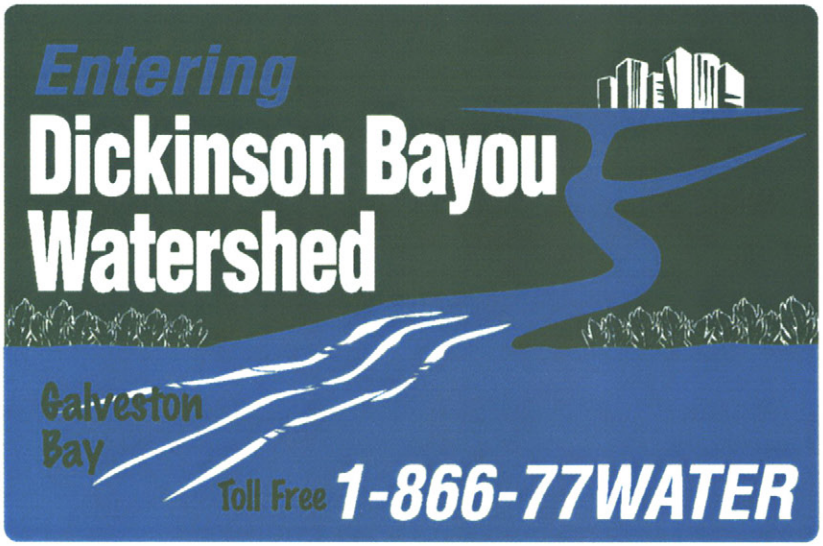
A Preliminary Total Maximum Daily Load (TMDL) Study on Dickinson Bayou



Galveston County Health District
Pollution Control Division

Prepared in cooperation with the Houston-Galveston Area Council
and the Texas Natural Resource Conservation Commission

August 31, 2001

Galveston County Health District
1205 Oak Street
P.O. Box 939
La Marque, Texas 77568

Dr. Ralph D. Morris, M.D., MPH
Executive Director

Ronald B. Schultz, Jr.
Director
Pollution Control Division

GCHD Project Representative:
Jean Wright
Special Projects Coordinator
Pollution Control Division

Project Participants:

Roy Drinnen
Stephen Gruber
Heather Paxton
Ben Boren
Lindsey Lucas
Sarah Henderson
Kathleen Faye
Juli Anna McNutt
Vu Nguyen
Kirk Kilfoyle
Casey Laycock

Houston-Galveston Area Council (HGAC)
Clean Rivers Project Representative:
Todd Running
Clean Rivers Program Coordinator

Acknowledgement

Special appreciation is extended to the following individuals for their invaluable assistance and expertise. GCHD could not have completed the various tasks of this contract without their help. They are listed by agency.

<u>HGAC</u>
Chuck Wemple
Karen Brettschneider
Patrick Horton
Jim McLaughlin

<u>USGS</u>
Jeff East
Dr. Bruce Moring
John Beauchamp
Dexter Brown
Michael Burnich
Lee Goldstein
Jennifer Hogan
Scott Jennings
Pat Keefe
Dale Melton
Russell Neill
Cerando Ramirez
John Rosendale
Jasper Schaer
Deb Sneck-Fahree
Ken VanZandt

<u>TNRCC</u>
Laurie Curra
Bill Saunders
Steve Smith
Lythia Metzmeier
Jason Maldonado
Bob McElyea
Marty Kelly
Chris Caudle

Table of Contents

1. Executive Summary

Dickinson Bayou is on the 303(d) list for low dissolved oxygen and high bacteria levels. To address these concerns, a partnership was formed between the Galveston County Health District (GCHD), the Houston-Galveston Area Council (HGAC), the U.S. Geological Service (USGS), and the Texas Natural Resource Conservation Commission (TNRCC) to conduct a Pre-Total Maximum Daily Load (TMDL) analysis. This document is a summary of the tasks performed to determine why the bayou does not meet its aquatic life use and contact recreation standards.

First, representative study sites were established and the necessary equipment procured. Then, nine multi-probe, in-situ data sondes were deployed for 5 consecutive days each month over the course of fifteen (15) months. Profiled water quality data was collected in the field while water samples were collected at sonde depths. After laboratory analysis was completed, sonde, field and laboratory data was compiled into meaningful graphs and tables which were interpreted to form generalized conclusions about the bayou. Major findings of the study confirmed that Dickinson Bayou's low dissolved oxygen levels are influenced by salinity, ambient temperature, and rainfall as well as algal blooms and organic loading.

In Dickinson Bayou, a saltwater wedge was found all the way upstream to Cemetary Road but not to Ginger. Investigators also found more saltwater encroachment during the warmer, drier summer months receding to little or no encroachment during rainy weather or cooler, winter months. This movement of the halocline influenced the severity and stratification of the DO concentrations in Dickinson Bayou. The halocline basically created a barrier between the fresh and salt water layers preventing the movement of dissolved oxygen between the two waters. The halocline disappeared only during high flow periods following significant rainfall events. Mixing of the bayou oxygenated the water column from top to bottom.

As expected, increasing ambient temperatures caused water temperatures to increase and, subsequently, the dissolved oxygen levels decreased throughout the entire bayou. Occasional algal blooms created the only exception to this natural process. Algal blooms create temporary increases in afternoon and early evening DO levels. Conversely, these same algal blooms cause the DO levels to plummet during the night, reaching lows shortly before sunrise. Additionally, as the algae organisms die, they fall to the bottom of the bayou and decompose. Organic matter falling through the halocline decomposes creating an anaerobic environment in the saltwater wedge. This phenomenon was seen repeatedly during the hot, dry summer months. Zero dissolved oxygen was frequently measured in the salt water wedge while higher DO levels were generally found above in the fresher water. Hydrogen sulfide production was even found to be a common occurrence during the hot, dry periods.

There is also a direct correlation between significant rainfall and high bacteria, ammonia, nitrate-nitrite, and ortho-phosphate levels. The reoccurring algal blooms will attest to this fact. Sufficient nutrients and warm, sunny weather are ideal conditions for algae to bloom. Higher bacteria levels were also repeatedly found at sampling sites in more rural settings due to a greater use of septic systems and rangeland run-off. However, with more residential and commercial development taking place in the Dickinson Bayou watershed, greater pressure will be placed on the Bayou to absorb and process the additional loading from both point and non-point source pollution. Low DO levels are the result of a combination of natural processes and anthropogenic influences.

2. Introduction

The Texas Natural Resource Conservation Commission (TNRCC) has designated Dickinson Bayou as having two (2) segments for the purposes of water quality management and designation of site-specific standards. Site-specific Uses and Criteria have also been assigned to both segments. These segments, and all designated segments in the State of Texas, are inventoried in the Clean Water Act, Section 305(b) Report. If a segment does not or is not expected to meet the applicable water quality standards, the TNRCC places that segment on the federally required Clean Water Act, Section 303(d) List of Impaired Water Bodies in the State of Texas. Dickinson Bayou is one of the water bodies on this list for low dissolved oxygen and re-occurring high bacterial contamination.

Dickinson Bayou's tidal segment is classified as "High Aquatic Life Use" and the upstream segment is classified as "Intermediate Aquatic Life Use." Occasionally, Dickinson Bayou has failed to meet the saltwater required average dissolved oxygen (DO) concentration of 4.0 mg/l and the minimum DO requirement of 3.0 mg/l. For the upstream freshwater segment, the mean DO concentration must be greater than or equal to 4.0 mg/l to meet its "Intermediate Aquatic Life Use" classification. Though not an annual event, large fish kills commonly associated with menhaden and fish kills involving multiple species and/or more desirable sport fish have been known to occur on Dickinson Bayou. Since the beginning of the study, GCHD has noted dead fish during three of the sampling events during 2000. The same investigators also noted dead fish in areas of the bayou again during the summer of 2001. Investigators believed all of these incidents to be associated with low dissolved oxygen.

Both Dickinson Bayou segments have also been designated as Contact Recreation waters. Elevated bacterial concentrations have prevented the bayou from meeting its contact recreation use indicating a potential public health risk as well as an excess nutrient loading concern.

Purpose and Scope

In response to these concerns and in keeping with the goal of the Clean Rivers Program, which is to maintain or improve the quality of water resources within each river basin in Texas, GCHD has teamed up with the HGAC, USGS, and TNRCC to conduct a pre-Total Maximum Daily Load (TMDL) analysis study on Dickinson Bayou. TMDL is the total amount of a substance that a water body can assimilate and still meet the established surface water quality standards. This study looks at what is happening within the water column of the bayou over a period of time at several locations throughout the tidal segment. In-situ monitors and intensive water sampling are being used to characterize how the DO fluctuates throughout the tidal segment in relation to how various chemical parameters change over time. Intensive bacteriological sampling is also being conducted at the same time to determine how bacteria loading varies along or within the bayou and to determine if bacteria has any relationship to other testing parameters. TNRCC will use the gathered data to conduct modeling on the bayou to determine how to proceed with completing the TMDL process required for the bayou.

This document describes how GCHD and its partner, TNRCC, collected the various pieces of water quality information needed, what results were found after compiling the data, and what conclusions could be drawn from the graphical comparisons of various parameters. GCHD evaluation of the data will draw conclusions about the natural processes of the bayou in reference to DO and bacterial contamination which are the causes of the 303(d) listing.

Description of Study Area

Dickinson Bayou is located in southeast Texas in the San Jacinto-Brazos Coastal Basin (Figure 1). The

Figure 1 - Dickinson Bayou Watershed in Southeast Texas

bayou originates north of the City of Alvin in Brazoria County and flows east through Galveston County for approximately 24 miles where it terminates in Dickinson Bay, one of the secondary bays of the Galveston Bay system. Major tributaries, both natural and altered, include (from east to west) an un-named ditch draining the Highway 3 & Humble Camp/Oil Field Road area, Gum Bayou, Benson Bayou, Magnolia (Giesler) Bayou, Bordens Gully, Drainage Ditches 9 & 12, Cedar Creek, and LaFlore's Bayou.

Dickinson Bayou is divided into two segments by the TNRCC. The above tidal reach (Segment 1104) begins upstream of Highway 35 in Alvin, Texas, and ends 1.2 miles downstream of FM 517 which is west of Cemetery Road. The tidally influenced reach (Segment 1103) begins 1.2 miles downstream of FM 517 and ends at the confluence with Dickinson Bay (Figure 2).

The channel and flow characteristics of the two segments are markedly different. The above tidal segment is a relatively shallow stream with moving water. Its depth varies from shallow riffles to pools 1-3 feet deep. The tidal reach is a very sluggish body of water dominated by a deep, v-shaped channel varying from 10-15 feet in depth. A channel was dredged from Dickinson Bay upstream to the railroad trestle near Highway 3 (¼ mile downstream) approximately twenty-five to thirty-five (25-35) years ago to accommodate fishing vessel and barge traffic on Dickinson Bayou. GCHD also found the average bayou depth from the trestle upstream to Cemetery Road to be approximately twelve (12) feet deep.

Between 1995-97, the USGS found the two segments to have different stream side vegetation as well. Investigators characterized the upstream segment as having dense riparian vegetation with limited sunlight exposure, whereas vegetation in the tidal segment is less dense, allowing more exposure to sunlight. Watershed topography gently slopes toward the bayou from 50 feet above sea level in the west to sea level at the confluence with Dickinson Bay in the east.

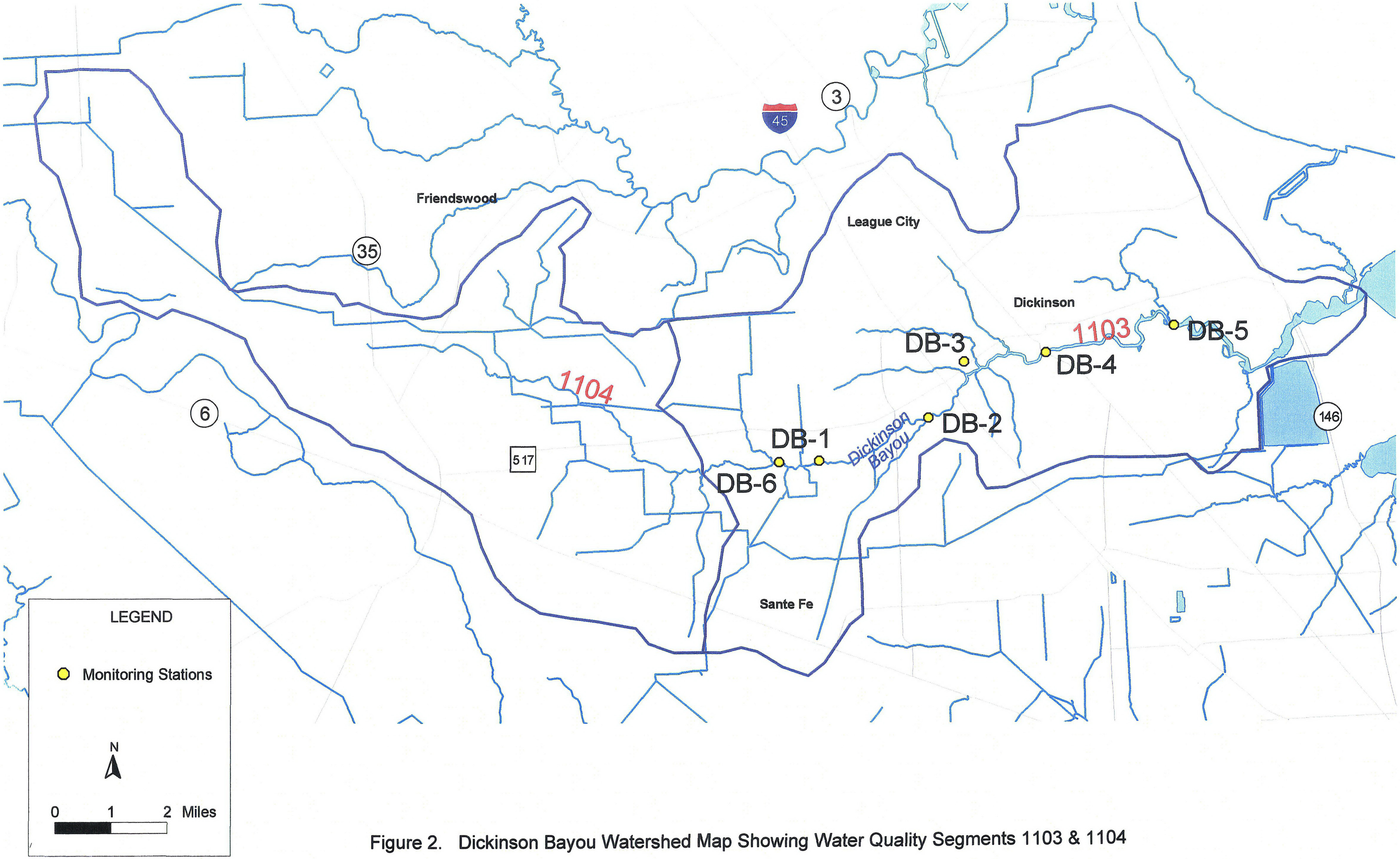


Figure 2. Dickinson Bayou Watershed Map Showing Water Quality Segments 1103 & 1104

Historical Perspective

Due to its impairments, Dickinson Bayou has been repeatedly studied by state and federal agencies. Its size, proximity to Houston and accessibility also makes it a prime location for reasearch. Intensive studies of Dickinson Bayou were conducted by the Texas Department of Water Resources (a predecessor agency of the TNRCC) in 1980 and 1982 and a waste-load evaluation was completed in June of 1985. The USGS, in cooperation with the Houston-Galveston Area Council (HGAC) and TNRCC, conducted a study titled *Nutrient Loading and Selected Water Quality and Biological Characteristics of Dickinson Bayou Near Houston, Texas, 1995-97* and completed the report in 1998. In addition to the loading from agricultural and urbanized activities, Dickinson Bayou receives or has received wastewater discharges from several permitted sources for many years. Dissolved oxygen has continuously been one of the limiting factors in the loading equations developed by the regulatory agencies who issue discharge permits. In addition, bacterial concentrations have repeatedly been high over the years.

