Element A: Identify Sources of Impairments and Loads

Stormwater Runoff is a fingerprint of the land

Water pollutants originate from both point and NPS on the land. Point sources have an identifiable origin such as a pipe or ditch from an industrial or commercial process discharging directly into a waterway. Discharges from point sources are usually covered by federal and state regulations and permits. Stormwater NPS pollution, also commonly called *runoff pollution*, refers to diffuse sources of pollution originating from multiple locations, such as lawns, roadways, homes, and businesses. Runoff from NPS is commonly understood to include fertilizers, insecticides, oils, sediment, and bacteria. Each NPS source might be small, but when considered together, they can exceed the pollution contribution from point sources. In fact, in many watersheds around the county, NPS pollution is the leading cause of water quality problems.

This means that how land is used determines what we see in the water. Development, for example, impacts both the *quantity* and the *quality* of stormwater runoff. Impervious surfaces alter stormwater runoff patterns and are a key indicator of loading and overall watershed health (Figure A-1). Impervious surfaces include all hard surfaces, such as roofs, driveways, parking lots, roadways, and even compacted soil. Due to changes in surface cover, developed or urbanized areas exhibit higher stormwater pollutant levels when compared with their pre-development runoff levels. As the amount of impervious surface cover increases in the watershed, the water quality of receiving water bodies degrades. Two neighboring properties, one developed and one undeveloped, both receive the same amount of rainfall but exhibit different runoff characteristics. The undeveloped property will allow water to infiltrate into the ground while the developed property sees increased runoff.

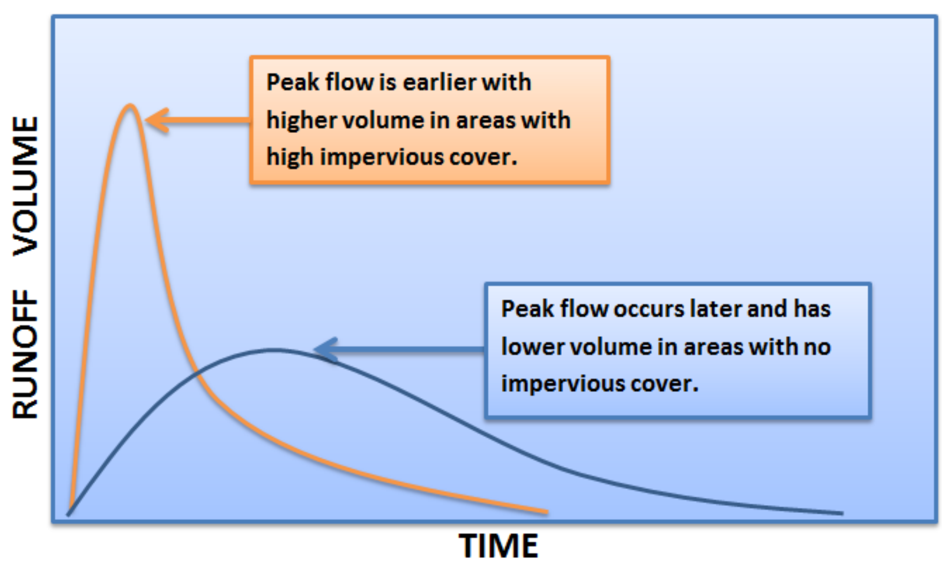


Figure A- 1. Generalized Hydrograph of Areas With and Without Impervious Surface Cover The Origin Denotes the Rainfall Event

NPS Quadrants in Highland Bayou

Stakeholder concerns about water quality were gathered and organized by the project team through a series of meetings and one-on-one conversations. The project team organized these concerns into four major categories. These quadrants were used to organize ideas and focus conversations on particular areas of activity (Figure 2). It is worth noting here that ‘Flow and Dredging’ (technically, hydrologic changes) is an unusual category for a WPP and is not itself a ‘source’ of pollutant loading. However, this quadrant was a primary concern for many, many stakeholders, and the prospect of addressing the bayou’s flow conditions kept participants engaged. More on this background is discussed in sections below.

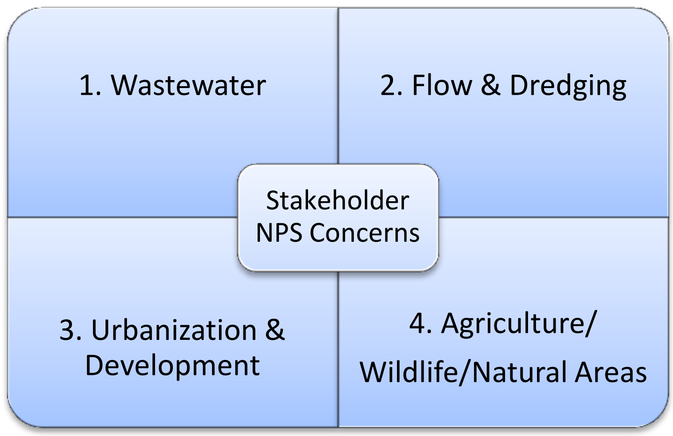


Figure A- 2. Quadrants used to organize project ideas

Activities associated these quadrants determine the NPS pollutant issues of significance and focuses the work group’s attention on what kinds of activities would be helpful for reducing NPS loads. The following table summarizes NPS sources that stakeholders discussed as likely contributors of NPS loads in the watershed.

Table A- 1. Pollutants by Source

Source	Bacteria	Nutrients [1]	Sediment
Quadrant 1: Wastewater			
Wastewater Treatment Facilities	x	x	
Sanitary Sewer Systems	x	x	
Septic Systems (OSSFs)	x	x	
Quadrant 2: Flow & Dredging (see discussion below)			
Quadrant 3: Urbanization & Development			
Urban Stormwater Runoff	x	x	x
Construction Runoff			x

Source	Bacteria	Nutrients [1]	Sediment
Lawn Care & Landscaping		x	x
Litter and Illegal Dumping		x	
Pets	x	x	
Quadrant 4: Agriculture/Wildlife/Natural Areas			
Feral Hogs	x		
Livestock and Pasture	x	x	x
Wildlife and Non Domestic Animals	x	x	x
Streambank Erosion		x	x

[1] Nutrients – nitrogen and phosphorus compounds.

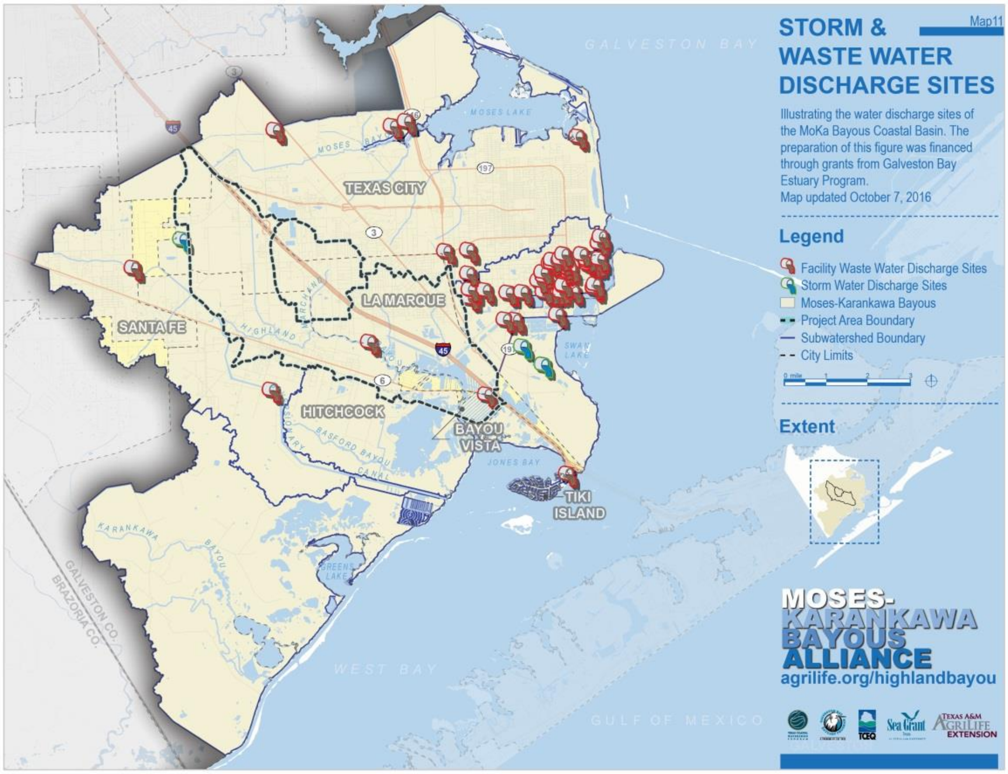
Quadrant 1: Wastewater

Permitted Wastewater Treatment Facilities

There are two permitted wastewater treatment facilities in the watershed. (Map-11). The Galveston County Municipal Utility District (MUD) 12 Wastewater Treatment Plant (WWTP) and La Marque's Westside WWTP discharge into Highland Bayou. These two major sources, City of Hitchcock and La Marque's Westside facility, are authorized by the TCEQ to discharge treated wastewater at a volume not to exceed an annual average flow of 3 million gallons per day (MGD). The Galveston County MUD 12 facility, considered a minor source, is authorized to discharge a daily average flow at a volume not to exceed 0.4 MGD. While the City of Hitchcock's WWTP lies outside of the watershed boundaries and discharges to the Diversionary Canal (a separate watershed), much of the associated collection system occurs within the Highland Bayou Watershed.

