Chapter 1

Introduction

In today's environmental engineering practice, many computer models have been developed which explain chemical and biological processes in lakes, estuaries, and rivers. In addition, advancements have been made in determining the pollutants which enter those water bodies. However, the connection between the spatially represented land surface pollutants to the in-stream processes has been relatively weak. Most water quality models concentrate just on modeling the system once the pollutants have reached the receiving waters, while many pollutant models never route the loadings into the water bodies to examine their effects. This lack of continuity presents a need of a method in order to link the spatially-based pollutant source characterization with the water quality modeling of the receiving waters. A link would provide an easier way to examine the cause and effect relationship which exists between these two areas. To establish such a connection, a system which can allow spatial representation of parameters, while still having the ability to retain tabular or one dimensional information is needed. With this type of system, the spatial modeling of the land surface to determine such parameters as non-point source pollutant loadings would be possible, along with the storage and manipulation of water quality modeling data. One computer programming and modeling environment which displays this relational capability is a Geographic Information System.

1.1 BACKGROUND

A Geographic Information System (GIS) is a computer system capable of spatially representing data on the land surface and linking additional data related to this spatial depiction, through tables and charts. In addition, GIS is used in the area of environmental modeling, by providing ease and accuracy in surface terrain representation, watershed delineation, precipitation data compilation, non-point source pollutant loading calculation, and other concepts related to environmental processes (Maidment, 1993; Saunders, 1996; Newell, *et al.*, 1992; Maidment, *et al.*, 1996). Consequently, GIS has emerged as more than just a viewing interface for engineers and city planners; it is a powerful modeling tool which can help provide the knowledge necessary to make sound engineering and management decisions. Numerous studies have utilized GIS for non-point source loading assessments, groundwater and surface water modeling predictions, agricultural chemical concentration estimations, and water balance forecasting (Saunders, 1996, Newell, *et al.*, 1992; Maidment, *et al.*, 1996, Mizgalewicz, 1996; Ye, 1996). Additional research has been dedicated to illustrating the strength of GIS as a management tool and decision support system in environmental areas such as permitting and watershed management (Furst, *et al.*, 1993; Chen, *et al.*, 1995; Sternberg, 1996)

Besides developing models within GIS, other studies have focused on the feasibility of connecting current environmental models to this information system, in order to make data manipulation and output presentation easier. Recent research has linked environmental numerical models to GIS to improve the pre- and post-processing of the model data (Biesheuvel and Hemker, 1993; Brown, *et al.*, 1996; Rindahl, 1996; Stuart and Stocks, 1993). Particular attention has been given to water quality and quantity models, such as the Hydrologic Simulation Program FORTRAN (HSPF), the Water Quality Analysis Simulation Program (WASP), and various models from the Agricultural Research Service (ARS) (Al-Abed and Whiteley, 1995; DePinto, *et al.*, 1994; Geter, *et al.*, 1995).

The majority of these past studies have mainly used two different GIS computer software systems: Arc/Info and Geographic Resource Analysis System (GRASS). Both of these programs have become widely accepted as the operating software programs for the rapidly growing GIS market. The Environmental Research Systems Institute, Inc. (ESRI), which is the creator of Arc/Info, also has a counterpart to Arc/Info, called ArcView. Until recently, ArcView, with its user-friendly Windows-based atmosphere, was mainly used as a display tool for viewing GIS coverages and related tables. Arc/Info, on the other hand, was the "number-crunching" software which created the coverages and tables and performed the environmental modeling. Arc/Info is also the software which many of the aforementioned studies utilized for their GIS/numerical model link. However, new versions of ArcView have made it possible to perform modeling and the model linkage within this Windows-based program. A relatively new programming language called Avenue allows the customization of an ArcView project to include mathematical functions, manipulation of tables and coverages, and the creation of new tables and coverages (ESRI, 1994). This new feature has made modeling and model connection through ArcView more feasible. Since this interface is more user-friendly and easier to learn, another user could very easily apply a "pre-programmed" customized project without having to relearn the programming or macro language of Arc/Info. However, general knowledge of GIS and the environmental model being used would still be necessary. The merit of this concept lies in the utilization of a GIS for watershed management in relation to investigating the benefits of engineering decisions.