3. Methodology

Partnerships

As this area's Clean Rivers Program river authority, HGAC facilitated a partnership between GCHD, USGS and TNRCC to address the concerns of Dickinson Bayou. This partnership brought together the resources and specialties of the four (4) agencies to collect data for the purposes of characterizing and understanding how Dickinson Bayou's natural processes work over time. Each agencies' responsibilities are discussed below. Funding was provided by TNRCC's TMDL Program and the Clean Rivers Program, as well as in-kind services.

First, HGAC purchased the majority of the in-situ monitors which were used to collect the continuous water quality data, plus they provided logistical and technical support. Second, GCHD was responsible for acquiring, maintaining and deploying the buoys and in-situ monitors as well as collecting the water quality field data and water samples. Majority, but not all, of the samples were analyzed at GCHD's Public Health Lab. GCHD is not equipped to perform three (3) of the desired analyses - Total Kjeldahl Nitrogen (TKN), Chlorophyll-a, and Pheophytin-a. Third, TNRCC provided technical support, one field person to help collect water samples, and laboratory support to perform the three (3) analyses not conducted by GCHD. TNRCC's field investigator delivered and maintained the chain-of-custody requirements of the Quality Assurance Project Plan (QAPP). Lastly, USGS supplied technical support, operated a continuous monitoring station at the Highway 3 bridge, conducted monthly flow measurements on the bayou while water samples were being collected, and provided a separate crew to perform habitat and biological characterizations of the bayou and several tributaries. All of this information will be sent to the TNRCC's TMDL group for modeling purposes. TNRCC would then determine how to proceed with the required Dickinson Bayou TMDL(s).

Development of the Quality Assurance Project Plan (QAPP) began shortly after the contract was signed between GCHD and HGAC in November 1999. Technical advice and directional guidance was received from HGAC, TNRCC, and USGS. The final QAPP was completed and signed in June 2000. (See Appendix 1 for a copy of the approved QAPP.) Field operations commenced in July 2000 and are expected to end in September 2001.

Reconnaissance of Dickinson Bayou

GCHD employed a two-phased approach to reconnoitering the bayou. First, personnel from GCHD, TNRCC, USGS, and HGAC drove around the watershed looking at access points to the bayou and tributaries and evaluating possible locations to place the monitors, perform hydrological monitoring, and/or conduct the habitat and biological characterization activities. Second, the team traveled by boat up and down the bayou checking cross-sectional depths and evaluating potential monitoring locations. Site selections were based on accessability from land and water, water depth, bayou width, proximity to confluences of bayou tributaries, and spatial distance along the length of the bayou. After the preliminary land and water reconnaissance, plus several follow up meetings by participating agencies, six (6) sample sites were established (Appendix 2). The Dickinson Bayou sites were then numbered for sampling purposes. Their identification numbers are DB6, DB1, DB2, DB3, DB4, and DB5 going from upstream to downstream (Appendix 3 & 4). The letters A or B following the site number indicates the depth of the sonde placement (Appendix 5). For example, DB2A is located near the surface while DB2B is located one (1) foot off the bottom of the bayou. In anticipation of investigative teams having to cross private property for access to the bayou over the next year and one-half, letters were sent and phone calls were made to get permission from all property owners (Appendix 6). Site photographs can be found in Appendix 7.

Photo 1 - YSI datasondes used in study.

Datasonde Instrumentation

The Yellow Springs Instrument (YSI) multi-parameter data logger, model YSI-600XLM was chosen for this project because of its reliability, the technical support system in place and, ultimately, because the investigation team was able to gather the most YSI sondes. Photo 1 shows two of the sondes. They are the same model but from two (2) different production years. For consistency in the study, a decision was made to use the same brand and model of equipment. A total of 12 YSI-600XLM data sondes were acquired for use in this project. Eight (8) sondes were carried to the deployment sites by way of a sonde transport bucket (Photo 2).

Photo 2 - Datasonde transport bucket.

Two (2) sondes are the property of GCHD, six (6) were purchased by HGAC, one (1) was borrowed from TNRCC's Region 12 office, and three (3) were dedicated for the length of the study by USGS (Appendix 8). Nine of the data sondes would be deployed monthly with the buoys; the three (3) USGS sondes were installed in a semi-permanent flow measuring gauge at the Highway 3 bridge.

The YSI-600XLM data sonde is a self-contained multi-probe meter designed to be left in the environment recording multiple parameters over a period of time. Sondes can be individually programed to choose which parameters will be measured, how often they will be measured, and when to start or stop recording measurements. The sondes used in this study were capable of executing and storing the multi-parameter recordings of dissolved oxygen, pH, specific conductivity, salinity, temperature, and depth. YSI technicians trained GCHD field personnel on "how to" program, calibrate, maintain, and troubleshoot the sondes as well as download and manipulate data from the sondes. (See Appendix 9 for the SOP's on Pre and post calibrations, maintenance, and troubleshooting.)

Datasonde Deployment

Since all the data sondes needed to be suspended in the center of the v-shaped channel, the four (4) downstream sites were considered to be within the navigable waters of the United States. Therefore, permission to deploy temporary buoys had to be acquired from the United States Coast Guard (USCG). After weeks of phone conversations and several letters of correspondence containing geographical positions and maps, permission to deploy the "private aids to navigation" was granted in June 2000 by the 8th Coast Guard District (Appendix 10). The Coast Guard requires research buoys to be yellow in color, identified with the agency name and contact information, and, in some instances, lighted. GCHD selected cylinder buoys made of yellow plastic (Photo 3). They are easy to maintain and light weight enough for one person to carry. They float high in the water and provide a good attachment point for the sondes. The buoys are anchored to a 225 pound (lb.), molded concrete weight connected via ¼ inch, galvanized chain and locking shackles (Photo 4). Lastly, a snap shackle deployment system was developed for safe placement of the buoy weights in the water (Photo 5).

Photo 3 - Yellow research buoy.


Photo 4 - Concrete weights showing chain and locking shackles.


Photo 5 - Concrete weight suspended from crane by deployment assembly.

Photo 6 - Crane mounted on bed of pick-up truck.

Once the buoys and weights were chosen for the project, a deployment and retrieval system had to be developed. The field crews had to move the weights into the bed of a pick-up truck once per month for transport to the bayou, plus they had to move the weights from the truck to the boat and from the boat to the water. Then, five (5) days later, the field crew had to pull the 225 lb. weights out of the bayou mud, lift them into the boat, lift them out of the boat onto the dock, and, finally, lift the weights into the pick-up truck. A receiving base for a crane was installed in both the bed of a pick-up truck and on the deck of the boat, then an inter-changeable, 500 pound capacity crane was purchased (Photos 6 & 7). To protect the truck and boat surfaces, sprayed-in protective coatings were applied. Additionally, a small, heavy-duty dolly was purchased to roll the weights from place to place.

Photo 7 - Crane mounted on deck of boat.

Photo 8 - Buoy and weight assembly with attached sondes.

The system also had to allow the sondes to be safely and efficiently connected and disconnected from the buoys and weights while they were in the water. Initially, GCHD found that trying to deploy a weight, buoy, and sondes at the same time was too difficult. A galvanized wire cable system, connected to both the weight and the buoy, but independent of the anchor chain, was made for each site (Photo 8). The sondes could now be raised or lowered through the water column as needed. Diagram 1, on the next page, is a drawing of the deployment assembly.

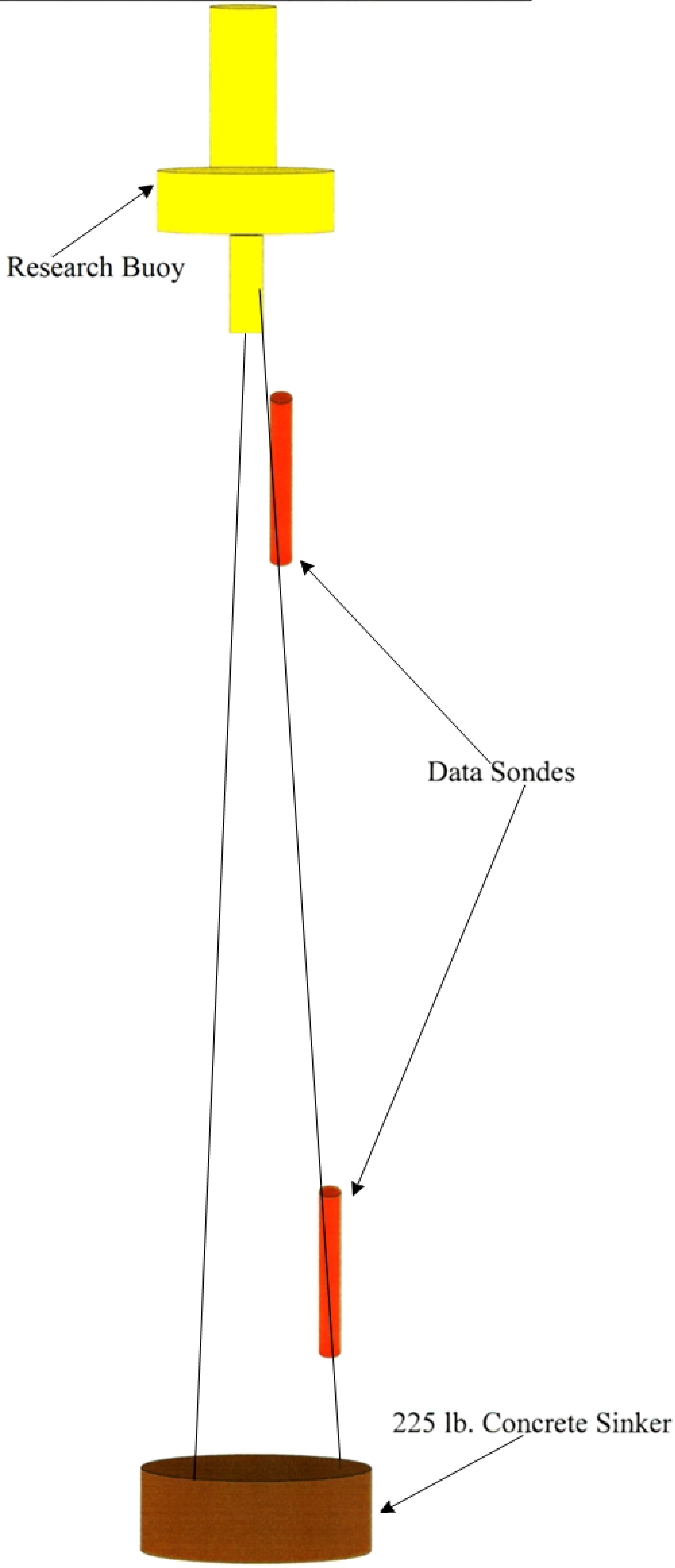
Dickinson Bayou is a popular recreation area which means lots of traffic from water crafts. Protective covers were designed and constructed for each sonde to minimize the chance of loss, tampering, theft, and/or damage. YSI representatives confirmed that our design of using three inch (3"), Schedule 80 PVC pipe with numerous 1" holes bored into the lower half of the tubes would allow for adequate water circulation around the sonde probes. Additionally, the anti-fouling paint which was used on the covers to minimize the amount of aquatic growth on the units would not interfere with the probe operations (Photo 9) .

Photo 9 - Protective PVC cover for sonde deployment.

Data & Sample Collection

Starting in July 2000, field investigators began deploying the sondes and collecting profiled water quality data and water samples for laboratory analysis. One week per month the sondes were suspended in Dickinson Bayou to collect water quality data continuously for 48-72 hours. The schedule for the monthly deployment was approved in advance and deviations had to be approved by all parties (Appendix 11). Once developed, the weekly itinerary remained the same throughout the study period. Each Sunday before deployment, preparations were made and a majority of the pre-calibration requirements were performed. On Monday, investigators completed the remaining pre-calibration requirements and deployed the buoys and sondes. On Tuesday and Thursday, profiled water quality data and profile water quality samples were collected. Then on Friday, the buoys and sondes were retrieved, post-calibration requirements were completed and data was down loaded from the sondes (Appendix 12). All the sondes were pre-set to collect data for the same time interval (Appendix 13). Every 15 minutes, the sondes

Diagram 1 - Dickinson Bayou TMDL Buoy Assembly



measured and recorded dissolved oxygen (DO), pH, specific conductivity, salinity, temperature, and depth. On Tuesday and Thursday, a USGS team of investigators collected cross-section profiles and flow measurements of the bayou concurrently with the monitoring and sampling team. See the USGS report for more information about findings related to flow. Appendix 14 includes checklists for each day of field work during the study.

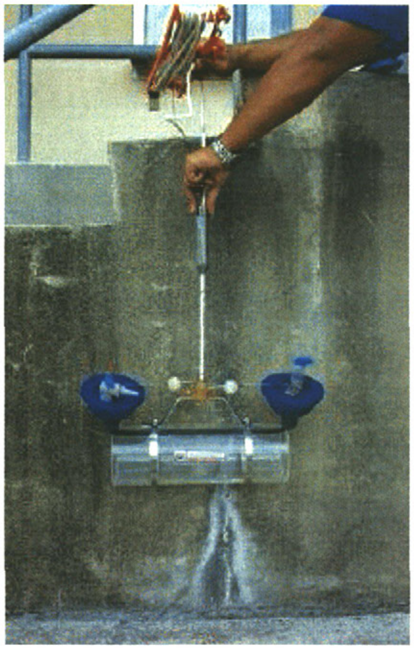


Photo 10 - Van Dorn bottle used to collect stratified water samples.

Vertical field data profiles were first collected at every site in one foot (1') increments from top to bottom using a Hydrolab 4a MiniSonde multi-probe hand held meter. All information was recorded and taken back to the office for data entry. Appendix 15 contains examples of the profile data field sheet, SOP for operating the Hydrolab. Water samples from various depths were collected using 2 liter, clear acrylic Van Dorn bottles (Photo 10). The sampler was lowered over the side of the boat to the appropriate depth, then discrete samples of water were collected. More than two (2) gallons of water were needed to perform the number of analytical tests required, so a 5 gallon mixing bucket was used to composite every sample. See Appendix 16 for a list of containers and preservation methods.

Ambient water quality for each sonde depth was gathered during water sampling events using the Hydrolab multi-probe. Meter values and field observations were recorded on the GCHD field data sheets and later entered into the Paradox 9 database (Appendix 17).

Water samples were delivered to the GCHD or TNRCC's laboratory and analyzed for multiple constituents. See Appendix 18 for a complete list of analytical test performed. Field data and laboratory data was manually entered into a Paradox 9.0 database while sonde data was down loaded directly into YSI's data management program called Eco Watch. See Appendix 19 for graphs, statistics, and raw data sheets. The following results section outlines what GCHD found in Dickinson Bayou for DO, fecal coliform, and basic water chemistry parameters.

4. Results

Following are the results of one year of sonde deployment, site profiling and laboratory testing. They definitely reveal significant problems associated with the natural processes of the bayou. Dickinson Bayou is on the 303(d) list for low DO and high fecal coliform, therefore the results and discussions will largely address those issues. Missing data points in the graphs are due to sonde malfunctions which are discussed in the lessons learned section of this report.