Table A-2 lists current permit and discharge information for the three permitted WWTPs. In the last five years La Marque has had three TCEQ inspections and Galveston County MUD 12 has had two, none resulting in enforcement actions. Two formal enforcement actions were reported for the City of Hitchcock. There have been nine reported effluent exceedances for both Hitchcock and La Marque and one for Galveston County MUD 12 between 7-31-2012 and 7-31-2015. Effluent measurements in Table A-2 are reported for the 2014 calendar year to ensure a complete dataset (at the time of the request, November and December 2015 data was unavailable). The *Enterococci* daily maximum threshold was exceeded during only on month for both the City of Hitchcock and Galveston County MUD 12. Other effluent parameters remain within discharge limits: nitrogen (ammonia total, as nitrogen), biochemical oxygen demand, and flow. Though not reported in the table, the following exceedances were noted for January through October 2015.The La Marque facility had nitrogen exceedances during three separate months. The daily average value for nitrogen for both the City of Hitchcock and La Marque facilities showed an approximate 200% increase when compared with 2014 values. Average nitrogen measured in lbs/day for the La Marque facility was 16.45 in 2014 and 47.27 in 2015. Average nitrogen measured in lbs/day for the Hitchcock facility was 1.60 in 2014 and 4.93 in 2015. The City of Hitchcock had an *Enterococci* daily maximum value exceedance during only month of 149 CFU/100mL. In October of

2015, the La Marque facility had a daily maximum value of 2420 CFU/100mL, their only exceedance of the 104 CFU/100mL discharge limitation. MUD 12 did not report any effluent limitation exceedances for January through October 2015.



Map- 11. Storm and Wastewater Discharge Sites

The Galveston County Health District (GCHD) Water Pollution Services Program offers quarterly inspections of WWTP operations for compliance with state and federal regulations as a contract, and have assisted Hitchcock and La Marque as recent as 2015. For the City of La Marque in FY2015, the GCHD reported an annual average removal rate for ammonia nitrogen of 88%, which exceeds the monthly removal rate of 85% required by the permit. The average *Enterococci* quantity was 1.53 CFU/100mL.

WWTP effluent is considered a point source of pollution, highly regulated through the Texas Pollutant Discharge Elimination System (TPDES) program. Due to the episodic nature of discharges that exceed established thresholds for bacteria and other contaminants, stakeholders expressed greater concern for releases from the sanitary sewer collection system. With additional growth in the basin and extra sewage to treat, it is reasonable to expect volumes to increase accordingly though discharges would be required to remain within the permit limitations.

Table A- 2. Permitted Wastewater Treatment Facilities in the Project Area including Permit and Discharge Information

		City of Hitchcock WWTP (Hitchcock)	Galveston County MUD 12 WWTP (Hitchcock)	Westside WWTP (La Marque)
	EPA ID and TPDES Permit Number	TX0062243; WQ0010690001	TX0020311; WQ0010435002	TX0114821; WQ0010410003
	Permit Type and Expiration Date	Major; October 1, 2018	Minor; October 1, 2018	Major; October 1, 2016
	Receiving Waters	Diversionary Canal (outside of watershed); Collection system is in Highland Bayou Watershed	Highland Bayou	Highland Bayou
	Comprehensive Compliance Inspections (5 yrs)	4	2	3
	Effluent Exceedances (3 yrs)	9	1	9
	Formal Enforcement Actions (5 yrs)	2	0	0
	Date of Last Formal Action	04/07/2013	-	-
	Penalties (5 yrs)	$64,137	-	-
Effluent Measurements Calendar year 2014	Ammonia as N, NH_3 (lbs/year)	579	-	5,963
	BOD (lbs/year)	8,640	1,790	11,808
	Ammonia as N, NH_3 (lbs daily)	1.60	-	16.45
	BOD (lbs daily)	23.21	5.36	32.22
	Enterococci Daily Maximum Concentration (count/100mL)	**155**	**186**	93
	Enterococci Daily Average Concentration (count/100mL)	5.97	5.29	7.04
	Total Annual Flow (MMGal)	471	-	-
	Average Daily Flow (MGD)	0.61	-	1.41

" _ "
Bold values indicate an exceedance in reported discharge concentrations when compared to authorized permit limits.
Abbreviations: BOD – Biochemical Oxygen Demand; lbs – pounds; MGD – million gallons per day; MMGal – MGal/year x 12 (the number of months); MUD – municipal utility district; N – nitrogen; TPDES – Texas Pollutant Discharge Elimination System; WWTP – wastewater treatment plant
Data Source: EPA Discharge Monitoring Report Pollutant Loading Tool and TCEQ Region 12 Water Section staff.

Sanitary Sewer Systems

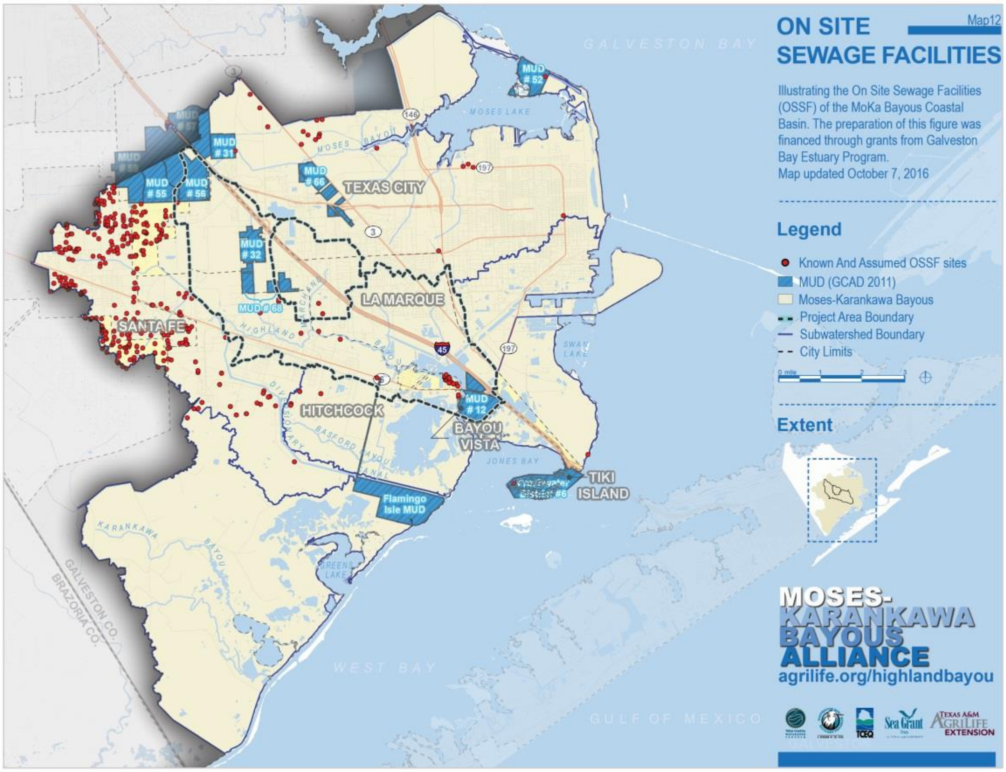
Collection systems bring sewage from home and businesses to wastewater treatment facilities. The collection systems include a network of sewer lines, pump stations, and supporting infrastructure. Most areas of the Highland Bayou Watershed are serviced by a collection system. Main lines usually follow highways and routes, into neighborhoods, and finally connecting to buildings. Anything poured or flushed down a drain flows into the collection system, meaning that sewage is a collection of human waste, urine, paper products, detergents, cosmetics, pharmaceuticals, cleaners, and any other liquids used at home or in businesses. SSOs are releases of untreated sewage from these collection systems. These releases can transmit high levels of bacteria to stormwater runoff. SSO of certain sizes or happening in certain locations (i.e., near drinking water sources) must be reported by the collection system TPDES permittee. SSOs usually occur as the result of a break, stoppage, or exceedance of capacity in the sanitary sewer conveyance system. If not directly discharged into the bayou, the overflows typically drain to the stormwater conveyance system and are transported to the bayou by stormwater runoff. Load reduction estimates are included in Element B. Since most of the watershed study area is serviced by a collection system, reductions are allocated on a pro-rated share of population in each watershed AU (Map-5).

