CHAPTER 2

PREVIOUS LOADING ESTIMATES

2.1 INTRODUCTION

The literature reviewed consisted of several reports and studies that would indicate the historical and current loading of conventional, nonconventional, and toxic pollutants to the Galveston Bay system from permitted dischargers, tributaries, and non-point sources. The earliest estimates of loading of conventional pollutants focused on the Houston Ship Channel and the Texas Ship Channel rather than on the Bay as a whole (e.g., Stanley 1989), although a few studies did estimate loadings to other portions of the Bay. Not until Neleigh (1974) and Goodman (1989) provided estimates of toxic pollutant loadings to Galveston Bay from permitted dischargers and tributaries were there any attempts to estimate the loads of these important materials. Prior to the work of Neleigh (1974), the Galveston Bay Project conducted studies on the toxicity of the Bay waters (Oppenheimer et al., 1973; Copeland and Fruh, 1970).

This chapter contains a review of these loading estimates and a short description of the Galveston Bay system so that loading sources and receiving systems can be identified.

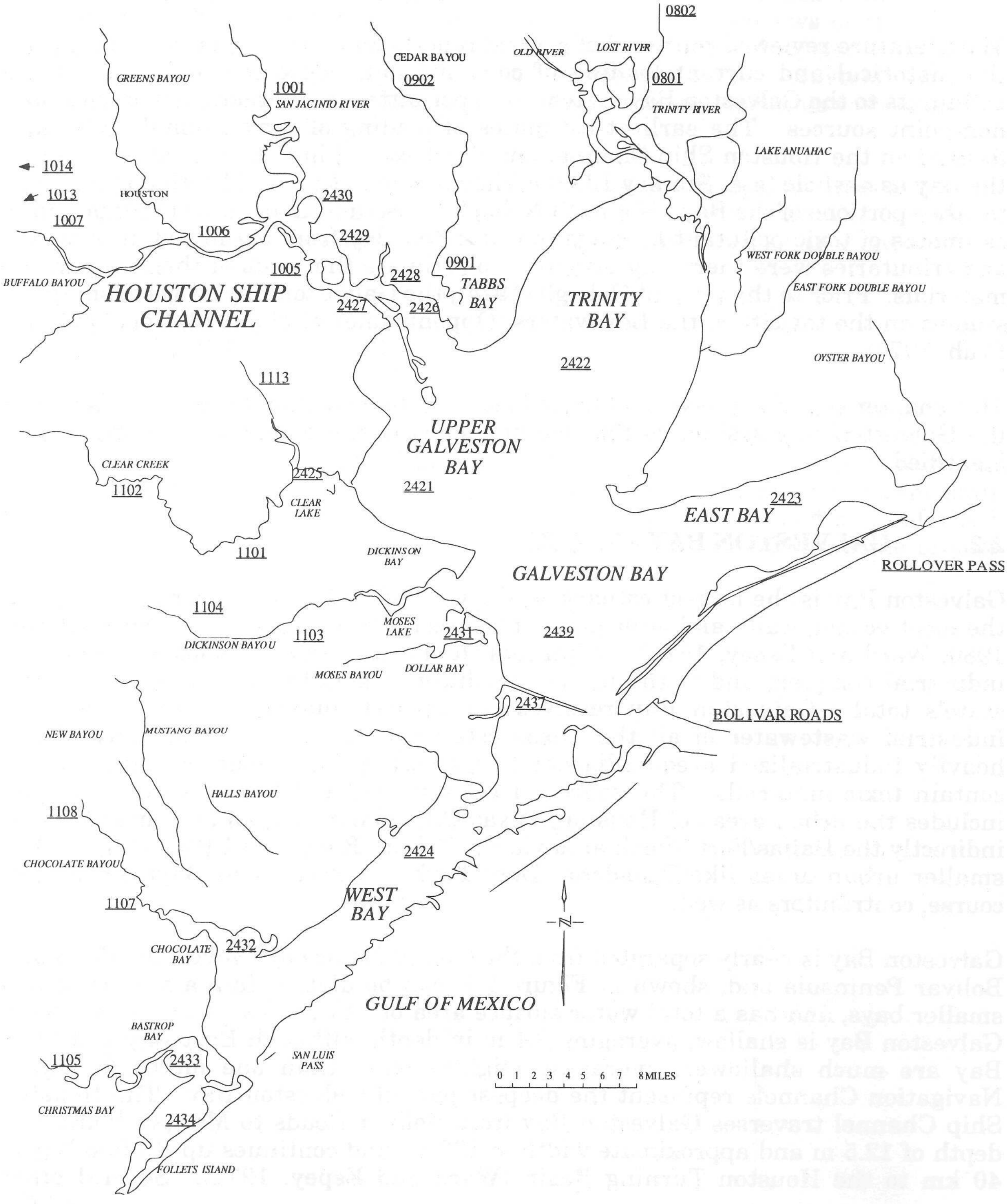
2.2 GALVESTON BAY SYSTEM

Galveston Bay is the largest estuary on the Gulf of Mexico and is considered to be the most economically and ecologically resourceful bay on the Texas coast (Ward, 1980; Ward and Espey, 1971). It harbors the largest seaport, houses the largest industrial complex, and is the largest producer of shellfish at 38 percent of the state's total. Galveston Bay receives the largest quantity of municipal and industrial wastewater of all the Texas estuaries, and as a consequence of the heavily industrialized areas adjacent to Galveston Bay, some of these wastes contain toxic materials. The source of wastewater, and hence toxic materials, includes the urban areas of Houston, Texas City, Galveston, and Clear Lake, and indirectly the Dallas/Fort Worth area via the Trinity River (US EPA, 1980). Other smaller urban areas like Pasadena, Deer Park, La Porte, and Baytown are, of course, contributors as well.

Galveston Bay is nearly separated from the Gulf of Mexico by Galveston Island and Bolivar Peninsula and, shown in Figure 2.1, can be divided into a system of five smaller bays, and has a total water surface area of 143,153 ha (Armstrong, 1982). Galveston Bay is shallow, averaging 2.1 m in depth, although East Bay and West Bay are much shallower, averaging slightly more than one meter in depth. Navigation Channels represent the deepest part of Galveston Bay. The Houston Ship Channel traverses Galveston Bay from Bolivar Roads to Morgan Point at a depth of 12.5 m and approximate width of 120 m, and continues up Buffalo Bayou 40 km to the Houston Turning Basin (Ward and Espey, 1971). Several other

Figure 2.1 - Galveston Bay system with bays, tributaries, and water quality segments

Point Source Characterization Project
Galveston Bay National Estuary Project



dredged channels traverse through the bay, namely the Galveston Channel, Trinity River Channel, Texas Ship Channel, the Bayport Channel, and the Intracoastal Waterway. TNRCC water quality segment numbers are shown in Figure 2.1 and are described in more detail in Chapter 3.

Galveston Bay receives a majority of its freshwater inflow from the Trinity River. Based on the ten-year average freshwater inflow data for Galveston Bay, the Trinity River contributes approximately 69% of the total freshwater inflow, the San Jacinto River (measured as spillover from the Lake Houston Reservoir) 18%, the Houston Ship Channel (Buffalo Bayou and tributaries) 7%, and Clear Creek less than 2% (Ward and Espey, 1971). Highest river discharges usually occur in March through June when mean monthly total discharges approach 400 m^3/sec and the low-flow period generally occurs from July through October when total discharges average 100 m^3/sec (Orlando et al., 1991). Armstrong (1982) has estimated the hydraulic residence time to be 0.23 years based on net freshwater inflow (freshwater inflow plus precipitation minus evaporation) and 0.11 years based on net freshwater inflow and tidal exchange.