All raw sonde, field and laboratory data can be found on the enclosed CD. Sonde data is stored in a QuattroPro 9.0 spreadsheet while the field and lab data is stored in a Paradox 9.0 database file.

Seasonal Dissolved Oxygen Variations

Several cumulative factors contributed to the variations seen in the bayou. Spatial, temporal, and seasonal variations were identified in the DO concentrations at all sites along the bayou. Raw sonde data was compiled from each site for the year and averaged for a 48-hour deployment window for each event, per the QAPP. A minimum, maximum, and mean number was generated for each month and graphed. Figures 1-2, on the next two pages, are examples of these graphs. A complete set of graphs is found in Appendix 20.

By comparing graphs from surface and bottom locations, an annual pattern in DO levels was seen. As expected, the highest DO levels are seen in January while the lowest levels are seen in the warmer months of June, July, and August. Plus, the surface sites always carried higher DO levels than the bottom sites. DO values of >10 mg/l and <1.0 mg/l were observed during the winter and summer months respectively for the surface sites. The bottom sites recorded highs of > 8.0 mg/l and lows of 0.00 mg/l during this same time period.

Figure 1 - DB1A 48 Hour Monthly Dissolved Oxygen

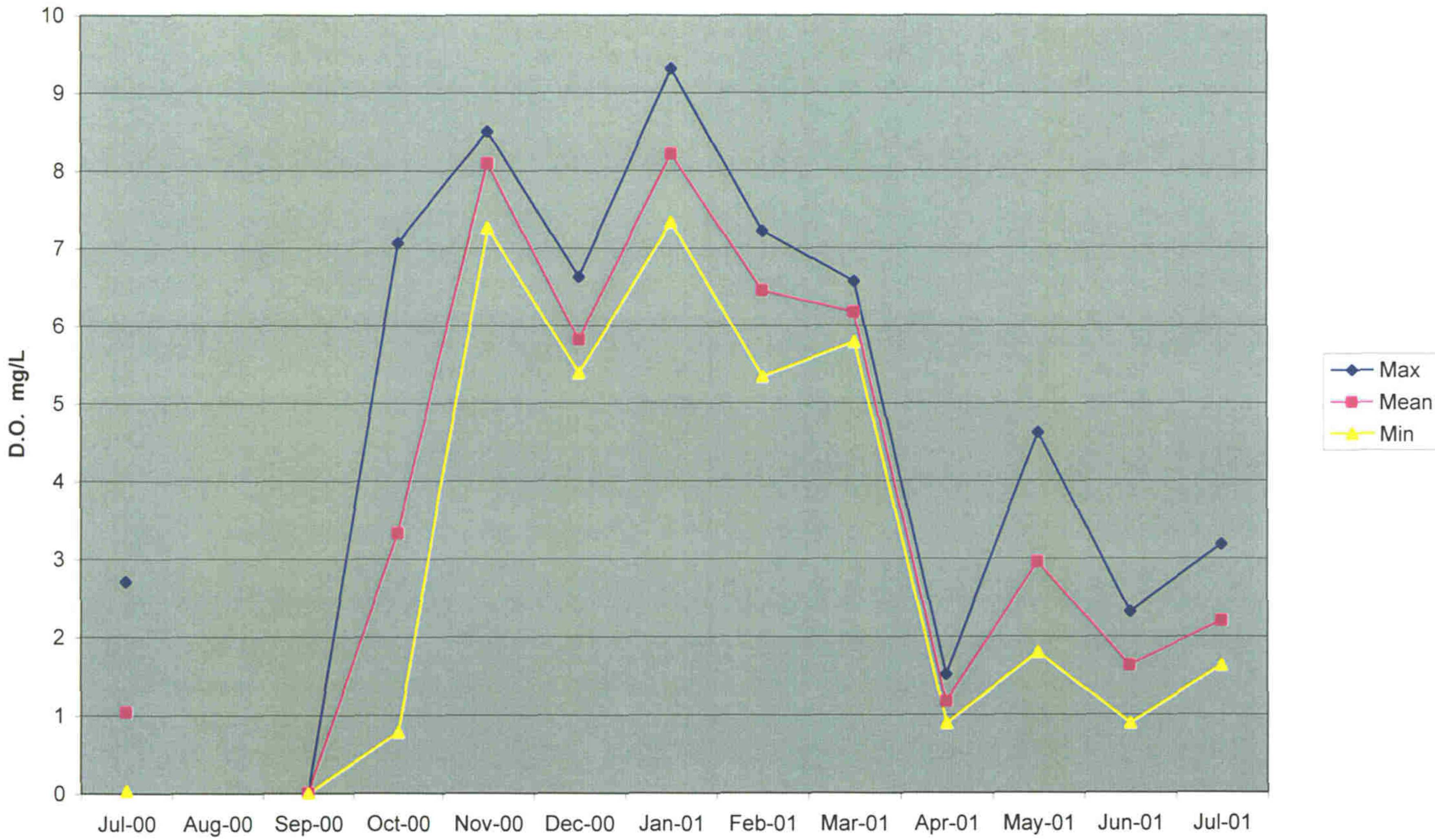
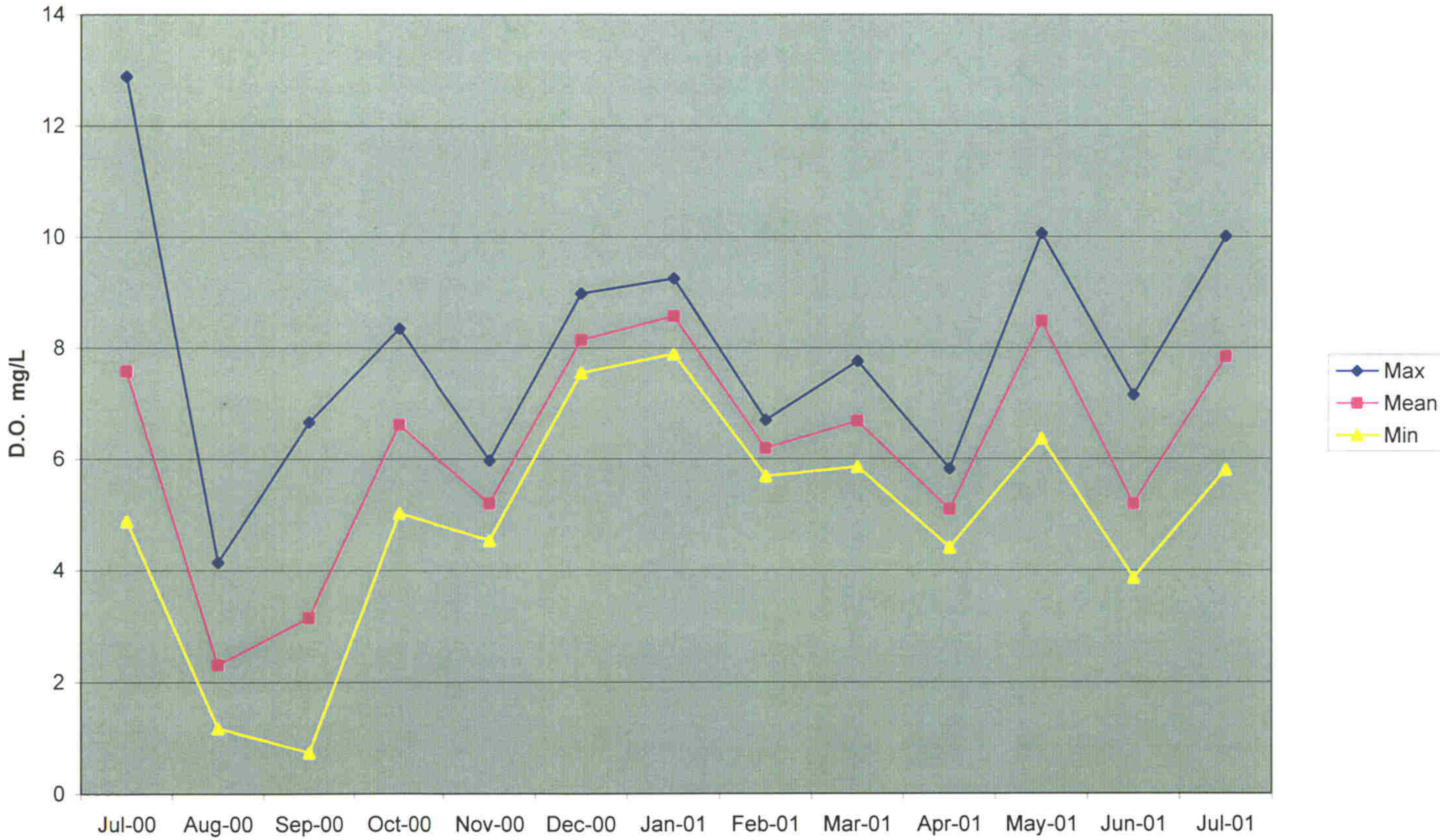


Figure 2 - DB5A 48 Hour Monthly Dissolved Oxygen



A general statement can be made that DO levels are higher during the winter months, decline over the spring reaching their lowest in the summer, then begin to rise again in the fall until they peak, once more, in winter.

Water Temperature vs. Dissolved Oxygen

Ambient water temperatures influenced DO levels at all sites along the bayou. As seen in the previous graphs, comparisons can be made between seasonal DO variations and the ambient temperatures. As seen in Figures 3 & 4 there is a noticeable decrease in DO during the hotter, summer months and a substantial increase during the cooler, winter months. During the summer, water temperatures were over 30° C and DO levels of <1.0 mg/l were observed. Winter water temperatures were 15° C or below with DO values >5.0 mg/l. Both surface and bottom numbers reflected the same trend, however, the deeper sites seemed to be affected more. (Appendix 21 contains a complete set of monthly mean temperature versus DO graphs.)

Rainfall was seen to have the affect of decreasing temperature and increasing DO levels at all sites and depths for a short time following the rain event. The bayou recovered quickly after a rainfall and reflected the previous values expected for the site, depths, and ambient monthly conditions.

Salinity vs. Dissolved Oxygen

Investigators found saltwater encroachment upstream from DB5 to site DB1, but not to DB6. Halocline influences on DO levels along the entire length of the bayou were studied and graphed. Figure 5 shows how the salt wedge disappeared between sites DB1 and DB6.

A saltwater wedge forms with the less dense freshwater on top and the denser saltwater on bottom. From data gathered, the halocline which occurs in Dickinson Bayou is a very distinct separation between the fresh/brackish water and saltwater. Salinity readings were often found to

