Existing Environmental Conditions of Buffalo Bayou, Houston, Texas and Environmental Issues Relative to Master Plan Development

2001 Master Plan Project

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Prepared for:

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Buffalo Bayou Partnership
Harris County Flood Control District

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INTRODUCTION

All the information compiled herein is to provide guidance relative to environmental issues to the 2001 Master Plan development undertaken by the Harris County Infrastructure and Public Works Department, Buffalo Bayou Partnership, and Harris County Flood Control District. Other issues, such as transportation and traffic, infrastructure, legal, economics, and flood control are addressed by others of the master planning technical support team.

Turner Collie & Braden Inc. (TC&B) has conducted numerous studies over the years investigating the conditions of Buffalo Bayou relative to flood control, erosion control, and infrastructure installation (TC&B 1980; TC&B 1981; TC&B 1993). There is also a wealth of printed and mapped information documenting conditions of Buffalo Bayou as far back as the 1840s when the City of Houston conducted surveys documenting the bank conditions, existing vegetation, adjacent land uses, and water quality.

In October 1978, the physical environment and socio-economic considerations of Buffalo Bayou were documented in a report to the U.S. Army Corps of Engineers (USACE) as part of an environmental assessment for alternative plan development to provide flood control (USACE 1977 and Spillways 1978). The study area documented in this report was from Shepherd Drive west to State Highway 6 and the Barker Reservoir. Among other data, this report documented physical features of geology; soils; terrestrial and aquatic environments, including typical species; plant communities; and habitat characteristics. The hydrology and air and water quality were also documented at that time for that study area.

A more recent survey of Buffalo Bayou, conducted in 1994 for the Harris County Flood Control District, entitled "Phase Two Report Buffalo Bayou Erosion Control and Bank Stabilization Report" investigated Buffalo Bayou, again, from Shepherd Drive west to State Highway 6 and the Barker Reservoir. This study was comprehensive in nature and documented existing data and file records available, the historical and recent developments of the Bayou, existing conditions of geology, soils, hydrology, and vegetation, and focused on erosional processes, erosion control improvements to date at that time, and erosion control recommendations. A part of the 1994 erosion control and bank stabilization study was the identification of issues relative to implementation and resulting environmental impacts. Identification of the areas of potential impacts addressed parks and recreational areas; biotic communities, including wetlands; threatened and endangered species; cultural resources; noise; air quality; floodplains and floodways; aesthetics; water quality; and soil resources.

The current 2001 Master Plan project is addressing a different project area from these earlier studies. The project area for the 2001 Master Plan project is from Shepherd Drive east to the Houston Ship Channel Turning Basin (*Exhibit 1*). While much of the information contained in these earlier reports and files is very helpful, more site specific and current data on environmental conditions is necessary to support the master planning efforts. This report, therefore, presents current findings about the environmental conditions of Buffalo Bayou, particularly within the project area.

This existing environmental conditions inventory compiled mapped and tabulated data relative to the watershed, climate, geology and soils, hydrology relative to habitat, changes made to the Bayou over

time relative to its current physical configuration, land uses and their effect on local air quality and bayou water quality and their ability to provide habitat for typical native vegetation and wildlife species, as well as visual character of the bayou. Sources for this information beyond field investigations undertaken by TC&B include the City of Houston, Texas Natural Resource Conservation Commission, Houston-Galveston Area Council, Texas Parks and Wildlife Department, USACE, and others, which are identified in the reference section of this report.

This 2001 existing environmental conditions report took into account the previously recorded information about Buffalo Bayou and also compiled current data from maps, aerial photography, Digital Ortho Quarter Quadrangle (DOQQ) images, and recent interviews with people who are personally or professionally familiar with the Bayou, as well as 2001 field investigations of the existing conditions inventory.

The field investigations of the project area included observations on soil and bank conditions, channel geometry, the presence of infrastructure, vegetation, adjacent land uses, wildlife utilization, and visual character. Field investigations were undertaken from windshield surveys, walking the project area on foot, and accessing the Bayou by boat. Photographs taken documenting existing conditions and highlighting relevant environmental issues are compiled in *Appendix A*.

Highlights about these findings include a significant open space resource at the western end of the project site in the 1,503-acre Memorial Park; scattered smaller parks including McKee Street Park, Guadalupe Park, York Street Park, and Hidalgo Park along the Bayou that serve to link local neighborhoods to the Bayou; the historic site of Allens Landing that marks the birth of the City of Houston; and the Port of Houston Visitor's Center near the Turning Basin on the eastern end of the project site that links not only the visitor to the Bayou but also documents Houston's heritage as a vital navigation resource to Galveston Bay (*Exhibit 1*). Also shown on *Exhibit 1* are areas along the Bayou that offer potential for a linked or continuous open space corridor that currently does not exist. The project site has many environmental problems such as the Velasco Street Incinerator site, also located along the banks of the Bayou (*Exhibit 1*). Nonetheless, the Bayou is recognized as a natural as well as cultural resource for the City of Houston. This recognition has been expressed in numerous ways such as the Bayou's art trail located at its intersections with Interstate Highway 45, Memorial Drive, and Allen Parkway as the Bayou enters downtown (*Exhibit 1*).

The existing environmental conditions of Buffalo Bayou have been completely modified from any pre-settlement or native condition. Background on the Bayou's natural condition, as well as modifications over time, indicate that all of the Bayou within the project site has been altered. A comparison was made between maps and aerial photographs of current conditions and 1871 and 1939 mapped information. Discussion of the Bayou's developmental history and the effects of this history on the current physical condition are generally intended to provide an overview, perspective, and frame of reference for the identified environmental issues relative to the planning efforts.

From an understanding of the current environmental inventory, one can then identify the opportunities and constraints of the environmental conditions that should be addressed in the 2001 master planning effort. In the second half of this report, the environmental issues are discussed relative to the current master planning effort. For example, recommendations for habitat

improvement based upon an assessment of the proper functioning condition (PFC) of the Bayou are presented. The PFC assessment used a standard checklist to record field observations with the findings discussed in *Section II.* Copies of the checklist are contained in *Appendix B*.

The history of changes to Buffalo Bayou is intrinsically linked to the development of the City of Houston and changes in Galveston Bay. The goal of a ship channel extending from the Gulf of Mexico through Galveston Bay and up Buffalo Bayou to the City of Houston predates not only the establishment of the City in 1836, but also the Texas Republic. The Bayou's potential for navigation was recognized by early Spanish explorers and colonists who desired a navigational outlet to the rich, interior agricultural lands of central Texas. The City of Harrisburg, established in 1826 before Houston, was located at the junction of Brays Bayou with Buffalo Bayou. Buffalo Bayou, from Brays Bayou to the San Jacinto River and Galveston Bay was wide and deep, and sufficient for navigation. The stretch of Buffalo Bayou beyond Brays Bayou to White Oak Bayou, and the location for the City of Houston, was more narrow and circuitous. However, an interest to develop Houston at the confluence of White Oak and Buffalo Bayou as a major port precipitated changes to Buffalo Bayou. (Rice 1867). The Bayou also serves as a major stormwater conveyance feature for the City and Harris County. As such, any master planning should take into consideration this history, current uses, and public interest for environmental protection and rehabilitation.

SECTION I – EXISTING ENVIRONMENTAL CONDITIONS

WATERSHED

Buffalo Bayou is approximately 75 miles long (USACE 1940a). The Bayou's headwaters are located in eastern Waller County (*Exhibit 2*). The Bayou generally flows from west to east as it meanders through the northern part of Fort Bend County and Harris County before it merges with the San Jacinto River about 9 miles above Galveston Bay (*Exhibit 2)*. Buffalo Bayou watershed is 369.6 square miles above the confluence of White Oak Bayou. White Oak watershed is an additional 112.9 square miles (USACE 1940a). Therefore, the size of the watershed for the portion of the Bayou through the project area is 482.5 square miles.

Buffalo Bayou has seven major tributaries, which include five northern tributaries: Greens Bayou, Halls Bayou, White Oak Bayou, Langham Creek, and South Mayde Creek; and two southern tributaries: Brays Bayou and Sims Bayou (*Exhibit 2*). The difference between a creek and a bayou is that the creek flows in one direction to a receiving water and is a freshwater aquatic system, while a bayou is tidally influenced with two directions of flow and, therefore, has salt or brackish water components to the aquatic system. *Table 1* lists the major tributaries with their minor tributaries and indicates which tributaries have been rectified.

Table 1. Tributaries to Buffalo Bayou

Major Northern Tributaries	**Minor Tributaries**
Greens*	Williams Gully*, Garners Bayou, Renhardt Bayou
Halls Bayou* to Greens to Buffalo	
Hunting Bayou* to Buffalo Bayou	
White Oak*	Little White Oak, Brickhouse Gully
Spring Branch	
Rummel Creek	
Horsepen Creek	
Langham Creek	
Dinner Creek	
Bear Creek*	
South Mayde*	
Mason Creek	
Willow Fork*	
Major Southern Tributaries	
Brays Bayou*	Keegans Bayou, Willow Waterhole
Sims Bayou*	Plum Creek, Berry Creek, Pine Gully, Vince Bayou, Little Vince

*Indicates tributary has been rectified

Note: A number of other smaller tributaries previously drained into Buffalo Bayou. Several experienced channel erosion and were subsequently filled as Houston developed.

In an effort to minimize flooding along the Buffalo Bayou, particularly in the City of Houston, the USACE conducted studies and considered numerous plans as early as 1939 (U.S. Army Corps of Engineers, 1940a). These plans included detention, channel rectification, and diversion. The detention measures implemented resulted in the creation of two reservoirs, the Barker and the Addicks Reservoirs, west of Houston in the headwater tributary areas of Buffalo Bayou (*Exhibit 2*).

This is a large watershed that contributes large volumes of stormwater runoff to Buffalo Bayou. According to information from the Houston-Galveston Area Council, a majority of this watershed, or approximately 80 percent, is urbanized (Running 2001). As this area develops, the time it takes water to move through the watershed is significantly reduced. This has an effect on the speed at which these bayous and creeks overflow their banks. The developing watershed also contributes numerous point and non-point sources of pollution that affects water quality (Running 2001). Research has shown that for a watercourse to be stable, i.e., maintain its proper functioning condition and experience minimal erosion, between 10 to 15 percent of the watershed should remain open and within wetland areas that can retain normal runoff and meter the flows to the watercourse at a normal rate.

The watershed of Buffalo Bayou lies entirely within the Texas Gulf Coast Plain which is a broad, flat, almost featureless region. The land surface rises gently toward the northwest from Galveston Bay with an average slope of 3 to 7 feet to the mile (Abbott 2001). The majority of the watershed was originally covered with native prairie grasses and forbs, except along the tributary drainage channels and Buffalo Bayou (Hosage 2001). These areas supported a wooded or riparian plant community associated with an adjacent forested floodplain and wooded zones that transitioned to the upland prairies.

A more detailed look at the relationship of the project site, particularly Buffalo Bayou as it joins the San Jacinto River at the northern or upper end of Galveston Bay, is illustrated in *Exhibit 3*. *Exhibit 3* also shows the location of the Houston-Galveston Navigation Ship Channel extending from Buffalo Bayou south toward Galveston. Also of interest on *Exhibit 3* are the areas of tidal inundation and some recorded high water levels from Hurricanes Carla and Beulah. According to the Bureau of Economic Geology, a 15.3-foot mean sea level (MSL) high water mark was recorded during Hurricane Carla at the Turning Basin, which is on the eastern end of the project site.

CLIMATE

Houston experiences severe weather most often as tropical storms and hurricanes. These storms and hurricanes develop in the Atlantic Ocean or the Gulf of Mexico and then move toward Houston. The last major hurricane to hit the Houston-Galveston area was on August 18, 1983 – Alicia, a Category 3 storm (Saffir-Simpson category rating), which killed 21 people according to the National Weather Service.

Tropical storms have been occurring more frequently (every 2 years) in recent years and occur more often than hurricanes. Tropical storms usually bring heavy rainfall and wind to the Houston area. During the week of June 4-10, 2001, Tropical Storm Allison caused rain gauges to overflow across the region, with many parts of Harris County recording record rainfall amounts of more than

10 inches. The area heaviest hit by Tropical Storm Allison was along Greens Bayou, a northern tributary of Buffalo Bayou, with almost 36 inches of rainfall. According to the National Weather Service, there were three severe cells within the perimeter of Tropical Strom Allison that equaled or exceeded 100- and 500-year rainfall numbers. These three cells were located north and northeast of downtown Houston causing significant rainfall on Greens, Halls, and White Oak Bayous. Therefore, the seasonal climate and daily weather affect not only the Bayou but also how people use the outdoors, particularly in the hot and humid summer months or during devastating storms.

The Texas Gulf Coastal Plain is characterized as being in the subtropical climatic belt. The largest factor controlling this region's climate is the Gulf of Mexico. The climate is characterized by high temperatures and high humidity. Temperatures are moderated by winds from the Gulf of Mexico resulting in mild winters and hot muggy summers.

Minimum temperatures of 32°F or lower on average occur less than 7 days per year within the City of Houston and 15 days or less in the outlying areas. If freezing temperatures occur, they only last a few hours and are usually between December 11 and February 5.

Typical precipitation in a normal year is between 48 to 52 inches—a substantial amount of rain for a low-lying coastal area. However, precipitation is usually well distributed throughout the year. Numerous storm events can typically add 4, 6, and 13 inches of rainfall at one time. Precipitation may vary substantially in different parts of Houston on a daily basis and over the entire watershed. Because the watershed is so large, isolated rainfall events in one portion of the watershed ultimately and directly affect the Bayou. The Harris County Office of Emergency Management and the Harris County Flood Control District have set up monitoring gauges on most of the local bayous. Based upon flooding history and amount of rainfall predicted, these entities know whether a bayou will overflow its banks and can warn the public of potential problems.

Prevailing winds are from the south/southeast in the summer. In winter, frequent passages of high-pressure from northern fronts cause prevailing north winds with temperature and humidity fluctuations and fog advisories. These fronts can move in and out of the area daily and result in very variable weather. Destructive windstorms are fairly infrequent, but thunder squalls, tropical storms, and hurricanes occasionally pass through this region causing great disturbance, loss of property, and sometimes loss of life.

GEOLOGY

A wealth of information exists on the geology of this area; therefore, only a brief summary is presented here. A recently published source of geological information relative to Houston is provided in the book *Houston Area Geoarcheology – A Framework for Archeological Investigation, Interpretation and Cultural Resource Management in the Houston Highway District by Texas Department of Transportation Environmental Affairs Division* (Abbott 2001).

The Texas Gulf Coastal Plain extends as far north as the Ouachita to the uplift in southern Oklahoma and westward to the Balcones escarpment (Abbott 2001). The Coastal Plain dips toward the Gulf of Mexico in a series of layers of sedimentary rocks. As a result of the geometry of this down-dip,

successively younger rock layers outcrop in subparalled bands as one moves from the original Gulf of Mexico basin margin toward the present day coastline (Hightower 1993).

With the subsequent rise and fall of sea level relative to glacial advances and retreats, broad expanses of the Coastal Plain and continental shelf were exposed to weathering and soil formation. Ancient rivers initiated early landscape development and resulted in entrenched valleys in their lower reaches. When water levels advanced and drowned the previous river valley, bays and estuaries like Galveston Bay, were formed. The present-day Brazos River, further west of Buffalo Bayou, is thought to be responsible for initially sculpting the earlier landscape and depositing the base material of Buffalo Bayou (Epps 1973).

Beaumont Formation

Erosion and bank instability are severe problems along Buffalo Bayou and a significant environmental issue to the 2001 Master Plan project. The extent of erosion problems along Buffalo Bayou can best be understood by beginning with a geologic context relative to the origin of the Beaumont Formation and the evolution of a surface drainage system overlaying the Formation, particularly the historical development of Buffalo Bayou itself. However, erosion and bank instability are also influenced by soils, fluvial processes, hydrology, vegetation, and physical configuration of the Bayou, which are addressed later in this report.

The Buffalo Bayou and its watershed are located just above the Beaumont Formation, the youngest of the Pleistocene-age geological formations. This formation, therefore, is closest to the surface and consists of clay, silt, and fine sand arranged in spatial patterns that reflect the distribution of fluvial and coastal mudflat marsh origins (Van Siclen 1985). Pleistocene fluvio-deltaic materials form the principal surface and near surface geologic deposits associated with Buffalo Bayou. Van Siclen (1985) identified a series of meander belt ridges that were deposited by the Brazos River between 0.8 to 1.7 million years ago. Buffalo Bayou developed within two of these ridges.

Buffalo Bayou has incised (or cut down) into the surface of the underlying Beaumont Formation. Approximately 150 years ago, the water surface of the Bayou was much higher or closer to the adjacent land surface elevation than it is today (Aronow 1990). The shoulders of the Bayou had an associated floodplain with wetlands, ponds, and a wooded riparian habitat similar to what can still be seen today in other local areas that are relatively undisturbed such as portions of the Brazos River floodplain, San Jacinto River floodplain, and Cypress Creek floodplain. Today, the water surface of Buffalo Bayou is probably 20 feet lower than in pre-settlement time. Causes of this incision include changes in hydrology, base level lowering in the Bayou as it readjusts to the Bay, decreased sediment supply to the system, and urban encroachment (Brown 2000).

The Beaumont Formation consists of gradations and layers of interbedded clays, silts, and fine sands. Calcite-cemented sandstone lenses are occasionally exposed in the Bayou's banks as overhanging sandstone layers in some locations (*Appendix A:* Sheet 21, Photo D). As the Bayou has cut down into the Beaumont Formation, these layers, including the fine sands, are exposed, making the banks extremely susceptible to erosion. The velocities of storm flows also continue to re-suspend the Beaumont Formation clay particles from the Bayou bottom that adds to decreased water clarity

(*Appendix A:* Sheet 4, Photo C; Sheet 15, Photo A). This gives the Bayou its murky, chocolate milk appearance and has an effect on fish species that rely on sight for feeding.

The clays formed from alluvial and coastal mud, deposited in broad, overbank floodplain areas. The sands are usually in meandering linear deposits and appeared to have formed from early river alluvial deposition. These were topographic ridges that rose a few feet above the alluvial floodplain at that time and were subsequently buried only for these meandering sand deposits to be exposed again later (*Appendix A:* Sheet 14, Photos B and C; Sheet 16, Photos B and C).

Buffalo Bayou evolved as an early surface drainage across the broad, flat, almost featureless area between the two river-created ridges (Abbott 2001; Aronow 1990). The drainage associated with the early development of the Bayou was controlled by relative sea-level changes associated with various advances and retreats of glaciers and the consecutive erosion of the land surface into a valley and floodplain associated with the Bayou and the Bay. The regional drainage system of the Houston area, including Buffalo Bayou, developed by downcutting from the Bayou mouth and heading inland through headward erosion caused by stormwater runoff (Abbott 2001; Aronow 1990). In other words, erosion starts at the lower end of the Bayou system and works its way up into the upper reaches. This process continues today and has been increased by numerous activities including removal of native vegetation along the Bayou, concentration of increased stormwater volumes and flow rates in the Bayou, and the creation and continued maintenance of the Houston-Galveston Navigation Ship Channel. Today, numerous mechanisms of erosion, not just headward erosion, are at work on the Bayou.

Current Erosion

The upper Texas Gulf Coast receives considerable amounts of precipitation, 48 to 52 inches per year, and is affected by significant tropical storms and hurricanes, which all contribute to stormwater runoff, bayou development, and continued erosion. The incised channel exposes clay and sand in the bank's sideslopes. The cumulative effect of excessive rainfall events contribute to rapid rates of erosion within Buffalo Bayou. Erosion is a natural process, however, where the energy contained in flowing water within the Bayou is being dissipated against the adjacent land prior to the water reaching its final destination, Galveston Bay, in this case. The Bayou is, therefore, always trying to re-establish equilibrium with the Bay. As the Bay changes over time, the Bayou changes too.

A dynamic equilibrium within the Bayou will not be reached until bank slopes, stream gradient, channel geometry, and the urban hydrology allow no erosion or deposition (Fischenich and Allen 1999). As conditions change in the Bay relative to the Bay bottom contours being deepened with the navigation channel and as more water is discharged to the Bayou as drainage and flood control measures address more of the watershed being developed, erosion within Buffalo Bayou will continue. Erosion will probably be more lateral or sideways into the banks than down cutting because cutting into the stiffer channel bottom clays of the Beaumont Formation will be more difficult as time goes by than to continue to proceed with lateral migration against the softer sideslope soils of the Bayou banks (Aronow 1990). Sideslope erosion is a real problem as it threatens adjacent buildings and infrastructure, as illustrated in photographs in Appendix A (See

Appendix A: Sheet 4, Photos A &B; Sheet 13, Photos D and E; Sheet 14, Photos A, B, C, and E; Sheet 16, Photo B; Sheet 20, Photos B, C, and D; Sheet 21, Photo D).

This sideslope erosion also results in significant soil loss from the banks which, in turn results in deposition within the Turning Basin and the navigation channel. One storm event, Tropical Storm Allison in May 2001, resulted in emergency dredging of these areas to remove approximately 500,000 cubic yards of sediment at a cost of over $1 million dollars (Gorini 2001).

Other components of the local geology include faults and subsidence. There are surface faults in the project area. These have not been documented within this report but are available elsewhere and should be investigated further depending upon master plan proposals. Subsidence was a significant issue and still is. The project area is within a zone that has been mapped by the U.S. Geologic Survey to show a predicted level of subsidence between 1 to 3 feet within the next 5 years, if current plans for reducing groundwater pumping are not implemented (U.S. Geological Survey 1999).

SOILS

Most recent geologic deposits on the Texas Gulf Coastal Plain include a diverse and intricate pattern of alluvial deposits from extant stream or river floodplain, delta, and back-barrier lagoon and marsh depositions, as well as eolian (wind) deposits (Aronow 1990). Most of this pattern is not mapped; however, Barnes 1968 and Barnes 1982 provide considerable detail. Further information about soils and this intricate pattern can be found in the Geologic Atlas of Texas, Houston Sheet. The result of this intricate pattern of various soil's deposition is that not all portions of the Bayou banks are the same. The erosion they experience and the sideslope treatments for stabilization, for example, will all differ from one area to the next. Different soils will also have an influence on vegetation and habitat conditions.

According to the U.S. Department of Agriculture Soil Conservation Service, now known as the Natural Resources Conservation Service, the soils of this project area were of two general types: nearly level, clayey soils and nearly level, loamy soils that formed under prairie conditions (U.S. Department of Agriculture 1976). This would support other information that indicates a majority of this area supported native prairie plant community with the exception of those areas within the floodplain of the Bayou which supported wooded or forested plant community. Over time, these plant communities influenced a soil formation.

Today's soils are the result of interaction between five soil-forming factors: 1) climate, 2) parent (geologic) material, 3) relief, 4) organisms, and 5) time. The mapped general distribution of surface soils indicates that the lower reaches of Buffalo Bayou consist of Ijam-Harris soils (Entisols-Mollisols including dredge spoil), surrounded on both the north and south of the Bayou, by Lake Charles, Bernard, Edna soils (Vertisols-Mollisols-Entisols). The northwestern section of the Buffalo Bayou watershed is predominantly Clodine-Addicks-Gessner soils (Affisols-Mollisols) while the southern half of the Buffalo Bayou watershed is a mosaic of Lake Charles, Bernard, Edna soils and Edna-Bernard-Verland complex (Affisols-Mollisol). These are predominantly upland soils with scattered inclusions of low-lying and hydric soils. In general, a hydric soil is a soil that is saturated,

flooded, or ponded with water long enough during the growing season to develop anaerobic (oxygen-lacking) conditions within the soil pore spaces in the upper, or rooting zone of the soil layer (U.S. Department of Agriculture 1991). Thus, the presence of hydric soil strongly influences plant species and is one of three mandatory criteria for USACE jurisdictional areas under the Clean Water Act Section 404 and Section 10 of the Rivers and Harbors Act.

The soils that consist predominantly of clays and muds have low permeability, high water holding capacity, high compressibility, high to very high shrink-swell potential, poor drainage, level to depressed relief, low shear strength, and high plasticity (U.S. Department of Agriculture 1976). The clayey sands and silts have moderate permeability and drainage, low to moderate compressibility and shrink-swell potential, level relief with local mounds and ridges, and high shear strength. The fine grain sands have high to very high permeability, low water holding capacity, low compressibility, low shrink-swell potential, good drainage, low ridge and depressed relief, high shear strength, and low plasticity.

Soil types specific to the project area as identified by the Soil Conservation Service (SCS) of USDA in the soil survey for Harris County are shown on an aerial photograph of the project area (*Exhibit 4)* and are described in *Table 2*. Specific information about project site soils would need to be gathered when plans and actual projects are proposed.

Table 2. Project Area Soils

Name of Soil Types	Description of Soil
An - Aldine Urban Land Complex Aldine Series	Somewhat poorly drained Very slowly permeable soils on Coastal Plains
Vn – Vamont Urban Land Complex Vamont Series	Deep Somewhat poorly drained Very slowly permeable soils that formed from alkaline clayey sediments
Bg – Bernard Urban Land Complex Bernard Series	Very deep Somewhat poorly drained Very slowly permeable soils that formed in thick clayey sediments on marine terraces of Pleistocene Age
Lu – Lakes Charles Urban Land Complex Lake Charles Series	Very deep Moderately well drained Very slow permeable soils that formed in clayey sediments
Mu – Midland Urban Land Complex Midland Series	Very deep Poorly drained Very slowly permeable soils that formed in clayey sediments of late Pleistocene
AtB – Atasco Fine Sandy Loam	Deep moderately well drained Very slowly permeable soils on Coastal Plains that formed in loamy and clayey sediments of Pleistocene Age
Ur – Urban Land Complex	Fill material

HYDROLOGY

Aspects of hydrology that affect the physical, chemical, and biological conditions of the Bayou include water volumes, flow types, flow rates, their translation into high, normal, and low water levels relative to the Bayou sideslope inundation and duration (Dunne and Leopold 1978; Fischenich and Allen 1999; Horton 1945). The flow in the Bayou is typically governed by precipitation events. These events are periodic and are strongly variable as indicated in the climate section of this report. The USACE regulates discharges of flow to the Bayou from two reservoirs, the Barker and Addicks Reservoirs, in the far western tributary area of the watershed (*Exhibit 1*). Base flow for Buffalo Bayou is a few cubic feet per second (cfs) (TC&B 1972). The mean weekly peak flow is ±30 cfs with highs exceeding 55 cfs (TC&B 1972). The 100-year discharge is 21,000 cfs (USACE 1977; USACE 1987).

Typically, the base flow is perennial or constant with a normal water surface elevation at 2.5 feet mean sea level (MSL). Elevations are based on the 1929 National Geodetic Vertical Datum (NGVD) with 1973 adjustment. TC&B, in a separate hydrology report for the 2001 Master Plan project, has documented some current water levels and water depths of the Bayou within the project site. These water levels and their fluctuations need to be considered in planning habitat improvements along the Bayou. There are numerous discharge points of storm sewers and treated municipal effluent that also significantly contribute to the base flow (see *Appendix A*: Sheet 2, Photo A; Sheet 12, Photo A; Sheet 13, Photo E; Sheet 17, Photo D; and Sheet 27, Photos B and D).

Flooding

A significant component of the Bayou's hydrology is driven by storm events that resulted in flooding, severe erosion of channel sideslopes, and vegetation loss (Harris County Flood Control District 1994). Six major floods occurred between 1854 and 1940 (USACE 1940b). Two of the most significant of these events were the 1929 and 1935 storms.

The rainfall for the 1929 storm ranged from 6 to 12 inches over White Oak and Buffalo Bayous. This resulted in 18,500 cfs of runoff above Main Street and devastating flooding of the city. The rainfall in 1935 averaged 15 inches over the drainage basin with a perk of 20.8 inches that resulted in 41,000 cfs passing in the Bayou just above Main Street. These flow velocities were sufficient to destroy buildings, pavement, and infrastructure. In recent times, Hurricanes Carla and Beulah and Tropical Storm Allison each caused severe flooding.

The headwaters of Buffalo Bayou originated in the coastal prairies about 30 miles west of the current City of Houston (Spillways 1978). The Bayou is an extension of Galveston Bay and the Gulf of Mexico and, as such, experiences tidal influences (*Exhibit 3*). According to R.M. Farrar (1926), at the foot of Main Street, Buffalo Bayou experienced about a 2-inch daily tidal rise and fall which then increased eastward toward the mouth with the Bay. The mean tidal range under ordinary conditions at this location in the Bayou is between 0.5 to 1.0 foot MSL. Fish species present today in this portion of the Bayou also indicate this continued tidal influence.

Because the Buffalo Bayou watershed is large and incorporates seven principal tributaries in a counterclockwise direction: Greens Bayou, Halls Bayou, White Oak Bayou, Langham Creek, South Mayde Creek, Brays Bayou, and Sims Bayou, any local storm event typically involves some portion of the Buffalo Bayou watershed. The project site is centrally located along the Buffalo Bayou (*Exhibit 2*) and is, therefore, also affected by storm events occurring within the watershed.

A review of over 40 years of rainfall data indicates that more frequent and heavier precipitation occurs in the northern tributaries to Buffalo Bayou, particularly White Oak and Greens Bayous (Abbott 2001). The heavy rainfall events are localized, influenced by the geography or land surface configuration, and the developed areas of Houston. Many of the high magnitude events affect the northern tributaries, particularly White Oak Bayou, which in turn affects the confluence area with Buffalo Bayou. This does not appear to be the case on Sims or Brays Bayous, which also drain to Buffalo Bayou from the south.

The drainage divides between the tributaries to Buffalo Bayou are almost imperceptible since the region is so flat. According to the Federal Emergency Management Agency (FEMA), the mapped floodplains for Buffalo Bayou are shown on *Exhibits 6a, b,* and *c*. The 100-year floodplain is shown as a light blue dash line and the 500-year floodplain is represented by the light blue solid line. During heavy rainfall events, which are a frequent occurrence, there is general overflow (Harris County Flood Control District 1994; TC&B 1972; USACE 1940a). The rate of rainfall can exceed the rate of drainage through the numerous storm sewer inlets and culverts. Therefore, flooding of the area has been and continues to be a problem. As early as 1939, the USACE identified the need for flood control on Buffalo Bayou (USACE 1940a). The USACE indicated at that time that rapid growth of Houston intensified flooding by encroaching on flood-prone areas. Flooding also causes excessive currents in the Houston-Galveston Navigation Ship Channel, which delay or disrupt navigation.

