# Desktop Study for Sediment-Related Problems at Sabine Neches Project

## VOLUME 3
## SUPPLEMENTARY REPORT

**September 2004**

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***Final Report***
**June 2005**

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# Volume 3: Supplementary Report
## Contents

# Draft Report on Additional Sediment-Related Studies for Sabine Neches Project September 2004

## Introduction

ERDC conducted Desktop Study for sediment-related problems at Sabine Neches Project. This study consisted of assessing the impact of the proposed navigation channel modifications on the following three sediment-related issues.

Study 1: Siltation in the modified navigation channel.
Study 2: Pleasure Island Erosion.
Study 3: Erosion of eastern shoreline of Sabine Lake.

ERDC also conducted numerical hydrodynamic modeling work for the Sabine Neches Project. The 2D model was set up as the first step and was verified with the then available field data on currents and water levels. The model was proposed to be converted later to 3D after results of additional field data on currents and salinity became available.

Results from the fully verified 3D numerical salinity model were not available for conducting the desktop sediment studies. However, in view of urgency of work it was decided to complete the sediment studies based on the data available from the 2D numerical model as of that time and re-visit the issue after the salinity model results were available.

A two-volume draft report covering all the three studies listed above was submitted to the Galveston District in December 2002 for review and comments. Volume 1 included the following 4 Parts and Volume 2 included Appendices A through L.

Part 1: Project Information and Background Study
Part 2: Effect of Navigation Channel Modifications
Part 3: Pleasure Island Erosion
Part 4: Sabine Lake Eastern Shore Erosion

Part 3 of this report on Pleasure Island Erosion was revised by ERDC for addressing the comments received from the District. The revised report was submitted in October 2003.

After reviewing and discussing the report extensively, the District supplied additional data and requested ERDC to make a second revision of Part 3 dealing with Pleasure Island Erosion. The District also needed explanation on some of the miscellaneous points covered earlier in the report. The Galveston District also requested a re-evaluation of navigation channel shoaling quantities estimated in Part 2 of the December 2002 Report by using the 3D numerical model study results, which are now available.

## Reports On New Work

The following three reports covering the new work conducted at ERDC have been prepared to address all the comments and to meet all the requirements of the Galveston

District. Report 1 is presented later in this section whereas Report 2 and Report 3 are presented separately.

## Report 1: Miscellaneous Explanation

Comment 1
Explain how Figure 3.2.1 in Part 3 (Revised) October 2003 Report was generated and whether it is site-specific.

## Report 2: Pleasure Island Erosion Study

This report has been completely rewritten to address all the comments offered by the Galveston District on the earlier ERDC Report.

"Part 3: Pleasure Island Erosion dated December 2002" as well as "Part 3 (Revised) Pleasure Island Erosion, dated October 2003" may now be discarded and the report submitted now be made a part of the ERDC Report on "Desktop study for sediment-related problems at Sabine Neches Project." The combined report will now be dated September 2004, which will include all the new work presented under Report 3 here.

The following comments have been taken into account while rewriting Report 2.
Comment 1.
Elaborate on the laboratory tests conducted for determining the critical shear strength of sediment samples.

Comment 2.
Obtain from the Galveston District information on the future vessel traffic predictions giving frequency and types of vessels after navigation channel modification and use it for more justifiable estimates of future erosion.

Comment 3.
Obtain from Galveston District historical data on aerial photographs, bathymetric and shoreline survey data on eroding shoreline at Pleasure Island. Use this information in making estimates of future shoreline recession rates.

Comment 4.
Provide more justification for the estimated 10 percent increase in bank erosion rate.

## Report 3: Re-evaluation of Navigation Channel Shoaling

Comment 1
Re-evaluate navigation channel shoaling estimate by using results of 3D hydrodynamic model.

# Supplementary Report 1

# Miscellaneous Explanation

# DRAFT

**September 2004**

**Supplementary Report 1**
**Miscellaneous Explanation**
**DRAFT**

**September 2004**

Comment
Explain how Figure 3.2.1 in Part 3 (Revised) October 2003 Report was generated and whether it is site-specific.
----------------------------------------------------------------------------------------------------

Figure 3.2.1 is reproduced below for ready reference.

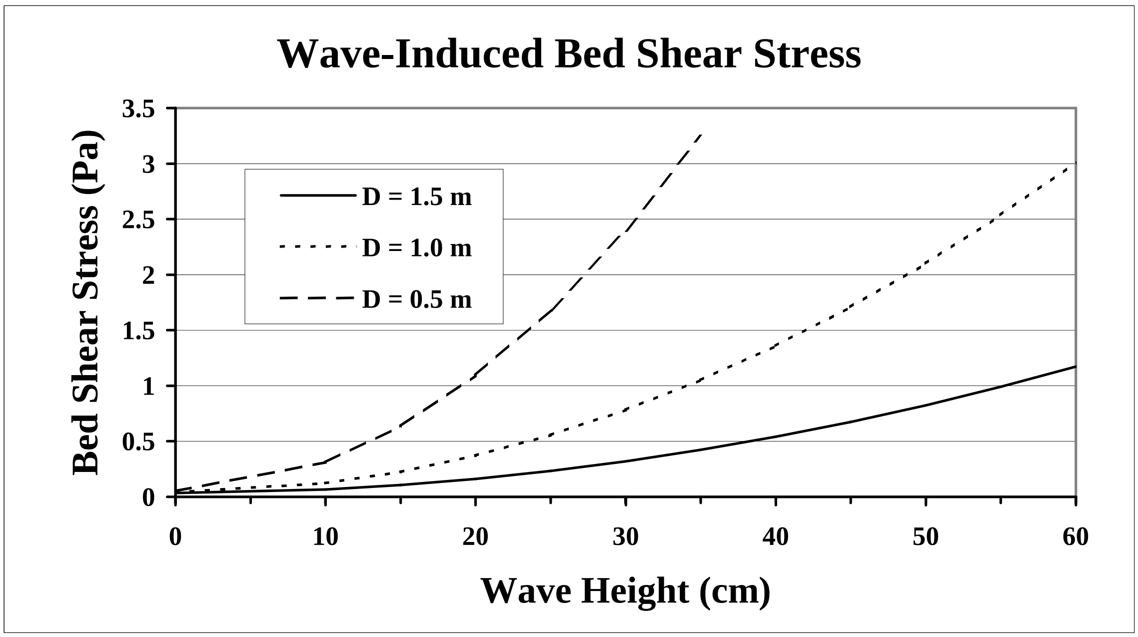



Figure 3.2.1: Wave-induced bed shear stresses under varying wave heights at 0.5, 1.0, and 1.5 meter water depth. (1 Pa is equal to 0.0209 pounds per square foot.)

The above figure provides values of bed shear stresses generated by waves of different heights in different water depths. This figure was generated through a complex algorithm, which calculates values of wave-induced bed shear stresses (Equation 9) and the magnitudes of sediment resuspension (Equation 2). The algorithm and the equations used are given below. The algorithm can be run on a desktop personal computer. Parchure et al (2001) provides more details in the report "Wave-induced sediment resuspension near the shoreline of the Upper Mississippi River System." The information contained in Figure 3.2.1 is not site-specific.

## Resuspension Algorithm

A commonly used form of erosion equation is

$$E = M\left[\frac{\tau_b - \tau_e}{\tau_e}\right] \qquad (1)$$

In this equation E is the erosion rate, M is the erosion rate constant, $\tau_b$ is the bed shear stress, and $\tau_e$ is the critical shear stress for erosion. The erosion rate constant M is the proportionality constant in the erosion rate equation. Typical results of laboratory tests are presented in the form of a plot of erosion rate as a function of flow-induced bed shear stress. Such plots give the critical shear stress for erosion and the slope of line gives erosion rate constant.

The sediment suspension model, VESTUNS, developed at the University of Florida, uses a one-dimensional (vertical, 1DV) numerical solution of the convection diffusion equation to compute the vertical profile of sediment. It accounts for sediment settling and deposition plus erosion from the bed and upward diffusion by short period waves and/or a superimposed current. It considers the bed to be formed of mud with significant quantities of cohesive material. VESTUNS is based on the model VEST (Mehta and Li, 1996).

The model solves the 1DV equation

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial C}{\partial z} + W_s C\right) \qquad (2)$$

where
$C$ = sediment mass concentration,
$t$ = time,
$z$ = vertical dimension,
$K$ = diffusion coefficient, and
$W_s$ = sediment settling velocity, with the latter two parameters calculated from the following expressions.

Equation (2) is solved by an implicit finite difference scheme.

$$K = \frac{\alpha_w H^2 \sigma \dfrac{\sinh^2(kz)}{2\sinh^2(kh)} + \kappa u_* z\left(1 - \dfrac{z}{h}\right)}{\left(1 + \alpha_0 R_i\right)^{\beta_0}} \qquad (3)$$

$$Ws = \begin{cases} W_{sf} & C < C_{sf} \\ \dfrac{a\, C_{m1}}{\left(C^2 + b^2\right)^{m2}} & C > C_{sf} \end{cases} \quad (4)$$

where

. $\alpha_w$ = wave diffusion constant,
$H$ = wave height,
$\sigma$ = wave frequency,
$k$ = wave number, = $2\Pi/L$
L = wave length
$h$ = water depth,
$\kappa$ = von Karman coefficient, taken to be 0.4,
$u_*$ = shear velocity
. $\alpha_0$, $\beta_0$ = empirical coefficients,
$W_{sf}$ = free settling velocity of sediment, determined by experiment,
$C_{sf}$ = upper concentration limit on free settling,
$a$, $b$, $m_1$, $m_2$ = empirical coefficients, and
$R_i$ = gradient Richardson number, given by:

$$R_i = \frac{-g \dfrac{\partial \rho}{\partial z}}{\rho \left( \dfrac{\partial u}{\partial z} \right)^2} \quad (5)$$

where
$g$ = acceleration of gravity,
$\rho$ = fluid density, and
$u$ = horizontal velocity (current plus wave).

The user specifies the initial concentration profile. Boundary conditions are zero concentration flux at the water surface and erosion/deposition flux at the bed, $F_n$, given by:

$$Fn = \begin{cases} -W_s C_{bed} \left[ 1 - \dfrac{\tau_b}{\tau_d} \right] & \tau_b \le \tau_d \\ 0 & \tau_d < \tau_b < \tau_e \\ +s\left(\tau_b - \tau_e\right) & \tau_b > \tau_e \end{cases} \quad (6)$$

where
$C_{bed}$ = sediment concentration just above the bed,

$\tau_b$ = bed shear stress,
$\tau_d$ = critical shear stress for deposition, determined by experiment,
$s$ = erosion rate constant, and
$\tau_e$ = critical shear stress for erosion, with the latter two given by:

$$s = s_{\max} e^{-a_r \tau_e^{b_r}} \qquad (7)$$

$$\tau_e = \alpha_e (\phi - \phi_e)^{\beta_e} \qquad (8)$$

where
$s_{\max}$, $a_r$, $b_r$, $\beta_e$ = empirical coefficients, and
$\phi$ = solids weight fraction, with $\phi_e$ the critical value below which the mud behaves like a fluid. The model allows for fluidization of the bed by waves, but that feature was not employed in this application.

The bed shear stress is calculated from:

$$\tau_b = \begin{cases} \frac{fw}{2} \rho u_b^2 & \textit{wave motion} \\ \frac{fc}{2} \rho U^2 & \textit{current} \end{cases} \qquad (9)$$

where
$f_w$ = wave friction factor,
$u_b$ = wave orbital velocity amplitude at the bed,
$U$ = depth averaged current velocity, and
$f_c$ = current friction factor.

$$\frac{1}{4\sqrt{f_w}} + \log \frac{1}{4\sqrt{f_w}} = -0.08 + \log \frac{A_{ab}}{K_s} \qquad (10)$$

$K$s = Nikuradse roughness parameter

$$A_{ab} = \frac{H/2 \cosh kh}{\sinh kh} \qquad (11)$$

$k$ = wave number, = $2\Pi/L$
L = wave length
$h$ = water depth,

$$fc = 2g \frac{n^2}{h^{1/3}} \qquad (12)$$

where

$n$ = Manning roughness coefficient.

**Reference**

T. M. Parchure, W. H. McAnally, and A. M. Teeter, Wave-induced sediment resuspension near the shorelines of the upper Mississippi River, Coastal and Hydraulics Laboratory, U. S. Army Engineer Research and Development Center, Vicksburg, MS. Interim Report ENV 20. Prepared for US Army Engineer Districts of Rock Island, St. Louis, and St. Paul.

# Supplementary Report 2

# Part 3_R2 (Second Revision)
# Pleasure Island Erosion Study

# DRAFT

**September 2004**

# Background Information About Supplementary Report 2

**December 2002**

A two-volume draft report covering all the three studies listed above was submitted to the Galveston District in December 2002 for review and comments. Volume 1 included the following 4 Parts and Volume 2 included Appendices A through L.

Part 1: Project Information and Background Study
Part 2: Effect of Navigation Channel Modifications
Part 3: Pleasure Island Erosion
Part 4: Sabine Lake Eastern Shore Erosion

**October 2003**

Part 3 of this report on Pleasure Island Erosion was revised by ERDC for addressing the comments received from the District. The revised report (R1) was submitted in October 2003.

**September 2004**

After reviewing and discussing the report extensively, the District supplied additional data and requested ERDC to make a second revision of Part 3 dealing with Pleasure Island Erosion. The District also needed explanation on some of the miscellaneous points covered earlier in the report. Hence a report with second revision (R2) was submitted in September 2004.

**June 2005**

The September 2004 report has been included in the Final June 2005 Report as “Supplementary Report 2” under Volume 3. It may be noted that the September 2004 report is included here only to provide a linkage to the first draft report dated December 2002. It has since been discarded and replaced by Part 3, Volume 1, Main Report dated June 2005.

Table of Contents

# Pleasure Island Erosion

# Chapter 3.1: Erosion Problem

## Historical Information

Pleasure Island (PI) is located between Port Arthur and Sabine Lake in Jefferson County, Texas (Figure 3.1.1). This is a man-made island, created from placement of dredged materials. The soil is very weakly consolidated, consisting primarily of silty clay with some sand.

Dredging of a privately financed channel 25 feet deep and 75 feet wide from Sabine Pass to the mouth of Taylor Bayou was completed in March 1899. By this time the jetties had been built sufficiently to obtain a 25 –foot draft channel up to the Sabine Pass area. The Sabine-Neches Canal was constructed to the same dimensions as the Port Arthur Canal and completed in 1916. Both the Port Arthur Canal and the Sabine-Neches Canal were excavated through low elevation land near the Sabine Lake shore, effectively creating a strip of land that is now an island. A review of a 1917 navigation chart suggests that the approximate location of the existing PI shoreline is where the Sabine Lake shoreline was when the original excavation was made. At that time the island appeared to be about 300 to 500 feet wide.

The navigation channel has been widened and deepened several times during the subsequent years. The channel depth was 30 feet in 1922, 34 feet in 1935, and 36 feet in 1946. By early 1960's the channel reached its present dimensions of 40 feet depth and 400 feet width. Essentially, all the width increases occurred on the east side of channel. Material taken out from the channel for both enlargement and maintenance was placed on the Pleasure Island, building up the land elevation. With each channel width increase (and progressive erosion) the original island with overlying hydraulic fill was removed and placed further to the east, thus creating the present island.

## Problem Description

About 6-mile length of the western shoreline of the Pleasure Island has been eroding significantly. The 6-mile shoreline extends from 1 mile south of the Martin Luther King (MLK) Bridge to 5 miles north of the bridge. It is feared that unless protective measures are taken, continued erosion would eventually threaten the T.B. Ellison Parkway, the sole access road to PI. The two critical areas are from station 198+86 to 268+60 for the Sabine Neches Canal and from station 130+00 to 230+00 for the Port Arthur Canal. The first area is west of the bulkhead and the second area is between the Round Island and Keith Lake. The erosion concern in Sabine Neches Canal reach is mainly along the bank of Pleasure Island whereas the erosion concern is along both the banks in the Port Arthur Canal reach. Although various types of shoreline protection efforts have been implemented on several sections of the shoreline, erosion continues and some protection measures have failed.

For the purpose of protecting the existing shoreline from further erosion, as authorized by the Texas Coastal Erosion Planning and Response Act (CEPRA), the Texas General Land Office (GLO) and Jefferson County have co-sponsored the Pleasure Island

Shoreline Protection Project. PBS&J Consultants, Houston, TX were appointed to develop a set of conceptual designs that would meet the project goals. The consultants have submitted a comprehensive Project Review Engineering Report dated November 2000 on the Pleasure Island shoreline protection project. Information related to history and description of site conditions contained in the consultant's report is reproduced in this chapter since it is relevant and unchanged.

Controlling erosion along this reach of Pleasure Island is important for many reasons. The first is that the eroding land provides useful public functions as parks, public facilities, and road rights-of way. A second reason is that eroded land is a contributor to the material that has to be removed from the navigation channel at public expense in maintenance dredging. A third reason is aesthetic, in that failed shoreline protection measures are unsightly and potentially dangerous.

## Scope of Study

The scope of work for all the sediment-related studies is given under Chapter 1.1. The contents related to Pleasure Island are again given below for ease of reference.

Scope (Part 1A): Sediment data available with the Galveston District will be examined and used in the study. The Measurement and Analysis Group of the CHL will collect additional sediment data, which will be analyzed in CHL laboratory. Laboratory results will be plotted and reviewed. Properties of sediment at site and their transportation characteristics will be evaluated for their use in the study. The cause of erosion will be assessed. Velocity data at selected stations will be extracted from the numerical solution files for the existing and plan conditions. Velocity data will be plotted for comparison. Change in the current pattern caused by navigation improvement will be assessed. Effect of velocity change on sediment erosion will be assessed. A letter report will be submitted.

Scope (Part 1B): Assess whether the sediment impact will be marginal and if so, recommend deferment for taking mitigation measures. If the impact is adverse and severe, then recommend that taking mitigation measures is essential. Recommend mitigation measures to alleviate the adverse impact of the proposed project.

## Previous Study

The PBS&J Consultants have taken into account the following factors in their report. This is a comprehensive list, which includes all the relevant parameters.

1. Characteristics of local soil
2. Shoreline and wave conditions
3. Available shoreline protection measures in the vicinity of the project area
4. Feasibility for phase construction
5. Beneficial use of existing structures
6. Costs and time associated with the alternatives
7. Considerations of the future plans for channel modification
8. Aesthetic considerations for various shoreline uses

9. Environmental aspects
10. Evaluation of the need for additional survey, studies and/or data collection efforts is also evaluated.

## Hydrologic Conditions

PI is located at the west side of Sabine Lake, south of the mouth of the Neches River. While most of the water in the Neches River flows directly into the Sabine Lake, a portion of the flow will go through Sabine-Neches Canal toward the Gulf of Mexico, especially during flooding events. This fresh water flow through the canal has some impact on salinity and current in the canal.

The sum of the flows in the three stations is the total Neches River flow entering Sabine Lake. The annual mean flows are 5,824, 894, and 490 cubic feet per second (cfs), respectively, totaling 7,208 cfs. The highest annual mean flow of 13,480, 2,248, and 1,167 cfs, respectively, totaling 16,895 cfs, is also reported for the three stations. However, there is no information indicating what portion of this flow is distributed through Sabine-Neches Canal.

## Geotechnical Conditions

Given that dredging the Sabine-Neches Canal created PI, soil on the surface of the island is dredged material. On the west side of the island where the original Sabine Lake shoreline was, the soil composition underneath the dredged material is most likely Beaumont Clay. Based on the Soil Survey by the Soil Conservation Service (1965), which has been renamed to Natural Resources Conservation Service (NRCS), typical Beaumont Clay has fine particles, with 55 to 75 percent less than 0.074 mm. The clay is considered to have poor shear strength, high compressibility, high plasticity, poor drainage, and very high shrink-swell potential. A more recent publication (National Cooperative Soil Survey, 1997) describes Beaumont Clay as a poorly drained, very slowly permeable soil formed in clayey sediments of the Pleistocene Age. Its taxonomic class is fine, smectitic, hyperthemic Chromic Dystraquerts. As for the dredged material, the NRCS (1965) classified the soil as Ma (Made Land) and described it as a mixture of clay loam, sand, and shells. No additional information is provided in the Soil Survey on Ma Soil due to its variability.

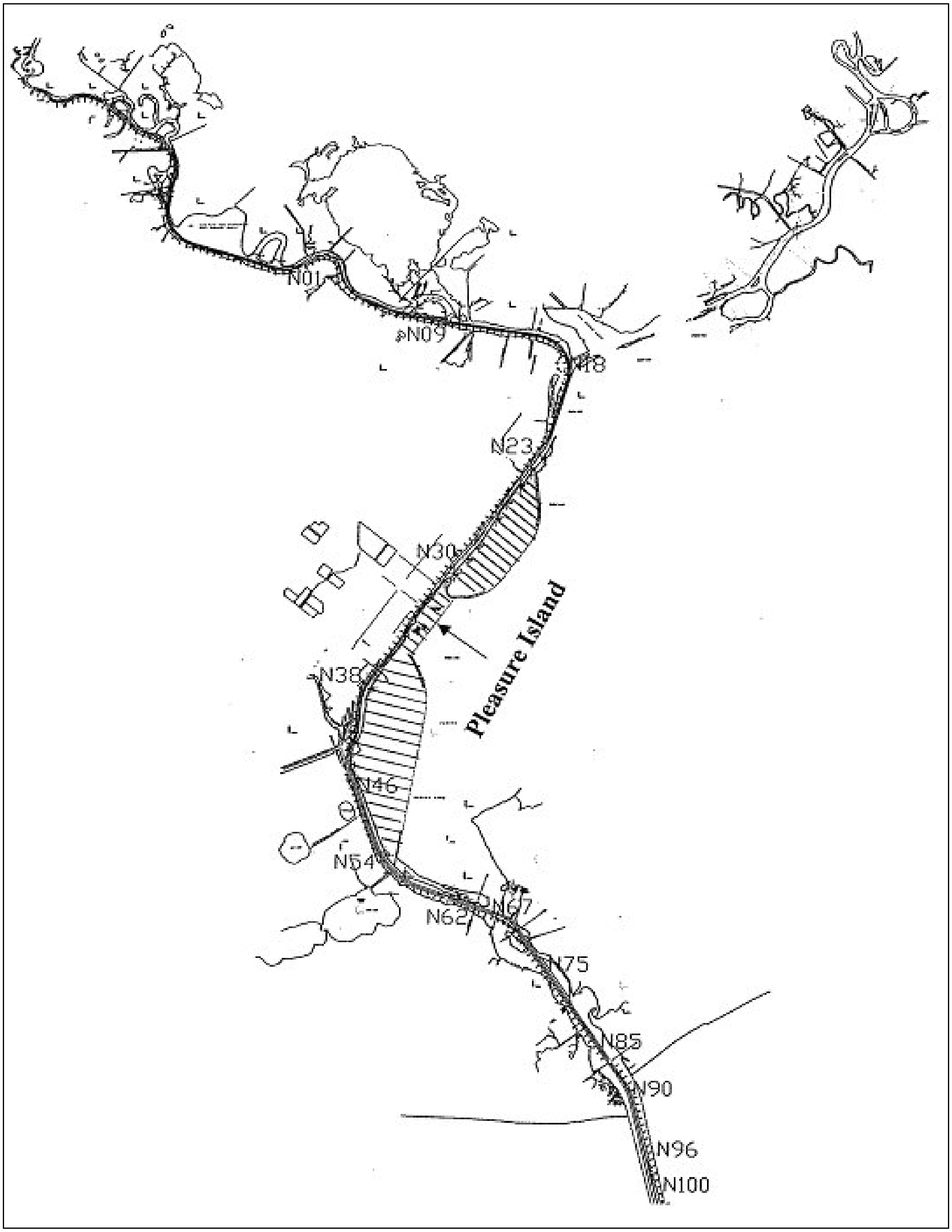



Figure 3.1.1: Pleasure Island location

# Chapter 3.2: Vessel-Induced Shoreline Erosion

This Chapter was not re-written in September 2004

# Chapter 3.3: Numerical Model Results

## Model Information

Chapter 1.4 of Part 1 of this report provides information on the numerical modeling done for the Sabine Neches Project. A hydrodynamic numerical model was initially set up to represent two-dimensional conditions. Results of this model were used while preparing Part 3 of the report in December 2002 and also in preparing the revised Part 3 in October 2003. Subsequently the numerical model was updated to three-dimensional so as to include vertical variations in velocity and salinity. Results of this 3D model have been used in the present revision of Part 3 of the report.

## Velocity Data

The grid for 3D numerical model changed when it was transformed from the previous 2D model. New nodes were selected that were close to the bed sample locations. The actual node numbers were assigned numbers P1 through P19 for convenience of reference. Nodes closest to the water line along the eroding bank of Pleasure Island were selected. While some nodes were located in shallow water, many were located in deeper water. Table 3.3.1 gives the station numbers, node numbers and water depths.

The operating test conditions used for the 2D model are described under Chapter 1.4. The 3D model used different conditions for running the model and also a different nomenclature for reporting results. Low fresh water flow represented flood dominance and median fresh water flow represented ebb dominance. Instead of the single depth-averaged values at each node, the 3D model provides velocity magnitudes at multiple depths. The velocity magnitudes in 3D model are assigned positive sign for currents going landward during flood tide and negative sign for currents going seaward during ebb tide.

In the context of Pleasure Island shoreline erosion, only the bottom velocities were relevant and hence only those are considered here. Also only the results with median fresh water flow were examined since they had higher magnitudes relevant to erosion. Velocity data with magnitude and direction were extracted from the solution files at selected nodes of the numerical model. Superposed bottom velocity magnitudes for base and plan condition for the selected 19 nodes (P1 through P19) are given in Appendix 3.3.1. The results are summarized in Tables 3.3.2 for flood and in Table 3.3.3 for the ebb, which offers a comparison of base and plan conditions. The velocities obtained in the numerical model show considerable variation with time represented by short and tall peaks in velocity magnitudes. Hence two very approximate groups of velocity magnitudes are made, namely short peaks and tall peaks for evaluation.

The following conclusions are drawn for the bottom velocities obtained with the median fresh water flow.

1. The ebb velocities are higher than the flood velocities for both the base and Plan.
2. The Plan velocities are higher than the Base velocities.
3. Variation in velocities for flood is as follows:

Short-Peaks: From 0.1 to 0.2 ft/s for Base and from 0.1 to 0.5 ft/s for Plan.

Tall-peaks: From 0.3 to 0.7 ft/s for Base and from 0.3 to 1.1 ft/s for Plan.

4. Variation in velocities for ebb is as follows:

Short-Peaks: From 0.15 to 0.4 ft/s for Base and from 0.2 to 0.6 ft/s for Plan.

Tall-peaks: From 0.25 to 0.7 ft/s for Base and from 0.25 to 0.7 ft/s for Plan.

5. Irrespective of the location, flood or ebb phase and Base or Plan condition, all the bottom velocities with median fresh water flow are mostly less than 1 ft/s on the average.

## Effect of Currents

Current induces bed shear stress, which may cause erosion. The magnitude of current-induced bed shear stress is a function of water depth, bed friction and current magnitude. It is estimated that current strength of 1, 2 and 3 feet per second would induce bed shear stress of 0.04, 0.18 and 0.4 Pa in water depth of 0.5 m. The magnitudes in 1 m depth will be 0.036, 0.14 and 0.32 Pa. The magnitudes in 1.5 m depth will be 0.032, 0.126 and 0.28 Pa. Erosion would occur at sustained as well as peak velocities if the flow-induced bed shear stress is greater than the bed shear strength. It is seen that the magnitudes of current-induced bed shear stress are significantly smaller than those induced by vessel-generated waves. Hence vessel-induced waves are more significant in the context of erosion of Pleasure Island shoreline.

