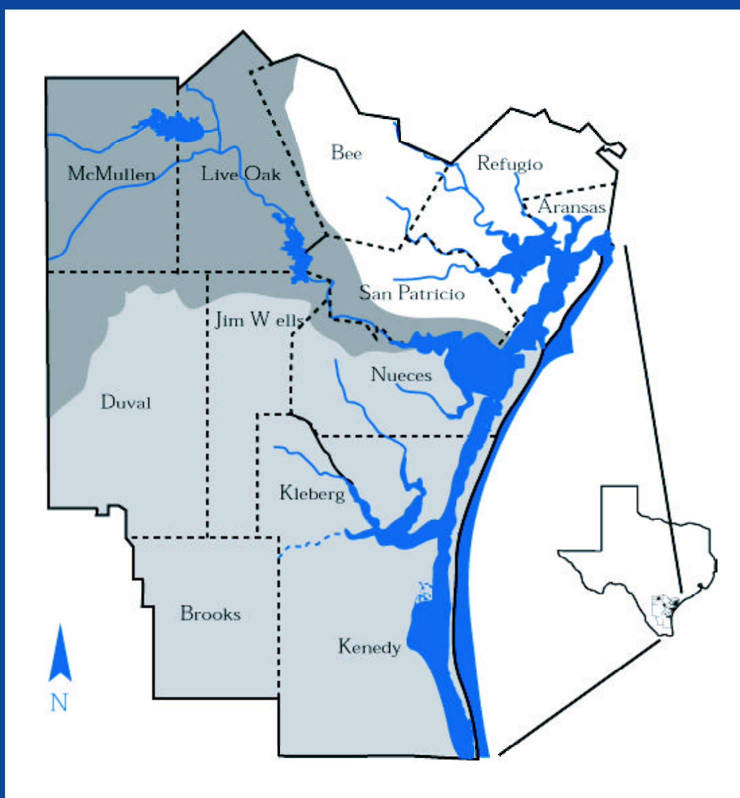
Total Loads and Water Quality in the Corpus Christi Bay System



Corpus Christi Bay National Estuary Program

CCBNEP-27 • June 1998

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

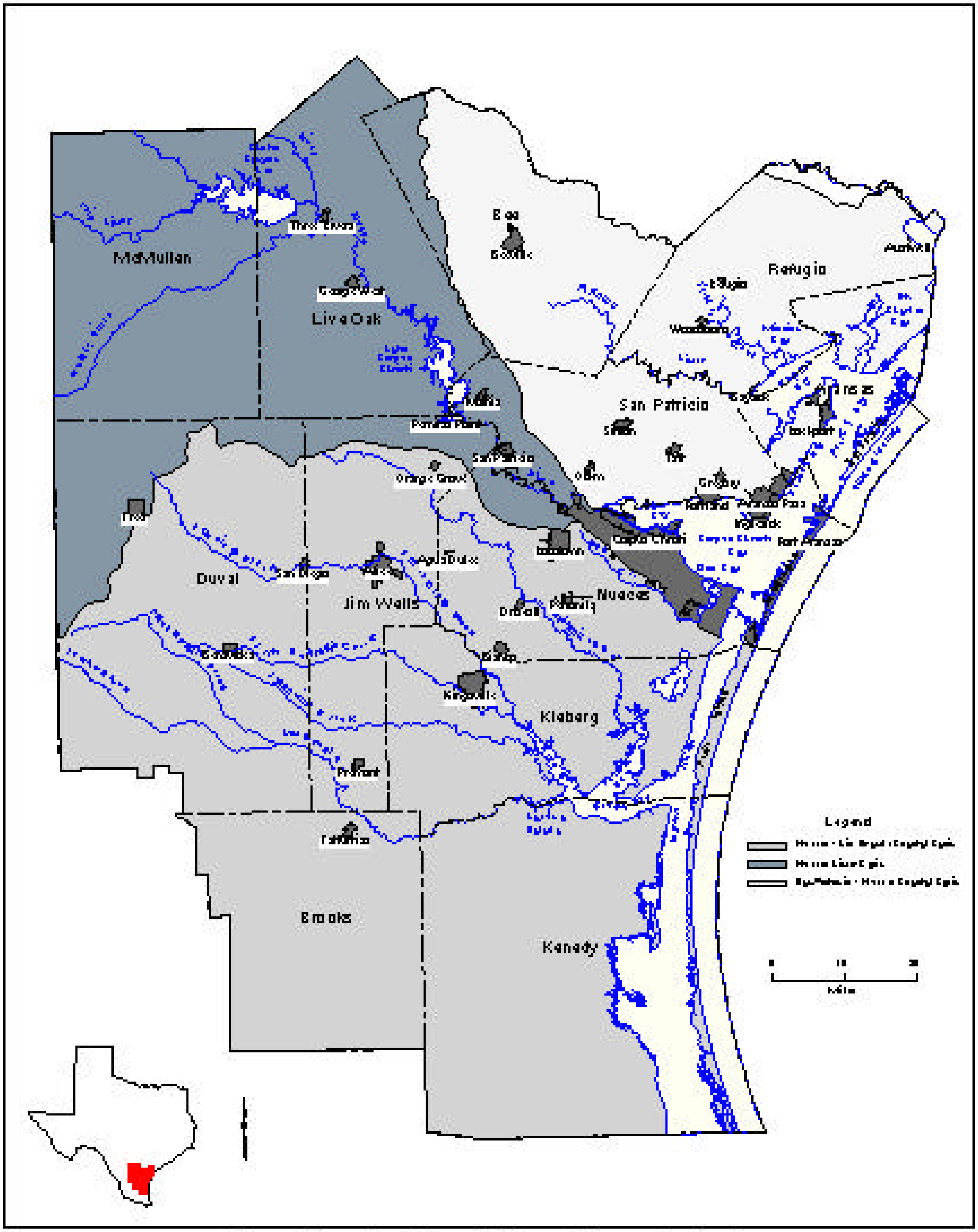
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

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TOTAL LOADS AND WATER QUALITY IN THE CORPUS CHRISTI BAY SYSTEM

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EXECUTIVE SUMMARY

A Geographic Information System (GIS) model of total constituent loadings and their impacts on receiving water quality is presented for the Corpus Christi Bay system. The model uses publicly available elevation, stream network, precipitation, stream discharge, water quality, and land use data sets. The model development begins by laying a fine mesh of 100m cells over a watershed within which the non-point source pollution loads are estimated from each cell of the land surface. Point sources and atmospheric deposition on the Bay system are separately accounted for, as is the load from the Nueces River inflow to the study region. The loads from the model are input to the receiving water to calculate the equilibrium concentrations in the Bay system. The coefficients of dispersion for the Bay segments are calibrated using salinity as a conservative tracer. The resulting constituent concentrations are compared with the average of those observed in each bay segment.

For summary purposes, the overall bay system is subdivided geographically into three large bay systems, north, middle and south. The middle bay system refers to the Corpus Christi and Nueces Bays and the smaller bays flowing into them. The other two categories refer to the bays north and south of the middle bay system; Aransas/Copano Bays, and Baffin Bay/Laguna Madre, respectively. The study methodology can be broken down into three components: first, the water balance of inflow, outflow, precipitation and evaporation; second, the total loadings of constituents from point, land surface, atmospheric and the Nueces River Basin; and third, the mass balance of each constituent in the bay system. The constituent mass balance analysis includes a comparison of the observed and calculated concentrations. Finally, the possible uses of the model for management purposes are assessed.

(1) Water Balance

The mean annual precipitation ranges from approximately 600 mm/yr (24 in/yr) at the southern end of the study region to approximately 1000 mm/yr (40 in/yr) at the northern end. At the southern end less than 2% of the precipitation becomes runoff while at the northern end more than 10% becomes runoff. Therefore, the runoff gradient from South to North is much more pronounced than is the gradient of precipitation. The runoff averages less than 10 mm/yr (0.4 in/yr) in the south to more than 100 mm/yr (4 in/yr) in the north. The reason for the steep runoff gradient is that the larger precipitation in the north saturates the soil more frequently causing a greater percentage of the precipitation to become runoff than in the south.

The runoff into the bay system from the land surface in the study region totals 36 m^3/s. An additional 20 m^3/s enters the bay system from the Nueces River outflow from Lake Corpus Christi. At the northern boundary of the bay system, an inflow of 16 m^3/s is assumed to come from the very substantial runoff of the Guadalupe and San Antonio Rivers which flow into San Antonio Bay, this estimate being 20% of the mean annual gauged discharge of those two rivers. At the southern boundary of the bay system, it assumed that there is no inflow from the Lower Laguna Madre. The total inflow to the bay system is 72 m^3/s of which 56% enters the north bays, 34% the middle bays and 10% the southern bays.

The average direct precipitation onto the surface of the bays is approximately 800 mm/yr and the average evaporation is approximately double that figure, or 1600 mm/yr. The mean annual outflow from the bay system to the Gulf of Mexico is only 6 m^3/s, so the remainder of the inflow is lost by evaporation. Since very little tidal flushing occurs and the bay system is not frequently flushed by inflow from the land surface, the bay system acts as a large sink that absorbs most of the loads that come into it from the land surface, atmosphere, and point sources.

The calculations in this study are all based on mean annual conditions. In years of high flow, there is a correspondingly greater outflow to the Gulf, while in years of low flow there is a net inflow of water from the Gulf to the bay system to sustain the net evaporation from the bay system. The disparity between inflow and outflow is particularly acute in the south bay system, in part because the precipitation is lowest there and in part because the surface area of the south bay system is larger than the combined surface areas of the north and central bay systems. There is also no point of exchange of water with the Gulf of Mexico in the south bay region. Hence, the south bay system flushes itself much less frequently and less completely than do the north or the central bay systems.

(2) Total Loadings

Total load calculations were made for thirteen constituents: ammonium, nitrite plus nitrate, total nitrogen, total phosphorus, oil and grease, and eight metals (copper, cadmium, chromium, lead, zinc, iron, arsenic, and mercury). There are significant gaps in the available data, notably for point source loadings of ammonium and nitrite plus nitrate, non-point source loadings of ammonium, atmospheric loadings of many constituents, and sediment loads of all constituents. Because of these data limitations, results are discussed for six constituents with the most reliable data: total nitrogen, total phosphorus, oil and grease, copper, chromium, and zinc.

The nutrients nitrogen and phosphorus have a combined loading of approximately 18,100 kg/day, of which 15,000 kg/day is total nitrogen and 3,100 kg/day is total phosphorus. Oil and Grease have a total load of 2,800 kg/day. The loadings for the metal constituents are much smaller, approximately 30 kg/day for copper, 26 kg/day for chromium and 108 kg/day for zinc. For total phosphorus and the metals, from one half to two thirds of the loads are derived from the land surface. Oil and grease sources are derived mostly from point sources. Atmospheric sources contribute about one third of the load of total nitrogen, about one half of this load comes from non-point sources on the land surface and one sixth from point sources. The atmospheric load in wet deposition over the land surface is approximately 35% of the land surface load for total nitrogen. For the metals, about one third of the load comes from point sources and two thirds from non-point sources. No sediment loads from the bay floor are included in these estimates, and atmospheric loads are also not accounted for in the case of phosphorus and the metal constituents.

(3) Water Quality

The impacts of the loadings on the bay system are evaluated using a water quality model, which takes into account advection, dispersion, and first order decay, but not detailed biological or chemical processes. The dispersion coefficients for each of the 20 bay segments within the three main bay segments were calibrated using salinity as a conservative constituent and held constant for all the other constituents. A set of mass balance calculations are first made assuming all constituents are conservative. A t-test was used to compare the predicted and observed concentrations in the bay segments. The t-test results showed that the conservative constituent assumption results in accurate prediction of observed concentrations of oil and grease, over-prediction of total nitrogen and phosphorus, and under-prediction of metals.

The long residence time of the three bay segments makes the concentrations sensitive to the overall gain and loss within the system. A second set of mass balance calculations was carried out to determine constituent decay. The decay rates take into account all the mechanisms (abiotic and biotic) of the gain and loss process. To reach the average observed concentrations in the bays for total nitrogen requires a decay rate of approximately 0.02 d^{-1}. This means that 2% of the mass of nitrogen is removed from the bay waters each day by decay processes. A similar computation for total phosphorus yields a decay rate of approximately 0.01 d^{-1}. These decay rates are reasonable when compared to corresponding values reported in the literature.

Using the conservative mass balance, the metals concentrations are under-predicted by a factor of three to four, which suggests that there are metals sources that are presently unaccounted for. Since the bays do not flush frequently, there exist long periods of time during which the metals are washed into the bays and deposited in bay sediments, creating a reservoir of metals in the sediments. A portion of these sediment metals may then re-enter the water column due to re-suspension and physical and chemical process. It is also possible that a reservoir of metals has been accumulated in the Bay sediments from industrial discharges of previous decades when wastewater discharge standards were not as stringent as they are now. The calculations suggest that this flux from the sediment reservoir may be the dominant control on the metals concentrations in the bay waters rather than current loadings from the land surface. It is also possible that the metal loadings from the other sources have been underestimated, either in the point sources, land surface or atmospheric loads. Clarifying this discrepancy in the mass balance for metals in the bay system requires further investigation.

The non-point source loadings for total nitrogen and total phosphorus are largely driven by runoff from agricultural lands. Ongoing field studies at the King Ranch and near Edroy, TX, suggest that the expected mean concentrations of nitrogen and phosphorus are less than half of those assumed originally in the mass balance study, whose expected mean concentration values were derived from data observed outside the Corpus Christi region. When other sources of nitrogen and phosphorus are also accounted for, the resulting reductions in total loads are about 27% from total nitrogen (from 15,000 Kg/d to 11,000 Kg/d) and about 28% for total phosphorus (from 3,1000 Kg/d to 1,900 Kg/d).

This study did not incorporate the City of Corpus Christi's water supply diversion from the Nueces River. It was assumed that all of the water leaving the Corpus Christi Dam enters the bay system. However, only fifteen percent of the discharge in the Nueces River is diverted to the City, with two thirds of that is discharged back to the bay system through the City's wastewater discharge (Ward, 1997). Overall, the constituent load from the Nueces River Basin upstream of Lake Corpus Christi has very little impact on the bay system.

(4) Model Uses and Developments

The original intent of the study was to determine the total loads and water quality to the Corpus Christi Bay System. However, the way that the GIS model is prepared, the study could be used for management purposes. By determining the source of load, different best management practices (BMP) can be analyzed in order to reduce that constituent load. The models can then be run again to calculate the reduction in loads due to the BMPs. This has been done in a parallel study concerned with water quality master planning being carried out for the City of Austin.

The Expected Mean Concentration (EMC) table, which links pollutant concentrations in runoff to land use, can be updated as new information is obtained. For example, once the Edroy and King Ranch studies are complete and the data is analyzed, the EMC table used in the model can be updated by changing the EMC values associated with the rangeland and agricultural land uses. The models can be run again in order to assess the change in loads due to the change in EMC values for these two land uses. The land use data employed in this study do not distinguish between improved pasture and row-crop agriculture. Once new landuses are obtained, the land use files can be updated. The new land use would then be linked to the EMC table and the models could be run again to determine the change in loads due to the new land use data.

The model can be used to assess the loads in small scale studies in problem areas in the Corpus

Christi Bay System. For example, the area draining into the Inner Harbor can be delineated and separated from the rest of the study area. The land surface and water quality models can be run on that area to determine the source of the loads ending up in the Inner Harbor. Different BMPs could be analyzed to determine the best solution to control the loads entering the receiving water in the Inner Harbor.

Since the study used mean annual values for flow, precipitation, and evaporation, the model results are a representation of total loads and the resulting water quality that occur during a year of normal weather. The model could be run using flow, precipitation, and evaporation representing flood and drought years in order to assess the water quality of the bay system during high and low flows. Also, the model could be run using the seasonal variations in flow, precipitation and evaporation by finding the average values for each of the seasons. The water quality for the seasonal variations could then be assessed.

Once new data is obtained, the model can be updated. For example, there are separate studies being done in the CCBNEP for atmospheric deposition. Once these studies are complete and the data is analyzed, the new loadings can be entered into the water quality model and the new equilibrium constituent concentrations can be calculated. This same calculation can be done once new load information is obtained for sediment fluxes, point sources, and land surface EMC data.

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1 INTRODUCTION

1.1 Background

The National Estuary Program was established through the Federal Water Quality Act of 1987 to identify and protect significant estuaries in our nation. Studies on twenty-eight estuaries are now funded and administered by the United States Environmental Protection Agency (EPA). Governor Ann Richards formally nominated corpus Christi Bay for the program in 1992. The Corpus Christi Bay National Estuary Program is designed to coordinate the activities of all regulatory authorities along with input from the non-government sector in assessing scientific information about the nature of the bay system and formulate a management plan to address environmental problems in the bay system.

This study is being done to determine the total constituent loadings to the bay system. Loads from the atmosphere, land surface, point sources, and the Nueces River upstream of the study region are calculated and entered into a bay water quality model to determine the equilibrium constituent concentrations. Mean annual flow conditions at steady state are the only flow conditions considered, so the computation in the bay system is a mean annual mass balance.

The results of this study synthesize many components of the Corpus Christi Bay National Estuary Program, including the results of separate studies on point, land surface, and atmospheric sources, and the status and trends study of observed water quality in the bay system. The sum of the loadings coming into the bays were used as inputs to a water quality model to try to match the observed concentrations in the bay system, so that the significance of various pollution sources can be judged against their contribution to impacts on the bay water quality.

1.2 Objectives

The total loadings project begins by simulating the watershed characteristics using the ArcView Geographic Information System (GIS). The land surface or land surface load, point source loads, upstream watershed loads, and atmospheric loads are also modeled using ArcView. A 100 meter grid is laid over the land surface in the study region. Each cell accounts for elevation, land use, constituent concentrations, mean annual precipitation, mean annual expected runoff, and annual land surface loads. In addition to the non-point source loads, loads from point sources, the atmosphere and the Nueces River inflow to the study region are added into the model. Benthic loadings from the bay sediments have not been explicitly accounted for because of lack of usable data.

By directing the flow of water from cell to cell, the loads are accumulated in the river network and bay system. The loads are then entered into the water quality model to calculate an equilibrium concentration in each of 20 bay segments.

For purposes of summarizing the research results, the bay segments are grouped into three regions: north, middle and south bays. The north bays comprise Copano and Aransas Bays and the smaller bays flowing into them. The middle bays are Nueces and Corpus Christi Bay, and those in the south are the Laguna Madre and Baffin Bay.

The study had a number of limitations. The use of mean annual calculations considers the flow and loads to be steady state parameters from year to year. The effects of flushing of pollutants through the system in substantial floods are not considered. Second, constituent concentrations on the land surface are related to general land use categories and do not to vary with more specific types of land uses. For example, different types of crops grown in an agricultural area may produce different amounts of runoff, but that effect is not considered here. Third, constituent loads were considered to be conservative in the river network as they are transported to the bay system, possibly causing an over-estimation of the constituent loads to the bay system. Fourth, some constituent loads are estimated from limited data. For example, the atmospheric data were collected at one site in Beeville, TX, and this site has limited data. Sediment loads are not estimated, and this limitation is particularly pronounced in the case of the metals where it appears that there are significant sediment sources for all metal constituents.

Despite all these limitations, the final model results bear a reasonable resemblance to the observed concentration data in the bay system when the two values are compared statistically. Where there are consistent discrepancies between observed and computed values, the explanations are readily apparent and can be accounted for by missing source loadings or the adjustment of the decay rates, in the case of metals and nutrients, respectively.

1.3 Study Area

The study area includes 75 miles of south-central Texas coastline; 550 square miles of water including all bays and saltwater bayous, Aransas Bay, Copano Bay, Redfish Bay, Nueces Bay, Corpus Christi Bay, Baffin Bay, and Laguna Madre. The twelve counties covered by the study are McMullen, Live Oak, Bee, Refugio, Aransas, San Patricio, Jim Wells, Duval, Nueces, Kleberg, Kenedy and Brooks. Padre Island also is included in the study.

The study area is bounded by the San Antonio Bay on the north and extends down to the Lower Laguna Madre. Three main rivers drain into the bay system; Mission River, Aransas River, and Nueces River. The Mission and Aransas Rivers flow into the Copano Bay while the Nueces River drains into the Nueces Bay. Figure 1.1 shows the location of the basin within the State of Texas, and Figure 1.2 shows the hydrologic features in the region. The large indentation on the inland side of the study region is the drainage area of Nueces River upstream of Lake Corpus Christi, which is treated as a point source so that no explicit representation of its land surface features is required. The water quality effluent from Lake Corpus Christi can be quantified with sufficient confidence using this method, so this simplification is reasonable.

The study area is characterized by pronounced topography in elevations in the northwest portion of the study region while near the coast and in the south portion of the area there is little change in elevation. The southern region of the study area is mostly covered by rangeland. The middle portion of the area is substantially cultivated for agriculture. The northern portion of the study area is used for a mix of agriculture and rangeland. Small portions of urban land use are scattered throughout the study region with the majority of the urban land use being centered in and around the city of Corpus Christi.

1.4 Report Outline

The report is divided into four chapters. This study has a unique combination of land surface loadings from a distributed parameter model of the landscape with a lumped parameter model of water quality in the bay system, both connected in the GIS using a map-based modeling approach that has not been accomplished previously. Chapter 2 shows how the runoff and constituent load values are developed for input to the total loadings model and demonstrates a very substantial south to north gradient in runoff from the land surface. Chapter 3 presents the results of the computations of water quality in the bays and statistically compares the calculated values with those observed. It shows that the bay system functions as a sink for constituents because most of the inflow to the bay is lost to evaporation and does not flow out into the Gulf of Mexico. Chapter 4 presents the conclusions of the study. Appendix A describes the data sources used in the study and how the data are compiled into a consistent database with a common geographic reference frame. A total of some 500MB of files were thus created, and this database will be of continuing value for other studies in the Corpus Christi region after this research is completed. The data developed in the study are documented in Appendix B and the computer programs in a separate Appendix which can be obtained from the Corpus Christi National Estuary Program Office.

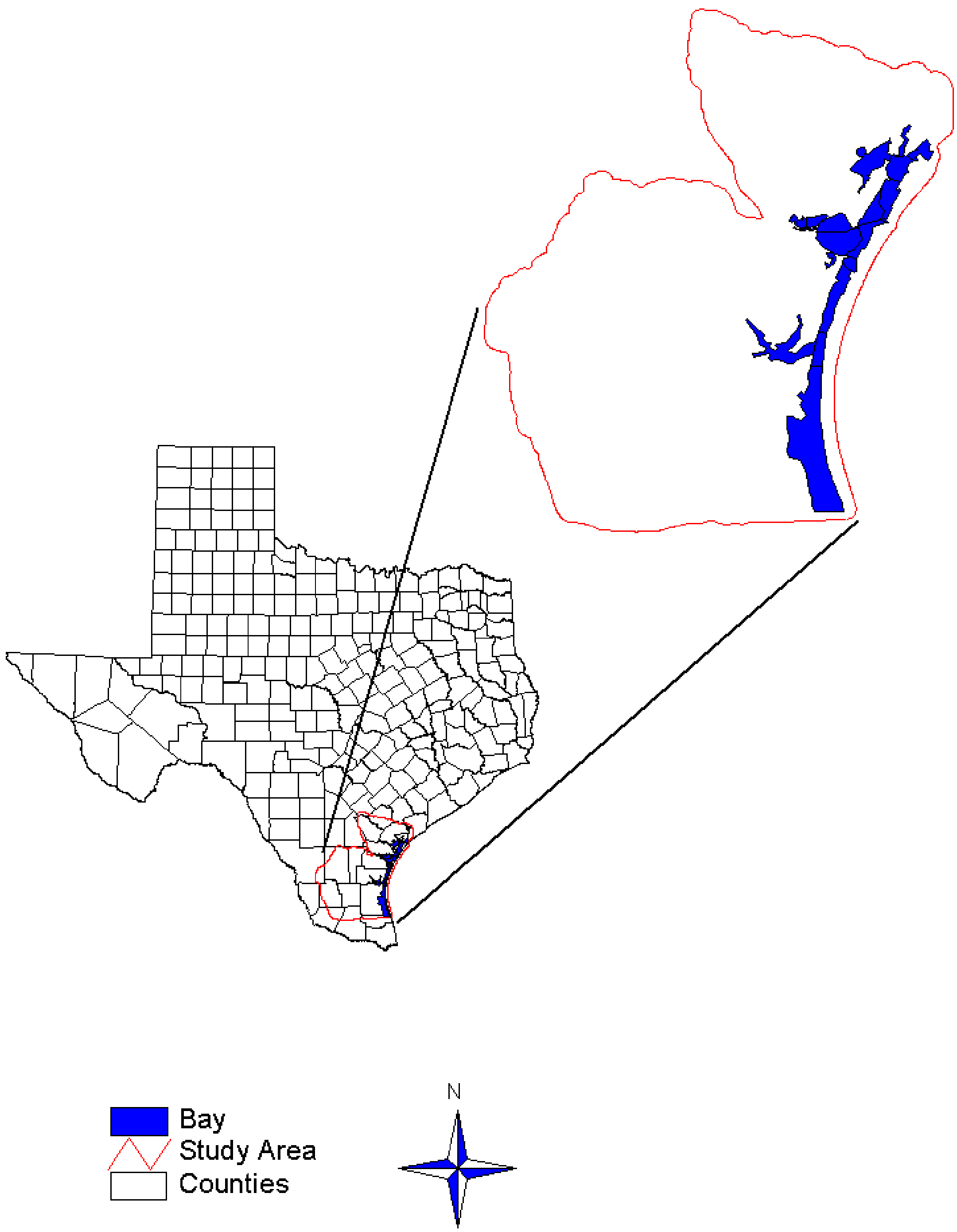

Figure 1.1: Study Region Location in the State of Texas.

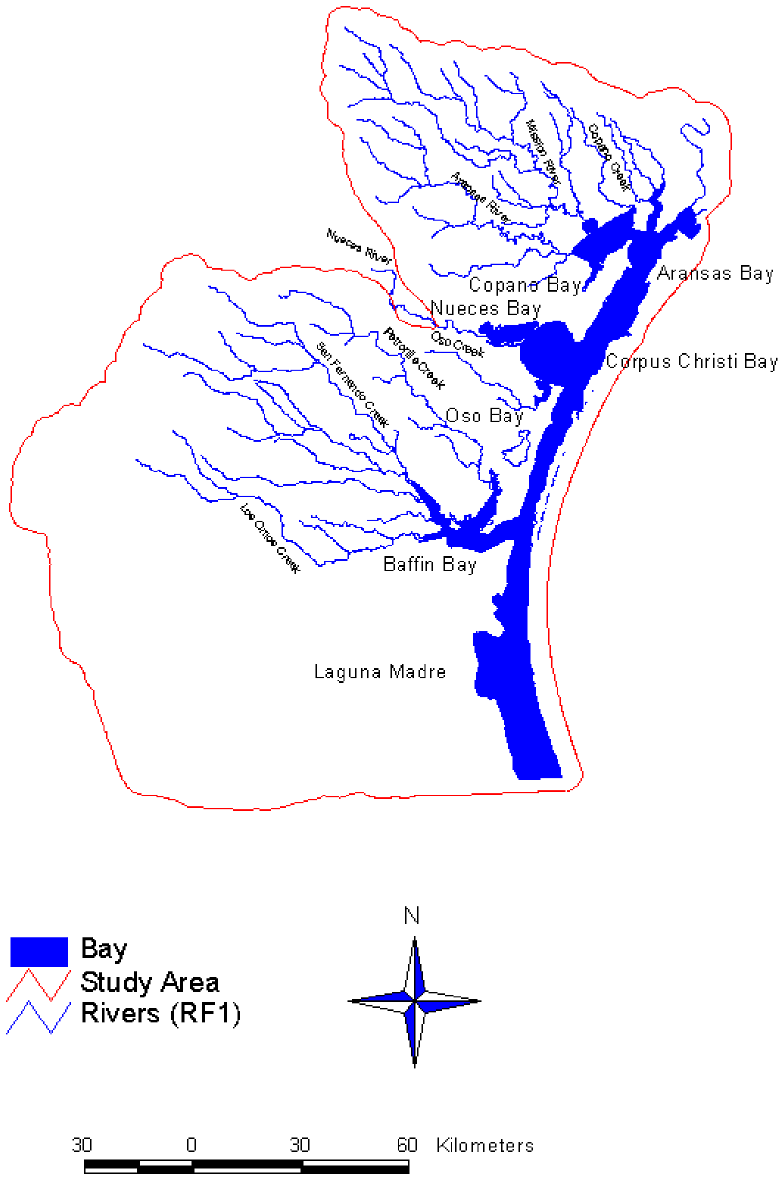

Figure 1.2: Hydrologic Features within the Study Region.

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2 METHODOLOGY

The ArcView project described in this section calculates the atmospheric, land surface, point source and Nueces River loads for the Corpus Christi National Estuary Program's total loadings study. The project includes calculations for land surface concentrations and runoff on a per cell basis. The project has capabilities to delineate watersheds. Finally, the project is able to calculate the receiving water body's equilibrium concentrations due to point, non-point, atmospheric, and upstream watershed loads.

In so far as possible, the commands used to accomplish the calculations are written in bold type, while the computer prompts are in italics. The programs used are listed in a separate Appendix which can be obtained from the Corpus Christi National Estuary Program Office.

2.1 Grid-Based Watershed Modeling Using Digital Elevation Data

To begin the assessment of land surface loadings, it is necessary to recondition the digital elevation model (DEM) which involves making the DEM and the hydrology digital line graph (DLG) files agree. This is so the precipitation can be directed from the land surface to the receiving waters using the DEM. The reconditioning process involves digging a trench into the DEM where the riverbed is located according to the DLG files. Once the DEM has been reconditioned, the river network and bay system are connected by dropping the centroid of the bay coverage below the value of the surrounding cells, so that the flow is accumulated at that point.

2.1.1 Recondition the DEM Surface Model

AGREE is a surface reconditioning system for a DEM. The system adjusts the surface elevation of the DEM to be consistent with a vector coverage. The vector coverage can be a stream or ridge line coverage. For the CCBNEP project, the vector coverage is the DLG discussed in Appendix A. The AGREE system is an alternative to the "burning in the streams" process which simply drops the elevation of the cells corresponding to the DLG files. The AGREE reconditioning process lowers the grid cells corresponding to the DLG files by an amount designated by the user, while the cells within a buffer distance of the rivers are altered to have a smooth transition from the unmodified land surface to the lowered river cells. Figure 2.1 shows the AGREE methodology.

The program is run within the ArcView environment. The elevation grid and the vector coverage should be active in the view. The script asks for five parameters, which are the 1) elevation grid, 2) vector coverage, 3) buffer distance, 4) smooth drop/raise distance, and 5) the sharp drop/raise distance. Once the program is running, the temporary grids do not need to be saved.

Figure 2.2 shows a sample area near Corpus Christi Bay of the recondition DEM streams and the DLG file. This process forces the DEM drainage to follow the mapped hydrology DLG streams.

Before further calculations can be done using the DEM, data errors must be corrected. The DEM may contain sinks, which are a single grid cell or groups of cells surrounded by cells of higher elevation. The errors are corrected by using the Arc command **Fill**, which assigns the elevation of each sink to be equal to the value of its lowest elevation neighbor. This is accomplished by using the ArcView's **Hydrology** extension's pulldown menu with the **Fill** option. The reconditioned grid must be active in the view.

2.1.2 Connecting the Bay System with the River Network

CONNECT is an Avenue script which connects a reconditioned DEM with a polygon coverage representing the segments of the bay system by dropping the centroid of the polygon coverage below the elevation of the surrounding cells. The elevation grid is altered to create artificial sinks corresponding to the centroid of the segments of the polygon coverage. Lowering the elevation in the segments an arbitrary amount creates the sinks, and then the bottom of the segment is sloped towards the centriod of the segment area. Figure 2.3 shows the methodology of the connection between river network and the bay system.

2.1.2.1 Bay Coverage

The bay coverage used in the total loadings study is developed using the River Reach Files (RF1) downloaded from the USGS Internet site (USGS 1997):
http://h2o.er.usgs.gov/nsdi/wais/water/rf1.html.

The bay segmentation is obtained from the report entitled C*orpus Christi Bay National Estuary Program, Ambient Water, Sediment and Tissue Quality of Corpus Christi Bay Study Area: Present Status and Historical Trends, Summary Report* (Ward, 1996). The bays are segmented according to natural bathymetry and water flow in the system. The original 189 segments defined in the report are too detailed for the total constituent loading project due to the time that would be involved in calibrating the equilibrium concentration model. The original bay coverage is clipped using the RF1 file to remove parts of the bay system which covered the land surface. A total of 14 segments are thus eliminated. The remaining segments are grouped together to form the 20 segments used in this study keeping the natural bathymetry an water flow in mind. Figure 2.4 compares the clipped segmentation with the new bay model, while Table 2.1 shows the comparison between the clipped and grouped segmentation.

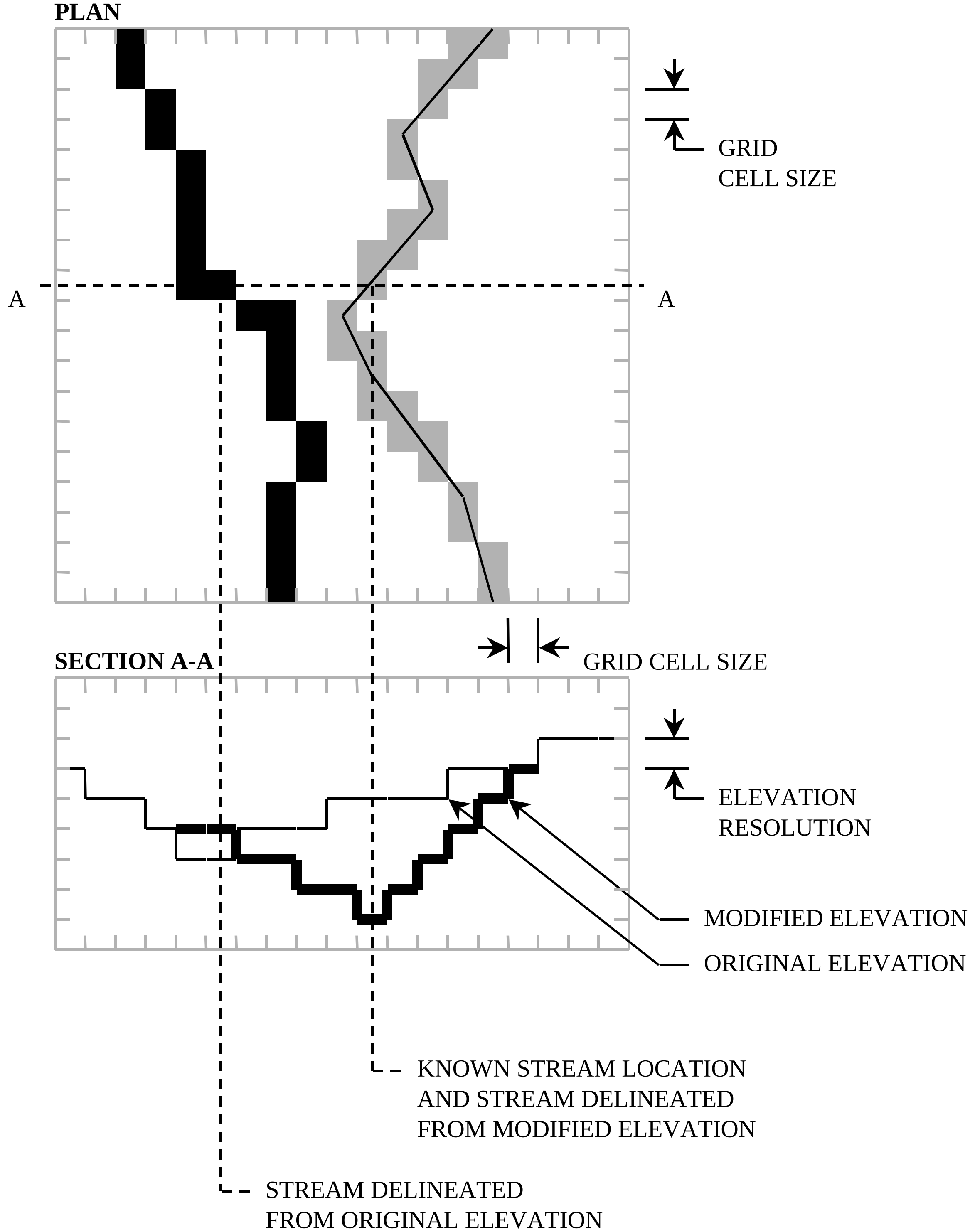


Fig. 2.1: Methodology of the Reconditioning System.

