FINAL REPORT

Freshwater Wetland Functional Assessment Study

Contract No. 582-7-77820

Chicken Road study site, Brazoria National Wildlife Refuge

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May 2010

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Executive Summary

Palustrine wetlands are the fastest disappearing wetland type in coastal Texas, and development pressure is only expected to increase in the area around Houston and Galveston Bay. The cumulative impact of wetland losses could have substantial detrimental impacts on the hydrology, water quality, and general ecosystem health of regional aquatic systems, including Galveston Bay and its tributaries. Although freshwater wetlands are abundant in the 32 quadrangle area around the bay, few quantitative data exist to evaluate the pollutant reduction and flood storage effectiveness of these coastal prairie wetlands (CPWs). In fact, there is little hydrologic or water quality data on CPWs in general. Such information is critical for developing linkages between wetland functions and the environmental integrity of jurisdictional waters such as Galveston Bay.

To better understand the value of these wetlands, our project assessed their water storage and water quality functions by conducting field studies and constructing functional assessment models. The study was designed to: (1) evaluate the capacity of CPWs to store water from precipitation events; (2) evaluate the water quality function of CPWs; and (3) develop water quality and flood storage functional assessment models that can be applied through a Geographic Information System (GIS) to similar wetlands within the study area. The results of this study will provide a basis for estimating their cumulative value on a regional scale.

CPWs are a component of the globally imperiled Coastal Prairie Ecosystem (USGS 2000). According to our analyses of NWI data, there are 10,349 palustrine wetlands within the 32 quad study area. The total area covered by these wetlands is approximately 512 km^2; or 9.5% of the 5,376 km^2 study area. When their catchment areas are included, they cover 28.9% of the landscape. On an areal basis the largest CPW class is emergent (42,313 ha, 83%) followed by forested (4,987 ha, 10%), unconsolidated bottom (2,080 ha, 4%) and scrub/shrub (1,735 ha, 3%). Two thirds of the total wetland area is classified as temporarily or seasonally flooded, and much of the remaining third are classified as “farmed” and are primarily the large tracts located in Chambers County. Although the typical CPW is small (<1 ha), we estimate that their total volume is approximately 47,000,000 m^3 (38,535 ac-ft).

We selected six CPW sites for a detailed study of water quality and hydrology, and later randomly selected additional sites to further evaluate wetland functions. At each sites we installed water level recorders, and at some sites tipping bucket rain gages and weirs were also

installed. From these data we described each site's hydroperiod and constructed water budgets that model runoff, evapotranspiration, and storage volumes. Runoff acounted for an average of 48% of water entering the wetlands, ranging from 5.9% to 89.5%. Runoff estimates were highly variable both temporally and seasonally and were strongly affected by catchment size and climate. Potential evapotranspiration losses (as a percentage of total water losses) ranged from 43% to 94% with an average of 69%, supporting assumptions that this is the major pathway for wetland water losses. Despite drought conditions for much of the study, all six wetlands overflowed during the monitoring period. The average duration of outflow was 27 days. On a volume basis, the six wetlands stored an average of 82% of incoming water and discharged 18%. Patterns of storage and discharge were strongly influenced by antecedent moisture conditions. These results, combined with the preliminary water level data from six additional CPWs, indicate that discharge appears to be a regular feature of most CPWs.

Surface water quality sampling was conducted on approximately 9-10 dates at the initial six CPWs. We also collected and analyzed precipitation as their primary source. Inorganic nitrogen levels, which can be particularly high in precipitation, has been linked to eutrophication of coastal waters in the Gulf of Mexico and to algal blooms in Galveston Bay. We found that each wetland was capable of reducing incoming nitrate-nitrogen by approximately 98%, regardless of land use, hydroperiods, or other model variables. Ammonia in wetland surface water was also significantly lower than in precipitation. Phosphate-phosphorus was not statistically different in wetland surface water than in precipitation. As expected, total nitrogen and total phosphorus levels were higher in CPWs than in precipitation due to increases in the organic component of these nutrients. The export of fixed carbon and nitrogen to estuaries and other receiving waters is acknowledged as a valuable wetland function (i.e. food chain export/support) and these data confirm that coastal freshwater wetlands lower inorganic nutrient concentrations and produce organic material both to support local biota and for export to receiving waters. We found no evidence of nutrient saturation or persistent water quality degradation at the twelve wetlands.

To model water quality and water storage function, we developed six conceptual models that predict a CPW's capacity for (1) water storage, (2) nitrate removal (3) ammonia removal, (4) phosphorus removal, (5) heavy metal removal, and (6) removal of organic compounds. The models were derived from literature reviews and are largely theoretical. They do not *measure* water quality function but rather, provide a *relative estimate of* the type and degree of functions that would be gained or lost in wetland conversions. The six models were comprised of variables that were obtained and applied through GIS and applied to all palustrine wetlands in the 32-quadrangle study area. They included geomorphic variables (volume, relative catchment size), hydrologic variables (water regime), soil characteristics (clay content, pH), vegetation (density) and land use.

Application of the models to the 10,349 CPWs resulting in the following generalizations: (1) Most of the models resulted in a normal or nearly normal distribution. (2) The water storage model was skewed toward lower function by approximately 1,000 wetlands that are excavated or impounded. Removal of these wetlands resulted in a nearly normal distribution of water storage model values. (3) The phosphorus, ammonium-N and heavy metal models indicated that CPWs have a moderate capacity for retaining/removing these pollutants.(4) The organic and nitrate models predicted that many CPWs have a high capacity for removing these pollutants. We were able to compare the nitrogen and phosphorus models to our field sampling; however we did not have evidence of organic or heavy metal loading with which to evaluate these models. Most of the precipitation and wetland samples analyzed for organics and heavy metals were below analytical detection limits. There was considerable disagreement between soil characteristics as mapped in soil databases and as evaluated in the field; however LiDAR derived elevations, water regimes, and land use characterizations were more reliable.

A. Introduction

Sabatia campestrus and *Limnosciadium pinnatum*, LeConte wetland, Chambers County, 27 April 2008

Project Overview

Palustrine wetlands in the Houston-Galveston area are being destroyed at an alarming rate, in part due to the recent Supreme Court rulings that removed many small wetlands from federal jurisdiction. They are the fastest disappearing wetland type in the area, making up almost 36% of wetland permits issued in Texas between 1991 and 2003 (Brody et. al. 2008). In Texas, population by shoreline kilometer was projected to double between 1960 and 2010 to 1,216 people per km, which makes the Texas Coast one of the fastest growing coastal regions in the country (Culliton et al. 1990). Inevitably, the increases in tourism, recreation, commercial projects, and residences will accelerate wetland alterations and may have negative impacts on local watersheds. The cumulative impact of wetland losses could also have substantial detrimental impacts on the hydrology, water quality, and general ecosystem health of nearby aquatic systems, particularly in Galveston Bay and its tributaries.

Few quantitative data exist to evaluate the pollutant reduction and flood storage effectiveness of coastal prairie wetlands. In fact, there is little hydrologic or water quality data on freshwater coastal prairie wetlands (CPWs) in general. Such information is critical for developing linkages between wetland functions and the environmental integrity of jurisdictional waters such as Galveston Bay. To better understand the cumulative value of these wetlands, our project assessed their water storage and water quality functions. The study was designed to: (1) evaluate the capacity of freshwater wetlands to store water during precipitation events; (2) evaluate the role of freshwater wetlands in maintaining water quality; and (3) develop water quality and flood storage functional assessment models that can be applied through a Geographic Information System (GIS) to similar wetlands within the study area. The results of this study will provide a more quantitative understanding of how CPWs perform water storage and water quality functions, and provide a basis for estimating their cumulative value on a regional scale.

This report summarizes project activities for the period August 22, 2007 through December 31, 2009. It includes an evaluation of the hydrologic and water quality monitoring at 12 field sites that are considered representative of wetlands throughout the study area. The report also describes the methods, results, and error associated with GIS based water storage and water quality models that were applied to over 10,000 wetlands in the study area.

Study Design

This project consists of four distinct components: 1) development of functional assessment models for water quality and water storage; 2) GIS application of these models; 3) hydrologic monitoring of selected CPWs; and 4) water quality monitoring of selected CPWs. These components and associated deliverables are related as shown in Figure A1. Briefly, conceptual models for water storage and various water quality functions were developed based on literature information. Field sampling provided data to evaluate and modify the models and to increase our understanding of the function and variability of CPWs. Models were finalized and applied to all CPWs in the study area. These results were then summarized and evaluated with respect to their distribution. To evaluate the error associated with the models, we compared field data on the model variables to data predicted using the GIS databases and algorithms. Final deliverables include electronic maps, databases, reports, and manuscripts.

Study Area

The study area is composed of 32 USGS 7.5-minute quadrangle maps (Fig. A2), which includes the 30 quads analyzed by White et al. (1993). Wetlands included in this study are all palustrine, and include ponds, emergent, scrub/shrub, forested and aquatic bed classes as mapped in the National Wetland Inventory (NWI) database.

Coastal Prairie Wetlands (CPWs) are a component of the globally imperiled Coastal Prairie Ecosystem (USGS 2000). This southernmost extension of the tall-grass prairie is a mosaic of depressional wetlands, and flats interspersed with pimple mounds (Moulton and Jacob 2000). Smeins et al. (1992) described the area as a “clay plain” due to the impervious soils and lack of incised drainageways. The geology of the study area is Pleistocene, Beaumont Formations characterized by fluvial-deltaic sediments. The Beaumont Formation includes meanderbelt sand, floodplain-overbank mud and mud veneer, and circular to irregular depressions on distributary-fluvial sands which appear to be remnants of abandoned channels (McGowen et al. 1976). The relict depositional topography consists of meanderbelt ridges with local relief of 1.5 to 3 m and lower floodbasins. The meanderbelt ridges have loamy and sandy soils, pimple mounds, undrained depressions, and segments of meandering stream channels (Aronow, S., 1986). The lower floodbasins have clayey and loamy soils that have high shrink-swell potential.

CPWs are characterized by microtopography and complex patterns of inundation that promote diverse plant communities. Some of these freshwater wetlands originated from ancient channel scars that have been reworked by aeolian erosion, while other “gilgai” wetlands are formed by the vertical action of clay soils (Sipocz 2002). The dominant soil types are Vertisols and Alfisols that developed over Pleistocene deposits flanking the Gulf coast. These wetlands have diverse and locally variable hydrology, ranging from temporarily flooded to intermittently exposed. Freshwater CPWs tend to have small watersheds, seasonal inundation, intermittent outflows, and hydrology driven largely by precipitation and evapotranspiration.

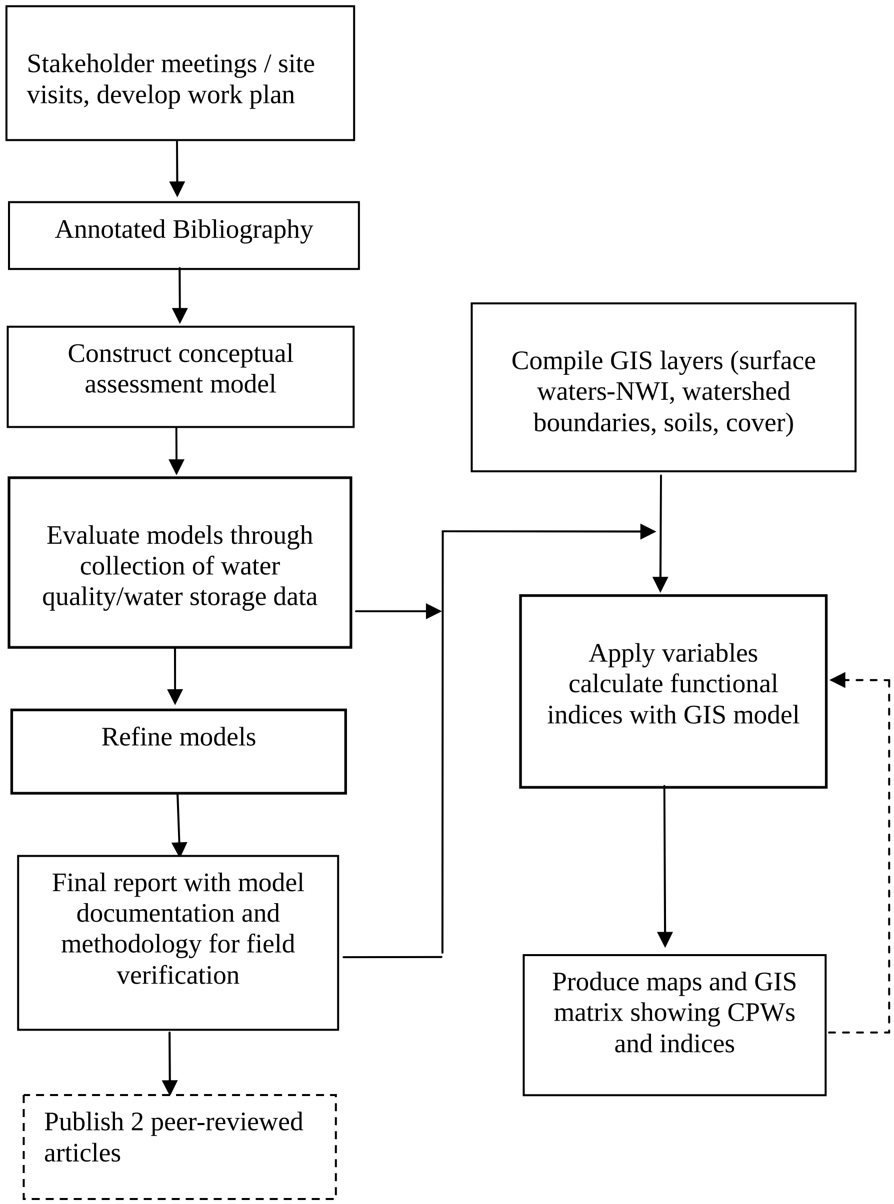

Figure A1. Flow chart of project activities.

Although few data have been collected to quantify the basic hydrologic and water quality processes in freshwater CPWs, recent analysis indicates that cumulative impacts from small water bodies on regional and global processes such as carbon cycling may be vitally important

(Downing et al. 2006). Unfortunately, CPWs are being lost at an alarming rate, particularly those within Harris County, Texas (Houston area) where 13 % disappeared between 1992 and 2002 (Jacob and Lopez 2005). Their new status as "geographically isolated" from navigable waters (Comer et al. 2005) puts them at even greater risk.

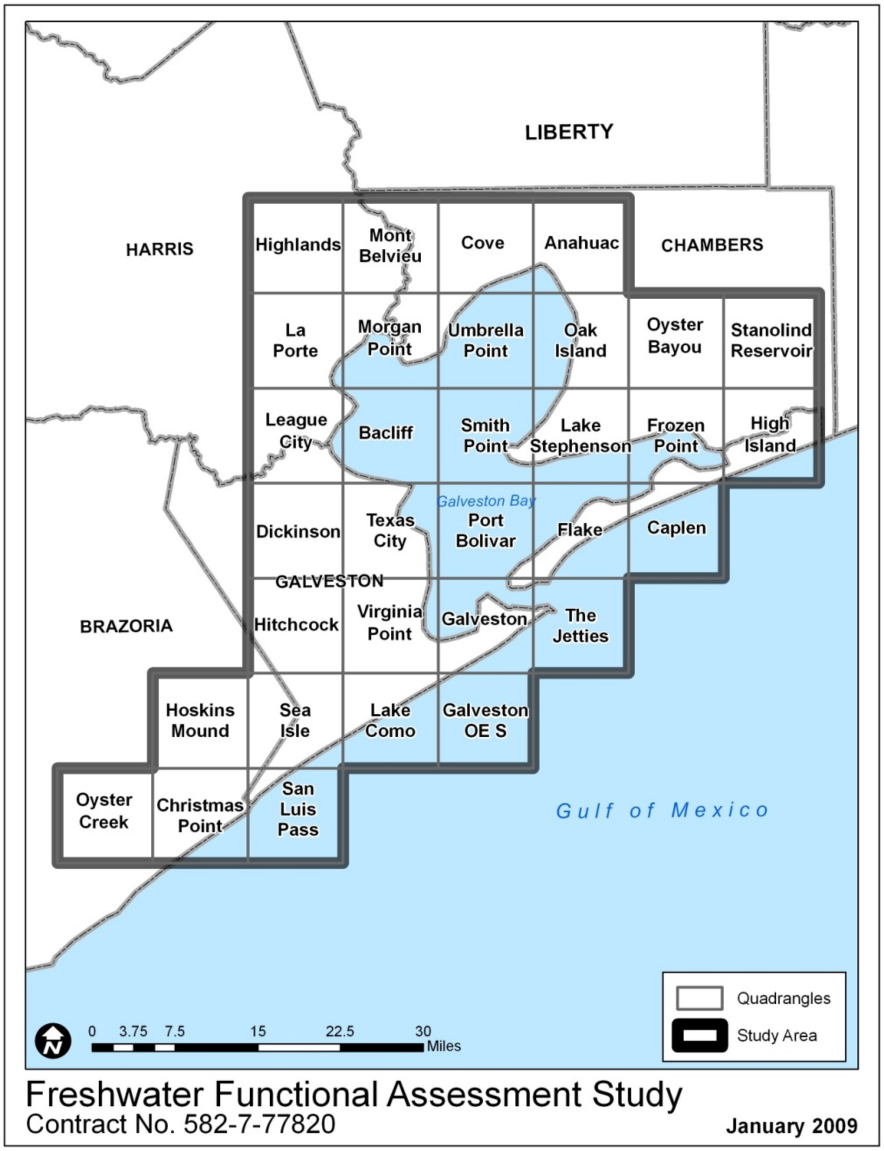

Figure A2. Study area consisting of 32 USGS 7.5-minute quadrangles.

Climate

Climate in the region is described as humid subtropical and is dominated by warm, moist tropical air masses from the Gulf of Mexico brought landward by the prevailing south-easterly winds. Annual precipitation (PPT) in the study area is approximately 127 cm (50 inches), ranging from approximately 110 cm (44 inches) to 137 cm (54 inches) from southwest to northeast respectively. PPT typically has the highest monthly totals from May to September and lowest totals from February to April with the rest of the months receiving relatively moderate PPT (Table A1). An important feature of the upper Gulf coastal climate is the occurrence of tropical storms and hurricanes that can drop a large amount of PPT in a short period of time accompanied by high winds. Landfall of these storms is infrequent, but these disturbances contribute to the long-term hydrology and natural history of the region (Smeins et al. 1992). Temperatures range from an average low of 7°C (45° F) in January to an average high of 34°C (94° F) in August; the mean annual temperature is approximately 21°C (70° F). Temperature ranges become wider farther inland as the buffering ability of the Gulf diminishes. Table A.1 contains monthly and annual mean values for PPT and temperature.

Table A1. Climate Normals: Houston Hobby Airport (source: National Weather Service, 1971-2000).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean PPT (cm)	10.8	7.6	8.1	8.8	13.0	17.4	11.1	11.5	14.3	13.4	11.5	9.6	137.1
Mean Temp (° F)	54.3	57.7	64.2	70.0	77.0	82.3	84.5	84.4	80.5	72.2	63.0	56.1	70.5
Average High (° F)	63.3	67.1	73.6	79.4	85.9	91	93.6	93.4	89.3	82	72.5	65.4	79.7
Average Low (° F)	45.2	48.2	54.8	60.6	68.1	73.5	75.3	75.3	71.6	62.3	53.4	46.7	61.3

Geomorphology

The study area occurs on fluviomarine Quaternary deposits gently sloping towards the coast, mostly deposited during the Pleistocene (> 10,000 years ago). Pleistocene deposits occurred as a result of alternating periods of glaciation and fluctuating sea-levels in which sediments were deposited. Holocene (10,000 years to present) deposits are found closer to the coast and on the flood plains of the many rivers crossing the landscape (Aronow 2000). Geologic processes and hydrology associated with climate changes are complex and have resulted in a seemingly homogenous flat landscape; however, slight differences in elevation and variation in substrate composition contribute to a diverse setting.

Soils in the study area are predominantly Vertisols, which are characterized by high clay content (up to 65%) and high shrink swell potential. Vertisols have low hydraulic conductivity and consequently may produce more runoff than other soils. On the other hand, the high shrink swell potential of these soils results in large surficial cracks in dry periods, which can direct runoff into the soil until soils become moist and swell resulting in closure of cracks. An important feature of Vertisols is the microtopography of small depressions and ridges they develop known as gilgai (Aronow 2000). Depressions associated with gilgai collect water from immediate uplands leading to variations in soil moisture, drying and cracking (Kishné 2009). Topographical relief between micro-highs and micro-lows is typically 10 to 40 cm (Nordt et al. 2004).

Meander ridges and channel scars are other important features characterizing the topography of the study area. These features have been reworked by wind and water resulting in shallow undrained depressions and distinctive soil patterns crossing the landscape. The elevated areas associated with these meander ridges are typically underlain by sandier, loamier substrates than the adjacent depressions. Meander ridges and channel scar depressions occur on the landscape as isolated fragments and as patterns extending several kilometers. Many of the topographical features discussed above have disappeared due to row-crop tillage, pasture improvement, drainage ditching, land-leveling and levee construction (Aronow 2000).

Study Sites

Six wetland sites were initially selected for hydrologic and water quality monitoring, as well as to assess general wetland characteristics that relate to the functional assessment models. The six sites were selected with input from the project Advisory Group. The sites, located in pairs to facilitate sampling of precipitation, were located at Brazoria National Wildlife Refuge (NWR), Armand Bayou Nature Center, and Anahuac NWR (Fig. A3, red markers).

During Phase II, six additional sites were selected (Fig. A3, green markers). The advisory group requested that additional sites be located outside the 100-yr floodplain; therefore, we randomly selected 70 wetlands outside the floodplain and attempted to obtain permission for access. From the randomly selected wetlands, we added four sites (DW, SE, LG, UH). After failed efforts to secure the final two sites on Exxon property, we included the fifth site near SE (KIL). The final site (HA) was added at the request of the Project Manager despite the fact that it was not within the study area. We did not calculate model indices for that site due to lack of GIS coverages. Table A2 summarized characteristics of the twelve sites.

Wetland sites were assessed for their soils and vegetation, as well as land use, and other characteristics related to the model variables. The hydrology of the initial six sites was characterized for nearly 18 months concurrent with water quality sampling. The random sites were sampled for water quality at least twice. Over the course of the study, many of the sites were impacted by hurricanes, drought, hogs, spraying, mowing, or other disturbances. We describe these events further in the report as they potentially impacted sampling results.

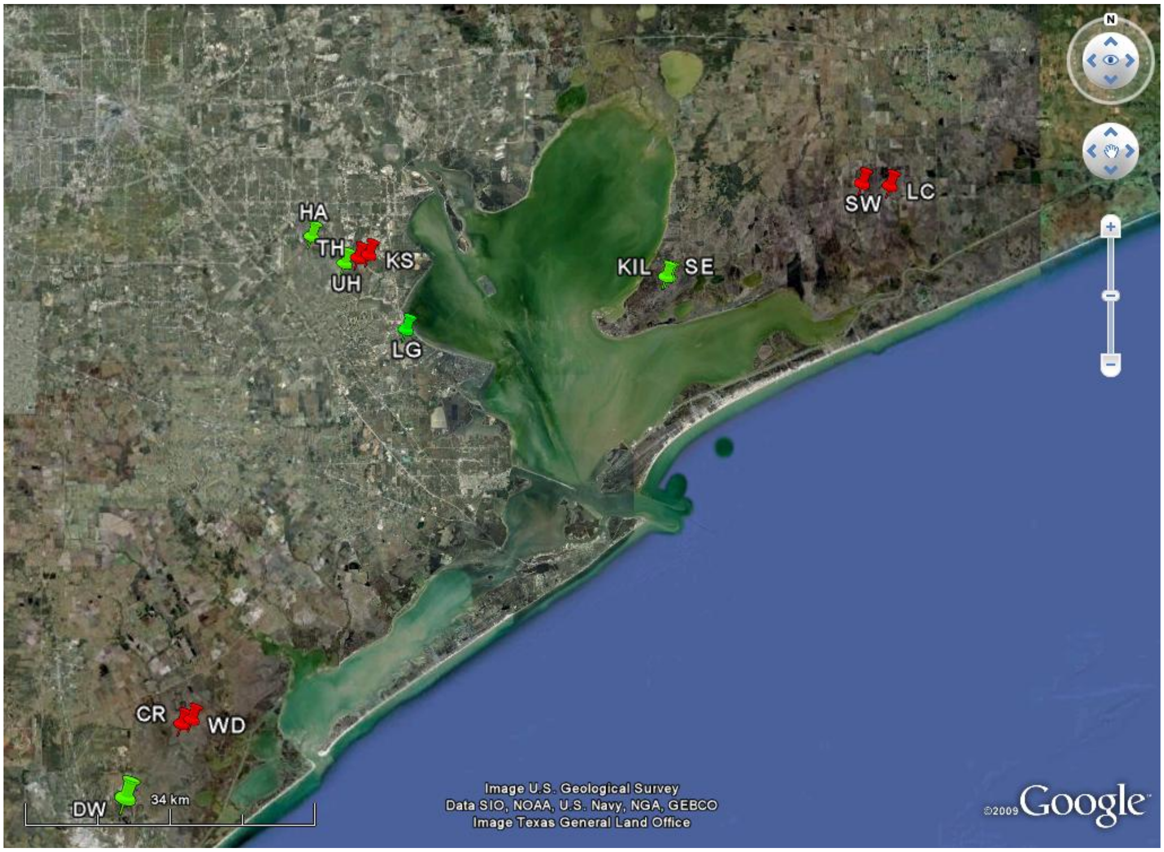

Figure A3. Locations of six initial study sites (red) and six randomly selected sites (green). DW=Dow, CR=Chicken Road, WD=Wounded Dove, LG=League City, UH=University of Houston, KS=Kite Site, TH=Turtle Hawk, HA=Harris, KIL=Kildeer, SE=Senna, SW=Sedge Wren, and LC=LeConte.

Table A2. Summary characteristics of wetland sites included in hydrologic and water quality sampling. Hydrologic monitoring began at the initial six sites in May-June 2008 and in July-Dec 2009 at the random sites.

Site	NWI Code	Size (ha)	Longitude (W)	Latitude (N)	Within 100-yr Floodplain?	Land Ownership
CR	PEM1C	0.53	95.28740	29.10366	Yes	Brazoria National Wildlife Refuge
WD	PEM1C	1.54	95.27451	29.11055	Yes	Brazoria National Wildlife Refuge
TH	PFO1A	4.82	95.07763	29.59315	No	Armand Bayou Nature Center
KS	PFO1A	3.44	95.06553	29.59794	Partially	Armand Bayou Nature Center
SW	PEMf	2.39	94.46955	29.67314	Yes	Anahuac National Wildlife Refuge
LC	PSSf	1.05	94.43611	29.67100	No	Anahuac National Wildlife Refuge
DW	PEM1C	0.97	95.35685	29.02015	No	Dow Chemical
LG	PEM1A	9.60	95.01972	29.51859	No	City of League City
UH	PFO1A	1.58	95.09415	29.58777	No	University of Houston
HA	PEM1C	1.00	95.13431	29.61630	No	Harris County
KIL	PEM1F	1.62	94.70628	29.57501	No	Private rancher
SE	PEM1A	0.20	94.70388	29.57519	No	Private rancher

Chicken Road and Wounded Dove

Chicken Road (CR) and Wounded Dove (WD) are emergent wetlands consisting mostly as thick grasses, rushes, and sedges (Fig. A4). Abundant vegetation at CR (Appendix I) was dominated by *Cyperus articulatus*, *Spartina patens*, *Ipomoaea sagittata*, *Paspalum vaginatum* and patches of *Juncus roemerianus*. Wounded Dove was dominated by *Spartina patens*, *Cyperus articulatus, Ipomoaea sagittata,and Eleocharis montevidensis.* Historically, land in the area was used for livestock pasture; presently the land is actively managed to maintain prairie habitat. The landscape is extremely flat (0 – 1% slopes), gently sloping towards the Gulf of Mexico. CR occurs within an ancient channel scar (Fig. A5) surrounded by upland on either side of the channel with approximately 1 m difference between the highest upland and the deepest part of the wetland. CR collects runoff from the surrounding upland. In times of sufficient rain, water may flow into CR from depressions farther up the ancient channel than those in its immediate catchment area. Once CR's depression fills up, water flows out through a culvert as it continues through the channel scar. WD is located approximately 1 mile east of CR on Gilgai formation characterized by microhighs and microlows differing by approximately 30 cm in altitude. WD does not have a visible channelized outlet. WD is the least disturbed, most pristine CPW of the 12 study sites.

Figure A4. Wounded Dove (left) and Chicken Road (right) with water level monitoring equipment.

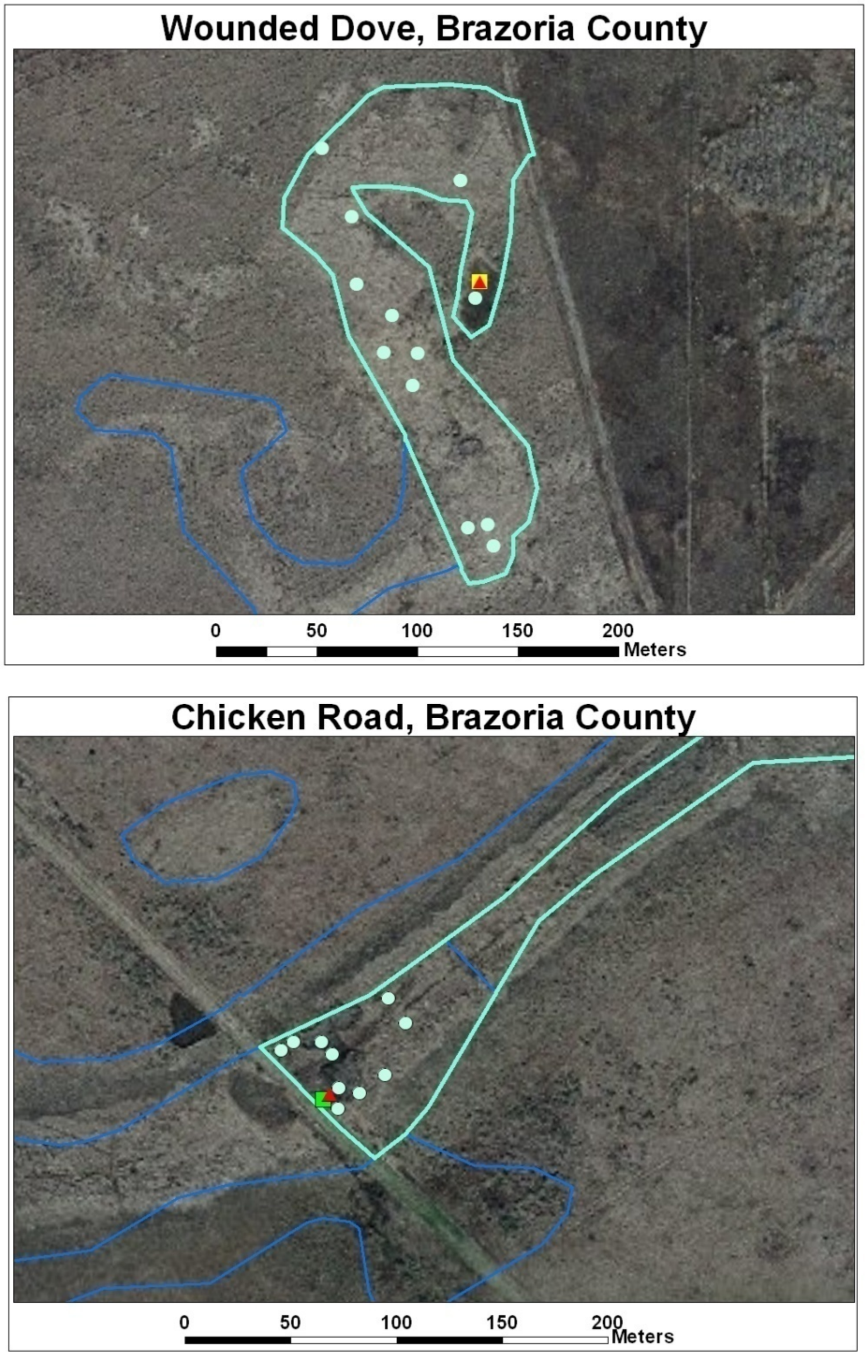

Figure A5. Aerial view of Wounded Dove (top) and Chicken Road (bottom) showing study area (aqua) and NWI boundaries (blue), water level recorders (red triangles), piezometers (yellow square), and sampling locations (aqua circles). Note different scales on top and bottom panels.

Turtle Hawk and Kite Site

Turtle Hawk and Kite Site wetlands are located at the Armand Bayou Nature Center, which consists of over 1,000 ha adjacent to Armand Bayou. TH is a forested wetland characterized by many small depressions. The deepest recorded water depth before overflow was approximately 12 cm. Discharge occurs through a culvert draining into Armand Bayou. The vegetation is multi-storied with the overstory dominated by *Ulmus americana*, *Sapium sebiferum* (Chinese tallow), and *Querca falcata*. The understory consisted of *Sabal minor*, *Vitis rotundifolia*, and other vines and saplings; while the ground cover was dominated by leaf litter, *Chasmanthium laxum*, *Polygonum* spp, and *Saccharum giganteum*. Kite site is an emergent, scrub/shrub, and forested wetland mapped on Beaumont Clay, a common soil in the region. Vegetation in the forested area was similar to Turtle Hawk and the rest of the sites was a mixture of S*abium sebiferum,* sedges, and *Saccharum giganteum*. A maximum depth at KS of approximately 35 cm produced discharge from a shallow drainage ditch that is conveyed across Red Bluff Road to Taylor Lake (Fig. A7).

Figure A6. Photos of monitoring equipment at TH bird blind (left) and KS (right).

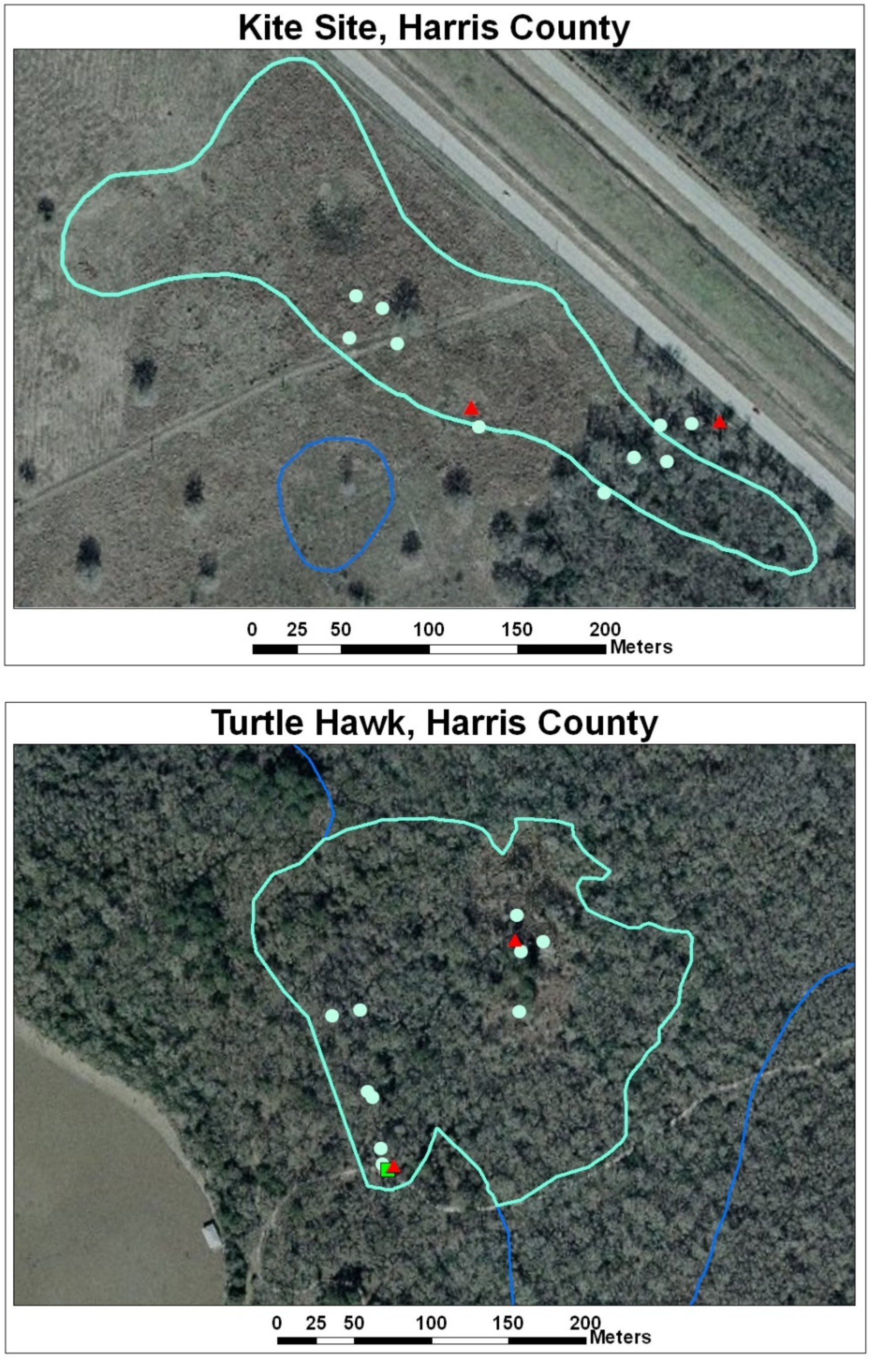

Figure A7. Aerial view of Kite Site (top) and Turtle Hawk (bottom) showing study area (aqua) and NWI boundaries (blue), water level recorders (red triangles), weirs (green boxes), and sampling locations (aqua circles). Note different scales on top and bottom panels.

Sedge Wren and LeConte

Sedge Wren (SW) and LeConte (LC) are located on the eastern side of Galveston Bay within the Anahuac NWR. Both SW and LC occur on similar clay soils. SW is a restored wetland created by the USFWS in a site previously farmed in rice (Fig. A8). The site has a water control structure that conveys discharge to Onion Bayou, an irrigation canal. The maximum observed water depth at SW was approximately 30 cm. SW has a catchment area delineated by Whites Ranch Road (FM 1985) to the north and a levee/service road on the other three sides. Vegetation at SW includes *Eleocharis montevidensis*, *E. quandrangulata*, *Alternanthera philoxeroides*, *Diodia virginiana*, and *Panicum hemitomum*.

LC is located approximately 2 miles to the east of SW on FM 1985. It is adjacent to an irrigation ditch to the south that is used for rice farming. LC is a smaller wetland with a maximum depth of approximately 15 cm. LC has a greater slope than the other study sites. It has a road ditch along its southern boundary(see photo) and we installed a weir and water level recorder in the ditch, about 30 m upslope of a drainage culvert that conveys runoff to the adjacent irrigation ditch (Fig. A9). LC is grazed by cattle, sometimes heavily, which made plant identification difficult at times. Plant species include *Alternanthera philoxeroides*, *Echinochloa* sp. *Panicum repens*, *Juncus validus, Eleocharis* sp. and *Ludwigia* sp.

Figure A8. Photos of monitoring equipment at LC (left) and SW (right). Note damage and wrack at LC from Hurricane Ike

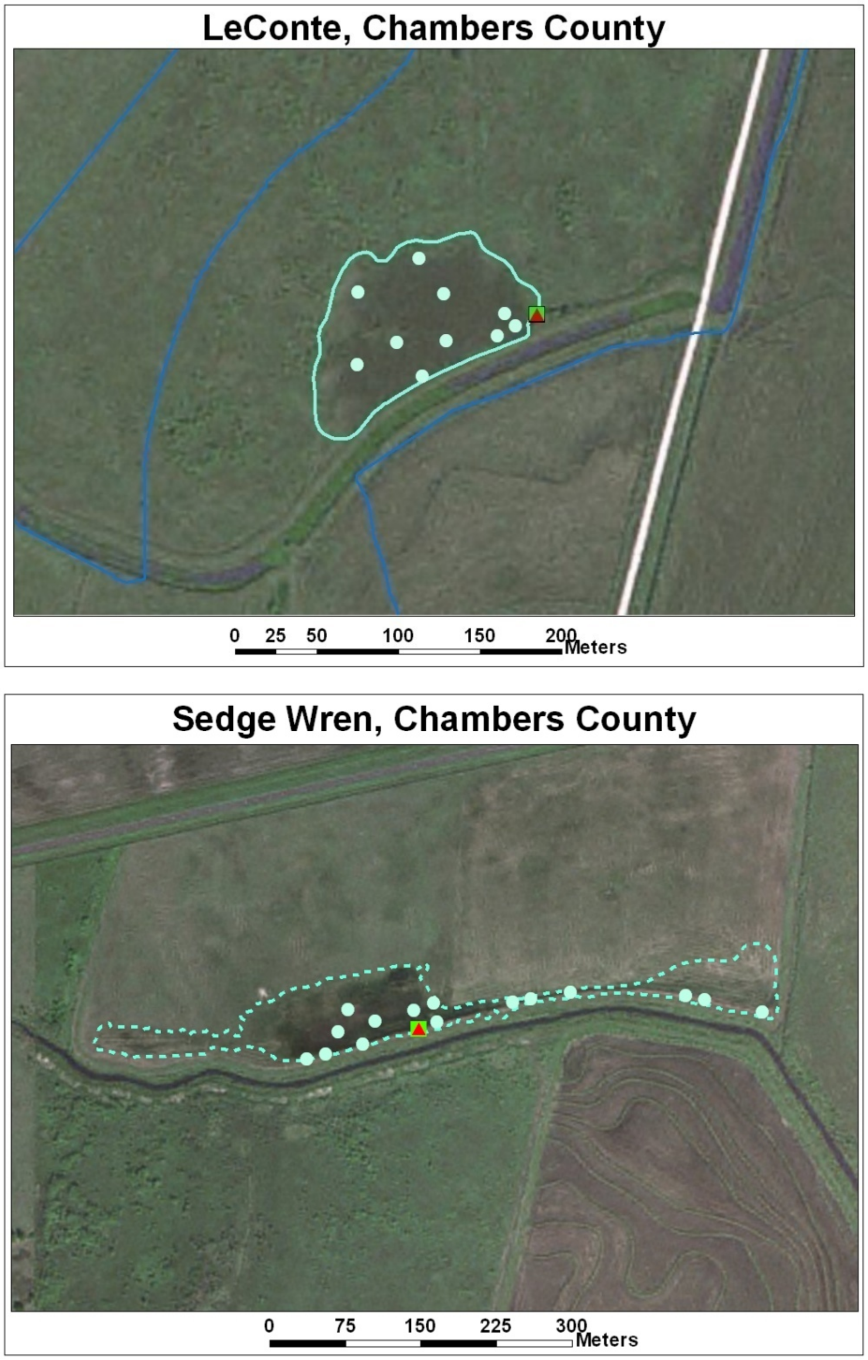

Figure A9. Aerial views of LeConte (top) and Sedge Wren (bottom) showing study area (aqua) and NWI boundary of adjacent wetlands (blue), water level recorders (red triangles), weirs (green boxes), and sampling locations (aqua circles). Sedge Wren boundaries were determined by walking the wet perimeter Note different scales on top and bottom panels.

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Killdeer and Senna

Killdeer (KIL) and Senna (SE) are located on private ranch land on the eastern side of Galveston Bay near Smith Point in Chambers County. Killdeer is a pothole-shaped pond (Fig. A10) and this morphology appears to be common in the surrounding landscape. Both sites were inundated with Hurricane Ike storm surge but only KIL is still saline (~7 ppt). According to the landowner, prior to Ike, Killdeer was densely vegetated with an unknown grass and we saw evidence of thick wrack on our first visit. No vegetation has reestablished at KIL, but adjacent wetlands have *Bacopa* sp. *E. quadrangulata*, and *Sesbania drummondii*. SE is a smaller depressional wetland located approximately 100 m east of KIL. Maximum SE water depths were only ~7 cm while KIL depths were over 40 cm. Vegetation at SE consisted of *Centella asiatica, S. drummondii, Panicum scoparium,* and *Juncus effusus*. Both sites are grazed by cattle and have considerable bare ground. Remnant furrows suggest cropping was a prior activity. Neither site has a channelized outlet.

Figure A10. Photos of installing monitoring equipment at KIL Aug 2009 (top) and SE Nov 2009 (bottom).

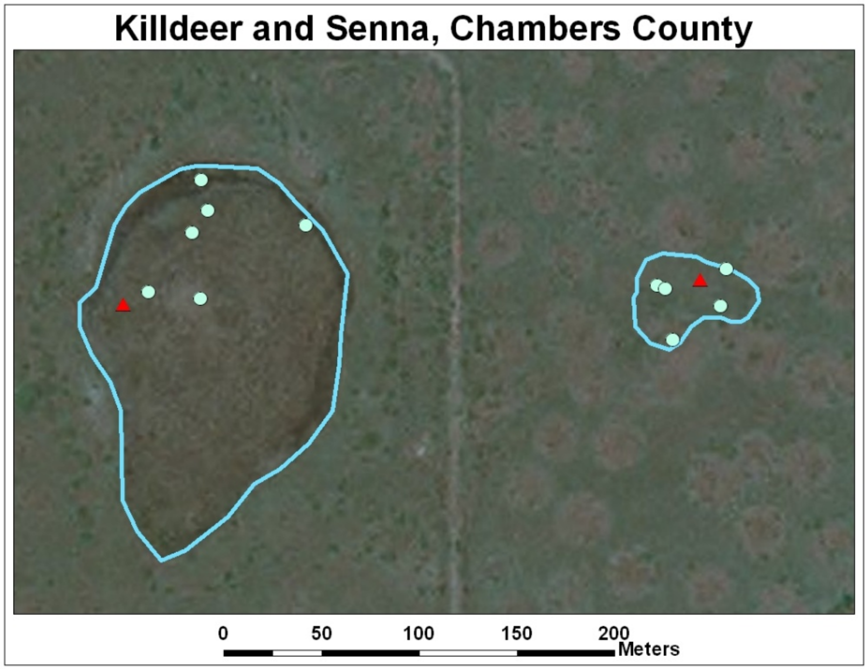


Figure A11. Aerial view of Killdeer (left) and Senna (right) showing study area (aqua/green) and NWI boundaries (blue), water level recorders (red triangles), and sampling locations (circles).

Dow and League City

Dow Chemical (DW) and League City (LG) wetlands are randomly selected wetlands located several km apart. DW is in Brazoria County northeast of Freeport, in the far southwestern corner of the study area and LG is in the northern part of Galveston County. DW is within 1-2 km of a chemical refinery complex in Brazoria County. Historically, the site probably drained into Oyster Creek; however, a large berm now separates the wetland from the creek. The site is actively grazed by cattle. In summer 2009, the site was dry with cracked soils and a monoculture of senna. Hydrologic equipment was installed in August, 2009 and by October 2009; rains had filled the wetland to over 50 cm depth. Submersed and emergent aquatic vegetation now dominate the site (Fig. A12). Plant species include *Paspalum vaginatum*, *Sagittaria* sp. *Echinodorus* sp. *Alternanthera philoxeroides*, and *Nymphaea* sp.

LG is a mitigation wetland that is managed by the City of League City. It is actively managed for Chinese tallow by mowing and since being dry in August has accumulated up to 28 cm of water. A residential development was recently built on its western boundary. The site contains intact mima mounds and a strikingly diverse vegetation community including grasses, sedges, and submersed aquatics. Water appears to discharge through a broad channel off site toward Galveston Bay (Fig. A13). Plant species include *Cyperus virens, Panicum* sp. *Pluchea foetida, Sapium sebiferum, Paspalum floridanum*, *Letpochloa fascicularis*, and *Proserpinaca palustris* and many other grasses and forbs.

Figure A12. Photos of monitoring equipment at DW (left) and LG (right).

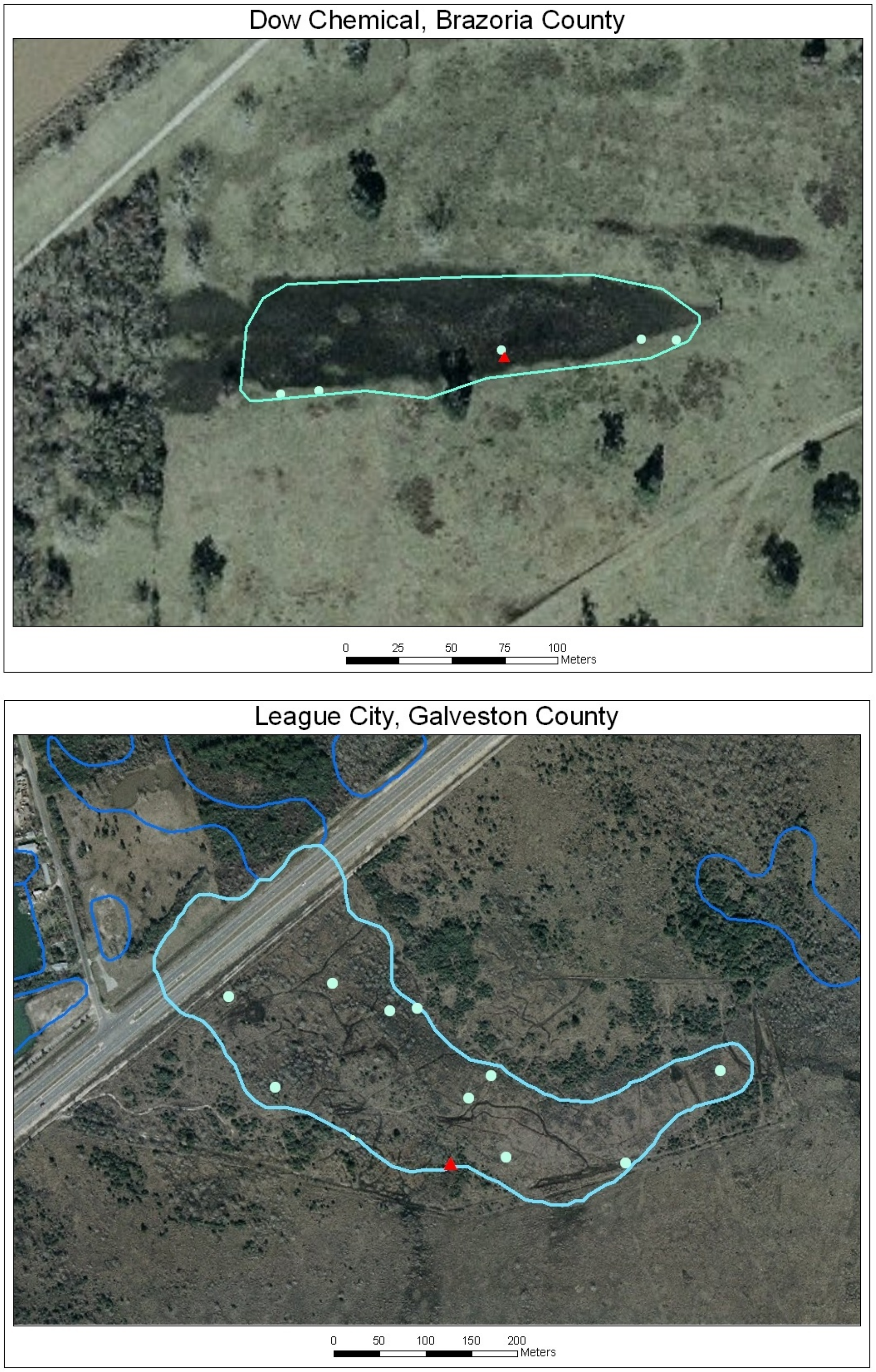


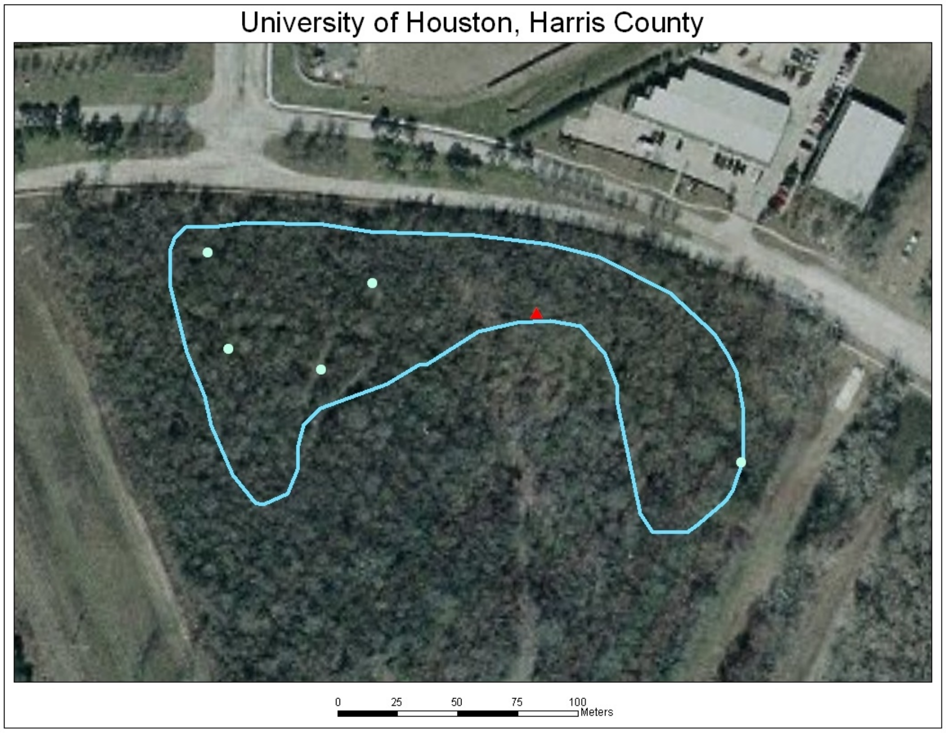
Figure A13. Aerial view of Dow (top) and League City (bottom) showing study area (aqua) and NWI boundaries (blue), water level recorders (red triangles), and sampling locations (circles). Note different scales on top and bottom panels.

