An Evaluation of the Hydrology of the Greens Bayou Wetlands Mitigation Bank: Subdivision A Phase 1 Final Report

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Introduction

The Harris County Flood Control District's Greens Bayou Wetlands Mitigation Bank is a 1,400-acre wetland project located in northeast Harris County, immediately south of Beltway 8 and east of the confluence of Greens and Garners Bayous (HCFCD 2006). The site contains a diverse mixture of pine/hardwood forests and open grassy prairies, interspersed with wetlands that exist in a system of old meanders and large depressions. The goal of this long-term mitigation bank project is to create a large, contiguous area of protected wetland habitats by enhancing existing wetlands, while also creating new wetlands from upland areas.

The purpose of the Greens Bayou mitigation bank is to provide mitigation wetlands for use by the Harris County Flood Control District and outside organizations which may need to compensate for future development or projects that impact Federal jurisdictional freshwater wetlands in Harris County. Mitigation credit is granted to applicants who purchase wetlands created at the mitigation site to compensate for unavoidable impacts to freshwater wetlands at their project site.

Subdivision A, Phase 1 (Sub A-1), is a 47 parcel of the mitigation bank (Figure 1). Sub A-1 contains an extensive network of created palustrine emergent (PEM) wetland swales and depressions (zone A) and ponds (zone B) and both relict and intended palustrine forested (PFO) wetland areas. The relict PFO wetland is part of an existing relict meander scar system located adjacent to and east of the site (Berg-Oliver Associates Inc. (BOA) 1995). Sub A-1 contains constructed wetlands intended to serve as banked wetland mitigation credits as set forth in the 1995 MOA between the HCFCD, USACE, and other members of the Mitigation Bank Review Team (MBRT).

Based on recent observations and limited monitoring data, the Harris County Flood Control District is concerned that selected portions of Sub A-1, appear to be experiencing and/or have experienced declines in surface water and associated wetland indicator plants (SWCA 2005a and 2005b). The density and aerial coverage of Zone A wetland vegetation appears to be declining (Table 1).

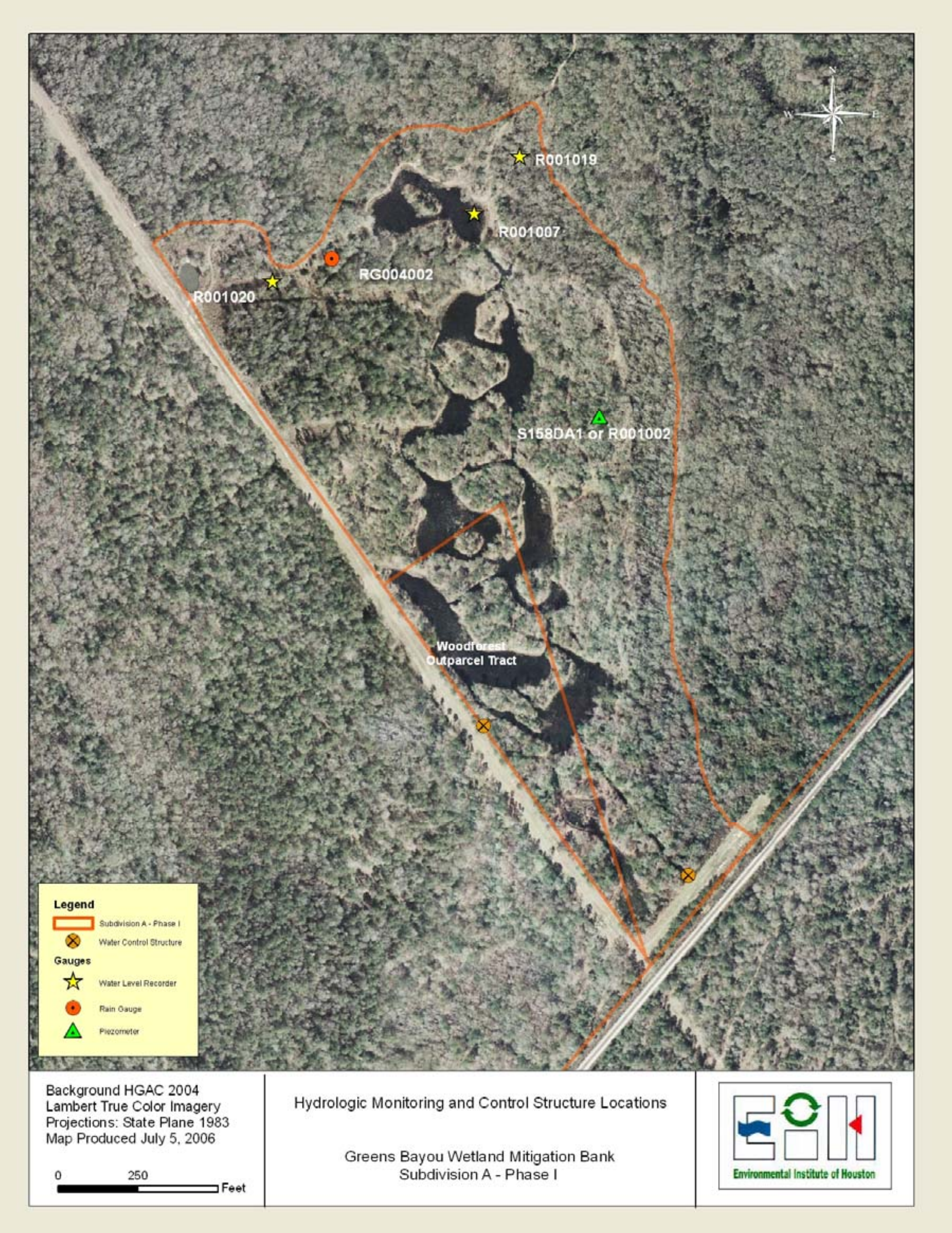


Figure 1. Subdivision A, Phase 1 (Sub A-1), the “47” acre parcel of the mitigation bank. Also depicted is the Woodforest Outparcel tract.

Table 1. SWCA estimates of hydrophytic vegetation in recent years 2004-2006. Source: (SWCA 2005a, 2005b, 2005c, 2005d, 2006a, 2006b)

		Percentage of Desirable Hydrophytic Aerial Coverage			***Daily Avg. Precip. (in)***	**No. of Positive Wetland Indicators**
Year	**Quarter**	**Zone A**	**Zone B**	**PFO**	**All Areas**	**All Areas**
2004	Fourth	65%				
2005	First	50%	79%	70%	0.13	26/32
	Second	44%	87%	80%	0.10	21/32
	Third	52%	89%	76%	0.18	56/115
	Fourth	68.5%	62%	42%	0.22	19/32
2006	First	42%	54%	64%	0.11	21/32

However, there appears to be considerable inter-annual and intra-annual variation that appears to be associated with precipitation and seasonal growing periods. For example based on their second quarter 2005 monitoring data they reported the following information (emphasis added by us) (SWCA 2005b).

> “Desirable hydrophytic aerial cover is 44% in Zone A, 87% in Zone B, and 80% in PFO (intended and relict) wetlands based on the data collected from the subsample of total sample plots. Compared to the results for this same subsample of sample plots in third quarter 2003, fourth quarter 2004, and first quarter 2005, results for Zone B and PFO wetlands during second quarter 2005 are *consistent* with previous monitoring events. Results for aerial cover in Zone A were below normal; however, previous monitoring events indicate that herbaceous vegetation in Zone A is primarily composed of *warm-season, perennial vegetation*. These species are typically not present, or are immature during the first half of the year, reaching maximum aerial cover nearer the latter portion of the year. The decrease in aerial cover from first quarter 2005 to second quarter 2005 is likely attributable to the presence and subsequent absence of annual herbaceous vegetation that is commonly abundant in spring. In addition, *near drought-like conditions throughout June may have limited early summer growth in Zone A*. In SWCA’s professional opinion, aerial cover in Zone A will most likely increase throughout the remainder of the year. Data collected from water level recorders were compared to third quarter 2003, fourth quarter 2004, and first quarter 2005 monitoring. This comparison revealed that *water levels at subsample locations during second quarter 2005 were substantially lower than those recorded in first quarter 2005*. Results from second quarter 2005 monitoring were similar to those observed during fourth quarter 2004. Water depths within Zone A, Zone B, and PFO wetland sample plots averaged 0.99, 14.67, and 0.10 inches, respectively, during second quarter 2005 monitoring."

The minimum success criteria (MSC) were defined in the original MOA between the HCFCD and the USCOE (HCFCD 1995). The MSC for Sub A-1 is specified in terms of both: A) palustrine emergent (PEM) Zone A and PEM Zone B wetlands and B) Palustrine Forested (PFO) Broad -leaved Deciduous Wetlands. In general terms PEM Zone A represents the swales and shallower pools, which are variably saturated but not likely to contain permanent surface water and usually containing facultative wetland indicator plants. PEM Zone B represents the deeper pools and ponds, in which surface water is present during specified seasons. Obligate plants are more likely to be present in this zone (HCFCD 1995). An evaluation of the wetland MSC for the Greens Bayou Wetland Mitigation Bank was performed by HCFCD in 1998. At that time the MSC as defined in the original MOA was met or exceeded (HCFCD 1998). Since then the HCFCD has used the WET 2.0 assessment methodology to monitor the extent and types of wetlands.

PEM Zone A coverage fluctuated between 65 and 68.5% during the last quarter of 2004 and 2005 (SWCA 2005a). They explained that this was due to the "seasonally variability of emergent vegetation". In addition, they documented the possible relationship between drought like conditions and the reduced amount of wetland plant species.

Adams and Harris (2000) constructed a “Beltway 8 water balance model” for evaluation of irrigation needs for the overall mitigation project. They noted the probability of dry conditions based on historical records that could reduce the amount of wetland coverage during drought conditions. They concluded that the addition of irrigation flows from a proposed power plant effluent could supplement the hydrology to:

1) Sustain the wetland in wetter conditions
2) Minimize the impact of dry hydrologic cycles
3) Allow for increasing the size of the wetland area
4) Allow for increasing the size of wetland area while minimizing the impact of dry hydrologic cycles.

It is to our understanding via conversations with Ms. Michele Wilkins (HCFCD) that Sub A-1 is continuing to meet the (MSC) for the property based on the 1995 U.S. Army Corps of Engineers (USACE) Memorandum of Agreement (MOA). However, after reviewing numerous technical reports from SWCA, water levels and Zone A and B, and PFO wetland areas have, at various times between 2003 and 2005, fallen below optimal conditions. It appears that based on these same reports, Zone B and PFO wetland areas have only occasionally been lower than desired, and are generally meeting the MOA requirements. Various reasons have been suggested for this observed decline including infiltration and drainage of surface water through hydrologic connections between excavated ponds and a perched groundwater table, and excessive evapotranspiration due to prolonged drought conditions. One of the primary questions that the project sponsors have is whether something other than meteorological conditions is responsible for this decline.

Objectives

The purpose of our study was 1) to determine whether water levels in the wetland mitigation site are actually dropping as previously reported, 2) to determine if these declines are “extreme” or below projected levels based on local meteorology and hydrology, 3) what are the mechanisms responsible for such declines and 4) and to determine if there are feasible approaches that can be used to reverse or reduce this decline.

Background: Wetland Hydrology

Wetland Water Budget

Determining water budgets for wetlands is imprecise, because as the climate varies from year to year so does the wetland water balance. The accuracy of the estimates of individual components depends on how well they can be measured and the magnitude of the associated errors. However, water budgets, in conjunction with information on the local geology, provide a basis for understanding the hydrologic processes within wetlands and predicting the effects of natural or human-induced hydrologic alterations. Each of the components is discussed below.