**Table 3.3.1: Node locations where data were extracted from 3D hydrodynamic model along the shoreline of Pleasure Island**

| Station | Node | Location | Depth |
|---|---|---|---|
| | | | |
| P1 | 8584 | 30+00 | -40.2 |
| P2 | 8669 | 40+00 | -36 |
| P3 | 8738 | 50+00 | -24.3 |
| P4 | 9110 | 110+00 | -29.3 |
| P5 | 9367 | 150+00 | -26.6 |
| P6 | 10247 | 270+00 | -48.4 |
| P7 | 10349 | 290+00 | -47 |
| P8 | 10689 | 10+00 | -21.2 |
| P9 | 12388 | 80+00 | -6.3 |
| P10 | 12485 | 100+00 | -6 |
| P11 | 15668 | 260+00 | -31.2 |
| P12 | 15939 | 280+00 | -6 |
| P13 | 16736 | 305+00 | -6 |
| P14 | 17280 | 335+00 | -6 |
| P15 | 18752 | 380+00 | -23.6 |
| P16 | 14498 | 410+00 | -48.3 |
| P17 | 13991 | 430+00 | -50.4 |
| P18 | 13473 | 460+00 | -15.9 |
| P19 | 12518 | 490+00 | -6 |

**Table 3.3.2: Flood Velocities along Pleasure Island Shoreline**
**Comparison of Peak Velocities**

| | Base Flood | Plan Flood | Base Flood | Plan Flood |
|---|---|---|---|---|
| | Short Peaks | Short Peaks | Tall Peaks | Tall Peaks |
| | ft/s | ft/s | ft/s | ft/s |
| P 1 | 0.2 | 0.4 | 0.7 | 1.1 |
| P 2 | 0.2 | 0.4 | 0.5 | 0.5 |
| P 3 | 0.2 | 0.2 | 0.4 | 0.4 |
| P 4 | 0.2 | 0.2 | --- | --- |
| P 5 | 0.1 | 0.2 | 0.2 | 0.3 |
| P6 | 0.1 | 0.5 | 0.5 | 0.5 |
| P 7 | 0.1 | 0.7 | --- | --- |
| P 8 | 0.15 | 0.4 | --- | --- |
| P 9 | 0.15 | 0.2 | --- | --- |
| P 10 | 0.15 | 0.15 | --- | --- |
| P 11 | 0.2 | 0.4 | --- | --- |
| P 12 | 0.15 | 0.15 | --- | --- |
| P 13 | 0.15 | 0.15 | --- | --- |
| P 14 | 0.10 | 0.1 | 0.3 | 0.3 |
| P 15 | 0.15 | 0.15 | 0.5 | 0.5 |
| P 16 | 0.1 | 0.5 | 0.5 | 0.5 |
| P 17 | 0.1 | 0.4 | 0.4 | 0.6 |
| P 18 | 0.1 | 0.3 | --- | --- |
| P 19 | 0.1 | | | |

**Table 3.3.3: Ebb Velocities along Pleasure Island Shoreline**
**Comparison of Peak Velocities**

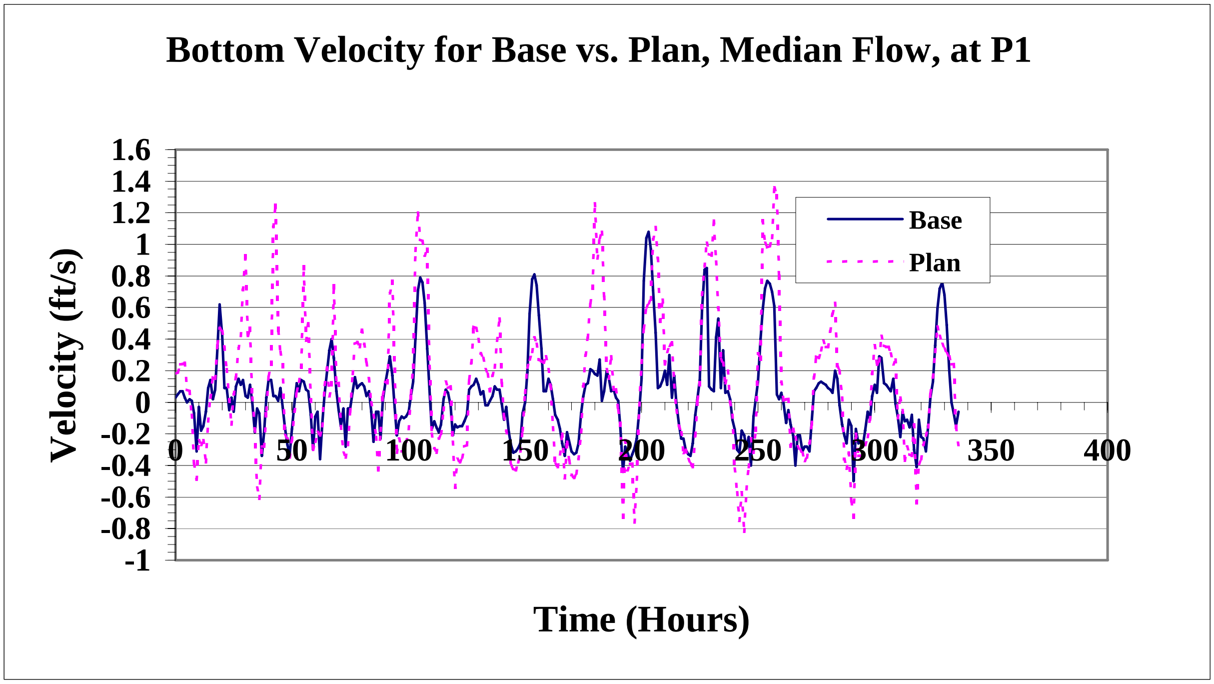
| | Base Flood | Plan Flood | Base Flood | Plan Flood |
|---|---|---|---|---|
| | Short Peaks | Short Peaks | Tall Peaks | Tall Peaks |
| | ft/s | ft/s | ft/s | ft/s |
| P 1 | 0.2 | 0.4 | 0.4 | 0.6 |
| P 2 | 0.2 | 0.2 | 0.4 | 0.35 |
| P 3 | 0.1 | 0.2 | --- | --- |
| P 4 | 0.15 | 0.25 | 0.25 | 0.4 |
| P 5 | 0.15 | 0.15 | 0.25 | 0.25 |
| P6 | 0.2 | 0.4 | 0.4 | 0.5 |
| P 7 | 0.2 | 0.5 | --- | --- |
| P 8 | 0.2 | 0.2 | 0.45 | 0.45 |
| P 9 | 0.3 | 0.45 | 0.6 | 0.6 |
| P 10 | 0.3 | 0.3 | 0.65 | 0.65 |
| P 11 | 0.4 | 0.4 | --- | --- |
| P 12 | 0.3 | 0.4 | --- | --- |
| P 13 | 0.3 | 0.3 | --- | --- |
| P 14 | 0.3 | 0.3 | 0.4 | 0.6 |
| P 15 | 0.4 | 0.4 | 0.7 | 0.7 |
| P 16 | 0.2 | 0.6 | 0.4 | 0.6 |
| P 17 | 0.25 | 0.4 | 0.4 | 0.5 |
| P 18 | 0.3 | 0.3 | --- | --- |
| P 19 | 0.2 | 0.4 | 0.4 | 0.5 |

# Supplementary Report 2

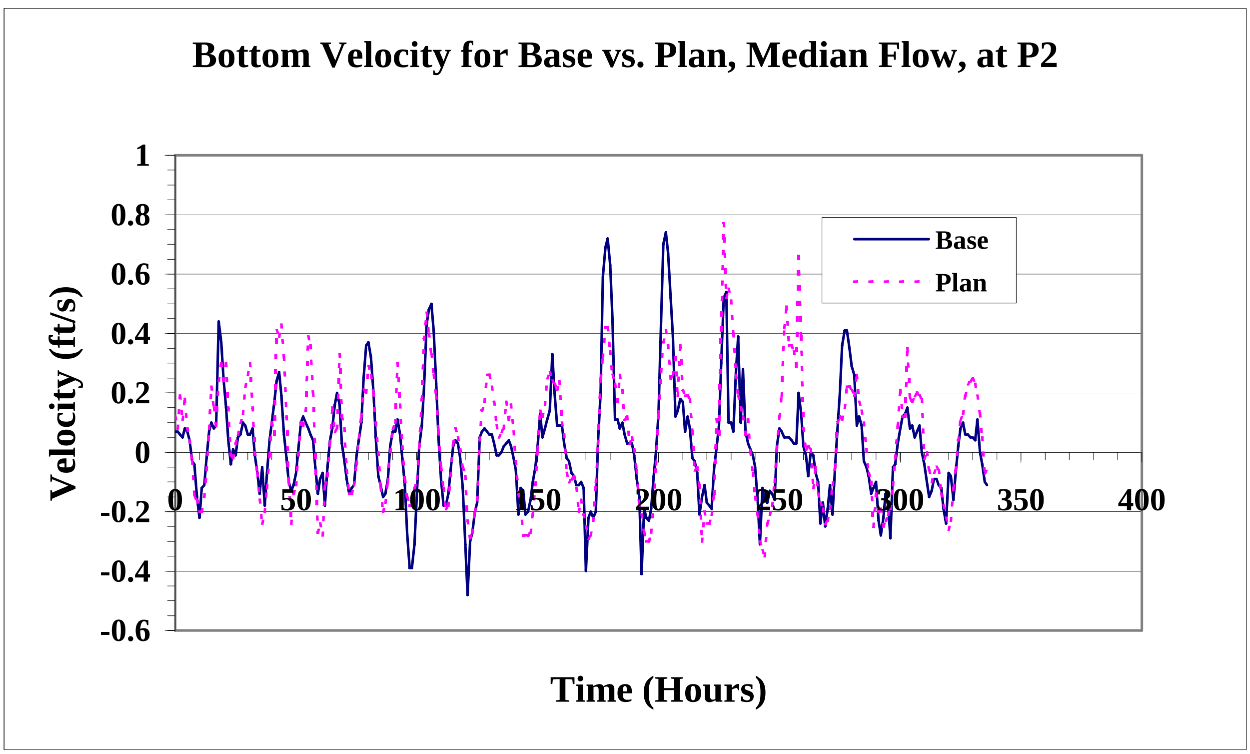
Pleasure Island Erosion Study

**Appendix 3.3.1**

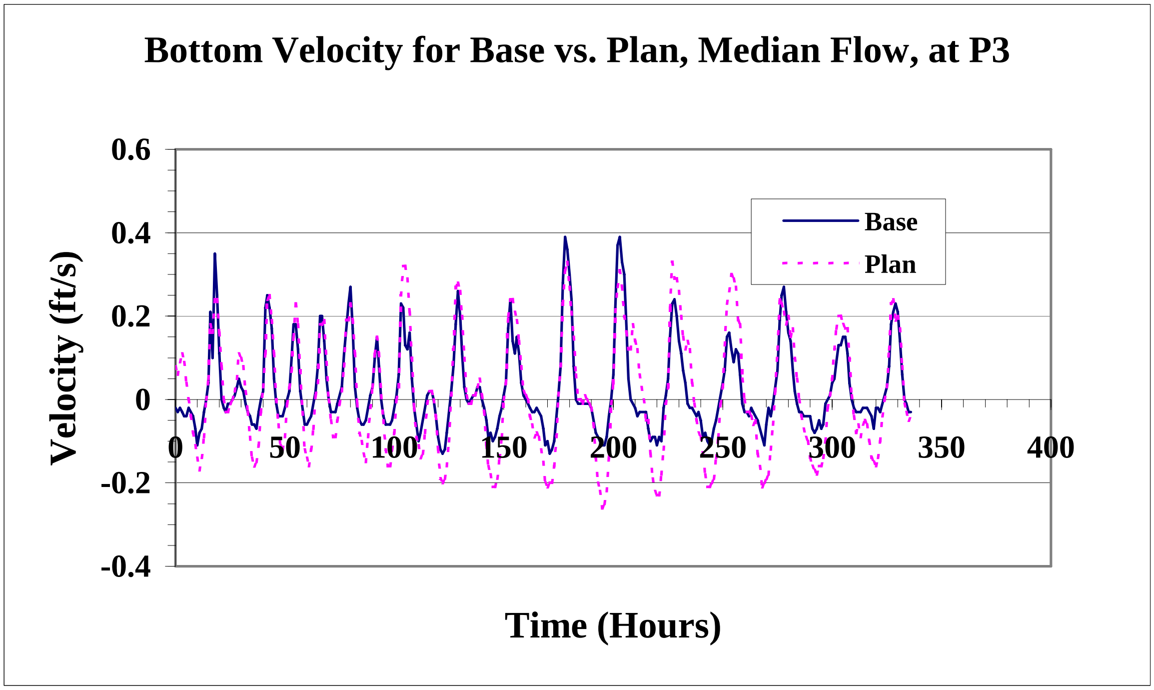
**Bottom tidal currents with median fresh water flow obtained in 3D numerical model for base and plan.**

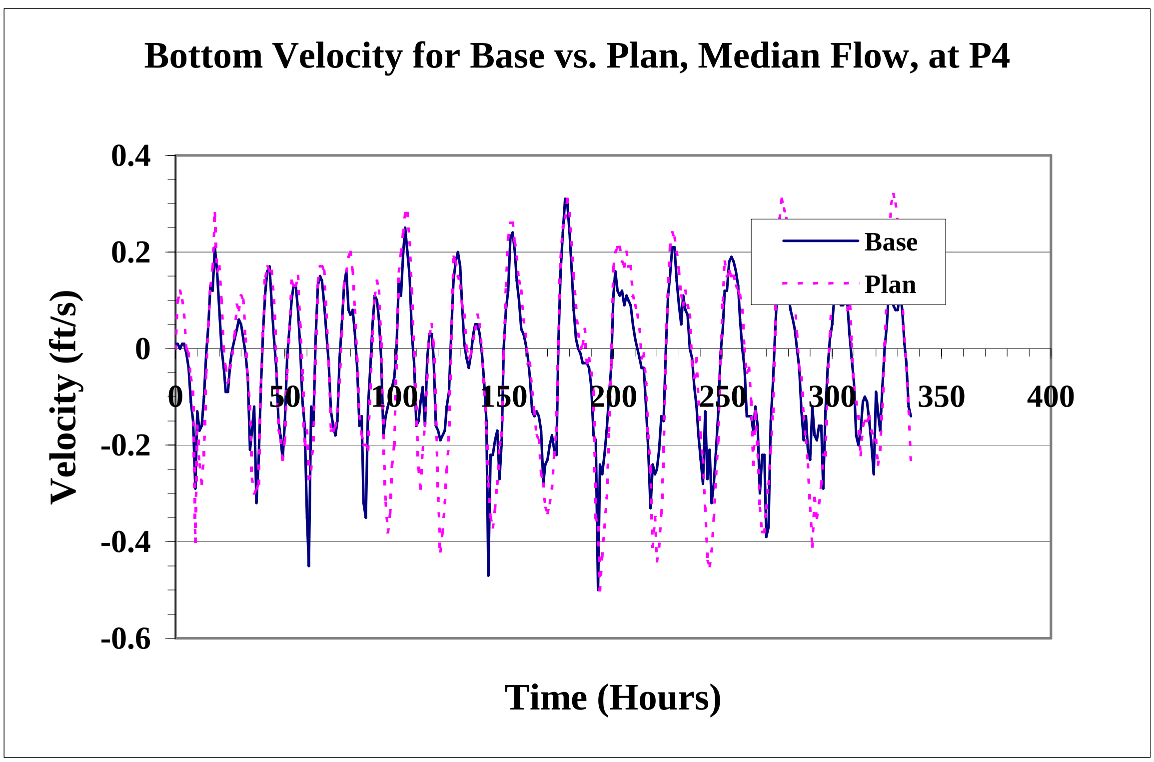


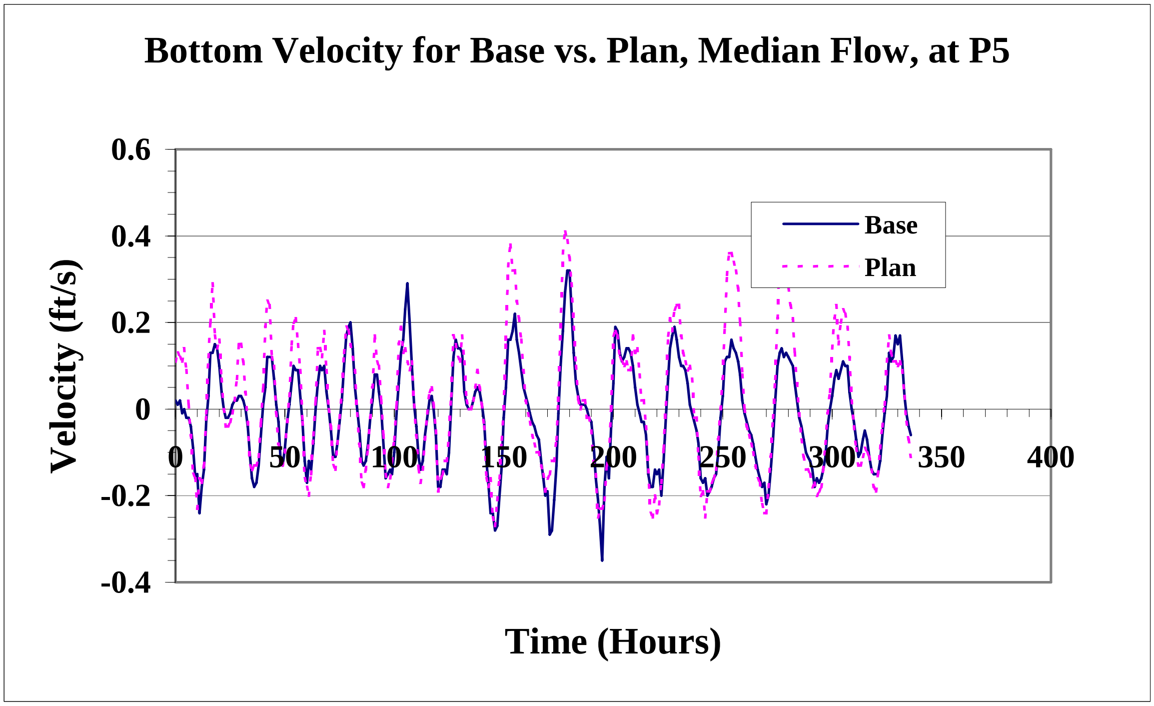
Bottom Velocity for Base vs. Plan, Median Flow, at P1
Velocity (ft/s)
Time (Hours)
Base
Plan
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400

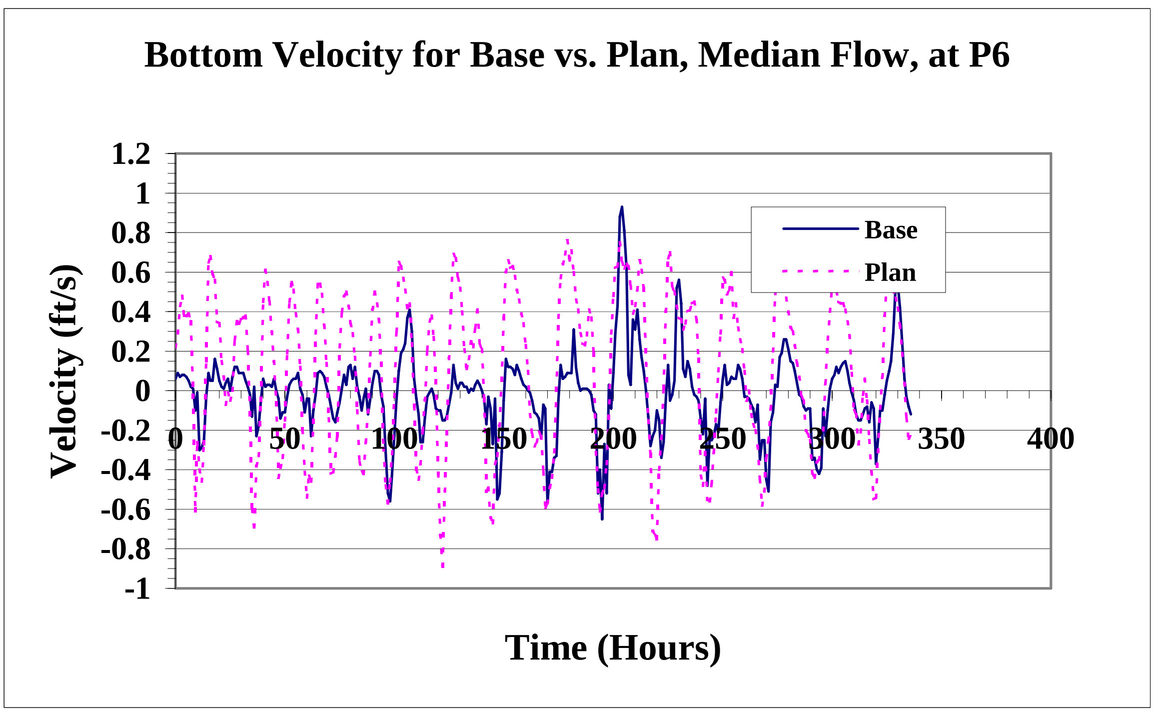



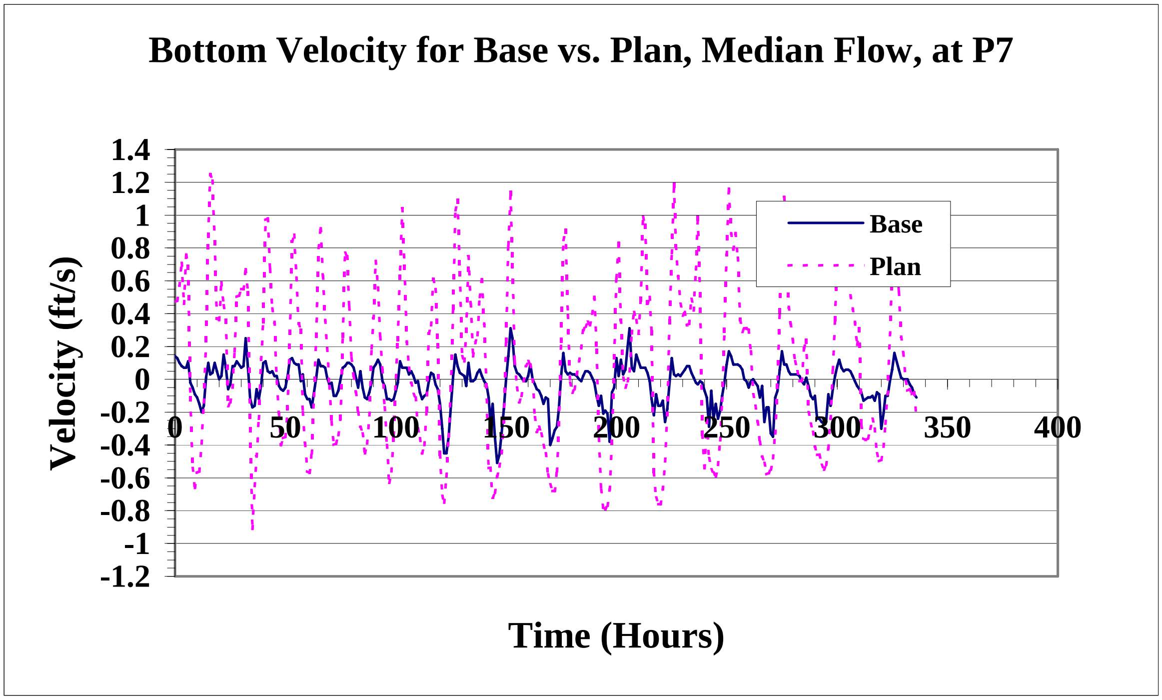
Bottom Velocity for Base vs. Plan, Median Flow, at P2
Velocity (ft/s)
Time (Hours)
Base
Plan
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400

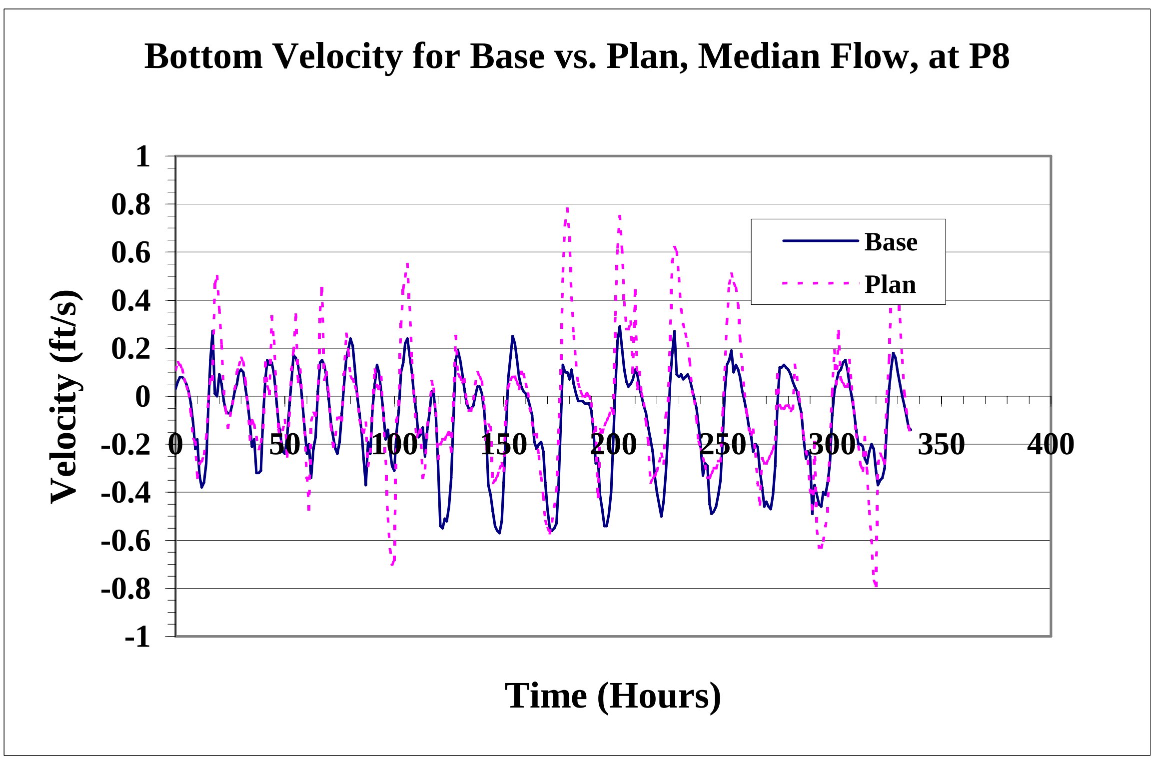

Bottom Velocity for Base vs. Plan, Median Flow, at P3
Velocity (ft/s)
0.6
0.4
0.2
0
-0.2
-0.4
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

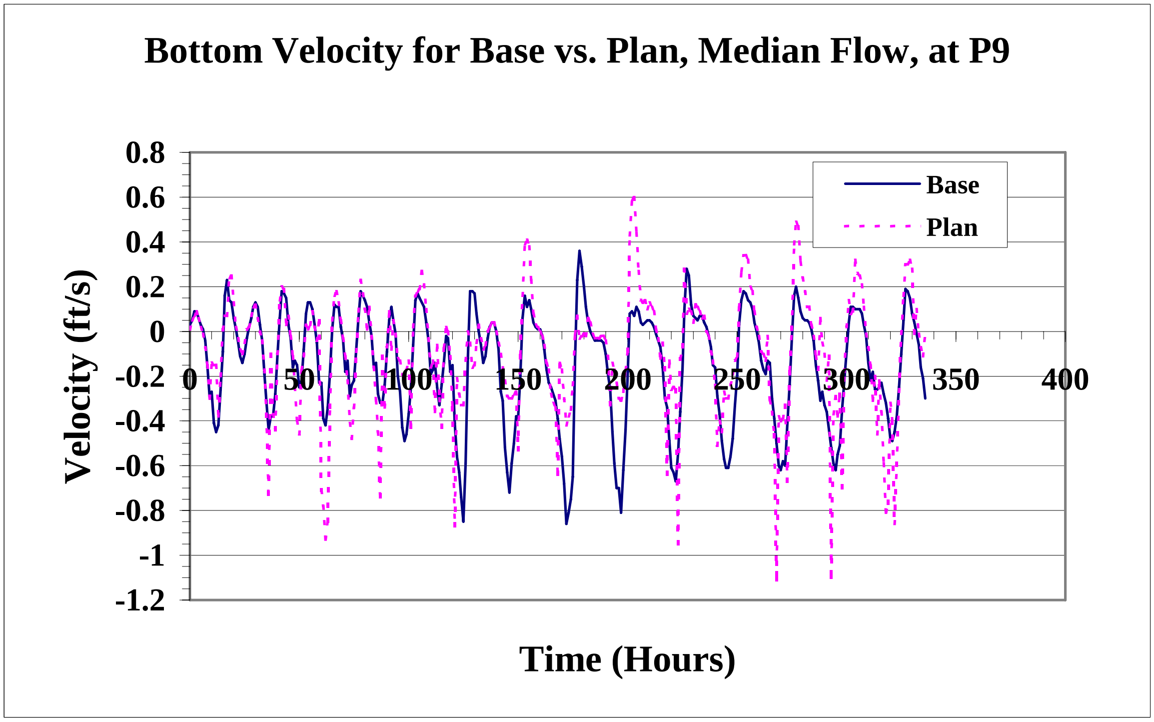

Bottom Velocity for Base vs. Plan, Median Flow, at P4
Velocity (ft/s)
0.4
0.2
0
-0.2
-0.4
-0.6
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