University of Houston and Harris County

University of Houston (UH) and Harris County mitigation site (HA) are located in developed areas of Harris County. UH is a forested wetland (Fig. A15) that lies within the Clear Lake UH campus grounds. The site is bounded on the north by Middlebrook Drive and we have witnessed the wetland discharge flowing across the sidewalk of this road on two occasions. The southern upland area adjacent to the wetland is used to dispose of landscaping material. The maximum recorded water depth at this site was 6-7 cm. Plants species at UH include *Rubus trivialis*, *Lonicera japonica*, *Sapium sebiferum*, *Ulmus americana*, *Ilex vomitoria* and *Carex* sp.

HA is east of Ellington Field and bisected by Space Center Blvd. HA is similar to LG in its vegetation and topography (wet prairie). The monitoring equipment was not installed at this site until December 2009. Plant species were surveyed in April 2010 and included *Panicum* sp. The site is managed by Harris County.

Figure A14. Photos of UH (left) and HA (right). The road behind HA is Space Center Blvd.



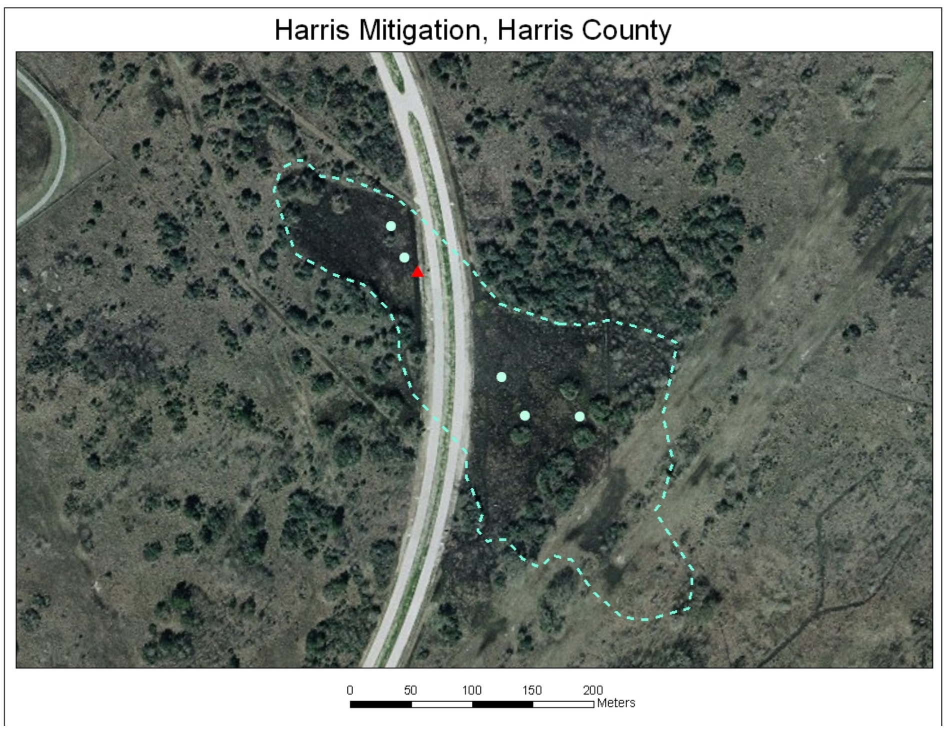


Figure A15. Aerial view of University of Houston (top) and Harris County (bottom) showing study area (aqua) and NWI boundaries (blue), water level recorders (red triangles), and sampling locations (aqua circles). Note different scales on top and bottom panels. The Harris County NWI boundary is approximate.

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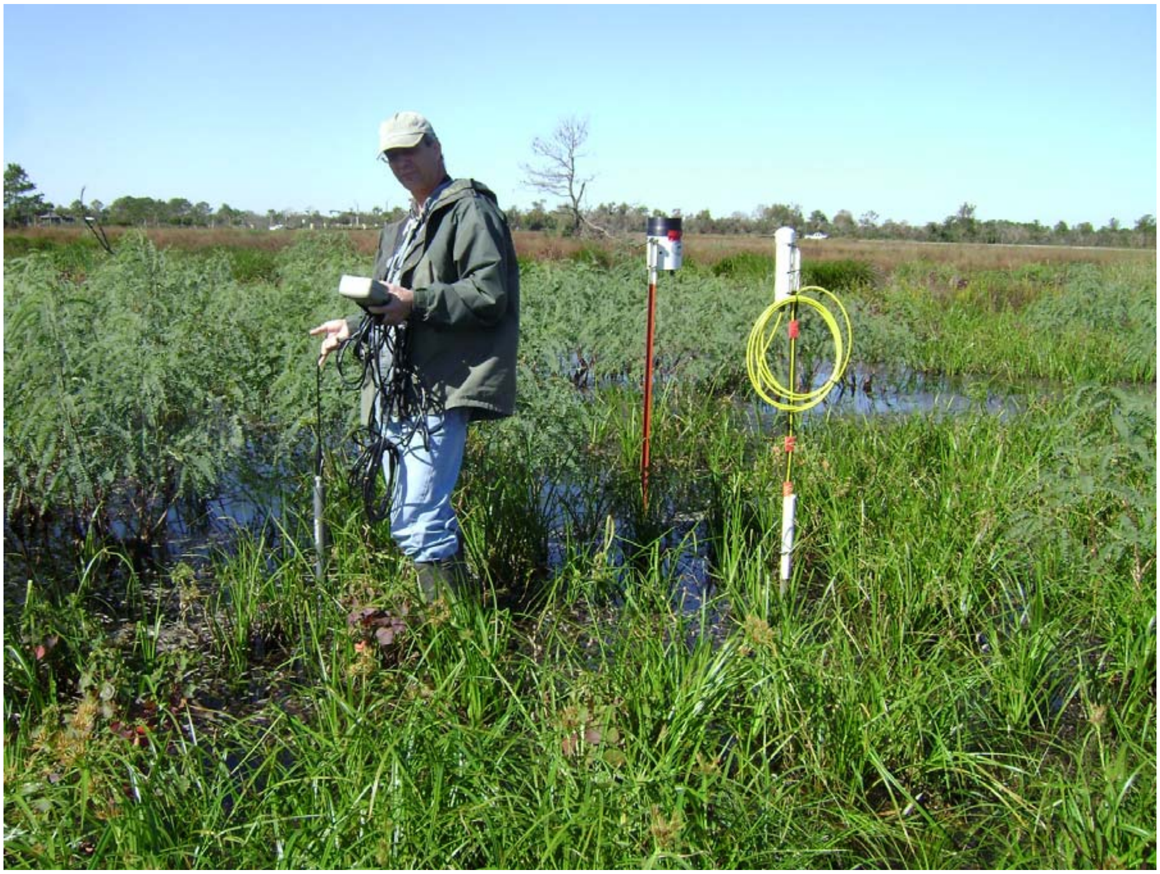
B. Functional Assessment Models



Robert Doyle at League City wetland, November 2009

Introduction

There is abundant evidence that wetlands have the capacity to improve water quality and provide storage and desynchronization of floodwaters. The inherent capacity to perform these functions is dependent on the physical, biological, and chemical characteristics of the wetland. Coastal Prairie Wetlands (CPWs) are an integral part of the Galveston Bay ecosystem, yet their water quality and flood storage functions have not been evaluated. This report presents six conceptual models that predict a CPW's capacity for (1) water storage, (2) nitrate removal (3) ammonia removal, (4) phosphorus removal, (5) heavy metal removal, and (6) removal of organic compounds. The models are derived from literature reviews of site specific research studies and functional assessment models (primarily hydrogeomorphic models) developed for other classes of wetlands. This literature was used in conjunction with the project team's professional judgment and what is known about hydrology and biogeochemical processes in CPWs.

Methods

The models presented in this document are consistent with previous HGM models derived for depressional wetlands (Gilbert et al. 2006, Lin 2006, Stutheit et al. 2004) and wetlands in south Florida (Zahina et al. 2001). Our approach to model development also incorporates some of the general guidelines for HGM modeling presented by Smith et al. (1995). Most functional assessment approaches predict a wetland's potential for performing a given function based on the wetlands' characteristics such as position in the landscape, morphology, hydrology, soils, vegetation, etc. The resulting predictive models *do not measure* whether the function is actually being performed and such verifications are rarely attempted. Instead, functional models provide a relative estimate of functional capacity. They typically provide qualitative values (low, medium or high) or indexed values (0.0 – 1.0) relative to a "fully functional" reference wetland. Some models (e.g. WET 2.0) include variables that account for the opportunity the wetland has to perform the function and the social significance of the function. Other approaches (e.g. HGM) do not include opportunity or social significance variables. The CPW functional models presented in this report do not include opportunity or social significance variables. They are also indexed to provide a relative estimate of function known as the Functional Capacity Index (FCI). The FCI can range from 0.0 – 1.0, where 0.0

indicates that the functional capacity is absent and a 1.0 indicating that the wetland functions at a level similar to the selected reference wetlands. It is important to understand that, although FCI provides a numerical value for wetland function, that value is relative and may best be interpreted as low, moderate, or high.

One important difference between the CPW models presented here and existing hydrogeomorphic (HGM) models is the use of reference wetlands. Development of an HGM approach for a regional class of wetlands requires extensive data collection in reference wetlands, which are wetlands believed to be performing at a high functional capacity (Smith et al. 1995). Data collected in reference wetlands are used to define the range of functionality and the range of values for predictor variables. Instead of using this somewhat subjective approach, we will evaluate the wetlands based on how well they perform the function. For example, wetland # 1 is considered to have a higher ammonium removal function if concentrations of ammonium are lower in wetland # 1 (relative to rainfall) than in the other wetlands evaluated. Conversely, if a wetland tends to have higher ammonium levels, it would be considered to have a lower functional capacity.

Variables used in HGM models characterize relative catchment size, land use, hydrology, soils, and vegetation. They are assigned values that range from 0.0 to 1.0 scaled to the range of expected values for the type of wetland. Variables selected for CPW models were defined so as to allow them to be quantified in the field either by direct measurement or by field indicators. Because GIS methods will be utilized to apply the models to CPWs in the study area, it was also necessary that each variable be applicable using GIS databases.

The final step in conceptualizing the assessment model is to develop an aggregation equation that combines model variables and derives the FCI. We used the approach developed by Smith and Wakeley (2001) for HGM development. In this approach, the types of interactions between model variables (Table B1) may be additive, where either variable alone or both in combination contribute to functional capacity. If the sum exceeds 1.0, the FCI is taken to be 1.0. A *limiting* relationship is one in which a low value for any one variable lowers the function. This type of relationship is defined by the minimum of the two variables. It is commonly used in habitat indices, where factors such as food, cover, or nesting sites are all necessary for survival. A *compensatory* relationship occurs when a high value for one variable compensates for a lower value of another variable. This type of relationship is defined by the maximum value of the two variables. A *partially compensatory* relationship occurs when two or more variables contribute equally and independently to the level of function. It is calculated as either the arithmetic mean or the geometric mean, with the former being more sensitive to low values. Another important difference between the arithmetic mean and the geometric mean is that with the geometric mean, if *any* variable is equal to zero, the resulting FCI is zero. A *controlling* feature is one that is critical to the performance of a function. For example, organic carbon export might be modeled by the following equation: $FCI = V_{FREQ} \times (V_{LITTER} + V_{CSD})/2$. Carbon export is affected by the abundance of leaf litter (V_{LITTER}) and coarse woody debris (V_{CSD}), which are grouped and averaged because they contribute equally and independently to the availability of material for export. However the export cannot occur until floodwaters scour the site (V_{FREQ}). Thus the product relationship allows V_{FREQ} to drive the FCI to zero at sites where no flooding occurs, despite high values of the other variables. Finally, variables may also be weighted if their contribution to the function is believed to be more important than other variables. Methods and supporting information for assigning values to model variables are provided in Appendix 1.

The models presented here may be revised to reflect the results of water quality data, water storage data, and model variable data collected at six CPWs in the study area. For example, two model variables have been eliminated due to limitations of available GIS databases. The first variable described the presence of modified wetland outlets. While this variable may impact water storage function, we could not develop a reliable method for identifying the presence of such outlets using available GIS databases. The second variable eliminated was soil organic matter. While potentially important for removal of nitrogen, metals, and organic contaminants, our laboratory analyses of soil organic matter (loss on ignition method) did not correlate well with soil organic matter values provided in the Soil Survey Geographic (SSURGO) database.

Table B1. Types of interactions between model variables and their mathematical expression for developing HGM assessment models (adapted from Smith and Wakeley 2001).

Type of Interaction	Mathematical Operation	Example
Cumulative	Addition	FCI = VA + VB + VC; if sum > 1.0 then FCI = 1.0
Limiting	Minimum	FCI = MIN (VA, VB)
Fully compensatory	Maximum	FCI = MAX (VA, VB)
Partially compensatory	Arithmetic mean	FCI = (VA + VB + VC)/3
	Geometric mean	FCI = (VA x VB x VC)1/3
Controlling	Product	FCI = VA x (VB + VC)/2
Weighted	Coefficient	FCI = 2(VA + VB + VC)/4

Results

Surface Water Storage Model

Surface water storage is defined as the capacity of a wetland to temporarily store and convey surface water during rainfall or flood events. This function is often referred to as flood attenuation or flood peak desynchronization. The primary source of surface water is from direct precipitation, with a secondary source from overland runoff. The water budget of depressional wetlands is influenced by precipitation within the catchment, groundwater recharge and discharge, evapotranspiration, and the configuration of the wetland outlet. In wetlands with flow-through, density and rigidity of emergent vegetation can retard water velocities by providing hydraulic roughness. In addition, vegetation may influence evapotranspiration rates. At any given moment, the water level in the wetland is a balance of these factors.

In general, the underlying geology and soils of the coastal plain area promote slow rates of exchange between ground water and surface water. In CPWs, therefore, precipitation and evapotranspiration (EVPT) are believed to play the largest role in determining fluctuations in the wetland water level (Smeins et al. 1992). Evapotranspiration may be the most important pathway for water losses in depressional wetlands; annual lake evaporation in the Galveston Bay Area is approximately 53 inches and annual class A pan evaporation is 70 to 75 inches (Dunne and Leopold 1978). Rates of EVPT have been shown to be higher in systems with abundant emergent vegetation. For example, wetlands dominated by broadleaf cattail (*Typha latifolia*) were demonstrated to have double or triple EVPT rates of an unvegetated area (Towler et al. 2004).

Wetlands with larger surface areas would also have greater potential for total EVPT. A wetland with higher evapotranspiration rates would be expected to have greater storage function because a wetland's capacity for flood attenuation is dependent upon the storage volume available at the onset of precipitation events. Thus overall wetland size and volume are important characteristics for predicting flood storage. The ratio of the wetland surface area to the surface area of its catchment (V_{catch}) has been proposed as an important characteristic for evaluating water storage function (Bradshaw 1991, Fennessy et al. 2004, Lin 2006). Wetlands that can store at least 25% of the catchment runoff from a 24-hr two-year rain event have been assigned a high water storage function (Simon et al. 1987, Bradshaw 1991). Water storage and flood attenuation tend to be greater in wetlands with substantial water level fluctuations, such as those with large wet meadow zones (Gilbert et al. 2006), or with intermittent, seasonal, temporary, or semi-permanent hydrologic regimes. Hydrological modifications or modifications that maintain water in the wetland typically reduce their effective storage volumes.

The conceptual model for water storage (Eq. 1) contains variables for wetland volume (V_{vol}), the presence of year-round or nearly year-round water in the wetland (V_{wet}), the ratio of wetland size to catchment size (V_{catch}) and percent of wetland area that is vegetated with macrophytes (V_{mac}). The wetland volume variable can be zero if the wetland has been filled or modified to drain completely.

$$FCI_{WS} = V_{vol} \times V_{wet}\left(\frac{V_{catch} + V_{mac}}{2}\right) \qquad \text{(Eq. 1)}$$

Water Quality Models

Wetlands have the ability to remove, reduce, degrade, or provide long-term storage of a variety of pollutants. Pollutants include elements such as heavy metals, nutrients such as nitrogen and phosphorus, compounds such as PAHs, herbicides and pesticides, and particulates. These compounds may enter wetlands through aerial deposition, surface runoff, groundwater exchange, or through streams or manmade conveyances. A quantitative *measure* of water quality function would require a determination of the amount of pollutant removed or retained per unit area during a specified period of time (e.g. g/m^2/year). Such data-intensive studies are rarely undertaken in the context of functional assessment. Rather, functional assessment models are used by regulators and land use managers to inform decisions regarding proposed activities in wetlands. In this context, functional assessment models have been used to *estimate* the type and degree of functions that would be gained or lost in wetland conversions.

Most HGM models developed for depressional wetlands have used a single model for retention or removal of nutrients, organics, heavy metals and other contaminants. However, most contaminants have unique fate and transport pathways. For example, the wetland characteristics that promote nitrogen removal will not necessarily optimize the removal of other pollutants. To incorporate our understanding of the fate and transport of specific contaminants in wetlands, we have developed separate water quality models for nitrogen, phosphorus, selected heavy metals, and organics.

Nitrogen Retention/Removal

Nitrogen pollution is an important consideration in the Galveston Bay area and near-shore ecosystems, particularly as anthropogenic inputs associated with development continue to increase. Nitrogen retention/removal function is defined as the capacity of a wetland to reduce the water column concentrations of ammonium and nitrate. This may occur through short term or long term storage of nitrogen in biota and sediments; or through permanent removal of nitrogen primarily through the nitrification-denitrification process.

Nitrogen may enter CPWs through precipitation, surface runoff, and from direct faunal deposition. Nitrogen transformations in wetlands may be substantial depending upon the nature of nitrogen loading as well as characteristics of the individual wetland. Nitrogen is removed from the water column primarily by four processes (Reddy and Patrick 1984): (1) uptake by plants, (2) immobilization by microorganisms during plant decomposition, (3) adsorption of ammonium onto organic matter and clay, and (4) most importantly, through the nitrification-denitrification process.

The nitrification–denitrification process leads to permanent removal of nitrogen from wetland systems. Nitrification is the microbially mediated oxidation of ammonium to nitrite and then nitrate. The process consumes approximately 4.3 grams of oxygen for each gram of nitrogen oxidized, and therefore occurs primarily in aerobic areas of the wetland (surface waters, unsaturated soils, rhizospheres of emergent plants, etc.). Once ammonium is oxidized, the resulting nitrate then diffuses to anaerobic areas of the wetland where it may be denitrified. This transport of the resulting nitrate from aerobic to anaerobic zones has been shown to be the rate limiting step in the removal of nitrogen from flooded systems (Patrick and Reddy 1976). In general however, nitrification rates can be limited in wetland systems due to nitrifying bacteria's sensitivity to reduced oxygen levels, temperature, toxicity, pH, and competition from bacteria that oxidize carbon rather than ammonium.

Denitrification is the reduction of nitrate into gaseous nitrous oxide (N_2O) and molecular nitrogen (N_2), which are then released to the atmosphere (Mitsch and Gosselink 1993). Denitrification occurs primarily in reduced soils and sediments where abundant organic matter is used as a carbon source for denitrifying bacteria. Denitrification has been shown to remove relatively large quantities of nitrogen from wetlands, particularly when the proportion of nitrate in incoming loads is high (Nelson et al. 2004).

Because nitrification and denitrification are promoted by different environmental conditions, their removal depends both on the incoming water and the characteristics of the individual wetland. For example, wetlands receiving inputs primarily from precipitation or runoff from undisturbed catchments will likely be able to process incoming nitrogen through the processes described earlier. In contrast, wetlands receiving runoff from fertilized agricultural fields or other enriched sources may not be able to nitrify ammonia rapidly enough to achieve background levels. In this case, a fluctuating hydrologic regime would facilitate nitrification by enhancing aeration (Figure B1). It has been demonstrated that nitrification is greater in wetlands where soil moisture contents fluctuate repeatedly (Patrick and Mahapatra 1968, Ponnamperuma 1972, Reddy and Patrick 1975), such as in the wet meadow zone.

In contrast, denitrification rates can be rapid in wetlands during periods of inundation or soil saturation. Denitrification rates have been shown to increase with higher initial concentrations of nitrate. Thus higher rates of nitrate removal may occur in wetlands receiving high nitrate runoff.

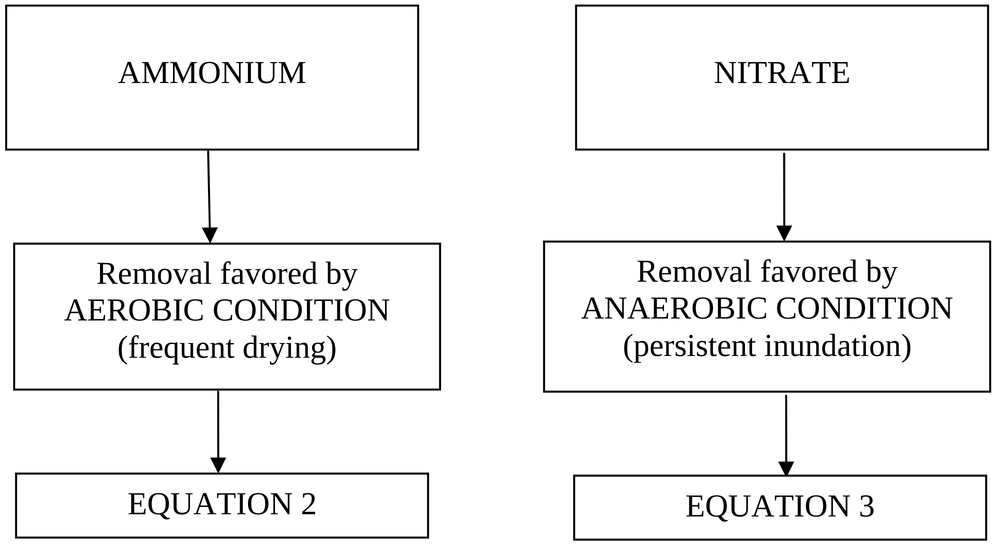


Figure B1. Conditions that promote ammonia and nitrate removal, and the corresponding functional capacity equations.

Two conceptual models are proposed for predicting nitrogen removal in CPWs. Equation 2 is for ammonium removal and Eq. 3 is for nitrate removal. Both models contain variables for percent of buffer that is vegetated (V_{buff}), and percent of wetland area that is vegetated with macrophytes (V_{mac}).

$$FCI_{NH3} = V_{dry} \times \left(\frac{V_{buff} + V_{mac} + V_{LU}}{3} \right) \qquad \text{(Eq. 2)}$$

The ammonia model contains two additional variables. The first variable (V_{dry}) describes the wetland hydroperiod, which is scaled to reflect the duration of inundation (Table 3, Appendix I). This variable describes the tendency of the wetland to dry out or draw down, which theoretically promotes nitrification. V_{dry} values are high for systems with frequently fluctuating water levels, such as those classified as seasonally flooded or saturated. Lower values would be assigned to wetlands classified as permanently flooded or intermittently flooded. The ammonia model also includes a term for wetland and catchment land use (V_{LU}). This variable is the observation that surface waters collected from a grazed site appear to have higher ammonia concentrations than waters collected from non-grazed sites. We used Table 5 (Appendix I), which was developed from phosphorus concentrations associated with runoff from different land uses, to assign values to V_{LU}.

$$FCI_{NO3} = \left(\frac{V_{buff} + V_{mac}}{2} \right) \qquad \text{(Eq. 3)}$$

Phosphorus Retention Model

Phosphorus retention is defined as the capacity of a wetland to remove phosphorus from overlying water and provide long-term storage of that phosphorus in sediments, soils, plant material, or other biota. Although phosphorus removal may occur when vegetation is harvested or sediment is removed, these processes are difficult to predict and therefore are not considered in this model.

Phosphorus enters CPWs primarily via wet and dry deposition, surface runoff, and piped or channelized inflows. Because phosphate has a strong affinity for clay and other mineral particles, much of an annual phosphorus load may enter wetlands sorbed to particulate matter during one or two large flood events (McKee et al. 2000). These particulate phosphorus loads often settle out in wetlands and become a permanent part of the bottom sediments. Thus wetlands with low water velocities and high hydraulic roughness would be expected to have good suspended sediment and particulate phosphorus removal. Macrophytes also contribute to total phosphorus retention by providing hydraulic roughness which slows water velocities and thus enhances sedimentation of particulate-phosphorus.

The primary mechanisms of wetland phosphorus storage are: (1) microbial uptake by plankton and periphytic organisms, (2) plant uptake, (3) incorporation of organic phosphorus into soil peat, and (4) soil adsorption (Richardson 1985). Inside the wetland, phosphorus may be taken up by plankton and periphyton, but this storage pool is small with rapid turnover. Macrophytic production may account for measurable phosphorus uptake, however approximately 30-75% of the nutrient is seasonally released back to the water column during senescence, with some permanent storage as peat and litter (Richardson and Craft 1993). Adsorption of dissolved phosphorus to soil and sediments is the largest retention processes in wetlands with mineral soils.

Whereas the atmosphere is the ultimate sink for nitrogen, the sediment-litter compartment contains greater than 95% of the phosphorus in natural wetlands (Faulkner and Richardson 1989). Phosphorus associates with sediments through sorption, precipitation, and incorporation into the crystalline lattice of iron, aluminum and calcium compounds (Nichols 1983). Several researchers have found that phosphorus sorption to natural and artificial substrates is correlated to their iron and aluminum contents (Sakadevan and Bavor 1998, Reddy and D'Angelo 1997, Pierzynski 1991). Although anaerobic conditions can lead to the release of iron-bound phosphates from sediments, soils with high mineral or clay contents are generally predicted to have high phosphorus retention capacities (Zahina et al. 2001, Masscheleyn et al. 1992, Cedfeldt et al. 2000). However, even wetlands with high phosphate-sorbing mineral soils can become saturated with respect to phosphorus. At high phosphorus loading rates (e.g. wastewater effluent at concentrations of 2 mg L^{-1} or higher), wetlands may eventually become a phosphorus source rather than a sink (Tilton and Kadlec 1979, Forbes et al. 2004).

Wetlands with shallow, slow moving water and dense vegetation would be predicted to have a high capacity for settling particulate phosphorus. In addition, wetlands with clay soils would be expected to retain phosphorus at low phosphorus loading rates. Wetlands with high vegetation production rates and prolonged inundation would also provide some long-term phosphorus storage through the accumulation of litter and peat (Mitsch and Gosselink 1993). A conceptual model for phosphorus retention in CPWs (Eq. 4) includes variables for adjacent buffer (V_{buff}), the density of macrophytes (V_{mac}), and the soil clay content (V_{clay}). To account for a wetland's potential for phosphorus saturation, land use (V_{LU}) and the ratio of the wetland surface area to catchment surface area (V_{catch}) are also included. Note that unimpacted land use categories such as forested or natural areas will have the highest value (i.e. 1.0) whereas land uses associated with phosphorus pollution (i.e. agriculture) will have small values (i.e. 0.05).

$$FCI_P = \left(\frac{V_{LU} + V_{catch}}{2}\right) \times \left(\frac{V_{buff} + V_{mac} + V_{clay}}{3}\right) \quad \text{(Eq. 4)}$$

Heavy Metal Retention Model

Heavy metal retention is defined as the capacity of a wetland to remove heavy metals from the overlying water and provide long-term storage in sediments, soils or plant material. Heavy metals enter wetlands from a variety of sources including fertilizer impurities, tire dust, cement production, wastewater, urban runoff, combustion products of fossil fuels, industrial sources, and natural sources. The dispersion of heavy metals into the atmosphere, both as particles and as vapors, often exceeds levels associated with natural releases (Stumm and Morgan 1996).

There are three primary mechanisms for heavy metal sequestration in wetlands (Kadlec and Knight 1996): (1) binding to particulates and soluble organics through cation exchange and chelation, (2) precipitation as insoluble salts, principally sulfides and oxyhydroxides, and (3) uptake by biota. Studies of heavy metal retention by treatment and natural wetlands indicate that sediments are the primary storage components for metals, with minor (~2%) retention in plant tissue (Lesage et al. 2007, Zuidervaart et al. 1999).

There is considerable variation in behavior and removal efficiencies among individual metals. For example, iron and manganese have been shown to increase in some treatment wetlands due to their solubilities under reducing conditions (Lesage et al. 2007, Nelson et al. 2004). Mercury is unique for several reasons: it is primarily transported atmospherically, it may volatilize from sediments to the atmosphere, it may be methylated under anaerobic conditions to a more toxic form (mono- and dimethyl mercury) which also bioconcentrates in animal tissue. Due to the unique properties of mercury, this metal is not included in the functional model.

In general, well buffered, alkaline soils and the presence of organic matter or clay increase the ability of wetlands to remove heavy metals from the water column via sorption and precipitation. In nonacidic soils with plentiful sulfates, carbonates, or phosphates, metals can form insoluble complexes (e.g. metal sulfides) and be retained more or less permanently in the sediments. Soil organic matter may also form stable complexes with metal ions, however this variable was eliminated due to our inability to represent it with GIS databases. The presence of vegetation and appropriate soil types adjacent to the wetland (buffer) also enhances retention of heavy metals by slowing runoff, settling particulates, and facilitating contact with soils. The functional assessment model for heavy metal retention is shown below (Eq. 5). The index increases when wetlands contain nonacidic soils, soils with high clay contents, dense macrophyte cover, and vegetated buffers. A low rating is assigned to wetlands with acidic soils or soils that are low in organic matter or clay, and with sparse vegetation.

$$FCI_{Me} = \frac{\frac{V_{buff} + V_{mac}}{2} + V_{clay} + V_{soilpH}}{3} \qquad \text{(Eq. 5)}$$

Organic Compounds Removal

Organic contaminant removal or retention is defined as the capacity of a wetland to remove or transform organic contaminants present in the water column. Organic contaminants include a wide variety of compounds, both natural and synthesized. Organics that are of particular concern for water quality include pesticides, petroleum hydrocarbons, and other industrial organics such as solvents. Additional pathways for the removal or retention of organics in wetlands are a function of their tendency to serve as food for microbes and to degrade over time particularly when exposed to the atmosphere and sunlight. The major pathways for removal of hydrocarbons from wetlands waters are: (1) volatilization, (2) photochemical oxidation, (3) sedimentation, (4) sorption, and (5) biological degradation (Kadlec and Knight 1996).

Photochemical oxidation rates are chemical specific. In general, however, longer hydraulic retention times and shallow water depths should result in greater degradation of organics via this process. The capacity of an organic contaminant to settle out of the wetland would be dependent upon its ability to associate with particulate matter. Charged (polar) organics may associate ionically with clays while nonpolar molecules tend to associate with organic matter in the wetland. Partitioning of organics between aqueous and solids (particulates, sediments, etc.) can be predicted to some extent using physicochemical properties of organic compounds such as the relative partitioning between the liquid octanol and water coefficient (K_{ow}) and water solubilities (Sawyer et al. 1994).

A conceptual model for removal or retention of organics (Eq. 6) includes variables for a wetland surface area to catchment surface ratio (V_{catch}), density of vegetation (V_{mac}). V_{catch}, which is correlated to relative hydraulic retention time, is predicted to have a greater role in functional capacity than vegetation density or soil organic matter.

$$FCI_{org} = \frac{V_{mac} + V_{catch}}{2} \qquad \text{(Eq. 6)}$$

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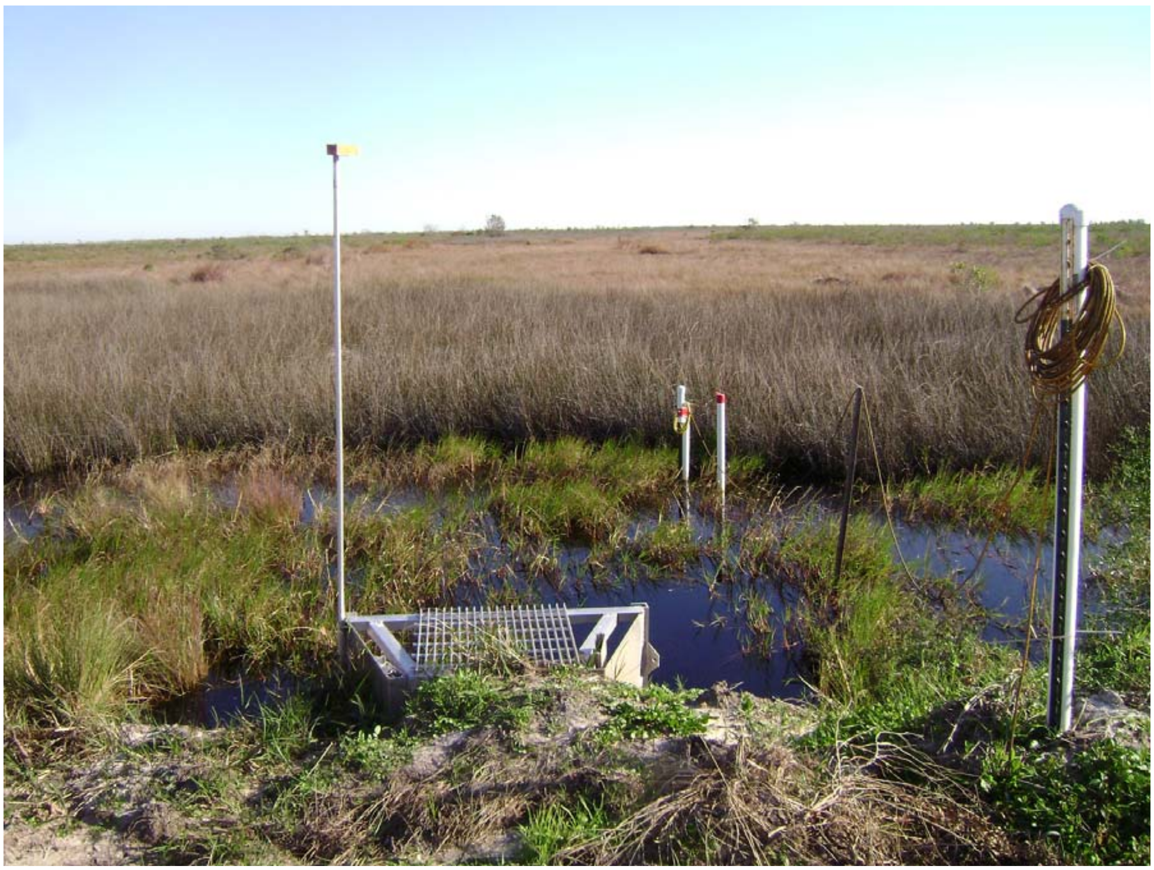
C. Hydrology



Weir and water level recorder at Chicken Road, Brazoria County, 17 November, 2009

Introduction

The hydrology of CPWs is an integral factor in the performance of several wetland functions, and is an important element for establishing a meaningful connection (i.e. nexus) between isolated wetlands and other surface waters. Of course no wetland is isolated from an ecological standpoint, but studies on isolated wetlands in other regions of the U.S. have shown that these wetlands often possess hydrologic connections to other water bodies by groundwater flow and intermittent surface flow (Tiner 2003a, Leibowitz and Nadeau 2003, Winter and LaBaugh 2003). Additionally, variations in wetland hydrology have important effects on wetland ecological structure and function (Sharitz 2003).

The frequency and duration of surface water connectedness is largely dependent on the magnitude, frequency, and timing of weather events as they relate to the antecedent moisture condition of the wetland and catchment area (Leibowitz and Vining 2003, Winter and LaBaugh 2003). In addition to climate variability and antecedent conditions, wetlands occurring on less permeable soils may be more likely to accumulate water and spill over (discharge) depending on their storage capacity (Winter and LaBaugh 2003).

The storage of local flood waters and flood peak desynchronization are also important function performed by CPWs. Capturing runoff increases evapotranspiration and infiltration thereby desynchronizing inputs to channels and attenuating peak flows, which can reduce flooding (McAllister et. al. 2000, Ward and Trimble 2003). Moreover, wetlands can regulate the volume and strength of freshwater runoff into streams (Demissie and Khan 1993) and estuaries with ecologically sensitive salinities (Tiner 2003b).

Unfortunately, few studies exist that describe the hydrology of CPWs. Sipocz (2002) studied the hydrology of four local watersheds containing CPWs: two at Armand Bayou, one within Addicks Reservoir, and one at the Nannie M Stringfellow Wildlife Management Area. Sipocz found that 25% of the annual precipitation left the watersheds as runoff and 76.5% of that runoff passed through CPWs prior to discharging into interstate waters. Sipocz described their hydrology as draining in a stair-step fashion. Miller and others (Kishne 2009) reported on two wetland hydrology studies along the coastal plain and concluded that most CPW soils are episaturated. Episaturation denotes a perched water table and is evidenced by soil that is saturated with water in one or more layers within 200 cm of the surface, with one or more unsaturated layers below the saturated layer. Thus, with the exception of coastal dune wetlands or CPWs occurring within sandy or alluvial soils, most CPWs have little groundwater exchange.

The objectives of this study were to describe the hydrologic processes of selected CPWs by measuring discharge and constructing water budgets. Both the flood storage capacity and the regularity of discharge are important issues for the regional valuation of CPWs. Therefore this study attempts to answer the following three questions:

1. What are the major processes controlling wetland water storage and discharge?
2. What is the water storage capacity of CPWs?
3. What is the frequency of CPW discharge?

Methods

Water Budget

Monthly water budgets were constructed for the six initial wetland sites. Discharge and rainfall measurements have been collected for the remaining six sites. Water budgets were quantified in terms of the change in storage (ΔS) described in Equation 1.

$$\Delta S = A(PPT - ET) + Inflow - Outflow \pm GW \quad \text{Eq. 1}$$

where:

ΔS = increase (negative values) or decrease (positive values) in storage capacity relative to previous time period (m^3)

A = area of the wetland (m^2)

PPT = precipitation (m)

ET = evapotranspiration (m)

Inflow = runoff from the wetland catchment area into the wetland (m^3)

Outflow = water flowing out of the wetland catchment area when the storage capacity of the wetland has been exceeded (m^3)

GW = net gain or loss in storage due to interaction with groundwater (m^3)

Wetland areas were obtained from the NWI database. Wetland volumes were determined from LiDAR data as described in Section E of this report. Wetland volumes were based on the amount of water held within the wetland at the spill-point elevation and were used to estimate the available storage based on the water budget calculations. Catchment areas were delineated from

LiDAR derived DEMs (Section E of this report) for four of the sites. For CR and WD, a 100-m wide buffer strip was used as a catchment area.

Precipitation, Potential Evapotranspiration and Actual Evapotranspiration

Precipitation (PPT) was measured with Onset tipping bucket rain gauges with Hobo data loggers. One tipping bucket was installed for each pair of study sites. The tipping buckets were installed at SW, CR, and KS. PPT data from nearby weather stations were used to replace missing data when gauges malfunctioned. Nearby weather stations were also used to estimate average monthly and annual PPT for each study area from the long-term record.

Estimates of potential evapotranspiration (PET) were calculated using the Thornthwaite empirical model (Eq. 2, Ward and Trimble 2003).

$$PET = N\ 16\ [10\ tc / I]^{a} \qquad \text{Eq. 2}$$

where:

PET = adjusted monthly potential evapotranspiration

tc = mean monthly temperature in degrees Celsius

I = the heat index for the year based on the average temperatures for the six months before and after tc: $I = \sum i12 = \sum [\ tc / 5]^{1.5}$

a = location-dependent coefficient calculated from the equation below:

$a = 6.7 \times 10^{-7} I^3 - 7.7 \times 10^{-5} I^2 + 1.8 \times 10^{-2} I + 0.49$

N = latitude correction which corrects for day length

The Thornthwaite model calculates monthly PET using a simple model developed for humid grasslands based on average monthly air temperatures and latitudinal correction. It was chosen for its simplicity and ease of use with available data. A shortcoming of the Thornthwaite model is that it defines PET as the water loss that will occur if there is no shortage of water; however, CPWs are seasonally inundated. Our estimates of wetland volumes do not include soil pore space; therefore, continued evaporation of soil water was not accounted for in the water budgets. Average monthly temperatures for Anahuac, Brazoria and Armand were obtained from National Weather Service, stations 410235, 413340, and 410586 respectively.

Runoff

Inflow associated with runoff from wetland catchment areas was calculated by the Stormwater Management and Design Aid (SMADA) via the NRCS curve number method. SMADA is a stormwater modeling computer program developed at the University of Central Florida. The NRCS procedure was chosen based on available data and calculates runoff (i.e. excess rainfall) by the relationship given by Equation 3.

$$Q = (P - I_a)^2 / (P - I_a + S) \quad \text{Eq. 3}$$

where:

Q = accumulated runoff or excess rainfall

P = the rainfall depth in inches

$S = 1000 / CN - 10$ where CN is the curve number

I_a = the initial abstraction in inches that includes surface storage and infiltration prior to runoff. I_a is commonly approximated as 0.2S, thus Eq. 3 becomes Eq. 4

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad \text{Eq.4}$$

The NRCS curve number is a function of the infiltration capacity of the soil as given by the hydrologic soil groups A-D, land use, and the antecedent soil moisture conditions (Ward and Trimble 2003).

Groundwater Exchange

Groundwater recharge, discharge, and infiltration were assumed to be negligible as a result of heavy clay soils underlying the region. Water can be absorbed by wetland and catchment area soils; however, transmission of water long distances through soil is limited by the clay pan. Investigations of wetland soils in the region have demonstrated that they tend to be episaturated, with a zone of unsaturated soils between the surface saturated soils and the unconfined groundwater table (Kishné 2009, Wes Miller personal communication 2010). We installed and monitored a shallow groundwater piezometer at WD and found that at 1 m below ground, variations in water levels did not reflect variations in surface water levels.

Discharge

Outflow volumes (discharge) were calculated using a weir constructed at the wetland spill point if a discrete outlet could be located. Weirs were calibrated to a known elevation and the water level in the weir was monitored by a pressure transducer installed near the weir. At WD, a discrete outlet could not be located, therefore water level data were analyzed to estimate a spill point elevation. The outlet level was determined by the rate of water level drop. The decrease in water level (slope of the hydrograph line) is steep when water is discharging; however, once the water level drops below the outlet level, water level declines are primarily due to ET. The spill point elevation at WD (47 cm) was determined by the occurrence of a near zero slope for a period of 5 hours (inset, Fig. C1). For WD, outflow was calculated by subtracting available storage from direct PPT and runoff from the catchment area. WD was treated as a rectangular pool where every rise in water level meant an equal proportion of volume in the wetland. This method was validated at study sites with obvious spill points. For example, the hydrograph from the KS weir revealed an approximate spill point of 20.5 cm (horizontal line, Fig. C2). Spill-point elevation was measured on 2 Nov 2009, 1430 hrs, when the water

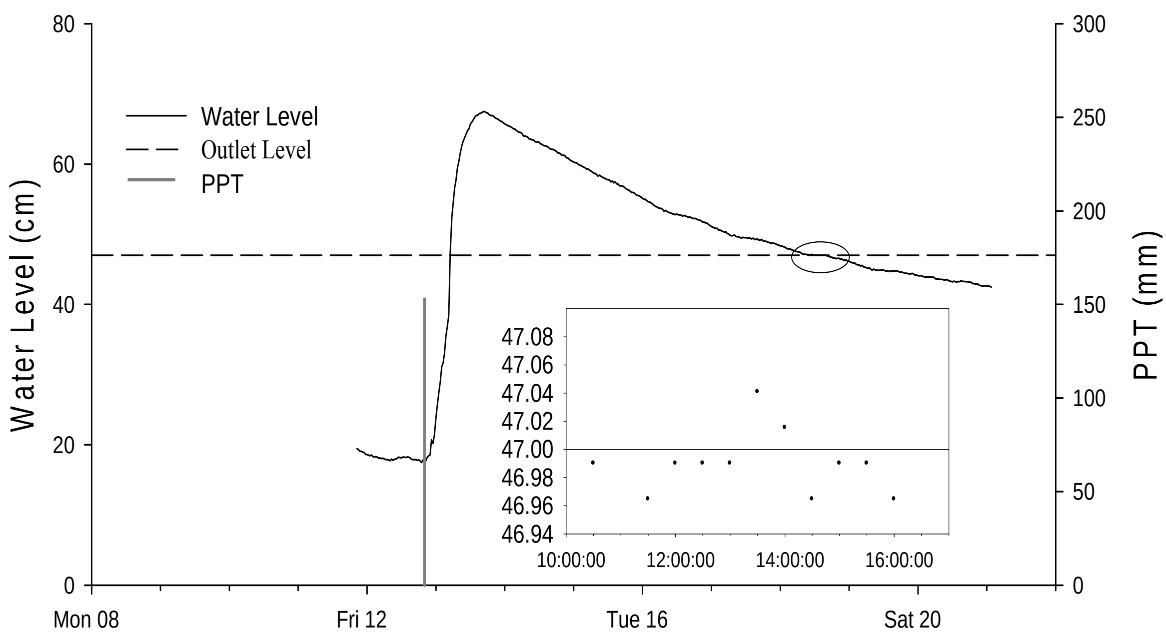


Figure C1. WD hydrograph from hurricane Ike relative to the estimated spill point elevation (47 cm). Inset: each dot represents a depth recorded by the pressure transducer. There is no noticeable change in water level over the five hour period.

was observed flowing through the weir. The water level was physically measured 2 cm above the v-notch and the transducer reading was 22.47 cm; thus, the simultaneous occurrence of a near zero water level slope and measured spill point elevation of 20.5 cm prediction of spill-point was confirmed.

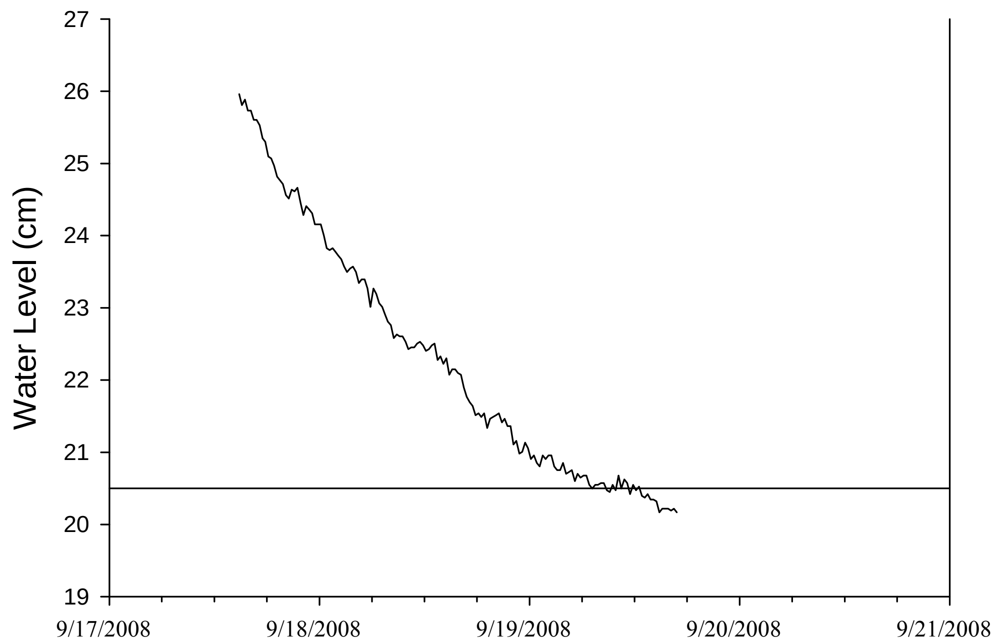


Figure C2. Water level at KS weir after Hurricane Ike relative to outlet level of 20.5 cm.

Results and Discussion

Study Period Climate

In general, the study period was drier than normal with a few wetter than normal months (Fig. C3, C4, and C5). Cumulative PPT measurements for 20 months shown were 2,263 mm, 1,544 mm, and 2,059 mm for Armand, Brazoria, and Anahuac respectively. These totals are 45%, 45%, and 50% below average for Armand, Brazoria, and Anahuac respectively. Above normal PPT occurred at Armand, Brazoria, and Anahuac only in 30%, 15%, and 20% of the months respectively. The drier than normal weather conditions provide a conservative estimate of discharge frequency and may lead to an overestimation of water storage, particularly for the Brazoria sites, which experienced the driest conditions.

