Houston Ship Channel Water Quality Conditions

Prepared for

TCEQ

H-GAC

Prepared by

CITY OF HOUSTON TEXAS

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HOUSTON SHIP CHANNEL WATER QUALITY CONDITIONS

Prepared for:

Houston-Galveston Area Council
Clean Rivers Program
Texas Commission on Environmental Quality

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EXECUTIVE SUMMARY

For most of the twentieth century the Houston Ship Channel (HSC) has been an example of water pollution. One of the first attempts to regulate waste discharges was made by the Texas Water Quality Board in 1972. This effort focused substantially on industrial discharges and resulted in some water quality improvements. However, in the late 1970s anoxic conditions were still common over much of the HSC. In 1984 the Texas Department of Water Resources published a new Waste Load Evaluation (WLE-1) that set stringent discharge permit limits for domestic as well as industrial sources. Through the implementation of WLE-1 there have been major improvements to water quality. Today the HSC meets criteria for dissolved oxygen (DO), and can be considered a success of the environmental regulatory process.

While the existing DO criteria are now attained, an issue remains with regard to the waste load evaluation and permits. Over the years the load of oxygen demanding material specified in the 1984 WLE study has been exceeded by the **permitted** amount of discharge, but the **actual** discharges have evolved to levels that are much smaller than the total allowable loading in WLE-1. This discontinuity between permitted and actual oxygen demand loads has been discussed extensively over the years.

EPA has indicated a concern that the permitted discharge exceeds the loading determined in WLE-1, and has asked the Texas Commission on Environmental Quality (TCEQ) to resolve the issue. The TCEQ worked with local interests in the Houston area to form an Advisory Subgroup for WLE-1 on the HSC. The group has been working since early 2000 and has been involved in two major actions: (1) planning for new water quality model development; and (2) analyzing a Monte Carlo approach to performing a new WLE.

As part of the process of developing a new and more accurate water quality model, a series of detailed water quality measurements, termed Intensive Surveys (IS), has been performed in cooperation with the TCEQ. This was supplemented with measurements of currents by the USGS. The TCEQ provided roughly half of the personnel and boats, and paid for the chemical analysis of water samples. The local or non-state part of the effort included the other half of the personnel and boats, and analyses of sediment samples. In the first two IS efforts most of the work was supported directly by the City of Houston with a major contribution by the City of West University Place for the USGS measurements. The local portion of the two most recent IS were supported by the Clean Rivers Program working with the City of Houston. The results of these four IS efforts are described in this report, along with relevant data from earlier studies, TCEQ monitoring data, and recent current measurements.

The major findings of the detailed IS efforts include:

> Density stratification is a major factor in HSC DO levels. With depths greater than 40 feet, the HSC is like many freshwater reservoirs that stratify in the summer, limiting oxygen transfer from the surface and producing low DO in the bottom waters. Texas Implementation

> Procedures and Assessment Guidelines recognize the role of stratification and the need to consider only the surface waters when determining criteria attainment. However, the rules for taking this into account are more restrictive on tidal waters than on reservoirs.

During dry weather when point sources are essentially the only flows into the system, there is very little oxygen demanding material in the water and stratification tends to be relatively weak. This is the condition addressed in the Waste Load Evaluation process. During these times DO levels are relatively good, indicating that there is little to be gained by additional wastewater restrictions.

There has been a trend of improved DO levels in the channel since WLE-1. Part of the reason has been the new wastewater treatment plants, particularly the 69th Street facility that came on line concurrent with WLE-1. Another reason is improvements that have been made to the wastewater collection system, greatly reducing but not completely eliminating sewer leaks. These changes are reflected in marked reductions in the organic content of the HSC sediments that appears to translate into reduced sediment oxygen demand.

When runoff events occur some oxygen demanding material is introduced to the channel. Some of the oxygen demand is exerted in the water and some settles to the bottom where it contributes to sediment oxygen demand, a major factor in the HSC DO balance. The input of fresh runoff water also increases density stratification. Surveys conducted immediately after rain events tended to show much lower DO levels.

The water quality model used for WLE-1 is a steady-state representation of the system that does not consider the dynamics of runoff, the mechanics of the density current, or the role of the mixed surface layer in determining attainment. It also does not reflect the major changes that have occurred in the system since WLE-1. As a result, it yields a very conservative (i.e. predicts DO levels lower than they actually are) representation of the system.

From the combined results of these IS events and other studies a measure of quantitative understanding of DO conditions in the HSC is emerging. A model to implement this understanding would have to have the following components:

- A representation of the runoff process,
- A representation of sediment oxygen demand and its relation to runoff and processes such as sanitary sewer leaks,
- An explicit description of density stratification and circulation, including the effect of channel deepening,
- Calculation of oxygen produced in photosynthesis and reaeration, and
- Conventional representation of waste discharges.

Such a model would be capable of representing the actual DO levels in the HSC under a range of conditions. It would be useful for evaluating the effects of possible management actions dealing with non-point source controls, where major expenditures are now being made. It could also be used to evaluate new waste load evaluations, measures such as direct aeration of the channel, and possible modifications in the DO criteria.

ACKNOWLEDGMENTS

This report summarizes the joint efforts of the TCEQ and the Houston community on a complex water quality issue. This is to recognize the contributions of key individuals.

From the TCEQ, Suzanne Vargas was instrumental in organizing and coordinating the Houston Ship Channel Advisory Group. Charles Marshall played a key role in the water quality modeling analysis. The first two joint field efforts were planned and organized by Don Ottmers. The last two were ably conducted by Steve Twidwell. All of the field efforts were very productive.

The contribution of the Houston Advisory Group on the Waste Load Evaluation of the Houston Ship Channel included both time and money. The membership includes:

Carl Masterson, Todd Running	H-GAC, Clean Rivers Program
Kerry Whelan	Reliant Energy
Leonard Levine	Gulf Coast Waste Disposal Authority
Patrick Walters	City of West University Place
Tom Stang	BP Amoco Chemicals and EHCMA
Teresa Battenfield, Bob Hunt	City of Houston
Michael Thornhill, Bruce Lawton	ECO Resources
Sara Metzger	City of Pasadena

The East Harris County Manufacturers Association (EHCMA) and the Gulf Coast Waste Disposal Authority supported the efforts of Tischler/Kocurek, who played a major role in the work. A grant by the Clean Rivers Program of H-GAC to the City of Houston supported much of the data gathering effort. The City of West University Place and the City of Houston contracted with the USGS to provide specialized current measurements. The City of Houston also provided support during the analytical process.

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1.0 INTRODUCTION

The Houston Ship Channel (HSC) has a long history of relatively low dissolved oxygen (DO) levels. For example, the City of Houston conducted monitoring that documented levels as far back as 1935. There are a number of reasons including:

- Waste Discharge – Wastewater from the Houston population and from industries built along the channel contribute oxygen demanding material.
- Physical – It is an artificially deepened and enlarged section of a small stream (Buffalo Bayou) where natural water depths were approximately 6 feet. The larger size means that water velocities are lower, allowing settling of particulate matter in runoff, and the establishment of vertical stratification. The settled runoff loads consume oxygen and stratification limits aeration, resulting in low DO in bottom waters.

DO conditions in the HSC have been studied extensively. The last major waste load evaluation (WLE) study was completed by the state environmental agency (the Texas Department of Water Resources [TDWR]) and the U.S. Environmental Protection Agency (EPA) in 1984 (TDWR, 1984). At that time the DO levels in the HSC were low and frequently did not meet the DO criteria that had been established. Other studies included an evaluation of the use of in-stream aeration to achieve DO criteria (Pate-Epsey, Huston & Associates (EH&A) Joint Venture, 1988a), and a major evaluation of wastewater strategy by the City of Houston, involving studies of sediment oxygen demand and reaeration in the channel (Pate-EH&A Joint Venture, 1988b).

This 1984 WLE-1 document defined effluent limits for dischargers of oxygen demanding material that were needed to meet water quality criteria. As these limits have been implemented, and as improvements in the sanitary sewer system have been made, there has been a steady improvement in channel DO levels to the point where today the criteria are attained with a comfortable margin. If DO conditions in the HSC are the measure, success has been achieved.

While the existing DO criteria are now attained, an issue remains with regard to the WLE and permits. Over the years the load of oxygen demanding material specified in the 1984 WLE study has been exceeded by the *permitted* amount of discharge, but the *actual* discharges have evolved to levels that are much smaller than the total allowable loading in the 1984 WLE.[1] This discontinuity between permitted and actual oxygen demand loads has been discussed extensively over the years.

EPA has indicated a concern that the permitted discharge exceeds the loading determined in the WLE, and has asked the Texas Commission on Environmental Quality (TCEQ) to resolve the issue. The TCEQ worked with local interests in the Houston area to form an Advisory Subgroup for WLE-1 on the HSC.

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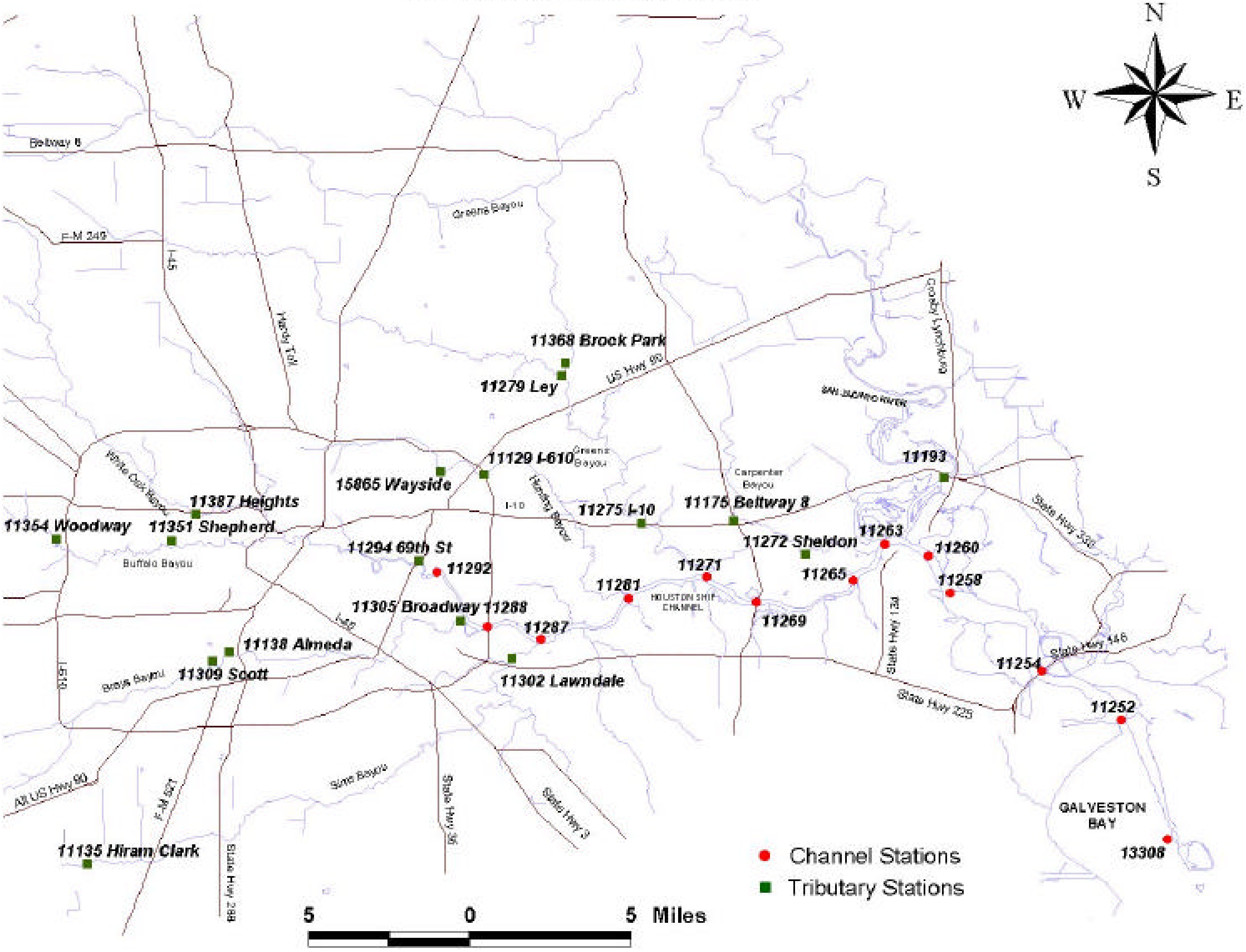
[1] This condition is common because permit limits represent maximum allowable loads while each permittee strives to operate well below the limits to assure continuous compliance.

This group consists of representatives of the Cities of Houston, Pasadena and West University Place; Gulf Coast Waste Disposal Authority; the East Harris County Manufacturers Association (ECHMA); Reliant Energy; the Clean Rivers Program of the Houston-Galveston Area Council (H-GAC) and ECO Resources. The group has been working since early 2000 and has been involved in two major actions: (1) planning for new water quality model development; and (2) analyzing a Monte Carlo approach to performing a new WLE.

As part of the process of developing a new and more accurate water quality model, a series of detailed water quality measurements, termed Intensive Surveys (IS), has been performed in cooperation with the TCEQ. This was supplemented with measurements of currents by the U.S. Geological Survey (USGS). The local or non-state part of the first two IS efforts was supported directly by the City of Houston with a major contribution by the City of West University Place for the USGS measurements. The two most recent IS were supported jointly by the TCEQ and by the Clean Rivers Program working with the City of Houston. The results of these four IS efforts are described in this report, along with relevant data from earlier studies, TCEQ monitoring data, and recent current measurements.

Figure 1-1 is a plan view of the HSC showing the sampling stations used in the IS work and major landmarks. With minor changes in some of the tributary sites, these stations were used for all four IS efforts. Section 2 of this report presents background on the reasons for intensive surveys and the importance of antecedent conditions. Section 3 addresses DO results and how they relate to standards attainment. Section 4 deals with the concentrations of oxygen demanding materials in the HSC, while Section 5 describes nutrients and related parameters. Section 6 describes the concentrations of various parameters in the tributaries to the HSC. Section 7 discusses the HSC sediments and how the data relate to earlier studies of sediment oxygen demand. Section 8 addresses the details of the currents in the channel, as measured with Acoustic Doppler Current Profiler (ADCP) equipment. Section 9 presents an analysis of the findings and recommendations.

FIGURE 1-1
LOCATIONS OF SAMPLING STATIONS



2.0 ANTECEDENT CONDITIONS AND INTENSIVE SURVEYS

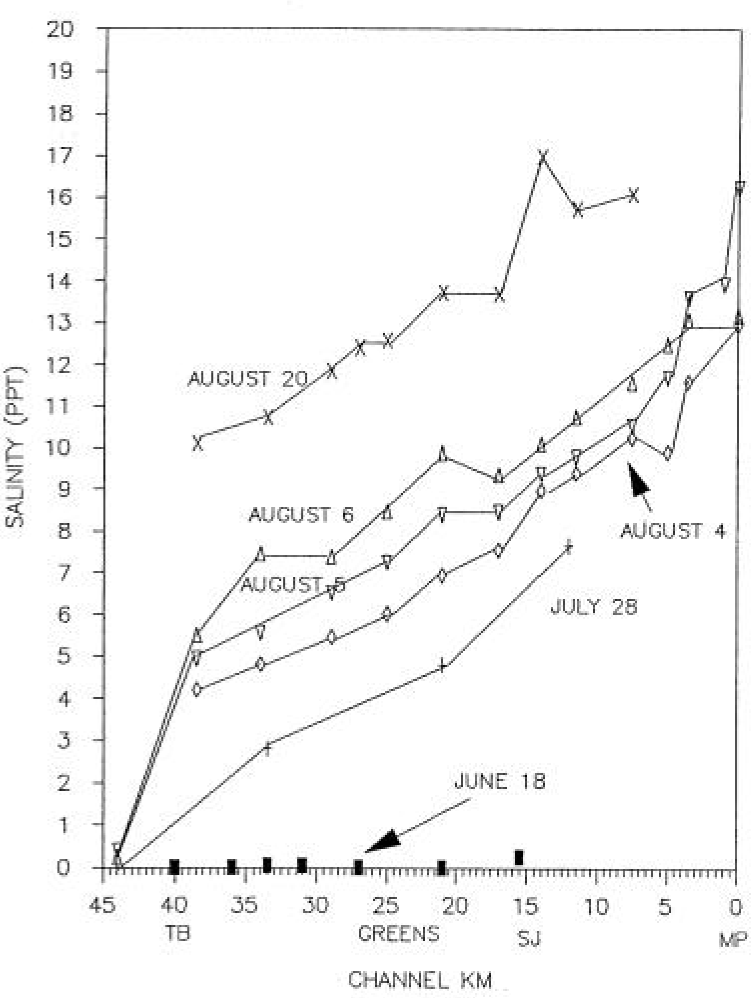
The basic idea behind an intensive survey is to obtain data that represent conditions calculated by available water quality models under the critical or design conditions. In Texas the model most often used is QUAL-TX, a one-dimensional steady state model. This was the model used in the 1984 WLE. In freshwater streams the critical condition is a dry (7-day, 2-year low flow) and warm condition. The model provides average steady state results, so diurnal variations are not simulated. An IS is designed to collect and average data over a 24-hour period to obtain values that match the average values produced in the model. In coastal waters a similar situation exists except that there is a need for averaging over tidal as well as light-dark cycles. Since tides on the gulf coast are frequently diurnal (as opposed to semidiurnal), the 24-hour averaging period is still appropriate.

