TMDL DEVELOPMENT FOR WATER QUALITY IMPAIRMENTS OF ADAMS AND COW BAYOUS

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Adams and Cow Bayou are sluggish, turbid, streams that drain portions of Orange, Jasper, and Newton Counties in far southeast Texas and discharge into the Sabine River just upstream of Sabine Lake (figure 1). The lower and middle reaches of Adams and Cow Bayous, and many of their tributaries, are tidally-influenced. The lower portions of both bayous have been channelized, straightened, and dredged for navigation, creating numerous oxbows from the more sinuous natural channels. Field surveys indicate that under low-flow conditions there is essentially no base flow in the upper, non-tidal reaches of Adams Bayou (TWC 1986). Similarly, flow in the upper, non-tidal reaches of Cow Bayou is considered intermittent, but there are numerous perennial pools.

As with many similar tidal streams along the Gulf Coast coastal plain, dissolved oxygen levels are often low in Adams and Cow Bayous, and in many places do not meet Texas surface water quality standards established to protect aquatic life. Portions of both bayous also do not meet water quality standards for contact recreation, due to elevated levels of fecal bacteria. Finally, pH levels in portions of Cow Bayou are sometimes low, and do not meet State water quality standards for general uses. For these reasons, the Texas Commission on Environmental Quality (TCEQ) added Adams Bayou, Cow Bayou, and several of their tributaries to the Clean Water Act Section 303(d) List of impaired water bodies.

Due to concerns that the water quality standards applied to Adams and Cow Bayou may not be attainable or appropriately indicative of ecological health, the TCEQ and the Texas Parks and Wildlife Department initiated a Use Attainability Analysis of Cow Bayou and other tidal streams along the Texas coast. This analysis is not yet complete.

The Texas Commission on Environmental Quality also initiated a project in 2002 to address the water quality impairments by determining the total maximum daily load (TMDL) of pollutants that these bayous and several of their tributaries can assimilate while meeting existing state water quality standards. The TCEQ selected Parsons and the Sabine River Authority (SRA) as contractors to assist in developing TMDLs. An assessment of existing water quality data (Parsons 2002) concluded with a high degree of confidence that water quality in Adams and Cow Bayou did not meet water quality standards, but that the sources of pollutants were not adequately quantified, and the impacts of sources were not known with sufficient confidence to develop a TMDL. The assessment also indicated that, because both nonpoint sources and in-stream conditions likely contributed to the impairment, it was advisable to develop and calibrate both a watershed model and an in-stream model to aid in identifying the TMDLs and allocating the allowable load among various point and nonpoint sources of pollutants.

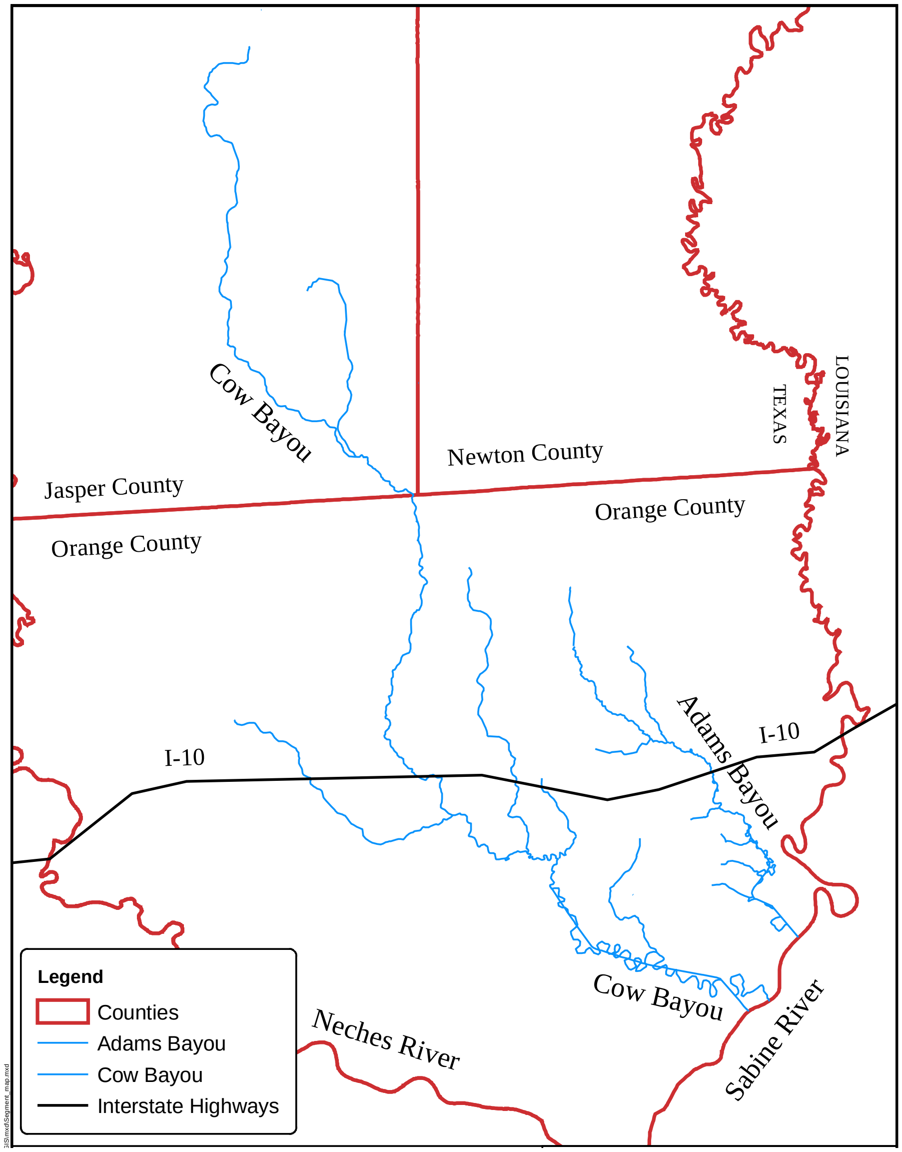

Figure 1. Adams and Cow Bayou location in far southeast Texas

In order to quantify existing loading, determine the TMDL, and evaluate reduced loading scenarios, several linked models were developed. The HSPF model (Bicknell et al., 2001) was used to simulate watershed loading processes for each bayou, as well as in-stream water quality for the above tidal reaches. The WASP Eutro model (Wool et al., 2001) was used to simulate in-stream water quality processes for tidal reaches. The U.S. Army Corps of Engineers RMA2 model (Donnell et al., 2001) was used to simulate hydrodynamic processes in the tidal reaches. The HSPF and RMA2 models served as inputs to the WASP model.

