Characterization of Non-Point Sources and Loadings to Galveston Bay

Galveston Bay
National Estuary Program

GBNEP-15
March 1992

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VOLUME I
TECHNICAL REPORT

AUTHORS

Charles J. Newell, Ph.D., P.E.
Hanadi S. Rifai, Ph.D., P.E.
Philip B. Bedient, Ph.D., P.E.

PROJECT TEAM

Groundwater Services, Inc.:
Charles J. Newell, Ph.D., P.E., Principal Investigator
Elaine A. Higgins

Rice University Department of Environmental Science and Engineering:
Philip B. Bedient, Ph.D., P.E., Co-Principal Investigator
Hanadi S. Rifai, Ph.D., P.E.
Andrew D. Arenson
Carol A. Ellinger
Beth C. Erlanson
Karl Kilborn

The Galveston Bay National Estuary Program

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Mr. Wes Oneth, Soil Conservation Services
Mr. Robert Organ, Texas Natural Resources Information System
Ms. Kay Roane, Texas Department of Highways and Public Transportation
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FINAL REPORT
CHARACTERIZATION OF NON-POINT SOURCES AND LOADINGS TO GALVESTON BAY

EXECUTIVE SUMMARY

The Galveston Bay National Estuary Program (GBNEP) is a multi-agency environmental management planning program established for the protection and improvement of water quality and living resources within the Galveston Bay Estuary. In general terms, the project was designed to address one directive of the Clean Water Act: to develop the relationship between in-place loads and point and non-point loadings of pollutants to the estuarine zone and the potential uses of the zone, water quality, and natural resources. To meet these goals, the GBNEP has embarked on a three phase plan as mandated by the National Estuary Program: First, the problems in the estuary are prioritized; second, the estuary is scientifically characterized to better define the problems and link them with causes; and third, a series of action plans are created to solve these problems. The problem prioritization phase, conducted in 1989, identified non-point source pollutants entering Galveston Bay to be an important problem requiring further assessment.

This study, initiated in November 1990, and completed by Groundwater Services, Inc. (GSI), and the Department of Environmental Science and Engineering at Rice University (RU) as subcontractor, was aimed at characterizing non-point sources and loads into Galveston Bay. Non-point sources include a wide array of diffuse pollutant types and sources from major storm water outfalls, land drainage, and human activity. Pollutants include toxics, fecal coliform bacteria, oxygen demand, nutrients and sediments. Source activities include urban development, agricultural activities, and runoff from industrial and residential developments. One important aspect regarding non-point pollutants is that they occur intermittently and are very dependent on the volume and distribution of local rainfall in the watershed.

The objective of this work was to conduct a geographic analysis and priority ranking of possible non-point sources and loads to Galveston Bay. The study area was defined by GBNEP to include the entire Galveston Bay drainage area with the exception of the Lake Houston and Lake Livingston watersheds (Figure E.1); loadings from these upper watersheds were not mapped but were subjected to a separate pollutant loading analysis. The primary elements for the non-point analysis included watershed hydrology, load estimates, ranking of subwatersheds, upper watershed influences, and mapping. Exhibit E.1 presents a summary of the entire non-point source load calculation.

Watershed Hydrology. The study area (see above) was divided into 21 watersheds and 100 subwatersheds (Table E.1 and Figure E.2). Three rainfall cases were formulated from raingage data in the basin: an average year, a wet year with a 10-year return period, and an individual storm. The rainfall amounts were transformed into runoff using the Soil Conservation Service curve number method.

Land Use. An original land use database was developed from interpreted satellite imagery to provide a high resolution (approximate mapping resolution: 30 meter by 30 meter) snapshot of the watershed land use as it existed in 1990. The land uses that were delineated included the following categories: high-density urban, residential, open/pasture, agricultural, barren (exposed, eroded land and construction areas), wetlands, water and forest. These categories were considered to be sufficient for the purposes of calculating non-point source loads. Table E.2 lists the land use breakdown by watershed in the basin. Overall, land use in the project area is divided almost evenly between urban areas, agricultural lands, open/pasture areas, wetlands, and forests, as shown below:

- High-density urban 10%
- Residential 9%
- Open/Pasture 23%
- Agricultural 22%
- Barren 1%
- Wetlands 15%
- Water 1%
- Forest 18%

Relative Non-Point Source Load Estimates by Land Use Category. Eight water quality parameters were identified for the GBNEP non-point source database: total suspended solids, total phosphorus, total nitrogen, biochemical oxygen demand, oil and grease, fecal coliform, dissolved copper, and pesticides.

To calculate non-point source loads from the basin, typical concentrations of each water quality constituent in runoff were estimated from a variety of local and nationwide data sources. These water quality data, defined as event mean concentrations (EMCs), were derived for each land use type defined for the Galveston Bay project (Table E.3 and Section 5.4).

The Houston area EMC database indicated that sediment, nutrient, and oxygen demanding substances in local urban runoff are typical of urban runoff in other parts of the country. Although the rural EMC data were not as extensive as the urban database, they indicated that agricultural NPS concentrations are in the lower range of reported data for sediment and nutrient loads. One possible explanation is the extensive rice cultivation in the watershed; flooded rice fields generate relatively low concentrations of sediments and nutrients compared to typical row crops.

The total loads calculated for each of the three storms considered are listed in Table E.4. In addition, the loads by land use for the average year are presented in Table E.5. In general, high density urban land use areas, consisting of industrial, commercial, multi-family residential, and transportation land uses, had higher NPS pollutant concentrations than most other non-urban land uses. Forest lands had the lowest concentrations of pollutants in runoff.

Ranking of Subwatershed Non-Point Source Loads. Based on the relative non-point source load estimates, subwatershed boundaries, and hydrologic features, each subwatershed was ranked relative to other subwatersheds for each of the non-point source parameter categories. The ranking for the three rainfall cases and for each non-point source parameter is presented in Table E.6 and shown graphically in several maps contained in Volume II of this report.

Upper Watershed Influence.
The Galveston Bay National Estuary Program designed this project to map NPS source loads from the immediate watershed around the bay, and did not include a mapping component for the larger watershed that extends upstream of Lake Houston (to near the Huntsville area) and upstream of Lake Livingston (up to and past the Dallas area). GBNEP identified three reasons for this approach: 1) the lakes provide for some reduction and attenuation of NPS loads, particularly for sediment and sediment-related parameters and 2) implementation of management programs may be more feasible in the watershed immediately adjacent to the bay, and 3) project resources were prioritized to map the watershed immediately adjacent to the bay (approximately 5,000 square miles) compared to the upper watersheds (over 20,000 square miles).

Pollutant loads from Lake Houston and Livingston were calculated for this project, however, in order to provide an total load estimate to the Bay and to identify the contribution of the upper watersheds. The calculation method was different than the spatial mapping calculation performed on the study area (lower watersheds). For both upper watersheds, historical runoff and water quality data were analyzed to arrive at estimates of Lake discharges for the three rainfall cases and to obtain average concentrations for lake runoff. Annual load estimates (comprised of point source loads, low-flow loads, and NPS loads) for the three cases were obtained by multiplying the average concentration for most parameters (or best estimate for parameters with limited data) by the total runoff for each rainfall event (Table E.4). Overall, Lake Livingston contributes a greater load to Galveston Bay than Lake Houston for all the parameters except for fecal coliform. Both lakes contribute substantial amounts of pollutants into the bay.

Mapping. A Geographic Information System (GIS) 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 load models were also incorporated into the system to enable flow and water quality calculations for different geographic regions. Finally, the GIS system was used to develop the final mapping products included in Volume II of this report.

The Galveston Bay GIS database consists of six elements:

1. USGS 1:100,000 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.

This database was developed using the ARC/INFO GIS software, a standard GIS package, and therefore can be used for future projects requiring manipulation of environmental mapping data.

Project Results

The major conclusions observed from the project results and maps are:

1. The precise sources of NPS loads are relatively difficult to determine due to their widespread, diffuse nature. The following table identifies major potential sources in the watershed:

Water Quality Parameter	Major Potential Non-Point Sources
Total Suspended Solids	Eroding urban areas, cultivated fields, and streambanks
Total Nitrogen	Eroding soils, fertilizer application, leaking sanitary sewers, overflows, by-passes, natural organic matter
Total Phosphorus	Eroding soils, fertilizer application, leaking sanitary sewers, overflows, by-passes, natural organic matter
Biochemical Oxygen Demand	Natural decaying organic matter, leaking sanitary sewers, overflows, by-passes, oil and grease, natural organic matter
Oil and Grease	Motor vehicles
Fecal Coliforms	Leaking sanitary sewers, bypasses, overflows, pets, cattle, wildlife
Dissolved Copper	Corrosion of copper plumbing, electroplating wastes, algicides, eroding soils
Pesticides	Urban and rural pesticide application

2. Annual loads for Case 1, a year with average rainfall, were the following (see Table E.4):

Annual Non-Point Source Loads
Average Year
(thousands kg/yr, except where noted)

	Study Area Only	Entire Watershed
Runoff	3,010 ac-ft/yr	9,050 ac-ft/yr
Total Suspended Solids	481,000	581,000
Total Nitrogen	6,420	23,128
Total Phosphorus	1,110	3,711
Biochemical Oxygen Demand	26,300	46,500
Oil and Grease	14,200	14,200
Fecal Coliforms	355×10^{15} cfu/yr	355×10^{15} cfu/yr
Dissolved Copper	10.9	34.0
Pesticides	0.8	1.5

ac-ft: acre-ft
cfu: colony forming unit
Entire Watershed includes loadings from study area, Lake Houston, and Lake Livingston.
Lake loadings include contribution from point and low flow sources.

3. To assess the impact of non-point sources under high annual rainfall conditions, Case 2 analyses were conducted assuming annual rainfall that occurs, on the average, once every 10 years. The resulting runoff and loads were 40-60% higher than those found for Case 1 or the average year (Table E.4).

4. Case 3 simulated the response of the watershed to an individual storm event that could be expected to occur, on the average, once per year. This individual storm load was approximately 15 to 20% of the total annual non-point source load to the bay (Table E.4). These data indicate that a significant portion of the annual loads occur during a few of the largest rainfall events during the year.

5. High density urban land use areas were the main contributor of NPS loads from the study area for all the parameters. For example, high density urban land uses contributed approximately 87% of the annual oil and grease loading, 59% of the annual fecal coliform loading, and 50% of the annual pesticides loadings from the study (see Table E.5).

6. The pollutant load from the upper watersheds, which originates as discharge from Lake Houston and Lake Livingston, varied considerably among parameters. Over 70% of the annual nitrogen load, for example, originates from the upper watersheds and overwhelms the contribution from the local watersheds. For oil and grease and bacteria, however, the contribution of the upper watersheds was minor compared to the local watersheds in the study area (Table E.4). The results from Case 3 indicate that the lakes have a much lower impact on loads for small storms centered over the Houston metropolitan area. The loads from the lakes are not more than 2% of the total for any of the parameters for Case 3, Individual storm. For dry periods in the Houston area, however, the discharge from the upper watersheds may have a significant impact on the water quality of the bay.

7. The load maps produced for this project identified the locations of highly concentrated non-point source loads generation. In general, the highly urbanized areas in the Houston metropolitan area, Baytown, Texas City, and Galveston show the highest loads per unit area for all of the water quality constituents. As would be expected, fecal coliform and oil and grease NPS loads are almost entirely derived from the urban areas. Urban areas were also shown to be high source zones for pesticides as well.

   The non-point source mapping indicated that the highest erosion rates and, consequently greatest sources of sediment, were occurring in a wedge-shaped area, having a point at the mouth of the Ship Channel and reaching through Houston to the watersheds upstream of Barker/Addicks reservoirs. The high sediment loads were attributed to a combination of eroding urban land areas in the Houston area and barren land in the rural western watersheds.

8. A priority ranking of subwatersheds by NPS loading (kg/ha/yr) is provided in Table E.6 for each water quality parameter. This ranking can be used for the development of management activities and the implementation of activity plans for the immediate Galveston Bay watershed. For example, by using the priority ranking and the NPS maps (provided in Volume II), water quality managers can:

   - Identify areas with high sediment loads for the purpose of implementing special erosion control measures or for constructing sediment control structures.

   - Determine which municipalities have jurisdiction over high NPS areas.

- Compare the relative differences in NPS loads between high NPS source areas and low NPS areas.

- Locate areas with high NPS loadings within individual watersheds.

- Identify NPS "hot spots" on a subwatershed basis using the priority ranking.

- Identify NPS "hot spots" within each subwatershed by evaluating the high resolution land use maps provided for each watershed (see Volume II).

These activities are examples of management information that can be derived directly from the priority ranking and the NPS maps provided in this report.

9. Actual impacts of local NPS pollutants on the Bay are difficult to assess without analyzing the change in pollutant concentrations in Galveston Bay itself. For example, NPS loads are relatively brief slugs of pollutants that enter the bay intermittently from numerous entry points in the presence of large volumes of runoff. The amount, timing, and duration of these NPS events are determined by rainfall conditions. Discharge from Lake Livingston and Lake Houston complicates this assessment, as the reservoirs change the timing and water quality of the discharge from the Trinity and San Jacinto rivers to the bay.

   While the loading data from this study cannot be used directly to quantify the effect on the bay or evaluate the denial of beneficial uses to users of the bay, it can serve as a foundation for future projects evaluating the actual impact of NPS loads to Galveston Bay. The three loading cases can be applied to answer different management questions regarding the water quality of the bay.

<ins>Summary.</ins> The non-point source load data generated for this project can be used to develop strategies for managing water quality in Galveston Bay. All of the water quality and GIS databases are available on electronic media so that the information can be used in future environmental studies or for development for the bay management plan. It is expected that the GIS mapping data developed for this project would serve as the foundation for future Galveston Bay projects that require an intensive mapping effort.

Table E.1 - 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 Subwatersheds	100

Notes:

1. See Section 6.1 for description of watersheds and subwatersheds

Table E.2 - Project Land Use by Watershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Land Use by Watershed (square miles)								Total	% of Total
	High-Density Urban	Residential	Open/ Pasture	Agriculture	Barren	Wetlands	Water	Forest		
Addicks Reservoir	13	9	32	66	3	10		1	134	3%
Armand/Taylor	15	10	28	10		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		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		19	1	1	101	2%
East Bay	10	28	72	73		89	6	8	288	7%
Green's Bayou	37	52	54	18	1	14		31	208	5%
North Bay	6	5	9	1		2		1	25	1%
San Jacinto	5	11	17	8		8	4	15	68	2%
Ship Channel	56	31	42	15	1	13	4	4	166	4%
Sims Bayou	23	15	34	11		8		1	93	2%
South Bay	25	6	22	7		12	6		78	2%
Trinity Bay	6	19	69	79		67	14	62	317	7%
Trinity River	11	34	135	145	2	151	7	613	1099	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 (sq mi)	418	400	962	947	22	648	62	779	4238	100%
% of Total	10%	9%	23%	22%	1%	15%	1%	18%	100%	

Notes:

1. Source LANDSAT imagery taken November, 1990 as interpreted by Intera Aero Services, Inc.

Table E.3 - Event Mean Concentrations (EMCs) Used for Non-Point Source (NPS) Calculation
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Water Quality Parameters Used for Mapping								
Land Use Category	Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Biochemical Oxygen Demand (mg/l)	Oil and Grease (mg/l)	Fecal Coliforms (colonies/ 100 ml)	Dissolved Copper (µg/l)	Pesticides (µg/l)
High Density Urban	166	2.10	0.37	9	13	22,000	3.1	0.4
Residential	100	3.41	0.79	15	4	22,000	3.1	0.4
Agricultural	201	1.56	0.36	4	0	2,500	3.1	0.1
Open/Pasture	70	1.51	0.12	6	0	2,500	3.1	0.1
Forest	39	0.83	0.06	6	0	1,600	3.1	0.1
Wetlands	39	0.83	0.06	6	0	1,600	3.1	0.0
Water		0.00	0.00	0	0	0	0.0	0.0
Barren	2200	5.20	0.59	13	0	1,600	3.1	0.1
Supplemental Metals and Synthetic Organic Hydrocarbons (not mapped) (µg/l)								
Land Use Category	Dissolved Lead	Dissolved Zinc	Dissolved Arsenic	Dissolved Cadmium	Dissolved Chromium	Dissolved Mecury	Dissolved Silver	
High Density Urban	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Residential	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Agricultural	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Open/Pasture	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Forest	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Wetlands	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Barren	2.4	18.3	3.0	0.5	5.0	0.1	0.5	

Table E.4 - Summary of Non-Point Source Loads
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

CASE 1 Average Year	Runoff Volume (thousand ac-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
GBNEP	3,010	481	6,420	1,110	26.3	14.2	355	10,900	749
Lake Houston	1,380	43	2,451	647	5.8	0.0 [1]	5.6	5,277 [2]	170 [3]
Lake Livingston	4,660	57	14,257	1,955	14.4	0.0 [1]	1.1	17,821	575 [3]
Total	9,050	581	23,128	3,711	46.5	14.2	362	33,998	1,494
% Lakes of Total	67%	17%	72%	70%	43%	0%	2%	68%	50%
CASE 2 Wet Year									
GBNEP	4,790	747	10,100	1,730	41.5	20.4	531	17,500	1,140
Lake Houston	2,200	68	3,908	1,031	9.2	0.0 [1]	9.0	8,413 [2]	271 [3]
Lake Livingston	6,800	84	20,804	2,852	21.0	0.0 [1]	1.6	26,005	839 [3]
Total	13,790	899	34,812	5,613	71.7	20.4	542	51,918	2,250
% Lakes of Total	65%	17%	71%	69%	42%	0%	2%	66%	49%
CASE 3 Individual Storm									
GBNEP	603	92	1,230	205	5.1	1.8	55	2,250	125
Lake Houston	2.1	0.1	3.7	1.0	0.01	0.0 [1]	0.01	8 [2]	0.3 [3]
Lake Livingston	5.4	0.1	16.4	2.3	0.02	0.0 [1]	0.001	21	0.7 [3]
Total	610	92	1,250	208	5.1	1.8	55	2,279	126
% Lakes of Total	1%	0%	2%	2%	0%	0%	0%	1%	1%

NOTES:
1. Calculated assuming GBNEP Oil & Grease concentration of 0.0 mg/l.
2. Calculated assuming GBNEP Copper concentration of 3.1 μg/l
3. Calculated assuming GBNEP Pesticide concentration of 0.1 μg/l.

Table E.5 - Non-Point Source (NPS) Loads by Land Use for Case 1 (Average Year)
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Parameter	Units	H. Den. Urb.	Residential	Open	Agriculture	Barren	Wetlands	Water	Forest	Total
Runoff Volume	thousand ac-ft	766	371	567	593	21	187	164	345	3,014
TSS	million kg	157	46	49	147	57	9	0	17	481
Total Nitrogen	thousand kg	1,985	1,561	1,056	1,142	134	192	0	353	6,422
Total Phosphorus	thousand kg	350	362	84	264	15	14	0	26	1,113
BOD	million kg	8	7	4	3	0	1	0	3	26
Oil and Grease	million kg	12	2	0	0	0	0	0	0	14
Fecal Coliform	xE15 col	208	101	17	18	0	4	0	7	355
Dissolved Copper	kg	2,930	1,419	2,167	2,269	80	716	0	1,318	10,900
Pesticides	kg	378	183	70	73	3	0	0	43	749
Total		6,794	4,051	4,014	4,510	311	1,123	164	2,110	23,077

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Suspended Solids (kg/ha/yr)								
	Subwatershed	TSS		Subwatershed	TSS		Subwatershed	TSS
1	TR02	1,829	34	AD01	649	67	CE04	395
2	BF05	1,163	35	GR02	629	68	CH03	373
3	BK01	1,125	36	GR01	626	69	CH02	369
4	BF04	1,101	37	CC03	622	70	TB02	356
5	BR03	1,028	38	NB01	621	71	EB01	355
6	WO05	997	39	AT01	615	72	EB02	351
7	SC04	991	40	SM01	611	73	GR05	346
8	BR07	969	41	GR03	595	74	WB01	345
9	BR05	967	42	SM03	574	75	WB07	336
10	WO02	936	43	SB03	570	76	WB03	332
11	SM04	920	44	CE01	542	77	DB02	326
12	WO03	911	45	AT04	535	78	TB04	326
13	SC01	897	46	SC08	524	79	DB01	320
14	BR06	876	47	CC01	509	80	AB03	318
15	WB06	845	48	BK02	508	81	TR11	317
16	SB02	841	49	SM02	505	82	TR13	315
17	SC06	837	50	GR06	497	83	TB01	305
18	SC09	832	51	CH01	494	84	WB04	303
19	SC02	821	52	AD02	486	85	WB05	288
20	WO04	805	53	GR04	462	86	EB03	283
21	BR04	798	54	SJ02	454	87	TB03	280
22	SC03	795	55	CC04	452	88	DB03	277
23	BF03	794	56	TR12	450	89	SB04	262
24	SM05	792	57	CC02	450	90	TR14	257
25	AT02	789	58	CE02	446	91	TR10	239
26	BR01	785	59	AT03	446	92	TR04	217
27	BF02	772	60	SB01	443	93	TR03	211
28	WO01	757	61	WB02	435	94	TR09	205
29	BR02	756	62	AB01	428	95	TR08	202
30	GR07	722	63	CE03	423	96	TR05	132
31	SC05	717	64	EB04	418	97	TR07	127
32	SC07	707	65	AB02	417	98	TR06	96
33	BF01	651	66	CC05	401			

NOTES:

1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:

AB = Austin/Bastrop	CE = Cedar	SC = Ship Channel
AD = Addicks Reservoir	CH = Chocolate	SJ = San Jacinto
AT = Armand/Taylor	DB = Dickinson	SM = Sims
BF = Buffalo	EB = East Bay	TB = Trinity Bay
BK = Barker Reservoir	GR = Greens	TR = Trinity River
BR = Brays	NB = North Bay	WB = West Bay
CC = Clear Creek	SB = South Bay	WO = White Oak

3. See Figures E.5 and 7.2 for map of loads.

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Nitrogen (kg/ha/yr)								
	Subwatershed	Nitrogen		Subwatershed	Nitrogen		Subwatershed	Nitrogen
1	TR02	24.58	34	CC03	9.29	67	CE01	5.20
2	BF05	16.59	35	AT02	9.27	68	CC01	5.08
3	BF04	16.04	36	BR01	9.15	69	WB07	4.87
4	WO05	15.71	37	AT04	9.02	70	TR11	4.79
5	BR07	15.07	38	BR02	9.02	71	DB01	4.78
6	BR05	14.84	39	GR02	8.91	72	EB02	4.71
7	BR06	14.66	40	AT01	8.81	73	WB05	4.64
8	BF02	14.38	41	SC08	8.58	74	EB01	4.63
9	WO04	14.33	42	BF01	8.45	75	TB02	4.63
10	SC01	14.04	43	SM01	8.18	76	TR13	4.59
11	BF03	14.02	44	CE04	7.90	77	TR14	4.57
12	WO03	13.97	45	SB03	7.50	78	CH03	4.49
13	BR03	13.92	46	CE03	7.47	79	AB01	4.43
14	WO02	13.62	47	CC04	7.29	80	WB01	4.26
15	SC04	13.47	48	SJ02	7.11	81	AB03	4.23
16	SM04	13.37	49	AT03	7.11	82	WB03	4.23
17	SC03	12.88	50	SM02	7.05	83	WB04	4.22
18	BR04	12.87	51	EB04	6.97	84	CH01	4.15
19	SC02	12.63	52	WB02	6.90	85	BK02	4.15
20	SM05	12.22	53	GR04	6.75	86	CH02	4.12
21	GR07	12.10	54	GR05	6.71	87	TB03	4.11
22	SC09	11.93	55	AD02	6.51	88	SB04	4.10
23	SC06	11.24	56	SB01	6.44	89	DB03	4.00
24	SB02	10.82	57	CC05	6.20	90	TB01	3.75
25	SC05	10.68	58	CC02	5.98	91	TR10	3.70
26	WO01	10.49	59	BK01	5.97	92	TR09	3.25
27	GR06	10.40	60	TB04	5.79	93	TR08	2.78
28	WB06	10.30	61	DB02	5.68	94	TR03	2.62
29	GR03	10.13	62	EB03	5.56	95	TR04	2.53
30	NB01	10.04	63	TR12	5.52	96	TR07	1.80
31	SM03	9.43	64	CE02	5.51	97	TR05	1.44
32	SC07	9.40	65	AD01	5.37	98	TR06	1.26
33	GR01	9.35	66	AB02	5.37			

NOTES:

1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:

AB = Austin/Bastrop	CE = Cedar	SC = Ship Channel
AD = Addicks Reservoir	CH = Chocolate	SJ = San Jacinto
AT = Armand/Taylor	DB = Dickinson	SM = Sims
BF = Buffalo	EB = East Bay	TB = Trinity Bay
BK = Barker Reservoir	GR = Greens	TR = Trinity River
BR = Brays	NB = North Bay	WB = West Bay
CC = Clear Creek	SB = South Bay	WO = White Oak

3. See Figures E.6 and 7.3 for map of loads.

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Phosphorus (kg/ha/yr)								
	Subwatershed	Phosphorus		Subwatershed	Phosphorus		Subwatershed	Phosphorus
1	TR02	3.28	34	BR01	1.62	67	CC01	0.87
2	BF05	3.08	35	SC07	1.62	68	EB02	0.86
3	WO05	3.05	36	BR02	1.61	69	CH01	0.85
4	BF04	2.98	37	GR02	1.60	70	AB01	0.84
5	BF02	2.90	38	BF01	1.58	71	AB02	0.82
6	BR07	2.84	39	AT02	1.57	72	EB01	0.82
7	BR06	2.83	40	CC03	1.56	73	WB07	0.80
8	WO04	2.82	41	CE04	1.55	74	CH03	0.80
9	BF03	2.79	42	SC08	1.48	75	TR14	0.79
10	BR05	2.78	43	AT01	1.44	76	DB01	0.76
11	WO03	2.69	44	SM01	1.34	77	TB02	0.76
12	SC01	2.64	45	CE03	1.32	78	BK02	0.75
13	BR03	2.53	46	SB03	1.28	79	WB03	0.75
14	WO02	2.51	47	CC04	1.27	80	WB05	0.74
15	SM04	2.49	48	GR05	1.25	81	AB03	0.74
16	BR04	2.46	49	SJ02	1.24	82	TR13	0.71
17	SC04	2.45	50	GR04	1.22	83	WB04	0.70
18	SC03	2.39	51	AD02	1.22	84	CH02	0.69
19	SC02	2.33	52	AT03	1.21	85	SB04	0.67
20	GR07	2.31	53	EB04	1.21	86	TB03	0.66
21	SM05	2.18	54	WB02	1.15	87	TR11	0.64
22	SC09	2.10	55	SM02	1.14	88	WB01	0.63
23	GR06	2.03	56	SB01	1.10	89	DB03	0.60
24	SC06	1.98	57	TB04	1.06	90	TB01	0.59
25	SC05	1.97	58	CE01	1.02	91	TR10	0.43
26	SB02	1.93	59	CC05	1.01	92	TR03	0.42
27	WO01	1.89	60	BK01	1.01	93	TR04	0.38
28	GR03	1.84	61	CC02	0.99	94	TR09	0.36
29	WB06	1.81	62	AD01	0.97	95	TR08	0.34
30	NB01	1.76	63	CE02	0.94	96	TR07	0.24
31	SM03	1.68	64	DB02	0.93	97	TR05	0.23
32	AT04	1.66	65	EB03	0.93	98	TR06	0.16
33	GR01	1.65	66	TR12	0.89			

NOTES:

1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:

AB = Austin/Bastrop	CE = Cedar	SC = Ship Channel
AD = Addicks Reservoir	CH = Chocolate	SJ = San Jacinto
AT = Armand/Taylor	DB = Dickinson	SM = Sims
BF = Buffalo	EB = East Bay	TB = Trinity Bay
BK = Barker Reservoir	GR = Greens	TR = Trinity River
BR = Brays	NB = North Bay	WB = West Bay
CC = Clear Creek	SB = South Bay	WO = White Oak

3. See Figures E.7 and 7.4 for map of loads.

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Biological Oxygen Demand (kg/ha/yr)								
	Subwatershed	BOD		Subwatershed	BOD		Subwatershed	BOD
1	TR02	125.95	34	AT04	37.76	67	AB02	20.68
2	BF05	68.13	35	CC03	37.59	68	TR10	19.90
3	BF04	66.05	36	GR02	36.47	69	WB07	19.81
4	WO05	65.13	37	AT02	36.16	70	WB05	18.91
5	BR07	62.41	38	BR01	35.67	71	BK01	18.67
6	BR05	61.27	39	SC08	35.26	72	DB01	18.60
7	BR06	61.05	40	AT01	35.24	73	EB02	18.31
8	BF02	60.67	41	BR02	35.12	74	TB02	18.15
9	WO04	60.07	42	CE04	33.91	75	AD01	18.03
10	BF03	59.03	43	BF01	33.08	76	CC01	17.96
11	SC01	57.96	44	SM01	32.15	77	TR09	17.95
12	WO03	57.57	45	CE03	31.47	78	EB01	17.76
13	BR03	56.46	46	SJ02	30.68	79	TB03	16.99
14	WO02	55.42	47	SB03	30.35	80	CE01	16.95
15	SC04	54.87	48	CC04	29.99	81	CH03	16.68
16	SM04	54.66	49	GR05	29.82	82	WB04	16.59
17	SC03	53.10	50	AT03	29.59	83	WB03	16.52
18	BR04	53.07	51	EB04	29.50	84	SB04	16.49
19	SC02	52.26	52	GR04	28.94	85	AB03	16.32
20	GR07	50.89	53	SM02	28.36	86	TB01	16.13
21	SM05	50.00	54	WB02	27.80	87	WB01	16.03
22	SC09	48.76	55	SB01	26.59	88	DB03	16.01
23	GR06	45.82	56	AD02	26.33	89	AB01	14.94
24	SC06	45.56	57	CC05	25.57	90	TR08	14.92
25	SC05	43.88	58	TB04	24.19	91	CH02	14.58
26	SB02	43.62	59	EB03	23.53	92	BK02	14.37
27	WO01	42.17	60	DB02	23.33	93	CH01	12.60
28	GR03	42.03	61	TR11	23.20	94	TR03	11.53
29	NB01	41.56	62	CC02	22.92	95	TR04	11.52
30	WB06	41.42	63	TR12	22.23	96	TR07	8.95
31	SM03	38.63	64	CE02	21.46	97	TR06	6.77
32	GR01	38.31	65	TR14	20.95	98	TR05	6.77
33	SC07	38.22	66	TR13	20.90			

NOTES:
1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:

AB = Austin/Bastrop	CE = Cedar	SC = Ship Channel
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BF = Buffalo	EB = East Bay	TB = Trinity Bay
BK = Barker Reservoir	GR = Greens	TR = Trinity River
BR = Brays	NB = North Bay	WB = West Bay
CC = Clear Creek	SB = South Bay	WO = White Oak

3. See Figures E.8 and 7.5 for map of loads.

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Oil and Grease (kg/ha/yr)								
	Subwatershed	O&G		Subwatershed	O&G		Subwatershed	O&G
1	BF05	83.36	34	SC05	30.70	67	TR02	7.06
2	BF04	79.28	35	GR01	30.37	68	DB03	6.49
3	WO05	65.98	36	BF01	30.23	69	WB04	6.35
4	BR07	65.59	37	GR03	29.10	70	DB01	5.66
5	BR05	64.85	38	GR02	28.09	71	CE02	5.55
6	SC04	61.78	39	SM03	27.24	72	EB03	5.45
7	BR03	61.23	40	SB01	27.20	73	CC01	5.19
8	SB02	59.71	41	AT04	26.22	74	TR11	5.06
9	SC01	59.48	42	SM01	24.85	75	CH03	4.94
10	WO02	57.90	43	GR06	22.52	76	BK02	4.44
11	BR06	57.35	44	SC08	22.36	77	TB02	4.04
12	WB06	53.81	45	CC04	21.41	78	TR14	3.76
13	SM04	52.77	46	EB04	19.49	79	AB03	3.72
14	SC02	51.80	47	CC05	18.89	80	TB03	3.70
15	WO03	51.05	48	SM02	17.67	81	WB01	3.55
16	WO04	50.86	49	AT03	17.17	82	AB01	3.38
17	SC03	49.71	50	WB02	17.09	83	EB02	3.20
18	SM05	48.71	51	WB07	16.61	84	TR12	3.03
19	SC09	48.08	52	GR04	15.98	85	EB01	2.90
20	BF03	48.02	53	CE03	15.02	86	CH02	2.89
21	SC06	47.83	54	SJ02	13.20	87	TR13	2.78
22	BF02	46.75	55	CE04	13.00	88	TR03	2.09
23	BR04	43.71	56	GR05	12.91	89	TR08	2.03
24	BR01	40.56	57	AD02	12.19	90	TR10	1.87
25	BR02	40.22	58	WB05	11.62	91	CE01	1.80
26	SC07	37.77	59	DB02	10.47	92	TR09	1.43
27	GR07	36.16	60	AD01	10.27	93	CH01	1.43
28	SB03	35.74	61	CC02	10.20	94	TB01	1.28
29	WO01	35.19	62	AB02	10.12	95	TR04	1.25
30	NB01	33.93	63	SB04	9.25	96	TR07	1.22
31	CC03	33.00	64	WB03	8.25	97	TR05	0.90
32	AT02	31.44	65	TB04	7.48	98	TR06	0.38
33	AT01	30.84	66	BK01	7.10			

NOTES:

1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:
   AB = Austin/Bastrop
   AD = Addicks Reservoir
   AT = Armand/Taylor
   BF = Buffalo
   BK = Barker Reservoir
   BR = Brays
   CC = Clear Creek
   CE = Cedar
   CH = Chocolate
   DB = Dickinson
   EB = East Bay
   GR = Greens
   NB = North Bay
   SB = South Bay
   SC = Ship Channel
   SJ = San Jacinto
   SM = Sims
   TB = Trinity Bay
   TR = Trinity River
   WB = West Bay
   WO = White Oak
3. See Figures E.9 and 7.6 for map of loads.

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Fecal Coliforms (xE12 col/ha/yr)								
	Subwatershed	FC		Subwatershed	FC		Subwatershed	FC
1	BF05	1.56	34	GR01	0.67	67	WB03	0.21
2	BF04	1.49	35	SB03	0.65	68	CE02	0.20
3	WO05	1.37	36	SM03	0.64	69	DB01	0.19
4	BR07	1.32	37	AT02	0.64	70	TR14	0.19
5	BR05	1.29	38	AT04	0.63	71	BK01	0.19
6	BR06	1.23	39	GR02	0.63	72	WB04	0.18
7	SC01	1.20	40	BF01	0.63	73	TR11	0.18
8	BR03	1.19	41	AT01	0.62	74	DB03	0.17
9	SC04	1.18	42	TR02	0.58	75	CH03	0.17
10	WO04	1.16	43	SC08	0.54	76	CC01	0.17
11	WO02	1.15	44	SM01	0.52	77	EB02	0.16
12	BF02	1.14	45	SB01	0.52	78	TR12	0.16
13	BF03	1.12	46	CC04	0.49	79	AB03	0.16
14	WO03	1.12	47	EB04	0.46	80	TB02	0.16
15	SM04	1.09	48	CE04	0.46	81	EB01	0.15
16	SC02	1.05	49	AT03	0.43	82	TB03	0.15
17	SC03	1.04	50	CE03	0.43	83	TR13	0.15
18	SB02	1.04	51	GR04	0.42	84	BK02	0.14
19	BR04	0.99	52	WB02	0.41	85	AB01	0.14
20	SM05	0.99	53	SM02	0.41	86	WB01	0.13
21	SC09	0.96	54	CC05	0.41	87	CE01	0.13
22	WB06	0.95	55	GR05	0.41	88	CH02	0.12
23	SC06	0.92	56	SJ02	0.39	89	TR10	0.10
24	GR07	0.88	57	AD02	0.37	90	TB01	0.09
25	WO01	0.76	58	WB07	0.34	91	CH01	0.09
26	BR01	0.75	59	DB02	0.30	92	TR03	0.09
27	BR02	0.74	60	TB04	0.29	93	TR09	0.09
28	NB01	0.74	61	CC02	0.28	94	TR08	0.08
29	SC07	0.74	62	WB05	0.27	95	TR04	0.07
30	SC05	0.73	63	AB02	0.25	96	TR07	0.05
31	GR03	0.70	64	EB03	0.24	97	TR05	0.05
32	GR06	0.69	65	AD01	0.24	98	TR06	0.03
33	CC03	0.67	66	SB04	0.23			

NOTES:

1. Key to Subwatershed identification:
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BF = Buffalo	EB = East Bay	TB = Trinity Bay
BK = Barker Reservoir	GR = Greens	TR = Trinity River
BR = Brays	NB = North Bay	WB = West Bay
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3. See Figures E.10 and 7.7 for map of loads.

Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Copper (kg/ha/yr)								
	Subwatershed	Copper		Subwatershed	Copper		Subwatershed	Copper
1	TR02	0.067	34	GR06	0.014	67	DB02	0.009
2	BF05	0.023	35	BR01	0.014	68	EB03	0.009
3	BF04	0.022	36	BR02	0.014	69	TR09	0.009
4	WO05	0.020	37	GR01	0.014	70	TB04	0.009
5	BR07	0.020	38	SM03	0.014	71	AD01	0.009
6	BR05	0.020	39	SC08	0.013	72	AD02	0.009
7	BR03	0.019	40	SM01	0.013	73	EB01	0.009
8	SC04	0.019	41	AT04	0.013	74	EB02	0.009
9	BR06	0.019	42	GR02	0.013	75	BK01	0.009
10	SC01	0.019	43	BF01	0.012	76	TR14	0.009
11	WO02	0.019	44	CE03	0.012	77	TB01	0.009
12	SM04	0.018	45	SM02	0.011	78	DB01	0.008
13	WO03	0.018	46	SJ02	0.011	79	AB01	0.008
14	WO04	0.018	47	TR12	0.011	80	CH03	0.008
15	SC03	0.018	48	SB03	0.011	81	CH01	0.008
16	SC02	0.018	49	AT03	0.011	82	TB03	0.008
17	BF03	0.017	50	CC04	0.011	83	WB07	0.008
18	BF02	0.017	51	CE04	0.011	84	WB01	0.008
19	SM05	0.017	52	EB04	0.011	85	CH02	0.008
20	SC09	0.017	53	TR11	0.011	86	WB04	0.008
21	BR04	0.017	54	WB02	0.011	87	WB03	0.008
22	SC06	0.017	55	CC02	0.010	88	AB03	0.008
23	GR07	0.016	56	CE02	0.010	89	TR08	0.008
24	SB02	0.016	57	GR04	0.010	90	WB05	0.007
25	SC05	0.015	58	CE01	0.010	91	DB03	0.007
26	WB06	0.015	59	TR13	0.010	92	BK02	0.007
27	WO01	0.015	60	GR05	0.010	93	SB04	0.007
28	NB01	0.015	61	CC05	0.010	94	TR04	0.006
29	CC03	0.014	62	SB01	0.010	95	TR03	0.006
30	SC07	0.014	63	TR10	0.010	96	TR07	0.005
31	AT02	0.014	64	CC01	0.009	97	TR06	0.004
32	AT01	0.014	65	AB02	0.009	98	TR05	0.003
33	GR03	0.014	66	TB02	0.009			

NOTES:
1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:
   AB = Austin/Bastrop
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   BF = Buffalo
   BK = Barker Reservoir
   BR = Brays
   CC = Clear Creek
   CE = Cedar
   CH = Chocolate
   DB = Dickinson
   EB = East Bay
   GR = Greens
   NB = North Bay
   SB = South Bay
   SC = Ship Channel
   SJ = San Jacinto
   SM = Sims
   TB = Trinity Bay
   TR = Trinity River
   WB = West Bay
   WO = White Oak
3. See Figures E.11 and 7.8 for map of loads.

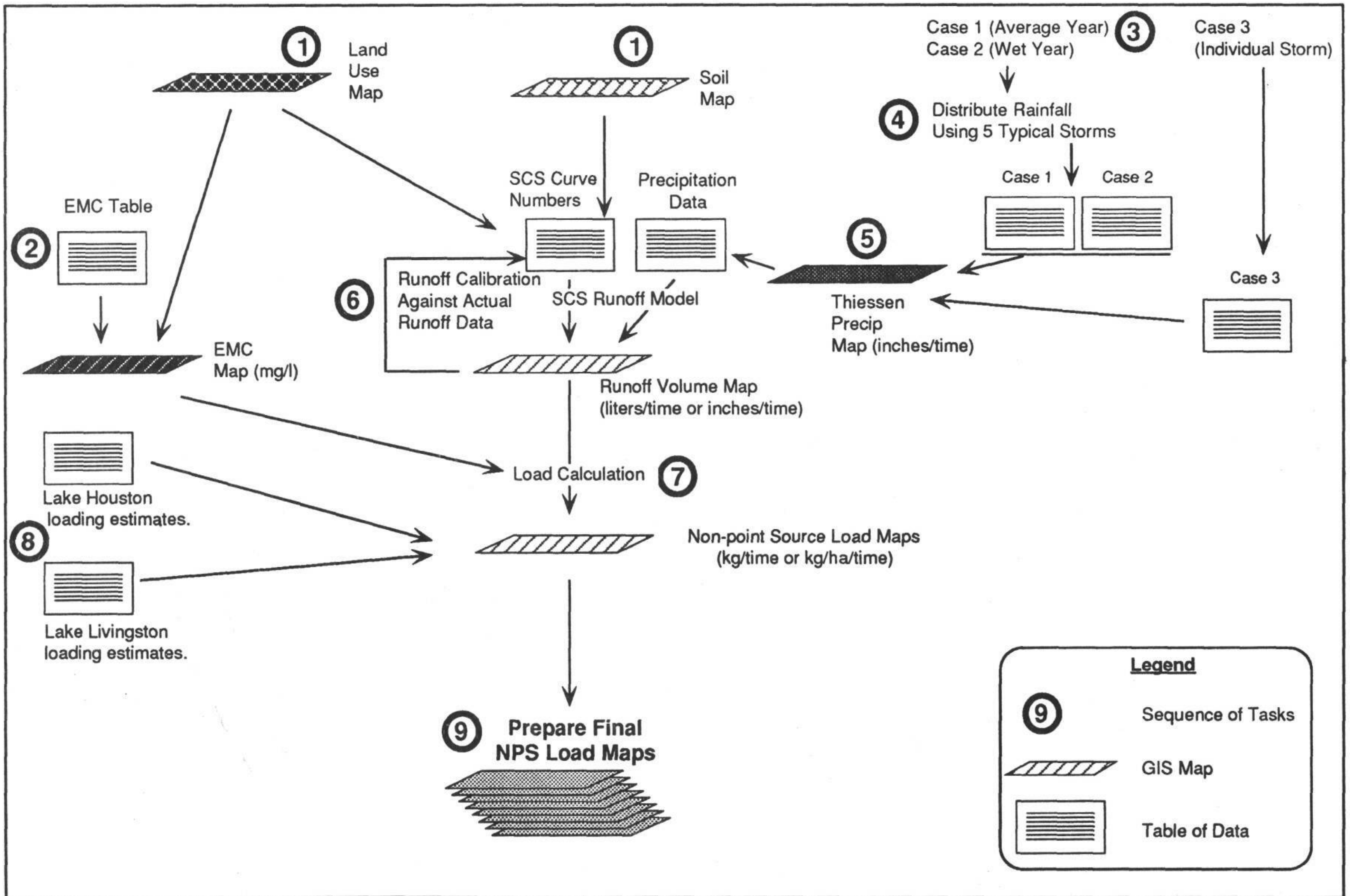
Table E.6 - Priority Ranking of Annual NPS Loads by Subwatershed for Case 1

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

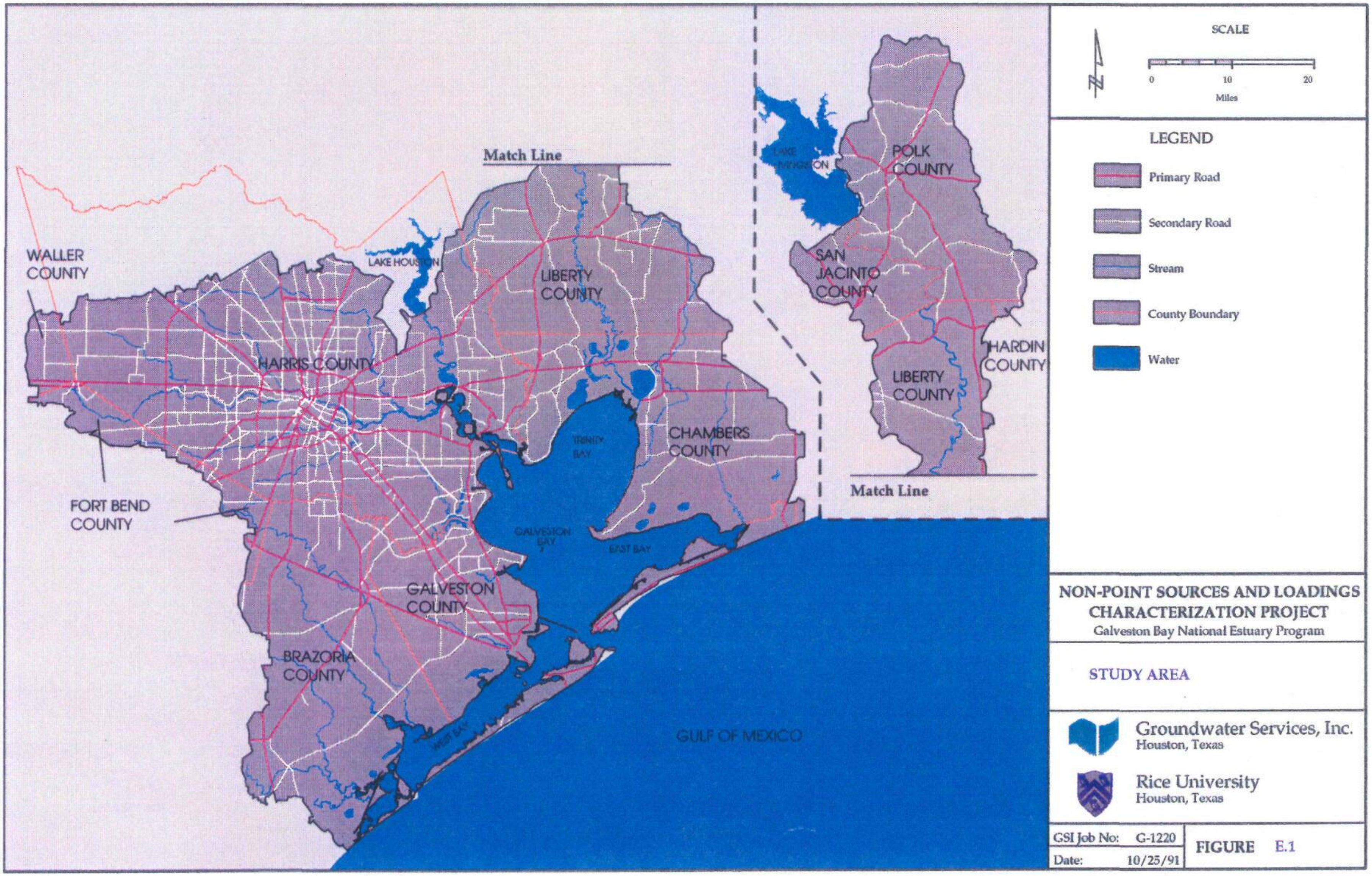
Total Pesticides (kg/ha/yr)								
	Subwatershed	Pesticides		Subwatershed	Pesticides		Subwatershed	Pesticides
1	BF05	0.00285	34	CC03	0.00131	67	TR11	0.00048
2	BF04	0.00273	35	GR01	0.00129	68	SB04	0.00047
3	WO05	0.00250	36	AT02	0.00125	69	TR12	0.00046
4	BR07	0.00243	37	SM03	0.00125	70	BK01	0.00046
5	BR05	0.00239	38	AT01	0.00122	71	TR14	0.00046
6	BR06	0.00227	39	SB03	0.00122	72	DB01	0.00045
7	TR02	0.00225	40	GR02	0.00122	73	WB03	0.00044
8	SC01	0.00223	41	AT04	0.00121	74	CC01	0.00043
9	BR03	0.00221	42	BF01	0.00120	75	TR13	0.00042
10	SC04	0.00218	43	SC08	0.00108	76	WB04	0.00041
11	WO02	0.00214	44	SM01	0.00106	77	CH03	0.00041
12	WO04	0.00214	45	SB01	0.00098	78	TB02	0.00040
13	BF02	0.00209	46	CC04	0.00096	79	DB03	0.00039
14	WO03	0.00208	47	CE04	0.00091	80	EB02	0.00039
15	BF03	0.00207	48	EB04	0.00088	81	CE01	0.00038
16	SM04	0.00204	49	CE03	0.00088	82	EB01	0.00037
17	SC02	0.00196	50	AT03	0.00087	83	AB03	0.00036
18	SC03	0.00195	51	GR04	0.00085	84	AB01	0.00036
19	SB02	0.00192	52	WB02	0.00084	85	TB03	0.00036
20	SM05	0.00186	53	SM02	0.00084	86	TR10	0.00035
21	BR04	0.00186	54	GR05	0.00082	87	WB01	0.00035
22	SC09	0.00181	55	SJ02	0.00082	88	BK02	0.00034
23	WB06	0.00176	56	CC05	0.00081	89	CH02	0.00032
24	SC06	0.00173	57	AD02	0.00073	90	TR09	0.00031
25	GR07	0.00167	58	WB07	0.00066	91	TB01	0.00031
26	WO01	0.00146	59	DB02	0.00063	92	CH01	0.00029
27	BR01	0.00142	60	CC02	0.00061	93	TR08	0.00028
28	SC05	0.00142	61	TB04	0.00059	94	TR03	0.00024
29	NB01	0.00142	62	AB02	0.00056	95	TR04	0.00022
30	BR02	0.00141	63	WB05	0.00056	96	TR07	0.00016
31	SC07	0.00139	64	AD01	0.00054	97	TR05	0.00013
32	GR03	0.00136	65	EB03	0.00052	98	TR06	0.00012
33	GR06	0.00133	66	CE02	0.00050			

NOTES:

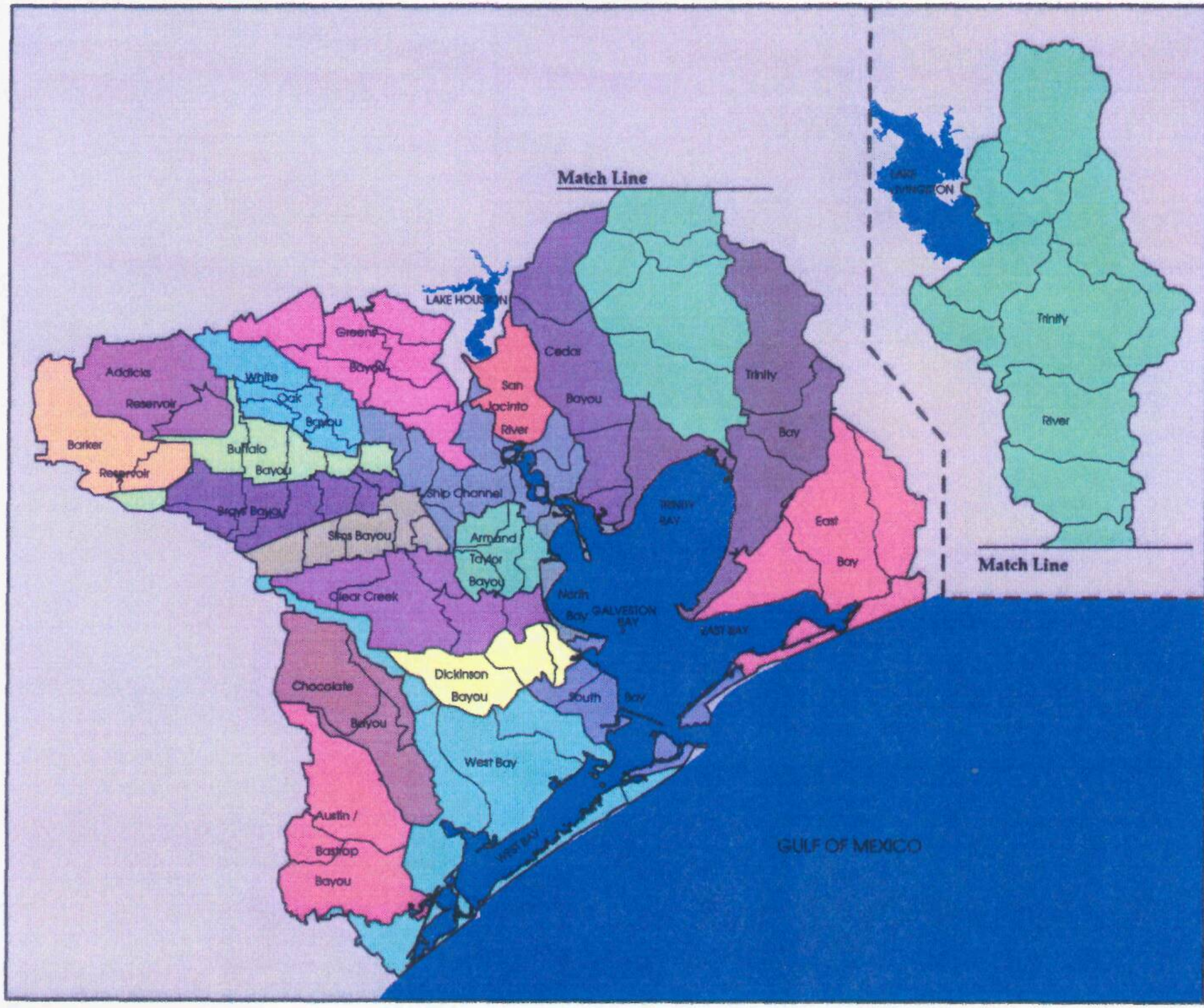
1. Key to Subwatershed identification:
   TR02 = Subwatershed 2 of the Trinity River Watershed (see Figure E.2)
2. Key to Watersheds:
   AB = Austin/Bastrop
   AD = Addicks Reservoir
   AT = Armand/Taylor
   BF = Buffalo
   BK = Barker Reservoir
   BR = Brays
   CC = Clear Creek
   CE = Cedar
   CH = Chocolate
   DB = Dickinson
   EB = East Bay
   GR = Greens
   NB = North Bay
   SB = South Bay
   SC = Ship Channel
   SJ = San Jacinto
   SM = Sims
   TB = Trinity Bay
   TR = Trinity River
   WB = West Bay
   WO = White Oak
3. See Figures E.12 and 7.9 for map of loads.



