6.0 GALVESTON BAY GEOGRAPHIC INFORMATION SYSTEM (GIS)

A Geographic Information System (GIS) is a relatively new computer technology that served as the fundamental tool for the entire Galveston Bay Non-Point Source assessment. The GIS system permitted the storage, manipulation and processing of the several hundred megabytes of electronic data required for the NPS calculation. Hydrologic and NPS load models were also incorporated into the system so that the flow and water quality calculations could be attributed to different geographic regions. Finally, the GIS system was used to develop the final mapping products included in this report. In summary, the Galveston Bay project is a demonstration of the power of GIS technology to make extensive mapping-based calculations for analyzing environmental problems.

GIS systems have three major components: computer hardware, application software modules, and an organizational context. The first two components are usually based on combinations of commercial products. For this project two SPARCstations, each equipped with 12 Mbytes of RAM, were used as the primary computational platforms. Peripheral equipment included over 2.2 Gbyte of mass storage, a pen plotter, and a large digitizing board. The GIS software that was used is a commercial program from Environmental Systems Research Institute (ESRI) known as ARC/INFO. The third component of any GIS system is the organizational context for the electronic maps; this was developed by the project team to ensure the simplicity, transferability, and integrity of the database. For example, the Galveston Bay GIS database uses SI units (such as meters) and the geometric coordinate system used is the Universal Transverse Mercator (UTM). This organizational context will enable the NPS database to be easily accessible to future mapping projects in the area.

After the organizational context of the project was determined, all of the project-specific mapping data were entered into the GIS database. The Galveston Bay GIS database consists of six elements:

1. USGS 1:100,000 and 1:24,000 scale maps that contain the hydrography and transportation networks for the study area.
2. Watershed/Subwatershed boundaries.
3. Hydrologic soil type.
4. Land use patterns.
5. Runoff calculation model
6. Non-point source load calculation model

6.1 GIS Watershed/Subwatershed Mapping

Two main divisions were defined for the drainage basin delineation: watersheds and subwatersheds. A watershed is defined as the drainage of a major stream flowing into Galveston Bay (such as Buffalo Bayou), and a subwatershed is a smaller area with generally uniform land use characteristics encompassing the vicinity of a tributary to a major stream. For this project, the study area was divided into 21 watersheds based on drainage and topographic characteristics (Figure 6.1). Within Harris County, the Harris County Flood Control District (HCFCD) watershed delineations for the major streams were utilized (Table 6.1). Watershed delineation outside Harris County was based on a variety of sources, such as the Corps of Engineers maps, USGS 1:24,000 topographic maps, and drainage maps from county engineers as can be seen in Table 6.1.

All watershed boundaries were digitized into the GIS database from maps having a scale of 1:24,000 to ensure an acceptable accuracy level. The digitization procedure involved transforming the watershed maps to the UTM coordinate system. This process was based on "match points" between the watershed maps and known coordinates on the equivalent USGS 1:24,000 topographic sheets for the watersheds.

Significant project resources were devoted to digitizing watersheds. The final digitized watershed boundaries are accurate both from a geographical location perspective and a total drainage area aspect. Table 6.2 compares the calculated areas of the digitized watersheds to area estimates from other sources; in general, the digitized data are considered to be more accurate than most of the previous area estimates.

Subwatershed delineation was completed using the following criteria:

1. Follow major watershed boundaries.
2. Utilize approximately 100 subwatersheds for the entire project area.
3. Size urban subwatersheds to have areas of 10 - 50 square miles.
4. Size non-urban subwatersheds to have areas of 50 - 200 square miles.
5. Locate subwatershed boundaries to match boundaries of watersheds that are monitored by USGS flow gaging stations.
6. To the extent possible, maintain similar major land uses in subwatersheds.

Figure 6.2 shows the delineated subwatersheds, and Table 6.3 lists the number of subwatersheds for each watershed. Subwatershed boundaries were digitized into the GIS database in a similar manner to watershed boundaries. A table comparing the GBNEP subwatersheds with a system employed by the USGS to identify hydrologic units is provided in Table 6.3a.

6.2 GIS Soils Mapping

Soil types within the project area were mapped using the county soil surveys published by the SCS (1960, 1969, 1976, 1978, 1981, 1983, 1985) and The Texas

A & M University System (1981a and b). The SCS surveys include both specific soil maps, typically covering about 5 square miles each, and a composite general map, portraying the county as a whole by soil associations. For this project, most counties were comprised of approximately 10 associations. Each soil association was broken down on a percentage basis into individual soil types and an average hydrologic soil type (i.e., Type A, B, C, D; see SCS, 1986) was assigned to that association. Table 6.4 lists the resulting total area of each hydrologic soil type in each county.

Two types of inaccuracies were introduced in the averaging process: (1) taking an average value of the known individual soil components, which in some counties existed over only fifty percent of the area, may not accurately portray the soil across all of the association; and (2) the averaging process introduced some error; for example, if an association had 50% A soil and 50% C soil, it would be considered soil type B because the arithmetic average of the soil combination is that of a B soil type. This phenomenon is particularly apparent in the tri-county Polk, Liberty, and San Jacinto area, where the soil appears to change markedly at the county borders (Figure 6.3, soil map).

These problems could have been minimized by using the detailed soil maps for each county. The information was not available in electronic format from the SCS, however, and was too massive to digitize as part of this project. Although there are some inaccuracies in the use of the general soil maps, the overall error was considered to be acceptable for the NPS calculation.