Septic Systems

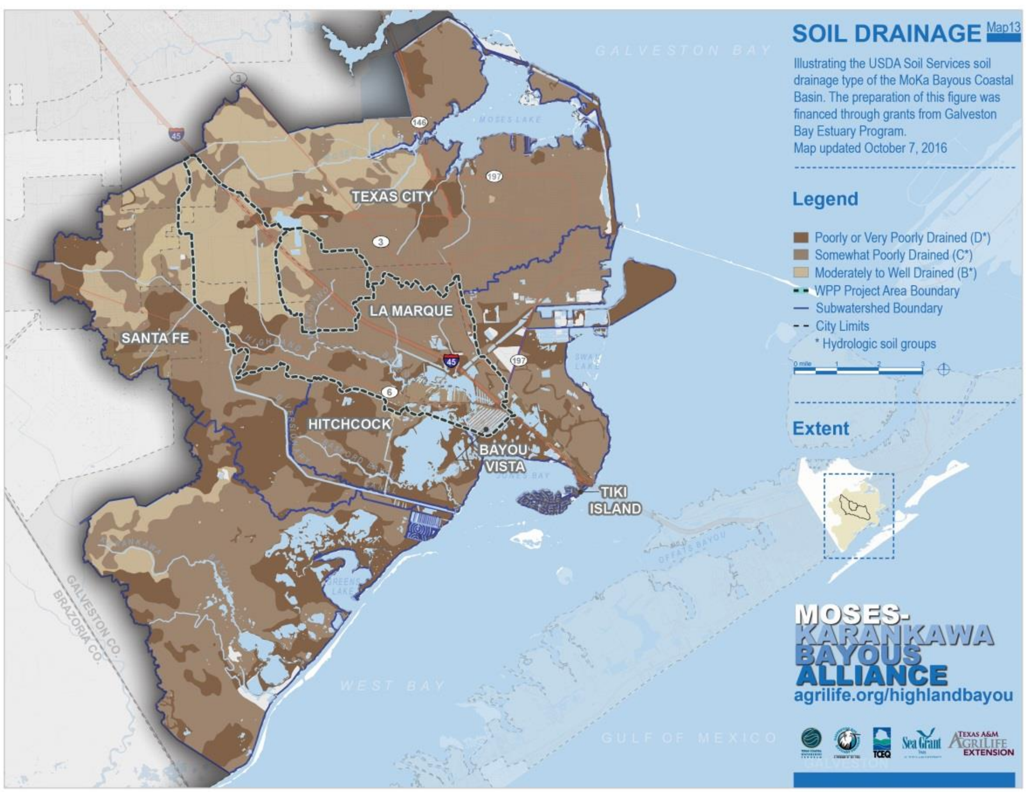
Onsite Sewage Facilities (OSSFs), commonly referred to as septic systems, are a standard method for treating home and business sewage on site. This is particularly true in areas of low population density. OSSFs within the watershed are not considered a significant source of pollutants for Highland Bayou. The number of permitted systems is low and unpermitted systems are assumed to be low, too. Known locations are based on permit information. Assumed locations are estimated by identifying structures both without a permitted OSSF and situated outside of a municipal service area boundary for sanitary sewer within the watershed; there is a cluster of OSSFs located near TX Highway 6 in the parts of unincorporated Galveston County, referred to as Freddiesville and Old Highland Bayou, just west of Bayou Vista. Parts of this area have been recently brought into Hitchcock's collection system service area. GCHD is sometimes contacted by residents reporting leakages from pipes and bulkheads in this area. These reports usually result in a determination that the leakage is connected to abandoned or unpermitted OSSFs. The area is limited in size and few other unknown OSSFs are believed to exist in the area. Outside of the watershed, the largest clusters of permitted OSSFs are in and around the City of Santa Fe, areas draining into the Diversionary Canal to the south or Dickinson Bayou to the north.

Although there are only a few OSSFs in the watershed, failing OSSFs contribute bacteria and nutrients by seepage from failing drain fields or from overflowing systems. Proper operation and maintenance of OSSFs is critical for protecting public health and surface water resources. System owners (i.e., homeowners) are responsible for the proper maintenance of their systems. Aerobic systems require specialized attention, and it is common that owners forget to add chlorine or utilize the wrong chlorine (i.e., pool chlorine). Poor or improper maintenance practices can result in the system becoming unbalanced and non-performing. With these kinds of failures, aerobic systems could be spraying raw sewage onto the ground. Maintenance agreements when required seem to help this.

Before the mid 1970's, no permit was required to install an onsite septic system in Galveston County, resulting in a legacy of unpermitted and possibly poorly performing or failing systems dotting the landscape. No federal permits are required for installing OSSFs. County regulations now require that the property owner acquire a permit and conduct a site evaluation of water tables and soil permeability, the two factors most likely to contribute to a septic system treatment failure. It is likely that older, unpermitted systems were not designed for the poor soil conditions especially if one assumes that the conventional soil leaching systems were used when they were installed in. Most soils in this watershed have shallow water tables and low permeability (Map-13). During periods of extended wet weather, there is a high probability of soil saturation, when untreated septage could rise to the surface and thence to nearby drainage ditches.



Map-12. Onsite Sewage Facilities



Map-13. USDA Soil Services Soil Drainage Types

Table A-3 includes the number of permits issued by year. (Source: Martin Entringer, Galveston County Health District in 2008.)

Table A- 3. Relative Change in Galveston County New OSSF Permits from Selected Years

Year	Percent standard soil treatment systems	Percent aerobic chlorinated (advanced) systems
1995	84	16
1998	68	32
2003	51	49
2006	23	77

Quadrant 2: Hydrologic Change- Flow and Dredging

Hydrological changes is an unusual NPS category and is not itself a pollutant 'source,' however it may impact loading characteristics in the bayou. Changes in the watershed since the 1970's has resulted in what stakeholders call a very perceptible change in the flow and character of the bayou. Stakeholders believe two forces are responsible for this. The first is the construction of the Diversionary Canal by the US Army Corps of Engineers in the early 1970's. Highland Bayou draining the City of Santa Fe was diverted at a point near Jack Brooks Park and into a constructed canal that now drains through the old Basford Bayou watershed south of Highland Bayou. The intent of the diversionary canal was to reduce flooding in Highland Bayou, but the resulting canal diverted over half of the headwaters towards another watershed. Floods do not occur as frequently now in Highland Bayou, but the average flow of water has predictably declined since then.

A second factor has been the steady development of the watershed over the decades. Sediment from development is transported down the drainage ditches and into the bayou. The combination of slower flow and increased accumulation of sediment has according to stakeholders resulted in a shallower and more stagnant bayou. Representatives from Drainage District 2 characterize the local soil as highly erodible, and they spend considerable resources managing and removing sediment from their ditches. The bayou channel itself, outside of the jurisdiction of the drainage district, has seen sediment accumulate. Several stakeholders shared pictures from decades ago of swimming holes in Highland Bayou that could be fished and used for jumping and swimming, places which now have only inches of stagnant, foul water.

The connection between hydrology and NPS loading is not entirely understood here. Many stakeholders in the watershed believe that an improved flow regime in the bayou would logically result in improved water quality. By dredging sediment from the bayou channel and managing the inflow of sediment, they believe that the bayou's flow conditions and tidal dynamics would improve. It is the opinion of the project team that the stakeholder group's foremost concern about the bayou's changes over the years is a powerful pathway for engaging community to understand the full range of land-based factors that are impacting the bayou. For this reason the project team has designated Flow and Dredging as a fully-fledged NPS quadrant.

Quadrant 3: Urbanization Activities

Construction

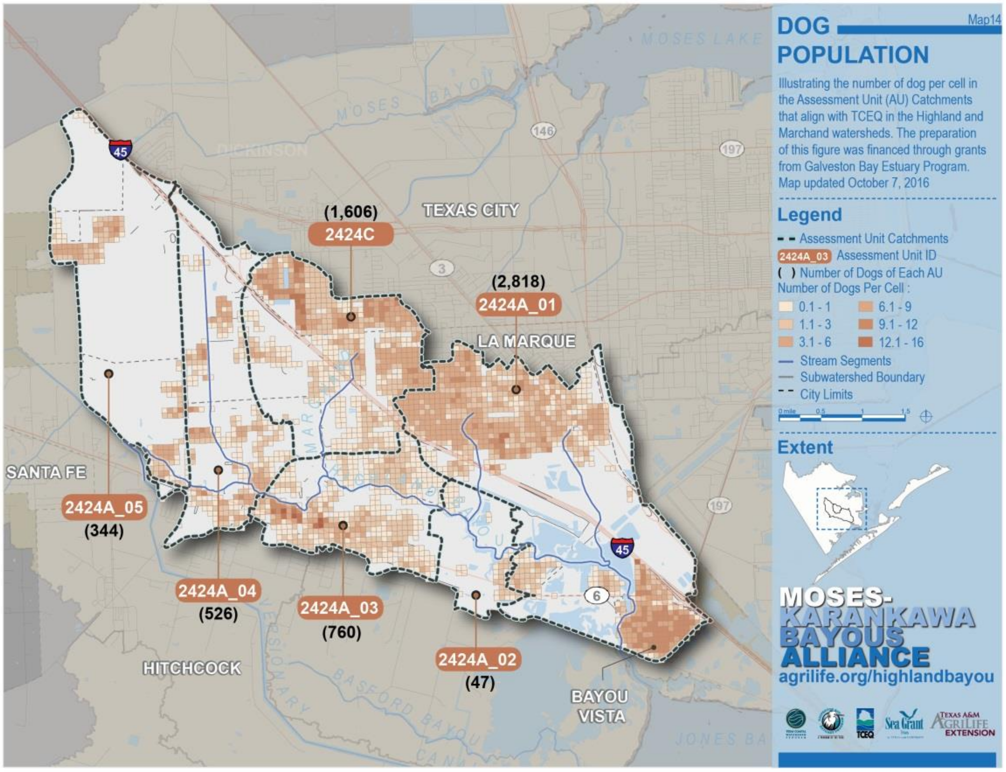
Construction and development activities usually disturb acres of soil surface and which can remain exposed for months or more. Disturbed surfaces include the construction pad, roads, maintenance yards, and newly excavated detention ponds. If not managed properly, erosion at these sites can transport significant sediment into drainage conveyances and eventually waterways. Erosion adds turbidity to the water column, and the accumulation of eroded sediment in waterways removes flow capacity and can harm habitat for aquatic species. As development continues into the watershed, particularly in the Highland bayou headwaters (AUs 2424A_4 and 2424A_5), the potential for sediment erosion is high. While Municipal Separate Storm Sewer Systems (MS4) rules are supposed to protect against construction site runoff, the impact of construction activities are still likely impacting the watershed.