A water quality monitoring plan (Parsons 2003a) and quality assurance project plan (Parsons 2003b) were then developed to collect data necessary to develop and calibrate the watershed, hydrodynamic, and water quality models. This data was collected by Parsons and the SRA between January and November 2004. The data collection effort consisted of 1) runoff sampling to calibrate pollutant loading factors for the watershed model, 2) sediment oxygen demand surveys, and 3) several intensive surveys addressing instream flows, water quality, and pollutant loading from wastewater discharges in Adams and Cow Bayou.

WATERSHED PROPERTIES

The Adams Bayou watershed of approximately 37 square miles lies almost entirely within Orange County, though it includes a small portion of southern Newton County. The Cow Bayou watershed comprises approximately 199 square miles covering substantial portions of Orange and Jasper Counties, as well as a small corner of Newton County. The combined watersheds cover 41% of Orange County, 8% of Jasper County, and 0.3% of Newton County.

Adams and Cow Bayou are located in the Gulf of Mexico coastal plain. The southeastern parts of their watersheds lie in the ecological region known as Gulf prairies and marshes, while the northwestern parts lie in the piney woods region. The terrain is level and low. The elevation of Adams Bayou varies from sea level at the Sabine River to 4.5 feet at its uppermost extent (TWC 1986), with an average slope of only 6 cm/km, or 0.006%. The elevation of Cow Bayou varies from sea level at the Sabine River to 7 feet at its upper-most extent (TWC 1986), and also has an average slope of 6 cm/km (TWC 1988).

Adams and Cow Bayou experience a subtropical humid climate. The average temperature varies from 50 degrees Fahrenheit in January to 83 degrees in August. Rain is abundant in this corner of Texas, with average annual rainfall of almost 60 inches. The frequency of significant rainfall (one half inch or more in a 24-hour period) has averaged approximately 3.2 days per month, or roughly one in ten days, over the last 30 years. Seasonal variations in precipitation frequency and magnitude are not great. July, December, and January have the most frequent rainfall, and June, October, and April have the least frequent.

Portions of the cities of Orange, West Orange, Pinehurst and Mauriceville lie within the Adams Bayou watershed, while portions of Bridge City, Vidor, Mauriceville, Evadale, and Buna lie within the Cow Bayou watershed. In the year 2000, the population of the Cow Bayou watershed (~23,900) was slightly higher than that of Adams Bayou (~17,500). Between 1990 and 2000, the population of the Adams Bayou watershed increased only 2%, while the Cow Bayou watershed population grew by 17%.

The major industries in the watersheds include chemical manufacturing, oil and gas production, forestry, and beef production. The major agricultural activities within the watersheds include beef cattle ranching and hay production. In addition to hay and other forage, the other major crop in Orange County is rice, but this is outside the watersheds of Adams and Cow Bayou. Cattle are the most abundant livestock by a large margin.

Sedimentary rocks comprise the geologic base of the watersheds of Adams and Cow Bayou. The Beaumont Clay is the surface formation over the entire watershed. It is composed of mixed sand, silt, clay and gravel. Soils are primarily fine sands, silts, and clays. Most are fine-textured, have high water holding capacity, and very slow water permeability. Soils also tend to be acid and have high organic matter content in the surface layer. Some soils have frequent flooding and/or surface ponding of water for long durations in the cooler months of the year. Finally, many of the soils are saturated in the cooler months, with water tables at or near the surface. Together with the low and level topography, these soil properties give rise to an abundance of wetlands within the watersheds.

Overall, 14 percent of the Adams Bayou watershed and 6 percent of the Cow Bayou watershed were considered developed or built-up land (residential, commercial, industrial, or transportation). More than 65 percent of the Cow Bayou watershed, and one third of the Adams Bayou watershed, is covered by forest, primarily evergreen and mixed evergreen/deciduous forest. Approximately 15 percent of the Cow Bayou watershed and 27 percent of the Adams Bayou watershed is classified as pastureland. Water and wetlands comprise approximately 10 percent and 22 percent, respectively, of the Cow and Adams Bayou watersheds.

HSPF MODEL DEVELOPMENT

Wetlands appear to exert a controlling influence on the hydrology of Cow Bayou. Basically, the wetlands act like a sponge, absorbing rainfall with little or no runoff until the sponge is saturated. For this reason, there is often very little flow in Cow Bayou in the summer, when evaporation and evapotranspiration by plants speeds the drying of the wetlands. To adequately simulate hydrology of Adams and Cow Bayou, new high water table, low gradient algorithms incorporated into version 12 of HSPF were applied. These algorithms, developed for wetlands, keep track of the groundwater levels (top of saturated zone) and the interaction between the saturated and unsaturated zone. Also, surface flow is simulated as a power function of the water storage on the land surface, rather than the traditional approach based on the length, slope, and roughness of the overland flow plane.

Key water quality constituents simulated in the HSPF model include E. coli bacteria, dissolved oxygen, pH, cBOD, nitrate nitrogen, ammonia nitrogen, orthophosphate phosphorus, alkalinity, and total suspended solids. Chlorophyll A and organic nitrogen and phosphorus were also simulated, but were not calibrated due to a lack of data. The cBOD parameter simulated is ultimate cBOD, rather than the more commonly measured 5-day cBOD.

The HSPF model of Cow Bayou hydrology was calibrated to USGS daily measured flows from Cow Bayou at State Highway 12 for the period from October 1, 2002 through March 28, 2005. The primary calibration targets included annual, seasonal, and monthly water balances, and the flow duration curve. Additionally, storm event runoff volumes were used as a calibration target. Figure 2 compares the simulated and observed flow duration curves for Cow Bayou at SH 12. A flow duration curve depicts the percentage of the time that a given flow is exceeded. It can be seen that the maximum flow observed at this site was approximately 3,000 cfs for the calibration period, the median flow was approximately 30 cfs, and there is less than 1 cfs of flow on about 74% of the days. The model simulation agrees well with the observed flow duration curve across all flow conditions.