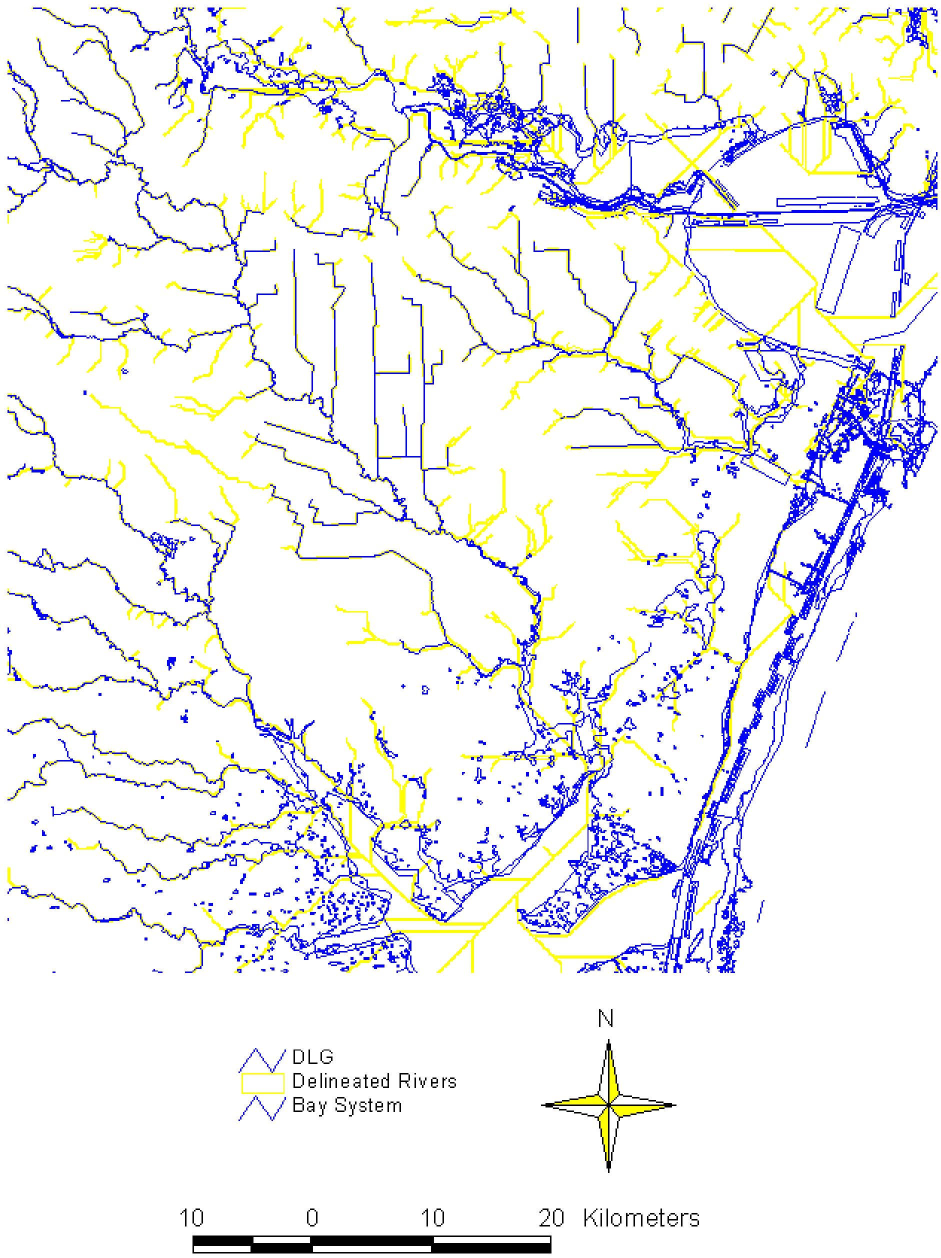


Figure 2.2: Delineated Rivers Compared to the DLG File.

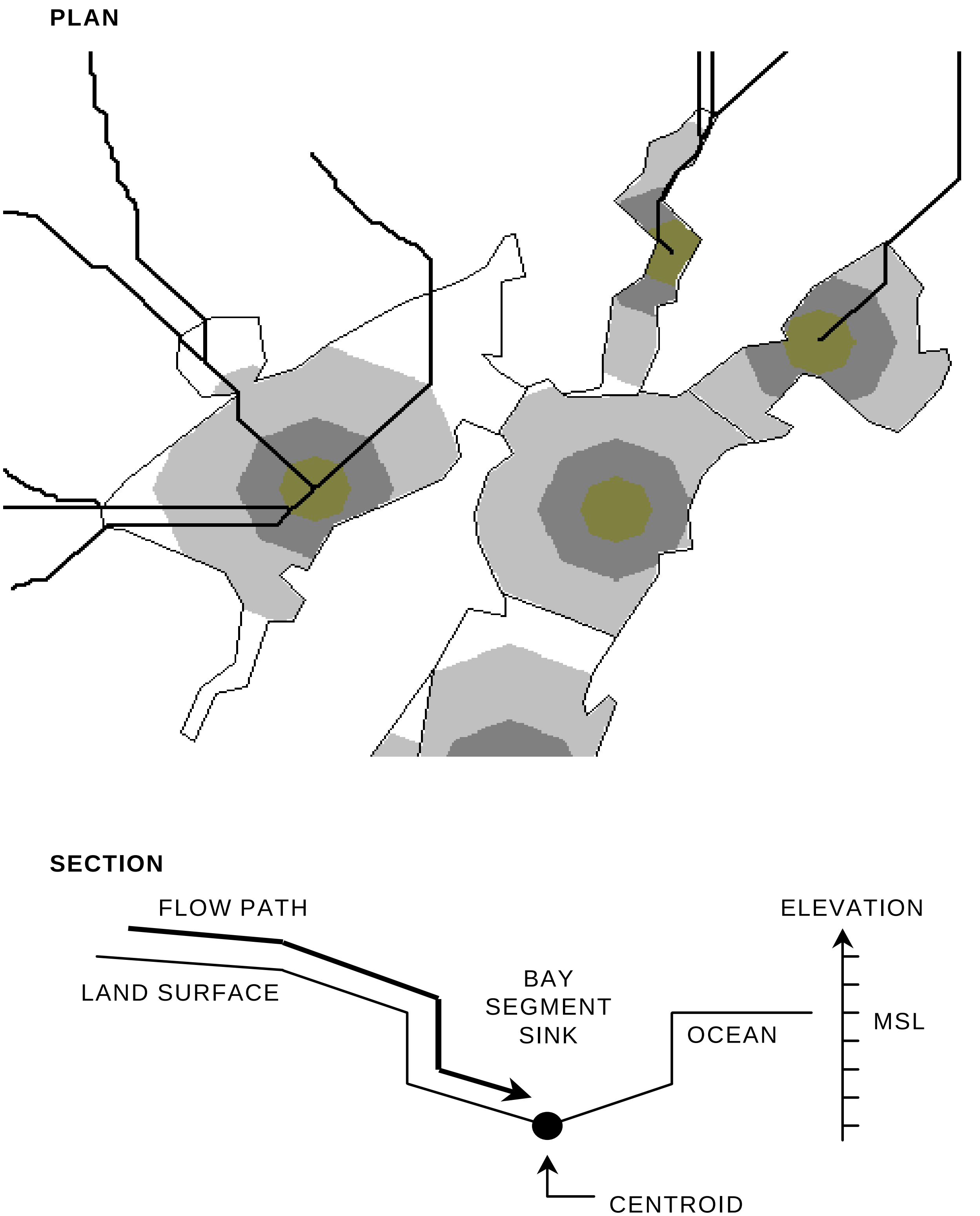


Figure 2.3: Methodology of the Connection between the River Network and the Bay System.

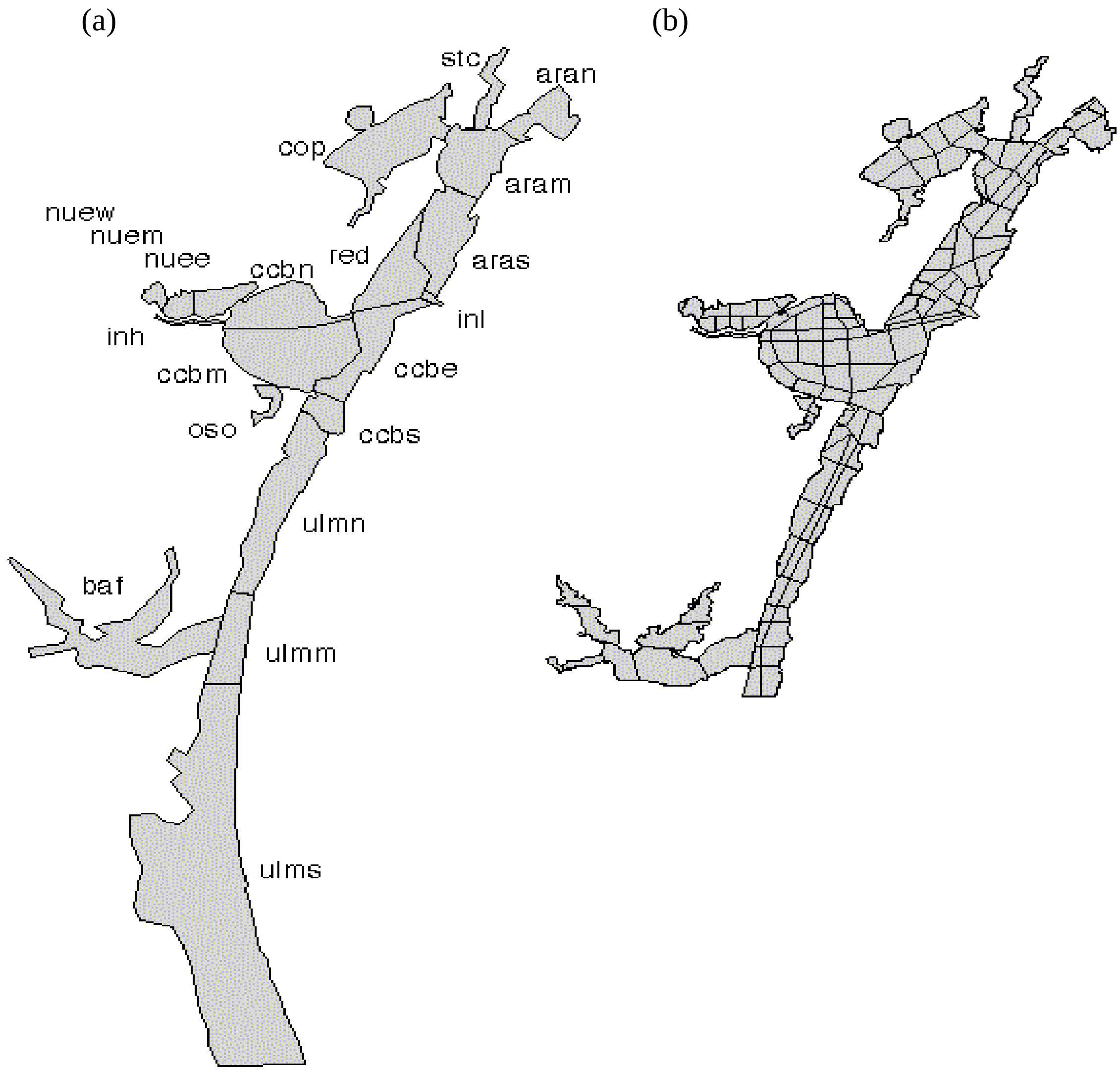


Figure 2.4: Comparison between the a) New Bay Segmentation and the b) Clipped Segmentation.

Table 2.1: Comparison between the Original Segmentation and the New Bay Model Segmentation.

Segment	ID	Ward and Armstrong Segments
St. Charles	stc	SC1, SC2, SC3
Copano	cop	M1, M2, AR1, PB1, PB2, CP01, CP02, CP03, CP04, CP05, CP06, CP07, CP08, CP09, CP10
Aransas North	aran	I1, I2, I3, AYB, MB1, MB2, CB, CBY1, CBY2
Aransas Middle	aram	A1, A2, A3, A4, A5, I4, I5, A8, A9, A10, LB
Aransas South	aras	A6, A11, A12, A13, I6, I7, I8, LAC
Redfish	red	RB1, RB2, RB3, RB4, RB5, RB6, RB7, RB8,
Inlet	inl	INL
Nueces West	nuew	ND1, ND2, ND3, ND4, NB1
Nueces Middle	nuem	NR1, NR2, NR3, NR4, NR5, NB2, NB3, NB4
Nueces East	nuee	NB5, NB6, NB7, NB8, NB9
Inner Harbor	inh	IH1, IH2, IH3, IH4, IH5, IH6, IH7
Corpus North	ccbn	LQ1, LQ2, C15, C16, C17, C18, C19, C20, C21, C22, C23, CCC3, CCC4, CCC5, CCC6, CCC7, CCC8
Corpus Middle	ccbm	C01, C02, C03, C04, C05, C06, C07, C08, C10, C11, C13
Corpus East	ccbe	CCC1, CCC2, EF, C12, C09, C14
Corpus South	ccbs	C24, I9, C25
Oso	oso	OS1, OS2, OS3, OS4, OS5, OS6, OS7
ULM North	ulmn	UL01, UL02, UL03, UL04, UL05, UL06, UL07, UL08, UL09, UL10, I10, I11, I12, I13, I14
ULM Middle	ulmm	UL11, UL12, UL13, UL14, I15, I16, I17, I18
ULM South	ulms	NONE
Baffin	baf	GR1, GR2, LS1, LS2, AL1, AL2, BF1, BF2, BF3

2.1.2.2 A Problem when Connecting the Land Surface with the Bay System.

A problem was encountered at the bay system boundaries when first applying the CONNECT methodology. An extended portion of the DEM was used to ensure all of the study site was encompassed. Therefore, in the northeast corner of the study site, some of the flow was directed into the north Aransas Bay segment. However, the flow from the land surface may actually flow north rather than directly into the bay. This problem was corrected manually by setting the runoff inflow into this bay segment to zero.

Figure 2.5 shows the flow error into the north segment of Aransas Bay caused by the extended DEM.

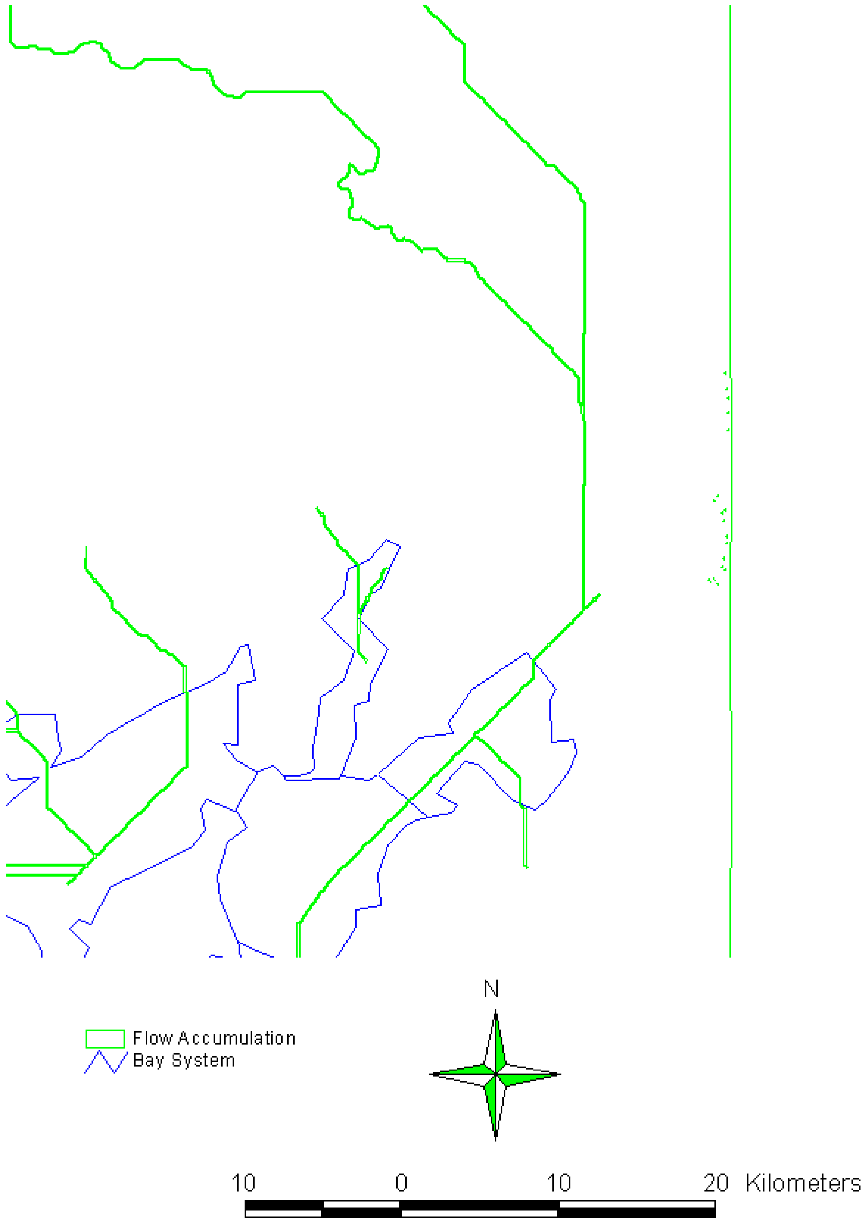


Figure 2.5: North Aransas Bay Segment Flow Problem Due to Extended DEM.

2.1.3 Eight Direction Pour Point Model

Once the reconditioned and filled elevation grid has been connected to the bay system, the direction of flow for each cell can be calculated. After the flow direction is determined the number of cells upstream of a given grid cell can be determined. These two processes are called flow direction and flow accumulation, respectively. The calculations are based on the eight-direction pour point model. The model begins by describing a cell surrounded by its eight neighbors. A cell drains to its neighbor of steepest descent as defined by the filled and connected elevation model. The drainage connections are traced from cell to cell to develop a flow direction network. The flow accumulation grid is calculated by counting the number of cells that occur upstream of each particular cell (Maidment, 1996).

The flow direction grid is calculated using the ArcView **Hydrology** extension's pulldown menu with the **Flow Direction** option. The connected grid must be active in the view. Again the ArcView **Hydrology** extension's menu is used, however this time the **Flow Accumulation** is used and the flow direction grid must be active in the view.

By acknowledging that surface runoff accumulates in creeks and streams, the flow accumulation values along streams should be greatest. Therefore, the flow accumulation grid can be queried to view the stream network that was embedded into the elevation grid. This is done using the ArcView extension's pulldown menu **Analysis**. The **Map Query** option is used to query the flow accumulation grid for all cell values above 20,000. The resulting grid reflects the string of cells whose flow accumulation values are greater than 20,000. Each cell is 100m in size or 0.01 Km^2 in area, so 20,000 cells is equivalent to an upstream drainage area of 200 Km^2.

Figure 2.6 shows the eight-direction pour point model, while Figure 2.7 shows the flow accumulation of the cells greater than 20,000 near Baffin Bay.

2.2 Calculating the Precipitation/Runoff Relationship

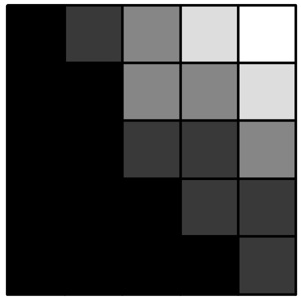
Non-point source constituents are carried over the land surface into the river networks and bay system by direct runoff. For this study, the runoff is assumed to be a function of precipitation and land use. The Regression Tool in the software package Microsoft Excel 5.0 is used to determine the relationship between streamflow, precipitation and percent land use.

2.2.1 Digital Delineation of Sub-Watershed Drainage Areas From the United States Geological Survey (USGS) Flow Gauges

The United States Geological Survey (USGS) streamflow gauges are obtained from the USGS Internet site as discussed in Appendix A. Only gauges in the study area with more than 10 years of record were used for the study. The gauges included are Los Omos, Chiltipin, Aransas, Medio, Mission, Oso, San Fernando, San Diego, and Copano.

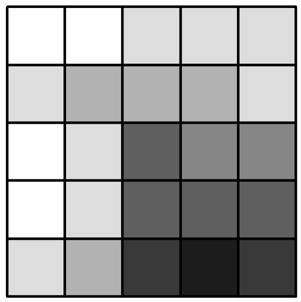
FLOW

4	5	12	17	23
3	3	10	12	16
2	2	6	8	10
0	1	4	7	8
0	0	3	4	7



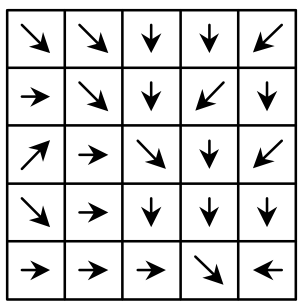
ELEVATION

67	56	49	46	50
53	44	37	38	48
58	55	22	31	24
61	47	21	16	19
53	34	12	11	12



FLOW DIRECTION

2	2	4	4	8
1	2	4	8	4
128	1	2	4	8
2	1	4	4	4
1	1	1	2	16



ACCUMULATED FLOW

0	0	0	0	0
0	9	17	40	0
0	0	93	0	16
0	0	1	133	0
0	0	5	163	8

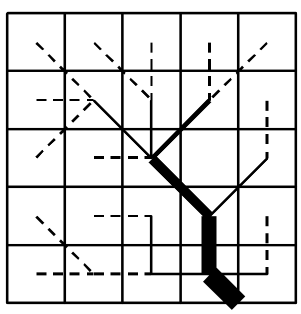


Figure 2.6: Eight-Direction Pour Point Model.

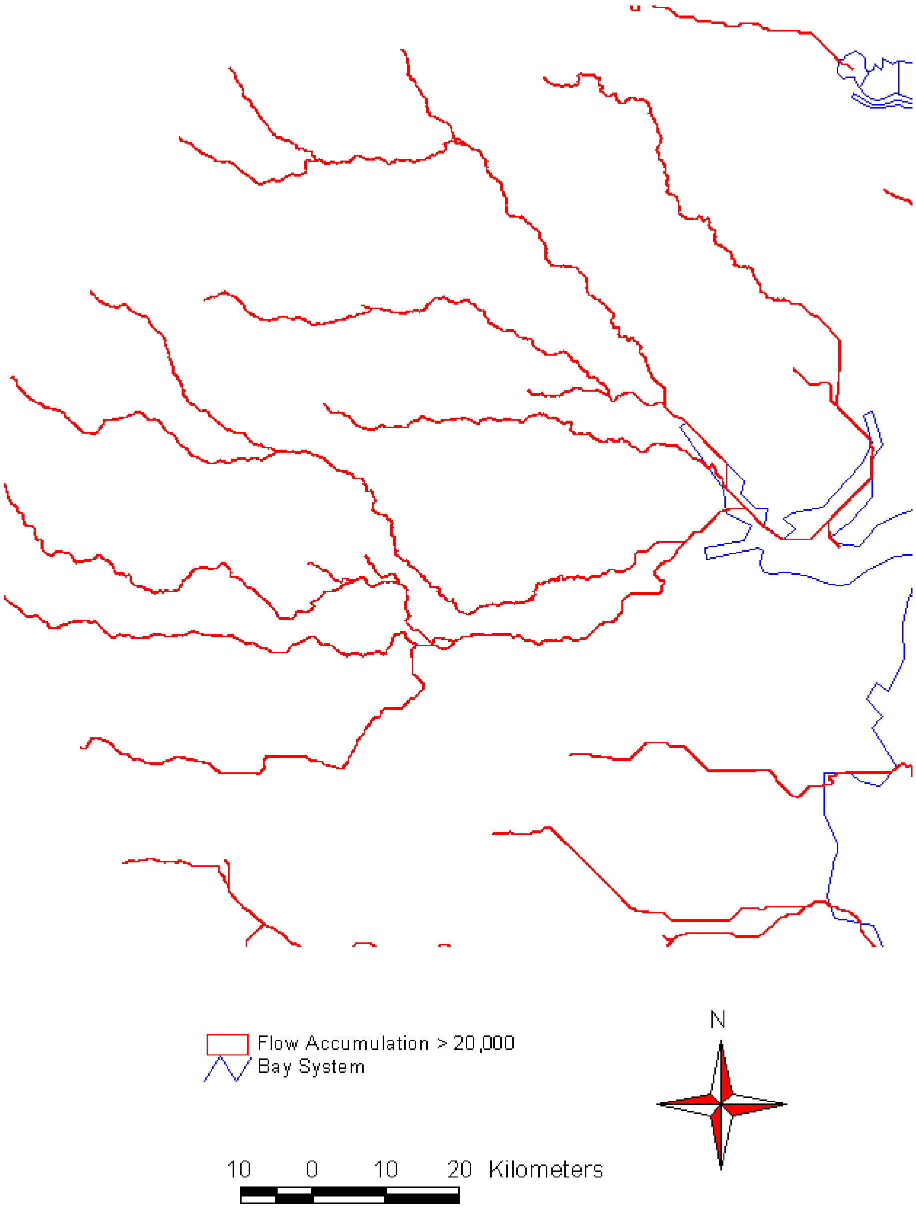


Figure 2.7: Streams with Flow Accumulation Greater than 20,000 Cells Near Baffin Bay.

The digital drainage areas are compared to the USGS drainage areas for the nine gauging stations used in the study for a quantitative check on the accuracy of the digital drainage basins. To begin the watershed delineation, a stream link grid must first be calculated to determine a stream network and direction. The Avenue script STRMLNK is run to determine the stream link grid, and the Avenue script WTRSHD is used to calculate the sub-watersheds in the study area.

For most of the sub-watersheds, the delineated drainage area is comparable to the USGS drainage area. However, the delineated drainage areas for Oso and Copano were smaller than the USGS drainage areas. This could be due to errors induced by the relatively flat topography near the coast. Another explanation of the drainage area disagreements is found when comparing the RF1 files and the DLG files developed by the USGS. The RF1 file has the Oso Creek extending farther northwest than the DLG file. Since the DLG file is used for the surface reconditioning process, the Oso Creek sub-watershed is smaller than it would have been using the RF1 files.

The problem was corrected by finding the depth of precipitation and depth of runoff for each of the sub-watersheds rather than the total precipitation and total runoff. The depths of precipitation and runoff are found by dividing total precipitation and total runoff by the appropriate drainage areas. This procedure is discussed in detail in sections 2.2.2 and 2.2.3 of this report.

Table 2.2 compares the delineated watershed areas to the USGS watershed areas, while Figure 2.8 shows the difference between the RF1 and the DLG files that was encountered within the Oso Creek watershed.

Table 2.2: Comparison of the USGS Calculated Drainage Areas and the Delineated Drainage Areas for Each of the Sub-Watersheds.

Station Name	USGS Area (sq Km)	Delineated Area (sq Km)
Los Omos	1243	1236
Chiltipin	332	339
San Fernando	1313	1393
San Diego	826	821
Oso	234	149
Aransas	640	629
Mission	1787	1801
Medio	528	527
Copano	227	141

Figure 2.9 shows the study area defined by the bay system drainage area and the delineated sub-watersheds.

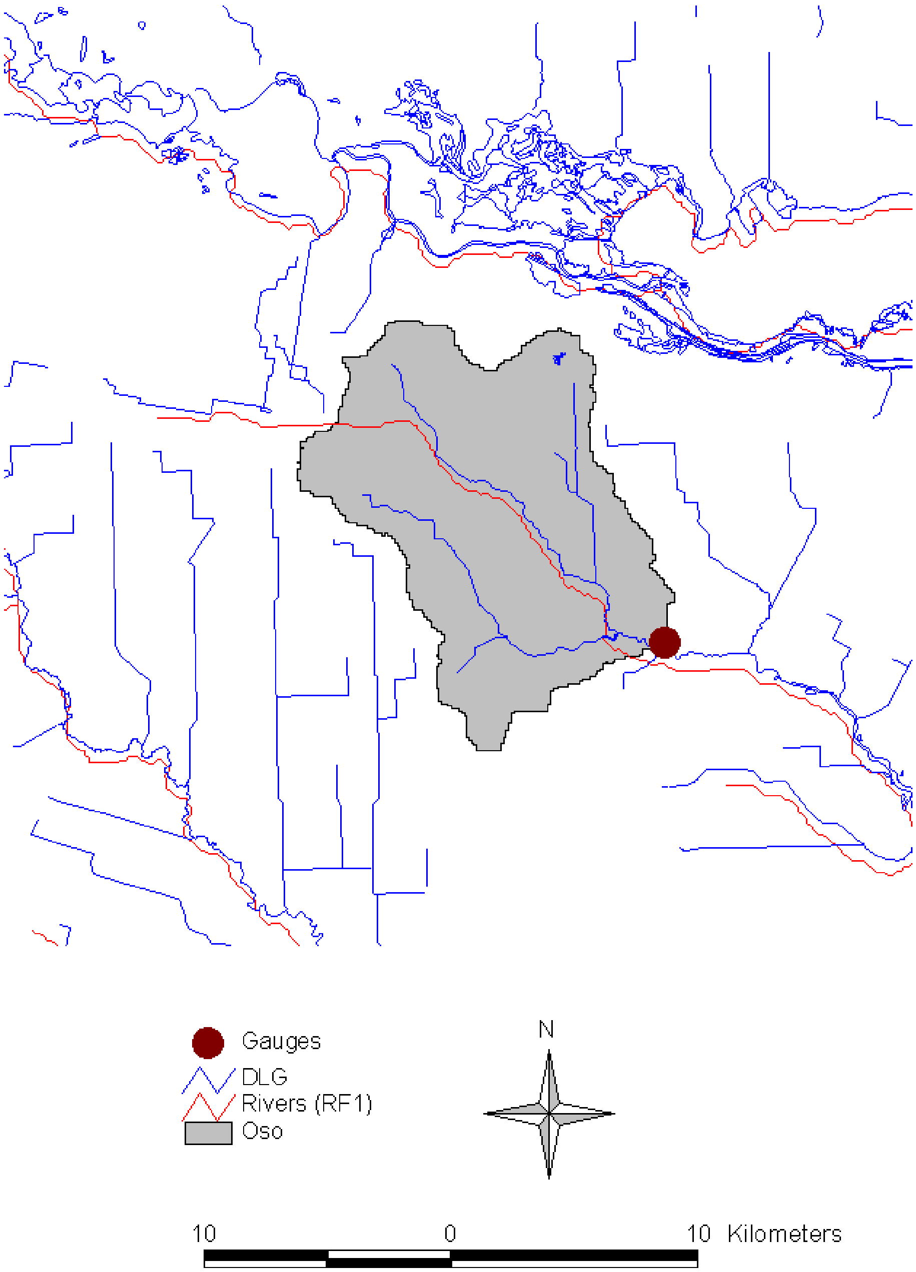


Figure 2.8: River Reach Files Compares to the Digital Line Graph File in the Oso Creek Sub-watershed.

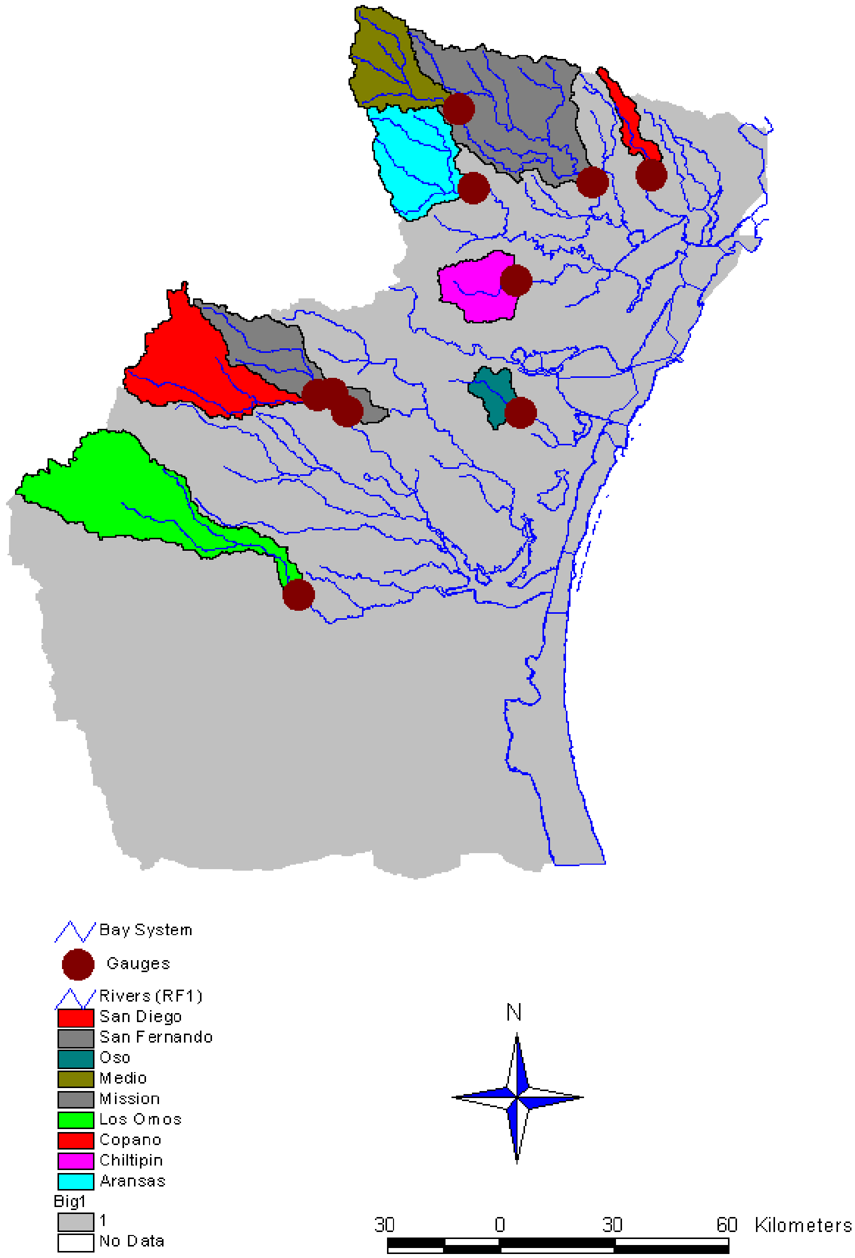


Figure 2.9: Sub-watersheds in the CCBNEP Study Region.

2.2.2 Average Precipitation for each Delineated Drainage Areas

A weighted flow accumulation operation is used to determine the average rainfall for each drainage area. A weighted flow accumulation is an extension of the flow accumulation discussed in section 2.1.2.1. Instead of counting the number of cells upstream of a particular grid cell, the weighted flow accumulation sums the grid values from a second grid called the weight grid. Using the precipitation grid as the weight grid, the total annual potential runoff is calculated for the study area. The Arc/Info console is used to calculate the accumulated precipitation grid.