Litter and Illegal Dumping

Stakeholders expressed concern for litter and illegal dumping near waterways and throughout the surrounding communities. Illegal dumping refers to improper disposal of tires, batteries, cars, boats, construction litter, and similar waste items. It has also been directly observed by the project team the illegal discharge of RV septic waste directly into the bayou. Problem areas for illegal dumping include vacant properties, dead end streets, the ditches along I-45, and within Highland Bayou Park (Stakeholder Meeting, 2015). Reducing litter and illegal disposal through clean-up efforts and community education would promote pride and awareness of the surrounding natural environment and good stewardship principals.

Pets

Dogs and cats are a significant contribution to surface water contamination when their fecal material is left on the ground (Environmental Protection Agency, 2001). Pet waste is washed into storm drains, where it eventually enters nearby surface waters and brings with it bacteria, resulting in conditions where fishing and swimming are not recommended and can lead to illness. Based on the number of homes and average pet ownership rates, it is estimated that there are over 5,000 dogs in the Highland Bayou Watershed, (see Map- 14 below). Since the Highland and Marchand Bayou watershed includes well developed areas, pet waste is expected to be a large source of contamination. Other pets such as horses, hogs, poultry, and rabbits exist in the watershed, but their numbers are not believed to be sizable enough to contribute significantly to bacteria levels.



Map- 14. Dog Population in the MoKa Coastal Basin

Lawn Care and Landscaping Practices

Improper management of landscaping debris, fertilizers, and pesticides was a prominent concern of stakeholders. Grass clippings, leaves, mulch and other plant matter swept or blown onto the road, driveway and storm drains introduce pollution to local waterways. There is a need for public education about water quality impacts associated with landscaping practices. Homeowner education for spraying pesticides was specifically recommended by stakeholders, including, how much to use, when to spray in relation to rain events, and for the homeowner to consider nearby waterbodies. Education for lawn contractors was also brought up by stakeholders as essential to reducing the amount of the above mentioned materials entering surface waters. Taken together, these related activities are a critical source of NPS load in developed areas.

Urban Stormwater: MS4

MS4s Phase II regulations began in 1999 to regulate the management of NPS pollution from MS4 systems, which refers to the system of stormwater conveyances that transfer stormwater into local waterways. Stormwater runoff is untreated and should not be confused with a centralized sewage treatment system. There are four Phase II regulated MS4s in the watershed, included in Table A-4 below. MS4 permittees must address 6 areas of stormwater management through local laws and enforcement. The primary concern of MS4s is the regulation of construction and post-construction activities, activities that generate disturbed soil surfaces and lead to erosion of sediment into the MS4 and local water ways.

MS4 entities must also have a program in place for illegal discharge detection and elimination, referring to non-stormwater discharges into the MS4.

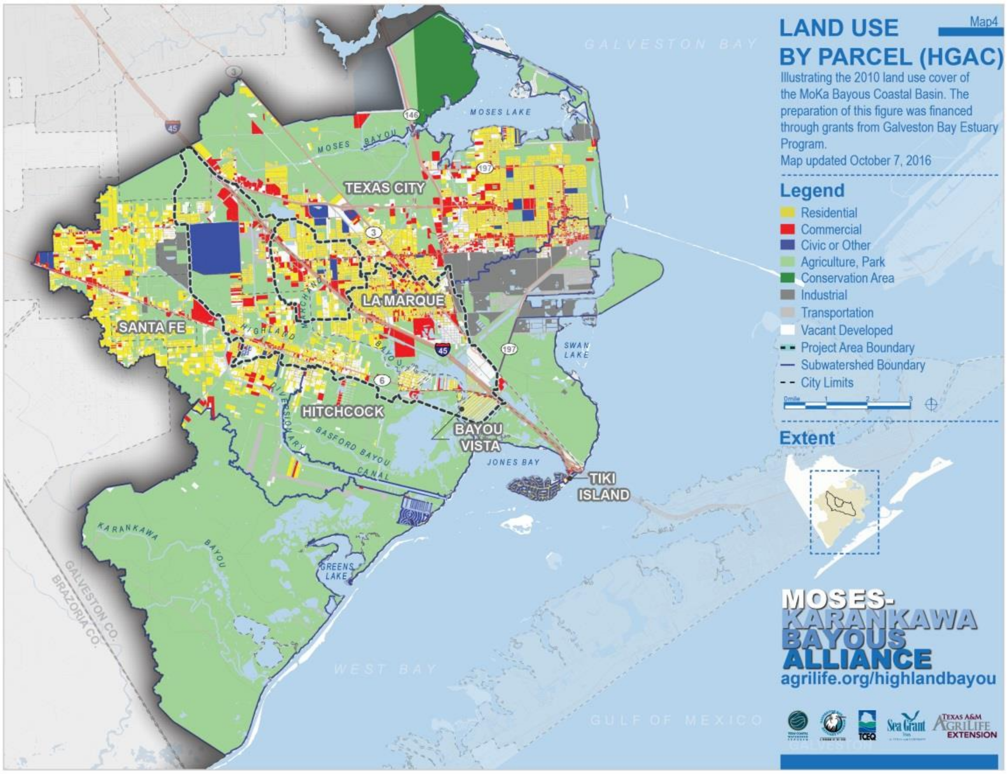
Table A- 4. Phase II Regulated MS4s in the Watershed

Regulated Entity Number	Active MS4 Permit	Permittee
RN105477434	TXR040590	City of Hitchcock
RN105538763	TXR040178	City of La Marque
RN105604987	TXR040364	Galveston County
RN105479513	TXR040024	City of Texas City

The GCHD Water Pollution Services Program monitors and evaluates stormwater samples for bacteria, DO, pH, chlorine, BOD, and ammonia. Many of the observed exceedances occur within three days of a rainfall event. During FY2015, bacteria levels at the eight stormwater sites within the City of La Marque exceeded the standard for single grab samples 50% of the time.

Urban Stormwater: Land Use

Land use is how people use the landscape (farm, pave, restore, etc) and what activities they conduct on that land (commercial, industrial, residential, etc). Map-4 illustrates existing land use on a parcel by parcel basis in the study area. The Houston-Galveston Area Council (H-GAC) assigned land use categories to data sets maintained by the Galveston County Appraisal District (CAD). Parcel data is primarily maintained for taxing purposes, but it can also inform an analysis for how land is ued. In addition, not every use is utilized at the same intensity across parcels. So, together with information about impervious surface and building density for certain uses, it is possible to estimate how much NPS pollution is generated in each subbasin- this is the approach utilized for NPS pollutant load estimates later in this section. Finally, the parcel land use map is useful in understanding where to emphasize certain public education efforts and implementation of Action Area projects.



Map- 4. 2010 Land Use Cover of the MoKa Coastal Basin

Urban Stormwater: Land Cover & Impervious Surface

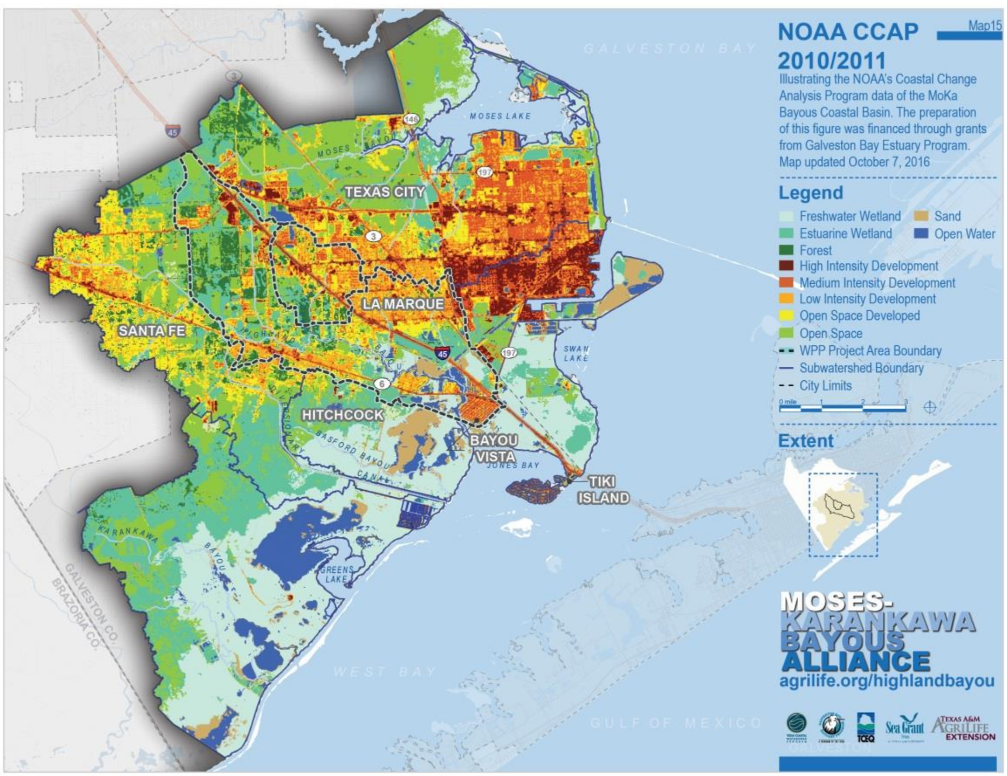
A land use-land cover change analysis was performed as part of this WPP effort, utilizing data from the National Oceanic and Atmospheric Agency (NOAA) Coastal Change Analysis Program (C-CAP) program, 1996-2010. The analysis looks at changes in how land is utilized and how much surface cover has increased from development over time. Maps and full tables of the analyses are included in Appendix 2, LULC Analyses. The following table (A-5) shows the increase in developed acreage in the watershed over a 14-year period. Impervious surface cover is the most important factor concerning land use changes and water quality indicators.

