SAMPLING PLAN FOR MODELING TO SUPPORT TMDL DEVELOPMENT IN ADAMS BAYOU TIDAL (SEGMENT 0508), COW BAYOU TIDAL (SEGMENT 0511) AND THEIR TRIBUTARIES

INTRODUCTION

The goal of this effort is to provide sufficient data for the calibration and verification of a water quality model to support development of total maximum daily loads (TMDLs) for *E. coli* bacteria and dissolved oxygen in Adams Bayou and its tributaries Gum Gully and Hudson Gully, and for a second water quality model to support development of TMDLs for *E. coli* bacteria, dissolved oxygen, and pH in Cow Bayou and its tributaries, Coon Bayou, Cole Creek, and Terry Gully.

The historical and current water quality data for the water bodies under investigation were assessed in detail in a companion report entitled *Assessment of Water Quality Impairments in Adams Bayou Tidal (Segment 0508), Cow Bayou Tidal (Segment 0511) and Their Tributaries (Parsons 2002)*. The report concluded that a review of ambient water quality data collected in the latest 5-year period indicated a high degree of confidence (>99%) that dissolved oxygen criteria are not met in portions of Segments 0508, 0508A, 0508C, 0511, 0511A, and 0511B. Similarly, data indicated with a high degree of confidence that fecal coliform criteria are not met in portions of Segments 0508, 0508A, 0508B, 0508C, 0511B, and 0511E. There is a small chance (about 5%) that the decision that the minimum pH criterion was not met in Cow Bayou Tidal was incorrect.

The selection of appropriate water quality models for development of these TMDLs was addressed in a technical memorandum entitled *Model Evaluation and Selection for TMDL Development in Adams Bayou Tidal (Segment 0508), Cow Bayou Tidal (Segment 0511) and their Tributaries.* This memorandum concluded that both a watershed and a receiving water model would be required for TMDL development. The dissolved oxygen depletion in these bayous appears to be largely controlled by sediment oxygen demand (SOD) and its concomitant depositional patterns throughout the bayous. An increased SOD zone midway through each bayou generally corresponds to the areas of maximum freshwater/saltwater mixing at the head of the oscillating tidal wedge. This is an area of rapidly changing electrochemical potential due to steep salinity gradients that often produces chemical and physical flocculation and coagulation. This can, in turn, effectively sweep suspended, and in some cases dissolved, oxygen-demanding materials out of the water column, deposit them into the sediments, and produce augmented SOD. The exacerbated bacterial respiration associated with this SOD is likely also responsible for the accompanying pH depression. The sources of both bacteria and the oxygen-demanding materials in the water column that eventually settle to produce the SOD are both point and nonpoint, but episodic nonpoint loading is believed to dominate the loads in most areas.

On the basis of several criteria, HSPF was determined to be the most appropriate watershed model, and WASP (using DYNHYD or EFDC as the hydrologic component) was determined to be the most appropriate receiving water model. The important processes that require modeling are discussed below.

MODEL PROCESSES

The important processes controlling dissolved oxygen, pH, and *E. coli* concentrations that are considered in the selected models include:

- re-aeration of the water column with atmospheric oxygen
- carbonaceous BOD - bacterial respiration of dissolved and particulate organic matter in the water column
- nitrification - bacterial-mediated oxidation of ammonia to nitrate (nitrogenous BOD)
- denitrification – conversion of nitrate to nitrogen gas (more important in sediments)
- settling of particulate CBOD to sediments
- re-suspension of particulate CBOD from sediments
- algal photosynthesis
- algal respiration
- algal death and decomposition
- sediment oxygen demand - bacterial respiration of organic matter in the sediments
- E. coli die-off
- E. coli settling
- E. coli re-suspension

Some processes not explicitly considered in the model include groundwater exchange, atmospheric deposition, photosynthesis and respiration by aquatic macrophytes, *E. coli* regrowth, sediment diagensesis, and chemical oxidation of iron, manganese, sulfide, and other redox-sensitive substances. Not all of these processes may be critically important in Adams Bayou and Cow Bayou. It is considered best to develop the simplest model that includes all the important processes affecting the observed water quality problems (USEPA, 1991). Thus, some less important processes, such as algal photosynthesis and respiration, may be de-emphasized in the models developed for Adams Bayou and Cow Bayou. Also, processes such as *E. coli* die-off, settling, and re-suspension may be combined to an overall net *E. coli* decay rate.

The rates and parameters required by these models are listed in Table 1. The values of these rates and parameters required by the model can be derived from several sources. They can be:

1. measured in the system being modeled,
2. calculated based on other more easily measurable parameters using established empirical or theoretical relationships, or
3. estimated based on measured values from other systems found in the scientific literature, or adjusted to achieve the best fit to observed response variables during calibration.

While models can be developed and run with few measurements in the system being modeled, their predictions are subject to large uncertainty (USEPA, 1990). To achieve the most accurate model and reduce uncertainty, it is best to measure as many of the key rates and parameters as possible in the system being modeled. Table 1 presents a recommended sampling plan to support the modeling effort, reflecting the modeler's subjective opinion of the most cost-effective approach to achieving a defensible model.