Figure 3 - DB1A Monthly Mean Water Temperature and Dissolved Oxygen

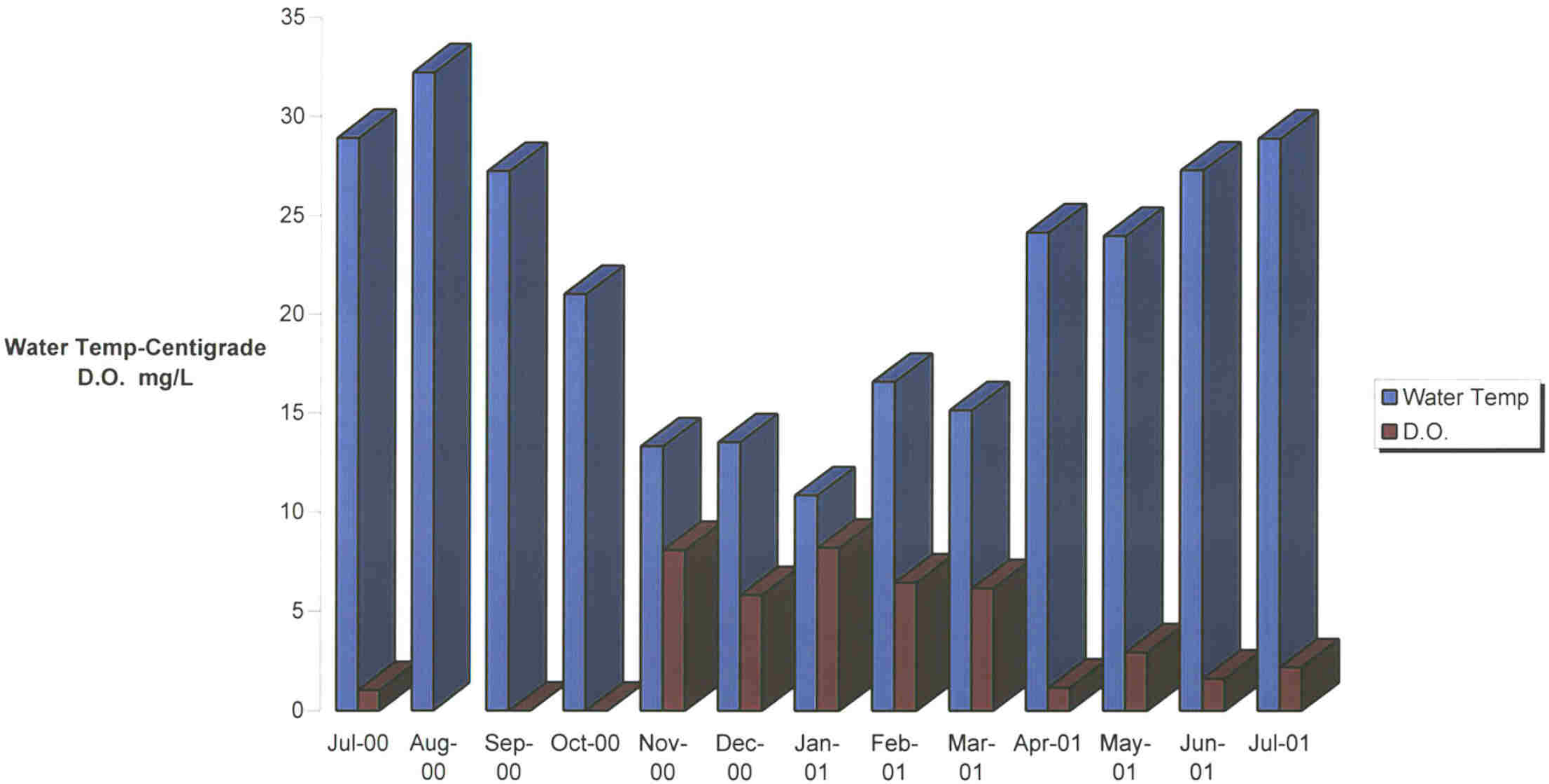


Figure 4 - DB5A Monthly Mean Water Temperature and Dissolved Oxygen

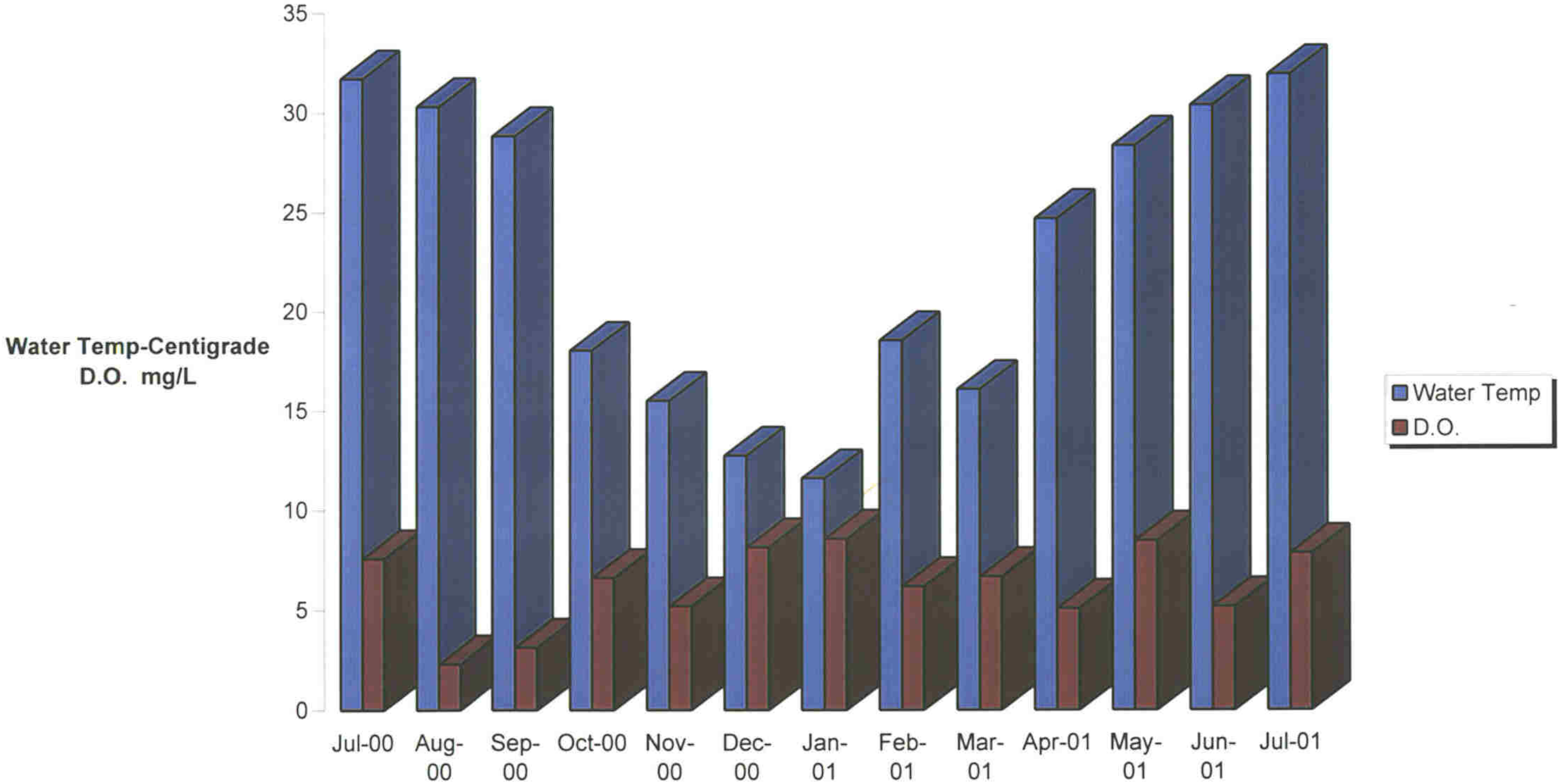
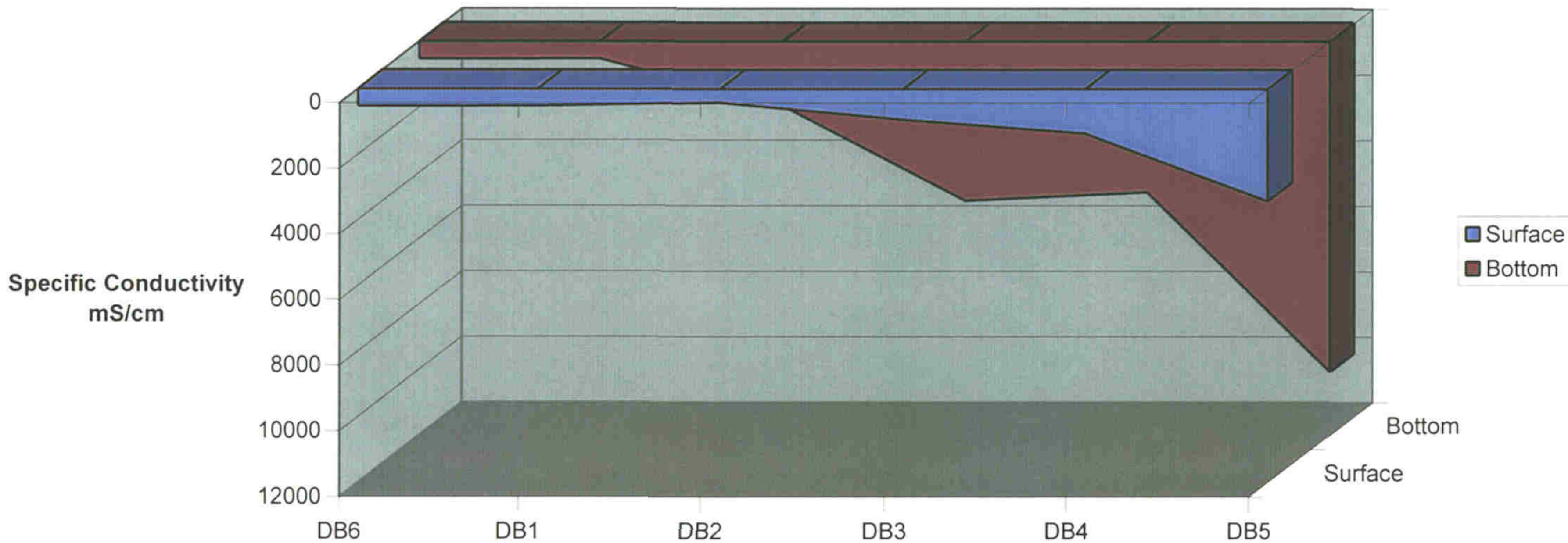


Figure 5 - July 2001 Specific Conductivity (Salinity) Upstream to Downstream



change from fresh/brackish water to saline waters in less than a one foot (1') increment. DO levels also declined drastically at and below this halocline boundary while the DO levels remain higher above. This phenomenon is illustrated by the stratified profiling at site DB5 and continuing upstream to DB1. Figure 6 illustrates a comparison between DO levels and salinity at site DB5.

An example of dry weather, saltwater encroachment can be seen in Figure 7. The saltwater wedge was easily tracked upstream from DB5 to DB1 exhibiting an excellent example of the DO/halocline boundary. Figures 8 - 10 illustrate three (3) wet weather event examples when the saltwater wedge was present at DB5, but had disappeared at the next upstream site. Appendix 22 contains additional graphs illustrating several examples.

The graphs also demonstrate the annual changes in the halocline at the 3 sites. There is more of a saltwater encroachment during the warmer, drier summer months receding to little or no encroachment during rainy weather or cooler, winter months. This movement of the halocline influences the severity and stratification of the DO concentrations in Dickinson Bayou.

