For Public Comment, May 2008

# Two Total Maximum Daily Loads for Dissolved Oxygen in Dickinson Bayou

Segments 1103 and 1104

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TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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Technical Support Document:
A Hydrodynamic and Water Quality Model of Dickinson Bayou (Segments 1103 and 1104)
Using the Environmental Fluid Dynamics Code (EFDC)

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# Two Total Maximum Daily Loads for Dissolved Oxygen in Dickinson Bayou

## Executive Summary

This document describes the total maximum daily loads (TMDLs) of pollutants associated with dissolved oxygen (DO) in Dickinson Bayou Tidal (Segment 1103) and Dickinson Bayou Above Tidal (Segment 1104). The results of surface water quality monitoring indicate that DO concentrations in Dickinson Bayou are lower than the criteria used to evaluate attainment of the high aquatic life use designated in Segment 1103 and the intermediate aquatic life use designated in Segment 1104. The DO criteria are the following:

- 24-hour average DO concentration $\geq$ 4.0 milligrams per liter (mg/L)
- 24-hour absolute minimum DO concentration $\geq$ 3.0 mg/L

The TCEQ and its predecessor agencies first identified the occurrence of low DO in Dickinson Bayou in 1976 and documented the non-attainment of DO criteria in the tidal portion of Dickinson Bayou in the *1996 Texas Water Quality Inventory and 303(d) List*. Dickinson Bayou extends for approximately 23 miles in rapidly urbanizing Galveston County and has a watershed area of approximately 105.6 square miles (27,350 hectares). The watershed is located in the San Jacinto-Brazos Coastal Basin southeast of Houston.

Intensive sampling conducted as part of the TMDL project confirmed that Dickinson Bayou is not meeting its assigned DO criteria and provided the detailed water quality information necessary to develop the TMDL. Pollutant discharges to Dickinson Bayou and its tributaries originate from point and nonpoint sources of pollution and include municipal wastewater treatment facilities and regulated and unregulated sources of rainfall runoff.

The TCEQ developed pollutant load allocations for both segments of Dickinson Bayou (Segment 1103 and 1104) for oxygen demanding substances collectively referred to as carbonaceous biochemical oxygen demand (CBOD). The TCEQ used a fully dynamic watershed model to simulate daily flow and watershed loadings of pollutants into Dickinson Bayou. The TCEQ then used the simulated flow and pollutant loadings to construct a three-dimensional hydrodynamic and water quality model of Dickinson Bayou. The simulations were validated and applied to determine the necessary load reductions and allowable CBOD loadings for point and nonpoint sources.

The TMDL models considered seasonal variations and used an implicit margin of safety reflected in the conservative assumptions and attainment targets used in the TMDL analysis. The results of the TMDL analysis show that a 10 percent reduction in CBOD loading entering Segment 1103 and a 10.6 percent reduction in CBOD loading entering Segment 1104 will result in a loading level protective of the DO criteria attainment frequency considered appropriate, achievable, and sustainable for both segments of Dickinson Bayou. However, simulations show that no reduction of CBOD loading will ultimately result in full achieve-

ment of the DO criteria as currently assessed, including a scenario simulating natural loading conditions and no wastewater discharges.

The results of the TMDL analysis also show that the natural depth pattern of Dickinson Bayou contributes significantly to the non-attainment of DO criteria as currently applied to the bayou and recommends a reassessment of the criteria or the criteria assessment methodology applied to the bayou.

# Introduction

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

In simple terms, a TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. In other words, TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. TMDLs must also estimate how much the pollutant load must be reduced from current levels in order to achieve water quality standards.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies. Additionally, the TMDL Program identifies water bodies that do not meet the criteria used by the TCEQ to determine support of the beneficial uses designated in the *Texas Surface Water Quality Standards* (30 TAC §§307.1-307.10), but for which no pollutant or man-induced condition can be identified as the cause for non-attainment with the assigned criteria. This TMDL addresses the impairment to the intermediate aquatic life use in Dickinson Bayou Above Tidal (Segment 1104) and the impairment of the high aquatic life use in Dickinson Bayou Tidal (Segment 1103) due to non-attainment of the DO criteria specified for these water bodies the in *Texas Surface Water Quality Standards* (TCEQ 2000).

Like many tidal streams located along the Texas Gulf Coast, Dickinson Bayou's ability to incorporate and retain DO is limited by its natural bathymetry and hydrology. This TMDL study offers further evidence that the DO criteria used to ascertain the bayou's ability to support normal aquatic life should be based on factors that include site-specific measurements.

Section 303(d) of the Clean Water Act and the implementing regulations of the U.S. Environmental Protection Agency (EPA) in Title 40 of the Code of Federal Regulations, Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

The TCEQ must consider certain elements in developing a TMDL; they are described in the following sections:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Seasonal Variation
- Margin of Safety
- Pollutant Load Allocation
- Public Participation
- Implementation and Reasonable Assurance

The commission adopted this document on Month, Day, Year. Upon EPA approval, this TMDL will become an update to the state's Water Quality Management Plan (WQMP). Future updates to this TMDL are subject to public notice and will supersede this TMDL. All TMDL amendments will become updates to the WQMP.

# Problem Definition

The state of Texas has identified low DO as a water quality issue of concern in Dickinson Bayou since 1976 (TWQB 1976). Non-attainment of the DO criteria was first documented in the *1996 Texas Water Quality Inventory and 303(d) List* (TNRCC 1996). The TCEQ used DO data collected as part of its Surface Water Quality Monitoring Program to determine that DO concentrations were occasionally lower than the criteria established to support aquatic life. In the *2006 Texas Water Quality Inventory and 303(d) List* (TCEQ 2006), the TCEQ extended the geographic area of non-attainment approximately 2.5 miles upstream to include a portion of the freshwater segment of Dickinson Bayou (Segment 1104) and approximately 4 miles downstream to include the portion of the tidally-influenced segment of Dickinson Bayou (Segment 1103) located between Highway 3 and the confluence with Gum Bayou (Figure 1).

The standards for water quality in Texas water bodies are defined in the *Texas Surface Water Quality Standards* (TCEQ 2000). The specific uses designated for Dickinson Bayou Tidal are contact recreation and a high aquatic life use; the uses designated for Dickinson Bayou Above Tidal are contact recreation and an intermediate aquatic life use. In the Draft *2008 Texas Water Quality Inventory and 303(d) List* (TCEQ 2007) the TCEQ reported that three assessment units in the tidally-influenced portion of Dickinson Bayou and one as-

sessment unit above tidal influence contained depressed DO concentrations, as had been reported in previous assessments. As with the 2006 Inventory and List, the draft 2008 Inventory and List reported that a portion of Segment 1104 also contained depressed DO concentrations. The area of non-attainment was limited to one of two assessment units (AUs) located farthest downstream and directly upstream of the tidally influenced segment of Dickinson Bayou (AU 1104_01).

## Dissolved Oxygen (DO) Criteria

Dissolved oxygen criteria for Dickinson Bayou consist of 24-hour average and absolute minimum concentrations. The criteria for protection of high aquatic life use in tidal streams and the criteria for protection of the intermediate aquatic life use in freshwater streams are numerically identical and consist of the following threshold concentrations:

- 24-hour average DO concentration $\geq$ 4.0 milligrams per liter (mg/L)
- 24-hour absolute minimum DO concentration $\geq$ 3.0 mg/L

The TCEQ considers that a water body is *fully supporting* if 10 percent or less of the sample sets are in exceedance of the DO criteria (i.e., $\geq$ 90 percent attainment) and *not supporting* if greater than 10 percent of the sample sets are in exceedance (i.e., < 90 percent attainment). The TCEQ uses a binomial method to specify the number of exceedances of the single sample criterion required to determine nonsupport of the aquatic life use.

Requirements for assessment of compliance with DO criteria include how and when surface water quality is monitored in a water body. Only 24-hour DO data collected during the warm weather Index Period (March 15 through October 15) are used for assessment of DO criteria and the data must be collected at locations that are representative of water quality conditions in the water body. In freshwater streams of sufficient depth, DO measurements are conducted at approximately one foot (0.3 meters) of depth. However, DO criteria in tidal streams only apply to depths that are within the "mixed surface layer," which is defined as the vertical portion of the water column from the surface to the depth at which specific conductivity exceeds the surface conductivity by 6,000 umhos.

## TMDL Data Collection

To provide a basis for TMDL model calibration and to also provide additional assessment data, the TCEQ, in partnership with the Galveston County Health District (GCHD), the Houston-Galveston Area Council (H-GAC) and the U.S. Geological Survey (USGS), conducted a series of monthly water quality monitoring events in 2000 and 2001 (GCHD 2001). The effort consisted of 15 separate 48-hour DO surveys and water quality sampling events in seven locations and at two separate depths:

- GCHD and others deployed buoy-mounted multiprobe instruments at near-surface and near-bottom depths at five locations in the Bayou, and at two other locations using bridge-mounted instruments.
- Every month for 15 consecutive months, the instruments recorded DO, pH, temperature, and specific conductivity at surface and bottom depths in Dickinson Bayou over a 48-hour period.

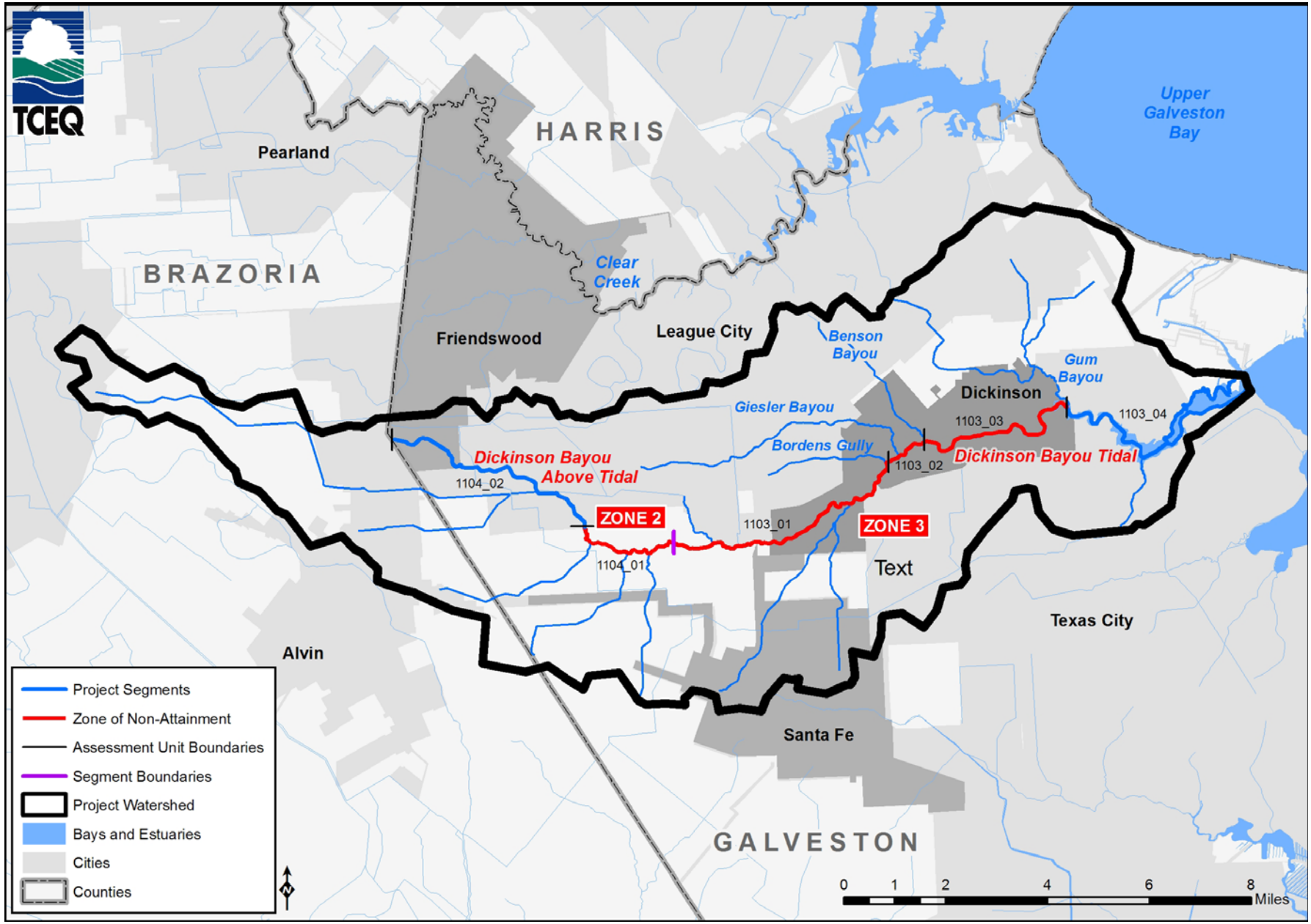



Figure 1. Dickinson Bayou Watershed

- GCHD and others also collected surface water samples and water samples at near-bottom depths for chemical analysis.

All data used in the assessment were collected under an approved quality assurance project plan which ensured the data were of known and appropriate quality (H-GAC 2000). In addition to the results of the GCHD study, additional data collected through the TCEQ's Surface Water Quality Monitoring Program was also used for TMDL model calibration and validation.

For water quality assessment purposes, the TCEQ has divided Segment 1104 into 2 assessment units (AUs) and Segment 1103 into 4 AUs (Figure 1). For the 2008 water quality assessment, the TCEQ used these same six assessment units to assess DO:

- Assessment unit 1103_01: From 2.5 miles downstream of FM 517 to the Bordens Gully confluence
- Assessment unit 1103_02: From the Bordens Gully confluence to the Benson Bayou confluence
- Assessment unit 1103_03: From the Benson Bayou confluence to the confluence with Gum Bayou
- Assessment unit 1103_04: From the Gum Bayou confluence to 1.3 miles downstream of SH 146.
- Assessment unit 1104_01: From the lower Segment boundary upstream to FM 517.
- Assessment unit 1104_02: From FM 517 upstream to FM 528

The draft 2008 Inventory and List (TCEQ 2007) shows that the 24-hour average and minimum DO concentrations did not meet the assigned criteria in AUs 1103_01, 1103_02, and 1103_03 in the tidal portion (Segment 1103) and in AU 1104_01 located upstream of tidal influence. Under current assessment methodology (TCEQ 2007a), these AUs were *not supporting* the high aquatic use in Segment 1103 and the intermediate aquatic life use in Segment 1104. A summary of assessment findings regarding support of aquatic life use is as follows:

- Assessment unit 1103_01: *not supporting*
- Assessment unit 1103_02: *not supporting*
- Assessment unit 1103_03: *not supporting*
- Assessment unit 1103_04: *fully supporting*
- Assessment unit 1104_01: *not supporting*
- Assessment unit 1104_02: *fully supporting*

The TCEQ also included both segments of Dickinson Bayou in the Draft 2008 Water Quality Inventory and 303(d) list for *not supporting* contact recreation in the same 4 AUs listed for low DO and 4 tidal tributaries. Despite consistent non-attainment of DO criteria, the TCEQ has not noted a concern for nutrient screening, excessive algal growth, or affected fish community in Dickinson Bayou.

## Watershed Overview

Dickinson Bayou is located in the San Jacinto-Brazos Coastal Basin (Hydrologic Unit Code 12040204), southeast of Houston, Texas, in Galveston County (Figure 1). The Dickinson Bayou watershed covers approximately 105.6 square miles (27,350 hectares), about 11 percent of the area of Galveston County and less than 1 percent of Brazoria County. The Dickinson Bayou watershed lies within a climatic region classified as subtropical humid, which is defined as having hot summers and dry winters. Between 1970 and 2000, the average annual rainfall was 49.3 inches, as measured at Sugar Land Regional Airport (NOAA 2004). During this same period, rainfall events of 0.1, 0.5, and 1 inch of rain were observed on average 64, 31, and 16 days per year, respectively. The Dickinson Bayou watershed is within the upper portion of the Northern Humid Gulf Coastal Prairies and Marshes ecoregion, an area characterized by nearly level, un-dissected plains with native vegetation types composed of tall grass prairie and oak savanna. The elevation of the area is approximately 11 meters above mean sea level.

Dickinson Bayou is 22.7 miles long and flows east towards Dickinson Bay. It is composed of two segments identified in the *Texas Surface Water Quality Standards* (TCEQ 2000) as Segment 1103 (Dickinson Bayou Tidal) and Segment 1104 (Dickinson Bayou Above Tidal). Segment 1103 begins at the confluence with Dickinson Bay, 2.1 kilometers east of SH 146, and ends at the tidal boundary with the freshwater segment (Segment 1104), 2.5 miles downstream of FM 517 in Galveston County. In the upper reaches of the tidal segment, Dickinson Bayou is typically a narrow, forested waterway. Near the City of Dickinson, the tidal bayou is wider and deeper. Downstream of the City of Dickinson, the bayou is relatively wide and slow moving. The portion of the watershed contributing flow directly to the tidal segment encompasses five incorporated areas: Dickinson, League City, Santa Fe, Baycliff, and San Leon. The tidal bayou provides recreational boating, fishing, water skiing, canoeing, and other water-based activities to local residents. The lower portion of the tidal bayou is also used for commercial shrimping and occasional barge traffic.

Segment 1104 begins at the tidal boundary and extends upstream to FM 528 in Galveston County. The undesignated portion of the bayou and an area comprising approximately one tenth of the contributing watershed extends northeast of FM 528 well into Brazoria County. The portion of the watershed contributing flow to Segment 1104 includes large areas of undeveloped land, including natural lands and some farmland. Segment 1104 is characterized as a narrow and shallow coastal prairie stream with low-lying, but abundant, riparian vegetation. The lower portion of the bayou, near the tidal boundary, also provides recreational boating, fishing, canoeing, and other water-based activities to local residents.

### Hydrology

Dickinson Bayou is perennial throughout most of its course. Flow in the uppermost reaches of Segment 1104 (Dickinson Bayou Above Tidal) is sustained by wastewater effluent generated southeast of the City of Friendswood (WQ0013632-001 Meadowland Utility Corp.). Rainfall runoff from rural creeks and ditches north of the City of Alvin and south of the City of Friendswood results in large seasonal flow variations. Prior to 1990, irrigation return flows from rice farming and other irrigated row crop production in this portion of the water-

shed also produced high seasonal flows (TWQB 1976). Since 1990, rice farming has diminished significantly in this portion of the watershed and irrigation return flows are currently thought to account for only a small portion of flow in the segment. Segment 1104 receives additional flow, downstream of FM 517, from three southern tributaries (Oak Creek, Algoa Bayou, and Hickory Bayou) which drain the mainly rural area between the municipalities of Alvin and Santa Fe. Flow velocities are typical of a shallow coastal prairie stream but decrease dramatically downstream of the confluence with Segment 1103 as depth increases and the stream becomes tidally influenced.

In addition to the flow from Segment 1104 (Dickinson Bayou Above Tidal), Segment 1103 receives direct flow from seven major tributaries, five from the north portion of the watershed (Gum Bayou, Bensons Bayou, Giesler Bayou, Bordens Gully and Cedar Creek) and two from the south (Hulen Park Bayou and Arcadia Bayou). The major tributaries to Segment 1103 are largely perennial and, like Segment 1103, are also tidally influenced, exhibiting abrupt changes in flow velocity at or near their tidal boundaries. Once an important part of the Gulf Intracoastal Waterway system, the lower third of the Dickinson Bayou was dredged for barge and boat traffic until 1983. Occasional barge traffic still occurs near the confluence with Dickinson Bay, but the majority of boat traffic in the tidal bayou is from sport and recreational boating and fishing activities.

## Land Use

The dominant land use category in the Dickinson Bayou watershed remains undeveloped natural land (open grassland, wooded land and wetlands), which accounts for 61 percent of the total area. Urban areas (mixed urban and residential) occupy 16 percent of land cover within the watershed, with the highest urban density occurring the middle portion of Segment 1103 near the City of Dickinson. Other land uses include pasture/hay at 13 percent, planted/cultivated at 6.0 percent, and open water at 3 percent (Figure 2).

## Population Density

The population of the Dickinson Bayou watershed in 2000 was estimated to be 66,517 (29,610 households) with an overall average population density of 628 persons per square mile (U.S. Census Bureau 2000). The population of Galveston County is estimated by the U.S. Census Bureau to have increased in population by approximately 13.3 percent between 2000 and 2006, so the 2008 watershed population probably exceeds 75,000.

The population distribution in the Dickinson Bayou watershed is skewed towards urban areas located in the northeastern portion of the watershed (i.e., near the cities of Dickinson and League City). However, there has also been recent residential development in the southeastern portion of the watershed near the cities of Alvin and Santa Fe. Table 1 provides Texas Water Development Board (TWDB) population growth estimates for selected cities within Galveston County for the period 2000 to 2020. Population growth patterns are expected to remain similar to those seen in the watershed since 2000, with urban growth increasing fastest in the northeast portion of the watershed.

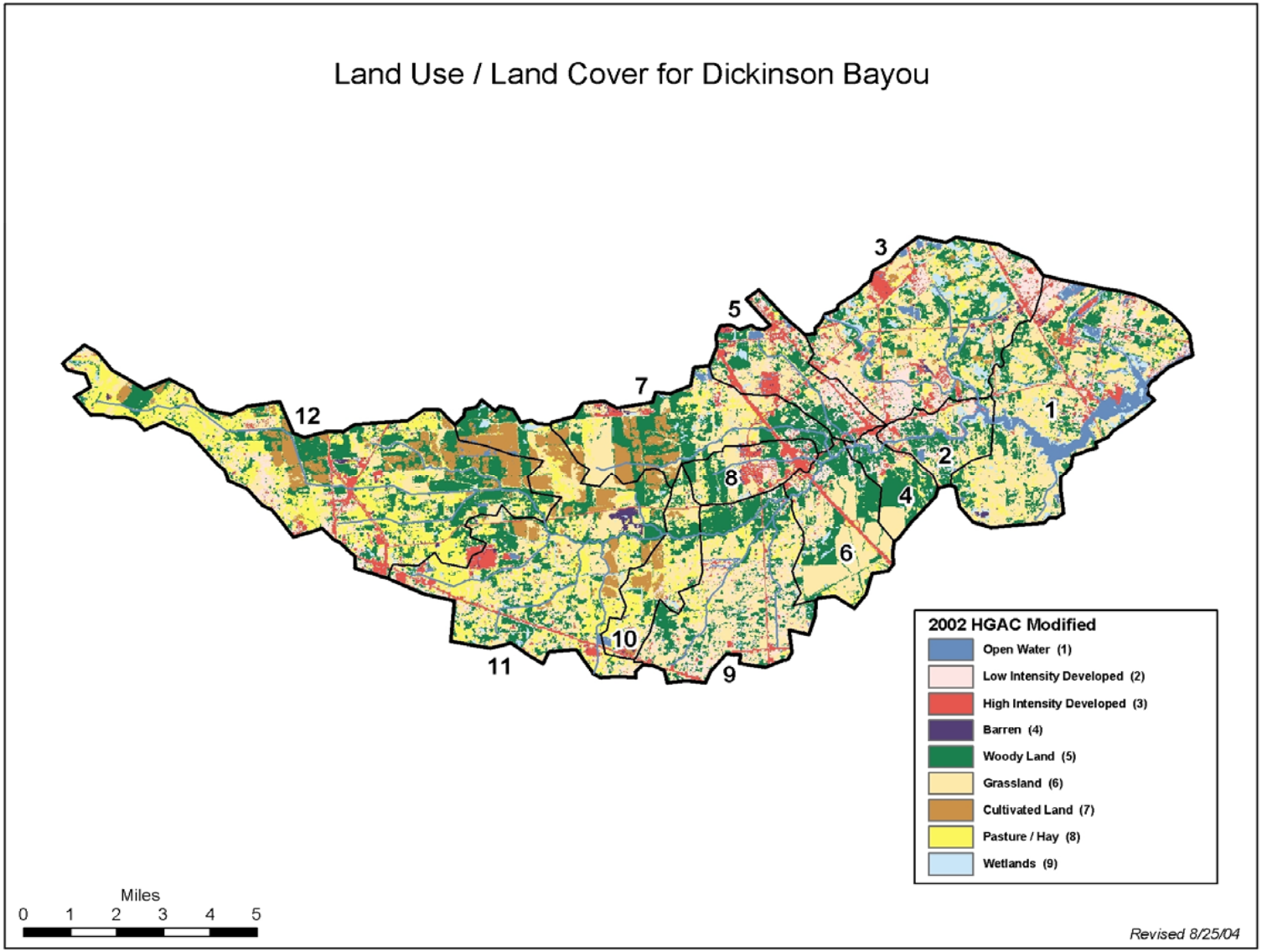



Figure 2. Land Use/Land Cover for the Dickinson Bayou Watershed

(Source: H-GAC 2002)

Table 1. Galveston County Population and Projected Increases by City, 2000 to 2020

| City | 2000 Census Population | 2010 Population | 2020 Population | Growth Rate (2000-2020) |
|---|---|---|---|---|
| Alvin | 21,413 | 23,231 | 25,123 | 15% |
| Dickinson | 17,093 | 19,955 | 22,425 | 24% |
| League City | 45,306 | 53,403 | 60,392 | 25% |
| Santa Fe | 9,548 | 10,141 | 10,653 | 10% |

Source: TWDB (2006).

## Wastewater Treatment Facilities

Many of the urbanized areas in the Dickinson Bayou watershed are served by sanitary sewer systems operated by licensed private or municipal operators. However, a significant portion of the watershed (mainly the southern quarter) is not included within the service areas of these operators. In the absence of specific county-level data, it is possible to estimate the number of housing units using onsite sewage disposal systems in a given area from service area boundaries in the watershed. Using this methodology, the H-GAC estimated in 2006 that approximately 11 percent of households in the watershed (about 3,267 units) were not connected to a sanitary sewer system (Figure 3). For the purpose of the TMDL, the assumption is that the majority of these households utilized septic tanks for sanitary waste disposal and that the other 89 percent of the households in the watershed were connected to a sanitary sewer system.

