Total Maximum Daily Loads for Dioxin In the Houston Ship Channel

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Load Allocation Document – Revision 4

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ACRONYMS AND ABBREVIATIONS

HSC	Houston Ship Channel
BAF	bioaccumulation factor
DD	direct deposition
dS	sediment loading
kg	kilogram
LA	load allocation
ng	nanogram
pg/L	picogram per liter
PS	point source
RO	runoff
TDSHS	Texas Department of State Health Services
TEF	toxicity equivalent factor
TEQ	toxicity equivalence
TMDL	total maximum daily load
WASP	Water quality analysis simulation program
WQ	water quality

ALLOCATION PROCESS

The model system (RMA2 + WASP) used for the Houston Ship Channel (HSC) dioxin project integrates the basic conceptual equation across time and space while incorporating transport and other physical phenomena that affect water quality. The summary spreadsheet organizes the model results into long-term averages amenable to use in the total maximum daily load (TMDL) equation (see Modeling Report, University of Houston and Parsons 2008). Stated as an illustrative "equation," the model predicts

Water quality (WQ) = function of (*flow, physical processes, point source, runoff, direct deposition, sediment loads*)

or, in shorter form, WQ = f*(Q, PhysProc; PS, RO, DD, Sed)*

It should be noted that in the equation above, *Sed* represents the effect of sediment-source loading on predicted water column concentrations. Running the model does require that initial bed sediment concentrations be specified and those were established based on field data and through the model calibration process. Figure 1 presents the distribution of initial dioxin concentrations in sediment across the HSC system. Figure 2 shows the resulting average TEQ concentrations in the water column, calculated using the modeled concentrations for the six main congeners.

After the model is calibrated to observed data, it is applied in two different modes: analysis and allocation. The analysis mode uses the calibrated model to derive estimates of the effect of sediment-source dioxins on water column concentration, which could not be directly measured. The allocation mode then changes simulated loading to determine reductions needed to achieve predetermined water quality targets. Results from the allocation simulations are then summarized as the TMDL equation.

1. MASS-BALANCE SPREADSHEET FOR EXISTING CONDITIONS (ANALYSIS MODE)

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

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

The model predicts water quality as a function of loads, flows, transport, settling/ resuspension, etc. Using the calibrated model, water quality in the form of "net load" is predefined by the observed conditions within the channel. Loading from point sources (direct and from upstream freshwater tributaries), runoff (direct and from upstream freshwater tributaries), and direct deposition, plus flows, transport, and settling/ resuspension, were also predetermined based on calibration. In the spreadsheet, the HSC system was divided into 22 intercommunicated compartments as shown in Figure 3. A detailed description of the connections among compartment is presented in the Modeling Report (University of Houston and Parsons 2008).

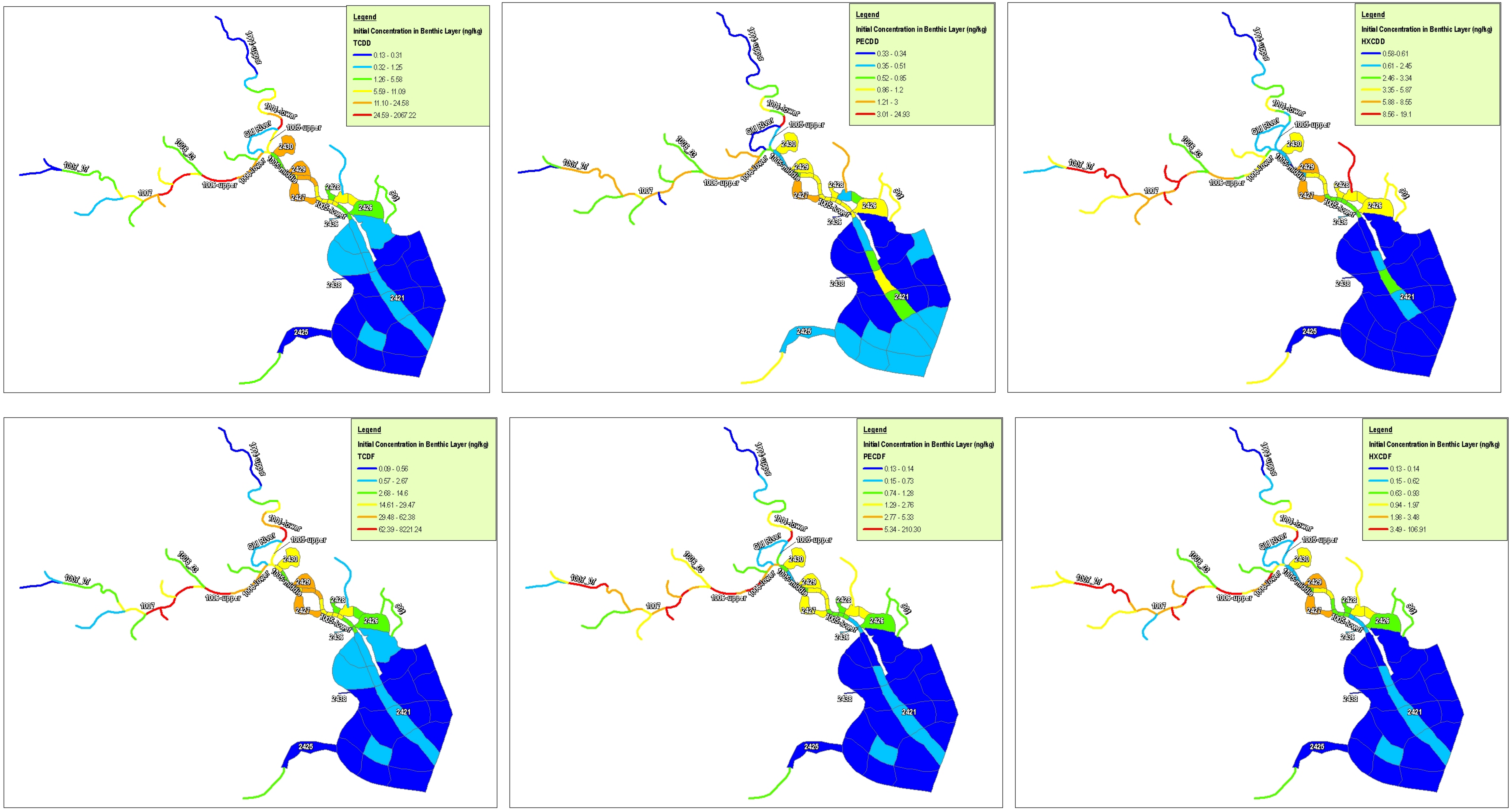


Figure 1 Distribution of Initial Dioxin Concentrations in Sediment in the WASP Model