Flood Control

Rainfall rates and flow volumes for the Bayou have been documented elsewhere outside of this report. The USACE and Harris County Flood Control District (HCFCD) have calculated design storms and the volume of water generated in order to size various flood control measures. As indicated earlier in this report, in 1939 the USACE considered numerous plans for flood control on Buffalo Bayou. These plans included detention, channel rectification, and diversion. The detention measures resulted in two reservoirs, the Barker and Addicks Reservoirs, west of Houston in the headwater tributary areas of Buffalo Bayou. White Oak Bayou was investigated for possible detention sites. There is ongoing construction of numerous small and large water detention structures within the watershed that will affect both baseline and peak flows. The location of these detention structures are not part documented in this report.

Channelization was investigated and the USACE indicated that increasing flow velocities would increase erosion (USACE 1940a). This in turn would increase siltation problems in the Houston-Galveston Navigation Ship Channel. Many structures and businesses are now located alongside or across the Bayou and may require removal if channel rectification is undertaken. These structures can be seen in aerial photographs of the project site as shown in *Exhibit 4* and in *Appendix A*: Sheet 7, Photos D and E; Sheet 9, Photo D; Sheet 11, Photos B and D; and Sheet 17, Photo C.

Diversion channels were also investigated and the USACE indicated that they would need to be very large in cross-section to convey the magnitude of volumes anticipated. The physical features of the watershed, i.e., flat and near the coast with multiple property ownerships would necessitate long deep channels cut through expensive right-of-way, requiring disposal of huge quantities of earth that would need to be removed (USACE 1940b). In 1939, the USACE estimated this volume of earth to be in excess of 100 million cubic yards. Plans looked at diverting water from Buffalo Bayou to the Brazos River and diverting water from White Oak to Hunting and Green's Bayous. A comprehensive study of drainage for metropolitan Houston was undertaken by TC&B for the City of Houston and Harris County (TC&B 1972). In 1980, TC&B investigated the feasibility of a White Oak diversion channel (TC&B 1980; TC&B 1981). The Bayou has been modified to accommodate flood conveyance as well as navigation (*Exhibit 5*).

For further information on hydrology, such as a new hydraulic model for flood control being developed by TC&B for HCFCD, refer to the separate hydrology report prepared for this 2001 Master Plan project. Data on existing and historic hydrology (discharge in cfs over time in hours), peak discharges, hydrograph volumes, rating curves, specific gauge analysis, water-surface and bank profiles, velocity profiles, hydraulic controls or constructions, and sediment gradient curves should be compiled and evaluated to assess hydrology of the Bayou and its effects on habitat improvements and other components of a master plan (Horton 1945; Lane 1955; Schiecht and Stern 1997; Allen and Leech 1997).

PHYSICAL CONFIGURATION AND VISUAL CHARACTER

This section addresses both built features and natural features, particularly as they affect the Bayou's physical configuration and visual character. The following descriptions are also illustrated in a sequence of color aerial photographs (*Exhibits 6a, b,* and *c*) and in color photographs (*Appendix A*) that are referenced to site locations shown on the aerial photographs.

History

The history of the Bayou plays a significant role in its current physical configuration. The history of the Bayou records numerous modifications over time (DeLeon 1905; Clopper 1909; Gray 1975). No portion of the Bayou within this project area remains undisturbed. For example, even before any changes were made to accommodate flood control, the lower reach of the Bayou, from downtown Houston to the Bay, was widened and deepened as part of the Houston-Galveston Navigation Ship Channel as early as 1871 (Chief of Engineers 1939). The upper portion of the Bayou from downtown Houston has also been dredged or widened as parts of various infrastructure installation projects and for maintenance of a shallow-draft channel. When early federal survey maps of 1871 and 1939 are overlaid on current aerial photography of the Bayou, channel modifications to the Bayou become apparent (*Exhibit 5*).

In 1871, the Bayou between Main Street and the City of Harrisburg, at the confluence with Brays Bayou (*Exhibit 5*), was reported to be at least 70 feet wide and "navigable to Houston for vessels drawing less than 4 feet" (Alperin 1977). By this time, clear cutting the Bayou banks of its native trees and development of the surrounding area had resulted in excessive erosion and shoaling of the Bayou from original depths of 15 to 20 feet to only 3 to 4 feet (Alperin 1977). Thus, the Bayou plan configuration at that time was relatively narrow and circuitous, or meandering. Some segments were even tortuous.

Deepening the channel to 6 feet and widening the channel from 70 feet to 100 feet was recommended in 1871 by the USACE Galveston District to provide adequate competition for a single railroad line from Houston to Galveston that existed at that time (*Exhibit 5*). The USACE indicated that this would reduce cost of goods to the interior, increase export of interior produce, and aid in railroad expansion. There was already a lot of commercial development along portions of the Bayou such as sawmills, docks, and wharves (Alperin 1977; Farrar 1926).

Before any work on the Bayou commenced; however, the USACE was also involved with widening and deepening a ship channel in Galveston Bay, and a private concern, headed by Commodore Charles Morgan, was making improvements around Morgan's Point in the Bay. Improvements to a ship channel in Galveston Bay were suspended from 1883 to 1888 mainly because the railroad from Houston to New Orleans had eliminated the need and slowed progress on both Bay and Bayou improvements. However, the Houston Cotton Exchange was recommending continued navigational improvement to the Bayou. Congress, therefore, authorized a study of Buffalo Bayou from Sims Bayou to White Oak Bayou in 1880. This resulted in clearing the Bayou banks and enlarging the channel to 12 feet deep and 100 feet wide. Thus, all the native overhanging trees that included oaks (*Quercus sp*.), cypress (*Taxodium sp*.), cottonwoods (*Populus deltoids*), pines (*Pinus taeda*), and magnolias (*Magnolia sp.*), roughly 700 trees per mile, were removed along this 11-mile stretch of Buffalo Bayou (*Exhibit 5*). These improvements were short-lived, however, because of chronic bank erosion adding sediment, snags, and logs following every heavy rain. Further, Houstonians were using the Bayou as a dumping ground for city sewage (Farrar 1926).

An issue to navigation that affects the existing physical configuration of the Bayou was where to terminate the navigable deep-water. This was a controversial and recurring issue throughout the historical development of the Bayou as a navigation channel (Farrar 1926). Currently in 2001, dredging maintains the deep channel to the Turning Basin, and the channel within Galveston Bay is being widened and deepened to 47 feet. This follows a series of channel improvements for over 121 years as the channel depth increased from between 3 to 4 feet to 12 feet in 1880, 18.5 feet in 1905, and 25 feet in 1914. In 1935, Congress authorized more widening and deepening to 34 feet. In 1936, the depth was increased to 36 feet deep, and in 1957 the channel was deepened to 40 feet. These deeper depths are associated specifically with the ship channel in the Bay and up to the Turning Basin. Past the Turning Basin along the Bayou to Shepherd Drive the water is more shallow.

The current 2001 bottom contours of the Bayou have been surveyed along the project site. Current channel depths within the eastern end of the project area range from -10 to -40 feet MSL relative to 1929 NVGD corrected in 1973, while channel depth in the downtown area is approximately 13.5 feet MSL. Other channel depths have been recorded by TC&B in a 2001 topographic survey of the Bayou within the project site. This survey went from top to top of the bank at a 50-foot transect spacing, recording a 2-foot contour interval. Results of this survey can be found in a separate report by TC&B for HCFCD.

Bayou Plan Alignment

The Bayou's overall plan alignment has not changed significantly from a sketch prepared in 1871 as part of the first federal survey (Alperin 1977) with the exception of those portions described above that were straightened, widened and deepened, and dredged for the Ship Channel and Turning Basin. Other portions of the Bayou's plan configuration have become channelized, straightened, and filled as part of the city's overall development or individual site development and shoreline stabilization along the Bayou (TC&B 1993; TC&B 1981). This includes numerous small tributaries and their associated wetlands.

A wetland is an area that is inundated or saturated (flooded) by water at a frequency and duration sufficient to contain certain soils (hydric soils) or soil conditions that are poorly drained and limited in oxygen between the pore spaces such that under normal circumstances these areas support a prevalence or majority of vegetation (hydrophytes) typically adapted to life in water logged and oxygen-depleted conditions. The description of the pre-settlement or natural conditions of the Bayou, which included wetlands, are provided later in this report in the vegetation and habitat sections.

A review of USACE project records, as well as HCFCD, City of Houston, and individual activities, also indicates a series of modifications to the Bayou over the past 100 years or more. These modifications included removal of bends and woody debris and pile dike construction in 1905. In 1919, the Turning Basin was enlarged to 30 feet deep. In 1925, the Bayou bottom was deepened to provide a light-draft vessel extension to White Oak Bayou. A meander that originally existed has been cut off as the Bayou was straightened (*Exhibit 5*). Other channel modifications occurred as numerous bridges, roads, drainage discharge pipes, and adjacent shoreline developments affected the physical configuration, particularly the bank slope condition and vegetation of the Bayou.

The Bayou length within the project site is 47,040 linear feet or approximately 9 miles (*Exhibit 7*). The straight line length is 38,100 feet or 7.2 miles. Therefore, the overall sinuosity is 1.2 (meander length ÷ straight length). Desirable sinuosity or degree of channel meandering is 1.5 to 2.0 (Fischerich and Allen 1999; Horton 1945; Leopold and Maddock 1953). The various reaches or segments can be classified according to Rosgen (1994) by assessing entrenchment, degree of meandering (or sinuosity), and generalized visual delineation of channel geometry. Based upon the generalized channel geometry and dominant bed material (silts and sands), the Bayou is classified as Stream Type A using Rosgen's classification system (Rosgen 1994). Again, using Rosgen's system, based upon sinuosity, the Bayou can have four stream types (*Exhibit 7*). From the western end of the project site to roughly 7,500 linear feet, the Bayou is Stream Type A because sinuosity is 1.0. The Bayou then transitions from Stream Type B and G, to C, then to Stream F, and back to Stream Type B and G, because of the variations in sinuosity (*Exhibit 7*). The channel width ranges from 150 feet at the western end to approximately 300 feet after the White Oak confluence. The width to depth ratio ranges on average from as high as 30 to as low as 7.5. Because of the number of tributaries or branches in the overall drainage network of the Bayou, Buffalo Bayou can be seen as a 4th or 5th order system (Horton 1945).

The upstream reach, Shepherd Drive to Sabine Street, consists of a realigned channel and broad overbank area cleared and re-graded for flood control in the 1940s (*Exhibit 6a*). Immediately upstream of Waugh Drive, the channel narrows and has extensive vegetation that is seen as a constriction to effective flood conveyance (see *Appendix A:* Sheet 1, Photos A, B, and C).

The channel reach between Sabine Street to Main Street is confined between sloped concrete walls, numerous bridge crossings, and extensive construction along the banks (see *Exhibits 6a, 6b* and *Appendix A*: Sheet 3, Photo C; Sheet 5, Photo B; and Sheet 7, Photos A through E). The channel within this reach tends to accumulate silt.

The Bayou tends to get wider and deeper toward the eastern end of the project site as it approaches the Turning Basin (see *Exhibit 6c* and *Appendix A:* Sheet 23, Photos A and B; Sheet 30, Photos B and C). Here the reach is confined on both sides by predominantly industrial land uses (*Appendix A*: Sheets 22, 23, 26, and 27). There was a significant meander in the channel as indicated above that has since been cut off and reduced to a dead end in terms of water circulation. The central "island" of this meander is used as industrial processing area where products arrive and depart by both rail, road, and boat (*Appendix A*: Sheet 24). Therefore, the majority of the Bayou shoreline along this island is bulkheaded. However, there is a significant wooded perimeter along the eastern and outside edge of this meander (*Appendix A*: Sheet 25).

Approximately 49 percent of the Bayou banks in the project site have a hard edge (protected) vs. 51 percent that are vegetated (*Exhibit 7*). The typical slopes of the vegetated or "unprotected" areas ranges from 1:1, 2:1, and 3:1 horizontal to vertical gradient (*Exhibit 8*). These ranges of slopes, given the soil conditions and hydrology, result in bank instability problems. The flatter grades, less than 3:1 and preferably 8:1, 12:1, and 20:1 with typical vegetated wetland shallow areas are not normally present within the project site. Only in limited instances (for example, a cut bank in Memorial Park) has a slope failure deposited material at the toe of the slope with potential to create shallow vegetated wetland. These areas are short-lived, however, in the current conditions given that the storm flow velocities that damage buildings and infrastructure can easily uproot vegetation and remove these newly forming wetland areas.

Buffalo Bayou's visual character changes over time not only with the various improvement projects but also from one segment of the Bayou to another. The visual character of today is far different from early travelers' descriptions of the Bayou. However, it does contain a somewhat natural appearance as the Bayou flows through Memorial Park and scattered areas past downtown Houston that retain vegetation along the banks (*Appendix A*: Sheet 1: Photos A, B, and C; Sheet 3, Photo A; Sheet 18: Photo D; and Sheet 25: Photos A and B).

The area through downtown has sideslopes treated with patterned and colored concrete blocks retaining vertical slopes and adjacent manicured landscaped areas providing public access and recreational areas (*Appendix A:* Sheet 7). Other areas such as the confluence with White Oak Bayou are lined with old historic wooden bulkheads, steel bulkheads, discharge pipes, warehouses, bridge piers, and a new park (*Appendix A:* Sheet 10). An area immediately past this confluence appears neglected and has a badly eroding area prior to the McKee Street Bridge (*Appendix A:* Sheet 13). Bank height in this area is in excess of 50 feet high and is slumping into the Bayou. The erosion exposes the various soil, sand, and sandstone layers (*Appendix A*: Sheet 14). There are a few areas that are open and grassy as opposed to wooded, such as an area from the McKee Street Bridge to US 59 (*Appendix A:* Sheet 15, Photo A and Sheet 17, Photo B). A complete record of the current visual condition of the Bayou is included in *Appendix A*, and the locations of these photographs relative to the project area are shown in *Exhibits 6a, b,* and *c*.

Much of the visual character has changed considerably since the 1870s because of changes to the physical condition (Rice 1867). Prior to settlement and clear cutting of the native trees, the native vegetation associated with the Bayou, as illustrated in early pen and ink drawings of the Bayou and

travelers' descriptions, described the character of the Bayou as heavily wooded with lots of Spanish moss (*Tillandsia usneoides*) dripping from the trees and so many magnolia (*Magnolia sp*.) flowers that the air was heavily perfumed (Gray 1975). In fact, Spanish moss is a graceful epiphyte and a member of the bromeliad family and not a moss at all (Reese 1983). This species is still present in the area and drapes and dangles from the branches of mature trees which no longer characterize the Bayou. Research about the native conditions of the area indicate that the Bayou would have also supported a combination of bald cypress (*Taxodium distichum*) swamps and mixed hardwood bottomland floodplain forest that meet this description of being heavily wooded (Mattoon 1915) (*Exhibit 9*). These conditions are in stark contrast to conditions of the 1940s (*Exhibit 10*) and the current conditions.

Naturally occurring landscape features within the Bayou floodplain would have included the meandering channel, oxbows and oxbow lakes, active and former natural levees, scattered wetland sloughs, ponds, and backwater swamps (Gosselink, Lee, and Muir 1990; Leopold and Maddock 1953) (*Exhibit 11*). A schematic cross-section through this undisturbed wooded floodplain would have had varying degrees of flooding or inundation that in turn influenced a variety of plant species being present (*Exhibit 12*). These species would typically characterize unique ecological transitional zones within the natural floodplain. These zones are labeled II through V, are illustrated in *Exhibit 12,* and are discussed in more detail later in the vegetation section of this report. An aerial view of the undisturbed Bayou (*Exhibit 13*) shows what the transition between wooded areas, known as riparian, and open herbaceous wetlands where the various tributaries intersected the Bayou may have looked like. These native conditions are no longer present within the project site.

When the current configuration of the Bayou is overlain with 1939 topographic information, it can be seen where the Bayou has been straightened and where the naturally occurring wider wetland areas and the smaller tributary stream channels have been removed (*Exhibit 5*). Some of these natural wetland areas, previously lost, present an opportunity for restoration and incorporation onto a proper functioning condition for the Bayou and habitat improvements. Proper functioning condition and habitat improvement potential are discussed in *Section II* of this report.

LAND USES

Land uses (*Exhibit 14*) within the project area are discussed in terms of a brief historic overview and then current uses within the project site, particularly noting those that have an effect on air and water quality. Buffalo Bayou is a major western tributary of the San Jacinto River and is, therefore, a major contributory to Galveston Bay. Galveston Bay is the largest bay on the Texas Gulf Coast and is a significant economic and recreational resource to the State of Texas. As a result, the land uses within the Buffalo Bayou watershed significantly affect water quality, habitat, and these eco-resources within the Bayou and the Bay. As indicated earlier, the predominant land use along the Bayou is industrial, particularly in the eastern half of the project site, as shown in purple on *Exhibit 14*. Downtown Houston is in the center of the project site and is predominantly commercial land use. The western half of the project site is a mix of land uses (*Exhibit 14*).

Because Buffalo Bayou is located inland from the Gulf of Mexico and the Bayou's mouth is protected from the Gulf, Buffalo Bayou became a significant port and navigational resource to the agricultural areas much further inland, as well as the industrial areas that developed along the Bayou banks (Siegel 1983). Pre-settlement and recent development of Houston, particularly along Buffalo Bayou, is documented more fully elsewhere (Farrar 1926; Knapp 1977; Alperin 1977). This description of land use will only highlight historic land uses and focus primarily on current conditions adjacent to the Bayou. The opportunities and constraints relative to land uses to enhance water quality, habitat, and public access are noted where applicable. A constraining land use feature that becomes apparent is the limited parks along the bayou represented by green in *Exhibit 14,* which in turn, represents a lack of continuous open space, natural areas, and public access along the Bayou.

There has been continuous permanent settlement along Buffalo Bayou as early as 1822 prior to the establishment of the City of Houston (Rice 1867). Houston was established in 1836 along Buffalo Bayou at the confluence with White Oak Bayou for freshwater and navigation. Downstream of this confluence, Buffalo Bayou was a navigable stream. Upstream of the White Oak Bayou confluence, Buffalo Bayou was relatively deep, but the removal of snags and logs was a continuous necessity to navigate past this point.

During 1820 through 1830, the predominant land use surrounding Buffalo Bayou was agricultural. The extent of cultivation of the area was recorded to have resulted in increased sedimentation and water quality reduction even at this early time. Between 1830 and 1860, cattle grazing was a significant land use of the area. Logging of the Bayou's extensive wooded floodplain and riparian corridor apparently kept saw mills along Buffalo Bayou busy from 1830 through 1890, over a 60-year period of time. Beginning in 1890 and through 1910, a significant amount of residential and industrial development had occurred along the Bayou. Another land use that affected the Bayou between 1910 and 1920 was sand mining. Numerous roads and railroad bridges began crossing the Bayou by the 1920s.

With the advance of the railroads, Houston grew in importance as a rail center, and there was less reliance on the Bayou for navigation as had been the initial focus. During the Civil War, Galveston thrived as Houston's navigational trades diminished. However, excessive charges from the Port at Galveston spurred Houston, specifically the Houston Direct Navigation Company, to improve navigational trade once again and to petition the federal government in 1867 for Houston to become a port of entry. The argument was that because Houston was a rail center, the advantages of improving Buffalo Bayou as a navigation channel were "obvious." This was granted in 1870 (Alperin 1977). Today, current land uses include both railroad lines and switching yards, as well as boat docks (see *Appendix A*: Sheet 13, Photo F).

The USACE conducted a survey of the Bayou in 1871 (Alperin 1977) and recommended improvements for navigation. Some improvements were made in 1880; however, it was not until the Rivers and Harbors Act of 1899 that the two projects, the widening and deepening of Galveston Bay and widening and deepening of Buffalo Bayou, became merged and known as "Galveston Ship Channel and Buffalo Bayou, Texas Project." This was a significant event since this project continues today and is called the Houston-Galveston Navigation Ship Channels, Texas Project. Work on the

project at that time slowed, as a result of the Spanish-American War, but resumed again with vigor because of the 1900 hurricane that devastated Galveston (Alperin 1977).

In 1900, downtown Houston had a working waterfront, and the actual Port of Houston was located at the intersection of Main Street with Buffalo Bayou (Farrar 1926). Historic photos from this time document the condition of the Bayou, particularly the presence of numerous boats and the extent of wooden bulkheads. Horse-drawn vehicles carried goods to and from Houston's downtown working waterfront. The wooden bulkheads lined the banks of the Bayou while wooden sand barges, with circa 1900 draglines, dredged the Bayou.

From the early 1800s to modern times, Buffalo Bayou played a significant role in city business and community life. There were notable parks along the Bayou that supported large gatherings of people such as Zero Park, Old Magnolia Park, and Merkel's Grove (Olson 2001). At one time, the Houston Lighting and Power Company had a generating plant at McKee Street that discharged water from the cooling system into Buffalo Bayou as evidenced from old historic photos.

The Buffalo Bayou project area is a dynamic area with many land use changes over time. For example, some of the early parks are no longer present nor is the generating plant at McKee Street still operational. Currently, the adjacent and nearby land uses include single and multi-family residential, commercial, institutional, industrial, and open spaces that are parks or vacant lots (*Exhibit 14*). There are numerous cultural features within the project area which include cemeteries and places of worship (*Exhibit 15*).

The west end of the project area includes Memorial Park (*Appendix A:* Sheet 1, Photo C). The Hogg brothers purchased the 1,503 acres, and sold it to the city as a park. Memorial Park had been the site of Fort Logan, a World War I training camp. The camp had barracks for 25,000 soldiers, hospital, stables, and artillery and machine gun ranges up to 1919. The hospital stayed in use until 1923. The west end of the project area from Memorial Park, around Shepherd Drive to Interstate Highway 45, is predominantly residential and is the 4th Ward, with a few large commercial office buildings (*Exhibit 14*). For example, the American General building, a multi-story office building, occupies an entire block of space from Waugh Drive to Montrose along Allen Parkway.

The surrounding residential areas are both old and new as well as a mix of single- and multi-family housing. This residential area is currently undergoing major revitalization. High-income apartments and townhomes are replacing the older dilapidated and low-income houses. This is causing many to move closer to downtown and repopulate these areas, which were once classified as economically depressed neighborhoods.

Past Memorial Park and Interstate Highway 45, the Bayou flows through downtown Houston (*Appendix A:* Sheet 3, Photo A; Sheet 4, Photos A through D; Sheet 7, Photos A through E). This section of Buffalo Bayou is undergoing many shoreline stabilization projects. In downtown, previously vacant warehouses and older buildings, some historic, are being made into lofts and commercial properties. Other buildings within the project area were torn down to make room for the new Houston Astros baseball stadium.

The City of Houston and the Cotswold Foundation have started a redevelopment plan called the Cotswold Project. The Cotswold is a neighborhood improvement project that covers a 90-block area and includes the south banks of the Buffalo Bayou from Milam to Crawford Streets in downtown. The Cotswold Project will improve streets, upgrade sidewalks, plant street trees, and install several fountains as well as have a recognizable and unifying visual theme. This project will also put new utilities and streetlights in this area.

The University of Houston (Downtown) and the Houston Police Station and municipal courts are located directly east and west of Interstate Highway 45 North on the north side of Buffalo Bayou (*Exhibit 14*). The university is on the northwestern bank at the confluence with White Oak Bayou (*Appendix:* Sheet 10, Photos D and E). Across from the University on the northeast side of the Bayou is the jail facility. The southern side of the Bayou at Main Street is a new park and boat launch area (*Appendix A*: Sheet 10, Photo B). North of the confluence of White Oak Bayou and Buffalo Bayou in downtown are industrial warehouse facilities (*Appendix A:* Sheet 11, Photo B). Pedestrian access across the Bayou is provided on several road bridges such as Main Street (*Appendix A:* Sheet 11, Photo D).

From US 59 East to the Turning Basin on both sides of the Bayou, the current land use is predominantly industrial (*Exhibit 14*). This industrial area is comprised of large and small facilities that include both active and abandoned businesses. This area is also intermingled with residential. The 5th Ward is on the north side of Bayou, and the 2nd Ward is on the south side. This area has five parks on the south side of the Bayou, with a majority adjacent to the Bayou.

There are a few notable open spaces and portions of shoreline that are vegetated and not bulkheaded (*Exhibits 7* and *15*) that offer opportunities for redevelopment and habitat improvement such as near the McKee Street Park, near Jensen, the segment between Hirsch and Lockwood, the portion of the Bayou just east of Lockwood including the cut-off meander, and areas near Hildalgo Park and the Turning Basin. The area near the Turning Basin is predominantly smaller industrial facilities and warehouses adjacent to some of the older neighborhoods of Houston. The major chemical plants and refineries are located further east of the Turning Basin along the Ship Channel, so that a majority of the current ship and barge traffic does not proceed west of the Turning Basin.

Other land uses along the Bayou from west to east include River Oaks Country Club, single- and multi-family residential, and the various commercial, educational, and recreational businesses associated with downtown Houston and the Theatre District (*Exhibits 14* and *15*). There are notable abandoned industrial facilities that include the Willow Street Pump Station, the Gable Street Power Plant, and the Velasco Street Incinerator Site (*Exhibit 15*). The Port of Houston's Visitor Center is located at the extreme east end of the project area on the north side of the Bayou.

Buffalo Bayou has some limited running and biking trails, and portions of the Bayou, particularly near downtown and Allens Landing, have large festivals and outdoor concerts for the City of Houston. There are also notable open places and parks: the McKee Street Park, an open space due west and east of US 59; Guadalupe Park, the open area associated with Velasco Street Incinerator; York Street Park; and Hidalgo Park (*Exhibit 1* and *Exhibit 15*). Hidalgo Park has a commanding

view of the Bayou overlooking a major meander of the Bayou with a heavily wooded shoreline (*Appendix A*: Sheet 29, Photo A). However, there is no public access to the water from either side of the Bayou. The park border with the Bayou is bulkheaded.

The Velasco Street Incinerator site (*Exhibit 1*), although an open site, has a large slag pile on the banks of the Bayou. This slag cascades down the approximate 20-foot bank into the water (*Appendix* A: Sheet 19, Photos A through E). Bank vegetation and slag material are eroding in this area. The water depth near the slag is shallow, less than 1.5 feet deep, and the bottom sediment is easily stirred up by boat activity. The bottom sediments are black and the water takes on an inky appearance when disturbed.

Guadalupe Park has public access to the Bayou (*Appendix A*: Sheet 23, Photo B). There is also major erosion just west of this park on the south bank where sandstone layers are exposed (*Appendix A*: Sheet 23, Photo D). York Street Park and McKee Street Park currently do not have public access to the Bayou. York Street Park is adjacent to an auto salvage yard (*Appendix A*: Sheet 21, Photo A). This park is a large open area that is used for soccer. A large concrete recycle materials and sand/gravel product pile is nearby and adjacent to the Bayou (*Appendix A*: Sheet 23, Photos B & D). This pile contributes coarse windblown particulate matter into the air.

There are two municipal wastewater treatment plants along the Bayou within the project site. One is closed (*Appendix A*: Sheet 23, Photo C) and the other is fully operational (*Appendix A*: Sheet 27, Photos A through D). Numerous industrial facilities are located adjacent to or in close proximity to the Bayou and are discussed in the following section.

Further information on roads, bridges, and infrastructure associated with the project site is being addressed in separate reports by others for the 2001 Master Plan Project. Information on the extent of bridges within the project site, particularly their physical condition and recommendations for preservation or demolition, is expected to be provided in the separate reports.

Hazardous Waste Sites

This section discusses existing and potential hazardous waste sites. These sites include facilities that generate, handle, and/or store material that is or can be a point source affecting air and water quality (*Exhibit 16*).

The U.S. Environmental Protection Agency (EPA), Texas Natural Resource Conservation Commission (TNRCC), and local city programs regulate these facilities that handle or generate hazardous wastes along Buffalo Bayou. During the field investigation, many industrial facilities were noted, particularly those that had the potential to handle hazardous waste. These facilities were reviewed against records of permitted facilities. A few permitted hazardous waste handling facilities and one active superfund site are in the project area. Examples of the industrial facilities include metal recycling and reclamation, auto salvage recycling, asphalt unloading, and animal feed and grease production. A complete inventory of every facility within a mile radius was not completed for this report; however, this information can be obtained elsewhere. Some industries in this area are discussed to highlight possible problems that would need to be considered in the master planning.

Superfund Sites

The National Priority List (NPL) Report, also known as the Superfund list, is an EPA listing of uncontrolled or abandoned hazardous waste sites. The definition of hazardous waste is any solid, liquid, or contained gaseous material that is no longer used or recyclable, and therefore a waste, and could cause injury or death or pollute land, air, or water. Two ways a waste may be considered hazardous is as a listed waste or a characteristic waste. A listed waste is defined by the federal regulations under the Resource Conservation and Recovery Act (RCRA) of 1976 and Hazardous and Solid Waste amendments located in Title 40 Code of Federal Regulations (CFR) Part 261. A characteristic waste is defined as meeting one of the following three requirements: (1) Ignitable, the combustibility or flammability of a waste (paint waste, certain degreasers and other solvents), flash point must be less that 140°F, (2) corrosive (waste rust removers, waste acid, alkaline cleaning fluids) having a pH less than or equal to 2 or greater than or equal to 12.5, or (3) reactive, unstable chemical that has rapid or violent reactions with water or other materials (cyanide plating waters, waste bleaches, and other oxidizers).

The listed sites are targeted for long-term remedial action under the Act. One Superfund site is located within the project site, one-half mile north of Buffalo Bayou (*Exhibit 16*). It is the Many Diversified Interests (MDI) site. The hazardous wastes at this site are arsenic, chromium, cobalt, lead, copper, and nickel. MDI went into bankruptcy, and the EPA took over cleanup of the site. The TNRCC is the MDI site coordinator and has sampled the outfall near Hirsch Bridge at the Bayou and also samples groundwater-monitoring wells to determine if any pollutants are reaching the Bayou. Monitoring indicates no evidence that any pollutants from the site are reaching the Bayou. There is always a possibility that waste could reach Buffalo Bayou from MDI; therefore, continuous monitoring is taking place (TNRCC 2001).

The EPA and TNRCC classify facilities by the quantity and type of waste generated. These facilities are required to identify the type of waste generated and also determine what regulatory requirements are specific to their facility. Many of the facilities along Buffalo Bayou have the potential to have hazardous waste but few of these facilities are permitted as hazardous waste generators. All facilities, nonetheless, are still required to meet federal and state regulations for waste that is stored or used onsite. All facilities listed by EPA and the TNRCC as industrial and permitted hazardous waste facilities in the project area are shown in *Exhibit 16*.