Figure 6 - DB5 Gum Bayou 12 July 2001

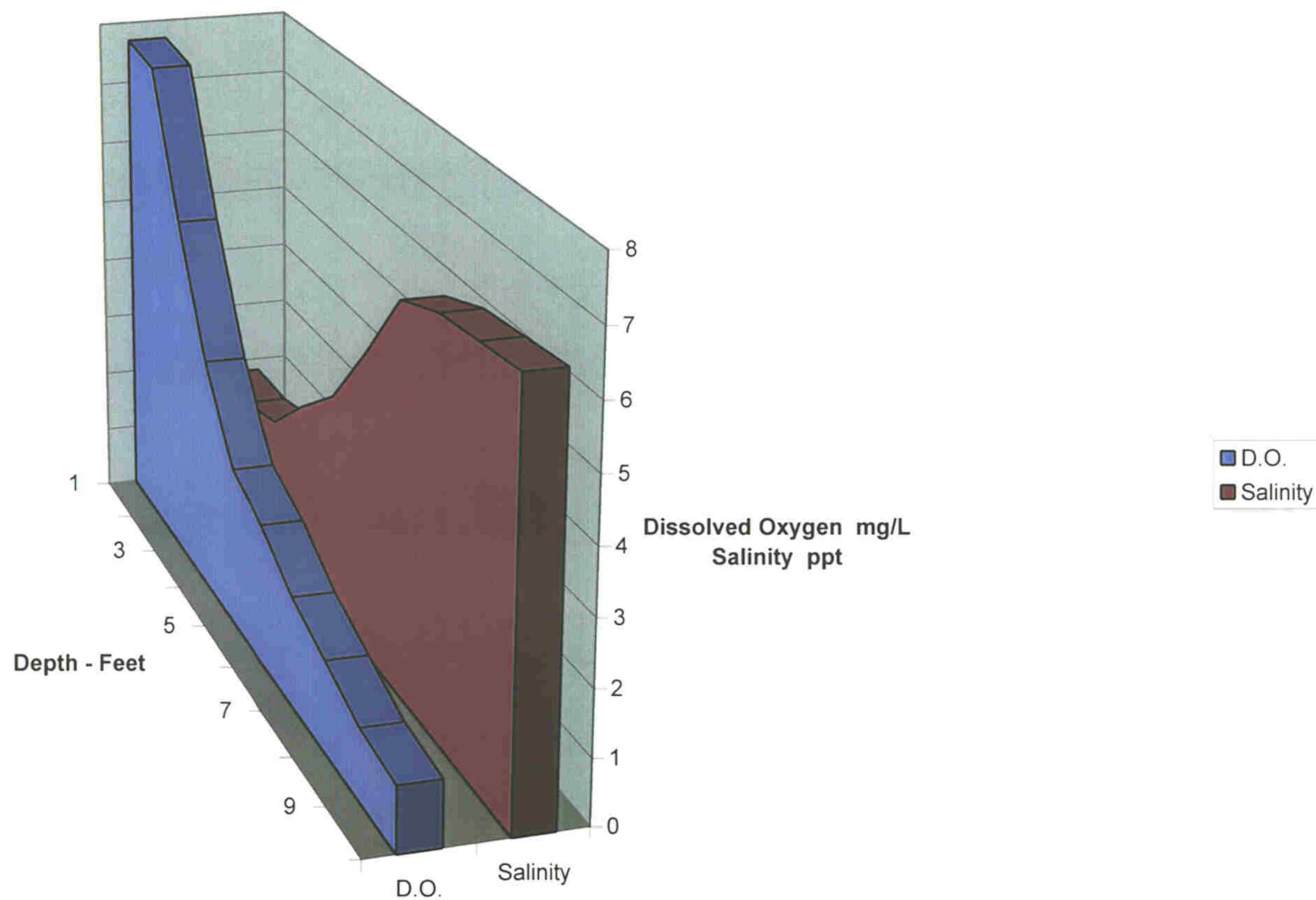


Figure 7 - DB1 Cemetery Road Bridge 12 September 2000

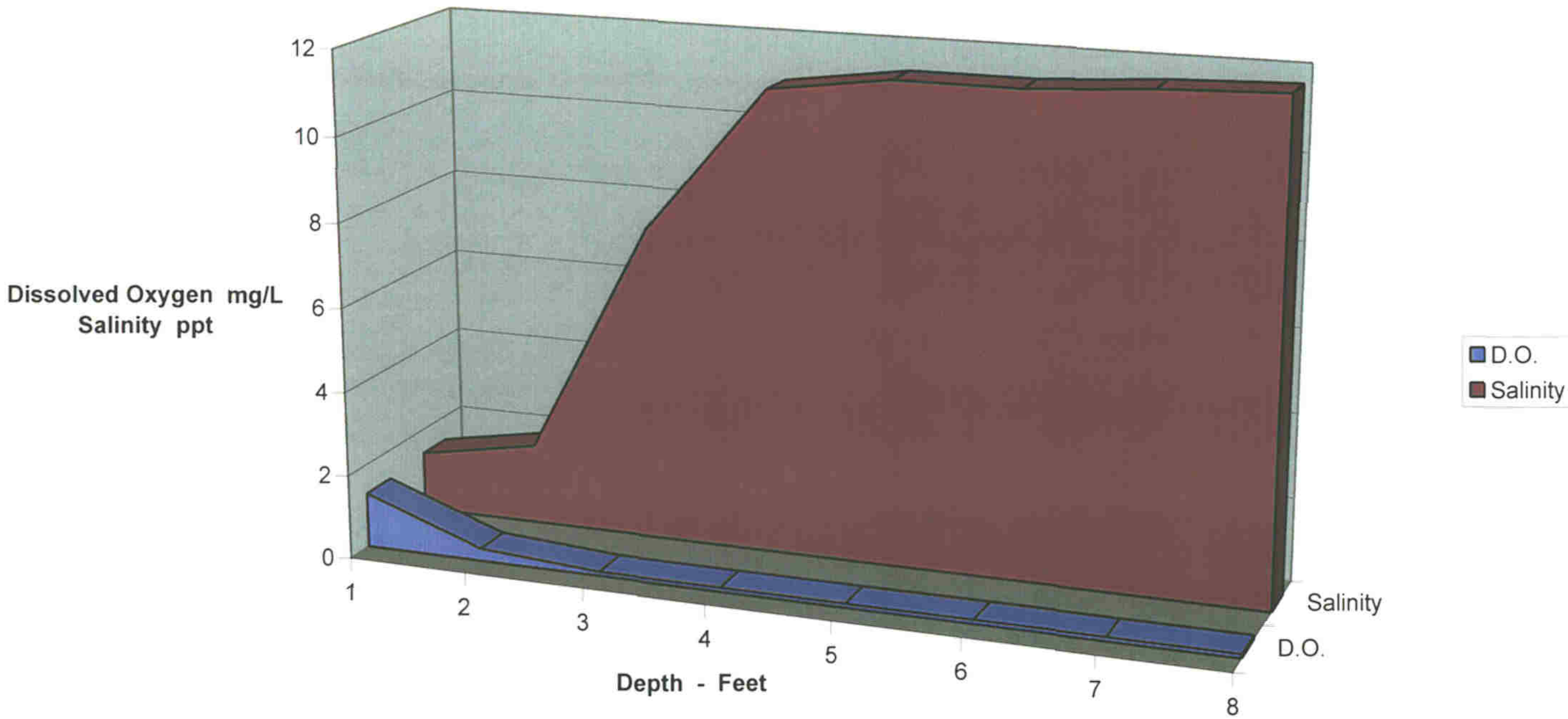


Figure 8 - DB5 Gum Bayou 20 March 2001

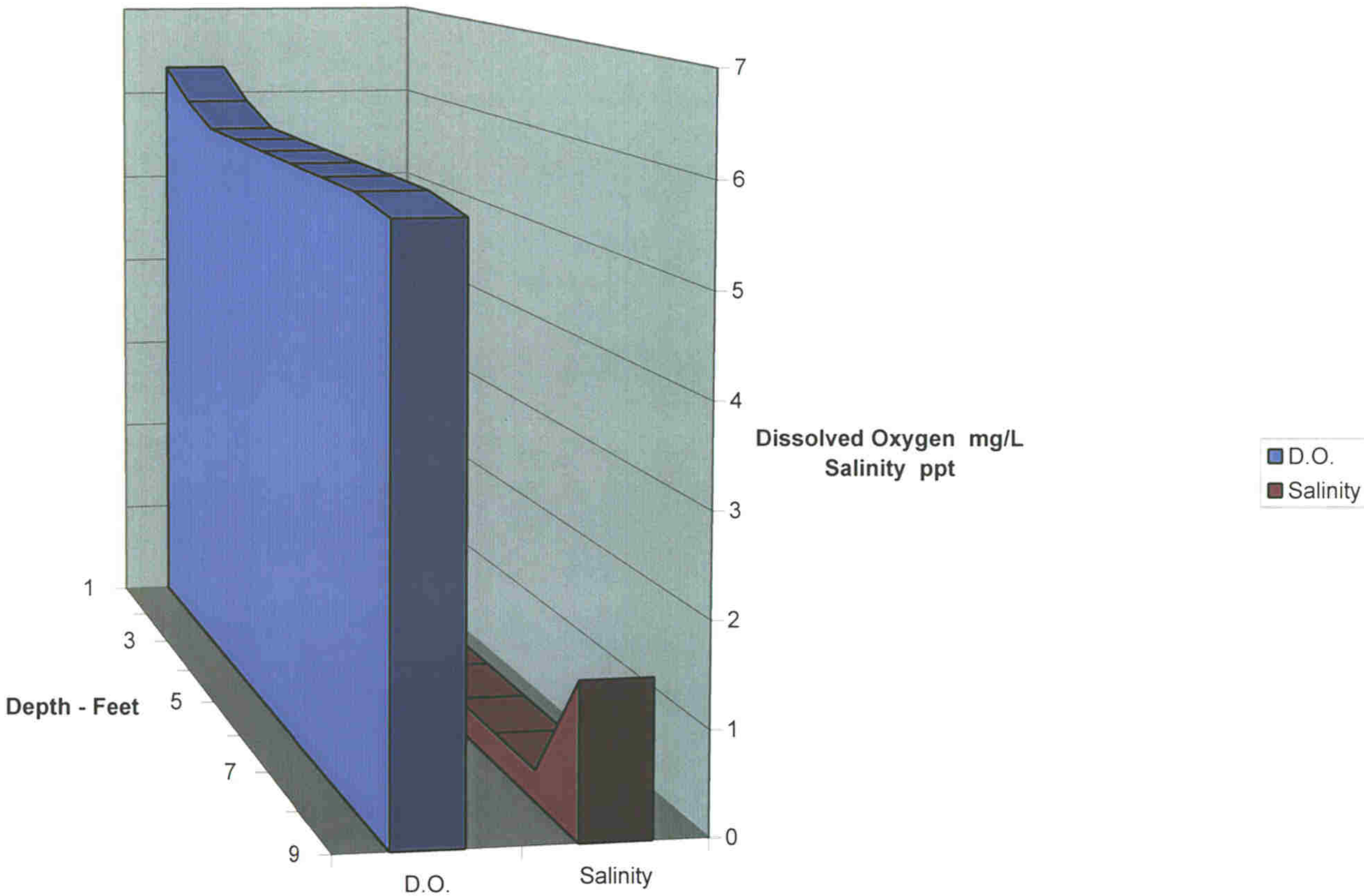


Figure 9 - DB3 Magnolia/Benson's Bayou 20 March 2001

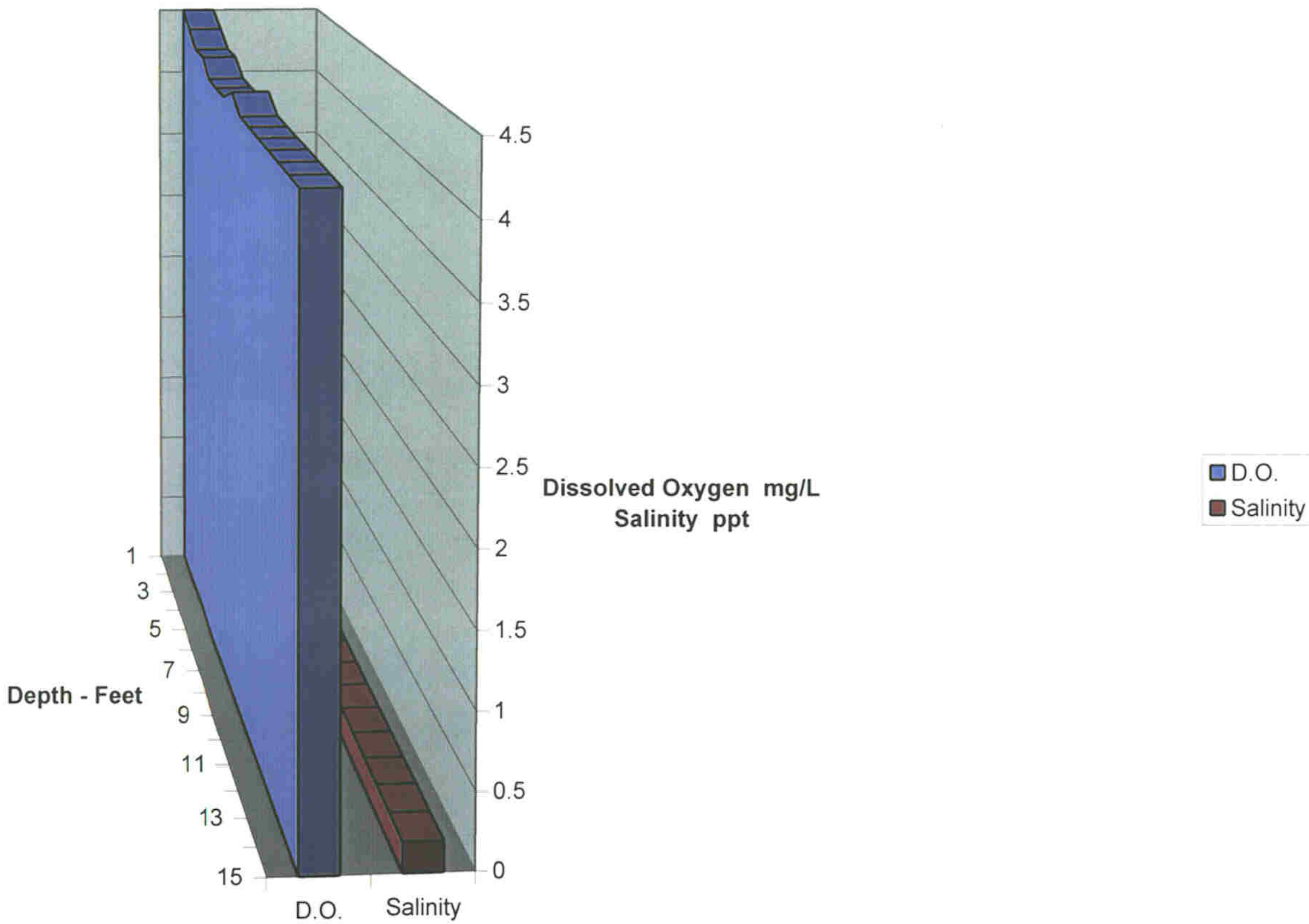
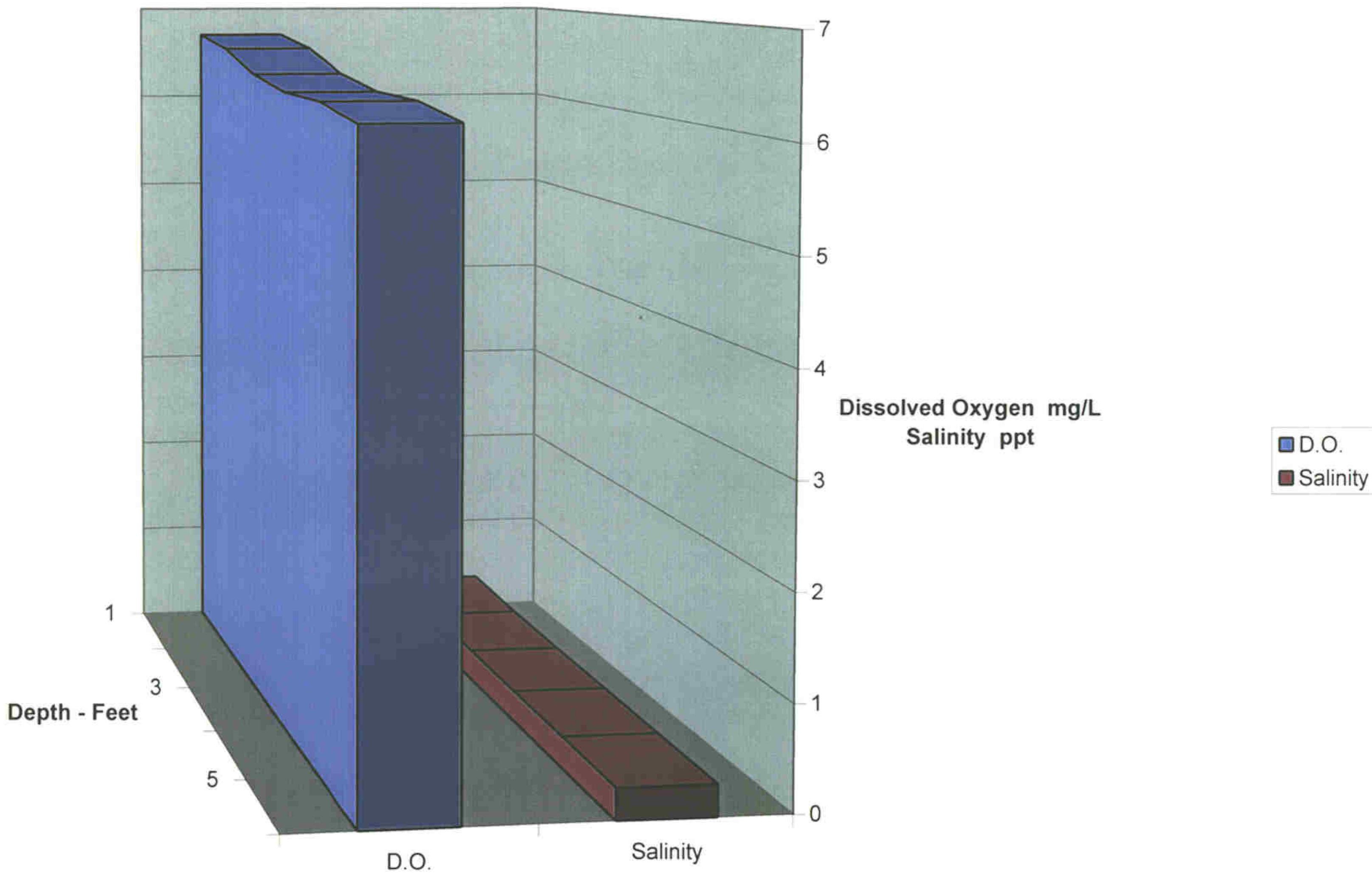


Figure 10 - DB1 Cemetery Road Bridge 20 March 2001



Bacteriological

As expected, rainfall influences the dispersion of fecal coliform bacteria into the bayou. This rainfall influence suggests a correlation between land usage and dispersion. Bacteriological data indicates differences in fecal coliform bacteria levels in the bayou when sampling was performed immediately after or during a rainfall event. Sampling conducted more than seven (7) days after a last rainfall event exhibited different results. Figures 11 -12 represent fecal coliform bacteria levels at every sample site on one sampling day over the course of the project. See Appendix 23 for graphs showing the annual bacteriological levels in the bayou by site.

Data from Clean Rivers ambient monitoring site, TNRCC 11467, located in non-tidal segment 1104, was reviewed to compare against data from sites farther downstream. Data showed fecal coliform bacteria increased during rainfall events and declines during "dry months." The bacteria data also shows a spatial difference between the six (6) sampling sites during rainfall events suggesting possible isolated non-point sources of bacteria in those areas. DB6, DB1, DB2 and DB 5 were the sites which exhibited the highest increases in fecal coliform bacteria levels after a rainfall event. A complete list of all coliform bacteria values for the study period can be found in Appendix 24. Fecal coliform bacteria, enterococci and *E. coli* levels of >3,000, >1,000 and >1,000 MPN/100 ml respectively are commonly observed at these sites after a significant rainfall. Likewise, values <100 MPN/ 100 ml for the indicator bacteria, fecal coliform, is common during dry sampling months. Table 1 on page 4 - 17 shows the drastic differences in fecal coliform bacteria levels between a dry weather sampling event and a wet weather sampling event.

