# Appendix C
# Historical Water Level Investigation

# Bayou Lafourche Historical Water Level Investigation – Summary of Findings and Recommendations

TO: Louisiana Department of Natural Resources

FROM: CH2M HILL

DATE: August 13, 2004

## Summary

This technical memorandum discusses the water level investigation that was conducted to determine the historical changes of the potential water elevations of the Bayou Lafourche if the dam were not constructed. The water level investigation determined that no statistical trend or change occurred over the 120-year period. The methodology to determine Bayou Lafourche water levels is based on interpolating water levels from the Mississippi River to the Gulf of Mexico. Water levels in the Bayou Lafourche have changed significantly since 1903, because of the changes in the hydraulic connection. However, water levels in the Mississippi River have not significantly changed since 1903.

## Project Background

The Bayou Lafourche is a major waterway in south central Louisiana. The predominantly freshwater channel was a major distributary of the Mississippi River until about 1903, when the Bayou Lafourche was dammed at its intersection with the Mississippi River. In the 1950s, a pump station was constructed at the intersection of the Bayou Lafourche and the Mississippi River to provide some freshwater inflow into the Bayou Lafourche.

The Mississippi River Reintroduction into the Bayou Lafourche Project was recently proposed to increase pumping of fresh water from the Mississippi River into Bayou Lafourche. This project could affect water levels along the Bayou Lafourche. Louisiana Department of Natural Resources (LDNR) requested that historical levels be investigated within the stretch of primary interest in the upper Bayou Lafourche, specifically the first 56 miles downstream of the Mississippi River.

## Project Purpose

This investigation determined the historical water levels in the Bayou Lafourche in 1903, which is considered to be the time that the Bayou Lafourche was isolated from the Mississippi River. This water level investigation included the following approaches:

- Determining the level of information available
- Evaluating the feasibility of identifying the historical levels

- Conducting statistical comparisons
- Summarizing these observations

## Bayou Lafourche Flow History

The flow into the Bayou Lafourche was generally natural until 1903 (Figure C-1). Any determination of the Bayou Lafourche levels prior to this period in history is assumed to represent natural conditions. After 1903, the dam changed the nature of the hydrology and Bayou Lafourche channel. Because the state has always owned submerged lands, historically submerged land should still be state land. State rights associated with *Waters of the State* depend on the mean low and high water levels.

The water levels change under the natural hydrologic processes, and the exact horizontal location depends on the Bayou Lafourche cross section shape. Furthermore, the cross sections can vary on or between properties. Prior to 1903, the natural waterways of the Bayou Lafourche cross sections generally varied because of geomorphologic processes, including scouring, settling, natural stabilization (e.g., vegetation and natural levees), or the human structures that existed at that time (i.e., levee enhancements and bridges). The cross sections during this period were defined as the natural water levels. Human improvements were not in the batture because the Bayou Lafourche was subject to periodic extreme flood flows.

After 1903, the flow in the Bayou Lafourche was mostly stagnant until the 1950s. Substantial deposition (also known as accreted land) occurred in the Bayou Lafourche during the 1950s. In addition, a subsequent pump station initiated a relatively constant water supply with sediment-laden river water. Currently, the Bayou Lafourche has relatively constant levels with storm flows that are relatively small compared to the flows occurring when the Bayou Lafourche was directly connected to the Mississippi River. Human development has encroached on the batture. This water level investigation identifies the natural low and high water levels around the time the Bayou Lafourche was closed to the Mississippi River, regardless of the encroachment.

## Review of Available Data

The water level investigation identified, collected, and compiled existing information that was used to estimate the water levels in Bayou Lafourche in 1903. Data reviewed for this investigation included existing maps, reports, project drawings, survey records, and other appropriate sources. As part of the Bayou Lafourche water reintroduction project, CH2M HILL collected recent data; however, much of the historical information needed to be further researched and analyzed. Prior to analyzing raw data, determining how to define *mean low* and *high* water levels was important.