Groundwater Services, Inc. Houston, Texas	Rice University Dept. of Environmental Science and Engineering	GSI JOB NO. G-1220 ISSUED: 10/25/91 REVISED: EXHIBIT: E.1	**FLOWCHART OF NON-POINT SOURCE LOAD CALCULATION** Non-Point Source Characterization Project Galveston Bay National Estuary Program



SOURCE: Digitized 1:100,000 USGS maps.



SCALE

0 10 20

Miles

LEGEND

- Austin/Bastrop Bayou
- Addicks Reservoir
- Armand/Taylor Bayou
- Buffalo Bayou
- Barker Reservoir
- Brays Bayou
- Clear Creek
- Cedar Bayou
- Chocolate Bayou
- Dickinson Bayou
- East Bay
- Greens Bayou
- North Bay
- South Bay
- Ship Channel
- San Jacinto River
- Sims Bayou
- Trinity Bay
- Trinity River
- West Bay
- White Oak Bayou

NON-POINT SOURCES AND LOADINGS CHARACTERIZATION PROJECT

Galveston Bay National Estuary Program

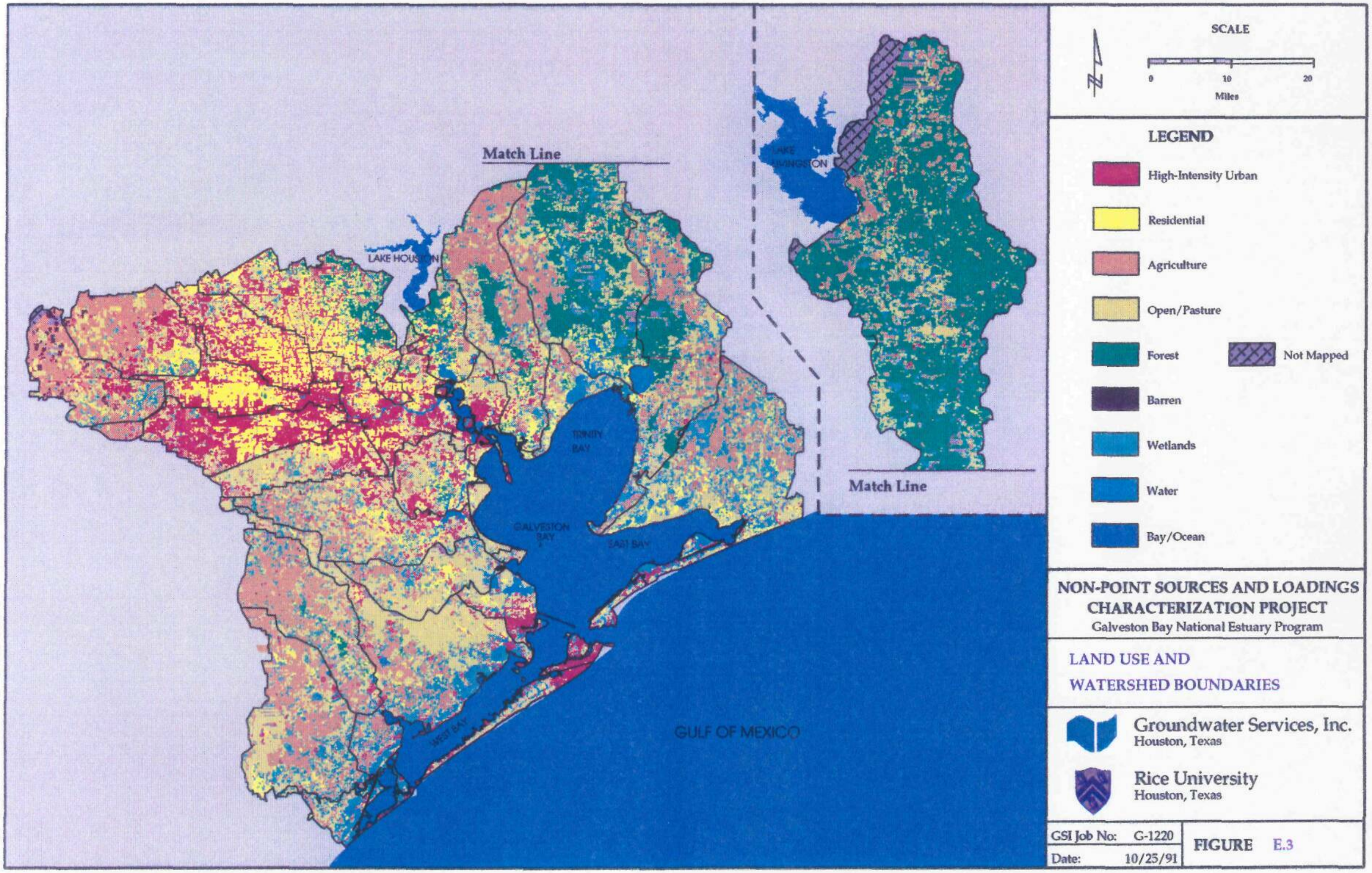
SUBWATERSHED DELINEATION

Groundwater Services, Inc.
Houston, Texas

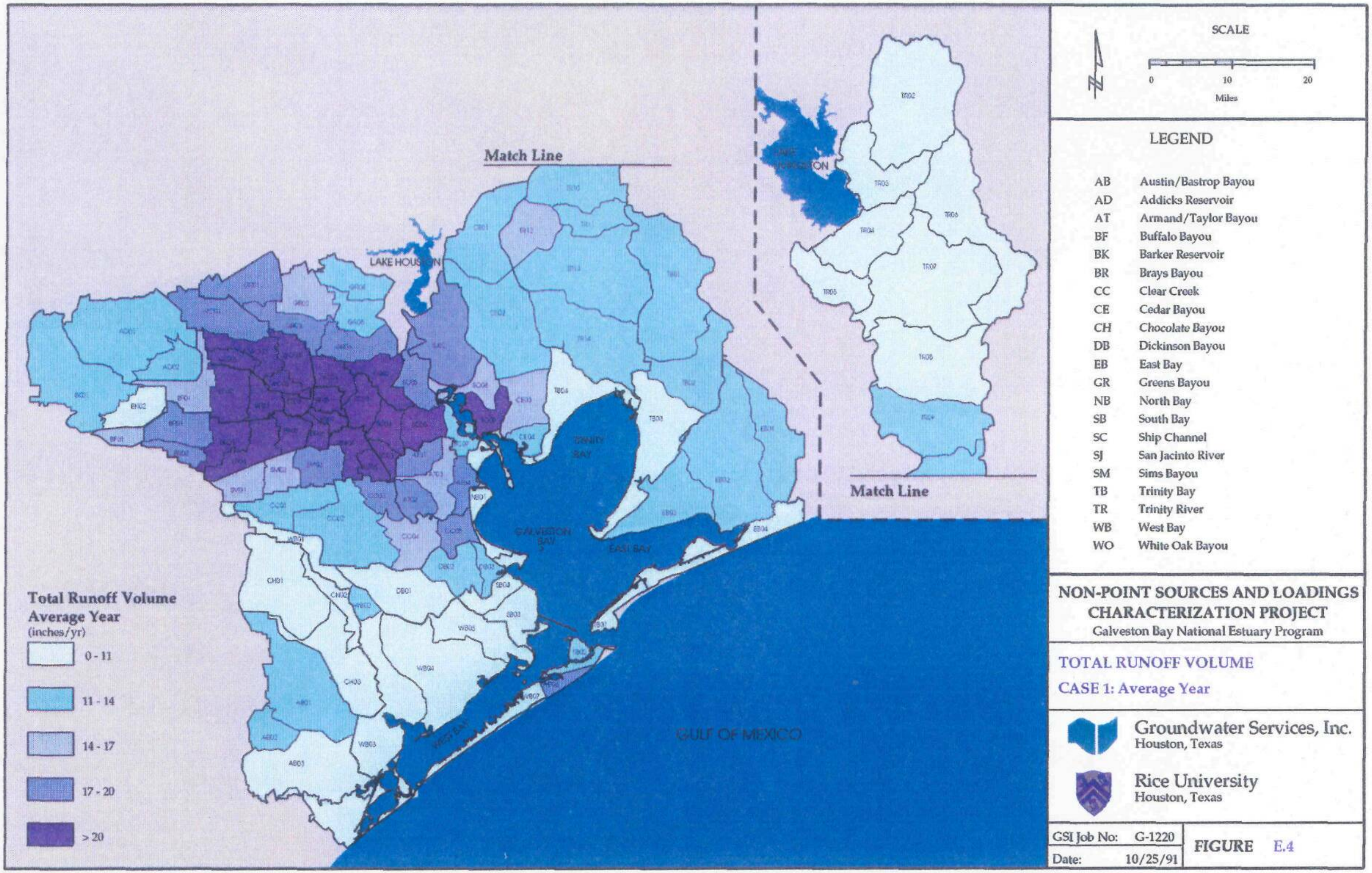
Rice University
Houston, Texas

GSI Job No:	G-1220
Date:	10/25/91

FIGURE E.2



SOURCE: LANDSAT imagery taken November, 1990. Interpretation performed by Intera Aero Service.


SCALE
0
10
20
Miles
LEGEND
AB Austin/Bastrop Bayou
AD Addicks Reservoir
AT Armand/Taylor Bayou
BF Buffalo Bayou
BK Barker Reservoir
BR Brays Bayou
CC Clear Creek
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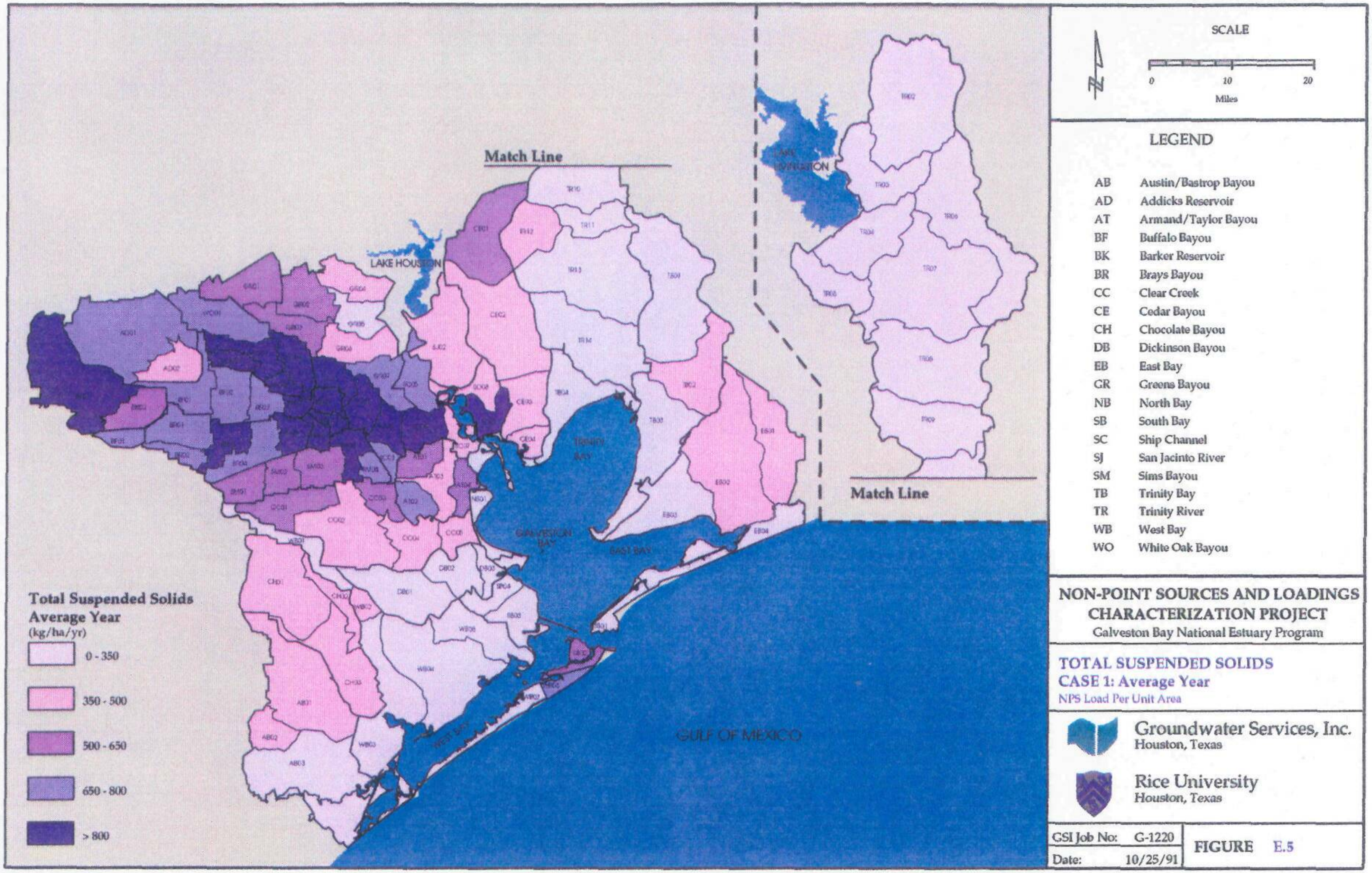
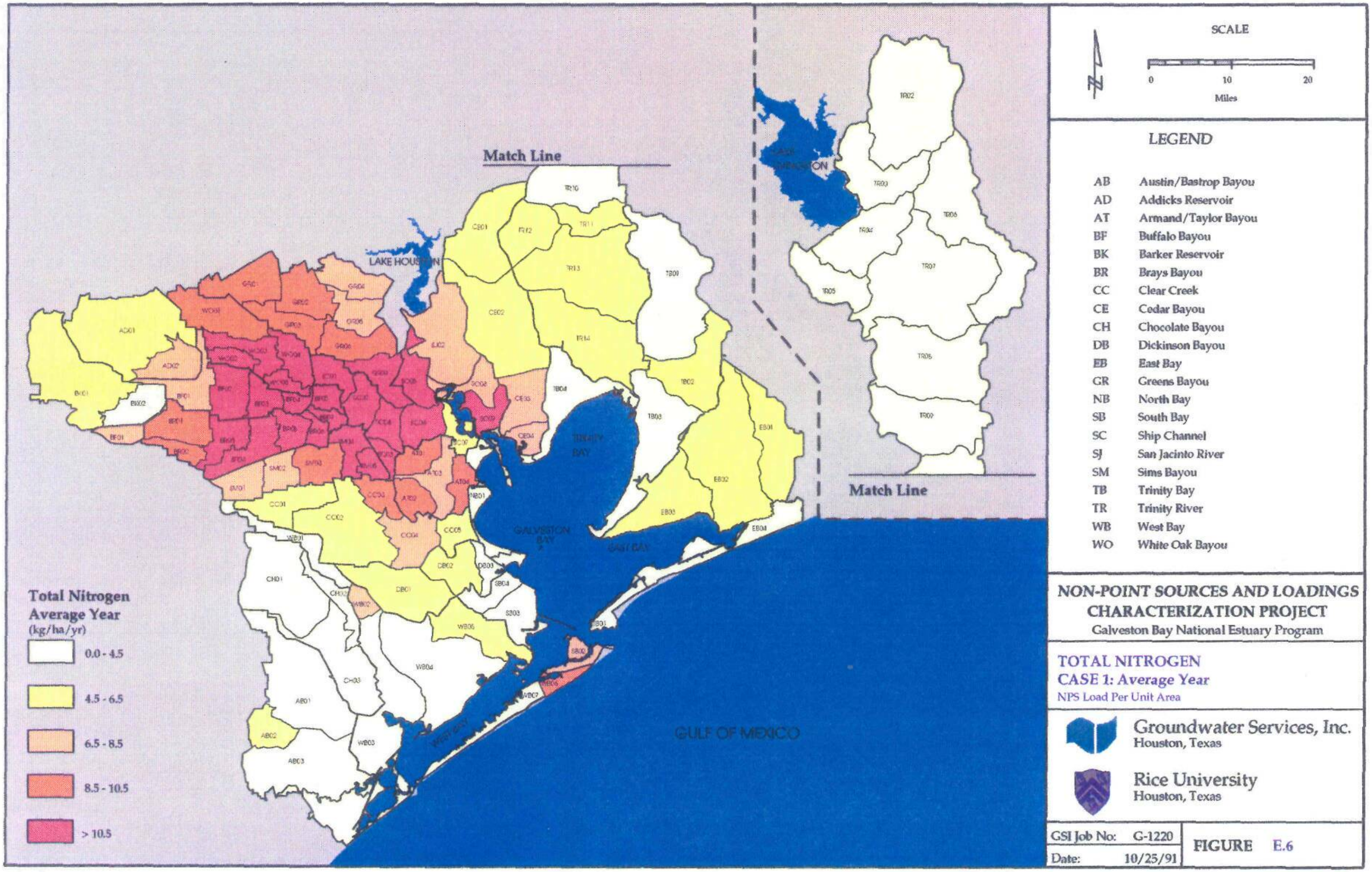
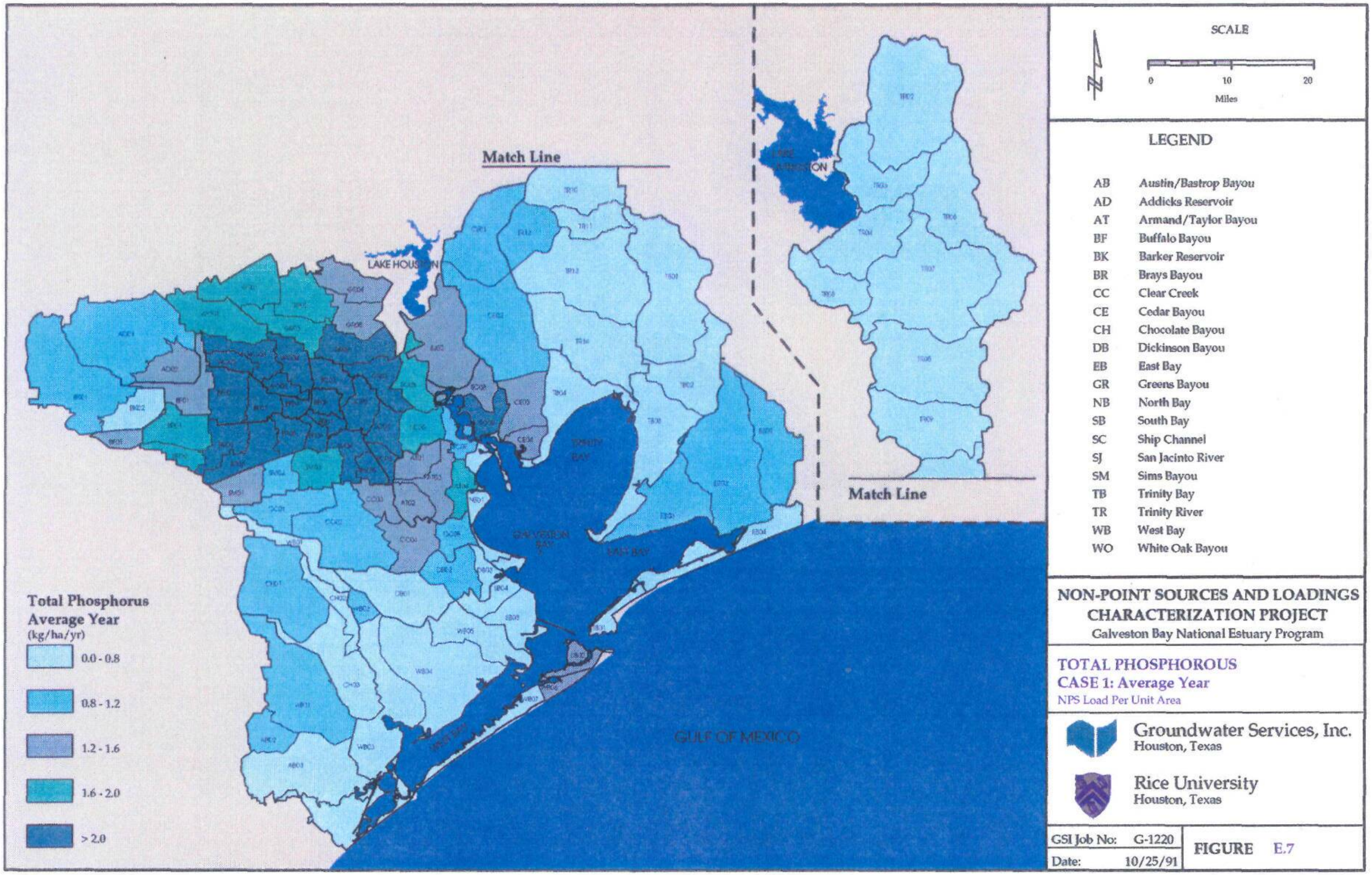
EB East Bay
GR Greens Bayou
NB North Bay
SB South Bay
SC Ship Channel
SJ San Jacinto River
SM Sims Bayou
TB Trinity Bay
TR Trinity River
WB West Bay
WO White Oak Bayou
NON-POINT SOURCES AND LOADINGS CHARACTERIZATION PROJECT
Galveston Bay National Estuary Program
TOTAL RUNOFF VOLUME
CASE 1: Average Year
Groundwater Services, Inc.
Houston, Texas
Rice University
Houston, Texas
GSI Job No: G-1220
Date: 10/25/91
FIGURE E.4
Match Line
Match Line
LAKE HOUSTON
GALVESTON BAY
TRINITY BAY
EAST BAY
WEST BAY
GULF OF MEXICO
Total Runoff Volume
Average Year
(inches/yr)
0 - 11
11 - 14
14 - 17
17 - 20
> 20



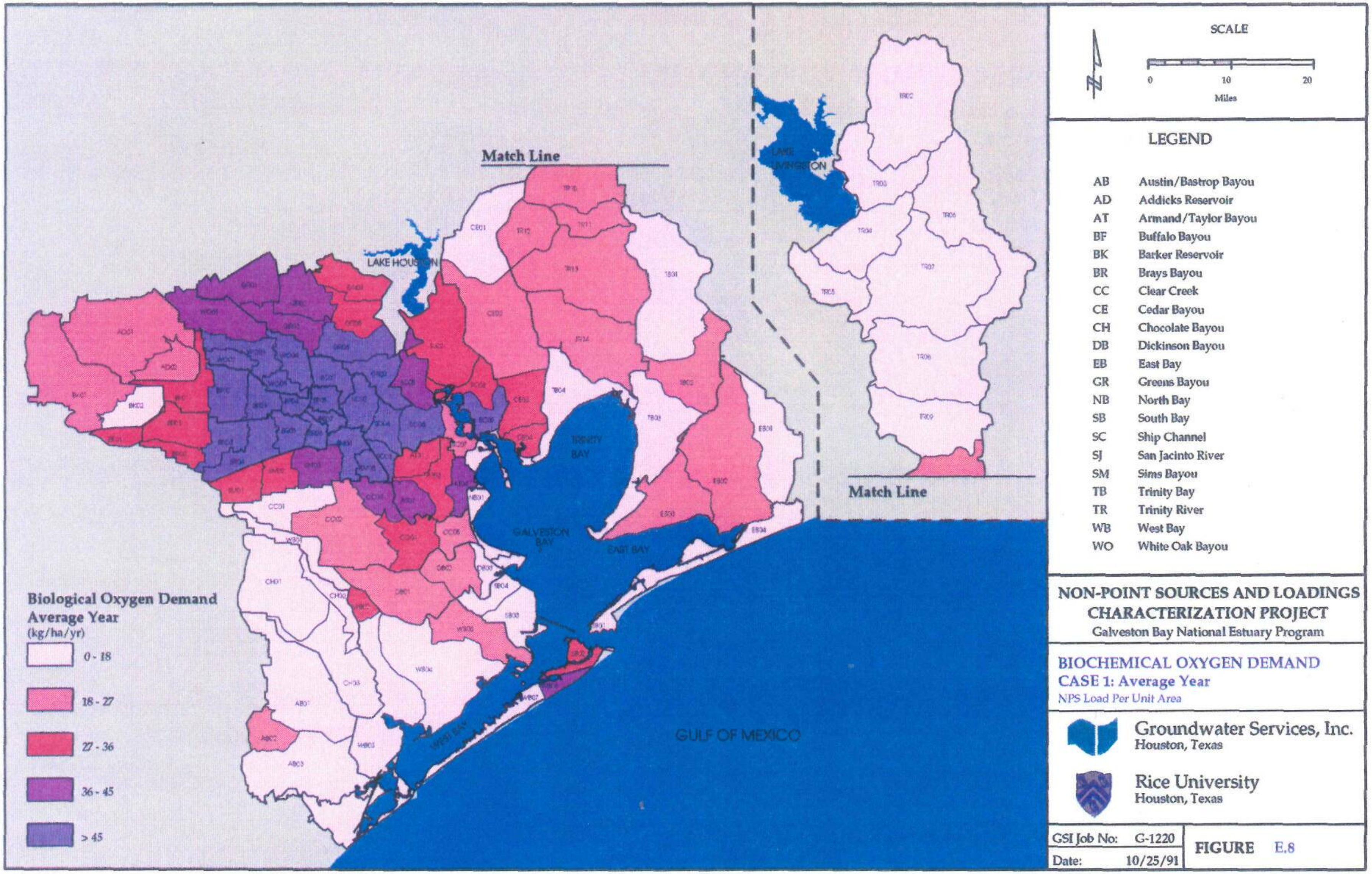
NOTE: 1 hectare (ha) = 2.47 acres.



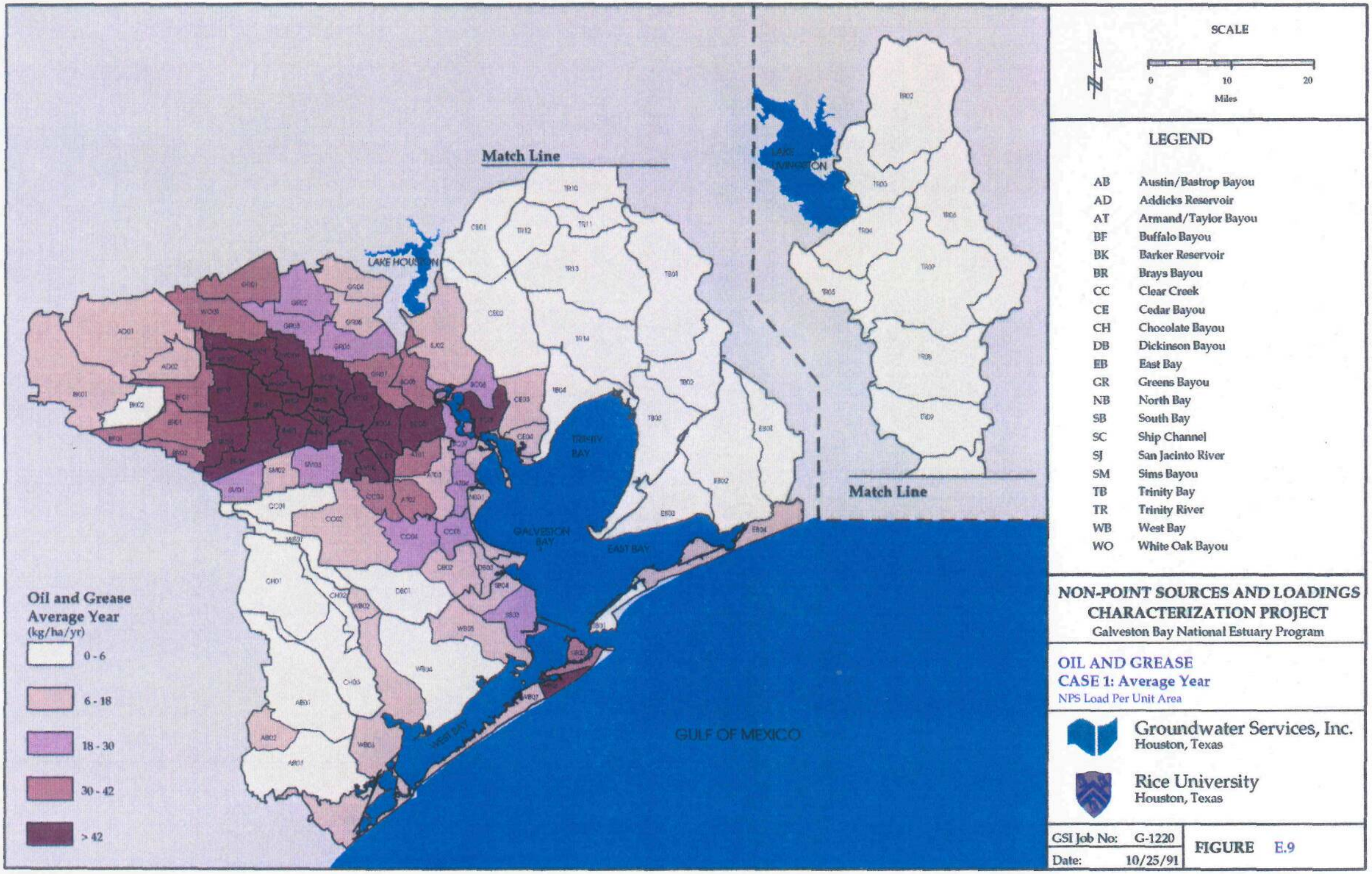
NOTE: 1 hectare (ha) = 2.47 acres.



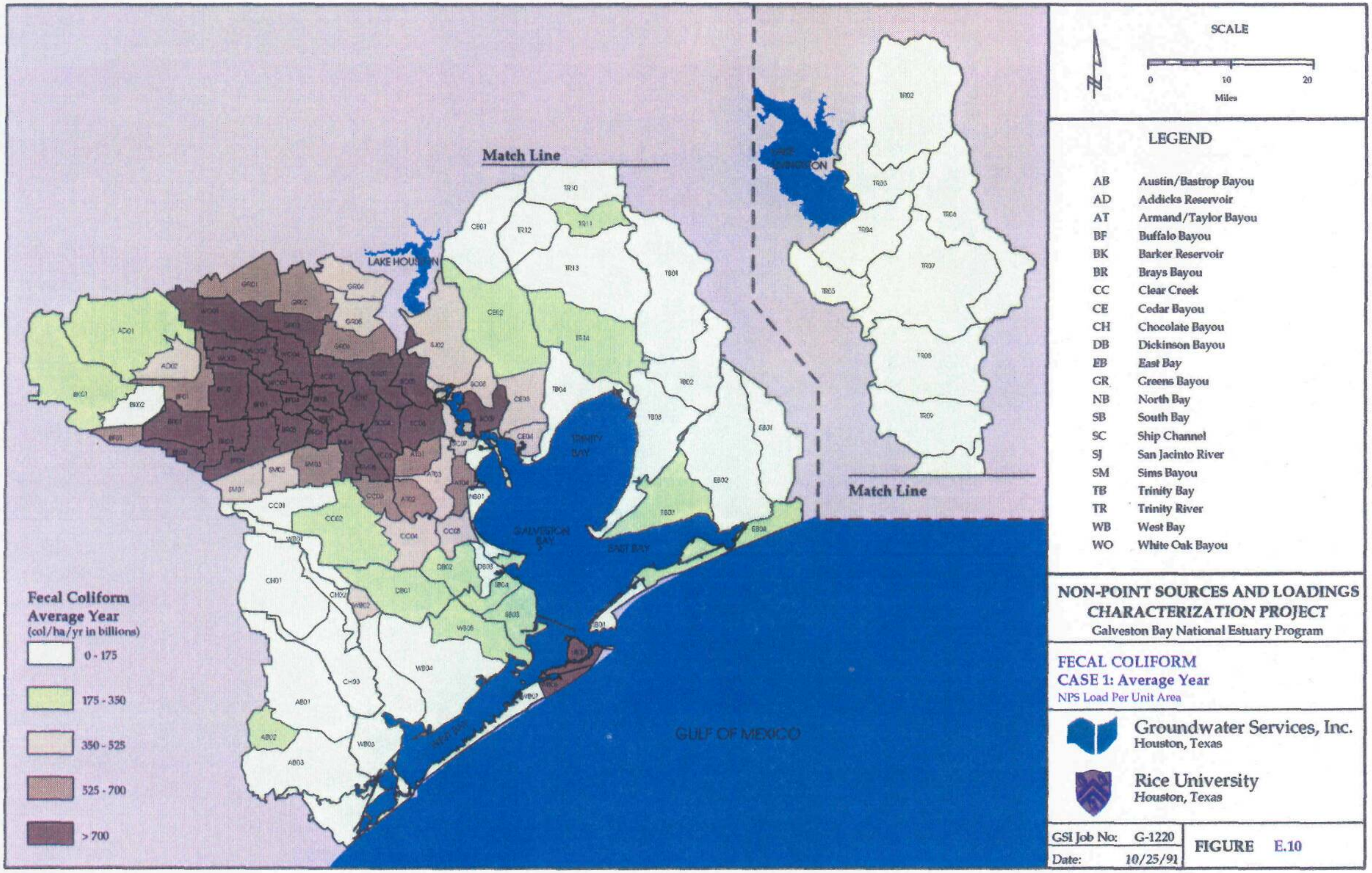
NOTE: 1 hectare (ha) = 2.47 acres.



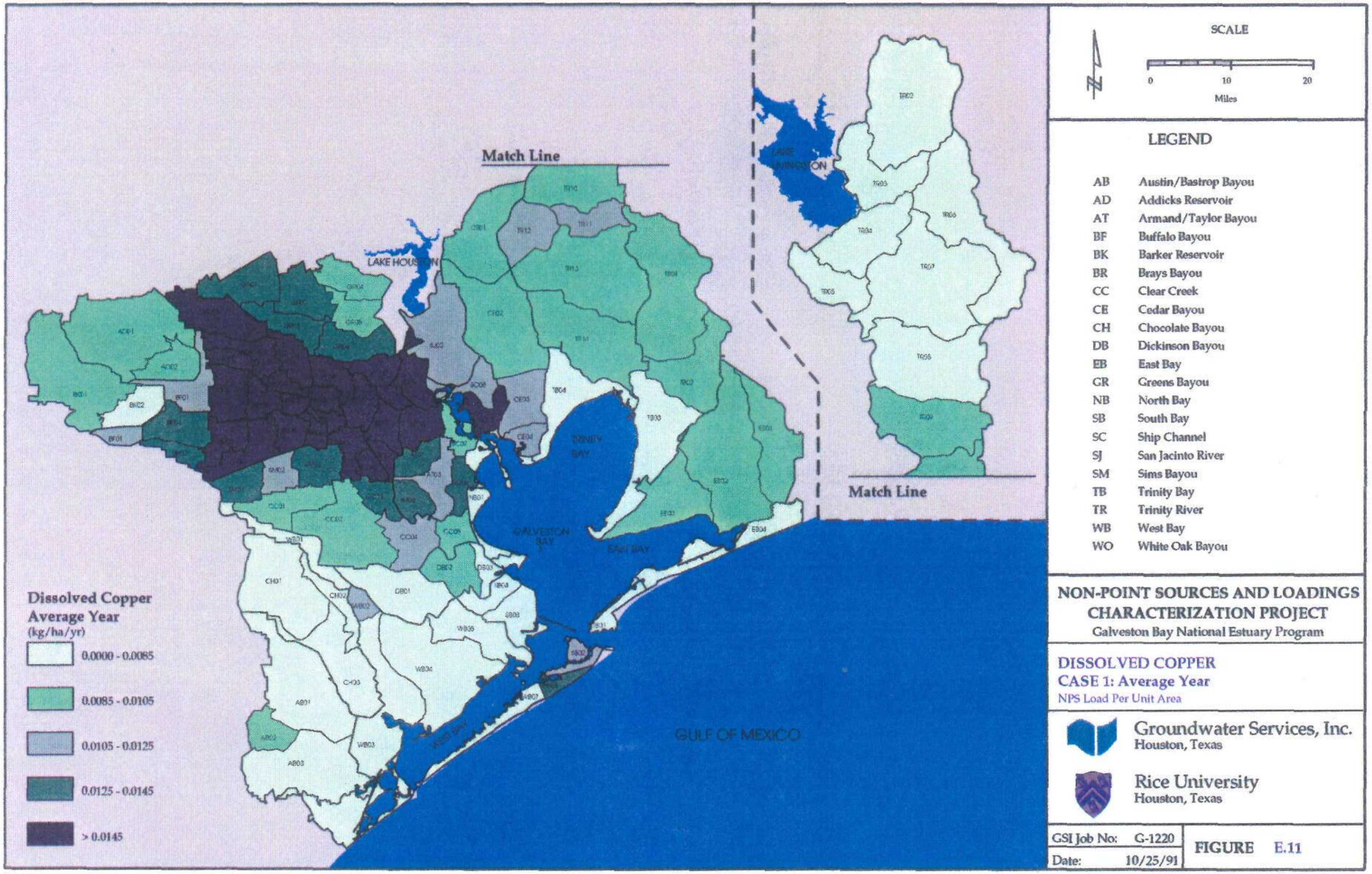
NOTE: 1 hectare (ha) = 2.47 acres.



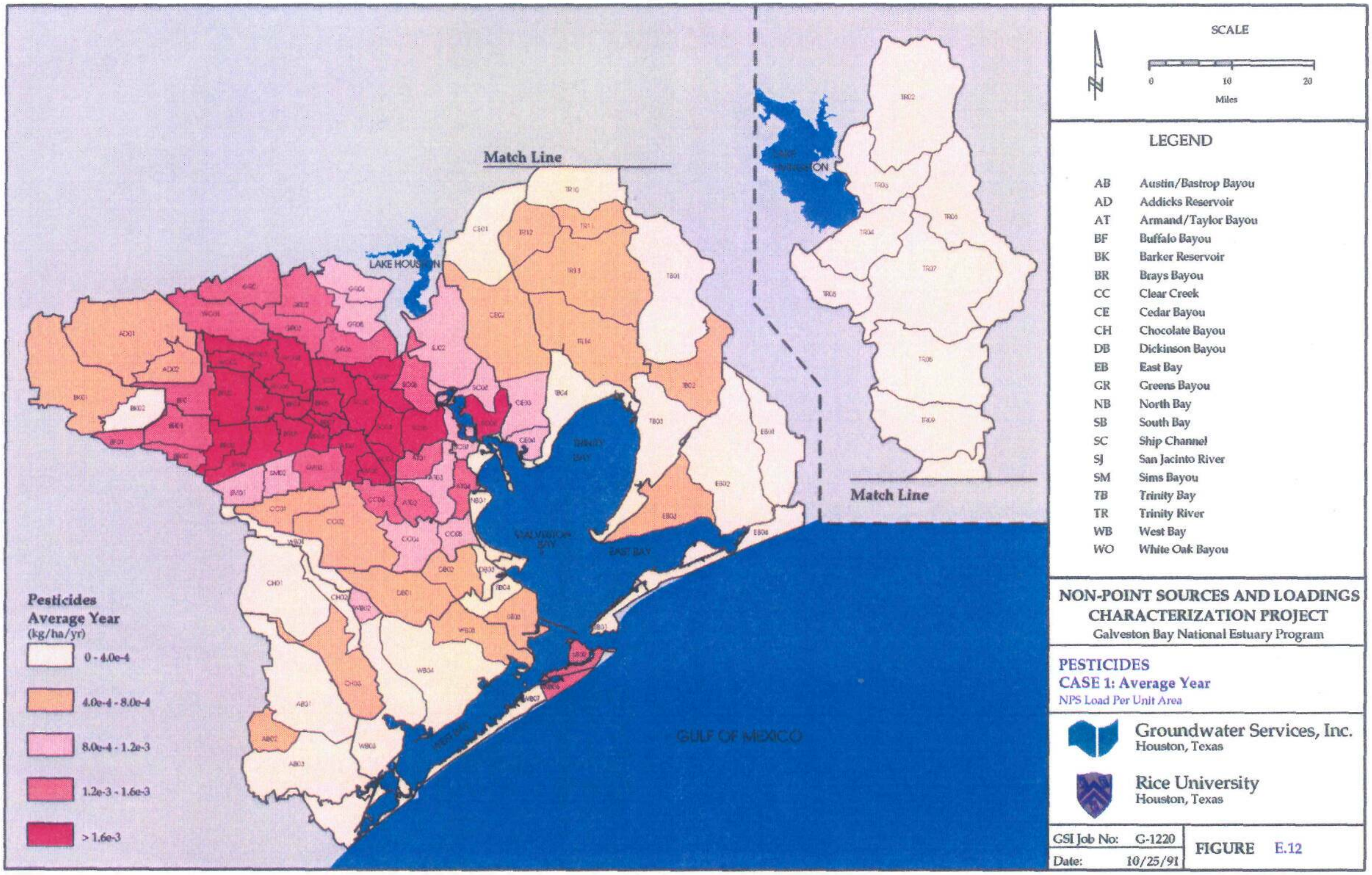
NOTE: 1 hectare (ha) = 2.47 acres.



NOTE: 1 hectare (ha) = 2.47 acres.



NOTE: 1 hectare (ha) = 2.47 acres.



NOTE: 1 hectare (ha) = 2.47 acres.

FINAL REPORT
CHARACTERIZATION OF NON-POINT SOURCES AND
LOADINGS TO GALVESTON BAY

1.0 INTRODUCTION

The Galveston Bay National Estuary Program (GBNEP) is a multi-agency environmental management planning program established for the protection and improvement of water quality and living resources within the Galveston Bay Estuary. In general terms, the project was designed to address one directive of the Clean Water Act: to develop the relationship between in-place loads and point and non-point loadings of pollutants to the estuarine zone and the potential uses of the zone, water quality, and natural resources. To meet these goals, the GBNEP has embarked on a three phase plan as mandated by the National Estuary Program: First, the problems in the estuary are prioritized; second, the estuary is scientifically characterized to better define the problems and link them with causes; and third, a series of action plans are created to solve these problems. The problem prioritization phase, conducted in 1989, identified non-point source pollutants entering Galveston Bay to be an important problem requiring further assessment.

This study, initiated in November 1990, and completed by Groundwater Services, Inc. (GSI), and their subcontractor Rice University (RU), was aimed at characterizing non-point sources and loads into Galveston Bay. Non-point sources include a wide array of diffuse pollutant types and sources, from major storm water outfalls, land drainage, and human activity. Pollutants include toxics, fecal coliform bacteria, oxygen demand, nutrients and sediments. Source activities include urban development and agricultural activities, septic tanks, and runoff from industrial and residential developments.

The present project was designed to be a "washoff" study; that is, a study of non-point source loads originating from different types of land use. Land use has been recognized as one of the major variables in non-point sources of pollution, and has been the focus of most of the non-point source studies performed in the U.S. to date. A unique and original land use/land cover database for Galveston Bay was developed in this case from interpreted satellite imagery that provided a high resolution snapshot of the basin land use as it existed in 1990.