The IS sampling consists of four individual observations taken over two days. The first is taken in the late afternoon of the first day, and the other three are taken in the early morning, late morning and early afternoon of the second day. For safety reasons, no observations are made at night. Each observation consists of sonde measurements (conductivity, temperature, pH, DO) at 5-foot intervals, and water samples obtained from the surface and near-bottom waters. The water samples from the four times are combined into a single composite sample of surface and bottom water at each station. The composite samples are analyzed for a range of parameters including 5-day Carbonaceous Biochemical Oxygen Demand ($CBOD_5$), Total Organic Carbon (TOC), Ammonia-N (NH_3-N), Nitrate-nitrite-N (NO_3+NO_2-N), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), Chlorophyll *a*, Total Suspended Solids (TSS), and Volatile Suspended Solids (VSS).

Estuaries like the HSC are by definition places of mixing between fresh and bay/ocean waters. A characteristic of such mixing zones is that they are frequently in the process of coming into equilibrium after a disturbance. For example, a large rain in the Houston area can flush most of the salt water out of the channel and Galveston Bay. It can take weeks to months for salinity to reintrude back to more typical levels. This is illustrated in Figure 2-1 that shows salinity profiles obtained during the summer of 1987. The channel was basically fresh in June and it was not until August that salinity became more typical. The rain impulse with a gradual return is the characteristic estuarine situation. Steady conditions exist, but they are not the most common circumstance.

A key requirement for a steady-state model is that field conditions measured and used for calibration be close to this ideal and not be changing significantly. That means that sampling needs to happen at a time when rains are essentially absent for a prolonged time or a few small showers each day such that the freshwater inflows and salinity in the HSC are essentially constant. If a larger, say 1–2 inch rain occurs over the entire HSC watershed, the runoff volume will be such that the steady-state requirement is not met.

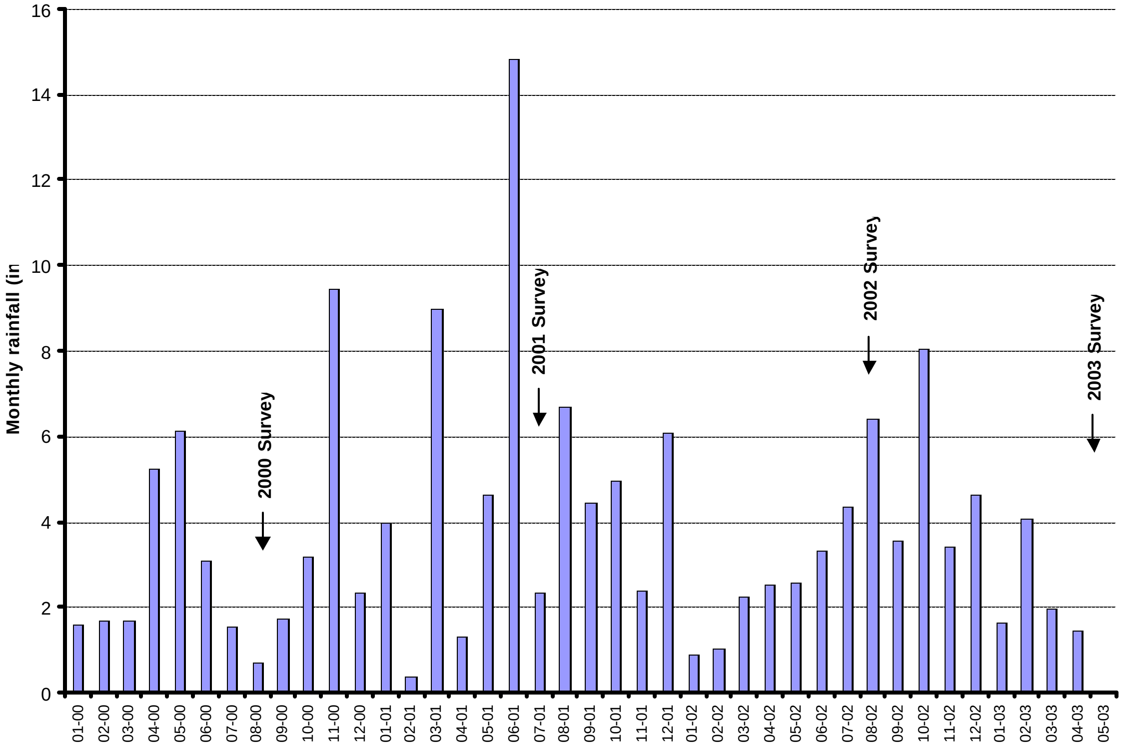
Figure 2-1
Time History of Summer, 1987 Values
Salinity Vertical Averages



Needless to say, meeting this requirement for steady conditions can be a challenge when planning a large IS undertaking involving multiple organizations and about 20 individuals. Fortunately, the goal of having steady conditions did not have to take priority because one of the reasons these IS efforts were being mounted was to provide new data to possibly replace the steady-state QUAL-TX model with a more modern dynamic model that could explicitly represent the tidal and diurnal fluctuations as well as changes in freshwater inflows. Because of this, the goal of having steady conditions was sought, but efforts were not cancelled if a rain occurred. This was fortunate because without that change, two of the four events would have been canceled.

Figure 2-2 illustrates the average rainfall leading up to the four events. The 2001 survey was about a month after tropical storm Allison provided heavy rains, while a moderate rain in 2002 occurred immediately before the IS. In both cases the decision was made to continue with the sampling. While

FIGURE 2-2
MONTHLY RAINFALL IN HOUSTON

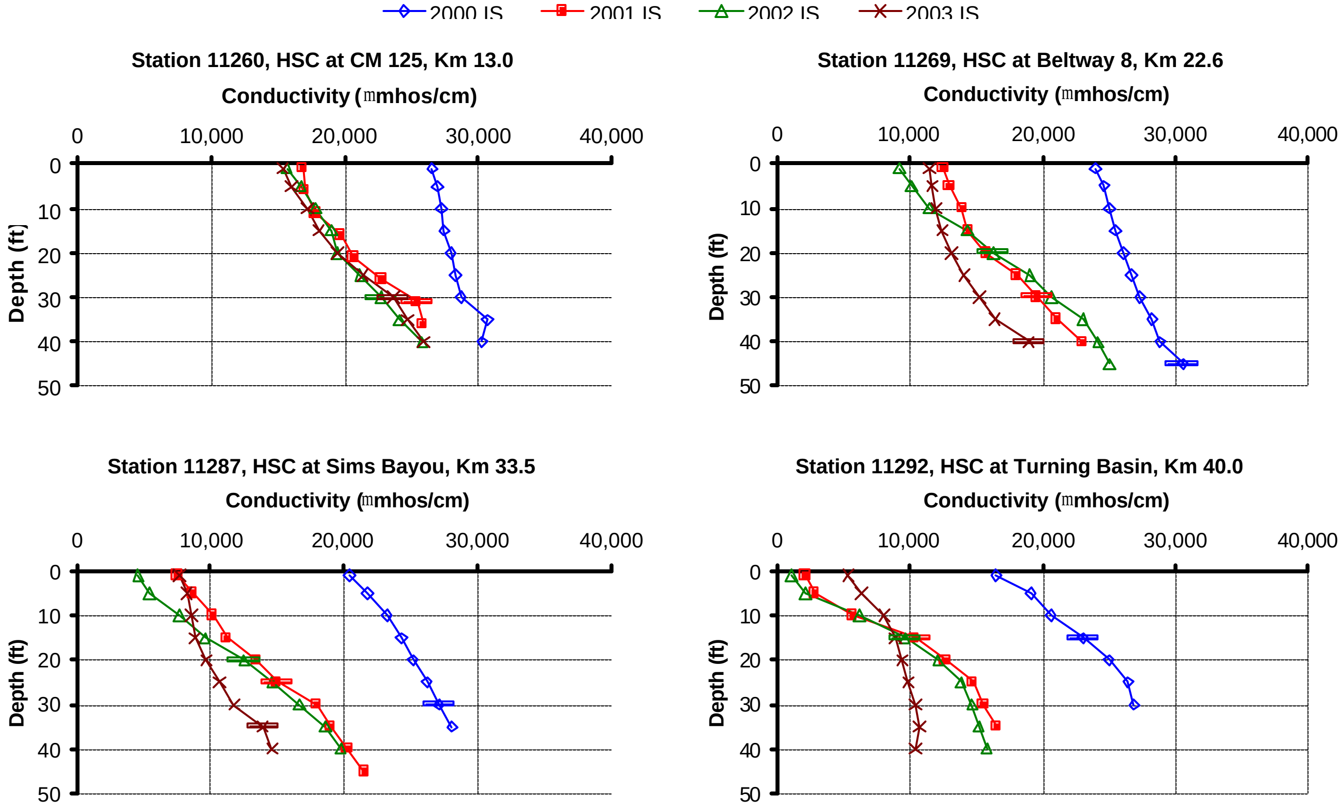


these data sets would not be suitable for use in QUAL-TX, they do provide useful information for a dynamic model. The 2003 IS was conducted after a prolonged and steady dry period and so provided data that are appropriate for use by QUAL-TX.

Figure 2-3 shows vertical conductivity plots at four locations along the channel, with the upper left (downstream of the San Jacinto River confluence) being the closest to the bay and the lower right being the Main Turning Basin, the first point going downstream on Buffalo Bayou where the channel cross-section increases substantially. Looking at the Turning Basin station, the profiles for 2001 and 2002 are similar, both reflecting nearly freshwater at the surface and a steep increase in salinity with depth. In these events the HSC was very stratified. In contrast, the 2003 conductivity profile is more vertical, with stratification that is not as sharp. The 2000 event is intermediate in stratification, but reflects much higher salinity levels overall. The main difference is that the salinity or conductivity in Galveston Bay was much higher in 2000 than in 2003, even though 2003 had been very dry in the Houston area in the months before the sampling.

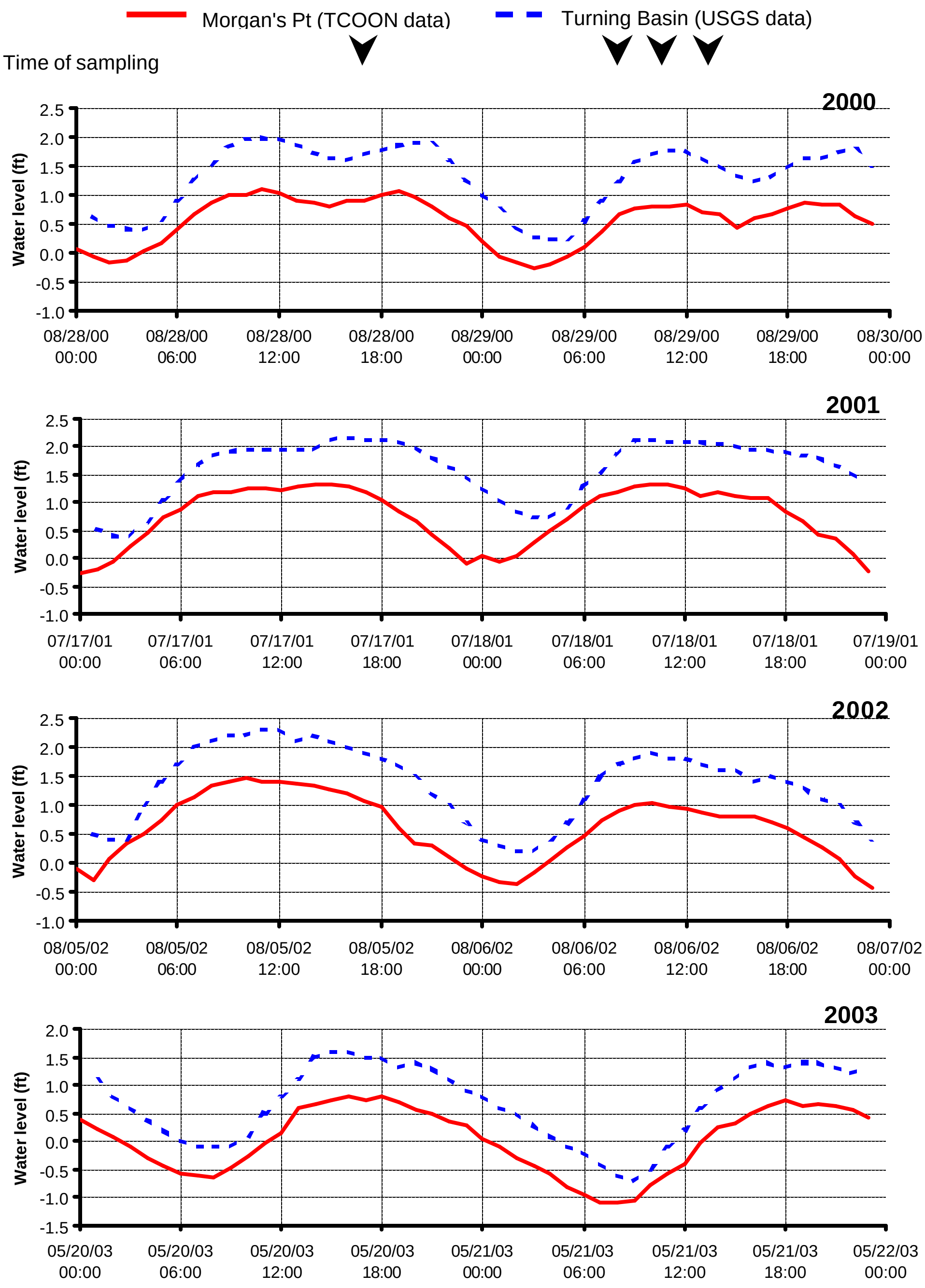
Tides in the HSC during the four sampling events are shown in Figure 2-4. In picking sampling times the effort was made to include periods where tides were fairly strong. It was somewhat surprising to find how similar the tides were during each of the events.

FIGURE 2-3
VERTICAL CONDUCTIVITY PROFILES AT SELECTED STATIONS



Horizontal bar shows depth at which conductivity is 6,000 μmhos/cm greater than that at surface.

FIGURE 2-4
WATER LEVELS DURING INTENSIVE SURVEYS



Note: Water levels at the two stations referenced to different datum.

3.0 DISSOLVED OXYGEN

This section presents the DO results obtained in the four surveys along with comparable information obtained by the TCEQ Region 12 monitoring program. All of the IS observations discussed below were made with probe observations made at 5-foot intervals (1-, 5-, 10-, 15-foot, etc. … to the bottom). Probes were checked and calibrated before and after data collection by TCEQ personnel.

Before going into the overall IS DO measurements it is worthwhile to look briefly at some of the actual DO profiles and discuss how criteria attainment is determined. Figure 3-1 shows the DO observations for the same stations where conductivity was presented in Figure 2-3. Particularly in the upper channel stations (lower part of the figure), there is a strong difference between the DO at the surface and 10 to 15 feet down. The difference of 2 to 4 milligrams per litre (mg/L) is fairly constant, but shifted in different events. In contrast, the lower channel stations in the upper part of the figure have a more gentle and constant DO decline with depth. The difference between surface and bottom DO is much smaller in the lower channel than in the upper channel.

The vertical conductivity variations shown in Figure 2-3 are important in determining whether the DO criteria are attained. The Texas Surface Water Quality Standards (TNRCC, 2000, Chapter 307.9) specify that under conditions of density stratification, a composite sample collected from the "mixed surface layer" shall be used to determine standards attainment. The mixed surface layer (MSL) is defined (TCEQ, 2003, Guidance for Assessing Surface and Finished Drinking Water Quality Data) as the depth where the difference between the conductivity at the surface is more than 6,000 micromhos per centimeter (µmhos/cm). During highly stratified periods after recent rains the mixed layer is shallower and more of the bottom water is excluded. During dry weather with little freshwater input, the 6,000 µmhos definition means the MSL extends all the way to the bottom. However, there is still strong density stratification during such periods.

Determining attainment in the MSL in tidal waters is similar to what is done in impoundments. Where there is thermal stratification, as typically occurs during the Texas summer, attainment is determined from samples collected in the epilimnion, defined as the "upper mixed layer" in the Standards. The typical textbook definition of the boundary or edge of the epilimnion (the metalimnion) is the point where there is a strong change in temperature. Both Wetzel, (1983) and Bennett (1970) refer to a change of 1 degree Celsus (ºC) per meter as typical of the metalimnion. However, the TCEQ Guidance for Assessing (2003) defines the MSL for impoundments as the water column from the surface to the depth at which the water temperature decreases by 0.5ºC. This is typically a very shallow depth, and seems very different in results from the conductivity-based definition.

It should be noted that the HSC often exhibits thermal in addition to salinity stratification. Figure 3-2 shows temperature profiles for the same group of stations where conductivity was shown in Figure 2-3. By the 0.5ºC definition, the MSL in the HSC is sometimes limited, particularly in the upper channel.