Table 1. Key Model Parameters and their Sources

Process	Parameter	Source of Parameter Estimate			Calculation Basis and Other Notes
		Measured	Literature values or model calibration	Calculated from other parameters	
re-aeration	re-aeration rate			√	water velocity, depth, wind speed, air & water temperature, salinity
carbonaceous BOD oxidation	CBOD conc.	√			
	CBOD oxidation rate constant and temp. coefficient		√		
	CBOD half-saturation constant		√		
nitrification	ammonia nitrogen conc.	√			
	nitrification rate constant and temp. coefficient		√		
	nitrification half saturation constant		√		
denitrification	nitrate nitrogen conc.	√			
	denitrification rate constant and temp. coefficient		√		
	denitrification half saturation constant		√		
organic carbon (as CBOD) settling	CBOD particulate fraction	√			
	particulate CBOD settling velocity			√	particle size and density, water velocity
re-suspension	upward re-suspension velocity		√		
algal photosynthesis, respiration, death, and decomposition	algal carbon			√	measured chlorophyll A with literature OC:ChlA ratios
	algal growth rate constant and temperature coefficient		√		

Process	Parameter	Source of Parameter Estimate			Calculation Basis and Other Notes
		Measured	Literature values or model calibration	Calculated from other parameters	
	algal respiration rate constant and temp. coefficient		√		
	algal death rate constant and temp. coefficient		√		
sediment oxygen demand	sediment oxygen demand	√			
	CBOD oxidation rate constant and temp. coefficient		√		
	Sediment denitrification rate constant and temp. coefficient		√		
	Sediment algal decomposition rate constant and temp. coefficient		√		
	diffusive exchange coefficient		√		
	active surface sediment layer thickness	√			
	sediment porosity, density, and grain size (% sand, silt, clay)	√			
	sediment-water interfacial area			√	channel width, average depth
E. coli settling	E. coli settling rate		√		
E. coli re-suspension	E. coli resuspension rate		√		
E. coli die-off	E. coli die-off rate		√		
Wasteloads	DO, EC, pH, Cl-, TSS, VSS, temp., salinity, alkalinity, $CBOD_5$, NO_3-N, NH_3-N, TKN, TP, OP, discharge	√			

Process	Parameter	Source of Parameter Estimate			Calculation Basis and Other Notes
		Measured	**Literature values or model calibration**	**Calculated from other parameters**	
NPS Loads	DO, EC, pH, Cl^-, TSS, VSS, temp, salinity, alkalinity, $CBOD_5$, NO_3-N, NH_3-N, TKN, TP, OP, discharge	√	√	√	utilization of literature values, long-term gage and precipitation data together with a limited amount of runoff monitoring to assist in calibrating the model for NPS loading
Boundary concentrations	DO, EC, pH, Cl^-, TSS, VSS, temp, salinity, alkalinity, discharge, $CBOD_5$, NO_3-N, NH_3-N, TKN, TP, OP, ChlA	√			
in-stream conditions	DO, EC, pH, Cl^-, TSS, VSS, temp, salinity, alkalinity, $CBOD_5$, NO_3-N, NH_3-N, TKN, TP, OP, ChlA, flow	√			Measured in the epilimnion and hypolimnion in areas with vertical stratification
hydrography	surface elevation	√			
	bottom elevation			√	surface elevation - depth
	surface area	√			
	volume			√	surface area x mean depth
	channel length, depth, width, and cross-sectional area	√			
	Manning's roughness coefficient		√		
	channel orientation	√			
	wind speed and direction	√			acquired data
	channel hydraulic radius			√	~ depth for wide channels
	mean channel velocity	√			

Process	Parameter	Source of Parameter Estimate			Calculation Basis and Other Notes
		Measured	Literature values or model calibration	Calculated from other parameters	
	tidal height versus time at downstream boundary	√			
	Cl^-, salinity, or conductivity	√			
meteorology	hourly precipitation	√			acquired data
	daily pan evaporation	√			acquired data
	daily min and max temperature	√			acquired data
	daily wind movement (speed and direction)	√			acquired data
	daily solar radiation	√			acquired data
	dew point temperature	√			acquired data
	average daily cloud cover	√			acquired data
watershed properties	digital elevation model	√			acquired data
	land use delineation	√			acquired data
	soils delineation, characteristics	√			acquired data
hydrography	channel length, width, and cross-sectional area	√			
	surface elevation	√			
	bottom elevation			√	surface - mean depth
	sediment particle size distribution	√			
	water diversions and point source discharges	√			acquired data
	contributing drainage area for each reach	√			

Table 2. Summary of Laboratory-Measured Parameters

Parameter	Sample Type	Total Sample Count#			
		Ambient†	Effluent†	Storm‡	Sediment
carbonaceous biochemical oxygen demand ($CBOD_5$)	water	374	26	84	0
ultimate biochemical oxygen demand (UBOD)	water	12	26	0	0
ammonia nitrogen (NH_3-N)	water	374	26	84	0
nitrate+nitrite nitrogen (NO_3+NO_2-N)	water	374	26	84	0
total Kjeldahl nitrogen (TKN)	water	374	26	84	0
ortho-phosphorus (OP)	water	374	26	84	0
chlorophyll A (ChlA)	water	134	0	0	0
total suspended solids (TSS)	water	374	26	84	0
volatile suspended solids (VSS)	water	374	26	84	0
E. coli (EC)	water	374	26	84	0
alkalinity, total and phenolphthalein	water	374	26	84	0
grain size (% sand, silt, & clay)	sediment	0	0	0	24
total percent solids (%solids)	sediment	0	0	0	24
volatile solids (VS)	sediment	0	0	0	24

includes quality control samples

† total includes four intensive surveys, two for each bayou system, with each lasting 48 hours.

‡ total includes two storm events at six or seven sites, which would be sampled in groups of two or three. Approximately ten to eighteen samples would be generated on a sampled day.

DATA COLLECTION CONSIDERATIONS

1. Model Duration and Temporal Resolution

Due to the nature of the impairment, a dynamic water quality simulation was recommended in the model selection technical memorandum. Because of the impact of the tidal cycle and the necessity to simulate storm runoff, the model timestep should be from one to three hours, and sampling should occur at least every 3 hours at most sites. Whenever possible, all locations should be sampled synoptically (USEPA, 1990).

The period being modeled has a strong influence on the sampling plan. There are several considerations in determining the length of this period. Of course, the shortest sufficient duration is preferable to the extent that it reduces the level of effort in collecting the data required by the model. The important considerations include the size of the domain being modeled versus the hydrologic time of travel, the time scale of hydrologic and reaction kinetics being simulated, and the time scale of the regulatory limits used as the water quality target. The model simulation duration should also be long enough to eliminate the effects of the initial conditions on important water quality constituents at critical locations (USEPA, 1990). In a tidally-influenced system, the model duration should include at least two full tidal cycles (Brown and Ecker 1978).