Brownfields

In Texas, many former industrial properties lie dormant or under-utilized due to liability associated with real or perceived contamination. These properties are broadly referred to as brownfields. The TNRCC, in close partnership with the EPA and other federal, state, and local redevelopment agencies such as the City of Houston's Brownfield Redevelopment Program and stakeholders are facilitating cleanup, transferability, and revitalization of brownfields through the development of regulatory, tax, and technical assistance tools.

In addition to the specific programs mentioned here, the TNRCC, available at no cost to local governments, will provide technical advice, education, and project partnering for brownfields

redevelopment projects. The Texas Voluntary Cleanup Program (VCP) provides incentives for properties with real and perceived contamination (brownfields) to be investigated, cleaned, and redeveloped. Currently, no sites are formally identified in the project area as brownfield sites under this program. Any property owner who wants to clean up a site can apply for assistance through the EPA, TNRCC, or the city's Brownfield Redevelopment Program. Specific information on brownfields can be obtained through the City of Houston's brownfield co-coordinator.

In January 2002, the State of Texas passed legislation limiting the liability of new property owners of some of these sites in an effort to encourage cleanup and reuse. The prospective owner should apply for an application to the TNRCC and complete the form "Innocent Owner & Operator Certificate." The prospective owner would need to undertake a search of title records and conduct a Phase I site assessment. Depending upon what is revealed in the title search, former land use, and site investigation, the Phase I report would indicate if a Phase II level of investigation is warranted. An engineering firm with experience in further detailed site investigation work is hired to determine what the site may be contain and also identify appropriate cleanup measures before cost estimates can be prepared.

The TNRCC has a Risk Reduction and Corrective Action Program administered through the City of Houston's Brownfield Redevelopment Program Coordinator, Dawn Moses (713-437-6552). Therefore, both should be contacted to help develop a strategy for cleanup. The TNRCC has various levels of allowable cleanup depending upon the proposed land use.

Levels of cleanup include industrial, commercial, and residential. Industrial level of cleanup means the site may still remain contaminated but pollutants are controlled and contained and are released from the site. Other industrial uses of the site can be undertaken. Commercial level of cleanup may involve paving over contaminants, keeping them in place and not adding more contaminants with the intended commercial use. The residential level of cleanup requires the most severe level of cleanup for a finding of "no further action" required. The intended land use of a public open space such as a park, would be included in the residential level of cleanup and therefore requires cleanup to the "no further action" level.

The city and state expect a prospective buyer to complete due diligence before they purchase a site. The intended land use then determines the level of cleanup required. The Phase I and Phase II site investigations determine findings and cleanup requirements. Cleanup could be as simple as topsoil removal, debris removal, or construction demolition or as complex as dealing with radioactive wastes and other problems.

Cleanup costs can range from thousands to millions of dollars per acre or per site. Cleanup of the city bus barn site that is one city block in size costs $3 million to $4 million to clean up the site for residential reuse. Costs would also include the environmental engineering consulting fees for undertaking the Phase I and Phase II investigations. A cost estimate for cleanup fees could only be made by a firm hired to review site conditions and after they have obtained more information about the site history, location, size, and intended use.

Neither the city's Brownfield Redevelopment Program nor the TNRCC provides legal counsel. This would need to be obtained separately by the prospective owner. Further, since much of the cleanup is through voluntary programs, there is not much in the way of policing on the cleanups, so the mechanism that stops most intended reuse of these properties without cleanup is the bank loan. Bank loans for re-development require disclosure and this is usually where cleanup is required, primarily prior to lending. A property may be purchased; however, to get the funds to redevelop, moving through the process of cleanup to get the TNRCC designations of clean for the intended land use. The TNRCC contact is the Volunteer Cleanup Program at 512-239-5891.

Potential Hazardous Waste Sites and Emission Sources

The now abandoned Velasco Street Incinerator Site (*Exhibit 1*) was mentioned earlier in this report in the discussion of land uses. The incinerator is gone, yet slag piles remain along the banks of the Bayou and erode into the water, resulting in the potential for hazardous waste leaching into the water (*Appendix A*: Sheet 19, Photos A through E).

The east end of the project area from York Bridge to 75th Street at the Turning Basin is predominantly industrial with associated neighborhoods and some small businesses. On the south side of Buffalo Bayou near the Lockwood Street Bridge, Danloc makes engine parts and has an auto salvage yard. This facility and the auto salvage area are located adjacent to Buffalo Bayou. No buffer is present between this facility and the Bayou. The cranes located at this facility could drop auto debris directly in the water. When precipitation occurs, automotive fluids can runoff directly into the Bayou. The auto debris and stormwater runoff could cause hazard to recreational boat traffic or public health concerns for fishing, especially near York Park.

Another adjacent facility is Hahn & Clay, located on the north side of the Bayou. Hahn & Clay manufactures oil and gas field equipment. The Occupational Safety & Health Administration (OSHA) released a statement about violations at Hahn & Clay concerning several health hazards. The workers were over-exposed to airborne silica and improper housekeeping for the accumulation of silica on the property. Airborne silica poses a major threat of lung-related diseases for long- and short-term exposure. If the general public were to be exposed to airborne silica, it could cause immediate danger to health and safety.

Two other facilities had visible air emissions near Buffalo Bayou during the field investigations (*Appendix A*: Sheet 22, Photos A through D; Sheet 23, Photo B; Sheet 24). Many companies that are located next to each other handle metal recycling and reclamation. As observed on the north side of Lockwood Bridge, an iron shop was conducting outdoor and unconfined blasting of metal. Particulate from this operation was visibly escaping beyond the boundaries of the facility. Blasting and welding metals could produce harmful gases and metal dust that could be transferred offsite depending on wind direction and speed. To minimize risks, public access and recreational activities should be restricted along this portion of the Bayou, particularly during the beginning of the year. This is when winds from northern fronts could transfer airborne pollutants from the facility to people using the Bayou. The problem with this restriction is that it appeared that several metal recycling

and reclaiming facilities were located on both the north and south sides of the Bayou, so minimizing public exposure to potential hazards may be difficult under current conditions.

Observations made from the Lockwood Bridge indicate an abandoned facility on the north side of the Bayou at this bridge. There are potential problems with old drums and chemical wastes left onsite that could wash into the Bayou. Visible air emissions were also noted from Southern Crush Concrete, which is also located south and near the Lockwood Bridge. Large product piles of recycled crushed concrete, gravel, and sand were stacked in excess of 30 feet high. A smokestack at this facility had billowing white smoke that blew directly over Buffalo Bayou. The white smoke observed may be harmless steam or it is a result of steam used for drying concrete mixtures to make final products. The potential for emissions from the process could be small amounts of minerals used in making the concrete. Additional emission sources include several concrete plants that are located on the west side of the oxbow. Shipping is conducted from these areas by boat and rail, and both are adjacent to the Bayou. During the field investigation it was noted that spills had occurred in the past, and a smell of dust with a coarser particulate content was apparent. This dust was carried offsite with minimal winds in the area. This could cause a danger for inhalation and eye irritation in humans and wildlife.

Another facility along the Buffalo Bayou east of Hedrick Road and a railroad bridge across Buffalo Bayou was Coastal Refining & Marketing, Inc. (Houston Asphalt Terminal). This facility was in close proximity to the Bayou (*Appendix A*: Sheet 26, Photo B). The asphalt terminal is a small site where trucks fill up with asphalt and then ship the material to vendors. Several trucks at the facility were observed to have black residue on top of the porthole on the trucks. This could be a potential problem with air emissions, if a spill were to occur when loading asphalt into trucks near the Bayou.

South of the Bayou, near the end of the project site at 75th Street next to the Turning Basin, several industrial facilities and shipping areas were noted. These facilities include Darling International, Jacob Sterling, PM Ag Products Incorporated, and the U.S. Customs dock (see *Appendix A*: Sheet 31, Photo A). The Customs dock has a sign posted regarding time limits for idling relative to minimizing air emissions. The other facilities have processing and transfer/shipping operations. For example, PM Ag Product manufactures low moisture feed blocks for livestock. Manufacturing of this product involves the cooking of molasses and fat blended with dry feed ingredients, minerals, and vitamins. Darling International is involved in rendering operations, which use animal and food waste to produce commercial goods like tallow, protein meals, and yellow grease. The operation of these facilities near a recreational area could cause problems from odor and potential releases of greases and animal waste products.

AIR QUALITY

In 1873, Edward King traveled along Buffalo Bayou and wrote “the Bayou is overhung by lofty and graceful magnolias and in the season of their blossoming, one may sail for miles along the channel with the heavy, passionate fragrance of the queen flower drifting about him” (Gray 1975). As the Bayou has been altered to support city growth and port development, the “prettiness and romance,” as Edward King depicted, is gone. Everything from raw sewage to industrial wastes has been

dumped into the Bayou, and the visual, recreational, and wildlife resources of the Bayou have been reduced as a consequence, including air quality.

The EPA has established primary and secondary standards known as the National Ambient Air Quality Standards (NAAQS) for six criteria pollutants: carbon monoxide (CO), ozone, nitrogen dioxide, lead, sulfur dioxide (SO2), and particulate matter (PM) 10 and 2.5 micrometers or less in diameter. Several continuous air monitoring stations (CAMS) stations operated by the TNRCC, City of Houston, and other private organizations are located in Houston and near the project area (*Exhibit 16*).

Houston is classified as severe non-attainment for ozone and does not meet the federal clean air standards for ozone. The NAAQS for ozone is not to exceed 125 parts per billion (ppb) in any 1-hour sample, more than three times in three years at any one monitor.

In 2001, TNRCC Region 12 area had 19 CAMS sites that exceeded the federal 1-hour ozone standard. Four CAMS sites are located adjacent to the project area near Buffalo Bayou (*Exhibit 16*). CAMS 81 violated the standard five times in 2001, the highest reading was at 175 ppb on May 25, 2001. CAMS 403 exceeded the standard five times, with the highest reading at 170 ppb on May 25, 2001. CAM 406 exceeded standards twice with the highest reading at 156 on July 22, 2001. CAM 411 exceeded the standard three times for ozone with the highest reading at 166 ppb on May 25, 2001.

Ozone is the primary air quality concern in the project area and is produced by a variety of natural and man-made sources. Ozone pollution is a key component of smog. It is primarily a daytime problem during the summer months. Strong sunlight and hot weather cause ground level ozone to form in harmful concentrations in the air. Ozone is not emitted directly into the air. Instead it is formed in sunlight, which initiates a series of complex atmospheric chemical reactions. These reactions primarily involve nitrogen oxide (NOx) and volatile organic compound (VOC) emissions, called precursors of ozone. There are numerous emission sources for these precursors. The biggest concern with high ozone concentrations is the damage it causes to human health and vegetation. High concentrations of ozone can cause shortness of breath, coughing or wheezing, headaches, nausea, and throat and lung irritation.

Therefore, an environmental issue is associated with air quality and the proposed master plan goals for Buffalo Bayou to bring the public more in contact with Buffalo Bayou for recreational and eco-tourism activities that would be a concern. Unless the air pollution problems are resolved or public access is limited to certain times in the day or certain seasons in the year. Currently, there are news reports that indicate “ozone warning” days when the public is advised not to be outside if practicable.

WATER USES

Water was a primary means of travel in the early 1800s (Rice 1867). Most early settlers and visitors to Texas arrived by boat to Galveston and then navigated up Galveston Bay to Buffalo Bayou and Houston. The arrival of the steamer, the *Laura*, in January 1837 proved that Buffalo Bayou was navigable. Daily steam ships left downtown Houston for trips to Galveston, Velasco, and Matagorda. At that time, Houston was the capitol of Texas until 2 years later, when a yellow fever

epidemic, resulted in the move of the capitol to Austin. Also in 1837, the Allen brothers paid the ship captain of the *Constitution* $1,000 to sail the frigate to the foot of Main Street. Unfortunately, he could not turn his ship around until he reached a wide section of the Bayou that became known as Constitution Bend. It was permanently widened for turning ships and today is known as the Turning Basin (Siegel 1983). By 1840, 5 miles of the Bayou were cleared of its native vegetation, regraded, and wharves constructed.

By 1844, the Bayou was full of navigation hazards from numerous boat wrecks. A bill was passed at that time to clean the Bayou of boat wrecks. During the Civil War in the 1860s, shipping on Buffalo Bayou slowed. Congress declared Houston a Port of Entry in 1870, and congressional appropriations for widening and deepening the channel were made in the amounts of $10,000 in 1872 and $1 million in 1902 (Knapp 1977).

Until an artesian well was drilled in 1887, Buffalo Bayou also provided drinking water to Houston (Knapp 1977). Buffalo Bayou was also an asset to the city for drainage.

In the late 1890s and early 1900s, the taxpayers of Houston and Harris County voted public funds for the improvements of the waterway and rail terminal facilities that serviced it. Cotton exporters, including Anderson, Clayton & Company and Alex. Sprunt & Son financed the construction of deep water cotton terminals. Oil refineries also recognized early the significance of Buffalo Bayou as a ship channel and contributed to its transformation from a sluggish backward Bayou to a ship channel of national importance (Farrar 1926).

In 1908, the Turning Basin was constructed, and by 1909 a group of businessmen presented a plan to the federal government to deepen the ship channel further to 25 feet. The plan was approved, funded, and constructed by 1914. By 1930, 65 industries were located along the Bayou, and the Port of Houston was becoming the second largest port in the U.S. (Farrar 1926).

During the field investigation in 2001, many large ships were docked at the Turning Basin and barges were navigating through Buffalo Bayou, particularly past Hidalgo Park. Hidalgo Park provides a prominent view of the Bayou. The general public utilizes the park for watching the boat traffic as evidenced by many cars parked along J. W. Peevy Street.

The physical configuration of the Bayou offers a challenge for navigation in this area. There is a fairly narrow, sharp bend in the Bayou directly adjacent to the park (*Appendix A*: Sheet 29, Photos B and C). A tugboat pushing a barge loaded with material was observed doing a great amount of maneuvering to move the barge through this bend at Hidalgo Park. This maneuvering of tug and barge traffic could be hazardous if combined with recreational boating because of the limited area and sight distances. This area also experiences loud noises from boat motors and horns, train whistles, and background vehicles. The movement of tanks and industrial equipment through this bend and others in the Bayou pose a risk for spills, which could result in reduced water quality.

The U.S. Customs dock had several barges waiting, with engines idling, for checks on customs limits and regulations. As indicated earlier, a sign was posted warning all boats stopping at the customs dock not to let their vessel (greater than 14,000 lbs) idle for more that 5 minutes during April 1 –

September 1 (*Appendix* A: Sheet 31, Photo A). This is in accordance with a voluntary agreement to reduce air pollution signed by the Texas Waterway Operators Association, the EPA, TNRCC, and HGAC. Air pollution in the shipping industry has not been regulated in past years, but it is now being recognized as a contributor to air pollution problems in the Houston area. Barges and ships that vent gases from products inside is another form of emissions in the project area. Barges containing petroleum products or chemical products must periodically vent volatile organic compounds (VOCs) from these types of shipments to prevent buildup of pressure in the barge. Emissions also occur when boats idle for long periods of time and continuously release diesel fumes.

The fumes from diesel engines and the potential releases from barges relieving pressure from products stored inside is a major health concern to the nearby general public. The other public health safety concerns come from the constant barge and boat traffic of this area. The area near Hidalgo Park is ideal for bird watching and boat watching but consideration must be made for the hazards from barge traffic in this area if recreational activities, water skiing, boating, and fishing, were to occur.

WATER QUALITY

Water quality is also of great concern within Buffalo Bayou. Complaints of water pollution began in the 1890s and continue to the present day (Knapp 1977). Information on water quality in the project area was received from the Houston Galveston Area Council (HGAC 2002). HGAC has recently completed a water quality monitoring report as part of the Clean Rivers Program. HGAC has collected water quality data from TNRCC, USGS, Houston Health and Human Services, and other monitoring groups in an effort to create an accurate, comprehensive database. This data has been compiled in the 2001 Basin Summary Report (BSR). This report addresses Buffalo Bayou and indicated several issues of concern for water quality in Buffalo Bayou. The following highlights information relating to Segments 1007 and 1013, which are both in the project area.

Segment 1007 is located along the Bayou from the Turning Basin to US 59 (downtown). Its designated use is for industrial purposes, industrial water supply, and navigation. The Segment 1013, upstream of US 59, is designated for contact recreation (*Exhibit 15)*.

The major parameter of concern in Segment 1007 is dioxin. Dioxin has been found in blue crab and catfish tissue samples. The Texas Department of Health (TDH) has issued a consumption advisory for the public not to eat fish and crab caught in this area. Dioxin in fish could cause serious health-related problems if eaten. Dioxin is considered by the EPA as a serious public threat and can cause cancer and severe reproductive and immune system damage. The 2001 BSR indicated problems with high amounts of ammonia nitrogen and high fecal coliform levels. The nitrites and nitrates in Buffalo Bayou could cause algal blooms, which deplete oxygen levels in water, resulting in fish kills.

A 2000 assessment report by EPA indicated minimal aquatic life in Segment 1007. Lab results indicated toxicity levels in the ambient sediment for arsenic, zinc, flouranthene, BIS (ethylhexyl) phthlate and benzo (B) flouranthene (HGAC 2002). The sources for these sediment contaminants could be stormwater runoff from nearby industries or carried in the air. There are over 100 wastewater outfalls within this segment. The contaminants in the sediment could be disturbed if

dredging were to occur. Information on these contaminants is available on Material Safety Data Sheets from various references.

Segment 1013 is from US 59 (downtown) to Shepherd Drive. The 2001 BSR indicated the parameters of concern are bacteria (fecal coliform, E. coli, enterrococcus) and nitrite+nitrate nitrogen. The bacteria are a major concern throughout this segment. All stations in this area report exceedances of federal standards 95 percent of the time sampled. This area is reported to have intermediate level of aquatic life. Fecal coliform is an indicator of raw sewage in the Bayou and is from sources such as stormwater runoff from cattle grazing and wildlife areas, residential areas with cats and dogs, illegal discharges of sewage, sewer leaks and blockages, and leaking septic fields and tanks all within the watershed. Fecal coliform could cause problems with the spread of disease and can out compete beneficial bacteria in the aquatic ecosystem.

Currently, certain areas of the project area are heavily industrial. Within a 1-mile radius of the Bayou, there are at least 135 sites that pose environmental risks such as underground leaking petroleum storage tanks; industrial hazardous waste generators, handlers, or storage facilities; CERCLA sites; and voluntary cleanup program sites (ESA database – 6/2001). The large number of industrial outfall points and the possibility of leaking septic tanks are thought to be the reasons why fecal coliform and other chemical pollutant levels are so high. Several groups are currently involved in assessing Total Maximum Daily Load (TMDL) projects to reduce these parameters and correct water quality problems.

An active municipal wastewater treatment facility is located within the project area (*Appendix A*: Sheet 27, Photos A through D). The treated effluent is discharged into Buffalo Bayou. The permitted flow of combined wastewater discharges into the Bayou is 112.25 mgd. A majority of the water in the Bayou is treated effluent and industrial waste discharges.

NON-POINT SOURCE POLLUTION

Buffalo Bayou is in the center of the fourth largest city in the United States. As a result, non-point sources of pollution from different activities throughout the city and the watershed are a normal consequence. Buffalo Bayou is the repository of this pollution and concentrates the amount of non-point pollution from the other bayous and streams through stormwater that washes every street and parking lot throughout Houston and surrounding communities. Therefore, after each storm event, an unfortunate occurrence is the accumulation and concentration of debris and pollutants such as an oil sheen observed in Buffalo Bayou (Photo 1). Non-point source pollution is difficult to collect and treat. Master planning efforts should look for opportunities where stormwater runoff and loose debris can be collected and/or treated near yet prior to reaching the Bayou as well as treating water in the Bayou through a variety of measures (Chasis et al. 1993).

A few weeks after Tropical Storm Allison had occurred, the storm had a large impact on the Bayou by depositing pollutants, trash, overflows of wastewater treatment facilities and sanitary sewers, and many other items picked up in the stormwater. For example, large piles of residential and commercial garbage collected along the streets in nearby neighborhoods and were easily washed into the Bayou (*Appendix A*: Sheet 31, Photo B). As a result of the flooding, debris, such as plastic

shopping bags, was deposited as much as 20 feet high in tree branches, making cleanup difficult at best (*Appendix A:* Sheet 21, Photo C).

Photo 1. Looking southeast along Buffalo Bayou from the Milam Bridge showing water edge condition in the area and a rainbow sheen on the water surface. This sheen indicates some type of oil product discharged into the Bayou.

Non-point source pollution is a major problem for Buffalo Bayou. The accumulation and concentration of trash, loose debris, oil and gasoline residues, and other chemical pollutants cause water quality as well as physical and visual problems in the Bayou, and ultimately in Galveston Bay. The master plan should take into consideration practicable measures for major cleanup of the areas now strewn with trash. The cleanup process would have to be continuous in order to make Buffalo Bayou an area the general public would want to use.

HABITAT

The discussion of habitat will address the aquatic and terrestrial environments as well as the vegetation and wildlife associated with Buffalo Bayou. It has been noted elsewhere within this report that the entire project site has been altered. Therefore, no undisturbed habitat exists within the project site. A majority of the vegetation and habitat present within existing conditions has re-established itself after natural disasters, such as catastrophic flood events, and man-made modifications to the channel bottoms and sideslopes. Much of the vegetation present is young (less than 20 to 25 years old) pioneer species (*Appendix A*: Sheet 2, Photo D; Sheet 3, Photos A through C; Sheet 9, Photo A; Sheet 13, Photos A & C; Sheet 17, Photo A).

The Buffalo Bayou watershed is located at the interface between three ecosystems: the East Texas Upland Piney Woods, which is an extension of the larger southeast and eastern mixed hardwood deciduous forest, the Gulf Coast Bluestem Prairie, and the Coastal Marsh Complex (Hatch et al. 1990) (*Exhibit 17*). Within each of these three broad ecosystems are distinct smaller units of plant and animal associations that respond to and are reflective of local changes in topography, soils, climate, and moisture regimes. For example, the convergence of forest and coastal marsh here along the San Jacinto River and portions of Buffalo Bayou supported bald cypress (*Taxodium distichum*) swamps (*Exhibit 9*).

In the headwater areas of Buffalo Bayou, the wooded riparian corridor through the bluestem prairie transitioned to oak-savannahs (Hosage 2001). This discussion of habitat relative to vegetation and wildlife highlights the native plant communities before habitat alterations, describes the current conditions relative to vegetation and habitat, and makes recommendations of target plant communities taking into account the current urban constraints.

It may not be possible to fully restore the natural physical, chemical, and biological conditions, and therefore, the habitats associated with pre-settlement Bayou conditions. However, attributes of these natural conditions can be created by revising conditions of the existing Buffalo Bayou to provide improved functions and values. Native plant and animal species that would typically characterize the natural aquatic and terrestrial habitats of Buffalo Bayou are described below. According to Hatch et al. (1990), the list of native and naturalized plants for Houston and vicinity includes 1,596 flowering plants, 35 ferns and fern allies, 67 mosses and liverworts, and 25 lichens. There are 59 species of native trees that occur in Memorial Park. The Houston Arboretum provides a good example of some of the habitat types native to the Bayou. An inventory of existing vegetation and wildlife observed is also given. A comparison of the existing inventory to what was once present along the Bayou further illustrates how much has changed. Recommendations for re-establishing native species to enhance the existing conditions are in *Section II* of this report.

Aquatic

According to the U.S. Fish and Wildlife Service's classification system (Cowardin 1979), the Bayou would be classified as a riverine open deep water habitat. The aquatic environment includes those areas that are permanently inundated within the Bayou configuration. These areas range in normal water depths of 3 to 4 feet to over 40 feet at the Turning Basin. The typical cross-section within much of the project area has 15 to 20 feet of water depth (*Exhibit 8*). The sideslopes of the Bayou generally are 1:1, 2:1, or 3:1 and do not provide an adequate flat, shallow area at the toe of the slope and water line to support vegetated wetlands along the Bayou (see *Appendix A:* Sheet 4, Photos A, and B).

Wetland was defined earlier in this report. Typically, as a transitional area between permanent open water and upland, wetlands associated with Buffalo Bayou should be present along the normal water level of the Bayou (Gosselink, Lee and Muir 1990). Currently, the project site has very limited wetlands because of past channel modifications and filling of the smaller natural drainage tributaries and wetlands, erratic fluctuations of water levels, and unstable bank conditions. Only in a half dozen

areas were potential wetlands present (see *Appendix A*: Sheet 25, Photo B; Sheet 28, Photo B). These wetlands would be classified as riverine, emergent, scrub-shrub, or forested habitats (Cowardin 1979). Wetlands are important features for the Bayou because of the numerous functions they provide (*Exhibit 18*).

The aquatic environment also includes the water column and the Bayou bottom sediments (*Exhibit 18).* Aquatic organisms would include finfish, shellfish, and bottom dwelling macroinvertebrates. Studies undertaken by HGAC indicate that because of past dredging and poor water quality in areas of the Bayou, the macroinvertebrates are severely limited to non-existent. Segment 1007 downstream of US 59 is reported to have minimal aquatic life. Segment 1013 upstream from US 59 is reported to have intermediate aquatic life (HGAC 2001).

For 20 years, staff from the inland fisheries program of the Texas Parks and Wildlife Department have been monitoring the presence of fish species at three locations in Buffalo Bayou and a location in White Oak Bayou approximately 1,500 feet upstream from the confluence of White Oak Bayou with Buffalo Bayou (Webb 2001). The locations within Buffalo Bayou are located near Milam Street Bridge, between Main Street and Fannin Street bridges, and near the outfall of the municipal wastewater treatment facility (*Exhibit 16*).

Fish species data was collected between 1976 to 1996 using electrofishing and seining methods by the Texas Parks and Wildlife Department Inland Fisheries Program (*Table 3*). Results indicate that there are 22 species of fish within the project site (Webb 2001). Some of these species are bottom feeders and others are sight feeders. All are typical of inland waterways like Buffalo Bayou and some indicate a tidal influence. All are important components of the food chain for other species such as shoreline wading birds like the Great Blue Heron (*Ardea herodias*), Great Egret (*Casmerodius albus*), Green-back heron (*Butorides striatus*), and others. No protected fish species were recorded within Buffalo Bayou. Shellfish, such as crayfish and shrimp, have not been sampled (Webb 2001).

Table 3. Fish Species Within Buffalo Bayou

Common Name	Scientific Name
Alligator gar	*Lepisosteus spatula*
Armored catfish	*Hypostomus sp.*
Blue catfish	*Ictalurus furcatus*
Blue tilapia	*Tilapia aurea*
Bullhead minnow	*Pimephalus vigilax*
Common carp	*Cyprinus carpio*
Flathead catfish	*Pylodictis olivaris*
Gizzard shad	*Dorosoma cepedianum*
Grass carp	*Ctenopharyngodon idella*
Green sunfish	*Lepomis cyanelius*
Inland silverside	*Menidia berylina*
Largemouth bass	*Micropterus salmoides*
Longear sunfish	*Lepomis megaiotis*
Longnose gar	*Lepisosteus osseus*
Mosquitofish	*Gambusia affinis*
Rio Grande cichlid	*Cichlosaoma cyanoguttatum*
Smallmouth buffalo	*Ictibus babalus*
Spotted gar	*Lepisosteus occulatus*
Striped mullet	*Mugil cephalus*
White bass	*Morone chrysops*
White crappie	*Pomoxis annularis*
White mullet	*Mugil curema*

(Source: Webb 2001)

Besides deep water, fish need a balanced food source, adequate cover, and appropriate water quality and temperature in order to survive well within the Bayou (Stroud 1992; Webb 2001). Where overhanging tree and shrub branches cast shadows on the water surface, leaf litter can fall into the water, and if stable water regimes exists and insects are plentiful, then ideal conditions for inland fish habitat are present.

Terrestrial

As indicated earlier, Buffalo Bayou once flowed through three ecosystems during pre-settlement times: the woodlands of the East Texas Upland Piney Woods, the open grasslands of the Gulf Coast Bluestem Prairie, and the wetland habitats of the Coastal Marsh Complex. The banks of the Bayou were known to have extensive wooded resources including the forested floodplain wetlands that kept sawmills busy for 60 years.

The wooded resources along the Bayou were a part of the much larger East Texas Piney Woods, a forest ecosystem that spanned north-northeast beyond Texas into northern Louisiana, southern

Arkansas, and up into the southern portion of the Mississippi River Valley (Mattoon 1915). This forest ecosystem is comprised of drier upland and low-lying floodplain woods (Gosselink, Lee and Muir 1990). Whether upland or floodplain, the wooded corridor along a bayou or river is called riparian. This riparian corridor would be continuous along both sides of the bayou and would span the entire length of a bayou. Today this corridor is non-existent.

Since the East Texas Piney Woods ecosystem covered a large geographic scale, it is not influenced by the Bayou. However, the local riparian corridor, typically 100 feet to several miles wide along both sides of the Bayou, was influenced by the hydrology of the Bayou. This corridor, particularly the low-lying areas, was composed of bald cypress swamp and mixed hardwood bottomland forest (*Exhibit 9*). The bald cypress-dominated swamps were characteristic of the southern floodplain forests (Rathbourne 1951; Sternitzke 1972; Ewel and Odum 1986; Williston et al. 1980). The bald cypress swamps ranged from central Texas east to Alabama and north to portions of Ohio as this species is associated with the lower Mississippi River Valley (*Exhibit 19*).

In its primitive or pre-settlement condition, Buffalo Bayou was noted to be an unusual stream (Farrar 1926). In the 1890s, J. P. Rembert described Buffalo Bayou as being "narrow, sluggish, crooked and shallow" and Buffalo Bayou was clogged with native wetland vegetation (Houston Post – Dispatch August 18, 1929). It had high banks in parts, deep water in parts, and was overhung with branches of large forest trees. The banks of the Bayou were noted for the mature woody vegetation. Charlotte Houston, in the mid-1940s described the Bayou as follows: "for a considerable distance from the mouth the shores were low, flat and swampy but the stream narrowed and there were high banks and the trees were quite beautiful such magnolias, eighty feet in height, and with the girt like huge forest trees-there were also a great number and variety of evergreens, laurels, bay, firs, rhododendrons, cistus and arbutus." "The trees and shrubs grew to a prodigious height and often met over the steamer" (Knapp 1977). *Exhibits 9, 21*, and *22* illustrate conditions of what portions of pre-settlement Buffalo Bayou may have looked like and what habitat creation efforts could produce.

The Gulf Coast Bluestern Prairie and Coastal Marsh Complex ecosystems were a larger influence on the Bayou and its inhabitants. The expanses of prairie covered a majority of the pre-settlement watershed of the Bayou and regulated flood flows and water quality. The prairie ecosystem was dominated by native grasses that produced an extensive standing biomass of thick, lush vegetation typically 4 to 6 feet tall with a structure belowground that penetrated down 6 to 8 feet into the stiff, slow draining clays of the region (Hatch et al. 1999). This extensive area of grasses and herbaceous forbs acted to intercept surface sheet flows of stormwater, slow it down, filter it, and transfer it by roots into a groundwater system (*Exhibit 20*).

