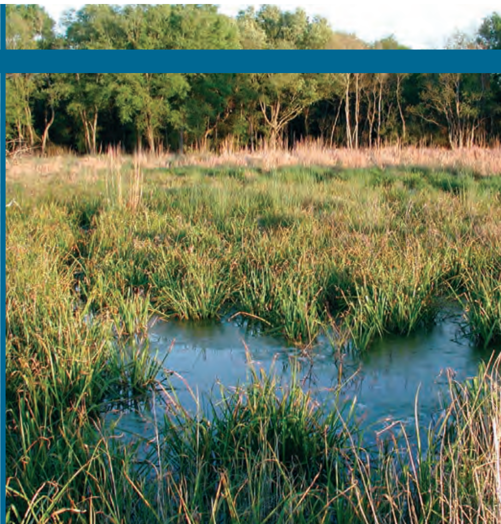

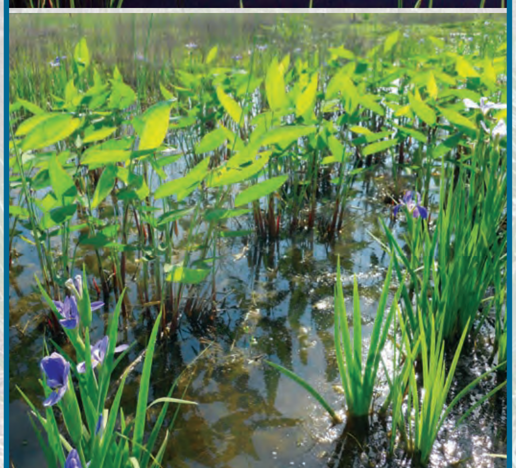


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Houston-Area Freshwater Wetland Loss, 1992–2010

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Unless otherwise noted, all photographs were taken by John S. Jacob.

Summary

Since 1992, the Greater Houston Metropolitan Area has lost at least 5.5 percent of its natural freshwater wetlands. Although a 5 percent loss in 20 years is unsustainable by any accounting, some areas experienced loss at rates that are catastrophic. For example, Harris County lost almost 30 percent of its freshwater wetlands, including most prominently the iconic prairie pothole-pimple mound complexes.

The eight-county Houston area is one of the fastest growing in the country. Metropolitan growth means development, which means the loss of wetlands. When wetlands are lost, with them go important ecological services for both nature and people.

Until now we have not had a clear picture of just how many acres of wetlands we might be losing. We report here our attempt to quantify freshwater, non-tidal wetland loss from 1992 to 2010 in the greater Houston region.

We developed a simple method for quickly estimating natural freshwater wetland loss. The method, a conservative approach that provides a minimal loss estimate that policy makers can rely on, compares National Wetland Inventory (NWI) maps developed in 1992–93 to more recent digital aerial photography.

The study found that most of the losses occurred in rapidly growing Harris, Montgomery, Brazoria, and Fort Bend Counties. The greatest loss occurred in Harris County: 15,855 acres (29 percent) from 1992 to 2010. This acreage loss is more than double that of the other seven counties combined. Losses in other rapidly growing counties, however, are on a track to equal that of Harris County.

Overall, the study reveals that development is seriously affecting the freshwater wetland resources in the Greater Houston Metro Area. These freshwater wetlands are the headwaters for virtually all of the water bodies feeding into Galveston Bay. Continued loss at the rates documented here will very likely have grave implications for the long-term health of the Galveston Bay System because it is losing the principal means of cleaning the polluted runoff that enters the bay.

A three-page synopsis on this study, *More Flooding, Fewer Fish: Freshwater Wetland Loss in the Houston Area, 1992–2010,* is available from the Texas A&M AgriLife Service Bookstore at https://www.agrilifebookstore.org/.

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Introduction

The population of the Greater Houston Metropolitan Area is skyrocketing, particularly in Houston and in the counties nearest to it[1]. Between 1990 and 2010, it added more than 2 million[2] inhabitants, and 3.5 million to 4 million more people are forecast for the next 20 to 30 years[3]. This growth has obvious impacts on wetland resources.

The U.S. Environmental Protection Agency (EPA) defines wetlands as "areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including during the growing season."[4] Wetlands are "transition zones"[5] that are neither land nor water but have characteristics of both as well as properties of neither (Fig. 1).

A wetland area need not be wet all year long—as few as 2 or 3 consecutive weeks of wetness can qualify an area as a wetland. However, most wetlands in the Houston area are wet for substantially longer periods.

Wetlands provide many functions, including detaining stormwater, controlling erosion, storing and cleansing water, and providing places for recreation for people and habitat for wildlife. When wetlands are destroyed, these services are also lost.

It is possible, however, for urban growth and wetlands to coexist. Among the strategies for protecting wetlands is to change the way that cities and their outlying regions are developed. But to take action, residents, businesses, and policy makers need reliable information on the extent of the problem. How many wetlands are actually being lost? Is this decrease significant? Where are the remaining wetlands that could be protected?

The Texas Coastal Watershed Program, a joint program of Texas A&M AgriLife Extension and Texas Sea Grant College Program devised a method to gather semi-quantitative data about wetland loss in the eight-county region surrounding Houston. While somewhat imprecise because of the limitations of the source data, this method is more than sufficiently reliable as to be actionable.

Study area

The study area consists of the eight counties that make up the Greater Houston Metropolitan Area: Brazoria, Chambers, Fort Bend, Galveston, Harris, Waller, Montgomery, and Liberty Counties (Fig. 2).

Figure 1: A coastal prairie pothole wetland in southeast Harris County (Source: Cliff Meinhardt)

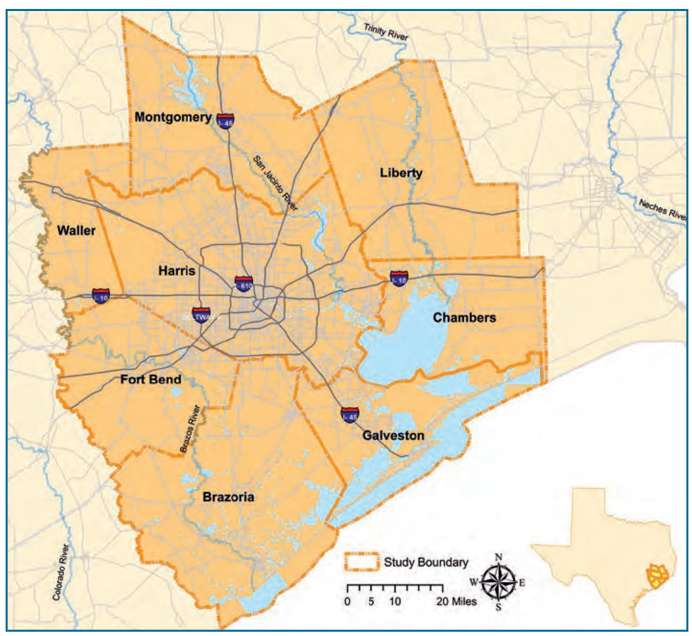

Figure 2: Project study area: the Greater Houston Metropolitan Area

[1] H-GAC-2035, August 2006, *2035 Regional Growth Forecast*
[2] US Census Bureau, March 2013, *State and County Quick Facts*
[3] H-GAC-2035, Aug 2006, *2035 Regional Growth Forecast*
[4] U.S. Environmental Protection Agency. 1995. *America's Wetlands: Our Vital Link Between Land and Water.* EPA843-K-95-001
[5] Moulton, D.W, and J. S. Jacob. 2000, *Texas Coastal Wetlands Guidebook*

Types of freshwater wetlands in the study area

Wetlands differ in hydrology, which is the movement, distribution, and quality of water. Four types of natural freshwater wetlands occur in the study area: barrier island interior wetlands, coastal flatwoods wetlands, prairie pothole wetlands, and riverine forested wetlands. For a map of where the different types of wetlands occur in this region, see the *Texas Coastal Wetlands Guidebook* by D. W. Moulton and J. S. Jacob.

Barrier island interior wetlands (Fig. 3) are fed by a combination of groundwater and runoff from nearby dunes. The water seeps easily through the sandy dunes and generally surfaces in the swales between the dunes. Although water rarely ponds in many of these swales, the groundwater remains just under the surface for extended periods.

Coastal flatwoods wetlands receive water primarily from local rainfall that runs off or seeps into the soil very slowly. They are typically wet in winter and early spring. The soil is saturated, and shallow water stands in many places.

Prairie pothole wetlands (freshwater marshes) receive water by direct rainfall and by runoff from surrounding flats. Some prairie potholes may have groundwater as a water source, particularly in sandy areas such as barrier islands.

Water movement and storage in pothole complexes are very diverse, with distinct differences occurring within just a few feet. Deeper potholes can remain saturated for more than 6 months of the year; nearby pimple mounds may be nearly semi-arid for most of the year. This hydrologic complexity engenders high habitat and biological diversity.

Riverine forested wetlands receive water primarily from overbank river flooding. Flooding occurs in most years and persists for at least several weeks at a time. Only larger rivers have watersheds big enough to maintain this kind of flooding. In most bottomland hardwood forests, flooding lasts for a few weeks to several months.

Swamps, on the other hand, stay flooded much longer; they may dry out only occasionally. Swamp forests occur in sloughs and other depressed areas of floodplains and occasionally in low floodplain terraces, where the dominant source of water may be runoff from rainfall.

Figure 3: Barrier island interior wetlands (Source: Earl Nottingham, Texas Parks and Wildlife Department)

Figure 4: Coastal flatwoods wetlands (Source: Andrew Sipocz, TPWD)

Figure 5: Prairie pothole with encroaching development

Figure 6: Riverine forested wetlands, Houston

Methodology

The tradeoff: sampling versus complete inventory

To estimate the amount of wetland loss, we established a baseline on which to compare subsequent trends. The National Wetland Inventory (NWI), conducted periodically by the U.S. Fish and Wildlife Service (wetlands.fws.gov), produces maps that could serve as a potential baseline in many parts of the country.

To determine whether the NWI maps were accurate for the Houston area, we compared them to maps we created using 1995 color infrared (CIR) aerial photographs supplied by the Texas Natural Resource Information System. We used a random number generator to select three USGS quarter-quadrangles from throughout the study area[6], and an experienced wetland mapper (the senior author) interpreted the photographs of these quarter-quadrangles.

Because the 1995 photographs were taken in winter under wet to normal conditions, the wetlands were relatively distinct. Winter photographs not only capture wetlands during their normal period of maximum inundation, but they also plainly distinguish between the typically deciduous nature of wetland vegetation and the often evergreen nature of upland vegetation in the Houston region.

We did not have access to the original photography used by the NWI project. No ground-truthing (confirming information from photographs by gathering data in the field) took place as part of this audit.

On average, this method found 50 to 75 percent more wetlands than what the NWI mapped on the same quarter quadrangles. No areas that the NWI mapped as wetlands had anything other than a wetland signature on the aerial photography. This finding confirmed our field experience of many years, and that of others, that the NWI underestimates the wetlands on the ground, and that very few if any NWI maps indicate wetlands where wetland signatures were lacking on the aerial photos.

The digital aerial photography had much higher resolution than that available to the NWI staff in 1992. Also, the later photographs were taken in a wetter year, when more wetlands would be distinguishable. Even under the best of circumstances, we would not expect the NWI to have matched the

6 This assessment did not examine areas of "farmed wetlands" (PEMf). This is a problem class for this area as discussed below.

accuracy of our later efforts. The important point is that the NWI maps identify precisely the wetlands that were observable using the photography available at the time. There were very few false positives in the NWI maps[7].

The NWI survey for the Greater Houston Metro Area thus constitutes an acceptable baseline for assessing wetland loss. The NWI grossly underestimates the true amount of wetlands on the ground, but there is a very high chance (we estimate more than 95 percent) that the NWI wetlands mapped are indeed wetlands.

Whether this sample is statistically representative in every way we cannot say, but we have no basis to assume that it is not representative. Without question, it constitutes a minimal estimate of the total amount of wetlands at the time. An analysis of loss of NWI wetlands thus gives policy makers a reliable bracket around the true value of wetland loss.

To identify changes in land use, we simply overlaid the digitized NWI lines from the latest year available at the time of this study (generally 1992 or 1993)[8] onto the latest digital aerial photography available (2010) and determined the amount of wetlands that had been lost to development. This procedure was accomplished using ArcGIS Desktop 10.1. For a detailed description of the GIS methodology, see Appendix B.

We were extremely cautious in identifying development in the aerial photos. The obvious cases of strip malls, residential developments, and the like posed no interpretive challenge. More difficult were vegetation removal and/or excavation/fill without further development. Only in cases of obvious wetland destruction did we classify a wetland as filled.

Our assessment of wetland loss is thus a very conservative assessment. The loss estimates reported here are not maximal, but minimal.

We subdivided development into the following categories:

- **Residential:** Generally homes and other residences; some light commercial and roads
- **Commercial/industrial:** Malls, strip malls, industrial and commercial facilities
- **Fill:** Undefined fill; obvious removal of vegetation; excavation
- **Water:** Wetlands replaced by an open water feature, such as a pond or lake
- **Mining:** Mining activity, generally gravel

Figures 7 through 11 depict the editing process and examples of each development type.

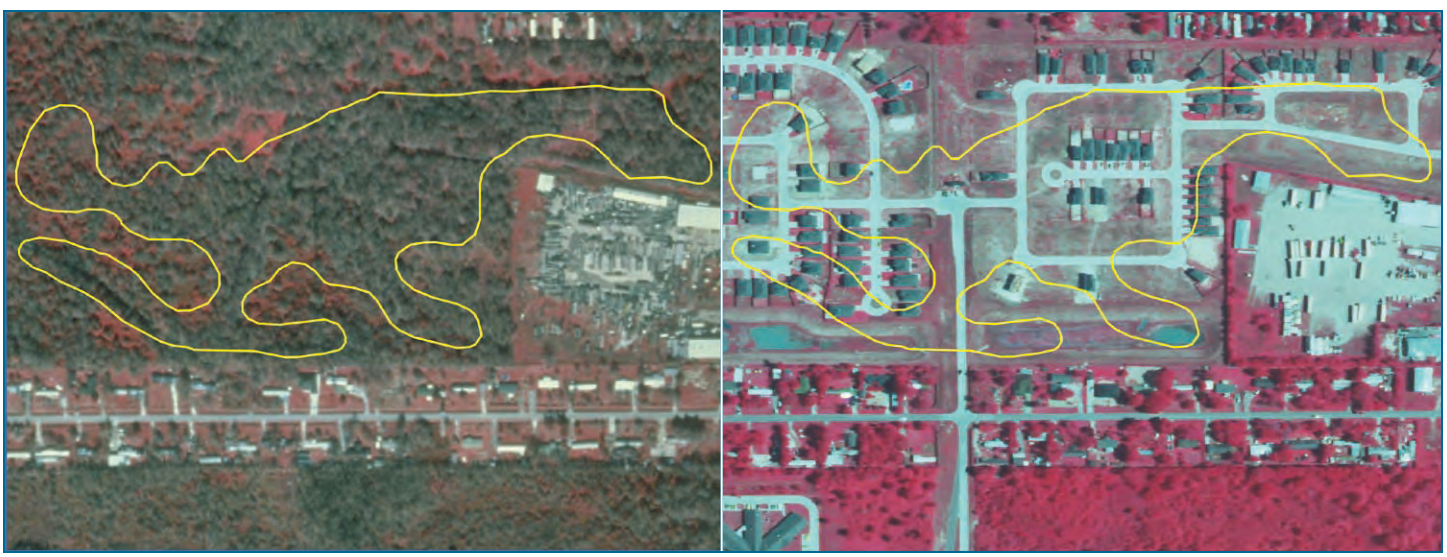

Figure 7: Left: 1995 aerial photo with NWI polygon (TNRIS color photograph). Right: 2010 aerial photo of the same area with the same superimposed NWI polygon, with obvious new development. (TNRIS CIR photography)

[7] Except for the special case of the palustrine farmed wetland class discussed in "Artificial and farmd wetland" on page 7.

[8] The NWI has recently been updated for Galveston County and the rest of the circum-Galveston Bay quadrangles. This report uses the 1992–93 lines as the baseline for wetland loss.

Figure 8: As above, with industrial development

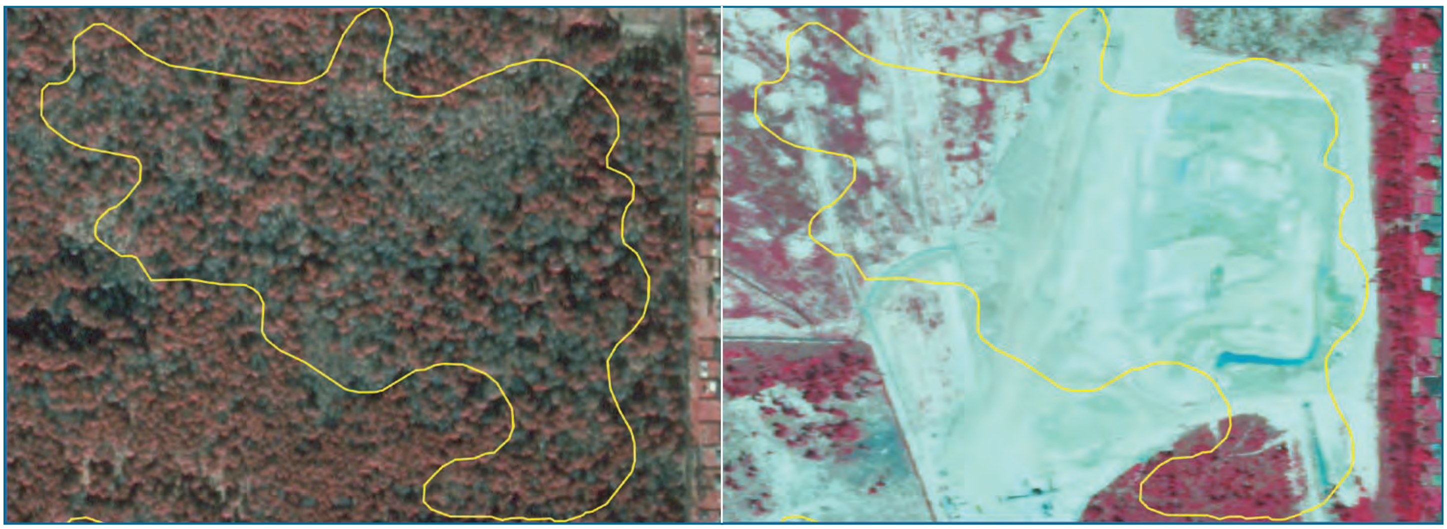

Figure 9: As above, with fill activity but no additional development beyond initial clearing and excavation. Note the small area of wetland not destroyed in the lower right of the photo on the right. This remaining area is obviously negatively impacted, but for the purposes of this report it was not considered a wetland loss.

Figure 10: As above, with land use changed to a water feature, which does not function as a wetland, and has nowhere near the ecological value of a wetland

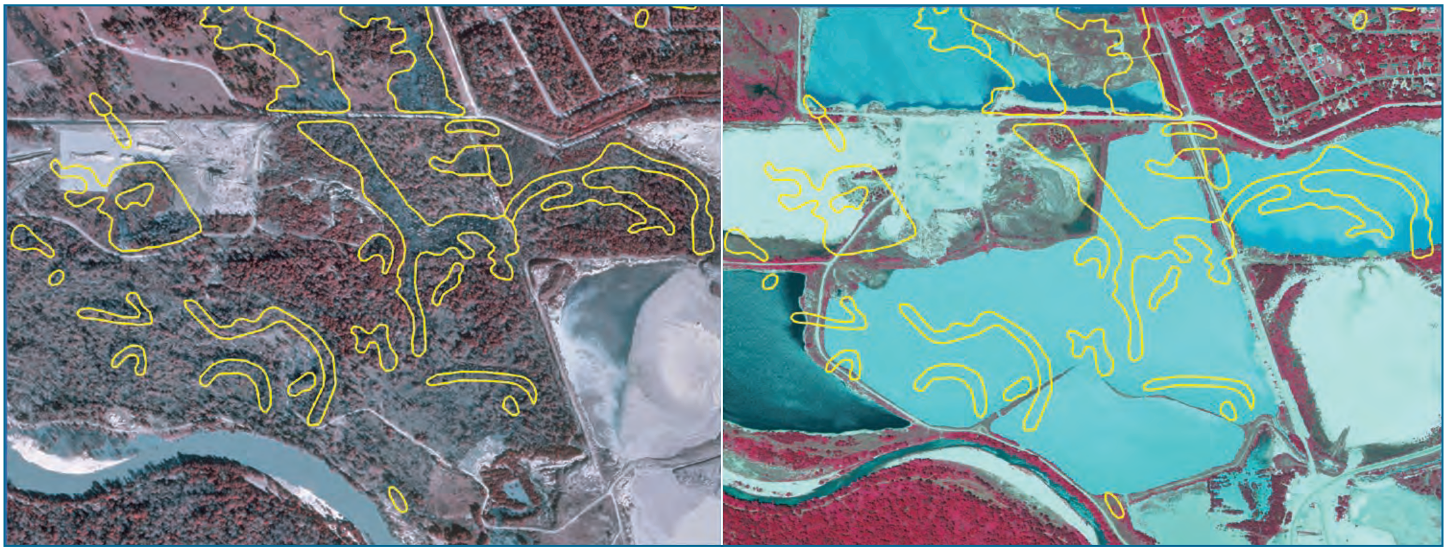

Figure 11: As above, mining activity. Note that some 1993 wetlands had already been lost to mining in 1996.

Cowardin classification

The Cowardin wetland classification is commonly used throughout the United States and is the system used by the NWI. It is a hierarchical system based primarily on hydrology and vegetation, and secondarily on the nature of the bottom or substrate.

This report focuses only on the palustrine (non-tidal inland freshwater wetlands) wetland system, the highest unit in the Cowardin scheme.

Riverine wetlands are limited to river channels; they comprise a tiny percentage of the study area. The lacustrine, or lake, system is also of relatively small percentage of the study area. Most freshwater wetlands in the study area are of the palustrine system (P). Its class taxa, based mainly on vegetation, are given in Table 1. The only significant palustrine wetlands in the study area are palustrine emergent, palustrine forested, and palustrine scrub shrub (Table 1).

Subclasses are based on hydrology, water chemistry, and the nature and persistence of vegetation. Subclasses are indicated by a series of letters or numbers after the class level. For example, PFO2T refers to a palustrine forested needle-leaved deciduous tidally influenced wetland (such as a cypress swamp near the mouth of a river).

The entire Cowardin classification is reproduced in Appendix D.