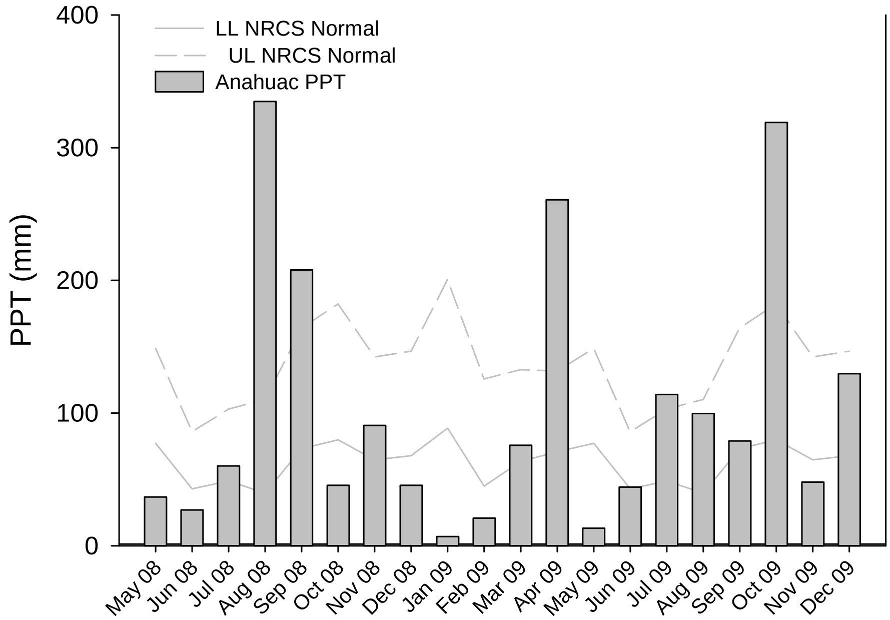


Figure C3. Monthly PPT at Anahuac sites compared to "normal" PPT. LL and UL represent the upper and lower limits of the normal ranges of monthly PPT defined by the NRCS.

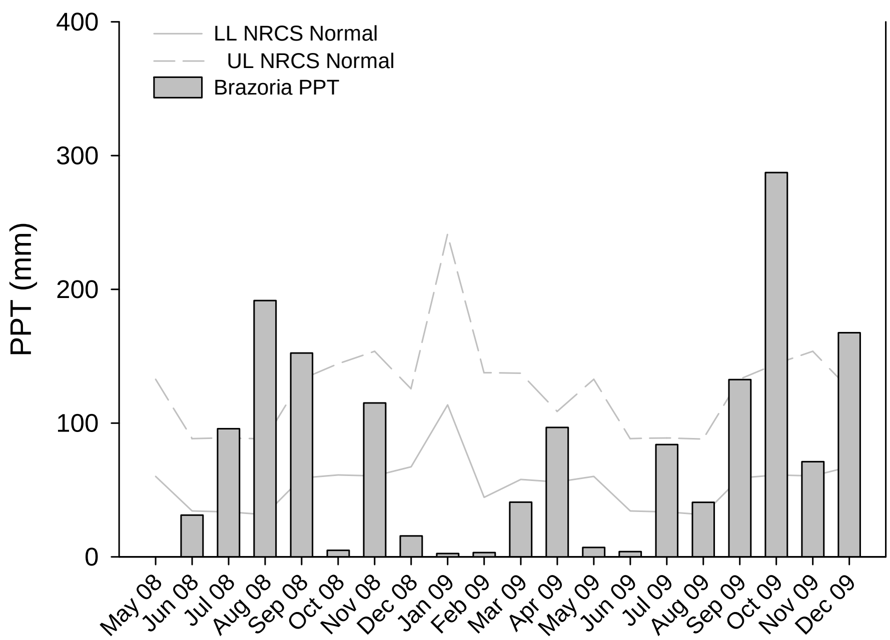


Figure C4. Monthly PPT at Brazoria sites compared to "normal" PPT. LL and UL represent the upper and lower limits of the normal ranges of monthly PPT defined by the NRCS.

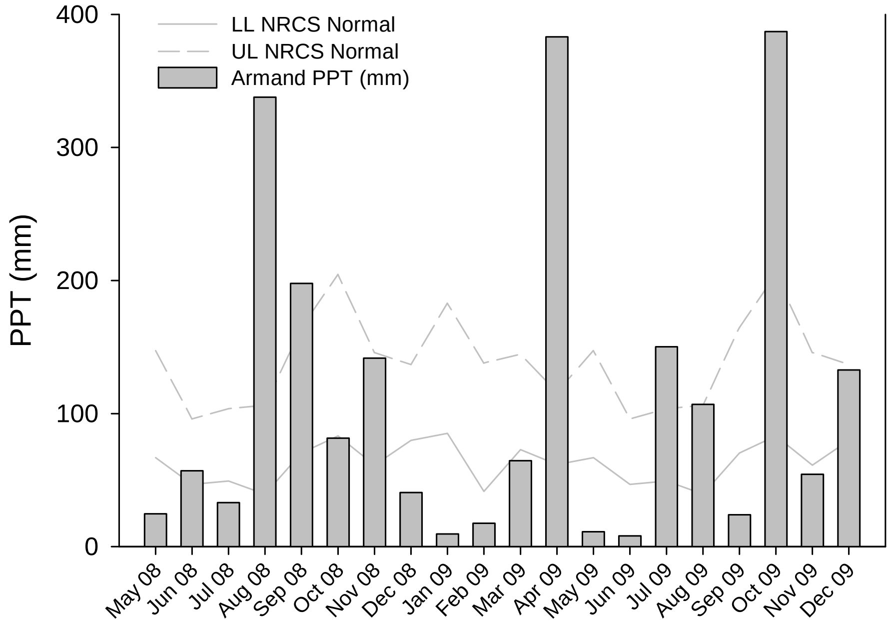


Figure C5. Monthly PPT at Armand sites compared to "normal" PPT. LL and UL represent the upper and lower limits of the normal ranges of monthly PPT defined by the NRCS.

Seasonal Water Budgets

Tables C1 – C7 summarize quarterly water budgets for the six sites for the period June 2008 through November 2009. Wetland water levels were largely dependent on the balance of PPT and ET which was strongly affected by season and weather events. For example, October 2009 was particularly wet with PPTs of 249 mm, 150 mm, and 193 mm above normal for Armand, Brazoria, and Anahuac respectively. Standing water remained through January at all sites except for LC.

Precipitation

Precipitation accounted for just over half of the water entering the wetlands, although at wetlands with relatively small catchments such as WD and TH, PPT accounted for over 90% of incoming water. Precipitation exceeded or equaled PET at all but the Brazoria sites, but this balance is likely to change with deviations from average climate conditions.

Table C1. Turtle Hawk seasonal water budget.

Time Period	PPT (mm)	PPT (m^3)	Runoff (mm)	Runoff (m^3)	PET (mm)	PET (m^3)	Outflow (m^3)	Δ Storage (m^3)	Hydroperiod	Percent Stored
Jun 08 - Aug 08	428	20671	90	1285	549	26515	890	-5448	24	96
Sep 08 - Nov 08	422	20381	125	1785	246	11881	8605	1680	42	61
Dec 08 - Feb 09	68	3284	0	0	79	3815	0	-531	2	100
Mar 09 - May 09	459	22168	134	1914	257	12412	9227	2443	24	62
Jun09- Aug 09	265	12798	9	129	546	26392	0	-13465	0	100
Sep 09 - Nov 09	502	24245	96	1371	240	11599	8155	5862	40	68
Total	2144	103547	454	6484	1918	92613	26877	-9459	132	76

Table C2. Kite Site seasonal water budget.

Time Period	PPT (mm)	PPT (m^3)	Runoff (mm)	Runoff (m^3)	PET (mm)	PET (m^3)	Outflow (m^3)	Δ Storage (m^3)	Hydroperiod	Percent Stored
Jun 08 - Aug 08	428	14643	107	123809	549	18783	0	119669	0	100
Sep 08 - Nov 08	422	14438	143	170303	246	8417	29036	147289	42	84
Dec 08 - Feb 09	68	2327	0	0	79	2703	0	-376	2	100
Mar 09 - May 09	459	15704	152	181079	257	8793	8767	179223	65	96
Jun09- Aug 09	265	9067	14	16392	546	18696	0	6763	24	100
Sep 09 - Nov 09	502	17175	115	137001	240	8217	12894	133065	60	92
Total	2144	73354	531	628585	1918	65608	50697	585633	193	93

Table C3. Chicken Road seasonal water budget.

Time Period	PPT (mm)	PPT (m^3)	Runoff (mm)	Runoff (m^3)	PET (mm)	PET (m^3)	Outflow (m^3)	Δ Storage (m^3)	Hydroperiod	Percent Stored
Jun 08 - Aug 08	319	32998	46	18735	561	58122	8763	-15152	13	83
Sep 08 - Nov 08	272	28211	80	32459	262	27144	25753	7773	90	58
Dec 08 - Feb 09	21	2196	0	0	86	8910	2	-6716	61	100
Mar 09 - May 09	145	14991	4	1455	258	26730	6978	-17261	50	58
Jun09- Aug 09	129	13344	0	0	570	59105	0	-45761	6	100
Sep 09 - Nov 09	491	50859	57	23193	281	29137	8014	36902	58	89
Total	1376	142601	187	75842	2019	209148	49510	-40215	278	77

Table C4. Wounded Dove seasonal water budget.

Time Period	PPT (mm)	PPT (m^3)	Runoff (mm)	Runoff (m^3)	PET (mm)	PET (m^3)	Outflow (m^3)	Δ Storage (m^3)	Hydroperiod	Percent Stored
Jun 08 - Aug 08	319	4939	46	580	561	8692	15	-3188	39	100
Sep 08 - Nov 08	272	4222	80	1005	262	4060	2068	-901	75	60
Dec 08 - Feb 09	21	329	0	0	86	1340	0	-1011	51	100
Mar 09 - May 09	145	2244	4	45	258	4007	0	-1718	38	100
Jun09- Aug 09	129	1997	0	0	570	8846	0	-6849	0	100
Sep 09 - Nov 09	491	7612	57	718	281	4361	0	3969	64	100
Total	1376	21342	187	2348	2019	31305	2083	-9698	267	91

Table C5. LeConte seasonal water budget. September and October 2008 outflow and hydroperiod were not quantified due to loss of equipment during Hurricane Ike.

Time Period	PPT (mm)	PPT (m^3)	Runoff (mm)	Runoff (m^3)	PET (mm)	PET (m^3)	Outflow (m^3)	Δ Storage (m^3)	Hydroperiod	Percent Stored
Jun 08 - Aug 08	393	4073	141	15610	494	5125	7250	7308	30	63
Sep 08 - Nov 08	344	3569	154	17053	232	2407	1299	16916	8*	94
Dec 08 - Feb 09	68	707	0	31	74	768	4	-34	37	99
Mar 09 - May 09	332	3442	84	9311	228	2366	8135	2253	25	36
Jun09- Aug 09	221	2298	30	3264	524	5440	0	122	13	100
Sep 09 - Nov 09	540	5603	190	20983	244	2527	7630	16428	20	71
Total	1898	19691	599	66251	1796	18632	24318	42992	125	72

Table C6. Sedge Wren seasonal water budget. Note that September and October 2008 outflow and hydroperiod were not quantified due to loss of equipment during Hurricane Ike.

Time Period	PPT (mm)	PPT (m^3)	Runoff (mm)	Runoff (m^3)	PET (mm)	PET (m^3)	Outflow (m^3)	Δ Storage (m^3)	Hydroperiod	Percent Stored
Jun 08 - Aug 08	422	10118	170	30875	494	11847	10941	18205	26	73
Sep 08 - Nov 08	331	7938	154	28045	232	5564	76*	30419*	37*	
Dec 08 - Feb 09	77	1847	0	69	74	1775	0	141	84	100
Mar 09 - May 09	276	6619	93	16975	228	5468	5433	12693	78	77
Jun09- Aug 09	247	5914	45	8264	524	12575	0	1603	29	100
Sep 09 - Nov 09	446	10691	95	17356	244	5840	7862	14345	61	72
Total	1798	43127	559	101585	1796	43069	24439	77203	338	83

Runoff

Runoff accounted for an average of 48% of water entering the wetlands, ranging from 5.9% at TH to 89.5% at KS. Runoff estimates were proportional to catchment area (Table C7). The low runoff percentage at TH wetland is due to the small catchment area in relation to the wetland area. Runoff estimates were also influenced by antecedent moisture conditions as several rainfall events may result in zero calculated runoff. Table C8 provides an example of three similar size storms and runoff associated with the three antecedent moisture conditions per NRCS methods. While accounting for slightly less than half water inputs, our runoff estimates do not clearly support our earlier assumptions that precipitation is the major source of water entering CPWs. Clearly runoff volume estimates are highly variable both temporally and seasonally. Furthermore, error associated with these estimates are compounded by errors in catchment size estimates.

Evapotranspiration

Calculated potential evapotranspiration losses (PET) exceeded incoming water at WD which is probably due to underestimation of catchment size and associated runoff volumes. PET accounted for an average of 69% of water lost from the wetlands. PET losses ranged from 43% at LC to 94% at WD. The Thornthwaite method may overestimate PET during times of drought, and underestimate PET at other times. Lu et al. (2005) found the Thornthwaite method to consistently yield the lowest long term average annual PET when compared to 6 other PET models at 39 weather stations across the Southeastern United States. Regardless of the uncertainty associated with calculated PET, our results support the assumptions that PET is the primary pathway for water losses in CPWs.

Storage

Water stored in the wetland (i.e. the portion of water not discharged) ranged from 72% of inputs at LC to 93% at KS. WD and SW stored 91% and 83% respectively. CR is located in a remnant channel and during larger PPT events, will receive water conveyed from a much larger area than we estimated. LC catchment does not include a large wetland just upgradient that discharges into LC during some events. We are in the process of recalculating these catchment areas and will subsequently recalculate runoff and water budgets for these two sites.

Table C7. Catchment and wetland areas of the six wetlands.

Study Site	Catchment Area (ha)	Wetland Area (ha)
Chicken Road	40.4	10.3
Wounded Dove	1.25	1.55
Turtle Hawk	1.4	4.8
Sedge Wren	18.2	2.4
Kite Site	115.7	3.4
LeConte	3.1	1.0

Table C8. Runoff calculations for three PPT events of similar magnitude.

PPT (mm)	Antecedent Moisture Condition	Curve Number	Runoff (mm)
30.00	1	63	0
26.16	2	80	2
23.40	3	91	8

Discharge Frequency

Hydrographs for the six wetlands are presented in Figures C6 through C11. Appendix X includes short-term hydrographs for the randomly selected wetlands. The dashed lines in these figures indicate the spill point elevation, therefore water levels above these lines indicate an outflow event (discharge). All study sites overflowed during the monitoring period. Wounded Dove overflowed the least (twice), while discharge at LeConte, the shallowest and most sloped wetland, was recorded 19 times throughout the study period.

Discharge volumes averaged 18% of incoming water to the six wetlands; however discharge was dependent on antecedent conditions and water levels. Frequent discharge occurred at all of the study sites during periods of limited storage capacity. The average outflow duration was 27 days, but periods of outflow ranged from 1 day for small outflow events to 98 days at Sedge Wren. Figure C12 shows the longest outflow event (98 days) recorded during the study period; several PPT events occurred during the discharge period, which sustained the water level above the spill-point elevation. The number of outflow days was greatest during autumns of 2008 and 2009 when there was a surplus of PPT and cool temperatures (Table C9).

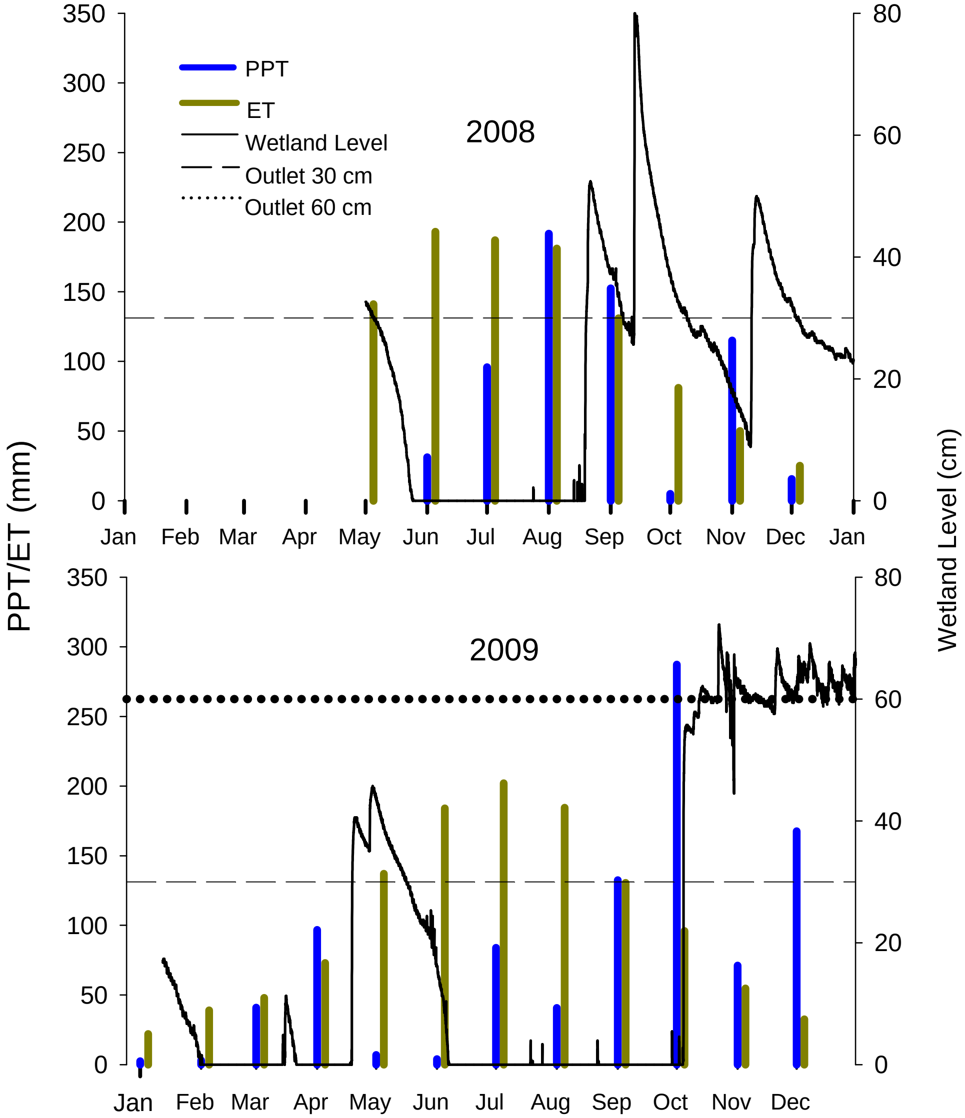


Figure C6. Chicken Road 2008 and 2009 hydrograph with monthly PPT and PET. The dashed line is the original weir outlet elevation. In Oct 2009, a new weir was installed, raising the spill point elevation from 30 to 60 cm.

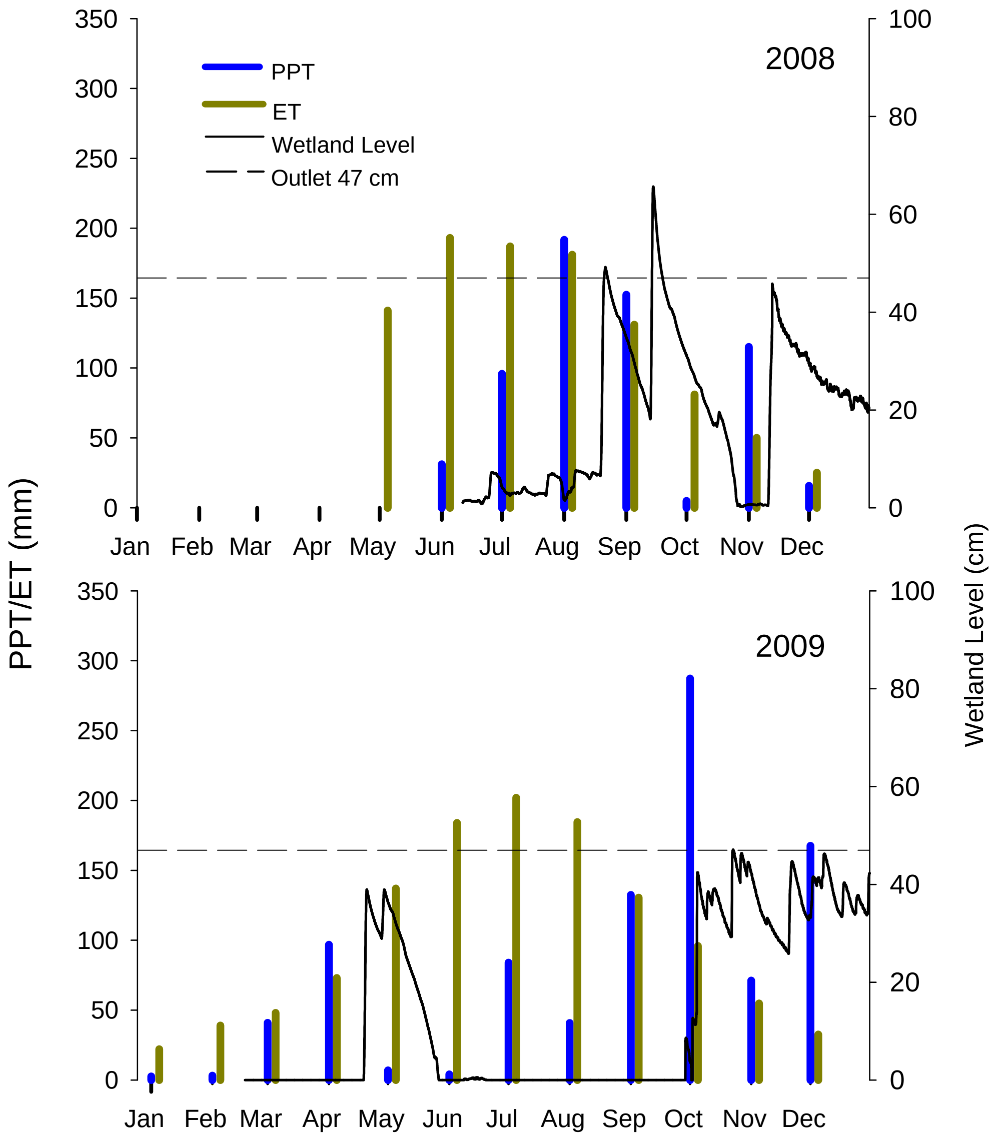


Figure C7. Wounded Dove 2008 and 2009 hydrograph with monthly PPT and PET. The dashed line is the original weir outlet elevation.

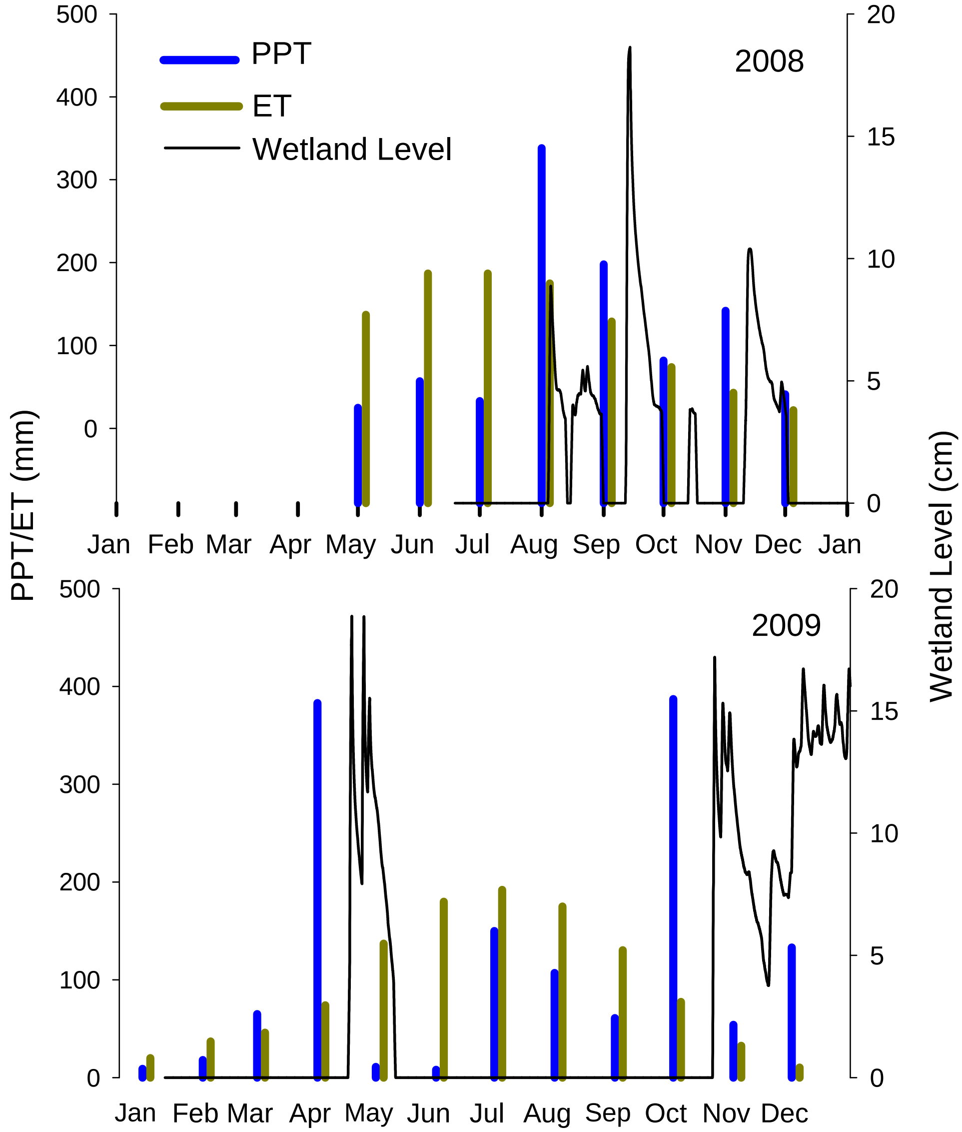


Figure C8. Turtle Hawk Bird Blind 2009 water level hydrograph with monthly PPT and PET. The dashed line is the outlet elevation.

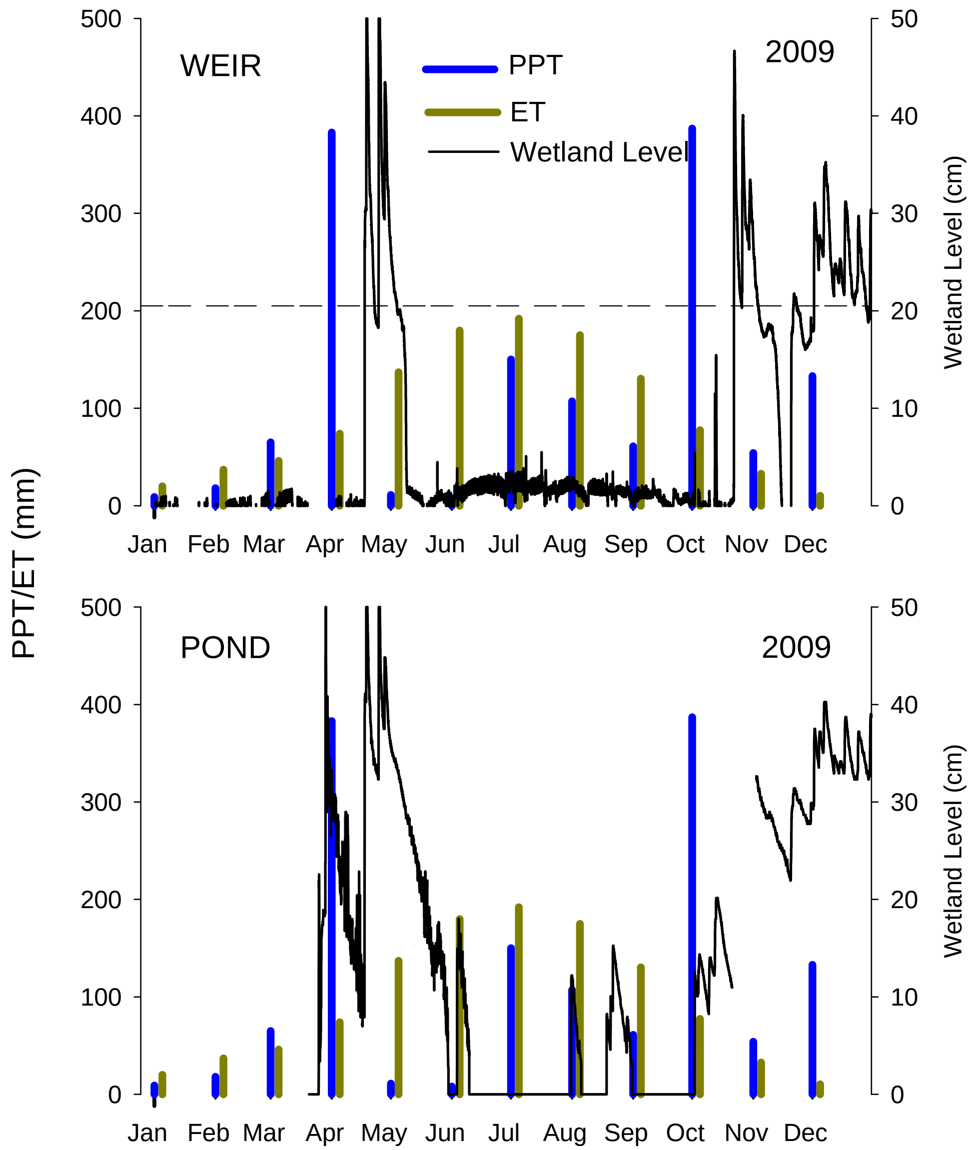


Figure C9. Kite Site 2009 weir and interior pond hydrographs with monthly PPT and PET. The dashed line is the weir outlet elevation.

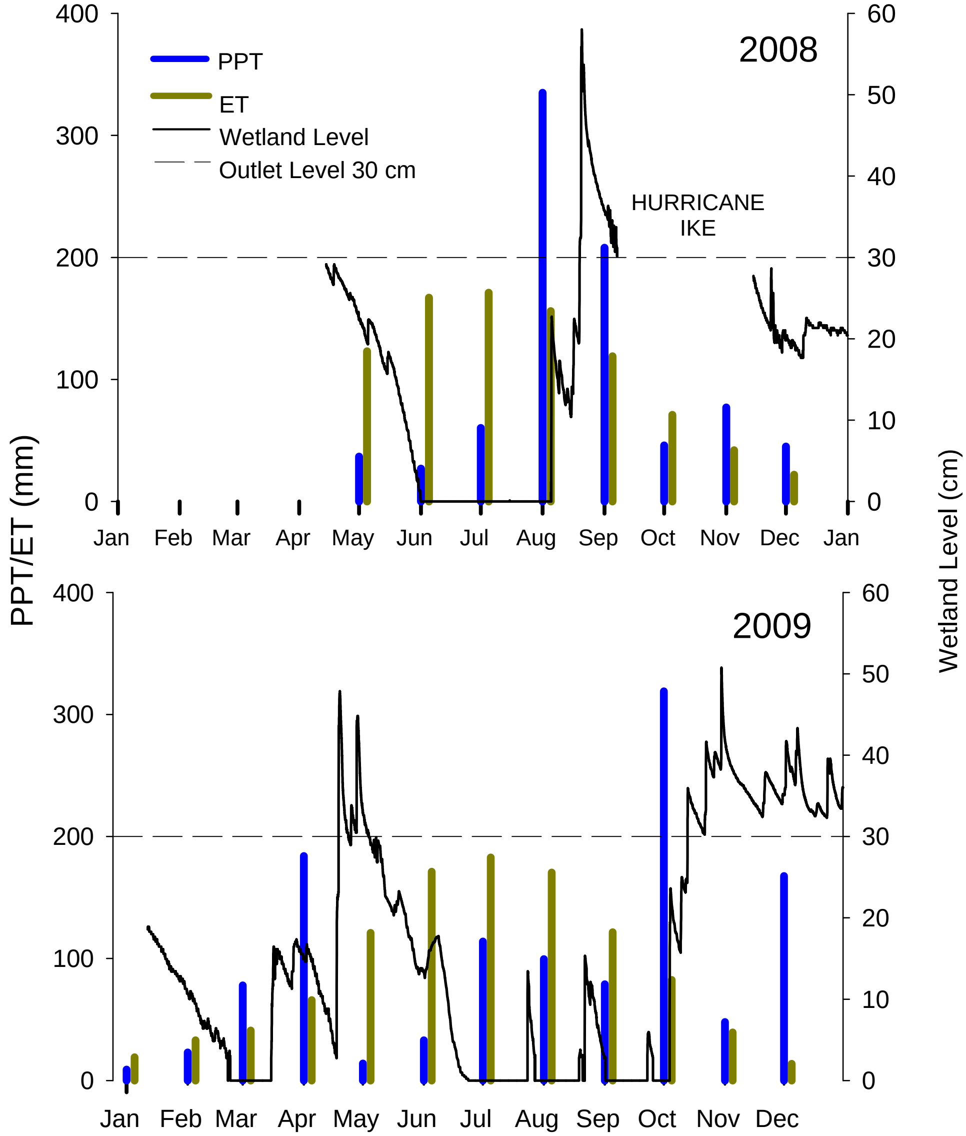


Figure C10. Sedge Wren 2008 and 2009 hydrograph with monthly PPT and PET. The dashed line is the outlet elevation.

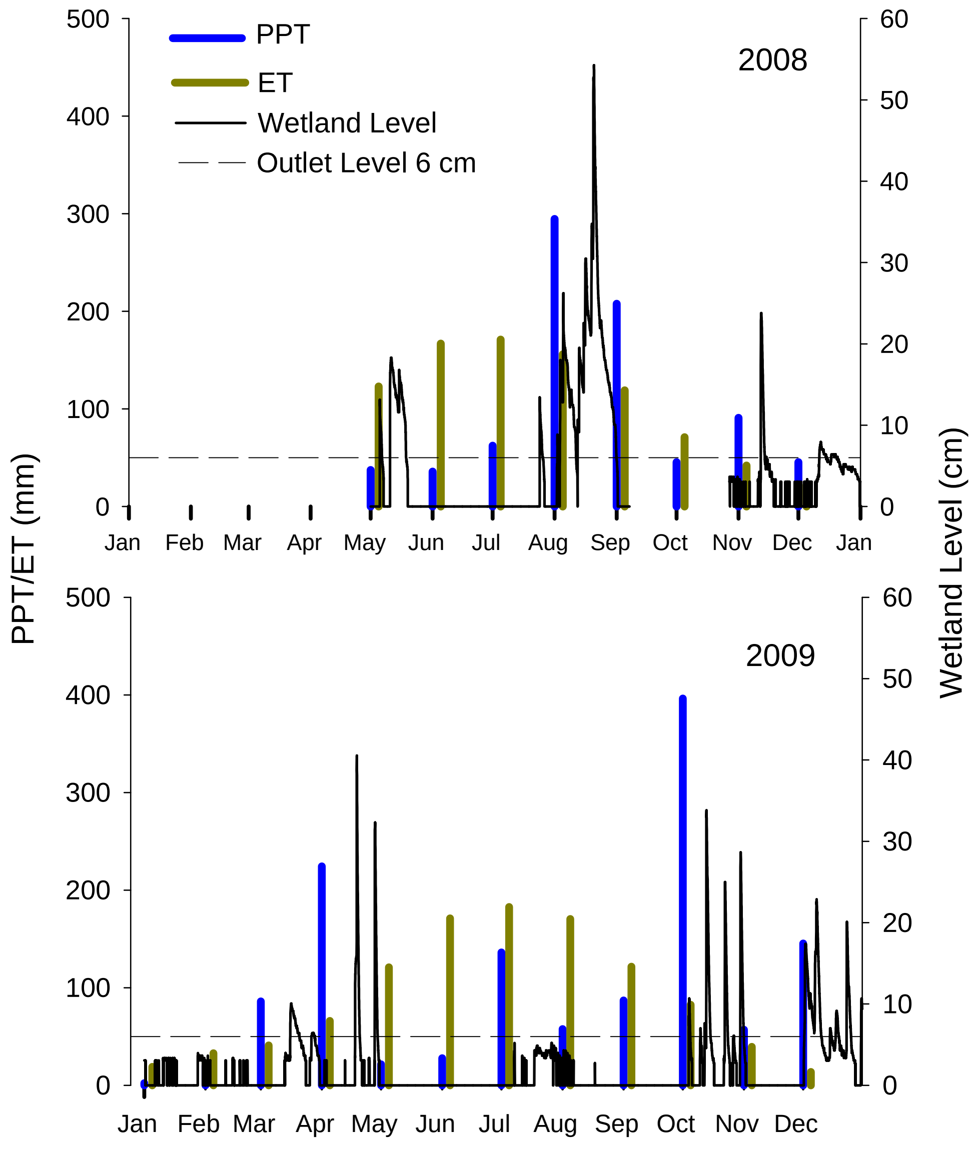


Figure C11. LeConte 2008 and 2009 hydrograph with monthly PPT and PET. The dashed line is the outlet elevation.

Based on the number of quarterly periods with discharge during the six quarters studied, the discharge frequency was 33% at WD, 50% at SW and KS, 67% at TH, and 83% at CR and LC. Thus, although on a volume basis most of the incoming water was stored in the CPWs, they also exhibited a regular discharge frequency.

Table C9. Average PPT, number of days inundated, discharge volume, and days with discharge for the six monitored wetland.

Season	PPT (mm)	Days Inundated	Discharge (m^3)	Days Outflow
Jun 08 - Aug 08	128	26	27045	12
Sep 08 - Nov 08	115	62*	127117	19*
Dec 08 - Feb 09	18	40	1	2
Mar 09 - May 09	101	47	6423	12
Jun 09 - Aug 09	70	12	0	0
Sep 09 - Nov 09	165	51	7426	16

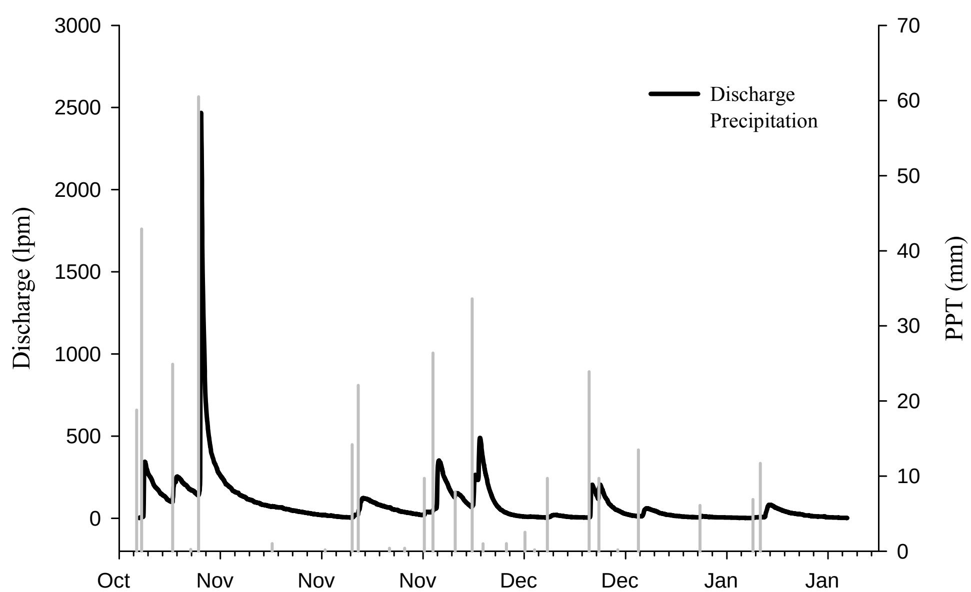


Figure C12. SW discharge event 10/21/2009 – 1/27/2010; the longest discharge event recorded throughout the study period..

Antecedent Moisture

Figure C13 illustrates the importance of antecedent moisture conditions as indicated by patterns of PPT. In this example, several PPT events occurred, but were quickly absorbed by the dry soil. Because these storms occurred within a short period of time and were able to saturate the soil, accumulation of surface water occurred on August 19th 2008 resulting in eventual discharge from the wetland at the 30 cm spill point elevation.

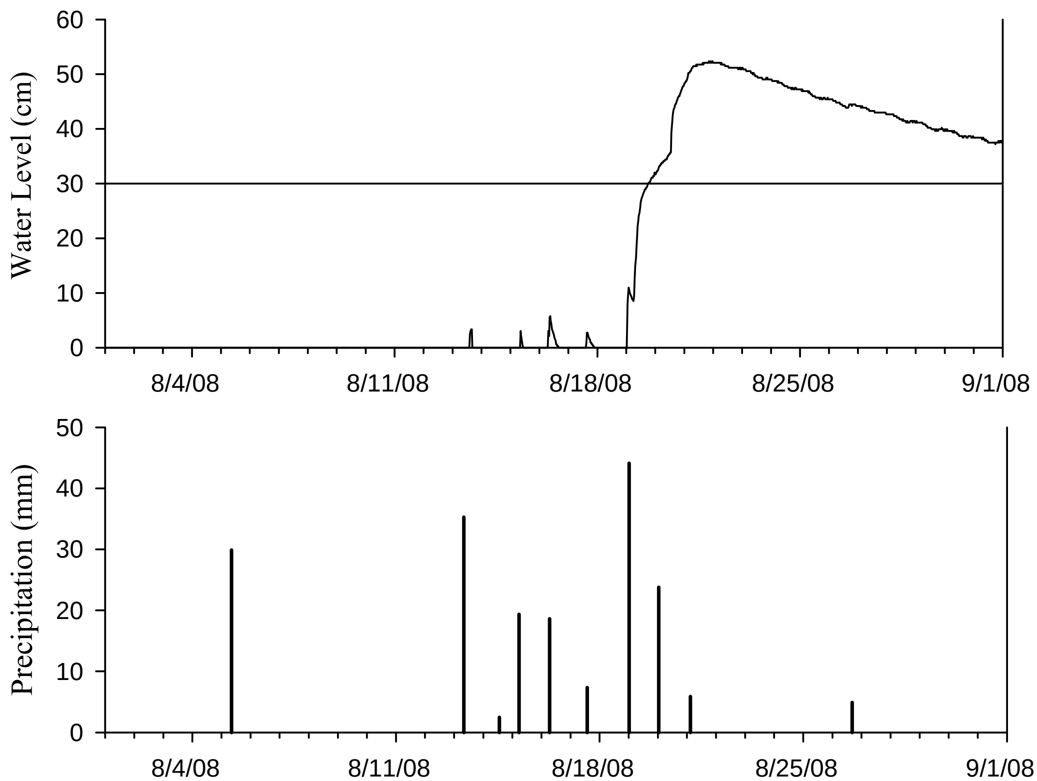


Figure C13. Chicken Road August 2008 water level hydrograph and PPT.

Limitations and Uncertainty

Catchment area is an important variable in runoff volumes calculation used in these water budgets. In the extremely low relief landscape that characterizes the study area, catchment size calculations represent a substantial source of error. The error is obvious for CR and LC, where measured discharge exceeded inflow. Furthermore, the ratio of wetland area to catchment area is considered constant when calculating water budgets. However, the area of land inundated with water fluctuates with fluctuating water levels. This will lead to an underestimation of runoff and overestimation of direct PPT in times when water level is low and the area of inundation is smaller than the wetland area. Because the actual inundated area is often smaller than the NWI wetland area, this error more often represents an overestimation of water entering the wetlands. Errors in wetland volumes determined from LiDAR derived DEMs affect the accuracy of storage estimates.

Hydrologic modifications have altered the hydrology of most watersheds in the study area. All but two sites (WD and TH) are impacted by a nearby road/culvert system at or near the downgradient end, however these culverts are placed at what appears to be a natural outlet level; that is, the wetlands are not artificially impounded.

The Thornthwaite method may overestimate or underestimate ET. Site specific conditions that are not accounted for by the Thornthwaite equation can produce errors in PET estimates. These conditions include wind, humidity, temperature variations, vegetation type, and canopy cover.

The accuracy of estimating discharge through a weir is affected by water level relative to the weir. Both the 90° V-notch weir and the rectangular weir are intended to measure flow that has a minimum head (drop) of 6 cm. The flat topography of the study area made it difficult to attain the necessary drop required for accurate weir calculations. Additionally, at higher flow rates, some weirs were overtopped. We observed this at the Kite Site weir, but it probably also happened during peak flows at the other sites with weirs. While insufficient drop would overestimate discharge, this would occur during low to moderate discharge events. Overtopping the weir would occur during high discharge events, and would constitute a significant underestimation of discharge volume. However neither factor affects the accuracy of discharge frequency which is based strictly on surface water elevation. Outflow volumes calculated without weirs depend on the accuracy of the determined spill-point elevation, precipitation volume, runoff volume, and wetland volume. Spill-point elevation of the wetlands without an obvious spill-point is determined from inferences made by observing the hydrograph.

Error in PPT measurements result from difference in spatial distribution of rainfall. Tipping bucket rain gauges were installed at each pair of sites; however, PPT volumes can still vary between the two sites. This error is probably greater during the late spring and summer months when PPT events are characterized by flashy thunderstorms that can drop considerably different volumes of rain in two locations a mile apart.

Conclusions

Water budgets synthesize several variables (e.g. catchment area, evapotranspiration, discharge) that are difficult to accurately measure. Additionally, the low relief landscape that characterizes this study area only compounds these difficulties. Potential errors were present in all components of the water budgets; however, estimates of catchment areas were probably the largest source of error in the quantification of the budgets. Even if these catchments were surveyed, they are likely to be dependent on the PPT event and during large events they would likely be meaningless. Catchment error most affected CR and LC. Further analyses are needed to more accurately determine the catchment area and percent storage for these two wetlands. Moreover, catchment size did not impact the accuracy of measurements of outflow frequency, PPT, or EVPT.

Despite these issues, our results represent the most detailed hydrologic description of CPWs in the study area and perhaps in the entire Coastal Prairie Ecosystem. CPWs in the study area likely provide considerable storage of PPT and flood waters within their catchment area. Most PPT events were completely stored by the wetlands. The majority of water entering the wetlands is stored and lost primarily to ET. Temporal patterns of discharge versus storage are largely a function of the PPT volume and intensity, and the antecedent moisture. For example, several small events in the fall and winter of 2009 triggered discharge at all sites except WD due to the presence of water in the wetlands from the previous month.

Although on a volume basis, these wetlands are able to store most of the water falling in their catchment areas, they also discharge regularly, even during drought years such as 2008. The patterns of storage versus discharge are strongly influenced by antecedent moisture conditions, as it may take 4 – 6 inches (10 – 15 cm) of PPT to satisfy soil moisture in dry, cracked, Vertisol soils (Wes Miller personal communication). Results of outflow events for study sites may not be indicative of all CPWs in the region. However, our preliminary results of monitoring the six “random” CPWs (Appendix V) revealed that discharge occurs with similar regularity in 4 of these 6 CPWs.

It is clear that CPWs have the storage capacity to play an integral role in moderating the flood peaks and providing water storage in the region. Our estimates (Section E this report) are that 28.9% (1,553 km^2) of the study area is occupied by CPWs and their catchments. The potential flood prevention role of these wetlands is enhanced by this density, their widespread distribution, and the impending increases in impervious surface that accompany development (Adamus and Stockwell 1983). In Wisconsin watersheds, Novitzki (1979) found that flood peaks were 60 to 65% lower in watershed with 15% of its land area in wetlands. In Florida, Ammon et al. (1981) projected that flood peak attenuation was substantial once wetland acreage exceeded 10 percent, and flood peak attenuation of up to 95% was indicated where 15% of the watershed was wetland. In Illinois, Demissie and Khan (1993) found that for every one percent increase in wetland area, flood volume decreased 1.4% and stream low flow (Q_{95}) increased 7.9%. The ability of CPWs to gradually release high quality water to receiving waters may be as important to the ecology of the Galveston Bay system as flood storage. The risk and potential cost associated with the loss of such an extensive water control system could have enormous adverse consequences for resident human and wildlife communities, not to mention the potential impacts to the waters of Galveston Bay and its tributaries.

Results of this study indicate that CPWs are hydrologically connected to navigable waters through regular discharge to navigable waters. The frequency and volume of discharge does not appear to be dependent upon the shape of the outlet or receiving area (i.e. channelized versus diffuse). Five of the six wetlands studied discharged into “channelized” conveyances and of these all but one appear to have been altered to facilitate drainage in a particular direction. While the cumulative, landscape scale effect of these discharges are not fully understood, the periodic discharge of high quality water to numerous tributaries of Galveston Bay would be expected to provide a critically important role in regional water supply and water quality.

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D. Water Quality

Frog eggs at Turtle Hawk wetland April 2009

Introduction

Water quality of small, geographically isolated wetlands nationwide has been poorly characterized and we are not aware of any water quality data on CPWs. Yet these wetlands occupy approximately 9.5 % of the landscape around Galveston Bay. These wetlands and their associated functions continue to be converted to other uses such as agriculture and urbanization, yet there is no data available to evaluate the cumulative impacts of such losses on receiving waters in the region.

As previously discussed in Section C of this report, the hydrology of CPWs is driven largely by patterns of precipitation and evapotranspiration. Overland flow (runoff) does not occur during many Rain events. Furthermore, most CPW catchment areas are small and form a continuum with respect to soils and vegetation with the wetlands they encompass. Therefore, for comparative purposes, we evaluated the water quality of precipitation (Rain) as the primary hydrologic input to wetlands.

During some weather events such as floods and hurricanes, substantial fluxes of material occur in and out of wetlands as the low-relief landscape is inundated. For example, Hurricane Ike impacted several of our sites prior to sampling. Material fluxes also occur biotically; for example, when animals consume wetland vegetation or defecate in the wetland. Within the wetland, many biogeochemical processes can occur that cycle chemicals between sediments, biota, water column, and the overlying atmosphere. This study does not attempt to construct a water quality budget for coastal prairie wetlands, but rather seeks to describe general water quality characteristics of wetland surface waters relative to precipitation and appropriate surface water benchmarks.

Methods

Beginning in September 2008, surface water grab samples were collected from multiple locations within six wetlands. On dates when the surface area of inundation was large, we collected samples through that area. However on many dates, water was only present at one or two areas within the wetland. On these dates, we collected at least one “field duplicate” sample within the inundated area and these were treated as independent samples. Temperature, pH, dissolved oxygen, and conductivity were measured *in situ* with a YSI multiparameter datasonde.

The samples were placed on ice and transferred to Baylor laboratories, where aliquots were prepared for total phosphorus, total nitrogen, total organic carbon, and turbidity analyses. Samples were then filtered for total suspended solids determination and the filtrates analyzed for dissolved nutrients (nitrate + nitrite, ammonium, phosphate, and dissolved organic carbon). A complete list of analytes and analytical methods is provided in Table D1. Detailed methods and quality control measures are provided in the Quality Assurance Project Plan (QAPP).

Table D1. Analytes, units and methods for water quality sampling.