The coastal marshes were located along the perimeter of the Bay and transitioned inland along the Bayou perimeter. Depending upon plant and animal species present, they also influenced the character and quality of the Bayou. For example, beaver were known to dam up the Bayou and create extensive wetland complexes within land adjacent to the Bayou (Davis and Schmidly 1994). These wetland complexes provided water detention and water treatment functions, among other benefits (*Exhibit 18*).

Current habitat conditions are poor to non-existent within Buffalo Bayou. Since the Bayou and its watershed have been significantly altered for over 150 years, very little habitat remains (USACE 1989; USACE 1994). The habitat that is present supports weedy plant species and is fragmented and is too small to support communities of animals, only individuals. The habitat is heavily and continuously degraded with excessive and rapid flood flows, tremendous amounts of debris, and poor water and air quality.

Within the project site, a few areas can be considered significant habitat because, within the project site, they represent a relatively large open area within the urban context, support a mix of native vegetation, and are areas noted due to wildlife presence and utilization. These areas include the open water component of the Bayou that supports a fish population; the wooded riparian corridor along the banks of the Bayou that provides some habitat support for resident and migratory wildlife species; areas set aside in adjacent parks, such as Memorial Park; the riparian area due east of the cut of meander/oxbow; and the riparian area near Hidalgo Park on both sides of the Bayou. There is also a drainage tributary supporting willow and other wetland vegetation at the water line of the Bayou. A scrub-shrub area upstream of the McKee Street Bridge along the north bank of the Bayou supported a noticeable amount of bird activity. The other areas are also noted because of the wildlife observed. The size of existing wooded and open areas along the Bayou range from as small as a few square feet to as large 1,503 acres within Memorial Park.

VEGETATION

The discussion of vegetation will address what was along Buffalo Bayou historically, what is present currently, and recommendations for proposed habitat improvements.

The Bayou once consisted of very large trees that hung with Spanish moss and numerous prairie grasses, rushes, and a great variety of wildflowers (Hosage 2001; Gray 1975; Hatch et al. 1990; Vines 1976). Evidently, there was a large floodplain with associated ponds, sloughs, and wetlands (*Exhibits 9, 11,* and 12). The vegetation along the Bayou was recorded by various early travelers and included species such as pecan, sweetgum, southern magnolia, red bay magnolia, sweet bay magnolia, cedar, pine, various oak species, wild peach, mulberry, yaupon, and grape.

The historic vegetation was also recorded during early surveys of the Bayou. These sources, in some instances, noted the species, size, and location as indicated in *Table 4*.

Table 4. Historic Vegetation Recorded During Early Bayou Surveys

Dates	Comments
1831	R.S. Gray noted large pine, cypress, some cedar, ash, pecan, oak, black walnut, little locust, red grapes, introduced china trees, live oak and red oak, wild peach, holly, cottonwood.
1836	Inexhaustible quantities of ash, cedar, oak with beautiful tall magnolias in abundance.
1837-1839	Dim forest on both banks consisting of gum, wild peach, cedar, palmettos, and hyacinths choked the ponds. Spanish moss was long and green. Beyond this spread the prairie grasslands dotted with pine groves for a distance of two miles.
1840	Four miles north of Houston, Buffalo Bayou extends into an extensive prairie and has narrow fringe of timber along the Bayou margin. Timber consisted of pine, oak, ash, magnolia, hickory, mulberry, and cypress.
1842	So polluted, the City prohibited bathing in Buffalo Bayou. Also prohibited was sawdust dumping into the Bayou since there was lots of debris, logjams, refuse, and silt. White sand called quick sand was noted at this time.
1845-1848	Bank survey undertaken by the City. Trees: 14-16 inches caliper, 24-inch, 30-inch, 40-inch consisting of red oaks, blackjack oaks, pines, and magnolias. Rocks, springs, and gullies noted along the Buffalo Bayou.

The current vegetative cover along the Bayou within the project area is relatively consistent. Where sideslopes are relatively stable and not hardened i.e. bulkheaded, concreted or otherwise treated with sheet piles, the plants are mainly woody (*Appendix A*: Sheet 3, Photo B). The ground cover vegetation is noticeably absent in many woody areas due to lack of sun, excessive wash over and soil movement, and lack of organic component and nutrients in the soil (*Appendix A:* Sheet 4, Photo A). Some areas have patches of herbaceous plants consisting of a mix of grasses and forbs depending upon the particular history of that area (*Appendix A:* Sheet 17, Photo B).

Current plant species present are listed in *Table 5* and generally respond to landscape position, bank slope condition, frequency of flooding, and soil condition. The landscape position relative to plant species location is as follows: top of bank above the normal floodway; dynamic bank side slope zone; and normal water's edge, which includes the high water flow, base flow, and low flow. From the normal water line to the normal high-water mark, vegetation is limited to willow, green ash, and box elder. The vegetation survey for this report did not include landscaped and maintained areas such as at Allens Landing and the Main Street Park and boat launch area.

Table 5. Plant Species Observed Along Buffalo Bayou During 2001

Common Name	Scientific Name	Remarks
American elm	*Ulmus americana*	Successional species
Beggerstick	*Bidens aristosa*	
Bermuda grass	*Cynodon dactylon*	
Black willow	*Salix nigra*	Numerous; early colonizer continues to re-establish itself in eroding areas water edge
Box elder	*Acer negundo*	Frequent pioneer; species water edge
Brownseed	*Paspalum plicatulum*	
Bushy bluestem	*Andropogen glomeratus*	
Catalpa	*Catalph bignonioides*	
Chinaberry	*Melia zedarach*	
Chinese tallow	*Sapium sebiferum*	
Consumption weed	*Baccharis halimuifolia*	
Cottonwood	*Populus deltoides*	Later pioneer species less frequent limited and not very old in the project area
Dallisgrass	Paspalum dilatatum	
Goldenrod	Solidago sp.	
Grapevine	Vitis aestiudis	
Green ash	*Fraxinus pennsylvania*	Fast growing, the most dominant species in existing inventory
Hackberry	*Celtis occidentals*	Number one most valuable species to wildlife and present in existing inventory
Honey locust	*Gleditsia triacanthos*	
Knotgrass	*Paspalum distichum*	
Live oak	*Quercus virginiana*	
Loblolly pine	*Pinus taeda*	
Panicum	*Panicum sp.*	
Peppervine	*Ampelopsis arborea*	
Phragmites	*Phragmites australis*	
Ragweed	*Ambrosia trifida*	
River birch	*Betula nigra*	
Ruellia	*Ruellia sp.*	Common throughout in limited areas
Scouring rush	*Equisetum hyemale*	
Smartweed	*Polygonum hydropiperoides*	In selected areas throughout
Spanish moss	*Tillandsia usneoides*	
Sycamore	*Platanus occidentalis*	
Trumpet creeper	*Campsis radicans*	
Virginia Creeper	*Parthenocissus quinqueflia*	
Willow oak	*Quercus phellos*	

Most recent eroded areas are devoid of any vegetation (*Appendix A*: Sheet 14, Photos A, B and C). Some areas appear to have been dump sites for industrial and/or municipal waste, and these areas are poorly vegetated as a result (*Appendix A*: Sheet 8, Photo B; Sheet 19, Photos A, B and E). Other areas have been planted and maintained as a more urban landscape setting. For example, a portion of Buffalo Bayou was channelized with the construction of a double bridge that connects Houston Avenue and the Gulf Freeway traffic and an extension with Buffalo Drive. As part of this work, a beautification project of the Buffalo Drive included the planting of live oak (*Quercus virginiana*) and other tree species such as golden rain and crepe myrtle, which are non-native species and still present today (Houston Post-Dispatch September 24, 1946).

Recommendations for what vegetation should be along the Bayou are the native vegetation of bottomland hardwood forests that are characterized by a high diversity of trees and shrubs that are adapted to grow in the wide variety of environmental conditions associated with routine flooding (Stutzenbaker 1999; Gosselink et al. 1990; Hatch et al. 1999). The most important environmental condition is the hydrology, which determines the "moisture gradient," or frequency and duration of flooding which varies in time and space across the floodplain. Slope or elevation is a critical factor affecting hydrology and the presence of vegetation and wildlife. Examples of local undisturbed habitat conditions illustrating flat slopes, shallow water depths, and normal vegetative bayou conditions are shown in *Exhibits 23* and *24*. The following is a brief description of the ecological transition zones within a natural floodplain. *Table 6* presents a list of tree and shrub species common to bottomland hardwood forests from wettest (ecological zone II) to driest (ecological zone VI) conditions.

Zone II – Vegetation in this zone is adapted to almost continuous flooding. Bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) usually dominate the canopy of the bottomland. Major associates include buttonbush (*Cephalanthus occidentalis*) and water elm (*Planera aquatica*).

Zone III – This zone supports vegetation such as black willow (*Salix nigra*) and cottonwood (*Populus deltoides*) in the pioneer stage. A more permanent association in this zone includes overcup oak (*Quercus lyrata*) and water hickory (*Carya aquatica*) which often occur in relatively small depressions in the floodplain. Several other species of green ash (*Fraxinus pennsylvania*) and river birch (*Betula nigra*) can be found in this zone. New point bars that form in the channel are often in this hydrologic zone and are colonized by stands of willow (*Salix sp*.), maple (*Acer sp*.), birch, or cottonwood.

Zone IV – This zone supports a wider array of trees and shrubs. Common species include laurel oak (*Quercus laurifolia*), green ash (Fraxinus pennsylvanica), American elm (*Ulmus americana*), and sweetgum (*Liquidambar styraciflua*). This zone can also support several other species of oaks such as willow oak (*Quercus phellos*), Nuttall oak (*Quercus nuttallii*), and Cherrybark oak (*Q. falcata*).

Zone V – Oaks (*Quercus* spp.) and hickories (*Carya* spp.) usually dominate the associations at this elevation in the floodplain. This zone is particularly difficult to delineate in the field due to the overlap of species with Zone IV. Some species of pine (*Pinus sp*.), for example loblolly pine (*Pinus taeda*), can occur in the zone.

Zone VI – This zone is no loner considered part of the wetland of the bottomland hardwood forest, but is a transition zone to the dry upland. Several species of oak (*Quercus sp*.), ash (*Fraxinus sp*.), and hickory (*Carya sp*.) are found in these generally aerobic soils. Trees that are intolerant of soil saturation first appear in this zone.

Table 6. Selected Tree And Shrub Species For Bottomland Mixed-Hardwood Forests (after Larson et al. 1981)

Note: X indicates where species are likely to occur relative to ecological zones that are differentiated by distance, elevation, and moisture regimes associated with river or bayou.

Ecological Zone

Species	II	III	IV	V	VI
Taxodium distichum (bald cypress)	X	X			
Nyssa aquatica (water tupelo)	X	X			
Cephalanthus occidentalis (buttonbush)	X	X			
Salix nigra (black willow)	X	X			
Forestiera acuminata (swamp privet)	X	X			
Fraxinus caroliniana (water ash)		X	X		
Ulmus americana (American elm)		X	X		
Quercus laurifolia (laurel oak)		X	X	X	
Carya aquatica (water hickory)		X	X		
Quercus lyrata (overcup oak)		X	X		
Styrax americana (smooth styrax)		X			
Gleditsia aquatica (water locust)		X	X		
Fraxinus pennsylvanica (green ash)		X	X		
Diospyros virginiana (persimmon)		X	X	X	X
Nyssa sylvatica var. *biflora* (swamp tupelo)		X			
Betula nigra (river birch)		X	X		
Populus deltoides (eastern cottonwood)		X	X		
Baccharis glomeruliflora (goundsel)			X	X	X
Cornus foemina (stiff dogwood)		X	X		
Viburnum obovatum (black haw)			X		
Celtis laevigata (sugar berry)			X	X	X
Liquidambar styraciflua (sweetgum)			X	X	
Acer negundo (box elder)			X	X	
Sabal minor (dwarf palmetto)			X	X	
Gleditsia triacanthos (honey locust)			X	X	X
Ilex decidua (possum haw)			X	X	X
Crataequs viridis (green hawthorn)			X		
Quercus phellos (willow oak)			X	X	X
Platanus occidentalis (sycamore)			X	X	X
Ulmus crassifolia (cedar elm)			X		

Table 6. Selected Tree And Shrub Species For Bottomland Mixed-Hardwood Forests (after Larson et al. 1981) *continued*

Note: X indicates where species are likely to occur relative to ecological zones that are differentiated by distance, elevation, and moisture regimes associated with river or bayou.

Ecological Zone

Species	II	III	IV	V	VI
Ulmus alata (winged elm)			X	X	X
Ulmus americana (American elm)			X	X	X
Quercus nuttallii (nuttall oak)			X		
Quercus virginiana (live oak)			X	X	X
Carya illinoensis (pecan)			X	X	X
M*yrica cerifera* (wax myrtle)			X	X	X
Morus rubra (red mulberry)			X	X	X
Sambucus canadenis (elderberry)			X	X	X
Magnolia virginiana (sweet bay)			X		
Sabal palmetto (sabal palm)			X	X	
Crataegus marshallii (parsley haw)			X	X	
Quercus nigra (water oak)			X	X	X
Quercus michauxii (swamp chestnut oak)			X	X	
Quercus falcata var. *pagodaefolia* (cherrybark oak)				X	X
Nyssa sylvatica (black gum)				X	X
Pinus taeda (loblolly pine)				X	X
Carya ovata (shagbark hickory)				X	X
Juniperus virginiana (eastern red cedar)				X	X
Callicarpa american (American beautyberry)				X	X
Asimina triloba (paw paw)				X	
Ilex opaca (American holly)				X	X
Prunus serotina (black cherry)				X	X
Magnolia grandiflora (southern magnolia)				X	X
Ostrya virginiana (eastern hop-hornbeam)				X	X
Sassafras albidum (sassafras)				X	X
Quercus alba (white oak)				X	X
Cornus florida (flowering dogwood)				X	X
Tilia caroliniana (basswood)					
Asimina parviflora (dwarf paw paw)				X	X
Euonymus americana (strawberry bush)				X	X
Carya glabra (pignut hickory)				X	X
Ptelea trifoliata (water ash)				X	X

WILDLIFE

During the field investigations, the following wildlife species were observed: Great Blue Heron, Great Egret, Green-black Heron, Little Blue Heron, Cardinal, Mockingbird, Brown-headed Cowbird, Woodpecker, Belted Kingfisher, Bank Swallow, starlings, wrens, hawk, turtles, frogs, Texas Diamond-Backed water snake, and squirrel.

The Great Blue Herons observed within the project site are territorial. They do not share foraging areas; therefore, when one is observed, it typically will be the same individual seen in the same spot again and again. The Great Blue Heron is a colonial water bird, which means it nests in a rookery somewhere else with other colonial water birds including egrets and cormorants. Since Great Blue Herons typically fly 7 to 15 miles from the colony to a defended foraging area, the individuals seen along Buffalo Bayou use the Bayou for foraging only and nest elsewhere, probably inland on Lake Houston, along the San Jacinto River, or along Galveston Bay since no rookery was observed within the project site. The Great Blue Heron, as well as the Great Egret, may be seen temporarily roosting during the day in canopy trees and large shrubs, but these species will return to the rookery by dusk. Great Blue Herons, as well as other colonial water birds and shoreline wading birds, can be increased along Buffalo Bayou by increasing the food source and providing shallow vegetated shoreline conditions conducive to wading (*Exhibit 23*). The Great Blue Heron is an opportunistic feeder, meaning it will eat just about anything small enough to swallow that it encounters i.e. turtles, snakes, frogs, and fish.

On occasion, reports indicate that the American alligator can be observed in portions of Buffalo Bayou. Although the alligator was listed as a threatened species by the federal government and as a protected species by State of Texas, now there are areas where alligator populations are large enough to support sanctioned hunting. Shoreline conditions within the project site are not normally conducive to providing habitat for this species (*Exhibit 24*).

Typical wildlife species that occur within portions of Buffalo Bayou, particularly in the vicinity of Memorial Park, are listed in *Tables 7* through *10*. These species include reptiles, amphibians, mammals, and birds.

According to the Houston Audubon Society, the Edith L. Moore Nature Sanctuary located along Rummel Creek near Memorial Drive, has documented 128 species of birds (HAS 2000). This sanctuary can be considered representative of bird species occurrence within healthy riparian habitats associated with Buffalo Bayou. According to the Houston Arboretum and Nature Center located within Memorial Park and due west of the project area, 164 species of birds that represent 39 families have been observed within the arboretum between 1979 and 1992. Many of these species are migratory and use the riparian areas, woodlands and thickets, ponds, wetlands, and the Bayou's stream channel during fall and spring migration. Approximately a dozen species are known to nest at the arboretum.

Table 7. Reptiles Observed in the Vicinity of Memorial Park

Common Name	**Scientific Name**
American Alligator	*Alligator mississipiensis*
Common Snapper	*Chelydra serpentine serpentina*
Mississippi Mud Turtle	*Kinosternon subrubrum Hippocrepis*
Western Chicken Turtle	*Deirochelys reticularia miaria*
Red-Eared Turtle	*Pseudemys scripta elegans*
Three-Toed Box Turtle	*Errapene Carolina triunguis*
Green Anole	*Anolis carolinensus*
Ground Skink	*Lygosoma laterale*
Five-Lined Skink	*Eumeces fasciatus*
Southern Prairie Skink	*Eumesces septenrionalis obtusirostris*
Western Slender Glass Lizard	*Ophisaurus attenuatus attenuatus*
Six-Lined Racerunner	*Cnemidophorus sexlineatus*
Northern Fence Lizard	*Sceloporus undulates hyacinthinus*
Rough Green Snake	*Haldea striatula*
Rough Earth Snake	*Opheodrys aestivus*
Yellow-Bellied Racer	*Oluber constrictor flaviventris*
Eastern Coachwhip	*Masticophis flagellum flagellum*
Eastern Hognose Snake	*Heterodon platyrhinos*
Eastern Ribbon Snake	*Thamnophis proximus*
Blotched Water Snake	*Natrix erythrogaster trnsversa*
Broad-Banded Water Snake	*Natrix fasciata confluens*
Diamond-Backed Water Snake	*Natrix rhombifera rhombifera*
Texas Brown Snake	*Storeria dekayi texana*
Texas Rat Snake	*Elaphe obsolete linddheimeri*
Prairie King Snake	*Lampropeltis calligaster calligaster*
Speckled King Snake	*Lampropeltis getulis holbrooki*
Mississippi Ringneck Snake	*Diadophis ppunctatus stictogenys*
Southern Copperhead	*Agkistrodon contortrix contortrix*
Western Cottonmouth	*Agkistrodon piscivorus leucostoma*
Texas Coral Snake	*Micrurus fulvius tenere*

Source: William L. McClure, Houston, Texas. Unpublished memo

Table 8. Amphibians Observed in the Vicinity of Memorial Park

Common Name	Scientific Name
Gulf Coast Toad	*Bufo valliceps*
Eastern Narrow-Mouthed Toad	*Gastrophryne carolinensis*
Cricket Frog	*Acris crepitans*
Squirrel Treefrog	*Hyla squirella*
Green Treefrog	*Hyula cinerea cinerea*
Gray Treefrog	*Hyla chrysosceles*
Upland Chorus Frog	*Pseudacris triseriata feriarum*
Leopard Frog	*Rana pipiens*
Bronze Frog	*Rana clamitans clamitans*
Bullfrog	*Rana catesbeiana*

Source: William L. McClure, Houston, Texas. Unpublished memo

Table 9. Mammals Observed in the Vicinity of Memorial Park

Common Name	Scientific Name
Opossum	*Didelphis marsupialis*
Little Short-Tailed Shrew	*Cryptotis parva*
Red Bat	*Lasiurus borealis*
Raccoon	*Procyon lotor*
Fox Squirrel	*Sciurus niger*
Hispid Cotton Rat	*Sigmoodon hispidus*
Eastern Cottontail	*Sylvilagus floridanus*
Nine-banded Armadillo	*Dasypus noveminctus*
Striped Skunk	*Mephistis mephistis*
Rat	*Rattus sp.*
House Mouse	*Mus musculus*

Source: William L. McClure, Houston, Texas. Unpublished memo

The limited open vegetated areas within the project site provide some habitat for a few common resident animals that can utilize the limited resources of trees, shrubs, and water available. A review of these common resident animals' habitat requirements provides further insight into the existing

conditions along the Bayou. All of these species utilize deciduous woodlands and keep to vegetated portions along the Bayou (Davis and Schmidly 1994).

The opossum is a native marsupial, or mammal with a pouch for its young. Opossums hunt strictly at night for small birds and mammals. They also forage for eggs, fruit, and insects. Habitat home range size is about 12 acres.

The little short-tailed shrew is a common native species that is only 4.5 inches in length, yet a very fierce mammal that can kill prey several times larger than itself. It typically consumes large quantities of vegetation matter. Also, it is a nocturnal mammal that is found in forested areas. It burrows in softer soils.

Red bat is a widespread species. It is very small, about 4.5 inches, and is recognizable by its rusty red fur. This species migrates so it may be seen mostly in winter in the project area. This species is excellent for the environment because of the amount of insects they consume.

The only representative of carnivores within the project area is the raccoon. It eats meat, such as fish, frog, etc. but will supplement its diet with fruits and berries. The raccoon is adaptable to water conditions since it is a good swimmer. It climbs trees and dens in hollows or earth burrows.

The fox squirrel, hispid cotton rat, rat, and house mouse are rodents within the project site. They are a very successful group and, therefore, are widespread. They generally gnaw woody plant parts and eat seeds, fruits, and berries.

The striped skunk is a member of the weasel family. All members of this family have scent glands; however, the skunk is the most powerful. The skunk is known for its white stripe along the backbone of an otherwise black fur. Skunks hunt at night for mice, rats, probably squirrels, and all kinds of insects and are also adaptable to the water.

The fox squirrel is a tree-dweller that eats acorns, fruit, and seeds of the local trees. The fox squirrel nests in the trees. The fox squirrel can be active in the day as well as the night. It preys on owls, hawks, and other carnivores. The fox squirrel is solitary, and nocturnal; forest or tree dwelling, and an adaptable species that has managed to survive within the urban context. The hispid cotton rat is a shaggy small mammal that occupies grassy weedy places.

The eastern cottontail is a member of the rabbit family and is easily adaptable to a range of habitat conditions and is, therefore, very widespread. It can survive in open parks, vacant lots, wooded riparian corridors, and residential yards. This species burrows in the ground or makes shelter in heaps of brushes and eats herbaceous vegetation.

The nine-banded armadillo is an odd mammal since it is protected with bony plates rather than fur. This species must burrow into the ground for protection since it cannot curl up into a ball. It is most active at night, foraging for grubs and other insects. It tends to concentrate along stream channels, like the Bayou, and dens in cracks and crevices of limestone outcrops or burrows in the bank. The

armadillo is easily affected by cold weather, and freezing weather will kill them. They are active at night during the summer and are active during the day in the winter.

Table 18. Bird Species Observed in Memorial Park at the Houston Arboretum and Nature Center

BIRD NAME	HABITAT	SP	SUM	F	W
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LEGEND

HABITAT

[illegible]

ABUNDANCE

[illegible]

SEASON

SP Spring
SUM Summer
F Fall
W Winter

[illegible]

THREATENED AND ENDANGERED SPECIES

According to the U.S. Fish and Wildlife Service, only the Bald Eagle (*Haliaectus eucocephalus*) is a federally listed animal species for Harris County, Texas. This species is listed as threatened; however, its population numbers have been increasing, and there are plans to remove this species from the protection status. The Bald Eagle is known to occur on the eastern side of Lake Houston, at Warren Lake west of Houston, and also nests in Fort Bend and Brazoria Counties. Habitat conditions for this species (such as large open water with fish, sizable net trees, and little human activity) do not occur within the project site. Prairie dawn (*Hymenoxys texana*) is the only federally listed plant species for Harris County, Texas. This species is listed as endangered. It is a very small plant that naturally occurs on mima mounds in open sandy or gravel areas within prairies. Habitat conditions are not present within the project area to support this species. Closest known occurrence of this plant is west in the Barker and Addicks Reservoirs areas.

Table 11 lists the state and federal threatened (T) and endangered (E) species indigenous to Harris County. Field surveys and available records show no evidence of or suitable habitat for any of these species within the project area. Of the listed federal and state plant and animal species, none are known to occur within the project site because habitat conditions are not conducive to support any of these species.

Table 11. State and Federal Threatened and Endangered Species of Harris County

Common Name	Scientific Name	State Status	Federal Status
AMPHIBIANS			
Houston Toad	*Bufo houstonensis*	E	
FISHES			
Creek Chubsucker	*Erimyzon oblongus*	T	
BIRDS			
American Peregrine Falcon	*Falco peregrinus anatum*	E	
Arctic Peregrine Falcon	*Falco peregrinus tundrius*	T	
Attwater's Greater Prairie Chicken	*Tympanuchus cupido attwateri*	E	
Bald Eagle	*Haliaeetus leucocephalus*	T	T
Brown Pelican	*Pelecanus occidentalis*	E	
Piping Plover	*Charadrius melodus*	T	
Reddish Egret	*Egretta rufescens*	T	
Swallow-Tailed Kite	*Elanoides forficatus*	T	
White-Faced Ibis	*Plegadis chihi*	T	
White-Tailed Hawk	*Buteo albicaudatus*	T	
Whooping Crane	*Grus americana*	E	
Wood Stork	*Mycteria americana*	T	
MAMMALS			
Rafinesque's Big-Eared Bat	*Corynorhinus rafinesquii*	T	
REPTILES			
Alligator Snapping Turtle	*Macroclemys temminckii*	T	
Atlantic Hawksbill Sea Turtle	*Eretmochelys imbricata*	E	
Green Sea Turtle	*Chelonia mydas*	T	
Kemp's Ridely Sea Turtle	*Lepidochelys kempii*	E	
Leatherback Sea Turtle	*Dermochelys coriacea*	E	
Loggerhead Sea Turtle	*Caretta caretta*	T	
Smooth Green Snake	*Liochlorophis vernalis*	T	
Texas Horned Lizard	*Phrynosoma cornutum*	T	
Timber/Canebrake Rattlesnake	*Crotalus horridus*	T	
VASCULAR PLANTS			
Texas Prairie Dawn	*Hymenoxys texana*	E	E

Note: All of the species in this list occur on the federal listing of threatened or endangered species; however, only those indicated in the Federal Status column are listed for this county by the Clear Lake office of the U.S. Fish and Wildlife Service (February 1999).

SECTION II – ENVIRONMENTAL ISSUES RELATIVE TO MASTER PLAN DEVELOPMENT

The rapid removal of a most extensive forest-riparian and wetland system consisting of bald cypress swamps mixed with other hardwood bottomland forested floodplain areas characterized the early history of the project area along Buffalo Bayou even prior to 1830s and development of the City of Houston. The human activities associated with urban development have had significant environmental impacts on Buffalo Bayou. These activities include clearcutting for logging, plowing, discing, and ditching associated with agricultural development; rapid development of the city and its industries, which required channelization, dredging, diversions, filling of stream tributaries and wetlands; water impoundments both large and small including Barker and Addicks Reservoirs; and various forms of channel modifications and bank stabilization to support navigation, flood control, and infrastructure (USACE 1989; USACE 1994).

Secondary effects from these activities include loss of vegetation and topsoil, increased sedimentation and turbidity in the channel, pesticide, fertilizer, sewage and refuse disposal in the water column reducing water quality, and significant alteration of natural hydrological flow regimes to urban hydrology. All these activities and secondary effects have had cumulative environmental impacts on one of the most important aquatic resources of the City of Houston: Buffalo Bayou. One of its most important environmental roles was in fisheries support, given the Bayou's proximity to Galveston Bay.

The floodplain played an important environmental role (Johnson and McCormick 1979). The U.S. Environmental Protection Agency (EPA) held a series of workshops in the late 1970s and early 1980s to identify ecological processes in forested wetland components of the floodplain and relate these processes to human activities that affect them (U.S. Department of Interior FWS 1980). Through this understanding, one can then work the cause and effect process "backward" or to the advantage of either preserving or re-creating the floodplain and the native plant and animal communities within the context of today's or tomorrow's Buffalo Bayou.

The 2001 Master Plan Project has identified aquatic ecosystem rehabilitation including providing significant habitat improvements as one of the project's goals. To meet this goal, several issues must be addressed. These issues relate to property ownership and jurisdiction, maintaining safe navigation, providing continued stormwater conveyance, minimizing erosion, proper functioning condition for the bayou which creates habitat for critical or target species, and improving water quality and public access.

OWNERSHIP AND JURISDICTIONAL CONSIDERATIONS

Private property ownership and different overlapping jurisdictional authorities create conflict when projects are proposed that involve the Bayou and adjacent land. The current private ownership of land within the project area was not identified for this report since it is available elsewhere. Conflicts have arisen, however, between private projects' goals, implementation, and acceptable levels of impact to a public resource such as the Bayou. The following demonstrates the need for consideration of regulatory jurisdiction and ownership.

An ordinance passed by the Houston City Council on June 10, 1841, established the Port of Houston with authority over all wharves, landings, slips, and roads on the banks of Buffalo and White Oak Bayous within the city limits (Farrar 1926). This provided the start of order along the waterfront and the collection of fees to be applied to waterfront and Bayou improvements. In 1842, the Texas Republic empowered the City of Houston to clear away wreckages in the Bayou to improve navigation between Harrisburg and Houston.

By the early 1850s, snags and overhanging limbs were cleared from the Bayou resulting in a new hazard to navigation: erosion. Heavy rains, typical for the area, easily eroded sands and clays which were washed from the cleared banks and developing areas causing shoaling of the Bayou depths, which necessitated dredging by 1852. This has been an ongoing and costly maintenance requirement ever since.

Even though the Port of Houston Authority (PHA) has authority over the Bayou and all major tributaries to the Bayou, granted to the PHA by the Texas State Legislature in 1927, the USACE also has jurisdiction over Buffalo Bayou associated with regulating work in the nation's waters with a primary focus to protect navigation and, according to the Clean Water Act, "protect the physical, chemical, and biological integrity of the nation's waters."

A regulatory program of the USACE is responsible for reviewing proposed projects that affect the nation's waters, in this case Buffalo Bayou, and either issue or deny permits to applicants who want to undertake a proposed activity within the Bayou. This permit review has been broadened since the 1960s to consider the full range of public interests for both utilization of water resources, navigation, and protection of the water resources for fisheries.