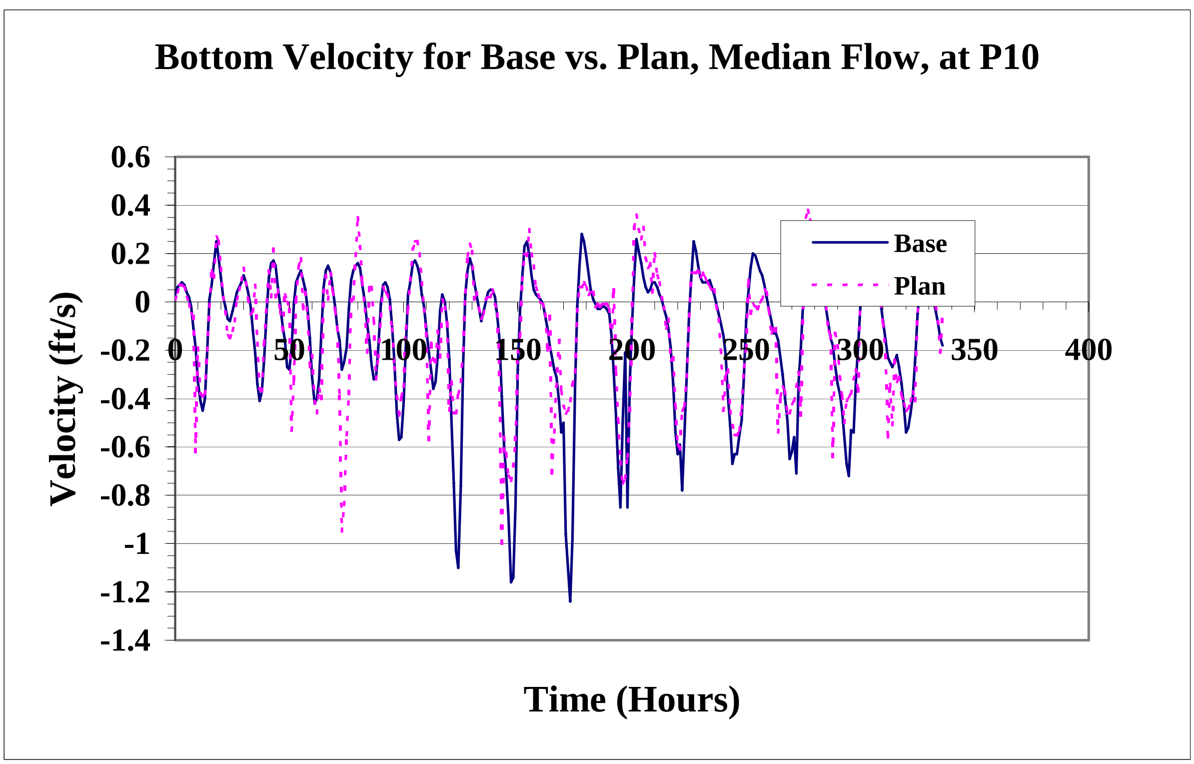

Bottom Velocity for Base vs. Plan, Median Flow, at P5
Velocity (ft/s)
0.6
0.4
0.2
0
-0.2
-0.4
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

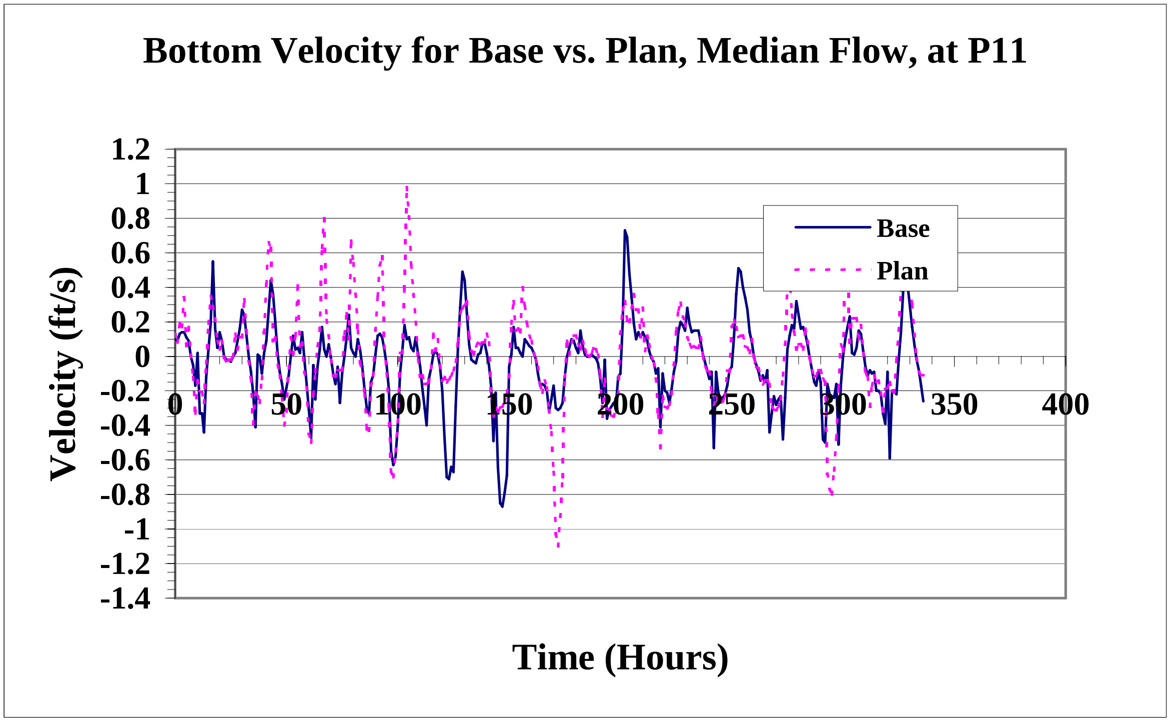

Bottom Velocity for Base vs. Plan, Median Flow, at P6
Velocity (ft/s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

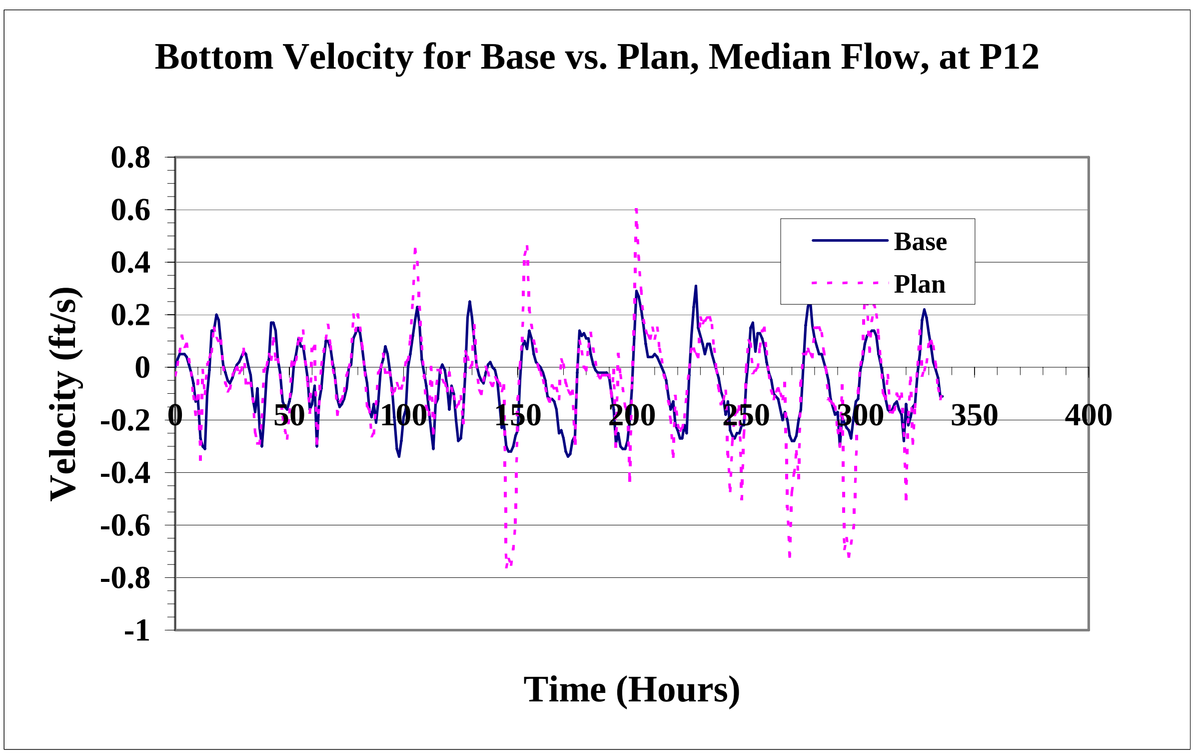

Bottom Velocity for Base vs. Plan, Median Flow, at P7
Velocity (ft/s)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

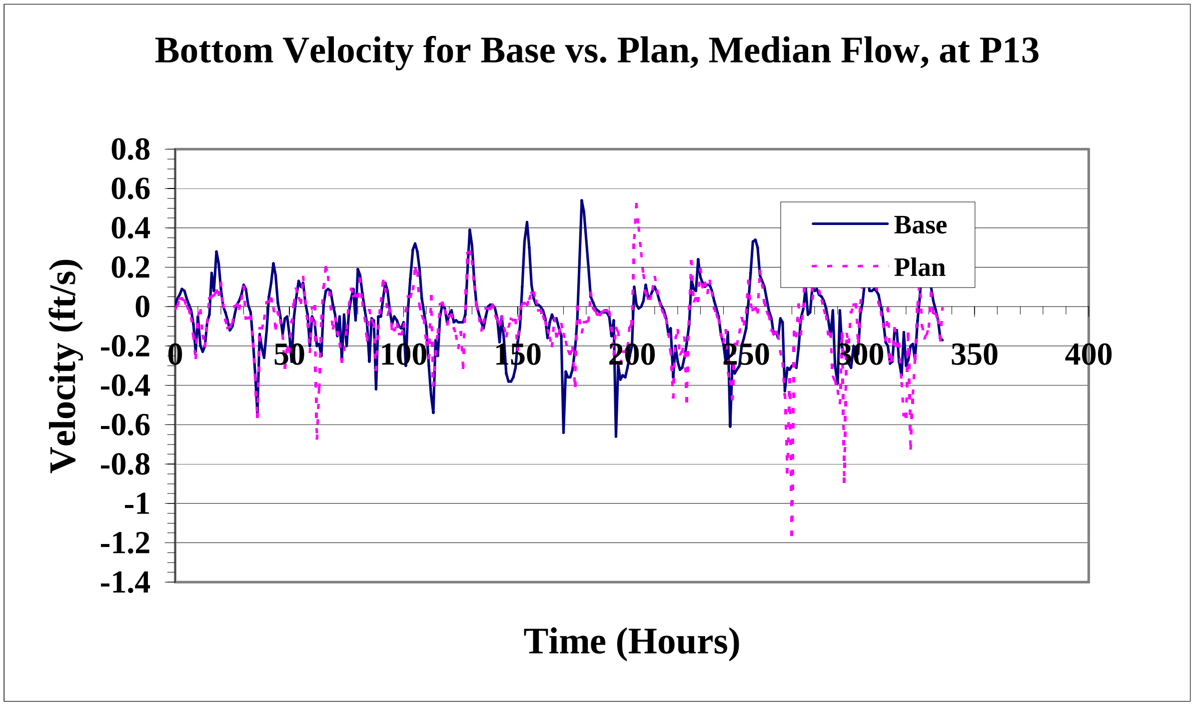

Bottom Velocity for Base vs. Plan, Median Flow, at P8
Velocity (ft/s)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

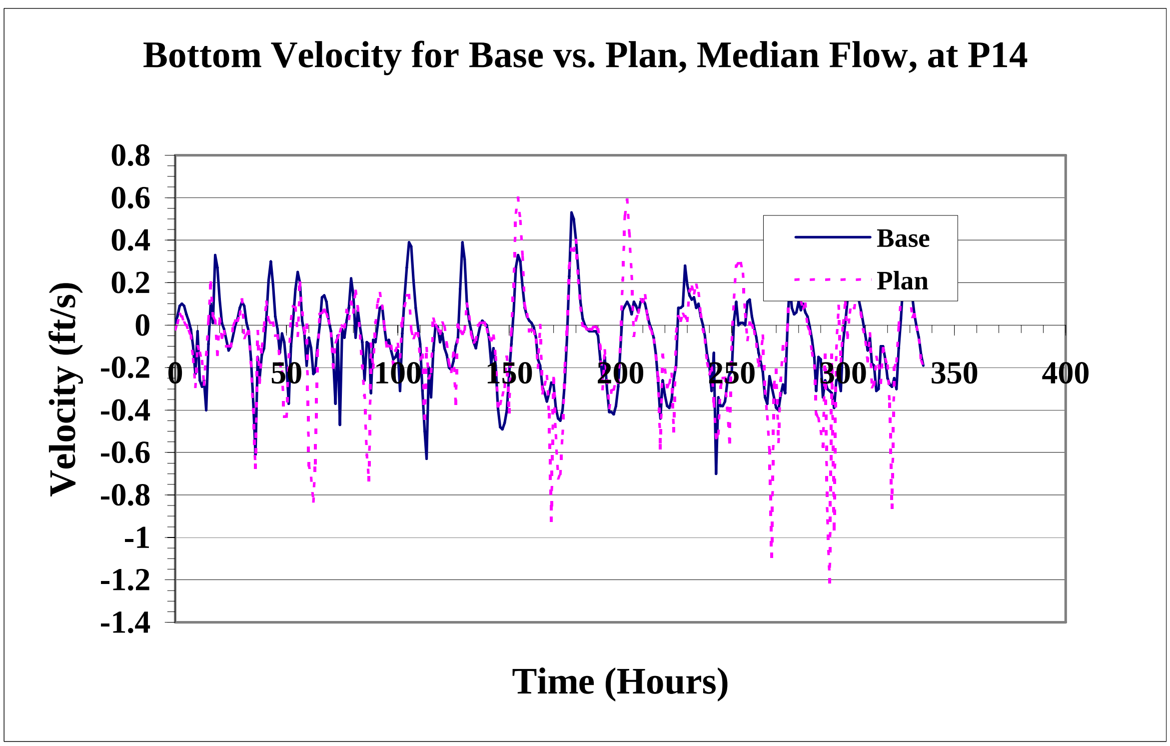

Bottom Velocity for Base vs. Plan, Median Flow, at P9
Velocity (ft/s)
Time (Hours)
Base
Plan
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
50
100
150
200
250
300
350
400

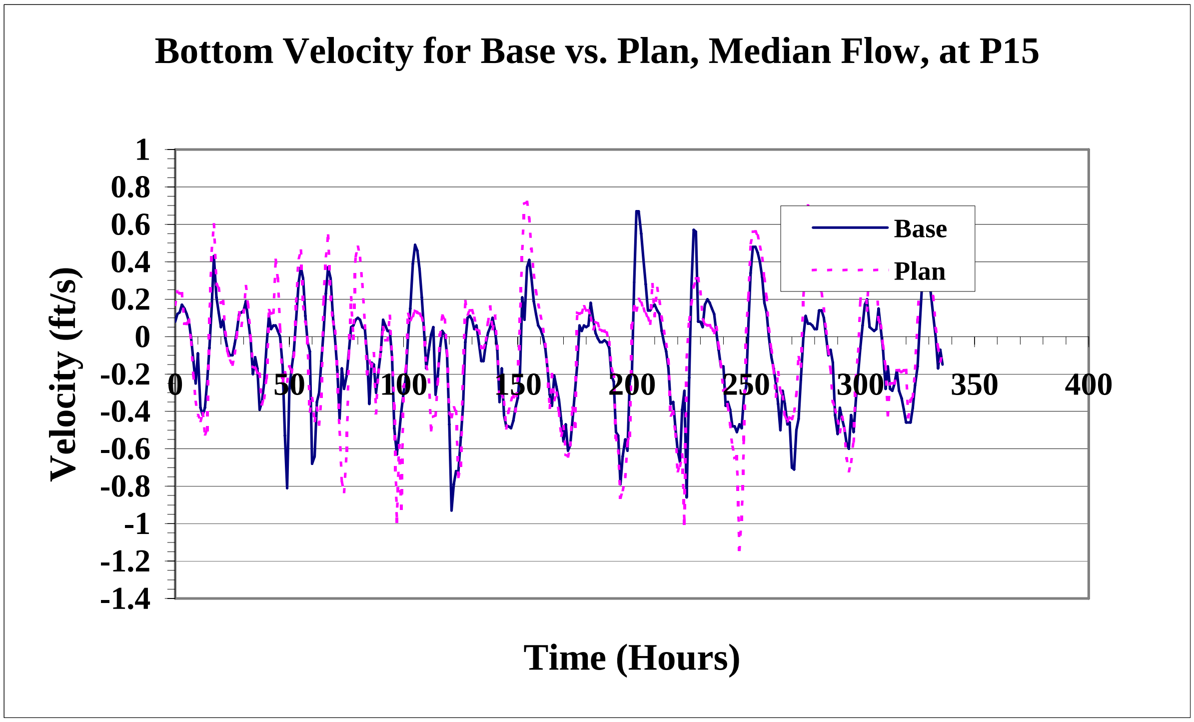

Bottom Velocity for Base vs. Plan, Median Flow, at P10
Velocity (ft/s)
Time (Hours)
Base
Plan
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
50
100
150
200
250
300
350
400


Bottom Velocity for Base vs. Plan, Median Flow, at P11
Velocity (ft/s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

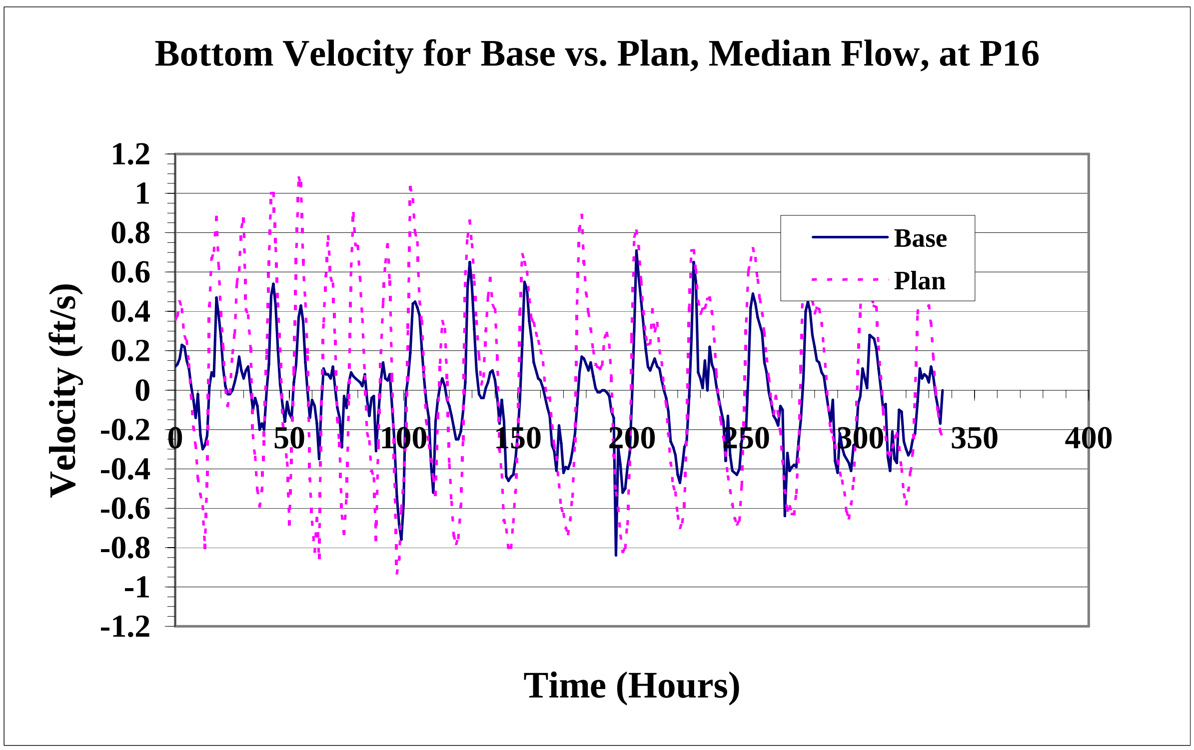

Bottom Velocity for Base vs. Plan, Median Flow, at P12
Velocity (ft/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan


Bottom Velocity for Base vs. Plan, Median Flow, at P13
Velocity (ft/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
50
100
150
200
250
300
350
400
Base
Plan
Time (Hours)

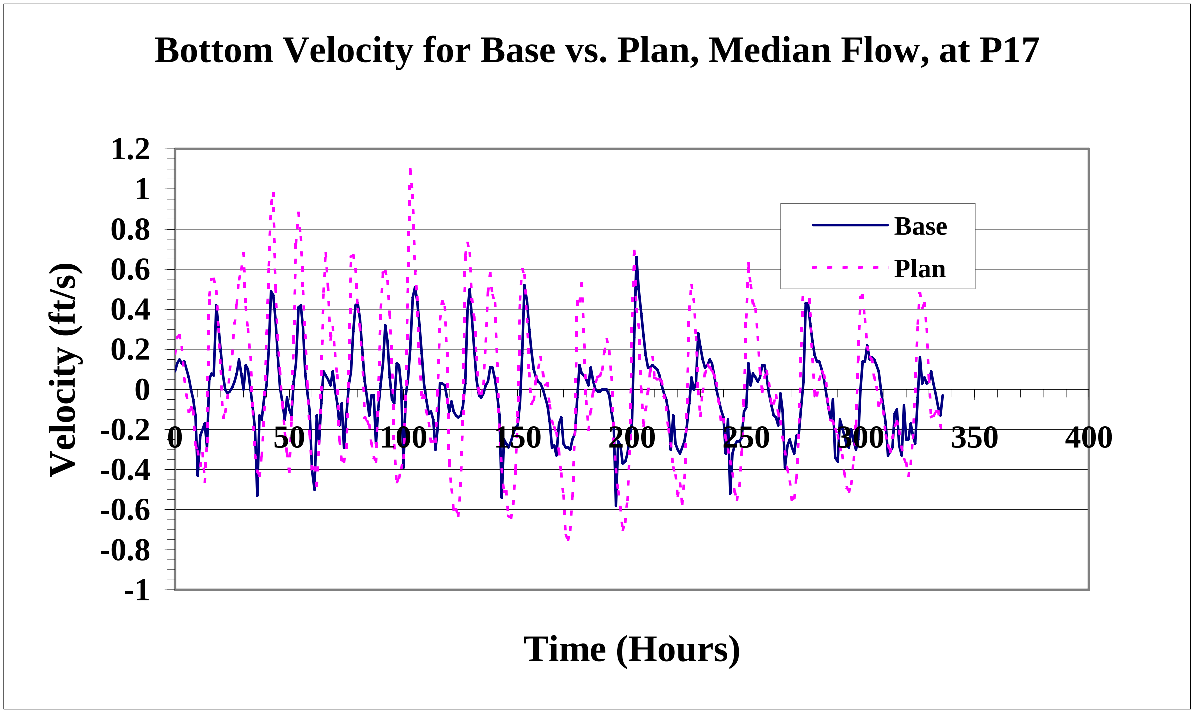

Bottom Velocity for Base vs. Plan, Median Flow, at P14
Velocity (ft/s)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
50
100
150
200
250
300
350
400
Base
Plan
Time (Hours)



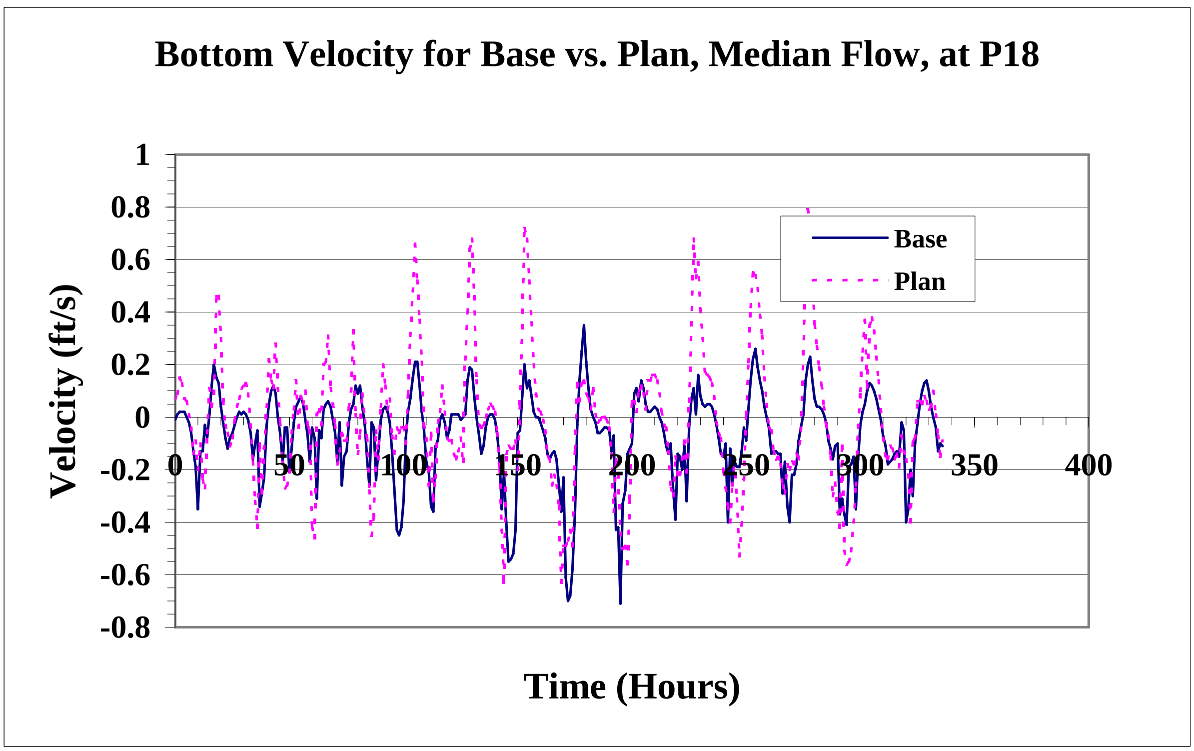
Bottom Velocity for Base vs. Plan, Median Flow, at P15
Velocity (ft/s)
Time (Hours)
Base
Plan
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
50
100
150
200
250
300
350
400

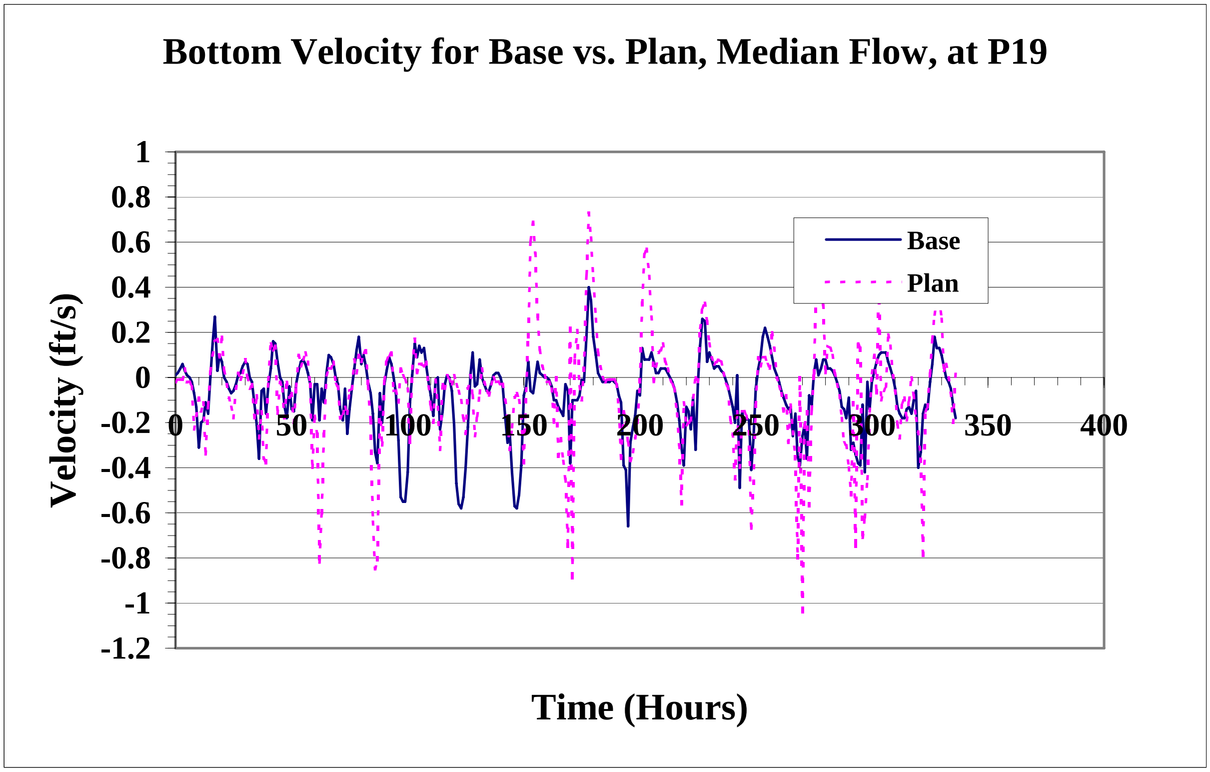
Bottom Velocity for Base vs. Plan, Median Flow, at P16
Velocity (ft/s)
Time (Hours)
Base
Plan
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
50
100
150
200
250
300
350
400



Bottom Velocity for Base vs. Plan, Median Flow, at P17
Velocity (ft/s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

Bottom Velocity for Base vs. Plan, Median Flow, at P18
Velocity (ft/s)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan



Bottom Velocity for Base vs. Plan, Median Flow, at P19
Velocity (ft/s)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

# Chapter 3.4: Sediment Data and Photographs

## Sediment Data

Bed samples were collected along the west shoreline of Pleasure Island at 19 locations. The locations are shown in Figures 3.4.1 through 3.4.4. The sample locations corresponding to the new node numbers of the three-dimensional numerical model are listed in Table 3.4.1. Two samples were collected at each location. One was just above the water line and the other was below the water line in about 3 feet depth. These are denoted by T and B respectively in Table 3.4.2. All the bed samples were analyzed in laboratory for the sand and silt split, particle size distribution for the fraction coarser than 64 microns and for the total organic contents. The results are given in Table 3.4.2. The particle size distribution curves are given in Appendix G.