Table A- 5. Increase in Developed Land, Highland and Marchand Bayous, 1996-2010

Watershed	Acres developed 1996	Acres developed 2010	Relative % increase	Increase as a % of the watershed
Highland Bayou	3,397	3,687	8.5	2.4
Marchand Bayou	1,046	1,138	8.8	3.7
Total	4,443	4,825	8.6	3.2

Land Cover and Impervious Surface in Highland Bayou. Highland saw a 14-year increase of 381 acres in developed land, including a 57 acre increase in high intensity development. Agricultural lands declined by 39 acres, undeveloped vegetated space declined by 247 acres, and wetlands of all types declined by 88 acres; this resulted in a net loss of 374 acres of undeveloped land. A loss of 90 acres of open water potentially corresponds with the 83 acres gained as beach or unconsolidated land. Although some of this may result from new sand mining operations in the basin. Approximately 7% of all developed land was high intensity development, 22% was medium intensity, 40% as low intensity, and 31% as open developed land. Approximately 44% of land in the basin is classified as developed, and it is estimated that 16% of the watershed is impervious surface cover. See Appendix 2 for detailed tables and maps.

Land Cover and Impervious Surface in Marchand Bayou. The Marchand Bayou watershed saw a 14-year increase of 109 acres of developed land, including a 20 acre increase in high intensity development and a 43 acre increase in medium intensity development. Pastures and vegetated undeveloped land decreased by 66 and 35 acres respectively, and wetlands of all types decreased by 6 acres; this resulted in a net loss of 103 acres of undeveloped land. A loss of only 2 acres of total beach or unconsolidated land was lost, however total open water did not change. These values indicated that suburbanization is the primary land conversion in the basin. Approximately 8% of all developed land in the basin was high intensity development, 23% was medium, 38% was low, and 31% was open developed land. Developed land constitutes approximately 68 % of the basin, and it is estimated that 21% of the watershed is impervious surface cover. See Appendix 2 for detailed tables and maps.



Map- 15. NOAA's C-CAP Data for the MoKa Bayous Coastal Basin

Quadrant 4: Agriculture/Wildlife/Natural Areas

Livestock

Farm animals such as cattle, horses, and goats contribute to bacterial loading, but they are not considered to be a significant source of bacteria in this watershed. Large scale domestic animal facilities or operations are not present in this urban watershed. Approximately 9% of Galveston County is categorized as agricultural by NOAA C-CAP. The 2012 USDA's National Agricultural Statistics Service was reviewed for the cattle and calves inventory in Galveston County. The total cattle population for the county was 9,772, ranking Galveston County 220 out of 254 Texas counties. At approximately 14,548 acres, the watershed covers only 2.6% of Galveston County and agricultural land use accounts for only 3% of the agricultural land use in Galveston County. Using NOAA C-CAP and USDA data, the estimated number of cattle within the watershed is 293.

Wildlife and Non Domestic Animals

Contributions of bacteria from wildlife are less easily controlled when compared to other sources since these animals move freely over the landscape and some are only present on a seasonal basis (e.g. migratory birds). Wildlife species in the watershed includes deer, raccoon, opossum, squirrels, birds, feral dogs and cats, and others. Stakeholders have reported pigeons in large numbers throughout the canal communities in the lower reach of the watershed. Pigeons are seen at bayou access points and nesting under boat houses. Whereas the population of many wildlife species is unknown, the Texas Colonial Waterbird Census conducted between 1973 and 2006 offers an example of just how many birds may present in the watershed during different seasons. The census consists of counts for 31 species at colonies along the north Texas Gulf Coast, many of which are observed in the watershed. Colony populations can be highly variable, from a few dozen to tens of thousands and beyond. Such a high volume of birds can significantly impact water quality near these areas. Common wading birds observed are the great blue heron, great egret, snowy egret, tricolor heron, little blue heron, ibises, and roseate spoonbills. Open water birds include royal terns, Caspian tern, least terns, sandwich terns, and neotropic cormorants.

Feral Hogs

Feral hogs are invasive non-domesticated hogs that disturb soils, eat small livestock, and transmit disease. Stakeholders within the watershed have observed wild hogs damaging property. Wild hogs prefer moist bottomlands along streams and marshes, and can be significant source of soil erosion. As feral hogs consume roots and ground vegetation, they can disturb substantial areas of soil, stripping away any stabilizing ground cover and making the area prone to soil erosion. As hogs continue to trample, eat, and damage crops, they pose a financial burden to agricultural producers. In Texas alone, feral hogs cause an estimated $52 million of damage to agriculture annually and they are increasing in numbers across the state (Timmons, et al., 2012). A combination of pig rooting behavior and deposits of fecal matter increases nitrogen levels in water, impacting water quality.

Feral hogs have established a population in the watershed and are frequently observed in Jack Brooks Park, the UH Coastal Center, and Mahan Park. Although, the exact population numbers are unknown at this time, interviews with stakeholders in the watershed have indicated their presence is impactful: "Feral hogs use the park as a playground, the UH Coastal Center as a hotel, and the landfill as a buffet."

Trapping efforts have occurred in both Jack Brooks Park and the UH Coastal Center. Management of feral hogs can be difficult for a variety of reasons including their ability to reproduce quickly and their lack of natural predators.

Streambank Erosion

Fallen trees and sediment from drainage ditches have filled in sections of Highland Bayou, creating stagnant pools of water in some areas. Trees and brush falling onto the banks is partly a natural process and it provide valuable habitat for aquatic organisms. However, the silting in of culverts and obstruction of flow within the channel has been a long standing concern for residents. In 1996 dozens of volunteers removed brush and trash from Highland Bayou during a bayou cleanup effort.

Open Space Preservation.

Individual properties within the watershed do not function as separate, isolated components but as a single, integrated natural system. Significant alteration of individual properties can disrupt the functioning of the watershed. Fragmentation of land tracts resulting from the breakup of larger undeveloped lands and habitat loss from development are some of the threats wildlife populations

Estimating NPS Loads: The Simple Method

To estimate pollutant loads for selected indicators (nitrogen, phosphorus, biochemical oxygen demand, sediment, and *Enterococci* bacteria), the Simple Method (Schueler, 1987) was determined to be the most appropriate model for the Highland Bayou Watershed. The Simple Method is just that –a very simple model based on just a few parameters. The Simple Method model is specifically designed for use in urbanized areas. The capacity of this method to easily estimate pollutant load for multiple land uses is one of its strengths. Schueler notes that the Simple Method "is designed to provide a quick, easy, and versatile means for estimating pollutant loads. Therefore, the method sacrifices precision for the sake of simplicity and generality. Despite its limitations, the Simple Method is considered precise enough to make reasonable and reliable nonpoint pollution management decision at the site-planning level" (1987).

The Simple Method is based on two key features –the coverage of impervious surface and an "event mean concentration" (EMC). The impervious cover directly impacts runoff: the more impervious a site, the greater the runoff. The EMC is a "flow-weighted" concentration of pollution that is representative of runoff from a particular land use. Impervious values in this plan were derived from NOAAs C-CAP data. EMC values were obtained from the literature.

According to Schueler, "the Simple Method provides estimates of pollutant loading that are probably close to the 'true' but unknown value for the site. It is important to not overemphasize the precision of the results obtained (1987). His example notes that a distinction between 34.3% and 36.9% would be "inappropriate." This same reasoning applies to interpretation of results here as aggregated load values for the watershed.

Known Data Gaps. Due to the lack of stream flow data in the basin, the loading values from the contributing runoff could not be calibrated with flow data, and thus obtain predictive values as to how reductions in loading will impact water quality in the stream. As of late 2016, a remedy for this deficiency is being sought through a supplementary study that will update the loadings estimated here.

The loading calculations were developed using the Community Health and Resources Management (CHARM) model data framework. The CHARM data is a 2.5 acre grid-based system for tracking characteristics about the land and community such as land area by different cover types, number of homes, and elevation. Primary data sources for the CHARM data are federal and state data sets (i.e., US Census, USSURGO). The watershed consists of 5,886 CHARM cells. Total NPS loads for catchments and the watershed are calculated by summing all cell values in those areas. This geospatial data structure provides a ready-made platform for using the Simple Method.

The Simple Method Load Equations

The primary equation for estimating loads using the Simple Method consists of three main variables and one unit-conversion value term. For estimating nutrients and sediment loads, the formula is:

$$L = 0.226 * R * C * A$$

Where:

L = annual load (pounds)
0.226 = unit conversion factor
R = annual runoff (inches)
C = pollutant concentration (mg/L)
A = area (acres)

For estimating bacteria loads, the equation is:

$$L = 0.00103 * R * C * A$$

Where:

L = annual load (billion colonies)
0.00103 = unit conversion factor
R = annual runoff (inches)
C = pollutant concentration (colonies/100mL)
A = area (acres)

Description of Simple Equation Terms

The terms R, C, A, and the unit conversion factor are further described here.

