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Houston Ship Channel Expansion Improvement Project (HSC ECIP), North of Morgan's Point Sediments, 404 Sediment Characterization and Testing

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New Work Dredged Material Refined Mixing Zone Modeling for Discharge in Glendale and Filterbed Upland Placement Areas

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Abstract

A prior evaluation using preliminary CDFATE modeling was conducted to evaluate mixing and dilution from upland placement areas (PAs) for the Houston Ship Channel Expansion Channel Improvement Project (HSC ECIP), North of Morgan's Point (Montgomery, Bourne and Stevens, USACE ERDC, 2023). In this evaluation, CDFATE modeling was refined to incorporate updated design details for Glendale and Filterbed PAs where new work dredge materials from Segments 5 and 6 of the HSC ECIP will be placed. The CDFATE model was used to determine the extent of mixing and resulting dilution within Buffalo Bayou/HSC at each discharge location based on characteristics of the effluent discharge and of the receiving waters. Modeled dilution as a function of plume distance downstream was used to delineate the required zone of initial dilution (ZID) and mixing zone requirements. Discharges resulting from estimated effluent from both 24-inch and 30-inch dredges were modeled at both PA discharge locations. Based upon the CDFATE modeling results and further consideration of site-specific lines of evidence, no significant adverse effects are anticipated from the discharge of dewatering effluent from either Glendale PA or Filterbed PA.

The USACE recommends that concurrence and a water quality certification be approved for Segments 5 and 6 of the HSC ECIP.

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Acronyms

7Q2	Minimum 7-day, 2-year discharge
ACR	Acute-to-Chronic Ratio
ADDAMS	Automated Dredging and Disposal Alternatives Modeling System
AF	Application Factor
CCC	Criterion Continuous Concentration
CDF	Confined Disposal Facility
CDFATE	Fate of Continuous Discharge from Dredging Operations into Open Water
CFS	Cubic feet per second
CMC	Continuous Maximum Concentration
COC	Contaminant of concern
DMMP	Dredged Material Management Plan
ECIP	Expansion Channel Improvement Project
ERDC	Engineer Research and Development Center
HSC	Houston Ship Channel
LC50	Concentration lethal to 50% of organisms (Median lethal concentration)
LOAEC	Lowest Observed Adverse Effects Concentration
LOE	Lines of Evidence
LOD	Limit of Detection
LOQ	Limit of Quantitation
LPC	Limiting Permissible Concentration
MAL	Minimum Analytical Level
MPRSA	Marine Protection, Research and Sanctuaries Act
MZ	Mixing Zone
NA	Not applicable
NAS	National Academy of Science
NMP	North of Morgan's Point
NOAA	National Oceanic and Atmospheric Administration
NOAEC	No Observed Adverse Effects Concentration
PA	Placement Area
RL	Reporting Limit
SWG	USACE, Galveston District
TCEQ	Texas Commission on Environmental Quality
TSWQS	Texas Surface Water Quality Standards
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WER	Water Effect Ratio
WQC	Water quality criteria
WQS	Water quality standard
ZID	Zone of initial dilution

1 Introduction

1.1 Background

Sediments proposed to be dredged as part of the Houston Ship Channel (HSC) Expansion Channel Improvement Project (ECIP) North of Morgan's Point (NMP) fall under Section 404 of the Clean Water Act (CWA). Section 404 requires evaluation of such activities to assess potential impacts to surface waters of the United States. Preliminary evaluation was presented in the *Sampling, Chemical Analysis, and Bioassessment in Accordance with CWA Section 404, Houston Ship Channel Expansion Channel Improvement Project, North of Morgan's Point, Houston Ship Channel, Texas* report (Montgomery, Bourne and Stevens, USACE ERDC, 2023). Under this effort, placement area (PA) discharge locations and design details for Glendale and Filterbed PAs were updated. This report describes how the modeling was refined for these PAs to evaluate mixing and dilution of effluent discharges from upland PAs that are anticipated to receive dredged material from the HSC-ECIP NMP.

1.2 Objectives

This report details the revised mixing zone modeling performed by the U.S. Army Engineer Research and Development Center (ERDC) to support a CWA Section 404 sediment testing characterization study for HSC ECIP, NMP. Simulations of new work dredged material discharges into upland PAs were run using the Fate of Continuous Discharge from Dredging Operations into Open Water (CDFATE) module, Windows version 1.0, (Havis 1994, Doneker and Jirka 1990, Akar and Jirka 1991, Jones 1990) of the ADDAMS model to establish compliance with water column toxicity criteria for HSC sediment samples.

This evaluation deals only with the refined CDFATE modeling for the new work dredged materials from Segments 5 and 6 of the HSC ECIP. Under this effort, PA discharge locations and design details were updated for Glendale and Filterbed PAs, along with bathymetry, flow and salinity data for the receiving water, Buffalo Bayou/HSC. No new samples were collected, and no new data were generated for site water, sediment, elutriate or toxicity for this modeling effort. The data were taken from the four locations within Segments 5 and 6 characterized in the 404 evaluation as samples HSCNew-NMP-06, -NMP-07, -NMP-09, -NMP-10 and -NMP-11, with proposed placement into the Glendale and Filterbed upland PAs. Analytical and elutriate bioassay data (Montgomery, Bourne and Stevens 2023) were reevaluated and applied in the modeling.

1.3 Dredging and Placement Locations

The dredging and placement plan for NMP Segments 5 and 6 is displayed in Figure 1, which includes placement of new work dredged material from Segment 5 and Segment 6 into the Glendale and Filterbed upland PAs. For the purposes of this evaluation, it is assumed that material from either segment could be placed into either of the two PAs.

Discharge locations and drainage paths to receiving waters for Glendale and Filterbed PAs are shown in Figure 2. The PA outlet structures tie into existing stormwater systems which ultimately drain into Buffalo Bayou/HSC approximately 1 mile and 2.6 miles downstream of the PA outlets for Filterbed and Glendale PAs, respectively. Both sites were previously operated as dredged material placement areas, primarily in the 1950s. New drop-outlet structures are being designed for both PAs.

A mixing zone evaluation is needed to determine if the effluent discharged from these PAs will be sufficiently diluted within allowable mixing zones to comply with applicable water quality and toxicity criteria.

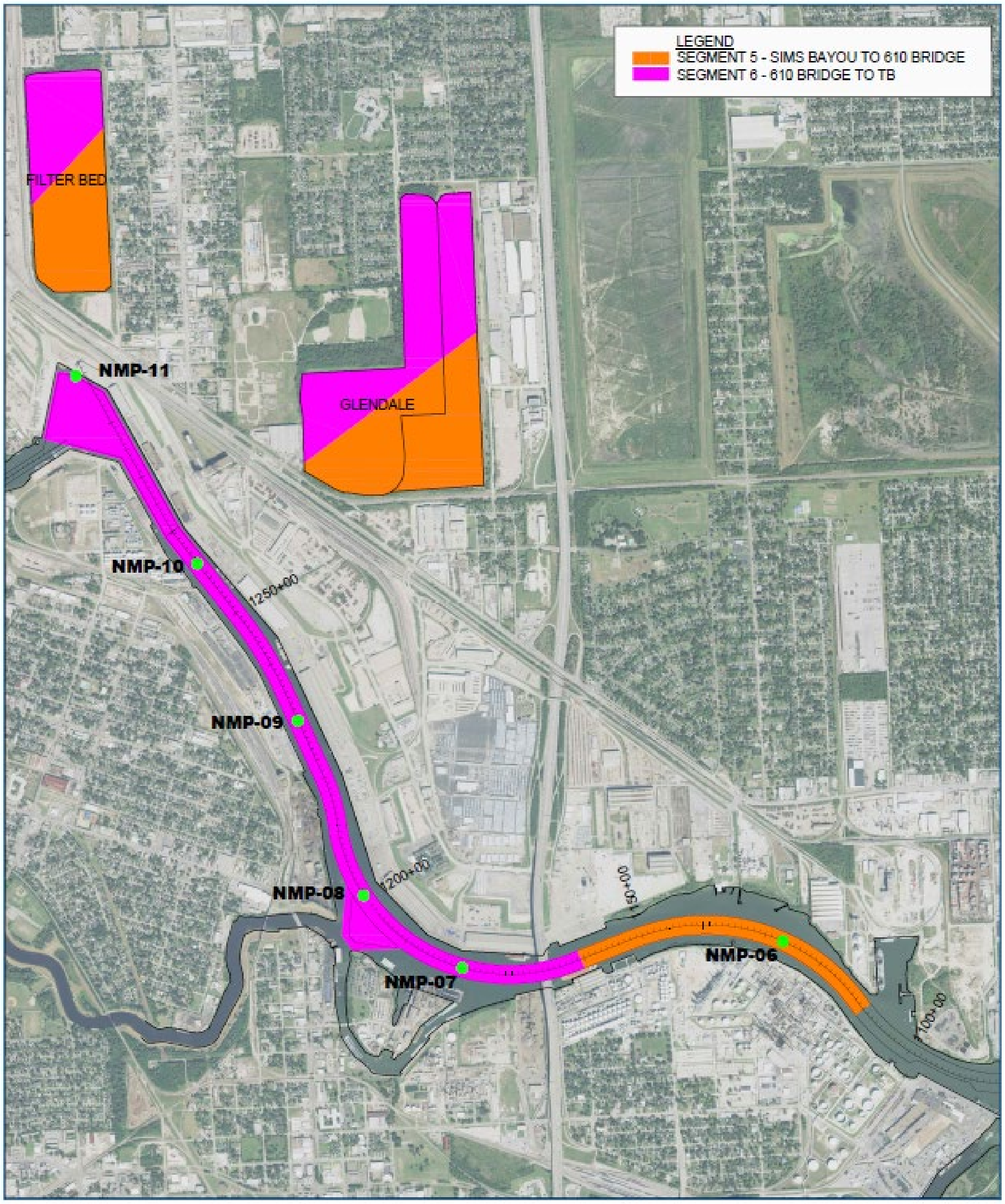


Figure 1. DMMP New Work Dredging and Placement Locations.

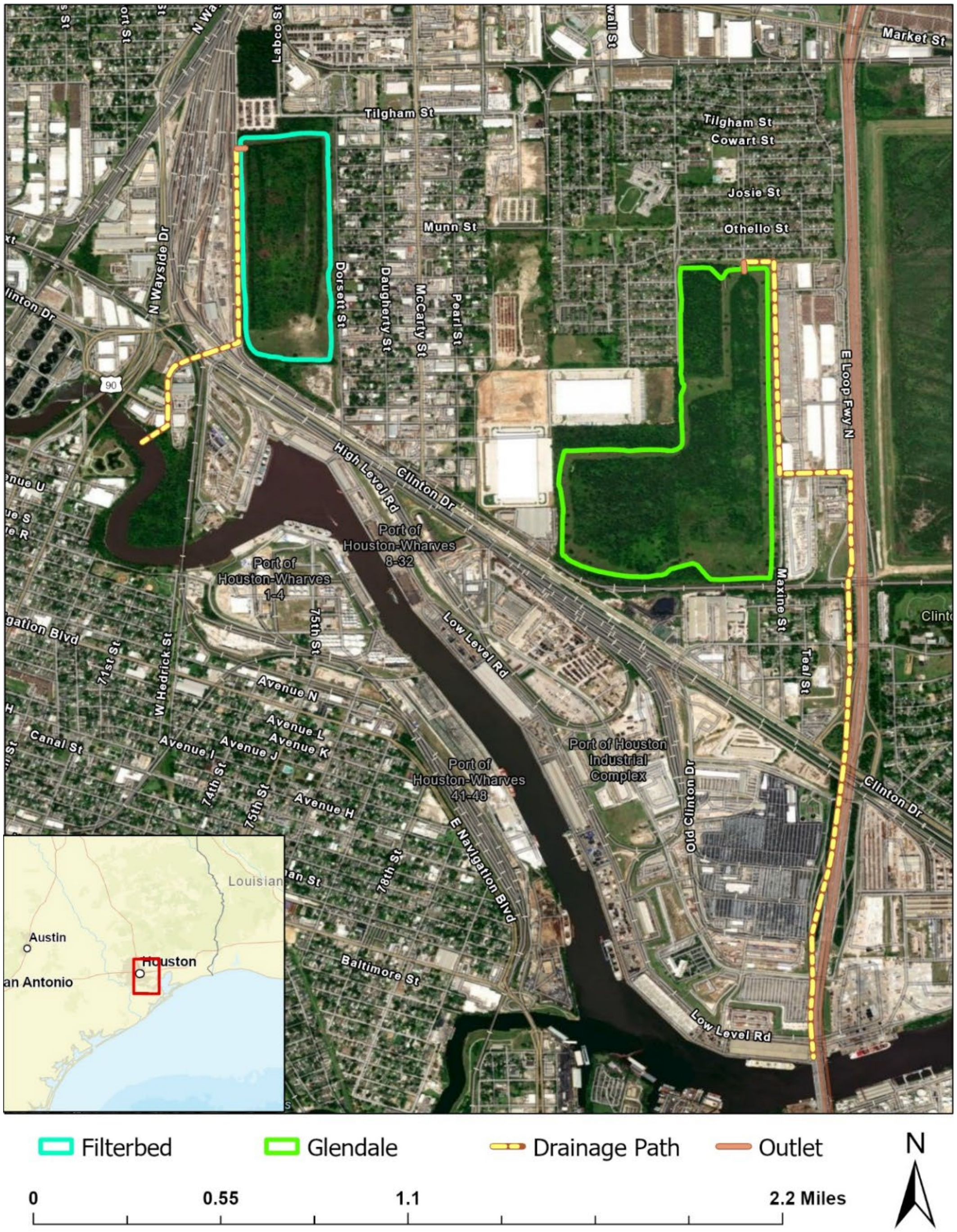


Figure 2. Glendale and Filterbed Upland Placement Area Discharge Locations and Drainage Paths to Receiving Water (HDR 2020a).

1.4 Mixing Zone Evaluation Approach

Dilution of effluent from the new work dredged material placement area occurs when the effluent discharge mixes with the receiving body waters. The extent to which the two streams (PA effluent and receiving body) mix depends on physical characteristics such as density and flow rate (or velocity) of both, geometry of the receiving body, and size and orientation of the effluent pipe (or channel).

The amount of dilution (D) that is required to meet water quality criteria (WQC) is a function of the contaminant concentration in the effluent discharge as represented by elutriate concentrations (C), the applicable WQC (C_{wq}) or limiting permissible concentration (LPC), and the background concentration of the receiving water (C_B). Required dilution is expressed in terms of how many parts of receiving water need to be mixed with one part of effluent to reach the applicable criteria. Equations to calculate dilution requirements for both water quality ($D_{a\text{-}wq}$) and toxicity ($D_{a\text{-}tox}$) are provided below.

$$D_{a\text{-}wq} = \frac{C - C_{wq}}{C_{wq} - C_B} \qquad (1)$$

Where:

$D_{a\text{-}wq}$ = dilution required to achieve concentration equivalent to WQC
C = contaminant concentration in elutriate sample
C_{wq} = WQC
C_B = background (receiving water) contaminant concentration

$$D_{a\text{-}tox} = \frac{100 - LPC}{LPC} \qquad (2)$$

Where:

$D_{a\text{-}tox}$ = dilution required to achieve LPC for toxicity
LPC = limiting permissible concentration based on elutriate toxicity evaluation

As shown in Equation 1, the quality (i.e. background contaminant concentrations) of the receiving water affects dilution requirements. The higher the background concentration, the greater the amount of water needed to dilute to meet WQC. The concentration of the mixture will necessarily fall between the concentration of the effluent and of the receiving water. If the receiving water concentration is above the WQC, then it is impossible to demonstrate sufficient dilution to reach the criteria.

Texas Surface Water Quality Standards (TSWQS) allow for application of a mixing zone (MZ) and zone of initial dilution (ZID). Acute toxicity is not allowed in a mixing zone, and chronic toxicity is not allowed beyond a mixing zone (TCEQ 2012). The ZID is a small area where initial dilution with receiving waters occurs and may not meet criteria applicable to the receiving water. Acute criteria may be exceeded within a ZID; thus acute criteria apply at the edge of the ZID. Chronic criteria apply at the edge of the mixing zone. Typically, the amount of mixing and dilution increases with distance from the discharge point. CDFATE models mixing within the receiving stream and is used to determine the location, measured as distance from the discharge point, where dilution is sufficient to reach acute and chronic criteria. This determines the dimensions needed for the ZID and MZ for each discharge location.

The CDFATE model was used to evaluate the extent of mixing for effluent from each PA into their respective receiving waters using elutriate chemistry and elutriate toxicity testing results. As shown in Section 2, elutriate chemistry and toxicity were compared against TSWQS to determine the dilution needed by mixing. The physical properties of the sediment and receiving water (Section 3) and characteristics of the PA effluent, PA outfalls and other receiving water conditions (Section 4) affect mixing and provide input to the CDFATE model. Section 5 reports the results of the mixing evaluation and compares the modeled dilution as a function of distance downstream to the dilution requirements based on TSWQS.

2 Testing Data Evaluation

Refining the CDFATE calculations used the same analytical data as in the initial CDFATE calculations (Montgomery, Bourne and Stevens 2023). Sediment samples HSCNew-NMP-06-SD, HSCNew-NMP-07-SD, HSCNew-NMP-08-SD, HSCNew-NMP-09-SD, HSCNew-NMP-10-SD, HSCNew-NMP-11-SD, were collected during October 2018; corresponding water samples were also collected from the same locations in October 2018. Elutriate samples were prepared from the sediment samples and elutriate toxicity tests run. Chemical analytical data were generated for sediment, surface water, and elutriate water chemistry (Montgomery, Bourne and Stevens 2023).

This section will evaluate elutriate chemistry and elutriate toxicity against TSWQS to determine the need for a mixing zone evaluation for each PA.

2.1 Elutriate Chemistry

Contaminants of concern (COCs) with elutriate concentrations below Texas State Water Quality Standards (TSWQS) (30 TAC §307.6(c)(1)) meet criteria. In the initial screening, 11 COCs were identified where either the elutriate concentration exceeded either acute and/or chronic screening criteria, or the reporting limits (RLs) were above the screening criteria and therefore could not be verified as meeting the criteria. The elutriate results for the 11 COCs whose reported results exceed TSWQS are presented below (Table 1). Non-detect analyses among these samples were compared to the minimum analytical level (MAL) (TCEQ 2012) for each analyte. Non-detects where the limits of quantitation (LOQ) were below the MAL, highlighted blue, were considered to be equal to zero.

After application of TCEQ's MALs in samples HSCNew-NMP-06 through HSCNew-NMP-11, only lead, zinc and silver reported concentrations that exceeded TSWQS (Table 2). For four of the samples, silver was non-detect, qualified "U" at the RL of 5 µg/L which exceeded the acute TSWQS of 2 µg/L; the limit of detection (LOD) (0.8 µg/L) was below 2 µg/L, and with the "U" qualifier, levels of silver can be assumed to be below the TSWQS acute criterion of 2 ug/L for those samples. Silver was detected in two of the samples, although below the limit of quantitation resulting in estimated values (J-qualified). Only one of these values, HSCNew-NMP-

09, exceeded the TSWQS acute criterion. To be conservatively protective, silver was evaluated further. Zinc required evaluation because HSCNew-NMP-08 and HSCNew-NMP-11 were detected above TSWQS acute criteria; all other samples were below TSWQS (acute and chronic) for zinc. Lead was detected above TSWQS chronic criteria once in sample HSCNew-NMP-10 and was further evaluated.

Background concentrations of the receiving water are needed to estimate dilution requirements. COC concentrations of site water samples collected within Segments 5 and 6 are shown in Table 2, with HSCNew-NMP-07 being nearest the Glendale PA discharge location and HSCNew-NMP-11 nearest the Filterbed PA discharge point. For both samples, lead concentrations were estimated values below TSWQS. Silver concentrations were non-detect, qualified “U”, with a RL of 5 μg/L which exceeds the acute TSWQS, but LOD of 0.8 μg/L which is below the TSWQS. The concentrations of zinc at these locations exceeded the marine chronic TSWQS. If background concentrations exceed WQS then mixing cannot achieve sufficient dilution to meet the WQS. Based on the analytical results of these two samples representing background concentrations, WQS cannot be achieved due to measured concentrations of zinc exceeding TSWQS. However, rather than relying solely on these two samples, additional data sources were sought to provide additional information about the receiving water quality.

Additional background data were identified in the HSC/Buffalo Bayou reach from a data set collected by Texas Commission on Environmental Quality (TCEQ) within the Turning Basin (Water Quality Portal Station TCEQMAIN-11292) as well as another data set collected by USGS Texas Water Science Center (Water Quality Portal Station USGS-08074700) located at 69th Street, approximately one quarter mile upstream of the Filterbed PA discharge. Both data sets provide multiple analyses across a range of time periods and river conditions and provide more data than the singular analyses taken at locations HSCNew-NMP-07 and HSCNew-NMP-11. A summary of lead and zinc data collected after year 2000 is shown in Table 3; silver data were not available.

Table 1. Summary of Analytes in Site Water and Elutriate Samples Requiring Further Evaluation.