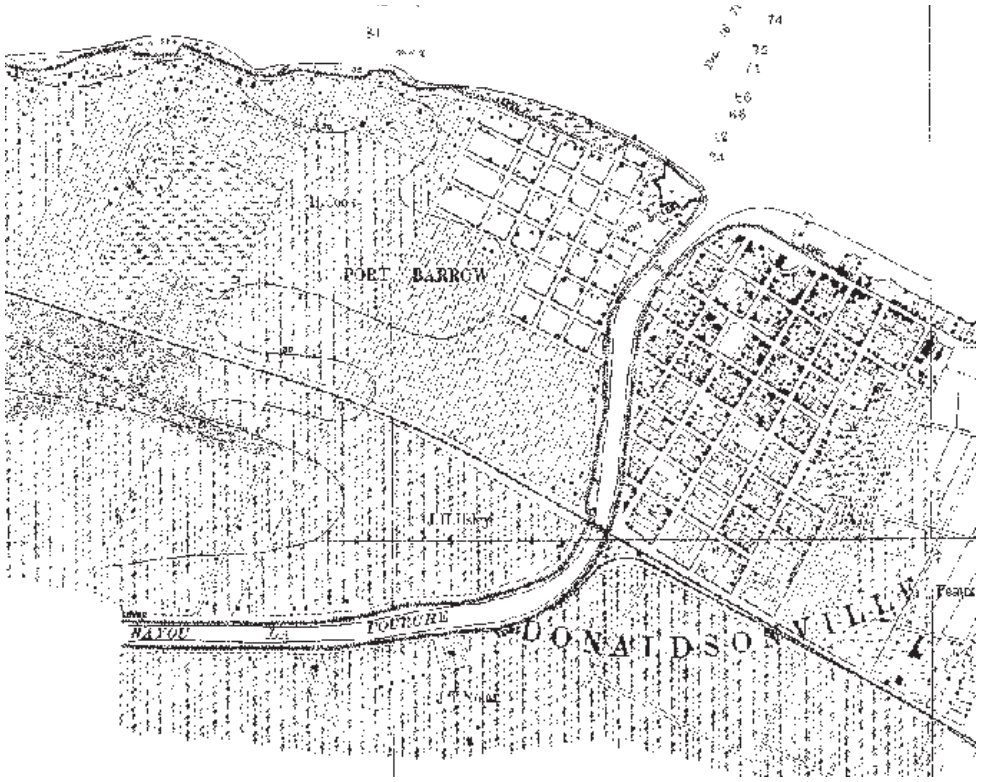



**FIGURE C-1**
**DONALDSONVILLE AND BAYOU LAFOURCHE**
**FROM AN 1879 SURVEY OF THE MISSISSIPPI RIVER**
MISSISSIPPI RIVER REINTRODUCTION INTO BAYOU LAFOURCHE
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
PHASE 1 DESIGN REPORT

## Procedure to Define Water Levels

The LDNR provided CH2M HILL with a study that a surveyor produced to determine the water level elevations for landowners near Donaldsonville (Morris P. Herbert, Inc. [MPH], 2003). CH2M HILL conducted a similar analysis for historical Mississippi River data. That procedure is described in this subsection[1].

The linear interpolation procedure determined the average water levels at the Mississippi River near Donaldsonville and the coast (Leeville). The surveyor calculated the average of the monthly low and high water elevations at these two locations from 1981 through 1999. Assuming that the change in water level would be nearly linear under these flow conditions, the surveyor linearly interpolated water elevations based on the location between the two gaging stations. Table C-1 presents the water levels determined in this investigation. The survey then determined the elevations on the ground to establish the property boundary by the Bayou Lafourche.

TABLE C-1
1981 through 1999 Water Levels for Mississippi River and Near Coast[a]

| Location | Miles from River | Mean Monthly High Water (NGVD29) | Mean Monthly Low Water (NGVD29) |
|---|---|---|---|
| Donaldsonville | 0.0 | 17.13 | 10.64 |
| Leeville | 93.2 | 10.64 | 0.90 |

[a]Source: MPH, 2003.

The linear interpolation procedure is easily described to landowners and other involved parties. Under low flow conditions, the water surface is nearly linear in a generally uniform channel; therefore, this approach is expected to be sufficient to determine monthly low water. Under extreme flood conditions, the linear assumption might not be accurate; however, the average of monthly high water is not an extreme flood level. This linear interpolation procedure is assumed valid and, therefore, has been applied in this water level investigation.

## Data Review Summary

For the water level investigation, CH2M HILL contacted the following agencies:

- Mississippi River Commission (MRC) and U.S. Army Corps of Engineers (USACE) in Vicksburg, Mississippi
- Louisiana Department of Transportation
- Louisiana State Land Office (SLO) (state historical repository of land information)

CH2M HILL also conducted an Internet review of the National Oceanic and Atmospheric Administration (NOAA) Web site and other pertinent online resources (NOAA, 2004b).

[1] Note that because the MPH memorandum (MPH, 2003) was used as supporting evidence to determine boundaries by the bayou, it was assumed that this established a precedent as an acceptable procedure. The LDNR must confirm this assumption. The original MPH study cited court case precedents; however, a legal review regarding the procedure's validity was beyond the scope of this water level investigation.

*Historical Changes in Bayou Lafourche* (Coastal Environments, Inc., 1997) provided a historical record of changes to the Bayou Lafourche and potential references.

The data search focused on three main areas, which are described in the following subsections.

### Aerial Maps

Existing conditions maps were used to compare historical data and information. CH2M HILL had previously obtained these from records for the Mississippi River Reintroduction into Bayou Lafourche Evaluation. The 1970 aerial maps, with surveyed cross sections from near the mouth to approximately 10,100 feet downstream, were also used to compare historical data and information. The cross sections were fairly similar to existing conditions, but the overall distance was only a small portion of the study area.

### Hydrology from Pre-1900s to Early 1900s

Stages and flow in the Mississippi River and Bayou Lafourche were obtained from the hydrology data search. To use linear interpolation procedure, a time series of observations was needed so that average annual conditions, and not just peak flood elevations, could be determined. Data of flows or levels in the Bayou Lafourche were limited; however, a long-term record of Mississippi River stages for the Donaldsonville location (including other nearby stations on the river) was available.

The division of flow between the river and Bayou Lafourche was determined not to be necessary by using the linear water level approach.

General drainage area boundary and other hydraulic connections between Bayou Lafourche and other water bodies were investigated. An 1860s sketch of the area was found, but it did not provide drainage boundaries or topography. The NOAA coastal survey had large-scale maps of the Bayou Lafourche basin since 1925, but no elevation data are available from these maps because they were primarily used for navigation.

The state's original land survey records for the project area were reviewed at SLO in January. These records were reviewed and some copied. The older maps and notes provided limited data. Mr. Clay Carter/SLO indicated that in the future many of the maps would be available on the Internet as .tif or .jpg files (Carter, 2004).