The more rural areas of the watershed have been historically served by septic systems. However, these areas remain sparsely populated and the highest density of septic systems was found in two areas of the watershed:

- areas north and northeast of Santa Fe in Subbasins 9, 10, and 11
- an area in the northwest portion of the watershed south of Pearland (Subbasin 1)

The density of septic tanks in these two areas was estimated at approximately 0.2 to 0.3 per acre.

## Bayou Shape and Depth

A well-documented feature of the tidal segment of Dickinson Bayou (Segment 1103) is that it is deeper in the middle section of the water body relative to the depths either directly upstream near the tidal boundary or downstream at the confluence with Dickinson Bay (Figure 4). Dickinson Bayou can be up to 22 feet deep with a width of only 100 feet in some areas. The cause of this "bathymetric sag" is not known, but one hypothesis is that high local and regional subsidence rates in this area of the Gulf Coast are responsible for this unique feature (Figure 5).

Compounding this bathymetric effect is the build-up of mud and silt also at the downstream portion of the bayou near the confluence with Dickinson Bay, which is thought to be the result of the geologic reworking of sediments deposited in Galveston Bay during the last

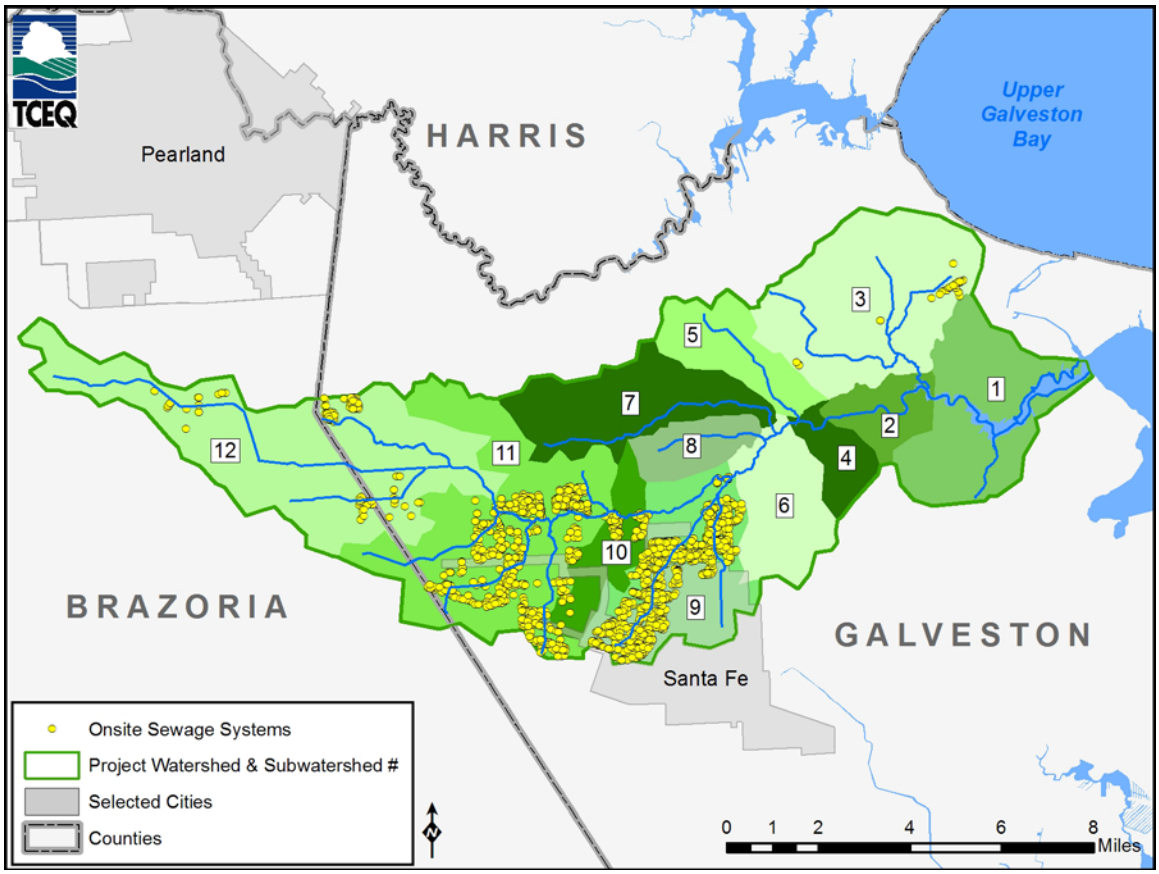



Figure 3. Potential Onsite Sewage Systems in the Dickinson Bayou Watershed, 2006

(Source: H-GAC)

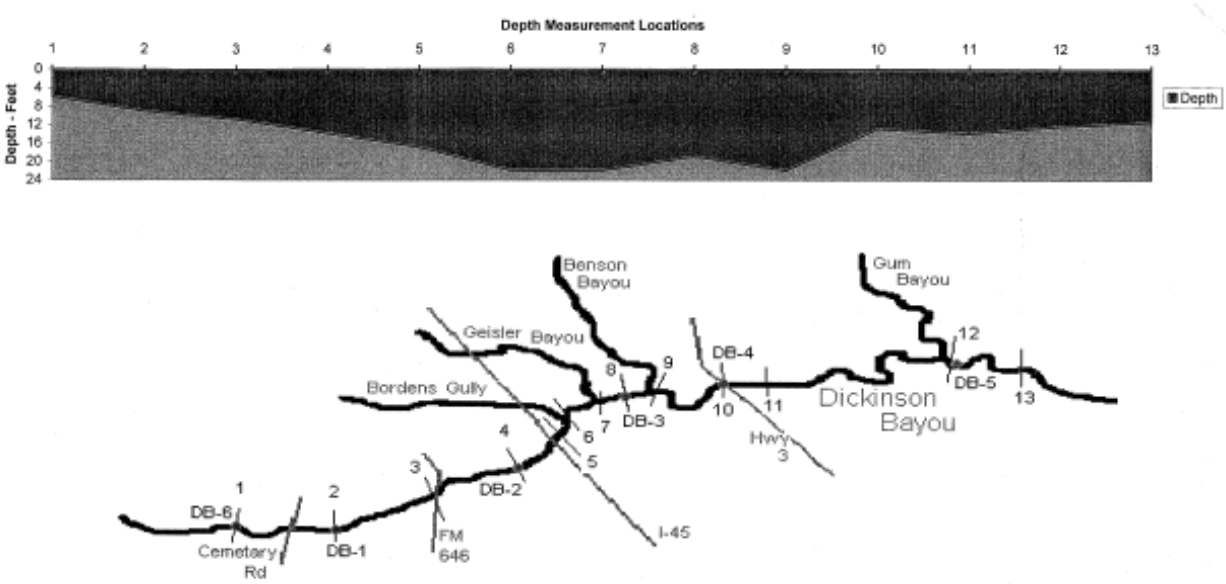



Figure 4. Longitudinal Depth Profile Measured During the Fall of 2001

(Source: GCHD 2001)

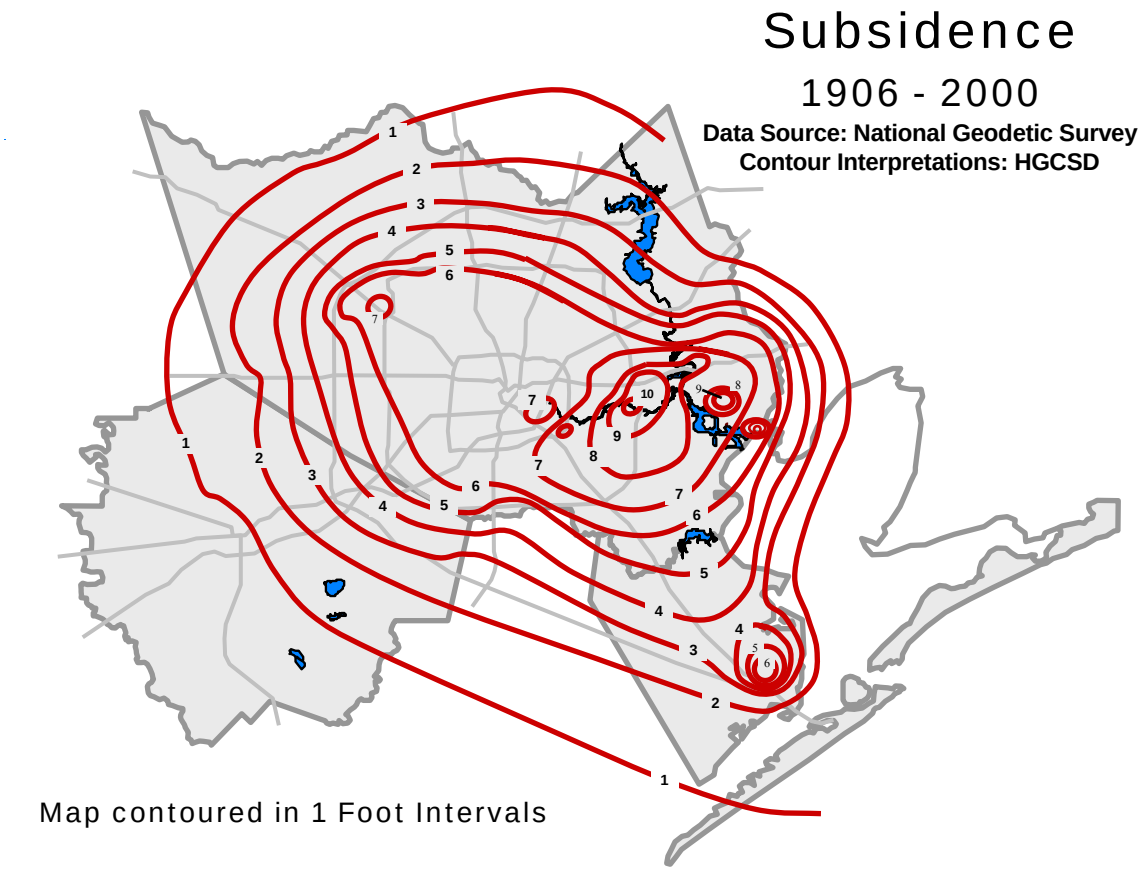



Figure 5. Subsidence Map of the Houston-Galveston Area

(Source: Harris-Galveston Subsidence District)

glacial period and the re-depositing of these sediments farther inland as a consequence of the associated rise in sea level that occurred after the Pleistocene period.

Tidal effects frequently bring heavier saline water to bottom depths in this portion of the bayou where a separation of surface and bottom layers, known as *salinity stratification*, commonly occurs under warm and dry conditions. A lack of mixing in the water column contributes to low DO levels at depth which can confine the oxygen-containing portion of a water column to a thin layer near the surface. An imbalance in the atmospheric oxygen diffused into the bayou (or produced by algae) and the oxygen biochemically consumed within the bayou is more rapidly and severely felt in a confined (i.e., stratified) surface layer of a water column.

# Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The standards for water quality for Dickinson Bayou, as defined in the *Texas Surface Water Quality Standards* (TCEQ 2000), were discussed in detail in the "Problem Definition" section of this TMDL document. The criteria include DO concentrations to protect the designated high aquatic life use in Dickinson Bayou Tidal (Segment 1103) and the intermediate aquatic life use in Dickinson Bayou Above Tidal (Segment 1104). Maximum loading limits are based on a 90 percent compliance with the 24-hour average and 24-hour minimum DO criteria as applied to conditions in the warm weather Index Period of March 15 through October 15 (Table 2).

Table 2. Aquatic Life Use and Dissolved Oxygen Criteria for Dickinson Bayou

| Stream Name | Designated Aquatic Life Use | 24-hr Average DO Criterion (mg/L) | 24-hr Minimum DO Criterion (mg/L) |
|---|---|---|---|
| Dickinson Bayou Tidal | High | 4 | 3 |
| Dickinson Bayou Above Tidal | Intermediate | 4 | 3 |

# Source Analysis

Pollutants may come from several sources. Point source pollutants come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES) managed by the TCEQ. Although diffuse in nature, storm water discharges from industries, construction activities, and the separate storm sewer systems of cities are considered point sources of pollution because the are regulated by the state and federal governments. Nonpoint source pollution is a diffuse source of contaminants originating from multiple locations, usually carried to surface waters by rainfall runoff. Many non-urban nonpoint sources of pollution are not regulated by permit under the TPDES.

Since DO is not a pollutant, the pollutants of concern in this TMDL are those which exert a demand on in-stream DO. The pollutants considered of greatest concern are carbonaceous biochemical oxygen demand (CBOD) which depletes oxygen from the water column and nutrients (nitrogen and phosphorus), which can stimulate algal growth to excessively high rates resulting in oxygen concentrations below the 24-hour DO criteria. CBOD is often analyzed and reported as $CBOD_5$ or 5-day biochemical oxygen demand, which is a measure of the amount of DO a CBOD sample consumes over a 5-day analysis period. $CBOD_5$ values can be converted to ultimate CBOD (CBODu), which is a measure of the total amount of DO consumed by a sample of CBOD. This is done by applying a factor to the $CBOD_5$ value (TCEQ uses a ratio of 1:2.3 $CBOD_5$:CBODu).

Establishing the pollutants of concern for this TMDL is the subject of the "Linkage Analysis" section of this TMDL document. However, the Source Analysis for this DO TMDL focuses on all potential pollutants of concern including CBOD, nutrients, and suspended sediment.

## Permitted Point Sources

The TCEQ has issued ten TPDES permits for the discharge of wastewater into Dickinson Bayou or its tributaries (Figure 6, Table 3). Two proposed facilities have pending applications for permits as of May 2008. For the sake of completeness, these two permits are also included in Table 3.

### Domestic Wastewater Treatment Facilities

Five of the active TPDES discharge permits in Dickinson Bayou are for domestic wastewater (sewage) treatment facilities and five are for discharge of industrial wastewater. The permit issued to Galveston County WCID #1 allows the largest discharge of wastewater into Dickinson Bayou at 4.8 million gallons per day (MGD). Only one other wastewater permit allows the discharge of wastewater into Dickinson Bayou at near this flow level, R. West Development Co., Inc. at 0.95 MGD. Although it holds an active TPDES discharge permit, this facility is not currently in operation. The remaining permitted domestic wastewater facilities currently in operation in the watershed have permitted flows below 0.1 MGD.

From approximately 1999 to mid-2002, the reported average daily domestic wastewater discharge to Dickinson Bayou was 2.88 MGD, which was below the permitted daily flow at the time of 3.82 MGD. Average daily domestic wastewater discharge to Dickinson Bayou in 2007 was 2.29 MGD. However, the permitted daily domestic wastewater flow in Dickinson Bayou in 2007 was 5.84 MGD and with the addition of the 2 proposed new wastewater facilities in 2008, the permitted daily flow of treated domestic wastewater to Dickinson Bayou would be 7.29 MGD. Increasing discharge limits for some municipal permittees in recent years and current applications for new discharge permits in Dickinson Bayou indicate a projected increase in wastewater input of CBOD and nutrient loadings into the bayou, which is consistent with the observed trend toward increasing urbanization of the watershed.

Although the overall volume of treated wastewater permitted to discharge into Dickinson Bayou has increased over time, efforts to improve water quality problems in Dickinson Bayou have a long history and a number of significant changes and improvements have occurred over the recent past, which have likely improved water quality:

- Following a Waste Load Evaluation performed by the Texas Water Commission in 1986 (TWC 1986), all dischargers of domestic wastewater into Dickinson Bayou were required to achieve effluent water quality concentrations of 10 mg/L $CBOD_5$, 3 mg/L NH3-N, and 4 mg/L DO; all permit limits for industrial dischargers were held at their final permitted values and any new industrial discharge permits would be commensurate with those of domestic wastewater dischargers and would be considered on a case-by-case basis.
- Since 2000, effluent limits for the largest domestic wastewater treatment facility in the watershed (Galveston Co. WCID #1) have been reduced to a $CBOD_5$ limit of 7 mg/L and an NH3-N limit of 1.5 mg/L. Also, a significant wastewater facility (League City's Bayridge facility) was removed from service in 2002 and its outfall eliminated from Gum Bayou, a major tributary to Dickinson Bayou.

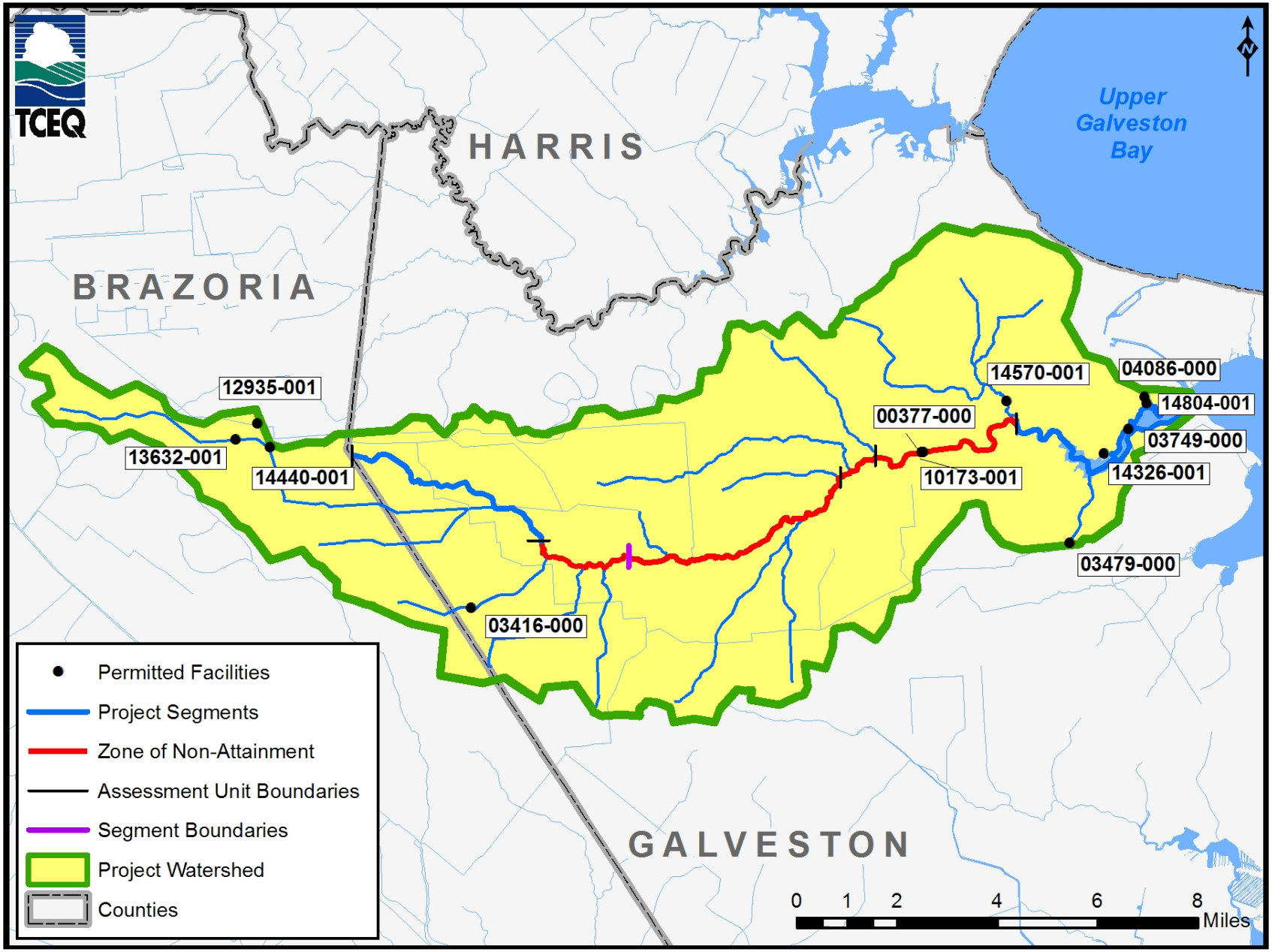



Figure 6. Dickinson Bayou, Major Tributaries, and Locations of Permitted Facilities

Table 3. Permitted Facilities, Existing Permit Limits, and Related Information for Dickinson Bayou Watershed

| TPDES Permit No. | Facility | Monthly Average Discharge 2007 (MGD)[1] | Final Permitted Discharge Limit (MGD)[1] | $CBOD_5$ (mg/L) | Total Suspended Solids (mg/L) | Ammonia-N (mg/L) | Dissolved Oxygen (mg/L) | Description of Discharge |
|---|---|---|---|---|---|---|---|---|
| WQ0013632-001 | Meadowland Utility Corp. | 0.007 | 0.0234 | 10.0 | 15.0 | 3.0 | 4.0 | Treated domestic wastewater |
| WQ0012935-001 | K.C. Utilities, Pine Colony Wastewater Treatment Facility | 0.03 | 0.05 | 10.0 | 15.0 | 3.0 | 4.0 | Treated domestic wastewater |
| WQ0014440-001 | R. West Development Co. Inc. | na | 0.95 | 10.0 | 15.0 | 3.0 | 4.0 | Treated domestic wastewater |
| WQ0003416-000 | Waste Management of Texas, Inc. | 0.13 | Report[5] | na | na | na | na | Storm water/ ground water |
| WQ0010173-001 | Galveston Co. WCID 1 | 2.26 | 4.8 | 7.0 | 15.0 | 1.5 | 6.0 | Treated domestic wastewater |
| WQ0000377-000 | Penreco (outfall 001) | 0.06 | 0.075 | 14.6 (lbs/day) $BOD_5$[4] | 20 | na | na | Process water |
| WQ0014570-001 | Marlin Atlantis White[3] | na | 0.5 | 5.0 | 15.0 | 2.0 | 6.0 | Treated domestic wastewater |
| WQ0014326-001 | CRVC Via Bayou LLC. | 0.001 | 0.02 | 10.0 | 15.0 | 3.0 | 4.0 | Treated domestic wastewater |
| WQ0003749-000 | Hillman Shrimp & Oyster Co. | 0.003 | 0.07 | 10.0 | 15.0 | 3.0 | 4.0 | Process water |
| WQ0003479-000 | Sea Lion Technology (outfall 201) | 0.07 | 0.02 | 10 $BOD_5$[4] | na | 3.0 | na | Treated domestic wastewater |
| WQ0004086-000 | Duratherm Inc.[2] | 0.08 | Report[5] | na | na | na | na | Treated storm water |
| WQ0014804-001 | South Central Water Co.[3] | na | 0.95 | 10.0 | 15.0 | 3.0 | 6.0 | Treated domestic wastewater |

Notes:

na – Not applicable

[1] Represents daily average flow for each month of the year

[2] Permit includes treated storm water discharge not to exceed 1.0 MGD

[3] Permit pending approval

[4] Current permit specifies a limit on $BOD_5$ only

[5] No effluent limit for this parameter; the current permit requires the facility only to report the concentration of the parameter in the effluent

It is also important to note that, although the permitted wastewater volume has increased, the average volume of treated domestic wastewater entering Dickinson Bayou has actually decreased since 2002.

### Industrial Wastewater Treatment Facilities

Four of the five facilities permitted to discharge industrial wastewater are located in the lower portions of Segment 1103 near the confluence with Dickinson Bay. Two are petrochemical facilities (Penreco, Duratherm) one is a power generation facility (Sea Lion Technology, Inc.) and one is a fresh and frozen seafood processing facility (Hillman Shrimp and Oyster Co.). Waste Management of Texas (TPDES Permit No. WQ003416-000), located upstream of the tidal boundary, holds a permit to dispose of groundwater pumped from a municipal solid waste landfill.

### Urban Storm water

As previously mentioned, storm water discharges from municipal separate storm sewer systems (MS4s) of cities covered under Phase I of the TPDES storm water regulations for large MS4s and Urbanized Areas (UAs) covered under TPDES General Permit TXR04000 for Phase II (small) MS4s are considered point sources of pollution. While the Dickinson Bayou watershed falls outside the boundaries of neighboring Phase I MS4s, it includes portions of several areas designated as UAs under the current TPDES rule for Phase II (small) MS4s (Figure 13).

Within the context of a TMDL, pollutants in storm water runoff emanating from portions of the watershed designated as Phase II UAs must be considered point source loads and, hence, are included in the waste load allocation (WLA) portion of the TMDL.

## Nonpoint Sources

Nonpoint source (NPS) pollutants enter a water body through diffuse and unspecific locations and are largely unregulated. Pollutant loading from non-point sources is largely a function of the land use within the watershed. The dominant land use category in the Dickinson Bayou watershed remains undeveloped natural land (open grassland, wooded land and wetlands), which accounts for 61 percent of the total watershed area. Other land uses contributing unregulated NPS pollution include pasture/hay at 13 percent and planted/cultivated at 6.0 percent. For the TMDL, pollutant loading to Dickinson Bayou from all NPS was estimated using the Hydrologic Simulation Program in Fortran (HSPF).

## Other Sources

Other sources of pollution are known to contribute loadings of oxygen demanding substances, nutrients, and sediment to Dickinson Bayou, both directly and via its tributaries. The Bayou Wildlife Park, located along the west bank of Segment 1104 at FM 517, is an 80-acre privately owned exotic animal park and zoo that offers safari rides, pony rides, and a petting zoo. The facility does not have a permit from the state of Texas to discharge wastewater, but contributes loadings of BOD, TSS and nutrients directly to Dickinson Bayou near the tidal boundary.

In addition to urban runoff, Dickinson Bayou also receives significant nonpoint source loadings of oxygen demanding pollutants in rainfall runoff from areas of the watershed occupied by non-urban land uses. Some of these areas contribute NPS loadings from failing wastewater collection infrastructure or failing onsite treatment systems. In 1998, East et al. estimated watershed loadings of BOD5, nutrients and other pollutants by land use category (USGS 1998). The USGS used monitoring data collected from four sub-watersheds during eight storm events and a low-flow synoptic event conducted between 1995 and 1997 to estimate pollutant loadings to Dickinson Bayou in pounds/day. East et al. found the highest pollutant concentrations coming from areas dominated by urban land uses.