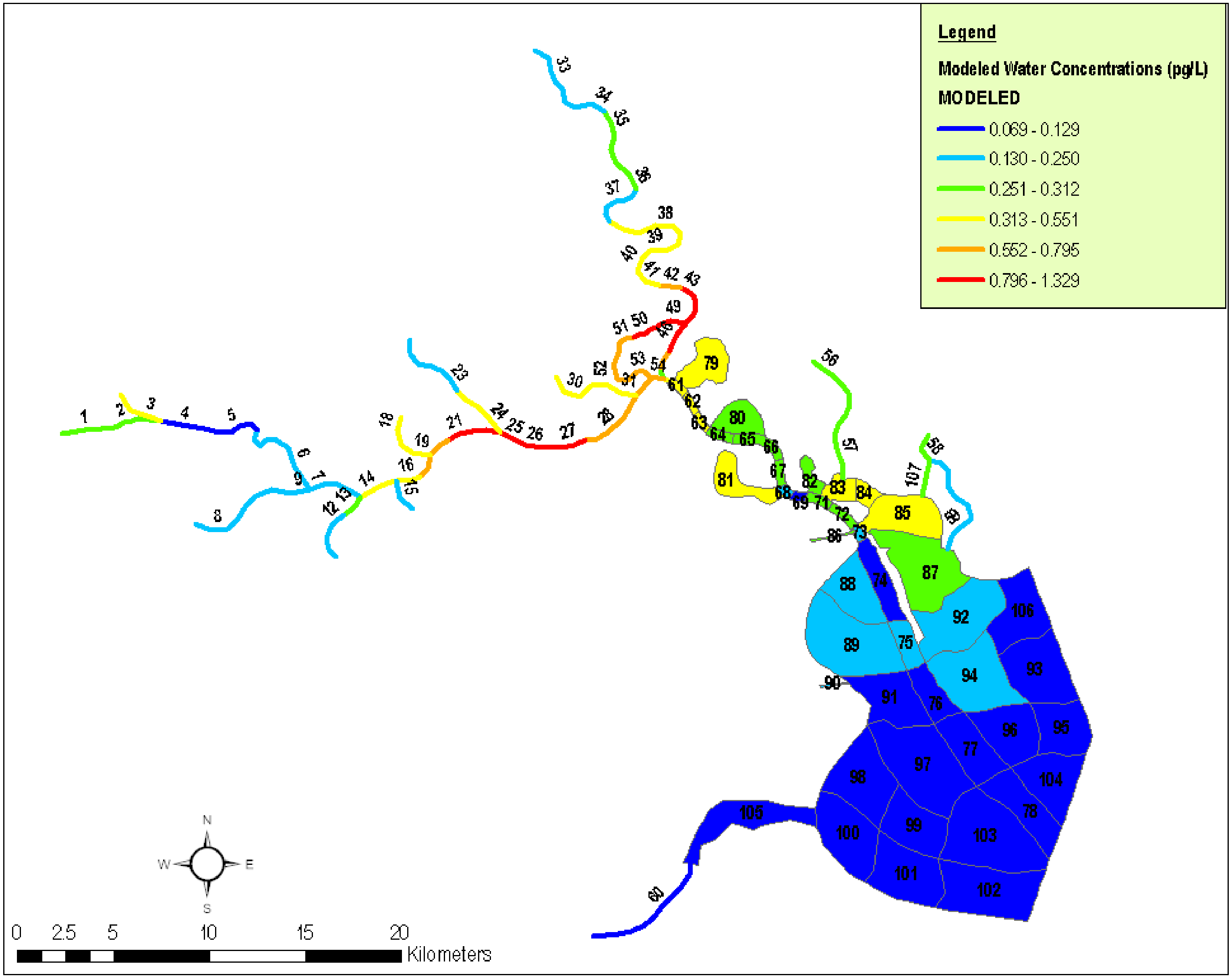


Figure 2 Modeled Average TEQ Concentrations by WASP Reach

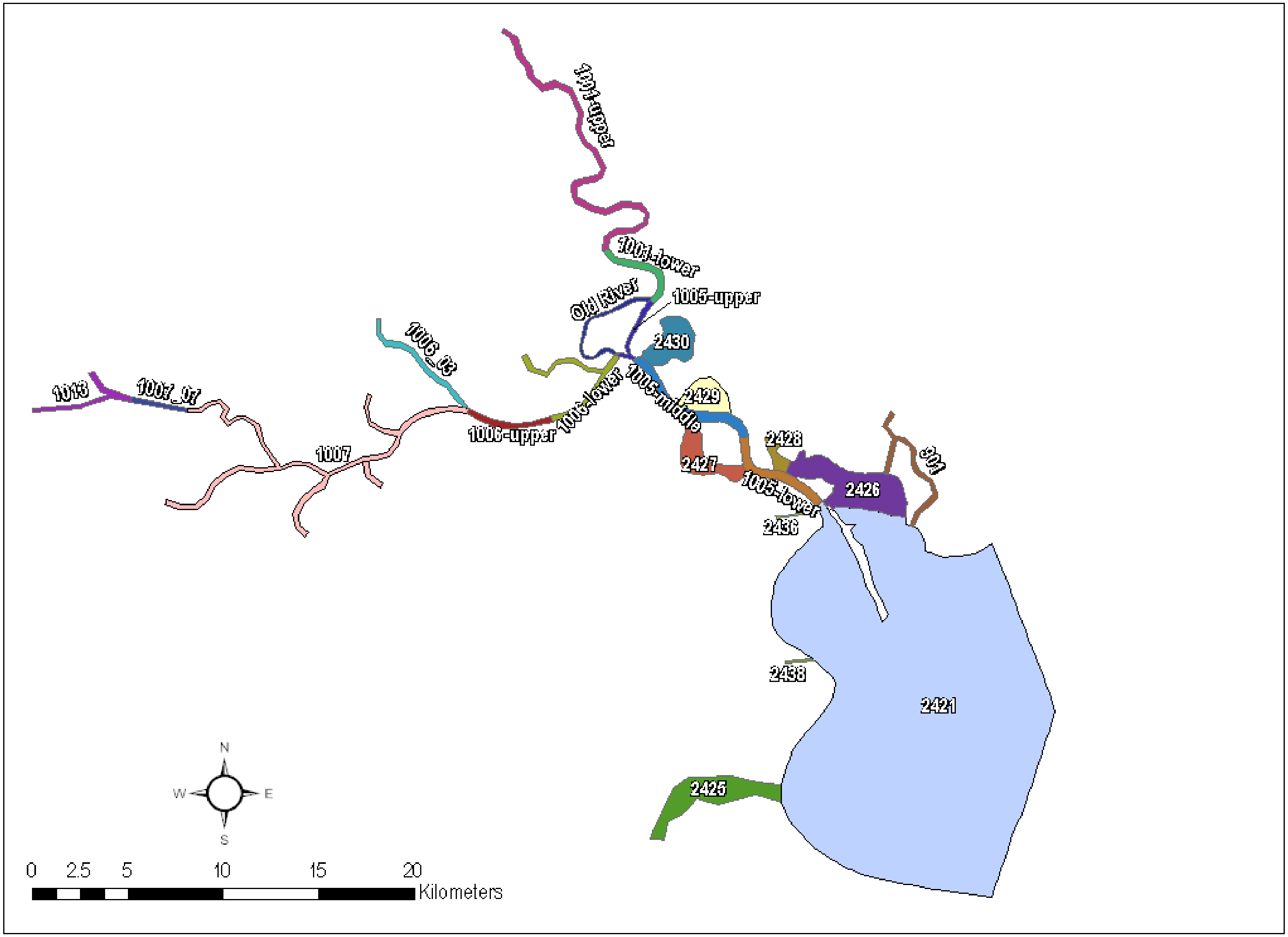


Figure 3 Spreadsheet Segmentation

For the HSC Dioxin TMDL project, the *dS* term in the loading equation above is used to estimate sediment loading effect. In the equation WQ = f(*Q, PhysProc, PS, RO, DD, U/S, Sed*), all terms except *Sed* are "known" and the summary spreadsheet is used to determine sediment loading using the following equation:

$$dS = \Sigma(Q_{outi}*C_{average}) - (PS + RO + DD + U/S + \Sigma(Q_{ini}*C_i))$$

When dS is positive, sediment resuspension or transport are indicated to be sources of dioxin loading to the water column. When dS is negative, sediment is a sink (water column dioxin settles or sorbs to bottom).

Transported sediment that accumulates due to channel hydraulic factors may be seen as a source in this analysis, so the model segments indicated to have sediment sources may not be the origin of the contaminated sediment. Because the channel is tidal and subject to back-and-forth flow, it is also possible that some transported load crossed and recrossed model segment lines and was "counted" more than once in summarizing the model. There is no discernable way to avoid that, but the extent to which it happens makes the analysis more conservative. However, the important point and conclusion from the analytical mode of model use is that sediment is a significant source of dioxin loading that affects water column concentrations, and by extension affects tissue concentrations as well.

Individual flux spreadsheets were developed for the six congeners modeled in WASP and the results were included in the Modeling Report (University of Houston and Parsons 2008). However, given that the water quality standard for dioxins in Texas is in terms of TEQ and there are not standards defined for individual congeners, it is necessary to combine the individual spreadsheets into a single TEQ mass balance spreadsheet. This is accomplished by adding the columns from the various spreadsheets weighted by the respective toxicity equivalent factor (TEF). Table 1 presents the summary of the TEQ calibration spreadsheet.

The total sediment associated-dioxin load into the system (sum of positive dS values) was calculated to be 19,517,672 ng/day, which corresponds to 86% of the TEQ load into the system. On the other hand, 12,315,933 ng TEQ/day (sum of negative dS values) redeposit within the model extent during the simulation period. Therefore, 7,201,739 ng TEQ/day (the total net sediment load) are transported between model segments as sediment, as a daily average over the model period. So sediment transports about 69.7% of the average daily dioxin flux among the model segments.

Table 1 Mass-balance Spreadsheet for TEQ – Calibration Scenario

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)								% total load from sediment[c]
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS[b]	dS action	
1013	Buffalo Bayou	23.5	0	11,483	444	363,294	4,108	564,659	185,330	SOURCE	33.1%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	10,333	261	0	575,915	262,970	-323,538	SINK	
1007	1007	41.0	117,062	71,713	6,906	210,005	2,470,800	5,158,288	2,281,801	SOURCE	84.9%
1006_03	Greens Bayou Tidal	9.1	2,297	20,053	795	106,549	210,649	270,828	-69,515	SINK	
1006-upper	1006-upper	50.1	35,389	10,872	2,442	0	7,603,710	8,890,673	1,238,259	SOURCE	96.2%
1006-lower	1006-lower	50.4	20,068	10,760	3,053	12,273	9,027,631	8,217,018	-856,767	SINK	
1001-upper	San Jacinto River	138.1	5,232	34,273	3,102	1,465,952	1,584,340	3,785,431	692,533	SOURCE	31.5%
1001-lower	San Jacinto River	137.9	1,608	2,174	1,307	0	7,262,791	12,362,025	5,094,145	SOURCE	99.9%
Old River	Old River	-0.5	704	4,120	1,342	0	2,508,826	2,937,807	422,815	SOURCE	98.6%
1005-upper	1005-upper	188.3	1,815	547	1,655	0	18,938,278	26,208,253	7,265,959	SOURCE	99.9%
2430	Burnett Bay	-0.012	0	1,561	7,923	0	937,883	971,878	24,510	SOURCE	72.1%
2429	Scott Bay	-0.009	251	4,793	6,072	0	832,160	815,015	-28,261	SINK	
1005-middle	1005-middle	188.2	2,147	2,916	6,065	0	24,912,227	17,595,047	-7,328,308	SINK	
2427	San Jacinto Bay	-0.009	1,523	7,804	6,694	0	547,510	579,827	16,295	SOURCE	50.4%
2428	Black Duck Bay	-0.002	0	990	2,157	0	275,970	235,952	-43,165	SINK	
2426	Tabbs Bay	1.7	1,299	11,833	17,817	13,401	2,257,058	2,838,736	537,328	SOURCE	92.4%
2436	Barbours Cut	-0.0005	105	640	385	0	24,358	26,612	1,123	SOURCE	49.8%
1005-lower	1005-lower	186.9	3,817	1,103	4,663	0	15,854,312	17,621,468	1,757,573	SOURCE	99.5%
2438	Bayport Channel	0.0001	3,773	287	292	0	9,372	9,925	-3,798	SINK	
2421	Upper Galveston Bay	209.1	2,042	17,476	378,409	0	22,284,736	19,083,390	-3,599,272	SINK	
901	Cedar Bayou	2.7	0	22,888	439	10,954	86,470	109,835	-10,916	SINK	
2425	Clear Lake	2.0	0	50,500	673	0	416,659	415,441	-52,392	SINK	
OVERALL			199,132	299,117	452,897	2,182,429	118,625,762	128,961,075	7,201,738	SOURCE	69.7%[d]

[a] Load from upstream freshwater reaches outside of the HSC System
[b] ΣQoutCout – (PS+RO+DD+U/S+ΣQinCin) = dS.
[c] dS/(PS+RO+DD+U/S+dS)
[d] Average daily dioxin flux among the modeled segments transported by sediment

2. CONVERTING DIOXIN FLUXES INTO LOAD ALLOCATION EQUATIONS (ALLOCATION MODE)

The same basic model equation WQ = f(*Q, PhysProc, PS, RO, DD,U/S, Sed*) still applies, with the WQ values now defined by the calculated water quality targets, while *Q* and *PhysProc* remain as in the calibrated model. The loading sources are changed for sequential model simulations. Results of the model simulations are used to determine loading combinations predicted to attain the water quality targets. Attainment is defined as predicted average concentrations that are equal to or less than the target values.

The conceptual basic equation for the spreadsheet summary of model results is rearranged, with sediment-source load (*Sed*) now separated from internal loss/assimilation effects (dS).

$$PS + RO + DD + U/S + Sed = \text{gross load}$$

or, using notation for the standard TMDL equation,

$$WLA + LA = TMDL$$

The allocations are conceptually related to water quality targets via the model simulations.

$$WQtarget = f(\text{gross load} - \text{internal loss/assimilation} = TMDL - dS) = f[\Sigma(Q_{outi} * C_{average})] = f(\text{net load})$$

The model simulations establish the connection between water quality targets expressed as concentrations and loading, taking into account the effects of physical processes that assimilate some loading. Summary analyses of the model simulations that show attainment of the water quality targets provide the gross loads that quantify the TMDL allocation.

Sediment accumulation (dS) is generally not part of the TMDL equation, but it is important for comprehending how the system functions and determining how to manage pollutants. In the HSC, sediment contaminates fish/crabs, so ultimately the goal is for sediment accumulation to be zero, or as near zero as possible.

In the allocation mode, model simulations that begin with initial sediment concentrations of dioxins set to zero depict a *Sed* gross load of zero. Only two scenarios for initial sediment concentrations were simulated – as calibrated, and set to zero.

Loading rates for PS, RO, and DD sources are also stipulated in model inputs, but as constant loading rates rather than initial values. When a particular model simulation scenario has demonstrated that the water quality targets are met, the input values for PS, RO, and DD from that scenario can be used as components of the TMDL equation.

A first scenario, thereafter called Scenario A, was completed with model runs that met the water quality targets developed using site-specific bioaccumulation factors (BAF) (see University of Houston and Parsons 2007 for a description of how the WQ targets were derived). Figure 4 shows the distribution of average TEQ concentrations and Table 2 presents a summary of the spreadsheets developed for Scenario A, expressed as TEQ. The gross loads in Table 2 represent the TMDLs for the various water quality segments. Individual summary tables for the six modeled congeners are included in Appendix A. Comparing the TMDL to the existing load (Table 1), yields the load reductions required to reach the WQ targets (0.0533 pg TEQ/L for the six major congeners). Reductions as low as 49% and as high as 97% were estimated for the different segments for Scenario A. In addition, a comparison of the total $\Sigma Q_{in}C_{in}$ and $\Sigma Q_{out}C_{out}$ values to their respective counterparts in Table 1 shows reductions of 86 and 90% in the internal flux of dioxins, reflecting changes in the gross loading.

Because the sources that need to be removed to achieve attainment of the water quality targets vary by congener, an alternative scenario, Scenario B, was run removing the most significant source for total TEQ (e.g., sediment). This was done to compare the final TEQ concentrations to those obtained from Scenario A. The distribution of average TEQ concentrations along the HSC System is shown in Figure 5. Table 3 shows the TEQ mass balance spreadsheet for Scenario B and the individual summary tables for the six congeners are included in Appendix B. Table 3 includes alternative TMDL values and their respective load reductions. The estimated required load reductions for Scenario B ranged between 33% and 93%. Similarly to the analysis completed for Scenario A, a comparison of the total $\Sigma Q_{in}C_{in}$ and $\Sigma Q_{out}C_{out}$ values in Table 3 to their respective counterparts in Table 1 shows reductions of 78 and 79% in the internal flux of dioxins.