As early as 1871, the USACE-Galveston District has been involved with surveying the Bayou and modifying and maintaining the Bayou for improved navigation within the Bayou. Section 10 of the River and Harbor's Act of 1899 authorized the USACE to continue to improve Buffalo Bayou for navigation. Section 404 of the Clean Water Act prohibits discharge of dredge or fill material into waters of the U.S. without a permit from the USACE. Section 401 of the Clean Water Act requires coordination between the USACE and the state for state water quality certification for proposed activities. Other applicable laws incorporated into the Section 404 and Section 10 permit processes bring other federal and state agencies into the process for review such as the National Environmental Policy Act (NEPA), the Coastal Zone Management Act, the Endangered Species Act, the Migratory Bird Species Act, and the National Historic Preservation Act.

The state and federal historic preservation offices are always involved if public funds are used. This is true, even on private property, on projects involving a USACE permit that could disturb cultural resources. The U.S. Fish and Wildlife Service and the Texas Parks and Wildlife Department (TPWD) are authorized to protect migratory birds as well as federal and state listed endangered or threatened species, which would include plants as well as animals. Further, the TPWD is responsible for protecting non-listed natural resources of Texas.

The Texas General Land Office's (TGLO) Coastal Coordination Council also may be involved with proposed projects that affect the coastal zone. For example, the Houston-Galveston Navigation Ship

Channels Project is reviewed by the TGLO. Another state regulatory agency is the TNRCC, which authorizes water quality certificates associated with the Clean Water Act's Section 401 and the National Pollution Discharge Elimination System (NPDES) permits. The TNRCC is also involved with regulating air quality.

Local authorities include the City of Houston, through issuing building permits and local ordinances, and the HCFCD, which does not have permitting authority yet. These authorities regularly review project plans of others as well as implement plans of their own to carry out their respective missions. The HCFCD has right-of-way, easements, and fee property along the Bayou and undertakes studies and develops projects to minimize city and county flood problems. Currently, the HCFCD has access through easements on private property to provide maintenance of the Bayou.

Two other federal laws authorize the USACE to undertake flood control activities: the 1946 Flood Control Act, Public Law 525, and the Flood Control Act of 1954, Public Law 780. Section 14 of the 1946 Flood Control Act authorizes the USACE to undertake steambank and shoreline erosion work while Section 208 of the Flood Control Act of 1954 authorizes the USACE to clear vegetation and remove snags.

Work remaining on USACE flood control project for Buffalo Bayou and its tributaries consists of planned rectification of 22 miles of the mainstem of Buffalo Bayou as authorized under Section 203 of the 1954 Flood Control Act. Thus far, the USACE has constructed two dams, Addicks and Barker, in the upper reaches of the Bayou; rectified 7 miles of Bayou channel below the dams; and acquired approximately 40 percent of the right-of-way along the 22 miles. Recreational development is provided for this project subject to conditions of non-federal cost-sharing under the Federal Water Project Recreation Act of 1965.

Section 1135 of the Water Resources Development Act of 1986 is to improve the quality of the environment by either modifying an existing USACE project or its operation or to restore degraded ecosystems when it is found that the project has contributed to the degradation of the environment. Section 206 of the Water Resources Development Act of 1986 is to restore degraded aquatic ecosystem structure, function, and dynamic process to a less degraded, more natural condition, which will involve consideration of the ecosystem's natural integrity, productivity, stability, and biological diversity. No relationship to an existing USACE project is required under Section 206. Funding for approved ecosystem restoration projects would be 75 percent USACE and 25 percent local sponsor. Plans for habitat improvements and ecosystem restoration could be funded under the Ecosystem Restoration Program as work under these sections.

Issues associated with ownership affect Bayou access and maintenance of the natural resources. Beyond direct property ownership along the Bayou, the public who lives within the Bayou's watershed and relies on its abilities to convey floodwaters is affected by activities within the Bayou and therefore, has an "ownership" stake. Furthermore, there are citizens who see the Bayou as an environmental and recreational resource as part of the nation's waters and are also part of this complicated ownership of Buffalo Bayou.

NAVIGATION

As indicated earlier, navigation is a primary use of the Bayou and is under the authority of PHA; however, maintenance is provided by USACE. Safety issues associated with navigation on the Bayou involve the pilots and U.S. Coast Guard. Navigational issues are addressed in a separate report, especially associated with proposals to increase public recreational boating within portions of the project area. Making changes to the Bayou for navigation has been shown in this report to have environmental consequences. Increasing public recreational boating in portions of the Bayou, particularly east of US 59, may require a change in water use designation, since currently the Bayou within the project site is designated for industrial use and water quality is not conducive to support contact recreation. Further, Bayou flooding causes excessive currents and turbulent flows in the ship channel which delays or disrupts navigation.

STORMWATER CONVEYANCE

Flood control, specifically providing for effective stormwater conveyance, is addressed in separate report. However, the environmental consequences of directing more and more water to the Bayou as the watershed has developed and the added environmental consequences of providing effective stormwater conveyance are not addressed in typical hydrology and hydraulic reports. The heavily urbanized watershed contributes to this high volume of storm flows at abnormal peak rates. This has a tendency to affect the natural character of normal runoff patterns shifting to an urban hydrology of more spiky or violative record of discharges and more often resulting in cumulative impacts on the environment of Buffalo Bayou (U.S. Department of Interior FWS 1980). Other components of the Bayou's hydrology indicate that future response of the Bayou downstream from Memorial Park will be continued degradation and widening. Identified problems include lateral and vertical instability of the Bayou from the Park and within the project site. This will lead to continued poor habitat conditions and other biological and chemical problems of the Bayou (Woodley 1993).

The problems to be addressed included excessive bank heights; the current limited flood carrying channel capacity; variable soils and slopes leading to variable erosion rates; and the need for multiple stabilization measures, limited right-of-way to work within, and numerous adjacent landowners to deal with.

Conflict between maintaining native woody vegetation and expediting flood flow conveyance needs to be addressed. Since the Bayou has been modified for navigation and flood control, the natural condition of the Bayou also has been significantly altered. The floodplain has been eliminated and habitat considerably reduced in size and quality. Floodwaters still inundate a considerable area, however, as seen by the recent occurrence of Tropical Storm Allison (May 2001), which resulted in as much as approximately 35 feet of water in some areas along the Bayou (near Bayou Place, for example).

Regardless of the measures taken for effective flood control, such as the removal of mature woody vegetation, conflict with other goals for the Bayou, such as maintaining or improving habitat, would

occur. Approaches to flood control would also need to address the desire for the Bayou to provide other functions and values (Restoration of Urban Streams and Flood Control Channels Workshop 2002). Recommendations for integrating effective flood control with habitat improvement could include the following:

- Grade control that could include incorporating riffle and pool sequences in the Bayou
- Bank stabilization
- Channel modifications to improve habitat quality and adequately handle anticipated stormwater conveyance volumes through re-establishing of a floodplain
- Detention storage to mitigate erratic flood peaks
- More meanders in the Bayou plan configuration that could become overflow detention areas
- Channel cross-section modifications to incorporate a floodwall at the perimeter of the right-of-way
- Bayou channel rehabilitation to include "floodplain" inside the wall
- Discharge inlet and modification to the Bayou and further up in the watershed to detain, slow, and treat flows

EROSION CONTROL

Addressing the project goals for habitat improvement, ecosystem restoration, and enhanced public use and recreation along the Bayou must include the resolution of the problems associated with erosion. This will need a systemwide watershed approach that will also begin to address the problems with water quality and with fisheries (Allen and Leech 1997). Further, a watershed approach will need local, state, and federal coordination with public, local industry, and navigation representatives (Naiman 1992). Erosion control in one area of the Bayou merely relocates the problem to another area and has cumulative impacts (Gray and Leiser 1982). Therefore, a broad, all-encompassing integrated approach is required. This was well noted in the *Erosion Control and Bank Stabilization Report* (1994) prepared by Brown and Root.

Project area soils are easily erodible. The Bayou is required to convey more water and at faster rates than can be handled by current conditions. Large amounts of bank erosion result in sedimentation affecting suspended solids in the water column, which increases turbidity in the water. Erosion also contributes to large amounts of silt smothering the Bayou bottom and benthic organisms. Sedimentation within the Turning Basin and Houston-Galveston Ship Channel contributes to the costs of maintenance dredging (Gorini 2001).

Erosion control and effective bank stabilization that includes habitat, water quality treatment, and the appearance of a natural Bayou environment should consider more than hardened edges and advocate the use of water bioengineering techniques (Schiecht and Stern 1997). This report does not identify specific erosion control and bank stabilization techniques. This report does address the existing

physical attributes of the Bayou and conditions necessary to minimize erosion as well as improve habitat and restore the aquatic ecosystem. These necessary conditions are discussed in the following section of this report.

PROPER FUNCTIONING CONDITION

Proper functioning condition (PFC) describes the physical attributes of a watercourse and its associated vegetation areas relative to those attributes being able to provide desired functions and social values (Restoration of Urban Streams and Flood Control Channels Workshop 2000). PFC also is a term that refers to a qualitative method for assessing the condition of the riparian and wetland areas of a watercourse (Pritchard 1998). This method has been developed over time and highlights hydrology, soils, erosion, and vegetation as the primary components. The main focus of this method is knowing what a natural watercourse should have in the way of physical attributes, assessing the current conditions of the watercourse of concern relative to the natural system, then developing a qualitative conclusion about the difference and suggesting changes to obtain the proper functioning condition for the watercourse of concern. If the physical form is not correct, then the proper function cannot be achieved.

The desirable functions for a given watercourse must be identified. For example, for the riparian and wetland areas, for the watercourse to function properly, there would be adequate open vegetated areas, a landform and physical configuration, and extent of large mature wood present to:

- Dissipate flow energy associated with high volumes, thereby reducing erosion and improving water quality
- Filter suspended sediment, capture bed load, and aid in floodplain development
- Improve floodwater retention in floodplain areas
- Develop root masses that stabilize banks against cutting action
- Develop diverse wetlands, ponds, and other natural channel characteristics to provide usable habitat with water depths, inundation durations, and temperature/oxygen necessary for fish production, waterfowl breeding, and other wildlife utilization
- Support greater biodiversity

The application of this PFC assessment to Buffalo Bayou is an effort to identify capability and potential of the environmental conditions given the urban context. Merely because the Bayou is within the urban context, however, a single use approach for the Bayou should not result. The intent in assessing the PFC is to provide recommendations for physical changes to the Bayou that take a multi-use approach and identify the problems and areas of opportunity relative to improved habitat condition and ecological function.

The PFC for Buffalo Bayou would have an accessible floodplain, floodplain area for stormwater storage and gradual release, a bank full width, adequate width to depth ratio, sinuosity, gradient or flow, and hydrologic controls. The vegetative condition would include a mix of young and mature native individuals to form plant communities, root densities sufficient to hold soils, an overhead

canopy, and recruitment/reproduction for continued plant survival. Banks should be stable with no signs of erosion, and shoreline soils should have a distribution of anaerobic (hydric) soils with capillary activity (soil infauna). The water quality should be good.

A good rating means the PFC and a diversity of native vegetation are present to support a full range of wildlife life cycle needs such as food, cover, resting, and/or breeding. Fair rating means that if the PFC is not present, it could be created or can be supplemented with a sufficient vegetative cover that provides some wildlife life support (migration, for example). A poor rating means that the physical conditions of the Bayou are not conducive to supporting normal wildlife utilization for a range of animal species; however, opportunity exists for habitat improvement. A rating of none means the physical conditions of the Bayou do not exist to provide any habitat utilization such as areas that are bulkheaded or paved. The standard checklist for the PFC method was utilized during field investigations to assess the PFC of Buffalo Bayou within the project area (*Appendix B*). Results recorded are as follows:

Portions of Buffalo Bayou can be considered at-risk, which means they posses some of these desirable physical conditions. However, a good portion of the Bayou is non-functional. The ratings for the Bayou include Fair, Poor, and None. These ratings were determined because the Bayou's condition is an incised channel with no accessible floodplain or natural floodplain features, little or no stable banks, the absence of diverse mature riparian and wetland vegetation or plant communities, and poor water quality.

Current wildlife utilization was investigated through lists of species known to occur in the Bayou. From an analysis of these lists, species habitat needs, such as plant community type and size, can be determined. The existing riparian habitat within the current conditions of the Bayou are at a minimum for species utilization. Riparian and wetland habitat must be increased in the Bayou to obtain improved PFC. Further, the plant species composition must also be increased in order to improve habitat conditions for targeted wildlife species.

Soil and slope conditions were reviewed, and the configuration of banks should be re-graded, in selected areas, in order to create conditions conducive to support adequate riparian and wetland areas along and within the Bayou (*Exhibits 23* and *24*). Given the width of the channel and need to convey flood flows and maintain navigation, alternative methods of creating wetlands and providing area for riparian habitat must be explored (*Exhibit 25*).

The capability and potential to improve the PFC of Buffalo Bayou does exist, however. Relic areas were investigated through a review of historic photos, old maps, and reports on channel improvements. Areas that seem to offer the best potential for preservation or rehabilitation were identified by overlaying a clear transparency of the 1939 topography with the current aerial photography. Several small drainage areas and wetlands that have been filled could be created because these areas remain open and unarmored.

The total shoreline length is approximately 108,500 linear feet. The vegetated portion is 55,800 linear feet. Therefore, the balance of shoreline, 52,700 linear feet, or 48.6 percent, is armored

with bulkheads, sheet piling, or building foundations. It is the current vegetated portions of shoreline that present the most feasible opportunities for habitat creation. A concept plan where wetlands can be preserved and/or rehabilitated has been prepared. A total of 23 areas have been identified where the potential for riparian and wetland habitat creation exists. An explanation of these proposed habitat improvement areas is provided in *Table 12.*

The PFC would include Bayou banks in selected locations to be laid back with a flatter gradient, 20:1, 12:1, or 8:1, that would support areas for inundation and the growth of various native plants in bottomland mix-hardwood forests. The physical slope condition of the banks to achieve proper function is shown *Exhibits 11* and *21* through *25.*

The following briefly describes various changes in current conditions along Buffalo Bayou where wetlands, increased floodplain, stream channels, and other natural Bayou features can be integrated into the landscape to increase habitat, improve water quality, and address a better functioning condition of the Bayou. These recommended habitat improvements, 1 through 23, are located on *Exhibit 26* and described below in *Table 12*.

Table 12. Proposed Habitat Improvements to Address Proper Functioning Condition

Habitat Number	Remarks
1	Create a series of wetlands that may step down that slope to treat runoff and create habitat. These wetlands may be small, shallow, herbaceous marshes that link to a larger created oxbow or wetland at bayou shoreline.
2	Cut the existing slope back to create an adjacent wooded bald cypress swamp
3	Create a wetland within school grounds for environmental education as well as capture stormwater runoff, treat it in the wetland (a deep and shallow marsh complex) and then discharge to a created stream channel that intersects with the Bayou.
4	Re-establish a pre-existing stream channel and wetland at intersection with Bayou
5, 6	Similar to 2
7	Re-establish two stream channels and create a fairly large floodplain area that provides some meander features like ponds, sloughs, and wetlands.
8, 9	Similar to 2
10	Similar to 4
11	Similar to 2
12	Similar to 1
13, 14	Similar to 7
15, 16	Similar to 7, 13, 14
17	Similar to 4 only re-establish two small tributary stream channels
18	Re-establish a series of stream channels that provide habitat
19	Similar to 7, 15, and 16, yet includes pulling bank back to establish an adjacent floodplain and wetland complex area
20	Lower the island to create a complex of native wetland types, particularly a large bald cypress swamp
21	Re-contour the bank to create floodplain area supporting both shallow and deep marsh
22	Re-establish the tributary stream channels and their associated wetlands
23	Similar to 13 and 14

Once areas have been determined suitable for habitat creation, appropriate native plant species must be determined to re-vegetate these areas given the nature of the hydrology and water quality. Lists of plant species known to have occurred historically and species that are present within the Bayou today provide a startling point for recommended plants for habitat creation. Given the current hydrology and water quality, plant species will need to be specified accordingly. Constructed wetlands have been shown to be effective for improving water quality as well (Moshiri 1993).

HABITAT AND CRITICAL SPECIES

Any proposed activities within the Bayou will need to address potential impacts to existing open space and habitat; parklands; and the aquatic resources of the Bayou that include water quantity, water quality, flow rates, water level changes, and aquatic organisms. In many areas along the Bayou, most noticeable in Memorial Park and selected areas in the eastern sector past downtown Houston, native vegetation is present. However, these vegetated areas provide limited habitat for local resident and migratory wildlife species. As the water surface is continuous, it provides a continuous migration corridor along the length of the Bayou for wildlife. However, wildlife presence and utilization is severely limited by current conditions.

The habitat is fragmented and in minimally sized areas. For the most part, these areas are weedy, disturbed, and degraded, and lack the presence of a mix of mature native tree, shrub, and herbaceous plant species. Plant species present are representatives of former native plant communities; however, it is difficult to describe the vegetative areas along the Bayou as plant communities.

The Texas Natural Heritage Program of the Texas Parks and Wildlife Department and the Endangered Species Coordinator of the U.S. Fish and Wildlife Service keep records of listed species occurrences. No listed species are found within the project area. The project area does not provide habitat conditions conducive to support these species.

There is no active natural floodplain. The channel is incised into the subsurface Beaumont Formation and no longer actively migrates laterally to a former natural extent. The terrestrial component lacks diversity of high quality natives and plant communities associated and habitat niches. Some structure and coves exist at some bank locations.

The interface between aquatic and terrestrial ecosystems is not only at the water's edge but also in the overhead woody canopy that provides shade, regulating water temperatures. Seasonal leaf fall adds to nutrient cycling soil and moisture. The aquatic system provides diversity and interspersion of habitat niches and corridors for migration and dispersal of wildlife, particularly migratory birds. However, there is minimal aquatic life in Buffalo Bayou, according to a 2000 Assessment Report, between US 59 and the Turning Basin.

Bayou is tidally influenced, and there is a permanent base flow as well as periodic releases from the Barker Reservoir. This tidal influence is an indication of habitat connection to the Bay. Majority of water surface is in full sun and measures to provide additional overhead canopy should be investigated as this would improve fisheries habitat conditions.

WATER QUALITY

High storm flows through long-time heavily industrialized sector contribute to reduced water quality, which affects recreational use and degrades habitat. High flows may wash thorough industrial areas, auto salvage yards, sewage treatment plans, etc. and transfer coarse debris as well as chemical pollutants, thereby affecting water quality. A major parameter of concern in the segment between the Turning Basin and US 59 are levels of dioxin in blue crab and catfish tissue. The segment between

US 59 to Shepherd Drive has high levels of fecal coliform, E. coli, and enterro cuccus. Nitrite and nitrate nitrogen are also a concern. There is a large accumulation of incinerator slag eroding into the Bayou. Poor water quality is being transferred to the Bay.

There are two sewage treatment facilities, one closed and one active, that discharge treated effluent to the Bayou. There are over 100 known industrial discharges to the Bayou including an animal by-products and render process facility. Other environmental issues related to water quality are the conflicts with industrial shipping of raw material and end products and the potential for would-be accidents or spills.

Based on a review of data provided by HGAC and TNRCC, the major parameters of concern are dioxin in aquatic life, high levels of bacteria, chemical contaminants in the sediment, and high levels of nitrite and nitrates. These health and safety concerns should be taken into consideration before encouraging recreational activity within these segments of Buffalo Bayou. The official designated use for Segment 1007 east of US 59 would need to be revised.

Constructed wetlands can be designed and incorporated into Buffalo Bayou to enhance the water quality by removal of certain nutrients and suspended solids and the reduction of fecal coliform bacteria (Moshiri 1993). Fecal coliform bacteria, biological oxygen demand (BOD) and excessive nutrients are related to sewage and animal waste runoff (HGAC 2001). The presence of fecal coliform or BOD in high numbers indicates that improper sewage disposal or cross contamination of storm sewers is occurring. A series of in-line constructed wetlands could significantly reduce levels of fecal coliform bacteria and improve other components of poor water quality (Hammer 1989). With a 6 to 7.5 day retention time for example, fecal coliform levels have been shown to be reduced by approximately 100-fold. Constructed treatment wetland systems have been shown to be effective and reliable in meeting secondary NPDES standards.

PUBLIC ACCESS AND RECREATION

Public perception of the Bayou limits the public's desire to use the Bayou. Buffalo Bayou is only visible from selected vantage points. Since it is incised in its channel and normal water level is down 15 to 20 feet within surrounding high banks, it is an unseen resource for many people. Selected buildings downtown could be identified where the public, either on their own or as part of a Bayou tour, can be directed to view the Bayou.

Once on the Bayou, in a boat for example, the views continual change, and one can be captivated by those portions of vegetated areas that still remain along the Bayou. Its width, in places is impressive and its meandering nature and attractive vegetated areas offer a divergent experience from the urban fabric that surrounds it. City noises disappear from one's conscience, and it is easy to be transported from the fourth largest metropolitan area in the United States.

However, physical access to the Bayou is very limited due to existing physical conditions of the banks. Safe and convenient public access points should be incorporated to increase recreation along and within the Bayou. Currently, there is little opportunity to put boats in or to take them out once one canoes down the Bayou. Boating for ecotourism is addressed further under a separate report.

A chronicle of events affecting the physical configuration of the Bayou have been prepared and recorded elsewhere in the Buffalo Bayou Design Development Study (TCB 1980). From this chronology, a limited history of public involvement with the Bayou is seen. Clear-cutting bald cypress and oaks began prior to the founding of the City of Houston in 1836, since lumber was already being supplied to saw mills. The first dock in 1840 and subsequent city development utilized additional lumber from the nearby floodplain forest. When widening and deepening of the Bayou began in 1869, the native vegetation was removed and the banks were altered at that time. From 1900 onward, bridges and infrastructure straddled the Bayou's configuration. In 1924, property along the Bayou, formerly Camp Logan, was purchased to create Memorial Park. This effort added to other efforts to create parks along the Bayou. By the 1940s the USACE had studied recurring flooding problems and acquired land for Addicks and Barker Reservoirs. From these reservoirs, the USACE regulates water level flows in the Bayou. In 1955, the Bayou was stripped of vegetation from Sabine to Shepherd, as the banks were regraded for street and bridge crossings. In 1963, plans to rectify and concrete the Bayou are defeated by Ms. Terry Hershey, the Bayou Preservation Association, and others. Hike and bike trails were developed along portions of the Bayou as the result of renewed interest in maintaining and improving public access and recreation along the Bayou.

The Highway of the Republic pedestrian trail has been conceptually laid out to connect Allens Landing to the Port of Houston's Visitor Center at the Turning Basin. This trail would generally follow the Bayou on the north side between Allens Landing and Jensen Drive, then cross at Jensen Drive to the south side of the Bayou until the Lockwood Drive Bridge, then follow the north side to the Port of Houston's Visitor Center. This plan would connect open areas and designated parks including McKee Street Park, Guadalupe Plaza Park, the abandoned Velasco Incinerator site, North York Park, and Hidalgo Park.

This plan for public access can be further enhanced with the proposed habitat improvement areas. These areas combined with other measures to stabilize banks and improve water quality would improve the fisheries within the Bayou and public access and recreational fishing. Habitat and water quality improvement would need to be undertaken in order to meet the plan objectives of providing fishing tournaments and canoe and sailboat racing on the Bayou. *Exhibit 1* illustrates a potential Bayou Open Space Corridor capitalizing on currently vacant land.

BAYOU REHABILITATION AND FEASIBILITY OF A PLAN

Improving habitat and establishing PFC requires an understanding of ecology and fluvial processes (Schueler 1995). These subjects, ecology and fluvial processes, are broad and complex and are not covered within this report. This section only highlights the need for further site assessments and more detailed design once elements of the master plan are identified and potential funding sources are found for what is recommended.

Generally, rehabilitation of the Bayou can take one of three approaches to achieve balance, equilibrium, and proper functioning condition. These approaches include undisturbed self-recovery, assisted recovery, and full rehabilitation. Because of the existing conditions of Buffalo Bayou and

the desire to provide improved water quality, contact recreation, and increased habitat among other things, full rehabilitation of the Bayou will be required.

Full rehabilitation means rebuilding physical, chemical, and biological functions that are currently beyond the self-repairing capacity of the Bayou. Full rehabilitation is also required because the proposed time frame, 10 to 20 years, is relatively short for achieving the master plan goals.

This approach, full rehabilitation, requires understanding the Bayou's current conditions and integration of its potential (what is proposed in the master plan) to balance rehabilitation of dynamic stream/bayou equilibrium with social needs, i.e. continued use for flood conveyance. Bayou rehabilitation, follow-up management, and beneficial long-term use requires estimating future channel changes, developing appropriate rehabilitation measures, and protecting the entire Bayou corridor, not just the current project site.

One strategy for achieving full rehabilitation, i.e. paying for all the necessary studies, planning, engineering, and implementation, would be to incorporate this rehabilitation into the USACE's Ecosystem Restoration Program authorized through Sections 1135 and 206 of the Water Resources Development Act. Other potential legal and funding avenues for USACE funding participation was noted earlier in this report, which included Section 14 of the Flood Control Act addressing streambank stabilization. Funding recreational elements of a project can now be included in USACE participation through an ecosystem restoration approach. There may be other partnerships available with other natural resource agencies, the Port of Houston Authority, the City of Houston, and Harris County.

The following points out additional data that need to be collected and analyses that would need to be undertaken to either develop more feasible detailed plans or to evaluate current plans for the Bayou. The first step is to determine the appropriate Bayou plan form. This has been described in the Physical Configuration section of this report as well as Proper Functioning Condition section.

The second step is looking at fluvial geomorphology and its creation and maintenance roles on the Bayou and combining it with flood conveyance goals and objectives. It has been noted earlier in this report that most of the natural fluvial geomorpholical features of the Bayou have been removed. The natural floodplain features, normal vegetative cover, and proper functioning condition are not present. The fluvial processes involved in channel response to urbanization are extremely complicated. The major factors influencing channel response in form and stability are (1) discharge; (2) sediment load and sediment composition; (3) longitudinal slope, sinuosity, and hydraulic geometry; (4) resistance factors; (5) vegetation; (6) geology and soils; and (7) man-made features.

Next step is looking at current fluvial processes, sediment transport or lack thereof, and urban hydrology that affects Bayou condition, functions and values, ecological characterization and habitat assessments, bank failures, and water quality problems. This step leads to the need for more detailed data collection and analysis before identification of specific rehabilitation measures. For the purposes of a master plan, a watershed approach is strongly recommended. This continues to point

to the need for more partnering with other funding and regulatory sources such as USACE, the city, and county.

Specific to the Bayou plan form, is it straight, modified braided, meandering, or tortuous? This report has shown it to be a combination of straight and modified meandering. The sinuosity has been calculated. This aids in classifying the Bayou and begins to help with an understanding of it. Other physical attributes also need to be measured including slope, channel widths, bed form, sediment loads, sediment composition, flows, etc. The Bayou lacks riffle and pool sequences, natural islands, and bars. It also lacks a floodplain. The channel width varies from wide to narrow, and there is some data on channel depth which varies from shallow to deep. The current 2001 topographic survey data also provides some bank and bed form information. This data needs information about flows, flow depths, and velocities included.

More definitive information about the sediment loads must be collected. Currently, the sediment composition is high and made of a combination of clays, silts, and sand. Sands are noncohesive and erodible where the clays are cohesive and typically more stable than sands.

However, with current steep slopes, lack of floodplain at the toe of these slopes, and the artificial or urban flows now put into the Bayou, stability is only relative to a point. Because of the flow quantities and velocities, the sediment loads accreting or creating and maintaining a floodplain or any type of depositional areas such as terraces, levees, point bars, or islands are not observed for very long. This material is then dredged out of the turning basin and the ship channel using PHA and USACE funds.

Stability is related to channel regime being in equilibrium. When channel regime not in equilibrium as current conditions indicate, then physical conditions cannot adjust bed form, flow depth, velocity without appreciably changing its slope, channel width, and plan form, hence, the extent of erosion and lack of mature vegetation seen along the Bayou banks (Rosgen 1996).

Channel physical conditions are affected by a range of flows. Flows can be referred to as discharges. Channel forming flows are bank full discharge, a specific event discharge, or effective discharge. These three discharges are roughly equivalent for stable channels, yet vary drastically in unstable channels. These flows would need to be quantified in order to assess the Bayou conditions, feasibility of a plan, or proposed rehabilitation measures.

Bank full discharge is the discharge that fills a stable active floodplain without overtopping the banks. Specific re-occurrence (event) interval discharge or a dominant discharge are graphed and then an average is taken based on a certain set of assumptions. Effective discharge, however, is the peak value of a curve generated by integrating the bed material sediment rating curve with the flow duration curve for a section or reach in question, i.e. the discharge that moves sediment and causes erosion. Computation of effective discharge requires the sediment data mentioned earlier.

However, the Bayou cannot be represented by a single discharge number even after all these discharge numbers are quantified. The Bayou cannot be described in one mathematical

equation or number. Consideration must be given to the flows that affect form and function, such as low flows and their effect on sustaining wetland habitat as well as extreme high flows and the 100-year flood flows design. All these should be tabulated to determine habitat rehabilitation, structural stability, stormwater conveyance needs, and the feasibility of any plan.

Assessing either existing or planned Bayou conditions includes flow characterization, not only how high and how low the water levels are. Analysis of flow put into models to address feasibility of plans usually assumes flows to be uniform and steady for modeling and prediction purposes. However, in reality flows are non-uniform and unsteady in natural channels, as is probably the case for Buffalo Bayou. Flow meters would need to be installed in the Bayou to determine actual site conditions. Regardless, there are four types of flow characters:

1. Uniform versus non-uniform
2. Steady versus unsteady
3. Laminar to turbulent
4. Subcritical to supercritical

Other components of the H&H models that are used to evaluate a plan include velocity and resistance. Further, hydraulic geometry of the channel, especially for incorporating wetland areas and other habitat improvements, as well as the hard structures being proposed, would need to be determined to identify appropriate depths, widths, velocities, and slopes in future detail design to begin to answer questions about sustainability of the plan elements. The underlying assumptions and limitations of mathematical equations used in the H&H analysis to assess existing and proposed hydraulic conditions and determine hydraulic geometry must be understood by the planner as well as by the hydrologist, engineer, and biologist. To a limited extent, some of this H&H assessment is underway for some components of the project but needs to be fully integrated into all project goals.

The Bayou is considered stable when sedimentation and erosion processes are balanced such that channel maintains shape or form. Channel form is the result of landform, geology, soil type, and vegetation as well as hydrology. Some of this information has been gathered already. The features such as dams (i.e. Barker Reservoir), bridges, and water levels of Galveston Bay all affect the Bayou form. Changes in the sediment load (increased erosion), flow regime (more runoff from paved areas and discharge pipes), and Bayou boundary conditions (bank shape) can all disturb the balance or stability.