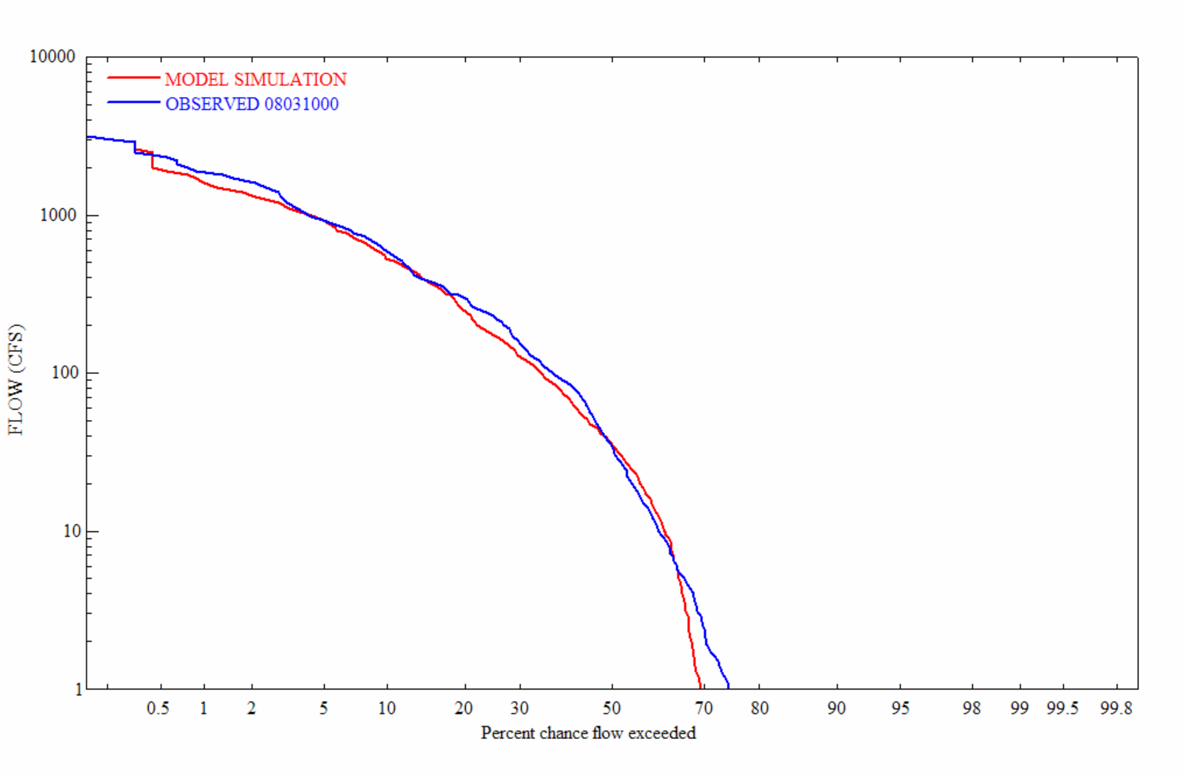

Figure 2. Observed and simulated flow duration curves for Cow Bayou at SH 12

POLLUTANT SOURCE ASSESSMENT

A nonpoint pollutant source inventory was developed for each watershed and sub-watershed using a system of linked Microsoft Excel spreadsheets. This tool was adapted from the Bacterial Indicator Tool developed by the USEPA (2000). The tool provides monthly and annual loading estimates of indicator bacteria for the HSPF model based on land use, livestock and wildlife populations, the number and failure rate of septic systems, and other watershed properties. Assumptions are easily modified to generate revised loading estimates for HSPF. This tool was modified to address watershed-specific conditions and sources, as well as the nitrate and ammonia nitrogen, orthophosphorus, and biochemical oxygen demand. The major potential sources of pollutants are briefly described below. Complete descriptions of assumptions, procedures, and calculations are provided in technical memorandum for the watershed and water quality modeling (Parsons 2006a; Parsons 2006b).

On-Site Sewage Facilities

On-site sewage facilities (OSSFs), such as septic tanks, can serve as nonpoint sources of pollutants. Malfunctioning septic tanks are those that have been improperly engineered or installed, poorly maintained, or where soils do not permit the sanitary absorption of septic effluent. In rural and some suburban areas of Adams and Cow Bayou, conventional septic tanks serve as the primary mechanism for sewage disposal. The most recent available data on the abundance of septic tanks in the watersheds comes from the 1990 decennial federal census. In the long questionnaire given to roughly 1 in 6 households, respondents were asked to identify the sewage disposal method of their housing unit as either “public sewer”, “septic tank or cesspool”, or “other means”. In the Adams Bayou watershed, 6,754 housing units (88%) were connected to a public sewer, 888 units (12%) used septic tanks or cesspools for sewage disposal, and 20 units reported an “other” sewage disposal method. In the Cow Bayou watershed, 2,205 housing units (28%) were connected to a public sewer, 5,582 units (71%) used septic tanks or cesspools, and 108 units (1%) reported an “other” sewage disposal method.

Conventional septic tank systems rely on absorption fields to disperse liquid components of sewage into the soil, after solids have settled into the tank. Several factors affect the suitability of soils for septic tank absorption fields (NRCS 2004).

- frequency and duration of flooding
- frequency and duration of surface ponding
- soil water permeability
- depth to the saturated zone
- Tendency for subsidence

Based on one or more of these factors, virtually all of the soils in the Adams and Cow Bayou watersheds are very limited in their utility for septic tank absorption fields, according to the Soil Survey Geographic Database (SSURGO) developed by the Natural Resource Conservation Service (NRCS) of the USDA. Project stakeholders with knowledge of the watersheds, including septic system inspectors, believe that the actual rate of malfunction of conventional septic systems in these watersheds is close to 100%. They cited observations that almost all conventional systems had the cap removed from the septic field drain line (due primarily to a seasonally high water table and low soil permeability) essentially conveying the septage directly from the tank to the ditch. In accordance with these estimates, it was assumed in the model that 95% of the conventional septic systems in these watersheds are chronically malfunctioning.

Livestock and Manure

Livestock fecal waste may serve as a major nonpoint source pollutant, either by runoff of fecal matter directly deposited on land by grazing animals on pastureland, or in water, or by application of manure from confined animals to fields as fertilizer. Manure production by livestock was estimated based on the animal population estimate from the 2002 USDA Census of Agriculture multiplied by the estimated average daily manure production rate from the American Society of Agricultural Engineers (ASAE 1998). The E. coli, ammonia nitrogen, and phosphorus production estimates were also derived from published ASAE estimates. Manure from cattle, horses, sheep, and goats was assumed to be directly deposited to pastureland. A portion of the manure from grazing cattle was assumed to be deposited directly in water as the animals drank from streams. However, on average, only 0.01% of the total fecal load from grazing cattle in the Adams Bayou watershed was assumed to be deposited directly into Adams Bayou or its tributaries, and 0.03% of the total fecal load from grazing cattle in the Cow Bayou watersheds was deposited to the bayous.

Wildlife
Wildlife are assumed to contribute pollutants to all land use categories and sub-watersheds. Pollutant production rates of wildlife were estimated based on Schueler (2001) and other references in the Bacterial Indicator Tool (USEPA 2000).

Atmospheric Deposition
Atmospheric deposition was assumed to contribute ammonia nitrogen and nitrate nitrogen to all land uses via wet (precipitation) and dry (particle) deposition. Annual wet and dry deposition rates of ammonia and nitrate nitrogen for the project watersheds were estimated from isopleth maps prepared by the National Atmospheric Deposition Program (NADP 2005).