FIGURE 3-1
VERTICAL DISSOLVED OXYGEN PROFILES AT SELECTED STATIONS

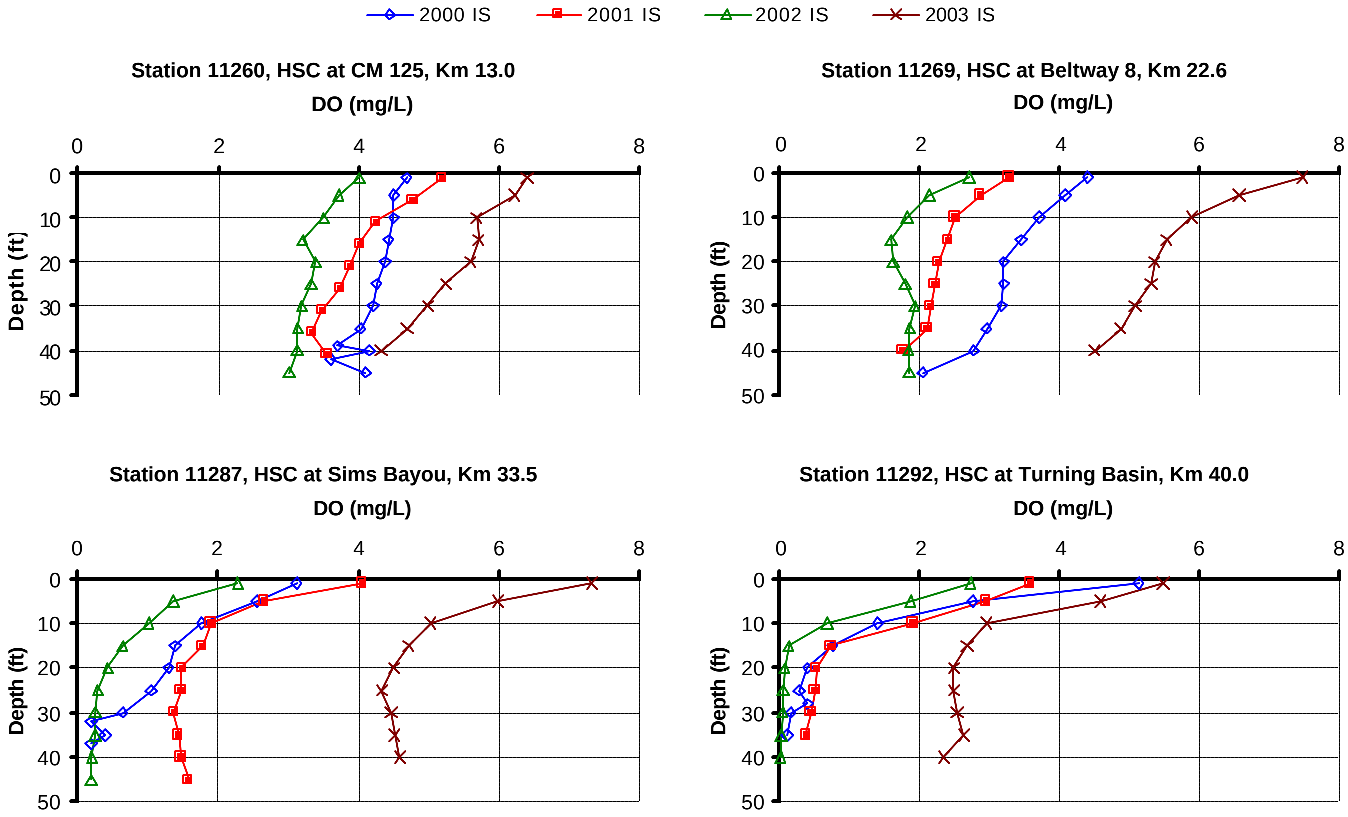
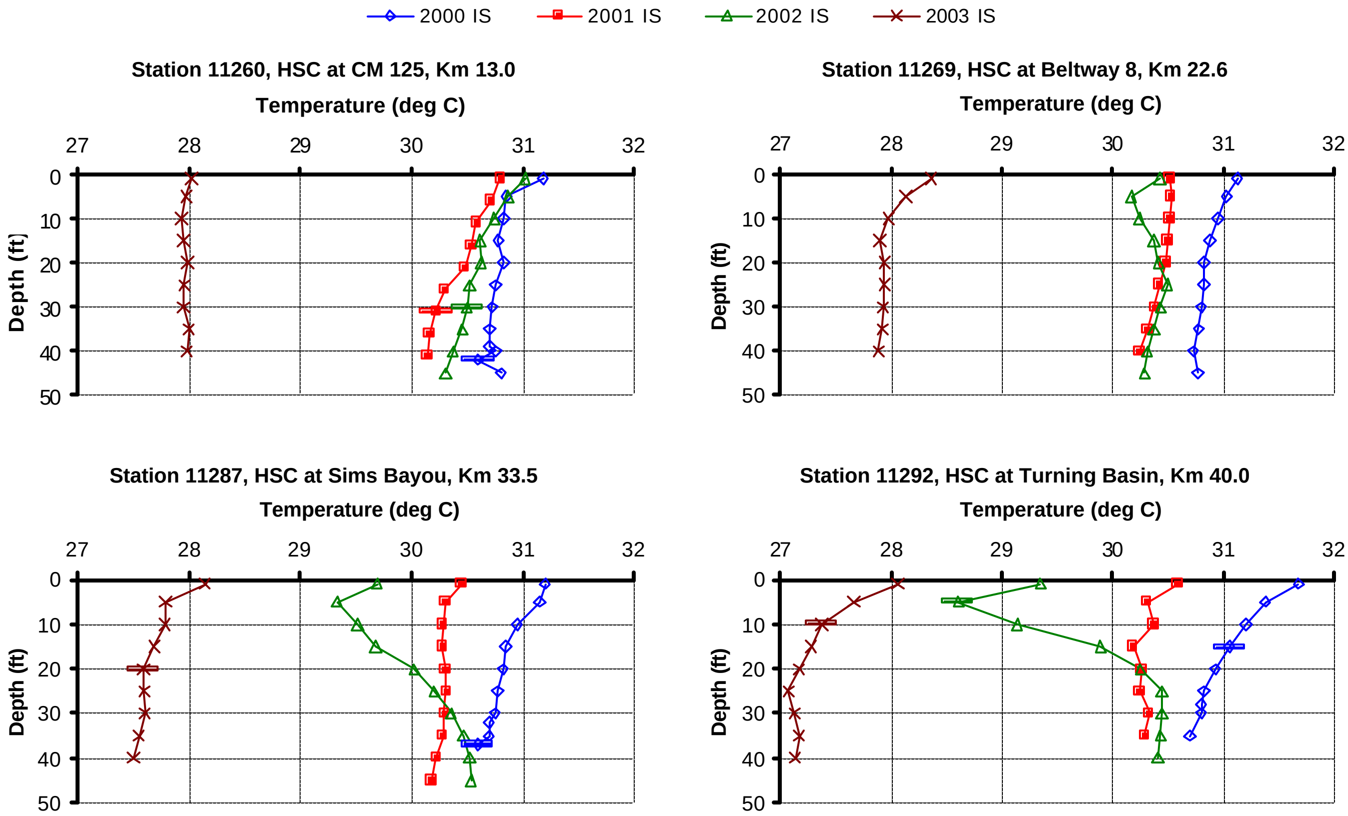


FIGURE 3-2
VERTICAL TEMPERATURE PROFILES AT SELECTED STATIONS



Horizontal bar shows depth at which temperature decreases by greater than 0.5 deg compared to that at surface.

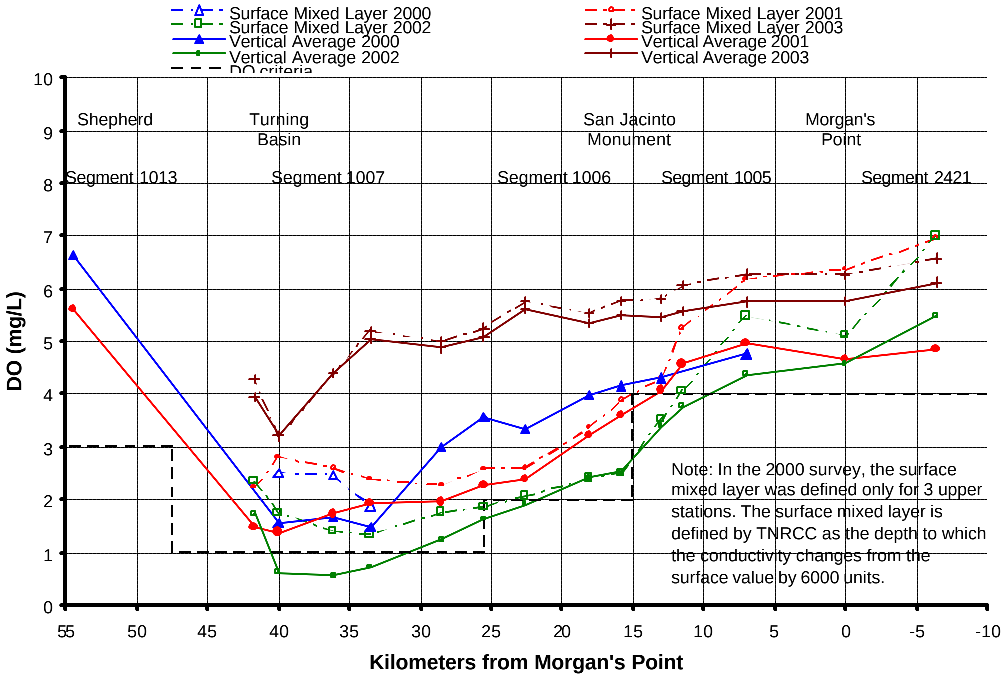
Figure 3-2 also shows the rather dramatic effect of the rain just before the 2002 IS. In the upper stations the surface water shows a sharp decline in temperature relative to the bottom water, reflecting the recent input of cooler runoff water to the surface.

The depth of the MSL as currently defined is shown on Figures 2-3 and 3-2 by a horizontal line on a profile. If no line is shown, the MSL extends all the way to the bottom. Comparing the MSL depth with the conductivity and temperature definitions, there are substantial differences. The average depth of the MSL based on conductivity in the Figure 2-3 profiles is 27.9 feet, while the average depth based on temperature in Figure 3-2 is only 22.6 feet. There are also major differences from event to event. One technical improvement that could be made is to refine the definition of the tidal water MSL in the Guidance for Assessing document to be in terms of density, (including both temperature and salinity). Several definitions could be explored including determining a consistent definition of when stratified conditions exist. If they exist, the boundary might be defined as the point of strongest density gradient, similar to the gradient concept in metalimnion technical definition, or it might be a percentage of the density difference between surface and bottom. This would be a substantial technical improvement over a definition based only on a fixed amount of difference in conductivity from the surface, and one that has a large difference in the definition between conductivity and temperature.

Figure 3-3 presents a longitudinal profile of both the vertical average and MSL average (6,000 µmhos definition) for each of the four IS events. In 2000 the channel was not strongly stratified and the MSL extended all the way to the bottom for all but three stations in the upper channel. In 2001, a month after Allison, the DO in the MSL was different from the vertical average at most stations, but always above the DO criteria. The 2002 survey was conducted just after a moderate rain and had the lowest DO values. Even then, the DO in the MSL was above the criteria except at the segment 1005–1006 boundary. The main difference between the events is the 2003 survey was conducted after a prolonged dry period. The DO in the 2003 survey was well in excess of the criteria for both the MSL and the entire water column. Another difference is that the water temperature in 2003 was about 2.5 degrees cooler than in the other surveys (Figure 3-2). This temperature difference accounts for about three tenths of a mg/L in the DO saturation value, a small part of the observed difference in the DO profiles in 2003.

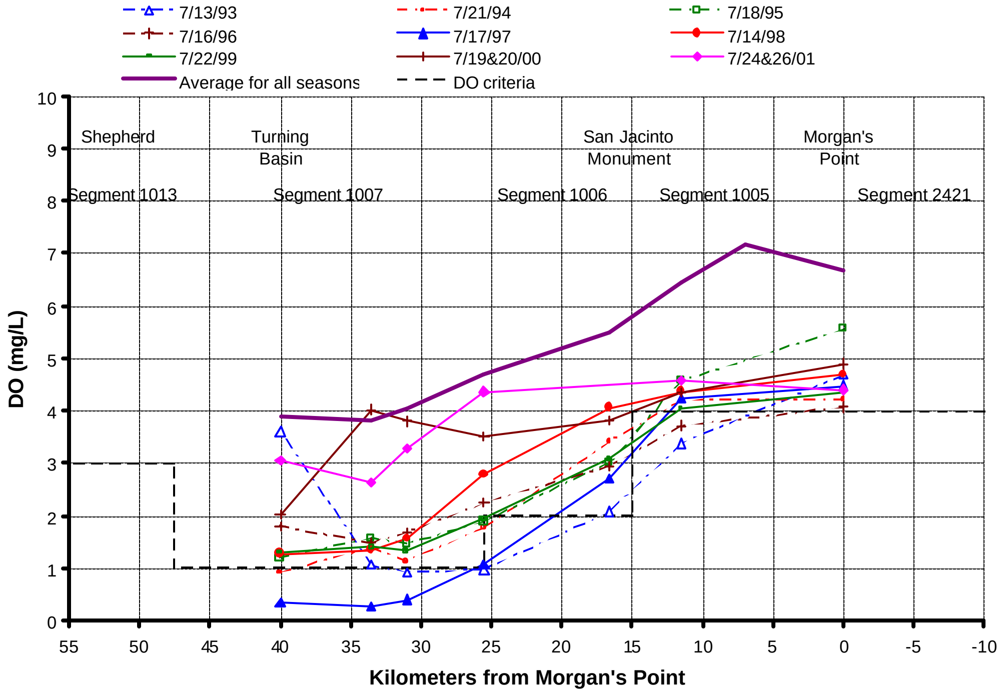
Figure 3-4 presents similar information from the quarterly monitoring of the TCEQ. The figure shows an average of all data, without considering the MSL, in the dark solid line. This can be seen to be well in excess of the criteria. If the MSL were considered the DO curve would be higher. These data explain why there is no 303(d) list concern for DO. The other plots show the warm weather or worst-case monitoring for each year. These are not averages over a 24-hour period like the IS, but they are nevertheless representative of summer, worst-case DO levels. The observations in 1993 and 1997 were below criteria, but most of the other worst-case samples were not.

FIGURE 3-3
DO LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003
INTENSIVE SURVEYS



Note: In the 2000 survey, the surface mixed layer was defined only for 3 upper stations. The surface mixed layer is defined by TNRCC as the depth to which the conductivity changes from the surface value by 6000 units.

FIGURE 3-4
VERTICAL AVERAGE DO LEVELS FROM TCEQ MONITORING



While DO levels in the HSC attain the criteria with the present procedures, there is a concern with details. Part of the procedures for assessing use support are in terms of a percentage of “routinely collected” observations below criteria, but routinely collected is not defined. With only quarterly sampling, adding observations in the summer or missing a winter observation could make a major change in the percentage. For that reason it is important that these IS collections not be counted as routinely collected monitoring data for purposes of standards attainment. They are special data collection efforts designed to assess critical water quality conditions.

4.0 OXYGEN DEMAND PARAMETERS IN THE WATER

This section addresses parameters associated with oxygen demand in the water column. This includes ammonia-N, TKN, CBOD, and TOC. These parameters are measured from composite water samples collected from the surface and bottom water, typically at about the 30-foot depth. Chemical analyses were performed by the LCRA laboratory in Austin for the 2001, 2002, and 2003 events.

Figure 4-1 shows the NH_3-N profiles for the surface and bottom water samples from the four events. In general it appears that the surface samples are higher than the bottom samples. This would be expected as the major source of NH_3-N would be expected to be wastewater discharges and they have lower salinity and will tend to stay with the surface water. With the exception of one station with a surface value over a mg/L in 2003, most of the data are less than 0.4 mg/L.

Figure 4-2 shows the TKN analyses. The TKN is the sum of NH_3-N and organic-N, and shows a similar pattern. Most of the TKN observations are less than 1.5 mg/L and surface values tend to be higher than bottom values.

Figure 4-3 presents the CBOD5 results. The 2000 samples were not analyzed by the LCRA laboratory and caused considerable concern when first encountered. The values were far higher than typically found by the TCEQ or reported by wastewater dischargers. Several experiments were planned for the summer of 2001 to see if the 2000 results were valid. However, subsequent LCRA results in 2001 were generally non-detects (at a 3 mg/L reporting level). Additional tests were performed by the City of Houston laboratory on samples collected near the San Jacinto River confluence (km 15) in 2001. These were found to be on the order of 1 mg/L. The LCRA laboratory was able to lower the reporting limits in the 2002 and 2003 to 1 mg/L and still had a high percentage of non-detects. It was concluded that the 2000 CBOD5 results were not representative.

Figure 4-4 shows the Total Organic Carbon (TOC) results. This is the sum of the organic carbon in dissolved form and also that in plankton and detrital matter. This parameter was not analyzed in the 2000 IS. The results are very similar for each of the three remaining surveys, with the surface and bottom samples grouping very closely.

A key point with the water column oxygen demand data is that it is very low. With $CBOD_5$ data being essentially at detection level, and NH_3-N concentrations being only a few tenths of a mg/L, there is no potential for significant oxygen consumption. A related point of interest is that there was little difference in the oxygen demand parameters between the 2001–2002 events that had some runoff influence, and 2003 where no runoff was involved. The major difference in DO is clearly not related to runoff effects in the water itself. With such low oxygen demand in the water, one might reasonably expect DO concentrations in the HSC to be high. While that was the case in 2003, it was not the case in the earlier surveys. Clearly something else is causing the DO levels in the upper channel to be low. Part of that is oxygen demand from the sediments, which will be discussed in Section 7. Another factor is the runoff process that brings a slug of higher oxygen demand water to the channel, some of which settles quickly to the sediments. However, the runoff process is not part of the waste load allocation process. The traditional IS data collection procedure is designed to avoid this situation. Other factors in the 2003 survey could be the lower temperature (0.3 mg/L of DO) and higher chlorophyll *a* levels, although diurnal variation in DO even in the surface samples was small.