When long-term erosion exceeds sedimentation, the Bayou channel incises or cuts into the streambed, and the normal water surface becomes lower than the surrounding land surface as described earlier in the geology and physical configuration sections of this report. The banks become higher and steeper. Channel incision continues with reduced sediment load to the Bayou due to dams upstream and increased peak flows caused by more urban development over time.

An area exhibiting instability (i.e. erosion) in the Bayou needs to be assessed as to whether it is a local problem or indicative of a system-wide channel instability problem. What this report indicates

is the latter. Therefore, caution is advised if only local treatment to one site is implemented. The proper treatment should also include methods to address the following:

1. Reduce discharge quantities to the Bayou.
2. Reduce erratic peak discharge to the Bayou.
3. Reduce flow rates within the Bayou to what soils and slopes can handle.
4. Increase size of the Bayou to meet anticipated flow volumes.
5. Restore floodplain of adequate size.
6. Assess types and extent of erosion occurring and determine appropriate repair measure per specific site conditions.
7. Assess proposed elements of the plan (i.e. hard edge treatments) and their effect on the remaining soft edges of the Bayou.

Plan objectives to meet project goals should include creating a stable Bayou channel geometry. The Bayou plan form should have appropriate meander, sinuosity, and length. The profile should include varying bottom depths or contours and riffle and pool sequence. An adequate riparian buffer, which includes re-vegetation with native plants should be provided and continuous canopy cover established. Retrofit the current storm drains, concrete aprons, etc. Stabilize existing outfalls with plunge pools, sediment and debris traps, stepped pools, and treatment wetlands as transitions from outfall to the Bayou. When a stable hydrologic and physical condition is achieved, then habitat improvements such as incorporating wetlands into Buffalo Bayou will be a long-term and self-sustaining situation.

After plan goals have been established, design tools to be implemented include the Rosgen stream classification system (if applicable). Bank full elevation and various effective discharges must be determined; desirable hydraulic geometry design parameters must be identified; extent of erosion and processes at work per site must be assessed; knowledge of fluvial processes of the system must be applied; hydrologic and hydraulic studies tailored to the plan must be undertaken; and field experience and appropriate bank stabilization methods must be applied.

Factors to consider include the following:

- Sediment load times the sediment size is proportional to the slope of the Bayou times the Bayou discharge.
- Bank full discharge is when stream stage is attainted on the average once every 1.5 to 2 years out of three (1.5 year recurrence interval).
- Bank full channel dimensions (depth, width, and cross-sectional area) are proportional to the drainage area. The drainage area above the confluence with White Oak Bayou is 369.60 miles. Therefore, graphed bank full width to drainage area curve data should be reviewed to determine appropriate bank full channel width. Currently, the channel width in some locations is 150 feet. This width is not the overbank full or floodplain width, however.

- The drainage area downstream from the White Oak confluence is 482.5 square miles. Therefore, according to graphed bank full width to drainage area curve data, the bank full channel width should be increased in size.

Bank full discharge is very important in bayou stability since it is the discharge that forms and maintains the channel. Discharges less than bank full do not move bed load or sediment. Discharges above bank full discharge can be determined from analysis of current meter discharge measurements from nearest gauge station, flow duration curves of daily discharges, combined with observations of field indicators. From data obtained from gauge stations, tabulate the annual flood for each year of record (last 10 years), arrange in rank orders, and compute the recurrence interval. Determine the discharge value for the 1.5-year flood from the flood-frequency curve. Tabulate and plot or graph these values with the drainage area and compare to regional graphs already prepared. Review published or recorded data by HCFCD or USGS on the gauge station such as flood frequency reports that include average annual flows and values of extreme events. If not included in the reports, plot a flood-frequency graph for comparison to gauge data. From hydraulic geometry curves, widths, depths, and velocity for average discharge and bank full discharge can be determined. Velocity is multiplied by the cross-sectional area to determine bank full discharge.

Some channel modifications could include widening and deepening segments prior to turns or meanders to reduce flow velocity and protect the turn and to create drop areas or deflections as protection against bank cutting. Numerous other techniques can be incorporated (Gray and Leiser 1982). "Eco mattress," which is a planted gabion structure or interlocking concrete blocks with spaces for soil backfill and vegetation establishment, is just an example of erosion control products available.

The following planning and design steps are intended for projects where all basic components of the Bayou system – bank full channel geometry, floodplain, riparian and wetland vegetation, and terrace(s) – require re-creation. These steps include:

- Determine watershed size and character, i.e. fully urbanized in order to determine adequate floodplain size.
- Collect gauge data and assess regional averages for bank full widths, depths, and discharges.
- Survey cross-sections of reference channels (with floodplains, terraces etc.) in the region that seem to be in equilibrium, and survey existing site conditions (channel geometry) and valley slope, channel slope).
- Undertake historical overview of what the system was like: widths, depths, meanders, flood stages, instream life including historic maps and photographs.
- Select restoration bank full discharge for determining restoration and assess history of flood events.
- Use the following equations to estimate appropriate channel meander length and amplitude:

- Average meander length = 11 x width of bank full channel (between 10 and 14 channel widths)
- Average meander amplitude = 2.7 x width of bank full channel
- Radius of curvature (of meander) = appropriately 1/5 of the meander length and averages 2.3 x bank full channel width.
- Using these average values for channel geometry, draw a calculated rehabilitation plan to scale on the project site plan or aerial photograph having adequate sinuosity and meander lengths.

  Sinuosity = valley slope/channel slope and for stable systems generally ranges 1.5 to 2.
- Make observations of reference stream and Bayou physical features.
- Add any floodplain features for rehabilitation to designed channel drawings and identify existing site condition opportunities and constraints to the proposed rehabilitation plan. Desirable slopes for channel banks can range from 1:1 to 1:3. Accommodating right-of-way and public access requirements will result in much flatter slopes ranging from 1:8 to 1:12 for the floodplain and terraces.
- If adequate channel form and geometry cannot be achieved with given site conditions, determine appropriate energy dissipating measures, i.e. pools and riffles; plunge pool deflectors. Determine flow velocities. If they range above 6 feet per second, consider enlarging floodplain areas to help absorb flow impacts. Bioengineering and bank stabilization measures may be required on sideslopes.
- Re-evaluate the release rates on upstream flood control reservoirs and consider other flood volume and flow velocity reduction measures.

CONCLUSIONS

In the low-lying relatively flat Coastal Plain, the physical landscape condition of the Bayou was conducive to the development of a meandering channel through a wide floodplain. The Bayou is, however, a significant resource for navigation and effective flood control. The natural floodplain is absent as a result of changes to the Bayou and its watershed. The Bayou is now deeply incised within its banks. It was within the floodplain that backwater swamps, sloughs, and oxbow lakes developed that supported the variety of plant community associations that expressed a gradient of different plant species as one proceeded from the wetter to drier hydrological conditions in the floodplain of the bottomland hardwood forest.

Changes will need to be made to the Bayou's banks since it is incised with no floodplain. Selected areas that could be changed to increase floodplain area have also been identified. Native plants suitable for floodplain and habitat creation have been identified within this report. Many of these species are suitable for street tree planting and park and waterfront improvements as well. The most notable trees that are strongly recommended for use in these areas are the southern magnolia and the bald cypress.

There is potential within the current condition of portions of the Bayou to replace some of this floodplain. The Bayou's commercial, industrial, residential, cultural, and recreational resources would be enhanced. Specific areas selected for floodplain creation should not adversely affect navigation and flood control and should not only increase habitat, particularly for fisheries, but also improve water quality and public recreation.

Eighty percent of Buffalo Bayou's watershed is urbanized, which affects hydrology, water quality, and other environmental conditions within the Bayou. To effectively improve conditions, a watershed approach is warranted.

Erratic water level fluctuations in the Bayou caused by variable weather-related events affect physical conditions and use of areas along the Bayou. This urban hydrology needs to be considered. Existing and historic hydrology data should be compiled and evaluated to assist with determining appropriate environmental improvements to the Bayou.

Erosion, even though a natural process, has been hastened by a number of human activities. More than likely, sideslope erosion rather than Bayou down-cutting will occur and threaten existing infrastructure and result in increased maintenance dredging costs in the Turning Basin and the Houston-Galveston Navigation Ship Channel. Rehabilitating the Bayou's physical attributes to create the proper functioning condition that addresses the current and future hydrology of the Bayou is critical in minimizing erosion (Schiecht 1980).

In review of proposed concept plans for a Bayou and neighborhood trail system and a Port to Port concept, the 23 areas identified for habitat creation would support these proposed plans. In order to implement plans, particularly for the 23 habitat areas identified within this report, further design development for each area will be required. The environmental issues associated with ownership and jurisdiction, navigation, stormwater conveyance, erosion control, water quality, public access to the Bayou, and increased recreation along the sides or within the bayou will need to be addressed in a coordinated and comprehensive approach to realize the potential envisioned in these plans.

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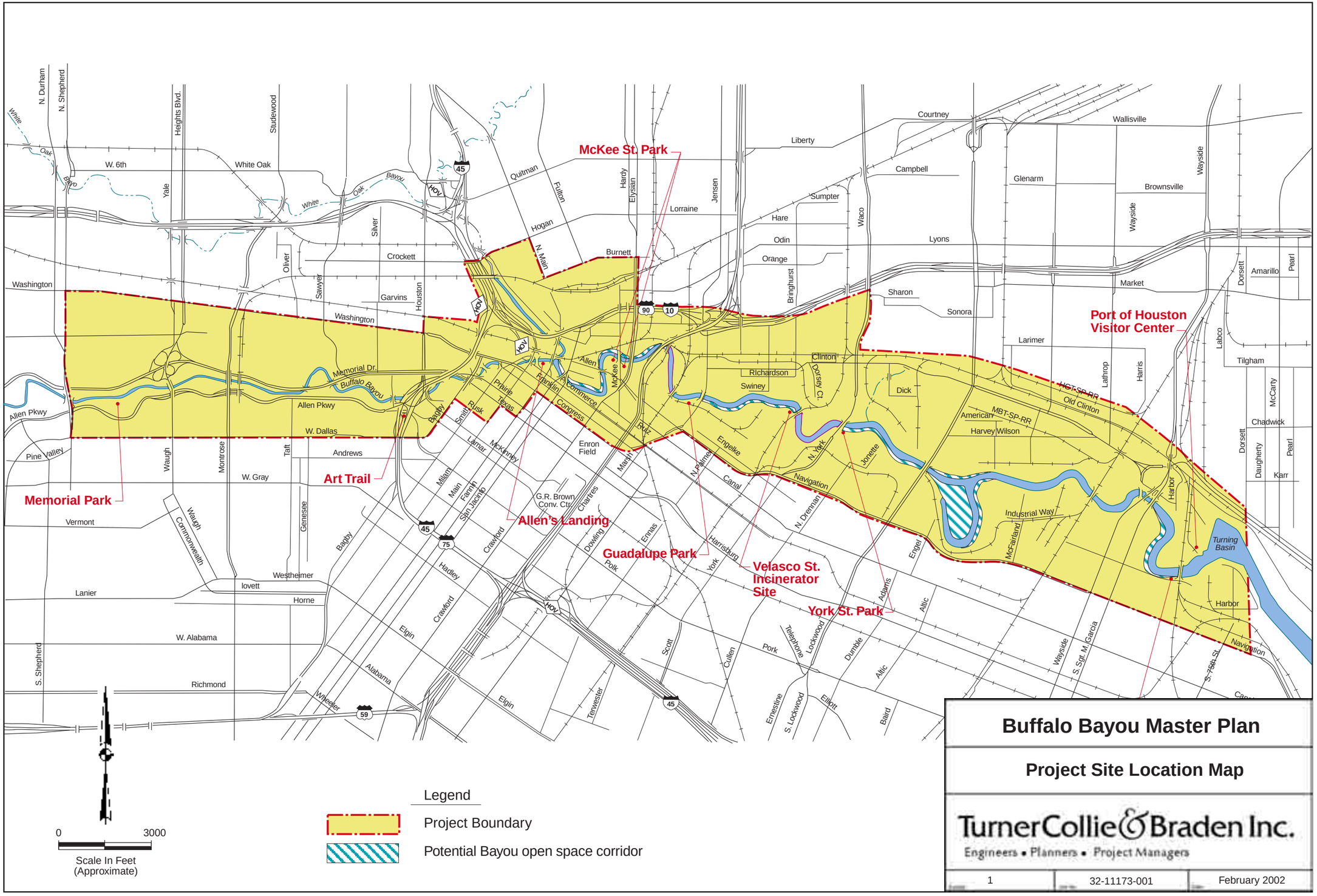

Buffalo Bayou Master Plan

Project Site Location Map

TurnerCollie & Braden Inc.
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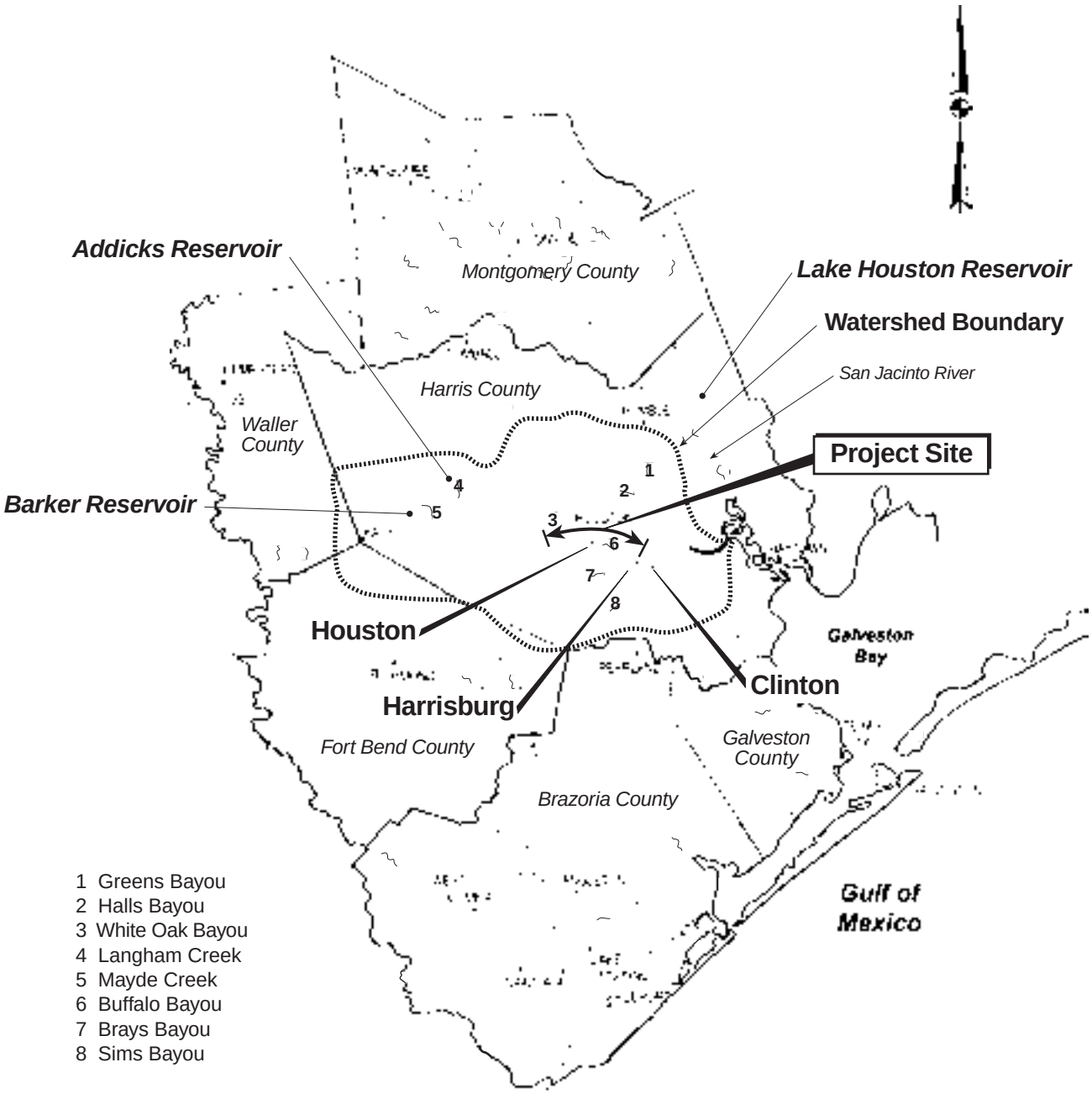

1 Greens Bayou
2 Halls Bayou
3 White Oak Bayou
4 Langham Creek
5 Mayde Creek
6 Buffalo Bayou
7 Brays Bayou
8 Sims Bayou

Buffalo Bayou Master Plan

Buffalo Bayou Watershed with Principal Tributary and Addicks and Barker Reservoirs

TurnerCollie & Braden Inc.
Engineers • Planners • Project Managers

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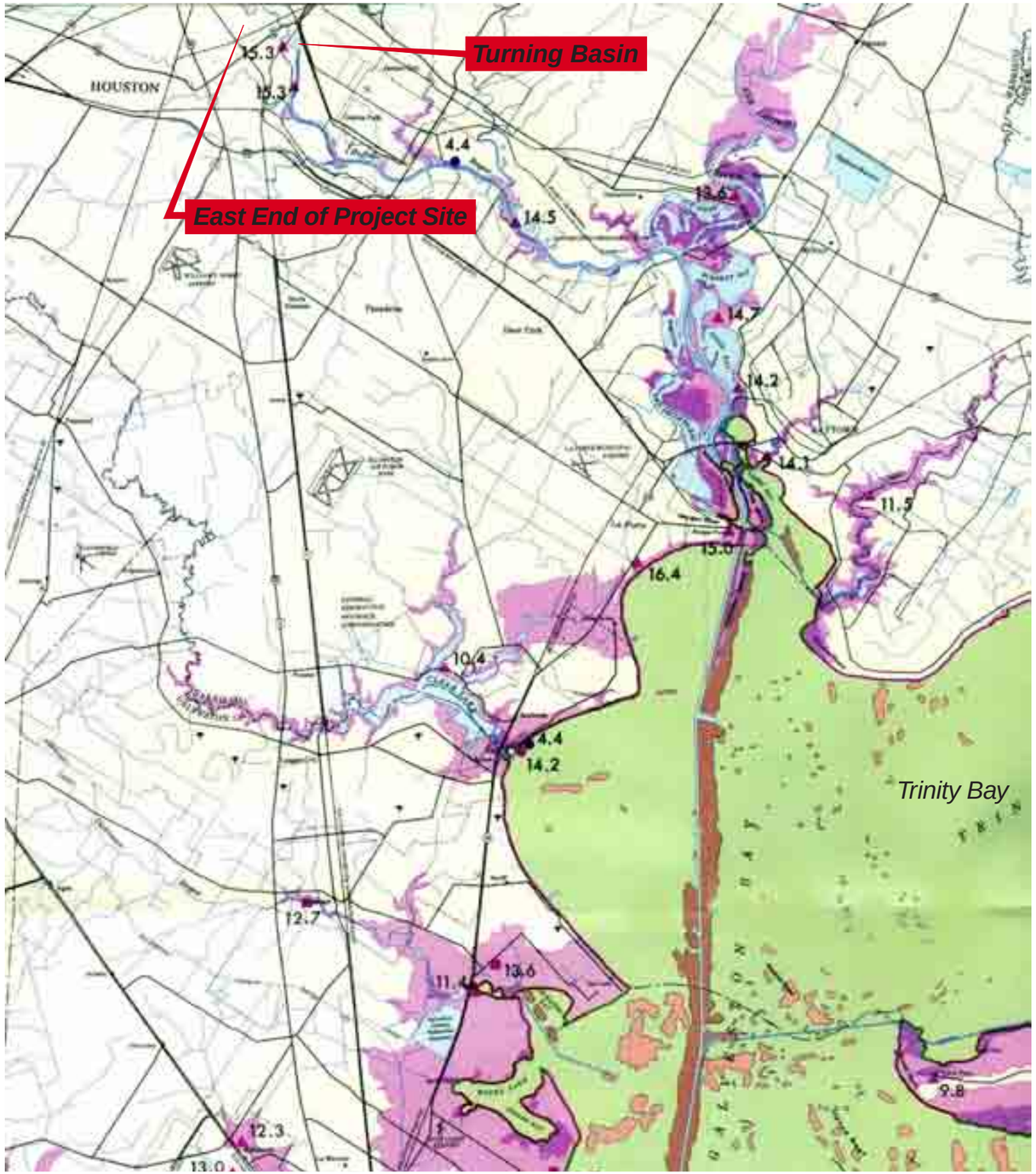


Legend

Lower shoreface and shelf, under normal conditions a decrease in wave and current energy occurs below 8 feet, burrowing by marine organisms common, some longshore and onshore sand in transport in shallow areas especially during storms, deposition of some fine suspended sediment

Normal surf or breaker zone, high wave energy area, shifting subaqueous bars, zone extends to depth of about 8 feet, longshore and onshore transport of sand common

Area of moderate erosion or scour to slight deposition, tidal channels shift laterally by cut and fill unless artificially stabilized

Area of rapid deposition, predominantly tidal delta accretion and aggradation or prodelta progradation

Site of active or potential hurricane washover channel

Shoreline, erosional, eolian processes active along Gulf side of barriers

Shoreline, depositional, accretion, eolian processes active along Gulf side of barriers

Shoreline in depositional-erosional equilibrium, eolian processes active along Gulf side of barriers

Shoreline stabilized by seawall, dredging, or other man-made structures

Area of slow to moderate deposition within bays, predominantly suspension deposition in deeper bay, accretion in some marginal areas

Area of active reworking and redistribution of subaqueous spoil by waves and currents within bays

Oyster reef deposition, predominantly vertical growth with some lateral growth, mapped reefs not necessarily all live communities

Area inundated by marine water, Hurricane *Carla* storm surge tide

8.8 Hurricane *Carla* recording tide or river gage, high water mark elevation, datum mean sea level

9.3 Hurricane *Carla* recording site, still high water mark elevation, datum mean sea level

10.9 Hurricane *Carla* storm surge and river flooding debris or drift line elevation, datum mean sea level

Area inundated by marine water, Hurricane *Beulah* storm surge tide

3.4 Hurricane *Beulah* recording tide or river gage, high water mark elevation, datum mean sea level

0 5 Mile

Map source: Bureau of Economic Geology Environmental Geologic Atlas of Texas Coastal Zone - Galveston - Houston Area (1972).

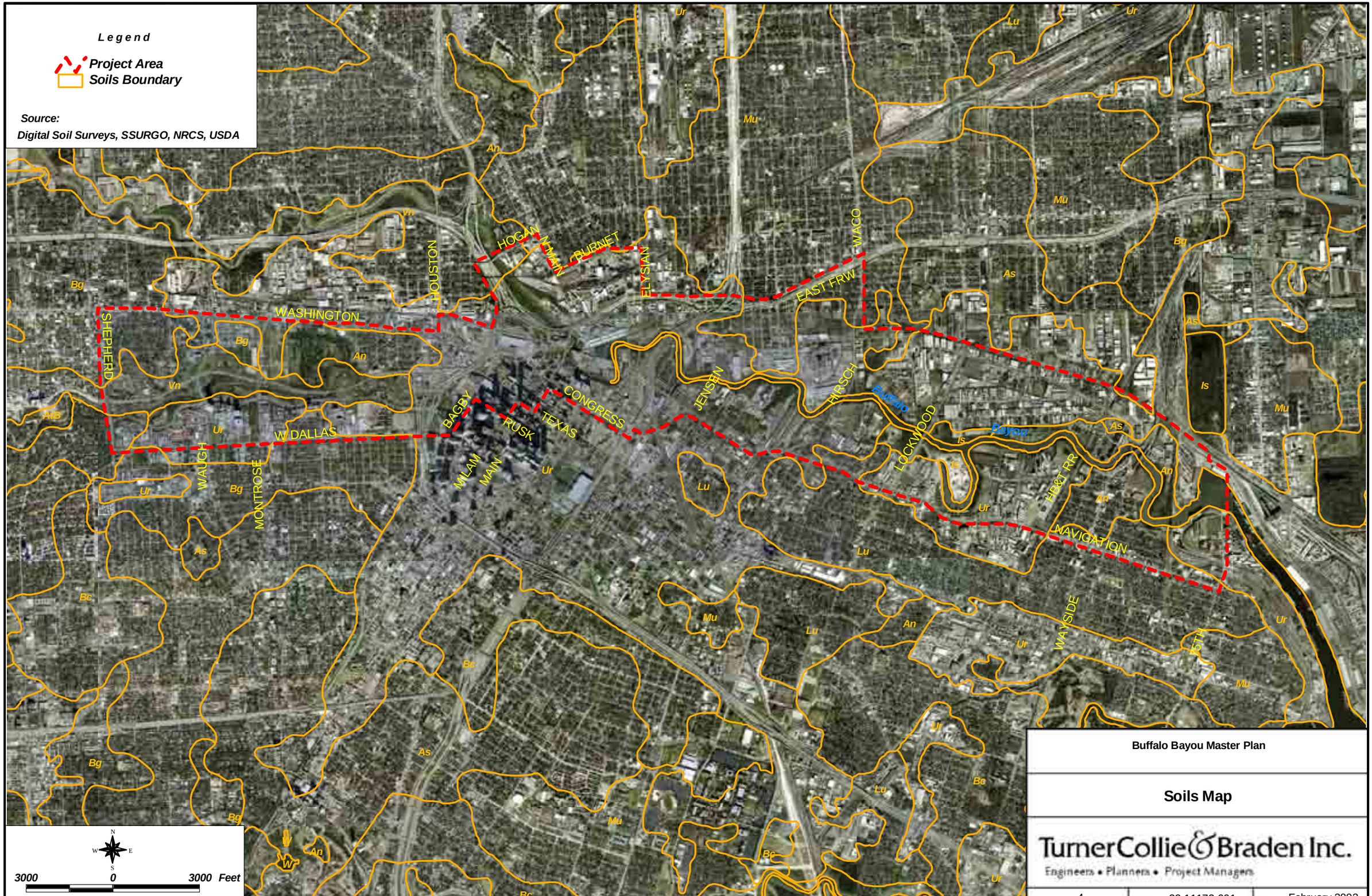
Buffalo Bayou Master Plan

Relationship of Project Site to San Jacinto River, the Galveston Bay, and Houston - Galveston Navigation Ship Channel

TurnerCollie & Braden Inc.

Engineers • Planners • Project Managers

3	32-11173-001	February 2002



Buffalo Bayou Master Plan

Soils Map

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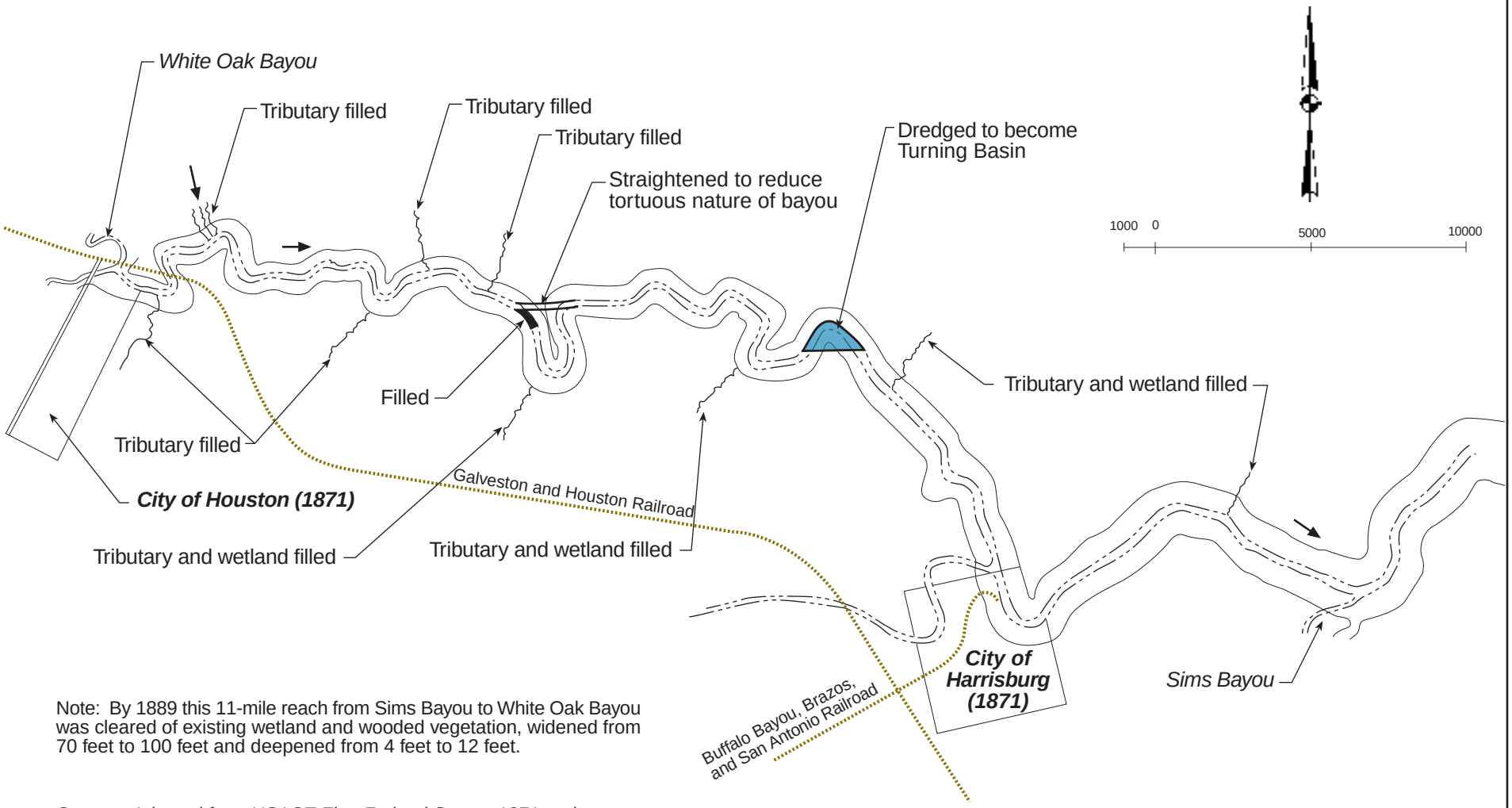
4	32-11173-001	February 2002



Note: By 1889 this 11-mile reach from Sims Bayou to White Oak Bayou was cleared of existing wetland and wooded vegetation, widened from 70 feet to 100 feet and deepened from 4 feet to 12 feet.