Table 1: Palustrine wetland classes

Class	Class ID	Name	Description
Palustrine aquatic bed	PAB	Aquatic bottom	Submergent vegetation
Palustrine emergent	PEM	Emergent	Herbaceous vegetation
Palustrine forested	PFO	Forested	Wooded areas
Palustrine scrub shrub	PSS	Scrub-shrub	Usually secondary growth (such as Chinese tallow tree or shrubby vegetation)
Palustrine unconsolidated bottom	PUB	Unconsolidated bottom	Very little/no vegetation, flooded wetlands subject to wave and current action
Palustrine unconsolidated shore	PUS	Unconsolidated shore	Sparse vegetation, flooded shoreline wetlands, sandy or muddy

Artificial and farmed wetlands

The NWI maps show artificial as well as natural wetlands. This study focuses only on natural wetlands. We excluded diked, excavated, spoil, and artificial substrate wetlands. The excluded wetlands are for the most part the result of human construction.

Farmed wetlands are of special interest. The NWI used the farmed prairie wetland category (PEMf in the NWI; see Appendix D) to map both natural wetlands that were farmed as well as large areas that were diked off for rice or for temporary waterfowl habitat. Figure 12 shows the location of farmed wetlands (PEMf) in northwest Harris County, and

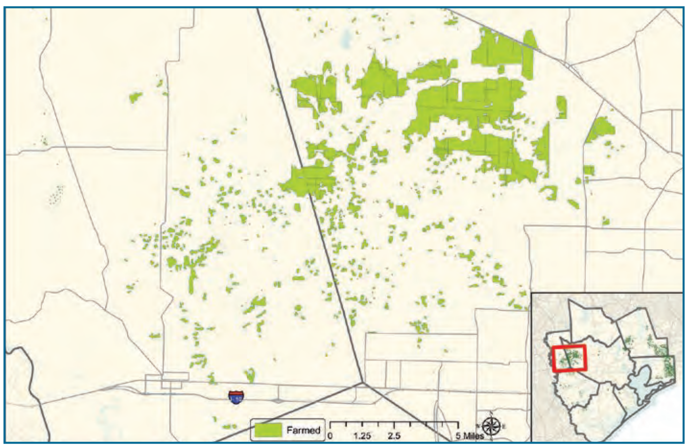

Figure 12: NWI delineations of farmed wetlands (PEMf) in northwest Harris County

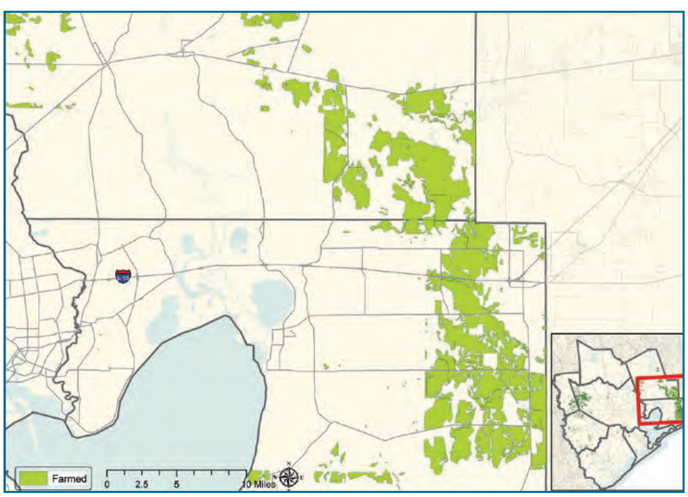

Figure 13: NWI delineations of farmed wetlands (PEMf) covering up half of Chambers County and parts of Liberty County

Figure 13 shows some farmed wetland areas in Chambers and Liberty Counties.

The farmed wetland areas form very large PEMf delineations in these areas. They were likely flooded at the time the NWI mapping occurred. When the 1992 NWI team mapped these areas, they might have been either rice fields or fallow-year inundations for attracting waterfowl. They are clearly much larger than the natural prairie potholes in the area.

These large areas should have been categorized as diked/impounded instead of farmed because the entire area is clearly not a permanent wetland.

The PEMf taxon covers large areas (about 173,787 acres, or 51 percent of the total PEM coverage of the study area; see the insets of Figs. 12 and 13). Clearly, bona fide wetlands are in each large PEMf polygon, but our project did not measure them.

Figure 14, taken from Google Earth, shows a large farmed wetland delineation on a 2010 aerial photograph with relatively few pothole wetlands, as compared to the larger delineation. The actual wetlands in that polygon appear to be less than 20 percent of the area. Because this farmed wetlands class vastly overmaps bona-fide wetlands, we simply removed this category from our analysis[9].

Our analysis did include farmed wetlands that were marked with the special modifier "d" (such as PEMd) for drained wetlands. Most of these drains were temporary, such as for draining rice fields. In these cases, the wetland depressions remain intact, as does their long-term hydrology.

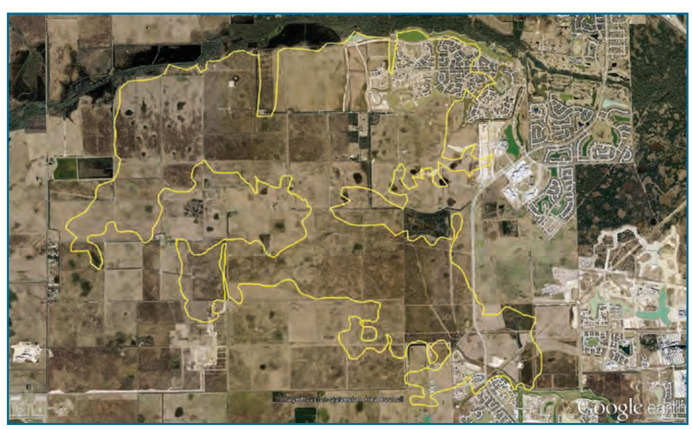

Figure 14: The yellow polygon is a PEMf delineation from the 1992 NWI data. This PEMf polygon is clearly overextended. Only the small dark areas (prairie potholes) are bona fide wetlands. 2010 Google Earth photo.

[9] The issue with PEMf wetlands should not be confused with the general underestimation of natural wetlands found in the NWI.

Logging

Logging occurs in some of the forested wetlands of the study area, mostly in Liberty and Chambers Counties and parts of Montgomery County. However, unless fill occurs, there is no reason to assume that logging destroys wetlands. For example, although some soil was disturbed as the result of logging that left the denuded or treeless area in Figure 15(a), the regrowth seen in the same spot in Figure 15(b) strongly suggests the absence of fill activity or major soil disturbance.

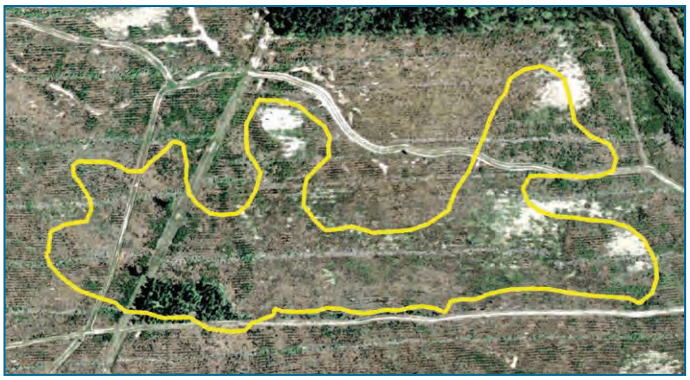

Figure 15(a): 1993 NWI PFO (Palustrine forested) polygon superimposed on a 2006 Image from Google Earth. The area has clearly been logged. But is this a wetland loss?

We did not categorize any of the areas showing extensive tree harvest (Fig.15a) as wetland losses, unless they were converted to development or were very obviously filled.

Figure 15(b): The same 1993 NWI PFO polygon in Fig. 15(a) superimposed on a 2012 aerial image from Google Earth. Trees are clearly growing, and the linear rows of planted trees are evident in the photo. A classification by means of digital algorithms, such as the one that the NOAA Coastal Change Analysis Program (C-CAP) uses, would have labeled the 2006 image a land use change, which clearly it is not, at least not on a 10–20 year time scale of tree growth. The 2006 image merely captures the area soon after a timber harvest. Thus it would be improper to count this polygon as a filled or lost wetland. That this wetland has been manipulated by harvest of the trees there is little doubt. But without intensive ground truthing, we cannot label the tree harvest as a wetland loss and still be consistent with the conservative approach we have taken in this project.

Results

The study found that by 2010, the Greater Houston Metro Area lost about 5.5 percent, or 24,600 of the 447,949 acres of natural freshwater wetlands mapped by NWI in 1992–93 (Table 2, Fig. 16).

Most of the losses occurred in rapidly growing Harris, Montgomery, Brazoria, and Fort Bend Counties. The greatest losses by far were in Harris County (Fig. 17), where almost 30 percent of the freshwater wetlands existing in 1992 have disappeared. Harris County lost 15,855 acres of wetlands (Fig. 18), almost twice the amount of the other seven counties combined (Fig. 16). Because these acreage figures are a minimal estimate, the actual number of acres lost could be well over 45,000 (see discussion above on NWI accuracy under "Methodology").

Table 2: Wetland loss by county

County	Total acres	Loss in acres	Loss as percentage of county wetlands
Brazoria	88,838	855	0.9%
Chambers	58,041	255	0.4%
Fort Bend	24,002	1,442	6%
Galveston	14,316	1,066	7.4%
Harris	54,479	15,853	29.1%
Liberty	165,987	1,951	1.2%
Montgomery	32,498	3,093	9.5%
Waller	9,788	83	0.8%
Total (all counties)	**447,949**	**24,600**	**5.5%**

The area of greatest loss in the study was western Harris County, where:

- The White Oak Bayou watershed lost 71 percent of the wetlands that were present in 1992 (Fig. 19)
- The Cypress Creek watershed lost 29 percent (Fig. 20)
- The Spring Creek watershed, 11 percent (Fig. 21)

Because White Oak Bayou is closer to the center of Houston, it would be expected to have more development. However, if current trends continue, wetland loss in the Cypress Creek and Spring Creek watersheds will soon equal that of White Oak Bayou, with the potential for consequent increases in flooding and reduction of water quality in the creeks.

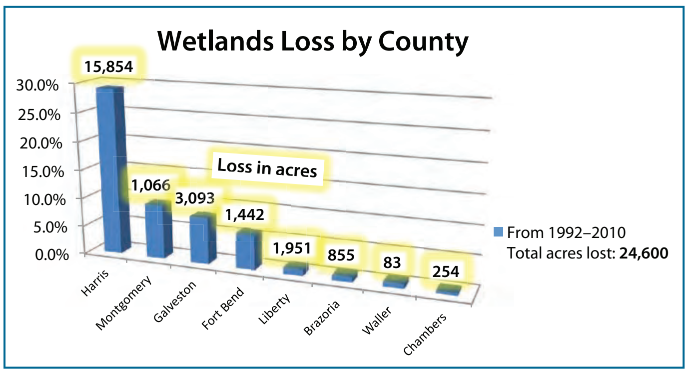

Figure 16: Graph of wetland loss by county, with percentage loss within each county

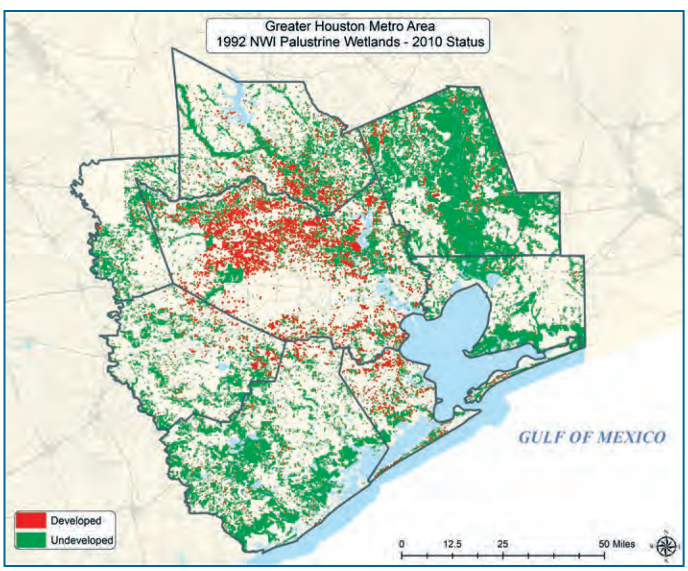

Figure 17: Total natural freshwater wetland loss in the Greater Houston Metro Area. Green areas are undeveloped wetlands. Red areas are developed or filled wetlands as of 2010.

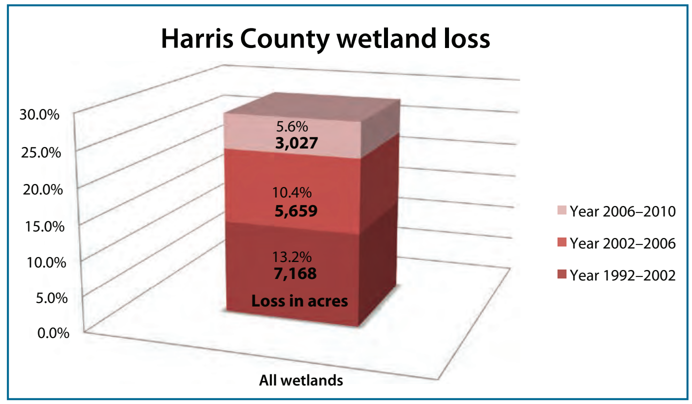

Figure 18: Harris County wetland loss in acreage and percentage by each period

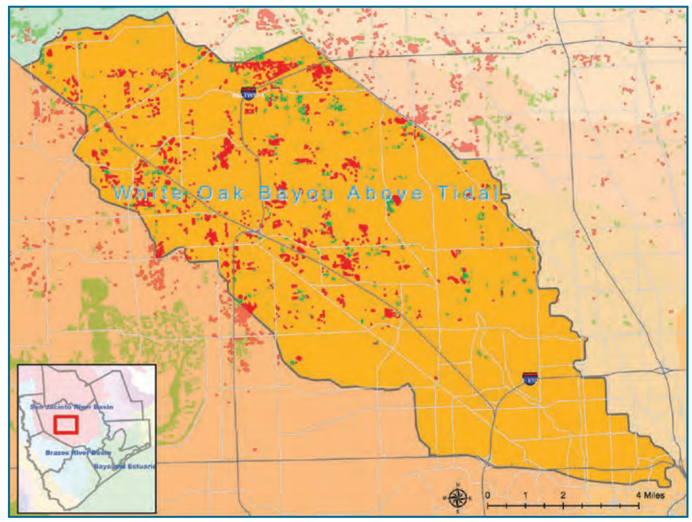

Figure 19: The White Oak Bayou watershed, which lost 71 percent of its wetlands (shown in red) from 1992 to 2010

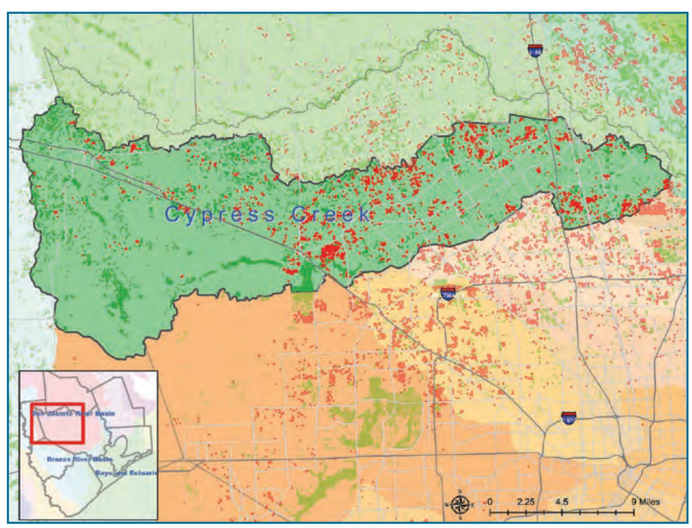

Figure 20: The Cypress Creek watershed, which lost 29 percent of its wetlands (shown in red) from 1992 to 2010

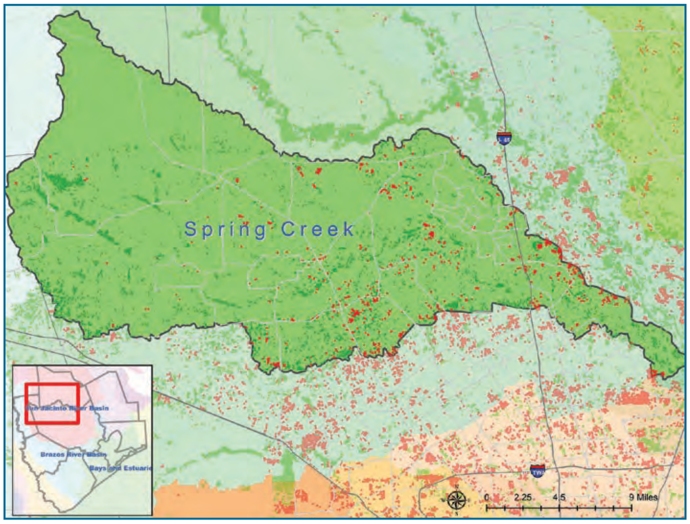

Figure 21: The Spring Creek watershed, which lost 11 percent of its wetlands (shown in red) from 1992 to 2010

Table 3: Wetland loss by type of destruction

Wetland loss type	NWI lost (acres)	NWI lost (%)
Residential (R)	12,805	52%
Commercial/ industrial (I)	2,989	12%
Filled (F)	6,622	27%
Water (W)	828	3.4%
Mined (M)	1,354	5.5%

Table 4: Total NWI wetland loss by wetland type, Greater Houston Metro Area

System-Class	Description	Total acres	Acres lost	% wetland loss
PAB	Palustrine aquatic bed	1,857	29	1.5%
PEM	Palustrine emergent	141,678	6,168	4.3%
PFO	Palustrine forested	276,695	15,562	5.6%
PSS	Palustrine scrub-shrub	23,239	2,751	11.8%
PUB	Palustrine unconsolidated bottom	4,310	75	1.7%
PUS	Palustrine unconsolidated shore	170	15	8.9%
Total		**447,949**	**24,600**	**5.5%**

We performed some intermediate assessments for Harris County. Figure 17 shows loss of wetlands in Harris County over three separate periods in the past 18 years. On a per-year basis, the period from 2002 to 2006 had the highest rate of loss, 1,400 acres, or about 2.6 percent per year. The other two periods had similar rates of loss, 600 to 700 acres, or about 1.3 percent per year. The 2006 to 2010 period included the beginning of the Great Recession, such that the number of acres lost in the first 2 years of that period was probably similar to that of the 2002–06 period.

The next highest wetland losses were 9.5 percent in Montgomery County and 7.4 percent in Galveston County. As the economy recovers from the Great Recession of 2008, losses in the high-growth Houston metro counties will probably equal those of Harris County.

Of the total losses for the entire study area, 64 percent could be attributed to completed development projects (Table 3), and 27 percent were wetlands that had been filled and destroyed but had not been developed. Figure 21 shows a map of the relative loss of the total natural freshwater wetlands across the entire study area, and Table 4 shows the loss by wetland type in the study area.

Total loss numbers for each county by Cowardin class are in Appendix A. Detailed maps of wetland loss are in the atlas in Appendix C.

This study documents the severity of the impact of development on freshwater wetland resources in the Greater Houston Metro Area. These freshwater wetlands are the “headwaters” for virtually all of the water bodies feeding into Galveston Bay. Continued loss at these rates will have grave implications for the long-term health of the Galveston Bay system.

Wetland loss in the context of recent Supreme Court rulings on wetlands

Since 2001, the U.S. Army Corps of Engineers (USACE) has deemed the vast majority of wetlands documented as lost in this study as outside of its jurisdiction. The Galveston District of the USACE currently considers almost all palustrine wetlands subject to development in this area to be "isolated" from the "waters of the U.S."

The study period for this project straddles two major U.S. Supreme Court rulings dealing with how wetlands are regulated. Both of these decisions center on a legal doctrine known as the "significant nexus." The fundamental question is how connected a wetland is to "a water of the U.S.," a water body within the regulatory authority of the federal government under the Clean Water Act. If a wetland is clearly connected to a water of the United States, it is very likely to be regulated.

SWANCC

In 2001, the U.S. Supreme Court ruled in *Solid Waste Agency of Northern Cook County (SWANCC) v. the Army Corps of Engineers,* 531 U.S. 159 (2001), that the Migratory Bird Rule was not a sufficient reason for regulating an otherwise isolated wetland.

After this decision, the Galveston District USACE defined hydrologically isolated wetlands narrowly, which rendered almost all wetlands outside of the FEMA 100-year floodplain in this district exempt from regulatory jurisdiction. The exceptions were the very few wetlands outside the floodplain with a "bed and banks" connection—a virtual river bed—to a floodplain or a water of the United States.

Figure 22 shows the distribution of palustrine wetlands (prairie and forested potholes) and FEMA 100-year floodplains in Harris County in the area of greatest wetland loss. The map gives a sense of the amount of wetlands no longer under Clean Water Act Section 404 protection (those outside of the 100-year floodplain). Most of the palustrine emergent wetlands (PEM, marsh or "prairie-pothole wetlands") are outside of the 100-year floodplains and, therefore, for the most part outside of Clean Water Act jurisdiction, under current USACE Galveston District interpretations.

Eighty-three percent of PEM wetlands lost in the study area occur outside of the 100 year floodplain (Table 5).

Rapanos

In 2006, the Supreme Court in *Rapanos v. United States,* 547 U.S. 715 (2006) further clarified the significant nexus rule. If a particular class of wetlands could be demonstrated to have a significant nexus to waters of the United States, then that class of wetlands could be considered jurisdictional without having to document the connection for every case.

In response to this ruling, the hydrology of coastal plain prairie potholes on the Upper Gulf

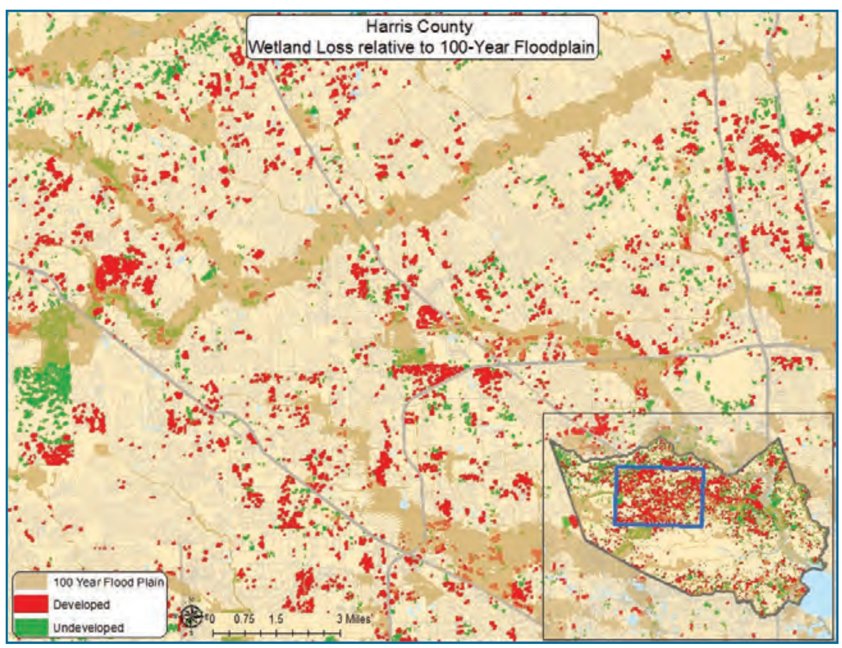

Figure 22: Harris County wetland loss under FEMA 100-year floodplain. Red areas are NWI wetlands that have been lost to development. The most recent FEMA 100-year floodplain overlay is also shown.