Analyte	Units	Method
Temperature	ºC	YSI 600 XLM® multiparameter datasonde
Conductivity/salinity	mS cm^{-1}/ Rain	
pH	unitless	
Dissolved oxygen	percent/mg L^{-1}	
Turbidity	NTU	Hach 2100N Turbidimeter
Suspended solids	mg L^{-1}	dry weight (103-105 ºC)
Nutrients		
Soluble reactive phosphate	µg L^{-1}	QuickChem 8500 Flow Injection Autoanalyzer – colorimetric methods
Nitrate + nitrite-nitrogen		
Ammonium – nitrogen		
Total nitrogen		
Total phosphorus		
Dissolved organic carbon	mg L^{-1}	Shimadzu TOC Analyzer
Heavy Metals		
Antimony	µg L^{-1}	Inductively coupled plasma-mass spectrometry (ICP-MS)
Beryllium		
Lead		
Selenium		
Zinc		
Polycyclic aromatic hydrocarbons		
Acenaphthylene	µg L^{-1}	Gas Chromatography / Ion Trap Mass Spectrometer with Electron Impact (GC/MS EI)
Acenaphthene		
Anthracene		
Benz[a]anthracene		
Benzo[k]fluoranthene		
Benzo[b]fluoranthene		
Benzo[e]pyrene		
Benzo[a]pyrene		
Benzo[ghi]perylene		
Chrysene		
Dibenz[a,h]anthracene		
Fluoranthene		
Fluorene		
Indeno[1,2,3-cd]pyrene		
Naphthalene		
Phenanthrene		

Precipitation (Rain) was collected in three to five collection barrels lined with plastic bags. Method blanks were used to assure that the bags did not contaminate the samples. Field duplicates, i.e. two samples from the same barrel, were collected as well, resulting in a maximum number of samples submitted for analyses of 52. To avoid pseudo-replication, Rain field duplicates were removed by averaging. Rain was collected at seven of the twelve sites. For sites that were located close together, (e.g. CR and WD), Rain collected at one of the sites was presumed to represent Rain at the nearby site. For example, Rain collected at KS was used for comparison to surface waters at nearby HA and UH.

All Rain collections included dry deposition, meaning that the barrels were placed in the field prior to an event and thus collected airborne deposits such as dust and insects. This is in contrast to “wet deposition only” Rain collection with automated devices that open when the event begins and close immediately afterwards. Wet+dry deposition is more representative of inputs to freshwater wetlands, however our method underestimates dry deposition, which occurs continuously. Our barrels were sometimes in place for days prior to an event. Other important sources of variability in concentrations of pollutants in Rain include wind speed and direction, number of days since the last event, and the magnitude of the event (i.e. dilution factor). These factors complicate comparison of Rain values among sites and dates.

We evaluated differences among the 12 sites and precipitation with two-way analysis of variance (ANOVA) using JMP® version 8.0. software (SAS Institute Inc.). The two factors were date and site (Rain treated as a site). Nutrients and conductivity had non-Gaussian distributions and were normalized by log transformation prior to statistical analyses. Where differences amongst site means were detected with ANOVA, we used Dunnett’s multiple range tests with Rain as the control ($\alpha = 0.05$) to determine which sites were different than precipitation.

Results

Rain was collected on 14 dates beginning October 2008 and ending November 2009. On some dates, Rain was collected at multiple sites, resulting in collection and analyses of a total of 20 Rain events. Table D2 lists the location and date of each collected Rain event.

Table D2. Date, location, and amount of Rain events collected.

Event	Date	Site	Amount (cm)
1	10/23/2008	CR*	0.50
2	11/11/2008	CR	8.70
3	12/9/2008	KS	1.15
4	1/6/2009	KS	0.56
5	2/10/2009	SW	0.33
6	2/11/2009	CR*	1.00
7	2/11/2009	SW	0.30
8	2/18/2009	SW	0.20
9	3/27/2009	KS	3.51
10	4/19/2009	KS	17.96
11	10/8/2009	DW	7.60
12	10/8/2009	KS	0.10
13	10/10/2009	KS	5.50
14	10/10/2009	LG	5.16
15	10/23/2009	CR	9.17
16	10/23/2009	KS	14.10
17	11/9/2009	KIL	0.40
18	11/9/2009	LC	14.70
19	11/16/2009	KIL	0.60
20	11/16/2009	LC	0.12
		TOTAL	91.66

*Rain gage failed, event amount is from Brazoria and Galveston weather stations

Wetland surface water was sampled on several occasions at the original six sites and at least twice at the randomly selected wetlands. Most collections occurred September through April because surface water was not normally present in summer. Typically, surface water was sampled in conjunction with Rain collection, and again 7-10 days later. This is important because it allows an assessment of short term nutrients trends in CPWs. Additional surface waters were collected outside of Rain events. The raw water quality data are provided in Appendix C1.

Depth

Water depth can affect water quality parameters as well as habitat function. As evapotranspiration occurs, particulate and dissolved solids, (e.g. ions) tend to increase and may result in higher concentrations even as other processes such as plant uptake may simultaneously reduce the total load of that constituent. Two sites, UH and SE, were shallow due to their topography (Table D3). When UH was sampled, the maximum water depth was approximately 5 cm and water was discharging from the site. At other wetlands, such as CR and SW, a portion of the site was often deep (30-40 cm) and thus these areas were sampled more frequently.

Table D3. Mean water depth and YSI parameters for Rain and wetland sites. Medians are presented for turbidity, total suspended solids (TSS), specific conductivity (SpC), and salinity due to non normal distribution. Mean all sites is the average of wetland site means or medians, not the average of all data. Note (*) sites impacted by IKE not included in mean for SpC and salinity at all sites.

Site	n	Depth (cm)	Temp (°C)	DO (%)	DO (mg/L)	pH	Turbidity (NTU)	TSS (mg/L)	SpC (mS/cm)	Salinity (Rain)
Rain	29-47	--	19.8	104	10	5.7	2.8	12	0.06	0.1
CR	58	22	18.7	58	5.4	6.5	7	16	1.0	0.5
DW	16	19	21.3	72	6.0	6.3	44	26	0.1	0.1
HA	8	12	14.5	77	7.8	6.3	25	24	0.1	0.0
KIL	18	26	19.4	125	11.2	8.4	6	17	15.6*	9.2*
KS	31	12	22.4	73	6.3	6.2	19	33	0.4	0.2
LC	26	10	20.3	95	8.6	7.0	18	31	2.8*	1.4*
LG	24	15	19.6	64	5.7	6.2	6	22	0.1	0.0
SE	6	3	13.7	107	11.2	6.7	56	25	0.2	0.1
SW	55	15	21.1	76	6.6	6.5	18	15	5.9*	3.2*
TH	32	8	21.9	69	5.9	6.4	9	18	0.1	0.1
UH	8	4	14.7	52	5.2	6.7	35	27	0.2	0.1
WD	41	13	17.7	62	5.8	6.8	40	53	0.6	0.3
MEAN ALL SITES		13.3	18.8	77.5	7.2	6.7	23.4	25.6	0.3*	0.2*

Table D4. Median dissolved organic carbon (DOC), phosphate-P (PO_4-P), ammonium-N (NH_4-N), nitrate+nitrite-nitrogen (NO_3-N), total nitrogen (TN), and total phosphorus (TP) for Rain and wetland sites. Mean all sites is the average of wetland site medians, not the average of all data.

Site	N	DOC mg/L	PO4-P (µg/L)	NH4-N (µg/L)	NO3-N (µg/L)	TN (µg/L)	TP (µg/L)
Rain	47	1	9	250	240	1030	51
CR	60	26	13	32	3.8	1633	124
DW	16	16	134	50	2.7	1860	890
HA	8	22	14	40	5.4	2007	114
KIL	18	35	15	30	3.5	2957	118
KS	31	22	21	34	6.3	2490	170
LC	26	37	17	400	8.5	4193	311
LG	24	31	14	45	3.0	2078	80
SE	6	30	7	10	4.8	4323	214
SW	56	17	14	81	5.0	1794	294
TH	35	34	21	90	18	1992	151
UH	8	30	15	22	185	2019	139
WD	41	25	23	69	3.9	1494	134
Wetlands Average of Medians		27	25	75	21	2403	228

Salinity

All six original sites (CR, WD, SW, LC, KS, and TH) were dry during the 2008 summer and were first sampled a few weeks after Hurricane Ike. Ike affected the sites differently. At KS and TH, there was heavy Rain and tree-fall, but no storm surge. At CR, we observed heavy wrack from storm surge on the seaward side of the site and believe that the storm surge reached CR but did not completely inundate the site. Both CR and WD had one sample (out of 12) with approximately 1 part per thousand (Rain) salinity, but the remaining samples were less than 1 Rain and the water depth was approximately 28 cm. A month later, however, as the water in the wetlands evaporated (depth ~ 3 cm), salinity levels in CR were 3-4 Rain (WD was dry). By 10 November, following the 9.6-cm precipitation event, the salinities at both sites were below 1 Rain. The two Anahuac sites (LC and SW) were inundated with approximately 3 m of Hurricane Ike storm surge (salinity ~ 19 Rain). USFWS personnel dRained SW shortly after Ike allowing some flushing to occur. Post-Ike salinities at SW declined rapidly to 3 Rain, while salinities at LeConte trended higher. We have continued to monitor the vegetation and soil salinity at the Anahuac sites.

Two of the randomly selected sites located in Chambers County were also inundated with storm surge. One of the sites, KIL, still has saline water (9 Rain) and the other (SE) was fresh water. All of the wetlands selected for this study are palustrine freshwater wetlands under normal conditions.

Dissolved Oxygen

Rain nearly always had dissolved oxygen (DO) concentrations that was at or near saturation. The average %DO ($\pm$ standard deviation) in Rain was 104% $\pm$ 9% (n = 33). Surface water DO varied by site and by date, with many wetlands having mean DO that was below saturation (Table D3). One wetland (KIL) had a higher DO than Rain (Tukey HSD, α=0.05). Three wetlands (SE, LC, and HA) had values that were not statistically different than Rain. KIL, SE, and occasionally LC had visible benthic or floating algal mats that contributed to supersaturated values during daytime when samples were collected. The remaining sites had a mean DO that was significantly lower than Rain, and most had values that ranged from supersaturated to low (Fig. D1). Only UH, which is forested, lacked high DO values. The small sample size for the randomly selected wetlands may affect these results. The range of DO values for the more frequently sampled sites is consistent with both the photosynthetic activity by floating and attached algae that contribute to high DO and the seasonal oxygen demand exerted by decaying biota that contributes to low DO.

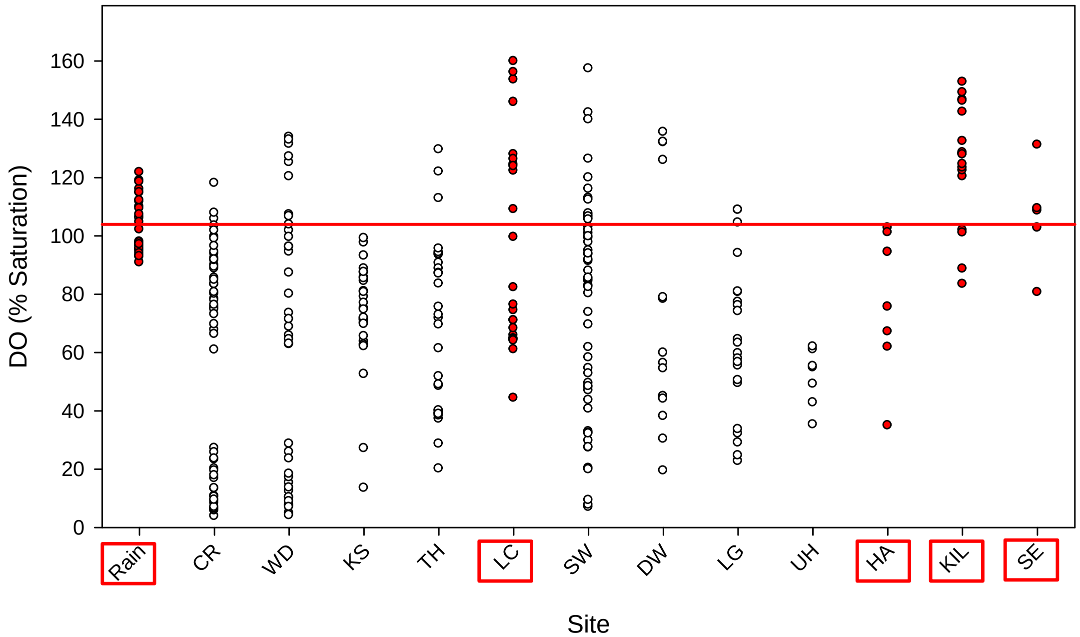

Figure D1. Means comparisons of dissolved oxygen (% saturation) with a control (Rain = Rain) using Dunnett's Method. Each dot represents a sample. Sites with red symbols and boxed site names are not significantly different than Rain. Red bar is the mean value for Rain.

Depth was not well correlated to DO at all sites, however at the deeper sites (CR, WD, and SW) DO was negatively correlated to depth (r = -0.716, -0.649, and -0.685 respectively). At these deeper areas, benthic and floating mats were not observed despite the presence of open water. The deeper water column at these sites was often darkly colored as well, which may have limited light penetration.

Suspended Solids and Turbidity

Total suspended solids (TSS) and turbidity varied in both surface water and Rain (due to dry deposition). Only one site, WD, was statistically higher in both turbidity and TSS than Rain (Fig. D2, Dunnett's, α=0.05). In general, the quiescent waters of wetlands produce low turbidity conditions, with a few exceptions. Three sites, CR, WD, and SW, were invaded by hogs at least once during the study and this disturbance created high turbidity and TSS. The higher values at WD were not due only to hog disturbance, however. Most of the surface waters at WD occur under a thick cover of grass (Fig. D3) and we observed abundant invertebrates (including crayfish) that shred the vegetation and contributed very fine particulate matter to the shallow water column. We did not obeserve this type of turbidity at other sites.

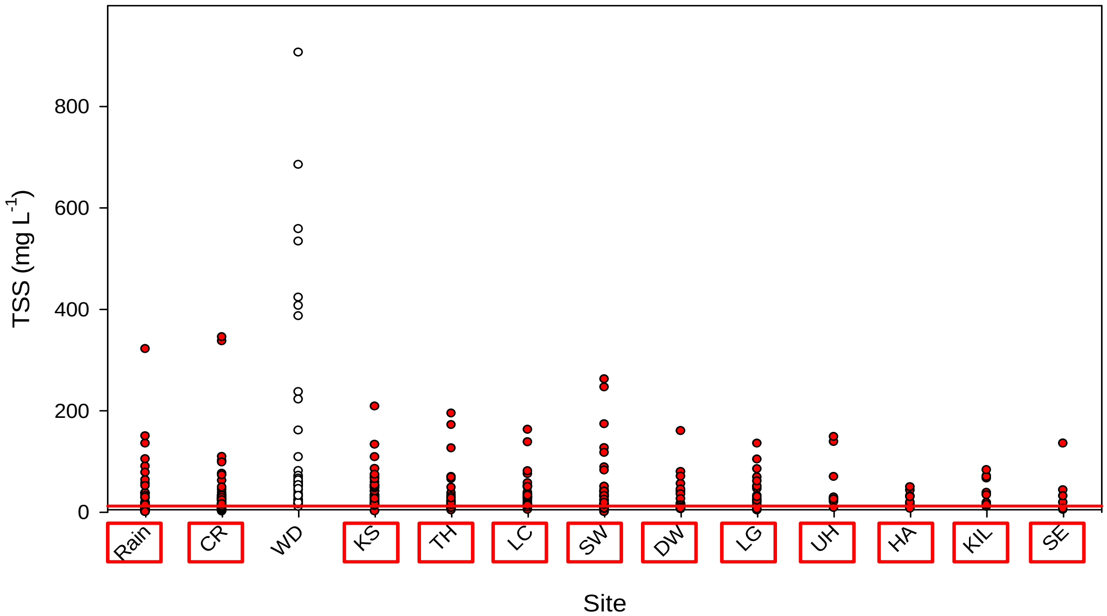

Figure D2. Means comparisons of TSS (mg/L) with a control (Rain = Rain) using Dunnett's Method. Each dot represents a sample. Sites with red symbols and boxed site names are not significantly different than Rain. Red bar is the mean value for Rain.

Figure D3. Sampling surface water under thick vegetation at Wounded Dove, Brazoria NWR, November 2008.

Phosphorus

Phosphorus concentrations in Rain and wetland surface water varied considerably over time and exhibited a log-normal distribution, therefore medians are presented in Table D4. To evaluate trends in nutrient transformations, we first compare all sources (Rain and wetland sites) and then examine the nutrient trends at groups of sites, paired with the Rain that occurred there.

Phosphate-P (PO_4-P) was highly variable in Rain, ranging over three orders of magnitude (Fig. D4). Variability (i.e. the range of values) was smaller within each wetlands, however it was high among the wetlands. Phosphate-P was statistically higher than Rain in only one wetland, DW. The DW wetland is located in a ag-pasture/natural area located north of Freeport. This area is approximately 3 km northeast of TCEQ Air Pollution Watch List (APWL 1201) Area of Concern for acrolein, cobalt, nickel, and vanadium. Precipitation collected at DW was not particularly high in PO_4-P (20 μg/l), although this concentration occurred during a large (~5 cm) Rain event which tends to dilute constituents. There are other sites (LC, KIL, and SE) that are ag-pasture that were not statistically higher than Rain. Livestock were present at all four sites.

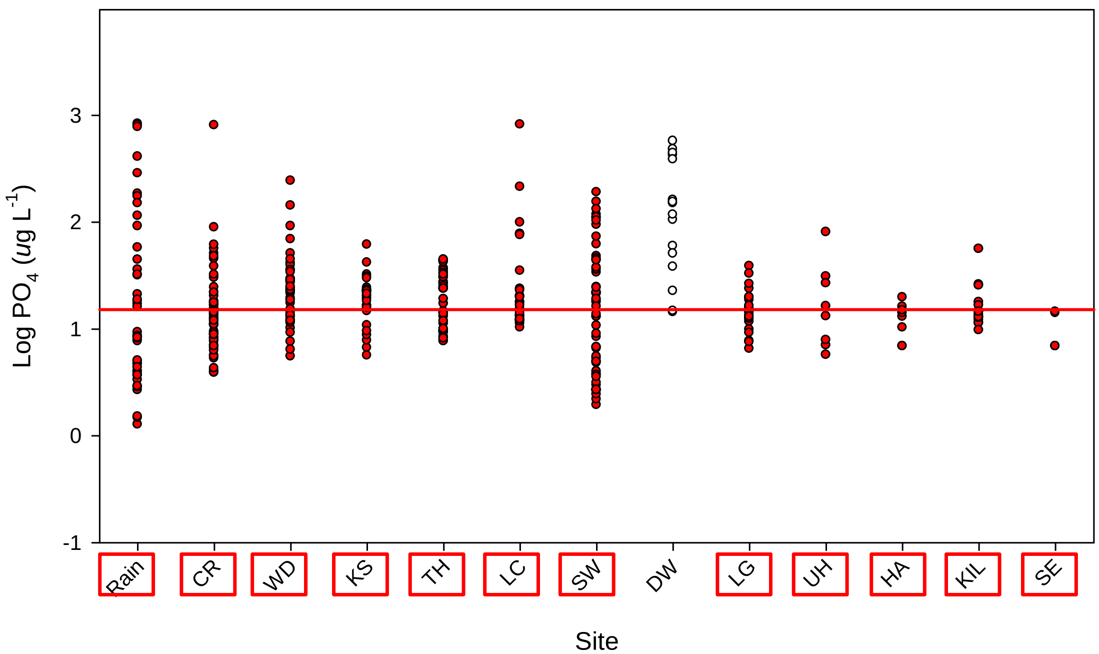

Figure D4. Means comparisons of log PO_4-P with a control (Rain = Rain) using Dunnett's Method. Each dot represents a sample. Sites with red symbols and boxed site names are not significantly different than Rain. Red bar is the mean value for Rain.

Total phosphorus (TP) was statistically higher than Rain at all but two wetland sites (UH and LG) (Fig. D5), although even at these sites the TP values tended to exceed that of Rain. The DW wetland had the highest median TP at 890 μg/l followed by 311 μg/l at LC and 294 μg/l at SW (Table D4); the SW site is not grazed but was recently cropped with rice.

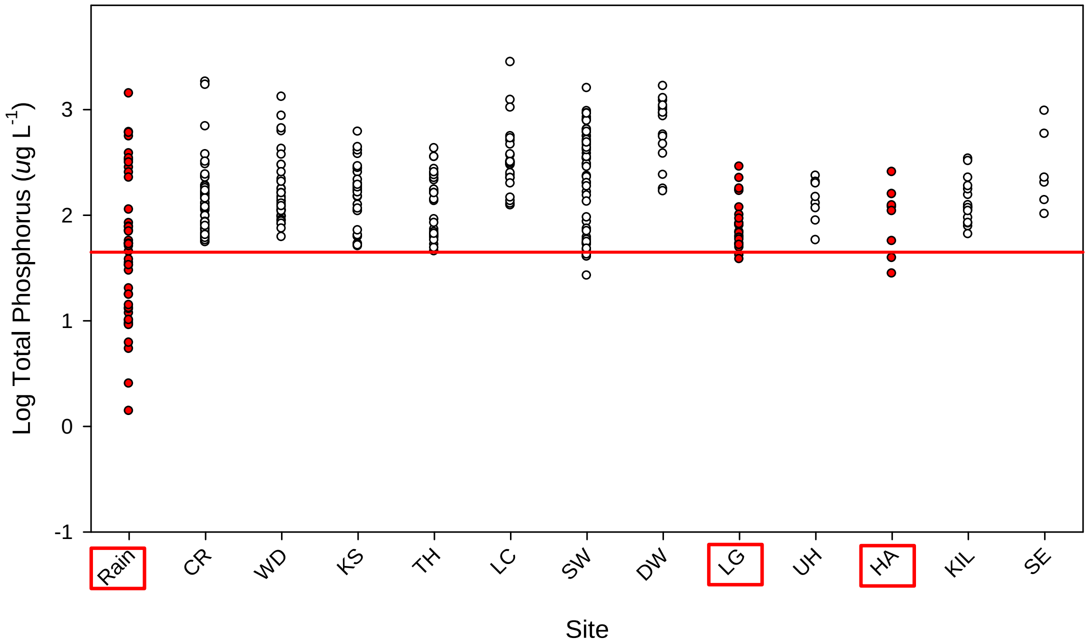

Figure D5. Means comparisons of log TP with Rain (=Rain) as the control using Dunnett's Method. Each dot represents a sample. Sites with red symbols and boxed site names (HA, LG) are not significantly different than the control. Red bar is the mean value for Rain.

Total phosphorus and phosphate concentrations varied considerably by date at all of the sites. TP in surface water was generally an order of magnitude higher than TP in most Rain. TP is the combination of both soluble and sorbed PO_4-P, plus organically bound P. Wetlands are among the most productive ecosystems on earth, and the annual cycles of biotic growth and scenescence, primarily by the large standing stocks of emergent vegetation, dominate nutrient cycles. Thus wetlands tend to be sinks for inorganic nutrients and sources or organically fixed nutrients. The production of organic matter is evident in the consistently higher TP relative to Rain.

Nitrogen

Precipitation is the primary process by which biologically available nitrogen (nitrate, nitrate, ammonia, some organic N) is transported to aquatic systems from the atmosphere (Paerl et al. 1990). Urban areas tend to have higher areal deposition of nitrogen, up to one-third of the total N load to watershed in the northeastern United States (Puckett, 1994). Products of the combustion of fossil fuels and other releases of agricultural and industrial N- compounds into the atmosphere are transported by wind and deposited into the water bodies either directly or through precipitation. In agricultural settings, substantial nitrogen inputs also come from agricultural fertilizers and animal manure.

Inorganic nitrogen in Rain was high in NH_4-N and NO_3-N with a geometric mean (+ SD) of 215 $\pm$ 3.4 and 272 $\pm$ 3.6 μg L^{-1} respectively. These values are higher than NH_4 and NO_3 concentration in Rain (wet deposition only), which is monitored by the National Atmospheric Deposition Program (NADP) at the Attwater Prairie Chicken preserve. The NADP geometric means ($\pm$ SD) of NH_4-N and NO_3-N for 1984-2009 was 150 $\pm$ 4 and 165 $\pm$ 3 respectively. Studies indicate that, although dry deposition is rarely measured, it is believed to be of the same order of magnitude as wet deposition (Valiela et al. 1997, Hinga et al. 1991). This dry deposition includes atmospheric particles and adsorption of NO_x gases and ammonia through leaves. Because our Rain collection barrels were not in place continuously, our Rain likely underestimates atmospheric deposition.

Inorganic nitrogen was lower in most of the coastal prairie wetlands than in Rain, indicating a substantial capacity of these wetlands to absorb or remove incoming NH_4-N and NO_3-N. Only LC had higher NH_4-N than Rain (Fig. D6), but these maxima occurred at LC in post-Ike samples in October and December of 2008. These samples consisted of storm surge and were noticeably foul smelling. SW also contained storm surge, but, as previously stated, the wetland had been dRained by the USFWS allowing some flushing to occur. Statistically, removal of these two LC sample dates changed the statistical grouping of LC from being grouped with Rain, to being grouped with the other wetlands.

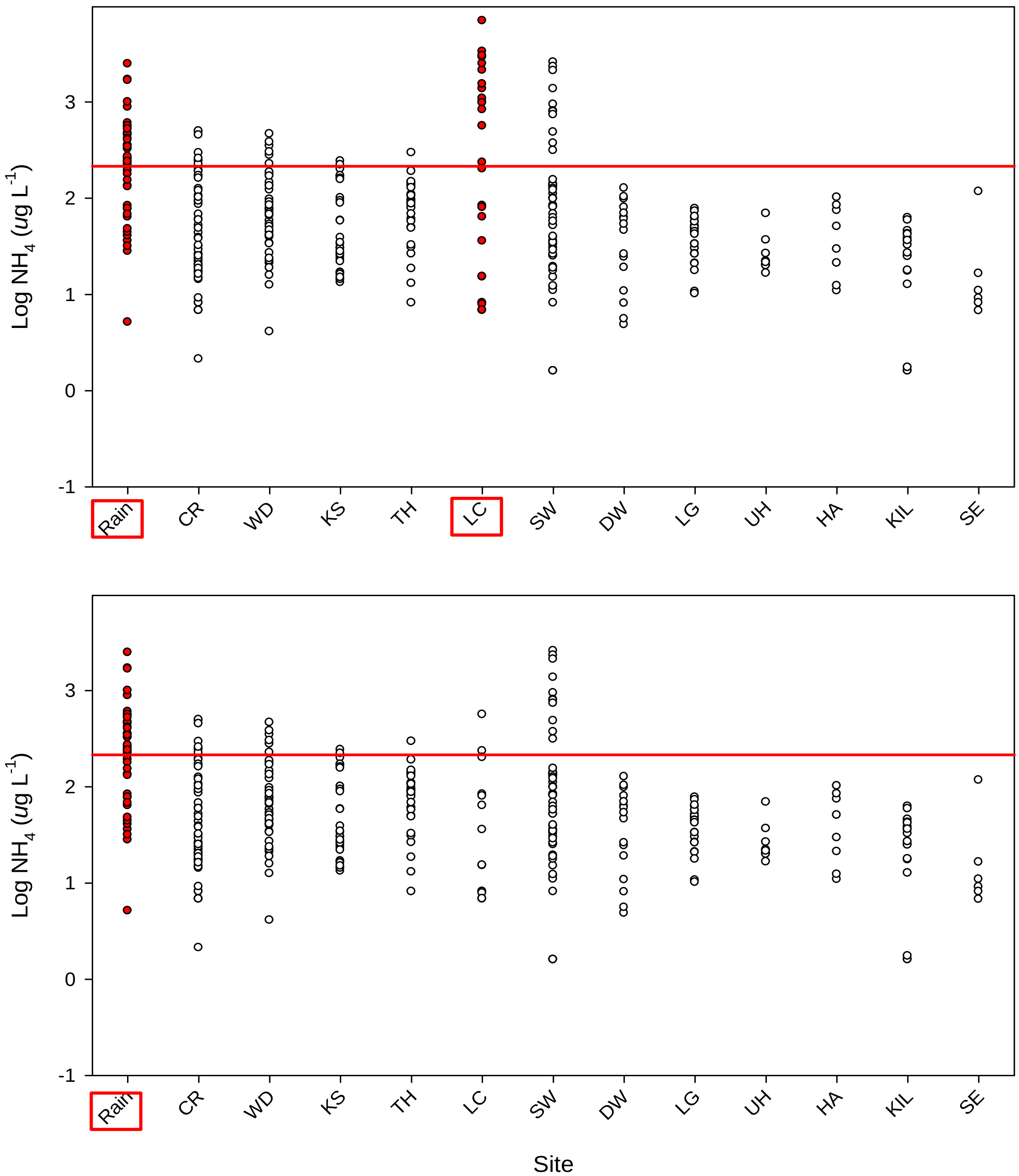

Figure D6. Means comparisons of log NH_4-N with Rain as the control using Dunnett's Method. Rain = Rain. Sites in red are not significantly different. Each dot represents a sample. Sites with red symbols and boxed site names (LG top panel) are not significantly different than the control. The top panel contains two sample dates impacted by Hurricane Ike at LC and the bottom panel omits those samples. Red bar is the mean value for Rain.

Nitrate-N (NO_3-N) was considerably lower in most wetland surface waters than in Rain at all but one of the sites (Fig. D7). At UH, nitrate was not significantly different than Rain with a geometric mean of 151 $\pm$ 11.9 *u*g L^{-1} NO_3-N. Note that despite the lack of statistical significance, this geometric mean is only 58% as large as the geometric mean for Rain. This wetland site wraps around a small upland area that is used to dispose of landscape waste such as brush, landscape plants, and soil. Although we have a limited number of samples at this sites, the close proximity and up-gradient location of fertilized soil and plant material could contribute to the elevated NO_3-N levels at this urban site.

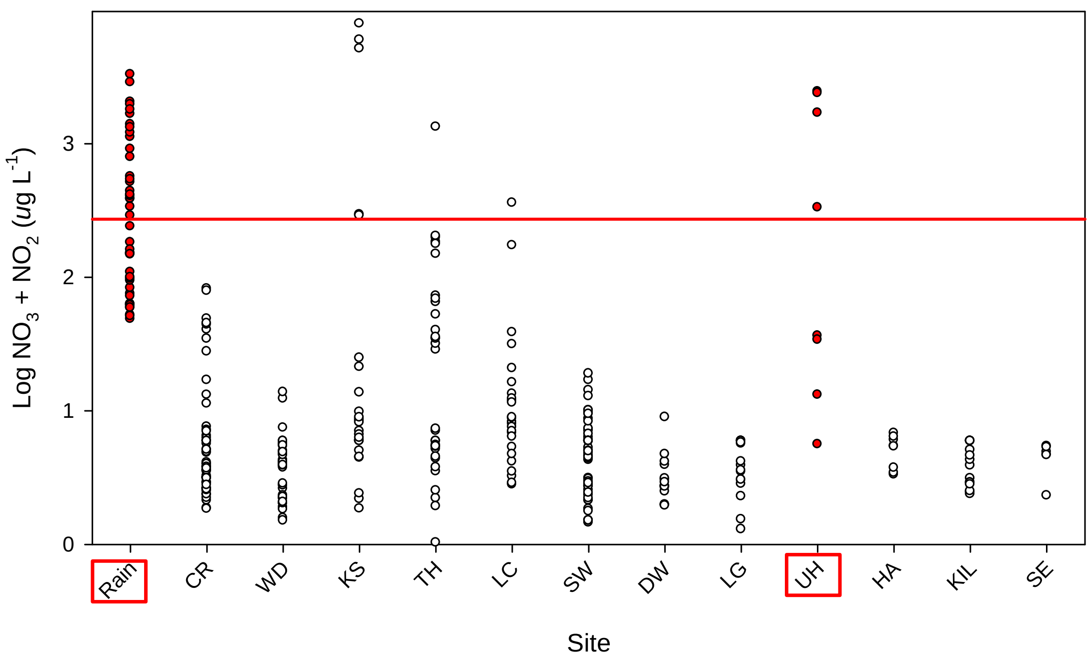

Figure D7. Means comparison of log Nitrate+Nitrite-N with Rain as the control using Dunnett's Method. Rain = Rain. Each dot represents a sample. Sites with red symbols and boxed site names (UH) are not significantly different than the control. Red bar is the mean value for Rain.

Total nitrogen (TN) was generally higher in wetland surface water than in Rain (Fig. D8) and this is primarily due to some Rain samples with very low TN concentrations. In other words, precipitation was occasionally as high in TN as wetland surface water. Rain was also very low on occasion (minimum = 146 μg L^{-1}) compared to the wetlands minimum of 783 μg L^{-1}. The two wetlands that were not statistically different than Rain were HA and WD, both wet prairie sites. However, even these wetlands had TN values above the mean for Rain.

There are many reasons why wetlands are high in total nitrogen, while low in inorganic nitrogen. The difference between TN and TIN is generally assumed to be organic nitrogen although some particulate inorganic nitrogen could be included in TN. As with TP, the general trend in wetlands is to fix inorganic nitrogen into plant material, which is then partially released as organic nitrogen when plant material decomposes. Much of the fixed nitrogen is buried in wetland soils and thus more or less permanently retained. The higher levels of ammonium-N in wetlands are probably due to the constant cycling (mineralization) of organic material within the wetlands, and the inputs from Rain.

Because of their anaerobic zones and abundant organic carbon supplies, wetlands also have a large capacity of denitrification, the conversion of nitrate to nitrogen gas (N_2), which is then returned to the atmosphere. This mechanism is undoubtedly responsible for the reduction of NO_3-N in Rain from a geometric mean of 272 $\pm$ 3.6 to a geometric mean of 6.0 $\pm$ 4.4 in the 12 wetlands (n=324). This represents a removal of 97.8%. An example of nitrogen removal capacity was observed at Kite Site during spring 2009 sampling. This site had been dry since Hurricane Ike in September 2008 and site managers mowed and sprayed the site with the herbicide Tordon K (Dow Chemical) at 2 quarts per acre. The herbicide contains Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid). We sampled the first Rain event that resulted in surface water after the application of this product to control Chinese tallow. The samples had a geometric mean NO_3-N of 6,244 μg L^{-1} on 27 March 2009 and 2.2 μg L^{-1} (n=2) on 4 April 2009. Subsequent sampling was slightly higher, but further KS samples maintained a low nitrate level.

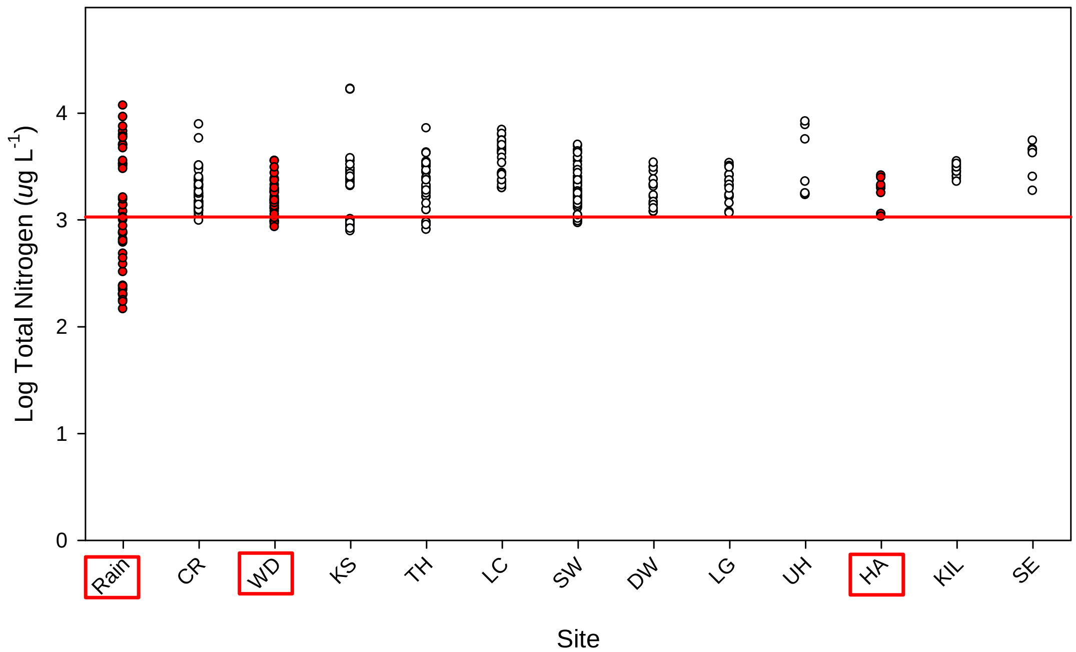

Figure D8. Means comparisons of log TN with Rain as the control using Dunnett's Method. Rain = Rain. Each dot represents a sample. Sites with red symbols and boxed site names (WD, HA) are not significantly different than the control. Red bar is the mean TN value for Rain.

Heavy Metals

Heavy metals were near or below detection levels and therefore were eliminated from the analyses after the first year. Of the five metals sampled, only lead (Pb) and zinc (Zn) were above the analytical detection limit. Mean Pb concentrations ranged from a high 4.5 μg L^{-1} at Wounded Dove to a low of 0.7 μg L^{-1} at Sedge Wren. Zinc levels ranged from 20.8 μg L^{-1} at Sedge Wren to 5 μg L^{-1} at Chicken Road and Wounded Dove. Based on our measurements of hardness (75-80 mg $CaCO_3$ L^{-1}), the ecological benchmark for acute Pb and Zn exposure is 50 and 80 μg L^{-1} respectively. The mean concentration of Pb and Zn in the sampled wetlands were not significantly different than those in precipitation (Dunnett's, α=0.05).

Polycyclic Aromatic Hydrocarbons

PAHs were near or below detection levels in Rain and these parameters were eliminated from the analyses after the first year. PAH results in wetland surface water samples from three of the wetlands indicate that the most frequently detected (n=6) analytes were naphthalene, fluorene, fluoranthene, pyrene, and benzo(a)anthracene. Average concentrations ranged from 65 to 430 ng L^{-1} (Table D5), with relative percent standard deviation (RPSD) ranging from 7.9 to 32%. The average surrogate recoveries for naththalene-d_8, acenaphthylene-d_8, phenanthrene-d_{10}, and fluoranthene-d_{10}, pyrene-$_{10}$ were 63%, 72%, 90%, 76%, 75%, respectively. These surrogates were used to quantify and recovery-correct for target analyte loss during the extraction procedure. Surrogates were added to the water samples prior to extraction via a 0.5-mL methanol surrogate solution.

Benzo(b)fluoranthene was detected in 5 of the 6 samples however could not be quantified due to poor surrogate recovery; benzo(a)pyrene-d_{12} had a 44% average recovery. Calibration check standards were run both before and after the batch.

PAHs with greater than 4 cyclic rings were infrequently or never detected in the six wetland aqueous samples. When measured in the atmosphere, PAHs with more than 4 cyclic rings are most commonly associated with the particulate phase while PAHs with less 2-4 cyclic rings are typically associated with the gas phase (Chang et al. 2003). The five most frequently detected analytes all contained 2-4 cyclic rings. It is important to note that acenaphthylene was only detected in half of the samples and anthracene was not detected in any of the wetland water samples. Anthracene typically has an atmospheric half-life that is 0.6 to 1.7 hours, which is approximately one tenth the atmospheric half-life of phenanthrene (Mackay et al. 1992). Both acenaphthylene and anthracene consists of 3 cyclic rings. Phenanthrene was detected in 5 of the 6 samples and had an average concentration of 127 ng L^{-1} and a RPSD of 27.3%. Phenanthrene was not detected in 11 November, Chicken Road sample. This may suggest that PAHs with more than 4 cyclic rings tend to be associated with the wetland substrate.

Average PAH concentrations ranged from 65 to 430 ng L^{-1} and never exceeded the "Ecological Benchmarks for Freshwater" described by TCEQ Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas (listed in Table D5). Most concentrations were 1 to 3 orders of magnitude lower than benchmarks. It is important to note that these samples also had fairly high concentrations of dissolved organic matter (DOM), which is characteristic of wetlands. DOM increases the apparent water solubility for sparingly soluble (hydrophobic) compounds (Schwarzenbach et al. 2003). DOM measured in the wetland may serve as a site where PAHs can partition, thereby increasing their apparent water concentrations.

Differences among Sites

Most wetland sites examined in this studied appeared to function similarly with respect to nutrient, metals, and organic carbon constituents. It is difficult, however, to detect differences among a large number of groups, because the threshold significance level (α) decreases with an increasing number of comparisons. To evaluate differences among sites more closely, we compared the first six sites to each other, without considering Rain, using a two-way ANOVA and Tukey HSD. We repeated that procedure with the six random sites. This is a reasonable approach because the sample size and sampling period was approximately the same for the first six sites, but substantially larger than the sampling size and time period for sites in the random group. These comparisons will facilitate an evaluation of the water quality functional assessment models presented in section B.

Table D5. PAH concentrations in six wetland aqueous samples.

RT	Target Analytes	Surrogate	Site %REC	Ecological Benchmarks*** for freshwater ng/L	CR WEIR 10/7/2008 ng/L	SW WEIR 10/8/2008 ng/L	SW1 10/8/2008 ng/L	LC9 10/8/2008 ng/L	CR5 11/11/2008 ng/L	CR4 11/11/2008 ng/L	Average	%RSD
5.214	Naphthalene	Naphthalene-d8	62.76	490000	267.9	228.6	249.6	237.9	260.7	294.9	257	9
7.161	Acenaphthylene	Acenaphthylene-d8	71.51		bdl	nd	nd	59.1	132.9	155.4	116	44
7.381	Acenaphthene	Acenaphthylene-d8	71.51	23000	126.9	144.3	183.9	239.1	266.7	bdl	192	31
8.436	Fluorene	Acenaphthylene-d8	71.51	11000	116.7	212.7	130.5	193.5	107.4	108	145	32
10.523	Phenanthrene	Phenanthrene-d10	89.68	30000	114.6	188.1	107.7	122.4	nd	103.8	127	27
10.558	Anthracene	Phenanthrene-d10	89.68	300	nd	nd	nd	nd	nd	nd		
13.14	Fluoranthene	Fluoranthene-d10	76.49	6200	72.3	64.8	60	64.8	58.5	70.5	65	8
13.704	Pyrene	Pyrene-d10	75.30	7000	109.2	115.5	116.1	129.9	99	103.5	112	10
16.954	Benz(a)anthracene*	Pyrene-d10	75.30	34600	417.3	421.8	454.2	484.5	410.4	389.4	430	8
17.097	Chrysene*	Pyrene-d10	75.30	7000	BQL	nd	nd	BQL	BQL	BQL		
19.809	Benzo(b)fluoranthene*	Benzo(a)pyrene-d12	44.56		detected	detected	detected	detected	detected	nd		
19.993	Benzo(k)fluoranthene*	Benzo(a)pyrene-d12	44.56		nd	nd	nd	nd	nd	nd		
20.509	Benzo(a)pyrene*	Benzo(a)pyrene-d12	44.56		BQL	BQL	BQL	BQL	BQL	BQL		
23.77	Indeno(1-2-3,c,d)Pyrene	Benzo(g,h,i)perylene-d12**			nd	nd	nd	nd	nd	nd		
23.887	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene-d12**		5000	nd	nd	nd	nd	nd	nd		
24.693	Benzo(g,h,i)perylene	Benzo(g,h,i)perylene-d12**			nd	nd	nd	nd	nd	nd		

*Poor Surrogate Recovery nd=not detected

**Matric interference bdl =below the detection limit

*** TNRCC Guidance for Conducting Ecological Risk Assessments at Remediation Sites in Texas

Tables D6 and D7 show the results of these comparisons for both groups, by nutrient. Note the mean is the least squares mean of the logged values and that it has been adjusted for the effect of "date" and therefore are not the original means.

Table D6. Significant differences in phosphorus among sites at initial sites (left side) and randomly selected sites (right side) using Tukey HSD after Two-way Anova with site and date as factors. α=0.05. LS Means are logged values and adjusted for effects of date.

Initial Sites				Random Sites			
PO_4-P							
Site			LS Means	Site			LS Means
WD	A		1.394	DW	A		2.016
LC	A	B	1.281	KIL		B	1.225
KS	A	B	1.241	HA		B	1.188
TH	A	B	1.236	UH		B	1.169
CR	A	B	1.202	LG		B	1.135
SW		B	1.152	SE		B	1.033

Initial Sites				Random Sites				
TP								
Site			LS Means	Site				LS Means
LC	A	B	2.388	DW	A			2.795
SW	A		2.334	SE	A	B		2.470
WD	A	B	2.231	KIL		B	C	2.116
KS	A	B	2.165	UH		B	C	2.112
CR	A	B	2.144	HA			C	2.003
TH		B	2.078	LG			C	1.910

Table D7. Significant differences in nitrogen species among sites at initial sites (left side) and randomly selected sites (right side) using Tukey HSD after Two-way Anova with site and date as factors. α=0.05. LS Means are logged values and adjusted for effects of date.

NH_4-N

INITIAL SITES Site				LS Means	RANDOM SITES Site			LS Means
TH	A			2.033	HA	A		1.818
LC	A	B		1.933	LG	A	B	1.495
SW	A	B		1.870	DW	A	B	1.452
KS	A	B		1.776	SE	A	B	1.384
WD		B		1.722	UH	A	B	1.328
CR			C	1.453	KIL		B	1.285

NO_3-N

INITIAL SITES Site				LS Means	RANDOM SITES Site			LS Means
TH	A			1.319	UH	A		2.228
KS	A	B		1.018	KIL		B	0.574
LC	A	B	C	0.964	HA		B	0.55
CR		B	C	0.678	SE		B	0.537
SW		B	C	0.666	DW		B	0.482
WD			C	0.521	LG		B	0.334

TN

INITIAL SITES Site				LS Means	RANDOM SITES Site				LS Means
LC	A			3.451	SE	A			3.559
KS	A	B		3.373	UH	A	B		3.482
TH	A	B	C	3.299	KIL	A	B		3.464
SW	A	B	C	3.276	LG		B	C	3.318
CR		B	C	3.235	DW			C	3.277
WD			C	3.182	HA		B	C	3.261

Conclusions

The water quality data presented here were collected span weather events such as drought – hurricanes – wet periods. While precipitation was the primary source of water at the Brazoria sites, surface waters at the Anahuac sites were a result of precipitation and the storm surge. Despite these large differences in climate and source water, the sites exhibited similar levels of nutrients and metals. Our water quality investigations revealed no indication of degraded water quality or impairment at any of the CFWs sampled.

Increased nitrogen loading to coastal watersheds is of concern because rates of primary production in coastal waters are largely limited by nitrogen supply (Valiela 1995, Howarth 1988). Eutrophication of coastal waters in the Gulf of Mexico has been linked both to increased nitrogen loading and decreased acreages of filtering capacity including the loss of wetlands (Day 2004). Although the contribution percentage of atmospheric nitrogen to U.S. coastal estuaries are estimate to be between 10% and 40%, estimates are lower (11%) for Galveston Bay due to the high total N loading (Li personal communication). Furthermore, total direct deposition is estimated to be 632 kg N km^2 y^{-1} which is on the high end of all U.S. estuaries.

Phosphate was generally similar to precipitation levels and dissolved ammonium was lower at most of the wetland sites than ammonia in Rain. Nitrate+nitrite was substantially lower, suggesting that the wetlands are a net sink for nitrate. As expected, solids, total nitrogen and total phosphorus levels were slightly higher in the wetland than in precipitation. Wetlands (and grasslands) are among the most productive ecosystems in the world, and these systems transform inorganic nutrients into organic forms. The export of fixed carbon and nitrogen to estuaries and other receiving waters is acknowledged as a valuable wetland function (i.e. food chain export/support) and these data confirm that coastal freshwater wetlands produce organic material both to support local biota and for export to receiving waters.

As expected, some parameters were statistically different among sites. These may be due to differences in many factors such as water depth, vegetation, soils, topography, land use, etc. Although these results do not permit a detailed analyses of causative factors, they do suggest that the inverse relationship between depth and suspended solids is site specific and may drive additional differences in related water quality parameters.

Land use may also explain some of the differences among sites, particularly with respect to nutrient levels. The LeConte site is heavily grazed by cattle. In fact, some of the wetland microtopography is a result of created by cattle hooves, and these hoof prints hold water and aquatic biota after much of the wetland has dRained. Cow dung is abundant and vegetation is kept short in summer. Although not always statistically significant, LeConte typically had higher levels of nutrients than the other sites.

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E. GIS Applications

Bruce Hunter and Nick Enwright at Wounded Dove, Brazoria County, 9 June 2008

Introduction

A Geographic Information System (GIS) was used to estimate model variables and calculate functional capacity indices (FCI), as described in the previous section, for NWI-mapped wetlands in the study area. A GIS approach to wetland functional assessment offers the advantage of applying conceptual models at a landscape scale using readily available geospatial data. A similar approach was used to estimate function and pollutant loadings of freshwater wetlands in south Florida (Zahina et al. 2001). That study utilized soil, land use/land cover, and NWI databases to derive variables in the functional assessment models. We also used soil, land use/land cover, and NWI databases, as well as topography and vegetation databases, to estimate variables in the functional assessment models for coastal prairie wetlands (CPW) in the study area. We generated the following items with these databases:

1. Geodatabases containing raw data and derived data;
2. Electronic map files (.pdf) for each quadrangle with color-coded model FCI values for each wetland and each of the six assessed functions (192 maps);
3. Maps were created for ArcReader, a free GIS viewer, for each model result
4. A description and analyses of potential error associated with databases and variables estimates.

Methods

The primary coordinate system used was Universal Transverse Mercator Zone 15N (North American Datum 1983). Databases used and their sources are summarized in Table E1. ESRI® ArcGIS 9.3 and ArcHydro Tools 1.3 (Environmental Systems Research Institute, Redlands, California) were used to calculate model variables from these data.

Wetland Presence and Size

The number, size, and class of wetlands assessed in this study were obtained from National Wetlands Inventory (NWI) shapefiles, which are maintained by the U.S. Fish and Wildlife Service. While the NWI database contains inaccuracies, it was considered the best available dataset for the 32-quad area. NWI files were downloaded for each of the 32 quadrangles (quads) in the study area. Most of the NWI data for the study area were recently updated in 2006; however, a few quads were updated in 1992. “Freshwater Emergent”, “Freshwater Ponds”, and “Freshwater Forested” wetlands were extracted from the NWI datasets. To avoid edge effects at the study area boundary, only wetlands completely within 125 m of the study area boundary were included in the study, resulting in a total of 10,349 wetlands with a total area of 51,126 ha.

Table E1. Source and description of geodatabases used to estimate variables.