	4,4'-DDT µg/L	Dieldrin µg/L	Endrin µg/L	Heptachlor µg/L	Heptachlor Epoxide µg/L	Toxaphene µg/L	Copper [1] µg/L	Lead µg/L	Silver µg/L	Zinc µg/L	Cyanide µg/L
Marine Water Screening Criteria:											
MAL [2]	0.02	0.02	0.02	0.01	0.01	0.3	2	0.5	0.5	5	10
TSWQS (Marine Acute) [3]	0.13	0.71	0.037	0.053	-	0.21	24.3	133	2	92.7	5.6
EPA WQC (Saltwater CMC) [4]	0.13	0.71	0.037	0.053	0.053	0.21	4.8	210	1.9	90	1
NOAA (Marine Acute) [5]	0.065	0.355	0.0185	0.0265	0.0265	0.21	4.8	210	0.95	90	1
EPA WQC (Saltwater CCC) [4]	0.001	0.0019	0.0023	0.0036	0.0036	0.0002	3.1	8.1	-	81	1
TSWQS (Marine Chronic) [3]	0.001	0.002	0.002	0.004	-	0.0002	6.48	5.3	-	84.2	5.6
Elutriate Samples [6] [7] [8] [9] [10] [11]:											
HSCNew-NMP-06-EL	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	5.0 U	5.0 U	5.0 U	71	10 Cl, U
HSCNew-NMP-07-EL	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	5.0 U	5.0 U	5.0 U	66	10 Cl, U
HSCNew-NMP-08-EL	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	5.0 U	5.0 U	5.0 U	162	10 Cl, U
HSCNew-NMP-09-EL	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	5.0 U	5.0 U	3.2 J	47	10 Cl, U
HSCNew-NMP-10-EL	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	0.7 J	16	1.2 J	73	10 Cl, U
HSCNew-NMP-11-EL	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	0.6 J	5.0 U	5.0 U	149	10 Cl, U
Site Water Samples [6] [7] [8] [9] [10] [11]:											
HSCNew-NMP-06-SW	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	2.3 J	5.0 U	5.0 U	91	10 Cl, U
HSCNew-NMP-07-SW	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	3.3 J	1.1 J	5.0 U	88	10 Cl, U

	4,4'-DDT µg/L	Dieldrin µg/L	Endrin µg/L	Heptachlor µg/L	Heptachlor Epoxide µg/L	Toxaphene µg/L	Copper [(1)] µg/L	Lead µg/L	Silver µg/L	Zinc µg/L	Cyanide µg/L
HSCNew-NMP-08-SW	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	2.1 J	5.0 U	5.0 U	83	10 Cl, U
HSCNew-NMP-09-SW	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	3.4 J	1.2 J	3.1 J	58	10 Cl, U
HSCNew-NMP-10-SW	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	2.5 J	0.9 J	1.2 J	65	10 Cl, U
HSCNew-NMP-11-SW	0.006 U	0.006 U	0.006 U	0.006 U	0.006 U	0.30 U	4.6 J	1.5 J	5.0 U	86	10 Cl, U

(1) TSWQS criteria for copper is the EPA conversion factor (acute - 13.5; chronic - 3.6) multiplied by the site-specific water effect ratio (WER) of 1.8 for Segment 1007 - Houston Ship Channel/Buffalo Bayou Tidal in Harris County (https://texreg.sos.state.tx.us/fids/202203625-7.pdf).

(2) MAL = Minimum analytical level.

(3) https://www.tceq.texas.gov/waterquality/standards/WQ_standards_intro.html.

(4) https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table. CMC = Criterion Maximum Concentration; CCC = Criterion Continuous Concentration.

(5) https://response.restoration.noaa.gov/sites/default/files/SQuiRTs.pdf.

(6) U = Not detected above the laboratory Limit of Detection (LOD).

(7) J = Estimated value detected between the LOD and the Limit of Quantitation (LOQ).

(8) Cl = Residual Chlorine or other oxidizing agent was detected in the container used to analyze this sample.

(9) **Bold text** indicates samples that exceeded screening criteria.

(10) Highlighted text indicates samples that were a) analytically reported at the LOQ and qualified U, b) whose LOQs were greater than or equal to the TSWQS, and c) whose LOQ is less than or equal to the MAL. As per TCEQ (2012), these values are considered to be a zero concentration.

(11) https://www.swg.usace.army.mil/Business-With-Us/Planning-Environmental-Branch/Documents-for-Public-Review/.

Table 2. Analytes of Interest for NMP Mixing Zone Analysis.

	Lead µg/L	Silver µg/L	Zinc µg/L
Marine Water Screening Criteria:			
MAL	0.5	0.5	5
TSWQS (Marine Acute)	133	2	92.7
TSWQS (Marine Chronic)	5.3	-	84.2
Elutriate Samples (1) (2) (3) (4) (5)**:**			
HSCNew-NMP-06-EL	5.0 U	**5.0 U** (6)	71
HSCNew-NMP-07-EL	5.0 U	**5.0 U** (6)	66
HSCNew-NMP-08-EL	5.0 U	**5.0 U** (6)	**162**
HSCNew-NMP-09-EL	5.0 U	**3.2 J**	47
HSCNew-NMP-10-EL	**16**	1.2 J	73
HSCNew-NMP-11-EL	5.0 U	**5.0 U** (6)	**149**
Site Water Samples (1) (2) (3) (4) (5)**:**			
HSCNew-NMP-06-SW	5.0 U	**5.0 U** (6)	91
HSCNew-NMP-07-SW	1.1 J	**5.0 U** (6)	88
HSCNew-NMP-08-SW	5.0 U	**5.0 U** (6)	83
HSCNew-NMP-09-SW	1.2 J	**3.1 J**	58
HSCNew-NMP-10-SW	0.9 J	1.2 J	65
HSCNew-NMP-11-SW	1.5 J	**5.0 U** (6)	**86**

(1) U = Analyte included in the analysis but not detected, reported at the reporting limit (RL)

(2) J = Detected but below the Limit of Quantitation; therefore, result is an estimated concentration

(3) **Bold text** indicates samples that exceed TSWQS

(4) Green highlighted text indicates sample exceeds TSWQS acute

(5) Yellow highlighted text indicates sample exceeds TSWQS chronic

(6) RL for silver was 5 µg/L, however the limit of detection (LOD) was 0.8 µg/L

Table 3. Summary Statistics, Background Concentrations (Lead and Zinc), Segments 5 and 6 of HSC ECIP NMP.

Water Quality Station	Lead	Zinc
USGS 8074700 (1)		
Average, µg/L	0.321	11.26
Maximum, µg/L	0.828	29
N	61	63
TCEQMAIN-11292 (2)		
Average, µg/L	0.957	31.56
Maximum, µg/L	5.03	100
N	39	27

(1) https://www.waterqualitydata.us/provider/NWIS/USGS-TX/USGS-08074700/

(2) https://www.waterqualitydata.us/provider/STORET/TCEQMAIN/TCEQMAIN-11292/

For the mixing evaluation based upon water chemistry, representative background concentrations were selected based on comparison of the additional background data alongside the site water concentrations at locations HSCNew-NMP-07 and HSCNew-NMP-11. For lead, site water concentrations at locations HSCNew-NMP-07 and HSCNew-NMP-11 were greater than the average concentrations at the TCEQMAIN-11292 and USGS-08074700 stations. As a conservative measure, the concentrations at locations HSCNew-NMP-07 and HSCNew-NMP-11 were used to represent background concentrations at Glendale and Filterbed PAs, respectively. The site water concentrations for zinc were also greater at locations HSCNew-NMP-07 and HSCNew-NMP-11 than the average concentrations at the TCEQMAIN-11292 and USGS-08074700 stations. Although it would be conservative to apply the higher concentrations, these concentrations appear to be outside the normal range of concentrations, and this would result in an inability to meet marine chronic TSWQS for zinc. Therefore, the average zinc concentration at TCEQMAIN-11292 was used to represent the background zinc concentration at Glendale PA, and the average concentration at USGS-08074700 was used to represent background conditions at Filterbed PA. As discussed, additional data for silver were not available for comparison. Silver concentrations at locations HSCNew-NMP-07 and HSCNew-NMP-11 were non-detect, qualified “U” at the RL of 5 µg/L, which exceeded the acute TSWQS of 2 µg/L. However, the LOD was 0.8 µg/L and this was conservatively used as the background concentration for silver at both PA discharge locations.

Of the three COCs (lead, zinc and silver) requiring further evaluation in CDFATE, lead required the greatest dilution to meet chronic Texas WQS for each PA (Table 4); zinc required the greatest dilution to meet acute WQS at Glendale PA and silver required the greatest dilution to meet acute WQS at Filterbed PA. These dilution requirements that are based on water chemistry will be compared to the requirements based on elutriate toxicity (Section 2.2) to determine the overall dilution requirements to adhere to TSWQS.

Table 4. Required Dilution of Lead, Silver and Zinc for Segments 5 and 6 of HSC ECIP NMP.

Parameter	Lead	Silver	Zinc
Acute, µg/L	133 (1)	2 (1)	92.7 (1)
Chronic, µg/L	5.3 (1)	-	84.2 (1)
Elutriate concentration, µg/L (2)	16	3.2	162
Glendale PA			
Background concentration, µg/L	1.1 (4)	0.8 (5)	31.56 (6)
Dilution to meet Acute (3)	NA	1.0	1.133
Dilution to meet Chronic (3)	2.548	NA	1.478
Filterbed PA			
Background concentration, µg/L	1.5 (7)	0.8 (5)	11.26 (8)
Dilution to meet Acute (3)	NA	1.0	0.851
Dilution to meet Chronic (3)	2.82	NA	1.067

(1) TSWQS Aquatic Life Protection Criteria, Saltwater 30 TAC §307.6(c)1, https://www.tceq.texas.gov/waterquality/standards/WQ_standards_intro.html

(2) Used highest concentration (worst case) from HSCNew-NMP-06, -07, -08, -09, -10 and -11

(3) Dilution ($D_{a\text{-}wq}$) = $(C - C_{WQ})/(C_{WQ} - C_{Background})$

Where: $D_{a\text{-}wq}$ = dilution required to achieve concentration equivalent to WQC

C = contaminant concentration in elutriate sample

C_{WQ} = WQC (TSWQS Acute or Chronic)

$C_{Background}$ = background (receiving water) contaminant concentration

(4) Lead concentration of HSCNew-NMP-07-SW

(5) HSCNew-NMP-07 and –11 silver concentrations were non-detect with a RL of 5 µg/L and limit of detection (LOD) of 0.8 µg/L. The LOD was applied as $C_{background}$ This is a conservative assumption.

(6) Average data from TCEQ sta 11292 2000-2022 (https://www.waterqualitydata.us/provider/STORET/TCEQMAIN/TCEQMAIN-11292/)

(7) Lead concentration of HSCNew-NMP-11-SW

(8) Average data from USGS sta 8074700 from 2000-2022 (https://www.waterqualitydata.us/provider/NWIS/USGS-TX/USGS-08074700/)

2.2 Elutriate Toxicity

The previous section (2.1) evaluated dilution requirements to meet TSWQS for elutriate chemistry. Similarly, this section will determine dilution requirements for compliance with water column toxicity criteria. As discussed, elutriate bioassay data described in Appendix 5 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023) were reevaluated to determine dilution requirements to account for toxicity displayed in those samples. Acute (96-hour) toxicity tests were conducted with each of the Segments 5 and 6 elutriate samples with the fish *Menidia beryllina* and the mysid shrimp *Americamysis bahia*; each test was compared to tests using a control (dilution water). Toxicity was indicated for tests where survival was reduced by at least 10% and was statistically different when compared to the control. For samples where toxicity was displayed, the no observed adverse effects concentration (NOAEC) and lowest observed adverse effects concentration (LOAEC) were determined, where concentration was expressed as percent elutriate (diluted with water). For tests with sufficient toxicity, an LC50 value was also calculated; LC50 is the concentration lethal to 50% of the organisms, and is the concentration considered to be acutely toxic.

Elutriate bioassay toxicity testing of the Segment 5 and 6 samples (Table 5) displayed statistically greater toxicity compared to control samples for five of the six elutriate samples and generated sufficient toxicity to yield a median lethal concentration (LC50) value for two of the samples. Two of the elutriate samples showed toxicity to shrimp (*A. bahia*) (HSC-NMP-7 and -8), and five samples showed toxicity to fish (*M. beryllina*) (HSC-NMP-6, -7, -8, -10 and -11). Of these, shrimp mortality was high enough to calculate an LC50 value for HSC-NMP-7 (79% elutriate) and fish mortality was high enough to calculate LC50 values for HSC-NMP-6 (95% elutriate), and HSC-NMP-7 (59% elutriate). According to Section 4.6 and Appendix 8 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023), the concentrations of ammonia measured in all of the elutriates in which acute toxicity was observed were high enough to cause mortality to both test organisms based on literature reported values for ammonia toxicity (Kennedy et al. 2015). For instance, for the samples that showed toxicity to shrimp, HSC-NMP-7 and -8, concentrations of un-ionized ammonia of 1.11 mg/L and 0.62 mg/L were measured during the tests, which are above the 0.5 mg/L toxicity threshold. Similarly, for toxicity to fish, HSC-NMP-6, -7, -8, -10 and -11 showed un-ionized ammonia concentrations of 0.65, 1.11, 0.62, 0.65 and 0.65 mg/L, respectively, compared to the 0.6 mg/L threshold for *M. beryllina*. For the bioassay test demonstrating the highest toxicity, HSC-NMP-7 using *M. beryllina*, un-iodized ammonia was measured at a concentration nearly twice the toxicity threshold, thus providing strong evidence that ammonia is the cause of the demonstrated toxicity.

Details of the bioassay results can be found in Section 4.6 and Appendix 8 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023). For samples where no LC50 was generated, the use of the NOAEC as acute criteria and one fifth of the NOAEC as chronic criteria for toxicity was previously discussed and agreed upon with TCEQ (email Peter Schaefer 12/4/20) for Segment 4. For the samples where LC50 values were calculated, the NOAEC was applied as the acute criteria, and chronic criteria were calculated as the LC50 multiplied by an application factor (AF). The AF generally represents the inverse of the acute-to-chronic ratio (ACR). An AF of 0.01 was recommended by the National Academy of Science (NAS) and adopted in the MPRSA and USEPA/USACE dredged material testing guidance (Kennedy et al. 2015). There is precedent, however, for applying AFs larger than 0.01 where a non-persistent contaminant such as ammonia is the driver of toxicity (Kennedy et al. 2015); AFs of 0.05 to 0.1 have been applied, although AFs as high as 0.14 have been suggested (Kennedy et al. 2015). An alternate AF is suggested for application here in light of the ammonia toxicity discussed in Section 4.6 and Appendix 8 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023). For the two samples with high ammonia levels that exhibited LC50 values, chronic criteria were calculated using both a conservative AF of 0.05 and a less conservative AF of 0.14 which is still within the range suggested by Kennedy et al. (2015). The acute and chronic toxicity criteria and corresponding dilution requirements for each sample are shown in Table 5.

As Table 5 shows, elutriate sample HSC-NMP-7 required the greatest dilution. Using a conservative AF of 0.05, dilution factors of 9 and 32.90, respectively, would be required to meet the acute and chronic toxicity criteria for this sample, based on toxicity to *M. beryllina*. Using an AF of 0.14 would result in dilution factors of 9 and 11.1, respectively, to meet the acute and chronic toxicity. If sufficient dilution is achieved to reduce water column toxicity for sample HSC-NMP-7, which displayed the most toxicity, then the other samples would be sufficiently diluted as well.

The dilution requirements stated above are part of a conservative approach based on the worst-case samples with the highest contaminant concentrations or toxicity. In reality, the new work material dredged from Segments 5 and 6 of the channel will be placed in the PAs, resulting in effluent mixing with lower dilution factors needed to achieve dilutions.

Table 5. Biological Testing Results for Houston Ship Chanel (HSC) Expansion Channel Improvement Project – New Work Elutriate Bioassay Results for NMP Mixing Zone Analysis (Army-ERDC 2019).

Sample	Endpoint (1)	96-h *Americamysis bahia*			96-h *Menidia beryllina*			Required Dilution (4)	
		Endpoint Result	Acute criteria (2)	Chronic criteria (3)	Endpoint Result	Acute criteria (2)	Chronic criteria (3)	Acute criteria	Chronic criteria
HSCNew-NMP-06	NOAEC	100%	NA	NA	50%	50%	4.75% (13.3%)	1	20.05 (6.52)
	LOAEC	NA (5)			100%				
	LC50	NA (5)			95% (78-117)				
HSCNew-NMP-07	NOAEC	50%	50%	3.95% (11.1%)	10%	10%	2.95% (8.26%)	9	32.90 (11.1)
	LOAEC	100%			50%				
	LC50	79%			59% (52-66)				
HSCNew-NMP-08	(73-86)		50%	10%	50%	50%	10%	1	9
	NOAEC	50%			100%				
	LOAEC	100%			NA (5)				
HSCNew-NMP-09	LC50	NA (5)	NA	NA	100%	NA	NA	NA	NA
	NOAEC	100%			NA (5)				
	LOAEC	NA (5)			NA (5)				
HSCNew-NMP-10	LC50	NA (5)	NA	NA	50%	50%	10%	1	9
	NOAEC	100%			100%				
	LOAEC	NA (5)			NA (5)				

Sample	Endpoint [1]	96-h *Americamysis bahia*			96-h *Menidia beryllina*			Required Dilution [4]	
		Endpoint Result	Acute criteria [2]	Chronic criteria [3]	Endpoint Result	Acute criteria [2]	Chronic criteria [3]	Acute criteria	Chronic criteria
HSCNew-NMP-11	LC50	NA [5]	NA	NA	50%	50%	10%	1	9
	NOAEC	100%			100%				
	LOAEC	NA [5]			NA [5]				

[1] NOEAC = no observed adverse effect concentration; LOAEC = lowest observed adverse effect concentration; LC50 = median lethal concentration

[2] Acute criteria determined as follows:
- For cases with no observed toxicity – NA (not applicable);
- NOAEC applied as acute criteria for cases with observed toxicity. Toxicity is indicated for tests where survival is reduced by at least 10% and is statistically different compared to the control. For samples not displaying toxicity, the NOAEC should be 100%.

[3] Chronic criteria determined as follows:
- For cases with no observed toxicity – NA (not applicable);
- for cases with observed toxicity but insufficient to calculate an LC50 – NOAEC*0.2 (email Peter Schaefer 12/4/20);
- for cases with a calculated LC50 – LC50*AF, showing results for AF = 0.05 and (AF = 0.14).

[4] Dilution ($D_{a\text{-}tox}$) = (100 – LPC)/LPC
(showing highest dilution requirement between *Americamysis bahia* and *Menidia beryllina*)
$D_{a\text{-}tox}$ = dilution required to achieve LPC for toxicity
LPC = limiting permissible concentration based on elutriate toxicity evaluation

[5] NA = not applicable due to no observed toxicity

2.3 Elutriate Chemistry and Toxicological Conclusions

Comparison of required dilutions for elutriate chemistry and elutriate toxicity at the Glendale PA shows that dilution of COCs was more restricted by toxicity requirements than acute and chronic WQS. To meet acute WQS, the greatest dilution factor required was 1.133 for zinc; to meet chronic WQS, the greatest dilution factor was 2.548 for lead. However, based on elutriate toxicity, sample HSCNew-NMP-07 required a dilution factor of 9 for acute conditions and a dilution factor of 32.9 for chronic toxicity conditions when the conservative AF (0.05) was applied. This dilution factor changes to 11.1 when the less conservative but still protective site-specific AF of 0.14 was applied.

Comparison of required dilutions for elutriate chemistry and elutriate toxicity at the Filterbed PA also showed that the dilution of COCs was more restricted by toxicity requirements than acute and chronic WQS. To meet acute WQS, the greatest dilution factor required was 1.0 for silver; to meet chronic WQS, the greatest dilution factor was 2.82 for lead. Based on elutriate toxicity, sample HSCNew-NMP-07 required dilution factors of 9 for acute conditions and either 32.9 for chronic conditions using a conservative default AF of 0.05, or 11.1 using the less conservative but still protective site-specific AF of 0.14.

Application of dilution requirements based on the selection of samples with the highest contaminant concentrations or toxicity values is a worst-case scenario, given the new work material dredged throughout the reach will be combined within the two PAs. This conservative approach ensures that the conclusions are both protective and applicable to both PAs.

3 New Work Dredged Material and Site Water Physical Properties

The previous section discussed the chemistry and toxicity of the new work dredged material elutriate and the resulting dilution that would be required to meet TSWQS criteria. This section discusses the physical properties of the sediment and receiving waters, as well as the characteristics of the PA effluent and outfalls that affect mixing and dilution of the effluent upon discharge to the receiving waters. These parameters provide input to the CDFATE model, which was used to predict dilution as a function of distance downstream of the discharge point.

The new work dredged slurry entering the PAs will consist of a mixture of the new work dredged material and entrained site water. Most of the solid particulates are expected to settle within the PA, so that the effluent will consist primarily of site water with some fraction (primarily fines) of suspended solids that did not settle. As discussed in Section 1.4, physical properties of both the effluent and receiving waters (e.g. density as a function of salinity and temperature) affect the mixing behavior between the effluent and receiving waters. Receiving water samples in the channel were collected at mid-point in the water column. Properties of the collected site waters are shown in Table 6.