# Linkage Analysis

Establishing the relationship between in-stream water quality and the source(s) of pollutant loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Dissolved oxygen is not itself a pollutant. To support aquatic life use, DO criteria, unlike most other criteria, are established to protect against low concentrations rather than high concentrations. Within this TMDL, the constituents or pollutants of concern are those which exert a demand on DO in the stream. Regarding depressed DO in Dickinson Bayou, the constituents considered of greatest concern are carbonaceous biochemical oxygen demand (CBOD), and nutrients (nitrogen and phosphorus). Organic matter exerts a demand on DO as it undergoes natural chemical and biological changes in surface water. Nutrients stimulate algal growth and can create an imbalanced in oxygen production.

Since the exact chemical makeup of organic matter in natural waters cannot be determined, the total amount of organic matter pollution in a water body is often expressed as the total amount of oxygen consumed (i.e., demanded) by the organic matter during its decomposition in natural surface water. Also of concern are nutrient concentrations (nitrogen and phosphorus) with nitrogen given special consideration in estuarine systems.

## Background Factors

An objective of the linkage analysis is to determine the most appropriate mathematical models that represent the conditions and sources under which non-attainment of DO criteria occurs and which can be applied to determine a TMDL and pollutant load allocations. Pertinent factors considered in the linkage analysis process and presented in more detail in DSLLC (2008) include the following:

- Dickinson Bayou is composed of two hydrologically distinct segments. Water movement in the tidally influenced segment (Segment 1103) is dominated by tidal forcing during low flow conditions and by freshwater inflow during periods of rainfall. Upstream of tidal influence, Dickinson Bayou is a shallow prairie stream dominated by wastewater effluent and seasonal rainfall runoff.

- Historical assessment monitoring shows that non-attainment of the DO criteria (average and minimum) usually occurs during spring and summer conditions and commonly in an area near the midpoint of the tidal bayou extending approximately 6 miles upstream of Hwy 3. This area also includes the deepest portions of the bayou where organic matter accumulates.
- In contrast to the tidal segment of Dickinson Bayou, non-attainment of the DO criteria in the Segment 1104 is a relatively recent observation which merits further investigation. The condition appears to be confined to one AU near the confluence with Segment 1103.
- In both segments, the temporal DO concentration pattern for the vast majority of 24-hour events exhibits the lowest concentrations about the time of sunrise and maximum concentrations in mid to late afternoon. The DO pattern exhibited is indicative of a system where aquatic plants (i.e., phytoplankton) are in sufficient abundance to exert a cyclic pattern on DO concentrations. This cyclic pattern in DO results from dominance of photosynthetic activity and DO production during daylight hours and a dominance of respiration and DO utilization in the absence of sunlight.
- For the tidal segment, non-attainment of the DO criteria is associated with increased water temperatures that prevail from approximately May through September. Available data indicate that non-attainment occurs under non-runoff influenced conditions. Lower stream velocities, seasonal reductions in reaeration rates, and high sediment oxygen demand all add to the complexities of this system and all of these have some role of unknown extent in the observed non-attainment.
- The TCEQ assesses support of the aquatic life use based on the frequency of compliance with the DO criteria (i.e., ≥ 90 percent compliance) for data collected in the mixed surface layer during the warm weather *Index Period*.

## Linkage Tool Selection

Model selection for Dickinson Bayou was based on the need to assess water quality in a hydrodynamically complex estuarine system (i.e., influenced by tidal forcing and accounting for the irregularities in depth found in the middle portions of the tidal segment) at depths within the mixed surface layer during the warm weather *Index Period*. The model should be able to dynamically depict changes in water quality, including simulation of diel fluctuations in DO, as a result of changes in the loading of dissolved and particulate pollutants from the watershed. Finally, in order to construct detailed frequency distributions of 24-hour average and minimum DO concentrations to assess compliance with the DO criteria the model should be able to produce continuous time series of simulated water quality parameters. Based on the factors described above, the TCEQ established a linkage between sources of pollution and (low) DO concentrations in Dickinson Bayou by developing a fully dynamic watershed model using the Hydrologic Simulation Program in Fortran (HSPF) and linking it to a hydrodynamic and water quality model (i.e., receiving water model) of Dickinson Bayou developed using the Environmental Fluid Dynamics Code (EFDC) water quality simulation software.

HSPF is a commonly used watershed-modeling program capable of producing a wide variety of pollutant loading estimates. The HSPF software is a comprehensive, conceptual, continuous watershed simulation model designed to simulate all the water quantity and water quality processes that occur in a watershed, including sediment transport and movement of contaminants.

HSPF can reproduce spatial variability by dividing the basin into hydrologically homogeneous land segments and simulating runoff for each land segment independently, using different meteorological input data and watershed parameters. The HSPF modeling software includes fitted parameters as well as parameters that can be measured in the watershed. HSPF is able to represent watershed processes is detail, however output of flow and water quality conditions in-stream is vertically averaged in HSPF and sediment oxygen demand is handled as a static user-defined parameter.

The HSPF modeling tool is not designed to represent flow in complex hydraulic systems such as estuaries and tidal streams. To address this limitation the TCEQ linked the HSPF watershed model to a three-dimensional hydrodynamic and water quality model of Dickinson Bayou (i.e., a receiving water model) capable of representing flow and water quality in more detail. The spatial domain used to represent the Dickinson Bayou watershed is shown in Figure 7. The HSPF watershed model segregates the watershed into subbasins, each contributing to a corresponding reach of Dickinson Bayou (Figure 7.) Subbasins 3, 5, 7 and 8 are subbasins contributing to tributaries of Dickinson Bayou. The continuous loading values generated by the HSPF watershed model were used as input in the EFDC receiving water model. The linked models provide a continuous simulation of physical and biochemical processes in the watershed and water body simultaneously.

EFDC is a state-of-the-art hydrodynamic and water quality modeling software that can be used to simulate aquatic systems in one, two, and three dimensions. It has evolved over the past two decades to become a widely used and technically defensible hydrodynamic and water quality modeling program. EFDC uses stretched or sigma vertical coordinates and Cartesian or curvilinear, orthogonal horizontal coordinates to represent the physical characteristics of a water body. It solves three-dimensional, vertically hydrostatic, free surface, turbulent averaged equations of motion for a variable-density fluid. Dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity, and temperature are also solved. The EFDC model allows for drying and wetting in shallow areas by a mass conservation scheme. The physics of the EFDC model and many aspects of the computational scheme are equivalent to the widely used Blumberg-Mellor model and U. S. Army Corps of Engineers' Chesapeake Bay model.

Although EFDC has been used for over 20 years, the program has evolved to include additional capabilities and functions. The recent advent of EFDC Explorer, a user interface that greatly facilitates model setup and post-processing, has helped to proliferate the use of the EFDC modeling software. The most recent version of EFDC available when this TMDL was developed (the version used in the TMDL allocation process) was Version DS071002P. EFDC will likely be included in subsequent versions of EPA's Better Assessment Science Integrating Point & Nonpoint Sources (BASINS), as is currently the case with HSPF.

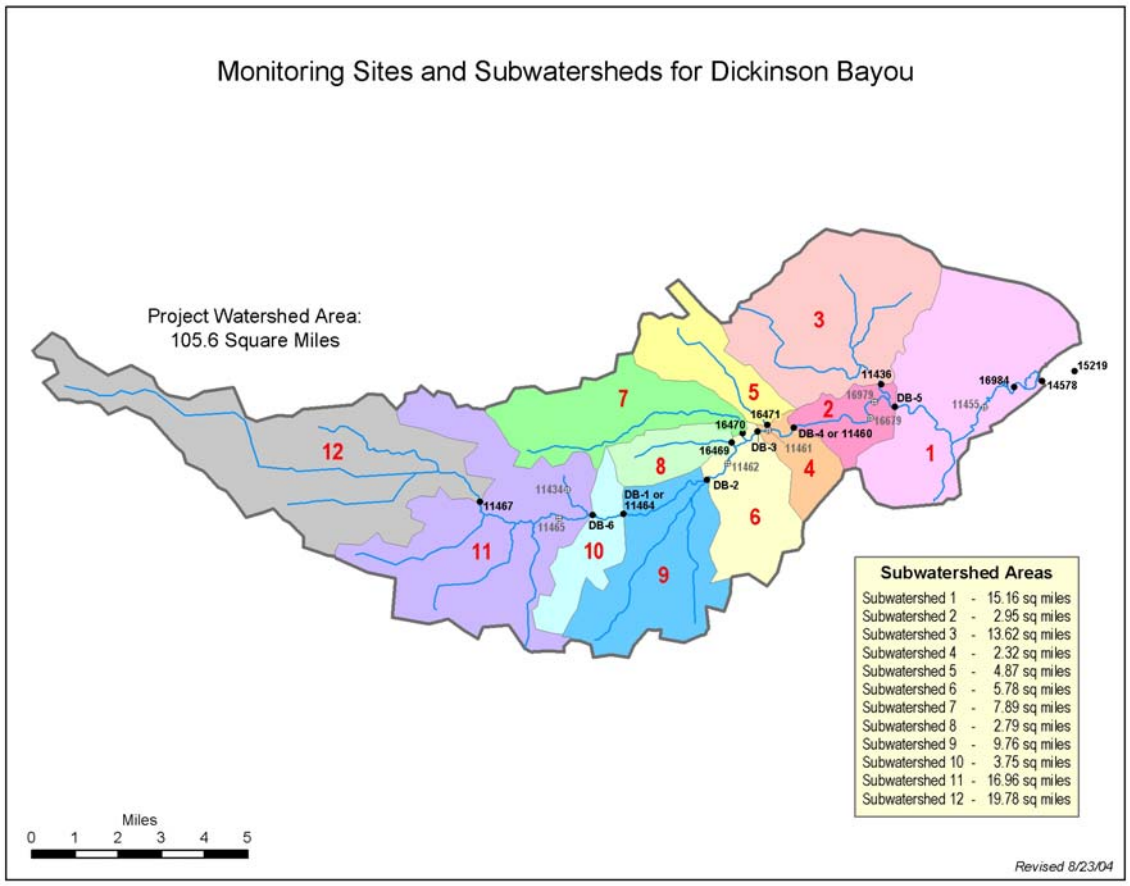



Figure 7. Subbasins of Dickinson Bayou as Represented In the HSPF TMDL Watershed Model and Monitoring Locations

Figure 8 shows the modeling domain for the EFDC receiving water model of Dickinson Bayou. The model domain includes the entire length of the Segment 1103 and from the confluence with Galveston Bay to the segment boundary, including most of Dickinson Bay, but the model domain only includes the lower AU of Segment 1104 from the tidal boundary to FM 517. The HSPF watershed model provides simulated headwater and tributary flow and pollutant loadings to the EFDC receiving water model at FM 517 as well as diffuse flow and nonpoint source loadings from each HSPF sub-basin as dynamic lateral inflows.

The linked watershed and receiving water models are capable of simulating flow and water quality conditions in Dickinson Bayou and its tributaries in response to rainfall runoff events in the watershed and to changes in steady-state pollutant loading (Figure 9). The linked models can also produce continuous time series of water quality simulated at various locations and depths, which can be used to derive detailed frequency distributions to assess compliance with DO criteria. The linked models can also produce continuous time series of loadings of various sources in the watershed used to determine TMDLs and load allocations. Both HSPF and EFDC are supported by EPA's Watershed and Water Quality Modeling Support Center.

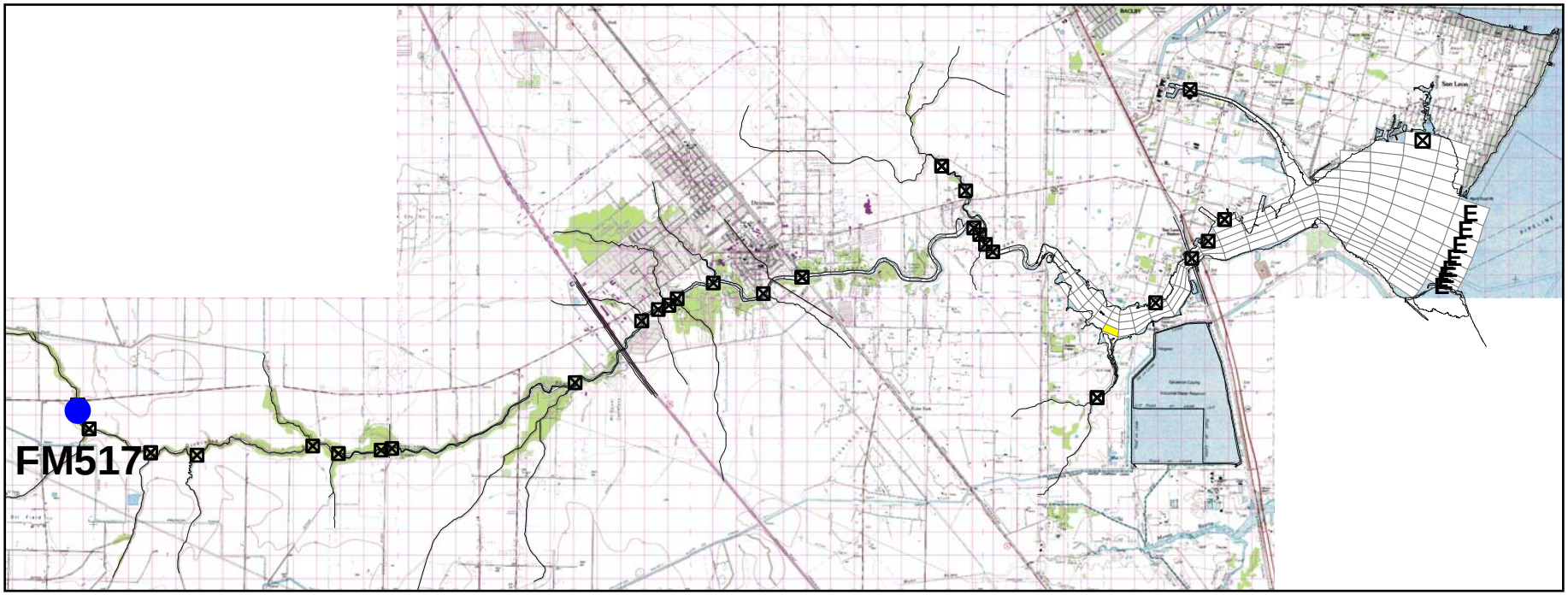



Figure 8. EFDC Computational Grid Showing the Spatial Modeling Domain of the Hydrodynamic and Water Quality Model of Dickinson Bayou

The points displayed indicate inflow boundary conditions. The open boundary condition on Galveston Bay is indicated with an "E."

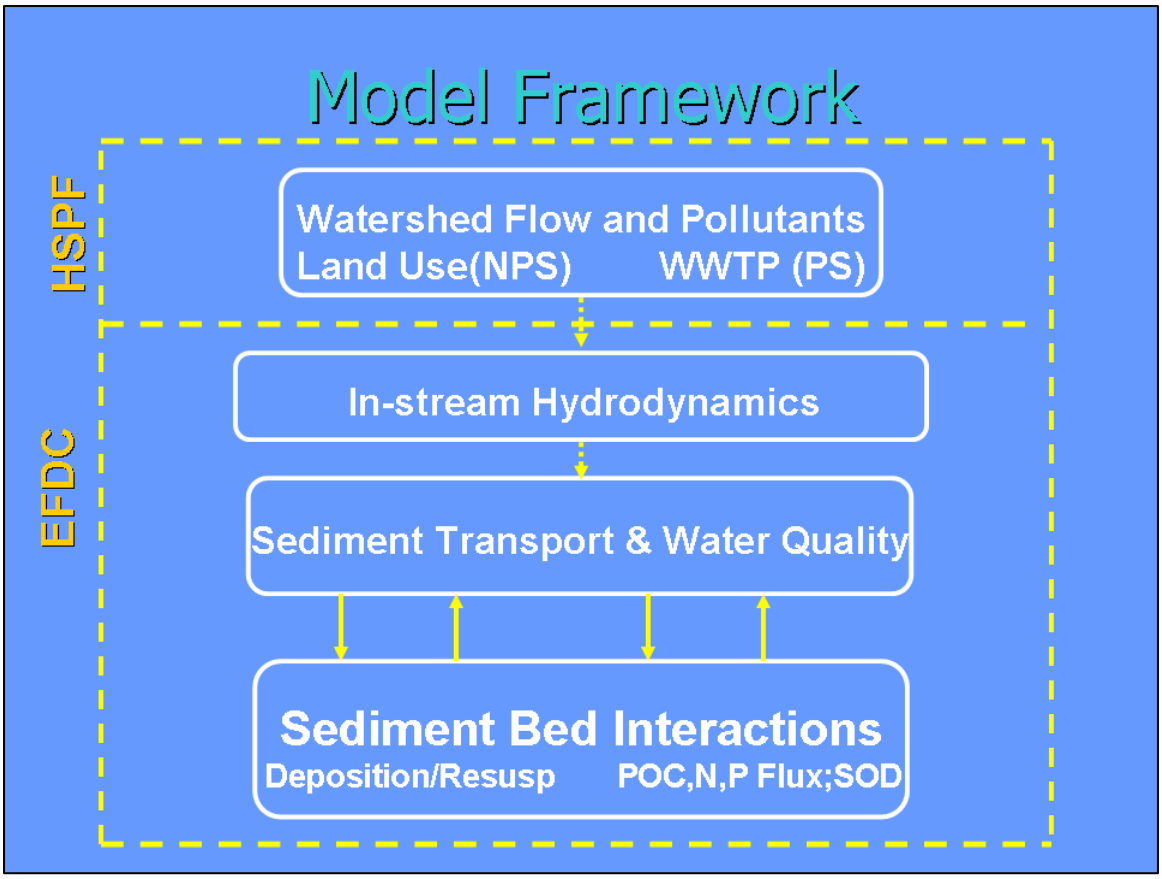



Figure 9. Schematic Showing Linked HSPF Watershed and EFDC Receiving Water Model

## Model Validation

The model validation step establishes model reliability, acceptability, and robustness for use in developing the TMDL allocation. There are two separate calibration and verification steps, which are collectively referred to as validation and which can be defined as follows:

- Calibration—the first stage testing and tuning of a model to a set of observational data, such that the tuning results in a consistent and rational set of theoretically defensible input parameters.
- Verification—Subsequent testing of a calibrated model to additional observational data to further examine model validity, preferably under different external conditions from those used during calibration (Thomann and Mueller 1987).

Using this process, calibration of the TMDL models was performed as a systematic procedure of selecting model input parameters that resulted in model predictions that best match the observed data. In addition, the adjustments of input parameters were restricted to be within literature-suggested ranges from such sources as TNRCC (1995) and HSPFPARM (2000). For any input parameters without direct measurement within the project area or found as literature values, professional judgment was utilized. Within the separate verification step, the input parameters defining such things as kinetic rates were kept at the values

used in the calibration step and separate sets of observational data were used for comparison purposes.

For the validation process, the simulation period of the models (July 1, 1999 through June 30, 2002) was divided into the following calibration and verification periods:

- Calibration (July 1, 2000- June 30, 2001)
- Verification #1 (July 1, 2001- June 30, 2002)
- Verification #2 (July 1, 1999- June 30, 2000)

The TCEQ validated the linked TMDL models separately and in combination. That is, the HSPF watershed model was validated based on observed water quality data collected in Dickinson Bayou and its tributaries and by comparing land-use-specific water quality output to edge-of-field pollutant concentrations from local and national NPS studies such as Winslow and Assoc., 1986, Chu 1995, USGS 1998, and NSQD 2006. The EFDC receiving water model was also validated using observed water quality data. In the final phase of validation, the linked model was adjusted according to the guidance provided through the validation process. Having adjusted rates, constants and other model parameters within theoretically defensible ranges in EFDC, the HSPF watershed loadings were adjusted in the final phase of validation to reduce the relative percentage error between simulated and observed water quality data in the EFDC model.

Observed data for validation of the HSPF and EFDC models were available from water quality monitoring conducted in Dickinson Bayou as part of the TCEQ's Surface Water Quality Monitoring (SWQM) Program and from the intensive data collection efforts (i.e., intensive surveys) conducted jointly by GCHD, USGS, and TCEQ in 2000 and 2001. SWQM data is typically collected near the surface (i.e., at a depth of 0.3m-1m) but includes 24-hour DO, temperature, specific conductance, and pH data. The intensive DO surveys and water quality sampling events were performed at a total of seven stream stations (6 in the tidal segment and 1 in the segment above tidal influence). These surveys occurred on a monthly basis for approximately 15 months and included a wide range of flow conditions from very high (i.e., tropical storm Allison, June, 2001), to near-steady state flow and low flow conditions and a wide range of ambient temperatures resulting from local seasonal variations. Each intensive survey included:

- 48-hour measurements of DO, temperature, specific conductance, and pH at two depths (near surface and near bottom) with instantaneous measurements of these parameters taken at 1-foot intervals over the entire water column (i.e., vertical profiles) once at the time of deployment of the buoy-mounted data sondes and again after retrieval of the data sondes,
- Ambient water quality grab samples collected at two depths at the same locations and dates of the surveys,
- Instantaneous flow measurements at FM 517 (above tidal influence) made at the time the DO surveys were conducted and continuous water surface elevation measurements at Hwy 3 for the duration of the 15 months of intensive survey events (July, 2000- September, 2001).

The HSPF and EFDC models of Dickinson Bayou were successfully validated to the intensive survey and SWQM data. Figure 10 shows an example of the simulated DO results from the linked HSPF and EFDC models for Dickinson Bayou and the monitoring data used for comparison at one of the intensive monitoring stations (DB-4, Dickinson Bayou at Hwy 3) for the entire validation time period. Additional plots of modeled concentrations vs. observed data for various water quality constituents can be found in Appendix B of this document.

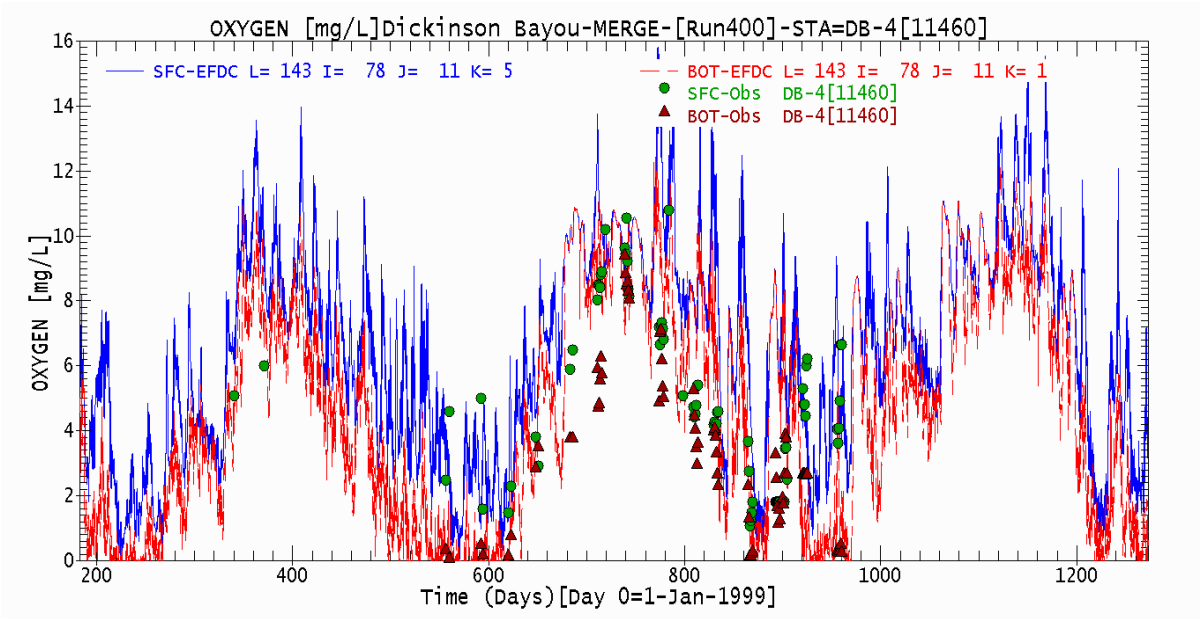



Figure 10. Simulated and Observed Dissolved Oxygen Concentrations at station DB-4 (Dickinson Bayou at Hwy 3). Surface DO simulation is represented in blue; bottom DO is in red.

## Biochemical Oxygen Demand Linkage Analysis

In order to determine the pollutants for which load reductions and allocations must be considered in Dickinson Bayou, the effects of the pollutants on DO concentrations in the bayou must be analyzed. Consistent with current water quality assessment methodology, the TCEQ evaluates compliance with DO criteria using simulated DO data such as is shown in Figure 10, but expressed as plots of frequency distributions. The simulated DO data are arranged in order of frequency of occurrence. Compliance with DO criteria (i.e., a 24-hour average DO concentration of 4.0 mg/L and a 24-hour minimum DO concentration of 3.0 mg/L) are achieved when the criteria are attained at least 90 percent of the time during the March-October warm weather Index Period.

In addition to plotting model output for data occurring only in the Index Period, the simulated data is also filtered to exclude values occurring below the mixed surface layer (see section "Dissolved Oxygen Criteria") and values occurring below the critical low flow, which the TCEQ has established to be 0.1 $ft^3$/sec (Smith 2008). Figure 11 shows the frequency distributions of simulated DO concentrations in the area of non-attainment of the

tidal segment (Zone 3) and the area of non-attainment of Dickinson Bayou Above Tidal (Zone 2) for the validation period (July 1, 1999-June 30, 2002).