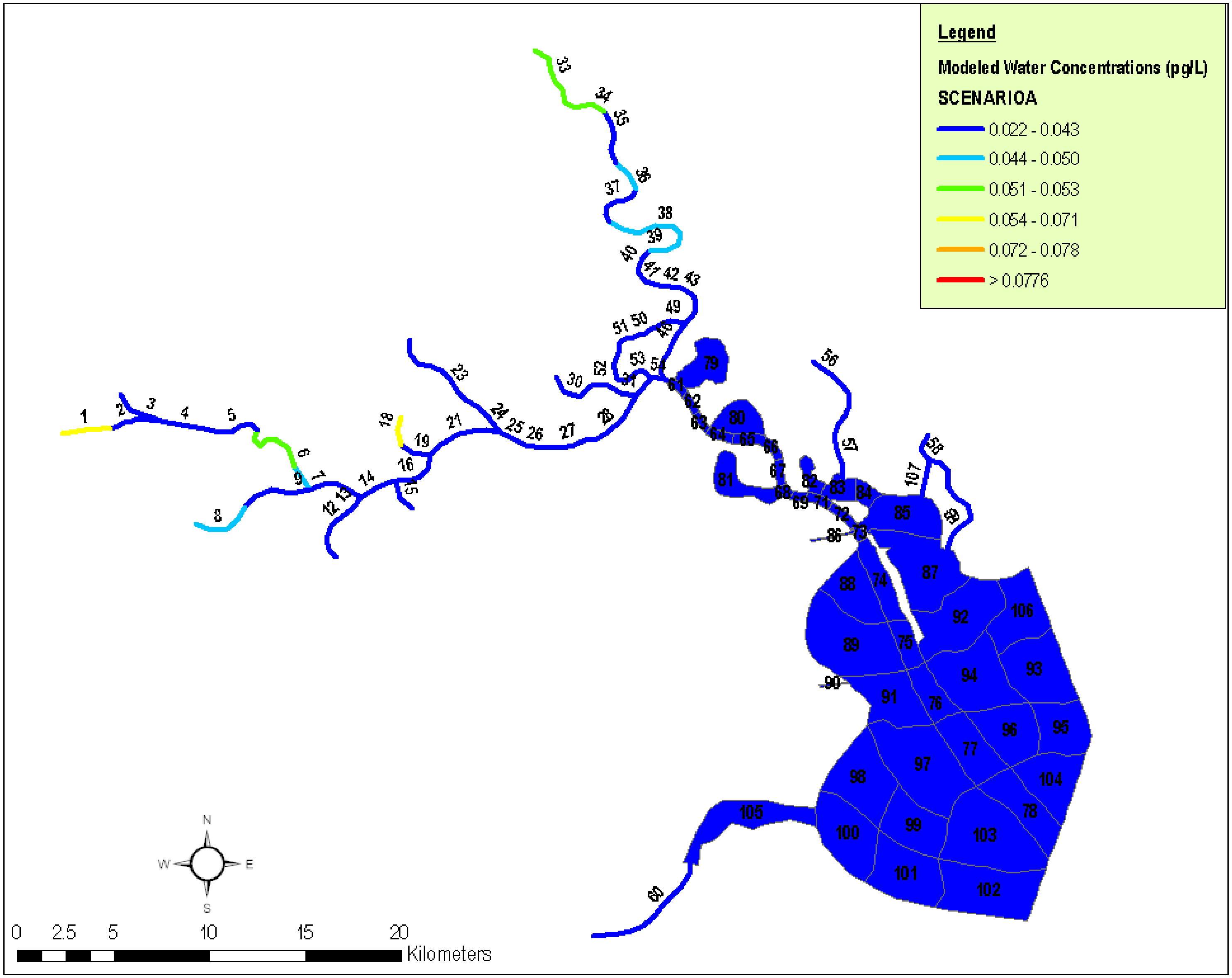


Figure 4 Modeled Average TEQ Concentrations for Scenario A

Table 2 Mass-balance Spreadsheet for TEQ –Scenario A[†]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	5,145	444	137,178	1,270	110,992	-33,045	144,037	564,659	74%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	4,633	261	0	114,628	80,430	-39,092	119,522	586,509	80%
1007	1007	41.0	66,615	32,131	6,906	103,767	128,270	297,004	-40,686	337,690	5,158,288	93%
1006_03	Greens Bayou	9.1	1,394	8,985	795	50,877	4,793	33,887	-32,957	66,845	340,343	80%
1006-upper	1006-upper	50.1	12,561	4,868	2,442	0	267,744	261,972	-25,643	287,615	8,890,673	97%
1006-lower	1006-lower	50.4	9,816	4,821	3,053	5,126	301,508	296,771	-27,555	324,326	9,073,785	96%
1001-upper	San Jacinto River	138.1	3,903	15,362	3,102	684,095	75,029	536,292	-245,198	781,489	3,785,431	79%
1001-lower	San Jacinto River	137.9	1,017	974	1,307	0	614,924	600,411	-17,812	618,223	12,362,025	95%
Old River	Old River	-0.5	489	1,845	1,342	0	89,831	97,157	3,650	97,157	2,937,807	97%
1005-upper	1005-upper	188.3	327	245	1,655	0	827,997	1,453,414	623,190	1,453,414	26,208,253	94%
2430	Burnett Bay	-0.01	0	700	7,923	0	43,459	45,120	-6,961	52,081	971,878	95%
2429	Scott Bay	-0.01	95	2,147	6,072	0	49,202	48,334	-9,182	57,516	843,275	93%
1005-middle	1005-middle	188.2	622	1,307	6,065	0	1,581,314	1,068,519	-520,788	1,589,307	24,923,354	94%
2427	San Jacinto Bay	-0.01	996	3,499	6,694	0	32,582	31,723	-12,048	43,771	579,827	92%
2428	Black Duck Bay	0.00	0	443	2,157	0	15,986	14,943	-3,644	18,586	279,117	93%
2426	Tabbs Bay	1.7	752	5,300	17,817	3,272	210,263	200,969	-36,436	237,405	2,838,736	92%
2436	Barbours Cut	-0.0005	69	287	385	0	2,276	2,255	-762	3,016	26,612	89%
1005-lower	1005-lower	186.9	2,844	494	4,663	0	1,289,290	1,226,091	-71,201	1,297,292	17,621,468	93%
2438	Bayport Channel	0.0001	2,074	128	292	0	2,147	2,203	-2,439	4,642	13,724	66%
2421	Upper Galveston Bay	209.1	1,545	7,831	378,409	0	11,110,547	6,242,893	-5,255,440	11,498,333	22,682,662	49%
901	Cedar Bayou	2.7	0	10,253	439	5,201	7,401	17,235	-6,059	23,293	120,751	81%
2425	Clear Lake	2.0	0	22,650	673	0	131,636	130,413	-24,546	154,959	467,833	67%
OVERALL			105,117	134,050	452,897	989,516	16,902,098	12,799,026	-5,784,653	19,210,519	141,277,008	86%

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (Table 1)
[†] Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.0533 pg/L for TEQ resulting from the six major congeners).

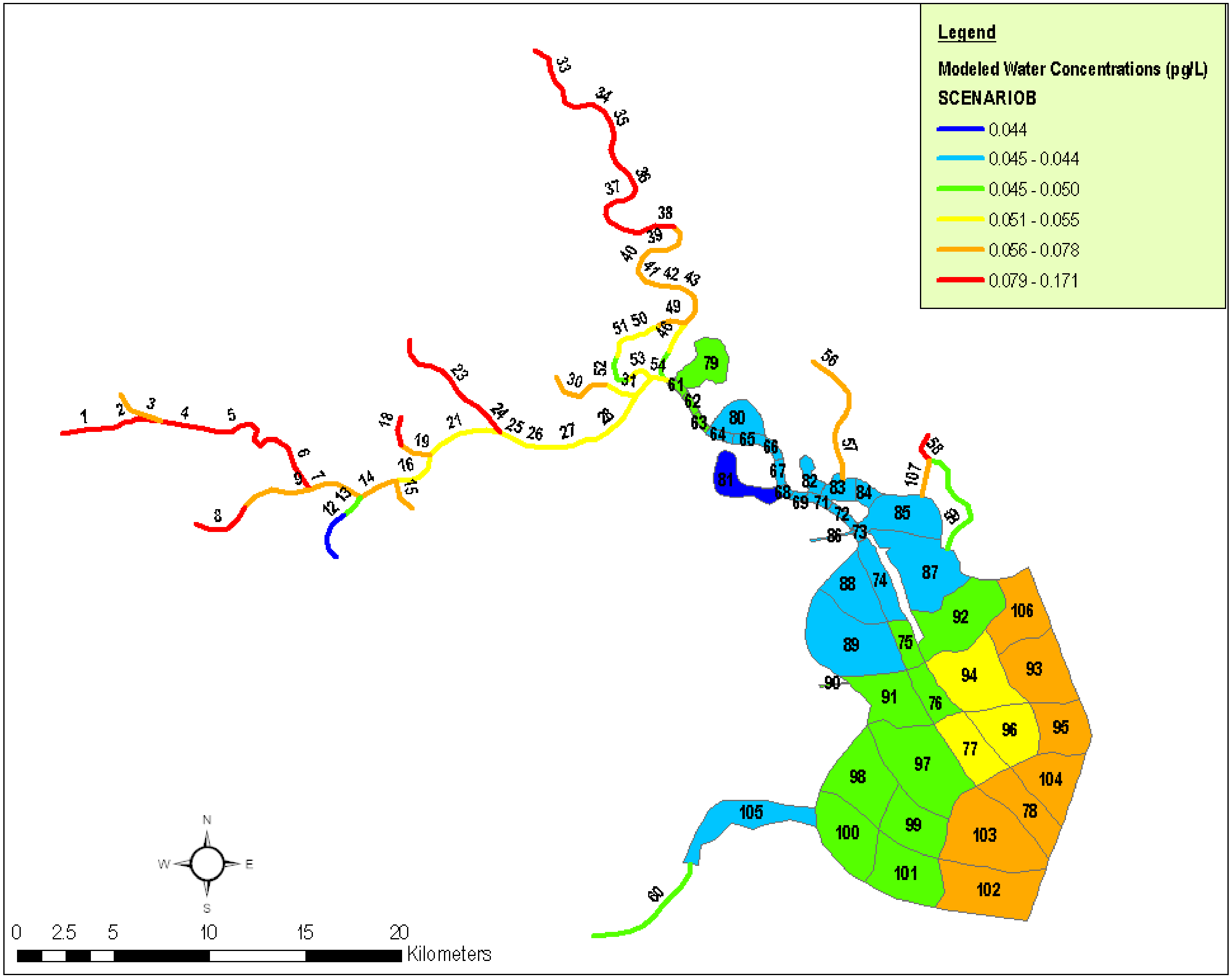


Figure 5 Modeled Average TEQ Concentrations for Scenario B

Table 3 Mass-balance Spreadsheet for TEQ – Scenario B[‡]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	11,483	444	363,294	3,385	274,753	-103,853	378,607	564,659	33%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	10,333	261	0	282,432	258,360	-34,666	293,026	586,509	50%
1007	1007	41.0	117,062	71,713	6,906	210,005	361,635	635,775	-131,547	767,322	5,158,288	85%
1006_03	Greens Bayou	9.1	2,297	20,053	795	106,549	10,119	105,908	-33,906	139,814	340,343	59%
1006-upper	1006-upper	50.1	35,389	10,872	2,442	0	621,829	594,064	-76,468	670,532	8,890,673	92%
1006-lower	1006-lower	50.4	20,068	10,760	3,053	12,273	692,687	696,364	-42,477	738,841	9,073,785	92%
1001-upper	San Jacinto River	138.1	5,232	34,273	3,102	1,465,952	130,899	1,290,245	-349,213	1,639,457	3,785,431	57%
1001-lower	San Jacinto River	137.9	1,608	2,174	1,307	0	1,445,061	1,389,511	-60,639	1,450,150	12,362,025	88%
Old River	Old River	-0.5	704	4,120	1,342	0	203,419	212,892	3,308	212,892	2,937,807	93%
1005-upper	1005-upper	188.3	1,815	547	1,655	0	1,962,978	3,760,947	1,793,953	3,760,947	26,208,253	86%
2430	Burnett Bay	-0.01	0	1,561	7,923	0	109,860	109,597	-9,746	119,344	971,878	88%
2429	Scott Bay	-0.01	251	4,793	6,072	0	140,222	136,478	-14,859	151,338	843,275	82%
1005-middle	1005-middle	188.2	2,147	2,916	6,065	0	4,067,229	3,158,682	-919,674	4,078,356	24,923,354	84%
2427	San Jacinto Bay	-0.01	1,523	7,804	6,694	0	76,540	73,087	-19,475	92,561	579,827	84%
2428	Black Duck Bay	0.00	0	990	2,157	0	34,717	33,530	-4,333	37,864	279,117	86%
2426	Tabbs Bay	1.7	1,299	11,833	17,817	13,401	401,731	370,944	-75,137	446,081	2,838,736	84%
2436	Barbours Cut	-0.0005	105	640	385	0	4,300	4,303	-1,128	5,431	26,612	80%
1005-lower	1005-lower	186.9	3,817	1,103	4,663	0	3,353,920	2,917,865	-445,639	3,363,503	17,621,468	81%
2438	Bayport Channel	0.0001	3,773	287	292	0	3,535	3,592	-4,295	7,887	13,724	43%
2421	Upper Galveston Bay	209.1	2,042	17,476	378,409	0	12,507,960	10,337,738	-2,568,148	12,905,886	22,682,662	43%
901	Cedar Bayou	2.7	0	22,888	439	10,954	14,642	48,225	-698	48,923	120,751	59%
2425	Clear Lake	2.0	0	50,500	673	0	197,350	181,938	-66,585	248,523	467,833	47%
OVERALL			199,132	299,117	452,897	2,182,429	26,626,451	26,594,799	-3,165,225	31,557,285	141,277,008	78%