Coast of Texas was investigated. The studies revealed that an average of about 15 to 20 percent of the precipitation and runoff that flows into these pothole wetlands flows into waters of the United States (Wilcox et al. 2011, Forbes et al. 2012).

As of this writing, the Galveston District of the USACE has not modified any policies based on these studies. However, a wetland connectivity review recently published by the EPA specifically addresses the so-called isolated wetlands that make up the losses documented in this study. The review notes the relatively large contribution of water to surface streams these wetlands supply. The science supports exerting federal jurisdiction over these wetlands (USEPA 2013).

Table 5: Wetland loss with respect to the FEMA 100-year floodplain

County	Total wetland acres	Total acres lost	Acres lost in 100-year floodplain	% lost in 100-year floodplain
Brazoria	88,838	855	209	24%
Chambers	58,041	255	31	12%
Fort Bend	24,002	1,442	237	16%
Galveston	14,316	1,066	232	22%
Harris	54,479	15,855	2,165	14%
Liberty	165,987	1,951	527	27%
Montgomery	32,498	3,093	845	27%
Waller	9,788	83	25	31%
Subtotal	447,949	24,600	4271	17%

Source: National Flood Hazard Layer (NFHL) dataset from FEMA, 2012, Harris, Waller, and Liberty Counties
FEMA Q3 1996 A zone floodplain data – Fort Bend, Montgomery, Galveston, Brazoria, and Chambers Counties

Implications

Loss of natural freshwater wetlands in the Greater Houston Metro Area over the 18 years of the study period (1992 to 2010) was massive and rapid. As shown in Table 4, the area lost 4.3 percent of the most endangered category of wetlands in the overall area, the palustrine freshwater marshes (PEM, prairie potholes in the local parlance).

In Harris County, however, a staggering 36 percent of its prairie marshes was lost (Appendix A), accounting for more than 70 percent of the total loss of the prairie marshes in the entire study area. As the economy improves, even more wetlands will be filled, and few losses will be mitigated.

Wetlands in Harris County are being lost so quickly that little can be done except to try to save a few critical last pieces of ecologically significant land. Counties surrounding Harris County can expect similar losses in the next few years.

Loss of services

Freshwater wetlands provide critical ecological services to the Galveston Bay System:

- Decreasing flooding
- Cleaning runoff water by filtering out pollution and sediment
- Soaking up water to help replenish groundwater supplies
- Reducing erosion
- Providing habitats for wildlife, including migratory birds
- Protecting coastal areas and shorelines by weakening the force of storms
- Providing places for boating, fishing, hiking, hunting, and bird-watching
- Offering an intangible sense of beauty and place in our culture

In the Houston area, wetlands are the principal means of cleaning polluted runoff that enters Galveston Bay.

The cost of replacing those services would be astronomical. For example, the wetland loss in the study area is equivalent to at least 12,000 acre-feet, or nearly 4 billion gallons, of stormwater detention. This stormwater detention is in addition to that provided by the native soils. At an average cost of $50,000[10] per acre-foot of stormwater detention, this loss corresponds to no less than $600 million. For Harris County, the loss is at least 7,000 acre-feet, or $350 million.

[10] Based on Harris County Flood Control figures courtesy of Carolyn White for some recent mid-sized detention basins in Harris County.

These values are just for stormwater detention. They do not take into account the water-cleansing value of the wetlands or any of the other benefits mentioned above. Counting these services, the loss is clearly in the billions.

Much of what is being lost now is among the most valuable habitat remaining on the entire Upper Texas Gulf Coast. Vast acreages of land were land-leveled for agriculture during the 20th century. Some of the best examples of undisturbed prairie pothole-pimple mound complexes are in urban fringe areas yet to be developed and in areas where agriculture has not yet penetrated. These are the wetlands now under the greatest threat.

What can be done?

Wetlands are essential to the long-term ecological stability of our entire region. They are a natural legacy that we can ill afford to lose. And yet we are losing them at an increasing pace as our economy revives. Now that we know how many wetlands we are losing and where we are losing them, we can begin to consider the alternatives to our current way of doing business:

- Because freshwater wetlands are being lost primarily to development, many wetlands would be preserved if cities and counties simply required that developers applying for building permits include evidence that they have a CWA permit or that the USACE does not recognize any wetlands on the site. Much of the development in the region occurs without any investigation of the presence of wetlands, much less with a Clean Water Act wetland permit. We suspect that half or even more of all development occurs this way.
- Cities and other jurisdictions could also require that the mitigation occur in the same watershed as the development, thus enabling more green space in or near the jurisdiction, without any additional costs to the citizens.
- Houston is set to gain another 3 million to 4 million people in the next 30 years. New development might cover 700 to 1,000 square miles. If the coastal prairie pothole wetlands, which make up most of the freshwater wetlands in the eight-county region, were fully protected under the CWA and their development mitigated appropriately, 25,000 to 35,000 acres of wetland habitat, the equivalent of an Anahuac National Wildlife Refuge, could be set aside every year.
- Coastal resource managers need to identify the critical habitat that remains and work with residents and conservationists to develop plans for preserving and restoring wetlands. The Texas Coastal Watershed Program, a joint program of Texas A&M AgriLife Extension and Texas Sea Grant College Program, in conjunction with the Houston–Galveston Area Council, has mapped out the remaining ecologically significant areas of high quality prairies and forests that have an abundance of wetlands (http://arcgis02.h-gac.com/ecologicalGIS/).
- Coastal resource managers and other conservationists also need to consider how wetland mitigation could play a much larger role in ecosystem restoration and maintenance in the region.
- Resource managers must work with local citizens to educate them on the implications of wetland loss in our area. Without citizen support, little can be done to preserve critical areas on the scale that is needed.

Figure 23: A prairie pothole marsh in Harris County (Source: Andrew Sipocz)

- Regulators who oversee the CWA permitting process should carefully consider recent scientific studies documenting the hydrologic connection of freshwater wetlands in the study region to Galveston Bay and other water bodies. Their decisions could greatly affect the quality of our coastal waters and ecosystems.
- Finally, residents can be involved by reporting unauthorized wetland fill activities directly to the USACE Galveston District office. A citizen can ask the Corps whether a permit is needed or has been obtained for development on a specific property.
- Citizens can also work with county and municipal governments to require wetland mitigation with their drainage and detention permitting for medium and large developments.

The wetlands that beautify our region and sustain us are an irreplaceable legacy of nature handed down to us by previous generations. If the current loss proceeds at its current increasing pace, *we* will be the generation responsible for the loss of this most precious resource.

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Figure 24: A freshwater marsh

Appendix A: Wetland loss by county

Abbreviations used in the following tables:

- PAB: Palustrine aquatic bed
- PEM: Palustrine emergent
- PFO: Palustrine forested
- PSS: Palustrine scrub shrub
- PUB: Palustrine unconsolidated bottom
- PUS: Palustrine unconsolidated shore

Harris County wetland loss by system-class

Wetland class	Total acres	Year 1992–2002		Year 2002–2006		Year 2006–2010		Year 1992–2010	
		Acres lost	%	Acres lost	%	Acres lost	%	Acres lost	%
PAB	78.6	18	22.8%	6.8	8.6%	1.7	2.2%	26.4	33.6%
PEM	12,474	2,259.7	18.1%	1,413.5	11.3%	804.7	6.4%	4,477.2	35.9%
PFO	37,137.5	4,033	10.9%	3,522	9.5%	1,905.3	5.1%	9,459.1	25.5%
PSS	4,309.7	834.1	19.4%	688.4	16%	300.4	7%	1,822.7	42.3%
PUB	411	19.4	4.7%	22.8	5.6%	10.5	2.5%	52.7	12.8%
PUS	68.4	3.6	5.2%	5.6	8.2%	5.2	7.6%	14.4	21%
Total	**54,479.3**	**7,167.7**	**13.2%**	**5,659.1**	**10.4%**	**3027.7**	**5.6%**	**15,852.5**	**29.1%**

Galveston County wetland loss by system-class

Wetland class	Total acres	Year 1992–2002		Year 2002–2010		Year 1992–2010	
		Acres lost	%	Acres lost	%	Acres lost	%
PAB	6	–	–	1	16.5%	1	16.5%
PEM	11,123.6	96.5	0.9%	297.4	2.7%	393.9	3.5%
PFO	1,867.1	88.2	4.7%	315.1	16.9%	403.3	21.6%
PSS	1,187.4	70.6	5.9%	193.5	16.3%	264	22.2%
PUB	97.3	2.2	2.3%	0.9	0.9%	3.1	3.2%
PUS	34.8	–	–	0.5	1.5%	0.5	1.5%
Total	**14,316.2**	**257.5**	**1.8%**	**808.3**	**5.6%**	**1065.8**	**7.4%**

Brazoria County wetland loss by system-class

Wetland class	Total acres	Year 1992 –2010	
		Acres lost	Percentage of loss
PAB	610.9	–	–
PEM	44,398.4	173.9	0.4%
PFO	40,517.9	570.3	1.4%
PSS	2,963.2	110.5	3.7%
PUB	343.6	0.7	0.2%
PUS	4	–	–
Total	**88,838.1**	**855.3**	**1.0%**

Liberty County wetland loss by system-class

Wetland class	Total acres	Year 1992 –2010	
		Acres lost	Percentage of loss
PAB	622	–	–
PEM	16,557.3	162.6	1%
PFO	13,9485.1	1,673.1	1.2%
PSS	8,479.4	113.6	1.3%
PUB	827.4	2.2	0.3%
PUS	15.4	–	–
Total	**165,986.6**	**1951.5**	**1.2%**

Chambers County wetland loss by system-class

Wetland class	Total acres	Year 1992–2010	
		Acres lost	Percentage of loss
PAB	124.5	–	–
PEM	41,466	32.3	0.08%
PFO*	12,852.8	182.7	1.4%
PSS*	2,378.4	39.3	1.4%
PUB	1,190.7	0.2	0.02%
PUS	28	–	–
Total	**58,040.5**	**254.5**	**0.4%**

Montgomery County wetland loss by system-class

Wetland class	Total acres	Year 1992 –2010	
		Acres lost	Percentage of loss
PAB	114.7	1.4	1.2%
PEM	5,943.4	536.6	9%
PFO	23,410.2	2,285.6	9.8%
PSS	2,597.5	261	10%
PUB	425.9	8.7	2.1%
PUS	6.3	–	–
Total	**32,498.1**	**3,093.2**	**9.5%**

Fort Bend County wetland loss by system-class

Wetland class	Total acres	Year 1992 –2010	
		Acres lost	Percentage of loss
PAB	278.4	–	–
PEM	5,662.4	322.5	5.7%
PFO*	16,543.0	980.4	5.9%
PSS*	749.5	136.7	18.2%
PUB	762.9	2.2	0.3%
PUS	6.1	0.4	6.5%
Total	**24,002.4**	**1,442.2**	**6%**

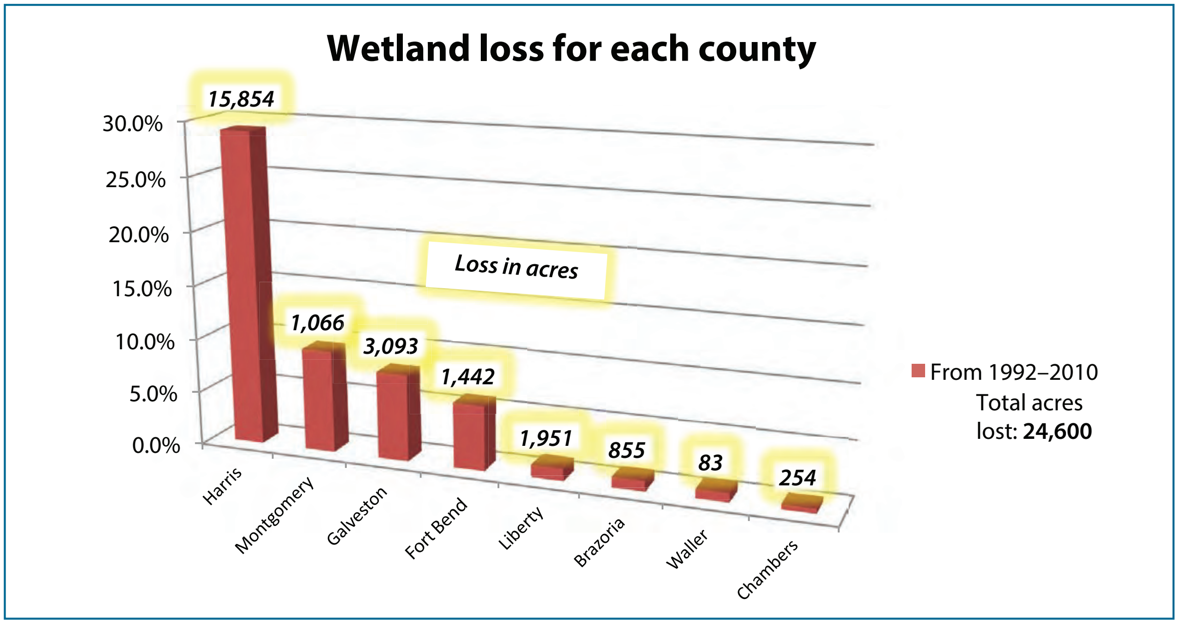
Waller County wetland loss by system-class

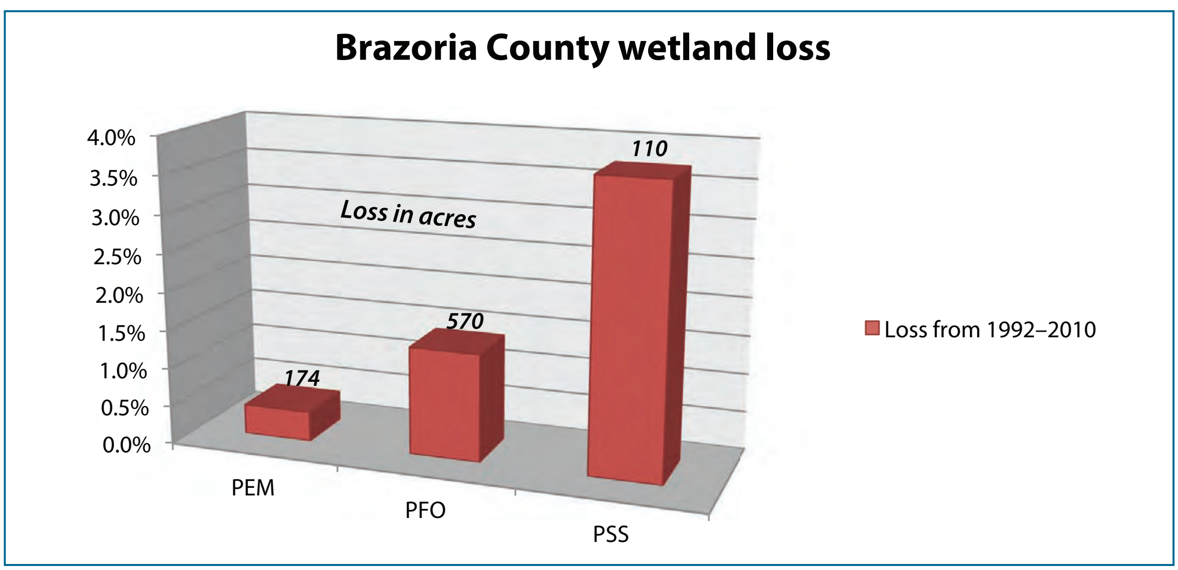
Wetland class	Total acres	Year 1992 –2010	
		Acres lost	Percentage of loss
PAB	21.5	–	–
PEM	4,052.4	67.9	1.7%
PFO	4,881.7	6.7	0.1%
PSS	573.4	3.2	0.6%
PUB	251.5	4.9	2%
PUS	7.3	–	–
Total	**9,787.8**	**82.7**	**0.8%**

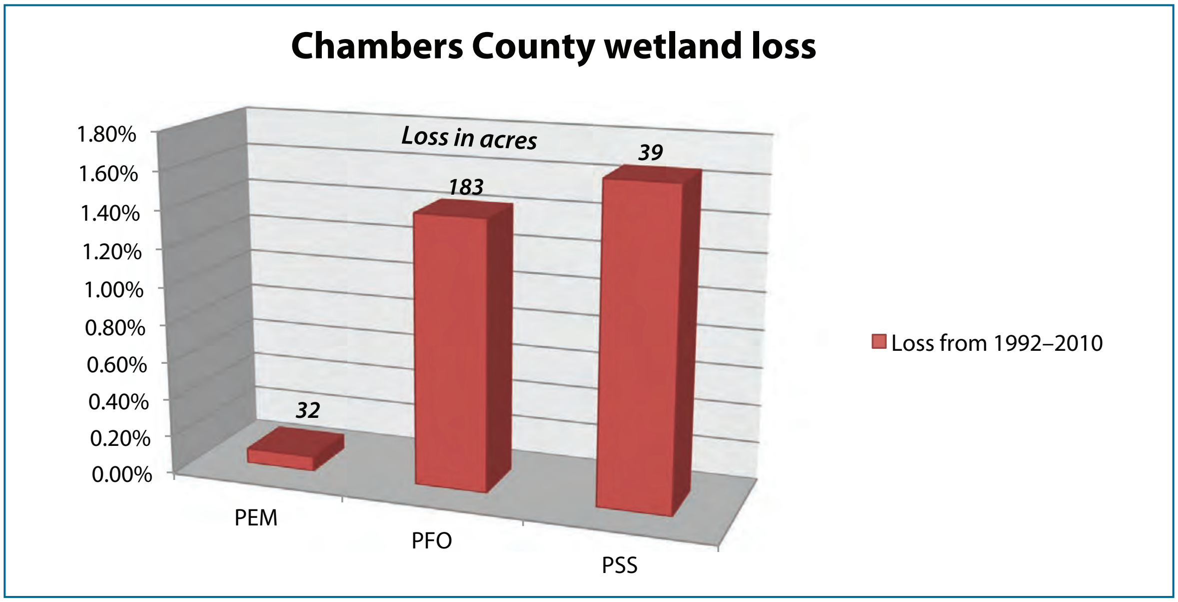
Appendix B: Graphs

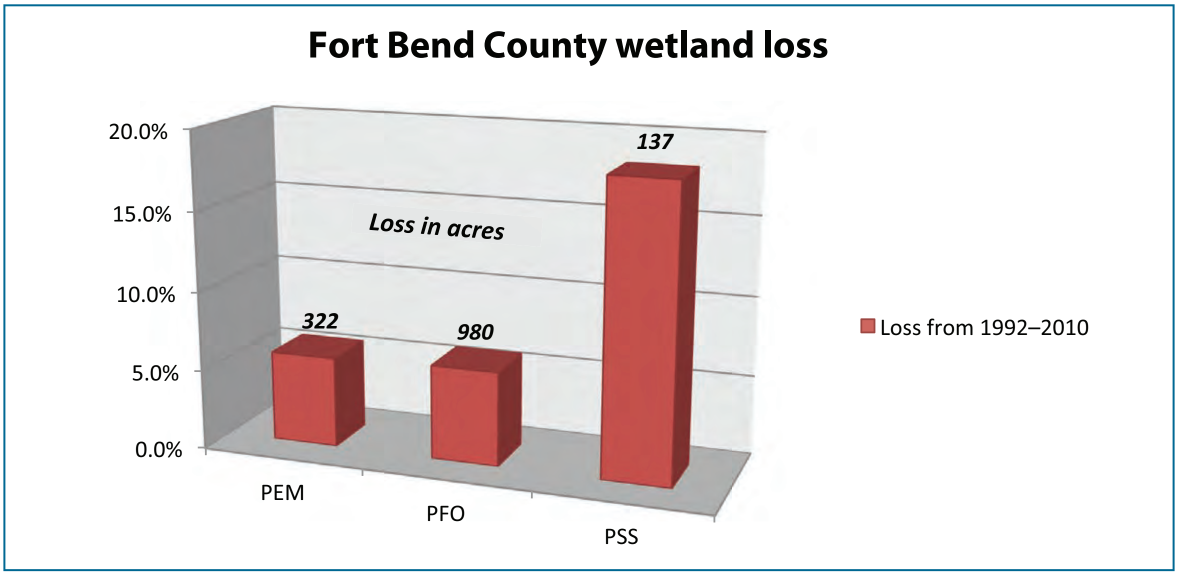
Abbreviations used in the following graphs:

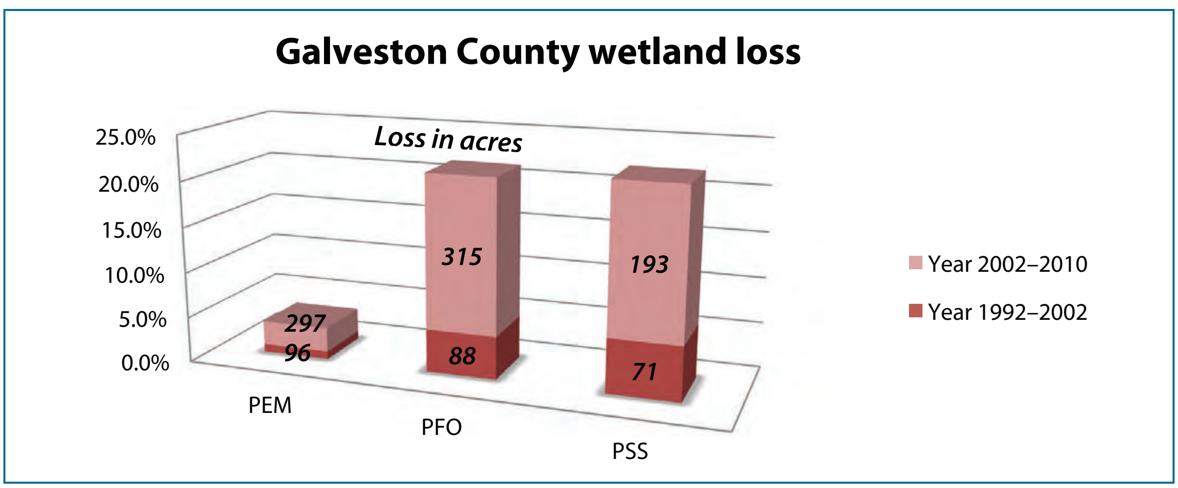
- PAB: Palustrine aquatic bed
- PEM: Palustrine emergent
- PFO: Palustrine forested
- PSS: Palustrine scrub shrub
- PUB: Palustrine unconsolidated bottom
- PUS: Palustrine unconsolidated shore