Grid: **accprecip2 = flowaccumulation (fdac2, precip) * 10**

Where the factor of ten is used to convert the precipitation units of depth (mm) to units of volume (m^3). Each cell has an area of 10,000 m^2. Or:

Equation 2.1

$$\text{Volume } (m^3) = \text{Depth (mm)} * \text{Area(\# cells)} * 10$$

Once the accumulated precipitation grid is calculated, it is added to the view. The USGS stream gauge coverage is overlaid and the ArcView inquiry tool is used to determine the accumulated precipitation for each of the delineated watersheds by clicking on the grid cell which contains the gauging station.

The depth of precipitation for each sub-watershed is found by dividing the accumulated precipitation by the delineated drainage area. Table 2.3 shows the depth of precipitation while Equation 2.2 is used to calculate the depth of precipitation.

Equation 2.2

$$\text{Depth (mm)} = (\text{Volume } (m^3) / \text{Area of watershed } (m^2)) * 1000 \text{ mm/m}$$

Table 2.3: Depth of Precipitation (mm/yr) for Each of the Drainage Areas.

Station Name	Precipitation (mm/yr)
Los Omos	618
Chiltipin	841
San Fernando	661
San Diego	665
Oso	775
Aransas	810
Mission	847
Medio	787
Copano	927

2.2.3 Determining Average Runoff per Unit Area at each USGS Gauge

The average streamflow record is determined using the daily streamflow values from each of the nine gauging stations used in the study. Only the USGS stations with a flow record longer than 10 years are used for the study. The mean annual flows are found for the years 1961 through 1990 and are shown in Table 2.4.

The Mission River station was the only station of the nine which had the full 30 years of record. For an accurate establishment of the precipitation/runoff relationship, the same 30 year period should be used for both the precipitation and streamflow data. Therefore, a projected 30 year average annual streamflow at each gauge, Q_g, are estimated using the average annual 1961-1990 streamflow at the Mission River gauge, Q_m. These estimates are calculated by multiplying Q_m by the ratio of q_g/q_m, where q_g is the average annual streamflow at the gauge and q_m is the average annual streamflow at the Mission gauge (Saunders, 1996). The Equation 2.3 is used, and the streamflow projections are shown in Table 2.5.

Equation 2.3

$$Q_g = Q_m * (q_g/q_m)$$

Where: Q_g = Mean annual flow at gauging station of interest calculated from period of record.
Q_m = Mean annual flow at Mission gauging station calculated from period of record.
q_g = Mean annual flow at gauging station of interest
q_m = Mean annual flow at Mission gauging station

The mean annual depth of streamflow (runoff per unit area) is found by dividing the 30-year average streamflow by the drainage area determined by the USGS and converting the units to mm/yr. The streamflow depth is used to represent the direct runoff for each of the drainage areas. Table 2.6 shows the streamflow depth for each sub-watershed.

Table 2.4: Mean Annual Flow (cfs) of Record for Each of the Nine USGS Gauging Stations.

Year	LosOmos	Chiltipin	Sanfern	SanDiego	Oso	Aransas	Mission	Medio	Copano
1961							64.60		
1962							45.89	7.34	
1963							6.38	4.22	
1964				1.75		5.84	11.94	3.51	
1965			9.85	4.07		13.98	52.70	12.55	
1966			12.05	2.73		26.68	119.05	1.60	
1967	42.59		86.55	43.77		206.85	708.51	182.90	
1968	2.01		4.31	0.16		20.73	147.38	14.42	
1969	0.82		4.38	0.26		16.49	83.24	3.24	
1970	0.41	7.42	4.64	0.34		16.70	73.72	8.26	34.77
1971	34.43	131.76	198.26	103.48		129.33	424.45	12.56	109.00
1972	3.23	40.15	7.00	1.09	18.31	39.07	198.44	7.27	64.88
1973	10.52	92.30	15.01	1.64	74.59	79.28	398.80	11.63	85.48
1974	4.62	13.85	13.71	3.70	10.42	59.34	119.52	0.83	24.61
1975	1.01	13.17	2.27	0.29	16.13	4.96	39.81	0.62	1.92
1976	4.32	66.67	23.70	4.23	55.03	34.38	282.66	20.48	47.79
1977	0.29	29.63	3.18	1.24	16.83	18.57	131.52	18.89	16.24
1978	0.60	17.84	3.24	1.14	36.92	7.46	69.10		64.73
1979	0.55	61.77	11.22	2.00	45.74	18.95	137.79		53.07
1980	5.46	64.28	37.89	5.82	50.95	23.57	128.31		12.07
1981	6.80	48.54	7.99	1.21	41.41	62.44	389.56		150.58
1982	12.40	28.42	2.64	0.50	24.58	12.76	126.61		24.54
1983	0.00	51.55	5.66	2.52	19.70	29.94	184.85		95.18
1984		45.90	2.70	0.35	31.95	8.88	29.10		8.69
1985		58.04	17.65	4.59	29.44	21.73	79.07		15.79
1986		1.23	5.40	0.79	16.90	3.93	44.69		13.30
1987		62.64		7.81	30.47	29.81	101.29		15.94
1988		2.49		0.14	4.86	10.14	9.22		0.00
1989		0.47		0.16	2.35	2.34	1.24		0.52
1990		2.08			18.65	56.05	200.80		36.75
Mean Annual Flow (cfs) for Record	7.65	40.01	21.79	7.53	28.70	35.56	147.01	19.40	41.71

Table 2.5: Thirty-year Projected Mean Annual Flow for the Period 1961-1990.

Year	LosOmos	Chiltipin	Sanferns	SanDiego	Oso	Aransas	Mission	Medio	Copano
1961	3.36	17.58	9.58	3.31	12.61	15.63	64.60	8.52	18.33
1962	2.39	12.49	6.80	2.35	8.96	11.10	45.89	7.34	13.02
1963	0.33	1.74	0.95	0.33	1.25	1.54	6.38	4.22	1.81
1964	0.62	3.25	1.77	1.75	2.33	5.84	11.94	3.51	3.39
1965	2.74	14.34	9.85	4.07	10.29	13.98	52.70	12.55	14.95
1966	6.20	32.40	12.05	2.73	23.24	26.68	119.05	1.60	33.78
1967	42.59	192.83	86.55	43.77	138.32	206.85	708.51	182.90	201.02
1968	2.01	40.11	4.31	0.16	28.77	20.73	147.38	14.42	41.81
1969	0.82	22.65	4.38	0.26	16.25	16.49	83.24	3.24	23.62
1970	0.41	7.42	4.64	0.34	14.39	16.70	73.72	8.26	34.77
1971	34.43	131.76	198.26	103.48	82.86	129.33	424.45	12.56	109.00
1972	3.23	40.15	7.00	1.09	18.31	39.07	198.44	7.27	64.88
1973	10.52	92.30	15.01	1.64	74.59	79.28	398.80	11.63	85.48
1974	4.62	13.85	13.71	3.70	10.42	59.34	119.52	0.83	24.61
1975	1.01	13.17	2.27	0.29	16.13	4.96	39.81	0.62	1.92
1976	4.32	66.67	23.70	4.23	55.03	34.38	282.66	20.48	47.79
1977	0.29	29.63	3.18	1.24	16.83	18.57	131.52	18.89	16.24
1978	0.60	17.84	3.24	1.14	36.92	7.46	69.10	9.12	64.73
1979	0.55	61.77	11.22	2.00	45.74	18.95	137.79	18.18	53.07
1980	5.46	64.28	37.89	5.82	50.95	23.57	128.31	16.93	12.07
1981	6.80	48.54	7.99	1.21	41.41	62.44	389.56	51.41	150.58
1982	12.40	28.42	2.64	0.50	24.58	12.76	126.61	16.71	24.54
1983	0.00	51.55	5.66	2.52	19.70	29.94	184.85	24.39	95.18
1984	1.51	45.90	2.70	0.35	31.95	8.88	29.10	3.84	8.69
1985	4.11	58.04	17.65	4.59	29.44	21.73	79.07	10.43	15.79
1986	2.33	1.23	5.40	0.79	16.90	3.93	44.69	5.90	13.30
1987	5.27	62.64	15.01	7.81	30.47	29.81	101.29	13.37	15.94
1988	0.48	2.49	1.37	0.14	4.86	10.14	9.22	1.22	0.00
1989	0.06	0.47	0.18	0.16	2.35	2.34	1.24	0.16	0.52
1990	10.45	2.08	29.76	10.29	18.65	56.05	200.80	26.50	36.75
Mean Annual Flow Projected (30yrs)	5.66	39.25	18.16	7.07	29.48	32.95	147.01	17.23	41.71

Table 2.6: Streamflow Depths for Each of the Sub-watersheds.

Station Name	Streamflow Depths (mm/yr)
Los Omos	4
Chiltipin	103
San Fernando	12
San Diego	8
Oso	113
Aransas	46
Mission	74
Medio	29
Copano	164

Note the varied runoff for each of the gauging stations. The northern stations (Chiltipin, Oso, Aransas, Mission, Medio, and Copano) have larger runoff depths than the southern gauging stations (Los Omos, San Fernando and San Diego).

2.2.4 Establishing a Mathematical Relationship between Precipitation Percent Land Use and Streamflow

Using the Microsoft Excel 5.0 Regression Tool, an equation is found to predict runoff using the relationship between streamflow depth, precipitation depth and percent land use in each of the nine watersheds. The depth of streamflow is used to represent the direct runoff from each of the drainage basins.

The percent land use is found by clipping the land use file with the sub-watershed coverage using the Arc command **Clip**. The watershed land use file is then queried in ArcView using the **Field** pulldown menu with the **Summarize** option. The landuse field is active in the watershed land use attribute table. In the Table Summary Menu, the field chosen is **Area** which is summarized by **Sum**. The **Add** button is clicked, and the file name is changed to reflect the watershed. The summary table is view in Microsoft Excel 5.0 where the individual summaries of land use areas are divided by the total area and multiplied by 100% to find the percent land use in the watershed.

Arc: **clip landuse2 aransas landara polygon #**

An equation is calculated for agricultural land use. The multiple regression tool is used with streamflow depth for the y-input and the precipitation depth and percent agricultural land are used as the x-inputs. Table 2.7 shows the input values that are used in the Regression tool.

Table 2.7: Input Values Used in the Excel Regression Tool.

Station Name	Streamflow Depths (mm/yr)	Precipitation (mm/yr)	% Agric	% Range
Los Omos	4	618	12	87
Chiltipin	103	841	86	11
San Ferna	12	661	22	77
San Diego	8	665	13	86
Oso	113	775	97	1
Aransas	46	810	58	38
Mission	74	847	25	73
Medio	29	787	41	58
Copano	164	927	7	67

The Microsoft Excel 5.0 Regression output, shown in Table 2.8, is used to determine the best equation to represent the relationship between precipitation and runoff for agricultural land use. The coefficients are plugged into Equation 2.4:

Equation 2.4

$$\ln Q = \ln a + b*P + c*\ln(\%A)$$

where: Q = runoff depth (mm/yr)
b = coefficient calculated using Regression tool
P = precipitation depth (mm/yr)
c = coefficient calculated using Regression tool
%A = Percent agricultural land use

The equation is solved for runoff, Q. If percent agriculture is assumed to be 100%, the last term in the equation, which represent percent agriculture, equals one and can then be dropped from the equation. Equation 2.5 results:

Equation 2.5

$$Q = 0.008312 * \exp (0.011415 * P)$$

where: Q = runoff depth (mm/yr)
P = precipitation depth (mm/yr)
0.008312 = exp (-4.79004056)

Again, the Microsoft Excel 5.0 Regression output, shown in Table 2.9, is used to determine the best equation to represent the relationship between precipitation and runoff for rangeland. The coefficients are plugged into Equation 2.6, and are solved for runoff, Q.

Table 2.8: Summary Output for the Agricultural Land Use, Precipitation, and Runoff Analysis.

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.956543917
R Square	0.914976265
Adjusted R Square	0.88663502
Standard Error	0.439935201
Observations	9

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	12.49678582	6.24839291	32.28427	0.00061464
Residual	6	1.161257884	0.193542981		
Total	8	13.6580437			

	Coefficients	*Standared Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-4.79004056	1.247823775	-3.839638696	0.008563	-7.842623502	-1.7374576
X Variable 1	0.01141489	0.001546613	7.380574565	0.000317	0.007630463	0.01519932
X Variable 2	0.346167599	0.16942563	2.043183194	0.08706	-0.068402285	0.76073748

Table 2.9: Summary Output for the Rangeland, Precipitation, and Runoff Analysis.

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.989748737
R Square	0.979602563
Adjusted R Square	0.972803417
Standard Error	0.215479731
Observations	9

ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	13.37945462	6.689727308	144.0773	8.48646E-06
Residual	6	0.278589088	0.046431515		
Total	8	13.6580437			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-5.239701761	0.583176391	-8.984763169	0.000106	-6.66668403	-3.812719
X Variable 1	0.010993081	0.000763542	14.39748217	7.03E-06	0.00912476	0.0128614
X Variable 2	-0.315150467	0.052227559	-6.034179522	0.000936	-0.44294679	-0.187354

Equation 2.6

$$\ln Q = \ln a + b*P + c*\ln(\%R)$$

where: Q = runoff depth (mm/yr)
b = coefficient calculated using Regression tool
P = precipitation depth (mm/yr)
c = coefficient calculated using Regression tool
%R = Percent rangeland land use

If percent rangeland is assumed to be 100%, the last term in the equation, which represented percent rangeland, equals one and can then be dropped from the equation. Equation 2.7 results:

Equation 2.7

$$Q = 0.0053 * \exp (0.010993 * P)$$

where: Q = runoff depth (mm/yr)
P = precipitation depth (mm/yr)
0.0053 = exp (-5.239702)

Since, there are no gauged watersheds in the study region which represent urban land use, an expected runoff depth was taken from a study being done in the City of Austin (Barrett, 1997). The city of Austin was chosen because it receives a similar average annual precipitation as Corpus Christi, the largest city in the CCBNEP study region. The typical depth of runoff in the city of Austin ranges from 170 mm/yr to 200 mm/yr. The average between the two values, 185 mm/yr, is used for the CCBNEP study. The average annual precipitation in the Oso Creek watershed is used due to the proximity of Corpus Christi to the gauging station. The expected runoff depth (185mm/yr) is divided by the mean annual precipitation depth (774.75 mm/yr) resulting in a runoff coefficient of 0.24. Therefore, the land use grid cells representing urban areas are assigned a runoff value of 24% of the mean annual precipitation for that grid cell (Equation 2.8).

Equation 2.8

$$Q = 0.24 * P$$

where: Q = runoff depth (mm/yr)
P = precipitation depth (mm/yr)

An attempt to find the urban land use runoff equation was done using the Regression tool, however the results gave unreasonably high runoff depths throughout the study area for urban land use areas due to the low percentage of urban land use in the study region.

The areas representing water are assigned a value of zero runoff because the precipitation over the bay system is already accounted for in the water quality model. By assigning a value of zero, the precipitation is not accounted for twice. Runoff in the wetland and barren land use areas were assigned the same equation as the rangeland. Figure 2.10 shows the precipitation versus expected runoff curves for urban, rangeland and agricultural land uses. It can be seen that the relationship between runoff and precipitation is not the same shape for urban land use as for agriculture and rangeland, but the lack of urban runoff data in the region precludes a more definitive analysis of this factor.

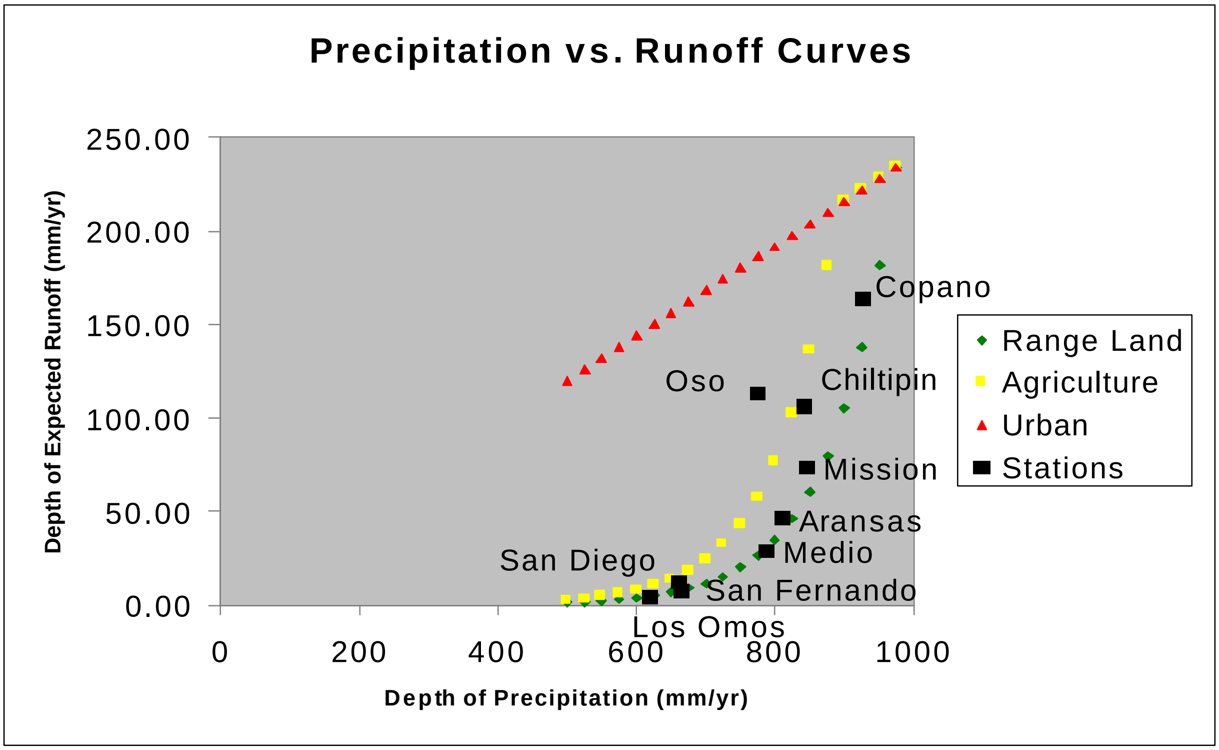


Figure 2.10: Depth of Precipitation (mm/yr) vs. Depth of Expected Runoff (mm/yr) for Each of the Land Uses.

2.2.5 Computing Expected Runoff

The Avenue script ROGRIDLAND is used to compute the runoff grid. The script runs in the ArcView environment and calculates the runoff grid using the percent land use, precipitation and runoff relationships developed in section 2.2.4 of this report.

The runoff grid is then divided by the precipitation grid to calculate a runoff coefficient grid. Any runoff coefficient greater than the urban runoff coefficient of 0.24 is set equal to 0.24. The final runoff grid is calculated by multiplying the precipitation grid by the runoff coefficient grid.

Figure 2.11 shows the runoff grid for the study region.

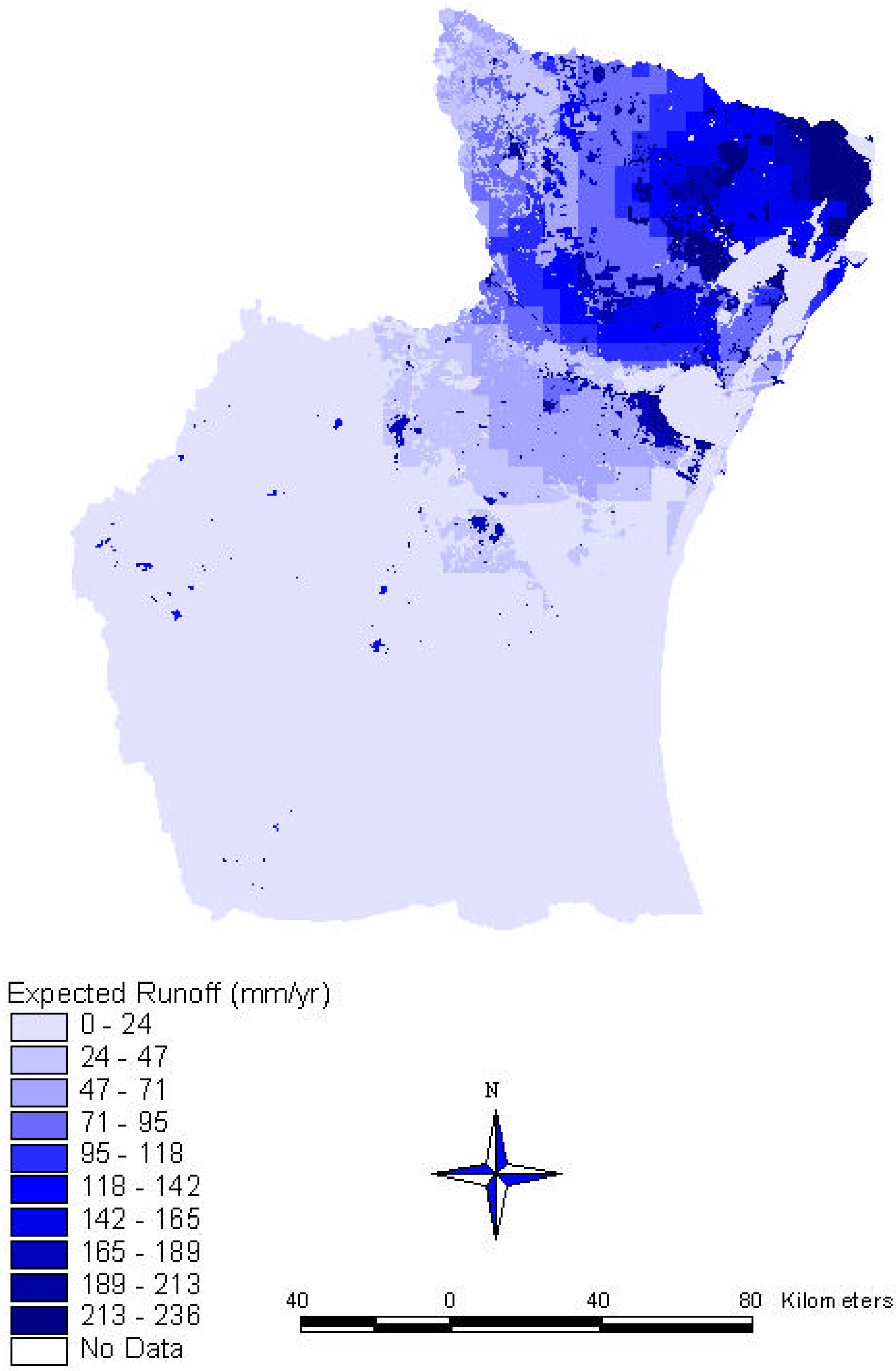


Figure 2.11: Runoff Grid Calculated Using the Relationship between Precipitation, Streamflow, and Percent Land Use.

2.3 Linking Expected Mean Concentration (EMC) Values to Land Use

The study uses the Event Mean Concentration (EMC) values discussed in Appendix A. The EMC values are obtained from a previous CCBNEP analysis, *Characterization of Non-point Sources and Loadings to the Corpus Christi Bay National Estuary Program Study Area* (Baird,1996). The Baird study developed EMC values from water quality analysis performed at the Oso Creek and Seco Creek USGS Stream Gauges. The Oso Creek gauge is located west of Corpus Christi and represents agricultural land use. The gauges located on Seco Creek are northwest of Hondo, TX, and represent range land uses. Table 2.10 shows the EMC table.

2.3.1 Computing Concentration Grid

The Avenue script CONCGRID is used to compute the concentration grids. CONCGRID runs in the ArcView environment and converts the land use polygons into a concentration grid. In this case, the cell value is equal to the constituent EMC field of choice.

2.4 Estimating Annual Loads Throughout the Watersheds

The purpose of the project is to estimate the total constituent loads throughout the study area. The non-point sources are estimated by multiplying the concentration grids developed from the EMC values by the runoff grid. The point source loads are calculated from the point source study done by Armstrong (1997) for the Corpus Christi National Estuary Program's Point Source Data Study. The upstream watershed load from the Nueces River watershed is calculated using Lake Corpus Christi as a point source assuming the concentrations in the Lake and the flow out of the Lake represented the loads from the upstream watershed. The atmospheric load is obtained from a National Atmospheric Deposition Program weather station in Beeville, TX (USGSNADP, 1997).

2.4.1 Computing Land Surface Loads

The Avenue script LOADGRID is used to compute the land surface load grids. The script runs in the ArcView environment and calculates the land surface loads by multiplying the concentration grid by the runoff grid and a conversion factor. To run the script properly, the concentration grid and the runoff grid must be in the view.

The script converts the concentration grid to a grid showing the land surface loads in Kg/day. The script makes a conversion of mg/l (concentration grid) * mm/yr (runoff grid) to the Kg/day (load grid). The conversion constant of 1/36525 is used to the inputs units of mm/yr and mg/l, and to the output units of Kg/d.

Table 2.10: Event Mean Concentration Table Used in the CCBNEP Study.

Constituent		Res 11	Comm 12	Ind 13	Trans 14	Mixed 16/17#	Agr 2*	Range 3*	Undev/Open 7*
Total Nitrogen	(mg/l)	1.82	1.34	1.26	1.86	1.57	4.4	0.7	1.5
Total Kjeldahl Nitrogen	(mg/l)	1.5	1.1	1.0	1.5	1.25	1.7	0.2	0.96
Nitrate + Nitrite	(mg/l)	0.23	0.26	0.3	0.56	0.34	1.6	0.4	0.54
Total Phosphorus	(mg/l)	0.57	0.32	0.28	0.22	0.35	1.3	<0.01	0.12
Dissolved Phosphorus	(mg/l)	0.48	0.11	0.22	0.1	0.23			0.03
Suspended Soids	(mg/l)	41	55.5	60.5	73.5	57.9	107	1	70
Dissolved Solids	(mg/l)	134	185	116	194	157	1225	245	
Total Lead	(ug/l)	9	13	15	11	12	1.5	5.0	1.52
Total Copper	(ug/l)	15	14.5	15	11	13.9	1.5	<10	
Total Zinc	(ug/l)	80	180	245	60	141	16	6	
Total Cadmium	(ug/l)	0.75	0.96	2	<1	1.05	1	<1	
Total Chromium	(ug/l)	2.1	10	7	3	5.5	<10	7.5	
Total Nickel	(ug/l)	<10	11.8	8.3	4	7.3			
BOD	(mg/l)	25.5	23	14	6.4	17.2	4.0	0.5	
COD	(mg/l)	49.5	116	45.5	59	67.5			40
Oil and Grease	(mg/l) **	1.7	9	3	0.4	3.5			
Fecal Coliform	(col./100ml) **	20000	6900	9700	53000	22400	26000	200	
Fecal Strep	(col./100ml) **	56000	18000	6100	26000	26525			

calculated as average of land uses 11-14

* these EMC's apply to all land uses in this category

** avg concentrations based on instantaneous rather than flow-averaged samples

Equation 2.9

$$\text{Load (Kg/d)} = \text{Runoff (mm/yr)} * \text{Concentration (mg/l)} * \text{Cell Area } (10{,}000\ m^2) * (1m/1{,}000mm) * (1yr/365.25d) * (1\ Kg/10^6 mg) * (1000 liters/1m^3)$$

$$\text{Load (Kg/d)} = \text{Runoff} * \text{Concentration} * \text{Cell Area} * (1/36525)$$

2.4.2 Computing Point Source Loads

The point source grid is based on the point source discharge data compiled by Armstrong (1997) for each of the surface water quality segments of the Texas Natural Resources Conservation Commission (TNRCC). Figure 2.12 shows the TNRCC water quality segments used in the study.

To create the point source load grid, a digital map of surface water quality segments was obtained from the TNRCC via their Internet Site: **http://www.tnris.state.tx.us/ftparea.html**. The files need to be converted into an Arc/Info format.

The Avenue script POINTLD is used to convert the water quality segment coverages to a point source grid. For streamlines the cell corresponding to the first point in the line was valued with the load and for polygon segments in the bay, a cell inside the area was valued with the loads.

2.4.3 Computing Upstream Watershed Loads

The loads from the upstream Nueces watershed are determined by using Lake Corpus Christi as a point source. The flow leaving the Lake at the Nueces River gauging station near Mathis, TX, is calculated as a thirty year average for the years 1961 - 1990, similar to the streamflow calculations used in the precipitation/runoff analysis. The resulting streamflow leaving Lake Corpus Christi is calculated to be 20 m^3/s. The water quality data representing the Lake are found from the TNRCC Internet site: **http://www.tnris.state.tx.us/ftparea.html.** The constituents used in the study were total nitrogen, total phosphorus and iron. The concentration values for the other constituents are too small to measure or no data existed at this location. The constituent load is found by multiplying the constituent concentration of the Lake by the flow out of the Lake.

Equation 2.10

$$\text{Load (Kg/d)} = \text{Concentration (mg/l)} * \text{Flow } (m^3/s) * (1Kg/10^6 mg) * (1000 \text{ liters}/1\ m^3) * (86{,}400 sec/d)$$

$$\text{Load (Kg/d)} = \text{Concentration (mg/l)} * \text{Flow } (m^3/s) * 86.4$$

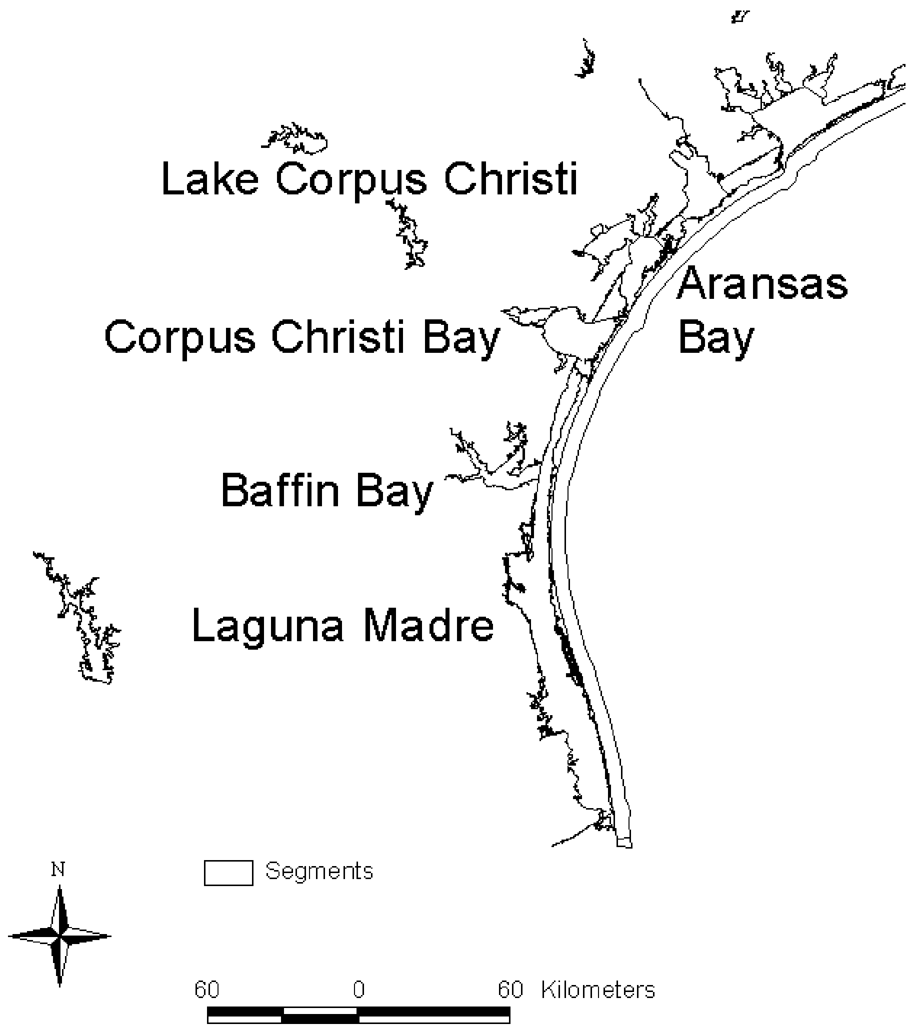


Figure 2.12: Texas Natural Resource Conservation Commission Water Quality Segments Used in the CCBNEP Study.

The total nitrogen, total phosphorus, and iron loads are added into the water quality segment coverage to the segment number which represented Lake Corpus Christi. The total phosphorus load is 58.52 Kg/d, while total nitrogen and iron loads are 81.11 Kg/d, and 2.23 Kg/d respectively.

2.4.4 Computing Atmospheric Loads

The atmospheric load is only applied to the bay system because on the land surface it is accounted for in the EMC values. The atmospheric deposition data was obtained from the USGS National Atmospheric Deposition Program's Internet Site:
http://h20.usgs.gov/nwc/NWC/pH/html/ph.html. The Beeville, Texas, station was used due to its location in the study area. The specific Internet site for the Beeville station is: **http://nadp.nrel.colostate.edu/NADP/cgi_scripts/sitepics.cgi?TX03.**

The Beeville constituent concentrations were compared with a study completed by Liljestrand et al. (1986). The ammonia and nitrate concentrations are similar in both the study and at the USGS Internet site. The study by Liljestrand found that atmospheric concentrations are 0.82 mg/l for nitrate and 0.25 mg/l for ammonium while the nitrate concentrations for the Beeville station are 0.81 mg/l and 0.29 mg/l for ammonium. The Beeville station data are used for the total loadings study because the data is more current.

The data from the Internet site is downloaded as a wet deposition annual average loading in units of Kg/ha/yr. The data are averaged for the years 1986 to 1997, and converted to Kg/m^2/day. Finally, the data is multiplied by the surface area of each of the bay segments. This gives a loading of Kg/d, which is the correct unit needed in the water quality model. Equation 2.11 explains the unit conversions used in the calculations:

Equation 2.11

$$\text{Load (Kg/d)} = \text{Load (Kg/ha/yr)} * \text{Area (m}^2\text{)} * (1/(3.6525 * 10^6))$$

The total nitrogen load is found by adding the nitrate load to the ammonium load.

A calculation is done to compare the amount of atmospheric load which falls on the land surface to the total land surface load. The loading data from the Beeville site is applied to the entire land surface using Equation 2.11. The entire load is then divided by the number of cells in the study area to determine a load per cell. The load per cell is multiplied by the runoff coefficient for each cell to calculate the amount of atmospheric load that is found in the runoff. Using the **Zonalmean** function in ArcView, the mean load per cell is found over the land surface (0.001 Kg/d). The total atmospheric load over the land surface is the product of the mean load per cell and the number of cells over the land surface (2733 Kg/d). The atmospheric load over the land surface is approximately 35% of the total land surface load. It is important to note that the atmospheric station is near Beeville, TX. Since the station is located inland, the atmosphere it samples is influenced by many sources such as volatilization of land surface loads, industries, etc. The mean annual concentration of total nitrogen present in the atmosphere is 1.10 mg/l (USGSNADP, 1997).

