ERDC/EL-CHL TR-OX-X

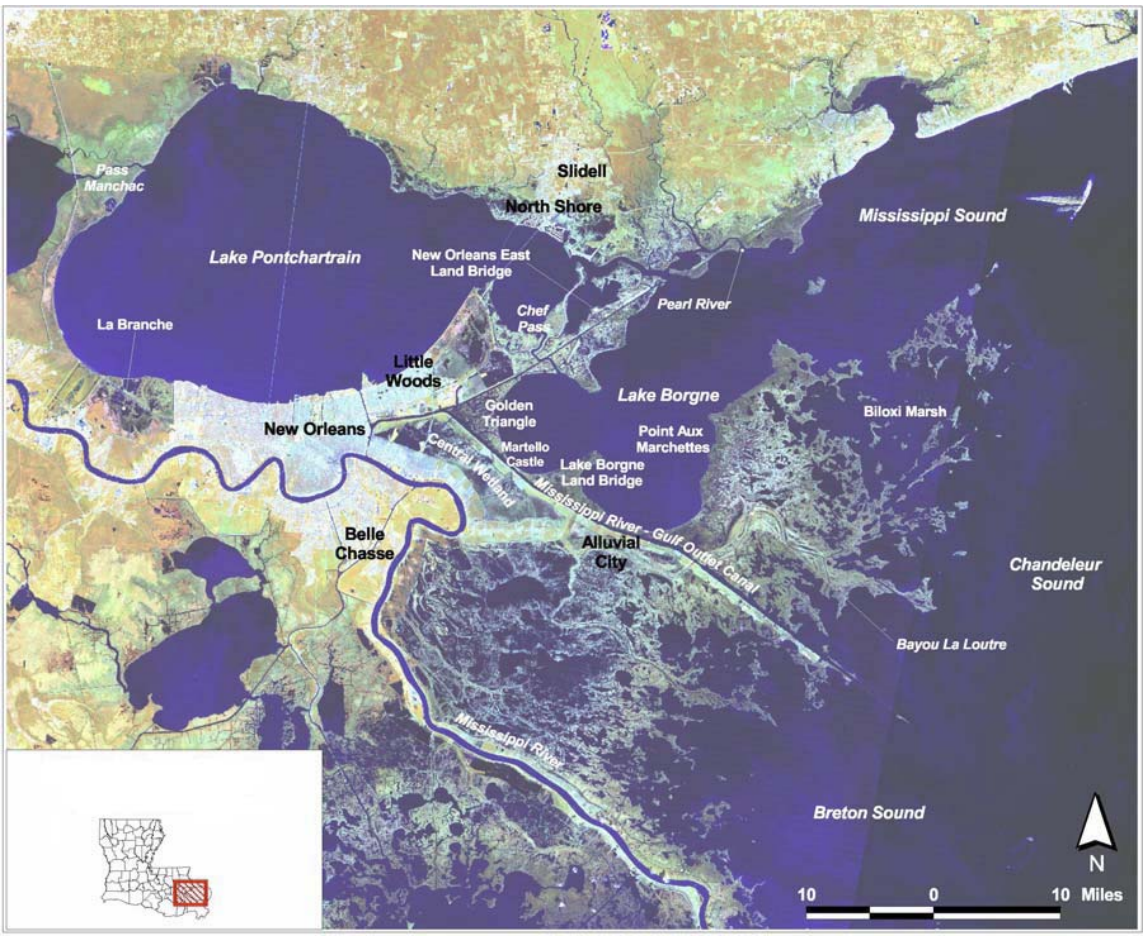
Engineer Research and Development Center

US Army Corps of Engineers®
Engineer Research and Development Center

Estimation of Dissolved Oxygen Concentrations of Two New Scenarios for Seabrook Conditions

Mansour Zakikhani, Darla C. McVan, and Keith Martin

November 2009



Approved for public release; distribution is unlimited.

ERDC/LAB TR-0X-X
November 2009

Estimation of Dissolved Oxygen Concentrations of Two New Scenarios for Seabrook Conditions

Mansour Zakikhani

Environmental Laboratory
U.S. Army Engineer Research and Development Center
Street Address
Vicksburg, MS 39180-6199

Darla C. McVan and Keith Martin

Coastal & Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
Street Address
Vicksburg, MS 39180-6199

Final report

Approved for public release; distribution is unlimited. [or a restricted statement]

Prepared for U.S. Army Corps of Engineers, New Orleans District

Abstract: This study examined the impacts on bottom dissolved oxygen (DO) within canal reaches comprising the Gulf Intracoastal Waterway (GIWW), the Mississippi River Gulf Outlet (MRGO), and the Inner Harbor Navigation Canal (IHNC) resulting from two scenarios of base and one alternative for proposed temporary 6-12 months Seabrook water control structures located within this system. The analytical model of reduced form that was developed for the same area was used for the analysis. Bottom water DO for each canal study reach was predicted using a steady-state, fully mixed, single reactor model. Three months of April, August, and September conditions were imposed for the assessment. Monthly average, bottom flushing flow rates were obtained from hourly bottom velocities output from a three-dimensional (3D) hydrodynamic and salinity model that was applied to the system. Likewise, monthly average surface and bottom salinities were also obtained from the 3D model output. The salinity data were used to estimate vertical eddy diffusivities, which were used in the model for DO exchange between surface and bottom water. The hydrodynamic information was provided for each study reach and for base and proposed scenarios. The model indicated that lower DO conditions should be expected within the system for the structural alternative being considered.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Contents

Figures and Tables iv

Preface vi

Unit Conversion Factors vii

1 Introduction 1

Background 1
Objective 1
Approach (summary) 1

2 Approach 3

General 3
Model Formulation 3
Model Implementation 6

3 Model Application 9

Scenario descriptions 9
Study Reaches 9
Hydrodynamic Conditions 12

4 Model Results 17

Salinity Stratification 17
Bottom DO Results 18
Evaluation of DO at a location near Seabrook Structure 21

5 Conclusions and Recommendations 25

References 27

Figures and Tables

Figures

Figure 1 Model Schematic 4
Figure 2 Cross-sections (Reach break locations) for hydrodynamic output 10
Figure 3 Reach break locations for Bayou Bienvenue 10
Figure 4 Location of Seabrook Structure 11
Figure 5 Location of selected coincided points (red circle) north of the Seabrook structure 21

Tables

Table 1 Scenario conditions 9
Table 2 Reach geometries 12
Table 3 Total cross-sectional residual flows, m3/sec, for April 13
Table 4 Total cross-sectional residual flows, m3/sec, for August 13
Table 5 Total cross-sectional residual flows, m3/sec, for September 13
Table 6 Bottom residual flows, m3/sec, for April, used to compute bottom DO. 14
Table 7 Bottom residual flows, m3/sec, for August, used to compute bottom DO. 14
Table 8 Bottom residual flows, m3/sec, for September, used to compute bottom DO. 15
Table 9 Reach water depths for Base and Proposed Scenarios 15
Table 10 April monthly averaged surface salinities, ppt 16
Table 11 August monthly averaged surface salinities, ppt. 16
Table 12 September monthly averaged surface salinities, ppt 16
Table 13 April monthly averaged bottom salinities, ppt 16
Table 14 August monthly averaged bottom salinities, ppt 16
Table 15 September monthly averaged bottom salinities, ppt 16
Table 16 Salinity stratification (surface and bottom salinity difference) for April 17
Table 17 Salinity stratification (surface and bottom salinity difference) for August 18
Table 18 Salinity stratification (surface and bottom salinity difference) for September 18
Table 19 Level of salinity stratification 18
Table 20 Computed bottom DO, mg/L for April 19
Table 21 Computed bottom DO, mg/L for August 19
Table 22 Computed bottom DO, mg/L for September 19
Table 23 Reach bottom DO averaged across all (two) scenarios 20
Table 24 Scenario bottom DO averaged across all reaches 20
Table 25 Reach geometries for new location (points) 22
Table 26 New Reach water depths for Base and Proposed Scenarios 22
Table 27 Bottom residual flows, m3/sec, used to compute DO 22

Table 28 Monthly averaged surface salinities, ppt 22
Table 29 Monthly averaged bottom salinities, ppt 23
Table 30 Salinity stratification (difference between surface and bottom salinity) 23
Table 31 Computed bottom DO for new location, mg/L 24

Preface

The model investigation presented in this report was authorized and funded by the U.S. Army Corps of Engineer, New Orleans District, Hurricane Protection Office (HPO) through MS. Alison Sleath and Ms. Laura Lee Wilkinson. The authors would like to appreciate their assistance in this study and for the peer-review of the report.