[a] Load from upstream freshwater reaches outside of the HSC System

[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values

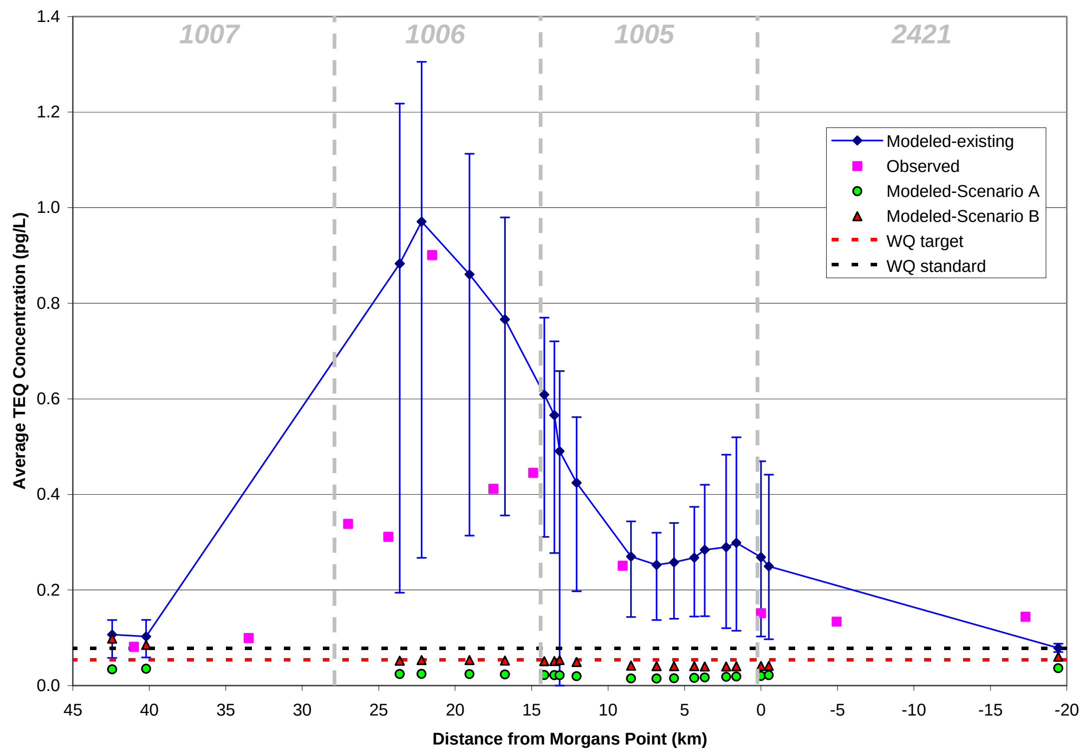
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (Table 1)

[‡] Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.

3. DEFINING AN ALLOCATION ALTERNATIVE

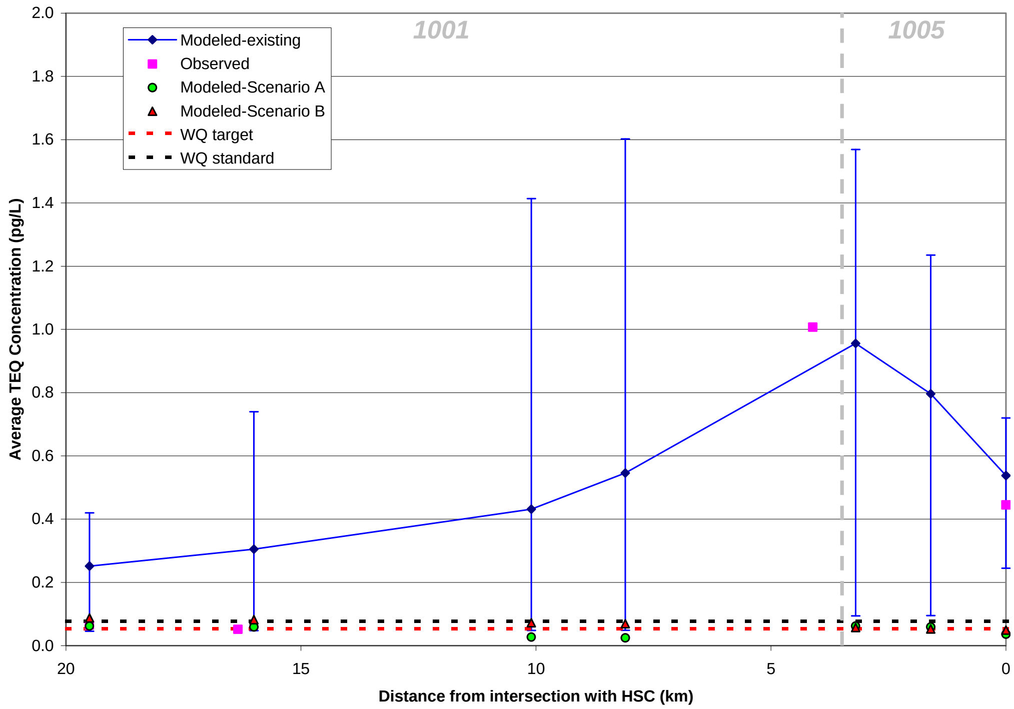
Load allocations can be performed using either Scenario A or Scenario B. In addition, load allocations can be based on the calculated HSC-specific water quality targets (WQ target in the figures, or 0.0533 pg TEQ/L) or on the Texas water quality standard (WQ standard in the figures, or 0.0776 pg TEQ/L).

To determine the alternative to follow, results from the three model scenarios discussed above are compared in Figures 6 through 9 for the main channel, San Jacinto River, Side Bays, and Galveston Bay. The observed and water quality target concentrations are also plotted to aid in the discussion.



*Error bars correspond to minimum and 90th percentile model concentrations for the calibration scenario. The WQ target is 0.0533 pg/L for the six modeled congeners, while the WQ standard for the six congeners is the Texas standard times the percent contribution of the six congeners to TEQ (0.0933*83.2% = 0.0776 pg/L).*

Figure 6 TEQ Concentrations in the Main Channel from Various Model Scenarios



*Error bars correspond to minimum and 90th percentile model concentrations for the calibration scenario. The WQ target is 0.0533 pg/L for the six modeled congeners, while the WQ standard for the six congeners is the Texas standard times the percent contribution of the six congeners to TEQ (0.0933*83.2% = 0.0776 pg/L).*

Figure 7 TEQ Concentrations in the San Jacinto River from Various Model Scenarios

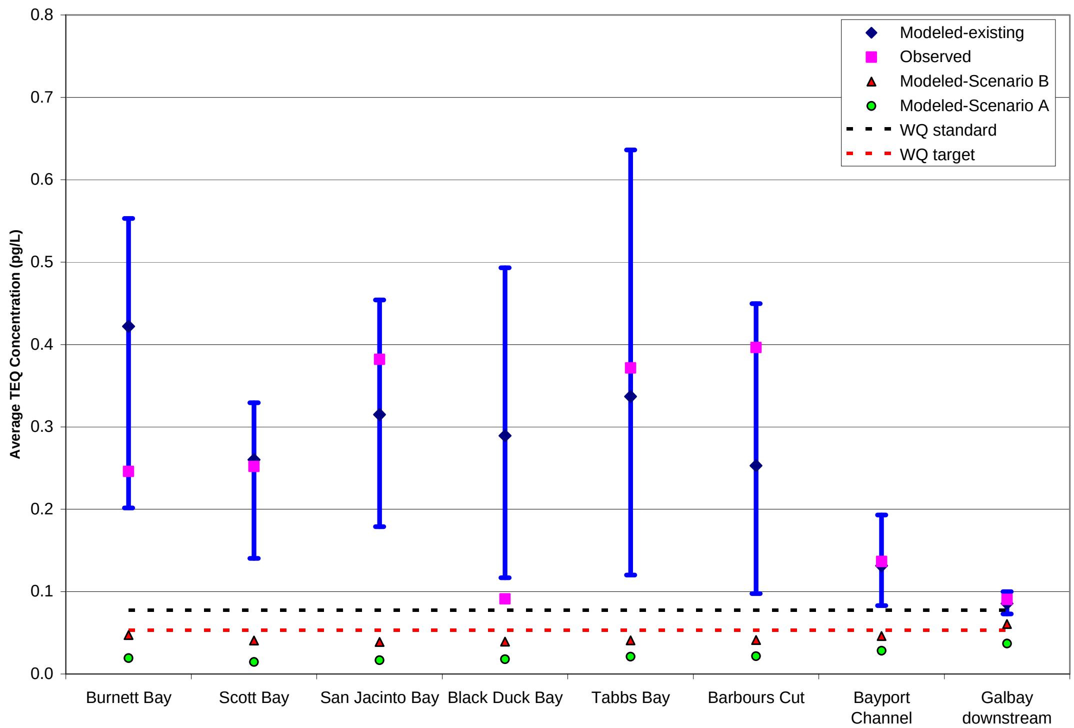
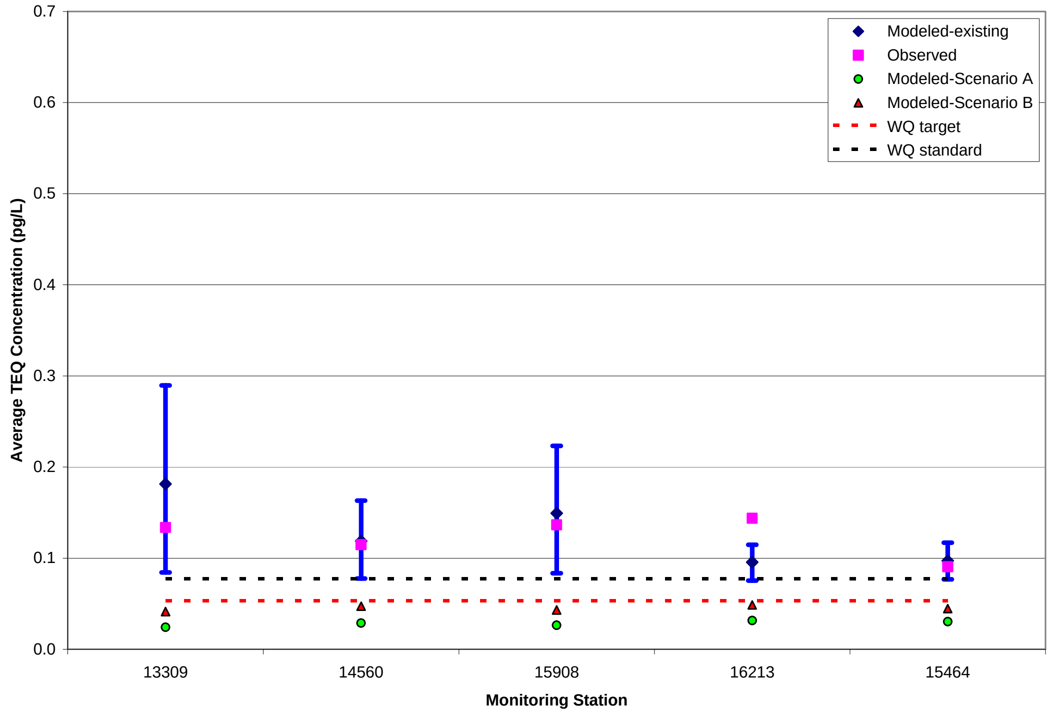


Figure 8 TEQ Concentrations in the Side Bays from Various Model Scenarios

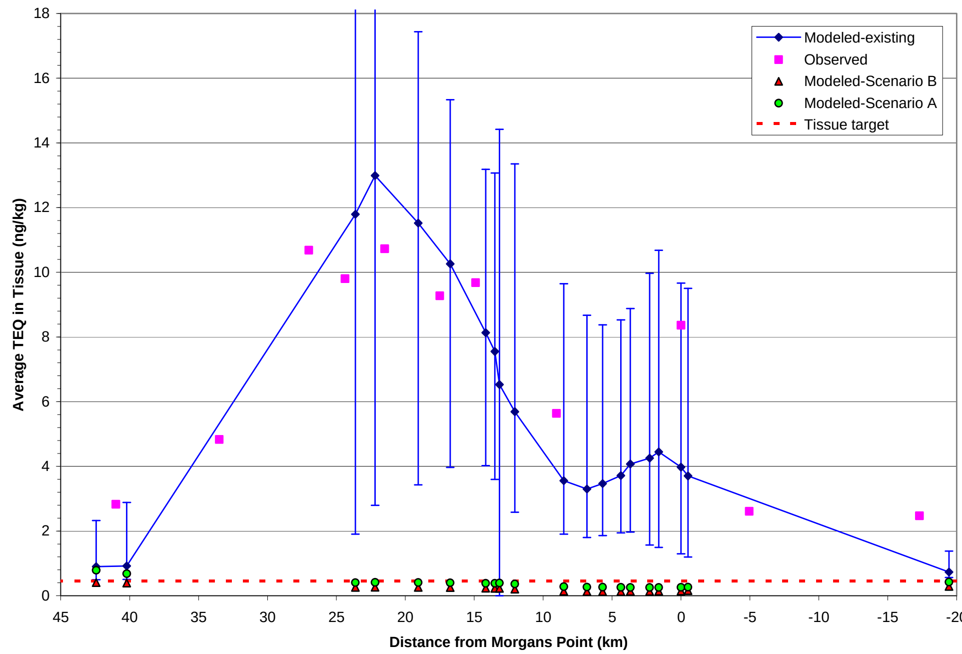


*Error bars correspond to minimum and 90th percentile model concentrations for the calibration scenario. The WQ target is 0.0533 pg/L for the six modeled congeners, while the WQ standard for the six congeners is the Texas standard times the percent contribution of the six congeners to TEQ (0.0933*83.2% = 0.0776 pg/L).*