2.4.5 Computing Sediment Loads

Sediment fluxes for nutrients are obtained from a report entitled *Benthic Nutrient Fluxes of Selected Estuaries in the Gulf of Mexico* (Montagna et al.,1997). The data are obtained from graphs which show the variance and the mean values. The mean values are extracted from the graphs as fluxes in μmol/m^2/hr. The report has data for Corpus Christi Bay and the Laguna Madre. The following flux assignments are made to the bays without data due to their geographic location to the bays with flux data. Baffin Bay is assigned the same flux as the Laguna Madre while Nueces Bay, Inner Harbor, and Oso Bay are assigned the same flux as Corpus Christi Bay. The mean flux for San Antonio Bay is also extracted from the graph to determine a linear trend northward from Corpus Christi Bay to San Antonio Bay, which is the northern boundary of the study area. The nitrate + nitrite flux data is assigned an upward trend from Corpus Christi Bay (75 μmol/m$_2$ hr) through Red Fish Bay, Copano Bay and Aransas Bay to San Antonio Bay (175 μmol/m^2/hr). Red Fish Bay and the Aransas Bay south segments are assigned a flux of 112.5 μmol/m^2/hr, which is 1.5 times higher than the Corpus Christi Bay flux. Copano Bay, and the Aransas Bay middle and north segments are assigned a nitrate plus nitrite flux of 150 μmol/m^2 hr which is twice as large as the Corpus Christi Bay flux. This gives linear flux values from Corpus Christi Bay to San Antonio Bay.

The San Antonio Bay mean ammonium flux is outside the range of the variance. The trend from Corpus Christi Bay to San Antonio Bay is decreasing, however the mean value is negative. Therefore, a downward linear trend is used to compute the Red Fish Bay, Aransas Bay and Copano Bay fluxes. Red Fish Bay and Aransas Bay south segment were assigned a value of 37.5 μmol/m^2/hr which is 75% of the flux measured in Corpus Christi Bay. Copano Bay and the Aransas Bay north and middle segments are assigned a value of 25 μmol/m^2/hr, which is 50% of the flux measured in Corpus Christi Bay.

Once the fluxes are calculated, the loads for each segment are calculated based on the surface area of the segment using Equation 2.12:

Equation 2.12

$$\text{Load (Kg/d)} = \text{flux } (\mu\text{mol/m}^2\text{ hr}) * 10^{-6}\ (\text{mol/}(\mu\text{mol}) * 24\text{ hr/d} * \#\text{ grams/mole} * \text{Area (m}^2) * \text{Kg/1000 g}$$

The resulting nutrient sediment loads are two orders of magnitude larger than the other calculated loads. This is could be due to the study being a measure of nutrient flux out of the sediment rather than being a net flux where the flux into the sediment is also measured. Therefore, the sediment load data is not used as part of the total loads to the water quality model.

2.5 Calibrating the Water Quality Model

A series of Avenue scripts making up the water quality model, BALANCE, is used to calculate the equilibrium constituent concentration in the bay system. The model uses an explicit finite difference algorithm. The software runs within the ArcView environment. The model uses the methodology presented by Thomann and Mueller (1987). Figure 2.13 is a graphical depiction of the methodology of the program.

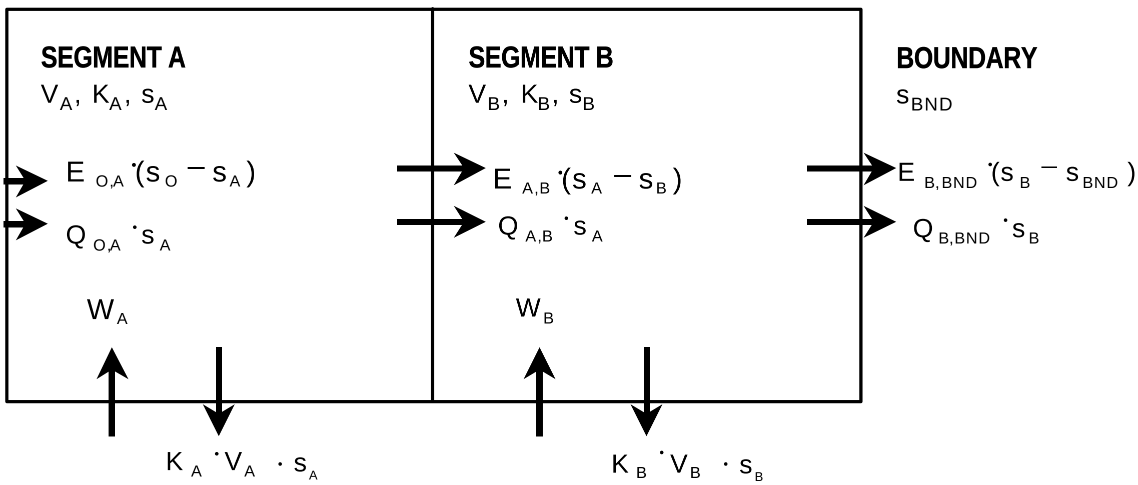


Figure 2.13: Water Quality Methodology Used in the Calculations of the Equilibrium Concentrations.

Equation 2.13

$$\frac{ds_B}{dt} * V_B = Q_{A,B} * s_A - Q_{B,BND} * s_B + E_{A,B} * (s_A - s_B) + E_{B,BND} * (s_B - s_{BND}) - K_B * V_B * s_B + W_B$$

where: $\frac{ds_B}{dt}$ = change in concentration of segment B / change in time

V_B = volume of segment B; (m^3)
$Q_{A,B}$ = flow from segment A to B; (m^3/s)
$Q_{B,BND}$ = flow from segment B to BND; (m^3/s)
s_A = concentration of constituent in segment A; (mg/l)
s_B = concentration of constituent in segment B; (mg/l)
s_{BND} = concentration of constituent at boundary; (mg/l)
$E_{A,B}$ = bulk dispersion coefficient between segments A,B; (m^3/s)
$E_{B,BND}$ = bulk dispersion coefficient between segments B,BND; (m^3/s)
K_B = decay rate in segment B; (/d)
W_B = waste load in segment B; (kg/yr)

Equation 2.13 is a mass balance around Segment B of Figure 2.13. Assuming steady state, the $(ds_B/dt)\ V_B$ term is zero. The rest of the terms represent:

- the advective load entering from segment A, $Q_{A,B} * s_A$
- the advective load leaving at the boundary, $Q_{B,BND} * s_B$
- the dispersive load across the segment A and segment B interface, $E_{A,B}(s_A - s_B)$
- the dispersive load across the segment B and boundary interface, $E_{B,BND}(s_B - s_{BND})$
- the load lost to decay, $K_B * V_B * s_B$
- the waste load into segment, W_B

The model is first calibrated against salinity data for dispersion coefficients. The calibration process began with segmenting the bay system using the 20 segment partitioning of the bay system described earlier. The water quality model reaches steady state by doing time varying computations from an assumed set of initial concentrations in each bay until concentration values converge to a steady value. The dispersion coefficients are obtained by a trial and error method which is described in detail in section 2.5.4.

2.5.1 Bay System Bathymetry

The bathymetry data for the water quality model is taken from a file from the Texas Water Development Board hydrodynamic model of the bay system developed by Junji Matsumto. The segment surface areas are calculated using the CALCAREA Avenue script. The segment and interface depths are calculated using the Surface Water Modeling System (SMS) graphical user interface. The segment volumes are calculated by multiplying the surface area and the segment depths. Because the inlet segment is small compared to other segments, it controlled the numerical stability of the model. The volume of the Inlet segment is increased by a factor of 1000 to allow for this. This did not change the model results for salinity because the model is solved for a steady state solution without decay. Table 2.11 shows the segment ID, segment depth, segment area, and segment volume while Table 2.12 shows the interface line length, interface length, interface depth and interface area.

Table 2.11: Segment Name, ID, Depth, Surface Area and Volume.

Segment	ID	Depth (m)	Area (m^2)	Volume (m^3)
St. Charles	stc	0.7	33173300	23221300
Copano	cop	1.3	19193100	249510000
Aransas North	aran	1.4	38094600	53332400
Aransas Middle	aram	2.2	110235000	242518000
Aransas South	aras	2.6	120451000	313173000
Redfish	red	1.6	98067500	156908000
Inlet	inl	14.0	4117510	57645100000
Nueces West	nuew	0.7	12096600	8467650
Nueces Middle	nuem	0.8	20349600	16279700
Nueces East	nuee	1.0	37515700	37515700
Inner Harbor	inh	14.0	6204910	86868700
Corpus North	ccbn	5.3	108541000	575267000
Corpus Middle	ccnm	3.4	200240000	680816000
Corpus East	ccbe	3.4	101090000	343707000
Corpus South	ccbs	0.6	35924600	21554800
Oso	oso	0.7	17746600	12422600
ULM North	ulmn	1.5	173796000	260694000
ULM Middle	ulmm	1.8	78999500	142199000
ULM South	ulms	1.8	217413000	391344000
Baffin	baf	1.3	239474000	311317000

2.5.2 Bay Evaporation and Precipitation

The evaporation data are obtained from a grid of mean annual open water evaporation provided by Reed et al. (1996). The evaporation grid was originally calculated by extrapolating pan evaporation data from the Texas Water Development Board.

Table 2.13 compares the evaporation and precipitation to the Texas Water Development Board's (Matsumoto, 1993) mean annual precipitation and evaporation. The two sets of values are comparable.

Table 2.12: Bay Segment Interface, Interface Line Length, Interface Length, Interface Depth, and Interface Area.

Interface From	To	Line Length (m)	Interface Length (m)	Depth (m)	Area (m^2)
St. Charles	Aransas Middle	3924	1600	0.80	1280
Copano	Aransas Middle	2946	2946	1.60	4714
Aransas North	Aransas Middle	4257	4257	1.70	7237
Aransas Middle	Aransas South	5953	5953	3.00	17859
Aransas South	Redfish	16607	830	2.10	1743
Aransas South	Inlet	2211	800	7.50	6000
Redfish	Corpus North	353	353	3.60	1271
Redfish	Inlet	1552	200	3.00	600
Inlet	Corpus East	2281	1100	9.30	10230
Corpus North	Corpus Middle	21123	211223	6.70	1415194
Corpus North	Corpus East	978	978	10.10	9878
Corpus North	Inner Harbor	522	522	14.00	7308
Nueces West	Nueces Middle	2618	2600	0.80	2080
Nueces Middle	Nueces East	4574	4100	0.90	3690
Nueces East	Corpus North	3458	2900	1.20	3480
Corpus Middle	Oso	385	200	1.30	260
Corpus Middle	Corpus East	19070	18070	3.50	63245
Corpus East	Corpus South	5637	4000	1.40	5600
Corpus East	Redfish	11235	4494	3.50	15729
Corpus South	ULM North	6449	1000	5.50	5500
ULM North	ULM Middle	3588	3000	1.60	4800
Baffin	ULM Middle	6798	6700	1.50	10050
ULM Middle	ULM South	5990	4200	1.90	7980

2.5.3 Inflow to Bay System

The inflows are determined by calculating a weighted flow accumulation with the runoff grid as the weight grid. The weighted flow accumulation routes the runoff over the land surface downstream into the river network and into the bay system. Table 2.14 shows the calculated runoff compared to the runoff calculated by the USGS (Ward, 1996) and the TWDB (Matsumoto, 1993). The three sets of numbers are comparable with the calculated runoffs from this study, for the most part, being in between the other data sets.

Since the bay system extends outside the CCBNEP study area, some inflow is routed into the Aransas North segment, which would normally be routed into another bay segment. This problem was discussed in section 2.1.2 and is corrected manually by setting the runoff to zero.

Table 2.13: Comparison of the Calculated Mean Annual Evaporation and Precipitation with the Texas Water Development Board's Bay System's Mean Annual Evaporation and Precipitation.

Segment	Mean Annual Precipitation (m/yr)	TWDB Precipitation (m/yr)	Pan Evaporation (m/yr)	TWDB Evaporation (m/yr)
stc	0.93	0.83	1.55	1.58
cop	0.89	0.83	1.57	1.58
aran	0.93	0.83	1.55	1.58
aram	0.91	0.83	1.55	1.58
aras	0.88	0.83	1.62	1.58
red	0.86	0.83	1.63	1.58
ccbn	0.83	0.83	1.63	1.58
nuee	0.81	0.83	1.63	1.58
nuew	0.81	0.83	1.63	1.58
nuem	0.81	0.83	1.63	1.58
inl	0.84	0.83	1.63	1.58
ccbe	0.84	0.83	1.63	1.58
inh	0.81	0.83	1.63	1.58
ccbm	0.82	0.83	1.63	1.58
oso	0.78	0.83	1.63	1.58
ccbs	0.81	0.83	1.63	1.58
ulmn	0.79	0.83	1.63	1.58
baf	0.73	0.83	1.63	1.58
ulmm	0.74	0.83	1.63	1.58
ulms	0.69	0.83	1.62	1.58

To determine the north boundary condition, an estimation of the inflow from the San Antonio Bay is calculated. The USGS gauging stations on the San Antonio River near Goliad, TX, and the gauging station on the Guadalupe River near Victoria, TX, are used to estimate the inflow into the San Antonio Bay. The flow data was downloaded from the USGS Internet site discussed in Appendix A of this report. The resulting inflow, 77.44 m^3/s, from the two rivers is found by taking a 30 year average over the time period from the years 1960 – 1991. The northern interface boundary is set equal to 20% of the inflow into the San Antonio Bay from the Guadalupe River and the San Antonio River. The north boundary inflow is set to 15.49 m^3/s. This result compares to a study done by the Texas Water Development Board where an estimate of 11 m^3/s was calculated for the freshwater portion of the inflow to the Aransas Bay from the San Antonio Bay (Brock, 1997). The Gulf of Mexico boundary is fixed as 6.33 m^3/s to close the water mass balance. The south interface boundary flow is treated as a no flow boundary.

Table 2.14: Comparison of the Calculated Runoff Inflows with Two Other Inflow Studies by the USGS and the TWDB.

Segment	Calc. Runoff (m^3/s)	USGS Runoff (m^3/s)	TWDB Runoff (m^3/s)
stc	5.4	2.9	3.3
cop	19.0	25.9	17.5
aran	0.0	0.0	0.0
aram	0.2	0.0	0.0
aras	0.0	0.0	0.0
red	0.2	0.5	0.0
ccbn	0.3	16.5	0.0
nuee	0.3	0.0	0.0
nuew	21.9	20.0	13.5
nuem	0.1	0.0	0.0
inl	0.0	0.0	0.0
ccbe	0.0	0.0	0.0
inh	0.3	0.0	0.0
ccbm	0.4	0.0	0.0
oso	1.1	0.0	2.7
ccbs	0.0	0.0	0.0
ulmn	0.2	0.0	0.0
baf	5.6	4.2	2.1
ulmm	0.0	0.0	0.0
ulms	1.2	0.2	0.0
total	56.1	70.2	39.1

2.5.4 Model Calibration Using Salinity

The salinity data are used to manually calibrate the interface flows and the dispersion coefficients. The interface flows and the dispersion coefficients are found using a trial-and-error method, and are modified as needed. The process is repeated until the calculated salinity's matched the observed salinity's.

A file of salinity measurements is obtained from Ward (1996). The measurements are grouped together according to this original segmentation. A time- and space-weighted average is used to average the salinity data because the two dimensions, time and space, needed to be considered when averaging the data. This method employs a process where each measurement is given a weight proportional to the time between the last measurement and the next measurement. If the time between the measurements exceeds one month, a weight corresponding to one month is assigned. This is done to prevent measurements at the end of a long no-measurement period from being assigned too much weight. The maximum time period is set to be close to the response time of the system. The Avenue script TIMEAVE is used for the time-weighted average. The observed data are then weighted according to the segment surface area Equation 2.14:

Equation 2.14

$$\textbf{Conc} = \frac{1}{\Sigma A_i} \sum (A_i * s_i)$$

where: A_i = surface area

s_i = observed concentration in segment

The north and south boundaries of the bay segmentation are assigned salinity's similar to their adjacent segments because observed salinity data are not available at these locations. The north boundary is set to 19.10 ppt while the south boundary is set to 37.65 ppt. The Gulf of Mexico boundary is set to the observed salinity concentration of 29.37 ppt.

The model calibrates the tidal dispersion coefficients. Because the model is based on a mean annual flow, the dispersion load calculations need to consider molecular diffusion, eddy diffusion, turbulent conditions, and tidal mixing. Therefore the bulk dispersion coefficients need to be calculated. The calibrated dispersion coefficients and the bulk dispersion coefficients are related by Equation 2.15 (Thomman and Mueller, 1987).

Equation 2.15

$$E_{bulk} = E_{cal} * A / \Delta x$$

Where: E_{bulk} = bulk dispersion coefficient

E_{cal} = calibrated dispersion coefficient

A = surface area

Δx = length of segment

The bulk dispersion coefficients are calculated using the Avenue script CALCEP. Table 2.15 shows the dispersion coefficients, the bulk dispersion coefficients, and the interface flows calculated from the calibration process.

Table 2.15: Salinity Interface Dispersion Coefficients, Bulk Dispersion Coefficients, and Interface Flows.

Interface	Dispersion Coeff. (m^3/s)	Bulk Disp. Coeff. (m^3/s)	Flow (m^3/s)
aran/boun	5000.00	1819.69	-15.49
aram/stc	160.00	14.85	-4.71
aram/cop	160.00	52.43	-14.87
aram/aran	500.00	275.64	-15.94
aras/aram	35.00	39.99	-33.49
red/aras	320.00	58.02	-28.35
aras/inl	50.00	27.96	2.33
red/inl	500.00	31.00	2.00
ccbe/inl	1000.00	757.99	2.08
ocean/inl	200.00	301.96	-6.33
ccbn/nuee	550.00	194.35	-20.41
nuem/nuew	300.00	195.75	-21.55
ccbe/red	30.00	27.74	-24.17
ccbn/red	250.00	17.19	0.00
nuem/nuee	420.00	241.99	21.14
ccbn/ccbe	500.00	309.97	0.00
inh/ccbn	7.00	3.39	0.10
ccbm/ccbn	100.00	1544.60	-18.05
ccbm/oso	5000.00	131.71	-0.57
ccbm/ccbe	1000.00	4901.24	13.93
ccbs/ccbe	1000.00	395.81	-33.48
ulmn/ccbs	500.00	153.13	-32.56
ulmm/ulmn	1000.00	182.47	-28.13
ulmm/baf	500.00	393.50	1.32
ulms/ulmm	5000.00	909.10	-24.57
ulms/boun	5000.00	1738.79	0.00

2.6 Computing Equilibrium Water Quality Concentrations in the Bay System

The variables used in the water quality model are:

_deltat = timestep, [T]
s = concentration, [M/ L^3]
sb = boundary concentration, [M/ L^3]
q = flow, [L^3/T]
ep = bulk dispersion coefficient, [L^3/T]
fad = advective mass flux, [M/T]
fdi = diffusive mass flux, [M/T]
v = volume, [L^3]
k = decay rate, [1/T]
wnp = non-point source load, [M/T]
wps = point source load, [M/T]
wat = atmospheric load, [M/T]

wot = other load, [M/T]
wse = sediment load, [M/T]
wad = net advective load, [M/T]
wdi = net diffusive load, [M/T]
wd = decay load, [M/T]

There are various inputs which BALANCE needs to run properly. The inputs should be listed in the attribute table. If the following attributes are not present in the attribute tables of the active themes, BALANCE will add the fields to the attribute tables:

Line Attributes
q = flow
ep = bulk dispersion coefficient
sb boundary concentration (only for boundary lines)

Polygon Attributes
v = volume
k = decay rate
wnp = non-point source load
wps = point source load
wat = atmospheric load
wse = sediment load
wot other load
so = initial concentration

The output data is stored in the attribute tables of the polygon and line coverages. The output is a mass balance at the last time step. The following attributes are computed during the water quality mass balance:

Line Attributes
fad = advective mass transport
fdi = diffusive mass transport

Polygon Attributes
s = concentration
wad = net advective load
wdi = net diffusive load
wd = decay load

To use the system, the attribute table should be filled with as much input data as possible. The units should be configured to SI (There is a bug in the program when using the English or Generic units). Data may be entered into the attribute tables by using the Graphical User Interface (GUI) tools, or by manually entering the data into the attribute table. The GUI tool, **C**, allows the configuration of the units. The GUI tool, **M**, allows the modification of the active theme's attribute table. This tool allows the user to click on the polygon or line of interest and make the change. The GUI tool, **B**, starts the BALANCE program.

The following control parameters are needed for the water quality program to run properly.

Delta t = Time step used
Converge delta s = If the maximum change in concentration from one time step to another is smaller than this value, the system assumes the steady state is reach, and the program is stopped
Diverge delta s = If the maximum change in concentration from one time step to the next is larger that this value, the system assumes unstable conditions, and the program is stopped.
Max t = Maximum time for the computation
User Observation Level = Specifies the amount of the information conveyed to the user during the computation
where: **level 1** = The ArcView status bar is updated periodically. Information displayed includes time, max change in s, and percent of max time.
level 2 = In addition to level 1, the legend is periodically updated. This is useful if, the polygons are colored based on concentration.
level 3 = In addition to level 2, the mass balance terms are plotted.
level 4 = In addition to level 3, the system pauses after every time step and displays the time and maximum change in concentration from the last step.

The model can be stopped for four reasons, 1) convergence, 2) divergence, 3) a time limit was reached, or 4) it can be stopped by user. To examine the results of the model, the GUI tool, **I**, may be used. The theme of interest should be active, and then click the polygon or line of interest. The message box will display the outputs discussed earlier in the report. The GUI tool, **P**, can be used to plot mass fluxes and loads. To configure the plot parameters, use the GUI, **C**, with the plot parameter option. Choose the parameters, which are desired on the plot.

An Excel 5.0 worksheet is used for some calculations instead of the BALANCE program. The worksheet uses the same methodology as the water quality model, but reduces the run time significantly. The worksheet is used to calibrate the water quality model using the salinity data, and it is also used to calculate the equilibrium constituent concentrations due to the total loads. The operation of the spreadsheet and the ArcView program were checked against each one another to consistency.

2.7 Loads from Weighted Flow Accumulations

The non-point source load is determined by multiplying the concentration grid by the land based runoff grid. The point source grid is calculated by using the CCBNEP point source data (Armstrong, 1997). The upstream load is found using Lake Corpus Christi as a point source to represent the Nueces River Watershed.

The weighted flow accumulation command is used to calculate the land surface, point source, and loads from the Nueces River Watershed. A weighted flow accumulation is an extension of the Flowaccumulation command discussed in section 2.1.2.1. Instead of counting the number of cells upstream of a particular grid cell, the weighted flow accumulation sums the grid values from a second grid called the weight grid. Using a load grid as the weight grid, the annual load is calculated for the study area. All loads are an average daily load in Kg/d.

First, the load grids were clipped to the size of the study area using the grid **big1**. The Arc/Info console is used to calculate the accumulated load grids. Each command is repeated for the constituents being modeled; nitrate + nitrite, ammonium, total nitrogen, total phosphorus, oil & grease, copper, cadmium, chromium, zinc, lead, iron, arsenic, and mercury. Three Arc Macro Language programs (AMLs) (pogridwf.aml, logridwf.aml, and lkgridwf.aml) are written for the calculations. Each AML is responsible for calculating the weighted flow accumulation of the point source grids, land surface load grids, and the upstream load grids. The following are sample calculations from the AMLs.

The weighted flow accumulation can also be calculated by using the Avenue script WFACGRID. The script uses the same methodology as the weighted flow accumulation command used in the Grid module.

After the weighted flow accumulation is calculated, the Avenue script PICKLOAD, is used to determine the loads from the land surface, point source and Nueces River.

The need for PICKLOAD is due to the unstability of the grid algorithms near the bay centroid. At the bottom of a sink the flow direction is undefined. This causes the flow accumulation algorithm to break down, therefore the cell located at the centroid of the segment does not contain the correct value. To avoid this problem, the grids are not queried at the centroid of the segment areas, but rather around the perimeter of a five-by-five square centered on the centroid. The program PICKLOAD does this calculation. The program automatically writes the load to the wnp field of the bay attribute table, thus connecting land surface loads into bay segment attributes.

The wnp field is used to obtain the loads to each of the segments. The land surface loads for the constituents, lead, copper, zinc, cadmium, chromium, and nickel are divided by 1000 since the concentration is in g/l. The Nueces River iron load is also divided by 1000 due to units of concentration being g/l.

2.8 Running the Model

Before the water quality model can be run, the total loads need to be entered into the wnp field of the bay attribute table. This can be done manually or by using the BALANCE tool button **M**. To run the water quality model, the bay polygon and bay arc coverages need to be active in the view, and the BALANCE tool button **B** needs to be clicked.

The run control parameters used for the CCBNEP Total Loadings project are as follows:

Delta t [hr] = **12**
Converge delta s [mg/l] = **0**
Diverge delta s [mg/l] = **10,000**
Max t [hr] = **60,000**

The total loads can either be entered into the wnp field in the BALANCE model load column or into the Excel 5.0 spreadsheet. The spreadsheet is used for the thirteen constituents; ammonium, nitrate + nitrite, total nitrogen, total phosphorus, oil and grease, copper, cadmium, chromium, lead, zinc, iron, arsenic, and mercury; and salinity.

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3 RESULTS AND DISCUSSION

To understand the bay system, it is important to look at where the water enters into the system. The system is driven by the inflow that enters into the bays from the north portion of the study region while the south portion of the study region contributes little inflow and most of the water in the bays is evaporated. Total loads are discussed as well as the specific source by which the load is contributed. Some of the data needed in the total loads calculations are missing, however overall equilibrium concentrations in the bay system can still be calculated within a reasonable error. For most of the metals, the expected concentrations are under-estimated which suggests that a load source is missing in the calculations. The nutrient concentrations are over-estimated compared to the observed concentrations, however, decay is not considered in the water quality model which causes the over-estimation. The calculated constituent concentration for oil and grease is estimated with in a reasonable error.

3.1 Inflow into Bay System

The inflow into the bay system is calculated by running a weighted flow accumulation on the expected runoff grid. The runoff is accumulated into the centroid of each bay segment. Two other inflows are added into the model, 1) inflow from the Nueces River Watershed, and 2) inflow from the San Antonio Bay. The total inflow into the entire bay system is 71.6 m^3/s as shown in Table 3.1.

For the runoff analysis, the bay system is broken into three sections; north, middle, and south. The land that drains into Aransas Bay, Copano Bay, and Redfish Bay constitute the north portion of the study region. The land that drains into Nueces Bay, Corpus Christi Bay, the Inner Harbor, and Oso Bay, and the Nueces River Watershed constitute the middle portion of the study region. The land that drains into Baffin Bay and the Laguna Madre, constitute the south portion of the study region.

The majority of the inflow into the system is from the north portion of the study region. Approximately, 56% of the inflow enters into this portion of the bay system. San Antonio Bay contributes approximately 21.5% of the inflow to the Aransas Bay, while the land surface drainage in the north portion contributes approximately 34.5% of the inflow into the system.

The total inflow into the middle section of the bay system is 24 m^3/s. The Nueces River contributes approximately 28% of the inflow, while the land surface in the middle portion of the study region contributes approximately 6% of the inflow.

Very little inflow enters into the system in the south portion of the study area. Only 10% of the inflow enters in from the south portion of the study region. Table 3.1 shows the total and percent inflow from each source.

Table 3.1: Percent Inflow to the Bay System from Different Sources.

Total Inflow (m^3/s)	% Inflow	
15.5	21.6	San Antonio Bay
24.8	34.6	Land Surface Inflow From North
40.3	**56.2**	**Total Inflow from North**
20.0	27.9	Nueces River Inflow
4.4	6.1	Land Surface Inflow from Middle
24.4	**34.0**	**Total Inflow from Middle**
7.0	**9.8**	**Land Surface Inflow from South**
71.6	**100.0**	**Total Inflow into Bay System**

The larger inflow into the bay system in the north portion of the system versus the south portion of the bay system can be explained by the precipitation and runoff gradient as you move from south to north in the study region. The precipitation is lower in the south than in the north portion of the study region. The runoff gradient has a steeper incline from south to north than the precipitation gradient. As the ground saturates from the increase in precipitation, less water infiltrates due to the saturated soil which in turn causes more of the water to become runoff.

Figure 3.1 shows graphically the precipitation and runoff gradients from south to north, while Figure 3.2 shows the runoff and precipitation gradients geographically.

At location A, south of Baffin Bay, a mean annual precipitation of 600mm/yr yields a runoff of 10 mm/yr, or a runoff coefficient of 0.02. At location B, near Copano Bay, 1000 mm/yr of mean annual precipitation converts to 100 mm/yr of runoff, or a runoff coefficient of 0.1. Thus, as one moves North the precipitation increases by a fraction of 1.7, but the runoff increases by a factor of 10 between the same two points. The wetter ground in the North yields a much greater percentage of the precipitation as runoff, as well as having more precipitation to begin with.

The average precipitation onto the bays is approximately 800 mm/yr and the average evaporation is approximately double that figure, or 1600 mm/yr. On average, nearly all the inflow to the bays is dissipated by the net evaporation from the bays, and the mean annual outflow from the bay system to the Gulf of Mexico is only 6 m^3/s. The remainder of the flow is lost by evaporation.

There is a significant amount of uncertainty as to the amount of flow entering the bay system from the San Antonio and Guadalupe Rivers. If this inflow is omitted, essentially all the drainage into the Corpus Christi Bay system is lost to evaporation and does not flow to the oceans. It follows that on average, the bay system is not substantially flushed by inflow, therefore it is a large sink that has to absorb most of the loads that come into it from the land surface, atmosphere, and point sources.

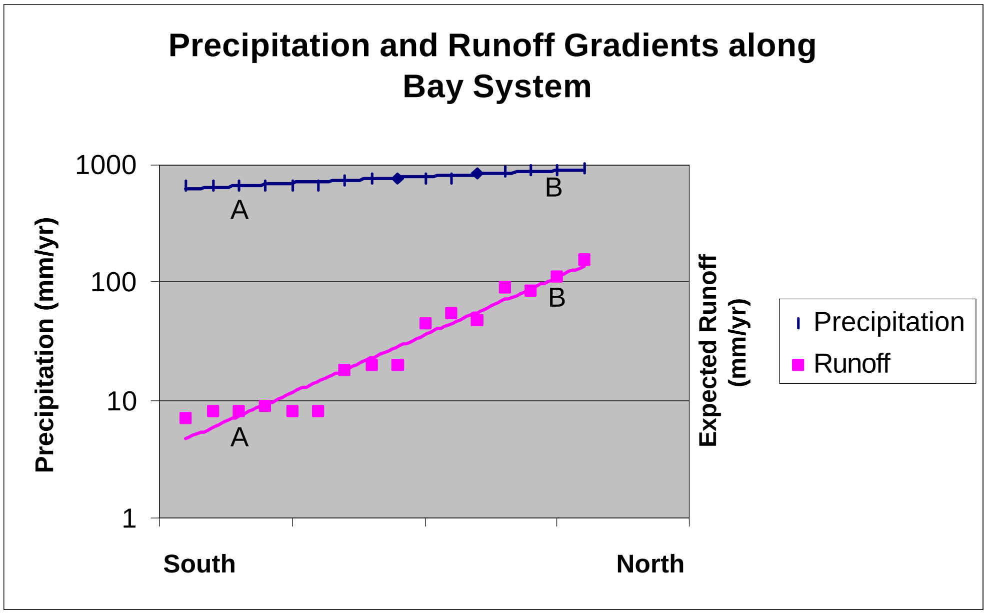
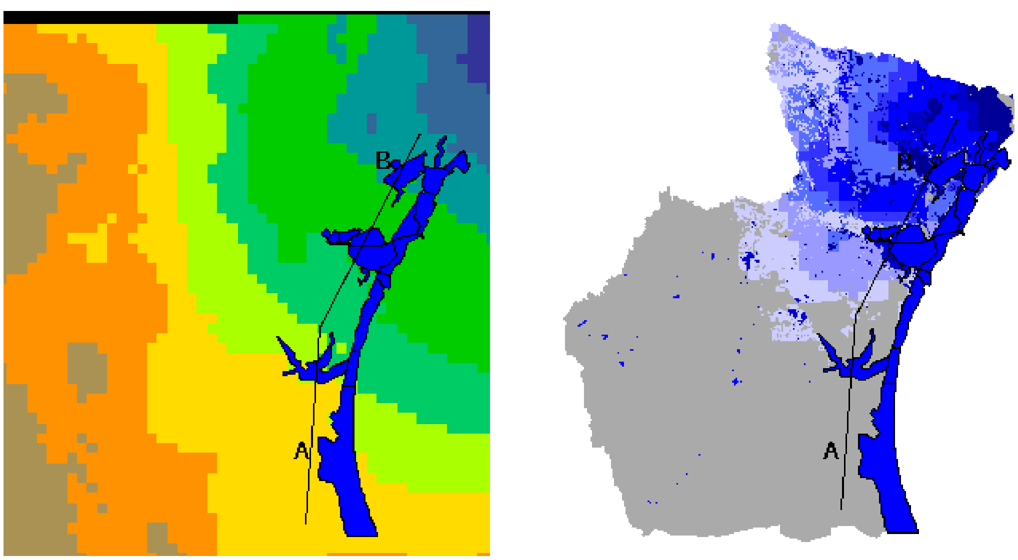


Figure 3.1: Precipitation and Runoff Gradient from South, A, to North, B, along the Bay System.



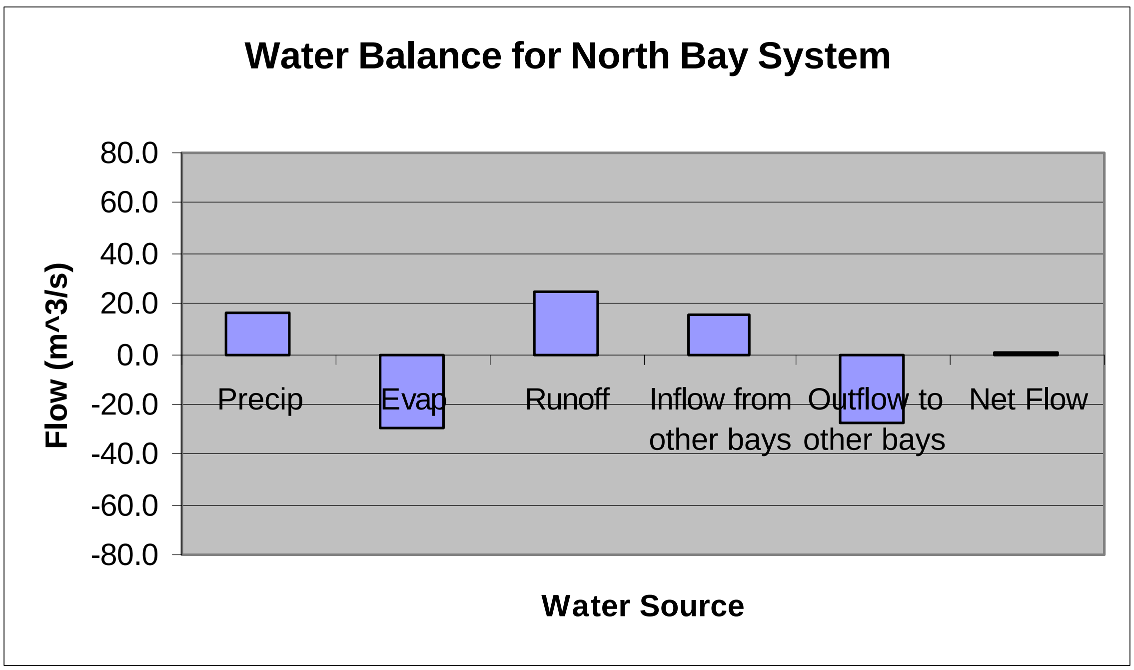
a) b)

Figure 3.2: a) Precipitation and b) Runoff Gradient Locations in the South, A, and the North, B, Portions of the Study Area.

