8. CONCLUSIONS AND RECOMMENDATIONS

8.1 The Data Base

The principal product of this study is the compilation of a digital data base composed of water-quality and sediment-quality data from 26 data collection programs performed in Galveston Bay. This compilation included data from the three most important ongoing monitoring programs in Galveston Bay: the Texas Water Commission Stream (a.k.a., Statewide, a.k.a. Surface-water) Monitoring Network (SMN), the Texas Parks and Wildlife hydrographic observations from its Coastal Fisheries program, and the hydrographic and biochemical data of the Texas Department of Health Shellfish Sanitation Program. The important surveys and research projects sponsored by the Texas Water Development Board and maintained in its digitized Coastal Data System are included. This compilation also entailed keyboarding of other major data sets, many of which exist in limited hardcopy and are virtually unobtainable, including the Galveston District U.S. Corps of Engineers (USCE) O&M water and sediment surveys, the USCE 1970's survey of the Trinity delta, the 1957-66 chemistry monitoring program of U.S. Bureau of Commercial Fisheries, biochemical data from the 1950's and 1960's of the Texas State Department of Health, and the submerged lands project of the Bureau of Economic Geology. This project benefited from the recovery of lost major data sets accomplished in the preceding GBNEP Data Inventory project, including the Galveston Bay Project (whose digital record at the Texas Water Commission had been lost) and about half of the digital record of the above-noted USBCF chemistry program. Other entries in this compilation include numerous research projects whose data are published only in limited technical reports or academic theses, all of which were keyboarded.

In addition, the project located and keyboarded digital data records of the TAMU Houston Ship Channel studies (part of its Estuarine Systems Project of 1967-75), older Texas Game and Fish Commission hydrographic measurements, and TAMU Trinity Bay monitoring prior to construction of the HL&P Cedar Bayou Generating Station. Also, after much effort the surviving tape copies of the post-construction HL&P Trinity Bay monitoring project were deciphered and translated. While these data sets were completed in digital form too late to be incorporated into the above data compilation and associated analyses, the data will be added to the present data base in the near future.

All told, the digital compilation is the most extensive and detailed long-term record of water quality ever assembled for Galveston Bay. Each measurement record includes the date, sample depth, latitude and longitude of the sample station, measured variable, estimated uncertainty of measurement expressed as a standard deviation, and a project code identifying the origin of the data. Major efforts of the project were devoted to determination of latitude/longitude coordinates and to determination of accuracy based upon sample technique and historical precision information. Spatial aggregation of the data was accomplished by two separate segmentation systems for Galveston Bay, the present TWC Water Quality Segmentation of 40 segments, and a system of 123 hydrographic segments devised by this project and designed to depict the effects of morphology and hydrography on water properties. Each system was codified by a network of nonoverlapping quadrilaterals by which the data records could be sorted using latitude/longitude coordinates of sampling stations. Detailed statistical analyses were performed of 73 water-quality parameters and 50 sediment-quality parameters, in addition to several supplementary, screened, or transformed variables. Each statistical analysis included basic sampling density information, means and standard deviations, with three different treatments of measurements below detection limits (BDL), and a linear trend analysis over the period of usable record, with confidence limits on the slope. Therefore, statistical analyses were performed of 73 + 50 parameters in 40 + 123 different segments, a total of about 20,000 independent statistical analyses.

It is appropriate to note several deficiencies of this data set, as they relate to the interpretation of water and sediment quality, and as motivation for recommendations proffered in the concluding section. Despite the hundreds of thousands of separate measurements compiled in this study, from extensive and overlapping routine monitoring and survey programs by several state agencies and numerous special surveys, when these data are subdivided by specific parameters, each of which measures a different aspect of the water quality "climate," aggregated by region of the bay (segments) and distributed over time, the data record is seen to be rather sparse. Generally, Galveston Bay is undersampled. This is relative to the high degree of variability of the bay. Unlike a lake or a river, which can be fairly stable in time and fairly homogeneous over large areas, an estuary such as Galveston Bay is subject to a variety of external controls, all of which contribute to variation in space and time. The intermixing of fresh and oceanic waters imposes spatial gradients in both the horizontal and the vertical. The effects of tides, meteorologically driven circulations, and transient inflows all contribute to extreme variability in time. Superposed upon all of this are the time- and space-varying influences of human activities.

Adequacy of a data base is relative to the ability to resolve the various scales of variation, and therefore in this respect the data base for Galveston Bay is sparse. Continuity in space is undermined by too few stations, and by inconsistency in the suite of measurements at different stations. Continuity in time is undermined by infrequent sampling, and the replacement of one parameter by another without sufficient paired measurements to establish a relation. Past and present sampling practice does not permit analysis of time scales of variation shorter than a few days. Ability to resolve long-term trends in the face of high intrinsic variability requires data over an extended period. The extant period of record for Galveston Bay, with adequate continuity for trends analysis, extends back only to about 1965, except for some traditional parameters and for certain areas of the bay, for which the record can be extended back to the late 1950's. As salinity and temperature are the most easily measured variables, they represent the densest and longest data record. For metals and for complex organics, the period of record may extend back only a decade or so. Many of these measurements are below detection limits. For sediment, the data base is even more limited, amounting to one sample per 5 square miles per year, and is much less for some metals and organic pollutants.

Data management is generally poor. Reference is made to the conclusions of Ward and Armstrong (1991) concerning data management practices and data loss in general. We were most surprised to encounter major data management problems in the TWC SMN data base, which must be considered the central data repository for the Galveston Bay system, as well as most Texas watercourses. These problems include data entry errors, position errors, and incorporation of "bogus" measurements into the data base. An additional problem is the cumbersome data retrieval and transmittal practices of the SMN which compound the retrieval process, and frustrate graphical display and statistical processing of the data.

8.2 The Environmental Quality "Climate"

8.2.1 Water Quality

Salinity acts as a conservative property of Galveston Bay waters whose concentration is primarily determined by boundary fluxes at the inflow points and at the inlets to the sea, and internal transport and mixing. Substantial gradients across the bay are a normal feature of salinity structure, declining on average from values about 30 ppt at the inlets to the bay to about 3 ppt out from the principal points of inflow, such as the Trinity River. Variability about these mean values is high, however, with a standard deviation of 5-6 ppt throughout the bay. Salinities in the open-bay reach of the Houston Ship Channel are higher, on the order of 2 ppt, than those of the adjacent waters. Vertical stratification of bay waters is slight, by estuarine standards, generally averaging less than 0.6 ppt/m, and averaging less than 0.3 ppt/m over about half of the bay area, with no correlation with water depth. Further, these averages are skewed by inflow events, when stratification is most pronounced, and a high proportion of the data record in each segment evidence zero or even reversed stratification.

While freshwater inflow is the ultimate control on salinity, inflow proves to be a poor statistical predictor of salinity, achieving only about 50% explained variance in the data even with long-term processing of the inflow. Improved salinity prediction will require more sophisticated accommodation of the time-response dependency of salinity on inflow and other internal transports operating in the system.

There has been a general decline in salinity over the three-decade period of record, of about 0.1-0.2 ppt per year, not clearly associated with freshwater inflow. Our favored hypotheses (whose testing exceeded the scope of this study) are variations in the time signal of inflow events and the associated salinity response, reduced salinities in the adjacent Gulf of Mexico, or reduced intensity of interaction between estuary and Gulf waters.

Because salinity is a direct measure of the proportion of salt water, many water quality parameters have a general spatial distribution homologous to salinity, either decreasing or increasing from points of inflow into the lower bay and to the inlets. Because the inflow regions are also generally the foci for loadings of solids, contaminants and nutrients, there is a similar distribution in many of these variates.

The parameter pH is rather uniform, with its higher values, on the order of 8, in the more saline regions of the bay, an expression of the high buffering capacity of sea water.

Temperature in Galveston Bay is primarily controlled by surface fluxes, especially the seasonal heat budget, and much less—if at all—by boundary fluxes and internal transports. The horizontal gradient across the bay ranges 1-2°C, with the higher values in winter, with little systematic stratification, though on average a slight stratification on the order of 0.2°C/m emerges from the data. We believe this stratification to be due to near-surface heat absorption, rather than density effects. The seasonal signal is, of course, the principal source of variation in water temperature. Over the three-decade period of record, water temperature, especially in the summer, has declined in Galveston Bay at a nominal rate of 0.05°C/yr. Our favored hypothesis for this decline is an alteration in climate (e.g., air temperature, wind, cloud cover), though this could not be tested within the scope of this project.

Dissolved oxygen is generally high throughout Galveston Bay, averaging near saturation through large areas of the bay, with frequent occurrence in the data record of supersaturation. Exceptions to this are in poorly flushed tributaries subjected to inflow and waste discharges, most notorious of which is the Houston Ship Channel above Morgans Point (discussed further below and in the following section). These near-saturated conditions are a manifestation of the intense vertical mixing processes in Galveston Bay, which produce mechanical surface aeration, as well as a manifestation of photosynthetic productivity. In the open, well-aerated areas of the bay, vertical stratification is on the order of 0.4 ppm/m. This stratification is much greater than the practically negligible stratification in solubility (due to the weak stratification in temperature and salinity), and is considered to be the result of DO influx near the surface in concert with water-column and sediment biochemical oxygen consumption.

Organic oxygen-demanding constituents are measured by BOD. In Galveston Bay, BOD ranges 2-3 ppm throughout the lower bay segments, and increases inland to 4-5 ppm in the upper bay along the north and west shores, and to values greater than 5 ppm in Clear Lake and the Houston Ship Channel. Substantial reductions in waste loads into Galveston Bay have been implemented in the last two decades. In the Houston Ship Channel, which receives the bulk of waste discharges in the system, the reduction in loading has been remarkable: a factor of 20 reduction in BOD loading since 1970. Within the upper HSC, the reach above the San Jacinto confluence, the DO deficit has been reduced about 4 ppm in the past 20 years.

Like all of the Texas bays, Galveston is turbid. Long-term average suspended solids range 30-40 ppm throughout most of the bay, somewhat higher in the upper bay (above Redfish Reef) and less in the lower bay, and 40-60 ppm within the tributaries and adjacent open-water segments. (These averages are biased by the fact that nearly half the data from Galveston Bay has been collected since 1985.) Stratification in TSS is noisy, but on the order of 5 ppm/m declining upward, which is consistent with settling of larger particles to the bottom as well as a near-bottom source of particulates from scour of the bed sediments.

The remarkable feature of TSS in Galveston Bay is its decline throughout the system: over the past three decades, an average reduction of about 2 ppm/yr to current levels on the order of 20 ppm (averaged over the period since 1988). We favor the hypothesis of a general reduction of TSS loading to the bay (in contrast to one of decreased sources within the bay itself, e.g. resuspension), due to one or a combination of TSS reduction by advanced waste treatment, TSS entrapment within reservoirs, and reduced TSS in runoff because of changing land use. The relative importance of these could not be tested within the scope of this study, since it would require detailed mass-budgeting. However, we note a reduction in Trinity River TSS (both load and concentration) by a factor of three since the closure of Livingston in 1970, and we estimate an order-of-magnitude reduction in TSS load from waste discharges, similar to the reduction in BOD loading.