Water time of travel was measured to be 0.272 feet per second in above tidal reaches of Cow Bayou in a 1986 intensive survey (Kirkpatrick 1988). At this rate, water would move approximately four and a half miles per day. Given that the total length of Cow Bayou is over 30 miles in length, approximately seven days would be required for water to flow from the headwaters to the Sabine River at this rate. The reversing tidal flows would tend to lengthen this period, while higher runoff flows would shorten it. Time of travel has not been measured in Adams Bayou, but Adams Bayou is substantially shorter.

The key reaction kinetics to be simulated are believed to include the re-aeration of the water column with atmospheric oxygen, die-off and settling of E. coli bacteria, bacterial respiration of organic matter in the water column, particulate BOD settling, nitrification, and bacterial respiration of organic matter in the sediments. BOD settling was found to be among the slowest kinetic factors in the 1986 waste load allocation for Adams and Cow Bayous, with rates of 0.05-0.15 day^{-1}. At a rate of 0.1 day^{-1}, 23 days would be required for 90% of the particulate BOD to settle. Thus, the hydraulic residence time limits the BOD settling. Ammonia nitrification and bacterial BOD respiration in the water column and sediments can also be limiting kinetic factors.

For practical reasons, the intensive data collection effort must be limited to approximately 48 hours, a sufficient period to allow for two complete tidal cycles. A maximum four-hour time period between measurements at each site is recommended, with suspended sampling in the dark. However, some sites should be monitored with 24-hour recording sondes to achieve continuous water level and water quality data. Other sites, such as some boundary or oxbow stations, may have reduced sampling.

2. Watershed Model and Nonpoint Source Loading

Due to the important impacts of nonpoint sources of fecal coliform and oxygen demanding substances, monitoring of runoff events for quantification of pollutant loads is recommended to assist in calibration of the HSPF watershed model. Ideally, the monitoring should include the in-stream response to the runoff loads and return to base flow conditions, when dissolved oxygen levels tend to be lowest. This is considered the situation most reflective of the impairments observed here, and would likely provide the most accurate model predictions. The probability of rainfall events of various magnitudes is given in Table 2. On average, a one-half inch rainstorm occurs approximately weekly in July. A one-half inch rainstorm is likely to produce measurable runoff. Review of precipitation and stream flow data for Cow Bayou indicates that three to five days are typically required following a significant runoff event to return to low flow conditions. Thus, an intensive survey covering a rainfall event and recovery to base flow conditions would likely require a full week of data collection. This type of sampling effort is precluded by the length of the sampling period, the uncertainty of rainfall, and the intensity of effort required to simultaneously measure runoff loads and the in-stream response. Instead, we plan to calibrate the in-stream model under low-flow conditions, and develop the watershed model separately. This will simplify scheduling, reduce the amount of personnel and equipment required, and reduce the expense.

In order to assist in quantifying runoff flows and nonpoint-source pollutant loads for the watershed model, runoff loads will be measured on six Adams and Cow Bayou tributaries that drain sub-watersheds with a variety of different land uses. Each site will be monitored twice, and antecedent dry periods will vary to estimate pollutant buildup and washoff parameters. In addition to this data, long-term records of rainfall and flow in Cow Bayou will be used to calibrate flow in the watershed model.

Table 3. Precipitation Frequency in the Orange County TMDL Project Area (from Miller and Frederick, 1966)

Month	Normal Number of 24-hour Periods with Specified Rainfall		
	0.5”	1”	2”
June	2.5 − 3	1.25 − 1.5	0.5 − 0.6
July	4 − 4.5	~ 2.5	0.8 − 1
August	3 − 3.5	1.5 − 1.75	~ 0.6
September	~ 3	1.5 − 1.75	~ 0.6

3. One-, Two-, or Three-Dimensional Model

The most basic in-stream WASP model would treat the stream as a horizontally and vertically well-mixed system, with a single upstream-downstream dimension. However, Adams and Cow Bayous are tidal systems with salinity-based density stratification. In other similar systems, a saltier wedge of water has been found to move up and down the bayou during a tidal cycle, with less dense freshwater flowing above it. In some cases, these two water layers flow in opposite directions. Because mixing between the surface and deeper waters may be very limited, the assumptions of a one-dimensional model are likely violated. Thus, a two-dimensional model including surface and deeper water masses will likely be required. This will not entail a great deal of additional modeling effort, but will require ambient water sampling of the surface and deeper waters, and vertical profiles of field parameters and flow, at stations where vertical stratification is present.

The oxbows comprising the historical river channel prior to its dredging create another potential difficulty for modeling. The oxbows are an additional reservoir of water. With the tidal cycle, water will move from these oxbows into the main channel and back. A portion of the flow down the stream may also travel through the oxbows rather than the main channel. From a modeling standpoint, the oxbows are expected to cause a time lag in changes of the concentrations of water quality constituents. This may hinder calibration of the model. The model can be modified to account for the oxbows, but additional hydrologic and water quality data must be collected in the oxbows to calibrate this three-dimensional model. Because we do not know the impact of the oxbows on flow and water quality, it is recommended that a limited amount of sampling on oxbows be performed to allow calibration of the three-dimensional model.

4. Model Calibration, Validation, and Analysis

Model calibration alone is not sufficient to determine the predictive capability of a model. Model confirmation testing, or validation, should be performed, using an ambient water quality data set independent from that used for calibration (USEPA, 1990). Thus, water quality monitoring should ideally include two separate and independent events, with one used to calibrate the model and the second to verify that the model adequately predicts water quality conditions. However, the cost of a second intensive survey on each bayou will be substantial. The availability of funding will dictate whether this independent model validation is performed.

5. Use of Existing Data

Some of the values required by the models have been measured in previous surveys of Adams and Cow Bayous. These values include:

- water quality constituent measurements in point source effluents, rainfall runoff, and in-stream locations;
- flow, cross-section, velocity, and time-of-travel measurements at in-stream locations;
- meteorology;
- primary productivity measurements in Cow Bayou;
- sediment oxygen demand measurements in Cow Bayou; and
- tidal measurements in Cow Bayou.