An 1886 survey of the profile of the Bayou Lafourche, including six cross section plots, was obtained from SLO. The profile primarily showed the bottom of the Bayou Lafourche and a high water profile from the Mississippi River to the Gulf of Mexico. The six cross sections included Donaldsonville, Napoleonville, Thibodaux, and others downstream. This map shows mean low water at 2 feet above gulf level and high water at approximately 26 feet. These elevations are not likely to be statistically based because the quality and regularity of data from this time is uncertain. The cross section plots reference other sections that were not available in SLO.

A 1902 copy of a profile of the Bayou Lafourche was also obtained. The profile included plots of the bottom of the Bayou Lafourche, natural surface of the ground, and top of levees. The profile also showed the high water line of 1987. These drawings provided only a limited number of cross sections.

Historical levels in the Gulf of Mexico determined the downstream the boundary conditions for the evaluation. The oldest continuous coastal record available is from Grand Isle, Louisiana, which only started in the mid-1940s.

### Topography and Structures in the Early 1900s

Cross sections along the Bayou Lafourche, including the channel, and the banks were researched. Ideally, these cross sections would be no farther than 0.5 mile apart (about 2,500 feet) to assist in a detailed characterization. However, a limited number of cross sections were available near Donaldsonville circa 1902 and 1970.

Natural levees or other types of above-water bank structures are of interest. An 1868 survey of the Mississippi River included a portion of the Bayou Lafourche near Donaldsonville. This survey documented the natural levees, but elevation data of the Bayou Lafourche area were not included. The 1902 survey provided a profile of the elevation of the levees. However, it is not clear if this is one side or the other, or an average. The cross sections from 1886 and 1902 provide limited characterization of the channel and levees.

CH2M HILL reviewed bridges and other structures that might have restricted flow within the Bayou Lafourche in the 1900s. The main structures across the Bayou Lafourche during the early 1900s appears to be a train bridge in Donaldsonville and another downstream of Thibodaux. Significant flow blockage was unlikely caused by these structures at that time, especially for low flows. A smaller bridge in Donaldsonville is documented in the 1902 map of the proposed dam. There might have been other smaller bridges, but they are not noted on the historical maps obtained to date.

Subsidence issues might affect how the elevation data are interpreted. Reported elevations might need to be adjusted to the current geodetic datum. This is discussed in the following sections.

## Water Level Records

The MRC was contacted for flow and elevation data in the Bayou Lafourche circa 1900. The librarian found only two references to these data, and all values were for one-time readings at several locations for a total of 8 days. These data are too infrequent to estimate an average water level. Therefore, the levels of the Mississippi River and Gulf of Mexico are the only available historical data. Because the data were collected using different elevation reference systems, they must be adjusted to a common reference point for comparison across time. Bill Hicks/USACE and Don Flowers/MRC were contacted to help obtain relevant datum adjustments. The following subsections provide a brief summary of the reference datum and results; including the known impacts of the issue of land subsidence, which is a major factor in the Bayou Lafourche area.

### Vertical Reference Datum Effects

In surveying, the datum is an imaginary plane that represents a fixed vertical reference level. The most common datum referenced in the United States is the 1929 vertical datum plane, often referred to as the National Geodetic Vertical Datum of 1929 (NGVD29). This datum plane was based on the average sea level from 29 gaging stations around the country.

Therefore, on average, an elevation of 0 feet NGVD29 would be close to the mean sea level (msl). There would be some variation at any given location along the coast because the reference is an average of many sites. NGVD29 was used until 1991 when a new vertical datum was adopted, known as the North American Vertical Datum of 1988 (NAVD88). This new datum differed from the 1929 reference plane because of the changes in sea levels and a large influx of new survey control points. Usually, elevations with references to NGVD or msl refer to the NGVD29 and, therefore, this assumption was applied to the reported literature discussed below.

Prior to 1929, most levels in the project area refer to the mean gulf level. The Gulf of Mexico water level varies over time because of the different vertical datums, long-term global rise in sea levels, and net result of subsidence. The surveys along the Mississippi River also were adjusted to what was known as the Cairo Datum, which refers to a benchmark in Cairo, Illinois (also sometimes called the New Cairo Datum). That benchmark was 20.43 feet above msl (NGVD29); therefore, 20.43 was subtracted from each Cairo Datum number to equate it to NGVD29 (Loyola University Center for Environmental Communication [LUCEC], 2004). Because the 1902 cross sections listed the mean gulf level at 21.26 Cairo Datum, it is concluded that the mean gulf level was about 0.83 foot NGVD29 at this time.

The U.S. Geological Survey listed the historical low water level to occur on January 12, 1918, as -0.39 foot NGVD29 (U.S. Geological Survey, 1999). This occurred during the period of interest for this project. The USACE-reported level from the gage at this time was 0.8 foot mean gulf level. Therefore, it appears that an adjustment of approximately -1.21 feet is required to translate 1918 data to the NGVD29 data reported in Table C-1. Furthermore, an online National Geodetic Service tool was used to translate NAVD88 data into NGVD29 at Donaldsonville. This adjustment was very small at -0.19 foot. Therefore, the total adjustment from 1918 levels to NAVD88 appears to be -1.40 feet.

The NOAA periodically adjusts its coastal gage readings based on a recent 18-year period of observed tidal data (NOAA, 2004a). According to the NOAA coastal gage readings, a natural 18-year lunar cycle occurs, and the ocean levels are generally rising. Between 1960 to 1978 and 1983 to 2001, there was a 0.07 foot increase. The impact of the gulf level changes should be small because the project area is located over 50 miles from the Gulf of Mexico, and the levels are linearly interpolated. Changes of 0.10 foot would be negligible when compared to the elevations in the Mississippi River.