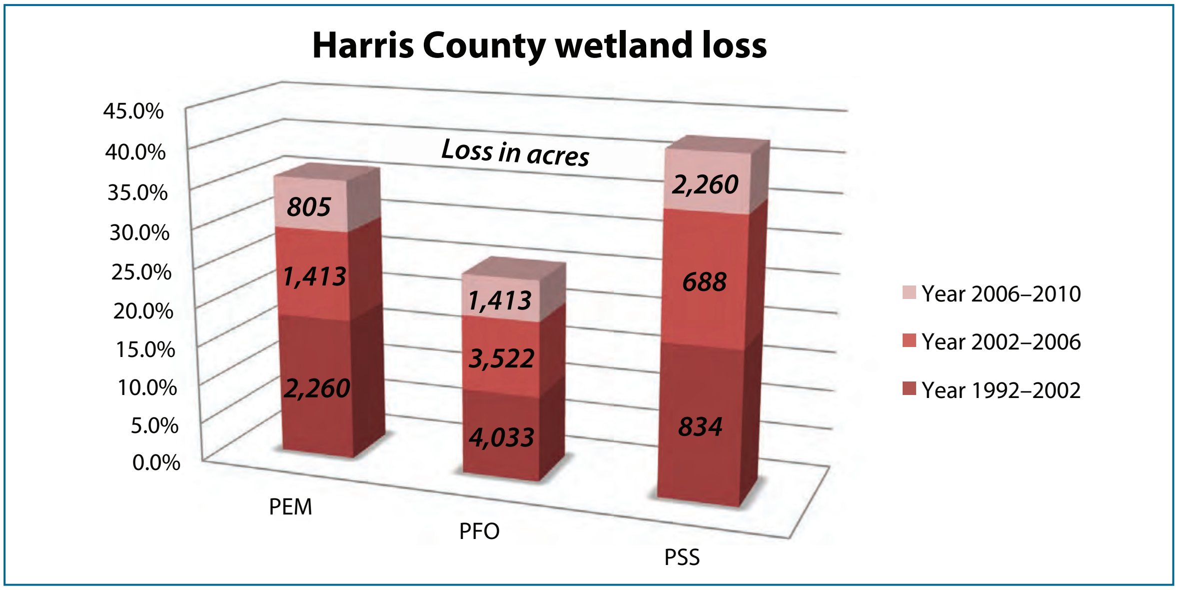


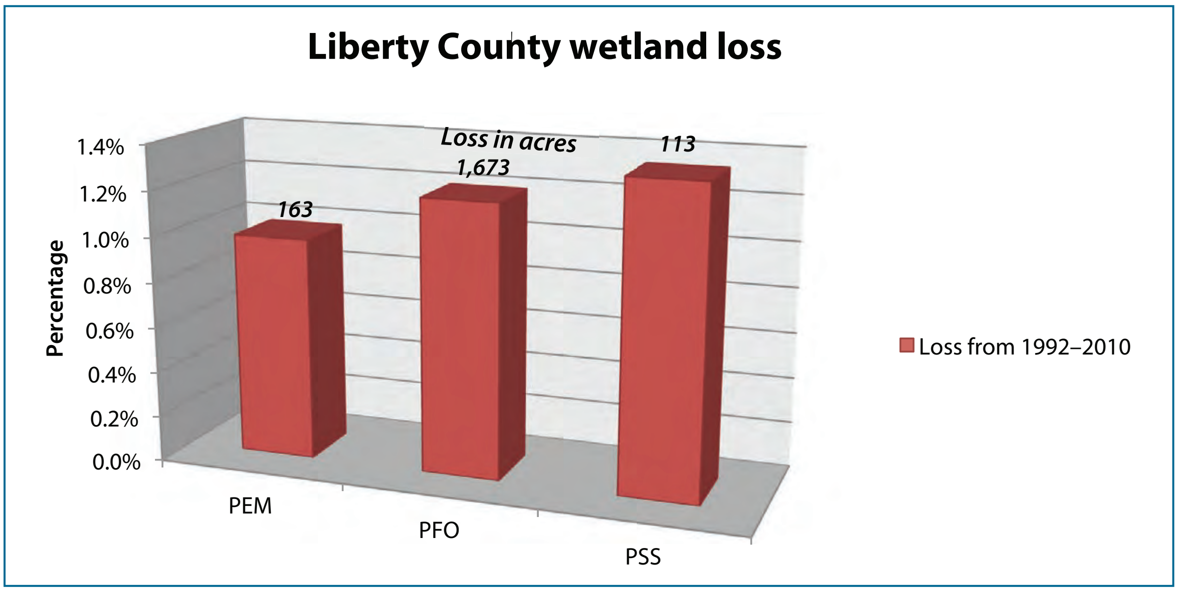


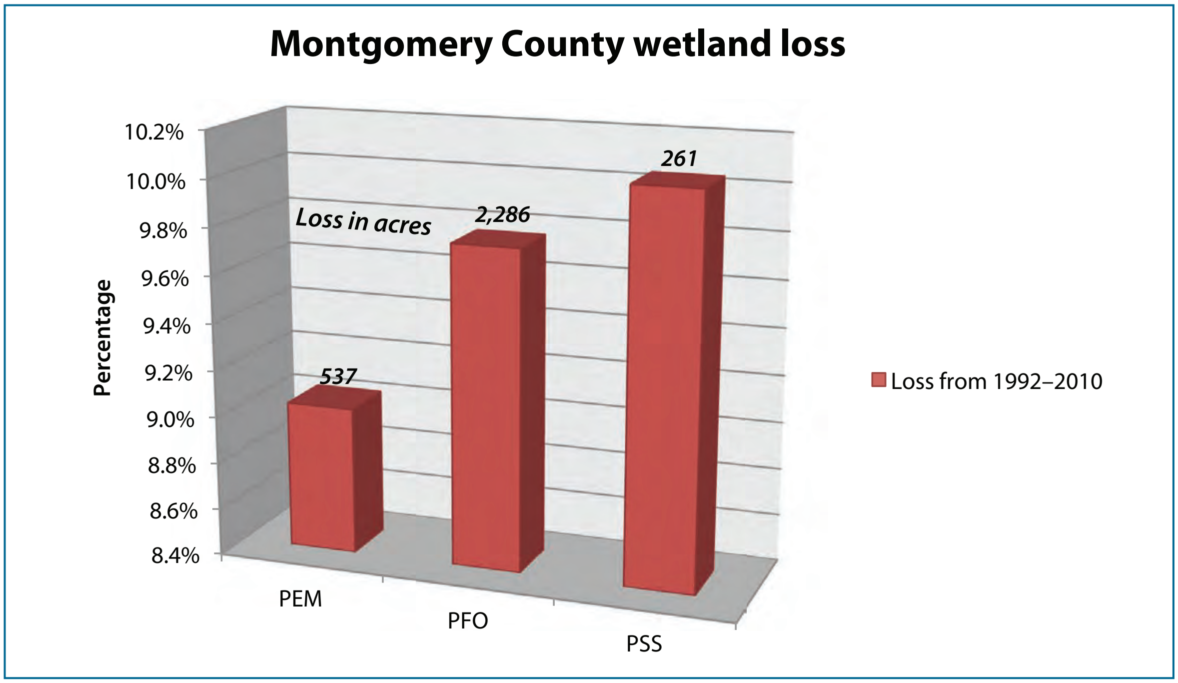

Chambers County wetland loss
1.80%
1.60%
1.40%
1.20%
1.00%
0.80%
0.60%
0.40%
0.20%
0.00%
Loss in acres
32
183
39
PEM
PFO
PSS
Loss from 1992–2010

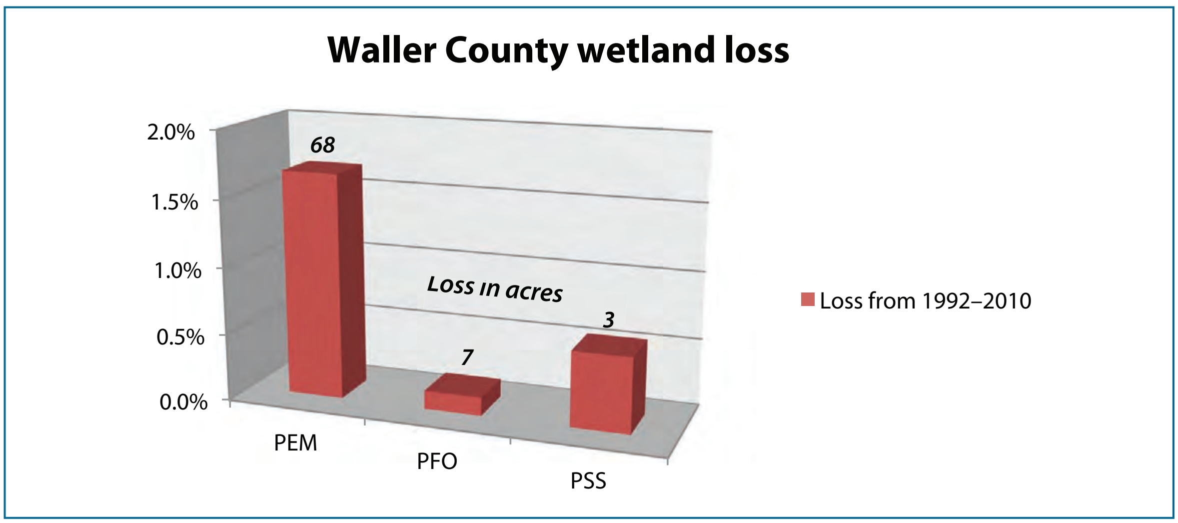

Fort Bend County wetland loss
20.0%
15.0%
10.0%
5.0%
0.0%
Loss in acres
322
980
137
PEM
PFO
PSS
Loss from 1992–2010


Galveston County wetland loss
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Loss in acres
297
96
315
88
193
71
PEM
PFO
PSS
Year 2002–2010
Year 1992–2002

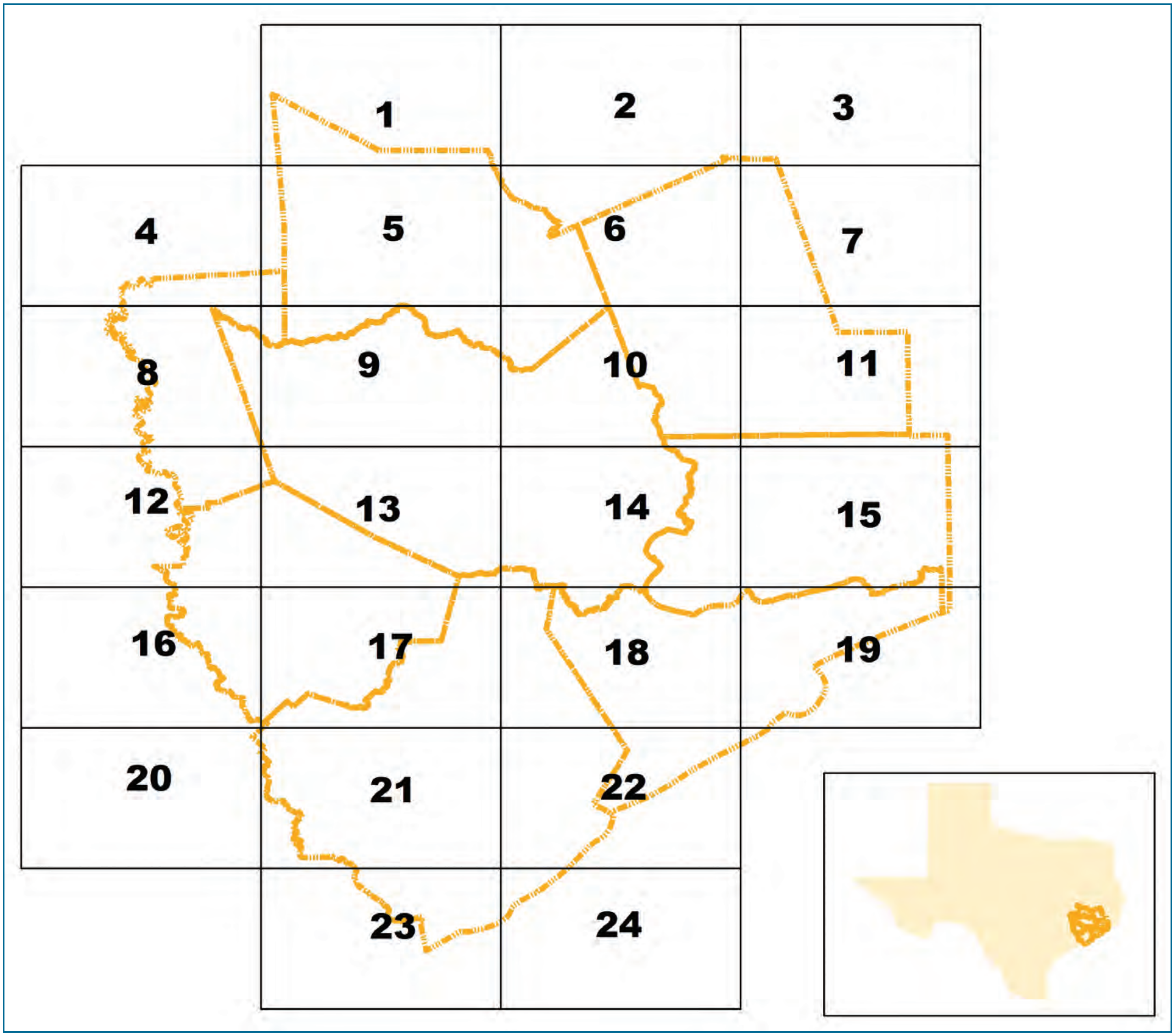

Harris County wetland loss
Loss in acres
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
805
1,413
2,260
1,413
3,522
4,033
2,260
688
834
PEM
PFO
PSS
Year 2006–2010
Year 2002–2006
Year 1992–2002


Liberty County wetland loss
Loss in acres
1.4%
1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
Percentage
163
1,673
113
PEM
PFO
PSS
Loss from 1992–2010


Montgomery County wetland loss
10.2%
10.0%
9.8%
9.6%
9.4%
9.2%
9.0%
8.8%
8.6%
8.4%
Percentage
Loss in acres
537
2,286
261
PEM
PFO
PSS
Loss from 1992–2010


Waller County wetland loss
2.0%
1.5%
1.0%
0.5%
0.0%
68
Loss in acres
7
3
PEM
PFO
PSS
Loss from 1992–2010

Appendix C. Atlas of wetland loss



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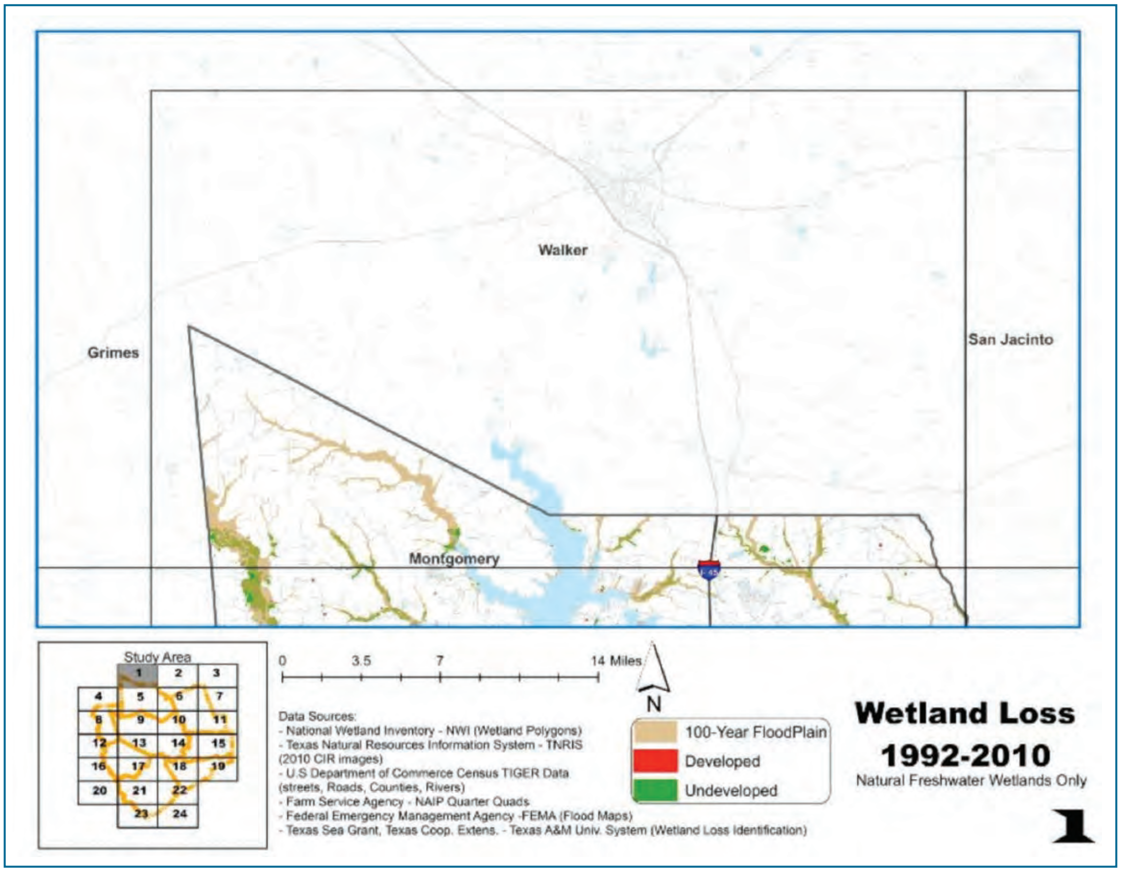
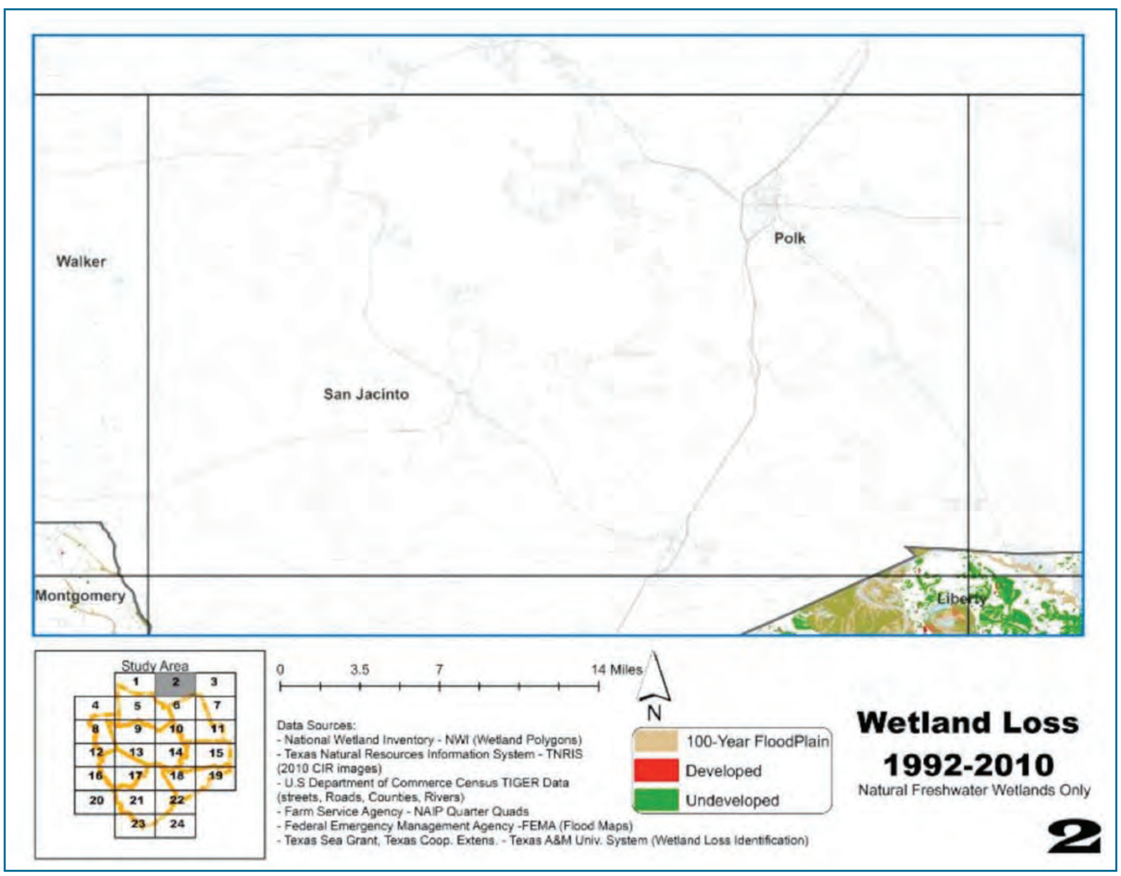
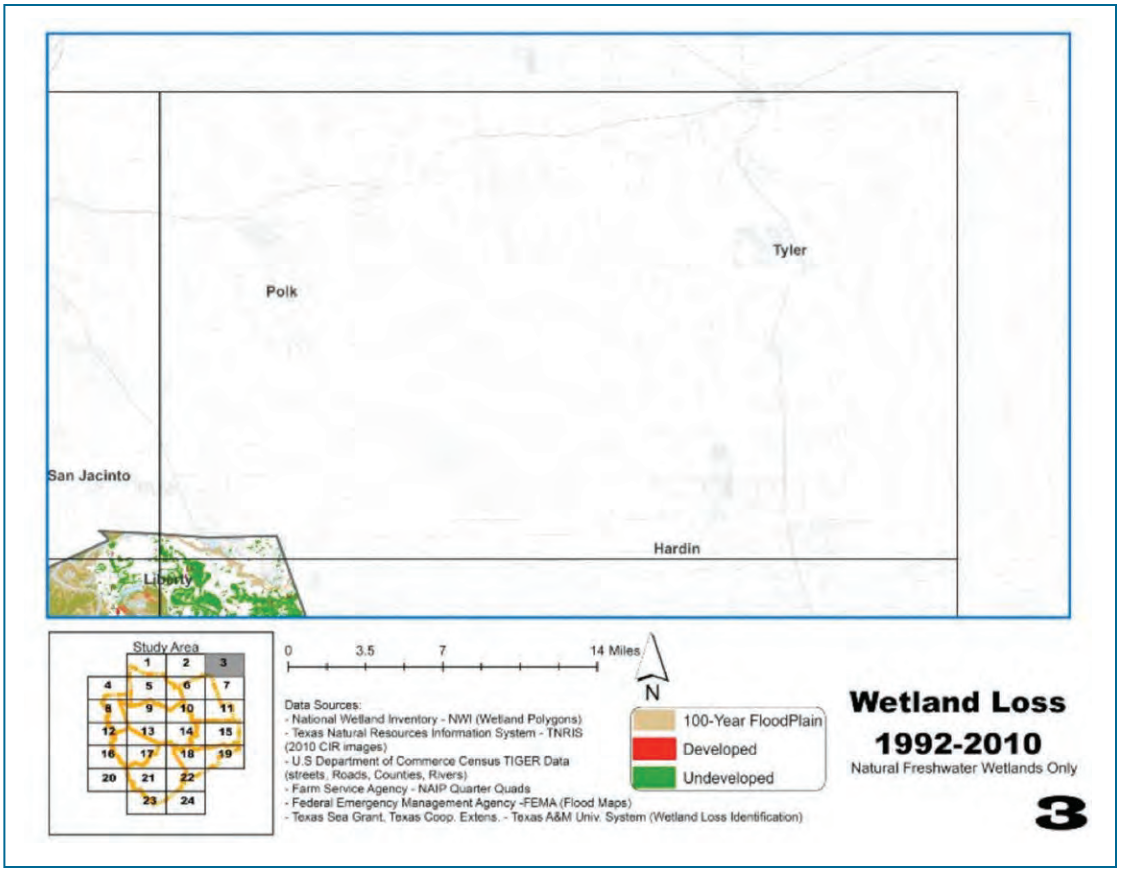