There are several problems with using the existing data to develop a water quality model. Most of the data was not collected on a synoptic basis, or at sufficient temporal resolution to allow calibration of a dynamic water quality model. Very little of the existing data includes coverage of upstream reaches and all the tributaries to be addressed for these TMDLs. The available data from intensive surveys that was collected on a synoptic basis is, for the most part, fifteen to twenty years old. Numerous changes have occurred since that time in wastewater discharges, nonpoint pollutant sources, and possibly flow and hydraulic properties of the bayous. The existing data from intensive surveys was collected in support of a steady-state model, which has different data requirements than a dynamic model. However, the existing data will be useful to guide selection of appropriate estimates for model parameters.

6. Coordination and Collaboration with Other Data Collection Efforts

Table 4 describes the data that will be collected independent of this TMDL project starting in 2003. These efforts could provide a significant portion of the data required for the Cow Bayou model, if the two data collection efforts can be scheduled to coincide with each other and share data. All efforts should be made to achieve this co-scheduling for Cow Bayou.

SUGGESTED DATA COLLECTION

Stormwater Measurements to Assist in Calibration of a Watershed Loading Model

Table 5 lists seven stormwater monitoring sites (displayed in Figure 1), from which six will be selected for monitoring based on site accessability and security considerations. The selected sites to be monitored are on non-tidal tributaries of Adams and Cow Bayou that have minimal or no point source wastewater inputs. The sites monitored include both rural and urban watersheds.

It is considered optimal, in calibrating a runoff model, if one of the two events sampled at each site has a short antecedent dry period before runoff sampling, while the other event sampled has a longer antecedent dry period. In practice, it may be difficult to achieve these conditions, and given that autosamplers are rented by the week and their installation at a site can be time-consuming, it is expected that all satisfactory rainfall samples will be acceptable. Over the course of the sampling, a sufficiently varied mix of short and long antecedent period rainfall events will likely be sampled to allow model calibration.

Sediment Oxygen Demand Measurements to Assist Calibration of the Instream Water Quality Models

Because SOD appears to be the proximate factor responsible for oxygen depletion, it will strongly influence the model. While SOD is difficult to accurately measure, a measured but approximate estimate is preferable to a baseless guess to bracket the range of potential SODs for the model. SOD will be measured at a number of stations, listed in Table 6 and displayed in Figure 2, in each of the designated portions of Adams and Cow Bayou. Because spatial heterogeneity in sediments can be much more substantial than temporal variation in sediments, SOD will be measured at a given station on only a single occasion, but at two or three adjacent locations at each station (e.g., 10-50 feet apart on a stream transect). In addition to SOD, sediment samples will be collected for laboratory analysis of volatile solids (primarily organic matter), total solids content, and grain size. Additionally, the active benthic layer thickness will be visually estimated from sediment cores.

Instream and Effluent Measurements as part of Intensive Surveys

Instream flow and ambient water quality measurements suggested as part of an intensive survey of Adams Bayou are listed in Table 7, displayed in Figure 3, and synoptic Adams Bayou effluent measurements are listed in Table 8. Instream flow and ambient water quality measurements suggested as part of an intensive survey of Cow Bayou are listed in Table 9, displayed in Figure 4, and synoptic Cow Bayou effluent measurements are listed in Table 10. For these ambient water quality measurements, vertical profiles of field parameters should be collected. In the case that the water column is stratified, water quality samples should be collected from both the epilimnion and hypolimnion (i.e., one foot below the surface and one foot above the bottom).

Budget

Because this sampling effort will be carried out by two entities, the Sabine River Authority and Parsons, it is difficult to determine an overall budget for this work. Parsons and the Sabine River Authority will separately provide their budgets for the portion of the work they will perform. However, it is believed that the data collection effort outlined in this plan can be completed for between $300,000 and $400,000.

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Table 4. Planned Water Quality Monitoring in Adams and Cow Bayous, 2003, External to this Project

Station ID	Site Description	Start Date	End Date	SC1/ SC2	Prog Code	Monitoring Frequency (Per Year)							
						24hr Field[1]	Flow[2]	Aquatic Habitat	Benthic Infauna	Routine Nekton	Bact.	Conv[3]	Field[4]
17877	Cow Bayou tidal approx 2.2 km upstream of SH 87 in original stream channel	Spring 2003	Fall 2004	PW/PW	TI TO	6	6	1 during study	3	6		6	6
10451	Cow Bayou at SH 87	Spring 2003	Fall 2004	PW/PW	TI TQ	6	6	1 during study	3	6		6	6
10454	Cow Bayou 50 yds downstream of Cole Creek	Spring 2003	Fall 2004	PW/PW	TI TQ	6	6	1 during study	3	6		6	6
10446	Cow Bayou approximately 2400 feet above confluence with the Sabine River	Spring 2003	Fall 2004	PW/PW	TI TQ	6	6	1 during study	3	6		6	6
10441	Adams Bayou at FM 1006 in Orange, TX, Subwatershed 1.03 (AB2)	September 2002	August 2003	SR/SR	IS						12	12	12
15107	Adams Bayou at FM 3247 NW of Orange, TX Subwatershed 1.03 (AB7)	September 2002	August 2003	SR/SR	DI IS	2					12	12	12
10449	Cow Bayou At FM 1442 (downstream crossing, Round Bunch Rd) east of Bridge City, TX , SW 1.02 (CB1)	September 2002	August 2003	SR/SR	IS						12	12	12
13781	Cow Bayou At FM 1442 (North Crossing) Between FM 105 And IH10, Subwatershed 1.02 (CB4)	September 2002	August 2003	SR/SR	DI IS	2					12	12	12

[1]24hr. Field Measurements: temperature, dissolved oxygen, specific conductance, salinity, depth, and pH, recorded every half hour with a logging sonde at two depths: 0.3 meter, and 1 meter above the bottom.