Forest Leaf Litter
Forest leaf litter deposition can be a nonpoint source of nitrogen, phosphorus, and cBOD to waters. An estimated 30 pounds of nitrogen and 2 pounds of phosphorus are deposited in leaf litter per acre of forest per year, based on the measurements of Finzi et al. (2001) for a mature loblolly pine/hardwood forest, similar to the dominant type in the Adams and Cow Bayou watersheds.

Residential Area Nonpoint Sources
Potential pollutant sources in residential areas that were considered in the model include malfunctioning septic systems, dog and cat fecal waste, wildlife fecal waste, and lawn fertilizer. Malfunctioning septic systems were described previously and incorporated in the model independently. The populations of dogs and cats were estimated based on the number of households in each subwatershed, along with the national average numbers of 0.58 dogs and 0.66 cats per household, from the American Veterinary Medicine Association (AVMA, 2002). Fecal production and pollutant concentrations were estimated from the Bacterial Indicator Tool (USEPA 2000) and from Baker et al (2001).

Unauthorized Discharges
Some common types of unauthorized discharges are leaks and overflows from the sanitary sewer system, and cross-connections between the sanitary and storm sewer systems. Unlawful discharges by septic tank and grease trap cleaners and haulers are also possible. These discharges are episodic and may impact the bayous in the vicinity of the discharge a great deal for a short period of time until the pollutants are dispersed. It is difficult to gage the magnitude of unauthorized discharges, as very few data exist. Inspection of permit files revealed only a few instances where unauthorized discharges were reported to state authorities, and these reports were only made since 2004, from two facilities where TCEQ inspectors noted that they had not been reporting sewage leaks. There is no reason to expect that problems with sewer systems are limited to these two facilities, so the magnitude of the problem is likely underestimated. To estimate annual loadings, the reported discharges from the years in which discharges were reported were assumed to be representative of other years.

Point Sources of Pollutants
Point source loadings were estimated based on a combination of self-reported effluent data (from January 2000 through March 2005) and effluent measurements made during the intensive surveys of the summer of 2004. Most facilities with permitted discharges to the bayous are

required to report each month the average measured flow rate of their discharge. Most facilities are also required to report on a monthly basis either the monthly total loads or average concentrations of one or more specific pollutants or other parameters in their wastewater discharge to the bayous. In cases where the facility did not self-report a pollutant concentration or load, that load was estimated using the self-reported monthly average flow and the average concentration measured during the intensive surveys.

In some cases, sewage treatment facilities receive more flow than they are able to treat during storm events. This is typically caused by inflow and infiltration into the sewers, as well as storm drains connected to the sanitary sewers. Facilities will typically disinfect but not otherwise treat these sewage flows exceeding capacity before discharging them to the bayou. Many sewerage facilities have made extensive efforts to reduce inflow and infiltration to sanitary sewers to minimize these untreated storm discharges. The extent of the remaining problem is not known.

Loading Summary

Though other parameters were simulated, the three primary pollutants impacting the impairments of contact recreation, pH, and aquatic life are E. coli bacteria, biochemical oxygen demand, and ammonia nitrogen. Loadings of these pollutants are summarized in figures 3 to 6 for Adams Bayou, and in figures 7 to 10 for Cow Bayou. Loads are divided into those upstream and downstream of Interstate 10. Some sources are grouped by land use category (residential, forest, pasture, wetlands), while others are for specific sources (failing septics, cattle in streams, point sources).

Nonpoint sources, particularly malfunctioning septic systems, were identified as the largest source of most pollutants. Point sources were significant sources of biochemical oxygen demand and nutrients only in downstream reaches of each bayou.

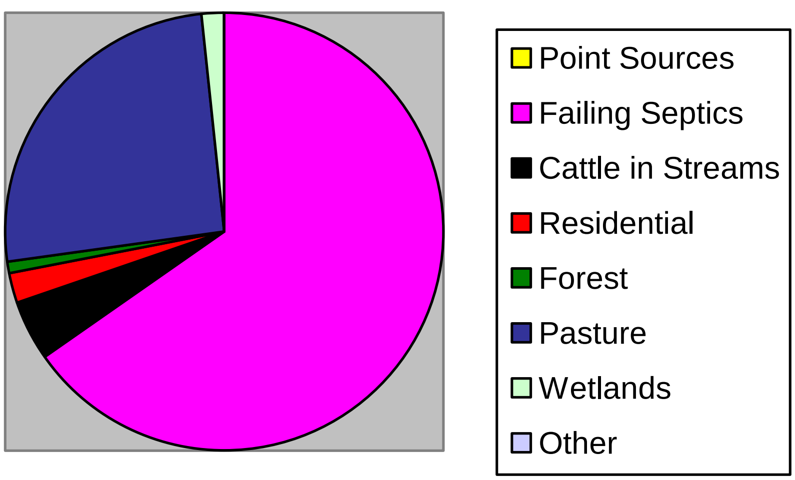

Figure 3. Sources of *E. coli* loading to Adams Bayou above I-10
Total annual load ~ 2.1x 10^{14} cfu

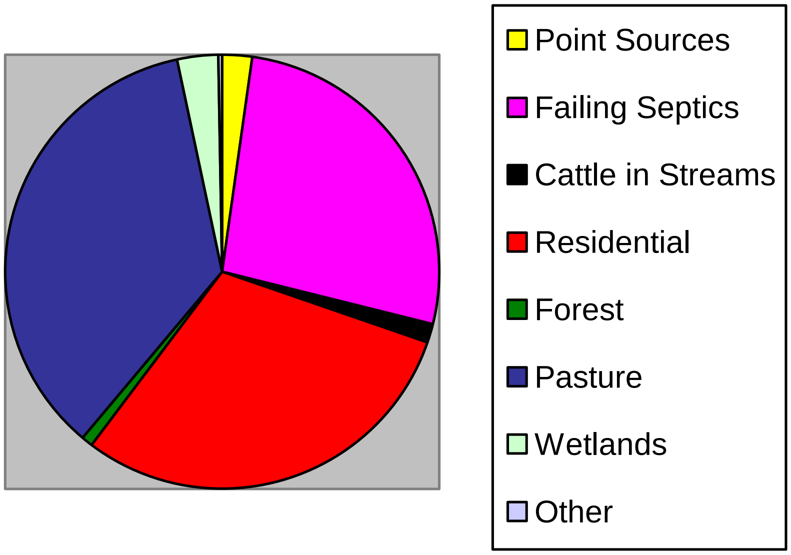

Figure 4. Sources of *E. coli* loading to Adams Bayou below I-10
Total annual load ~ 5.6 x 10^{13} cfu