The major components of the hydrologic cycle in wetlands include precipitation, surface-water flow, ground-water flow, and evapotranspiration. Wetlands and their adjacent upland areas exchange water with the atmosphere, adjacent bayous, and ground water. A suitable geologic scenario and an adequate and constant supply of water are necessary for the long term existence of wetlands. The wetland water budget consists of the total of inflows and outflows of water from a wetland. The relationships between these components of a budget are illustrated in the equation below.

> Equation 1. ($P + SWI + GWI = ET + SWO + GWO + \Delta S$): *where P is precipitation, SWI is surface-water inflow, SWO is surface-water outflow, GWI is ground-water inflow, GWO is ground-water outflow, ET is evapotranspiration, and* ΔS *is change in storage.*

The relative importance of each component in maintaining wetlands varies both spatially and temporally, but all of these interact to create the hydrology of a wetland. Temporal variability includes both seasonal and annual trends. For example, within the project area extended periods or elevated rainfall, often occur during late fall through spring. Less predictable are the periods of drought or heavy rainfall (e.g. tropical storms).

Isolated basin wetlands, such as those found in many coastal prairie systems, receive direct precipitation and some runoff from surrounding upland areas, and may sometimes receive ground-water inflow. They lose water primarily through evapotranspiration and possibly through seeps into ground water. Some may overflow during periods of excessive rainfall. These wetlands can range from very wet to dry depending on seasonal and long-term climatic cycles. Wetlands located on bayou flood plains can also receive water from bayous when they exceed flood stage. Water can drain back to the bayou as floodwaters recede. Wet and dry cycles in these types of wetlands are commonly closely linked to bayou water-level fluctuations. Based on the best available information it appears that much of Sub A-1 functions primarily as semi-isolated wetlands, except during floods events when nearby Garners and Greens Bayou can and do overflow their banks. The flood stage for Garners and Greens Bayou are 51 and 61 ft respectively (USGS 2006). The majority of Sub A-1 is approximately 6 feet above the river banks of these bayous, and 20 ft above the average surface water height. (TSARP 2002, SWCA 2004 and USGS 2006).

Precipitation provides water for wetlands directly and indirectly. Water is provided for a wetland directly when precipitation falls on the wetland or indirectly when precipitation falls outside the wetland and is transported to the wetland by surface- or ground-water inflow. The distribution of precipitation across Texas is affected by major climatic patterns. In Texas, maximum rainfall is found in the eastern part of the state and declines to minimal levels in the west. Most freshwater wetlands in Texas are therefore found in the eastern part of the state. For our analysis we utilized two sources primarily for information on precipitation. This included the onsite precipitation gage and another site located at the George Bush Airport (IAH) which possessed a longer period of record (Figure 1). The IAH gage is located approximately 5 miles northwest of the site.

The loss of water to the atmosphere is an important component of the wetland water budget. Water is removed by evaporation from soil or surfaces of water bodies and by transpiration by plants. The combined loss of water by evaporation and transpiration is called evapotranspiration (ET). Sunlight, windspeed, relative humidity, available soil moisture, and plant type and density affect the rate of ET. Evaporation can be measured fairly easily. However, ET measurements, which include measuring how much water is being transpired by plants, are much more difficult to make. Scientists often use a variety of formulas to estimate ET. There is however some disagreement as to which is the best approach to use (Carter, 1986). Another problem is that evapotranspiration is highly variable both seasonally and daily. Seasonal changes in ET are related to the water-table level (more water evaporates from the soil or is transpired by plants when the water table is closer to land surface) and also to temperature changes (more water evaporates or is transpired in hot weather than in cold). ET losses from wetlands also vary with plant species, density, and plant dormancy or metabolism. ET is usually estimated for a region using potential evapotranspiration (PET) estimates. PET, or reference evapotranspiration, is currently estimated using data from sparsely located weather stations around the state. In general however, more than 70% of the precipitation falling on the United States is returned to the atmosphere through evapotranspiration. Although site specific information for evaporation or ET would provide valuable information on the overall water budget for the project site, it is currently lacking. We were, however, able to work under the assumption that ET varies consistently on an annual basis, since no major changes in land use or vegetation have occurred during the period of evaluation. Adams and Harris (2000a and 2000b) estimated ET using region pan evaporation estimates of evaporation and theoretical relationships with ET. They estimated monthly ET varied approximately between 1.8 and 7.0 inches between winter and summer months. They estimated the total annual average ET to 48.51 inches, while total annual average precipitation was 47.55 inches (Adams and Harris 2006b). There were slight differences annually and seasonal fluctuations were fairly consistent.

By most legal and technical definitions, surface water may be permanently, seasonally, or temporarily present in a freshwater wetland. Surface water is supplied to wetlands through normal streamflow, flooding from rivers and bayous, overland flow, and ground-water discharge. Ground water discharged into wetlands becomes surface water. Surface water outflow from wetlands is greatest during the wet season and especially after flood events. Surface water may flow in channels or across the surface of a wetland. Flow paths and velocity of water over the surface of a wetland are affected by the topography and vegetation within the wetland. Surface water flow within the Sub A-1 wetland is, based on our review of literature, poorly understood. However, based on our limited review of the topography, it appears that there is little surface water connectivity between Sub A-1 and the adjacent bayous during most times of the year. However, linkages via groundwater may exist in portions of the project area.

Groundwater originates as precipitation or as seepage from surface-water bodies. Precipitation moves slowly downward through unsaturated soils and rocks until it reaches the saturated zone. Water also seeps from bayous and rivers, and wetlands into the saturated zone. This process is known as ground-water recharge and the top of the saturated zone is known as the water table. Shallow water table levels are typically measured using piezometers. For assessment of shallow groundwater levels we used data from a piezometer located onsite (Figure 1).

Ground water in the saturated zone flows through aquifer systems composed of permeable earth materials and soil in response to hydraulic heads (pressure). Ground water can flow in shallow local aquifer systems where water is near the land surface or in deeper confined intermediate and regional aquifer systems. Differences in hydraulic head can cause ground water to move back to the land surface or into surface-water bodies. This process is called ground-water discharge. Ground-water discharge occurs through seepage or springs, man-made wells, and through ET where the water table is near the land surface and plant roots can reach it.

In most cases, wetlands are ground-water discharge areas. However, ground-water recharge can also occur in wetlands. Ground-water recharge or discharge in wetlands is affected by topographic position, hydrogeology, sediment and soil characteristics, ET, season, and climate. Recharge rates in wetlands can be much slower than those in adjacent uplands if the upland soils are more permeable than the slightly permeable clays that usually underlie wetlands.

The soil types at the wetland site and in the watershed are important to the success of a wetland creation/restoration project. Wetland soils come in two major types—organic and mineral. Organic soils are made up primarily of plant material; either decomposed or undecomposed (e.g. "peat"). Depending on the size of the soil grains, mineral soils are generally described (from largest grain size to smallest) as sand, silt, and clay. Sandy wetland soils are the most permeable, allowing water to move easily between the wetland and the groundwater, depending on the depth of the water table. Less permeable clayey soils are more likely to maintain water in the wetland even if the water table is low. Some sites have "hard pan" layers underneath them, impermeable layers of clay, and essential to the ecology of the wetland. These hard subsurface layers may allow water to stay ponded for much longer than would occur otherwise, resulting in unique ecosystems, such as "vernal pool" habitats.

For wetlands dependent on overland flow or precipitation, impermeable soils need to be present at the wetland site and in the watershed for flow to go into and stay in the wetlands basin. For wetlands dependent on a combination of surface and groundwater, impermeable soils are needed in the watershed to channel water into the wetland. Permeable soils, such as sandy loams would be necessary where groundwater infiltration occurs.

Much of the project site is covered by soils characterized as Midland silty clay loam and Boy loamy fine sand which are characterized as being poorly or somewhat poorly drained (USDA SCS 1976). Adams and Harris (2000) note that some soils in the overall mitigation bank may have higher hydraulic conductivities and limit the establishment of wetlands in those areas. In Sub A-1, soils below 20 inches in wetland zones were generally characterized as having low permeability (Jacob1994). Based on his assessment Jacobs (1994) predicted that "this condition would support extensive ponding of water and is expected to stay wet most if not all year". Other areas would have a much reduced hydro-period, but still remain ponded several weeks to months each year.

Storage in a wetland consists of the sum total of surface water, soil moisture, and ground water. The storage capacity of a wetland refers to the space available for water storage at a particular point in time under given conditions. A wetland water table generally fluctuates seasonally in response to rainfall and ET. The storage capacity of wetlands is lowest when the water table is near or at the surface. This usually occurs during the dormant season when plants are not transpiring, and/or during the wet season. Storage capacity increases during the growing season as the water table declines and ET increases. When storage capacity is increased, infiltration may occur and the wetland will experience reduced runoff. When the water table is high and storage capacity is low, any additional water that enters the wetland will probably run off. Within Sub A-1 we would expect the storage capacity to be highest during the summer when ET is generally highest and precipitation is lower. Increased precipitation occurring during the late fall through spring, which is also the same period of increasing plant dormancy, reduces the storage capacity as the wetland ponds and low areas are filled.

Methodology and Data Review

Groundwater Resources, Topography and Watershed Delineation

Groundwater Resources

The Sub A-1 site overlies major deep confined coastal aquifers including the Chicot and Evangeline (Weiss 1992). There have been historical declines in these aquifers since the 1940's due to increased groundwater removals for urban and agricultural use (Garbysch and Bonnet 1975). During 1943 to 1973, water levels in wells utilizing the Chicot aquifer declined from 75 to 100 ft. However, this rate had slightly decreased between 1964 and 1973 when levels decreased between 20 and 40 feet. A similar pattern emerges with the Evangeline aquifer (Garbysch and Bonnet 1975). A decline of water levels of 100 to 150 ft in wells utilizing the Evangeline aquifer was observed between1943 and 1973. Similar to the Chicot this rate had decreased between 1964 and 1973, when levels decreased between 40 and 60 feet.

Information on recent levels of deeper confined aquifer levels were obtained from published data compiled by Kasmarek and Strom (2002). In 1996, the measured potentiometric surface of the Chicot aquifer was -100 to -150 ft bsl (below sea level). Within the mitigation bank area the depth of the base of Chicot Aquifer is estimated to be approximately -300 ft bsl. During the same year the measured potentiometric surface of the Evangeline was -150 to -200 ft bsl. The depth of base of Evangeline Aquifer in mitigation bank area is approximately -1800 to -2000 ft bsl.

Historical land-surface subsidence data was obtained from Gabrysch and Bonnet (1975). Due to extensive regional groundwater removal, land surface subsidence has increased in recent years (Gabrysch and Bonnet 1975). This is important since the use of older topographic maps and resources for determination of land surface elevations may be misleading. Land surface subsidence from 1906 to 1943 was estimated to be 0.2 to 0.4 ft. Between 1943 and1973, subsidence had increased to approximately 1.5 to 2.0 ft.

Topography and Watershed Delineation

Several GIS data sets were evaluated to assist in determining the surface water hydrology on Sub A–1. Data sets used for determine of flow direction and accumulation, were derived using the Harris County Flood Control District's Tropical Storm Allison Recovery Project (TSARP) Digital Elevation Models (DEMs) (TSARP 2002). These data sets were generated from LIDAR imagery.