Data	Source	Year	Resolution	Accuracy	
Wetlands	National Wetland Inventory	2006	1:24,000		
Soils	County Soil Survey Geographic Database (SSURGO)	various	1:24,000		
Vegetation	National Agriculture Imagery Program (NAIP)	2004	1 m		
Land Use/ Cover	USGS National Land cover Dataset (NLCD)	2001	30 m		
Elevation				**Horiz**	**Vert**
Harris County	Harris County Flood Control District LiDAR	2008	1 m	0.67 m	0.09 m
Other Counties	Texas Natural Resource Information Systems (TNRIS) LiDAR	2006	1.4 m	0.73 m	0.37 m

Catchment Delineation

Delineating watersheds or “catchments” was one of the most challenging aspects of the study. Topographical coverages used to define catchments were derived from LiDAR (Light Detection and Ranging) data. LiDAR coverages were obtained from Harris County Flood Control District (Harris County) and from TNRIS (Chambers, Brazoria, and Galveston Counties). LiDAR data are generated by firing a laser beam from an airplane-based instrument and recording the time increment required for the beam return. Elevations are calculated based on the time/distance of the surface to the exact position of the aircraft as determined by highly accurate Global Positioning System (GPS). Once processed, LiDAR data provides both horizontal (x,y) and vertical or elevation coordinates (z). The x,y,z output tables from available

LiDAR were used to create a digital elevation model (DEM), a raster dataset in which cell/pixel values represent the elevation at that location. DEMs were then used to determine water flow direction across surfaces (Fig. E1) based on the principle that water flows from high to low elevations and takes the shortest route possible. Catchment delineation was determined computationally by identifying the breaklines, or watershed boundaries, between drainage systems. Because DEMs used for this project were created from two LiDAR datasets with dissimilar resolutions, the Harris County data were resampled to 1.4 m to match the resolution of the data for the other counties. Both LiDAR datasets were post-processed to remove vegetation, buildings, and other structures and represent "bare earth".

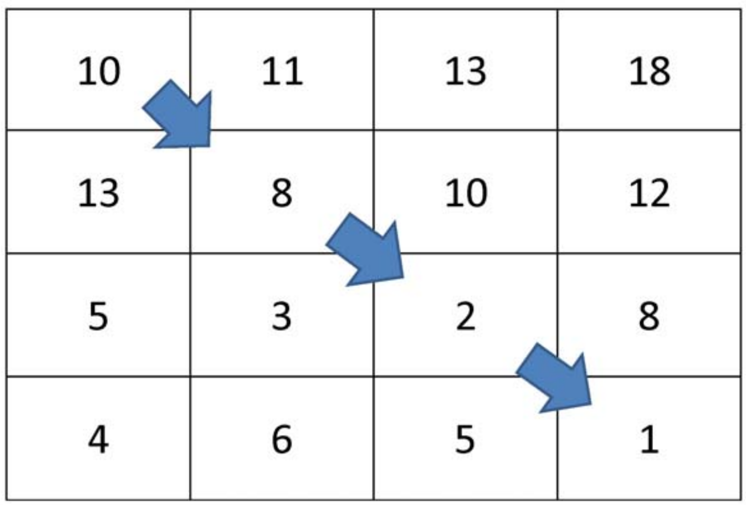

Figure E1. Example of flow direction from cell to cell on a DEM.

Delineating catchments for depressional wetlands was based on identification of "sinks" (Fig. E2). Sinks are defined as locations where surface water flow is interrupted. Sinks can occur through an error during interpolation to create a DEM; however, sinks can also represent natural depressions. In traditional catchment delineation all sinks are filled and watersheds are delineated at locations on streams (pour points). ArcHydro Tools 1.3 offers functionality to preserve natural sinks (wetlands) while filling other sinks (errors in DEM). Wetland catchments were delineated using a tiled approach. Using the DEM, tiles were designed along natural breaklines (roads, rivers, etc) to avoid edge effects. When this was not possible, a smoothing process was

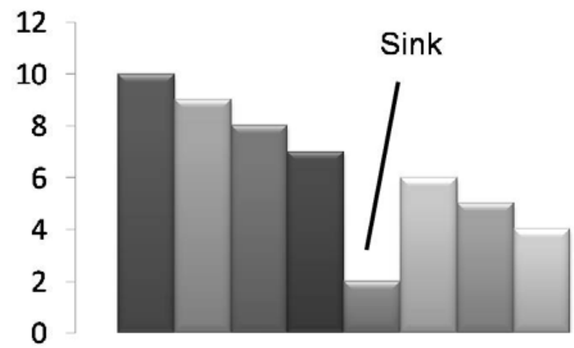

Figure E2. Profile view of a sink as identified on a DEM. The y-axis represents DEM elevation.

used to avoid edge effects caused by tile boundaries. After delineating all catchments within a tile, the tile borders were buffered by 0.5 km and catchments were delineated for wetlands falling inside the buffer. All of the catchments were combined into a seamless dataset for the study area. The NWI dataset was used to confirm which sinks were natural depressions. If a sink occurred that was not overlapped by an NWI wetland, the sink was filled and not regarded as a natural depression in the catchment delineation process.

The NWI mapping process often divides an individual wetland into smaller conjoined wetlands based on observable characteristics such as hydroperiod or dominant vegetation. However, for catchment delineations and volume calculations, we treated conjoined wetlands as one wetland system (Fig. E3).

Individual catchments were delineated for 3,843 wetlands that are outside of the 100-yr floodplain. An example of a delineated catchment in Harris County is shown in Fig. E4. Note that the catchment area includes the wetland surface area. Catchment delineation for wetlands within the 100-yr floodplain presented a unique problem because these wetlands tend to share the same watersheds as their adjacent systems. For example, attempts to delineate catchments along the Trinity River system produced some large catchment areas that extended into several counties. To address this, we substituted a catchment area that was calculated from a 100-m buffer around the perimeter of the wetland. This approach was also used for wetlands with a $V_{catch} \leq 0.01$ (i.e. small wetlands with extremely large catchments); and wetlands with a $V_{catch} >$ 1), which could result from poor LiDAR data resolution or error in the NWI coverage. These wetlands were flagged to indicate greater uncertainty with respect to catchment size. Of the 3,843 wetlands outside the 100-yr floodplain, we were unable to delineate catchments for 167 (~4%). 100-m wide buffer strips were substituted for these wetlands as well.

Figure E3. Example of a conjoined NWI wetland system. The 4 wetlands (PEM1A, PEM1C, PSS1C, and PEM1Cx) were treated as separate wetlands for water regime, vegetation and other water quality variables, but as a single wetland for volume and catchment calculations.

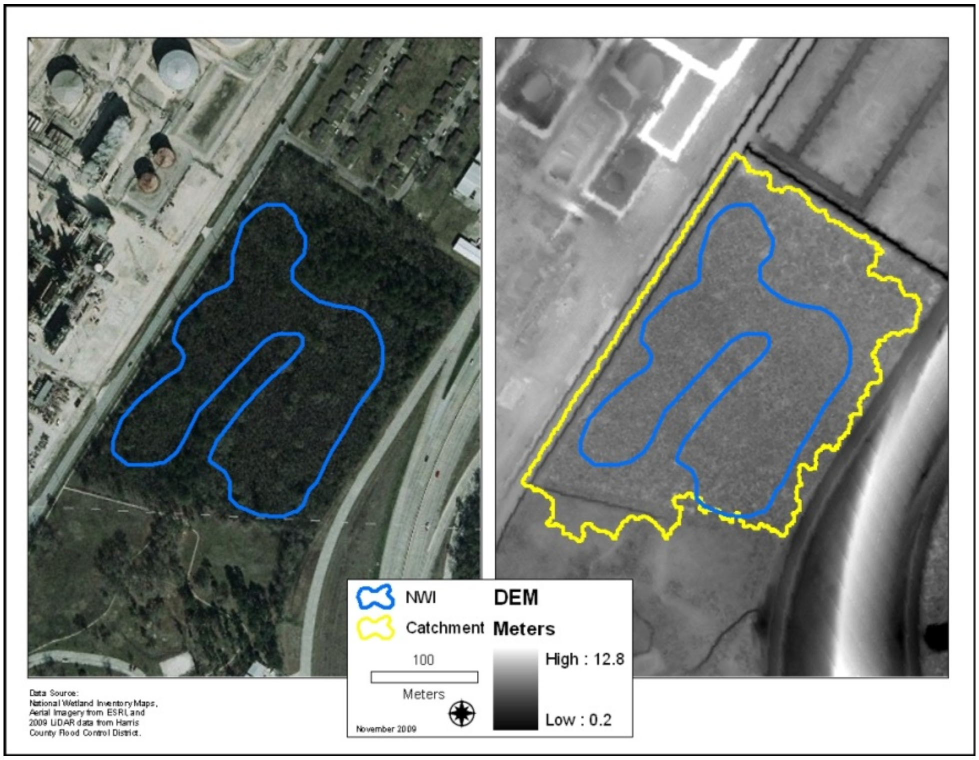

Figure E4. Example of catchment delineation in Harris County using ArcHydro "sink watershed delineation" method. The left panel shows the NWI and the right panel includes the delineated catchment (yellow line).

Catchment delineation using the tools discussed above involves assumptions and uncertainties that affect the accuracy of resulting catchment size. First, very shallow wetlands may not be recognized as natural depressions using LiDAR datasets with a vertical accuracy of 0.37 m (TNRIS data), as was used for much of the study area. Second, it may be difficult to identify an exact boundary where a wetland ends and upland begins. This is particularly true for NWI coverages, which are mapped primarily using aerial photography and may not correspond exactly with LiDAR generated DEMs. In reality, boundaries between wetland and catchment upland are temporally dynamic, fluctuating both with season and annually with climate, thus the catchment:wetland ratio would increase during periods of drought and decrease during wetter climates. Furthermore, in the low relief landscape that characterizes the study area, a large precipitation event could create a temporary but very large catchment area as the breakpoint elevations are exceeded. Third, many wetlands have been drained and filled, or bisected by roads or irrigation canals and these features may lead to issues in the catchment delineation process.

For example, the two wetlands in the upper right quadrant of the highlighted catchment in Figure E5 were not detected by LiDAR and thus no catchment could be delineated.

The ratio of wetland area:catchment area was calculated to yield V_{catch} raw. These values were then normalized to produce the model variable (V_{catch}) which has a potential value from 0.0 to 1.0. Details of the normalization are provided in Section B, Functional Assessment Models.

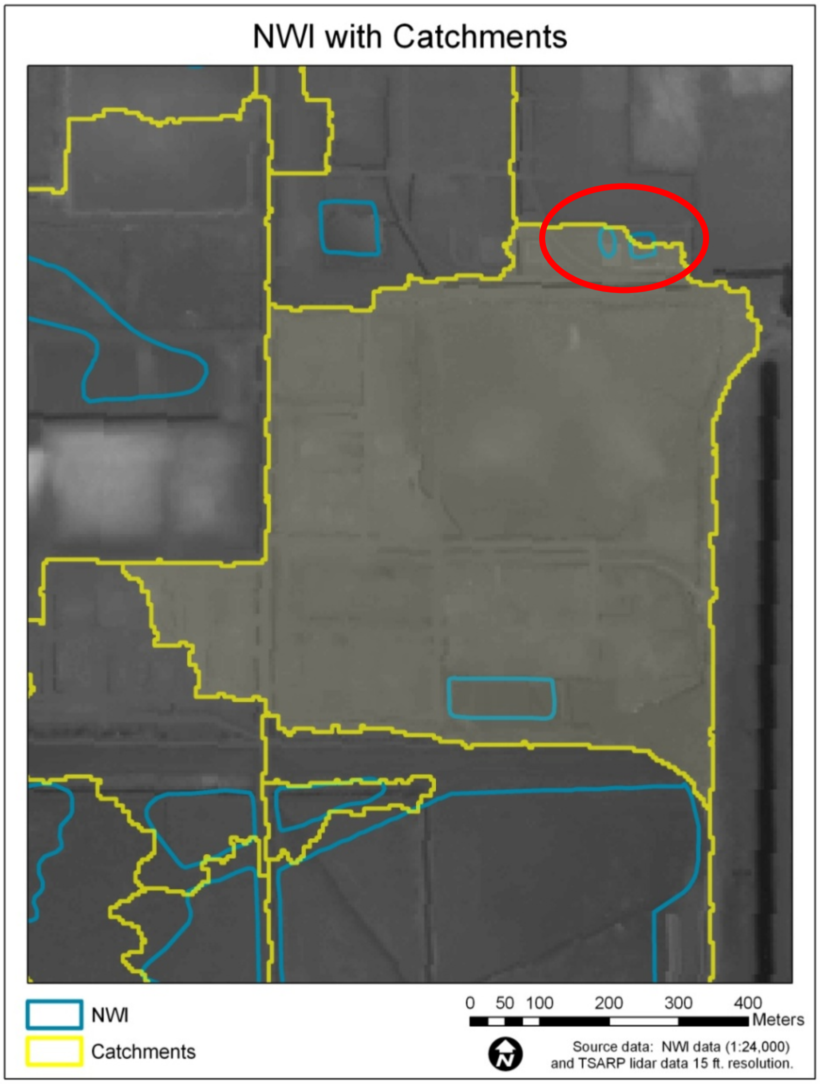

Figure E5. Two small NWI wetlands in Harris County (red circle) that have apparently been filled and thus no volume or catchment estimates were made.

Wetland Volumes

Wetland volumes were estimated with a method developed by Antonic et al. (2001) that fills in depressions in DEMS. This “fill sinks” function fills depressions in order to remove the flow interruption caused by a sink (Fig. E6). First, a single DEM for the entire study area was created by joining LiDAR-derived DEM data from the four counties. Wetland volumes were calculated by determining the differences between the filled DEM and the original DEM. Specifically, subtracting the elevation of the filled DEM from the original DEM elevation determined the wetland depth for each pixel. Next, the depth per pixel was multiplied by the area of the pixel (1.96 m^2) to obtain the volume per pixel. Finally, using ArcMap zonal statistics, pixel volumes were summed over the wetland area as delineated by the NWI to obtain the total potential volume of each wetland or wetland system as well as the mean depth. V_{vol} values were ranked and normalized based on percentile groups. For example wetlands in the smallest 0 - 15% of volumes were assigned a value of 0.1, wetlands with volumes in the 15 - 25% were given a value of 0.2, so on. Details of these normalizations are included in Section B of this report.

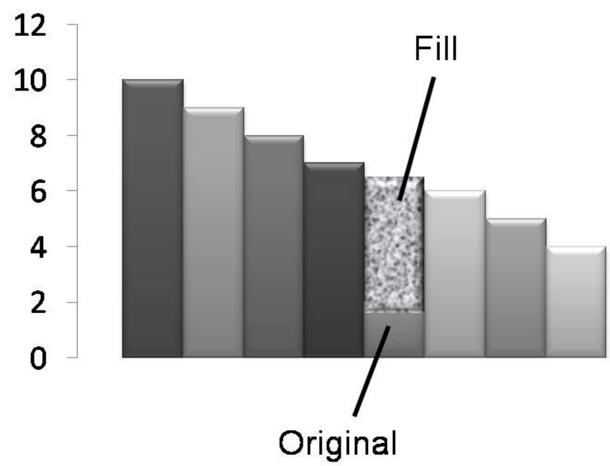

Figure E6. Conceptual cross-section of filling a DEM-depression using GIS “fill sinks” function.

Land Use\Land Cover

Land cover\land use for the study area was obtained from the 2001 USGS National Land Cover Dataset (NLCD). This raster dataset has a resolution of 30 m and was resampled to 1.4 m to match the LiDAR resolution. Land use was used in two water quality models, ammonium removal and phosphorus reduction. Because nitrogen loadings were not available, we used phosphorus loading estimates as a surrogate for both nitrogen and phosphorus loading. We used loading values associated with different land cover types from a study conducted by Adamus and Bergman (1995) and converted to a relative scale from 0 to 1 (as detailed in Appendix Y). Calculated as the mean weighted average for each catchment, the resulting variable (V_{LU}) was high for land uses such as agriculture and low for undeveloped forest and grassland.

Vegetation Density

Color infrared images from National Agriculture Imagery Program (NAIP) were used to calculate a Normalized Difference Vegetation Index (NDVI). NDVI is a standard vegetation index used by remote sensors to identify general vegetative cover types. The index is obtained using the equation:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

where NIR is the near infrared band and RED is the red band in the imagery. The equation is based on plant chlorophyll absorption of red visible light and reflection of near-infrared light. Application of the equation produces a raster dataset with pixel values ranging from -1.0 to 1.0. Negative values and near zero values represent open water features and bare soil; generally, values of 0.1 – 1.0 represent vegetated areas. Using 2005 true-color NAIP imagery, transitions from bare soil areas to vegetated areas were sampled and a value of 0.1 was assigned as the lowest detectable value (threshold) for the presence of vegetation. Values below this threshold were considered unvegetated pixels (Fig. E7), allowing the calculation of percent vegetated cover of the wetland (V_{mac}) or its 30-m buffer (V_{buff}). The zonal statistics tool in ESRI® ArcMap was used to calculate a mean weighted average from variable-valued rasters within a polygon.

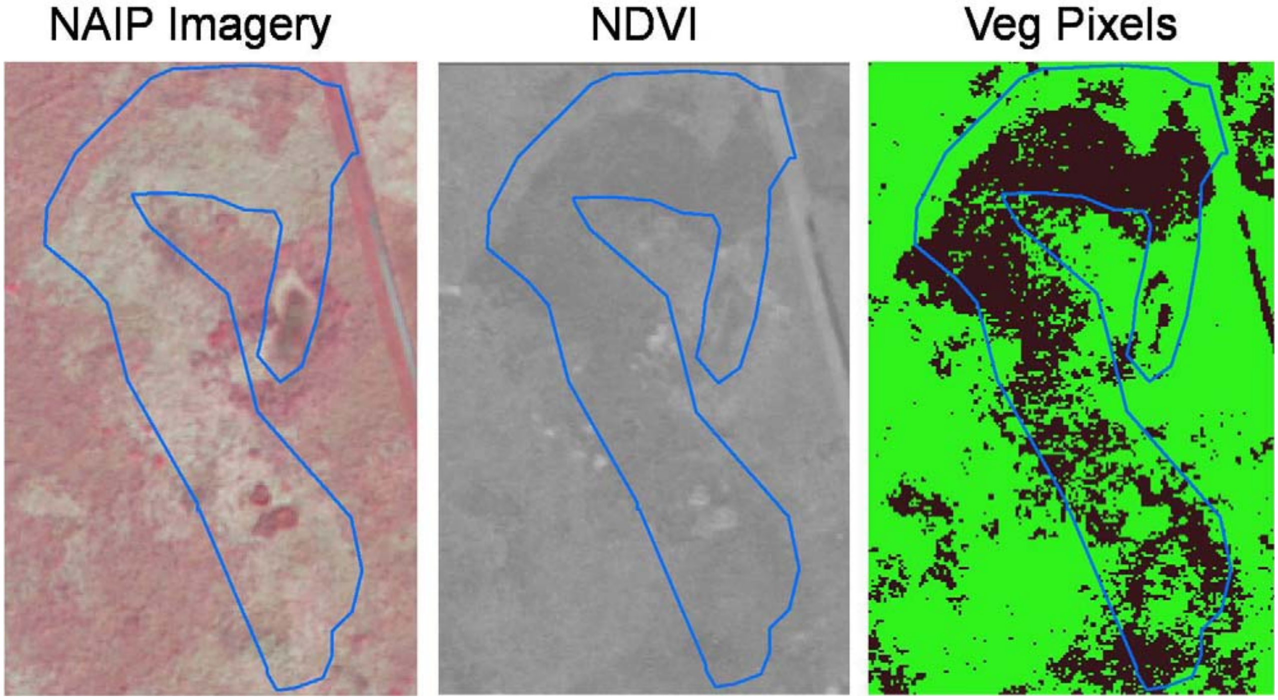

Figure E7. Example of a NAIP image converted to an NDVI image and finally to an image of vegetated pixels, in which bright green represents vegetation.

Soil Parameters

Soil data (SSURGO) were used to derive parameters as percent clay (V_{clay}) and soil pH (V_{soilpH}) variables. SSURGO data are identified by soil map units dominated by 1-3 types of soil. Soil data were overlaid with the NWI to assign V_{clay} and V_{soilpH} to each wetland. Where multiple map units occurred within a wetland, a mean weighted average of the soil parameter was calculated. SSURGO data sometimes assigns a zero value to a map unit (e.g. water). In these cases, the value of the dominant neighboring soil map units was assigned to the map unit; and these wetlands were flagged to indicate greater uncertainty associated with the variable estimate.

Overlapping Polygons

ESRI's Zonal Statistics tool, which was used to calculate a mean-weighted average for vegetation, soils, and other variable-value raster sets, cannot process data with overlapping polygons (zones). Therefore, the zonal statistics in Hawth's Tools (version 3.27) was used to calculate the following variables for overlapping polygons:

1) V_{buff} – Vegetated area within 30 meter buffer of wetlands; and

2) V_{LU} – Mean weighted average of normalized phosphorus loading value for watersheds and wetlands where a 100 m buffer was used as the catchment.

Model Result Maps

A set of electronic maps with color coded Functional Capacity Index (FCI) values for individual wetlands has been created as a deliverable for this project. These maps are quadrangle maps and thus there are 32 maps for each model for a total of 192 maps. These maps, as well as the GIS geodatabase containing all raw and output data layers, are provided on a hard drive. Adobe® Acrobat® Professional was used to create mapbooks for each model, with maps in the PDF file format. This was accomplished using the Adobe® link tool to draw links with relative paths to topo quad maps on map indexes for each model. An advantage of using a PDF mapbook is that users may use the zoom and pan tools to navigate within the maps and examine specific wetland sites in detail. Additionally, the Adobe® interface offers easy print options including printing in large format (native format) or letter size. The mapbooks were burned to a DVD and contain data dictionary documentation.

Maps for each model result were published for ESRI ArcReader, a free GIS viewer. The ArcReader maps content and symbology is similar to the topo quad maps, however, they offer more advanced functionality including the ability to easily zoom or pan anywhere within the study area, querying a wetland to view model variables and other information.

Results

Wetland Presence and Size

According to NWI, there are 10,349 palustrine wetlands within the 32 quad study area. The total area covered by these wetlands is approximately 51,200 ha (512 km^2) and the study area is 5,376 km^2 (32 quads x 168 km^2 per quad), resulting in an estimate of 9.5% of the landscape occupied by these wetlands. Nearly half of the wetlands are classified as emergent (Fig. E8, top panel), followed by unconsolidated bottom (25%), forested (19%), scrub/shrub (9%), and aquatic bed (1%). Most of the emergent wetlands have a subclass of persistent vegetation. On an areal basis (Fig. E8, bottom panel), the largest class is emergent (42,313 ha, 83%) followed by forested (4,987 ha, 10%), unconsolidated bottom (2,080 ha, 4%) and scrub/shrub (1,735 ha, 3%). Aquatic bed wetlands cover only 72 ha (<1%).

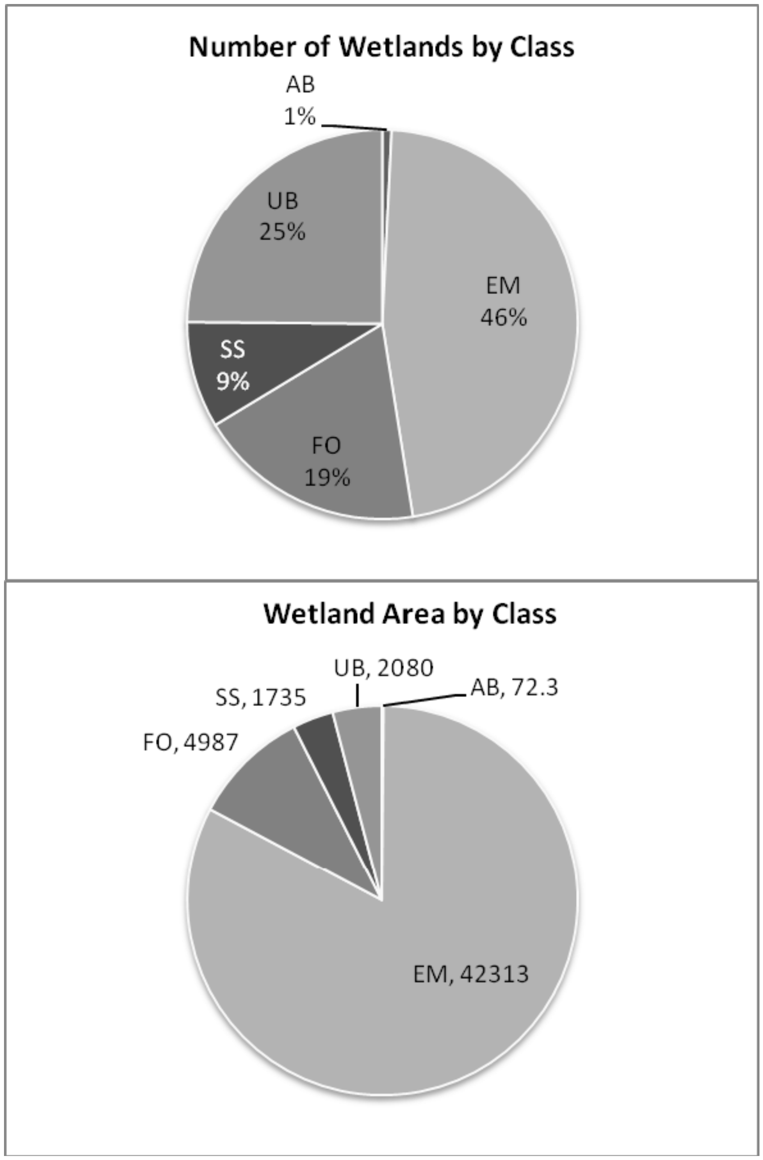

Figure E8. Top: Percent by class of number of palustrine wetlands in study area. Bottom: Total wetland area (ha) by class. AB=aquatic bed, EM=emergent, FO=forested, SS=scrub/shrub, UB=unconsolidated bottom. Data source: NWI.

Model Variables

Catchment Delineation (V_{catch})

Of the 10,349 NWI-mapped wetlands in the study area, nearly 3,000 were conjoined wetlands, reducing to approximately 7,360 the number of “wetland systems” for which catchments and volumes were calculated. Figure E9 shows the distribution of catchment values that were delineated (top panel), and catchment values that were calculated from buffer strips (bottom panel). The median size of delineated catchments was 37 ha and the median catchment size of buffer strips was 61.5 ha. This suggests that actual wetland catchments may be smaller than a 100-m perimeter strip.

The model variable V_{catch} was derived by normalizing the ratio of wetland area to catchment area. Therefore, we first calculated V_{catch} raw (Fig. E10) for the combined dataset of delineated and buffer strip catchments. V_{catch} raw ranged from 0.005 to 0.9996 with a median of 0.09. A V_{catch} raw of 0.09 means that the area of the [wetland+catchment] is 11 times larger than the area of the wetland alone. This analysis confirms that these wetlands tend to be small with small catchments.

Wetland Volume (V_{vol})

Of the ~7,360 wetland systems for which volume estimates were calculated, seven wetlands were eliminated because, according to aerial photography, they were converted to other land uses. These wetlands were coded as -9999 and omitted from further analyses. Additionally a volume of zero was calculated for 22 wetlands (0.3% of the total). Zero volumes could result from: 1) wetland has been filled; 2) wetland was deeply flooded and LiDAR did not penetrate the water; or, 3) depression was too shallow to be detected by the LiDAR due to error associated with LiDAR. Wetlands with zero volumes were flagged and assigned the minimum V_{vol} value of 0.1.

The distribution of wetland volumes was lognormal (Fig. E11). Note that 1 m^3 was added to all values to allow logarithmic transformation of the zero-volume wetlands. Wetland volumes ranged from a minimum of zero to a maximum of 10,353,582 m^3. The median wetland volume was 235 m^3 (0.19 ac-ft) and the total volume of all the wetlands was approximately 47,000,000 m^3 (38,535 ac-ft). The largest wetlands were located in Chambers County. Some wetlands, such as those coded with a hydrologic modifier of “x” (excavated), “f” (farmed) or “r” (artificial) have been modified to increase their volumes, often resulting in steep contours. These wetlands, (e.g. holding ponds, stock tanks) tend to have greater depths and volumes and do not represent the natural morphology for coastal prairie wetlands. The larger volume does not enhance their water storage capacity because much of this volume nearly always contains water.

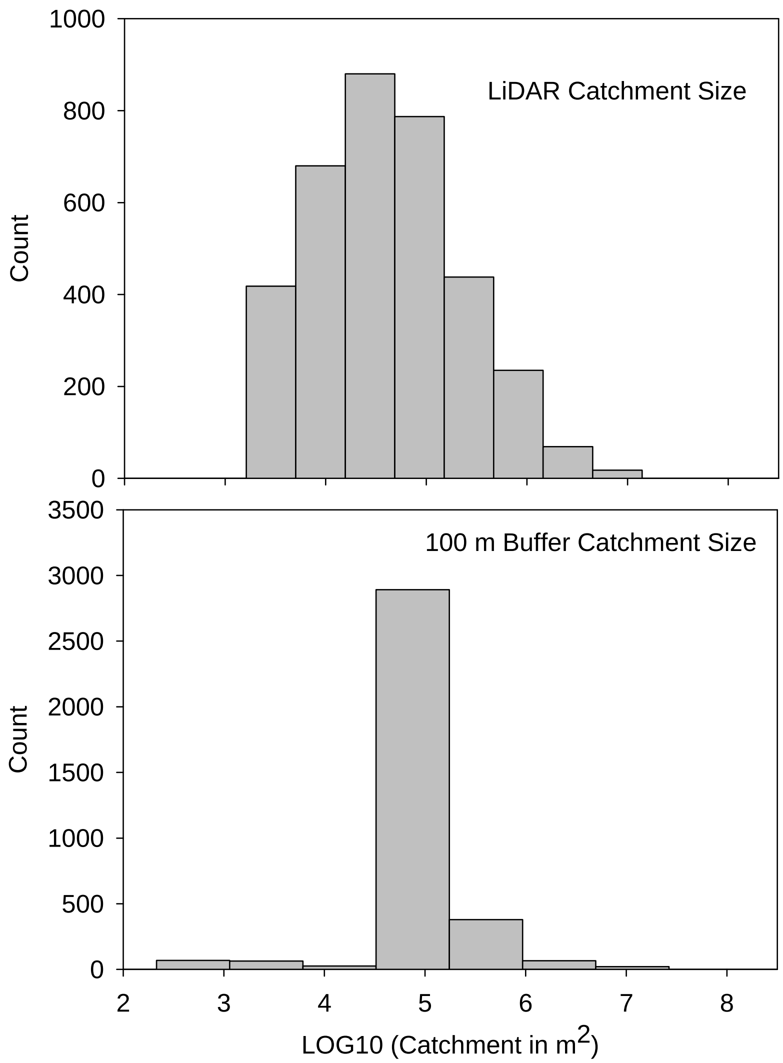

Figure E9. Histograms for log of catchment areas for wetlands that had LiDAR delineated catchment areas (top panel) and 100-m buffer strip catchment areas (bottom panel).

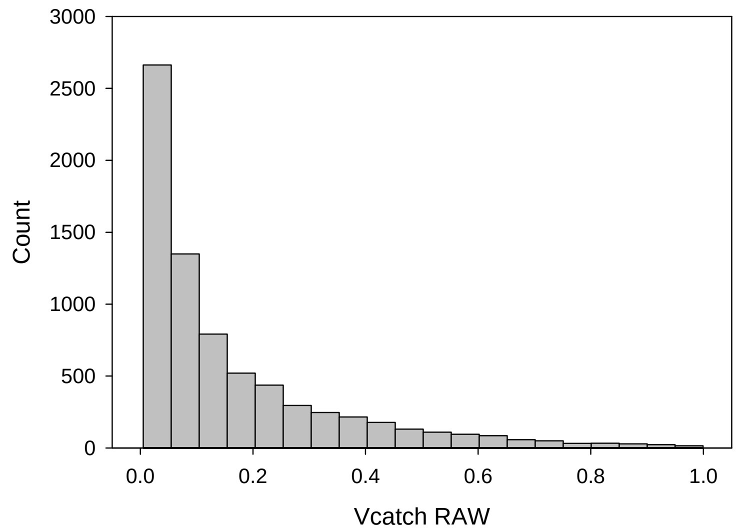

Figure E10. Histograms for VcatchRAW (Wetland Area:Catchment Area).

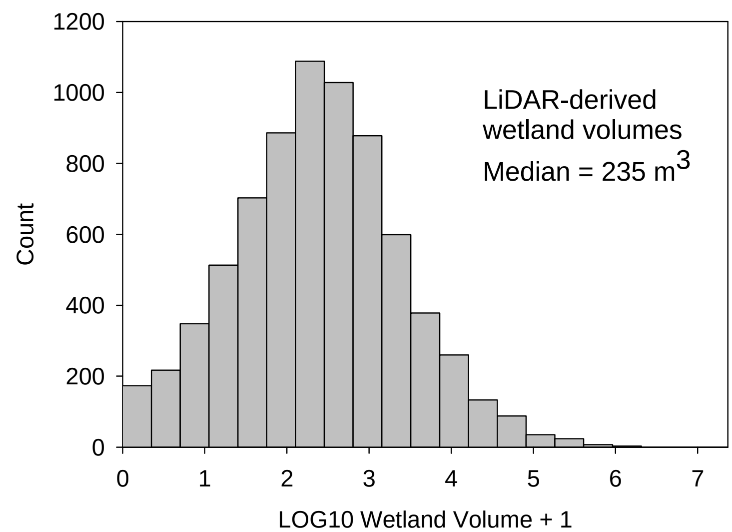

Figure E11. Histogram of wetland volumes. Note log scale.

Water Regimes (Vwet and Vdry)

The distributions of the six model variables, including V_{wet}, are shown in Figure E12. The NWI-hydroperiod classifications were used to determine V_{wet} and V_{dry} according to the details provided in Appendix Y of this report. According to these classifications, approximately one third of the total wetland area in the study area is temporarily flooded and one third is seasonally flooded (Table E2). Much of the remaining third are classified as “farmed” and are primarily the large tracts located in Chambers County. The water regime that best described “farmed” wetlands in the study area depends primarily on whether they are grazed pasture or rice fields (David Mathei, Anahuac NRCS, personal communication). We used NCLD coverages to determine which of these activities was occurring. Wetlands classified as grazed pasture (n = 121, area = 10,191 ha) were assigned the dominant hydroperiod of the adjacent wetlands and rice (n = 63, area = 5,422 ha) was assigned an intermittently exposed hydroperiod. Although slightly over 3,000 wetlands are assigned a low value for V_{wet}, 60% (6,261) were assigned 1.0, the highest value for V_{wet}.

Wetlands with V_{wet} = 1.0 are flooded less than 18 weeks per year. This feature generally enhances water storage capacity because such wetlands have more frequent and greater available storage to capture precipitation. As wetlands dry out in summer, the soil moisture capacity increases as well. Many biogeochemical processes are also enhanced by drawdown, as oxygen is introduced and rates of some metabolic processes such as nitrification and decomposition can increase. These enhancements are reflected in the assignment of V_{wet} and V_{dry} variables for the water quality and water storage models. The seasonal droughts that occur in these wetlands also provide an important ecological disturbance that help to maintain the diversity of plant species and fauna such as amphibians. In contrast, artificially and permanently flooded palustrine wetlands can become persistently anaerobic and tend to have lower flora and faunal diversity. Of the 10, 349 wetlands, 1,972 (19%) were coded with the “x” (excavated) modifier. Artificially and permanently flooded wetlands, particularly excavated wetlands, generally have lower water storage function.

Vegetation Density

The distributions of model variables V_{mac} and V_{buff} are shown in Figure E12. The most abundant class for both variables was the fully vegetated condition. NAIP data may classify open water area as unvegetated, even though most natural wetlands with open water likely have either submersed vegetation (e.g. *Chara*, pondweeds, bladderworts) or the vegetation had not yet emerged from the water surface.

Table E2. Distribution of hydroperiod type by count and area. P=irregularly flooded, S=temporarily flooded-tidal, V=permanently flooded-tidal.

NWI Code	Description	Weeks Flooded	Area (ha)	Area (%)	Count
A	Temporarily Flooded	1 - 4	17,316	34	4,233
C	Seasonally Flooded	5 - 17	11,628	23	2,215
F	Semipermanently Flooded	18 - 40	2,382	4.7	2,296
H	Permanently Flooded	52	1,056	2.1	776
K	Artificially Flooded	52	819	1.6	269
R	Seasonally Flooded-Tidal	5-17	1,021	2.0	152
T	Semipermanently Flooded-Tidal	18-40	1,206	2.4	141
NC/f	Not classified/farmed	various	15,625	31	184
Other	P, S, & V	various	134	0.3	83
	Totals		51,187	100%	10,349

Soil pH and Clay

The distribution of variable values for V_{soilpH} and V_{clay} as derived from SSURGO databases are also shown in Figure E12. For soil pH, values increase with increasing alkalinity. For example, the V_{soilpH} value of 0.6 corresponds to a soil pH of between 6.6 – 7.3 (neutral). This variable is used in the phosphorus and heavy metals models. For V_{clay}, the variable is analagous to approximate percentage clay content, thus sites with higher V_{clay} values have greater clay content. The largest category was sandy loam/loamy sand, followed by sandy clay/silty clay loam.

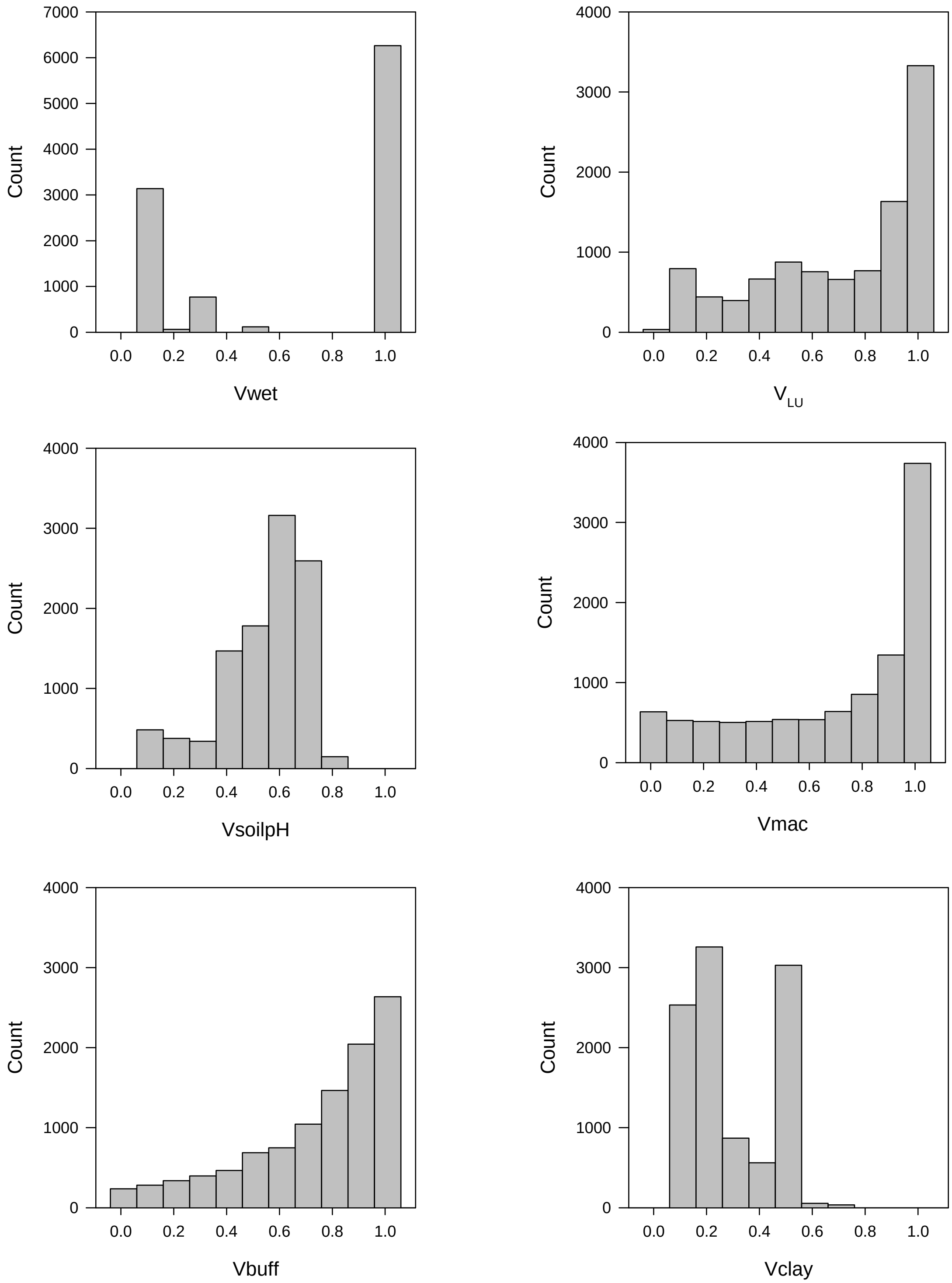

Figure E12. Distribution of model variables V_{wet} V_{LU}, V_{soilpH}, V_{mac}, V_{buff} and V_{clay}.

Land Use

Over 32% of wetlands were located in an area with a land use classification of "natural", and these were assigned a V_{LU} of 1.0. The remaining wetlands were evenly distributed among the other land use classes, with the exception of 34 wetlands with V_{LU} near 0.0. Wetlands toward the low end of V_{LU} are located in agricultural settings or high density residential/commercial settings.

Model Results

Water Storage Model (FCI_{ws})

A wetland with an FCIws = 1 would be seasonally flooded (or less frequently) with a volume in the top 10 percentile, have >90% emergent vegetation, and a moderately sized catchment area. The mean ($\pm$ SD) FCI_{WS} for all wetlands in the study area was 0.3 $\pm$ 0.28 and the median was 0.2. The distribution is skewed, that is a greater number of wetlands have a low water storage capacity. Over 1,000 wetlands (~10%) are artificially flooded (i.e. permanently flooded) or have hydrologic modifications, resulting in a V_{wet} of 0.1. Excluding these wetlands from the model results in a more normal distribution and a median FCI_{WS} of 0.4. The distribution of FCI_{ws} shown in Fig. E13 includes these wetlands. Thus, wetlands in our study period with a natural hydroperiod have a moderate potential to store surface water during precipitation events.

Ammonium Removal Model (FCI_{NH3})

A wetland with an FCI_{NH3} = 1 would be intermittently flooded, have >90% density of wetland and buffer vegetation, and be located in a natural area. The mean and the median FCI_{NH3} was 0.37 and 0.40 respectively (Fig. E13). Note that similar to FCI_{WS}, the distribution of FCI_{NH3} is somewhat skewed. This is due to the influence of the variable V_{dry}, which, like V_{wet}, has low values (0.1) for permanently and artificially flooded wetlands, and those with hydrologic modifications. Removing these resulted in a more normal distribution of the results. Based on these results, natural wetlands in the study area have a moderate capacity to remove ammonium.

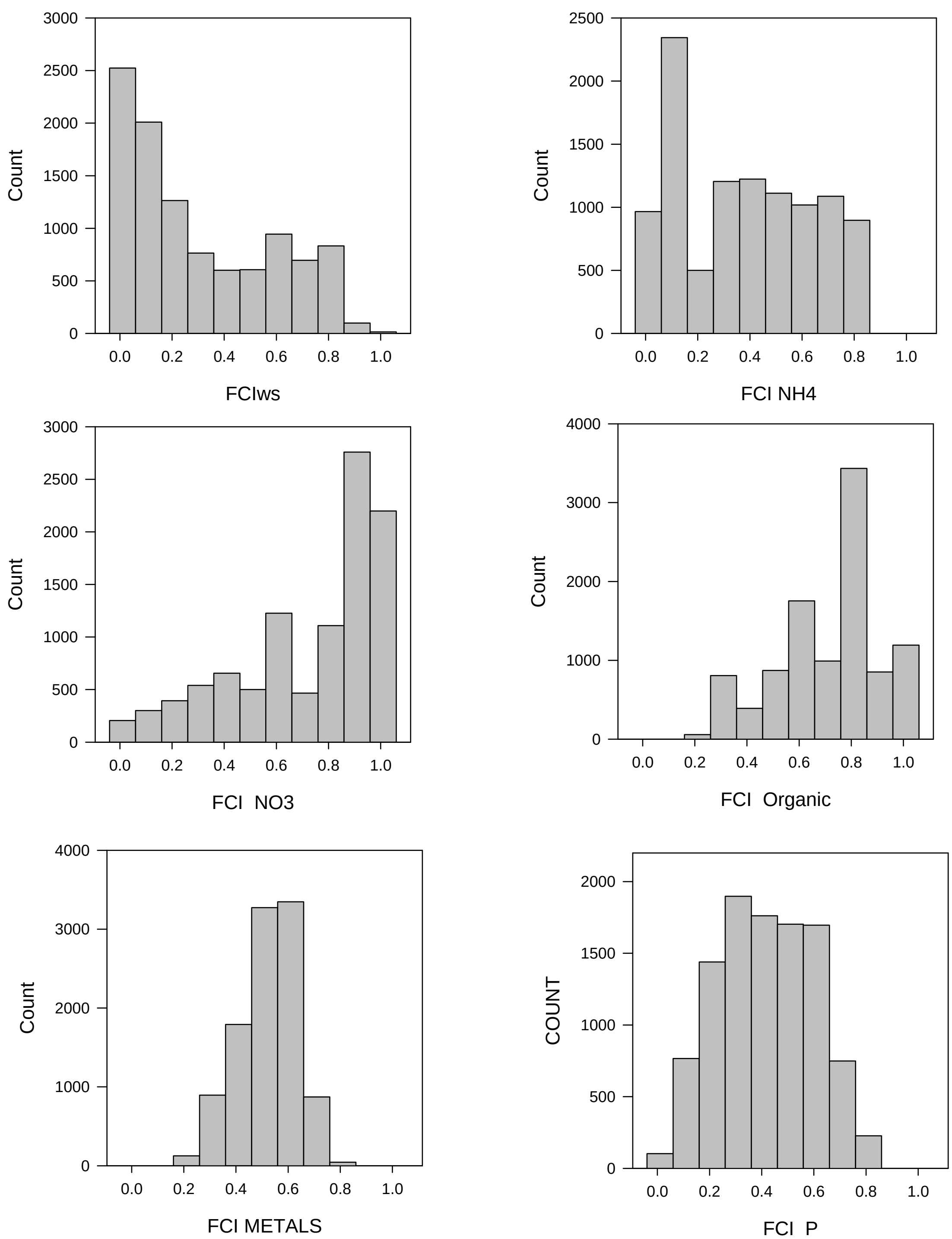

Figure E13. Distributions of functional capacity index (FCI) for six models.

Nitrate Removal Model

A wetland with an FCI_{NO3} = 1 have >90% vegetation density in both the wetland and its buffer. The distribution of FCI_{NO3} for all wetlands is skewed toward higher nitrate removal capacity (Fig. E13). This is primarily a result of the high values of the variables associated with nitrate removal, V_{buff} and V_{mac}. Most CPWs contain abundant vegetation both within the wetland itself and within a 30-meter buffer of the wetland. Model results with all wetlands had a mean of 0.7 and a median of 0.8. These values suggest that CPWs in the study area provide a high nitrate removal function.

Phosphorus Retention Model Results

A wetland with an FCI_P = 1 would have >90% vegetation density in the wetland and buffer, a natural area land use, clay soils, and a moderately sized catchment area. The results for phosphorus retention, when including all wetlands, had an approximately normal distribution, with a mean of 4.0 and a median of 0.41 (Fig. E13). Although our study area is described as being dominated by clay soils, most soil types have enough sand and silt, that the V_{clay} variable was relatively low with a median value of 0.2. The model results suggest that wetlands in the study area have a moderate capacity for phosphorus retention.

Heavy Metals

A wetland with an FCI_{metal} = 1 would have >90% vegetation density in the wetland and buffer, clay soils, and very strongly alkaline soil pH. Functional capacity indices for heavy metal removal were approximately normally distributed, as reflected in the mean and median of 0.5 (Fig. E13). The distribution of values for heavy metal retention had the least variability of all the models.

Organic Compounds

A wetland with an FCI_{org} = 1 would have >90% emergent vegetation, and a moderately sized catchment area. The distribution of indices for organic retention/removal had a mean of 0.7 and a median of 0.8 (Fig. E13). This model is driven primarily by density of emergent vegetation, which tended to be high throughout the study area. The model results suggest that wetlands in the study area have a high capacity to retain/remove organic material.

Error and Uncertainty

Considerable uncertainty and error (henceforth referred to as error) exists in any project of this scale. Of course the addition of conceptual models increases this error, as such models are theoretically based and thus predict only qualitative or indexed values. We present here an analyses of error associated with the model variables, followed by a discussion of error in the model results. Our analyses is based on a comparison of GIS derived information to data collected in the field and laboratory from selected wetland sites within the study area. Twelve wetlands were evaluated, however the Harris County site was located outside the study area and GIS coverages were not available for a comparison at this site. A brief description of the methods used to derive GIS and field/laboratory data for model variables is included in Table E3. A detailed description of the model variables in included in Appendix Y.

Model Variables

The error associated with estimating model variables derives primarily from two types of error. The first is error associated with the geodatabases used to quantify the model variables, specifically NWI, SSURGO, and NLCD. Data and variables with this type of error include wetland presence, size (V_{vol} and V_{catch}), water regime (V_{wet} and V_{dry}), wetland soil (V_{clay} and V_{soilpH}) and landuse (V_{LU}). The second is error associated with applying a GIS technique to estimate values from a geospatial database. Data and variables with this type of error include wetland volume and catchment size (V_{vol} and V_{catch}), and buffer/wetland vegetation density (V_{mac} and V_{buff}).

Table E3. Functional assessment model variables, field/laboratory methods and GIS databases. GPS = global positioning system, LAI = leaf area index, NLCD = National Land Cover Database, NAIP = National Agricultural Imagery Program, SSURGO = Soil Survey Geographic Database.

Variable (symbol)	Field/Laboratory Method	GIS Method
Wetland Volume (V_{vol})	Topographic survey	ArcMap "fill analysis"
Wetland Area to Catchment Area Ratio (V_{catch})	Wetland area determined by walking perimeter with GPS	ArcHydro Tools 1.3 "sink watershed delineation"
Wetland Outlet (V_{out})	Direct observation	Aerial photography
Land Use (V_{LU})	Direct observation	NLCD covers
Macrophyte Density (V_{mac})	LAI within wetland at randomly selected plots and percent cover by species	NAIP data
Wetland Buffer (V_{buff})	LAI in buffer (10 m intervals to 30 m width)	NAIP data
Soil Organic Matter (V_{som})	Loss on ignition (ash free dry weight)	SSURGO soil data
Soil Clay Content (V_{clay})	Texture by feel	SSURGO soil data
Soil pH (V_{pH})	Soil-water slurry (1:1 ratio)	SSURGO soil data

Errors in Wetland Presence and Size

The NWI databases are generally believed to be conservative in establishing wetland boundaries; therefore, the total area of wetlands addressed in this study may be underestimated. On the other hand, the NWI database is approximately 4 years old, and thus changes in land use or wetland condition that has occurred since the aerial imagery was flown and interpreted are another source of error. For example, our study site Sedge Wren is a USFWS restoration wetland and was not mapped on the NWI. Quantifying NWI error is beyond the scope of this study, however, based on our field knowledge of the remaining 11 wetlands evaluated in this study, the NWI boundaries appear to be reasonable.