To demonstrate the value of linking an environmental model to GIS, this research chose a study area which had a large amount of available data and an exhibited need for a modeling effort. In addition, the area had to display a need for future management decisions, based on environmental modeling and engineering practices. Once a GIS/model link is established, it can be enhanced to eventually be used as a management tool for engineers, city planners, and politicians, while also acting as a powerful communication tool to the general public. One area which fit these criteria is the Galveston Bay System, specifically, the Houston Ship Channel (HSC). This Bay was declared part of the National Estuary Program in 1988 by the U.S. Environmental Protection Agency (USEPA) (GBNEP, 1996). The result of this action was millions of dollars being invested into the Bay for research, data collection, and data compilation. The final product of this effort was the establishment of a comprehensive “plan” for the system, detailing the major problems associated with the Bay and outlining future management of the system (Shipley and Kiesling, 1994). These factors support the concept of using the Galveston Bay, or part of the Bay, as the study area for the connection of a water quality model to GIS. The next few sections give a brief overview of Galveston Bay, specifically the HSC; its water quality conditions, historically an presently; past water quality modeling efforts; and an outline of this project’s overall objectives.

1.2 Need for Study

Galveston Bay is a 1550 km^2 estuary located in Southeast Texas, on the Gulf of Mexico (see Figure 1-1). The estuary is home to the largest petrochemical complex in the nation (GBNEP, 1996). This profitable industry depends on the Houston Ship Channel, to provide a transportation route for ships and barges from the industrial hub of Houston to the Gulf of Mexico. The HSC, which begins at the Turning Basin, near the downstream end of the Buffalo Bayou, was first dredged around the year 1900 (Ward, 1993). After its starting point at the Turning Basin, the Channel travels in an easterly direction for approximately 25 km, where it then joins with the San Jacinto River. After the river, the HSC bends and continues in a south easterly direction, until meeting the main part of Galveston Bay at Morgan's Point. The dredged channel then travels through the Main Bay in a southern direction, where it finally reaches the Gulf of Mexico at the Bolivar Inlet, between the jetties located off of Pelican Island and the Bolivar Peninsula (see Figure 1-1). The channel averages about 10 m in depth, 1000 m in width and has a total length of approximately 85 km. The upstream 25 km of the Channel has an average discharge and velocity of about 25.5 m^3/sec and 0.02 m/sec (Ward, 1993).

Galveston Bay is believed to have once provided a stable environment for a thriving ecosystem of marine plants and animals. However, since the 1950's more than 20% of the wetlands and 90% of the sea grasses have been lost (GBNEP, 1996). Point sources from the numerous petrochemical industries and non-point sources (NPS) from the urbanized area of Houston have both contributed to the poor water quality found in the Bay (GBNEP, 1996). The area of the Bay that has been most affected by these discharges is the 25 km section of the HSC between the Turning Basin and the San Jacinto River, termed the Upper Houston Ship Channel. Nearly 350 point source flows from industry eventually reach this part of the Channel. Of those 350 sources, approximately 70 discharge directly into the channel waters, while the rest are located along the tributary bayous (Visnovski, 1996). Besides the point sources, about 2600 km^2 of primarily urbanized land drains into this 25 km reach.