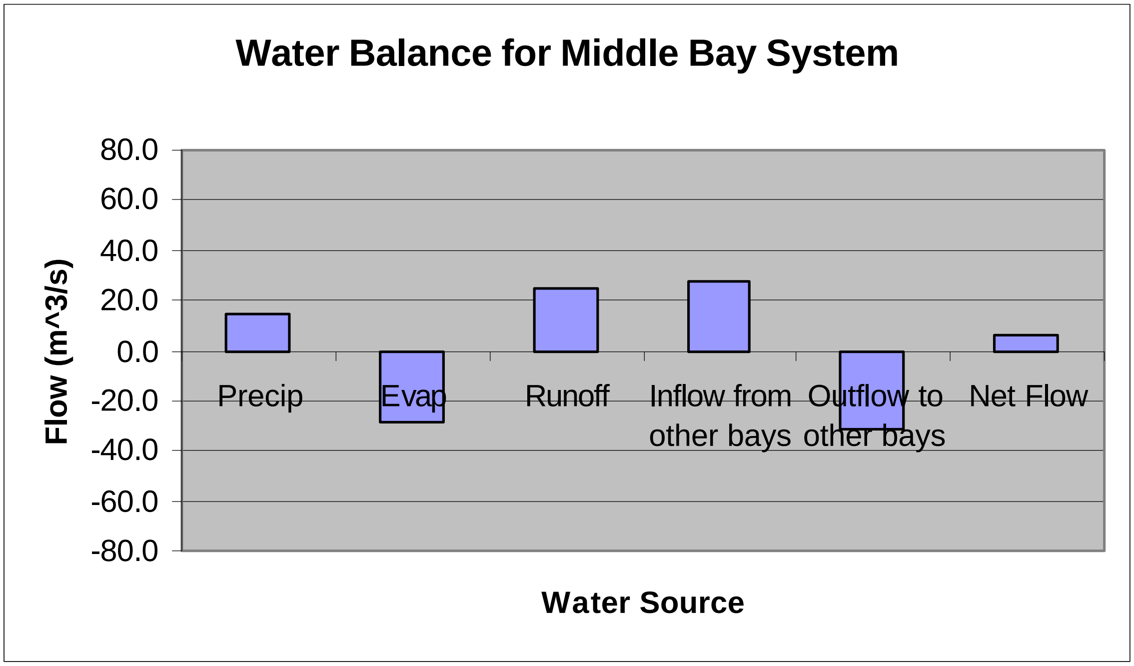
The conclusion that the system acts as a sink coincides with a study by Ward (1997), *Current Status and Historical Trends of Estuarine Circulation*. The Ward study states that there are three components to the Gulf of Mexico astronomical tides; 12.4-hour semidiurnal, 24.8-hour lunar diurnal, and the 13.6-day fortnightly cycle in the magnitude of declination of the moon. The bays act as stilling wells due to the fact that the slower, longer-period variations are passed through the connecting conduits, but the shorter-period variations are significantly filtered out.

Figure 3.3 shows the water balance for each of the three bay systems and the entire bay system. As it is shown, the inflow into the north bay system is largely contributed by the runoff, and the flow is lost to the middle bay and evaporation. The inflow to the middle bay is largely due to the runoff and inflow from the north bay system, and the flow is lost to the ocean, evaporation and the south bay system. The south bay system loses its inflow to evaporation. The entire bay system loses most of its inflow to evaporation.

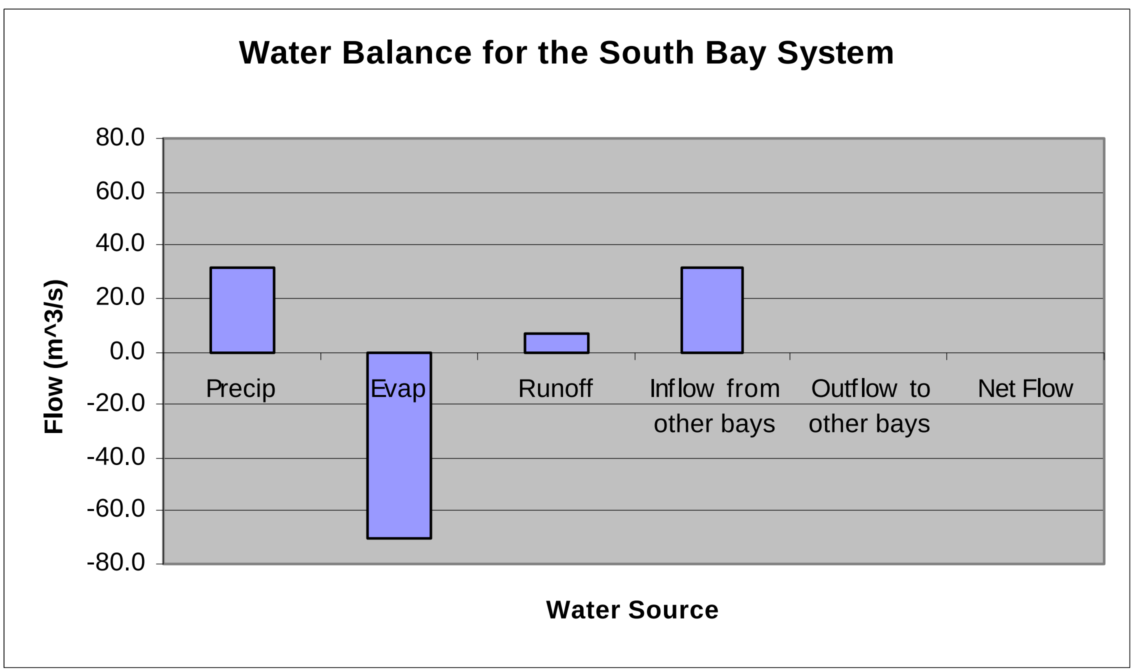
a)



b)


Water Balance for Middle Bay System
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
Flow (m^3/s)
Precip
Evap
Runoff
Inflow from other bays
Outflow to other bays
Net Flow
Water Source

c)


Water Balance for the South Bay System
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
Flow (m^3/s)
Precip
Evap
Runoff
Inflow from other bays
Outflow to other bays
Net Flow
Water Source

d)

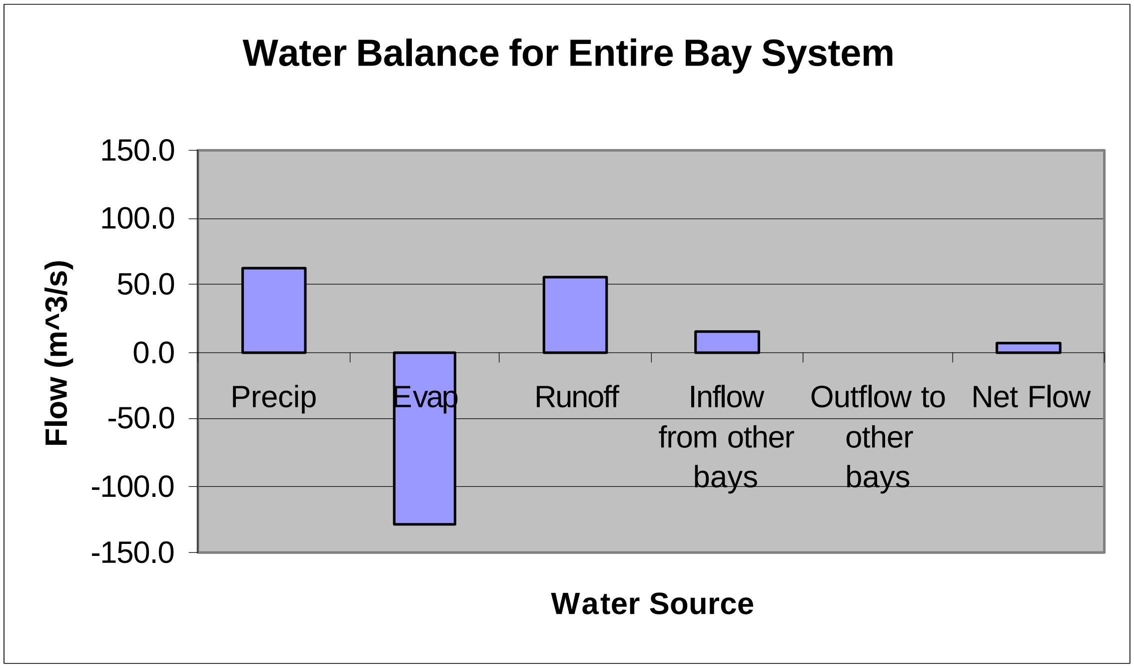


Figure 3.3: Water Balances for the a) North Bay Sytem, b) Middle Bay System, c) South Bay System, and d) the Entire Bay System.

3.2 Total Constituent Loads into Bay System

The constituent loads are determined from the land surface, point sources, atmosphere, and the Nueces River Watershed. Some of the data is missing for certain constituents at specific sources. For example, data are available for ammonium only in the atmosphere. There is ammonium in the point source and non-point source loads, however data are only available for total nitrogen for the point sources and total nitrogen and nitrate + nitrite for the non-point sources. Table 3.2 shows the constituent loads for each bay segment, the source in which the load originated, and where data is missing.

Atmospheric Loads

The atmospheric loads show constituent load contributions from ammonium, nitrate, and total nitrogen. Many of the other constituents are not found in rain water or are not measured at the sampling site at Beeville, TX.

Table 3.2: Constituent Loadings for Each Bay Segment, a) Atmospheric Loads, b) Point Source Loads, c) Land Surface (Non-point Loads), d) Nueces River Watershed Loads, e) Total Loads.

a)

	Atmospheric Loads												
Segment	NH4 (Kg/d)	NO3+ NO2 (Kg/d)	TN (Kg/d)	TP (Kg/d)	O & G (Kg/d)	Cu (Kg/d)	Cd (Kg/d)	Cr (Kg/d)	Pb (Kg/d)	Zn (Kg/d)	Fe (Kg/d)	As (Kg/d)	Hg (Kg/d)
stc	18.26	51.74	70.00	**	**	**	**	**	**	**	**	**	**
cop	105.62	299.36	404.98	**	**	**	**	**	**	**	**	**	**
aran	34.94	99.03	133.97	**	**	**	**	**	**	**	**	**	**
aram	60.66	171.94	232.60	**	**	**	**	**	**	**	**	**	**
aras	66.29	187.87	254.16	**	**	**	**	**	**	**	**	**	**
red	53.97	152.96	206.93	**	**	**	**	**	**	**	**	**	**
ccbn	59.73	169.29	229.03	**	**	**	**	**	**	**	**	**	**
nuee	20.65	58.51	79.16	**	**	**	**	**	**	**	**	**	**
nuew	6.66	18.87	25.52	**	**	**	**	**	**	**	**	**	**
nuem	11.20	31.74	42.94	**	**	**	**	**	**	**	**	**	**
inl	2.27	6.42	8.69	**	**	**	**	**	**	**	**	**	**
ccbe	55.63	157.67	213.30	**	**	**	**	**	**	**	**	**	**
inh	3.41	9.68	13.09	**	**	**	**	**	**	**	**	**	**
ccbm	110.19	312.32	422.51	**	**	**	**	**	**	**	**	**	**
oso	9.77	27.68	37.45	**	**	**	**	**	**	**	**	**	**
ccbs	19.77	56.03	75.80	**	**	**	**	**	**	**	**	**	**
ulmn	95.64	271.08	366.72	**	**	**	**	**	**	**	**	**	**
baf	131.78	373.52	505.30	**	**	**	**	**	**	**	**	**	**
ulmm	43.47	123.22	166.69	**	**	**	**	**	**	**	**	**	**
ulms	478.58	1356.43	1835.00	**	**	**	**	**	**	**	**	**	**
Total	1388.48	3935.36	5323.84	**	**	**	**	**	**	**	**	**	**

b)

Segment	Point Source Loads NH4 (Kg/d)	NO3+ NO2 (Kg/d)	TN (Kg/d)	TP (Kg/d)	O & G (Kg/d)	Cu (Kg/d)	Cd (Kg/d)	Cr (Kg/d)	Pb (Kg/d)	Zn (Kg/d)	Fe (Kg/d)	As (Kg/d)	Hg (Kg/d)
stc	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
cop	**	**	183.48	91.73	146.78	0.26	0.31	0.56	0.59	2.16	9.17	0.42	0.00
aran	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
aram	**	**	24.87	12.44	19.90	0.04	0.04	0.07	0.08	0.29	1.24	0.06	0.00
aras	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
red	**	**	44.10	22.05	35.28	0.06	0.08	0.14	0.14	0.53	2.20	0.10	0.00
ccbn	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nuee	**	**	60.37	30.18	48.30	2.78	0.10	0.18	0.19	0.71	3.02	0.14	0.00
nuew	**	**	285.13	142.57	232.28	0.48	0.56	1.09	0.95	3.99	14.25	0.45	0.01
nuem	**	**	292.80	146.40	345.20	2.00	0.54	2.00	0.08	7.27	14.64	0.71	0.04
inl	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ccbe	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
inh	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ccbm	**	**	81.43	40.71	65.14	0.50	0.72	0.91	0.40	2.56	4.07	0.58	0.09
oso	**	**	892.84	446.42	714.27	4.79	1.54	2.74	2.87	10.52	44.64	2.04	0.02
ccbs	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ulmn	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
baf	**	**	280.35	140.18	226.94	0.76	0.48	0.86	0.90	3.30	14.02	0.64	0.10
ulmm	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ulms	**	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**	**	2145.37	1072.68	1834.09	11.67	4.37	8.55	6.20	31.33	107.25	5.14	0.26

c)

Segment	Land Surface Loads NH4 (Kg/d)	NO3+ NO2 (Kg/d)	TN (Kg/d)	TP (Kg/d)	O & G (Kg/d)	Cu (Kg/d)	Cd (Kg/d)	Cr (Kg/d)	Pb (Kg/d)	Zn (Kg/d)	Fe (Kg/d)	As (Kg/d)	Hg (Kg/d)
stc	**	399.34	1013.90	253.08	23.69	2.61	0.21	2.67	1.51	6.32	**	**	**
cop	**	1516.96	3968.46	1022.72	361.71	9.52	0.92	9.53	5.99	37.45	**	**	**
aran	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**	**	**
aram	**	5.51	22.25	4.91	22.22	0.22	0.01	0.08	0.14	1.18	**	**	**
aras	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**	**	**
red	**	5.33	16.66	2.77	14.52	0.17	0.00	0.09	0.11	0.65	**	**	**
ccbn	**	25.86	77.40	21.85	28.95	0.19	0.03	0.14	0.15	1.97	**	**	**
nuee	**	28.76	80.73	23.37	9.73	0.07	0.02	0.11	0.07	0.83	**	**	**
nuew	**	204.05	573.79	164.97	47.29	0.63	0.13	0.78	0.47	4.08	**	**	**
nuem	**	13.35	36.56	10.51	2.00	0.03	0.01	0.05	0.03	0.29	**	**	**
inl	**	0.35	1.94	0.50	4.76	0.02	0.00	0.01	0.01	0.14	**	**	**
ccbe	**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**	**	**
inh	**	9.54	41.20	10.99	72.93	0.29	0.00	0.12	0.23	2.79	**	**	**
ccbm	**	8.89	49.71	13.21	123.81	0.45	0.03	0.02	0.33	3.63	**	**	**
oso	**	111.57	321.54	92.55	83.45	0.45	0.09	0.47	0.37	4.06	**	**	**
ccbs	**	0.30	1.79	0.50	2.11	0.02	0.00	0.00	0.01	0.09	**	**	**
ulmn	**	11.60	26.98	5.35	0.55	0.14	0.00	0.12	0.00	0.18	**	**	**
baf	**	481.72	1301.54	346.28	193.75	2.87	0.30	2.79	1.85	12.56	**	**	**
ulmm	**	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**	**	**
ulms	**	43.84	83.68	4.56	3.32	0.96	0.00	0.73	0.49	0.82	**	**	**
Total	**	2866.99	7618.17	1978.12	994.79	18.62	1.77	17.70	11.75	77.04	**	**	**

d)

Segment	NH4 (Kg/d)	NO3+ NO2 (Kg/d)	TN (Kg/d)	TP (Kg/d)	O & G (Kg/d)	Cu (Kg/d)	Cd (Kg/d)	Cr (Kg/d)	Pb (Kg/d)	Zn (Kg/d)	Fe (Kg/d)	As (Kg/d)	Hg (Kg/d)
	Nueces River Watershed Loads												
stc	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
cop	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
aran	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
aram	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
aras	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
red	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ccbn	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
nuee	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
nuew	**	**	81.11	58.52	**	**	**	**	**	**	2.22	**	**
nuem	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
inl	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ccbe	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
inh	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ccbm	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
oso	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ccbs	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ulmn	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
baf	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ulmm	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
ulms	**	**	0.00	0.00	**	**	**	**	**	**	0.00	**	**
Total	**	**	81.11	58.52	**	**	**	**	**	**	2.22	**	**

e)

Segment	Total Loads NH4 (Kg/d)	NO3+ NO2 (Kg/d)	TN (Kg/d)	TP (Kg/d)	O & G (Kg/d)	Cu (Kg/d)	Cd (Kg/d)	Cr (Kg/d)	Pb (Kg/d)	Zn (Kg/d)	Fe (Kg/d)	As (Kg/d)	Hg (Kg/d)
stc	18.26	451.08	1083.90	253.08	23.69	2.61	0.21	2.67	1.51	6.32	0.00	0.00	0.00
cop	105.62	1816.32	4556.92	1114.45	508.49	9.78	1.23	10.09	6.58	39.61	9.17	0.42	0.00
aran	34.94	99.03	133.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
aram	60.66	177.45	279.72	17.35	42.12	0.26	0.05	0.15	0.22	1.47	1.24	0.06	0.00
aras	66.29	187.87	254.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
red	53.97	158.29	267.69	24.82	49.80	0.23	0.08	0.23	0.25	1.18	2.20	0.10	0.00
ccbn	59.73	195.15	306.43	21.85	28.95	0.19	0.03	0.14	0.15	1.97	0.00	0.00	0.00
nuee	20.65	87.27	220.26	53.55	58.03	2.85	0.12	0.29	0.26	1.54	3.02	0.14	0.00
nuew	6.66	222.92	965.55	366.06	279.57	1.11	0.69	1.87	1.42	8.07	16.47	0.45	0.01
nuem	11.20	45.09	372.30	156.91	347.20	2.03	0.55	2.05	0.11	7.56	14.64	0.71	0.04
inl	2.27	6.77	10.63	0.50	4.76	0.02	0.00	0.01	0.01	0.14	0.00	0.00	0.00
ccbe	55.63	157.67	213.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
inh	3.41	19.22	54.29	10.99	72.93	0.29	0.00	0.12	0.23	2.79	0.00	0.00	0.00
ccbm	110.19	321.21	553.65	53.92	188.95	0.95	0.75	0.93	0.73	6.19	4.07	0.58	0.09
oso	9.77	139.25	1251.83	538.97	797.72	5.24	1.63	3.21	3.24	14.58	44.64	2.04	0.02
ccbs	19.77	56.33	77.59	0.50	2.11	0.02	0.00	0.00	0.01	0.09	0.00	0.00	0.00
ulmn	95.64	282.68	393.70	5.35	0.55	0.14	0.00	0.12	0.00	0.18	0.00	0.00	0.00
baf	131.78	855.24	2087.19	486.46	420.69	3.63	0.78	3.65	2.75	15.86	14.02	0.64	0.10
ulmm	43.47	123.24	166.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ulms	478.58	1400.27	1918.68	4.56	3.32	0.96	0.00	0.73	0.49	0.82	0.00	0.00	0.00
Total	1388.48	6802.35	15168.49	3109.32	2828.88	30.29	6.14	26.25	17.95	108.37	109.47	5.14	0.26

** No data

Point Source Loads

Point source loads show constituent load contributions from total nitrogen, total phosphorus, oil and grease, copper, cadmium, chromium, lead, zinc, iron, arsenic and mercury. No data is found for ammonium and nitrate + nitrite, however these constituents are present in the point source. Because there is a total nitrogen estimate of the point source loads, these other constituents are present implicitly. Since the percentage of these two components of the total nitrogen is not known, the constituent loads for ammonium and nitrate + nitrite could not be calculated.

Land Surface Loads

Non-point source loads show constituent load contributions from nitrate + nitrite, total nitrogen, total phosphorus, oil and grease, copper, cadmium, chromium, lead, and zinc. The ammonium constituent is not accounted for, and the metals; iron, arsenic, and mercury; have no data. These constituents are not present in the EMC table used in the study.

The atmospheric load over the land surface is 35% of the total land surface load (Section 2.4.4). However, the atmospheric load is only added directly to the bay system because the EMC values account for both land surface applications and atmospheric deposition over the land surface.

Nueces RiverWatershed Loads

The Nueces River has loads for total nitrogen, total phosphorus and iron. The constituents ammonium, nitrate + nitrite, oil and grease, copper, cadmium, chromium, lead, zinc, arsenic, and mercury are not accounted for. These constituents are either non-detectable or are not measured.

Relative Total Loads

For the constituents analyzed, the largest load contribution to the entire bay system is the total nitrogen load with nitrate + nitrite being the second largest load. Total phosphorus, oil and grease and ammonium are large load contributors to the bay system. The ammonium and nitrate + nitrite load would be a large contributor if more were known about the constituents coming from point, non-point and the Nueces River sources. Very little of the total load is from the metal loads.

Figure 3.4 shows the percentage of loads from the total load to the entire system from each of the constituents. The metals are lumped into one category so that the small load can be compared to the larger loads presented with the data.

When each constituent load is broken down into its percent source contribution, it can be determined which source the majority of the load is coming from. Figure 3.5 shows the percentage of the constituent load that is contributed from a specific source to the entire bay system.

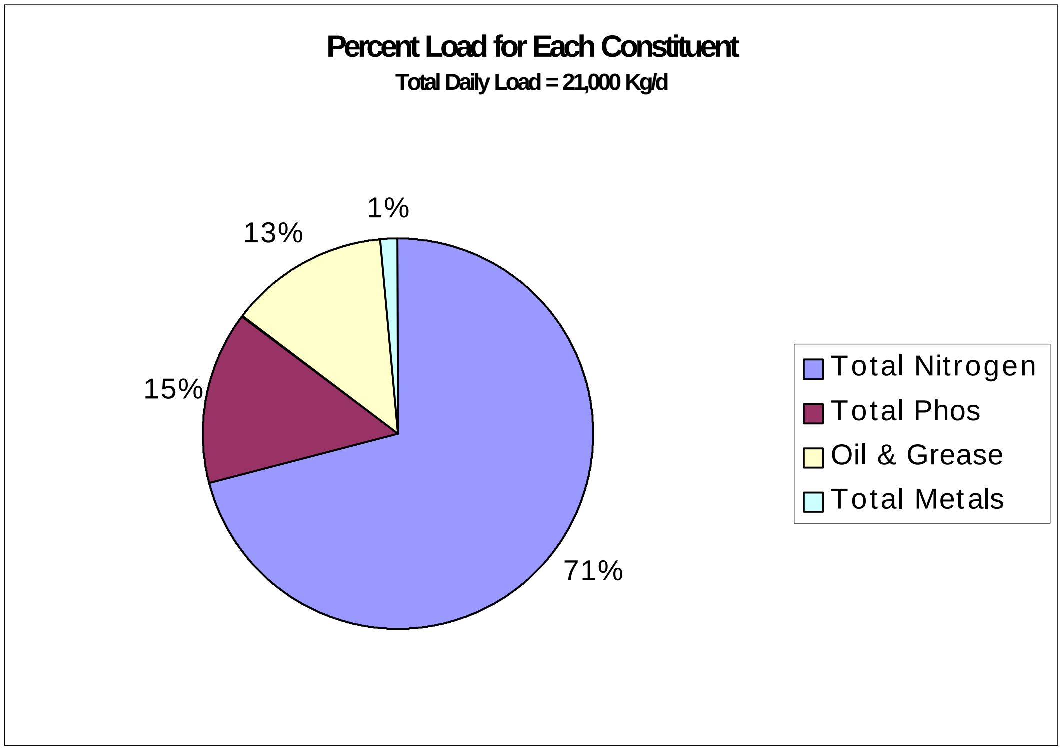


Figure 3.4: Percent Constituent Loads of the Total Load for the Entire System.

The largest contributor to the total nitrogen load is from the land surface. The atmosphere and the point sources also largely contribute to the total nitrogen load. The total phosphorus load comes mostly from the land surface with large contribution from point sources and a smaller contribution from the Nueces River. The oil and grease load is due to point sources and non-point sources. The land surface and the point sources largely contribute to the copper, chromium and zinc loads in the bay system.

When each constituent load is broken down into its percent bay contribution, it can be determined where majority of the load is going. Figure 3.6 shows the percentage of the constituent load that is contributing to a specific bay region

The majority of the total nitrogen and total phosphorus load is received in the middle and north portions of the bay. The oil and grease load ends up mostly in the middle section of the bay system. The middle and north sections of the bay system receive the majority of the copper load. The north portion of the bay system receives almost half of the chromium load with the middle and south portions receiving the rest of the load. The zinc load is received in the north and middle section of the bay system with the south section of the bay system receiving a smaller portion of the load. Almost all of the constituent loads are received in the middle and north portions of the bay system due to the increased runoff in those areas and the majority of the point sources being located in those areas.

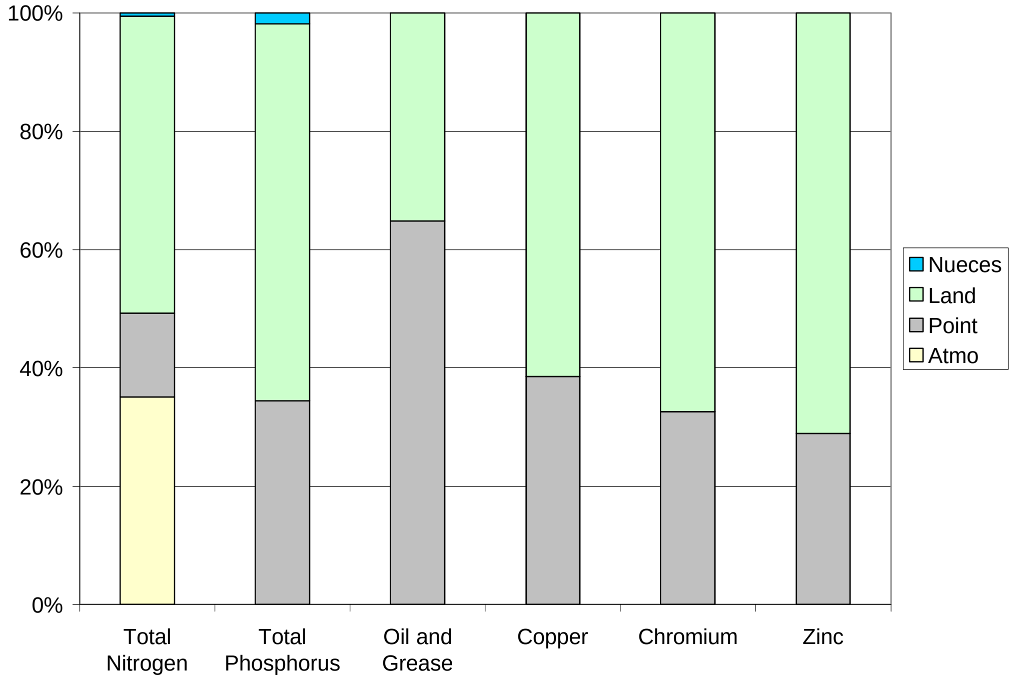


Figure 3.5: Percent of Total Constituent Load which Comes from a Specific Source for Entire System.

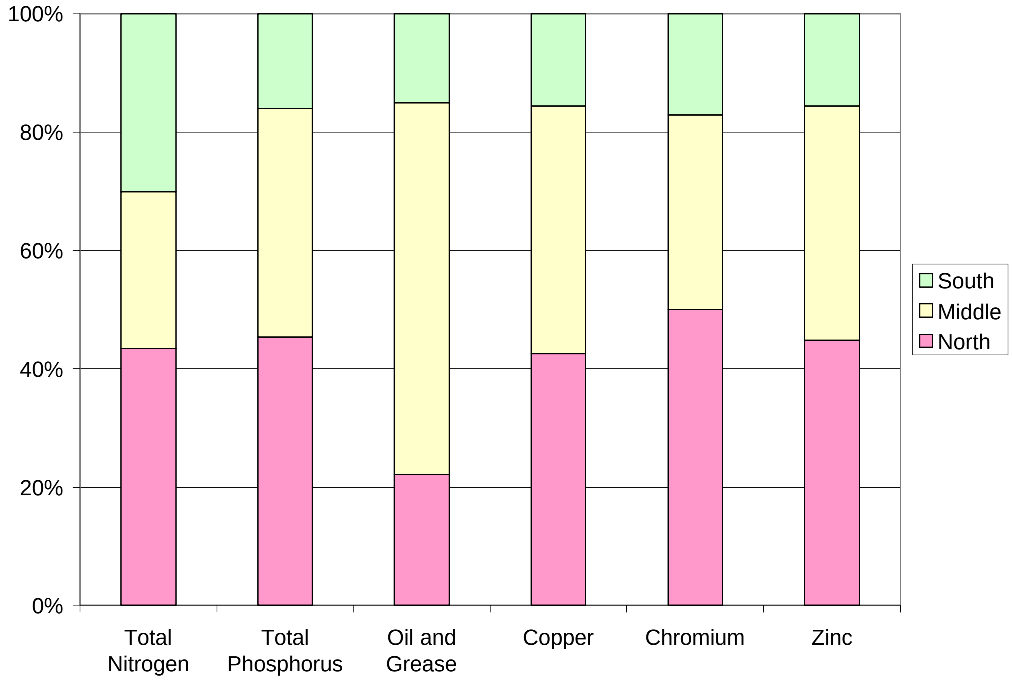


Figure 3.6: Percent of Total Constituent Load which Comes from a Specific Source for the North, Middle and South Bay.

3.3 Constituent Concentrations in the Bay System

After the water quality model is run on the constituents, the expected concentrations are compared to the observed concentrations. A statistical analysis is run on the observed concentrations to determine an area- and time-weighted mean as well as a standard deviation. A statistical t-test is calculated between the expected and the observed concentrations to determine if the model predicts the equilibrium concentration within a reasonable range.

3.3.1 Comparing the Expected Concentrations to the Observed Concentrations using the T-Test

The t-test is used to compare the expected concentrations calculated using the water quality model to the observed concentrations. The t-test is a statistical analysis which compares the observed concentrations with the expected concentrations normalized with the standard deviation and the square root of the number of samples (Hirsch et al., 1993). A positive t-test result indicates the observed concentrations are greater than the expected concentrations while a negative t-test result indicates the observed concentrations are less than the expected concentrations. If the t-test result is larger than ±2, the expected value is not statistically the same as the observed values. The Equation 3.1 is used to calculate the t-statistic.

Equation 3.1

$$\text{t-test} = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$

where: $\bar{x}$ = mean of observed concentrations, mg/l

$$= \frac{1}{\sum n_i} \sum (n_i * s_i)$$

where: n_i = number of samples

s_i = observed concentration in segment

μ = expected concentration computed from model, mg/l

$$= \frac{1}{\sum A_i} \sum (A_i * s_i)$$

where: A_i = surface area

s_i = observed concentration in segment

s = standard deviation of observed concentrations, mg/l

n = number of samples

Table 3.3 shows the expected concentration, the observed concentration, the standard deviation, the number of samples, and the t–test result for each of the bay segments.

For the most part, the t-test result is negative for the nutrient constituents, total nitrogen and total phosphorus. This suggests a higher expected concentration than the observed concentrations. Because decay is not accounted for in the water quality model, this result is reasonable.

The t-test results for the metals are positive for most of the metal constituents. This suggests lower expected concentration than the observed concentrations. This is probably due to a missing load source in the calculations. Since the bays do not flush frequently, there exist long periods of time during which the metals are washed into the bays and deposited in bay sediments, creating a reservoir of metals in the sediments. A portion of these sediment metals may then re-enter the water column due to resuspension and physical and chemical process. The net flux of metal concentrations out of the sediment is not accounted for in the water quality model due to lack of metal sediment flux data. There could also be a missing data source from the atmosphere, land surface and point sources.

Oil and grease, for the most part, has a t-statistic within the ±2 range, which indicates a reasonable estimation of the constituent concentrations in the bay system.

The average t-test results for each bay system is calculated based on a number of sample weighted average over each of the three bay sections. Equation 3.2 illustrates this calculation. Table 3.4 shows the average t-test result for each of the constituents. The nutrient t-test results are negative, again suggesting that decay should be used in the water quality model. The average t-test result for copper, chromium, and zinc, are positive which suggests a data source is missing in the load calculations. Oil and Grease has a low average t-test result which suggests the model predicts the equilibrium concentrations close to the observed concentrations.

Equation 3.2

$$\textbf{Ave T-Test} = \frac{1}{\Sigma n_i} \sum (n_i * t_i)$$

where: n_i = number of samples

s_i = observed concentration in segment

Table 3.3: Expected and Observed Concentrations, Standard Deviation, Number of Samples, and the T-Test Result for Each Bay Segment: a) Total Nitrogen, b) Total Phosphorus, c) Oil and Grease, d) Copper, e) Chromium, and f) Zinc.

a)

Total Nitrogen					
segment	exp (mg/l)	obs (mg/l)	std dev	# samples	t-test
stc	0.9	0.1	0.4	176	-30.6
cop	1.1	0.6	0.7	514	-15.5
aran	0.2	0.1	0.3	262	-2.0
aram	0.4	0.1	0.1	191	-47.9
aras	0.4	0.1	0.2	288	-24.8
red	0.3	0.1	0.6	348	-6.5
ccbn	0.3	0.1	0.3	1335	-18.1
nuee	0.3	0.2	0.6	707	-5.6
nuew	0.4	0.6	0.1	130	19.0
nuem	0.4	0.1	0.3	631	-20.0
inl	0.2	0.1	0.4	4	-0.5
ccbe	0.3	0.1	0.3	691	-17.4
inh	0.5	0.4	1.1	482	-0.1
ccbm	0.3	0.1	0.1	711	-32.7
oso	0.4	0.2	4.9	192	-0.6
ccbs	0.3	0.2	0.5	287	-3.7
ulmn	0.2	0.3	0.1	417	15.7
baf	0.3	0.1	0.2	802	-21.3
ulmm	0.2	0.1	0.2	248	-5.8

b)

Total Phosphorus					
segment	exp (mg/l)	obs (mg/l)	std dev	# samples	t-test
stc	0.3	0.1	0.1	177	-24.9
cop	0.3	0.1	0.1	519	-56.5
aran	0.1	0.1	0.1	216	-1.1
aram	0.2	0.1	0.1	193	-22.4
aras	0.1	0.1	0.0	293	-33.4
red	0.1	0.1	0.1	346	-27.6
ccbn	0.1	0.1	0.1	941	-36.2
nuee	0.2	0.1	0.1	298	-8.5
nuew	0.2	0.2	0.1	15	1.4
nuem	0.2	0.2	0.3	297	-2.0
inl	0.1	0.1	0.0	2	-0.2
ccbe	0.1	0.0	0.1	352	-27.9
inh	0.2	0.1	0.2	429	-6.7
ccbm	0.1	0.1	0.1	589	-32.4
oso	0.2	0.4	1.5	182	1.7
ccbs	0.1	0.1	0.0	240	-19.8
ulmn	0.1	0.1	0.0	186	-20.4
baf	0.1	0.1	0.7	306	0.3
ulmm	0.1	0.1	0.0	127	-7.7

c)

Oil and Grease					
segment	exp (mg/l)	obs (mg/l)	std dev	# samples	t-test
stc					
cop					
aran	10.2	10.4	9.4	7	0.1
aram	9.2	9.1	6.3	26	-0.1
aras					
red					
ccbn	2.7	2.0	1.2	34	-3.4
nuee					
nuew					
nuem					
inl	2.7	6.3	7.8	2	0.6
ccbe					
inh	2.8	7.3	11.8	27	2.0
ccbm					
oso					
ccbs					
ulmn					
baf					
ulmm					

d)

Copper					
segment	exp (ug/l)	obs (ug/l)	std dev	# samples	t-test
stc	2.4	6.8	2.1	2	2.9
cop	2.6	24.5	34.4	8	1.8
aran					
aram	1.1	2.9	2.3	57	5.8
aras	1.8	3.5	1.6	15	4.1
red	2.3	13.2	31.2	10	1.1
ccbn	3.0	9.8	37.8	133	2.1
nuee	3.0	15.0	26.6	15	1.7
nuew					
nuem					
inl					
ccbe	3.0	0.8	2.1	10	-3.2
inh	3.8	9.9	13.8	92	4.2
ccbm	3.0	4.5	4.7	5	0.7
oso	3.4	41.4	52.4	3	1.3
ccbs					
ulmn	5.7	10.1	23.4	18	0.8
baf	7.7	26.9	31.8	8	1.7
ulmm					

e)

Chromium					
segment	exp (ug/l)	obs (ug/l)	std dev	# samples	t-test
stc	3.9	10.0	0.0	2	
cop	4.1	28.8	31.1	8	2.3
aran	2.5	21.8	2.3	13	29.8
aram	3.0	5.8	2.1	57	9.9
aras	3.8	7.6	2.9	14	4.8
red	4.2	12.5	30.9	10	0.8
ccbn	4.6	15.3	21.0	132	5.9
nuee	4.4	19.9	25.2	15	2.4
nuew					
nuem					
inl					
ccbe					
inh	4.8	16.4	21.0	84	5.1
ccbm	4.6	24.0	21.4	5	2.0
oso	4.9	42.1	52.0	3	1.2
ccbs					
ulmn	4.3	13.9	22.6	18	1.8
baf	4.1	42.2	36.4	10	3.3
ulmm					

f)

Zinc					
segment	exp (ug/l)	obs (ug/l)	std dev	# samples	t-test
stc	9.7	13.2	12.4	2	0.4
cop	12.9	34.4	288.1	8	0.2
aran	5.9	5.7	51.9	13	0.0
aram	7.8	19.2	33.6	57	2.6
aras	10.8	34.6	28.1	15	3.3
red	12.6	13.2	31.3	10	0.1
ccbn	14.1	80.7	222.5	134	3.5
nuee	13.7	51.3	49.2	14	2.9
nuew					
nuem					
inl	14.0	7.5	8.9	5	-1.6
ccbe	14.0	2.1	3.8	10	-9.9
inh	22.9	47.8	50.4	89	4.7
ccbm	14.1	133.8	152.5	5	1.8
oso	15.3	44.9	50.4	3	1.0
ccbs					
ulmn	11.8	12.8	22.9	18	0.2
baf	10.3	51.3	34.0	10	3.8
ulmm	9.8	8.6	113.1	2	0.0

Table 3.4: Average T-Test Result for Each Constituent.