Figure 9 TEQ Concentrations in Galveston Bay from Various Model Scenarios

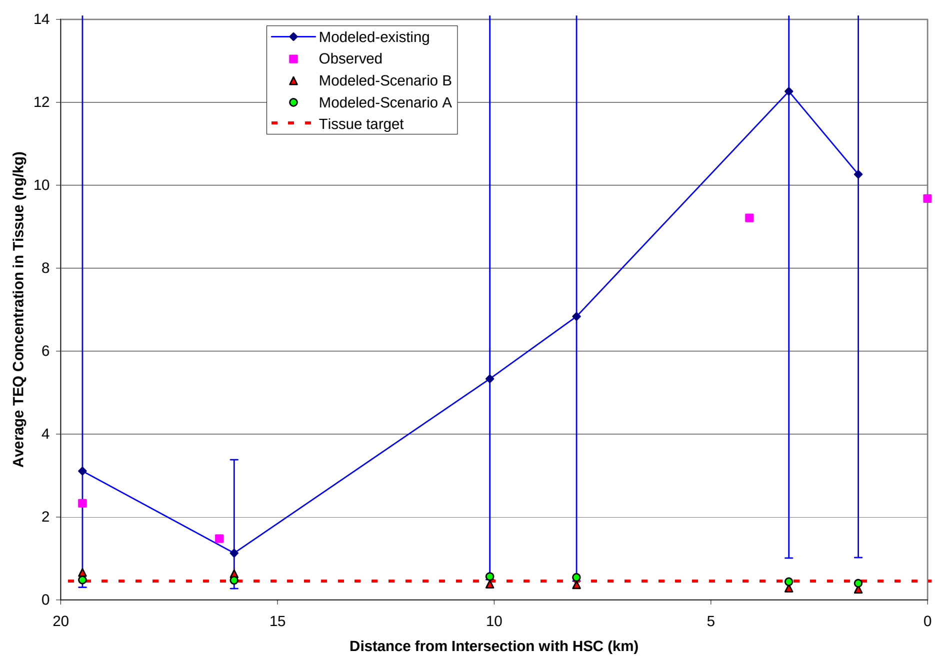
A review of the TEQ concentrations obtained from Scenarios A and B indicated that the WQ target (0.0533 pg/L) is exceeded respectively in 2 and 35% of the studied WASP reaches. The water quality standard (0.0776 pg/L for the six congeners) is not exceeded in any of the reaches in Scenario A and in 15% of the reaches for Scenario B. This may indicate that using Scenario A (and, thus, reducing point and non-point sources) is needed. However, a closer look at the results plotted in Figures 6 through 9 shows that Scenario B will result in average concentrations at or below the targets. This is because the majority of the reaches for which WASP predicts average concentrations higher than the targets correspond to sections of the model that over predicted the existing concentrations in the calibrated model (i.e., upstream reaches of the main channel and San Jacinto River). Other reaches predicted to exceed the targets include the boundary reaches for the freshwater tributaries, as well as the downstream boundary reaches in Galveston Bay. These concentrations may be over predicted as well since the upstream boundaries were set on the "high side" to be conservative. Furthermore, data in the figures indicate that when targets are exceeded, the values are generally very near the existing WQ standard.

In summary, while Scenario B is less stringent than Scenario A, it is still conservative and protective of human health as indicated by estimated tissue values lower than 0.47 ng/kg (the screening value used by the Texas Department of State Health Services (TDSHS) in the fish consumption advisories). The expected tissue concentrations, calculated using the model results and the site-specific bioaccumulation factors, are plotted in Figures 10 to 12.



Error bars correspond to minimum and 99th percentile model concentrations for the calibration scenario. The tissue target is 0.47 ng/kg.

Figure 10 Average TEQ Concentrations in Tissue from the Main Channel for Various Model Scenarios



Error bars correspond to minimum and 99th percentile model concentrations for the calibration scenario. The tissue target is 0.47 ng/kg.

Figure 11 Average TEQ Concentrations in Tissue from the San Jacinto River for Various Model Scenarios

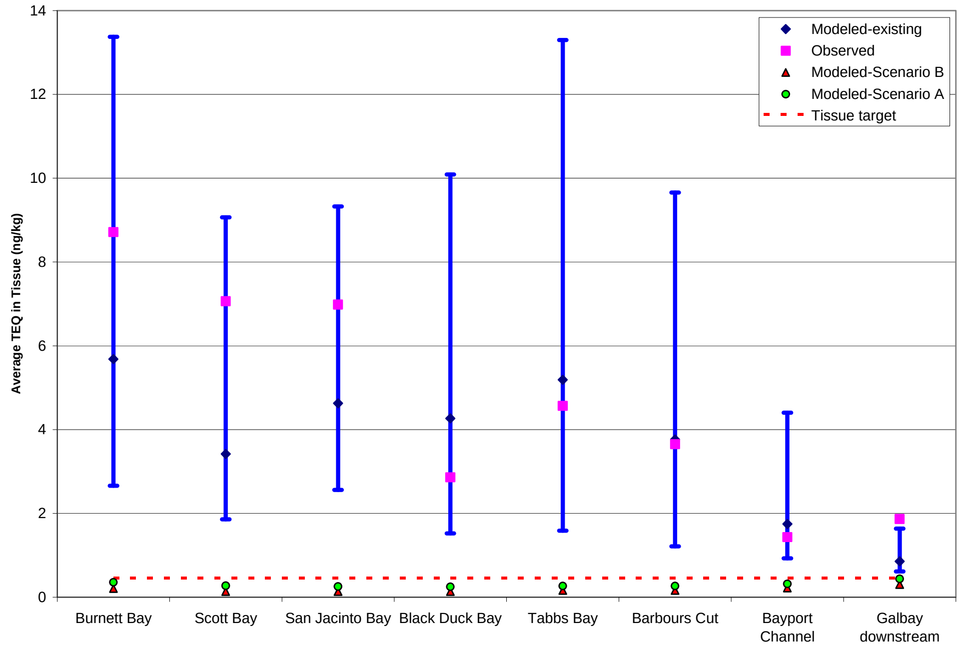
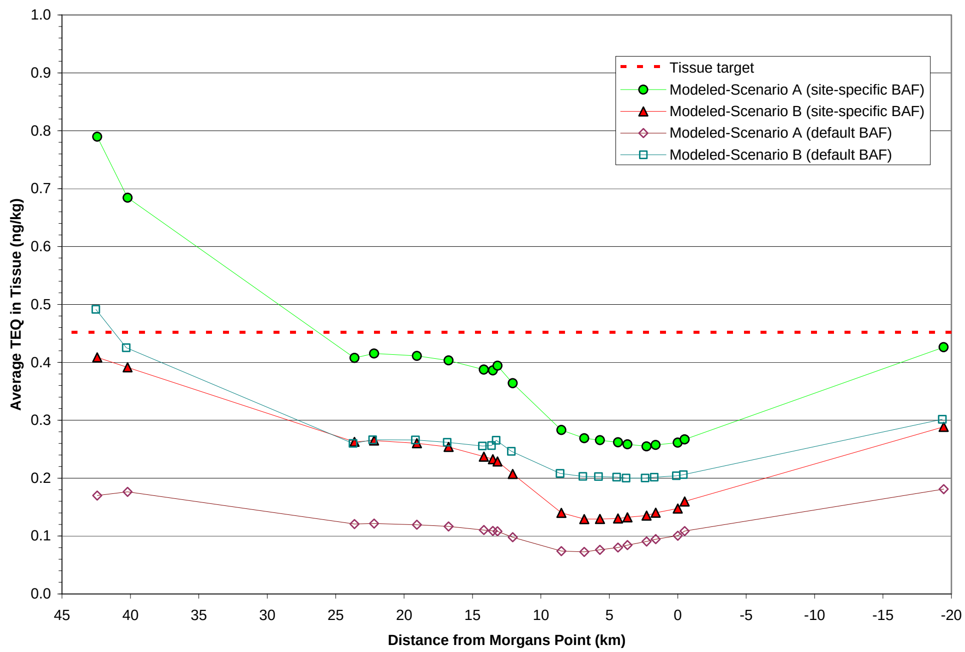


Figure 12 Average TEQ Concentrations in Tissue from the Side Bays for Various Model Scenarios

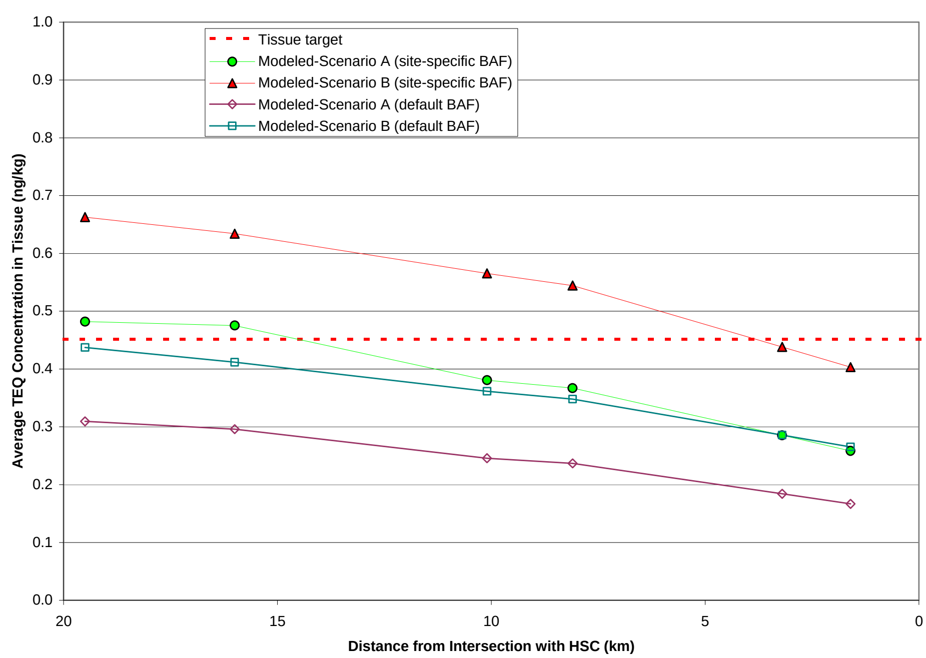
Finally, tissue concentrations were back-calculated using the water concentrations for the two allocation scenarios and a BAF of 5,000 L/kg, which is the default value used to determine the Texas WQ standard. These concentrations are plotted along with the concentrations calculated using site-specific BAFs in Figures 13 to 15 for comparison purposes. As can be seen, the TEQ concentrations in tissue calculated using the default BAF value are significantly lower than those predicted using site-specific BAFs (ratios between 0.42 and 0.79). In addition, the default BAF-derived concentrations are, with a single exception, much lower than the tissue target of 0.47 ng/kg. This further indicates that there is a margin of safety in the analyses.

Based on the data presented, the project team recommends developing TMDLs using Scenario B runs and the site-specific WQ targets.



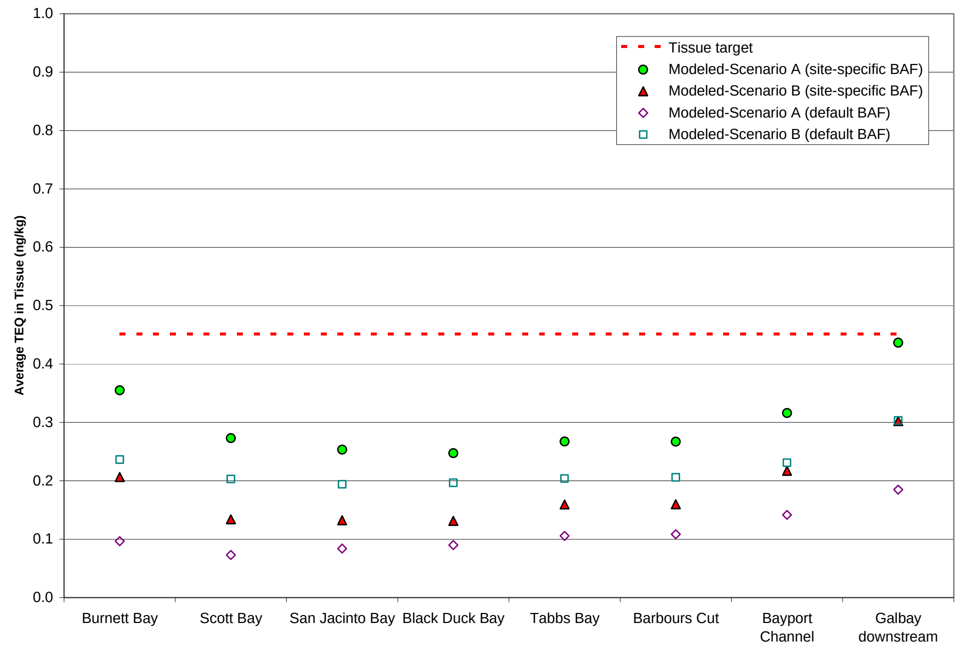
Lines are added to facilitate visualization and do not imply continuity. The tissue target is 0.47 ng/kg.