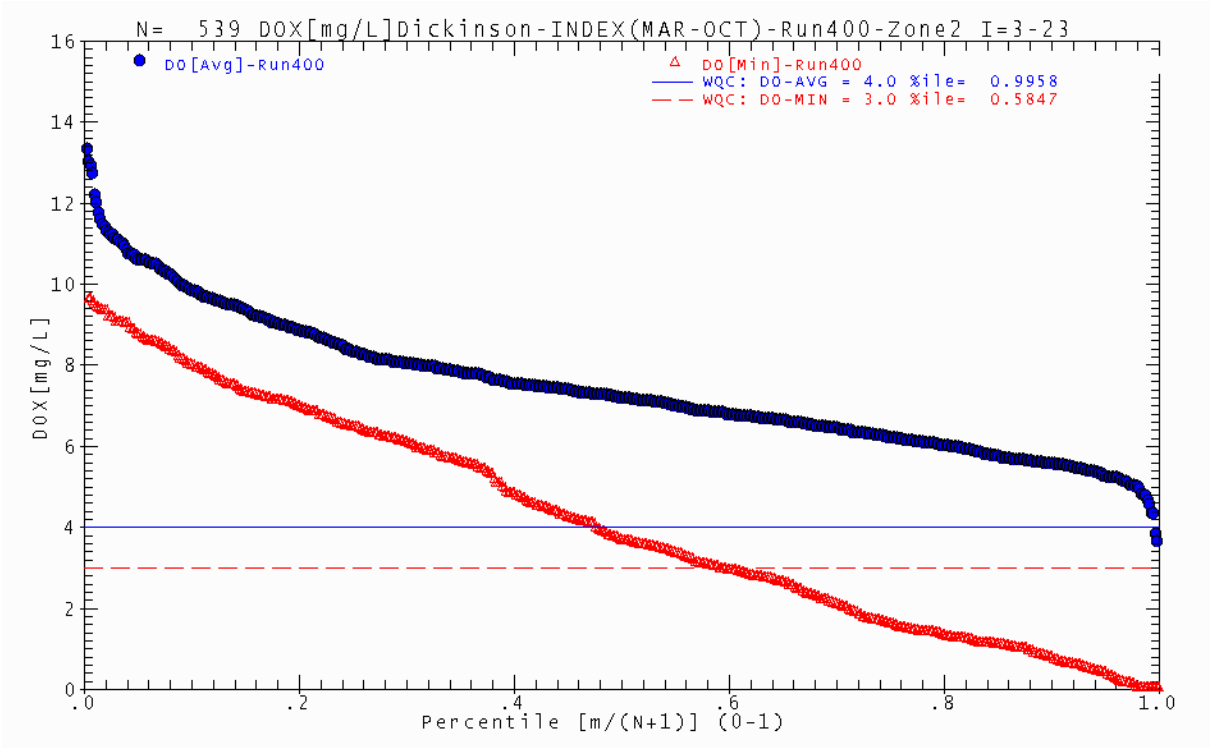
In order to determine the pollutants on which to base TMDL allocations, the TCEQ performed a sensitivity analysis of the linked TMDL model, simulating alternative reductions in the loading of the constituents of concern associated with DO dynamics in Dickinson Bayou from a base line, which was set at the constituent loadings associated with the model validation period (Table 4). The constituents of concern were CBOD, total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS). For both segments of Dickinson Bayou, the linked TMDL model was applied using the segmentation and kinetic rates developed during the model validation process. Applications of the model were made under the full range of temperature and flow conditions occurring during the validation period.

Table 4. Dissolved Oxygen Criteria Attainment Frequencies in Dickinson Bayou under Different Loading Scenarios

| Scenario | Index Period Criteria Attainment Percentile | | | |
|---|---|---|---|---|
| | Zone 2 (Non-tidal) | | Zone 3 (Tidal) | |
| | Avg. | Min. | Avg. | Min. |
| 1. Validation Run | 99.58 | 58.47 | 59.40 | 16.34 |
| 2. 95% Pollutant Reduction | 99.68 | 58.22 | 46.03 | 19.19 |
| 3. 95% Reduction in CBOD Only | 99.62 | 57.70 | 64.71 | 21.18 |
| 4. 95% Reduction in TN Only | 99.62 | 58.05 | 38.59 | 11.91 |
| 5. 95% Reduction in TP Only | 99.58 | 57.88 | 47.57 | 11.59 |
| 6. 95% Reduction in TSS Only | 99.57 | 57.50 | 58.97 | 21.29 |
| 7. 2008 Run (full permitted wastewater flow) | 92.40 | 25.97 | 53.95 | 15.07 |
| 8. 10% Increase in CBOD Only | 99.57 | 58.55 | 58.66 | 16.08 |
| 9. 10% Increase in TN and TP Only | 99.58 | 58.19 | 59.82 | 15.98 |
| 10. Natural Loading Run | 100.00 | 63.04 | 38.23 | 13.57 |
| 11. Altered Bathymetry Run | 99.57 | 58.37 | 65.04 | 28.48 |

Alternative 95 percent reductions of CBOD, TN, TP, and TSS yielded a higher attainment frequency in Segment 1103 only for the CBOD reduction scenario. All other load reduction scenarios yielded lower attainment frequencies for either the 24-average criterion or the 24-hour minimum criterion or both in Segment 1103. One explanation for this result is that DO dynamics in the upper reaches of the tidal segment relies heavily on primary production to balance DO demand and declines in nutrient levels cause a decline in photosynthetic oxygen production, while a reduction in CBOD at current nutrient levels reduces DO demand while keeping photosynthetic oxygen production unchanged.

a) Segment 1104




b) Segment 1103

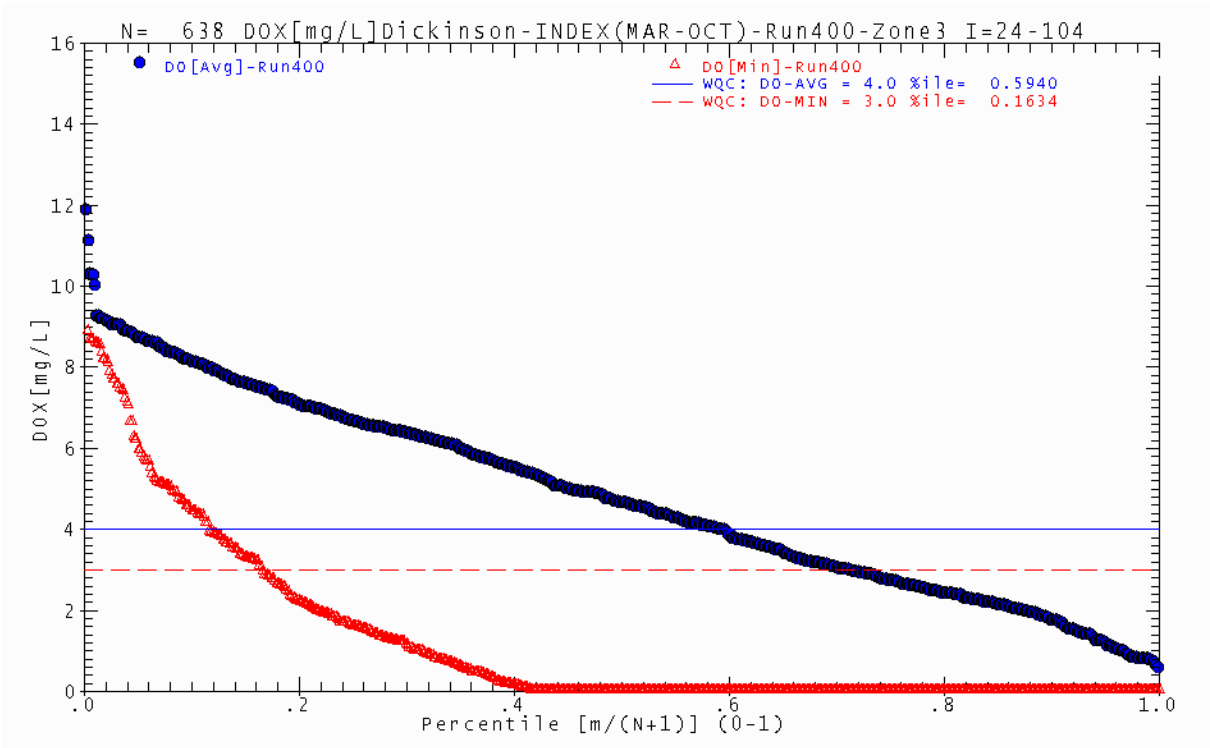



Figure 11. Frequency Distribution of Simulated Dissolved Oxygen Concentrations during the Validation Period (July 1, 1999 through June 30, 2002)

a) Zone 2 (Segment 1104 downstream of FM 517) b) Zone 3 (Segment 1103 upstream of Gum Bayou)
Frequency distributions include DO concentrations in all surface elements within each zone.

Alternative 95 percent reductions of CBOD, TN, TP, and TSS did not vary the attainment frequency significantly in Segment 1104. However, increases in CBOD beyond the levels used in the validation simulation result in a decrease in attainment frequency for both DO criteria, the 24-hour average and 24-hour minimum. Attainment frequency is not significantly affected by a commensurate increase in nutrient levels in Segment 1104 (Table 4). Given the results of the sensitivity analysis described above, the TCEQ selected CBOD as the constituent of concern associated with dissolved DO dynamics in Dickinson Bayou and on which to base load allocations for the TMDL.

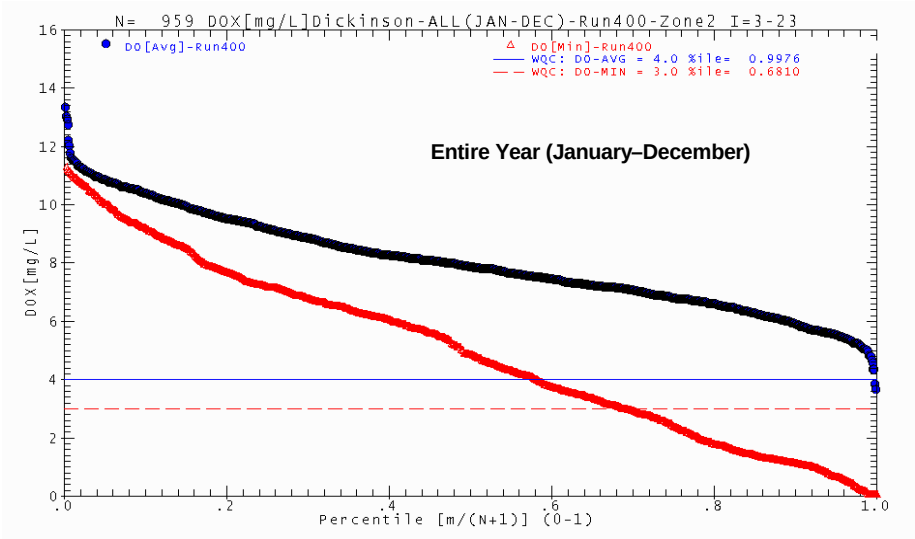
# Seasonal Variation

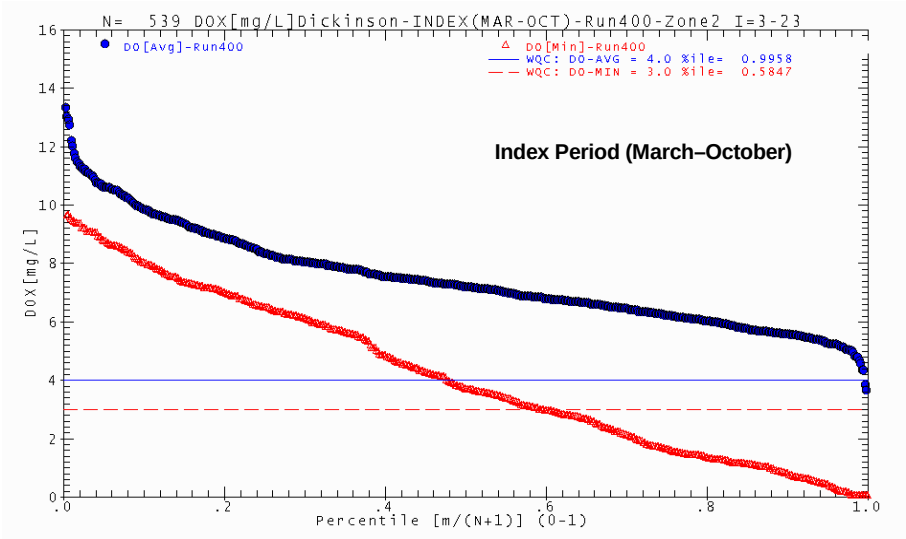
The Tidal Segment of Dickinson Bayou (Segment 1103) has a long history of depressed DO concentrations, and occasional associated fish kills dating back to the late 1960s. These depressed DO conditions typically occur during the spring and summer months (TWQB 1976). Beginning in the early-1970s, a number of improvements in treatment and relocation or discontinuation of wastewater discharges has substantially changed the volume and content of discharges into Segment 1103. However, depressed DO and occasional fish kills continued to occur in the spring and summer seasons. Historical TCEQ SWQM monitoring data shows very few instances of non-attainment of the DO criteria for sampling events conducted outside the warm weather Index Period (March-October). Typical seasonal DO patterns are also reflected in the simulated DO model output (Figure 10).

Further evidence of a warm weather bias in non-attainment periods in Dickinson Bayou is revealed when comparing the frequency distributions of simulated DO concentrations occurring in the *Index Period* with those occurring through out the entire year (Figure 12). These results are consistent with observed water quality and historical fish kill records and serve to further support the assumption that the warm weather Index Period is the time when attainment of DO criteria is most challenging and often not accomplished. This is consistent with similar patterns in DO dynamics observed in Tidal streams and bayous throughout Texas and in other areas of the Gulf coast (i.e., Louisiana, Mississippi, Alabama, etc.) regardless of the amount of human-related pollutant loadings.

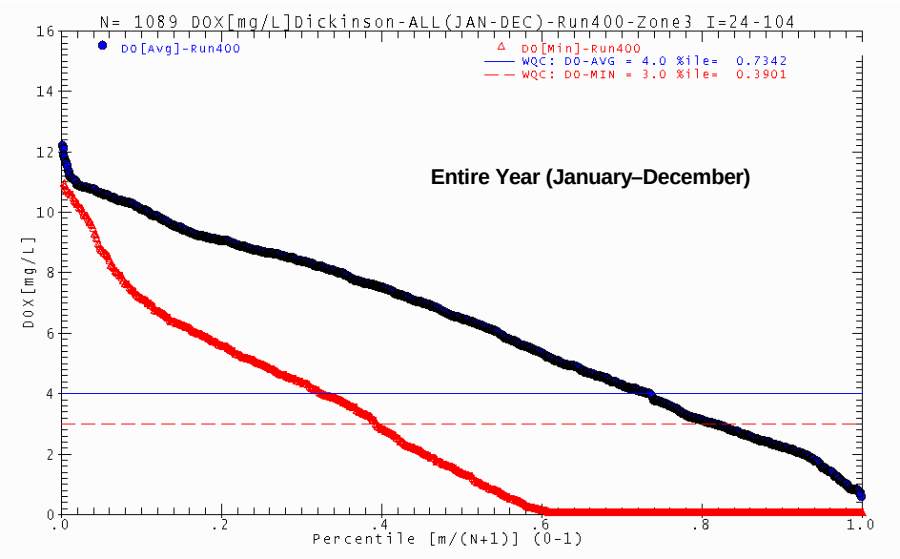
Based on analysis of observed data, simulated DO results and in accordance with current assessment methodology, the TMDL and all TMDL load allocations presented in this document are based on attainment of the DO criteria during the warm weather *Index Period* of March 15, through October 15. However, the influence on DO concentrations of detrital CBOD washed into Dickinson Bayou during episodes of high flow is substantial. Colloidal and particulate organic matter exported to Dickinson Bayou from its watershed, along with plant debris and sediment, is transformed into sediment oxygen demand (SOD) which exerts its influence most heavily on DO concentrations in Dickinson Bayou during the low-flow, high temperature conditions of the warm weather Index Period. This biochemical process is included in the Dickinson Bayou DO TMDL model.

**Zone 2: Segment 1104 from the Tidal Boundary to FM 517**




**Zone 3: Segment 1103 from Gum Bayou to the Tidal Boundary**



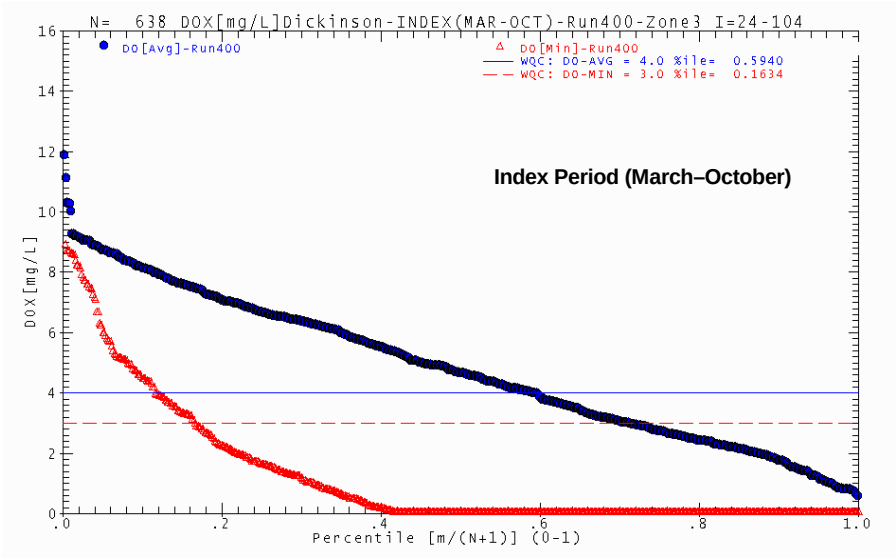




Figure 12. Frequency Distributions of Simulated DO Concentrations Occurring in the Index Period (March-October) vs. Entire Year (January-December)

# Margin of Safety

The margin of safety (MOS) should account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA 1991), the MOS can be incorporated into the TMDL using two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The margin of safety is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The TCEQ used an implicit MOS for this TMDL. First, the evaluation of the loading was performed under full permitted limits and evaluation of attainment during warm weather *Index Periods*, which are usually periods of low flow, which is an unlikely combination of circumstances. Second, the TCEQ used conservative assumptions when choosing many of the model input parameters. Lastly, the CBOD loading chosen to represent the TMDL yielded DO criteria attainment frequencies that did not differ significantly from those resulting from an optimum CBOD loading scenario (i.e., Scenario 1, validation run).

# Pollutant Load Allocation

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding the water quality standard. The load allocations for this TMDL are calculated using the following equation.

**Equation 1**

$$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS$$

where:

TMDL = total maximum daily load
WLA = waste load allocation (point source contributions)
LA = load allocation (nonpoint source contributions)
MOS = margin of safety (implicit)

Typically, there are several possible allocation strategies that would achieve the TMDL endpoint. Available control options depend on the number, location, and character of pollutant sources.

As of November 2002, the WLA component of TMDLs must include TPDES-regulated storm water sources (EPA 2002). WLAs must be expressed in numeric form, but TPDES-

regulated discharges that implement WLAs in TMDLs may be expressed in the form of best management practices. For this reason, the LA category in this TMDL is divided into a load allocation for non- regulated storm water and a $WLA_2$ for TPDES-regulated Urban Areas ($WLA_2$).

The TMDL equation is then expressed in the follow way.

**Equation 2**

$$TMDL = \Sigma\ WLA_1 + \Sigma\ NPS + MOS$$

where:

TMDL = total maximum daily load
$WLA_1$ = waste load allocation 1 (point source contributions)
NPS = LA + $WLA_2$
LA = load allocation (non-regulated nonpoint source contributions)
$WLA_2$ = waste load allocation 2 (TPDES-regulated nonpoint source contributions)
MOS = margin of safety (implicit)

As previously presented under the "Linkage Analysis" section of this document, the pollutant which most affects DO concentrations in Dickinson Bayou is CBOD. Sensitivity analyses show that reductions in the loading of CBOD have the highest effect on DO. Commensurate reductions in TN and TP could not be linked through the TMDL model to depressed concentrations of 24-hour average or minimum DO in Dickinson Bayou. In fact, the TMDL model shows reduction of these constituents has the effect of further depressing DO concentrations in the Bayou. Consequentially, these constituents are not allocated pollutants of this TMDL.

For the TMDL allocation process as defined in the equation above, $WLA_1$, $WLA_2$ and LA comprise the various sources of CBOD to Dickinson Bayou. $WLA_1$ is defined as consisting of contributions from wastewater treatment facilities (WWTFs). Individual $WLA_1$ for specific facilities are presented in Appendix A. $WLA_2$ is defined as consisting of pollutant contributions from TPDES-regulated UAs. LA is defined as the pollutant contributions from non-regulated areas of the watershed.

Regulated storm water discharges from UAs in the watershed will be included in the corresponding Phase II MS4 permits. This TMDL presumes that implementation of best management practices (BMPs) identified in each of these permits will result in achievement of the load allocation specified in the TMDL (i.e., $WLA_2$). Therefore, the $WLA_2$ described above is not separated into individual $WLA_2$s. Monitoring of these storm water discharges and evaluation of BMP effectiveness over time will determine if this presumption is correct or needs to be modified.

## Applications of Linked Watershed-Receiving Water Model

To determine maximum allowable loading of CBOD, the TCEQ first examined the TMDL model output for the validation period (Scenario 1, July 1, 1999, through June 30, 2002).

During this period, the first three AUs in Segment 1103 were not attaining the DO criteria (24-hour average and minimum). This (impaired) portion of Segment 1103 is referred to as Zone 3 in Figures 11 and 12. The attainment frequency of simulated 24-hour average DO concentrations in Zone 3 during this period was only 59.40 percent and the attainment frequency of simulated 24-hour minimum DO concentrations was only 16.34 percent; both well below the 90$^{th}$ percentile target (Table 4). The result of a simulation in which a 95 percent reduction in CBOD loading to the watershed is imposed (Scenario 3) shows a significant improvement in the frequency of attainment, but still falls short of the 90$^{th}$ percentile target (Table 4).

In Segment 1104, during the validation period, all AUs were attaining the DO criteria (24-hour average and minimum) as assessed by the TCEQ in 2004. However, in 2006, the first assessment unit (AU1104_01) of Segment 1104 was listed as impaired for low DO. This (impaired) portion of Segment 1104 is referred to as Zone 2 in Figures 11 and 12. The frequency distribution of simulated 24-hour average and 24-hour minimum DO concentrations in Zone 2 during the validation period shows that the 24-hour average DO criteria is met well over 90 percent of the time (99.58th percentile), but the 24-hour minimum DO criteria is met only 58.47 percent of the time (Figure 11). The result of a simulation in which a 95 percent reduction in CBOD loading to the watershed is simulated (Scenario 3) does not show a significant difference in the frequency of attainment (Table 4). Simulation results with a 10 percent increase in CBOD loading to the watershed (Scenario 8) also shows little difference in attainment frequency for both, the simulated 24-hour average and 24-hour minimum DO concentrations (Table 4).

Next the TCEQ examined TMDL model output for the different modeling scenarios, including a simulation with 2008-adjusted land use and full permitted flow (Scenario 7, 2008 Run), simulated natural loadings (Scenario 10, Natural Load Run) and a simulation with the depth of the bayou altered (Scenario 11) to eliminate deeper areas in the middle of the tidal segment (Table 4).

The attainment frequency of simulated 24-hour average DO concentrations for Scenario 7, the 2008 simulation (i.e., full permitted flow), was reduced in Segment 1104 from 99.58 percent in the validation simulation to 92.40 percent and the attainment frequency of simulated 24-hour minimum DO concentrations also decreased markedly from 58.47 percent to only 25.97 percent in Segment 1104. This is significant since a 10 percent increase in CBOD (Scenario 8) does not seem to affect the attainment frequency. The simulation using estimated natural loadings (Scenario 10) showed a mild increase in the attainment frequencies in Segment 1104 and, as expected, the simulation using validation simulation loadings with an altered bathymetry (Scenario 11) had no appreciable effect on attainment frequencies in Segment 1104.

The DO criteria attainment frequencies in Segment 1103 for the 2008 simulation (Scenario 7, full permitted flow) show a decrease in attainment of the 24-hour average DO criteria from 59.40 percent in the validation simulation (Scenario 1) to 53.95 percent and from 16.34 percent to 15.07 percent for the simulated 24-hour minimum DO criteria; noticeably lower than the simulation using a 10 percent increase in CBOD (Scenario 8). The simula-

tion using estimated natural loadings (Scenario 10) showed a drastic decrease in DO criteria attainment frequency in Segment1103, reflecting a reduction in photosynthetic oxygen production as a direct result of the reductions in nutrients. A TMDL model simulation using altered bathymetry and the loadings used during the validation period (scenario 11) showed the largest increase in DO criteria attainment frequencies in Segment 1103 of all other simulated loading scenarios.

The following conclusions can be drawn from analysis of the results of the TMDL model simulations shown in Table 4.

## Segment 1103

- Following the current assessment methodology, the first three AUs in Dickinson Bayou Above Tidal (Segment 1103) appear to be unable to attain the DO criteria (24-hour average and minimum) under any of the loading scenarios simulated, including a 95 percent reduction in pollutants of concern and under estimated natural loading conditions.
- Attainment frequencies in Segment 1103 are noticeably lower in a simulation conducted with 2008-adjusted land use and full permitted wastewater flow than in a simulation of the validation period. Total CBOD loads in the 2008 simulation are approximately 18 percent higher than CBOD loads in the validation simulation.
- The biggest improvement in attainment frequencies in Segment 1103 results from a simulation in which the bathymetry of the bayou is altered; the second biggest improvement in attainment frequencies comes from a simulation in which total CBOD loading was reduced by 95 percent.
- Neither an adjustment in the bayou's bathymetry nor a 95 percent reduction in CBOD loading is feasible. The simulation using natural watershed loadings results in a decrease in attainment frequencies and a 10 percent increase in CBOD does not significantly affect attainment frequencies in Segment 1103. Therefore, the CBOD loading that represents the Total Maximum Load for Dickinson Bayou is Scenario 8 (i.e., the simulated 10 percent increase in CBOD loading from that of the validation period).
- CBOD loading higher than that used in Scenario 8 (but lower than Scenario 7, which represents an 18 percent increase in CBOD loading) may result in DO criteria attainment frequencies that are not significantly different from the base validation run. However, for added margin of safety, the TCEQ has chosen the CBOD load used in Scenario 8 as the total maximum load of CBOD to Segment 1103.

## Segment 1104

- Although easily attaining the 24-hour average DO criteria, using the current assessment methodology, the downstream AU of Segment 1104 does not appear to be capable of attaining the 24-hour minimum criteria under any of the loading scenarios simulated, including a 95 percent reduction in pollutants of concern (Scenarios 2-6) and under estimated natural loading conditions (Scenario 10).