In addition, the project utilized a relatively new technology, Geographical Information Systems (GIS), to achieve the objectives set forth in the work plan. The GIS was used to map the geographic characteristics of the study area, analyze the land use data, complete the NPS calculations, and finally graphically present the project results. The resulting GIS database can be used as a very effective management tool for Galveston Bay.

This report presents the results from the GSI/RU NPS project. Section 2.0 lists the objectives and the approach adopted in the work. Sections 3 and 4 provide a brief overview of the study area and the nationwide and local non-point source studies that have been performed to date. A detailed description of the project methodology is included in Sections 5.0 and 6.0. The project results are discussed in Section 7.0, while conclusions are summarized in Section 8.0. The Figures referenced in this report are located in Volume II while the Appendices are located in Volume III.

2.0 OBJECTIVES

The objective of this work was to conduct a geographic analysis and priority ranking of possible NPS sources and loads to Galveston Bay. The study area was defined by GBNEP and includes the entire Galveston Bay drainage area with the exception of the Lake Houston and Lake Livingston watersheds (see Table 2.1 for a list of the Texas Water Quality Segments in the study area). The primary elements for the NPS analysis included watershed hydrology, NPS load estimates, ranking of subwatersheds, upper watershed influences, and mapping. The approach for handling each element is discussed in more detail below.

- **Watershed Hydrology.** The entire Galveston Bay drainage basin (excluding watersheds draining into Lake Houston and Lake Livingston) would be mapped and divided into approximately 15 watersheds and 100 subwatersheds.

- **Land Use.** A detailed land cover/land use analysis would be developed to provide a basis for the non-point source load calculation.

- **Relative NPS Load Estimates by Land Use Category and NPS Parameters.** Empirical data, collected from local studies where possible, would be used as the basis of the NPS database for this study, and representative Event Mean Concentrations (EMCs) would be compiled to quantify water quality of runoff from different land uses.

- **Ranking of Subwatershed NPS Loads.** Based on the relative load estimates (developed as described above), subwatershed boundaries, and hydrologic features, each subwatershed would be ranked relative to other subwatersheds for each of the NPS parameter categories.

- **Upper Watershed Influence.** Because NPS loads entering Lake Houston and Lake Livingston are either greatly reduced or attenuated by the reservoirs, the upstream watersheds of the San Jacinto River and the Trinity River would be excluded by GBNEP from the mapping analysis. Existing water quality data, collected at regular periods below the reservoirs, would be statistically analyzed in detail and compared to the hydrologic record to estimate total pollutant loads (comprised of point source loads, low-flow loads, and NPS loads) from the two reservoirs.

- **Mapping.** A Geographic Information System (GIS) known as ARC/INFO would be used to process the land use and NPS database and prepare all final project maps. The final electronic versions of the GIS products would be delivered to the GBNEP so that other researchers could utilize the database for future projects.

The final project would be used to develop strategies for managing the water quality of Galveston Bay. Future environmental projects can utilize this information to assess the impacts of non-point source pollutants on the bay, and can employ the GIS system to help design pollution control measures as needed to achieve water quality goals.

Table 2.1 - Subwatersheds by TWC Stream Segment Number
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	TWC Stream Segment	TWC Name
Chocolate Bayou	CH01	1108	San Jacinto - Brazos Coastal Basin
	CH02	1108	
	CH03	1107	
Austin/Bastrop Bayous	AB01	1105	
	AB02	1105	
	AB03	1105	
Dickinson Bayou	DB01	1104	
	DB02	1103	
	DB03	1103	
	DB04	1103	
Clear Creek	CC01	1102	
	CC02	1102	
	CC03	1102	
	CC04	1101	
	CC05	1101	
Buffalo Bayou	BF01	1014	San Jacinto River Basin
	BF02	1014	
	BF03	1013	
	BF04	1013	
	BF05	1007	
Greens Bayou	GR07	1007	
Brays Bayou	BR07	1007	
Sims Bayou	SM04	1007	
Ship Channel	SC02	1007	
	SC04	1007	
	SC06	1006	
	SC07	1006	
	SC08	1005	
	SC09	1005	
San Jacinto River	SJ02	1001	
Cedar Bayou	CE01	0902	Trinity - San Jacinto Coastal Basin
	CE02	0902	
	CE03	0901	
	CE04	0901	
Trinity Bay	TB02	0802	Trinity River Basin
	TB03	0802	
	TB04	0802	
Trinity River	TR02	0802	
	TR03	0802	
	TR04	0802	
	TR05	0802	
	TR06	0802	
	TR07	0802	
	TR08	0802	
	TR09	0802	
	TR10	0802	
	TR11	0802	
	TR12	0802	
	TR13	0802	
	TR14	0801	

NOTES:
1. Bay and Estuary segments included in study: 2421 - Upper Galveston Bay, 2422 - Trinity Bay, 2423 - East Bay, 2424 - West Bay, 2425 - Clear Lake, 2426 - Tabbs Bay, 2427 - San Jacinto Bay, 2428 - Black Duck Bay, 2429 - Scott Bay, 2430 - Burnett Bay, 2431 - Moses Lake, 2432 - Chocolate Bay, 2433 - Bastrop Bay/Oyster Lake, 2434 - Christmas Bay, 2435 - Drum Bay, 2436 - Barbours Cut, 2437 - Texas City Ship Channel, 2438 - Bayport Channel, and 2439 - Lower Galveston Bay.
2. See Section 6.1 for a definition of Watersheds and Subwatersheds.

3.0 DESCRIPTION OF STUDY AREA

3.1 The Galveston Bay Estuary System

The Galveston Bay system covers about 560 square miles (1,430 square kilometers) and includes East Bay, Galveston Bay, Trinity Bay, West Bay and other smaller bays. The Trinity-San Jacinto estuary, to which Galveston Bay is sometimes referred, tends to be shallow with average depths ranging from 1.6 m in its upper bays to between 2 and 4 m in the lower reaches. Drainage areas contributing freshwater to the Galveston Bay system include the Trinity and San Jacinto River basins, the Trinity-San Jacinto coastal basin, and parts of the Neches-Trinity and San Jacinto-Brazos coastal basins.

The Trinity River basin, by far the largest of the drainage basins (17,969 square miles or 46,540 square kilometers, Stanley, 1989), empties into Trinity Bay. Lake Livingston is the largest reservoir in the Trinity River basin and is the only lake on the main stem of the Trinity between Dallas and Galveston Bay. The San Jacinto River basin has a much smaller drainage area - 3,976 square miles (10,230 square kilometers). Emptying into the Houston Ship Channel, the San Jacinto depends for its flow almost entirely upon overflow at the dam on Lake Houston, which is the principal water supply reservoir for the City of Houston.

While the San Jacinto is generally the most important source of freshwater to the lower Houston Ship Channel, the principal source of inflow to the upper channel during dry periods is wastewater discharge. This is primarily because of the small watershed of Buffalo Bayou, the lower reach of which was widened and deepened in the early part of this century to form the Ship Channel. Much of the growth and development of the Houston area in attributable to the completion of the Ship Channel in 1914, in combination with the discovery of oil in the State. The channel permitted ocean-going vessels to traverse the shallow Galveston Bay all the way to Houston, resulting in a tremendous upsurge in industrial growth in Houston.

The Galveston Bay system is integral to the economy of the State. Over 3.2 million people live in the four-county area adjacent to the bay (Harris, Galveston, Brazoria, and Chambers), with most of the population residing northwest of the bay in Harris County. Nearly one-half of the total chemical production in the U. S. takes place in the four-county area surrounding the bay. Thirty percent of the total U. S. petroleum industry is located adjacent to the bay, mostly along the upper Houston Ship Channel and in the Texas City vicinity (Stanley, 1989). Galveston Bay historically has been the overall leading fisheries resource base in Texas. In addition, the bay has supported many recreational industries such as boating, sport fishing, duck hunting, swimming, camping, picnicking and sightseeing. Two national wildlife refuges, Brazoria and Anahuac, and several State parks exist in the bay area.

3.2 Major Watersheds

The focus of this NPS study was on the 4,238 square mile drainage area comprised of land immediately downstream of the Lake Houston and Lake Livingston reservoirs and adjacent watersheds (Figure 3.1), all of which drain directly into Galveston Bay. Major urban watersheds within the drainage basin include the Houston Ship Channel-Buffalo Bayou system and its associated tributaries: Whiteoak Bayou, Brays Bayou, Sims Bayou, Hunting Bayou, and Greens Bayou. Significant rural watersheds include the lower Trinity River, Chocolate Bayou, and Austin/Bastrop Bayous.

3.3 Soils

Most of the soils in the project area are comprised of clay, clay loams, and fine sandy loams that are poorly drained and have low permeability. These soils exhibit very low infiltration rates when wetted and have a very high runoff potential. A small section of more permeable sandy loams are found in the upper part of the Trinity Basin in Polk County.

3.4 Hydrology

The climate of the Houston area, including Galveston Bay, is characterized by short mild winters, long hot summers, high relative humidity, and prevailing southeasterly winds. The mean annual Houston temperature (1941-70) is 68.9°F (20.5°C); the lowest temperature recorded was 5°F (-15°C) in 1930; and the maximum recorded was 108°F (42°C) in 1909.

The average annual rainfall for Houston is approximately 48 inches/year, which is distributed uniformly throughout the year. The maximum annual rainfall was 72.86 inches in 1900; the minimum was 17.66 inches in 1917. The primary spatial trend for precipitation shows higher rainfalls as one heads east across the basin. Although rainfall is generally uniform throughout the year, very significant rainfall can occur over short time periods due to hurricanes and intense thunderstorm cells. For example, in 1979 more than 43 inches of rain was recorded from an unofficial raingage in Alvin, Texas, in a 24 hour period.

Runoff varies significantly across the basin and is usually controlled by land use and land cover. In the urbanized Brays Bayou watershed, for example, 1.4 cubic feet per second per square mile are observed compared to 0.94 cubic feet per second per square mile for the less urbanized Greens Bayou watershed. Although flooding and calculation of peak flows are important hydrologic issues, this project focused on the calculation of runoff volume to estimate non-point source loads to the bay.

3.5 Land Use

Generally, intense urbanization is located in and around the Ship Channel, downtown Houston and Buffalo Bayou, and residential patterns extend northward to Cypress Creek, westward and northward past Addicks-Barker Reservoir, and southward into Brays and Sims Bayous. Other large high intensity urbanized areas are located near Clear Creek and Clear Lake and further south in the Texas City area and on Galveston Island.

Land use in the non-urban portion of the study area consists of roughly equivalent fractions of open/pasture, agriculture and forest. Wetlands account for 5-15% of the total area, and water and barren areas each account for less than 1%.

The bulk of the Trinity River basin (1,099 square miles below Lake Livingston Dam) is forested and has large areas of open/pasture, agriculture and wetlands, especially near Trinity Bay. Residential and urban areas are minimal. Much of Chambers County to the east is composed of wetlands, agriculture and open/pasture. The west bay drainage area consists largely of open/pasture, wetlands and agriculture. The far western area (west of Addicks-Barker) consists of mostly agricultural and open/pasture areas.

4.0 LITERATURE REVIEW

4.1 Non-Point Source Processes

Several general characteristics describe non-point source pollution according to Novotny and Chesters (1981):

- Non-point source discharges enter surface waters in a diffuse manner and at intermittent intervals that are related mostly to the occurrence of meteorological events.
- Pollution arises over an extensive area of land and is in transit overland before it reaches surface waters.
- Non-point sources generally cannot be monitored at their point of origin, and their exact source is difficult or impossible to trace.
- Elimination or control of pollutants must be directed at specific sites.
- In general, the most effective and economical controls are land management techniques and conservation practices in rural zones and architectural control in urban zones.
- Compliance monitoring for non-point sources is carried out on land rather than in water.
- Non-point source pollutants cannot be measured in terms of effluent limitations.
- The extent of non-point source pollution is related, at least in part, to certain uncontrollable climatic events, as well as geographic and geologic conditions, and may differ greatly from place to place and year to year.
- Non-point sources are derived from operations on extensive units of land, as opposed to industrial activities that typically use repetitive operations on intensive (small) units of land.

4.1.1 Rural (Non-Urban) Non-Point Sources

In general, rural non-point sources are related to agricultural and silvicultural activities, such as fertilizer and pesticide application, tillage and logging. Since these operations do not occur continuously, non-point source loads from rural areas can fluctuate significantly from storm to storm. For many agricultural areas, high sediment, nutrient, and fertilizer loads are observed in the spring, when plowing and agricultural chemicals are added to the soil. Much lower loads are observed after harvesting, when cultivated fields are converted to pasture or lie fallow.

For the Galveston Bay watershed, some local research indicates that rice production may result in significantly lower pollutant loads of sediment, nutrients, and pesticides than row crops (McCauley, 1991). During the growing season water is impounded behind small dikes, limiting the potential for any sheet or rill erosion. Published research on pollutant export from rice fields (USEPA, 1978) indicates that high concentrations of these pollutants are found in runoff at certain times during the year (for example, high nutrient concentrations were observed shortly after fertilizer application) but that very low concentrations were also observed during much of the growing season. The complicated hydrology of rice fields and the variable water quality over time make it very difficult to estimate an average NPS-related concentration in rice-field runoff.

Non-point source loads from forested watersheds change dramatically due to the effects of silvicultural activities. Forests usually exhibit very low sediment and nutrient yields; during logging operations, however, erosion rates can increase by several orders of magnitude.

4.1.2 Urban Non-Point Sources

Urbanization and related hydrologic modifications increase pollution loads to values that are significantly above the original or background levels. A variety of sources have been identified as NPS contributors: urban bird and pet populations, street litter accumulation, tire wear of vehicles, oil from car crankcases, fertilizer and pesticide application, eroded areas, abrasion of road surfaces by traffic, and construction activities. Water quality constituents of concern in urban runoff include sediments, nutrients, oxygen-demanding compounds, oil and grease, bacteria, heavy metals, and synthetic organic chemicals.

Of all the urban land uses, low-density residential zones and open areas yield the lowest NPS loads, while highest pollution loads are associated with high-density commercial areas, industrial centers and, above all, construction sites. During construction activities considerable areas are stripped of vegetative cover, exposing open soil. The NPS loadings from construction areas can be an order of magnitude higher than other land uses, and can dominate the total NPS loadings in some watersheds.

4.1.3 Important Water Quality Constituents in Runoff

<u>Total Suspended Solids</u> (TSS) refers to the concentration of suspended sediment in water. TSS is measured by weighing the undissolved material trapped on a 0.45 micrometer filter after filtration. The constituents that pass

through the filter are designated Total Dissolved Solids (TDS) and are comprised of ions such as iron, chloride, sodium, sulfate, etc. TSS is a measure of the amount of erosion occurring in a watershed.

Total Nitrogen (TN) consists of all the various forms of inorganic and organic nitrogen present in water. Nitrogen (N) usually occurs in water in the form of nitrate (NO_3), nitrite (NO_2), organic N, or ammonia (NH_4). Total Kjeldahl Nitrogen (TKN) refers to an analytical procedure that measures organic nitrogen and ammonia together. Nitrogen, particularly the nitrate form, is an indicator of fertilizer application.

Total Phosphorous (TP) occurs in natural waters in the form of orthophosphate and organic phosphorous. As with nitrogen, phosphorous is associated with fertilizer runoff and treatment plant effluent.

Biochemical Oxygen Demand (BOD or BOD_5) is an indirect measure of biodegradable organics in water, and is determined by measuring the dissolved oxygen decrease in a controlled water sample over a five-day period. During this five-day period, aerobic bacteria decompose organic matter in the sample and consume dissolved oxygen in proportion to the amount of organic material that is present. Stormwater runoff with a high Biochemical Oxygen Demand can have an adverse affect on water quality by depleting the oxygen in a receiving stream, lake, or bay.

Fecal Coliforms are bacteria that are present in the intestines or feces of warm blooded animals and are often used as indicators of bacteriological water quality. Concentration is expressed as number of colony forming units (CFU) per 100 milliliters of sample. Standards for contact recreation are 200 CFU per 100 milliliters of sample and 2,000 CFU per milliliter for non-contact recreation.

Heavy Metals occur naturally in soils and derive from a variety of human sources, including industry, automobiles, and agriculture. The primary constituents of interest in non-point source water quality include arsenic, cadmium, chromium, copper, lead, mercury, and zinc.

Oil and Grease is a measure of free-phase organic contamination. The primary source is motor vehicles.

Synthetic Organic Chemicals comprise a large class of compounds that includes pesticides, poly-chlorinated biphenyls, and other trace-level hydrocarbons. Chlorinated hydrocarbons, such as many pesticides, are of most concern.

4.2 National Non-Point Source Studies

In 1981-82 the EPA funded 30 applied research projects as part of an effort to complete a report to Congress on water quality impacts and control of urban runoff pollution. The resulting data collection effort, known as the Nationwide Urban Runoff Program (NURP) yielded the most extensive NPS database assembled in the country to date (USEPA, 1983).

Under NURP, field monitoring was conducted to characterize urban runoff flows and NPS pollutant concentrations. This was done for a variety of pollutants at 80 sites in 21 cities located throughout the country. The collected data represent a cross-section of regional climatology, land use types, slopes, and soil conditions and thereby provides a basis for identifying patterns of similarities or differences and testing their significance.

The collected data showed that urban runoff flows and concentrations of contaminants are quite variable. Experience shows that substantial variations occur within a particular event and from one event to the next at a particular site. The primary conclusions from the NURP study focused on the effects of urban runoff on natural stream systems:

WATER QUALITY EFFECTS (taken directly from USEPA, 1983).

Freshwater Aquatic Life

1. Heavy metals, in particular, are the urban runoff contaminants having the greatest potential for impacts on aquatic life. This conclusion is based on the fact that a number of heavy metals are consistently found in urban runoff in high concentrations relative to suggested toxic limits for aquatic life.

2. Despite the high concentrations of heavy metals in urban runoff, few significant problems traceable to urban runoff were found in the water column.

3. Several projects had identified possible problems in the sediments because of the build-up of priority pollutants contributed wholly or in part by urban runoff. However, the NURP studies in this area were few in number and limited in scope, and the findings must be considered only indicative of the need for further study, particularly as to long-term impacts.

4. The physical aspects of urban runoff, e.g., erosion, scour, etc., can be a significant cause of habitat disruption and can affect the type of fishery present. However, this area was studied only incidentally by several of the projects under the NURP program and more concentrated study is necessary.

5. Organic priority pollutants in urban runoff do not appear to pose a general threat to freshwater aquatic life.

6. Adverse effects of urban runoff in marine waters will be a highly specific local situation. It is not a beneficial use generally threatened by urban runoff, though specific instances where it is impaired or denied can be of significant local and even regional importance. Coliform bacteria present in urban runoff is the primary indicator of concern, causing direct impacts on shellfish harvesting.

Recreation

1. Coliform bacteria are present at high levels in urban runoff and affect all types of water bodies - streams, lakes, bays, estuaries, and oceans. However, only a portion of the coliform bacteria found in urban runoff is from sewage contamination, the sources of sewage contamination can be numerous, the most common being unrecorded connections. In areas without sanitary sewers, septic tank leaks may be substantial. In areas with sewers, house connections have been identified as a source of sewage contamination. In addition to sewage, domestic animal waste (i.e., pet waste) may contribute to high fecal coliform counts. However, natural sources appear to be the largest overall contributor to coliforms in urban runoff. Bacteria counts can be expected to exceed State criteria during and immediately after storm events in many surface waters used for body contact recreation.

2. Nutrients in urban runoff may accelerate eutrophication problems and severely limit recreational uses, especially in lakes. However, NURP's lake projects indicate that the degree of beneficial use impairment varies widely, as does the significance of the urban runoff component.

4.3 State and Local Non-Point Source Studies

In 1988, the Texas Water Commission prepared a non-point source assessment of the State of Texas as part of the requirements of the Water Quality Act (Section 319(a). To gather non-point source data in the Houston area, the Houston-Galveston Area Council (HGAC) conducted a survey of 245 local governments and local, state, and federal agencies involved with water quality in the 13-county HGAC area (which includes almost all of this project's study area). Respondents were asked to identify the waterbodies/watersheds with non-point source problems, categories of non-point sources, the means of assessing whether a problem exists, specific pollutants of concern, and types of non-point source controls in each jurisdiction.

A total of 49 responses from the survey were received, and they indicated that 105 different waterbodies/watersheds were impacted to some degree by non-point source pollution. While the City of Houston Public Works Department and the Galveston County Health District reported that actual monitoring data had been collected in local watersheds, the rest of the respondents relied on visual inspection, word of mouth, records of complaints, personal opinion or data more than 5 years old to assess current non-point source problems. The survey indicated that the most common problems were oxygen reducing materials, toxic chemicals/heavy metals, bacteria, sediment, and trash. Detention ponds, septic tank ordinances, litter/trash removal programs, and street sweep were identified as the most common best management practices for managing non-point source pollution.

The report recommended the following watersheds for inclusion into the state assessment report:

- Lake Houston Watershed: East Fork San Jacinto River (Segment 1003), Cypress Creek (Segment 1009), and Luce Bayou;

- Houston Ship Channel Watershed: Houston Ship Channel (Segment 1005, 1006, 1007), Buffalo Bayou Tidal (Segment 1013), and Buffalo Bayou Above Tidal (Segment 1014);

- Clear Creek/Clear Lake Watershed: Clear Creek Tidal (Segment 1101), Clear Creek Above Tidal (Segment 1102), and Clear Lake (Segment 2425).

The HGAC conducted several other projects related to local NPS pollution problems. The Areawide Waste Treatment Management Plan for the Greater Houston Area included an assessment of local non-point sources related to urban runoff, septic tanks, agricultural runoff, construction sites, dredging, and benthic oxygen demand (HGAC, 1977). In addition, NPS control strategies, costs, and impacts were also presented. The assessment of NPS loads were developed using the Stormwater Management Model (SWMM) with existing NPS monitoring data; no additional sampling was performed. An HGAC management study was conducted on the Clear Lake watershed (HGAC, 1983) to delineate land use, define activities associated with non-point source pollution, and to identify control measures. A similar management study was conducted on Lake Houston by HGAC (HGAC, 1984), with the exception that monitoring data from Rice University studies (discussed below) were also incorporated into the report.

The Texas Water Quality Inventory provides a summary of water quality in the state in accordance with Section 305(b) of the Clean Water Act (Texas Water Commission, 1990). The inventory includes water quality assessments of each of the designated water quality segments in Texas, and contains a discussion of the state's water pollution control program and non-point source control strategy.

The Texas Water Commission (TWC) established a 27-member Nonpoint Source Advisory Committee to plan NPS control activities for the state over a 20-year planning horizon. In September 1990 the committee issued fourteen recommendations that comprise a comprehensive program for NPS control in Texas (Nonpoint Source Advisory Committee, 1990). Three main areas are represented in the recommendations: education, best management practices, and NPS monitoring.

The Texas State Soil and Water Conservation Board is also addressing NPS problems in the state. A detailed assessment of watershed impacts on water quality, published in January, 1991, provides estimated NPS sediment loads for 23 river and coastal basins from two sources: gross sheet and rill erosion, and gross gully and streambank erosion (Texas State Soil and Water Conservation Board, 1991). In addition, information on range and forestry issues, impacts of water quality, and the method used to estimate sediment loads is included.

Several local studies have focused on the actual measurement of non-point source loads and correlations to local land use patterns in the Houston area. The following sections summarize these sources of local NPS data and identify the primary references.

4.3.1 Rice University

Characklis et al. (1978), Bedient et al. (1978a & b), Bedient and Quevedo (1979), and Bedient et al. (1980a) performed some of the first detailed NPS research in the Houston area. Monitoring programs were conducted in The Woodlands and Westbury areas and in the Brays Bayou and Hunting Bayou watersheds. Sediment and nutrients were the primary parameters of concern. The data were used to construct load-runoff curves relating total storm load in lb/acre (kg/ha) to total storm runoff (in or cm). More recently, a number of studies were performed on the inflows and pollutant loads to Lake Houston (Baca et al., 1982; Bedient et al., 1980b & c; Bedient and Anderson, 1983; Newell, 1981), the major surface water supply for the City of Houston. Results from the Rice University studies were used to develop the NPS database for this project as discussed in Section 5.0.

4.3.2 USGS Studies

The USGS sampled urban runoff in Houston between 1968 and 1984 as part of the Houston Urban Runoff Program (HURP), and collected over 1500 samples for analysis. The database covers a variety of watersheds of varying land use and has been invaluable in assessing the impact of urbanization on water quality in Houston. Most of the resulting data were published in a series of reports by Ferguson, Ranzau, Fisher and King, Hutchison, and Liscum et al., (USGS, annual reports from 1968-1984). Although significant research has been conducted on rainfall/runoff processes, relatively little interpretation of the extensive water quality database has been reported to date. This project made extensive use of the USGS database as discussed in Section 5.0.

An important water quality study was performed by the USGS in the Barker-Addicks Reservoirs (Liscum et al, 1987) and also provided data for this project.

4.3.3 Houston Ship Channel Non-Point Source Study

Winslow and Associates (1986) completed a large study on NPS loads to the Houston Ship Channel which included over 500 samples of storm data at 7 main tributary sites and six small homogeneous land use sites. A detailed analysis of the USGS historical data was combined with actual sampling results to compute NPS loads to the Houston Ship Channel. The Winslow study concluded that NPS loads accounted for 99% of the TSS load, 43% of ammonia N, and 63% of TKN for the data analyzed by tributary sampling (Table 4.1). The data also suggested that construction may have a major impact on NPS loads, as TSS loads from the single land use were approximately half of what was observed in the main tributaries.

Finally, a significant amount of the resources from the 1986 project were devoted to quantifying the effect of sanitary sewer overflows and bypasses. Based on this data, the authors concluded that these sources contributed approximately 11% of the annual BOD load, 7% of the annual TSS load, and 7% of the annual ammonia load to the Ship Channel.

4.3.4 Other Sources of NPS Information

During this project, several water quality and environmental planning groups were contacted as part of the NPS data collection and literature review effort. Three companion GBNEP projects being conducted concurrently with this project were contacted: a wetlands survey being conducted by the U.S. Fish and Wildlife Service, a tributary loading assessment being conducted by the University of Texas, and a point/non-point source assessment now being performed by a private contractor. Other agencies and governmental organizations that were contacted and the type of information obtained included the Houston-Galveston Area Council (land use and population data), the Texas Water Commission (state NPS reports and planning documents), the U.S. Environmental Protection Agency (background NPS information), the City of Houston (water quality data related to collection systems), Texas A&M University (rice cultivation information), the U.S. Soil Conservation Service (soil maps and agricultural information), NOAA (current NPS estimates), and private contractors who performed earlier NPS studies in the Houston area.

Table 4.1 - Summary of Annual Load Estimates
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Source	$CBOD_5$	TSS	NH_3 - H	TKN
Tributary Sampling Method				
Wet weather tributary load	16.18	692.0	1.78	5.53
WWTP load, no-rain days	1.79	3.2	2.04	2.74
Industry load	1.99	5.6	0.29	0.52
TOTAL	19.96	701.0	4.01	8.79
Individual Component Evaluation				
Urban runoff	20.19	282.0	0.99	5.84
Overflows	2.73	20.5	0.28	0.56
Bypasses	0.40	0.7	0.03	0.07
Wet weather WWTP	1.15	2.3	1.08	1.45
WWTP load, no-rain days	1.79	3.2	2.04	2.74
Industry	1.99	5.6	0.29	0.52
TOTAL	28.25	314.0	4.71	11.18
Tributary Sampling Evaluation / Individual Component Evaluation	0.70	2.23	0.83	0.78

NOTES:
1. From Winslow & Associates (1986).
2. All loads are in millions of lbs/yr.
3. WWTP = Wastewater Treatment Plant.
4. $CBOD_5$ = Cabonaceous Biochemical Oxygen Demand
   NH_3 - H = Ammonia Nitrogen
   TSS = Total Suspended Solids
   TKN = Total Kjeldahl Nitrogen as Nitrogen

5.0 HYDROLOGIC AND WATER QUALITY METHODOLOGY

5.1 Introduction

To calculate non-point source loads to Galveston Bay, a variety of environmental data were collected from a number of sources and synthesized together within a computerized Geographic Information System (GIS). The project data requirements included detailed rainfall and runoff information from area hydrologic monitoring networks, available local non-point source monitoring data from the past 15 years, and a detailed land use database of the study area. For this project, an original land use map was developed from interpreted satellite imagery to provide a high resolution (approximate mapping resolution: 30 by 30 meter) snapshot of the watershed land use as it existed in 1990. All of this information was incorporated into the Rice University ARC/INFO GIS system (Section 6.0) for the purpose of illustrating the spatial trends in non-point source loads to the bay.

This project was designed to be a "washoff" study; that is, a study of non-point source loads originating from different land uses. Land use has been recognized as one of the major factors affecting non-point sources of pollution, and has been the focus of most of the non-point source studies performed in the U.S. to date. Because of the emphasis on surface runoff from different land uses, however, several other secondary factors were not incorporated directly in this calculation, such as septic tanks, sanitary sewer by-passes and overflows, sanitary sewage leakage into storm sewers, and atmospheric deposition (see Section 5.4.3). A more detailed assessment of total non-point source loads to the bay may need to consider these secondary NPS factors.

A total of eight different water quality constituents or constituent classes were evaluated for the study: sediment, nutrients (total phosphorous and total nitrogen), biochemical oxygen demand, oil and grease, fecal coliforms, heavy metals, and synthetic organic constituents. For each land use class, typical concentrations of each constituent were estimated from available NPS data, in particular, data collected from Houston-area NPS studies. Total NPS loads were then calculated by multiplying runoff volumes (Sections 5.2 and 5.3) estimated by an SCS hydrologic model (SCS, 1986) with the appropriate NPS concentration for each land use (Section 5.4). The magnitude of upper watershed loads (Lake Houston and Lake Livingston) to Galveston Bay is discussed in Section 5.5.

In summary, the non-point source calculation for Galveston Bay focused on the effects of land use in the watershed immediately adjacent to Galveston Bay. As described in Section 6.0, a detailed land use map based on selected land use categories was developed, incorporated into the GIS system, and used as the basis for the load calculation. Exhibit 5.1 presents a summary of the entire non-point source load calculation.

5.2 Description of Three Cases Used for NPS Calculations

To evaluate the effect of non-point sources to the bay under varying conditions, three different cases were evaluated:

- **Case 1: Annual NPS Loads During an Average Year**

- **Case 2: Annual NPS Loads During a Wet Year**

- **Case 3: NPS Loads During an Individual Storm Event**

The first two cases were analyzed to evaluate annual non-point source loads to the bay, first under average rainfall conditions and second under wet conditions, when higher NPS loads would be expected. For example, the two annual cases may be useful for devising management strategies for conservative (non-degrading) water quality constituents that may accumulate in the bay over time, such as heavy metals and sediment.

The third case was analyzed to estimate water quality conditions during an actual storm event. To understand the effect of non-conservative NPS constituents on bay water quality, loads generated by individual storm events are a more accurate indicator of potential NPS problems than annual loads. For example, knowledge of fecal coliform loads during a single storm is important, as NPS fecal coliforms are not persistent in the bay and affect the resources of the bay only during and immediately after rainfall events. The individual storm reflects a generic storm with an approximately uniform rainfall pattern, and does not account for any particular season or antecedent conditions.

Management of water quality in Galveston Bay needs to account for both long-term and short-term NPS problems. The three cases described above provide NPS data that can be used to analyze different types of water quality problems and eventually develop appropriate management strategies.

5.3 Hydrology

Although land use is the primary variable in this project, the NPS process is driven by a hydrologic process, the rainfall/runoff response. This section describes the methods used to calculate runoff volumes for each of the three cases. Also included is a summary of the input data and assumptions used in the runoff calculation.

5.3.1 Rainfall Analysis

To provide the statistical basis for the rainfall input, precipitation from ten raingages maintained by National Oceanic and Atmospheric Administration (NOAA) were analyzed in detail. The ten gages were selected to ensure that 1) at least 20 years of data could be used in the statistical evaluation, 2) the raingages provided a representative coverage of the entire watershed, and 3) a higher density of raingages would be provided in the Houston metropolitan area. Figure 5.1 shows the location and Table 5.1 provides a brief description of each raingage.

Each gage was analyzed using 21 years of annual rainfall data (see Table 5.2). First, high or low recorded rainfall outliers at each gage were identified and removed from the data, using the method set forth by the Water Resources Council in 1967 (Chow, 1988). The complete outlier analysis is included in Appendix I. The method determines outliers by defining a maximum permissible range (V) for the log-transformed data set. The acceptable range of annual rainfalls were then defined using

$$V = \mu \pm \sigma^* K_n$$

where μ is the mean of the transformed data, σ is the standard deviation, and K_n is a coefficient dependent on the sample size (see Appendix I for values of K_n). Based on this analysis, one high-rainfall outlier (1979 data from the Alvin gage), and four low-rainfall outliers (1988 data from the Barker, Houston WSMCO, Cleveland, and San Jacinto Dam gages) were removed from the statistical analysis. The high outlier was affected by intense tropical storm-related precipitation, while the low outliers reflected severe drought conditions that were experienced in the watershed during 1980.

<u>Case 1: Average Year</u>
For Case I, a Log Pearson Type III (Bedient and Huber, 1988) analysis of twenty-one years of data (excluding the outliers) was performed to estimate the mean annual rainfall for each gage (see Appendix I for calculation summaries for each gage). The resulting annual rainfalls ranged from 41.57 inches per year at Galveston to 57.43 inches per year at Liberty, farther to the east (Table 5.3). The calculated average rainfall for the Houston WSMCO (Intercontinental Airport) was 47.74 inches per year. Although the rainfall pattern was not a smooth spatial distribution across the watershed, the expected pattern of higher rainfalls in the eastern portion of the study area was observed in the data.

<u>Case 2: Wet Year</u>
For Case 2, the wet year, a ten-year annual rainfall was derived from a Log Pearson Type III analysis of the raingage data. This case corresponds to a

rainfall which is equaled or exceeded on the average once every ten years, or ten times every 100 years. In general, Case 2 rainfalls were approximately 30% higher than the Case 1 rainfalls (Table 5.3). The Liberty gage had the highest annual rainfall calculated for this case: 74.49 inches per year.

Case 3: Individual Storm

The rainfall calculation for Case 3, the individual storm, required a different approach than the annual rainfall analyses used for the other two cases. The annual maximum daily rainfall was determined from the daily rainfall data collected at the Houston WSMCO gage (Intercontinental Airport) during the period 1970 through 1990. For example, the maximum daily rainfall in 1970 was 4.64 inches, and represents the highest rainfall recorded for any single day during the entire year. The mean of the annual maximum daily rainfalls from the 21 year period of record was used as the basis for the Case 3 rainfall (Table 5.4). The resulting rainfall value, 4.89 inches, was adjusted to represent an average rainfall from an individual storm over the entire 4,200+ square mile basin. The adjustment factor, based on a relationship presented in Chow et. al. (1988) reduced the point rainfall value of 4.89 inches to an areally-adjusted rainfall value of 4.5 inches, an 8% reduction. This value was used at all 10 raingages for the Case 3 hydrologic modeling tasks.

Thiessen Weighting Procedure

To perform the hydrologic modeling, rainfall for each raingage was distributed over the watershed using the Thiessen polygon method (Bedient and Huber, 1988), an areal weighting procedure (Figure 5.1). In the Thiessen method, the rainfall at any location is assumed to be equal to the rainfall at the nearest gage, as defined by a series of polygons constructed from perpendicular bisectors of lines connecting a raingage with its closest neighbors. By weighting each gage according to the area of its Thiessen polygon, an average rainfall for the entire study area was calculated. The Thiessen weights are presented in Table 5.5, and the actual weighted rainfalls for each gage and the average watershed rainfall are shown in Table 5.6.

Rainfall/Runoff Calibration

By using the average watershed rainfalls in Table 5.5, actual rainfall records that were similar to Case 1 and Case 2 were selected for the purpose of calibrating the rainfall runoff model. For Case 1, a year closest to the average year, 1987, was selected as a representative average year for calibration purposes. For Case 2, 1983 was selected. In addition, actual storm events were selected for the purpose of calibrating the rainfall/runoff model.

5.3.2 Runoff Methodology

To convert the calculated rainfalls to runoff volumes, the Soil Conservation Service (SCS) curve number method (1986) was selected. The advantages of the SCS approach included simplicity, ability to account for different land uses and soil types, and the widespread application of this model for a variety of hydrologic problems. The main disadvantage of this method is that it does not provide an estimate of annual runoff volumes directly; only runoff from individual storms can be calculated.

Description of SCS Method

The SCS curve number method was originally developed as a means to estimate runoff over 24-hour periods from ungaged agricultural basins. A series of "curve numbers" were developed empirically from daily rainfall/runoff data collected from research plots. The curve numbers reflect land use, land cover, and soil type, and their effects on the amount of runoff expected from a given 24-hour rainfall.

In 1975 the original curve number method was expanded to include urban watersheds (SCS, 1975; See Appendix IV). This method allowed consideration of a variety of urban land uses, as shown in Table 5.7. Runoff volume, Q in inches, is calculated as a function of curve number (CN), initial abstraction I_a in inches, (the amount of rainfall that either infiltrates or accumulates on the ground surface before runoff begins) and 24-hour rainfall P in inches:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

S, the potential maximum retention after runoff begins, is related to the soil and cover conditions of the watershed through the CN. The CN has a range of 0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN} - 10$$

Higher curve numbers, for example, represent land uses with less infiltration potential, and therefore higher, runoff potential.

Calculation of Annual Runoff

To adapt the SCS methodology for the estimation of runoff due to annual rainfall, a statistical evaluation of hourly rainfall data from an existing NPS study (Winslow and Associates, 1986) was used. Application of a rainfall statistics program, SYNOP, indicated that during an average year approximately 84 separate storms with more than 0.01 inches of rainfall occur in the area. The mean rainfall of the 84 events was 0.308 inches (assuming a log-normal distribution), and the coefficient of variation was 1.154 (in log space). Using this information, a statistical analysis was performed to distribute a year's worth of rainfall into different sizes of storms. For example, the Case 1 annual rainfall was divided into five different size storms for each gage, such as the distribution shown below. As can be seen above, the rainfall totals were selected to provide an equal number of storms per year:

Storm Type	Rainfall (inches)	Number of Storms per Year
Very small storms	0.049	17
Small storms	0.16	17
Average storms	0.30	17
Large storms	0.566	17
Very large storms	1.873	17
Annual Rainfall	**50.13**	**85**

The theoretical distribution of rainfall was used for two reasons: 1) it could be derived quickly and efficiently compared to an empirical distribution, which would have required use of the SYNOP program; and 2) the theoretical distribution was easier to apply in the ARC/INFO program. The extensive rainfall database could be represented statistically in the runoff calculation using the data listed above rather than a detailed empirical distribution consisting of hundreds or thousands of rainfall values.

A summary of the rainfall distributions used for Cases 1 and 2 are shown in Tables 5.8 and 5.9, respectively. Calculation methods for the rainfall analyses are shown in Appendix II. For Case 3, a uniform 4.5 inch Type-II rainfall over a 24-hour period was assumed for each raingage.

The actual runoff calculation and calibration was performed using the ARC/INFO GIS. This methodology is described in more detail in Section 6.0.

5.4 Event Mean Concentrations (EMCs)

Rainfall data and the SCS runoff methodology were employed to calculate the volume of runoff from different land uses, subwatersheds, and watersheds in the study area. To calculate NPS loads from these areas, typical concentrations of each water quality constituent in runoff were required. These water quality data, defined as event mean concentrations or EMCs, were developed for each land use type defined for the Galveston Bay project.

An EMC is the average concentration of water quality constituents over the course of an entire storm event. If several water quality samples are collected at different times during the storms, an event mean concentration can be calculated by flow-weighting the water quality data. The result is that samples collected during high-flow periods near the peak of the storm are weighted more heavily than samples collected during periods with lower flow rates.

Eight water quality constituents were evaluated for the purpose of developing EMCs:

- Total Suspended Solids (TSS), reported in mg/l
- Total phosphorous (TP), reported in mg/l
- Total Nitrogen (TN), reported in mg/l
- Five-Day Biochemical Oxygen Demand (BOD), reported in mg/l
- Oil and Grease (O&G), reported in mg/l
- Fecal Coliform (FC), reported in colony forming units per 100 ml, abbreviated as cfu/100 ml or colonies per 100 ml
- Dissolved Copper (Cu), reported in mg/l
- Chlorinated Hydrocarbon and Organophosphorous Pesticides, reported in mg/l, abbreviated as pesticide

In addition, an annual NPS load assessment was developed using EMCs for the following dissolved metals: Lead, Zinc, Arsenic, Cadmium, Chromium, Mercury, and Silver.

These parameters are an expanded version of an original list developed by GBNEP. Biochemical oxygen demand was added to the original list because of the importance of oxygen demanding substances on water quality. Dissolved copper was selected for the detailed mapping analysis because the NURP program indicated copper as a metal of concern; for example 50% of the priority pollutant samples collected during the NURP program exceeded the freshwater ambient 24-hour instantaneous maximum criterion established by EPA ("acute" criterion; Cole et al, 1984). Dissolved copper was selected instead of total copper because little local total copper data were available for the Houston area. One major implication of using dissolved rather than total copper is that the reported loadings are more accurate for doing dilution calculations and comparing against water quality standards (which are based on dissolved metals) than for estimating the total amount of copper in the water column and on sediments.

Most of the EMCs used in the Galveston Bay NPS calculation were derived from an extensive compilation and analysis of local non-point source water quality data. When local data were not available, EMCs from the technical literature or studies such as the EPA's NURP were used.

5.4.1 Houston Area EMC Database

The Houston area EMC database was derived from three main sources as described in Section 4.3:

- Rice University NPS Studies
- USGS Houston Urban Runoff Program Data
- Texas Water Commission/Winslow Associates Houston Ship Channel NPS Study

EMCs were compiled from over 30 different stations and approximately 250 station-storms (a separate storm event at a sampling station). For the Rice University studies, EMCs were taken directly from journal articles and technical reports summarizing studies performed in the 1974 - 1978 time frame. Data from the HURP, which was active from approximately 1968 - 1984, were obtained after meeting with Dr. Fred Liscum of the Houston USGS office and obtaining a file from the USGS water quality database. The data, consisting of discrete water quality sampling and flow information, were weighted to obtain EMC values for each station-storm. The TWC Ship Channel study, performed in 1986, had both flow-composited sampling data (samples composited automatically in the field) and discrete sampling data performed at specific times during a storm. Unfortunately, flow data were not reported and could not be located for individual samples, preventing the flow weighting of some of the concentration data. A simple average was performed to estimate the EMCs from the TWC study.

The resulting 250 EMCs represent a comprehensive collection of Houston area NPS data in one database. To incorporate this information into the Galveston Bay study, the EMC data were divided into land use/watershed area categories as shown in the following table.

Designation	Area	Land Use	Example Watershed
A1	< 10 sq. mi.	> 50% Residential	Lazybrook Storm Sewer
A2	< 10 sq. mi.	> 50% Comm. + Indust.	Bettina St. Ditch
A3	< 10 sq. mi.	Forest	Basin P-10, Woodlands
A5	< 10 sq. mi.	Mixed	Sherwood Storm Sewer

B1	10 - 100 sq. mi.	< 10 % Developed	Basin P-30, Woodlands
B2	10 - 100 sq. mi.	10 - 50 % Developed	Keegan's Bayou @ Roark Rd.
B3	10 - 100 sq. mi.	> 50% Developed	Brays Bayou @ Main Street
C1	> 100 sq. mi.	< 10% Developed	Cypress Creek @ I-45
C2	> 100 sq. mi.	10 - 50 % Developed	Buffalo Bayou @ Shepherd

Summary statistics for each of the EMC categories are provided in Table 5.10, and the actual EMC database is provided in Appendix III. The A1, A2, and A3 categories provided the principal sources of EMC data for the Galveston Bay project (see Section 5.4.3).

5.4.2 Other Sources of EMC Data

Despite the relatively large size of the Houston Area EMC database, several data gaps remained to be filled before an EMC could be assigned to each land use and water quality parameter combination. For example, very little oil and grease data were collected in Houston during the studies described above. Sources of additional NPS data collected outside of the Houston area are summarized below:

- Final Report of the Nationwide Urban Runoff Program (USEPA, 1983)
- Priority Pollutant Survey from the NURP Program (Cole et al, 1984)
- Oil and grease studies performed by Stenstrom et al (1984)
- USGS Austin NPS study (Veehnius & Slade, 1990)
- Various agricultural NPS studies (see Appendix III)

Results from these studies were used to fill in the data gap when the final EMC/land use table for the Galveston Bay project was prepared as described below.

5.4.3 Selection of Project EMCs

Project EMCs are presented in Table 5.11. For example, total suspended solids EMCs range from 201 mg/l for agricultural areas to 39 mg/l for forested areas. Oil and grease EMCs ranged from 4 to 13 mg/l in urban areas, and were assumed to be present at very low concentrations elsewhere. EMCs for the water land use category (lakes and streams) were assumed to be zero for all parameters.

A detailed description of the data sources and explanations used to select these EMCs is presented in Table 5.12, and a subjective assessment of the relative accuracy of each EMC value is then provided in Table 5.13. The major factors used to select EMCs are the following:

- The Houston area EMC database was used in determining TSS, TN, and TP values for the urban, residential, and forest land uses. For open and barren land uses, NURP data were used for all of these parameters except TSS.

- Most EMCs were based on data from small watersheds (<10 sq. miles), with one predominate land use. This was done to ensure the best correlation between the final EMCs and actual land use. One consequence of this approach was that the contribution from some sources, such as by-passes, overflows, and sanitary sewage leakage into large storm sewers, is probably not represented in the EMCs.

- The 1987 USGS study of the watersheds upstream of Barker/Addicks reservoirs (USGS, 1987) was used for most of the agricultural EMCs.

- Data collected by Stenstrom (1984) were used for the oil and grease EMCs for urban areas.

- Because of the lack of wetlands data, an assumption was made that wetlands had low EMCs, similar to forested areas. The process of pollutant reduction and attenuation in wetlands was not addressed, also because of a lack of reliable data. Because wetlands loads are generally low compared to most other land uses (except for the possible exception of the total nitrogen parameter), it was assumed that wetlands had low EMCs that were similar to the low EMCs exhibited by forest lands.

- Heavy metals EMCs for the two urban land use categories were calculated using the entire Houston Area EMC database (see category E1 in Table 5.10 and Table E1 in Appendix III). Values reported as "not detected" were assumed to be equal to half the detection limit. Rural heavy metal EMCs were based on the Barker/Addicks reservoir study (USGS, 1987). The Barker/Addicks watersheds, which are predominantly agricultural and open/pasture, exhibited concentrations of heavy metals that were very similar to concentrations from the urban watersheds (see Appendix III). The limitation in the metals database prevented a more detailed analysis of appropriate EMCs, or the possible reason why urban EMCs appear to be similar to non-urban EMCs (although the urban and non-urban EMCs may be similar, urban loads will still be significantly higher because of higher urban runoff volumes). All metals data reported in the project are based on dissolved metals analysis performed by the USGS; little total metals data were available.

- Pesticides were evaluated using two USGS studies: a combined urban/rural study conducted in Austin, Texas (Veehnius and Slade, 1990), and the Barker/Addicks reservoir study (USGS, 1987). The Austin data was selected because an extensive urban pesticide database for the Houston area was not available. The urban EMC data were derived from urban catchments in the Austin project, while rural data were developed from the Barker/Addicks study. There were no local pesticide loading data from different rural land uses, and therefore all rural land uses were assumed to have the same EMCs as measured from the Barker/Addicks reservoir study. Because most of the pesticide data had numerous "below detection limit" values, a simple methodology based on percentage of reported values was developed to provide representative EMCs (see Appendix III). The pesticides include the following compounds: Aldrin, Chlordane, DDD, DDE, DDT, Diazinon, Dieldrin, Endosulfan, Endrin, Heptochlor, Heptochlorepoxide, Lindane, Malathion, Methoxychlor, Mirex, Parathion, and Trihion. Diazinon, an organophosphorous compound, was the most common pesticide in both studies, found in 31 of 36 urban samples from Austin and 94 of 179 samples in the Barker/Addicks study (a rural watershed). Chlorinated pesticides were more common in the urban areas than rural areas.

Other organic compounds, such as phenol, pentachlorophenol, chloroform, 2-methoxy-2-methyl propane and bis(2-ethylhexyl)phthalate were not included in the load calculation either because of lack of local NPS data or a large number of "not detected" values in the database. Pesticides were the only synthetic organic constituents with field data at high enough concentrations to perform an NPS load assessment with any confidence. Cole et al (1984) provides the most detailed review of priority pollutants found in NURP urban runoff samples; widely varying analytical detection limits greatly complicate the analysis of this data, however.