Walker
Grimes
San Jacinto
Montgomery
Study Area
1 2 3
4 5 6 7
8 9 10 11
12 13 14 15
16 17 18 19
20 21 22
23 24
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
1


Walker
Polk
San Jacinto
Montgomery
Liberty
Study Area
1 2 3
4 5 6 7
8 9 10 11
12 13 14 15
16 17 18 19
20 21 22
23 24
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
2


Tyler
Polk
San Jacinto
Hardin
Liberty
Study Area
1
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4
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6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
0
3.5
7
14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
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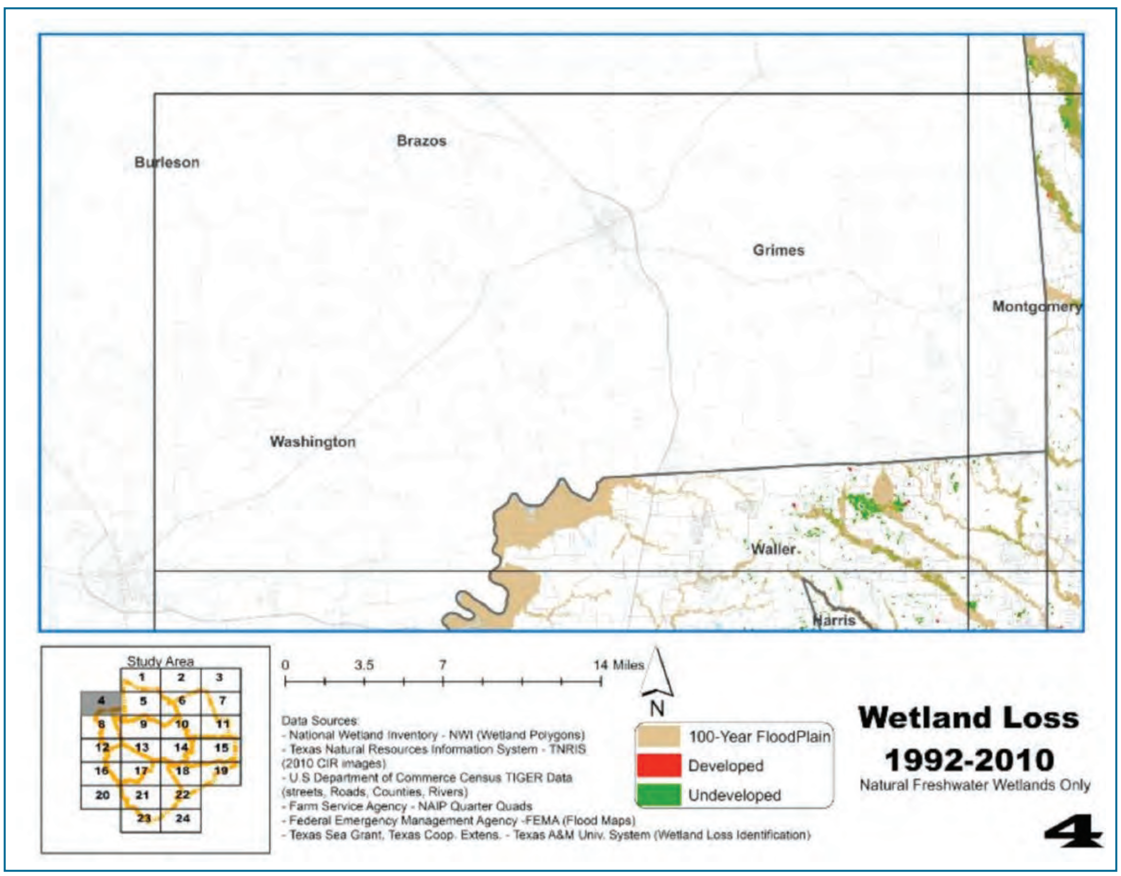
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
3


Burleson
Brazos
Grimes
Montgomery
Washington
Waller
Harris
Study Area
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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24
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Data Sources:
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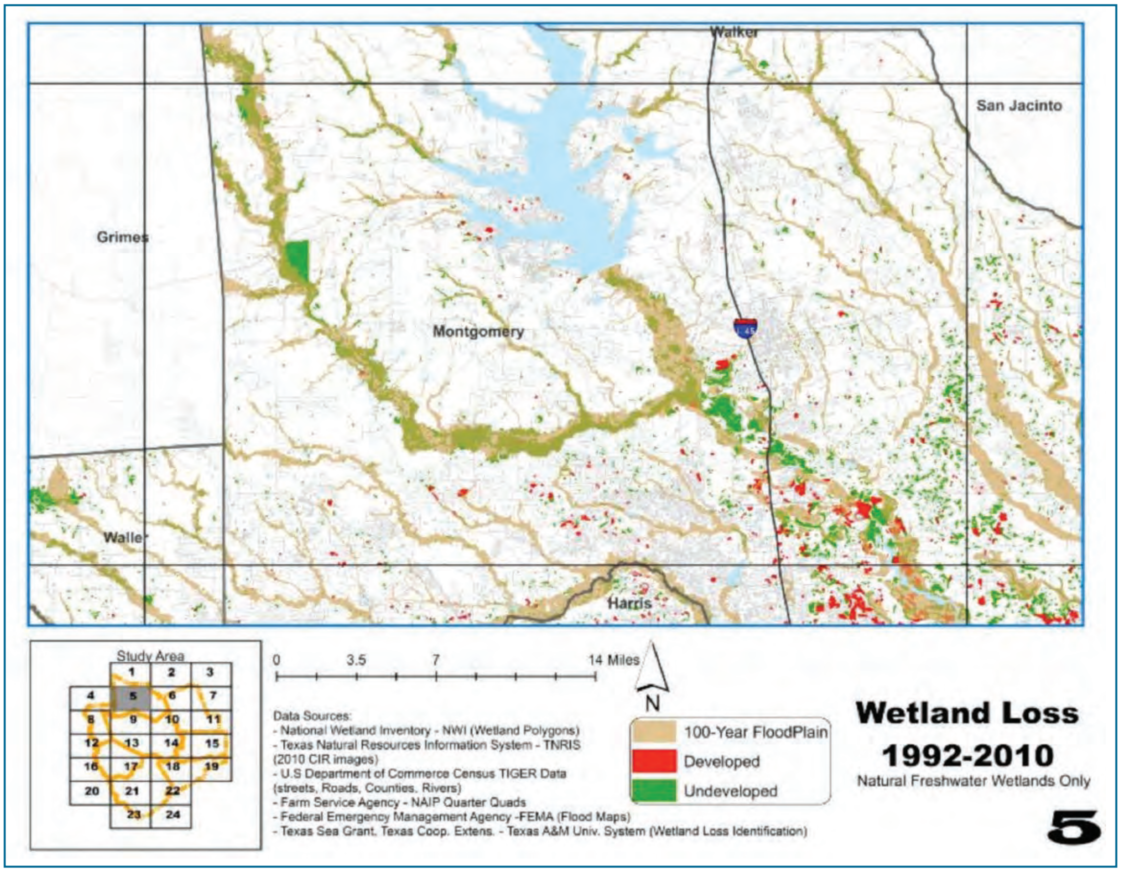
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
4


Walker
San Jacinto
Grimes
Montgomery
Waller
Harris
Study Area
0 3.5 7 14 Miles
N
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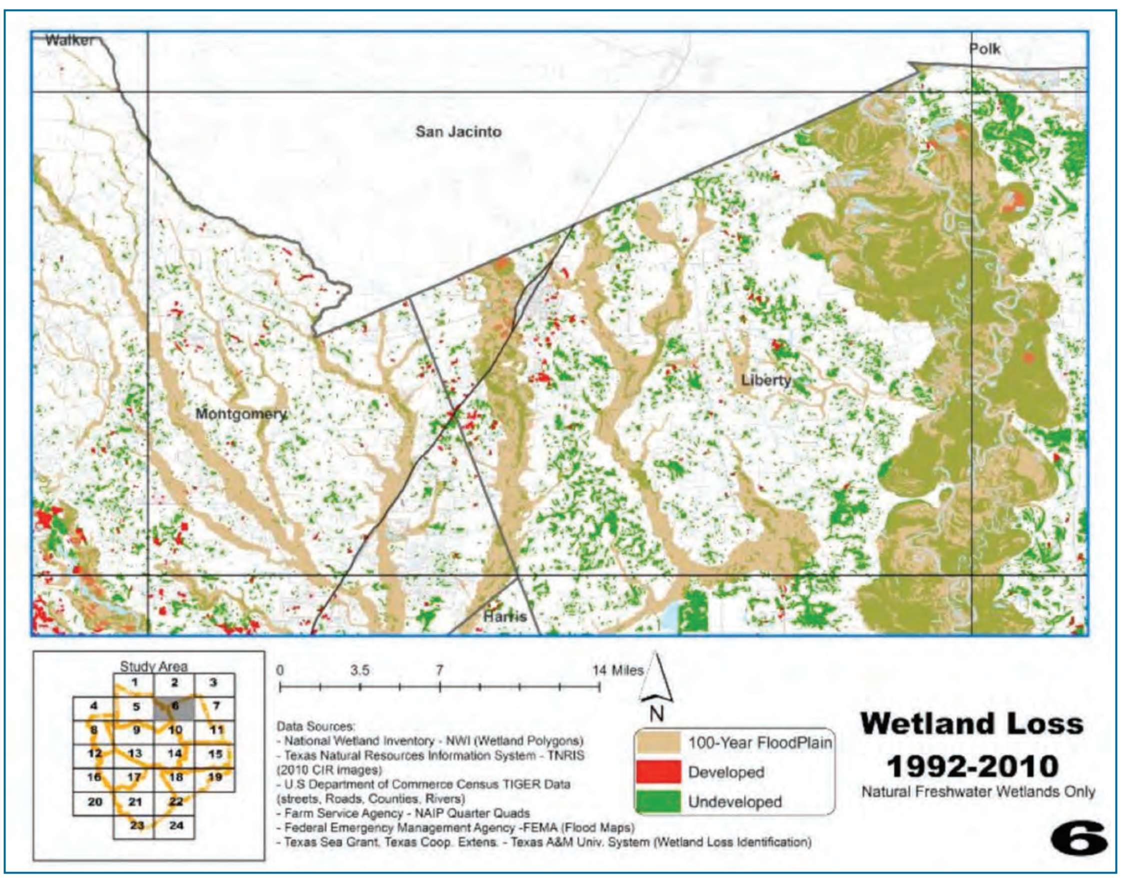
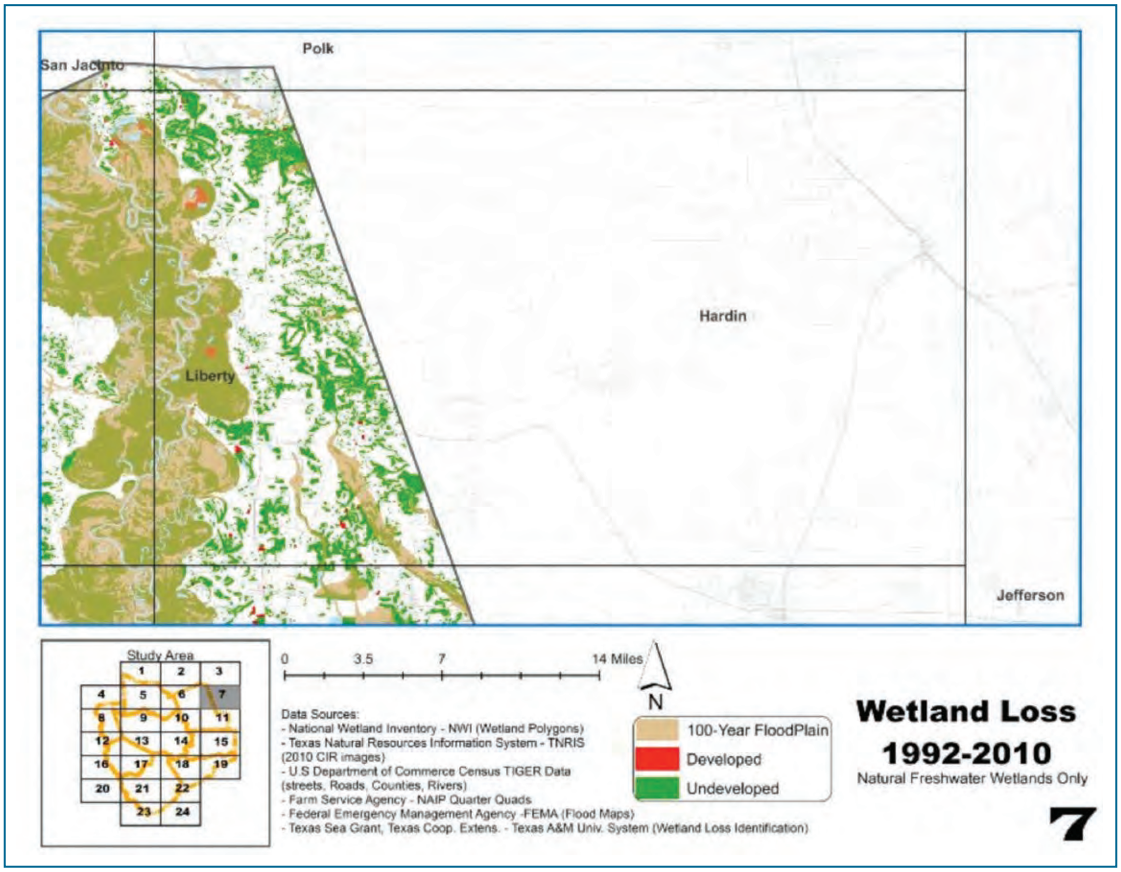
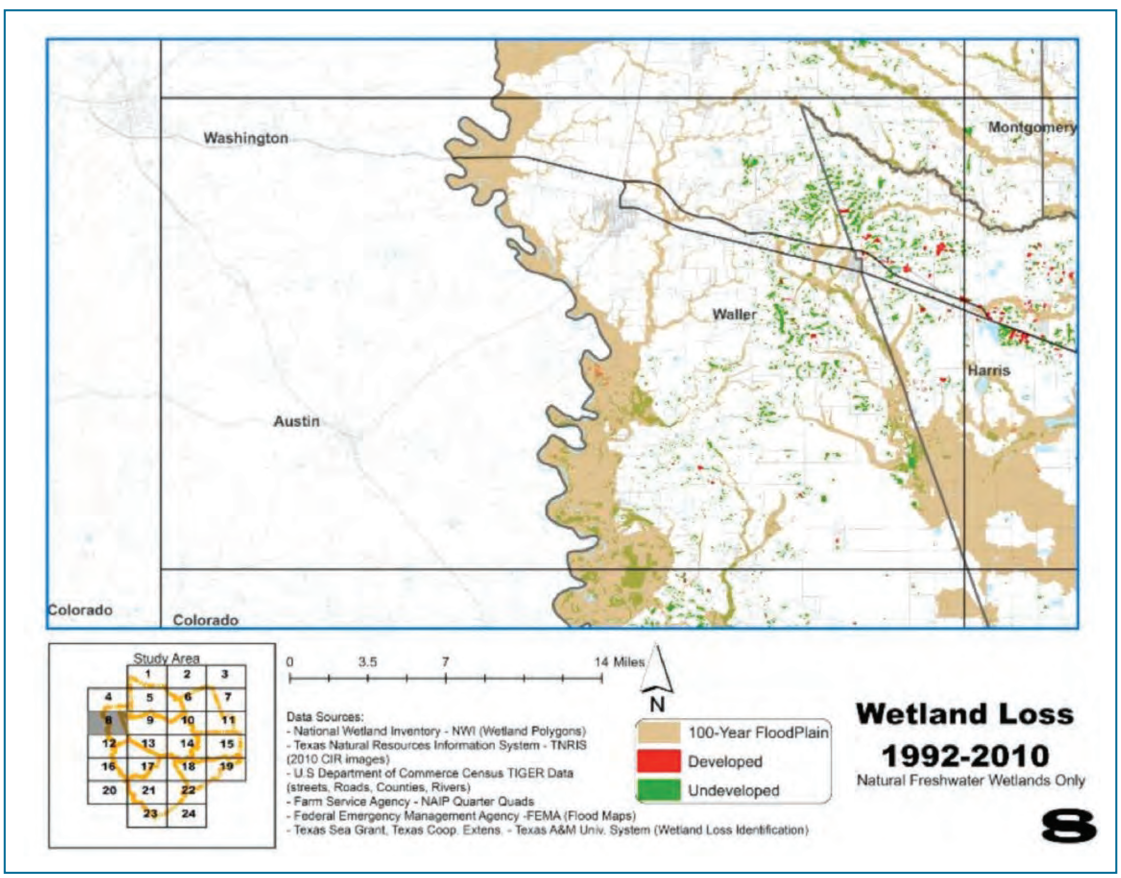
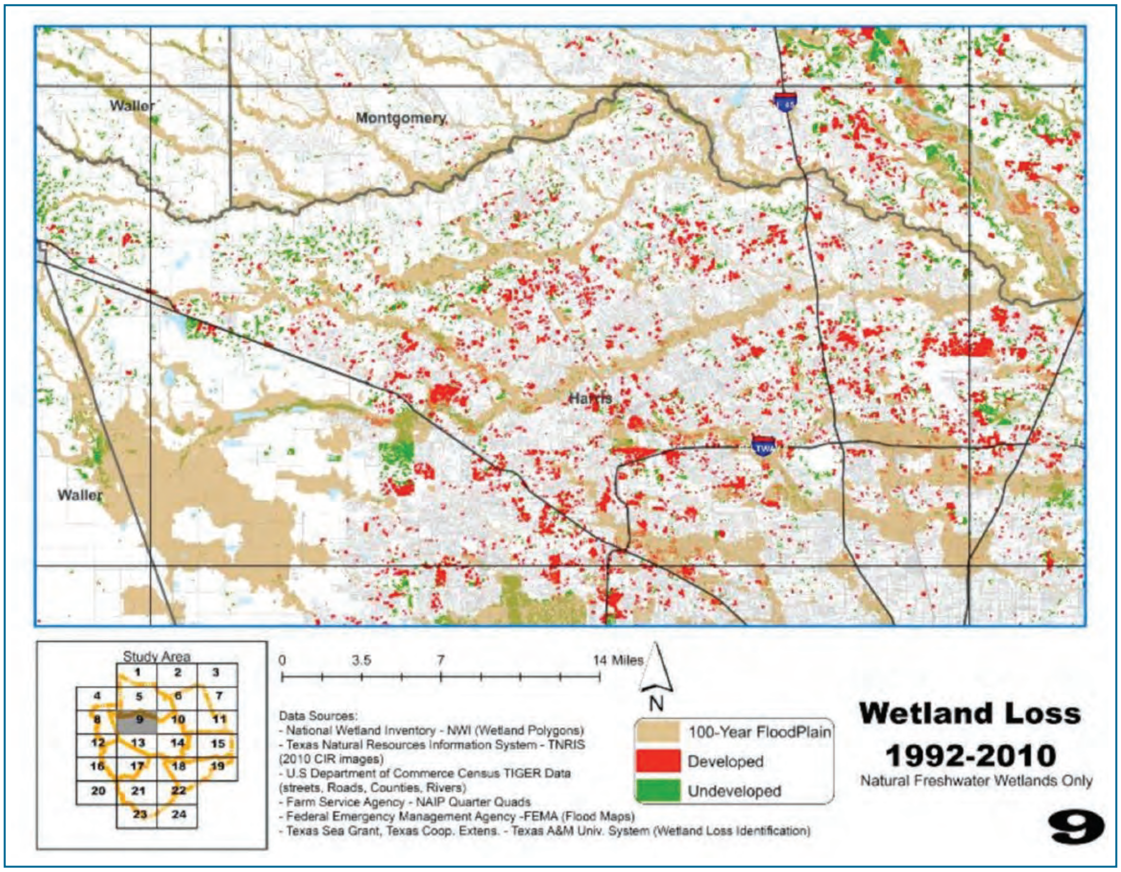
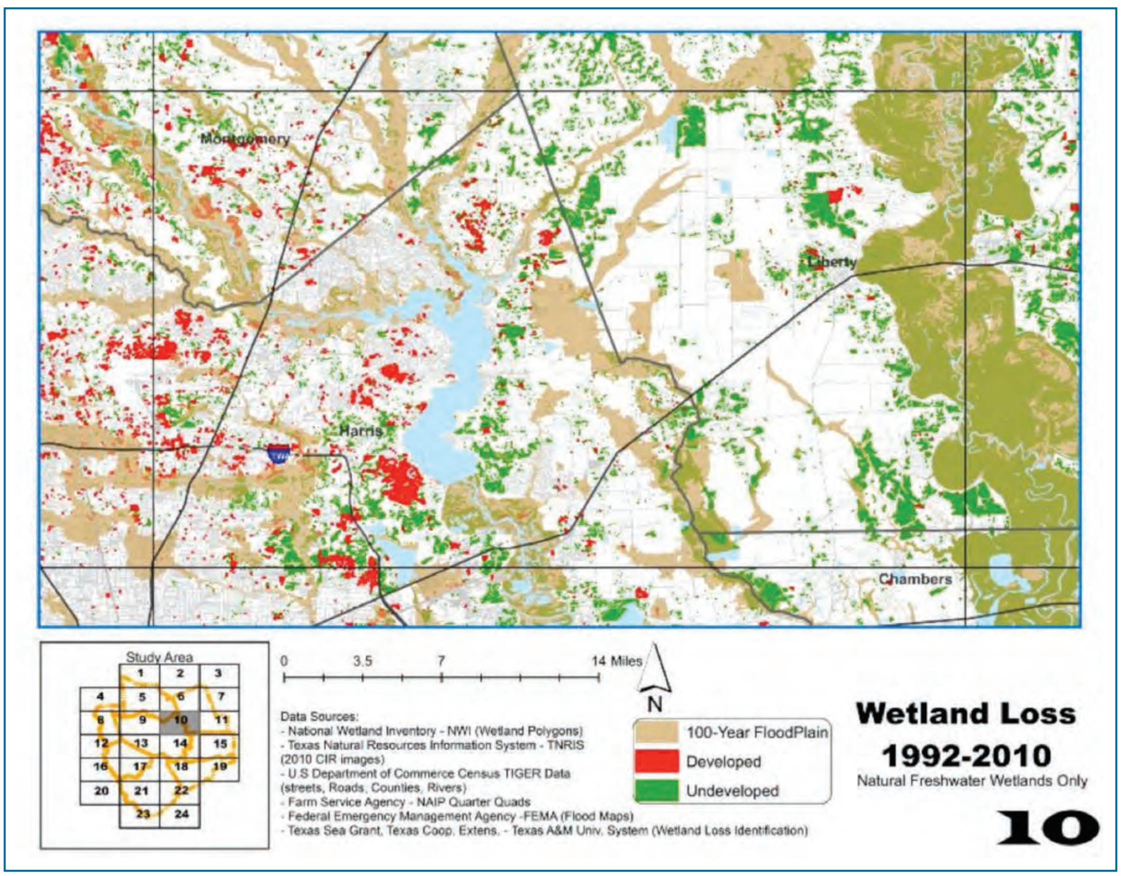
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
5