The hydrologic soil type map obtained from the soils analysis discussed above was digitized into the GIS project database by county. The general soil maps from the SCS soil surveys were enlarged from their 11 in by 17 in size (approximately 1:200,000 scale) to about 2.5 ft by 4 ft with a scale close to 1:75,000 to allow for more accurate digitization. Because the general soil maps were not mapped in any geometric coordinate system, it was necessary to use county boundaries as a link between the general soil maps and the UTM coordinate system selected for the project database using county boundaries.

As can be seen from Figure 6.3, Hydrologic Soil Type D, clay soils with high runoff potential, is predominant in the study area. The most notable exceptions are seen in the upper Trinity watershed near Lake Livingston, and along the major streams in some watersheds. Table 6.5 lists the areas of each soil type in each watershed.

6.3 GIS Land Use Mapping and Land Use Categories

6.3.1 LANDSAT Imagery

Land use for the entire study area was mapped using LANDSAT satellite image interpretation. Prior to selecting this remote sensing methodology, other sources for land use data were investigated: the Soil Conservation Service (SCS) land cover database, the Houston-Galveston Regional Transportation Study Office (H-GRTS) land use database, and aerial photography. The SCS database was relatively old (1960's-1970's), had limited urban land use data, and existed only in hard copy format. The main disadvantage of the H-GRTS database was that the land use information was not correlated to small-scale geographical location; rather, land use data were presented per census tract. Aerial photography interpretation was not selected because of the difficulty of interpretation and the expense involved in converting the data to digital format.

LANDSAT is an unmanned satellite system which acquires images of the earth's surface features. The main advantage of utilizing LANDSAT imagery for land use is the ability to obtain current, high resolution land use information in a digital format suitable for computer and GIS processing. The resolution of LANDSAT interpreted land use maps is 30 m x 30 m pixels (picture elements), which correspond to approximately 12 million land use/land cover data points for the Galveston Bay study area.

Two LANDSAT 5 scenes encompassing the study area, dated November 6, 1990, were purchased from EOSAT (a private sole source company) after careful consideration of weather conditions and cloud cover. Heavy cloud cover results in a poor image that is not suitable for land use interpretation. The November 6, 1990, scenes had minimal cloud cover over parts of Boliver Peninsula and Galveston. False images caused by the cloud reflection were adjusted manually in the final GIS land use data.

The two scenes were obtained with the Thematic mapper (TM) deployed on LANDSAT 5. TM is a cross-track scanner which has seven spectral bands, one of which is a thermal infrared band (Sabins, 1978). Spectral bands refer to the wavelength associated with sunlight reflected from the earth's surface. These different electrical signatures can be used individually or in combination to determine land use and land cover characteristics. For example, band 3 is important for discriminating vegetation types, and band 1 is useful for distinguishing soil from vegetation.

6.3.2 Land Use Categories

The U. S. Geological Survey (USGS) developed a multilevel land use and land cover classification system associated with remote sensing (Anderson, 1976). The USGS defined land use as "man's activities on land", and land cover as "the vegetational and artificial constructions covering the land surface." For this project the term land use is being used to mean both land use and land cover. The USGS classification system consists of three levels: I, II and III (see Table 6.6 for a listing of levels I and II). For the purposes of this project, Level I classification was adopted with slight modifications to the "urban or built-up land" class to provide more resolution on the land use map. Two subclasses were defined: 1) "High density urban," consisting of industrial, commercial, multi-family residential, transportation facilities, and some high density single-family residential areas; and 2) "residential," consisting primarily of single-family residential areas with some limited coverage of other low density urban land uses. The final land use categories used for the project are shown in Table 6.6.

Similarly, the "agricultural land" class was divided into an agricultural subclass, consisting of cultivated land, and an "open/pasture" subclass, representing open grassy fields in urban or rural settings.

A Level I classification was considered to be sufficient for GBNEP purposes because the accuracy of the non-point source calculation would not be enhanced by further classification. The calculated runoff volume per area for industrial, commercial, transportation, and light industry areas, for example, would be similar as all of these land uses have a relatively high percentage of impervious area. The event mean concentrations (EMCs) for these land uses can also be considered similar, as indicated by data from the NURP program (USEPA, 1983).

6.3.3 Interpretation of LANDSAT Imagery

Level I land use interpretation was completed by Intera Aero Service (Intera), a subcontractor to Rice University. Intera used ERDAS, a commercial interpretation computer program, to conduct a multispectral classification of the November, 1990, LANDSAT imagery. Multispectral classification is an information-extraction process that analyzes the spectral signatures recorded in the satellite images and then assigns pixels to categories based on similar signatures.

The two major approaches to multispectral classification are 1) supervised and 2) unsupervised. Supervised classification, the approach that was used for this project, can be described as follows: the analyst defines on the image a small area, called a training site, which is representative of each land use category or class. Spectral values for each pixel in a training site are used to define the decision space or criteria for that class. Seven or eight training sites were used for each land use category for this project. The training sites were defined from existing land use maps for the City of Houston, composite land use maps assembled from USGS quadrangle maps, and maps for 1980 delineation of wetlands provided by the Fish and Wildlife Service.

Two iterations of land use classification were completed by Intera. In the first classification effort, the training sites were predominantly located in the urban sections of the watershed. The resulting land use image was then visually compared to the existing mapped resources of land use that were discussed earlier.

On a global scale, two problems were specifically noted with the initial classification: 1) in the Trinity River watershed, large sections of land were misclassified as residential instead of forest or agriculture. This was basically due to the fact that the training sites that were used for the residential category classification included areas in Memorial Park (which is a mixed forested-residential area). The Memorial Park training sites were eliminated and additional forested training sites in the Trinity were included in the second classification iteration; and 2) the classified wetlands areas were more extensive than those mapped by the Fish and Wildlife 1980 classification. More training sites were added for the wetlands category in the second iteration which helped somewhat but still produced more wetlands than the Fish and Wildlife classification.