The study was conducted by Dr. Mansour Zakikhani of the Water Quality and Contaminant Modeling Branch (WQCMB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL) of the U.S. Army Engineer Research and Development Center (ERDC).

This work was conducted under the general direction of Dr. Beth Fleming, Director, EL; Dr. Richard Price, Chief, EPED; and Dr. Quan Dong, Chief, WQCMB.

Hydrodynamic modeling that provided information to support this study was conducted by Ms. Darla McVan and Mr. Keith Martin of the Coastal and Hydraulics Laboratory (CHL) of ERDC. Ms. Darla and Mr. Martin worked under the general direction of: Mr. Thomas W. Richardson, Director, CHL; Dr. Rose Kress, Chief of the Navigation Division, CHL; Mr. Bruce Ebersole, Chief of the Flood Protection Division, CHL; and Dr. Robert T. McAdory, Chief of the Estuarine Engineering Branch, CHL.

Dr. James R. Houston was Director of ERDC. COL Gary E. Johnston was Commander and Executive Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
miles (nautical)	1,852	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters

1 Introduction

Background

The U.S. Army Engineer Research and Development Center (ERDC) previously studied the impacts on bottom dissolved oxygen (DO) within canal reaches comprising the Gulf Intracoastal Waterway (GIWW), the Mississippi River Gulf Outlet (MRGO), and the Inner Harbor Navigation Canal (IHNC) resulting from various alternatives for proposed water control structures located within this system (Dortch and Martin, 2008). The New Orleans District (CEMVN), Hurricane Protection Office (HPO) contacted the Environmental Laboratory (EL) to use the developed approach to estimate two new scenarios for Seabrook Conditions.

Objective

The objective of this study is to estimate April, August, and September bottom DO concentrations for the following structural alternatives:

1) *Base scenario* -- GIWW opening is 150 ft, MRGO at La Loutre and Bayou Bienvenue closed, and **Seabrook open.** The flow opening of the IHNC-Seabrook barrier is relatively narrow (110 feet) and shallow (16 feet).

2) *Proposed action scenario* -- GIWW opening is 150 ft, MRGO at La Loutre and Bayou Bienvenue closed, and **Seabrook closed.** This represents the 6-12 month period would be in place during the construction of the proposed sector and vertical lift gates. Therefore, no flow would be exchanged between the IHNC and Lake Pontchartrain.

Approach (summary)

Bottom layer residual (tidal filtered) velocities were extracted from TABS-MDS model simulation results for three months of the year, April, August, and September of the study area (Martin and McAlpin, 2008). These residual velocities were used to determine bottom residual flows for inclusion in a dissolved oxygen model. Surface water and bottom layer salinities

were provided by the Coastal and Hydraulics Laboratory (CHL) and were used in the simulations.

The DO model is based upon a steady-state mass balance for a continuously stirred tank reaction (CSTR). This modeling approach is commonly used for screening DO impacts associated with wastewater discharges in ponds, lakes, lagoons, bayous, and bays. It is a simplified approach that provides useful screening-level estimates of DO impacts. The model is simple enough that the calculations can be conducted in a spreadsheet and furnished to various groups if interested. Summer conditions and typical default values for water quality kinetic parameters will be used. A key input required by the CSTR DO model is flushing flow rate of external boundary water. These flow rates were provided by CHL (ERDC) for each velocity station. In turn, these flows were used to estimate DO from the CSTR model for each velocity station.

2 Approach

General

A screening-level analytical water quality modeling approach that was developed for other proposed scenarios (Dortch and Martin, 2008) was used. The analytical approach is dependent on the flushing flow rate of aerated ambient waters from outside the canal system. The approach is bolstered by the fact that flushing flows were determined from a three-dimensional (3D) hydrodynamic and salinity model of the area of interest from the TABS-MDS model code by CHL of ERDC. Thus, there is a solid basis for the driving variables used in the analysis.

The analytical approach assumes steady-state, spring (April) and summer (August and September) conditions applied to a CSTR. CSTR models are frequently used to conduct screening-level assessments of DO resulting from proposed wastewater discharges. The approach is based on the mass balance of DO and biochemical oxygen demand (BOD) at steady-state (Thomann and Mueller, 1987). Concentrations are uniform in space for each constituent due to the fully mixed CSTR assumption. Thus, there is no spatial dimensionality.

The DO CSTR model is solved using a spreadsheet. For this study, the CSTR represents the bottom depth of 1 meter (100 cm) of water along the reach of the canal being assessed.

Model Formulation

The sources of DO are: inflow from waters entering from outside the canal, such as from the Gulf and Lake Borgne, and diffusion of aerated surface water into bottom water with lower DO. The sinks of DO are outflow due to flushing, exertion of sediment oxygen demand, and oxidation of BOD. The sources of BOD are diffusion from the surface water and in-flushing. The sinks of BOD are out-flushing and BOD loss, which is all attributed to oxidation assuming no settling of BOD. A conceptual schematic of the model formulation is shown in Figure 1.

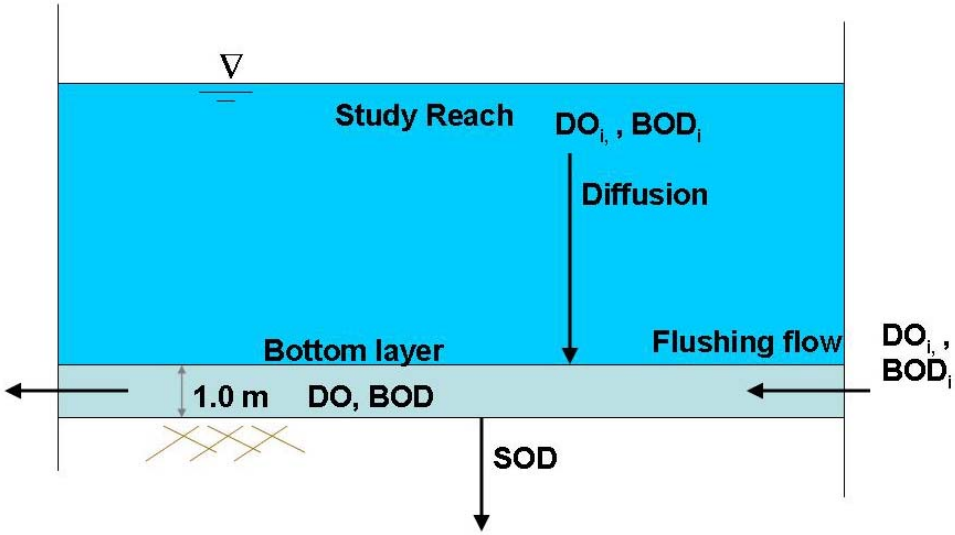


Figure 1 Model Schematic

The mass balance equations for DO and BOD are as follows:

$$V\frac{d\,DO}{d\,t} = Q\,DO_i - Q\,DO - A\,SOD + E_z^{'}\left(DO_s - DO\right) - k_1 V\,BOD \quad (1)$$