Nitrogen and phosphorus nutrients in Galveston Bay exhibit the same general spatial distributions as BOD and TSS, *viz.* elevated concentrations in tributaries and regions adjacent to inflow points, declining to lower concentrations at the inlets. Because these nutrients (at least in certain forms) have an affinity for fine-grain particulates, their association with TSS is more than coincidental. The levels of concentration of total inorganic nitrogen range up to about 0.2 ppm in the lower bay (below the mid-bay constriction at Redfish Reef), 0.2-0.5 in the upper bay, and as much as an order of magnitude greater in the upper Houston Ship Channel. No quantitative information exists defining an "optimal" level of nitrogen and phosphorus in Galveston Bay. These mean concentrations in Galveston Bay are more-or-less typical of other Texas bays. Copeland and Fruh (1970), in their ecological studies in the Galveston Bay Project, determined that nitrogen was probably the limiting nutrient in Galveston Bay. The results of Armstrong and Hinson (1973) were consistent with this, though these authors found indication from *in situ* productivity measurements that light may also be limiting.

These nutrients, as well as total organic carbon, all exhibit declines in concentration throughout the bay over the past two decades, total ammonia N on the order of 0.1 ppm/yr, total nitrate on the order of 0.01 ppm/yr and total phosphorus on the order of 0.05 ppm/yr. We favor the hypothesis that these reductions in nitrogen and phosphorus are a consequence of decreased wasteloads from advanced waste treatment and decreased loadings in the inflows, perhaps due to reservoir entrapment or altered land uses. (Nitrate exhibits increasing trends in the tributaries, which is almost certainly a result of increased nitrification due to advanced waste treatment. However, the net inorganic nitrogen load is decreasing.)

Total organic carbon since 1988 has averaged about 3-5 ppm in the open bay and about 8 ppm in the Houston Ship Channel. As noted above, total organic carbon exhibits baywide declining trends similar to nitrogen and phosphorus, except in West Bay (where there is no discernible trend), on the order of 0.5 ppm/yr. The recent levels given above are about one-third of the concentrations of the mid-1970's. This decline could be a direct result of reduced carbon loading, or an indirect effect of the general decline in nutrients on decreased productivity. Some credence is given the latter possibility by the decreases in chlorophyll-a in the open bay, to levels about one-half of those a decade ago.

Contaminants such as oil & grease, coliforms, metals and trace organics (pesticides, PCB's) show elevated levels in regions of runoff and waste discharge, with generally the highest values in the upper Houston Ship Channel, and generally low values in the open bay waters. The metals cadmium, copper, nickel and zinc have elevated concentrations generally throughout Galveston Bay (relative to the values presented in Moore and Ramamoorthy, 1984b, typifying uncontaminated coastal and marine waters). Most of the metals are declining in areas of maximal concentrations. While this may well be an artifact of changing analytical techniques, we favor the hypothesis that this general decline in metals is closely related to the decline in suspended solids. Most measurements of trace organics such as pesticides are below detection limits, so we have no statistically reliable information on trends.

8.2.2 Sediment Quality

The conventional organic measures and metals in Galveston Bay sediments appear to follow the same general spatial distribution as most of the water quality parameters, *viz.* elevated concentrations in regions of runoff, inflow and waste discharges, and lower, more-or-less uniform concentrations in the open bay, with the Houston Ship Channel generally the focus of maximal concentrations in the system. The available data for conventional organic measures are sparse, with large areas of the bay unsampled, and generally too noisy for reliable detection of trends.

The metals chromium and lead are generally elevated in sediments throughout Galveston Bay (relative to the data compiled in Moore and Ramamoorthy, 1984b, typifying natural aquatic systems), though, again, large areas of the bay are undersampled. The metals arsenic, cadmium, mercury and nickel are generally low, *including* the Houston Ship Channel (relative to values compiled by Moore and Ramamoorthy, 1984b). Copper and zinc follow the pattern of being low in the open bay segments and elevated in the Houston Ship Channel.

Where trends in the sparse, noisy data for sediment metals are statistically discernible (i.e., at a 5% significance), they tend to be declining, especially in the upper Houston Ship Channel. In the Channel, the rates of decline are sufficient to reduce after a decade sediment concentrations of chromium, mercury and zinc by a factor of two, copper and nickel by a factor of three, and arsenic, cadmium and lead by an order of magnitude.

8.3 Water and Sediment Quality Problem Areas

With the marshalling of the data of this project, one central concern is whether there are indicated any regions of the bay exhibiting degraded quality or exhibiting a trend of degradation that could bode an incipient problem. "Quality," of course, is a relative term; here it refers to the suitability of the watercourse to sustain biological activities and a viable ecosystem, and to support quality-limited human uses typical of the nature of the watercourse, e.g. recreation but (for an estuary) not water supply. This is quantified by the most recent standards and criteria applicable to Galveston Bay. For water quality, the sources are the Texas Surface Water Standards (TWC, 1991) and the EPA "Gold Book" (EPA, 1986). These are summarized by parameter in Table 8-1. It should be noted that the Texas Standards, as *standards*, apply both to a parameter and to a region of the bay (specifically identified by its TWC segment), while the EPA criteria pertain to a parameter in the marine or estuarine environment, without regional specificity, and therefore subject to revision as warranted by local conditions and organisms. In the present context, we regard these as convenient quantifications of parameter levels which *may* be indicative of degraded water quality.

A comparison of the mean concentrations with the criteria of Table 8-1 is given in Tables 8-2 through 8-10. As our principal concern is the present quality of Galveston Bay, we have focused on data collected since 1985, though for comparative purposes we occasionally show data prior to 1985 separately.

For temperature, the only violations of the 95°F (35°C) state standard (since January 1985) occurred in the Houston Ship Channel, Segments H1 (5.3%) and H17 (6.4%). Hyperthermality is not a problem in Galveston Bay.

The state standard for dissolved oxygen requires special comment. Prior to 1984, standards attainment was established by comparison with a surface measurement of DO. With the 1984 revisions, attainment was based upon a vertical profile of DO, either depth-integrated or "under conditions of density stratification, a composite sample collected from the mixed surface layer." This was motivated by the increasing use of mathematical models in waste allocation, because these models predict vertical-mean DO rather than surface values. Since the numerical value of the DO standard concentration was unchanged, this revision amounted to a stringent upgrade in the DO standard. For present purposes, we use the older convention of the surface measurement as a basis for comparison, for simplicity and uniformity of analysis. Also, we note that application of the state water quality standard is related to a critical threshold of freshwater inflow specific to each segment (in most cases, the low 7-day-mean flow with 2-year recurrence). For simplicity, we do not discriminate the data analysis by flow condition. Therefore, some of the conditions in Table 8-2 *et seq.* counted as "standard violations" may not in fact have been so.

Table 8-1
Standards and Criteria for Water Quality
(Table 3-1 entries in boldface)

parameter	*State of Texas Standard*	*EPA criterion (chronic) fresh*	*marine*
	WATER QUALITY INDICATORS:		
Dissolved oxygen (mg/L)	4.0 2.0 in 1006 1.0 in 1007	4[m]	
Fecal coliforms (org/100mL)	200[a] 2000[a] in: 1006 & 1007 14[a] in: 2421,2422,2423, 2424,2432,2433, 2434,2435,2439	126(406)[c]	14[s]
Temperature (°F)	95		
	METALS (dissolved):		
Arsenic (μg/L)	78	190	36
Cadmium (μg/L)	10.01	1.1	9.3
Chromium (μg/L)		11	50
Chromium (hex) (μg/L)	50		
Copper (μg/L)	4.37	12	
Lead (μg/L)	5.6	3.2	5.6
Mercury (μg/L)	1.1	0.012	0.025
Nickel (μg/L)	13.2	96	7.1
Selenium(μg/L)	136	35	54
Silver (μg/L)	0.92	0.12	
Zinc (μg/L)	89	47	58

[m] one-day minimum
[a] 30-day geometric mean
[s] shellfish harvesting, median w/<10% exceeding 43
[c] light contact recreation, 406 single-sample max

Table 8-1
(continued)

	State of Texas Standard	*EPA criterion (chronic)* *fresh*	*marine*
PESTICIDES AND RELATED PARAMETERS:			
DDT, Total (µg/L)	0.001	0.0010 (1.1)**	0.0010 (0.13)
DDE, Total (µg/L)		0.0010 (1.1)	0.0010 (0.13)
DDD, Total (µg/L)		0.0010 (1.1)	0.0010 (0.13)
Chlordane, Total (µg/L)	0.004	0.0043 (2.4)	0.0040 (0.09)
Dieldrin (µg/L)	0.0019	0.0019	0.0019
Endosulfan (µg/L)	0.0087		
Endosulfan-I (µg/L)		0.056	0.0087
Endrin (µg/L)	0.0023	0.0023	0.0023
Toxaphene (µg/L)	0.0002	0.013	
Heptachlor (µg/L)	0.0036	0.0038	0.0036
Methoxychlor (µg/L)	0.03	0.03	0.03
PCB's, Total (µg/L)	0.03	0.014	0.030
Malathion (µg/L)	0.01	0.1	0.1
Parathion (µg/L)		0.04	0.04
2,4,5 Trichlorophenol	12		
Hexachlorobenzene (µg/L)		30	129
PAH, Total (µg/L)			300*
Napthalene (µg/L)		620	
Acenaphthene (µg/L)		520	500
Fluoranthene (µg/L)			16

* acute toxicity
** instantaneous values in parentheses

TABLE 8-2

Frequency of occurrence
of surface dissolved oxygen (WQDO within upper 0.5 m) less than 4.0 ppm
All measurements after 31 December 1984

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
C1	0	0	0	0	0.3333	0	0	0	0	0	0	0	0.0244
C2	0	-	0	0	0	0	0	0	0	0	0	0	0
C3	-	0	-	-	0	-	-	-	-	-	0	-	0
C4	-	-	-	0	-	-	0	-	-	-	0	-	0
C5	0	0	0	0	-	0	0.1667	0	0	0	0	0	0.0149
C6	0	0	0	0	0	0	0	0	0	0	-	0	0
D1	0	-	-	0.1667	-	-	0	-	-	0.2	-	-	0.087
D2	-	0	0	-	0	0	0	-	0	0	0	-	0
D3	0	0	0	0.125	0	0	0	0.5	0	0	0	-	0.0526
D4	0	0	0	0	0	0	0	0.3333	0	0	0	0	0.0417
D5	-	0	-	0	0	-	-	0	0	0	0	0	0
E1	0	0	0	0.0192	0.0377	0	0.0222	0	0.0238	0	0	0	0.011
E2	0	0	0	0	0.0227	0.0256	0.0357	0.0323	0	0	0	0	0.0095
E3	0	0	0	0	0	0	0	0	0.2222	0	0	0	0.025
E4	0	0	0	0.1333	0	0	0.5	0	0	0	0	0	0.0288
E5	0	0	-	0	0	0	0	1	0	0	0	-	0.0417
E6	-	-	0	0	-	-	0	-	-	0.5	0	-	0.0833
E8	-	-	-	0	-	0	0	-	-	-	-	-	0
E9	0	0	0	0	0	-	0	0	-	-	-	-	0
E10	-	0	-	0.5	-	-	-	-	-	-	-	0	0.25
G1	0	0	0	0	0	0.25	0	0	0	0.4	0.5	0	0.1
G2	0	0	0	0	0	0.5	0.25	0	0	0	0	0	0.069
G3	0	0	0	0	0	0	0	0	0	0	0	0	0
G4	0	0	0	0	0.3636	0	0	0	0	0	0	0	0.0471
G5	0	0	0	0	0	0	0	0	0	0	0	0	0
G6	0	0	0.0714	0	0	0	0	0	0.2	0	0	0	0.0273
G7	0	0	0	0.1	0	0	0	0.0769	0.0625	0.1333	0.05	0	0.029
G8	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 8-2