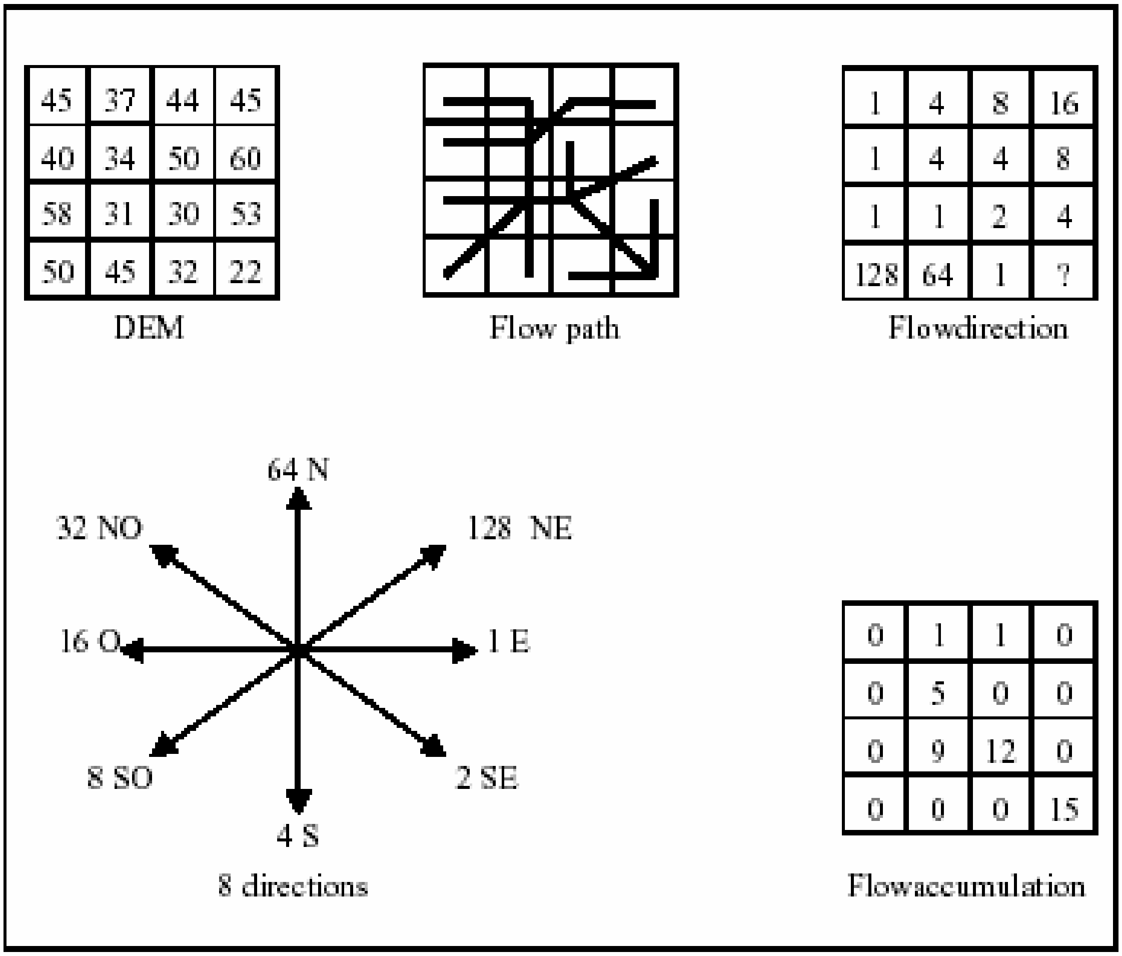
We used ArcGIS™ with the Arc Hydro™ extension software package to evaluate surface water flow at Sub A-1 (Maidment 2002). Flow direction is calculated by the software using an algorithm that evaluates the steepest descent from a particular cell to an adjacent cell. The cell value is the elevation based on the TSARP DEMs. The horizontal and vertical accuracy of the DEM data is 0.5 meter (1.6 ft), and 15 centimeters (0.5 ft) respectively. The flow accumulation function within Arc-Hydro uses as input the previously generated flow direction grid. It computes the resulting flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid. This grid predicts locations where water would most likely accumulate. A graphical representation of this process is provided in figure 2.

After the analysis the software produces a graphic image that depicts flow direction using a color coded grid, and flow accumulation using a black to white gradient coded grid. Areas depicted in white on the flow accumulation map image represent areas most likely to accumulate surface water, whereas dark areas are locations where runoff is likely.

Due to the low topographic gradient encountered in wetlands, and the inherent limitation in vertical accuracy of the DEM data, the Arc Hydro™ based analysis is limited to detecting water movement in areas where sufficient topographic differences was present and detected. Also, the software algorithm does not incorporate the processes of infiltration, evapotranspiration, and groundwater recharge and discharge in calculation of flow direction. In addition, the presence of surface water in ponds is treated as a false elevation signal (positive bias) in the LIDAR imagery and associated DEM data.

Hydrological Analysis

In order to evaluate potential mechanisms that could be contributing to the observed decline we evaluated existing accessible published and unpublished data collected at the site, and within the watershed. Our approach was limited to conducting a critical review and analysis of existing data to identify and evaluate the most probable mechanisms affecting surface water levels at the site.
As delineated in the scope of work, no additional field data was conducted at the site. The primary purpose of this aspect of the project was to assess the hydrological condition of the Sub A-1 wetland. This assessment entailed an evaluation of all of the available hydrological data including local and regional precipitation, local groundwater and surface water levels, and finally the behavior of nearby bayous. Collectively this assessment allowed us to determine if the declines in the wetted areas in Sub A-1 is related to the climate or if perhaps there may be other factors involved.



45	37	44	45
40	34	50	60
58	31	30	53
50	45	32	22

DEM

1	4	8	16
1	4	4	8
1	1	2	4
128	64	1	?

Flowdirection

0	1	1	0
0	5	0	0
0	9	12	0
0	0	0	15

Flowaccumulation

Figure 2. Representation of the Arc Hydro™ flow direction and accumulation algorithm. DEM data is used to generate a flow path. The flow path grid is then used to generate a flow accumulation grid showing most probable flow direction and location of ponded surface water (Maidment 2002).

Environmental data that was reviewed and/or used during our analysis to evaluate hydrology at the site and various management options included both on site data, previously published reports, and government sources. ArcGIS™ compatible shape files and associated databases for land cover, wetland zones and location of rain gauges, piezometers and water level indicators were obtained from the Harris County Flood Control District (HCFCD) and their contractors.

Precipitation data was obtained from several online data sources. The annual precipitation average from 1961 to 1990 for the GBWMB site was obtained from the National Atlas (National Atlas 2006). Monthly average precipitation from 1969 to 1997, were obtained from the National Climate Data Center (National Climate Data Center 2006). Historical 100-year climate data was obtained from the United States Historical Climatology Network (USHCN 2006). To extend the precipitation time series, we included regional rainfall data from the George Bush National Weather Service station. This station is located approximate 5 miles northwest from the project site. Other meteorological data that was reviewed included evapotranspiration and precipitation data maintained by the Texas Water Development Board (TWDB 2006).

Streamflow data was obtained from the U.S. Geological Survey district office (J. East pers. comm. 2006). Streamflow data was compiled from gauge 8076000 located in Greens Bayou upstream of the western edge of the property boundary, and gauge # 8076180, which is located in Garners Bayou near Humble near the northwestern corner of property boundary.

Shallow ground water in the saturated zone was evaluated using on site piezometer data collected at mitigation bank Sub A-1 and Subdivision B.
On site piezometer data was obtained from the HCFCD for the period of 1996 to 2000, and from SWCA for 2002 to 2006 (Schaap, pers. comm. 2006).

Response of Wetland Zones to Hydrology

We also attempted to create a GIS model to visually depict areas that were inundated and to predict water levels in Zone A and Zone B within the property boundary in Sub A-1 under varying hydrological conditions. We planned to use as input the surface water level and precipitation records, and the recurrence interval projections generated by our hydrological analysis. Our objective was to construct a GIS model that would allow us to predict how frequently and in what spatial proportions would Zone A and B be submerged. We requested GIS pond boundary and surface elevation ESRI shape-files from HCFCD contractor Ms. Lisa Grabowski (SWCA). If this data existed, it could be used to conduct spatial analyses/modeling to determine present and future hydrological conditions that may be correlated to actual and projected amounts of rainfall and associated water levels measured at each monitoring site.

If detailed elevation and water depth data were available to “map” the surface water levels and depth of Zone A and B, a hydrological model could be produced to visually estimate water depth in both zones in relation to the corresponding measured water levels from gages within a given time period. This could then be correlated and linked to previous rainfall amounts. Unfortunately, after discussions with Ms. Grabowski from SWCA and the HCFCD staff, we concluded that the existing topographic data sets lacked the appropriate and sufficient detail to conduct such an analysis. Consequently, we were not able to conduct this analysis. We feel that this is a major data gap that should be addressed in future studies. If these data were available we may have been able to provide the HCFCD with projected probabilities of inundation of various wetland zones.

Potential Management Options

We used the results of our hydrological analysis to evaluate the need and feasibility of various management approaches to maintain surface water levels at the site during dry periods. We have provided a preliminary feasibility analysis of various approaches that could be used to reduce future surface water level declines at the site during drought periods. We decided to conduct this feasibility analysis even if our hydrological analysis indicated that the recent drop in surface water level was due to meteorological events and not any unusual site characteristics or hydrology. Our approach included focusing on ways to increase water input and facilitate distribution of surface water into Zone A swale areas, which appear most at risk of not meeting minimum design criteria. This was done primarily by reviewing common strategies to enhance wetland conditions and contacting a limited number of potential contractors with previous wetland restoration experience or surface and ground water distribution systems. We also conducted an assessment of any regulatory requirements and provided initial cost estimates for implementation of each approach. Specific engineering designs have not been included. Future refinement and implementation of any of these approaches may require the services of a professional engineer.

Results

Topography and Watershed Delineation

Due to the presence of complex topography, extensive forest canopy, and small differences in elevation it is very difficult to define the contributing watershed for Sub A-1. Neither the flow accumulation nor the flow direction analyses demonstrated any conclusive results (Figures 3 and 4). It was difficult to determine any distinct flow direction or accumulation based on the small study area as well as the TSARP DEM resolution. This limits the use of this method for mapping swale topography and hydrology.