Considerable care was devoted to ensuring representative EMCs for this project because the final project NPS loads were very sensitive to the EMC data. A subjective assessment of EMC accuracy was performed, based on the amount and quality of local NPS data (see Table 5.13). Largely because of the extensive local NPS database, the conventional water quality parameters, such as TSS, BOD, and nutrients, have a higher degree of accuracy associated with them than do metals or synthetic organic constituents. Also, EMCs associated with urban land uses have a higher degree of confidence than do rural EMCs because more of the Houston area data were collected in urban areas. Overall, the accuracy of most of the EMCs is considered to be relatively good due to the extensive local database on NPS pollutants collected over a number of years by several different groups.

5.4.4 Comparison With Other EMC Data

The EMC data used for this project are similar to NPS data reported in other studies (Table 5.14). Fecal coliform concentrations matched other data sources very closely. Although the rural EMC data were not as extensive as those in the urban database, they indicated that agricultural NPS concentrations lie at the low end of the reported range for sediment and nutrient loads from other agricultural watersheds. One possible explanation is the extensive rice cultivation in the watershed: flooded rice fields are relatively low generators of sediments and nutrients compared to typical row crops (McCauley, 1991).

5.5 Assessment of Upper Watershed Non-Point Source Loads

As described in Section 2.0, Objectives, the Galveston Bay NPS project defined by GBNEP focused on the immediate drainage areas around the bay, a 4,238 square mile area. The larger "upper watersheds," consisting of the 2,828 square mile Lake Houston and the 16,600 Lake Livingston drainage, were not included directly in the non-point source assessment performed with the GIS System. The reasons for the secondary emphasis on the upper watersheds were three-fold:

1. The upper watersheds are some distance from the bay, and, therefore, do not have the same effect on water quality as the watersheds immediately adjacent to the bay.

2. The two large reservoirs, Lake Houston and Lake Livingston, act as natural treatment systems for pollutants and serve to reduce or attenuate some loads before they reach the bay (Baca, 1982; Hydroscience, 1976).

3. The design of the Galveston Bay study emphasized assessing the impacts of land use, particularly urban land uses, on NPS loads. Both upper watersheds can be considered to be generally rural in nature, with the exception of the Dallas metroplex on the Upper Trinity River. Therefore, most of the urban areas of interest were located in watersheds immediately adjacent to the bay.

Lake Houston, completed in 1954, lies to the north of the study area and is used as a water supply and recreational area for the City of Houston and surrounding communities. Approximately 150,000 to 200,000 acre-ft of water are diverted each year for municipal and industrial purposes. Approximately 73% of the drainage is forested, 14% open land, and less than 5% is represented by urban development (Baca, 1982; Newell, 1981). Average inflow into the 146,000 acre reservoir is approximately 2000 cfs, yielding a typical hydraulic residence time of 1-2 months. Newell (1981) provides more information on NPS loads to the Lake and Baca (1982) provides data regarding the ability of Lake Houston to attentuate and reduce pollutant loadings to the bay.

In the northernmost portion of the project study area lies Lake Livingston, a 2,000,000 acre-ft reservoir that drains a 16,600 square mile watershed encompassing much of north-central Texas. The dam was completed in 1968 and shortly afterward impoundment began for the purpose of municipal and industrial water supply for the Houston metropolitan region. Average discharge from the reservoir is approximately 7,000 cfs, corresponding to a hydraulic residence time of 4-5 months.

To assess the impacts of the upper watersheds, a statistical analysis of historical runoff and water quality data was conducted to: (1) calculate the total volume of runoff that would be expected from the two lakes for the three cases, and (2) calculate the average concentrations for pollutants discharged from the lakes. Lake loads were then calculated by multiplying runoff volume and average concentration (comprised of point source loads, low flow loads, and NPS loads).

5.5.1 Runoff Analysis

In order to estimate the total runoff volume for Cases 1 and 2, the annual discharge data for the two upper watersheds were compared to the annual Galveston Bay project rainfall using a linear regression as shown in Exhibits 5.2 and 5.3. A relatively strong correlation (r^2=0.76) was observed with the Lake Houston data; this is to be expected because of the proximity of the Lake Houston drainage area to a large portion of the study area. The Lake Livingston correlation was not as strong (r^2=0.53) but still indicated that annual rainfall in the Houston area and runoff from the lakes are not independent parameters. Therefore, the regression relationships were used to estimate the annual runoff volume from the upper watersheds for the two annual cases: Case 1 (average year) and case 2 (wet year).

Using the regression equations (based on actual discharge data) and GBNEP basin-wide rainfalls, the following annual runoff volumes were estimated for the upper watersheds:

	Lake Houston	Lake Livingston
Case 1 (average year)	1.4 million acre-ft	4.7 million acre-ft
Case 2 (wet year)	2.2 million acre-ft	6.8 million acre-ft

For Case 3, the individual storm, the selection of representative runoff volumes was much more difficult. An assessment of 20 actual storm events indicated a weak relationship at best between a large rainfall event over the

Houston metropolitan area and discharge from the two dams. Therefore, median daily discharge values were computed from runoff data provided by the Texas Water Development Board (Brock, 1991) and the flowrate (in cubic feet per second) was converted to runoff volume for a 24-hour period for the NPS assessment:

	Lake Houston	Lake Livingston
Case 3 (individual storm)	3,482 acre-ft	5,368 acre-ft

The 24-hour flow duration was selected to correspond to the duration of the Case 3 rainfall event: 24 hours. The runoff estimates shown above may under-represent the effect of the lakes during actual storm events, however, as large runoff events in the Houston area typically occur over periods longer than 24 hours.

5.5.2 Water Quality Data Analysis

A water quality data analysis was performed to determine average concentrations of water quality parameters in the discharge from each lake. The two databases were utilized: the Texas Water Commission (TWC) and the USGS Water Resources publications (USGS, 1970-1989). The parameters of interest included total nitrogen, total phosphorous, fecal coliform, biochemical oxygen demand, total suspended solids, oil and grease, arsenic, cadmium, chromium, copper, nickel, lead, and zinc. To ensure that the data reflected pollutant removal/transformation processes occurring in the lakes, only stations representative of dam discharge (i.e., located either immediately downstream of the lakes or directly upstream of the dam near the discharge point) were used for the calculation. Note that the lake discharge data represents a mixture of point source loads, low-flow loads, and NPS loads that have been exposed to any in-lake attenuation processes.

The historical data were obtained from the TWC and the USGS databases and averaged by parameter, year, and source of data. Table 5.15 lists the calculated concentrations from the analysis for each parameter. The average annual concentration for each parameter was extracted from the two databases to calculate an overall average for the parameter for the whole period of record from both data sources. For parameters with little data, or data with a large percentage of "below detection" values, concentrations representative of non-urban runoff EMCs were used. Oil and grease, heavy metals, and synthetic organic constituent concentrations for the lakes were estimated using the non-urban EMCs in Table 5.11.

5.5.3 Upper Watershed Load Estimates

Annual load estimates for the three cases were performed by multiplying the average concentration for each parameter by the total runoff for each rainfall event. The load estimates for Lake Houston and Livingston are listed in Table 5.16. Overall, Lake Livingston contributes more loads to Galveston Bay than Lake Houston for all the parameters except for fecal coliform. Both lakes contribute substantial amounts of pollutants into the bay. For example, in an average year, BOD from Lake Houston is about 5.8 million kilograms, and that from Lake Livingston is approximately 14.0 million kilograms. The impacts of these loads on Galveston Bay are discussed in Section 7.0.

5.5.4 Comparison with Other Studies

In order to evaluate the accuracy of results from this analysis, the calculated total suspended solids, total phosphorous, and total nitrogen loads were compared to results from the 1988 Texas Water Development Board's (TWDB) "Suspended-Sediment Load of Texas Streams" study, a journal article on loads to Lake Houston by Baca, Bedient, and Olsen (1982), and a draft report by Stanley (1989).

For Lake Houston, the calculated GBNEP TSS loads were within 20% of those calculated by Baca et al. (1982): 43 million kg/yr for the GBNEP total versus 36 million kg/yr for the 1981 study (Table 5.17). The nutrient loads for Lake Livingston from Stanley et al. (1989), were also very close to the nutrient loads calculated for this project. The TWDB load rates published in 1988 for the Lake Livingston discharge (Trinity River at Romayor) were 10 times higher than the GBNEP loads (57 million kg/yr versus 650 million kg/yr). The reasons for this difference are unknown.

Table 5.1 - Location and Period of Record for Raingages

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

STATION	LATITUDE	LONGITUDE	PERIOD OF RECORD
Alvin (Houston Area WSO)	29°25'	95°13'	1918 to 1990
Anahuac TBCD	29°47'	94°40'	1918 to present
Cleveland	30°22'	95°05'	1955 to present
Galveston WSO	29°18'	94°48'	1918 to present
Houston WSMCO (Intercontinental)	29°58'	95°21'	1969 to present
Houston FAA Airport (Hobby)	29°39'	95°17'	1932 to present
Houston - Barker	29°49'	95°44'	1949 to present
Houston - Independent Heights	29°52'	95°25'	1949 to present
Houston - San Jacinto Dam	29°55'	95°09'	1960 to present
Houston WSO	29°28'	95°05'	1990 to present
Liberty	30°03'	94°48'	1918 to present

NOTES:
1. Gage locations and periods of record in NOAA, 1918 - 1990.
2. See Figure 5.1 for locations of raingages.
3. On November 1, 1990, the Alvin (Houston Area WSO) gage located in eastern Brazoria county, became inactive. The rainfall amounts from the Houston WSO gage, located in Galveston county were used for November and December of 1990.

Table 5.2 - Annual Rainfall Summary

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Year	ANNUAL RAINFALL (inches)									
	Alvin	Anahuac	Cleveland	Galveston WSO	Houston WSMCO (Intercontinental Airport)	Houston FAA Airport (Hobby Airport)	Houston - Barker	Houston - Independent Heights	Houston - San Jacinto Dam	Liberty
1970	48.82	58.91	42.15	48.47	48.19	56.31	48.04	53.79	53.26	52.02
1971	38.27	43.90	39.96	35.97	37.83	36.91	41.44	41.37	44.48	39.27
1972	53.34	47.47	53.15	39.95	50.80	55.22	39.04	59.79	56.72	59.26
1973	71.93	75.98	89.38	60.47	70.16	80.65	59.54	74.46	70.88	83.26
1974	51.85	54.13	66.56	43.26	49.29	57.97	56.25	55.89	54.54	63.54
1975	43.73	63.47	56.02	48.54	50.97	49.07	46.35	49.51	46.29	59.65
1976	54.52 [3]	47.05	53.30	42.06	54.62	69.66	44.74	60.49	57.85	53.50
1977	34.53	45.15	39.43	42.07	34.94	41.79	36.81	41.62	42.95	61.11
1978	41.43	37.84	45.80	29.28	44.93	44.47	41.05	42.79	45.01	42.35
1979	102.58	70.65	75.87	59.35	58.97	83.02	53.15	64.43	77.00	70.11
1980	41.15	53.96	38.37	34.58	38.99	39.70	34.46	41.39	51.28	56.77
1981	52.79	64.88 [1]	58.50	46.78	55.98	82.14	51.05	47.90 [1]	75.23 [1]	65.57 [1]
1982	42.89	47.81	53.04	34.26	42.87	46.41	33.04	39.89	37.11 [1]	57.10
1983	60.48	61.48 [1]	59.76	53.90	53.21	56.47 [2]	52.34	60.77	59.78	83.62
1984	45.99	35.42	45.74	35.64	48.19	49.72	45.02	44.95	40.61	47.46
1985	59.12	59.46	53.31	41.24	49.14	47.54	48.28	47.15	50.42 [2]	61.92
1986	51.75	52.99	66.21	36.34	44.93	53.82	49.99	51.72	57.02	63.63
1987	49.59	51.65	52.51	36.84	40.60	44.10	41.47	47.47	57.96	61.48
1988	34.19	33.78	25.01	39.88	22.93	26.65	24.94	28.99	27.32 [1]	34.18
1989	44.02 [1]	58.60	65.20	40.59	52.73	53.30	36.82	59.12	57.26 [4]	62.52
1990	36.8 [5]	50.50	46.77	38.19	40.37	35.90 [1]	36.84	38.70	53.04 [4]	54.00

NOTES:

1. Record incomplete - one month of records missing.
2. Records incomplete - one or more days missing.
3. Angleton gage used due to lack of information on Alvin gage.
4. Baytown gage used due to lack of information on San Jacinto Dam gage.
5. In 1990, the Houston Area WSO gage was moved from Alvin to Galveston County. There are two months missing in this record.
6. Data from NOAA, 1970 - 1990.
7. See Figure 5.1 for locations of the raingages.

Table 5.3 - Case 1 and Case 2 Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

RAINGAGE	Case 1: Average Year Rainfall (inches)	Case 2: Wet Year Rainfall (inches)
Alvin (Houston Area WSO)	46.99	60.55
Anahuac TBCD	51.98	67.71
Cleveland	53.72	72.18
Galveston WSO	41.57	53.06
Houston WSMCO (Intercontinental)	47.74	59.35
Houston FAA Airport (Hobby)	50.89	73.27
Houston - Barker	44.19	54.79
Houston - Independent Heights	50.33	63.87
Houston - San Jacinto Dam	53.46	68.74
Liberty	57.43	74.49

NOTES:
1. Derivation of rainfall amounts shown in Appendix I.
2. See Figure 5.1 for the locations of the raingages.

Table 5.4 - Case 3 Rainfall

Non-point Source Characterization Project
Galveston Bay National Estuary Program

Annual Maximum Daily
Rainfall at Houston WSMCO
(Intercontinental) Gage

Year	(inches)
1970	4.64
1971	3.28
1972	7.47
1973	5.63
1974	2.84
1975	3.57
1976	8.16
1977	2.64
1978	3.36
1979	6.92
1980	3.36
1981	5.98
1982	3.59
1983	6.69
1984	9.25
1985	3.18
1986	3.81
1987	2.42
1988	1.94
1989	10.34
1990	3.52
Total	102.59

21-year average = 4.89 inches

Areally Adjusted Rainfall = (21-year average)*(weighting factor)
= (4.89)*(0.92)
= 4.50 inches

NOTES:

1. Rainfall values located in NOAA, 1970 - 1990.
2. See Figure 5.1 for the location of the raingage.
3. Areal Distribution Weighting Coefficient, 92% obtained for 2000+ square miles from Chow et al (1988).

Table 5.5 - Thiessen Weights for Raingages

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

RAINGAGE	AREA OF THIESSEN POLYGON (square miles)	WEIGHTING COEFFICIENTS FOR RAINGAGES (percent)
Alvin (Houston Area WSO)	824	19.4
Anahuac TBCD	599	14.1
Cleveland	739	17.4
Galveston WSO	160	3.8
Houston WSMCO (Intercontinental)	87	2.1
Houston FAA Airport (Hobby)	454	10.7
Houston - Barker	354	8.3
Houston - Independent Heights	254	6.0
Houston - San Jacinto Dam	309	7.3
Liberty	466	11.0
Total	4245	100

NOTE:
1. Areas of Thiessen polygons obtained from ARC/INFO GIS System.
2. See Figure 5.1 for locations of raingages.

Table 5.6 - Thiessen Weighted Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Year	ANNUAL WEIGHTED RAINFALLS (inches)										Annual Galveston Bay Watershed Rainfall
	Alvin	Anahuac	Cleveland	Galveston WSO	Houston WSMCO (Intercontinental Airport)	Houston FAA Airport (Hobby Airport)	Houston - Barker	Houston - Independent Heights	Houston - San Jacinto Dam	Liberty	
1970	9.48	8.31	7.34	1.82	.99	6.02	4.00	3.22	3.88	5.71	50.76
1971	7.43	6.19	6.96	1.35	.78	3.95	3.45	2.47	3.24	4.31	40.13
1972	10.35	6.70	9.25	1.50	1.04	5.91	3.25	3.58	4.13	6.50	52.21
1973	13.96	10.72	15.56	2.27	1.44	8.63	4.96	4.45	5.16	9.13	76.29
1974	10.07	7.63	11.59	1.63	1.01	6.20	4.69	3.34	3.97	6.97	57.10
1975	8.49	8.95	9.75	1.83	1.05	5.25	3.86	2.96	3.37	6.54	52.05
1976	10.58	6.64	9.28	1.58	1.12	7.45	3.73	3.62	4.21	5.87	54.08
1977	6.70	6.37	6.86	1.58	.72	4.47	3.07	2.49	3.13	6.70	42.09
1978	8.04	5.34	7.97	1.10	.92	4.76	3.42	2.56	3.28	4.65	42.04
1979	19.91	9.96	13.21	2.23	1.21	8.88	4.43	3.85	5.61	7.69	76.99
1980	7.99	7.61	6.68	1.30	.80	4.25	2.87	2.48	3.73	6.23	43.93
1981	10.25	9.15	10.18	1.76	1.15	8.79	4.25	2.86	5.48	7.19	61.07
1982	8.33	6.74	9.23	1.29	.88	4.96	2.75	2.39	2.70	6.26	45.54
1983	11.74	8.67	10.40	2.03	1.09	6.04	4.36	3.63	4.35	9.17	61.50
1984	8.93	5.00	7.96	1.34	.99	5.32	3.75	2.69	2.96	5.21	44.14
1985	11.48	8.39	9.28	1.55	1.01	5.08	4.02	2.82	3.67	6.79	54.10
1986	10.05	7.47	11.52	1.37	.92	5.76	4.16	3.09	4.15	6.98	55.48
1987	9.63	7.28	9.14	1.39	.84	4.72	3.45	2.84	4.22	6.75	50.25
1988	6.64	4.76	4.35	1.50	.47	2.85	2.08	1.73	1.99	3.75	30.13
1989	8.55	8.26	11.35	1.53	1.08	5.70	3.07	3.54	4.17	6.86	54.10
1990	7.14	7.12	8.14	1.44	.83	3.84	3.07	2.31	3.86	5.92	43.68

NOTES:
1. See Figure 5.1 for locations of raingages.
2. Weighted rainfall were calculated by multiplying the actual rainfalls in Table 5.2 by the Thiessen Weighting Coefficients located in Table 5.5.

Table 5.7 - SCS Runoff Curve Number Table
Non-Point Source Characterization Project
Galveston Bay Natioonal Estuary Program

Land Use Description	Curve Number by Hydrologic Soil Group A	B	C	D
Agriculture				
Cultivated land				
Without conservation treatment	72	81	88	91
With conservation treatment	62	71	78	81
Pasture or range land				
Poor Condition	68	79	86	89
Good Condition	39	61	74	80
Meadow				
Good Condition	30	58	71	78
Wood or Forest Land				
Thin stand, poor cover, no mulch	45	66	77	83
Good cover	25	55	70	77
Open spaces, lawns, parks, golf courses, cemeteries, etc.				
Good condition: grass cover on 75% or more of the area	39	61	74	80
Fair condition: grass cover on 50-75% of the area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious)	81	88	91	93
Residential				
1/8 ac or less (65% impervious)	77	85	90	92
1/4 ac or less (38% impervious)	61	75	83	87
1/3 ac or less (30% impervious)	57	72	81	86
1/2 ac or less (25% impervious)	54	70	80	85
1 ac or less (20% impervious)	51	68	79	84
Paved parking lots, roofs, driveways, etc.	98	98	98	98
Streets and roads				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89

Notes:

1. Source of Curve Number Table: SCS, 1986
2. Hydrologic Soil Type
   - A: generally sand, loamy sand, or sandy loam high infiltration potential
   - B: generally silt loam or loam soils with moderate infiltration potential
   - C: generally sandy clay loam with low infiltration potential
   - D: generally clay loam, silty clay loam, sandy clay, silty clay, or clay with very low infiltration potential

Table 5.8 - Case 1: Average Year Rainfall Summary

Non-Point Source Characterization Project

Galveston Bay National Estuary Program

Rainfall by Storm Size:

Storm Size	Rainfall (inches)
Very small storm (P1)	0.049
Small storm (P2)	0.16
Average storm (P3)	0.301
Large storm (P4)	0.566
Very large storm (P5)	1.873
Size	50.13

Gage	Actual Annual Rainfall (inches)	Ratio of Annual Rainfall to 50.13 inches	Rainfall by Storm Size (inches)					Number of Storms for each Storm Size	Calculated Annual Rainfall (inches)
			P1	P2	P3	P4	P5		
Alvin (Houston Area WSO)	46.99	0.94	0.05	0.15	0.28	0.53	1.76	17	46.99
Anahuac	51.98	1.04	0.05	0.17	0.31	0.59	1.94	17	51.98
Cleveland	53.72	1.07	0.05	0.17	0.32	0.61	2.01	17	53.72
Galveston	41.57	0.83	0.04	0.13	0.25	0.47	1.55	17	41.57
WSMCO (Intercontinental)	47.74	0.95	0.05	0.15	0.29	0.54	1.78	17	47.74
FAA Airport (Hobby)	50.89	1.02	0.05	0.16	0.31	0.57	1.90	17	50.89
Barker	44.19	0.88	0.04	0.14	0.27	0.50	1.65	17	44.19
Independent Heights	50.33	1.00	0.05	0.16	0.30	0.57	1.88	17	50.33
San Jacinto Dam	53.46	1.07	0.05	0.17	0.32	0.60	2.00	17	53.46
Liberty	57.43	1.15	0.06	0.18	0.34	0.65	2.15	17	57.43

NOTES:

1. Actual Rainfalls taken from Table 5.3.
2. Calculated Annual Rainfalls = ratio * ((P1*17) + (P2*17) + (P3*17) + (P4*17) + (P5*17) + (P6*17))

Table 5.9 - Case 2: Wet Year Rainfall Summary
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Rainfall by Storm Size:

Storm Size	Rainfall (inches)
Very small storm (P1)	0.049
Small storm (P2)	0.16
Average storm (P3)	0.301
Large storm (P4)	0.566
Very large storm (P5)	1.873
Size	50.13

Gage	Actual Annual Rainfall (inches)	Ratio of Annual Rainfall to 50.13 inches	Rainfall by Storm Size (inches)					Number of Storms for each Storm Size	Calculated Annual Rainfall (inches)
			P1	P2	P3	P4	P5		
Alvin (Houston Area WSO)	60.55	1.21	0.06	0.19	0.36	0.68	2.26	17	60.55
Anahuac	67.71	1.35	0.07	0.22	0.41	0.76	2.53	17	67.71
Cleveland	72.18	1.44	0.07	0.23	0.43	0.81	2.70	17	72.18
Galveston	53.06	1.06	0.05	0.17	0.32	0.60	1.98	17	53.06
WSMCO (Intercontinental)	59.35	1.18	0.06	0.19	0.36	0.67	2.22	17	59.35
FAA Airport (Hobby)	73.27	1.46	0.07	0.23	0.44	0.83	2.74	17	73.27
Barker	54.79	1.09	0.05	0.17	0.33	0.62	2.05	17	54.79
Independent Heights	63.87	1.27	0.06	0.20	0.38	0.72	2.39	17	63.87
San Jacinto Dam	68.74	1.37	0.07	0.22	0.41	0.78	2.57	17	68.74
Liberty	74.49	1.49	0.07	0.24	0.45	0.84	2.78	17	74.49

NOTES:
1. Actual Rainfalls taken from Table 5.3.
2. Calculated Annual Rainfalls = ratio * ((P1*17) + (P2*17) + (P3*17) + (P4*17) + (P5*17) + (P6*17))

Table 5.10 - Event Mean Concentrations (EMCs) by Watershed Type
Houston EMC Database
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed			Parameter (mg/l except fecal coliform in col/100ml)											Dissolved Metals (µg/l)						
Type	Area/Land Use		TSS	TN	TP	BOD	O&G	FC	NH3	TKN	NO3+NO2	NO2	NO3	Cu	Cd	Cr	Pb	Hg	Ag	Zn
A1:	< 10 sq mi > 50% Residential																			
		Median	**166**	**2.10**	**0.37**	**8.5**	9.4		1.09	1.62	0.36	0.06	0.44	4.16	1.00	10.00	2.18	0.10	1.00	35.37
		Average	236	2.63	0.62	9.3	11.7		1.19	2.15	0.51	0.07	0.43	4.88	1.30	9.00	4.59	0.09	0.90	49.09
		Std Dev	259	2.62	0.81	4.4	7.1		0.89	2.34	0.39	0.03	0.08	2.63	0.95	3.16	4.77	0.03	0.32	46.40
		No. Data Pts	52	45	53	28	14		10	53	42	8	5	10	10	10	10	10	10	10
A2:	< 10 sq mi > 50% Commercial & Industrial																			
		Median	**100**	**3.41**	**0.79**	**15.0**	8.3	**4.3**	0.52	2.88	0.57	0.03	0.38	3.97	1.00	0.00	4.16	0.10	0.00	55.20
		Average	145	3.50	0.84	17.8	7.6	4.3	0.52	2.94	0.64	0.03	0.38	4.14	1.38	4.81	7.89	0.12	0.18	75.40
		Std Dev	140	1.46	0.42	9.3	4.8	0.0	0.53	1.30	0.32	0.01	0.01	3.62	0.97	8.08	8.90	0.04	0.40	68.43
		No. Data Pts	27	26	26	13	21	3	2	26	24	2	2	6	6	6	6	6	6	6
A3:	< 10 sq mi Forest																			
		Median	**39**	**0.83**	**0.06**			**3.2**	0.07	0.75		0.00	0.04							
		Average	70		0.06			3.1	0.07	0.81		0.01	0.06							
		Std Dev	76		0.02			0.4	0.04	0.60		0.00	0.04							
		No. Data Pts	7	6	6			5	8	6		8	8							
A5:	< 10 sq mi Mixed																			
		Median	92	2.12	0.32	7.1				1.81	0.41									
		Average	232	5.55	0.36	7.9				5.11	0.44									
		Std Dev	345	6.57	0.14	3.5				6.42	0.36									
		No. Data Pts	6	6	6	6				6	6									
B1:	10 - 100 sq mi < 10% Developed																			
		Median	171	1.20	0.15			3.6	0.10	1.22		0.01	0.15							
		Average	243	1.20	0.17			3.5	0.15	1.15		0.01	0.17							
		Std Dev	247	0.74	0.12			0.5	0.11	0.59		0.01	0.12							
		No. Data Pts	11	9	9			9	12	8		12	12							

NOTES:
1. Data Source: Houston Area EMC Database. See Appendix and text for description of watershed type. Values in bold used in Table 5.11.
2. Abbreviatons:
BOD - Biochemical Oxygen Demand (5-day)
TSS - Total Suspended Solids
NH3 - Ammonia Nitrogen
TKN - Total Kjeldahl Nitrogen
NO3 - Nitrate Nitrogen
NO2 - Nitrite Nitrogen
TN - Total Nitrogen
TP - Total Phosphorus
O&G - Oil and Grease
FC - Fecal Coliforms in Log (colonies)/100 ml
3. TN does not equal the sum of the constituent parts because of differences in original data and rounding errors.

Table 5.10 - Event Mean Concentrations (EMCs) by Watershed Type
Houston EMC Database
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed			Parameter (mg/l except FC in col/100 ml)											Dissolved Metals (µg/l)						
Type	Area/Land Use		TSS	TN	TP	BOD	O&G	FC	NH3	TKN	NO3+NO2	NO2	NO3	Cu	Cd	Cr	Pb	Hg	Ag	Zn
B2:	10 - 100 sq mi 10 - 50% Developed																			
		Median	316	3.54	1.03	9.0		4.6	0.27	2.18	0.76	0.30		3.00	1.00	7.23	1.00	0.10	0.32	
		Average	429	3.95	1.02	12.2		4.6	0.31	2.65	1.02	0.25		3.12	1.32	5.64	4.85	0.14	0.47	25.61
		Std Dev	350	3.24	0.51	10.6		0.4	0.15	2.69	0.78	0.10		1.86	0.82	6.00	9.74	0.13	0.49	32.48
		No. Data Pts	48	36	45	32		2	3	44	36	3		19	19	19	19	19	17	19
B3:	10 - 100 sq mi > 50% Developed																			
		Median	260	3.27	0.81	8.6		3.9	0.65	2.22	0.74	0.15		3.00	1.00	10.00	2.36	0.10	0.10	13.29
		Average	322	4.02	1.01	11.0		3.9	0.62	2.63	1.16	0.26		3.21	1.11	5.77	3.70	0.11	0.49	16.52
		Std Dev	253	2.18	0.73	9.5		1.0	0.34	1.70	1.08	0.25		2.61	0.85	5.32	3.40	0.09	0.52	13.17
		No. Data Pts	86	75	85	73		2	10	85	76	10		27	27	27	27	27	27	27
C1:	> 100 sq mi < 10% Developed																			
		Median						3.5												
		Average						3.6												
		Std Dev						0.7												
		No. Data Pts						9												
C2:	> 100 sq mi 10 - 50% Developed																			
		Median	391	2.78	1.02	6.0		4.9	0.30	2.02	0.94	0.45		2.00	0.00	0.00	0.00	0.22		20.00
		Average	507	3.80	1.29	8.5		4.9	0.30	2.58	1.22	0.48		3.35	0.33		0.66	0.27		41.34
		Std Dev	373	2.63	0.78	8.6			0.03	1.39	1.37	0.09		2.34				0.21		52.37
		No. Data Pts	21	20	21	21		2	4	20	20	3		3	3	3	3	3	2	3
	Entire Houston Area EMC Data Base for Metals																			
		Median												3.30	0.50	5.00	2.40	0.05	0.50	18.30
		Average												3.70	0.80	7.00	5.60	0.09	0.63	30.10
		Std Dev												1.90	0.50	3.20	7.60	0.08	0.26	38.90
		No. Data Pts												58	55	37	52	60	34	64

NOTES:
1. Data Source: Houston Area EMC Database. See Appendix and text for description of watershed type. Values in bold used in Table 5.11.
2. Abbreviatons:
BOD - Biochemical Oxygen Demand (5-day)
TSS - Total Suspended Solids
NH3 - Ammonia Nitrogen
TKN - Total Kjeldahl Nitrogen
NO3 - Nitrate Nitrogen
NO2 - Nitrite Nitrogen
TN - Total Nitrogen
TP - Total Phosphorus
O&G - Oil and Grease
FC - Fecal Coliforms in Log (colonies)/100 ml
3. TN does not equal the sum of the constituent parts because of differences in original data and rounding errors.

Table 5.11 Event Mean Concentrations (EMCs) Used for Non-Point Source (NPS) Calculations
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Water Quality Parameters Used for Mapping								
Land Use Category	Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Biochemical Oxygen Demand (mg/l)	Oil and Grease (mg/l)	Fecal Coliforms (colonies/100 ml)	Dissolved Copper (µg/l)	Pesticides (µg/l)
High Density Urban	166	2.10	0.37	9	13	22,000	3.1	0.4
Residential	100	3.41	0.79	15	4	22,000	3.1	0.4
Agricultural	201	1.56	0.36	4	0	2,500	3.1	0.1
Open/Pasture	70	1.51	0.12	6	0	2,500	3.1	0.1
Forest	39	0.83	0.06	6	0	1,600	3.1	0.1
Wetlands	39	0.83	0.06	6	0	1,600	3.1	0.0
Water	0	0	0	0	0	0	0.0	0.0
Barren	2200	5.20	0.59	13	0	1,600	3.1	0.1
Supplemental Metals and Synthetic Organic Hydrocarbons (not mapped) (µg/l)								
Land Use Category	Dissolved Lead	Dissolved Zinc	Dissolved Arsenic	Dissolved Cadmium	Dissolved Chromium	Dissolved Mecury	Dissolved Silver	
High Density Urban	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Residential	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Agricultural	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Open/Pasture	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Forest	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Wetlands	2.4	18.3	3.0	0.5	5.0	0.1	0.5	
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Barren	2.4	18.3	3.0	0.5	5.0	0.1	0.5	

Table 5.12 - Sources of Event Mean Concentrations (EMCs) Used for Non-Point Source (NPS) Calculation
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Land Use by Category	Total Suspended Solids	Total Nitrogen	Total Phosphorus	Biochemical Oxygen Demand
High density urban	Houston Area EMC Database, Table A1 Median Value	Houston Area EMC Database, Table A1 Median Value	Houston Area EMC Database, Table A1 Median Value	Houston Area EMC Database, Table A1 Median Value
Residential	Houston Area EMC Database, Table A2 Median Value	Houston Area EMC Database, Table A2 Median Value	Houston Area EMC Database, Table A2 Median Value	Houston Area EMC Database, Table A2 Median Value
Agricultural	USGS Barker - Addicks Reservoir Study, 1987 Median of Inflow Stations, Table 12	USGS Barker - Addicks Reservoir Study, 1987 Median of Inflow Stations, Table 12	USGS Barker - Addicks Reservoir Study, 1987 Median of Inflow Stations, Table 12	USGS Barker - Addicks Reservoir Study, 1987 Median of Inflow Stations, Table 12
Open/Pasture	Nationwide Urban Runoff Program, 1983 Median of "Open" Land Uses, Table 6.12	Nationwide Urban Runoff Program, 1983 Median of "Open" Land Uses, Table 6.12	Nationwide Urban Runoff Program, 1983 Median of "Open" Land Uses, Table 6.12	Nationwide Urban Runoff Program, 1983 Based on BOD/COD ratio of Residential Land Use and Median COD of Open Land Use, Table 6-12
Forest	Houston Area EMC Database, Table A3 Median Value	Houston Area EMC Database, Table A3 Median Value	Houston Area EMC Database, Table A3 Median Value	Assumed = Open/Pasture
Wetlands	Assumed = Forest	Assumed = Forest	Assumed = Forest	Assumed = Open/Pasture
Water	Assumed = 0	Assumed = 0	Assumed = 0	Assumed = 0
Barren	Bedient, et al, 1980b and Newell, 1981	Nationwide Urban Runoff Program, 1983 CA1 Watershed (Basin with highest erosion and "open" land use)	Nationwide Urban Runoff Program, 1983 CA1 Watershed (Basin with highest erosion and "open" land use)	Nationwide Urban Runoff Program, 1983 CA1 Watershed (Basin with highest erosion and "open" land use)

NOTES:
1. Tables A1, A2, and A3 for Houston Area Database are included in Appendix II and summarized in Table 5.10.
2. All tables other than A1, A2, and A3 refer to tables in the original source.

Table 5.12 - Sources of Event Mean Concentrations (EMCs) Used for Non-Point Source (NPS) Calculation
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Land Use by Category	Oil and Grease	Fecal Coliforms	Dissolved Copper	Pesticides	Other Dissolved Metals						
					Lead	Zinc	Arsenic	Cadmium	Chromium	Mecury	Silver
High density urban	Stenstrom, et al, 1984 Table 8	Houston Area EMC Database, Table A2 and C1 Nationwide Urban Runoff Program, 1983 (Warm weather conditions)	Houston Area EMC Database, Table E; (see text)	USGS Austin Study 1990 (see text)	See Dissolved Copper						
Residential	Stenstrom, et al, 1984 Table 8	Houston Area EMC Database, Table A2 and C1 Nationwide Urban Runoff Program, 1983 (Warm weather conditions)	Houston Area EMC Database, Table E; (see text)	USGS Austin Study 1990 (see text)	See Dissolved Copper						
Agricultural	Assumed = 0	USGS Barker - Addicks Reservoir Study, 1987 Median of Inflow Stations, Table 12	USGS Barker - Addicks Reservoir Study, 1987 (see text)	USGS Barker - Addicks Reservoir Study, 1987 (see text)	See Dissolved Copper						
Open/Pasture	Assumed = 0	Assumed same as agricultural	Assumed same as agricultural	Assumed same as agricultural	See Dissolved Copper						
Forest	Assumed = 0	Houston Area EMC Database, Table A3	Assumed same as agricultural	Assumed same as agricultural	See Dissolved Copper						
Wetlands	Assumed = 0	Assumed = Forest	Assumed same as agricultural	Assumed same as agricultural	See Dissolved Copper						
Water	Assumed = 0	Assumed = 0	Assumed = 0	Assumed = 0	See Dissolved Copper						
Barren	Assumed = 0	Assumed = Forest	Assumed same as agricultural	Assumed same as agricultural	See Dissolved Copper						

NOTES:
1. Tables A1, A2, and A3 for Houston Area Database are included in Appendix and summarized in Table 5.10.
2. All tables other than A1, A2, and A3 refer to tables in the original source.

Table 5.13 - Relative Accuracy of Project Event Mean Concentrations (EMCs)
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Estimated Relative Accuracy of EMCs								
Land Use Category	Total Suspended Solids	Total Nitrogen	Total Phosphorus	Biochemical Oxygen Demand	Oil and Grease	Fecal Coliforms	Dissolved Copper	Pesticides
High Density Urban	Good	Good	Good	Good	Fair	Good	Fair	Poor
Residential	Good	Good	Good	Good	Fair	Good	Fair	Poor
Agricultural	Fair	Fair	Fair	Fair	Fair	Fair	Poor	Poor
Open/Pasture	Fair	Fair	Fair	Fair	Fair	Fair	Poor	Poor
Forest	Good	Good	Good	Fair	Fair	Good	Poor	Poor
Wetlands	No data	No data	No data	No data	No data	No data	No data	No data
Water	No data	No data	No data	No data	No data	No data	No data	No data
Barren	Good	Fair	Fair	Fair	Fair	Fair	Poor	Poor

Estimated Relative Accuracy of EMCs								
Land Use Category	Dissolved Lead	Dissolved Zinc	Dissolved Arsenic	Dissolved Cadmium	Dissolved Chromium	Dissolved Mercury	Dissolved Silver	
High Density Urban	Fair	Fair	Fair	Fair	Fair	Fair	Fair	
Residential	Fair	Fair	Fair	Fair	Fair	Fair	Fair	
Agricultural	Poor	Poor	Poor	Poor	Poor	Poor	Poor	
Open/Pasture	Poor	Poor	Poor	Poor	Poor	Poor	Poor	
Forest	Poor	Poor	Poor	Poor	Poor	Poor	Poor	
Wetlands	Poor	Poor	Poor	Poor	Poor	Poor	Poor	
Water	Poor	Poor	Poor	Poor	Poor	Poor	Poor	
Barren	Poor	Poor	Poor	Poor	Poor	Poor	Poor	

NOTES:
1. Good rating refers to EMCs based on extensive Houston-Area NPS data.
2. Fair rating refers to EMCs based on either large national database or single local NPS study.
3. Poor rating refers to EMCs based on limited database or database with significant non-detect values that indicate large range in possible EMCs.

Table 5.14 - Comparison of GBNEP Event Mean Concentrations (EMCs) With Other Studies
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

	Total Suspended Solids		Total Nitrogen	
Land Use Category	Data Souce	Reported EMCs (mg/l)	Data Souce	Reported EMCs (mg/l)
High density urban	**GBNEP**	**166**	**GBNEP**	**2.10**
	NURP, Table 6.12	69	NURP, Table 6-12	1.75
	USGS Austin, Table 3	379 - 2740	USGS Austin, Table 3	2.08 - 4.35
	NOAA, Table 5	180	NOAA, Table 5	2.76
	TWC/Winslow, Table 2.6	77 - 126	TWC/Winslow, Table II-6	1.92
Residential	**GBNEP**	**100**	**GBNEP**	**3.41**
	NURP, Table 6-12	101	NURP, Table 6-12	2.64
	USGS Austin, Table 3	379 - 2740	USGS Austin, Table 3	2.08 - 4.35
	NOAA,Table 5	180	NOAA,Table 5	2.76
	TWC/Winslow, Table II-6	67 - 95	TWC/Winslow, Table II-6	1.98 -3.28
Agricultural	**GBNEP**	**201**	**GBNEP**	**1.56**
	Literature (see Appendix D)	153 - 720	Literature (see Appendix D)	12.15 - 23.3
			Omernik, 1977	6.08
Open/Pasture	**GBNEP**	**70**	**GBNEP**	**1.51**
	TWC/Winslow, Table II-6	88	TWC/Winslow, Table II-6	2.22
	Literature (see Appendix D)	1524	Literature (see Appendix D)	4.30
			USGS Austin, Table 3 (?)	0.44 - 0.56
Forest	**GBNEP**	**39**	**GBNEP**	**0.83**
	Literature (see Appendix D)	28 - 174	Literature (see Appendix D)	0.55 - 2.69
			Omernik, 1977	0.50

NOTES:
1. NURP: U.S. EPA, 1983.
2. USGS Austin: USGS, 1990.
3. NOAA: NOAA, 1987b.
4. NOAA Urban EMCs derived from NURP data, using different calculation method
5. TWC/Winslow: Winslow and Associates, 1986.

Table 5.14 - Comparison of GBNEP Event Mean Concentrations (EMCs) With Other Studies
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

	Total Phosphorus		Fecal Coliforms	
Land Use Category	Data Souce	Reported EMCs (mg/l)	Data Souce	Reported EMCs (Colonies per 100 ml.)
High density urban	**GBNEP**	**0.37**	**GBNEP**	**22,000**
	NURP, Table 6-12	0.20	NURP, Table 6-18	21,000
	USGS Austin, Table 3	0.44 - 1.70	USGS Austin, Table 3	600 - 49,000
	NOAA, Table 5	0.42	NOAA, Table 5	21,000
Residential	**GBNEP**	**0.79**	**GBNEP**	**22,000**
	NURP, Table 6-12	0.38	NURP, Table 6-12	101
	USGS Austin, Table 3	0.44 - 1.70	USGS Austin, Table 3	600 - 49,000
	NOAA, Table 5	0.42	NOAA, Table 5	21,000
Agricultural	**GBNEP**	**0.36**	**GBNEP**	**2,500**
	Literature (see Appendix D)	1.86 - 1.91	Literature (see Appendix D)	9,772
	Omernik, 1977	0.21		
Open/Pasture	**GBNEP**	**0.12**	**GBNEP**	**2,500**
	Literature (see Appendix D)	0.10	Literature (see Appendix D)	6,310 - 31,623
	Omernik, 1977	0.10	USGS Austin, Table 3 (?)	340 - 2,900
	USGS Austin 1990, Table 3 (?)	0.015 - 0.02		
Forest	**GBNEP**	**0.06**	**GBNEP**	**1,600**
	Literature (see Appendix D)	<0.1 - 0.82		
	Omernik, 1977	0.02		

NOTES:
1. NURP: U.S. EPA, 1983.
2. USGS Austin: USGS, 1990.
3. NOAA: NOAA, 1987b.
4. NOAA Urban EMCs derived from NURP data, using different calculaton method.
5. TWC/Winslow: Winslow and Associates, 1986.

Table 5.15 - Average Concentrations for Lake Houston and Lake Livingston Non-Point Source Load Calculations

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Parameter	Units of Concentration	Lake Houston		Lake Livingston	
		Average Conc.	Number of Samples	Average Conc.	Number of Samples
Suspended Solids [1]	(mg/l)at 105° C	25	121	10	205
Total Nitrogen [1]	(mg/l as N)	1.44	217	2.48	43
Total Phosphorus [1]	(mg/l as P)	0.38	216	0.34	257
Oil & Grease [2]	(mg/l)	0	-	0	-
Fecal Coliforms [1]	(colonies/100 ml)	330	54	19	88
BOD [1]	(mg/l)	3.4	97	2.5	154
Dissolved Copper [2]	(mg/l)	3.1	-	3.1	-
Pesticides [2]	(µg/l)	0.1	-	0.1	-
DISSOLVED METALS					
Lead [2]	(µg/l as Pb)	2.4	-	2.4	-
Zinc [2]	(µg/l as Zn)	18.3	-	18.3	-
Arsenic [2]	(µg/l as As)	3.0	-	3.0	-
Cadmium [2]	(µg/l as Cd)	0.5	-	0.5	-
Chromium [2]	(µg/l as Cr)	0.1	-	0.1	-
Silver [2]	(µg/l as Ag)	0.5	-	0.5	-

NOTES:
1. Source: Average of Texas Water Commission and United States Geological Survey (USGS) data. See Appendix IV, Table IV.5.
2. Source: Assumed equal to GBNEP Forest/Agricultural/Open/Pasture Land Uses after evaluating available USGS data (see Table 5.11).

Table 5.16 - Lake Houston and Lake Livingston Loads for Cases 1, 2, and 3
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

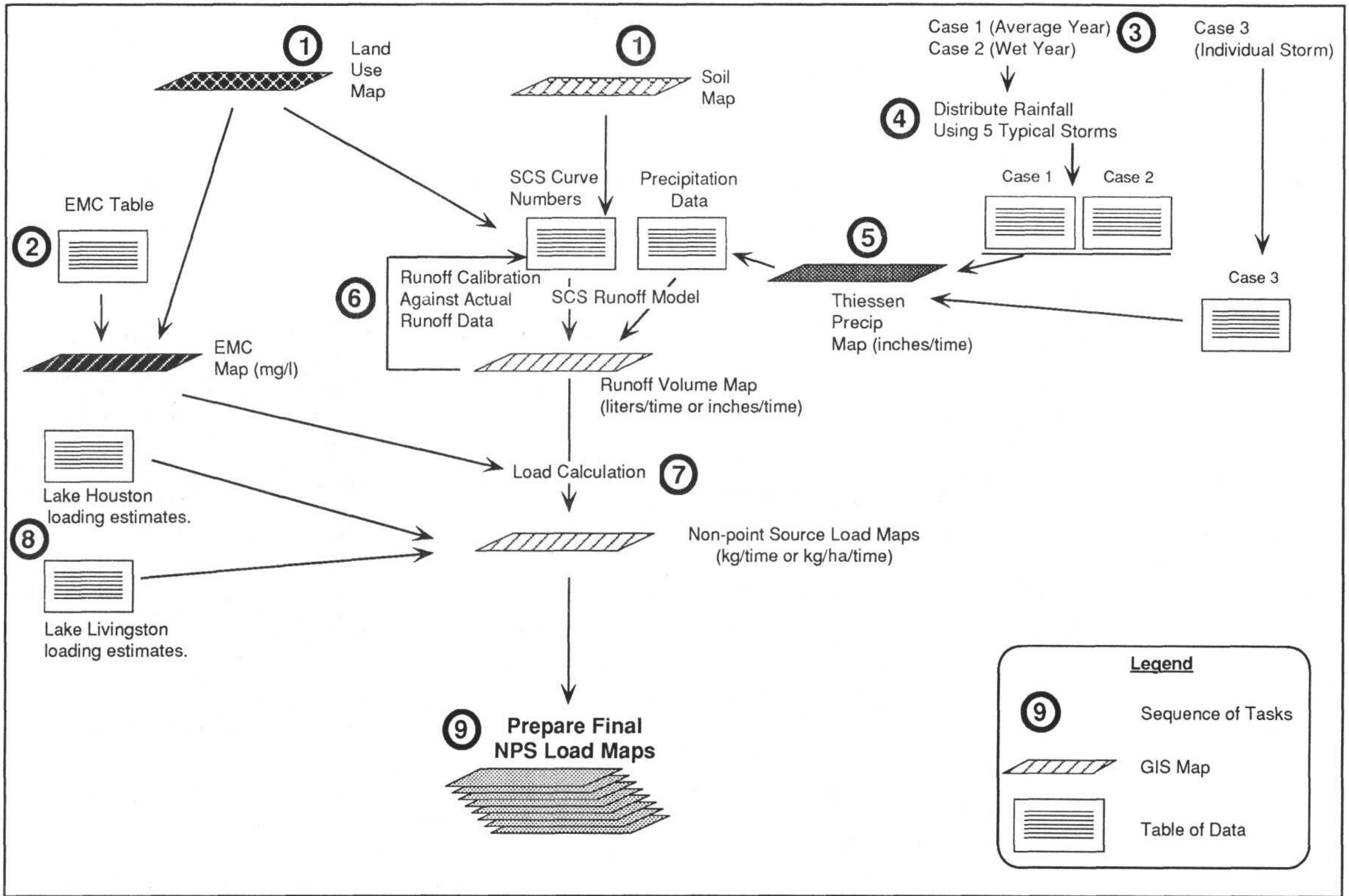
		Case 1		Case 2		Case 3	
Parameter	Units	Lake Houston	Lake Livingston	Lake Houston	Lake Livingston	Lake Houston	Lake Livingston
Runoff Volume	(thousand acre-ft)	1,380	4,660	2,200	6,800	2.1	5.4
Total Suspended Solids	(million kg)	43	57	68	84	0.1	0.1
Total Nitrogen	(thousand kg)	2,451	14,257	3,908	20,804	3.7	16.4
Total Phosphorus	(thousand kg)	647	1,955	1,031	2,852	1.0	2.3
Biochemical Oxygen Demand	(million kg)	5.8	14	9.2	21	0.01	0.02
Oil and Grease [5]	(million kg)	0	0	0	0	0	0
Fecal Coliform	(xE15 col)	5.6	1.1	9.0	1.6	0.01	0.001
Dissolved Copper	(kg)	5,277 [3]	17,821	8,413 [3]	26,005	8.0 [3]	20.5
Pesticides	(kg)	170 [4]	575 [4]	271 [4]	839 [4]	0.26 [4]	0.66 [4]

NOTES:
1. All parameter data is the result of a compilation of USGS Water Resources Data for Texas and information from the Texas Water Development Board.
2. For discharge values refer to section 5.5.1.
3. Calculated assuming GBNEP Copper concentration of 3.1 µg/l.
4. Calculated assuming GBNEP Pesticide Concentration of 0.1 µg/l.
5. Calculated assuming Oil and Grease concentration of 0.0 mg/l

Table 5.17 - Comparison of Lake Houston and Lake Livingston Calculated Loads to Other Studies
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

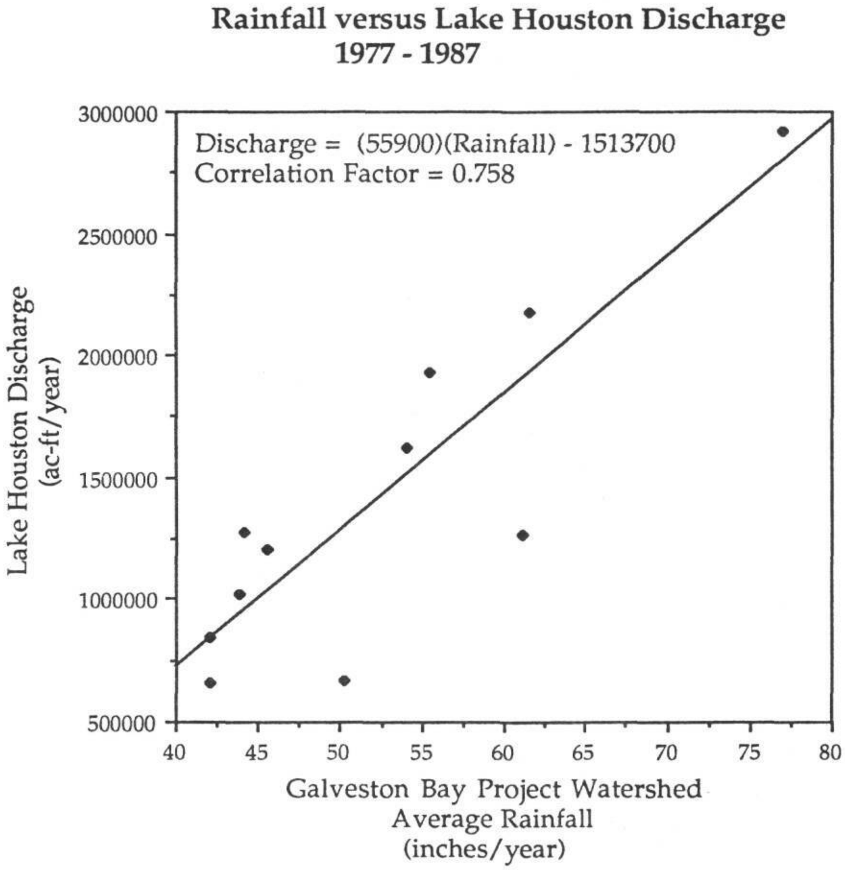
Lake Houston			Lake Livingston			
Parameter	GBNEP	Baca, et al., 1982	Discharge	GBNEP	Stanley, 1989	TWDB, 1988
Total Suspended Solids (million kg/year)	43	36	Total Suspended Solids (million kg/year)	57	-	650
Total Nitrogen (thousand kg/year)	2,451	1,783	Total Nitrogen (thousand lbs/year)	14,257	12,894	-
Total Phosphorus (thousand kg/year)	647	707	Total Phosphorus (thousand lbs/year)	1,955	2,361	-

NOTES:
1. All GBNEP Loads from Case 1, Average Year.
2. See Table 5.1 and 5.2 for methodology for calculation of GBNEP Case 1 Discharge from Lake Houston and Lake Livingston.
3. Discharge used by Baca, et al (1982) from 1975 (Average Flow Year).
4. Discharge used by Stanley from 1975 (Average Flow Year).
5. Values reported by Stanley originally from Hydroscience, 1976, Eutrophication Analysis of Lake Livingston Reservoir, Report to Texas Water Quality Board, Austin.