On a local scale, the urban areas in the classified image (the City of Houston and Harris County specially) were magnified and a detailed one-to-one comparison with the existing land use maps for those areas was completed. Specific misclassified areas were noted and adjusted in the second iteration by adding more training sites. Examples of misclassified local areas included highways and roads which had extensive grassed medians or shoulders and were misclassified as agriculture or open/pasture, and parks which were misclassified as agriculture.

6.3.4 Manipulation of Mapping Data in the ARC/INFO System

For GIS non-point source modeling purposes, each pixel in the land use database was associated with a specific subwatershed and a specific soil type. A soil type/subwatershed composite polygon map was obtained by overlaying the soils and the subwatershed layers in ARC/INFO. Each of the composited polygons had a unique soil type and belonged to a certain subwatershed. The soils/subwatershed composited polygons were transformed to pixels through an ARC/INFO transformation process referred to as "polygon-to-grid". A software utility was developed to overlay the input soils/subwatersheds pixels and the land use pixels and to output data aggregated by the land use category, subwatershed and soil type attributes of each pixel in the study area.

For mapping and presentation purposes, the classified land use pixels were transformed to polygons through an ARC/INFO process known as "grid-to-polygon." Polyganization replaces clusters of pixels belonging to the same land use category with a polygon having an attribute of the associated land use class. The large number of data points necessitated resampling of the database to a 120 m x 120 m resolution before polyganization of the land use data. The predominant land use category in the sixteen 30 m x 30 m pixels composing the 120 m x 120 m cell was assigned as the land use class for the 120 m x 120 m cell.

In other words, all data processing for calculating NPS loads was done at a 30 m x 30 m resolution. Because of the computational effort required to map all 12 million land use pixels, the printed maps are shown using 120 m x 120 m resolution.

6.3.5 Project Land Use Map

The interpreted land use at the 120 m x 120 m resolution scale for the entire study area is shown in Figures 6.4 and 6.5. Urban areas are shown in red (high density urban) and yellow (residential areas) as can be seen in the Greater Houston area. Agricultural areas and open/pasture areas are shown as light tan and brown. Surrounding forested areas are shown in green, as can be seen in the Trinity River watershed and parts of Memorial Park in Houston (use the mylar inset to determine locations on the map). For illustration purposes, the data in Figures 6.6 through 6.8 show the distribution of urban land use, agricultural and open/pasture areas, and forests and wetlands in the study area.

Of the 4,238 square miles covered by the 21 watersheds, approximately 10% is high-density urban, 9% is residential, 23% is open/pasture, 22% is agricultural, 1% is barren, 15% is wetlands, 1% is water, and 18% is forested (with some forest being bottomland forested wetlands) (Table 6.7). Most of the high-density urban is concentrated in the Brays Bayou, Ship Channel, Greens Bayou, Buffalo Bayou, White Oak Bayou, West and South Bays, Sims and Clear Creek watersheds as can be seen in Figure 6.5. Residential areas are also found in many of the same watersheds. Most of the forested land is concentrated in the Trinity River watershed. Barren lands are found in the Addicks and Barker Reservoir watersheds, and wetlands are located mainly in Trinity Bay, East and West Bay watersheds. Table 6.7 lists the land use breakdown for each watershed. The data in Figures 6.9 through 6.29 show the interpreted land use for each watershed at a resolution of 120 m x 120 m.

Some limitations to the LANDSAT imagery can be seen in the project land use map shown in Figure 6.4. The "grid-to-polygon" process, described in Section 6.3.4, caused some streaking in the map. This phenomenon is particularly evident in the upper Trinity Watershed, where streaks in the almost uniform forest land use are present. Streaking is only an artifact of the map production, and does not affect the NPS calculation.

The current agricultural map does not distinguish between different types of agriculture, such as row crops versus rice fields, although these activities do have different hydrologic and NPS characteristics. An attempt was made to find a map of rice fields that could be incorporated into the GIS system, but after consultation with SCS representatives no map could be located. Agricultural breakdowns by county were obtained, but could not be used because the GIS mapping process was based on over ten million 30 meter by 30 meter mapping units rather than county-sized areas.

Some minor classification problems can be observed in certain areas of the map as well. For example, parts of both Pelican Island (north of Galveston) and Atkinson Island (near Baytown) are classified as "high density urban" areas as opposed to open or barren areas. These islands have exposed sediments which provide a bright reflection similar to concrete, leading to the erroneous classification. In general, however, these problems probably do not compromise the overall accuracy of the Galveston Bay NPS calculation.

6.3.6 Comparison with Other Land Use Studies

In addition to the "ground truthing" procedure conducted for the interpretation of the satellite images, a comparison was made between the land use data developed for this project and land use information provided by the National Oceanic and Atmospheric Administration (NOAA) from the National Coastal Pollutant Discharge Inventory (NCPDI) Database (NOAA, 1991). The two land use databases are very different: the NOAA information was obtained from USGS land use/land cover data compiled in 1979, and contains land use by watershed and county and therefore could not be used for a high resolution mapping project such as the GBNEP project. The ARC/INFO land use database, on the other hand, contains interpreted LANDSAT land use from 1990 with very high resolution (approximately 30 meters by 30 meters). [Although the two databases were different, they could be and were compared over the entire study area.]

Watershed area was compared first. NOAA's estimate of the Galveston Bay Estuarine Drainage Area (EDA) of 3,984 square miles was smaller than the drainage area considered for this project (4,238 square miles). The area discrepancy was due to the smaller Trinity River watershed defined in NOAA's study.