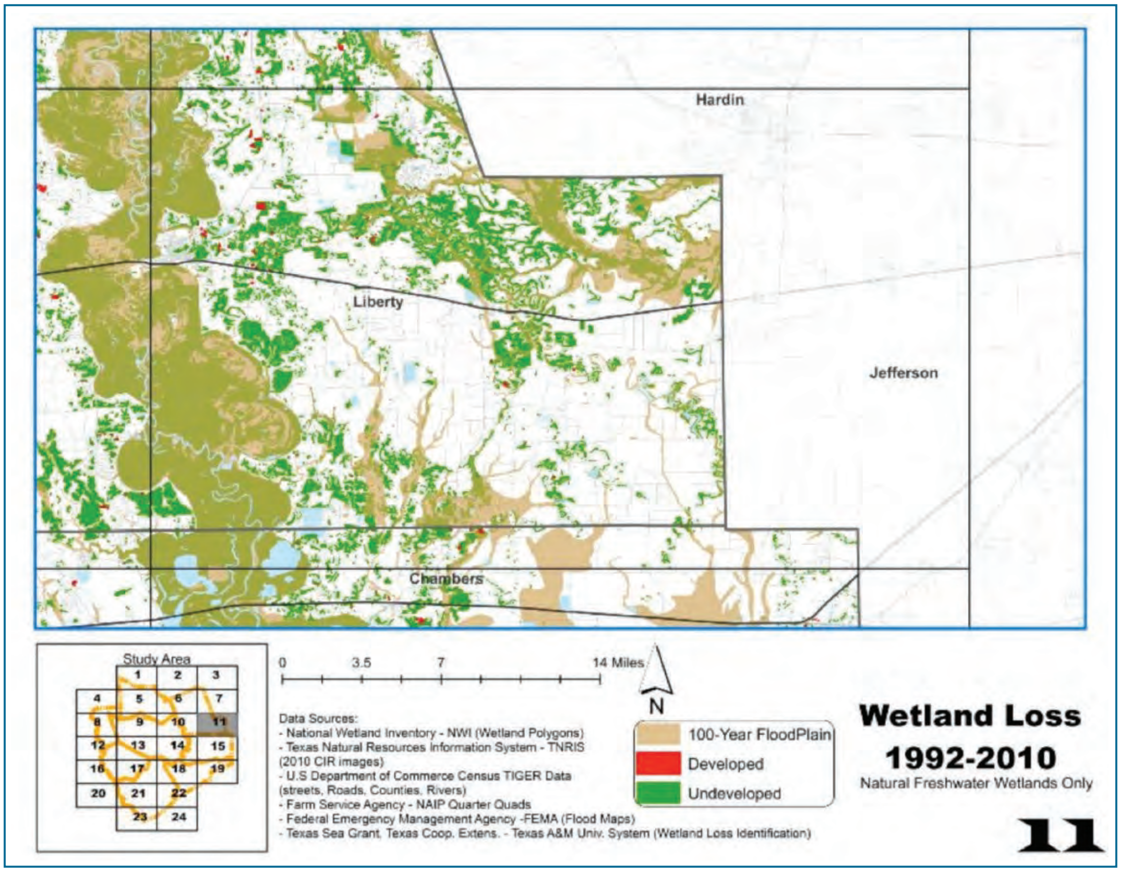

Walker
Polk
San Jacinto
Montgomery
Liberty
Harris
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
6

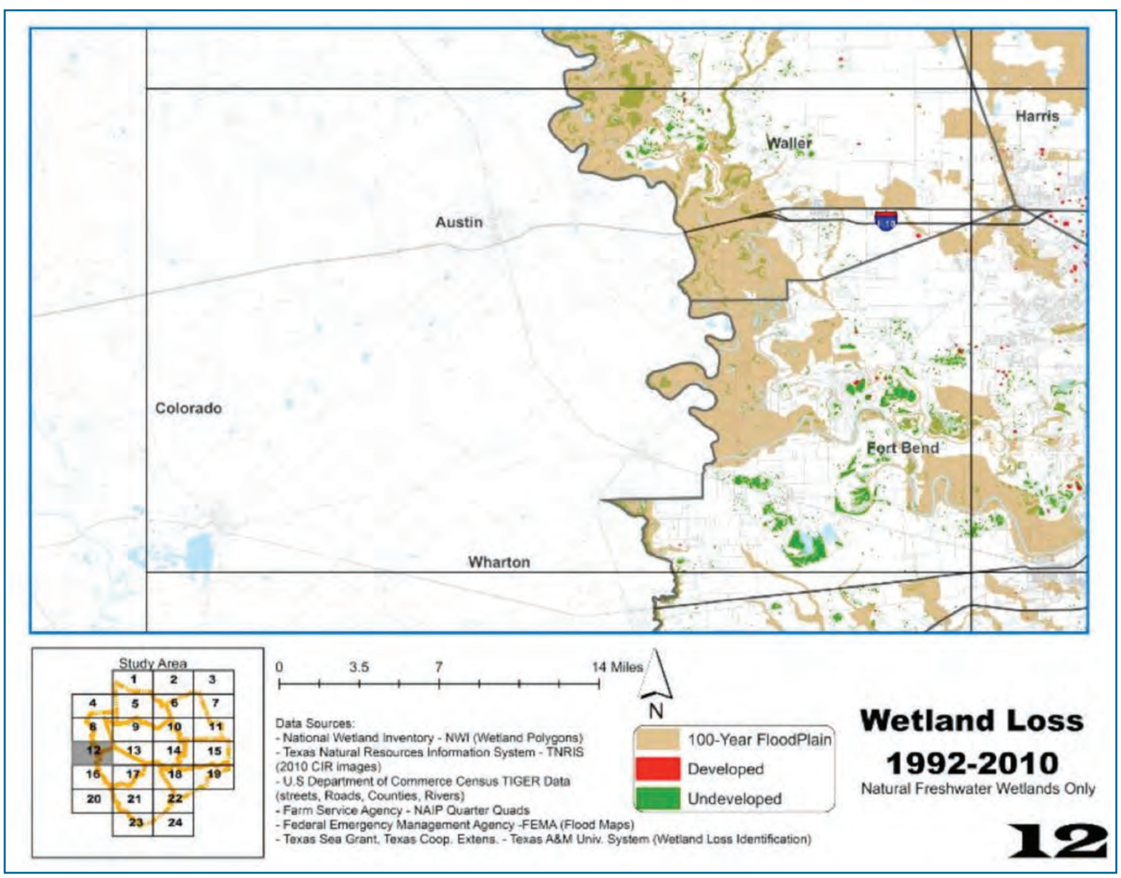

Polk
San Jacinto
Hardin
Liberty
Jefferson
Study Area
1 2 3
4 5 6 7
8 9 10 11
12 13 14 15
16 17 18 19
20 21 22
23 24
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
7

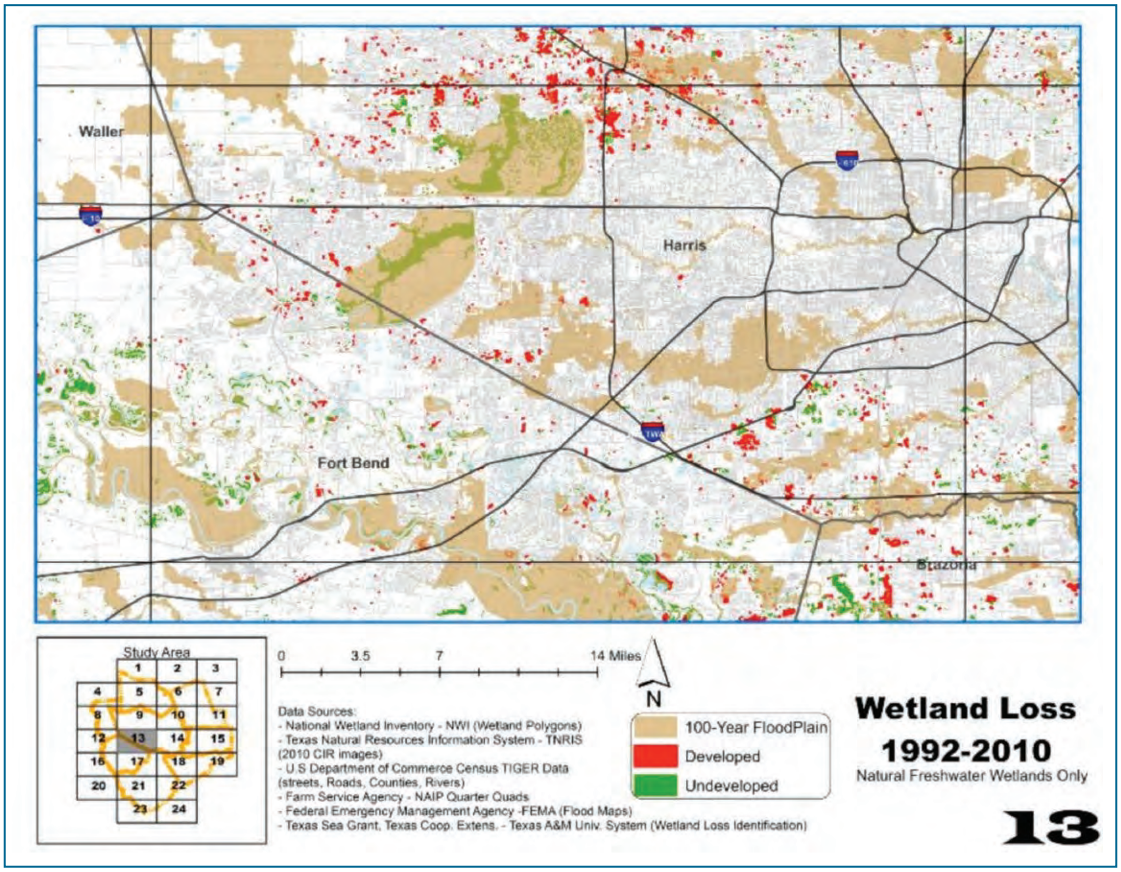

Washington
Montgomery
Waller
Harris
Austin
Colorado
Colorado
Study Area
1 2 3
4 5 6 7
8 9 10 11
12 13 14 15
16 17 18 19
20 21 22
23 24
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
8

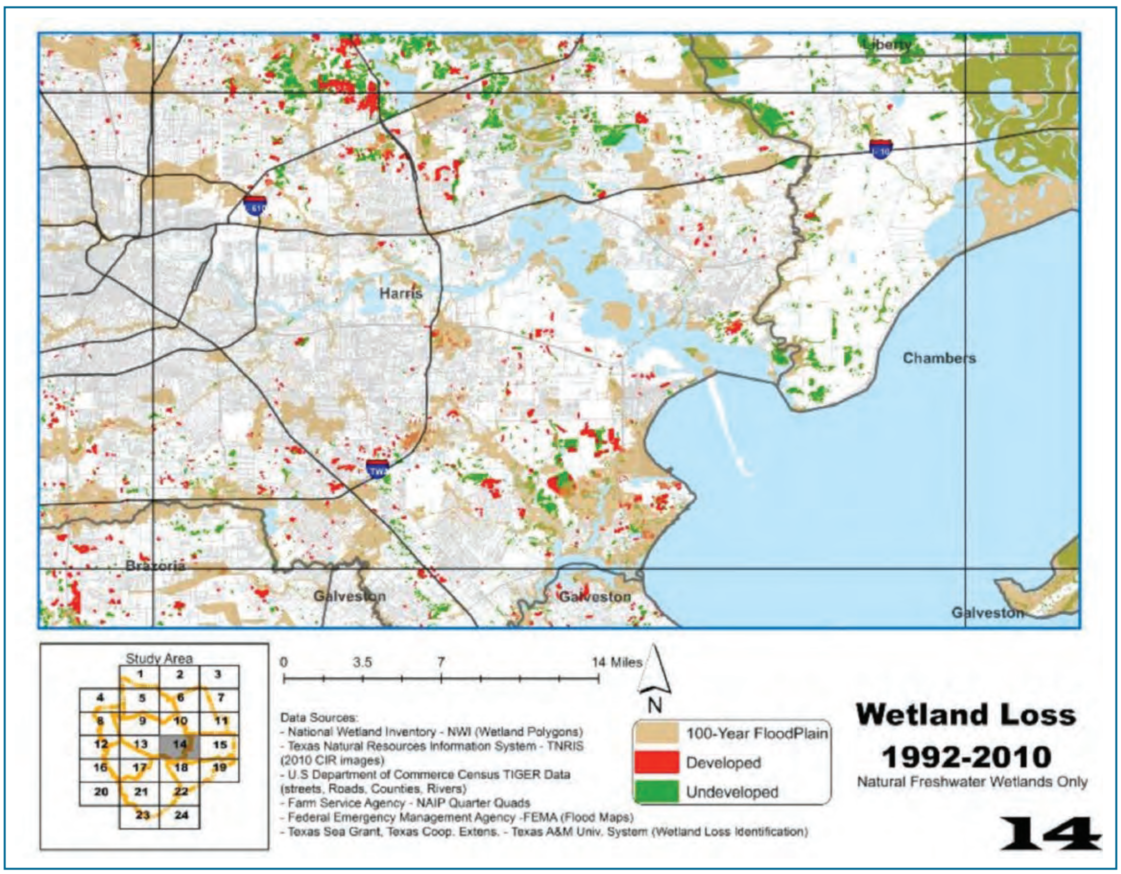

Waller
Montgomery
Harris
Waller
Study Area
0
3.5
7
14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS
(2010 CIR images)
- U.S Department of Commerce Census TIGER Data
(streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
9

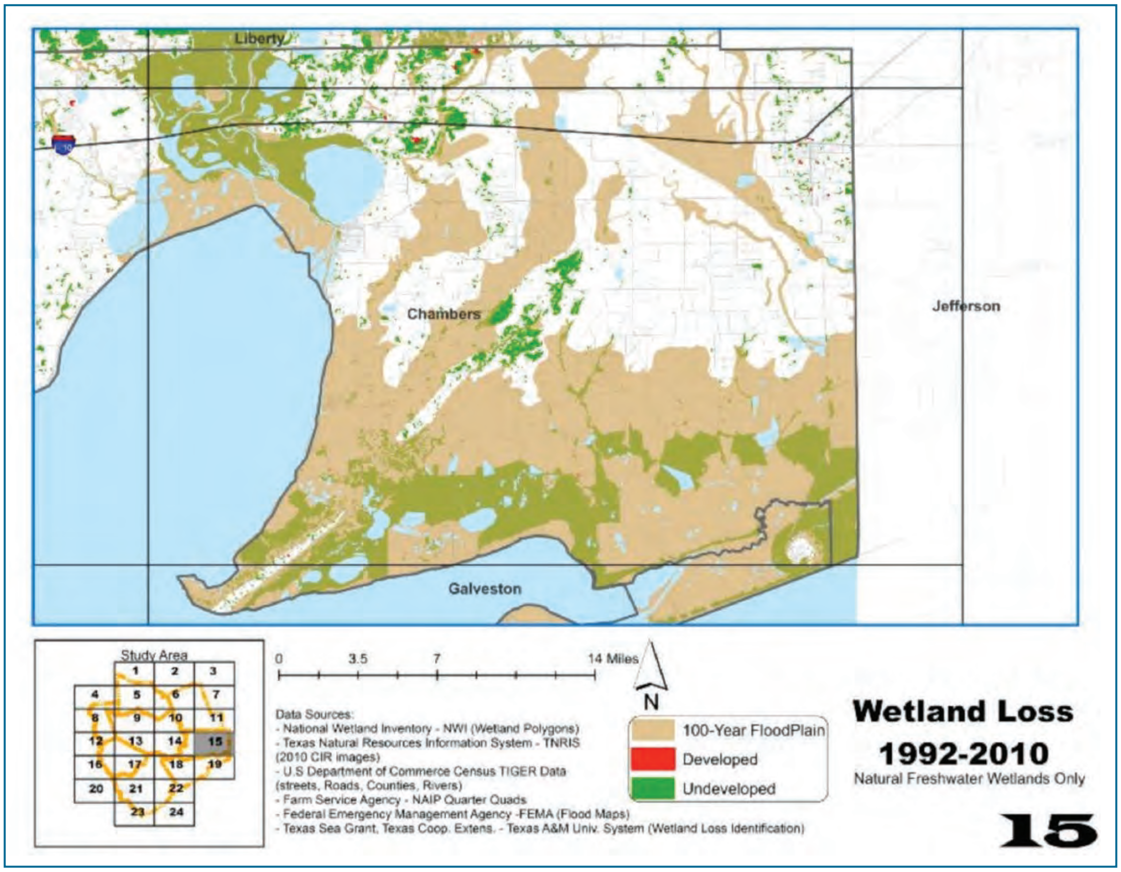

Montgomery
Harris
Liberty
Chambers
Study Area
0
3.5
7
14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS
(2010 CIR images)
- U.S Department of Commerce Census TIGER Data
(streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
10

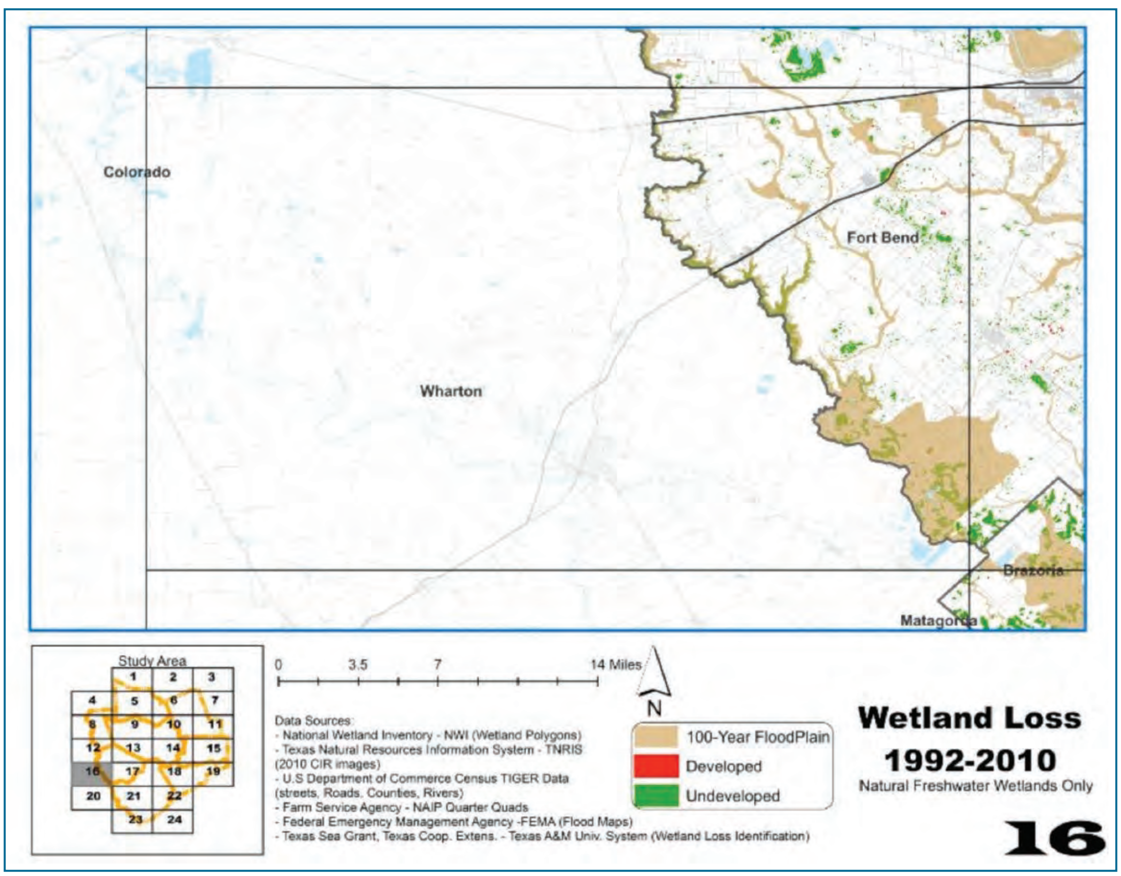

Hardin
Liberty
Jefferson
Chambers
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
11