It may be seen from Table 3.4.2 that the sediment contained a substantial fraction of silt and clay (less than 64-micron size) particles. The quantity of silt and clay varied mostly between 70 and 100 percent. This sediment is easily erodible under the current and wave climate prevailing along the west shoreline of Pleasure Island.

## Beach Profiles

Cross-sections of navigation channel were examined for the beach slopes in the vicinity of Pleasure Island. Figure 3.4.5 provides an illustration of cross sections of navigation channel in Port Arthur canal. Figure 3.4.6 provides an illustration of cross sections of navigation channel in Sabine Neches canal. The right bank of these sections represents the shoreline of Pleasure Island. Bank slopes were measured for three zones of each section, namely above water level (0 to +10 feet elevation), and below water level (0 to –10 feet and –10 to –20 feet elevation). Tables 3.4.3 and 3.4.4 provide slopes for these three zones at various locations in the Port Arthur Canal and Sabine Neches Canal respectively. It is seen that the slopes in the Port Arthur Canal area in zones above and below water level are mild varying from 1 in 7 to 1 in 56. Corresponding slopes in the Sabine Neches Canal are mostly steeper in many locations varying from 1 in 2 to 1 in 10. Slopes in deeper water from –10 to –20 feet are relatively steeper than the slopes in the other two slope areas for both the canals. Flat beach slopes attenuate currents and wave heights due to bed friction and hence the bank erosion is less than the erosion at locations with steeper slopes.

## Critical Shear Strength

The Galveston District prepared a report on the analysis of shoreline erosion at Sabine Neches project, which is given in Chapter 3.5. A summary of findings is given in Table 3.5.2. Seven areas of erosion were examined, which were given seriatim numbers 1 through 7. The locations are shown in Figures 3.5.1 through 3.5.4.

Bed samples closest to the seven areas were identified and were tested in the sediment laboratory for determining their critical shear strengths. The results are shown in Figures

3.4.7 through 3.4.10. Critical shear stress for each sample was obtained by extrapolating the plot representing higher rate of erosion to meet the horizontal axis. Physical characteristics of the sediment samples and their critical shear strengths for erosion are presented in Table 3.4.5.

## Photographs

Photographs of the SNWW project shorelines are given in Appendix H. All of them are not taken at the Pleasure Island, however they offer a graphic description of the general bank erosion problem. The photographs are presented in the following groups:

Appendix H-A: Sequence of Photographs showing propagation of transverse stern waves generated by passage of ship

Appendix H-B: Photographs showing vessel-generated waves attacking the shore

Appendix H-C: Photographs showing bank protection measures adopted at Sabine

**Table 3.4.1: Bed sample locations along Pleasure Island and corresponding Node Numbers**

| Bed Sample # | Model Node # | Water Depth |
|---|---|---|
| | | |
| P1 | 8584 | -40.2 |
| P2 | 8669 | -36 |
| P3 | 8738 | -24.3 |
| P4 | 9110 | -29.3 |
| P5 | 9367 | -26.6 |
| P6 | 10247 | -48.4 |
| P7 | 10349 | -47 |
| P8 | 10689 | -21.2 |
| P9 | 12388 | -6.3 |
| P10 | 12485 | -6 |
| P11 | 15668 | -31.2 |
| P12 | 15939 | -6 |
| P13 | 16736 | -6 |
| P14 | 17280 | -6 |
| P15 | 18752 | -23.6 |
| P16 | 14498 | -48.3 |
| P17 | 13991 | -50.4 |
| P18 | 13473 | -15.9 |
| P19 | 12518 | -6 |

**Table 3.4.2: Results of bed sediment samples along Pleasure Island**

| Original Sample # | New Sample # | % Sand | % Silt/Clay | % Moisture Content | % Organic Content |
|---|---|---|---|---|---|
| P36T | P1T | 29.23 | 70.77 | 0.37 | 3.03 |
| P37B | P1B | 76.64 | 23.36 | 0.35 | 1.79 |
| P38T | P2T | 7.66 | 92.34 | 0.44 | 3.8 |
| P39B | P2B | 3.82 | 96.18 | 0.64 | 4.2 |
| P40T | P3T | 2.79 | 97.21 | 0.45 | 3.61 |
| P41B | P3B | 4.04 | 95.96 | 0.60 | 5.18 |
| P42T | P4T | 0.45 | 99.55 | 0.57 | 6.7 |
| P43B | P4B | 6.21 | 93.79 | 0.40 | 4.92 |
| P44T | P5T | 12.78 | 87.22 | 0.62 | 6.1 |
| P45B | P5B | 28.17 | 71.83 | 0.47 | 5.8 |
| P46T | P6T | 7.32 | 92.68 | 0.47 | 4.82 |
| P47B | P6B | 21.82 | 78.18 | 0.55 | 4.24 |
| P48B | P7B | 25.79 | 74.21 | 0.46 | 3.77 |
| P49T | P7T | 4.37 | 95.63 | 0.55 | 5.6 |
| P60T | P8T | 4.55 | 95.45 | 0.46 | 21.92 |
| P61B | P8B | 0.66 | 99.34 | 0.65 | 5.75 |
| P62B | P9B | 52.28 | 47.72 | 0.43 | 3.19 |
| P63T | P9T | 0 | 100.00 | 0.60 | 6.44 |
| P64T | P10T | 0.06 | 99.94 | 0.55 | 5.65 |
| P65B | P10B | 18.89 | 81.11 | 0.44 | 4.13 |
| P66T | P11T | 12.58 | 87.42 | 0.37 | 3.46 |
| P67B | P11B | 0.44 | 99.56 | 0.36 | 2.45 |
| P68T | P12T | 13.79 | 86.21 | 0.25 | 2.2 |
| P69B | P12B | 49.07 | 50.93 | 0.34 | 1.64 |
| P70T | P13T | 60.68 | 39.32 | 0.42 | 5.27 |
| P71B | P13B | 60.07 | 39.93 | 0.38 | 2.07 |
| P72B | P14B | 5.17 | 94.83 | 0.32 | 1.89 |
| P73T | P14T | 5.24 | 94.76 | 0.34 | 3.80 |
| P74B | P15B | 38.70 | 61.30 | 0.37 | 3.46 |
| P75T | P15T | 4.07 | 95.93 | 0.39 | 4.55 |
| P76B | P16B | 80.29 | 19.71 | 0.29 | 1.29 |
| P77T | P16T | 1.56 | 98.44 | 0.46 | 5.00 |
| P78T | P17T | 32.82 | 67.18 | 0.39 | 3.66 |
| P79B | P17B | 24.31 | 75.69 | 0.57 | 4.00 |
| P80B | P18B | 15.72 | 84.28 | 0.43 | 3.50 |
| P81T | P18T | 25.11 | 74.89 | 0.43 | 4.02 |
| P82B | P19B | 5.91 | 94.09 | 0.37 | 2.23 |
| P83T | P19T | 3.05 | 96.95 | 0.41 | 5.63 |

**Table 3.4.3: Port Arthur Canal Right Bank Slopes (Pleasure Island)**

| Section at | Bank Slope 0 to +10’ | Bank Slope 0 to –10’ | Bank Slope -10’ to - 40’ |
|---|---|---|---|
| 10 + 00 | 1 : 40 | 1 : 07 | 1 : 2.5 |
| 30 + 00 | 1 : 15 | 1 : 12 | 1 : 4.0 |
| 70 + 00 | 1 : 08 | 1 : 50 | 1 : 3.3 |
| 90 + 00 | 1 : 20 | 1 : 33 | 1 : 3.3 |
| 110 + 00 | 1 : 25 | ----- | 1 : 4.0 |
| 130 + 00 | 1 : 12 | 1 : 20 | 1 : 3.0 |
| 140 + 00 | 1 : 05 | 1 : 40 | 1 : 3.0 |
| 150 + 00 | 1 : 14 | 1 : 56 | 1 : 3.0 |
| 180 + 00 | 1 : 10 | 1 : 25 | 1 : 4.0 |
| 210 + 00 | 1 : 10 | 1 : 30 | 1 : 2.3 |
| 230 + 00 | 1 : 08 | 1 : 25 | 1 : 3.0 |
| 250 + 00 | 1 : 10 | 1 : 25 | 1 : 3.3 |
| 270 + 00 | 1 : 40 | ------ | 1 : 3.0 |
| 284 +44 | 1 : 20 | ------ | 1 : 2.5 |
| 299 + 60 | 1 : 15 | ------ | 1 : 3.3 |
| 308 + 84 | ------ | ------- | ------ |
| 325 + 41 | ------ | ------- | ------ |

**Table 3.4.4: Sabine Neches Canal Right Bank Slopes (Pleasure Island)**

| Section at | Bank Slope 0 to +10’ | Bank Slope 0 to –10’ | Bank Slope -10’ to - 40’ |
|---|---|---|---|
| 18 + 93 | 1 : 10 | 1 : 13 | 1 : 6.0 |
| 38 + 69 | 1 : 3.5 | 1 : 40 | 1 : 7.0 |
| 58 + 58 | 1 : 8 | 1 : 48 | 1 : 6.0 |
| 78 + 73 | 1 : 5 | 1 : 37 | 1 : 7.0 |
| 104 + 64 | 1 : 2 | 1 : 15 | 1 : 5.0 |
| 118 + 96 | 1 : 15 | ---- | 1 : 2.8 |
| 138 + 72 | 1 : 3 | 1 : 5 | 1 : 4.3 |
| 158 + 55 | 1 :10 | 1 : 2 | 1 : 2.0 |
| 172 + 89 | 1 : 3 | 1 : 8 | 1 : 7.0 |
| 189 + 44 | 1 : 4 | 1 : 4 | 1 : 4.0 |
| 198 + 86 | 1 : 6 | 1 : 5 | 1 : 3.0 |
| 213 + 72 | 1 : 32 | 1 : 3 | 1 : 3.0 |

**Table 3.4.5: Critical shear stress values (Tau C) for Sabine Sediment samples for each of the seven eroding areas**

| Bed Sample # | Eroding Area # | % Sand | % Silt/Clay | % Moisture Content | % Organic Content | Tau C (Pa) |
|---|---|---|---|---|---|---|
| | | | | | | |
| P1 | 1 | 52.95 | 47.05 | 36.00 | 2.41 | 0.50 |
| | | | | | | |
| P6 | 2 & 3 | 14.57 | 85.43 | 51.00 | 4.53 | 0.45 |
| | | | | | | |
| P7 | 4 | 15.08 | 84.92 | 50.00 | 4.68 | 0.45 |
| | | | | | | |
| P9 | 5 | 26.14 | 73.86 | 31.00 | 4.81 | 0.48 |
| | | | | | | |
| P15 | 6 | 21.39 | 78.61 | 38.00 | 4.00 | 0.48 |
| | | | | | | |
| P19 | 7 | 4.48 | 95.52 | 39.00 | 3.93 | 0.40 |