Table 6. Results of In-Situ Site Water Parameters. (1)

	HSC New NMP-06-SW	HSC New NMP-07-SW	HSC New NMP-08 - SW	HSC New NMP-09-SW	HSC New NMP-10-SW	HSC New NMP-11-SW
Water Depth (ft)	10.3	20.2	40.2	40.1	32.6	40.3
Sample Depth (ft)	5.1	10	20.1	20	16	20.1
Water Temperature (°C)	22.87	19.43	23.08	20.24	23.09	19.5
Salinity (ppt)	1.76	1.18	1.81	2.32	1.8	1.13
Turbidity (NTU)	9.8	9.5	7.6	12.1	12.9	26.3

(1) Full site water analysis report provided in Appendix 5 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023)

Sediment samples were also collected as part of this sampling event. The physical properties of these samples are provided in Section 4.2 and Appendix 4 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023) and Table 7 in this report.

Table 7. Results of Physical Analyses for Composited New Work Dredged Material Samples. [1]

	HSC New NMP-06-SD	HSC New NMP-07-SD	HSC New NMP-08-SD	HSC New NMP-09 -SD	HSC New NMP-10-SD	HSC New NMP-11-SD
Solids, %	68	68	69	69	66	72
Specific Gravity (g/cc)	2.65	2.66	2.64	2.65	2.69	2.66
Atterberg Liquid Limit (%)	42	45	57	55	56	32
Atterberg Plastic Limit (%)	17	16	19	21	20	14
Grain Size Percentages						
Gravel	1.5	0	0	0	0	0
Sand Coarse	0.1	0.2	0.1	0.4	0.2	0.4
Sand Medium	1.3	1.7	0.6	0.5	0.4	0.6
Sand Fine	16.7	28.4	13.5	7.7	12.4	41.4
Sand Total	18.1	30.3	14.2	8.6	13.0	42.4
Silt	38.1	30.6	17.7	18.3	23.0	23.0
Clay	42.3	39.1	68	73.1	63.9	34.7

(1) Full particle size distribution report provided in Appendix 4 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023)

Although these site water and new work dredged material properties are not used directly in the CDFATE modeling, the physical properties of these media are always useful as lines-of-evidence (LOE) when interpreting the results (Section 6).

4 CDFATE Input Parameters

Mixing zone calculations are made using the CDFATE model (Havis 1994, Doneker and Jirka 1990, Akar and Jirka 1991, Jones 1990). The CDFATE model uses four categories of input parameters for these calculations: 1) discharge parameters; 2) site receiving water conditions, 3) effluent density modeling, and 4) mixing zone data. Each of these are discussed below.

4.1 Discharge Parameters

The discharge parameters for the two PAs are summarized in Table 8. The PA effluent discharge rate is dependent on the influent rate, which is related to the dredge size, as well as weir design and operation. At the time of this analysis, the dredge size had not yet been specified and the weir structure was still under design. A 24-inch hydraulic cutterhead dredge was evaluated in the initial CDFATE evaluation (Appendix 7 of the HSC ECIP NMP Report (Montgomery, Bourne and Stevens 2023). Design documents for Segment 4 suggested that a 30-inch dredge may be utilized, and weir structures for those PAs would be designed to handle flows from dredges up to 30-inches with an estimated flow velocity of 15 ft/s operating 20 hours per day. For modeling purposes, a 30-inch pipeline dredge was assumed with a typical pipeline velocity of 15 ft/s. These values yielded a flow rate of 73.6 cfs (2.08 m^3/s) into the PAs. However, when model results showed difficulty meeting dilution requirements, a 24-inch dredge size (47.1 cfs (1.33 m^3/s)) was evaluated as a potential operational modification. It was assumed the discharge rate from the PAs would be equal to the inflow rate. The effluent from both PAs will be discharged through storm sewers so there is potential for greater flow rates as well as significant dilution due to mixing with storm water. As a conservative measure, mixing with storm water was not considered for modeling purposes. Each candidate PA is discussed further below.

Table 8. CDFATE Input – Discharge Parameters.

Parameter	Glendale	Filterbed
Type Discharge	CDF Discharge from Side Stream	CDF Discharge from Partially Full Pipe
Water Depth at Discharge Point (m) (1)	10.36	3.21
Angle of Receiving Water Side (deg)	60	11.3
Horizontal Discharge Angle (deg)	90.0	107
Discharge Rate (m^3/s) (2)	2.09/1.33	2.09/1.33
Width of Channel/Pipe Carrying Effluent (m) (3)	3.66	3.20
Depth of Flow in Channel/Pipe (m) (2) (4)	0.41/0.31	0.82/0.65
Protruding Distance (m)	0.51 (5)	0.00

(1) Depth of water (m) at a point 2-3 m from the end of the protruding distance; represents the approximate location where near-field mixing stops and far-field mixing begins.

(2) Discharge rate from 30-in (2.05 m^3/s) and 24-in dredges (1.33 m^3/s) were evaluated.

(3) Glendale PA discharges into a storm sewer 12 ft (3.66 m) wide. Filterbed PA discharges into a storm sewer with 10.5 ft diameter (3.20 m).

(4) Flow depths were determined using Manning's equation for discharges from a 30-in dredge and 24-in dredge.

(5) Computed by CDFATE

4.1.1 Placement Area – Glendale

The Glendale PA is located on the northwest side of the HSC, less than a mile east of the Main Turning Basin at Latitude 29° 45' 02", Longitude 95° 16' 19" (Figure 2). The site has been previously operated as a dredged material placement area with peak activity in the late 1950s/early 1960s. The current drainage weir is outdated, with section loss found in multiple columns and horizontal members; however, the PA improvements will include dike raising and replacement of the existing drop outlet structures (weir) along the northern dike prior to dredging. Effluent from the site will discharge via a weir in the northeastern perimeter and into the storm sewer system leading to Buffalo Bayou/HSC. Based on the drainage path from the PA (Figure 2) and information about the storm drain gravity mains from Houston Public Works Department, it appears the PA will discharge into the storm drain system which will in turn discharge into Buffalo Bayou/HSC near the I610 bridge, approximately perpendicular to the channel through a rectangular culvert 132 inches tall by 144 inches wide. The extent to which the culvert protrudes into the channel is not known, so the distance was calculated within CDFATE. Though not specified, the culvert was assumed to be reinforced concrete. Using Manning's equation, and assuming a roughness value of 0.011 for a straight section of concrete culvert, and an assumed slope of 0.001, a flow depth of 1.35 ft (0.41 m) was calculated. Bathymetry for Buffalo Bayou/HSC at the discharge location was obtained from USACE hydrographic surveys (eHydro). A survey of the Sims Bayou to Houston Ship Channel Turning Basin section, dated 06 Jun 2023 provided bathymetry of the navigation channel. A cross section (Figure 3) was developed based on the bathymetry, for which an average depth was calculated as 35.5 ft (10.81 m). The channel width in that vicinity is approximately 540 ft (165 m). Although bathymetry did not extend to the bank edges, the water depth at the end of the discharge point was estimated as 34 ft (10.36 m).

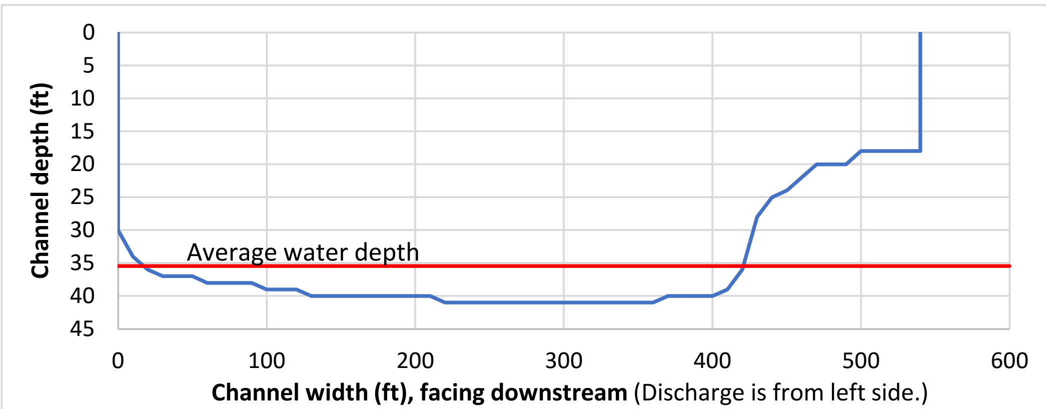
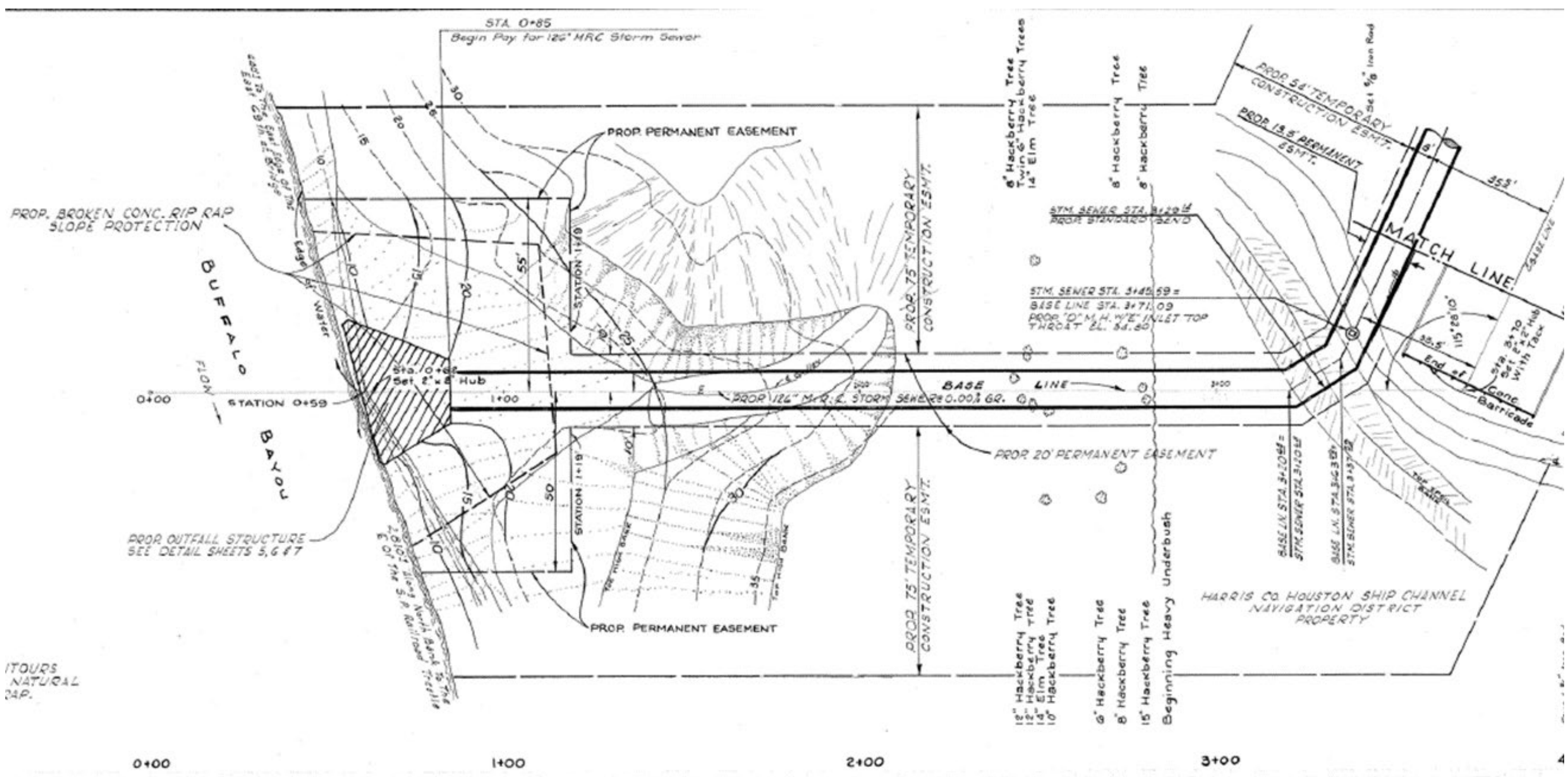


Figure 3. Buffalo Bayou/HSC Cross Section at Glendale PA Discharge Point.

4.1.2 Placement Area – Filterbed

The Filterbed PA is also located on the northwest side of the HSC just north of the Main Turning Basin, at Latitude 29° 45' 36", Longitude 95° 17' 21" (Figure 2). Filterbed PA has also been previously operated as a dredged material placement area. The location of the existing drop-outlet structure would obstruct future dike raises, therefore, the existing drop-outlet structure will be demolished and removed, and a new outlet structure designed and constructed in the northern portion of the west dike prior to dredging, when the PA dikes will be raised.

Effluent from Filterbed PA will discharge into the storm sewer system. Plans from the City of Houston Department of Public Works, McCarty Street Area Storm Sewer System Dorsett Street to Buffalo Bayou Sta. 0+00 to 4+00 (Figure 4) show the effluent from the Filterbed PA will ultimately discharge into Buffalo Bayou/HSC through a 126-inch (3.20 m) reinforced concrete storm sewer with the pipe bottom at the edge of water at an elevation of 7.0 ft. The storm sewer meets Buffalo Bayou/HSC at an angle of approximately 17^{o} upstream from perpendicular. The pipe terminates near the bank edge rather than protruding into the channel. Using Manning's equation, and assuming a roughness value of 0.015 for the sewer pipe and an assumed slope of 0.001, a flow depth of 2.676 ft (0.8155 m) was calculated. Although the water depth of Buffalo Bayou/HSC at the discharge point appears to be relatively shallow, CDFATE requires the input depth to be at least 67% of the mean receiving water depth, which is 3.21 m. Bathymetry for Buffalo Bayou/HSC at the Filterbed PA discharge location was obtained from USACE hydrographic surveys (eHydro) and a survey of the Buffalo Bayou: Houston Turning Basin to 69th Street Bridge section, dated 30 Sep 2020 provided the bathymetry of the navigation channel. A cross section (Figure 5) was developed based on the bathymetry, giving the width of approximately 300 ft (91.4 m), and an average depth was calculated as 15.7 ft (4.79 m).


STA. 0+85
Begin Pay for 126" MRC Storm Sewer
PROP. PERMANENT EASEMENT
PROP. BROKEN CONC. RIP RAP SLOPE PROTECTION
BUFFALO
BAYOU
STATION 0+59
Sta. 0+68 Set 2"x8" Hub
PROP. 126" M.R.C. STORM SEWER
BASE LINE
PROP. 75' TEMPORARY CONSTRUCTION ESMT.
PROP. 20' PERMANENT EASEMENT
PROP. OUTFALL STRUCTURE SEE DETAIL SHEETS 5, 6 & 7
PROP. PERMANENT EASEMENT
STATION 1+19
PROP. 54' TEMPORARY CONSTRUCTION ESMT.
PROP. 13.5' PERMANENT ESMT.
MATCH LINE
HARRIS CO. HOUSTON SHIP CHANNEL NAVIGATION DISTRICT PROPERTY
Beginning Heavy Underbush
0+00
1+00
2+00
3+00

a)

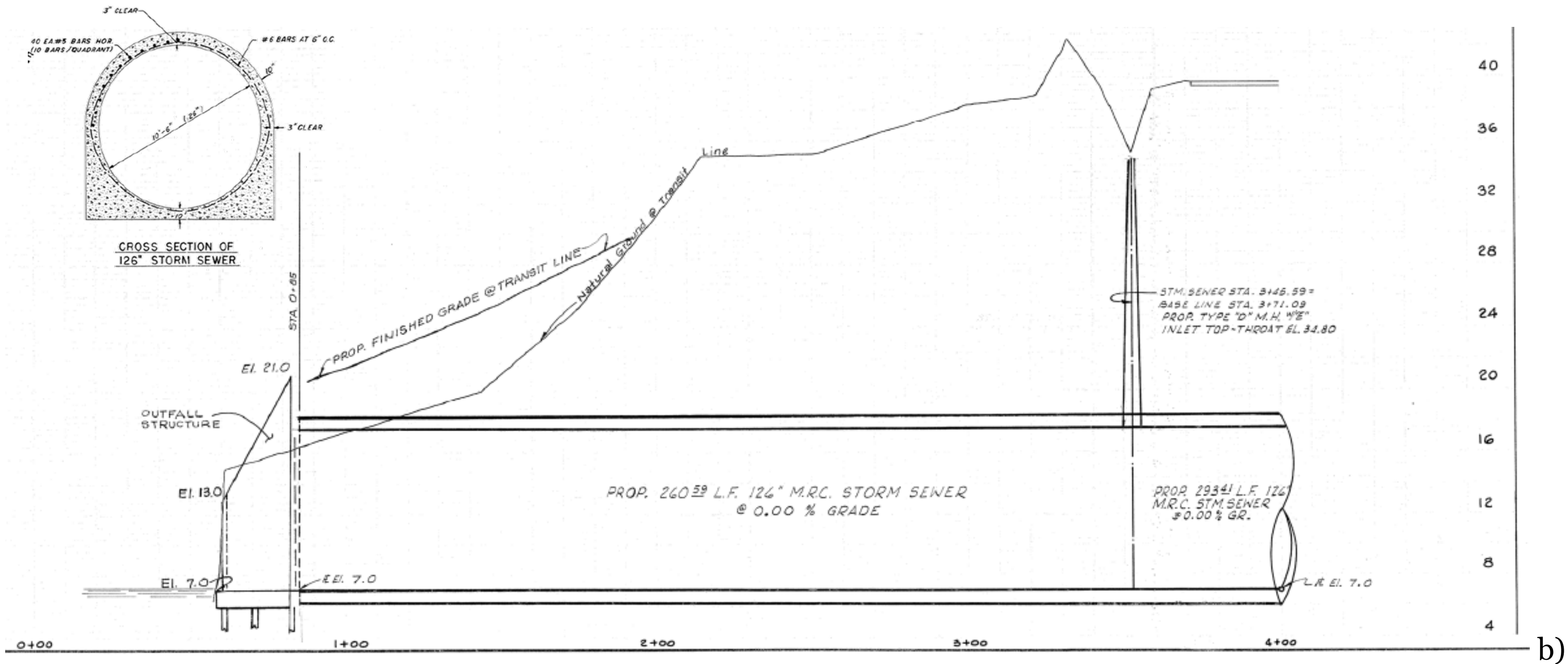


Figure 4. Schematic of Storm Sewer Outfall from Filterbed PA into Buffalo Bayou/HSC – McCarty Street Area Storm Sewer System, Dorsett Street to Buffalo Bayou Sta 0+00 to Sta 4+00. Plan (a) and section (b) views.

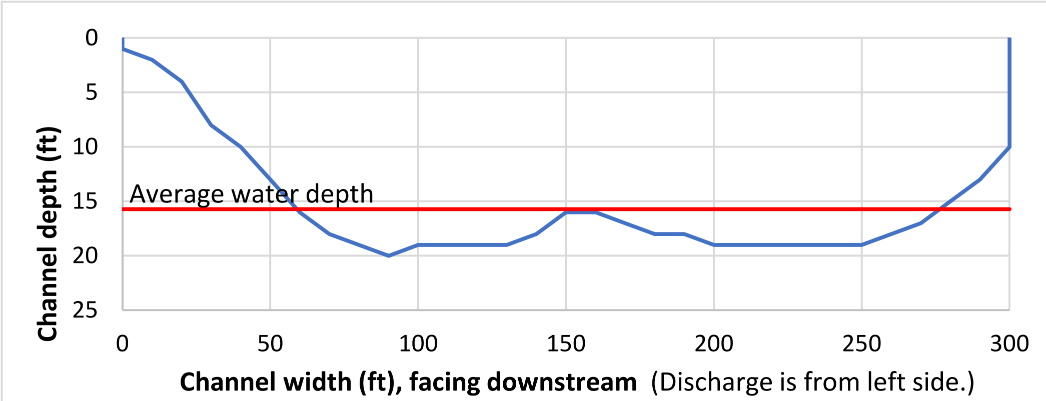


Figure 5. Buffalo Bayou/HSC Bathymetry at Outfall from Filterbed PA Discharge Point.

4.2 Site Receiving Water Conditions

Data input for the receiving water for each PA is provided in Table 9. Receiving water widths and depths were provided based on bathymetry or assumptions discussed above. As a conservative assumption, the channel was assumed to be narrow (bounded) for each PA, even though the channel widths at both discharge locations are wide. Receiving water density was calculated based on temperature and salinity. Water temperature was obtained from the collected water samples (Table 6), with location of NMP-07 being nearest the Glendale PA discharge. The location of sample NMP-11 is the closest data to the Filterbed discharge location and was assumed representative for this PA, even though it was just under a mile downstream and in deeper water. Although the salinities measured at mid-depth (Table 6) may not be representative of the salinity of the new work dredge slurry from a cutterhead dredge operating at the sediment surface, they were assumed to be representative for the purposes of the model.

Table 9. CDFATE Input – Receiving Water Data – Site Conditions.