(continued)

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
G9	0	0	0	0	0	0.1875	0	0	0	0	0	0	0.0185
G10	0	0	0	0	0	0	0	0	0	0.3333	0.125	0	0.0167
G11	0	0	0	0	0	0	0	0	0	0	0	0	0
G12	0	0	0	0	0	0	0	1	0	0	0	0	0.0217
G13	0	0.1	0	0	0	0	0.2	0	0	0	0.1111	0.0625	0.0317
G14	0	0	0	0	0	0	0	0.2	0	0	0	0	0.0208
G15	0	0	0	0	0	0	0	0	0.25	0	0	0	0.011
G16	-	0	0	0	0	0	0	0	0	0	0	0	0
G17	-	0	0	0	0	-	0	0	1	0	0	1	0.1429
G18	0	0	0	0	0	0	0	0	0	0	0	0	0
G19	0	0	0	0	0	0	0	0	0	-	0	0	0
G20	0	0	0	0	-	0	-	0	0	-	0	0	0
G21	-	-	0	-	-	-	0	-	-	-	-	-	0
G22	0	0	-	0	0	0	0	0	-	0	0	0	0
G23	0	0.25	0	0	0.0909	0	0	0	0.2857	0.1667	0	0	0.0789
G24	0	0	0	0	0	0	0	0	0	0.1111	0	0	0.0062
G25	0	0	0	0	0	0	0	0	0.125	0	0.5	0	0.0319
G26	0	0	0	0	0	0	0	0	0.1333	0	0.0476	0	0.0138
G27	0	0.0556	0	0	0.0417	0	0	0	0	0	0	0	0.0078
G28	0	0	0	0	0	0.0625	0	0	0	0	0	0	0.0105
G29	0	0	0	0	0.0625	0	0	0	0	0	0	0.2	0.0159
G30	0	0	0	0.1111	0	0.0625	0	0	0.2143	0	0	0	0.0297
G31	0.0833	0	0	0	0	0	0.0345	0	0.1667	0	0	0	0.024
G32	0	0	0	0	0	0	0	0	0	0	0.0714	0	0.0067
G33	-	0	0	-	-	0	0	-	-	0	-	-	0
G34	0	0	0	0	0.2	-	0	0.5	0	0	-	0	0.0909
G35	0	0	0	-	0	0	0	-	0	-	0	0	0
G37	-	0	0	-	0	0	-	0	0	-	0	0	0
G38	-	-	-	0	-	-	-	-	-	-	-	-	0

TABLE 8-2

(continued)

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
H1	0	0	0	0	0	0	0	0	0.1429	0	0	0	0.013
H2	0	0	-	0	-	-	0	-	-	0	0	-	0
H3	0	0	-	0	0.1429	0.3333	0	-	0	0	-	-	0.069
H4	0	0	-	0	0	0	0	0	-	0	0	-	0
H5	0	0	0	0	-	-	0	-	0	0	0	0	0
H6	-	-	-	0	0	-	-	0	0	-	-	-	0
H7	0	0	0	-	-	-	-	0	-	0	0	-	0
H8	0.25	0	-	0	-	-	0	-	-	0	0	-	0.04
H9	-	-	0	-	-	0	-	-	-	-	-	-	0
H10	0	0	-	0	-	0	0	-	0	0	0	0	0
H11	0	0	0	0	0	0.4	0.3333	0	0.1667	0	0	0	0.0676
H12	-	0	-	-	-	-	-	-	-	-	-	-	0
H13	0	0	0	0	0.75	1	0.8571	1	1	0.2	0	0	0.3582
H14	0	0.1429	0	0	1	1	1	1	1	-	-	-	0.3636
H15	0	0.1818	0.5	0.5	1	1	1	1	0.8	0.6	0.4	0	0.5373
H16	0	0.8	-	-	-	-	-	-	-	0	-	-	0.5714
H17	0.0833	0.1154	0.5714	0.8333	1	1	0.9524	0.9	0.8947	0.9167	0.3571	0.2727	0.6561
H18	-	0	-	-	-	-	-	-	-	-	-	-	0
H19	0	0.1818	0.75	0.3333	0.6	0.6	0.6667	1	1	0.4	0.6	0	0.4545
H20	0.1667	0.1429	0.3333	0.3333	0.1111	0.5625	0.75	0.6667	0.9231	0.2222	0.1818	0	0.415
M1	0	-	-	-	-	-	-	-	-	-	-	0	0
M4	-	-	-	-	-	-	-	-	0	-	-	-	0
S1	-	0	-	0	-	-	-	-	-	-	-	-	0
T1	0	0	0	0	0	0	0	0	0.2	0	0.1429	0	0.0231
T2	0	0	0	0	0	0	0	0	0	0	0.1667	0	0.0141
T3	0	0	0	0	0	-	0	0	0	0	0	-	0
T4	0	0	0	0	0	0	0	0	0	0	0.25	0	0.027
T5	0	0	0	0	0	0	0	0.0909	0	0	0.125	0	0.0328
T6	0	0	0	0	0	0	0.25	0	0	0	0.3333	-	0.0909
T7	-	-	-	-	-	-	-	-	-	-	-	0	0

TABLE 8-2

(continued)

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
T9	0	0	-	0	0	-	0	0.25	-	0	0	-	0.05
T10	0	0.0714	0	0	0	0	0	0	0.0909	0	0.2857	0	0.0241
T11	0	0	0	0	0	0	0	0.0667	0	0	0	0	0.0112
T12	0	0	0	0	-	0	-	0	1	-	0	-	0.0833
T13	-	-	-	-	-	-	-	0	-	-	-	-	0
T14	0	0	0	0	0.125	0	0	0	0	0	0	0	0.0222
T15	0	0	0	0	0.3077	0	0	0	0	0	0	0	0.0597
T16	0	-	-	-	0	-	0	-	0	-	0	0	0
T17	-	-	0	-	-	-	-	-	-	-	0	-	0
W1	0	0	0	0	0.0294	0.0909	0	0.4	0	0.05	0	0	0.0347
W2	0	0	0	0	0	0	0.25	0.1111	0.3333	0	0	0	0.0362
W3	0	-	0	0.2	0.2222	0	0	-	1	-	0	0	0.1818
W4	0	0	0	0	0	0.1429	0	0	0.0625	0	0	0	0.0177
W5	0	0	0	0	0	0.3333	0	0	0	0	0	0	0.0238
W6	-	0	0	0	0	0	0	-	0	0	0	0	0
W7	0	0	0	0	0.3333	0	0	0	0	0.1111	0	0	0.0392
W8	-	0	0	0	-	0	0	0	0	0	0	0	0
W9	0	0	0	0	0	0.1	0	0	0.0417	0	0	0	0.0137
W10	0	0	0	0	0.0714	0.3	0	0	0	0.1667	0	0	0.0438
W11	0	0	0	0	0.0588	0.1875	0	0	0.2353	0	0	0	0.0537
W12	-	-	0	-	0	0	0	-	0	0	0	-	0
W13	0	0	0	0	0	0	0	0	0.2	0	0	-	0.025
W14	0	-	0	0	0	0.1429	0	0	0	0.3333	0	0	0.0253
W15	-	0	0	0	0	0	0	0	0	0	0	0	0
W16	0	0	0	0	0.0556	0.1	0	0	0.087	0	0	0	0.0364
W17	0	0	0	0	0	0	0	0	0.5	0	0	0	0.0213
W18	0	0	0	-	0	0	-	0	0	0	0	0	0
W19	0	0	0	0	0.3333	0	0	0	-	0	0	0	0.0455
W20	-	0	-	0	0	0.25	-	0	0	0	-	-	0.05
W21	-	0	0	0	0.1667	0	-	0.5	0.1667	0	0	0	0.0833

TABLE 8-3

Frequency of occurrence
of surface dissolved oxygen (WQDO within upper 0.5 m) less than 2.0 ppm
Houston Ship Channel TWC Segments 1005 and 1006

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
TEXAS WATER COMMISSION SEGMENT 1005													
measurements before 1 January 1985													
H1	0	0	0.0714	0.0588	0.0833	0	0.0278	0	0	0	0	0	0.0179
H7	0	0	0	0.1702	0.1633	0.0833	0.0833	0.0469	0.2353	0.0303	0.1429	0.0702	0.0903
H11	0.1538	0.0303	0.1	0.12	0.125	0.0714	0.2245	0.125	0.3143	0.3235	0.1852	0.3226	0.1795
H12	0.0769	0	0.0909	0.2	0.2143	0.375	0.1818	0.1481	0.6957	0.2083	0.3529	0.05	0.2312
measurements after 1 January 1985													
H1	0	0	0	0	0	0	0	0	0	0	0	0	0
H7	0	0	0	-	-	-	-	0	-	0	0	-	0
H11	0	0	0	0	0	0	0	0	0	0	0	0	0
H12	-	0	-	-	-	-	-	-	-	-	-	-	0
TEXAS WATER COMMISSION SEGMENT 1006													
measurements before 1 January 1985													
H13	0.2857	0.1304	0.15	0.2727	0.2414	0.6	0.425	0.7576	0.6129	0.5385	0.3462	0.4231	0.4164
H14	0.5294	0.4444	0.56	0.5217	0.7037	0.9375	0.7429	1	1	0.6471	0.4545	0.6429	0.68
H15	0	0.1538	0.4286	0.2	0.9333	0.8571	0.875	0.7143	0.8125	0.6	0.2	0.0833	0.5455
measurements after 1 January 1985													
H13	0	0	0	0	0	0.2	0	0	0	0	0	0	0.0149
H14	0	0	0	0	0	0	0	0.5	0	-	-	-	0.0455
H15	0	0	0	0	0.5	0.4	0.5	0.2	0	0	0	0	0.1194

TABLE 8-4

Frequency of occurrence
of surface dissolved oxygen (WQDO within upper 0.5 m) less than 1.0 ppm
Houston Ship Channel TWC Segment 1007

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
						measurements before 1 January 1985							
H16	1	1	0.5	0.6667	0.8	1	0.1818	0.4286	0.75	0.6667	1	1	0.5593
H17	0.1	0.129	0.375	0.4444	0.6667	0.6	0.4146	0.4177	0.4286	0.375	0.1563	0.1333	0.3655
H18	0	0	0	0.2	0	0.4	0.5	0.56	0	0	0	0	0.2973
H19	0.3158	0.3333	0.5556	0.7059	0.6087	0.7619	0.6296	0.641	0.4783	0.55	0.6471	0.3889	0.5615
H20	0	0.0769	0.375	0.3636	0.2258	0.1538	0.1739	0.28	0.1481	0.3684	0.25	0.125	0.2066
						measurements after 1 January 1985							
H16	0	0	-	-	-	-	-	-	-	0	-	-	0
H17	0	0	0	0	0	0.2353	0.1429	0.15	0.0526	0	0	0	0.0582
H18	-	0	-	-	-	-	-	-	-	-	-	-	0
H19	0	0	0	0	0	0	0.1667	0	0	0	0	0	0.0152
H20	0	0	0	0	0	0	0	0.1333	0	0	0	0	0.0136