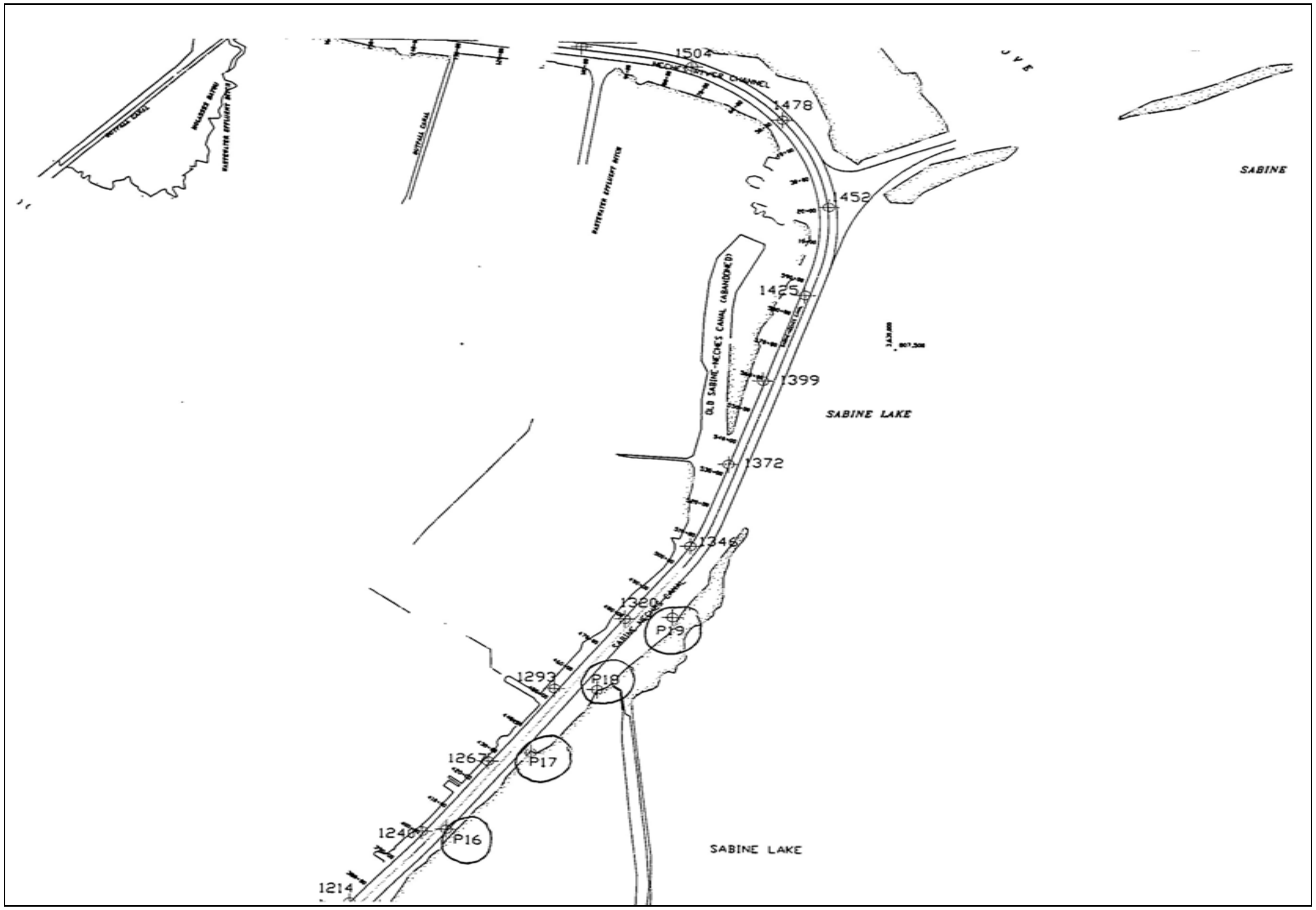



Figure 3.4.1: Pleasure Island bed sample locations P19-P16

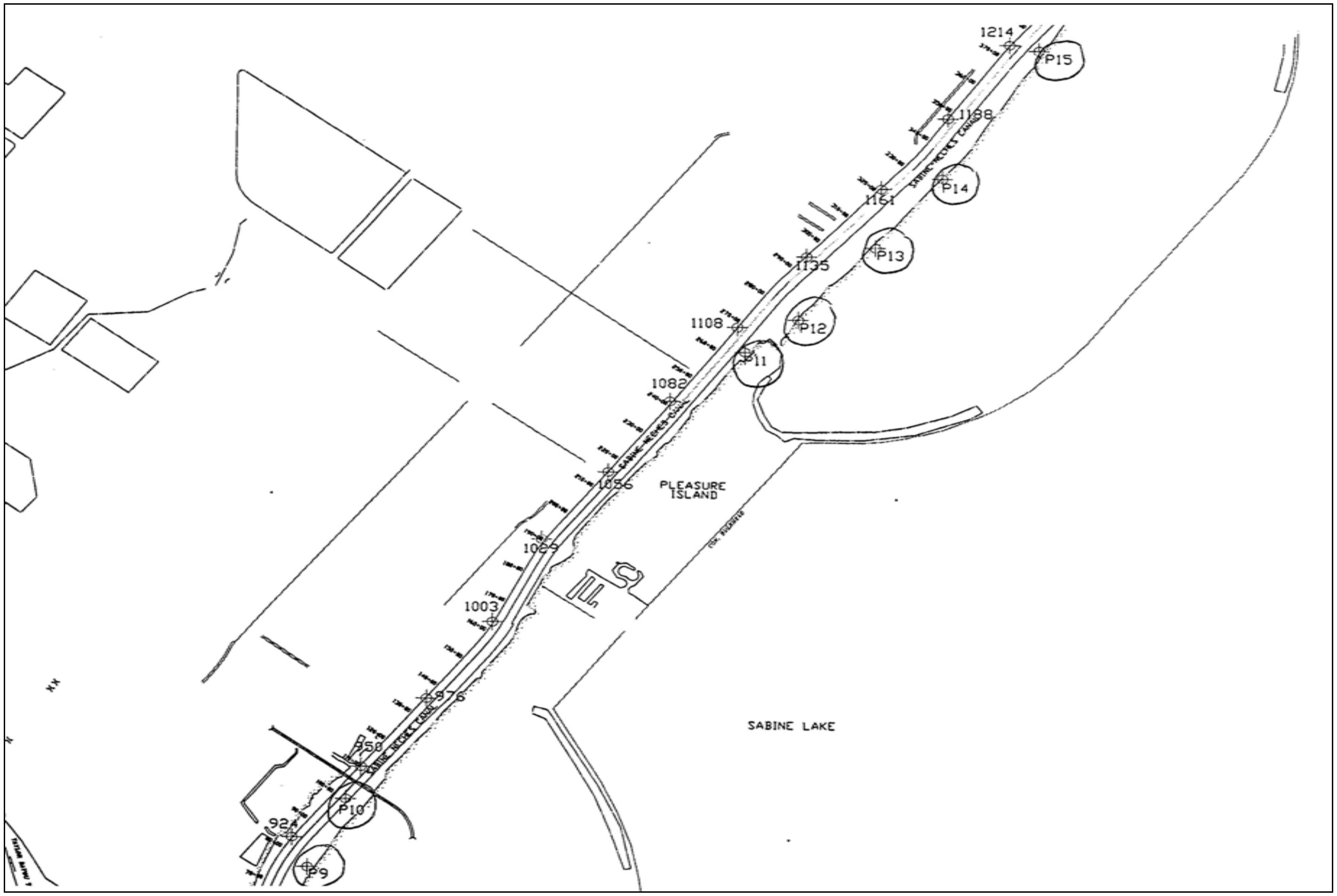



Figure 3.4.2: Pleasure Island bed sample locations P15-P19

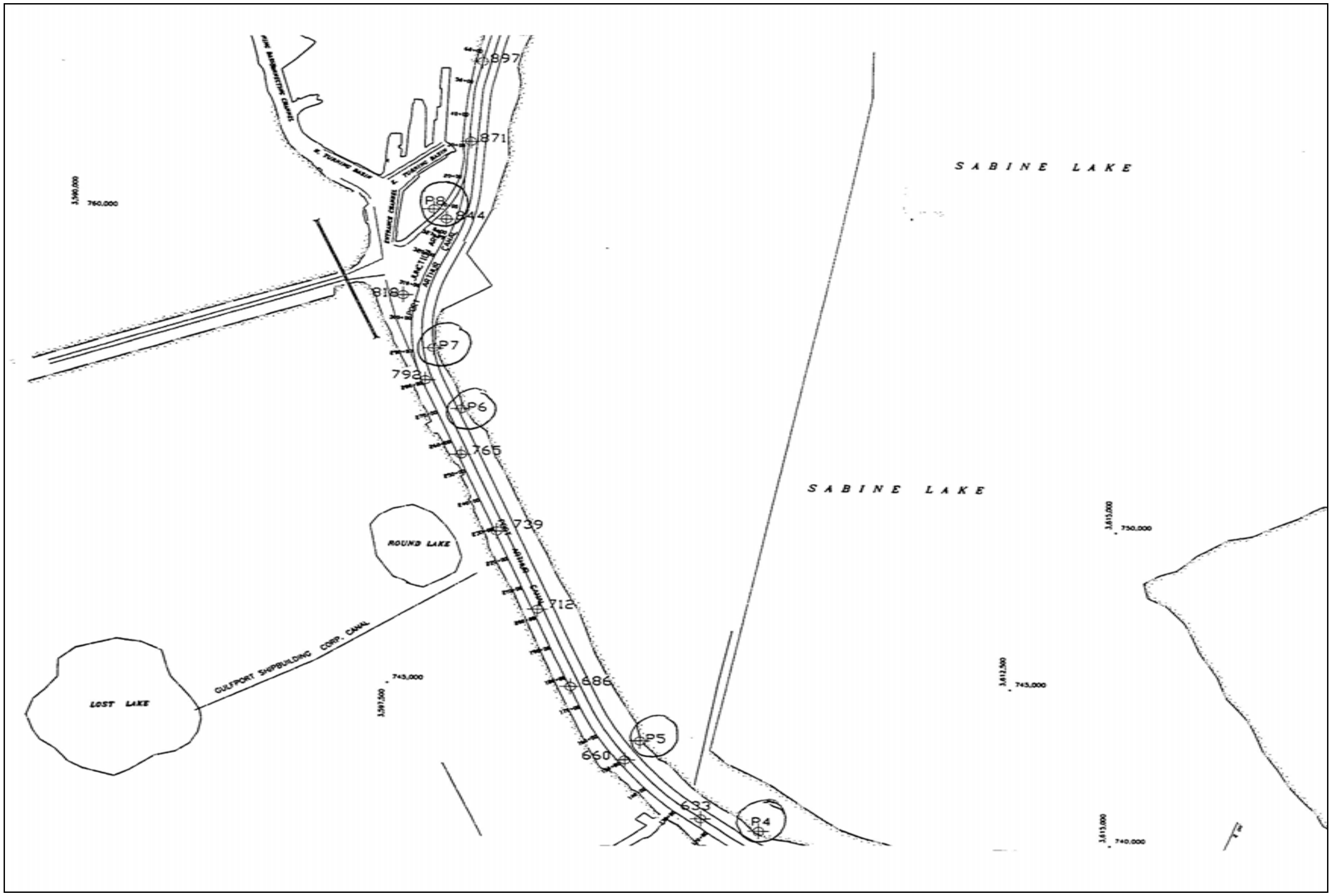



Figure 3.4.3: Pleasure Island bed sample locations P8-P4

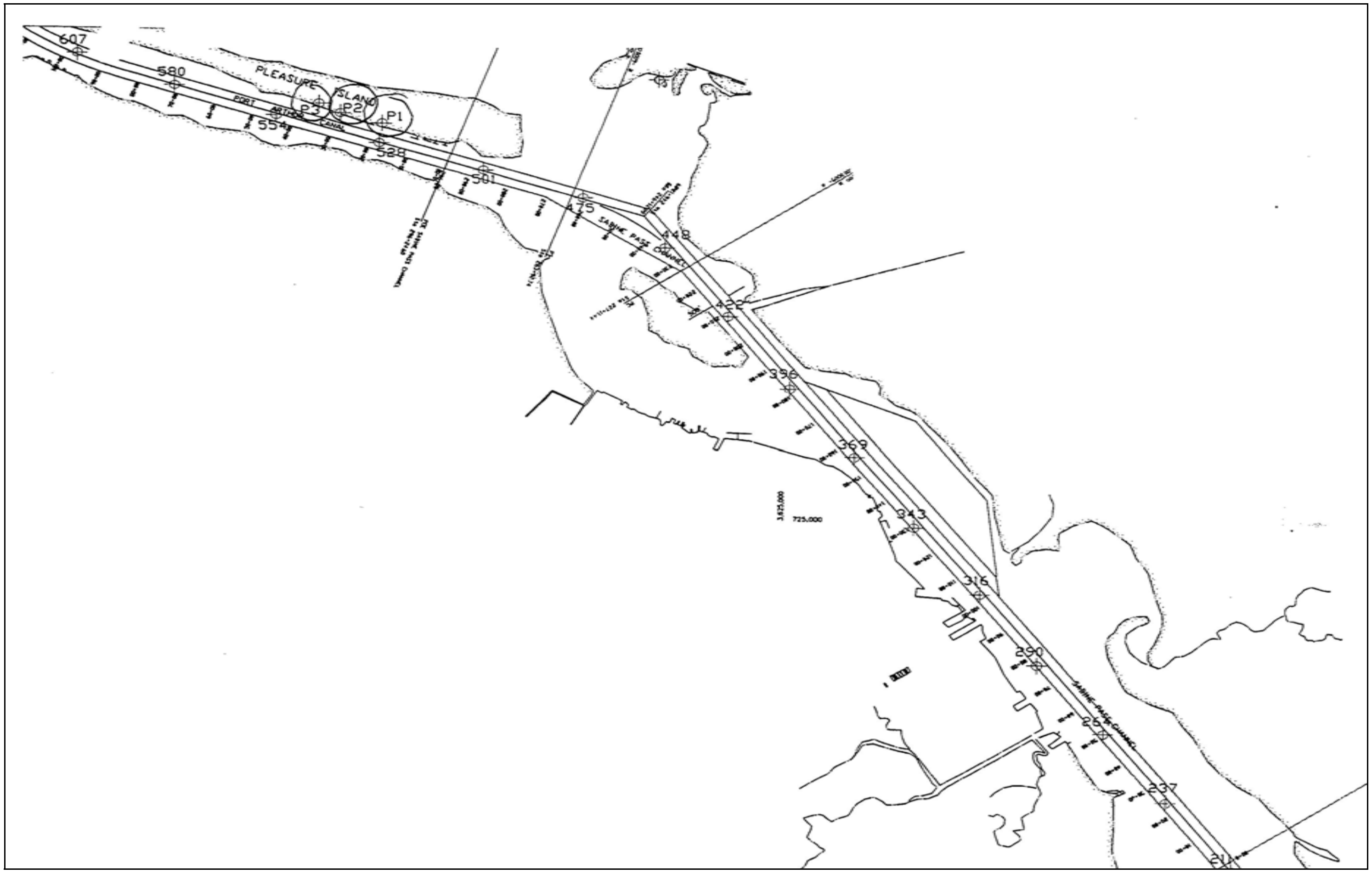



Figure 3.4.4: Pleasure Island bed sample locations P3-P1

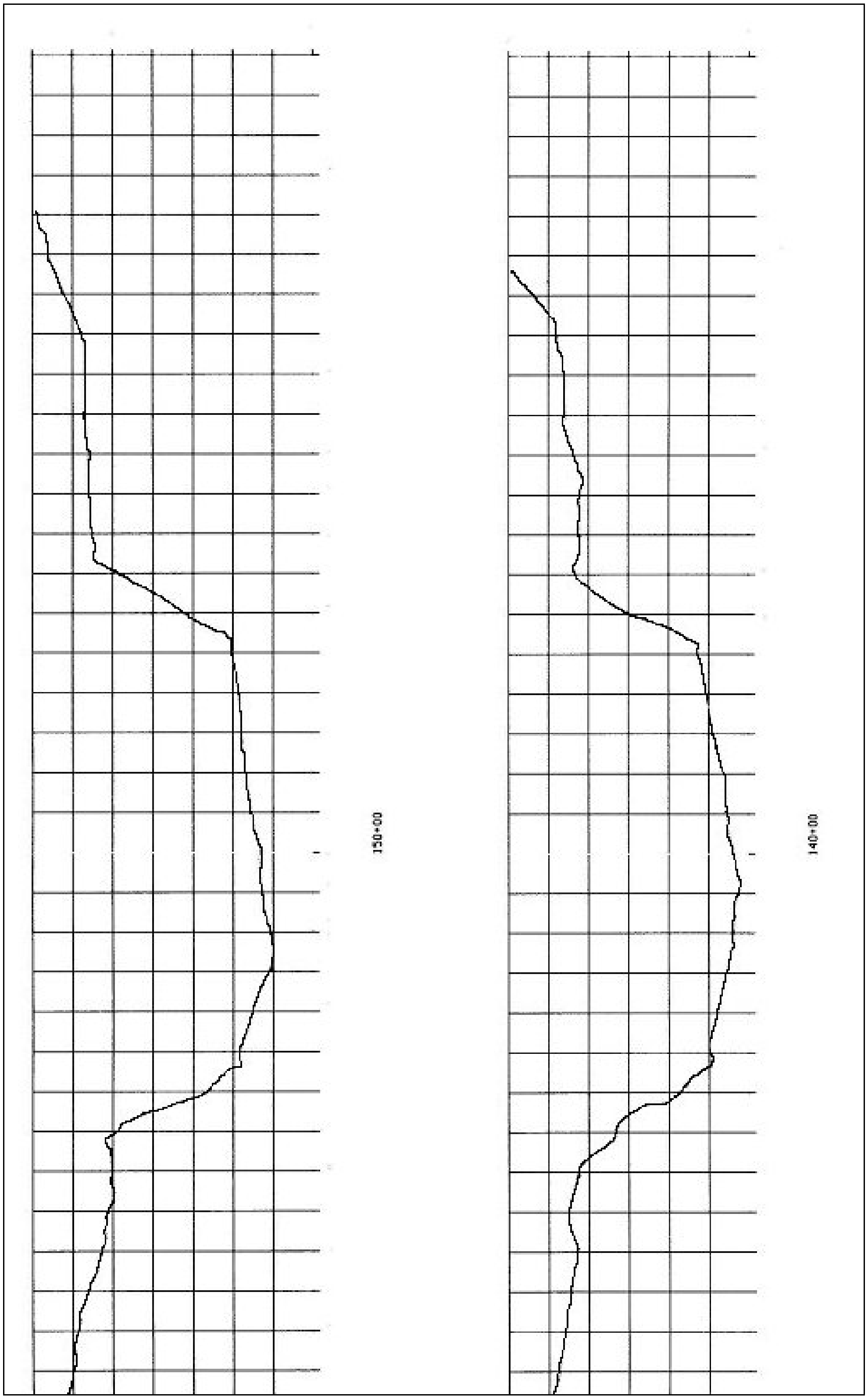



Figure 3.4.5: Port Arthur Canal Cross-Sections

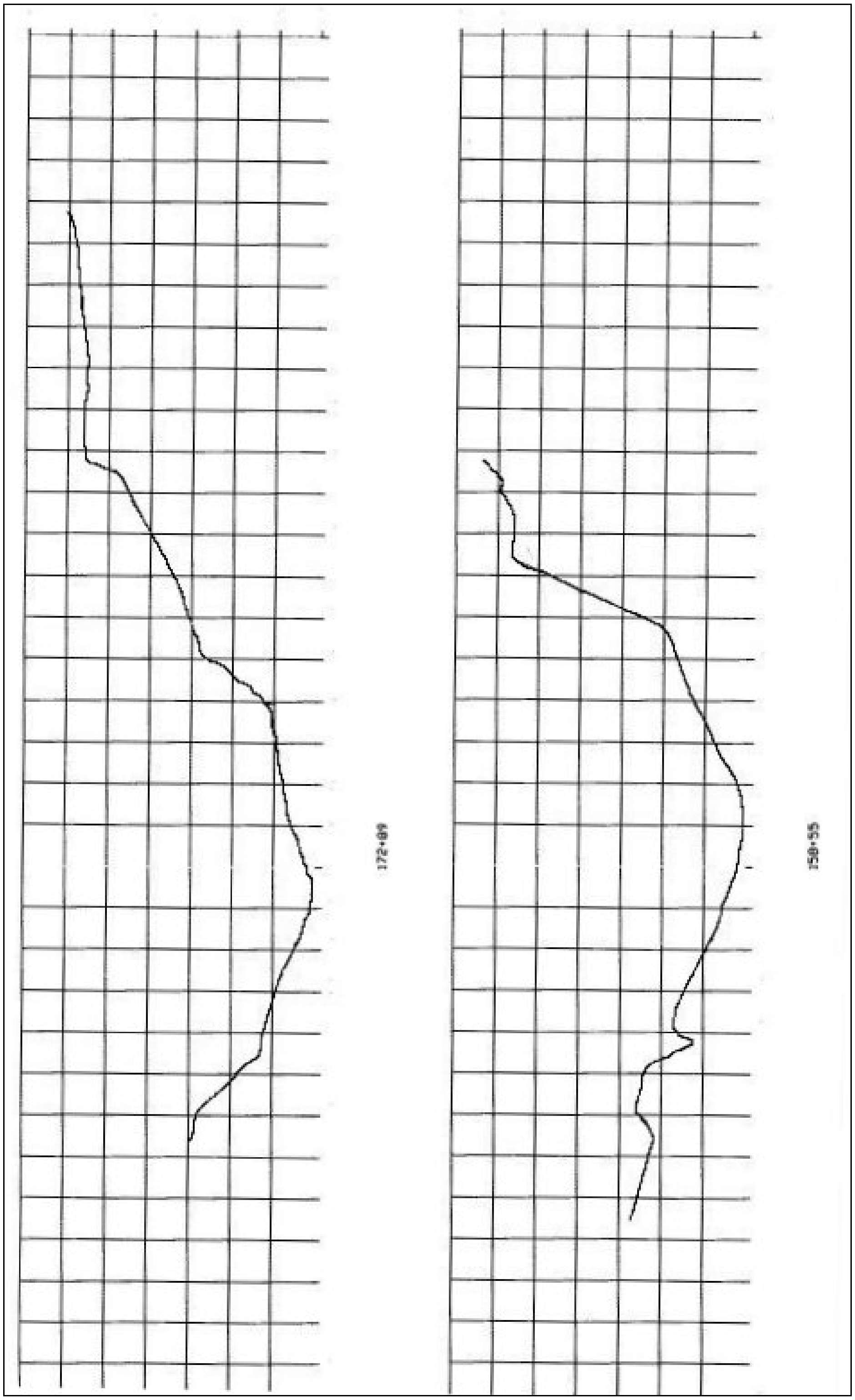



Figure 3.4.6: Sabine Neches Canal Cross-Sections

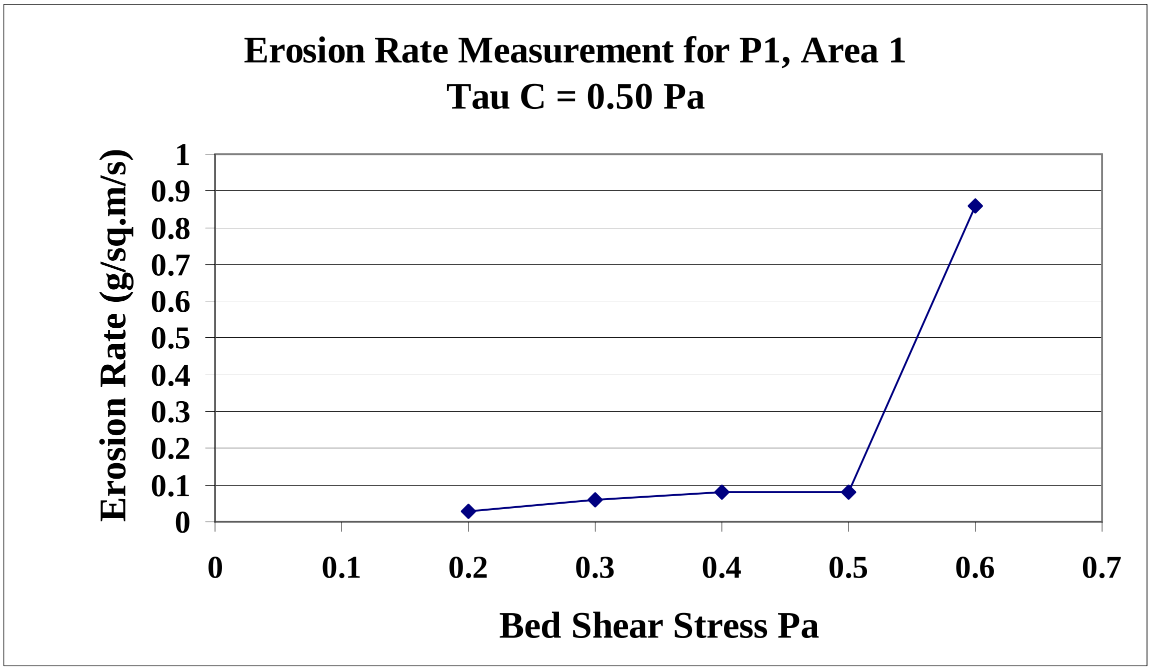



Figure 3.4.7: Critical bed shear stress for bed sediment sample at P1

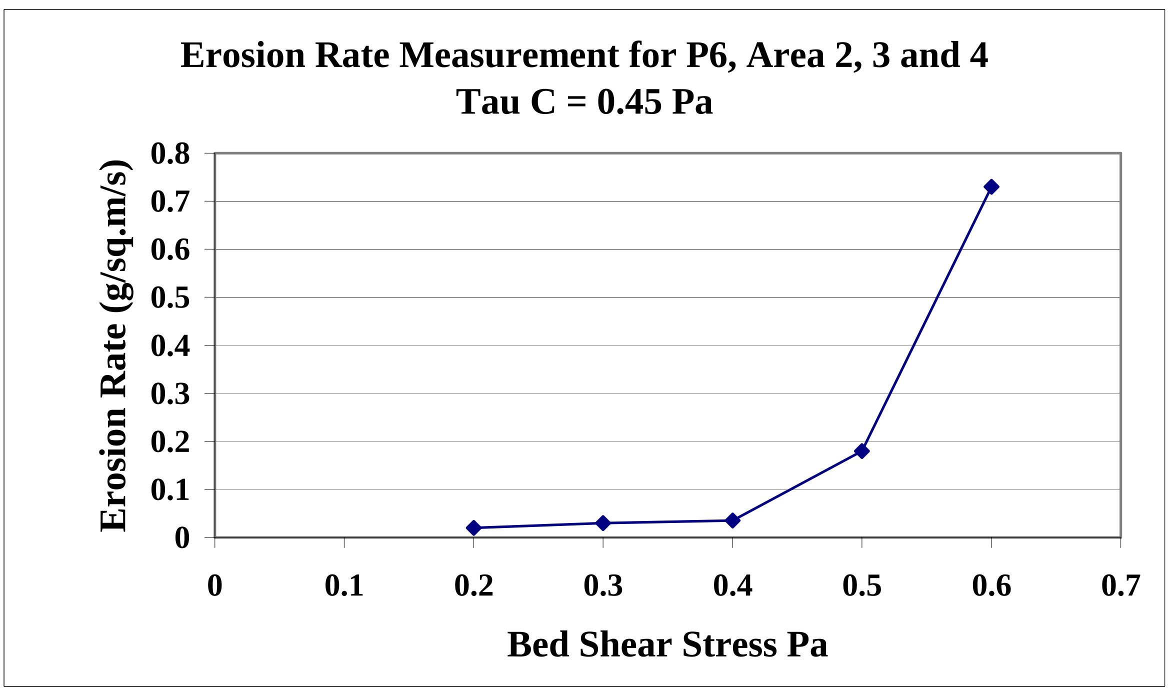



Figure 3.4.8: Critical bed shear stress for bed sediment sample at P6

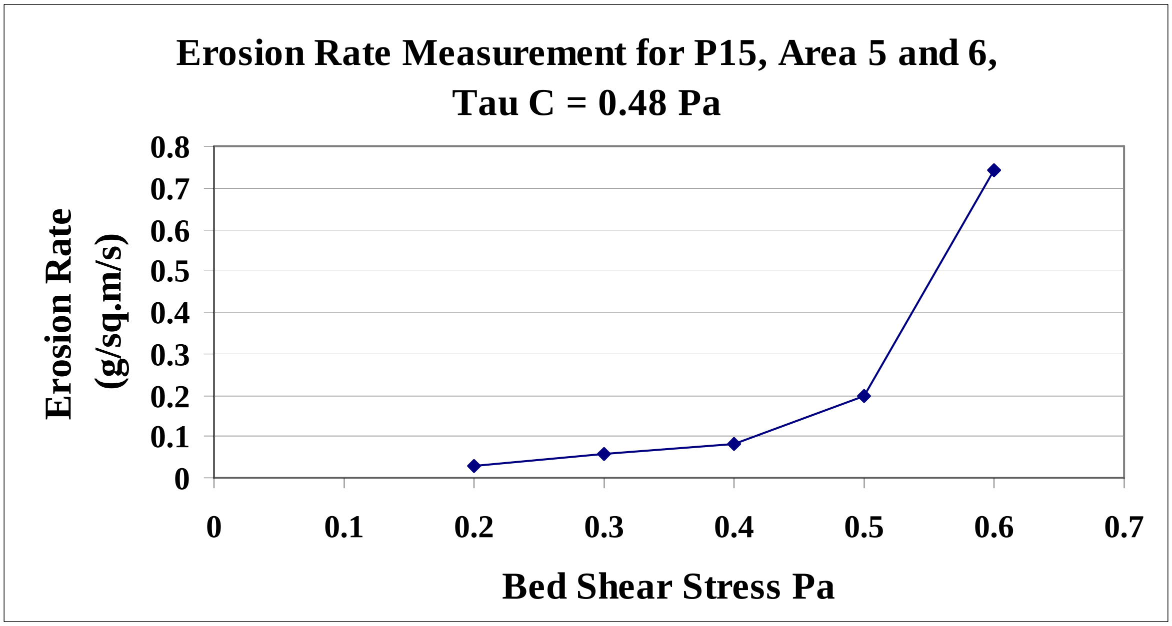



Figure 3.4.9: Critical bed shear stress for bed sediment sample at P15

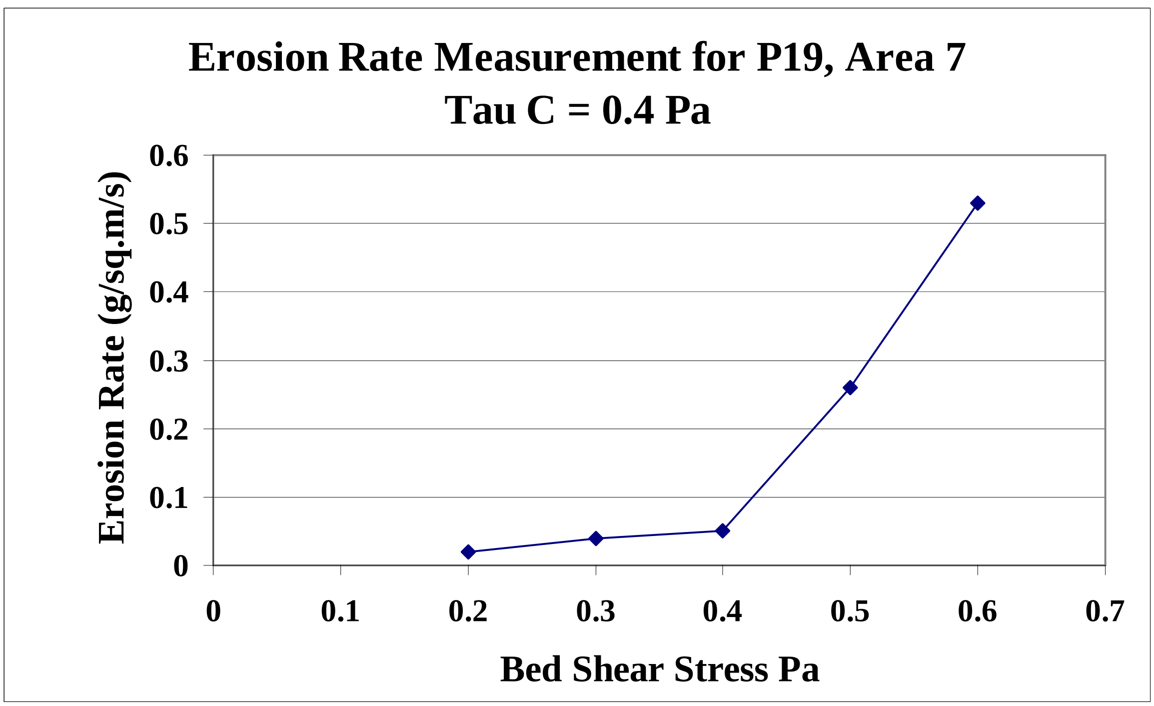



Figure 3.4.10: Critical bed shear stress for bed sediment sample at P19

# Chapter 3.5: Erosion Evaluation

## Present Erosion Condition

The primary reasons for sever erosion along portions of the Pleasure Island shoreline are a) land composed of highly erodible unconsolidated silts and clays and b) vessel wakes and surges. This is a purely man-made environment with neither the soils nor the waves of natural origin. Controlling the erosion will require a similar degree of human intervention.

The island consists of easily erodible hydraulic fill placed on native stiff clay soils that exist at approximate sea level. As water moves in and out of the fill material in response to waves, fine particles are suspended and carried out if not constrained in some fashion. The water movement includes the normal astronomical; wind waves, waves from all types of passing vessels, and surges from larger passing vessels. In view of the highly erodible nature of the soil on the island, the shoreline would continue to erode from tidal currents and wind wave action alone. Vessel-generated waves and surges would accelerate the process.

## Existing Shoreline Protection

It appears that clay soils exist near sea level on Pleasure Island and that all the soils above sea level are hydraulic fill from excavation of the Sabine-Neches Canal. Most of the lower soil layers appear to contain clay balls. These are chunks of relatively stiff clay removed in dredging that are typically 1 to 2 inches in diameter. When discharged from a dredge pipe, these settle and become compacted to some degree, forming a soil that can serve many functions. Most of the structures on the island are built on such materials. However, when exposed to moving water the unconsolidated fine silts and clays surrounding the clay balls can be washed out easily. Where there is no protection, water attacks the base of the shoreline and the overlying material falls into the canal, forming an erosion scarf or cut bank that is typical of much of the present shoreline.

In 1994 and 1995, the City of Port Arthur and the PI Commission installed erosion controls using concrete slabs cut out of the MLK Bridge. These were placed over filter fabric along the shoreline. In the process of removing the slabs from the bridge, holes were cut in the concrete sections to allow lifting. In portions of the shoreline work, these slab sections were installed in a double layer, with the top layer offset from the bottom so the holes would be covered. In other places, a single layer of slab was placed.

Where concrete slabs have protected the filter fabric, the erosion has somewhat slowed. However, in places, the filter fabric has developed gaps where water pipes in and out strongly when vessels produce large drawdown and surge. Over time many of these slabs have been undermined and left in the water as the shoreline has migrated to the east.

There are some examples of effective erosion protection in the project area. One is the granite blocks placed along the shore at the Corps and USCG office locations. These close-fitting granite blocks are placed over smaller stones that are in turn placed over fine sand after the shore was shaped. The bottom course of these granite blocks is placed on the natural stiff clay, and the toe of the slope is protected from scour by additional riprap. These were installed following a standard Corps design in the 1970's and have held up very well.

Another example of effective protection is the sheet piling placed as part of the same location. These have served for almost 40 years, and except for some degree of corrosion, they are still serving their intended purpose today.

A third example of effective erosion protection is some of the concrete slabs placed over filter fabric in 1994-95.

Sections that appear to have functioned reasonably well include several key elements such as 1. Filter fabric was installed all the way down to the virgin clay, 2. A double layer of concrete slab was overlapped at the joints, 3. The slabs were extended up the slope to a sufficient height, and 4. Stones were used to protect the toe of the slopes.

Many shore protection measures have been provided over short lengths along the shoreline of SNWW. They include rubble and woven mattresses of concrete bricks. These were placed on filter fabric, however their failures are seen at many places for various reasons. Photographs of shore erosion are given in Appendix H.

## Pleasure Island Erosion Analysis

The Galveston District conducted an analysis of Pleasure Island shoreline erosion. Their report is reproduced below. The seven sites where erosion was evaluated are shown in Figures 3.5.1 through 3.5.4. It is noted from this analysis that the rate of erosion at the selected seven sites varied between 2.6 and 16.5 feet per year. The average rate of shoreline erosion for all the sites considered together was 10 feet per year during the 20-year period 1974 through 1993.

## Galveston District Report

> "The trends in shoreline erosion, dating from 1970, along the waterway were evaluated at seven locations. The current channel configuration was established in the late 1960s and thus, this analysis did not evaluate the shoreline erosion patterns prior to 1970. The study locations were primarily located along Pleasure Island, on both the east and west sides of the channel. Location No. 1 (at the junction of Sabine Pass and Port Arthur Channels) was the farthest southern point on Pleasure Island, at Mesquite Point. Locations 2, 3, and 4 were located along the Port Arthur Canal. Locations 5, 6, and 7 were located along the Sabine Neches Canal.
>
> The analyses were conducted by establishing identical points on each quad and measuring the distance to the existing shoreline. At all but two locations (#1 and #5) measurements were taken approximately perpendicular to the channel. At locations #1 and #5, the axis of measurement was approximately 65 degrees to the channel. Measurements were taken from digitized copies of the quadrangle maps. Measurements were rounded to the nearest tenths. These measurements include an

inherent error that is relative to the quad scale (1 inch = 2000 ft). The results of these analyses (given in Table 3.5.2) are meant to provide an indication of erosional trends of the shoreline and are not meant to replace more precise topographic surveying methods."

## Current-induced Bank Erosion

The numerical model showed that the bottom current velocities in the vicinity of the Pleasure Island shoreline increase by a small extent after navigation channel modifications. The current velocities for both flood and ebb conditions are mostly less than 1 ft/s on the average. The sediment prevailing along the west shoreline of Pleasure Island consists of a mixture of fine and coarse fractions. The fine sediment component would erode under these current strengths.

Critical shear stress for erosion of non-cohesive (coarse) sediments decreases with particle size. Critical shear stress values are given below in Table 3.5.1

**Table 3.5.1: Critical shear stress for non-cohesive sediment particles**

| Particle size (micron) | Particle size (mm) | Shear Stress ($lb/ft^2$) | Shear Stress (Pa) |
|---|---|---|---|
| | | | |
| 2000 | 2.0 | 0.03 | 1.43 |
| 1000 | 1.0 | 0.012 | 0.57 |
| 100 | 0.1 | 0.004 | 0.19 |

Silt consists of particles smaller than 64 microns. Clays and organic substances provide binding of particles, which increases the shear strength of sediment mixtures. Laboratory tests showed that the nearshore sediment consisting of 90 percent particles with clays and silt, and 4 percent organic matter had critical shear strength of about 0.4 Pa, and the rate of erosion was low.

## Table 3.5.2: Summary of Sabine Neches Waterway shoreline erosion analysis

| Location # | Channel Location | Approx. Station | Approximate Location (NAD 27) | | USGS Quad Sheet | Shoreline Change | | Estimated Annual Erosion Ft/Yr | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | Latitude | Longitude | | 1970-1974 | 1974-1993 | | |
| 1 | Sabine Pass | 285+00 | 29 45' 38" N | 93 53' 59" W | Port Arthur South | 60' | 0 | 2.6 | |
| 2 | Pt Arthur | 220+00 | 29 47' 58" N | 93 57' 14" W | Port Arthur South | | 240' | 12.6 | No measurable shoreline erosion from 1970 to 1974. |
| 3 | Pt Arthur | 240+00 | 29 48' 16" N | 93 57' 09" W | Port Arthur South | | 180' | 9.5 | No measurable shoreline erosion from 1970 to 1974. |
| 4 | Pt Arthur | 300+00 | 29 49' 10" N | 93 57' 38" W | Port Arthur South | | 80' | 4.2 | No measurable shoreline erosion from 1970 to 1974. |
| 5 | Sabine Neches | 80+00 | 29 50' 48" N | 93 56' 53" W | Port Arthur South | 120' | 260' | 16.5 | |
| 6 | Sabine Neches | 370+00 | 29 54' 35" N | 93 53' 26" W | Port Arthur North | | 300' | 15.8 | Photo revisions were done in 1970-75. |
| 7 | Sabine Neches | 550+00 | 29 57' 00" N | 93 51' 47" W | West of Greens Bayou | | 170' | 8.9 | No Quad sheets prior to 1970-74 photo revisions could be found. |

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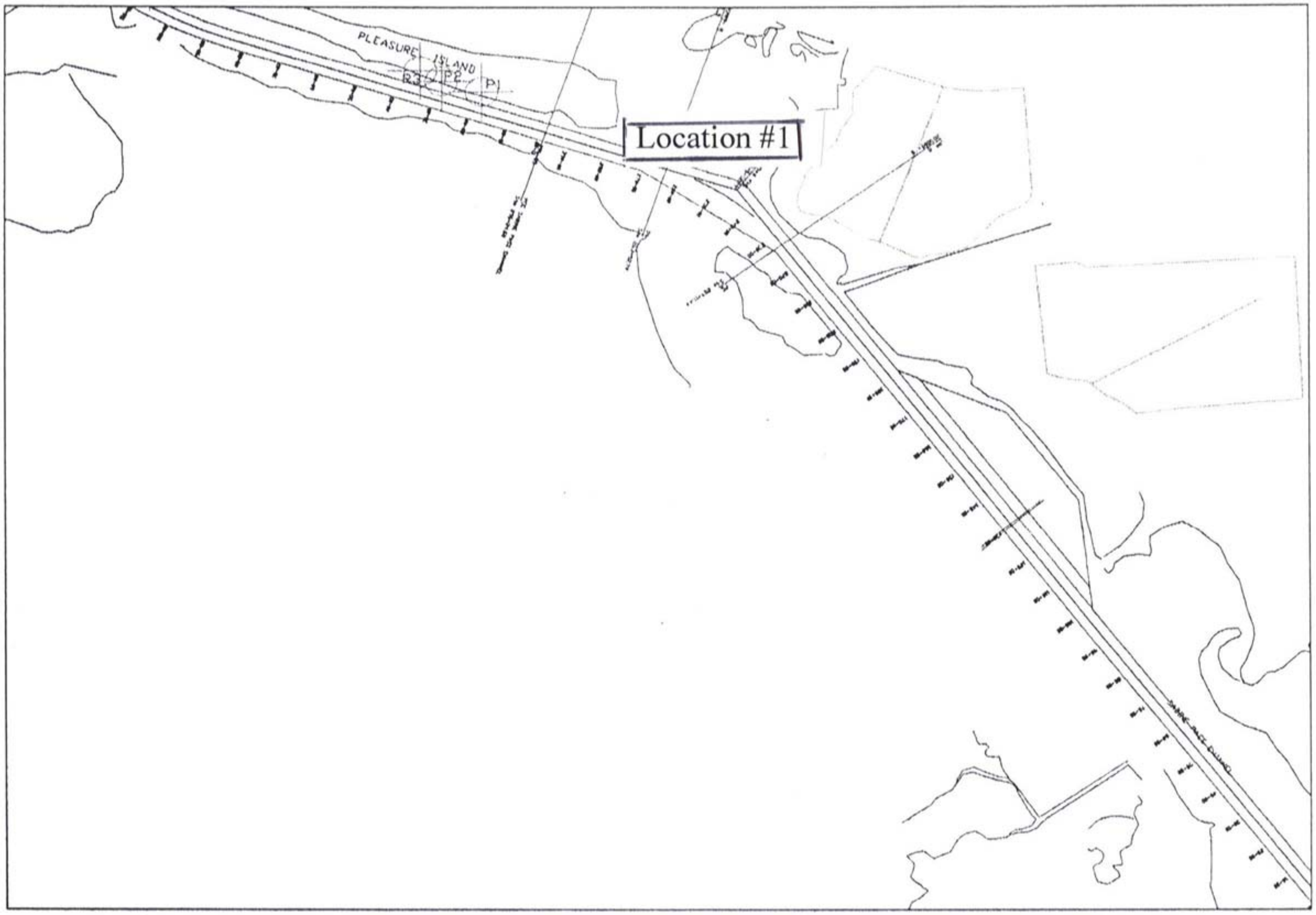