[2]Flow: recording Acoustic Doppler flow meter installed for at least 24 hours at Station 10446, with instantaneous flows at other stations

[3]Conv.:may include total dissolved solids, chloride, sulfate, total suspended solids, volatile suspended solids, 5-day carbonaceous biochemical oxygen demand, total organic carbon, chlorophyll A, pheophytin A, total Kjehdahl nitrogen, ammonia nitrogen, nitrate+nitrite nitrogen, total phosphorus, and orthophosphate.

[4]Field: temperature, dissolved oxygen, pH, specific conductance, salinity, depth, days since last significant rainfall, flow, flow severity, and Secchi depth.

Table 5. Stormwater Measurement Stations

Station ID	Site Description	Number of Events	Area (km^2)	Land Use
16058	Cow Bayou at Jasper CR 826	2	120	70% forest, 12% pasture, 9% wetlands, 6% transitional, 3% developed
TBD	Dognash Gully at County Road 826	2	51	67% forest, 25% wetlands, 5% pasture, 1% developed, 1% transitional
16060	Cole Creek at IH-10	2	32	64% forest, 21% pasture, 7% developed, 6% wetlands, 1% open water
16040	Terry Gully at IH-10	2	10	65% forest, 19% developed, 15% pasture, 1% wetlands, 1% open water
16049	Gum Gully at Halliburton Rd. (GG)	2	9	47% pasture, 38% forest, 12% wetland, 2% developed, 1% open water
16041	Hudson Gully at Lexington (HG)	2	7	37% developed, 36% pasture, 23% forest, 2% wetland
16053	Adams Bayou Lateral #8 at Bancroft Road (AL8)	2	6	58% pasture, 22% forest, 9% open water, 8% developed, 3% wetland

Note: six of these seven sites wil be selected for stormwater measurements based on site access and safety considerations. Station 16053 is included as an alterante site.

Table 6. Sediment Oxygen Demand Measurements to Calibrate the Instream Water Quality Model

Station ID	Site Description
15107	Adams Bayou at FM 3247 (AB7)
10443	Adams Bayou at IH 10 (AB6)
14990	Adams Bayou at Park Ave. (AB5)
16059	Adams Bayou at Green Ave. (AB4)
10442	Adams Bayou at Western Ave. (AB3)
10441	Adams Bayou at FM 1006 (AB2)
10337	Cow Bayou at SH12 (CB6)
10457	Cow Bayou at IH 10 (CB5)
13781	Cow Bayou at FM 1442 North Crossing (CB4)
10453	Cow Bayou at FM 105 (CB3)
10451	Cow Bayou at SH 87 (CB2)
10449	Cow Bayou At FM 1442 (CB1)

Table 7. Ambient Water Quality Stations to be Monitored as part of an Intensive Survey of Adams Bayou to Calibrate the Instream Water Quality Model

Station ID	Site Description	24 hr Field	Instantaneous Field	Flow/ Hydrography	Conv. + Bact. Grab
14964	Adams Bayou at FM 1078 (AB8)	√		√	√
15107	Adams Bayou at FM 3247 (AB7)		√	√	√
10443	Adams Bayou at IH 10 (AB6)	√		√	√
14990	Adams Bayou at Park Ave (AB5)		√	√	√
16059	Adams Bayou at Green Ave (AB4)	√		√	√
10442	Adams Bayou at Western Ave (AB3)		√	√	√
10441	Adams Bayou at FM 1006 (AB2)	√		√	√
TBD	Sabine River at confluence with Adams Bayou		√		√
16049	Gum Gully at Halliburton Rd (GG)	√		√	√
16041	Hudson Gully at Lexington (HG)		√	√	√
16056	Adams Bayou Lateral #8 at Bancroft Rd. (AL8)*		√	√	√
16057	Adams Bayou Lateral #1 at FM 2177 (AL1)*		√	√	√
16053	Adams Bayou Lateral #2 at Flint Rd. (AL2)*		√	√	√
TBD	Adams Bayou oxbow #11*		√	√	√
TBD	Adams Bayou oxbow #12*		√	√	√

*conventional parameters and flow will be measured at a reduced frequency on some oxbow and tributary stations

Table 8. Effluents to be Monitored as part of an Intensive Survey of Adams Bayou to Calibrate the Instream Water Quality Model

Effluent samples would be collected twice per intensive survey, once per day. Measurements at each site would include field parameters, as well as samples for conventional and bacteria analysis. Wastewater flow measurements of each facility would be measured or acquired from each facility, if available.

Station ID	Site Description
16044	Orange County WCID #2 WWTP (AW2) - Permit WQ0010240.001
16043	City of Pinehurst WWTP 001 (AW3) - Permit WQ0010597.001

Table 9. Ambient Water Quality Stations to be Monitored as part of an Intensive Survey of Cow Bayou to Calibrate the Instream Water Quality Model

Station ID	Site Description	24 hr Field	Instantaneous Field	Flow/ Hydrography	Conv + Bact Grab
16058	Cow Bayou at Jasper CR 826 (CB7)		√	√	√
10337	Cow Bayou at SH12 (CB6)	√		√	√
10457	Cow Bayou at IH 10 (CB5)		√	√	√
16060	Cole Creek at IH 10 (CC)		√	√	√
13781	Cow Bayou at FM 1442 North Crossing (CB4)	√		√	√
10454	Cow Bayou 50 yds downstream of Cole Creek		√	√	√
10453	Cow Bayou at FM 105 (CB3)	√		√	√
10452	Cow Bayou halfway between FM 105 and SH 87		√	√	√
10451	Cow Bayou at SH 87 (CB2)	√		√	√
10449	Cow Bayou At FM 1442 (CB1)		√	√	√
TBD	Cow Bayou approx. 8500 ft upstream from Sabine River	√		√	√
10392	Sabine River at confluence with Cow Bayou		√		√
16052	Coon Bayou at SH 87 (CNB)		√	√	√
TBD	Terry Gully at FM 1442		√	√	√
TBD	Cow Bayou Oxbow 2*		√	√	√
TBD	Cow Bayou Oxbow 3*		√	√	√
17877	Cow Bayou tidal approx 2.2 km upstream of SH 87 in original stream channel (Oxbow 4*)	collected by TPWD staff			

*conventional parameters and flow will be measured at a reduced frequency on some oxbow and tributary stations

Table 10. Effluents to be Monitored as part of an Intensive Survey of Cow Bayou to Calibrate the Instream Water Quality Model

Effluent samples would be collected twice per intensive survey, once per day. Measurements at each site would include field parameters, as well as samples for conventional and bacteria analysis. Wastewater flow measurements of each facility would be measured or acquired from each facility, if available.