The comparison with NOAA's land use data was completed using NOAA's Hydrologic Cataloging Units: Buffalo-San Jacinto (#12040104) which is mostly Harris County drainage areas except for Clear Creek, Armand and Taylor Bayou watersheds; West Galveston Bay (#12040204) which is mostly Galveston County watersheds in addition to Clear Creek, Armand and Taylor Bayous; and North Galveston Bay (#12040203) which includes Trinity Bay and East Bay drainage areas and Cedar Bayou. It was also necessary to aggregate NOAA's land use categories to match GBNEP's land use categories. Table 6.8 lists the results from the land use comparison analysis.

In general, the GBNEP land use classification closely resembled NOAA's. The GBNEP estimate indicated more urban land use in all three basins; this is probably due to the intense urban development that occurred during the 1979-1990 period. Other differences are related more to the LANDSAT interpretation; for example, some high density residential areas are probably classified as "high density urban." The last significant difference in the two databases is that wetlands classification for this project was relatively difficult using LANDSAT, and therefore wetlands areas may be overrepresented. The LANDSAT wetlands classification does not necessarily correspond to the regulatory definition of wetlands, which is based on soil, hydrology and biota.

6.4 GIS Runoff Modeling

A GIS model for calculating runoff from the study area using the SCS TR-55 Runoff Curve Number (CN) method described in Section 5.3.2 was developed. SCS methodology was coded into the GIS system and used precipitation (P), initial abstraction (Ia, the amount of rainfall that either infiltrates or accumulates on the ground surface before runoff begins), and curve numbers (CN) as input data. A matrix of values relates the CN parameter to hydrologic soil type and the land use (SCS, 1986). The runoff model also requires as input an aggregate table of the spatial distribution of soil types and land use in the study area (see Sections 6.1 and 6.2).

The runoff calculation model was used initially in a calibration mode to estimate representative Ia and CN values for the watershed. Ten USGS stream flow gaging stations were selected for the calibration effort (Table 6.9). The gages were selected such that there would be gages in many different parts of the study area that represented different land uses. The Long King Creek at Livingston flow gage, for example, was chosen because it gaged a predominantly forested area in the Trinity River watershed. Figure 5.1 shows the locations of the stream flow gages.

The runoff calibration was completed using measured annual rainfall and runoff data for the years 1983 (a wet year, similar to Case 2) and 1987 (an average year, similar to Case 1; see Table 6.10). The listed values in Table 6.11 have been adjusted for base flow (see Table 6.12). Median annual base flow in Table 6.12 was subtracted from the annual runoff reported by the USGS for the years 1983 and 1987 to obtain an estimate of runoff volume.

The data in Table 6.11 show the results from the calibration runs for 1987 and 1983 and the CN table that was used in the calibrations. As the initial annual runoff volumes were too low for both years, the initial abstraction was reduced from 20% to 10% of potential storage. This value has been suggested as an accurate estimate for Ia in urban areas (Kibler, 1982). Numerous additional simulations were made with different curve numbers in an attempt to minimize the overall percentage difference between predicted and actual runoff volumes. As seen in Table 6.11, the calculated runoff volume from the total gaged area was very close to the measured flow (less than 3% difference) from the same area for the years 1983 and 1987. The comparison between the calculated and measured flows at the individual gages was not as good, however, with individual percent differences ranging between less than 1% to 40% in the two year runs, values which fall in the range of most hydrologic planning studies. These differences are probably related to rainfall distribution and the overall general limitation of the SCS runoff approach.

Additional calibration efforts were also made with individual storms. These simulations did not change the Ia and CN values generated using annual runoff data.

The runoff calculation model was used to calculate the runoff from the whole basin for the three rainfall cases discussed in Section 5.3.1. Results from the basin-wide runoff calculation are presented in Section 7.0.

6.5 GIS Non-Point Source Loading Calculation

A companion non-point source load calculation model was also developed in the project ARC/INFO System. The load model requires as input calculated runoff volumes (see Section 5.3.2) and EMC values for each pollution parameter based on land use (see Section 5.4). The load from a given soil/land use intersection was calculated by multiplying the calculated runoff volume from that area with the appropriate EMC value. Total loads for a watershed, for example, were calculated by summing the loads from all the contributing soil/land use intersections in the watershed.

The resulting NPS loads were reported in two ways:

- Total NPS loads to each watershed (generally reported in kilograms)

- NPS loads per unit area for each subwatershed (generally reported in kilograms/hectare)

Table 6.1 - Watersheds in the Study Area
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed Name	Area (square miles)	Source of Hydrologic Data
Addicks Reservoir	134	Harris County Flood Control
Armand/Taylor	77	Harris County Flood Control
Barker Reservoir	122	Harris County Flood Control
Bastrop/Austin	213	USGS 1:24,000 Topographic Maps
Brays Bayou	127	Harris County Flood Control
Buffalo Bayou	105	Harris County Flood Control
Cedar Bayou	211	Harris County Flood Control
Chocolate Bayou	170	Snowden Engineering, Inc.
Clear Creek	182	Harris County Flood Control
Dickinson Bayou	101	Galveston County Engineering Dept.
East Bay	288	USGS 1:24,000 Topographic Maps
Greens Bayou	208	Harris County Flood Control
North Bay	25	USGS 1:24,000 Topographic Maps
San Jacinto	68	US Army Corps of Engineers
Ship Channel	166	USGS 1:24,000 Topographic Maps
Sims Bayou	93	Harris County Flood Control
South Bay	78	USGS 1:24,000 Topographic Maps
Trinity Bay	317	USGS 1:24,000 Topographic Maps
Trinity River	1,099	USGS 1:24,000 Topographic Maps
West Bay	344	USGS 1:24,000 Topographic Maps
White Oak Bayou	110	Harris County Flood Control
Total Area	**4,238**	

NOTES:
1. Slight differences in the Harris County Flood Control District maps were observed in the common watershed boundary for Sims Bayou and Clear Creek. The Sims Bayou map boundary was used as the watershed boundary in this project.
2. Areas do not include bay and ocean but do include lakes and wetlands.