## Water Levels

The historical water levels from the Mississippi River were obtained from the MRC. Many of these data were obtained from hardcopy reports. Table C-2 provides the analysis of the historical Mississippi River water levels collected during a 35.6-year period (1890 through 1926). This period contains the oldest records available prior to the major flood of 1927 that affected the Mississippi River valley. The more recent levels from Table C-1 are included in Table C-2 for easy reference. There appears to be only a small difference (0.5 foot) between the mean low water values of the two periods. However, this does not include the vertical datum adjustment.

Because of the datum changes, the mean water levels in the Mississippi River were approximately 1.4 feet lower in the early 1900s than current mean water levels. The average

monthly low water level during 1981 to 1999 was reported to be 10.64 feet NGVD29 (MPH, 2003). The average monthly low water level in the Mississippi River was 8.95 feet NGVD29 (=10.16-1.21).

TABLE C-2
Average Monthly Values for Mississippi River Stages near Donaldsonville from 1890 through 1926

| | Monthly High Water Level | Monthly Low Water Level |
|---|---|---|
| Maximum Reported Value | 35.94 | 33 |
| Minimum Reported Value | 2.6 | 0.8 |
| Average of Monthly | 16.12 | 10.16 |
| Reported 1981 to 1999 Averages in Exhibit 2 (NVGD29) | 17.13 | 10.64 |

Figure C-2 plots the monthly data used to compute the averages in Table C-2. The range of scatter of the data on Figure C-2 is large. Because of the amount of variability, the values from 1900s, when compared to the 1980s, are statistically indistinguishable.

In addition to the plot of data points, the trend lines showing increasing water levels is included on Figure C-2. This trend (the slope of the line of about 0.004 foot per month or 0.6 inch per year) would add up over a long period. Over 80 years, the change in levels would be approximately 48 inches (or a 4-foot rise), which is not supported by the data.

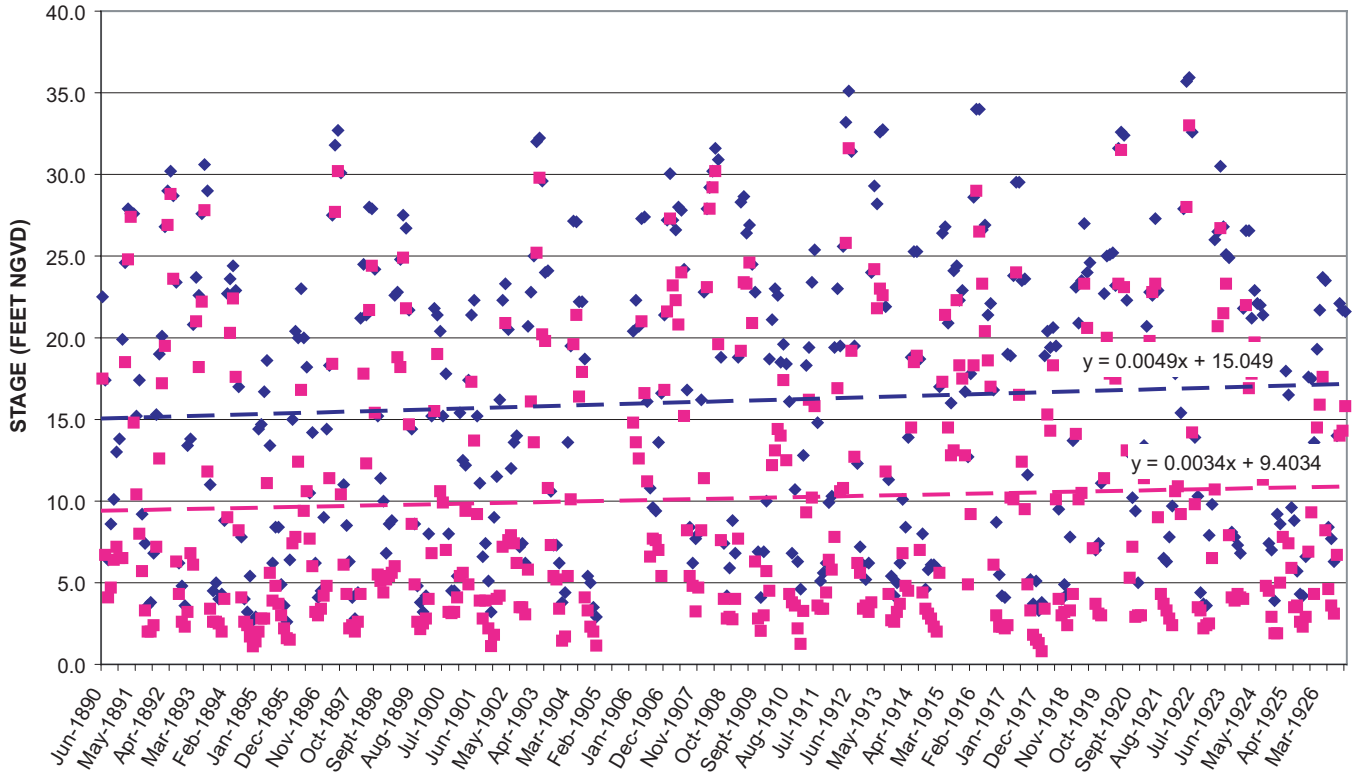
Because of the scatter in these data, an analysis of the continuous data was developed. All available data from 1890 through April 2003 were obtained. In addition, the monthly high and low water levels in the Mississippi River at Donaldsonville were adjusted to the same reference datum (NGVD29) and analyzed.