2.3 EARLY ESTIMATES OF POLLUTANT LOADING

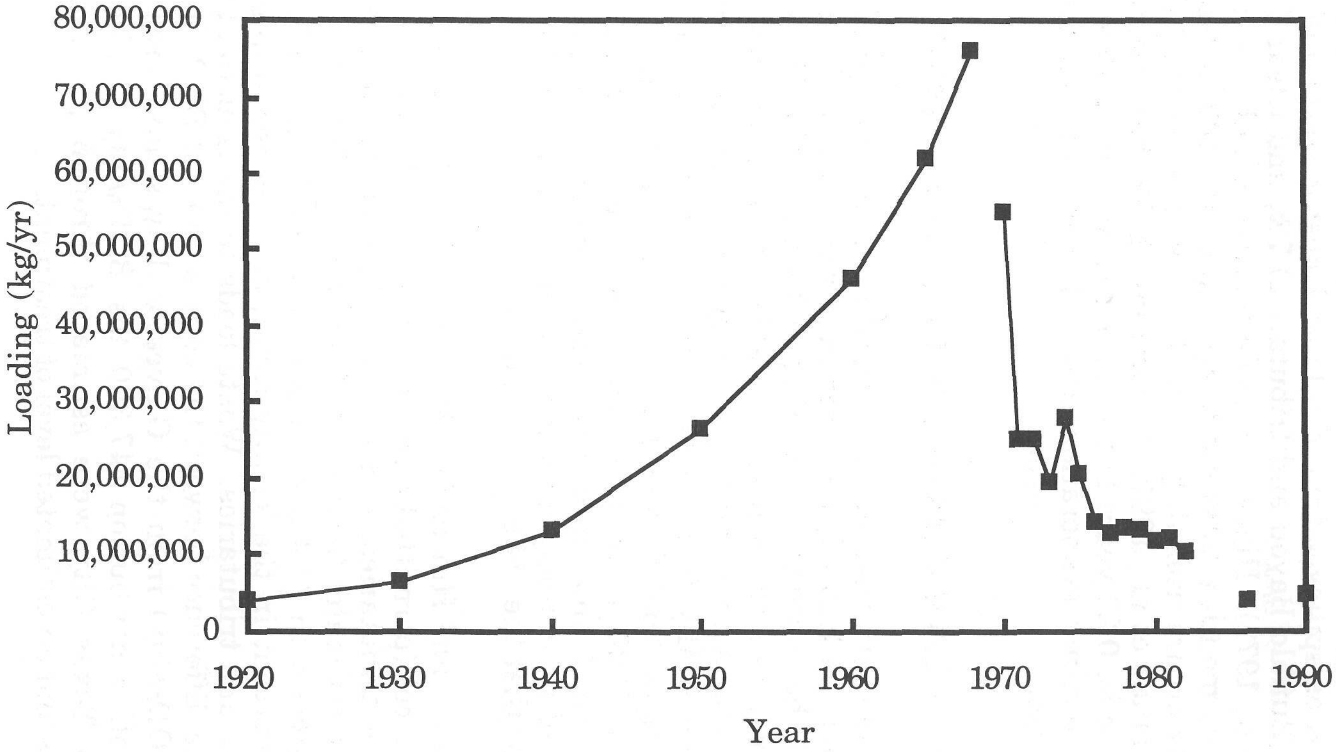
Firm estimates of conventional, nonconventional, and toxic pollutant loadings prior to 1968 could not be located, but estimates appearing in Bernard Johnson, Inc. (1975) indicate the increase in loading of BOD_5 to the Houston Ship Channel thought to occur from 1920 through the 1960s. These estimates, combined with the post-1968 estimates summarized by Stanley (1989) illustrate how BOD_5 loadings increased exponentially from 1920 to 1968 then decreased dramatically with increased implementation of wastewater treatment so that 1986 loads were roughly equal to those in 1920, at least in magnitude (see Figure 2.2). Increases in the number of municipal and industrial dischargers and the increase in the urban population served by municipal facilities existing in 1920 indicate the remarkable decrease in loads that the 1986 BOD_5 loads represent.

In 1973, Armstrong and Hinson (1973) estimated the loading of BOD_5 to Galveston Bay from all sources (permitted discharges from the Houston area, Texas City, and Galveston, major tributaries, and local runoff) and obtained the results given in Table 2.1. These estimates for circa 1970 show a total BOD_5 load of 91.4 x 10^6 kg/yr (201.5 x 10^6 lbs/yr) with 75.4 percent of that load originating in the Houston Ship Channel, 14.9 percent in the Trinity River, and the remaining 9.7 percent from other discharges and tributaries. Waste loads to the Houston Ship Channel were estimated as the difference between the estimated total BOD_5 load in the Channel (470,000 lbs BOD_5/day) from the Galveston Bay study (Tracor, 1971) and the estimated runoff contribution (47,300 lbs BOD_5/day). Mass discharges for Galveston and Texas City were estimated through per capita waste BOD_5 generation rates and an estimated level of treatment.

In a survey of waste discharges in the Texas coastal zone, Malina (1970) examined waste discharge permit data available from the TWQB and TWDB at that time and determined the number of, quantity of flow from, and loading of BOD (presumably

Figure 2.2 - Historical BOD_5 Loadings to the Houston Ship Channel

Point Source Characterization Project
Galveston Bay National Estuary Program



Sources: Bernard Johnson, Inc. (1975); Stanley (1989); Armstrong and Hinson (1973); and this study

Table 2.1 - Historical Loading of BOD_5 to the Galveston Bay System (circa 1970)

Source	BOD_5 (10^6 kg/yr)	Percent Of Total (%)
Chocolate Bayou	0.23	0.25
Dickinson Bayou	0.14	0.16
Double Bayou	0.36	0.40
Clear Creek	0.14	0.16
Trinity River	13.57	14.85
Cedar Bayou	0.09	0.07
Brays Bayou	0.85	0.94
Sims & Vance Bayou	0.87	0.95
Greens & Hunting Bayou	1.08	1.19
San Jacinto River	2.74	3.00
Goose Creek	0.01	0.01
Buffalo Bayou	0.72	0.79
Houston Ship Channel Wastes	68.95	75.44
Texas City	0.64	0.69
Galveston	1.01	1.10
TOTALS	91.39	100.00

Source: Armstrong and Hinson (1973)

BOD_5), suspended solids, and phosphates from municipal and industrial wastewater discharges for roughly the 1970 period. He aggregated his results by county, and for Chambers, Galveston, Harris, and Liberty Counties his results are given in Table 2.2. Although it is unclear in his report exactly how loadings were calculated, Malina (1970) apparently used a combination of flows and concentrations reported with permit applications, reports of flow and constituent data for various dischargers, typical concentrations of BOD_5, TSS, COD, and phosphates in municipal and industrial wastewaters at that time. Loads were then estimated from the product of flows and concentrations. Of note is that his estimate for total BOD_5 discharged in the four county area was 125.8×10^6 kg/yr, very similar to that of Armstrong and Hinson (1970). Malina (1970) also reported on the discharge of salt brine from oil production wells based on a survey by the Texas Railroad Commission in 1961 (see Table 2.3). Again, aggregating by county, he found that a total of 4,529.6 MG/yr of salt brine was being produced and disposed of, and of that amount 1,686.3 MG/yr (or 37.2 percent) was being discharged to surface waters.