Table 6.2 - Comparison of Watershed Areas with Other Sources
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

	Estimated Area		Source of Data
	Digitized (sq mi)	Other (sq mi)	
Watershed Name			
Armand/Taylor	77	77	Harris County Flood Control
Brays Bayou	127	130	Harris County Flood Control
Buffalo Bayou	105	101	Harris County Flood Control
Cedar Bayou	211	212	Harris County Flood Control
Clear Creek	182	177	Harris County Flood Control
Greens Bayou	208	208	Harris County Flood Control
Sims Bayou	93	92	Harris County Flood Control
White Oak Bayou	110	110	Harris County Flood Control
Carpenters Bayou	25	24	Harris County Flood Control
Areas Draining to USGS Flow Gage			
Brays Bayou at Houston	93	95	USGS Water Resources Data
Buffalo Bayou near West Belt	346	307	USGS Water Resources Data
Cedar Bayou near Crosby	66	65	USGS Water Resources Data
Chocolate Bayou near Alvin	89	88	USGS Water Resources Data
Clear Creek near Pearland	36	39	USGS Water Resources Data
Greens Bayou near Houston	69	70	USGS Water Resources Data
Halls Bayou at Houston	27	28	USGS Water Resources Data
Long King Creek at Livingston	141	141	USGS Water Resources Data
Sims Bayou at Houston	66	63	USGS Water Resources Data
White Oak Bayou at Houston	89	86	USGS Water Resources Data

Table 6.3 - Legend for Subwatersheds
Non-point Source Characterization Project
Galveston Bay National Estuary Program

Abbreviation	Watershed	# Subwatersheds
AB	Austin/Bastrop Bayous	3
AD	Addicks Reservoir	2
AT	Armand/Taylor Bayous	4
BF	Buffalo Bayou	5
BK	Barker Reservoir	2
BR	Brays Bayou	7
CC	Clear Creek	5
CE	Cedar Bayou	4
CH	Chocolate Bayou	3
DB	Dickinson Bayou	3
EB	East Bay	4
GR	Greens Bayou	7
NB	North Bay	1
SB	South Bay	4
SC	Ship Channel	9
SJ	San Jacinto River	2
SM	Sims Bayou	5
TB	Trinity Bay	4
TR	Trinity River	14
WB	West Bay	7
WO	White Oak Bayou	5
	Total Subwatershed	100

Notes:

1. See Section 6.1 for description of watersheds and subwatersheds

Table 6.3a - Comparison of Subwatersheds and USGS Hydrologic Units

Non-Point Source Characterization Project

Galveston Bay National Estuary Program

Watershed	Sub-Watershed	USGS Hydrologic Unit
Trinity River	TR01	12030202
	TR02	12030202
	TR03	12030202
	TR04	12030202
	TR05	12030202
	TR06	12030202
	TR07	12030202
Trinity Bay	TB02	12030202/12030203
	TB03	12030202/12030203
Trinity River	TR08	12030203
	TR09	12030203
	TR10	12030203
	TR11	12030203
	TR12	12030203
	TR13	12030203
	TR14	12030203
Trinity Bay	TB01	12030203
	TB04	12030203/12040203
Barker Res.	BK01	12040104
	BK02	12040104
Addicks Res.	AD01	12040104
	AD02	12040104
Brays Bayou	BR01	12040104
	BR02	12040104
	BR03	12040104
	BR04	12040104
	BR05	12040104
	BR06	12040104
	BR07	12040104
Buffalo Bayou	BF01	12040104
	BF02	12040104
	BF03	12040104
	BF04	12040104

Watershed	Sub-Watershed	USGS Hydrologic Unit
Buffalo B.	BF05	12040104
White Oak Bayou	WO01	12040104
	WO02	12040104
	WO03	12040104
	WO04	12040104
	WO05	12040104
Greens Bayou	GR01	12040104
	GR02	12040104
	GR03	12040104
	GR04	12040104
	GR05	12040104
	GR06	12040104
	GR07	12040104
Sims Bayou	SM01	12040104
	SM02	12040104
	SM03	12040104
	SM04	12040104
	SM05	12040104
Ship Channel	SC01	12040104
	SC02	12040104
	SC03	12040104
	SC04	12040104
	SC05	12040104
	SC06	12040104
	SC07	12040104/12040203
	SC08	12040104/12040203
San Jacinto	SJ02	12040104/12040203
East Bay	EB01	12040202
	EB02	12040202
	EB03	12040202
	EB04	12040202
Cedar Bayou	CE01	12040203
	CE02	12040203

Watershed	Sub-Watershed	USGS Hydrologic Unit
Cedar Bayou	CE03	12040203
	CE04	12040203
Clear Creek	CC01	12040204
	CC02	12040204
	CC03	12040204
	CC04	12040204
	CC05	12040204
Armand/ Taylor Bayous	AT01	12040204
	AT02	12040204
	AT03	12040204
	AT04	12040204
North Bay	NB01	12040204
Dickinson Bayou	DB01	12040204
	DB02	12040204
	DB03	12040204
West Bay	WB01	12040204
	WB02	12040204
	WB04	12040204
	WB05	12040204
	WB06	12040204
	WB07	12040204
South Bay	SB01	12040204
	SB02	12040204
	SB03	12040204
	SB04	12040204
Chocolate Bayou	CH01	12040204
	CH02	12040204
	CH03	12040204
West Bay	WB03	12040204/12040205
Austin/ Bastrop Bayous	AB01	12040205
	AB02	12040205
	AB03	12040205