Because of the significant cycle over the 18-year period, the continuous data were plotted for the following periods:

- 1881 to 1909
- 1918 to 1936
- 1951 to 1970
- 1971 to 1990

The mean monthly low and high water levels varied between all of these periods. A plot of how the water levels were affected is shown on Figures C-3 and C-4 for the low and high water levels, respectively. The 1902 profile data were included for reference in these plots. From Figures C-3 and C-4, it appears that there could be a difference of up to 3 feet between the lows, and similar results for the highs. The 95 percent confidence interval between these averages is approximately 2.1 feet. Any given 18-year study period could vary from another one by a fair amount. No trend occurred between periods because the 1960 results were the lowest and the 1980 results were the highest. Thus, all 1,348 months of data were analyzed as one group. Results are plotted on Figure C-5.

The results shown on Figure C-5 are based on the mean monthly low water levels being 8.95 feet (NVGD29) at Donaldsonville and 0.0 feet at the Gulf of Mexico (109 miles downstream). The 95 percent confidence interval of this estimate was 0.39 foot. Therefore,




**LEGEND**

- HIGH
- LOW
- HIGH MONTHLY LEVEL TREND
- LOW MONTHLY LEVEL TREND

## FIGURE C-2
## MONTHLY STAGES OF THE MISSISSIPPI RIVER AT DONALDSONVILLE

MISSISSIPPI RIVER REINTRODUCTION INTO BAYOU LAFOURCHE
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
PHASE 1 DESIGN REPORT