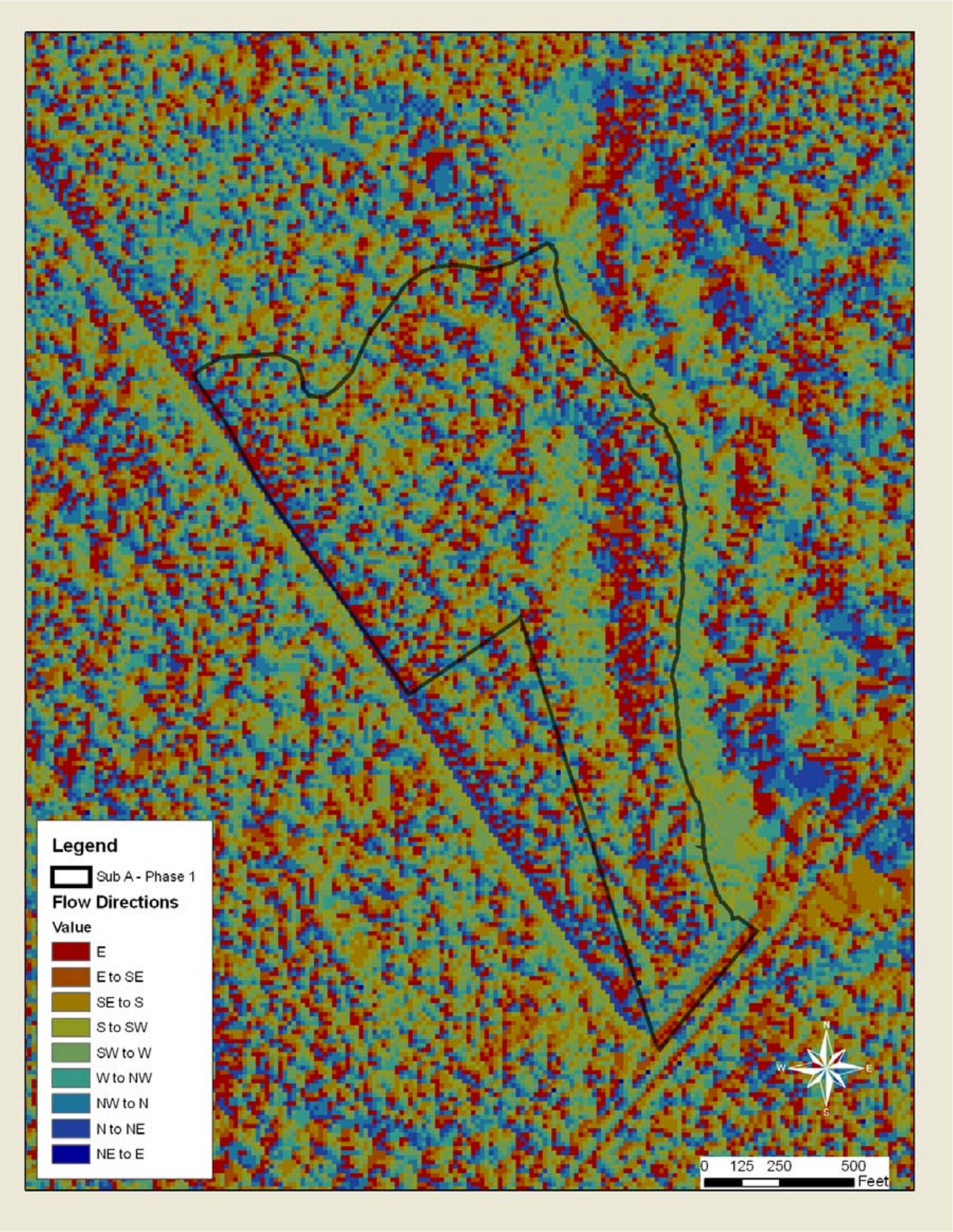


Figure 3. Estimated flow direction using the ArcGIS™ extension Arc Hydro™ and the TSARP DEM.

Figure 4. Estimated flow accumulation using the ArcGIS™ extension Arc Hydro™ and the TSARP DEM. Areas in white represent the areas most likely to accumulate surface water.

Based on our analysis of the TSARP DEM data using Arc Hydro™ we determined that the watershed for Sub A–1 parcel could include additional acreage not originally delineated in the original boundary (Figure 5). The west and south side of the Sub A-1 are clearly blocked by the railroad to the south and a raised berm to the west. The east side of Sub A-1 is delineated by the low relic formation. However, the areas immediately to the east and north of Sub A-1 could contribute to runoff into the project site.

Using the DEM data provided by the HCFCD we estimated the total acreage for Sub A-1 to be only 44.6 acres without the Woodforest Outparcel. This is contrast to the frequently cited figure of 47 acres. This may be due to certain non-wetland parcels (e.g. berms or railroad) being included in this estimate. Recent information provided by HCFCD indicates that the correct surveyed acreage for Subdivision A-1 is actually 44.62 acres (Wilkins pers. comm). We projected that by including the areas east and north of Sub A-1 the estimated contributing watershed could be as high as 65.13 acres (Figure 5). This included the original "47" (44.62) acre site, the Woodforest Outparcel (7.48 acres), an additional 3.64 acres located along the eastern border, and an additional 9.38 acres located along the northern border of the site. If however, you do not include the additional land to the north and east and only measure Sub A-1 and the Woodforest Outparcel, the total area is estimated to be 52.11 acres.

When we examined the DEM data we also identified a low lying area in the northeast section of Sub A-1, between two high areas, that could possibly drain the northeast section of area into the low relic formation on the east side of the subdivision. In addition, there appears to be a low area adjacent to the berm on the northwest side of Sub A-1 which extends north, past the Sub A-1 boundary. This could also provide a pathway for runoff to the north.

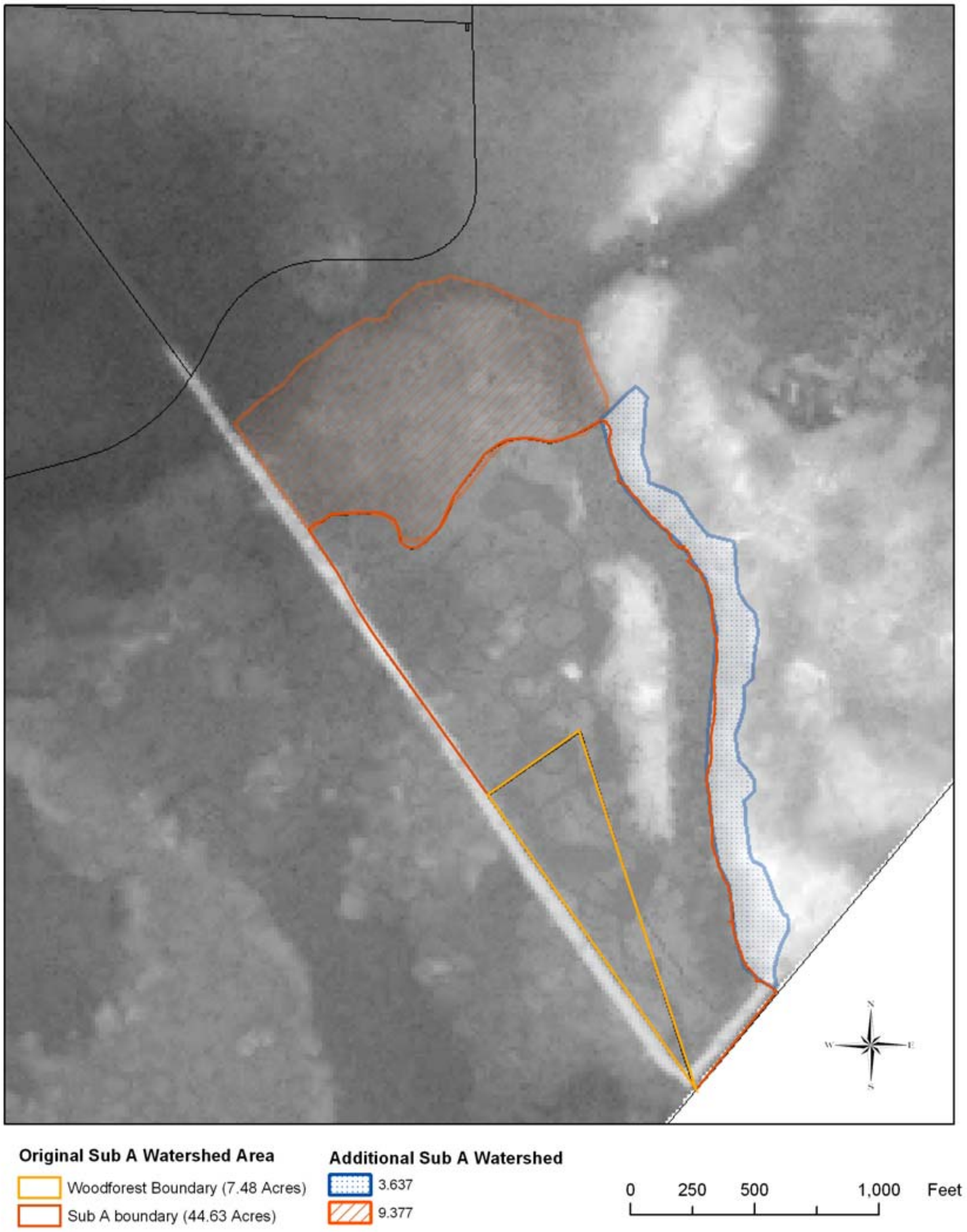


Figure 5. Estimates of the contributing watershed for Sub A-1 based on Arc Hydro™ analysis.The areas located along the northwest and eastern boundary of Sub A-1 could possibly contribute to the watershed.

Hydrological Analysis

Precipitation

For this portion of the study we evaluated monthly precipitation that was collected on the site and compared these results will a longer term precipitation record that has been determined at the site of George Bush International Airport (IAH). By comparing the shorter-term local precipitation with longer-term precipitation we are better able to put the results into context.

Local Precipitation

Precipitation has been recorded at one location on site (RG004001) from January 2003-March 2006. A summary of these data appear in the Table 2.

Table 2. Summarized values for precipitation at gauge RG004001.

	Rainfall (inches)				
	2003	2004	2005	2006	Average
January	2.2	5.2	2.7	3.3	3.3
February	4.3	0.7	6.3	1.7	3.2
March	2.1	0.3	2.7	0.1	1.3
April	1.4	5.8	1.1		2.8
May	0.0	10.0	6.7		5.6
June	11.2	14.4	0.9		8.8
July	4.1	3.6	7.5		5.1
August	4.2	1.8	5.2		3.7
September	6.9	2.4	2.7		4.0
October	6.4	2.4	1.5		3.4
November	9.7	15.1	2.0		8.9
December	3.4	2.1	5.0		3.5
Annual	55.6	63.7	44.3		
October-March	25.6	31.2	13.6		

Annual rainfall in 2005 was 10-20 inches lower than for 2003 and 2004. Most of this difference is accounted for in lower rainfall during the cool season (October – March) during 2005-2006. Monthly rainfall for the period of record is presented in the figure 6.

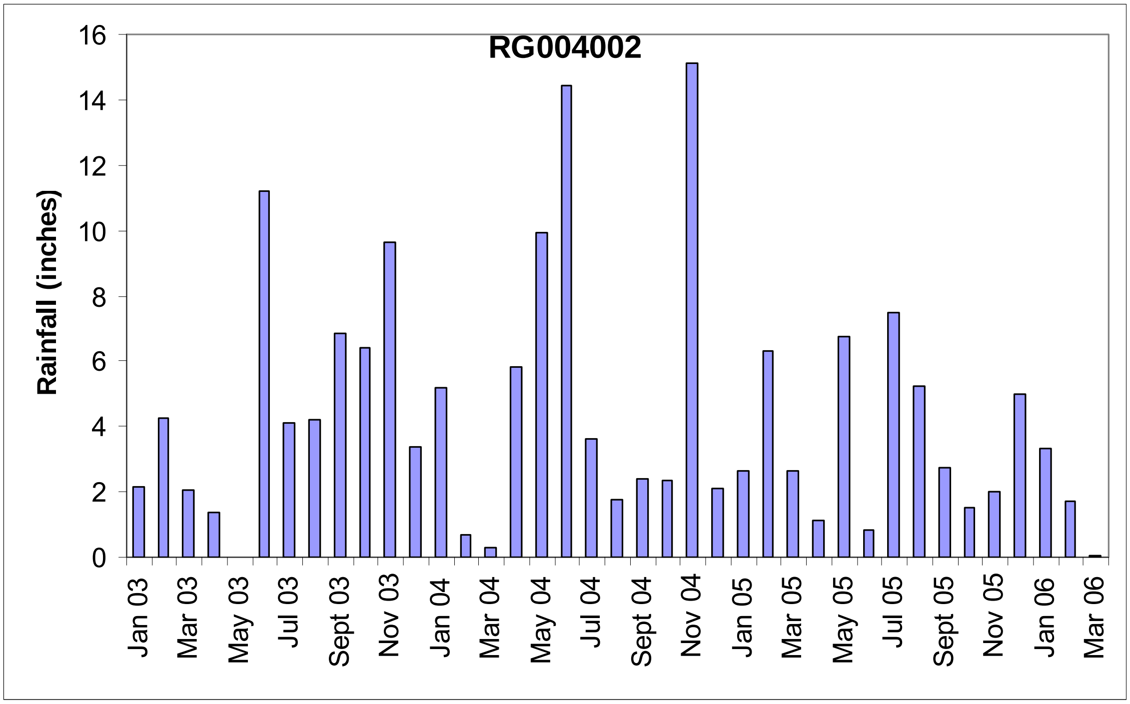


Figure 6. Monthly precipitation at gauge RG004002

Probably the most significant aspect of these data is the relatively low cool-season precipitation in 2005-2006. Cool-season precipitation in 2005 was 11-17 inches lower than for the two previous years.