$$V\frac{d\,BOD}{d\,t} = Q\,BOD_i - Q\,BOD + E_z^{'}\left(BOD_s - BOD\right) - k_1 V\,BOD \quad (2)$$

where,

DO = DO in bottom water, mg/L or g/m^3

DO$_i$ = inflowing DO concentration due to flushing, mg/L or g/m^3

DO$_s$ = DO concentration of surface water, mg/L or g/m^3

Q = water flushing flow rate in bottom water, m^3/day

A = surface area of the bottom water in the canal, m^2

E'_z = bulk diffusion exchange coefficient, m^3/day

SOD = sediment oxygen demand, g/m^2/day

BOD = ultimate BOD remaining or un-oxidized in bottom water, mg/L or g/m^3

BOD$_i$ = inflowing ultimate BOD concentration due to flushing, mg/L or g/m^3

BOD_s= ultimate BOD concentration in surface water, mg/L or g/m^3

V = volume of the canal bottom water, m^3

t = time, days

k_1 = BOD decay (oxidation) rate, day^{-1}

For steady-state conditions, Equations 1 and 2 become,

$$DO = DO_i - \frac{A}{Q + E_z^{'}} SOD - \frac{k_1 V}{Q + E_z^{'}} BOD \tag{3}$$

$$BOD = \frac{Q + E_z^{'}}{Q + E_z^{'} + k_1 V} BOD_i \tag{4}$$

where it is assumed that $DO_s = DO_i$ and $BOD_s = BOD_i$. Equation 4 is solved first for BOD, and the BOD solution is then used in Equation 3 to solve for DO.

The bulk diffusion exchange between surface and bottom water, $E^{'}_z$, can be estimated as follows,

$$E_z^{'} = \frac{E_z A}{\Delta Z} \tag{5}$$

where

A = canal surface area, m^2

ΔZ = vertical distance between the surface layer and bottom, m

E_z = vertical eddy diffusivity, m^2/day

It was assumed that A is the product of the canal width at the featured cross-section and the length of the canal reach under study, and ΔZ was taken as the water depth at the featured cross-section. E_z in units of cm^2/sec can be estimated from (Thomann and Mueller, 1987)

$$E_z = 1.7x10^{-4} N^{-0.83} \tag{6}$$

where N is the stability frequency (sec^{-2}) given by

$$N = \frac{g}{\rho}\frac{\partial \rho}{\partial Z} \tag{7}$$

for g as the acceleration of gravity (9.8 m/sec^2), ρ as the density of water in g/cm^3, and Z as depth in m. The density of water can be computed from water temperature, T, (^{o}C) and salinity, S, (parts per thousand, ppt) as follows (Thomann and Mueller, 1987),

$$\rho = 1 + \left\{10^{-3}\left[\left(28.14 - 0.0735T - 0.00469T^2\right) + \left(0.802 - 0.002T\right)\left(S - 35\right)\right]\right\} \tag{8}$$

Equation 8 is used to compute surface and bottom water density with known temperature and salinity, and the difference in surface and bottom water density is divided by the water depth to compute N from Equation 7. The value of N is then used to compute E_z from Equation 6, and the resulting value of E_z is used to compute E'_z from Equation 5 where the resulting value is used in Equations 3 and 4. For conditions with no density difference (i.e., no salinity difference for a given temperature) between surface and bottom, E_z is infinitely large from Equation 6. So for conditions of no stratification, a value of E_z had to be specified for the model. An upper limit on E_z of 2.0 cm^2/sec was set, which is consistent with values that occur with very small temperature differences between surface and bottom water that are likely to exist. A temperature difference of only a few tenths of a degree C and 20 ppt salinity can result in E_z values of about 2 cm^2/sec. Similarly, a salinity difference of only 0.007 ppt results in an E_z value of 2 cm^2/sec at 30 ^{o}C. Thus, an upper limit on E_z of 2.0 cm^2/sec is quite reasonable.

Model Implementation

The TABS-MDS 3-D numerical hydrodynamic model was applied by Martin et al. (2008) for MRGO-GIWW-IHNC system. The model was reapplied for scenarios presented in this report. Information was extracted from this modeling to feed data needs for DO analysis described above. Specifically, monthly average flushing rate in the bottom one meter (100 cm) of water for each canal reach was required to set values for Q used in Equations 3 and 4. April, August, and September flow conditions from the 3D model at selected cross-sections were used to obtain Q for use in Equations 3 and 4. Canal cross-sections and geometry of reaches are discussed in Chapter 3. The monthly time average of Q for April, August, and Sep-

tember were determined from computed every half-hour bottom velocities that were provided by CHL from the hydrodynamic modeling.

The variables A and V in Equations 3 and 4 were established as follows. A is the product of the canal width and length. The width was assumed uniform and corresponded to the width of the canal at each cross-section. The canal length was equal the entire canal reach corresponding to each cross-section. The bottom layer volume, V, is the product of A and 1.0 m. A bottom layer thickness of 1.0 m was arbitrarily set, but the goal was to prescribe a layer that is thin enough to represent the near-bottom velocity and flow. The variable ΔZ is essentially the water depth for each cross-section.

The ambient dissolved oxygen of waters flushed or diffused into the bottom layer, DO_i, was assumed to be at a value of 80 percent of saturation for the ambient temperature and salinity. Saturation DO (DO_{sat}) can be computed from (Thomann and Mueller, 1987),

$$DO_{sat} = Exp\left\{\begin{array}{l} -139.34411 + \dfrac{1.575701x10^5}{T_k} - \dfrac{6.642308x10^7}{T_k^{\,2}} + \dfrac{1.243800x10^{10}}{T_k^{\,3}} \\ -\dfrac{8.621949x10^{11}}{T_k^{\,4}} - S\left(0.017674 - \dfrac{10.754}{T_k} + \dfrac{2140.7}{T_k^{\,2}}\right) \end{array}\right\} \quad (9)$$

where T_k is temperature in degrees Kelvin, which is T + 273.15. August water temperatures for this system are typically about 30 ^oC based upon examination of USGS records, thus, this value was used for all scenarios. A salinity of 20.0 ppt was assumed for ambient water for all scenarios for computing DO_{sat} from Equation 9. This is the computed salinity of water in Lake Borgne for September Base conditions (existing conditions without MRGO closure) as reported by Martin et al. (2008). With a temperature of 30 ^oC and salinity of 20 ppt, 80 % DO_{sat} = 5.42 mg/L. With a decrease in salinity of 3 ppt (thus 17.0 ppt), 80 % DO_{sat} = 5.51 mg/L.

Ultimate BOD of ambient water, BOD_i, must be converted from observed five-day BOD values, BOD_5. The conversion from BOD_5 to ultimate BOD, BOD_u, is

$$BOD_u = \frac{BOD_5}{1 - \exp\left(-5k_1\right)} \quad (10)$$

The BOD decay rate is typically on the order of 0.1 day^{-1} at 20 ^{o}C, which results in a value of 2.54 for the ratio of BOD_u to BOD_5 at 20 ^{o}C. The value of k_1 used for the modeling was 0.1 day^{-1} at 20 ^{o}C ($k_{1@20}$) for all cases. Values of k_1 for other temperatures can be computed from

$$k_1 = k_{1@20}\left(1.047^{T-20}\right) \tag{11}$$

Examination of USGS records (USGS, 2005) for this system indicated that BOD_5 at 20 ^{o}C varied between 1.3 and 4.0 mg/L, with a mean of about 2.5 mg/L. Thus, the input BOD_5 at 20 ^{o}C for ambient water for all scenarios was set to 2.5 mg/L. Equation 10 was used to compute BOD_u for ambient water (BOD_i) using Equation 11 to compute k_1 at 30 ^{o}C. The resulting BOD_i for all conditions was 4.57 mg/L.