- A simulation conducted with 2008-adjusted land use and full permitted wastewater ( an 18 percent increase in the CBOD loads used in the validation simulation) results in marked decrease in the attainment frequencies for both DO criteria (24-hour average and minimum) most significantly in attainment of the 24-hour minimum criteria.
- The loading scenarios shown in Table 4 do not significantly affect the attainment frequency in the downstream AU of Segment 1104 (AU 1104_01), including Scenario 8, a simulation in which CBOD loadings are increased by 10 percent from those used in the validation simulation. The only exceptions are the simulation scenarios conducted using the 2008-adjusted land use with full permitted wastewater flow (Scenarios 7) and estimated natural watershed loadings (Scenario 10).
- The simulation using a 10 percent increase in CBOD loading (Scenario 8) does not significantly affect attainment frequencies in Segment 1104 and the simulation conducted with 2008-adjusted land use and full permitted wastewater ( Scenario 7, an 18 percent increase in the CBOD loads used in the validation simulation) results in marked decrease in attainment frequencies. Therefore, the CBOD loading that represents the Total Maximum Load for Dickinson Bayou is Scenario 8.
- CBOD loading higher than that used in Scenario 8 (but lower than Scenario 7) may result in DO criteria attainment frequencies that are not significantly different from the base validation run. However, for added margin of safety, the TCEQ has chosen the CBOD load used in Scenario 8 as the total maximum load of CBOD to Segment 1104.

## Defining WLA and LA Inputs

Domestic wastewater treatment facilities (WWTFs) were represented in the input data to the Dickinson Bayou DO TMDL model in different ways depending on the simulation scenarios conducted. Wastewater discharges in the validation simulation were derived from self-reported effluent flow and concentrations obtained from EPA's Permit Compliance System (PCS) database (EPA 2005). Self-reported $CBOD_5$ values were converted to ultimate CBOD or $CBOD_u$ using the TCEQ's default multiplier of 2.3 as needed for input to the TMDL model. When available, effluent concentrations of ammonia nitrogen (NH3-N) were obtained directly from PCS self-reported data. When not available, NH3-N effluent concentrations were derived using a chemical ratio applied to the CBOD effluent concentrations obtained from PCS (1:4 NH3N:CBOD). Effluent nitrate and nitrite (NO2+NO3), total organic nitrogen (TON), dissolved phosphorus (DP) and total organic phosphorus (TOP) concentrations were also derived using chemical ratios, also known as stoichiometric ratios, applied to the CBOD concentrations obtained from the EPA's PCS database (0.025:0.275:0.20:0.021:1 NO2+NO3:TON:DP:TOP:CBOD).

All other simulation scenarios presented in Table 4 were conducted using pollutant loadings derived by applying a factor (0.05 and 1.10) to time series of pollutant loadings used in the validation simulation, including loadings from WWTFs, except for the 2008 simulation and the natural loading simulation. Wastewater discharges in Scenario 7 (the 2008 simulation)

were represented at full permitted flow and effluent concentrations; wastewater discharges were removed completely in the natural loading simulation (Scenario 10).

The data input into the TMDL model to define LA contributions was supplied by the HSPF watershed simulation component of the TMDL model. The HSPF watershed model estimated nonpoint source loadings from the specific land use, land cover, soils and rainfall occurring in the watershed during the validation period. For the 2008 simulation (Scenario 7), watershed land use and land cover were updated to reflect changes that have occurred in the watershed since 2002. For the natural loading simulation (Scenario 10), all land use in the watershed was converted to natural land uses (i.e., natural herbaceous, natural woody, wetlands, and open water) and all point sources of pollutants were removed from the model.

To determine pollutant loadings associated with Phase II UAs, the TCEQ computed the ratio of the area of the watershed falling under designated UAs to the total area in the watershed and applied the ratio to the total nonpoint source CBOD loading produced in the watershed (Figure 13).

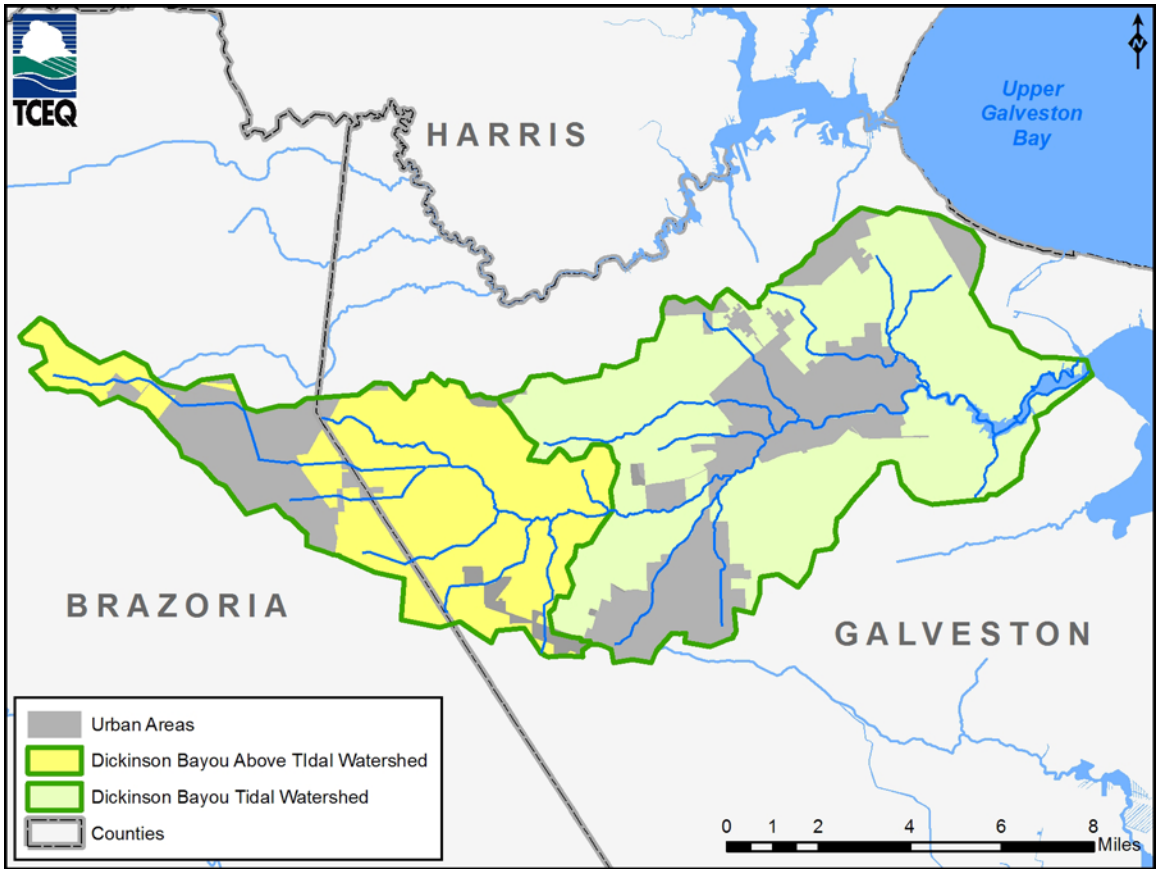



Figure 13. Storm Water Phase II MS4 Urbanized Areas in the Dickinson Bayou Watershed

## Load Reduction and $WLA_1$ for Segment 1103

The initial applications of the Dickinson Bayou TMDL model to both Segments of Dickinson Bayou were performed for various hypothetical loading scenarios (Table 4). The second set of model applications were performed to estimate DO criteria attainment frequencies for (1) 2008-adjusted land use conditions and with existing permit limits for WWTFs (Scenario 7), (2) determine the effects on DO dynamics under a natural loading scenario (Scenario 10), and (3) determine the effects on DO dynamics under an altered bathymetry scenario (Scenario 11).

As described previously in the section "Applications of Linked Watershed-Receiving Water Model," the CBOD loading associated with simulation Scenario 8 (10 percent increase in CBOD from validation period) is considered the maximum allowable CBOD load, because this scenario does not significantly affect DO criteria attainment frequencies in the non-attainment zone of Segment 1103 (Zone 3) in comparison to an optimum CBOD loading baseline (i.e., Scenario 1, the validation simulation).

Because of its location directly downstream of Segment 1104 and because tidal action forces pollutants to travel upstream during the high tide, the non-attainment zone in Segment 1103 (Zone 3) receives CBOD contributions from the entire Dickinson Bayou Watershed. Table 5 shows the existing and permitted $CBOD_u$ loading (Scenario 7; 2008 Run) and allowable $CBOD_u$ loading (Scenario 8; 10 percent increase in CBOD from validation period) in kilograms per year by source category in Segment 1103. The NPS source category in Table 5 is equivalent to the NPS described in the second TMDL equation (2) presented at the beginning of the "Pollutant Load Allocation" section of this document (i.e., $NPS = LA + WLA_2$).

Table 5. Existing and Permitted $CBOD_u$ Annual Loading, Allowable $CBOD_u$ Annual Loading and Percent Reductions of $CBOD_u$ Needed for Segment 1103 (Dickinson Bayou Tidal)

| Source Category | Existing and Permitted Loading of $CBOD_u$ (kg/yr) | Allowable Loading of $CBOD_u$ (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| Waste Load Allocation 1 ($WLA_1$) [a] | 154,420 | 139,704 | 10 |
| NPS [b] | 508,477 | 460,022 | 10 |
| **Total Loading** | 662,897 | 599,726 | 10 |

[a] $WLA_1$ for existing and permitted loading includes loads estimated at full permitted flow and effluent concentration limits for all permitted wastewater treatment facilities in the watershed; it excludes permits currently pending approval

[b] NPS includes all nonpoint sources including contributions from Phase II UAs (i.e., NPS=LA+WLA2)

The allowable loading of $CBOD_u$ for the $WLA_1$ and NPS source categories presented in Table 5 is based on the total annual $CBOD_u$ loading reduction necessary to achieve the DO criteria attainment frequencies produced by simulation Scenario 8 (10 percent increase in

CBOD from validation period). The distribution of the necessary load reduction between $WLA_1$ and NPS was accomplished by applying the total percent loading reduction needed proportionally between $WLA_1$ and NPS.

## Load Reduction and $WLA_1$ for Segment 1104

As described previously in the section "Applications of Linked Watershed-Receiving Water Model," the CBOD loading associated with simulation Scenario 8 (10 percent increase in CBOD from validation period) is considered the maximum allowable CBOD loading into the zone of non-attainment in Segment 1104 (Zone 2) because the attainment frequency of the 24-hour average DO criteria is greater than 90 percent and the frequency of attainment of the 24-hour minimum criteria (58.5 percent) is not significantly affected compared to the other loading scenarios, with the exception of Scenario 10 (i.e., natural loading scenario). CBOD loadings associated with simulation Scenario 7 (2008-adjusted land use and full permitted flow) are higher and yield significantly lower attainment frequencies in Zone 2 (Table 4).

Table 6 shows the existing and permitted $CBOD_u$ loading (Scenario 7; 2008-adjusted land use and full permitted flow) and allowable $CBOD_u$ loading (Scenario 8; 10 percent increase in CBOD from validation period) in kilograms per year by source category in Segment 1104. It should be noted that Table 6 includes only the point and nonpoint sources contributing CBOD to the portion of the zone of non-attainment located in Segment 1104 (Zone 2).

Table 6. Existing and Permitted $CBOD_u$ Annual Loading, Allowable $CBOD_u$ Annual Loading and Percent Reductions of $CBOD_u$ Needed in Segment 1104 (Dickinson Bayou Above Tidal)

| Source Category | Existing and Permitted Loading of $CBOD_u$ (kg/yr) | Allowable Loading of $CBOD_u$ (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| Waste Load Allocation 1 ($WLA_1$) [a] | 36,579 | 32,711 | 10.6 |
| NPS [b] | 134,967 | 120,696 | 10.6 |
| **Total Loading** | 171,545 | 153,407 | 10.6 |

[a] $WLA_1$ for existing and permitted loading includes loads estimated at full permitted flow and effluent concentration limits for all permitted wastewater treatment facilities in the watershed; it excludes permits currently pending approval

[b] NPS includes all nonpoint sources including contributions from Phase II UAs (i.e., NPS=LA+ $WLA_2$)

As with Segment 1103, the allowable loading of $CBOD_u$ for the $WLA_1$ and NPS source categories presented in Table 6 is based on the total annual $CBOD_u$ loading reduction necessary to achieve the DO criteria attainment frequencies in Zone 2 produced by simulation Scenario 8 (10 percent increase in CBOD from validation period). The distribution of the load reduction between $WLA_1$ and NPS was accomplished by applying the total percent loading reduction needed proportionally between $WLA_1$ and NPS.

## LA and $WLA_2$ for Segment 1103

The NPS source category shown in Table 5 represents the total CBOD loading from all nonpoint sources in the Dickinson Bayou watershed. This NPS category is composed of the two distinct nonpoint source subcategories:

1) $WLA_2$, defined as the TPDES-regulated nonpoint source contribution of CBOD, and
2) LA, defined as the non-regulated nonpoint source contribution of CBOD.

TPDES-regulated UAs comprise approximately 27.7 percent of the portion of the Dickinson Bayou watershed contributing to the zone of impairment. In order to separate TPDES-regulated nonpoint sources from non-regulated nonpoint sources of CBOD to Segment 1103, the TCEQ determined the proportion of the Dickinson Bayou watershed designated as TPDES-regulated UAs (Figure 13) and applied this proportion (i.e., ratio of UA area to total watershed area) to the total NPS CBOD loading presented in Table 5.

Table 7 shows existing and allowable NPS $CBOD_u$ loading for Segment 1103 separated into $WLA_2$ and LA source categories. It should be noted that although defined as CBOD loading contributions from TPDES-regulated UAs, $WLA_2$ includes contributions from various land use categories. This is because TPDES-regulated UAs are based on population density and not on actual land use category.

Table 7. Existing and Allowable NPS $CBOD_u$ Annual Loading for Segment 1103 Separated by $WLA_2$ and LA Source Categories

| Source Category | Existing and Permitted Loading of $CBOD_u$ (kg/yr) | Allowable Loading of $CBOD_u$ (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| Waste Load Allocation 2 ($WLA_2$) [a] | 140,848 | 127,426 | 10 |
| Load Allocation (LA)[b] | 367,629 | 332,596 | 10 |
| **Total NPS Loading** | 508,477 | 460,022 | 10 |

[a] $WLA_2$ is the portion of total NPS loading contributed by TPDES-regulated UAs

[b] LA is the portion of total NPS loading contributed by non-regulated nonpoint sources

## LA and $WLA_2$ for Segment 1104

TPDES-regulated UAs comprise approximately 25.9 percent of the portion of the Dickinson Bayou watershed contributing flow and CBOD loading to Segment 1104. Table 8 shows existing and allowable NPS $CBOD_u$ loading for Segment 1104 separated into $WLA_2$ and LA source categories.

Table 8. Existing and Allowable NPS $CBOD_u$ Annual Loading for Segment 1104 Separated by $WLA_2$ and LA Source Categories

| Source Category | Existing and Permitted Loading of $CBOD_u$ (kg/yr) | Allowable Loading of $CBOD_u$ (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| Waste Load Allocation 2 ($WLA_2$) [a] | 34,956 | 31,260 | 10.6 |
| Load Allocation (LA)[b] | 100,011 | 89,436 | 10.6 |
| **Total NPS Loading** | 134,967 | 120,696 | 10.6 |

[a] $WLA_2$ is the portion of total NPS loading contributed by TPDES-regulated UAs

[b] LA is the portion of total NPS loading contributed by non-regulated nonpoint sources

## TMDL Allocation Summary for Segments 1103 and 1104

Tables 9 and 10 show a summary of existing and permitted $CBOD_u$ annual loading, allowable $CBOD_u$ annual loading and percent reductions in $CBOD_u$ needed in Segments 1103 and 1104 separated into $WLA_1$, $WLA_2$ and LA source categories.

Segment 1104 and its sub-watershed are located upstream of Segment 1103 (Dickinson Bayou Tidal) and contribute pollutant loadings into the portion of the zone of non-attainment located downstream in Segment 1103 (Zone 3). The percent reductions in CBOD loading estimated for Segment 1104 and described in previous sections of this TMDL document were based on achievement of DO criteria attainment frequency goals in Segment 1104 (Zone 2). These loading reductions (10.6 percent) are slightly higher than those required to achieve the DO criteria attainment frequencies goals set for Segment 1103 (Zone 3), which requires a 10 percent reduction in the loading of CBOD.

## Conversion of Total Maximum Annual Loadings to Total Maximum Daily Loadings

In accordance with current EPA guidance (EPA 2007), the total allowable annual loading of $CBOD_u$ described in Tables 9 and 10 must be expressed as total maximum daily loads. To determine total maximum daily loads for the $WLA_1$ source category, the TCEQ divided the total maximum annual $WLA_1$ loadings presented in Tables 9 and 10 by the average number of days in a year (i.e., 365.25 days). This method of converting long-term average point source loads into daily loads is justified because wastewater effluent flow is considered to be steady state or near steady state. For the LA and $WLA_2$ source categories, the TCEQ used the combined daily NPS CBOD loading dataset generated from the output of the HSPF watershed model to determine maximum daily loads for each of the two NPS source category in both segments of Dickinson Bayou.

To determine the total maximum daily LA and $WLA_2$ loads for Dickinson Bayou, the TCEQ identified the $99^{th}$ percentile of the daily NPS $CBOD_u$ loading time series generated as output from the HSPF watershed model and applied the same ratio used to separate the

maximum annual NPS loads into annual LA and $WLA_2$ loads (i.e., 27.7 percent for Segment 1103, and 25.9 percent for Segment 1104). This is justified because of the nonsteady-state nature of NPS pollutant loading. Tables 11 and 12 show the maximum allowable $CBOD_u$ annual loading and corresponding maximum allowable $CBOD_u$ daily loading for each source category in Segments 1103 and 1104 respectively.

Table 9. Existing and Permitted $CBOD_u$ Annual Loading, Allowable $CBOD_u$ Annual Loading and Percent Reductions in $CBOD_u$ Needed in Segment 1103 (Dickinson Bayou Tidal)

| Source Category | Existing and Permitted Loading of $CBOD_u$ (kg/yr) | Allowable Loading of $CBOD_u$ (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| Waste Load Allocation 1 ($WLA_1$) [a] | 154,420 | 139,704 | 10 |
| Waste Load Allocation 2 ($WLA_2$) [b] | 140,848 | 127,426 | 10 |
| Load Allocation (LA)[c] | 367,629 | 332,596 | 10 |
| **Total Loading** | 662,897 | 599,726 | 10 |

[a] $WLA_1$ for existing and permitted loading includes loads estimated at full permitted flow and effluent concentration limits for all permitted wastewater treatment facilities in the watershed; it excludes permits currently pending approval

[b] $WLA_2$ is the portion of total NPS loading contributed by TPDES-regulated Urban Areas (UAs)

[c] LA is the portion of total NPS loading contributed by non-regulated nonpoint sources

Table 10. Existing and Permitted $CBOD_u$ Annual Loading, Allowable $CBOD_u$ Annual Loading and Percent Reductions in $CBOD_u$ Needed in Segment 1104 (Dickinson Bayou Above Tidal)

| Source Category | Existing and Permitted Loading of $CBOD_u$ (kg/yr) | Allowable Loading of $CBOD_u$ (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| Waste Load Allocation 1 ($WLA_1$) [a] | 36,579 | 32,711 | 10.6 |
| Waste Load Allocation 2 ($WLA_2$) [b] | 34,956 | 31,260 | 10.6 |
| Load Allocation (LA)[c] | 100,011 | 89,436 | 10.6 |
| **Total Loading** | 171,545 | 153,407 | 10.6 |

[a] $WLA_1$ for existing and permitted loading includes loads estimated at full permitted flow and effluent concentration limits for wastewater treatment facilities in the watershed; it excludes permits currently pending approval

[b] $WLA_2$ is the portion of total NPS loading contributed by TPDES-regulated Urban Areas (UAs)

[c] LA is the portion of total NPS loading contributed by non-regulated nonpoint sources

Table 11. Maximum Allowable Annual Loading of $CBOD_u$ and Corresponding Allowable Daily $CBOD_u$ Loading for Each Source Category Contributing to Segment 1103

| Source Category | Allowable Annual Loading of $CBOD_u$ (kg/yr) | Allowable Daily Loading of $CBOD_u$ (kg/day) |
|---|---|---|
| Waste Load Allocation 1 ($WLA_1$) [a] | 139,704 | 382 |
| Waste Load Allocation 2 ($WLA_2$) [b] | 127,426 | 3,319 |
| Load Allocation (LA)[c] | 332,596 | 8,663 |
| **Total Loading** | 599,726 | 12,364 |

[a] $WLA_1$ is the loading allocation for all permitted facilities in the watershed

[b] $WLA_2$ is the portion of total NPS loading contributed by TPDES-regulated Urban Areas (UAs)

[c] Load Allocation (LA) is the portion of total NPS loading contributed by non-regulated nonpoint sources

Table 12. Maximum Allowable Annual Loading of $CBOD_u$ and Corresponding Allowable Daily $CBOD_u$ Loading for Each Source Category Contributing to Segment 1104

| Source Category | Allowable Annual Loading of $CBOD_u$ (kg/yr) | Allowable Daily Loading of $CBOD_u$ (kg/day) |
|---|---|---|
| Waste Load Allocation 1 ($WLA_1$) [a] | 32,711 | 89.56 |
| Waste Load Allocation 2 ($WLA_2$) [b] | 31,260 | 1,126 |
| Load Allocation (LA)[c] | 89,436 | 3,221 |
| **Total Loading** | 153,407 | 4,437 |

[a] $WLA_1$ is the loading allocation for all permitted facilities in the watershed

[b] $WLA_2$ is the portion of total NPS loading contributed by TPDES-regulated Urban Areas (UAs)

[c] Load Allocation (LA) is the portion of total NPS loading contributed by non-regulated nonpoint sources

## Allowance for Future Growth

The TMDL allocations for Dickinson Bayou presented in this TMDL document do not preclude nor prevent consideration of expansions to WWTFs and addition of new WWTFs. The TCEQ will evaluate expansions and additional facilities on a permit-by-permit basis. This evaluation will be conducted using the HSPF/EFDC model used to determine the TMDL or an updated replacement model. Additional allowable loadings, if any, under new permits and amendments for permit expansions will be determined subject to the outcome of the modeling and predicted DO concentrations using information specific to each WWTF as well as the analysis that supports this TMDL or an updated TMDL analysis.

# Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

An official TMDL steering committee of stakeholders was established for the Dickinson Bayou DO TMDL project in 2004. Two TMDL steering committee meetings were held, one in August 2004 and another in February 2005. A project Web page was established to provide project information, meeting summaries, committee ground rules, and a list of steering committee members to the general public. The project Web page can be accessed at <ww.tceq.state.tx.us/implementation/water/tmdl/17-dickinson.html>.

In April, 2005, the TCEQ partnered with the Texas AgriLife Extension Service (formerly Texas Cooperative Extension) to develop a watershed protection plan (WPP) for Dickinson Bayou. This effort has been conducted concurrently with the development of the TMDL for DO and also with a separate TMDL effort currently underway to address bacteria pollution in the Dickinson Bayou.

As part of the WPP effort, the Texas AgriLife Extension Service formed the Dickinson Bayou Watershed Partnership. The Partnership represents a broad array of interests in the watershed, such as local industries, representatives of wastewater treatment facilities, landowners, environmental groups, and local, state, and regional government groups. In 2006, the Dickinson Bayou Watershed Partnership established a Partnership Steering Committee to guide WPP decision-making. To avoid duplication of effort, in 2006 the TCEQ combined the TMDL and WPP public participation efforts by merging the TMDL and Watershed Partnership steering committees, using the Partnership as the main stakeholder group for the TMDL.

The Dickinson Bayou Watershed Partnership Advisory Committee holds meetings on a quarterly basis and the Partnership at large meets at least twice a year. The Watershed Steering Committee has had very little turnover during the life of the project. The committee members' knowledge of the watershed, consistency in attending meetings and willingness to provide input have been—and will continue to be—a valuable resource for improving water quality in Dickinson Bayou. The TCEQ has provided numerous presentations on the progress of the DO TMDL at Partnership and Steering Committee meetings. The advice and comments received at these meetings have been very useful in refining the DO TMDL investigation.

Information on the Dickinson Bayou Watershed Partnership can be found on the Web at <www.dickinsonbayou.org/index.htm>.

# Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

1) **a TMDL**, which determines the maximum amount of pollutant a water body can receive in a single day and still meet applicable water quality standards, and
2) **an Implementation Plan (I-Plan)**, which is a detailed description and schedule of the regulatory and voluntary management measures necessary to achieve the pollutant reductions identified in the TMDL.

The TCEQ is committed to developing I-Plans for all TMDLs adopted by the commission and to ensuring the plans are implemented. I-Plans are critical to ensure water quality standards are restored and maintained. They are not subject to EPA approval.

The TCEQ works with stakeholders to develop the strategies summarized in the I-Plan. I-Plans may use an adaptive management approach that achieves initial loading allocations from a subset of the source categories. Adaptive management allows for development or refinement of methods to achieve the environmental goal of the plan.

Periodic and repeated evaluations of the effectiveness of implementation methods assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. This adaptive approach provides reasonable assurance that the necessary regulatory and voluntary activities to achieve the pollutant reductions will be implemented.

## Implementation Processes to Address the TMDL

Together, the TMDL and I-Plan direct the correction of unacceptable water quality conditions that exist in surface waters that do not attain water quality standards. A TMDL identifies a total loading from the combination of point sources and nonpoint sources that allows attainment of the water quality standard.

Specific components of the WPP will be used as the basis for development of the I-Plan. The I-Plan specifically identifies required or voluntary implementation actions that will be taken to achieve the pollutant loading goals of the TMDL. Regulatory actions identified in the I-Plan could include:

- adjustment of an effluent limitation in a wastewater permit,
- a schedule for the elimination of a certain pollutant source,
- identification of any nonpoint source discharge that would be regulated as a point source,
- a limitation or prohibition for authorizing a point source under a general permit, or
- a required modification to a storm water management program (SWMP) and pollution prevention plan (PPP).

Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a

response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to the non-attainment of water quality standards.

The individual $WLA_1$ values presented in Appendix A show what can be anticipated at this time. The TCEQ intends to implement these individual WLAs through the permitting process as modifications to current effluent limitations or as the basis for establishing effluent limitations for new facilities. However, there may be a more economical or technically feasible means of achieving the goal of improved water quality and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, these individual WLAs are non-binding until implemented via a separate TPDES permitting action, which will involve preparation of a "Water Quality Management Plan Update." Regardless, all permitting actions will demonstrate compliance with the TMDL.

The commission understands that this TMDL is, by definition, the total of the sum of the waste load allocation, the sum of the load allocation, and the margin of safety. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the actual TMDL; instead, changes will be made through updates to the TCEQ's Water Quality Management Plan. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

## Assessment of Aquatic Life Uses and Dissolved Oxygen Criteria

The complexity of the physical and biochemical processes occurring in Dickinson Bayou necessitate continued investigation to advance the understanding of DO dynamics and its relationship to aquatic life uses in both the tidal and above tidal segments. Low DO in Dickinson Bayou is not a recent or unique phenomenon. Reports of low DO and the occurrence of fish kills during the warm, dry months of late spring and early summer can be found dating back to the late 1960's (TWQB 1976) and similar conditions are known to exist in surrounding tidal streams and coastal bayous (TCEQ 2007).

As a result of recommendations issued in a Waste Load Evaluation study (TWC 1986), the Texas Water Commission (TWC) conducted a Use Attainability Analysis (UAA) of Dickinson Bayou, defining aquatic life uses based on physical, chemical and biological data collected in the bayou (TWC 1988). However, data collection for the UAA was limited to Segment 1104 and did not address aquatic life uses in the tidal segment, which was designated a high aquatic life use.

Within the tidal segment (Segment 1103); the apparent inability of the water body to achieve the 24-hour average and 24-hour minimum DO criteria with the required frequency (i.e., 90 percent attainment during the warm weather Index Period) is not addressed by this TMDL. The water quality simulations used to determine the TMDL show that reduction of controllable pollutants such as CBOD, nutrients, or sediment to infeasible levels will not achieve the DO criteria at the 90 percent attainment frequency required under the current

assessment methodology (Table 4). Additionally, water quality simulations conducted using watershed loadings generated under a natural land use scenario and no wastewater sources yielded DO criteria attainment frequencies that were significantly lower than simulations using current pollutant loading levels (Table 4).

The most likely explanation for these results is that the lower nutrient levels produced under a natural loading scenario reduce primary productivity, which is a large component of the total DO production in Dickinson Bayou. Also, flows provided by wastewater dischargers may enhance natural mixing and reaeration and help to transport pollutants downstream.

Water quality modeling conducted for this TMDL study also indicates that the hydrodynamic environment in the tidal segment of Dickinson Bayou is an important factor affecting DO dynamics in Segment 1103 and contributes significantly to the observed non-attainment of the DO criteria in this segment. As mentioned previously, an interesting feature of Dickinson Bayou is that the middle portion of the water body is notably deeper than the downstream portions of bayou near the confluence with Dickinson Bay (Figure 4).

In order to gage the effects of this "bathymetric sag" on DO dynamics, the TCEQ conducted a hypothetical water quality simulation of Dickinson Bayou altering the three-dimensional computational grid of the EFDC hydrodynamic model to reflect a change in bathymetry. The TCEQ altered the computational grid by raising the depth of the bayou through the middle portion, thus creating a gently sloping bottom surface and eliminating the "bathymetric sag" (Figure 14).

The results of the water quality simulation show that this change in bathymetry improved DO criteria attainment frequencies in Segment 1103 more than any other TMDL modeling scenario conducted, including combined and individual reductions in pollutant loadings (Table 4). However, even under this situation, the DO criteria are not achieved as currently assessed.

## Recommendations

In view of the evidence presented in this TMDL report and other historical information, it is advisable to consider whether the existing DO criteria and/or the methodology currently used to assess compliance with the DO criteria are appropriate for this water body. An analysis of Dickinson Bayou's ability to support normal aquatic life should be based on factors that include site-specific measurements. Such an analysis could result in a reclassification of the DO impairment currently listed on the State of Texas' 303(d) list.

For the non-tidal portion of Dickinson Bayou (Segment 1104), the TCEQ TMDL Program recommends conducting additional monitoring studies during the implementation process to obtain a better understanding of the conditions resulting in non-attainment of the 24-hour minimum DO criteria. The TCEQ also recommends investigating load contributions from the Bayou Wildlife Park to Dickinson Bayou to better assess the impact on water quality from this facility and to evaluate the need for pollution control measures. This investigation could result in the issuance of a TPDES discharge permit or other pollutant control strategy.

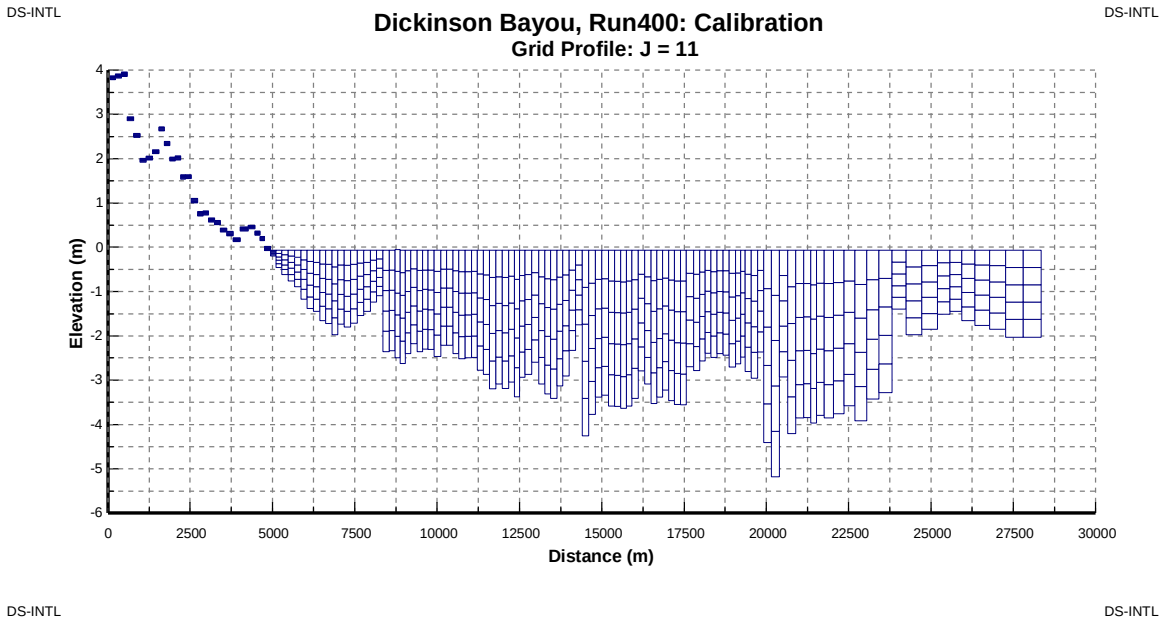
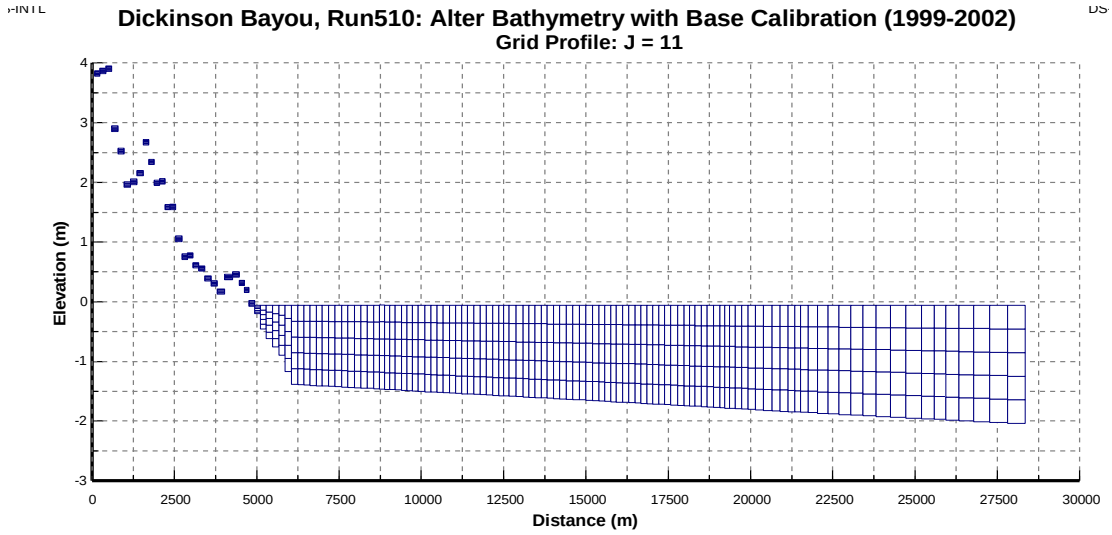



Figure 14. Adjustment of EFDC Computational Grid to Eliminate the "Bathymetric Sag"



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# Appendix A: $WLA_1$ for Individual WWTFs

Tables A-1 and A-2, below, show $WLA_1$ apportioned by individual wastewater treatment facility (WWTF) in the Dickinson Bayou watershed. The TCEQ apportioned the $WLA_1$ described previously in Table 10 of this document according to the proportion of the total wastewater flow corresponding to each individual WWTF. To facilitate the use of the information contained in this appendix in the issuance of wastewater permits, the values presented in Tables A-1 and A-2 are shown as 5-day carbonaceous biochemical oxygen demand ($CBOD_5$). These values were derived by dividing the total allowable daily $CBOD_u$ values for $WLA_1$ presented in Table 11 by a factor of 2.3, which is the $BOD_u/BOD_5$ conversion factor used by the TCEQ.

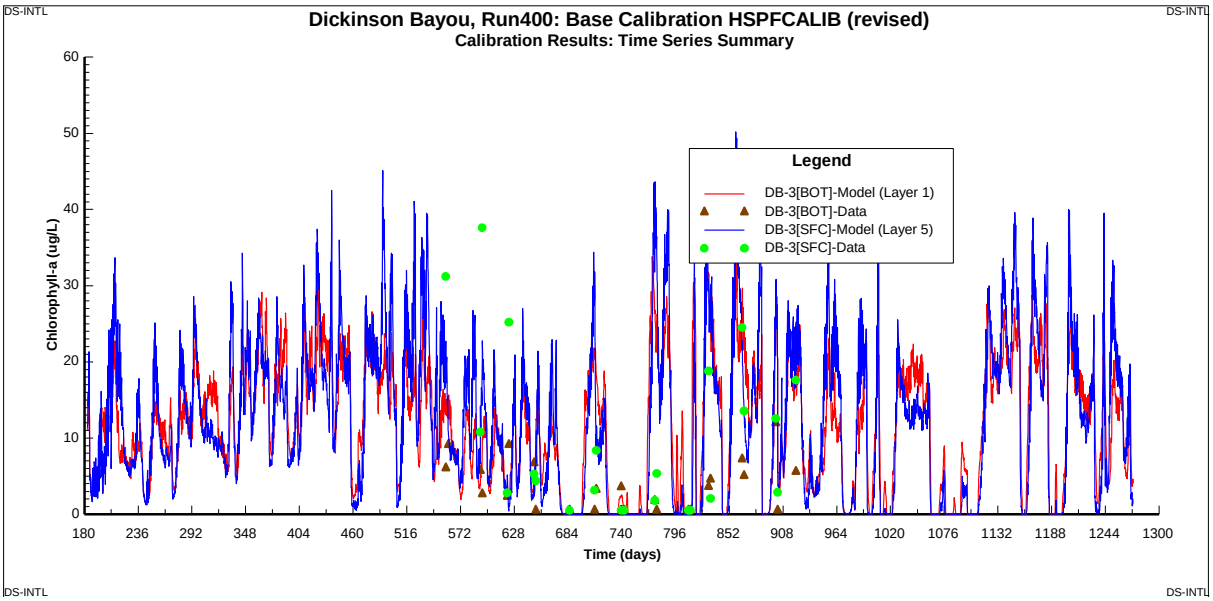
Table A-1. $WLA_1$ for Individual Wastewater Treatment Facilities (WWTFs) Currently Permitted under TPDES

| Facility | Permit Number | Final Permitted Discharge (MGD) | Allowable $CBOD_5$ Loading (kg/d) |
|---|---|---|---|
| Penreco | WQ0000377-000 | 0.075 | 2.07 |
| Sea Lion Technology, Inc. | WQ0003479-000 | 0.02 | 0.55 |
| Hillman Shrimp and Oyster Co. | WQ0003749-000 | 0.07 | 1.93 |
| Galveston WCID#1 | WQ0010173-001 | 4.8 | 132.58 |
| CRV Via Bayou LLC | WQ0014326-001 | 0.02 | 0.55 |
| KC Utilities, Inc. | WQ0012935-001 | 0.05 | 1.38 |
| Meadowland Utility Corp. | WQ0013632-001 | 0.0234 | 0.65 |
| R. West Development Co., Inc. | WQ0014440-001 | 0.95 | 26.24 |
| **Total** | All permitted facilities | 6.01 | 166 |

Table A-2. $WLA_1$ for Individual Wastewater Treatment Facilities (WWTFs) with Current and Pending (proposed) Permits under TPDES

| Facility | Permit Number | Final Permitted Discharge (MGD) | Allowable $CBOD_5$ Loading (kg/d) |
|---|---|---|---|
| Penreco | WQ0000377-000 | 0.075 | 1.67 |
| Sea Lion Technology, Inc. | WQ0003479-000 | 0.02 | 0.45 |
| Hillman Shrimp and Oyster Co. | WQ0003749-000 | 0.07 | 1.56 |
| Galveston WCID#1 | WQ0010173-001 | 4.8 | 106.81 |
| CRV Via Bayou LLC | WQ0014326-001 | 0.02 | 0.45 |
| KC Utilities, Inc. | WQ0012935-001 | 0.05 | 1.11 |
| Meadowland Utility Corp. | WQ0013632-001 | 0.0234 | 0.52 |
| R. West Development Co., Inc. | WQ0014440-001 | 0.95 | 21.14 |
| Marlin Atlantis White | WQ0014570-001 | 0.5 | 11.13 |
| South Central Water Co. | WQ0014804-001 | 0.95 | 21.14 |
| **Total** | All permitted and proposed facilities | 7.46 | 166 |

# Appendix B:
# Plots of Simulated vs. Observed Water Quality

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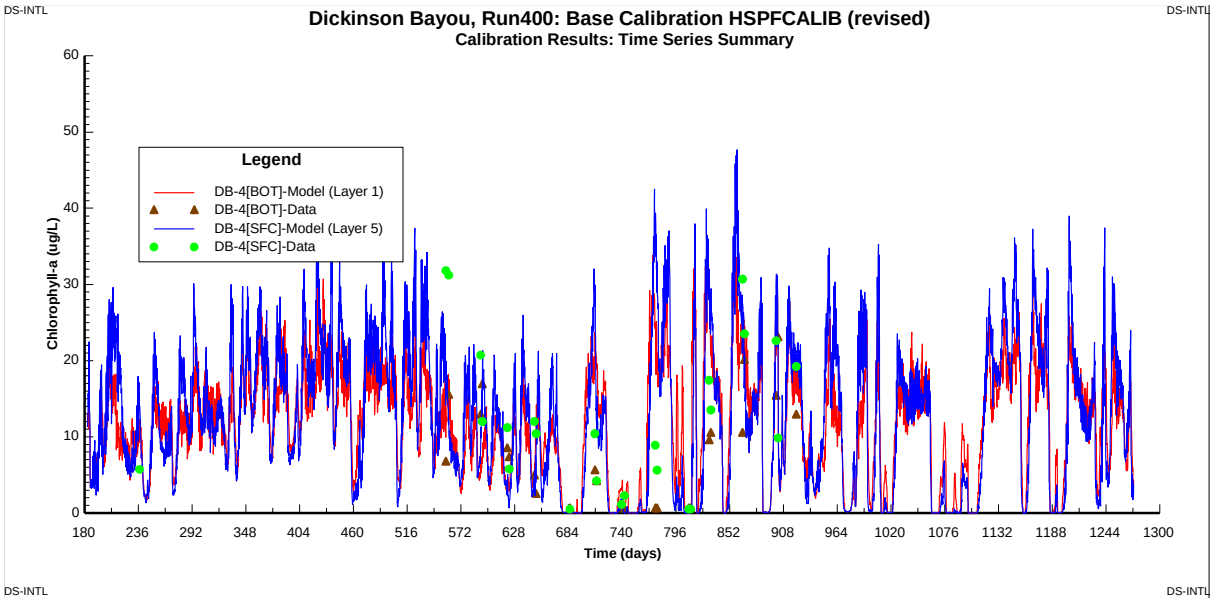


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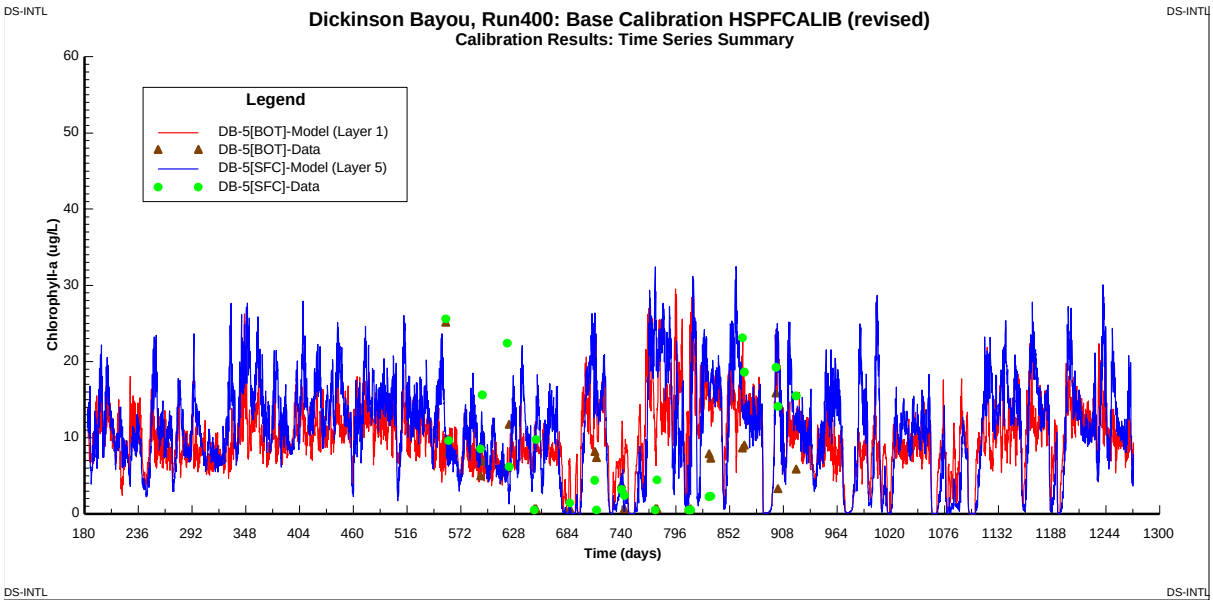


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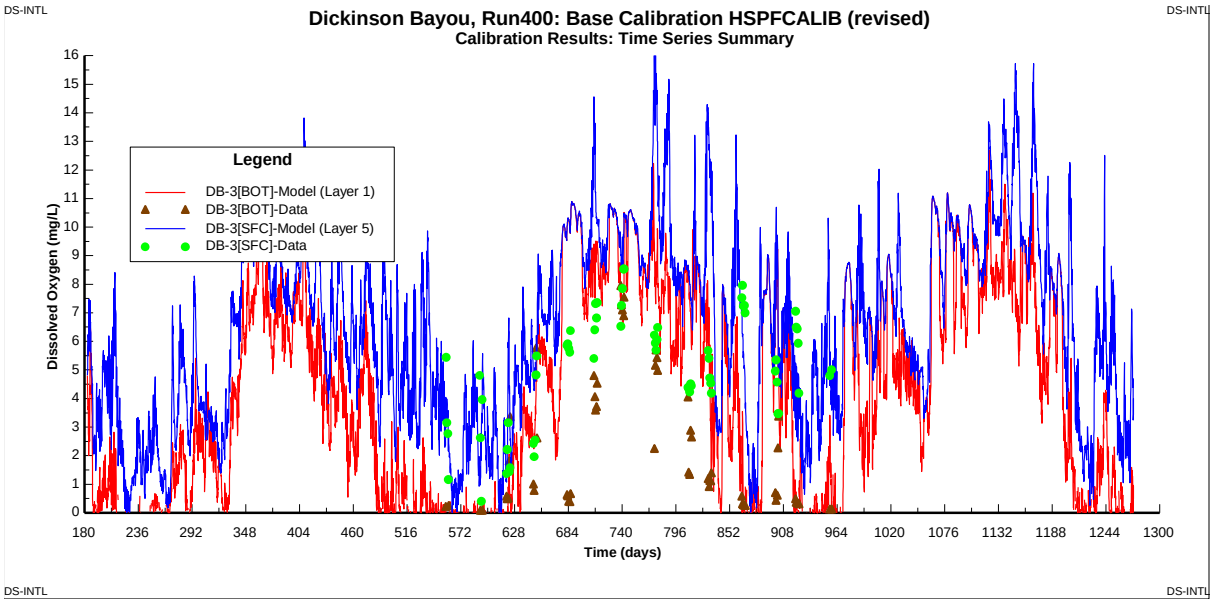


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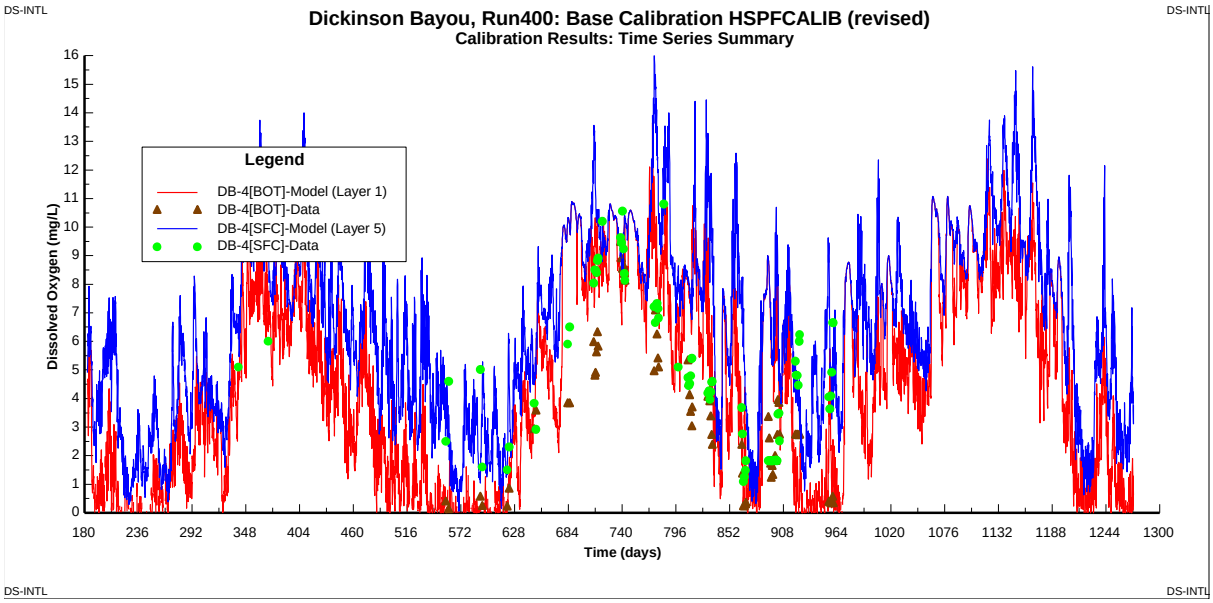


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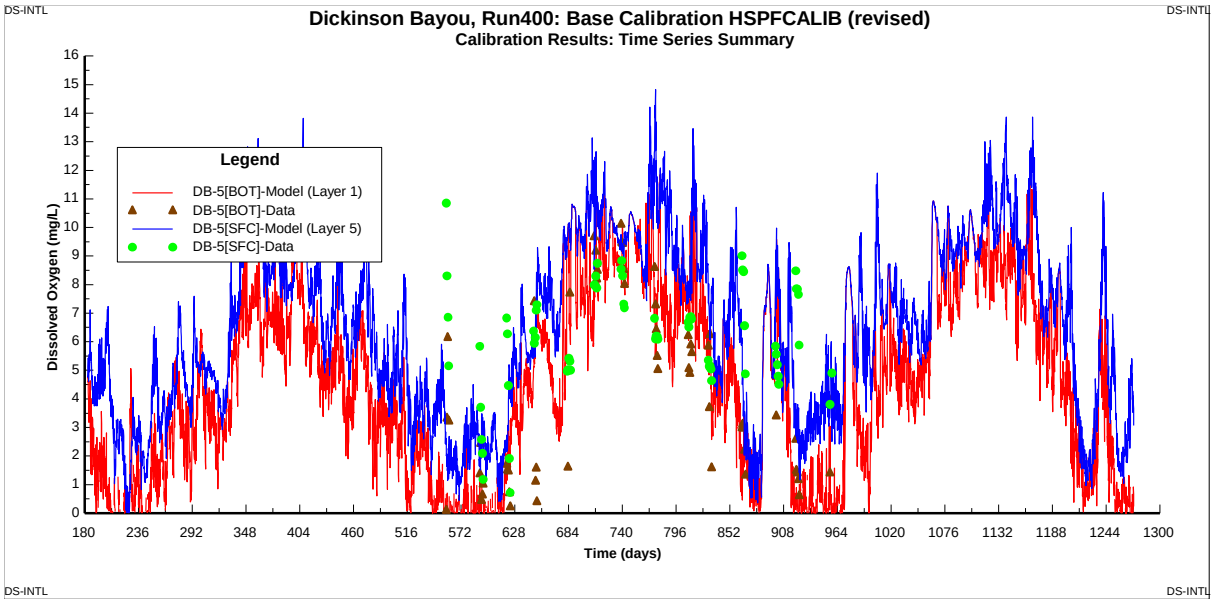