FIGURE 4-1
NH3-N LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

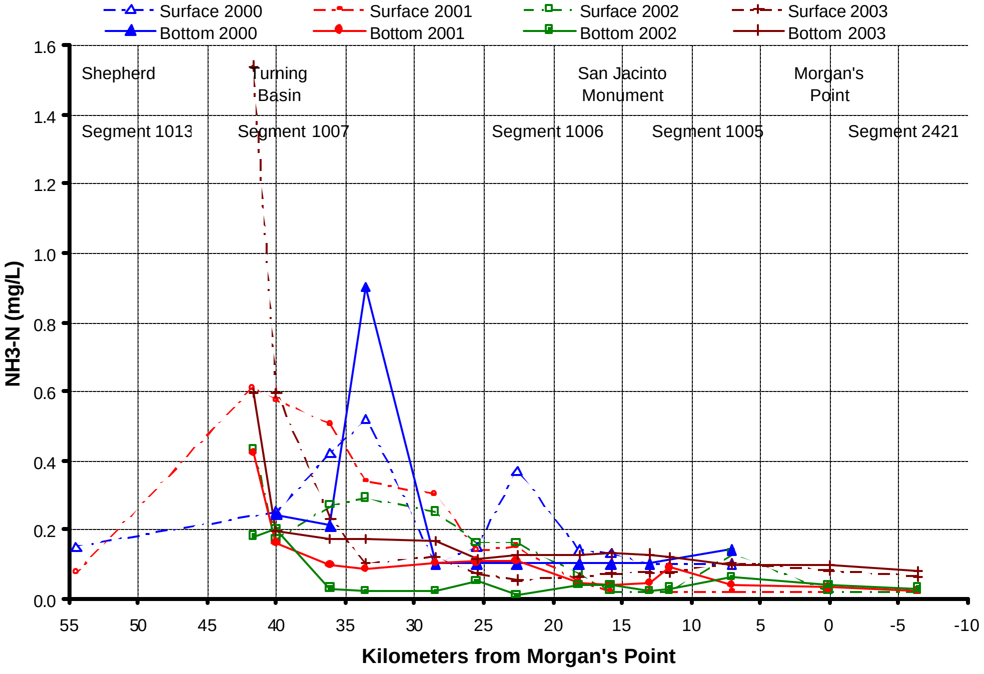


FIGURE 4-2
TKN LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

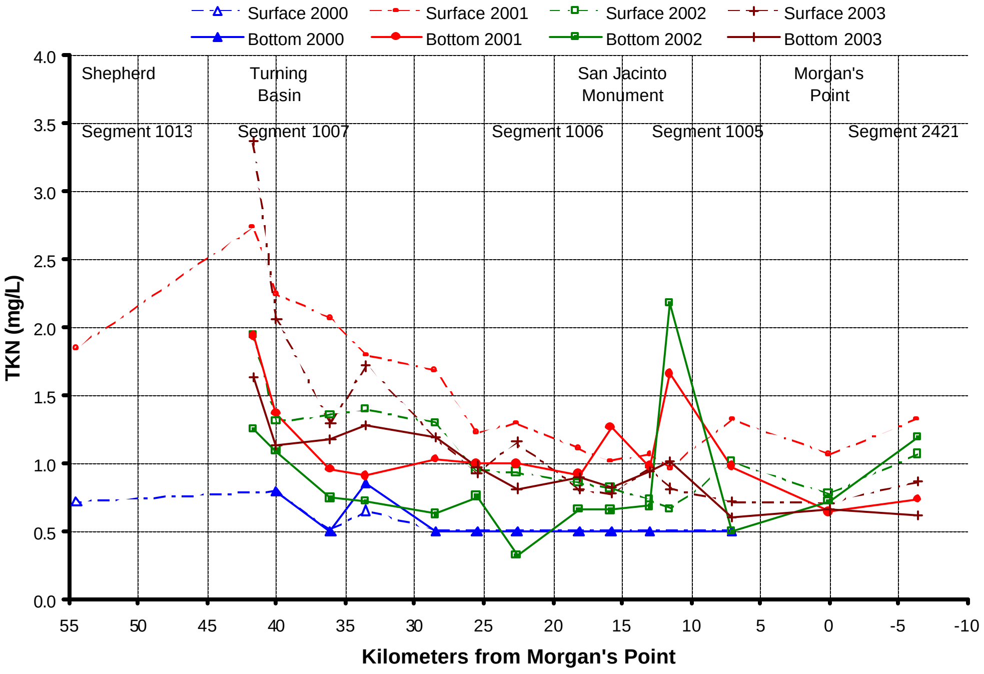


FIGURE 4-3
CBOD5 LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

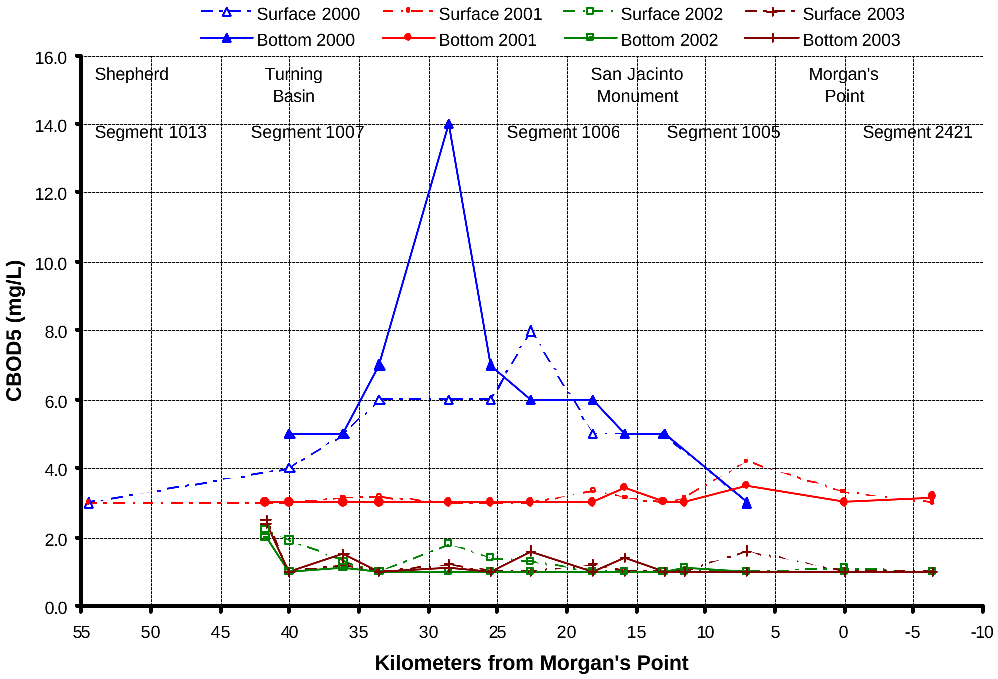
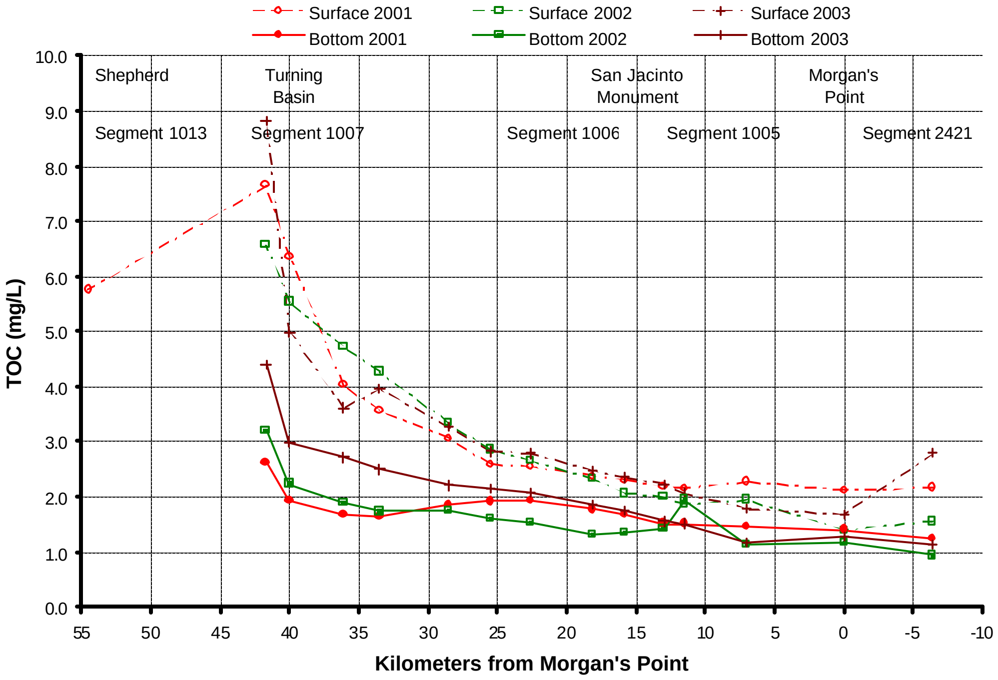


FIGURE 4-4
TOC LEVELS IN HSC DURING JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



5.0 NUTRIENTS, CHLOROPHYLL *a*, SECCHI DEPTH, AND SOLIDS

This section addresses the water column data for nutrients (except NH_3-N already presented), chlorophyll *a*, Secchi depth, and solids. The data were obtained in a similar fashion to the oxygen demanding parameters, with composite samples collected over a 24-hour period from surface and bottom waters.

Nitrate+nitrite-N (NO_3+NO_2-N) data are shown in Figure 5-1. There is a different pattern to these data than the NH_3-N shown in Figure 4-1, with the NO_3+NO_2-N levels being higher overall, particularly in the upper channel. The two dry weather events, 2000 and 2003, have concentrations in the middle and upper channel that are substantially higher than the 2001 and 2002 surveys, and also are higher than the NH_3-N levels. This appears to reflect the importance of wastewater effluent during dry periods, and the fact that wastewater nitrification during the summers is substantially complete. Surface data tends to have higher NO_3+NO_2-N concentrations than the bottom waters. This is probably due to the sources being to the surface and denitrification removing NO_3+NO_2-N from the bottom water.

Figure 5-2 shows the Total Phosphorus (TP) levels. The same general pattern of dry periods having a greater influence from wastewater and showing higher concentrations in the upper channel is evidenced. Surface data tends to have higher TP concentrations than the bottom waters.

Figure 5-3 shows the chlorophyll *a* data for 2001, 2002, and 2003. The surface data for 2003 is by far the highest, particularly in the upper channel. This may reflect the effect of substantial residence time for plankton growth and relatively good water clarity from the absence of runoff flows. It may also partially explain the very high DO data in 2003. An interesting detail is the pattern of the bottom water samples of chlorophyll *a*. For both 2002 and 2003 these concentrations appear to be higher in the lower channel and decrease upstream. This may be a reflection of this bottom water coming from Galveston Bay and slowly losing its chlorophyll *a* to settling and the lack of light for growth. The surface data in 2001 show no particular pattern, but the surface data in 2002 is higher in the lower channel, while the 2003 surface data are higher in concentration in the upper channel.

Figure 5-4 presents the Secchi depth observations for 2001, 2002, and 2003. The general pattern appears to be better water clarity moving up the channel. This may be a result of more sheltered water and possibly lower vessel traffic in the upper channel. The Secchi depths in 2003 were lower than the other years and may reflect the higher chlorophyll *a* concentrations.

Figure 5-5 presents the Total Suspended Solids (TSS), Figure 5-6 presents the Volatile Suspended Solids (VSS), and Figure 5-7 presents the percentage of solids that are volatile. The data from the 2001 survey is much higher than the other years in VSS and may reflect the influence of Tropical Storm Allison. The main pattern of note is that for TSS, the highest concentrations are in the lower channel, with a gradual reduction in concentration with distance upstream. Also, it is common for the TSS and VSS in the bottom water to be higher than in the surface water. This may be a result of deep-draft vessels passing close to the bottom and resuspending sediment. The exception is again the 2001 survey where bottom water VSS was higher than surface water. The percentage of solids that are volatile in Figure 5-7 shows higher percentages in the upper channel, a pattern reversed to that of TSS. Again, the 2001 VSS values are the anomaly.

FIGURE 5-1
NO3+NO2-N LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

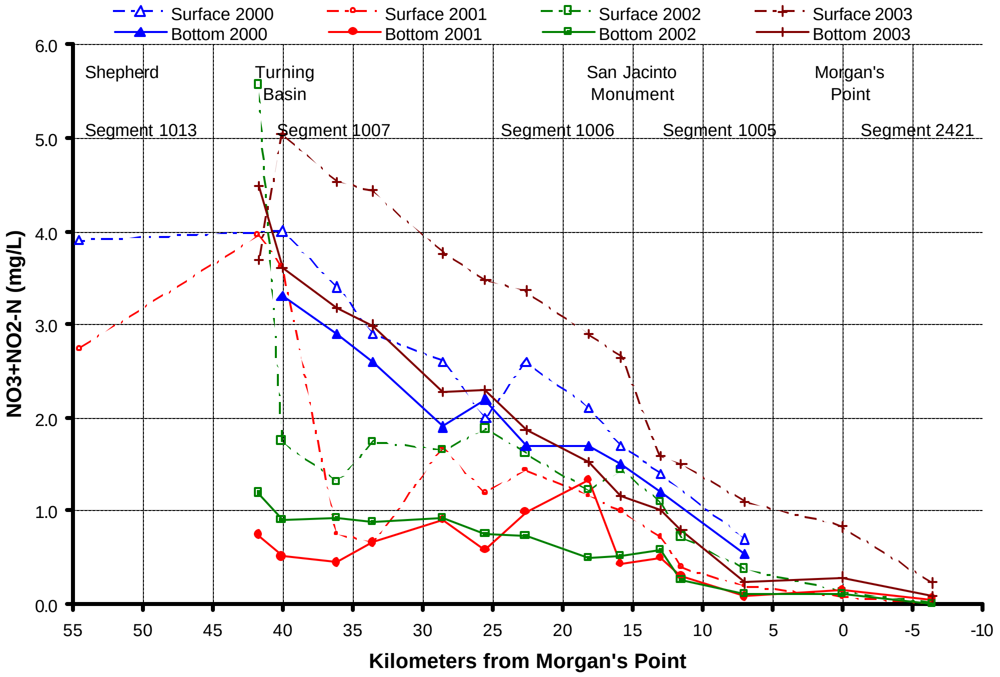


FIGURE 5-2
TOTAL PHOSPHORUS LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002, AND MAY 2003 INTENSIVE SURVEYS

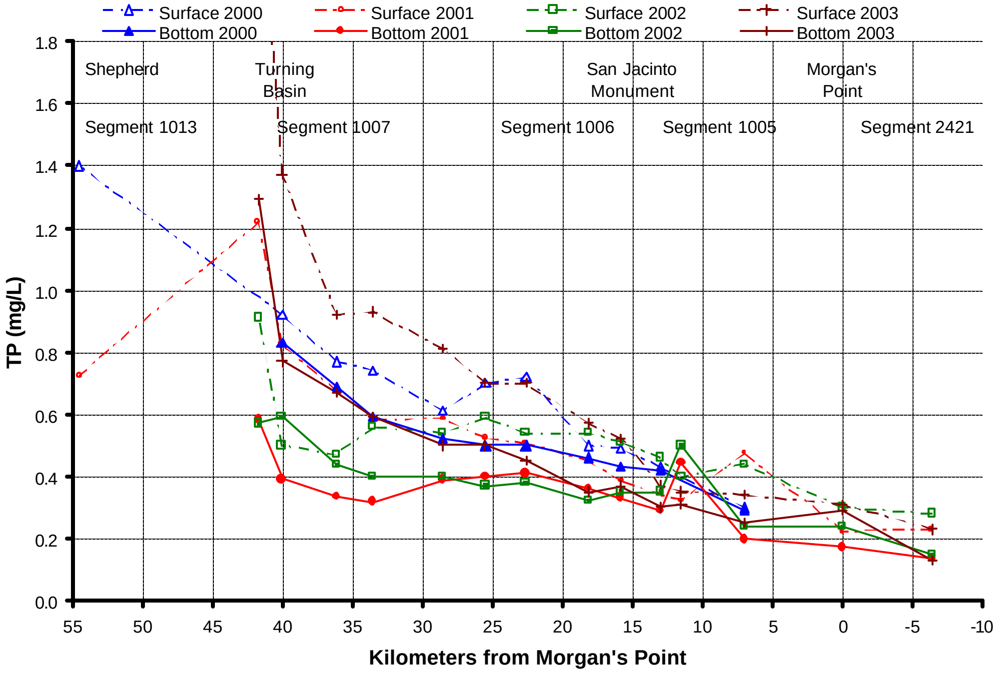


FIGURE 5-3
CHLOROPHYLL *a* LEVELS IN HSC DURING JUL 2001, AUG 2002, AND MAY 2003 INTENSIVE SURVEYS

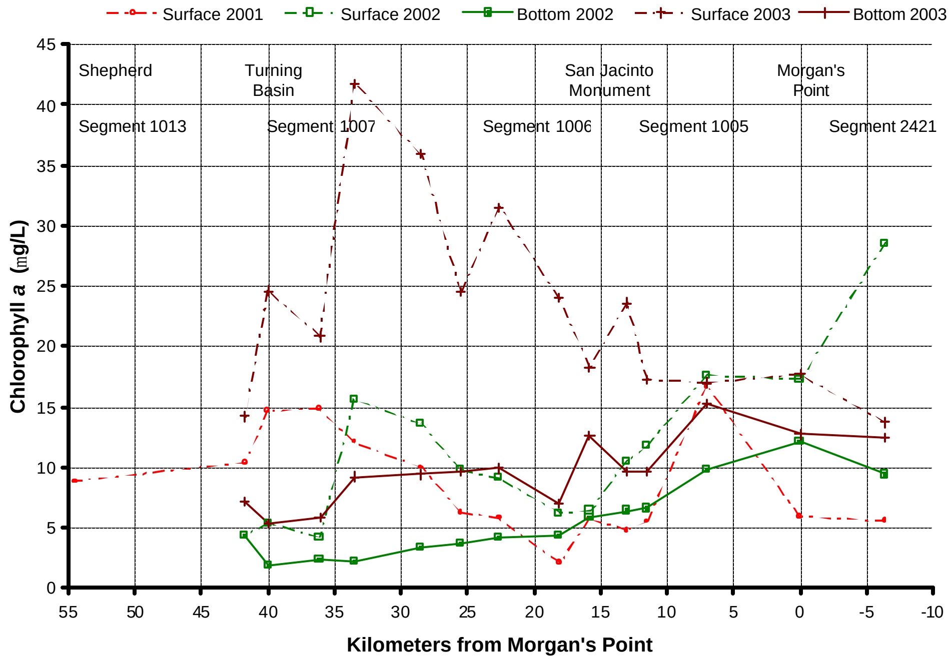


FIGURE 5-4
SECCHI DEPTHS IN HSC DURING JUL 2001, AUG 2002, AND MAY 2003 INTENSIVE SURVEYS

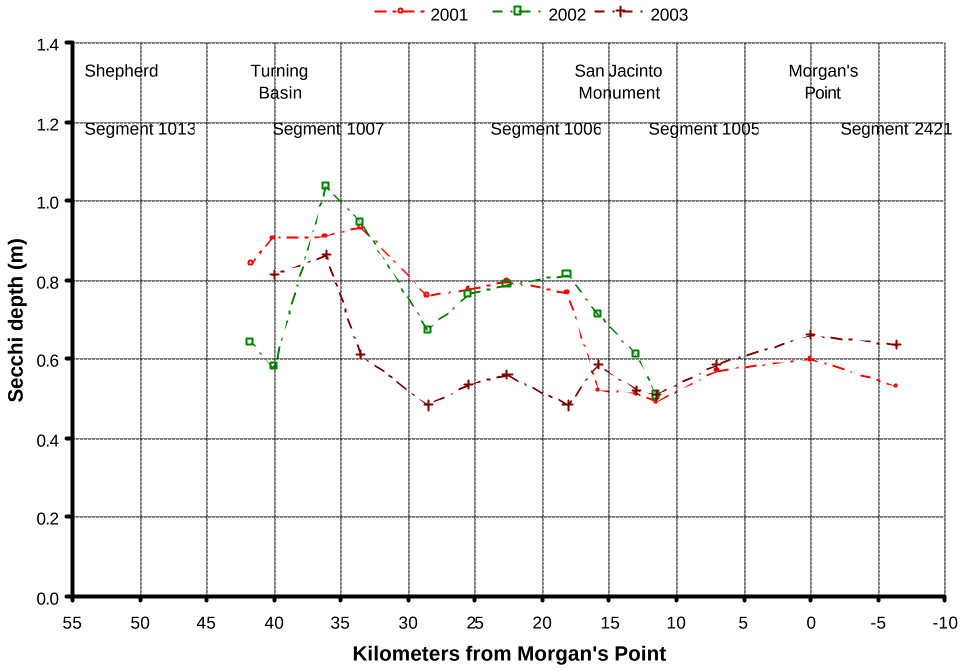


FIGURE 5-5
TSS LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002, MAY 2003 INTENSIVE SURVEYS