Surface and bottom salinity predicted from the 3D hydrodynamic model for each scenario were used to estimate vertical eddy diffusivity (see Equations 6 through 8). The temperature value used in Equation 8 was assumed to be 30 ^{o}C for all scenarios since temperature has a relatively minor effect on water density when there are variations in salinity.

Typical values of SOD for marine waters range from about 0.5 to 2.0 g/m^2/day (Chapra, 1997). A value of 1.0 at 20 ^{o}C was assumed for all scenarios. SOD at 20 ^{o}C (SOD_{20}) is converted to SOD at ambient temperature according to

$$SOD = SOD_{20}\left(1.074^{T-20}\right) \tag{12}$$

The value of SOD at 30 ^{o}C for all conditions tested is 2.04 g/m^2/day.

Reach-specific variables included:

a. Canal length, width, and depth
b. Bottom flushing flow rate
c. Surface and bottom salinity

The canal length, width, and depth were based upon cross-section characteristics as described in the next chapter. Bottom flushing flow rate and surface and bottom salinity were obtained from the 3D hydrodynamic model and varied for each scenario. These values are also described in the next chapter.

3 Model Application

Scenario descriptions

Two scenario conditions simulated are summarized in Table 1. Figures 2 and 3 show locations of reaches (CSTR) used for DO calculations. The proposed structure referenced in Table 1 is shown in Figures 4. Bottom water DO was computed for each of the scenarios listed in Table 1, for each canal reach described in the next section, and for months of April, August, and September.

Table 1 Scenario conditions

DO Scenario	Hydrodynamic modeling scenario	Conditions
1	Base	GIWW opening is 150 ft, MRGO at La Loutre and Bayou Bienvenue closed, and **Seabrook open**. The flow opening of the IHNC-Seabrook barrier is relatively narrow (110 feet) and shallow (16 feet).
2	Proposed(During Construction Phase)	GIWW opening is 150 ft, MRGO at La Loutre and Bayou Bienvenue closed, and **Seabrook closed**. This represents the 6-12 month period would be in place during the construction of the proposed sector and vertical lift gates. Therefore, no flow would be exchanged between the IHNC and Lake Pontchartrain.

Study Reaches

Hydrodynamic output, including cross-sectional residual flows, bottom velocities, and surface and bottom salinity, were provided by CHL at select cross-sections (Reach Break) as shown in Figure 2. Bottom DO was computed for reaches that spanned each of these cross-sections. As stated previously, it was necessary to define a study reach in order to provide the reactor length, width, and volume required to compute DO, which is assumed to be uniform in the reactor, or along the reach. The reach breaks were selected such that the cross-sections were located between points where flow could enter or leave the canals or a canal ended. Thus, each reach break was located where either a structure is proposed, a canal has a bifurcation, or where there is a water passage to/from the canal, such as connection to Lake Borgne or Bayou Bienvenue.