TABLE 8-5

Frequency of occurrence of monthly geometric-mean fecal coliforms (WQFCOLI) above 200/100 mL, applicable segments, measurements before 1 January 1985

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
C1	0.8	0.5714	0.6667	0.125	0.4	0	0.4	0.5	0.125	0.5	0.6667	0.75	0.4684
C2	0.5	0.125	0.3333	0.3333	0.125	0	0.1429	0.2	0.1429	0.1667	0.75	0.6667	0.2597
C3	-	0.3333	0.3333	1	0	-	0	0	0	0	-	-	0.1875
C5	0.3636	0.375	0.3333	0.3	0.1667	0	0.3333	0.2	0	0.4	1	1	0.3448
D1	0.8	0.75	0.6667	0.5385	-	0	0.8333	0.5	1	0.6667	0.5	0.5	0.6667
D2	0.4	0.25	0.5	0.3333	0.5	0.8	0.5	0.6667	1	0.1	0.5	0.6667	0.4355
D3	0.5	0	0.1667	0	0	0	0	0	0	0	0	0	0.06
D4	0.3333	0.1	0	0.1429	0	0.1667	0.1667	0	0.2	0.3333	0	0.4	0.1176
D5	0	0.25	0	0	0	0	0	0	0	0	0	0.3333	0.069
G2	-	0	-	-	0.2857	0	0	0	0	-	0.125	0	0.0769
G22	0.5714	0	0	0	0	0	0	0	0.3333	0	0	0	0.0926
H1	0.3636	0.0909	0.1667	0	0.2143	0.0833	0.1818	0	0.1538	0	0.0833	0.0833	0.1197
H2	0.3333	0	-	0	0	-	0	0	0	0	0	-	0.0526
H3	0	0	-	0	0.2	-	0	0	0	0.25	0	-	0.0909
H4	0	0	-	0.4	0	-	0.75	0	0	0.1667	0.5	-	0.2188
H5	0.4286	0	-	0.1667	0	-	0	0	0	0.2	0	-	0.1429
H7	1	1	1	1	0.6667	0	0	0	0.6667	0.3333	1	0.5	0.5769
H8	0.7143	0	-	0	0.25	-	0.2	0	0	0.2	0	-	0.2093
H10	0.5	0	-	0.1667	0	-	0.1667	0	0	0.1111	0	-	0.1463
H11	0.625	0.6923	0.6667	0.4	0.5333	0.1667	0.5455	0.2222	0.4615	0.3571	0.8182	0.6	0.5072
H12	-	-	-	-	1	-	-	-	-	-	-	-	1
S1	1	1	1	1	1	0.5	0.6667	0.5	1	0.6667	1	1	0.8462
T9	0.1818	0.5	0	0.2	0	0	0.3333	0.5	0	0.4	0.6667	0.25	0.2687
T17	0.75	0.5	0.5	0.3333	-	0.3333	0	0	1	0.3333	0	-	0.4167
T18	0.75	1	0.5	0.3333	0	0	0.6667	0	1	0.3333	0	-	0.4444
W18	0	0	0	0	0	0	0	0	0.1	-	0	0	0.0159

TABLE 8-6

Frequency of occurrence of
monthly geometric-mean fecal coliforms (WQFCOLI) above 200/100 mL,
applicable segments, measurements after 1 January 1985

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
C1	0	1	0.75	0.5	1	0	0	0	0.6	1	1	0	0.4138
C2	0	1	0.3333	0	-	0.3333	0	0	0.3333	1	1	0	0.2609
C3	-	1	-	-	-	0	-	-	-	-	-	-	0.5
C5	0	1	0.3333	0	-	0	0	0	0	1	1	0.2	0.2174
D1	0.8333	-	-	0.8	-	-	0.6	-	-	0.6	-	-	0.7143
D2	0	-	0	-	1	-	0	-	-	0	0	-	0.125
D3	0.1667	0.4	0.25	0	0.1667	0	0	0	0	0	0.5	0.2	0.15
D4	0	-	-	0	0.5	0	0	0	0	0	0	-	0.0714
D5	0	-	-	-	-	-	-	-	-	-	-	-	0
G2	0	0	0	0	0	-	0.25	0	0	0	0	0	0.0526
G22	0.2	0	0	0	0	0	0.2	0	0	0	0	0	0.0444
H1	0.1667	0	0	0	0	0	0.1429	0	0	0	0.3333	0.1667	0.0676
H2	0.2	0	-	0	-	-	0.2	-	-	0	0	-	0.1176
H4	0.25	0	-	0	1	-	0	0	-	0.3333	0	-	0.1667
H5	0.2	0	-	0	-	-	0.2	-	-	0	0	-	0.0952
H8	0	0.5	-	0	-	-	0.2	-	-	0	0	-	0.1176
H10	0.25	0.5	-	0.3333	-	-	0.2	-	-	0	1	-	0.2941
H11	0.25	0	0.1667	0.5	0	0	0.25	0	0	0.2	0.6	0.8	0.2407
T9	0.5	0	-	0	0.3333	-	0	0.25	-	0	0	-	0.1579
T18	0	-	0	-	-	0.5	-	0	-	-	1	-	0.3333
W3	0.5	0.25	0.3333	0	-	0	0	-	-	0	0	0	0.1579
W8	-	1	0	0	-	0	0	-	0	1	-	0.3333	0.2353
W18	0	0	0	0	0.2	0	0	0	0	0	0	0	0.0333

TABLE 8-7

Frequency of occurrence of monthly geometric-mean fecal coliforms (WQFCOLI) above 14/100 mL, measurements before 1 January 1985

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
						TWC SEGMENT 2421							
G1	0.5714	0.6	1	0.6	0.5	0	0.2222	0	0.5	0.25	0.4	0.75	0.4462
G3	0.2222	0	0.5	0	0.4	0	0.3333	0.1667	0.3333	0.1429	0.3333	0.4	0.25
G4	0.625	1	0.75	0.5714	0.5	0.4	0.3333	0.1429	0.6667	0.6667	0.25	0.25	0.5263
G5	0.3333	0.2	0.4444	0.1429	0.2857	0	0.2	0.1429	0.2857	0.2	0	0.2	0.2143
G6	0.5	0.25	1	0.6	0.5714	0.5	0.5	0.3333	0.2	0.75	0.4	0.75	0.5303
G10	0.5	0.3333	1	0.4	0.2	0	0	0	0.6667	0	0.25	1	0.3409
G13	0.5	0	0.2	0.2222	0.3	0.25	0.2727	0	0.6667	0.0909	0.1	0.4444	0.2404
G15	0.4444	0.8333	1	0.5	0.5714	0.2857	0.1	0.1667	0.5714	0.2	0.6	0.4	0.4699
G16	1	0.5	1	1	0.5	0	0	0	0	0	0	0	0.3077
G17	0.5	0.5	0	0	0.25	0	0	0	0	0	0	0.5	0.1471
G18	0.375	0	0.2222	0.3333	0.1429	0.1	0.1	0.1818	0.1111	0	0.1111	0.1111	0.1393
G23	0.7143	0.5	0.4286	0.2	0.3333	0.25	0.125	0	0.6667	0	0.3333	0.5	0.3125
G24	0.4	0.5	0.2222	0.4286	0	0	0.2222	0	0.1429	0	0.1667	0	0.1566
						TWC SEGMENT 2422							
T1	0	0.5	0	0	0.4	0	0.2	0	0	0	0	0	0.0976
T2	0.5	0.2727	0.375	0.6667	0.3	0.1429	0.2857	0.125	0	0.2	0.375	0.3333	0.2889
T3	1	0.25	0.5	1	0.4286	0	0	0.25	0	0	0.8333	1	0.4146
T4	0	0	0.125	0.1429	0	0	0.1667	0	0	0	0	0.5	0.0741
T5	0	0.25	0	0	0.2727	0	0.1111	0.1111	0	0	0.2	0.1667	0.1122
T6	0.75	0.5	0.6667	0.5	0.5	0.25	0	0.2	0.5	0.2222	1	0.6667	0.431
T10	0.2222	0	0.0769	0.3	0	0	0.125	0	0	0	0.25	0.1667	0.101
T11	0.5	0.4167	0.5	0.4286	0.3	0	0.125	0.25	0	0.0909	0.3333	0.3333	0.2766
T12	1	0.5	0.3333	0.5	0.3333	0	0	-	0	0	-	0.5	0.3182
T15	1	1	1	0.5	1	0.75	0.6667	1	1	0.6667	0	-	0.7857

TABLE 8-7
(continued)

segment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	all data
						month							
						TWC SEGMENT 2423							
E1	0	0.1667	0.25	0.1667	0	0.25	0.1667	0	0	0	0	0	0.0847
E2	0.3333	0.3	0.1667	0.1429	0.1	0	0	0.125	0	0	0	0	0.1047
E3	1	0	0.5	0.3333	0.3333	1	0	0	1	0	0.5	-	0.3913
E4	1	0	0.5	0.3333	0.6667	0.5	0	0	1	0	0.5	-	0.3913
E5	1	-	-	-	-	-	-	-	-	-	-	-	1
						TWC SEGMENT 2424							
W4	0	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0.1154
W5	-	0	-	-	0	0	-	0	0	-	0	0	0
W6	0.2	0.5714	0.6667	0.1429	0.4	0	0	0	0.2	0.1429	0.3333	0	0.2063
W9	0	0	0	0	0.5	0	0	0	0	0	0	0	0.0294
W10	0	0	0	0.1111	0.1429	0.1667	0	0	0	0	0	0	0.0313
W11	0.25	0.25	0	0	0.5	0	0	0	0	0	0.5	0	0.1081
W12	0.25	0.75	0	0.1429	0.25	0	0	0	0	0.3333	0.2	0	0.1569
W13	0.75	0.75	0.5	0.4	0.5	0	0	0	0	0	1	0	0.3333
W15	0.5	0.2222	0.8	0.2	0.2	0	0	0	0.1667	0	1	0	0.2295
						TWC SEGMENT 2432							
W7	1	0.8571	0.4	0.4	0.25	0	0	0.125	0.25	0.4	0.75	0.1667	0.3667
						TWC SEGMENT 2433							
W2	0.3333	0.375	0.1667	0	0.25	0.2	0	0	0.2	0.6667	0.2	0	0.1833