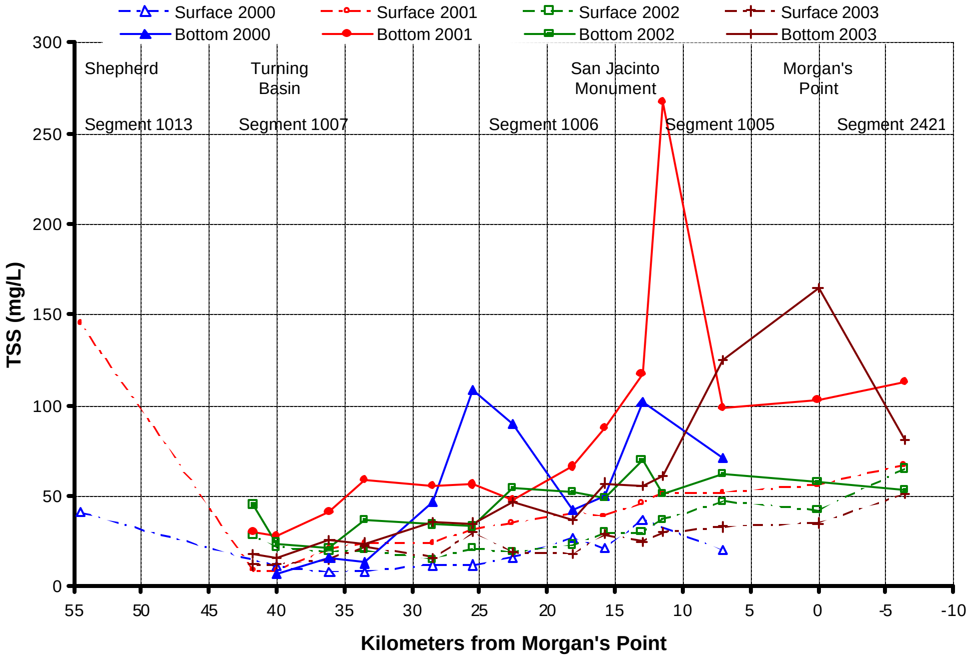


FIGURE 5-6
VSS LEVELS IN HSC DURING AUG 2000, JUL 2001, AUG 2002, AND MAY 2003 INTENSIVE SURVEYS

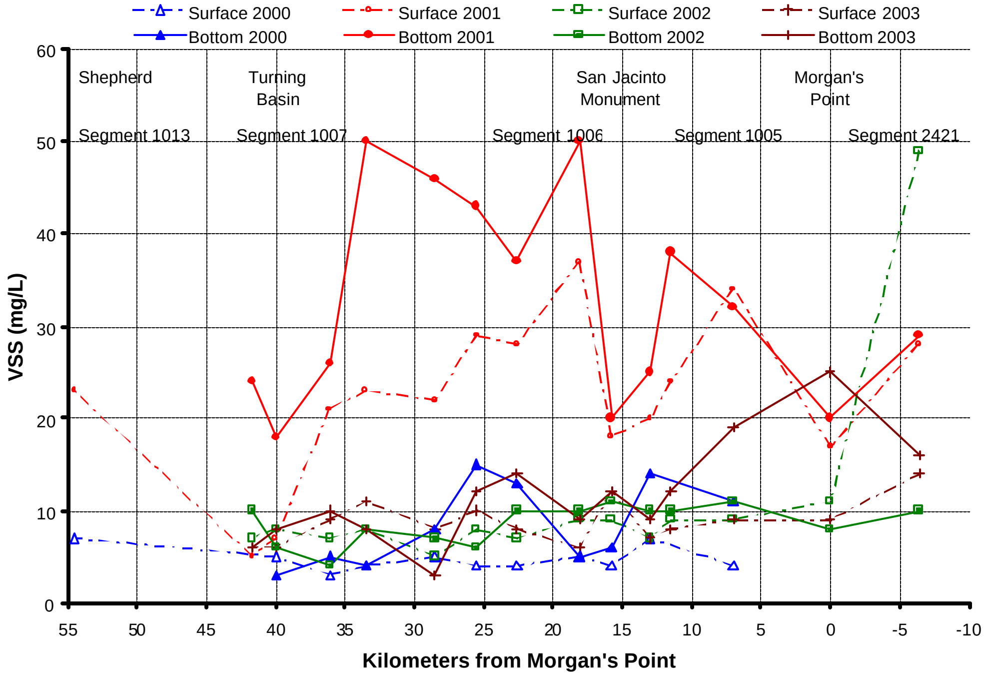
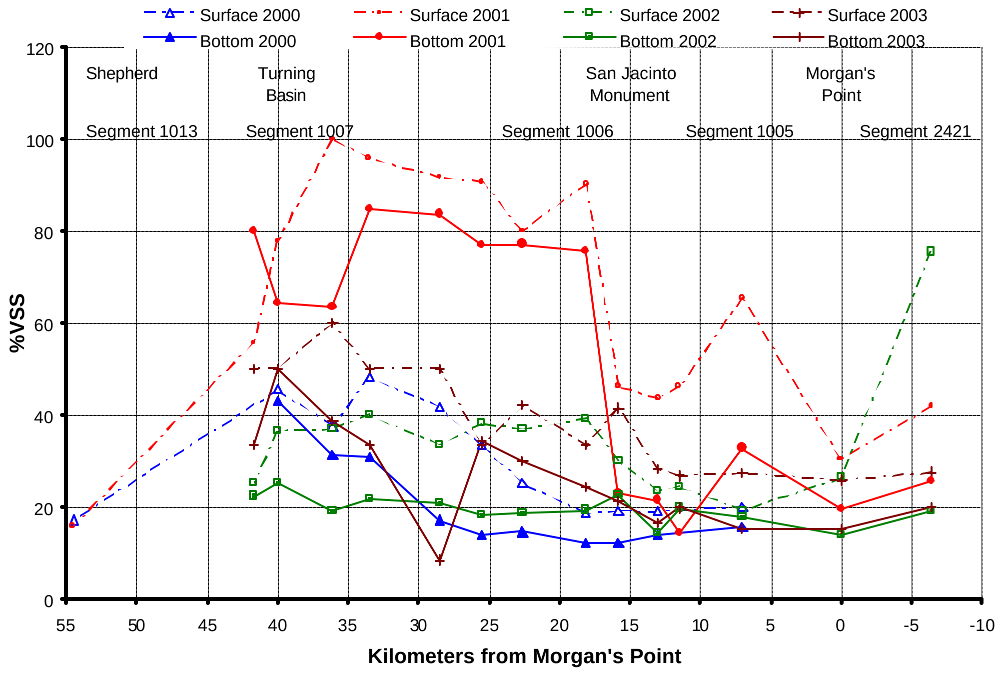


FIGURE 5-7
%VSS IN HSC DURING AUG 2000, JUL 2001, AUG 2002, AND MAY 2003 INTENSIVE SURVEYS



6.0 TRIBUTARY SAMPLING DATA

This section presents the results of the tributary sampling for all of the parameters discussed before. The data for each parameter are presented graphically in two series of bar charts, one showing stations along the north side of the HSC and the other showing stations on the south side of the HSC. Each chart presents the data from each of the four IS events. With each tributary the name of the cross street where sampling was conducted is listed. In a few cases there was a change in the station employed on a particular tributary. Both stations are listed but the data are grouped together.

Figure 6-1 presents the DO data. Most of the tributaries had DO concentrations over 5 mg/L. For those stations with lower levels, the 2002 survey, after the rain, seemed to have the lowest data.

Figure 6-2 shows the NH_3-N data, Figure 6-3 the TKN data, Figure 6-4 the NO_3+NO_2-N data and Figure 6-5 the TP data. The NH_3-N data are all very low on the northern side of the channel, but slightly higher on the south on Brays Bayou. This pattern can be seen in the TKN data, but not in the NO_3+NO_2-N data or the TP data. In general, the N and P parameters reflect values typical of effluent dominated streams during good weather conditions. Values are much lower than the permitted effluent concentrations and this is reflected in the low values for these parameters in the channel waters.

The TOC concentrations shown in Figure 6-6 are quite uniform. The upward shift in time at Carpenter Bayou probably reflects a shift to a more upstream station. The lower values at the San Jacinto River station reflect the fact that this station is more estuarine than riverine, with the samples collected by boat.

The chlorophyll *a* data in Figure 6-7 reflect much more variation by year and location than the other parameters. A major factor in this variation is likely to be the amount of residence time available for algae growth, as all stations have an ample supply of nutrients.

The solids information is shown in Figures 6-8 (TSS), 6-9 (VSS), and 6-10 (% VSS). There is substantial variation in TSS levels between stations, but many of the stations have TSS concentrations that are higher than the wastewater TSS levels (typically less than 10 mg/L) that make up the bulk of the tributary flows. One reason is that these tributaries convey silts and clays that are not easily settled even in dry weather. Another is that algae and other microorganism growth takes place in the streams. This contribution to solids is almost entirely organic or volatile solids. The stations on Brays and Sims have relatively low TSS levels but the percentage of VSS in the samples tends to be higher than other stations.

FIGURE 6-1
DO LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

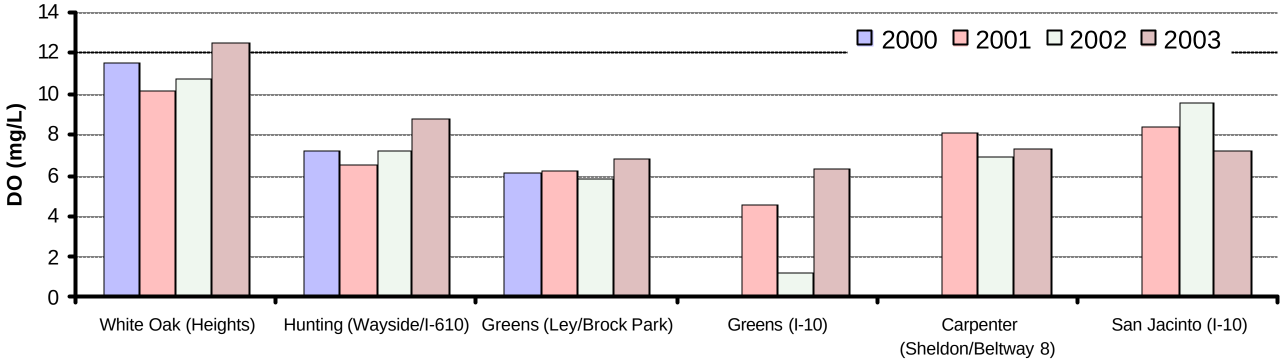


FIGURE 6-1 (CONCLUDED)
DO LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

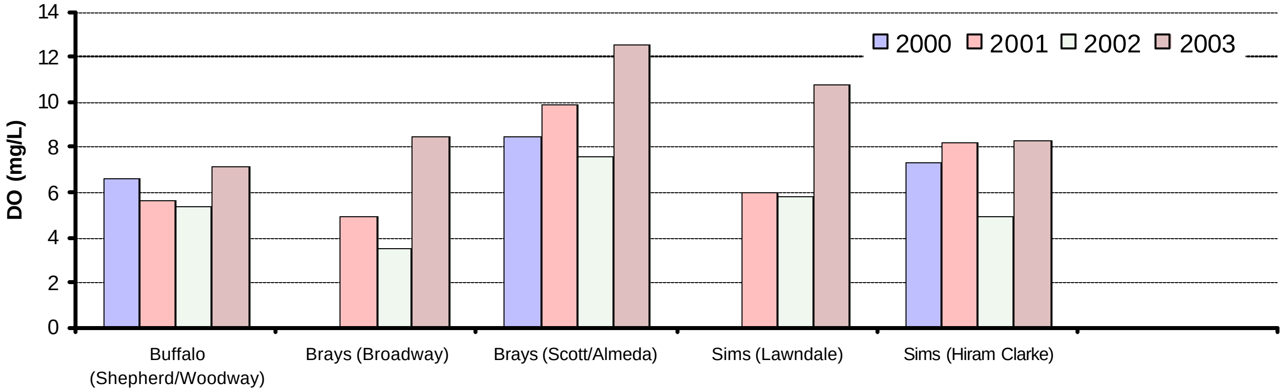


FIGURE 6-2
NH3-N LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

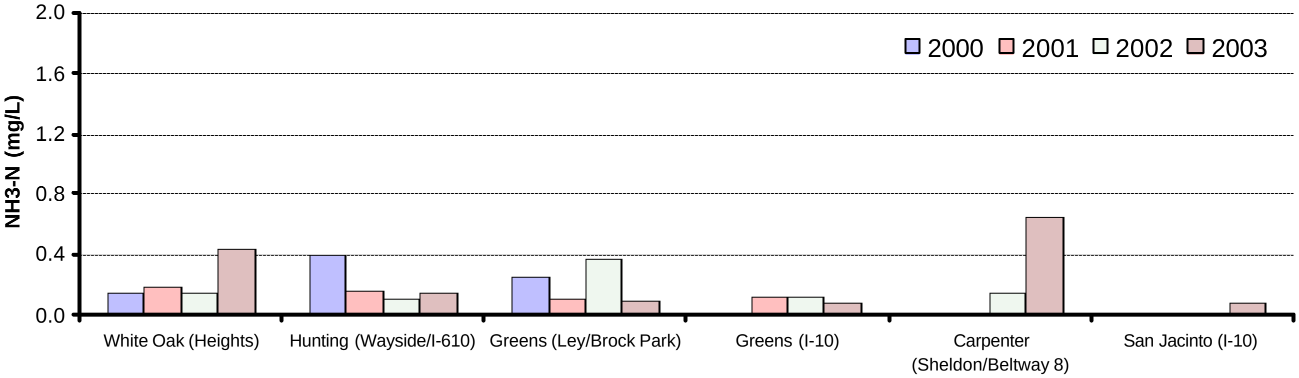


FIGURE 6-2 (CONCLUDED)
NH3-N LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

