6551583	13.96896949	-5.845467585	0.004271287	-120.4393156	-42.87100104	-120.439316	-42.87100104

Set Intercept to Zero



SUMMARY OUTPUT

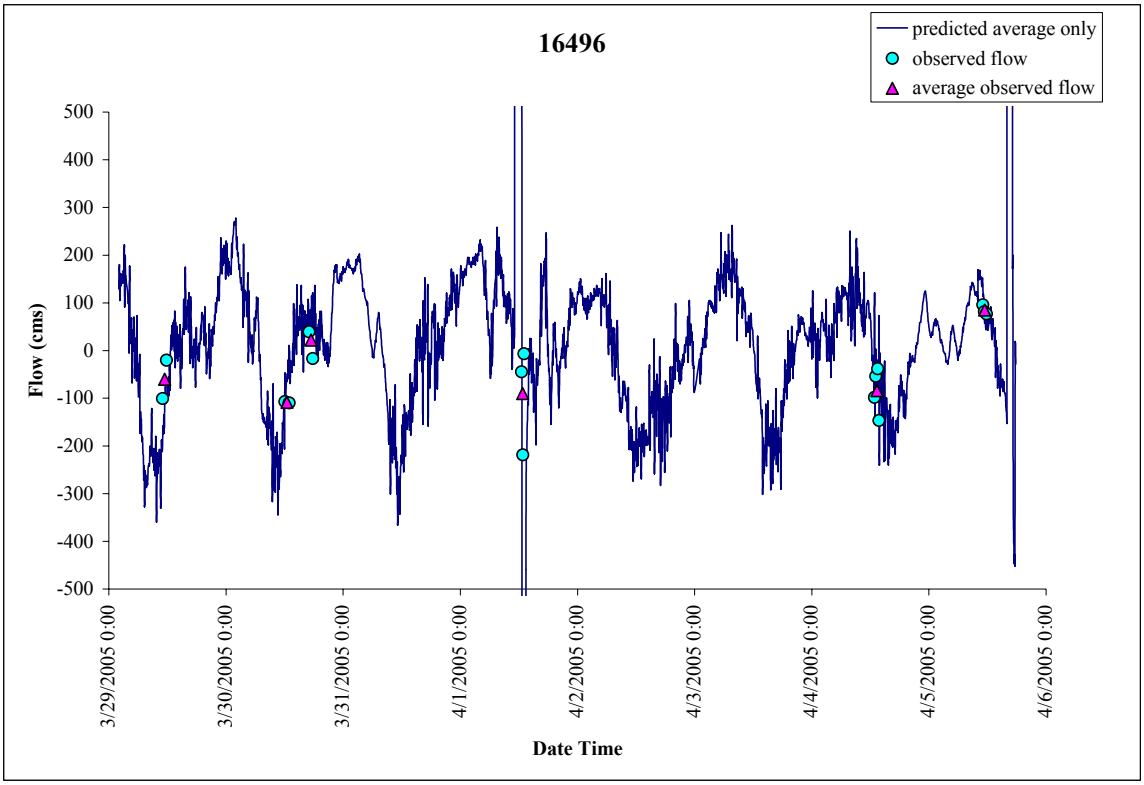
60

Regression Statistics	
Multiple R	0.945844948
R Square	0.894622666
Adjusted R Square	0.694622666
Standard Error	2.324661349
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	229.3940153	229.3940153	42.44853375	0.002864975
Residual	5	27.02025194	5.404050387		
Total	6	256.4142672			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-81.1697672	12.18336479	-6.66234399	0.001149907	-112.488052	-49.8514821	-112.488052	-49.8514821



Site	Date	Time	Total Q	Variation
16496	03/29/05	11:23	-60.40	-94%
16496	03/30/05	12:30	-108.45	-2%
16496	03/30/05	17:23	21.90	153%
16496	04/01/05	12:48	-89.96	-126%
16496	04/04/05	13:09	-63.24	-49%
16496	04/05/05	11:23	84.76	12%

Data points in red were not used for the regression

SUMMARY OUTPUT

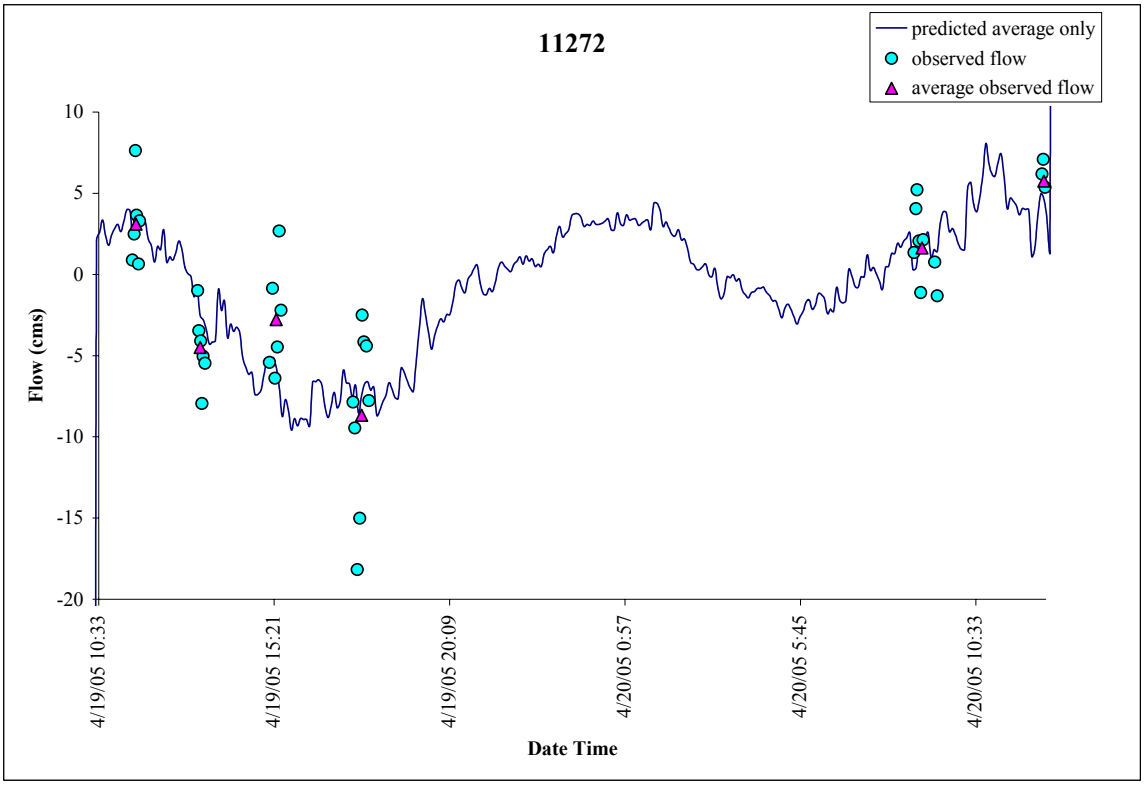
60

Regression Statistics	
Multiple R	0.870310361
R Square	0.757440125
Adjusted R Square	0.676586834
Standard Error	43.98185678
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	18121.64937	18121.64937	9.368080266	0.054961378
Residual	3	5803.211177	1934.403726		
Total	4	23924.86055			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	15.04792036	23.63919615	0.6365665	0.569654218	-60.18262266	90.27846339	-60.1826227	90.27846339
X Variable 1	-2205.11284	720.4527718	-3.060731982	0.054961378	-4497.917253	87.69157238	-4497.91725	87.69157238



Site	Date	Time	Total Q	Variation
11272	04/19/05	11:35	3.10	82%
11272	04/19/05	13:21	-4.50	-51%
11272	04/19/05	15:24	-2.78	-121%
11272	04/19/05	17:43	-8.67	-63%
11272	04/20/05	9:06	1.64	139%
11272	04/20/05	12:25	5.75	20%

SUMMARY OUTPUT

105

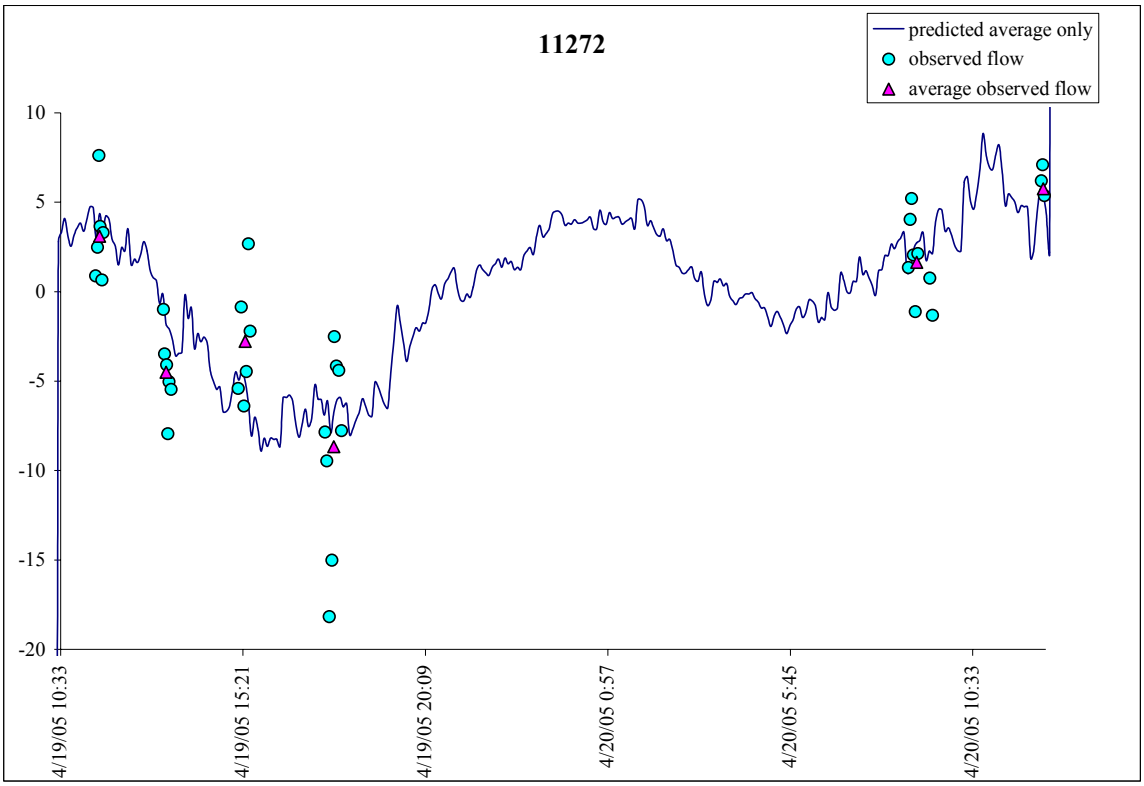
Regression Statistics	
Multiple R	0.94433731
R Square	0.891772955
Adjusted R Square	0.864716194
Standard Error	1.970151751
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	127.9316043	127.9316043	32.95933861	0.004561272
Residual	4	15.52599169	3.881497922		
Total	5	143.457596			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.72602758	0.804943386	-0.901961052	0.418078819	-2.960913338	1.508858171	-2.96091334	1.508858171
X Variable 1	-64.6347745	11.25840827	-5.741022436	0.004561272	-95.89319175	-33.37635719	-95.8931917	-33.37635719

Set Intercept to Zero



SUMMARY OUTPUT

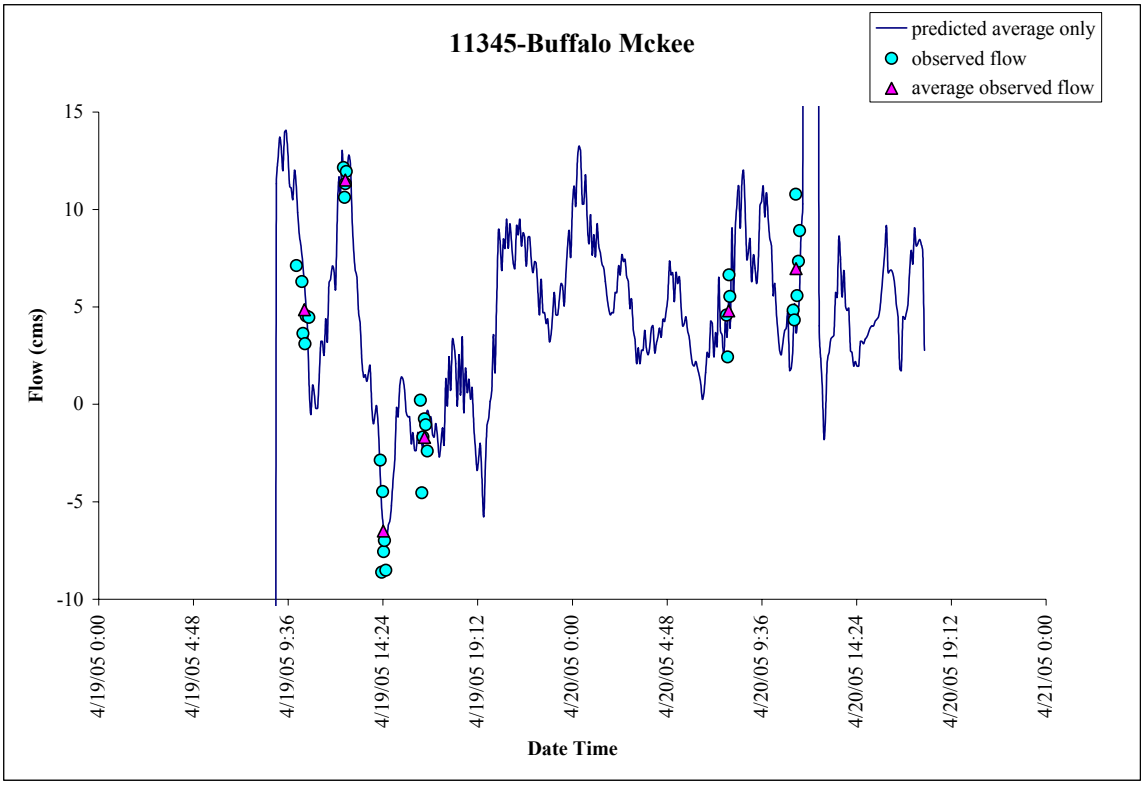
105

Regression Statistics	
Multiple R	0.932609976
R Square	0.869761367
Adjusted R Square	0.669761367
Standard Error	1.933066021
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	124.7738748	124.7738748	33.39106633	0.004454518
Residual	5	18.68372121	3.736744241		
Total	6	143.457596			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
X Variable 1	-65.0371894	11.03780504	-5.89222125	0.002001829	-93.4107242	-36.6636546	-93.4107242	-36.6636546



Site	Date	Time	Total Q	Variation	USGS Flow
11345	04/19/05	10:22	4.87	32%	3.96
11345	04/19/05	12:28	11.51	6%	4.39
11345	04/19/05	14:24	-6.50	-36%	1.98
11345	04/19/05	16:28	-1.70	-97%	2.41
11345	04/20/05	7:53	4.80	37%	3.65
11345	04/20/05	11:21	6.96	36%	3.91

SUMMARY OUTPUT

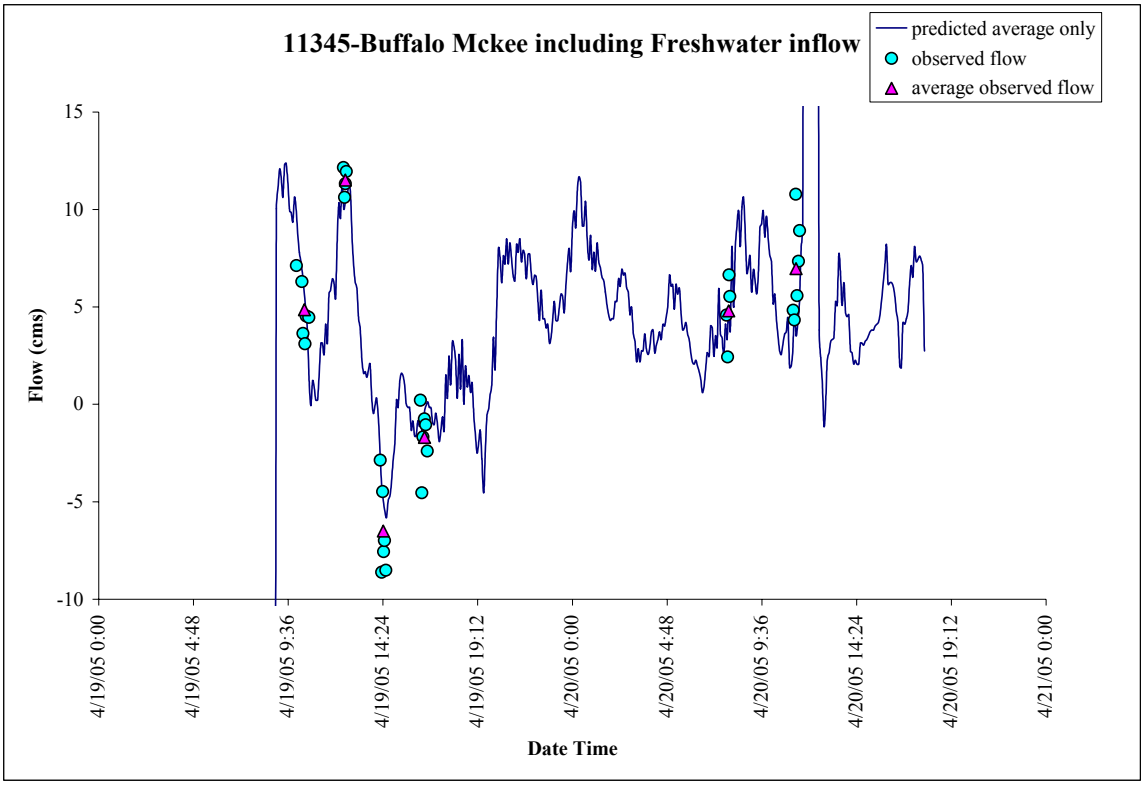
45

Regression Statistics	
Multiple R	0.966336925
R Square	0.933807052
Adjusted R Square	0.917258815
Standard Error	1.848921807
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	192.9045665	192.9045665	56.42939822	0.00168073
Residual	4	13.6740474	3.418511849		
Total	5	206.5786139			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	4.481816324	0.770410182	5.817441706	0.004346823	2.342810314	6.620822334	2.342810314	6.620822334
X Variable 1	-113.940704	15.16792558	-7.511950361	0.00168073	-156.053704	-71.82770406	-156.053704	-71.82770406



SUMMARY OUTPUT

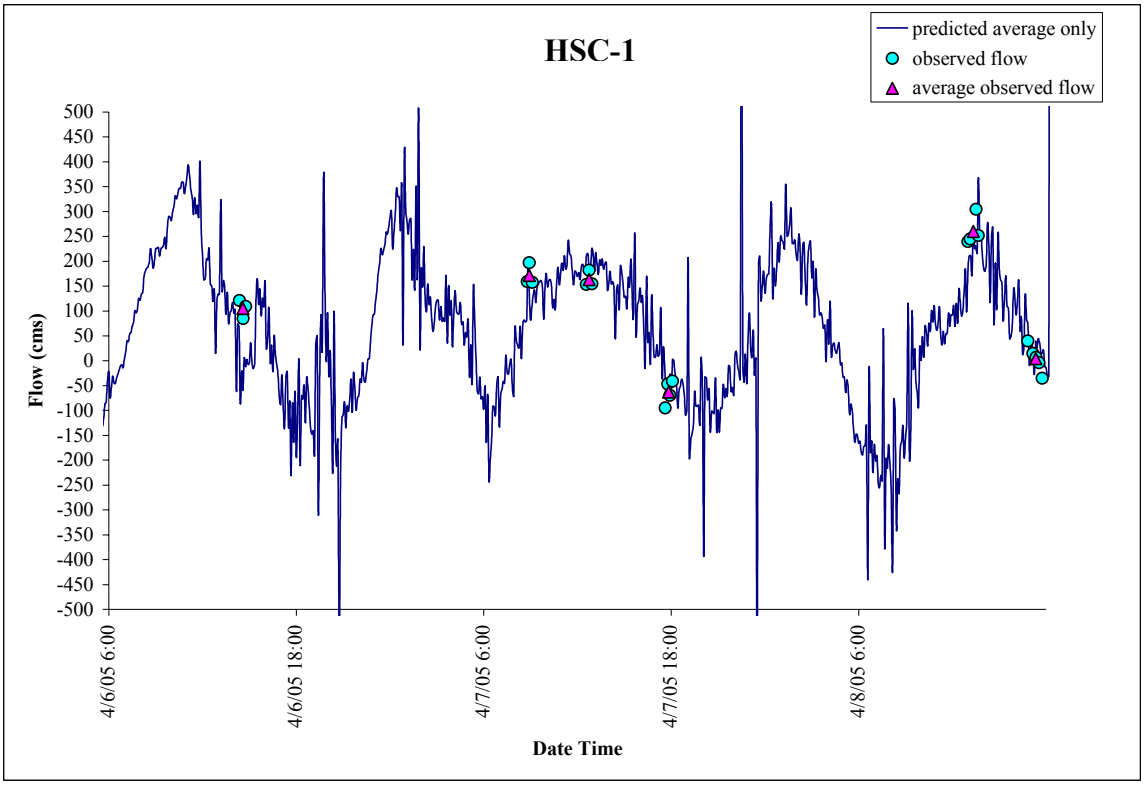
45

Regression Statistics	
Multiple R	0.963963103
R Square	0.929224863
Adjusted R Square	0.911531079
Standard Error	1.634450232
Observations	6

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	140.2954209	140.2954209	52.51702235	0.001924587
Residual	4	10.68571024	2.671427561		
Total	5	150.9811312			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.927444199	0.681043999	1.361797771	0.244913284	-0.963440994	2.818329393	-0.96344099	2.818329393
X Variable 1	-97.1693712	13.40847373	-7.246862932	0.001924587	-134.3973396	-59.94140288	-134.39734	-59.94140288



Site	Date	Time	Total Q	Variation
TBD	04/06/05	14:34	105.12	18%
TBD	04/07/05	8:56	171.23	13%
TBD	04/07/05	12:45	163.31	10%
TBD	04/07/05	17:51	-63.02	-39%
TBD	04/08/05	13:20	259.98	12%
TBD	04/08/05	17:19	4.36	630%

Data points in red were not used for the regression

SUMMARY OUTPUT

60

Regression Statistics	
Multiple R	0.977187042
R Square	0.954894515
Adjusted R Square	0.939859354
Standard Error	32.4738957
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	66975.51808	66975.51808	63.51075838	0.004122062
Residual	3	3163.661707	1054.553902		
Total	4	70139.17979			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	52.58223302	16.05723617	3.274675197	0.046612428	1.480893163	103.6835729	1.480893163	103.6835729
X Variable 1	-2083.62767	261.4547082	-7.969363737	0.004122062	-2915.694022	-1251.56132	-2915.69402	-1251.56132

APPENDIX E – SEDIMENT LOAD STUDY

tively. Sulfide results are presented in Figure 5.2-5. Because there is typically no oxygen in the sediments at between Arco (km 33.5) and the Turning Basin, and very little nitrate was seen, sulfate reduction and anoxic organic decay are probably the principle reactions occurring in the sediments. Both of these processes release substances (CH4, NH4-N, Fe2S, HS2, etc) which are probably diffusing into the water column and consuming all oxygen which is available from reaeration and point source input, causing the water column to stay anoxic.

The interstitial water concentrations varied more with depth than did the solid concentrations. As with the solids, the interstitial water NH4-N and COD concentrations were higher in the upper part of the channel, indicating anoxic reduction processes. Because of the lack of careful sample handling procedures, part of the sulfide, COD, NH4-N, and TOC were likely oxidized before measurements were taken in the water sample.

5.2.2 Analysis of Sources and Sinks

Having estimated the nature of the HSC sediments from available laboratory information, the next step is to attempt to understand the sources and sinks of this material. With this information, plus the rate information developed in the laboratory studies, the SOD model can be calibrated and applied. This section is organized into sources, solids accumulation, removal, balance calculations, sensitivity to assumptions, and discussion.

Sources

The loads of total suspended solids (TSS) and volatile suspended solids (VSS) were computed by both the tributary sampling and the individual component method as presented in the "Houston Ship Channel Urban

Runoff Nonpoint Source Study" (WAI and Associates, WAI, 1986). Figure 5.2.2-1 provides background on these two calculation methods.

The tributary sampling method calculates runoff loads based on sampled event mean concentrations (EMC) of TSS in the primary tributaries from the combined WAI and USGS databases (see Figure 5.2.2-2). In addition, unmonitored area loads were calculated based on the load/sq. mi. developed in the monitored area, with WWTP and bypass loads removed. The specific WWTP and bypass loads for the unmonitored areas were then added to the total, along with industrial loads, and dry and transition WWTP loads.

The individual component method calculates loads from each contributing land use type and specific sources. Runoff load is calculated based on land use, overflow load is based on the number and frequency of overflow events, bypass and wet weather loads are based on self reporting data, and industrial and dry and transition WWTP loads (as defined by WAI) are calculated as for the tributary sampling method.

Although the individual component method has the advantage of tracing loads to contributing sources, the TSS calculated is approximately half of that calculated by the tributary sampling method, possibly as a result of not being able to quantify other sources of sediment such as construction in the HSC watershed (WAI, 1986).

TSS and VSS loads for the upper HSC watershed (Greens Bayou and above) are presented in Table 5.2.2-1. This indicates the substantial difference between TSS loads calculated by the two methods. The VSS loads are relatively close with the two calculation methods.

Loads for areas below Greens Bayou, which were not included in the WAI report, are extrapolated based on drainage area. The exception was the San Jacinto River spills at Lake Houston which were based on annual

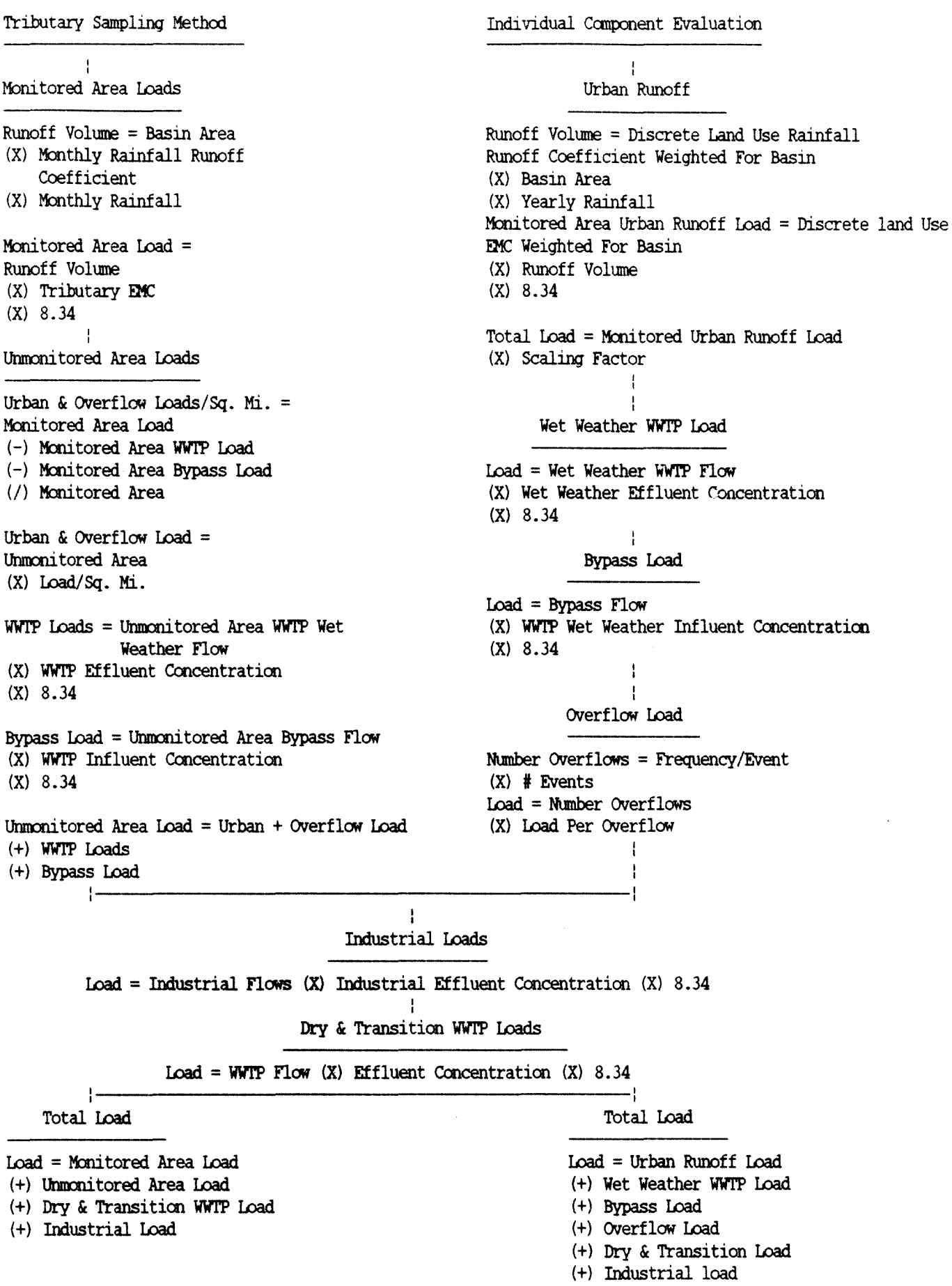
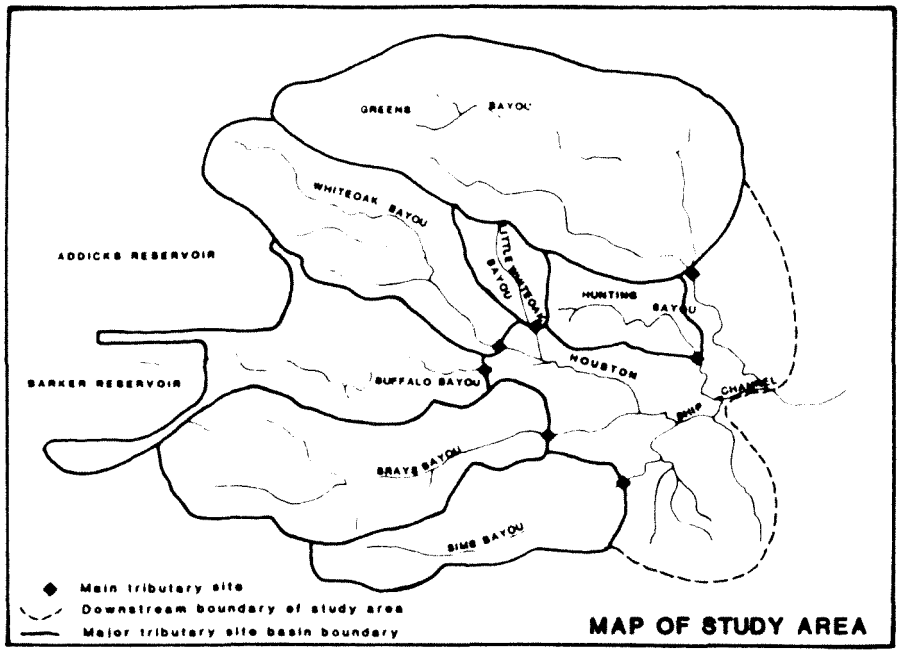


Figure 5.2.2-1 Tributary and Individual Component Method Calculations (from WAI, 1986)