Parameter	Glendale PA	Filterbed PA
Receiving Water	Buffalo Bayou/HSC	Buffalo Bayou/HSC
Receiving Water Depth (m) (1)	10.81	4.79
Is Stream Narrow (Bounded)?	Yes	Yes
Receiving Water Density		
Stratification	Linear	Linear
Surface Temperature (°C)	19.43 (2)	19.5 (2)
Surface Salinity (ppt)	0.9 (3)	0 (4)
Surface Density (kg/m³) (3)	999.0966 (5)	998.3693 (5)
Bottom Temperature (°C)	19.43 (2)	19.5 (3)
Bottom Salinity (ppt)	2.5 (3)	1 (4)
Bottom Density (kg/m³) (4)	1000.335 (5)	999.1446 (5)
Channel Geometry	Straight	Straight
Channel Width (m)	164.60	91.44
Channel discharge (m³/s)	21.08 (6)	18.25 (7)
Bottom Roughness (Manning's)	0.015 (8)	0.015 (8)
Wind Speed (9)	Medium (1.0 – 6.0 m/s)	Medium (1.0 – 6.0 m/s)

(1) Average channel depth across channel cross-section

(2) From Table 6, sample NMP-07-SW for Glendale and sample NMP-11-SW for Filterbed

(3) Surface and bottom salinity near Glendale, between Sims Bayou and Turning Basin, modeled by McAlpin et al. (2019)

(4) Surface and bottom salinity near Filterbed PA estimated based on salinity at Turning Basin, modeled by McAlpin et al. (2019)

(5) Calculated based on temperature and salinity

(6) Tenth percentile daily mean flow from one-year of model run at Glendale PA outfall on Buffalo Bayou/HSC (McAlpin et al. 2019)

(7) Determined by adjusting the low flow discharge at Glendale PA outfall (6) to exclude low flows from Brays Bayou.

(8) Roughness based on McAlpin et al. (2019)

(9) NOAA 8770777 station at Manchester, TX

According to City of Houston and PBS&J (2003), there is significant density stratification within the artificially deepened Buffalo Bayou/HSC. Salinity/conductivity profiles with depth, taken over several years, showed a steep increase in salinity with depth in wetter years, and less stratification in drier years when overall salinity was higher. Plots of the mean salinity profile with depth were provided for modeling results (McAlpin et al. 2019) at Sims Bayou and Turning Basin for present without project conditions (i.e. existing conditions prior to channel expansion). The Glendale outfall was estimated to lie approximately half of the distance upstream from Sims Bayou to Turning Basin. A weighted average between the salinities at the two locations was used to estimate salinities at the top and bottom of the water column near the Glendale outfall as 0.9 ppt and 2.5 ppt, respectively. The Filterbed PA discharge location along Buffalo Bayou/HSC lies less than a mile upstream of the Turning Basin. Salinity at Turning Basin modeled by McAlpin et al. (2019) for present without project conditions was 0.1 ppt at the surface of the water column and 1.3 ppt at the bottom. Salinity at the Filterbed PA discharge point was expected to be somewhat lower and was estimated as 0 ppt at the top of the water column and 1 ppt at the bottom. For the purposes of the CDFATE model, the receiving waters near both the Glendale PA and Filterbed PA discharges were assumed to have linear stratification.

Stream gauges with discharge or velocity data were not in the immediate vicinity of any discharge locations. The closest gauge located for the two outfalls on Buffalo Bayou/HSC was the USGS 08074000 gauge approximately 8 mi upstream at Shepherd Drive, which is above the confluence with Whiteoak Bayou and may not represent flows at the discharge locations. To obtain channel discharge near the Glendale outfall location at Buffalo Bayou/HSC, the model by McAlpin et al. (2019) was run for one year at the outfall location using “present with project” conditions (i.e. existing conditions but with channel expansion) and “present without project” conditions (i.e. existing conditions without channel expansion). The resulting discharges for present without project conditions, output every 3 hours, were evaluated, showing the magnitude of the discharge to range from 0.009 to 833 m^3/s, with the daily mean ranging from 11.9 m^3/s to 816 m^3/s, and the 7-day average from 17.5 m^3/s to 483 m^3/s. TCEQ evaluates discharges based on the 7Q2 discharge frequency which is defined as the minimum quantity of water discharged over seven consecutive days, with a recurrence interval of two years, statistically determined from historical data. A 7Q2 value was not identified in the literature for the project location and could not be determined from the one year of modeled discharges. In the absence of 7Q2 data, the tenth percentile daily mean flow of 21.084 m^3/s was selected as a conservative, worst-case mixing condition at the Glendale PA outfall location.

The stream discharge of Buffalo Bayou/HSC at Filterbed PA was expected to be less than the flow downstream at discharge location of Glendale PA due to additional input from runoff and tributaries between the two locations. The main tributary between the two locations is Brays Bayou. Reported flow conditions for Brays Bayou (TCEQ 2009) showed lowest flows to be around 100 cfs (2.83 m^3/s). The flow condition at the Filterbed PA discharge was estimated as the flow at the Glendale PA discharge location discussed above adjusted by subtracting the Brays Bayou flow to yield 18.254 m^3/s.

Manning's roughness values were obtained for Buffalo Bayou/HSC as 0.015 from McAlpin (2019). Hourly wind speeds at the NOAA 8770777 station at Manchester, TX averaged 2.5 m/s during the year 2018.

4.3 Effluent Density Modeling

Table 10 provides CDFATE input data for the effluent discharged from the PAs and entering the receiving streams. The total suspended solids (TSS) content of the effluent was estimated as 0.1 kg/m^3 and was assumed to consist mostly of clay with some fine silt. The assumed concentration of TSS was considered sufficient for modeling purposes because density is controlled more so by the salinity than the solids content. The effluent densities were calculated based on temperature and salinity at the corresponding sample locations on Buffalo Bayou/HSC. Due to the discussed stratification (Section 4.2), it was assumed the salinity of the new work dredge slurry would be best represented by the bottom salinity in the channel, although some stratification is expected within the PA.

Table 10. CDFATE Input – Effluent Density and Modeling Parameters.

Parameter	Glendale PA	Filterbed PA
Effluent Clearwater Density (1)	999.86	999.38
Temperature (°C)	21.7	19.5
Salinity (ppt)	2.5	1.3
Effluent concentration of solids (kg/m³)	0.1	0.1
Percent Clumps (Specific gravity = 2.7)	0	0
Percent Sand (Specific gravity = 2.7)	0	0
Percent Fine Silt (Specific gravity = 2.65)	10	10
Percent Clay (Specific gravity = 2.65)	90	90
Effluent Density (kg/m³) (2)	999.92	999.45
Modeling Parameters		
Max Distance of the Plume Model (m)	2000	600
Number of Reporting Periods	100	100

1) Calculated based on temperature and salinity

2) Calculated based on effluent clearwater density and solids concentration and specific gravity

Based on Figure 1, both Glendale PA and Filterbed PA will receive new work dredged material from Segments 5 and 6 between Sims Bayou and Turning Basin. For effluent density modeling purposes, where physical properties need to be considered, it was assumed material from the upper portion of the reach will likely go to Filterbed, and material from the lower portion to Glendale. Based on the salinities provided by McAlpin (2019), the bottom salinity at Turning Basin was 1.3 ppt and should be representative of the effluent from Filterbed PA; the average salinity between Sims Bayou and Turning Basin was approximately 2.5 ppt, and should be representative of the effluent salinity from Glendale PA. The water temperature of the Filterbed effluent was estimated as that at NMP-11 (19.5°C), and the Glendale effluent temperature was estimated as the average temperature at locations NMP-6 through NMP-10 (21.7°C). A maximum distance of 2000 m and 100 reporting periods (locations at which concentration is reported) were used to fully delineate mixing zone requirements and provide sufficient resolution.

4.4 Mixing Zone Data

Mixing zone input is provided in Table 11. CDFATE modeling was performed to delineate dilution with distance. This portion of the input for the model was only used to calculate dilution due to mixing; actual contaminant concentrations resulting from dilution were calculated separately.

Table 11. CDFATE Input – Mixing Zone Data.

Parameter	Glendale PA	Filterbed PA
Name of Chemical ("Pollutant")	NA	NA
Concentration of Pollutant above Background (1)	100	100
Background Concentration (2)	0	0
First Order Reaction Rate (sec^{-1})	0	0
Surface Heat Exchange Coefficient	0	0
Criterion Maximum Concentration (CMC)	10	10
Criterion Continuous Concentration (CCC)	1	1
Mixing Zone Distance (m)	500	500

1) Unitless. Represents the percent of the initial concentration of any constituent of interest.

2) Unitless. A background concentration of zero to determine dilution with distance downstream. Actual background and elutriate concentrations were subsequently applied to calculate concentrations of individual constituents from the dilution output.

For modeling purposes, a generic chemical with a concentration of 100 and a background concentration of zero were input. Concentration units were arbitrary, as the value merely represented 100% of the initial concentration of any chemical of interest. These concentrations do not affect the physical degree of mixing and dilution and were merely used in determining dilution with distance. Once dilution with distance was determined by the model, concentrations for each individual chemical were calculated based on the initial and background concentrations using the equation below.

$$C = \frac{C_0 + D \times C_B}{D + 1} \qquad (3)$$

Where:

C = concentration
C_o = initial concentration in effluent
D = dilution achieved through mixing, as parts receiving water added per part effluent
C_B = background (receiving water) concentration

For water quality COCs, initial concentrations (elutriate) and background concentrations (Section 2.1) at each PA discharge location for lead, silver, and zinc, are provided in Table 4. For toxicity, elutriate was generated in the laboratory from sediment to represent effluent discharge and concentration was in terms of the percentage of elutriate, with C_0 = 100% and C_B = 0%. Effluent at the discharge point was 100% (undiluted effluent), but as the plume disperses and water from the receiving stream mixes into the plume, the plume concentration becomes a fraction of the original effluent concentration.

5 Mixing Zone Results

CDFATE model runs were performed using the input outlined in Section 4. Results are provided below for Glendale PA and Filterbed PA. For each PA, the dilution/mixing achieved within a given distance downstream from the discharge was compared to the dilutions required to achieve acute and chronic concentrations of COCs. This comparison determined the distance required for the ZID and mixing zone. Concentrations of each constituent with distance were calculated based on the modeled dilution and initial and background concentrations, as described in Section 4.4. These evaluations do not include COCs which were excluded from the evaluation (Sections 2.1 – 2.3 above).

5.1 Placement Area – Glendale

The model results for discharges from Glendale PA into Buffalo Bayou/HSC are displayed in Figure 6, which shows dilution achieved with distance downstream from the discharge point. Based on this dilution, the predicted concentrations of percent elutriate, lead, silver and zinc as a function of distance are provided in Figure 7, Figure 8, Figure 9 and Figure 10, respectively. The green and red lines on these figures indicate the concentrations associated with acute and chronic criteria; therefore, the distances where concentration drops below these lines indicate the points where sufficient dilution was achieved. The predictions assumed conservative initial concentrations by selecting the highest concentrations observed in the elutriate tests and did not account for mixing that would occur during actual dredging; 16 µg/L for lead in sample HSCNew-NMP-10-EL, 3.2 µg/L for silver in sample HSCNew-NMP-09-EL and 162 µg/L for zinc in sample HSCNew-NMP-08-EL. As shown in Figure 8, the chronic TSWQS for lead was met within 3.6 m (11.7 ft) of discharge where the lead concentration dropped below the chronic TSWQS of 5.3 µg/L (red line); the corresponding plume width at this distance was 4.8 m (15.8 ft). The acute TSWQS for silver (2 µg/L) was met within 1.0 m (3.2 ft) (Figure 9). For zinc (Figure 10), the acute standard (92.7 µg/L) was met within 1.2 m (3.8 ft) and the chronic TSWQS for zinc (84.2 µg/L) was met within 1.6 m (5.3 ft).

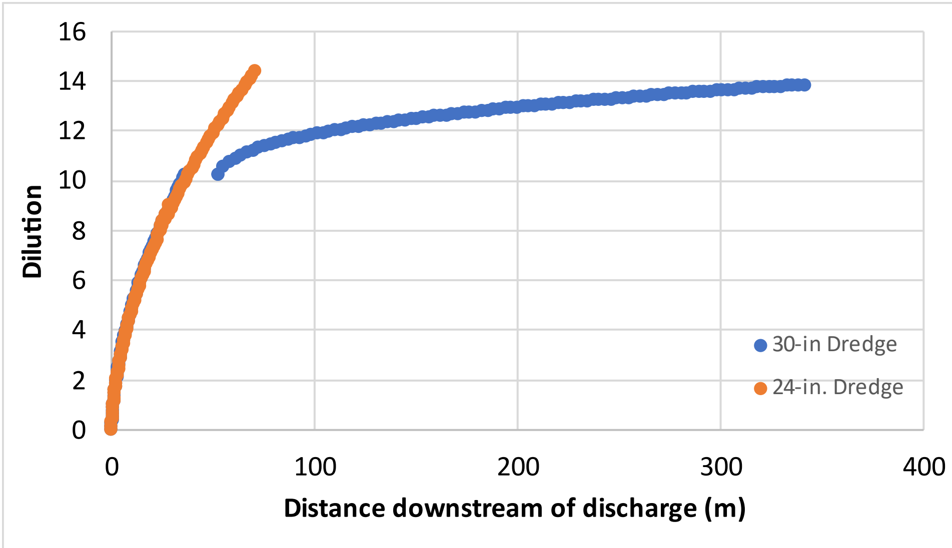


Figure 6. Dilution vs. Distance Glendale PA Discharge into Buffalo Bayou/HSC.

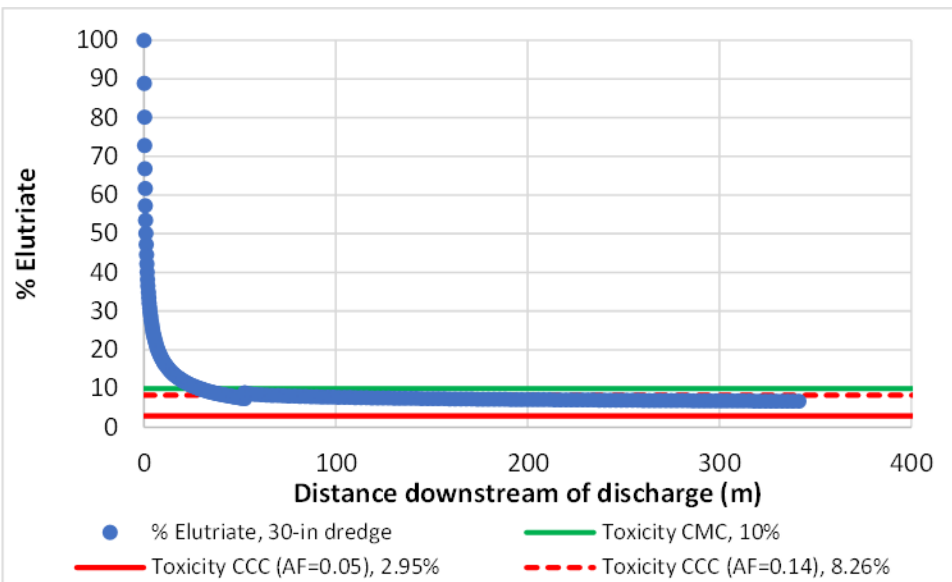


Figure 7. Elutriate Concentration (%) vs. Distance, Glendale PA 30-in Dredge Discharge into Buffalo Bayou/HSC.

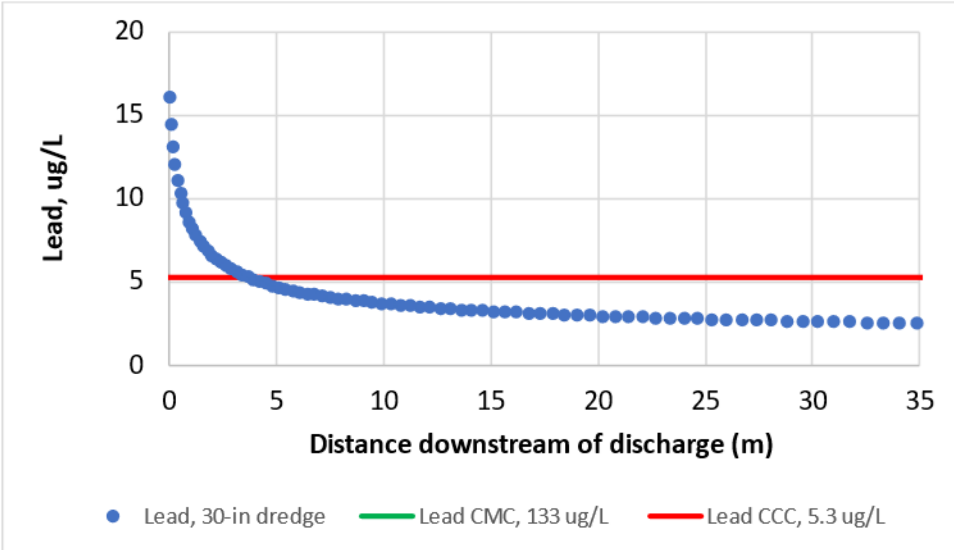


Figure 8. Lead Concentration vs. Distance, Glendale PA 30-in Dredge Discharge into Buffalo Bayou/HSC.

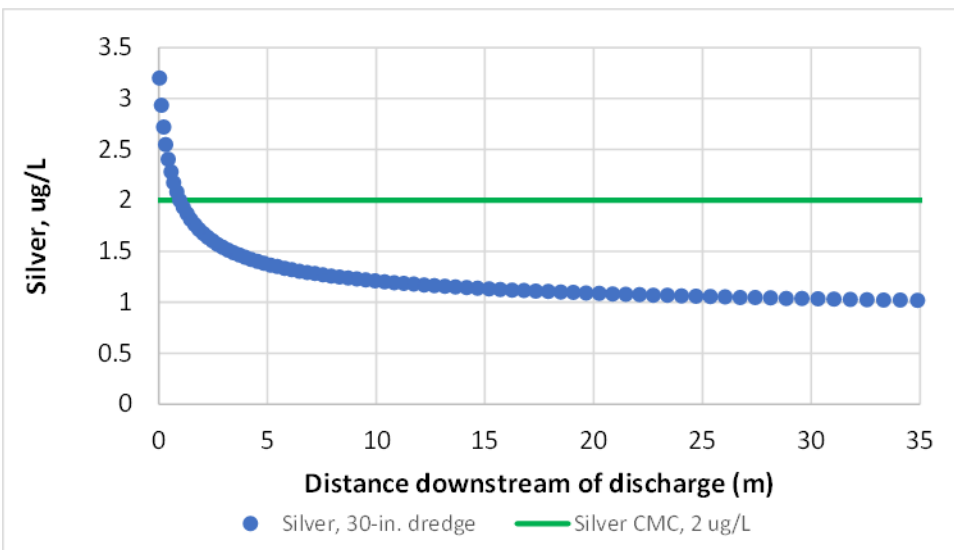


Figure 9. Silver Concentration vs. Distance, Glendale PA 30-in Dredge Discharge into Buffalo Bayou/HSC. (No TSWQS CCC for silver).

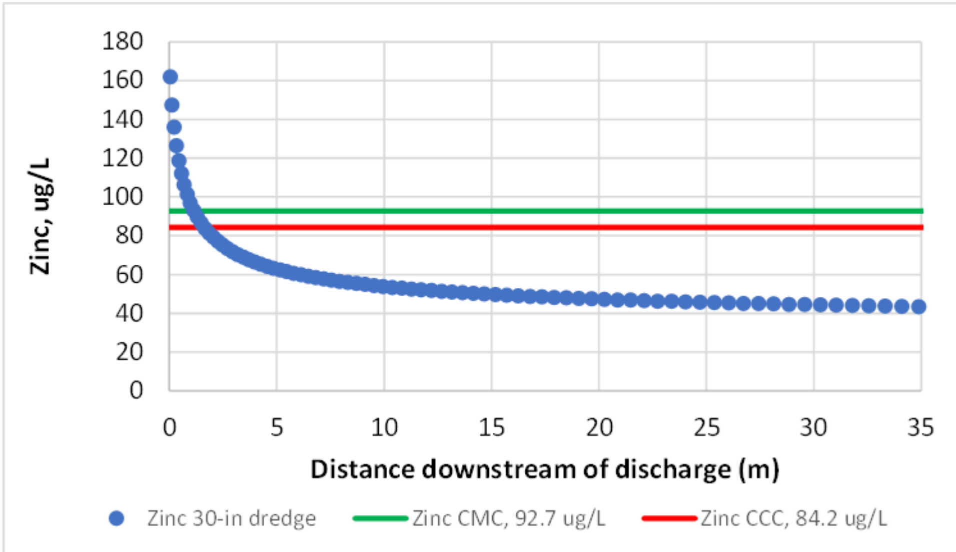


Figure 10. Zinc Concentration vs. Distance, Glendale PA 30-in Dredge Discharge into Buffalo Bayou/HSC.

As shown in Figure 6, a maximum dilution of 13.84 was reached for discharges from a 30-inch dredge at 341 m (1120 ft) downstream or a dilution of 14.36 from a 24-inch dredge at 70.9 m (232 ft). Figure 7 shows the required dilution factor of 9 to meet elutriate toxicity standard of 10 percent for acute conditions (green line), was achieved at a distance of 28.8 m (94.6 ft) where the plume width was 78.8 ft (24 m), for discharge from a 30-inch dredge. The ability to achieve mixing to meet chronic elutriate toxicity standards depends on the AF used to calculate the standard. The conservative default AF of 0.05 (2.95 percent, solid red line) required a dilution factor of 32.9 which was not achieved with either dredge size. However, application of a less conservative but still defensible AF of 0.14 (Section 4.2, Kennedy et al. (2015)), resulted in a chronic toxicity standard of 8.26 percent (dashed red line) that required an 11.1 dilution factor that can be achieved by both dredge sizes within 44.1 m (145 ft).