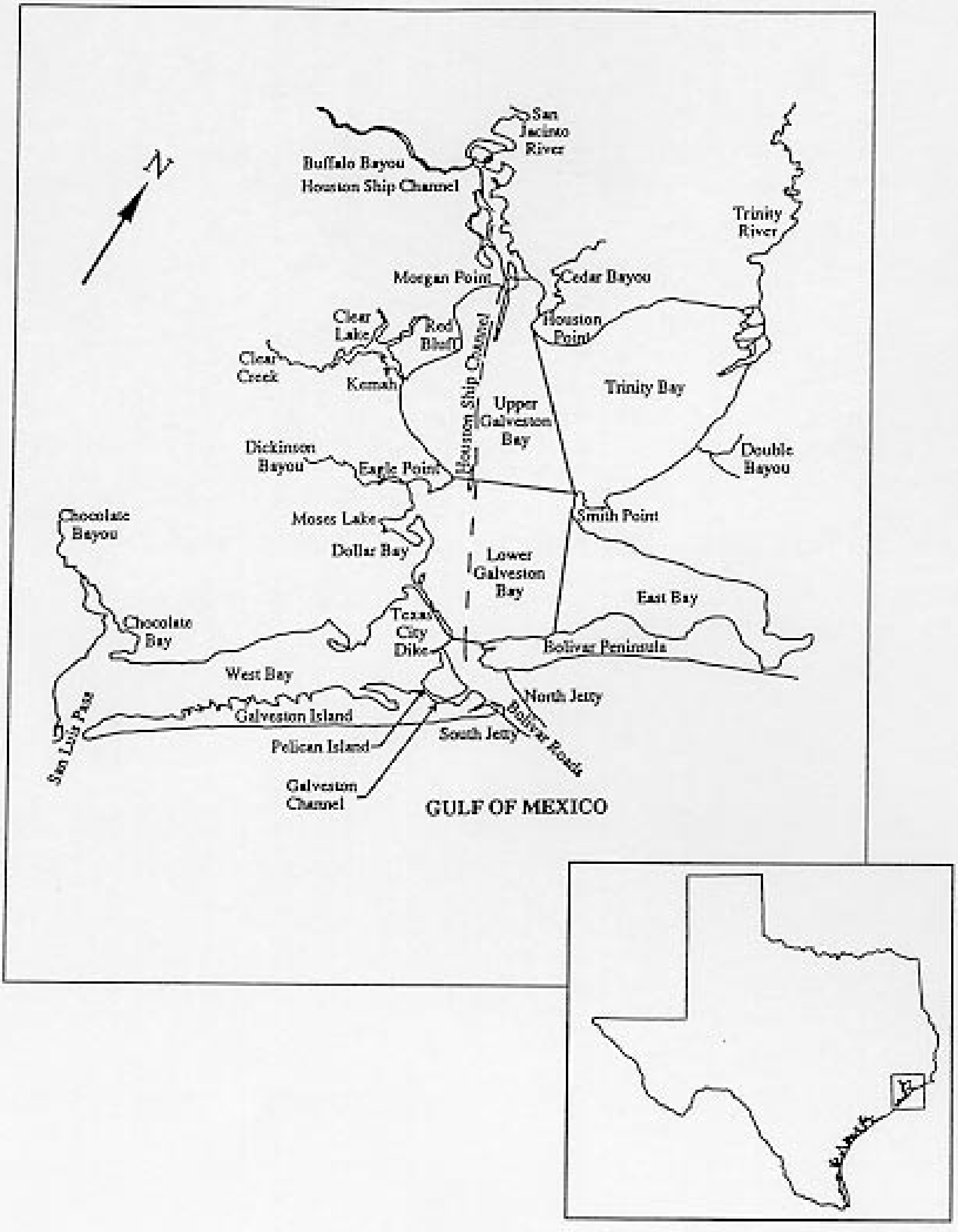

Figure 1-1 Galveston Bay and the Houston Ship Channel (Clarke, 1993). Inset shows location of Galveston Bay on Texas coast.

Of particular concern, both historically and present day, is the dissolved oxygen deficiency that exists in the Upper HSC. It is generally accepted that a daily minimum average of 5 mg/L of dissolved oxygen (DO) is needed to support marine life (Thomann and Mueller, 1987). However, records have indicated, that DO levels in the upper HSC have historically been at or very near zero (Gloyna and Malina, 1964; Ward and Armstrong, 1992). The primary sink of DO is biochemical oxygen demand (BOD). Typically, wastewater treatment plants are the primary dischargers of this pollutant (Thomann and Mueller, 1987). Gloyna and Malina (1964) found that average BOD concentrations from sewage treatment plants which discharged into the channel ranged from 0 mg/L to 160 mg/L for monthly data in the 1930’s, with the yearly average in 1933 being around 20 mg/L. The same study reported that by 1941, the average annual BOD from those same dischargers had reduced to about 8 mg/L, due to increased treatment practices. Measurements taken in the channel waters in 1951 showed the BOD daily averages at around 10 mg/L (Gloyna and Malina, 1964). Because of these dischargers and ongoing pollution problems, prior to the 1970's, the USEPA listed the HSC as one of the 10 most polluted bodies of water in the United States (USEPA, 1980).

Since the early 1970’s millions of dollars have been invested in the HSC and Galveston Bay to help improve the water quality and reduce the pollutant loadings from municipal and industrial dischargers. Consequently, significant improvements in the DO concentration and BOD loadings have been seen in the Galveston Bay Area, especially in the HSC. Ward and Armstrong (1992) reported that the DO in the Upper HSC has increased by 4 mg/L since 1970. In addition, the same study reported that the BOD loading from the point sources has declined by a factor of 20, in the last two decades (Ward and Armstrong, 1992). In 1980, the USEPA singled out the HSC as the “most notable improvement” for Texas waterways in relation to its water quality (USEPA, 1980).