TABLE 8-7
(continued)

segment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	all data
						month							
						TWC SEGMENT 2434							
W1	0	0	0	-	0	0	0	0	0	0	0	0	0
						TWC SEGMENT 2439							
G7	0.2727	0	0.1818	0.1111	0.0625	0	0	0.0909	0	0.1667	0	0	0.0758
G8	0	0	0	0	0.3333	0	0	0	0	-	0	0	0.0345
G9	0	0.6667	1	0.5	0	0.5	0.3333	0.5	0.6667	0	0	0.5	0.3793
G14	0.5556	0.25	0	0.25	0.1667	0.2	0.125	0	0.3333	0.1	0.125	0	0.1733
G19	0.25	0	0.1818	0.1111	0.1	0.1429	0.1538	0	0	0	0	0.1111	0.0965
G20	0.1429	0.1429	0.2	0.1429	0.2857	0.4	0.1667	0	0.5714	0.125	0	0.25	0.2
G29	0	0	0.25	0.1667	0	0.25	0.2	0	0	0	0	0	0.0702
G30	0.2	0.1	0.1	0	0.0833	0.1111	0.1111	0	0	0	0	0.125	0.069
G32	0	0	0	0	0.1429	0.3333	0	0	0	0	0	0	0.0351
G34	0	0.25	0	0	0	0	0	0.25	0	0	0	0	0.0625
G36	1	0.3333	0.5	0.25	0.3333	0.6667	0.5	0	0	0.3333	0.5	0	0.3514
G37	-	-	-	-	-	-	-	-	0	-	-	-	0
W16	0.8571	0.7273	0.7	0.875	0.8	0.8333	0.7778	0.2222	0.4615	1	0.5	0.6	0.6733
W17	0	0	0	0	0.3333	0	0	0	0	-	0	0	0.0435
W19	0.2	0	0.125	0	0.125	0.2857	0	0	0.2727	0	0.3333	0	0.1184
W21	0.3333	0.8	0.5714	0.6667	0.6667	0.6	0.5	1	0.3333	0.5	1	0.6667	0.6

TABLE 8-8
Frequency of occurrence of monthly geometric-mean fecal coliforms (WQFCOLI) above 14/100 mL, measurements after 1 January 1985

segment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	all data
						month							
						TWC SEGMENT 2421							
G1	0.75	1	0.6667	0	0	0.6667	-	0	0	0	0.5	0.3333	0.4074
G3	0.1667	0	0.4	0	0	0	0	0	0.25	0.2	0.25	0.1667	0.1296
G4	0.7143	1	0.6667	0.25	0.25	0.3333	0	0	0.5	0.6667	0.6667	0.6	0.5217
G5	0.2857	0.3333	0.1429	0.1667	0.4	0	0	0	0	0.4	0	0.3333	0.1897
G6	0.4286	0.2	0.7143	0.3333	0.4	0.5	0	0.1667	0.6	0.5	0.6	0.5	0.4242
G10	0.5	1	0.3333	0	0	0	-	0	0	0	0.3333	0.3333	0.2188
G13	0	0.25	0	0.1429	0	0	0	0	0	0.2	0.3333	0.1667	0.0896
G23	0.6	0.3333	0.6667	0.3333	0	0	0	0.25	0	0.3333	0.4	0.6	0.3256
G24	0.1667	0.25	0	0.2857	0	0.1667	0	0	0	0	0.2	0.3333	0.1311
G26	0	-	-	-	-	-	-	-	0	-	-	-	0
						TWC SEGMENT 2422							
T1	0.25	0.5	0.6667	0.5	0	0	0	0	0	0	0	0.2	0.1538
T2	0	0.5	0.3333	0	0	0	0	0.3333	0	0	0	0	0.0833
T3	0	1	-	0	0.6667	-	-	0	-	-	0.2	-	0.2941
T4	0	0.5	0.1667	0	0	0	0	0	0	0	0	0.2	0.0638
T5	0.25	0.25	0.3333	0	0	0	0	0	0	0	0	0.25	0.098
T6	0.3333	1	1	0	0	0.25	0	0	0	0	0.75	0	0.3214
T10	0.1667	0	0.1667	0	0	0	0	0	0	0.25	0	0.3333	0.0962
T11	0.25	0.25	0.2	0	0	0	0	0	0	0	0.1667	0.25	0.098
T12	-	1	1	-	-	1	-	-	-	-	0	0	0.6
T15	1	-	0	-	-	0.5	-	1	-	-	1	-	0.6667

TABLE 8-8
(continued)

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
						TWC SEGMENT 2423							
E1	0.2	0	0	0	0	0	0	0	0	0	0	0	0.0217
E2	0.2	0.3333	0.2	0	0.1667	0	0	0	0	0.25	0	0.25	0.1224
E3	0.6667	0.5	0.6667	0	0	0	0	-	-	-	0	0.3333	0.3529
E4	1	0.5	0.6667	0	0	0	0	-	-	-	0	0.3333	0.4444
						TWC SEGMENT 2424							
W4	0	-	0	-	-	0.5	-	-	0	1	0	0	0.1333
W6	0.3333	0.5	0.3333	0	-	0	-	-	-	0	0	1	0.2667
W9	0	0.5	0	0	-	0	-	-	-	0	0	0	0.0625
W10	0	0.2	0	0	-	0.25	0	0	0	0	0	0	0.0426
W11	0.2	0.5	0.1667	0	-	0	-	-	-	0	0	0.25	0.1471
W12	0.25	0.4	0.1667	0	-	0	1	-	-	0	0	0.25	0.1667
W13	0.3333	0.5	0.6667	0.6667	-	0	-	-	-	0	0	0.5	0.4118
W14	-	-	0.5	0	-	0.6667	-	-	0	0	-	0.3333	0.3125
W15	0.2	0.25	0.6667	0.1667	-	0.25	-	0	0	0	0	0.1667	0.2045
W21	-	0.5	0.25	0	0	0.25	-	0	0.3333	-	0	0	0.1818
						TWC SEGMENT 2432							
W7	1	-	0.3333	-	-	0	-	-	0	-	1	0.5	0.4118
						TWC SEGMENT 2433							
W2	0.25	0.25	0.2	0	-	0.25	0	-	-	0	0.3333	0	0.1613

TABLE 8-8
(continued)

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
						TWC SEGMENT 2434							
W1	0	0	0	0	-	0	0	-	-	0	0	0	0
						TWC SEGMENT 2439							
G7	0.1429	0.2857	0.1429	0	0	0	0	0	0	0	0.3333	0.3333	0.1111
G8	0.25	0.3333	-	-	0	0	-	0	-	0	-	-	0.1667
G14	0.1429	0.25	0.4286	0.1429	0	0	0	0	0	0.4	0.5	0.1667	0.1818
G15	0.6667	0.8	0.6667	0.8	0.6667	0	0.25	0	0.5	0	0.4	0.5	0.4407
G16	0	0.5	0.5	0.3333	0	0.3333	0	0	1	0.5	0.3333	0.2	0.3
G17	0.2857	0.3333	0.6	0.2	0	0.25	0	0	0.25	0.2	0	0.2	0.2157
G18	0.1429	0.2	0.1429	0.1429	0	0	0.1429	0	0	0	0	0.1667	0.0833
G19	0	0.1667	0	0.1429	0	0	0	0	0	0	0.1667	0.1667	0.0556
G20	0.1667	0.25	0.2	0.4	0	0	0	0	0	0	0.25	0.2	0.125
G29	0	0	0	0	0	0	0	0	0	0	0	0.2	0.0208
G30	0.125	0.2	0	0	0	0	0	0	0	0	0	0.1667	0.0455
G32	0	0	0	0	0	0	0.3333	0	-	0	0	0	0.0526
G34	0	0.3333	0	0	0	0	0	0	-	0	0	0	0.0357
G37	-	0.5	0	-	0.5	1	-	0.2	-	-	0	0.5	0.3333
W16	0.2	0.4	0	1	0.8	0.5	0	0.3333	-	0	0.25	0	0.3333
W17	0	0.5	0	0	0	0	0	0	-	0	0	0.5	0.1053
W19	-	0	-	-	-	-	-	-	-	-	-	-	0

TABLE 8-9

Frequency of occurrence of monthly geometric-mean fecal coliforms (WQFCOLI) above 2000/100 mL, Upper Houston Ship Channel

segment	month												all data
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Measurements before 1 January 1985													
TWC SEGMENT 1006													
H13	0.625	0.1818	0.3	0.25	0.1538	0.1111	0.5	0.1818	0.1111	0.1	0.5455	0.1	0.2542
H14	0.75	0.75	0.75	0.6667	0.6667	0.5	0.5	0.6667	0.75	0.75	1	0.6667	0.6923
H15	0.7	0.5455	0.5833	0.2727	0.4615	0.3333	0.625	0.2	0.4615	0.4167	0.6667	0.3333	0.4632
TWC SEGMENT 1007													
H16	1	1	1	1	1	1	0.6667	0.5	1	1	1	1	0.9231
H17	0.6429	0.7692	0.7857	0.7692	0.8667	0.7143	0.9167	0.9231	0.6875	0.9333	0.6923	0.8571	0.7952
H18	0.75	0.6	1	1	0.6	0.6	0.6	0.8	0.75	1	0.6667	0.5	0.74
H19	0.6429	0.6923	0.7143	0.6364	0.7333	0.7857	0.6667	0.8571	0.75	0.8571	0.7143	0.7692	0.7378
H20	0.3333	0.625	0.5714	1	0.7778	0.5	1	1	1	0.8	0.7778	0.5	0.7375
Measurements after 1 January 1985													
TWC SEGMENT 1006													
H13	0.4	0	0	0	0	0	0.2	0	0	0	0.6	0.2	0.1207
H15	0.4	0.25	0.1667	0.2	0.25	0.1667	0.2	0	0.2	0.25	0.6	0.6	0.2667
TWC SEGMENT 1007													
H17	0.6	0.5	0	0.4	0.5	0.5	0.3333	0.5	0	0.4	0.8	0.4	0.4032
H19	0.2	0.2	0	0.4	0.6	0.6	0.4	0.5	0.8	0.6	0.6	0.6	0.4483
H20	0.3333	0.25	0.2	0.5	0.25	0.6	0.4	0.8	0.5	0.5	0.8	1	0.5192

TABLE 8-10

Frequency of occurrence of violations of metals criteria (Table 8-1), measurements after 1 January 1985

seg-	As	---Cd---		---Cr---		Cu	Pb	Hg	---Ni---		---Se---		Ag	---Zn---	
ment	mar	frsh	mar	frsh	mar	frsh	frsh	frsh	frsh	mar	frsh	mar	frsh	frsh	mar
C6	0	0	0	0	0	0	1.000	0	0	1.000	0	0	-	0	0
E5	0	0	0	0	0	0	0	0	0.333	0.667	0	0	-	0.333	0.333
E6	0	0	0	0	0	0	0	0	0	0	0	0	-	1.000	1.000
E8	0	0	0	0	0	0	0	0	0.143	0.143	0	0	-	0.571	0.571
E9	0	0	0	0	0	0	0	0	0	0	0	0	-	0.286	0.286
E10	0	0	0	0	0	0	0	0	0	0.400	0	0	-	0.600	0.600
G2	0.200	0.200	0	0	0	0.400	0.600	0.200	0.200	0.400	0	0	0.200	0.400	0.200
G10	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
G11	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
G13	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
G14	0	1.000	0	1.000	0	0	0	1.000	0	0	-	-	-	1.000	1.000
G15	0.250	0.375	0	0.375	0	0.375	0	0.375	0	0.250	0	0	-	0.125	0
G16	0	0.333	0	0.333	0	0.333	0	0.333	0	0.333	0	0	-	0	0
G17	0.167	0.500	0	0.500	0	0.500	0	0.500	0	0	0	0	-	0.167	0
G18	0.177	0.412	0	0.294	0	0.235	0.118	0.471	0.059	0.353	0.077	0	0	0.412	0.235
G19	0	0.500	0.500	0.500	0	0	0	0.500	0	0	0	0	-	0	0
G22	0	0	0	0	0	0	1.000	0	0	1.000	0	0	-	1.000	0.750
G23	0	0	0	0	0	0	0.667	0	0	0.667	0	0	-	0	0
G24	0	0.333	0	0.333	0	0.333	0	0.333	0	0.333	0	0	-	0	0
G26	0	0.750	0	0.750	0	0	0	0.750	0	0	0	0	-	0	0
G33	0	0	0	0	0	0	0	0	0	0	0	0	-	0.143	0.143
G34	0	0	0	0	0	0.143	0	0.143	0	0	0	0	-	0.143	0.143
G35	0	0	0	0	0	0	0	0	0	0	0	0	-	0.167	0.167
G36	0	0	0	0	0	0	0	0	0	0	0	0	-	0.333	0.333
G37	0	0	0	0	0	0	0	0	0	0	-	-	-	0	0
G38	0	0.250	0	0	0	0	0	0	0	0	0	0	-	0	0
H1	0.154	0.385	0.154	0.154	0	0.423	0.346	0.240	0	0.500	0.191	0.095	0.095	0.385	0.346
H7	0	0	0	0	0	0	0.500	0	0	1.000	0	0	-	0.500	0
H11	0.056	0.222	0.111	0.111	0	0.389	0.333	0.222	0	0.389	0.111	0.111	0.125	0.444	0.444