Table 6.4 - Soils by County
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

County	Area of County in Study Area	Hydrologic Soil Type					
		B		C		D	
		Area (sq mi)	% of Area	Area (sq mi)	% of Area	Area (sq mi)	% of Area
Brazoria	642.2	7.5	1			634.7	99
Chambers	529.8					529.8	100
Fort Bend	98.0					98.0	100
Galveston	377.3					377.3	100
Hardin	5.2	5.2	100				
Harris	1,246.8			39.4	3	1,207.4	97
Liberty	729.2	34.9	5	73.3	10	621.0	85
Polk	423.4	202.4	48	177.8	42	43.2	10
San Jacinto	127.1	84.3	66	40.3	32	2.5	2
Waller	43.3					43.3	100
Basin Total	4,222	334	8%	331	8%	3557	84%

NOTES:
1. Data derived from Non-Point Source Characterization Project.
2. Hydrologic soil Type B: generally silt loam or loam soils with moderate infiltration potential.
3. Hydrologic soil Type C: generally sandy clay loam with low infiltration potential.
4. Hydrologic soil type D: generally clay loam, silty clay loam, sandy clay, silty clay, or clay with very low infiltration potential
5. Total area of counties in study area (4,222 sq mi) does not match the total study area (4,238 sq mi) primarily because water areas were not assigned soil types.

Table 6.5 - Soil Type by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Hydrologic Soil Type					
	B		C		D	
	Area (sq mi)	% of Watershed	Area (sq mi)	% of Watershed	Area (sq mi)	% of Watershed
Addicks Reservoir					134.4	100
Armand/Taylor Bayou			1.6	2	75.1	98
Austin/Bastrop Bayou	1.6	1			211.6	99
Barker Reservoir					125	100
Brays Bayou					127.4	100
Buffalo Bayou					104.9	100
Cedar Bayou					211.3	100
Chocolate Bayou	0.1	0*			169.7	100
Clear Creek					180	100
Dickinson Bayou					101	100
East Bay					288	100
Greens Bayou			10.1	5	198	95
North Bay			1.5	6	23	94
San Jacinto River			13.6	21	52	79
Ship Channel			13.7	8	150	92
Sims Bayou					93	100
South Bay					78	100
Trinity Bay					317	100
Trinity River	326.7	29	291.4	25	526	46
West Bay	5.8	2			338	98
White Oak Bayou			0.7	1	110	99

NOTES:
1. Source: Non-Point Source Characterization Project.
2. Hydrologic soil Type B: generally silt loam or loam soils with moderate infiltration potential.
3. Hydrologic soil Type C: generally sandy clay loam with low infiltration potential.
4. Hydrologic soil type D: generally clay loam, silty clay loam, sandy clay, silty clay, or clay with very low infiltration potential

Table 6.6 - Land Use and Land Cover Classification System

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Level I	Level II	Classes Used in Project
1 Urban or Built-up Land	11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications, and Utilities 15 Industrial and Commercial complexes 16 Mixed Urban or Built-up Land 17 Other Urban or Built-up Land	**Residential** **High-Intensity Urban**
2 Agricultural Land	21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land	**Agriculture** **Open/Pasture**
4 Forest Land	41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land	**Forest**
5 Water	51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries	**Water**
6 Wetlands	61 Forested Wetland 62 NonForested Wetland	**Wetlands**
7 Barren Land	71 Dry Salt Flats 72 Beaches 73 Sandy Areas other than Beaches 74 Bare Exposed Rock 75 Strip Mines, Quarries, and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land	**Barren Land**

Notes:
1. Source of Level I and Level II Classification System: Anderson, 1976

Table 6.7 - Basin Land Use by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

	Land Use by Watershed (square miles)									%
Watershed	High-Density	Residential	Open/ Pasture	Agriculture	Barren	Wetlands	Water	Forest	Total	of Total
Addicks Reservoir	13	9	32	66	3	10		1	134	3%
Armand/Taylor	15	10	28	10	0	9	1	3	77	2%
Barker Reservoir	7	4	23	65	8	13			122	3%
Bastrop/Austin	6	13	58	88	1	42	2	3	213	5%
Brays Bayou	53	27	26	16	1	4			127	3%
Buffalo Bayou	39	32	15	14	0	4		1	105	2%
Cedar Bayou	8	18	50	80	1	31	1	24	211	5%
Chocolate Bayou	4	6	32	95	1	26	1	5	170	4%
Clear Creek	20	15	67	44	1	28	3	3	182	4%
Dickinson Bayou	5	9	45	20	0	19	1	1	101	2%
East Bay	10	28	72	73	0	89	6	8	288	7%
Green's Bayou	37	52	54	18	1	14		31	208	5%
North Bay	6	5	9	1	0	2		1	25	1%
San Jacinto	5	11	17	8	0	8	4	15	68	2%
Ship Channel	56	31	42	15	1	13	4	4	166	4%
Sims Bayou	23	15	34	11	0	8		1	93	2%
South Bay	25	6	22	7	0	12	6		78	2%
Trinity Bay	6	19	69	79	0	67	14	62	317	7%
Trinity River	11	34	135	145	2	151	7	613	1,099	26%
West Bay	30	22	105	79	1	94	11	2	344	8%
White Oak Bayou	39	32	25	10	1	3			110	3%
Total (square miles)	418	400	962	947	22	648	62	779	4,238	100%
% of Total	10%	9%	23%	22%	1%	15%	1%	18%	100%	

Notes:

1. Source LANDSAT imagery taken November, 1990.

Table 6.8 - GBNEP-NOAA Land Use Comparison
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Buffalo-San Jacinto (Hydrologic Unit # 12040104)