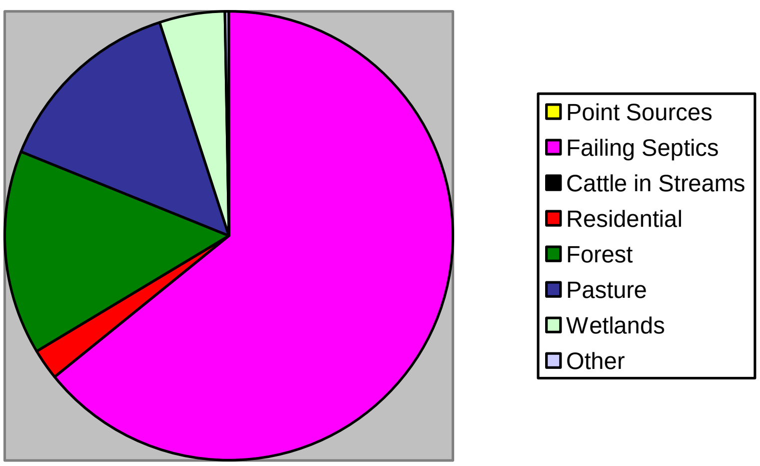

Figure 5. Sources of cBOD loading to Adams Bayou above I-10
Total annual load ~ 80,600 pounds

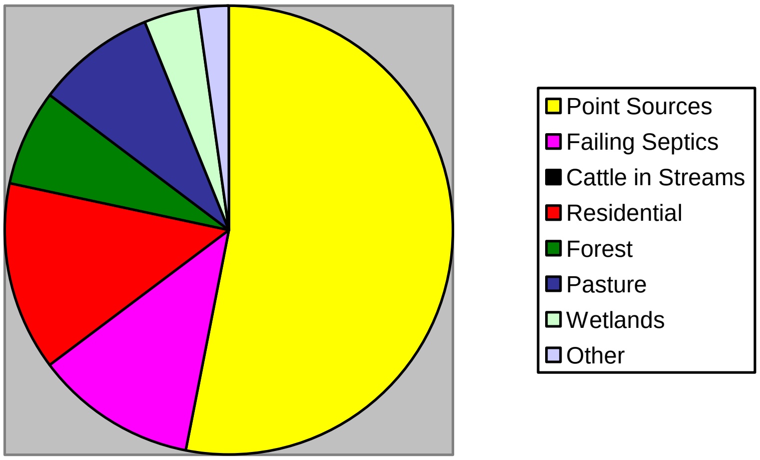

Figure 6. Sources of cBOD loading to Adams Bayou below I-10
Total annual load ~ 47,100 pounds

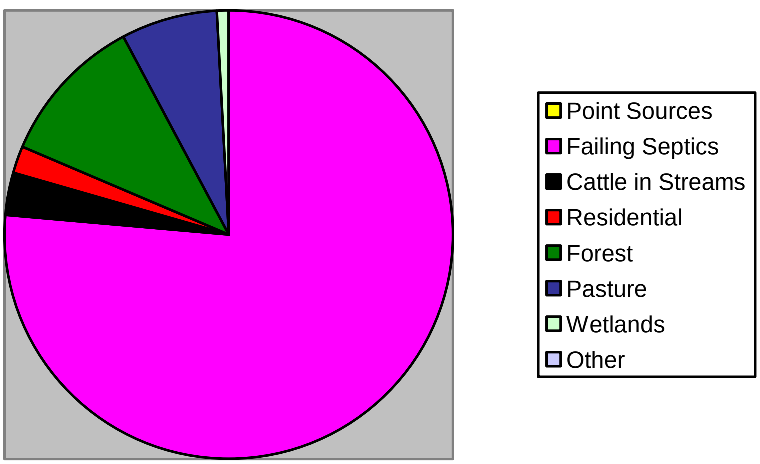

Figure 7. Sources of *E. coli* loading to Cow Bayou above I-10
Total annual load ~ 1.1 x 10^{15} cfu

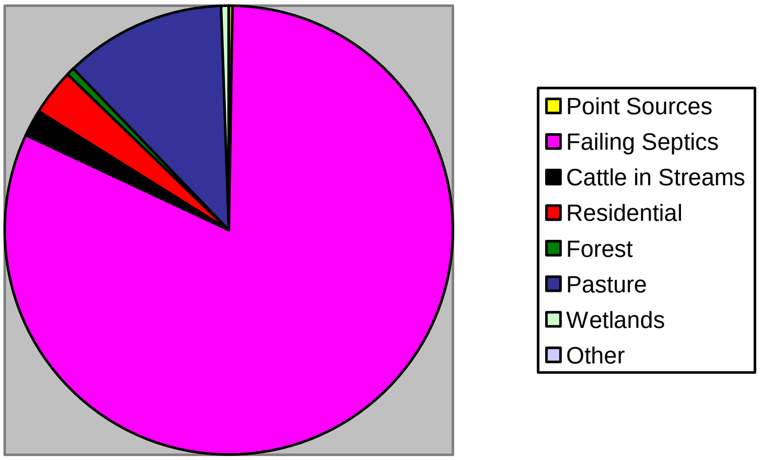

Figure 8. Sources of *E. coli* loading to Cow Bayou below I-10
Total annual load ~ 7.8 x 10^{14} cfu

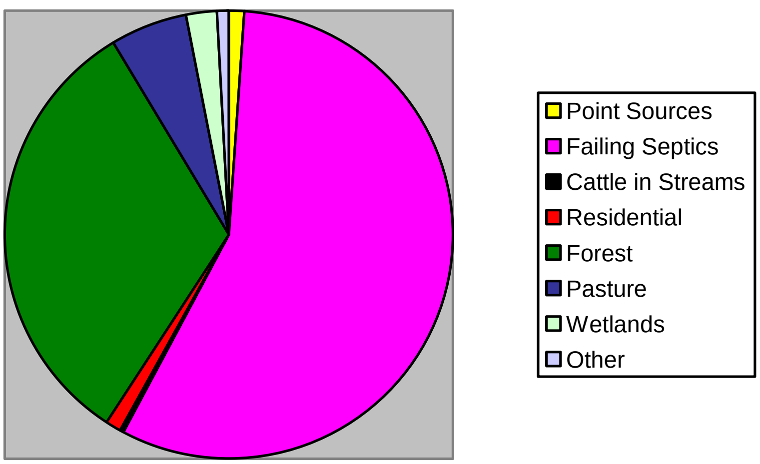

Figure 9. Sources of cBOD loading to Cow Bayou above I-10
Total annual load ~ 601,000 pounds