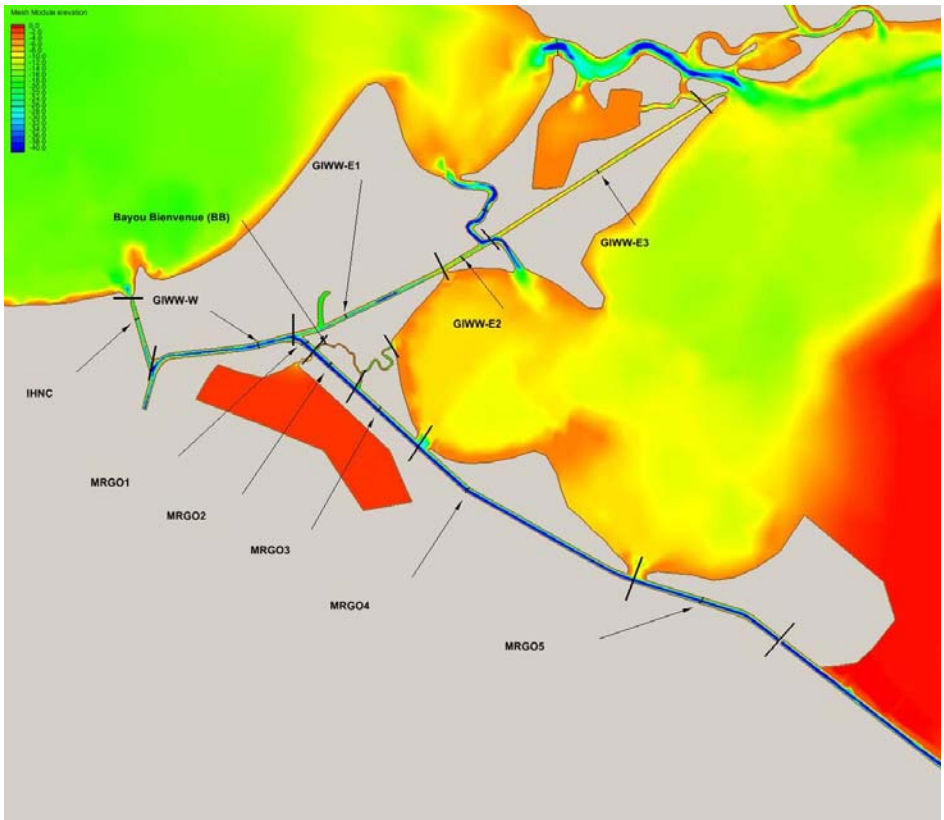


Figure 2 Cross-sections (Reach break locations) for hydrodynamic output

Figure 3 Reach break locations for Bayou Bienvenue

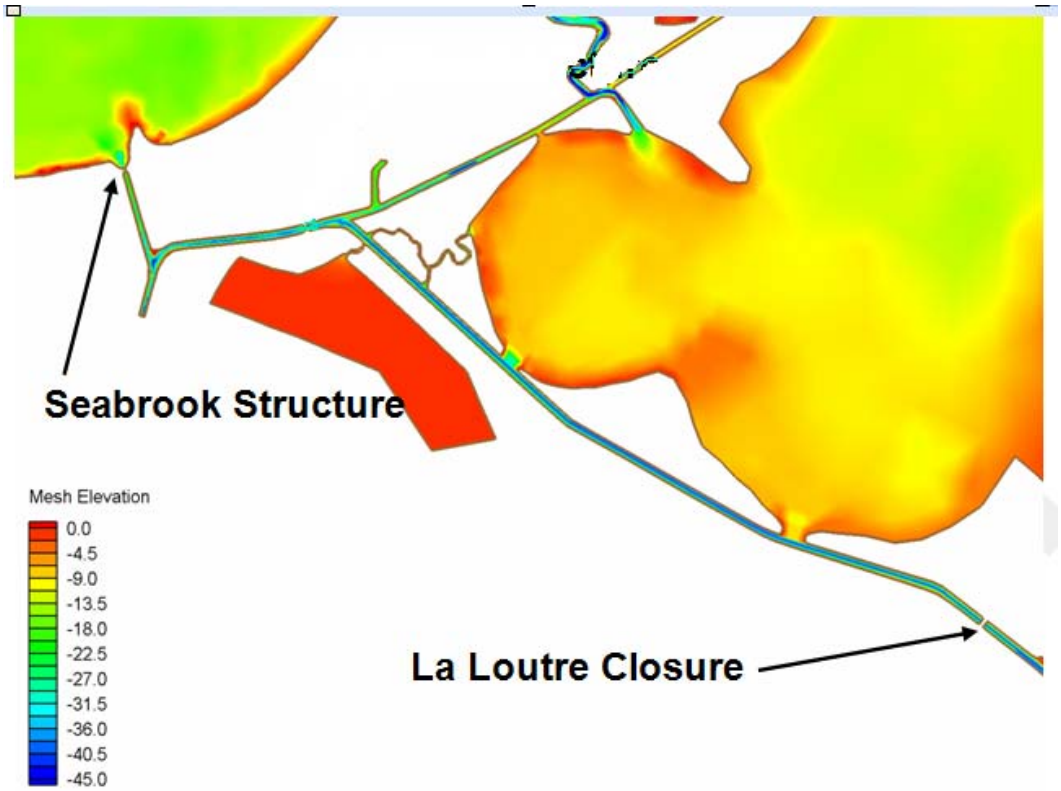


Figure 4 Location of Seabrook Structure

Version 10 of the Surface Water Modeling System (SMS, 2002) was used to estimate reach lengths. Canal widths at cross-section locations were provided by CHL from hydrodynamic model geometric inputs and correspond to widths at the canal bottom. These widths were assumed to be representative of the entire canal reach. The canal width and reach length were used to compute reach surface area. The area times the layer depth of 1.0 m (for bottom water) were used compute reach volume. The reach lengths, widths, surface areas, and bottom water volumes are given in-Table 2. With 11 study reaches and 2 scenarios and 3 months of simulations, there are 66 different combinations that required 66 spreadsheets to calculate bottom water DO for each reach and each scenario.

Table 2 Reach geometries

Study reach	Length, m	Width, m	Area of bottom surface, m^2	Volume, m^3
GIWW-W	9,264	260	2,411,414	2,411,414
GIWW-E1	10,691	141	1,508,162	1,508,162
GIWW-E2	3,654	113	414,577	414,577
GIWW-E3	16,355	59	960,919	960,919
MRGO-1	1,664	156	259,967	259,967
MRGO-2	3,511	150	527,508	527,508
MRGO-3	5,489	154	845,530	845,530
MRGO-4	16,423	159	2,617,115	2,617,115
MRGO-5	10,388	122	1,265,663	1,265,663
BB	8,325	75	624,251	624,251
IHNC	4,782	130	622,657	622,657

Hydrodynamic Conditions

The hydrodynamics for each scenario and each reach break (CSTR) were provided by CHL. These consisted of hourly bottom velocities, hourly unfiltered total cross-sectional flows (bank to bank and surface to bottom), hourly filtered total cross-sectional flows (tidal component or influence were removed), and monthly averaged surface and bottom salinities for the month of April, August, and September. The filtered flows had tidal components were filtered out using a program that employed a Fast Fourier Transform method and a boxcar filter. The filtering removed the tidal signal (influence) from the total flow across the cross-section and the results were the residual flow that needed to calculate DO. The bottom velocities were archived from the last 7-node vertical mesh from the bottom. The surface water velocities could be obtained from the top-most node of the 7-node vertical mesh. Only bottom (one meter) water velocities, surface and bottom salinities, and water depths at the cross-sections were used for DO calculations.

The bottom velocities were averaged to obtain the monthly average residual velocities. These residual velocities were multiplied by the canal bottom width of the cross section and 1.0 m of depth to obtain the residual bottom flow needed for the DO analysis.

The monthly average of the hourly, filtered cross-sectional total flows are shown in Tables 3, 4, and 5 for each scenario, each cross-section, and each month of simulation, where positive flow is in the northward and west-

ward direction, i.e., towards Lake Pontchartrain and negative flow represents the opposite or south east direction (Dortch and Martin 2008). For the Bayou Bienvenue (BB) cross-section, a net zero cross-sectional residual flow is expected since flow can only enter and leave at one location, thus, there should be no net flow entering or leaving. However, as shown in the tables, the total residual flow is small, but not exactly zero, which could be expected when computing Eulerian residual flows (Dortch et al. 1991). As this is a tidal system, it is probable that the residual for the surface is travelling in the opposite direction of the bottom and therefore combining it with the bottom residual would produce a residual much closer to zero. IHNC is not a completely closed system for the proposed scenario; therefore there will be always some amount of flow, especially when there is wind on the system. The flow values for IHNC (the proposed scenario) have been greatly reduced from the base scenario.

Table 3 Total cross-sectional residual flows, m3/sec, for April

Cross-section scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO3	MRGO4	MROG5	Bayou Bienve-nue(BB)	IHNC
Base	7.44	1.20	-6.28	-5.03	9.54	-2.16	-4.95	11.12	14.34	-0.0019	10.00
Proposed	-8.84	-6.42	-6.38	-5.21	7.95	-2.23	-6.60	9.53	14.40	-0.0019	-1.55

Table 4 Total cross-sectional residual flows, m3/sec, for August

Cross-section scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO3	MRGO4	MROG5	Bayou Bienve-nue(BB)	IHNC
Base	81.76	69.47	39.24	-5.15	31.17	40.43	116.50	397.90	33.90	0.0007	40.16
Proposed	45.78	58.96	35.95	-5.09	31.98	40.44	86.20	396.43	33.78	0.0004	11.79

Table 5 Total cross-sectional residual flows, m3/sec, for September

Cross-section scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO3	MRGO4	MROG5	Bayou Bienve-nue(BB)	IHNC
Base	143.97	82.10	39.18	-3.96	26.73	39.75	114.03	398.19	35.78	0.0010	49.91
Proposed	55.22	75.00	35.74	-3.96	24.79	39.81	84.02	396.64	35.65	0.0005	12.11

The hydrodynamic simulations provided total cross-sectional residual flows as shown in Tables 3 through 5 and the bottom residual velocities (Tables 6 through 8). As shown in the above tables, the spring (April) flows are lower than the summer flow (August/September), while one could expect higher flow for April simulations since the spring floods occurring in April. We compared the results with other simulated flow data using another model (ADH) for the same location. The ADH model also

showed similar results (higher flow for March than for September). We are using the tidal signal at our boundary for the year 2006. The ADH model of the same system using 2008 tidal data and September water surface elevations were higher than March water surface elevations which would indicate more flow in September than in March. ADH model had a comparison of the tidal signal for March and September and from the 2008 data, the March tides are more extreme and less set up. This is due to the effects of the spring floods and wind. Where as the September tides, the diurnal spring-neap is more established. It appears that more water is getting into the system during September. Because both models seem to agree, we are assuming that the tidal signal for April is more extreme and less set up where as the tidal signal for August and September is more established, therefore more water is getting into the system in the later months.

The bottom residual velocities were used to calculate bottom residual flows (Q in Equations 3 and 4). The calculated monthly averaged bottom flows are shown in Table 6 through 8. The bottom residual flows also seem reasonable for most cross-sections and scenario conditions. For example, there is a consistently zero residual bottom flow for BB cross-section. The positive values of the residual bottom flows indicate that flow is moving toward the Lake on the bottom, and there is most likely a reverse residual flow on the surface moving towards the Gulf. As shown later in Section on Evaluation of DO at a location near Seabrook Structure, at a location very close to the proposed Seabrook Structure, the bottom flow would be zero.

Table 6 Bottom residual flows, m3/sec, for April, used to compute bottom DO.

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO3	MRGO4	MRGO5	BB	IHNC
Base	0.56	-0.33	-0.40	-0.44	-0.51	-0.83	-0.27	0.67	1.44	0.00	1.13
Proposed	-0.75	-1.07	-0.41	-0.44	-0.37	-0.84	-0.36	0.60	1.44	0.00	-0.18

Table 7 Bottom residual flows, m3/sec, for August, used to compute bottom DO.

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO3	MRGO4	MRGO5	BB	IHNC
Base	7.00	7.16	4.11	-0.19	-1.72	3.34	5.76	19.04	2.51	0.00	4.73
Proposed	3.91	6.13	3.80	-0.20	-1.78	3.33	4.51	18.97	2.51	0.00	1.40

Table 8 Bottom residual flows, m3/sec, for September, used to compute bottom DO.