Source: Adapted from USACE First Federal Survey 1871 and 1939 Buffalo Bayou Flood Control Drainage Basin Map.

Buffalo Bayou Master Plan

Channel Modifications to Buffalo Bayou

TurnerCollie & Braden Inc.
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5	32-11173-001	February 2002

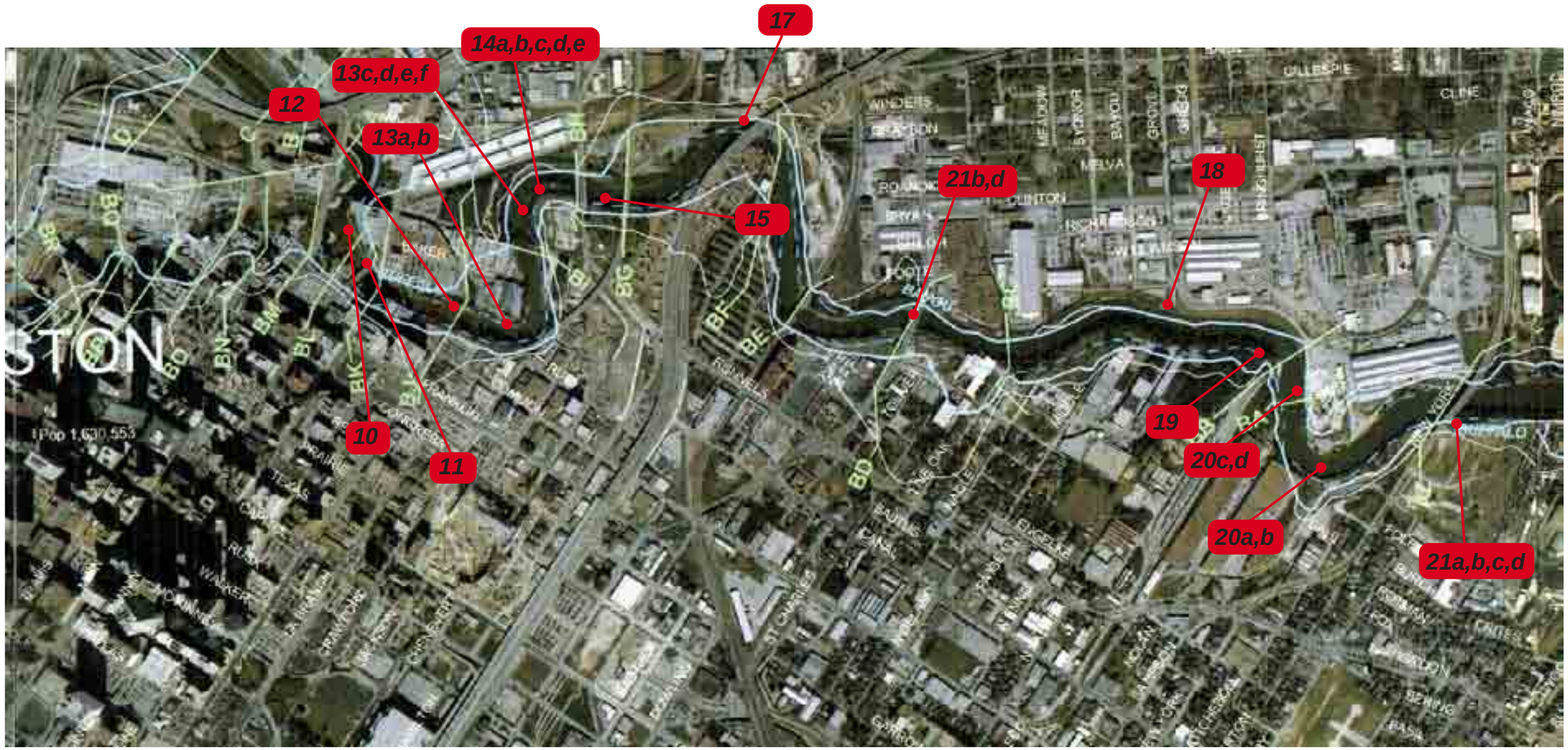
Note: Numbers and letters refer to Sheet Number and Photograph letter found in Appendix A.

Buffalo Bayou Master Plan

Site Photograph Locations on Aerial Photograph of Project Area

TurnerCollie & Braden Inc.
Engineers • Planners • Project Managers

6a	32-11173-001	February 2002



Note: Numbers and letters refer to Sheet Number and Photograph letter found in Appendix A.

Buffalo Bayou Master Plan

Site Photograph Locations on Aerial Photograph of Project Area

TurnerCollie & Braden Inc.
Engineers • Planners • Project Managers

6b	32-11173-001	February 2002

Note: Numbers and letters refer to Sheet Number and Photograph letter found in Appendix A.

Buffalo Bayou Master Plan

Site Photograph Locations on Aerial Photograph of Project Area

TurnerCollie & Braden Inc.
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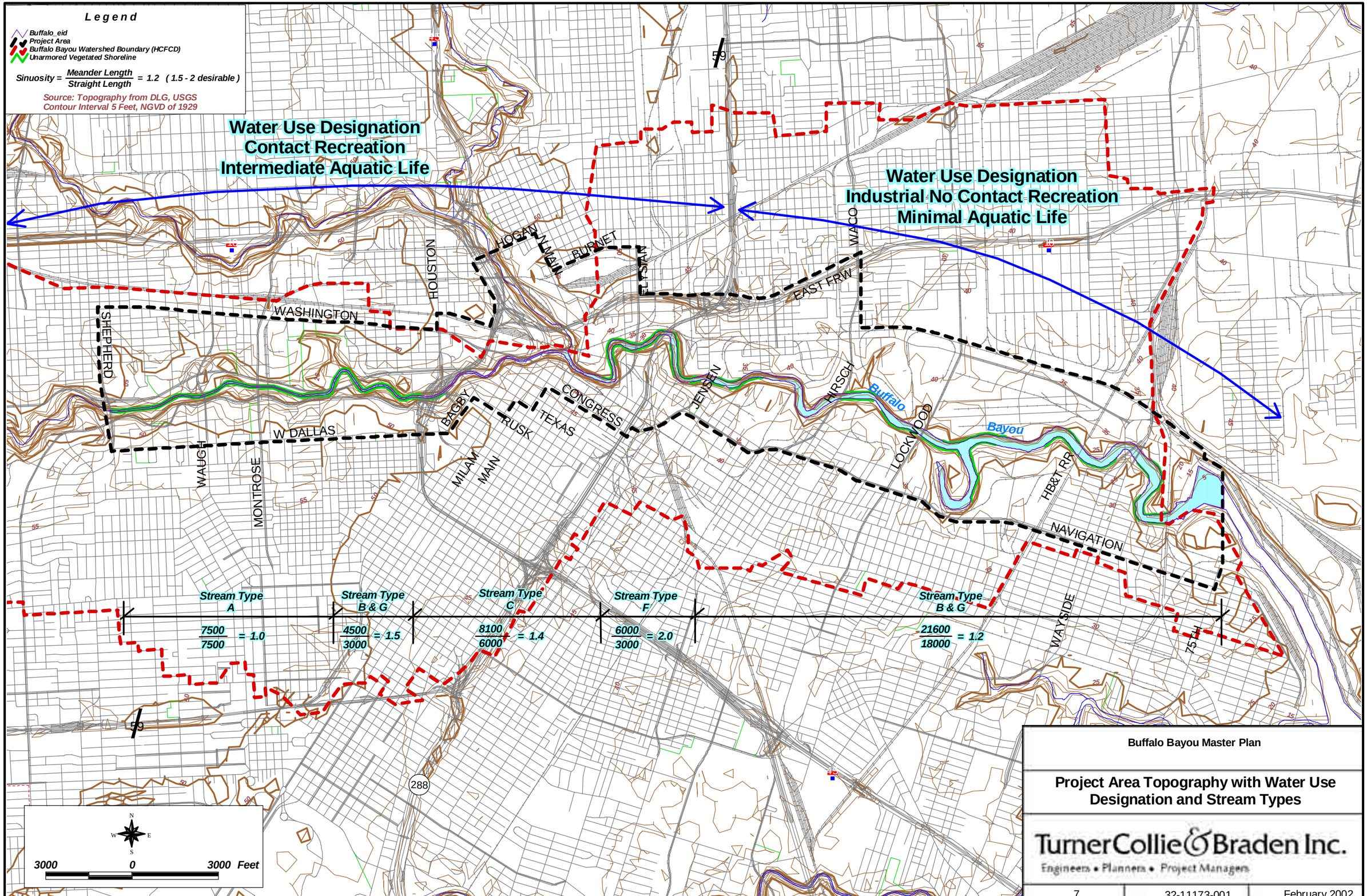
6c	32-11173-001	February 2002



Buffalo Bayou Master Plan

Project Area Topography with Water Use Designation and Stream Types

TurnerCollie & Braden Inc.
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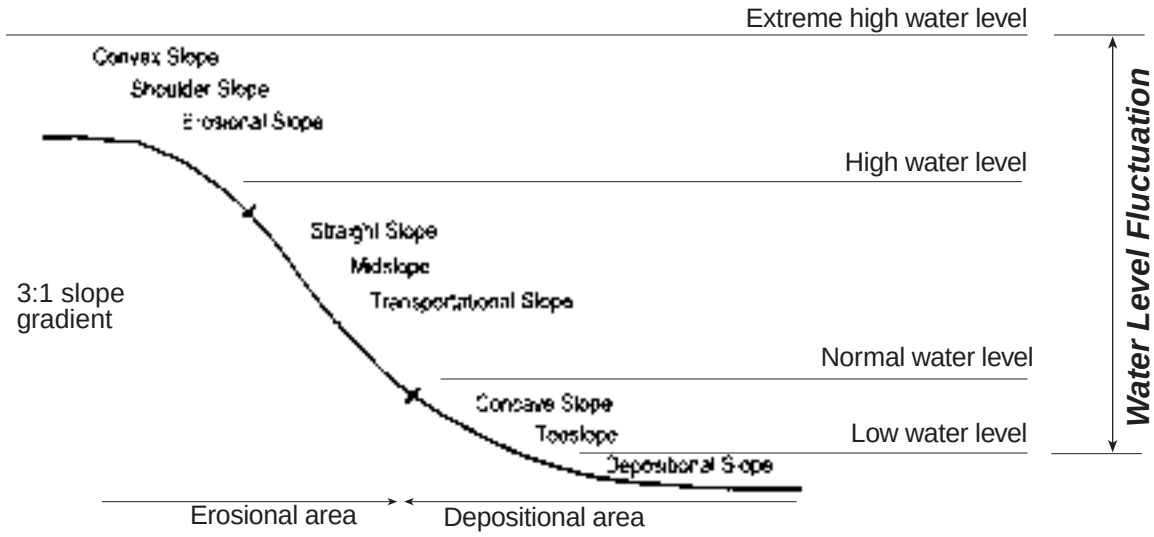
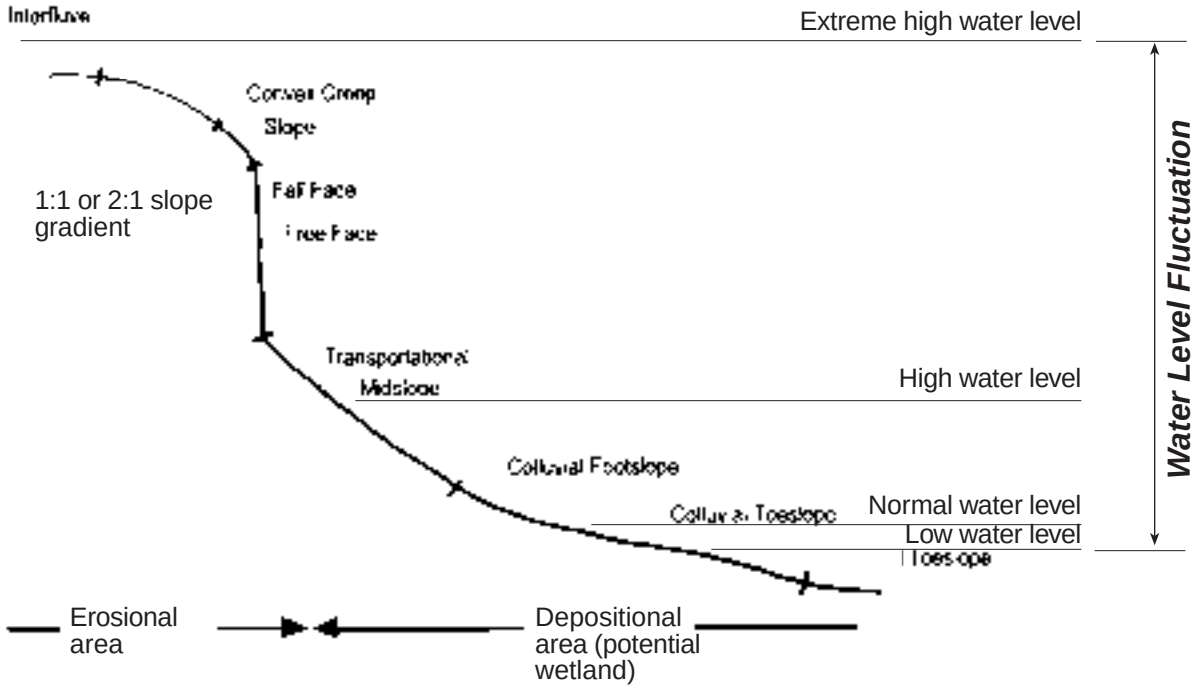
7	32-11173-001	February 2002



(Note: Typical side slope gradient varies from 1:1, 2:1, to 3;1)



Adapted from: Abbott 2001.

Buffalo Bayou Master Plan

Schematic Illustrations through Buffalo Bayou Side Slope Conditions with Slope Terminology and Erosion - Deposition Areas.

TurnerCollie & Braden Inc.
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Buffalo Bayou Master Plan

Examples of Local Conditions of Wooded Floodplain Areas
Bald Cypress Swamp (above) and
Bottomland Mix-Hardwood (below).

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9	32-11173-001	February 2002

Source: USACE, 1940b

Line indicates flood height

Buffalo Bayou Master Plan

Conditions along portions of Buffalo Bayou in the 1940's

TurnerCollie & Braden Inc.

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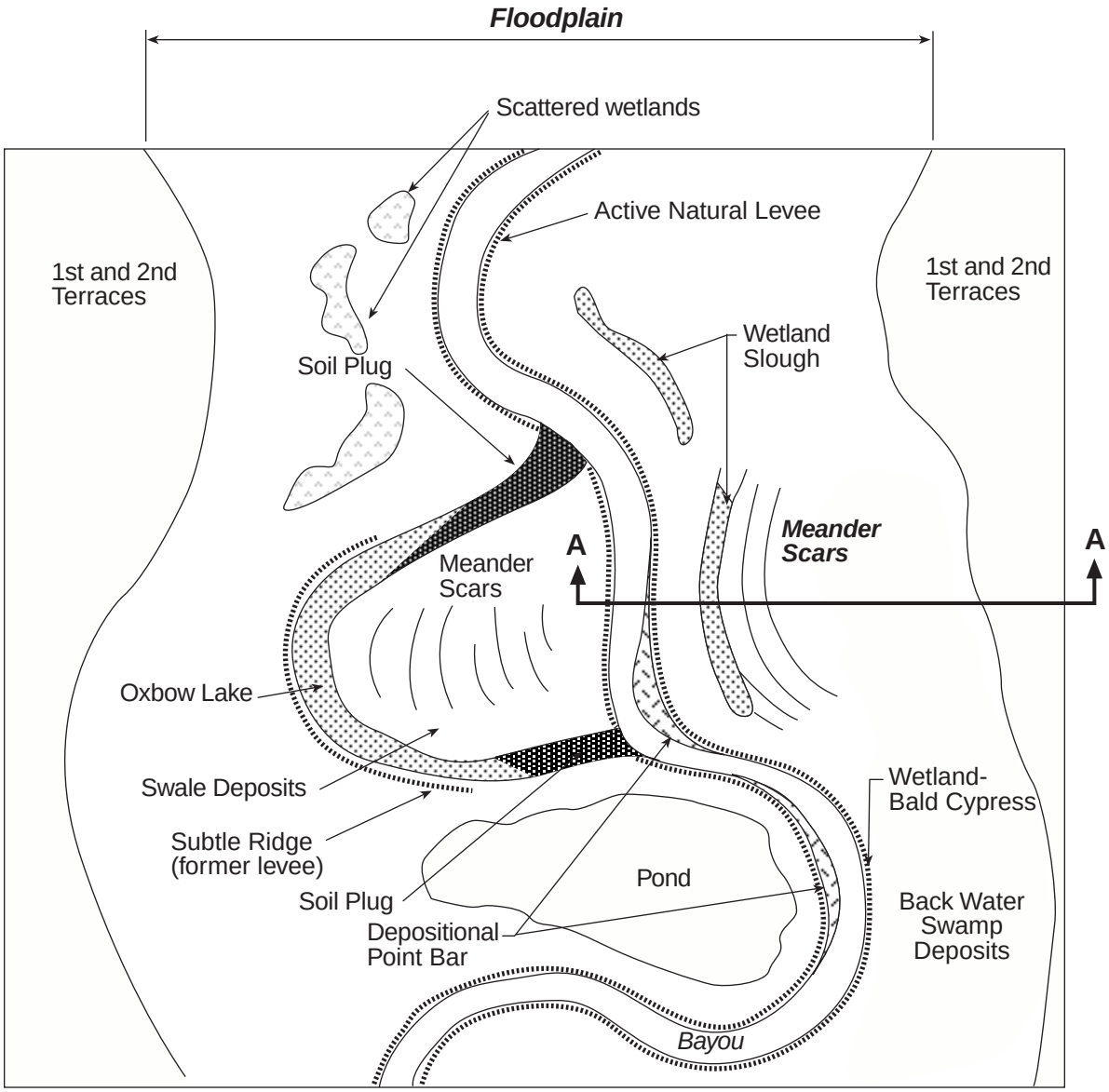
10	32-11173-001	February 2002



Note: Cross-section A-A shown in Exhibit 12.
Adapted from Gosslink et al 1990.

Buffalo Bayou Master Plan

Landscape Features of Natural Floodplain

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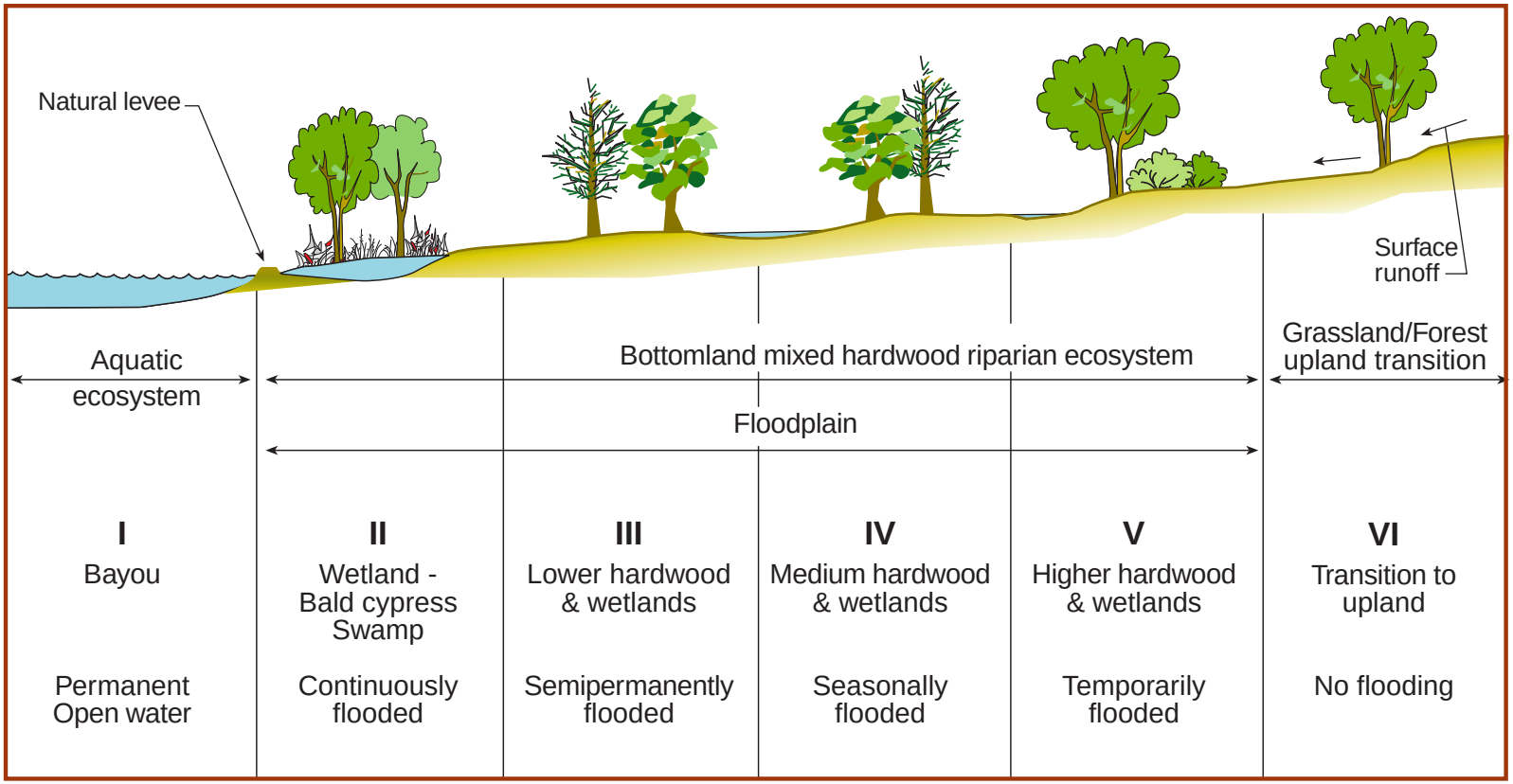
11	32-11173-001	February 2002



(Adapted from Mitsch and Gosselink, 1986)

Buffalo Bayou Master Plan

Schematic Cross-Section AA through Undisturbed Mixed Hardwood Bottomland Floodplain.

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Buffalo Bayou Master Plan

Aerial view of Undisturbed Riparian - Wetland Ecosystem

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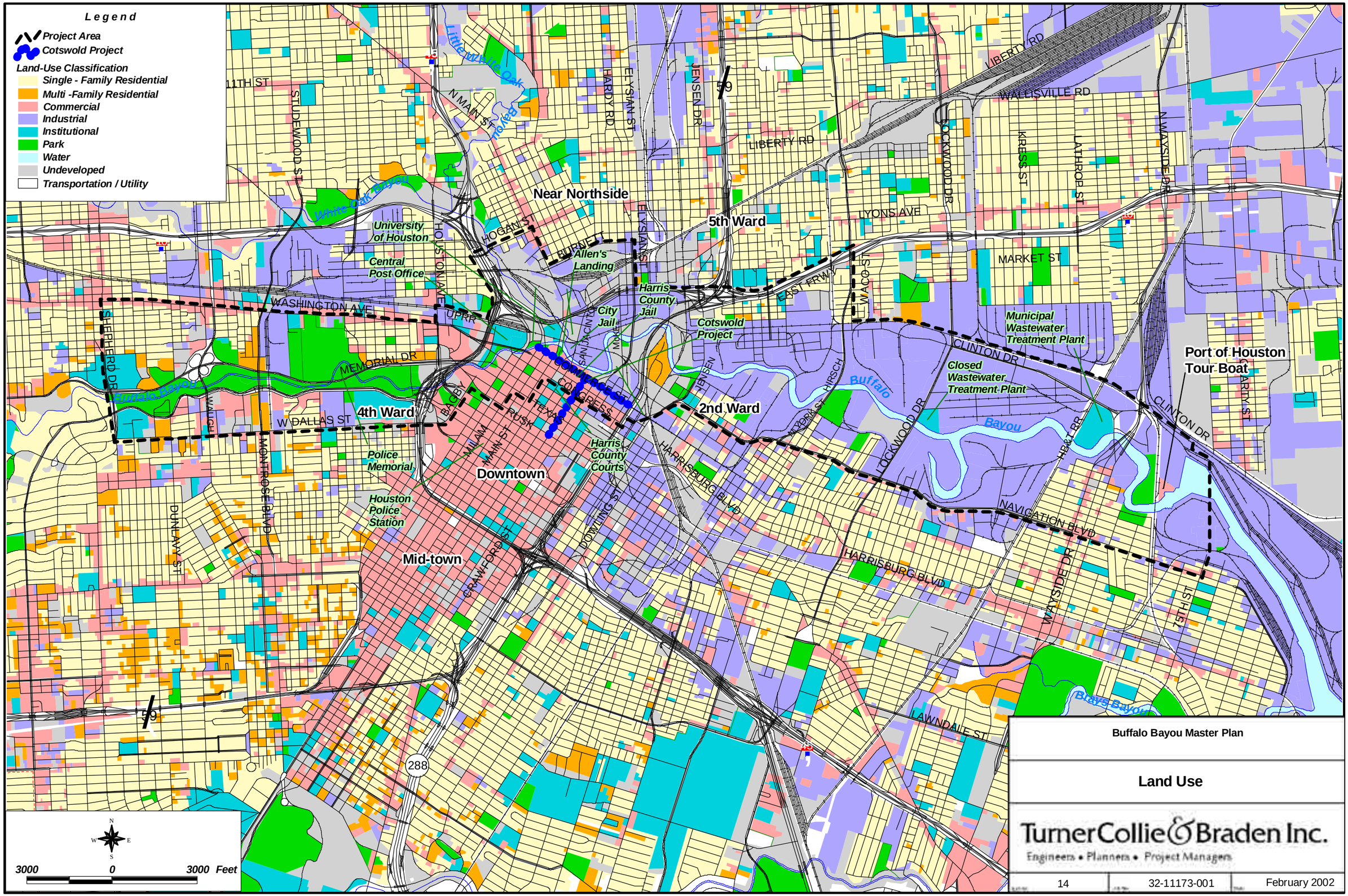
13	32-11173-001	February 2002


Legend
Project Area
Cotswold Project
Land-Use Classification
Single - Family Residential
Multi -Family Residential
Commercial
Industrial
Institutional
Park
Water
Undeveloped
Transportation / Utility
Near Northside
5th Ward
4th Ward
2nd Ward
Downtown
Mid-town
University of Houston
Central Post Office
Allen's Landing
Harris County Jail
City Jail
Cotswold Project
Municipal Wastewater Treatment Plant
Closed Wastewater Treatment Plant
Port of Houston Tour Boat
Harris County Courts
Police Memorial
Houston Police Station
Buffalo Bayou
Little White Oak Bayou
White Oak Bayou
Brays Bayou
11TH ST
STUDEWOOD ST
N MAIN ST
HARDY RD
ELYSIAN ST
JENSEN DR
LIBERTY RD
WALLISVILLE RD
ROCKWOOD DR
KRESS ST
LATHROP ST
N WAYSIDE DR
LYONS AVE
MARKET ST
HOGAN ST
BURNET
HOUSTON AVE
WASHINGTON AVE
UPRR
EAST FRWY
WACO ST
CLINTON DR
MEMORIAL DR
SHEPHERD DR
WALSH
W DALLAS ST
BAGBY
MILAM
MAIN ST
RUSK
TEXAS
COMMERCE ST
CONGRESS
SAN JACINTO
MOORE
NEUNER
HIRSCH
HOUSTON
HARRISBURG BLVD
DOWLING ST
CRAWFORD ST
MONTROSE BLVD
DUNLAVY ST
NAVIGATION BLVD
HB&T RR
CARTER ST
15TH ST
LAWNDALE ST
59
288
N
S
E
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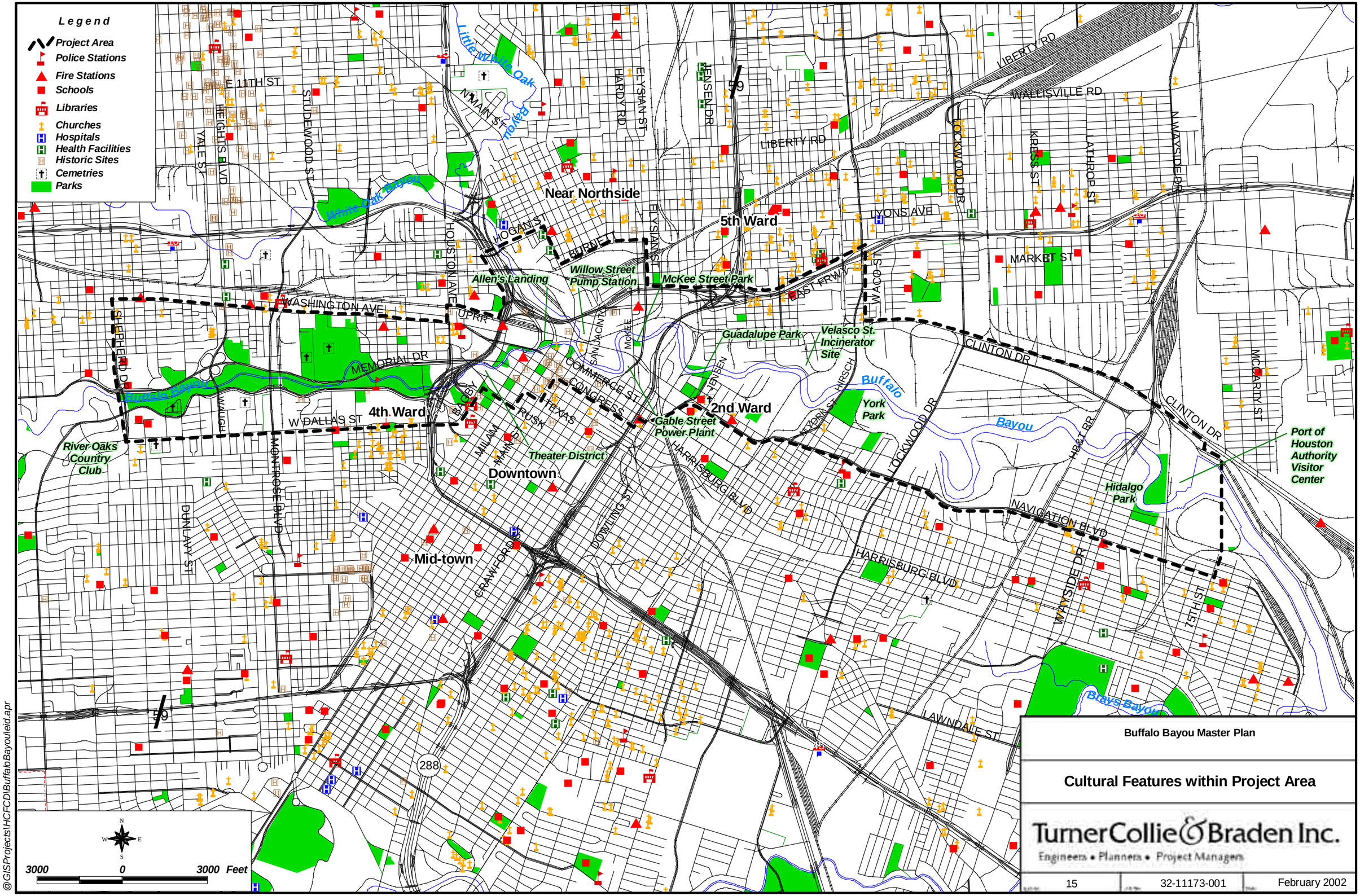
3000 0 3000 Feet
Buffalo Bayou Master Plan
Land Use
TurnerCollie & Braden Inc.
Engineers • Planners • Project Managers
14
32-11173-001
February 2002