Constituent	Bay System	Average t-test
Total Nitrogen	North	-18.2
	Middle	-14.5
	South	-8.2
	Total	-14.2
Total Phosphorus	North	-33.1
	Middle	-21.9
	South	-7.5
	Total	-23.8
Oil and Grease	North	-0.1
	Middle	-1.0
	South	
	Total	0.0
Copper	North	4.6
	Middle	2.6
	South	1.1
	Total	3.0
Chromium	North	10.0
	Middle	5.2
	South	2.3
	Total	6.4
Zinc	North	1.9
	Middle	3.2
	South	1.4
	Total	2.7

3.3.2 Calculating the Decay Rates in the Three Bay Systems

The previous calculations assumed that there was no constituent decay or deposition in the bays. The appropriate decay rates to bring the computed and observed concentrations into balance can be determined. To do this, the bay system is broken into three smaller systems being the north, middle and south sections. The decay rates calculated included all abiotic and biotic processes.

A simplified model is used to determine the load which is not transported out of the system. The same mass balance equation is used for the simplified model as is used for the model which broke the system into twenty segments, however the equation is solved for the decay rate rather than the equilibrium concentrations. The simplified system is used to calculate the decay rate needed to reach the observed concentrations given the constituent load to the system. The model assumes the only unknown into the system is the decay rate. The average observed concentrations are calculated using the time- and space-weighted average observed concentrations for each segment explained in section 2.5.4. The concentrations are averaged over time and space for each of the 20 segments. The average observed concentrations for the three sections is a weighted averaged based on the number of samples taken for that segment. This is done using Equation 3.3.

Equation 3.3

$$C_{ave} = \frac{1}{n_i}\sum(n_i * s_i)$$

where: C_{ave} = average observed concentration

n_i = number of samples

s_i = observed concentration in segment

Once the average concentrations for each bay segment are calculated, the decay rates are calculated using Equation 3.4. The methodology for the decay rate calculations is the same as the water quality mass balance (Figure 2.13).

Equation 3.4

$$K = (Q_{N,M}*s_N - Q_{M,S}* s_M - Q_{M,Oc}*s_M + E_{N,M}(s_N-s_M) + E_{M,Oc}(s_M-s_{Oc}) + E_{M,S}(s_M-s_S) + W_M) / (V_M*s_M)$$

where: K = the decay rate

$Q_{N,M}*s_N$ = Advective load from the north segment

$Q_{M,S}* s_M$ = Advective load leaving the middle segment to the south segment

$Q_{M,Oc}* s_M$ = Advective load leaving the middle segment to the ocean

$E_{N,M}(s_N-s_M)$ = dispersive load between the north and middle segments

$E_{M,Oc}(s_M-s_{Oc})$ = dispersive load between the middle segment and the ocean

$E_{M,S}(s_M-s_S)$ = dispersive load between the middle and south segments

W_M = waste load entering the middle segment

V_M*s_M = load volume in the segment

For the north system, the advective load from the boundary is added to total waste load from the land surface, point sources, non-point sources, and atmospheric deposition. The advective load to middle segment is subtracted from the system, and the dispersive loads are added or subtracted depending on the concentration gradient.

For the middle system, the advective load from the first segment is added to total load from the land surface, point sources, non-point sources, and atmospheric deposition. The advective load to south segment and the ocean are subtracted from the system, and the dispersive loads are added or subtracted depending on the concentration gradient.

For the south system, the advective load from the middle section is added to total load from the land surface, point sources, non-point sources, and atmospheric deposition. The advective load leaving at the south boundary is subtracted from the system, and the dispersive loads are added or subtracted depending on the concentration gradient.

The interface flows, bulk dispersion coefficients, segment volumes, and boundary conditions are the same as the twenty segment model. Because the dispersion coefficients are large, they govern the mass balance equation. Therefore, the boundary conditions are set equal to the concentration in the bay adjacent to the boundary interface making the dispersion flow at the boundaries negligible. Table 3.5 shows the decay rates calculated from the mass balance for the constituents total nitrogen and total phosphorus.

Table 3.5: Decay Rates for Total Nitrogen and Total Phosphorus.

Constituent	Bay Section	Decay Rate (/d)	Ave Decay Rate (/d)
Total Nitrogen	North	0.030	
	Middle	0.011	
	South	0.024	0.022
Total Phosphorus	North	0.013	
	Middle	0.004	
	South	0.009	0.009

The long residence time of the three bay segments makes the concentrations sensitive to the overall gain and loss within the system. The decay rate takes into account all the mechanisms of the gain and loss process either by biotic or abiotic processes. These processes include photosynthetic uptake, excretion, chemical transformations, hydrolysis of dissolved organic nutrients, detritus decomposition, sediment decomposition and release, and external loading (EPA, 1997).

The small decay rate values suggest they are within the right order of magnitude and are comparable to the United States Environmental Protection Agency (EPA) suggested decay rates in the surface water quality modeling online report at the Internet site: **http://www.epa.gov/ORD/WebPubs/surfaceH2O/surface.htm.**

3.3.3 Edroy and King Ranch EMC Study

Two runoff studies as part of the Corpus Christi National Estuary Program and supervised by the USGS are being done to determine representative EMC values for nutrients from agricultural landuse within the Corpus Christi National Estuary Programs study area. The studies are being completed on the King Ranch and on an agricultural area near the Town of Edroy. Because the studies are still in progress, the data is provisional. The following calculation made from these data is for comparison purposes with results of the original EMC data in Section 2.3.

The provisional EMC values were 1.49 mg/l and 0.47 mg/l for total nitrogen and total phosphorus, respectively. The provisional values were calculated from 29 runoff samples for total nitrogen and 32 runoff samples for total phosphorus. The median values were reported by the USGS (Ockerman, 1998). For comparison, the original EMC values were 4.40 mg/l for total nitrogen and 1.30 mg/l for total phosphorus, as discussed in Section 2.3, Table 2.10.

The EMC results from the studies at the King Ranch and Edroy agricultural fields were entered into the land surface runoff model by replacing the original agricultural land use EMC values, with the new provisional EMC values. The EMC values were changed for the Anderson Land Use Classification number 21 which represents agricultural crop and pasture land.

Table 3.6 shows the land surface load for nitrogen and phosphorus to the bay system using the original and the provisional EMC data. The land surface loads were reduced by 54% for total nitrogen and 60% for total phosphorus using the provisional EMC data compared to the original EMC data.

Table 3.6: Land Surface Loads for Total Nitrogen and Total Phosphorus to Bay System Using Original and Provisional EMC Values.

	Total Nitrogen		Total Phosphorus	
Segment	Original (Kg/d)	Provisional (Kg/d)	Original (Kg/d)	Provisional (Kg/d)
North	5021.27	2268.98	1283.48	498.46
Middle	1184.66	530.17	338.45	151.78
South	1412.24	669.7	356.19	144.38
Total	7618.17	3468.85	1978.12	794.62

Table 3.7 shows the total loads to the bay system for nitrogen and phosphorus using the original and the provisional EMC data. Total loads to the bay system were found by adding together the land surface loads, atmospheric loads, point source loads, and Nueces River Watershed loads as discussed in Section 2.4. The total load was reduced by 27% and 38% for total nitrogen and total phosphorus, respectively.

Table 3.7: Total Loads for Total Nitrogen and Total Phosphorus to Bay System Using Original and Provisional EMC Values.

	Total Nitrogen		Total Phosphorus	
Segment	Original (Kg/d)	Provisional (Kg/d)	Original (Kg/d)	Provisional (Kg/d)
North	6576.35	3824.06	1409.7	624.68
Middle	4025.84	3371.35	1203.25	1016.58
South	4566.3	3823.76	496.37	284.56
Total	15168.49	11019.17	3109.32	1925.82

In section 2.4.4, the atmospheric contribution to the total nitrogen land surface load was found to be 2,733 Kg/d. This is 35% of the original nitrogen load from land surface sources and 79% of the provisional nitrogen load from land surface sources. It is important to note that the atmospheric station is near Beeville, TX. Since the station is located inland, the atmosphere it samples is influenced by many sources such as volatilization of land surface loads, industries, etc. The mean annual concentration of total nitrogen present in the atmosphere is 1.10 mg/l (USGSNADP, 1997).

The water quality model was run using the provisional loads to the bay system, assuming conservative transport (no decay). As with the original data, the expected concentrations were again higher than the observed constituent concentrations because no decay is considered in the calculation. Table 3.8 and 3.9 compare the observed nutrient concentrations in the bay system to the original provisional concentrations. The concentrations in the north bay system dropped considerably when the provisional data was used. However, the concentrations in the middle and south bay systems stayed relatively the same.

Table 3.8: Total Nitrogen Concentrations in the Bay System Using Original and Provisional EMC Data Compared to the Observed Data.

Segment	Original exp (mg/l)	Provisional exp (mg/l)	obs (mg/l)
North	0.55	0.34	0.19
Middle	0.33	0.32	0.22
South	0.23	0.21	0.18

Table 3.9: Total Phosphorus Concentrations in the Bay System Using Original and Provisional EMC Data Compared to the Observed Data.

Segment	Original exp (mg/l)	Provisional exp (mg/l)	obs (mg/l)
North	0.20	0.12	0.08
Middle	0.15	0.13	0.13
South	0.09	0.08	0.07

The system was again broken into the north, middle and south portions to calculate the decay rates needed to match the calculated and the observed concentrations in the bay system. Table 3.10 shows the decay rates calculated for the original loads and the provisional loads to the bay system. The decay rates need for new total nitrogen and total phosphorus data are the smaller than the decay rates calculated for the original data in the north bay system. However, the decay rates in the middle and south bay segments are relatively the same for both the original and provisional loads. In all cases, the decay rates are within reasonable limits.

Table 3.10: Comparing Decay Rates for Total Nitrogen and Total Phosphorus Using Original and Provisional Data.

Constituent	Bay Segment	Decay Rate Original (/d)	Decay Rate Provisional (/d)
Total Nitrogen	North	0.030	0.017
	Middle	0.011	0.009
	South	0.024	0.021
	Average	0.022	0.016
Total Phosphorus	North	0.013	0.005
	Middle	0.004	0.003
	South	0.009	0.008
	Average	0.009	0.005

The provisional data calculations show that a reduction in the EMC value produces a reduction in the land surface load to the bay system. However, the total load to the system does not show as large of a reduction in load. The concentrations in the north bay system were reduced while the middle and south bay system concentrations did not show as much of a reduction. This is expected since the runoff gradient increases as you move North through the study area bringing along with it a larger load to the bay system. Since, the two agricultural runoff studies are being conducted in the south and middle portions of the study area, and the majority of the runoff and load is in the north portion of the study area, a runoff study should be conducted in that region in order to obtain a true EMC value representative of agricultural land use in the study region.

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4 CONCLUSIONS

For summary purposes, the overall bay system is subdivided geographically into three large bay systems, north, middle and south. The middle bay system refers to the Corpus Christi and Nueces Bays and the smaller bays flowing into them. The other two categories refer to the bays north and south of the middle bay system; Aransas/Copano Bays, and Baffin Bay/Laguna Madre, respectively. The study methodology can be broken down into three components: first, the water balance of inflow, outflow, precipitation and evaporation; second, the total loadings of constituents from point, land surface, atmospheric and the Nueces River Basin; and third, the mass balance of each constituent in the bay system. The constituent mass balance analysis includes a comparison of the observed and calculated concentrations. Finally, the possible uses of the model for management purposes are assessed.

(1) Water Balance

The mean annual precipitation ranges from approximately 600 mm/yr (24 in/yr) at the southern end of the study region to approximately 1000 mm/yr (40 in/yr) at the northern end. At the southern end less than 2% of the precipitation becomes runoff while at the northern end more than 10% becomes runoff. Therefore, the runoff gradient from South to North is much more pronounced than is the gradient of precipitation. The runoff averages less than 10 mm/yr (0.4 in/yr) in the south to more than 100 mm/yr (4 in/yr) in the north. The reason for the steep runoff gradient is that the larger precipitation in the north saturates the soil more frequently causing a greater percentage of the precipitation to become runoff than in the south.

The runoff into the bay system from the land surface in the study region totals 36 m^3/s. An additional 20 m^3/s enters the bay system from the Nueces River outflow from Lake Corpus Christi. At the northern boundary of the bay system, an inflow of 16 m^3/s is assumed to come from the very substantial runoff of the Guadalupe and San Antonio Rivers which flow into San Antonio Bay, this estimate being 20% of the mean annual gauged discharge of those two rivers. At the southern boundary of the bay system, it assumed that there is no inflow from the Lower Laguna Madre. The total inflow to the bay system is 72 m^3/s of which 56% enters the north bays, 34% the middle bays and 10% the southern bays.

The average direct precipitation onto the surface of the bays is approximately 800 mm/yr and the average evaporation is approximately double that figure, or 1600 mm/yr. The mean annual outflow from the bay system to the Gulf of Mexico is only 6 m^3/s, so the remainder of the inflow is lost by evaporation. Since very little tidal flushing occurs and the bay system is not frequently flushed by inflow from the land surface, the bay system acts as a large sink that absorbs most of the loads that come into it from the land surface, atmosphere, and point sources.

The calculations in this study are all based on mean annual conditions. In years of high flow, there is a correspondingly greater outflow to the Gulf, while in years of low flow there is a net inflow of water from the Gulf to the bay system to sustain the net evaporation from the bay system. The disparity between inflow and outflow is particularly acute in the south bay system, in part because the precipitation is lowest there and in part because the surface area of the south bay system is larger than the combined surface areas of the north and central bay systems. There is also no point of exchange of water with the Gulf of Mexico in the south bay region. Hence, the south bay system flushes itself much less frequently and less completely than do the north or the central bay systems.

(2) Total Loadings

Total load calculations were made for thirteen constituents: ammonium, nitrite plus nitrate, total nitrogen, total phosphorus, oil and grease, and eight metals (copper, cadmium, chromium, lead, zinc, iron, arsenic, and mercury). There are significant gaps in the available data, notably for point source loadings of ammonium and nitrite plus nitrate, non-point source loadings of ammonium, atmospheric loadings of many constituents, and sediment loads of all constituents. Because of these data limitations, results are discussed for six constituents with the most reliable data: total nitrogen, total phosphorus, oil and grease, copper, chromium, and zinc.

The nutrients nitrogen and phosphorus have a combined loading of approximately 18,100 kg/day, of which 15,000 kg/day is total nitrogen and 3,100 kg/day is total phosphorus. Oil and Grease have a total load of 2,800 kg/day. The loadings for the metal constituents are much smaller, approximately 30 kg/day for copper, 26 kg/day for chromium and 108 kg/day for zinc. For total phosphorus and the metals, from one half to two thirds of the loads are derived from the land surface. Oil and grease source are derived mostly from point sources. Atmospheric sources contribute about one third of the load of total nitrogen, about one half of this load comes from non-point sources on the land surface and one sixth from point sources. The atmospheric load in wet deposition over the land surface is approximately 35% of the land surface load for total nitrogen. For the metals, about one third of the load comes from point sources and two thirds from non-point sources. No sediment loads from the bay floor are included in these estimates, and atmospheric loads are also not accounted for in the case of phosphorus and the metal constituents.

(3) Water Quality

The impacts of the loadings on the bay system are evaluated using a water quality model, which takes into account advection, dispersion, and first order decay, but not detailed biological or chemical processes. The dispersion coefficients for each of the 20 bay segments within the three main bay segments were calibrated using salinity as a conservative constituent and held constant for all the other constituents. A set of mass balance calculations are first made assuming all constituents are conservative. A t-test was used to compare the predicted and observed concentrations in the bay segments. The t-test results showed that the conservative constituent assumption results in accurate prediction of observed concentrations of oil and grease, over-prediction of total nitrogen and phosphorus, and under-prediction of metals.

The long residence time of the three bay segments makes the concentrations sensitive to the overall gain and loss within the system. A second set of mass balance calculations was carried out to determine constituent decay. The decay rates take into account all the mechanisms (abiotic and biotic) of the gain and loss process. To reach the average observed concentrations in the bays for total nitrogen requires a decay rate of approximately 0.02 d^{-1}. This means that 2% of the mass of nitrogen is removed from the bay waters each day by decay processes. A similar computation for total phosphorus yields a decay rate of approximately 0.01 d^{-1}. These decay rates are reasonable when compared to corresponding values reported in the literature.

Using the conservative mass balance, the metals concentrations are under-predicted by a factor of three to four, which suggests that there are metals sources that are presently unaccounted for. Since the bays do not flush frequently, there exist long periods of time during which the metals are washed into the bays and deposited in bay sediments, creating a reservoir of metals in the sediments. A portion of these sediment metals may then re-enter the water column due to re-suspension and physical and chemical process. It is also possible that a reservoir of metals has been accumulated in the Bay sediments from industrial discharges of previous decades when wastewater discharge standards were not as stringent as they are now. The calculations suggest that this flux from the sediment reservoir may be the dominant control on the metals concentrations in the bay waters rather than current loadings from the land surface. It is also possible that the metal loadings from the other sources have been underestimated, either in the point sources, land surface or atmospheric loads. Clarifying this discrepancy in the mass balance for metals in the bay system requires further investigation.

The non-point source loadings for total nitrogen and total phosphorus are largely driven by runoff from agricultural lands. Ongoing field studies at the King Ranch and near Edroy, TX, suggest that the expected mean concentrations of nitrogen and phosphorus are less than half of those assumed originally in the mass balance study, whose expected mean concentration values were derived from data observed outside the Corpus Christi region. When other sources of nitrogen and phosphorus are also accounted for, the resulting reductions in total loads are about 27% from total nitrogen (from 15,000 Kg/d to 11,000 Kg/d) and about 28% for total phosphorus (from 3,1000 Kg/d to 1,900 Kg/d).

This study did not incorporate the City of Corpus Christi's water supply diversion from the Nueces River. It was assumed that all of the water leaving the Corpus Christi Dam enters the bay system. However, only fifteen percent of the discharge in the Nueces River is diverted to the City, with two thirds of that is discharged back to the bay system through the City's wastewater discharge (Ward, 1997). Overall, the constituent load from the Nueces River Basin upstream of Lake Corpus Christi has very little impact on the bay system.

(4) Model Uses and Developments

The original intent of the study was to determine the total loads and water quality to the Corpus Christi Bay System. However, the way that the GIS model is prepared, the study could be used for management purposes. By determining the source of load, different best management practices (BMP) can be analyzed in order to reduce that constituent load. The models can then be run again to calculate the reduction in loads due to the BMPs. This has been done in a parallel study concerned with water quality master planning being carried out for the City of Austin.

The Expected Mean Concentration (EMC) table, which links pollutant concentrations in runoff to land use, can be updated as new information is obtained. For example, once the Edroy and King Ranch studies are complete and the data is analyzed, the EMC table used in the model can be updated by changing the EMC values associated with the rangeland and agricultural land uses. The models can be run again in order to assess the change in loads due to the change in EMC values for these two land uses. The land use data employed in this study do not distinguish between improved pasture and row-crop agriculture. Once new land use are obtained, the land use files can be updated. The new land use would then be linked to the EMC table and the models could be run again to determine the change in loads due to the new land use data.

The model can be used to assess the loads in small scale studies in problem areas in the Corpus Christi Bay System. For example, the area draining into the Inner Harbor can be delineated and separated from the rest of the study area. The land surface and water quality models can be run on that area to determine the source of the loads ending up in the Inner Harbor. Different BMPs could be analyzed to determine the best solution to control the loads entering the receiving water in the Inner Harbor.

Since the study used mean annual values for flow, precipitation, and evaporation, the model results are a representation of total loads and the resulting water quality that occur during a year of normal weather. The model could be run using flow, precipitation, and evaporation representing flood and drought years in order to assess the water quality of the bay system during high and low flows. Also, the model could be run using the seasonal variations in flow, precipitation and evaporation by finding the average values for each of the seasons. The water quality for the seasonal variations could then be assessed.

Once new data is obtained, the model can be updated. For example, there are separate studies being done in the CCBNEP for atmospheric deposition. Once these studies are complete and the data is analyzed, the new loadings can be entered into the water quality model and the new equilibrium constituent concentrations can be calculated. This same calculation can be done once new load information is obtained for sediment fluxes, point sources, and land surface EMC data.

APPENDIX A: Data Description

The National Estuary Program was established through the Federal Water Quality Act of 1987 to identify and protect significant estuaries in our nation. Twenty-eight estuaries are now funded and administered by the United States Environmental Protection Agency (EPA). Corpus Christi Bay was formally nominated for the program in 1992 by Governor Ann Richards.

The Corpus Christi Bay National Estuary Program is designed to coordinate the activities of all regulatory authorities along with input from the non-government sector. The project includes 75 miles of south-central Texas coastline; 550 square miles of water including all bays and saltwater bayous, Aransas Bay, Corpus Christi Bay, Baffin Bay, and Upper Laguna Madre; twelve counties including McMullen, Live Oak, Bee, Refugio, Aransas, San Patrico, Jim Wells, Duval, Nueces, Kleberg, Kenedy and Brooks; and includes Padre Island.

The boundary for the study area was defined from the political boundaries and eventually the watershed boundaries. It was also decided to use Lake Corpus Christi as a point source to reduce the study area.

Figure 1.1, which was shown in Chapter 1 of this report, shows where the study region is located.

*** Digital Database Description**

To complete the total loadings project, the study uses raster and vector data to describe the landscape. Raster data are also termed grids as the data set is stored in a uniform rectangular array. Vector data are also known as coverages and contain points, lines, and/or polygons as the geographic features. Point coverages describe features located by a single point or a set of points. Geographic features in a line coverage are defined by a series of line segments with nodes specifying the starting and ending points of each line. Geographic features in a polygon coverage are formed by a series of connected lines. The data sets also have tables associated with the coverage or grid that present descriptive data about the geographic feature which they represent (Environmental System Research Institute, 1990).

*** Map Projection**

Because of the different data sources and the different map projections, in which each data source is found, a standard map projection is needed. Spatial data sets are also found in various map scales and in different coordinate systems. Arc/Info allows raster and vector data to be viewed together as long as they have a common datum, map projection and coordinate system. Arc/Info converts the data from one map projection to another.

The Texas State Mapping System (TSMS) coordinate system is used for this study. TSMS uses a Lambert conformal conic projection which preserves shape. However, this study uses a variation of the TSMS, an Albers equal-area projection. The equal-area projection is preferred for the study because of the calculations of water and mass balances over a region which require preserving the correct earth surface area in the map projection, which the Lambert projection does not do (Snyder, 1987).

*** Establishing a Digital Database**

To begin the total loadings study for the CCBNEP a digital database was established. This section of the report describes each of the databases needed for the study, as well as the location of the data source. The steps needed for the database establishment are provided along with a short narrative describing the process or information gathered. The actual Arc/Info and ArcView commands are listed when possible. When the step is more efficiently completed using an automated program, such as Avenue scripts and Arc Macro Language (AML) programs, the scripts or programs are listed in a separate Appendix which can be obtained from the Corpus Christi National Estuary Program Office or in the report itself.

*** Political Boundaries**

The twelve counties involved in the CCBNEP are McMullen, Live Oak, Bee, Refugio, Aransas, San Patricio, Jim Wells, Duval, Nueces, Kleberg, Kenedy and Brooks. For a rough estimate of the amount of land within the study area, the political boundaries were used to begin defining the study area. The political boundaries are obtained from a database established at the Center for Research in Water Resources (CRWR).

The counties involved in the study were selected using the Arc command Reselect.

Arc: **reselect counties count**
>: **res name = "MCMULLEN"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "LIVE OAK"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "BEE"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "REFUGIO"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "ARANSAS"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "SAN PATRICIO"**

>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "JIM WELLS"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "DUVAL"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "NUECES"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "KLEBERG"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "KENEDY"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares name = "BROOKS"**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **n**

The coverage file with the political boundaries is projected from a LAMBERT projection to an ALBERS projection. The ALBERS projection is used in the Texas State Mapping System. The projection file used is written in an Arc Macro Language (AML) file called lamtsms.prj and is presented below.

LAMTSMS.PRJ

Input
projection LAMBERT
units meters
datum NAD83
parameters
34 00 0.000
27 25 0.000
-100 00 0.000
31 10 0.000

```
1000000.00000
1000000.00000
output
projection ALBERS
units meters
datum NAD83
parameters
27 25 00
34 55 00
-100 00 00
31 10 00
1000000.0
1000000.0
End
```

The Arc command Project is used to project the file to the Texas State Mapping System. Once the projection is done, the Arc command Build must be used to establish polygon topology.

Arc: **project cover count countt lamtsms.prj**
Arc: **build countt poly**

Figure A.1 shows the twelve counties involved in the CCBNEP study area.

*** Hydrologic Unit Codes (HUC)**

Hydrologic Unit Codes (HUC) boundaries are a subdivision of the United States made by the United States Geological Survey (USGS), to show major and minor river basins. Hydrologic Unit Maps divide the United States into 21 major hydrologic regions, 222 subregions, 352 accounting units, and 2,100 cataloging units. The major basins within the United States have a 2 digit HUC boundary code, and smaller subbasins have 4, 6, and 8 digit codes (USGS, 1996). The USGS 1:250,000-scale HUC gives approximate drainage basin boundaries for this study. The HUC files were obtained from a database established at CRWR. The data files can be obtained from the Internet site: **http://nsdi.er.usgs.gov/nsdi/products/huc.html**

The HUC numbers were found using the identification icon in ArcView. The HUCs in the study area were selected using the Arc command Reselect.

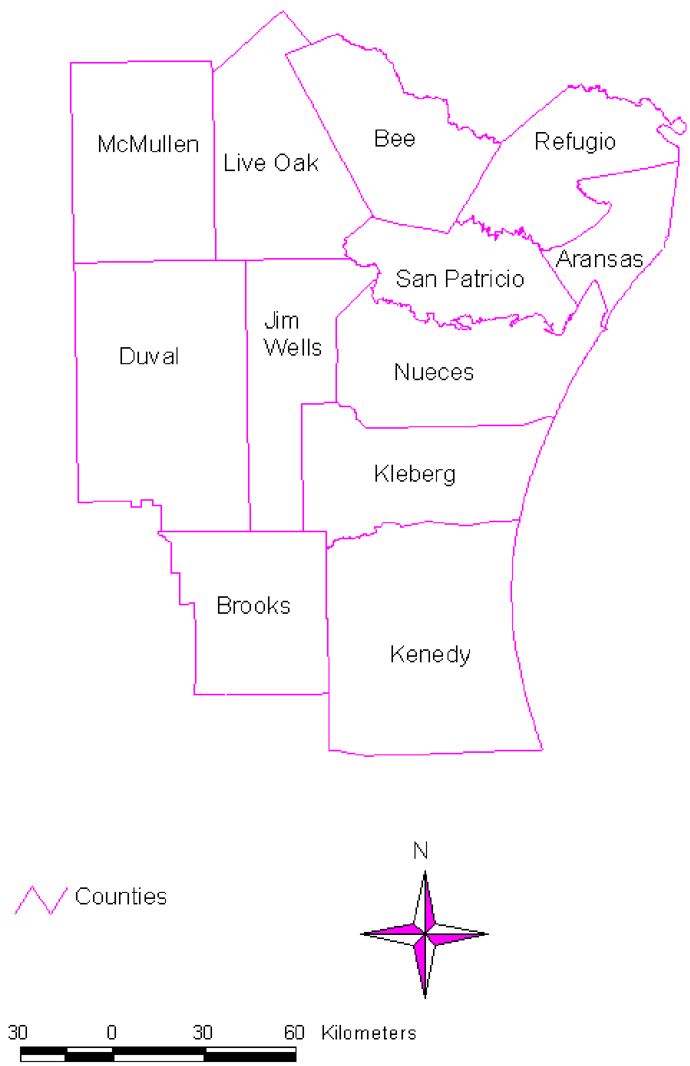

Figure A.1: Counties Participating in the CCBNEP.

Arc: **reselect huc250 cchuc**
>: **res huc >= 12110201**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **res huc <= 12110207**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **ares huc >= 12100404**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **res huc >= 12100405**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **res huc >= 12100406**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **res huc >= 12100407**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **y**
>: **res huc >= 12111011**
>:~
Do you wish to re-enter expression? (y/n) **n**
Do you wish to enter another expression? (y/n) **n**

The HUC cover needs to be projected from ALBERS projection with datum NAD27 to an ALBERS projection with datum NAD28. The ALBERS projection with datum NAD28 is used in the Texas State Mapping System. The projection file used is written in a file called **huctsms.prj** and is shown below.

HUCTSMS.PRJ

Input
projection ALBERS
units meters
datum NAD27
parameters
29 30 0.000
45 30 0.000

-96 00 0.000
23 00 0.000
0.00000
0.00000
output
projection ALBERS
units meters
datum NAD83
parameters
27 25 0.000
34 55 0.000
-100 00 0.000
31 00 0.000
1000000.00000
1000000.00000
End

The final projected HUC file must then be built to establish polygon topology. This can be done using the Arc command Project and the Arc command Build.

Arc: **project cover cchuc cchuctsms huctsms.prj**
Arc: **build cchuctsms poly**

Figure A.2 shows the HUC files along with the names and numbers of each of the HUCs.

*** Digital Elevation Model (DEM)**

Digital elevation models are a sampled array of elevations for ground positions. The maps are distributed by the USGS. This study used 1-degree DEMs which are also called 3-second or 1:250,000 scale DEM data (USGS, 1996). The nine compressed DEM files which are needed for the study area are Beeville-e, Beeville- w, Crystal_City-e, Corpus_Christi-e, Corpus_Christi-w, Laredo-e, Laredo-w, Port_Isabel-w, and McAllen-e. These files were downloaded via the Internet from the USGS Internet site: **http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html**

Once the Internet page is accessed, click on the area of interest. A magnified view of the area will appear. Again, click on the desired area of interest. Each map sheet has prompts for the uncompressed and compressed ftp sites. Click on the uncompressed DEM file. Once the file is downloaded use the **Save-as** command in the pulldown menu **File** of the web browser to save the file to the desired directory.

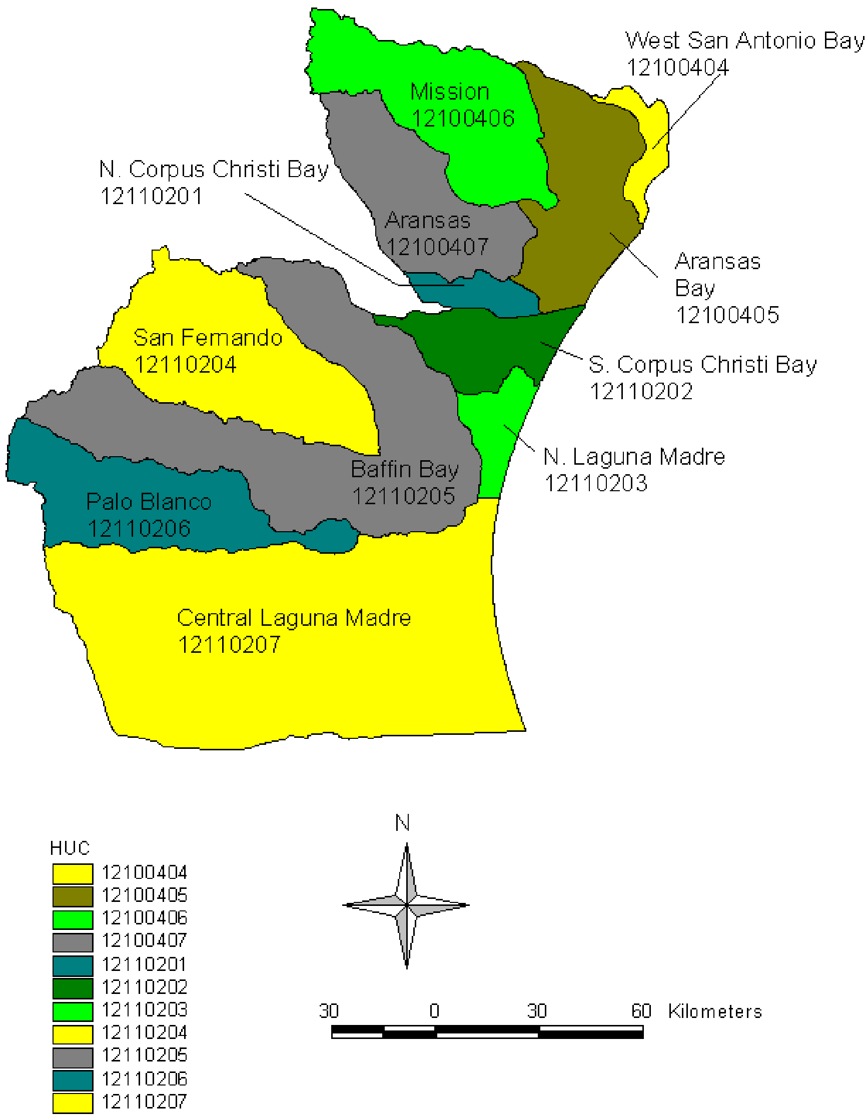

Figure A.2: Hydrologic Unit Code Boundaries within the CCBNEP Study Area.