Figure 3.5.1: Shoreline erosion location 1


Figure 3.5.2: Shoreline erosion locations 2, 3, and 4

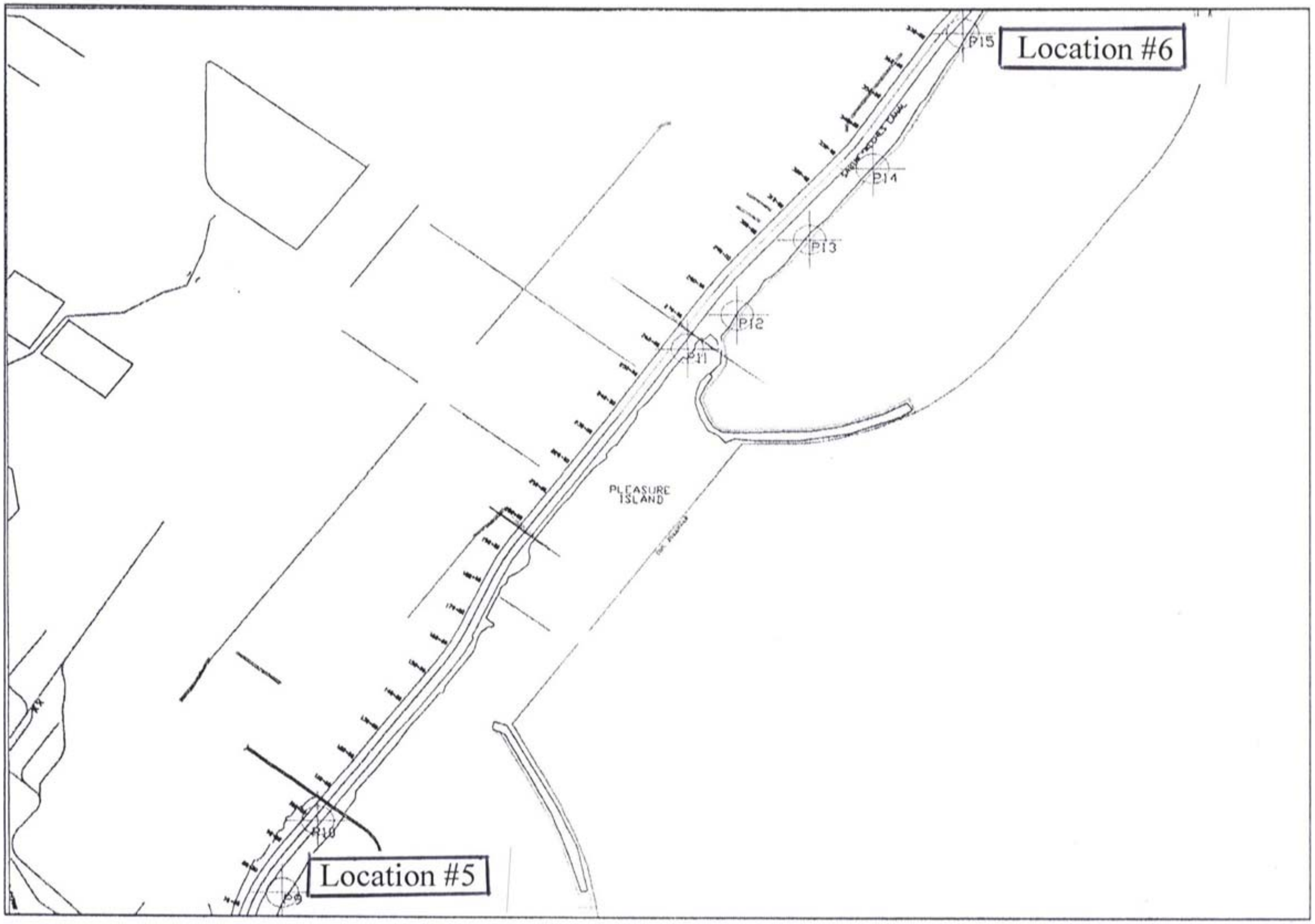


Figure 3.5.3: Shoreline erosion locations 5 and 6

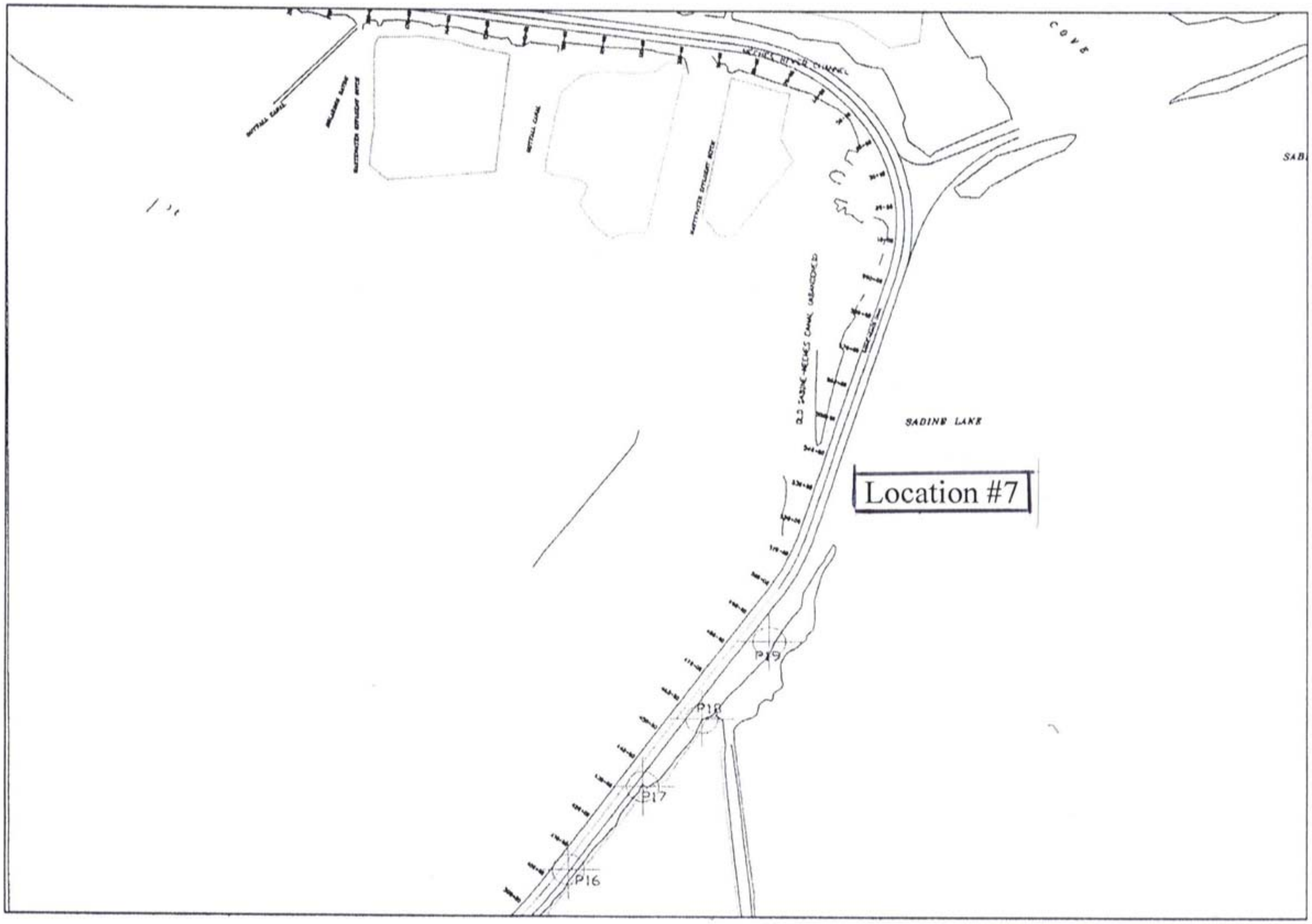


Figure 3.5.4: Shoreline erosion location 7

# Chapter 3.6: Concluding Remarks

1. In view of the highly erodible and weakly compacted soil on the Pleasure Island, the shoreline would likely continue to erode from tidal currents and wind waves. Vessel-generated waves and surges would continue to accelerate the process as in the past.

2. It is estimated that a 30-cm vessel-induced wave would generate bed shear stress of 0.35, 0.8 and 2.4 Pa in water depths of 1.5 m, 1.0 m, and 0.5 m respectively. The magnitudes of current-induced bed shear stress are significantly smaller than those induced by vessel-generated waves. Hence vessel-induced waves are more significant in the context of erosion of Pleasure Island shoreline.

3. The magnitude of tidal current varies continually with time. The present peak values near the shore are on the order of 1 ft/s. It may be noted that 1.This is only the peak value, 2. It is not observed at all the locations, 3. It is obtained for the select combination of tides, wind and river discharge conditions used for running the numerical model. The average sustained value of tidal current would be less than 1 ft/s. Intermittent bank erosion is expected to occur near the peak values of flow velocities.

4. As a result of navigation channel modifications, the peak bottom current velocity is expected to be higher in percentage but continues to be small in its absolute magnitude. Again the three factors mentioned in the above paragraph apply.

6. Since the fetch is limited for the constricted waterway, wind waves are relatively small in magnitude and may not be of concern related to bank erosion.

7. The erosion appears to be caused predominantly by surges, stern waves, and rapid drawdown resulting from vessel traffic within the constricted Sabine Neches waterway.

8. The characteristics of vessel-induced waves and surges and their effect on the bank depend on several factors, such as waterway geometry, bank slope, shoreline bathymetry, flow conditions, vessel characteristics (draft, tonnage, bow), vessel operating conditions (speed), and the volume of vessel traffic.

9. Beach slopes above and below water line are relatively mild and hence would be mostly stable. However, there are regions where the wave attack has caused caving, leaving unstable, close to vertical profile cliffs.

10. Several types of bank protection measures have been adopted along the navigation channel shoreline. While a few measures have been successful, many others appear to have failed. At several locations that do not have structural protection, a bluff has formed due to erosion and severe setbacks of land have occurred. The main cause of failure appears to be inability of the measure to retain the unconsolidated soil underneath the revetments.

11. The following conceptual shoreline protection alternatives have been considered by the PBS&J Consultants. 1. Two-layer concrete slabs, 2. New revetments using either articulated concrete blocks or revetment mattress, and 3. Use of Gabions or geotubes to serve as a wave barrier. Detailed studies are needed for comparison of merits of these and other options.

12. Use of a filter layer (geotextile) under the armoring structures is often very effective. However, it is seen at site that such fabric has not been always effective, probably due to defective construction practices, tearing of fabric at places, lack of adequate anchoring to the bed to prevent uplifting of the mattress, toe failure and so on. Hence adequate care is needed in selecting, designing and using filter fabrics.

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# Supplementary Report 3

# Re-evaluation of Navigation Channel Shoaling for Sabine Neches Project

**DRAFT**

**September 2004**

# Table of Contents

**Supplementary Report 3**
**Re-evaluation of Navigation Channel Shoaling for**
**Sabine Neches Project**

**September 2004**

## Proposed Development

The Galveston District proposed to deepen the Sabine Neches navigation channel to accommodate larger ships drawing greater draft. The minimum water depth provided for safe navigation is called Project Depth. It is customary to dredge navigation channels at a depth greater than the project depth. This excess dredging, referred to as over-depth, covers various allowances for safe navigation and also minimizes the need for emergency dredging for small loss of depths due to shoaling.

The existing project depth in the inner Sabine Neches navigation channel is 42 feet plus 1-foot over-depth. The outer channel has 44 feet depth plus 2-feet over-depth in the outer channel.

Based on several considerations, the team members at Galveston District had selected the project depth of 50-foot for the navigation channel and connected areas such as turning circles and harbor basins. For the SNWW project the depths would be as follows:

a) For the interior navigation channel inside the jetties:

| | |
|---|---|
| Project depth | 50 feet |
| Over-depth | 2 feet |
| Total depth of dredged channel | 52 feet |

b) For navigation channel outside the jetties:

| | |
|---|---|
| Project depth | 52 feet |
| Over-depth | 2 feet |
| Total depth of dredged channel | 54 feet |

The following bottom widths for the base and plan are used for the present study for the 48-foot project, which are the same for the 50-foot project. The dredged depths including over-depth are 50 feet and 52 feet for the inner channel and outer channel respectively for the 48-foot project.

| | Base | Plan |
|---|---|---|
| Reach 1 and 2 | 400 ft | 400 ft |
| Reach 3 and 4 | 500 ft | 700 ft |
| Reach 5 | 600 ft | 750 ft |
| Reach 6 and 7 | 800 ft | 800 ft |
| Reach 8 | 800 ft | 700 ft |

## Background of Earlier Study

ERDC conducted numerical hydrodynamic modeling work for the Sabine Neches Project. The 2D model was set up as the first step and was verified with the then available field data on currents and water levels. The model was proposed to be converted later to 3D after results of additional field data on currents and salinity became available.

ERDC also conducted Desktop Study for sediment-related problems at Sabine Neches Project. This study consisted of assessing the impact of the proposed navigation channel modifications on the sediment-related issues. A two-volume draft report was submitted to the Galveston District in December 2002 for review and comments. Volume 1 included the following three sediment-related issues.

Study 1: Siltation in the modified navigation channel.
Study 2: Pleasure Island Erosion.
Study 3: Erosion of eastern shoreline of Sabine Lake.

Volume 2 included Appendices A through L.

Results from the fully verified 3D numerical salinity model were not available for conducting the desktop sediment studies. However, in view of urgency of work it was decided to complete the sediment studies based on the data available from the 2D numerical model as of that time and re-visit the issue after the salinity model results were available. Estimation of siltation was worked out for the proposed project depth of 50 feet.

## 2D Numerical Model Information

A hydrodynamic numerical model was initially set up to represent two-dimensional conditions. Chapter 1.4 in Part 1 of the ERDC Report dated December 2002 provides information on the 2D numerical modeling done for the Sabine Neches Project.

## 3D Numerical Model

The 2D numerical model was subsequently updated to three-dimensional so as to include vertical variations in velocity and salinity. The 3D model was run for project depth of 48 feet. Results of this 3D model have been used in the present report for re-evaluating navigation channel shoaling quantities after channel modifications. The existing condition is referred to as “Base” and the modified channel condition is referred to as “Plan” in this report.

The grid for 3D numerical model was changed while it was transformed from the previous 2D model. New nodes along the centerline of the navigation channel were selected that were close to the bed sample locations. The actual node numbers of numerical model were called Station Numbers and were assigned numbers N01 through N124 for convenience of reference. Numerical model data on currents and salinity were extracted at some of these nodes. Table 1 gives the station numbers and corresponding node numbers of the numerical model.

The operating test conditions used for the 2D model are described under Chapter 1.4 in the December 2002 report. The 3D model used different conditions for running the model and also a different nomenclature for reporting results. Low fresh water flow represented flood dominance and median fresh water flow represented ebb dominance. Instead of the single depth-averaged values at each node, the 3D model provides velocity magnitudes at multiple depths. The velocity magnitudes in 3D model are assigned positive sign for currents going landward during flood tide and negative sign for currents going seaward during ebb tide.

The Sabine Neches Waterway is divided into seven geographical reaches and each segment is identified by a different name. Figure 1 shows these seven reaches. The existing navigation channel with a project depth of 42 feet will have to be extended to meet the natural available depth of 48 feet in the sea for the proposed deeper channel. The portion of navigation channel extended beyond the present end of channel is named Reach 8 for the present study. A total of ten nodes representative of the seven reaches were selected. These are listed in Table 2.

## Velocity Data

The bottom velocities under median fresh water flow were examined. Velocity data with magnitude and direction were extracted from the solution files at selected nodes of the numerical model. Superposed bottom velocity magnitudes for base and plan condition for the selected 10 nodes are given in Appendix 3.1. Positive values of velocity represent flood whereas negative values represent ebb. The velocities obtained in the numerical model show considerable time-variation. Hence only the peak values of velocity are considered for evaluation. The results are summarized in Table 3 for flood and in Table 4 for the ebb, which offers a comparison of base and plan conditions.

It may be seen from Tables 3 and 4 that the bottom velocity magnitudes are quite small, less than 0.5 ft/s in most cases. For the Flood phase, the variation is between 0.02 and 0.6 ft/s for the base condition and between 0.02 and 1.4 ft/s for the plan condition. For the ebb phase, the variation is between 0.01 and 0.5 ft/s for the base condition and between 0.01 and 0.9 ft/s for the plan condition. At all the nodes covering the channel up to the end of jetties, plan peak velocities are somewhat higher than the base peak velocities both for the flood and for the ebb but the absolute magnitudes are still small. These low velocities near the bottom of navigation channel offer conditions favorable for sediment deposition.

## Salinity Data

The bottom salinity values under median fresh water flow were examined. Salinity data were extracted from the solution files at selected 10 nodes of the numerical model. Superposed bottom salinity magnitudes for base and plan condition for the selected nodes are given in Appendix 3.2. The entire navigation channel may be divided into three broad and approximate groups for describing the salinity variation. Group 1 is the upstream group, which includes reaches 1, 2, and 3. It shows relatively gradual time-variation. Group 2 is the middle group, which includes reaches 4 and 5, extending to the end of jetties. This group shows rapid time-varying fluctuations in salinity. Group 3 is the outer channel beyond the jetties on the seaside and it shows almost constant salinity at 30 ppt.

The salinity obtained in the numerical model at each node shows considerable time-variation. Hence the range of time-variation of salinity values at each node location is considered for evaluation. The results are summarized in Table 5, which gives the range of variation in salinity values for the base and plan conditions. It also shows the three groups and seven reaches mentioned earlier.

It may be seen from Table 5 that range of salinity variation for plan over the reaches 1 through 4 is higher than the corresponding range for the base condition. This indicates a greater penetration of salt water towards upstream as a result of channel deepening. The most upstream node, namely node N01 shows zero salinity for both the base and plan, indicating that salinity intrusion stops downstream of this location. As would be expected, salinity magnitudes increase continually as we proceed towards sea along the navigation channel.

Fine sediments remain in suspension in fresh water for times extending over weeks or months but they are known to flocculate and settle faster after getting into saline water. The effect is most dramatic for salinity increasing from zero to about 5 parts per thousand (ppt) by weight. The effect decreases rapidly from 5 ppt to about 10 ppt. Between 10 and 15 ppt, the effect is negligible and beyond 15 ppt there is no effect of salinity on flocculation. It may be noted from Table 5 that plan salinities are higher than base salinities, particularly in the reaches 2, 3, and 4. Hence increased shoaling in these reaches would be expected as a result of deepening.

## Study Plots

Node 01 is the uppermost node considered for this study. A comparison of surface and bottom velocities and salinities for base and plan at node N1 are given in Figures 4 and 5 respectively. Node N90 is at the entrance to the estuary. A comparison of surface and bottom velocities and salinities for base and plan at node N90 are given in Figures 6 and 7 respectively. These plots cover the length of estuary under study.

## Shoaling Prediction

Estimated quantities of shoaling in navigation channel after its modification were given in Table 2.6.7 of the December 2002 report. This Table is reproduced as Table 6 for ready reference. Since the navigation channel depth has changed from 50 feet to 48 feet, new area factors have been worked out and used in Table 7, which gives the estimated quantities of dredging for the 48-foot project.

The annual quantities of shoaling in the 48-foot channel will be higher than the present 42-foot project for the following reasons:

a. Low velocities near the bottom of navigation channel offer conditions favorable for sediment deposition.
b. Increased salinity intrusion with deeper channel would result in greater flocculation of fine sediments, resulting in their faster deposition.
c. Deeper channel will have greater surface area near existing seabed and a larger

volume below the seabed. Hence it would function as a larger sediment trap.

d. Increased length of the channel results in higher quantities of dredging in an area, which is not required to be currently dredging.

The reasons listed above are taken into account by adopting relevant multiplication factors applied to the present quantities of dredging. The factors are related to the effect of area, velocity, salinity and other factors such as sediment trapping efficiency, waves, navigation etc. Considering the results of 3D numerical model, it is noted that most of the factors applied for velocity and salinity are appropriate. Revised factors were provided where needed. Factors related to change in channel depth were changed. New factors as given in Table 7 were applied and shoaling quantities were worked again. Based on the results of 3D model for the 48-foot project, the total annual quantity worked out to 15.59 million cubic yards instead of 16.67 million cubic yards estimated earlier for the 50-foot project based on the results of 2D model.

## Conclusions

**A. Flow Velocities along Navigation Channel**

1. For the Flood phase, the variation is between 0.02 and 0.6 ft/s for the base condition and between 0.02 and 1.4 ft/s for the plan condition.

2. For the ebb phase, the variation is between 0.01 and 0.5 ft/s for the base condition and between 0.01 and 0.9 ft/s for the plan condition.

3. At all the nodes covering the channel up to the end of jetties, plan peak velocities are somewhat higher than the base peak velocities both for the flood and for the ebb.

4. The bottom velocity magnitudes are quite small, less than 0.5 ft/s in most cases covering base and plan as well as flood and ebb.

**B. Salinity along Navigation Channel**

1. The entire navigation channel may be divided into three broad and approximate groups for describing the salinity variation. Group 1 is the upstream group, which includes reaches 1, 2, and 3. It shows relatively gradual time-variation. Group 2 is the middle group, which includes reaches 4 and 5, extending to the end of jetties. This group shows rapid time-varying fluctuations in salinity. Group 3 is the outer channel beyond the jetties on the seaside and it shows almost constant salinity at 30 ppt.

2. The range of salinity variation for plan over the reaches 1 through 4 is higher than the corresponding range for the base condition. This indicates a greater penetration of salt water towards upstream as a result of channel deepening.

3. The most upstream node, namely node N01 shows zero salinity for both the base and plan, indicating that salinity intrusion stops downstream of this location.

4. As would be expected, salinity magnitudes increase continually as we proceed towards sea along the navigation channel.

**C. Estimated Shoaling in Navigation Channel**

Based on the results of 3D model for the 48-foot project, the total annual quantity worked out to 15.59 million cubic yards instead of 16.67 million cubic yards estimated earlier for the 50-foot project based on the results of 2D model.

**Table 1: Node locations where data were extracted from 3D hydrodynamic model along the centerline of navigation channel**

| Node # | Station # |
|---|---|
| 25710 | N01 |
| 21833 | N09 |
| 18971 | N18 |
| 18923 | N23 |
| 15557 | N30 |
| 11212 | N38 |
| 10098 | N46 |
| 9430 | N54 |
| 8660 | N62 |
| 8349 | N67 |
| 7382 | N75 |
| 5847 | N85 |
| 4970 | N90 |
| 4931 | N96 |
| 4763 | N100 |
| 3943 | N103 |
| 3919 | N105 |
| 3808 | N107 |
| 3360 | N110 |
| 2726 | N114 |
| 1956 | N118 |
| 1518 | N122 |
| 1239 | N124 |

**Table 2: Nodes selected for examining velocity and salinity information from 3D model for each of the seven reaches of navigation channel.**

| Reach Number | Name of Reach | Relevant Node Numbers |
|---|---|---|
| | | |
| Reach 1 | Neches River Channel | N01, N18 |
| Reach 2 | Sabine Neches Canal | N30 |
| Reach 3 | Port Arthur Canal | N46 |
| Reach 4 | Sabine Pass Channel | N75 |
| Reach 5 | The Sabine Pass Jetty Channel | N90, N100 |
| Reach 6 | Sabine Pass Outer Bar Channel | N105 |
| Reach 7 | Sabine Bank Channel | N114, N124 |
| | | |

**Table 3: Bottom Flood Velocities along Navigation Channel**
**Comparison of Peak Velocities for Base and Plan**

| Reach # | Node # | Base Flood Peak Velocity (ft/s) | Plan Flood Peak Velocity (ft/s) |
|---|---|---|---|
| 1 | N 01 | 0.03 | 0.04 |
| | N 18 | 0.15 | 0.25 |
| | | | |
| 2 | N 30 | 0.05 | 0.35 |
| | | | |
| 3 | N 46 | 0.20 | 0.45 |
| | | | |
| 4 | N 75 | 0.30 | 0.55 |
| | | | |
| 5 | N 90 | 0.60 | 1.40 |
| | N 100 | 0.20 | 0.40 |
| | | | |
| 6 | N 105 | 0.07 | 0.10 |
| | | | |
| 7 | N 114 | 0.02 | 0.02 |
| | N 124 | 0.02 | 0.02 |

**Table 4: Bottom Ebb Velocities along Navigation Channel**
**Comparison of Peak Velocities for Base and Plan**

| Reach # | Node # | Base Flood Peak Velocity (ft/s) | Plan Flood Peak Velocity (ft/s) |
|---|---|---|---|
| 1 | N 01 | 0.05 | 0.10 |
| | N 18 | 0.05 | 0.10 |
| | | | |
| 2 | N 30 | 0.05 | 0.45 |
| | | | |
| 3 | N 46 | 0.05 | 0.20 |
| | | | |
| 4 | N 75 | 0.20 | 0.25 |
| | | | |
| 5 | N 90 | 0.50 | 0.90 |
| | N 100 | 0.15 | 0.20 |
| | | | |
| 6 | N 105 | 0.02 | 0.02 |
| | | | |
| 7 | N 114 | 0.01 | 0.01 |
| | 0.01 | 0.02 | 0.02 |

**Table 5: Bottom Salinity along Navigation Channel**
**Comparison of Peak Velocities**

| Group # | Reach # | Node # | Salinity Variation Base (ppt) | Salinity Variation Plan (ppt) |
|---|---|---|---|---|
| I | 1 | N 01 | 0 | 0 |
| | | N 18 | 0 – 1 | 0 – 6 |
| | | | | |
| | 2 | N 30 | 0 – 5 | 1 – 10 |
| | | | | |
| | 3 | N 46 | 2 – 11 | 3 – 15 |
| | | | | |
| II | 4 | N 75 | 3 – 26 | 6 – 26 |
| | | | | |
| | 5 | N 90 | 6 – 29 | 6 – 29 |
| | | N 100 | 6 – 30 | 6 – 30 |
| | | | | |
| III | 6 | N 105 | 29 – 30 | 29 - 30 |
| | | | | |
| | 7 | N 114 | 30 | 30 |
| | | N 124 | 30 | 30 |

**Table 6: Estimated average annual shoaling quantities after channel modifications for the 50-foot project**
**Reference: December 2002 Report, Table 2.6.7**

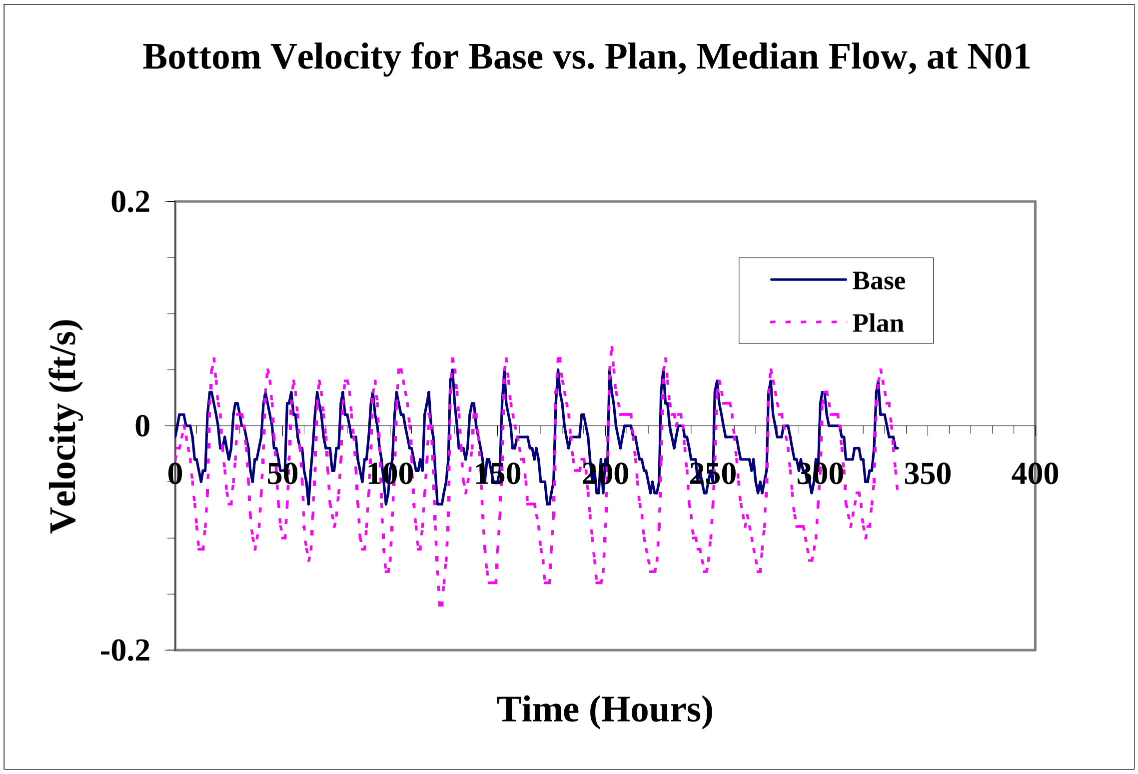
| Reach | Area | Present Dredging (Cu yd) | Area Factor | Velocity Factor | Salinity Factor | Other Factors | Combined Factor | Estimated Dredging (Cu yd) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 8 | EXTENDED OUTER CHANNEL | (1,249,617) | 0.82 | 1.00 | 1.00 | 1.20 | 1.02 | 1,274,609 |
| | | | | | | | | |
| 7 | SABINE BANK CHANNEL | 1,249,617 | 1.05 | 2.30 | 1.00 | 1.20 | 2.55 | 3,186,523 |
| | | | | | | | | |
| 6 | SABINE PASS OUTER BAR | 1,944,987 | 1.21 | 1.93 | 1.00 | 1.20 | 2.34 | 4,551,269 |
| | | | | | | | | |
| 5 | SABINE PASS JETTY CHANNEL | 223,444 | 1.19 | 1.05 | 1.00 | 1.20 | 1.44 | 321,759 |
| | | | | | | | | |
| 4 | SABINE PASS CHANNEL | 768,528 | 1.41 | 1.05 | 1.15 | 1.15 | 1.76 | 1,352,609 |
| | | | | | | | | |
| 3 | PORT ARTHUR CANAL | 1,694,231 | 1.41 | 1.05 | 1.15 | 1.15 | 1.76 | 2,981,846 |
| | | | | | | | | |
| 2 | SABINE-NECHES CANAL | 976,551 | 1.08 | 1.05 | 1.10 | 1.15 | 1.38 | 1,347,640 |
| | | | | | | | | |
| 1 | NECHES RIVER CHANNEL | 1,203,310 | 1.08 | 1.05 | 1.05 | 1.20 | 1.38 | 1,660,567 |
| | | | | | | | | |
| | TOTAL | 8,060,670 | | | | | | 16,676,825 |