The distances at which dilution was achieved for acute and chronic TSWQS from Glendale PA are summarized in Table 12 and

Table 13, for PA discharges resulting from a 30-inch and 24-in dredge, respectively. Table 12, for a 30-inch dredge, showed that a ZID would be needed to meet acute criteria with downstream length requirements of 0.98 m to meet the 2 µg/L acute criterion for silver, 1.15 m to meet the 92.7 µg/L criterion for zinc, and 28.8 m to meet 10% elutriate criterion for toxicity. To ensure each of the acute criteria were met, a conservative ZID distance of 28.8 m was selected. Results for a 24-inch dredge (Table 13) are similar, requiring ZID dimensions of 1.01 m to meet acute criteria for silver, 1.19 m for zinc, and 28.6 m for toxicity.

Table 12. Distances Required for ZID and Mixing Zones for New Glendale PA Discharge – 30-in Dredge.

	Toxicity		Lead	Silver	Zinc
Elutriate concentration	100 %		16 µg/L	3.2 µg/L	162 µg/L
Background concentration	0 %		1.5 µg/L	0.8 µg/L	11.3 µg/L
CMC	10 %		133 µg/L	2 µg/L	92.7 µg/L
Dilution factor required to meet CMC	9		NA	1.0	1.133
Distance to meet CMC (ZID), m (ft)	7.4 (24.4)		0 (0)	0.98 (3.20)	1.15 (3.78)
CCC	AF=0.05	AF = 0.14	5.3 µg/L	--	84.2 µg/L
	2.95 %	8.26 %			
Dilution factor required to meet CCC	32.9	11.1	2.548	NA	1.067
Distance to meet CCC (Mixing Zone), m (ft)	Not possible	43.2 (142)	3.57 (11.7)	NA	1.60 (5.26)

1) Gray highlighted text refers to determinations based on an AF of 0.05, included as a default value but not applicable to the project-specific application.

Table 13. Distances Required for ZID and Mixing Zones for New Glendale PA Discharge – 24-in Dredge.

	Toxicity		Lead	Silver	Zinc
Elutriate concentration	100 %		16 µg/L	3.2 µg/L	162 µg/L
Background concentration	0 %		1.5 µg/L	0.8 µg/L	11.3 µg/L
CMC	10 %		133 µg/L	2 µg/L	92.7 µg/L
Dilution factor required to meet CMC	9		NA	1.0	0.851
Distance to meet CMC (ZID), m (ft)	7.4 (24.4)		0 (0)	1.56 (5.12)	1.46 (4.79)
CCC	AF=0.05	AF = 0.14	5.3 µg/L	--	84.2 µg/L
	2.95 %	8.26 %			
Dilution factor required to meet CCC	32.9	11.1	2.82	NA	1.067
Distance to meet CCC (Mixing Zone), m (ft)	Not possible	14.4 (47.3)	1.99 (6.54)	NA	1.60 (5.26)

1) Gray highlighted text refers to determinations based on an AF of 0.05, included as a default value but not applicable to the project-specific application.

Mixing zone length requirements to meet chronic criteria included 3.57 m for lead (5.3 µg/L) and 1.63 m for zinc (84.2 µg/L). The chronic criterion for toxicity depends on the AF utilized to calculate the criterion, and that two AFs were evaluated – a conservative AF of 0.05 and an alternate AF of 0.14. Table 12 shows that there was insufficient mixing available to achieve the 32.9 dilution factor (2.95 percent elutriate) if the conservative AF of 0.05 was applied. However, application of the alternate AF of 0.14, required a dilution factor of 11.1 (8.26 percent elutriate) for which the modeling showed was met at a downstream distance of 43.2 m. Comparing Table 12 for a 30-inch dredge and Table 13 for a 24-in dredge showed that dredge size had minimal impact on the ZID and mixing zone length requirements.

5.2 Placement Area – Filterbed

CDFATE modeling results were evaluated for mixing conditions at the discharge point for effluent from Filterbed PA into Buffalo Bayou/HSC. CDFATE modeling showed that because the storm sewer is angled slightly upstream, the discharge mixes a short distance upstream before further mixing downstream. Dilution was modeled over 600 m (Figure 11). After 240 m, a maximum dilution of 12.3 was shown for discharge from a 30-inch dredge (2.09 m^3/s); likewise, the discharge from a 24-inch dredge (1.33 m^3/s) was modeled reaching a maximum dilution factor of 13.5 as it interacted with both banks approximately 25 m downstream of the discharge.

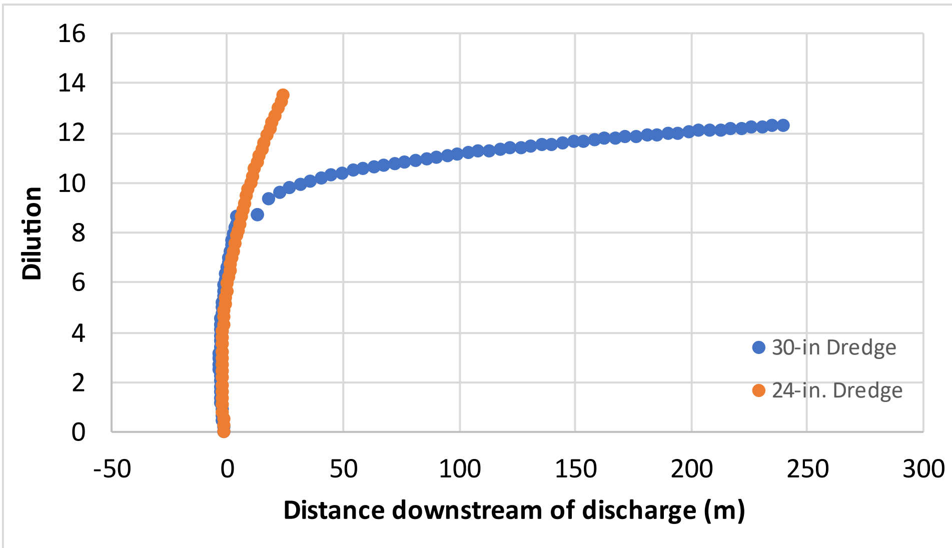


Figure 11. Dilution vs. Distance Filterbed PA Discharge into Buffalo Bayou/HSC.

Based on the modeled dilution, the predicted concentrations of percent elutriate, lead, silver and zinc as a function of distance were calculated (Section 4.4) and are provided in Figure 12, Figure 13, Figure 14 and Figure 15, respectively. The green and red lines on the figures indicate the concentrations associated with TSWQS acute and chronic criteria; sufficient dilution to meet the criteria was achieved at the distances at which concentrations fall below the criteria.

Table 14 and Table 15 summarize the distances required to meet the toxicity and water quality criteria for discharges from Filterbed PA resulting from 30-inch and 24-inch dredges, respectively.

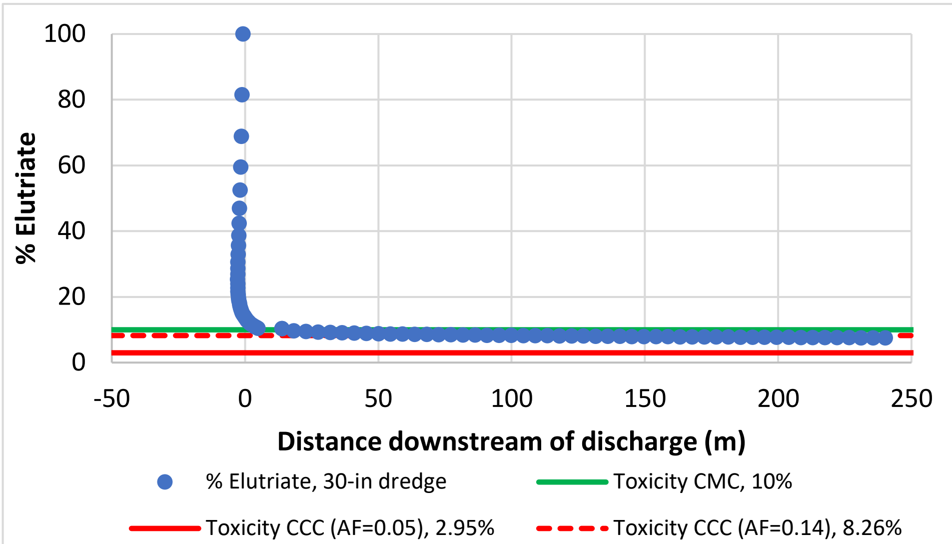


Figure 12. Elutriate Concentration (%) vs. Distance, Filterbed PA 30-in Dredge Discharge into Buffalo Bayou/HSC.

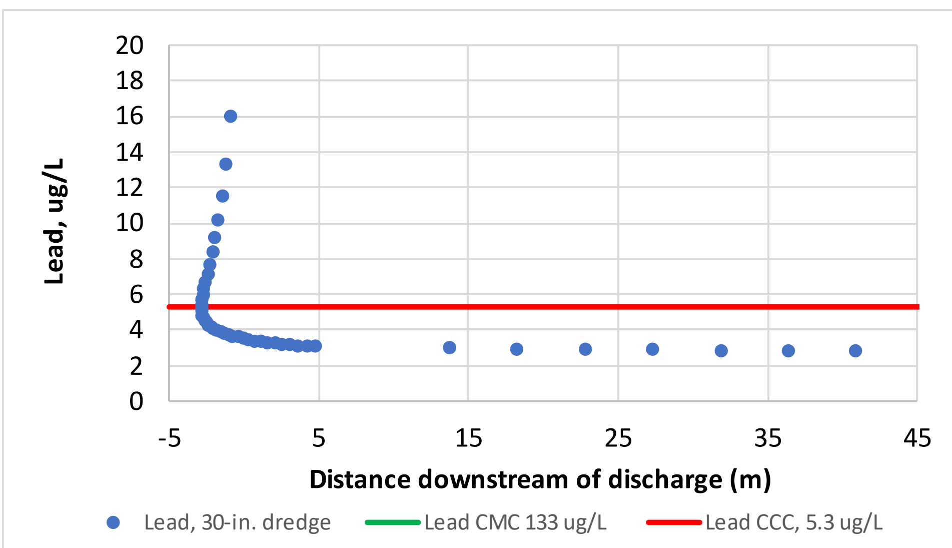


Figure 13. Lead Concentration vs. Distance, Filterbed PA 30-in Dredge Discharge into Buffalo Bayou/HSC.

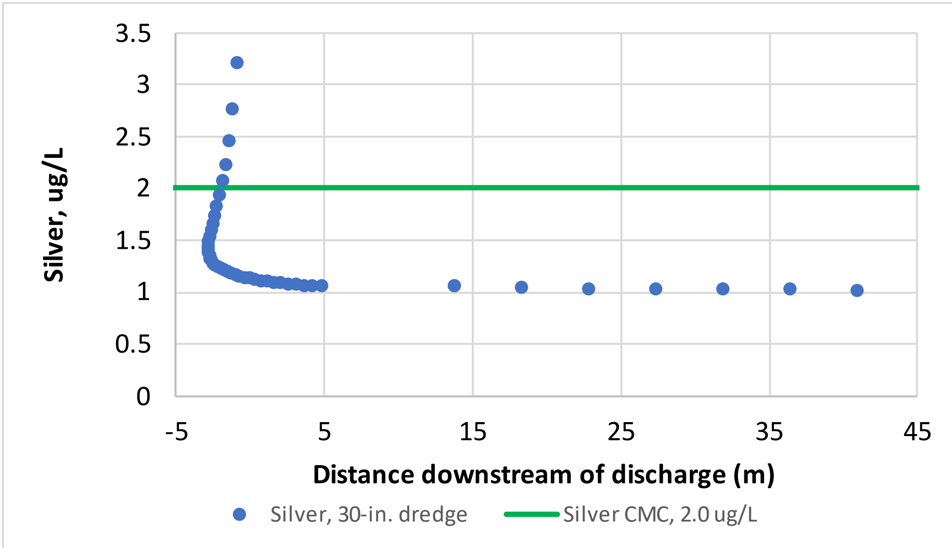


Figure 14. Silver Concentration vs. Distance, Filterbed PA 30-in Dredge Discharge into Buffalo Bayou/HSC. (No TSWQS CCC for silver.).

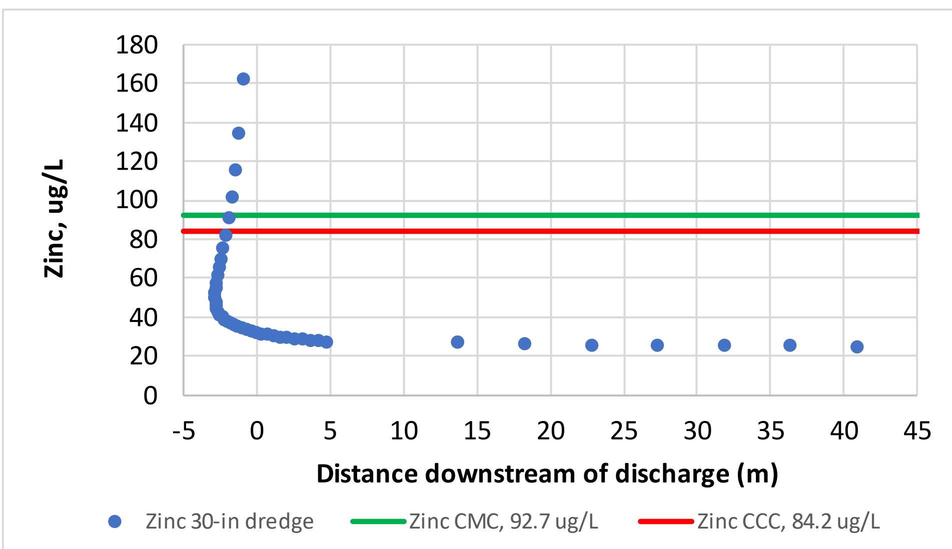


Figure 15. Zinc Concentration vs. Distance, Filterbed PA 30-in Dredge Discharge into Buffalo Bayou/HSC.

Table 14. Distances Required for ZID and Mixing Zones for Filterbed PA Discharge – 30-in Dredge.

	Toxicity		Lead	Silver	Zinc
Elutriate concentration	100 %		16 μg/L	3.2 μg/L	162 μg/L
Background concentration	0 %		1.5 μg/L	0.8 μg/L	11.3 μg/L
CMC	10 %		133 μg/L	2 μg/L	92.7 μg/L
Dilution factor required to meet CMC	9		NA	1.0	0.851
Distance to meet CMC (ZID), m (ft)	15.9 (52.3)		0 (0)	1.95 (6.41)	1.82 (5.98)
CCC	AF=0.05	AF = 0.14	5.3 μg/L	--	84.2 μg/L
	2.95 %	8.26 %			
Dilution factor required to meet CCC	32.9	11.1	2.82	NA	1.067
Distance to meet CCC (Mixing Zone), m (ft)	Not possible	97.5 (320)	2.77 (9.10)	NA	2.01 (6.59)

1) Gray highlighted text refers to determinations based on an AF of 0.05, included as a default value but not applicable to the project-specific application.

Table 15. Distances Required for ZID and Mixing Zones for Filterbed PA Discharge – 24-in Dredge.

	Toxicity		Lead	Silver	Zinc
Elutriate concentration	100 %		16 μg/L	3.2 μg/L	162 μg/L
Background concentration	0 %		1.5 μg/L	0.8 μg/L	11.3 μg/L
CMC	10 %		133 μg/L	2 μg/L	92.7 μg/L
Dilution factor required to meet CMC	9		NA	1.0	0.851
Distance to meet CMC (ZID), m (ft)	7.4 (24.4)		0 (0)	1.56 (5.12)	1.46 (4.79)
CCC	AF=0.05	AF = 0.14	5.3 μg/L	--	84.2 μg/L
	2.95 %	8.26 %			
Dilution factor required to meet CCC	32.9	11.1	2.82	NA	1.067
Distance to meet CCC (Mixing Zone), m (ft)	Not possible	14.4 (47.3)	1.99 (6.54)	NA	1.60 (5.26)

1) Gray highlighted text refers to determinations based on an AF of 0.05, included as a default value but not applicable to the project-specific application.

The CDFATE model results showed that the acute toxicity criterion (10% elutriate) was met within 15.9 m and 7.4 m, respectively for PA discharges from a 30-inch (Table 14, Figure 12) and 24-inch dredge (Table 15). Acute water quality criteria for silver (2 µg/L) and zinc (92.7 µg/L) were both achieved within 2 m of the discharge point for either dredge size. A minimum ZID of 15.9 m (30-inch dredge) or 7.4 m (24-inch dredge) would be required to meet the acute criterion considering both toxicity and chemistry.

Based upon chemistry, dilution of 2.82 was required to meet chronic TSWQS criteria for lead, and dilution of 1.07 was required to meet chronic TSWQS criteria for zinc. Dilution for lead was achieved within 2.77 m (Table 14) and within 1.99 m (Table 15) for discharges from a 30-inch and 24-inch dredge, respectively. Zinc was sufficiently diluted to meet chronic criteria within 2.01 m for a 30-inch dredge (Table 14) and within 1.6 m for a 24-inch dredge (Table 15). Using the less conservative but still reasonable AF of 0.14 yielded a chronic toxicity criterion of 8.26% elutriate which required a dilution factor of 11.1; this was achieved at 97.5 m (320 ft) or at 15.5 m (47.3 ft) based on PA discharge resulting from a 30-inch or 24-inch dredge, respectively.

5.3 CDFATE Model Conclusions

CDFATE has shown that TSWQS (i.e. concentration) acute and chronic dilution conditions were met within 4 m of discharge of effluent from both Glendale PA and Filterbed PA into Buffalo Bayou/HSC.

CDFATE has shown acute toxicity dilution conditions can be met within 30 m of discharge from Glendale PA and within 16 m from Filterbed PA. Chronic toxicity dilution conditions can be met within 45 m of discharge from Glendale PA and within 100 m of Filterbed PA when a site-specific but still protective AF of 0.14 was applied to determine chronic toxicity criteria. An additional margin of safety can be added to these conclusions when a Lines of Evidence (LOE) evaluation is taken into consideration (Section 6).

6 Lines of Evidence (LOE) Evaluation

CDFATE has shown that dilution conditions for acute and chronic Texas WQS and acute toxicity criteria are met within 30 m of the discharge of effluent from Glendale PA and 16 m of the Filterbed PA discharge into Buffalo Bayou/HSC using conservative default model input parameters. Dilution conditions for chronic toxicity criteria are met within 45 m and 100 m, respectively for Glendale and Filterbed PAs if a site-specific but still protective AF of 0.14 is used to determine the criteria. Several steps contribute to conservatism in the CDFATE modeling and where appropriate, the bias these introduce are discussed below in a more site-specific manner as a LOE:

- The ECIP new work dredged materials are comprised of unexposed materials from the base geological formation. As such, these materials are consistent with local conditions and inherently clean.
- The maximum zinc concentration generated in the elutriate tests was 162 µg/L, which is only a two-fold exceedance of both the acute (92.7 µg/L) and chronic (84.2 µg/L) Texas WQCs for zinc; given the conservatism built into screening values and experimental uncertainty in the toxicity numbers used as input parameters for the development of screening values, the original exceedance of zinc was not a biologically significant finding. Further the mean of the zinc concentrations was 94.7 µg/L, which was essentially equivalent to the acute and chronic criteria when experimental error was considered. Selection of the maximum concentration and comparison to conservative screening values introduced positive bias to the modeling.
- The zinc elutriate concentration was based on the highest result for one sample, HSCNew-NMP-08-EL; only one other elutriate result exceeded WQS (HSCNew-NMP-11-EL). The new work material dredged from the reach will be combined within the two PAs, so a mean concentration would be more representative of the effluent zinc concentration. The default selection of the maximum concentration instead of an arithmetic mean, introduced positive bias to the modeling.
- Lead was detected in only one elutriate sample at 16 µg/L, which was only a three-fold exceedance of the chronic Texas WQC (5.3 µg/L) and was well below the acute WQC (133 µg/L). The new work material

dredged from the reach will be combined within the two PAs, so a mean concentration would be more representative of the effluent lead concentration. The default selection of the maximum concentration instead of an arithmetic mean, introduced positive bias to the modeling. The mean lead concentration from all the elutriate samples, assuming non-detect concentrations to be zero, was 2.7 µg/L which was well below acute and chronic criteria. Therefore, use of the single detected value in the model introduced positive bias to the outcome.

- Silver was detected in only two elutriate samples, both of which were below the level of quantitation. Only one of the concentrations (HSCNew-NMP-09-EL) at 3.2 µg/L exceeded Texas acute WQS (2 µg/L). The new work material dredged from the reach will be combined within the two PAs, so a mean concentration would be more representative of the effluent lead concentration. The default selection of the maximum concentration instead of an arithmetic mean, introduced positive bias to the modeling. The mean silver concentration from all the elutriate samples, assuming non-detect concentrations to be zero, was 0.73 µg/L which was well below the acute criterion. Use of the highest detected value for silver introduced positive bias.
- Of the six elutriate samples from Segments 5 and 6, only two elutriate samples showed sufficient toxicity to generate an LC50. Three elutriate samples displayed some acute toxicity (NOAEC 50%) for both 96-h *Americamysis bahia* and 96-h *Menidia beryllina*, but not sufficient toxicity to generate an LC50. Selection of the sample demonstrating the highest toxicity for the toxicity input parameter was conservative and protective, introducing positive bias to the modeling.
- The concentrations of ammonia measured in all the elutriate samples in which acute toxicity were observed were high enough to cause mortality to the test organisms based on literature reported values for ammonia toxicity. Ammonia concentrations recorded during the 96-h *Menidia beryllina* bioassay test of HSC-NMP-7 (worst-case) were at 11.1 mg/L, which was nearly twice the threshold (0.6 mg/L) for ammonia toxicity. This is a strong indication that ammonia, a non-persistent contaminant, was responsible for causing the demonstrated elutriate toxicity and justified the use of alternate AF for calculating chronic toxicity criteria. Residual ammonia toxicity introduced

positive bias into the modeling (Montgomery, Bourne and Stevens 2023).