Runoff (R).

The value for runoff, R, is the product of the annual rainfall for the region in inches, the fraction of rainfall events producing measurable runoff, and a coefficient for the fraction of impervious surface cover in the analysis area. Output units are in inches. The formula per the Simple Method is:

$$R = P * P_j * Rv$$

Where:

R = annual runoff (inches)
P = annual rainfall (inches)

P_j = Fraction of effective rainfall (usually 0.9)
Rv = Runoff coefficient

Annual Rainfall (P). Rainfall units are inches. For this effort, the assumed annual rainfall value for the basin is 40 inches. This is based on an average figure for the basin. Historical values vary widely.

Percentage of Rainfall Events Producing Runoff (Pj). The *Pj* component of the Annual Runoff formula is an empirical value representing the percentage of precipitation events producing measurable runoff, in effect, reducing the annual rainfall by that fraction of non-runoff rainfall events. According to Schueler' s analysis (based on National Urban Runoff Program data), 90% of rain events will produce runoff (1987), and this is the assumed value for this effort.

Runoff Coefficient (Rv). The runoff coefficient is dimensionless and is a based on the fraction of impervious surface cover for the area. This formula is determined by Schueler to be the best fit line for the empirical relationship between stormwater runoff and imperviousness (1987). This coefficient is calculated using the formula:

$$Rv = 0.05 + (0.9 * Ia)$$

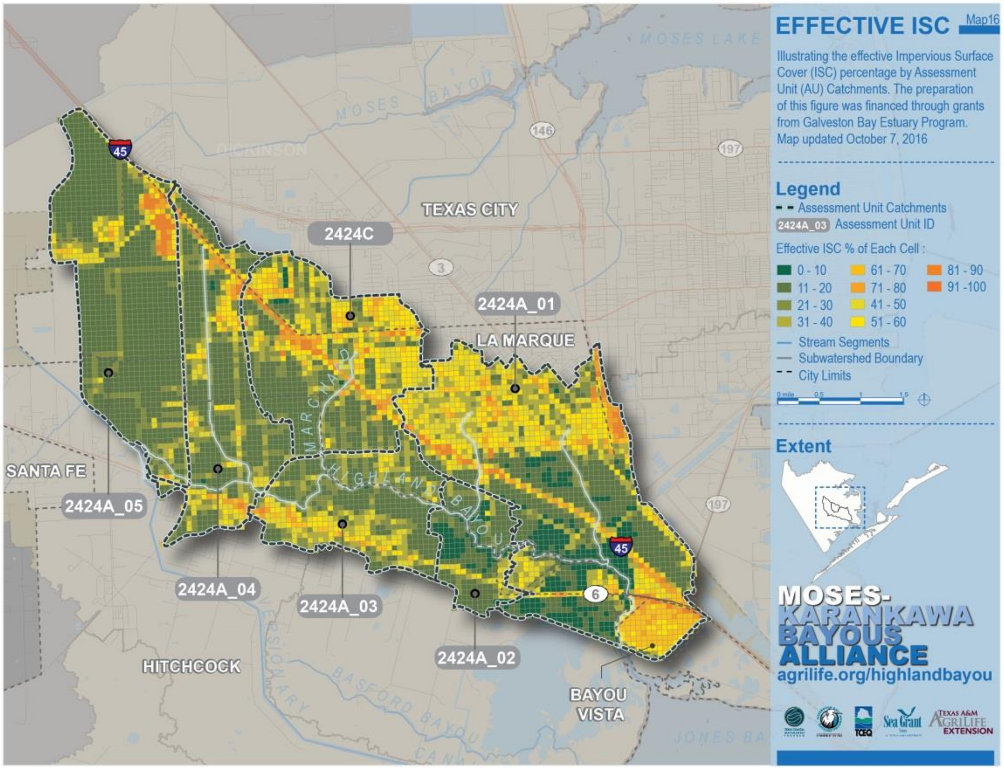
Where:

Ia = Fraction of impervious surface

The value *Ia* is the percent of impervious surface cover in the area of analysis. Geographic Information System (GIS) is used to assign this value through an analysis of development intensity in the CHARM data, derived from NOAA's C-CAP data. Values are taken from NOAA C-CAP data definitions for all developed coverages (See Appendix 2, Table 4). For undeveloped coverages, the underlying soil curve number (CN) was alternatively utilized. While the Simple method term *Ia* is utilized here, the more accurate term would be *effective impervious surface cover*, since GIS weights runoff values by the percent share of multiple surface types in each CHARM cell. The following table defines the values for *Ia* per cover type.

Table A- 6. Values for *Ia* Per Land Use Cover Type

Land Cover Classification	*Ia* (% effective Impervious Surface Cover)
High Intensity Development	0.9
Medium Intensity Development	0.65
Low Intensity Development	0.35
Open Space Development	0.1
Road	0.9
All Undeveloped Areas (based on soil CN)	0.05-0.15



Map-16. Effective Impervious Surface Cover Percentage by Assessment Unit Catchments

Event Mean Concentration, C.

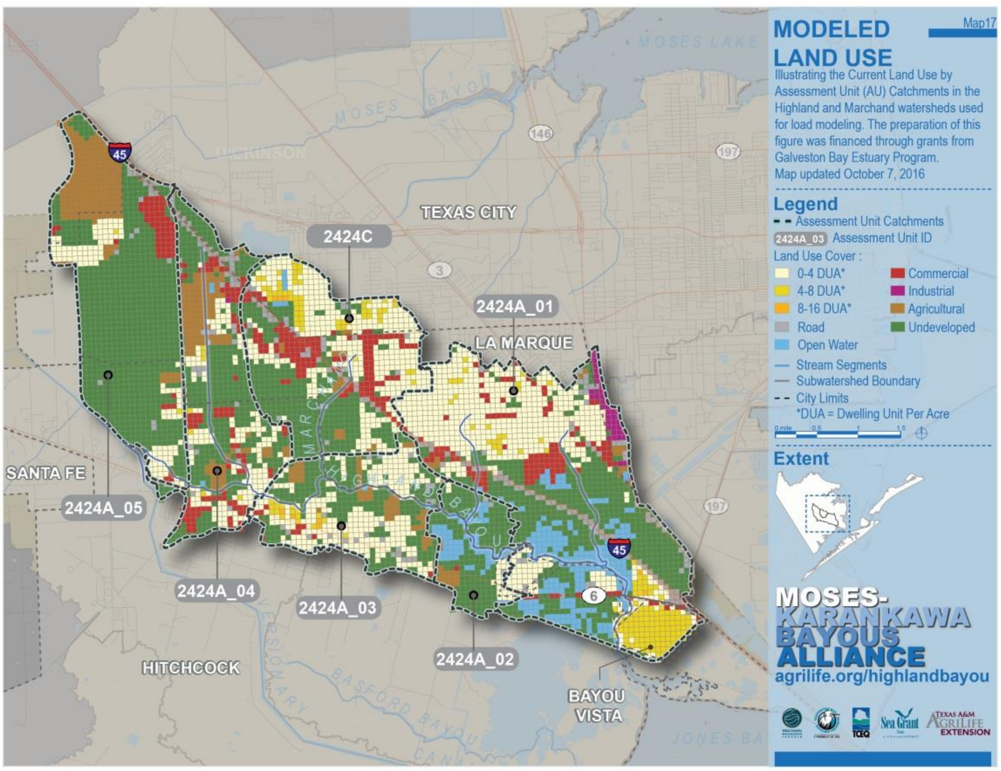
The EMC is the concentration of pollutant mass per runoff volume from a particular land use, such as residential, commercial or industrial. In order to determine the appropriate EMC, the land use must be known. In this modeling effort, the land use classification for each cell was assigned based on the dominant land use in that cell. Land uses for each cell were determined in GIS using a series of if-then statements assessing the number of homes, overlapping parcel land use code, and acreage of undeveloped open space to determine the most likely land use in each CHARM cell (See Map- 17). Nine primary land uses were defined for this modeling effort, and are utilizing the EMC listed in Table A-7.

Table A- 7. Nine Primary Land Uses and Associated Event Mean Concentration

Land Use Category	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Biochemical Oxygen Demand (mg/L)	Total Suspended Solids (mg/L)	Total *Enterococci* (colonies/100mL)
0 to 4 DUA	1.80	0.26	6.2	190	22,000
4 to 8 DUA	2.00	0.31	8.7	190	22,000
8 to 16 DUA	2.25	0.36	10.8	190	22,000
Agriculture	2.20	0.42	3.9	130	2,500
Commercial	1.80	0.20	7.7	60	22,000
Industrial	1.60	0.27	8.2	135	22,000

Land Use Category	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Total Biochemical Oxygen Demand (mg/L)	Total Suspended Solids (mg/L)	Total *Enterococci* (colonies/100mL)
Water	0.00	0.00	0.0	0	0
Road	1.90	0.23	7.5	135	22,000
Undeveloped	1.65	0.23	4.8	65	2,500

DUA stands for dwelling units per acre, and describes the residential density of the land use.
0-4 DUA per acres represents single family homes, while the higher end 8-16 DUA per acre consist of duplexes and apartment complexes.