		DATA COLLECTED BY WINSLOW AND ASSOCIATES (WAI)						DATA COLLECTED BY THE USGS					
		TSS	VSS	CBOD5	NH3-N	TKN	NO2+3	TSS	VSS	BOD5	NH3-N	TKN	NO2+3
BRAYS BAYOU AT MAIN STREET	MEDIAN	101	29	9.0	0.92	2.43	1.58	392	41	12.0	0.99	2.38	2.43
	LG STD	0.716	0.761	0.526	0.415	0.313	0.351	0.13	1.19	1.17	0.67	0.56	0.84
	MEAN	234	39	10.3	1.00	2.55	1.68	395	83	23.7	1.24	2.79	3.45
	CV	0.819	0.886	0.564	0.433	0.320	0.362	0.13	1.77	1.71	0.75	0.61	1.01
	N	7	7	7	7	7	7	4	4	4	4	4	4
BUFFALO AT SHEPHERD	MEDIAN	186	16	5.7	0.43	2.07	0.91	288	40	7.0	0.26	1.45	-
	LG STD	0.429	1.115	0.377	0.621	0.654	1.523	0.61	0.59	0.34	0.62	0.36	-
	MEAN	204	29	6.1	0.52	2.56	2.90	347	48	7.41	0.32	1.55	0.
	CV	0.449	1.571	0.391	0.686	0.730	3.020	0.67	0.65	0.35	0.68	0.37	
	N	5	5	5	5	5	5	2	2	2	2	2	1
GREENS BAYOU AT LEY ROAD	MEDIAN	80	12	7.3	0.16	1.03	0.45	1098	159	15.2	0.41	2.23	0.39
	LG STD	0.560	0.469	0.109	0.217	0.534	0.422	0.24	0.23	0.28	0.61	0.15	0.65
	MEAN	93	13	7.4	0.17	1.19	0.49	1129	163	15.78	0.49	2.25	0.48
	CV	0.606	0.496	0.109	0.220	0.574	0.442	0.24	0.23	0.29	0.67	0.15	0.73
	N	7	7	5	7	7	7	4	4	4	4	4	4
HUNTING BAYOU AT IH-10 (IH-610 FOR USGS)	MEDIAN	621	55	7.4	0.74	2.92	1.35	179	33	15.6	1.17	2.77	0.84
	LG STD	0.346	0.515	0.474	0.950	0.443	0.442	0.48	0.27	0.49	0.34	0.30	0.30
	MEAN	660	63	8.3	1.16	3.22	1.49	201	34	17.6	1.24	2.9	0.88
	CV	0.357	0.551	0.502	1.211	0.466	0.465	0.51	0.28	0.52	0.35	0.31	0.31
	N	6	6	6	6	6	6	5	5	5	5	5	5
LITTLE WHITE OAK AT TRIMBLE	MEDIAN	216	26	9.0	0.38	2.19	0.80	354	41	18.0	0.45	2.72	0.40
	LG STD	0.516	0.669	0.473	0.393	0.353	0.706	0.49	0.83	0.50	0.24	0.28	0.37
	MEAN	247	32	10.0	0.41	2.33	1.02	399	58	20.4	0.46	2.83	0.43
	CV	0.552	0.751	0.501	0.409	0.364	0.803	0.52	1	0.53	0.24	0.29	0.38
	N	8	8	7	7	7	7	5	5	5	5	5	5
SIMS BAYOU AT TELEPHONE ROAD	MEDIAN	206	25	5.8	0.37	1.85	1.41	112	37	11.2	1.53	3.09	-
	LG STD	0.554	0.748	0.370	1.063	0.325	0.936	0.61	0.59	0.34	0.62	0.36	-
	MEAN	240	33	6.2	0.65	1.95	2.18	135	44	11.9	1.85	3.29	0.88
	CV	0.599	0.866	0.383	1.447	0.333	1.183	0.67	0.65	0.35	0.68	0.37	-
	N	8	7	7	7	7	7	2	2	2	2	2	1
WHITE OAK AT HEIGHTS	MEDIAN	290	36	13.0	0.31	4.14	1.17	282	45	20.8	0.85	3.19	0.68
	LG STD	0.753	0.929	0.827	0.549	0.849	0.427	0.92	0.87	0.55	0.41	0.37	0.07
	MEAN	385	55	18.4	0.36	5.94	1.29	430	65	24.1	0.92	3.41	0.68
	CV	0.873	1.170	0.990	0.593	1.028	0.447	1.15	1.06	0.59	0.43	0.38	0.07
	N	5	5	4	5	5	5	6	6	6	6	6	6

MEDIAN: ANTILOG OF LOGNORMAL MEAN
LG STD: LOGNORMAL STANDARD DEVIATION
MEAN: MEAN OF LOGNORMAL DISTRIBUTION IN ARITHMETIC SPACE
CV: COEFFICIENT OF VARIATION
N: NUMBER OF SAMPLES

FIGURE 5.2.2-2 **TRIBUTARY SAMPLING METHOD EVENT MEAN CONCENTRATIONS (from WAI 1988)**

TABLE 5.2.2-1

SEDIMENT/ORGANIC SOURCES

Comparison of Calculated Loads	Greens Bayou and Above	
Description	TSS lb/yr*10**6	VSS lb/yr*10**6
Tributary Sampling Method		
Monitored area wet weather tributary flows	587.3	79.9
Unmonitored area urban runoff and overflows	103.0	36.5
Unmonitored area bypass	0.4	0.3
Unmonitored area wet weather WWTP	1.2	1.1
Wet Weather Total	691.9	117.8
Dry and transition WWTP	3.2	2.9
Industrial	5.6	1.4
TOTAL	700.7	122.1
Individual Components Method		
Monitored area urban runoff	240.0	72.0
Unmonitored urban runoff	42.2	12.7
Overflows	20.7	8.6
Bypasses	0.7	0.6
Wet Weather WWTP	2.3	2.1
Wet Weather Total	305.9	96.0
Dry and transition WWTP	3.2	2.9
Industrial	5.6	1.4
TOTAL	314.7	100.3

average volumes and TSS/VSS concentrations developed in a separate study. Table 5.2.2-2 shows these calculations with the TSS values based on the (higher) tributary sampling method results. Note that the TSS loads from the large area above Lake Houston are greatly reduced by trapping in the Lake.

Solids Accumulation

The distribution of sediment accumulation on the HSC was examined using Corps of Engineers dredging records. The specific objective was to determine average sediment accumulation rates over the last 10 to 15 years by channel location. Hydrographic surveys conducted by the Corps before and after dredging (BD and AD) were employed. The basic procedure was to obtain for a particular station, the AD survey along with the BD survey for the next dredging, (generally three to five years later) and difference the bottom elevations at five points (both toes, mid-channel, and 100 ft in from toes) between the two surveys. The average of these differences, converted to an accumulation rate in ft/year, is presented along with location in Table 5.2.2-3 and illustrated in Figure 5.2.2-3.

It can be seen that along with considerable scatter, there is a general trend for accumlation rates to be higher in the upper and lower channel and lower in the mid-range. Part of the scatter is due to variations in channel cross-sectional area (for example, stations in turning areas had much higher rates than those in confined reaches), and part is due to temporal variations in sediment deposition. Allowing for this scatter in the results, it still appears that upper channel rates are in the range of 1-2 ft/yr. Station 1087+57, at the lower end of the Sims Bayou turning area is probably representative of the main turning basin. Below Greens Bayou (km 25) the rate drops to about 0.5 ft/yr and below km 10, it appears to increase to over 1 ft/yr. Rates in Galveston Bay below Morgan's Point (not shown in the data) were in the range of 2 ft/yr. The

TABLE 5.2.2-2

TSS AND VSS LOADS, GREENS BAYOU TO MORGAN'S POINT

	Drainage Areas (sq.mi.)(1)	TSS Loads (2) (lb/yr * 10**6)	VSS Loads (3) (lb/yr * 10**6)
Goose Creek	24.9	17.7	3.1
Carpenters Bayou	74.4	53.0	9.2
San Jacinto River below Lake Houston	69.4	49.4	8.6
Lake Houston Spills TSS Export (4)	2828.0	80.0	14.0
TOTALS	2996.7	200.1	34.9
TOTAL LOADS (mt/yr)		90,977	15,866

(1) USACE, 1987, Final Feasibilty Report and EIS, Galveston Bay Area Navigation Study. Volume 6., Appendix F. Plan Effects.
(2) Loadings estimated based on drainage areas and loads for Greens Bayou and above except Lake Houston.
(3) Organic percent based on VSS/TSS ratios determined in WAI (1986).
(4) Baca, E., P.B. Bedient and R. Olsen. 1982. Urban Impacts of Water Supply Reservoir. ASCE., J. Env. Engr. Div. 108(EE1):73-87.

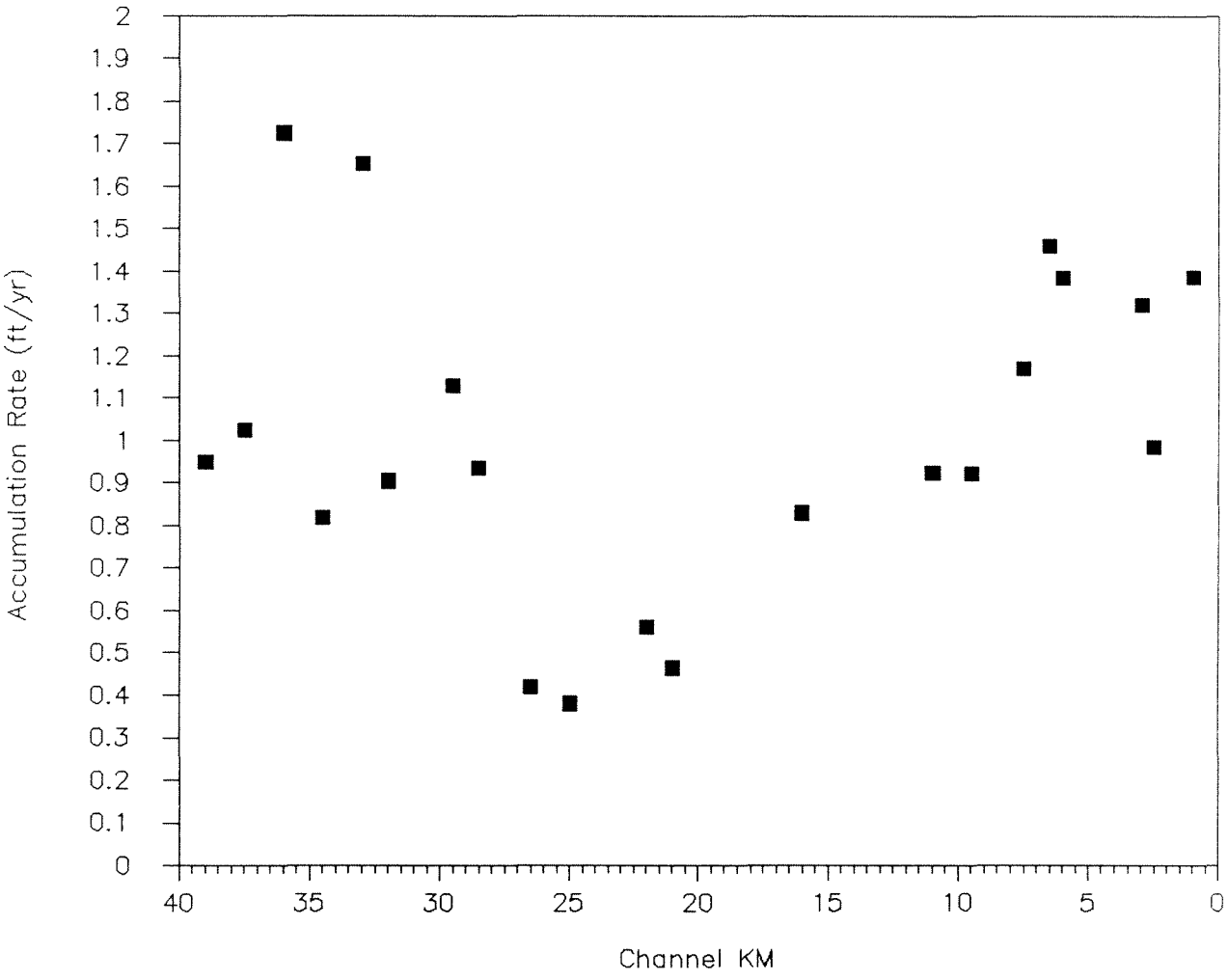
TABLE 5.2.2-3

SEDIMENT ACCUMULATION RATES ON THE HSC

USCE STATION	CHANNEL KM	PERIOD	RATES (ft/yr)	AVERAGE (ft/yr)
0+00	1.0	72-75	2.27	1.39
		75-80	0.50	
53+00	2.5	72-75	0.95	0.99
		75-80	1.02	
105+00	3.2	72-75	1.75	1.32
		75-80	0.89	
165+00	5.8	72-75	2.27	1.39
		75-80	0.50	
210+00	6.4	72-75	2.50	1.46
		75-80	0.42	
250+00	7.5	72-75	1.82	1.17
		75-80	0.52	
310+00	9.4	72-75	1.36	0.92
		75-80	0.48	
355+00	10.9	72-75	1.57	0.93
		75-80	0.28	
525+00	16.0	77-80	0.83	0.83
685+35	20.9	68-74	0.46	0.47
		74-82	0.47	
730+00	22.2	68-74	0.90	0.56
		74-82	0.22	
825+00	25.1	68-75	0.51	0.38
		75-79	0.25	
875+00	26.7	68-75	0.53	0.42
		75-80	0.31	
928+74	28.3	68-75	0.67	0.94
		75-80	1.20	
975+00	29.7	68-75	1.06	1.13
		75-80	1.20	
1035+00	31.8	68-75	0.83	0.91
		75-80	0.98	
1087+57	33.2	68-75	1.26	1.66
		75-80	2.05	
1136+00	34.5	71-75	1.04	0.82
		75-79	0.60	
1180+00	35.9	71-75	1.83	1.73
		75-79	1.62	
1223+00	37.3	71-75	1.31	1.03
		75-79	0.74	
1281+40	39.0	71-75	1.39	0.95
		75-79	0.51	

Figure 5.2.2-3

Sediment Accumulation Rates



increase in deposition rate below Morgan's Point can be attributed to lower velocities in the Bay plus the addition of Bay sediments which are resuspended during strong wind wave periods. The increase above Morgan's Point is probably related to these Bay sediments transported up the channel by flooding tides (and the density current). The accumulation rates in the upper channel are almost certainly related to runoff.

Sediment and Organics Removal

Removal of material from the channel is estimated from Corps of Engineer's maintenance dredging records and analysis of sediment solids and volatile solids contents performed in this study. In addition, the amount of organics removed by decay is estimated. Table 5.2.2-4 presents the results. Note that a large volume of material is dredged from Galveston Bay below Morgan's Point. While most of this material comes from upland sources, part of it is from resuspended Bay sediments which settle in the Channel and shoreline erosion in the upper Bay area.

Sediment and Organics Balance

The next step is to integrate the calculated loads and removals to check the calculations and to identify important processes. Table 5.2.2-5 presents the calculations for the upper channel, lower channel (Greens to Morgan's Point) and upper Galveston Bay.

Comparing the TSS loads to the upper channel, 165% more TSS enters this area than is removed by dredging. However, for the reach between Greens and Morgan's Point, upland sources account for only 38% of the TSS removed on average. Clearly, a substantial portion of the solids which enter the upper channel does not settle until transported to the lower channel.

TABLE 5.2.2-4

SEDIMENT AND ORGANIC SINKS

Component	Channel Reach: Turning Basin-Greens Bayou	Channel Reach: Greens Bayou-Morgan's Point	Channel Reach: Morgan's Point-Redfish Reef	Total
DREDGING (1)				
Annual Volume (1000 cy)	562.0	800.0	2560.0	3,922
Average % Solids (%)	40.0	30.0	30.0	
Solids removed (mt/yr)	192,483	238,524	763,277	1,194,284
VSS (% dry wt)	10.5	7.0	5.0	
Density (kg/l)	1.12	1.30	1.30	
Organic conc. (gm/l)	47.0	27.3	19.5	
Organics removed (mt/yr)	20,211	16,697	38,164	75,071
IN-SITU DECAY (2)				
Average SOD (gm/sq m/dy)	4	2	1	
Bottom area (hectares)	150	275	143	
Organics removed (mt/yr)	2,190	2,008	522	4,719
TOTAL (mt/yr)	22,555	18,981	38,830	80,366

(1) Corps of Engineers (1986).
(2) Based on the stabilization of organic carbon from SOD rates & channel bottom area
Based on ratio of 1 gm organic matter stabilized per gm oxygen consumed.

TABLE 5.2.2-5

SEDIMENT AND ORGANIC BALANCES

	Channel Reach			
	Turning Basin-Greens Bayou	Greens Bayou-Morgan's Point	Morgan's Point-Redfish Reef	Total
SEDIMENT				
TSS Sources (mt/yr) (1)	318,500	90,977		409,477
TSS Sinks (mt/yr) (2)	192,483	238,524	763,277	1,194,284
Balance	126,017	(147,547)	(763,277)	(784,807)
Source % of Sink	165%	38%		34%
ORGANICS				
VSS Sources (mt/yr) (1)	55,500	15,866		71,366
VSS Sinks (mt/yr) (2)	22,555	18,981	38,830	80,366
Balance	32,945	(3,115)	(38,830)	(9,000)
Source % of Sink	246%	84%		89%

(1) Sources as calculated in Tables 5.2.2-1 and 5.2.2-2
(2) Sinks include dredged material and for organics in-situ decay from Table 5.2.2-4

The amount of additional upland sources below Morgan's Point is fairly small (e.g. Cedar Bayou, Clear Creek, etc.) and no attempt is made to quantify these runoff and point sources. Clearly, the amount of solids removed by dredging in this reach cannot be accounted for by additional upland sources. Some of this dredged material comes from sediments eroded from the shoreline and resuspended from the Bay bottom, and some enters from above Morgan's Point. Considering solids removed in upper Galveston Bay, upland and point source TSS loads can only account for 34% of the solids removed by dredging. If the analysis is restricted to the area above Morgan's Point, the sources and sinks are in rough balance. However, it must be recognized that much of the dredging sink in the lower channel is concentrated in the area immediately above Morgan's Point and is thus strongly influenced by Galveston Bay sediment sources. Based on this, it appears that the TSS source load to the channel is an underestimate.

The organics (VSS) balance is also interesting. It appears that a markedly higher percentage of upper channel organic loads are transported to the lower channel than is the case with TSS. Calculated VSS sources above Greens Bayou exceed the dredged sinks by 246% compared with 165% for TSS. This difference is due to the higher VSS percentage in runoff (17%) than found in the sediments (10.5%). The probable explanations include more rapid settling of inorganic than organic solids and organic decay. The less settleable organic solids are more likely to be transported to the lower channel, and to some extent are also decayed in the water column. While the calculated sources and sinks in the lower channel appear to be in rough balance, there is a large amount of organic solids removed below Morgan's Point, even considering the fact that these sediments are substantially less organic than those in the upper channel. Overall, the calculated loads do not account for the organics removed by dredging. The difference is more marked considering that a portion of the upper Bay sediment VSS comes from organics generated in the water column in the same

way that lake sediments receive a substantial portion of their organics from settled phytoplankton and other aquatic life forms.

Efforts at refining this sediment balance would require a much greater data base and more extensive field work. However, the sediment sources considered probably contain the main upland sources of inorganic and organic material. From this analysis, it is clear that upland (non-point and point) sources do not account for all the TSS and VSS which accumulates in the navigation channels. For inorganic solids, the difference is probably accounted for by a combination of shoreline erosion and resuspended bay sediments. For organic solids, the difference is probably due to biological activity in the Bay and lower channel and limitations on nonpoint source sampling where some materials (e.g. paper, large leaves, branches, etc.) are not quantified.

Calculation of Sediment Loads for Future Scenarios

To facilitate working with the nonpoint source data generated by WAI (1986), a spreadsheet was developed which incorporates each of the sources considered. This is shown in Table 5.2.2-6. The annual load column is taken directly from the WAI report for TSS and the VSS, using the individual component method. The next three columns (number, flow and concentration) provide the basis of the WAI calculations. For domestic WWTPs, the sources include tables III-9, III-16 and III-8. Bypasses are from tables III-10, Overflows are from II-8, industrial is from tables III-7 and III-8, and runoff is from table III-11 of the WAI report.

VSS values were not always reported. It was assumed that WWTP (domestic and industrial) effluents would have 75% of their TSS as VSS. The data reported by WAI on overflows (their Table II-8) indicate that average TSS measurements are 281 mg/l while VSS averages 69 mg/l, for a percentage of 24.6%. This percentage is lower than for runoff, and

APPENDIX F - BACKGROUND FOR STATISTICAL ANALYSES

Appendix F1 - Principal Component and Cluster Analysis Background

Principle Components Analysis is an exploratory data analysis method which reduces the dimensionality of a dataset by considering the characteristic vectors of a covariance matrix as orthogonal (perpendicular) linear combinations which explain the maximum amount of variance in the first few components. This means that instead of analyzing all of the original variables, the components can be used instead. This method allows a simpler analysis utilizing the first few components which capture most (approximately 90%) of the original variance of the dataset. Historically, this method has been used in anthropology, psychology, and college entry exam interpretation, among other fields of study. Presently, this method has been found useful to quantify the spatial variability in the distribution of a contaminant in the environment. Many researchers have found this method useful for explaining the concentration patterns of PCDD/Fs in the environment, including studies in British Columbia, Italy, and the Great Lakes.

"Cluster Analysis is a term used to describe a family of statistical procedures specifically designed to discover classifications within complex data sets." (Tinsley, Brown 2000) What this means is that cluster analysis is used to place variables or sample points into clusters that share the same relative characteristics as that sample point. This is done using multivariate observations and many different algorithms in statistical programs. There are many different clustering methods, and the methods chosen for this study will be further explained below.

The first step in completing a PCA is creating a covariance matrix. SPLUS statistical package was used for this and all other aspects of PCA testing. Covariance is the default SPLUS choice, and it was chosen instead of a correlation matrix because the data were of all the same

type and had previously been normalized. The scores of the loadings generated from the transposition of the data and creating of components was utilized as a way to generate scatter plots. Principle Components one and two were graphed together and patterns, or clusters, were looked for. As a way to further validate or explain clustering in the PCA, cluster analysis was employed to explore the relationships within clusters.

Several different types of cluster analysis were examined for this project. It is important to note that cluster analysis utilizes a dissimilarity matrix, while the PCA algorithm generates a similarity matrix. Four major types of cluster analysis were explored: k-means, partitioning around mediods (pam), fuzzy, and agglomerative hierarchical. With k-means, pam, and fuzzy analysis, the analysis was carried out in SPLUS.

For these three clustering techniques, the number of clusters must be chosen. This was accomplished by looking at a silhouette plot of the data. In order to create a silhouette plot, a silhouette value (si) was computed and represented the bar length in the plot (Mathsoft, 77). If si=1, then the point was well classified, if it was zero, the point did not fit into the cluster (Mathsoft, 78). By changing the number of clusters specified in the analysis, one can look at the overall silhouette width of the plot. The larger the width number, the better. However, if the bars lie to the left of zero, there are points which do not fit into any of the clusters. Utilizing this method, it was possible to determine the correct number of clusters for the data set.

When considering the PCDD/F data from the Houston Ship Channel, all three methods were utilized and the results compared. It was found that the k-means method was not very effective and so discarded. Using pam and fuzzy analysis gave different cluster memberships,

and no apparent pattern was evident. A more robust method was needed in order to generate results.

Agglomerative Hierarchical Clustering (AHC) was chosen as another alternative, since the number of clusters is not pre-chosen in order to run the analysis. SPSS was the statistical program used to complete this analysis. The method begins with all the data points in their own cluster, and then combines the points with the next point least dissimilar, or more similar, until there is one large group.

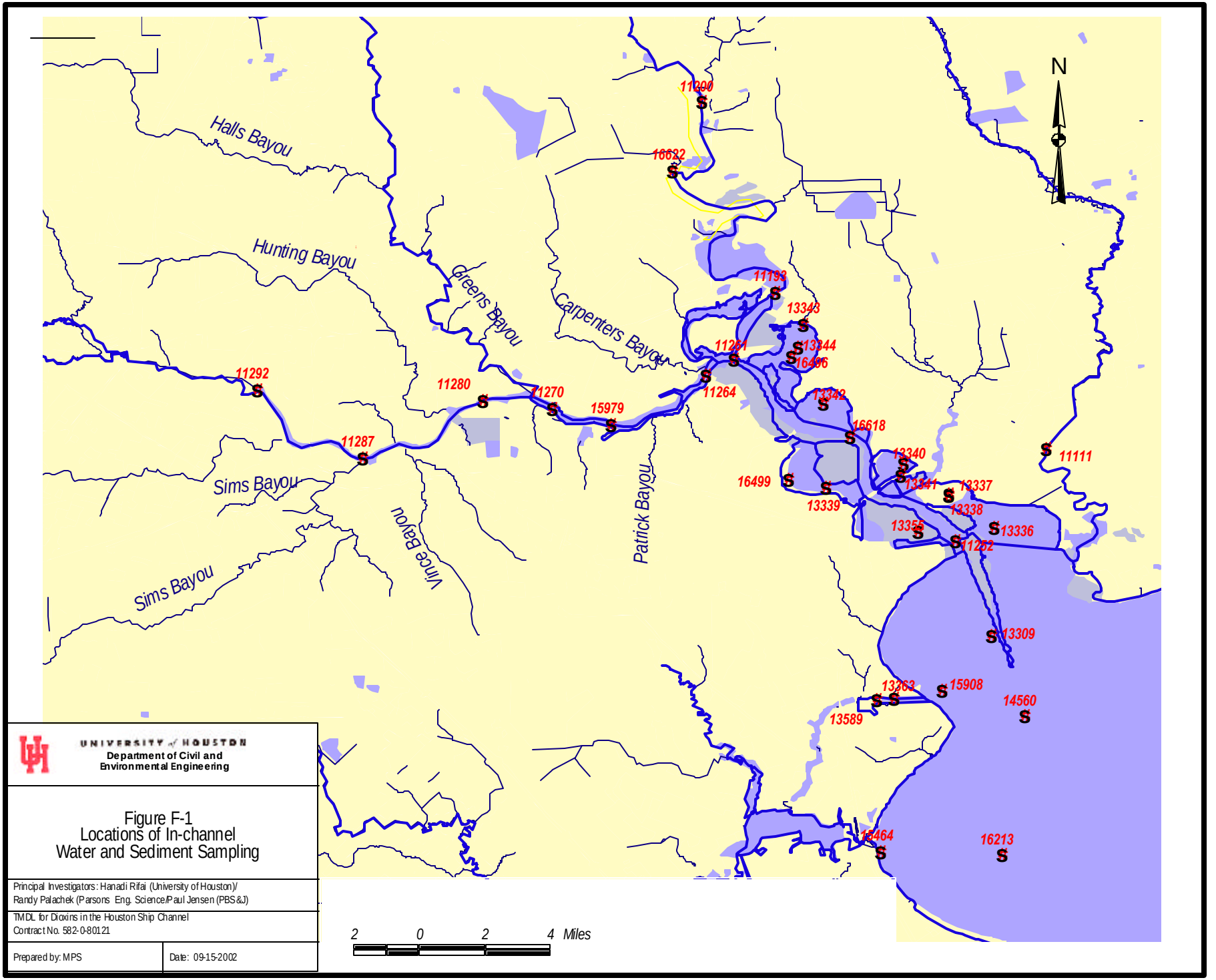
Ward's method was chosen as the measure of similarity between points in a cluster. This method was chosen as it gives the same amount of variance within clusters. It also assumes that the clusters are spherical in hyperspace. This may not be true, but it seems reasonable to look for clusters which have the same variance within them when looking at this data. It would be difficult to interpret the cluster results if the clusters had different amounts of variation within them.

There are several differences between k-means, pam, and fuzzy cluster analysis. First of all, k-means and pam are "crisp" clustering methods. This means that each point will be assigned to exactly one cluster, while fuzzy cluster analysis can give a data point partial assignment to more than one cluster. Secondly, there are differences in how the center of the cluster is determined. The k-means algorithm utilizes a centroid "the multidimensional version of the mean" and assigns each data point to the group with which it most closely resembles that number. The centroids change as more points are considered in the analysis and are determined using a least squared method. The partitioning around mediods (pam) partitions a set of objects into k clusters by finding k objects to represent the heart of each cluster (mediods). The mediods are

determined by minimizing the sum of dissimilarities instead of the sum of squared Euclidean distances (Mathsoft, 76).

Fuzzy cluster analysis is a little different than either k-means or pam cluster analysis. Because cluster assignments are not crisp, when looking at the output from a fuzzy cluster analysis, it is important to look at the Dunn's partition coefficient. If all the data points have multiple memberships, then the coefficient will be equal to 1/k, (k=number of data points) and if each point belongs to only one cluster the coefficient will be equal to one (Mathsoft, 88).