- Dilution was modeled using a conservative low-flow condition, which was not expected to be experienced throughout most, if any, of the project period, and therefore introduced positive bias.
- Further dilution of PA effluent was expected due to on-site precipitation and mixing with storm water within the storm sewers used convey the effluent. Use of undiluted PA effluent in the modeling introduced positive bias.

7 Conclusions and Recommendations

Based upon evaluation of the CDFATE modeling results and further consideration of site-specific LOE, no significant adverse effects are anticipated from the discharge of dewatering effluent from either Glendale PA or Filterbed PA for the new work dredge materials from Segments 5 and 6 of the HSC ECIP.

The USACE recommends that a concurrence for a water quality certification be issued for Segments 5 and 6 of the HSC ECIP.

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Appendix A. CDFATE Model Output

Appendix A

CDFATE Model Output

APPENDIX A - TABLE OF CONTENTS

CDFATE Model Output

Discharge from Glendale PA into Buffalo Bayou/HSC
30-Inch Dredge

```
CORMIX3 PREDICTION FILE:
33333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                          Subsystem version:
 Buoyant Surface Discharges
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         HSC-ECIP Glendale Run1
 Design case:
 FILE NAME:               cormix\sim\        .cx3
 Time of Fortran run:

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =    164.60  AS    =   1779.33  QA    =     21.35
 HA    =     10.81  HD    =     10.36
 UA    =     0.012 F     =     0.008 USTAR =0.3790E-03
 UW    =     5.000 UWSTAR=0.5525E-02
 Density stratified environment
 STRCND=  A         RHOAM =  999.5500
 RHOAS =  999.1000  RHOAB = 1000.0000  RHOAEF=  999.5500  E     =0.0000E+00

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =      0.00  Configuration:
 Rectangular channel geometry:
 B0    =     3.660 H0    =     0.410 A0    =0.1501E+01  AR    =     0.112
 SIGMA =     90.00  SLOPE =     60.00
 U0    =     1.393 Q0    =     2.090       =0.2090E+01
 RHO0  =  999.5500  DRHO0 =0.0000E+00  GP0   =0.0000E+00
 C0    =0.1000E+03  CUNITS=  X
 IPOLL =  1         KS    =0.0000E+00  KD    =0.0000E+00

FLUX VARIABLES (metric units)
 Q0    =0.2090E+01  M0    =0.2911E+01  J0    =0.0000E+00
 Associated length scales (meters)
 LQ    =      1.22  LM    =  99999.00  Lm    =    142.18  Lb    =      0.00

NON-DIMENSIONAL PARAMETERS
 FR0   =  99999.00  FRCH  =  99999.00  R     =    116.06

FLOW CLASSIFICATION
 3333333333333333333333333333333333333333
 3  Flow class (CORMIX3)      =    SA1    3
 3  Applicable layer depth HS =    10.36  3
 3333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    =0.1000E+03  CUNITS=  X
 NTOX  =  1         CMC   =0.1000E+02  CCC   =  CSTD
```

```
 NSTD  =  1         CSTD  =0.1000E+01
 REGMZ =  1
 REGSPC=  1         XREG  =    500.00  WREG  =      0.00  AREG  =      0.00
 XINT  =    600.00  XMAX  =    600.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:      0.00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP =100 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)

Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      0.04     4.77    0.00      1.0 0.100E+03   0.65     1.95
 Cumulative travel time =           3. sec

END OF MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE

 Surface JET into a crossflow

Near-field limitation in bounded channel.
Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      0.04     4.77    0.00      1.0 0.100E+03   0.65     1.95
      0.12     6.04    0.00      1.1 0.889E+02   0.81     2.09
      0.22     7.31    0.00      1.2 0.801E+02   0.96     2.23
      0.32     8.58    0.00      1.4 0.728E+02   1.11     2.37
      0.44     9.85    0.00      1.5 0.668E+02   1.25     2.51
      0.56    11.12    0.00      1.6 0.617E+02   1.40     2.65
      0.69    12.39    0.00      1.7 0.573E+02   1.54     2.79
      0.83    13.66    0.00      1.9 0.535E+02   1.69     2.93
      0.97    14.93    0.00      2.0 0.501E+02   1.83     3.07
```

1.13	16.19	0.00	2.1	0.472E+02	1.97	3.21
1.30	17.46	0.00	2.2	0.446E+02	2.11	3.35
1.47	18.73	0.00	2.4	0.422E+02	2.25	3.49
1.65	20.00	0.00	2.5	0.401E+02	2.39	3.63
1.85	21.27	0.00	2.6	0.382E+02	2.54	3.77
2.05	22.54	0.00	2.7	0.365E+02	2.68	3.91
2.26	23.81	0.00	2.9	0.349E+02	2.82	4.05
2.48	25.08	0.00	3.0	0.335E+02	2.96	4.19
2.70	26.35	0.00	3.1	0.321E+02	3.10	4.33
2.94	27.62	0.00	3.2	0.309E+02	3.24	4.47
3.18	28.89	0.00	3.4	0.297E+02	3.38	4.61
3.44	30.15	0.00	3.5	0.287E+02	3.52	4.75
3.70	31.42	0.00	3.6	0.277E+02	3.66	4.89
3.97	32.69	0.00	3.7	0.268E+02	3.80	5.03
4.25	33.96	0.00	3.9	0.259E+02	3.94	5.17
4.54	35.23	0.00	4.0	0.251E+02	4.08	5.31
4.84	36.50	0.00	4.1	0.243E+02	4.22	5.44
5.15	37.77	0.00	4.2	0.236E+02	4.36	5.58
5.46	39.04	0.00	4.4	0.230E+02	4.50	5.72
5.79	40.31	0.00	4.5	0.223E+02	4.64	5.86
6.12	41.58	0.00	4.6	0.217E+02	4.78	6.00
6.47	42.85	0.00	4.7	0.211E+02	4.92	6.14
6.82	44.11	0.00	4.9	0.206E+02	5.06	6.28
7.18	45.38	0.00	5.0	0.201E+02	5.20	6.42
7.55	46.65	0.00	5.1	0.196E+02	5.34	6.56
7.92	47.92	0.00	5.2	0.191E+02	5.48	6.70
8.31	49.19	0.00	5.4	0.187E+02	5.62	6.84
8.71	50.46	0.00	5.5	0.183E+02	5.76	6.98
9.11	51.73	0.00	5.6	0.179E+02	5.90	7.12
9.52	53.00	0.00	5.7	0.175E+02	6.04	7.26
9.95	54.27	0.00	5.8	0.171E+02	6.18	7.40
10.38	55.54	0.00	6.0	0.167E+02	6.32	7.54
10.82	56.80	0.00	6.1	0.164E+02	6.46	7.68
11.27	58.07	0.00	6.2	0.161E+02	6.60	7.82
11.72	59.34	0.00	6.3	0.158E+02	6.74	7.96
12.19	60.61	0.00	6.5	0.155E+02	6.88	8.10
12.67	61.88	0.00	6.6	0.152E+02	7.02	8.24
13.15	63.15	0.00	6.7	0.149E+02	7.16	8.38
13.64	64.42	0.00	6.8	0.146E+02	7.30	8.52
14.15	65.69	0.00	7.0	0.144E+02	7.44	8.66
14.66	66.96	0.00	7.1	0.141E+02	7.58	8.80
15.18	68.23	0.00	7.2	0.139E+02	7.72	8.93
15.70	69.50	0.00	7.3	0.136E+02	7.86	9.07
16.24	70.76	0.00	7.5	0.134E+02	8.00	9.21
16.79	72.03	0.00	7.6	0.132E+02	8.14	9.35
17.34	73.30	0.00	7.7	0.130E+02	8.28	9.49
17.91	74.57	0.00	7.8	0.128E+02	8.42	9.63
18.48	75.84	0.00	8.0	0.126E+02	8.55	9.77
19.06	77.11	0.00	8.1	0.124E+02	8.69	9.91
19.65	78.38	0.00	8.2	0.122E+02	8.83	10.05

```
     20.25    79.65    0.00     8.3 0.120E+02   8.97    10.19
     20.86    80.92    0.00     8.5 0.118E+02   9.11    10.33
     21.47    82.19    0.00     8.6 0.117E+02   9.25    10.47
     22.10    83.46    0.00     8.7 0.115E+02   9.39    10.61
     22.73    84.72    0.00     8.8 0.113E+02   9.53    10.75
     23.38    85.99    0.00     9.0 0.112E+02   9.67    10.89
     24.03    87.26    0.00     9.1 0.110E+02   9.81    11.03
     24.69    88.53    0.00     9.2 0.109E+02   9.95    11.17
     25.36    89.80    0.00     9.3 0.107E+02  10.09    11.31
     26.04    91.07    0.00     9.5 0.106E+02  10.23    11.45
     26.73    92.34    0.00     9.6 0.104E+02  10.37    11.59
     27.42    93.61    0.00     9.7 0.103E+02  10.51    11.73
     28.13    94.88    0.00     9.8 0.102E+02  10.65    11.87
     28.84    96.15    0.00    10.0 0.100E+02  10.79    12.01
 ** CMC HAS BEEN FOUND **
  The pollutant concentration in the plume falls below CMC value of 0.100E+02
    in the current prediction interval.
  This is the extent of the TOXIC DILUTION ZONE.
     29.57    97.42    0.00    10.1 0.993E+01  10.93    12.15
     30.30    98.68    0.00    10.2 0.980E+01  11.07    12.29
     31.04    99.95    0.00    10.3 0.969E+01  11.21    12.42
     31.79   101.22    0.00    10.4 0.957E+01  11.35    12.56
     32.55   102.49    0.00    10.6 0.946E+01  11.48    12.70
     33.32   103.76    0.00    10.7 0.935E+01  11.62    12.84
     34.09   105.03    0.00    10.8 0.924E+01  11.76    12.98
     34.88   106.30    0.00    10.9 0.914E+01  11.90    13.12
     35.67   107.57    0.00    11.1 0.903E+01  12.04    13.26
     36.47   108.84    0.00    11.2 0.893E+01  12.18    13.40
     37.29   110.11    0.00    11.3 0.883E+01  12.32    13.54
     38.11   111.37    0.00    11.4 0.874E+01  12.46    13.68
     38.93   112.64    0.00    11.6 0.865E+01  12.60    13.82
     39.77   113.91    0.00    11.7 0.855E+01  12.74    13.96
     40.62   115.18    0.00    11.8 0.846E+01  12.88    14.10
     41.48   116.45    0.00    11.9 0.837E+01  13.02    14.24
     42.34   117.72    0.00    12.1 0.829E+01  13.16    14.38
     43.21   118.99    0.00    12.2 0.820E+01  13.30    14.52
     44.10   120.26    0.00    12.3 0.812E+01  13.44    14.66
     44.99   121.53    0.00    12.4 0.804E+01  13.58    14.80
     45.89   122.80    0.00    12.6 0.796E+01  13.72    14.94
     46.80   124.07    0.00    12.7 0.788E+01  13.85    15.08
     47.71   125.33    0.00    12.8 0.781E+01  13.99    15.22
     48.64   126.60    0.00    12.9 0.773E+01  14.13    15.36
     49.58   127.87    0.00    13.1 0.766E+01  14.27    15.50
     50.52   129.14    0.00    13.2 0.759E+01  14.41    15.64
     51.47   130.41    0.00    13.3 0.751E+01  14.55    15.78
     52.44   131.68    0.00    13.4 0.744E+01  14.69    15.91
  Cumulative travel time =          529. sec

  Some concentration build-up near bank/shore due to recirculation effects.
    Find concentration and thickness values for the RECIRCULATION REGION
```

```
   at end of MOD329!

END OF MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------

 The LIMITING DILUTION (given by ambient flow/discharge ratio) is:    11.2
   This value is below the computed dilution of    13.4 at the end
   of the NFR.
 Mixing for this discharge configuration is constrained by LOW AMBIENT FLOW!

 The previous module predictions are unreliable since the limiting dilution
   cannot be exceeded for this discharge into a deep unstratified layer.

 A subsequent module (MOD381) will predict the properties of the
   cross-sectionally fully mixed plume with limiting dilution and will
   compute a POSSIBLE UPSTREAM WEDGE INTRUSION.
-----------------------------------------------------------------------------
BEGIN MOD381: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION

 The DOWNSTREAM flow field for this unstable shallow water discharge is
     VERTICALLY FULLY MIXED.
 The mixing is controlled by the limiting dilution =     11.2

 NO UPSTREAM INTRUSION will occur since the discharge is NON-BUOYANT.

       X        Y       Z        S        C       BV       BH
     52.44     0.00    0.00    11.2 0.892E+01  10.36   164.60
 Cumulative travel time =         529. sec

 Vertically and laterally fully mixed over layer depth: END OF SIMULATION!

END OF MOD381: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD327: STRONGLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE

 JET INTERACTS WITH FAR BANK in this region.

Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y       Z        S        C       BV       BH
     52.44   131.68    0.00    11.2 0.892E+01  46.52    50.39
     55.32   134.04    0.00    11.5 0.866E+01  47.23    51.10
     58.21   135.41    0.00    11.7 0.852E+01  47.64    51.51
     61.10   136.43    0.00    11.9 0.841E+01  47.95    51.81
     63.99   137.27    0.00    12.0 0.833E+01  48.20    52.07
```

66.88	137.99	0.00	12.1	0.826E+01	48.41	52.28
69.77	138.62	0.00	12.2	0.820E+01	48.60	52.47
72.66	139.19	0.00	12.3	0.814E+01	48.77	52.64
75.54	139.71	0.00	12.4	0.809E+01	48.93	52.80
78.43	140.20	0.00	12.4	0.804E+01	49.08	52.94
81.32	140.65	0.00	12.5	0.800E+01	49.21	53.08
84.21	141.07	0.00	12.6	0.796E+01	49.34	53.20
87.10	141.46	0.00	12.6	0.793E+01	49.46	53.32
89.99	141.84	0.00	12.7	0.789E+01	49.57	53.43
92.87	142.20	0.00	12.7	0.786E+01	49.68	53.54
95.76	142.54	0.00	12.8	0.783E+01	49.78	53.64
98.65	142.87	0.00	12.8	0.780E+01	49.88	53.74
101.54	143.18	0.00	12.9	0.777E+01	49.97	53.84
104.43	143.48	0.00	12.9	0.774E+01	50.06	53.93
107.32	143.77	0.00	13.0	0.772E+01	50.15	54.01
110.21	144.06	0.00	13.0	0.769E+01	50.23	54.10
113.09	144.33	0.00	13.0	0.767E+01	50.32	54.18
115.98	144.59	0.00	13.1	0.764E+01	50.40	54.26
118.87	144.85	0.00	13.1	0.762E+01	50.47	54.33
121.76	145.10	0.00	13.2	0.760E+01	50.55	54.41
124.65	145.34	0.00	13.2	0.758E+01	50.62	54.48
127.54	145.58	0.00	13.2	0.756E+01	50.69	54.55
130.42	145.81	0.00	13.3	0.754E+01	50.76	54.62
133.31	146.03	0.00	13.3	0.752E+01	50.83	54.69
136.20	146.25	0.00	13.3	0.750E+01	50.89	54.75
139.09	146.47	0.00	13.4	0.748E+01	50.96	54.82
141.98	146.68	0.00	13.4	0.746E+01	51.02	54.88
144.87	146.88	0.00	13.4	0.745E+01	51.08	54.94
147.76	147.09	0.00	13.5	0.743E+01	51.14	55.00
150.64	147.28	0.00	13.5	0.741E+01	51.20	55.06
153.53	147.48	0.00	13.5	0.740E+01	51.26	55.12
156.42	147.67	0.00	13.5	0.738E+01	51.32	55.18
159.31	147.85	0.00	13.6	0.737E+01	51.37	55.23
162.20	148.04	0.00	13.6	0.735E+01	51.43	55.29
165.09	148.22	0.00	13.6	0.734E+01	51.48	55.34
167.97	148.39	0.00	13.7	0.732E+01	51.54	55.40
170.86	148.57	0.00	13.7	0.731E+01	51.59	55.45
173.75	148.74	0.00	13.7	0.729E+01	51.64	55.50
176.64	148.91	0.00	13.7	0.728E+01	51.69	55.55
179.53	149.08	0.00	13.8	0.727E+01	51.74	55.60
182.42	149.24	0.00	13.8	0.725E+01	51.79	55.65
185.31	149.40	0.00	13.8	0.724E+01	51.84	55.70
188.19	149.56	0.00	13.8	0.723E+01	51.89	55.74
191.08	149.72	0.00	13.9	0.721E+01	51.93	55.79
193.97	149.87	0.00	13.9	0.720E+01	51.98	55.84
196.86	150.02	0.00	13.9	0.719E+01	52.03	55.88
199.75	150.17	0.00	13.9	0.718E+01	52.07	55.93
202.64	150.32	0.00	14.0	0.716E+01	52.12	55.97
205.52	150.47	0.00	14.0	0.715E+01	52.16	56.02
208.41	150.62	0.00	14.0	0.714E+01	52.20	56.06

211.30	150.76	0.00	14.0	0.713E+01	52.25	56.10
214.19	150.90	0.00	14.0	0.712E+01	52.29	56.15
217.08	151.04	0.00	14.1	0.711E+01	52.33	56.19
219.97	151.18	0.00	14.1	0.710E+01	52.37	56.23
222.86	151.31	0.00	14.1	0.709E+01	52.41	56.27
225.74	151.45	0.00	14.1	0.708E+01	52.45	56.31
228.63	151.58	0.00	14.2	0.707E+01	52.49	56.35
231.52	151.72	0.00	14.2	0.706E+01	52.53	56.39
234.41	151.85	0.00	14.2	0.705E+01	52.57	56.43
237.30	151.98	0.00	14.2	0.703E+01	52.61	56.47
240.19	152.10	0.00	14.2	0.703E+01	52.65	56.51
243.07	152.23	0.00	14.3	0.702E+01	52.69	56.54
245.96	152.36	0.00	14.3	0.701E+01	52.73	56.58
248.85	152.48	0.00	14.3	0.700E+01	52.76	56.62
251.74	152.60	0.00	14.3	0.699E+01	52.80	56.66
254.63	152.73	0.00	14.3	0.698E+01	52.84	56.69
257.52	152.85	0.00	14.4	0.697E+01	52.87	56.73
260.41	152.97	0.00	14.4	0.696E+01	52.91	56.76
263.29	153.08	0.00	14.4	0.695E+01	52.94	56.80
266.18	153.20	0.00	14.4	0.694E+01	52.98	56.84
269.07	153.32	0.00	14.4	0.693E+01	53.01	56.87
271.96	153.43	0.00	14.4	0.692E+01	53.05	56.90
274.85	153.55	0.00	14.5	0.691E+01	53.08	56.94
277.74	153.66	0.00	14.5	0.691E+01	53.12	56.97
280.62	153.77	0.00	14.5	0.690E+01	53.15	57.01
283.51	153.89	0.00	14.5	0.689E+01	53.18	57.04
286.40	154.00	0.00	14.5	0.688E+01	53.22	57.07
289.29	154.11	0.00	14.5	0.687E+01	53.25	57.11
292.18	154.22	0.00	14.6	0.686E+01	53.28	57.14
295.07	154.32	0.00	14.6	0.686E+01	53.32	57.17
297.96	154.43	0.00	14.6	0.685E+01	53.35	57.20
300.84	154.54	0.00	14.6	0.684E+01	53.38	57.23
303.73	154.64	0.00	14.6	0.683E+01	53.41	57.27
306.62	154.75	0.00	14.7	0.683E+01	53.44	57.30
309.51	154.85	0.00	14.7	0.682E+01	53.47	57.33
312.40	154.95	0.00	14.7	0.681E+01	53.51	57.36
315.29	155.06	0.00	14.7	0.680E+01	53.54	57.39
318.17	155.16	0.00	14.7	0.679E+01	53.57	57.42
321.06	155.26	0.00	14.7	0.679E+01	53.60	57.45
323.95	155.36	0.00	14.7	0.678E+01	53.63	57.48
326.84	155.46	0.00	14.8	0.677E+01	53.66	57.51
329.73	155.56	0.00	14.8	0.677E+01	53.69	57.54
332.62	155.65	0.00	14.8	0.676E+01	53.72	57.57
335.51	155.75	0.00	14.8	0.675E+01	53.74	57.60
338.39	155.85	0.00	14.8	0.674E+01	53.77	57.63
341.28	155.95	0.00	14.8	0.674E+01	53.80	57.66

Cumulative travel time =   24600. sec

Some concentration build-up near bank/shore due to recirculation effects.
  Find concentration and thickness values for the RECIRCULATION REGION

```
   at end of MOD329!

END OF MOD327: STRONGLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD329: STRONGLY DEFLECTED PLUME WITH LEESIDE RECIRCULATION ZONE
```