Station ID	Site Description
16068	City of Bridge City WWTP 001 (CW1) - Permit WQ0010051.001
16063	Orangefield ISD WWTP (CW5) - Permit WQ0011607.001
16064	PCS Development Co (CW8) – Permit WQ0011916.001
16062	Oak Terrace WWTP 001 (CW10) - Permit WQ0011357.001
16045	Jasper WCID #1 WWTP 001 (CW13) - Permit WQ0010808.001
16047	Bayer Corp. COBR Outfall 001 (CI1) - Permit WQ0001167.001
16070	Bayou Pines Park (Edward N. Smith, Jr.) – Permit WQ0011315.001
16066	TXDOT Orange Co. Comfort Station – Permit WQ0011457.001
16073	Firestone Polymers Inc. Outfall 001 (CI4) - Permit WQ0000454.001
16074	Chevron Phillips Chemical Co. (CI3) - Permit WQ0000359.001
TBD	Honeywell International Outfall 001 - Permit WQ0000670.001

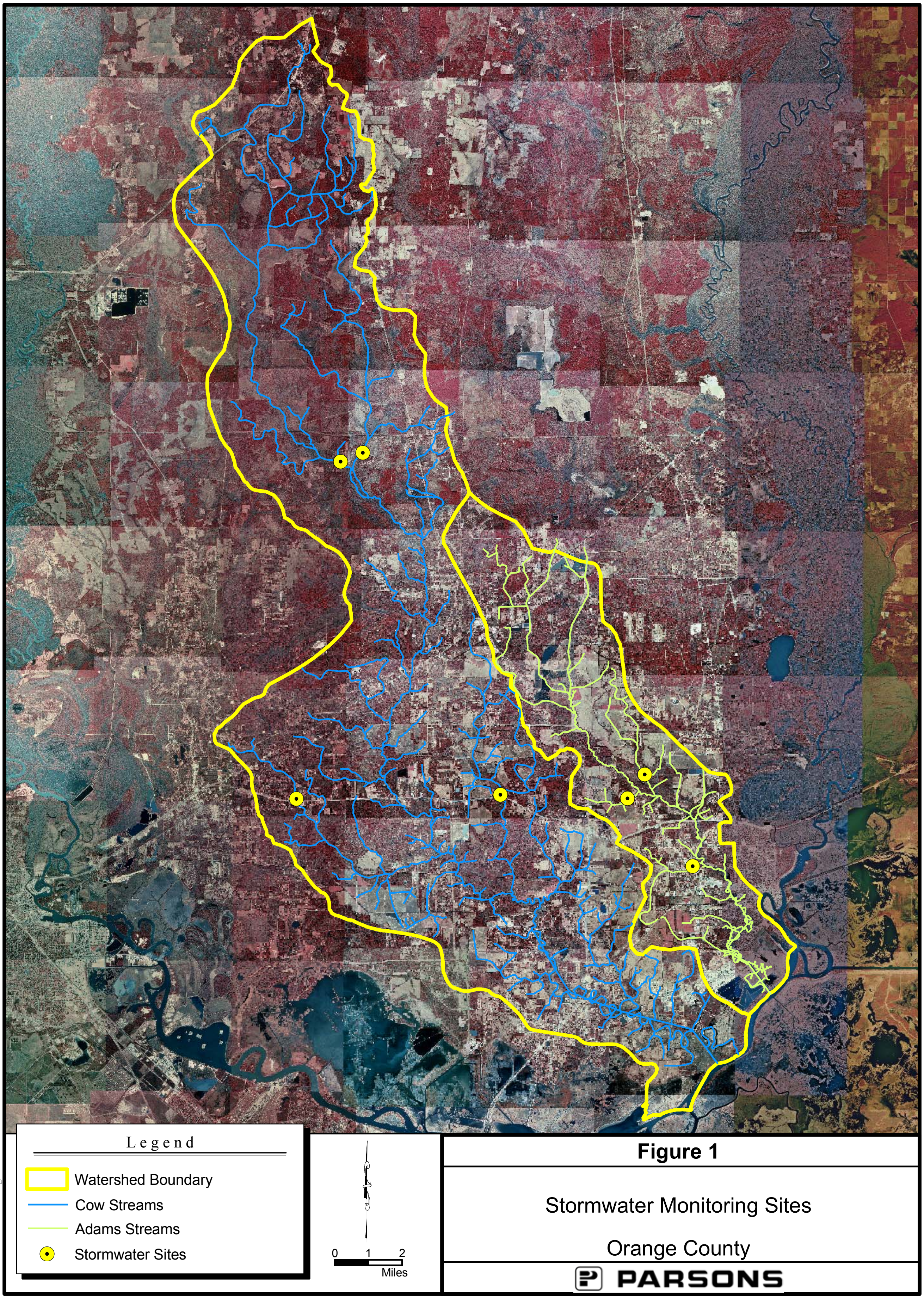


Figure 1

Stormwater Monitoring Sites

Orange County

PARSONS

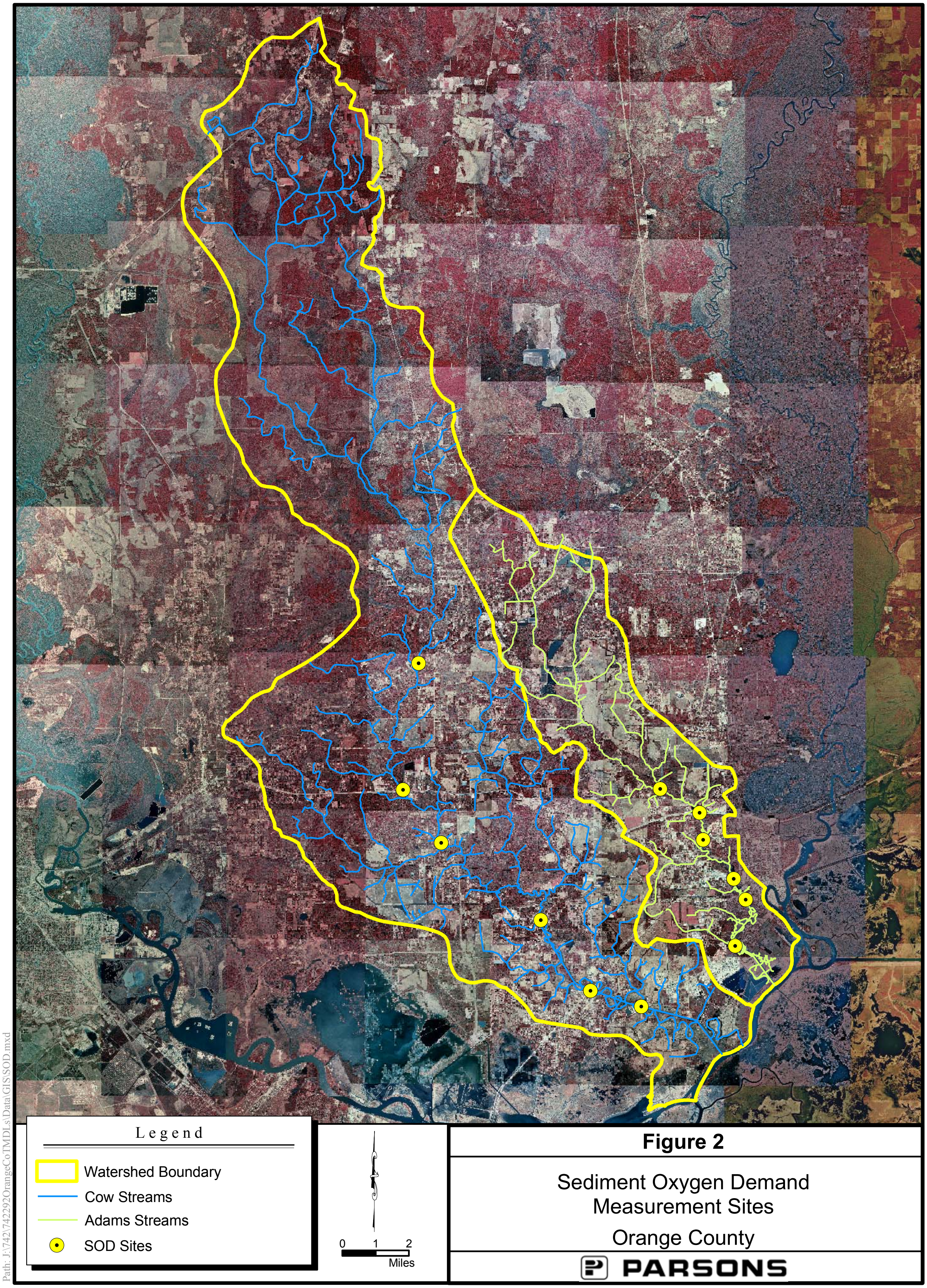
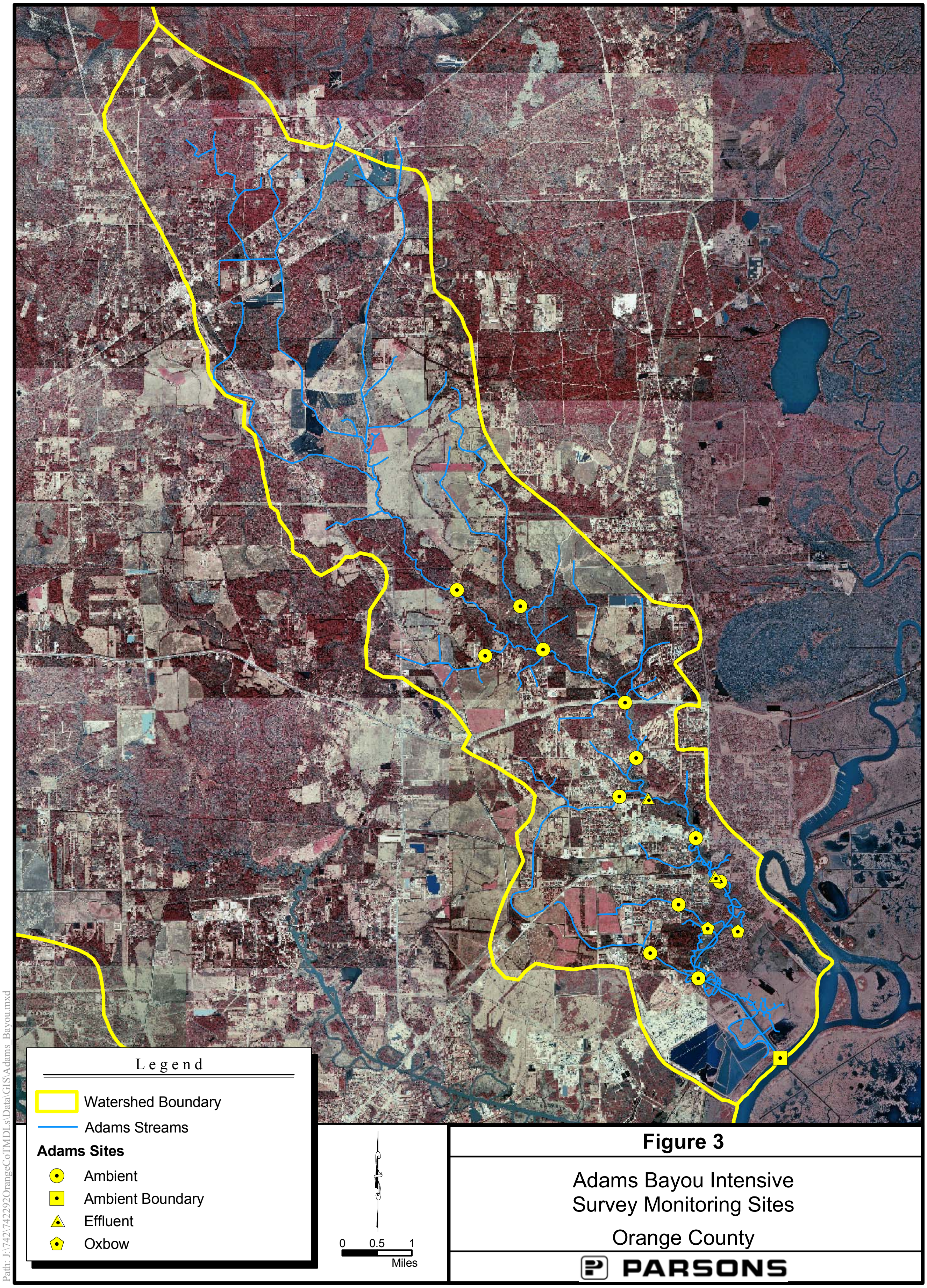