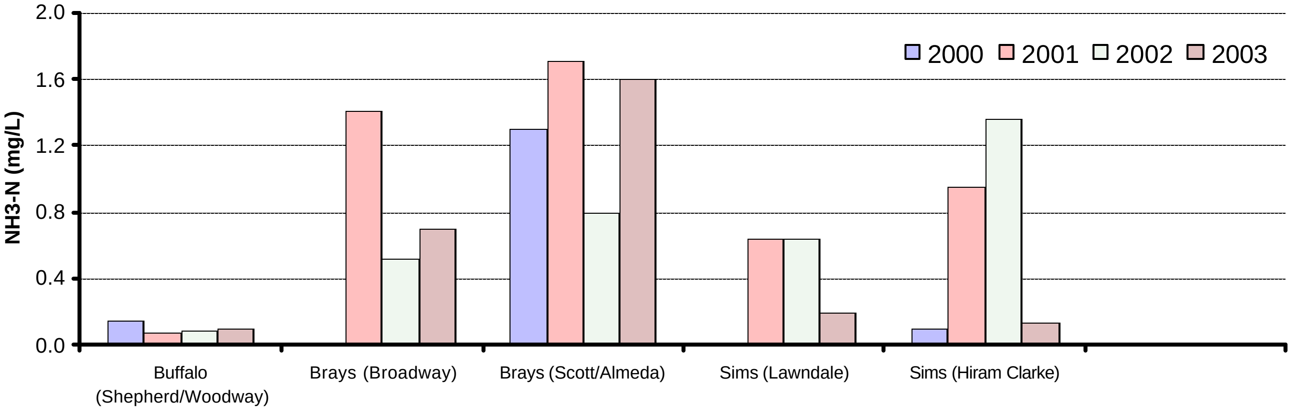


FIGURE 6-3
TKN LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

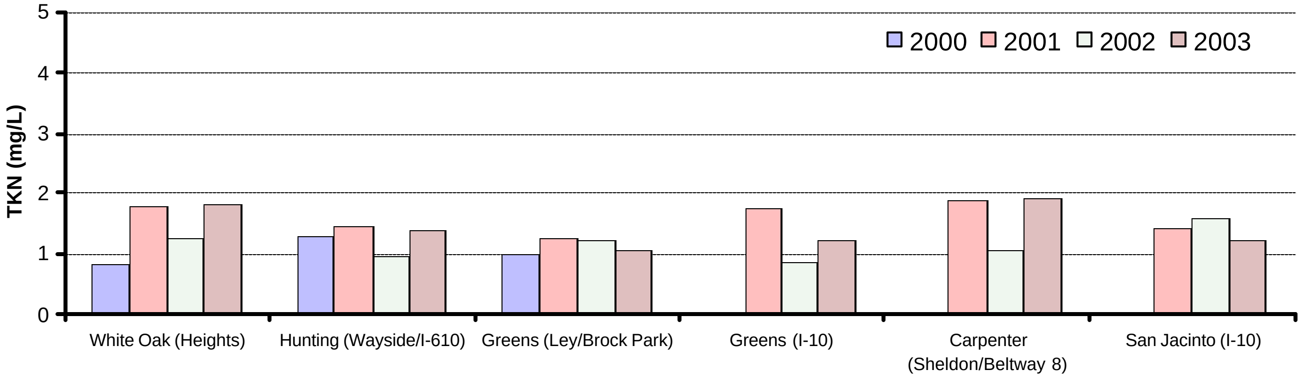


FIGURE 6-3 (CONCLUDED)
TKN LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

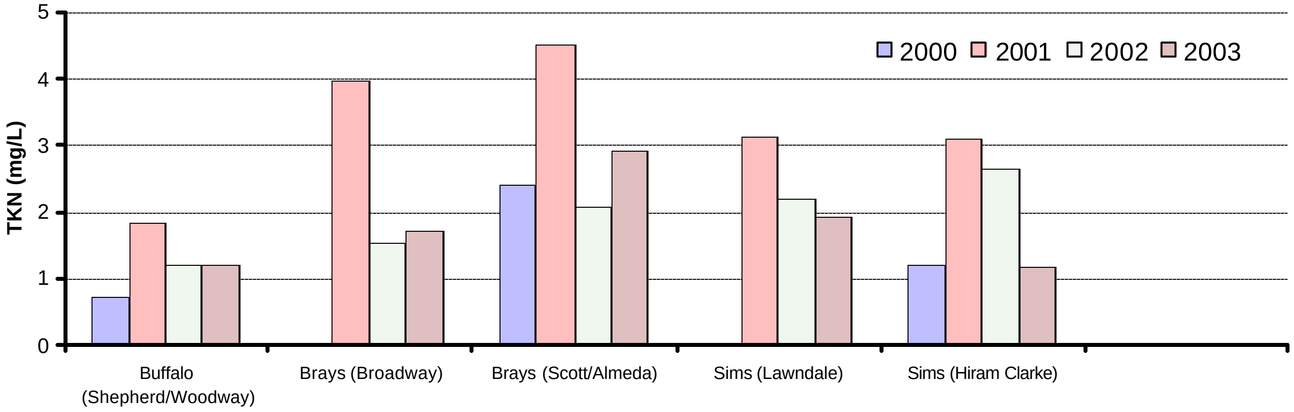


FIGURE 6-4
NO3+NO2-N LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

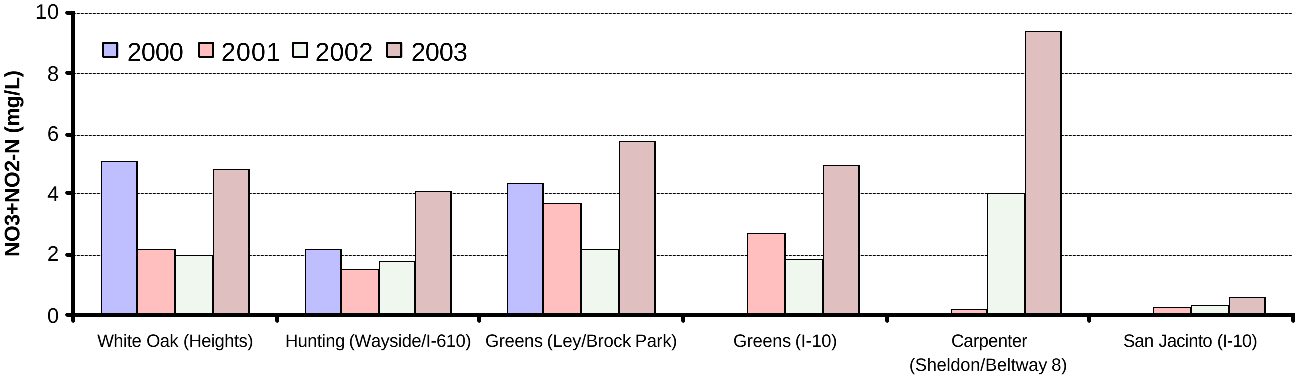


FIGURE 6-4 (CONCLUDED)
NO3+NO2-N LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

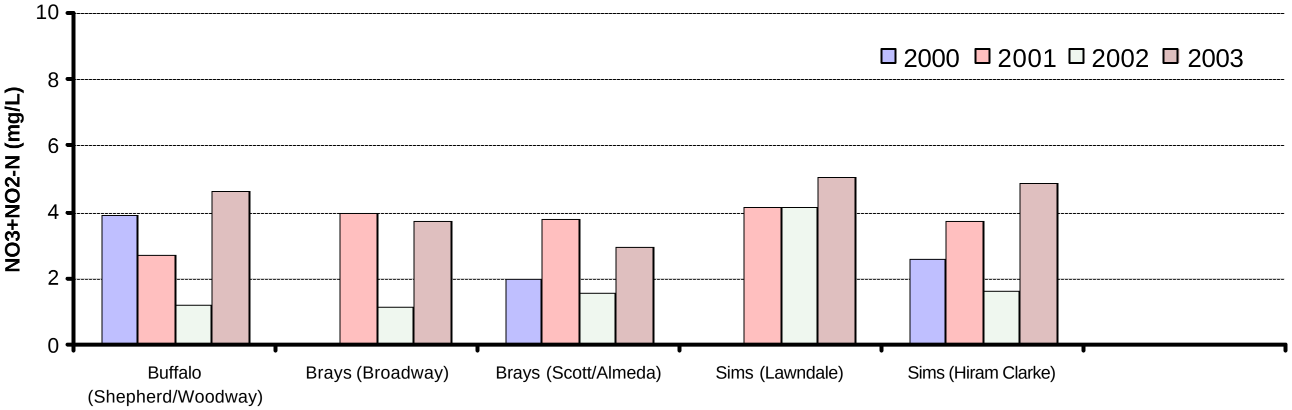


FIGURE 6-5
TP LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003
INTENSIVE SURVEYS

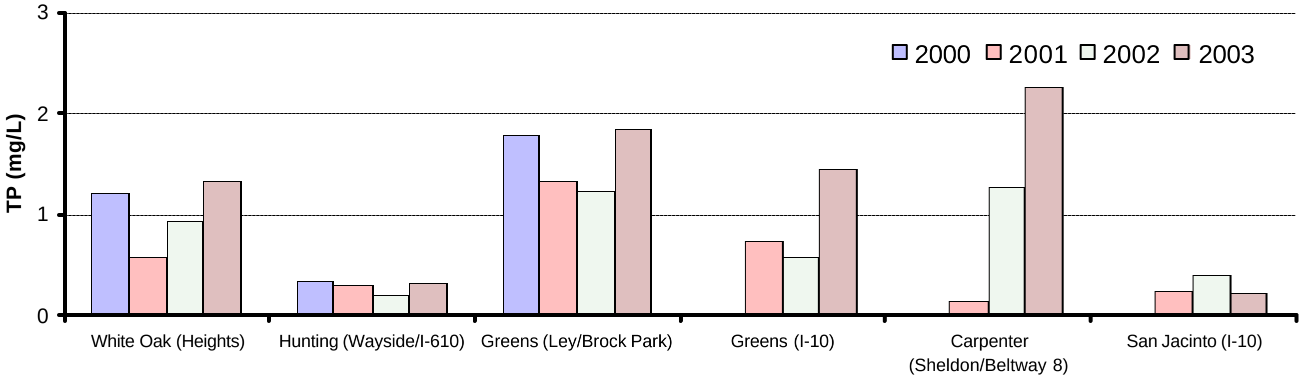


FIGURE 6-5 (CONCLUDED)
TP LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003
INTENSIVE SURVEYS

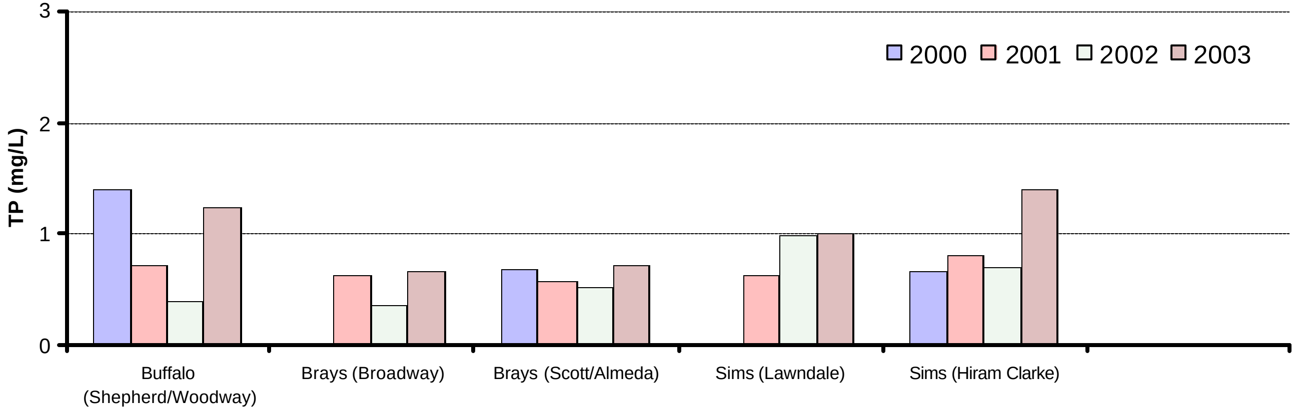


FIGURE 6-6
TOC LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

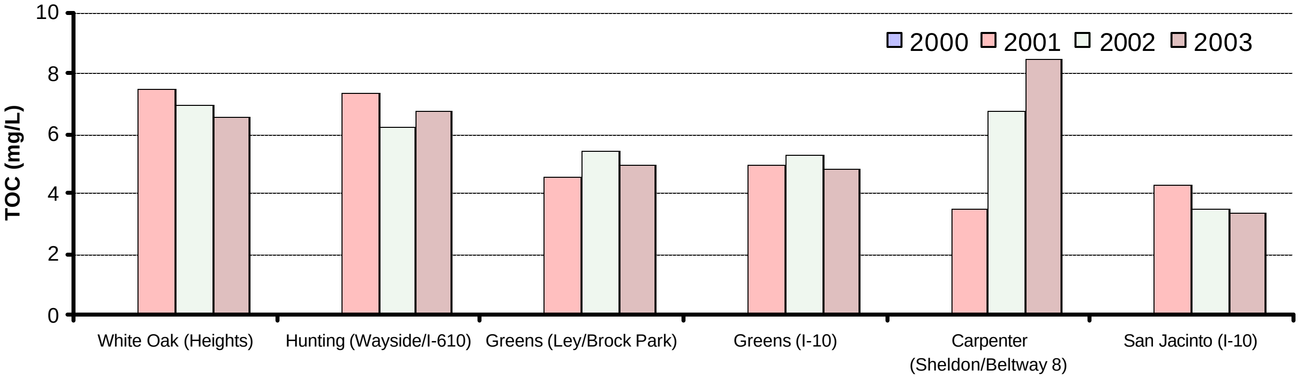


FIGURE 6-6 (CONCLUDED)
TOC LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

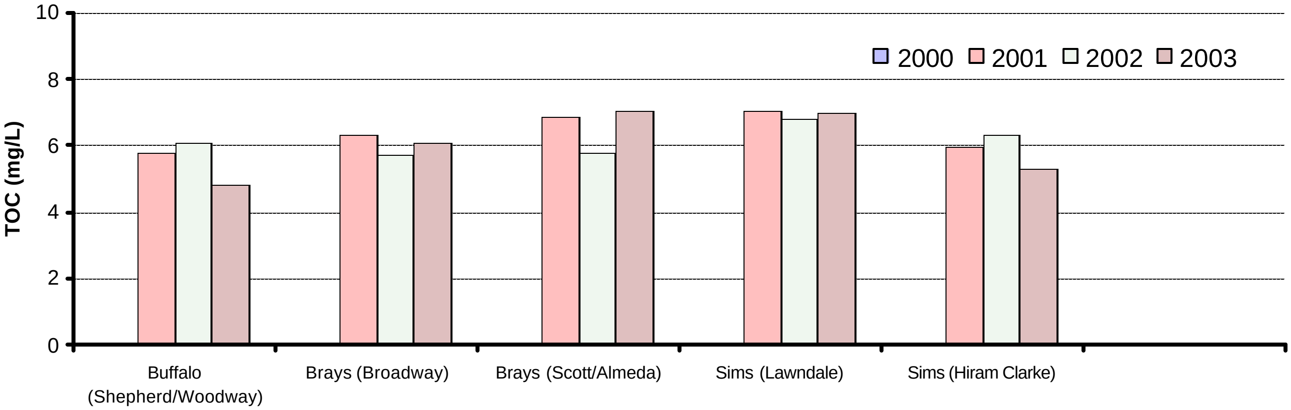


FIGURE 6-7
CHLOROPHYLL *a* LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

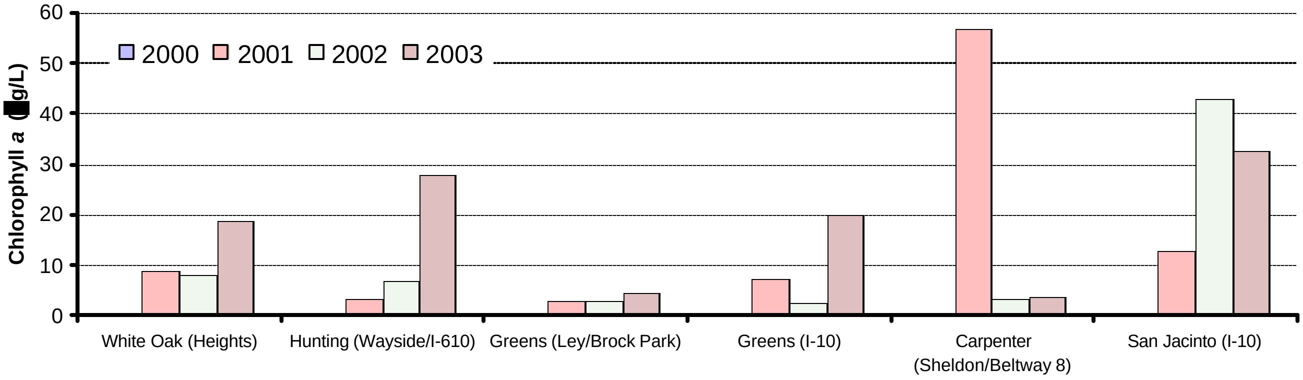


FIGURE 6-7 (CONCLUDED)
CHLOROPHYLL *a* LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

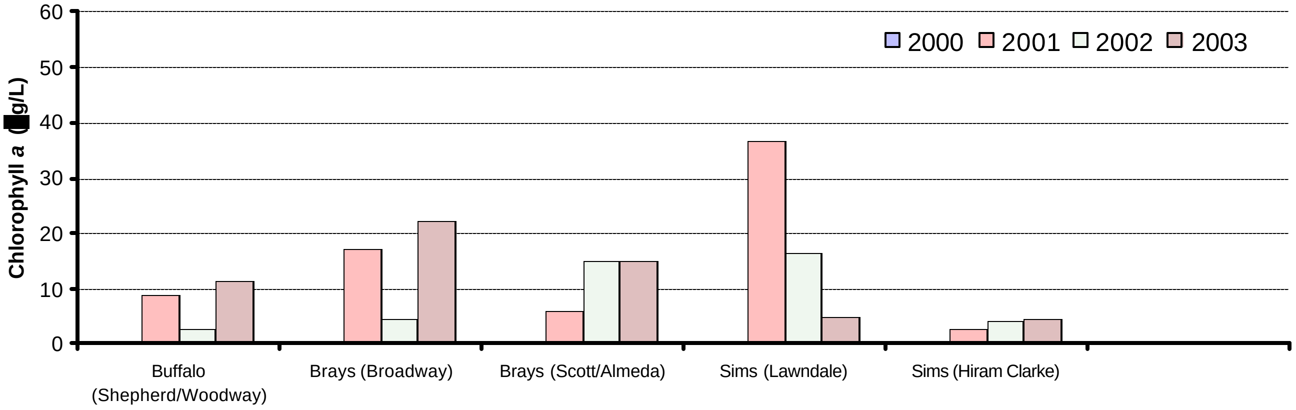


FIGURE 6-8
TSS LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

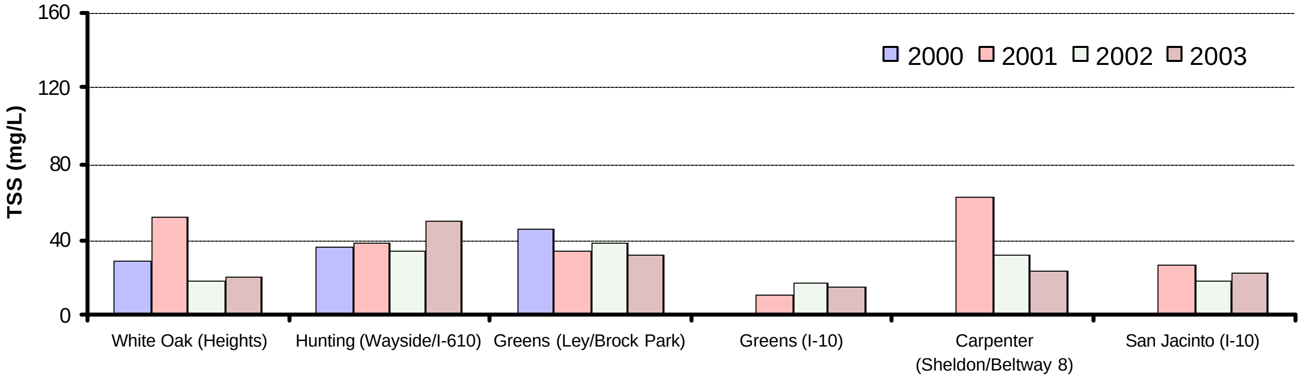


FIGURE 6-8 (CONCLUDED)
TSS LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