Appendix F2 - Locations Sampled in 2002


N
Halls Bayou
Hunting Bayou
Greens Bayou
Carpenters Bayou
Patrick Bayou
Vince Bayou
Sims Bayou
Sims Bayou
11290
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13343
11261
13344
16496
11264
13342
16618
13340
11111
16499
13341
13337
13339
13338
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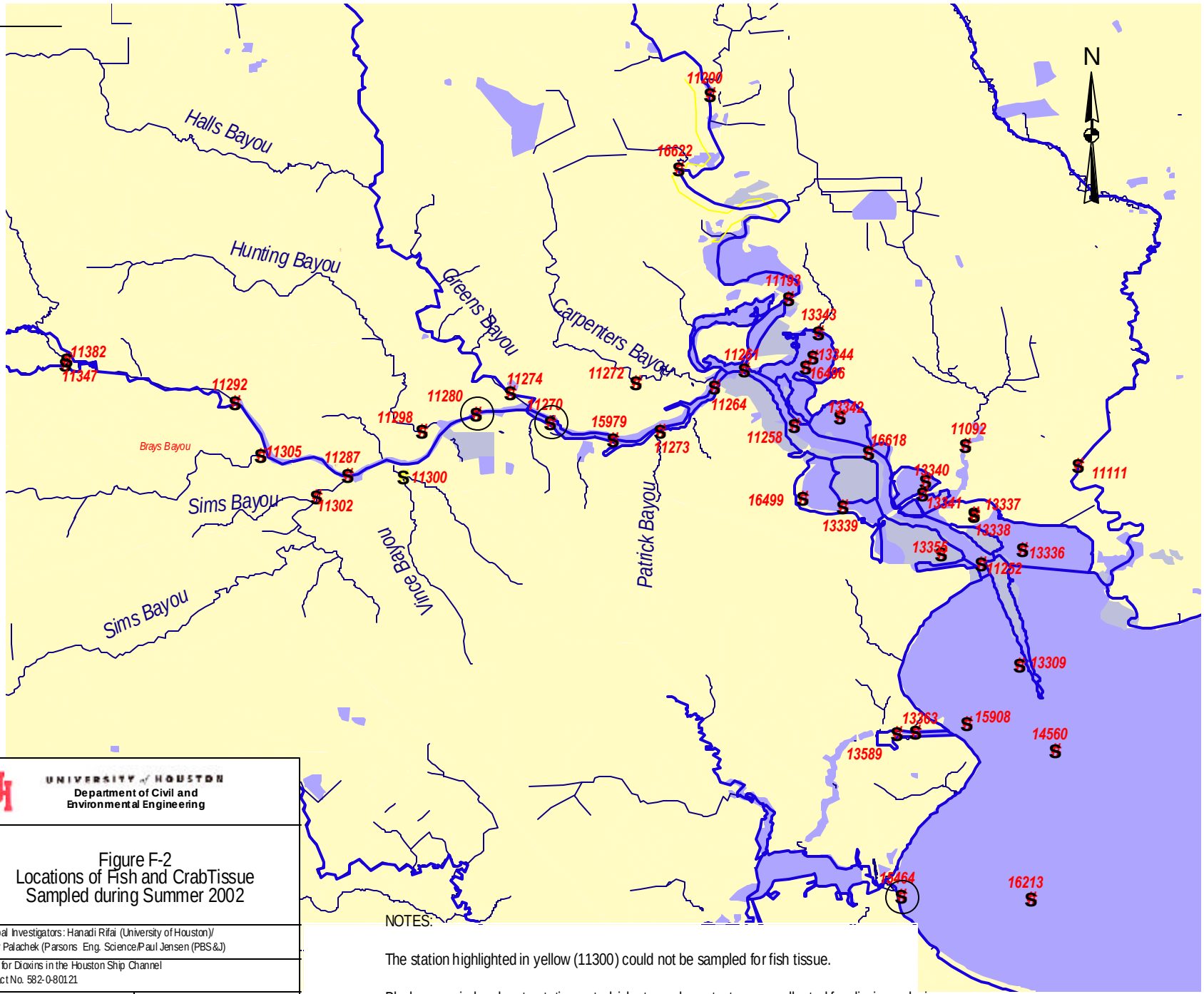
11252
13309
13363
15908
14560
13589
16464
16213
11292
11280
11270
15979
11287
2 0 2 4 Miles
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure F-1
Locations of In-channel
Water and Sediment Sampling
Principal Investigators: Hanadi Rifai (University of Houston)/
Randy Palachek (Parsons Eng. Science/Paul Jensen (PBS&J)
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121
Prepared by: MPS
Date: 09-15-2002



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Department of Civil and Environmental Engineering

Figure F-2
Locations of Fish and CrabTissue Sampled during Summer 2002

Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Eng. Science/Paul Jensen (PBS&J)

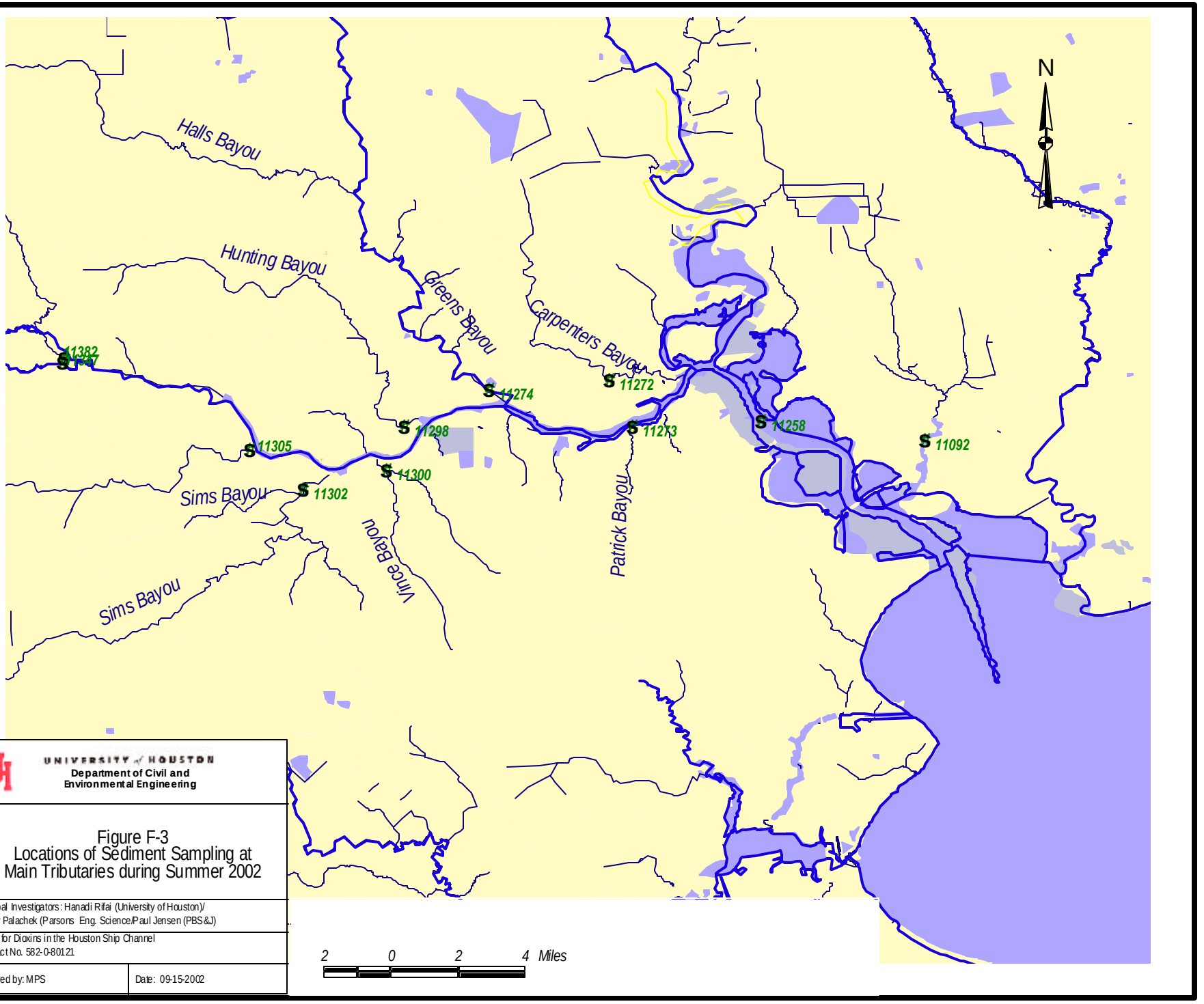
TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 09-15-2002

NOTES:

The station highlighted in yellow (11300) could not be sampled for fish tissue.

Black open circles denote stations at which stomach contents were collected for dioxin analysis.



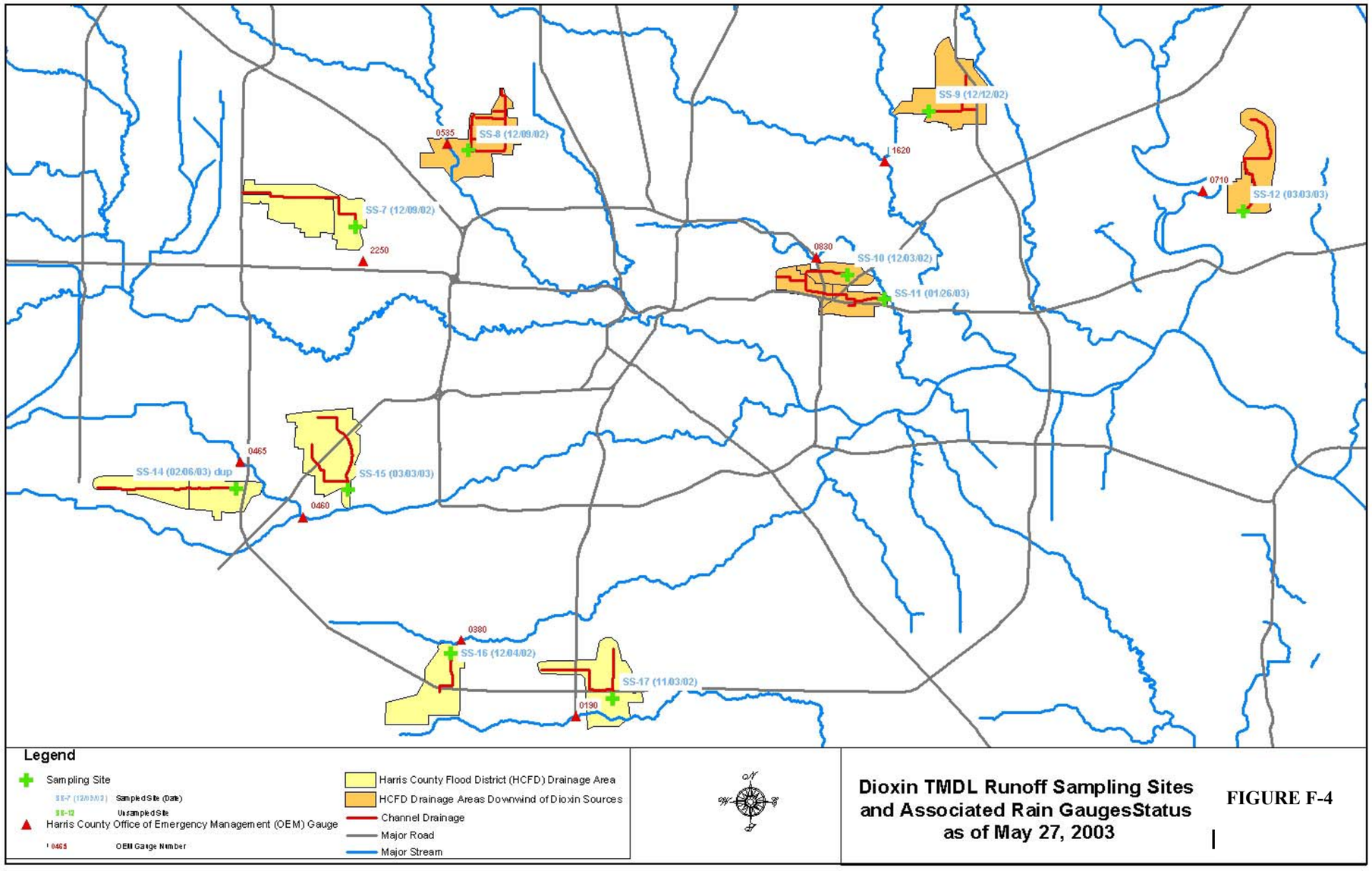
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering

Figure F-3
Locations of Sediment Sampling at Main Tributaries during Summer 2002

Principal Investigators: Hanadi Rifai (University of Houston)/ Randy Palachek (Parsons Eng. Science/Paul Jensen (PBS&J)

TMDL for Dioxins in the Houston Ship Channel
Contract No. 582-0-80121

Prepared by: MPS | Date: 09-15-2002



Dioxin TMDL Runoff Sampling Sites and Associated Rain GaugesStatus as of May 27, 2003

FIGURE F-4

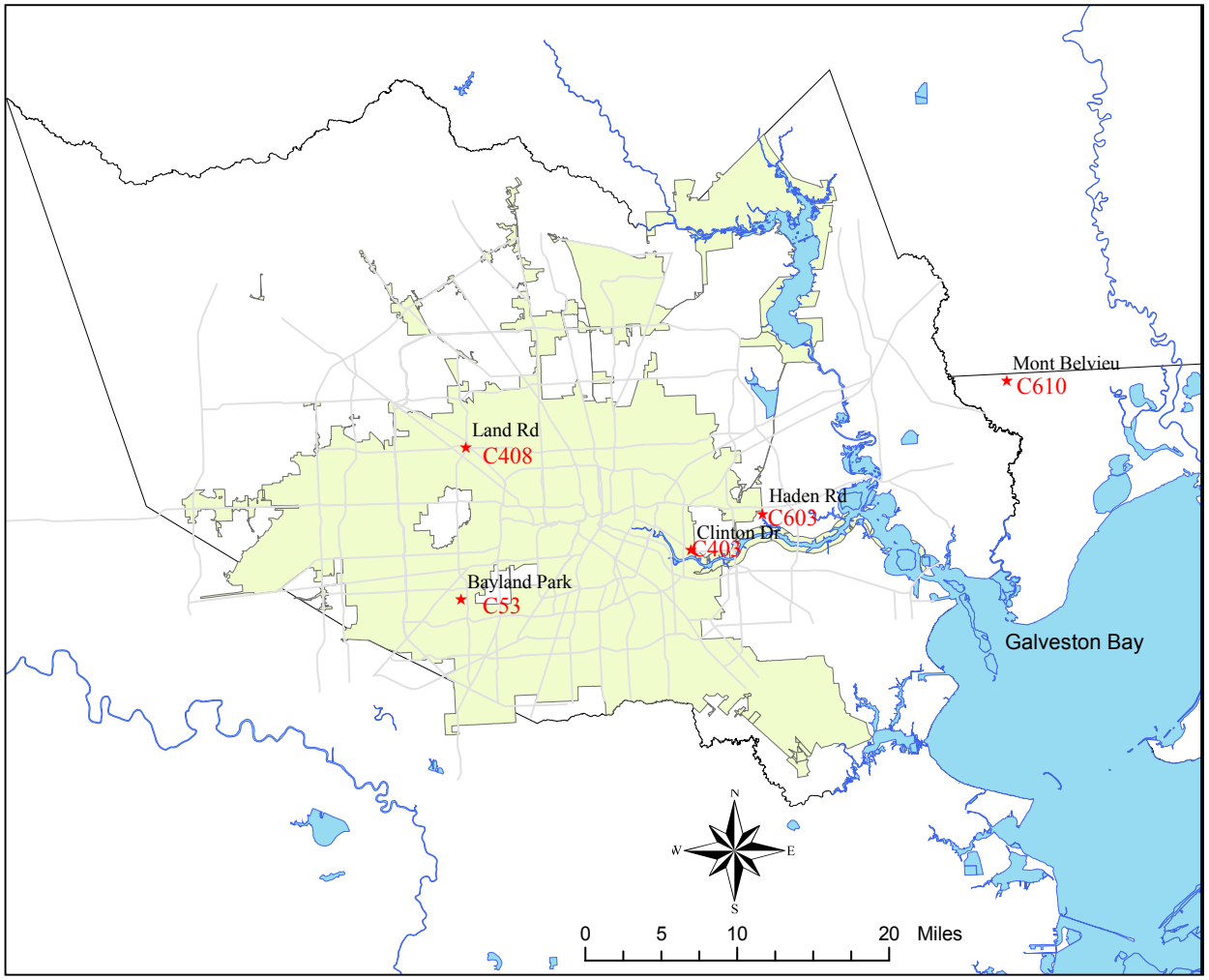


Figure F-5 Locations of Air Samples Included in Multivatiate Analysis

Appendix F3 - Mann-Kendall Test Background

Resource: Statistical Methods for Detection and Quantification of Environmental Contamination

Robert D. Gibbons and David E. Coleman. John Wiley and Sons, NY, 2001, pp194-199.

The steps followed to perform the Mann-Kendall test were: " First, order the data by sampling date….where x_i is the measured value on occasion i. Second, record the signs of each of the N' possible differences $x_{i'}$-x_i, where $i' > i$. …" (Gibbons and Coleman). This means that if the difference is positive, then record *a +1*, if it is negative, record *a -1*, and if there is no difference record a 0. The Mann-Kendall statistic is computed by subtracting the number of negative differences from the number of positive differences. Using the table values for the Mann-Kendall test, with a sample size of n=5, and S = 0-10, the probabilities are given in Table F1.

Table F1. Critical values for the Mann-Kendall Test for Trend

MK critical values		
S	**df=5**	**Trend**
0	0.592	No trend
1	0.500	Shows trend
2	0.408	
3	0.325	
4	0.242	
5	0.180	
6	0.117	
7	0.080	
8	0.042	Significant trend
9	0.035	
10	0.028	

This procedure was completed for all congeners at all sampling stations for all media. The result was considered significant if the value associated with a given *S* was less than the alpha value of 0.05. This would only occur for a value of *S* greater than 7.

APPENDIX G – HOUSTON SHIP CHANNEL MEGA-TX MODEL SEGMENTATION AND INPUT/OUTPUT FILES

Appendix G-1 Model Segmentation

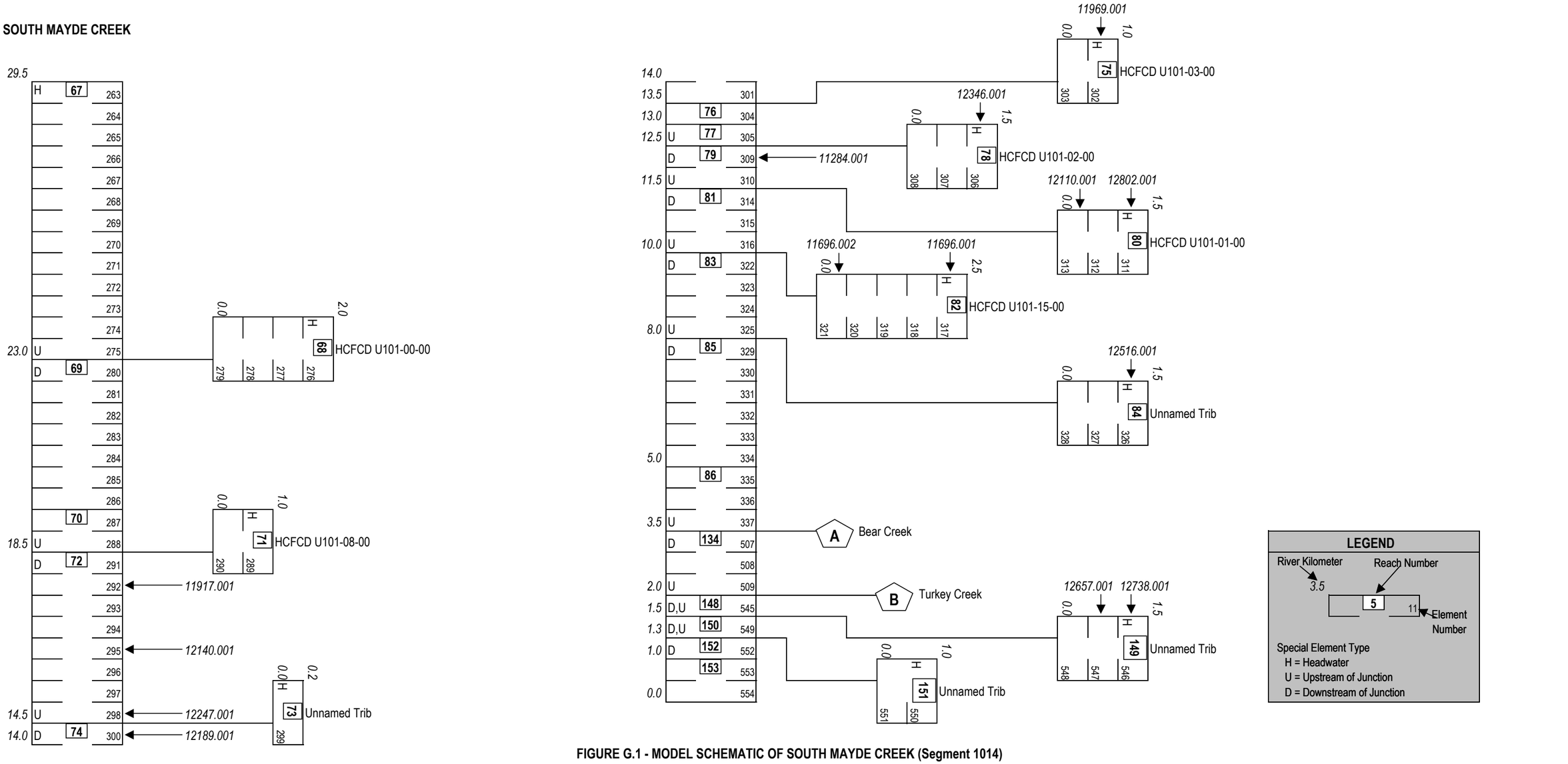
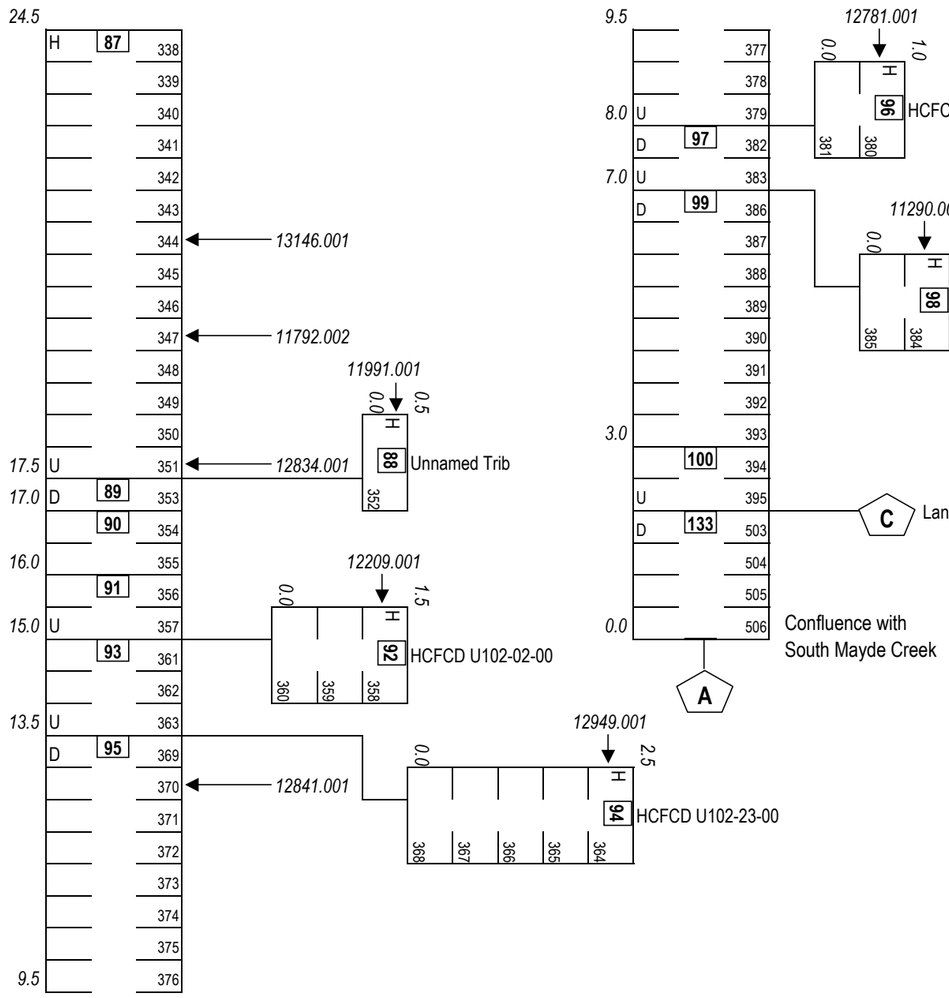


FIGURE G.1 - MODEL SCHEMATIC OF SOUTH MAYDE CREEK (Segment 1014)

BEAR CREEK



TURKEY CREEK

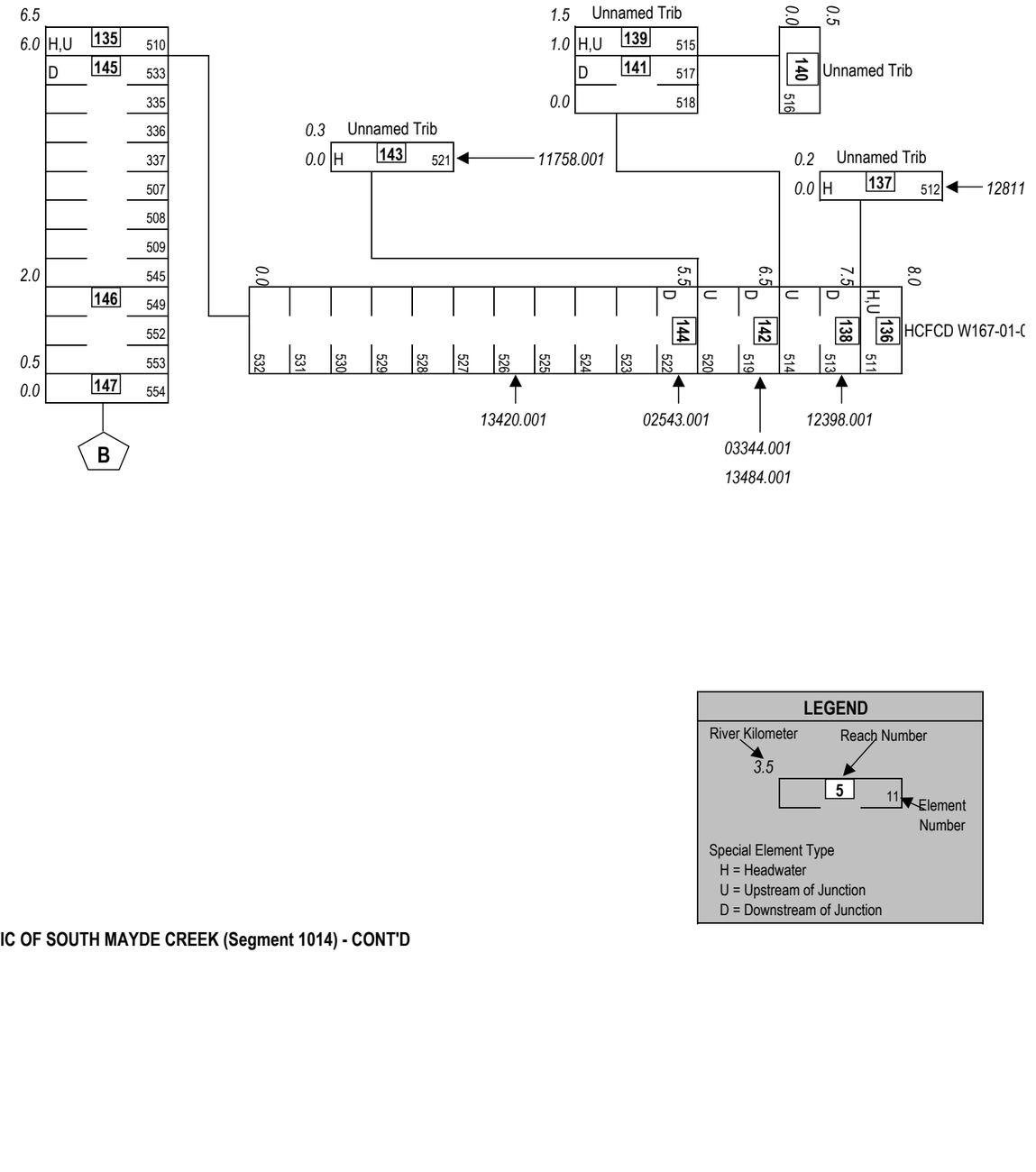
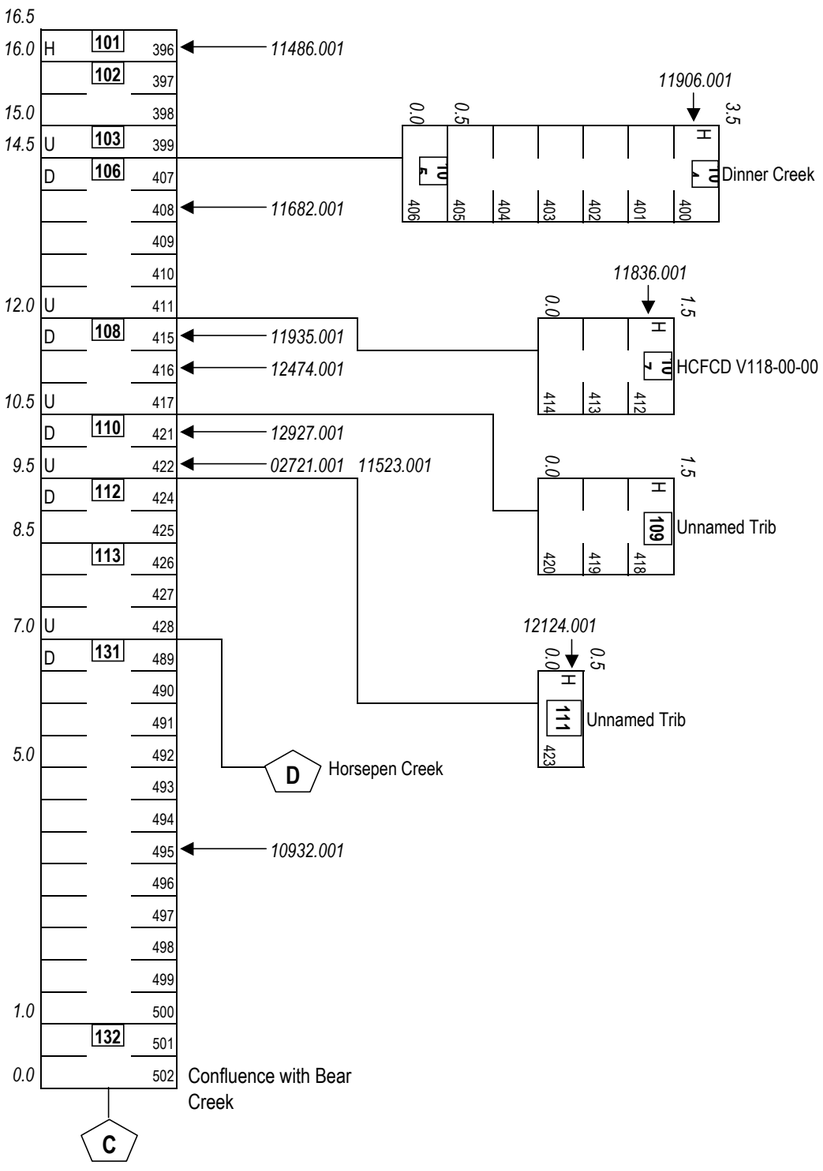
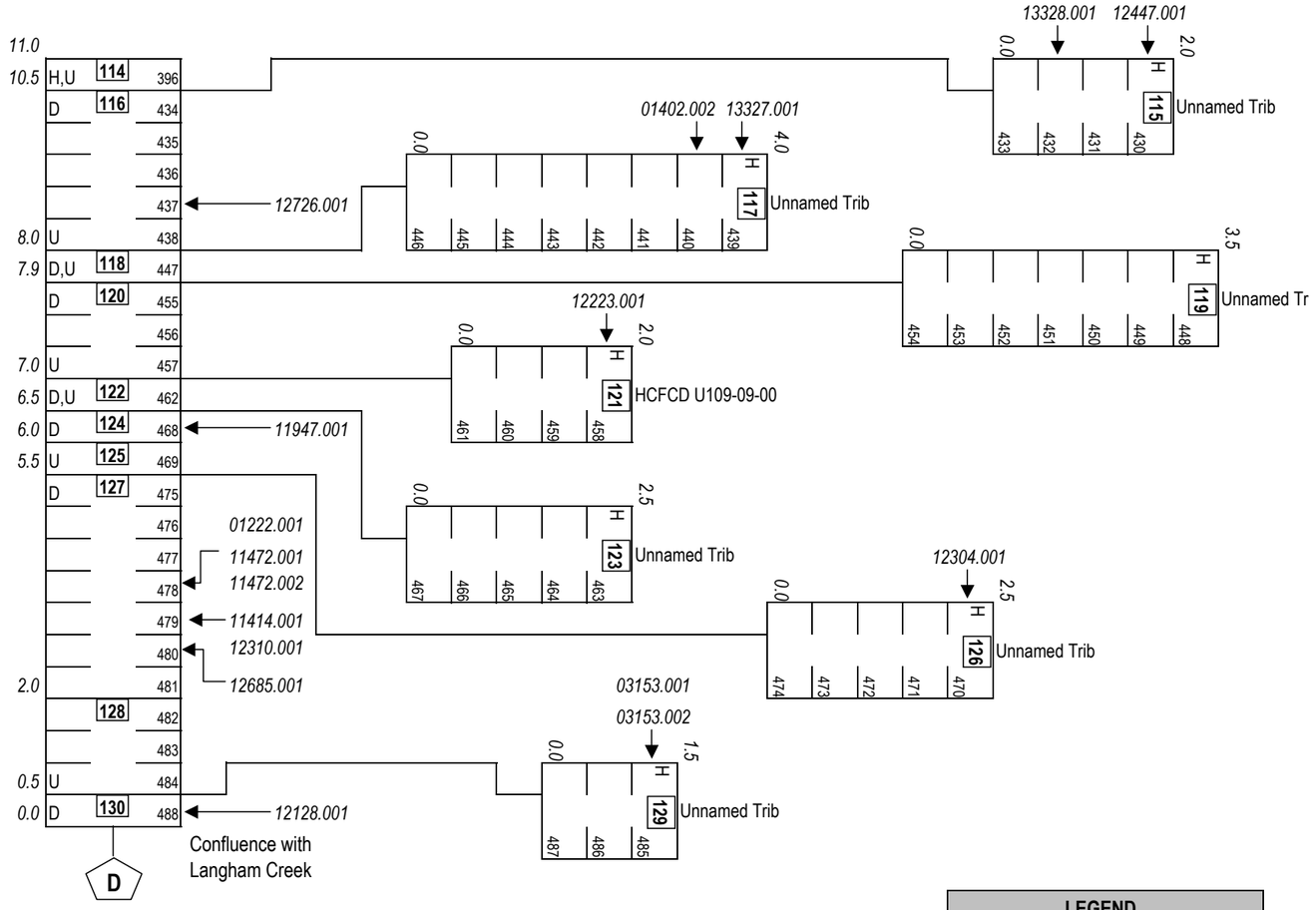