CH2MHILL

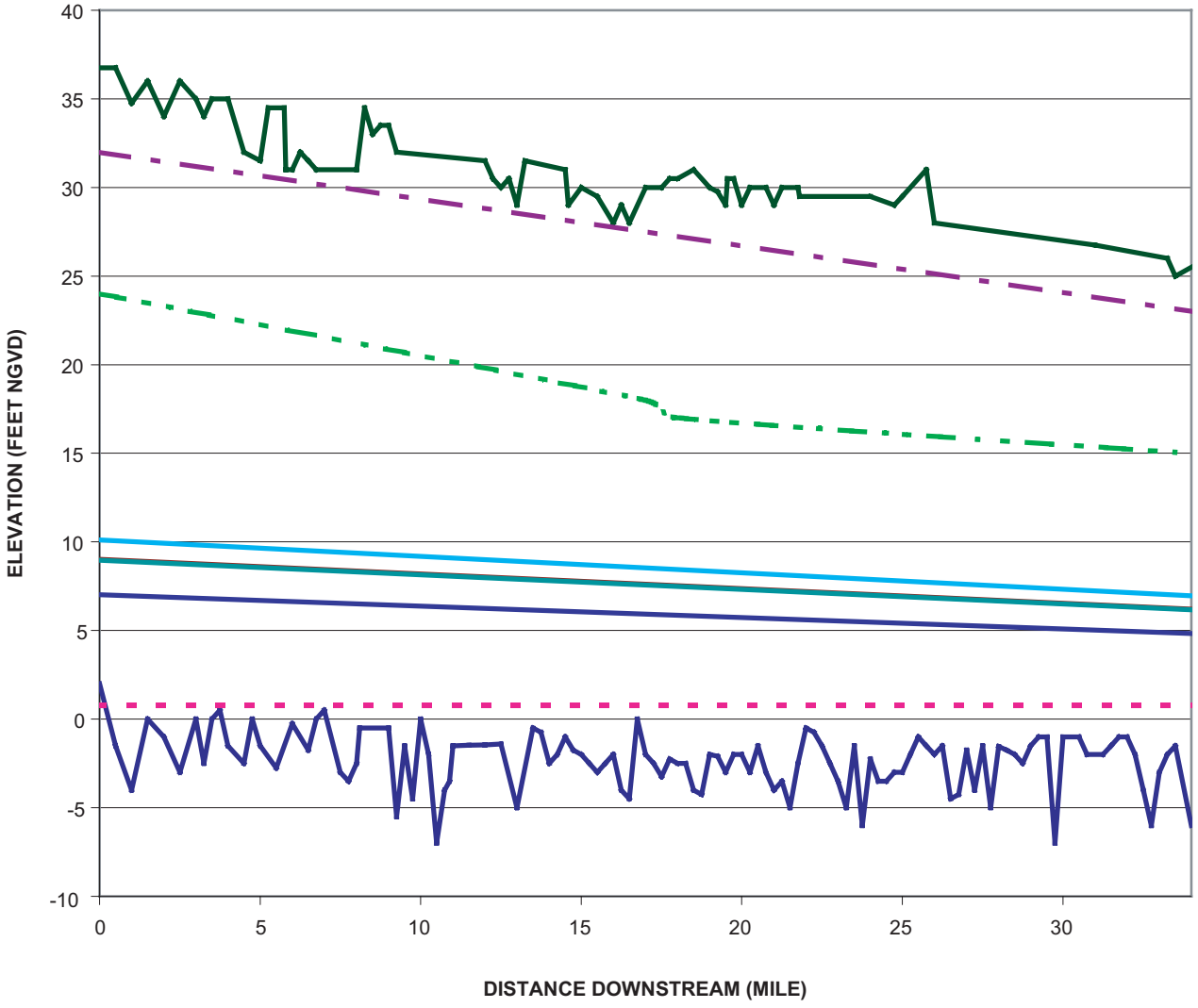
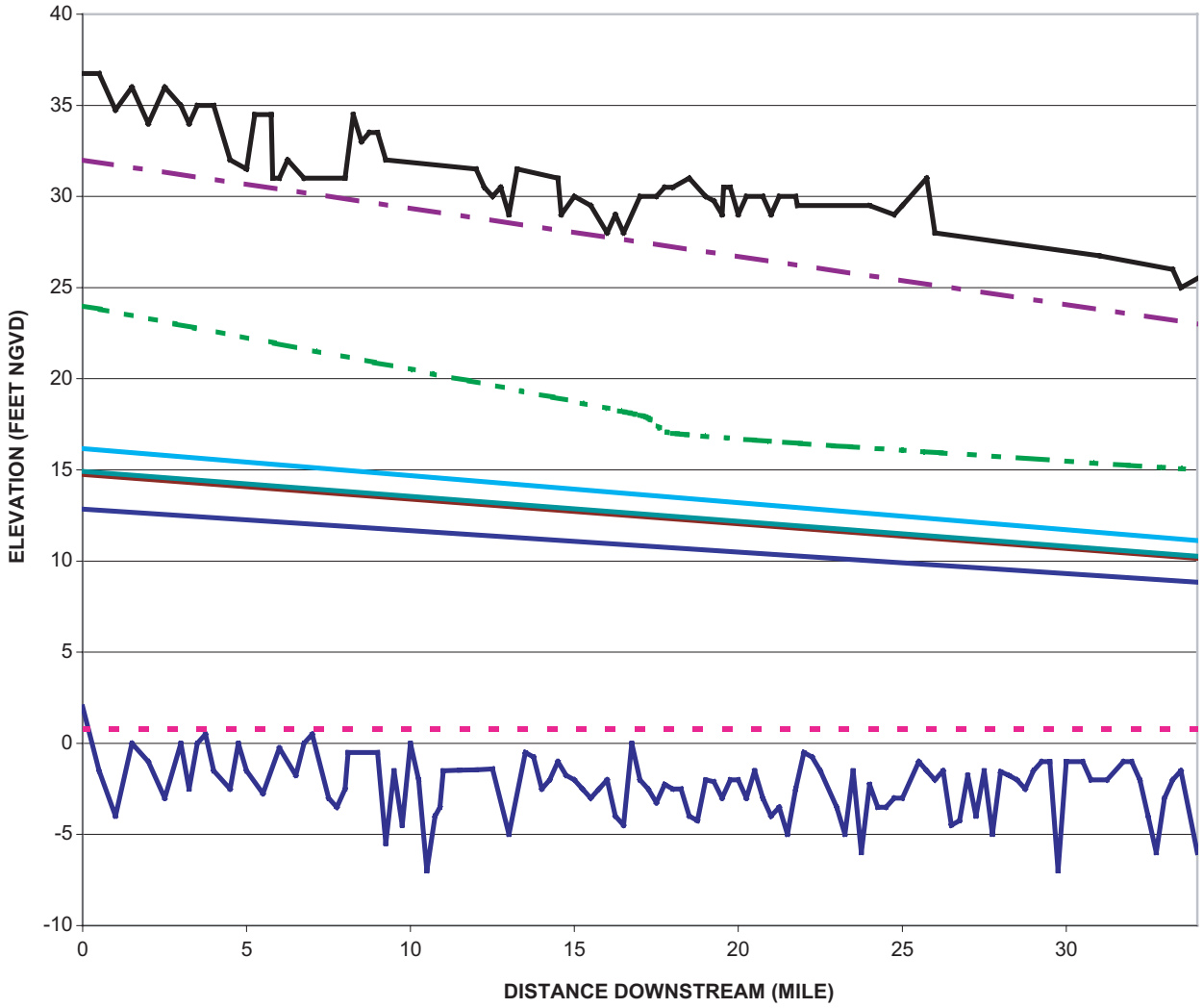



**FIGURE C-3**
**AVERAGE MISSISSIPPI RIVER MONTHLY LOW LEVELS**
MISSISSIPPI RIVER REINTRODUCTION INTO BAYOU LAFOURCHE
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
PHASE 1 DESIGN REPORT




**LEGEND**

- 1903 CHANNEL BOTTOM
- MEAN GULF
- 1903 REPORTED NATURAL GROUND
- 1903 TOP LEVEE
- 1897 HIGH WATER
- 1891-1909 HIGH
- 1918-1936 HIGH
- 1951-1970 HIGH
- 1971-1990 HIGH

**FIGURE C-4**
**AVERAGE MISSISIPPI RIVER MONTHLY HIGH LEVELS**
MISSISSIPPI RIVER REINTRODUCTION INTO BAYOU LAFOURCHE
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
PHASE 1 DESIGN REPORT

the mean monthly low water could vary from approximately 8.6 to 9.3 feet (NGVD29; shift by -0.19 foot to obtain NAVD88). The mean monthly high water level at the same location was 15 feet, with a 95 percent confidence interval of 0.46 foot.

Other factors could contribute to the Mississippi River elevations being higher now than historically. The Mississippi River basin is much more regulated by dams since the 1900s. The need to raise levees because of subsidence is well known (LUCEC, 2004). This causes floods of longer duration, which can cause peak water levels to average slightly higher. Upstream levees keep more water in the river channel and move river channel water downstream more effectively. These Mississippi River basin factors that could cause higher elevations are not easy to quantify. However, because of the long record and the general agreement of average levels between 1900 and 1990, the 120-year averages are assumed to be the best estimates to use for estimating mean low and high water levels.