Regional Precipitation Characteristics

Rainfall records for Greens Bayou were compared with the longer term record from the nearby George Bush International Airport (IAH). The 70 year average from this location is around 48 inches and 2005 was the 7th lowest rainfall year in the last 30 years (Figure 7). In Figure 8, annual cool season precipitation is presented for the last 30 years.

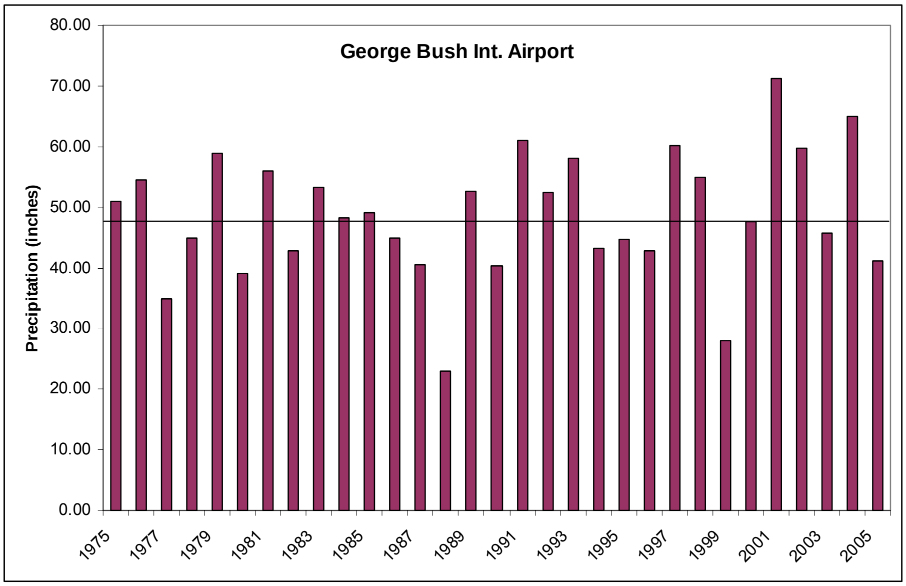


Figure 7. Annual rainfall at IAH from 1975-2005. The long-term average annual precipitation is 48 inches as depicted by the solid line.

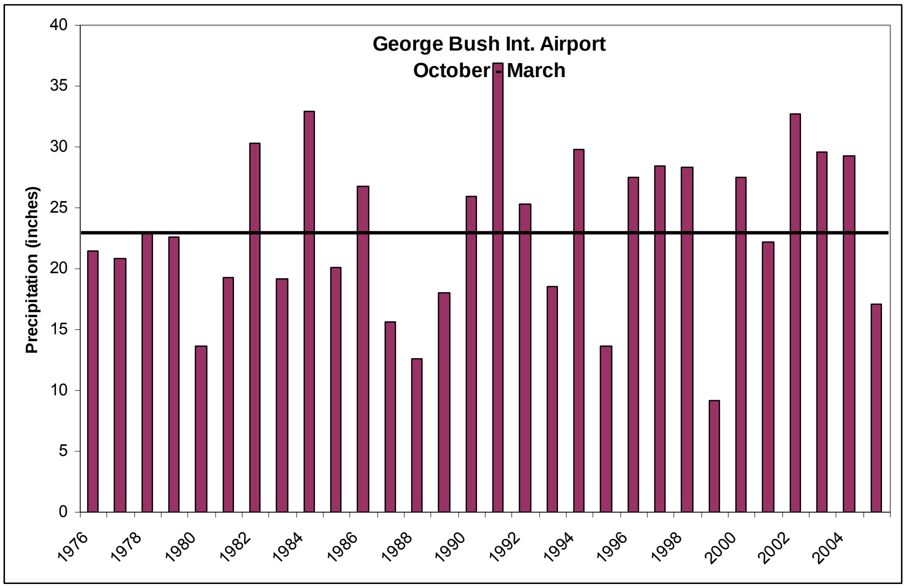


Figure 8. Cool season precipitation (October – March) at IAH. The 70 year average cool season precipitation is around 23 inches/year.

Our comparison of local with regional precipitation highlights the following facts. Average annual precipitation is around 48 inches per year. Annual precipitation at the site in 2005 was 44 inches. In comparison with the long-term average this is not terribly low. However, cool season precipitation on the site in 2005 (13.6 inches) was much lower than the regional average cool-season precipitation (23 inches) (Figure 8). Cool season precipitation of 13.6 inches or lower has only occurred at IAH on 4 occasions in the last 35 years.

Groundwater Analysis

In this section we evaluated shallow unconfined groundwater levels that have been collected for Subdivision A and B. Detailed information on groundwater data is available from around 2002 to 2006 at some of the sites.

Subdivision A

There were records for two piezometers (Piezo_R001008 and Piezo_R001002) that were evaluated. Piezo_R001008 is located nearby in Subdivision B. The record is most complete for Piezo_R001002, located in Sub A-1, and is presented below (Figure 9). These data highlight the seasonal nature of the water table for this location in Subdivision A. In the years 2002-2005 there was a repeatable pattern of a rising water table during the fall and winter, with the rise beginning in October or November and the decline around April. For the winter of 2005-2006 there was no rise in the water table. At this location (Piezo_R001002) the water table never reached the surface. The highest level attained was within 20 inches of the surface.

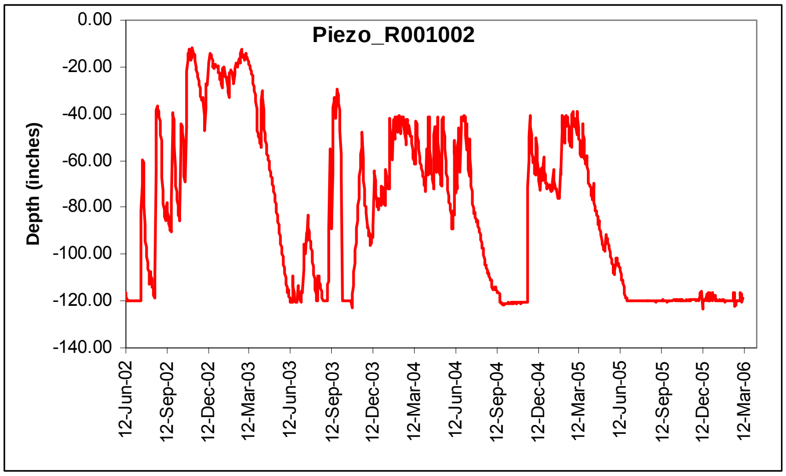


Figure 9. Shallow groundwater levels for piezometer R001002.

Subdivision B.

Data for 12 piezometers were provided for analysis. Of these data only two had a near complete record for 2003-2005. These are EastHbt and WESTHAB and are presented in the figure 10. Groundwater depth is between 50 and 20 inches below the surface. These data do not indicate an obvious trend for the period of observation, but there are indications that the winter of 2005-2006 is dryer than the previous two winters.

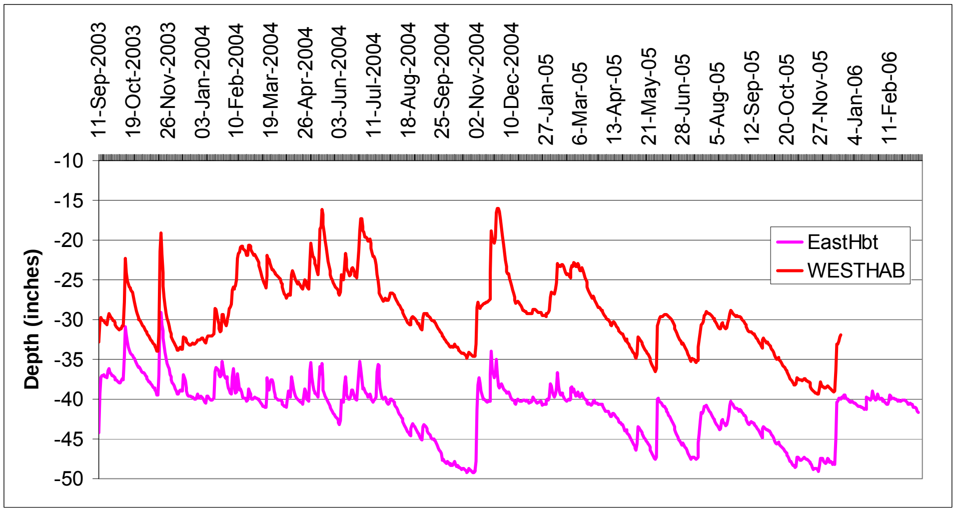


Figure 10. Shallow groundwater levels in subdivision B

At all of the piezometer locations, we see that shallow groundwater fluctuates with the seasons. In other words there is a strong seasonal change in ground water level which is very much dependent on precipitation. Not coincidentally groundwater levels were lowest in 2005 when cool season precipitation was 10 inches below normal. These data give no indication that there is a long-term decline in near-surface groundwater at this location.

In all likelihood, the groundwater being monitored at all locations is a shallow perched water table, with a restrictive layer close to the surface.

Surface Water Level

There are two water level recorders in Subdivision A. These are SWL_R001019 and SWL_R001020. Data for each are presented in the figure 11. The surface water level at each location exhibited roughly the same pattern with predictable annual fluctuations. Typically the pond, where the recorder was located, was dry at some point in the summer or late summer. For the period of record the longest extended dry period was the fall of 2005. The year 2006 is the driest period on record.

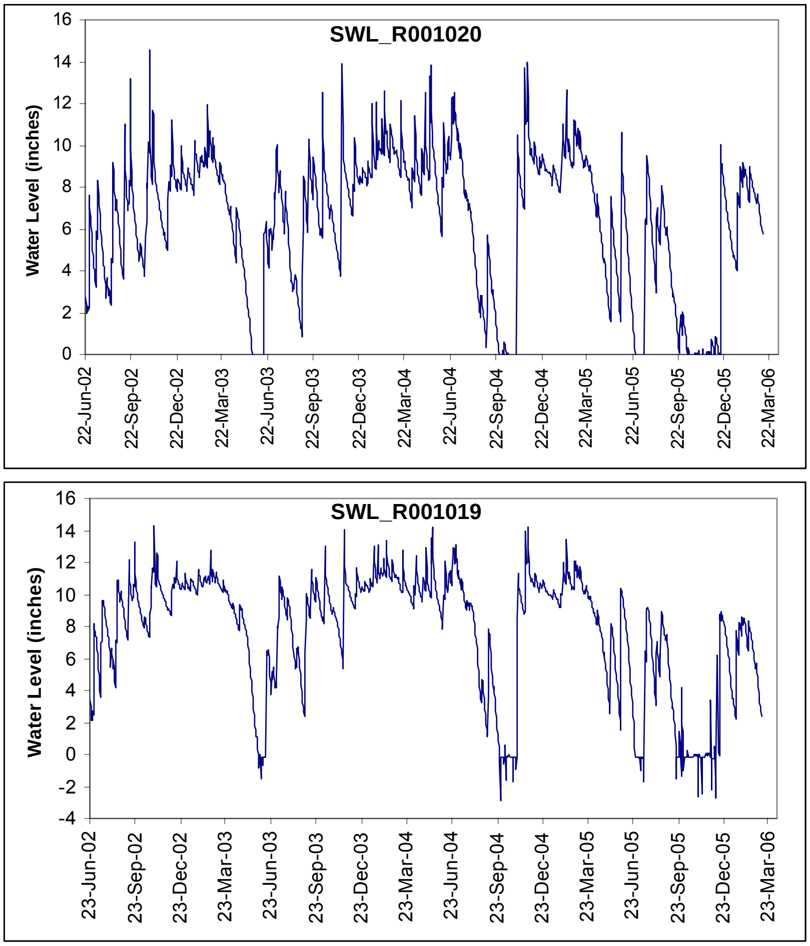


Figure 11. Surface water levels at two locations (SWL_R001019, SWL_R001020) in Subdivision A.