Figure 13 Average TEQ Tissue Concentrations using Site-specific and Default BAFs – Main Channel



Lines are added to facilitate visualization and do not imply continuity. The tissue target is 0.47 ng/kg.

Figure 14 Average TEQ Tissue Concentrations using Site-specific and Default BAFs – San Jacinto River



The tissue target is 0.47 ng/kg.

Figure 15 Average TEQ Tissue Concentrations using Site-specific and Default BAFs – Side Bays

REFERENCES

University of Houston and Parsons. (2007). Total Maximum Daily Loads for Dioxin in the Houston Ship Channel - Final Report Work Order 582-6-70860-08. Prepared for the Texas Commission on Environmental Quality. Austin, TX, November 2007.

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

APPENDIX A

SUMMARY MASS-BALANCE SPREADSHEETS BY CONGENER FOR SCENARIO A

Table A-1 Mass-balance Spreadsheet for 2378-TCDD – Scenario A[†]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	1,291	104	63,723	722	54,250	-11,588	65,839	66,384	1%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	1,160	61		55,896	55,373	-1,744	57,117	60,216	5%
1007	1007	41.0	18,066	8,074	1,611	44,832	80,378	143,947	-9,015	152,962	3,405,502	96%
1006_03	Greens Bayou	9.1	564	2,256	185	17,384	2,538	20,495	-2,431	22,927	177,685	87%
1006-upper	1006-upper	50.1	6,511	1,221	566		147,107	141,815	-13,590	155,405	6,567,047	98%
1006-lower	1006-lower	50.4	5,775	1,210	708	1,731	160,816	157,314	-12,925	170,239	6,660,156	97%
1001-upper	San Jacinto River	138.1	1,893	3,856	720	245,924	39,694	275,922	-16,166	292,088	2,203,061	87%
1001-lower	San Jacinto River	137.9	681	245	305		315,025	310,405	-5,851	316,255	8,490,536	96%
Old River	Old River	-0.5	210	464	312		45,951	50,344	3,407	50,344	2,119,314	98%
1005-upper	1005-upper	188.3	135	62	385		430,928	783,651	352,142	783,651	18,466,875	96%
2430	Burnett Bay	-0.01	0	176	1,850		21,845	22,912	-959	23,871	713,323	97%
2429	Scott Bay	-0.01	46	539	1,410		19,854	19,621	-2,228	21,849	582,171	96%
1005-middle	1005-middle	188.2	187	328	1,409		786,663	477,407	-311,180	788,587	17,781,374	96%
2427	San Jacinto Bay	-0.01	610	878	1,460		11,194	10,823	-3,320	14,142	468,722	97%
2428	Black Duck Bay	0.00	0	111	501		5,407	4,782	-1,237	6,019	231,537	97%
2426	Tabbs Bay	1.7	355	1,331	4,169	1,567	77,188	72,072	-12,538	84,610	2,443,112	97%
2436	Barbours Cut	-0.0005	39	72	91		766	754	-214	968	21,840	96%
1005-lower	1005-lower	186.9	1,930	124	1,090		511,639	440,845	-73,938	514,783	13,807,108	96%
2438	Bayport Channel	0.0001	1,070	32	69		770	799	-1,142	1,941	7,514	74%
2421	Upper Galveston Bay	209.1	631	1,967	88,287		2,650,484	2,322,607	-418,761	2,741,368	12,126,741	77%
901	Cedar Bayou	2.7	0	2,577	102	1,507	2,780	7,548	581	7,548	76,398	90%
2425	Clear Lake	2.0	0	5,680	156		52,528	54,805	-3,559	58,364	281,795	79%
OVERALL			38,702	33,652	105,549	376,669	5,420,175	5,428,491	-546,256	6,330,877		

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
[†] Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.022 pg/L for 2378-TCDD).

Table A-2 Mass-balance Spreadsheet for 12378-PeCDD – Scenario A[†]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	5,970	254	0	345	4,187	-2,382	6,569	187,992	97%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	5,380	149		5,588	9,300	-1,817	11,117	143,231	92%
1007	1007	41.0	41,316	37,256	3,946	0	19,447	40,777	-61,188	101,965	366,909	72%
1006_03	Greens Bayou	9.1	918	10,430	453	0	950	7,438	-5,314	12,752	70,420	82%
1006-upper	1006-upper	50.1	6,432	5,650	1,389		56,309	54,239	-15,541	69,780	279,483	75%
1006-lower	1006-lower	50.4	5,238	5,593	1,735	0	57,560	51,671	-18,455	70,126	328,345	79%
1001-upper	San Jacinto River	138.1	2,023	17,822	1,764	0	7,058	20,751	-7,916	28,668	714,639	96%
1001-lower	San Jacinto River	137.9	419	1,130	746		30,411	32,463	-242	32,706	494,359	93%
Old River	Old River	-0.5	415	2,140	763		11,389	11,407	-3,300	14,707	89,070	83%
1005-upper	1005-upper	188.3	106	284	944		73,526	154,431	79,571	154,431	1,566,958	90%
2430	Burnett Bay	-0.01	0	811	4,520		6,751	6,960	-5,122	12,082	57,215	79%
2429	Scott Bay	-0.01	26	2,490	3,460		8,721	8,731	-5,967	14,697	77,517	81%
1005-middle	1005-middle	188.2	487	1,517	3,453		174,969	166,852	-13,574	180,426	1,745,763	90%
2427	San Jacinto Bay	-0.01	293	4,060	3,880		4,064	4,293	-8,004	12,297	44,814	73%
2428	Black Duck Bay	0.00	0	515	1,230		1,533	1,587	-1,691	3,278	17,046	81%
2426	Tabbs Bay	1.7	362	6,148	10,204	0	14,702	11,984	-19,431	31,415	176,086	82%
2436	Barbours Cut	-0.0005	41	333	221		134	143	-586	729	2,266	68%
1005-lower	1005-lower	186.9	894	574	2,668		141,987	127,482	-18,642	146,123	1,542,944	91%
2438	Bayport Channel	0.0001	1,240	149	168		46	52	-1,551	1,603	2,696	41%
2421	Upper Galveston Bay	209.1	1,414	9,085	216,174		3,784,095	66,360	-3,944,408	4,010,768	4,979,477	19%
901	Cedar Bayou	2.7	0	11,890	250	0	1,383	4,918	-8,605	13,522	22,727	41%
2425	Clear Lake	2.0	0	26,300	383		6,497	4,741	-28,439	33,180	77,364	57%
OVERALL			61,624	155,528	258,753	0	4,407,464	790,767	-4,092,602	4,962,941		

[a] Load from upstream freshwater reaches outside of the HSC System

[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values

[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)

[†] Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.005 pg/L for 12378-PeCDD).

Table A-3 Mass-balance Spreadsheet for 123678-HxCDD – Scenario A[†]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day) PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS	TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
1013	Buffalo Bayou	23.5	0	0	492	0	42	404	-130	534	602,817	100%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	0	289		536	666	-159	825	481,114	100%
1007	1007	41.0	0	0	7,662	0	15,408	46,764	23,694	46,764	1,216,234	96%
1006_03	Greens Bayou	9.1	0	0	885	0	1,794	2,148	-531	2,679	271,626	99%
1006-upper	1006-upper	50.1	0	0	2,724		80,596	96,049	12,728	96,049	1,323,606	93%
1006-lower	1006-lower	50.4	0	0	3,406	0	135,203	148,062	9,452	148,062	1,423,247	90%
1001-upper	San Jacinto River	138.1	0	0	3,454	0	32,742	394,978	358,782	394,978	3,044,952	87%
1001-lower	San Jacinto River	137.9	0	0	1,450		434,225	417,715	-17,960	435,675	2,036,913	79%
Old River	Old River	-0.5	0	0	1,494		53,993	58,420	2,933	58,420	351,853	83%
1005-upper	1005-upper	188.3	0	0	1,838		547,254	1,040,745	491,652	1,040,745	6,677,073	84%
2430	Burnett Bay	-0.01	0	0	8,780		30,877	27,905	-11,753	39,657	214,103	81%
2429	Scott Bay	-0.01	0	0	6,750		39,076	37,198	-8,628	45,826	297,825	85%
1005-middle	1005-middle	188.2	0	0	6,755		1,087,673	908,762	-185,666	1,094,428	7,374,681	85%
2427	San Jacinto Bay	-0.01	0	0	7,590		17,749	15,950	-9,389	25,339	170,386	85%
2428	Black Duck Bay	0.00	0	0	2,400		7,277	7,307	-2,370	9,677	71,191	86%
2426	Tabbs Bay	1.7	0	0	19,723	0	59,122	59,071	-19,774	78,845	846,398	91%
2436	Barbours Cut	-0.0005	0	0	424		681	693	-412	1,105	9,895	89%
1005-lower	1005-lower	186.9	0	0	5,154		832,799	694,562	-143,392	837,953	6,567,189	87%
2438	Bayport Channel	0.0001	0	0	322		261	258	-325	583	9,062	94%
2421	Upper Galveston Bay	209.1	0	0	419,345		17,596,300	311,119	-17,704,526	18,015,645	22,253,726	19%
901	Cedar Bayou	2.7	0	0	489	0	2,338	2,496	-331	2,827	93,484	97%
2425	Clear Lake	2.0	0	0	751		9,875	11,120	494	11,120	434,529	97%
OVERALL			0	0	502,177	0	20,985,823	4,282,390	-17,205,609	22,387,735		

[a] Load from upstream freshwater reaches outside of the HSC System

[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values

[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)

[†] Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.016 pg/L for 123678-HxCDD).

Table A-4 Mass-balance Spreadsheet for 2378-TCDF – Scenario A[†]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	8,690	204	234,289	3,567	185,537	-61,212	246,749	248,350	1%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	7,830	120		197,828	201,377	-4,400	205,778	214,777	4%
1007	1007	41.0	278,916	54,294	3,168	157,551	321,656	595,211	-220,373	815,584	9,225,392	91%
1006_03	Greens Bayou	9.1	3,709	15,140	367	67,838	11,519	87,246	-11,326	98,572	501,788	80%
1006-upper	1006-upper	50.1	28,340	8,220	1,133		656,648	617,112	-77,229	694,341	17,058,722	96%
1006-lower	1006-lower	50.4	14,224	8,151	1,417	9,153	686,163	671,441	-47,667	719,108	16,958,073	96%
1001-upper	San Jacinto River	138.1	9,980	25,945	1,436	1,373,063	184,081	1,340,809	-253,695	1,594,504	7,695,771	79%
1001-lower	San Jacinto River	137.9	1,274	1,643	600		1,537,476	1,496,079	-44,914	1,540,993	28,102,162	95%
Old River	Old River	-0.5	708	3,118	620		207,378	227,111	15,287	227,111	6,233,069	96%
1005-upper	1005-upper	188.3	1,392	414	763		1,995,709	3,071,548	1,073,271	3,071,548	47,006,226	93%
2430	Burnett Bay	-0.01	0	1,180	3,640		86,033	98,608	7,755	98,608	1,628,501	94%
2429	Scott Bay	-0.01	355	3,630	2,800		121,678	119,789	-8,674	128,463	1,262,556	90%
1005-middle	1005-middle	188.2	1,910	2,204	2,802		3,859,896	2,399,667	-1,467,145	3,866,812	39,198,707	90%
2427	San Jacinto Bay	-0.01	2,394	5,910	3,150		121,518	119,991	-12,980	132,972	578,037	77%
2428	Black Duck Bay	0.00	0	749	996		65,558	61,698	-5,605	67,303	216,222	69%
2426	Tabbs Bay	1.7	2,161	8,959	8,122	4,208	897,643	878,861	-42,231	921,092	1,783,365	48%
2436	Barbours Cut	-0.0005	92	485	174		10,199	10,092	-857	10,950	21,557	49%
1005-lower	1005-lower	186.9	4,670	835	2,132		4,128,315	4,594,739	458,787	4,594,739	18,065,221	75%
2438	Bayport Channel	0.0001	3,840	217	132		9,711	9,897	-4,003	13,900	16,534	16%
2421	Upper Galveston Bay	209.1	2,068	13,221	173,663		25,491,583	25,569,963	-110,572	25,680,535	32,386,284	21%
901	Cedar Bayou	2.7	0	17,310	203	10,366	28,643	61,483	4,962	61,483	83,213	26%
2425	Clear Lake	2.0	0	38,200	312		574,103	574,710	-37,905	612,615	678,955	10%
OVERALL			356,033	226,344	207,953	1,856,467	41,196,902	42,992,971	-850,727	45,403,761		

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
[†] Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.201 for 2378-TCDF).