Water Regime Error

The NWI water regime classes were also used to estimate V_{wet} and V_{dry}. Although we have sufficient hydrologic data to confirm the hydrologic class for six of the wetlands studied, that data represents only one point within the wetland. Our water level recorders were placed in the deepest portion of the wetlands and although we observed dry conditions at every water level recorder at least once during the study, our hydrology data is skewed toward more frequent inundation. On many occasions, a large portion of a wetland lacked surface water while the deeper portion (with the water level recorders) still had surface water. In spite of this, our monthly observations of the 12 wetland sites provide a qualitative basis for evaluating the error associated with using NWI water regimes. Table E4 below lists the sites with their NWI water regime and assigned V_{wet} value. One incorrect V_{wet} occurred where a value of 0.2 was assigned to LeConte, although we know that this wetland is flooded less than 18 weeks annually. All V_{wet} and V_{dry} assignmments for farmed wetlands were flagged to indicate greater uncertainty. Error associated with V_{dry} is likely to be somewhat greater than error associated with V_{wet} because V_{dry} had a great number of categories. In conclusion, our observations support the broader finding that most natural palustrine wetlands in the study area have a frequent wet - dry cycle.

Table E4. Comparison of water regime for six study sites and observed inundation. NC/f = water regime not classified, land use is farmed. *Class assigned based on nearest wetland class, not included in NWI.

Site	NWI Code	Water Regime	Weeks Flooded	V_{wet}	Correct?
Chicken Road	PEM1C	C	5 - 17	1.0	Yes
Wounded Dove	PEM1C	C	5 - 17	1.0	Yes
Kite Site	PFO1A	A	1 - 4	1.0	Yes
Turtle Hawk	PFO1A	A	1 - 4	1.0	Yes
LeConte	PSSf	NC/f	18 - 40	0.2	No
Sedge Wren	PEMf*	NC/f	<18	1.0	Yes
Dow	PEM1C	C	5 - 17	1.0	Yes
League City	PEM1A	A	1 - 4	1.0	Yes
Univ. of Houston	PFO1A	A	1 - 4	1.0	Yes
Kildeer	PEM1F	F	18 - 40	0.3	Yes
Senna Bean	PEM1A	A	1 - 4	1.0	Yes

Vegetation Density Error

Vegetation density in the field was measured during vegetation surveys at selected plots. These surveys provide an error estimate for both V_{mac} and V_{buff}. The imagery used to calculate the NDVI contained minimal cloud cover. If deep water was present in the imagery, submerged vegetation may not have been recognized, resulting in an underestimation of vegetation density. Conversely, forested wetlands may lead to overestimation in the emergent macrophytic vegetation variable (V_{mac}). Tree canopies are typically identified in the NDVI, and the wetland may appear to have a high percent cover of vegetation. However, understory vegetation may be more important to the removal of pollutants.

Surveys on the original six sites were performed in spring and summer of 2008 when wetlands were in a fully vegetated condition. The average percent cover of the 10-15 surveyed plots for each site are shown in Table E5, together with the NDVI percent cover estimated from NAIP coverages (=V_{mac}). The table gives an overall RMS error as well as a modified RMS error that eliminated 3 of the 11 sites for various reasons discussed below. Note that cover for the three wetlands with forested area were described in field surveys according to ground, understory, and overstory values which sum to greater than 100%.

Two wetlands, Killdeer and Senna, were surveyed after Hurricane Ike and reflect the impacts of storm surge on the vegetation at these sites. Killdeer was, according to the landowner, fully vegetated prior to the hurricane. Sedge Wren was surveyed prior to the hurricane, however the wetland was a rice field when the NAIP data was obtained and therefore the error represents change in land use. These three wetlands were eliminated from the calculation of adjusted RMS error, resulting in an error estimate of 33%.

Error in the Dow survey may be due to time of survey, which was conducted early in the season when the wetland was flooded (63.3% open water) and emergent vegetation was not fully established. Our initial visit to the site in August, however, revealed 100% cover by senna bean plants and no standing water. Thus this wetland has two distinct vegetation types and the error associated with this type of wetland sites may be due to time of year vegetation was surveyed.

Table E5. Comparison of NDVI derived vegetation cover and field surveys. Adjusted RMS error removed sites surveyed after Hurricane Ike and Sedge Wren restoration site.

	Percent Cover				NAIP/NDVI	
SiteName	Ground	Understory	Overstory	Total	Vmac	Error
Chicken Road	100.0			100	0.9	-0.10
Dow	31.2			31.2	0.9	0.59
League City	100.0			100	0.5	-0.50
LeConte	100.0			100	0.9	-0.10
Sedge Wren	100.0			100	0.1	-0.90
Kildeer	0.0			0.0	0.7	0.70
Senna Bean	43.4			43.4	1.0	0.57
Wounded Dove	100.0			100	0.5	-0.50
Kite Site	37.8	16.5	14.7	100	1.0	0.00
Turtle Hawk	37.9	19.8	46	100	1.0	0.00
Univ. of Houston	79.0	29	30	100	1.0	0.00
					Net error	-0.02
					RMS error	0.48
				adjusted	RMS error	0.33

Two grass dominated sites, League City and Wounded Dove, were poorly characterized by NDVI analyses. The Wounded Dove NDVI imagery is shown in Figure E7. We have visited this site regularly since August of 2008 and it is always densely vegetated throughout, yet the NDVI failed to read much of the area dominated by grasses (mostly *Spartina patens*). League City also has abundant grass cover and was poorly characterized by the NDVI.

Soil Parameters

Wetland soil data was generated from soil collected at multiple plots at each of the 12 wetlands (Appendix soil). The GIS values for percent clay and pH were derived from SSURGO databases. SSURGO data are from county soil surveys which typically analyze limited soil samples to derive information about a soil type. This limited sampling can result in substantial error when compared to a similarly mapped soil unit at another location. As previously stated, we eliminated one soil parameter due to poor agreement between field and SSURGO data.

Table E6 below shows soil pH ranges from soil collected at each site to data from the SSURGO database. Lab pH measurements were consistently lower than SSURGO values and possibly result from our collection of soils from frequently inundated areas (in order to collect water samples), rather than distributing our sample plots throughout the soil mapped area. Greater inundation and flushing would tend to lower the soil pH by removing cations that are replaced by hydrogen ions. One exception to this general trend is the Kildeer wetland site, which was inundated by Hurricane Ike and soil samples were collected while storm surge water was in the wetland, which raised the pH of the soil. Based on these results, the GIS model could overestimate heavy metal removal in coastal prairie wetlands.

Soil clay content exhibited a similar lack of agreement between field collected soils and SSURGO databases (Table E7). The disagreements were biased in the opposite direction than soil pH, however, SSURGO underestimated the amount of clay in site soils in 6 of the 7 results that were different. Thus the models may underestimate phosphorus and heavy metal removal in these wetlands.

Table E6. Comparison of soil pH as measured in lab and from GIS SSURGO database. High, Med, Low rating in italics indicate disagreement with lab results.

	LAB DATA			Qual	SSURGO DATA			Qual
SiteName	pH-range	median	Vsoil pH	rating	pH range	median	VsoilpH	rating
KS	4.6 - 5.1	4.8	0.2	LOW	5.3	5.3	0.3	LOW
LC	4.4 - 5.4	4.8	0.2	LOW	4.3 – 5.8	5.3	0.3	LOW
SW	4.3 - 5.1	4.8	0.2	LOW	4.3 – 6.2	5.3	0.3	LOW
TH	3.6 - 4.8	4.4	0.1	LOW	5.3	5.3	0.3	LOW
UH	4.3 - 4.8	4.6	0.2	LOW	4.7 - 6.7	5.8	0.4	*MED*
KIL	6.2 - 6.5	6.4	0.5	HIGH	5.8	5.8	0.4	*MED*
SB	4.5 - 5.6	4.8	0.2	LOW	5.8	5.8	0.4	*MED*
WD	4.6 - 7.0	5.2	0.3	LOW	7.3	5.8	0.6	*HIGH*
CR	4.2 - 5.6	4.4	0.1	LOW	6.2 – 7.3	6.3	0.5	*HIGH*
LG	4.2 - 4.9	4.3	0.1	LOW	6.2 – 7.3	6.3	0.5	*HIGH*
DW	4.5 - 4.7	4.6	0.2	LOW	7.5	7.5	0.7	*HIGH*

Table E7. Comparison of soil clay content as measured in lab and from GIS SSURGO database. High, Med, Low rating in italics disagree with lab results.

Site	**LAB** Dominant Soil Type	Vclay	Qual Rating	**SSURGO** Dominant Soil Type -	Vclay	Qual. Rating
League City	sandy clay loam	0.37	MED	loam	0.20	*LOW*
LeConte	sandy clay loam	0.37	MED	silt loam/clay	0.30	MED
Senna Bean	sandy clay loam	0.37	MED	loamy sand	0.10	*LOW*
Kildeer	sandy loam	0.22	LOW	loamy sand	0.10	LOW
Chicken Road	silty clay	0.64	HIGH	loam	0.20	*LOW*
Dow	silty clay	0.64	HIGH	silt loam	0.20	*LOW*
Sedge Wren	silty clay	0.64	HIGH	silt loam/clay	0.30	*MED*
Wounded Dove	silty clay	0.64	HIGH	clay	0.40	HIGH
Univ. of Houston	silty clay loam	0.44	MED	clay	0.50	*HIGH*
Kite Site	silty clay/clay	0.64	HIGH	silty clay loam	0.30	*MED*
Turtle Hawk	silty/sandy clay loam	0.40	MED	silty clay loam	0.30	MED

Land Use / Land Cover Data

Land use data was compared to our observed land uses determined during site visits. The Sedge Wren site land use changed from a rice farm to a restored wetland since the NLCD coverage was developed. Table E8 below compares these coverages by site. The net error of the 11 sites was negative, indicating that the models may underestimate function associated with this variable.

Table E8. Comparison of land use categories with observed land use.

Site	Observed Landuse	V_{LU}	**NLCD** Landuse	V_{LU}	Difference
League City	Natural Area	1.0	Natural Area	0.6	-0.4
LeConte	Ag - Pasture	0.1	Natural/Crop/	0.3	+0.2
Senna Bean	Ag - Pasture	0.1	Ag - Pasture	0.1	0.0
Kildeer	Ag - Pasture	0.1	Ag - Pasture	0.1	0.0
Chicken Road	Natural Area	1.0	Natural Area	1.0	0.0
Dow	Ag - Pasture	0.1	Natural Area	1.0	+0.9
Sedge Wren	Natural Area	1.0	Crop/Natural	0.1	-0.9
Wounded Dove	Natural Area	1.0	Natural Area	1.0	0.0
Univ. of Houston	Natural/Dev Low	0.8	Natural /Developed	0.8	0.0
Kite Site	Natural Area	1.0	Natural/Ag - Pasture	0.6	-0.4
Turtle Hawk	Natural Area	1.0	Natural Area	1.0	0.0
			Net Error		-0.6

LiDAR Derived Data

A significant source of potential error associated with LiDAR data used in this project involves the poor penetration of laser into standing water. This feature most affects the accuracy of wetland volume calculations. Terrestrial LiDAR systems use laser beams with a spectral resolution of near-infrared (0.75 – 1.4 μm), which is partially absorbed by water. LiDAR systems for mapping bathymetry use lasers with a spectral reference in the green band and infrared band. The return of the infrared laser indicates the surface of the water and the return from the green laser is the bottom of the waterbody (Guenther, 2007). The LiDAR used in this study was obtained to map floodplains and delineate catchments, thus terrestrial LiDAR was used. It is important to note that if water was present in wetlands during LiDAR flights, it would theoretically create additional uncertainty in the volume measurements, resulting in an underestimation of wetland volume.

To evaluate the error associated with LiDAR-derived elevations, topographical surveys were performed at four of the six study sites. For each survey, the elevation difference between a control point and randomly selected individual survey points were compared to the elevation difference in LiDAR for the same locations. Although the error associated with the topographical surveys is unknown, the LiDAR horizontal error is ±0.73 m and the GPS horizontal error is approximately 1 m for differentially corrected data. Differences in elevation between LiDAR and manually surveyed points are partially attributable to differences in horizontal position. To minimize horizontal error, sample elevations from LiDAR were compared to GPS using both a "spot check approach" and a "neighborhood approach". The neighborhood approach involves calculating the mean elevation for a nine-pixel neighborhood and assigning that elevation to the point falling in the center pixel of the neighborhood.

The results of the vertical error (root mean square error) analysis for three wetland sites are detailed in Appendix GIS A. The average RMS vertical error for the analysis at the three sites was 0.14 m using the spot check approach and 0.13 m for the neighborhood approach. Dense canopy can also contribute to error in LiDAR data. When the laser beam hits tree canopy, multiple beam returns occur. The first return is the canopy and the last return is assumed to be the ground. However in areas with very dense canopy where one cannot see the sky, it is unlikely that the laser beam will reach the ground. Post-processing of raw LiDAR data identifies the ground returns and smooths areas where anomalies exist (Fowler et al. 2007). For example, an area in a forest where the last return was not the "ground" return would be smoothed using surrounding data. This may result in a loss of microtopography for some forested wetlands.

Conclusions

Overall, results from this study found CPW have capability to perform numerous functions. The GIS models predict that most CPWs have a high capacity to remove nitrate and retain\remove organic compounds. While we do not have data for evaluating the organics model, the nitrate model is supported by our water quality sampling. Two models, water storage and ammonium removal, highlight the functional differences between hydrologically altered wetlands (~10% of all wetlands in the study area) and those with a natural hydroperiod. The remaining CPWs had a moderate capacity to store surface water from precipitation events, remove ammonium, and retain phosphorus and heavy metals.

One of the objectives of this study was to construct a GIS model that would yield detailed information on wetlands within a large study area. This information would then be used to estimate the relative function of this wetland type. The resulting estimates are only as accurate as the databases used to derive the estimates and the validity of the theoretical models. The LiDAR derived catchment areas and volumes are probably among the most accurate estimates developed in this project. The SSURGO soils data, on the other hand, appear to have the greatest uncertainty. The primary use of datasets such as SSURGO soils, NWI, and NLCD should be as a regional screening tool. It must be remembered that with over 10,000 individual wetlands, it is not possible to verify model variables for each site. Results from this study are useful in analyzing the general capacity of wetlands to perform specific functions. For this reason, conclusions should not be made about individual wetlands without a field visit.

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APPENDICES

APPENDIX I

Percent Cover

Vegetation by Species

and Site

Chicken Rd

Wetland Vegetation Percent Cover
Date: 6-9-2008
Site: Chicken Road at Brazoria NWR
GPS coord: 3221594.21 277377.41

Quadrat #	T1-6	T1-1	T8-3	T3-1	T2-6	T3-4	T5-1	T3-5	T8-5	T2-2
GPS coordinates										
Species Name	**Percent Cover**									
Juncus effusus	9									
Ipomoea sagittata	10	25	25	5			28		10	
Paspalum vaginatum (Unkg1-grooved nodes) *	40	5			90					
Unknown grass 2	40									
Cyperus articulatus *	1	3	3	2.5	2		2			
Sagittaria platyphylla*		2								
Rubus trivialis		1								
Paspalum vaginatum		55								
Sesbania sp.		1								
Bare ground		8								
Juncus roemerianus						45		100		100
Spartina patens *			70	90	8		70		90	
Unkown grass 3 *				2.5						
Juncus roemerianus wrack						55				
unknown grass 4			2							
TOTAL										
*** herbarium**	100	100	100	100	100	100	100	100	100	100

Wounded Dove

Wetland Vegetation Percent Cover

Date:6-9-2008 and 6-10-2008

Site: Wounded Dove at Brazoria NWR

GPS coord: 322291.08N x 278711.4 E

Quadrat #	T20-3	T19-3	T6-2	T11-2	T21-1	T22-1	T19-2	T21-2	T10-1	T15-1	T27-3	T8-1	T8-2	T26-3	T18-2
Species Name	**Percent Cover**														
Bare ground											75				
Spartina patens	54	50	100	80	90	85	85	80	70	90	5	80	70	70	80
Ipomoea sagitatta	2	5		10	5		5	5	10	5			15	20	5
Cyperus articulatus	4	5		5	5	5	5	5	5	5	5	15	5	5	3
Eleocharis montevidensis (Mullins i.d.) *	40	40				5	5	5	5		10				10
Typha dominguensis								5							
Rhynchospora corniculata? *														5	2
Paspalum vaginatum*						5			5		5				
Eleocharis quadrangulata									5				10		
Neptunia lutea				5								5			
Note: Lythrum alata seen near plots-purple flowers*															
TOTAL	100	100	100	100	100	100	100	100	100	100	25	100	100	100	100

*** herbarium**

Kite Site

Wetland Vegetation Percent Cover Date: 6-11/16-2008
Site: Kite Site at Armand Bayou
GPS coord: 3280646.37 N 881333.52E

Quadrat #	T2-2	T2-2	T2-2	T2-4	T2-4	T2-4	T3-3	T3-3	T3-3	T3-5	T3-5	T3-5	T3-7	T9.5-5	T11-1	T11-0	T11-0	T12-2	T13-0	T13-0
	G	US	OS	G	US	OS	G	US	OS	G	US	OS	G	G	G	G	U	G	G	U
Species Name	**Percent Cover**																			
Bare ground / leaf litter	80			70			83			50			82	15	50	80		32	40	
Unk forb 1 (ground cover)				10																
Rubus trivialis	15			12																
Ilex vomitoria*				5	5															
Quercus sp				2		30	2													
unknown shrub 1				1																
Locust sp					20		2					30								
Quercus phellos	5	20	30			5														
Sapifera sabium			20			2	5	50					10		5			60		20
Chasmanthium laxum										50										
Ulmus americanum												30	1							
unknown rush 1 - tenuis?*							5													
Juncus effusis							3											5		
Rhyncospora sp.														83						
Unknown grass 1*														1						
Tripsacum dactyloides*														1						
Mikania scandens*													3		5	10		3	30	
Saccharum giganteum																				30
Sesbania sp.																	20			
Carex lurida															40					
Smilax bona-nox													3							
Polygonum sp.													1							
TOTAL	100	20	50	100	25	37	100	50	0	100	0	60	100	100	100	90	20	100	70	50

*** herbarium**

Turtle Hawk

Wetland Vegetation Percent Cover
Date: 6-10-2008 (and confirmation in Sept)
Site: Turtle Hawk, Armand Bayou Nature Center, Harris Co. TX
GPS coord: 29°35'37.74"N, 95°04'38.35"W
G=ground; U= understory; OS=overstory

Quadrat #	T1-1	T1-1	T1-1	T2-1	T2-1	T2-1	T5-1	T5-1	T5-1	T6-1	T6-1	T6-1	T12-1	T12-1	T12-1	T12-3	T12-3	T12-3
	G	U	OS	G	U	OS	G	U	OS	G	U	OS	G	U	OS	G	U	OS
Species Name	**Percent Cover**																	
Bare ground	100			75														
Leaf litter							40			78			96			99		
Sabal minor		20												3				
Ulmus americana			100			100				2		79	1					
Ulmus crassifolia																		
Ligustum sinense *				15						2								
Vitis rotundifolia*					100													
Sapium sebiferum									60	2		1				1		
Chasmanthium laxum*				10			26											
Juncus tenuis*?							2			1								
Eupatorium capillifolium*																		
Quercus falcata (cherrybark oak)*																		50
Quercus phellos (willow oak)*															30			
Cyperus surinamensis*																		
Unknown sedge 2*										3								
Sesbania sp.*																		
Mikania scandens*																		
Unknown sedge 1*										4								
Pluchea camphorata*																		
Unknown grass 2*							30											
Oplismenus hirtellus							1											
Polygonum sp.*							1			8			3					
Saccharum giganteum*																		
Juncus effusis																		
Pinus tata (loblolly pine)																		
Hydrocotyle umbellata																		
TOTALs **herbarium*	100	20	100	100	100	100	100	0	60	100	0	80	100	3	30	100	0	50

Turtle Hawk continued

Wetland Vegetation Percent Cover
Date: 6-10-2008 (confirmation in Sept)
Site: Turtle Hawk, Armand Bayou Nature Center, Harris Co. TX
G=ground; U= understory;OS= overstory

Quadrat #	T15-3	T15-3	T15-3	T20-2	T20-2	T20-2	T22-1	T22-1	T22-1	T22-2	T22-2	T22-2
	G	U	OS	G	U	OS	G	U	OS	G	U	OS
Species Name	PERCENT COVER											
Bare ground				40			10			60		
Leaf litter	81											
Sabal minor												
Ulmus americana	3											
Ulmus crassifolia		40		1						2		
Ligustum sinense *												
Vitis rotundifolia*												
Sapium sebiferum				10	5						30	
Chasmanthium laxum*												
Juncus tenuis*?												
Eupatorium capillifolium*				1						1		
Quercus falcata (cherrybark oak)*												
Quercus phellos (willow oak)*						20						
Cyperus surinamensis*	2											
Unknown sedge 2*												
Sesbania sp.*												
Mikania scandens*	3			15			9			15		
Unknown sedge 1*												
Pluchea camphorata*	10											
Unknown grass 2*												
Oplismenus hirtellus												
Polygonum sp.*				25			1			22		
Saccharum giganteum*							70					
Juncus effusis	1						10					
Pinus tata (loblolly pine)			20									
Hydrocotyle umbellata				8								
TOTAL	100	40	20	100	5	20	100	0	0	100	30	0

LeConte

Wetland Vegetation Percent Cover
Date: 6-17-2008
Site: Le Conte, Anahuac NWR Chambers Co TX
GPS coord: 29°40'15.39"N 94°26'09.62"W

Quadrat #	T1-2	T2-2	T2-5	T3-7	T3-9	T1-7	T1-3	T4-4	T6-4	T6-7
Species Name	**Percent Cover**									
bare ground		15		25		11	5	20		20
Echinochloa sp.	47	32	3	15	2	16	45	10		49
Panicum repens *	47	33	40	15	35	27	45		40	
Juncus validus*	1				10	6				5
Alternanthera philoxeroides	5	20	5	12	10	21	5	15	15	5
Typha latifolia			5							
Juncus effusus			15	10					10	10
Eleocharis sp.			30	15	37			45	32	10
Ludwigia sp (small seed box)			1		1	1			1	
Limnosciadium pinnatum			1							1
Cyperus virens				5	5					
Centella asiatica				1					1	
Galium tinctorium				1						
Acmella oppositifolia				1						
Hydrocotyle umbellata						3				
Eleocharis quadrangulata						4				
Iva annua									1	
Juncus marginatus *						11		10		
TOTAL	100	100	100	100	100	100	100	100	100	100

Sedge Wren

Wetland Vegetation Percent Cover
Date: 6-18-2008
Site: Sedge Wren Site, Anahuac NWR Chambers Co TX
GPS coord: 94°28'10.28297"W 29°40'23.198"N

Quadrat #	T1-1	T1-4	T1-5	T1-11	T1-13	T2-21	T1-22	T1-25	T2-23	T1-24	T3-22	T2-19	T1-14	T1-18	T2-18
Species Name	**Percent Cover**														
Bare ground (unvegetated)				40	5	43		20	30		95	60		50	6
Wrack (of panicum hemitomum)		50	85												
Wrack (dead plant material)						10	65	7		30					
Acmella oppisitifolia **															10
Alternanthera philoxeroides				55	50	3	5	15		10			57	30	
Aster tenuifolius*								8							10
Coreopsis sp. (yellow flower *)								1	1						
Cyperus virens *														10	
Diodia virginiana *						10		30			1	10			2
Eleocharis montevidensis **				5	45	3				5		4	38		20
Eleocharis quadrangulata						13			20			15			
Eryngium hookeri (purple thistle)						2		1							
Iva annua											2				
Juncus effusus										25					50
Juncus validus								1							1
Leptochloa fascicularis															1
Ludwigia octavalis *								5	5						
Panicum hemitomum	50	50	15				30			30			5		
Paspalum vaginatum						10			44						
Polygonum hydropiperoides *						1		10						10	
Rhyncospora corniculata						5									
Unknown forb 3											1	1			
Unknown grass 1												2			
Unknown gray green bunchgrass											1	8			
unknown sedge								2							
TOTAL	50	50	15	60	95	47	35	73	70	70	5	40	100	50	94

*** herbarium**

Dow

Wetland Vegetation Percent Cover

Date:10/19/09

Site: DOW Brazoria Co TX

GPS coord: 29.02011N, -95.3568514E

	Plot				
	DW-1	DW-2	DW-3	DW-4	DW-5
Species Name	**Percent Cover**				
Bare ground				40	
Open water	83	60	55		55
Ambrosia psilostachya (western ragweed)				51	
Unknown forb 1*				5	
Unkn sedge (nutgrass)				2	
Verbena brasiliensis				2	
Paspalum vaginatum*	10	26	35		33
Sagittaria sp		5	4		2
Echinodorus sp.		5			4
Unk forb#2*		2	6		
Alternanthera philoxeroides		2			2
Nymphaea odorata	5				2
Eleocharis sp.					2
Lemna minor	2				
TOTAL VEG	17	40	45	60	45
TOTAL COVER	**100**	**100**	**100**	**100**	**100**

*** herbarium**

League City

Wetland Vegetation Percent Cover Date: 10-01-2009 Site: League City, Brazoria Co TX

GPS coord: 29.51860, -95.019700 Note: site had just been mowed

Plot #	LG13	LG5	LG1	LG16	LG14	LG6	LG7	LG10	LG11	LG4	LG18
Species Name	**Percent Cover**										
bare ground											
wrack		30	25	50	30	35	50	60	35	22	15
Cyperus virens		5	5	13	20	65		5	35		25
Panicum sp. (unk grass # 1*)	50		60	20						8	10
Pluchea foetida			6	5	10					5	
*Justicia ovata (purple flower)**		8					8	2			
Sapium sebiferum		55							15		
*Paspalum floridanum**	50										10
Leptochloa fascicularis (Unk g3)				5	20						
Unk. Forb # 7										5	10
Coelorachis rugosa (unk grass 2)*											20
Eleocharis sp.		2									
Ipomoea sp.			2								
Unk forb #2			2								
Diodia virginica				2							
Centella asiatica				5							
unk forb # 3 aster-like					20						
unk grass # 4							40				
Proserpinaca palustris							2				
Panicum anceps								33			
Croton capitatus									15		
Lippia lanceolata										15	
Eragrostis spectabilis										15	
Eupatorium leucolepsis										25	
Hedyotis nigricans											10
Panicum scoparium										5	
TOTAL VEG	100	100	100	100	100	100	100	100	100	100	100
TOTAL COVER	100	100	100	100	100	100	100	100	100	100	100

* herbarium

University of Houston

Wetland Vegetation Percent Cover
Date: 9-21-2009
Site: Univ of Houston, Harris Co. TX
GPS coord: 29.587800, -95.094150
G=ground; U= understory;OS= overstory

Quadrat #	UH-1	UH-1	UH-1	UH-2	UH-2	UH-2	UH-3	UH-3	UH-3	UH-4	UH-4	UH-4	UH-5	UH-5	UH-5
	G	US	OS	G	US	OS	G	US	OS	G	US	OS	G	US	OS
Species Name	**Percent Cover**														
bare ground															
leaf litter/woody debris							5			55			45		
moss										3					
Ulmus americana						40			40						
Chasmanthium sp.				65									5		
Carex sp 1	30			20			45								
Rubrus trivialis	40			15			5			30			35		
Juniperus virginiana	10														
***Lonicera japonica **	5	15			10		5	5		5	10	10			
Ilex vomitoria	5				30			20							
unk grass*	10														
Myrica cerifera (wax myrtle)							40				30				
Celtis laevigata (hackberry)											5				
Sapium sebiferum												20		20	20
unk sedge										7					
Quercus falcata															20
Quercus phellos													5		
unk forb													2		
unk vine													5		
unk grass*													3		
TOTAL VEGETATION	100	15	0	100	40	40	100	25	40	100	45	30	100	20	40
TOTAL	100	30	0	200	80	80	200	50	80	200	90	60	200	40	80

Killdeer

Wetland Vegetation Percent Cover

Date:11/16/09

Site: Killdeer Chambers Co TX

GPS coord: 29.575013, -94.706277

Quadrat #	WL-1	WL-2	WL-3	WL-4	WL-5
GPS coordinates					
Species Name	**Percent Cover**				
Bare ground					
Open water	100	100	100	100	100
There is no vegetation at this site except along					
shoreline and none of the plots are along shoreline					
The site used to be vegetated but is now full					
of water with salinity approx 7 - 9 ppt					
	100	100	100	100	100

*** herbarium**

Senna

Date:9/30/09

Site: SENNA Chambers Co TX
GPS UTM: 3272928N, 334953E

Quadrat #	SE-1	SE-2	SE-3	SE-4	SE-5
GPS coordinates					
Species Name	**Percent Cover**				
Bare ground				30	14
Open water	25	45	60		
Wrack/litter	5	5			
Pluchea odorata		5			
Eleocharis sp. (very small)		5	5		
Leptochloa fascicularis					
Unknown grass #1(grazed)	25	35		52	10
Juncus effusus	28	5			35
Sesbania drummondia	2			2	2
Eragrostis spectablis	5				35
Centella asiatica	10		20		
Unknown forb (chickweed)			10		
Unknown grass #2			2		
Unknown grass #3			3		
Eupatorium capitata				8	
Panicum scoparium				2	2
Unknown forb 2				6	
Unknown forb 3 (sprouting)					2
PERCENT COVER VEG	75	55	40	70	86
TOTAL PERCENT COVER	100	100	100	100	100

*** herbarium**

APPENDIX II

Model Variables

Definitions, Rationales

and

Measurement Methods

List of Variables by Model

The following variables are defined and their measurements explained in the order that they appear in the previous section:

Water Storage Model

1. Wetland Volume (V_{vol})
2. Water Regime (V_{wet})
3. Wetland Area to Catchment Area Ratio (V_{catch})
4. Macrophyte Density (V_{mac})

Ammonium Removal Model

1. Wet-dry Potential (V_{dry})
2. Wetland Buffer (V_{buff})
3. Macrophyte Density (V_{mac})
4. Wetland and Catchment Land Use (V_{LU})

Nitrate Removal Model

1. Wetland Buffer (V_{buff})
2. Macrophyte Density (V_{mac})

Phosphorus Retention Model

1. Wetland and Catchment Land Use (V_{LU})
2. Wetland Area to Catchment Area Ratio (V_{catch})
3. Wetland Buffer (V_{buff})
4. Macrophyte Density (V_{mac})
5. Soil Clay Content (V_{clay})

Heavy Metal Retention Model

1. Wetland Buffer (V_{buff})
2. Macrophyte Density (V_{mac})
3. Soil Clay Content (V_{clay})
4. Soil pH (V_{soilpH})

Organic Retention / Removal Model

1. Macrophyte Density (V_{mac})
2. Wetland Area to Catchment Area Ratio (V_{catch})

Model Variables

Wetland Volume (V_{vol})

Definition: The wetland volume refers to the storage volume capacity of the wetland. It represents the maximum volume of water that can be stored by the wetland if the wetland was empty at the onset of a precipitation event.

Rationale: The wetland volume is an important predictor of the wetland's capacity to store water and to attenuate flooding of downstream areas.

Measure/Units: Cubic meters.

Field Measurement: The water storage volume of the wetland is calculated by multiplying the wetland area by the average wetland flood storage depth. Average flood storage depth is defined as half the elevation range of the wetland. The elevation range is the difference in elevation of the deepest portion of the wetland and the shallowest part of the wetland, which is assumed to be zero. Practically, the mean wetland depth is half the maximum wetland depth. The wetland area could be determined in the field by walking the wet perimeter with a hand-held GPS unit. However, for the purpose of comparison to GIS volume estimates, we used NWI wetland areas to calculate the wetland volumes.

GIS Measurement: Wetland volumes were determined using Digital Elevation Models (DEM) derived from LiDAR aerial photography. ArcHydro Tools 1.3 "sink" tool was used to fill the depressions within NWI areas. The volume of a fill represents the wetland volume.

Variable Uncertainties: Wetland volume estimates do not account for soil moisture (soil pore space) and thus underestimate the storage capacity of wetlands during dry conditions. Wetland volumes are calculated from NWI wetland areas and thus propagate errors associated with NWI boundaries. NWI areas are generally considered conservative and thus this error may also contribute to underestimation of wetland volumes. LiDAR, DEM, and ArcHydro sink tool all have associated errors. These errors do not appear to bias the volume calculation by over- or underestimating, however they affect the accuracy of a single wetland volume. The vertical accuracy of LiDAR ranges from 0.09 m (Harris County) to 0.37 m (all other counties). In addition, the affect of deep standing water on the vertical accuracy of LiDAR is unclear. It has been noted (REF) that LiDAR cannot penetrate deep water, however the exact depth at which LiDAR is compromised is not known. Our comparison of LiDAR-DEM elevations to surveyed elevations for four wetlands indicates that LiDAR was not affected by standing water present in these wetlands.

Water Regime (Vwet)

Definition: Water regime refers to the duration of inundation in a wetland as determined by the NWI database. Most palustrine wetlands in the study area are seasonally inundated. However, changes in the natural drainage structure or other modifications may result in an artificially prolonged hydroperiod. For example, wetlands that are excavated for use as holding ponds tend to be permanently flooded. Also wetlands farmed for rice are artificially flooded for most of the year. These wetlands typically have classifications of H (permanently flooded) or a hydrologic modifier of x (excavated), f (farmed), or h (diked, impounded). Table 2 provides general guidelines for NWI water regime classifications as well as the V_{wet} value assigned to the water regime.

Rationale: Permanently and artificially flooded wetlands have a reduced capacity to store precipitation and runoff from storm events.

Measure/Units: Not applicable.

Field Measurement: The hydroperiod of an individual wetland can be observed seasonally in the field or measured with hydrologic equipment.

GIS Measurement: The value of V_{wet} is derived from NWI water regime codes and modifiers as shown in Table 2.

Table 2. V_{wet} values based on Cowardin classification of water regimes.

Water Regime	Weeks Flooded	Description of Surface Water	NWI symbol	V_{wet}
Permanently flooded Artificially flooded	52	Present year round	H, V, K, h, x, hs	0.1
Intermittently exposed	41 – 51	Present except during extreme drought	G , f (rice)	0.2
Semipermanently flooded	18 - 40	Present most of year, when absent, very shallow water table	F,T	0.3
Seasonally flooded	5 - 17	Wet during growing season, typically exposed during some period of each year	C,R, d, s, f (not rice)	1.0
Saturated	seldom	Seldom present but soils saturated for extended periods	B	1.0
Temporarily flooded	1 – 4	Present for brief periods, lower water table, facultative vegetation	A,S	1.0
Intermittently flooded	seldom	If present, no seasonal pattern, hydric soils unlikely	J	1.0

Variable Uncertainties: For field measurements, the error associated with V_{wet} results primarily from an inadequate observation period. An individual wetland should be observed seasonally to determine its water regime and for more than one year to observe the wetland during both an above-normal or below-normal year (i.e. most years).

For GIS estimates of V_{wet}, error is primarily associated with the accuracy of the NWI characterizations. A subset of wetlands with modifiers such as “K” and “x” (artificially flooded, excavated) were examined with aerial photography and based on the subset, all such wetlands were assigned a water regime (Table 3). The wetland group with the greatest uncertainty were farmed wetlands (modifier “f”). Farmed wetlands occur primarily in Chambers County and include primarily pasture or cropland. Farmed pasture was assumed to have the same water regime as adjacent non-farmed land. Cropland is primarily cultivated rice fields, which were assigned an intermittently exposed water regime. The rice field assignment has the greatest uncertainty because they are cultivated with rice for a year and then left fallow for grazing for 2-4 years (David Manthei, NRCS, 2009, personal communication). We used National Land Use Databases to distinguish between pasture and cropland in the study area.

Wetland Area to Catchment Area Ratio (V_{catch})

Definition: The ratio of the wetland surface area to the surface area of that wetland's catchment (watershed). The catchment area includes the wetland.

Rationale: The ratio of watershed size to wetland size provides an estimate for relative hydraulic retention time. Wetlands that can store 25% or more of the runoff from their catchment have been assigned a high water storage function.

Measure/Units: Unitless ratio.

Field Measurement: Catchment delineation of individual wetlands could be determined using topographic maps, surveys, or other elevation data. Our individual wetland catchments were determined using the GIS method described below.

GIS Measurement: Catchments for wetlands outside the 100-year floodplain were delineated using LiDAR derived DEMs and ArcHydro 1.3 sink watershed delineation tools. A 100-m buffer area around the perimeter of each wetland was used to determine the catchment area for wetlands within the 100-year floodplain. For all catchments, a theoretical 2-yr rainfall event (5 cm in one hour) and a runoff coefficient of 0.15 was used to estimate the volume of runoff from 1 m^2 of catchment. The median wetland depth (4.9 cm) and an infiltration rate of 15% was used to estimate the available volume of a typical wetland. This estimate resulted in wetlands with a wetland area:catchment area ratio of between 0.04 and 0.18 able to store 25-100% of runoff and these wetlands were assigned a value of 1.0 (Table 3). Ratios smaller than this range (storage between 10-25%) were assigned a value of 0.6 and ratios associated with less than 10% storage were assigned a value of 0.4. Ratios greater than 0.18 represent wetlands that have more storage capacity than runoff and were assigned a V_{catch} value of 0.6.

Table 3. Wetland area: catchment area ranges, approximate runoff storage, and Vcatch values.

Wetland Area: Catchment Area	Approximate Runoff Storage Capacity (%)	Vcatch	Number of wetlands
0.005 – 0.017	< 10	0.4	779
0.018 – 0.044 0.181 – 0.999	10-<25 >100	0.6	3723
0.045 – 0.180	25-100	1.0	2861

Variable Uncertainties: It is not within the scope of this project to accurately determine catchment areas, runoff volumes or infiltration rates. The calculations used to obtain a gross estimate of runoff volumes do not account for the antecedent moisture, soil type, or groundwater potentials of individual wetlands. These and other variables are likely to vary considerably among wetlands and with season and climate. For example, wetlands located on sandier soil may have enhanced or reduced runoff storage related to groundwater recharge/discharge potentials. During summer, wetlands may store many times more water than during winter due to soil moisture conditions that increase infiltration and high evapotranspiration rates. Delineated catchment area estimates (n=4,006) are particularly problematic due to the low-relief topography that characterizes the coastal plain. In contrast, 100-m wide buffer areas (n=3,357) are arbitrary estimates of catchment size. For these reasons, catchment area may not be valid when applied to an individual wetland within the study area. Furthermore, values assigned to the V_{catch} should be considered qualitative and are designed to provide a relative rating to a wide range of wetlands.

Macrophyte Density (V_{mac})

Definition: The relative coverage of the wetland area by erect vegetation. Submersed vegetation is not included.

Rationale: High densities of emergent wetland vegetation are associated with abundant dissolved and particulate organic matter and the buildup of litter and peat substrates. Abundant plant matter also indicates that microbial activity is high and reducing conditions would be likely. These qualities are predictive of long-term phosphorus storage, sequestration of metals, partitioning of organic contaminants, and denitrification.

Measure/Units: Fraction (unitless).

Field Measurement: A 0.25-m^2 quadrat was used to determine percent cover in the wetland. A 50-point grid pattern was imposed on the wetland surface and 10 to 15 plots were randomly selected from the 50 points. The percent cover from these plots was averaged to obtain percent cover vegetation for the wetland.

GIS Measurement: A Normalized Difference Vegetation Index (NDVI) was created from remotely sensed images. NDVI is a standard vegetation index used by remote sensors to identify general vegetative cover types. NAIP imagery is analyzed to produce a raster dataset with pixel values ranging from -1.0 to 1.0. Negative values and near zero values represent open water features and bare soil; generally, values of 0.1 – 1.0 represent vegetated areas. Using 2005 true-color NAIP imagery, transitions from bare soil areas to vegetated areas were sampled and a value of 0.1 was assigned as the lowest detectable value (threshold) for the presence of vegetation.Values below this threshold were considered unvegetated pixels allowing the calculation of percent vegetated cover of the wetland (V_{mac}) or its 30-m buffer (V_{buff}).

Variable Uncertainties:
Errors associated with NDVI coverages are related to cloud cover, forest cover, and inundation. Percent vegetated area within wetland polygons was extracted from a NDVI dataset that contained minimal cloud cover. However, water was likely present in some of the wetlands at the time the images were taken, thus submerged vegetation may have been underestimated. Forested wetlands may lead to uncertainty in the emergent macrophytic vegetation variable (V_{mac}) because tree canopies are typically identified in the NDVI, and the wetland may appear to have a high percent cover of vegetation. However, understory vegetation may be more important to the removal of pollutants.

Wet-Dry Potential (V_{dry})

Definition: Wet-dry potential refers to the tendency of a wetland to periodically dry out or drawn down. Most wetlands in the CPW study area tend to dry out seasonally or intermittently due to rainfall patterns and high summer evapotranspiration rates.

Rationale: Wetlands that dry out periodically have more oxygen which facilitates nitrification and ammonia removal.

Measure/Units: Not applicable.

Field Measurement: Where hydrologic data is available, the observed hydroperiod of individual wetlands may be used to determine V_{dry}.

GIS Measurement: The value of V_{dry} will be derived from NWI water regime codes and modifiers as shown in Table 4.

Table 4. V_{dry} values based on Cowardin classification of water regimes.

Water Regime	Weeks Flooded	Description of Surface Water	NWI symbol	V_{dry} Eq. 3
Permanently flooded Artificially flooded	52	Present year round	H,V,K, h, hs, x	0.1
Intermittently exposed	41 – 51	Present except during extreme drought	G, f (if rice)	0.2
Semipermanently flooded	18 - 40	Present most of year, when absent, very shallow water table	F,T	0.4
Seasonally flooded	5 - 17	Wet during growing season, typically exposed during some period of each year	C,R, d, s, f (not rice)	0.5
Saturated	seldom	Seldom present but soils saturated for extended periods	B	0.6
Temporarily flooded	1 – 4	Present for brief periods, lower water table, facultative vegetation	A,S	0.8
Intermittently flooded	seldom	If present, no seasonal pattern, hydric soils unlikely	J	1.0

Variable Uncertainties: Errors associated with Vdry are similar to those associated with Vwet.

Buffer Density (V_{buff})

Definition: The extent to which the area immediately adjacent to the wetland (30 m from wetland perimeter) is vegetated.

Rationale: High density of vegetation within the buffer area around the wetland contributes to filtration of particulate matter that carries pollutants. During runoff events, these moist soil areas may also contribute to transformation and sequestration of nitrogen, phosphorus, metals, and organics through microbial and sorption processes. The buffer area can be thought of as an extension of the wetland ecosystem, particularly during wet periods, during which the buffer areas may exhibit wetland characteristics such as hydric soils and vegetation.

Measure/Units: Unitless.

Field Measurement: LAI was used to determine average percent cover in the wetland buffer areas. Transects were laid out perpendicular to the perimeter every 40 m and LAI was measured at points approximately10 m and 30 m from the wetland edge.

GIS Measurement:: A Normalized Difference Vegetation Index (NDVI) was created from within the 30-m wide buffer around the wetland polygons and vegetative cover was determine in the same manner as percent cover vegetation within the wetland.

Variable Uncertainties: Errors associated with V_{buff} are similar to those associated with V_{mac}.

Land Use (V_{LU})

Definition: The dominant land use in the catchment area (including the wetland) based on categories defined in the National Land Cover Database.

Rationale: Land uses in the catchment predict the quality and quantity of runoff that will enter the wetland. This variable is used to determine whether high levels of phosphorus or ammonium are present in the wetland or wetland catchment.

Measure/Units: Unitless.

Field Measurement: Direct observation will confirm the predominant land uses in the area for comparison to aerial photography.

GIS Measurement: Land use was obtained from the 2001 National Land Cover Database (NLCD). The total phosphorus loading was based on mean runoff concentrations for various land use categories shown in Table 5. Because the NLCD did not distinguish between residential, commercial and industrial categories, the mean loading of these three categories were used to estimate total phosphorus in runoff from developed land use categories. Table 6 summarizes the loading values as well as the corresponding FCI for each NLCD category.

For catchments with more than one land use, a mean weighted average was calculated. The weighted average of phophorus pollution associated with each land uses (Table 6) was multiplied by the percentage of that land use present in the wetland catchment and the sum of the coverages was calculated.

Table 5. Mean runoff concentrations from selected land use types (from Adamus and Bergman 1995). Value set to zero to indicate no additional pollution loading from natural lands.

Land Use Category	Total Phosphorus (mg L^{-1})
Low Density Residential	0.18
Medium Density Residential	0.30
High Density Residential	0.47
Low Intensity Commercial	0.15
High Intensity Commercial	0.43
Industrial	0.31
Agriculture - Pasture	0.48
Agriculture - Crops	0.42
Agriculture - Other	0.34
Mining	0.15
Recreation, Open Space, Range	0.15
Natural Areas	0.00

Table 6. Estimated phosphorus concentrations in runoff and FCI values for NLDC land use categories.

NLCD Code	NLCD Definition	Land Use Category (Adamus and Bergman 1995)	Total Phosphorus Conc. in Runoff (mgL^{-1})	FCI
11	Open Water	Natural Areas	0	1.0
21	Developed Open Space	Recreation, Open Space, Range[a]	0.05	0.53
22	Developed, Low Intensity	Low Density Residential, Commercial and Industrial[a]	0.21	0.41
23	Developed, Medium Intensity	Medium Density Residential, Commercial and Industrial[a]	0.30	0.24
24	Developed, High Intensity	High Density Residential, Commercial and Industrial[a]	0.40	0.15
31	Barren land	Mining and Natural Areas[a]	0.075	0.78
41	Deciduous Forest	Natural Areas	0	1.0
42	Evergreen Forest	Natural Areas	0	1.0
43	Mixed Forest	Natural Areas	0	1.0
52	Shrub/Scrub	Natural Areas	0	1.0
71	Grassland/Herbaceous	Natural Areas	0	1.0
81	Pasture/Hay	Agriculture - Pasture	0.48	0.07
82	Cultivated Crops	Agriculture - Crop	0.68	0.0
90	Woody Wetlands	Natural Areas	0	1.0
95	Emergent Herbaceous Wetlands	Natural Areas	0	1.0

a. Phosphorus concentrations for these land use categories were averaged to obtain corresponding NLDC values.

Variable Uncertainties: Error is associated with both the NLCD coverages, which have a 30-m resolution, and the estimated loadings associated with land uses. These loading estimates should be viewed as providing a relative pollution loading potential and may not be valid when applied to an individual wetland within the study area.

Soil Clay Content (V_{clay})

Definition: The percentage of a soil sample, by weight, that is comprised of material classified as <0.002 mm in size.

Rationale: Clay particles in soil have very high surface areas as well as a surface chemistry that enhance the sorption of polar molecules such as ammonium, heavy metals, some organics, and phosphates. Soils with high clay contents are also more likely to retain these contaminants over time.

Measure/Units: unitless.

Field Measurement: Soil samples were taken from a subset of locations and the "Texture-by-feel" method (Figure 2) was used to determine the soil textural class (clay, silt, sand, etc.). The class was then used to determine the average clay content as indicated by the soil pyramid (Figure 3.). The textural class of soil was indexed to provide values between 0.0 and 1.0 (Table 6).

GIS Measurement: Soil clay content was estimated from percent clay data included in the Soil Survey Geographic (SSURGO) database. The FCI value was determined from the midpoint of the range of clay percentiles associated with the soil type (Table 7). For example, a soil with a SSURGO clay content of 32 percent was assigned an V_{clay} value of 0.32. If more than one toil type occurs within the wetland, a weighted average was calculated.

Table 7. V_{clay} FCI values based on soil surface texture categories.

Textural Classification	Range of Clay Content (%)	FCI Value
Clay	56-100	1.00
Silty clay	40-60	0.64
Sandy clay	38-56	0.60
Silty clay loam	28-40	0.44
Clay loam	28-40	0.44
Sandy clay loam	20-38	0.37
Loamy sand	10-15	0.23
Sandy loam	15-20	0.22
Loam	8-28	0.18
Silt loam	0-28	0.16
Silt	0-12	0.08
Sand	0-10	0.06

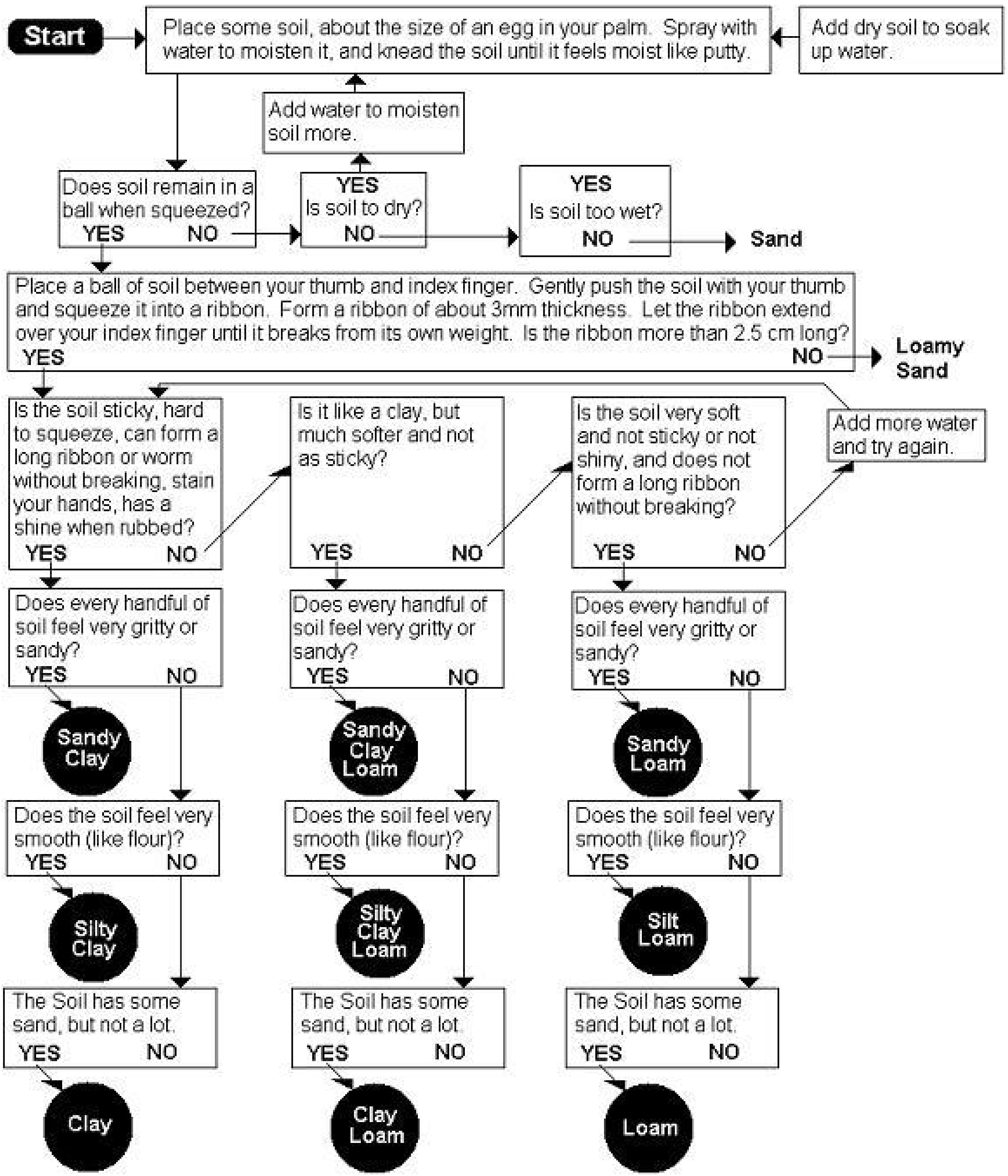

Figure 2. A method for determining soil class by surface texture. Modified from S.J. Thien. 1979. A flow diagram for teaching texture by feel analysis. *Jour. of Agron. Educ.* 8:54-55. http://soils.usda.gov/education/resources/k_12/lessons/texture/

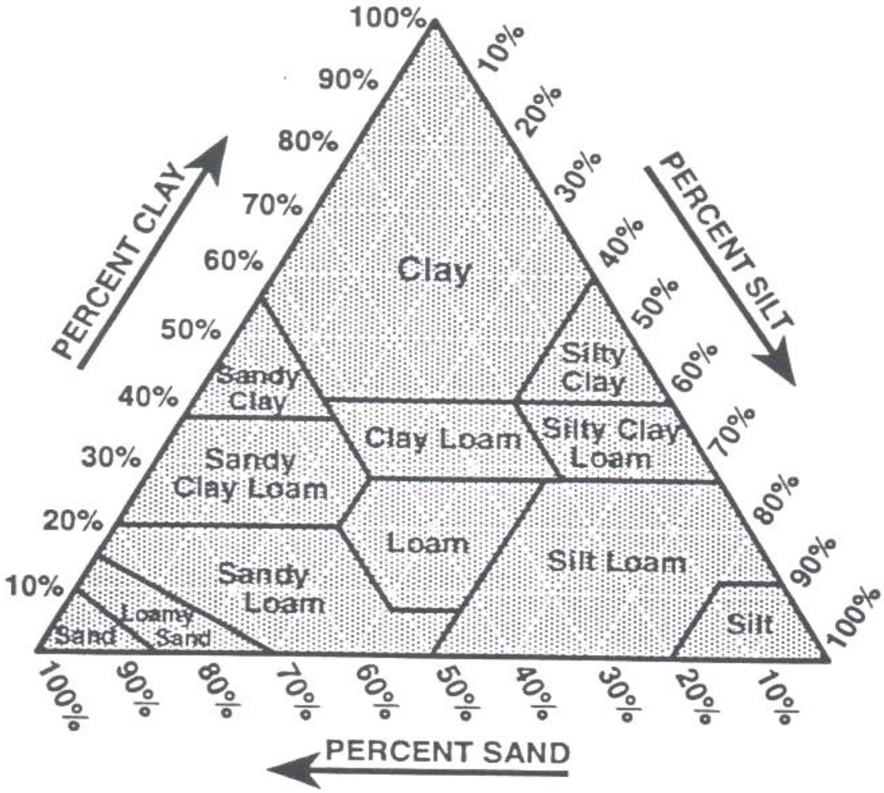

Figure 3. Soil pyramid for textural classifications.