2.4 TOXIC POLLUTANT LOADING

2.4.1 Neleigh's Loading Estimates

The attempt by Neleigh (1974) to define the sources and quantity of toxic pollutants released to the Galveston Bay System included a number of materials, but not as extensive a list as used by Goodman (1989) given below. Further, the estimates are limited to 68 permitted industrial discharges and to two tributaries only; no loads from municipal effluents were included. The information used by Neleigh was for industrial discharges only and was based on data obtained by the USACE and the EPA through the Rivers and Harbors Refuse Act of 1899 self-reporting permit applications submitted during the summer of 1971. This in turn was compared with TWQB Waste Control Orders and Registrations issues as of 1974. Dischargers not listed in the Corps data but holding a Waste Control Order were added to the final list of dischargers. Pollutant concentrations in effluents were considered to be the most reliable from the Corps data, and, if no concentration data were available from the USACE, the discharger's Waste Control Order file at the TWQB was reviewed for data. If the discharger was permitted for a particular pollutant, the permitted concentration was used. If no permitted values were given but concentration data were available, the concentration data were used. Of the 56 Waste Control Order files reviewed by Neleigh (1974), some 45 files had neither permitted concentrations for toxic materials nor sample analysis information. Data for the Gulf Coast Waste Disposal Authority (GCWDA) was obtained from their permit effective April 1, 1974 and was considered to be the most accurate of all dischargers included in the analysis. Discharge flows used were those listed by the TWQB as average daily flows as of March 1974. Thus, Neleigh's loadings are considered to be representative of 1974. Data on the pollutant concentrations in fresh water flows to the Bay was found in the U.S. Geological Survey (USGS) data for the State of Texas, and these concentrations are generally for dissolved forms of pollutants in contrast to the total concentrations usually measured in effluents. Only two tributaries were considered: the Trinity River and the San Jacinto River and the loads from the

Table 2.2 - Estimates of Municipal and Industrial Wastewater Discharges by County (circa 1970)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Municipal Discharges

County	No. Of Discharges	Estimated Flow (MG/yr)	BOD_5 (1000s kg/yr)	Suspended Solids (1000s kg/yr)	Phosphates (1000s kg/yr)
Chambers	7	88	14.2	32.6	13.7
Galveston	17	5,457	2,695.9	1,863.8	296.0
Harris	100	72,066	12,490.6	21,311.6	439.7
Liberty	6	350	44,206	54.5	5.8
Totals	130	77,960	15,245.0	23,262.4	4,712.9

Industrial Discharges

County	No. Of Discharges	Estimated Flow (MG/yr)	BOD_5 (1000s kg/yr)	Suspended Solids (1000s kg/yr)	COD (1000s kg/yr)
Chambers	3	1,434	140.2	76.5	5,093.6
Galveston	17	45,694	18,670.2	49,771.8	157,428.5
Harris	116	122,522	91,765.5	92,025.6	235,565.6
Liberty	1	-	-	-	-
Totals	137	169,681	110,575.9	141,873.9	398,087.7

Total of Dischargers

Totals	267	247,641	125,820.9	165,136.3	

Source: Malina (1970)

Table 2.3 - Estimates of Salt Brine Discharges and Disposal Method by County in the Galveston Bay Area (circa 1961)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

County	Total Flow (MG/yr)	Injection Wells (MG/yr)	Open Pits (MG/yr)	Surface Water (MG/yr)	Other (MG/yr)
Chambers	1,193.6	664.3	87.6	434.4	7
Galveston	879.6	390.6	102.2	379.6	7
Harris	1,868.8	759.2	255.5	850.4	4
Liberty	587.6	492.8	73.0	21.9	<4
Totals	4,529.6	2,306.8	518.3	1,686.3	<22

Source: Malina (1970)

former were entered into Water Quality Segment 0802 while the latter were added to Segment 1002.

The load estimates compiled by Neleigh (1974) aggregated by Water Quality Segment are given in Table 2.4. Municipal flows were largest in the Houston Ship Channel where over 80 percent of the total municipal flow was discharged. For industrial waste, sixty-five percent of the flow was discharged into the Houston Ship Channel and almost 20 percent into the Texas Ship Channel. Cooling water from electrical utilities dominated the return flows to the Bay. Total load estimates of each constituent are broken down by industry contribution, tributary contribution, and major industrial contributor where one was noted by Neleigh are given in Table 2.5. It should be noted that tributary contributions for metals are based on dissolved concentrations while loads from industries are assumed to be based on total metal concentrations. Thus, tributary contributions of total metal forms were actually higher that those estimated by Neleigh (1974). In his conclusions, Neleigh (1974) noted that significant amounts of constituents were discharged to the Galveston Bay system from permitted discharges. These included oil and grease, aluminum, zinc, phenol, nickel, manganese, titanium, barium, bromide, fluoride, chromium, and copper. The overall major contributors of these materials were found to be the GCWDA's Washburn Tunnel Treatment Facility and the Diamond Shamrock Corporation based solely on total loads of the pollutants included. They were responsible for 42.2 percent of all reported materials discharged to the Bay in industrial wastes and rivers. It was concluded that, in addition to the Houston Ship Channel, the Trinity River was a major source of toxic materials. Of the total mass emission rates to Galveston Bay, the Trinity River provided 69 percent of the arsenic, sixty percent of the cadmium, seventy-nine percent of the copper, ninety-three percent of the fluoride, seventy-one percent of the manganese, eighty-five percent of the mercury, five percent of the nickel, eighty percent of the zinc, ninety-eight percent of the oil and grease, and twenty-six percent of the phenols. Neleigh stated, based on previous work, that Galveston Bay waters were toxic, in varying degrees, to phytoplankton, zooplankton, invertebrates, and fish. Several EPA and TWQB effluent standards effective at that time were found to be violated in the Bay. EPA's proposed effluent standards for cadmium, cyanide, and mercury were and the TWQB's effluent standards for arsenic, cadmium, copper, lead, manganese, mercury, and zinc were violated (Neleigh, 1974).

2.4.2 Goodman's Loading Estimates

Goodman's (1989) loading estimates of pollutants to the Galveston Bay system included 234 industrial and municipal waste discharges over the period 1985-87. Loading estimates were compiled from self reporting data obtained from the TWC and for only those municipalities and industries permitted to discharge any constituent other than conventional constituents.. The list of such constituents, when combined with the list of constituents used by Neleigh (1974), totaled 61 pollutants. Goodman calculated monthly loading for each pollutant and for each of the dischargers as their average daily flow times their average daily concentration times the number of days discharging each month. The monthly values were summed to give annual loads for each of the three years examined, and these

Table 2.4 - Neleigh's Estimated Loads of Selected Pollutants into the Galveston Bay System by Water Quality Segment (circa 1974)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Water Quality Segment	Municipal Wastewater Flow (MG/yr)	Industrial Wastewater Flow (MG/yr)	Cooling Water Flow (MG/yr)	Total Municipal and Industrial Flow (MG/yr)
0801	518	0	0	518
0802	372	1,657	0	2,029
0901	825	6,023	0	6,847
0902	112	1,825	0	1,937
1001	887	1,157	0	2,044
1002	0	0	0	0
1005	241	10,366	0	10,607
1006	50,991	139,503	186,150	376,644
1007	26,828	1,215	0	28,043
1101	1,829	34	0	1,862
1102	723	186	0	909
1103	2,613	55	0	2,668
1104	0	0	0	0
1107	0	1,971	0	1,971
1108	35	0	0	35
2421	5,329	18,031	411,757	435,117
2422	335	0	346,750	347,085
2424	55	183	0	237
2425	1,949	53	411,757	413,758
2426	1,197	35	0	1,232
2427	1	4,198	269,078	273,276
2428	0	0	0	0
2429	0	504	0	504
2430	259	42	0	301
2431	2,117	230	0	2,347
2432	14	0	0	14
2436	0	0	0	0
2437	0	42,048	0	42,048
Totals	97,229	229,314	1,625,491	1,952,033
Percent of Total	5.0%	11.7%	83.3%	

Source: Neleigh (1974)