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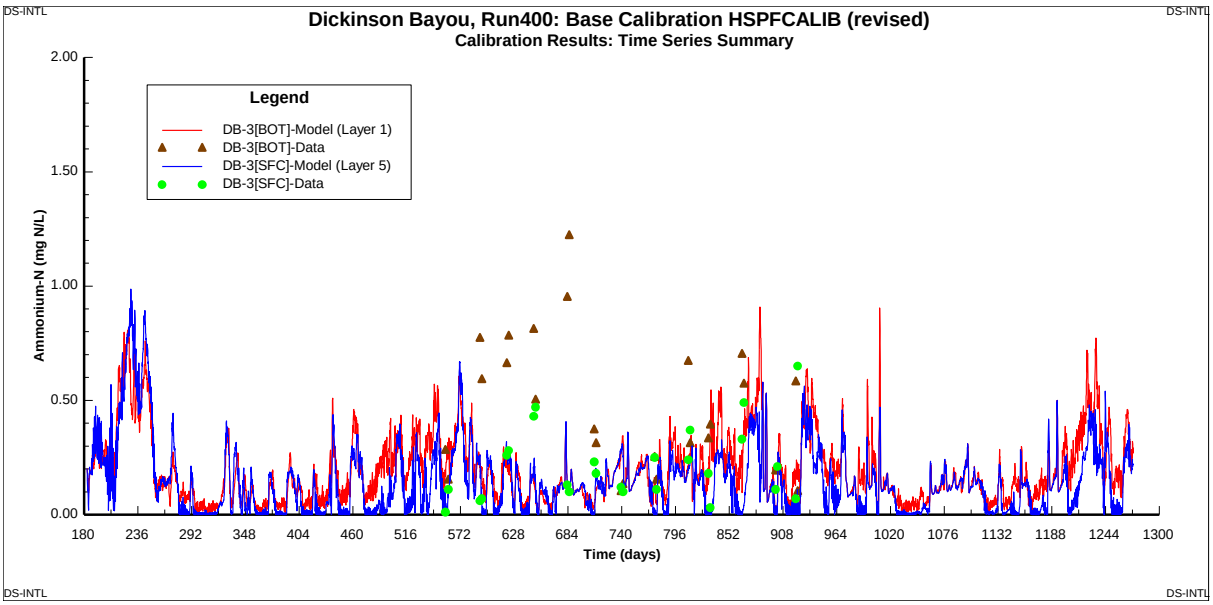


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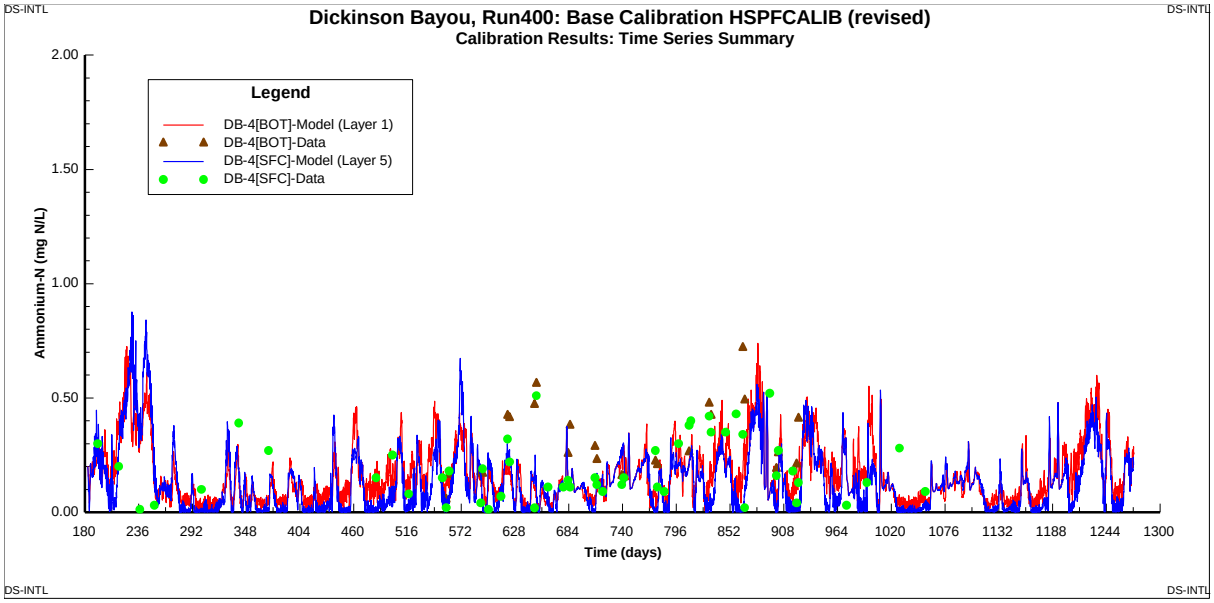


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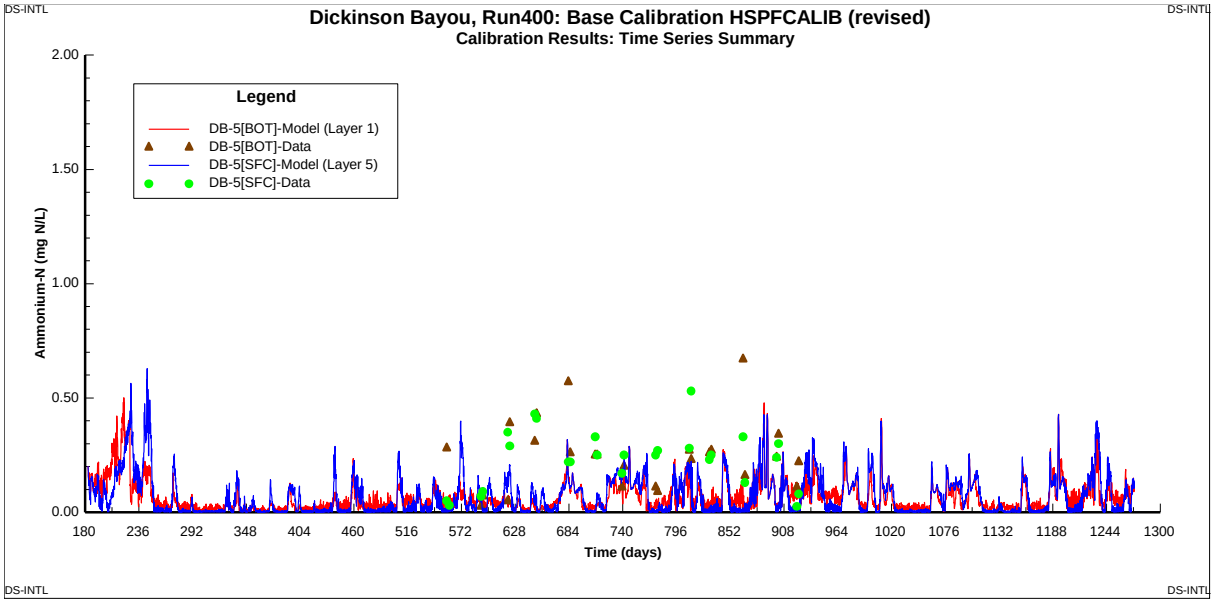


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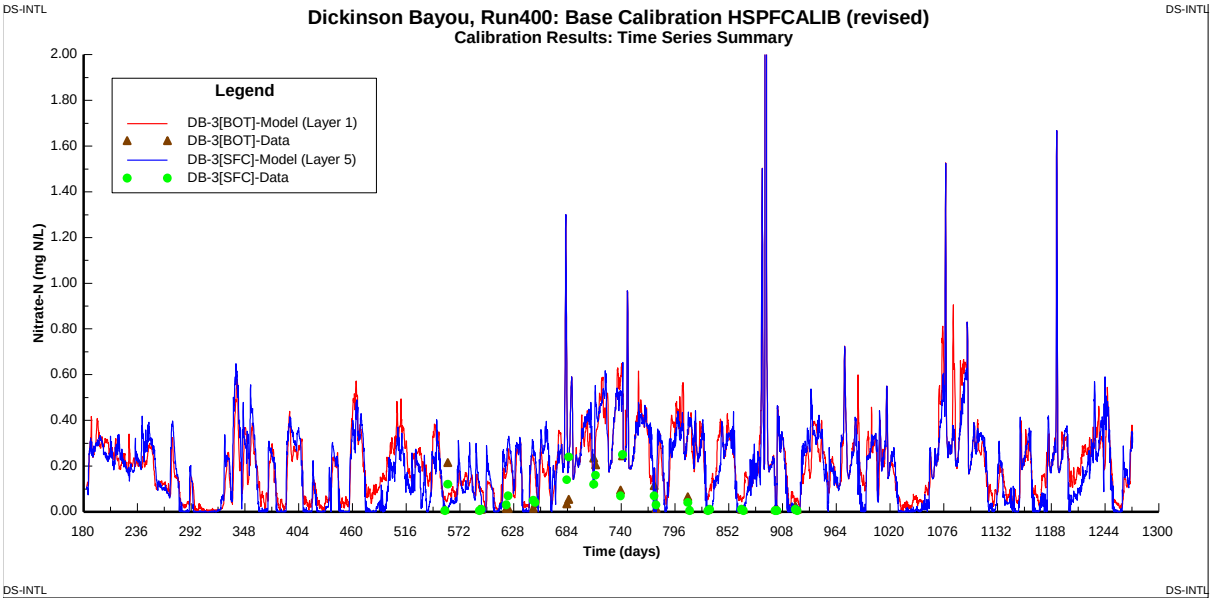


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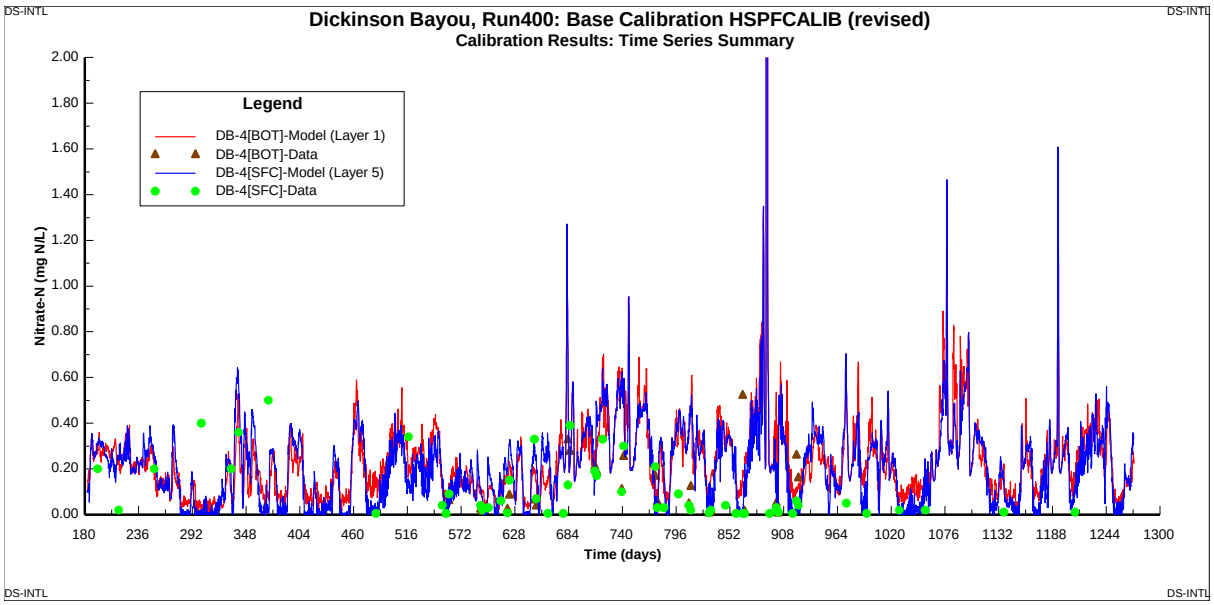


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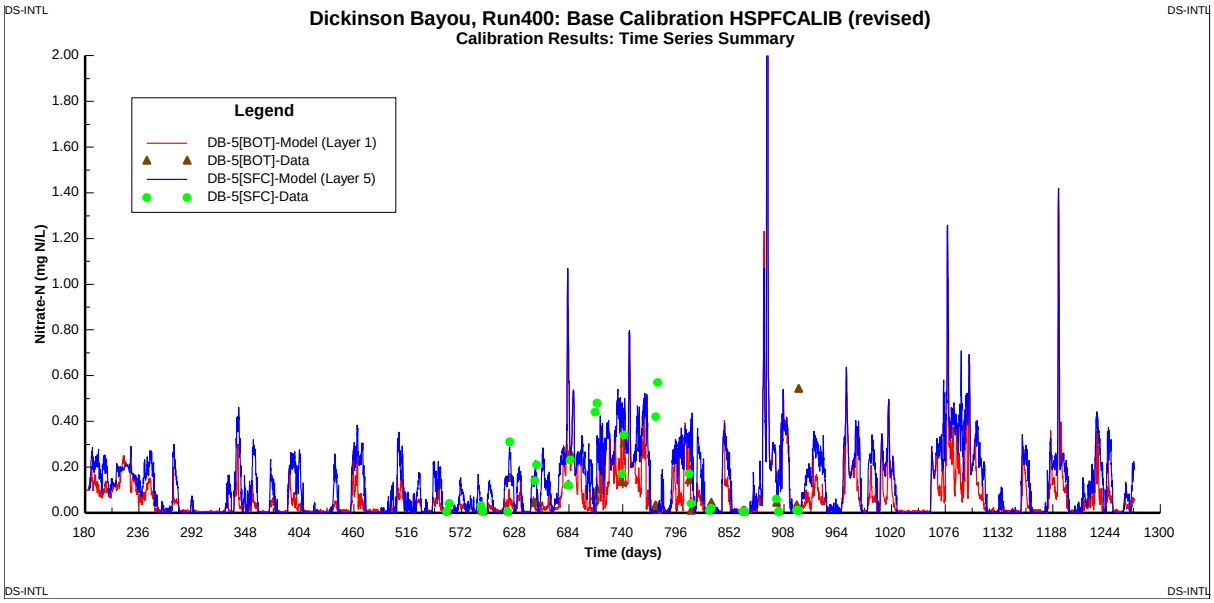


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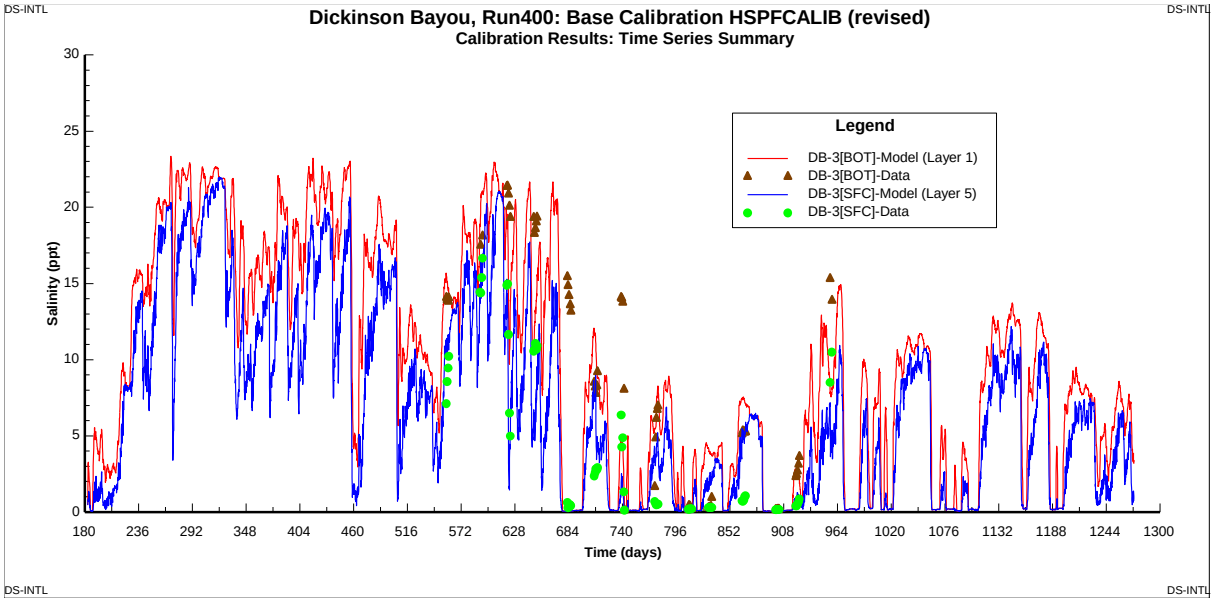


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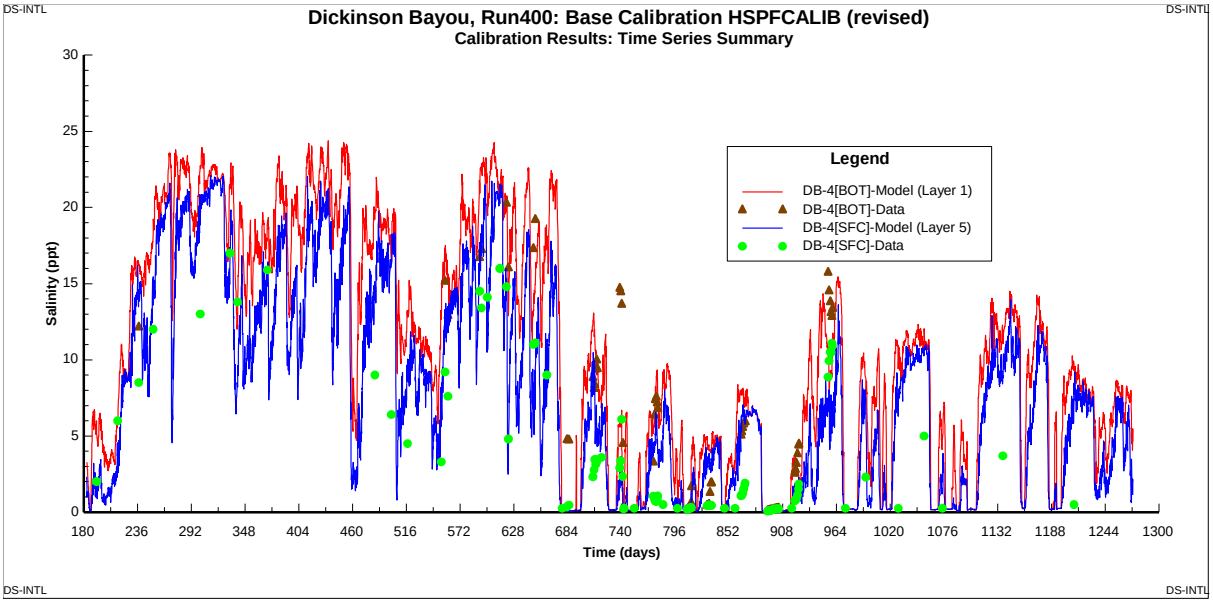


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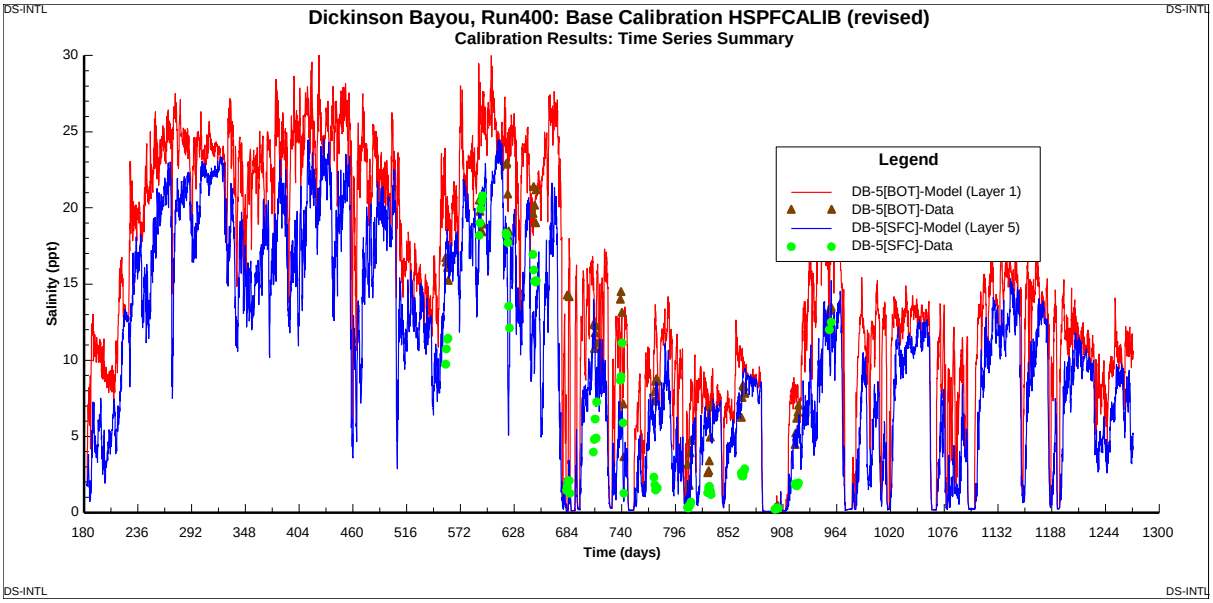


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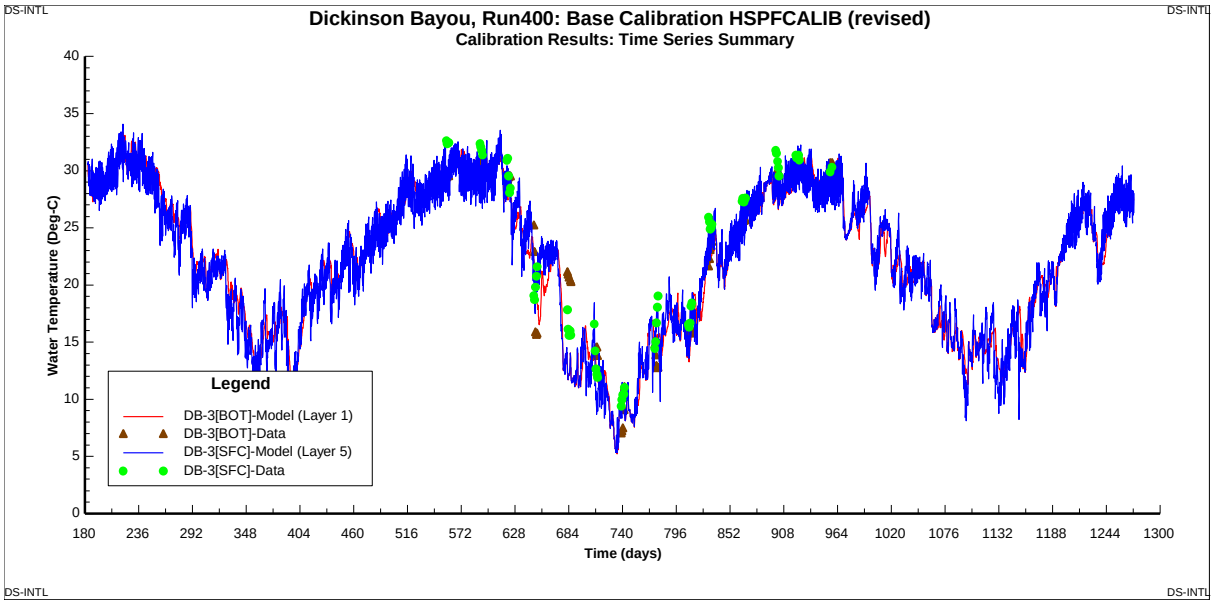


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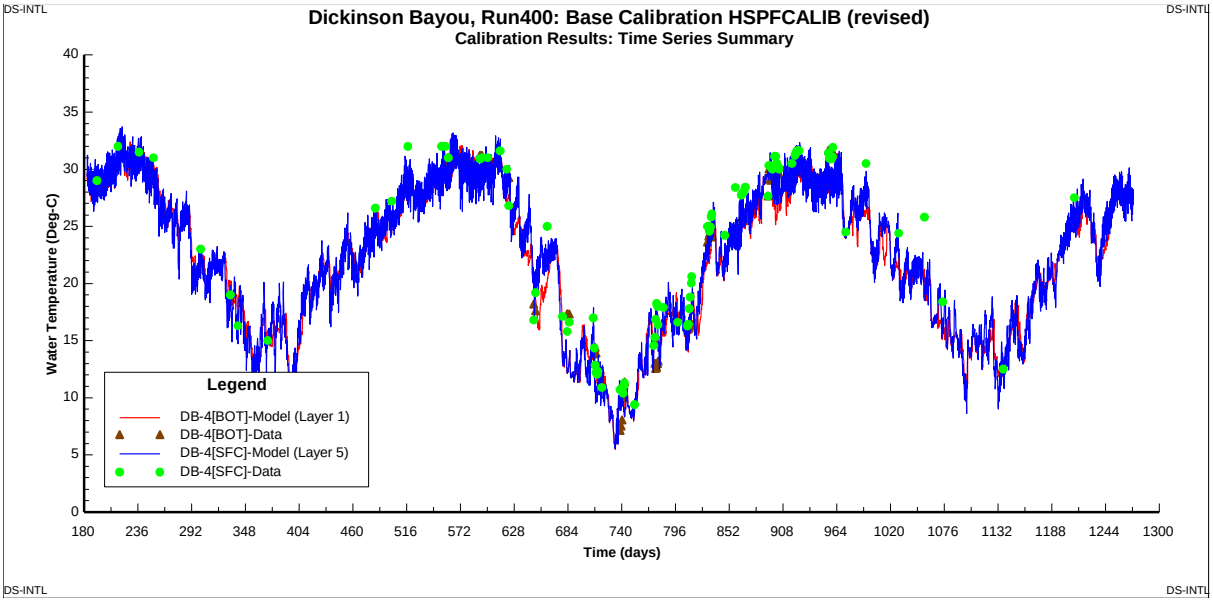