### Landscape Subsidence and Rising Ocean Effects

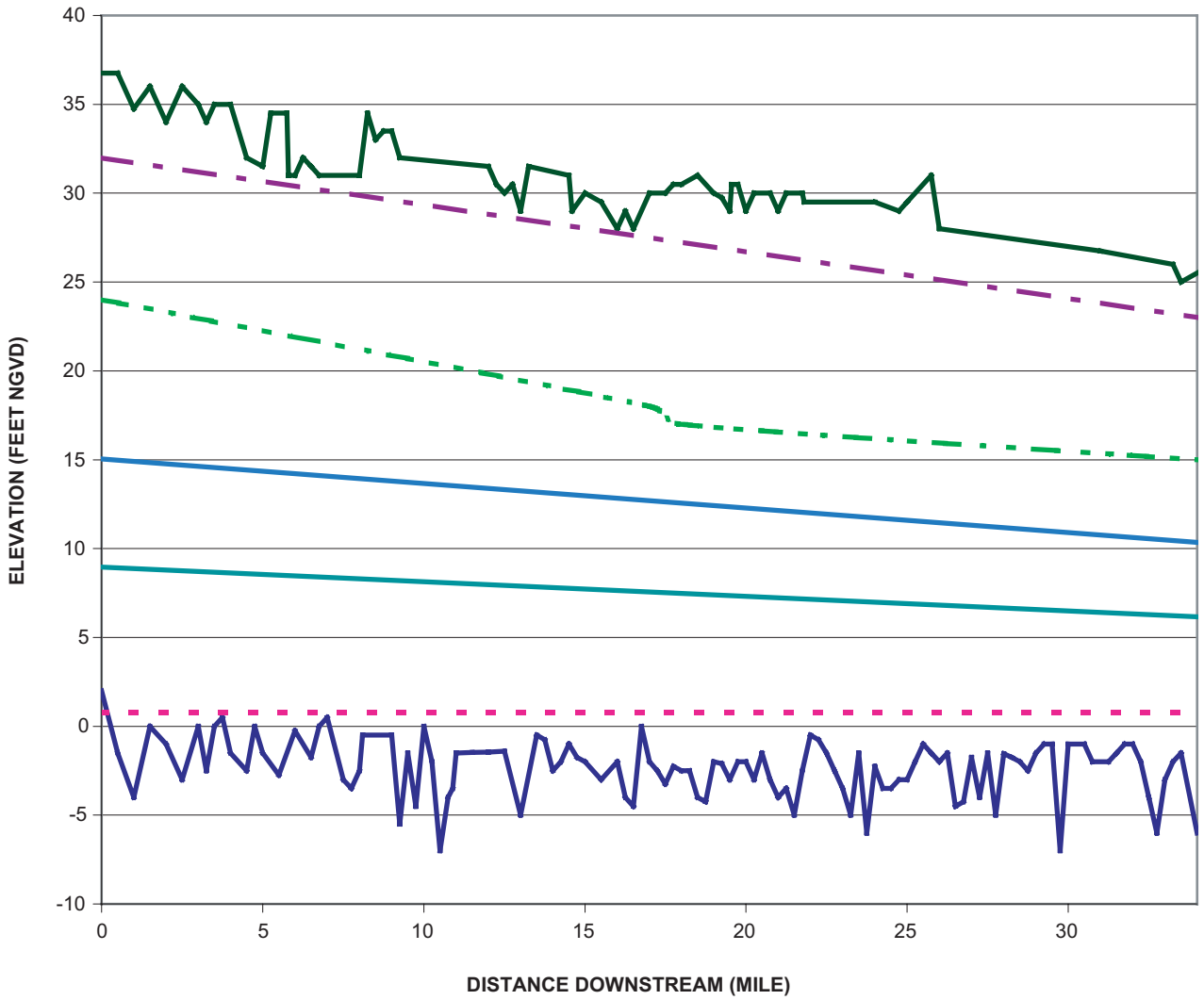
Coastal Louisiana is sinking primarily because of the settling of the landscape. The NOAA conducted a study of long-term trends in water levels (Zervas, 2001). Of the long-term coastal gages around the nation, Grand Isles had the highest rate of change, with levels rising 9.85 millimeters per year (3.23 feet per century). Figure C-6 shows the NOAA trend analysis. However, this trend includes the global rising of the oceans and vertical land movement (i.e., subsidence) of the landscape near the gage.

The global rising sea levels were reported to range from 1 to 2.4 millimeters per year (or 0.3 to 0.7 foot per century) (Zervas, 2001), which is also about the rate of change that NOAA noted when it recently adjusted its gage station datum (0.07 foot per 18 years equals 0.4 foot per century). By deduction, the subsidence must range from 7.45 (=9.85 – 2.4) to 8.85 millimeters per year (=9.85 – 1.0, or 2.4 to 2.9 feet per century). This trend is lower than the linear regression trend estimated from the average of the monthly low and high water levels described previously (Figure C-3). The NOAA analysis was more rigorous than the initial analysis and, therefore, was considered a better reference.

