8.0 CONCLUSIONS

8.1 Methodology and Data Collection

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

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

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

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

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

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

8.2 Project Results

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

8.3 Limitations to Non-Point Source Assessment

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

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

8.4 Future Research

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

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

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

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

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

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

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

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

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

8.5 Summary

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

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