Figure 11 - Surface Site Bacterial Levels for 19 June 2001

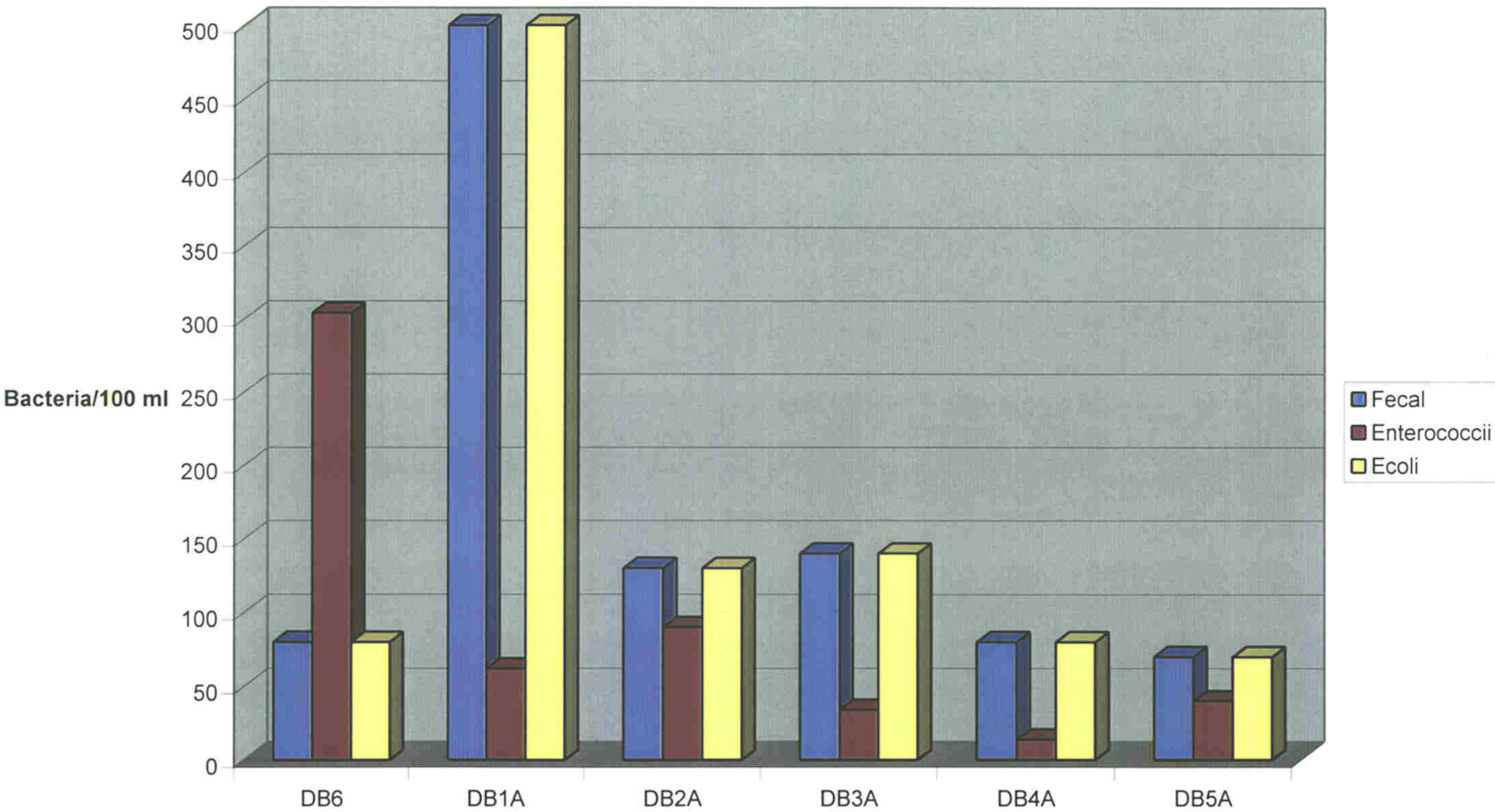


Figure 12 - Bottom Site Bacterial Levels for 19 June 2001

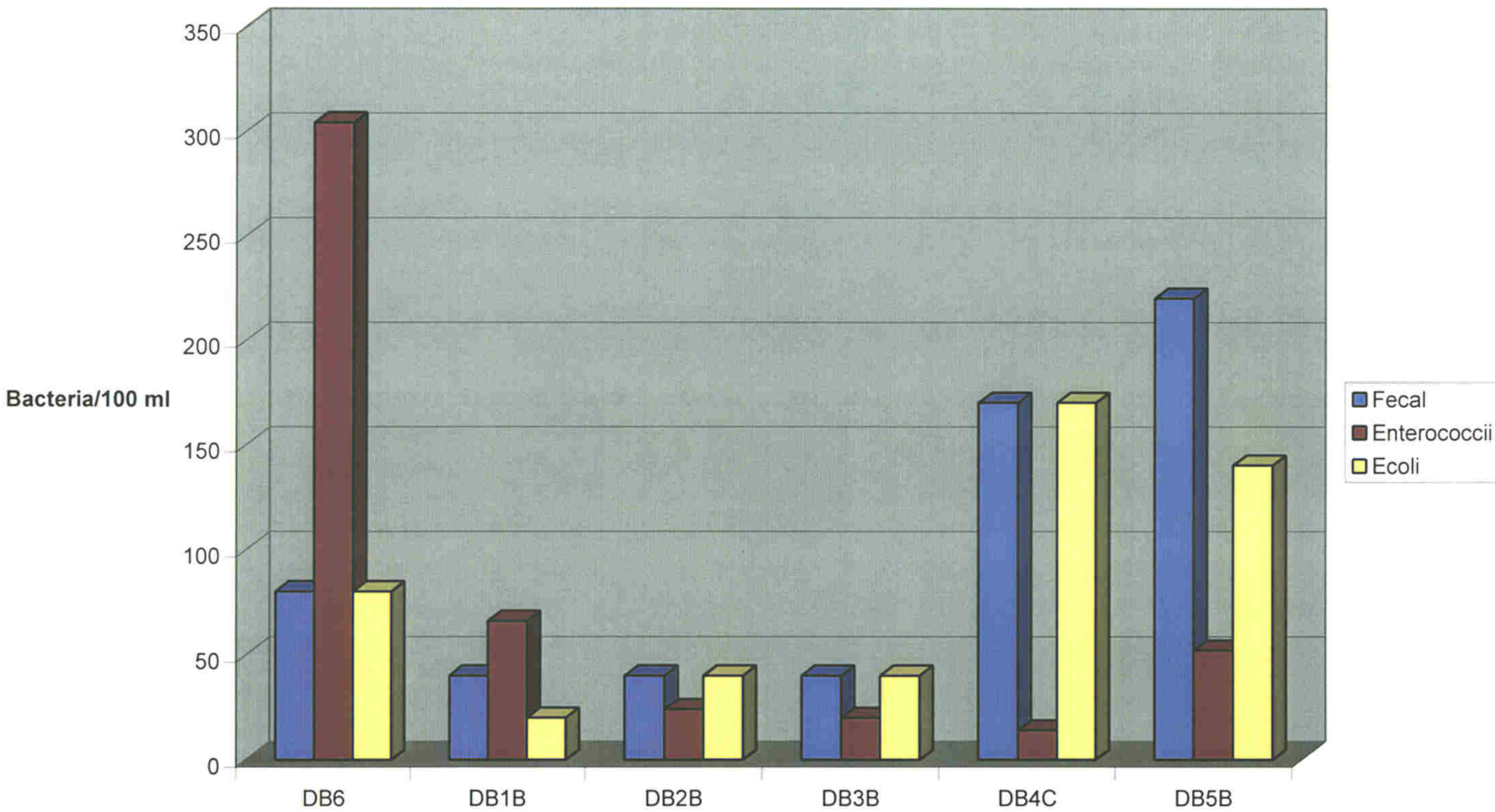


Table 1 - Fecal Coliform, Enterococci, and *E. coli* Concentrations for Dry and Rain Events

17 August 2000 - Dry Weather Event						
Site	DB6	DB1A	DB2A	DB3A	DB4A	DB5A
Raining	No	No	No	No	No	No
Days Prior	>7	>7	>7	>7	>7	>7
Fecal Coliforms* /100ml	80	80	40	80	70	<20
Enterococci* /100ml	142	8	4	18	38	2
*E. coli** /100ml	80	80	40	80	70	<20

11 January 2001 - Wet Weather Event						
Site	DB6	DB1A	DB2A	DB3A	DB4A	DB5A
Raining	No	No	No	No	No	No
Days Prior	<1	<1	<1	<1	<1	<1
Fecal Coliforms* /100ml	16,000	>16,000	>16,000	300	9,000	>16,000
Enterococci* /100ml	7,900	4,000	12,700	5,200	3,000	380
*E. coli** /100ml	9,000	>16,000	>16,000	300	500	>16,000

*Most Probable Number (MPN)

Nutrients

GCHD's laboratory performed several different analyses for nutrient parameters during each sampling event of the study. Carbonaceous Biochemical Oxygen Demand ($CBOD_5$) is the amount of DO consumed in the biological process in the breakdown of organic matter in water. Generally, the higher the $CBOD_5$, the greater degree of pollution that is present. Ammonia nitrogen (NH_3) and nitrate plus nitrite nitrogen ($NO_3 + NO_2$) are found in wastewater and occur during the breakdown of compounds containing organic nitrogen. They are the chemical indicators of possible sewage pollution sources. Ortho-phosphate (o-PO_4) is the most important inorganic phosphate in water. It is the least abundant and, therefore, it is a limiting factor. An essential nutrient to plant growth, it is found in wastewater, agricultural drainage, and industrial wastes. High levels in surface waters can cause severe algal blooms. Chloride is also a major inorganic ion in wastewater. It can be elevated by discharges from industrial processes.

As demonstrated in Figure 13, data shows elevated levels of ammonia, nitrate+nitrite and ortho-phosphorus during rain events and depressed levels during dry weather. The asterisk following the date designates a rain event. Appendix 25 contains a complete set of nutrient graphs for the study.

Since the nitrate+nitrites are results of the oxidation breakdown of ammonia, elevated levels of nitrate+nitrite will follow after high levels of ammonia. High wet weather values were 1.22 mg/l for ammonia and 0.57 mg/l for nitrate+nitrite while dry weather lows of 0.01mg/l occurred for both. The high levels of ammonia and nitrate+nitrites correspond to elevated levels of the bacteria indicator for the bayou. Ortho-phosphorus also exhibits an increase during rainfall events as well. A high measurement of 0.78 mg/l occurred in March 2001 after a significant rainfall event but common averages of 0.01-0.05 mg/l were seen during other times of the year.

$CBOD_5$ levels were highest during July, August, and September and occurred at the upstream sites of DB1, DB2, and DB3. High values of >14 mg/l were observed during this time and were present during dry weather conditions. Figure 14 illustrate monthly fluctuations in $CBOD_5$ values for site DB4A. See Appendix 26 for additional $CBOD_5$ graphs for all sites. Appendix 27 contains tables of all the nutrient values, as well as additional lab test values.

Figure 13 - DB4A Nutrient Constsituents

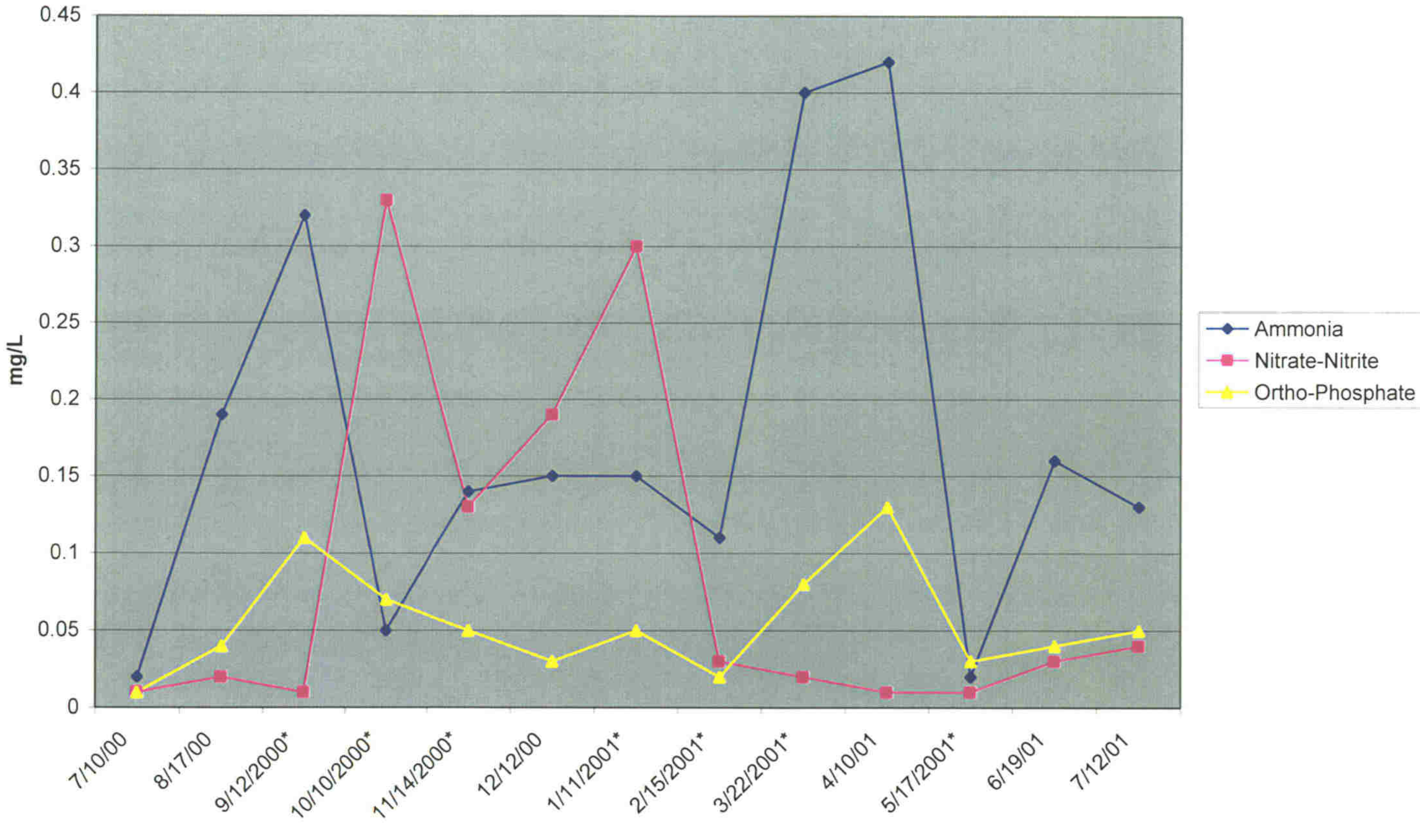
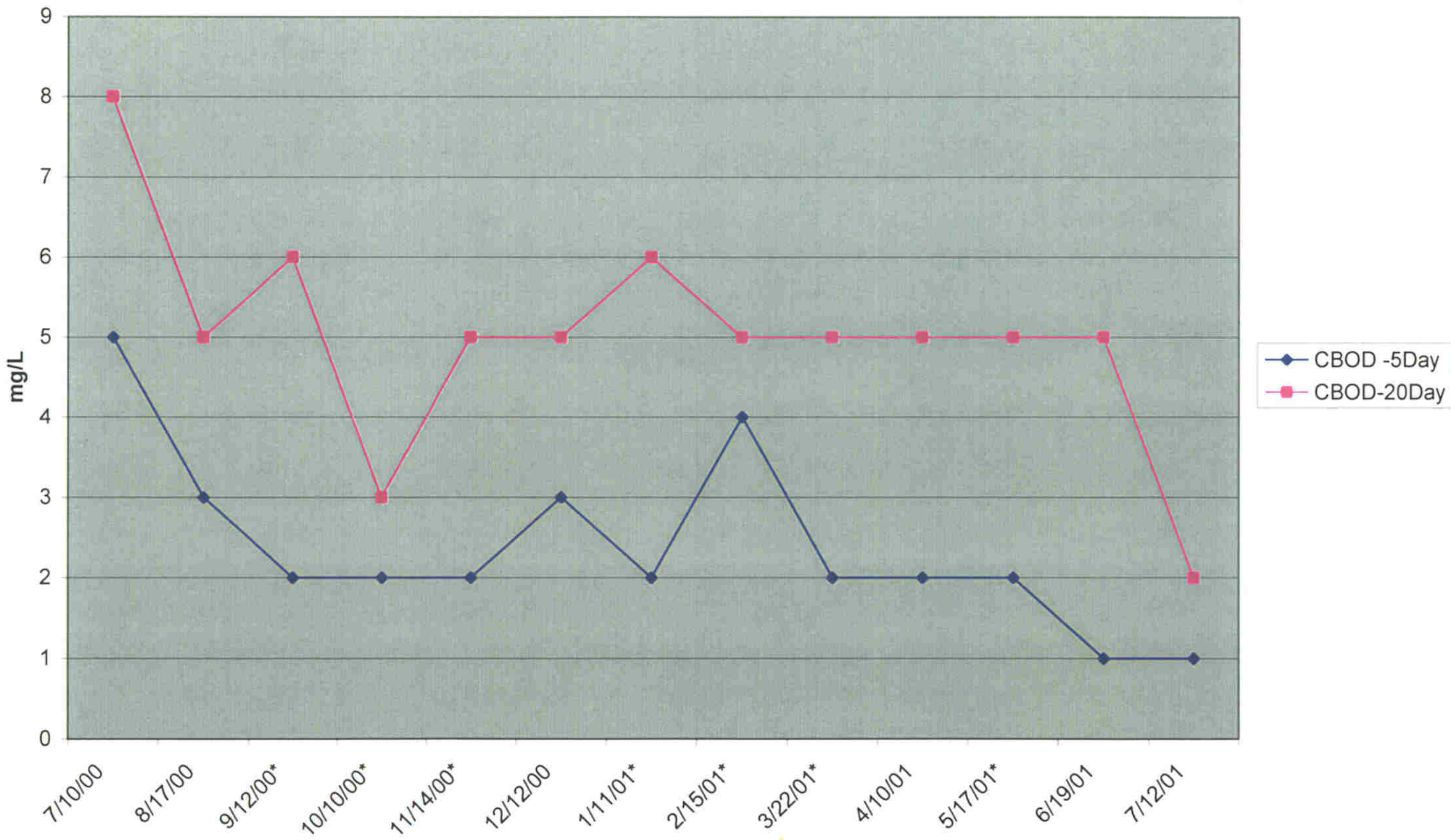


Figure 14 - DB4A CBOD Values



5. Discussion

Dickinson Bayou tidal segment (1103) is listed on the 303(d) list for low dissolved oxygen concentrations and elevated fecal coliform densities. Field measurements and analytical laboratory data gathered during this Pre-TMDL study confirms that this water body is impaired. The data reflects a synergistic effect of all physical, biological, and chemical parameters tested during the project to come to this conclusion.

Dissolved Oxygen (DO)

In Dickinson Bayou, DO is physically influenced by saltwater encroachment, seasonal temperature changes, flow conditions, and rainfall. Saltwater encroachment typically lowers the DO below the halocline boundary. Reasons include no mixing between the layers which traps decomposing organic matter leading to anaerobic conditions. Hence, the production of hydrogen sulfide.