Table 2.4 - Neleigh's Estimated Loads of Selected Pollutants into the Galveston Bay System by Water Quality Segment (circa 1974)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Water Quality Segment	Aluminum (kg/yr)	Antimony (kg/yr)	Arsenic (kg/yr)	Barium (kg/yr)	Beryllium (kg/yr)	Boron (kg/yr)	Bromide (kg/yr)
0801	0	0	0	0	0	0	0
0802			19,106				
0901	7,197	0	0	0	0	0	0
0902	24,851	0	0	0	0	0	0
1001	28	0	0	0	0	0	0
1002							
1005	5	0	0	0	0	0	0
1006	1,110,107	0	5,563	261,094	0	33,080	464
1007	45	341	10	300	0	0	5
1101	0	0	0	0	0	0	0
1102	0	0	7	0	0	0	0
1103	0	0	0	0	0	0	0
1104							
1107	3,248	0	0	0	0	0	0
1108							
2421	9,805	15	672	6,833	45	29,818	0
2422	0	0	0	0	0	0	0
2424	0	0	0	0	0	0	0
2425	397	0	99	0	0	0	0
2426	0	0	0	0	0	0	0
2427	6,826	0	2,541	0	0	0	187,750
2428							
2429	0	0	0	0	0	0	0
2430	0	0	0	0	0	0	0
2431	0	0	0	0	0	0	0
2432							
2436							
2437	823		38	36	0	0	0
Totals	1,163,332	356	28,037	268,263	45	62,898	188,218

Source: Neleigh (1974)

Table 2.4 - Neleigh's Estimated Loads of Selected Pollutants into the Galveston Bay System by Water Quality Segment (circa 1974)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Water Quality Segment	Cadmium (kg/yr)	Chromium (kg/yr)	Copper (kg/yr)	Cyanide (kg/yr)	Fluoride (kg/yr)	Lead (kg/yr)	Manganese (kg/yr)
0801	0	0	0	0	0	0	0
0802	5,866	0	132,335		4,337,777	0	195,034
0901	1,795	89	1,795	179	430	1,795	897
0902	0	24,851	0	0	0	0	0
1001	0	17	0	3	12	2	0
1002		0	15,055		1,192,723	0	130,415
1005	0	311	0	0	0	0	0
1006	1,210	52,269	12,770	6,748	100,083	13,063	73,047
1007	141	60	53	93	0	1,460	33
1101	0	0	0	0	0	0	0
1102	3	621	690	0	0	7	41
1103	0	0	0	0	0	0	0
1104							
1107	0	4,656	144	0	0	55	15
1108							
2421	437	65,481	3,437	12,623	13,369	1,371	1,959
2422	0	0	0	0	0	0	0
2424	0	0	0	0	0	0	0
2425	2	79	0	0	0	40	0
2426	0	0	0	0	2	0	0
2427	111	15,243	220	442	220,862	111	55,232
2428							
2429	0	0	0	0	0	0	0
2430	0	0	0	0	0	0	0
2431	0	0	0	0	0	0	0
2432							
2436							
2437	35	6,278	25	212	33,858	79	20
Totals	9,599	169,955	166,524	20,300	5,899,117	17,982	456,693

Source: Neleigh (1974)

Table 2.4 - Neleigh's Estimated Loads of Selected Pollutants into the Galveston Bay System by Water Quality Segment (circa 1974)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Water Quality Segment	Mercury (kg/yr)	Molyb-denum (kg/yr)	Nickel (kg/yr)	Selenium (kg/yr)	Silver (kg/yr)	Tin (kg/yr)	Titanium (kg/yr)
0801	0	0	0	0	0	0	0
0802	4,656		50,480				
0901	2	0	0	0	0	0	0
0902	0	0	3,452	0	0	0	0
1001	0	0	0	0	0	0	5
1002	391		7,821				
1005	0	0	0	0	0	0	0
1006	252	5,843	911,430	1,127	710	0	354,638
1007	2	5	40	0	46	245	333
1101	0	0	0	0	0	0	0
1102	0	0	7	0	0	0	0
1103	0	0	0	0	0	0	0
1104							
1107	0	0	0	0	0	0	0
1108							
2421	162	0	2,543	0	45	0	0
2422	0	0	0	0	0	0	0
2424	0	0	0	0	0	0	0
2425	0	0	477	0	0	0	20
2426	0	0	0	0	0	0	0
2427	12	1,104	531	0	0	0	2,209
2428							
2429	0	0	0	0	0	0	0
2430	0	0	0	0	0	0	0
2431	0	0	0	0	0	0	0
2432							
2436							
2437	0	0	45	5	13	0	0
Totals	5,475	6,952	976,826	1,132	815	245	357,204

Source: Neleigh (1974)

Table 2.4 - Neleigh's Estimated Loads of Selected Pollutants into the Galveston Bay System by Water Quality Segment (circa 1974)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Water Quality Segment	Zinc (kg/yr)	Oil & Grease (kg/yr)	Phenol (kg/yr)	Chlorinated Hydro carbons (kg/yr)	Pesticides (kg/yr)
0801	0	0	0	0	0
0802	818,548	155,795,724	107,782	0	136
0901	1,795	12,013	288	18	0
0902	5,523	0	0	0	0
1001	3	0	2	0	0
1002	78,212	26,010,104	16,033	0	0
1005	3	39,570	63	0	0
1006	38,262	2,092,729	337,419	0	0
1007	818	56,242	70	0	579
1101	0	0	0	0	0
1102	414	6,904	0	0	0
1103	0	995	0	0	0
1104					
1107	2,728	10,493	381	0	0
1108					
2421	16,040	465,400	248	0	0
2422	0	0	0	0	0
2424	0	0	0	0	0
2425	22	0	0	20	0
2426	2	498	0	0	0
2427	41,871	311,923	3,046	3,513	176,822
2428					
2429	0	6,669	134	0	0
2430	0	4,255	0	0	0
2431	0	0	0	0	0
2432					
2436					
2437	1,601	95,232	1,402	0	0
Totals	1,005,843	184,908,753	466,869	3,551	177,538

Source: Neleigh (1974)

Table 2.5 - Neleigh's Estimated Loads of Selected Pollutants into the Galveston Bay System by Pollutant (circa 1974)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Pollutant	Industrial Contribution (kg/yr)	Tributary Contribution (kg/yr)	Total Load (kg/yr)	Major Contributor(s)	Major Contributor's Load (kg/yr)
Aluminum	1,130,637	-	1,130,637	GCWDA	1,040,186
Antimony	356	-	356		
Arsenic	8,674	19,306	27,980		
Barium	268,214	-	268,214	GCWDA	257,485
Beryllium	<1	-	<1		
Boron	62,914	-	62,914	GCWDA	32,715
Bromide	188,246	-	188,246	E.I. DuPont	187,750
Cadmium	3,808	5,795	9,603		
Chromium	169,869	-	169,869	American Oil, GCWDA, Mobay	78,140
Copper	34,106	132,451	166,557	GCWDA	
Cyanide	20,364	-	20,364		
Fluoride	430,466	5,529,838	5,960,304		
Lead	18,046	-	18,046	GCWDA	10,099
Manganese	131,127	325,499	456,626	E.I.DuPont, GCWDA	104,901
Mercury	828	4,636	5,464		
Molybdenum	6,954	-	6,954	GCWDA	4,305
Nickel	926,331	50,497	976,828	Diamond Shamrock	908,450
Selenium	0	-	1,126		
Silver	0	-	811		
Tin	0	-	248		
Titanium	0	-	357,122	GCWDA	354,141
Zinc	109,272	896,695	1,005,967		
Oil and Grease	3,129,160	181,789,272	184,934,988		
Phenol	343,049	123,842	466,890	GCWDA	316,227
Chlorinated Hydrocarbons	3,560	-	3,560	E.I. DuPont	3,510
Pesticides	177,650	-	177,650	E.I. DuPont	176,822

Source: Neleigh (1974)

annual loads were averaged to give a three-year annual average. Loads for each discharger and pollutant were aggregated by water quality segment so that spatial trends in loading could be discerned. Total loadings of each of these 61 pollutants for 25 water quality segments in the Galveston Bay area are shown in Table 2.6. Discharge flows are also given. When none of the 234 point source dischargers were listed in the TWC self-reporting forms as discharging a particular material to a segment, a zero was reported for that segment. This was the case for several metals such as aluminum and antimony, and it should be noted that these metals were included in Neleigh's (1974) analysis but were not permitted by the TWC at the time Goodman (1989) did his work.