CDFATE Model Output

Discharge from Glendale PA into Buffalo Bayou/HSC
24-Inch Dredge

```
CORMIX3 PREDICTION FILE:
33333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                          Subsystem version:
 Buoyant Surface Discharges
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         HSC-ECIP Glendale Run2 - 24in dredge
 Design case:
 FILE NAME:               cormix\sim\        .cx3
 Time of Fortran run:

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =    164.60  AS    =   1779.33  QA    =     21.35
 HA    =     10.81  HD    =     10.36
 UA    =     0.012 F     =      0.008 USTAR =0.3790E-03
 UW    =     5.000 UWSTAR=0.5525E-02
 Density stratified environment
 STRCND=  A         RHOAM =  999.5500
 RHOAS =  999.1000  RHOAB = 1000.0000  RHOAEF=  999.5500  E     =0.0000E+00

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =      0.00  Configuration:
 Rectangular channel geometry:
 B0    =     3.660 H0    =      0.310 A0    =0.1135E+01  AR    =      0.085
 SIGMA =     90.00  SLOPE =     60.00
 U0    =     1.172 Q0    =      1.330       =0.1330E+01
 RHO0  =  999.5500  DRHO0 =0.0000E+00  GP0   =0.0000E+00
 C0    =0.1000E+03  CUNITS=  X
 IPOLL =  1         KS    =0.0000E+00  KD    =0.0000E+00

FLUX VARIABLES (metric units)
 Q0    =0.1330E+01  M0    =0.1559E+01  J0    =0.0000E+00
 Associated length scales (meters)
 LQ    =      1.07  LM    =  99999.00  Lm    =    104.05  Lb    =      0.00

NON-DIMENSIONAL PARAMETERS
 FR0   =  99999.00  FRCH  =  99999.00  R     =     97.68

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)      =    SA1    3
 3  Applicable layer depth HS =    10.36  3
 333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    =0.1000E+03  CUNITS=  X
 NTOX  =  1         CMC   =0.1000E+02  CCC   =  CSTD
```

```
 NSTD  =  1         CSTD  =0.1000E+01
 REGMZ =  1
 REGSPC=  1         XREG  =    500.00  WREG  =      0.00  AREG  =      0.00
 XINT  =   2000.00  XMAX  =   2000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:      0.00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP =100 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)

Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y       Z        S       C       BV       BH
      0.04     4.13    0.00     1.0 0.100E+03   0.50     1.92
 Cumulative travel time =           4. sec

END OF MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE

 Surface JET into a crossflow

Near-field limitation in bounded channel.
Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y       Z        S       C       BV       BH
      0.04     4.13    0.00     1.0 0.100E+03   0.50     1.92
      0.14     5.41    0.00     1.1 0.874E+02   0.66     2.06
      0.26     6.68    0.00     1.3 0.777E+02   0.82     2.20
      0.39     7.96    0.00     1.4 0.699E+02   0.97     2.35
      0.53     9.23    0.00     1.6 0.635E+02   1.12     2.49
      0.68    10.51    0.00     1.7 0.582E+02   1.27     2.63
      0.84    11.78    0.00     1.9 0.537E+02   1.41     2.77
      1.02    13.06    0.00     2.0 0.499E+02   1.56     2.91
      1.21    14.33    0.00     2.1 0.465E+02   1.70     3.05
```

1.41	15.61	0.00	2.3	0.436E+02	1.84	3.19
1.62	16.88	0.00	2.4	0.410E+02	1.99	3.33
1.85	18.16	0.00	2.6	0.387E+02	2.13	3.47
2.09	19.44	0.00	2.7	0.367E+02	2.27	3.61
2.34	20.71	0.00	2.9	0.349E+02	2.41	3.75
2.60	21.99	0.00	3.0	0.332E+02	2.55	3.89
2.87	23.26	0.00	3.2	0.317E+02	2.70	4.03
3.16	24.54	0.00	3.3	0.303E+02	2.84	4.17
3.46	25.81	0.00	3.4	0.290E+02	2.98	4.31
3.77	27.09	0.00	3.6	0.279E+02	3.12	4.45
4.09	28.36	0.00	3.7	0.268E+02	3.26	4.59
4.43	29.64	0.00	3.9	0.258E+02	3.40	4.73
4.78	30.92	0.00	4.0	0.249E+02	3.54	4.87
5.14	32.19	0.00	4.2	0.240E+02	3.68	5.01
5.51	33.47	0.00	4.3	0.232E+02	3.83	5.15
5.89	34.74	0.00	4.4	0.225E+02	3.97	5.29
6.29	36.02	0.00	4.6	0.218E+02	4.11	5.43
6.70	37.29	0.00	4.7	0.211E+02	4.25	5.57
7.12	38.57	0.00	4.9	0.205E+02	4.39	5.71
7.55	39.84	0.00	5.0	0.199E+02	4.53	5.85
8.00	41.12	0.00	5.2	0.194E+02	4.67	5.99
8.46	42.39	0.00	5.3	0.188E+02	4.81	6.13
8.93	43.67	0.00	5.5	0.183E+02	4.95	6.27
9.41	44.95	0.00	5.6	0.179E+02	5.09	6.41
9.90	46.22	0.00	5.7	0.174E+02	5.23	6.55
10.41	47.50	0.00	5.9	0.170E+02	5.37	6.69
10.93	48.77	0.00	6.0	0.166E+02	5.51	6.84
11.46	50.05	0.00	6.2	0.162E+02	5.65	6.98
12.00	51.32	0.00	6.3	0.158E+02	5.79	7.12
12.56	52.60	0.00	6.5	0.155E+02	5.93	7.26
13.12	53.87	0.00	6.6	0.151E+02	6.08	7.40
13.70	55.15	0.00	6.7	0.148E+02	6.22	7.54
14.30	56.43	0.00	6.9	0.145E+02	6.36	7.68
14.90	57.70	0.00	7.0	0.142E+02	6.50	7.82
15.52	58.98	0.00	7.2	0.139E+02	6.64	7.96
16.15	60.25	0.00	7.3	0.137E+02	6.78	8.10
16.79	61.53	0.00	7.5	0.134E+02	6.92	8.24
17.44	62.80	0.00	7.6	0.131E+02	7.06	8.38
18.11	64.08	0.00	7.8	0.129E+02	7.20	8.52
18.78	65.35	0.00	7.9	0.127E+02	7.34	8.66
19.47	66.63	0.00	8.0	0.124E+02	7.48	8.80
20.17	67.90	0.00	8.2	0.122E+02	7.62	8.94
20.89	69.18	0.00	8.3	0.120E+02	7.76	9.08
21.62	70.46	0.00	8.5	0.118E+02	7.90	9.22
22.35	71.73	0.00	8.6	0.116E+02	8.04	9.36
23.10	73.01	0.00	8.8	0.114E+02	8.18	9.50
23.87	74.28	0.00	8.9	0.112E+02	8.32	9.64
24.64	75.56	0.00	9.0	0.111E+02	8.46	9.78
25.43	76.83	0.00	9.2	0.109E+02	8.60	9.92
26.23	78.11	0.00	9.3	0.107E+02	8.74	10.06

27.04	79.38	0.00	9.5	0.106E+02	8.88	10.20
27.87	80.66	0.00	9.6	0.104E+02	9.02	10.34
28.70	81.94	0.00	9.8	0.102E+02	9.16	10.48
29.55	83.21	0.00	9.9	0.101E+02	9.30	10.62

** CMC HAS BEEN FOUND **

The pollutant concentration in the plume falls below CMC value of 0.100E+02 in the current prediction interval.

This is the extent of the TOXIC DILUTION ZONE.

30.41	84.49	0.00	10.1	0.995E+01	9.44	10.76
31.28	85.76	0.00	10.2	0.981E+01	9.58	10.90
32.17	87.04	0.00	10.3	0.967E+01	9.72	11.04
33.07	88.31	0.00	10.5	0.954E+01	9.86	11.18
33.98	89.59	0.00	10.6	0.941E+01	10.00	11.33
34.90	90.86	0.00	10.8	0.928E+01	10.14	11.47
35.83	92.14	0.00	10.9	0.916E+01	10.28	11.61
36.78	93.41	0.00	11.1	0.904E+01	10.42	11.75
37.74	94.69	0.00	11.2	0.893E+01	10.56	11.89
38.71	95.97	0.00	11.3	0.881E+01	10.71	12.03
39.69	97.24	0.00	11.5	0.870E+01	10.85	12.17
40.69	98.52	0.00	11.6	0.860E+01	10.99	12.31
41.69	99.79	0.00	11.8	0.849E+01	11.13	12.45
42.71	101.07	0.00	11.9	0.839E+01	11.27	12.59
43.75	102.34	0.00	12.1	0.829E+01	11.41	12.73
44.79	103.62	0.00	12.2	0.819E+01	11.55	12.87
45.85	104.89	0.00	12.4	0.810E+01	11.69	13.01
46.91	106.17	0.00	12.5	0.800E+01	11.83	13.15
47.99	107.45	0.00	12.6	0.791E+01	11.97	13.29
49.09	108.72	0.00	12.8	0.782E+01	12.11	13.43
50.19	110.00	0.00	12.9	0.774E+01	12.25	13.57
51.31	111.27	0.00	13.1	0.765E+01	12.39	13.71
52.44	112.55	0.00	13.2	0.757E+01	12.53	13.85
53.58	113.82	0.00	13.4	0.749E+01	12.67	13.99
54.73	115.10	0.00	13.5	0.741E+01	12.81	14.13
55.90	116.37	0.00	13.6	0.733E+01	12.95	14.27
57.08	117.65	0.00	13.8	0.725E+01	13.09	14.41
58.27	118.93	0.00	13.9	0.718E+01	13.23	14.55
59.47	120.20	0.00	14.1	0.710E+01	13.37	14.69
60.69	121.48	0.00	14.2	0.703E+01	13.51	14.83
61.91	122.75	0.00	14.4	0.696E+01	13.65	14.97
63.15	124.03	0.00	14.5	0.689E+01	13.79	15.11
64.41	125.30	0.00	14.7	0.683E+01	13.93	15.25
65.67	126.58	0.00	14.8	0.676E+01	14.07	15.39
66.95	127.85	0.00	14.9	0.669E+01	14.21	15.53
68.23	129.13	0.00	15.1	0.663E+01	14.35	15.67
69.53	130.40	0.00	15.2	0.657E+01	14.49	15.82
70.85	131.68	0.00	15.4	0.651E+01	14.63	15.96

Cumulative travel time = 716. sec

Some concentration build-up near bank/shore due to recirculation effects.
Find concentration and thickness values for the RECIRCULATION REGION

```
   at end of MOD329!

END OF MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------

 Because of the strong horizontal momentum flux of this discharge, severe
   PLUME INTERACTION WITH BOTH BANKS occurs.
 Consider a different discharge design with a reduced offshore momentum flux.

 In the next prediction module, the plume centerline will be set
   to follow the bank/shore.

 A subsequent module (MOD381) will predict the properties of the
   LATERALLY mixed plume with the given near-field dilution and will
   compute a POSSIBLE UPSTREAM WEDGE INTRUSION.

-----------------------------------------------------------------------------
BEGIN MOD381: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION
```

CDFATE Model Output

Discharge from Filterbed PA into Buffalo Bayou/HSC
30-Inch Dredge

```
CORMIX3 PREDICTION FILE:
33333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                        Subsystem version:
 Buoyant Surface Discharges
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         HSC_Fiterbed Run1
 Design case:
 FILE NAME:               cormix\sim\        .cx3
 Time of Fortran run:

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =     91.44  AS    =    438.00  QA    =     18.26
 HA    =      4.79  HD    =      3.21
 UA    =      0.042 F     =      0.015 USTAR =0.1806E-02
 UW    =      5.000 UWSTAR=0.5527E-02
 Density stratified environment
 STRCND=  A         RHOAM =  998.8000
 RHOAS =  998.4000  RHOAB =  999.2000  RHOAEF=  998.8000  E     =0.0000E+00

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =      0.00  Configuration:
 Circular discharge pipe:
 D0    =      3.200 A0    =      0.602
 Dimensions of equivalent rectangular discharge:
 B0    =      0.734 H0    =      0.820 A0    =0.6015E+00  AR    =      1.118
 SIGMA =    107.00  SLOPE =     11.30
 U0    =      3.475 Q0    =      2.090       =0.2090E+01
 RHO0  =  998.8000  DRHO0 =0.0000E+00  GP0   =0.0000E+00
 C0    =0.1000E+03  CUNITS=  X
 IPOLL =  1         KS    =0.0000E+00  KD    =0.0000E+00

FLUX VARIABLES (metric units)
 Q0    =0.2090E+01  M0    =0.7262E+01  J0    =0.0000E+00
 Associated length scales (meters)
 LQ    =      0.78  LM    =  99999.00  Lm    =     64.62  Lb    =      0.00

NON-DIMENSIONAL PARAMETERS
 FR0   =  99999.00  FRCH  =  99999.00  R     =     83.32

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)      =    SA1    3
 3  Applicable layer depth HS =     3.21  3
 333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
```

```
 C0    =0.1000E+03  CUNITS=  X
 NTOX  =  1         CMC   =0.1000E+02  CCC   =  CSTD
 NSTD  =  1         CSTD  =0.1000E+01
 REGMZ =  1
 REGSPC=  1         XREG  =    500.00  WREG  =      0.00  AREG  =      0.00
 XINT  =   2000.00  XMAX  =   2000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:      0.00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 50 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)

Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
     -0.84     2.88    0.00     1.0 0.100E+03   0.93     0.55
 Cumulative travel time =           1. sec

END OF MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE

 Surface JET into a crossflow

Near-field limitation in bounded channel.
Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
     -0.84     2.88    0.00     1.0 0.100E+03   0.93     0.55
     -1.13     4.28    0.00     1.2 0.815E+02   1.09     0.71
     -1.40     5.69    0.00     1.5 0.688E+02   1.26     0.87
     -1.65     7.09    0.00     1.7 0.595E+02   1.42     1.03
     -1.87     8.50    0.00     1.9 0.525E+02   1.58     1.19
     -2.06     9.90    0.00     2.1 0.469E+02   1.75     1.35
     -2.24    11.31    0.00     2.4 0.424E+02   1.91     1.52
```

```
     -2.39    12.71    0.00     2.6 0.387E+02   2.07     1.68
     -2.51    14.12    0.00     2.8 0.356E+02   2.23     1.84
     -2.61    15.53    0.00     3.0 0.329E+02   2.40     2.00
     -2.69    16.93    0.00     3.3 0.306E+02   2.56     2.16
     -2.74    18.34    0.00     3.5 0.286E+02   2.72     2.32
     -2.77    19.74    0.00     3.7 0.269E+02   2.88     2.48
     -2.78    21.15    0.00     3.9 0.253E+02   3.04     2.64
     -2.76    22.55    0.00     4.2 0.240E+02   3.20     2.80
     -2.72    23.96    0.00     4.4 0.227E+02   3.36     2.96
     -2.66    25.36    0.00     4.6 0.216E+02   3.53     3.13
     -2.57    26.77    0.00     4.9 0.206E+02   3.69     3.29
     -2.45    28.18    0.00     5.1 0.197E+02   3.85     3.45
     -2.32    29.58    0.00     5.3 0.189E+02   4.01     3.61
     -2.15    30.99    0.00     5.5 0.181E+02   4.17     3.77
     -1.97    32.39    0.00     5.8 0.174E+02   4.33     3.93
     -1.76    33.80    0.00     6.0 0.167E+02   4.49     4.09
     -1.53    35.20    0.00     6.2 0.161E+02   4.66     4.25
     -1.27    36.61    0.00     6.4 0.155E+02   4.82     4.41
     -0.99    38.01    0.00     6.7 0.150E+02   4.98     4.58
     -0.69    39.42    0.00     6.9 0.145E+02   5.14     4.74
     -0.36    40.82    0.00     7.1 0.141E+02   5.30     4.90
     -0.01    42.23    0.00     7.3 0.136E+02   5.46     5.06
      0.37    43.64    0.00     7.6 0.132E+02   5.62     5.22
      0.77    45.04    0.00     7.8 0.128E+02   5.78     5.38
      1.19    46.45    0.00     8.0 0.125E+02   5.94     5.54
      1.64    47.85    0.00     8.2 0.121E+02   6.11     5.70
      2.11    49.26    0.00     8.5 0.118E+02   6.27     5.86
      2.61    50.66    0.00     8.7 0.115E+02   6.43     6.02
      3.13    52.07    0.00     8.9 0.112E+02   6.59     6.19
      3.67    53.47    0.00     9.2 0.109E+02   6.75     6.35
      4.24    54.88    0.00     9.4 0.107E+02   6.91     6.51
      4.83    56.29    0.00     9.6 0.104E+02   7.07     6.67
      5.44    57.69    0.00     9.8 0.102E+02   7.23     6.83
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of 0.100E+02
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
      6.08    59.10    0.00    10.1 0.994E+01   7.39     6.99
      6.75    60.50    0.00    10.3 0.972E+01   7.55     7.15
      7.43    61.91    0.00    10.5 0.951E+01   7.72     7.31
      8.14    63.31    0.00    10.7 0.931E+01   7.88     7.47
      8.88    64.72    0.00    11.0 0.912E+01   8.04     7.64
      9.64    66.12    0.00    11.2 0.893E+01   8.20     7.80
     10.42    67.53    0.00    11.4 0.876E+01   8.36     7.96
     11.22    68.94    0.00    11.6 0.859E+01   8.52     8.12
     12.05    70.34    0.00    11.9 0.842E+01   8.68     8.28
     12.91    71.75    0.00    12.1 0.826E+01   8.84     8.44
     13.78    73.15    0.00    12.3 0.811E+01   9.00     8.60
 Cumulative travel time =         113. sec
```

```
 Some concentration build-up near bank/shore due to recirculation effects.
   Find concentration and thickness values for the RECIRCULATION REGION
   at end of MOD329!

END OF MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------

 The LIMITING DILUTION (given by ambient flow/discharge ratio) is:     9.7
   This value is below the computed dilution of    12.3 at the end
   of the NFR.
 Mixing for this discharge configuration is constrained by LOW AMBIENT FLOW!

 The previous module predictions are unreliable since the limiting dilution
   cannot be exceeded for this discharge into a deep unstratified layer.

 A subsequent module (MOD381) will predict the properties of the
   cross-sectionally fully mixed plume with limiting dilution and will
   compute a POSSIBLE UPSTREAM WEDGE INTRUSION.
-----------------------------------------------------------------------------
BEGIN MOD381: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION

 The DOWNSTREAM flow field for this unstable shallow water discharge is
     VERTICALLY FULLY MIXED.
 The mixing is controlled by the limiting dilution =      9.7

 NO UPSTREAM INTRUSION will occur since the discharge is NON-BUOYANT.

       X        Y        Z        S        C        BV       BH
     13.78     0.00     0.00      9.7 0.103E+02   3.21    91.44
 Cumulative travel time =         113. sec

 Vertically and laterally fully mixed over layer depth: END OF SIMULATION!

END OF MOD381: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD327: STRONGLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE

 JET INTERACTS WITH FAR BANK in this region.

Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
     13.78    73.15     0.00      9.7 0.103E+02  24.76    23.66
     18.31    75.61     0.00     10.3 0.967E+01  25.50    24.39
     22.84    76.66     0.00     10.6 0.943E+01  25.81    24.71
```

27.37	77.41	0.00	10.8	0.926E+01	26.04	24.93
31.89	78.01	0.00	10.9	0.913E+01	26.22	25.11
36.42	78.52	0.00	11.1	0.903E+01	26.37	25.27
40.95	78.97	0.00	11.2	0.893E+01	26.51	25.40
45.47	79.37	0.00	11.3	0.885E+01	26.63	25.52
50.00	79.73	0.00	11.4	0.878E+01	26.73	25.63
54.53	80.07	0.00	11.5	0.871E+01	26.83	25.73
59.06	80.38	0.00	11.6	0.865E+01	26.93	25.82
63.58	80.67	0.00	11.6	0.859E+01	27.02	25.91
68.11	80.94	0.00	11.7	0.854E+01	27.10	25.99
72.64	81.20	0.00	11.8	0.849E+01	27.17	26.07
77.16	81.45	0.00	11.8	0.844E+01	27.25	26.14
81.69	81.68	0.00	11.9	0.840E+01	27.32	26.21
86.22	81.91	0.00	12.0	0.836E+01	27.39	26.28
90.75	82.12	0.00	12.0	0.832E+01	27.45	26.35
95.27	82.33	0.00	12.1	0.828E+01	27.51	26.41
99.80	82.53	0.00	12.1	0.824E+01	27.57	26.47
104.33	82.72	0.00	12.2	0.821E+01	27.63	26.53
108.85	82.91	0.00	12.2	0.817E+01	27.69	26.58
113.38	83.09	0.00	12.3	0.814E+01	27.74	26.64
117.91	83.26	0.00	12.3	0.811E+01	27.79	26.69
122.44	83.43	0.00	12.4	0.808E+01	27.85	26.74
126.96	83.60	0.00	12.4	0.805E+01	27.90	26.79
131.49	83.76	0.00	12.5	0.802E+01	27.94	26.84
136.02	83.92	0.00	12.5	0.799E+01	27.99	26.88
140.55	84.07	0.00	12.6	0.797E+01	28.04	26.93
145.07	84.22	0.00	12.6	0.794E+01	28.08	26.98
149.60	84.37	0.00	12.6	0.791E+01	28.13	27.02
154.13	84.51	0.00	12.7	0.789E+01	28.17	27.06
158.65	84.65	0.00	12.7	0.787E+01	28.21	27.10
163.18	84.79	0.00	12.8	0.784E+01	28.25	27.15
167.71	84.92	0.00	12.8	0.782E+01	28.29	27.19
172.24	85.06	0.00	12.8	0.780E+01	28.33	27.23
176.76	85.19	0.00	12.9	0.778E+01	28.37	27.26
181.29	85.31	0.00	12.9	0.775E+01	28.41	27.30
185.82	85.44	0.00	12.9	0.773E+01	28.45	27.34
190.34	85.56	0.00	13.0	0.771E+01	28.48	27.38
194.87	85.68	0.00	13.0	0.769E+01	28.52	27.41
199.40	85.80	0.00	13.0	0.767E+01	28.56	27.45
203.93	85.92	0.00	13.1	0.765E+01	28.59	27.48
208.45	86.03	0.00	13.1	0.764E+01	28.62	27.52
212.98	86.14	0.00	13.1	0.762E+01	28.66	27.55
217.51	86.26	0.00	13.2	0.760E+01	28.69	27.59
222.03	86.37	0.00	13.2	0.758E+01	28.73	27.62
226.56	86.47	0.00	13.2	0.756E+01	28.76	27.65
231.09	86.58	0.00	13.3	0.755E+01	28.79	27.68
235.62	86.69	0.00	13.3	0.753E+01	28.82	27.71
240.14	86.79	0.00	13.3	0.751E+01	28.85	27.75