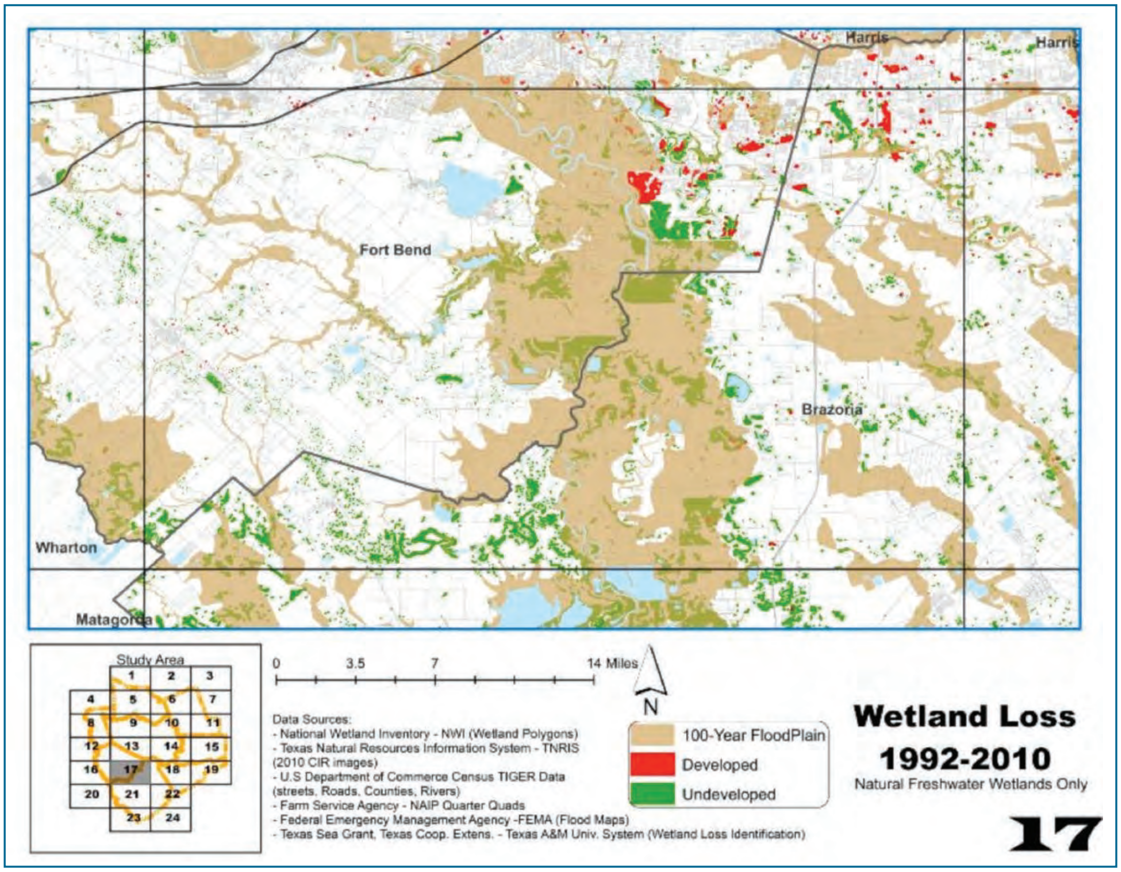

Waller
Harris
Austin
Colorado
Fort Bend
Wharton
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
12

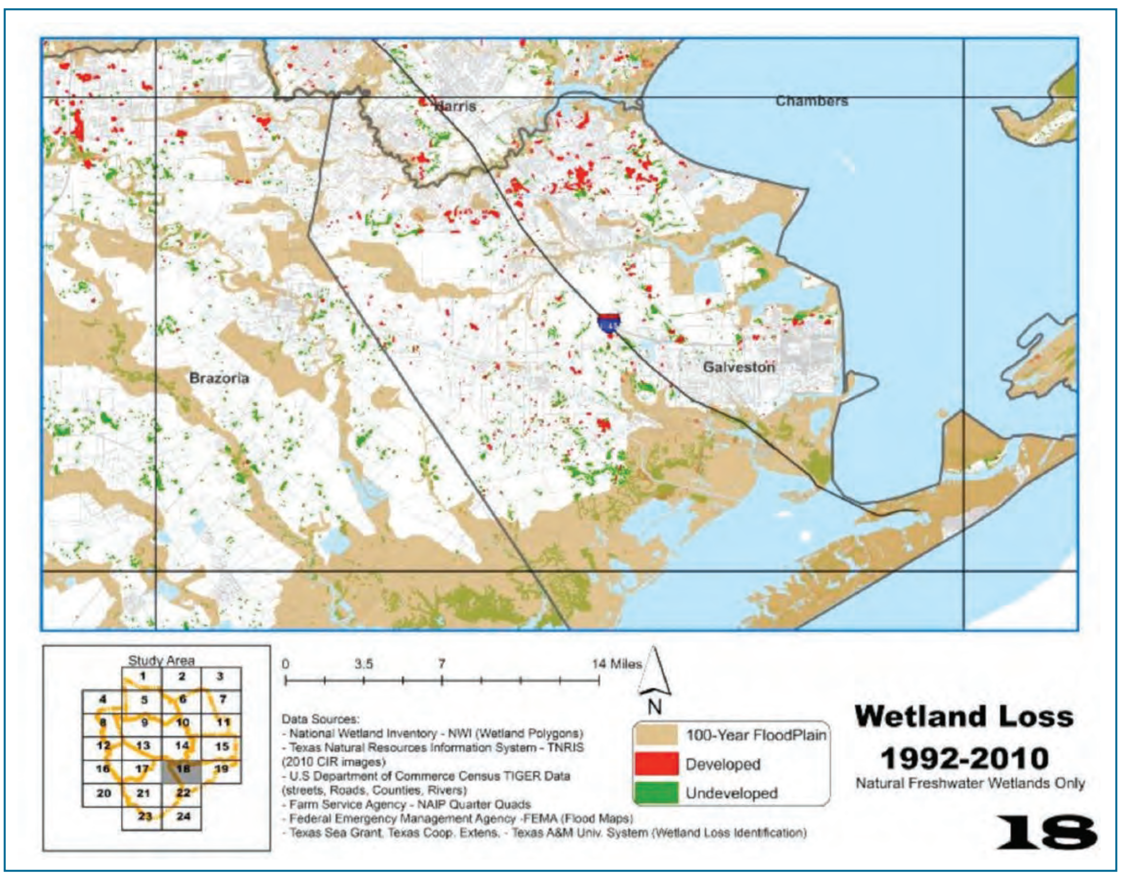

Waller
Harris
Fort Bend
Brazoria
Study Area
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
13

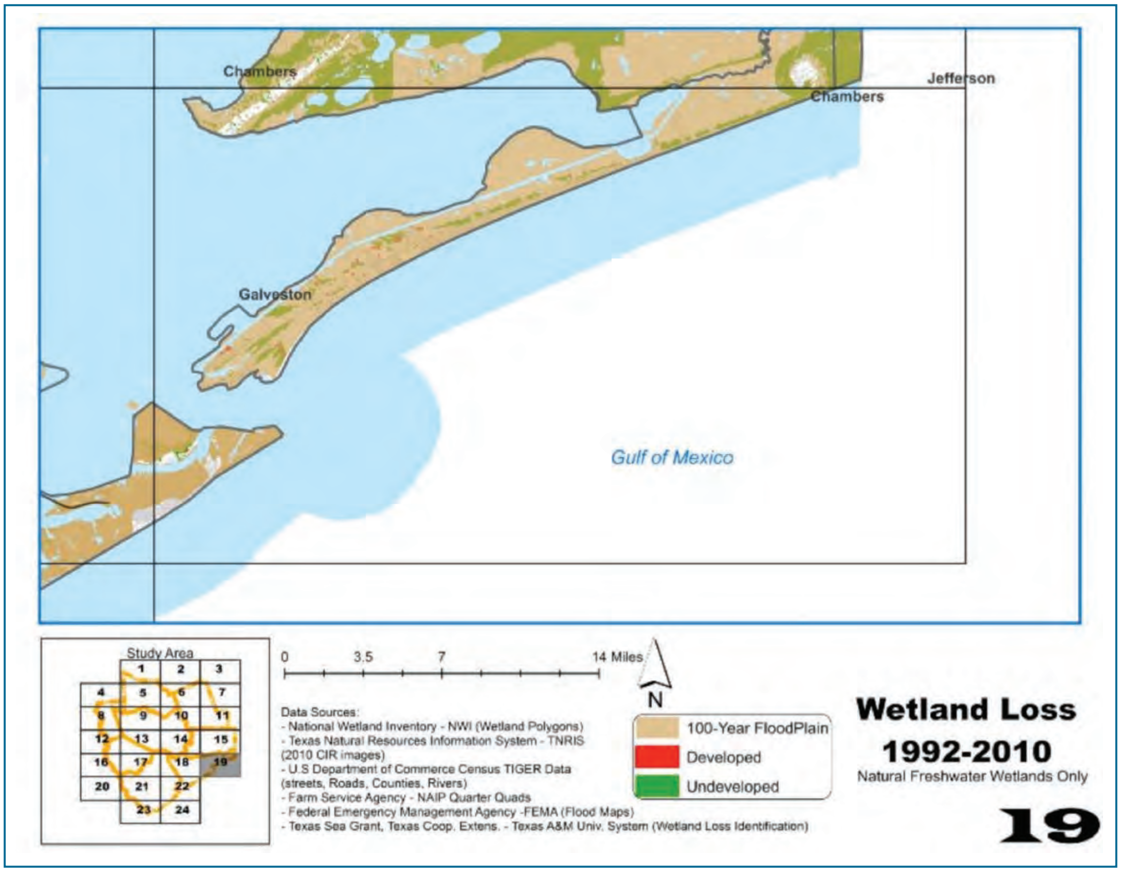

Liberty
Harris
Chambers
Brazoria
Galveston
Galveston
Galveston
Study Area
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
14

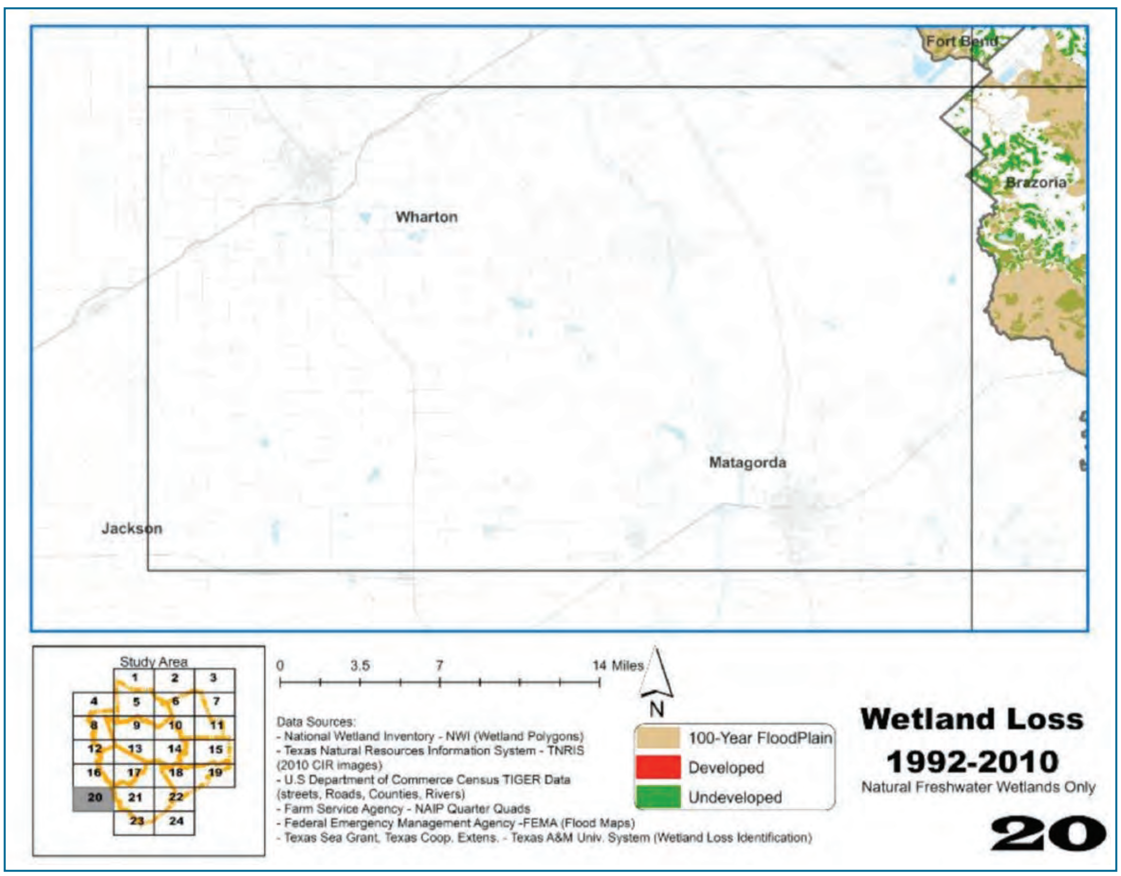

Liberty
Chambers
Jefferson
Galveston
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
15

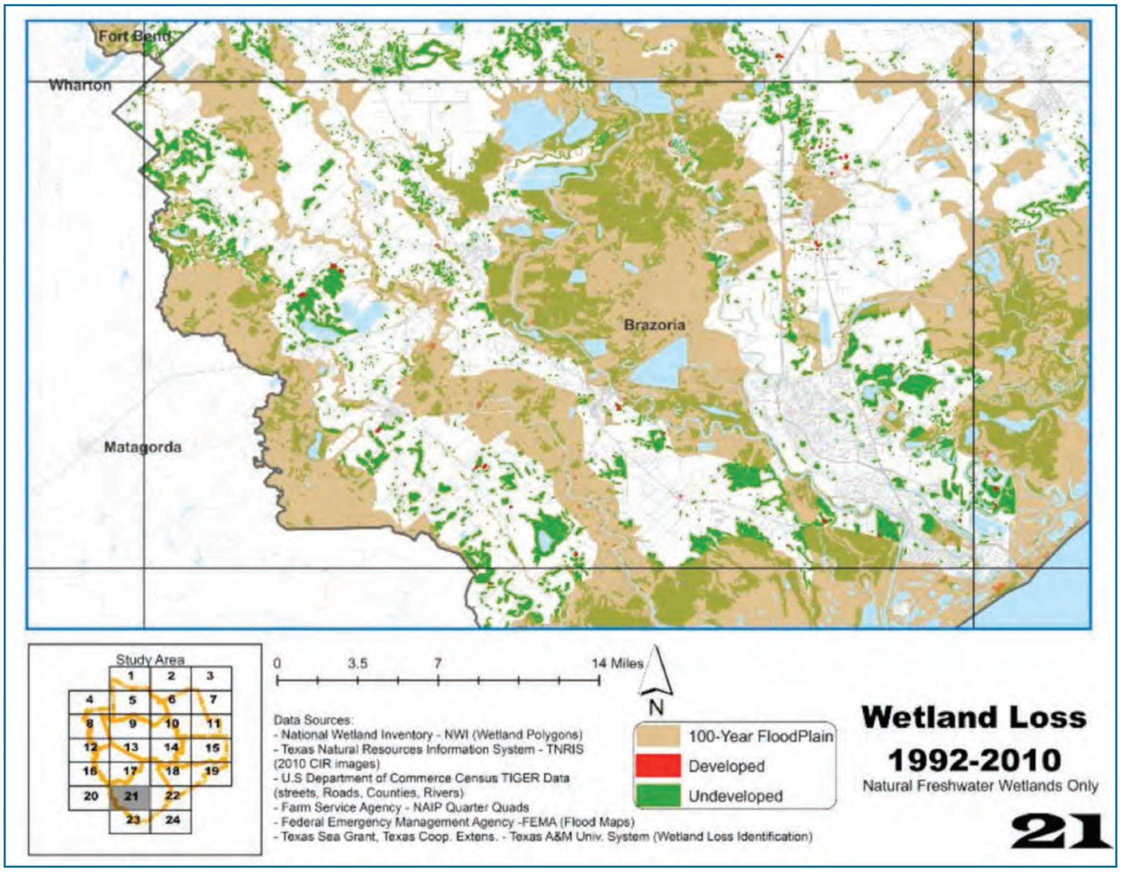

Colorado
Fort Bend
Wharton
Brazoria
Matagorda
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
16


Harris
Harris
Fort Bend
Brazoria
Wharton
Matagorda
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
17


Harris
Chambers
Brazoria
Galveston
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
18


Chambers
Jefferson
Chambers
Galveston
Gulf of Mexico
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
19


Fort Bend
Brazoria
Wharton
Matagorda
Jackson
Study Area
0 3.5 7 14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
20



Fort Bend
Wharton
Brazoria
Matagorda
Study Area
0 3.5 7 14 Miles
N
Data Sources:
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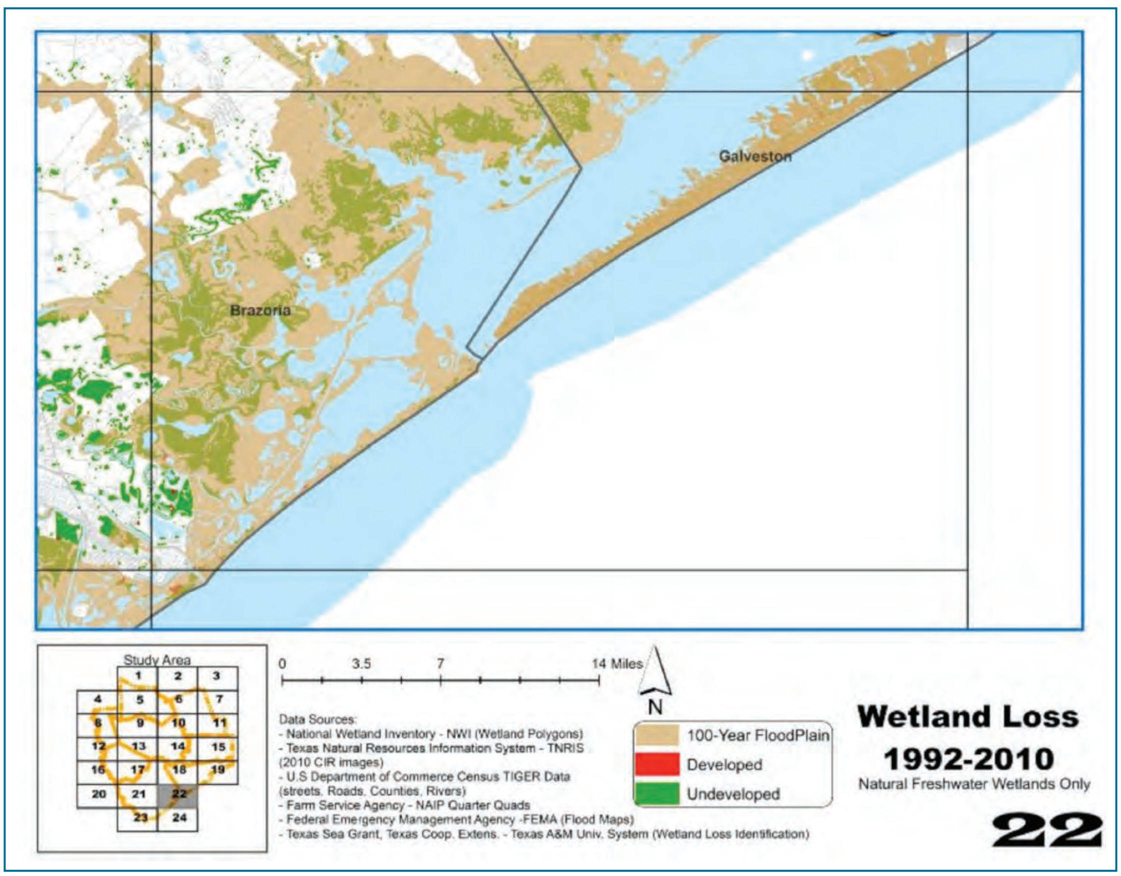
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
21