FIGURE G.1 - MODEL SCHEMATIC OF SOUTH MAYDE CREEK (Segment 1014) - CONT'D

LANGHAM CREEK



HORSEPEN CREEK



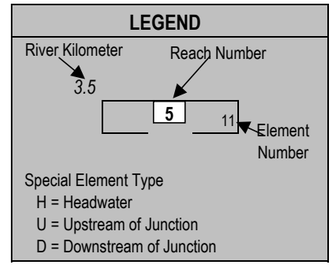


FIGURE G.1 - MODEL SCHEMATIC OF SOUTH MAYDE CREEK (Segment 1014) - CONT'D

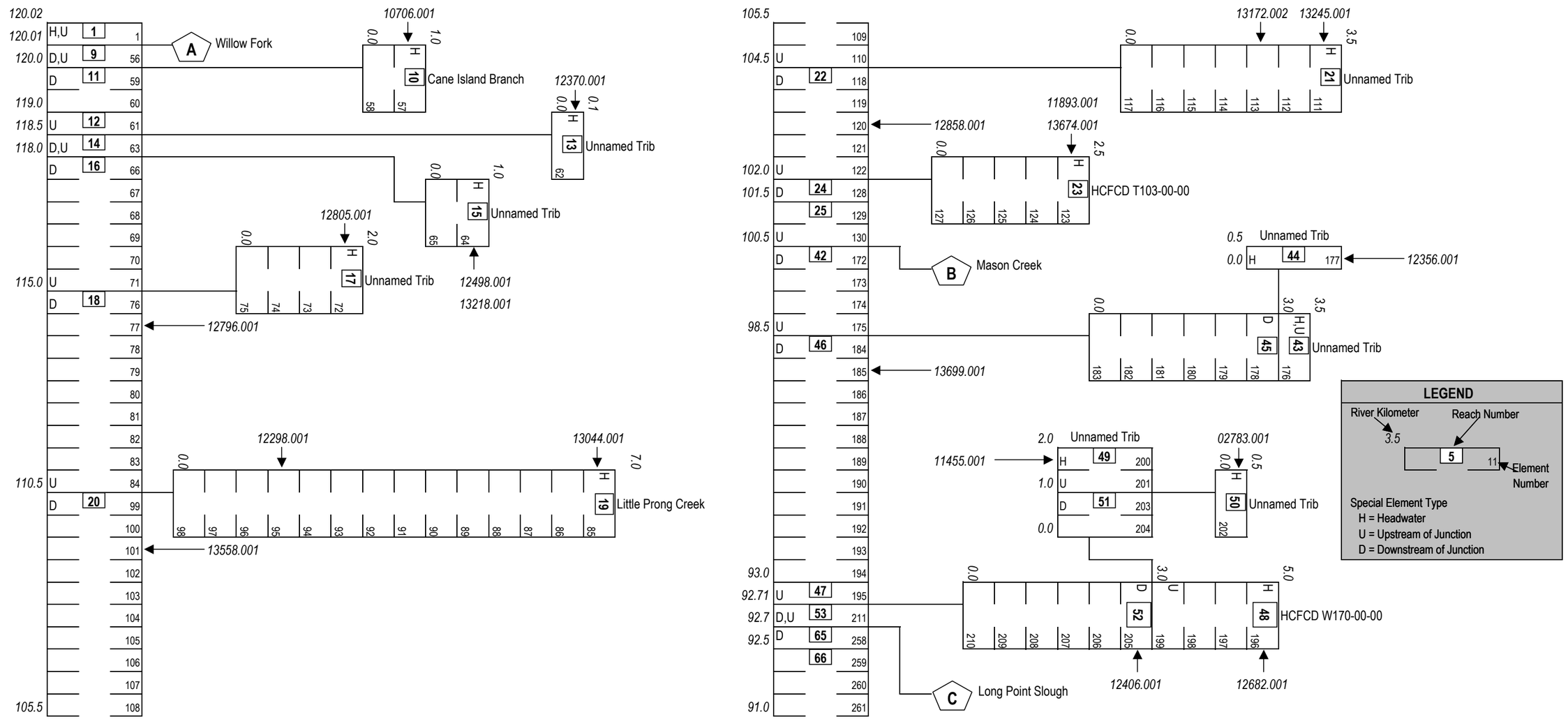


FIGURE G.2 - MODEL SCHEMATIC OF BUFFALO BAYOU (Segment 1014)

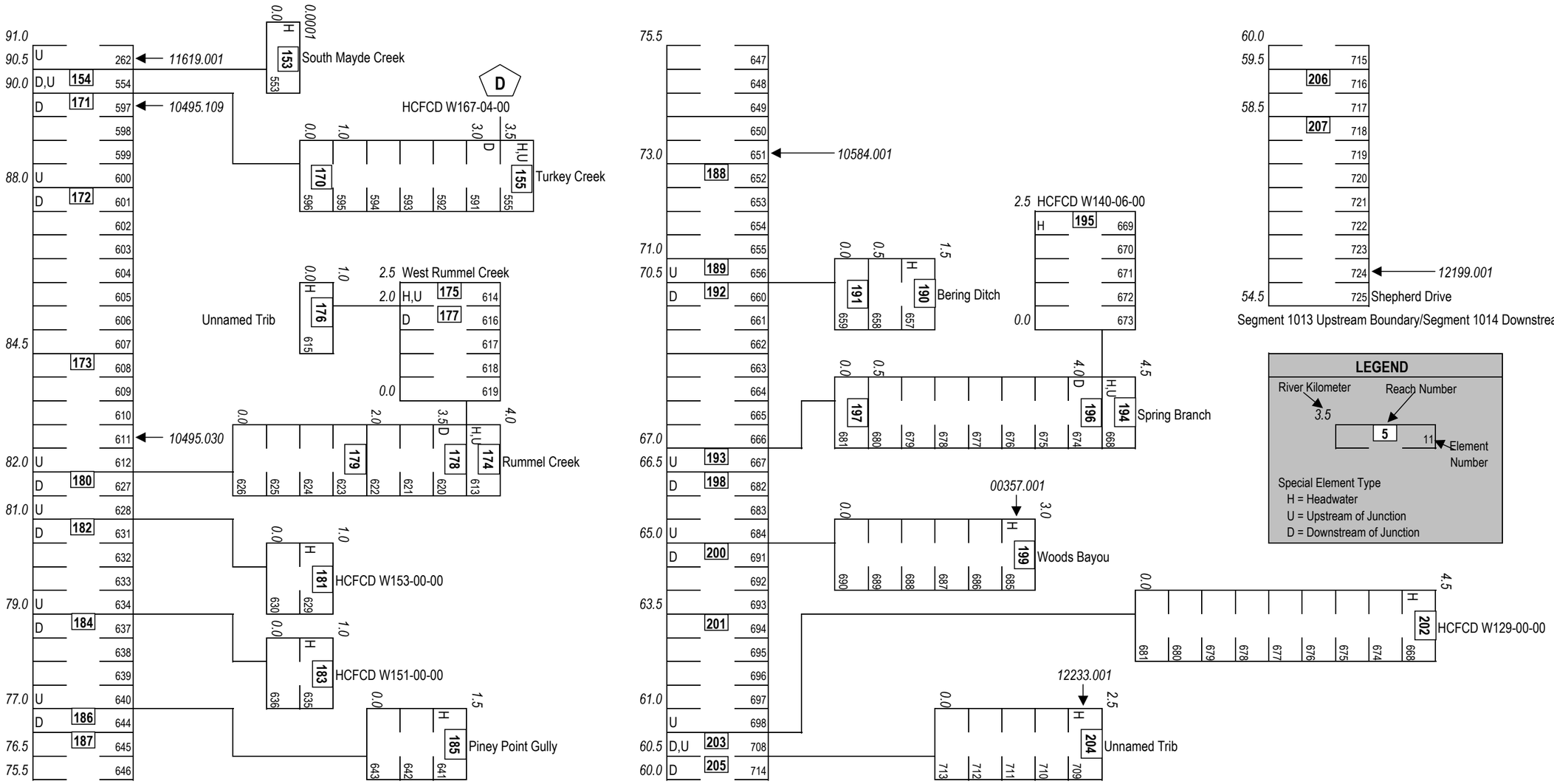
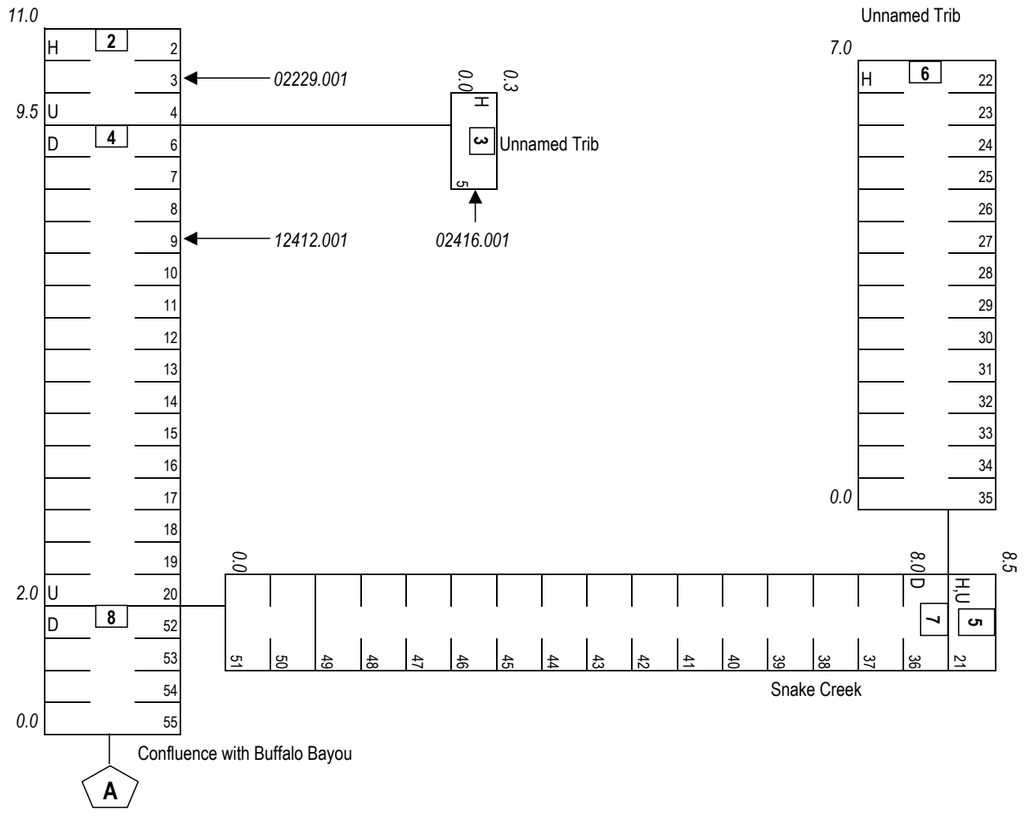


FIGURE G.2 - MODEL SCHEMATIC OF BUFFALO BAYOU (Segment 1014) - CONT'D



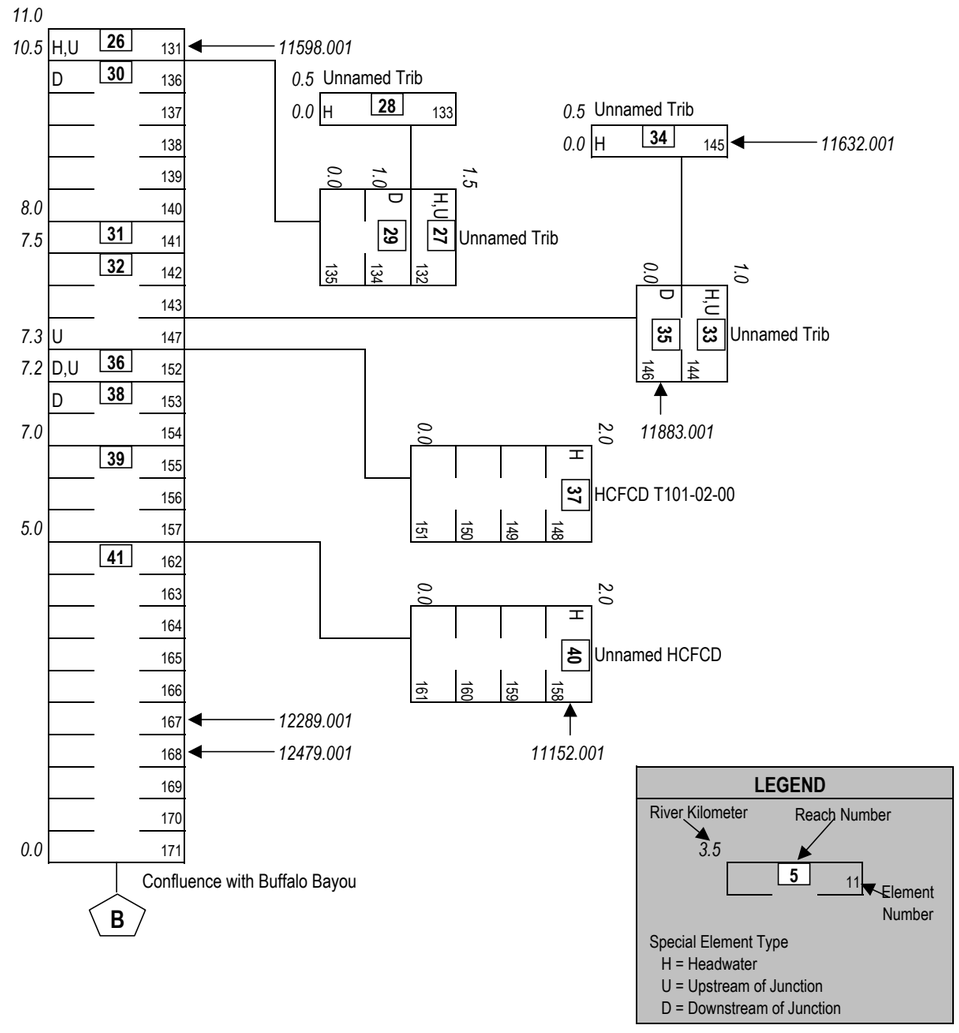
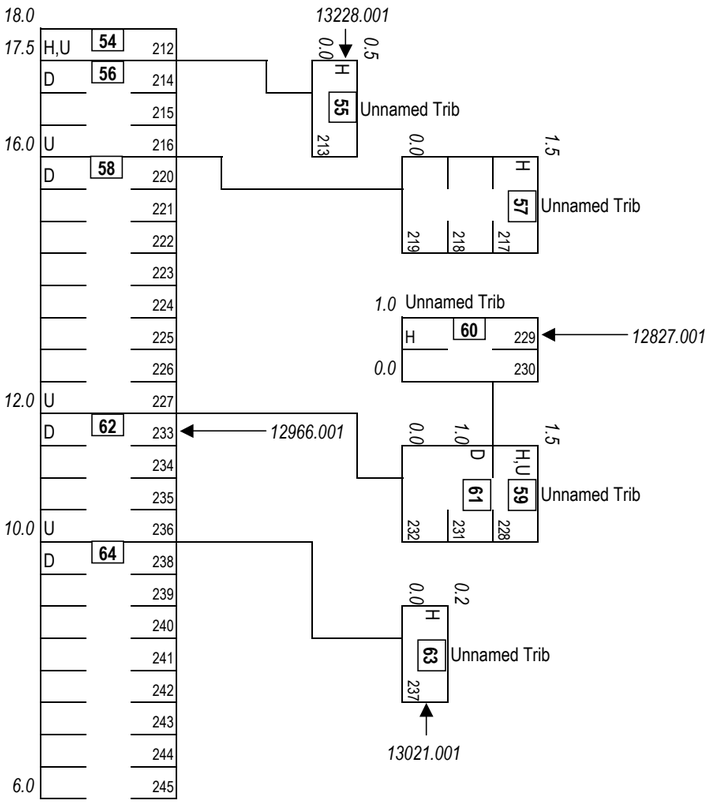
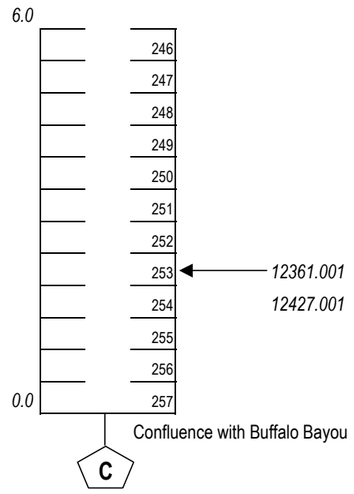


FIGURE G.2 - MODEL SCHEMATIC OF BUFFALO BAYOU (Segment 1014) - CONT'D

LONG POINT SLOUGH





HCFCD W167-04-00

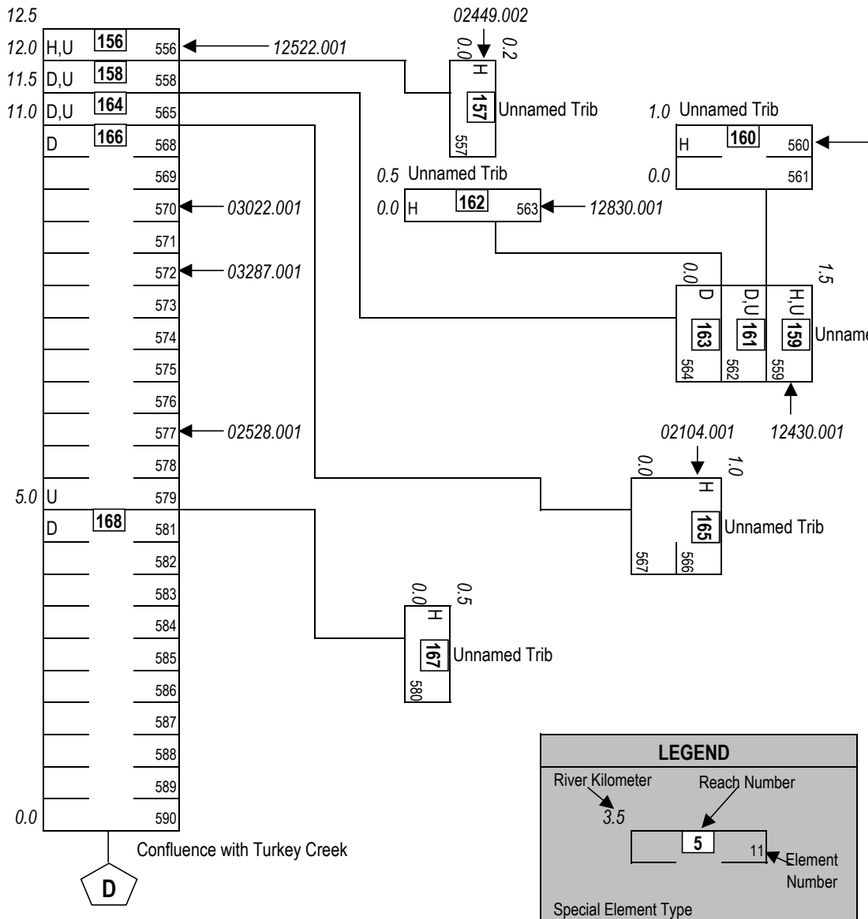


FIGURE G.2 - MODEL SCHEMATIC OF BUFFALO BAYOU (Segment 1014) - CONT'D

WHITE OAK BAYOU

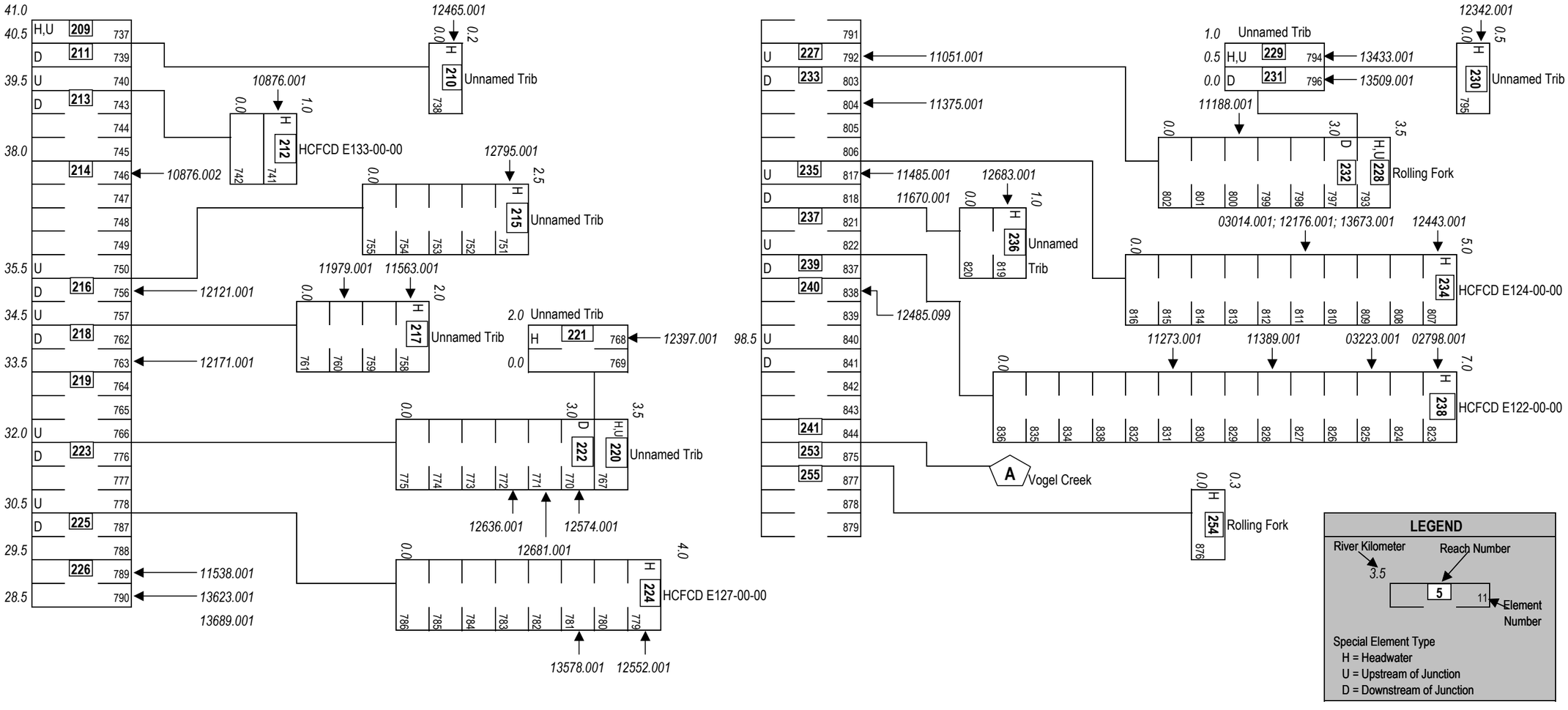


FIGURE G.3 - MODEL SCHEMATIC OF WHITE OAK BAYOU (Segment 1017)
VOGEL CREEK

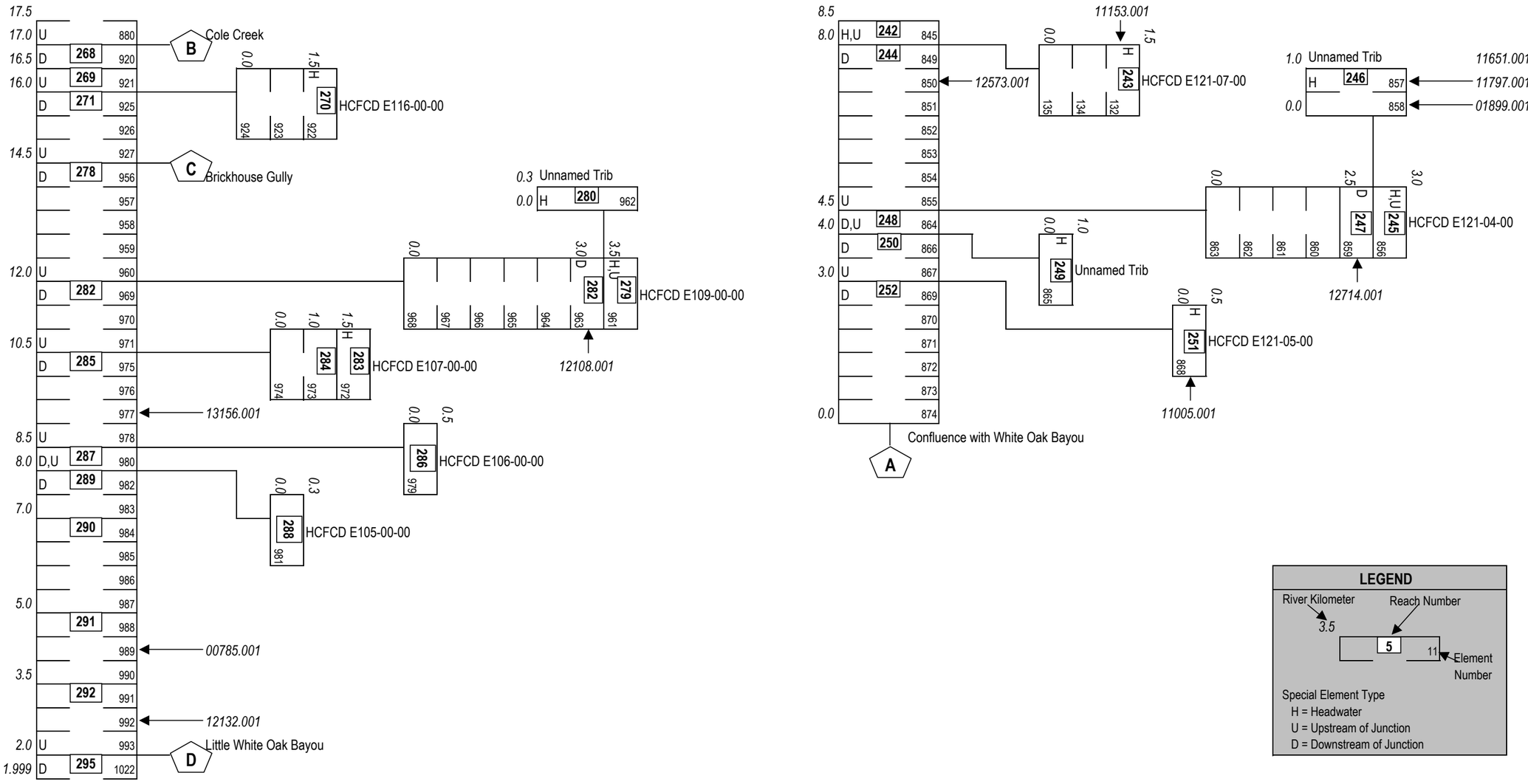


FIGURE G.3 - MODEL SCHEMATIC OF WHITE OAK BAYOU (Segment 1017) - CONT'D

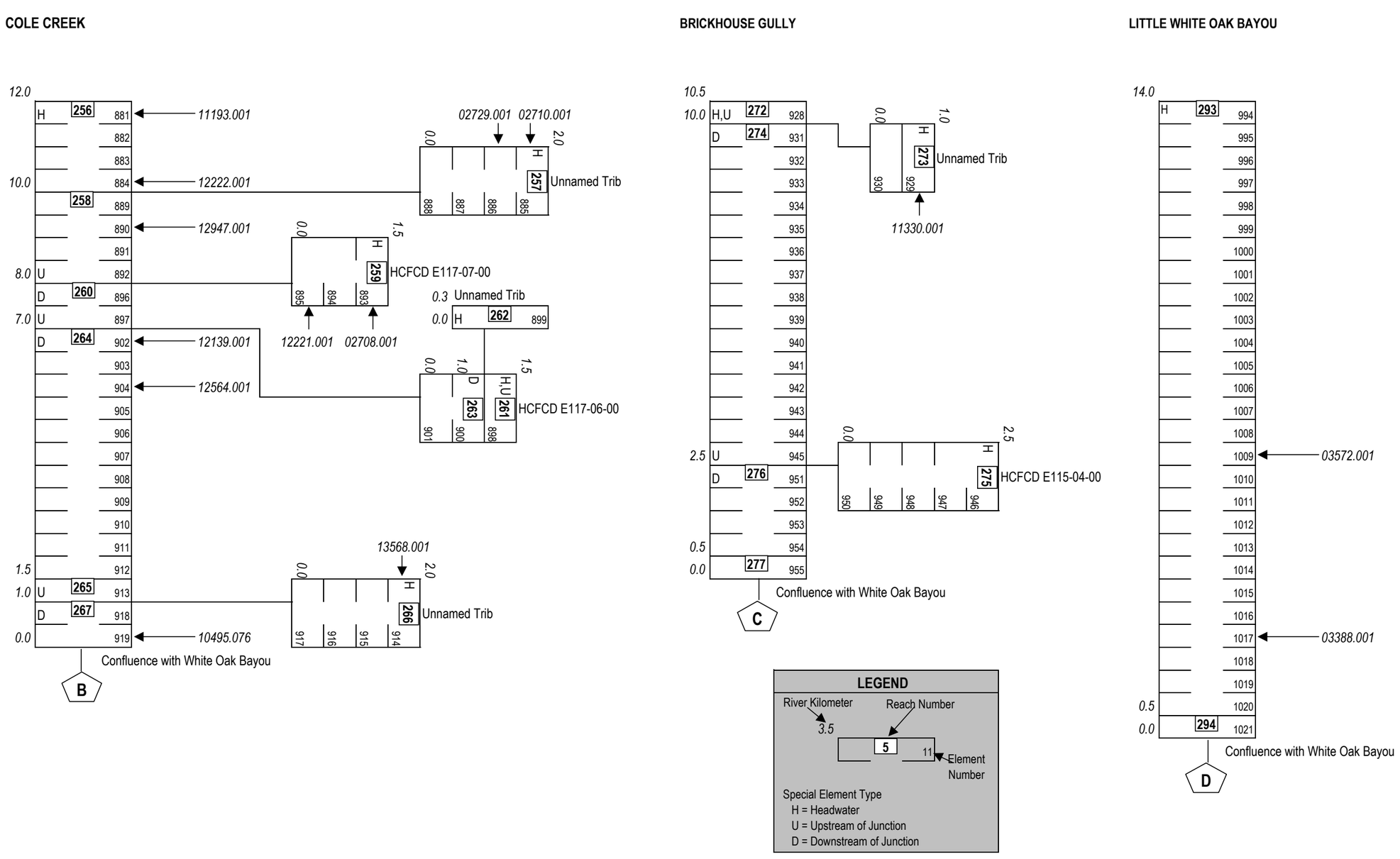


FIGURE G.3 - MODEL SCHEMATIC OF WHITE OAK BAYOU (Segment 1017) - CONT'D

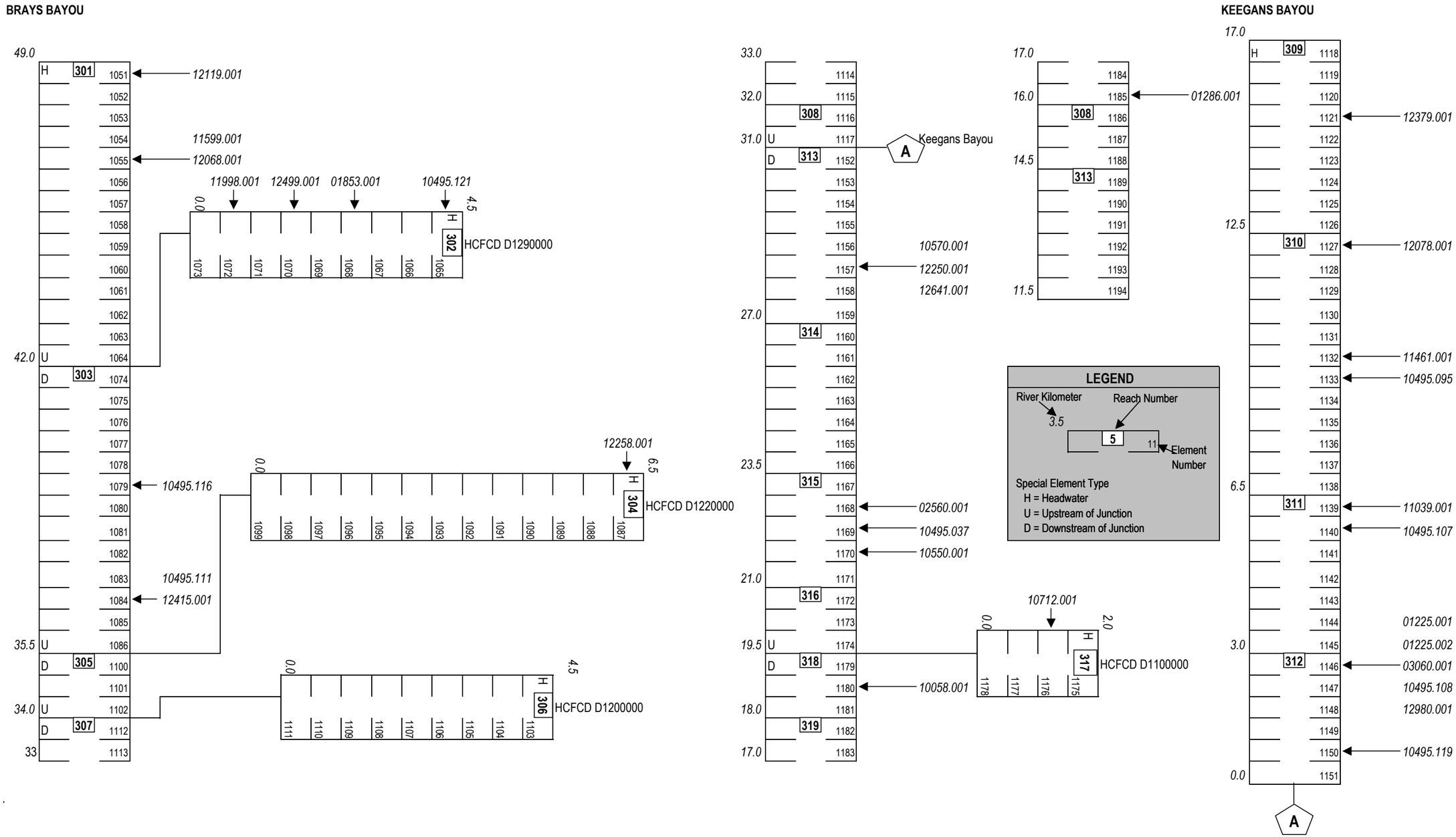


FIGURE G.4 - MODEL SCHEMATIC OF BRAYS BAYOU (Segment 1007)