The total permitted point source waste flow to the Galveston Bay study area was 542 million gallons per day as given in Table 2.6. As would be expected, the greatest flows were for those water quality segments of the Houston Ship Channel. The combined flow of the Houston Ship Channel segments (1005, 1006, 1007) accounts for 80 percent of the reported point source Bay total. It is also clear from the table that oil and grease and ammonia-N were discharged in quantities far greater than all of the other substances listed. Considerable amounts of zinc, grease, fluoride, cadmium and chromium were also being discharged, however. Table 2.7 gives the total amounts of these 61 pollutants discharged to Galveston Bay by permitted point source discharges, the Trinity River, the San Jacinto River, and the major contributor of each pollutant as identified by Goodman (1989). GCWDA and Mobay Chemical Corporation are listed most frequently as major contributors, and again it should be recognized that they are discharging permitted amounts of the pollutants for which they are the major contributors.

The non-point source loadings considered consisted of the Trinity River and the San Jacinto River which, as noted before, actually included permitted and unpermitted point source discharges also. Like Neleigh (1974), Goodman (1989) used the dissolved metal concentrations published by the USGS, and the loading estimates will not reflect the total metal loading which is what waste dischargers reported. The results of the calculations done to determine the amount of pollutant loading delivered by these two rivers are given in Table 2.7. The contributions from the two fresh water non-point sources clearly dominated point source discharge for at least thirteen of the seventeen toxic materials listed for non-point sources. The pollutants for which this was the case are: arsenic, barium, beryllium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, and zinc.

After having determined the loading to the Galveston Bay system of all pollutants other than conventional ones which was permitted by the TWC or was introduced to the study area by the Trinity River and the San Jacinto River, the following conclusions were reached by Goodman (1989):

1. The TWC's monthly self-reporting discharger permit files were reviewed and provided flow and concentration information for 234 dischargers of industrial and municipal waste and 61 different toxic materials to 35 water quality segments in the Galveston Bay area;

Table 2.6 - Estimated Loading of Nonconventional and Toxic Pollutants into the Galveston Bay System (1985-87)

Point Source Characterization Project
Galveston Bay National Estuary Program

Flow/Pollutant	Units	Water Quality Segment									
		0801	0802	0901	0902	1001	1005	1006	1007	1013	1101
Flow	MG/yr	26	21.1	2,022	173.4	7,884	7,665	30,587	120,450	4,052	1,073
Acrylonitrile	kg/yr								0.175		
Aluminum	kg/yr										
Amiben	kg/yr										
Ammonia-N	kg/yr		0.082	41.610		24.711	215.715	307.33	1,321.3	9.709	13.286
Analine	kg/yr										
Anthracene	kg/yr										
Antimony	kg/yr										
Arsenic	kg/yr							0.004			
Barium	kg/yr										
Benzene	kg/yr			0.053		0.005					
Beryllium	kg/yr										
Boron	kg/yr										
Bromide	kg/yr										
Cadmium	kg/yr			16.900					0.069		
Chlorinated benzenes	kg/yr			1.303							
Chlorinated hydrocarbons	kg/yr						0.143	2.073	0.011		
Chlorine, Total Residual	kg/yr						0.181		3.942		
Chloroform	kg/yr								1.172		
Chlorophenol	kg/yr										
Chromium	kg/yr			0.423	0.007	0.960	2.066	3.113	4.563	0.012	
Chromium (hexavalent)	kg/yr							0.095			
Chromium (trivalent)	kg/yr										
Copper	kg/yr			0.108			0.374	0.001	1.106		
Cyanide	kg/yr			0.679				3.606	1.905		
Daconil	kg/yr										
Dacthal	kg/yr										
Diazinon	kg/yr										
Dichloroethane (1,2) or EDC	kg/yr							0.188			
Dinitrotoluene (2,4)	kg/yr			0.082							
Dinitrotoluene (2,6)	kg/yr			0.116					0.777		
Ethyl benzene	kg/yr			0.003							
Fluoride	kg/yr								11.060		
Grease	gal/yr							52.925		9.563	
Iron	kg/yr										
Isoprene	kg/yr								0.064		
Lead	kg/yr			0.228			0.002	0.624	0.562		
Manganese	kg/yr							0.008	5.658		
Mercury	kg/yr								0.009		
Methylene Chloride	kg/yr			1.285							
Molybdenum	kg/yr										
Napthalene	kg/yr										
Nickel	kg/yr			0.642			0.548		1.548		
Nitrophenol (ortho)	kg/yr			0.040							
Oil and Grease	kg/yr	1.416	0.243	26.134	1.445	12.848	57.670	33.799	255.135	0.114	
Nitrophenol (para)	kg/yr			0.105							
Paraquat	kg/yr										
Pentachlorophenol	kg/yr										
Pesticides	kg/yr										
Phenol	kg/yr	0.007		0.210	0.003	0.001	0.507	0.301	1.471		
Phosphate-P	kg/yr										
Selenium	kg/yr			0.024					0.342		
Silver	kg/yr										
Styrene	kg/yr								0.001		
Sulfide	kg/yr						1.376	0.369	5.950		
Tin	kg/yr										
Titanium	kg/yr										
Toluene	kg/yr			0.006		0.005					
Toxaphene	kg/yr										
Trichloroethane (1,1,1)	kg/yr										
Trichlorophenol	kg/yr										
Xylene	kg/yr						0.001		0.000		
Zinc	kg/yr			0.650		2.081	4.052	0.357	6.716	0.012	

Source: Goodman (1989)

Table 2.6 - Estimated Loading of Nonconventional and Toxic Pollutants into the Galveston Bay System (1985-87)

Point Source Characterization Project
Galveston Bay National Estuary Program

Flow/Pollutant	Units	Water Quality Segment									
		1102	1103	1107	1108	2421	2424	2425	2426	2427	2430
Flow	MG/yr	2,887	20.9	3,099	0.4	44.5	55.1	51.1	2,168	2,778	2.4
Acrylonitrile	kg/yr			0.045							
Aluminum	kg/yr										
Amiben	kg/yr										
Ammonia-N	kg/yr	11.461		7.665				0.005	29.565	24.455	
Analine	kg/yr			0.006						0.047	
Anthracene	kg/yr										
Antimony	kg/yr										
Arsenic	kg/yr						0.001				
Barium	kg/yr						0.011				
Benzene	kg/yr			0.004							
Beryllium	kg/yr										
Boron	kg/yr										
Bromide	kg/yr										
Cadmium	kg/yr						0.000				
Chlorinated benzenes	kg/yr									0.005	
Chlorinated hydrocarbons	kg/yr										
Chlorine, Total Residual	kg/yr										
Chloroform	kg/yr										
Chlorophenol	kg/yr										
Chromium	kg/yr			0.230			0.000			0.518	
Chromium (hexavalent)	kg/yr										
Chromium (trivalent)	kg/yr										
Copper	kg/yr						0.002				
Cyanide	kg/yr									0.053	
Daconil	kg/yr										
Dacthal	kg/yr										
Diazion	kg/yr										
Dichloroethane (1,2) or EDC	kg/yr										
Dinitrotoluene (2,4)	kg/yr										
Dinitrotoluene (2,6)	kg/yr										
Ethyl benzene	kg/yr			0.004							
Fluoride	kg/yr									27.959	
Grease	gal/yr										
Iron	kg/yr										
Isoprene	kg/yr										
Lead	kg/yr						0.001			0.012	
Manganese	kg/yr						0.013			0.770	
Mercury	kg/yr										
Methylene Chloride	kg/yr									0.016	
Molybdenum	kg/yr										
Napthalene	kg/yr			0.005							
Nickel	kg/yr						0.002			0.060	
Nitrophenol (ortho)	kg/yr										
Oil and Grease	kg/yr		1.274		0.002	0.621	0.141	0.303	0.081	4.928	0.037
Nitrophenol (para)	kg/yr										
Paraquat	kg/yr										
Pentachlorophenol	kg/yr										
Pesticides	kg/yr										
Phenol	kg/yr			0.061						0.027	
Phosphate-P	kg/yr										
Selenium	kg/yr						0.000				
Silver	kg/yr						0.000				
Styrene	kg/yr										
Sulfide	kg/yr									0.001	
Tin	kg/yr										
Titanium	kg/yr										
Toluene	kg/yr			0.004							
Toxaphene	kg/yr										
Trichloroethane (1,1,1)	kg/yr										
Trichlorophenol	kg/yr										
Xylene	kg/yr										
Zinc	kg/yr			58.035			0.001			0.358	