Cumulative travel time = 5541. sec

```
 Some concentration build-up near bank/shore due to recirculation effects.
   Find concentration and thickness values for the RECIRCULATION REGION
   at end of MOD329!

END OF MOD327: STRONGLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD329: STRONGLY DEFLECTED PLUME WITH LEESIDE RECIRCULATION ZONE

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

 The near-shore RECIRCULATION REGION extends back to the discharge location:
    Concentration C within that region:        0.376E+01
    Layer thickness BV within that region:    28.85

END OF MOD329: STRONGLY DEFLECTED PLUME WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX3: Buoyant Surface Discharges                    End of Prediction File
3333333333333333333333333333333333333333333333333333333333333333333333333333333
```

CDFATE Model Output

Discharge from Filterbed PA into Buffalo Bayou/HSC
24-Inch Dredge

```
CORMIX3 PREDICTION FILE:
333333333333333333333333333333333333333333333333333333333333333333333333333333
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX3:                                          Subsystem version:
 Buoyant Surface Discharges
------------------------------------------------------------------------------
------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:         HSC_Fiterbed Run2 - 24in dredge
 Design case:
 FILE NAME:               cormix\sim\        .cx3
 Time of Fortran run:

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS    =     91.44  AS    =    438.00  QA    =     18.26
 HA    =      4.79  HD    =      3.20
 UA    =      0.042 F     =      0.010 USTAR =0.1509E-02
 UW    =      5.000 UWSTAR=0.5527E-02
 Uniform density environment
 STRCND=  U         RHOAM =  998.4000

DISCHARGE PARAMETERS (metric units)
 BANK  =  RIGHT     DISTB =      0.00  Configuration:
 Circular discharge pipe:
 D0    =      3.200 A0    =      0.428
 Dimensions of equivalent rectangular discharge:
 B0    =      0.659 H0    =      0.650 A0    =0.4282E+00  AR    =      0.987
 SIGMA =    107.00  SLOPE =     11.30
 U0    =      3.106 Q0    =      1.330       =0.1330E+01
 RHO0  =  998.4000  DRHO0 =0.0000E+00  GP0   =0.0000E+00
 C0    =0.1000E+03  CUNITS=  X
 IPOLL =  1         KS    =0.0000E+00  KD    =0.0000E+00

FLUX VARIABLES (metric units)
 Q0    =0.1330E+01  M0    =0.4131E+01  J0    =0.0000E+00
 Associated length scales (meters)
 LQ    =      0.65  LM    =  99999.00  Lm    =     48.74  Lb    =      0.00

NON-DIMENSIONAL PARAMETERS
 FR0   =  99999.00  FRCH  =  99999.00  R     =     74.49

FLOW CLASSIFICATION
 333333333333333333333333333333333333333333
 3  Flow class (CORMIX3)      =    SA1    3
 3  Applicable layer depth HS =     3.20  3
 333333333333333333333333333333333333333333

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0    =0.1000E+03  CUNITS=  X
```

```
 NTOX  =  1         CMC   =0.1000E+02  CCC   =  CSTD
 NSTD  =  1         CSTD  =0.1000E+01
 REGMZ =  1
 REGSPC=  1         XREG  =    500.00  WREG  =      0.00  AREG  =      0.00
 XINT  =    600.00  XMAX  =    600.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the WATER SURFACE and at center of discharge
      channel/outlet:      0.00 m  from the RIGHT bank/shore.
    X-axis points downstream
    Y-axis points to left as seen by an observer looking downstream
    Z-axis points vertically upward (in CORMIX3, all values Z = 0.00)
NSTEP = 50 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)

Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y       Z        S       C       BV       BH
     -0.70     2.42    0.00     1.0 0.100E+03   0.75     0.49
 Cumulative travel time =           1. sec

END OF MOD301: DISCHARGE MODULE (FLOW ESTABLISHMENT)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE

 Surface JET into a crossflow

Near-field limitation in bounded channel.
Profile definitions:
   BV = Gaussian 1/e (37%) vertical thickness
   BH = Gaussian 1/e (37%) horizontal half-width, normal to trajectory
   S = hydrodynamic centerline dilution
   C = centerline concentration (includes reaction effects, if any)

       X        Y       Z        S       C       BV       BH
     -0.70     2.42    0.00     1.0 0.100E+03   0.75     0.49
     -0.98     3.83    0.00     1.3 0.787E+02   0.91     0.65
     -1.22     5.25    0.00     1.5 0.649E+02   1.08     0.81
     -1.43     6.66    0.00     1.8 0.552E+02   1.24     0.97
     -1.61     8.08    0.00     2.1 0.481E+02   1.40     1.13
     -1.76     9.49    0.00     2.4 0.425E+02   1.57     1.30
     -1.87    10.91    0.00     2.6 0.382E+02   1.73     1.46
     -1.96    12.32    0.00     2.9 0.346E+02   1.89     1.62
```

-2.01	13.73	0.00	3.2	0.316E+02	2.05	1.78
-2.03	15.15	0.00	3.4	0.291E+02	2.22	1.94
-2.01	16.56	0.00	3.7	0.270E+02	2.38	2.11
-1.97	17.98	0.00	4.0	0.252E+02	2.54	2.27
-1.89	19.39	0.00	4.2	0.236E+02	2.70	2.43
-1.78	20.81	0.00	4.5	0.222E+02	2.86	2.59
-1.64	22.22	0.00	4.8	0.209E+02	3.03	2.75
-1.47	23.64	0.00	5.1	0.198E+02	3.19	2.92
-1.26	25.05	0.00	5.3	0.188E+02	3.35	3.08
-1.02	26.47	0.00	5.6	0.179E+02	3.51	3.24
-0.75	27.88	0.00	5.9	0.171E+02	3.68	3.40
-0.45	29.30	0.00	6.1	0.163E+02	3.84	3.56
-0.12	30.71	0.00	6.4	0.156E+02	4.00	3.73
0.25	32.13	0.00	6.7	0.150E+02	4.16	3.89
0.65	33.54	0.00	6.9	0.144E+02	4.32	4.05
1.08	34.96	0.00	7.2	0.139E+02	4.49	4.21
1.54	36.37	0.00	7.5	0.134E+02	4.65	4.37
2.03	37.78	0.00	7.8	0.129E+02	4.81	4.54
2.56	39.20	0.00	8.0	0.125E+02	4.97	4.70
3.12	40.61	0.00	8.3	0.121E+02	5.13	4.86
3.71	42.03	0.00	8.6	0.117E+02	5.30	5.02
4.33	43.44	0.00	8.8	0.113E+02	5.46	5.18
4.99	44.86	0.00	9.1	0.110E+02	5.62	5.35
5.67	46.27	0.00	9.4	0.107E+02	5.78	5.51
6.39	47.69	0.00	9.6	0.104E+02	5.94	5.67
7.14	49.10	0.00	9.9	0.101E+02	6.11	5.83

** CMC HAS BEEN FOUND **

The pollutant concentration in the plume falls below CMC value of 0.100E+02 in the current prediction interval.

This is the extent of the TOXIC DILUTION ZONE.

7.93	50.52	0.00	10.2	0.982E+01	6.27	5.99
8.74	51.93	0.00	10.5	0.957E+01	6.43	6.16
9.59	53.35	0.00	10.7	0.932E+01	6.59	6.32
10.47	54.76	0.00	11.0	0.910E+01	6.75	6.48
11.38	56.18	0.00	11.3	0.888E+01	6.92	6.64
12.32	57.59	0.00	11.5	0.867E+01	7.08	6.80
13.30	59.01	0.00	11.8	0.847E+01	7.24	6.97
14.31	60.42	0.00	12.1	0.828E+01	7.40	7.13
15.35	61.83	0.00	12.3	0.810E+01	7.56	7.29
16.42	63.25	0.00	12.6	0.793E+01	7.73	7.45
17.52	64.66	0.00	12.9	0.776E+01	7.89	7.61
18.66	66.08	0.00	13.2	0.760E+01	8.05	7.78
19.83	67.49	0.00	13.4	0.745E+01	8.21	7.94
21.03	68.91	0.00	13.7	0.730E+01	8.37	8.10
22.26	70.32	0.00	14.0	0.716E+01	8.53	8.26
23.52	71.74	0.00	14.2	0.702E+01	8.70	8.42
24.82	73.15	0.00	14.5	0.689E+01	8.86	8.59

Cumulative travel time = 148. sec

Some concentration build-up near bank/shore due to recirculation effects.

```
   Find concentration and thickness values for the RECIRCULATION REGION
   at end of MOD329!

END OF MOD317: WEAKLY DEFLECTED JET (3-D) WITH LEESIDE RECIRCULATION ZONE
-----------------------------------------------------------------------------

 Because of the strong horizontal momentum flux of this discharge, severe
   PLUME INTERACTION WITH BOTH BANKS occurs.
 Consider a different discharge design with a reduced offshore momentum flux.

 In the next prediction module, the plume centerline will be set
   to follow the bank/shore.

 A subsequent module (MOD381) will predict the properties of the
   LATERALLY mixed plume with the given near-field dilution and will
   compute a POSSIBLE UPSTREAM WEDGE INTRUSION.

-----------------------------------------------------------------------------
BEGIN MOD381: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION
```

Appendix B. TCEQ Email Correspondence

Appendix B

TCEQ Email Correspondence

From:	Peter Schaefer
To:	Montgomery, Cheryl R CIV USARMY CEERD-EL (USA)
Cc:	Michael Pfeil
Subject:	[Non-DoD Source] RE: Mike Pfeil"s e-mail for HSC dredging question
Date:	Friday, December 4, 2020 4:37:18 PM

Sounds good, Cheryl. Here is a link to our Texas Integrated Report web page:
https://www.tceq.texas.gov/waterquality/assessment

Here's a link to the current 303-d list which is in that Integrated Report web page.
https://www.tceq.texas.gov/assets/public/waterquality/swqm/assess/20txir/2020_303d.pdf If you look at segment 1007 which is the Houston Ship Channel and is the first "classified" waterbody that hunting bayou reaches, you'll notice that the listing is broken down into various different waterbodies that would drain to the segment. Hunting Bayou is shown as Hunting Bayou Tidal (1007_03) and is listed of dioxin and PCBs in edible tissue. Classified segments are the major waterbodies in Texas that have been assigned specific uses and criteria in Appendix A of the Texas Surface Water Quality Standards.

Here's a link to our web page that shows Classified Segments with TMDLs:
https://www.tceq.texas.gov/waterquality/tmdl/nav/tmdlsegments You'll notice that Segment 1007 was broken up into numerous sub segment with letter suffixes (i.e. 1007A – 1007V). The only TMDLs for these waterbodies are for bacteria.
As far as flow in Hunting Bayou, there is a permitted wastewater outfall located on Hunting Bayou approximately 1 mile upstream of where Turkey Run (I think that's the name of the waterbody) confluences with Hunting Bayou. Our critical conditions reviewer determined that the 7Q2 flow (low flow conditions) in Hunting Bayou is 3.16 cfs and the harmonic mean flow is 7.33 cfs. For the purposes of determining flow at the Turkey Run confluence, you can add 1.85 cfs to the 7Q2 number to account for the flow from the permitted discharge.

Hopefully this information is helpful.

Let me know if you have any questions.

Thanks,

Peter

Peter Schaefer, Team Leader
Standards Implementation Team (MC 150)
Water Quality Assessment Section
Water Quality Division, TCEQ
email: *peter.schaefer@tceq.texas.gov*
phone: 512-239-4372
fax: 512-239-4420

From: Montgomery, Cheryl R CIV USARMY CEERD-EL (USA) <Cheryl.R.Montgomery@usace.army.mil>
Sent: Friday, December 4, 2020 10:32 AM
To: Peter Schaefer <peter.schaefer@tceq.texas.gov>
Cc: Michael Pfeil <michael.pfeil@tceq.texas.gov>
Subject: RE: Mike Pfeil's e-mail for HSC dredging question

Thanks Peter.

I am heading into another call but will send the tox testing appendix this afternoon.

Thanks for your time this morning.

~C

From: Peter Schaefer <peter.schaefer@tceq.texas.gov>
Sent: Friday, December 4, 2020 10:47 AM
To: Montgomery, Cheryl R CIV USARMY CEERD-EL (USA) <Cheryl.R.Montgomery@usace.army.mil>
Cc: Michael Pfeil <michael.pfeil@tceq.texas.gov>
Subject: [Non-DoD Source] Mike Pfeil's e-mail for HSC dredging question

Cheryl,

I've cc'ed Mike on this e-mail so you'll have his address.

Thanks,

Peter

Peter Schaefer, Team Leader
Standards Implementation Team (MC 150)
Water Quality Assessment Section
Water Quality Division, TCEQ
email: *peter.schaefer@tceq.texas.gov*
phone: 512-239-4372
fax: 512-239-4420

From:	Michael Pfeil
To:	Montgomery, Cheryl R CIV USARMY CEERD-EL (USA); Peter Schaefer; Gregg Easley
Cc:	Bailey, Susan E CIV USARMY CEERD-EL (USA); Brown, Harmon III CIV USARMY CESWF (USA); Fisher, Melinda CIV USARMY CESWF (USA); Bourne, Ellen M (Michelle) CIV (USA)
Subject:	[Non-DoD Source] RE: HSC - NMP CDFate Backup Into
Date:	Wednesday, December 9, 2020 4:02:46 PM

Cheryl-

I didn't say we prefer a chronic endpoint, only that we assess one for perennial waters, just explaining how we monitor for toxicity. That said, using an acute to chronic ratio seems logical to me and 5 sounds very protective, so I have no issues with that if nobody else does.

I will allow Peter to address the second question.

Thanks.

Mike

From: Montgomery, Cheryl R CIV USARMY CEERD-EL (USA) <Cheryl.R.Montgomery@usace.army.mil>
Sent: Wednesday, December 9, 2020 2:26 PM
To: Michael Pfeil <michael.pfeil@tceq.texas.gov>; Peter Schaefer <peter.schaefer@tceq.texas.gov>; Gregg Easley <gregg.easley@tceq.texas.gov>
Cc: Bailey, Susan E CIV USARMY CEERD-EL (USA) <Susan.E.Bailey@usace.army.mil>; Brown, Harmon III CIV USARMY CESWF (USA) <Harmon.Brown@usace.army.mil>; Fisher, Melinda CIV USARMY CESWF (USA) <Melinda.Fisher@usace.army.mil>; Bourne, Ellen M (Michelle) CIV (USA) <Michelle.Bourne@usace.army.mil>
Subject: RE: HSC - NMP CDFate Backup Into

Mike/Peter/Greg:

At this point we have two questions that we need to resolve to proceed:

1. Toxicity Value: We only have acute testing from our new work dredge material testing and TCEQ has indicated that they prefer a chronic endpoint. We do not have a chronic test result or an LC50, only a NOEC. I am going to suggest drawing upon CERCLA ecorisk practices where an acute value is "converted" to chronic number by dividing by a safety margin or safety factor. For this case, I am suggesting converting the NOEC obtained from the acute to into an equivalent chronic value by dividing by 5. So, since our acute NOEC was a 50%, our chronic would be a 10%. Even zinc, which was out largest exceedance, still did not generate an LC50, so these new work materials really are very benign. What do you thing about this approach? Overly simplistic or elegantly simple?
2. Pump Rates: Peter forwarded some information of 7Q2 flows in Hunting Bayou, which gave us 5.01 cfs which in turn converts to roughly 3.24 MGD. We need to double check this, but current design could yield pump rates of 61.4 cfs which is roughly 40 MGD. So, a pump rate

that is substantially larger than current 7Q2. Thoughts?

Just as a reminder, these new work dredge materials are undisturbed geological formations, they are not shoaled in materials as you would in maintenance dredging.

Do you think we might be able to chat briefly Thurs or Fri of this week? Since time is really crunching us here, tomorrow morning would be ideal, but Friday afternoon also works.

Let us know?

Thanks.

~C

From: Montgomery, Cheryl R CIV USARMY CEERD-EL (USA)
Sent: Wednesday, December 9, 2020 11:08 AM
To: Michael Pfeil <michael.pfeil@tceq.texas.gov>
Cc: Bailey, Susan ERD (Susan.E.Bailey@usace.army.mil) <Susan.E.Bailey@usace.army.mil>
Subject: RE: HSC - NMP CDFate Backup Into

Mike – thanks for getting back to us. Susan and I have plans to meet this afternoon to discuss this modeling, so we will "mull it over" and get back to you.

Thanks!

~C

From: Michael Pfeil <michael.pfeil@tceq.texas.gov>
Sent: Wednesday, December 9, 2020 11:02 AM
To: Montgomery, Cheryl R CIV USARMY CEERD-EL (USA) <Cheryl.R.Montgomery@usace.army.mil>
Subject: [Non-DoD Source] RE: HSC - NMP CDFate Backup Into

Cheryl-

I have been given this a great deal of thought and still am uncertain what you mean by "criteria". I think you are asking how we would apply WET testing, especially since Peter has mentioned our critical conditions reviewer (Kati Cunningham) and how he provided you with the flow in another email. If that's the case, here is how we would proceed.

WET testing can be thought of as a water-quality based effluent limit or monitoring requirement, since it takes into account the flow of the discharge and its dilution in the receiving waters.

For industrial dischargers, we look at the highest monthly flow as MGD in the past 2 years (say, 1 MGD). We then look at the RW flow and convert that flow from cfs to MGD by multiplying it by 0.6463 (say, 2 cfs * 0.6463 = 1.3). Then we calculate the percentage of effluent at the edge of the mixing zone, also known as the critical dilution: 1 X 100/1 + 1.3 = 43%. This is the dilution in which we would assess compliance for WET testing.

For WET testing, we use either hypothesis testing (NOEC) or point estimate (IC25), both being roughly equivalent in assessing a 25% difference when compared to a control. I see you used a 10% difference wen assessing for toxicity, i.e., and IC25 for lethality. For perennial waters such as in your example, we assess two endpoints, acute (survival) and chronic (growth/reproduction).

So we could use the information based on a critical conditions memo and try and calculate the critical dilution. However, with dredged material, there is no set flow value to use in the calculation. You would have to come up with some value. But once that is done, we could do the calculation and set up the test to assess for significant toxicity based on the IC25 for survival.

If that is nothing at all what you had in mind or are asking, than I am at a complete loss as to what to use for a criterion, I am sorry.

Let me know after you have thought it over.

Mike

From: Montgomery, Cheryl R CIV USARMY CEERD-EL (USA) <Cheryl.R.Montgomery@usace.army.mil>
Sent: Friday, December 4, 2020 3:08 PM
To: Michael Pfeil <michael.pfeil@tceq.texas.gov>
Cc: Peter Schaefer <peter.schaefer@tceq.texas.gov>; Brown, Harmon III CIV USARMY CESWF (USA) <Harmon.Brown@usace.army.mil>; Fisher, Melinda CIV USARMY CESWF (USA) <Melinda.Fisher@usace.army.mil>; Bailey, Susan E CIV USARMY CEERD-EL (USA) <Susan.E.Bailey@usace.army.mil>
Subject: HSC - NMP CDFate Backup Into

Michael – attached are two files. One is the appendix that contains all of the supporting biological data for the new work dredging project and the other is the appendix of the chemical analytical tables. I figure if you are anything like me, looking at one piece of data in isolation really doesn't give me a feel for things, so we figured the chemical analytical data would not go amiss. Please let us know if there are other data that would be helpful and feel free to contact us to discuss or get clarification of any kind.

By way of summary from our meeting:

1. Peter to send Michael's email to Cheryl: DONE
2. Cheryl to send Michael and Peter bioassay appendix (added chemical analytical appendix): DONE
3. Michael to review data and get back to us on toxicity number derivation + other thoughts:
4. Peter to check on flow information for Hunting Bayou:
5. Peter to send TMDL URL
6. Peter to send TexTox URL
7. Peter to send URL for Texas Integrated Report (background info)
8. Peter to check TCEQ database for additional local/regional background concentrations for COCs in surface water

In terms of schedule expectations for Susan and I, we need to have the calculations completed and be able to report back to the PDT (consists of SWG and PHA staff) on the outcome of these calculations before we break for Christmas. The final report isn't due until the new calendar year, but getting these input parameters sorted and completing these calculations is on a compressed timeline since the other field data came in late (story of my life it seems), so any low hanging fruit that you can pick and get to us quickly would be greatly appreciated.

We so appreciate the opportunity to work collaboratively on this – it is simply a much more productive way to do this, so many thanks again for your time today.

~C

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