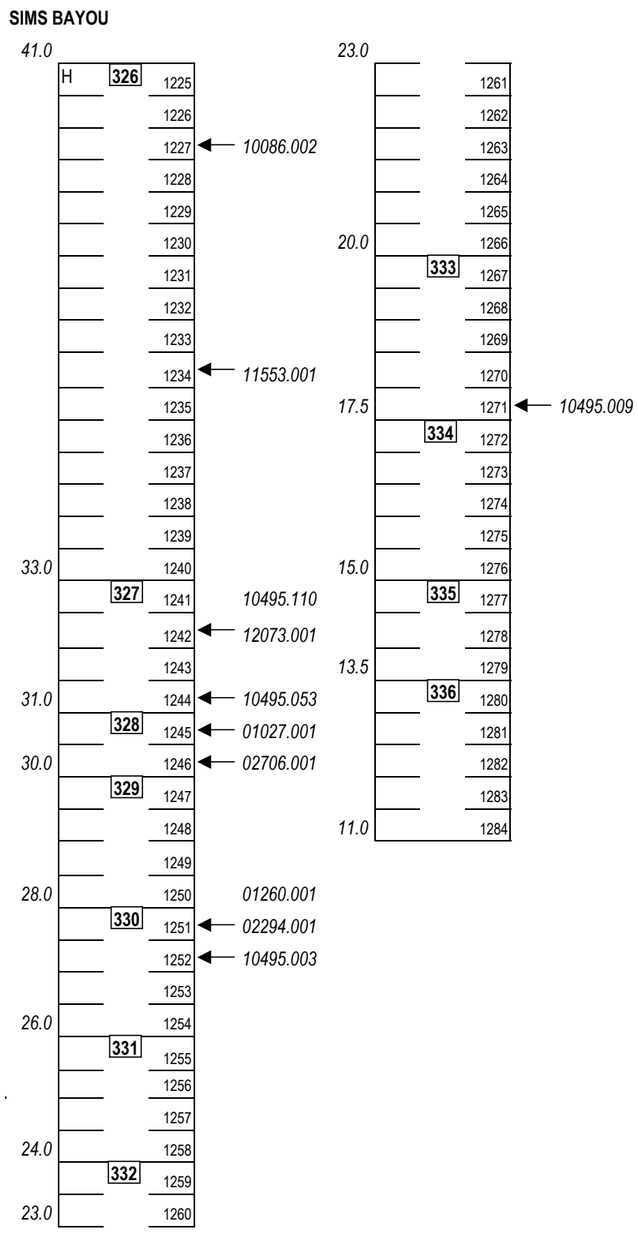


FIGURE G.5 - MODEL SCHEMATIC OF SIMS BAYOU (Segment 1007)

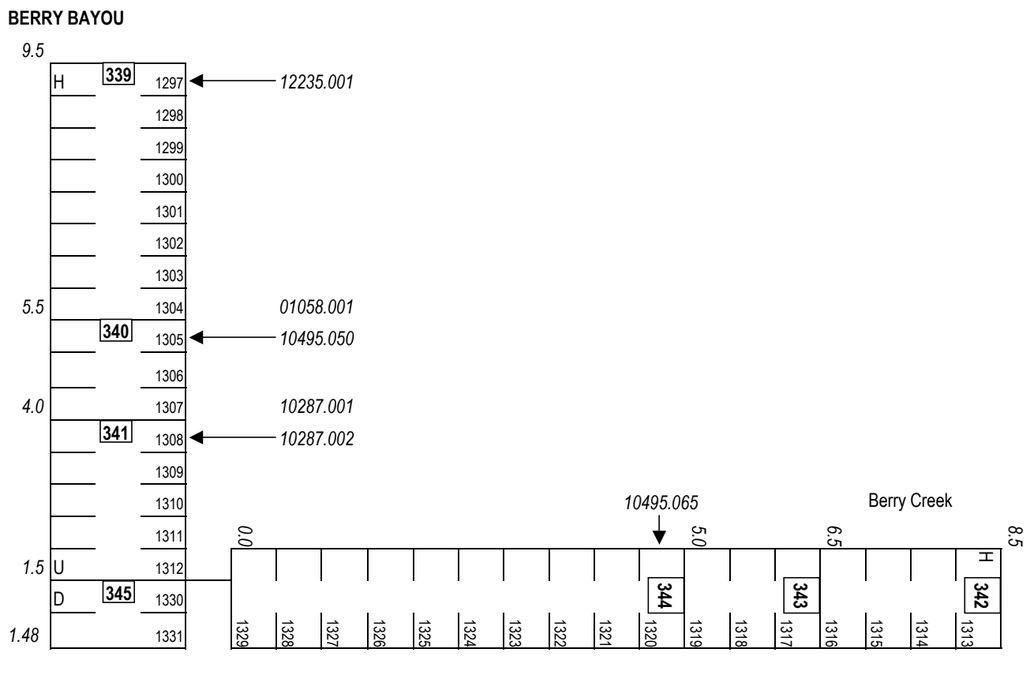
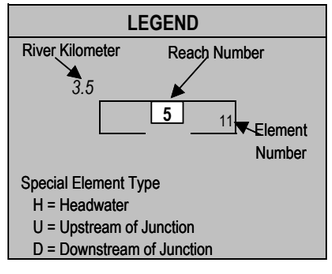


FIGURE G.6 - MODEL SCHEMATIC OF BERRY BAYOU (Segment 1007)



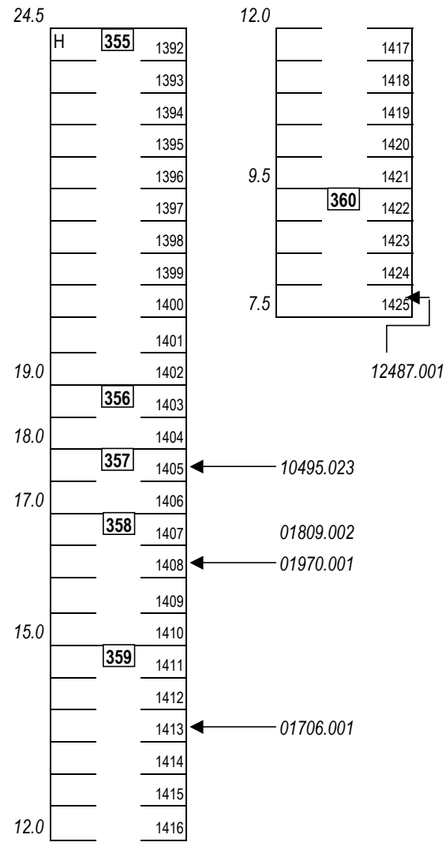


FIGURE G.7 - MODEL SCHEMATIC OF HUNTING BAYOU (Segment 1007)

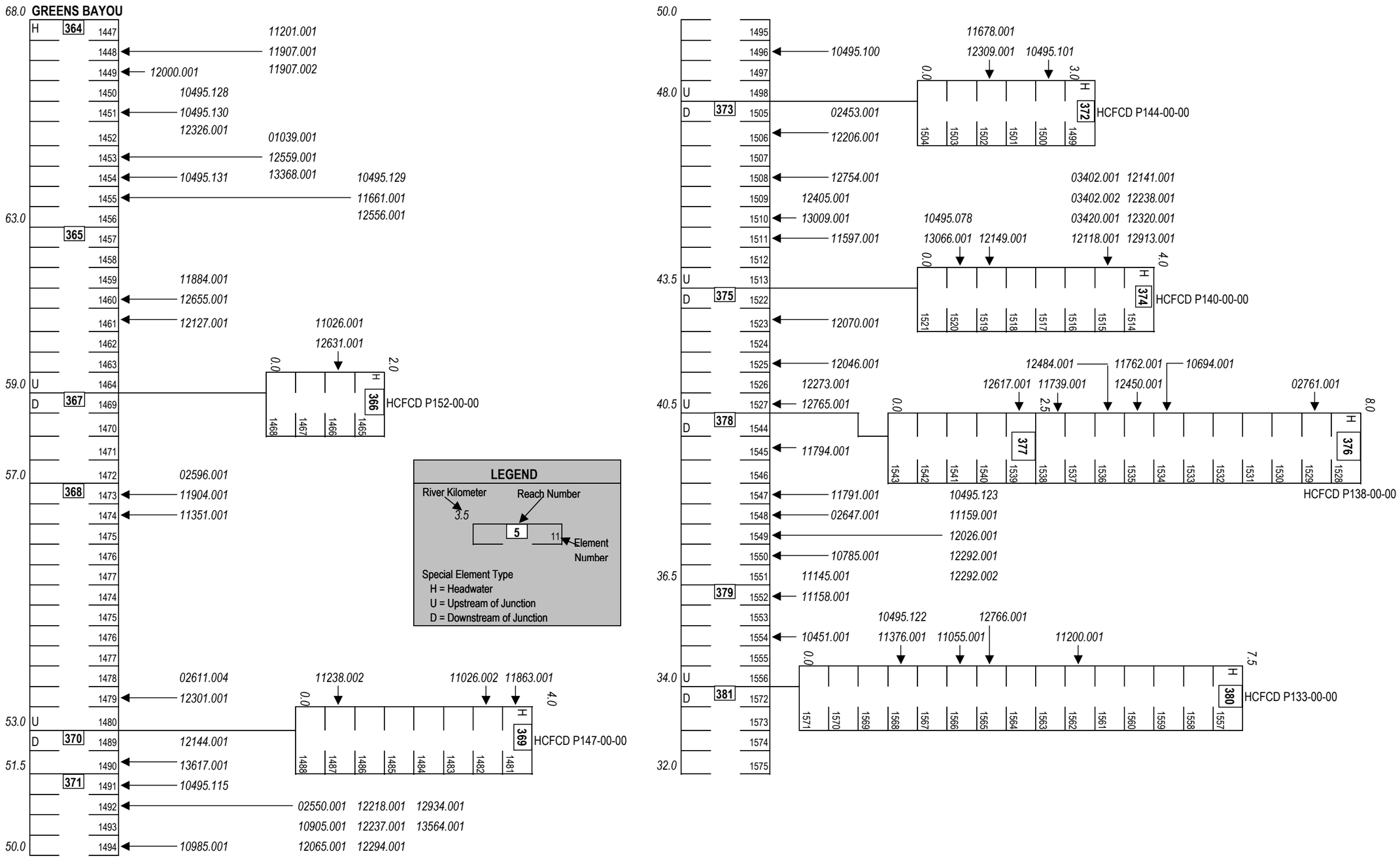


FIGURE G.8 - MODEL SCHEMATIC OF GREENS BAYOU (Segment 1016)

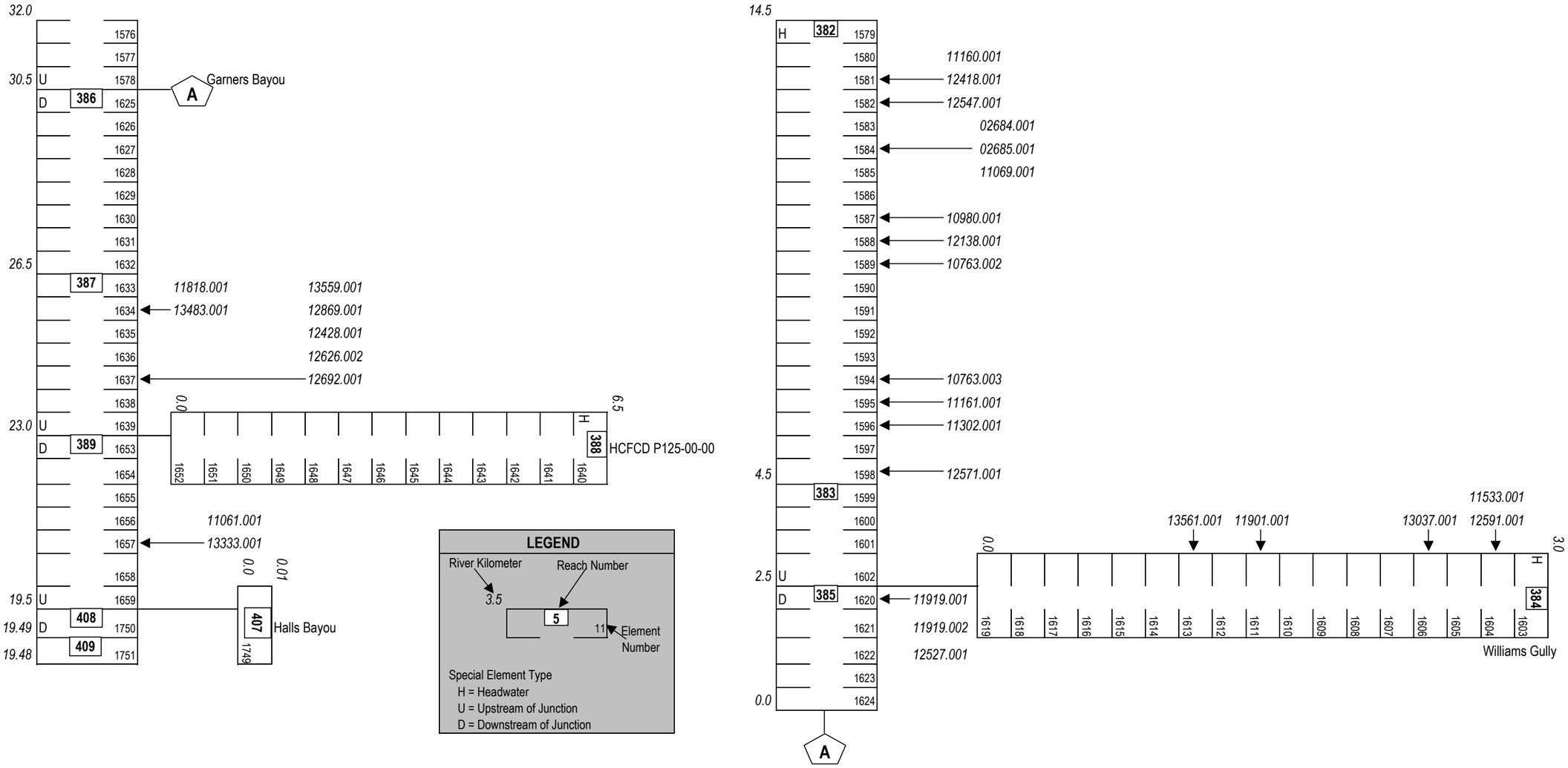


FIGURE G.8 - MODEL SCHEMATIC OF GREENS BAYOU (Segment 1016) - CONT'D

HALLS BAYOU

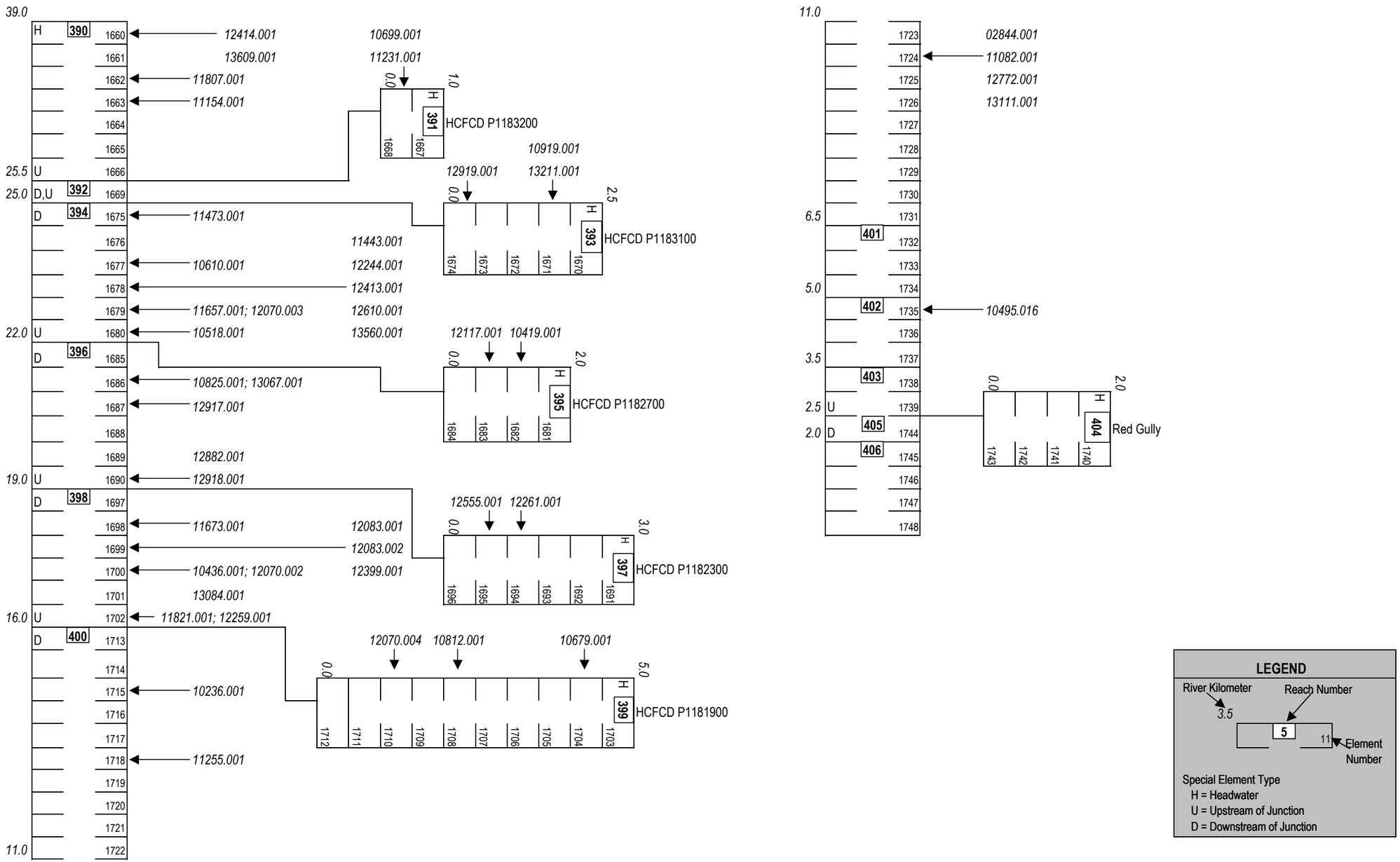
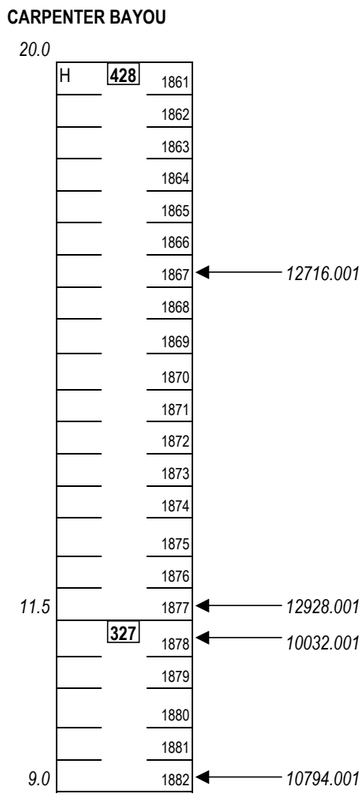


FIGURE G.9 - MODEL SCHEMATIC OF HALLS BAYOU (Segment 1006)



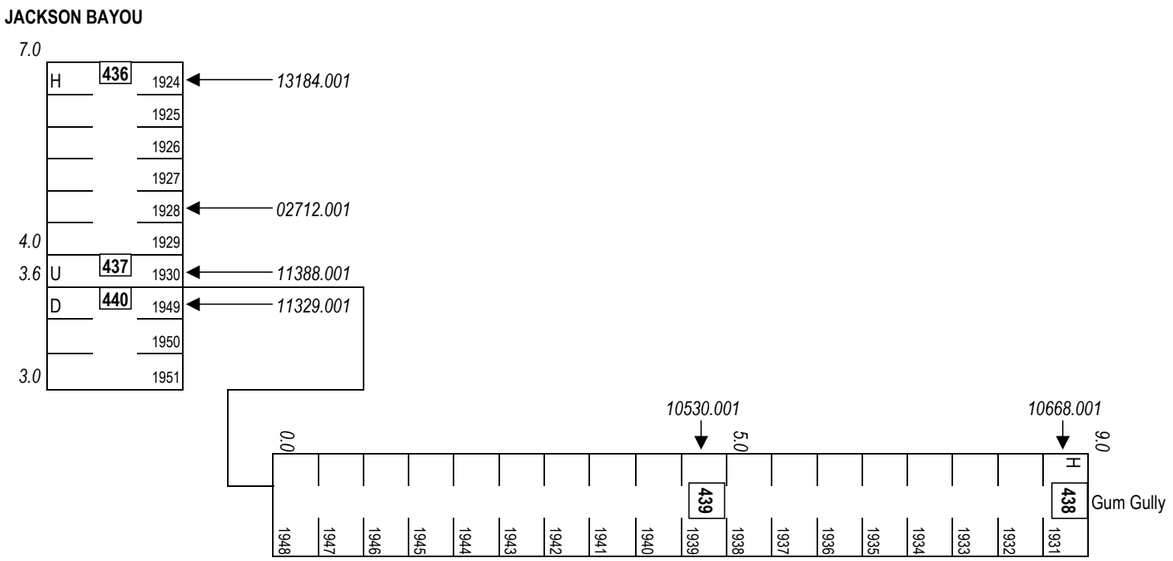


FIGURE G.11 - MODEL SCHEMATIC OF JACKSON BAYOU (Segment 1001)

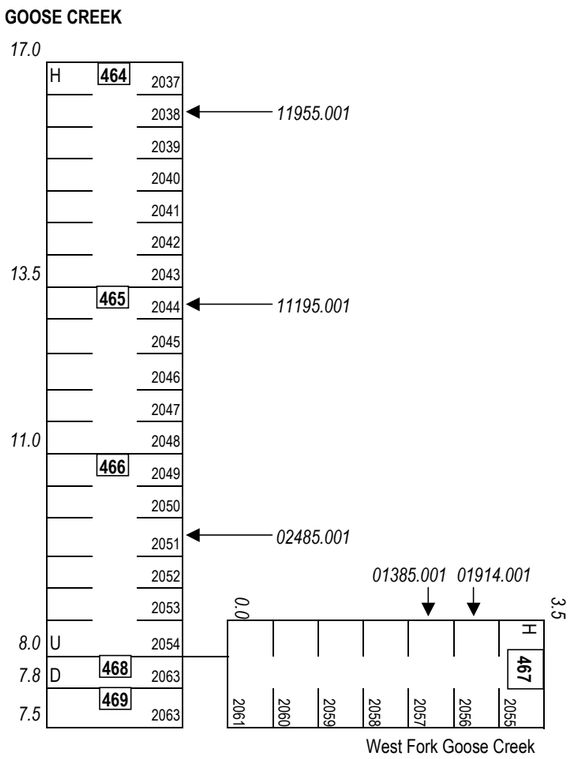
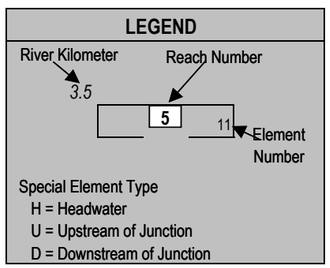


FIGURE G.12 - MODEL SCHEMATIC OF GOOSE CREEK (Segment 2426)

FIGURE G.10 - MODEL SCHEMATIC OF CARPENTER BAYOU (Segment 1006)



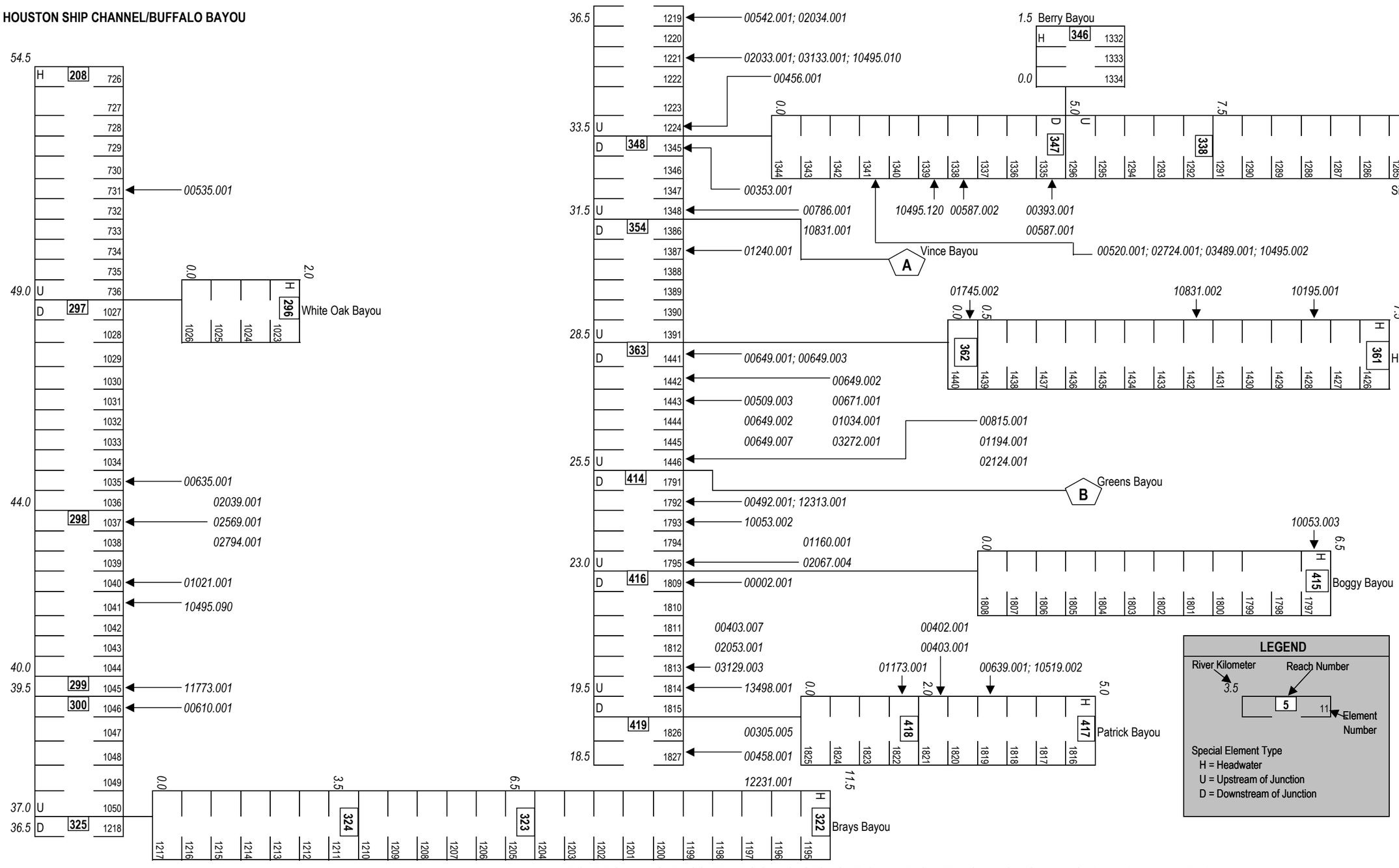


FIGURE G.13 - MODEL SCHEMATIC OF HOUSTON SHIP CHANNEL/BUFFALO BAYOU (SegmentS 1001,1005,1006,1007,1013)