TABLE 8-10
(continued)

seg-	As	---Cd---		---Cr---		Cu	Pb	Hg	---Ni---		---Se---		Ag	---Zn---	
ment	mar	frsh	mar	frsh	mar	frsh	frsh	frsh	frsh	mar	frsh	mar	frsh	frsh	mar
H12	0	0	0	0	0	0	1.000	0	0	1.000	0	0	-	1.000	1.000
H13	0.111	0.333	0.111	0.167	0.056	0.389	0.167	0.167	0	0.667	0.222	0.056	0.111	0.667	0.611
H14	0	0	0	0	0	0.167	0	0.500	0	0	0	0	-	0	0
H15	0.083	0.208	0.125	0.042	0.042	0.333	0.125	0.292	0	0.333	0.136	0.046	0.105	0.417	0.333
H16	0	0	0	0.500	0	0	0	0	0	0	0	0	-	1.000	0.500
H17	0	0.182	0.091	0.091	0	0.273	0.273	0.227	0.046	0.273	0.046	0.046	0.294	0.727	0.682
H18	0	0	0	0	0	0.250	1.000	0	0	0.500	0	0	-	0.750	0.500
H19	0.044	0.217	0.174	0.130	0.044	0.522	0.304	0.261	0	0.474	0	0	0.091	0.435	0.391
H20	0	0	0	0.800	0	0.400	1.000	0	0	1.000	0	0	-	1.000	1.000
M3	0	0	0	0.333	0	0	0	0.333	0.133	0.333	0	0	-	0.467	0.333
S1	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
S2	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0
T5	0	0.500	0	0	0	1.000	0.500	0	0	0.500	0	0	0.500	0	0
T11	0	0	0	0	0	0.333	0.200	0.467	0	0	0	0	0	0.200	0.200
T12	0	0	0	0	0	0	0.400	0.400	0	0	0	0	-	0.400	0.400
T15	0	0	0	0.333	0.333	1.000	0	1.000	0	0	0	0	-	0.333	0
T17	0	0	0	0	0	0	0	1.000	0	0	0	0	-	0	0
W2	0	0	0	0	0	0	0.333	0.667	0	1.000	0	0	0	0.667	0.667
W6	0	0	0	0.200	0	0.400	0	1.000	0	1.000	-	-	-	0.400	0.400
W7	0.111	0.778	0.111	0.111	0	0.556	0.889	0.111	0	0.778	0.111	0	0.500	0.556	0.556
W8	0.286	0.429	0	0	0	0.143	0.429	0.143	0	0.429	0.143	0.143	0.500	0.714	0.714
W16	0	0	0	0	0	0.500	0	0.900	0	0.500	-	-	-	0.500	0.500
W18	0	0.400	0	0.400	0	0.400	0.400	0.200	0	0	0	0	0	0.200	0.200
W19	0	0	0	0	0	0	0.333	0.167	0	0	0	0	-	0.333	0.333
W20	0	0	0	0	0	1.000	0	0.600	0	1.000	-	-	-	0.600	0.200

As: no violations of the freshwater criterion in the data set
Pb: one less violation of marine criterion (Segment H15) than freshwater
Hg: same frequency of violation for both fresh and marine criteria

For dissolved oxygen, Table 8-2, there are scattered violations of the 4.0 standard throughout the bay, generally on the order of 2% of the data, and most frequently in proximity to sources of inflow and wasteloads. Chocolate Bay (W7) and the Houston Ship Channel downstream from the Monument (H11) exhibit somewhat higher frequencies of violation. (A few of the segments are skewed by small data samples, e.g. E10 and G2.) Given the high degree of variability in DO (as well as many other parameters), we do not consider these to evidence any serious or systematic water quality problem. (They do argue against the wisdom of an absolute-minimum, inviolate DO standard. A statistical formulation, instead, is much better suited to real-world variability.) The particular case of the Houston Ship Channel above Morgans Point, especially Segments 1006 and 1007, is treated in Tables 8-3 and 8-4. Here, the TWC Segment is broken into its component hydrographic segments for better spatial resolution. The remarkable advance in water quality is demonstrated by comparison to the pre-1985 conditions, also shown in these tables. In 1005, all violations of the 2.0 ppm DO minimum have been eliminated (and the standard for this segment is now 4.0 ppm), and in 1006 these have been substantially reduced. While violation frequencies of 50% in 1006 are now past, there is still a substantive number of violations, in excess of 10% frequency in the upper reach of this segment. In 1007, Table 8-4, where the standard is 1.0 ppm, the rate of violation has been markedly reduced from pre-1985 conditions, and is now much less than 5% except in the Long Reach, H17.

The state coliform standard applies to a 30-day geometric mean of at least five "representative" samples. For comparative purposes, we computed monthly geometric means for each segment, for each month with at least five measurements, for which the frequency of violation was determined relative to all such monthly means for the segment. These are shown in Table 8-5 *et seq.*; again, we display both pre-1985 and post-1984 data. For the non-bay segments, where the 200 org/100mL standard applies, there is no systematic change between the earlier and the recent data. This is consistent with the trends analysis of Chapter 5. Recent coliform measurements may be biased to higher values as a sampling artifact, since in recent years, for regulatory purposes, the sampling has been directed more to events which would be expected to cause increases in coliforms. This may also be the reason for the rather high frequency of standards violations indicated in these results. Among the bay segments, Tables 8-7 and 8-8, the most frequent violations are logged in the segments out from Clear Lake, the Houston Ship Channel, the Trinity River, Chocolate Bayou and Galveston Channel, nor is there any systematic improvement in the post-1984 observations. In the upper Houston Ship Channel, where the standard is 2000 org/100mL, there appears to have been a substantive reduction in the violation rate since 1985, though recent frequencies are still high.

The state standards for metals and pesticides apply to the dissolved parameter. Those values given in Table 8-1 are the chronic marine criteria. The direct applicability of these and the EPA criteria for metals, which are developed for "acid-soluble" metal concentrations, to the Galveston Bay data base is problematic, because there are so few measurements of dissolved fractions from Galveston Bay, and these are generally below detection limits. Therefore, we have applied these criteria to the Galveston Bay data base for "total" (i.e., unfiltered) metals, which will be greater in concentration, depending upon the specific metal and the nature of suspended matter in the sample. The values in Table 8-1 are almost certainly too conservative and may indicate a water quality problem that does not in fact exist. The EPA values in Table 8-1 for mercury are especially stringent, as these are based upon final residue values for methylmercury rather than final chronic values for mercury (II), due to high biomagnification potential in certain fish and shellfish. Moreover, some of these criteria, e.g. cadmium, lead, mercury, and nickel, are less than the detection limits in the data set (see Table A-1 in the Appendices).

The violation frequency of a representative selection of these criteria for total metals, based on measurements since January 1985, are summarized in Table 8-10. Monthly breakdowns are not presented, because a seasonal effect is not expected and because the data are so sparse that too few measurements would be available for each month. For arsenic, cadmium, chromium and nickel, significantly more violations are indicated for the more stringent of the EPA freshwater and marine criteria, suggesting that concentrations in Galveston Bay are at the threshold of what would be satisfactory for an estuarine regime. For lead, mercury, selenium, and zinc, the frequency of violations are practically identical for fresh and marine criteria. One generalization one can infer from Table 8-10 is that concentrations in excess of the criteria are generally associated with shipping in the bay, i.e. along the Houston Ship Channel, in both its open-bay and landlocked reaches, along the GIWW, and in the turning basins. This may be due in part to the concentration of urban activity and waste discharges in these same areas, and the fact that shipping regions are generally sampled more intensively due to dredging activity, thus allowing a greater opportunity for occasional high measurements. We emphasize that dissolved metals—if we had a sufficient data base available—would exhibit lower frequencies of violations than these total-metals measurements.

With respect to pesticides and trace organics, the data base is even sparser. Analysis of the available data from Galveston Bay indicated violations of the criteria of Table 8-1 for only DDT and PCB's, as follows:

parameter	*segment*	*violations / measurements*
DDT (extended: WQ-XDDT)	H14	1/6
	H15	1/12
PCB's	H16	2/2
	H17	4/11
	S2	2/3

Of course, virtually all measurements are below detection limits, hence the rarity of criteria violation.

For sediment, the information base for standards and criteria is not nearly so great as for water quality. At present, published criteria and standards for biological and human activities do not exist. (There are criteria developed by EPA for determining disposal practices of dredged material in coastal and marine areas, but we consider the basis and applicability of these to be too narrow for a general sediment-quality characterization.) EPA is in the process of preparing such criteria. Those available are compiled in Table 8-11, as of August 1991, and are drawn from several draft publications provided by EPA in a plain brown wrapper for use in this project, but which are prohibited from citation because of their tentative nature. It is evident that only a few pesticides and PAH's are treated; criteria for metals and other organics are still in the research and development stage.

Criteria for sediment are not expressed in concentration, because the effects of contaminants in sediments are modulated by the bioavailability of the constituent, which is in turn a function of the partitioning of the constituent between the particulate and interstitial water components of the sediment, and the make-up of the sediment itself. EPA has adopted the Equilibrium Partitioning approach to determination of sediment quality. The EqP model is a means of deriving equivalent sediment quality impacts from already-extant results for water quality, and in particular models the partitioning and bioavailability of the contaminant by its behavior with respect to sediment organic carbon. Therefore, the criteria in Table 8-11 are applicable to the contaminant concentration normalized to the concentration of organic carbon in the sediment, hence the units are contaminant mass per unit mass of organic C. In order to test field data against these criteria, the measured concentrations must be divided by the concentration of organic carbon in the sediment.

Although a general distribution of organic carbon in the bed sediments of Galveston Bay has been compiled (Appendix C), the extreme heterogeneity of organic C requires that the contaminant and TOC analyses be performed on the same sample. Clearly, if sediment organic carbon was not measured on the same sample as the contaminant, unfortunately the usual case for Galveston Bay data, the criteria cannot be strictly applied. In order to determine, at least approximately, whether any of these criteria are violated in Galveston Bay, we have employed the segment average TOC distributions in such an evaluation. For only two parameters were there violations of the criteria, DDT and Dieldrin, to wit:

parameter	*segment*	*violations (%)*
DDT (extended: SED-XDDT)	H14	16
	H15	50
	H17	18
	W21	33
Dieldrin (SED-DIEL)	H17	33
	W21	33

All of these segments are in regions exposed to urban runoff.