Although numerous improvements have been made, notable problems still exist. A recent study has indicated that the marine life in the Upper Houston Ship Channel was deficient due to lack of DO (Shipley and Kiesling, 1994). Although the point source dischargers have improved their effluents, BOD loadings have also been attributed to the runoff originating in the urbanized areas of Houston and ultimately reaching the HSC. In the Upper HSC, both point source and NPS BOD are still a concern. Armstrong and Ward (1994) found that of all of the annual point source BOD loadings entering the entire Galveston Bay System (i.e. the five bay sections and the HSC shown in Figure 1-1), those loads that eventually reach just the Upper HSC account for a little over 50% of the total. In 1992, Newell, *et al.* listed the subwatersheds draining into the Upper HSC as the top concerns in relation to non-point source BOD loading.

Modeling efforts concerning the BOD/DO relationship and the HSC have been conducted in the past. In 1968, a study conducted by Hydroscience, Inc. developed one of the first mathematical models for the Channel to help explain the DO deficiency in the waters (Hydroscience, 1968). This early research set the foundation for a report published in 1971 by Tracor, Inc. In the Tracor report, the 1968 model was further refined to model the BOD/DO relationship in the Channel. The 1971 investigation concluded that portions of the Upper HSC experienced periods of zero DO (Espey, *et al.*, 1971). In 1984, the Texas Department of Water Resources (TDWR) conducted a full scale modeling effort on the channel, in order to evaluate waste loads entering the HSC (TDWR, 1984). In 1994, Espey, Huston, and Associates studied sanitary sewer overflow effects on the surface water quality of particular bayous of the Bay (EH&A, 1994). However, this study only looked at two particular bayous on the upstream end of the HSC and did not consider the entire system.

Although these models were accurate at the time performed, changes to the point source loadings and new knowledge of NPS loading has resulted in the need for a redevelopment of a water quality model in the Houston Ship Channel. In addition, with the continually changing area of Houston, a model which can be modified to reflect future conditions or possible management practices is a benefit when trying to project the effectiveness of a particular engineering decision, such as flow augmentation, land use changes, or effluent flow diversion. Much of the data on the HSC is available, but it does not exist in a easily attainable or reproducible form. By importing data related to the Channel, such as point source discharge locations and loads, watershed land uses, projected runoff, and measured precipitation, into GIS, the information can be viewed and queried more easily. Once the data is formatted into GIS, the computer software can model important watershed characteristics, such as the areal distribution of NPS loads or the potential runoff over an area. These models could be standardized in GIS and used to depict the changes, if watershed characteristics were to be modified. In addition, a link established between GIS and a water quality model serves as a way of illustrating the effects of these watershed changes on the water quality of the natural system.

1.3 OBJECTIVE

The objective of this research was to develop a two-way (forward and reverse) link between the GIS software, ArcView and the USEPA water quality model, WASP5. This initial link could serve as the groundwork for a decision support system within GIS, for describing and modeling possible changes in the natural system, given a modification of the current engineering practices or the environment. The test area for this link was the Upper Houston Ship Channel, which has a substantial amount of data from previous research to utilize the powerful database management system found within GIS. The area also supports a need for a method of evaluating the effects of a proposed engineering practice or watershed characteristic change on the water quality of the area. This overall objective was met by the following specific objectives:

1. Represent all data necessary to perform a BOD/DO modeling effort in GIS format. The data may take the form of tables, coverages, or grids within the GIS software, ArcView and Arc/Info.
2. Determine the non-point source loadings into the Upper Houston Ship Channel, using a method developed from the methods of Newell *et al.*, (1992) and Saunders (1996).

3. Develop a simple BOD/DO model for the Upper Houston Ship Channel, looking at steady-state conditions and considering both point and non-point source loadings while using the USEPA supported model, WASP5.
4. Establish a link between the data represented in GIS, and the water quality model, WASP5, by using the ArcView programming language, Avenue.

1.4 SCOPE

This project was completed in five phases: literature review, GIS data development, non-point source BOD loading determination, WASP5 modeling, and model connection to GIS. The following are specific tasks which were completed within each phase.

Phase I Literature Review

This phase investigated previous modeling efforts performed in the study area, along with additional research conducted related to water quality and watershed management. Previous studies utilizing the connection of GIS with existing numerical models were also examined. The specific steps were:

1. Review literature on previous research and modeling efforts done in the Houston Ship Channel.
2. Review literature on point and non-point source loadings into the Houston Ship Channel.
3. Review literature on the uses of GIS in watershed management, water quality modeling, and linkage to numerical models.