Source: Goodman (1989)

Table 2.6 - Estimated Loading of Nonconventional and Toxic Pollutants into the Galveston Bay System (1985-87)

Point Source Characterization Project
Galveston Bay National Estuary Program

Flow/Pollutant	Units	Water Quality Segment					Totals
		2431	2436	2437	2438	2439	
Flow	MG/yr	135	27.2	1,219	3,030	8,322	197,830
Acrylonitrile	kg/yr						0.220
Aluminum	kg/yr						
Amiben	kg/yr						
Ammonia-N	kg/yr	0.154	0.111	44.165	20.696	106.945	2,178.977
Analine	kg/yr						0.053
Anthracene	kg/yr						
Antimony	kg/yr						
Arsenic	kg/yr					0.069	0.074
Barium	kg/yr						0.011
Benzene	kg/yr				0.026		0.088
Beryllium	kg/yr						
Boron	kg/yr						
Bromide	kg/yr						
Cadmium	kg/yr						16.969
Chlorinated benzenes	kg/yr				0.042		1.351
Chlorinated hydrocarbons	kg/yr				0.453		2.679
Chlorine, Total Residual	kg/yr						4.123
Chloroform	kg/yr				0.246		1.418
Chlorophenol	kg/yr				0.093		0.093
Chromium	kg/yr			0.298	0.298	0.610	13.099
Chromium (hexavalent)	kg/yr			0.037		0.065	0.197
Chromium (trivalent)	kg/yr				0.042		0.042
Copper	kg/yr					0.010	1.601
Cyanide	kg/yr						6.243
Daconil	kg/yr						
Dacthal	kg/yr						
Diazion	kg/yr				0.015		0.015
Dichloroethane (1,2) or EDC	kg/yr						0.188
Dinitrotoluene (2,4)	kg/yr						0.082
Dinitrotoluene (2,6)	kg/yr						0.894
Ethyl benzene	kg/yr						0.006
Fluoride	kg/yr						39.019
Grease	gal/yr						62.488
Iron	kg/yr						
Isoprene	kg/yr						0.064
Lead	kg/yr					0.229	1.658
Manganese	kg/yr					0.193	6.642
Mercury	kg/yr					0.000	0.010
Methylene Chloride	kg/yr						1.300
Molybdenum	kg/yr						
Napthalene	kg/yr						0.005
Nickel	kg/yr					0.120	2.919
Nitrophenol (ortho)	kg/yr						0.040
Oil and Grease	kg/yr		0.277	21.097	67.525	131.765	616.850
Nitrophenol (para)	kg/yr						0.105
Paraquat	kg/yr				0.028		0.028
Pentachlorophenol	kg/yr						
Pesticides	kg/yr				0.588		0.588
Phenol	kg/yr			0.427		0.383	3.397
Phosphate-P	kg/yr						
Selenium	kg/yr						0.366
Silver	kg/yr						0.000
Styrene	kg/yr						0.001
Sulfide	kg/yr			0.099		0.785	8.579
Tin	kg/yr						
Titanium	kg/yr						
Toluene	kg/yr				0.026		0.041
Toxaphene	kg/yr						
Trichloroethane (1,1,1)	kg/yr				0.106		0.106
Trichlorophenol	kg/yr				0.060		0.060
Xylene	kg/yr						0.001
Zinc	kg/yr			0.132	0.858	0.219	73.469

Source: Goodman (1989)

Table 2.7 - Estimates of Selected Pollutant Loadings into the Galveston Bay System (1985-87) from Permitted Discharges and Major Tributaries

Point Source Characterization Project
Galveston Bay National Estuary Program

Pollutant	Units	Permitted Dischargers	Trinity River	San Jacinto River	Total Load	Major Contributor(s)
Flow	MG/yr	197,830	2,457,180	333,084	2,988,094	
Acrylonitrile	kg/yr	219			219	Goodyear Tire & Rubber Co.
Aluminum	kg/yr					
Amiben	kg/yr					
Ammonia-N	kg/yr	2,182,700	569,400		2,752,100	City of Houston Sims Bayou
Aniline	kg/yr	55			55	Dow Chemical Co.
Anthracene	kg/yr	0			0	Koppers Co.
Antimony	kg/yr					
Arsenic	kg/yr	73	168,995	631	169,699	Textin Corp.
Barium	kg/yr	11	459,900	79,935	539,846	McGinnes Industrial Maint. Corp.
Benzene	kg/yr	88			88	Chevron Chemical Co.
Beryllium	kg/yr		2,336		2,336	
Boron	kg/yr					
Bromide	kg/yr					
Cadmium	kg/yr	16,973	4,636	631	22,239	Mobay Chemical Corp.
Chlorinated Benzenes	kg/yr	1,351			1,351	Mobay Chemical Corp.
Chorinated Hydrocarbons	kg/yr	2,679			2,679	Occidental Chemical Co.
Chlorine, Total Residual	kg/yr	4,125			4,125	Houston, Lighting & Power Co.
Chloroform	kg/yr	1,416			1,416	GCWDA
Chlorophenol (2)	kg/yr	91			91	GCWDA
Chromium (Hex)	kg/yr	197			197	Shell Oil Co.
Chromium (Tri)	kg/yr	13,104			13,104	GCWDA
Chromium, Total	kg/yr	13,301	4,636	6,315	24,251	
Copper	kg/yr	1,599	19,747	6,169	27,514	GCWDA
Cyanide	kg/yr	6,205			6,205	Rohm & Hass Texas, Inc.
Daconil	kg/yr					
Dacthal	kg/yr					
Diazinon	kg/yr	15			15	GCWDA
Dichloroethane (1,2)	kg/yr	190			190	Ethyl Corporation
Dinitrotoluene (2,4)	kg/yr	80			80	Mobay Chemical Corp.
Dinitrotoluene (2,6)	kg/yr	894			894	GCWDA
Ethyl Benzene	kg/yr	6			6	Monsanto Co., Chevron Chem. Corp.
Fluoride	kg/yr	39,055	2,755,750		2,794,805	E.I. DuPont De Nemours & Co.
Grease	gal/yr	62,415			62,415	West Road WSC
Iron	kg/yr		199,655	26,974	226,629	
Isoprene	kg/yr	62			62	Chemical Exchange Industries
Lead	kg/yr	1,657	20,367	2,190	24,214	GCWDA
Manganese	kg/yr	6,607	29,273	30,405	66,284	GCWDA
Mercury	kg/yr	10	548	62	619	GCWDA
Methylene Chloride	kg/yr	1,299			1,299	Mobay Chemical Corp.
Molybdenum	kg/yr		46,720		46,720	
Napthalene	kg/yr	5			5	Monsanto Corp.
Nickel	kg/yr	2,924	39,420		42,344	GCWDA
Oil and Grease	kg/yr	616,850			616,850	GCWDA
Ortho-Nitrophenol	kg/yr	40			40	Mobay Chemical Corp.
Para-Nitrophenol	kg/yr	106			106	Mobay Chemical Corp.
Paraquat	kg/yr	28			28	GCWDA
Pentachlorophenol	kg/yr					
Pesticides	kg/yr	588			588	GCWDA
Phenol	kg/yr	3,760			3,760	GCWDA
Phosphate as Phosphorus	kg/yr					
Selenium	kg/yr	365	4,636	631	5,632	GCWDA
Silver	kg/yr	0	4,636	631	5,267	McGinnes Industrial Maint. Corp.
Styrene	kg/yr	1			1	Amoco Chemicals Co.
Sulfide	kg/yr	8,578			8,578	GCWDA
Tin	kg/yr					
Titanium	kg/yr					
Toluene	kg/yr	40			40	GCWDA
Toxaphene	kg/yr					
Trichloroethane	kg/yr	106			106	GCWDA
Trichlorophenol	kg/yr	62			62	GCWDA
Xylene	kg/yr	1			1	La Porte Chemicals Corp.
Zinc	kg/yr	73,365	70,445	45,260	189,070	Amoco Chemicals Co.