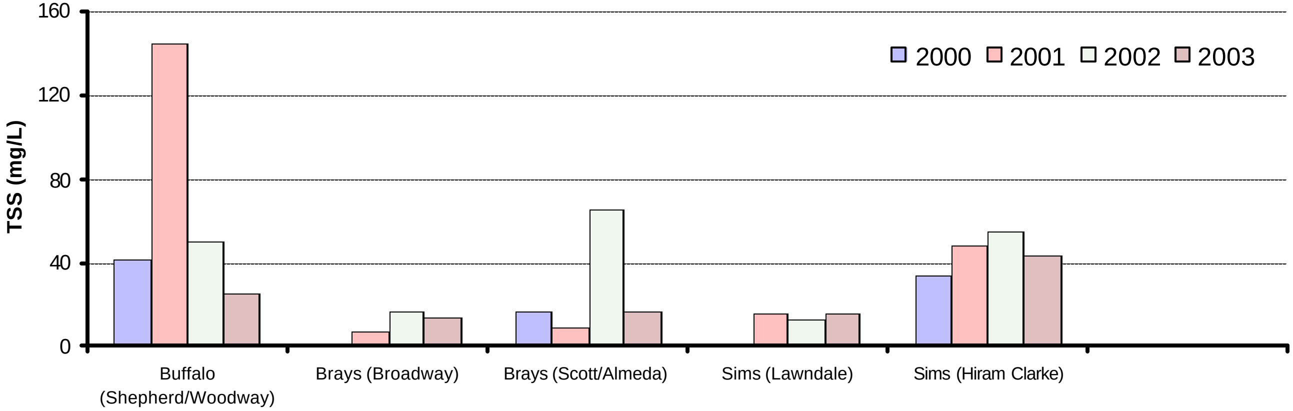


FIGURE 6-9
VSS LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

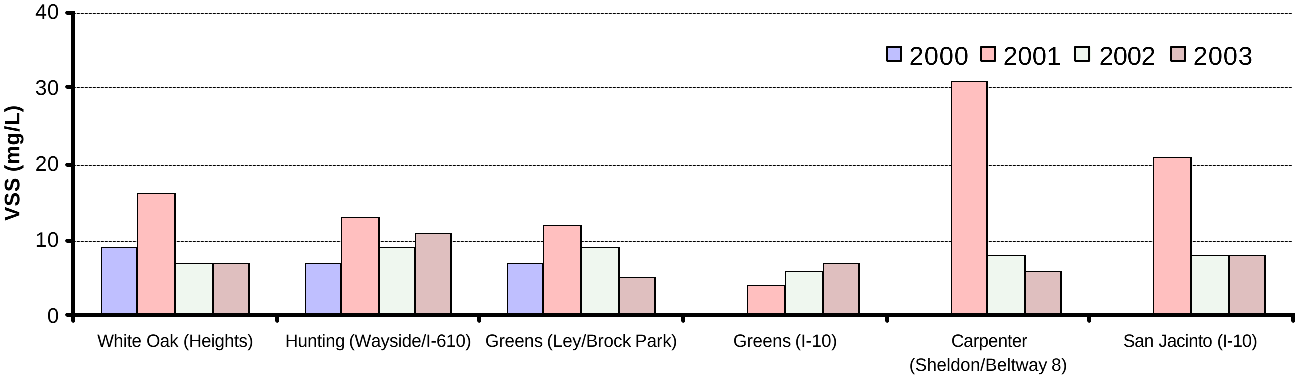


FIGURE 6-9 (CONCLUDED)
VSS LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

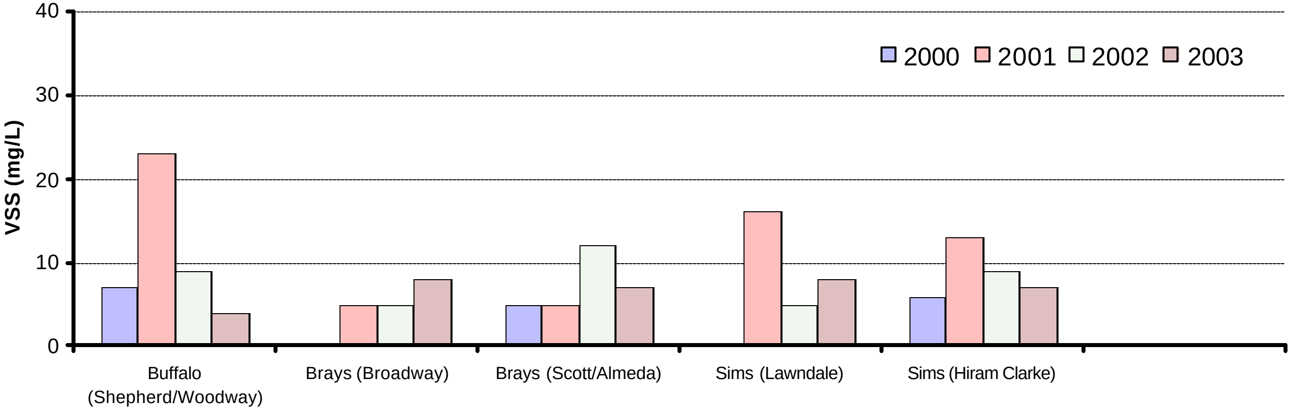


FIGURE 6-10
%VSS LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS

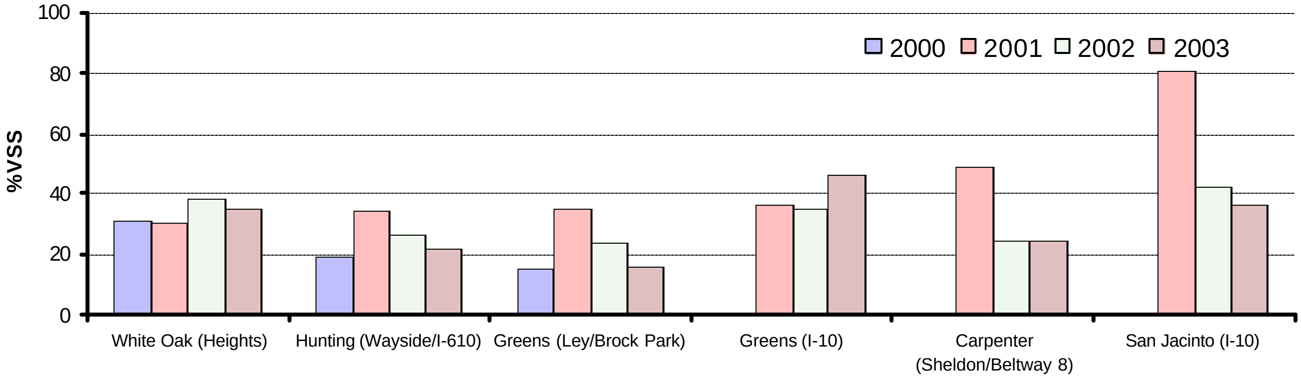
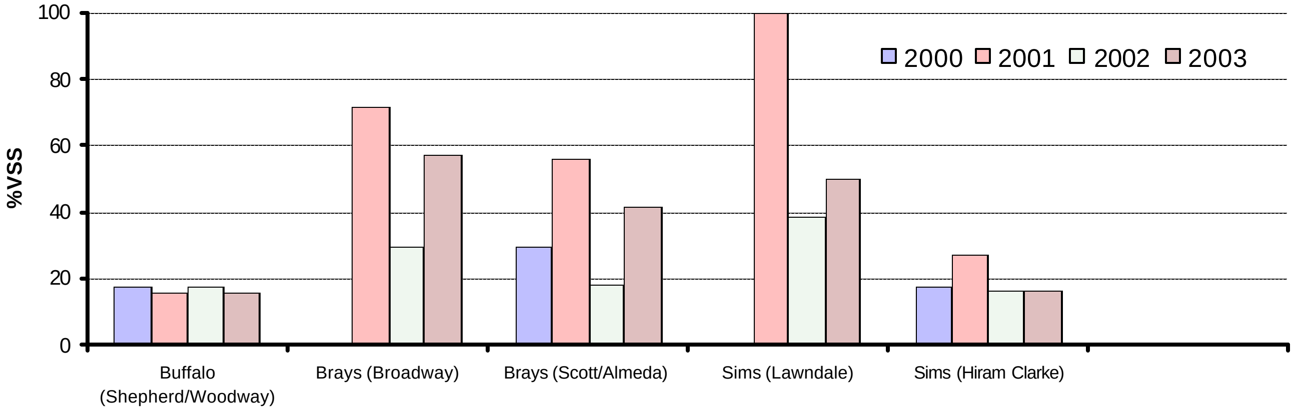


FIGURE 6-10 (CONCLUDED)
%VSS LEVELS AT TRIBUTARY STATIONS DURING AUG 2000, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



7.0 SEDIMENT DATA

It is often the case that sediments play a major role in determining water quality conditions. In impoundments and some tidal streams where the water stratifies, restricting exchange with the air, the oxygen demand from the sediments depletes oxygen from deeper waters. Under anaerobic conditions sediments can release phosphorus, ammonia-N and other oxygen demanding material and remove nitrogen through the process of denitrification. This section presents the data on the HSC sediments that have been obtained in the IS efforts. It also includes comparisons with earlier studies of HSC sediments and sediment oxygen demand (SOD) performed for the City of Houston (Pate-EH&A, 1987c). Finally, sediment monitoring data from Region 12 are included where comparable measurements are available.

The sediment samples collected in the last two IS events were conducted for the Clean Rivers Program under an approved QAPP (PBS&J, 2002). However, methods for the 2001 sampling were the same. Each sediment sample consists of a manual composite from three sediment grabs collected from mid-channel and on both banks.

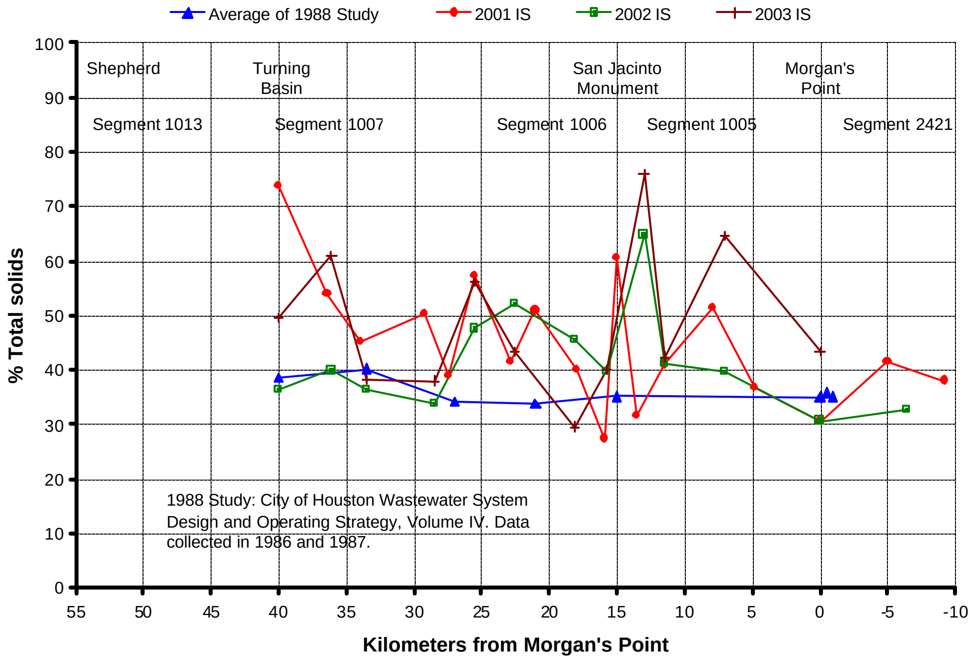
Figure 7-1 presents the % Total Solids in sediment samples and Figure 7-2 shows the % volatile solids. The difference between the sediment in 1986–1987 and the recent IS measurements is reasonably clear. The percentage of solids is higher in recent sampling and the percentage of volatile solids (organic matter) in the 1986–1987 period is substantially higher than is the case today. These figures suggest that the character of the HSC sediments has changed. The mud in the 1980s had more entrained moisture and more organic matter than is the case today. Figure 7-3 presents the percentage of solids that are volatile in the IS sampling. The 1980s sediments are more organic overall, but in both samplings the upper channel stations appear to have a higher proportion of organic or volatile solids than the lower channel stations. In comparing the different IS events, it appears that the 2001 sampling (post Allison) has higher VSS levels than the more recent events.

Figure 7-4 shows the % total solids in recent years at three stations from TCEQ monitoring. In general, these data appear consistent with the IS monitoring. However, there may be a pattern in the data of higher solids content upstream that is not shown in the IS sampling.

Figure 7-5 shows the sediment TOC concentrations and Figure 7-6 shows the sediment TKN levels. The expectation was that the 2003 TOC and TKN levels would be relatively low because of the absence of recent runoff to replenish the organic matter in the sediment. That seemed to be the case with TKN, but no particular pattern could be seen with the TOC values.

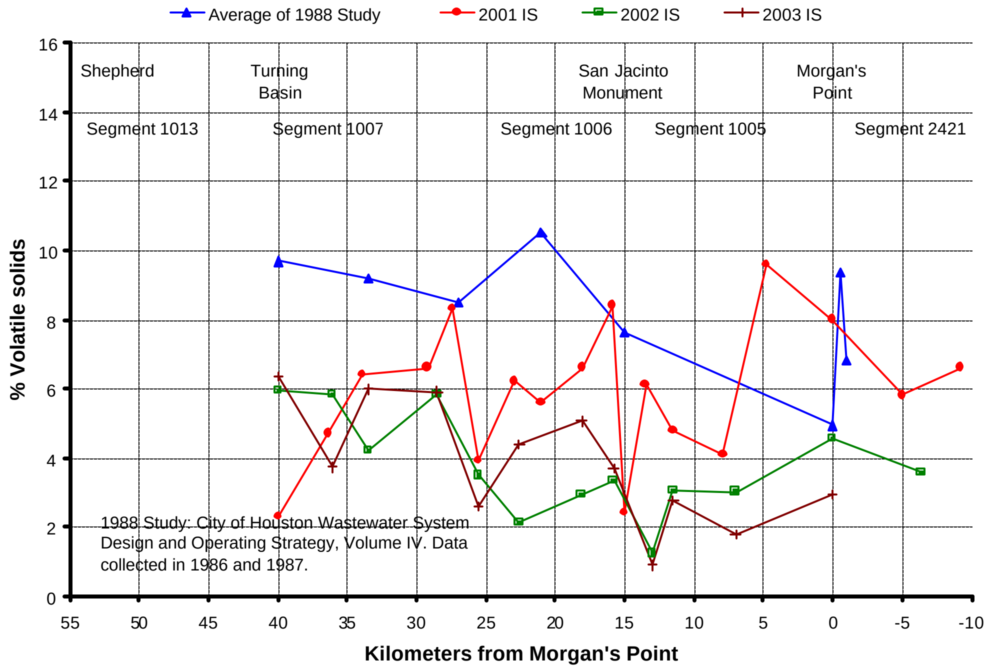
A general finding appears to be that there has been a marked change in channel sediments since the mid 1980s. The percentage of solids is higher (i.e., the moisture content is lower) and the solids appear to have a lower concentration of organic matter today than in the past. This may have translated into somewhat lower sediment oxygen demand values. That would appear to explain the higher DO levels observed in channel waters in recent years.

FIGURE 7-1
% TOTAL SOLIDS IN HSC SEDIMENTS IN 1988 STUDY, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



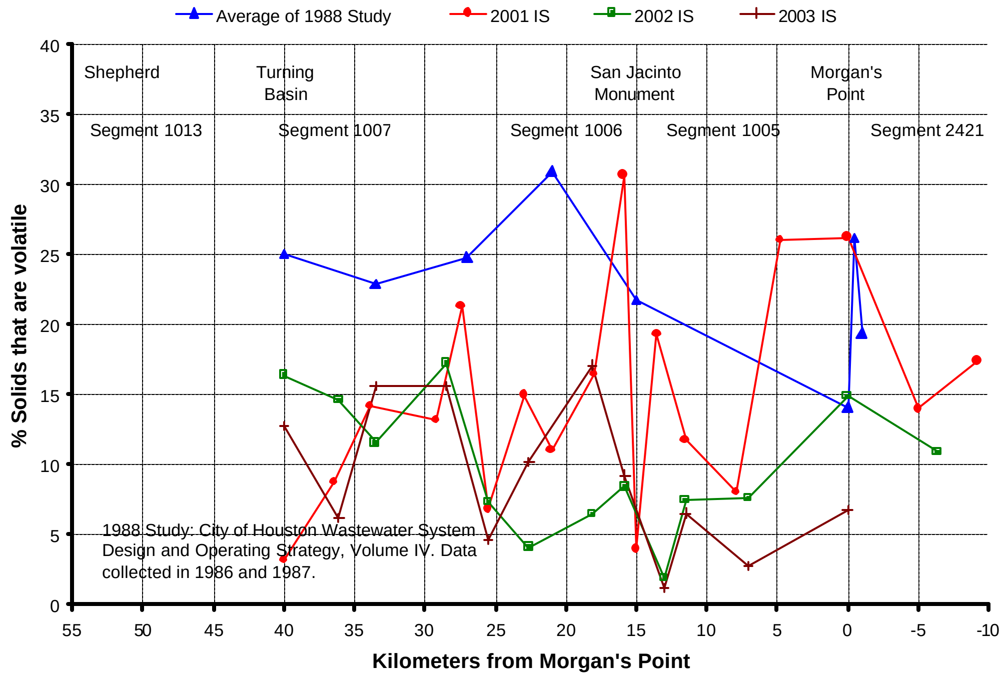
1988 Study: City of Houston Wastewater System Design and Operating Strategy, Volume IV. Data collected in 1986 and 1987.