As demonstrated by stratified profiling data, no mixing occurs between the less dense freshwater and denser saltwater layers. Freshwater travels over the saline water at the halocline boundary and doesn't start mixing with the column until site DB5. This lack of mixing does not allow DO to reach the water below the halocline. Large amounts of organic matter (ie. tree leaves, plants, etc.) fall into the bayou and settle to the bottom. Bacterial decomposition follows and depletes DO levels creating an anaerobic environment low in DO and high in hydrogen sulfide. The high temperatures encountered during the summer only exaggerate the problem. This phenomenon changes temporarily during rainfall events causing recession of the saltwater wedge. The increased flow of freshwater through the bayou after a rainfall event initiates mixing throughout the water column bringing much needed DO to the anaerobic regions of the bayou. The heavy influx of fresh water also drives the halocline farther downstream.

Seasonal temperature changes affect the DO concentrations in the bayou by lowering DO in the warmer months and elevating it during the cooler months. Water has a greater affinity for absorbing oxygen at cooler temperatures and less at warmer temperatures. Data clearly shows this relationship along the bayou. The warmer temperatures contribute to an already oxygen stressed environment exaggerating the effects of other factors. Rainfall temporarily relieves this stress by lowering the water temperature and mixing the water to allow oxygen diffusion through the water column. Once rainfall run-off ceases, low flow conditions return creating the low DO environment caused by a lack of layer mixing.

Biological Influences

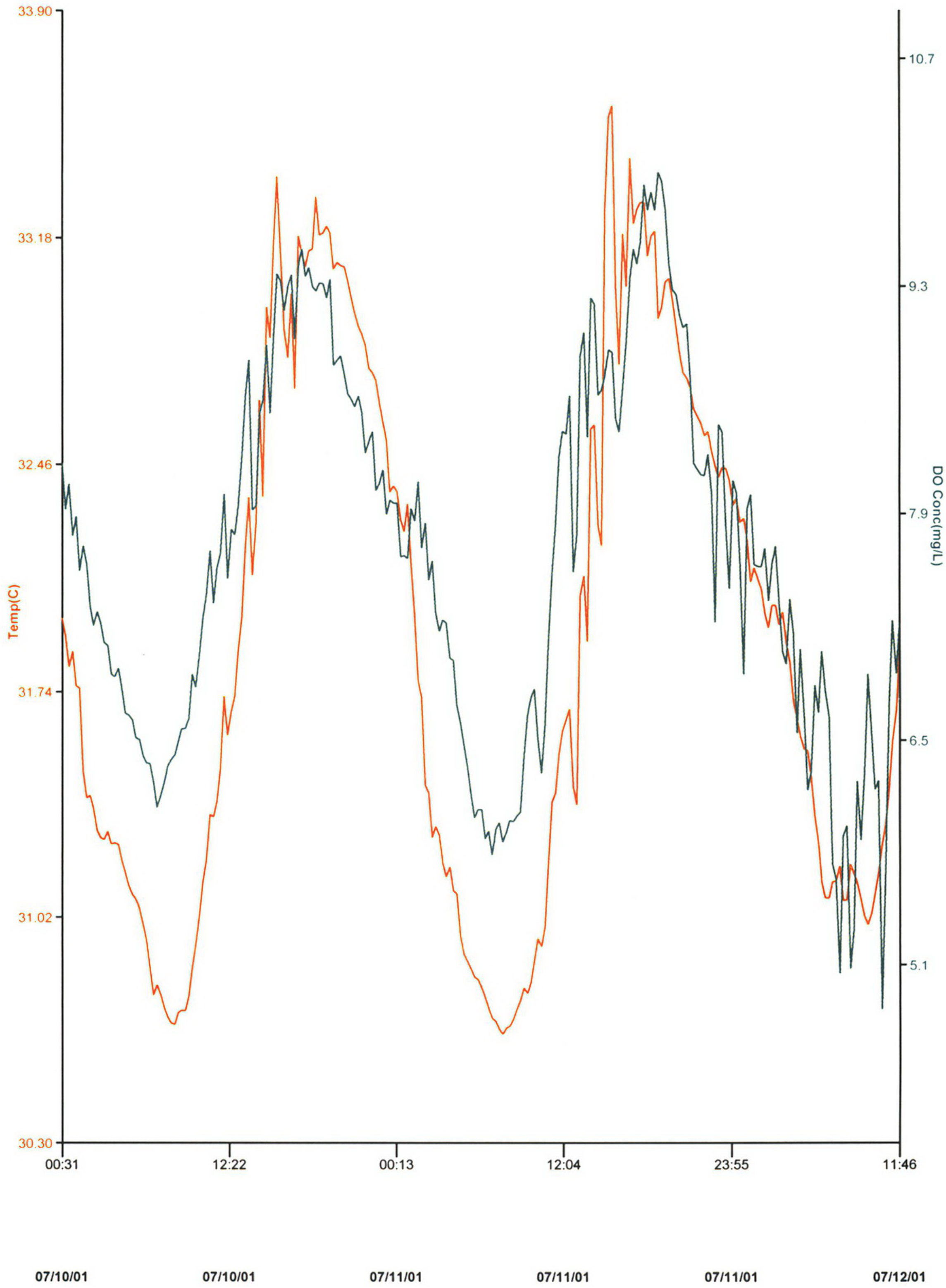
Algal blooms along Dickinson Bayou also affect the DO levels. The majority of algal blooms occur during the warmer months along the parts of the bayou which are most exposed to ambient sunlight and experience low flows. The natural diurnal cycle of the algae produces high DO levels, >10 mg/l, late in the afternoon and extremely low DO levels, <4.0 mg/l, in the early morning. Figure 15 illustrates an example of a forty-eight (48) hour period when an algal bloom was occurring. The water temperature increased throughout the daylight hours peaking in the middle of the night while the DO levels also increased throughout the day. Then, at night the algae began to respire and use the DO and the DO level reached its low early in the morning before sun rise.

As an algal bloom declines, decomposition occurs and lowers the DO back to <4.0 mg/l which can be seen even in the late afternoon when higher DO values should be expected. The resulting low DO values are detrimental to aquatic life and can lead to fish kills.

Oxygen demanding ($CBOD_5$) and nutrient (NH_3, NO_3-NO_2, and o-PO_4) constituents contribute to algal blooms and the problems associated with them. These constituents can find their way into the bayou through point source and non-point sources in agricultural run-off, septic systems, domestic waste and wastewater, and industrial discharges.

Figure 15 - DB5A Gum Bayou

July 2001



NH_3 and NO_3-NO_2 are decomposition elements of fecal matter and can be seen at high levels in the bayou after significant rainfall events. These elevated levels correlate with the increased run-off to the bayou raising values above the acceptable screening levels for tidal waters. Standard screening levels are 0.40 mg/l for both constituents.

Fecal contaminated run-off contributes bacteria to the bayou. These indicator bacteria are not necessarily pathogenic, but can be indicative of potential contamination by the feces of warm-blooded animals. Contact recreation standards for *E. coli* at 126/100 ml in freshwater, Enterococci at 35/100 ml and fecal coliform at 200/100 ml in saltwater are often exceeded within the bayou throughout the year. Upstream sites and DB5 exhibit the highest values, possibly due to land use influences from septic systems and agricultural applications.

Figure 16 displays the commercial and residential land use development for the Dickinson Bayou watershed. The dark red areas represent more densely developed areas while the lighter sections are rural/agricultural areas.

In conclusion, physical and chemical water quality data gathered and analyzed for the Dickinson Bayou Pre-TMDL project suggest that Dickinson Bayou (Segment 1103) routinely fail to meet their established water quality standards for contact recreation and high aquatic life use.

Low DO levels are the result of a combination of natural processes and anthropogenic influences. High bacteria levels were repeatedly found at sampling sites in more rural settings due to a greater use of septic systems and rangeland run-off. With more residential and commercial development taking place in the Dickinson Bayou watershed, greater pressure will be placed on the Bayou to absorb and process the additional loading from point and non-point source pollution.

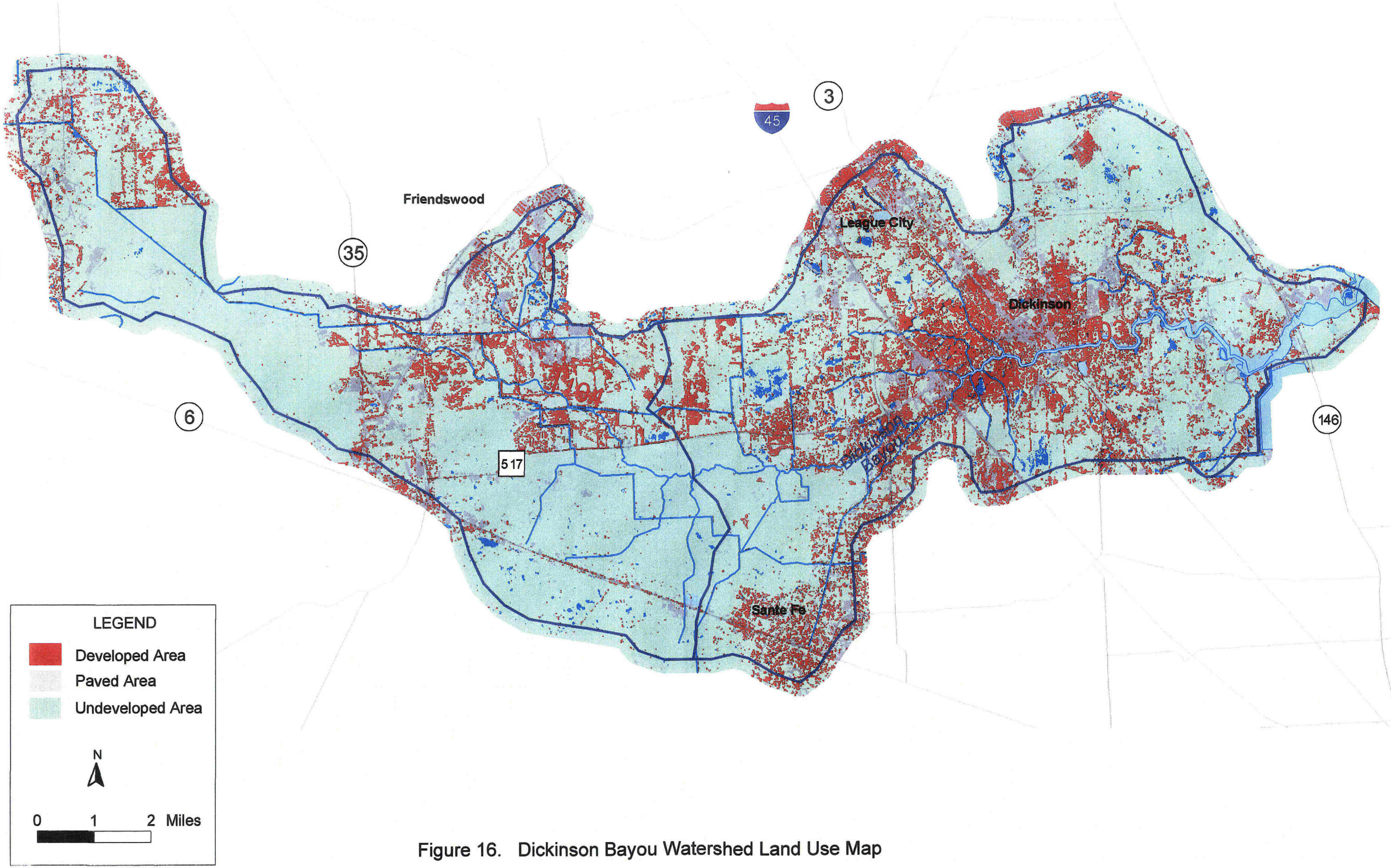


Figure 16. Dickinson Bayou Watershed Land Use Map

6. Lessons Learned

GCHD determined that no one should attempt to deploy buoys and collect water samples on the same day. Not only were the days extremely long, but the water samples were delivered to the lab very late in the day. Lab personnel ended up staying past 7:00 p.m. to complete all of the analytical work required for samples having no holding time. Water samples being tested for fecal coliform bacteria, enterococci, and *E. coli*, BOD_5, BOD_{20}, TSS, VSS, ortho-phosphate and alkalinity are processed the same day they are collected and received. Additional concerns included stirring up the water column or disturbing the bottom muds by dropping the 225 lb. weight and the attached buoy.

Lesson Learned #1: Regardless of how many buoys and sondes are being deployed or the number of samples being collected, GCHD recommends designing a schedule to deploy buoys and sondes on one day and, then, collect water samples on another.

GCHD read in the literature that new batteries should have enough energy to power the sonde functions for 30 days. When the sondes were deployed in August of 2000, the pre-calibration diagnostics indicated that the batteries still had plenty of energy to last through another week of deployment. That decision was a mistake in that the probes quit functioning half way through the deployment period. Since changing the procedure, there have been no battery failures.

Lesson Learned #2: Batteries shall be changed in the sondes every time they are deployed regardless of what the literature recommends and the pre-calibration diagnostics indicate.

The buoys are deployed using galvanized chain and 225 lb. weights. The sondes are deployed by locking them in protective covers and securing both to an independent cabling system which operates similar to a flag pole. Originally, the cable was shackled directly to the "eye" of the buoy and anchor weight, but the D-rings which secure the sondes would not slide through the shackle. The size and shape of the shackle created an obstacle for the cable D-rings, preventing


Photo 11 - D-rings shackled directly to the "eye" of the buoy.

the sondes from being raised or lowered. Investigators shackled four-inch (4") diameter galvanized rings to both the top and bottom "eyes," then ran the cable through the rings attaining a smooth operating cable system. The cable D-rings no longer snag on the smaller opening of the shackles (Photos 11 & 12) .

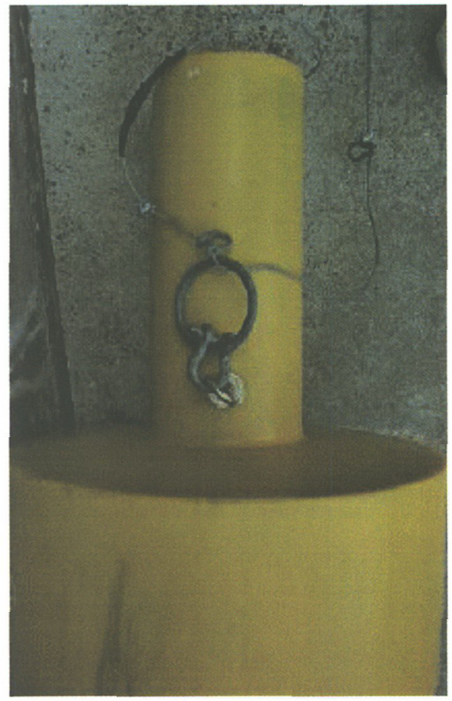


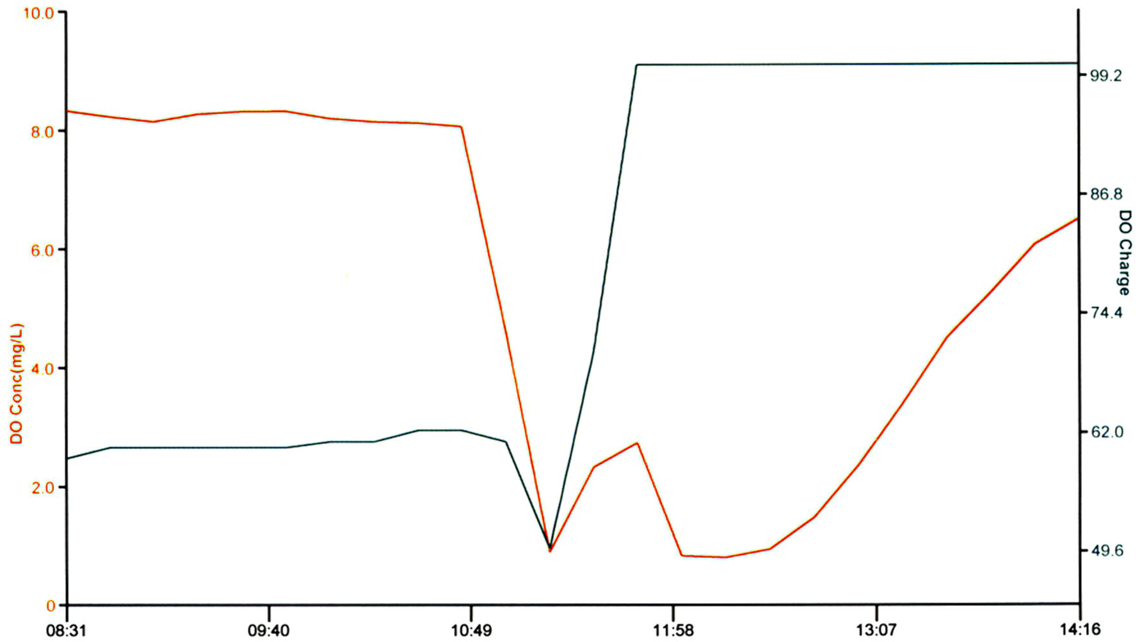
Photo 12 - Four inch (4") galvanized ring attached to "eye" of buoy.