*** Converting Files to Arc/Info Format**

The DEM files that were downloaded need to be converted into Arc/Info format. The following commands rearrange the block sizes for Arc/Info processing.

$ **dd if=beeville-e of=beee.dem cbs=1024 conv=unblock**

This should be done for each of the files which are saved.

Next, the files need to be converted to Arc/Info format. This can be done by starting Arc and typing the following:

Arc: **demlattice beee.dem beeedem usgs**

This produces an Arc/Info grid called **beeedem** which contains the raw DEM data
in geographic coordinates.

*** Merging the Grids**

The nine grids are then merged to one large grid which covers the entire area.

Arc: **grid**
Grid: **corpus2 = merge (beeedem, beewdem, ccedem, cowdem, coedem, laedem, lawdem, piwdem, maedem)**

The nine grids are merged to form the large grid called **corpus2**. The grid can be viewed either by ArcView or the by using Grid display. The following commands enable the reader to view the merged grid via Grid display.

Grid: **display 9999**
Grid: **mape corpus2**
Grid: **gridpaint corpus2 value linear nowrap gray**

Next, the DEM grid needs to be projected from GEOGRAPHIC projection to an ALBERS projection. The WGS84 datum is used in the Texas State Mapping System. This datum is functionally equivalent to the NAD83 datum used for the previous data sets. The projection file used is written in an AML file called **demtsms.prj** and is shown below.

DEMTSMS.PRJ

Input
projection GEOGRAPHIC
datum WGS72

units ds
parameters
output
projection ALBERS
datum WGS84
units meters
parameters
27 25 00
34 55 00
-100 00 00
31 10 0.000
1000000.0
1000000.0
End

The Arc projection command is shown below.

Arc: **project grid corpus2 corptsms demtsms.prj**

*** Reducing the DEM to the Study Area**

The DEM needs to be clipped to a smaller size to fit the study area. This is accomplished by making a 5000 m buffer from the projected HUC file. Next, this coverage is used to clip the DEM file to a more workable size. The buffer needs to include more than the study area to ensure all the drainage into the study area is encompassed.

Arc: **buffer cchuc2tsms tsmsbuff # # 5000 # poly flat #**
Arc: **grid**
Grid: **display 9999**
Grid: **mape tsmsbuff**
Grid: **arcs tsmsbuff**
Grid: **gridpaint corptsms value linear nowrap gray**
Grid: **setwindow tsmsbuff corptsms**
Grid: **corp2tsms = corptsms**

Figure A.3 shows the DEM of the study area within the buffered HUC boundaries.

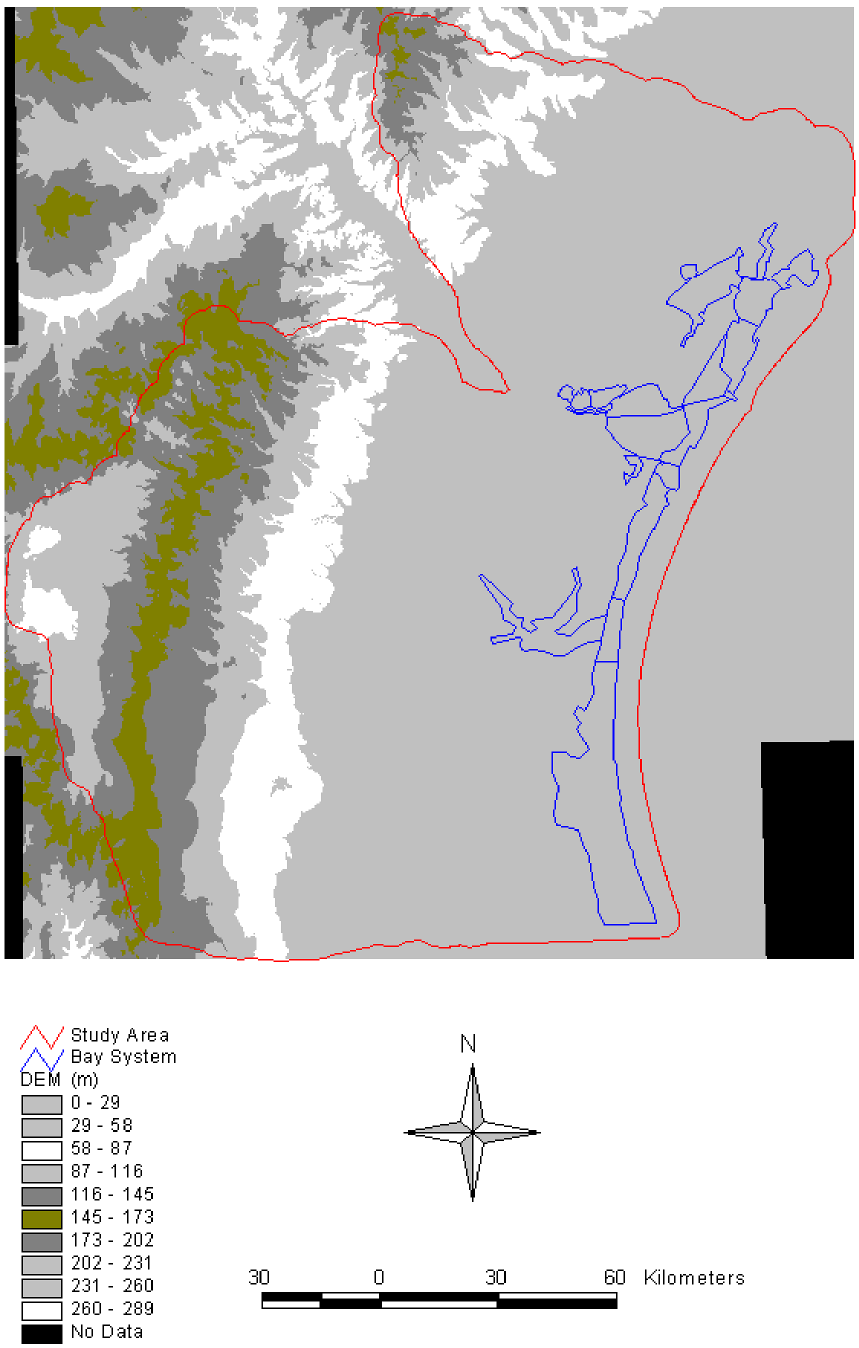

Figure A.3: Digital Elevation Model for the CCBNEP Study Area.

*** USGS Land Use Data**

Land use data files describe the vegetation, water, natural surface, and cultural features on the land surface (USGS, 1996). The land use data was obtained from the Texas Natural Research Information System's Internet Site: **http://www.tnris.state.tx.us/pub/GIS/topography/LULC/**. Once at the site, click on the download prompt, followed by clicking on the index of files prompt. Finally, the land use prompt is selected, with the 250k files being selected last.

The land use files for the map sheets **Beeville**, **McAllen**, **Corpus Christi**, **Crystal City** and **Laredo** were downloaded in export format (e.00).

The land use/land cover files use the Anderson Land Use Code classification system, in which land use types are broken into 9 basic categories with the second digit distinguishing subcategories of these principal categories.

1 = urban
2 = agriculture
3 = range land
4 = forest
5 = water
6 = wetlands
7 = barren
8 = tundra
9 = ice and snow
Subcategories
11 = urban residential
12 = urban commercial
13 = urban industrial
etc.

This land use classification was made in the late 1970's, and the land use has obviously changed in the years since, particularly urban areas have grown in size. However, the land use/land cover files are still the standard land use classification of the United States as a whole. Certain areas of the United States have developed updated land use maps, for example the area surrounding Corpus Christi Bay which was described with a separate land use coverage, as described in the **Updating Land Use** section of Appendix A.

*** Converting the Files to Arc/Info Format**

The land use files need to be imported into a format which Arc/Info can read. Once this is done, the Arc Build command needs to be used to build polygon, node and line topology. Before the build command can be used, it is a good idea to use the Clean command to trim extraneous arcs and to join arcs which are within the fuzzy tolerance.

Arc: **import cover beeville.e00 lubee**
Arc: **clean lubee**
Arc: **build lubee**

Do this for all the files that are downloaded from the Texas Natural Resource Information System's Internet Site. The files also need to be dissolved. This eliminates any overlaying lines in the maps.

Arc: **dissolve lubee lubeed landuse-id poly**

The maps then need to be edited using ArcEdit. This is due to the lines and nodes which do not line up due to map making errors. The command to use in ArcEdit is called Edgematch. Use an edit coverage and a snap coverage. Nodes are used as the edit feature for both coverages. The procedure is done manually using the Add Automatically and Delete Many commands.

*** Joining Land Use Maps**

Once the maps are edited, they must be joined together.

Arc: **mapjoin lucorp**
Enter the 1st coverage: **lubeed**
Enter the 2nd coverage: **lucod**
Enter the 3rd coverage: **luccd**
Enter the 4th coverage: **lula**
Enter the 5th coverage: **luma**
Enter the 6th coverage: **~**
Done entering coverage names?(y/n): **y**
Do you wish to use the above coverages?(y/n): **y**

The land use maps need to be cleaned once the maps are joined to clip off extraneous arcs. They also needed to have node, line and polygon topology built. Finally, the Arc command Dissolve needs to be used on the big map to rid the map of overlapping arcs.

Arc: **clean lucorp lucorp # # line**
Arc: **clean lucorp lucorp # # poly**
Arc: **build lucorp node**
Arc: **build lucorp line**
Arc: **build lucorp poly**
Arc: **dissolve lucorp lucorpd landuse poly**

The polygon coverage needs to be projected from LAMBERT projection to an ALBERS projection. The projection file used is written in an AML file called **lamtsms.prj** and was shown earlier in the report in the **Political Boundaries** section of Appendix A.

Arc: **project cover lucorpd lucorptsms lamtsms.prj**

The land use map was clipped using the buffered HUC file discussed in the **Hydrologic Unit Code (HUC)** section of Appendix A. This is done to reduce the file to a more usable size.

Arc: **clip lucorptsms tsmsbuff landuse poly #**

*** Updating Land Use**

The patch of unknown land use which lies within the study region, south of Baffin Bay and west of the South Laguna Madre was filled in manually using ArcEdit. The unknown portion was assigned to a land use classification of range land.

Figure A.4 shows the range land polygon added to the land use file.

An updated land use file became available later in the study. The Texas Park and Wildlife prepared the files (Hinson, 1995). This new land use file covered approximately 19,000 Km^2 surrounding Corpus Christi Bay and was added to the original land use file. The land use files were downloaded from the TNRIS Internet site**:** **http://www.tnris.state.tx.us/pub/GIS/wetlands/aquatic/cwh/corpus/**. All 71 land use files in the directory were downloaded in a .e00.z format

Unlike the original land use files, the new land use files were grids rather than coverages. The files were unzipped using the Guzip command and imported using the Arc command Import.

$ **gunzip -d agua.e00.z**
$ **arc**
Arc: **import grid agua.e00 agua**
:
$ **gunzip -d yarpoee.e00.z**
$ **arc**
Arc: **import grid yarpoee.e00 yarpoee**

The files were merged into six files and then those six files were merged into one large file.

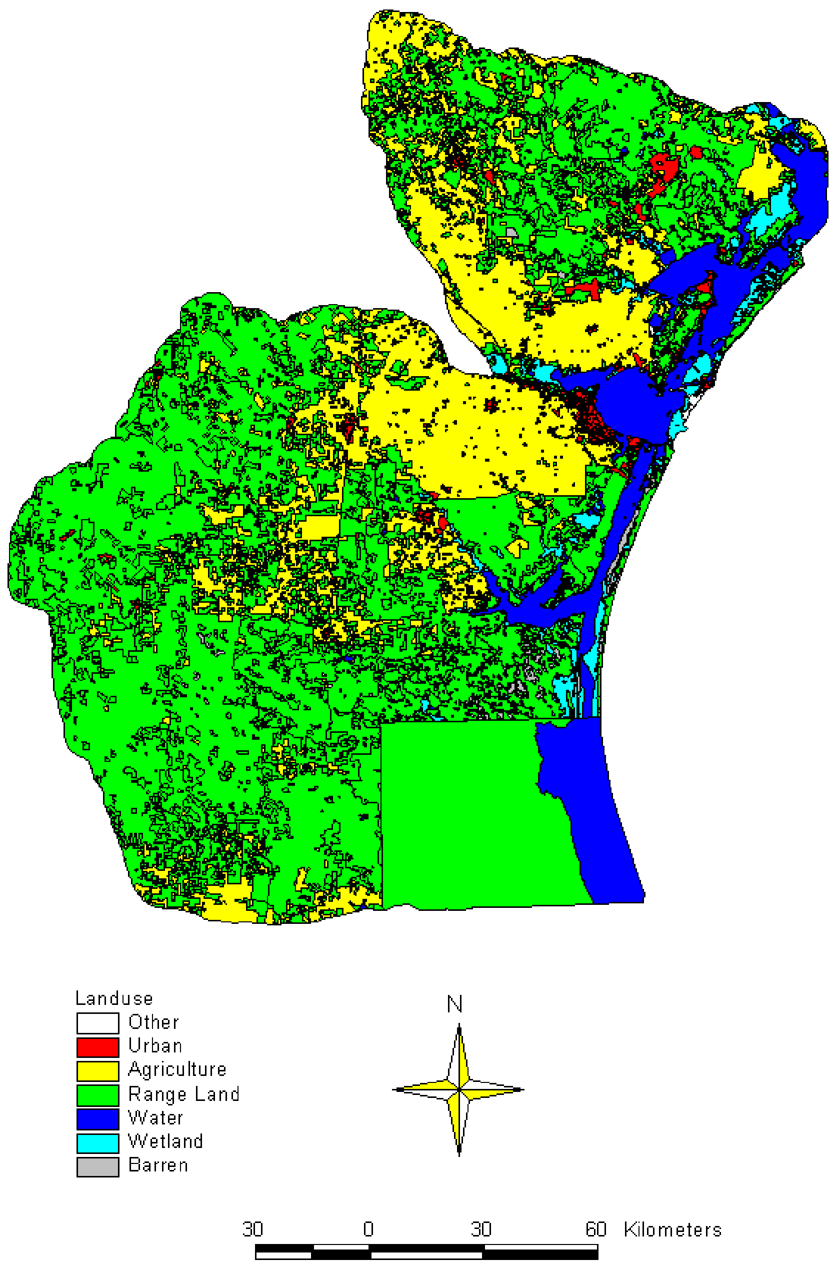

Figure A.4: Land Use in the CCBNEP Study Area with the Missing Data Area Being Assigned Range Land.

Arc: **grid**
Grid: **nland1 = merge (agua, alices, allyns, anna, aranpass, banq, bayside, bense, bhead, chapman, cinw, cinwoee)**
Grid: **nland2 = merge (cisw, conc, corp, cranell, dinero, drisce, driscw, edroy, ella, escon, estes, greg)**
Grid: **nland3 = merge (kinge, kingnw, kingw, kleberg, lamar, laureles, mathis, mesq, mission, odem, orange, osone)**
Grid: **nland4 = merge (osonw, paisano, panth, papa, petrne, pita, por, portland, premonte, prtaran, prtingl, rbeach)**
Grid: **nland5 = merge (rbne, rbnw, ricardo, rinc, riviera, robs, rock, sandia, sanpat, sbi, sbinw, sbise)**
Grid: **nland6 = merge (sintone, sintonw, stcb, stcbse, stcbsw, taft, tynan, woods, wsinton, yarp, yarpoee)**
Grid: **nland = merge (nland1, nland2, nland3, nland4, nland5, nland6)**

The final merged grid needs to be projected from UNIVERSAL TRANSVERSE MERCATOR projection to an ALBERS projection. The projection file used is written in an AML file called **utmtex.prj** and is shown below.

UTMTEX.PRJ

```
input
projection UTM
units meters
datum NAD83
zone 14
parameters
output
projection ALBERS
units meters
datum NAD83
parameters
27 25 00
34 55 00
-100 00 00
31 10 00
1000000.0
1000000.0
end
```

Arc: **project cover nland newland utmtex.prj**

The new land use files use a different land use classification numbering system that the original files (Hinson, 1995). The **newland** gridvalue field was manually converted to reflect the Anderson Land Use System. The ArcView pulldown menu Edit was used to begin editing the **newland** grid attribute table. A new field was added called landuse. The following list shows the gridvalue number from the new land use file and the converted Anderson Land Use System's classification and number.

Updated Land Use Gridvalue	Type of Land Use	Anderson Land Use Number
0	no data	0
1	commercial	12
2	commercial	12
3	industrial	13
4	residential	11
5	residential	11
6-9	agricultural	20
10-27	range land	30
28-30	barren	70
31-70	wetlands	60
71-79	water	50

The part of the **newland** grid which contained zero as its grid cell value was calculated to equal the original land use file. This was done by first converting the original land use files to grids using the Arc command Polygrid. Next, the Grid command Con was used to redefine the zero value grid cells to the old land use cell values.

Arc: **grid**
Grid: **biglandg = polygrid (lucorptsms, landuse, #, #, 100)**
Grid: **landuseg = polygrid (landuse, landuse, #, #, 100)**
Grid: **newlandbg = merge (biglandg, landuseg)**
Grid: **newland2 = con (newland == 0, biglandg, newland)**
Grid: **newlandbg2 = merge (newlandbg, newland2)**

The new land use grid needs to be clipped to the study area size for a more manageable file. The command uses the delineated watershed grid for the study area which is discussed in Chapter 2. This states that the new land use file equals no data if the file lies outside of the study area, but equals the land use grid value if inside the study region.

Grid: **landuseg2 = con (big1 == 1, newlandg2, big1)**

The newly merged land use grid is converted to a polygon coverage and cleaned.

Grid: **landuse2 = gridpoly (landuseg2)**
Grid: **q**
Arc: **clean landuse2**

Once this is completed, the **landuse2** attribute table is opened in ArcView, and a new field called landuse is added. The new landuse field is calculated to equal the gridvalue field using the ArcView pulldown menu **Field** with the **Calculate** option.

Figure A.5 shows the updated land use within the study region.

*** USGS Stream Gauges**

The stream gauge locations in the study area can be obtained from the Texas USGS Internet site:
http://txwww.cr.usgs.gov/cgi-bin/nwis1_server

At the web page, click on the item that will allow data to be viewed by an Index of Gauging by HUC (140kb). From this page, download the stream gauges in each of the HUCs associated with the project which are West San Antonio Bay, Aransas Bay, South Corpus Christi Bay, North Laguna Madre, Baffin Bay, Central Laguna Madre, Palo Blanco, San Fernando, and North Corpus Christi Bay.

Table A.1 shows the HUC number which the stream gauge is located, the stream gauge number, the stream gauge location, the latitude and longitude, and the dates which data is available. (TXUSGS, 1996).

*** Create a Stream Gauge Coverage**

Once the stream gauge files are downloaded, a data file needs to made using the text editor listing the stream gauge latitude and longitude in decimal degree format. This can be done using the following formula:

$$DD = D + Min/60 + Sec/3600$$

The following is the beginning of the data file created for the study area. The file is called **lonlat.dat**.

```
1 -98.1356 27.2642
2 -98.0333 27.7722
:
```

Note that West longitude is treated as negative in decimal degree format.

Table A.1: Data for the Stream Gauges in the CCBNEP Study Region.

HUC	Sta	Location	Latitude	Longitude	Date
12110205	8212400	Los Omos Creek near Falfurrias, TX	27 15 51	098 08 08	Jan 1, 1967-Sept 30, 1983
12110204	8211900	San Fernando Creek at Alice, TX	27 46 20	098 02 00	Jan 1, 1965-Mar 5, 1987
	8211800	San Diego Creek at Alice, TX	27 45 59	098 04 31	Oct 10, 1963-Oct 1, 1989
12110202	8211520	Oso Creek at Corpus Christi, TX	27 42 40	097 30 06	Sept 9, 1972-present
12100407	8189800	Chiltipon Creek at Sinton, TX	28 02 48	097 30 13	July 23, 1970-Apr, 06, 1987
					Aug 4, 1987-Sept 4, 1991
	8189700	Aransas River near Skidmore, TX	28 16 56	097 37 14	Apr 1 , 1964-present
12100406	8189500	Mission River at Refugio, TX	28 17 30	097 16 44	July 1, 1939-present
	8189300	Medio Creek near Beeville,TX	28 28 58	097 39 23	Mar 1, 1962-Sept 17, 1977
12100405	8189200	Copano Creek near Refugio, TX	28 18 12	097 06 44	June 17, 1970-present

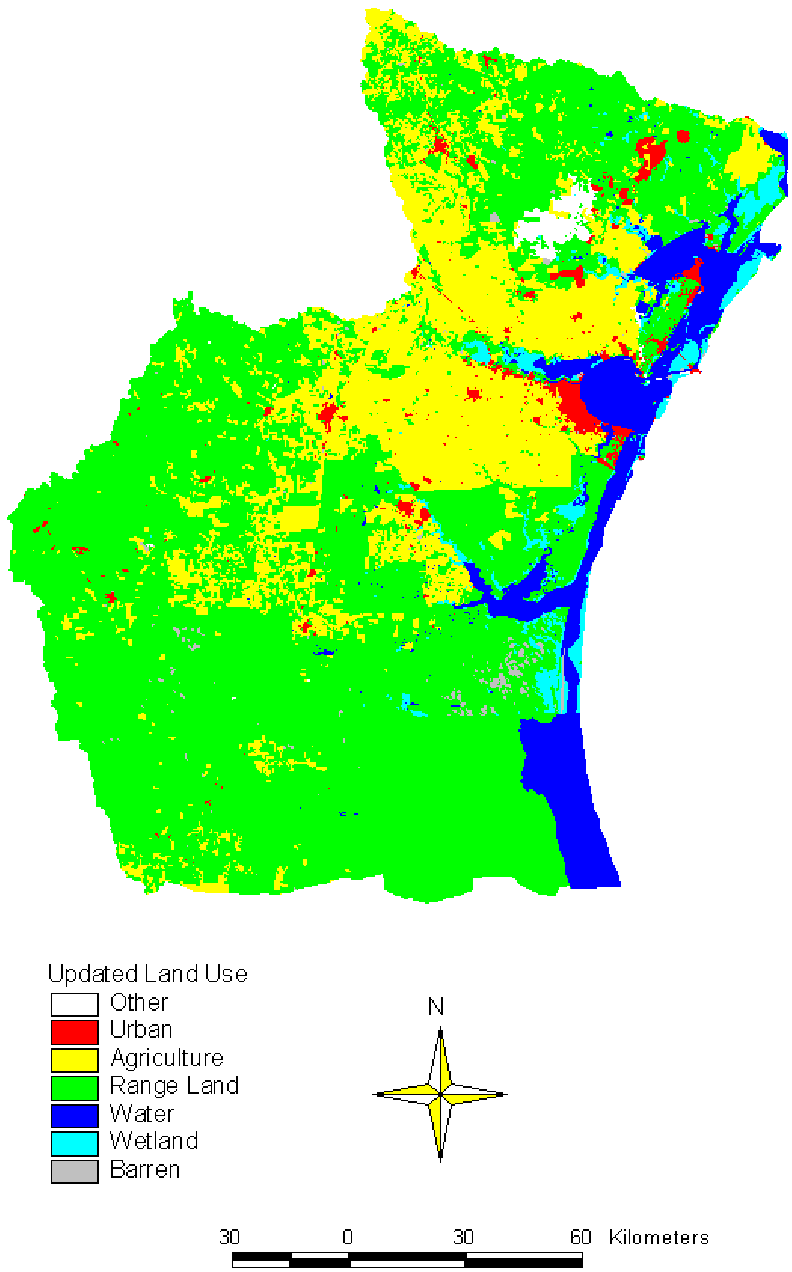

Figure A.5: Updated Land Use in the CCBNEP Study Region.

A point coverage of the digital coordinate data is built using the ARC/Info Generate command. The **lonlat.dat** file is specified as the input and points as the geographic feature type. Once the coverage is created, point topology is established through the Build command. The digital coordinate values are added as attributes to each point by using the Addxy command.

Arc: **generate station**
Generate: **input lonlat.dat**
Generate: **points**
Creating points with coordinates loaded from lonlat.dat
Generate: **quit**
Externally BND and TIC..
Arc: **build station points**
Arc: **addxy station**

A second data file is created for the station name and number. The file was called **statname.dat**. The beginning of this file is shown below:

1 08212400 Los_Omos
2 08211900 San_Fernando
:

The following commands are used to create an attribute table for the stream gauge point coverage.

Arc: **tables**
Enter Command: **define attribut.dat**
1
Item name: **stations-id**
Item width: **4**
Item Output Width: **4**
Item Type: **i**
5
Item Name: **stat-num**
Item width: **10**
Item Output Width: **10**
Item Type: **c**
15
Item Name: **stat-name**
Item width: **15 7**
Item Output Width: **15**
Item Type: **c**
Item Name:
Enter Command: **add from statname.dat**

Finally, the attribute tables need to be joined to the point coverage, and the point coverage needs to be projected from GEOGRAPHIC projection to an ALBERS projection. The projection file used is written in an AML file called **geotsms.prj** and is shown below.

GEOTSMS.PRJ

```
Input
projection GEOGRAPHIC
units dd
datum NAD83
spheroid GRS1980
parameters
output
projection ALBERS
units meters
datum NAD83
spheroid GRS1980
parameters
27 25 00
34 55 00
-100 00 00
31 10 00
1000000.0
1000000.0
end
```

Arc: **Joinitem stations.pat attribut.dat stations.pat stations-id stations-id**
Arc: **project cover stations corpgages geotsms.prj**

Figure A.6 shows the nine stream gauges within the CCBNEP study area.

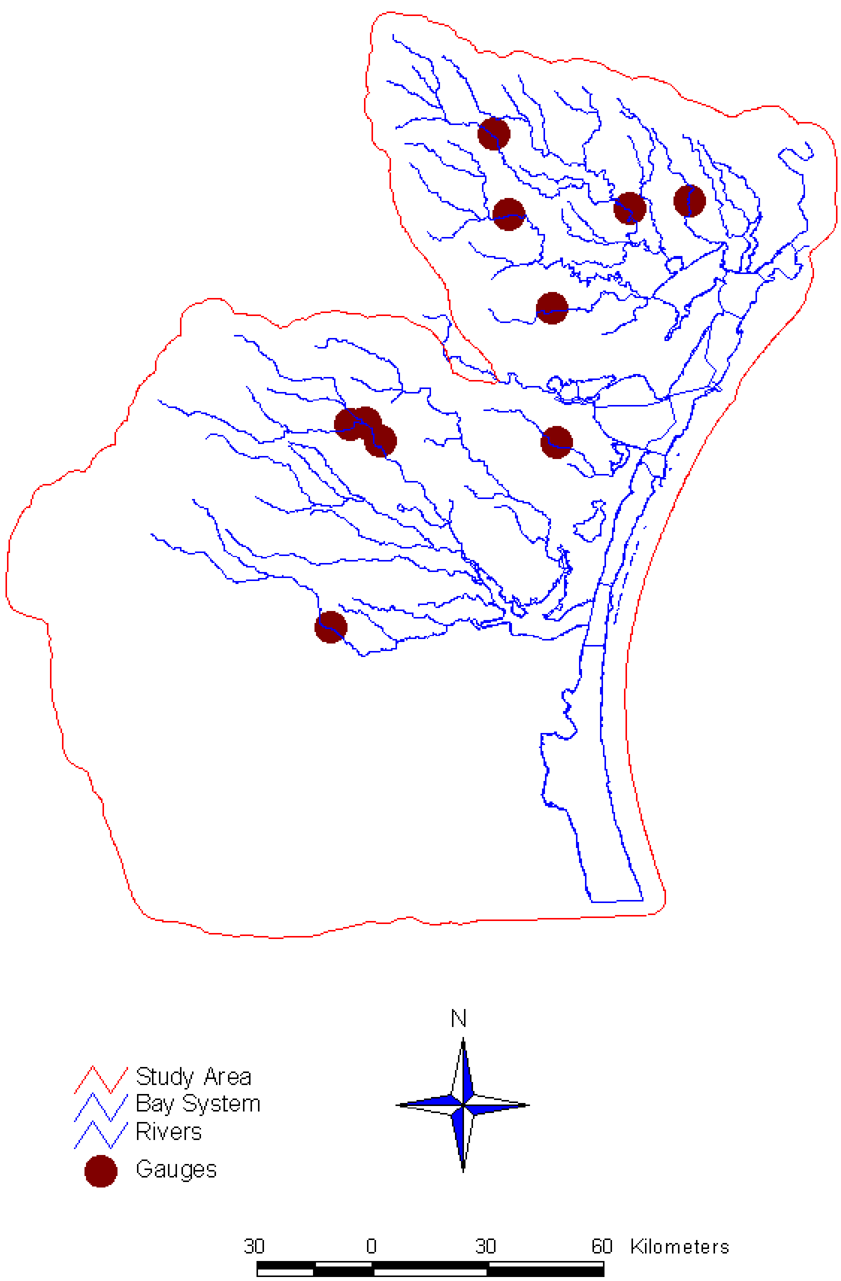

Figure A.6: Stream Gauges in the CCBNEP Study Area.

*** Precipitation Data**

The precipitation grid was obtained from an Oregon State University anonymous ftp site: **fsl.orst.edu**. The precipitation grid was originally projected to the Texas State Mapping System which is an Albers projection for the *Spatial Water Balance of Texas* (Reed, 1996).

The precipitation data from Oregon State University is a mean annual precipitation grid for the United States. The grid was developed using an interpolation process called PRISM, and is verified by consultation with State Climatologists. The data is the years 1961 to 1990 (Oregon, 1996). Figure A.7 shows the precipitation grid downloaded from Oregon State University.

No coordinate system was defined for the precipitation grid. However, the X and Y boundary values shown indicate that the precipitation grid is in a geographic projection with the decimal degrees specified as the units of measure. In order to select a smaller portion of the grid the buffered HUC file is projected from the ALBERS projection used in the Texas State Mapping System to the GEOGRAPHIC projection. This newly projected file, **geobuff**, is used to reduce the precipitation file to a more usable size.

The projection file **tsmsgeo.prj** is listed below:

TSMSGEO.PRJ

```
input
projection ALBERS
units meters
datum NAD83
spheroid GRS1980
parameters
27 25 00
34 55 00
-100 00 00
31 10 00
1000000.0
1000000.0
output
projection GEOGRAPHIC
units dd
datum NAD83
spheroid GRS1980
parameter
end
```

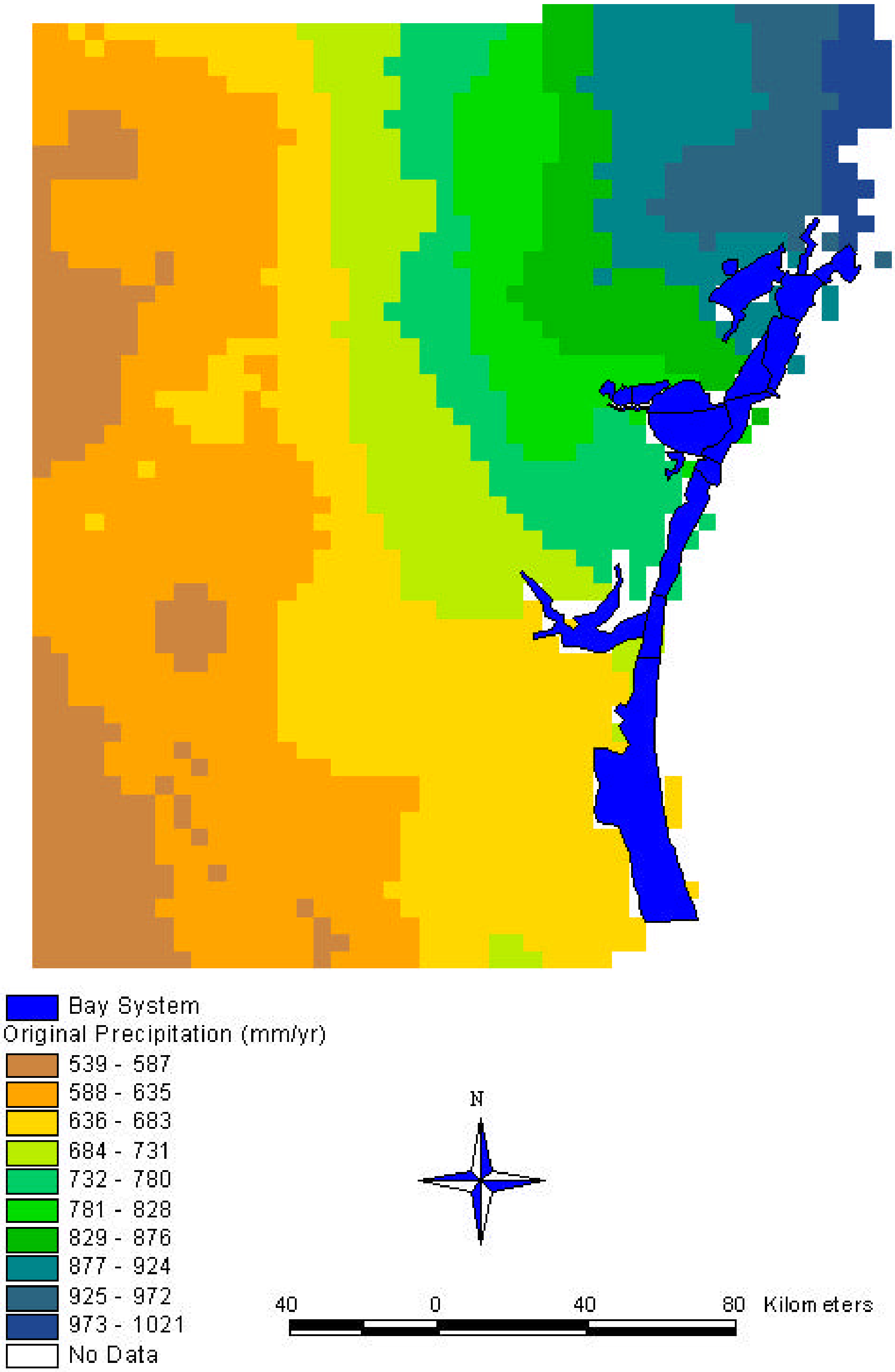

Figure A.7: Original Precipitation Used in the Study.

Arc: **project cover tsmsbuff geobuff tsmsgeo.prj**

The Grid Setwindow command is used to reduce the analysis window to the mapextent of the buffered coverage. A smaller precipitation grid which
contains the values from the large precipitation grid is defined within this window. The smaller grid is then projected to the ALBERS projection from the
GEOGRAPHIC projection using the **demtsms.prj** projection file. This file was listed in **Digital Elevation Model (DEM)** section of Appendix A.

Arc: **grid**
Grid: **display 9999**
Grid: **mape geobuff**
Grid: **linecolor 3**
Grid: **arcs geobuff**
Grid: **setwindow geobuff p_ann**
Grid: **precip = p_ann**
Arc: **project grid precip precip2 geotsms.prj**

The precipitation grid covered the land surface over the study area, however much of the bay system did not have precipitation data. A series of Grid commands are used to fill in the missing data. The Setcell command is used to set the cell size to equal the original precipitation grid. Setwindow is used to decrease the size of the area of the precipitation grid to be analyzed. The Grid command Gridpoint converted the precipitation grid to a point coverage, which is used with the Trend command to create the new grid. The Trend command performs a trend interpolation on a point coverage and calculates the new grid. The inputs are a point coverage, name of the item to be used for the interpolation, the order of the equation to be used for the analysis, the cell size, and the extent of the analysis. The Setwindow and Setcell commands determine the extent of the analysis and the cell size of the new grid. A second order equation is specified while using the Trend function. The point coverage was calculated using the Gridpoint command where the grid value was named "rain". The new precipitation grid and the original precipitation grid are merged together to create a new grid with the no data cells of the original grid filled in with the new grid. The original precipitation grid was displayed in the Grid Display window before the calculations were begun.