Although sediment criteria *per se* are not available, in order to explore whether there is a pattern of elevated sediment metals, measurements since January 1985 were normalized to segment-mean TOC, and the frequency of occurrence was

Table 8-11

Sediment Quality Criteria (saltwater) for Study Parameters
(Compiled from unpublished EPA sources)

parameter	*concentration** (mg/kg C)*
DDT	0.828
Dieldrin	0.130
Endrin	0.49**
Heptachlor	0.104
PCB (1254)	41.8
Fluoranthene	1883
Benzo(a)pyrene	1063

*Based on the lower of the Final Chronic Value and the Final Residue Value, if both are given.

**From Pre-draft Criterion of August 1991.

determined of exceedance of one standard deviation above the baywide mean. This, of course, is a relative measure, and only serves to display a pattern of higher TOC-normalized metals. It does not in itself imply a sediment-quality problem. Moreover, TOC may not serve the same utility of normalizing metals for bioavailability as it does for trace organics. (Some recent research sponsored by EPA suggests that acid volatile sulfide will be more suitable for metals.) Our purpose, however, is to employ some measure of sediment bioaccessible organic content. The results are presented in Table 8-12. (This was based upon assigning a zero value to a BDL measurement. Therefore, the mean and the standard deviation will be biased to a lower value, and the relative frequency of an excess over the standard deviation will be biased to a higher value.) There tends to be a high degree of association among a suite of metals in several segments of the Houston Ship Channel, including two in the open bay (G16 and G18), in Bolivar Roads (Segments G35, G36 and M3), Chocolate Bay, and in the vicinity of the Causeway (Segments W15 and W16). Most of these elevated values are due to a combination of metals concentration and low TOC (less than 5 g/kg). If the bioavailability model of the EqP approach is valid, such low TOC would signal possible enhanced biological exposure to the metal.

In summary, the geographical problem areas of Galveston Bay hold no real surprises; they are where we expect them to be: in regions of intense human activity, including urban areas, points of surface runoff, waste discharges, and shipping. Perhaps unexpectedly, the quality of the bay is generally good, and where it is degraded there is a pattern of improvement. Earlier trend analyses of Galveston Bay, such as TWQB (1977) for the Houston Ship Channel and Stanley (1989) for Galveston Bay, arrived at essentially the same conclusions. Stanley (1989) in particular examined several of the same data sets included in this study, e.g., the Galveston Bay Project and the SMN. In order to keep his study within workable bounds, he used representative stations in each of the four main subdivisions of the bay, East Bay, West Bay, Trinity Bay and upper Galveston Bay, as well as the Houston Ship Channel, focused on a more limited suite of parameters, and restricted his trend analysis to examination by eye of temporal data plots. In many respects, therefore, the present study extends that of Stanley (1969) to a much larger data base, over many more sections of the bay, and many more parameters, and, further, carries out quantitative objective statistical analyses on all of these. These analyses confirm the trends determined by Stanley of declining BOD, nitrogen, and some metals. While Stanley did not opine a trend in phosphorus, our examination of his figures lead us to believe that a declining trend, albeit noisy, would have been computed from his data using quantitative statistics.

From a systemic point of view, the most significant potential problem area affecting the bay as a whole is the general decline in particulates and nutrients. Of course, whether this is a problem or an improvement depends upon the optimum levels for Galveston Bay. Much more research is needed on the total ecosystem to establish these optima. While no definitive statement is possible, there is a discomforting chain of speculation. With the assumption that some of these nutrients, especially nitrogen, are limiting, and are at or below optimum (as is suggested by early work in the 1970's in the Galveston Bay Project), their

TABLE 8-12

Frequency of occurrence in sediment metals per unit carbon of one standard deviation above baywide mean, measurements after 1 January 1985

segment	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
C1	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0
C5	0	0	0	1.00	0	0	0	0
C6	0	0	0	0	0	0	0	0
D1	0	0	0	0	0	0	0	0
D4	0.50	0	0	0	0	0	0	0
E2	0.33	0	0	0.33	0.33	0	0	0
E5	0	0	0	0	0	0	0	0
E6	0	0	0	0	0	0	0	0
E9	0	0	0	0.14	0	0	0	0.14
E10	0	0	0	0	0	0	0.40	0
G10	0.43	0	0.57	0	0	0	0.29	0
G11	0	0	0	0	0	0	0	0
G13	0	0	0	0	0	0	0	0
G14	1.00	0	0	1.00	0	0	1.00	0
G15	0	0	0	0	0	0	0	0
G16	0.33	0	0.33	0.67	0.67	0.33	0.33	0
G17	0	0	0	0	0	0	0	0
G18	0.50	0.10	0.38	0.25	0.25	0.19	0.25	0.33
G19	0	0	0	0	0	0	0	0
G22	0	0	0	0	0.14	0	0	0
G23	0	0	0	0	0	0	0	0.33
G24	0	0	0	0	0	0	0	0
G26	0	0	0	0	0	0	0	0
G32	0.17	0	1.00	0	0	0	0.33	0
G33	0.14	0	0	0	0	0	0	0
G34	0	0	0	0	0	0	0.14	0
G35	0.33	0.17	0.17	0	0.33	0	0.17	0
G36	0.33	0.33	0	0	0	0	0	0
G37	0	0	0	0	0	0	0	0
G38	0	0	0	0	0	0	0	0
H1	0	0	0	0	0.11	0	0.11	0.11
H3	0	0	0.40	0	0	0	0	0
H7	0	0	0	0	0	0	0	0
H11	0	0	0	0	0	0	0.50	0.50
H12	0	0	0	0	0	0	0	0
H14	0	0	0	0	0	0.33	0	0
H15	0.11	0.56	0.67	0.67	0.56	0.67	0.22	0.67
H16	0	0	0	0	0	0	0	0
H17	0	0.44	0	0.33	0.22	0.22	0	0.22
H18	0	0	0	0	0	0	0	0

TABLE 8-12

(continued)

segment	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn
H20	0	0	0	0	0	0	0	0
M3	0.27	0	0.20	0.07	0.07	0.07	0.27	0.07
S1	0	0	0	0	0	0	0	0
T3	1.00	0	0	0	0	0	0.50	0.50
T11	0.07	0	0	0	0	0.20	0	0
T12	0	0.20	0	0	0	0.40	0	0
T15	0	0	0.33	0.33	0	0	0	0.33
W2	0	0	0	0	0	0	0	0
W5	0	0	0	0	0.67	0	0	0
W6	0	0	0	0.20	0	0	0	0
W7	0.13	0.63	0.38	0	0.63	0.13	0.13	0.13
W8	0.14	0.43	0.14	0	0.14	0	0	0
W9	0	0	0	0	1.00	0	0	0
W10	0.20	0	0	0	0	0.20	0.20	0.20
W11	0	0	0	0	0	0	0	0
W15	0.33	0	0.67	0	0.33	0.22	0.11	0.11
W16	0	0	0.17	0	0.08	0.08	0.50	0.17
W18	0.17	0	0.33	0.33	0.17	0	0	0
W19	0	0	0	0	0	0	0	0
W21	0	0	0	0	0	0	0	0

decline in the last two decades should directly affect the phytoplankton of the bay. The effect would be gradual in time, because of the large mass of nutrients locked up in phytoplankton and their cycling internal to the bay. The observed decline in chlorophyll-a is consistent with such an algal response. If this trend is indicative of a large-scale decline of the base of the food chain, there should be a correlated decline in abundance of some higher organisms. This would be best manifest in those low-trophic-level organisms that are more or less permanent residents of the bay or sustain most of their growth to adulthood in the bay. This is in contrast to those diadromous species whose successive immigration and emigration invoke other factors affecting their abundance. Our candidates for those species which would most probably exhibit a response are: oyster (for which no growth data were available), blue crab, mullet, and white shrimp. (These, too, have a life cycle involving exchange with the Gulf, but are more restricted to the littoral and nearshore, and their migrations are not so complex as most of the other diadromous species.)

Trend data for these three are presented in the companion GBNEP study report on Status and Trends of Living Resources (Green et al., 1991). It is unfortunate that these choices were not recorded in a hermetically sealed Mason jar at Funk and Wagnalls, to establish that they were selected prior to consulting this report. For blue crab, the results of Green et al. (1991) show an increasing trend in young of the year since 1983 (a function of recruitment and therefore not reflecting habitat within the bay), declining trends in juveniles and first-time spawners (by trawl, but no trend for first-time spawners by gill net), and a rather precipitous drop in larger adults, by a factor of three since 1986. Green et al. (1991) express concern at these declining patterns, and note also a decrease in mean size by over 20% since 1982. For striped mullet, the longest period of data for adults presented by Green et al. (1991) is gill-net records extending back to 1975. These show a nonlinear decline, the entirety of which is due to a reduction in catch of roughly a factor of three between 1975-77 and 1978-89. White shrimp exhibit the most dramatic decline of all. Green et al. (1991) display a steep decrease since the early 1980's, in all size classes and by all gear types. This decline is on the order of a factor of five in abundance. Certainly overharvesting is a probable culprit, as Green et al. (1991) suggest, but it may not be the only factor.

Few inferences can be more fraught with hazard than assigning causality to correlated trends. Nor do we wish to be guilty of oversimplifying a complex and dynamic system. On the other hand, the pathway from nutrient-particulate loads through receiving-water concentrations to algal uptake thence assimilation into the food chain is fundamental to the estuarine ecosystem. That a correlated trend seems to be manifest in indicators of every element of this pathway, and that this trend points toward a declining productivity for the bay, are sufficient to warrant increased attention.

8.4 Recommendations

8.4.1 Data Collection and Archiving

The primary requirement of any data collection program is to perform measurements targetted at the principal question or function that program addresses. For research studies, the data-collection strategy is tailored to the scientific hypothesis to be tested. Many state and federal agency programs have statutorily defined missions, that in turn dictate their sampling strategies. Therefore, to the extent that any given survey is properly designed to achieve its mission, our recommendations for its performance are superfluous.

On the other hand, few programs can afford the investment of long-term, intensive data collection in a system such as Galveston Bay. To address scientific and management questions that require such massive data bases, we must depend upon the use of data collected by different agencies for perhaps different purposes. In this sense, data collection should be regarded as a collective enterprise, and its design should reflect a certain degree of scientific altruism, to ensure maximal utility of the data without unduly hampering the measurement procedures or project resources. It is in this spirit that we offer several concrete recommendations. In summary, these recommendations argue that data programs should be somewhat more careful, collect somewhat more measurements, and facilitate somewhat better their data dissemination, than strictly required for the mission at hand. These are founded on four precepts of data collection effectiveness, addressed in Chapter 3 above; we summarize these here, and submit that observation of these precepts will go far in achieving broader utility of collected data.