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO3	MRGO4	MRGO5	BB	IHNC
Base	12.35	8.37	3.99	-0.09	-1.44	3.25	5.61	18.91	2.54	0.00	5.82
Proposed	4.69	7.74	3.66	-0.10	-1.34	3.25	4.36	18.84	2.54	0.00	1.42

The flows in Tables 6, 7, and 8 were entered into each of the 66 spreadsheets to provide the flushing flow rate to compute DO. Water depth for each cross-section (reach CSTR, Figure 2) was determined by examining model bathymetry depths with SMS software. The cross-section depths were assumed to represent the average reach depth. The depth of each reach used for DO modeling is shown in Table 9. As shown in Table 9, the water depth for base and proposed scenarios are almost the same for every study reach except at Bayou Bienvenuse (BB), where the proposed water depths are lower for all three months of the hydrodynamic simulations. As the actual elevations for BB are actually less than this, the proposed simulation afforded an opportunity to correct the elevation for BB. The base simulations had already been performed in the previous study and the mesh runs for this study (the proposed scenario) was modified only for the BB closure.

Table 9 Reach water depths for Base and Proposed Scenarios

Reach	Total water depth, meters					
	Simulation Months in 2006					
	Base Scenario			Proposed Scenario		
	April	August	September	April	August	September
GIWW-W	12.45	11.91	11.98	12.44	11.89	11.96
GIWW-E1	11.20	10.62	10.67	11.21	10.62	10.67
GIWW-E2	7.40	6.82	6.87	7.38	6.81	6.86
GIWW-E3	5.55	4.99	5.04	5.54	4.98	5.03
MRGO1	12.88	12.34	12.41	12.93	12.38	12.44
MRGO2	13.19	12.59	12.63	13.19	12.59	12.63
MRGO3	13.19	12.59	12.63	13.19	12.59	12.63
MRGO4	13.19	12.60	12.64	13.19	12.60	12.64
MROG5	13.19	12.63	12.67	13.19	12.63	12.67
Bayou Bienvenue(BB)	6.78	6.24	6.31	3.78	3.23	3.30
IHNC	9.29	8.74	8.81	9.13	8.58	8.65

Hourly surface and bottom salinities output by the hydrodynamic model were averaged over April, August, and September for use in the DO model to compute vertical eddy diffusivities. The monthly averaged surface and bottom salinities are shown in Tables 10, 11, and 12 for surface water salinities and Tables 13, 14, and 15 for the bottom salinities for each scenario and cross-section. These data complete the data input requirements for the DO model.

Table 10 April monthly averaged surface salinities, ppt

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue (BB)	IHNC
Base	8.168	7.905	7.348	7.126	8.309	8.043	8.009	8.169	8.652	8.370	6.946
Proposed	9.560	8.452	7.389	7.136	9.381	8.138	8.083	8.200	8.674	9.434	9.999

Table 11 August monthly averaged surface salinities, ppt

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue(BB)	IHNC
Base	8.696	10.497	11.940	13.492	9.171	13.146	13.413	13.722	13.085	9.119	6.508
Proposed	9.347	7.913	11.980	13.518	9.915	13.020	13.311	13.746	13.110	9.346	9.337

Table 12 September monthly averaged surface salinities, ppt

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue(BB)	IHNC
Base	10.259	12.897	14.767	16.194	10.991	16.341	16.559	16.816	16.265	10.898	7.408
Proposed	11.278	13.153	14.794	16.217	11.615	16.238	16.476	16.835	16.286	11.517	9.166

Table 13 April monthly averaged bottom salinities, ppt

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue BB)	IHNC
Base	8.167	7.903	7.343	7.127	8.312	8.043	8.009	8.169	8.652	8.370	7.010
Proposed	9.561	8.453	7.383	7.138	9.400	8.138	8.083	8.200	8.674	9.434	9.998

Table 14 August monthly averaged bottom salinities, ppt

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO4	MROG 5	Bayou Bienve-nue(BB)	IHNC
Base	8.767	8.248	11.928	13.501	9.169	13.147	13.415	13.722	13.084	9.120	6.814
Proposed	9.347	11.257	11.968	13.527	9.913	13.021	13.313	13.108	13.108	9.346	9.338

Table 15 September monthly averaged bottom salinities, ppt

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue (BB)	IHNC
Base	10.674	13.759	14.755	16.201	11.041	16.342	16.560	16.816	16.264	10.898	8.031
Proposed	11.281	13.881	14.783	16.224	11.627	16.238	16.478	16.835	16.285	11.517	9.162

4 Model Results

Salinity Stratification

Salinity stratification has a strong influence on the mixing of surface water with higher DO into bottom water with lower DO. Low (weaker) stratification means a fully mixed or less difference between surface and bottom salinity and is usually indicative of higher bottom DO, and High (stronger) stratification means much difference between surface and bottom salinity and is usually the reverse.

The degree of salinity stratification for the two scenarios and months of simulations are given in Tables 16 through 19. The green, yellow and orange colors indicate strength of stratification of low, medium, and high, respectfully. The symbol (–) indicates none stratification. For this study, we selected arbitrary ranges (classes) of Low, Medium, and High to indicate the degree of differences between the surface and bottom salinities. Table 19 shows the level of salinity stratification with levels of relatively high, low, and medium and range (value) of salinities for this classification. As shown in the tables, the salinity stratifications were low for most of the DO values. There were a few locations that exhibited high stratification such as GIWW-E1 reach for the months of August and September.

The DO formulation used in this study requires that the surface water salinity number to be lower than the bottom water salinity value (Dortch and Martin 2008). There were some locations (reaches) that exhibited salinity inversions (calculated surface water salinity was greater than bottom salinity). An inversion was treated as fully mixed, or no salinity stratification, which results in higher bottom DO.

Table 16 Salinity stratification (surface and bottom salinity difference) for April

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue (BB)	IHNC
Base	0.001	0.002	0.005	0.001	0.003	-	-	-	-	-	0.064
Proposed	0.001	0.001	0.006	0.002	0.019	-	-	-	-	-	0.001

Green Color = Low Stratification
Yellow = Medium Stratification
Orange Color = High Stratification

Table 17 Salinity stratification (surface and bottom salinity difference) for August

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue (BB)	IHNC
Base	0.071	2.249	0.012	0.009	0.002	0.001	0.002	-	0.001	0.001	0.306
Proposed	-	3.344	0.012	0.009	0.002	0.001	0.002	0.638	0.002	-	0.001

Green Color = Low Stratification
Yellow = Medium Stratification
Orange Color = High Stratification

Table 18 Salinity stratification (surface and bottom salinity difference) for September

Cross-section Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MROG 5	Bayou Bienve-nue (BB)	IHNC
Base	0.415	0.862	0.012	0.007	0.050	0.001	0.001	-	0.001	-	0.623
Proposed	0.003	0.728	0.011	0.007	0.012	-	0.002	-	0.001	-	0.004

Green Color = Low Stratification
Yellow = Medium Stratification
Orange Color = High Stratification

Table 19 Level of salinity stratification

Reach Scenario	GIWW - W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO1	MRGO2	MRGO 3	MRGO 4	MRGO 5	BB	IHNC
Simulation Month	April										
Base	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium
Proposed	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low
Simulation Month	August										
Base	M	High	Low	Low	Low	Low	Low	Low	Low	Low	Medium
Proposed	Low	High	Low	Low	Low	Low	Low	High	Low	Low	Low
Simulation Month	September										
Base	High	High	Low	Low	Medium	Low	Low	Low	Low	Low	High
Proposed	Low	High	Low	Low	Low	Low	Low	Low	Low	Low	Low

Salinity values for 0.00 ≤ Low ≤ 0.012 ppt
0.019 ≤ Medium ≤ 0.306
0.415 ≤ High ≤3.344

Bottom DO Results

Bottom DO values that were computed with the spreadsheet model are shown in Tables 20, 21, and 22 for each reach, scenario, and month of simulation. Louisiana DO standards are 5.0 mg/L for freshwater and coastal marine waters with salinity less that 10 ppt and 4.0 mg/L for estuarine waters with salinity greater than 10 ppt. A DO standard of 4.0 mg/L was used for comparison with results.