$: **arc**
Arc: **grid**
Grid: **setcell precip2**
Grid: **setwindow precip2**
Grid: **mape precip2**
Grid: **gridpaint precip2 value linear nowrap gray**
Grid: **setwindow ***
Define box
Grid: **precip3 = precip2**
Grid: **precippnt = gridpoint (precip3, rain)**

Grid: **precipgrid = trend (precippnt, rain, 2, linear, 100, #)**

Coeff #	*coeff*
0	*-306.535*
1	*0.003*
2	*-0.007*
3	*0.000*
4	*0.000*
5	*0.000*

RMS Error = 25.002
Chi-square = 507561.475

Grid: **setcell precip2**
Grid: **setwindow precip2**
Grid: **precipmerge = merge (precip2, precipgrid)**

Figure A.8 shows the precipitation trend grid, and Figure A.9 shows the merged precipitation grids. This process does not effect any of the cells in the original precipitation grid, but fills in the missing cells over the bays and barrier islands with reasonable precipitation values.

*** Digital Line Graphs (DLG)**

The 1:100,000 DLG files include hydrologic features such as stream networks, standing water, and coastlines. The USGS also produces DLG files for roads, railways, and pipelines (USGS, 1996). The DLG files are obtained from the USGS Internet site:
http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html.

This Internet page has various sites to obtain information. Page down to the100,000-Scale Digital Line Graph (DLG)site and click on: **via graphics (DLG)**

The DLG files can also be obtained from a USGS 14-volume Compact Disc-Read Only Memory (CD-ROM) set which can be obtained from the USGS Earth Science Information Center in Reston, VA. The DLG files for this study are downloaded from Volume 8 (Texas and Oklahoma) of the CD-ROM series (USGS, 1996). The Hydrology files were located in the 100k_dlg directory. This directory contains directories for each of the map sheet in the Texas/Oklahoma region. The Internet site is used to obtain the map sheet names needed for the study. The hydrology files for each of the map sheets were downloaded from the CD-ROM to a PC workspace, and were then brought over to the UNIX workspace by ftp. The files needed for this study are listed below:

NAME	FILE
Goliad	be1hydro.zip
Port Lavaca	be2hydro.zip
Beeville	be3hydro.zip

San Antonio Bay	be4hydro.zip
Corpus Christi	cc1hydro.zip
Allyns Bight	cc2hydro.zip
Baffin Bay	cc3hydro.zip
Laredo	ly1hydro.zip
Alice	ly2hydro.zip
San Ygnacio	ly3hydro.zip
Falfuria	ly4hydro.zip
Encino	m32hydro.zip
Pleasanton	x42hydro.zip
George West	x44hydro.zip
Port Mansfield	zi1hydro.zip

*** Converting the Files to Arc/Info Format**

Each of these files needs to be unzipped. This creates eight coverages. An example for the first file is shown.

$ **unzip be1hydro.zip**
Exploding: be3hyf01
Exploding: be3hyf02
:
Exploding: be3hyf08

The files then need to be converted from a DLG format to an Arc/Info format. The Dlgarc command is used for this. After the files are converted, the line topology must be built using the Build command. An example for the first file is shown.

Arc: **dlgarc optional be1hyf01 be1f01**
Arc: **build be1f01**

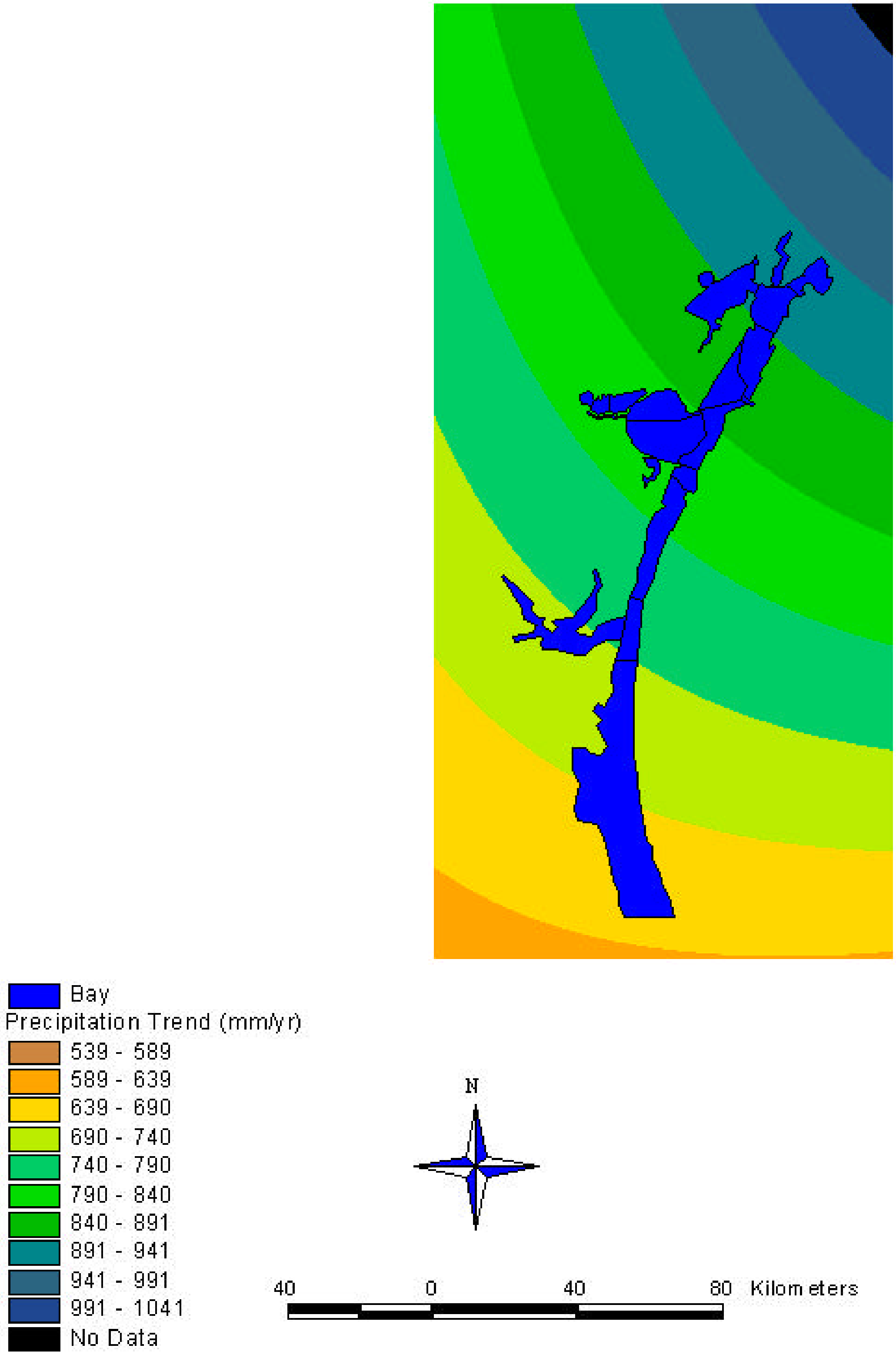

Figure A.8: Precipitation Trend Found Using the Grid Function Trend.

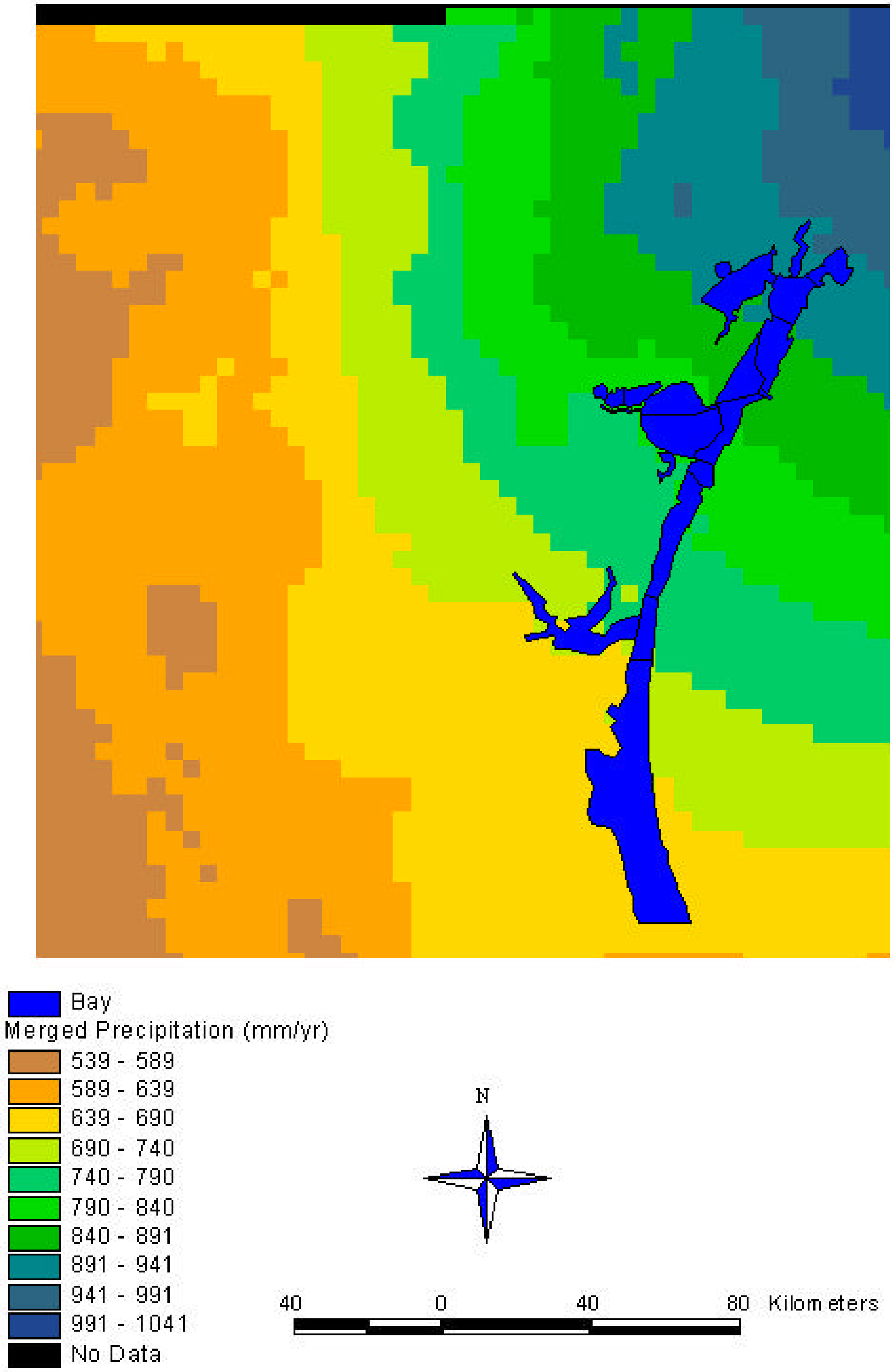

Figure A.9: Merged Precipitation Grids.

*** Joining the DLG Coverages**

The border around each map needs to be removed. This is done by acknowledging that all arcs in a line coverage have left and right polygon numbers associated with them. The value of the exterior polygon number is always one. The Arc Reselect command is used to remove the lines from the coverage.

Arc: **reselect be1f01 be101 line # line**
>: **res rpoly# > 1**
>: **~**
Do you wish to re-enter expression? (Y/N) **n**
Do you wish to enter another expression? (Y/N) **y**
>: **res lpoly# > 1**
>: **~**
Do you wish to re-enter expression? (Y/N) **n**
Do you wish to enter another expression? (Y/N) **n**

Once the border is removed, the DLG coverages can be joined together using the Arc Append command. The Build command is used to add line topology to the large map. Finally, the appended coverage is projected from the UNIVERSAL TRANSVERSE MERCATOR (UTM) projection to the Texas State Mapping System which is in an ALBERS projection with the projection file **utmtsms.prj**.

Arc: **append bigmap**
Enter the 1st coverage: **be101**
Enter the 2st coverage: **be102**
:
:
Enter the 116st coverage: **zi101**
Done entering coverage names?(Y?N) **y**
Do you wish to use the above coverages? (Y/N) **y**

Appending coverages...

Arc: **build bigmap line**
Arc: **project cover bigmap dlgtsms utmtsms.prj**

The projection file is shown below:

UTMTSMS.PRJ

Input
projection UTM
units meters

datum NAD27
spheroid CLARKE1866
zone 14
parameters
output
projection ALBERS
units meters
datum NAD83
spheroid GRS1980
parameters
27 25 00
34 55 00
-100 00 00
31 10 00
1000000.0
1000000.0
end

Figure A.10 shows the DLG file for the study area. Note how the low amount of runoff draining to the South Laguna Madre leads to a poorly defined stream network in this region.

*** Event Mean Concentration (EMC)**

Constituent concentrations need to be assigned to each cell in order to calculate the land surface loads. This study uses Event Mean Concentration (EMC) values obtained from a previous CCBNEP analysis, *Characterization of Non-point Sources and Loadings to the Corpus Christi Bay National Estuary Program Study Area* (Baird,1996). This study developed EMC values from water quality analysis performed at the Oso Creek and Seco Creek USGS Stream Gauges. The Oso Creek gauge is located west of Corpus Christi and represents agricultural land use. The gauges located on Seco Creek are northwest of Hondo, TX, and represent range land uses.

EMC values for 18 constituents were listed in this study and are shown in Table 2.10, as shown in Chapter 2 of this report. The values in the table are typical concentrations of constituents found in runoff water from each particular land use. The values are compiled from many studies done by the USGS and other organizations.

Two EMC studies are being conducted near Edroy, TX and at the King Ranch which is located in southeast Texas. The Edroy study represents agricultural land use, where as the King Ranch study represents rangeland. Preliminary results from the two studies are showing lower total nitrogen EMC values for rangeland and agricultural land uses. Once the EMC studies are completed, it would be feasible to incorporate the data into the Total Loading Project for the Corpus Christi National Estuary Program.

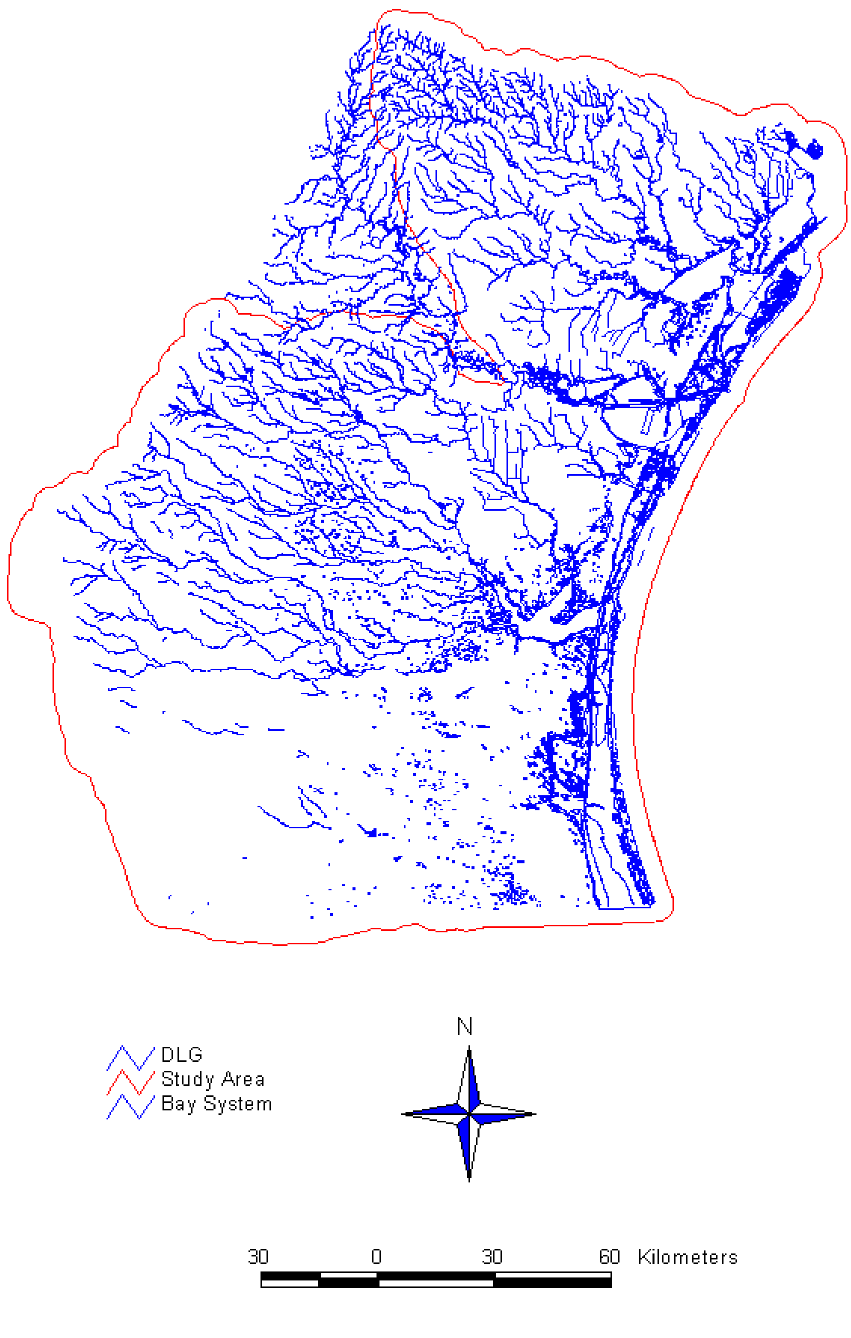

Figure A.10: Digital Line Graph File Used in the Study.

Table of Contents

APPENDIX B: Data Dictionary

Data File	Description	Class	Attributes
accprecip2	Accumulation of the precipitation grid. Units are cubic meters/year.	Grid	Accumulated Precipitation
AGREE	Avenue script that reconditions the digital elevation surface to coincide with the DLG files.		
aransas	Sub-watershed delineated using the script WTRSHD. For the Aransas River gauge.	Grid/Poly	
BALANCE	Avenue scripts for calculating the equilibrium constituent concentrations in the bay system.		
bay	Bay coverage which is the final 20 segments. Contains information for each of the segments.	Poly	Area Volume etc.
bayevap	Zonal mean of evaporation over the bay system which are integer values.	Poly	Evaportation
bayprecip	Zonal mean of precipitation over the bay system which are integer values.	Poly	Precipitation
big	Copy of the grid of the study are obtained from the delineated watersheds.	Grid	
big1	Grid of the study are obtained from the delineated watersheds where all cells equal one and the Lake Corpus Christi Watershed is equal to no data.	Grid	
biglandg	Original land use file converted to a grid from the lucorptsms file.	Grid	Land Use
bigmap	Appended DLG files. Original files were obtained from the USGS CD-ROM.	Arc	Land Use
baygrid	Grid of the bay segments	Grid	
CALCAREA	Avenue script used to calculated the surface area of the bay segments.		
CALCEP	Avenue scripts used to calculate the bulk dispersion coeffiecents from the dispersion coeffiecents.		
CALCLENGTH	Avenue script used to calculated the interface length between each of the bay segments.		
ccbnep.apr	ArcView project file containing all the scripts needed to complete the CCBNEP total loadings and water quality project.		
cchuc	HUC files for the study area. Albers projection with NAD27 datum.	Poly	HUC number and name

Data File	Description	Class	Attributes
cchuc2tsms	HUC files for the study area. Albers projection with NAD28 datum.	Poly	HUC number and name
chiltipin	Sub-watershed delineated using the script WTRSHD. For the Chiltipin Creek gauge.	Grid/Poly	
cogrid	Land surface constituent concentration grid. Constituent abbreviation is tacked onto the end of the cogrid label. Ten constituents were analyzed over the land surface. Units are mg/l.	Grid	Constituent Concentration
CONCGRID	Avenue script which calculated the land surface concentrations from the EMC values.		
CONNECT	Avenue script which connects the DEM to the bay coverage.		
copano	Sub-watershed delineated using the script WTRSHD. For the Copano Creek gauge.	Grid/Poly	
corpgages	Point file with all the gauging stations in the study region projected from a georaphic projection to the Texas State Mapping System.	Point	Latitude Longitude
corptsms	Projected digital elevation grid. Clipped using the buffered HUC files. Elevation values in each grid cell are in units of meters above sea level.	Grid	Elevation
corpus2	Merged DEM files originating from nine smaller DEM files obtained from the USGS Internet site. Map sheet = Beeville-e, Beeville-w,Crystal_City-e, Corpus_Christi-e, Corpus_Christi-w, Laredo-e, Laredo-w, Port_Isabel-w, and McAllen-e. Elevation values in each grid cell are in units of meters above sea level.	Grid	Elevation
count	A coverage of the counties in the study area. Lambert Projection	Poly	County name
countt	A coverage of the counties in the study area. Texas State Mapping System.	Poly	County name
counties	A coverage of the counties in Texas.	Poly	County name
dem	Projected digital elevation grid renamed. Elevation values in each grid cell are in units of meters above sea level.	Grid	Elevation

Data File	Description	Class	Attributes
demtsms.prj	Projection file writtem in the Arc Macro Language to project from a geographic projection to the Texas State Mapping System.		
dlgtsms	The projected and appended DLG file. Projected from the UTM projection to the Texas State Mapping System.	Arc	
dlg2	The renamed projected DLG file.	Arc	
evap	Grid coverage of the evaporation taken from the quadsp file of evaporation.	Grid	Evaporation
evapzone	Zonal mean of evaporation over the bay system. Units are mm/yr.	Grid	Evaporation
evapzone2	Zonal mean of evaporation over the bay system which are integer values.	Grid	Evaporation
facac2	Integer number of cells that fall upstream of each cell. A flow accumulation after the Avenue scripts AGREE and CONNECT are run on the original DEM.	Grid	Flow Accumulation
fdac2	A flow direction after the Avenue scripts scripts AGREE and CONNECT are run.	Grid	Flow Direction
geotsms.prj	Projection file writtem in the Arc Macro Language to project from a geographic projection to the Texas State Mapping System.		
gridagree2	Digital elevation grid which was calculated using the script AGREE. Units are meters above sea level.	Grid	Elevation

Data File	Description	Class	Attributes
gridconnect2	Digital elevation grid which was calculated after using the script CONNECT. Elevation values in each grid cell are in units of meters above sea level.	Grid	Elevation
gridfilla2	Digital elevation grid which was filled after the AGREE script was run. Elevation values in each grid cell are in units of meters above sea level.	Grid	Elevation
huc250	HUC files for the United States	Poly	HUC number and name
lamtsms.prj	Projection file writtem in the Arc Macro Language to project from a lambert projection to the Texas State Mapping System.		
landara	Land use coverage for the sub-watershed Aransas.	Poly	Land Use
landchil	Land use coverage for the sub-watershed Chiltipin.	Poly	Land Use
landcop	Land use coverage for the sub-watershed Copano.	Poly	Land Use
land.dbf	Database file which contains the EMC values for ten constituents.		
landlos	Land use coverage for the sub-watershed Los Omos.	Poly	Land Use
landmed	Land use coverage for the sub-watershed Medio.	Poly	Land Use
landmis	Land use coverage for the sub-watershed Mission.	Poly	Land Use
landoso	Land use coverage for the sub-watershed Oso.	Poly	Land Use
landsdie	Land use coverage for the sub-watershed San Diego.	Poly	Land Use
landsfer	Land use coverage for the sub-watershed San Fernando.	Poly	Land Use
landuse	Original land use cover created by clipping the lucortsms coverage with the outline coverage.	Poly	Land Use
landuse2	Updated land use file converted to a polygon coverage from the landuseg2 file.	Poly	Land Use
landuseg	Original land use file converted to a grid. from the landuse file.	Grid	Land Use

Data File	Description	Class	Attributes
landuseg2	Merged land use file clipped using the big1 file which outlines the study area.	Grid	Land Use
lkcc	Grid of the Lake Corpus Christi watershed.	Grid	
lkg	Nueces River load grid clipped to study area.	Grid	
lkgrid	Nueces River Watershed source constituent loadings grid. Three constituent loads were analyzed. Constituent abbreviations are tacked onto the end of the lkgrid label. Units are Kg/d.	Grid	
lkgridwf	Weighted flow accumulation for the Nueces River Watershed load grids. Constituent abbreviationsare tacked on the end of lkwfgrid.	Grid	
lkgridwf.aml	AML used to calculate the weighted flow accumulations for the Nueces River loads.		
LOADGRID	Avenue script which calculated the land surface laods from the concentration grids.		
log	Land surface load grid clipped to study area.	Grid	Load
logrid	Land surface constituent loadings grid. Constituent abbreviation is tacked onto the end of the logrid label. Ten constituents were analyzed over the land surface. Units are Kg/d.	Grid	Load
logridwf	Weighted flow accumulation for the land surface load grids. Constituent abbreviations are tacked on the end of lowfgrid.	Grid	Load Accumulation
lonlat.dat	File containing the longitude and latitude of all the gauging stations in the study area in decimal degree format.		
losomos	Sub-watershed delineated using the script WTRSHD. For the Los Omos Creek gauge.	Grid/Poly	

Data File	Description	Class	Attributes
lucorp	Merged land use cover downloaded from the TNRIS Internet site. Map Sheets = Beeville, McAllen, Corpus Christi, Chrystal City, and Laredo.	Poly	Land Use
lucorpd	Dissolved land use cover downloaded from the TNRIS Internet site.	Poly	Land Use
lucorptsms	The projected land use cover downloaded from the TNRIS Internet site. Texas State Mapping System.	Poly	Land Use
map	Outline grid of the study area obtained from the merged delineated watersheds.	Grid	
medio	Sub-watershed delineated using the script WTRSHD. For the Medio gauge.	Grid/Poly	
mission	Sub-watershed delineated using the script WTRSHD. For the Mission River gauge.	Grid/Poly	
newland	Updated land use map projected from a UTM projetion to the Texas State Mapping System.	Grid	Land Use
newland2	New land use file where no data cells are equal to biglandg else they are equal to newland.	Grid	Land Use
newlandbg	Original land use file created by merging the biglandg and landuseg files.	Grid	Land Use
newlandbg2	Merged land use file created from the newlandbg and newland2 files.	Grid	Land Use
nland1-6	Updated land use files which were created by merging the smaller land use files.	Grid	Land Use
nland	Final updated and merged land use file.	Grid	Land Use
oso	Sub-watershed delineated using the script WTRSHD. For the Oso Creek gauge.	Grid/Poly	
outline	A buffered outline coverage of the study area renamed.	Poly	
outlineg	Outline grid of the study area.	Grid	

Data File	Description	Class	Attributes
p_ann	Precipitation grid obtained from the CRWR database. Covers all of the United States and is a mean annual precipitation in mm/yr.	Grid	Precipitation
PICKLOAD	Avenue script which extracts the loading to the centroid of the bay system.		
pog	Point source load grid clipped to study area.	Grid	Load
pogrid	Point source constituent loadings grid. Constituent abbreviation is tacked onto the end of the pogrid label. Units are Kg/d.	Grid	Load
pogridwf	Weighted flow accumulation for the point source grids. Constituent abbreviations are tacked on the end of powfgrid.	Grid	Load Accumulation
pogridwf.aml	AML used to calculate the weighted flow accumulations for the point source loads.		
POINTLD	Avenue script which calculates the point loads by placing the load in the centroid of the stream polygon or the beginning of the stream segment.		
precip	Clipped precipitation grid using the buffered HUC files.	Grid	Precipitation
precip2	Clipped and projected precipitation grid. projected from Geographic projection to the Texas State Mapping System.	Grid	Precipitation
precip3	A portion of the clipped and projected precipitation grid along the coast line.	Grid	Precipitation
precipgrid	Precipitation grid created using the trend function and the precipitation point file along the coast line.	Grid	Precipitation
precipmerge	Preciptation grid created by merging the original preciptation grid and the trend grid.	Grid	Precipitation
precippnt	Point file of the precipitation grid along the coast line.	Grid	Precipitation
precipzone	Zonal mean of precipitation over the bay system. Units are mm/yr.	Grid	Precipitation
precipzone2	Zonal mean of precipitation over the bay system which are integer values.	Grid	Precipitation
quadsp	Large file of evaporation for the state of Texas.	Poly	Anntot
rf1	The clipped and projected river reach files.	Arc	

Data File	Description	Class	Attributes
riv20000	Flow accumulation with cells greater than 20,000 accumulation.	Grid	Flow Accumulation
rogrid	Large runoff grid caclulated by merging the small Anderson Land Use classification grids. Units are mm/yr.	Grid	Runoff
rogrida	Runoff grid with Anderson Land Use Classification >=20 and <=29.	Grid	Runoff
rogridr1	Runoff grid with Anderson Land Use Classification >=30 and <=49.	Grid	Runoff
rogridr2	Runoff grid with Anderson Land Use Classification >=70 and <=79.	Grid	Runoff
rogridr3	Runoff grid with Anderson Land Use Classification <=10.	Grid	Runoff
rogridu	Runoff grid with Anderson Land Use Classification >=11 and <=19.	Grid	Runoff
rogridw	Runoff grid with Anderson Land Use Classification >=50 and <=59.	Grid	Runoff
rogridwe	Runoff grid with Anderson Land Use Classification >=60 and <=69.	Grid	Runoff
runcoeff	Runoff coefficient grid calculated by dividing the runoff grid by the precipitation grid.	Grid	Runoff Coefficient
runcoeff2	Runoff coefficient grid with all cells being less than 0.24.	Grid	Runoff Coefficient
runland2	Runoff grid calculated by multiplying the runoff coefficient grid with values less than 0.24 and the precipitation grid. Units are mm/yr.	Grid	Runoff
sandiego	Sub-watershed delineated using the script WTRSHD. For the San Diego gauge.	Grid/Poly	
sanfern	Sub-watershed delineated using the script WTRSHD. For the San Fernando Creek gauge.	Grid/Poly	
segments	TNRCC stream segment coverage.	Arc/Poly	
station	Point coverage file of the gauging stations in the study area.	Point	
statname.dat	Data file which contains gauging station name and number.		

Data File	Description	Class	Attributes
strmlnk	Stream Link grid calculated from the script STRMLNK and used to delineate the sub-watersheds in the study area.	Grid	Stream Links
STRMLNK	Avenue script which calculates the stream link grid used to delineate sub-watersheds.		
TIMEAVE	Avenue scripts for calculating the average observed concentrations over time and space.		
tsmsbuff	A buffered outline coverage of the study area created from the HUC files.	Poly	
WTRSHD	Avenue script which delineates watersheds.		

APPENDIX C: References

Armstrong, N. E. 1997. Point Source Data for the Corpus Christi National Estuary Program. Corpus Christi National Estuary Program, Corpus Christi, TX.

Baird, F. C., T. J. Dybala, M. E. Jennings and D.J. Ockerman. 1996. Characterization of Non-Point Sources and Loadings to the Corpus Christi Bay National Estuary Program Study Area. Corpus Christi National Estuary Program, Corpus Christi, TX.

Barrett, M. 1997. Personal Communication, The University of Texas at Austin.

Brock, D.A. 1997. Personal Communication, The Texas Water Development Board.

Environmental Protection Agency (EPA). 1997. Online Report: Surface Water Quality Modeling. Internet site: http://www.epa.gov/ORD/WebPubs/surfaceH2O/surface.html.

Hinson, J.M., W.P. Pulich, C. Blair, and R. Gallacher. 1995. Compilation of a Digital Layer Composed of Wetland Habitats and Coastal Land Cover Data: Final Report to Natural Resources Inventory Program. Texas Parks and Wildlife.

Hirsch, R.M., D.R. Helsel, T.A. Cohn, and E.J. Gilroy. 1993. Handbook of Hydrology. McGrawHill, Inc. New York.

Liljestrand, H. M., J. D. Mohr, and M. A. Stradfford. 1986. Methods for the Validation of Precipitation pH: Applications to Texas Data. J. Environ. Sci. A21(2): 151-168.

Maidment, D.R. and W.K. Saunders. 1996. Non-Point Pollution Assessment Of The San Antonio-Nueces Coastal Basin. Paper Presented to the Scientific and Technical Advisory Committee, Corpus Christi Bay National Estuary Program, Corpus Christi, TX.

Matsumoto, J., 1993. User's Manual for the Texas Water Development Board's Hydrodynamic and Salinity Model: TxBLEND - DRAFT February 1993. Environmental Section in the Planning Division, Texas Water Development Board.

Montagna, P. A., R.R. Twilley, J. Cowan, T. Miller-Way. 1997. Benthic Nutrient Fluxes of Selected Estuaries in the Gulf of Mexico.

Ockerman, D.J. 1998. Personal Communication. United States Geological Survey.

Oregon State University Forest Science Department's Anonymous ftp Site: fsl.orst.edu, 1996.

Reed, S. et al. 1996. Spatial Water Balance of Texas. The University of Texas at Austin., Center for Research in Water Resources.

Saunders, W.K. and D.R. Maidment. 1996. A Gis Assessment of Non-Point Source Pollution in the San Antonio-Nueces Coastal Basin. The University of Texas, Center for Research in Water

Resources. CRWR online report 96-1.

Snyder, J.P. 1987. Map Projections-A Working Manual. US Geological Survey Paper #1395, US Government Printing Office, Washington, DC.

Texas Natural Resources Information System (TNRIS). 1996. Internet Site, http://www.tnris.state.tx.us/pub/GIS/topography/LULC/.

Texas Natural Resources Information System (TNRIS). 1997. Internet Site, http://www.tnris.state.tx.us/pub/GIS/wetlands/aquatic/cwh/corpus/.

Texas United States Geological Survey (TXUSGS) 1996. Internet Site, http://txwww.cr.usgs.gov/.

Texas Nartural Resource Conservation Commission (TNRCC). 1997. Internet site, http://www.tnris.state.tx.us/ftparea.html.

United States Geological Survey (USGS). 1993. 1:100,00-scale Digital Line Graph Data: Hydrology And Transportation – Area 8, Texas And Oklahoma. US GeoData Compact Disc. US Geological Survey, Reston, VA.

United States Geological Survey (USGS). 1996. Internet Site, http://h2O.cr.usgs.gov/nsdi/wais/water/rf1.HTML.

United States Geological Survey (USGS). 1996. Internet Site, http://nsdi.cr.usgs.gov/nsdi/products/huc.html.

United States Geological Survey (USGS). 1996. Internet Site, http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html

United States Geological Survey National Atmospheric Deposition Program (USGSNADP). 1997. Internet site, http://h2o.usgs.gov/nwc/NWC/pH/html/ph.html

Thomann, R.V. and J.A. Mueller. 1987. Principles of Surface Water Quality Modeling and Control. Harper Collins Publishers Inc., New York.

Ward, G. H., and Armstrong, N. E. 1996. Corpus Christi Bay National Estuary Program, Ambient Water, Sediment and Tissue Quality of Corpus Christi Bay Study Area: Present Status and Historical Trends, Summary Report; Draft. The University of Texas at Austin, Center for Research in Water Resources.

Ward, G.H. 1997. Corpus Christi Bay National Estuary Program: Current Status and Historical Trends of Estuarine Circulation; Draft. The University of Texas at Austin, Center for Research in Water Resources.