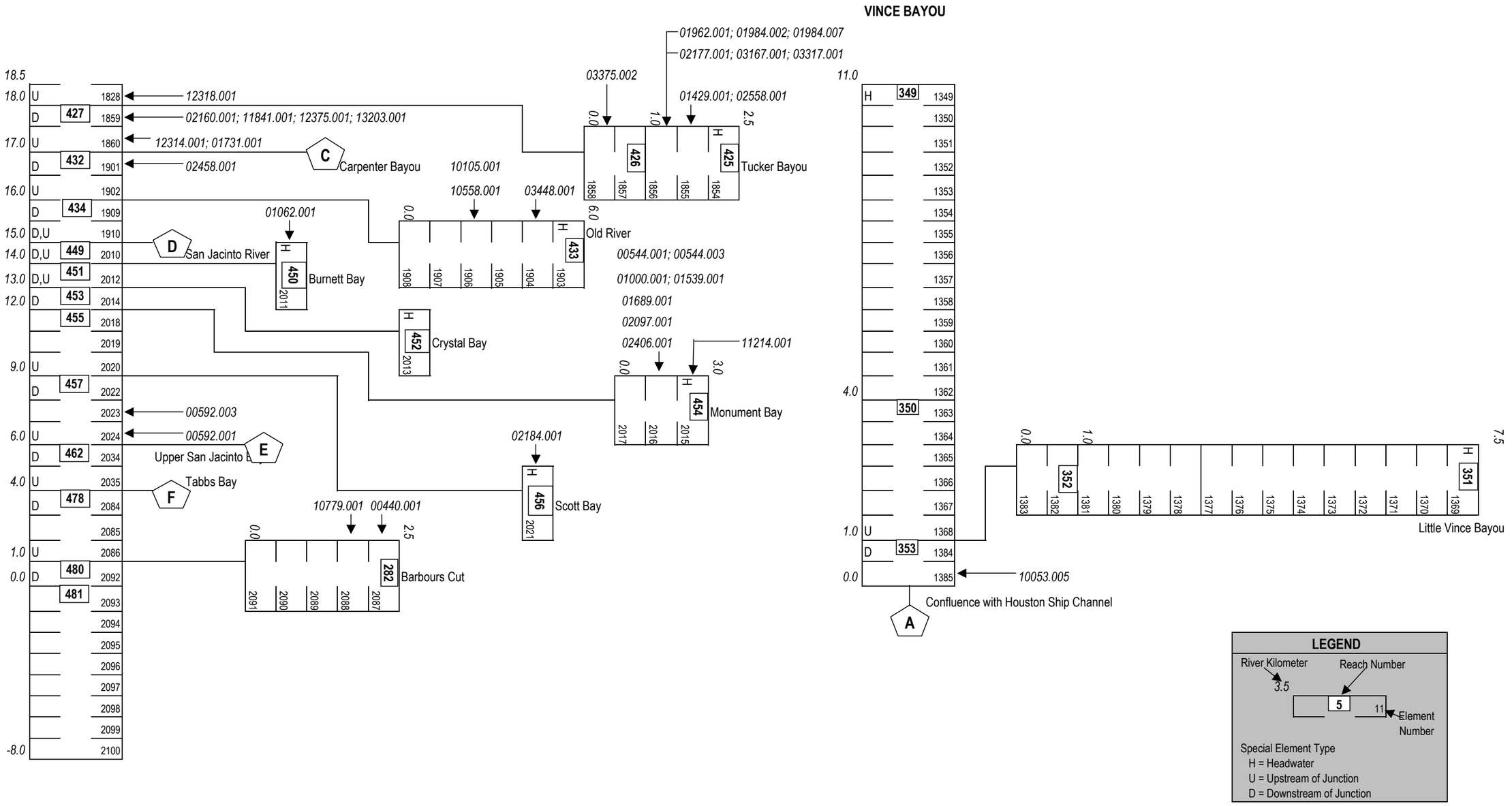


FIGURE G.13 - MODEL SCHEMATIC OF HOUSTON SHIP CHANNEL/BUFFALO BAYOU (SegmentS 1001,1005,1006,1007,1013) - CONT'D

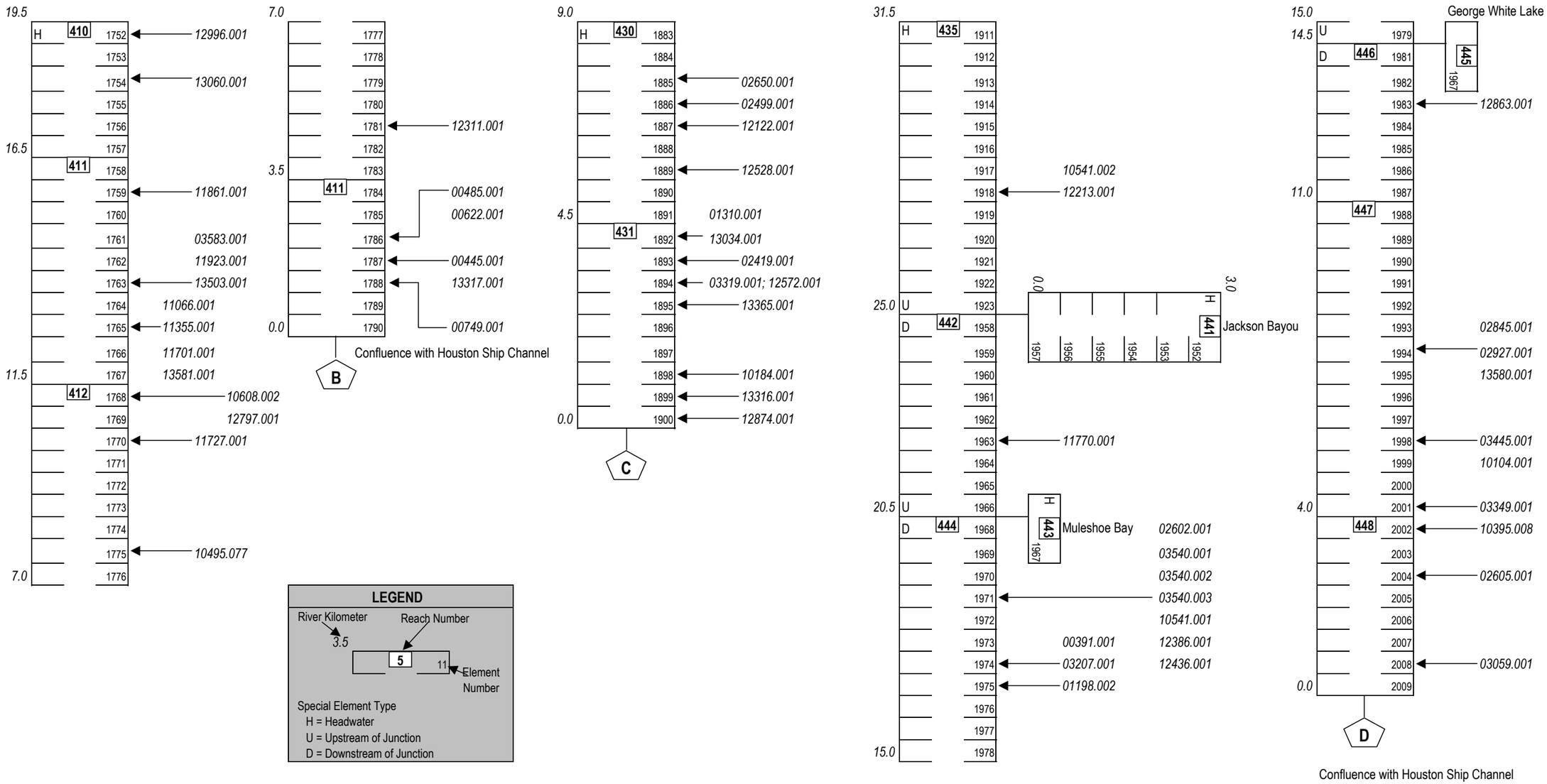
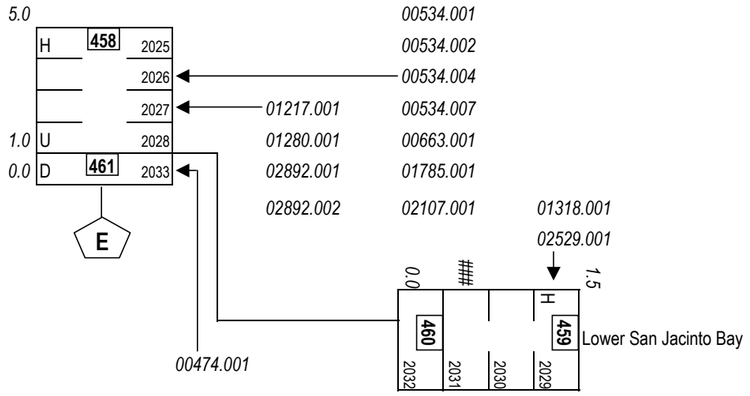
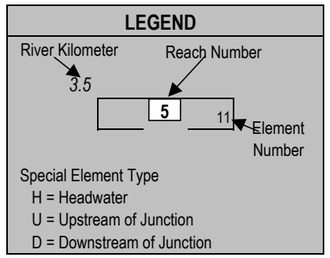


FIGURE G.13 - MODEL SCHEMATIC OF HOUSTON SHIP CHANNEL/BUFFALO BAYOU (SegmentS 1001,1005,1006,1007,1013) - CONT'D

UPPER SAN JACINTO BAY





TABBS BAY

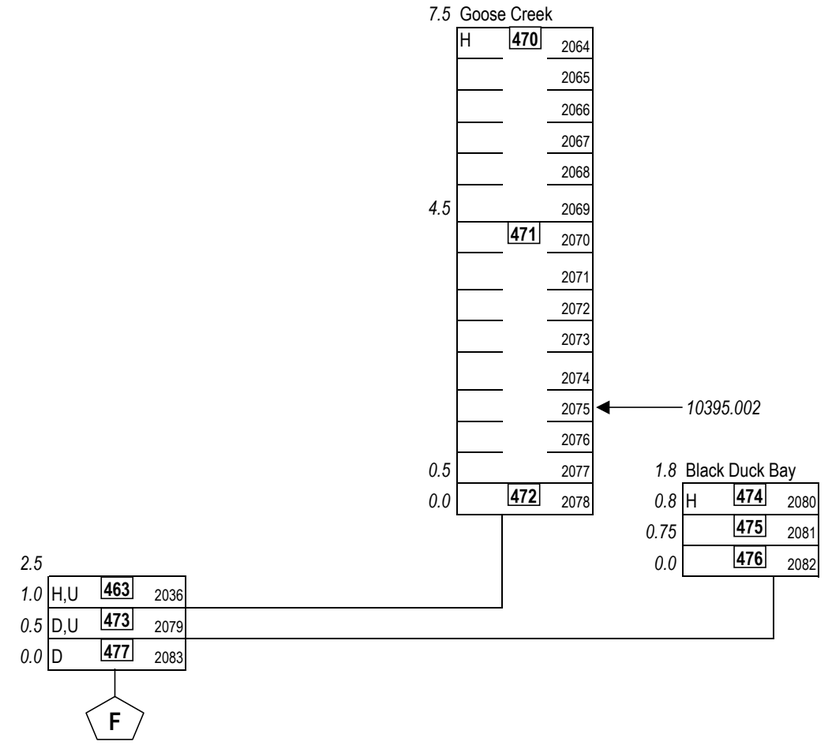


FIGURE G.13 - MODEL SCHEMATIC OF HOUSTON SHIP CHANNEL/BUFFALO BAYOU (SegmentS 1001,1005,1006,1007,1013) - CONT'D

Appendix G-2 QUAL-TX Input/Output Files

- TEQ simulation using permitted flows for PS (File names: *TEQ_permitted_base.inp and TEQ_permitted_base.out*)
- TEQ simulation using average self-reported flows for PS(File names: *TEQ_self_base.inp and TEQ_self_base.out*)
- TEQ simulation with additional source in 1006 (File names: *TEQ_suspected.inp and TEQ_suspected.out*)
- 2378-TCDD simulation using permitted flows for PS (File names: *TCDD_permitted_base.inp and TCDD_permitted_base.out*)
- 2378-TCDD simulation using average self-reported flows for PS(File names: *TCDD_self_base.inp and TCDD_self_base.out*)
- 2378-TCDD simulation with additional source in 1006 (File names: *TCDD_suspected.inp and TCDD_suspected.out*)

APPENDIX H - INPUT DATASET FOR BASE CASE OF THE WASP SIMPLIFIED MODEL

****

Water Quality Analysis Simulation Program (WASP6)

****

Developed:
US EPA Region 4
31 Forsyth St
Atlanta, GA 30303
For Technical Support:
Email: wool.tim@epa.gov
Voice: 404/562-9260 / Fax: 404/562-9224

Version 6.10
Compiled on: Date: May 2002

Maximum Parameters for this Model

Systems: 6	Segments: 2000	Break Points: 4000
Parameters: 23	Constants: 1800	Boundary Cond: 150
Waste Loads: 150	Print Interval: 40	Time Function: 17

****

Number of Segments ---> 39 Number of Systems ---> 6

System Bypass Options for System 1 TO 6 are 0 0 1 1 1 1

****

Simulation Time Steps
Option 1 Selected

DT	T	DT	T	DT	T
0.50000	4.00000	0.50000	90.00000		

Print Intervals

PRINT INTERVAL	ELAPSED TIME	PRINT INTERVAL	ELAPSED TIME	PRINT INTERVAL	ELAPSED TIME
5.000	0.00	5.000	90.00		

Exchange Coefficients

Number of Exchange Fields = 2

FIELD 1 has 7 Time Functions

SCALR = 0.100E+01 CONVR = 0.100E+01

Time Function 1 has 6 Exchanges

X-Area	Length	From	To
0.247E+04	0.368E+04	18	19
0.247E+04	0.416E+04	19	20
0.247E+04	0.232E+04	20	21
0.247E+04	0.232E+04	21	22
0.247E+04	0.184E+04	22	23
0.247E+04	0.120E+04	23	39

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.704E+03	0.000E+00	0.704E+03	0.900E+02		

Time Function 2 has 8 Exchanges

X-Area	Length	From	To
0.247E+04	0.256E+04	8	18
0.163E+04	0.296E+04	6	7
0.247E+04	0.280E+04	7	8
0.163E+04	0.360E+04	5	6
0.163E+04	0.320E+04	1	2
0.163E+04	0.320E+04	4	5
0.163E+04	0.264E+04	2	3
0.163E+04	0.232E+04	3	4

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.704E+03	0.000E+00	0.704E+03	0.900E+02		

Time Function 3 has 5 Exchanges

X-Area	Length	From	To
0.169E+03	0.800E+03	24	19
0.833E+03	0.800E+03	25	20
0.661E+03	0.800E+03	26	21
0.129E+03	0.800E+03	26	22
0.365E+03	0.800E+03	38	23

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.119E+03	0.000E+00	0.119E+03	0.900E+02		

Time Function 4 has 8 Exchanges

X-Area	Length	From	To
0.465E+03	0.400E+04	10	1
0.168E+03	0.161E+04	12	2
0.505E+03	0.161E+04	11	3
0.186E+03	0.161E+04	13	4
0.529E+03	0.161E+04	14	5
0.717E+03	0.161E+04	15	6
0.260E+03	0.161E+04	16	8
0.110E+04	0.161E+04	17	18

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.119E+03	0.000E+00	0.119E+03	0.900E+02		

Time Function 5 has 1 Exchanges

X-Area	Length	From	To
0.247E+04	0.800E+03	39	0

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.119E+04	0.000E+00	0.119E+04	0.900E+02		

Time Function 6 has 1 Exchanges

X-Area	Length	From	To
0.405E+04	0.245E+01	23	9

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.100E-01	0.000E+00	0.100E-01	0.900E+02		

Time Function 7 has 13 Exchanges

X-Area	Length	From	To
0.146E+05	0.244E+01	22	9
0.892E+04	0.244E+01	21	9
0.146E+05	0.244E+01	20	9
0.221E+05	0.305E+01	19	9
0.677E+04	0.350E+01	18	9
0.998E+04	0.396E+01	8	9
0.939E+04	0.305E+01	6	9
0.748E+04	0.396E+01	7	9
0.654E+04	0.460E+01	5	9
0.541E+04	0.460E+01	1	9
0.725E+04	0.305E+01	4	9
0.597E+04	0.460E+01	2	9
0.341E+04	0.460E+01	3	9

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.100E-01	0.000E+00	0.100E-01	0.900E+02		

FIELD 2 has 2 Time Functions

SCALR = 0.100E+01 CONVR = 0.100E+01

Time Function 1 has 5 Exchanges

X-Area	Length	From	To
0.719E+04	0.100E+00	17	9
0.444E+04	0.100E+00	24	9
0.146E+05	0.100E+00	25	9
0.868E+04	0.100E+00	26	9
0.339E+04	0.100E+00	27	9

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.100E-06	0.000E+00	0.100E-06	0.900E+02		

Time Function 2 has 14 Exchanges

X-Area	Length	From	To
0.541E+04	0.100E+00	1	9
0.597E+04	0.100E+00	2	9
0.341E+04	0.100E+00	3	9
0.725E+04	0.100E+00	4	9
0.654E+04	0.100E+00	5	9
0.939E+04	0.100E+00	6	9
0.748E+04	0.100E+00	7	9
0.998E+04	0.100E+00	8	9
0.677E+04	0.100E+00	18	9
0.221E+05	0.100E+00	19	9
0.146E+05	0.100E+00	20	9
0.892E+04	0.100E+00	21	9
0.146E+05	0.100E+00	22	9
0.405E+04	0.100E+00	23	9

Number of Breaks in Time Function = 2

Dispersion	Time	Dispersion	Time	Dispersion	Time
0.100E-06	0.000E+00	0.100E-06	0.900E+02		

R Bypass Options for Systems 1 to 6 are 0 0 1 1 1 1
1

VOLUMES

Bed Volume Option = 0 Bed Time Step = 0.100E+02

Scale Factor = 0.1000E+06 Conversion Factor = 0.1000E+01

Seg #	BOTSG	Type	Volume	V mult	V exp	D mult	D exp
1	9	1	49.400	0.004	0.400	1.200	0.600
2	9	1	54.600	0.004	0.400	1.200	0.600
3	9	1	31.200	0.004	0.400	1.200	0.600
4	9	1	44.200	0.004	0.400	1.200	0.600
5	9	1	59.800	0.004	0.400	1.200	0.600
6	9	1	57.200	0.004	0.400	1.200	0.600
7	9	1	59.300	0.004	0.400	1.200	0.600
8	9	1	79.100	0.004	0.400	1.200	0.600
9	0	3	0.042	0.004	0.400	1.200	0.600
10	0	1	37.400	0.004	0.400	1.200	0.600
11	0	1	16.200	0.004	0.400	1.200	0.600
12	0	1	5.380	0.004	0.400	1.200	0.600
13	0	1	5.950	0.004	0.400	1.200	0.600
14	0	1	16.900	0.004	0.400	1.200	0.600
15	0	1	23.100	0.004	0.400	1.200	0.600
16	0	1	8.370	0.004	0.400	1.200	0.600
17	0	1	35.100	0.004	0.400	1.200	0.600
18	9	1	47.400	0.004	0.400	1.200	0.600
19	9	1	134.000	0.004	0.400	1.200	0.600
20	9	1	71.170	0.004	0.400	1.200	0.600
21	9	1	43.490	0.004	0.400	1.200	0.600
22	9	1	71.170	0.004	0.400	1.200	0.600
23	9	1	19.770	0.004	0.400	1.200	0.600
24	9	1	2.710	0.004	0.400	1.200	0.600
25	9	1	13.300	0.004	0.400	1.200	0.600
26	9	1	10.600	0.004	0.400	1.200	0.600
27	9	1	2.070	0.004	0.400	1.200	0.600
28	0	1	0.000	0.004	0.400	1.200	0.600
29	0	1	0.000	0.004	0.400	1.200	0.600
30	0	1	0.000	0.004	0.400	1.200	0.600
31	0	1	0.000	0.004	0.400	1.200	0.600
32	0	1	0.000	0.004	0.400	1.200	0.600
33	0	1	0.000	0.004	0.400	1.200	0.600
34	0	1	0.000	0.004	0.400	1.200	0.600
35	0	1	0.000	0.004	0.400	1.200	0.600
36	0	1	0.000	0.004	0.400	1.200	0.600
37	0	1	0.000	0.004	0.400	1.200	0.600
38	0	1	5.830	0.004	0.400	1.200	0.600
39	0	1	39.500	0.004	0.400	1.200	0.600

1

FLOWS

Flow Option 2 Used
Number of Flow Fields = 6

Field 1 has 23 Inflows
SCALQ = 0.100E+01 CONVQ = 0.100E+01

Inflow Number 1

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	28	1	0.100E+01	1	2	0.100E+01	2	3
0.100E+01	3	4	0.100E+01	4	5	0.100E+01	5	6
0.100E+01	6	7	0.100E+01	7	8	0.100E+01	8	18
0.100E+01	18	19	0.100E+01	19	20	0.100E+01	20	21
0.100E+01	21	22	0.100E+01	22	23	0.100E+01	23	39
0.100E+01	39	0						

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.394E-03	0.000E+00	0.394E-03	0.900E+02		

Inflow Number 2

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	29	2	0.100E+01	2	3	0.100E+01	3	4
0.100E+01	4	5	0.100E+01	5	6	0.100E+01	6	7
0.100E+01	7	8	0.100E+01	8	18	0.100E+01	18	19
0.100E+01	19	20	0.100E+01	20	21	0.100E+01	21	22
0.100E+01	22	23	0.100E+01	23	39	0.100E+01	39	0

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.249E+01	0.000E+00	0.249E+01	0.900E+02		

Inflow Number 3

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	30	3	0.100E+01	3	4	0.100E+01	4	5
0.100E+01	5	6	0.100E+01	6	7	0.100E+01	7	8
0.100E+01	8	18	0.100E+01	18	19	0.100E+01	19	20
0.100E+01	20	21	0.100E+01	21	22	0.100E+01	22	23
0.100E+01	23	39	0.100E+01	39	0			

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.440E+00	0.000E+00	0.440E+00	0.900E+02		

Inflow Number 4

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	31	4	0.100E+01	4	5	0.100E+01	5	6
0.100E+01	6	7	0.100E+01	7	8	0.100E+01	8	18
0.100E+01	18	19	0.100E+01	19	20	0.100E+01	20	21
0.100E+01	21	22	0.100E+01	22	23	0.100E+01	23	39
0.100E+01	39	0						

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.142E+01	0.000E+00	0.142E+01	0.900E+02		

Inflow Number 5

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	32	5	0.100E+01	5	6	0.100E+01	6	7
0.100E+01	7	8	0.100E+01	8	18	0.100E+01	18	19
0.100E+01	19	20	0.100E+01	20	21	0.100E+01	21	22
0.100E+01	22	23	0.100E+01	23	39	0.100E+01	39	0

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.163E+01	0.000E+00	0.163E+01	0.900E+02		

Inflow Number 6

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	33	6	0.100E+01	6	7	0.100E+01	7	8
0.100E+01	8	18	0.100E+01	18	19	0.100E+01	19	20
0.100E+01	20	21	0.100E+01	21	22	0.100E+01	22	23
0.100E+01	23	39	0.100E+01	39	0			

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.901E+00	0.000E+00	0.901E+00	0.900E+02		

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.112E+00	0.000E+00	0.112E+00	0.900E+02		

Inflow Number 10

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	37	21	0.100E+01	21	22	0.100E+01	22	23
0.100E+01	23	39	0.100E+01	39	0			

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.170E+01	0.000E+00	0.170E+01	0.900E+02		

Inflow Number 11

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	0	10	0.100E+01	10	1	0.100E+01	1	2
0.100E+01	2	3	0.100E+01	3	4	0.100E+01	4	5
0.100E+01	5	6	0.100E+01	6	7	0.100E+01	7	8
0.100E+01	8	18	0.100E+01	18	19	0.100E+01	19	20
0.100E+01	20	21	0.100E+01	21	22	0.100E+01	22	23
0.100E+01	23	39	0.100E+01	39	0			

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.158E+02	0.000E+00	0.158E+02	0.900E+02		

Inflow Number 12

Inflow Number 7

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	34	7	0.100E+01	7	8	0.100E+01	8	18
0.100E+01	18	19	0.100E+01	19	20	0.100E+01	20	21
0.100E+01	21	22	0.100E+01	22	23	0.100E+01	23	39
0.100E+01	39	0						

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.111E+01	0.000E+00	0.111E+01	0.900E+02		

Inflow Number 8

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	35	18	0.100E+01	18	19	0.100E+01	19	20
0.100E+01	20	21	0.100E+01	21	22	0.100E+01	22	23
0.100E+01	23	39	0.100E+01	39	0			

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.502E+00	0.000E+00	0.502E+00	0.900E+02		

Inflow Number 9

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	36	19	0.100E+01	19	20	0.100E+01	20	21
0.100E+01	21	22	0.100E+01	22	23	0.100E+01	23	39
0.100E+01	39	0						

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	0	12	0.100E+01	12	2	0.100E+01	2	3
0.100E+01	3	4	0.100E+01	4	5	0.100E+01	5	6
0.100E+01	6	7	0.100E+01	7	8	0.100E+01	8	18
0.100E+01	18	19	0.100E+01	19	20	0.100E+01	20	21
0.100E+01	21	22	0.100E+01	22	23	0.100E+01	23	39
0.100E+01	39	0						

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.467E+01	0.000E+00	0.467E+01	0.900E+02		

Inflow Number 13

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	0	11	0.100E+01	11	3	0.100E+01	3	4
0.100E+01	4	5	0.100E+01	5	6	0.100E+01	6	7
0.100E+01	7	8	0.100E+01	8	18	0.100E+01	18	19
0.100E+01	19	20	0.100E+01	20	21	0.100E+01	21	22
0.100E+01	22	23	0.100E+01	23	39	0.100E+01	39	0

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.124E+01	0.000E+00	0.124E+01	0.900E+02		

Inflow Number 14

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	0	13	0.100E+01	13	4	0.100E+01	4	5
0.100E+01	5	6	0.100E+01	6	7	0.100E+01	7	8

```
 0.100E+01    8   18      0.100E+01   18   19      0.100E+01   19   20
 0.100E+01   20   21      0.100E+01   21   22      0.100E+01   22   23
 0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.238E+01 0.000E+00      0.238E+01 0.900E+02

                          Inflow Number 15
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   14      0.100E+01   14    5      0.100E+01    5    6
 0.100E+01    6    7      0.100E+01    7    8      0.100E+01    8   18
 0.100E+01   18   19      0.100E+01   19   20      0.100E+01   20   21
 0.100E+01   21   22      0.100E+01   22   23      0.100E+01   23   39
 0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.990E+00 0.000E+00      0.990E+00 0.900E+02

                          Inflow Number 16
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   15      0.100E+01   15    6      0.100E+01    6    7
 0.100E+01    7    8      0.100E+01    8   18      0.100E+01   18   19
 0.100E+01   19   20      0.100E+01   20   21      0.100E+01   21   22
 0.100E+01   22   23      0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
```

```
 0.337E+01 0.000E+00      0.337E+01 0.900E+02

                          Inflow Number 17
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   16      0.100E+01   16    8      0.100E+01    8   18
 0.100E+01   18   19      0.100E+01   19   20      0.100E+01   20   21
 0.100E+01   21   22      0.100E+01   22   23      0.100E+01   23   39
 0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.990E+00 0.000E+00      0.990E+00 0.900E+02

                          Inflow Number 18
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   26      0.100E+01   26   21      0.100E+01   21   22
 0.100E+01   22   23      0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.300E-01 0.000E+00      0.300E-01 0.900E+02

                          Inflow Number 19
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   24      0.100E+01   24   19      0.100E+01   19   20
```

```
 0.100E+01   20   21      0.100E+01   21   22      0.100E+01   22   23
 0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.300E-01 0.000E+00      0.300E-01 0.900E+02

                          Inflow Number 20
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   25      0.100E+01   25   20      0.100E+01   20   21
 0.100E+01   21   22      0.100E+01   22   23      0.100E+01   23   39
 0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.300E-01 0.000E+00      0.300E-01 0.900E+02

                          Inflow Number 21
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   27      0.100E+01   27   22      0.100E+01   22   23
 0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.300E-01 0.000E+00      0.300E-01 0.900E+02
```

```
                          Inflow Number 22
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01   38   23      0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.300E-01 0.000E+00      0.300E-01 0.900E+02

                          Inflow Number 23
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01    0   17      0.100E+01   17   18      0.100E+01   18   19
 0.100E+01   19   20      0.100E+01   20   21      0.100E+01   21   22
 0.100E+01   22   23      0.100E+01   23   39      0.100E+01   39    0

 Number of Breaks in Time Function =     2

    Flow      Time           Flow      Time           Flow      Time
 0.404E+02 0.000E+00      0.404E+02 0.900E+02

                  Field  2 has   2 Inflows
                  SCALQ = 0.100E+01  CONVQ = 0.100E+01

                          Inflow Number  1
 Continuity Array:
    Flow    From   To        Flow    From   To        Flow    From   To
 0.100E+01   17    9      0.100E+01   24    9      0.100E+01   25    9
 0.100E+01   26    9      0.100E+01   27    9
```

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.100E-02	0.000E+00	0.100E-02	0.900E+02		

Inflow Number 2

Continuity Array:

Flow	From	To	Flow	From	To	Flow	From	To
0.100E+01	1	9	0.100E+01	2	9	0.100E+01	3	9
0.100E+01	4	9	0.100E+01	5	9	0.100E+01	6	9
0.100E+01	7	9	0.100E+01	8	9	0.100E+01	18	9
0.100E+01	19	9	0.100E+01	20	9	0.100E+01	21	9
0.100E+01	22	9	0.100E+01	23	9			

Number of Breaks in Time Function = 2

Flow	Time	Flow	Time	Flow	Time
0.100E-02	0.000E+00	0.100E-02	0.900E+02		

Field 3 has 4 Inflows
SCALQ = 0.100E+01 CONVQ = 0.100E+01

Inflow Number 1

Solids Transport:

Area	From	To	Area	From	To	Area	From	To
0.100E+01	24	9	0.100E+01	25	9	0.100E+01	26	9
0.100E+01	27	9						

Number of Breaks in Time Function = 2

Velocity	Time	Velocity	Time	Velocity	Time
0.100E-02	0.000E+00	0.100E-02	0.900E+02		

Field 4 has 0 Inflows
SCALQ = 0.100E+01 CONVQ = 0.100E+01

Field 5 has 0 Inflows
SCALQ = 0.100E+01 CONVQ = 0.100E+01

Field 6 has 0 Inflows
SCALQ = 0.100E+01 CONVQ = 0.100E+01

Q Bypass Options for Systems 1 to 6 are 0 0 1 1 1 1
1

Boundary Conditions

Boundary Concentrations for System 1
BC Option 0 Used No.Of BC'S Read 13
Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	BC(T)	T	BC(T)	T
10	2	0.3990000E-11	0.00	0.3990000E-11	90.00
17	2	0.1700000E-09	0.00	0.1700000E-09	90.00
12	2	0.8330000E-11	0.00	0.8330000E-11	90.00
11	2	0.1703000E-10	0.00	0.1703000E-10	90.00
13	2	0.2980000E-10	0.00	0.2980000E-10	90.00
14	2	0.2480000E-09	0.00	0.2480000E-09	90.00
15	2	0.3660000E-10	0.00	0.3660000E-10	90.00
16	2	0.4210000E-09	0.00	0.4210000E-09	90.00
24	2	0.3440000E-09	0.00	0.3440000E-09	90.00
26	2	0.2650000E-09	0.00	0.2650000E-09	90.00
25	2	0.2100000E-09	0.00	0.2100000E-09	90.00
27	2	0.1970000E-09	0.00	0.1970000E-09	90.00
39	2	0.5800000E-10	0.00	0.5800000E-10	90.00

Boundary Concentrations for System 2
BC Option 0 Used No.Of BC'S Read 13
Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	BC(T)	T	BC(T)	T
10	2	0.2800000E+02	0.00	0.2800000E+02	90.00
17	2	0.1900000E+02	0.00	0.1900000E+02	90.00
12	2	0.1500000E+02	0.00	0.1500000E+02	90.00
11	2	0.1700000E+02	0.00	0.1700000E+02	90.00
13	2	0.1600000E+02	0.00	0.1600000E+02	90.00
14	2	0.2300000E+02	0.00	0.2300000E+02	90.00
15	2	0.3000000E+02	0.00	0.3000000E+02	90.00
16	2	0.3000000E+02	0.00	0.3000000E+02	90.00
24	2	0.2200000E+02	0.00	0.2200000E+02	90.00
26	2	0.2200000E+02	0.00	0.2200000E+02	90.00
25	2	0.2200000E+02	0.00	0.2200000E+02	90.00
27	2	0.2200000E+02	0.00	0.2200000E+02	90.00
39	2	0.1500000E+02	0.00	0.1500000E+02	90.00

Boundary Concentrations for System 3
BC Option 0 Used No.Of BC'S Read 13
Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	BC(T)	T	BC(T)	T
10	0				
17	0				
12	0				
11	0				
13	0				
14	0				
15	0				
16	0				
24	0				
26	0				
25	0				
27	0				
39	0				

Boundary Concentrations for System 4
BC Option 0 Used No.Of BC'S Read 13
Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	BC(T)	T	BC(T)	T
10	0				
17	0				
12	0				
11	0				
13	0				