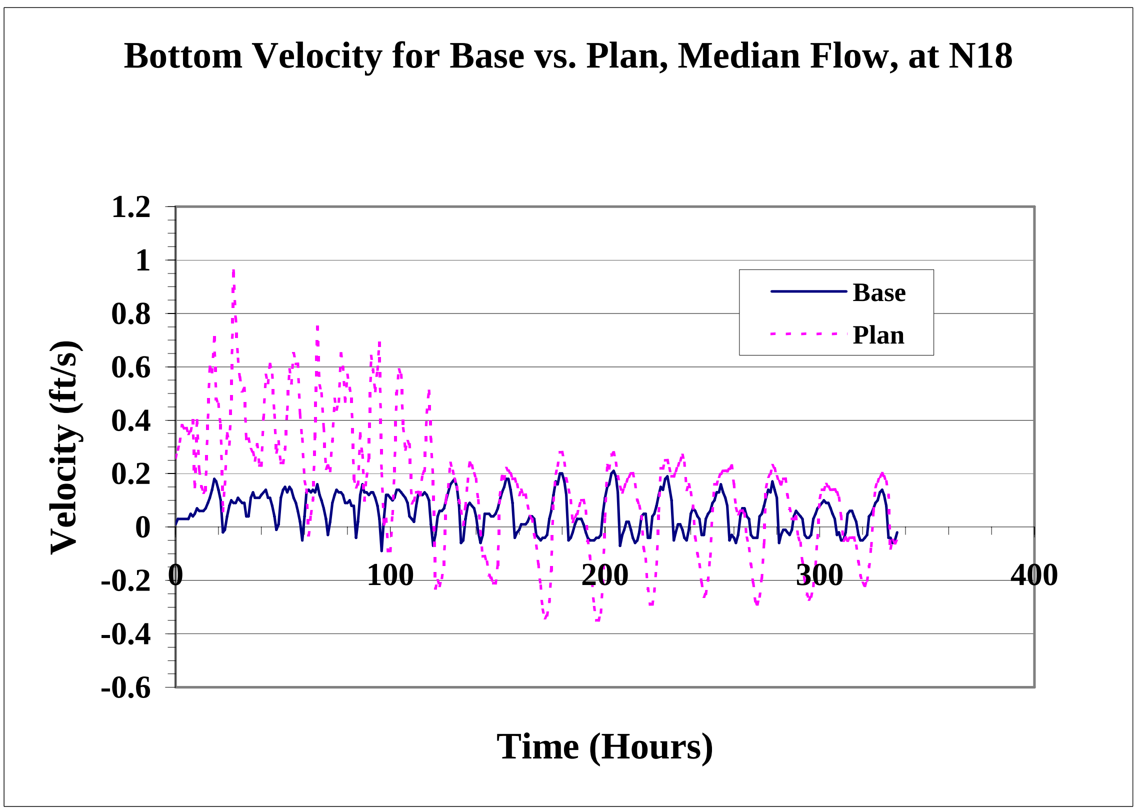
**Table 7: Estimated average annual shoaling quantities after channel modifications for the 48-foot project**

| Reach | Area | Present Dredging (Cu yd) | Area Factor | Velocity Factor | Salinity Factor | Other Factors | Combined Factor | Estimated Dredging (Cu yd) |
|---|---|---|---|---|---|---|---|---|
| 8 | EXTENDED OUTER CHANNEL | (1,249,617) | 0.6 | 1.00 | 1.00 | 1.00 | 0.6 | 749,770 |
| 7 | SABINE BANK CHANNEL | 1,249,617 | 1.04 | 2.00 | 1.00 | 1.20 | 2.24 | 2,799,142 |
| 6 | SABINE PASS OUTER BAR | 1,944,987 | 1.17 | 1.93 | 1.00 | 1.20 | 2.3 | 4,473,470 |
| 5 | SABINE PASS JETTY CHANNEL | 223,444 | 1.18 | 1.05 | 1.00 | 1.20 | 1.43 | 319,525 |
| 4 | SABINE PASS CHANNEL | 768,528 | 1.39 | 1.05 | 1.15 | 1.15 | 1.74 | 1,337,239 |
| 3 | PORT ARTHUR CANAL | 1,694,231 | 1.39 | 1.05 | 1.15 | 1.15 | 1.74 | 2,947,962 |
| 2 | SABINE-NECHES CANAL | 976,551 | 1.06 | 1.05 | 1.10 | 1.15 | 1.36 | 1,328,109 |
| 1 | NECHES RIVER CHANNEL | 1,203,310 | 1.06 | 1.05 | 1.05 | 1.20 | 1.36 | 1,636,502 |
| | TOTAL | 8,060,670 | | | | | | 15,591,719 |

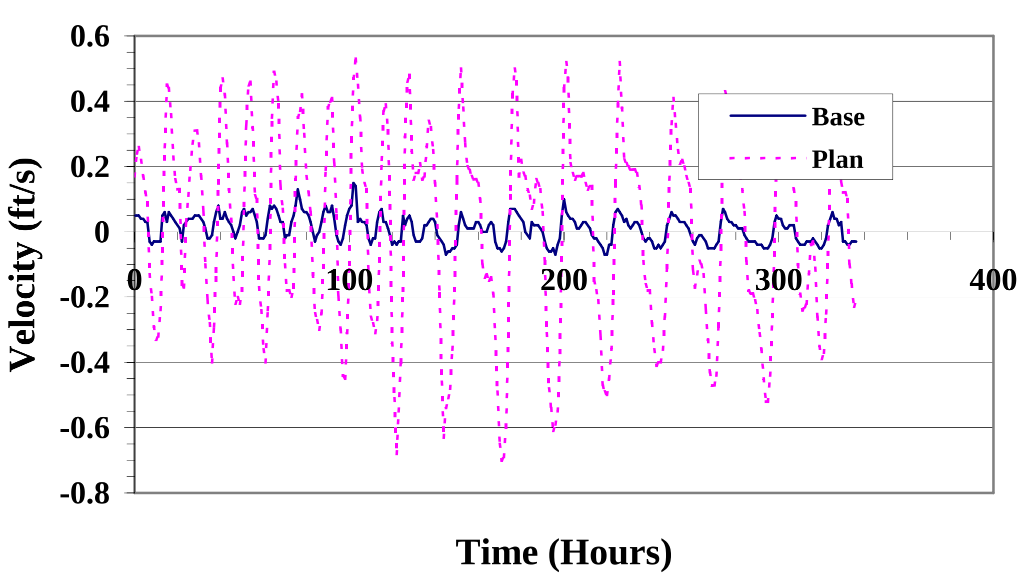
# Appendix 3.1

## Bottom velocity under median fresh water flow obtained in 3D numerical model for base and plan

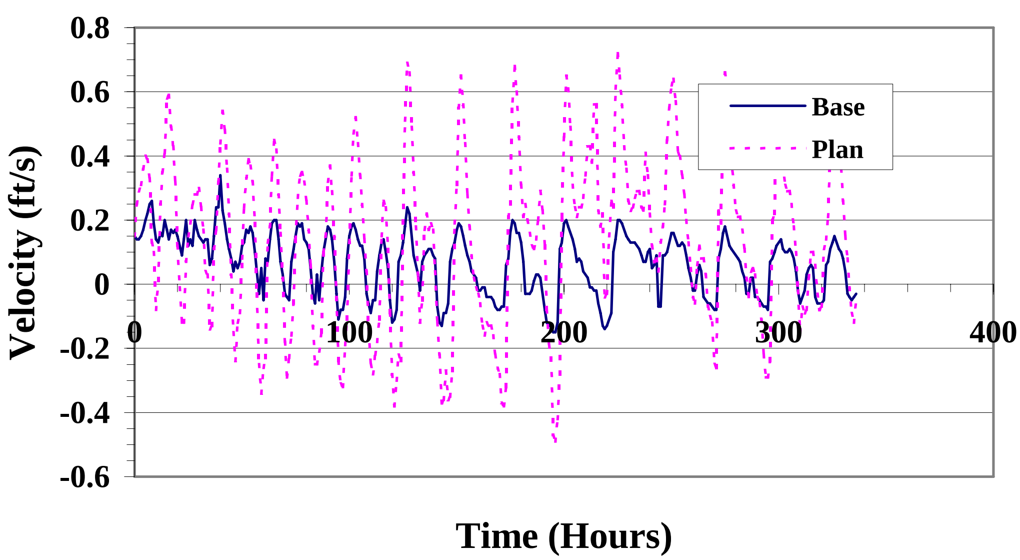

Bottom Velocity for Base vs. Plan, Median Flow, at N01
Velocity (ft/s)
0.2
0
-0.2
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan

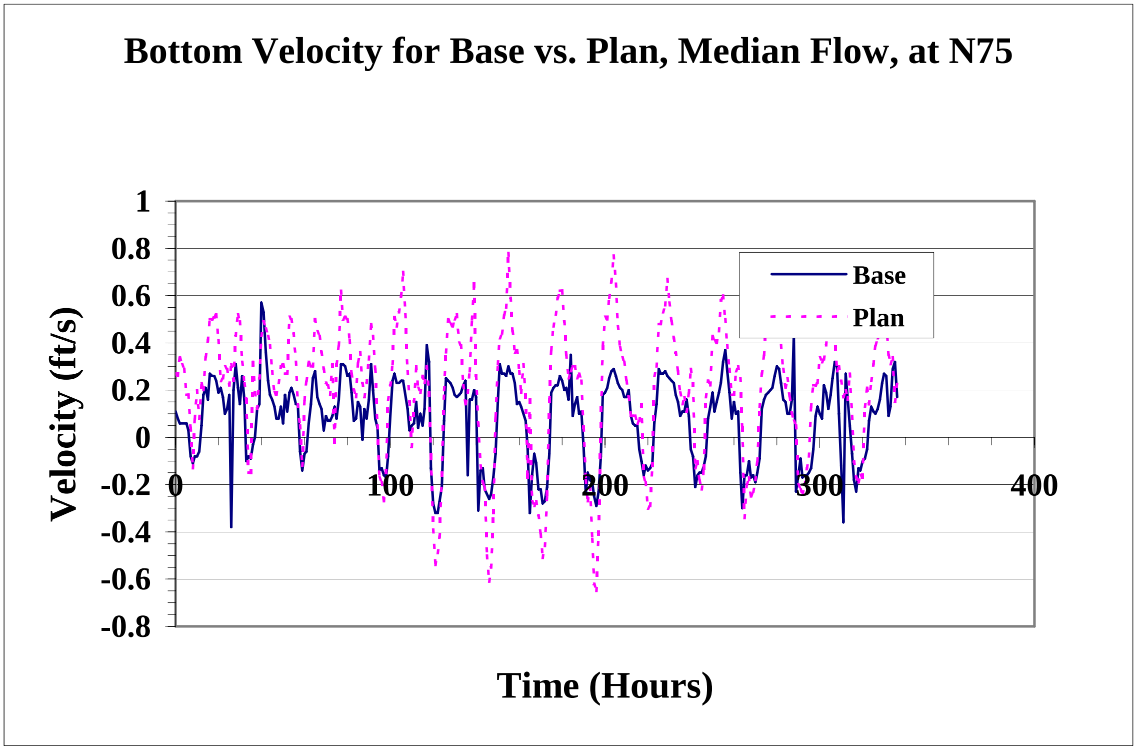

Bottom Velocity for Base vs. Plan, Median Flow, at N18
Velocity (ft/s)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
100
200
300
400
Time (Hours)
Base
Plan

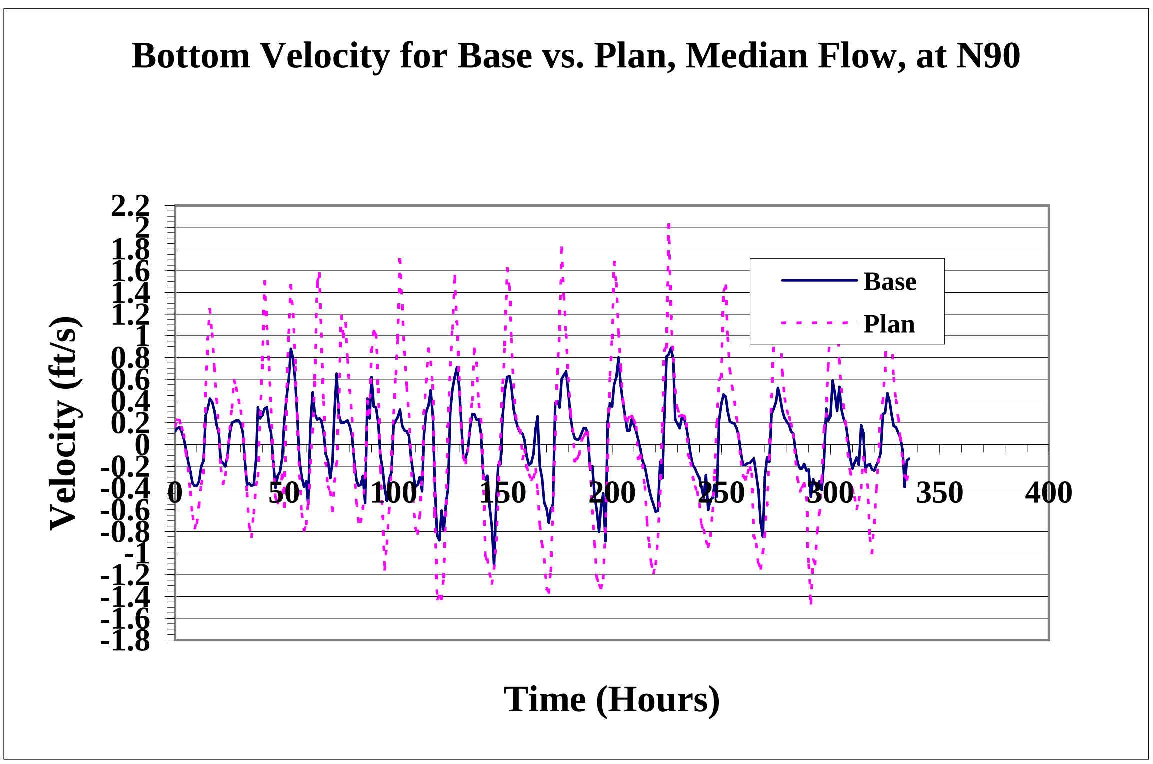
## Bottom Velocity for Base vs. Plan, Median Flow, at N30

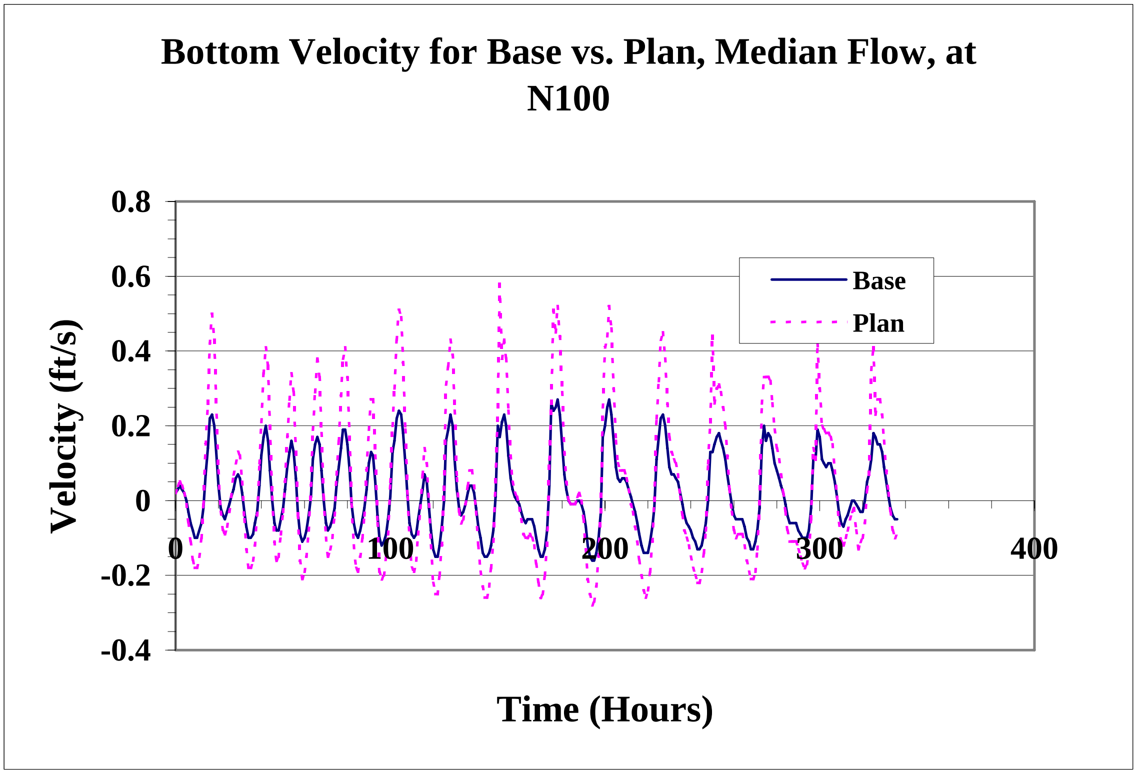


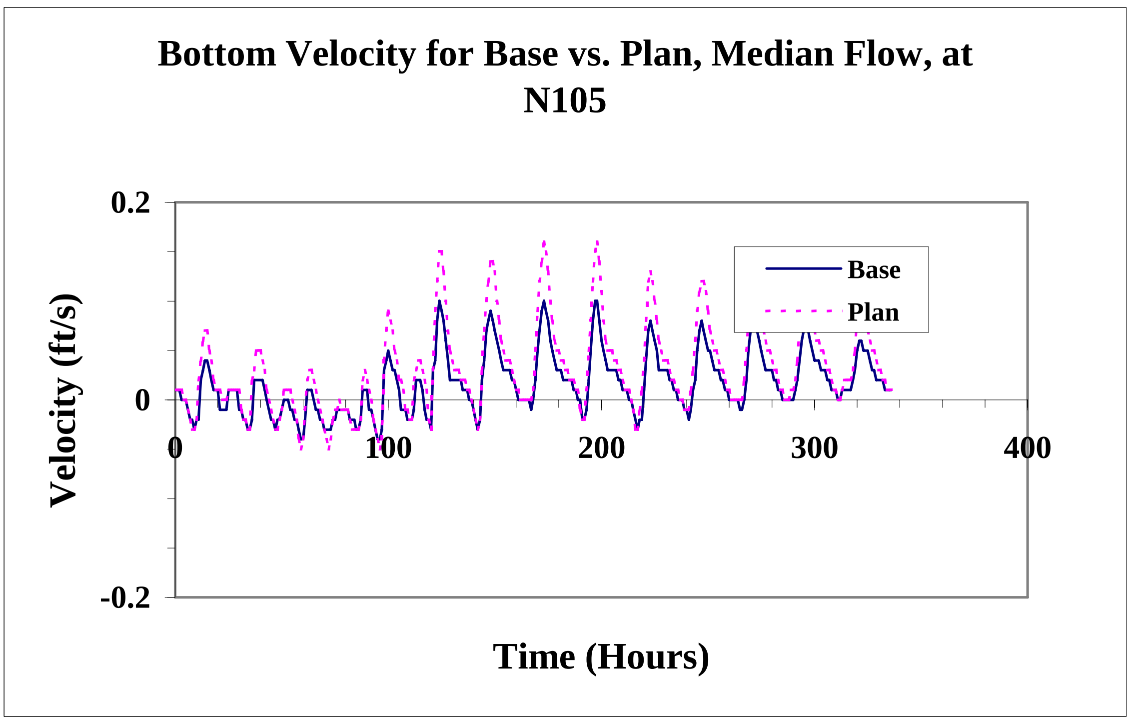

## Bottom Velocity for Base vs. Plan, Median Flow, at N46

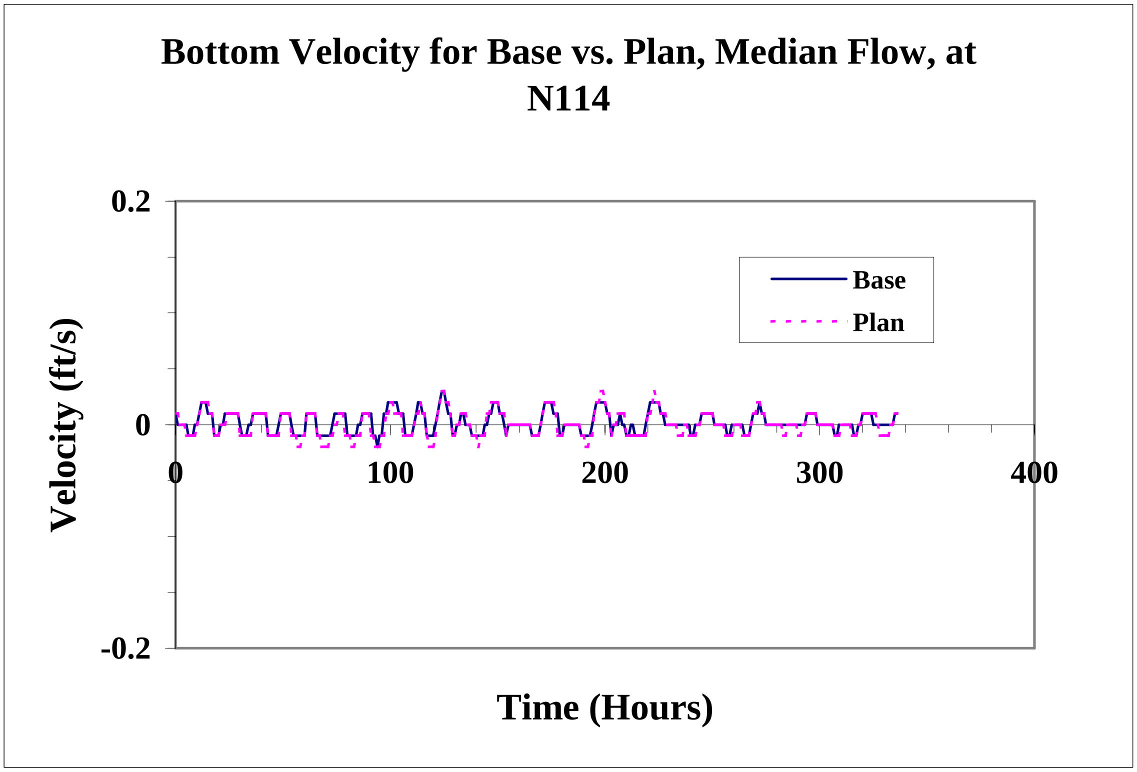


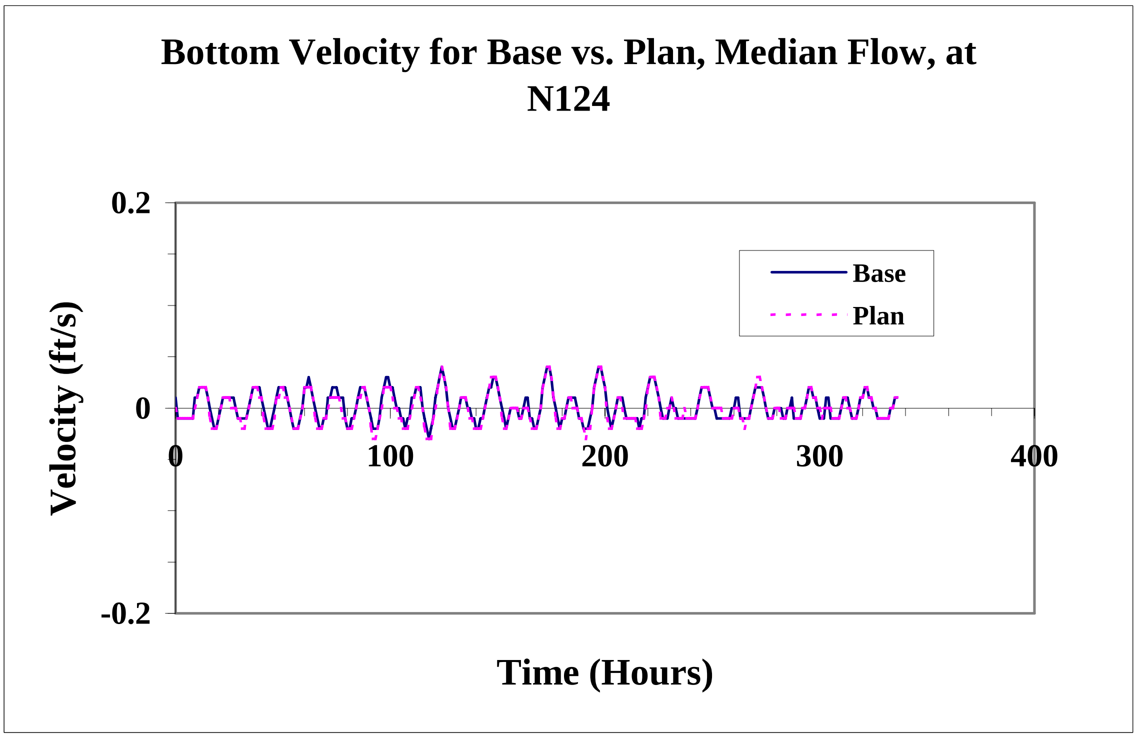

Bottom Velocity for Base vs. Plan, Median Flow, at N75
Velocity (ft/s)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
0
100
200
300
400
Time (Hours)
Base
Plan


Bottom Velocity for Base vs. Plan, Median Flow, at N90
Velocity (ft/s)
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
0
50
100
150
200
250
300
350
400
Time (Hours)
Base
Plan


Bottom Velocity for Base vs. Plan, Median Flow, at N100
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Velocity (ft/s)
0
100
200
300
400
Time (Hours)
Base
Plan

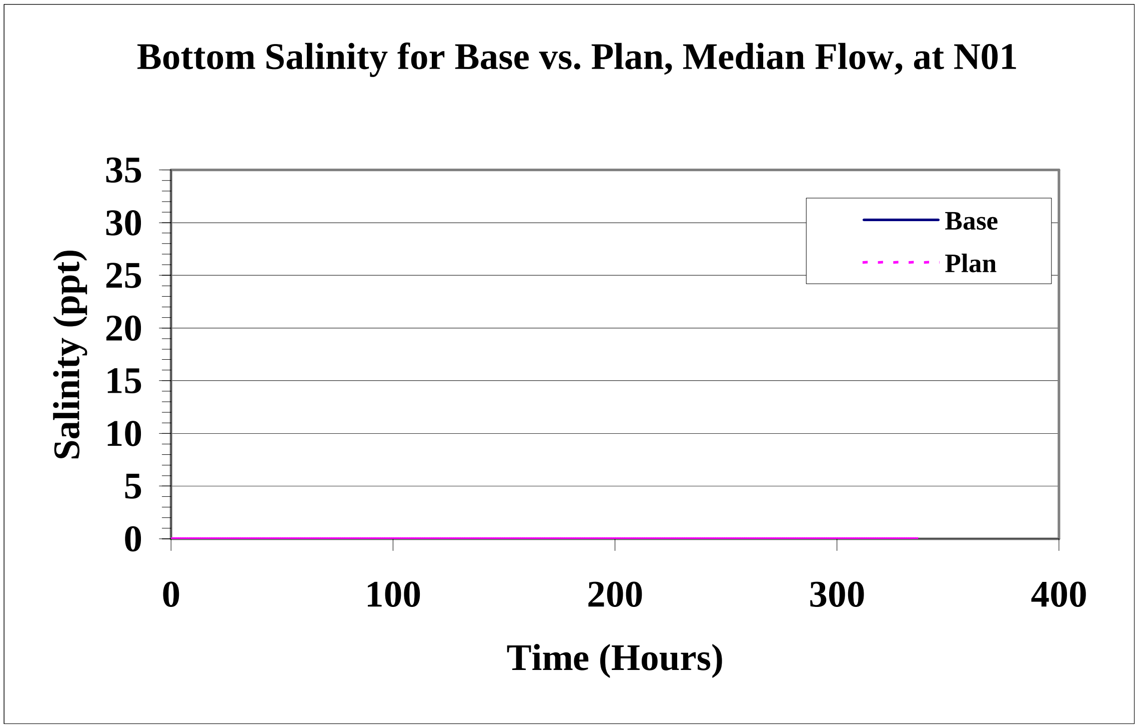

Bottom Velocity for Base vs. Plan, Median Flow, at N105
0.2
0
-0.2
Velocity (ft/s)
0
100
200
300
400
Time (Hours)
Base
Plan