Map-17. Current Land Use by Assessment Unit Catchments Used for Load Modeling

Area, A

The area, A, is acres of land. Each CHARM grid cell is prepopulated with attribute information about land cover and open water. The values for A in each cell range from 2.5 acres (all land) to zero (all open water).

Conversion Factor

The conversion factor is a fixed, dimensionless value that converts input units to output units. For nutrients, the factor converts the input 'volume- mass per volume' to pounds. For bacteria, the factor converts the input 'volume-count per volume' to billions of CFUs.

Calculation Methods

Software

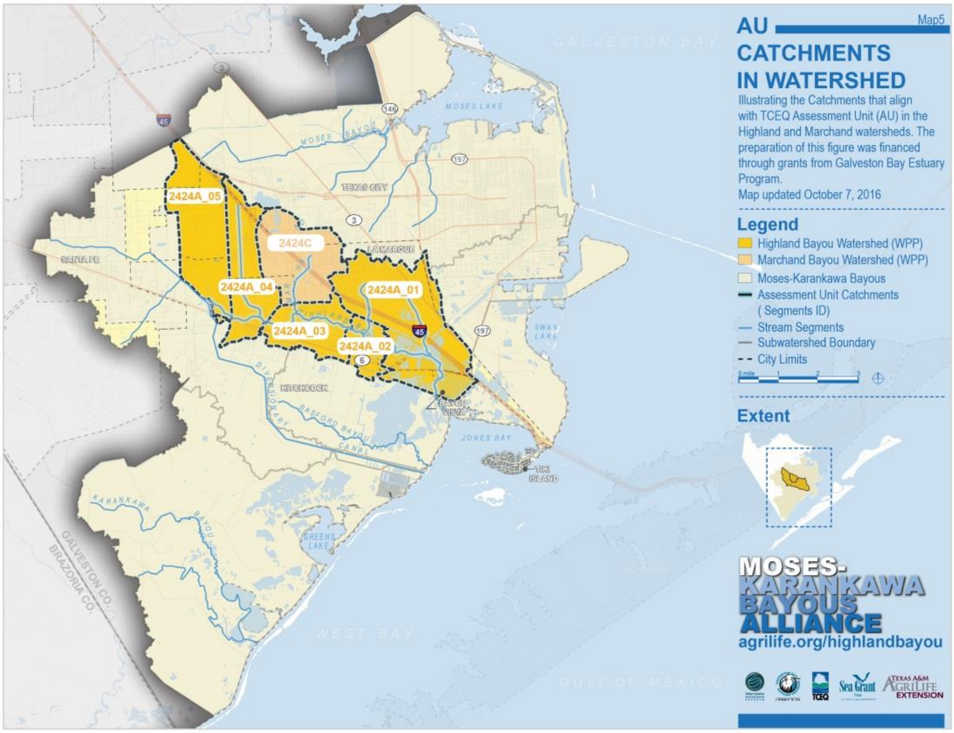
GIS was used to organize data and run calculations for the Simple Method. For this effort, ESRI ArcGIS 10.3 Advanced was utilized with a third-party software plug in, CommunityViz 360 ®. CommunityViz provides additional GIS functionality not included with ESRI software, primarily the ability to update data based on user defined formulae for variable assumptions or for how to interpret overlaying mapping data. As users update input values, CommunityViz recalculates all dependent data and attributes in real time. Aggregate load values by AU catchment were exported to excel for formatting and layout.

Unit of Analysis: the CHARM Grid

The unit of analysis is a CHARM grid cell, a regular grid of 2.5 acre cells. Each cell represents a discrete area and is stored as a unique record in a geodatabase. Twenty four pre-defined attributes are included in the CHARM grid, of which several are used for the Simple Method. Outputs are recorded for each cell, including dominant land use, land coverage fraction, intermediate calculated values, and final load calculations for each pollutant of concern.

NPS Loads by Assessment Unit Catchments

Pollutant loads that were calculated for each CHARM cell were then aggregated by their overlapping assessment unit (AU) catchment area. The AU catchment areas were generated using ESRI's Spatial Analyst tools and digital elevation data. Initially, the project team used each of the 19 surface water quality monitoring (SWQM) points in the watershed to define their upstream catchment area, that is, select all areas upstream that flow to each SWQM point. This analysis generated 19 unique catchments in the watershed. Then, using the SWQM point nearest to the bayou's segment ID, these 19 unique catchments were dissolved into one of 6 catchments coincident with each AU segment ID. These 6 AU catchments are used consistently in this WPP for NPS load estimates here and load reductions in Element B.



Map-5. Catchments that Align with TCEQ Assessment Units

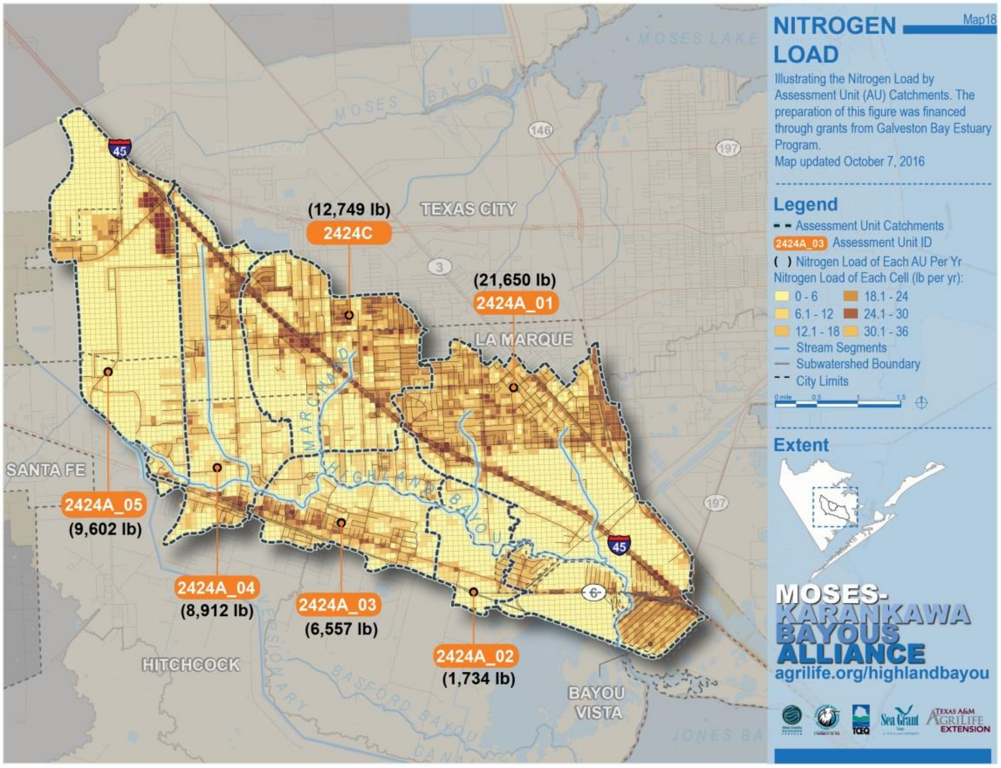
NPS Pollutant Loads

Loading totals were calculated by summing all cells within each AU and the entire watershed. Summary totals for each AU and the entire watershed are included in Table A-8 below. Detailed calculation tables are included in Appendix 3, Loading Tables. Loading tables in the appendices include summaries of each NPS pollutant of concern by AU (6 tables) and each AU by NPS pollutant of concern (5 tables). Values in detailed by the 9 land use classes and their acreages.

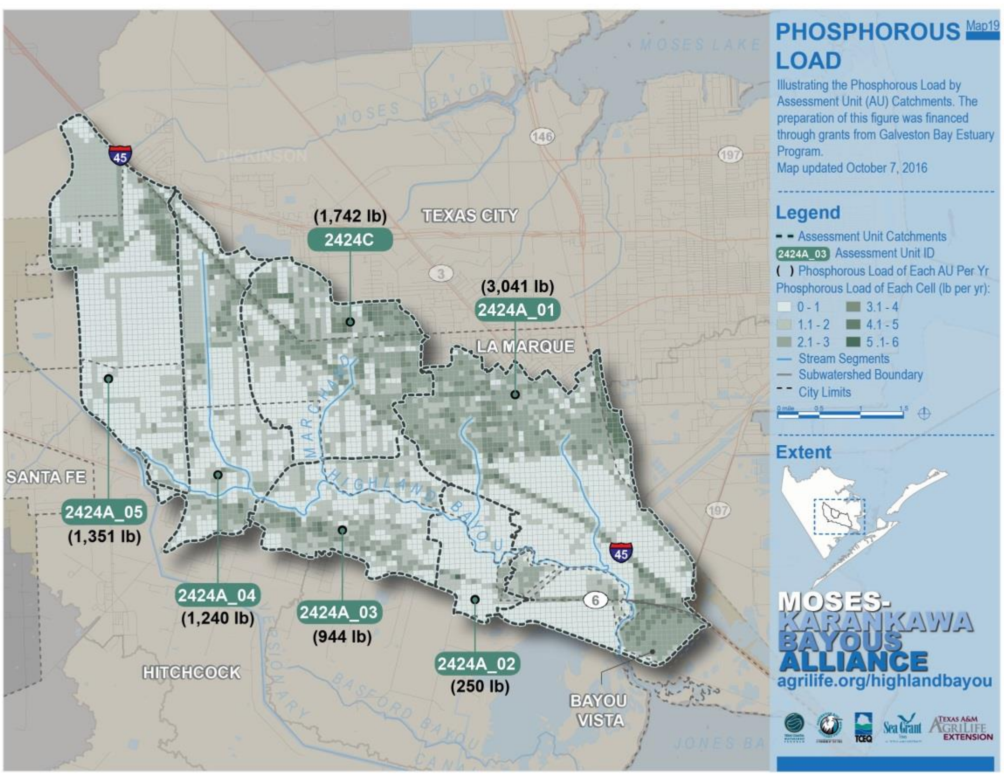
Based on Map-18 through Map-22, and as one would expect from the simple equation, the loads are largest for the largest catchments and where there is the most development. The maps illustrate quite nicely through a graded color scheme pollutant loads across the watershed and 'hot spots' that are likely priority areas for action areas defined in this plan (see Element C for action areas). Load reductions for selected Action Areas are provided in Element B.