Figure 2

Sediment Oxygen Demand Measurement Sites

Orange County


Legend
Watershed Boundary
Adams Streams
Adams Sites
Ambient
Ambient Boundary
Effluent
Oxbow
0 0.5 1
Miles
Figure 3
Adams Bayou Intensive
Survey Monitoring Sites
Orange County
PARSONS
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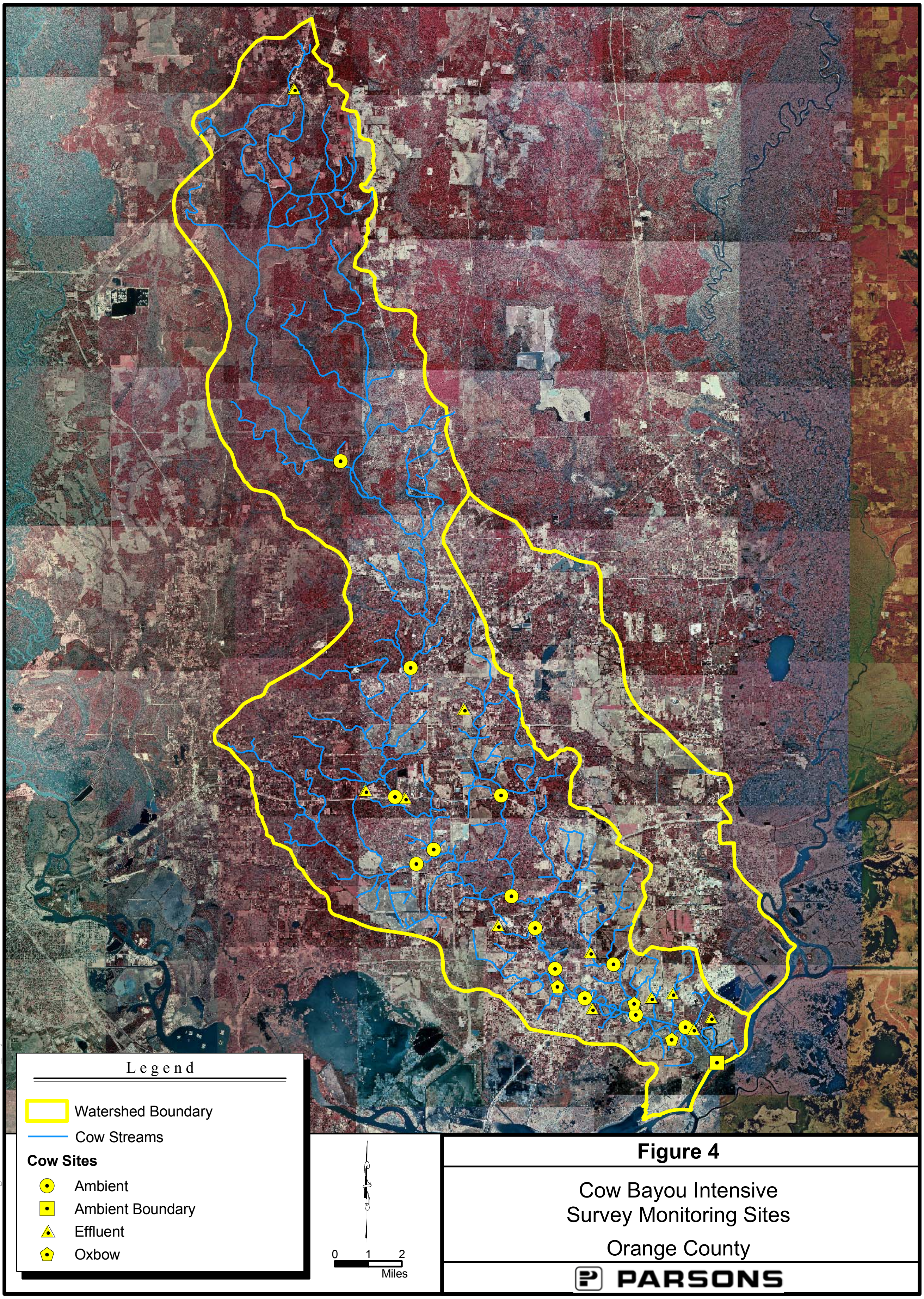

Figure 4

Cow Bayou Intensive Survey Monitoring Sites

Orange County

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