Galveston
Brazoria
Study Area
0 3.5 7 14 Miles
N
Data Sources:
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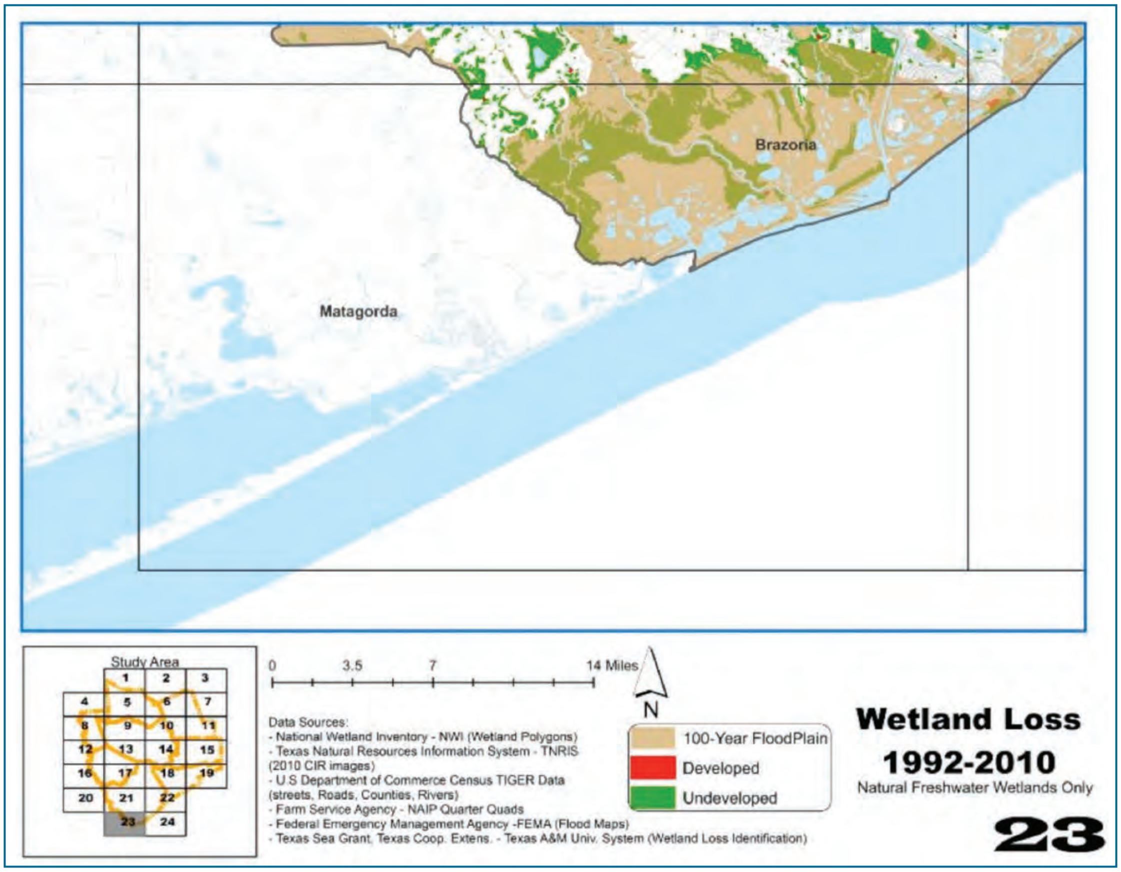
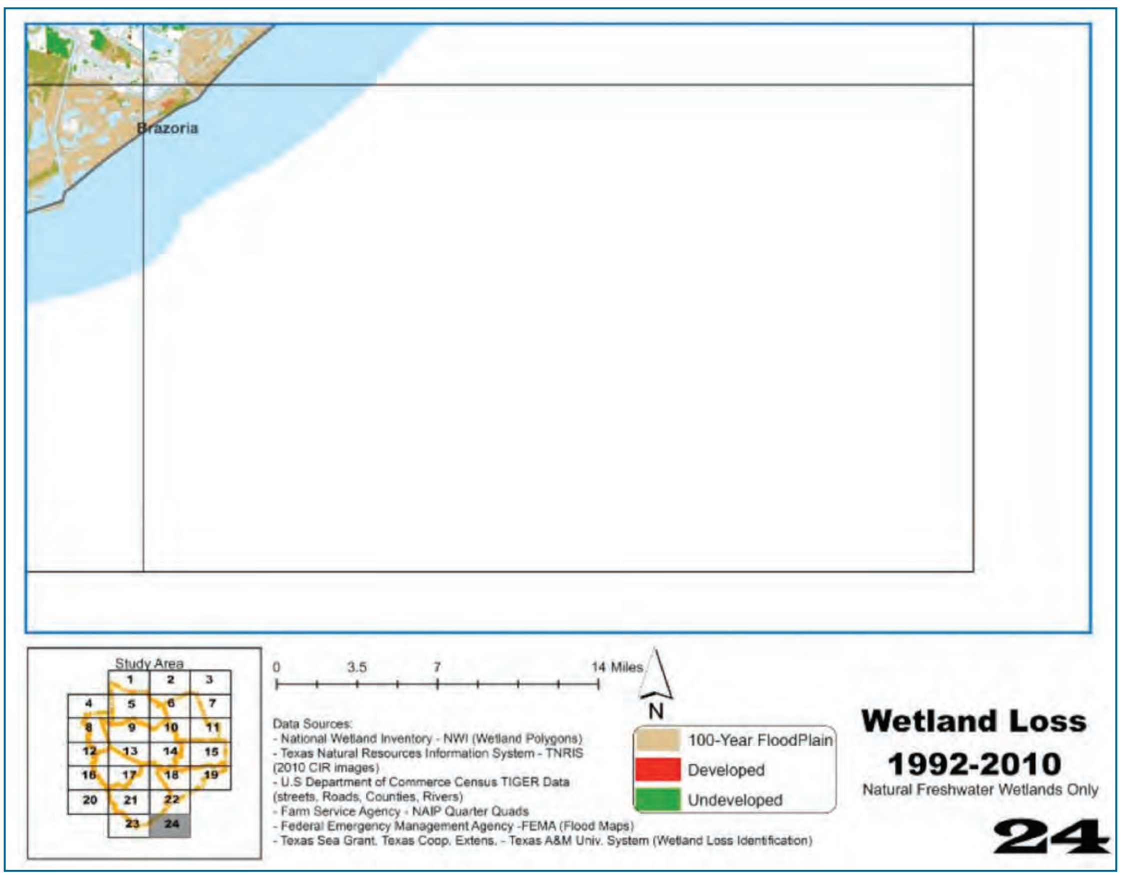
- Texas Natural Resources Information System - TNRIS (2010 CIR images)
- U.S Department of Commerce Census TIGER Data (streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
22



Brazoria
Matagorda
Study Area
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
0
3.5
7
14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS
(2010 CIR images)
- U.S Department of Commerce Census TIGER Data
(streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
23



Brazoria
Study Area
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
0
3.5
7
14 Miles
N
Data Sources:
- National Wetland Inventory - NWI (Wetland Polygons)
- Texas Natural Resources Information System - TNRIS
(2010 CIR images)
- U.S Department of Commerce Census TIGER Data
(streets, Roads, Counties, Rivers)
- Farm Service Agency - NAIP Quarter Quads
- Federal Emergency Management Agency -FEMA (Flood Maps)
- Texas Sea Grant, Texas Coop. Extens. - Texas A&M Univ. System (Wetland Loss Identification)
100-Year FloodPlain
Developed
Undeveloped
Wetland Loss
1992-2010
Natural Freshwater Wetlands Only
24

Appendix D: Cowardin Classification

Map codes of wetland habitat types used in this application follow the classification system in *Classification of Wetlands and Deepwater Habitats of the United States,* 1979, by Lewis M. Cowardin, et al.

The code structure is hierarchical, progressing from systems and subsystems, to classes, subclasses, and dominance types. Modifiers for water regime, water chemistry and soils are applied to classes, subclasses and dominance types. Special modifiers describe wetlands and deepwater habitats that have been created or highly modified by people or beavers.

Wetlands and deepwater habitats classification

```
System         Subsystem            Class                   Subclass
                                    |- Rb=Rock Bottom                  1=Bedrock
                                    |                                  2=Rubble
                                    |
                                    |- Ub=Unconsolidated Bottom  1=Cobble-Gravel
                                    |                                  2=Sand
                                    |                                  3=Mud
                                    |                                  4=Organic
                                    |
                     |-- 1=Subtidal------|- Ab=Aquatic Bed       1=Algal
                     |              |                                  3=Rooted Vascular
                     |              |                                  5=Unknown Submergent
                     |              |
                     |              |- Rf=Reef                         1=Coral
                     |              |                                  3=Worm
                     |              |
                     |              |- Ow=Open Water/Unknown Bottom (Used On Older Maps)
M=Marine------       |
                     |
                     |              |- Ab=Aquatic Bed                  1=Algal
                     |              |                                  3=Rooted Vascular
                     |              |                                  5=Unknown Submergent
                     |              |
                     |              |- Rf=Reef                         1=Coral
                     |-- 2=Intertidal---  |                      3=Worm
                     |
                                    |- Rs=Rocky Shore                  1=Bedrock
                                    |                                  2=Rubble
                                    |
                                    |- Us=Unconsolidated Shore   1=Cobble-Gravel
                                                                       2=Sand
                                                                       3=Mud
                                                                       4=Organic
```

System	Subsystem	Class	Subclass
E=Estuarine	1=Subtidal	Rb=Rock Bottom	1=Bedrock
			2=Rubble
		Ub=Unconsolidated Bottom	1=Cobble-Gravel
			2=Sand
			3=Mud
			4=Organic
		Ab=Aquatic Bed	1=Algal
			3=Rooted Vascular
			4=Floating Vascular
			5=Unknown Submergent
			6=Unknown Surface
		Rf=Reef	2=Mollusc
			3=Worm
		Ow=Open Water/Unknown Bottom (Used On Older Maps)	
	2=Intertidal	Ab=Aquatic Bed	1=Algal
			3=Rooted Vascular
			4=Floating Vascular
			5=Unknown Submergent
			6=Unknown Surface
		Rf=Reef	2=Mollusc
			3=Worm
		Sb=Streambed	3=Cobble-Gravel
			4=Sand
			5=Mud
			6=Organic
		Rs=Rocky Shore	1=Bedrock
			2=Rubble
		Us=Unconsolidated Shore	1=Cobble-Gravel
			2=Sand
			3=Mud
			4=Organic
		Em=Emergent	1=Persistent
			2=Nonpersistent
		Ss=Scrub-Shrub	1=Broad-Leaved Deciduous

```
System          Subsystem          Class                                    Subclass
                                        |
                                        |                                               2=Needle-Leaved Deciduous
                                        |                                               3=Broad-Leaved Evergreen
                                        |                                               4=Needle-Leaved Evergreen
                                        |                                               5=Dead
                                        |                                               6=Indeterminate Deciduous
                                        |                                               7=Indeterminate Evergreen
                                        |
                                        |- Fo=Forested                            1=Broad-Leaved Deciduous
                                                                                        2=Needle-Leaved Deciduous
                                                                                        3=Broad-Leaved Evergreen
                                                                                        4=Needle-Leaved Evergreen
                                                                                        5=Dead
                                                                                        6=Indeterminate Deciduous
                                                                                        7=Indeterminate Evergreen
                                        |- Rb=Rock Bottom                               1=Bedrock
                                        |                                               2=Rubble
                                        |
                                        |- Ub=Unconsolidated Bottom               1=Cobble-Gravel
                                        |                                               2=Sand
                |--1=Tidal----------   |                                          3=Mud
                |                       |                                               4=Organic
                |                       |
                |                       |-*Sb=Streambed                                 1=Bedrock
                |                       |                                               2=Rubble
                |                       |                                               3=Cobble-Gravel
                |--2=Lower              |                                               4=Sand
                | Perennial----        |                                          5=Mud
                |                       |                                               6=Organic
                |                       |                                               7=Vegetated
                |                       |
                |                       |- Ab=Aquatic Bed                               1=Algal
R=Riverine---   |--3=Upper              |                                               2=Aquatic Moss
                | Perennial----        |                                          3=Rooted Vascular
                |                       |                                               4=Floating
                |                       |                                                Vascular
                |                       |                                               5=Unknown
                |                       |                                                Submergent
                |-4=Intermittent-      |                                          6=Unknown Surface
                |                       |
                |                       |- Rs=Rocky Shore                               1=Bedrock
```

System | Subsystem | Class | Subclass

```
                    |                 |                                    2=Rubble
                    |                 |
                    |                 |- Us=Unconsolidated Shore     1=Cobble-Gravel
                    |--5=Unknown   |                                 2=Sand
                    | Perennial----|                                 3=Mud
                    (Used On Older |                                 4=Organic
                    Maps)          |                                 5=Vegetated
                                      |
                                      |-**Em=Emergent                        2=Nonpersistent
                                      |
                                      |- Ow=Open Water/Unknown Bottom (Used On Older Maps)
                                      |
                                      |-*Streambed Is Limited To Tidal And
                                      | Intermittent Subsystems, And Comprises
                                      | The Only Class In The Intermittent Subsystem.
                                      |
                                      |-**Emergent Is Limited To Tidal And Lower
                                      | Perennial Subsystems.


                                      |- Rb=Rock Bottom                       1=Bedrock
                                      |                                      2=Rubble
                                      |
                                      |- Ub=Unconsolidated Bottom    1=Cobble-Gravel
                                      |                                      2=Sand
                                      |                                      3=Mud
                                      |                                      4=Organic
                                      |
                    |-- 1=Limnetic----- |- Ab=Aquatic Bed                    1=Algal
                    |                 |                                      2=Aquatic Moss
                    |                 |                                      3=Rooted Vascular
                    |                 |                                      4=Floating Vascular
                    |                 |                                      5=Unknown Submergent
                    |                 |                                      6=Unknown Surface
                    |                 |
                    |                 |- Ow=Open Water/Unknown Bottom (Used On Older
                    |                                          Maps)
L=Lacustrine----|
                    |
                    |                 |- Rb=Rock Bottom                       1=Bedrock
                    |                 |                                      2=Rubble
                    |                 |
                    |                 |- Ub=Unconsolidated Bottom    1=Cobble-Gravel
                    |                 |                                      2=Sand
                    |                 |                                      3=Mud
                    |                 |                                      4=Organic
                    |                 |
                    |                 |- Ab=Aquatic Bed                      1=Algal
                    |                 |                                      2=Aquatic Moss
```

System	Subsystem	Class	Subclass
			3=Rooted Vascular
			4=Floating
	2=Littoral-----		Vascular
			5=Unknown Submergent
			6=Unknown Surface
		Rs=Rocky Shore	1=Bedrock
			2=Rubble
		Us=Unconsolidated Shore	1=Cobble-Gravel
			2=Sand
			3=Mud
			4=Organic
			5=Vegetated
		Em=Emergent	2=Nonpersistent
		Ow=Open Water/Unknown Bottom (Used On Older Maps)	
		Rb=Rock Bottom	1=Bedrock
			2=Rubble
		Ub=Unconsolidated Bottom	1=Cobble-Gravel
			2=Sand
			3=Mud
			4=Organic
		Ab=Aquatic Bed	1=Algal
			2=Aquatic Moss
			3=Rooted Vascular
			4=Floating Vascular
			5=Unknown Submergent
			6=Unknown Surface
		Us=Unconsolidated Shore	1=Cobble-Gravel
			2=Sand
			3=Mud
			4=Organic
			5=Vegetated
		Ml=Moss-Lichen	1=Moss
			2=Lichen
P=Palustrine--		Em=Emergent	1=Persistent
			2=Nonpersistent
		Ss=Scrub-Shrub	1=Broad-Leaved Deciduous
			2=Needle-Leaved Deciduous

```
System          Subsystem           Class                       Subclass
                     |                                                                  3=Broad-Leaved Evergreen
                     |                                                                  4=Needle-Leaved Evergreen
                     |                                                                  5=Dead
                     |                                                                  6=Indeterminate Deciduous
                     |                                                                  7=Indeterminate Evergreen
                     |
                     |- Fo=Forested                                          1=Broad-Leaved Deciduous
                     |                                                                  2=Needle-Leaved Deciduous
                     |                                                                  3=Broad-Leaved Evergreen
                     |                                                                  4=Needle-Leaved Evergreen
                     |                                                                  5=Dead
                     |                                                                  6=Indeterminate Deciduous
                     |                                                                  7=Indeterminate Evergreen
                     |
                     |- Ow=Open Water/Unknown Bottom (Used On Older Maps)

                                        Modifiers
                                        |- A=Temporarily Flooded
                                        |- B=Saturated
                                        |- C=Seasonally Flooded
                                        |- D=Seasonally Flooded/Well Drained
                                        |- E=Seasonally Flooded/Saturated
                                        |- F=Semipermanently Flooded
                     |--Non-Tidal----------     |- G=Intermittently Exposed
                     |                  |- H=Permanently Flooded
                     |                  |- J=Intermittently Flooded
                     |                  |- K=Artificially Flooded
                     |                  |- W=Intermittently Flooded/Temporary (Used On Older Maps)
                     |                  |- Y=Saturated/Semipermanent/Seasonal (Used On Older Maps)
                     |                  |- Z=Intermittently Exposed/Permanent (Used On Older Maps)
Water Regime-        |                  |- U=Unknown
                     |
                     |
                     |
                     |                  |- K=Artificially Flooded
                     |                  |- L=Subtidal
                     |                  |- M=Irregularly Exposed
                     |                  |- N=Regularly Flooded
                     |--Tidal----------------|- P=Irregularly Flooded
```

System **Subsystem** **Class** **Subclass**

|-*S=Temporary-Tidal
|-*R=Seasonal-Tidal
|-*T=Semipermanent-Tidal
|-*V=Permanent-Tidal
|- U=Unknown
|
|-*These water regimes are only used in
| tidally influenced, freshwater systems.

|- 1=Hyperhaline
|- 2=Euhaline
|--Coastal |- 3=Mixohaline (Brackish)
| Salinity------------ |- 4-Polyhaline
| |- 5=Mesohaline
| |- 6=Oligohaline
| |- 0=Fresh
|
|
Water-Chemistry |
| |- 7=Hypersaline
|--Inland |- 8=Eusaline
| Salinity------------ |- 9=Mixosaline
| |- 0=Fresh
|
|
|
|--Ph Modifiers |- A=Acid
For All |- T=Circumneutral
Fresh Water------ |- I=Alkaline

Soil-- |- G=Organic
|- N=Mineral

|- B=Beaver
|- D=Partially Drained/Ditched
Special Modifiers----------------------- |- F=Farmed
|- H=Diked/Impounded
|- R=Artificial Substrate
|- S=Spoil
|- X=Excavated

U = Uplands

Appendix E: Freshwater wetland loss geo-spatial data processing

The analysis and mapping of wetland loss to development involves at its simplest level comparing the 1992 National Wetland Inventory (NWI) polygons with the most recent aerial photography available (2010). Development has a markedly different pattern than undisturbed wetlands, which makes it easy to delineate the developed area (see Figs. 7 through 11 in the text).

To perform the geospatial processing, 2010 NAIP color infrared (CIR) images were used as backdrop imagery where 1992 NWI data in digital format were merged, overlaid, and edited using heads-up digitizing (on-screen). NWI polygon features were cut to reflect destruction of wetlands due to urban development or other causes. NWI attribute tables were modified to include a field that tracks polygon change.

Other fields were added to individual NWI dataset attribute tables before merging, to facilitate analysis and exporting of detailed data at different levels: quarter quads, county, watershed, or the whole study area. The entire geoprocessing effort is described below.

1. Input data

1.1. Study area

The Greater Houston Metro Area is covered by 600 NAIP quarter quadrangles. The study area covers the eight counties surrounding and including Harris County.

1.2 Wetlands vector data

Wetland datasets from 1992 and 1993 were downloaded in shapefile (.shp) format from the official NWI website (http://www.fws.gov/wetlands/Data/Data-Download.html).

All NWI datasets were merged using the same coordinate system, projection, and datum (Universal Transverse Mercator (UTM) projection, Zone 15 using NAD 83 datum, units: meters). Output vector datasets were re-projected and delivered using different projections to allow users to correctly overlay vector data to raster imagery stored in different coordinate systems.

The quarter quads were used as a layer to keep track of the reviewed and marked wetland polygons.

1.3 Aerial photography

The 2010 NAIP 1M CIR aerial images from the Texas Natural Resources Information System were used for each county. These photos have the following projection and datum:

Universal Transverse Mercator projection, zone 15. Datum: NAD 1983. Units: meters.

1.4 Floodplain data

100-year floodplain data was taken from National Flood Hazard Layer dataset, which is a compilation of the effective Digital Flood Insurance Rate Map database and Letters of Map Changes for Texas.

For Harris, Waller, and Liberty Counties, 2012 floodplain data were used; for Galveston, Fort Bend, Brazoria, Chambers, and Montgomery Counties, the 1996 FEMA Q3 floodplain data were used. A DVD of the 2012 data was ordered from FEMA's product catalog: https://msc.fema.gov/webapp/wcs/stores/servlet/StoreCatalogDisplay?storeId=10001&catalogId=10001&langId=-1&userType=G

2. Geospatial processing

ESRI ArcGIS Desktop 10 and 10.1 were used as main editing software to perform the entire geo-processing.

2.1 NWI polygon editing

This step included modifying (cutting) polygon features where urban development or other change was detected, based on aerial imagery (TNRIS 2010 photos). The NWI shapefile was placed over the NAIP imagery to look for wetlands that were filled by development.

Then, the attribute table of the NWI polygon layer was edited simultaneously to reflect the cause of change. An additional field "DEV_2010" was added to the attribute table, to input the appropriate category of change (R, C/I, M etc.)

Each county NWI dataset was clipped out to work on separately so as to simplify the database. This process made the selection of any required attribute and the calculation of lost acreage and percentage much easier than with a combined dataset.

The following are the categories of change:

R: Residential

C/I: Commercial/Industrial

F: Filled

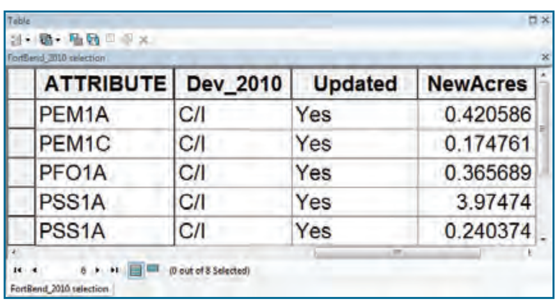
W: Water

D: Deforested

M: Mining

Deforested values were not considered in the calculations of wetland loss but were marked for future reference and more investigation on the logging process in the marked areas.

In addition, another field called "Calc_geo"/"Newacres" was created to calculate the geometry of the edited polygons in their respective coordinate systems, with the attributes of the acres of wetlands lost. An image of the attribute table is shown in Figure B1.



ATTRIBUTE	Dev_2010	Updated	NewAcres
PEM1A	C/I	Yes	0.420586
PEM1C	C/I	Yes	0.174761
PFO1A	C/I	Yes	0.365689
PSS1A	C/I	Yes	3.97474
PSS1A	C/I	Yes	0.240374

Figure B1: Attribute table

3. Map output

3.1 Atlas of wetland loss

A 24-page map book was created by defining data-driven pages using ArcMap 10.1 and exporting the maps into high resolution jpeg format for the purpose of the report. The grid was indexed and custom sized to cover the study area.

3.2 Tabular output data

MS Excel was the main program used to produce tabular reports. The attribute table in GIS was also used to perform statistics that were then incorporated into Excel.

MS Excel

MS Excel files were first created by exporting the ARCGIS attribute table into a DBF file and then reading and converting this file into an MS Excel worksheet file format. Further calculations were performed using Excel's embedded mathematical functions. (See Appendix A for tabular results).

The tables in Excel were sorted and calculated according to the requirements (Fig. B2). For example, the exported data was sorted by attribute and then each of the attributes was summed to come up with the value of each type. The number of each type of development was also calculated by sorting the data by the development type (C/I, R, M, F, W).

The geometry of wetlands was calculated mostly in the NAD 1983 UTM zone 15N projected coordinate system. Wetland loss within floodplains was calculated in NAD_1983_StatePlane_Texas_South_Central_FIPS_4204_Feet Projected Coordinate System.

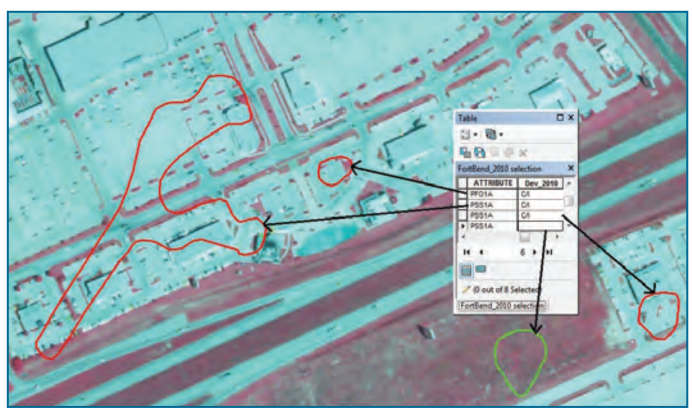


Figure B2: Wetland polygon from the NWI overlain on 2010 color photo. The developed area is cut out and reclassified as "C/I" (Commercial/Industrial) in the attribute table. The undeveloped area is left blank in the new field for 2010 status. A query method allows the change in the 1992–3 wetlands to be calculated.

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