River Flow

We also examined the dynamics of streamflow for two adjacent bayous, Greens Bayou and Garners Bayou. These data are collected and archived by the US Geological Survey. The rational for doing this is to gain further insight into the natural climatic variability in the region and especially how the year of 2005 might compare to other years. Comparatively more data are available at Greens Bayou, where streamflow has been monitored since 1952. For Garners Bayou, continuous data are available from around 2000.

One obvious trend in streamflow at Greens Bayou is that of increasing flow (Figure 12), that is resulting from urbanization in the Houston area. The increasing streamflow trend makes it a little more difficult to compare 2005 with historical flow, but even with the increasing trend in flow, annual streamflow in 2005 was lower than the preceding four years. This is especially the case for flow during the cool season (Figure 13). Similarly, at Garners Bayou, annual and cool-season flow was lower in 2005. We present cool-season flow in Figure 14.

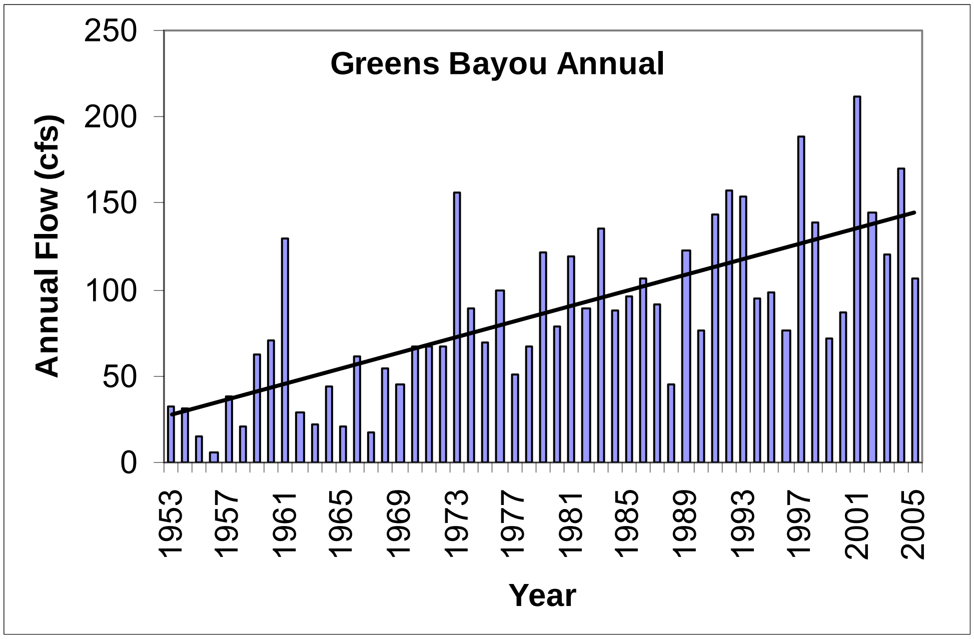


Figure 12. Annual flow at Greens Bayou since 1953 expressed in average cubic feet per second. The trend line in the figure highlights the increasing trend in flow as a result of urbanization.

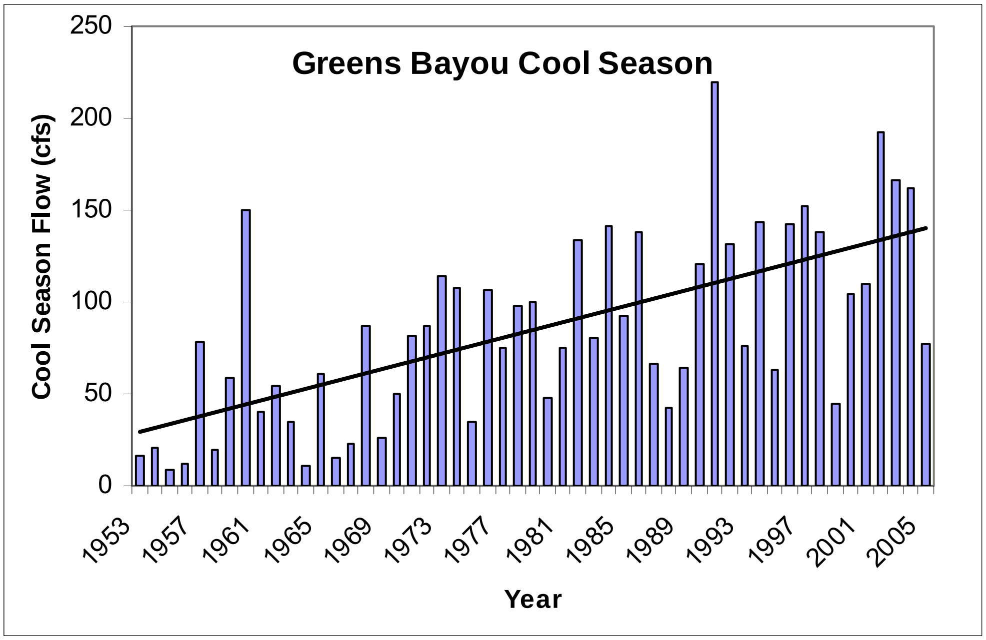


Figure 13. Average cool-season flow at Greens Bayou since 1953. The cool season is October – March.

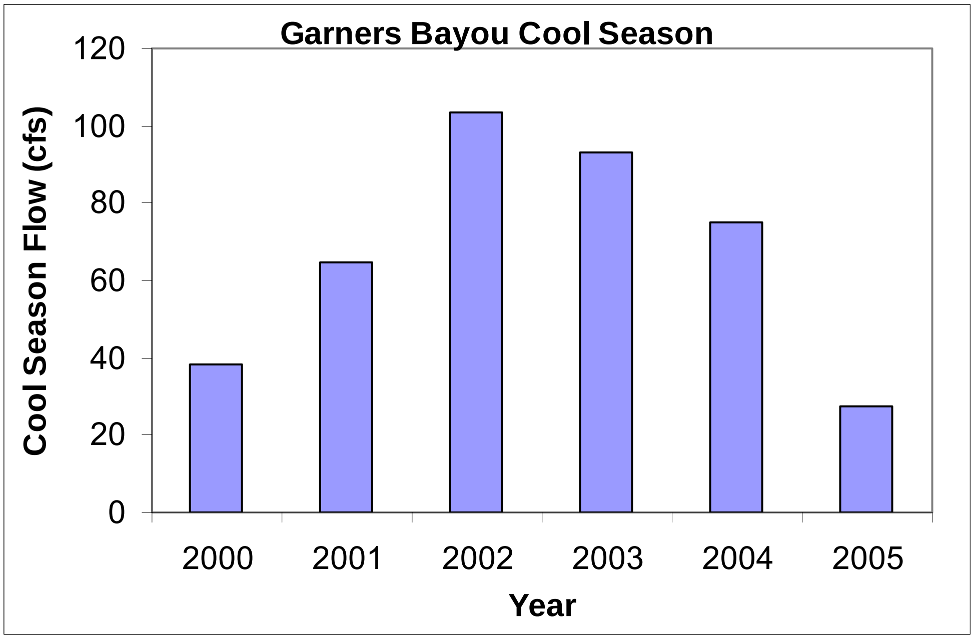


Figure 14. Average cool-season flow at Garners Bayou since 2000. The cool-season is October – March.

Projected Surface Water Deficits During Dry Periods.

Cumulative precipitation amounts during the wet season (October to March) in recent dry years were compared to long-term average values compiled for the IAH rain gage. As previously discussed we used DEM data based on recent LIDAR imagery, and processed using Arc Hydro™, to construct an estimate of the contributing watershed. To evaluate the range of management options we decided to include the range of potential contributing watershed estimates and their respective estimates of rainfall deficits. In review, if you include the area on the east and north side of Sub A-1 the watershed could include up to 65.13 acres. If however, you do not include the additional land to the North and only measure Sub A-1 and the Woodforest out parcel the calculated watershed is 52.11 acres.

Using these estimates of contributing watershed and precipitation we generated an estimate of the 6 month cool season precipitation deficit in terms of acre-ft and gallons. This was done to determine the overall deficit that would be expected during similar years and to help project the needed “irrigation” water to offset this deficit by proposed management options. We developed an irrigation deficit generating function for various levels of precipitation for a 65.13 and 52.11 acre watershed (Figure 15).

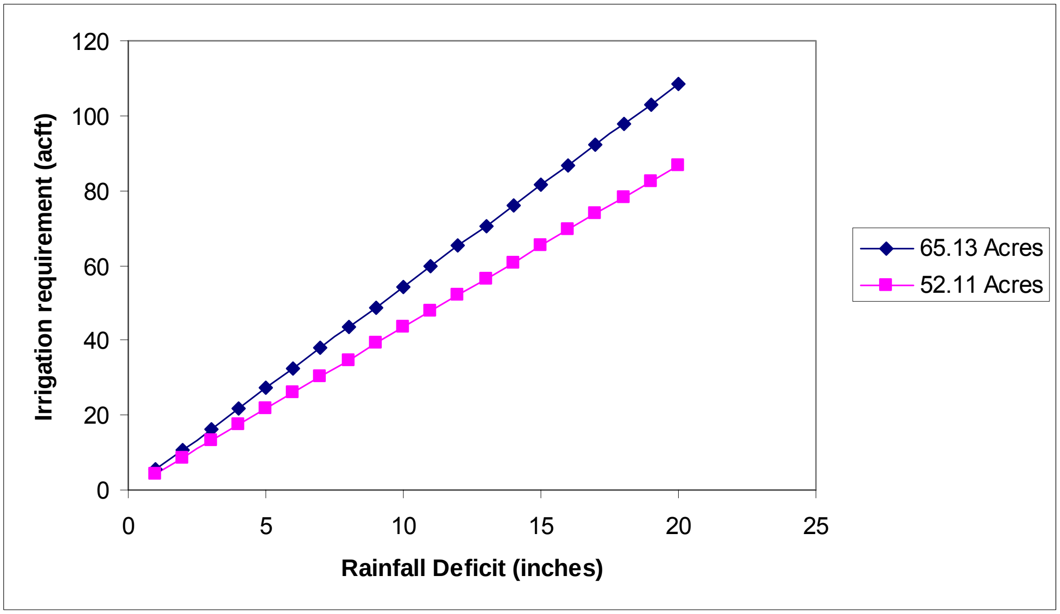


Figure 15. Irrigation requirements for the Sub A-1 mitigation site.

For example, using this relationship and assuming a 10 inch precipitation deficit as computed by using the difference between the long-term average condition the and 2005 cool season (6 month - October-March period) data, we projected that a total of 54.275 ac-ft or 17,685,563 gallons of water would be needed to offset this deficit for a 65.13 acre watershed.   Over a six month period this would translate to an average of about 98,253 gallons per day (gpd) or 4,094 gallon per hour (gph).   Also, we estimated that a total of 43.43 ac-ft or 14,150,080 gallons of water would be needed to offset the projected rainfall deficit for a 52.11 acre watershed. Over a six month cool season this would translate to an average of about 78,612 gpd or 3,275 gph.

Potential Management Options

Based on the results of the hydrological analysis we focused our management options on strategies that either increased the supply of water or redistributed existing water to expand coverage of zone A. Our feasibility analysis included evaluation of modification of existing topography and alteration of surface water hydrology. This included four major alternatives including 1) No active water management and amending the MOA to account for meteorological variation, 2) removal of small berms separating Zone A swales and wetlands from Zone B ponds, 3) increased irrigation using future impounded surface water or diversion of bayou water during dry periods, and 4) utilization of deep confined aquifer ground water for irrigation during dry periods using either wind or solar power. These options were selected based on several criteria including cost, regulatory requirements, sustainability, technological feasibility, and lack of readily available utilities.