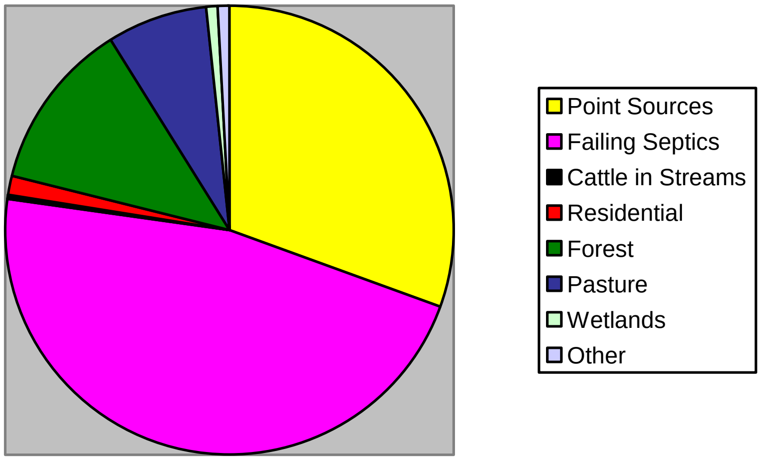

Figure 10. Sources of cBOD loading to Cow Bayou below I-10
Total annual load ~ 504,000 pounds

RMA2 HYDRODYNAMIC MODEL DESCRIPTION

RMA2 is a two-dimensional, vertically averaged, finite element hydrodynamic model supported by the U.S. Army Corps of Engineers. It computes water surface elevations and horizontal velocities for subcritical, free-surface two-dimensional flows (Donnell et al., 2005). Separate hydrodynamic models were developed for the Adams and Cow Bayou systems. Both models extended from the Sabine River (the downstream boundary) to the upstream limits of tidal influence of each bayou and their tributaries. Oxbow channels were also included in the model, either explicitly modeled as discrete elements or included as off-channel water storage attached to the main channel.

Tidal water surface oscillations in the Sabine River drive tidal water movements through the Adams and Cow Bayou systems. Tide height data from a continuous gage at the Rainbow Bridge (where SH 87 crosses the Neches River just upstream from Sabine Lake) were used as the Sabine River downstream boundary water surface elevation condition in the models. The average daily tidal range at the Rainbow Bridge is 0.284 m (0.93 feet). Upstream inflows to the model from above tidal reaches were predicted by the calibrated HSPF watershed model and entered as boundary inflows to a number of tributaries. Large (>0.3 mgd) point source discharge inflows were also included in the RMA2 model as boundary inflows.

The model was first calibrated to measured water surface elevations, then to measured water velocities and flows. The parameters adjusted in calibration included the channel geometry, off-channel storage area, and Manning's N surface roughness. Calibration performance was judged first visually, then based on the root mean square error (RMSE), and essentially adjusted until no further improvement could be obtained.

INSTREAM WATER QUALITY MODEL DEVELOPMENT

For this project, the EUTRO module in WASP version 7.1 was applied to simulate both dissolved oxygen (DO) and E. coli (EC). Separate models were developed for each bayou system, and for DO and EC. Thus, a total of four WASP models were developed.
In WASP version 7.1, EUTRO can be run with various levels of complexity, simulating the transport and transformations of up to thirteen state variables: dissolved oxygen (DO), carbonaceous biochemical oxygen demand (cBOD), ammonia nitrogen (NH3N), nitrate nitrogen (NO3N), organic nitrogen (OrgN), orthophosphate phosphorus (PO4P), organic phosphorus (OrgP), phytoplankton chlorophyll a (ChlA), benthic algae, detritus (nonliving particulate organic matter), suspended and bed solids, salinity, and sediment oxygen demand (SOD). In the Adams and Cow Bayou DO models, all of these parameters were simulated except benthic algae.

The results of model calibration for DO are displayed in figures 11 and 12 for Adams and Cow Bayou, respectively. While there is some tendency in the model to overestimate the lowest DO observations and underestimate the highest observed DO levels, the models do a good job overall of simulating the range and spatial patterns of DO in the bayous. Both models make more accurate predictions of daily average DO concentrations than daily minimum concentrations. The average r-squared values were 0.902 for daily average DO and 0.859 for daily minimum DO in Adams Bayou. The root mean square error (RMSE) was 0.91 mg/L. Comparing model prediction to measured data throughout the Cow Bayou system, the average r-squared values were 0.873 for daily average DO and 0.826 for daily minimum DO. RMSE was 0.75 mg/L in the Cow Bayou system.

The Adams Bayou also did a fairly good job of simulating all parameters. The Cow Bayou model did a fairly good job of simulating all parameters except ChlA. The model did was not able to accurately simulate an algal bloom and die-off during the first intensive survey, when ChlA concentrations in middle reaches of Cow Bayou ranged from 50 to 84 µg/l, then declined rapidly to 10-20 µg/l in the same day.

The results of model calibration for EC are displayed in figures 13 and 14 for Adams and Cow Bayou, respectively. While there is significant scatter in the data, there are clear relationships between observed and predicted levels of EC. For the Adams Bayou model, the correlation r^2 value was 0.604, but only 0.344 for the Cow Bayou model. This is largely due to the fact that the range of measured EC in the Adams Bayou system (16 – 6,130 MPN/100 ml) was an order of magnitude greater than that in the Cow Bayou system (2 – 461 MPN/100 ml). Bacteria are difficult to model in part because they are living organisms that can multiply very rapidly. They also vary are also difficult to measure reproducibly, with two water samples taken simultaneously from the same volume of water sometimes yielding quite different results. Most statistics on bacteria concentration, including the primary water quality criterion for E. coli (geometric mean of 200/100 ml of water) are based on log-transformed data. The $\log_{10}$ RMSE of model predictions for the Adams Bayou EC model was 0.33 log units for the calibration period and 0.45 for the verification period. In the Cow Bayou model, the $\log_{10}$ RMSE was 0.30 log units for the calibration period and 0.39 for the verification period.