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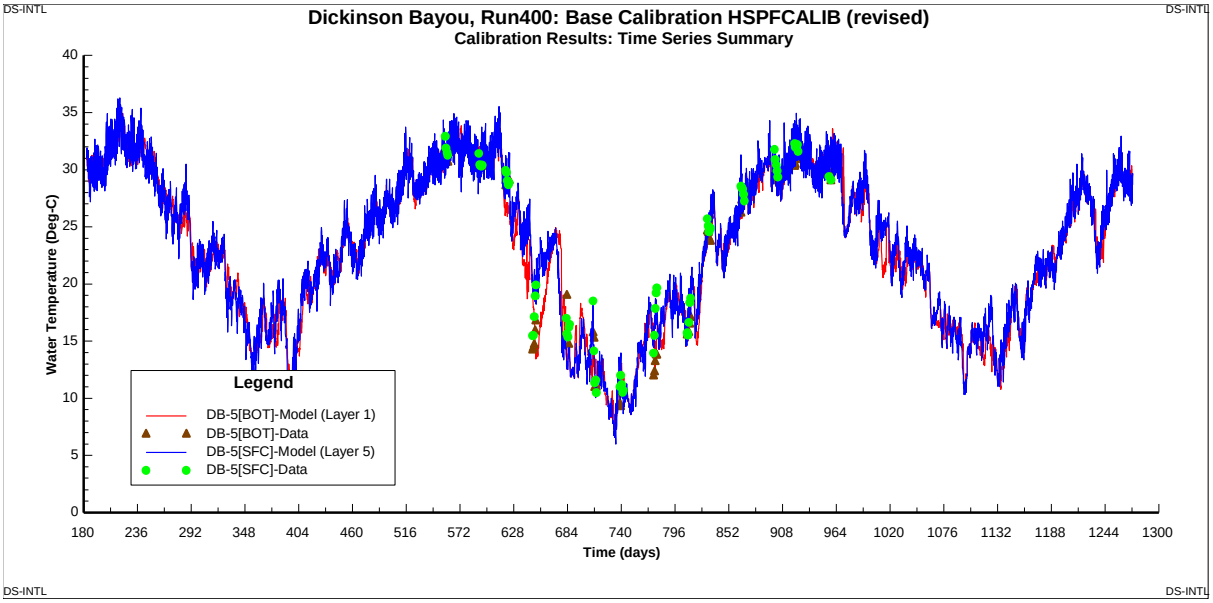


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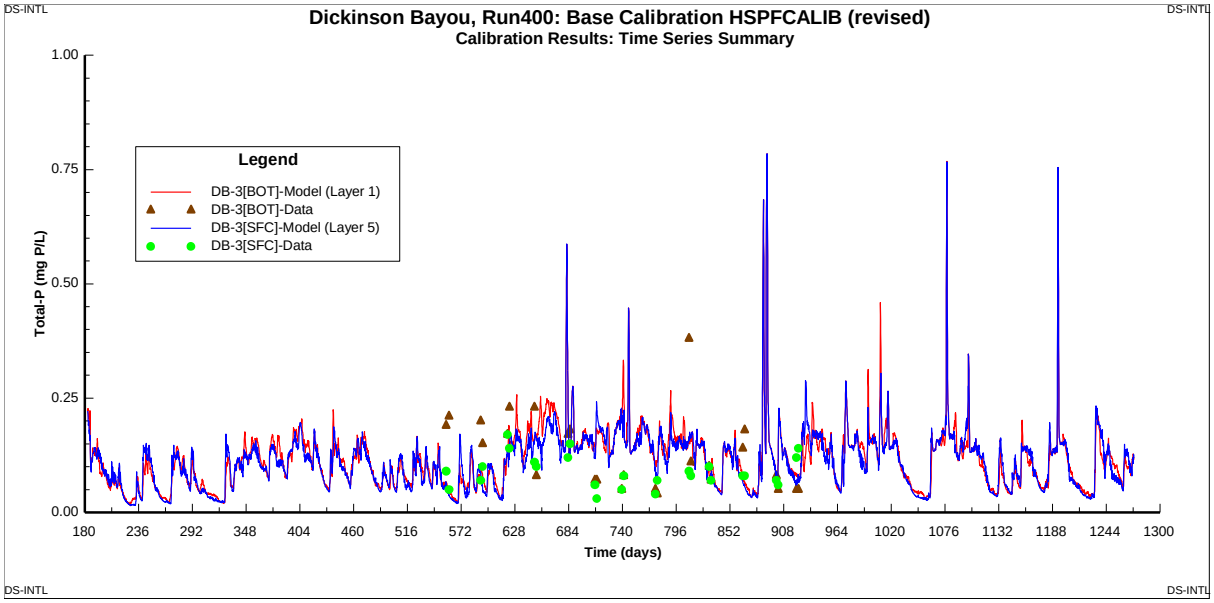


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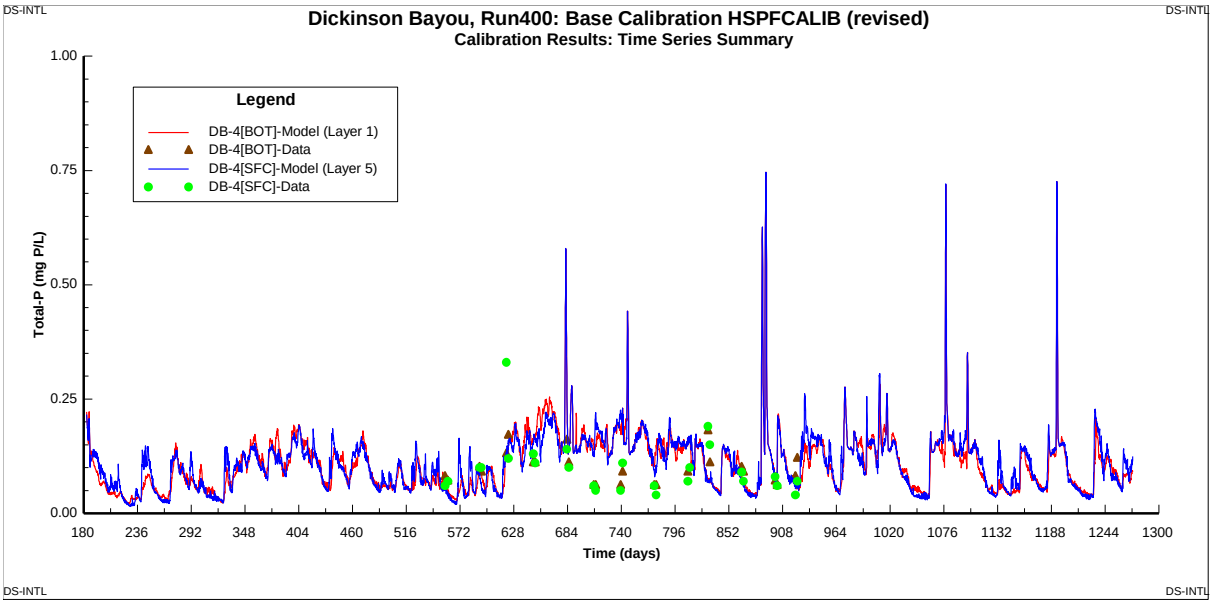


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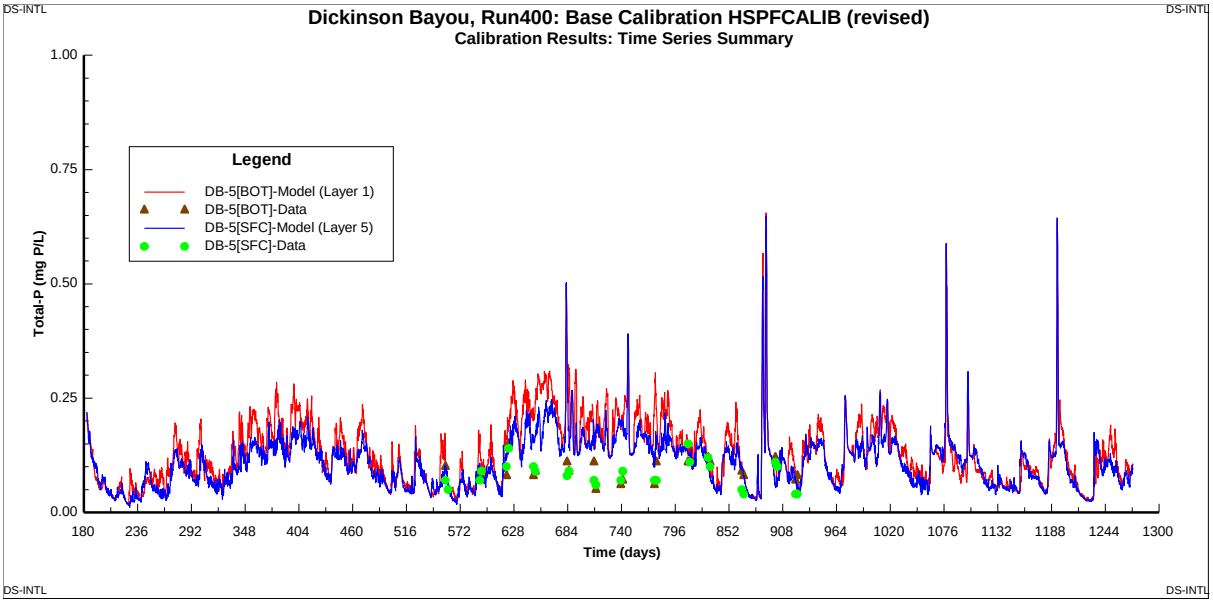


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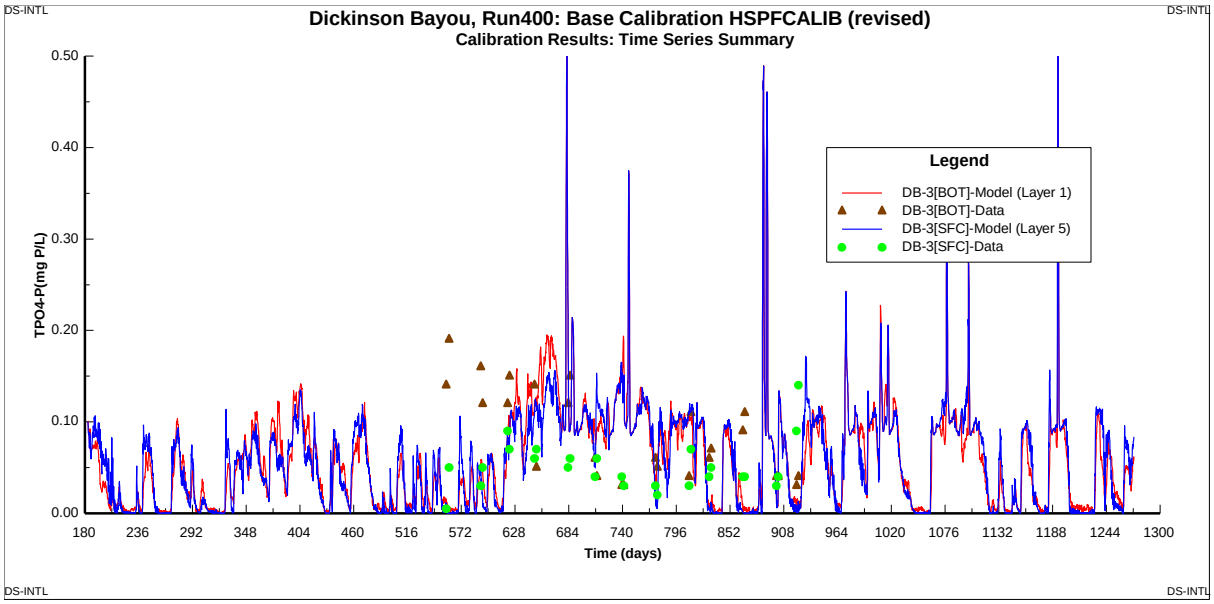


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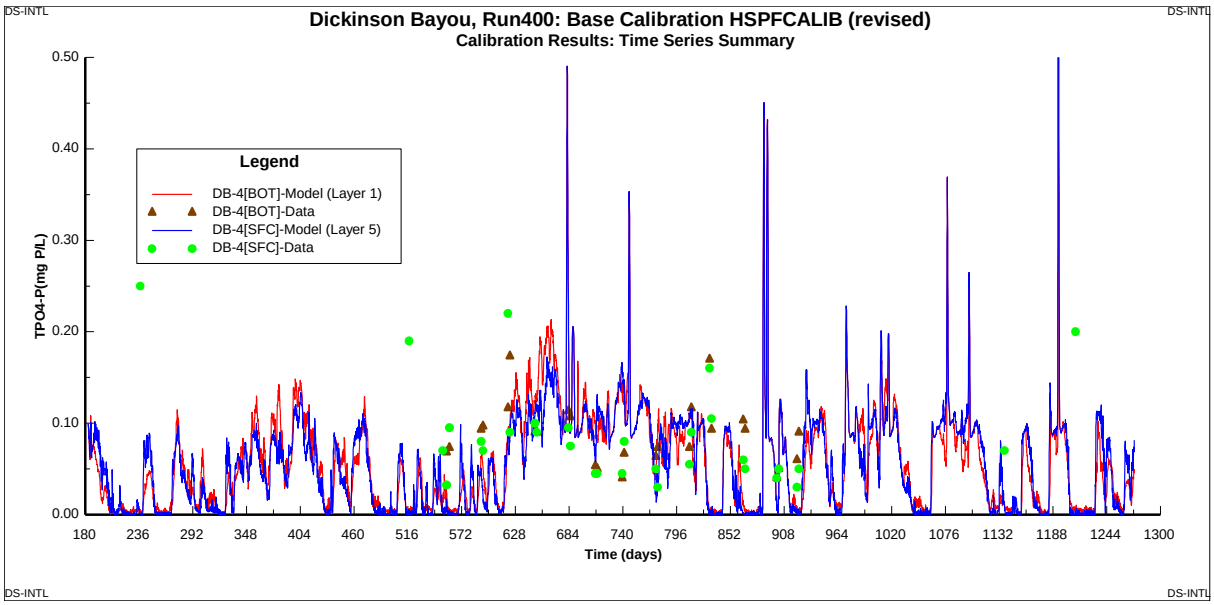


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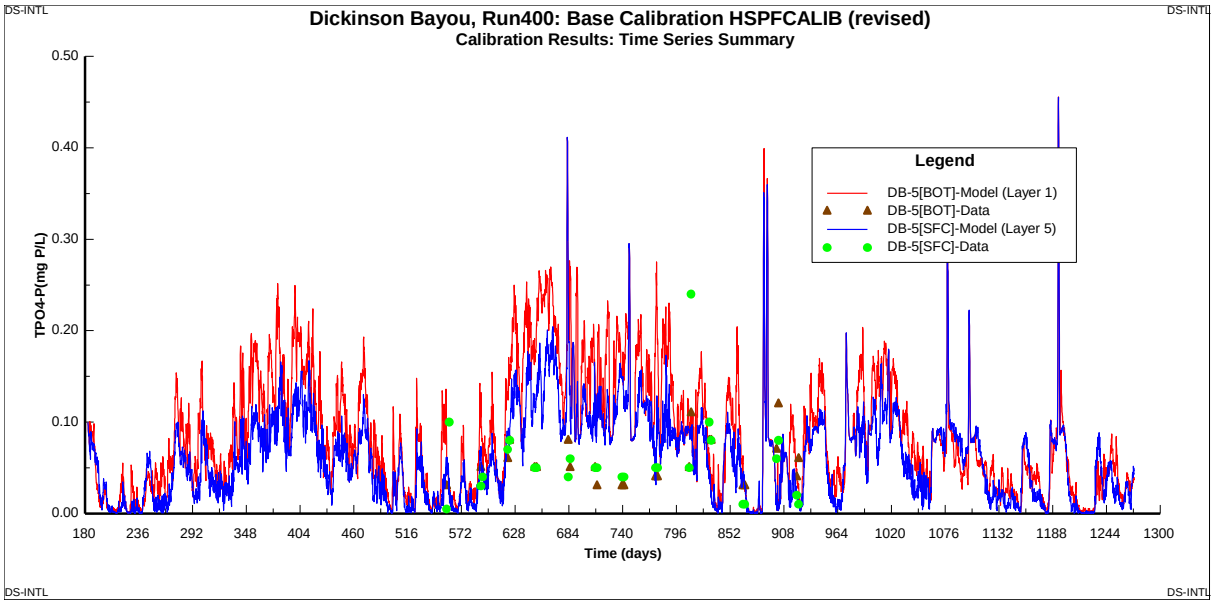


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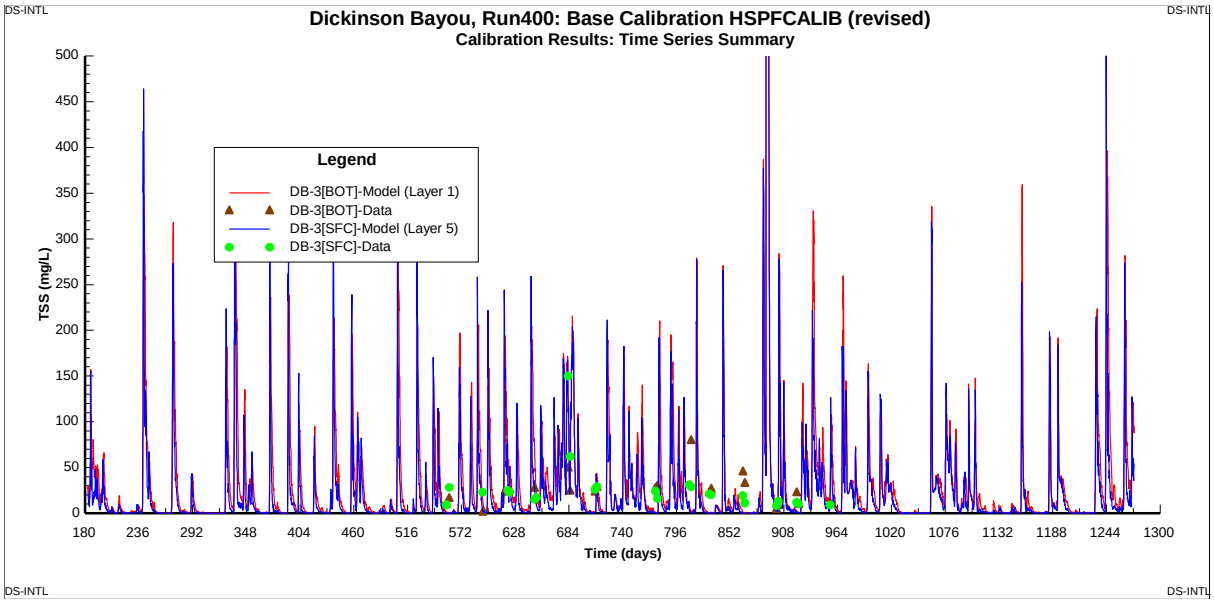


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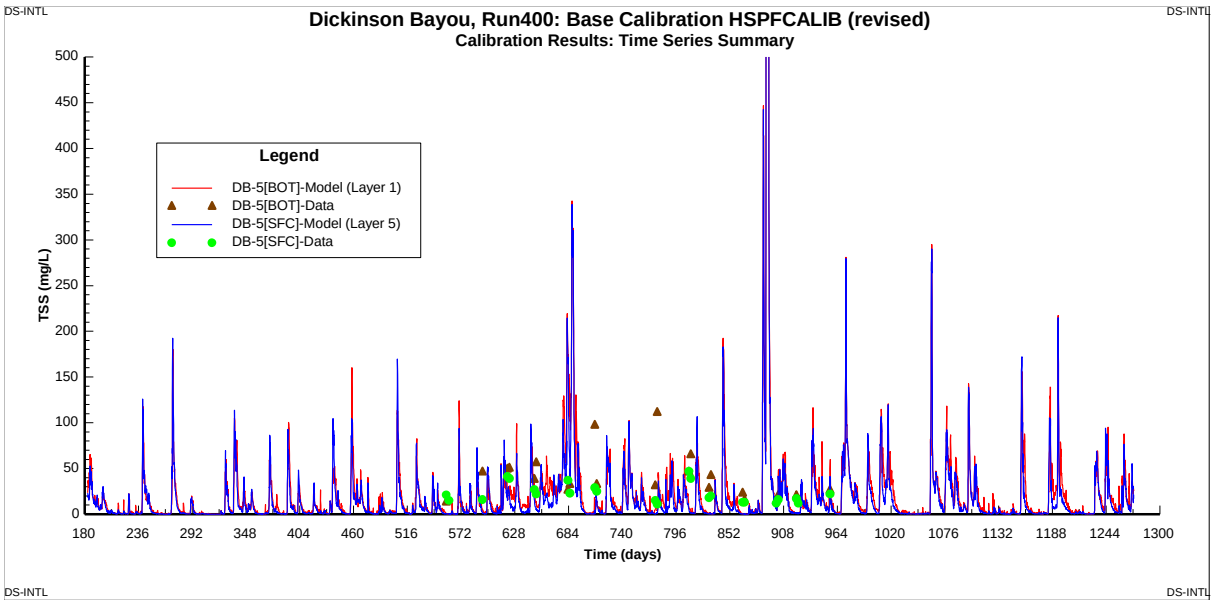


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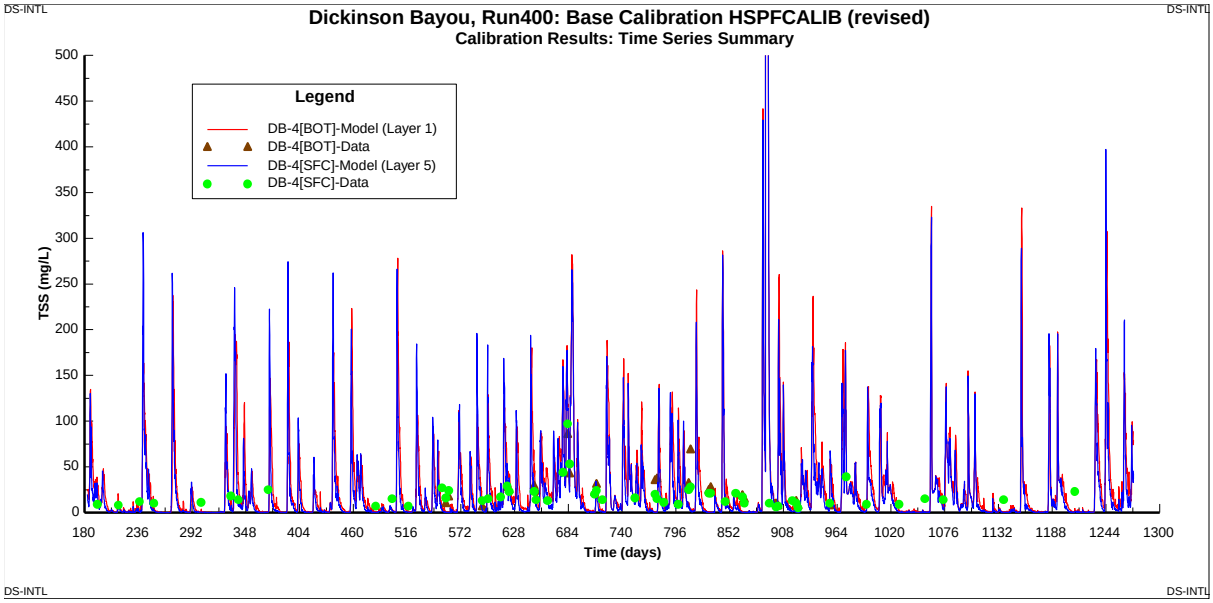


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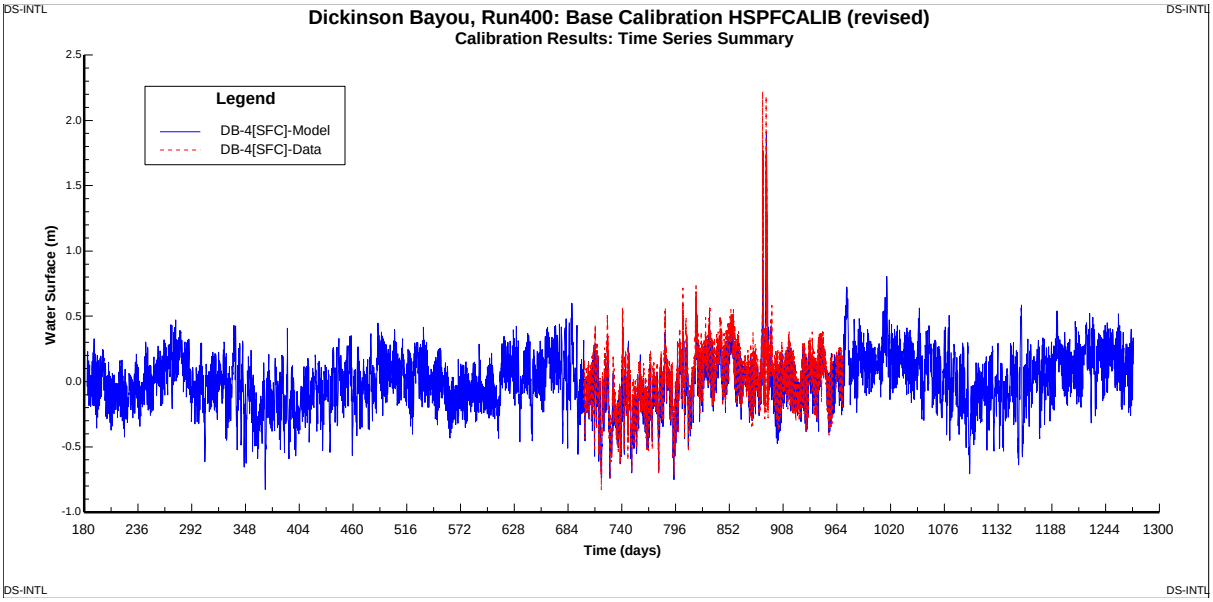


Calib_WaterEl_DB-4