Table A-5 Mass-balance Spreadsheet for 23478-PeCDF – Scenario A[†]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	0	248	100,053	26	72,103	-28,224	100,327	696,605	86%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	0	146		72,183	367	-71,962	72,329	706,495	90%
1007	1007	41.0	0	0	3,866	86,360	6,695	132,986	36,065	132,986	999,939	87%
1006_03	Greens Bayou	9.1	0	0	446	53,418	681	747	-53,798	54,546	75,368	28%
1006-upper	1006-upper	50.1	0	0	1,372		29,682	35,379	4,325	35,379	583,468	94%
1006-lower	1006-lower	50.4	0	0	1,717	4,960	51,071	55,172	-2,576	57,748	655,209	91%
1001-upper	San Jacinto River	138.1	0	0	1,743	601,729	19,912	152,067	-471,316	623,384	713,104	13%
1001-lower	San Jacinto River	137.9	0	0	732		172,746	162,130	-11,348	173,478	946,865	82%
Old River	Old River	-0.5	0	0	754		22,204	23,379	421	23,379	190,061	88%
1005-upper	1005-upper	188.3	0	0	928		203,054	345,021	141,039	345,021	2,330,589	85%
2430	Burnett Bay	-0.01	0	0	4,440		12,102	11,265	-5,278	16,542	85,581	81%
2429	Scott Bay	-0.01	0	0	3,410		16,846	16,366	-3,890	20,256	97,901	79%
1005-middle	1005-middle	188.2	0	0	3,404		406,215	335,861	-73,758	409,619	2,329,323	82%
2427	San Jacinto Bay	-0.01	0	0	3,830		10,416	9,918	-4,328	14,246	45,305	69%
2428	Black Duck Bay	0.00	0	0	1,210		4,908	4,781	-1,337	6,118	15,537	61%
2426	Tabbs Bay	1.7	0	0	9,962	2,567	59,014	57,121	-14,422	71,544	139,165	49%
2436	Barbours Cut	-0.0005	0	0	215		696	688	-222	911	1,831	50%
1005-lower	1005-lower	186.9	0	0	2,610		408,647	373,519	-37,738	411,257	1,590,284	74%
2438	Bayport Channel	0.0001	0	0	163		708	719	-152	871	3,147	72%
2421	Upper Galveston Bay	209.1	0	0	211,933		3,457,400	2,589,677	-1,079,656	3,669,333	4,268,341	14%
901	Cedar Bayou	2.7	0	0	247	5,314	1,619	1,610	-5,570	7,180	19,896	64%
2425	Clear Lake	2.0	0	0	378		34,574	28,844	-6,109	34,952	60,040	42%
OVERALL			0	0	253,754	854,401	4,991,400	4,409,720	-1,689,834	6,281,404		

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
[†] Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.010 for 23478-PeCDF).

Table A-6 Mass-balance Spreadsheet for 123678-HxCDF – Scenario A†

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	0	197	0	20	22	-195	217	800,576	100%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	0	116		99	195	-20	215	318,405	100%
1007	1007	41.0	0	0	3,062	0	11,143	19,783	5,578	19,783	658,015	97%
1006_03	Greens Bayou	9.1	0	0	356	0	1,083	3,601	2,162	3,601	130,604	97%
1006-upper	1006-upper	50.1	0	0	1,100		39,168	40,315	46	40,315	782,643	95%
1006-lower	1006-lower	50.4	0	0	1,377	0	42,402	40,845	-2,934	43,779	837,197	95%
1001-upper	San Jacinto River	138.1	0	0	1,394	0	1,669	3,819	756	3,819	1,844,236	100%
1001-lower	San Jacinto River	137.9	0	0	580		11,506	13,304	1,218	13,304	1,496,024	99%
Old River	Old River	-0.5	0	0	602		9,458	8,666	-1,394	10,060	230,411	96%
1005-upper	1005-upper	188.3	0	0	737		44,830	88,074	42,508	88,074	4,242,749	98%
2430	Burnett Bay	-0.01	0	0	3,510		4,961	4,446	-4,025	8,471	131,248	94%
2429	Scott Bay	-0.01	0	0	2,720		4,897	4,662	-2,955	7,617	173,570	96%
1005-middle	1005-middle	188.2	0	0	2,716		93,016	89,122	-6,610	95,732	4,470,980	98%
2427	San Jacinto Bay	-0.01	0	0	3,050		2,210	2,009	-3,251	5,260	87,597	94%
2428	Black Duck Bay	0.00	0	0	965		751	762	-954	1,716	31,865	95%
2426	Tabbs Bay	1.7	0	0	7,810	0	5,410	5,511	-7,709	13,220	317,309	96%
2436	Barbours Cut	-0.0005	0	0	167		68	67	-168	235	4,084	94%
1005-lower	1005-lower	186.9	0	0	2,057		62,230	58,155	-6,132	64,287	3,482,357	98%
2438	Bayport Channel	0.0001	0	0	127		28	27	-128	155	7,286	98%
2421	Upper Galveston Bay	209.1	0	0	167,681		5,305,279	41,595	-5,431,365	5,472,960	5,254,917	0%
901	Cedar Bayou	2.7	0	0	197	0	217	255	-158	413	59,668	99%
2425	Clear Lake	2.0	0	0	303		1,737	2,319	279	2,319	165,536	99%
OVERALL			0	0	200,823	0	5,642,182	427,553	-5,415,452	5,895,550		

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
† Scenario A for each congener is defined as that that generates average concentrations in all the WASP segments at or below the water quality targets developed with site-specific BAF values (0.020 for 123678-HxCDF).

APPENDIX B

SUMMARY MASS-BALANCE SPREADSHEETS BY CONGENER FOR SCENARIO B

Table B-1 Mass-balance Spreadsheet for 2378-TCDD – Scenario B[‡]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	1,291	104	63,723	722	54,250	-11,588	65,839	66,384	1%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	1,160	61		55,896	55,373	-1,744	57,117	60,216	5%
1007	1007	41.0	18,066	8,074	1,611	44,832	80,378	143,947	-9,015	152,962	3,405,502	96%
1006_03	Greens Bayou	9.1	564	2,256	185	17,384	2,538	20,495	-2,431	22,927	177,685	87%
1006-upper	1006-upper	50.1	6,511	1,221	566		147,107	141,815	-13,590	155,405	6,567,047	98%
1006-lower	1006-lower	50.4	5,775	1,210	708	1,731	160,816	157,314	-12,925	170,239	6,660,156	97%
1001-upper	San Jacinto River	138.1	1,893	3,856	720	245,924	39,694	275,922	-16,166	292,088	2,203,061	87%
1001-lower	San Jacinto River	137.9	681	245	305		315,025	310,405	-5,851	316,255	8,490,536	96%
Old River	Old River	-0.5	210	464	312		45,951	50,344	3,407	50,344	2,119,314	98%
1005-upper	1005-upper	188.3	135	62	385		430,928	783,651	352,142	783,651	18,466,875	96%
2430	Burnett Bay	-0.01	0	176	1,850		21,845	22,912	-959	23,871	713,323	97%
2429	Scott Bay	-0.01	46	539	1,410		19,854	19,621	-2,228	21,849	582,171	96%
1005-middle	1005-middle	188.2	187	328	1,409		786,663	477,407	-311,180	788,587	17,781,374	96%
2427	San Jacinto Bay	-0.01	610	878	1,460		11,194	10,823	-3,320	14,142	468,722	97%
2428	Black Duck Bay	0.00	0	111	501		5,407	4,782	-1,237	6,019	231,537	97%
2426	Tabbs Bay	1.7	355	1,331	4,169	1,567	77,188	72,072	-12,538	84,610	2,443,112	97%
2436	Barbours Cut	-0.0005	39	72	91		766	754	-214	968	21,840	96%
1005-lower	1005-lower	186.9	1,930	124	1,090		511,639	440,845	-73,938	514,783	13,807,108	96%
2438	Bayport Channel	0.0001	1,070	32	69		770	799	-1,142	1,941	7,514	74%
2421	Upper Galveston Bay	209.1	631	1,967	88,287		2,650,484	2,322,607	-418,761	2,741,368	12,126,741	77%
901	Cedar Bayou	2.7	0	2,577	102	1,507	2,780	7,548	581	7,548	76,398	90%
2425	Clear Lake	2.0	0	5,680	156		52,528	54,805	-3,559	58,364	281,795	79%
OVERALL			38,702	33,652	105,549	376,669	5,420,175	5,428,491	-546,256	6,330,877		

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
[‡] Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.

Table B-2 Mass-balance Spreadsheet for 12378-PeCDD – Scenario B‡

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	5,970	254	180,713	1,047	135,265	-52,719	187,984	187,992	0%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	5,380	149		137,657	120,554	-22,632	143,186	143,231	0%
1007	1007	41.0	41,316	37,256	3,946	111,448	151,716	245,085	-100,597	345,682	366,909	6%
1006_03	Greens Bayou	9.1	918	10,430	453	53,720	2,885	40,680	-27,726	68,406	70,420	3%
1006-upper	1006-upper	50.1	6,432	5,650	1,389		196,705	181,449	-28,727	210,176	279,483	25%
1006-lower	1006-lower	50.4	5,238	5,593	1,735	6,511	217,466	222,184	-14,359	236,543	328,345	28%
1001-upper	San Jacinto River	138.1	2,023	17,822	1,764	656,825	26,190	400,129	-304,496	704,625	714,639	1%
1001-lower	San Jacinto River	137.9	419	1,130	746		441,480	411,913	-31,861	443,775	494,359	10%
Old River	Old River	-0.5	415	2,140	763		62,976	61,514	-4,780	66,295	89,070	26%
1005-upper	1005-upper	188.3	106	284	944		607,401	1,334,982	726,247	1,334,982	1,566,958	15%
2430	Burnett Bay	-0.01	0	811	4,520		41,138	41,743	-4,725	46,469	57,215	19%
2429	Scott Bay	-0.01	26	2,490	3,460		60,321	58,634	-7,663	66,296	77,517	14%
1005-middle	1005-middle	188.2	487	1,517	3,453		1,514,494	1,352,692	-167,258	1,519,950	1,745,763	13%
2427	San Jacinto Bay	-0.01	293	4,060	3,880		32,341	31,930	-8,645	40,574	44,814	9%
2428	Black Duck Bay	0.00	0	515	1,230		13,982	13,565	-2,162	15,727	17,046	8%
2426	Tabbs Bay	1.7	362	6,148	10,204	9,297	143,331	133,342	-35,999	169,341	176,086	4%
2436	Barbours Cut	-0.0005	41	333	221		1,579	1,600	-574	2,174	2,266	4%
1005-lower	1005-lower	186.9	894	574	2,668		1,397,998	1,221,374	-180,760	1,402,134	1,542,944	9%
2438	Bayport Channel	0.0001	1,240	149	168		1,122	1,129	-1,550	2,679	2,696	1%
2421	Upper Galveston Bay	209.1	1,414	9,085	216,174		4,689,301	3,504,153	-1,411,822	4,915,974	4,979,477	1%
901	Cedar Bayou	2.7	0	11,890	250	5,124	5,283	19,843	-2,705	22,548	22,727	1%
2425	Clear Lake	2.0	0	26,300	383		50,454	39,690	-37,447	77,137	77,364	0%
OVERALL			61,624	155,528	258,753	1,023,637	9,796,867	9,573,449	-1,722,960	12,022,656		

[a] Load from upstream freshwater reaches outside of the HSC System

[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values

[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)

‡ Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.