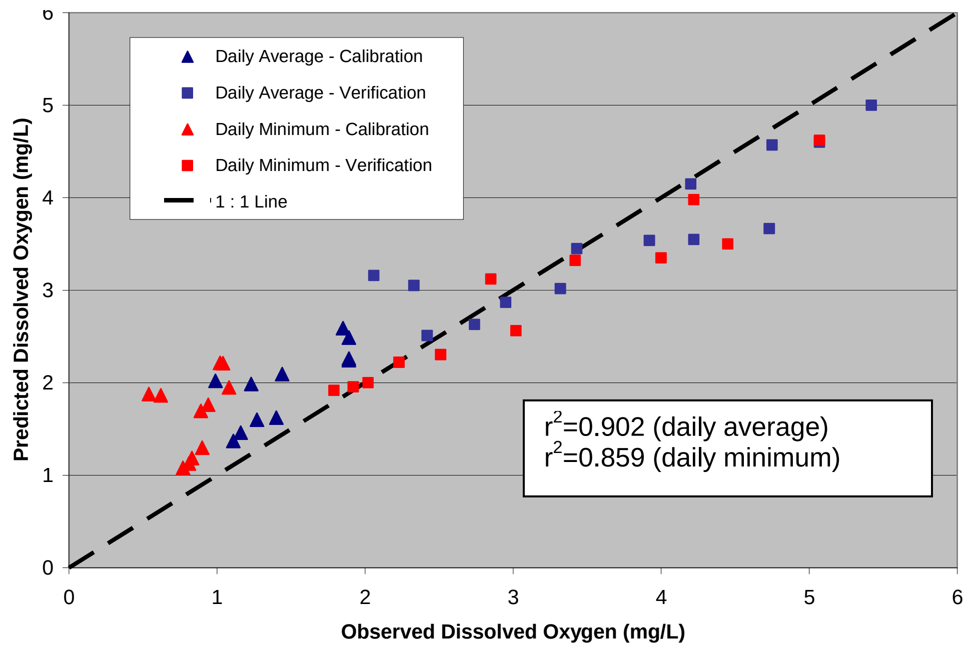

Figure 11. Adams Bayou dissolved oxygen model calibration performance

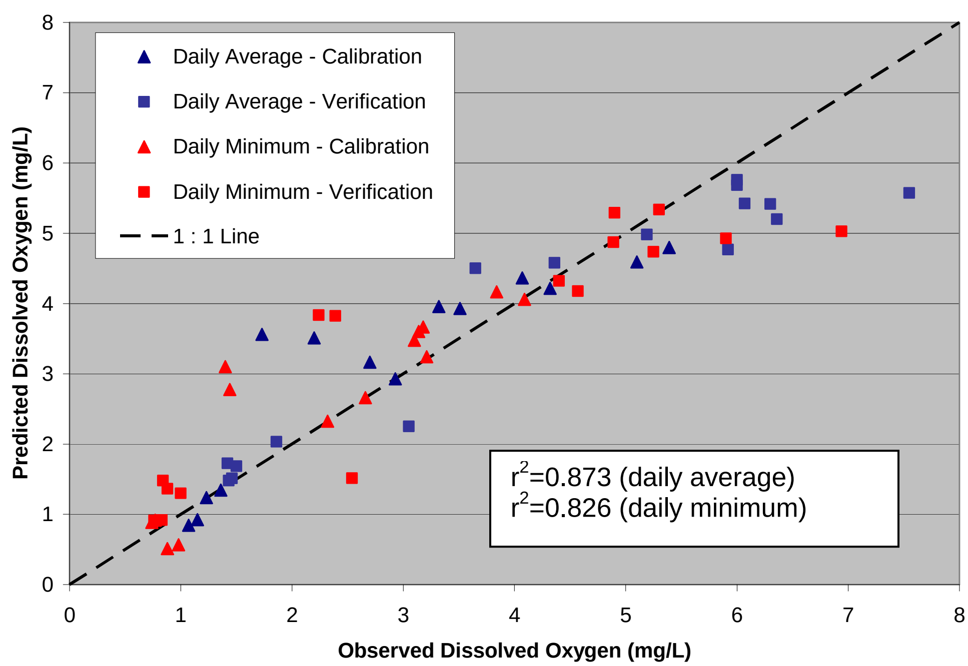

Figure 12. Cow Bayou dissolved oxygen model calibration performance

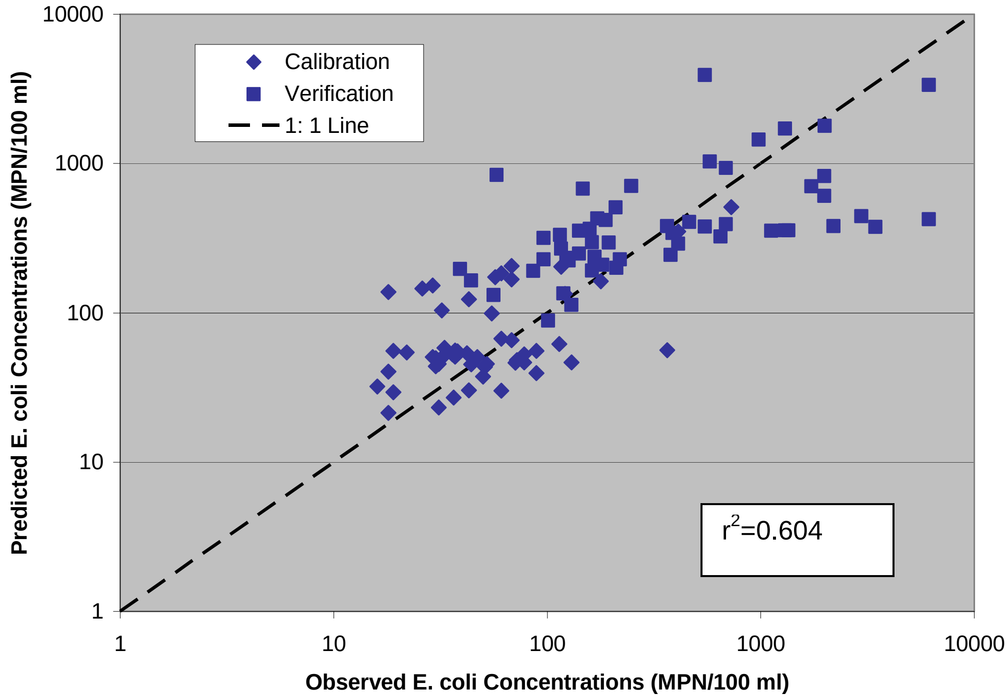

Figure 13. Adams Bayou E. coli model calibration performance – all sites

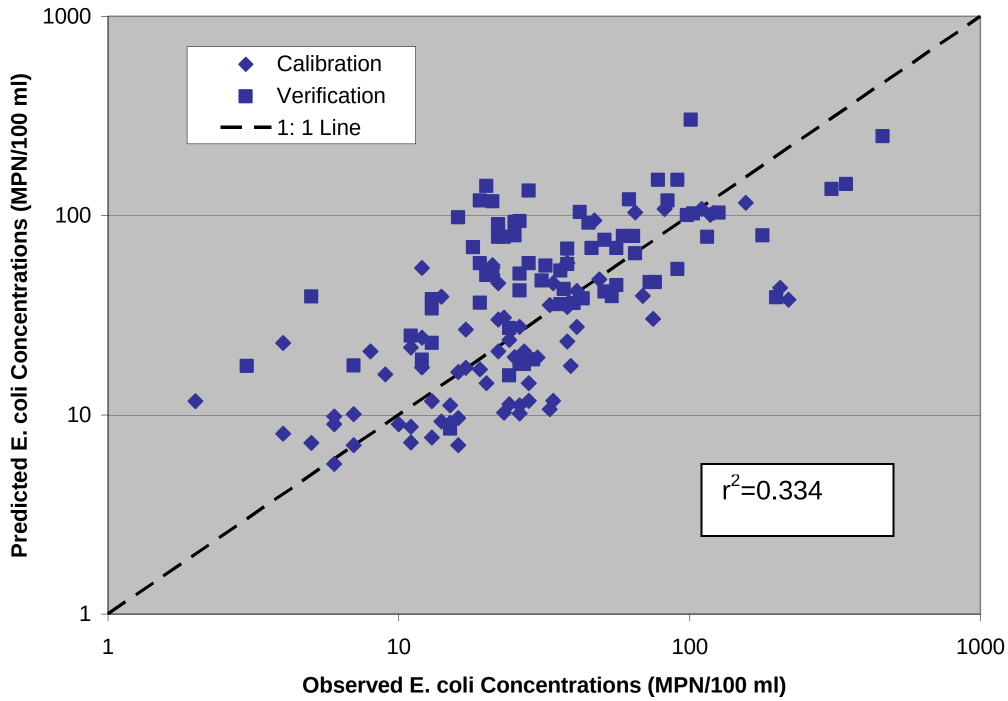

Figure 14. Cow Bayou E. coli model calibration performance – all sites

MODEL RESULTS

Following calibration and verification of the RMA2 and WASP models with 7-day simulations, longer-term simulations were performed to evaluate the reach-specific status with respect to existing impairments of water quality criteria. Additional simulations were performed with reduced pollutant loadings (e.g., 10%, 20%, .. 100% reductions) to identify the level of reductions required to meet water quality standards. The long-term period simulated was from January 1, 2002 to March 26, 2005.

Load reductions were applied uniformly to all existing loads, as the objective was not to evaluate specific pollutant sources but to calculate the TMDL, or the maximum amount of loading the waterbody could assimilate while still meeting water quality standards. EC load reductions were applied only to EC loads. For the dissolved oxygen models, however, load reductions were applied to cBOD and nutrient (NH3N, NO3N, OrgN, PO4P, OrgP) loads. All of these parameters affect instream dissolved oxygen levels, and most pollutant sources contribute both cBOD and nutrients so that a reduction in cBOD loading could not be done without a similar reduction in nutrient loading. SOD levels were also reduced by the same fraction. Because the source of SOD is water column cBOD and ammonia that have settled to the sediment bed, a reduction of cBOD and nutrient loading is expected to yield a similar reduction in SOD, albeit with some time lag.

WATER QUALITY TARGETS

The water quality standards for E. coli state that the geometric mean of EC should not exceed 126 colonies/100 ml, and single samples should not exceed 394 colonies/100 ml. Note that contact recreation criteria also exist for other indicator bacteria (enterococcus and fecal coliform), the EC criterion was selected because the water bodies addressed are primarily comprised of fresh water and fecal coliform are no longer a recommended indicator species. For the geometric mean criterion, the geometric mean of all water quality samples at each site is directly compared to the criterion to determine whether water quality standards are supported. For the single sample criterion, it is the practice of TCEQ that the standards are considered attained if less than 25% of ambient water samples from a site meet the single sample criterion. Failure to meet either the single-sample or geometric mean criteria is sufficient for a determination that water quality standards are not supported.

The water quality standards for DO require that daily average DO concentrations at any site in Cow Bayou tidal or Adams Bayou tidal must be at least 4 mg/l, and daily minimum DO concentrations must be above 3 mg/l. In Adams Bayou above tidal and Cow Bayou above tidal, the criteria are 3 mg/l and 2 mg/l for daily average and daily minimum DO concentrations, respectively. In order for water quality standards to be judged as fully supported, no more than 10% of measurements can fall below these criteria. Failure to meet either the daily average or daily minimum criterion is sufficient for a determination that water quality standards are not supported.