GBNEP Watershed	Land Use by Watershed (square miles)									Total
	High-Density	Residential	Open/ Pasture	Agriculture	Ag + Open	Barren	Wetlands	Water	Forest	
Addicks Reservoir	13	9	32	66	99	3	10	0	1	134
Barker Reservoir	7	4	23	65	89	8	13	0	0	122
Brays Bayou	53	27	26	16	42	1	4	0	0	127
Buffalo Bayou	39	32	15	14	29	0	4	0	1	105
Green's Bayou	37	52	54	18	72	1	14	0	31	208
San Jacinto	5	11	17	8	25	0	8	4	15	68
Ship Channel	56	31	42	15	57	1	13	4	4	166
Sims Bayou	23	15	34	11	46	0	8	0	1	93
White Oak Bayou	39	32	25	10	35	1	3	0	0	110
	Total Land Use for Watersheds (square miles)									
GBNEP	272	215	269	224	493	16	77	9	53	1135
NOAA	148	260	N/A	N/A	519	9	10	21	147	1116
	Percentages of Land Use for Watersheds									
GBNEP	24%	19%	24%	20%	43%	1%	7%	1%	5%	100%
NOAA	13%	23%	N/A	N/A	47%	1%	1%	2%	13%	100%

NOTES:
1. Source: NOAA, 1991.
2. Shaded Area represents the sum of Open/Pasture and Agriculture.

Table 6.8 - GBNEP-NOAA Land Use Comparison
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

West Galveston Bay (Hydrologic Unit # 12040204)

GBNEP Watershed	High-Density	Residential	Open/ Pasture	Agriculture	Ag + Open	Barren	Wetlands	Water	Forest	Total
	Land Use by Watershed (square miles)									
Armand/Taylor	15	10	28	10	38	0	9	1	3	77
Clear Creek	20	15	67	44	112	1	28	3	3	182
Dickinson Bayou	5	9	45	20	65	0	19	1	1	101
Chocolate Bayou	4	6	32	95	128	1	26	1	5	170
West Bay	30	22	105	79	184	1	94	11	2	344
Bastrop/Austin	6	13	58	88	146	1	42	2	3	213
North Bay	6	5	9	1	11	0	2	0	1	25
South Bay	25	6	22	7	29	0	12	6	0	78
	Total Land Use for Watersheds (square miles)									
GBNEP	136	92	388	352	741	3	245	31	18	1266
NOAA	55	62	N/A	N/A	666	13	71	26	28	920
	Percentages of Land Use for Watersheds									
GBNEP	11%	9%	28%	26%	78%	1%	20%	3%	2%	125%
NOAA	6%	7%	N/A	N/A	72%	1%	8%	3%	3%	100%

NOTES:
1. Source: NOAA, 1991.
2. Shaded Area represents the sum of Open/Pasture and Agriculture.

Table 6.8 - GBNEP-NOAA Land Use Comparison
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

North Galveston Bay (Hydrologic Unit # 12040203)

GBNEP Watershed	Land Use by Watershed (square miles)									Total
	High-Density	Residential	Open/ Pasture	Agriculture	Ag + Open	Barren	Wetlands	Water	Forest	
Trinity Bay	6	19	69	79	148	0	67	14	62	317
East Bay	10	28	72	73	146	0	89	6	8	288
Cedar Bayou	8	18	50	80	130	1	31	1	24	211
	Total Land Use for Watersheds (square miles)									
GBNEP	24	65	191	232	423	1	187	21	94	816
NOAA	30	16	na	na	456	1	215	21	42	781
	Percentages of Land Use for Watersheds									
GBNEP	3%	8%	23%	28%	52%	0%	23%	3%	12%	100%
NOAA	4%	2%	na	na	58%	0%	28%	3%	5%	100%

Notes:
1. Source: NOAA, 1991.
2. Shaded Area represents the sum of Open/Pasture and Agriculture.

Table 6.9 - Location of Flow Gages used for Runoff Calibration

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Station	Gage Number	Location		1987 Q (ac-ft)	1983 Q (ac-ft)
		Latitude	Longitude		
Long King Creek at Livingston	8066200	30°42'58"	94°57'31"	62124	90622
Cedar Bayou near Crosby	8067500	29°58'21"	94°59'08"	75193	77410
Buffalo Bayou near West Belt	8073600	29°45'43"	95°33'27"	177562	262014
Whiteoak Bayou at Houston	8074500	29°46'30"	95°23'49"	66755	112633
Brays Bayou at Houston	8075000	29°41'49"	95°24'43"	118651	171112
Sims Bayou at Houston	8075500	29°37'07"	95°26'45"	61479	87541
Halls Bayou at Houston	8076500	29°51'42"	95°20'05"	18529	32070
Greens Bayou near Houston	8076000	29°55'05"	95°18'24"	49090	80987
Clear Creek near Pearland	8077000	29°35'50"	95°17'11"	26557	36429
Chocolate Bayou near Alvin	8078000	29°22'09"	95°19'14"	40253	93495

NOTES:
1. Data obtained from USGS Water Resources Data for Texas.
2. See Figure 5.1 for locations of gages.

Table 6.10 - 1987 and 1983 Rainfall Used for Runoff Calibration

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

RAINGAGE	1987 Rainfall [1] (inches)	1983 Rainfall [2] (inches)
Alvin (Houston Area WSO)	49.59	60.48
Anahuac TBCD	51.65	61.48
Cleveland	52.51	59.76
Galveston WSO	36.84	53.90
Houston WSMCO (Intercontinental)	40.60	53.21
Houston FAA Airport (Hobby)	44.10	56.47
Houston - Barker	41.47	52.34
Houston - Independent Heights	47.47	60.77
Houston - San Jacinto Dam	57.96	59.78
Liberty	61.48	83.62

NOTES:
1. Used for Case 1 - Average Year Rainfall/Runoff Calibration.
2. Used for Case 2 - Wet Year Rainfall/Runoff Calibration.
3. See Figure 5.1 for the locations of the raingages.
4. Data obtained from NOAA, 1970 - 1990.