Phase II GIS Data Development

This phase was centered on the development of existing data in to a format that is representable in GIS. The majority of this step was concerned with the creation of coverages and grids to digitally and spatially represent known information, along with the generation of related data tables. The specific steps were:

1. Digitally represent the Upper Houston Ship Channel waterway, watersheds, tributaries, current water quality, and model segmentation.
2. Digitally represent the Upper Houston Ship Channel watershed, including surface terrain, watershed boundary, land use, and any other spatial data, such as areal precipitation.
3. Develop tables within GIS to represent channel characteristics and model parameters, such as depth, reaeration coefficients, and tributary flow. Link these tables to the coverages of the channel and its model segmentation.

Phase III *Non-point Source BOD Loading Determination*

Using the coverages, grids, and tables developed in Phase II, this step estimated the steady-state BOD loading from non-point sources. This phase followed a method developed by Saunders (1996), where land-use-based constituent concentrations were linked to projected runoff to obtain an areal distribution of NPS loading. The specific steps were:

1. Establish the average runoff per unit cell over the watershed area grid.
2. Determine the estimated mean concentrations (EMCs) for each land use in the land use coverage from Phase II.
3. Link the EMCs with the land use and, likewise, multiply by the areal runoff to obtain a NPS load of BOD for each unit cell
4. Route the areal loading over the watershed area to the Upper Houston Ship Channel and establish the total steady-state NPS loading to each model segment.

Phase IV *WASP5 Modeling*

This phase established the model parameters and channel characteristics needed to run WASP5. The model executed was actually EUTRO5, a WASP5 subprogram designed for dissolved oxygen and eutrophication modeling. A level one complexity for EUTRO5, involving simple Streeter-Phelps BOD/DO equations, was used. In addition, the level one complexity for WASP's subprogram TOXI5, was used to calibrate the model. The specific steps were:

1. Become familiar with WASP5 and its eutrophication sub-model, EUTRO5.
2. Establish the model segmentation and parameters to be used for the Upper Houston Ship Channel.
3. Calibrate the model with WASP5's subprogram TOXI5, using salinity as the conservative substance.
4. With the information established in Phases II and III, determine the total steady-state BOD loading (point and non-point sources) into each model segment
5. Perform steady-state modeling scenario.
6. Compare the model predictions of DO and BOD with the historical measurements.

Phase V *GIS/WASP5 Connection*

The connection was established using ArcView's programming language, Avenue and simple formatting FORTRAN programs in order to write the necessary WASP5 input file from GIS coverages and tables. The model output was also read by FORTRAN programs and rewritten in a form that was readable by Avenue.

1. Connect the WASP5 model to GIS, by using Avenue programming and FORTRAN to produce the necessary formatted input files for the model from the ArcView coverages and tables.
2. Reformat the WASP5 output files, using FORTRAN, so that they may be imported back into GIS, through ArcView.
3. Display the model results, using Avenue programming to allow the user generate new tables, charts, and coverages.

These phases, although itemized here, were performed concurrently. For example, it would have been redundant to establish the location of the point sources into the segments by hand and then by GIS. Instead, that information was established through GIS and initially entered into the model by hand. Then, once the GIS/WASP5 connection was established, the manual input step was eliminated. The final product of this research was an established link between the WASP5 model, developed for the Upper HSC, and ArcView, using Avenue and

FORTRAN. Although the initial link has some limitations, once established, it can be further enhanced as the information needed becomes available.

1.5 CONTRIBUTION TO KNOWLEDGE

The completion of this project introduces some new concepts which are important in the area of water quality modeling, GIS, and the Houston Ship Channel. The primary contributions of this research to existing knowledge are:

- The establishment of an ArcView-based connection of models to GIS, rather than Arc/Info-based.
- The linkage of the a spatially represented land surface pollutant loading model to an in-stream water quality model.
- The assembly of a GIS database for the Houston Area, including, but not limited to, digital representation of land use, precipitation, runoff, water bodies, water quality parameters, and their related parameters.
- The development of a non-point source loading analysis for the Upper Houston Ship Channel, using GIS. Specifically, the establishment of a method for spatial distribution of runoff and flow over the watershed area, so that land-based estimated mean concentrations can be used to determine areal loads.