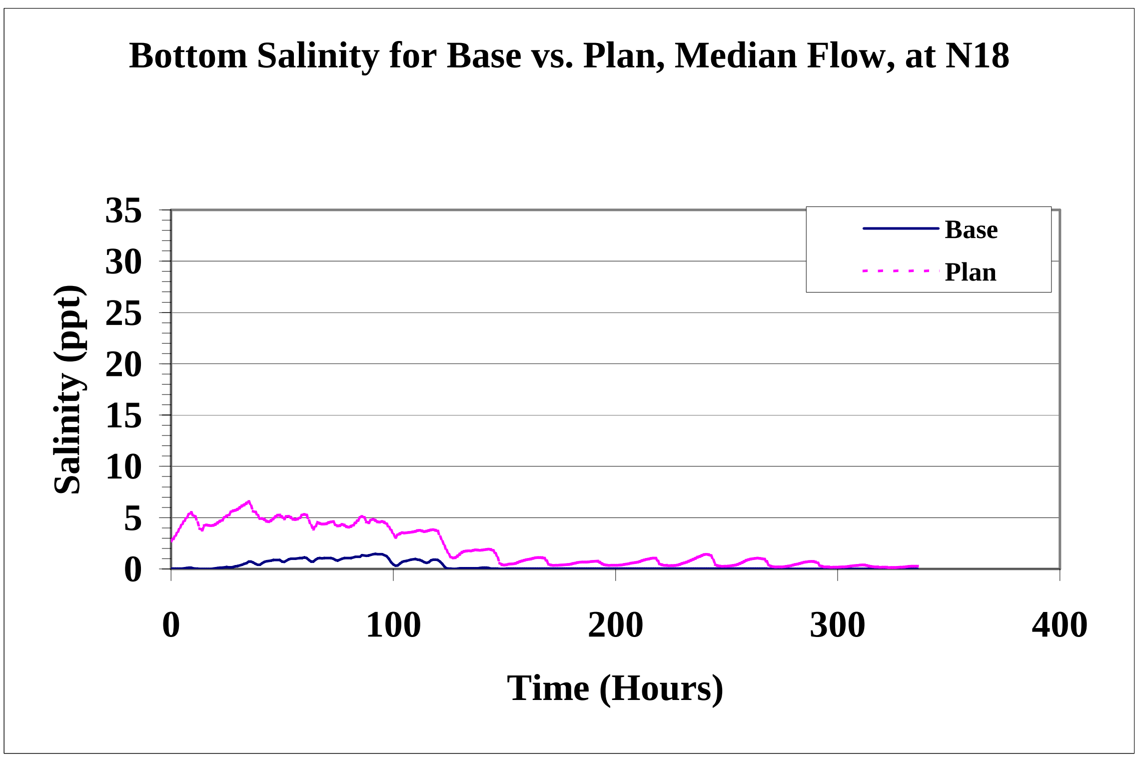

Bottom Velocity for Base vs. Plan, Median Flow, at N114
0.2
0
-0.2
Velocity (ft/s)
0
100
200
300
400
Time (Hours)
Base
Plan

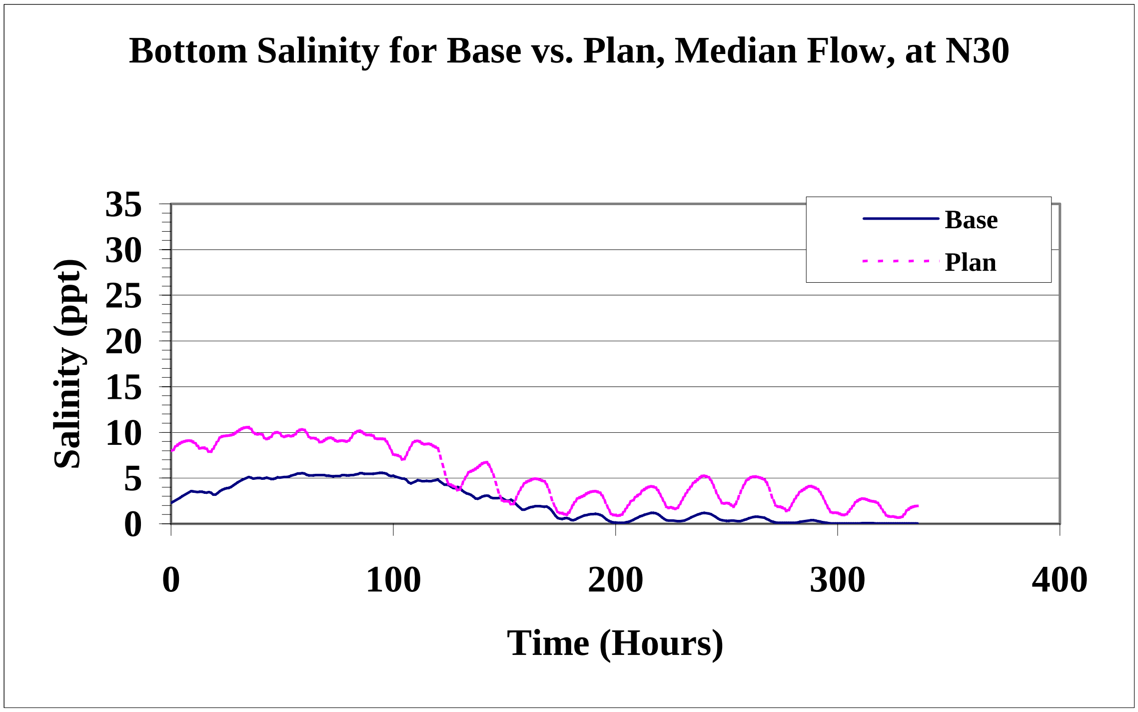

Bottom Velocity for Base vs. Plan, Median Flow, at N124
0.2
0
-0.2
Velocity (ft/s)
0
100
200
300
400
Time (Hours)
Base
Plan

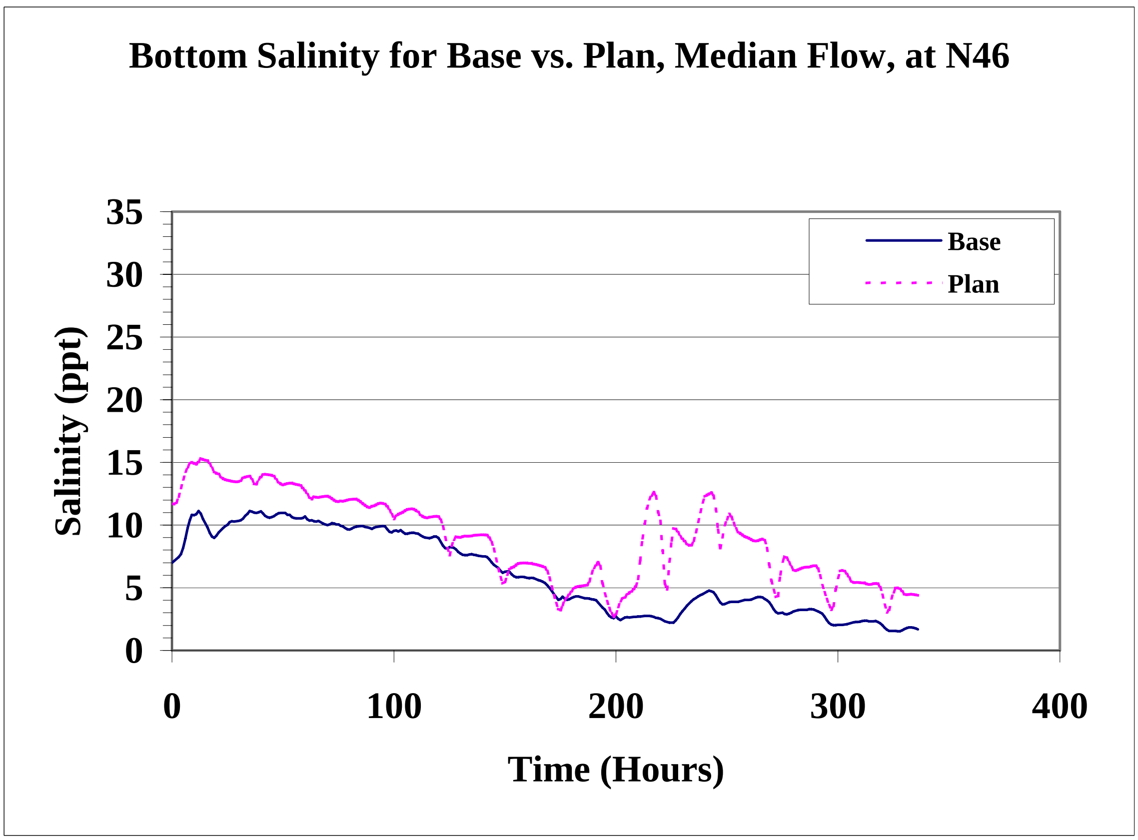
# Appendix 3.2

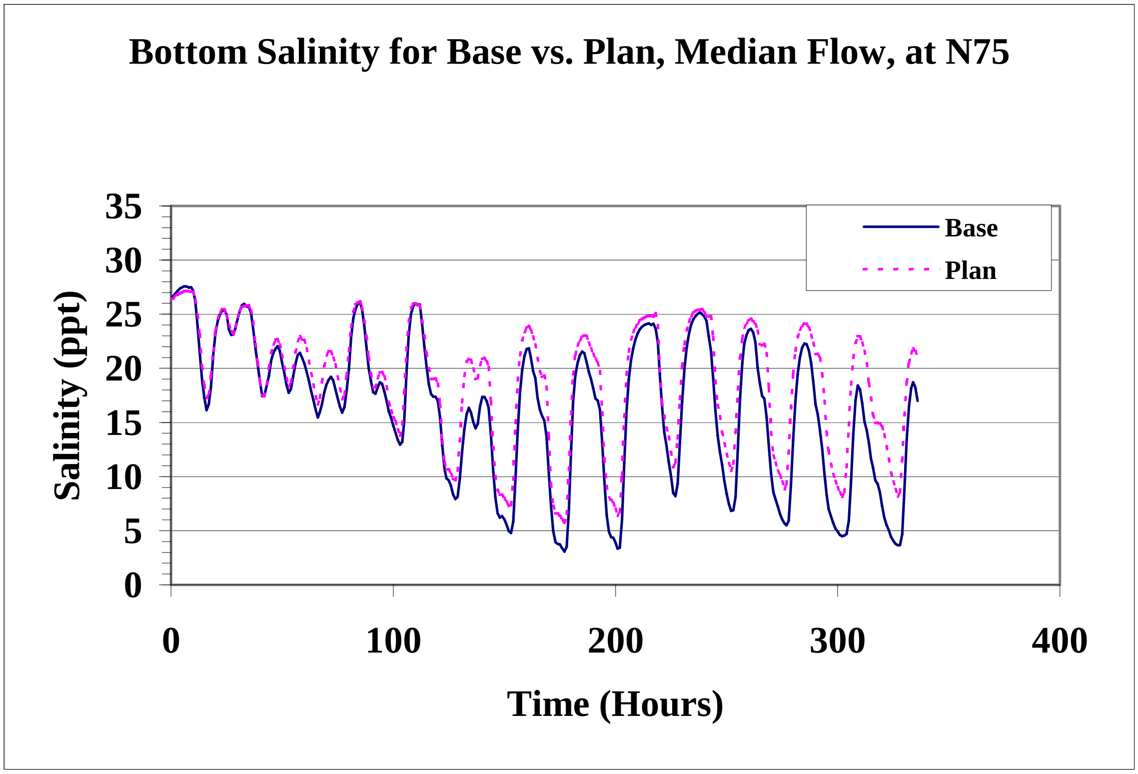
## Bottom salinity under median fresh water flow obtained in 3D numerical model for base and plan

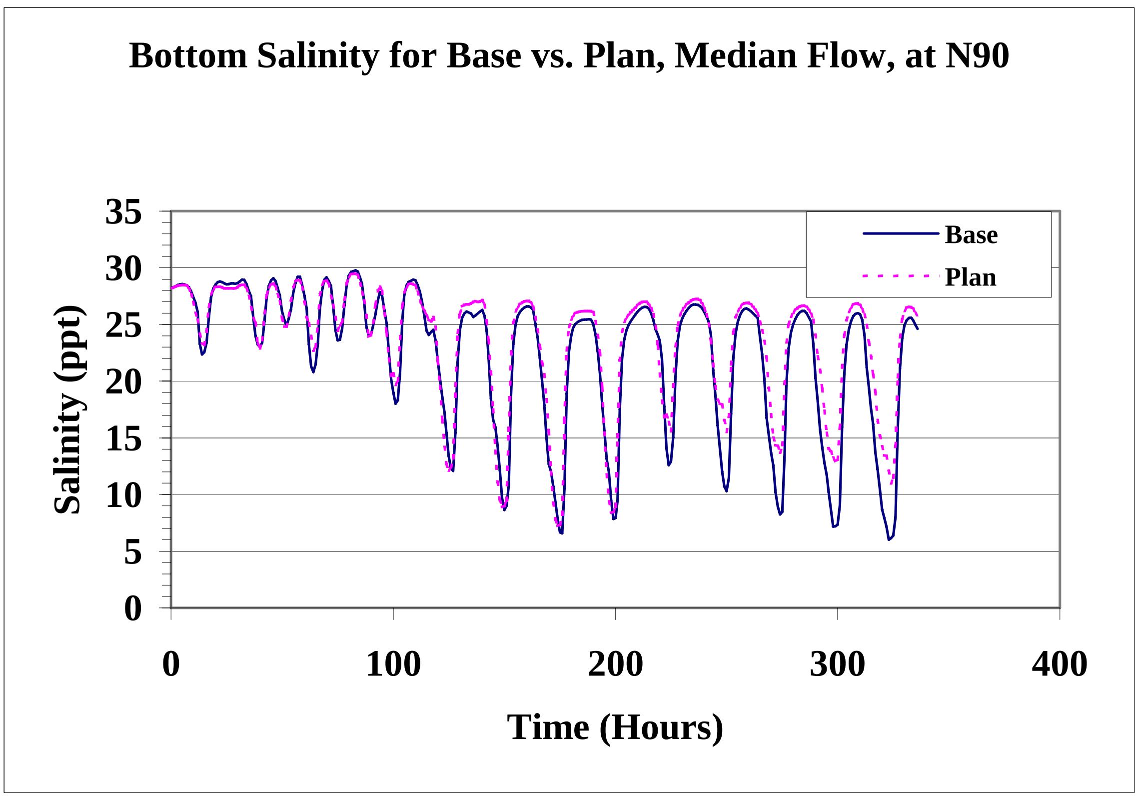

Bottom Salinity for Base vs. Plan, Median Flow, at N01
Salinity (ppt)
35
30
25
20
15
10
5
0
0
100
200
300
400
Time (Hours)
Base
Plan

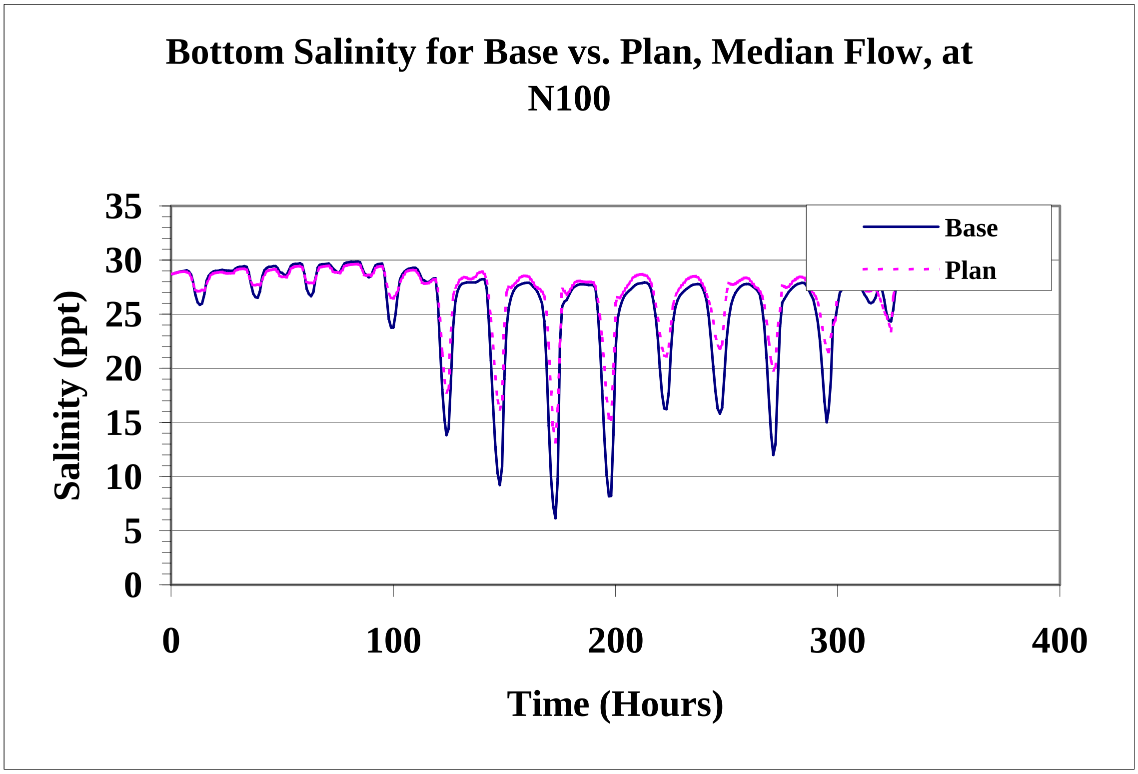

Bottom Salinity for Base vs. Plan, Median Flow, at N18
Salinity (ppt)
35
30
25
20
15
10
5
0
0
100
200
300
400
Time (Hours)
Base
Plan

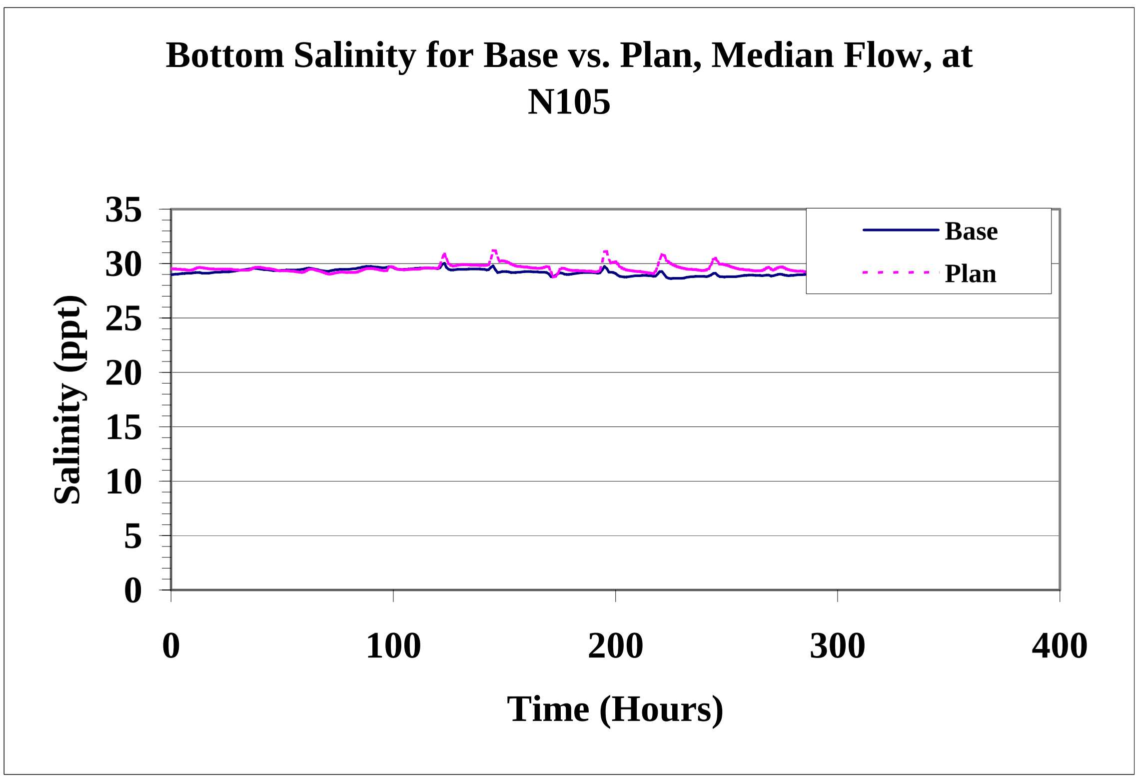

Bottom Salinity for Base vs. Plan, Median Flow, at N30
Base
Plan
35
30
25
20
15
10
5
0
Salinity (ppt)
0
100
200
300
400
Time (Hours)

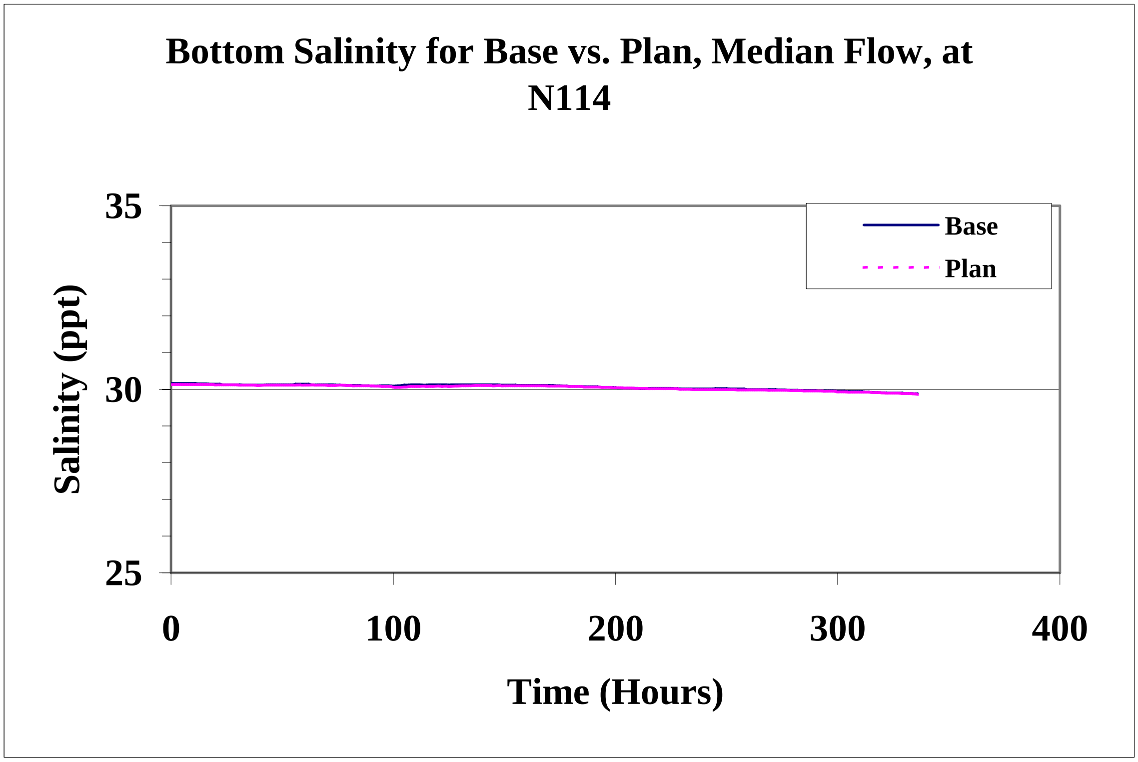

Bottom Salinity for Base vs. Plan, Median Flow, at N46
Base
Plan
35
30
25
20
15
10
5
0
Salinity (ppt)
0
100
200
300
400
Time (Hours)

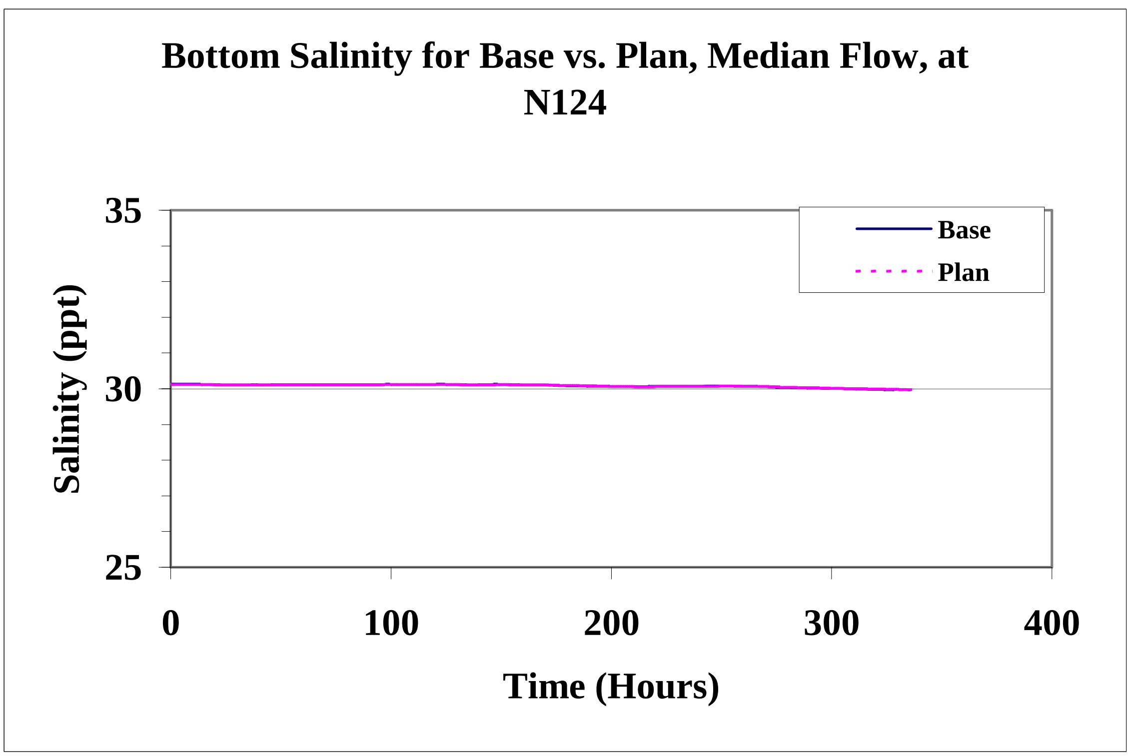

Bottom Salinity for Base vs. Plan, Median Flow, at N75
Salinity (ppt)
35
30
25
20
15
10
5
0
0
100
200
300
400
Time (Hours)
Base
Plan


Bottom Salinity for Base vs. Plan, Median Flow, at N90
Salinity (ppt)
35
30
25
20
15
10
5
0
0
100
200
300
400
Time (Hours)
Base
Plan


Bottom Salinity for Base vs. Plan, Median Flow, at N100
Salinity (ppt)
Time (Hours)
Base
Plan
0
5
10
15
20
25
30
35
0
100
200
300
400


Bottom Salinity for Base vs. Plan, Median Flow, at N105
Salinity (ppt)
Time (Hours)
Base
Plan
0
5
10
15
20
25
30
35
0
100
200
300
400


Bottom Salinity for Base vs. Plan, Median Flow, at N114
35
30
25
0
100
200
300
400
Salinity (ppt)
Time (Hours)
Base
Plan


Bottom Salinity for Base vs. Plan, Median Flow, at N124
35
30
25
0
100
200
300
400
Salinity (ppt)
Time (Hours)
Base
Plan