Table 6.11 - Calibration Run Results and Curve Number Table

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

1987 Calibration Gage	Gage Number	Measured Flow (thousand ac-ft)	Calculated Flow (thousand ac-ft)	% Difference
Long King Creek at Livingston	8066200	63	61	-3%
Cedar Bayou near Crosby	8067500	75	54	-29%
Buffalo Bayou near West Belt	8073600	178	217	21%
Whiteoak Bayou at Houston	8074500	67	93	40%
Brays Bayou at Houston	8075000	118	91	-22%
Sims Bayou at Houston	8075500	61	45	-27%
Halls Bayou at Houston	8076500	18	23	26%
Greens Bayou near Houston	8076000	49	54	10%
Clear Creek near Pearland	8077000	27	18	-34%
Chocolate Bayou near Alvin	8078000	41	53	30%
Total Basin		**697**	**708**	**2%**

1983 Calibration Gage	Gage Number	Measured Flow (thousand ac-ft)	Calculated Flow (thousand ac-ft)	% Difference
Long King Creek at Livingston	8066200	93	80	-14%
Cedar Bayou near Crosby	8067500	76	56	-26%
Buffalo Bayou near West Belt	8073600	263	323	23%
Whiteoak Bayou at Houston	8074500	113	134	19%
Brays Bayou at Houston	8075000	171	129	-25%
Sims Bayou at Houston	8075500	87	67	-23%
Halls Bayou at Houston	8076500	32	34	7%
Greens Bayou near Houston	8076000	81	81	1%
Clear Creek near Pearland	8077000	36	28	-23%
Chocolate Bayou near Alvin	8078000	94	77	-18%
Total Basin		**1,046**	**1,010**	**-3%**

Final Curve Numbers from Runoff Calibration	Hydrologic Soil Group			
	A	B	C	D
High-Density Urban	94	96	96	97
Open/Pasture	39	61	74	80
Agriculture	62	71	78	81
Barren	68	79	86	89
Wetlands	67	67	67	67
Residential	51	75	83	87
Water	100	100	100	100
Forest	25	55	70	77

NOTES:

1. Initial Abstraction = 0.1 X Potential Storage
2. Measured flows: annual discharge at gage, adjusted for base flow, Source USGS, 1983, 1984, 1987, and 1988.
3. Calculated flows from Non-Point Source Characterization Project.

Table 6.12 - Base Flow Calculation Used in the Runoff Calibration
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

1987	Long King Creek at Livingston 8066200	Cedar Bayou near Crosby 8067500	Buffalo Bayou near West Belt 8073600	White Oak Bayou at Houston 8074500	Brays Bayou at Houston 8075000	Sims Bayou at Houston 8075500	Greens Bayou at Houston 8076000	Halls Bayou near Houston 8076500	Clear Creek near Pearland 8077000	Chocolate Bayou near Alvin 8078000
	Monthly Minimum Daily Discharge (CFS)									
January	25	9	88	42	106	36	28	14	7	11
February	21	4	52	39	94	31	23	9	5	7
March	19	4	51	34	88	48	29	9	4	7
April	7.3	1	39	33	104	30	22	9	3	3
May	6.5	3	50	34	100	45	26	10	4	6
June	4.4	2	239	36	108	47	27	9	6	15
July	2.1	3	84	38	111	48	23	9	10	40
August	0.45	1	58	34	101	47	20	8	7	30
September	1	4	60	30	90	42	17	7	4	9
October	0.7	1	58	28	87	45	20	5	5	1
November	1	3	60	26	98	43	18	5	0	0
December	18	2	64	28	88	40	19	7	0	2
Median Discharge (cfs)	5	3	59	34	99	44	23	9	4	7
Base Flow in ac-ft	3946	1,919	42,714	24,615	71,673	31,855	16,289	6,552	3,113	5,032

1983	Long King Creek at Livingston 8066200	Cedar Bayou near Crosby 8067500	Buffalo Bayou near West Belt 8073600	White Oak Bayou at Houston 8074500	Brays Bayou at Houston 8075000	Sims Bayou at Houston 8075500	Greens Bayou at Houston 8076000	Halls Bayou near Houston 8076500	Clear Creek near Pearland 8077000	Chocolate Bayou near Alvin 8078000
	Monthly Minimum Daily Discharge (CFS)									
January	37	7	62	33	95	35	26	11	1	9
February	38	7	89	36	99	44	31	10	3	20
March	33	2	62	34	98	46	29	12	2	9
April	12	0	50	32	96	33	25	11	1	7
May	6	3	54	31	97	34	22	9	2	9
June	16	6	48	33	100	35	20	10	2	25
July	4	5	43	32	94	38	18	9	1	25
August	4	12	121	41	112	41	26	10	2	20
September	7	7	91	31	111	42	28	10	3	10
October	3	1	58	28	87	45	20	5	5	1
November	4	3	60	26	98	43	18	5	0	0
December	15	2	64	28	88	40	19	7	0	2
Median Discharge (cfs)	9	4	61	32	98	41	24	10	2	9
Base Flow in ac-ft	6,697	3,041	44,162	23,167	70,587	29,321	17,013	7,022	1,195	6,624

NOTES:
1. Annual base flow was defined as the median lowest daily discharge per month.
2. Low flows obtained from USGS Water Resources Data.