Lesson Learned #3: Shackle a four-inch (4") galvanized steel ring to the "eye" of the buoy and anchor weight to allow the cable and d-rings to pass through unrestricted.

Hydrogen sulfide (H_2S) interferes with the operation of the dissolved oxygen probe on the YSI data sondes. Specifically, H_2S interrupts the electrical signal being sent from the silver electrode to its companion gold electrode (anode-cathode) which causes the probe to stop functioning. H_2S also corrodes the silver electrode and will eventually render the probe totally inoperable. GCHD has gathered data which demonstrated the two phenomenon. Figure 17 illustrates how the H_2S became too concentrated and the probe quit functioning for the remainder of the deployment period. The graph shows where the DO probe was compromised within 45 minutes after immersion at site DB2B. A noticeable drop in DO occurred along with an increase of the DO charge exceeding acceptable limits. The DO probe remained disabled for the duration of the deployment. Whereas Figure 18 shows the H_2S concentrations went high enough for the probe to stop working for a period of time, but then, the H_2S level dropped and the probe started recording

Figure 17 - DB2B   Ditch 9/12

August 2000



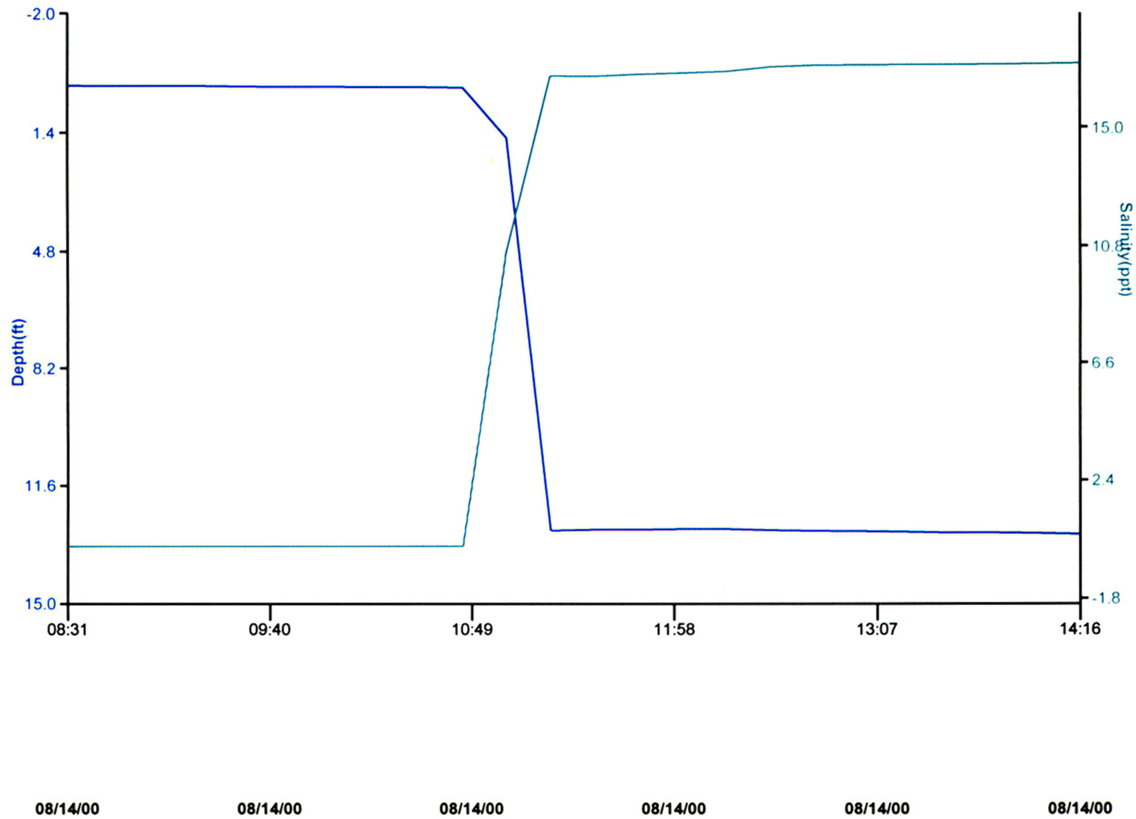
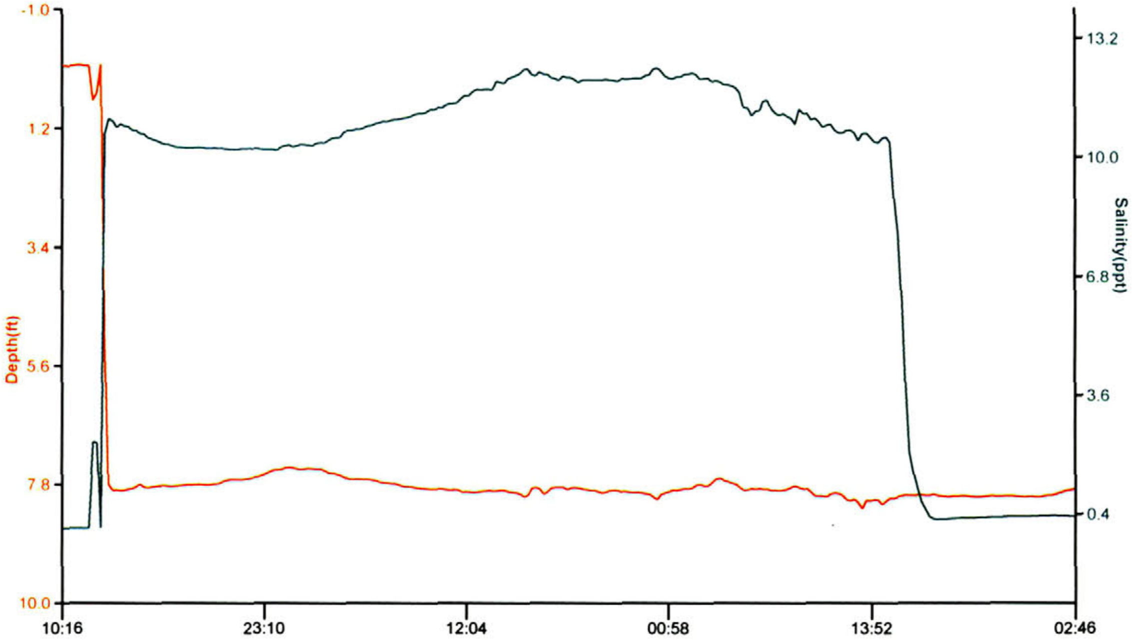
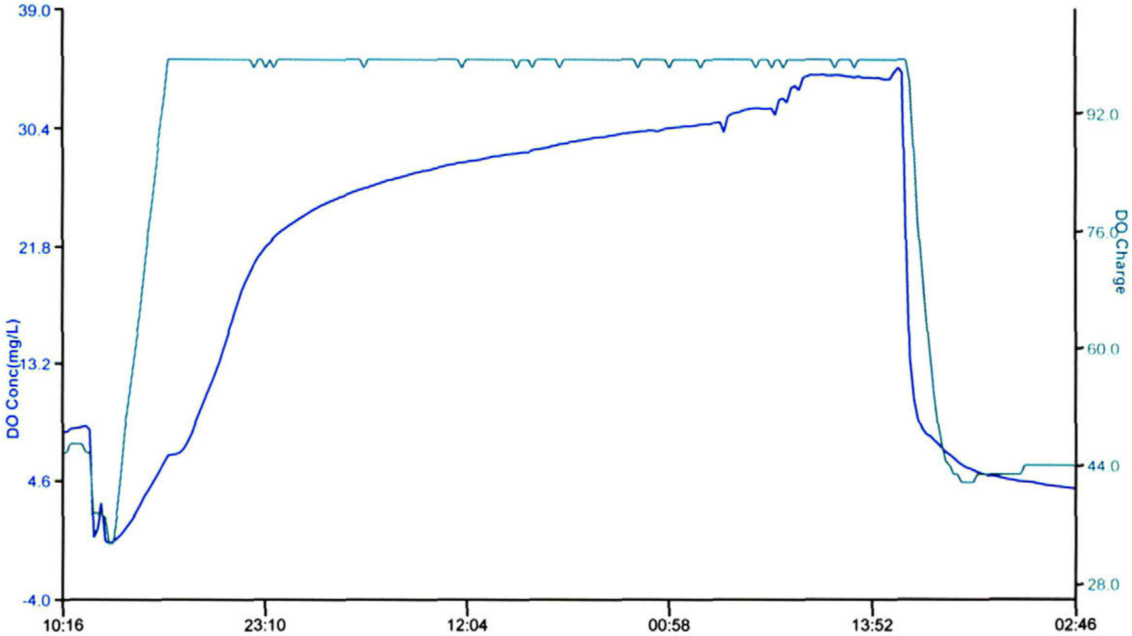


Figure 18 - DB1B   Cemetery Road Bridge

September 2000





09/11/00 09/11/00 09/12/00 09/13/00 09/13/00 09/14/00 dissolved oxygen again in the later portion of the deployment period. Acceptable DO diagnostic value ranges for the YSI data sonde should fall between 25 ans 75. Any value above or below that range renders the DO data unacceptable.

Lesson Learned #4: Consultation with a YSI representative and technicians did not resolve this issue. TNRCC Region 12 investigators recommended that we view those data sets as "zero" dissolved oxygen because H_2S production is a by-product of anaerobic decomposition.

Excessively high and unusually low levels of water in the bayou created dangerous or difficult working conditions as well as frustrating circumstances. The Gulf Coast region experienced only one (1) tropical storm during the period of study but there were several flood stage events that occurred on the upper section of the bayou due to heavy rain storms. Investigators completed deployment, sampling and retrieval operations in all kinds of weather except during lightning storms and flood stage. The photographs in Appendix 28 show the contrast between normal and flood stages on the bayou.

Lesson Learned #5: Investigators and laboratory support services must remain flexible and in constant communication, to adapt to changing weather conditions. Safety and common sense should always be a priority.

As expected, this type of project and the level of effort expended is very expensive and time consuming. GCHD calculated that approximately 425 personnel hours were dedicated every month to collecting and analyzing the Dickinson Bayou samples (See Tables 2 & 3). This number includes the hours of personnel funded by the Clean Rivers program as well as GCHD's in-kind personnel. While Clean Rivers funded three full-time equivalent (FTE) positions to work on various projects (2 field & 1 lab technician), GCHD contributed two (2) additional field investigators and four (4) laboratory analysts. The previously stated personnel hours do not include TNRCC's field investigator's time nor their laboratory's time for analyzing the TKN,

Table 2. Field personnel hours during deployment week.

Field Personnel (FP) Individual Hours					
	FP # 1	FP # 2	FP # 3	FP # 4	Total Hours
Sunday	6	0	0	0	6
Monday	10	6	6	6	28
Tuesday	10	8	6	6	30
Wednesday	2	0	0	0	2
Thursday	10	8	6	6	30
Friday	10	8	6	6	30
					126

Table 3. Laboratory personnel hours required to analyze samples.

Lab Personnel (FP) Individual Hours						
	FP # 1	FP #2	FP # 3	FP # 4	FP # 4	Total Hours
Monday	8	8	7	7	7	37
Tuesday	8	8	7	7	7	37
Wednesday	8	8	7	7	7	37
Thursday	8	8	7	7	7	37
Friday	8	8	7	7	4	33
Sunday	0	0	0	0	4	4
Monday	8	8	4	4	2	26
Tuesday	8	8	4	4	2	26
Wednesday	8	8	4	4	2	26
Thursday	8	8	4	4	2	26
Friday	8	8	4	4	0	24
						314

Pheophytin-a, and Chlorophyll-a. Also excluded from this total are the hours dedicated by USGS personnel. Approximately 125 field hours are required to deploy and retrieve buoys, prepare data sondes, and obtain water samples. While more than 300 laboratory hours are required to analyze all water samples delivered to the lab for the Dickinson Bayou project.

Lesson Learned #6: Partnerships are the only means by which comprehensive, synoptic surveys can be conducted in the least costly manner. Therefore, GCHD willingly became partners with HGAC, TNRCC, and the USGS because of the project's value to the local Cities of Dickinson and League City and the Water Control & Improvement District #1 (WCID #1) also known as the Water Company. Development around the Dickinson Bayou watershed is increasing rapidly, particularly in League City, and, subsequently, the bayou stress factors are increasing along with development. The information gathered will be useful to the communities for future ordinance development and land use planning.

SELECTED REFERENCES

East, Jeffery W., Edna M. Paul, and Stephen D. Porter, *Nutrient Loading and Selected Water-Quality and Biological Characteristics of Dickinson Bayou Near Houston, Texas, 1995-97* (U.S. Geological survey, Water-Resources Investigations Report 98-4012) Austin, Texas 1998.

Houston-Galveston Area Council, *Regional Assessment of Water Quality: Trinity-San Jacinto Coastal Basin, San Jacinto River Basin, San Jacinto-Brazos Coastal Basin, and the Brazos-Colorado Coastal Basin, October 1996*, Houston, Texas.

Houston-Galveston Area Council, *Regional Assessment of Water Quality: Trinity-San Jacinto Coastal Basin, San Jacinto River Basin, San Jacinto-Brazos Coastal Basin, and the Brazos-Colorado Coastal Basin, October 1998* , Houston, Texas.

Hydrolab Corporation, *Data Sonde 4 and MiniSonde Water Quality Multiprobes User's Manual*, Revision D, (HL #003078), Austin, Texas, August 1997.

The Texas Clean Rivers Program Long Term Action Plan 1992-2000, Texas Natural Resource Conservation Commission, Austin, Texas.

Texas Department of Water Resources, *Waste Load Evaluation for Dickinson Bayou in the San Jacinto-Brazos Coastal Basin - Segment 1103 - Dickinson Bayou Tidal & Segment 1104 - Dickinson Bayou Above Tidal*, Austin, Texas 1985.

Texas Natural Resource Conservation Commission, *State of Texas - 1998 Clean Water Act Section 303(d) List and Schedule for Development of Total Maximum Daily Loads* (Document #SFR-58), Austin, Texas June 26, 1998.

Texas Natural Resources Conservation Commission, *Surface Water Quality Monitoring Procedures Manual*, (Document #GI-252), Austin, Texas, June 1999.

Yellow Springs Instruments, Incorporated, *6-Series Environmental Monitoring Systems Operations Manual*, Revision A, (Item #069301), Yellow Springs, Ohio, August 1998.