Gulf of Mexico water elevations are based on the ocean level and periodically adjusted. Because the study area is the upstream portion of the Bayou Lafourche, the effect of selecting a gulf level of 0 feet is small at the upstream portion. For example, if the Gulf of Mexico rises an average of 0.5 foot per century, the change in slope of the water levels at the upstream end of the Bayou Lafourche would be 0.5/109 = 0.005 foot per mile. Furthermore, the datum adjustment from mean gulf level to NGVD29 is -0.78; and the adjustment from NGVD29 to NAVD88 is -0.19 for a total change of -0.97 foot because of the datum shift. Because the datum shift would offset rising waters in the Gulf of Mexico and the effect would be small in the project area, no adjustments were made to the gulf level.

## Conclusions

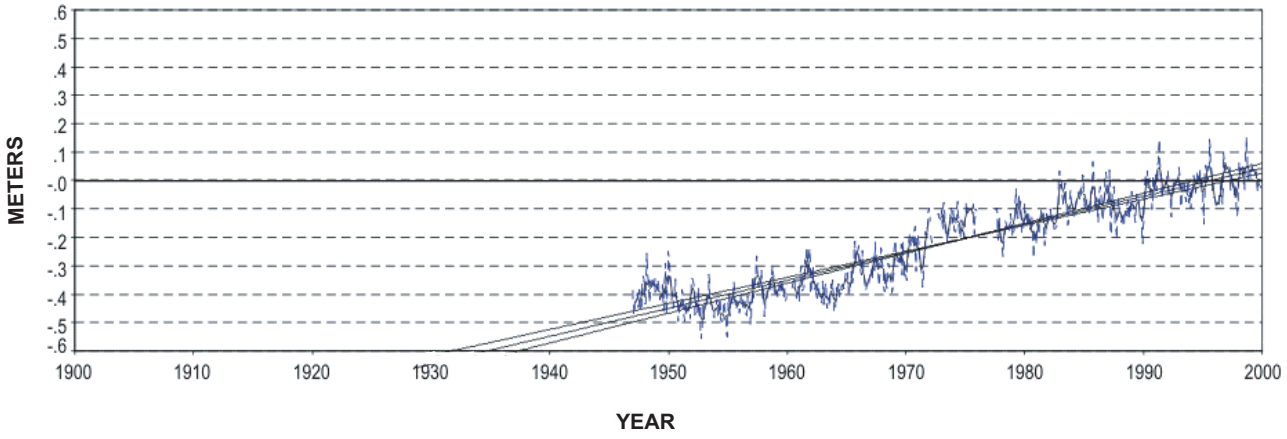
The literature identified an approach that establishes the mean low water levels along Bayou Lafourche by linearly interpolating between the Mississippi River and Gulf of Mexico coast levels. It is assumed that this would be the best approach for future property boundary determinations.




**LEGEND**

- 1903 CHANNEL BOTTOM
- MEAN GULF
- 1903 REPORTED NATURAL GROUND
- 1903 TOP LEVEE
- 1897 HIGH WATER
- 1951-1970 HIGH
- 1918-1936 HIGH

**FIGURE C-5**
**120-YEAR MISSISSIPPI RIVER**
**MEAN MONTHLY HIGH AND LOW**
MISSISSIPPI RIVER REINTRODUCTION INTO BAYOU LAFOURCHE
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
PHASE 1 DESIGN REPORT




SOURCE:
ZERVAS, C. 2001. "SEA LEVEL VARIATIONS OF THE UNITED STATES1854-1990." *NOAA TECHNICAL REPORT NOS CO-OPS 36*. JULY.

**FIGURE C-6**
**TREND ANALYSIS OF LOUISIANA GULF LEVEL CHANGES**
MISSISSIPPI RIVER REINTRODUCTION INTO BAYOU LAFOURCHE
LOUISIANA DEPARTMENT OF NATURAL RESOURCES
PHASE 1 DESIGN REPORT

Reported historical water levels are similar between the 1900 and 1990s. A review of several different 18-year time periods reveals differences of approximately 3 feet between specific time periods. The entire 120-year record was averaged to determine the mean low and high water levels in the Mississippi River near Donaldsonville. The 95 percent confidence interval of these estimates is about 0.4 foot (i.e., mean ±0.4 foot) at the upstream end of the profile.

The water levels in the Gulf of Mexico (and oceans, in general) are reported to have risen about 0.5 foot during the last century (range of 0.3 and 0.7 foot).

# References

Carter, Clay/Louisiana State Land Office (SLO). 2004. Personal communication with CH2M HILL.

Coastal Environments, Inc. 1997. *Historical Changes in Bayou Lafourche*.

Loyola University Center for Environmental Communication (LUCEC). 2004. *What is Causing Coastal Erosion?* http://www.loyno.edu/lucec/mrderosion.html.

Morris P. Herbert, Inc. (MPH). 2003. *Untitled Memorandum*. August 22.

National Oceanographic and Atmospheric Administration (NOAA). 2004a. *Station Information for Grand Isle, LA*. http://co-ops.nos.noaa.gov/cgi-bin/station_info.cgi?stn=8761724-GrandIsle,LA.

National Oceanographic and Atmospheric Administration (NOAA). 2004b. "Historical Map & Chart Project." *Office of Coast Survey – Cartographic and Geospatial Technology*. http://historicals.ncd.noaa.gov/historicals/histmap.asp.

U.S. Geological Survey. 1999."Daily Stage for 1998 Mississippi River at Donaldsonville, Louisiana." *Surface Water Supply of the United States*.

Zervas, C. 2001. "Sea Level Variations of the United States 1854-1999." *NOAA Technical Report NOS CO-OPS 36*. July.