Alternative 1. Amending the MOA to account for meteorological variation

Based on our analysis, it appears that the shallow groundwater, surface water levels and subsequent wetland vegetation are responding to seasonal and long-term trends in regional precipitation. We believe that the extent of wetland ponds and vegetation will continue to oscillate in response to these variations. Given this inherent variation that is recognized by wetland scientists and technical experts in both regulatory and natural resource agencies, it is not unreasonable to expect periods of time when a wetland will experience less than optimal conditions. A reasonable alternative is to consider the use of a long-term average or probability function for MSC target values. For example, in recent dry years the extent of target wetland vegetation has reached MSC periodically. Perhaps, using this approach the HCFCD with the concurrence of COE, could allow vegetation coverage to drop to 10 or 20% of its target value during drought periods. This would provide a realistic definition which recognizes the inherent variability associated with the hydrological and biological features of wetlands. Another justification for this approach is that even if we can assume we could develop an irrigation system to replace reduced precipitation during dry periods, it is highly unlikely we could do so under all drought conditions. Also irrigation would be problematic because the highest need typically occurs when the irrigation source water might also in short supply. One of the most critical obstacles is the shear amount of water that would be needed during dry periods, as we have defined it, to offset the lack of precipitation (up to 98,253 gpd or 4,094 gph).

Alternative 2 – Removal of small berms separating swales and zone A wetlands from primary ponds

On April 13, 2006 we conducted an onsite visit with Mr. Brian Krueger (ApachEco Environmental Services, Inc.). We contacted Mr. Krueger because of his familiarity with the overall mitigation bank wetland vegetation. During our site visit we found that at many locations there were elevated berms or sills between the main pond body (Zone B) and the finger swales (Zone A) that projected from them. We examined some of the pre-project planning documents and schematics and could not find any mention or depiction of these berms. We are unclear as to whether these were actually designed into the project or were later created by active earth movement or some natural deposition. Although we were not able to conduct follow-up detailed surveys due to bad weather, we estimate that these sills probably range from 4 to 12 inches higher than the water level in the main ponds during the dry period when we observed them initially. These berms could effectively isolate the interconnecting swales from main ponds during low water periods.

We requested a preliminary estimate from Mr. Krueger to conduct minor earth movement work at the site to increase connectivity from the ponds (Zone B) to the swales (Zone A) to increase the frequency of inundation. He provided preliminary estimate of construction costs necessary to increase the flow between the ponds and swales. He estimated that it would cost $3,000 to $5,000. Obviously without a detailed topographical survey of the elevated berm sites and specific plans or defined tasks it is difficult to quantify the exact costs. However, we believe that several major areas (berms) created a barrier between the two zones. The work estimate reflects mainly work needed to remove these berms to allow water to flow from the ponds into the swales.

Although we believe that reconnection of these swales might improve conditions and increase periods of inundation of Zone A, due to mass balance, the total amount of areas inundated in both Zone A and B using this proposed approach might be equivalent to not doing anything at all. Also, the increased surface area overall might lead to increased evapotranspiration. However, the overall reduction of water levels throughout the project site (Zone A and B) would be less perceptible versus the current scenario in which declines are more readily visible in the isolated swales of Zone A.

Alternative 3) - Increased irrigation using impounded surface water during drought periods

In the past the HCFCD had considered diverting water from a planned power plant discharge located northeast of Sub A-1, for use at the mitigation bank (Adams and Harris 2000a). As previously mentioned, they conducted an evaluation of irrigation needs for the overall mitigation project. They noted that there was a reasonable probability of dry conditions based on historical records. The reported that during these dry conditions the amount of wetland coverage would be naturally reduced. They concluded that the addition of irrigation flows from a proposed power plant effluent could supplement the hydrology to minimize the impact of dry hydrologic cycles. In their assessment they modeled different scenarios of land use for wetland development. For example they considered 1,300 total candidate acres, with a target range of 60-90% utilization, where up to 30% of an estimated 1.5 mgd of power plant effluent was diverted to the mitigation bank for irrigation use. They noted marginal improvements in desirable submergence probabilities (e.g. about 10% of the time you would have an additional 1 foot increase in depth) at maximum irrigation rates for submergence of marginal ponded, littoral and transitional zones. The power plant was never constructed so this option for the entire project was never implemented. In our conversations with HCFCD staff, it is highly unlikely that the facility will ever be built.

As previously mentioned we developed an irrigation deficit function for various levels of precipitation for a 65.13 acre watershed. Using this relationship and assuming a 10 inch precipitation deficit as computed using the difference between the long-term average and 2005 cool season (October-March), we projected that a total of 54.275 ac-ft or 17,685,563 gallons of water would be needed to offset this deficit for a 65.13 acre watershed. Over a six month period this would translate to an average of about 98,253 gallons per day (gpd) or 4,094 gallon per hour (gph) to offset this deficit. To offset this deficit, a high water storage and/or capacity automated delivery system would be needed.

One option that we considered to partially or totally offset this deficit was to utilize solar powered pumps to divert water from Garners Bayou either directly or through a previously planned storm water detention basin system. We understand through conversations with HCFCD staff, that the HCFCD is planning to install a regional storm water detention basin along Garners Bayou for flood damage reduction. HCFCD staff described how the system would basically function. During flood events when the bayou reached a certain height, the water would overflow into the basin via a spillway. Then, when the water levels receded, the basin would drain via an outflow pipe at the bottom of the structure back to bayou. If there is sufficient storage and capacity it is possible that some of this water could be stored and diverted to the wetlands during dry periods as well.

The estimated distance from the middle of Sub A-1 to the middle of the proposed detention basin area is approximately 0.5 miles or 2,640 ft. From the edge of the detention basin boundary to the northern edge of the Sub A-1 boundary the distance is 0.2 miles or 1,600 ft. Therefore, the length of pipe necessary to move surface water from the proposed detention basin or Garners Bayou would be range between 1,600 and 2,640 ft.

If the current ponds could not be utilized we would recommend building an additional holding pond (<200 acre-ft). It would receive water from the retention ponds during high rainfall and stream flow events and store the water to irrigate Sub A-1 in times of drought or low rainfall. Based on our evaluation of project maps, the additional irrigation pond could be located between the original detention basin along Garners Bayou and Sub A-1. If we assume that after a flood we start with a full 20 acre pond, 10 feet deep this would yield a maximum capacity of 200 ac-ft. We further assume that we have an average 6 month cool season ET rate of 17.5 inches (3 inches per month)(based on 1970 projections provided in Adams and Harris 2006b). Under a worst case “drought” condition, that is assuming no additional rain, we would expect to lose about 29 ac-ft of water during the cool season, leaving us with 171 ac-ft for irrigation at an elevation of approximately 48 feet. As previously mentioned for recent dry period conditions we would need about 54 ac-ft of water to irrigate Sub A-1 to make up for the deficit in rainfall. At maximum drawdown that would leave about 124 ac-ft of water in the basin at a projected 45 feet elevation. Given the projected excess storage, the HCFCD could use a smaller detention pond, e.g. 100 ac-ft (20 acres X 5 feet deep) instead. This would leave an excess of only 24 acres.

If you assume that water was drawn directly from Garners Bayou instead you would need to incorporate the following operational constraints. Since water levels vary depending on river stage and precipitation conditions it is difficult to estimate the total amount of lift necessary under all conditions. The USGS calculated base flow elevation for Garners Bayou is 37.07 ft and the lowest elevation at the proposed storm detention basin location is about 48 ft. Therefore you would need to vertically lift water 11 ft to reach the detention basin or base elevation. The average elevation for Zone A recorded at the Sub A-1 complex is approximately 54 ft. Given this information the pump would need to provide sufficient power to lift water at least 20 ft vertically during low flow conditions to reach the elevation of Sub A-1 wetlands. However, due to the great horizontal distance (1,600 - 2,640 ft) that the water would need to transported, a combination pump and gravity system would probably be needed. If you use this type of system you would need a minimum slope for the water to flow efficiently. For example, the minimum recommended grade however for 6 inch sanitary sewer line to allow for efficient movement of water is 0.6 feet/100 ft (TWUA 1981). Given these conditions, if water is drawn directly from Garners Bayou during base flow conditions the initial vertical height of the pump would need to be 15.8 feet above the target elevation of 54 feet, or 69.8 feet. This translates to an initial vertical lift of 22 ft (69.8-48 ft). If water is drawn from the detention basin the initial vertical lift needed under best case conditions would be 25 ft (69.8-45 ft).

We would recommend that the conveyance system use 3-6 inch enclosed pipes to reduce evaporation. This may still require some limited excavation along the 0.5 mile conveyance route. In design principle this would operate much like a wastewater collection lift station. We would recommend against using an open channel conveyance system due to various operational hazards and drawbacks including increased water loss due to evaporation, and less predictable and potentially hazardous re-routing of the Garners Bayou channel during flood events.

The highest capacity solar powered pumps that we were able to locate were rated for 25,000 to 40,000 gallons per day. The highest production rate for winter periods is probably 25,000 gallons per day. Therefore, three to four units would probably be needed to move sufficient water to make up for the deficit 98,253 gallons per day. Including installation of the pumps, solar panels, and the associated conveyance systems, the total costs for this option could run from $20,000 to $60,000. If in the future we can locate a larger capacity single pump system, this estimate could be reduced substantially. This cost does not include construction costs for any additional dedicated reservoir system, or any support structure needed to elevate the pump to the desired target level. There may other safety and operational issues involved with the location of the facility. It would need to be placed in a structure designed to withstand flood conditions (water levels and associated flows). Our cost estimate does not include permitting fees and processing. Final feasibility analysis and design of such a system would probably require the services of a professional engineer.

The permitting of such a pond and associated conveyance system might fall under what is called a "Wildlife Management Exemption". In 2001, the Texas State Legislature added wildlife management as an exempt use of surface water. Under this use, you may build on your own property a dam or reservoir that normally holds no more, than 200 acre-feet of water. This reservoir must also be, on *qualified open-space, land,* as defined by Section 23.51 of the Texas Tax Code. Under 23.51 a *"Qualified open-space land means land that is currently devoted principally to agricultural use to the degree of intensity generally accepted in the area and that has been devoted principally to agricultural use or to production of timber or forest products for five of the preceding seven years or land that is used principally as an ecological laboratory by a public or private college or university. Qualified open-space land includes all appurtenances to the land. For the purposes of this subdivision, appurtenances to the land mean private roads, dams, reservoirs, water wells, canals, ditches, terraces, and other reshapings of the soil, fences, and riparian water rights." (State of Texas 2006).*

We contacted and discussed with Kathy Hopkins from TCEQ's Water Rights Permitting Team on May 17, 2006, the feasibility of diverting water from Garners Bayou to provide additional hydrology to irrigate Sub A-1 in times of low rainfall or drought conditions. We mentioned that we were working under contract to the HCSWCD who was under contract to HCFCD. She explained that HCFCD would have to apply for a surface water permit from TCEQ and establish an agreement with the City of Houston (COH), one of the primary surface water rights holders in the basin, to allow HCFCD to divert water from Garners bayou. Any alteration of flow from Garners Bayou, and therefore Greens Bayou, could affect the overall hydrology of the lower San Jacinto River for which the COH has surface water rights. Ms. Hopkins mentioned that a similar project had been considered by HCFCD in the past. It would have irrigated a wetland habitat area near or at Aldine High School using storm water. She mentioned that her contact was Mr. Glen Laird. According to Ms. Hopkins, this project may fall under the Wildlife Management Exemption. To apply for this exemption and obtain more information the HCFCD would need to consult with TCEQ (2006).