Groundwater Services, Inc. Houston, Texas	Rice University Dept. of Environmental Science and Engineering	GSI JOB NO. G-1220 ISSUED: 10/25/91 REVISED: EXHIBIT: 5.1	**FLOWCHART OF NON-POINT SOURCE LOAD CALCULATION** Non-Point Source Characterization Project Galveston Bay National Estuary Program

Exhibit 5.2 - Case 1 and Case 2 Discharges from Lake Houston
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

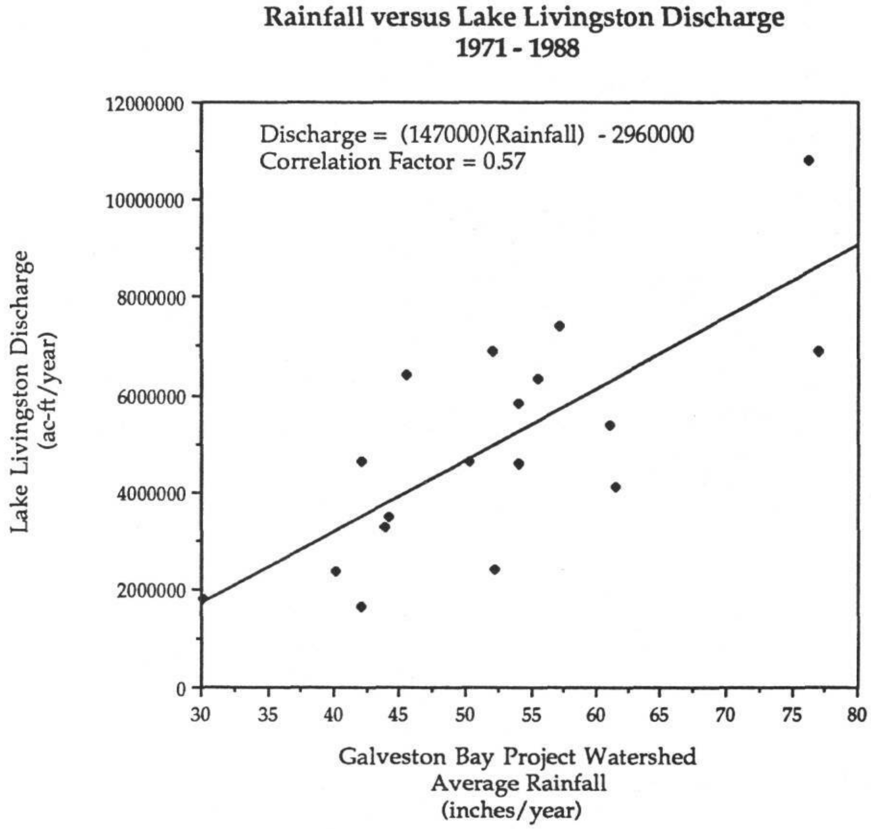


Case 1 Rainfall =	51.81 in	Case 2 Rainfall =	66.37 in
Case 1 Discharge =	1,381,495 ac-ft	Case 2 Discharge =	2,195,122 ac-ft

Note:
1. Lake Houston Discharge data obtained from the Texas Water Development Board.
2. Rainfall data obtained from Table 5.3.

Exhibit 5.3 - Case 1 and Case 2 Discharges from Lake Livingston

Non-Point Source Characterization Project
Galveston Bay National Estuary Program



Case 1 Rainfall =	51.81 in	Case 2 Rainfall =	66.37 in
Case 1 Discharge =	4,656,070 ac-ft	Case 2 Discharge =	6,796,390 ac-ft

Note:

1. Discharge data for Lake Livingston taken from flow measurements at the USGS Trinity at Goodrich gage.
2. Rainfall data obtained from Table 5.4.

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
	Digitized (sq mi)	Other (sq mi)	of Data
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	Watershed	Sub-Watershed	USGS Hydrologic Unit	Watershed	Sub-Watershed	USGS Hydrologic Unit
Trinity River	TR01	12030202	Buffalo B.	BF05	12040104	Cedar Bayou	CE03	12040203
	TR02	12030202	White Oak Bayou	WO01	12040104		CE04	12040203
	TR03	12030202		WO02	12040104	Clear Creek	CC01	12040204
	TR04	12030202		WO03	12040104		CC02	12040204
	TR05	12030202		WO04	12040104		CC03	12040204
	TR06	12030202		WO05	12040104		CC04	12040204
	TR07	12030202	Greens Bayou	GR01	12040104		CC05	12040204
Trinity Bay	TB02	12030202/12030203		GR02	12040104	Armand/ Taylor Bayous	AT01	12040204
	TB03	12030202/12030203		GR03	12040104		AT02	12040204
Trinity River	TR08	12030203		GR04	12040104		AT03	12040204
	TR09	12030203		GR05	12040104		AT04	12040204
	TR10	12030203		GR06	12040104	North Bay	NB01	12040204
	TR11	12030203		GR07	12040104	Dickinson Bayou	DB01	12040204
	TR12	12030203	Sims Bayou	SM01	12040104		DB02	12040204
	TR13	12030203		SM02	12040104		DB03	12040204
	TR14	12030203		SM03	12040104	West Bay	WB01	12040204
Trinity Bay	TB01	12030203		SM04	12040104		WB02	12040204
	TB04	12030203/12040203		SM05	12040104		WB04	12040204
Barker Res.	BK01	12040104	Ship Channel	SC01	12040104		WB05	12040204
	BK02	12040104		SC02	12040104		WB06	12040204
Addicks Res.	AD01	12040104		SC03	12040104		WB07	12040204
	AD02	12040104		SC04	12040104	South Bay	SB01	12040204
Brays Bayou	BR01	12040104		SC05	12040104		SB02	12040204
	BR02	12040104		SC06	12040104		SB03	12040204
	BR03	12040104		SC07	12040104/12040203		SB04	12040204
	BR04	12040104		SC08	12040104/12040203	Chocolate Bayou	CH01	12040204
	BR05	12040104	San Jacinto	SJ02	12040104/12040203		CH02	12040204
	BR06	12040104	East Bay	EB01	12040202		CH03	12040204
	BR07	12040104		EB02	12040202	West Bay	WB03	12040204/12040205
Buffalo Bayou	BF01	12040104		EB03	12040202	Austin/ Bastrop Bayous	AB01	12040205
	BF02	12040104		EB04	12040202		AB02	12040205
	BF03	12040104	Cedar Bayou	CE01	12040203		AB03	12040205
	BF04	12040104		CE02	12040203			

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	**Residential**
	12 Commercial and Services	**High-Intensity Urban**
	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	
2 Agricultural Land	21 Cropland and Pasture	**Agriculture**
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	**Open/Pasture**
	23 Confined Feeding Operations	
	24 Other Agricultural Land	
4 Forest Land	41 Deciduous Forest Land	**Forest**
	42 Evergreen Forest Land	
	43 Mixed Forest Land	
5 Water	51 Streams and Canals	**Water**
	52 Lakes	
	53 Reservoirs	
	54 Bays and Estuaries	
6 Wetlands	61 Forested Wetland	**Wetlands**
	62 NonForested Wetland	
7 Barren Land	71 Dry Salt Flats	**Barren Land**
	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	

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

Watershed	Land Use by Watershed (square miles) 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	Land Use by Watershed (square miles)									Total
	High-Density	Residential	Open/ Pasture	Agriculture	Ag + Open	Barren	Wetlands	Water	Forest	
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

	Monthly Minimum Daily Discharge (CFS)									
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
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

	Monthly Minimum Daily Discharge (CFS)									
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
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.

7.0 RESULTS AND PROJECT MAPS

The results from the runoff and load calculations for the project area are presented for the three rainfall cases graphically and in detail in Figures 7.1 through 7.39, and listed numerically for each watershed in Tables 7.1 through 7.3. For proper interpretation of the results shown on the Figures, it is necessary to observe the following:

<u>Subwatershed Based Figures: Example Figures 7.1 - 7.9</u>

There are a set of eight subwatershed based figures for each rainfall case analyzed:

- Each Figure presents a single parameter.
- The loads are presented in kilograms per hectare and runoff volume is in inches.
- One hectare equals 2.47 acres.
- The ranges of values used in the color coding of subwatersheds are listed in a legend on the lower left corner of the Figure.
- To assist in locating specific areas within the basin, a mylar overlay has been provided in Volume II which contains the Figures.

The data analysis for the subwatershed Figures 7.1 through 7.9, for example, indicates that the highest runoff volume contribution in inches (runoff per unit area) is actually from the urban center of Harris County. Similarly, the highest TSS load contribution on a per hectare basis is from the urbanized areas in the watershed. The actual values for all the parameters for each of the three cases are listed in Appendix III.

<u>Watershed Based Figures: Example Figures 7.10 - 7.12</u>

There is a set of three watershed-based Figures for each rainfall case analyzed. These Figures follow the subwatershed based maps and summarize the total runoff and loads by watershed for the study area.

- Figures are typically divided into four quarters. The runoff calculation results are always presented in the northwest quarter, while the load results are portrayed in the other three with the parameter name listed in the top left hand corner of each quarter.
- Runoff volumes and loads are presented for each individual watershed and are not accumulated as one proceeds towards the bay.

- Figures do not include the data for Lake Livingston and Lake Houston. For information on the reservoir loads, refer to Section 5.5.

- The color schemes used in these Figures are the same as for the subwatershed based Figures, however, the ranges of values and units are different (see the legend in the left hand corner of each quarter).

- Results shown on the Figures are based on total watershed area.

- The Figure Title indicates the rainfall case that is being shown.

- To assist in locating specific areas within the basin, a mylar overlay has been provided in Volume II which contains the Figures.

  The analysis of data from Figures 7.10 - 7.12, for example, would indicate that, for Case 1, the Trinity River, Trinity Bay, and West Bay watersheds contribute the largest amounts of runoff into the bay, as would be expected due to their large drainage areas. The Trinity River watershed, being the largest watershed, has the highest load values for TSS, TN, and TP. The urban watersheds such as the Ship Channel and Brays Bayou, contribute relatively high volumes of NPS oil and grease to the bay because of the high oil and grease EMCs for urban land uses. Tables 7.1a, b and c provide the actual parameter values for each watershed in three units: kilogram, mg/l and kilogram per hectare.

The remainder of the Results section will summarize the general trends observed in Figures 7.1 through 7.39 for each of the three storms.

1. Tables 7.1a, b and c present non-point source loads by watershed in three units: kilogram, mg/l and kilograms per hectare for Case 1. These data indicate that non-point source impacts on the Bay from the adjacent drainage areas are rather significant. During an average year, it is estimated that 481 million kilogram of TSS and 26.3 million kilogram BOD, for example, would be delivered to the bay.

   For an average year, the highest TSS, TN, TP, BOD, dissolved copper, and pesticide total loads are received from the Trinity River watershed due to its size. The Ship Channel watershed is the major contributor of oil and grease and fecal coliform.

   The highest NPS concentrations, except for TSS, evolve from the urbanized watersheds, Buffalo Bayou and Brays Bayou. The Addicks and Barker watersheds have high TSS concentrations due to their relatively large percentage of barren land (3 and 8%, respectively).

The data in Table 7.1c indicate that, on a per area basis, the White Oak Bayou watershed has the highest TN, TP, BOD, dissolved copper and pesticides contributions. Brays Bayou has the highest oil and grease and fecal coliform loads per area and the Barker Reservoir watershed has the highest TSS load per area.

2. Case 2 (the wet year analysis) results presented in Tables 7.2a, b, and c show similar trends to Case 1. Overall, Case 2 loads were 40-60% higher than Case 1.

3. The individual storm loads, as can be seen from Case 3 results (Tables 7.3a, b and c), amount to 15-20% of the annual NPS loads.

4. Tables 7.4a and 7.4b list NPS loads and percentages by land use category for Case 1. The data in Tables 7.4a and 7.4b indicate that the high density urban land use category is the main contributor of NPS loads to the bay for all of the parameters. Most notable is their high percentage contribution of Oil & Grease (87%), Fecal Coliform (59%), and Pesticides (50%).

5. Table 7.5 is a summary of the basin NPS loads for the three cases as well as the total loads (combined point source, low-flow, and NPS loads) from Lakes Houston and Livingston. In the annual Cases 1 and 2, the lakes provide a substantial fraction of the total Galveston Bay load for TN, TP, BOD, dissolved copper and pesticides.

6. The calculated total suspended solids for large urban watersheds such as Brays Bayou (see Figure 7.37), were lower than the measured TSS values for those watersheds (see Table 5.10, Land Use Category B3). Although the difference is not large, the apparent discrepancy has been noted in other Houston-area NPS studies (Winslow, 1986). Possible explanations are:

   - The water quality data was collected in the early 1980s during a period of intense urban development when considerable land was exposed for construction. The LANDSAT imagery, taken in 1990, does not reflect the construction areas that existed in the 1980s and therefore may not correlate exactly to the EMC database.

   - Much of the intense erosion may be occurring in areas smaller than the minimum resolution of the LANDSAT imagery (30 meters by 30 meters). Therefore the actual "barren land" and its associated high TSS loads are underrepresented.

   - The intense urbanization of the Houston area in the 1980s has greatly increased the runoff volume and peak flows that occur during storm events. Heavy streambank erosion in grass-lined swales and channels could be responsible for the very high TSS loads; this was observed for one of the Nationwide Urban Runoff program sampling locations.

7. Annual NPS loads for other heavy metals besides dissolved copper are presented in Table 7.6. Only results from Case 1, an average year, are shown.

Table 7.1a - Case 1: Average Year Total Non-Point Source (NPS) Loads by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved copper (kg)	Pesticides (kg)
Project Area	4,238	3,010	481	6,420	1,110	26.3	14.2	355	10,900	749
Addicks Reservoir	134	82	22	195	36	0.7	0.4	9	312	20
Armand/Taylor Bayou	77	70	12	167	29	0.7	0.5	11	255	22
Austin/Bastrop Bayou	213	121	21	245	44	0.9	0.2	9	442	21
Barker Reservoir	122	71	32	181	31	0.6	0.2	6	271	14
Brays Bayou	127	147	29	406	75	1.7	1.7	34	561	63
Buffalo Bayou	105	116	22	337	65	1.4	1.3	27	445	51
Cedar Bayou	211	153	26	321	58	1.2	0.3	13	576	30
Chocolate Bayou	170	95	19	188	36	0.6	0.1	5	354	15
Clear Creek	182	138	22	301	51	1.2	0.7	16	503	34
Dickinson Bayou	101	60	8	130	21	0.5	0.2	6	223	13
East Bay	288	193	26	388	68	1.6	0.5	17	679	36
Greens Bayou	209	184	30	497	92	2.1	1.4	34	702	66
North Bay	25	25	4	65	11	0.3	0.2	5	94	9
San Jacinto River	68	65	8	126	22	0.5	0.2	7	202	14
Ship Channel	166	198	34	498	90	2.0	**1.9**	**39**	713	74
Sims Bayou	93	91	16	235	41	1.0	0.8	17	346	33
South Bay	78	68	10	138	24	0.6	0.6	12	211	22
Trinity Bay	317	225	26	356	59	1.5	0.3	12	708	32
Trinity River	**1,099**	**572**	**62**	**877**	**124**	**4.3**	0.5	27	**2,110**	**82**
West Bay	344	212	30	405	68	1.6	0.9	21	706	44
White Oak Bayou	110	128	24	365	69	1.5	1.3	29	488	54
Median	134	121	22	301	51	1.2	0.5	13	445	32
Maximum	1,099	572	62	877	124	4.3	1.9	39	2,110	82
Minimum	25	25	4	65	11	0.3	0.1	5	94	9

Note:
1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.1b - Case 1: Average Year Total Non-Point Source (NPS) Concentrations by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	NPS Concentrations: Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Biochemical Oxygen Demand (mg/l)	Oil and Grease (mg/l)	Fecal Coliform (col/100 ml)	Dissolved copper (µg/l)	Pesticides (µg/l)
Project Area	4,238	3,010	130	1.73	0.30	7.1	3.8	9,576	2.9	0.20
Addicks Reservoir	134	82	213	1.94	0.35	6.8	3.7	9,122	3.1	0.20
Armand/Taylor Bayou	77	70	135	1.94	0.33	7.9	5.9	12,991	3.0	0.26
Austin/Bastrop Bayou	213	121	141	1.64	0.30	6.0	1.6	5,858	3.0	0.14
Barker Reservoir	122	71	**368**	2.06	0.35	6.6	2.4	6,557	3.1	0.16
Brays Bayou	127	147	158	2.24	0.41	9.1	**9.2**	18,558	3.1	0.35
Buffalo Bayou	105	116	151	**2.36**	**0.46**	**9.7**	8.9	**19,178**	**3.1**	**0.36**
Cedar Bayou	211	153	136	1.70	0.31	6.5	1.8	6,686	3.1	0.16
Chocolate Bayou	170	95	164	1.61	0.31	5.4	1.1	4,703	3.0	0.13
Clear Creek	182	138	131	1.77	0.30	6.9	4.0	9,590	3.0	0.20
Dickinson Bayou	101	60	112	1.76	0.28	7.0	2.5	7,876	3.0	0.17
East Bay	288	193	109	1.63	0.29	6.6	1.9	6,983	2.9	0.15
Greens Bayou	209	184	133	2.19	0.40	9.3	6.0	15,003	3.1	0.29
North Bay	25	25	129	2.09	0.37	8.6	7.1	15,365	3.0	0.29
San Jacinto River	68	65	101	1.58	0.27	6.8	2.9	8,671	2.5	0.18
Ship Channel	166	198	139	2.04	0.37	8.4	7.9	16,157	2.9	0.30
Sims Bayou	93	91	142	2.10	0.37	8.5	6.9	15,039	3.1	0.29
South Bay	78	68	120	1.64	0.28	6.7	7.3	13,691	2.5	0.26
Trinity Bay	317	225	92	1.28	0.21	5.3	1.0	4,475	2.6	0.11
Trinity River	**1,099**	**572**	88	1.24	0.18	6.1	0.7	3,833	3.0	0.12
West Bay	344	212	114	1.55	0.26	6.1	3.3	8,081	2.7	0.17
White Oak Bayou	110	128	152	2.32	0.44	9.5	8.5	18,332	3.1	0.34
Median	134	121	135	1.77	0.31	6.8	3.7	9,122	3.0	0.20
Maximum	1,099	572	368	2.36	0.46	9.7	9.2	19,178	3.1	0.36
Minimum	25	25	88	1.24	0.18	5.3	0.7	3,833	2.5	0.11

Note:
1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.1c - Case 1: Average Year Total Non-Point Source (NPS) Loads per Area by Watershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)	Biochemical Oxygen Demand (kg/ha)	Oil and Grease (kg/ha)	Fecal Coliform (bil. col/ha)	Dissolved copper (1/1000 kg/ha)	Pesticides (1/1000 kg/ha)
	NPS Loads by Unit Area									
Project Area	4,238	3,010	438	5.85	1.0	24.0	12.9	323	9.9	0.7
Addicks Reservoir	134	82	618	5.60	1.0	19.7	10.7	264	9.0	0.6
Armand/Taylor Bayou	77	70	584	8.41	1.4	34.1	25.5	564	12.8	1.1
Austin/Bastrop Bayou	213	121	380	4.44	0.8	16.1	4.2	158	8.0	0.4
Barker Reservoir	122	71	**1,022**	5.73	1.0	18.2	6.7	182	8.6	0.4
Brays Bayou	127	147	867	12.30	2.3	50.0	**50.6**	**1,018**	17.0	1.9
Buffalo Bayou	105	116	795	12.40	2.4	51.2	46.7	1,008	16.4	1.9
Cedar Bayou	211	153	469	5.86	1.1	22.5	6.3	230	10.5	0.5
Chocolate Bayou	170	95	434	4.27	0.8	14.3	2.9	125	8.0	0.3
Clear Creek	182	138	474	6.39	1.1	25.1	14.4	346	10.7	0.7
Dickinson Bayou	101	60	317	4.97	0.8	19.7	7.2	222	8.5	0.5
East Bay	288	193	348	5.21	0.9	21.0	6.1	223	9.1	0.5
Greens Bayou	209	184	559	9.20	1.7	38.9	25.4	630	13.0	1.2
North Bay	25	25	621	10.06	1.8	41.6	33.9	740	14.6	1.4
San Jacinto River	68	65	454	7.12	1.2	30.7	13.2	391	11.4	0.8
Ship Channel	166	198	787	11.56	2.1	47.3	44.6	914	16.5	1.7
Sims Bayou	93	91	660	9.76	1.7	39.6	32.2	697	14.4	1.3
South Bay	78	68	503	6.87	1.2	27.8	30.5	572	10.5	1.1
Trinity Bay	317	225	312	4.34	0.7	18.0	3.4	151	8.6	0.4
Trinity River	**1,099**	**572**	217	3.08	0.4	15.0	1.9	95	7.4	0.3
West Bay	344	212	335	4.55	0.8	18.0	9.6	237	7.9	0.5
White Oak Bayou	110	128	840	**12.78**	**2.4**	**52.5**	46.9	1,012	**17.1**	**1.9**
Median	134	121	503	6.39	1.1	25.1	13.2	346	10.5	0.7
Maximum	1,099	572	1,022	12.78	2.4	52.5	50.6	1,018	17.1	1.9
Minimum	25	25	217	3.08	0.4	14.3	1.9	95	7.4	0.3

Note:

1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.2a - Case 2: Wet Year Total Non-Point Source (NPS) Loads by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved copper (kg)	Pesticides (kg)
			NPS Loads							
Project Area	4,238	4,790	747	10,100	1,730	41.5	20.4	531	17,500	1,140
Addicks Reservoir	134	120	31	282	52	1.0	0.5	13	457	28
Armand/Taylor Bayou	77	124	20	293	50	1.2	0.8	19	457	37
Austin/Bastrop Bayou	213	191	33	385	69	1.4	0.3	13	704	32
Barker Reservoir	122	105	47	264	45	0.8	0.3	8	401	20
Brays Bayou	127	226	43	630	117	2.6	2.5	51	866	95
Buffalo Bayou	105	167	31	486	94	2.0	1.8	39	640	72
Cedar Bayou	211	241	40	500	90	1.9	0.5	19	908	46
Chocolate Bayou	170	151	30	297	56	1.0	0.2	8	566	23
Clear Creek	182	242	39	520	87	2.0	1.0	26	889	56
Dickinson Bayou	101	94	13	201	32	0.8	0.3	9	351	19
East Bay	288	308	41	615	107	2.5	0.6	25	1,100	55
Greens Bayou	209	268	43	720	132	3.1	1.9	48	1,030	94
North Bay	25	44	7	111	19	0.5	0.3	8	163	15
San Jacinto River	68	96	12	189	33	0.8	0.3	10	307	21
Ship Channel	166	310	53	779	140	3.2	**2.9**	**60**	1,120	114
Sims Bayou	93	159	27	408	71	1.7	1.2	28	609	54
South Bay	78	97	14	198	34	0.8	0.8	16	307	30
Trinity Bay	317	355	41	572	93	2.4	0.4	19	1,160	50
Trinity River	**1,099**	**986**	**103**	**1,480**	**205**	**7.4**	0.8	43	**3,660**	**137**
West Bay	344	323	46	621	103	2.5	1.2	31	1,100	65
White Oak Bayou	110	181	34	518	98	2.1	1.8	40	692	75
Median	134	181	34	486	87	1.9	0.8	19	692	50
Maximum	1,099	986	103	1,480	205	7.4	2.9	60	3,660	137
Minimum	25	44	7	111	19	0.5	0.2	8	163	15

Notes:

1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.2b - Case 2: Wet Year Total Non-Point Source (NPS) Concentrations by Watershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

			NPS Concentrations							
Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Biochemical Oxygen Demand (mg/l)	Oil and Grease (mg/l)	Fecal Coliform (col/100 ml)	Dissolved copper (µg/l)	Pesticides (µg/l)
Project Area	4,238	4,790	127	1.71	0.29	7.0	3.5	9,001	3.0	0.2
Addicks Reservoir	134	120	211	1.91	0.35	6.7	3.3	8,593	3.1	0.2
Armand/Taylor Bayou	77	124	132	1.92	0.33	7.8	5.3	12,113	3.0	0.2
Austin/Bastrop Bayou	213	191	140	1.64	0.29	6.0	1.4	5,569	3.0	0.1
Barker Reservoir	122	105	**360**	2.04	0.35	6.5	2.2	6,171	3.1	0.2
Brays Bayou	127	226	156	2.26	0.42	9.2	**8.8**	18,215	3.1	0.3
Buffalo Bayou	105	167	149	**2.36**	**0.46**	**9.7**	8.6	**18,913**	**3.1**	**0.4**
Cedar Bayou	211	241	134	1.68	0.30	6.4	1.7	6,334	3.1	0.2
Chocolate Bayou	170	151	162	1.60	0.30	5.4	1.0	4,458	3.0	0.1
Clear Creek	182	242	130	1.74	0.29	6.8	3.4	8,723	3.0	0.2
Dickinson Bayou	101	94	111	1.74	0.28	6.9	2.3	7,402	3.0	0.2
East Bay	288	308	108	1.62	0.28	6.6	1.7	6,617	2.9	0.1
Greens Bayou	209	268	131	2.18	0.40	9.2	5.7	14,512	3.1	0.3
North Bay	25	44	125	2.07	0.36	8.6	6.5	14,600	3.0	0.3
San Jacinto River	68	96	101	1.60	0.28	6.9	2.8	8,458	2.6	0.2
Ship Channel	166	310	138	2.04	0.37	8.4	7.5	15,715	2.9	0.3
Sims Bayou	93	159	139	2.08	0.36	8.5	6.3	14,145	3.1	0.3
South Bay	78	97	121	1.66	0.28	6.8	7.0	13,406	2.6	0.3
Trinity Bay	317	355	94	1.31	0.21	5.5	0.9	4,368	2.7	0.1
Trinity River	**1,099**	**986**	85	1.22	0.17	6.1	0.6	3,574	3.0	0.1
West Bay	344	323	114	1.56	0.26	6.2	3.0	7,667	2.8	0.2
White Oak Bayou	110	181	151	2.32	0.44	9.6	8.2	17,988	3.1	0.3
Median	134	181	132	1.74	0.30	6.8	3.3	8,593	3.0	0.2
Maximum	1,099	986	360	2.36	0.46	9.7	8.8	18,913	3.1	0.4
Minimum	25	44	85	1.22	0.17	5.4	0.6	3,574	2.6	0.1

Notes:

1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.2c - Case 2: Wet Year Total Non-Point Source (NPS) Loads per Area by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

			NPS Loads by Unit Area							
Watershed	Area (sq mi)	Runoff Volume (1000 acre-ft)	Total Suspended Solids (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)	Biochemical Oxygen Demand (kg/ha)	Oil and Grease (kg/ha)	Fecal Coliform (bil. col/ha)	Dissolved copper (1/1000 kg/ha)	Pesticides (1/1000 kg/ha)
Project Area	4,238	4,790	681	9.20	1.58	37.8	18.6	484	15.9	1.0
Addicks Reservoir	134	120	896	8.10	1.48	28.4	14.1	365	13.1	0.8
Armand/Taylor Bayou	77	124	1,012	14.75	2.50	59.9	40.6	931	23.0	1.9
Austin/Bastrop Bayou	213	191	596	6.97	1.24	25.4	5.9	237	12.7	0.6
Barker Reservoir	122	105	**1,475**	8.35	1.43	26.5	8.9	253	12.7	0.6
Brays Bayou	127	226	1,315	**19.09**	**3.55**	**77.6**	**74.3**	**1,537**	**26.2**	**2.9**
Buffalo Bayou	105	167	1,130	17.89	3.47	73.6	65.1	1,432	23.6	2.7
Cedar Bayou	211	241	729	9.13	1.64	34.9	8.9	343	16.6	0.8
Chocolate Bayou	170	151	686	6.75	1.27	22.7	4.0	188	12.9	0.5
Clear Creek	182	242	822	11.04	1.84	43.1	21.7	552	18.9	1.2
Dickinson Bayou	101	94	489	7.68	1.22	30.6	10.1	328	13.4	0.7
East Bay	288	308	552	8.26	1.44	33.4	8.7	337	14.8	0.7
Greens Bayou	209	268	800	13.33	2.44	56.5	34.6	887	19.1	1.7
North Bay	25	44	1,048	17.28	3.02	72.1	54.0	1,221	25.4	2.4
San Jacinto River	68	96	678	10.68	1.84	46.2	18.4	565	17.4	1.2
Ship Channel	166	310	1,220	18.08	3.25	74.3	66.6	1,392	26.0	2.6
Sims Bayou	93	159	1,129	16.94	2.95	68.9	51.5	1,150	25.3	2.2
South Bay	78	97	716	9.85	1.68	40.1	41.8	796	15.3	1.5
Trinity Bay	317	355	500	6.97	1.14	29.3	4.9	233	14.1	0.6
Trinity River	**1,099**	**986**	362	5.20	0.72	25.9	2.7	153	12.9	0.5
West Bay	344	323	511	6.98	1.16	27.6	13.4	343	12.4	0.7
White Oak Bayou	110	181	1,180	18.13	3.43	74.6	63.7	1,404	24.2	2.6
Median	134	181	800	9.85	1.68	40.1	18.4	552	16.6	1.2
Maximum	1,099	986	1,475	19.09	3.55	77.6	74.3	1,537	26.2	2.9
Minimum	25	44	362	5.20	0.72	22.7	2.7	153	12.4	0.5

Notes:

1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.3a - Case 3: Individual Storm Total Non-Point Source (NPS) Loads by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (thousand kg)	Oil and Grease (thousand kg)	Fecal Coliform (xE15 col)	Dissolved copper (kg)	Pesticides (kg)
	NPS Loads									
Project Area	4,238	603	91.6	1,230	205	5,100	1,840	55	2,250	125
		0								
Addicks Reservoir	134	20	5.1	46	8	159	55	2	78	4
Armand/Taylor Bayou	77	12	1.9	28	5	114	62	2	45	3
Austin/Bastrop Bayou	213	30	5.0	59	10	216	34	2	112	4
Barker Reservoir	122	19	7.4	44	8	139	31	1	71	3
Brays Bayou	127	23	4.4	63	12	255	212	5	88	9
Buffalo Bayou	105	19	3.4	55	11	224	166	4	72	8
Cedar Bayou	211	30	4.8	60	11	232	44	2	114	5
Chocolate Bayou	170	24	4.6	46	9	156	18	1	91	3
Clear Creek	182	27	4.1	57	9	224	86	3	101	6
Dickinson Bayou	101	14	1.9	30	4	119	27	1	54	3
East Bay	288	39	5.1	76	13	315	59	3	145	6
Greens Bayou	209	33	5.0	85	15	366	177	5	127	10
North Bay	25	4	0.6	10	2	43	27	1	16	1
San Jacinto River	68	10	1.3	21	4	92	29	1	36	2
Ship Channel	166	29	4.8	73	13	302	**229**	5	107	10
Sims Bayou	93	15	2.5	38	6	154	95	2	58	5
South Bay	78	13	1.9	28	5	114	94	2	45	4
Trinity Bay	317	44	5.2	73	12	313	37	2	155	6
Trinity River	**1,099**	**127**	**12.5**	**185**	**24**	**949**	66	**5**	**479**	**17**
West Bay	344	49	6.7	93	15	377	125	4	177	8
White Oak Bayou	110	20	3.5	57	11	232	167	4	75	8
Median	134	23	4.6	57	10	224	62	2	88	5
Maximum	1,099	127	12.5	185	24	949	229	5	479	17
Minimum	25	4	0.6	10	2	43	18	1	16	1

Notes:

1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.3b - Case 3: Individual Storm Total Non-Point Source (NPS) Concentrations by Watershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Area (sq mi)	Runoff Volume (thousand acre-ft)	NPS Concentrations: Total Suspended Solids (mg/l)	Total Nitrogen (mg/l)	Total Phosphorus (mg/l)	Biochemical Oxygen Demand (mg/l)	Oil and Grease (mg/l)	Fecal Coliform (col/100 ml)	Dissolved copper (µg/l)	Pesticides (µg/l)
Project Area	4,238	603	123	1.66	0.28	6.9	2.5	7,460	3.0	0.2
Addicks Reservoir	134	20	201	1.83	0.33	6.3	2.2	6,766	3.1	0.2
Armand/Taylor Bayou	77	12	125	1.88	0.31	7.6	4.2	10,535	3.0	0.2
Austin/Bastrop Bayou	213	30	136	1.59	0.28	5.9	0.9	4,725	3.0	0.1
Barker Reservoir	122	19	**325**	1.92	0.33	6.1	1.3	4,889	3.1	0.1
Brays Bayou	127	23	153	2.22	0.41	9.0	**7.5**	16,379	3.1	0.3
Buffalo Bayou	105	19	145	**2.35**	**0.46**	**9.6**	7.1	**17,141**	**3.1**	**0.3**
Cedar Bayou	211	30	130	1.62	0.29	6.3	1.2	5,449	3.1	0.1
Chocolate Bayou	170	24	158	1.56	0.29	5.3	0.6	3,873	3.1	0.1
Clear Creek	182	27	124	1.71	0.28	6.7	2.6	7,492	3.0	0.2
Dickinson Bayou	101	14	105	1.66	0.25	6.7	1.5	6,089	3.1	0.1
East Bay	288	39	106	1.58	0.27	6.5	1.2	5,737	3.0	0.1
Greens Bayou	209	33	121	2.09	0.38	9.0	4.3	12,472	3.1	0.3
North Bay	25	4	117	2.04	0.35	8.5	5.3	12,991	3.1	0.3
San Jacinto River	68	10	101	1.63	0.27	7.2	2.2	7,807	2.8	0.2
Ship Channel	166	29	133	2.05	0.37	8.4	6.4	14,397	3.0	0.3
Sims Bayou	93	15	131	2.03	0.35	8.2	5.1	12,339	3.1	0.2
South Bay	78	13	118	1.70	0.28	7.0	5.8	11,782	2.8	0.2
Trinity Bay	317	44	96	1.34	0.21	5.8	0.7	4,032	2.9	0.1
Trinity River	**1,099**	**127**	80	1.18	0.16	6.1	0.4	3,145	3.1	0.1
West Bay	344	49	111	1.55	0.25	6.3	2.1	6,356	2.9	0.1
White Oak Bayou	110	20	145	2.33	0.44	9.6	6.9	16,568	3.1	0.3
Median	134	23	125	1.71	0.29	6.7	2.2	7,492	3.1	0.2
Maximum	1,099	127	325	2.35	0.46	9.6	7.5	17,141	3.1	0.3
Minimum	25	4	80	1.18	0.16	5.3	0.4	3,145	2.8	0.1

Notes:

1. Boldface/underline indicates highest watershed load for the parameter.

Table7.3c - Case 3: Individual Storm Total Non-Point Source (NPS) Loads per Area by Watershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

			NPS Loads by Unit Area							
Watershed	Area (sq. mi.)	Runoff Volume (acre-ft)	Total Suspended Solids (kg/ha)	Total Nitrogen (kg/ha)	Total Phosphorus (kg/ha)	Biochemical Oxygen Demand (kg/ha)	Oil and Grease (kg/ha)	Fecal Coliform (bil. col/ha)	Dissolved copper (1/1000 kg/ha)	Pesticides (1/1000 kg/ha)
Project Area	4,238	603	83	1.12	0.19	4.6	1.7	50	2.0	0.1
Addicks Reservoir	134	20	145	1.32	0.24	4.6	1.6	49	2.2	0.1
Armand/Taylor Bayou	77	12	94	1.41	0.23	5.7	3.1	79	2.3	0.2
Austin/Bastrop Bayou	213	30	91	1.06	0.18	3.9	0.6	32	2.0	0.1
Barker Reservoir	122	19	**235**	1.39	0.24	4.4	1.0	35	2.2	0.1
Brays Bayou	127	23	132	1.91	0.35	7.7	**6.4**	141	2.7	0.3
Buffalo Bayou	105	19	124	**2.01**	**0.39**	**8.2**	6.1	**147**	**2.7**	**0.3**
Cedar Bayou	211	30	88	1.10	0.19	4.2	0.8	37	2.1	0.1
Chocolate Bayou	170	24	105	1.04	0.19	3.5	0.4	26	2.1	0.1
Clear Creek	182	27	88	1.21	0.20	4.8	1.8	53	2.1	0.1
Dickinson Bayou	101	14	71	1.13	0.17	4.5	1.0	41	2.1	0.1
East Bay	288	39	69	1.02	0.17	4.2	0.8	37	1.9	0.1
Greens Bayou	209	33	92	1.58	0.29	6.8	3.3	94	2.4	0.2
North Bay	25	4	92	1.60	0.27	6.7	4.1	102	2.4	0.2
San Jacinto River	68	10	73	1.18	0.20	5.2	1.6	57	2.0	0.1
Ship Channel	166	29	110	1.70	0.30	7.0	5.3	120	2.5	0.2
Sims Bayou	93	15	102	1.58	0.27	6.4	3.9	96	2.4	0.2
South Bay	78	13	97	1.38	0.23	5.7	4.7	96	2.3	0.2
Trinity Bay	317	44	64	0.89	0.14	3.8	0.5	27	1.9	0.1
Trinity River	**1,099**	**127**	44	0.65	0.09	3.3	0.2	17	1.7	0.1
West Bay	344	49	75	1.05	0.17	4.2	1.4	43	2.0	0.1
White Oak Bayou	110	20	123	1.98	0.37	8.1	5.8	141	2.6	0.3
Median	134	23	92	1.32	0.23	4.8	1.6	53	2.2	0.1
Maximum	1,099	127	235	2.01	0.39	8.2	6.4	147	2.7	0.3
Minimum	25	4	44	0.65	0.09	3.3	0.2	17	1.7	0.1

Notes:

1. Boldface/underline indicates highest watershed load for the parameter.

Table 7.4a - NPS Loads by Land Use for Case 1 (Average Year)
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Parameter	Units	H. Den. Urb.	Residential	Open	Agriculture	Barren	Wetlands	Water	Forest	Total
Runoff Volume	thousand ac-ft	766	371	567	593	21	187	164	345	3,014
TSS	million kg	157	46	49	147	57	9	0	17	481
Total Nitrogen	thousand kg	1,985	1,561	1,056	1,142	134	192	0	353	6,422
Total Phosphorus	thousand kg	350	362	84	264	15	14	0	26	1,113
BOD	million kg	8	7	4	3	0	1	0	3	26
Oil and Grease	million kg	12	2	0	0	0	0	0	0	14
Fecal Coliform	xE15 col	208	101	17	18	0	4	0	7	355
Dissolved Copper	kg	2,930	1,419	2,167	2,269	80	716	0	1,318	10,900
Pesticides	kg	378	183	70	73	3	0	0	43	749
Total		6,794	4,051	4,014	4,510	311	1,123	164	2,110	23,077

NOTES:
1. H. Den. Urb. = High Density Urban Land Use

Table 7.4b - Percent of NPS Loads by Land Use for Case 1 (Average Year)
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Parameter	Units	H. Den. Urb.	Residential	Open	Agriculture	Barren	Wetlands	Water	Forest	Total
Runoff Volume	% of total	25%	12%	19%	20%	1%	6%	5%	11%	100%
TSS	% of total	33%	10%	10%	31%	12%	2%	0%	3%	100%
Total Nitrogen	% of total	31%	24%	16%	18%	2%	3%	0%	5%	100%
Total Phosphorus	% of total	31%	32%	8%	24%	1%	1%	0%	2%	100%
BOD	% of total	31%	26%	16%	11%	1%	5%	0%	10%	100%
Oil and Grease	% of total	87%	13%	0%	0%	0%	0%	0%	0%	100%
Fecal Coliform	% of total	59%	28%	5%	5%	0%	1%	0%	2%	100%
Dissolved Copper	% of total	27%	13%	20%	21%	1%	7%	0%	12%	100%
Pesticides	% of total	50%	24%	9%	10%	0%	0%	0%	6%	100%

NOTES:
1. H. Den. Urb. = High Density Urban Land Use

Table 7.5 - Summary of Non-Point Source Loads
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

CASE 1 Average Year	Runoff Volume (thousand ac-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
GBNEP	3,010	481	6,420	1,110	26.3	14.2	355.	10,900	749
Lake Houston	1,380	43	2,451	647	5.8	0.0 [1]	5.6	5,277 [2]	170 [3]
Lake Livingston	4,660	57	14,257	1,955	14.4	0.0 [1]	1.1	17,821	575 [3]
Total	9,050	581	23,128	3,711	46.5	14.2	361.7	33,998	1,494
% Lakes of Total	67%	17%	72%	70%	43%	0%	2%	68%	50%
CASE 2 Wet Year									
GBNEP	4,790	747	10,100	1,730	41.5	20.4	531.	17,500	1,140
Lake Houston	2,200	68	3,908	1,031	9.2	0.0 [1]	9.	8,413 [2]	271 [3]
Lake Livingston	6,800	84	20,804	2,852	21.0	0.0 [1]	1.6	26,005	839 [3]
Total	13,790	899	34,812	5,613	71.7	20.4	541.5	51,918	2,250
% Lakes of Total	65%	17%	71%	69%	42%	0%	2%	66%	49%
CASE 3 Individual Storm									
GBNEP	603.	91.6	1,230.	205	5.1	1.8	55.4	2,250	125.
Lake Houston	2.1	.1	3.7	1.0	0.01	0.0 [1]	.009	8 [2]	.3 [3]
Lake Livingston	5.4	.1	16.4	2.3	0.02	0.0 [1]	.001	21	.7 [3]
Total	610.5	91.7	1,250.2	208	5.1	1.8	55.41	2,279	125.9
% Lakes of Total	1%	0%	2%	2%	0%	0%	0%	1%	1%

NOTES:
1. Calculated assuming GBNEP Oil and Grease concentration of 0.0 mg/l.
2. Calculated assuming GBNEP Copper concentration of 3.1 µg/l
3. Calculated assuming GBNEP Pesticide concentration of 0.1 µg/l.

Table 7.6 - Case 1 (Average Year): Dissolved Heavy Metal Loads
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Flow (acre-ft)	Dissolved Heavy Metal Loads (Kg/yr)						
		Lead	Zinc	Arsenic	Cadmium	Chromium	Mercury	Silver
Addicks Reservoir	81,800	242	1,840	302	50	50	10	50
Armand/Taylor Bayous	70,000	198	1,510	247	41	41	8	41
Austin/Bastrop Bayou	121,000	342	2,610	428	71	71	14	71
Barker Reservoir	71,200	210	1,600	263	44	44	9	44
Brays Bayou	147,000	434	3,310	543	91	91	18	91
Buffalo Bayou	116,000	345	2,630	431	72	72	14	72
Cedar Bayou	153,000	446	3,400	557	93	93	19	93
Chocolate Bayou	94,600	274	2,090	343	57	57	11	57
Clear Creek	138,000	389	2,970	486	81	81	16	81
Dickinson Bayou	60,000	172	1,310	215	36	36	7	36
East Bay	193,000	526	4,010	657	110	110	22	110
Greens Bayou	184,000	543	4,140	679	113	113	23	113
North Bay	25,100	72	552	91	15	15	3	15
San Jacinto River	64,800	156	1,190	195	33	33	7	33
Ship Channel	198,000	552	4,210	690	115	115	23	115
Sims Bayou	90,700	268	2,050	335	56	56	11	56
South Bay	68,200	163	1,250	204	34	34	7	34
Trinity Bay	225,000	549	4,180	686	114	114	23	114
Trinity River	572,000	1,630	12,400	2,040	340	340	68	340
West Bay	212,000	546	4,170	683	114	114	23	114
White Oak Bayou	128,000	377	2,880	472	79	79	16	79
Total Basin	**3,010,000**	**8,440**	**64,300**	**10,500**	**1,760**	**1,760**	**352**	**1,760**

NOTES:
1. Loads are for GBNEP Project Area only.
2. Lake Livingston and Lake Houston Loads not included.

8.0 CONCLUSIONS

8.1 Methodology and Data Collection

1. A methodology was developed to estimate non-point source (NPS) loads to Galveston Bay for three different cases: an average year, a wet year, and an individual storm. The NPS load calculation accounts for pollutants that wash off areas of various land uses in the 4,238 square mile watershed immediately adjacent to Galveston Bay. A companion study of pollutant loads from the two large upper watersheds, draining into Lake Houston and Lake Livingston, was also performed to calculate total NPS loads into the bay.

2. Geographic Information Systems (GIS), a relatively new computer mapping and data interpretation technology, was successfully applied to the problem of mapping NPS trends over a large watershed characterized by varied land use.