Variable Uncertainties: Resolution of GIS datasets such as SSURGO soils data, can be a problem. SSURGO data are typically derived from aerial photographs and the parameters are not sampled at the resolution of individual wetlands.

Soil pH (V_{soilpH})

Definition: The pH (acidity) of a soil-water mixture on a scale of 0 to 14 with 7.0 being neutral.

Rationale: Soil pH influences water quality and sorption/precipitation mechanisms. Many pollutants are more soluble in acidic conditions. In alkaline soils, calcium and magnesium will form insoluble precipitates with many pollutants, especially phosphates and metals.

Measure/Units: Soil pH ranges and categories are included in USDA Soil Survey Manuals for each mapped soil type. The pH ranges are converted to index values as shown in Table 6.

Field Measurement: Soil collected for determination of clay content were used for determination of soil pH. After determination of soil dry weight, 40 grams of dried soil will be added to an equal weight of distilled water and mixed. A pH probe will be used to determine the pH of the supernatant. Three replicates will be analyzed for pH(Table 8).

GIS Measurement: Soil pH data were obtained from the SSURGO database and converted to FCI values according to Table 8. If more than one soil type occurs within the wetland, a weighted average was calculated.

Table 8. Soil pH classes, associated pH values, and indices values for $V_{soilpH.}$

Soil pH Class	Soil pH Range[a]	FCI Value
Ultra acid	< 3.5	0.0
Extremely acid	3.5 – 4.4	0.1
Very strongly acid	4.5 – 5.0	0.2
Strongly acid	5.1 – 5.5	0.3
Moderately acid	5.6 – 6.0	0.4
Slightly acid	6.1 – 6.5	0.5
Neutral	6.6 – 7.3	0.6
Slightly alkaline	7.4 – 7.8	0.7
Moderately alkaline	7.9 – 8.4	0.8
Strongly alkaline	8.5 – 9.0	0.9
Very strongly alkaline	> 9.0	1.0

a. National Soil Survey Handbook (USDA 1993).

Variable Uncertainties: Resolution of GIS datasets such as SSURGO soils data, can be a problem. SSURGO data are typically derived from aerial photographs and the parameters are not sampled at the resolution of individual wetlands.

APPENDIX III

Physical and Chemical
Soil Characteristics

Table II. Minimum, maximum, and medians of physical-chemical parameters of soils from 12 palustrine wetlands.

Site	N	Soil Moisture %	Soil Organic Matter %	pH	Sp Cond mS cm^{-1}	Salinity ppt	Clay %
CR	10	13 – 26 19	2.4 – 8.5 5.2	4.2 – 5.6 4.4	0.59 – 1.44 0.84	0.29 – 0.91 0.42	17.5 – 50 50
WD	15	15 – 27 22	4.8 – 12.9 7.1	4.6 – 7.0 5.2	0.29 – 0.79 0.46	0.14 – 0.39 0.22	29 – 78 50
KS	10	15 – 31 26	3.5 – 11.4 6.0	4.6 – 5.1 4.8	0.07 – 0.39 0.11	0.03 – 0.18 0.05	34 – 78 50
TH	10	10 – 26 15	2.7 – 7.1 4.9	3.6 – 4.8 4.4	0.16 – 0.72 0.24	0.07 – 0.23 0.12	29 – 34 29
SW	15	1.5 – 24 7	1.8 – 10.3 3.1	4.3 – 5.1 4.8	0.06 – 0.44 0.16	0.03 – 0.21 0.07	12.5 – 78 50
LC	10	8.8 – 55 12	5.7 – 19 11.5	4.4 – 5.4 4.8	0.26 – 1.1 0.50	0.13 – 0.55 0.24	18 – 78 29
DW	5	16 – 32 30	3.6 – 6.3 4.6	4.5 – 4.7 4.6	0.12 – 0.21 0.18	0.06 – 0.105 0.08	29 – 29 29
LG	12	19 – 43 29	4.1 – 11.2 5.3	4.2 – 4.9 4.3	0.14 – 0.34 0.23	0.07 – 0.17 0.11	17.5 – 38 31.5
UH	5	17 – 22 18	4.8 – 11.6 8.0	4.3 – 4.8 4.6	0.17 – 0.25 0.20	0.08 – 0.12 0.09	34 – 34 34
HA	5	19 – 24 21	1.5 – 2.8 1.9	4.3 – 4.8 4.6	0.17 – 0.25 0.20	0.08 – 0.12 0.09	29 – 38 38
KIL	5	39 – 57 47	4.2 – 11.5 7.8	6.2 – 6.5 6.4	2.4 – 6.5 3.2	1.3 – 3.6 1.7	17.5 – 17.5 17.5
SE	5	18 – 36 23	3.2 – 6.0 3.9	4.5 – 5.6 4.8	0.04 – 0.09 0.06	0.02 – 0.04 0.03	17.5 – 29 29

SM = soil moisture, SOM = soil organic matter, Sp Cond = specific conductivity, Sal = salinity

APPENDIX IV

Water Quality Data

Water Quality Data for Freshwater Wetland Functional Assessment Study

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
9/22/2008	CR	CR1	25.54	1.92	23.3	1.85	12.2	6.48	
9/22/2008	CR	CR10	11.23	1.22	78.4	8.6	11.2	7.36	
9/22/2008	CR	CR2	25.03	1.66	27.23	2.10	16.5	6.22	
9/22/2008	CR	CR3	25.11	1.52	25.76	2.06	11.7	6.26	
9/22/2008	CR	CR4	13.91	1.04	75.1	7.84	10.0	7.16	
9/22/2008	CR	CR5	12.19	1.034	80.4	8.61	10.2	7.11	
9/22/2008	CR	CR6	11.43	0.577	77.9	8.5	8.5	7.05	
9/22/2008	CR	CR7	14.51	1.013	75.7	7.72	9.7	6.89	
9/22/2008	CR	CR8	14.38	0.978	74.8	7.65	9.5	6.94	
9/22/2008	CR	CR9	10.52	0.946	83.4	9.3	9.8	7.2	
9/22/2008	TB	TB							
9/22/2008	WD	WD1	11.65	2.117	87.4	9.52	7.7	7.47	
9/22/2008	WD	WD10	11.17	0.599	65.8	7.24	2.8	7.27	
9/22/2008	WD	WD11	11.82	0.479	107.3	11.62	3.3	7.16	
9/22/2008	WD	WD2	9.33	0.677	62.8	7.2	1.2	7.33	
9/22/2008	WD	WD3	9.58	0.535	64.5	7.34	1.8	7.32	
9/22/2008	WD	WD5	9.12	0.494	68.8	7.92	2.8	7.39	
9/22/2008	WD	WD6	10.41	0.534	63	7.04	1.8	7.24	
9/22/2008	WD	WD7	10.85	0.504	101.8	11.25	2.4	7.2	
9/22/2008	WD	WD8	12.6	0.59	73.5	7.82	2.2	7.13	
9/22/2008	WD	WD9	10.67	0.723	71.4	7.94	3.3	7.25	
10/7/2008	CR	CR WEIR	26.95	5.23	90	7.48	2	6.38	
10/7/2008	WD	WD1	27.86	1.845	106.7	8.67	7.5	6.74	
10/8/2008	LC	LC1	21.17	9.725	61.1	5.22	4	7.9	
10/8/2008	LC	LC10	26.64	16.81	71	4.25	2	6.63	
10/8/2008	LC	LC2	22.69	10.28	65.9	5.4	3	7.29	
10/8/2008	LC	LC3	23.65	6.282	64.7	5.22	3	7.49	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
10/8/2008	LC	LC4	23.91	11.42	74.5	6.03	3	6.97	
10/8/2008	LC	LC5	24.94	11.38	64.8	5.2	2.5	7.03	
10/8/2008	LC	LC7	11.43	12.64	64.4	5.11	2.5	6.58	
10/8/2008	LC	LC8	25.73	15.83	68.3	6.62	1.5	6.69	
10/8/2008	LC	LC9	25.88	12.02	64.5	5.07	2	6.32	
10/8/2008	LC	LC-irr ditch	25.61	13.81	46.2	3.6	48	6.85	
10/8/2008	LC	LC-weir	25.76	9.842	64.1	5.07	4	6.66	
10/8/2008	SW	SW PD	31.59	11.41	73.8	5.24	4	6.71	
10/8/2008	SW	SW WCS	28.06	12.27	142.3	10.7	4	6.89	
10/8/2008	SW	SW1	26.9	10.79	80.3	6.19	3	6.9	
10/8/2008	SW	SW2	27.54	10.84	83	6.37	3	6.93	
10/8/2008	SW	SW3	28.7	10.62	95	7.09	3	6.94	
10/8/2008	SW	SW4	28.88	10.58	113	8.5	3	6.87	
10/8/2008	SW	SW5	28.22	16.43	126.4	9.35	1.5	6.75	
10/8/2008	SW	SW6	28.58	16.54	157.4	11.54	0.5	6.41	
10/8/2008	TB	TB							
10/23/2008	CR	CR1	19.72	6.98	80.1	7.1	3.7	6.56	
10/23/2008	CR	CR10	24.24	7.70	105.8	8.68	0.5	6.91	
10/23/2008	CR	CR2	18.82	6.79	83.4	7.6	2.0	6.54	
10/23/2008	CR	CR3	20.07	6.26	85.6	7.46	1.9	6.52	
10/23/2008	CR	CR4	17.19	6.37	67.8	6.3	1.5	6.59	
10/23/2008	CR	CR5	20.89	6.32	92.3	8.05	1.0	6.75	
10/23/2008	CR	CR6	20.51	6.45	93.9	8.24		6.98	
10/23/2008	CR	CR7	19.16	6.49	88.8	7.99	0.7	6.56	
10/23/2008	CR	CR8	21.81	6.61	89.4	7.66	1.6	6.62	
10/23/2008	CR	CR9	20.54	6.33	83.4	7.32	0.3	6.42	
10/23/2008	R	CR RAIN							
10/23/2008	TB	TB							
11/11/2008	CR	CR weir	24.47	1.7	94.5	7.84		6.01	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
11/11/2008	CR	CR1	25.39	1.719	76.3	6.21	9.2	6.16	
11/11/2008	CR	CR10	25.66	1.095	69.7	5.66	7.05	6.47	
11/11/2008	CR	CR2	24.6	1.489	73.1	6.15	9.9	6.23	
11/11/2008	CR	CR4	24.18	1.752	84.9	7.07	7.9	6.27	
11/11/2008	CR	CR5	24.59	1.812	66.3	5.48	6.15	6.26	
11/11/2008	CR	CR9	24.69	2.13	80.7	6.68	6.14	6.25	
11/11/2008	LC	LC irr							
11/11/2008	R	CR RAIN	13.94	0.16	119	12.31		6.92	
11/11/2008	R	CR RAIN	13.98	0.159	121.8	12.7		7.35	
11/11/2008	TB	TB							
11/11/2008	WD	WD1	27.09	1.628	80.1	6.36	3.65	6.26	
11/11/2008	WD	WD11	25.25	2.815	94.6	7.31	2.85	5.87	
11/11/2008	WD	WD2	26.16	1.12	96.2	7.77	1.92	6.35	
11/11/2008	WD	WD5	25.25	1.296	96.2	7.87	3.5	6.59	
11/11/2008	WD	WD7	25.31	1.224	99.6	8.14	2.51	6.66	
11/11/2008	WD	WD9	27.58	1.611	103.9	8.14	4	6.61	
11/20/2008	CR	CR weir	20.85	0.989	118.1	10.4	8	6.71	
11/20/2008	CR	CR1	21.19	1.019	103.5	9.07	5.6	6.76	
11/20/2008	CR	CR10	20.34	0.721	99.7	8.94	5	6.84	
11/20/2008	CR	CR2	19.27	0.952	107.9	9.89	9.1	6.71	
11/20/2008	CR	CR4	19.16	1.084	99.1	9.13	6.4	6.62	
11/20/2008	CR	CR5	17.95	1.102	101.8	9.5	6.4	6.61	
11/20/2008	CR	CR9	19.42	1.07	96.5	8.85	6	6.59	
11/20/2008	TB	TB							
11/20/2008	WD	WD1	22.33	1.42	125.2	10.69	6.8	6.18	
11/20/2008	WD	WD11	22.37	1.598	120.4	10.41	1.4	6.69	
11/20/2008	WD	WD2	22.58	1.279	131.5	11.31	0.33	6.66	
11/20/2008	WD	WD5	24.4	1.161	127.2	10.59	1.5	6.71	
11/20/2008	WD	WD7	22.69	1.193	133.9	11.5	0.55	6.72	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
11/20/2008	WD	WD9	23.13	1.133	133	11.34	1.1	6.75	
12/9/2008	LC	LC irr	21.87	20.41	96.9	7.92		6	
12/9/2008	LC	LC1	21.86	14.25	82.3	6.88	3.6	6.01	
12/9/2008	LC	LC2	22.11	20.52	99.6	8.43	2.4	5.92	
12/9/2008	R	KSR2	12.42	0.185	116.0	12.37		6.21	
12/9/2008	R	KSR3	11.87	0.182	114.9	12.41		6.15	
12/9/2008	R	KSR1	11.11	0.197	114.8	12.6		6.12	
12/9/2008	SW	SW irr	20.42	9.143	116.2	10.16		5.77	
12/9/2008	SW	SW1	22.45	6.14	88	7.47	5.7	6.01	
12/9/2008	SW	SW4	22.22	5.869	106	9.4	7.8	6	
12/9/2008	SW	SW5	22.08	5.873	107.1	9.23	6.83	5.55	
12/9/2008	SW	SW7	21.94	5.753	107.7	9.25	2.95	5.96	
12/9/2008	SW	SW8	22.27	5.481	103.1	8.83	2.38	5.09	
12/9/2008	SW	SW9	22.29	5.991	106.6	9.16	3.7	6.03	
12/9/2008	TB	TB	18.48	0.051	65.8	6.8		4.65	
1/6/2009	R	KSR1	18.12	0.181	111.8	10.56		4.54	
1/6/2009	R	KSR2	14.07	0.165	118.5	12.17		6.19	
1/9/2009	MB	teflon bag+DI	21.91	0.127	84.1	7.37		7.11	
1/20/2009	CR	CR BP	17.01	2.971	103.9	9.91		6.53	
1/20/2009	CR	CR1	18.00	5.037	91.6	8.57	2	5.73	
1/20/2009	CR	CR2	18.05	4.942	91.9	8.56	4.5	6.27	
1/20/2009	LC	LC irr	16.72	16.87	107.8	9.89			
1/20/2009	SW	SW irr	15.58	4.867	88.5	8.7		8.08	
1/20/2009	SW	SW1	17.46	6.112	84.5	8.01	5.4	7.91	
1/20/2009	SW	SW4	16.36	6.226	100.9	9.72	6.5	7.8	
1/20/2009	SW	SW5	15.96	6.121	99.3	9.77	7.3	7.94	
1/20/2009	SW	SW7	16.61	6.484	85.1	8.12	2.75	7.45	
1/20/2009	SW	SW8	16.76	6.524	82.4	7.81	1.83	7.54	
1/20/2009	SW	SW9	17.17	6.77	85.6	8.13	2.8	7.26	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
1/20/2009	TB	TB	10.47	0.175	96.1	10.69		4.56	
2/10/2009	LC	LC irr	18.86	18.65	79.0	6.78		5.84	
2/10/2009	R	SWR1							
2/10/2009	R	SWR2							
2/10/2009	SW	SW irr	20.35	9.515	89.2	7.79		7.55	
2/10/2009	SW	SW1	21.31	8.364	112.4	9.71	1.7	7.59	
2/10/2009	SW	SW4	21.4	8.548	93.6	8.07	3.7	7.38	
2/10/2009	SW	SW5	21.07	8.593	91.3	7.91	2.5	7.44	
2/10/2009	SW	SW6	21.37	8.705	105.6	9.09	1.5	7.35	
2/10/2009	TB	TB							
2/11/2009	R	CRR1							
2/11/2009	R	CRR2							
2/11/2009	R	SWR1							
2/11/2009	R	SWR2							
2/18/2009	R	SWR1		0.38	104.7	11.92		8.73	
2/18/2009	R	SWR2		0.22	93	11.36		8.26	
3/27/2009	KS	KS 5	22.43	2.014	87.4	7.51	1.13	5.20	
3/27/2009	KS	KS 6	22.16	2.013	81	6.98	2.00	5.49	
3/27/2009	KS	KS 6 FD	22.24	1.995	79.1	6.85	2.00	5.56	
3/27/2009	R	KSR1	18.63	0.112	93.2	8.68		5.24	
3/27/2009	R	KSR2	20.27	0.115	102.2	9.23		5.04	
3/27/2009	R	KSR3	20.73	0.116	95.2	8.51		5.19	
3/27/2009	TB	TB	22.08	0.156	76.4	6.65		4.90	
3/27/2009	TH	TH6	25.04	0.254	93.5	7.71	2.00	6.17	
4/4/2009	KS	KS6	21.65	2.387	80.7	7.03	1.83	6.99	
4/4/2009	KS	KS6 FD	20.45	2.362	84.5	7.5	1.83	5.72	
4/4/2009	TB	TB	25.88	0.127	88.2	6.9	NA	7.22	
4/8/2009	SW	SW1	24.58	8.001	97.8	7.92	2.40	5.77	
4/8/2009	SW	SW4	28.11	6.407	102	7.85	3.40	4.31	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
4/8/2009	SW	SW5	24.69	5.992	91.9	7.48	4.65	4.36	
4/8/2009	SW	SW5 FD	26.15	5.899	93.9	7.47	4.65	4.35	
4/8/2009	SW	SW7	26.2	6.105	139.9	11.2	1.42	4.32	
4/8/2009	SW	SW8	25.66	6.854	120	9.5	1.19	4.29	
4/8/2009	SW	SW9	26.73	7.517	116.1	9.09	1.19	4.24	
4/8/2009	TB	TB	24.83	0.714	98	8.01		6.27	
4/19/2009	KS	KS6	17.92	0.166	85.8	8.12	5.7	5.90	
4/19/2009	KS	KS6 FD	17.90	0.169	88.8	8.38	5.7	5.96	
4/19/2009	R	KSR1	20.30	0.141	91.5	8.24		6.07	
4/19/2009	R	KSR1 FD	19.44	0.140	104.5	9.67		5.89	
4/19/2009	R	KSR2	19.48	0.140	96.6	8.85		5.83	
4/19/2009	R	KSR2 FD	19.51	0.138	98	9.07		5.78	
4/19/2009	TH	TH5	18.02	0.160	93.8	8.91	6.7	5.88	
4/19/2009	TH	TH5 FD	18.00	0.161	90.7	8.59	6.7	5.76	
4/25/2009	KS	KS1	26.16	0.16	75.2	6.08	7.6	6.69	
4/25/2009	KS	KS10	24.80	0.153	63.8	5.29	4.6	6.24	
4/25/2009	KS	KS2	24.77	0.159	71.7	5.77	3.6	6.58	
4/25/2009	KS	KS5	24.83	0.171	77.0	6.37	7.2	6.45	
4/25/2009	KS	KS6	25.46	0.174	62.7	5.53	9.6	6.65	
4/25/2009	KS	KS6FD					9.6		
4/25/2009	KS	KS9	24.80	0.156	74.7	6.14	5.2	6.42	
4/25/2009	TB	TB	19.88	0.124	87.4	7.86		6.91	
4/25/2009	TH	TH1	26.05	0.157	71.8	5.76	2.6	6.48	
4/25/2009	TH	TH4	26.05	0.162	61.4	4.90	2.9	6.3	
4/25/2009	TH	TH5	26.77	0.163	83.6	6.61	6.7	6.45	
4/25/2009	TH	TH5 FD	26.00	0.157	94.4	7.61	6.7	6.4	
4/25/2009	TH	TH7	26.31	0.157	88.8	7.06	5.8	6.43	
4/25/2009	TH	TH8	26.50	0.167	87.3	6.87	3.1	6.41	
4/25/2009	TH	TH9	26.01	0.152	87.0	7.00	2.8	6.3	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
5/11/2009	KS	KS5	36.53	0.378	71.3	4.82	1.1	7.5	
5/11/2009	KS	KS6	34.50	0.361	85.4	5.95	5.2	7.46	
5/11/2009	KS	KS6FD	34.48	0.365	87.6	6.11	5.2	7.45	
5/11/2009	TB	TB	19.31	0.178	82.6	7.33		9.25	
5/11/2009	TH	TH4	28.84	0.197	95.6	7.37	3	7.53	
5/11/2009	TH	TH5	34.27	0.208	122	8.62	1.8	7.4	
5/11/2009	TH	TH5 FD	34.69	0.205	129.6	9.13	1.8	7.33	
5/11/2009	TH	TH7	34.03	0.208	112.9	8.01	1.5	7.36	
9/30/2009	KIL	KIL1	20.45	15.97	88.7	7.33	6.0		
9/30/2009	KIL	KIL2	18.96	15.81	83.5	11.09	6.0		
9/30/2009	KIL	TB	10.67	0.049	101.9	11.09			
10/8/2009	DW	DW1	33.52	0.141	135.6	9.63	5	6.47	
10/8/2009	DW	DW2	33.8	0.127	126	9.02	9	6.44	
10/8/2009	DW	DW3	33.17	0.128	132.1	9.24	10	6.52	
10/8/2009	DW	DW4	33.31	0.114	132.2	9.45	9	6.23	
10/8/2009	DW	DW4 FD					9		
10/8/2009	DW	TB	16.29	0.002	56.1	5.45		5.47	
10/8/2009	R	DWR1	31.29	0.055	110	8.13		4.37	
10/8/2009	R	DWR1 FD							
10/8/2009	R	DWR2	31.43	0.03	106.5	7.85		4.53	
10/8/2009	R	DWR2 FD							
10/8/2009	R	KSR1	28.95	0.01	94.8	7.3		5.23	
10/8/2009	R	KSR1FD	28.95	0.01	96.6	7.44		5.30	
10/8/2009	R	KSR2	28.88	0.011	97.7	7.53		5.65	
10/8/2009	R	KSR3	28.9	0.009	97.1	7.48		5.00	
10/9/2009	KS	KS6	22.03	0.622	93.2	8.02	5	5.39	
10/9/2009	KS	KS6FD	22.04	0.569	97.7	8.45	4	6.19	
10/9/2009	KS	KS6FD2	21.61	0.545	99.2	8.66	3	6.15	
10/10/2009	LG	LG1	26.63	0.113	108.9	9.12	4	6.26	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
10/10/2009	LG	LG2	23.6	0.06	77.3	6.5	7	5.60	
10/10/2009	LG	LG3	24.4	0.061	76.2	6.32	6	5.50	
10/10/2009	LG	LG4	26.06	0.093	94.1	7.64	10	5.96	
10/10/2009	LG	LG4 FD	26.02	0.084	104.5	8.47	10	5.95	
10/10/2009	LG	LG5	26.23	0.144	108.9	8.77	8	6.25	
10/10/2009	R	KSR1	18.91	0.026	113.5	10.54		5.13	
10/10/2009	R	KSR1FD	18.78	0.019	110.1	10.26		5.28	
10/10/2009	R	KSR2	19.07	0.02	112.2	10.4		5.61	
10/10/2009	R	KSR3	18.88	0.018	109.4	10.18		5.32	
10/10/2009	R	LGR1	20.7	0.012	106.1	9.62		5.19	
10/10/2009	R	LGR1 FD							
10/10/2009	R	LGR2	20.6	0.012	107.3	6.94		4.96	
10/10/2009	TB	TB							
10/18/2009	KS	KS6a	22.72	0.455	71	6.07	4.5	5.83	
10/18/2009	KS	KS6b	23.47	0.481	70.2	5.97	4	5.95	
10/18/2009	KS	KS6c	23.59	0.478	62.1	5.23	5	6.00	
10/18/2009	KS	KS6cFD	25.61	0.482	65.6	5.28	5	6.06	
10/18/2009	LG	LG1	24.02	0.094	49.5	4.13	2	6.07	
10/18/2009	LG	LG2	24.12	0.069	64.5	5.41	4	5.9	
10/18/2009	LG	LG3	23.1	0.076	80.7	6.92	4.5	5.97	
10/18/2009	LG	LG4	23.89	0.078	74.2	6.26	5.5	5.99	
10/18/2009	LG	LG4 FD	24.17	0.076	63.3	5.32	5	5.87	
10/18/2009	LG	LG5	23.35	0.163	59.7	5.09	10	6.18	
10/19/2009	DW	DW1	21.78	0.167	59.9	5.2	4.5	6.77	
10/19/2009	DW	DW2	21.3	0.165	45	3.99	4	6.09	
10/19/2009	DW	DW2FD	21.3	0.165	45	3.99	4	6.09	
10/19/2009	DW	DW3	24.06	0.117	78.3	6.58	3	6.51	
10/19/2009	DW	DW5	23.47	0.208	78.9	6.71	3	6.95	
10/19/2009	DW	TB	14.5	0.13	78.6	8.02		4.69	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
10/19/2009	MB	MB							
10/23/2009	CR	CR weir	19.96	0.216	16.9	1.52	17	6.23	
10/23/2009	CR	CR weir P	19.27	0.247	3.9	0.34	17	6.19	
10/23/2009	CR	CR1	20.73	0.137	6.6	0.59	13.5	6.31	
10/23/2009	CR	CR2	19.24	0.162	13.3	1.23	24	6.28	
10/23/2009	CR	CR5	21.94	0.337	10.7	0.92	13	6.48	
10/23/2009	CR	CR5 FD					13		
10/23/2009	CR	CR9	22.23	0.287	5.8	0.5	13	6.44	
10/23/2009	R	CRR1	16.55	0.022	96.6	9.49		5.05	
10/23/2009	R	CRR2	15.77	0.021	95.5	9.39		5.3	
10/23/2009	R	KSR1	18.88	0.017	94.0	8.73		5.95	
10/23/2009	R	KSR2	17.03	0.014	92.8	8.95		5.5	
10/23/2009	R	KSR3	16.52	0.013	90.9	8.87		5.24	
10/23/2009	TB	TB							
10/23/2009	UH	UH1	16.69	0.139	42.9	4.2	0.75	6.09	
10/23/2009	UH	UH2	16.03	0.423	49.2	4.85	1	7.2	
10/23/2009	UH	UH3	16.51	0.105	61.1	5.96	2	6.27	
10/23/2009	UH	UH4	16.14	0.1	35.3	3.48	1.5	6.12	
10/23/2009	UH	UH4 FD					1.5		
10/23/2009	WD	WD1	21.07	0.298	15.3	1.36	10.5	6.58	
10/23/2009	WD	WD11	20.08	0.476	10.2	0.93	8.5	6.61	
10/23/2009	WD	WD2	19.83	0.191	12.5	1.14	6.5	6.5	
10/23/2009	WD	WD5	21.83	0.31	5	0.43	6.5	6.63	
10/23/2009	WD	WD5 FD							
10/23/2009	WD	WD9	20.83	0.537	17.2	1.51	10.5	6.59	
10/24/2009	TH	TH weir	19.89	0.088	69.6	6.34		6.1	
10/24/2009	TH	TH1	18.75	0.076	72.9	6.72	5	6.19	
10/24/2009	TH	TH4	18.2	0.048	39	3.65	1	5.72	
10/24/2009	TH	TH5	17.99	0.069	37.3	3.53	4	5.91	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
10/24/2009	TH	TH5 FD					4		
10/24/2009	TH	TH7	17.61	0.069	51.8	4.92	2.5	6.03	
10/24/2009	TH	TH9	20.37	0.072	38.4	3.47	1.5	6.2	
11/2/2009	CR	CR weir	16.87	0.188	20.2	2.09		6.11	
11/2/2009	CR	CR weirP	16.13	0.176	10.7	1.03	16.0	6.03	
11/2/2009	CR	CR1	16.48	0.166	6.0	0.65	9.0	6.25	
11/2/2009	CR	CR2	17.18	0.187	8.4	0.8	11.0	6.31	
11/2/2009	CR	CR5	17.54	0.186	9.3	0.87	12.5	6.37	
11/2/2009	CR	CR5 FD	16.23	0.187	6.5	0.60	12.5	6.33	
11/2/2009	CR	CR9	16.47	0.196	7.0	0.66	10.25	6.33	
11/2/2009	TB	TB							
11/2/2009	TH	TH weir	18.72	0.08	75.6	7.5	6.5	6.53	
11/2/2009	TH	TH1	18.68	0.081	40	3.73	5	6.33	
11/2/2009	TH	TH4							
11/2/2009	TH	TH5	17.58	0.084	39.2	3.74	3.25	6.23	
11/2/2009	TH	TH5 FD							
11/2/2009	TH	TH7	19.88	0.093	40.1	3.64	1.25	6.27	
11/2/2009	TH	TH9							
11/2/2009	WD	WD1	18.05	0.332	18.4	1.73	10	6.76	
11/2/2009	WD	WD11	16.56	0.43	10.3	1.02	5.5	6.65	
11/2/2009	WD	WD2	16.08	0.415	7.8	0.77	4.5	6.73	
11/2/2009	WD	WD5	15.09	0.337	7.4	0.74	5	6.78	
11/2/2009	WD	WD5 FD					6		
11/2/2009	WD	WD9	15.59	0.365	9.0	0.89	8	6.64	
11/9/2009	KIL	KIL1	21.49	13.32	120.4	10.14	10.5	8.19	
11/9/2009	KIL	KIL2	21.52	13.43	132.5	11.18	10.5	8.32	
11/9/2009	KIL	KIL3	21.49	13.39	122.4	10.35	10	8.24	
11/9/2009	KIL	KIL4	21.78	13.46	128.1	10.74	8	8.29	
11/9/2009	KIL	KIL4 FD					8		

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
11/9/2009	KIL	KIL5	21.58	13.49	128.6	10.84	10	8.32	
11/9/2009	LC	LC1	20.42	1.108	71	6.36	4.0	7.04	
11/9/2009	LC	LC1 FD	19.93	0.912	44.4	4.03	4.0	6.92	
11/9/2009	LC	LC2	20.62	1.841	109.1	9.75	4.0	6.76	
11/9/2009	LC	LC4	20.95	1.464	76.4	6.79	2.0	6.72	
11/9/2009	LC	Lcirr	20.16	0.785	73	6.61	6.0	7.09	
11/9/2009	R	LCR1							
11/9/2009	R	LCR2		no YSI					
11/9/2009	R	LCR3							
11/9/2009	R	WLR2							
11/9/2009	SW	SW weir	20.86	0.173	29.8	2.66		6.58	
11/9/2009	SW	SW1	19.93	0.224	20.4	1.89	7.5	6.67	
11/9/2009	SW	SW4	19.92	0.158	7.0	0.64	12	6.39	
11/9/2009	SW	SW5	19.68	0.155	7.8	0.69	30	6.54	
11/9/2009	SW	SW7	20.22	0.221	9.4	0.85	9	6.62	
11/9/2009	SW	SW8	21.05	0.148	40.7	3.63	7	6.78	
11/9/2009	SW	SW9	20.94	0.153	32.9	2.94	8	6.63	
11/9/2009	TB	TB							
11/16/2009	KIL	KIL1	21.77	15.68	127.9	10.77	11.0	8.25	
11/16/2009	KIL	KIL2	21.92	15.71	146.7	12.32	11.0	8.40	
11/16/2009	KIL	KIL3	21.78	15.7	123.4	9.90	14.0	8.10	
11/16/2009	KIL	KIL4	22.08	15.64	152.8	12.65	7.5	8.46	
11/16/2009	KIL	KIL5	27.78	15.67	124.6	10.61	10.0	8.24	
11/16/2009	LC	LC1	21.32	2.136	153.6	13.34	3.5	7.15	
11/16/2009	LC	LC1 FD	21.14	1.948	128	11.49	4.0	7.1	
11/16/2009	LC	LC2	21.62	2.751	122.3	10.49	2.0	6.82	
11/16/2009	LC	LCirr	21.42	1.692	74.4	6.57		7.14	
11/16/2009	R	KILR1							
11/16/2009	R	KILR2							

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
11/16/2009	R	LCR1			no YSI				
11/16/2009	R	LCR2							
11/16/2009	R	LCR3							
11/16/2009	SW	SW weir	20.57	0.201	27.4	2.44	8.5	6.49	
11/16/2009	SW	SW1	20.25	0.296	27.5	2.51	7.0	6.64	
11/16/2009	SW	SW4	20.44	0.212	32.4	2.91	10.5	6.52	
11/16/2009	SW	SW4 FD					10.5		
11/16/2009	SW	SW5	19.94	0.2	19.9	1.82	14.5	6.48	
11/16/2009	SW	SW7	21.06	0.251	32.2	2.8	7.0	6.66	
11/16/2009	SW	SW8	22.06	0.175	43.7	3.84	6.0	6.79	
11/16/2009	SW	SW9	22.26	0.212	48.1	4	7.5	6.77	
11/16/2009	TB	TB							
11/17/2009	CR	CR weir	14.49	0.25	23.5	2.4	19.5	6.43	
11/17/2009	CR	CR1	13.42	0.211	19.5	2.04	7.5	6.57	
11/17/2009	CR	CR2	15	0.239	23.6	2.33	9.0	6.50	
11/17/2009	KS	KS6	15.45	0.163	27.2	2.74	6.0	6.56	
11/17/2009	KS	KS6 FD							
11/17/2009	LG	LG1	14.65	0.088	56.4	5.74	7.5	6.55	
11/17/2009	LG	LG2	16.15	0.077	32.2	3.46	5.0	6.33	
11/17/2009	LG	LG3	14.17	0.1	57.9	5.93	3.0	6.67	
11/17/2009	LG	LG4	16.71	0.073	55.5	5.33	3.0	6.33	
11/17/2009	LG	LG5	14.31	0.153	22.8	2.35	9.0	6.75	
11/17/2009	TH	TH5	14.28	0.094	48.5	4.97	1.0	6.55	
11/17/2009	TH	TH5 FD							
11/17/2009	WD	WD1	12.58	0.464	25.9	2.78	10.5	6.93	
12/9/2009	CR	CR weir	10.33	0.184	10.5	1.17	16	6.08	
12/9/2009	CR	CR1	10.54	0.157	13.4	1.4	10	6.17	
12/9/2009	CR	CR2	9.74	0.165	9.5	1.05	14	6.21	
12/9/2009	DW	DW1	8.79	0.084	44.1	5.11	11	5.81	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
12/9/2009	DW	DW3	8.65	0.07	56.4	6.58	12	6.21	
12/9/2009	DW	DW5	8.79	0.079	19.5	1.86	14	6.05	
12/9/2009	KS	KS1 weir	11.61	0.091	71.9	7.7	4	5.92	
12/9/2009	KS	KS3	11.53	0.094	69.8	7.54	3	6.13	
12/9/2009	KS	KS6	12.37	0.099	52.6	5.6	15	6.12	
12/9/2009	LG	LG WLR	10.98	0.17	50.5	5.55	11	6.31	
12/9/2009	LG	LG3	11.8	0.058	80.9	8.86	5	5.96	
12/9/2009	LG	LG4	12.24	0.345	56.7	6.09	3	6.67	
12/9/2009	LG	LG4 FD					3		
12/9/2009	TB	TB							
12/9/2009	TH	TH weir	13.68	0.09	49.0	4.59	2.4	6.26	
12/9/2009	TH	TH5	14.05	0.105	28.7	2.95	5.5	6.1	
12/9/2009	TH	TH7	14.13	0.123	20.2	2.04	1.6	6.16	
12/9/2009	UH	UH ditch	12.95	0.223	54.9	5.85	3	6.62	
12/9/2009	UH	UH1	11.9	0.999	55.3	5.83	2	7.52	
12/9/2009	UH	UH1 FD	12.41	1.403	62	6.53	1.5	7.3	
12/9/2009	WD	WD1	10.72	0.502	28.7	2.89	5	6.76	
12/9/2009	WD	WD2	11.04	0.222	13.7	1.48	6	6.59	
12/9/2009	WD	WD4	10.07	0.371	23.6	2.6	16	6.79	
12/10/2009	HA	HA1	13.29	0.091	75.7	7.75	10	6.23	
12/10/2009	HA	HA2	12.98	0.162	67.2	7.05	6	6.52	
12/10/2009	HA	HA3	13.85	0.052	102.8	10.69	2	6.53	
12/10/2009	HA	HA4	12.21	0.055	101.2	10.67	6	6.45	
12/11/2009	KIL	KIL3	8.23	13.65	102	11.33	10	7.97	
12/11/2009	KIL	KIL4	8.02	13.58	101.1	11.41	12	7.96	
12/11/2009	LC	LC1	9.63	0.642	124.5	14.17	8	7.00	
12/11/2009	LC	LC2	9.76	0.692	126.3	14.31	8	6.91	
12/11/2009	LC	LC4	10.01	0.658	123.9	13.94	5	7.16	
12/11/2009	SE	SE WLR	8.7	0.171	131.2	15.25	1	5.84	

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
12/11/2009	SE	SE WLR FD					1		
12/11/2009	SE	SE1	9.42	0.121	80.7	9.23	2	5.49	
12/11/2009	SE	SE3	9.37	0.112	102.8	11.77	2	5.72	
12/11/2009	SW	SW weir	8.67	0.255	58.3	6.77	8	6.58	
12/11/2009	SW	SW1	8.27	0.379	49.5	5.86	7	6.63	
12/11/2009	SW	SW5	8.79	0.3	54.6	6.33	12	6.57	
12/11/2009	SW	SW9	8.83	0.273	52.8	6.13	7	6.57	
1/27/2010	KIL	Kil1	17.73	15.55	142.5	13.01	19	9.09	
1/27/2010	KIL	KIL2	16.54	15.65	149.2	13.8	9	9.1	
1/27/2010	KIL	KIL3	16.61	15.66	146.3	13.6	10.5	9.12	
1/27/2010	LC	LC3	19.04	1.084	159.9	14.81	6	8.16	
1/27/2010	LC	LC1	19.49	0.968	145.9	13.38	4	8.18	
1/27/2010	LC	LC2	18.53	1.049	156.1	14.57	5	7.56	
1/27/2010	LC	LC2 FD					5		
1/27/2010	SE	SE1	21.68	0.506	108.6	9.59	1	8.07	
1/27/2010	SE	SE2	19.27	0.46	109.4	10.09	1.25	8.42	
1/27/2010	SW	SW weir	17.77	0.365	69.6	6.61	5	6.93	
1/27/2010	SW	SW1	15.71	0.517	47	4.83	8	6.69	
1/27/2010	SW	SW4	15.17	0.441	48.4	5.09	10	7.01	
1/27/2010	SW	SW5	16.56	0.365	61.8	5.85	12	6.82	
1/27/2010	SW	SW9	18.44	0.311	99.8	9.29	6	7.41	
1/27/2010	SW	SW9 FD					6		
1/28/2010	CR	CR1	13.73	0.212	17.8	1.79	9.5	6.01	
1/28/2010	CR	CR10	14.90	0.265	61	5.81	9	6.71	
1/28/2010	DW	DW1	16.01	0.078	54.5	5.43	8	5.92	
1/28/2010	DW	DW2	15.94	0.04	38.2	3.77	9	5.93	
1/28/2010	DW	DW5	15.85	0.074	30.4	3.64	5	5.85	
1/28/2010	HA	HA1	15.9	0.075	35	3.45	9	6.33	
1/28/2010	HA	HA1 FD							