FIGURE 7-2
% VOLATILE SOLIDS IN HSC SEDIMENTS IN 1988 STUDY, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



1988 Study: City of Houston Wastewater System Design and Operating Strategy, Volume IV. Data collected in 1986 and 1987.

FIGURE 7-3
% SOLIDS THAT ARE VOLATILE IN HSC SEDIMENTS IN 1988 STUDY, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



1988 Study: City of Houston Wastewater System Design and Operating Strategy, Volume IV. Data collected in 1986 and 1987.

FIGURE 7-4
% TOTAL SOLIDS IN HSC SEDIMENTS FROM TCEQ MONITORING

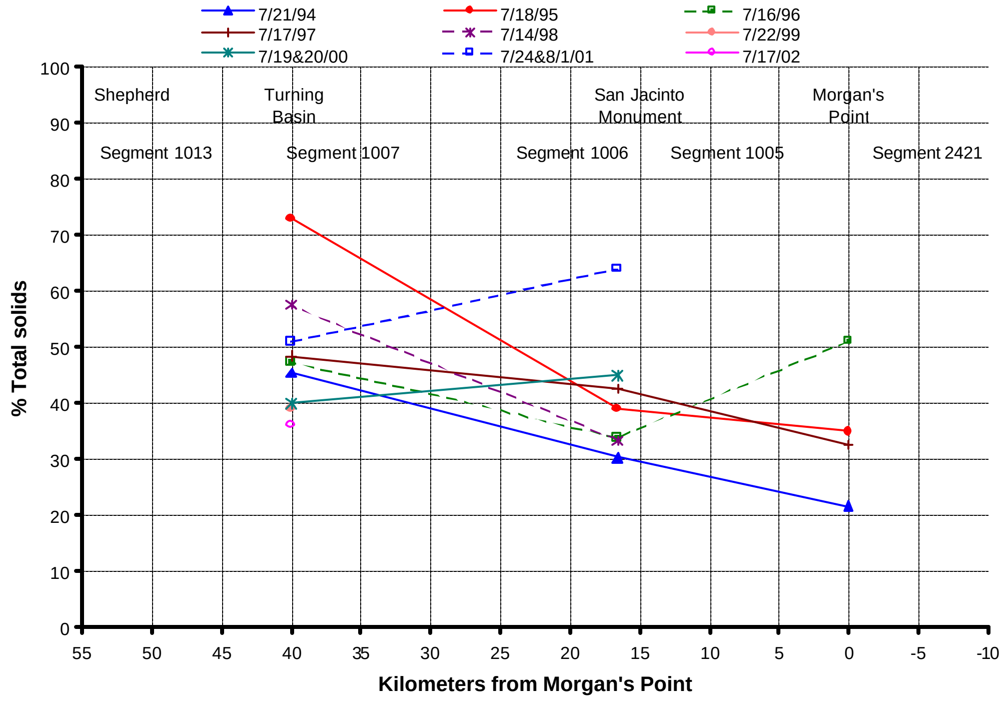
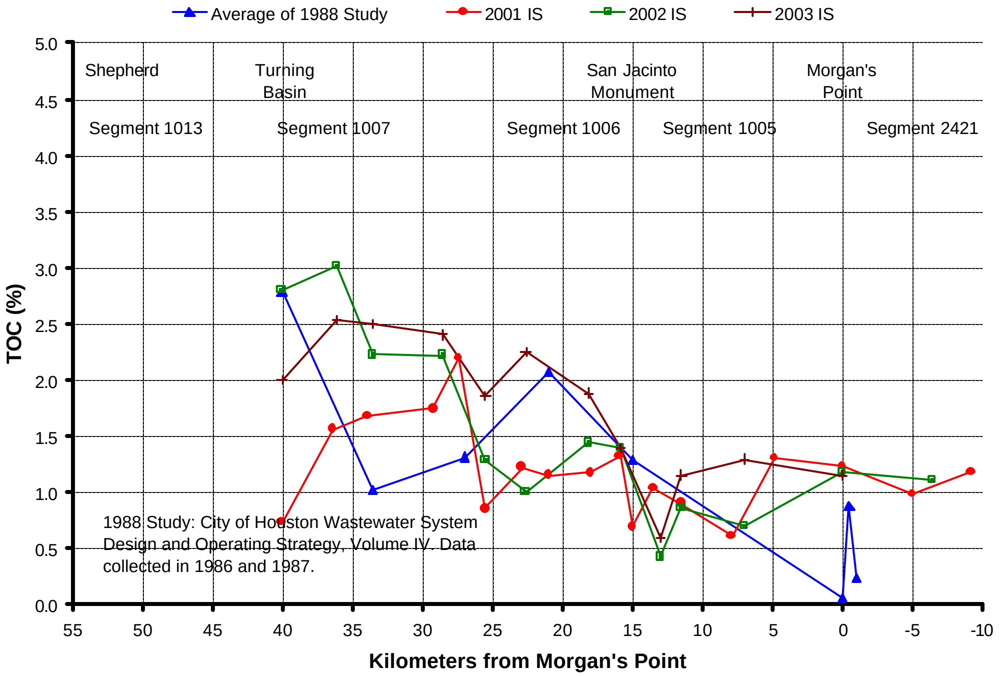
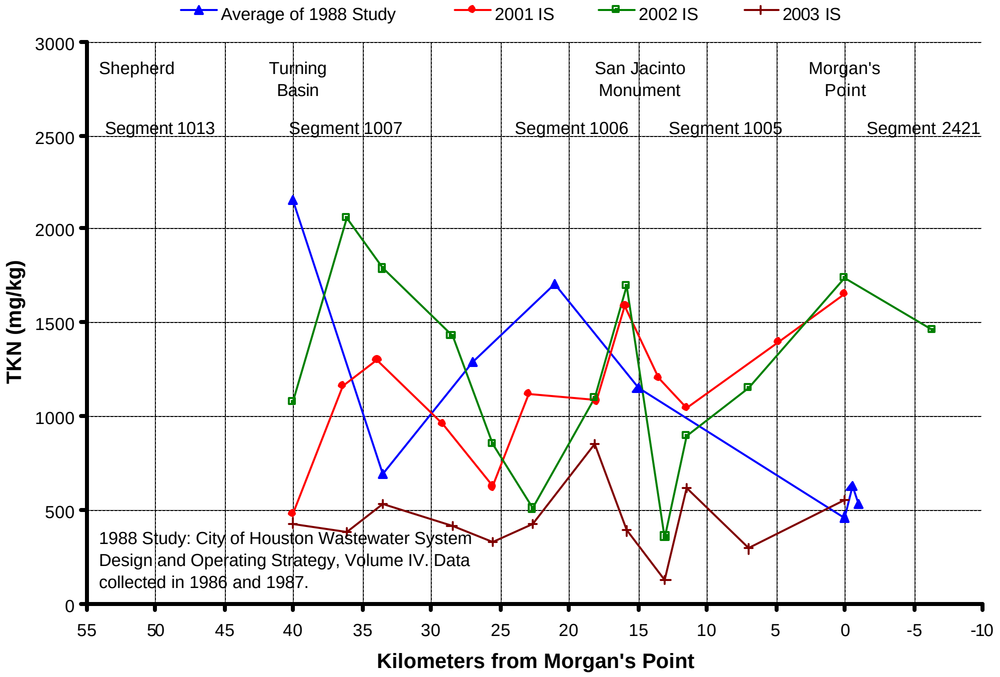


FIGURE 7-5
TOC LEVELS IN HSC SEDIMENTS IN 1988 STUDY, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



1988 Study: City of Houston Wastewater System Design and Operating Strategy, Volume IV. Data collected in 1986 and 1987.

FIGURE 7-6
TKN LEVELS IN HSC SEDIMENTS IN 1988 STUDY, JUL 2001, AUG 2002 AND MAY 2003 INTENSIVE SURVEYS



1988 Study: City of Houston Wastewater System Design and Operating Strategy, Volume IV. Data collected in 1986 and 1987.

8.0 WATER CIRCULATION

A major characteristic of estuaries is the density current, where cooler and more saline (heavier) water from the Gulf intrudes under the lighter freshwater entering from tributary flows and wastewater. This density current is an important feature in the mixing process. A one-dimensional steady-state model like QUAL-TX represents mixing from the density current by using inflated dispersion coefficients between model segments. A more modern multi-layer model would represent the density current and associated mixing explicitly.

Calibration of a modern model should be done with explicit measurements of the currents. To obtain such data, the Subgroup worked with the USGS that has Acoustic Doppler Current Profiler (ADCP) equipment. The USGS measurement effort in 2001 was supported by the City of West University Place. The efforts in 2002 and 2003 were supported by the City of Houston.

The ADCP is a device that sends sound pulses out at slightly different angles and obtains returns from small debris in the water. The differences in the returns with the different angles is used to determine a current velocity at different depths. The equipment employed provided current measurements at 1-foot depth intervals along the stream cross-section. Figure 8-1 shows the ADCP transducer out of the water, and Figure 8-2 shows it in place with data being collected as the boat moves slowly across the channel.

During the IS work, the USGS boat moved up and down the channel, making transects at most of the stations where water quality data were collected. Figure 8-3 is an example of the current readout in real time, with the current strength shown as a color code. Individual observations are made in a fraction of a second and contain considerable scatter. To obtain better averages over the deep channel sections, the boat moved slowly, and averaging was performed. Figure 8-4 represents several examples of the average vertical current profiles. The classic situation of bottom currents moving upstream with surface currents moving downstream was commonly observed.

This report presents some samples of the ADCP data to illustrate the general nature of the current fields. A full record of the three data sets is being retained on CD format for more detailed analysis, if and when a more detailed model is calibrated.

FIGURE 8-1
ADCP TRANSDUCER

FIGURE 8-2
DATA COLLECTION WITH TRANSDUCER IN PLACE

FIGURE 8-3
CONTOUR PLOT OF VELOCITY AT HIGHWAY 146 ON MAY 20, 2003 AT 16:42
(Ebb Tide, Flow = 11,400 cfs)

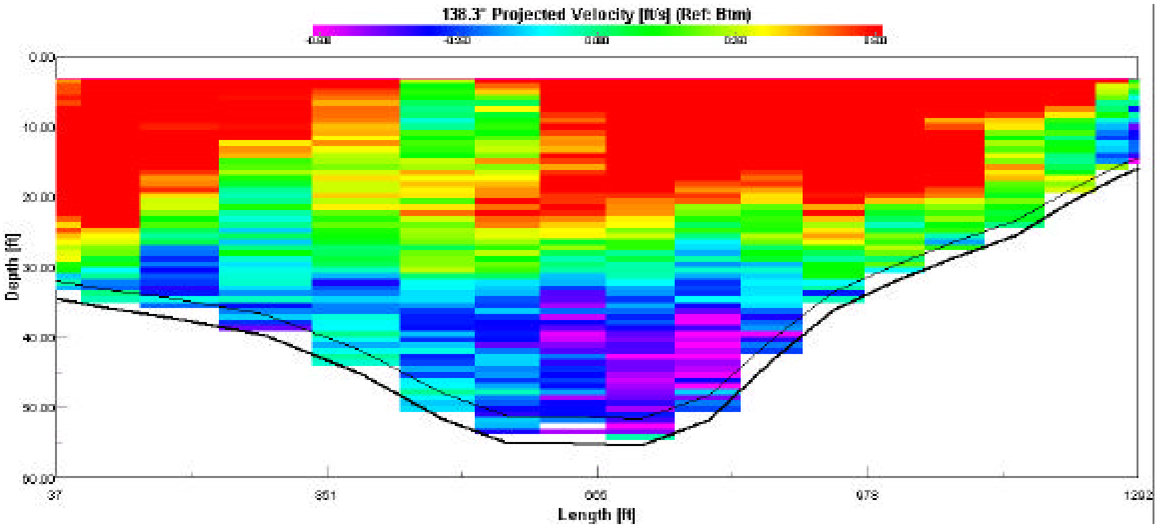
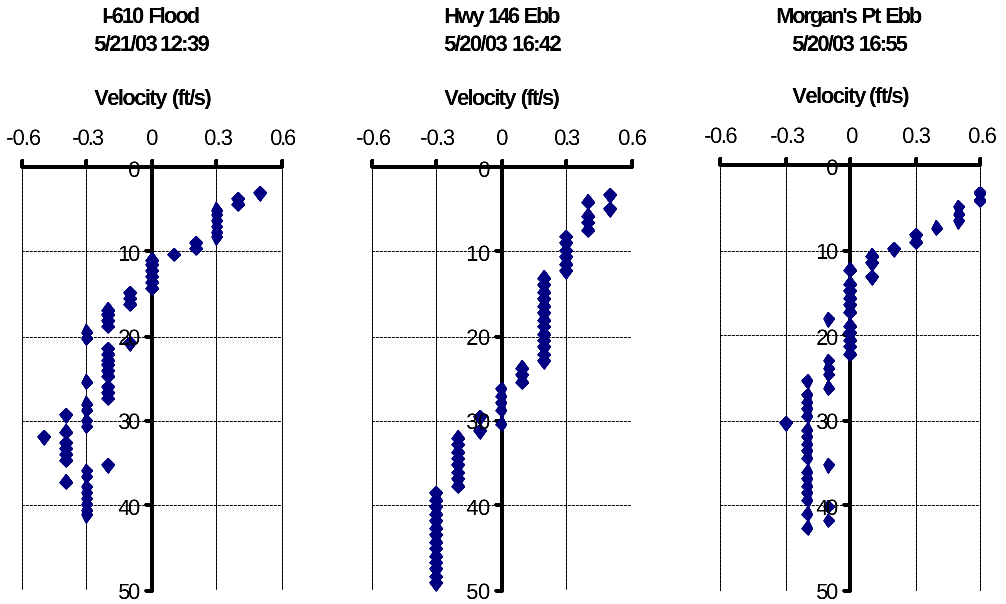


FIGURE 8-4
CURRENT VERTICAL PROFILES



9.0 DISCUSSION AND RECOMMENDATIONS

Over the last 4 years a considerable body of data under near worst-case conditions has been collected through a joint endeavor between the TCEQ and the Houston community. These data are summarized in this document.

The first and most dramatic finding is that relative to the 1980s, DO levels have improved substantially. DO levels today meet the established water quality criteria and attainment screening procedures with a substantial margin of safety. This is not to say DO levels are always high. Three of the four IS samplings produced DO profiles that were close to criteria at a few locations, and one survey had some DO values below criteria. The difference with the 1980s is that where non-attainment was once the rule, it is now the exception. Many things have changed including reduced waste loads, reductions in sewer leaks, and a deepening of the HSC allowing the density current to play a bigger role.

Another major finding is that the concentration of oxygen demanding materials in the water during any of the IS events was very low, to the point where significant oxygen demand cannot be exerted by materials in the water. Point sources are the major source of water to the channel in dry conditions. With little oxygen demand from the water, sediment oxygen demand combined with limited aeration from density stratification is the main source of lower DO levels.

It appears that the lowest DO levels, those in the 2001 and 2002 surveys, occur during warm weather after significant rainfall runoff events. The runoff contains organic matter that consumes oxygen readily, and much of the particulate material quickly settles to the sediment. The most recent IS, conducted after a prolonged dry period when runoff was not a factor and the only significant contribution to the channel was point source discharges, showed DO levels much higher than have been traditionally observed in the channel. This would suggest that point source inputs are not having a significant deleterious effect. Other relatively minor factors that contributed to the unusually high DO levels in 2003 include the slightly cooler temperature and the effect of somewhat higher chlorophyll *a* concentrations. This latter point is probably small because the photic zone is limited and surface diurnal DO differences were small.

From the combined results of these IS events and other studies a measure of quantitative understanding of DO conditions in the HSC is emerging. A model to implement this understanding would have to have the following components:

- A representation of the runoff process,
- A representation of sediment oxygen demand and its relation to runoff and processes such as sanitary sewer leaks,
- An explicit description of density stratification and circulation, including the effect of channel deepening,

- Calculation of oxygen produced in photosynthesis and reaeration, and
- Conventional representation of waste discharges.

Such a model would be capable of representing the actual DO levels in the HSC under a range of conditions. It would be useful for evaluating the effects of possible management actions dealing with non-point source controls, where major expenditures are now being made. It could also be used to evaluate new WLEs, measures such as direct aeration of the channel, and possible modifications in the DO criteria. The only existing water quality model of the HSC, QUAL-TX, is 20-year-old technology with limited usefulness in dealing with such issues.

In short, from these joint studies the data and technical capability now exists to greatly improve our ability to model water quality on the HSC. There are many good reasons to implement this improved modeling capability in the coming years. One reason, but perhaps not the main reason, is to help resolve a difference between permitted and actual point source waste loads.

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