1. *The density of independent measurements of a parameter should be commensurate with the space and time variability of that parameter and over the range of variation of the external factors.*

2. *Incremental cost relative to the total investment in effort to obtain a suite of measurements should be the governing criterion for inclusion of additional measurements.*

3. *Sampling design should be cognizant of the historical record of related parameters: the value of an extended historical record transcends the current utility of the parameter.*

4. *Data recording and archiving should minimize potential loss of information.*

We re-emphasize that Galveston Bay is a highly variable environment, subject to many external factors, each of which contributes a degree of "noise" in any measured parameter. To filter this noise, and expose variations in time and space, requires that sufficient independent measurements be available over the range of variation of the external factors. For time variability, continuity of data record is an all-important property of any data base. For space variability, a high density of sampling stations repeatedly sampled is necessary. Specific recommendations, as well as some amplification of these precepts, are as follows:

(1) A greater sensitivity is recommended to the investment in putting a sampling crew (and usually a boat) on a specific station, versus the efficiency of observations once there, as expressed by *Precept 2*. The incremental cost in acquiring additional measurements (including loss of efficiency) must be weighed against the (much larger) cost of occupying the station, in specifying the suite of parameters to be obtained. Whether these additional measurements have immediate application is unimportant; they may be peripheral or irrelevant to the objective of the project, but have great value for other objectives and therefore justify the small incremental cost for their acquisition.

When the major investment of time and expense is to place a boat crew on station, a few *in situ* measurements should be standard procedures. If the crew is equipped with electrometric over-the-side probes, a vertical profile instead of a single depth should be routine. (Yet there are manifold examples of violation of this practice.) Some limited water sampling may also be simply accommodated, perhaps just surface grab samples for straightforward lab analyses. Notation should always be made of conditions, sampling location, and time and date. (This seems trivial, but there are numerous examples of omission of some or all of these.)

We suggest that short lists be formulated of "recommended" parameters, to be included within suites of measurements of various classes (e.g, *in situ* parameters, non-fixed water samples, sediment sampling for chemical analysis, etc.), to provide guidance to anyone undertaking a sampling project.

(2) The same principle of incremental cost versus benefits should be considered in specifying laboratory analyses. Many procedures, e.g. mass spectrometry or grain-size by settling tube, are cost-loaded in sample preparation, and can admit additional parameters or greater resolution with minor incremental cost. A certain altruistic philosophy is necessary in the sampling agency, to acquire measurements that may be irrelevant to the immediate objective, but from which others will benefit.

(3) Necessity for both continuity in time and continuity in space must be recognized, as well as the need for maintenance of a long period of sampling. (*Precept 3*.) There are numerous examples in the data record when a parameter is suspended from further measurement. In most cases, this has involved a replacement of the old parameter with a new one. Figure 7-4a is an example for nitrates. As another example, in recent years, there has been a shift of emphasis from rather gross and imprecise measurements such as oil & grease, volatile solids and total PAH's, to specific hydrocarbon parameters. While the more precise measures are welcome, the termination of the record of the others is lamentable.

When a new, more accurate parameter is considered to replace another, there should be a continuation of data for the older variable together with the new parameters to at least establish an empirical relation. It may be more important to continue the measurement of the older parameter, to preserve the continuity of record, even if the utility of that parameter is limited compared to the new one.

(4) We note that the intratidal-diurnal scale of variability is virtually unsampled in Galveston Bay, yet there are several parameters, such as dissolved oxygen, temperature and salinity, with significant variation on these scales. (*Precept 1.*) The use of electrometric sensing and automatic data logging now permit the recovery of nearly continuous, fine-scale time signals of several of these parameters, and should be incorporated into routine monitoring of the bay, perhaps in association with tide gauging. The Texas Water Development Board has made significant advances in the application of these techniques, though its emphasis thus far has been on the lower bays on the coast. *NB*, such data acquisition should not replace routine sampling, since routine sampling provides far better spatial continuity than is practical to achieve with automatic monitors.

(5) *Precept 4* above addresses the need for great sensitivity to potential loss of information. Data entry (i.e., transcription) errors are a prime cause of information loss, and any data entry procedure should include a means of verification. The error rate in the TWC SMN is surprisingly high, considering the central importance of this data base to water management in Texas.

Any data collection program should include procedures of data screening and data-entry verification, from the original lab sheets to the digital data file. While this may seem trivially obvious, the occurrence of obvious errors in all of the state data bases (to say nothing of inobvious errors) indicate that present procedures are inadequate. When the data entry is recent and the raw data sheets are still available, errors are easiest to detect and correct. Error correction at the data entry step may very well track back to the recording and/or acquisition of data. For this reason, data entry should be performed in a timely manner, not months after the event.

Data-checking procedures represent the obverse face of *Precept 3*. Their implementation may be viewed as a redundant cost item in data acquisition, absorbing funds that might be better spent in a boat. Such a view is myopic, because the expense of data checking shrinks to negligibility compared to the unit cost of acquiring and analyzing a water sample. One can not afford to lose that considerable investment because of an errant keystroke. Moreover, the place that water sample potentially holds in a space or time trend may be invaluable. Data checking is an absolutely indispensable investment to preserve the information in a measurement.

(6) Data entry error is not the only means of losing information from data collection. Replacing a series of raw measurements over time or space by an average, failing to preserve information on sampling time, position or conditions, or intermixing actual measurements with "estimated" values without any means of separation, all represent losses of information, and are all practices that can be avoided with care and forethought. One particularly ubiquitous practice is to combine measurements from one's own data collection with data drawn from

other sources, perhaps processed. This is ubiquitous because of the use of combined data bases in scientific analysis, exactly as carried out in this project. This intermixing may be compounded by further processing, e.g. averaging together. The danger lies in not maintaining a separate and uncorrupted file of the original measurements. We recommend adherence to the same principle of preservation of data integrity observed in this project. Agencies should differentiate between the data record of observations obtained by that agency, and a compiled data record of those and other external measurements, possibly further processed. At present, several agencies, e.g. TWC and TWDB, intermix such data in a single data base.

Additional recommendations specific to data collection practices in Galveston Bay are as follows:

(7) Some measure of suspended solids (e.g. turbidity) should be included in routine monitoring. For nutrients, metals, organic pesticides, PAH's or similar constituents that have an affinity for particulates, suspended solids *per se* should be routinely determined as part of the suite of measurements. Further, the analysis should include grain-size distribution or at least a simple filtration to determine partitioning of clays-and-finer and silts-and-finer.

(8) A ubiquitous deficiency of the sediment data base is that there are almost no paired measurements of chemistry and sediment texture (i.e., grain-size distribution). Analysis of the variability of many of the parameters of concern in environmental management, such as heavy metals and pesticides, must consider the grain-size fractions. We recommend that texture analysis be instituted as a routine aspect of any chemical analysis of a sediment sample.

(9) Because of the future potential rôle sediment organic carbon may play in evaluating sediment chemistry with respect to a standard, presuming the EPA EqP approach is adopted, we recommend that organic carbon be instituted as a routine aspect of any chemical analysis of sediment involving non-ionic organic contaminants, especially organohalogens. While it is premature to offer this as a recommendation, we draw attention to the possible rôle of acid volatile sulfide as a normalizing parameter for standards for metals in sediments hence the desirability of instituting this parameter as a routine aspect of any chemical analysis of sediment involving heavy metals.

8.4.2 Water and Sediment Quality

On a more strategic level, regarding our understanding of water and sediment quality and information needed for effective management of the Galveston Bay resources, we recommend the following:

(1) The data base assembled in this project is capable of many more analyses. In particular, it may be useful to examine the effects of varying temporal sample density on statistical bias, to normalize the data to uniform periods of record, and to carry out more sophisticated statistical examinations than could be mounted

within the scope of this project. Detailed mass-budgeting studies are needed to determine the probable cause of the apparent declines in particulates and nutrients, perhaps in concert with hydrographic analyses or deterministic models, using the data base compiled in this project. These should include detailed information on waste discharges and reservoir entrapment. Event-scenario analysis as well as time-series studies could both provide insight. This should be extended to include numerical modeling, as an "interpolator" in space and time.

(2) Additional analysis of chlorophyll-a and related measurements from Galveston Bay, in association with *in situ* productivity studies are needed. Some special-purpose data collection activities, such as the Intensive Surveys of the Texas Water Commission and the National Marine Fisheries Service might be profitably used in a more targeted analysis. These studies should include detailed examination of phytoplankton dynamics in Galveston Bay, and its dependence on water quality.

(3) Metals and trace organics remain a major concern. The present analysis was significantly delimited by the sparsity of data and the precision of measurement. Clearly, more and better measurements are necessary to assess and monitor this suite of variables. On the other hand, the investment in complex and demanding analyses does not at the moment seem highly critical to the management of Galveston Bay, apart from the present state and federal activity in wasteload regulation. While monitoring should continue, we do not believe that merely intensifying that monitoring will yield information in proportion to investment. We recommend a research focus on:

(a) improved measurement methodology, including relations with and among older methods, for interpretation of historical data, and better determination of precision and accuracy,
(b) bioaccumulation of metals and trace organics,
(c) detailed studies on kinetics and fluxes in carefully selected regions of the bay subject to identifiable and quantifiable controls,
(d) exploration of suitable tracers and their measurement, such as aluminum, to separate natural and anthropogenic sources of metals.

While information is needed on open-bay environments in general, the greater effort should be invested in those regions already manifesting a proclivity for elevated metals and pesticides, i.e. in regions of runoff, inflow, waste discharges and shipping.

(4) In an estuary as turbid as Galveston Bay, the rôle of sediments in suspension and in the bed is quintessential. Every element of the sediment transport process is imperfectly understood, as manifested in our inability for quantification, from riverine loads to exchange with the Gulf, from scour and deposition on the estuary bottom to shoreline erosion. The affinity of many key pollutants for particulates, especially metals and pesticides, and the dynamics of transport and exchange within the estuary, render an understanding of sediments absolutely indispensable to the management of water quality in general. This is

compounded by the activity in Galveston Bay of dredging, shoreline alteration, and trawling, as well as the clear alterations in suspended sediments in recent years. In our view, sediment dynamics should be the focus of a renewed research effort in the bay, ranging from more detailed observation on grain-size spectrum and its effects, to biokinetic processes operating within the sediment itself.

(5) The observed decline in temperature is probably not a serious concern from the water-quality management standpoint, but additional examination of its cause, especially if of climatological origin, may provide additional insight into other processes, such as the decline of chlorophyll-a and the kinetics of dissolved oxygen. We would recommend some modest examination of long-term variability in the climatological controls of the surface heat budget.

(6) The salinity data base assembled in this project is the most comprehensive available for Galveston Bay (and probably any of the Texas bays) and will support analytical studies of salinity response heretofore not possible. It is recommended that salinity variability in Galveston Bay be examined using sophisticated methods of time-series and response analysis to better delineate the rôle of inflow and other hydrographic factors on salinity. This would be valuable, not only because of the intrinsic importance of salinity as a hydrographic and ecological variable, but to yield insight into the time-response behavior of other, less intensely sampled parameters whose concentrations are dominated by internal transports.

(7) The significant observed decline in salinity underscores the gaps in our understanding of even as fundamental (and conservative) a parameter as this. We recommend additional studies of the external controls on salinity. This could probably be most usefully pursued, at least at the outset, by extending the scope of empirical analysis to include the hydrography of the nearshore Gulf of Mexico. As with nutrient and particulate loading, we believe event-scenario and time-series analysis to be most promising. There is also a place for hydrodynamic modeling, but only after the essential controls and responses of the system are much better defined.