Source: Goodman (1989)

2. From 1974 to 1987 there were significant reductions in loading to Galveston Bay for chromium, copper, fluoride, manganese, mercury, nickel, oil and grease, pesticides, phenols, and zinc, with the greatest reduction being over 99 percent for oil and grease.

3. Pollutants with greater loading to Galveston Bay in 1987 compared to 1974 reported by Neleigh (1974) were arsenic, barium, beryllium, cadmium, lead, molybdenum, selenium, and silver.

4. Notable amounts of ammonia-N, chlorinated benzenes, and cyanides were discharged to Galveston Bay in the 1985-87 period.

5. Aluminum, antimony, boron, bromide, and tin were not permitted to any dischargers according to the TWC files, however, large amounts of aluminum, boron and bromide and small amounts of antimony and tin were reported as discharged to Galveston Bay by Neleigh in (1974).

6. The GCWDA Washburn Tunnel Facility contributed the greatest amount of these permitted pollutants at 9.4 percent of the Galveston Bay total followed by the Exxon Company USA at 8.3 percent.

7. The San Jacinto and Trinity Rivers clearly dominated discharge of thirteen of these pollutants considered in this study, namely arsenic, barium, beryllium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, and zinc.

The work of Neleigh (1974) and Goodman (1989) provide a basis for determining the historical trends in pollutant loading to Galveston Bay. Comparing results of the two studies, some 17 of the 25 materials decreased in loading to Galveston Bay. One of the most significant decreases has been in oil and grease. Neleigh (1974) stated that he had "reasonable confidence that since the GCWDA permit was recent and the Authority was under at least limited public control, the effluent values listed for the Washburn facility were accurate." Neleigh, however, did not extend the same confidence to the USACE self-reporting forms or to the TWQB's Waste Control Orders which formed a large part of his database in 1974. The Board, Neleigh said, did not normally list constituents, other than oil and grease, on the Waste Control Orders. For the above reasons Neleigh concluded that his estimates of mass emission rates for waste dischargers were conservative.

Additional treatment and reduced production are the most obvious reasons for the reduction of oil and grease as well as other pollutants. From the reasoning of the above paragraph, Neleigh's least conservative estimate was for oil and grease. This may be part of the reason that such a significant decrease in oil and grease, relative to other materials, is indicated between the two studies. What may be more significant was that five of the pollutants (aluminum, antimony, boron, bromide, and tin) were not permitted to any of the Galveston Bay dischargers.

Neleigh (1974) had found that the GCWDA Washburn Tunnel Treatment Plant waste flow comprised only 9 per cent of the total but contributed 25 percent, by mass, of the toxic material discharge to the Galveston Bay in 1974. The cause of this discrepancy, Neleigh thought, was due to a lack of reporting of toxic constituents by some of the dischargers. Goodman's work appeared to clarify the situation as he found the GCWDA Washburn Tunnel Treatment Plant reported about 9 per cent of the reported point source Galveston Bay mass loading and 7 percent of the total waste flow. This was a good indication of the more extensive and accurate database that was available through the TWC's monthly self-reporting forms.

Urban and rural runoff may deliver considerable amounts of pollutants to the Galveston Bay system. Neleigh (1974) found that Turtle Bayou, which had no permitted discharges at the time of his study, accounted for ten percent of the total pollutant loading. Hann and Slowey (1972) also mention urban runoff as a possible source of toxic material to the upper Houston Ship Channel.

Sources of toxic material may also include the heavy shipping traffic of the ship channel, causing hydraulic mixing and resuspension of toxic-laden sediment, and the waste from development and production of oil and gas (EPA, 1980).

2.4.3 Pacheco Et Al. (1990) Loading Estimates

More recently, Pacheco et al. (1990) estimated the discharge of conventional, nonconventional, and toxic pollutants to the Galveston Bay system as part of a larger study to estimate loadings of pollutants to the Texas coast. Their report summarized annual wastewater pollutant discharge estimates for 15 pollutants (process flow, BOD_5, TSS, total nitrogen, total phosphorus, fecal coliforms, oil and grease, and eight metals, arsenic, cadmium, total chromium, copper, iron, lead, mercury, and zinc) for 307 Major and 2,274 Minor (Major and Minor are EPA categories) point sources in the National Coastal Pollutant Discharge Inventory (NCPDI) study in Texas. The estimates reflected discharges between December 1986 and November 1987 and are organized by eight estuarine drainage areas, one of which is the Galveston Bay system. The sources they used to derive their estimates included the EPA's Permit Compliance System, the Industrial Facility Discharge File, and the 1986 Construction Grants Needs Survey, the TWC's self-monitoring reports, NPDES permit files containing monitoring data, and interviews and discussions with Commission staff.

Pacheco et al. (1990) found that less than half of all dischargers identified in the study area based on EPA information were included in the TWC inventory. They noted that the difference in these facility counts could be attributed to the fact that EPA's Permit Compliance System is required to maintain a record for every facility that discharges or proposes to discharge to surface waters, whereas the TWC only issues a discharge permit to a facility if it determines that the facility has a significant impact on the receiving water. Whether that ratio pertained to the Galveston Bay system was unclear. They did identify 173 Major and 1,122 Minor facilities in the Galveston Bay system of which 173 Major and 643 Minor facilities were used for loading estimates, and of these 816 total facilities, some 559 were wastewater treatment plants, 247 were industrial discharges, and 10 were power plants. Of the 816 facilities used, only 172 were considered significant enough to list in detailed tabular form in their report.

Discharge estimates were based on monitoring data, permit data, typical concentrations of pollutants in effluents (based on SIC category), and other information. Generally, Pacheco et al. (1990) found that monitoring data were available for flow, BOD_5 and TSS, but such data for metals were poor. Monitoring data taken from NPDES compliance monitoring results, reported in each facility's Discharge Monitoring Reports, for the period December 1986 through November 1987 were used wherever possible. If monitoring data were not available, NPDES permit limits were used. If no monitoring or permit data were available, Typical Pollutant Concentrations were used The typical concentrations were assigned based on the type of industrial or commercial activity taking place at the facility, or, if the facility was a wastewater treatment plant, the level of wastewater treatment. Daily discharge estimates were computed, adjusted to annual discharges given the number of days of discharge and adjusted seasonally if appropriate. The authors caution that the discharge estimates should be used for screening purposes only. Some facilities may have been missed, and the Typical Pollutant Concentrations were based on effluent limit development document information which was 10 to 15 years old and thus might be erroneous.