According to the hydrodynamic simulations data, Cross-sections GIWW-E1 had unique results for month of August. Surface salinity reduced from 10.497 ppt to 7.913 ppt, but the bottom (1 m) salinity increased from 8.248 ppt to 11.257 ppt when comparing base with proposed. This caused the DO value to decrease from 4.09 to 0.0 mg/L. However, if we assume a fully mixed of salinity between surface and bottom water, the DO value would be 4.05 mg/L (Table 21).

Table 20 Computed bottom DO, mg/L for April

Reach Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MRGO 5	BB	IHNC
Base	3.51	3.69	4.29	4.55	3.63	3.56	3.41	3.40	3.51	4.35	1.87
Proposed	3.52	3.73	4.30	4.55	3.57	3.56	3.42	3.40	3.51	4.82	4.00

Yellow Color = DO equal or greater than 4.0 mg/L

Table 21 Computed bottom DO, mg/L for August

Reach Scenario	GIW W-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MRGO 5	BB	IHNC
Base	1.97	4.09	4.61	4.60	4.04	4.01	4.04	4.06	3.67	4.43	2.18
Proposed	3.72	0.00	4.60	4.60	4.05	4.01	3.94	4.06	3.67	4.91	4.19
Proposed (assuming mixed salinity between surface and bottom water at GIWW-E1		4.05									

Yellow Color = DO equal or greater than 4.0 mg/L
Red Color = DO calculation required more explaining (see the text)

Table 22 Computed bottom DO, mg/L for September

Reach Scenario	GIWW-W	GIWW-E1	GIWW-E2	GIWW-E3	MRGO 1	MRGO 2	MRGO 3	MRGO 4	MRGO 5	BB	IHNC
Base	0.78	0.65	4.60	4.62	3.12	3.99	4.02	4.06	3.66	4.42	2.46
Proposed	3.74	0.42	4.59	4.62	3.94	3.99	3.93	4.06	3.66	4.89	4.18

Yellow Color = DO equal or greater than 4.0 mg/L
Orange Color = Shows Lowest DO for both base and proposed conditions

The above results indicate that proposed scenario may increase the DO values at some locations and decrease the values at other locations (see Tables 20, 21, and 22). For example, the DO values at IHNC cross-section would increase for all months of the simulations. This is because the salinity stratification changed from Medium and High (base) to Low (proposed). DO values at GIWW-W reach was improved also significantly for

month of September. The proposed scenario may improve DO value at MRGO1 only during September flow conditions. The DO value at GIWW-E1 was reduced during the August simulation from 4.09 mg/L at the base condition to zero at the proposed condition. The reason for this was major differences between the average calculated surface and the bottom salinities at GIWW-E1 cross-section from the August hydrodynamic simulations (see Tables 11 and 14). However, if we assume a fully mixed of surface water salinity and bottom water salinity, the DO value for the proposed condition would change to 4.05 mg/L as shown in Table 21. The cross-sections (reaches) that have DO of 4.0 mg/L and higher are shown in yellow colors in the tables. The bottom DO values for each reach were averaged across all scenarios as given in Table 23 in the rank order of lowest to highest. Reach BB exhibited the highest average bottom DO for all months of the simulations, while reach IHNC exhibited the lowest with an average of 2.94 mg/L during April; GIWW-E1 exhibited the lowest with an average of 2.05 mg/L during August and average of 0.54 mg/L during September.

Table 23 Reach bottom DO averaged across all (two) scenarios

Average DO, mg/L					
Reach	April	Reach	August	Reach	September
IHNC	2.94	GIWW-E1	2.05	GIWW-E1	0.54
MRG04	3.40	GIWW-W	2.85	GIWW-W	2.26
MRG03	3.42	IHNC	3.19	IHNC	3.32
MRG05	3.51	MRG05	3.67	MRG01	3.53
GIWW-W	3.52	MRG03	3.99	MRG05	3.66
MRG02	3.56	MRG02	4.01	MRG03	3.98
MRG01	3.60	MRG01	4.05	MRG02	3.99
GIWW-E1	3.71	MRG04	4.06	MRG04	4.06
GIWW-E2	4.30	GIWW-E3	4.60	GIWW-E2	4.60
GIWW-E3	4.55	GIWW-E2	4.61	GIWW-E3	4.62
BB	4.59	BB	4.67	BB	4.66

The bottom DO values for each scenario were averaged across all the reaches (Table 24) in the rank order of lowest to highest. Overall, according to Table 24, the proposed scenario may provide slightly higher (negligible changes) DO values for the whole system for all three months of the simulations the base scenario. Considering all assumptions used in the modeling and other uncertainties, the DO changes between two scenarios would not measurable.

Table 24 Scenario bottom DO averaged across all reaches

Scenario	Average DO, mg/L		
	April	August	September
Base	3.62	3.79	3.31
Proposed	3.85	3.80	3.82

Evaluation of DO at a location near Seabrook Structure

To correctly evaluate the effect of the temporary closure of the Seabrook structure during construction (the proposed scenario) on DO, three numerical points (one physical location) very close to the structure were selected for DO calculations as these three points graphically coincide with each other and shown as a small red circle in Figure 5.

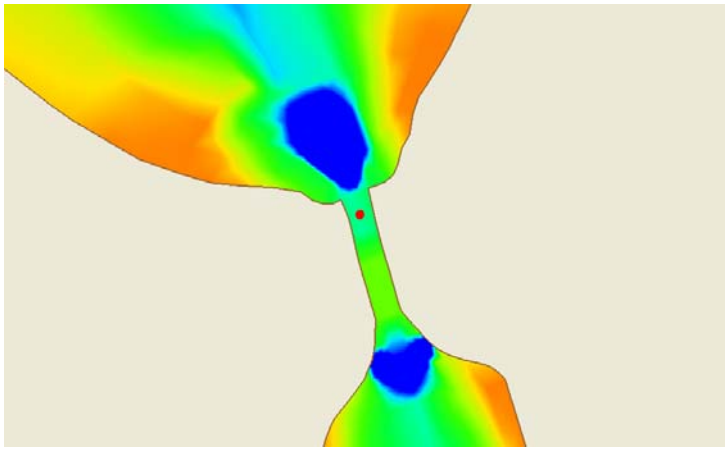


Figure 5 Location of selected coincided points (red circle) north of the Seabrook structure

The geometry information for this selected location is given in Table 25. Other hydrodynamic data required for DO calculations were extracted from the simulation results that were done for other locations (reaches). The flow rates are zero for the proposed scenario (Seabrook Structure closed) at this location. The hydrodynamic data are given in Tables 26 through 29. The average values of these three numerical points were used for DO calculations. Tables 28 and 29 provide salinity data for the surface and bottom water. The salinity stratification (salinity difference between surface and bottom water) is given in Table 30. The salinity stratification changes from low in the base scenario to none in the proposed scenario (Table 30). Table 31 provides DO calculations for three months of simulations and for base and proposed scenarios. As shown in Table 31, the proposed scenario would decrease the DO values at this location north of Seabrook structure.