Date	Site	Plot	Temp (˚C)	Sp Cond (mS cm-1)	DO (%)	DO (mgL-1)	Depth (in)	pH	Note
1/28/2010	HA	HA3	17.07	0.063	94.5	9.12	2	6.12	
1/28/2010	HA	HA4	16.43	0.059	61.9	6.05	4	5.75	
1/28/2010	KS	KS6	13.45	0.128	13.6	1.4	9	5.68	
1/28/2010	KS	KS6 FD							
1/28/2010	LG	LG1	14.58	0.088	24.7	2.43	6	5.71	
1/28/2010	LG	LG2	15.75	0.090	33.7	3.4	5	6.23	
1/28/2010	LG	LG4	14.22	0.204	29.1	2.96	8	6.76	
1/28/2010	TB	TB							
1/28/2010	TH	TH5	15.24	0.092	38.9	3.99	4.5	6.29	
1/28/2010	TH	TH5 FD							
1/28/2010	WD	WD1	15.43	0.778	7	0.7	8	6.74	
1/28/2010	WD	WD1 FD	15.53	0.788	4.2	0.41	8	6.52	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
9/22/2008	CR	CR1	3.58	0.97	3.2	15.6	26.2	2.9	1390	74.2	
9/22/2008	CR	CR10	1.93	0.61	1.8	11.9	15.0	6.5	1660	63.3	
9/22/2008	CR	CR2	3.05	0.66	5.0	8.2	20.7	4.0	1260	62.1	
9/22/2008	CR	CR3	2.06	0.81	1.4	9.4	20.1	3.2	1430	55.7	
9/22/2008	CR	CR4	1.75	0.52	16.0	15.1	23.8	3.6	1350	71.2	
9/22/2008	CR	CR5	1.93	0.52	2.4	13.5	17.8	3.2	1335	55.5	
9/22/2008	CR	CR6	2.21	0.28	25.2	9.0	14.3	2.5	1320	59.4	
9/22/2008	CR	CR7	3.25	0.5	101	11.2	25.8	2.9	1350	67.1	
9/22/2008	CR	CR8	1.92	0.49	7.8	7.6	17.2	1.9	1323	57.8	
9/22/2008	CR	CR9	2.49	0.47	43.5	15.3	19.4	4.8	1407	65.5	
9/22/2008	TB	TB				1.21		2.1	19	2.16	
9/22/2008	WD	WD1	8.13	1.09	160.6	142.7	58.0	2.6	1851	422	
9/22/2008	WD	WD10	30.8	0.29	22.7	19.3	75.6	1.9	1517	135	
9/22/2008	WD	WD11	29.5	0.23	32.3	29.3	278.3	1.6	1912	124	
9/22/2008	WD	WD2	305	0.33	422.5	35.6	136.5	4.3	2110	298	
9/22/2008	WD	WD3	162	0.26	236.5	29.3	348.0	3.9	2415	177	
9/22/2008	WD	WD5	56.2	0.24	108.3	91.6	465.5	3.9	3555	372	
9/22/2008	WD	WD6	44.1	0.26	51.5	50.7	381.7	2.0	2330	208	
9/22/2008	WD	WD7	47.2	0.25	80.6	41.5	301.5	4.2	1925	149	
9/22/2008	WD	WD8	36.1	0.29	49.8	28.0	145.3	2.2	1791	164	
9/22/2008	WD	WD9	30.8	0.36	55.3	39.5	177.5	1.5	1823	176	
10/7/2008	CR	CR WEIR	8.78	2.8	24	804.7	92	7.6	1621	1828	
10/7/2008	WD	WD1	8.74	0.93	69	44.6	97	4.9	1634	1318	
10/8/2008	LC	LC1	8.67	5.4	23	20.3	1374	31.4	4440	316	
10/8/2008	LC	LC10	28.4	6.62	35	15.3	2135	8.8	6920	307	
10/8/2008	LC	LC2	13.4	5.38	29	23.7	1003	8.0	4340	367	
10/8/2008	LC	LC3	11.9	3.42	30	11.3	2500	38.7	6230	298	
10/8/2008	LC	LC4	8.74	6.49	20	13.2	1090	8.3	4200	237	
10/8/2008	LC	LC5	8.19	6.47	75	10.3	1535	16.3	6350	249	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
10/8/2008	LC	LC7	17.4	7.25	34	99.2	3350	6.8	5520	1228	
10/8/2008	LC	LC8	21.6	9.26	28	17.9	2935	5.3	5230	312	
10/8/2008	LC	LC9	16.6	6.85	26	13.0	3020	4.2	4850	322	
10/8/2008	LC	LC-irr ditch	17	7.97	31	74.4	585	9.1	3300	385	
10/8/2008	LC	LC-weir	17.6	5.5	28	819.0	977	13.4	4570	2815	
10/8/2008	SW	SW PD	147	6.43					3510	460	
10/8/2008	SW	SW WCS	54.3	6.99	50	18.3	372	5.0	2250	349	
10/8/2008	SW	SW1	55.8	6.09	88	117.0	1369	2.1	4480	1595	
10/8/2008	SW	SW2	50.3	6.12	34	33.8	941	2.7	3775	645	
10/8/2008	SW	SW3	30.6	5.97	23	21.5	806	2.1	2260	341	
10/8/2008	SW	SW4	42.8	5.92	38	24.6	788	4.3	2180	425	
10/8/2008	SW	SW5	135	9.59	261	8.4	313	6.1	2060	302	
10/8/2008	SW	SW6		9.66	126	5.3	737	7.1	3020	344	
10/8/2008	TB	TB				16.7	30	3.6	-30	3	
10/23/2008	CR	CR1	54	3.87	75.4	50.7	106.0	2.1	2349	304	
10/23/2008	CR	CR10	8.54	4.26	109	12.4	43.6	3.5	2295	115	
10/23/2008	CR	CR2	7.05	3.74	28.8	17.5	170.0	5.7	2022	120	
10/23/2008	CR	CR3	22.3	3.42	24.8	8.8	195.0	11.3	2337	80	
10/23/2008	CR	CR4	30.7	3.49	21.4	10.8	246.5	13.2	1992	128	
10/23/2008	CR	CR5	5.27	3.46	12.8	10.9	244.0	6.2	2409	115	
10/23/2008	CR	CR6	11.5	3.54	28.6	14.1	295.0	3.2	3090	163	
10/23/2008	CR	CR7	53.4	3.56	26.9	17.7	487.0	3.6	2904	190	
10/23/2008	CR	CR8	20.3	3.62	10.8	12.9	498.5	3.1	3210	110	
10/23/2008	CR	CR9	18.6	3.46	10.8	18.1	452.0	3.8	3210	114	
10/23/2008	R	CR RAIN			56.0	184.0	472.3	567	3352	383	
10/23/2008	TB	TB				39.8	19.0	18.0	20	43	
11/11/2008	CR	CR weir	6.05	0.86	11.0	56.4	189.0	82.2	1758	232.0	
11/11/2008	CR	CR1	10.1	0.87	15.8	38.4	125.0	79.0	1474	156.5	
11/11/2008	CR	CR10	10.7	0.54	37.6	21.9	86.0	40.4	1758	186.0	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
11/11/2008	CR	CR2	7.08	0.75	31.8	20.3	225.5	44.1	2100	159.0	
11/11/2008	CR	CR4	7	0.89	26.4	16.6	171.0	48.8	1448	150.0	
11/11/2008	CR	CR5	9.15	0.92	32.5	16.5	257.7	45.2	1608	143.0	
11/11/2008	CR	CR9	7.27	1.09	14.9	12.5	161.0	27.8	1208	129.5	
11/11/2008	LC	LC irr						12	824	132	
11/11/2008	R	CR RAIN	1.37	0.1	0.2	4.7	134.0	151.0	196	5.4	
11/11/2008	R	CR RAIN	1.58	0.1	0.1	3.7	131.5	151.0	241	6.2	
11/11/2008	TB	TB				19.8	8	8.05	5.39	17.6	
11/11/2008	WD	WD1	25.4	0.82	29.8	243.5	34.1	12.4	969	871.0	
11/11/2008	WD	WD11	29.9	1.46	57.8	22.4		4.2	953	161.0	
11/11/2008	WD	WD2	30.7	0.55	53.7	27.1	21.1	7.5	945	112.0	
11/11/2008	WD	WD5	40.1	0.64	71.1	14.2	33.5	5.9	962	97.9	
11/11/2008	WD	WD7	40.9	0.61	66.2	10.1	4.1	4.0	917	97.1	
11/11/2008	WD	WD9	61.4	0.81	60.2	17.4	44.4	1.8	1056	134.0	
11/20/2008	CR	CR weir	23.1	0.49	12.8	4.1	17.0	2.3	1065	232.0	
11/20/2008	CR	CR1	18.2	0.51	20.3	3.9	31.6	2.4	1207	156.0	
11/20/2008	CR	CR10	30.4	0.35	31.9	6.6	51.9	4.9	1725	186.0	
11/20/2008	CR	CR2	23.6	0.47	24.1	3.9	29.0	3.2	1078	159.0	
11/20/2008	CR	CR4	24.2	0.54	31.9	4.3	60.5	3.1	1147	150.0	
11/20/2008	CR	CR5	37	0.55	61.5	5.3	93.3	3.8	1474	142.0	
11/20/2008	CR	CR9	28.9	0.53	48.8	5.6	67.7	7.2	1291	129.0	
11/20/2008	TB	TB				0.7	9	5.36	5.39	3	
11/20/2008	WD	WD1	21.5	0.71	17.1	21.4	90.7	2.0	1060	142.5	
11/20/2008	WD	WD11	94.2	0.81	406.5	5.5	186.0	5.6	1264	128.0	
11/20/2008	WD	WD2	271	0.64	533.0	12.1	226.3	13.8	1579	218.5	
11/20/2008	WD	WD5	188	0.58	386.0	6.4	122.0	3.8	1036	95.7	
11/20/2008	WD	WD7	133	0.59	222.0	7.6	169.0	4.0	1326	160.5	
11/20/2008	WD	WD9	142	0.56	558.0	9.2	133.7	5.7	1199	111.0	
12/9/2008	LC	LC irr	12	12.21	39.8	8.5	57.8	3.2	1211	106	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
12/9/2008	LC	LC1	50.4	8.28	80.3	12.1	831	173.3	4245	299	
12/9/2008	LC	LC2	47.5	12.29	162.3	20.0	6980	360.3	5505	376	
12/9/2008	R	KSR2	5.27	0.09	10.5	17.1	257	384.5	749	33.3	
12/9/2008	R	KSR3	2.4	0.09	7.5	18.1	216	440.3	768	45.0	
12/9/2008	R	KSR1	6.47	0.09	15.5	9.3	235	239.5	990	37.9	
12/9/2008	SW	SW irr	21.1	5.13	28.6	7.1	84.8	10.7	1545	109	
12/9/2008	SW	SW1	3.58	3.35	9.5	1.9	52.2	8.7	1068	46.7	
12/9/2008	SW	SW4	4.3	3.19	11.2	3.0	82.4	5.3	1410	61.4	
12/9/2008	SW	SW5	3.53	3.19	12.4	2.7	485	14.2	1930	54.4	
12/9/2008	SW	SW7	5.51	3.12	10.3	2.6	2593	17.0	4875	53.7	
12/9/2008	SW	SW8	5.44	2.97	10.2	5.0	2324	12.9	4200	58.3	
12/9/2008	SW	SW9	3.02	3.26	11.6	3.8	2112	19.0	3255	52.7	
12/9/2008	TB	TB	0.144	0.02	2.0	1.3	88	2.2	1.56	3.2	
1/6/2009	R	KSR1		0.09	2.7	16.1	885	514.3	1191	20.2	
1/6/2009	R	KSR2		0.09	3.0	7.7	352	182.0	1384	17.6	
1/9/2009	MB	teflon bag+DI	0.074	0.06	0.0	2.2	35.7	4.4	1.11	4.8	
1/20/2009	CR	CR BP	10.8	1.56	29.2	11.9	109	7.8	3245	169	
1/20/2009	CR	CR1	224	2.72	336.6	24.4	120	34.6	5775	693	
1/20/2009	CR	CR2	91.1	2.67	344.8	45.3	102	17.0	7805	1710	
1/20/2009	LC	LC irr	15.5		36.4	5.5	107	4.8	2305	75.6	
1/20/2009	SW	SW irr	8.65	2.62	11.00	3.8	76	4.0	1003	53.5	
1/20/2009	SW	SW1	8.25	3.34	15.12	13.0	137	2.6	2500	201	
1/20/2009	SW	SW4	4.7	3.41	0.00	6.7	131	7.2	2500	86.1	
1/20/2009	SW	SW5	7.28	3.35	0.00	6.6	141	7.3	2405	94.9	
1/20/2009	SW	SW7	3.31	3.56	29.88	3.1	136	3.1	1900	40.3	
1/20/2009	SW	SW8	4.74	3.59	14.07	2.2	132	1.5	1835	74.0	
1/20/2009	SW	SW9	5.08	3.73	5.88	4.8	137	2.7	2910	70.2	
1/20/2009	TB	TB	1.64	0.08	5.70	1.9	124	1.2	128	2.1	
2/10/2009	LC	LC irr	12.8	11.1	29.15	5.7	997	3.4	3280	48.9	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
2/10/2009	R	SWR1	8.22		28.7	285	524	1320	4660	314	
2/10/2009	R	SWR2	8.49		13.6	150	326	1795	6010	602	
2/10/2009	SW	SW irr	20.7	5.36	28.04	6.5	121	3.4	2080	80.9	
2/10/2009	SW	SW1	94.7	4.66	173.2	9.0	126	2.8	5010	552	
2/10/2009	SW	SW4	38.8	4.77	33.18	2.4	155	2.7	4350	305	
2/10/2009	SW	SW5	39.5	4.80	82.2	5.5	111	5.0	3810	381	
2/10/2009	SW	SW6	44.8	4.87	44.24	6.7	121	3.1	4210	353	
2/10/2009	TB	TB	0.422		-6.1	1.7	124	0.9	110	4.1	
2/11/2009	R	CRR1							6270	282	
2/11/2009	R	CRR2	22.3		134.92	91.5	561	794	5070	331	
2/11/2009	R	SWR1	11.2			44.4	325	289	1550	53	
2/11/2009	R	SWR2					342		5850	53	
2/18/2009	R	SWR1	3.33		0.0	18.7	417	539	1609	69.8	
2/18/2009	R	SWR2	3.25		0.0	114	404	909	2986	33.5	
3/27/2009	KS	KS 5	16.6	1.03	32.7	22.2	200	7907	16800	109.5	
3/27/2009	KS	KS 6	15.5	1.03	33.2	14.65	243	5985	16480	198.0	
3/27/2009	KS	KS 6 FD	12.6	1.02	27.8	10.79	223	5145	16640	125.0	
3/27/2009	R	KSR1	3.57		12.0	3.33	193	387	1030	29.8	
3/27/2009	R	KSR2	8.1		12.3	2.68	225	405	1364	53.7	
3/27/2009	R	KSR3	3.4		18.5	8.36	243	414	1366	56.9	
3/27/2009	TB	TB	0.983		-0.2	3.06	90	2	18.7	-0.2	
3/27/2009	TH	TH6		0.12	65.1	9.51	96	1336	4260	161.5	
4/4/2009	KS	KS6	50.4	1.23	49.0	5.65	101	2.19	2234	148.5	
4/4/2009	KS	KS6 FD	10.7	1.22	58.6	6.66	94	2.40	2067	109.0	
4/4/2009	TB	TB		0.06	-0.5	3.17	61	5.18	9.85	3.2	
4/8/2009	SW	SW1	9.5	4.43	15.3	4	84	2.3	1314	53.5	
4/8/2009	SW	SW4	3.67	3.48	15.4	2.68	81	1.5	993	55.4	
4/8/2009	SW	SW5	3.78	3.25	11.6	2.68	100	1.5	970	42.1	
4/8/2009	SW	SW5 FD	3.68	3.21	10.0	2.68	81	1.5	1650	40.3	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
4/8/2009	SW	SW7	1.83	3.31	7.6	3.7	99	1.8	1060	26.7	
4/8/2009	SW	SW8	2.07	3.76	12.3	3.55	98	1.8	1426	42.3	
4/8/2009	SW	SW9	1.53	4.12	12.4	4.9	69	2.2	1280	47.9	
4/8/2009	TB	TB	0.097	0.35	-0.2	3.15	70	2.1	15	-0.8	
4/19/2009	KS	KS6	18.0	0.08	-0.3	22.85	166	294	973	53	
4/19/2009	KS	KS6 FD	19.5	0.08	1.6	22.7	169	289	974	53	
4/19/2009	R	KSR1	39.0	0.07	36.3	11.6	461	159	889	55	
4/19/2009	R	KSR1 FD	11.3	0.07	35.5	5.54	447	162	847	47	
4/19/2009	R	KSR2	35.8	0.07	89.6	8.09	554	148	1055	84	
4/19/2009	R	KSR2 FD	39.3	0.06	118.6	8.415	573	148.5	1020	71	
4/19/2009	TH	TH5	6.0	0.08	22.7	11.2	61	28.6	1230	64.65	
4/19/2009	TH	TH5 FD	5.6	0.08	6.9	13.05	50	31.7	1235	65	
4/25/2009	KS	KS1	29.1	0.07	15.7	16.5	33.5	13.7	783	51	
4/25/2009	KS	KS10	46.4	0.07	22.2	22.2	89	9.81	1010	115	
4/25/2009	KS	KS2	39.5	0.07	20.2	24.2	58.7	24.9	866	52	
4/25/2009	KS	KS5	25.3	0.08	11.9	19.4	30.5	8.69	898	62	
4/25/2009	KS	KS6	31.8	0.08	14.6	16.5	58	8.41	891	63	
4/25/2009	KS	KS6FD			17.1	18.95	26.9	7.05	931	64	
4/25/2009	KS	KS9	51.1	0.07	40.7	20.1	38.9	8.17	825	72	
4/25/2009	TB	TB	0.241	0.06	-0.5	3.15	3.56	1.81	72	2	
4/25/2009	TH	TH1	9.11	0.07	8.5	27.3	80.3	52.4	889	63	
4/25/2009	TH	TH4	5.30	0.08	6.9	36.9	86	65	806	136	
4/25/2009	TH	TH5	10.2	0.07	18.9	14.2	105	149	913	73	
4/25/2009	TH	TH5 FD	9.31	0.07	12.2	14.55	91.5	184	896	61	
4/25/2009	TH	TH7	12.2	0.07	6.0	17.2	109	198	947	69	
4/25/2009	TH	TH8	6.00	0.08	4.5	19	132	203	941	62	
4/25/2009	TH	TH9	7.58	0.07	6.2	13.8	108	177	893	53	
5/11/2009	KS	KS5	4.94	0.18	11.8	32.3	171	21.3	2760	175	
5/11/2009	KS	KS6	4.87	0.17	13.9	22.1	160	5.0	2740	150	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
5/11/2009	KS	KS6FD	4.17	0.17	29.9	23.3	156	6.0	2890	170	
5/11/2009	TB	TB	0.302	0.09	-0.7	3.1	120	0.5	163	-3	
5/11/2009	TH	TH4	16.2	0.09	33.5	9.6	297	3.5	3140	272	
5/11/2009	TH	TH5	5.31	0.10	21.7	11.8	135	1.0	2780	168	
5/11/2009	TH	TH5 FD	7.84	0.09	13.2	30.2	139	2.2	2860	174	
5/11/2009	TH	TH7	10.4	0.10	37.3	23.7	139	2.5	7180	239	
9/30/2009	KIL	KIL1	2.13	9.37	11.7	56.0	62.6	3.9	3435	342	
9/30/2009	KIL	KIL2	2.23	9.28	13.0	56.0	59.0	5.1	2957	324	
9/30/2009	KIL	TB	0.333	0.02	ND	3.3	1.4	2.0	18.5	5	
10/8/2009	DW	DW1	15.8	0.06	6.6	574	127	3.93	2112	1040	
10/8/2009	DW	DW2	10.4	0.06	16.6	480	80.1	4.15	1629	990	
10/8/2009	DW	DW3	22.9	0.06	15.0	425	24.4	2.73	1686	914	
10/8/2009	DW	DW4	15.1	0.05	5.2	443	62.9	2.67	1404	866	
10/8/2009	DW	DW4 FD				386	46.5	2.72	1467	930	
10/8/2009	DW	TB	0.31	0.00	ND	2.96	-1.2	3.73	44	-2	
10/8/2009	R	DWR1	3.77	0.02	4.4	28.75	264	86.25	685	75	
10/8/2009	R	DWR1 FD	6.33		ND	13.2	158	36.9	625	68	
10/8/2009	R	DWR2	6.29	0.01	6.8	5.25	82	83.2	397	37	
10/8/2009	R	DWR2 FD	7.43		5.6	4.15	74.2	82.8	366	34	
10/8/2009	R	KSR1	0.975	0.00	1.6	3.92	28.1	62.9	227	10	
10/8/2009	R	KSR1FD	1.42	0.00	ND	5.98	53.3	62.8	248	14	
10/8/2009	R	KSR2	3.26	0.00	5.6	31.7	263	94.1	611	76	
10/8/2009	R	KSR3	1.96	0.00	18.0	5.04	5.14	59.1	199	13	
10/9/2009	KS	KS6	18.5	0.3	16.8	61.35	14.35	0.38	2823	280	
10/9/2009	KS	KS6FD	22.6	0.28	40.8	41.7	23.4	0.794	3532	380	
10/9/2009	KS	KS6FD2	22.9	0.26	52.0	20.6	16.9	1.85	3756	189	
10/10/2009	LG	LG1	8.74	0.05	5.0	12.9	51.3	2.29	1638	80	
10/10/2009	LG	LG2	8.16	0.03	4.4	14.3	77.8	1.3	1707	80	
10/10/2009	LG	LG3	13.2	0.03	19.0	11.7	49.8	0.943	1635	69	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
10/10/2009	LG	LG4	14.1	0.04	22.0	7.68	47.2	3.9	1695	54	
10/10/2009	LG	LG4 FD	14.9	0.04	8.8	9.86	33.3	5.66	1698	49	
10/10/2009	LG	LG5	12.2	0.07	10.2	38.6	30	1.54	2595	224	
10/10/2009	R	KSR1	2.13	0.01	3.4	3.6	261	98.6	448	9.4	
10/10/2009	R	KSR1FD	1.26	0.01	8.8	3.74	282	96.5	512	17	
10/10/2009	R	KSR2	1.02	0.01	37.3	32.1	355	109	633	54	
10/10/2009	R	KSR3	0.854	0.01	14.2	2.84	178	99.7	435	14	
10/10/2009	R	LGR1	2.41	0	ND	4.6	61.95	61.35	185	2.0	
10/10/2009	R	LGR1 FD				4.12	65.8	61.5	167	3.1	
10/10/2009	R	LGR2	1.59	0	ND	3.67	68.05	58.95	170	1.4	
10/10/2009	TB	TB				3.5	-5.89	1.99	73		
10/18/2009	KS	KS6a	11.2	0.22	25.8	23	24.9	0.38	2955	273	
10/18/2009	KS	KS6b	12.2	0.23	46.6	15.8	16.7	0.38	2793	254	
10/18/2009	KS	KS6c	12.5	0.23	49.4	30.8	13.3	0.38	2424	408	
10/18/2009	KS	KS6cFD	16.6	0.23	108.4	29.75	21.9	0.38	2373	279	
10/18/2009	LG	LG1	7.47	0.04	45.6	15.6	48.4	0.38	2640	118	
10/18/2009	LG	LG2	4.05	0.03	19.0	12.45	33.25	0.38	2055	53	
10/18/2009	LG	LG3	3.42	0.03	11.2	14.4	62.3	0.38	3210	63	
10/18/2009	LG	LG4	1.22	0.04	13.0	18.7	26.4	0.38	2073	42	
10/18/2009	LG	LG4 FD	1.66	0.03	25.2	6.49	26.1	0.38	2049	68	
10/18/2009	LG	LG5	4.34	0.08	3.2	32.9	56.3	0.38	2622	172	
10/19/2009	DW	DW1	270	0.08	159.6	105	98.5	8.96	3120	1670	
10/19/2009	DW	DW2	46.5	0.10	39.8	117	60.5	1.97	2382	1210	
10/19/2009	DW	DW2FD	58.3	0.10	55.6	150	103	1.98	2829	1280	
10/19/2009	DW	DW3	64.7	0.05	78.9	161	69.5	1.95	3060	1090	
10/19/2009	DW	DW5	48.3	0.10	44.5	59.6	53.6	0.84	3420	576	
10/19/2009	DW	TB	1.52	0.06	-3.8	0.797	7.42	0.335	51.9	-0.7	
10/19/2009	MB	MB	0.29		-1.0	3.12	-6.84	0.485	189.0	-0.5	
10/23/2009	CR	CR weir	6.5	0.1	5.1	89	22	3	1671	179	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
10/23/2009	CR	CR weir P		0.12	97.7	8	22	7	1484	85	
10/23/2009	CR	CR1	15	0.06	13.9	31	39	2	1614	165	
10/23/2009	CR	CR2	8.28	0.08	16.3	11	24	3	1338	98	
10/23/2009	CR	CR5	5.65	0.14	8.7	48	19	2	2151	226	
10/23/2009	CR	CR5 FD			10.9	30	7	2	2454	376	
10/23/2009	CR	CR9	5.65	0.14	7.3	61	59	4	2504	320	
10/23/2009	R	CRR1	0.527	0.01	-0.3	9	77	75	324	18	
10/23/2009	R	CRR2	0.609	0.01	2.7	4	83	72	219	10	
10/23/2009	R	KSR1	0.48	0.01	1.9	1	32	49	146	9	
10/23/2009	R	KSR2	0.316	0.01	1.7	3	44	52	201	9	
10/23/2009	R	KSR3	0.261	0.00	3.4	3	48	51	201	10	
10/23/2009	TB	TB			0.2	1	7	1	40	1	
10/23/2009	UH	UH1	38.5	0.07	69.2	13	69	36	1752	129	
10/23/2009	UH	UH2	7.56	0.2	28.7	81	20	2453	5650	235	
10/23/2009	UH	UH3	31.6	0.05	23.4	6	17	333	1698	58	
10/23/2009	UH	UH4	44.4	0.05	138.3	7	22	13	2274	148	
10/23/2009	UH	UH4 FD	27.7		148.0	8	37	6	1719	89	
10/23/2009	WD	WD1	40.1	0.14	24.4	19	40	3	1278	97	
10/23/2009	WD	WD11	9.98	0.23	16.4	36	41	2	1404	118	
10/23/2009	WD	WD2	28.1	0.09	24.1	24	53	4	1488	110	
10/23/2009	WD	WD5	34.7	0.15	35.7	24	78	2	1494	108	
10/23/2009	WD	WD5 FD			20.3	22	66	2	1270	109	
10/23/2009	WD	WD9	10.1	0.26	42.6	28	51	2	1435	298	
10/24/2009	TH	TH weir	9.78	0.04	3.3	9	19	35	1623	45	
10/24/2009	TH	TH1	8.38	0.03	3.7	9	26	35	1647	49	
10/24/2009	TH	TH4	3.14	0.02	8.1	35	57	2	3300	248	
10/24/2009	TH	TH5	4.24	0.03	125.9	33	92	73	2019	428	
10/24/2009	TH	TH5 FD	4.82		69.2	26	79	69	1851	161	
10/24/2009	TH	TH7	3.54	0.03	19.0	8	13	4	1416.0	91.0	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
10/24/2009	TH	TH9	6.25	0.03		NS	NS	NS			
11/2/2009	CR	CR weir	5.17	0.09	3.1	7	7	3	1212.0	61.3	
11/2/2009	CR	CR weirP	5.34	0.08	1.7	6	7	3	1404.0	60.8	
11/2/2009	CR	CR1	7.40	0.08	6.1	8	20	4	1473.0	65.3	
11/2/2009	CR	CR2	8.09	0.09	8.6	14	19	5	1644	80.7	
11/2/2009	CR	CR5	4.73	0.09	27.7	12	7	5	1671	97.7	
11/2/2009	CR	CR5 FD	4.66	0.09	72.4	9	38	4	2049	242	
11/2/2009	CR	CR9	6.52	0.09	23.1	6	15	3	1596	86.2	
11/2/2009	TB	TB			-0.4	1	7	4	43	0.6	
11/2/2009	TH	TH weir	12.3	0.04	10.7	8	88	40	1965	57.7	
11/2/2009	TH	TH1	11.2	0.04	8.3	8	87	36	2088	66.2	
11/2/2009	TH	TH4				NS	NS	NS		NS	
11/2/2009	TH	TH5	13.2	0.04	27.4	43	146	5	2469	220	
11/2/2009	TH	TH5 FD	8.67		48.0	43	148	7	2349	213	
11/2/2009	TH	TH7	11.1	0.04	30.8	31	69	4	2343	224	
11/2/2009	TH	TH9				NS	NS	NS			
11/2/2009	WD	WD1	25.1	0.16	13.0	13	16	5	1542	89.7	
11/2/2009	WD	WD11	11.6	0.21	15.7	12	13	4	1335	82.3	
11/2/2009	WD	WD2	25.6	0.20	16.1	13	22	4	1437.0	61.9	
11/2/2009	WD	WD5	49.1	0.16	62.3	23	77	5	1791.0	88.3	
11/2/2009	WD	WD5 FD	59.3		52.9	15	27	5	1974.0	121	
11/2/2009	WD	WD9	14.6	0.18	45.4	34	85	5	1512.0	206	
11/9/2009	KIL	KIL1	6.65	7.69	71	15	36	2	3000	119	
11/9/2009	KIL	KIL2	1.52	7.79	17	12	38	2	2412	78	
11/9/2009	KIL	KIL3	6.31	7.74	35	13	46	3	2829	155	
11/9/2009	KIL	KIL4	1.87	7.78	13	11	25	3	2535	66	
11/9/2009	KIL	KIL4 FD	3.49		12	11	25	2		83	
11/9/2009	KIL	KIL5	1.71	7.79	10	13	43	3	2730	94	
11/9/2009	LC	LC1	7.71	0.55	11	78	36	8	2262	311	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
11/9/2009	LC	LC1 FD	27.1	0.45	38	75	84	12	2745	506	
11/9/2009	LC	LC2	16.7	0.941	15	35	235	21	2628	224	
11/9/2009	LC	LC4	32.7	0.74	138	214	80	9	4185	1040	
11/9/2009	LC	Lcirr	14.8	0.38	6	10	81	38	973	135	
11/9/2009	R	LCR1	2.25		32	174	240	1964	3156	253	
11/9/2009	R	LCR2			27	409	464	1663	4945	556	
11/9/2009	R	LCR3	5.19		63	2	153	1391	3552	226	
11/9/2009	R	WLR2	1.95		6	1	36	336	743	113	
11/9/2009	SW	SW weir	20.9	0.08	117	109	36	10	1674	643	
11/9/2009	SW	SW1	14.8	0.11	50	155	52	6	2085	844	
11/9/2009	SW	SW4	11.5	0.07	10	132	34	10	1389	560	
11/9/2009	SW	SW5	15.1	0.07	30	111	39	10	1503	605	
11/9/2009	SW	SW7	35.1	0.10	41	48	33	8	1548	411	
11/9/2009	SW	SW8	26.7	0.07	40	18	15	7	1100	285	
11/9/2009	SW	SW9	27.1	0.07	40	21	18	10	929	165	
11/9/2009	TB	TB	0.213		0	1	7	3	124	7	
11/16/2009	KIL	KIL1	5.67	9.18	17.4	18	13	5.9	3200	117	
11/16/2009	KIL	KIL2	5.56	9.20	13.5	15	33	5.9	3265	119	
11/16/2009	KIL	KIL3	6.19	9.20	17.9	15	42	5.9	2825	124	
11/16/2009	KIL	KIL4	4.85	9.15	14.1	10	27	5.9	2555	111	
11/16/2009	KIL	KIL5	5.70	9.16	14.1	14	36	5.9	3520	116	
11/16/2009	LC	LC1	58	1.09	51.2	23	64	7	3790	558	
11/16/2009	LC	LC1 FD	74.6	0.89	48.5	12	564	12	4980	464	
11/16/2009	LC	LC2	62.7	1.43	50.3	13	202	9	3400	533	
11/16/2009	LC	LCirr	16.5	0.86	15.1	7	71	47	1170	83	
11/16/2009	R	KILR1			36.9	36	602	1120	3290	345	
11/16/2009	R	KILR2			321.1	832	2488	2055	6700	1420	
11/16/2009	R	LCR1			77.5	813	1708	3290	11700		
11/16/2009	R	LCR2			149.3	776	1682	2870	9160		

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
11/16/2009	R	LCR3			51.2	58	999	1205	7430	608	
11/16/2009	SW	SW weir	35.6	0.09	245.7	44	62	6	2725	963	
11/16/2009	SW	SW1	13.0	0.14	29.4	94	57	6	1840	922	
11/16/2009	SW	SW4	19.5	0.10	9.7	46	31	6	1350	794	
11/16/2009	SW	SW4 FD	21.8		11.0	62	35	6	1600	797	
11/16/2009	SW	SW5	17.7	0.1	6.8	36	26	6	1490	780	
11/16/2009	SW	SW7	14.4	0.12	15.1	22	25	6	1400	495	
11/16/2009	SW	SW8	28.7	0.08	15.5	13	26	6	1075	203	
11/16/2009	SW	SW9	33.9	0.10	31.9	16	19	6	967	234	
11/16/2009	TB	TB	0.173		-0.1	2	14	6	107	5	
11/17/2009	CR	CR weir	5.64	0.12	5	32	49	5.9	1865	119	
11/17/2009	CR	CR1	4.34	0.1	7	15	16	5.9	1750	85	
11/17/2009	CR	CR2	7.15	0.11	9	18	32	5.9	2100	143	
11/17/2009	KS	KS6	13.1	0.08	208	16	30	5.9	3020	439	
11/17/2009	KS	KS6 FD	10.6		69	18	34	5.9	3260	616	
11/17/2009	LG	LG1	5.13	0.04	4	16	50	5.9	2280	61	
11/17/2009	LG	LG2	7.65	0.04	68	13	45	5.9	3380	169	
11/17/2009	LG	LG3	6.64	0.05	135	20	45	5.9	3180	82	
11/17/2009	LG	LG4	6.45	0.03	85	13	57	5.9	3085	83	
11/17/2009	LG	LG5	2.83	0.07	50	24	73	5.9	2330	82	
11/17/2009	TH	TH5	8.47	0.04	171	32	128	5.9	4195	238	
11/17/2009	TH	TH5 FD	28.9		194	42	190	5.9	3480	254	
11/17/2009	WD	WD1	7.04	0.23	10	69	19	5.9	2330	254	
12/9/2009	CR	CR weir	54.8	0.09	13	9.22	8.15	2.54	1815	73	
12/9/2009	CR	CR1	61	0.07	13	8.83	8.15	3.79	980	65	
12/9/2009	CR	CR2	16.7	0.03	14	6.9	9.135	3.69	1230	119	
12/9/2009	DW	DW1	50.3	0.04	35	154	26.1	3.04	1180	552	
12/9/2009	DW	DW3	43.8	0.03	26	50.7	19	3.11	1190	382	
12/9/2009	DW	DW5	54.1	0.04	70	38.1	10.8	2.49	2034	471	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
12/9/2009	KS	KS1 weir	394	0.04	132	7.77	26	8.91	2676	216	
12/9/2009	KS	KS3	249	0.04	53	8.73	16.1	4.45	2394	164	
12/9/2009	KS	KS6	144	0.05	65	9.49	27.9	4.49	2490	289	
12/9/2009	LG	LG WLR	6.26	0.08	32	9.18	42.2	3.02	2082	101	
12/9/2009	LG	LG3	9.81	0.03	104	7.51	10.7	4.17	2334	178	
12/9/2009	LG	LG4	3.32	0.17	50	12.5	10.2	2.83	1180	58	
12/9/2009	LG	LG4 FD	3.85		61	13	64.25	3.05	1150	38	
12/9/2009	TB	TB	0.527		0	17	8.15	3.8	101	5	
12/9/2009	TH	TH weir	24.3	0.04	15	9.96	8.15	5.36	1767	84	
12/9/2009	TH	TH5	12.7	0.05	14	25	30.8	5.53	1872	141	
12/9/2009	TH	TH7	26.2	0.06	17	44.5	106	5.42	3390	355	
12/9/2009	UH	UH ditch	66.1	0.11	20	16.3	19.9	34	1764	116	
12/9/2009	UH	UH1	22.4	0.49	8	30.9	21.5	2388	7710	206	
12/9/2009	UH	UH1 FD	47.5	0.52	25	26.7	26.6	1700	8310	199	
12/9/2009	WD	WD1	74.3	0.24	15	13.4	46.4	2.07	853	87	
12/9/2009	WD	WD2	55.1	0.11	18	11.4	41	2.76	1120	83	
12/9/2009	WD	WD4	39	0.18	32	11.9	23.6	2.85	2721	74	
12/10/2009	HA	HA1	47	0.04	42	10.3	29.5	5.44	2052	256	
12/10/2009	HA	HA2	13.1	0.08	14	13	21.2	3.33	1962	39.25	
12/10/2009	HA	HA3	28.9	0.02	11	6.9	10.925	3.44	1130	56.5	
12/10/2009	HA	HA4	8.2	0.03	7	6.9	12.3	3.74	1070	27.9	
12/11/2009	KIL	KIL3	31.4	7.84	38	16.6	17.5	4.28	2265	109	
12/11/2009	KIL	KIL4	6.21	7.83	33	12.8	17.8	4.61	2805	84	
12/11/2009	LC	LC1	14.1	0.31	32	17.3	15.2	6.39	1995	123	
12/11/2009	LC	LC2	11.4	0.34	4	12.0	8.15	3.23	1974	128	
12/11/2009	LC	LC4	11.5	0.32	9	11.8	8.15	11.50	1983	136	
12/11/2009	SE	SE WLR	226	0.08	18	6.9	10.9	4.67	5500	971	
12/11/2009	SE	SE WLR FD	595		43	6.9	16.5	4.92	4560	587.5	
12/11/2009	SE	SE1	31.6	0.06	4	6.9	9.12	5.43	1860	102	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
12/11/2009	SE	SE3	16.3	0.05	7	6.9	8.15	4.65	2517	138	
12/11/2009	SW	SW weir	13.2	0.12	14	22.0	18.8	4.41	1060	228	
12/11/2009	SW	SW1	39.3	0.18	22	37.4	28.8	4.56	1713	433	
12/11/2009	SW	SW5	13.3	0.14	24	24.3	11.9	4.81	1020	200	
12/11/2009	SW	SW9	55.8	0.13	12	10.7	8.15	9.45	1100	153	
1/27/2010	KIL	Kil1	40.2	9.11	66	14.5	1.6	2.86	3090	175	
1/27/2010	KIL	KIL2	35.6	9.18	69	26	1.6	2.89	3090	188	
1/27/2010	KIL	KIL3	36.1	9.19	83	25.4	1.74	2.8	3330	225	
1/27/2010	LC	LC3	14.4	0.54	13	19.8	15.3	4.72	2619	199	
1/27/2010	LC	LC1	26.5	0.48	15	14	6.8	3.5	2100	146	
1/27/2010	LC	LC2	42.3	0.52	57	16.5	7.86	2.8	2706	318	
1/27/2010	LC	LC2 FD	54.4		50	12.3	6.86	2.88	2331	224	
1/27/2010	SE	SE1	80.2	0.24	135	14.1	6.77	2.32	4455	202	
1/27/2010	SE	SE2	20.2	0.22	31	14.5	117	5.33	4190	225	
1/27/2010	SW	SW weir	22.1	0.18	14	72.9	1.6	4.58	1827	513	
1/27/2010	SW	SW1	12.6	0.25	6	190	39.9	4.49	2331	916	
1/27/2010	SW	SW4	19.9	0.21	10	103	1.6	4.96	1827	612	
1/27/2010	SW	SW5	17.7	0.18	7	43.7	1.6	2.95	1632	486	
1/27/2010	SW	SW9	21	0.15	14	19	11	2.87	1761	187	
1/27/2010	SW	SW9 FD	17.9		18	13.7	12.2	2.43	1509	134	
1/28/2010	CR	CR1	3.26	0.1	11	14.3	2.12	2.58	1377	78.4	
1/28/2010	CR	CR10	5.68	0.13	16	21.8	25.1	2.77	2121	170	
1/28/2010	DW	DW1	27.9	0.04	13	22.6	4.86	4.73	2145	240	
1/28/2010	DW	DW2	20.4	0.03	10	14.4	8.08	2.7	1371	177	
1/28/2010	DW	DW5	21.4	0.02	7	14.7	5.57	2.91	1275	168	
1/28/2010	HA	HA1	22.7	0.03	31	16.1	74.6	6.04	2103	119	
1/28/2010	HA	HA1 FD	16.8		19	14.1	50.8	5.4	1779	158	
1/28/2010	HA	HA3	28.1	0.03	49	14.9	102	6.81	2583	123	
1/28/2010	HA	HA4	35.6	0.03	29	19.7	84.4	6.39	2466	109	

Date	Site	Plot	Turbidity (NTU)	Salinity (ppt)	Suspended Solids (mgL-1)	SRP (µg L-1)	NH4-N (µg L-1)	NO3-N (µg L-1)	TN (µg L-1)	TP (µg L-1)	Note
1/28/2010	KS	KS6	141	0.06	85	22.5	14.3	6.62	2526	182	
1/28/2010	KS	KS6 FD	138		74	21.2	15	6.25	2100	193	
1/28/2010	LG	LG1	5.07	0.04	23	19.8	21	3.5	2115	287	
1/28/2010	LG	LG2	1.94	0.04	29	16.4	20.75	5.77	1953	92.2	
1/28/2010	LG	LG4	1.31	0.1	6	26.3	17.7	3.58	1425	52	
1/28/2010	TB	TB	0.644		-0.4	5.3	3.73	3.34	14.7	8.03	
1/28/2010	TH	TH5	5.4	0.04	27	23.7	48.75	4.53	2889	161	
1/28/2010	TH	TH5 FD	8.8		68	23.8	32.6	7.32	3390	356	
1/28/2010	WD	WD1	889	0.38	684	28.7	70.4	5.48	3540	624	
1/28/2010	WD	WD1 FD	1054	0.39	906	24.8	67.5	4.89	3090	660	

APPENDIX V

Hydrographs for Random Sites

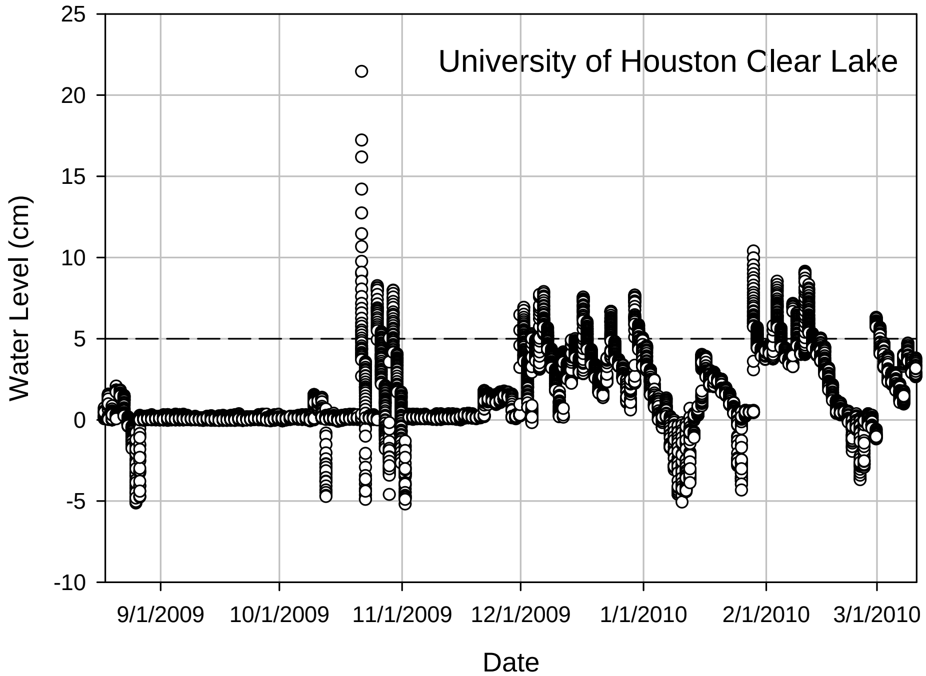

Figure V.1 Hydrograph for University of Houston Clear Lake (UH) showing approximate elevation of spill point.

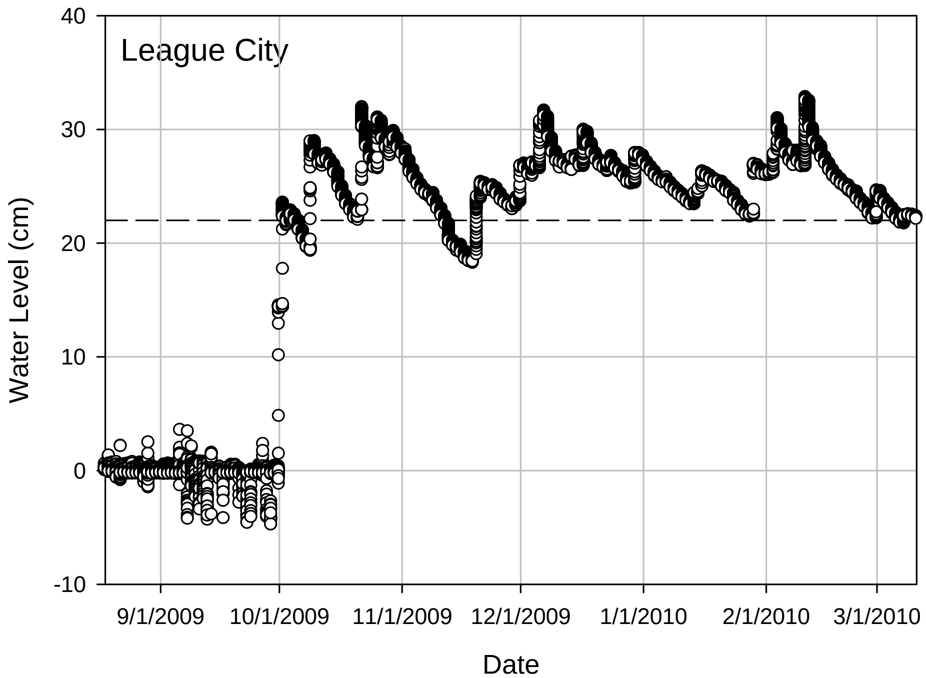

Figure V.2 Hydrograph for League City (LG) showing approximate elevation of spill point.

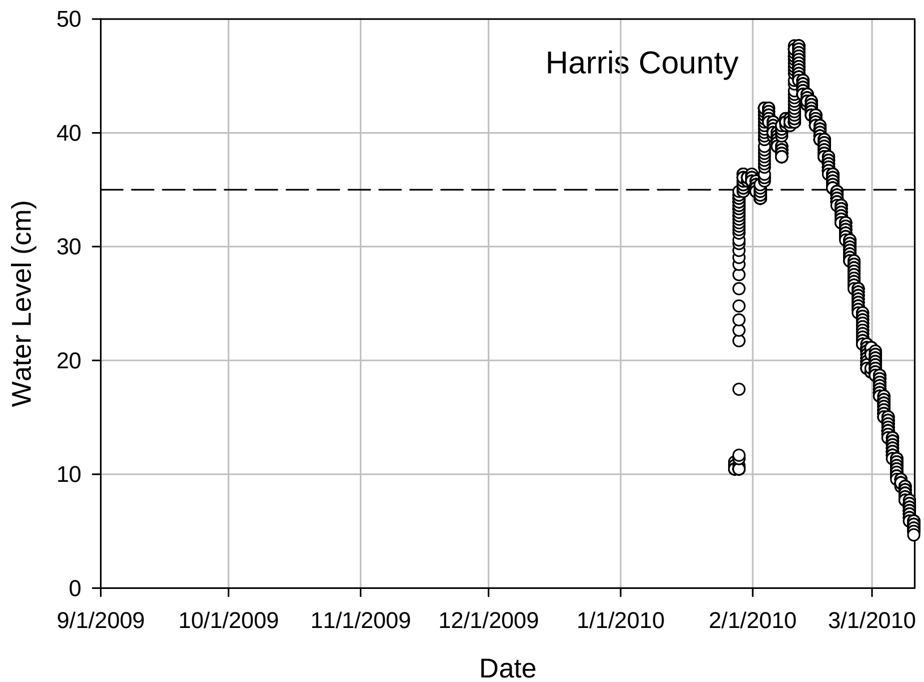

Figure V.3 Hydrograph for Harris County Mitigation Site (HA) showing approximate elevation of spill point.

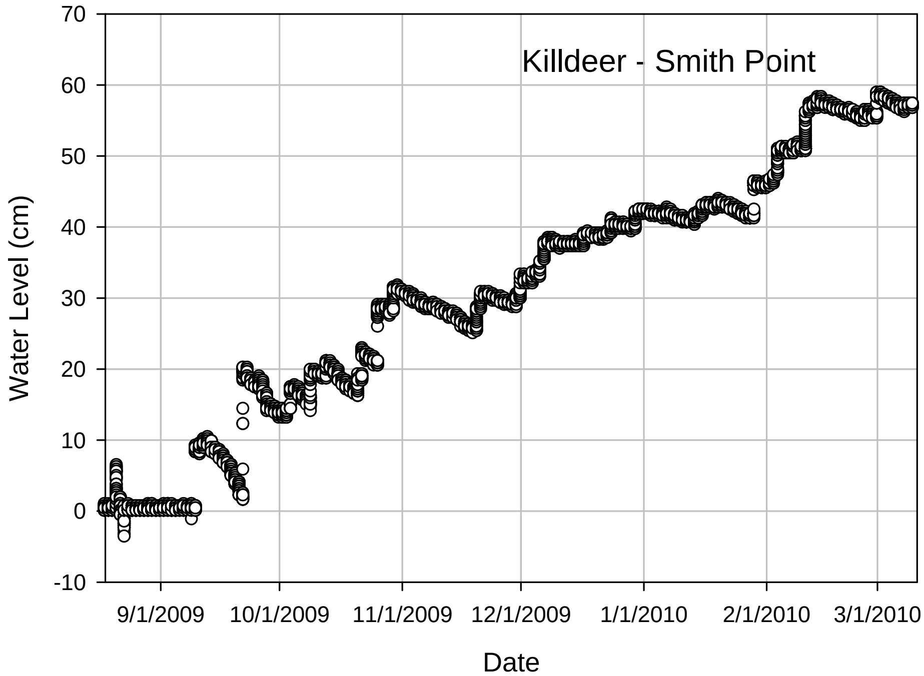

Figure V.4 Hydrograph for Killdeer (KIL) which has not reached its water storage capacity.

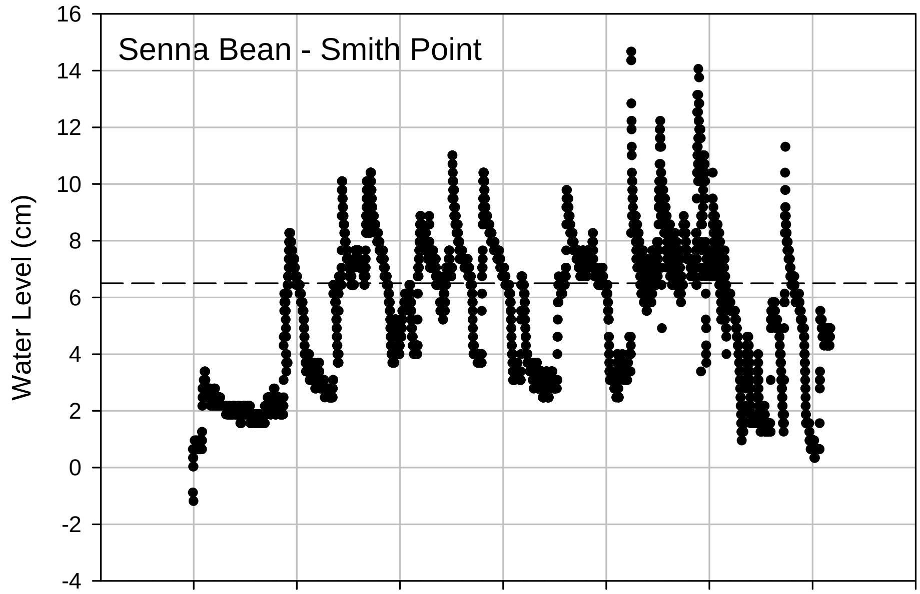

Figure V.5 Hydrograph for Senna Bean Pond (SE) and approximate spill point elevation.

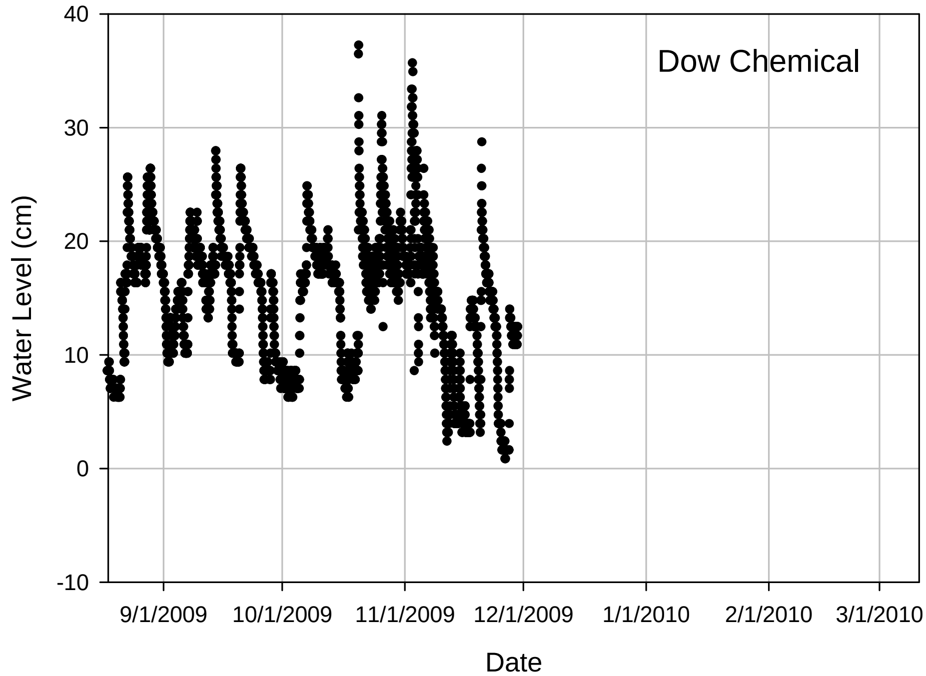

Figure V.6 Hydrograph for Dow Chemical (DW) which has not reached its water storage capacity.

APPENDIX VI

Lidar Elevation Error Analysis

Le Conte

	Field Data	Lidar Data			
		Spot Check Approach		Neighborhood Approach	
Survey Label	Relative Diff (m)	Relative Diff (m)	**Error(m)**	Relative Diff (m)	**Error (m)**
1.3	-0.20	-0.29	0.09	-0.06	0.14
1.9	-0.16	-0.30	0.14	-0.29	0.14
2.1	-0.34	-0.10	0.24	-0.15	0.19
2.2	-0.13	-0.18	0.05	-0.14	0.02
2.9	-0.21	-0.14	0.07	-0.26	0.05
2.10	-0.12	-0.17	0.05	-0.08	0.04
3.1	-0.23	0.02	0.25	-0.17	0.06
3.7	-0.10	-0.26	0.16	-0.18	0.08
4.2	-0.17	-0.17	0.00	-0.36	0.19
4.5	-0.09	-0.16	0.07	-0.20	0.10
4.7	-0.18	0.01	0.19	-0.23	0.05
5.2	-0.21	-0.08	0.13	-0.19	0.02
5.3	-0.19	-0.11	0.08	-0.23	0.04
5.5	-0.23	-0.08	0.15	-0.20	0.03
5.7	-0.14	0.05	0.19	-0.14	0.00
5.8	-0.23	-0.36	0.13	-0.23	0.00
6.6	-0.16	-0.21	0.05	-0.37	0.21
4.3	-0.12	-0.27	0.15	-0.15	0.02
2.6	-0.06	-0.27	0.21	-0.01	0.06
2.7	-0.20	-0.16	0.04	-0.25	0.05
RMSE			**0.14**		**0.10**
Vertical Accuracy (95%) M			**0.27**		**0.19**
Difference +			**9**		**7**
Difference -			**10**		**11**

Sedge Wren

	Field Data	Lidar Data			
		Spot Check Approach		Neighborhood Approach	
Survey Label	Relative Diff (m)	Relative Diff (m)	**Error(m)**	Relative Diff (m)	**Error (m)**
1.1	-------	-------	-------	-------	-------
1.4	0.07	-0.06	0.13	-0.01	0.08
1.6	0.06	-0.07	0.13	-0.07	0.13
1.11	-------	-------	-------	-------	-------
1.12	-0.25	-0.03	0.22	0.02	0.27
1.13	0.04	0.04	0.00	0.01	0.03
1.17	-0.01	-0.11	0.10	-0.13	0.12
1.18	0.02	-0.13	0.15	-0.14	0.16
1.19	0.05	-0.11	0.16	-0.14	0.19
1.24	-0.22	-0.01	0.21	-0.04	0.18
1.26	0.03	0.10	0.07	0.04	0.01
1.27	-0.01	0.16	0.17	0.12	0.13
2.19	0.05	-0.12	0.17	-0.13	0.18
2.20	0.02	-0.11	0.13	-0.15	0.17
2.21	-0.01	-0.10	0.09	-0.12	0.11
2.23	-0.01	-0.14	0.13	-0.18	0.17
2.26	-0.07	-0.04	0.03	-0.06	0.01
3.24	0.04	-0.07	0.11	-0.13	0.17
4.19	0.02	-0.08	0.10	-0.13	0.15
4.20	0.01	0.01	0.00	-0.03	0.04
4.23	-0.07	-0.06	0.01	-0.11	0.04
4.24	0.04	-0.04	0.08	-0.10	0.14
RMSE (m)			**0.13**		**0.14**
Vertical Accuracy (m) (95%)			**0.25**		**0.28**
Difference +			**6**		**5**
Difference -			**13**		**15**

Kite Site

	Field Data	Lidar Data			
		Spot Check Approach		Neighborhood Approach	
Survey Label	Relative Diff (m)	Relative Diff (m)	**Error(m)**	Relative Diff (m)	**Error (m)**
2.2	-0.05	-0.06	0.01	0	0.05
2.3	-0.11	-0.08	0.03	0.1	0.21
2.4	0.05	-0.04	0.09	0.08	0.03
3.1	-0.25	-0.18	0.07	-0.11	0.14
3.2	-0.02	-0.03	0.01	0.06	0.08
3.6	-0.04	0.02	0.06	-0.03	0.01
3.7	-0.05	0.09	0.14	-0.01	0.04
4.6	-0.05	0.03	0.08	0.00	0.05
8.5.4	-0.05	-0.17	0.12	-0.23	0.18
8.5.5	-0.14	-0.51	0.37	-0.37	0.23
9.5.3	0.07	-0.19	0.26	-0.15	0.22
10.2	-0.03	-0.20	0.17	-0.05	0.02
10.3	-0.17	-0.18	0.01	-0.03	0.14
10.4	-0.15	-0.48	0.33	-0.40	0.25
12	0.00	0.07	0.07	0.02	0.02
12.3	0.04	0.17	0.13	0.07	0.03
12.4	0.03	0.06	0.03	0.07	0.04
13	-0.01	-0.21	0.20	-0.25	0.24
14	0.01	0.09	0.08	-0.02	0.03
14.1	0.02	-0.07	0.09	-0.10	0.12
RMSE (m)			**0.15**		**0.14**
Difference +			**15**		**13**
Difference -			**5**		**7**

***Not normally distributed**