3. To perform the NPS assessment, several unique databases related to the Galveston Bay system were compiled, including:

- A comprehensive water quality database with most of the NPS monitoring data collected in the Houston area during the period 1976 to the present. Over 30 stations and 250 event mean concentrations (EMCs, or average pollutant concentrations during runoff events) are contained in the new Houston area EMC database.

- A detailed land use database of the 4,238 square mile study area was developed from LANDSAT satellite imagery and incorporated into the GIS system. The land use map contains over 12 million pixels, each being 30 meter by 30 meter in size.

- Watersheds, soils, streams, and other physical and man-made features were mapped using the GIS system.

8.2 Project Results

1. The precise sources of NPS loads are relatively difficult to determine due to their widespread, diffuse nature. The following table identifies major potential sources in the watershed:

Water Quality Parameter	Major Potential Non-Point Sources
Total Suspended Solids	Eroding urban areas, cultivated fields, and streambanks
Total Nitrogen	Eroding soils, fertilizer application, leaking sanitary sewers, overflows, by-passes, natural organic matter
Total Phosphorus	Eroding soils, fertilizer application, leaking sanitary sewers, overflows, by-passes, natural organic matter
Biochemical Oxygen Demand	Natural decaying organic matter, leaking sanitary sewers, overflows, by-passes, oil and grease, natural organic matter
Oil and Grease	Motor vehicles
Fecal Coliforms	Leaking sanitary sewers, bypasses, overflows, pets, cattle, wildlife
Dissolved Copper	Corrosion of copper plumbing, electroplating wastes, algicides, eroding soils
Pesticides	Urban and rural pesticide application

2. Land use in the project area is divided evenly between urban areas, agricultural lands, open/pasture areas, wetlands, and forests, as shown below:

• High-density urban	10%
• Residential	9%
• Open/Pasture	23%
• Agricultural	22%
• Barren	1%
• Wetlands	15%
• Water	1%
• Forest	18%

For this project, the LANDSAT interpretation process combined commercial areas, heavy industry, light industry, multi-family residential areas, high density single family residential areas, and transportation into the category "high density urban" areas, while "residential" was comprised primarily of low density single family residential areas. Open/pasture areas correspond to any open areas with a good grass cover.

3. The Houston area EMC database indicated that sediment, nutrient, and oxygen demanding substances in local urban runoff are typical of urban runoff in other parts of the country.

Although the rural EMC data were not as extensive as the urban database, they indicated that agricultural NPS concentrations are in the lower range of reported data for sediment and nutrient loads. Extensive rice cultivation in the watershed may explain these low concentrations, because flooded rice fields are relatively low generators of sediments and nutrients compared to typical row crops (McCauley, 1991).

In general, high density urban land use areas had higher NPS pollutant concentrations than most non-urban land uses. Forest lands had the lowest runoff concentrations.

4. Annual loads for Case 1, a year with average rainfall, were the following for the project study (excluding contributions from Lake Houston and Lake Livingston):

Annual Non-Point Source Loads
Average Year
(thousands kg/yr, except where noted)

	Study Area	Entire Watershed
Runoff	3,010 ac-ft/yr	9,050 ac-ft/yr
Total Suspended Solids	481,000	581,000
Total Nitrogen	6,420	23,128
Total Phosphorus	1,110	3,711
Biochemical Oxygen Demand	26,300	46,500
Oil and Grease	14,200	14,200
Fecal Coliforms	355×10^{15} cfu/yr	355×10^{15} cfu/yr
Dissolved Copper	10.9	34.0
Pesticides	0.8	1.5

ac-ft: acre-ft
cfu: colony forming unit
Entire Watershed includes loadings from study area, Lake Houston, and Lake Livingston. Lake loadings include contribution from point and low flow sources.

5. To assess the impact of NPS sources under high annual rainfall conditions, Case 2 was conducted assuming annual rainfall that occurs on the average, once every 10 years. The resulting runoff and NPS values were 40-60% higher than Case 1, the average year.

6. Case 3 simulated the response of the watershed to an individual storm event that could be expected to occur, on the average, once per year. The individual storm loads were approximately 15 to 20% of the total annual NPS load. These data indicate that a significant portion of the annual NPS loads occur during a few of the largest rainfall events during the year.

7. The load maps produced for this project identified areas of high non-point source load generation. In general, the highly urbanized areas in Houston, Baytown, Texas City, and Galveston show the highest loads per unit area for all water quality constituents. As would be expected, fecal coliform and oil and grease NPS loads are almost entirely associated with the urban areas. Urban areas were also shown to be intense source zones for high pesticide concentrations as well.

8. NPS mapping indicated that the highest erosion rates, and thus sources of sediment were occurring in a wedge-shaped area, having a point at the mouth of the Ship Channel and reaching through Houston to the watersheds upstream of Barker/Addicks reservoirs. The high sediment loads were attributed to a combination of erosion in urban land use areas in the Houston vicinity and of barren land in the rural western watersheds.

9. The pollutant load from the upper watersheds, which originates as discharge from Lake Houston and Lake Livingston, varied considerably among parameters. Over 70% of the annual nitrogen load, for example, originates from the upper watersheds and overwhelms the contribution from the local watersheds. For oil and grease and bacteria, however, the contribution of the upper watersheds was minor compared to that of the local watersheds in the study area.

8.3 Limitations to Non-Point Source Assessment

1. The LANDSAT imagery process has resulted in some apparent misclassification of land uses in the watershed. For example, wetlands areas may be overrepresented and portions of Pelican and Atkinson Islands are classified as high density urban areas rather than open or barren lands. Although the impact of the problems on the overall NPS calculation is minor, strict interpretation of the existing land use map can lead to errors during the development of NPS management plans.

2. Local non-point source data were limited for some land use-water quality parameter combinations, requiring application of engineering judgement and data from other areas for estimating EMCs. As would be expected, the accuracy of these EMCs are considered to be lower than the EMCs developed from local NPS data.

8.4 Future Research

The results from this project indicated the following future research and study needs:

1. Despite the extensive database developed for this project, a more accurate calculation of NPS loads could have been prepared with detailed NPS monitoring data from small agricultural areas in the watershed. In addition, there were little or no local data on oil and grease, total metals, urban pesticides, and non-pesticide organic priority pollutants. Future research is needed to better define the expected range of these constituents in area runoff.

2. Partitioning of pollutants between the sediment and water column must be defined better to describe transport mechanisms for heavy metals and synthetic organic constituents.

3. Future land use delineations using LANDSAT data should be performed periodically to map the change in land use in the watershed over time. A more detailed land use investigation, based on a combination of LANDSAT and SPOT data (a high altitude land use imagery with 10 meter by 10 meter resolution) could be conducted to develop a Level II land use analysis. This would produce a much more detailed and useful land use map for bay management purposes.

4. A better statistical technique, such as probit analysis, should be investigated during future studies for the evaluation of NPS water quality data with a significant number of "non-detect" values. During this study, the analysis of the metals and pesticide data was hampered by the presence of a high percentage of "non-detect" values.

5. The actual sources of high sediment loads in urban watersheds should be investigated to determine where the intense areas of erosion are located. Both streambank erosion and small areas of erosion should be evaluated.

6. The effect of secondary sources of NPS pollutants, such as septic tanks, sanitary sewer by-passes and overflows, sanitary sewage leakage into storm sewers, and atmospheric deposition needs to be evaluated in more detail. More actual NPS sampling data, particularly regarding leaking collection systems, is needed.

7. The reliability of the pollutant loading estimates from the upper watersheds (discharge from Lake Houston and Lake Livingston) needs to be increased. Recommended activities include intensive NPS sampling data from the reservoirs, further analysis of the ability of the reservoirs to reduce and attenuate NPS loadings, and the development of correlations between water quality and flow conditions for reservoir discharge. An assessment of NPS source areas upstream of the reservoirs should also be considered.

8. The actual impact of NPS pollutants to the bay should be assessed using the load data from this study. The development of the Galveston Bay National Estuary Program Management Plan for the bay may address this research need.

8.5 Summary

The NPS load data generated for this project can be used to develop strategies for managing water quality in Galveston Bay. The information can be used to evaluate possible NPS impacts in different time scales. The annual NPS loads, for example, are useful for estimating the effect of accumulative pollutants, such as heavy metals, on the resource. The individual storm loads indicate how water quality in the bay might change during an actual rainstorm.

All of the NPS water quality and GIS databases are available on electronic media so that the information can be used in future environmental studies or for development of the bay management plan. It is expected that the GIS mapping data developed for this project would serve as the foundation for future Galveston Bay projects that require an intensive mapping effort.

APPENDIX I
SUPPLEMENTAL RAINFALL DATA

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Table I.1 - Calculation of Outliers

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Year	ANNUAL RAINFALL (log of inches)									
	Alvin	Anahuac	Cleveland	Galveston WSO	Houston WSMCO (Intercontinental AP)	Houston FAA Airport (Hobby AP)	Houston - Barker	Houston - Independent Heights	Houston - San Jacinto Dam	Liberty
1970	1.69	1.77	1.62	1.69	1.68	1.75	1.68	1.73	1.73	1.72
1971	1.58	1.64	1.60	1.56	1.58	1.57	1.62	1.62	1.65	1.59
1972	1.73	1.68	1.73	1.60	1.71	1.74	1.59	1.78	1.75	1.77
1973	1.86	1.88	1.95	1.78	1.85	1.91	1.77	1.87	1.85	1.92
1974	1.71	1.73	1.82	1.64	1.69	1.76	1.75	1.75	1.74	1.80
1975	1.64	1.80	1.75	1.69	1.71	1.69	1.67	1.69	1.67	1.78
1976	1.74	1.67	1.73	1.62	1.74	1.84	1.65	1.78	1.76	1.73
1977	1.54	1.65	1.60	1.62	1.54	1.62	1.57	1.62	1.63	1.79
1978	1.62	1.58	1.66	1.47	1.65	1.65	1.61	1.63	1.65	1.63
1979	2.01	1.85	1.88	1.77	1.77	1.92	1.73	1.81	1.89	1.85
1980	1.61	1.73	1.58	1.54	1.59	1.60	1.54	1.62	1.71	1.75
1981	1.72	1.81	1.77	1.67	1.75	1.91	1.71	1.68	1.88	1.82
1982	1.63	1.68	1.72	1.53	1.63	1.67	1.52	1.60	1.57	1.76
1983	1.78	1.79	1.78	1.73	1.73	1.75	1.72	1.78	1.78	1.92
1984	1.66	1.55	1.66	1.55	1.68	1.70	1.65	1.65	1.61	1.68
1985	1.77	1.77	1.73	1.62	1.69	1.68	1.68	1.67	1.70	1.79
1986	1.71	1.72	1.82	1.56	1.65	1.73	1.70	1.71	1.76	1.80
1987	1.70	1.71	1.72	1.57	1.61	1.64	1.62	1.68	1.76	1.79
1988	1.53	1.53	1.40	1.60	1.36	1.43	1.40	1.46	1.44	1.53
1989	1.64	1.77	1.81	1.61	1.72	1.73	1.57	1.77	1.76	1.80
1990	1.57	1.70	1.67	1.58	1.61	1.56	1.57	1.59	1.72	1.73
average	1.69	1.72	1.71	1.62	1.66	1.71	1.63	1.69	1.71	1.76
std dev	0.11	0.09	0.12	0.08	0.10	0.12	0.09	0.09	0.10	0.09
Vh	1.955	1.940	2.002	1.812	1.903	2.005	1.849	1.916	1.964	1.986
Vl	1.421	1.492	1.427	1.426	1.425	1.408	1.418	1.465	1.464	1.532

NOTES:

1. Source of Original Data: NOAA, 1970 - 1990.
2. Shaded box denoted calculated outlier; 1979 Alvin annual rainfall represents a high outlier (extemely wet year), while 1988 annual rainfall for Cleveland, Houston WSMCO, Houston - Barker, and Houston - San Jacinto Dam represent low outliers (extremely dry year).
3. Vh = high outlier threshold.
4. Vl = low outlier threshold.
5. For calculation procedure see text, Section 5.3.1.

Table I.2 - Values of Kn

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Skew Coefficient C_s	Recurrence Interval in Years							
	1.0101	2	5	10	25	50	100	200
	Percent Chance (≥) = 1 - F							
	99	50	20	10	4	2	1	0.5
1.9	-1.037	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.140	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-1.256	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-1.518	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	-1.588	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
.9	-1.660	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
.8	-1.733	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
.7	-1.806	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
.6	-1.880	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
.5	-1.955	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
.4	-2.029	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
.3	-2.104	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
.2	-2.178	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.400	2.670
.0	-2.326	0.000	0.842	1.282	1.751	2.054	2.326	2.576
- .1	-2.400	-0.017	0.846	1.270	1.716	2.000	2.252	2.482
- .2	-2.472	0.033	0.850	1.258	1.680	1.945	2.178	2.389
- .3	-2.544	0.050	0.853	1.245	1.643	1.890	2.104	2.294
- .4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
- .5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
- .6	-2.755	0.099	0.857	1.200	1.528	1.720	1.880	2.016
- .7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
- .8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
- .9	-2.957	0.148	0.854	1.147	1.407	1.549	1.660	1.749
-1.0	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.180	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.210	0.838	1.064	1.240	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.270	1.318	1.351
-1.5	-3.330	0.240	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.388	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.970	1.075	1.116	1.140	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.920	0.996	1.023	1.037	1.044

NOTES:
1. Source: Bedient and Huber, Table 3.4.

Table I.3 - Calculation of Average and Ten Year Rainfalls

Non-Point Source Characterization Project

Galveston Bay National Estuary Program

Year	ANNUAL RAINFALL (log of inches)									
	Alvin	Anahuac	Cleveland	Galveston WSO	Houston WSMCO (Intercontinental AP)	Houston FAA Airport (Hobby AP)	Houston - Barker	Houston - Independent Heights	Houston - San Jacinto Dam	Liberty
1970	1.69	1.77	1.62	1.69	1.68	1.75	1.68	1.73	1.73	1.72
1971	1.58	1.64	1.60	1.56	1.58	1.57	1.62	1.62	1.65	1.59
1972	1.73	1.68	1.73	1.60	1.71	1.74	1.59	1.78	1.75	1.77
1973	1.86	1.88	1.95	1.78	1.85	1.91	1.77	1.87	1.85	1.92
1974	1.71	1.73	1.82	1.64	1.69	1.76	1.75	1.75	1.74	1.80
1975	1.64	1.80	1.75	1.69	1.71	1.69	1.67	1.69	1.67	1.78
1976	1.74	1.67	1.73	1.62	1.74	1.84	1.65	1.78	1.76	1.73
1977	1.54	1.65	1.60	1.62	1.54	1.62	1.57	1.62	1.63	1.79
1978	1.62	1.58	1.66	1.47	1.65	1.65	1.61	1.63	1.65	1.63
1979	-	1.85	1.88	1.77	1.77	1.92	1.73	1.81	1.89	1.85
1980	1.61	1.73	1.58	1.54	1.59	1.60	1.54	1.62	1.71	1.75
1981	1.72	1.81	1.77	1.67	1.75	1.91	1.71	1.68	1.88	1.82
1982	1.63	1.68	1.72	1.53	1.63	1.67	1.52	1.60	1.57	1.76
1983	1.78	1.79	1.78	1.73	1.73	1.75	1.72	1.78	1.78	1.92
1984	1.66	1.55	1.66	1.55	1.68	1.70	1.65	1.65	1.61	1.68
1985	1.77	1.77	1.73	1.62	1.69	1.68	1.68	1.67	1.70	1.79
1986	1.71	1.72	1.82	1.56	1.65	1.73	1.70	1.71	1.76	1.80
1987	1.70	1.71	1.72	1.57	1.61	1.64	1.62	1.68	1.76	1.79
1988	1.53	1.53	-	1.60	-	1.43	-	1.46	-	1.53
1989	1.64	1.77	1.81	1.61	1.72	1.73	1.57	1.77	1.76	1.80
1990	1.57	1.70	1.67	1.58	1.61	1.56	1.57	1.59	1.72	1.73
average	1.67	1.72	1.73	1.62	1.68	1.71	1.65	1.69	1.73	1.76
std dev	0.08	0.09	0.10	0.08	0.07	0.12	0.07	0.09	0.08	0.09
skew	0.187	-0.368	0.430	0.494	0.173	-0.037	-0.037	-0.299	0.156	-0.610
K	1.300	1.235	1.319	1.323	1.299	1.278	1.278	1.245	1.297	1.198
10 year	1.78	1.83	1.86	1.72	1.77	1.86	1.74	1.81	1.84	1.87
	Average and Ten Year Rainfalls at Gages (inches)									
average	46.99	51.98	53.72	41.57	47.74	50.89	44.19	49.03	53.46	57.43
10 year	60.55	67.71	72.18	53.06	59.35	73.27	54.79	64.13	68.74	74.49

NOTES:

1. Source of Original Data: NOAA, 1970 - 1990.
2. Based on Log Pearson Type III analysis.
3. For calculation procedure see text, Section 5.3.1.

APPENDIX II
RAINFALL CALCULATIONS

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Rainfall Analysis

RAINFALL ANALYSIS

GOAL: Determine a reasonable distribution of different storms that represent an entire year of rainfall for an average year. This rainfall distribution defined by two terms:

1) rainfall for a storm type (P) and
2) the number of storms for the storm type per year (N).

INPUT DATA:

Rainfall statistics taken from analysis of 1971 - 1981 hourly rainfall data from Houston Intercontinental Airport gage using the SYNOP program (Figure III-1, Winslow, 1986).

Average Yearly Precipitation = 50.13 inches

Average Precipitation per Storm (μ_x) = 0.600 inches/storm

$$\text{Number of Storms per Year} = \frac{50.13}{0.600} \sim 84 \text{ storms}$$

Coefficient of Variation of Storm Size (CV_x) = 1.67

Standard Deviation of Storm Size (σ_x) = 1.00 inches

STATISTICAL ANALYSIS:

Assume rainfall per storm is represented by a Log-Normal Distribution. Transform μ_x and σ_x to μ_y and σ_y using the following expressions (Bedient and Huber, 1988):

$$CV_x = e^{(\sigma_y)^2} - 1 \qquad \mu_x = e^{(\mu_y - \sigma_y^2/2)}$$

Rearrange: Rearrange:

$$\sigma_y = \left[\ln\left(CV_x^2 + 1\right)\right]^{1/2} \qquad \mu_y = \ln(\mu_x) + \frac{\sigma_y^2}{2}$$

$$\sigma_y = \ln[(1.67)^2 + 1]^{1/2} \qquad \mu_y = \ln(0.600) + (1.1542)^2/2$$

$$\sigma_y = 1.1542 \qquad \mu_y = -1.1769$$

ASSUMPTIONS: All storms during a year will be represented by five storm types. For example, the rainfall for an average year can be distributed as such:

Storm Type	Rainfall (inches)	Number of Storms per Year
Very small storms	P1	N1
Small storms	P2	N2
Average storms	P3	N3
Large storms	P4	N4
Very large storms	P5	N5

P_{total} = P1*N1 + P2*N2 + P3*N3 + P4*N4 + P5*N5 = 50.13 inches (average annual rainfall from SYNOP program)

Since there are approximately 85 storms in a year, assume

$N_1 = N_2 = N_3 = N_4 = N_5 = 17$ storms

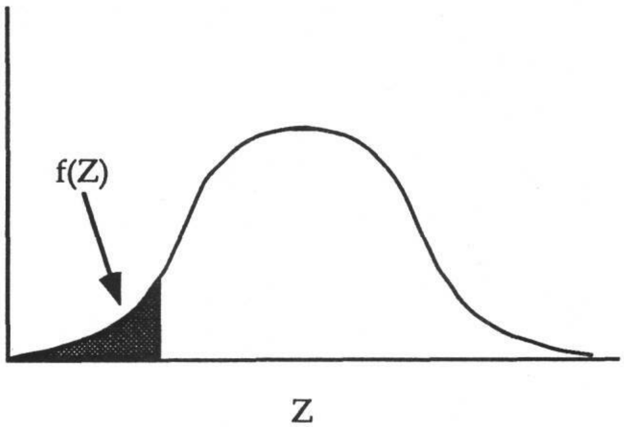
CALCULATIONS:

After transforming the data to log-space, use normal distribution relationships to determine values for P_1, P_2, P_3, P_4, and P_5.

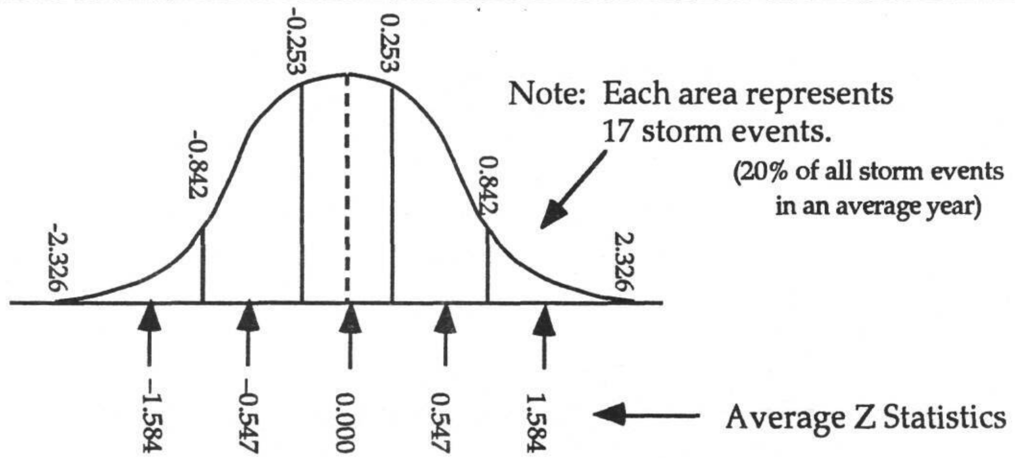
$$Y = \mu_y + Z\,\sigma_y$$

Using table D.3.2 (page 591, Bedient and Huber), calculate the following data:

Storm Type	Description	Upper Storm Percentile f(Z)	Lower Storm Percentile f(Z)	Upper Storm Z Statistic	Lower Storm Z Statistic	Average Z Statistic
Very Small Storm	Smallest 20%	0.20	0.01	-0.842	-2.326	-1.584
Small Storm	Next 20%	0.40	0.20	-0.253	-0.842	-0.547
Average Storm	Middle 20%	0.60	0.40	0.253	-0.253	0.000
Large Storm	Next 20%	0.80	0.60	0.842	0.253	0.547
Very Large Storm	Largest 20%	0.99	0.80	2.326	0.842	1.584



Relationship between f(Z) and Z



Relationship between f(Z) and average Z for GBNEP Project

Determine P for each storm size, assuming

1. Rainfall per storm is log-normal
2. μ_y = -1.1768 (see "Statistical Analysis")
   σ_y = 1.1542 (see "Statistical Analysis")
3. $Y = \mu_y + Z\,\sigma_y$
4. $P_{storm} = \exp Y$

Storm Size	Description	Average Z	P_{storm}	N	P_{total}
Very Small Storm	Smallest 20%	-1.584	P_1= 0.050	17	0.850
Small Storm	Next 20%	-0.547	P_2= 0.164	17	2.788
Average Storm	Middle 20%	0.000	P_3= 0.308	17	5.236
Large Storm	Next 20%	0.547	P_4= 0.580	17	9.860
Very Large Storm	Largest 20%	1.584	P_5 = 1.918	17	32.606

P_{total} (entire year) = 52.34 inches

CALIBRATION:

Predicted Annual Rainfall from this calculation = 52.34 inches

Actual Annual Rainfall from SYNOP program = 50.13 inches

Calibrate distribution by adjusting P_1, P_2, P_3, P_4, and P_5 by the following factor:

$$\frac{50.13}{52.34} = 0.977$$

Storm Size	Rainfall (unadjusted)	**Final Rainfall Distribution**	
		Rainfall (calibrated)	**Number of Storms**
Very Small Storm	0.050	$\mathbf{P_1 = 0.049}$	$\mathbf{N_1 = 17}$
Small Storm	0.164	$\mathbf{P_2 = 0.160}$	$\mathbf{N_2 = 17}$
Average Storm	0.308	$\mathbf{P_3 = 0.301}$	$\mathbf{N_3 = 17}$
Large Storm	0.580	$\mathbf{P_4 = 0.566}$	$\mathbf{N_4 = 17}$
Very Large Storm	1.918	$\mathbf{P_5 = 1.873}$	$\mathbf{N_5 = 17}$

P_{total} = 50.13 inches

APPLICATION:

Use final rainfall distribution for all annual rainfall models.

APPENDIX III
HOUSTON AREA EMC DATABASE
SUPPLEMENTAL LAND USE DATA
SUBWATERSHED LOAD DATA

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Table III.1 - Event Mean Concentrations (EMCs)

A1. Small Watershed, High Density Urban (commercial + industrial >40%)

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
11th St. Storm Sewer	0.21	1	7	10/14/85	AVE	8.0	137	0.20	0.60	0.32	0.08		0.92	0.29										
11th St. Storm Sewer	0.21	2	7	10/14/85	AVE	7.5	96		0.80	0.30			1.10	0.22										
11th St. Storm Sewer	0.21	3	7	5/17/86	AVE	9.6	57		1.64	0.76			2.40	0.11										
Bettina St. Ditch	1.37	145	15	5/14/82	FWA	9.3	299		1.22	0.20			1.42	0.37										
Bettina St. Ditch	1.37	146	15	5/18/82	FWA																			
Bettina St. Ditch	1.37	147	15	6/18/82	FWA																			
Bettina St. Ditch	1.37	148	15	6/23/82	FWA	18.0	90		4.10	0.94			5.00	1.30			100.0	1.00	10.00	8.00	16.00	0.10	1.00	30.0
Bettina St. Ditch	1.37	149	15	7/13/82	FWA																			
Bettina St. Ditch	1.37	150	15	7/14/82	FWA		14																	
Bettina St. Ditch	1.37	151	15	7/16/82	FWA				2.43	0.71			3.13	0.22										
Bettina St. Ditch	1.37	152	15	9/18/82	FWA																			
Bettina St. Ditch	1.37	153	15	11/2/82	FWA		163		1.70	0.16			1.86	1.23										
Bettina St. Ditch	1.37	155	15	5/21/83	FWA	6.8	74		1.79	0.34			2.13	0.24			14.5	1.00	10.00	3.00	4.88	0.10	1.00	19.3
Bettina St. Ditch	1.37	157	15	3/23/84	FWA		190		2.25	0.35			2.61	0.96										
Bettina St. Ditch	1.37	1	7	10/21/85	AVE	7.5	21		2.23	0.32			2.55	0.61										
Bettina St. Ditch	1.37	2	7	3/12/86	AVE	10.3	38		0.50	0.61			1.11	0.38										
Bettina St. Ditch	1.37	3	7	5/1/86	AVE	8.3	343		1.57	0.64			2.21	0.53										
Bettina St. Ditch	1.37	4	7	5/17/86	AVE	20.4	46		4.49	1.20			5.68	0.82										
Bettina St. Ditch	1.37	5	7	6/8/86	AVE	5.1	75		1.46	0.13			1.59	0.21										
Bettina St. Ditch	1.37	6	7	10/21/85	AVE	7.0	68		1.20	0.36			1.56	0.37										
Bingle Rd. Storm Sewer	0.21	1	7	9/9/85	AVE	9.0	13	0.42	2.00	2.00	0.13		4.00	5.37										
Bingle Rd. Storm Sewer	0.21	2	7	11/11/85	AVE	<3	157	0.08	1.15	0.04	<0.05		1.19	0.19										
Bingle Rd. Storm Sewer	0.21	3	7	11/11/85	AVE	3.0	152		1.48	0.06			1.54	0.20										
Bingle Rd. Storm Sewer	0.21	4	7	2/5/86	AVE	5.8	170		1.14	0.27			1.41	0.24										
Bingle Rd. Storm Sewer	0.21	5	7	5/17/86	AVE	4.1	85		1.17	0.98			2.15	0.10										
Bingle Rd. Storm Sewer	0.21	6	7	5/27/86	AVE	5.9	185		1.28	0.32			1.60	0.18										
Bingle Rd. Storm Sewer	0.21	7	7	5/30/86	AVE	5.8	233		1.82	0.44			2.26	1.50										
Bingle Rd. Storm Sewer	0.21	96	15	6/9/80	FWA	19.0	451		1.99	0.30			2.32	0.18										
Bingle Rd. Storm Sewer	0.21	97	15	7/21/80	FWA	8.6			1.79	1.15			2.92	0.19										
Bingle Rd. Storm Sewer	0.21	98	15	2/25/81	FWA	10.2			1.01	0.53			1.53	0.17										
Bingle Rd. Storm Sewer	0.21	99	15	4/23/81	FWA	10.3	639		1.61	0.32			1.94	0.24										
Bingle Rd. Storm Sewer	0.21	100	15	7/7/81	FWA		44		0.99	0.38			1.38	0.09										
Bingle Rd. Storm Sewer	0.21	101	15	8/12/81	FWA	16.0	298		1.59	0.74			2.31	0.52										
Bingle Rd. Storm Sewer	0.21	102	15	8/31/81	FWA												0.0	0.00	0.00	1.00	2.00	0.00	0.00	10.0
Bingle Rd. Storm Sewer	0.21	103	15	10/5/81	FWA																			
Bingle Rd. Storm Sewer	0.21	109	15	6/14/82	FWA	0.0	0	0. 0	0. 0	0.00	0.00	0	0.00	0.00	0	0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.0
Bingle Rd. Storm Sewer	0.21	105	15	3/22/82	FWA												100.0	1.00	10.00	6.88	7.34	0.10	1.00	164.4
Bingle Rd. Storm Sewer	0.21	107	15	5/6/82	FWA	11.0	170		1.80	0.30			2.10	0.18			23.0	3.00	10.00	6.00	8.00	0.10	1.00	21.0
Bingle Rd. Storm Sewer	0.21	108	15	5/12/82	FWA	7.5	64		1.70	0.42			2.10	0.42			41.0	3.00	10.00	4.00	1.00	0.10	1.00	18.0
Bingle Rd. Storm Sewer	0.21	109	15	6/14/82	FWA																			

Table III.1 - Event Mean Concentrations (EMCs)

A1. Small Watershed, High Density Urban (commercial + industrial >40%)

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Bingle Rd. Storm Sewer	0.21	110	15	6/26/82	FWA																			
Bingle Rd. Storm Sewer	0.21	111	15	7/13/82	FWA												32.9	1.00	10.00	4.33	1.30	0.10	1.00	87.4
Bingle Rd. Storm Sewer	0.21	112	15	7/16/82	FWA				2.20	1.08			3.29	0.21										
Bingle Rd. Storm Sewer	0.21	113	15	7/19/82	FWA												48.4	1.00	10.00	3.14	1.00	0.10	1.00	50.1
Bingle Rd. Storm Sewer	0.21	114	15	7/30/82	FWA		252																	
Bingle Rd. Storm Sewer	0.21	115	15	8/30/82	FWA												33.8	1.00	10.00	9.45	2.35	0.10	1.00	40.7
Bingle Rd. Storm Sewer	0.21	116	15	11/2/82	FWA		272		1.28	0.15			1.43	0.37										
Bingle Rd. Storm Sewer	0.21	117	15	11/16/82	FWA		103		1.46	0.68			2.14	0.15										
Bingle Rd. Storm Sewer	0.21	118	15	11/19/82	FWA		204		1.51	0.33			1.84	0.24										
Bingle Rd. Storm Sewer	0.21	119	15	2/5/83	FWA		48		1.33	0.80			2.14	0.67										
Bingle Rd. Storm Sewer	0.21	120	15	2/9/83	FWA		227		1.62	0.21			1.84	0.16										
Bingle Rd. Storm Sewer	0.21	121	15	2/15/83	FWA		82		1.05	0.32			1.37	0.13										
Bingle Rd. Storm Sewer	0.21	122	15	2/20/83	FWA		176		1.48	0.36			1.84	0.20										
Bingle Rd. Storm Sewer	0.21	123	15	6/15/83	FWA		121		1.82	0.87			2.69	0.35										
Bintliff at Bissonnet	4.41	1	2	11/1/77	FWA		517		0.90					1.23										
Bintliff at Bissonnet	4.41	2	2	11/21/77	FWA		292		1.32					0.44										
Bintliff at Bissonnet	4.41	3	2	12/13/77	FWA		727		2.05					0.78										
Bintliff at Bissonnet	4.41	4	2	1/11/78	FWA		658		2.25					1.42										
Bintliff at Bissonnet	4.41	5	2	2/12/78	FWA		933		2.23					1.09										
Bintliff at Bissonnet	4.41	6	2	5/29/78	FWA		1091		2.73					1.05										
Bintliff at Bissonnet	4.41	7	2	6/7/78	FWA		1114		5.38					2.22										
Hunting Bayou at Falls St.	3.09	1	3	3/20/74	FWA		71	2.44	ND		0.05	0.438		ND										
Hunting Bayou at Falls St.	3.09	2	3	3/26/74	FWA		197	2.51	3.52		0.07	0.509	4.09	0.41										
Hunting Bayou at Falls St.	3.09	3	3	4/11/74	FWA		122	0.73	1.56		0.07	0.338	1.96	0.90										
Hunting Bayou at Falls St.	3.09	4	3	5/8/75	FWA		207	1.20	3.25		0.06	0.511	3.82	1.08										
Hunting Bayou at Falls St.	3.09	5	3	6/30/75	FWA		182	2.10	3.94		0.04	0.373	4.36	1.28										
Sherwood Storm Sewer	0.18	1	7	8/20/85	AVE	13.0	38	1.07	17.38	0.89														
Sherwood Storm Sewer	0.18	2	7	11/11/85	FWA	4.0	186	1.10	2.01	0.08														
Median						8.5	166	1.09	1.62	0.36	0.00	0.44	2.10	0.37			37.4	1.00	####	4.16	2.18	0.10	1.00	35.4
Average						9.3	236	1.19	2.15	0.51	0.07	0.43	2.63	0.15			49.4	1.30	9.00	4.88	4.59	0.09	0.90	49.1
Standard deviation						4.4	259	0.89	2.34	0.39	0.03	0.08	2.62	0.24			37.5	0.95	3.16	2.63	4.77	0.03	0.32	46.4
Coefficient of variation						0.5	1	0.75	1.09	0.76	0.39	0.18	0.99	0.67			0.8	0.73	0.35	0.54	1.04	0.35	0.35	0.9
Number of data points						28	52	10	53	42	8	5	45	0			10	10	10	10	10	10	10	10

References:

2. Bedient, P.B. et al. Stormwater Pollutant Load-Runoff Relationships. JWPCF, 52:9 (September 1980).
3. Characklis, W.G. et al. Stormwater Runoff Quality: Data Collection, Reduction and Analysis. 1979.
7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.
15. USGS Database.

Note:

Underlined values represent values calculated for GBNEP Project.

FWA = Flow Weighted Average.

AVE = Average of all discrete samples.

Table III.1 - Event Mean Concentrations (EMCs)
A2. Small Watershed, Residential (residential > 50%)
Non-Point Source Characterization Project
Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Westbury	0.33	1	3,4	5/8/75	FWA		24	0.89	2.19		0.04	0.371	2.60	0.73		4.34								
Westbury	0.33	2	3,4	6/30/75	FWA		70	0.15	1.48		0.03	0.388	1.89	1.14		4.34								
Westbury	0.33	3	4	11/26/75	FWA											4.28								
Hunting Bayou at Falls St.	2.57	82	15	1/27/79	FWA	29.8	211		4.98	0.95			5.89	1.21			100.0	2.00	0.00	6.00	2.00	0.10	0.00	70.0
Hunting Bayou at Falls St.	2.57	83	15	9/19/79	FWA	19.2	405		3.44	0.55			3.99	0.81			80.0	3.00	0.00	0.00	2.00	0.10	0.00	20.0
Hunting Bayou at Falls St.	2.57	85	15	4/26/80	FWA	14.0	184		3.71	0.56			4.26	1.90										
Hunting Bayou at Falls St.	2.57	86	15	7/8/81	FWA	15.0	117		4.62	0.45			5.09	0.94			78.3	1.00	9.48	10.00	10.00	0.10	0.05	60.4
Lazybrook St. Storm Sewer	0.13	124	15	4/25/80	FWA	23.3	184		3.38	0.50			3.91	0.87			30.0	1.00	0.00	4.00	25.00	0.20	0.00	50.0
Lazybrook St. Storm Sewer	0.13	125	15	3/4/81	FWA																			
Lazybrook St. Storm Sewer	0.13	126	15	4/23/81	FWA	18.6	223		3.97	1.50			5.47	1.49			361.3	0.28	0.00	0.90	3.32	0.10	0.00	41.4
Lazybrook St. Storm Sewer	0.13	127	15	5/4/81	FWA		32																	
Lazybrook St. Storm Sewer	0.13	128	15	6/25/81	FWA		34		2.75	1.25			4.00	0.87										
Lazybrook St. Storm Sewer	0.13	129	15	7/7/81	FWA		13		1.38	0.49			1.91	0.41										
Lazybrook St. Storm Sewer	0.13	130	15	7/10/81	FWA		25		1.90	0.66			2.53	0.72										
Lazybrook St. Storm Sewer	0.13	131	15	10/5/81	FWA		37		6.50	0.34			6.85	1.42										
Lazybrook St. Storm Sewer	0.13	132	15	1/12/82	FWA	12.0	77		1.77	0.58			2.37	0.59										
Lazybrook St. Storm Sewer	0.13	133	15	2/25/82	FWA																			
Lazybrook St. Storm Sewer	0.13	134	15	3/6/82	FWA																			
Lazybrook St. Storm Sewer	0.13	135	15	7/30/82	FWA																			
Lazybrook St. Storm Sewer	0.13	136	15	8/2/82	FWA																			
Lazybrook St. Storm Sewer	0.13	137	15	11/2/82	FWA		387		2.46	0.17			2.84	0.21										
Lazybrook St. Storm Sewer	0.13	138	15	11/16/82	FWA		41		3. 0	0.10			1.10	0.32										
Lazybrook St. Storm Sewer	0.13	139	15	2/9/83	FWA		123		2.02	0.42			2.50	0.41										
Lazybrook St. Storm Sewer	0.13	140	15	2/15/83	FWA		21		1.16	0.45			1.61	0.24										
Lazybrook St. Storm Sewer	0.13	141	15	2/20/83	FWA		81		3.85	0.50			4.36	0.70										
Lazybrook St. Storm Sewer	0.13	142	15	3/23/84	FWA		136		3.09	0.63			3.72	0.96										
Lazybrook St. Storm Sewer	0.13	143	15	7/6/84	FWA		62		1.50	0.70			2.20	0.65			24.1	1.00	19.37	3.94	5.00	0.10	1.00	210.6
Lazybrook St. Storm Sewer	0.13	1	7	3/12/86	AVE	41.4	113		4.46	0.93			5.39	1.06										
Lazybrook St. Storm Sewer	0.13	2	7	5/17/86	AVE	8.0	100		3.51	1.03			4.55	0.87										
Lazybrook St. Storm Sewer	0.13	3	7	5/30/86	AVE	18.7	402		3.20	0.67			3.87	1.53										
Lazybrook St. Storm Sewer	0.13	4	7	8/20/85	AVE	10.0	26		2.33	0.78			3.11	0.76										
Vince Bayou at Pasadena	7.32	41	15	4/21/77	FWA	11.1	281		2.32	0.39			2.68	0.60										
Vince Bayou at Pasadena	7.32	42	15	3/20/79	FWA	10.8	513		1.50	0.85			2.34	0.48										
Median						15.0	100	0.52	2.88	0.57	0.03	0.38	3.41	0.79	8.30	4.34	79.2	1.00	0.00	3.97	4.16	0.10	0.00	55.2
Average						17.8	145	0.52	2.94	0.64	0.03	0.38	3.50	0.84	7.55	4.32	112.3	1.38	4.81	4.14	7.89	0.12	0.18	75.4
Standard deviation						9.3	140	0.53	1.30	0.32	0.01	0.01	1.46	0.42	4.77	0.03	125.6	0.97	8.08	3.62	8.90	0.04	0.40	68.4
Coefficient of variation						0.5	1	1.02	0.44	0.50	0.28	0.03	0.42	0.50	0.63	0.01	1.1	0.70	1.68	0.87	1.13	0.35	2.31	0.9
Number of data points						13	27	2	26	24	2	2	26	26	21	3	6	6	6	6	6	6	6	6

References:
3. Characklis, et al. Stormwater Runoff Quality: Data Collection, Reduction and Analysis. July 1979.
4. Davis, Bacterial Characteristics of Stormwaters in Developing Rural Areas, August 1979.
7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.
15. USGS Database.

Note:
Underlined values represent values calculated for GBNEP Project.
FWA = Flow weighted average.
AVE = Average of all discrete samples.

Table III.1 - Event Mean Concentrations (EMCs)

A3. Small Size (<10 sq mi) or Single Land Use Watershed, Forest

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
P-10	25.08	7	3,4	12/5/74	AVE		27	0.09	0.83		0.00	0.012	0.84	0.08		3.20								
P-10	25.08	9	3,4	3/13/75	FWA		67	0.09	1.61		0.00	0.103	1.72	0.09		2.93								
P-10	25.08	10	3,4	4/8/75	FWA		39	0.08	1.37		0.00	0.065	1.44	0.06		3.36								
P-10	25.08	13	3,4	9/5/75	FWA		7	0.03	0.10		0.00	0.03	0.13	0.03		2.41								
P-10	25.08	14	3,4	10/25/75	FWA		8	0.05	0.26		0.01	0.03	0.30	0.05		3.48								
P-10	25.08	15	3,4	3/7/76	FWA		212	0.06			0.01	0.047												
P-10	25.08	16	3,4	3/8/76	FWA		130	0.02			0.01	0.023												
P-10	25.08	17	3,4	4/4/76	FWA			0.16	0.67		0.01	0.135	0.81	0.06										
Median							39	0.07	0.75		0.00	0.04	0.83	0.06		3.20								
Average							70	0.07	0.81		0.01	0.06		0.06		3.08								
Standard deviation							76	0.04	0.60		0.00	0.04		0.02		0.43								
Coefficient of variation							1	0.59	0.74		0.73	0.77		0.34		0.14								
Number of data points							7	8	6		8	8	6	6		5								

References:

3. Characklis, et al. Stormwater Runoff Quality: Data Collection, Reduction and Analysis. July 1979.
4. Davis, Bacterial Characteristics of Stormwaters in Developing Rural Areas, August 1979.

Note:
Underlined values represent values calculated for GBNEP Project.
FWA = Flow weighted average.
AVE = Average of all discrete samples.

Table III.1 - Event Mean Concentrations (EMCs)
A4. Small Watershed, Open
Non-Point Source Characterization Project
Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Little Prong at Katy-Gaston		1	7	5/2/86	AVE		199	5.88	2.75	0.39	0.59													
Little Prong at Katy-Gaston		2	7	6/9/86	AVE		74	5.67	2.30	1.94	0.88													
Median							137	5.77	2.52	1.16	0.73													
Average							137	5.77	2.52	1.16	0.73													
Standard deviation							88	0.15	0.31	1.09	0.20													
Coefficient of variation							1	0.03	0.12	0.94	0.28													
Number of data points							2	2	2	2	2													

References:
7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.

Note:
AVE = Average of all discrete samples.

Table III.1 - Event Mean Concentrations (EMCs)
A5. Small Watershed, Mixed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Sherwood Storm Sewer	0.18	1	7	11/11/85	AVE	10.5	929		7.10	0.06			7.16	0.61										
Sherwood Storm Sewer	0.18	2	7	5/17/86	AVE	5.4	57		1.23	0.79			2.02	0.21										
Sherwood Storm Sewer	0.18	3	7	5/27/86	AVE	8.8	100		1.60	0.55			2.15	0.28										
Sherwood Storm Sewer	0.18	4	7	6/8/86	AVE	5.5	85		1.32	0.27			1.59	0.36										
Sherwood Storm Sewer	0.18	5	7	8/20/85	AVE	13.0	38		17.38	0.89			18.27	0.28										
Sherwood Storm Sewer	0.18	6	7	11/11/85	AVE	4.0	186		2.01	0.08			2.09	0.41										
Median						7.1	92		1.81	0.41			2.12	0.32										
Average						7.9	232		5.11	0.44			5.55	0.36										
Standard deviation						3.5	345		6.42	0.36			6.57	0.14										
Coefficient of variation						0.4	1		1.26	0.81			1.18	0.39										
Number of data points						6	6		6	6			6	6										

References:
7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.

Note:
Underlined values represent values calculated for GBNEP Project.
AVE = Average of all discrete samples.

Table III.1 - Event Mean Concentrations (EMCs)

B1. Medium Size Watershed (10-100 sq mi), <10% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
P-30	33.76	1	3,4	1/18/74	FWA		236	0.03			0.00	0.029		ND		3.63								
P-30	33.76	5	3,4	4/22/74	FWA		939	0.33	1.34		0.01	0.235	1.59	0.48		3.89								
P-30	33.76	6	3,4	10/28/74	FWA		305	0.09			0.01	0.037	0.04	0.10		3.63								
P-30	33.76	7	3,4	12/5/74	FWA		86	0.10	0.91		0.01	0.023	0.93	0.10		3.86								
P-30	33.76	8	3,4	3/4/75	FWA		47	0.10	1.66		0.01	0.107	1.77	0.13		3.00								
P-30	33.76	9	3,4	3/13/75	FWA		90	0.07	1.09		0.00	0.111	1.20	0.16		2.41								
P-30	33.76	10	3,4	4/8/75	FWA		171	0.15	1.39		0.01	0.154	1.55	0.09		3.38								
P-30	33.76	13	3,4	9/5/75	FWA		100	0.20	0.44		0.02	0.305	0.76	0.18		3.39								
P-30	33.76	14	3,4	10/25/75	FWA		169	0.08	0.31		0.01	0.147	0.46	0.15		4.17								
P-30	33.76	15	3,4	3/7/76	FWA		237	0.06			0.02	0.252												
P-30	33.76	16	3,4	3/8/76	FWA		290	0.17			0.01	0.178												
P-30	33.76	17	3,4	4/4/76	FWA			0.39	2.04		0.02	0.42	2.48	0.15										
Median							171	0.10	1.22		0.01	0.15	1.20	0.15		3.63								
Average							243	0.15	1.15		0.01	0.17	1.20	0.17		3.48								
Standard deviation							247	0.11	0.59		0.01	0.12	0.74	0.12		0.53								
Coefficient of variation							1	0.74	0.51		0.64	0.72	0.62	0.71		0.15								
Number of data points							11	12	8		12	12	9	9		9								

References:

3. Characklis, et al. Stormwater Runoff Quality: Data Collection, Reduction and Analysis. July 1979.
4. Davis, Bacterial Characteristics of Stormwaters in Developing Rural Areas, August 1979.

Notes:

Underlined values represent values calculated for GBNEP Project.

FWA = Flow weighted average.