Alternative 4) - Utilization of deep confined aquifer ground water for irrigation during drought periods

The final option we considered was the installation of an onsite wind or solar powered groundwater based irrigation system. We quickly concluded that the use of windmills would probably be difficult to implement due to the heights of surrounding trees. For example, according to the SWCA (2006b) report, the canopy cover for trees at least 20 ft in height is 70% within the PFO delineated area. The report did not give any other height information, but the following species of trees exist at the site:

Red Maple
Water Oak, Willow Oak, Shumard Oak
Loblolly Pine
Yaupon
Rough-leaf Dogwood
Sweetgum
Chinese Tallow

Many of these are known to grow larger than 20 ft tall and some as high as 50 ft. Based on this information we believe that the windmill option is unfeasible.

The other option we considered was the installation of an onsite solar powered groundwater irrigation system. For illustration, we have provided an image of a groundwater irrigation system that is currently installed at the University of Houston at Clear Lake, Environmental Institute of Houston 37 acre facility (Figure 16). It consists of a low volume solar powered groundwater irrigation system. This low volume pump is used to irrigate a small wetland area (1-2 acres). In addition, the HCFCD currently has two water wells located in their Subdivision B area. These are located in the southeast and northeast corner of the area. During 2005 14,000 gpy, (38 gpd, 3 gpm) was pumped from the 6 inch electric powered well. During the same year, 733,000 gallons (2,008 gpd, 167 gpm) was pumped from the 8 inch northern well.

To address the project needs we evaluated a larger system for the Sub A-1 site. To insure a reliable source of irrigation water we would recommend drilling to the deeper confined aquifer, documented in the past to be generally 100 to 150 ft deep in the project area. The average yield from 3 inch diameter casing water well drilled within the region is 39,038 gpd (HGCSD 2006b). This option has the benefit of being operationally simpler and cheaper to use, and excludes the need to install an elaborate conveyance system depending on the location of the well. The highest capacity solar powered pumps that we were able to locate were rated for 25,000 to 40,000 gallons per day (Solar Water Technologies (2006).

Figure 16. Solar powered irrigation system installed at the University of Houston Clear Lake campus.

The highest production rate for winter periods is probably 25,000 gallons per day. Therefore, at least three to four units would probably be needed to move sufficient water to make up for the deficit 98,253 gallons per day. Including installation of pumps, solar panels, and the associated well, the total costs for this option could run from $60,000 to $75,000. If in the future we can locate a larger capacity single pump system, this estimate could be reduced substantially. This estimate does not include permitting application and processing costs. That information is provided below. Final feasibility analysis and design of such a system would probably require the services of a professional engineer.

The HCFCD Greens Bayou Wetlands Mitigation Bank is location with the jurisdiction of the Area 3 of the Harris Galveston Coastal Subsidence District (HGCSD) 1999 Regulatory Areas within census tract 232200. From a regulatory stand point, the permitting of such a solar powered groundwater well would require a permit from the Harris County Subsidence District. Since there is surface water in the general area, the HCFCD must demonstrate that it is less feasible or desirable to use this as a source. All groundwater users using greater than 10 million gallons per year (mgy), (excluding agricultural use) in Area 3 are required by the HGCSD's 1999 District Regulatory Plan (Amended 9-12-01) to complete a Groundwater Reduction Plan (GRP) to identify alternate sources of water according to the requirements within the plan. The requirements include:

1. By 2010 – Reduce and maintain groundwater withdrawals to no more than 70 % of permittee's total water supply
2. By 2020 – Reduce and maintain groundwater withdrawals to no more than 30 % of permittee's total water supply
3. By 2030 – Reduce and maintain groundwater withdrawals to no more than 20% of the total water supply.

All users which pump less than or equal to 10 mgy (excluding agricultural use) in Area 3 must convert to 80% alternative water when it is available. Based on conversations with Tom Michel, a representative of HGCSD, the Greens Bayou Wetlands Mitigation Bank would not qualify as agricultural use since the proposed irrigation would not be used for plants grown for food or fiber for human or animal consumption. Wetlands, lakes, etc. do not qualify under the agricultural use. He further stated that there are a lot of questions regarding alternate surface water use that would need to be answered before HGCSD would grant a permit. An entity can apply for a well permit online at: http://www.subsidence.org/Forms/frmNewWell.aspx. A fee of $100 applies to each application.

Conclusions and Recommendations

Hydrological Analysis

We have examined a number of hydrological variables including (1) regional and local precipitation (2) local groundwater (3) local pond levels and (4) regional streamflow. An examination of all of the hydrological trends points to the same phenomena—below average rainfall, particularly in the cool season has lead to lower than average levels in the groundwater, surface water and bayous in 2005. Cool-season precipitation in 2005 was at least 10 inches below normal and as much as 17 inches lower than the previous years.

In terms of the specific objectives of this project we conclude the following

Objective 1: to determine whether water levels in the wetland mitigation site are actually dropping as previously reported.

Groundwater and surface water levels at the Greens Bayou Sub A-1 wetlands have decreased since late summer of 2005.

Objective 2: to determine if these declines are extreme or below projected levels based on local meteorology and hydrology.

These drying conditions are associated with below average precipitation, particularly since September 2005. Precipitation in 2005 was below average but only by about 4 inches. The real factor in the low pond levels is small amount of cool season precipitation.

Objective 3: what are the mechanisms responsible for the declines?

As noted above the most important driver was the abnormally low amounts of cool-season precipitation. Cool season precipitation (October – March) for 2005-2006 was only 13 inches. This is 10 inches below the long-term average at IAH. The recurrence interval for dry years like this would be about 1 year in ten.

Potential Management Options

Our final 4th objective was to determine whether there are there are feasible approaches that can be used to reverse or reduce the observed decline in surface water levels and the spatial extent of Zone A wetlands. Overall we do not believe that there is a systematic long-term trend in declining surface water levels or wetlands at the site that can be attributable to any unusual hydrology. Based on our observations, the water levels in the wetland area are responding to fluctuations in meteorology in a manner typical of most wetlands. Natural wetlands by their definition and nature experience periods of inundation and dryness. We do not recommend implementing any additional active management measures at this time. We recommend instead that HCFCD implement *Alternative 1*, that is meet with the COE as necessary to provide them with a copy of our analysis that documents this natural fluctuation. If the COE is receptive a proposed reasonable approach would be to adopt a meteorological/hydrological based MOA that incorporates this natural variability. For example, MSC could be reduced under drought situations in recognition of natural variability in meteorology and hydrology. This could also be expressed in terms of probability based exceedance criteria, which is a common approach used in environmental regulations and flood management hydrology. Another approach would be to adopt a long-term average or median MSC which incorporates long-term variability. Again similar environmental criteria have been routinely used in water quality permitting and standards evaluation. However if the HCFCD proactively desires to enhance current conditions to insure desirable percentages of wetland species, we offer the following recommendations.

Alternative 2 – Removal of small berms separating swales and Zone A wetlands from primary ponds (Zone B)

We believe that management alternative 2 will only marginally reduce the probability of aerial exposure of Zone A wetlands. This is due to the fact that no new water is introduced into the system and instead existing water is spread out more evenly between existing ponds and swales. This option may actually increase evapotranspiration by increasing the amount of surface area of the continuous Zone B ponds while simultaneously decreasing overall depth in Zone A and B. Selected swale areas might not evaporate as quickly, but the overall net affect would be negligible or in fact reduce the overall amount of water in Zone A and B wetlands. One benefit of this approach would be increased connectivity and habitat value for aquatic life in Zone A swale areas. However, some species of amphibians that thrive in isolated vernal pool habitat, which the isolated Zone A swales currently provide, might benefit from the lack of fish predation. One more additional feasible sub-alternative would be to incorporate this management measure with alternatives 3 and 4, which is augmentation of water supply. This would provide an overall better solution to maintaining Zone B according to the current MSC.

Alternative 3) - Increased irrigation using impounded surface water during drought periods

This alternative is technologically feasible, but can be potentially the most costly option if you include unknown costs associated with any modification or building of additional storm water detention ponds. Depending on configuration it will also be dependent on coordination and construction of storm water detention basins. There may other safety and operational issues involved with the location of the facility. It would need to be placed in a structure designed to withstand flood conditions (water levels and associated flows).

It can probably provide most if not all the water needed to offset the projected deficit of water during dry periods. However, during extreme long-term drought conditions, it too may not contain sufficient capacity to remediate low surface water levels in Zone A of Sub A-1. Acess to the site during drilling and for transport of heavy machinery and trucks may be problematic due to the small roads and unpredictable weather conditions that make all roads impassable. Final feasibility analysis and design of such a system would probably require the services of a professional engineer.

Alternative 4) - Utilization of deep confined aquifer ground water for irrigation during drought periods

We believe that this option is technologically feasible, but potentially costly as well. Acess to the site during drilling and for transport of heavy machinery and trucks may be problematic due to the small roads and unpredictable weather conditions that make all roads impassable. A major obstacle may be the permitting process required by the HGCSD. Since available surface water may be present in Garners Bayou, HGCSD may be reluctant to grant a groundwater well permit. In addition, even if a permit were granted it may still face regulatory obstacles. For example, a Groundwater Reduction Plan (GRP) to identify alternate sources of water would still be required. Final feasibility analysis and design of such a system would probably require the services of a professional engineer.

If this alternative is implemented we suggest instead that a smaller scale demonstration solar well for supplementing water levels be installed at first. This would extract less water and although it would only partially offset the water deficit during dry periods, it would allow HCFCD to determine whether wetland surface water augmentation with groundwater is a viable option given the current regulatory requirements. One modification that may enhance this limited groundwater augmentation system is the creative use of a distribution system. For example, water could be strategically delivered to the now isolated swales in Zone A. This sub-alternative may require that berms are not removed as discussed under alternative 2.

Future Monitoring and Research Needs

We strongly recommend that HCFCD consider a more comprehensive wetland monitoring program including more additional groundwater monitoring locations, runoff monitoring (weirs, gages), soil water measurements, installation of more comprehensive (precipitation, evaporation, wind speed and direction, solar radiation, humidity, air temperature) meteorological weather stations, and execution of detailed surveys of swale and pond topography and associated water depths. This information would be used to develop a comprehensive catchment model that could be used to predict the response of hydrology, wetland zone spatial coverage, plant communities, and success of meeting MSC in response to varying meteorological conditions. An associated GIS based model using this information could also be used to visually depict and estimate 2D and 3D features such as water levels, pond depths, and vegetation wetland zone fluctuations in response to vary precipitation.

In addition to meteorological and hydrological monitoring, we recommend expansion of existing water quality and biological monitoring network within the aquatic environment. One of the major functions of wetlands is to provide habitat to aquatic and semi-aquatic organisms and the purification of water that may eventually drain back to adjacent streams. Suggested components of this monitoring should include installation and long-term operation of automated continuous water quality measurement instruments that measure temperature, dissolved oxygen, pH, conductivity, turbidity and chlorophyll-a. In addition, measurement of atmospheric, wetland surface water, and runoff nitrogen concentrations would help quantify the function and value of these created wetlands in relation to the urban environment of Houston. Due to ongoing air pollution problems and continued land development, the value of remaining and created wetlands needs be carefully evaluated in terms of overall watershed protection and planning.

One additional monitoring issue that we have encountered is the limited access to the site during wet periods. Although not considered part of this scope of work, one recommendation that HCFCD may want to consider for future monitoring and assessment would be the deployment of automated surveillance camera systems that could be programmed to take digital pictures of the site at various intervals for documentation of wet and dry periods. As an added benefit, if sufficient numbers of these cameras were deployed, they could also be used for documentation of wildlife use at the site.

We believe that full implementation of these additional monitoring and research recommendations would greatly enhance the ability of HCFCD to proactively manage Sub A-1 of the wetlands mitigation bank, and provide them with useful information for designing future sites We estimate costs associated with full implementation of most of the major components discussed would be approximately $40-60K per year for a total of 4 years.

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