14	0				
15	0				
16	0				
24	0				
26	0				
25	0				
27	0				
39	0				

Boundary Concentrations for System 5

BC Option 0 Used No.Of BC'S Read 13

Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	BC(T)	T	BC(T)	T
10	0				
17	0				
12	0				
11	0				
13	0				
14	0				
15	0				
16	0				
24	0				
26	0				
25	0				
27	0				
39	0				

Boundary Concentrations for System 6

BC Option 0 Used No.Of BC'S Read 13

Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	BC(T)	T	BC(T)	T
10	0				
17	0				
12	0				
11	0				
13	0				
14	0				
15	0				
16	0				
24	0				
26	0				
25	0				
27	0				
39	0				

Waste Loads

Forcing Functions For System 1

Wk Option 3 Used No.of WK'S Read 25

Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	WK(T)	T	WK(T)	T
1	2	0.3100000E-07	0.00	0.3100000E-07	90.00
2	2	0.1160000E-07	0.00	0.1160000E-07	90.00
3	2	0.7330000E-08	0.00	0.7330000E-08	90.00
4	2	0.2040000E-08	0.00	0.2040000E-08	90.00
5	2	0.2750000E-08	0.00	0.2750000E-08	90.00
6	2	0.1440000E-07	0.00	0.1440000E-07	90.00
7	2	0.3611000E-09	0.00	0.3611000E-09	90.00
8	2	0.2210000E-08	0.00	0.2210000E-08	90.00
18	2	0.1800000E-07	0.00	0.1800000E-07	90.00
19	2	0.0000000E+00	0.00	0.0000000E+00	90.00
20	2	0.0000000E+00	0.00	0.0000000E+00	90.00
21	2	0.0000000E+00	0.00	0.0000000E+00	90.00
22	2	0.2147000E-08	0.00	0.2147000E-08	90.00
23	2	0.1157000E-08	0.00	0.1157000E-08	90.00
9	2	0.0000000E+00	0.00	0.0000000E+00	90.00
28	2	0.5676000E-12	0.00	0.5676000E-12	90.00
29	2	0.2034000E-08	0.00	0.2034000E-08	90.00
30	2	0.2895000E-08	0.00	0.2895000E-08	90.00
31	2	0.5072000E-10	0.00	0.5072000E-10	90.00
32	2	0.1610000E-09	0.00	0.1610000E-09	90.00
33	2	0.1741000E-08	0.00	0.1741000E-08	90.00
34	2	0.1326000E-07	0.00	0.1326000E-07	90.00
35	2	0.2728000E-08	0.00	0.2728000E-08	90.00
36	2	0.1416000E-08	0.00	0.1416000E-08	90.00
37	2	0.3299000E-08	0.00	0.3299000E-08	90.00

Forcing Functions For System 2

Wk Option 3 Used No.of WK'S Read 29

Scale Factor = 0.1000E+01 Conversion Factor = 0.1000E+01

Segment	No.Brk.	WK(T)	T	WK(T)	T
1	2	0.4672800E+05	0.00	0.4672800E+05	90.00
2	2	0.3085200E+05	0.00	0.3085200E+05	90.00
3	2	0.1002500E+05	0.00	0.1002500E+05	90.00
4	2	0.3878000E+04	0.00	0.3878000E+04	90.00
5	2	0.5213000E+04	0.00	0.5213000E+04	90.00
6	2	0.5585900E+05	0.00	0.5585900E+05	90.00
7	2	0.1242000E+04	0.00	0.1242000E+04	90.00
8	2	0.7617000E+04	0.00	0.7617000E+04	90.00
18	2	0.6173500E+05	0.00	0.6173500E+05	90.00
19	2	0.1000000E+00	0.00	0.1000000E+00	90.00
20	2	0.1000000E+00	0.00	0.1000000E+00	90.00
21	2	0.1000000E+00	0.00	0.1000000E+00	90.00
22	2	0.4150000E+04	0.00	0.4150000E+04	90.00
23	2	0.3979000E+04	0.00	0.3979000E+04	90.00
24	2	0.1000000E+00	0.00	0.1000000E+00	90.00
25	2	0.1000000E+00	0.00	0.1000000E+00	90.00
26	2	0.1000000E+00	0.00	0.1000000E+00	90.00
27	2	0.1000000E+00	0.00	0.1000000E+00	90.00
9	2	0.1000000E+06	0.00	0.1000000E+06	90.00
28	2	0.8870000E-02	0.00	0.8870000E-02	90.00
29	2	0.1792000E+04	0.00	0.1792000E+04	90.00
30	2	0.3100000E+03	0.00	0.3100000E+03	90.00
31	2	0.9840000E+03	0.00	0.9840000E+03	90.00
32	2	0.1593000E+04	0.00	0.1593000E+04	90.00
33	2	0.6230000E+03	0.00	0.6230000E+03	90.00
34	2	0.7680000E+03	0.00	0.7680000E+03	90.00
35	2	0.3470000E+03	0.00	0.3470000E+03	90.00
36	2	0.7700000E+02	0.00	0.7700000E+02	90.00

```
            37         2      0.1173000E+04      0.00      0.1173000E+04
90.00

                          Forcing Functions For System  3
                          ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

                     Wk Option  3 Used     No.of WK'S Read    0


                        No Forcing Function for System  3
                           Forcing Functions For System  4
                           ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

                     Wk Option  3 Used     No.of WK'S Read    0


                        No Forcing Function for System  4
                           Forcing Functions For System  5
                           ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

                     Wk Option  3 Used     No.of WK'S Read    0


                        No Forcing Function for System  5
                           Forcing Functions For System  6
                           ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

                     Wk Option  3 Used     No.of WK'S Read    0


                        No Forcing Function for System  6
                                  Segment Parameters
                                  ~~~~~~~~~~~~~~~~~~

 PARM     SCALE       PARM     SCALE       PARM     SCALE       PARM     SCALE
 ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
         1
0.1000E+01
    1
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    2
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    3
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    4
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    5
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    6
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    7
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    8
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
    9
  ISC:   7  Scale:     1.0000  Value: 0.1500E-01
   10
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   11
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   12
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   13
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   14
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   15
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   16
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   17
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   18
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   19
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   20
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   21
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   22
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   23
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   24
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   25
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   26
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   27
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   28
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   29
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   30
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   31
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   32
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   33
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   34
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   35
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   36
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   37
  ISC:   7  Scale:     1.0000  Value: 0.0000E+00
   38
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
   39
  ISC:   7  Scale:     1.0000  Value: 0.2500E+00
1
                        Environmental and Chemical Constants
                        ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

         2
     Const       101  0.7110E+01     Const        81  0.1000E+01
1



                          No Time Functions have been Entered
for this Simulation
1


                           Initial Conditions
                           ~~~~~~~~~~~~~~~~~~


          Initial Conditions for System  1
          ================================
    Particulate Form Transported by Solids Field    3
    Density of System =     1.0000


  Segment     Concentration     Fraction Dissolved
  ~~~~~~~     ~~~~~~~~~~~~~     ~~~~~~~~~~~~~~~~~~
    1:         0.1350E-10             1.00
    2:         0.3000E-11             1.00
    3:         0.8500E-11             1.00
    4:         0.1000E-10             1.00
    5:         0.2260E-09             1.00
    6:         0.3000E-09             1.00
    7:         0.5020E-09             1.00
    8:         0.2700E-09             1.00
    9:         0.2300E+02             0.00
   10:         0.1000E-23             1.00
   11:         0.1000E-23             1.00
   12:         0.1000E-23             1.00
   13:         0.1000E-23             1.00
   14:         0.1000E-23             1.00
   15:         0.1000E-23             1.00
   16:         0.1000E-23             1.00
   17:         0.1700E-09             1.00
   18:         0.2270E-09             1.00
   19:         0.1000E-23             1.00
   20:         0.1000E-23             1.00
   21:         0.1000E-23             1.00
   22:         0.1000E-23             1.00
   23:         0.5800E-10             1.00
   24:         0.3440E-09             1.00
   25:         0.2100E-09             1.00
   26:         0.2650E-09             1.00
   27:         0.1970E-09             1.00
   28:         0.1000E-23             1.00
   29:         0.1000E-23             1.00
   30:         0.1000E-23             1.00
   31:         0.1000E-23             1.00
   32:         0.1000E-23             1.00
   33:         0.1000E-23             1.00
   34:         0.1000E-23             1.00
   35:         0.1000E-23             1.00
   36:         0.1000E-23             1.00
   37:         0.1000E-23             1.00
   38:         0.1000E-23             1.00
   39:         0.5800E-10             1.00


          Initial Conditions for System  2
          ================================
    Particulate Form Transported by Solids Field    3
    Density of System =     2.0000


  Segment     Concentration     Fraction Dissolved
  ~~~~~~~     ~~~~~~~~~~~~~     ~~~~~~~~~~~~~~~~~~
    1:         0.2200E+02             0.00
    2:         0.2200E+02             0.00
    3:         0.2200E+02             0.00
    4:         0.2200E+02             0.00
    5:         0.2200E+02             0.00
    6:         0.2200E+02             0.00
    7:         0.2200E+02             0.00
    8:         0.2200E+02             0.00
    9:         0.1000E+05             0.00
   10:         0.2200E+02             0.00
   11:         0.2200E+02             0.00
   12:         0.2200E+02             0.00
   13:         0.2200E+02             0.00
   14:         0.2200E+02             0.00
   15:         0.2200E+02             0.00
   16:         0.2200E+02             0.00
   17:         0.2200E+02             0.00
   18:         0.2200E+02             0.00
   19:         0.2200E+02             0.00
   20:         0.2200E+02             0.00
   21:         0.2200E+02             0.00
   22:         0.2200E+02             0.00
   23:         0.2200E+02             0.00
   24:         0.2200E+02             0.00
   25:         0.2200E+02             0.00
   26:         0.2200E+02             0.00
   27:         0.2200E+02             0.00
   28:         0.1000E-23             0.00
```

29:	0.1000E-23	0.00
30:	0.1000E-23	0.00
31:	0.1000E-23	0.00
32:	0.1000E-23	0.00
33:	0.1000E-23	0.00
34:	0.1000E-23	0.00
35:	0.1000E-23	0.00
36:	0.1000E-23	0.00
37:	0.1000E-23	0.00
38:	0.1000E-23	0.00
39:	0.2200E+02	0.00

Initial Conditions for System 3

Particulate Form Transported by Solids Field 3

Density of System = 1.0000

Segment	Concentration	Fraction Dissolved
1:	0.1000E-23	1.00
2:	0.1000E-23	1.00
3:	0.1000E-23	1.00
4:	0.1000E-23	1.00
5:	0.1000E-23	1.00
6:	0.1000E-23	1.00
7:	0.1000E-23	1.00
8:	0.1000E-23	1.00
9:	0.1000E-23	1.00
10:	0.1000E-23	1.00
11:	0.1000E-23	1.00
12:	0.1000E-23	1.00
13:	0.1000E-23	1.00
14:	0.1000E-23	1.00
15:	0.1000E-23	1.00
16:	0.1000E-23	1.00
17:	0.1000E-23	1.00
18:	0.1000E-23	1.00
19:	0.1000E-23	1.00
20:	0.1000E-23	1.00
21:	0.1000E-23	1.00
22:	0.1000E-23	1.00
23:	0.1000E-23	1.00
24:	0.1000E-23	1.00
25:	0.1000E-23	1.00
26:	0.1000E-23	1.00
27:	0.1000E-23	1.00
28:	0.1000E-23	1.00
29:	0.1000E-23	1.00
30:	0.1000E-23	1.00
31:	0.1000E-23	1.00
32:	0.1000E-23	1.00
33:	0.1000E-23	1.00
34:	0.1000E-23	1.00
35:	0.1000E-23	1.00
36:	0.1000E-23	1.00

37:	0.1000E-23	1.00
38:	0.1000E-23	1.00
39:	0.1000E-23	1.00

Initial Conditions for System 4

Particulate Form Transported by Solids Field 3

Density of System = 1.0000

Segment	Concentration	Fraction Dissolved
1:	0.1000E-23	1.00
2:	0.1000E-23	1.00
3:	0.1000E-23	1.00
4:	0.1000E-23	1.00
5:	0.1000E-23	1.00
6:	0.1000E-23	1.00
7:	0.1000E-23	1.00
8:	0.1000E-23	1.00
9:	0.1000E-23	1.00
10:	0.1000E-23	1.00
11:	0.1000E-23	1.00
12:	0.1000E-23	1.00
13:	0.1000E-23	1.00
14:	0.1000E-23	1.00
15:	0.1000E-23	1.00
16:	0.1000E-23	1.00
17:	0.1000E-23	1.00
18:	0.1000E-23	1.00
19:	0.1000E-23	1.00
20:	0.1000E-23	1.00
21:	0.1000E-23	1.00
22:	0.1000E-23	1.00
23:	0.1000E-23	1.00
24:	0.1000E-23	1.00
25:	0.1000E-23	1.00
26:	0.1000E-23	1.00
27:	0.1000E-23	1.00
28:	0.1000E-23	1.00
29:	0.1000E-23	1.00
30:	0.1000E-23	1.00
31:	0.1000E-23	1.00
32:	0.1000E-23	1.00
33:	0.1000E-23	1.00
34:	0.1000E-23	1.00
35:	0.1000E-23	1.00
36:	0.1000E-23	1.00
37:	0.1000E-23	1.00
38:	0.1000E-23	1.00
39:	0.1000E-23	1.00

Initial Conditions for System 5

Particulate Form Transported by Solids Field 3

Density of System = 1.0000

Segment	Concentration	Fraction Dissolved
1:	0.1000E-23	1.00
2:	0.1000E-23	1.00
3:	0.1000E-23	1.00
4:	0.1000E-23	1.00
5:	0.1000E-23	1.00
6:	0.1000E-23	1.00
7:	0.1000E-23	1.00
8:	0.1000E-23	1.00
9:	0.1000E-23	1.00
10:	0.1000E-23	1.00
11:	0.1000E-23	1.00
12:	0.1000E-23	1.00
13:	0.1000E-23	1.00
14:	0.1000E-23	1.00
15:	0.1000E-23	1.00
16:	0.1000E-23	1.00
17:	0.1000E-23	1.00
18:	0.1000E-23	1.00
19:	0.1000E-23	1.00
20:	0.1000E-23	1.00
21:	0.1000E-23	1.00
22:	0.1000E-23	1.00
23:	0.1000E-23	1.00
24:	0.1000E-23	1.00
25:	0.1000E-23	1.00
26:	0.1000E-23	1.00
27:	0.1000E-23	1.00
28:	0.1000E-23	1.00
29:	0.1000E-23	1.00
30:	0.1000E-23	1.00
31:	0.1000E-23	1.00
32:	0.1000E-23	1.00
33:	0.1000E-23	1.00
34:	0.1000E-23	1.00
35:	0.1000E-23	1.00
36:	0.1000E-23	1.00
37:	0.1000E-23	1.00
38:	0.1000E-23	1.00
39:	0.1000E-23	1.00

Initial Conditions for System 6

Particulate Form Transported by Solids Field 3

Density of System = 1.0000

Segment	Concentration	Fraction Dissolved
1:	0.1000E-23	1.00
2:	0.1000E-23	1.00
3:	0.1000E-23	1.00
4:	0.1000E-23	1.00
5:	0.1000E-23	1.00
6:	0.1000E-23	1.00
7:	0.1000E-23	1.00
8:	0.1000E-23	1.00
9:	0.1000E-23	1.00
10:	0.1000E-23	1.00
11:	0.1000E-23	1.00
12:	0.1000E-23	1.00
13:	0.1000E-23	1.00
14:	0.1000E-23	1.00
15:	0.1000E-23	1.00
16:	0.1000E-23	1.00
17:	0.1000E-23	1.00
18:	0.1000E-23	1.00
19:	0.1000E-23	1.00
20:	0.1000E-23	1.00
21:	0.1000E-23	1.00
22:	0.1000E-23	1.00
23:	0.1000E-23	1.00
24:	0.1000E-23	1.00
25:	0.1000E-23	1.00
26:	0.1000E-23	1.00
27:	0.1000E-23	1.00
28:	0.1000E-23	1.00
29:	0.1000E-23	1.00
30:	0.1000E-23	1.00
31:	0.1000E-23	1.00
32:	0.1000E-23	1.00
33:	0.1000E-23	1.00
34:	0.1000E-23	1.00
35:	0.1000E-23	1.00
36:	0.1000E-23	1.00
37:	0.1000E-23	1.00
38:	0.1000E-23	1.00
39:	0.1000E-23	1.00

Stability Criteria for Numerical Integration

System	Maximum Concentration
1	1000000.00
2	1000000.00
3	100.00
4	100.00
5	100.00
6	100.00

Molecular Wt. for Chemical 2 was 0, set to 1

Molecular Wt. for Chemical 2 was 0, set to 1

APPENDIX I – SUPPORT OF STAKEHOLDER ACTIVITIES

Appendix I1 - Slides Presented at Stakeholder Meetings (Electronic)

Appendix I2 - Response to Comments from Oxy Vinyls on Final report WO4

TOTAL MAXIMUM DAILY LOADS FOR DIOXIN IN THE HOUSTON SHIP CHANNEL

Response to Comments from Oxy Vinyls/Daniel Smith on the Final Report for WO4

On February 16, 2004, Oxy Vinyls submitted comments on the final report for Work Order 4 of the dioxin TMDL project. The comments were written by Dan Smith from Conestoga-Rovers & Associates of Exton, PA. The main concerns/comments expressed by Dr. Smith can be summarized as follows:

- The underlying assumption of steady-state is critical, unproven, and potentially incorrect,
- Estimates of the BAF and BSAF should be reconsidered, and
- Trends in concentrations of persistent toxic substances (PTS) in fish are not good indicators of external loading.

The following document addresses the issues raised by Oxy Vinyls and provides additional data to clarify the responses. Prior to addressing the Oxy comments, the following noteworthy considerations with regard to dioxins in the Houston Ship Channel (HSC) are listed to provide a framework for the discussion:

- The HSC has received dioxin inputs for many years, including historical paper and pulp mill discharges and on-going inputs from air and water sources.
- The HSC, unlike the Great Lakes, is a riverine system that is tidally influenced. As such, it presents its own unique set of flow and fate and transport dynamics that need to be understood and related to the observed dioxin levels in the various media.
- The channel is continuously dredged and the relationship between the dredging activities and the dioxin pollution has not been studied yet.
- In contrast with PCBs in the Great Lakes, the HSC dioxin issue has only recently been studied through the TMDL process. The data gathering process is on-going as is the modeling and assessment of sources and pathways.

The following sections address each of the Oxy comments and provide data and information related to the issues discussed.

- **The underlying assumption of steady-state is critical, unproven, and potentially incorrect.**

Technically, and in the context of water quality modeling, steady-state is understood to mean a lack of change in flow and loading (boundary) conditions over time, which should result in unchanging concentrations as predicted downstream. The project team is in agreement that dioxin loading to the system has changed and continues to change over time. However, and based on the data gathered to date, concentrations of dioxin in the HSC do not appear to change significantly over time (although the dataset is relatively limited). The assumption of steady-state conditions is appropriate in the context of the

QUAL-TX model. Transient source modeling is not possible due to the lack of dioxin loading data over time. The assumption of steady-state loadings may be appropriate given that dioxin concentrations in tissue and sediment do not appear to have changed over the last 10 years, even with the reductions from the paper and pulp mills. Also, the water concentrations measured during three different events in 2002 and 2003 do not show statistically significant differences (Figures 1 to 3).

Preliminary modeling using QUAL-TX was intended to provide a better understanding of the system and the aspects of the problem that may require further research. The QUAL-TX model was mainly developed for screening purposes and to examine loads and distributions in ambient water and the effect of the various flows into the system. More sophisticated modeling using WASP6 is planned. The project team intends to include all the major processes affecting dioxin concentrations in the HSC, including sediment resuspension (Figure 4).

The discussion above should be qualified by stating that the project team understands that the partitioning of dioxin among the various media and the dioxin loading from various sources constantly change over time and that at the local scale, the system may not be at steady-state. Furthermore, the project team understands the need for integrating the contributions from sediments to the water column concentration into the water quality model and plans to do so with more sophisticated models in the on-going Phase III of the TMDL.

The project team is in agreement that dioxins in bottom sediments and dissolved water do not seem to be at equilibrium as indicated by fugacity ratios different from 1 (Figure 5). It is noted, however, that the referred to water column measurements were taken at depths between 1-2 feet and would not be expected to be at equilibrium with deeper bottom sediments if the channel exhibits stratification. The possibility of stratification has not been addressed yet in this TMDL. In addition, it is pointed out that the sediment fugacity calculation is very sensitive to K_{oc} values (Figure 6), and given that site-specific K_{oc} measurements are not available, any assumption of flux direction (from sediment to water column or from water column to sediment) is fairly uncertain.

Disequilibrium seems to be randomly distributed along the HSC so, even though dioxin flux from sediment could be a source of dioxin to the water column, it does not explain the very high concentrations observed at specific locations. Furthermore, fingerprint data from water are different from sediment fingerprints as indicated by Principal Component Analysis (Figure 7). This difference is especially significant for stations 15979 and 11193, which exhibit the highest dioxin concentrations in the HSC. If sediment resuspension were the major source of contamination into the water column, the fingerprints would match. This difference in congener signatures may suggest the presence of additional/continuous sources at those locations, and possible stratification effects.

Regarding system response time, the Oxy document points out correctly that in systems such as Lake Ontario, fish tissue response to reduced loadings may occur over time scales

of decades or more. However, the HSC system is drastically different from Lake Ontario. Water residence time in the HSC system is 10-100x shorter than that in Lake Ontario. Also, 1-2 feet of sediments are deposited each year in the HSC, which are dredged every few years. By contrast, sediment deposition rates in Lake Ontario are probably on the order of 1 cm/year. As it is pointed out in the Oxy comments, the short water residence times and high sediment dredging and removal rates imply that dioxin concentrations in sediment and water should respond more rapidly to changes in external loading.

The correlation pointed out in the Oxy comments between sediment deposition rate and model error (predicted-observed dioxin concentrations in water) is interesting, but is opposite to what the project team would expect – i.e., high sediment deposition areas should be more in equilibrium with water concentrations. This relationship does not support the hypothesis that the major dioxin source is internal loading from historical contamination of HSC sediments, as suggested in the Oxy document. One scenario that may reconcile the observations would involve rapid downstream migration of historically contaminated dioxin-laden sediments from one or more tributaries into the HSC, without substantial mixing into the water column. However, measurements to date have not turned up an extremely contaminated sediment source.

Finally, it is noted that the sediment mass balance presented in Section 4.4 of the October 2002 report was preliminary and based on an overall assessment of dredging records. A more thorough look at dredging activities and their relationship to dioxin is underway. Several issues are noted: the water column within the ship channel itself (i.e. the 400 to 500 feet wide dredged pathway) is often thoroughly mixed by ship passage displacing water and "prop wash." An observer can see bottom sediment reaching the surface after a heavy-loaded ship passes. However, off to the side from the dredged channel, where ships do not go and where most sampling occurred, stratification may be more persistent. Also, from looking at some Corps of Engineers plans for HSC maintenance dredging, it is clear that only sediment that impinges on the flat bottom of the channel design cross section is meant to be removed. In many places, that does not include the entire width of the 400 foot cut, so not all sediment is removed when dredging occurs. Throughout much of the channel, including Segment 1006, only about half or less of the water surface width is in the Corps' maintenance dredging zone - some parts of the side areas are dredged by dock owners/operators, but not all. Finally, the channel has recently been deepened by several feet and increasing the channel depth may have cut into older sediments not previously reached by dredges, thus removing some of the older sediments. These complexities need to be understood and studied in the context of observed dioxin levels and the project team is currently undertaking a more thorough look at the available dredging records. Additionally, planned sediment core sampling will attempt to determine true deposition rates for the channel using geochronology.

While the project team agrees that fluxes from sediment could be a significant source of dioxins to the water column, the team does not discount the possibility of current and significant external sources of dioxin into the channel. This is still under study. The data gathered to date suggest that there is a continuous load of dioxins to the sediment.

- **Estimates of the BAF and BSAF should be reconsidered.**

As stated earlier, dioxin concentrations in the different media have not changed significantly over time. Thus, BAF ratios are not expected to significantly vary over time either. As a result of the last stakeholder meeting (January 7, 2004), Lial Tischler requested that the team evaluate the EPA approach for deriving congener-specific BAFs, BSAFs, and BEFs (EPA, 1995). In response to Dr. Tischler's comment, the project team evaluated three different methods for calculating congener-specific BAFs and BSAFs for the entire HSC (see Chapter 2, Quarterly Report 2-WO7). The three methods generate targets for the various congeners and the correlations used to develop those targets are statistically weak indicating high uncertainty in the results. An alternate approach may be needed. For example, and according to EPA (2003), proper use of BAFs for compounds like dioxin should be based on water and tissue concentrations that are averaged over a lengthy period of time (like months to years) and a significant area (not one station, but entire water body). EPA's reasoning in this approach is intended to reflect the fact that long-term exposure is the real human-health concern, and to reduce the difficulty of dealing with short-term/short-range changes in concentrations (which fits the steady-state model context too). It is also noted that the request by Lial Tischler appears to be opposite of the Oxy comment regarding estimation of site-specific BAFs and BSAFs. Oxy Vinyls, Lial Tischler, and the project team will need to discuss these differing opinions and resolve this issue.

BAFs and BSAFs are being used as simple empirical factors to relate tissue concentrations to concentrations in sediment and water. Clearly, the project team found that at sites where dioxins were high in tissue, they also tended to be high in sediment and water. While the relationships are not as strong as would be hoped, perhaps due to non-equilibrium, they are adequate for use in developing water quality targets for TMDL purposes.

Additionally, it is pointed out that the log of tissue/dissolved and tissue/sediment ratios do not vary significantly along the HSC as indicated in Table 2. Thus, the average log BAF and log BSAF are considered to be fairly representative of the whole system.

Finally, the project team has not attempted to establish a bioaccumulation model because the team feels that without good data on food web bioenergetics, a food web model is of no more value than the empirical BAF/BSAF approach, and may lead to inappropriate conclusions. Quantifying food web energetics would be a major data collection effort and is beyond the funded scope of Phase III of the TMDL.

Table 2. Average BAF and BSAF Ratios (± Standard Deviation) for Selected Congeners in the HSC

Ratio	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	2,3,7,8-TCDF	2,3,4,7,8-PeCDF
log BAF - Fish	4.969±0.300	4.873±0.193	3.650±0.467	4.637±0.294
log BAF - Crab	4.677±0.275	4.695±0.317	4.448±0.356	4.479±0.297
log BSAF - Fish	-2.060±0.549	-2.502±0.239	-3.331±0.741	-2.557±0.510
log BSAF - Crab	-2.320±0.505	-2.725±0.483	-2.377±0.625	-2.806±0.582

Notes:
Only detected concentrations were included in the analysis
The standard deviation is on average 7% and 19% of the average log BAF and log BSAF, respectively.

- **Trends in concentrations of PTS in fish are not good indicators of external loading**

Specific sites in the state of Texas where dioxins have decreased following pollutant reductions include International Paper on Sulphur River, Temple Inland on Sabine River, and Dow Chemical on Brazos River Tidal. Similar declines have not occurred in the HSC system. For example, data collected for 10 years at the San Jacinto Monument by GCWDA/Donohue Industries (Figure 2) indicate that, in general, there has been little change in congener concentrations with time. Linear regressions for each of the curves showed that, for most of the congeners the slope of the best-fit line was not significantly different from zero. The only exceptions were the congeners 2,3,7,8-TCDD, 1,2,3,4,7,8-HxCDD, 1,2,3,7,8,9-HxCDF, and 1,2,3,4,7,8,9-HpCDF, which exhibited a slightly increasing trend with time (p-values between 0.01 and 0.05 and r^2 between 0.3 and 0.5). Results from a Mann-Kendall test for this data set confirmed the results from the linear regressions. The total TEQ showed an increasing trend with time (*p*-value=0.05).

- **Specific comments**

Correlation between TOC in sediments and PCDD/PCDF, 2378-TCDD, and TEQ concentrations were recalculated using a non-parametric test to minimize the impact of outliers. As shown in Table 3, the correlations between TOC and PCDD/Fs and TEQ were strong (r=0.73 and 0.63, respectively), while 2378-TCDD was not strongly correlated with organic carbon in sediment (r=0.35).

Table 3. Spearman's Correlation between Dioxin Concentrations and TOC in Sediments from the HSC

	2378-TCDD (ng/kg dry wt)	Total TEQ (ng/kg dry wt)	Total PCDD/F (ng/kg dry wt)
Correlation Coefficient	0.3523	0.6385	0.7330
Sig. (2-tailed)	0.0030	1E-06	1E-06
N	69	83	83

All the correlations are statistically significant at the α=0.01 level.

REFERENCES

Govers, H.A. and H.B. Krop. **1998**. "Partition Constants of Chlorinated Dibenzofurans and Dibenzo-*p*-dioxins." *Chemosphere*, 37(9-12):2139-2152.

Jackson, D. R., M. H. Roulier, H. M. Grotta, S. W. Rust and J. S. Warner. **1986**. "Solubility of 2,3,7,8-TCDD in Contaminated Soils." In: Chlorinated Dioxins and Dibenzofurans in Perspective. C. Rappe, G. G. Choudhry and L. H. Leith (Eds.). Chelsea, MI, Lewis Publishers: 185-200.

Karickhoff, S.W., Brown, D.S., and Scott, T.A. **1979**. *Water Resources*, 13: 241-250.

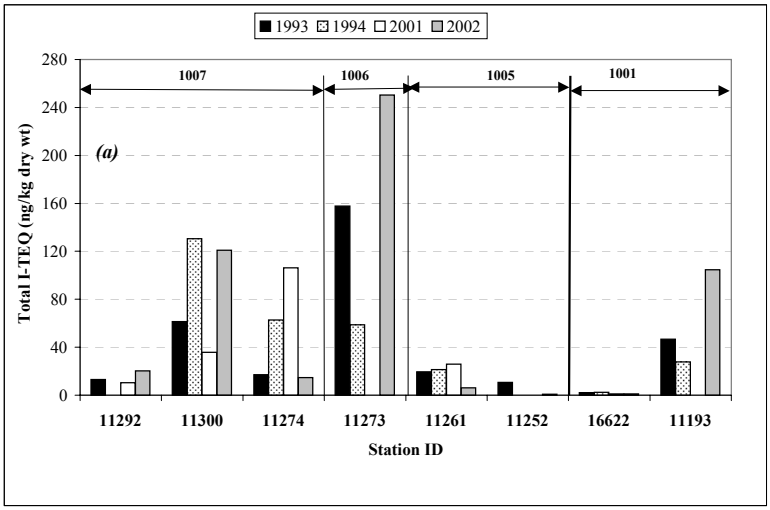
Puri, R. K., T. E. Clevenger, S. Kapila, A. F. Yanders and R. K. Malhotra. **1989**. "Studies of Parameters Affecting Translocation of Tetrachlorodibenzo-p-dioxin in Soil." *Chemosphere*, 18: 1291-1296.

Sarna, L. P., P. E. Hodge and G. R. B. Webster. **1984**. "Octanol-Water Partition Coefficients of Chlorinated Dioxins and Dibenzofurans by Reversed-phase HPLC using Several C18 Columns." *Chemosphere,* 13: 975-983.

Schwarzenbach, R.P. and Westall, J. **1981**. "Transport of nonpolar organic compounds from surface water to groundwater. Laboratory sorption studies." *Environmental Science and Technology,* 15(11):1360-1367.

U.S. Environmental Protection Agency. **1995**. "Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors." EPA-820-B-95-005. Office of Water, Washington, DC.