Table III.1 - Event Mean Concentrations (EMCs)

B2. Medium Size Watershed (10-100 sq mi), 10-50% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Greens Bayou at Hwy 59	69.6	19	15	3/8/76	FWA	12.3	1737		2.693	1.02			3.72	1.43		4.82		0.00	0.00	8.00	0.00	0.50		20.0
Greens Bayou at Hwy 59	69.6	20	15	6/9/78	FWA	10.1	1350		1.528	0.17			1.72	0.42										
Greens Bayou at Hwy 59	69.6	21	15	4/19/79	FWA	12.2	632		1.22	0.32			1.58	0.25			100.0	2.00	0.00	2.00	0.00	0.10	0.00	20.0
Greens Bayou at Hwy 59	69.6	22	15	1/23/80	FWA	6.6	426		1.482	0.08			1.53	0.20			070.0	1.00	0.00	2.00	0.00	0.10	0.00	3.0
Greens Bayou at Hwy 59	69.6	23	15	8/31/81	FWA	4.9	498		1.814	0.22			2.05	0.53			049.0	1.00	0.00	3.00	2.00	0.10	0.00	3.0
Greens Bayou at Hwy 59	69.6	24	15	5/13/82	FWA	14.4	567		3.06	0.75			3.80	1.57			120.0	3.00	10.00	3.00	1.00	0.10	1.00	12.0
Greens Bayou at Hwy 59	69.6	27	15	5/11/83	FWA	14.0	718		3.577	0.55			4.13	0.90			108.6	1.00	10.00	2.61	6.93	0.10	1.00	6.7
White Oak Bayou at Heights	86.3	1	7	8/20/85	AVE	10.0	316	0.18	2.95	1.00	0.14		3.95	1.79										
White Oak Bayou at Heights	86.3	2	7	9/29/85	AVE	<3	342	0.27	14	0.38	0.3		14.38	1.15										
White Oak Bayou at Heights	86.3	3	7	10/28/85	AVE	5.0	122	0.47	1.6	0.99	0.32		2.59	0.93										
White Oak Bayou at Heights	86.3	4	7	8/21/85	AVE	12.0	365		2.86	1.49			4.35	1.29										
White Oak Bayou at Heights	86.3	5	7	9/30/85	AVE	3.8	276		13.85	3.67			17.52	1.11										
White Oak Bayou at Heights	86.3	6	7	10/28/85	AVE	3.8	75		1.333	1.88			3.21	1.43										
White Oak Bayou at Heights	86.3	7	7	5/25/86	AVE	32.3	190		2.757	1.07			3.82	0.94										
White Oak Bayou at Heights	86.3	8	7	6/9/86	AVE	1.5	176		1.326	0.45			1.77	1.19										
White Oak Bayou at Heights	86.3	9	15	11/19/75	FWA	38.7	181		3.427	0.77			4.46	1.76		4.29		0.00	0.00	4.00	36.00	0.50		140.0
White Oak Bayou at Heights	86.3	10	15	4/17/77	FWA	41.6	458		5.469	0.67			6.17	2.14										
White Oak Bayou at Heights	86.3	11	15	1/8/79	FWA	9.8	265		1.9	0.59			2.51	0.90			081.6	2.00	0.00	4.63	0.00	0.10	0.32	26.3
White Oak Bayou at Heights	86.3	12	15	10/23/79	FWA	32.5	171		2.405	0.73			3.17	1.17			100.0	1.00	0.00	0.00	2.00	0.00	0.00	30.0
White Oak Bayou at Heights	86.3	13	15	1/18/80	FWA	23.7	1072		3.689	0.67			4.35	1.03			060.0	1.00	10.00	5.00	27.00	0.20	0.00	20.0
White Oak Bayou at Heights	86.3	14	15	5/7/82	FWA	16.0	276		3.328	0.69			4.05	1.24			059.2	3.00	10.00	3.17	6.66	0.10	1.00	19.7
White Oak Bayou at Heights	86.3	15	15	5/20/83	FWA	8.0	726		2.331	0.44			0.44	0.59			054.7	1.00	10.00	4.16	2.69	0.10	1.00	9.3
White Oak Bayou at Heights	86.3	16	15	5/22/83	FWA	6.8	332		1.957	0.31			0.31	0.47			086.0	1.00	10.00	4.00	1.00	0.10	1.00	14.0
Brays Bayou at Gessner Rd.	53.4	1	2	5/29/78	FWA		518		1.8					0.81										
Brays Bayou at Gessner Rd.	53.4	2	2	1/1/04	FWA		55		0.17					0.28										
Brays Bayou at Gessner Rd.	53.4	3	2	1/1/04	FWA		229		0.38					0.17										
Keegans Bayou at Roark Rd.	12.4	1	2	1/30/77	FWA		83							0.56										
Keegans Bayou at Roark Rd.	12.4	2	2	2/10/77	FWA		560																	
Keegans Bayou at Roark Rd.	12.4	3	2	9/7/77	FWA		146		0.46					0.58										
Keegans Bayou at Roark Rd.	12.4	4	2	11/21/77	FWA		72		0.17					0.50										
Keegans Bayou at Roark Rd.	12.4	5	2	1/11/78	FWA		315		2.43					1.87										
Keegans Bayou at Roark Rd.	12.4	6	2	5/29/78	FWA		54		0.17					0.11										
Keegans Bayou at Roark Rd.	12.4	7	2	6/7/78	AVE		818		1.55					1.67										
Keegans Bayou at Roark Rd.	12.4	66	15	1/8/79	FWA	5.6	590		1.444	0.68			2.14	0.59			040.0	2.00	20.00	2.00	0.00	0.10	0.00	3.0
Keegans Bayou at Roark Rd.	12.4	67	15	4/3/79	FWA	8.2	1027		2.364	1.14			3.48	1.06			100.0	2.00	0.00	2.00	0.00	0.10	0.00	20.0
Keegans Bayou at Roark Rd.	12.4	68	15	12/13/79	FWA	11.5	468		2.105	1.32			3.42	1.34			100.0	1.00	0.00	0.00	0.00	0.10	0.00	30.0

Table III.1 - Event Mean Concentrations (EMCs)

B2. Medium Size Watershed (10-100 sq mi), 10-50% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Keegans Bayou at Roark Rd.	12.4	69	15	4/24/81	FWA	18.4	187		2.19	0.75			2.95	1.41										
Keegans Bayou at Roark Rd.	12.4	70	15	9/2/81	FWA	2.5	276		1.75	0.31			2.06	0.48			029.8	1.00	7.23	2.72	1.95	0.11	0.72	6.5
Keegans Bayou at Roark Rd.	12.4	71	15	6/19/82	FWA		243																	
Keegans Bayou at Roark Rd.	12.4	73	15	7/15/82	FWA		869		2.28	1.50			3.79	1.25										
Keegans Bayou at Roark Rd.	12.4	74	15	7/31/82	FWA		298																	
Keegans Bayou at Roark Rd.	12.4	75	15	8/11/82	FWA		149		2.38	1.88			4.27	1.38			052.8	1.00	10.00	2.00	1.00	0.10	1.00	79.1
Keegans Bayou at Roark Rd.	12.4	76	15	11/4/82	FWA	7.6	613		2.16	1.23			3.39	1.27			087.0	1.00	10.00	5.00	4.00	0.10	1.00	24.0
Keegans Bayou at Roark Rd.	12.4	77	15	11/20/82	FWA	2.8	341		2.13	1.42			3.55	0.95										
Keegans Bayou at Roark Rd.	12.4	78	15	11/26/82	FWA		183		2.07	2.22			4.30	1.66										
Keegans Bayou at Roark Rd.	12.4	79	15	1/20/83	FWA	2.9	168		2.95	3.19			6.14	1.77										
Keegans Bayou at Roark Rd.	12.4	80	15	2/10/83	FWA	6.3	813		2.59	1.16			3.76	1.01										
Keegans Bayou at Roark Rd.	12.4	81	15	2/17/83	FWA	4.1	256		2.36	1.18			3.53	0.76										
Median						9.0	316	0.27	2.18	0.76	0.30		3.54	1.03		4.56	81.6	1.00	7.23	3.00	1.00	0.10	0.32	20.0
Average						12.2	429	0.31	2.65	1.02	0.25		3.95	1.02		4.56	76.4	1.32	5.64	3.12	4.85	0.14	0.47	25.6
Standard deviation						10.6	350	0.15	2.69	0.78	0.10		3.24	0.51		0.38	26.5	0.82	6.00	1.86	9.74	0.13	0.49	32.5
Coefficient of variation						0.9	0.8	0.48	1.02	0.76	0.39		0.82	0.50		0.08	0.3	0.62	1.06	0.59	2.01	0.92	1.03	1.3
Number of data points						32	48	3	44	36	3		36	45		2	17	19	19	19.00	19.00	19.00	17	19.0

References:

2. Bedient, et al. Stormwater Pollutant Load-Runoff Realtionships, JWPCF, 52:9 (September 1980).

7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.

15. USGS Database.

Note:

Underlined values represent values calculated for GBNEP Project.

FWA = Flow weighted average.

Table III.1 - Event Mean Concentrations (EMCs)

B3. Medium Size Watershed (10-100 sq mi), >50% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3+NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no / 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Sims Bayou at Telephone Rd.	63	1	7	[illegible]/14/85	AVE	8.0	433	0.36	1.50	1.14	0.11		2.64	1.06										
Sims Bayou at Telephone Rd.	63	2	7	10/28/85	AVE	5.0	178	0.68	1.80	1.68	0.54		3.48	1.18										
Sims Bayou at Telephone Rd.	63	3	7	10/28/85	AVE	6.5	264		1.60	2.47			4.07	1.71										
Sims Bayou at Telephone Rd.	63	4	7	11/14/85	AVE	2.9	109		2.17	0.29			2.46	0.45										
Sims Bayou at Telephone Rd.	63	5	7	4/10/86	AVE	5.0	98		2.60	2.36			4.95	1.92										
Sims Bayou at Telephone Rd.	63	6	7	5/2/86	AVE	9.1	206		2.68	2.74			5.42	1.35										
Sims Bayou at Telephone Rd.	63	7	7	5/26/86	AVE	4.0	112		3.11	5.43			8.54	1.46										
Sims Bayou at Telephone Rd.	63	8	7	6/5/86	AVE	2.0	206		0.98	0.84			1.83	0.71										
Sims Bayou at Telephone Rd.	63	9	7	6/9/86	AVE	5.6	223		1.77	0.91			2.68	0.81										
Sims Bayou at Telephone Rd.	63	10	15	9/29/76	FWA	11.0	410		2.76	0.41			3.17	1.31		5								
Sims Bayou at Telephone Rd.	63	11	15	3/11/77	FWA	11.9	135		3.29	2.39			5.68	2.27										
Sims Bayou at Telephone Rd.	63	12	15	9/21/83	FWA	4.6	458		4.52	0.21			4.73	0.78			23.0	1.00	10.00	3.00	2.00	0.10	1.00	5.0
Sims Bayou at Telephone Rd.	63	13	15	5/22/85	FWA	9.7	129		3.84	2.26			6.10	1.82			79.0	1.00	15.00	7.50	11.50	0.10	1.50	24.5
Sims Bayou at Telephone Rd.	63	14	15	8/14/86	FWA	7.8	215		1.27	2.17			3.44	1.56			42.3	1.00	10.00	3.16	5.00	0.10	1.00	12.2
Brays Bayou at Main St.	94.9	1	7	10/28/85	AVE	6.0	82	0.69	2.60	1.43	0.78		4.03	1.22										
Brays Bayou at Main St.	94.9	2	7	4/10/86	AVE	7.0	89	1.44	2.87	1.86	0.12		4.73	1.53										
Brays Bayou at Main St.	94.9	3	7	2/5/86	AVE	7.8	171		1.50	1.24			2.74	1.28										
Brays Bayou at Main St.	94.9	4	7	4/10/86	AVE	8.2	180		3.80	2.23			6.03	2.26										
Brays Bayou at Main St.	94.9	5	7	5/2/86	AVE	10.0	305		3.67	1.34			5.00	1.12										
Brays Bayou at Main St.	94.9	6	7	5/26/86	AVE	6.3	231		1.84	2.12			3.97	1.41										
Brays Bayou at Main St.	94.9	7	7	6/9/86	AVE	1.2	193		1.18	1.94			3.12	0.90										
Brays Bayou at Main St.	94.9	8	2	7/8/77	FWA		121		0.62					0.28										
Brays Bayou at Main St.	94.9	9	2	7/28/77	FWA		64		0.44					0.16										
Brays Bayou at Main St.	94.9	10	2	8/77/77	FWA		15		0.07					0.11										
Brays Bayou at Main St.	94.9	11	2	9/6/77	FWA		214		0.66					0.53										
Brays Bayou at Main St.	94.9	12	2	11/1/77	FWA		153		1.08					0.63										
Brays Bayou at Main St.	94.9	13	2	11/8/77	FWA		222		1.10					0.47										
Brays Bayou at Main St.	94.9	14	2	11/21/77	FWA		266		1.38					1.02										
Brays Bayou at Main St.	94.9	15	2	12/13/77	FWA		493		1.92					0.68										
Brays Bayou at Main St.	94.9	16	2	1/11/78	FWA		814																	
Brays Bayou at Main St.	94.9	17	2	2/12/78	FWA		652		2.22					1.32										
Brays Bayou at Main St.	94.9	33	15	3/11/77	FWA	25.8	351		3.97	1.72			5.76	2.27										
Brays Bayou at Main St.	94.9	34	15	9/9/77	FWA	6.3	475		1.48	0.74			2.23	0.54			100.0	0.00	0.00	3.00	0.00	0.50	0.00	60.0
Brays Bayou at Main St.	94.9	35	15	1/8/79	FWA	8.9	820		2.06	0.58			2.68	0.61			50.0	2.00	0.00	3.00	0.00	0.10	0.00	5.0
Brays Bayou at Main St.	94.9	37	15	12/13/79	FWA	38.8	381		3.75	0.64			4.44	0.96			100.0	1.00	10.00	0.00	6.00	0.00	0.00	30.0
Brays Bayou at Main St.	94.9	38	15	9/2/81	FWA	3.2	369		1.45	0.23			1.68	0.44			50.7	1.00	0.00	3.90	2.90	0.11	0.10	13.9

Table III.1 - Event Mean Concentrations (EMCs)

B3. Medium Size Watershed (10-100 sq mi), >50% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3+NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Brays Bayou at Main St.	94.9	39	15	2/10/83	FWA	9.0	496		2.80	0.58			3.62	0.73			35.3	1.00	10.00	4.56	1.46	0.10	1.00	22.1
Brays Bayou at Main St.	94.9	40	15	9/21/83	FWA	3.4	234		1.44	0.12				0.39			18.0	1.00	10.00	1.00	1.00	0.10	1.00	4.0
Hunting Bayou at IH-10	23.1	1	7	8/20/85	AVE	10.0	504	0.36	3.38	1.65	0.38		5.03	1.24										
Hunting Bayou at IH-10	23.1	2	7	10/14/85	AVE	7.0	423	0.71	2.20	1.25	0.11		3.45	1.14										
Hunting Bayou at IH-10	23.1	3	7	10/28/85	AVE	4.0	502	0.67	1.80	0.90	0.35		2.70	0.88										
Little White Oak at Trimble	18	1	7	9/29/85	AVE	<3	164	0.27	3.80	4.31	0.03		8.11	0.56										
Little White Oak at Trimble	18	2	7	10/14/85	AVE	10.0	396	0.35	2. 0	0.57	0.17		2.57	0.76										
Little White Oak at Trimble	18	3	7	10/28/85	AVE	5.0	94	0.63	1.40	0.40	0.05		1.80	0.54										
Little White Oak at Trimble	18	54	15	8/31/78	FWA	58.1	161		8.81	0.69			9.69	2.45			100.0	0.00	0.00	2.00	8.00	0.10	0.00	20.0
Little White Oak at Trimble	18	55	15	8/16/79	FWA	37.1	52		2.22	0.75			2.94	0.47										
Little White Oak at Trimble	18	56	15	12/13/79	FWA																			
Little White Oak at Trimble	18	57	15	1/18/80	FWA																			
Little White Oak at Trimble	18	62	15	9/1/81	FWA	3.5	136		1.62	0.24			1.82	0.43										
Little White Oak at Trimble	18	63	15	5/7/82	FWA	16.6	190		2.86	0.35			3.22	0.65			55.2	3.00	10.00	4.00	9.04	0.10	1.00	18.5
Little White Oak at Trimble	18	64	15	6/23/82	FWA	26.4	365		2.62	0.51			3.12	0.53			150.9	1.00	10.00	4.48	3.95	0.10	1.00	15.1
Little White Oak at Trimble	18	65	15	6/15/83	FWA		273		3.66	0.71			4.36	0.69										
Little White Oak at Trimble	18	1	7	9/29/85	AVE	4.5	281		9.40	2.92			12.32	0.62										
Little White Oak at Trimble	18	2	7	3/12/86	AVE	15.5	136		2.29	0.46			2.74	0.71										
Little White Oak at Trimble	18	3	7	5/1/86	AVE	12.5	275		1.95	0.82			2.77	0.56										
Little White Oak at Trimble	18	4	7	5/25/86	AVE	10.3	156		2.73	0.55			3.27	0.41										
Little White Oak at Trimble	18	5	7	5/30/86	AVE	8.8	287		3.24	0.56			3.80	1.09										
Little White Oak at Trimble	18	6	7	6/9/86	AVE	1.9	453		1.37	0.69			2.07	0.56										
Little White Oak at Trimble	18	7	7	9/29/85	AVE	1.5	164		3.80	4.31			8.11	0.56										
Little White Oak at Trimble	18	8	7	10/14/85	AVE	10.0	396		2. 0	0.57			2.57	0.76										
Little White Oak at Trimble	18	9	7	10/28/85	AVE	5.0	94		1.40	0.40			1.80	0.54										
Berry Bayou at Forest Oaks St.	10.7	15	15	8/16/76	FWA	5.7	41		2.57	4.42			6.99	5.11		3								
Berry Bayou at Forest Oaks St.	10.7	16	15	4/21/77	FWA	13.0	712		2.41	0.38			2.83	0.59										
Berry Bayou at Forest Oaks St.	10.7	17	15	1/17/78	FWA	8.6	456		2.19	0.43			2.65	0.65			100.0	0.00	0.00	2.00	3.00	0.10	0.00	0.0
Berry Bayou at Forest Oaks St.	10.7	18	15	6/5/81	FWA	4.2	110		1.17	0.19			1.37	0.32			200.0	1.00	10.00	10.00	10.00	0.10	0.00	10.0
Brickhouse Gulley at Costa Rica St.	11.4	50	15	1/17/78	FWA	5.6	683		1.29	0.24			1.56	0.37										
Brickhouse Gulley at Costa Rica St.	11.4	51	15	5/31/78	FWA	27.5	973		2.32	0.85			3.21	0.63	5.32		300.0	1.96	0.36	4.00	3.96	0.10	0.00	20.0
Brickhouse Gulley at Costa Rica St.	11.4	52	15	10/31/79	FWA	21.1	301		1.80	0.40			2.20	0.53	3.01		60.0	1.00	0.00	0.00	6.00	0.00	0.00	10.0
Brickhouse Gulley at Costa Rica St.	11.4	53	15	8/9/82	FWA		182		2.88	0.83			3.70	0.51	7.93		140.7	1.00	10.00	2.00	1.00	0.10	1.00	13.3
Halls Bayou at Jensen Dr.	27.6	87	15	4/19/79	FWA	12.8	639		2.48	0.50			2.95	0.82	6.9		100.0	0.00	0.00	0.00	0.00	0.10	0.00	20.0
Halls Bayou at Jensen Dr.	27.6	88	15	7/8/79	FWA	18.9	180		4.49	0.27			4.75	2.43	8.83		105.6	1.11	0.00	2.00	2.00	0.10	0.00	3.9
Halls Bayou at Jensen Dr.	27.6	89	15	1/23/80	FWA	7.0	256		1.81	0.19			1.99	0.39	9.37		70.0	1.00	0.00	0.00	0.00	0.00	0.00	9.0

Table III.1 - Event Mean Concentrations (EMCs)

B3. Medium Size Watershed (10-100 sq mi), >50% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Halls Bayou at Jensen Dr.	27.6	91	15	9/2/81	FWA	5.7	216		1.76	0.27			2.03	0.63			49.0	1.00	0.00	2.00	2.00	0.10	0.00	3.0
Halls Bayou at Jensen Dr.	27.6	92	15	5/14/82	FWA	11.3	169		2.70	0.36			3.07	1.03			85.0	3.00	10.00	2.00	1.00	0.10	1.00	12.0
Halls Bayou at Jensen Dr.	27.6	94	15	6/23/82	FWA	20.7	25		10.35	0.49			11.19	3.19			220.2	1.00	10.00	3.46	2.36	0.10	1.00	10.0
Halls Bayou at Jensen Dr.	27.6	95	15	5/11/83	FWA	13.7	385		4.37	0.51			4.88	1.05			97.8	1.00	10.00	1.66	1.66	0.10	1.00	14.8
Hunting Bayou at IH-610	15.8	43	15	4/21/77	FWA	12.1	271		4.98	1.15			6.15	1.04										
Hunting Bayou at IH-610	15.8	44	15	1/27/79	FWA	31.4	144		3.11	0.99			4.10	1.22			100.0	0.00	0.00	5.00	2.00	0.10	0.00	40.0
Hunting Bayou at IH-610	15.8	45	15	8/23/79	FWA	11.8	406		2.28	0.36			2.63	0.99										
Hunting Bayou at IH-610	15.8	46	15	4/27/80	FWA	15.7	265		3.64	1.09			4.73	1.08										
Hunting Bayou at IH-610	15.8	47	15	7/9/81	FWA	6.5	77		2.02	0.69			2.70	0.81			83.8	1.00	10.51	10.00	10.00	0.19	0.54	37.7
Hunting Bayou at IH-610	15.8	48	15	5/13/82	FWA	13.2	323		1.81	0.53			2.37	0.78			37.0	3.00	10.00	3.00	4.00	0.10	1.00	12.0
Hunting Bayou at IH-10	22.7	1	7	2/5/86	AVE	9.2	826		2.27	0.59			2.86	1.33										
Hunting Bayou at IH-10	22.7	2	7	5/2/86	AVE	13.5	977		2.97	1.93			4.90	0.72										
Hunting Bayou at IH-10	22.7	3	7	5/30/86	AVE	7.0	1557		5.83	1.37			7.19	1.26										
Hunting Bayou at IH-10	22.7	4	7	8/20/85	AVE	10.0	504		3.38	1.65			5.03	1.24										
Hunting Bayou at IH-10	22.7	5	7	10/14/85	AVE	7.0	423		2.20	1.25			3.45	1.14										
Hunting Bayou at IH-10	22.7	6	7	10/28/85	AVE	4.0	502		1.80	0.90			2.70	0.88										
Median						8.6	260	0.65	2.22	0.74	0.15		3.27	0.81		3.93	85.0	1.00	10.00	3.00	2.36	0.10	0.10	13.3
Average						11.0	322	0.62	2.63	1.16	0.26		4.02	1.01		3.93	94.6	1.11	5.77	3.21	3.70	0.11	0.49	16.5
Standard deviation						9.5	253	0.34	1.90	1.08	0.25		2.18	0.73		1.03	63.6	0.85	5.32	2.61	3.40	0.09	0.52	13.2
Coefficient of variation						0.9	1						0.54	0.72		0.26	0.7	0.76	0.92	0.81	0.92	0.81	1.08	0.8
Number of data points						73	86	10	85	76	10		75	85		2	27	27	27	27	27	27	27	27

References:

2. Bedient, et al. Stormwater Pollutant Load-Runoff Realtionships, JWPCF, 52:9 (September 1980).
7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.
15. USGS Database.

Note:

Underlined values represent values calculated for GBNEP Project.

FWA = Flow weighted average.

AVE = Average of all discrete samples.

Table III.1 - Event Mean Concentrations (EMCs)

C1. Large Size Watershed (>100 sq mi), <10% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Cypress Creek at IH-45	323	1	13	10/10/84	GM											4.54								
Cypress Creek at IH-45	323	2	13	3/16/85	GM											3.49								
Cypress Creek at IH-45	323	3	13	6/19/85	GM											4.02								
Spring Creek at IH-45	446	1	13	10/10/84	GM											3.54								
Spring Creek at IH-45	446	2	13	3/16/85	GM											2.74								
Spring Creek at IH-45	446	3	13	6/19/85	GM											3.54								
West Fork San Jacinto at IH-45	956	1	13	10/10/84	GM											4.62								
West Fork San Jacinto at IH-45	956	2	13	3/16/85	GM											2.64								
West Fork San Jacinto at IH-45	956	3	13	6/19/85	GM											3.37								
Median																3.54								
Average																3.61								
Standard deviation																0.69								
Coefficient of variation																0.19								
Number of data points																9								

Reference:

13. Symons, Linkages Between Wastewater Treatment Plant Discharges, Lake Houston Water Quality, and Potable Water Supply During Storm Events, 1986.

Note:

GM = Geometric mean.

Table III.1 - Event Mean Concentrations (EMCs)

C2. Large Size Watershed (10-100 sq mi), 10-50% developed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program, Houston, Texas

Subcategory	Area sq mi	Storm No.	Ref	Date	Type of Sample	BOD5 mg/L	TSS mg/L	NH3 mg/L	TKN mg/L	NO3 + NO2 mg/L	NO2 mg/L	NO3 mg/L	TN mg/L	TP mg/L	O&G mg/L	FC log no/ 100 ml	Ba µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Pb µg/L	Hg µg/L	Ag µg/L	Zn µg/L
Buffalo Bayou at 69th St	NA	1	15	12/3/71	FWA	38.6	370							3.52		4.81		0.00	0.00	6.05	1.99	0.22		101.0
Buffalo Bayou at Shepherd	358	1	7	9/29/85	AVE	1.5	112		6.20	3.96			10.16	1.02										
Buffalo Bayou at Shepherd	358	2	7	10/28/85	AVE	4.0	148	0.28	1.50	0.97	0.41		2.47	0.86										
Buffalo Bayou at Shepherd	358	3	7	12/11/85	AVE	5.0	168	0.33	1.27	0.08	ND		1.35	1.89										
Buffalo Bayou at Shepherd	358	4	7	10/28/85	AVE	2.8	128		1.60	0.85			2.45	0.99										
Buffalo Bayou at Shepherd	358	5	7	12/11/85	AVE	3.5	150		1.82	0.07			1.89	0.75										
Buffalo Bayou at Shepherd	358	6	7	2/5/86	AVE	9.8	261		2.78	1.17			3.96	1.61										
Buffalo Bayou at Shepherd	358	7	7	5/25/86	AVE	2.8	58		4.78	5.59			10.36	2.11										
Buffalo Bayou at Shepherd	358	8	7	6/9/86	AVE	6.0	297		1.73	1.35			3.08	0.86										
Buffalo Bayou at Shepherd	358	32	15	9/9/77	FWA	7.4	347		1.55	0.90			2.46	0.55			100.0	0.00	0.00	2.00	0.00	0.50	0.00	20.0
Greens Bayou at Ley Rd.	182	1	15	9/22/76	FWA	6.3	788		1.24	0.18			1.41	0.51		4.92								
Greens Bayou at Ley Rd.	182	2	15	12/14/77	FWA	23.7	1574		2.65	0.53			3.19	0.78										
Greens Bayou at Ley Rd.	182	3	15	6/9/78	FWA	11.3	936		2.05	0.17			2.26	0.35										
Greens Bayou at Ley Rd.	182	4	15	1/22/80	FWA	7.8	546		1.60	0.18			1.80	0.28			80.0	1.00	0.00	2.00	0.00	0.10	0.00	3.0
Greens Bayou at Ley Rd.	182	5	15	2/5/86	FWA	7.5	733		1.99	0.46			2.45	1.01										
Greens Bayou at Ley Rd.	182	6	15	5/2/86	FWA	14.7	764		5.15	2.16			7.31	1.39										
Greens Bayou at Ley Rd.	182	7	15	5/31/86	FWA	5.8	864		3.15	1.12			4.26	2.54										
Greens Bayou at Ley Rd.	182	8	15	6/5/86	FWA	1.5	736		2.64	1.73			4.38	1.29										
Greens Bayou at Ley Rd.	182	9	15	6/10/86	FWA	3.0	391		1.74	0.49			2.23	1.84										
Greens Bayou at Ley Rd.	182	10	7	8/20/85	AVE	12.0	592	0.27	3.81	1.42	0.45		5.23	1.50										
Greens Bayou at Ley Rd.	182	11	7	10/28/85	AVE	4.0	692	0.31	2.30	1.04	0.58		3.34	1.54										
Median						6.0	391	0.30	2.02	0.94	0.45		2.78	1.02		4.87	90.0	0.00	0.00	2.00	0.00	0.22		20.0
Average						8.5	507	0.30	2.58	1.22	0.48		3.80	1.29		4.87	90.0	0.33		3.35	0.66	0.27		41.3
Standard deviation						8.6	373	0.03	1.39	1.37	0.09		2.63	0.78			14.1			2.34		0.21		52.4
Coefficient of variation						1.0	1	0.09	0.54	1.12	0.19		0.69	0.61			0.2			0.70		0.75		1.3
Number of data points						21	21	4	20	20	3		20	21		2	2	3	3	3	3	3	2	3

References:

7. Winslow, et al. Relative Significance of Waste Loads Entering the Houston Ship Channel, Sept. 1986.

15. USGS Database.

Note:

Underlined values represent values calculated for GBNEP Project.

FWA = Flow weighted average.

AVE = Average of all discrete samples.

Table III.2 - Land Use by Subwatershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	Land Use: High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
Austin/Bastrop Bayous	AB01	sq mi	2.46	4.35	55.23	21.14	1.15	13.36	1.54	0.25	99.49
		%	2.48	4.37	55.51	21.25	1.16	13.43	1.55	0.26	100.00
	AB02	sq mi	1.87	1.16	4.70	11.04	0.16	2.72	0.07	0.14	21.86
		%	8.54	5.32	21.50	50.51	0.75	12.42	0.34	0.63	100.00
	AB03	sq mi	2.08	7.51	28.35	25.75	1.27	26.07	0.60	0.21	91.83
		%	2.26	8.17	30.87	28.04	1.38	28.39	0.65	0.23	100.00
Addicks Reservoir	AD01	sq mi	10.66	3.11	61.70	25.23	0.02	5.05	0.46	2.40	108.62
		%	9.81	2.86	56.80	23.23	0.02	4.65	0.42	2.21	100.00
	AD02	sq mi	2.30	6.34	4.68	7.20	0.65	4.57	0.01	0.43	26.18
		%	8.77	24.23	17.90	27.49	2.50	17.44	0.02	1.65	100.00
Armand/Taylor Bayous	AT01	sq mi	4.29	1.38	2.18	8.15	0.03	1.43	0.00	0.04	17.50
		%	24.52	7.90	12.45	46.57	0.16	8.16	0.02	0.22	100.00
	AT02	sq mi	4.49	1.61	3.61	6.54	0.12	1.42	0.00	0.26	18.05
		%	24.88	8.91	19.99	36.23	0.66	7.89	0.01	1.44	100.00
	AT03	sq mi	3.13	3.77	2.87	8.89	1.94	4.38	0.59	0.08	25.65
		%	12.20	14.71	11.17	34.67	7.58	17.07	2.29	0.32	100.00
	AT04	sq mi	2.88	3.51	1.44	4.02	0.88	2.20	0.58	0.03	15.54
		%	18.51	22.58	9.29	25.86	5.68	14.15	3.71	0.22	100.00
Buffalo Bayou	BF01	sq mi	11.17	6.44	11.96	8.29	0.06	1.93	0.02	0.27	40.13
		%	27.82	16.06	29.80	20.65	0.15	4.81	0.05	0.67	100.00
	BF02	sq mi	9.48	14.48	0.96	3.35	0.51	0.59	0.00	0.06	29.43
		%	32.22	49.19	3.25	11.37	1.74	2.02	0.01	0.21	100.00
	BF03	sq mi	5.65	7.27	0.59	1.85	0.68	0.47	0.00	0.05	16.57
		%	34.08	43.89	3.56	11.17	4.09	2.87	0.02	0.33	100.00
	BF04	sq mi	5.11	1.84	0.15	0.62	0.00	0.30	0.01	0.01	8.05
		%	63.52	22.82	1.84	7.75	0.01	3.75	0.16	0.16	100.00
	BF05	sq mi	7.10	2.33	0.29	0.66	0.00	0.32	0.00	0.03	10.72
		%	66.20	21.71	2.73	6.14	0.00	2.94	0.04	0.24	100.00
Barker Reservoir	BK01	sq mi	6.59	2.89	55.11	19.70	0.21	6.52	0.07	7.98	99.07
		%	6.65	2.92	55.63	19.89	0.21	6.58	0.07	8.06	100.00
	BK02	sq mi	0.98	1.23	12.07	4.34	0.22	6.62	0.03	0.52	26.02
		%	3.75	4.75	46.39	16.70	0.83	25.45	0.12	2.01	100.00

Table III.2 - Land Use by Subwatershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	Land Use								
			High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
Brays Bayou	BR01	sq mi	11.88	2.12	7.59	6.48	0.03	1.77	0.00	0.34	30.20
		%	39.33	7.01	25.14	21.44	0.09	5.86	0.00	1.12	100.00
	BR02	sq mi	4.87	0.81	3.37	2.56	0.00	0.76	0.00	0.10	12.46
		%	39.04	6.53	27.00	20.51	0.03	6.11	0.00	0.78	100.00
	BR03	sq mi	10.81	4.49	1.46	4.93	0.01	0.26	0.00	0.24	22.21
		%	48.68	20.20	6.59	22.21	0.04	1.19	0.00	1.08	100.00
	BR04	sq mi	9.42	9.96	2.51	6.93	0.04	0.86	0.00	0.17	29.89
		%	31.51	33.33	8.40	23.18	0.13	2.89	0.00	0.57	100.00
	BR05	sq mi	8.01	4.38	0.53	2.69	0.04	0.34	0.00	0.04	16.02
		%	50.00	27.32	3.28	16.79	0.23	2.13	0.02	0.23	100.00
	BR06	sq mi	3.91	3.31	0.32	1.44	0.03	0.19	0.00	0.01	9.20
		%	42.45	35.93	3.48	15.62	0.32	2.09	0.00	0.10	100.00
	BR07	sq mi	3.71	2.16	0.18	1.05	0.01	0.25	0.00	0.02	7.37
		%	50.31	29.37	2.41	14.19	0.13	3.36	0.02	0.22	100.00
Clear Creek	CC01	sq mi	1.39	1.04	15.19	10.25	0.69	6.85	0.04	0.30	35.75
		%	3.89	2.91	42.48	28.66	1.94	19.17	0.12	0.83	100.00
	CC02	sq mi	5.75	5.39	21.90	30.29	0.70	12.70	0.06	0.21	76.99
		%	7.46	7.00	28.45	39.34	0.90	16.50	0.07	0.27	100.00
	CC03	sq mi	4.70	2.02	1.91	7.78	0.12	1.57	0.06	0.03	18.19
		%	25.86	11.11	10.49	42.77	0.65	8.65	0.32	0.16	100.00
	CC04	sq mi	5.85	5.17	3.78	12.51	1.05	4.84	0.27	0.04	33.52
		%	17.47	15.44	11.29	37.32	3.14	14.43	0.80	0.11	100.00
	CC05	sq mi	2.74	1.59	1.54	6.58	0.32	2.26	2.32	0.02	17.38
		%	15.78	9.15	8.84	37.87	1.84	13.02	13.36	0.14	100.00
Cedar Bayou	CE01	sq mi	0.64	1.96	41.26	9.84	3.94	8.17	0.19	0.13	66.12
		%	0.96	2.96	62.41	14.88	5.96	12.35	0.29	0.20	100.00
	CE02	sq mi	3.36	6.21	32.48	26.44	14.23	15.24	0.53	0.34	98.82
		%	3.40	6.28	32.87	26.75	14.40	15.43	0.53	0.34	100.00
	CE03	sq mi	3.15	6.09	4.44	10.83	4.00	4.66	0.14	0.03	33.33
		%	9.44	18.26	13.33	32.48	11.99	13.99	0.43	0.08	100.00
	CE04	sq mi	0.83	3.70	1.91	2.41	1.45	2.64	0.16	0.00	13.11
		%	6.33	28.25	14.56	18.42	11.07	20.14	1.20	0.02	100.00

Table III.2 - Land Use by Subwatershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	Land Use								
			High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
Chocolate Bayou	CH01	sq mi	0.94	1.49	62.83	9.00	1.38	11.49	0.05	0.45	87.63
		%	1.07	1.70	71.70	10.27	1.57	13.11	0.06	0.52	100.00
	CH02	sq mi	0.44	0.50	8.09	6.71	0.33	3.32	0.00	0.05	19.44
		%	2.29	2.57	41.63	34.49	1.71	17.05	0.00	0.27	100.00
	CH03	sq mi	2.30	3.87	24.21	16.75	3.34	11.47	0.71	0.16	62.81
		%	3.66	6.16	38.55	26.67	5.32	18.25	1.13	0.25	100.00
Dickinson Bayou	DB01	sq mi	2.41	4.60	14.16	26.97	0.57	10.19	0.02	0.06	59.00
		%	4.09	7.80	24.01	45.72	0.97	17.28	0.04	0.10	100.00
	DB02	sq mi	2.36	3.99	3.87	13.97	0.79	5.28	0.16	0.01	30.44
		%	7.75	13.11	12.73	45.89	2.60	17.36	0.51	0.04	100.00
	DB03	sq mi	0.62	0.44	2.04	4.35	0.06	3.47	0.54	0.01	11.54
		%	5.42	3.82	17.65	37.73	0.49	30.10	4.71	0.09	100.00
East Bay	EB01	sq mi	0.82	3.86	20.51	13.69	2.35	17.78	0.50	0.01	59.53
		%	1.38	6.48	34.45	23.00	3.95	39.87	0.84	0.02	100.00
	EB02	sq mi	1.77	9.85	42.41	24.83	4.11	41.16	0.60	0.00	124.74
		%	1.42	7.90	34.00	19.91	3.30	33.00	0.48	0.00	100.00
	EB03	sq mi	1.35	8.78	6.98	22.79	1.74	16.26	2.29	0.00	60.20
		%	2.24	14.59	11.59	37.86	2.89	27.01	3.81	0.01	100.00
	EB04	sq mi	5.92	5.86	3.51	11.07	0.25	14.20	2.22	0.03	43.07
		%	13.75	13.61	8.15	25.71	0.57	32.97	5.16	0.08	100.00
Greens Bayou	GR01	sq mi	8.92	7.18	3.85	13.15	1.98	2.82	0.00	0.22	38.12
		%	23.40	18.82	10.10	34.50	5.19	7.40	0.00	0.58	100.00
	GR02	sq mi	7.41	6.58	3.95	9.64	2.53	2.50	0.00	0.33	32.94
		%	22.49	19.97	12.00	29.28	7.68	7.58	0.01	0.99	100.00
	GR03	sq mi	5.55	7.00	1.63	10.27	0.73	1.52	0.00	0.11	26.81
		%	20.72	26.10	6.07	38.30	2.71	5.68	0.00	0.41	100.00
	GR04	sq mi	3.50	5.61	3.81	5.36	8.69	2.17	0.00	0.27	29.40
		%	11.89	19.09	12.95	18.23	29.55	7.37	0.00	0.93	100.00
	GR05	sq mi	1.95	6.05	1.99	4.54	7.66	1.94	0.03	0.05	24.21
		%	8.07	25.00	8.24	18.75	31.64	7.99	0.12	0.19	100.00
	GR06	sq mi	3.80	11.46	1.12	5.52	7.53	1.89	0.00	0.06	31.39
		%	12.12	36.49	3.58	17.58	23.99	6.02	0.01	0.21	100.00
	GR07	sq mi	6.02	8.18	1.84	5.45	2.34	1.58	0.03	0.15	25.58
		%	23.53	31.95	7.19	21.30	9.14	6.18	0.12	0.58	100.00

Table III.2 - Land Use by Subwatershed

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	Land Use								
			High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
North Bay	NB01	sq mi	6.28	4.78	1.34	9.27	0.58	2.30	0.22	0.05	24.82
		%	25.30	19.26	5.39	37.36	2.34	9.25	0.88	0.22	100.00
South Bay	SB01	sq mi	3.76	1.25	0.72	3.90	0.00	3.43	0.30	0.02	13.38
		%	28.09	9.31	5.40	29.15	0.02	25.60	2.27	0.15	100.00
	SB02	sq mi	7.95	0.78	1.41	0.94	0.00	1.32	0.08	0.02	12.51
		%	63.57	6.27	11.27	7.52	0.00	10.57	0.62	0.17	100.00
	SB03	sq mi	11.05	1.99	1.93	7.67	0.01	3.53	3.04	0.14	29.35
		%	37.64	6.79	6.56	26.13	0.03	12.01	10.37	0.47	100.00
	SB04	sq mi	1.96	1.97	3.11	9.18	0.10	3.50	2.46	0.02	22.30
		%	8.79	8.84	13.96	41.15	0.44	15.68	11.04	0.10	100.00
Ship Channel	SC01	sq mi	8.50	5.07	0.96	3.25	0.05	0.58	0.00	0.02	18.43
		%	46.14	27.48	5.23	17.63	0.27	3.14	0.00	0.11	100.00
	SC02	sq mi	8.21	4.97	1.07	4.53	0.24	1.38	0.36	0.05	20.82
		%	39.46	23.88	5.12	21.77	1.16	6.64	1.71	0.25	100.00
	SC03	sq mi	3.17	2.23	0.51	2.32	0.00	0.21	0.00	0.01	8.45
		%	37.51	26.38	6.07	27.46	0.02	2.47	0.00	0.07	100.00
	SC04	sq mi	8.46	2.92	1.38	2.74	0.02	1.13	0.55	0.12	17.32
		%	48.84	16.85	7.97	15.84	0.11	6.54	3.17	0.67	100.00
	SC05	sq mi	5.21	5.83	3.54	6.73	2.04	1.74	0.03	0.20	25.33
		%	20.55	23.02	13.97	26.58	8.06	6.88	0.13	0.80	100.00
	SC06	sq mi	8.83	2.87	2.66	5.66	0.19	1.61	1.22	0.14	23.18
		%	38.10	12.36	11.49	24.43	0.82	6.93	5.24	0.61	100.00
	SC07	sq mi	4.25	1.45	1.41	3.77	0.11	2.19	0.91	0.10	14.20
		%	29.95	10.24	9.91	26.55	0.78	15.46	6.43	0.68	100.00
	SC08	sq mi	3.11	3.18	2.36	7.85	0.71	2.63	0.30	0.03	20.16
		%	15.42	15.75	11.69	38.91	3.52	13.03	1.51	0.17	100.00
	SC09	sq mi	6.56	2.90	1.16	5.44	0.30	1.20	0.82	0.11	18.48
		%	35.52	15.68	6.28	29.45	1.60	6.47	4.42	0.57	100.00
San Jacinto River	SJ02	sq mi	5.38	11.12	7.92	16.66	14.84	7.72	4.25	0.40	68.29
		%	7.88	16.29	11.59	24.39	21.73	11.30	6.22	0.59	100.00

Table III.2 - Land Use by Subwatershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	Land Use								
			High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
Sims Bayou	SM01	sq mi	4.15	1.69	3.81	9.63	0.14	1.66	0.03	0.12	21.23
		%	19.53	7.95	17.93	45.36	0.68	7.83	0.15	0.57	100.00
	SM02	sq mi	2.36	1.65	2.52	7.59	0.29	3.16	0.01	0.11	17.69
		%	13.34	9.32	14.25	42.89	1.65	17.88	0.06	0.60	100.00
	SM03	sq mi	5.03	5.27	2.86	9.76	0.25	2.37	0.00	0.06	25.60
		%	19.65	20.58	11.18	38.12	0.98	9.27	0.00	0.22	100.00
	SM04	sq mi	7.29	4.73	1.54	3.82	0.05	0.59	0.00	0.15	18.17
		%	40.10	26.05	8.46	21.03	0.28	3.23	0.02	0.82	100.00
	SM05	sq mi	3.88	2.02	0.55	3.66	0.01	0.16	0.00	0.02	10.30
		%	37.66	19.63	5.34	35.54	0.06	1.58	0.00	0.19	100.00
Trinity Bay	TB01	sq mi	0.81	3.22	34.75	20.28	42.76	22.17	0.37	0.17	124.53
		%	0.65	2.59	27.91	16.29	34.33	17.80	0.29	0.14	100.00
	TB02	sq mi	1.57	2.60	18.70	15.92	7.87	12.30	0.85	0.02	59.82
		%	2.62	4.34	31.26	26.61	13.16	20.57	1.42	0.03	100.00
	TB03	sq mi	1.75	4.40	16.65	20.25	8.09	21.54	7.65	0.01	80.34
		%	2.18	5.48	20.72	25.20	10.06	26.81	9.52	0.02	100.00
	TB04	sq mi	1.88	8.51	8.81	12.70	3.26	11.26	5.53	0.03	51.99
		%	3.62	16.37	16.94	24.42	6.28	21.66	10.64	0.06	100.00
Trinity River	TR02	sq mi	0.62	1.62	21.17	11.89	90.20	15.50	0.01	0.14	14.16
		%	0.44	1.15	15.00	8.42	63.90	10.98	0.01	0.10	100.00
	TR03	sq mi	0.85	1.85	11.25	6.94	33.36	9.45	0.17	0.12	64.00
		%	1.33	2.89	17.58	10.85	52.13	14.76	0.27	0.19	100.00
	TR04	sq mi	0.48	1.64	11.78	7.66	33.46	9.45	0.17	0.26	64.90
		%	0.74	2.52	18.15	11.81	51.56	14.56	0.27	0.40	100.00
	TR05	sq mi	0.20	1.34	5.24	1.92	29.24	2.78	0.03	0.22	40.96
		%	0.49	3.26	12.79	4.69	71.38	6.79	0.07	0.54	100.00
	TR06	sq mi	0.32	0.69	12.43	4.94	91.27	10.73	0.01	0.11	120.51
		%	0.27	0.57	10.32	4.10	75.74	8.90	0.01	0.09	100.00
	TR07	sq mi	1.34	2.44	15.86	20.54	94.80	21.40	0.88	0.16	157.42
		%	0.85	1.55	10.07	13.05	60.22	13.59	0.56	0.00	100.00
	TR08	sq mi	1.67	1.61	10.97	10.68	72.62	17.10	0.42	0.36	115.43
		%	1.44	1.40	9.51	9.25	62.92	14.82	0.36	0.31	100.00

Table III.2 - Land Use by Subwatershed
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
Trinity River	TR09	sq mi	0.67	1.19	5.49	11.45	50.09	12.11	0.15	0.13	81.28
		%	0.82	1.47	6.75	14.08	61.63	14.90	0.18	0.17	100.00
	TR10	sq mi	0.82	1.54	5.83	11.02	45.02	14.22	0.18	0.17	78.80
		%	1.04	1.95	7.40	13.98	57.13	18.05	0.23	0.22	100.00
	TR11	sq mi	0.79	1.05	2.30	5.76	11.65	4.52	0.07	0.08	26.21
		%	3.00	3.99	8.76	21.97	44.45	17.24	0.27	0.32	100.00
	TR12	sq mi	0.57	1.67	11.85	9.87	9.68	4.65	0.01	0.12	38.42
		%	1.49	4.34	30.85	25.68	25.20	12.11	0.02	0.31	100.00
	TR13	sq mi	1.44	6.90	22.49	22.76	47.79	20.13	0.42	0.16	122.09
		%	1.18	5.65	18.43	18.65	39.14	16.49	0.34	0.13	100.00
	TR14	sq mi	1.29	10.97	15.07	14.13	33.79	15.66	5.00	0.00	95.93
		%	1.34	11.44	15.72	14.73	35.22	16.33	5.21	0.01	100.00
West Bay	WB01	sq mi	0.76	0.99	7.26	13.23	0.42	4.86	0.03	0.15	27.70
		%	2.75	3.58	26.21	47.76	1.50	17.56	0.10	0.54	100.00
	WB02	sq mi	1.35	1.35	1.29	4.90	0.06	0.86	0.02	0.03	9.85
		%	13.75	13.67	13.10	49.72	0.61	8.72	0.17	0.25	100.00
	WB03	sq mi	8.33	7.27	35.26	24.28	0.42	42.16	4.94	0.24	122.79
		%	6.78	5.92	28.72	19.77	0.34	34.33	4.02	0.12	100.00
	WB04	sq mi	5.53	6.42	27.70	33.40	0.90	33.11	3.28	0.04	110.38
		%	5.01	5.82	25.09	30.26	0.82	29.99	2.97	0.04	100.00
	WB05	sq mi	4.86	4.24	4.21	20.60	0.37	7.12	1.85	0.06	43.31
		%	11.22	9.80	9.72	47.56	0.85	16.45	4.26	0.14	100.00
	WB06	sq mi	5.22	0.70	0.65	1.53	0.00	0.70	0.25	0.11	9.16
		%	57.01	7.60	7.10	16.73	0.00	7.64	2.73	1.18	100.00
	WB07	sq mi	3.47	1.30	2.50	7.12	0.00	5.17	0.77	0.02	20.35
		%	17.06	6.37	12.30	34.98	0.00	.25.40	3.80	0.08	100.00

Table III.2 - Land Use by Subwatershed

Non-Point Source Characterization Project

Galveston Bay National Estuary Program

Watershed	Subwatershed	Area or Percent	Land Use								
			High Density Urban	Residential	Agricultural	Open/Pasture	Forest	Wetlands	Water	Barren	Total
White Oak Bayou	WO01	sq mi	11.82	8.55	6.30	14.41	0.08	2.37	0.01	0.43	43.98
		%	26.88	19.45	14.34	32.77	0.19	5.39	0.02	0.97	100.00
	WO02	sq mi	5.17	2.56	1.05	2.49	0.00	0.03	0.00	0.05	11.35
		%	45.51	22.59	9.25	21.90	0.01	0.30	0.00	0.44	100.00
	WO03	sq mi	8.95	8.45	1.71	3.97	0.00	0.35	0.00	0.22	23.66
		%	37.83	35.72	7.24	16.77	0.02	1.47	0.00	0.93	100.00
	WO04	sq mi	7.79	9.05	0.54	3.36	0.03	0.45	0.00	0.03	21.25
		%	36.65	42.60	2.55	15.83	0.13	2.11	0.00	0.14	100.00
	WO05	sq mi	5.08	3.67	0.39	0.73	0.00	0.18	0.00	0.04	10.09
		%	550.34	36.36	3.89	7.25	0.01	1.79	0.00	0.36	100.00