Table B-3 Mass-balance Spreadsheet for 123678-HxCDD – Scenario B[‡]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	23,900	492	575,414	2,999	454,439	-148,366	602,805	602,817	0%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	21,500	289		459,239	429,776	-51,252	481,028	481,114	0%
1007	1007	41.0	44,917	149,220	7,662	328,075	582,132	1,021,683	-90,323	1,112,006	1,216,234	9%
1006_03	Greens Bayou	9.1	416	41,700	885	205,274	14,502	203,414	-59,362	262,776	271,626	3%
1006-upper	1006-upper	50.1	12,076	22,650	2,724		1,001,351	905,405	-133,395	1,038,801	1,323,606	22%
1006-lower	1006-lower	50.4	9,076	22,383	3,406	22,681	1,066,997	1,087,949	-36,593	1,124,543	1,423,247	21%
1001-upper	San Jacinto River	138.1	2,088	71,230	3,454	2,849,210	115,366	1,800,192	-1,241,156	3,041,348	3,044,952	0%
1001-lower	San Jacinto River	137.9	519	4,523	1,450		1,996,018	1,921,769	-80,741	2,002,510	2,036,913	2%
Old River	Old River	-0.5	254	8,573	1,494		299,394	306,735	-2,980	309,715	351,853	12%
1005-upper	1005-upper	188.3	463	1,139	1,838		2,902,007	6,174,736	3,269,290	6,174,736	6,677,073	8%
2430	Burnett Bay	-0.01	0	3,250	8,780		181,679	173,279	-20,429	193,709	214,103	10%
2429	Scott Bay	-0.01	102	9,980	6,750		258,382	250,394	-24,820	275,214	297,825	8%
1005-middle	1005-middle	188.2	801	6,059	6,755		6,868,277	5,827,813	-1,054,078	6,881,892	7,374,681	7%
2427	San Jacinto Bay	-0.01	1,333	16,200	7,590		137,848	125,427	-37,544	162,971	170,386	4%
2428	Black Duck Bay	0.00	0	2,060	2,400		64,188	62,109	-6,538	68,648	71,191	4%
2426	Tabbs Bay	1.7	651	24,617	19,723	47,565	738,176	677,803	-152,930	830,733	846,398	2%
2436	Barbours Cut	-0.0005	42	1,330	424		7,916	7,901	-1,810	9,711	9,895	2%
1005-lower	1005-lower	186.9	894	2,293	5,154		6,259,616	5,471,139	-796,818	6,267,957	6,567,189	5%
2438	Bayport Channel	0.0001	1,780	596	322		6,321	6,279	-2,739	9,019	9,062	0%
2421	Upper Galveston Bay	209.1	667	36,362	419,345		21,642,235	18,026,268	-4,072,341	22,098,609	22,253,726	1%
901	Cedar Bayou	2.7	0	47,600	489	17,645	27,247	86,807	-6,173	92,980	93,484	1%
2425	Clear Lake	2.0	0	105,000	751		327,907	270,809	-162,849	433,658	434,529	0%
OVERALL			76,078	622,165	502,177	4,045,863	44,959,796	45,292,128	-4,913,950	53,475,368		

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
[‡] Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.

Table B-4 Mass-balance Spreadsheet for 2378-TCDF – Scenario B[‡]

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day) PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS	TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
1013	Buffalo Bayou	23.5	0	8,690	204	234,289	3,567	185,537	-61,212	246,749	248,350	1%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	7,830	120	0	197,828	201,377	-4,400	205,778	214,777	4%
1007	1007	41.0	278,916	54,294	3,168	157,551	321,656	595,211	-220,373	815,584	9,225,392	91%
1006_03	Greens Bayou	9.1	3,709	15,140	367	67,838	11,519	87,246	-11,326	98,572	501,788	80%
1006-upper	1006-upper	50.1	28,340	8,220	1,133	0	656,648	617,112	-77,229	694,341	17,058,722	96%
1006-lower	1006-lower	50.4	14,224	8,151	1,417	9,153	686,163	671,441	-47,667	719,108	16,958,073	96%
1001-upper	San Jacinto River	138.1	9,980	25,945	1,436	1,373,063	184,081	1,340,809	-253,695	1,594,504	7,695,771	79%
1001-lower	San Jacinto River	137.9	1,274	1,643	600	0	1,537,476	1,496,079	-44,914	1,540,993	28,102,162	95%
Old River	Old River	-0.5	708	3,118	620	0	207,378	227,111	15,287	227,111	6,233,069	96%
1005-upper	1005-upper	188.3	1,392	414	763	0	1,995,709	3,071,548	1,073,271	3,071,548	47,006,226	93%
2430	Burnett Bay	-0.01	0	1,180	3,640	0	86,033	98,608	7,755	98,608	1,628,501	94%
2429	Scott Bay	-0.01	355	3,630	2,800	0	121,678	119,789	-8,674	128,463	1,262,556	90%
1005-middle	1005-middle	188.2	1,910	2,204	2,802	0	3,859,896	2,399,667	-1,467,145	3,866,812	39,198,707	90%
2427	San Jacinto Bay	-0.01	2,394	5,910	3,150	0	121,518	119,991	-12,980	132,972	578,037	77%
2428	Black Duck Bay	0.00	0	749	996	0	65,558	61,698	-5,605	67,303	216,222	69%
2426	Tabbs Bay	1.7	2,161	8,959	8,122	4,208	897,643	878,861	-42,231	921,092	1,783,365	48%
2436	Barbours Cut	-0.0005	92	485	174	0	10,199	10,092	-857	10,950	21,557	49%
1005-lower	1005-lower	186.9	4,670	835	2,132	0	4,128,315	4,594,739	458,787	4,594,739	18,065,221	75%
2438	Bayport Channel	0.0001	3,840	217	132	0	9,711	9,897	-4,003	13,900	16,534	16%
2421	Upper Galveston Bay	209.1	2,068	13,221	173,663	0	25,491,583	25,569,963	-110,572	25,680,535	32,386,284	21%
901	Cedar Bayou	2.7	0	17,310	203	10,366	28,643	61,483	4,962	61,483	83,213	26%
2425	Clear Lake	2.0	0	38,200	312	0	574,103	574,710	-37,905	612,615	678,955	10%
OVERALL			356,033	226,344	207,953	1,856,467	41,196,902	42,992,971	-850,727	45,403,761	209,099,045	

[a] Load from upstream freshwater reaches outside of the HSC System
[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values
[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)
[‡] Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.

Table B-5 Mass-balance Spreadsheet for 23478-PeCDF – Scenario B‡

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	4,600	248	100,053	2,623	117,328	9,803	117,328	696,605	83%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	4,140	146		122,802	115,170	-11,918	127,088	706,495	82%
1007	1007	41.0	84,727	28,740	3,866	86,360	154,509	252,413	-105,789	358,202	999,939	64%
1006_03	Greens Bayou	9.1	1,545	8,040	446	53,418	3,705	44,984	-22,171	67,155	75,368	11%
1006-upper	1006-upper	50.1	25,669	4,360	1,372		234,526	220,497	-45,431	265,928	583,468	54%
1006-lower	1006-lower	50.4	14,037	4,309	1,717	4,960	253,080	251,280	-26,822	278,102	655,209	58%
1001-upper	San Jacinto River	138.1	2,075	13,743	1,743	601,729	46,587	493,446	-172,431	665,877	713,104	7%
1001-lower	San Jacinto River	137.9	837	871	732		548,475	517,315	-33,600	550,915	946,865	42%
Old River	Old River	-0.5	306	1,651	754		73,234	75,249	-697	75,945	190,061	60%
1005-upper	1005-upper	188.3	1,721	219	928		721,439	1,342,256	617,949	1,342,256	2,330,589	42%
2430	Burnett Bay	-0.01	0	625	4,440		38,823	37,015	-6,873	43,888	85,581	49%
2429	Scott Bay	-0.01	211	1,920	3,410		50,739	49,213	-7,067	56,280	97,901	43%
1005-middle	1005-middle	188.2	2,300	1,169	3,404		1,420,854	1,128,788	-298,939	1,427,727	2,329,323	39%
2427	San Jacinto Bay	-0.01	693	3,130	3,830		23,198	21,743	-9,108	30,851	45,305	32%
2428	Black Duck Bay	0.00	0	397	1,210		9,575	9,754	-1,428	11,182	15,537	28%
2426	Tabbs Bay	1.7	849	4,743	9,962	2,567	100,146	84,424	-33,843	118,268	139,165	15%
2436	Barbours Cut	-0.0005	45	257	215		1,031	1,045	-503	1,548	1,831	15%
1005-lower	1005-lower	186.9	1,590	441	2,610		1,086,628	854,771	-236,498	1,091,270	1,590,284	31%
2438	Bayport Channel	0.0001	2,050	115	163		774	789	-2,313	3,102	3,147	1%
2421	Upper Galveston Bay	209.1	775	7,002	211,933		3,843,291	2,675,649	-1,387,351	4,063,000	4,268,341	5%
901	Cedar Bayou	2.7	0	9,170	247	5,314	4,001	19,448	717	19,448	19,896	2%
2425	Clear Lake	2.0	0	20,200	378		38,884	30,999	-28,463	59,462	60,040	1%
OVERALL			139,429	119,843	253,754	854,401	8,778,925	8,343,576	-1,802,776	10,774,821		

[a] Load from upstream freshwater reaches outside of the HSC System

[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values

[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)

‡ Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.

Table B-6 Mass-balance Spreadsheet for 123678-HxCDF – Scenario B‡

Segment	Description	Average Downstream Net Flow (m^3/s)	Loads (ng/day)							TMDL (ng/day)[b]	Current Gross Load (ng/day)[c]	% Reduction Required
			PS	RO	DD	U/S[a]	ΣCinQin	ΣCoutQout	dS			
1013	Buffalo Bayou	23.5	0	16,480	197	782,185	1,721	302,086	-498,497	800,583	800,576	0%
1007_07	Buffalo Bayou Tidal/HSC	23.6	0	14,800	116		305,994	220,096	-100,815	320,910	318,405	0%
1007	1007	41.0	35,910	102,900	3,062	177,068	377,657	813,897	117,300	813,897	658,015	0%
1006_03	Greens Bayou	9.1	895	28,780	356	82,847	16,838	135,144	5,429	135,144	130,604	0%
1006-upper	1006-upper	50.1	87,860	15,590	1,100		933,065	990,248	-47,367	1,037,615	782,643	0%
1006-lower	1006-lower	50.4	23,260	15,453	1,377	16,236	1,212,824	1,263,788	-5,361	1,269,149	837,197	0%
1001-upper	San Jacinto River	138.1	828	49,165	1,394	1,685,239	248,712	2,534,355	549,017	2,534,355	1,844,236	0%
1001-lower	San Jacinto River	137.9	1,200	3,120	580		2,817,095	2,727,076	-94,920	2,821,996	1,496,024	0%
Old River	Old River	-0.5	371	5,917	602		386,849	407,826	14,086	407,826	230,411	0%
1005-upper	1005-upper	188.3	5,810	785	737		3,778,585	7,140,483	3,354,566	7,140,483	4,242,749	0%
2430	Burnett Bay	-0.01	0	2,240	3,510		212,635	201,172	-17,213	218,385	131,248	0%
2429	Scott Bay	-0.01	403	6,880	2,720		268,324	259,156	-19,171	278,327	173,570	0%
1005-middle	1005-middle	188.2	2,950	4,186	2,716		7,400,746	6,177,866	-1,232,732	7,410,598	4,470,980	0%
2427	San Jacinto Bay	-0.01	477	11,200	3,050		116,394	108,859	-22,262	131,121	87,597	0%
2428	Black Duck Bay	0.00	0	1,420	965		45,562	47,081	-866	47,947	31,865	0%
2426	Tabbs Bay	1.7	576	16,989	7,810	7,241	392,230	343,227	-81,617	424,845	317,309	0%
2436	Barbours Cut	-0.0005	95	919	167		4,175	4,276	-1,080	5,356	4,084	0%
1005-lower	1005-lower	186.9	887	1,582	2,057		5,611,750	4,323,591	-1,292,685	5,616,276	3,482,357	0%
2438	Bayport Channel	0.0001	4,960	411	127		2,139	2,161	-5,475	7,637	7,286	0%
2421	Upper Galveston Bay	209.1	431	25,073	167,681		8,777,980	5,656,076	-3,315,089	8,971,164	5,254,917	0%
901	Cedar Bayou	2.7	0	32,900	197	14,262	16,307	62,025	-1,640	63,666	59,668	0%
2425	Clear Lake	2.0	0	72,500	303		99,514	72,367	-99,950	172,317	165,536	0%
OVERALL			166,912	429,290	200,823	2,765,078	33,027,095	33,792,857	-2,796,341	40,629,597		

[a] Load from upstream freshwater reaches outside of the HSC System

[b] TMDL = PS + RO + DD + U/S + ΣQinCin + positive dS values

[c] Gross load = loading that enters the segment from any external source before any loss or assimilation = Σ(PS, RO, DD, ΣQiCin, positive dS) for calibrated models (see Modeling Report)

‡ Scenario B corresponds to that for which the initial dioxin concentrations in sediment were set to zero. For 2378-TCDD and 2378-TCDF, this scenario is equal to Scenario A.