Table 25 Reach geometries for new location (points)

Base Scenario				
Study reach	Length, m	Width, m	Surface area, m^2	Volume, m^3
Point (s), north of Seabrook Structure	79	29	2,295	2,295
Proposed Scenario				
Study reach	Length, m	Width, m	Surface area, m^2	Volume, m^3
Point (s), north of Seabrook Structure	79	29	2,295	2,295

Table 26 New Reach water depths for Base and Proposed Scenarios

New Reach	Total water depth, meters					
	Simulation Months in 2006					
	Base Scenario			Proposed Scenario		
	April	August	September	April	August	September
Point (s)	8.36	7.83	7.90	8.35	7.81	7.88

Table 27 Bottom residual flows, m3/sec, used to compute DO

New Reach	Point 1	Point 2	Point 3	Average
	April			April
Base	0.02	0.20	0.24	0.22
Proposed	0.00	0.00	0.00	0.00
	August			August
Base	0.45	0.41	0.23	0.36
Proposed	0.00	0.00	0.00	0.00
	September			September
Base	0.60	0.59	0.37	0.52
Proposed	0.00	0.00	0.00	0.00

Table 28 Monthly averaged surface salinities, ppt

New Reach	Point 1	Point 2	Point 3	Average
	April			April
Base	6.463	6.493	6.523	6.493
Proposed	6.212	6.212	6.212	6.212
	August			August
Base	5.835	5.889	5.943	5.889
Proposed	5.459	5.459	5.459	5.459
	September			September
Base	6.386	6.473	6.560	6.473
Proposed	5.846	5.845	5.845	5.845

Table 29 Monthly averaged bottom salinities, ppt

New Reach	Point 1	Point 2	Point 3	Average
	April			April
Base	6.441	6.437	6.428	6.435
Proposed	6.212	6.212	6.212	6.212
	August			August
Base	5.843	5.831	5.812	5.829
Proposed	5.459	5.459	5.459	5.459
	September			September
Base	6.497	6.475	6.445	6.472
Proposed	5.845	5.845	5.845	5.845

Table 30 Salinity stratification (difference between surface and bottom salinity)

New Reach	Point 1	Point 2	Point 3	Average
	April			April
Base	0.022	0.056	0.095	0.058
Proposed	-	-	-	-
	August			August
Base	0.008	0.058	0.131	0.060
Proposed	-	-	-	-
	September			September
Base	0.111	0.002	0.115	0.001
Proposed	0.001	-	-	-

Yellow = Low Stratification
Green = None or Negligible Stratification

The DO formulation presented here (Chapter 2) requires that surface water salinity to be lower than the bottom salinity. There were some reach locations that exhibited salinity inversions (surface salinity greater than bottom salinity. An inversion was treated as fully mixed, or no salinity stratification, which results in higher bottom DO. Of particular concern was the inversion associated with base scenario for the location near north of Seabrook structure. Although Table 31 shows a low stratification for base scenario, a fully mixed (none stratification) was used for the base scenario DO values given in Table 31.

Table 31 Computed bottom DO for new location, mg/L

New Reach	New Location (North IHNC)	
Simulation Month	DO (April)	Salinity Stratification
Base	5.15	Low
Proposed	4.11	None
Simulation Month	DO (August)	
Base	5.24	Low
Proposed	4.19	None
Simulation Month	DO (September)	
Base	5.29	Low
Proposed	4.18	None

5 Conclusions and Recommendations

The Dissolved Oxygen results presented in this report rely on the hydrodynamic data used as input. Among the hydrodynamic parameters used in DO calculations the salinity stratifications has a major role.

Chapters 2 and 3 describe parameters and assumptions used in the development and implementation of the DO model and those that affect the model uncertainty. For example, it was assumed that the DO of ambient water that mixes down from the surface and flushes into the canals from external waters was at 80-percent saturation for an ambient temperature and salinity of 30 oC and 20 ppt, respectively, yielding an ambient DO value of 5.42 mg/L. The saturation of 80 percent is reasonable, but actual values could be higher or lower.

We assumed that in-flushing *DO (*80-percent saturation) came from outside the system. For some inner reaches, the inflowing water and *DO* can come from an adjacent reach that can have lower *DO*. In these cases, the actual bottom *DO* could be less than the estimates presented. A potential refinement to the model would be to consider flushing from adjacent reaches rather than from outside waters for the inner, isolated reaches.

Sediment oxygen demand could be higher or lower than the assumed value of 1.0 g/m2/day at 20 °C. The upper limit of vertical eddy diffusivity was set at 2.0 cm^2/sec, which is reasonable based upon the existence of the slightest temperature difference between surface and bottom water. Results are more sensitive to salinity stratification for weak stratification and more sensitive to canal flushing flow rate for stronger stratification. However, it should be recognized that stratification and flushing flow are co-dependent.

There were some DO calculations that exhibited salinity inversions (surface salinity greater than bottom salinity. Of particular concern was the inversion associated with base scenario for the location near north of Seabrook structure. An inversion was treated as fully mixed, or no salinity stratification, which results in higher bottom DO.

Salinity stratification and canal bottom water flushing flow rates were the only scenario-dependent input variables, and both were extracted from the 3D hydrodynamic model. Use of these inputs helped to reduce model uncertainty. Potential improvements could be made to the model, such as considering bottom *DO* from adjacent reaches for in-flushing *DO* for inner, isolated reaches. However, the best approach for minimizing model error and uncertainty would be to apply a fully 3D water quality model, coupled to a 3D hydrodynamic model. Application of a 3D water quality model would greatly reduce the number of assumptions and uncertainty while providing time-varying responses with much greater spatial resolution. However, it is advisable to have access to quality observational data sets for model calibration and validation when applying comprehensive numerical water quality models, and it appears that this system may be lacking adequate observational data at this time for such applications. It would be prudent to begin collection of sufficient field water quality data to support more detailed future model-based analyses with less uncertainty.

The screening-level model described herein provides first-order estimates of bottom *DO* impacts resulting from the structural alternative within the canals. Given the model simplicity, these *DO* results should not be used as exact predictions, rather the results are indicative of what to expect. In this case, the modified canal system is expected to experience bottom *DO* that is less than state standards at multiple locations during the spring and summer seasons.

IHNC is not a completely closed system for the proposed scenario; therefore there will be always some amount of flow, especially when there is wind on the system. The flow values for IHNC (the proposed scenario) have been greatly reduced from the base scenario. However, the DO values at IHNC cross-section would increase for all months of the simulations because the salinity stratification changed from Medium and High in the base scenario to Low in the proposed scenario.

For a location very close and north of the Seabrook structure, the salinity stratification changed from low in the base scenario to none in the proposed scenario. The flow in this area would be zero during the construction. The proposed scenario DO calculated values were slightly lower than the base DO values at this location north of Seabrook structure.

References

Chapra, S. C. 1997. *Surface Water Quality Modeling*, McGraw-Hill, New York, NY.

Dortch, M.S., Martin, S. K., 2008. Estimation of Bottom Water Dissolved Oxygen in the Mississippi River Gulf Outlet and Gulf Intracoastal Waterway Resulting from Proposed Structures," ERDC/EL TR-08-9, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Dortch, M. S., Chapman, R. S., and Abt, S. R. 1991. "Application of Three-Dimensional, Lagrangian Residual Transport," *J. Hydraulic Engineering*, ASCE, Vol. 118, No. 6, pp. 831-848.

Martin, S. K., and McAlpin, T. O. 2008. "Flood Gate Analysis of the Mississippi River Gulf Outlet and Gulf Intracoastal Waterway, " draft technical report, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

SMS. 2002. "Version 8.0 Reference Manual for the Surface Water Modeling System," Brigham Young University, Engineering Graphics Laboratory, Provo, Utah. http://chl.wes.army.mil/software/tabs/docs.htp]

Thomann, R. V., and Mueller, J. A. 1987. *Principles of Surface Water Quality Modeling and Control*, Harper Collins *Publishers*, New York, NY.

U.S. Geological Survey (USGS). 2005. Water Resources Data, Louisiana, Water Year 2005 . Water-Data Report LA-05-1. U.S. Department of the Interior, U.S. Geological Survey.