Table III.3 - Subwatershed Load Data
Case 1 - Average Annual Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads									
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Addicks Reservoir	AD01	66	18	151	27	0.5	0.3	7	252.1	15.2
	AD02	16	3	44	8	0.2	0.1	3	60.4	5.0
	Total	82	22	195	36	0.7	0.4	9	312.5	20.2
Armand & Taylor Bayous	AT01	17	3	40	7	0.2	0.1	3	63.5	5.5
	AT02	17	4	43	7	0.2	0.1	3	66.6	5.9
	AT03	21	3	47	8	0.2	0.1	3	73.8	5.8
	AT04	15	2	36	7	0.2	0.1	3	51.6	4.9
	Total	70	12	167	29	0.7	0.5	11	255.5	22.0
Austin & Bastrop Bayous	AB01	59	11	114	22	0.4	0.1	4	210.6	9.3
	AB02	14	2	30	5	0.1	0.1	1	52.6	3.2
	AB03	48	8	101	18	0.4	0.1	4	178.8	8.7
	Total	121	21	245	44	0.9	0.2	9	442.1	21.2
Barker Reservoir	BK01	59	29	153	26	0.5	0.2	5	223.2	11.8
	BK02	13	3	28	5	0.1	0.0	1	48.0	2.3
	Total	71	32	181	31	0.6	0.2	6	271.3	14.1
Brays Bayou	BR01	28	6	72	13	0.3	0.3	6	108.2	11.1
	BR02	12	2	29	5	0.1	0.1	2	44.4	4.5
	BR03	29	6	80	15	0.3	0.4	7	111.1	12.7
	BR04	34	6	100	19	0.4	0.3	8	130.3	14.4
	BR05	22	4	62	12	0.3	0.3	5	83.2	9.9
	BR06	12	2	35	7	0.1	0.1	3	45.3	5.4
	BR07	10	2	29	5	0.1	0.1	3	38.4	4.6
	Total	147	29	406	75	1.6	1.7	34	560.9	62.7
Buffalo Bayou	BF01	34	7	88	16	0.3	0.3	7	128.0	12.5
	BF02	35	6	110	22	0.5	0.4	9	132.9	15.9
	BF03	20	3	60	12	0.3	0.2	5	74.9	8.9
	BF04	12	2	33	6	0.1	0.2	3	45.9	5.7
	BF05	17	3	46	9	0.2	0.2	4	63.4	7.9
	Total	116	22	337	65	1.4	1.3	27	445.0	50.9

Table III.3 - Subwatershed Load Data
Case 1 - Average Annual Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Cedar Bayou	CE01	46	9	89	18	0.3	0.0	2	174.2	6.5
	CE02	71	11	141	24	0.5	0.1	5	264.4	12.8
	CE03	26	4	65	11	0.3	0.1	4	99.7	7.6
	CE04	10	1	27	5	0.1	0.0	2	37.5	3.1
	Total	153	26	321	58	1.2	0.3	13	575.9	30.0
Chocolate Bayou	CH01	48	11	94	19	0.3	0.0	2	182.2	6.6
	CH02	10	2	21	3	0.1	0.0	1	40.0	1.6
	CH03	36	6	73	13	0.3	0.1	3	132.3	6.6
	Total	95	19	188	36	0.6	0.1	5	354.5	14.9
Clear Creek	CC01	23	5	47	8	0.2	0.0	2	87.5	3.9
	CC02	54	9	119	20	0.5	0.2	6	206.7	12.2
	CC03	18	3	44	7	0.2	0.2	3	67.5	6.2
	CC04	26	4	63	11	0.3	0.2	4	96.1	8.3
	CC05	18	2	28	5	0.1	0.1	2	45.0	3.6
	Total	138	22	301	51	1.2	0.7	16	502.7	34.3
Dickinson Bayou	DB01	34	5	73	12	0.3	0.1	3	128.2	6.8
	DB02	19	3	45	7	0.2	0.1	2	72.1	4.9
	DB03	7	1	12	2	0.0	0.0	1	22.3	1.2
	Total	60	8	130	21	0.5	0.2	6	222.6	12.9
East Bay	EB01	37	5	71	13	0.3	0.0	2	135.1	5.7
	EB02	75	11	152	28	0.6	0.1	5	281.6	12.5
	EB03	43	4	87	14	0.4	0.1	4	141.5	8.2
	EB04	38	5	78	14	0.3	0.2	5	121.0	9.9
	Total	193	26	388	68	1.6	0.5	17	679.3	36.2

Table III.3 - Subwatershed Load Data
Case 1 - Average Annual Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Loads										
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Greens Bayou	GR01	35	6	92	16	0.4	0.3	7	134.6	12.8
	GR02	29	5	76	14	0.3	0.2	5	109.1	10.4
	GR03	25	4	70	13	0.3	0.2	5	97.2	9.4
	GR04	21	4	51	9	0.2	0.1	3	78.7	6.5
	GR05	16	2	42	8	0.2	0.1	3	62.7	5.2
	GR06	29	4	85	17	0.4	0.2	6	112.5	10.8
	GR07	28	5	80	15	0.3	0.2	6	106.9	11.1
	Total	184	30	497	92	2.1	1.4	34	701.6	66.1
North Bay	NB01	25	4	65	11	0.3	0.2	5	93.6	9.1
	Total	25	4	65	11	0.3	0.2	5	93.6	9.1
San Jacinto River	SJ02	65	8	126	22	0.5	0.2	7	201.6	14.4
	Total	65	8	126	22	0.5	0.2	7	201.6	14.4
Ship Channel	SC01	24	4	67	13	0.3	0.3	6	90.7	10.6
	SC02	26	4	68	13	0.3	0.3	6	94.5	10.6
	SC03	10	2	28	5	0.1	0.1	2	38.6	4.3
	SC04	24	4	60	11	0.2	0.3	5	85.9	9.8
	SC05	26	5	70	13	0.3	0.2	5	99.3	9.3
	SC06	30	5	67	12	0.3	0.3	6	100.4	10.4
	SC07	16	3	35	6	0.1	0.1	3	52.6	5.1
	SC08	19	3	45	8	0.2	0.1	3	68.6	5.6
	SC09	24	4	57	10	0.2	0.2	5	82.7	8.7
	Total	198	34	498	90	2.0	1.9	39	713.3	74.3
Sims Bayou	SM01	19	3	45	7	0.2	0.1	3	72.1	5.8
	SM02	14	2	32	5	0.1	0.1	2	52.5	3.8
	SM03	24	4	62	11	0.3	0.2	4	90.3	8.3
	SM04	22	4	63	12	0.3	0.2	5	85.3	9.6
	SM05	12	2	33	6	0.1	0.1	3	46.4	5.0
	Total	91	16	235	41	1.0	0.8	17	346.5	32.5

Table III.3 - Subwatershed Load Data
Case 1 - Average Annual Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
South Bay	SB01	10	2	22	4	0.1	0.1	2	34.3	3.4
	SB02	14	3	35	6	0.1	0.2	3	51.9	6.2
	SB03	29	4	57	10	0.2	0.3	5	86.0	9.3
	SB04	16	2	24	4	0.1	0.1	1	38.7	2.7
	Total	68	10	138	24	0.6	0.6	11	211.0	21.6
Trinity Bay	TB01	74	10	121	19	0.5	0.0	3	277.9	9.9
	TB02	40	6	72	12	0.3	0.1	2	142.1	6.2
	TB03	65	6	86	14	0.4	0.1	3	166.8	7.5
	TB04	47	4	78	14	0.3	0.1	4	121.7	8.0
	Total	225	26	356	59	1.5	0.3	12	708.5	31.6
Trinity River	TR02	64	7	90	12	0.5	0.0	2	245.5	8.2
	TR03	25	3	43	7	0.2	0.0	1	96.1	4.0
	TR04	26	4	42	6	0.2	0.0	1	99.2	3.6
	TR05	9	1	15	2	0.1	0.0	0	34.6	1.4
	TR06	30	3	39	5	0.2	0.0	1	112.9	3.6
	TR07	51	5	73	10	0.4	0.0	2	184.9	6.7
	TR08	60	6	83	10	0.4	0.1	2	224.4	8.3
	TR09	50	4	68	8	0.4	0.0	2	190.3	6.6
	TR10	53	5	76	9	0.4	0.0	2	201.9	7.2
	TR11	19	2	33	4	0.2	0.0	1	73.5	3.3
	TR12	30	4	55	9	0.2	0.0	2	113.0	4.6
	TR13	84	10	145	22	0.7	0.1	5	316.2	13.2
	TR14	70	6	114	20	0.5	0.1	5	215.9	11.4
	Total	572	62	877	124	4.3	0.5	27	2,108.6	82.1

Table III.3 - Subwatershed Load Data
Case 1 - Average Annual Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
West Bay	WB01	15	2	31	5	0.1	0.0	1	57.3	2.5
	WB02	7	1	18	3	0.1	0.0	1	27.3	2.1
	WB03	75	11	135	24	0.5	0.3	7	240.3	14.0
	WB04	66	9	121	20	0.5	0.2	5	219.0	11.7
	WB05	26	3	52	8	0.2	0.1	3	84.0	6.3
	WB06	10	2	24	4	0.1	0.1	2	35.7	4.2
	WB07	13	2	26	4	0.1	0.1	2	42.1	3.5
	Total	212	30	405	68	1.6	0.9	21	705.6	44.3
White Oak Bayou	WO01	45	9	120	21	0.5	0.4	9	170.1	16.6
	WO02	14	3	40	7	0.2	0.2	3	55.4	6.3
	WO03	29	6	86	17	0.4	0.3	7	110.1	12.8
	WO04	26	4	79	16	0.3	0.3	6	98.9	11.8
	WO05	14	3	41	8	0.2	0.2	4	53.0	6.5
	Total	128	24	365	69	1.5	1.3	29	487.5	54.0
Entire Project Watershed		3,014	481	6,422	1,113	26.3	14.2	355	10,900	749

Table III.3 - Subwatershed Load Data
Case 2 - Ten Year Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Addicks Reservoir	AD01	97	26	219	40	0.7	0.4	9	369.0	21.3
	AD02	23	5	64	12	0.3	0.1	4	88.2	7.0
	Total	120	31	282	51	1.0	0.5	13	457.2	28.3
Armand & Taylor Bayous	AT01	29	5	69	11	0.3	0.2	5	112.0	9.2
	AT02	31	6	75	13	0.3	0.2	5	117.2	9.7
	AT03	38	5	85	14	0.4	0.2	5	135.9	9.9
	AT04	26	4	64	12	0.3	0.2	4	91.9	8.2
	Total	124	20	293	50	1.2	0.8	19	456.9	37.0
Austin & Bastrop Bayous	AB01	93	17	180	34	0.6	0.1	5	335.3	14.3
	AB02	22	4	47	7	0.2	0.1	2	81.7	4.7
	AB03	77	12	158	27	0.6	0.1	6	287.2	13.2
	Total	191	33	385	69	1.4	0.3	13	704.2	32.2
Barker Reservoir	BK01	86	42	223	38	0.7	0.2	7	328.8	16.6
	BK02	19	5	41	7	0.1	0.0	1	72.3	3.3
	Total	105	47	264	45	0.8	0.3	8	401.1	19.9
Brays Bayou	BR01	39	8	98	17	0.4	0.4	8	149.1	14.9
	BR02	16	3	40	7	0.2	0.2	3	61.2	6.1
	BR03	41	8	112	20	0.5	0.5	9	155.1	17.5
	BR04	58	10	171	33	0.7	0.5	13	223.2	24.0
	BR05	36	7	103	19	0.4	0.4	9	137.8	16.1
	BR06	20	3	59	11	0.2	0.2	5	76.0	8.9
	BR07	17	3	48	9	0.2	0.2	4	63.6	7.6
	Total	226	43	630	117	2.6	2.4	51	865.8	95.0
Buffalo Bayou	BF01	47	9	122	23	0.5	0.4	9	179.1	17.0
	BF02	49	8	157	32	0.7	0.5	12	188.6	22.4
	BF03	28	5	86	17	0.4	0.3	7	106.2	12.5
	BF04	17	3	46	9	0.2	0.2	4	63.1	7.8
	BF05	27	5	75	14	0.3	0.4	7	102.7	12.7
	Total	167	31	486	94	2.0	1.8	39	639.7	72.4

Table III.3 - Subwatershed Load Data
Case 2 - Ten Year Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Cedar Bayou	CE01	73	15	140	27	0.5	0.0	3	276.3	10.1
	CE02	111	18	219	37	0.9	0.2	8	416.4	19.4
	CE03	41	6	99	17	0.4	0.2	5	156.2	11.3
	CE04	16	2	41	8	0.2	0.1	2	59.1	4.7
	Total	241	40	500	90	1.9	0.5	19	908.1	45.5
Chocolate Bayou	CH01	77	18	150	31	0.5	0.0	3	292.2	10.3
	CH02	17	3	33	5	0.1	0.0	1	64.1	2.5
	CH03	57	9	114	20	0.4	0.1	4	210.2	10.0
	Total	151	30	297	56	1.0	0.2	8	566.4	22.9
Clear Creek	CC01	44	9	89	15	0.3	0.1	3	169.0	7.1
	CC02	102	16	220	36	0.8	0.3	9	390.2	21.4
	CC03	31	5	76	13	0.3	0.2	5	118.5	10.2
	CC04	39	6	94	16	0.4	0.3	6	144.7	12.0
	CC05	25	3	41	7	0.2	0.1	3	67.1	5.2
	Total	242	39	520	87	2.0	1.0	26	889.5	55.9
Dickinson Bayou	DB01	53	8	114	18	0.4	0.1	4	203.0	10.3
	DB02	30	4	69	11	0.3	0.1	3	112.2	7.3
	DB03	11	1	19	3	0.1	0.0	1	35.5	1.7
	Total	94	13	201	32	0.8	0.3	9	350.6	19.3
East Bay	EB01	60	9	115	20	0.4	0.1	4	221.7	8.9
	EB02	123	18	245	44	1.0	0.2	8	462.3	19.5
	EB03	68	7	138	23	0.6	0.1	6	229.5	12.6
	EB04	57	7	118	20	0.5	0.3	7	187.9	14.4
	Total	308	41	615	107	2.5	0.6	25	1101.4	55.4

Table III.3 - Subwatershed Load Data
Case 2 - Ten Year Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Loads										
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Greens Bayou	GR01	51	9	133	23	0.5	0.4	9	196.0	18.0
	GR02	40	7	107	19	0.4	0.3	7	154.6	14.3
	GR03	37	6	102	18	0.4	0.3	7	141.5	13.3
	GR04	30	5	74	13	0.3	0.2	4	114.6	9.1
	GR05	24	3	61	11	0.3	0.1	4	92.0	7.3
	GR06	44	6	126	24	0.6	0.3	8	169.5	15.9
	GR07	41	7	117	22	0.5	0.3	8	157.2	15.9
	Total	268	43	720	132	3.0	1.9	48	1025.3	93.8
North Bay	NB01	44	7	111	19	0.5	0.3	8	163.4	15.2
	Total	44	7	111	19	0.5	0.3	8	163.4	15.2
San Jacinto River	SJ02	96	12	189	33	0.8	0.3	10	307.4	21.2
	Total	96	12	189	33	0.8	0.3	10	307.4	21.2
Ship Channel	SC01	33	6	94	18	0.4	0.4	8	126.9	14.7
	SC02	43	7	115	21	0.5	0.4	9	159.0	17.3
	SC03	17	3	48	9	0.2	0.2	4	65.4	7.1
	SC04	39	7	100	18	0.4	0.4	8	142.0	15.8
	SC05	39	7	103	19	0.4	0.3	7	147.2	13.4
	SC06	49	8	113	20	0.5	0.5	9	168.9	16.9
	SC07	27	4	59	10	0.2	0.2	4	90.5	8.4
	SC08	28	4	67	11	0.3	0.2	4	103.4	8.1
	SC09	34	6	82	14	0.3	0.3	6	119.4	12.2
	Total	310	53	779	140	3.2	2.9	60	1122.7	113.7
Sims Bayou	SM01	34	6	79	13	0.3	0.2	5	129.0	9.7
	SM02	25	4	58	9	0.2	0.1	3	96.5	6.5
	SM03	42	7	110	19	0.5	0.3	7	160.6	14.0
	SM04	38	7	106	20	0.4	0.4	8	143.8	15.7
	SM05	21	3	55	10	0.2	0.2	4	78.7	8.1
	Total	159	27	408	71	1.7	1.2	28	608.6	54.1

Table III.3 - Subwatershed Load Data
Case 2 - Ten Year Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
South Bay	SB01	14	2	32	5	0.1	0.1	3	50.4	4.8
	SB02	19.	4	49	9	0.2	0.3	5	72.7	8.6
	SB03	41	6	81	14	0.3	0.4	7	123.6	12.9
	SB04	23	2	36	6	0.1	0.1	2	60.0	4.0
	Total	97	14	198	34	0.8	0.8	16	306.7	30.2
Trinity Bay	TB01	121	16	197	30	0.9	0.1	5	459.5	15.9
	TB02	64	9	115	19	0.5	0.1	4	231.5	9.7
	TB03	99	9	137	22	0.6	0.1	5	273.1	11.6
	TB04	71	7	122	22	0.5	0.1	6	195.0	12.2
	Total	355	41	572	93	2.4	0.4	19	1159.1	49.5
Trinity River	TR02	117	12	162	21	0.8	0.0	4	448.9	14.7
	TR03	46	6	47	12	0.3	0.1	2	175.4	7.0
	TR04	49	6	76	11	0.4	0.0	2	183.4	6.5
	TR05	19	3	30	5	0.1	0.0	1	71.2	2.8
	TR06	60	6	77	10	0.4	0.0	2	227.9	7.1
	TR07	96	9	137	17	0.7	0.1	4	355.4	12.2
	TR08	106	10	145	17	0.8	0.1	4	400.1	14.2
	TR09	82	7	111	12	0.6	0.0	3	312.9	10.6
	TR10	86	8	121	14	0.7	0.1	3	327.6	11.3
	TR11	31	3	51	7	0.2	0.0	2	117.4	5.0
	TR12	47	7	86	14	0.3	0.0	2	180.0	7.2
	TR13	135	16	230	35	1.1	0.1	7	510.3	20.6
	TR14	110	10	181	31	0.8	0.1	7	352.9	17.8
	Total	985	103	1454	205	7.4	0.8	43	3,663.5	136.9

Table III.3 - Subwatershed Load Data
Case 2 - Ten Year Rainfall
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Loads										
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
West Bay	WB01	24	4	48	7	0.2	0.0	1	91.5	3.8
	WB02	11	2	26	4	0.1	0.1	2	41.5	3.1
	WB03	115	16	208	36	0.8	0.4	10	379.6	20.6
	WB04	102	13	187	31	0.7	0.3	8	347.8	17.4
	WB05	39	5	79	12	0.3	0.2	4	129.3	9.1
	WB06	14	3	34	6	0.1	0.2	3	50.3	5.8
	WB07	19	3	68	6	0.2	0.1	3	63.8	5.0
	Total	323	45	651	103	2.5	1.2	31	1103.8	64.8
White Oak Bayou	WO01	64	12	171	31	0.7	0.5	12	245.1	23.3
	WO02	20	4	56	10	0.2	0.2	5	77.6	8.7
	WO03	41	8	121	23	0.5	0.4	10	155.4	17.8
	WO04	37	6	112	22	0.5	0.4	9	139.7	16.5
	WO05	19	4	57	11	0.2	0.2	5	73.7	9.0
	Total	181	34	518	98	2.1	1.8	40	691.5	75.3
Entire Project Watershed		4,789	747	10,073	1,727	41.5	20.4	531	17,493	1,138

Table III.3 - Subwatershed Load Data
Case 3 - Individual Storm Event
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Loads										
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (thousand kg)	Oil and Grease (thousand kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Addicks Reservoir	AD01	17	4.3	36	7	117	41	1	63	3.1
	AD02	4	0.7	10	2	42	14	1	15	1.0
	Total	20	5.1	46	8	159	55	2	78	4.1
Armand & Taylor Bayous	AT01	3	0.4	6	1	26	17	0	11	.8
	AT02	3	0.6	7	1	27	18	0	11	.8
	AT03	4	0.5	8	1	36	14	0	14	.9
	AT04	3	0.3	6	1	26	13	0	9	.7
	Total	12	1.9	28	5	114	62	2	45	3.2
Austin & Bastrop Bayous	AB01	14	2.7	28	5	93	13	1	53	2.0
	AB02	3	0.5	7	1	26	8	0	12	.6
	AB03	12	1.8	24	4	97	14	1	47	1.9
	Total	30	5.0	59	10	216	34	2	112	4.5
Barker Reservoir	BK01	15	6.6	37	6	113	26	1	57	2.5
	BK02	4	0.9	7	1	26	5	0	14	.5
	Total	19	7.4	44	8	139	31	1	71	3.0
Brays Bayou	BR01	5	1.1	13	2	49	45	1	20	1.7
	BR02	2	0.4	5	1	20	18	0	8	.7
	BR03	4	0.8	12	2	47	43	1	16	1.7
	BR04	5	0.9	16	3	64	42	1	20	2.1
	BR05	3	0.5	9	2	36	33	1	12	1.3
	BR06	2	0.3	5	1	22	17	0	7	.7
	BR07	1	0.2	4	1	17	15	0	5	.6
	Total	23	4.4	63	12	255	212	5	88	8.9
Buffalo Bayou	BF01	7	1.3	17	3	66	46	1	26	2.1
	BF02	5	0.9	17	4	74	46	1	21	2.4
	BF03	3	0.5	9	2	40	26	1	12	1.3
	BF04	2	0.3	5	1	19	20	0	6	.7
	BF05	2	0.4	6	1	25	28	1	8	1.0
	Total	19	3.4	55	11	224	166	4	72	7.5

Table III.3 - Subwatershed Load Data
Case 3 - Individual Storm Event
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Cedar Bayou	CE01	9	1.8	18	3	58	4	0	35	1.2
	CE02	14	2.1	26	4	105	17	1	53	2.2
	CE03	5	0.6	11	2	49	16	1	19	1.2
	CE04	2	0.2	5	1	21	6	0	7	.5
	Total	30	4.8	60	11	232	44	2	114	5.1
Chocolate Bayou	CH01	12	2.8	24	5	73	5	0	47	1.6
	CH02	3	0.5	5	1	18	2	0	10	.4
	CH03	9	1.4	17	3	65	11	1	33	1.4
	Total	24	4.6	46	9	156	18	1	91	3.3
Clear Creek	CC01	5	0.9	10	2	35	6	0	19	.7
	CC02	11	1.7	23	4	89	25	1	42	2.0
	CC03	3	0.4	7	1	28	19	0	11	.9
	CC04	5	0.7	12	2	51	25	1	20	1.4
	CC05	3	0.3	5	1	22	11	0	9	.6
	Total	27	4.1	57	9	224	86	3	101	5.6
Dickinson Bayou	DB01	8	1.1	17	3	67	13	1	32	1.4
	DB02	4	0.5	10	2	40	12	0	17	.9
	DB03	2	0.2	3		11	3	0	6	.2
	Total	14	1.9	30	4	119	27	1	54	2.5
East Bay	EB01	8	1.1	15	3	58	6	0	30	1.1
	EB02	16	2.4	31	5	126	15	1	63	2.3
	EB03	8	0.9	17	3	74	12	1	30	1.5
	EB04	6	0.7	13	2	57	26	1	22	1.4
	Total	39	5.1	76	13	315	59	3	145	6.2

Table III.3 - Subwatershed Load Data
Case 3 - Individual Storm Event
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

NPS Loads										
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
Greens Bayou	GR01	6	1.0	15	3	64	38	1	23	1.9
	GR02	5	0.9	14	2	57	32	1	21	1.7
	GR03	4	0.7	12	2	49	26	1	17	1.4
	GR04	4	0.7	10	2	45	17	1	17	1.2
	GR05	4	0.4	9	2	39	12	0	14	1.0
	GR06	5	0.6	14	3	61	23	1	19	1.6
	GR07	4	0.7	12	2	51	28	1	16	1.5
	Total	33	5.0	85	15	366	177	5	127	10.3
North Bay	NB01	4	0.6	10	2	43	27	1	15	1.3
	Total	4	0.6	10	2	43	27	1	15	1.3
San Jacinto River	SJ02	10	1.3	21	4	92	29	1	36	2.2
	Total	10	1.3	21	4	92	29	1	36	2.2
Ship Channel	SC01	3	0.6	10	2	41	35	1	13	1.4
	SC02	4	0.6	10	2	42	34	1	14	1.4
	SC03	2	0.2	4	1	18	13	0	6	.6
	SC04	3	0.6	8	2	34	33	1	12	1.3
	SC05	4	0.7	11	2	44	24	1	16	1.3
	SC06	4	0.7	10	2	40	34	1	15	1.4
	SC07	2	0.4	5	1	21	17	0	8	.7
	SC08	3	0.4	7	1	30	14	0	12	.8
	SC09	3	0.5	8	1	33	26	1	12	1.1
	Total	29	4.8	73	13	302	229	5	107	9.9
Sims Bayou	SM01	3	0.6	8	1	30	16	0	13	.8
	SM02	3	0.4	6	1	23	10	0	10	.6
	SM03	4	0.6	10	2	43	23	1	16	1.2
	SM04	3	0.6	9	2	38	30	1	13	1.3
	SM05	2	0.3	5	1	20	16	0	7	.7
	Total	15	2.5	38	6	154	95	2	58	4.6

Table III.3 - Subwatershed Load Data
Case 3 - Individual Storm Event
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

		NPS Loads								
Watershed	Subwatershed	Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
South Bay	SB01	2	0.3	5	1	20	15	0	8	.6
	SB02	2	0.5	6	1	24	29	1	9	1.0
	SB03	5	0.8	11	2	45	42	1	17	1.6
	SB04	3	0.4	6	1	25	9	0	11	.6
	Total	13	1.9	28	5	114	94	2	45	3.7
Trinity Bay	TB01	17	2.1	26	4	116	6	1	63	2.0
	TB02	8	1.1	15	2	59	8	0	31	1.1
	TB03	11	1.2	18	3	75	10	1	37	1.4
	TB04	8	0.8	15	3	63	14	1	25	1.4
	Total	44	5.2	73	11	313	37	2	155	5.9
Trinity River	TR02	16	1.5	21	3	114	3	0	61	1.9
	TR03	6	0.7	10	1	46	4	0	24	.9
	TR04	7	0.8	10	1	49	3	0	25	.8
	TR05	3	0.4	5	1	23	1	0	12	.4
	TR06	10	0.8	12	1	68	2	0	36	1.1
	TR07	14	1.3	19	2	102	6	0	53	1.7
	TR08	14	1.2	18	2	101	7	0	52	1.7
	TR09	10	0.8	13	1	74	3	0	38	1.2
	TR10	10	0.8	14	2	76	4	0	39	1.2
	TR11	4	0.3	5	1	28	4	0	13	.5
	TR12	5	0.8	9	1	39	3	0	20	.8
	TR13	16	1.7	26	4	121	11	1	59	2.2
	TR14	14	1.3	23	4	108	14	1	47	2.1
	Total	127	12.5	185	24	949	66	5	479	16.6

Table III.3 - Subwatershed Load Data
Case 3 - Individual Storm Event
Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Watershed	Subwatershed	NPS Loads: Runoff Volume (thousand acre-ft)	Total Suspended Solids (million kg)	Total Nitrogen (thousand kg)	Total Phosphorus (thousand kg)	Biochemical Oxygen Demand (million kg)	Oil and Grease (million kg)	Fecal Coliform (xE15 col)	Dissolved Copper (kg)	Pesticides (kg)
West Bay	WB01	4	0.6	7	1	28	4	0	15	.5
	WB02	2	0.2	4	1	14	6	0	6	.4
	WB03	17	2.4	30	5	123	36	1	60	2.6
	WB04	15	2.0	28	4	113	25	1	55	2.3
	WB05	7	0.8	13	2	55	21	1	23	1.3
	WB06	2	0.4	4	1	17	19	0	6	.7
	WB07	3	0.4	6	1	25	14	0	11	.7
	Total	49	6.7	93	15	377	125	4	177	8.4
White Oak Bayou	WO01	7	1.3	19	3	78	50	1	28	2.4
	WO02	2	0.4	6	1	24	21	0	8	.9
	WO03	4	0.8	13	3	54	39	1	17	1.8
	WO04	4	0.6	12	2	52	36	1	15	1.7
	WO05	2	0.4	6	1	25	21	0	7	.9
	Total	20	3.5	57	11	232	167	4	75	7.7
Entire Project Watershed		603	91.6	1,227	205	5,096	1,839	55	2,248	124.7

APPENDIX IV
LAKE HOUSTON
AND
LAKE LIVINGSTON
WATER QUALITY DATA

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Table IV.1 - United States Geological Survey Lake Houston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Year	Site	Phosphorus			Nitrogen			BOD			Fecal Coliforms			Suspended Solids		
		Data (mg/l)	No of Obs	Annual Mean	Data (mg/l)	No of Obs	Annual Mean	Data (mg/l)	No of Obs	Annual Mean	Data (col/100ml)	No of Obs	Annual Mean	Data (mg/l)	No of Obs	Annual Mean
1983	AC	0.06	1		1.23	1		3.35	1		84	1		21.0	1	
	CC	0.07	1		1.33	1		2.60	1					60.0	1	
	EC	0.03	1		1.45	1		2.65	1		120	1		23.5	1	
	FC	0.22	1	0.10	1.60	1	1.40	3.65	1	3.06	210	1	138	113.0	1	54.4
1984	AC	0.13	4		0.95	4		1.58	3		130	1		20.0	3	
	CC	0.17	4		1.17	4		2.05	3					15.3	3	
	EC	0.09	4		1.08	4		2.28	3		20	1		15.0	3	
	FC	0.37	4	0.19	1.47	4	1.17	4.40	3	2.58	63	3	68	44.8	3	23.8
1985	AC	0.15	4		1.13	4		2.65	2		27	1		16.8	2	
	CC	0.18	4		1.13	4		3.35	2					22.0	2	
	EC	0.11	4		1.00	4		3.00	2		130	1		16.8	2	
	FC	0.62	4	0.27	1.48	4	1.19	5.20	2	3.55	180	1	112	28.8	2	21.1
1986	AC	0.20	6		1.11	6		2.33	2		240	1		15.5	2	
	CC	0.15	6		1.08	6		2.58	2					25.5	2	
	EC	0.10	6		1.11	6		3.03	2		2,800	1		58.8	2	
	FC	0.41	5	0.21	1.32	6	1.16	4.50	2	3.11	1,000	1	1,347	77.0	2	44.2
1987	AC	0.21	10		1.38	10		2.03	3		170	1		17.7	3	
	CC	0.25	10		1.35	11		2.53	3					32.8	3	
	EC	0.13	11		1.32	11		2.43	3		32	1		79.3	3	
	FC	0.48	12	0.27	1.65	12	1.43	4.13	3	2.78	130	1	111	61.2	3	47.8
1988	AC	0.16	12		0.79	12		1.92	3		230	1		14.0	3	
	CC	0.23	12		0.79	12		2.10	3					29.2	3	
	EC	0.19	12		0.88	12		2.70	3		54	1		18.5	3	
	FC	0.86	11	0.23	1.39	11	0.61	4.50	3	1.60	60	1	57	25.3	3	12.4
1989	AC	0.22	10		1.08	10		1.50	4		685	2		19.5	8	
	CC	0.25	10		0.96	10		2.40	4					25.4	5	
	EC	0.16	10		0.96	10		2.76	4		120	1		27.1	7	
	FC	0.63	10	0.32	1.79	10	1.20	3.06	4	2.43	193	3	345	87.3	2	29.4

Table IV.2 - United States Geological Survey
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Year	Site	Phosphorus			Nitrogen		
		Data (mg/l)	No of Obs	Annual Mean	Data (mg/l)	No of Obs	Annual Mean
1975		0.15	1	0.15	0.27	1	0.27
1976		0.12	1	0.12	0.13	1	0.13
1977		0.17	1	0.17	0.34	1	0.34
1978	AC	0.62	1		1.80	1	
	DC	0.29	1		0.18	1	
	GC	0.81	1		0.79	1	
	JC	1.00	1	0.68	2.23	1	1.25
1979	AC	0.27	1		0.25	1	
	DC	0.32	1		0.33	1	
	GC	0.43	1		0.40	1	
	JC	0.53	1	0.39	0.81	1	0.45
1980	AC	0.38	1		1.58	1	
	DC	0.33	1		1.15	1	
	GC	0.46	1		1.83	1	
	JC	1.06	1	0.56	2.37	1	1.73
1981	AC	0.32	1		1.51	1	
	DC	0.53	1		1.97	1	
	GC	0.81	1		3.41	1	
	JC	0.72	1	0.60	3.75	1	2.66
1982	AC	0.53	2		2.30	2	
	DC	0.18	2		1.63	2	
	GC	0.24	2		3.13	2	
	JC	0.32	2	0.32	2.01	2	2.27
1983	AC	0.39	1		1.83	1	
	DC	0.40	1		1.73	1	
	GC	0.30	1		2.00	1	
	JC	0.70	1	0.45	3.90	1	2.37
1984	AC	0.36	2		1.33	2	
	DC	0.29	2		1.33	2	
	GC	0.89	2		3.53	2	
	JC	0.84	2	0.60	3.25	2	2.36
1985	AC	0.48	2		1.83	2	
	DC	0.25	2		1.50	2	
	GC	0.39	2		2.22	2	
	JC	0.70	2	0.46	4.48	2	2.51
1986	AC	1.21	2		1.67	2	
	DC	0.22	2		1.97	2	
	GC	0.34	2		2.20	2	
	JC	0.97	2	0.69	4.33	2	2.54
1987	AC	0.46	2		2.43	2	
	DC	0.61	2		1.87	2	
	GC	0.29	2		1.83	2	
	JC	0.46	2	0.46	2.43	2	2.14

Table IV.3 - Texas Water Commission
Lake Houston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		Nitrogen		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
6/30/81	0.56		0.72		2.00		200		16.0	
7/13/81	0.25		1.14		-		200		12.5	
7/27/81	0.34		-		-		200		4.0	
12/14/81	1.38	0.63	2.19	1.35	-	2.00	450	263	18.0	12.6
1/5/82	0.54		1.58		4.00		200		25.0	
1/11/82	0.42		1.85		-		800		23.0	
3/1/82	0.25		5.41		-		450		12.0	
3/9/82	0.07		1.06		2.00		500		6.0	
3/15/82	0.00		0.50		-		200		1.0	
5/3/82	2.42		2.47		12.00		200		8.5	
5/11/82	0.15		1.03		4.00		200		22.0	
5/24/82	1.00		1.34		-		200		18.0	
7/12/82	1.32		3.39		-		20		22.5	
7/27/82	0.25		3.20		2.00		20		11.0	
8/2/82	0.25		1.03		-		20		6.0	
8/30/82	0.17		1.34		-		20		8.5	
9/7/82	0.05	0.53	0.33	1.89	5.00	4.83	20	219	20.0	14.1
3/14/83	0.07		3.97		-		330		18.0	
5/3/83	0.44		0.53		2.00		20		21.0	
5/9/83	2.66		0.59		-		20		9.5	
5/17/83	0.14		0.60		2.00		50		3.0	
6/2/83	0.20		1.03		4.00		50		23.0	
6/7/83	0.40		8.27		12.00		50		6.0	
6/13/83	0.50		5.21		-		20		11.0	
6/21/83	0.40		2.19		2.00		20		7.0	
6/27/83	4.28		1.35		1.35		20		10.0	
7/5/83	0.50	0.96	2.57	2.63	19.00	6.05	20	60	34.0	14.3
2/22/84					4.00	4.00	940	940	4.0	4.0
1/20/88					6.00				5.0	
2/22/88					3.00				6.0	
2/24/88					2.00				8.0	
3/2/88					2.00				6.0	
3/9/88					2.00				6.0	
3/16/88					2.00				10.0	
3/21/88					2.00				10.0	
3/23/88					5.00				12.0	
4/27/88					3.00				4.0	
5/2/88					6.00				12.0	
5/4/88					2.00				-	
5/9/88					4.00				16.0	
5/18/88					8.00				5.0	
5/25/88					2.00				3.0	
6/13/88					3.00				2.0	
6/27/88					-	3.47			8.0	7.5

Table IV.4 - Texas Water Commission
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
1/23/75	0.21		1.00		-		11.3	
1/30/75	0.25		1.60		-		6.0	
2/3/75	0.26		1.10		110		8.3	
2/9/75	0.02		0.70		2		8.4	
2/18/75	0.19		1.30		3		10.5	
2/25/75	0.23		1.80		3		18.0	
3/5/75	2.55		1.00		-		10.0	
3/12/75	1.90		0.80		-		11.5	
3/18/75	0.24		2.30		21		26.0	
3/27/75	0.16		1.80		-		1.5	
4/8/75	0.20		1.70		-		5.5	
4/22/75	0.11		1.50		-		5.5	
5/1/75	0.29		1.50		-		20.5	
5/8/75	0.71		1.80		-		17.0	
5/15/75	0.18		3.00		-		11.5	
5/20/75	0.16		3.20		-		8.0	
5/29/75	0.20		1.60		-		26.0	
6/5/75	0.28		2.10		-		10.0	
6/11/75	0.20		1.10		-		10.7	
6/24/75	0.12		1.70		1		7.6	
7/2/75	0.23		1.40		-		7.0	
7/10/75	0.14		2.20		5		8.0	
7/17/75	0.20		1.40		3		7.5	
7/22/75	0.20		2.30		1		7.3	
7/31/75	0.26		1.20		8		5.5	
8/21/75	0.29		1.40		-		5.0	
8/28/75	0.36		2.10		-		6.0	
9/2/75	0.20		1.80		-		6.0	
9/11/75	2.35		0.90		-		5.3	
9/16/75	0.16		4.00		-		7.3	
9/18/75	0.16		2.00		-		6.5	
9/25/75	0.27		2.50		-		14.0	
10/8/75	0.38		2.70		-		14.0	
10/16/75	0.15		1.80		3		8.0	
10/21/75	0.14		-		-		22.5	
10/30/75	0.15		3.10		2		11.5	
11/6/75	0.14		1.80		-		8.5	
11/11/75	0.20		4.10		5		7.5	
11/18/75	0.06		1.10		3		-	

Table IV.4 - Texas Water Commission
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
11/24/75	0.13		2.20		-		9.5	
12/11/75	0.10		0.80		4		7.3	
12/18/75	0.10		1.70		44		7.5	
12/23/75	0.08	0.35	1.30	1.82	50	16	8.0	10.1
1/6/76	0.09		0.90		-		7.3	
1/13/76	0.09		1.7		-		5.3	
1/22/76	0.11		1.70		-		-	
1/29/76	0.09		-		-		5.0	
2/4/76	0.09		3.10		-		12.4	
2/10/76	0.10		2.10		-		10.7	
2/17/76	0.65		2.60		5		5.5	
2/26/76	0.10		1.30		-		8.3	
3/9/76	0.16		1.00		-		11.0	
3/16/76	0.12		1.50		16		24.7	
3/30/76	0.13		1.70		-		23.0	
4/19/76	-		1.60		-		10.5	
4/26/76	0.18		2.60		-		18.0	
5/4/76	0.23		3.00		-		10.0	
5/10/76	0.19		2.40		-		8.5	
5/18/76	0.33		3.50		-		15.0	
6/3/76	0.19		3.10		-		4.7	
6/10/76	0.15		2.40		-		7.0	
6/16/76	-		4.30		-		9.3	
7/15/76	-		2.00		-		2.0	
7/29/76	0.20		2.00		-		15.0	
8/13/76	0.31		2.00		-		7.0	
8/25/76	0.23		2.00		-		7.0	
9/7/76	0.40		3.00		-		2.0	
9/16/76	-		3.00		-		2.5	
9/30/76	0.26		4.00		-		5.5	
10/1/76	0.22		2.00		-		-	
10/4/76	0.25		2.00		-		5.3	
10/14/76	0.23		2.70		-		23.0	
11/1/76	0.15		2.80		-		7.3	
11/9/76	0.12		1.80		-		7.5	
11/11/76	0.15		4.70		-		5.6	
12/15/76	-		1.80		-		10.0	
12/20/76	-		2.50		-		44.7	
12/28/76	-	0.20	0.05	2.32	-	11	3.3	10.4

Table IV.4 - Texas Water Commission
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
1/4/77	-		0.05		-		6.7	
1/10/77	-		0.05		-		11.3	
1/25/77	-		0.21		-		9.3	
2/4/77	-		-		-		21.0	
2/28/77	-		0.40		-		16.0	
3/15/77	-		0.16		-		6.0	
3/31/77	0.46		1.40		-		17.0	
4/7/77	0.20		2.20		-		11.3	
4/20/77	0.20		2.00		-		6.0	
4/27/77	0.20		2.20		-		12.7	
5/3/77	1.40		2.50		-		5.3	
5/24/77	0.3		1.8		-		6.7	
5/31/77	0.20		1.20		-		4.7	
6/7/77	0.20		-		-		8.0	
6/13/77	0.20		1.30		-		3.3	
6/16/77	0.20		1.50		-		5.3	
6/23/77	0.10		1.40		-		-	
6/28/77	0.20		2.90		-		4.0	
7/11/77	0.20		4.30		-		5.3	
7/18/77	0.30		3.60		-		5.3	
8/1/77	0.20		-		-		6.0	
8/3/77	0.20		3.20		-		4.7	
8/9/77	0.30		3.70		-		9.0	
8/16/77	0.50		3.00		-		6.0	
8/29/77	0.20		3.40		144		7.3	
9/8/77	0.20		2.10		0		4.7	
9/20/77	0.40		1.80		-		3.3	
9/29/77	0.30		1.70		-		2.0	
10/5/77	0.10		2.60		0		4.0	
10/11/77	0.04		1.90		-		12.0	
11/3/77	0.20		2.50		-		4.0	
11/28/77	0.20		1.10		-		-	
12/12/77	0.30	0.28	1.10	1.91	30	44	17.0	7.9
1/6/78	0.16		-		10		2.0	
1/11/78	0.20		1.40		-		7.3	
1/24/78	0.12		33.00		5		3.7	
2/6/78	0.18		1.00		-		6.0	
2/21/78	0.21		1.40		-		20.0	
3/16/78	0.07		3.60		-		12.0	

Table IV.4 - Texas Water Commission
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
3/24/78	0.17		1.90		-		12.0	
3/29/78	1.30		1.30		-		12.7	
4/6/78	2.40		2.40		0		3.0	
4/13/78	2.60		2.60		-		7.3	
4/18/78	0.06		2.10		-		9.3	
4/27/78	0.16		1.40		25		11.0	
5/4/78	0.17		2.10		-		10.0	
5/23/78	0.16		1.90		-		8.7	
6/15/78	0.96		-		160		8.7	
7/6/78	0.36		3.00		-		8.0	
7/18/78	0.50		2.80		15		6.5	
7/25/78	0.34		-		30		6.0	
8/2/78	0.45		4.40		35		7.5	
8/9/78	0.36		4.50		-		8.7	
8/17/78	0.44		5.20		-		6.7	
8/30/78	0.45		-		-		14.0	
9/14/78	0.43		1.60		70		14.0	
9/20/78	0.38		3.2		10		4	
9/26/78	0.45		2.30		0		9.0	
10/18/78	0.29		2.40		25		6.0	
10/25/78	0.25		-		-		9.0	
11/15/78	0.35		1.20		0		5.0	
11/29/78	0.19		1.90		-		2.0	
12/5/78	0.24		2.40		0		10.0	
12/13/78	0.07	0.47	2.10	3.58	10	26	8.0	8.3
1/3/79	-		2.00		-		5.0	
2/14/79	0.23		1.40		20		10.0	
2/27/79	0.64		-		30		11.0	
3/14/79	0.35		2.30		5		10.0	
4/18/79	0.33		1.70		-		16.0	
5/22/79	0.30		2.00		40		13.0	
5/31/79	0.30		1.00		30		11.0	
6/20/79	0.22		1.00		20		35.0	
7/5/79	-		1.00		-		-	
7/17/79	0.20		2.00		0		9.0	
8/8/79	-		-		-		3.0	
9/26/79	0.20		3.00		-		32.0	
11/5/79	0.40	0.32	-	1.74	40	23	7.0	13.5
1/9/80	0.20		2.10		-		-	

Table IV.4 - Texas Water Commission
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
2/21/80	0.20		3.20		10		10.0	
2/27/80	0.20		4.00		-		13.0	
3/19/80	0.20		1.60		-		8.0	
4/17/80	0.20		-		100		24.0	
5/29/80	0.20		5.00		4		24.0	
6/5/80	0.70		2.00		-		16.0	
6/18/80	0.20		3.00		-		11.0	
7/29/80	0.30		4.00		2		9.0	
8/27/80	0.20		2.00		40		8.0	
10/10/80	0.20		5.00		0		12.0	
11/7/80	0.20	0.25	2.20	3.10	-	26	9.0	13.1
1/23/81	0.10		2.00		-		5.0	
5/28/81	0.10	0.10	-	2.00	0	0	8.0	6.5
4/28/82	0.10	0.10	-		-		12.0	12.0
5/24/83	0.10		-		10		5.0	
7/26/83	0.20		-		10		5.0	
8/10/83	-		-		-		-	
8/30/83	0.10		-		20		1.0	
10/11/83	0.20		-		-		6.0	
11/29/83	0.10	0.13	-		10	13	-	5.8
1/11/84	0.10		-		10		14.0	
2/7/84	0.10		-		-		8.0	
3/27/84	0.10		-		10		8.0	
4/25/84	0.2		-		-		10	
5/14/84	-		-		-		11.0	
6/18/84	0.20		-		10		8.0	
7/16/84	0.30		-		10		4.0	
8/27/84	0.30		-		10		8.0	
9/25/84	0.20		-		10		7.0	
10/16/84	0.20		-		10		5.0	
12/11/84	0.20	0.19	-		-	10	26.0	9.9
2/19/85	0.20		-		10		7.0	
3/19/85	0.20		-		-		8.0	
4/9/85	0.20		-		-		10.0	
5/20/85	0.20		-		20		10.0	
6/25/85	0.20		-		10		3.0	
8/13/85	0.40		-		10		5.0	
9/24/85	0.20		-		10		9.5	
10/22/85	0.20		-		20		7.0	

Table IV.4 - Texas Water Commission
Lake Livingston Water Quality Data

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Date	Phosphorus		BOD		Fecal Coliforms		Suspended Solids	
	Data (mg/l)	Annual Mean	Data (mg/l)	Annual Mean	Data (col/100ml)	Annual Mean	Data (mg/l)	Annual Mean
11/25/85	0.20		-		60		8.0	
12/11/85	0.20	0.22	-		40	23	19.0	8.7
1/21/86	0.20		-		20		12.0	
2/11/86	0.20		-		10		28.0	
3/18/86	0.20		-		10		10.0	
4/8/86	0.20		-		-		3.0	
5/6/86	0.20		-		20		9.0	
6/10/86	0.20		-		60		12.0	
7/7/86	0.20		-		20		3.0	
8/9/86	0.10		-		20		5.0	
9/9/86	0.20		-		20		12.0	
10/7/86	0.10		-		20		7.0	
11/4/86	0.10		-		20		11.0	
12/16/86	0.20	0.18	-		20	22	18.0	10.8
1/26/87	0.20		-		20		14.0	
2/17/87	0.20		-		20		13.0	
3/10/87	0.20		-		20		16.0	
4/7/87	0.20		-		20		15.0	
5/12/87	0.10	0.18	-		20	20	5.0	12.6

Table IV.5 - Example Calculation of Average Concentration for Lakes

Non-Point Source Characterization Project
Galveston Bay National Estuary Program

Total Suspended Solids for Lake Houston					
Year	USGS Annual Average	Number of Observations	TWC Annual Average	Number of Observations	GBNEP Annual Average
1981		0	12.6	4	12.6
1982		0	14.1	13	14.1
1983	54.4	4	14.3	10	25.7
1984	23.8	12	4.0	1	22.3
1985	21.1	8	7.5	15	12.2
1986	44.2	8		0	44.2
1987	47.8	12		0	47.8
1988	12.4	12		0	12.4
1989	29.4	22		0	29.4
Annual Average Total Suspended Solids Load =					25 mg/l

NOTES:

1. GBNEP Annual Average Concentration calculated for Total Suspended Solids, Fecal Coliforms, Total Nitrogen, Total Phosphorus, and BOD for both Lake Livingston and Lake Houston.
2. Results reported in Table 5.15, Volume I.