Table A- 8. Pollutant Load Summary Totals for Each Assessment Unit.

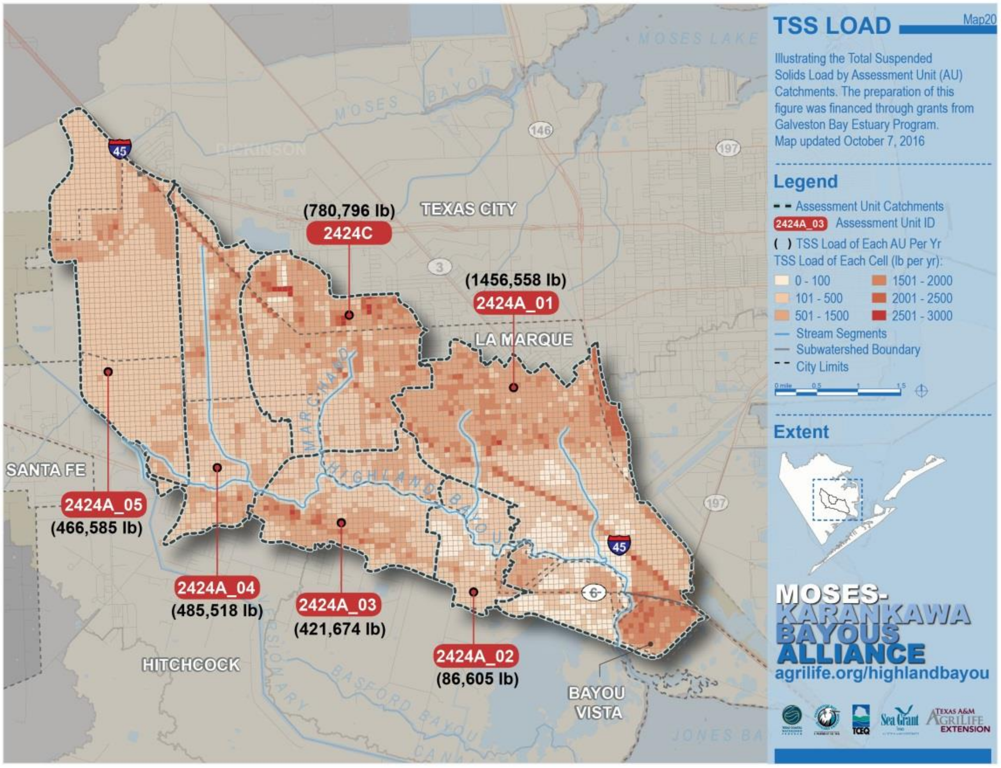
Pollutant of Concern	Total	2424A_01	2424A_02	2424A_03	2424A_04	2424A_05	2424C_01
N (lb)	**61,204**	21,650	1,734	6,557	8,912	9,602	12,749
P (lb)	**8,568**	3,041	250	944	1,240	1,351	1,742
BOD (lb)	**3,697,738**	1,456,559	86,605	421,674	485,518	466,585	780,797
TSS (lb)	**212,567**	79,361	5,152	21,835	29,760	30,381	46,078
Enterro (B. CFUs)	**422,535**	175,635	5,396	44,646	54,349	41,936	100,573



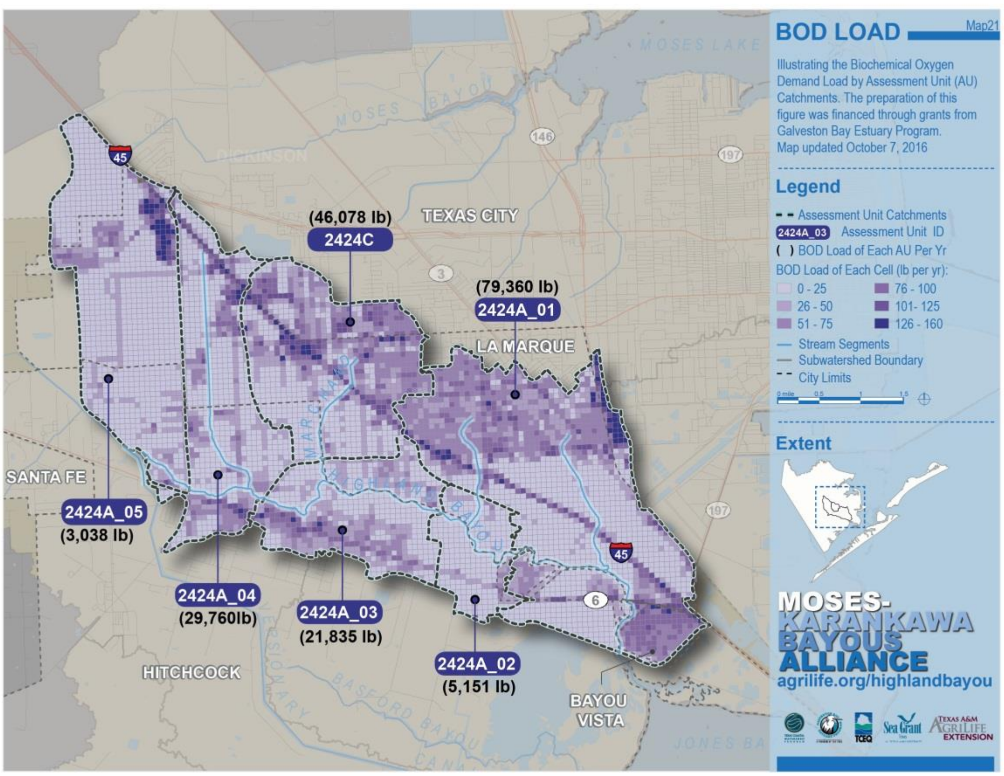
Map-18. Nitrogen Load by Assessment Unit Catchment



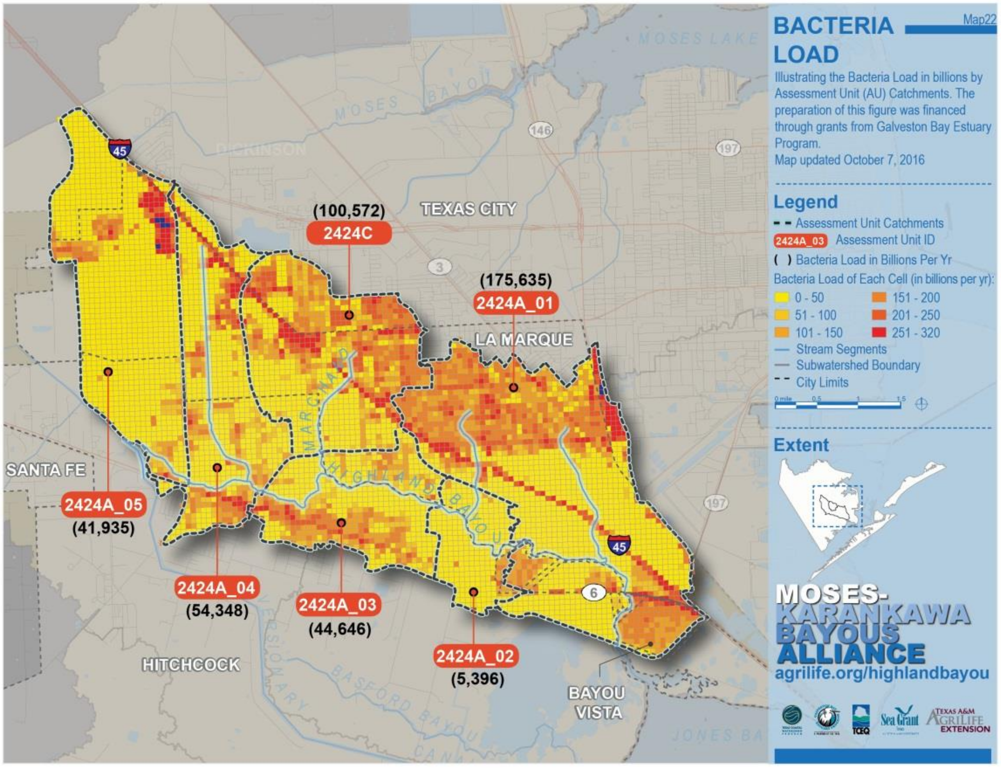
Map-19. Phosphorus Load by Assessment Unit Catchments



Map-20. Total Suspended Solids (TSS) Load by Assessment Unit Catchments



Map-21. Biochemical Oxygen Demand Load by Assessment Unit Catchments



Map-22. Bacteria Load in Billions by Assessment Unit Catchments