LOAD REDUCTIONS AND TMDLS

The load reductions required to meet the geometric mean contact recreation criteria are in all cases greater than those required to meet the single sample criterion. The required load reductions were calculated at each ambient monitoring site, and the load reductions for the segment are those from the site requiring the greatest load reductions. Required load reductions ranged from 73% in Adams Bayou to 77% in Adams Bayou above tidal. Cow Bayou tidal and Cow Bayou above tidal are projected to currently meet water quality standards for contact recreation without load reductions.

Load reductions required to meet dissolved oxygen criteria were similar throughout the Adams Bayou system ranging between 51% in Adams Bayou above tidal and 60% in Adams Bayou tidal. In the Cow Bayou system, Cow Bayou tidal is predicted to require a 69% load reduction to meet DO criteria. These load reductions were primarily required in a zone extending from the head of tide for several miles downstream. The head of tide is the upstream limit of tidal influence in a water body. In this zone, the salinity begins to be elevated above freshwater levels. The increasing salt content is believed to de-stabilize much of the suspended clay mineral load, resulting in their aggregation and deposition to sediments. Sediment oxygen demand represents a major fraction of the oxygen demand in this zone.

Cow Bayou above tidal is an interesting case. The HSPF model, used to simulate water quality in the above tidal reaches of Cow Bayou, predicts that DO criteria are not met 36% of the time. These violations of DO criteria were predicted by the model to occur when there was no flow but perennial pools in the bayou. This is known to occur somewhat frequently. Reducing cBOD loads in the model, even up to 100%, did not predict that DO levels would improve. It is not known how well the model predicts re-aeration under these “no flow” conditions. Additional field monitoring under “no-flow” conditions would be required to confirm these model predictions. Since load reductions could not be shown to lead to attainment of water quality standards, a TMDL cannot be established for this segment.

The water quality impairments are not uniformly distributed throughout the larger waterbodies such as Cow Bayou tidal, Adams Bayou tidal, and Cow Bayou above tidal. Neither are the pollutant loads mixed throughout the waterbodies, and assimilative capacity often varied greatly with distance from the Sabine River. The load reductions described apply only to the case where a single uniform load reduction percentage is applied to all pollutant sources to the waterbody. The actual load reductions required to allow water quality standards to be met will vary with the pollutant source, and reducing some specific loads may not result in improved water quality. The models may be used to evaluate the impact of varying load reductions on a source-specific basis. Following adoption of the TMDL by the TCEQ, an implementation plan will be developed with stakeholders in the watershed to reduce pollutant loads to the bayous.

Table 1. Summary of load reductions required to meet water quality standards for DO and EC

Waterbody	cBOD, nutrients	EC
Adams Bayou tidal	60%	73%
Adams Bayou above tidal	51%	77%
Cow Bayou tidal	69%	0%
Cow Bayou above tidal	?	0%

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