Buffalo Bayou Master Plan

Cultural Features within Project Area

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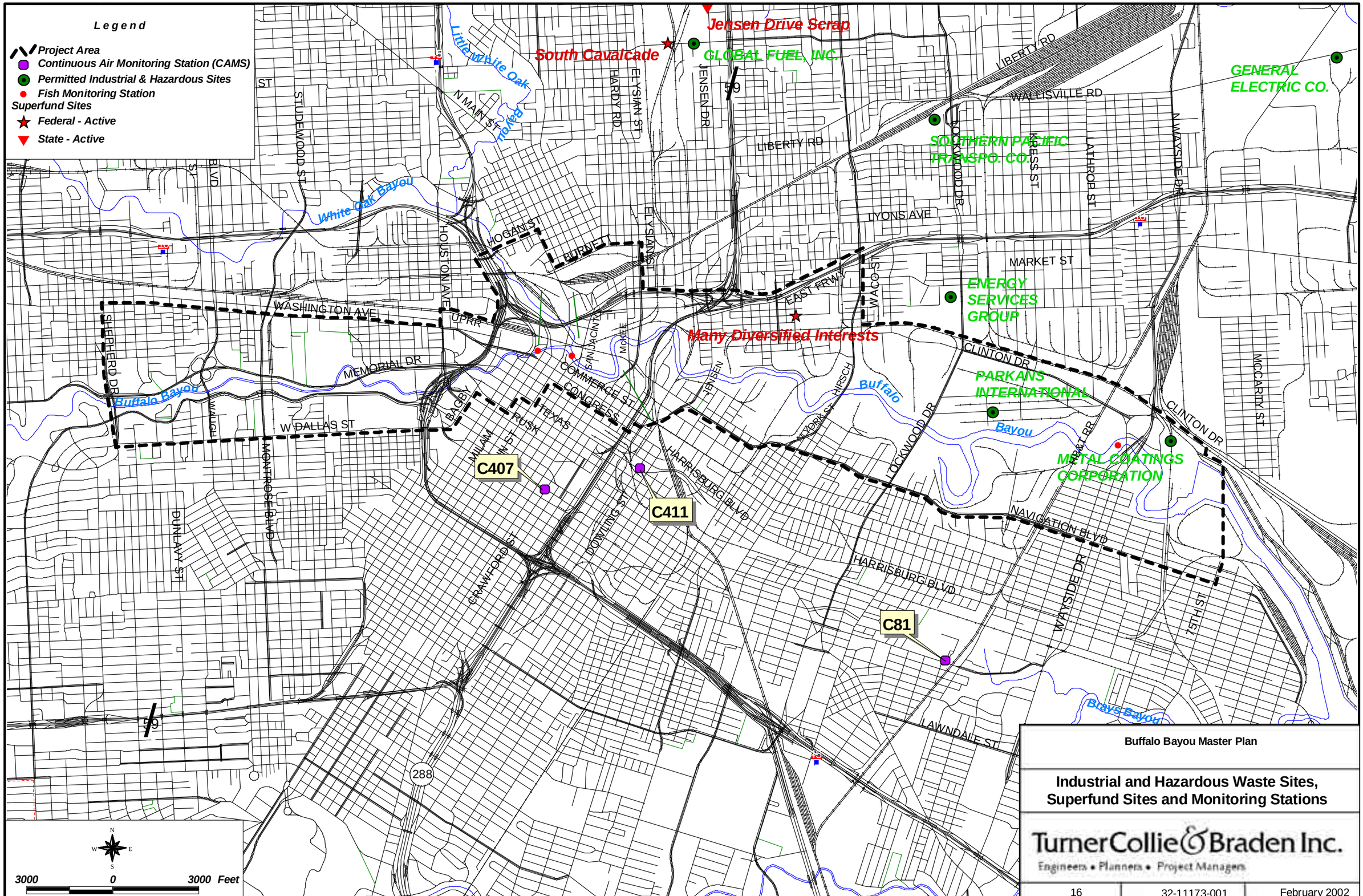
15	32-11173-001	February 2002

@GISProjects\HCFCD\BuffaloBayou\eid.apr



Buffalo Bayou Master Plan

Industrial and Hazardous Waste Sites, Superfund Sites and Monitoring Stations

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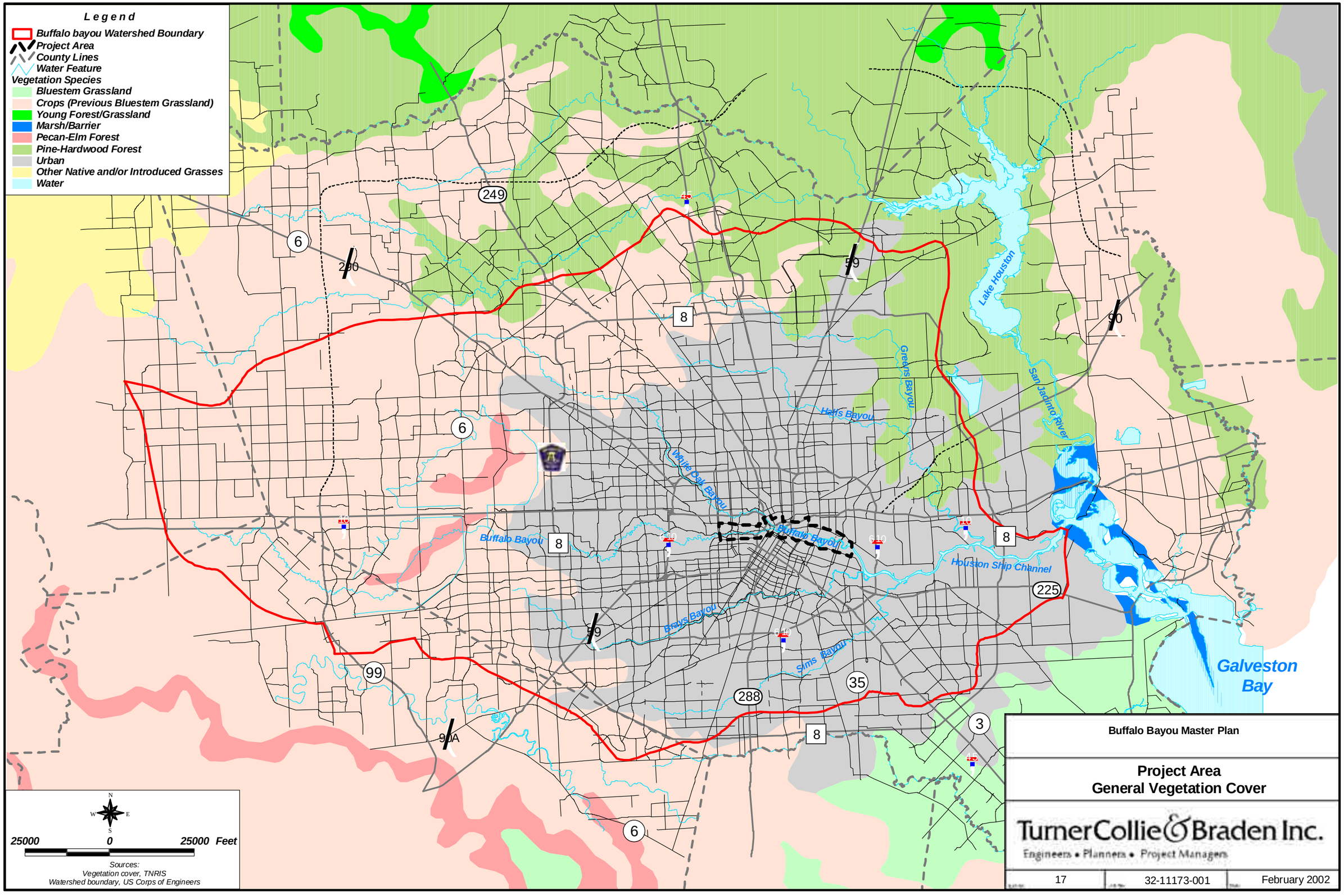
16	32-11173-001	February 2002



Buffalo Bayou Master Plan

Project Area
General Vegetation Cover

TurnerCollie & Braden Inc.
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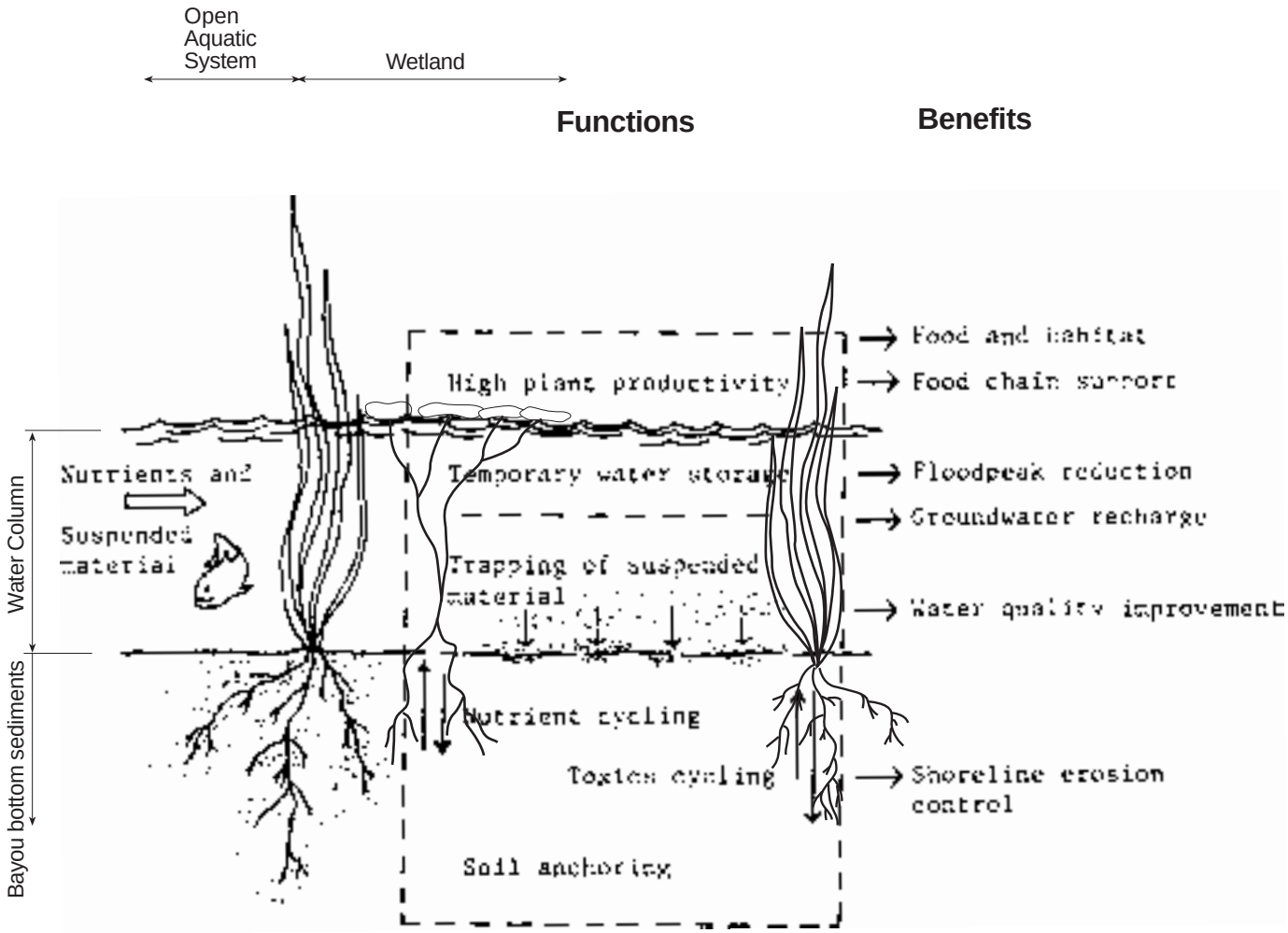
17	32-11173-001	February 2002



Buffalo Bayou Master Plan

Relationship between Wetland Functions and Benefits.

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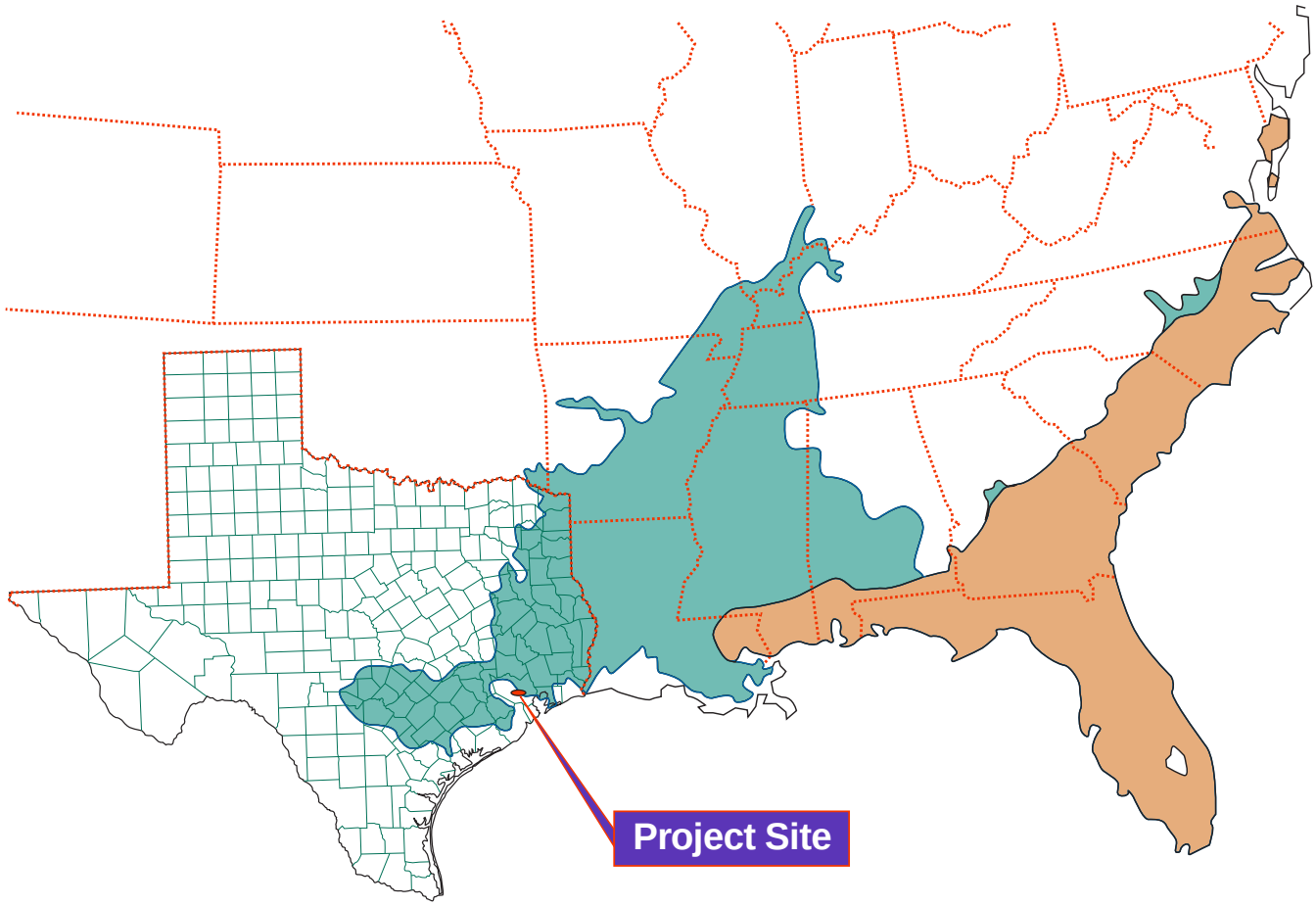
18	32-11173-001	February 2002



Legend

Range of bald cypress

Range of pond cypress

Buffalo Bayou Master Plan

Range of Cypress in Southern Bottomland Floodplain Forests

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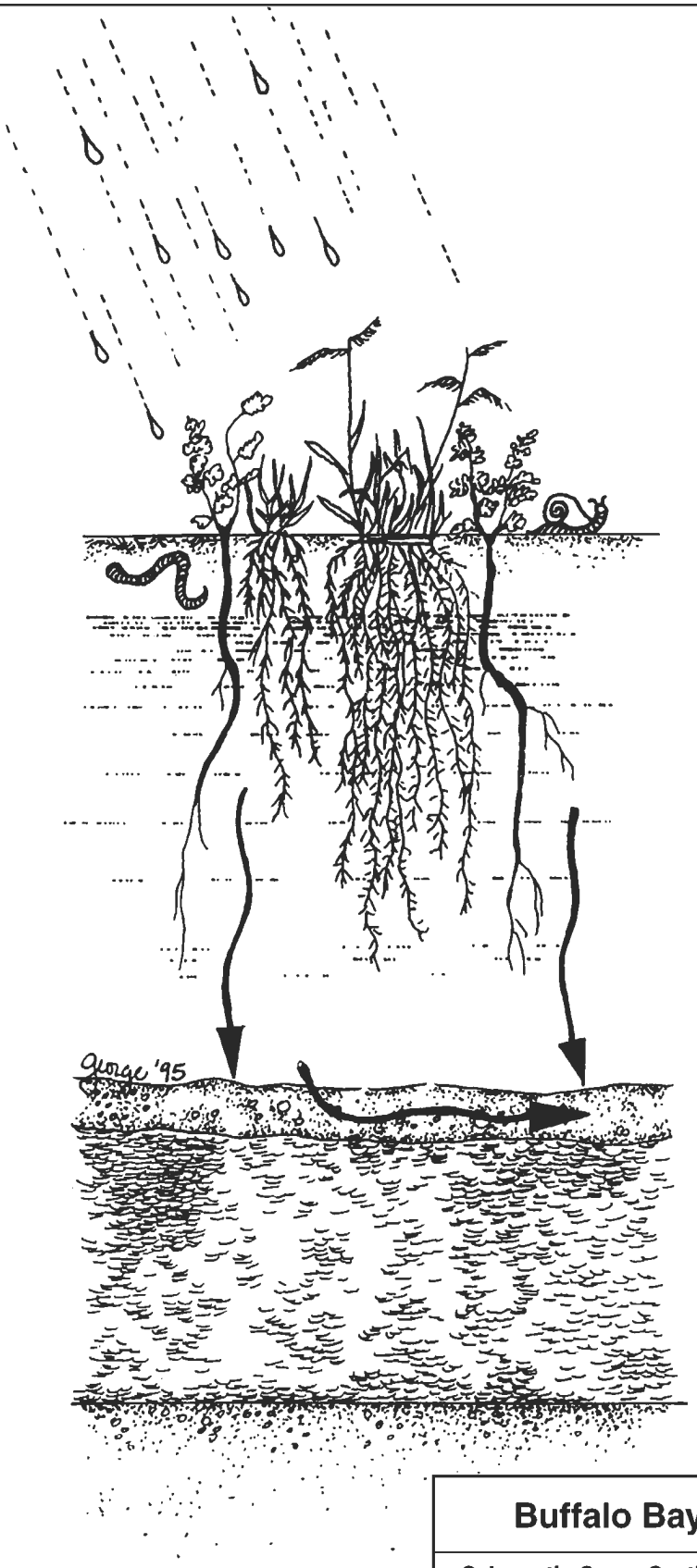
19	32-11173-001	February 2002



Buffalo Bayou Master Plan

Schematic Cross-Section through Prairie showing Relationship to Groundwater Infiltration

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Exhibit	20	Job No.	32-11173-001	Date	February 2002

Buffalo Bayou Master Plan

Example of a Pond and Deep Marsh Associated with Riparian Corridor in Zone III or IV of the Floodplain

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21	32-11173-001	February 2002

Buffalo Bayou Master Plan

Example of Prairie Slough Typical of the Blue Stem Grassland Plant Community

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22	32-11173-001	February 2002

Buffalo Bayou Master Plan

Example of Shoreline Proper Functioning Condition with Shallow Vegetated Areas

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Buffalo Bayou Master Plan

Examples of Local Undisturbed Bayou Conditions withShallow Vegetated Ares and Flat Sideslopes for Wildlife Utilization.

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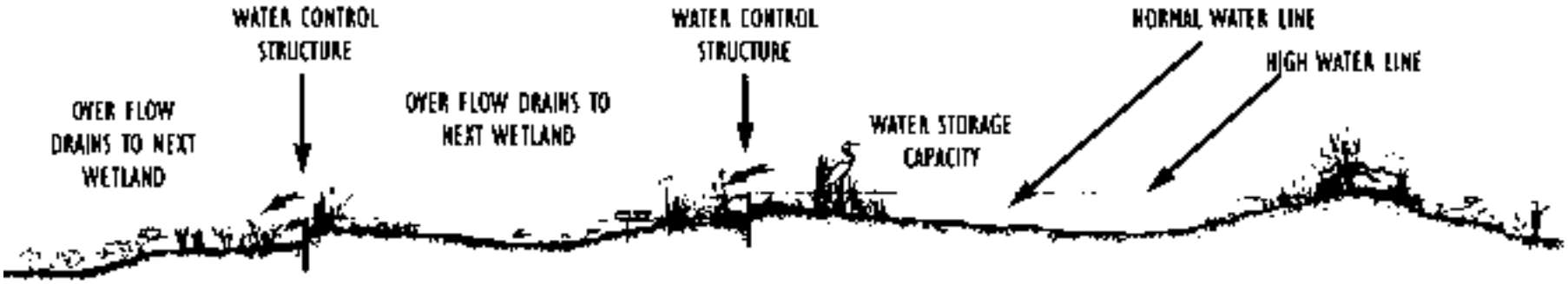
24	32-11173-001	February 2002



Buffalo Bayou Master Plan

Cross-Section through Series of Wetlands

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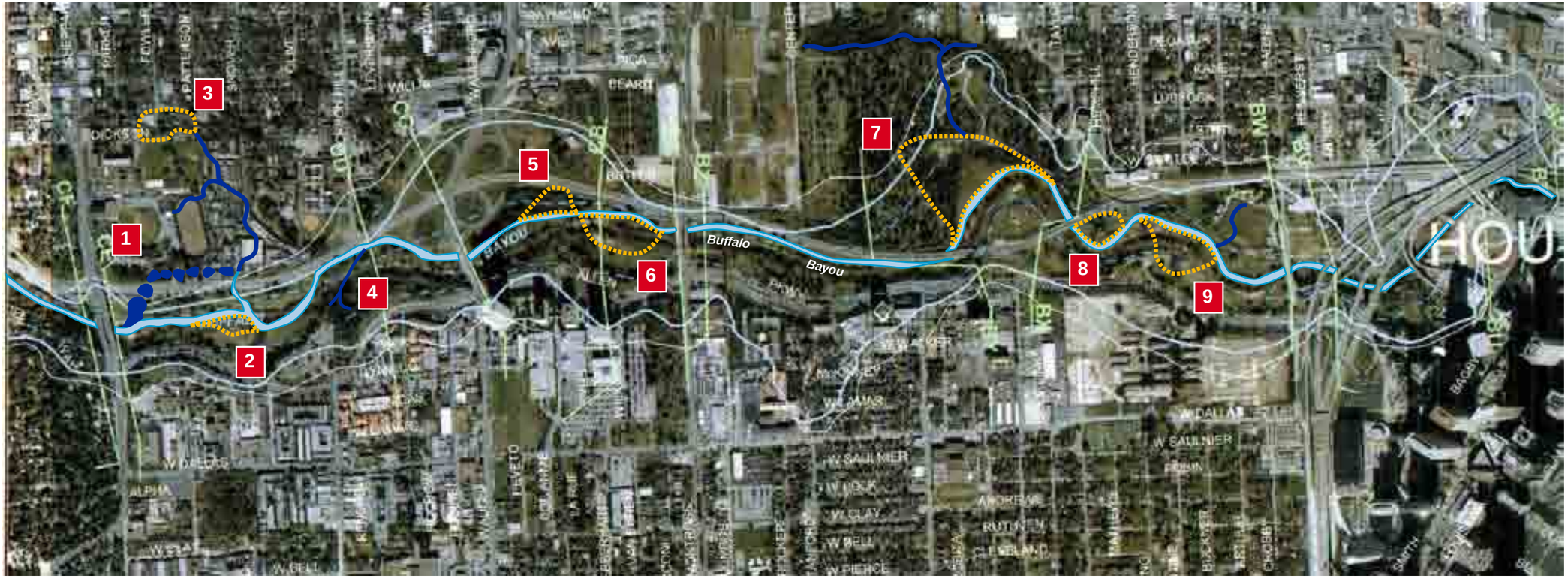
25	32-11173-001	February 2002



Note: Refer to Table 12 for Habitat Improvement Descriptions.

Legend

- FEMA Cross Sections
- Floodway
- 100-yr Floodplain
- 500-yr Floodplain

0 1000

Scale In Feet
(Approximate)

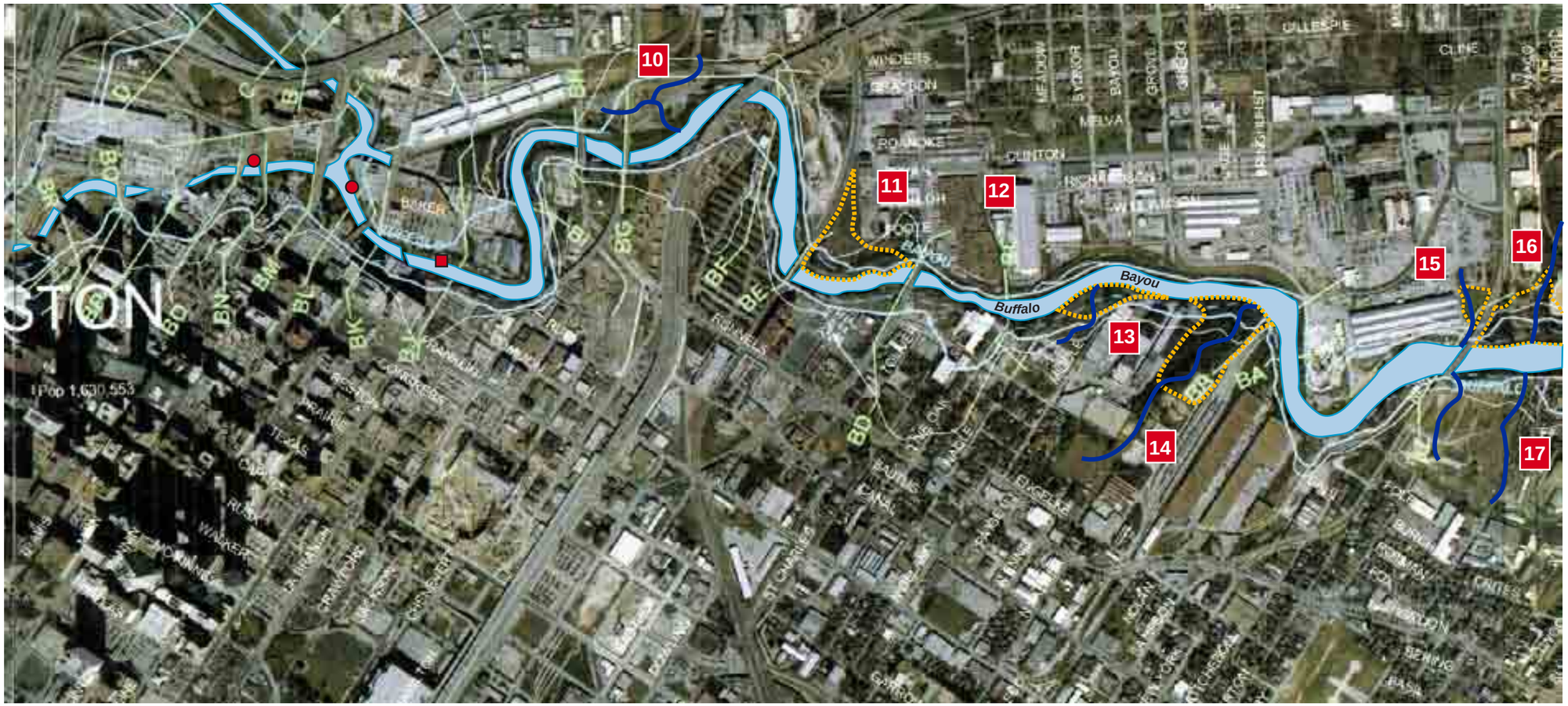
Buffalo Bayou Master Plan

Proposed Areas for Habitat Improvements along Buffalo Bayou

TurnerCollie & Braden Inc.

Engineers • Planners • Project Managers

26a	32-11173-001	February 2002



Note: Refer to Table 12 for Habitat Improvement Descriptions.

Legend

- FEMA Cross Sections
- Floodway
- 100-yr Floodplain
- 500-yr Floodplain
- Fish Monitoring
- Waste Water (Industrial Outfall)

0 1000

Scale In Feet
(Approximate)

Buffalo Bayou Master Plan

Proposed Areas for Habitat Improvements along Buffalo Bayou

TurnerCollie & Braden Inc.

Engineers • Planners • Project Managers

26b	32-11173-001	February 2002

Legend

- FEMA Cross Sections
- Floodway
- 100-yr Floodplain
- 500-yr Floodplain
- Fish Monitoring

0 1000

Scale In Feet
(Approximate)

Buffalo Bayou Master Plan

Proposed Areas for Habitat Improvements along Buffalo Bayou

TurnerCollie & Braden Inc.

Engineers • Planners • Project Managers

26c	32-11173-001	February 2002

Appendix A –

Photo Documentation of 2001 Site Conditions

(in a separate document)

Appendix B –

Checklist for Proper Functioning Conditions