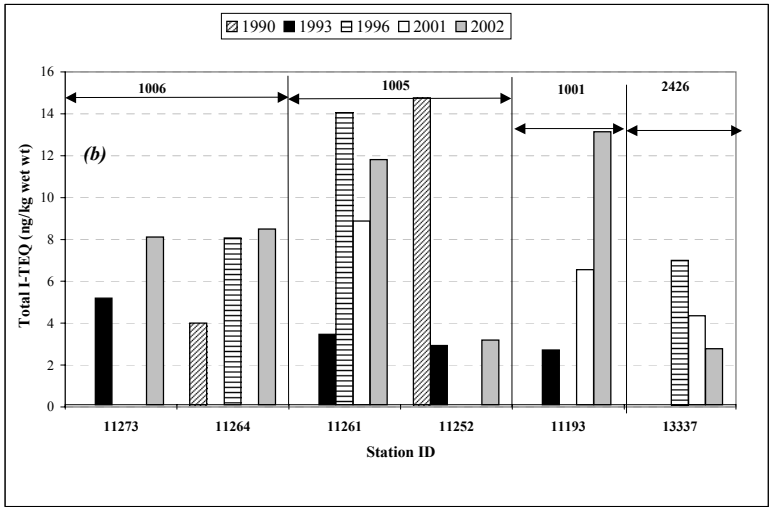
U.S. Environmental Protection Agency. **2003**. " EPA Methodology Guidance, Volume 2." EPA-822-R-03-030. Office of Water, Washington, DC.



ANOVA

Source of Variation	Between Groups	Within Groups	Total
SS	3395.64995	90805.56391	94201.2
df	3	23	26
MS	1131.88332	3948.067996	
F	0.28669296		
P-value	0.83449979		
F crit	3.02799918		

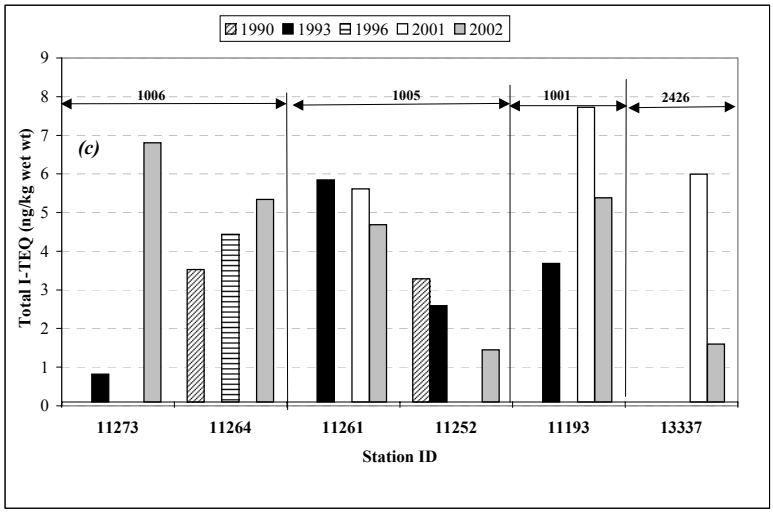
Data grouped by year. Groups are not statistically different.



ANOVA

Source of Variation	Between Groups	Within Groups	Total
SS	96.8143497	257.5309988	354.345
df	4	18	22
MS	24.2035874	14.30727771	
F	1.6916976		
P-value	0.19569215		
F crit	2.92774871		

Data grouped by year. Groups are not statistically different.

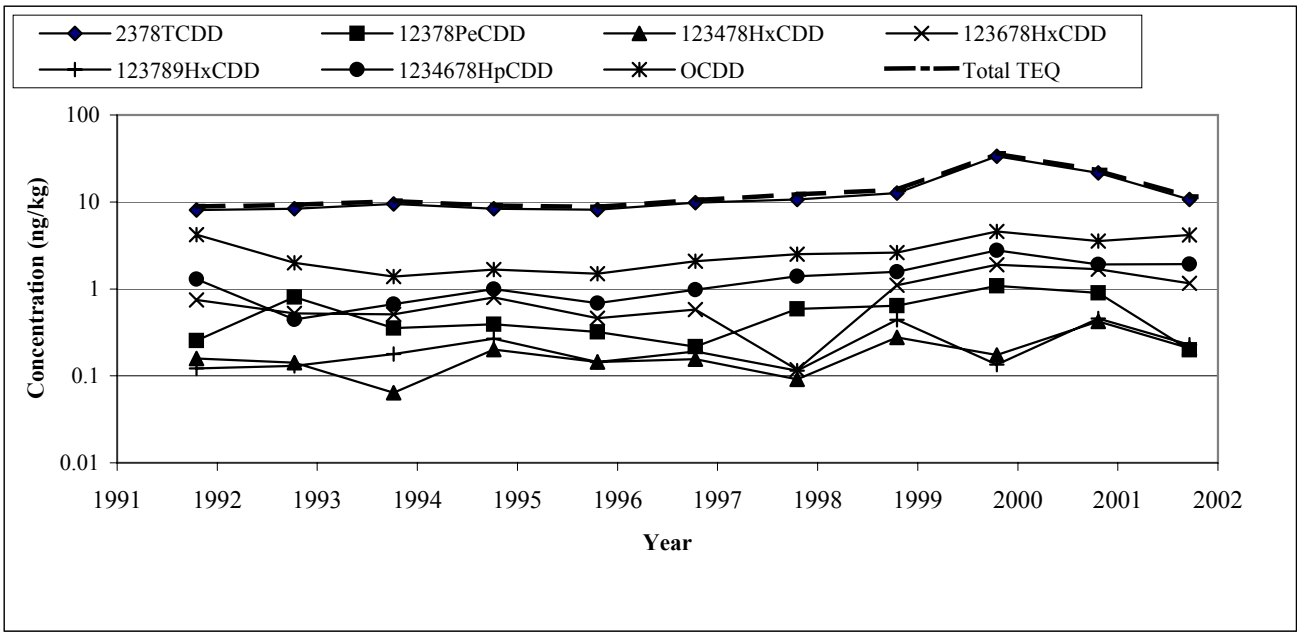


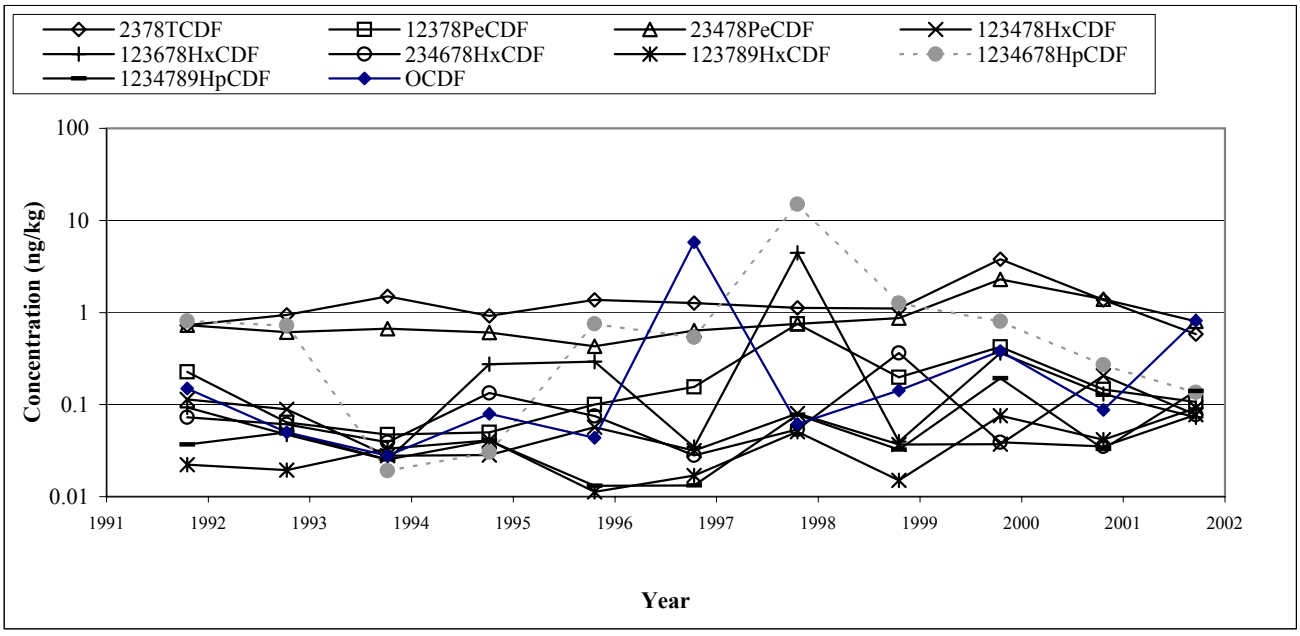
ANOVA

Source of Variation	Between Groups	Within Groups	Total
SS	6.61257957	89.76005969	96.3726
df	4	18	22
MS	1.65314489	4.986669983	
F	0.33151279		
P-value	0.85313425		
F crit	2.92774871		

Data grouped by year. Groups are not statistically different.

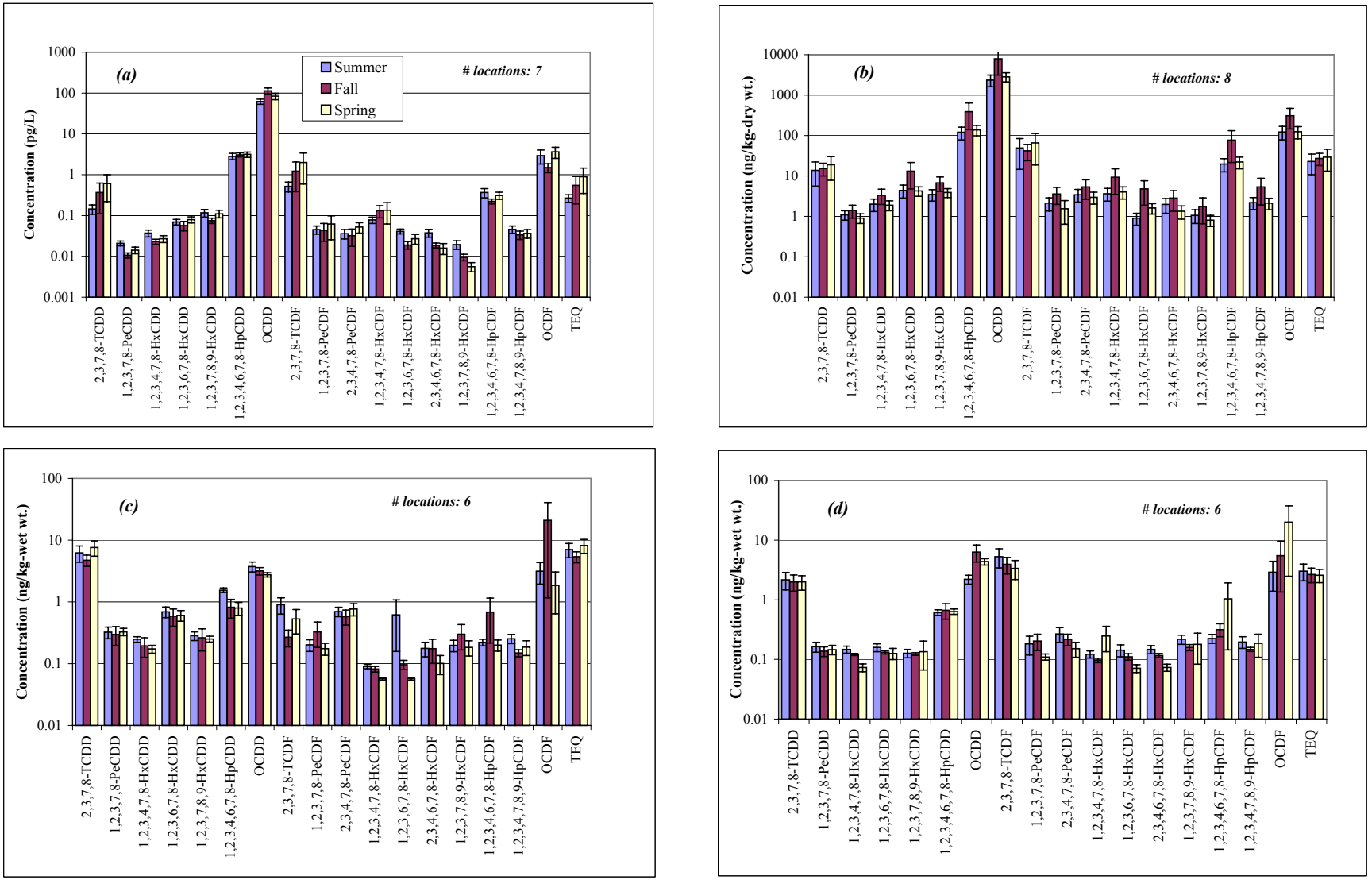
Figure 1. Comparison of Past and Current TEQ Levels in (a) Sediment, (b) Catfish, and (c) Crab from the HSC





Data from GCWDA/Donohue Study (1992-2001) and this study (2002)
Data normalized to 3% lipid content

Figure 2. Time Series of Dioxin Concentrations in Catfish at San Jacinto Monument



Error bars represent the standard error of the mean for each data set.

Figure 3. PCDD/PCDF Congener Profiles

(a) Water (b) Sediment (c) Fish (d) Crab

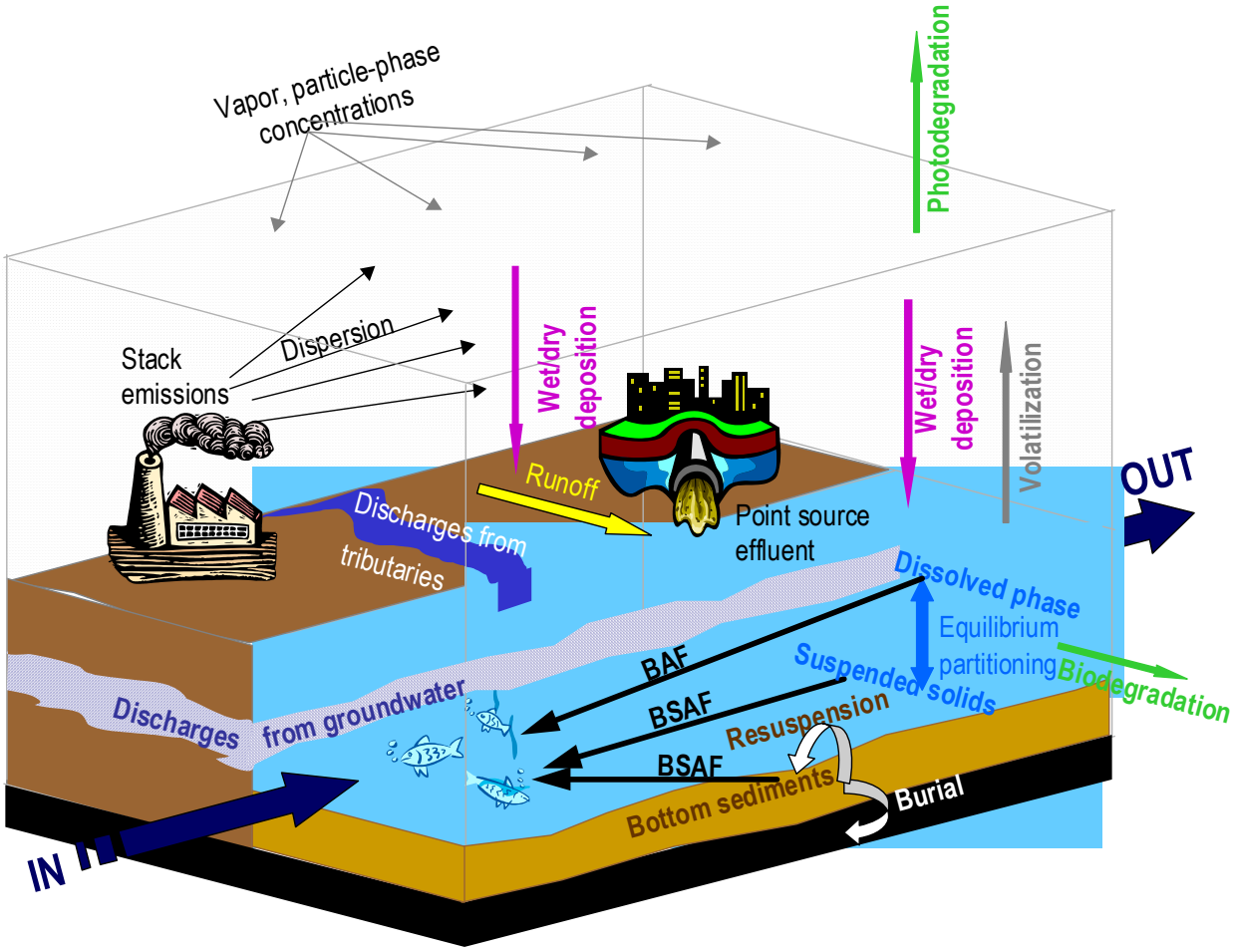
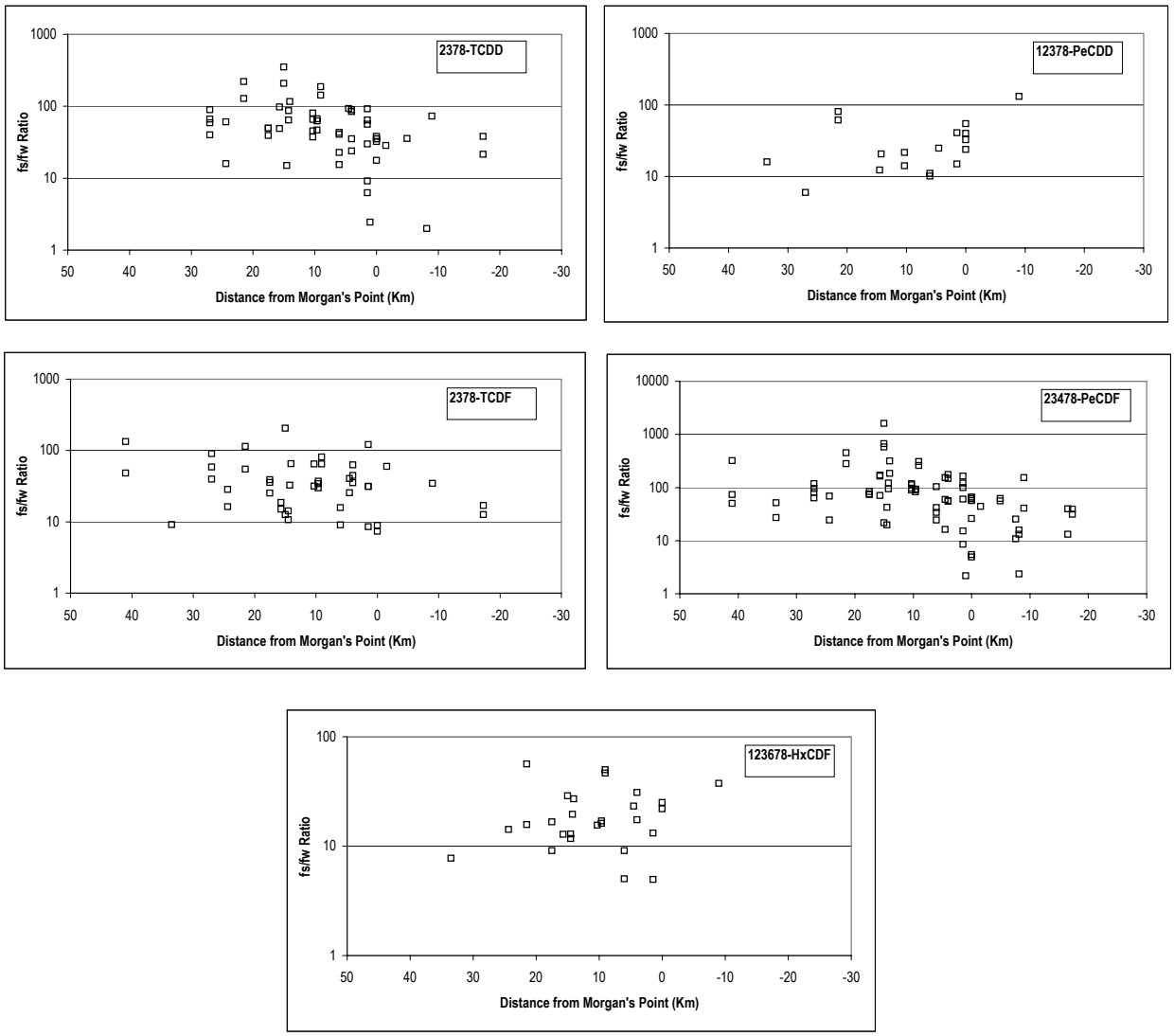


Figure 4. Conceptual Model for Dioxins in the HSC

Parameter		2,3,7,8-TCDD	1,2,3,7,8-PeCDD	2,3,7,8-TCDF	2,3,4,7,8-PeCDF	1,2,3,6,7,8-HxCDF
H [Pa m^3/mol][a]		3.311	1.479	1.175	0.575	1.096
log Kow[a]		6.96	7.50	6.46	7.11	7.57
log Koc[b]		5.50	5.89	5.14	5.61	5.94
Water Fugacity [Pa]	min	5.02E-14	9.43E-15	4.22E-14	5.34E-15	5.18E-15
	25th	3.81E-13	1.94E-14	1.93E-13	1.50E-14	1.09E-14
	50th	5.28E-13	2.64E-14	5.34E-13	2.22E-14	2.71E-14
	75th	7.68E-13	3.97E-14	8.24E-13	3.51E-14	3.58E-14
	max	2.68E-12	1.00E-13	3.43E-12	9.05E-14	9.79E-14
Sediment Fugacity [Pa]	min	8.72E-13	1.58E-13	1.07E-12	9.02E-14	1.27E-13
	25th	6.65E-12	5.23E-13	1.00E-11	4.77E-13	3.04E-13
	50th	2.57E-11	7.74E-13	5.09E-11	9.32E-13	4.93E-13
	75th	3.82E-11	9.79E-13	7.66E-11	1.23E-12	8.00E-13
	max	5.91E-10	2.67E-12	1.55E-09	6.11E-12	5.53E-12

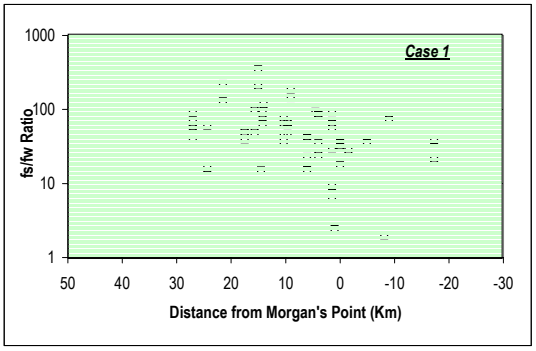
[a] From Govers and Krop, 1998

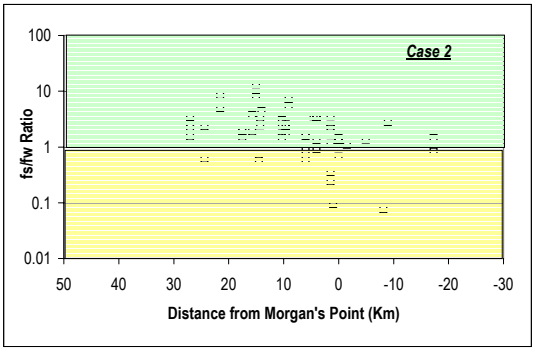
[b] Relationship reported by Schwarzenbach and Westall (1981) $log\ K_{oc} = 0.72 * log\ K_{ow} + 0.49$

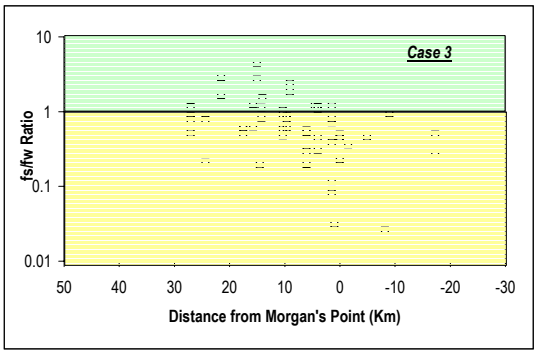


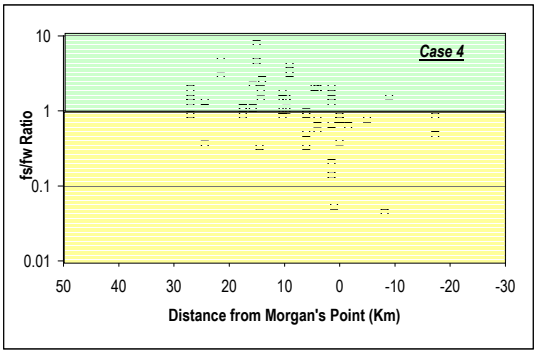
NOTE: Only detected concentrations were used for the calculations

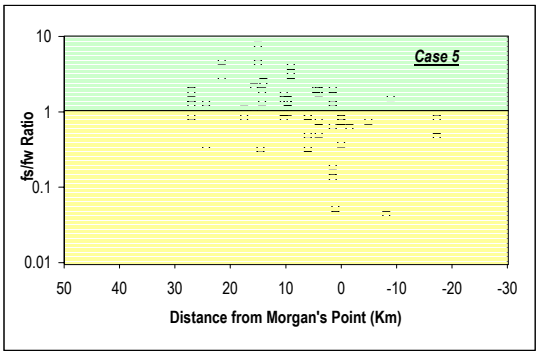
Figure 5. Sediment/Dissolved Fugacity Ratios for Selected Congeners

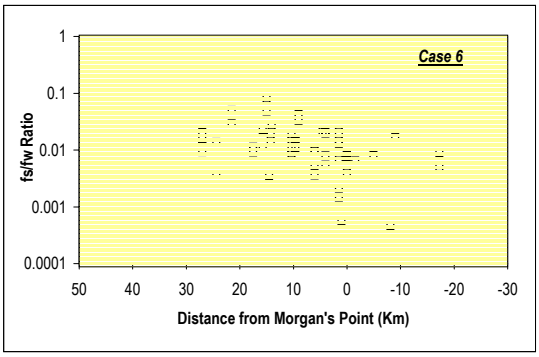


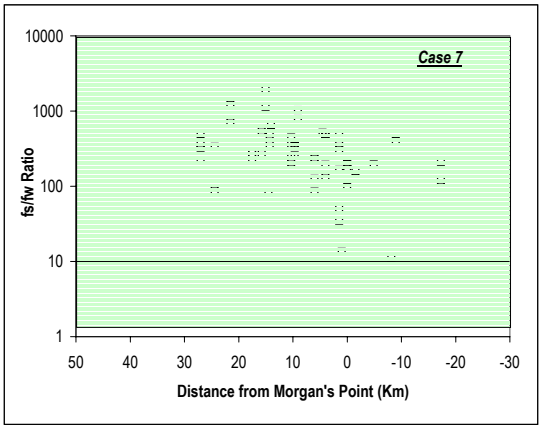










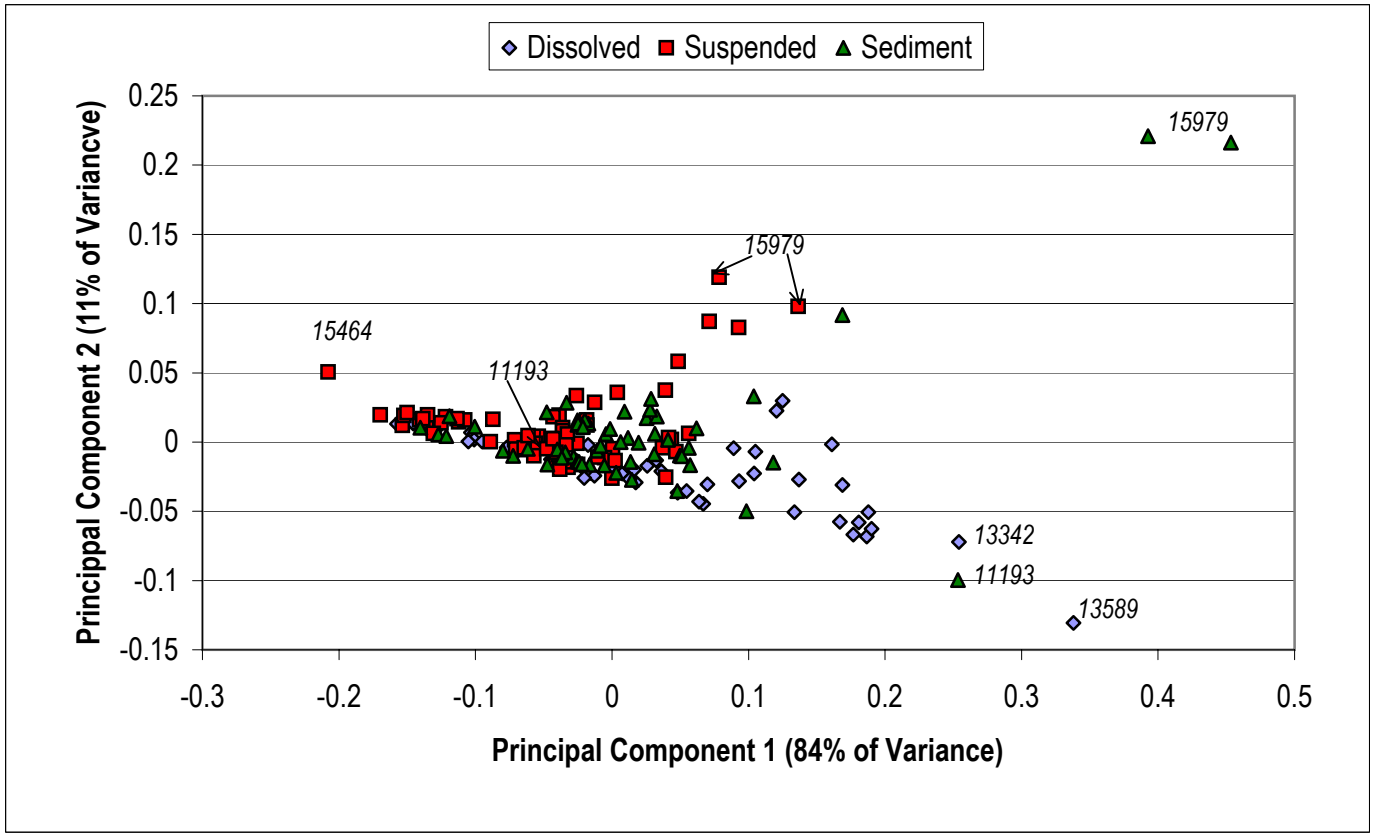


Case	Description
1	log K_{ow}=6.96[a], log K_{oc}=0.72*log K_{ow}+0.49[b]
2	log K_{ow}=8.93[c], log K_{oc}=0.72*log K_{ow}+0.49[b]
3	log K_{oc}=7.39[d]
4	log K_{oc}=7.15[e]
5	log K_{ow}=6.96[a], log K_{oc}=log K_{ow}+0.21[f]
6	log K_{ow}=8.93[c], log K_{oc}=log K_{ow}+0.21[f]
7	log K_{oc}=4.76[g]

[a] From Govers and Krop, 1998
[b] Relationship reported by Schwarzenbach and Westall (1981)
[c] From Sarna *et al* ., 1984
[d] From Jackson *et al* ., 1986 (measured in soil)
[e] Average log sediment-oc/dissolved ratios measured in this project
[f] Relationship reported by Karickhoff *et al* . (1979)
[g] From Puri *et al* ., 1989 (measured in 45% sand 35% silt soil)

Notes:
Green shading indicates 2378-TCDD flux from sediment to water column
Yellow shading indicates 2378-TCDD flux from water column to sediment
Only detected concentartions were used for the calculations

Figure 6. 2378-TCDD Sediment/Dissolved Fugacity Ratios for Various K_{oc} Values



Notes:

Sediment concentrations not normalized by organic carbon content

Only detected concentrations were used in the analysis

PCA analysis conducted with the ratio (homolog group concentration/total dioxins+furans)

Figure 7. Principal Component Analysis for Dioxin Concentrations in Water and Sediment