With the understanding about the completeness and accuracy of the discharge data in mind, the reader is referred to Table 2.8 which contains the estimates of pollutant discharges by Pacheco et al. (1990). Their estimates were given in pounds per year, and those estimates have been converted to kg/yr to correspond to units used herein. It is important to note that total flow includes process flow and cooling water flow and that process flow is discharge wastewater. Only 18 percent of the discharge flow to Galveston Bay was estimated by Pacheco et al. (1990) to be process water; most of the discharge flow was from once-through cooling systems. Almost 10 million kg/yr of BOD_5 was estimated to be discharged to Galveston Bay from permitted point sources, over 16 million kg/yr of TSS, just under 9 million kg/yr of total nitrogen, over 5 million kg/yr of total phosphorus, various amounts of heavy metals (most under 100,000 kg/yr), and over 8 million kg/yr of oil and grease. Except for TSS, municipal wastewater dischargers dominated loadings of all the pollutants considered.

Pacheco et al.'s (1990) loading estimates for metals from municipalities and industries were generally greater than those of Goodman (1989). The most likely reason is that Goodman based his loadings on data contained in the TWC self-reporting files only while Pacheco et al. used typical pollutant concentrations to estimate loads for discharges that did not report metal concentrations. It is unlikely that overall metal loads were increasing given the increased attention to them during third round permitting which was taking place in the late 1980s. Comparisons of Pacheco et al.'s estimates to those determined in this study will be given in Chapter 5.

Table 2.8 - Annual Pollutant Discharges by Major Source Category and Percent of Annual Total Discharge (1987)

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Item/Constituent	Units	WWTP	Industry	Power Plants	Total
Number of Facilities	No.	559	247	10	816
	%	68.5	30.3	1.2	100
Total Flow	10^9 gal/yr	174	128	914	1,216
	%	14.3	10.5	75.2	100
Process Flow	10^9 gal/yr	174	49	1	224
	%	77.7	21.9	0.4	100
BOD_5	10^3 lbs/yr	13,527	7,950	1	21,478
	%	63.0	37.0	0.0	100
	kg/yr	6,135,847	3,606,120	454	9,742,421
Total Suspended Solids	10^3 lbs/yr	17,100	18,315	122	35,537
	%	48.1	51.5	0.3	100
	kg/yr	7,756,560	8,307,684	55,339	16,119,583
Total Nitrogen	10^3 lbs/yr	16,236	3,044	4	19,284
	%	84.2	15.8	0.0	100
	kg/yr	7,364,650	1,380,758	1,814	8,747,222
Total Phosphorus	10^3 lbs/yr	10,080	1,464	2	11,546
	%	87.3	12.7	0.0	100
	kg/yr	4,572,288	664,070	907	5,237,266
Fecal Coliform Bacteria	10^9 col./yr	1,315,112	205,159	297	1,520,568
	%	86.5	13.5	<0.1	100
Arsenic	10 lbs/yr	4,682	466	10	5,158
	%	90.8	9.0	0.2	100
	kg/yr	21,238	2,114	45	23,397
Cadmium	10 lbs/yr	1,638	250	2	1,890
	%	86.7	13.2	0.1	100
	kg/yr	7,430	1,134	9	8,573
Chromium	10 lbs/yr	6,219	3,582	9	9,810
	%	63.4	36.5	0.1	100
	kg/yr	28,209	16,248	41	44,498
Copper	10 lbs/yr	5,393	1,553	759	7,705
	%	70.0	20.2	9.9	100
	kg/yr	24,463	7,044	3,443	34,950
Iron	10 lbs/yr	101,476	10,909	256	112,641
	%	90.1	9.7	0.2	100
	kg/yr	460,295	49,483	1,161	510,940
Lead	10 lbs/yr	6,480	2,775	3	9,258
	%	70.0	30.0	0.0	100
	kg/yr	29,393	12,587	14	41,994
Mercury	10 lbs/yr	43	34	0	77
	%	55.8	44.2	0.0	100
	kg/yr	195	154	0	349
Zinc	10 lbs/yr	23,934	5,774	99	29,807
	%	80.3	19.4	0.3	100
	kg/yr	108,565	26,191	449	135,205
Oil and Grease	10^3 lbs/yr	16,236	2,487	25	18,748
	%	86.6	13.3	0.1	100
	kg/yr	7,364,650	1,128,103	11,340	8,504,093

Source: Pacheco et al. (1990)

2.4.4 Newell Et Al. (1992) Loading Estimates

A parallel study to this one in the Galveston Bay National Estuary Program was the estimation of non-point source loads by Newell et al. (1992). They coupled runoff estimates with event mean concentrations for a number of discrete drainage areas around Galveston Bay (below Lake Houston and Lake Livingston) to derive loading estimates for essentially the same constituents as used herein. Three loading estimates were obtained: an average year; a wet year; and a single large storm event. The estimate most comparable to those developed in this study were those for the average year. The total non-point source loads from the entire drainage area around Galveston Bay and those for the Buffalo Bayou, White Oak Bayou, Brays Bayou, Sims Bayou, and Greens Bayou are given in Table 2.9.

Total non-point source flows during the average year amounted to 3,010,000 acre-ft/yr (4,158 cfs). This flow is about half of the freshwater inflow to the Bay from the Trinity River (at Romayor) and over the spillway at Lake Houston; thus, it represents a substantial freshwater input to the Bay. The flows contributed by the five separate drainage areas listed in Table 2.9 make up only a small portion of that total. For BOD_5, TSS, and oil and grease loadings, the separate drainage areas contribute a substantial portion of the total non-point source load while for the metals their combined contribution is proportionately smaller.

While the Newell et al. (1992) study did not deal with municipal and industrial point source discharges, the loads they estimated may be compared to those developed in this study and coupled with those from this study to provide an overall picture of major loading sources to the Bay; this is done in Chapter 5.

Table 2.9 - Non-Point Source Loads into Galveston Bay for Average (1987) Year

Point Source Load Characterization Project
Galveston Bay National Estuary Program

Flow/Constituent	Units	Total Nonpoint Sources	Buffalo Bayou	Whiteoak Bayou	Brays Bayou	Sims Bayou	Greens Bayou
Runoff Volume	10^3 acre-ft/yr	3,010	116	128	147	91	184
	MG/yr	979,502	37,748	41,653	47,836	29,613	59,877
	cfs	4,158	160	177	203	126	254
BOD_5	10^3 kg/yr	26,300	1,400	1,500	1,700	1,000	2,100
TSS	10^3 kg/yr	481,000	22,000	24,000	29,000	16,000	30,000
Total Nitrogen	10^3 kg/yr	6,420	337	365	406	235	497
Total Phosphorus	10^3 kg/yr	1,110	65	69	75	41	92
Oil & Grease	10^3 kg/yr	14,200	1,300	1,300	1,700	800	1,400
Fecal Coliforms	xE^{15}/yr	355	27	29	34	17	34
Dissolved Arsenic	kg/yr	10,500	431	472	543	335	679
Dissolved Cadmium	kg/yr	1,760	72	79	91	56	113
Dissolved Chromium	kg/yr	1,760	72	79	91	56	113
Dissolved Copper	kg/yr	10,900	445	488	561	346	702
Dissolved Lead	kg/yr	8,440	345	377	434	268	543
Dissolved Mercury	kg/yr	352	14	16	18	11	23
Dissolved Zinc	kg/yr	64,300	2,630	2,880	3,310	2,050	4,140

Source: Tables 7.1a and 7.6 of Newell et al. (1992)