A GIS ASSESSMENT OF NONPOINT SOURCE POLLUTION IN THE SAN ANTONIO-NUECES COASTAL BASIN

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ABSTRACT

An Arc/Info Geographic Information System (GIS) method has been developed for the assessment of nonpoint source pollution in a watershed. This method makes use of publicly available elevation, stream network, rainfall, discharge, and land use data sets and uses a digital discretization, or grid representation, of a watershed for the approximation of average annual pollutant loads and concentrations.
The San Antonio-Nueces Coastal Basin in south Texas is identified as the test site for execution of the method.

A digital grid replica of the basin stream network is first created, employing a "burn-in" process to affix the USGS Digital Line Graph stream network to the Digital Elevation Model of the basin. Precipitation is then compared with historical discharge at five gauge locations in the basin and a mathematical relationship between rainfall and runoff is established, using a regression analysis. Literature-based Expected Mean Concentrations (EMC's) of pollutant constituents are associated with land uses in the watershed. The products of these spatially distributed EMC's and the runoff in each digital basin grid cell are calculated and then summed in the downstream direction to establish spatially distributed grids of average annual pollutant loads in the basin. Finally, grids of nonpoint source pollutant concentrations are created by dividing the average annual pollutant load grids by a grid of total annual cumulative runoff.

In an effort to refine the process, a method of simulating suspected nutrient point sources in the basin is investigated and an optimization routine is used with pollutant measurement data at four major sampling points to adjust the literature-based Expected Mean Concentration values for phosphorus.

The GIS nonpoint source pollution assessment method is performed for four pollutant constituents: phosphorus, nitrogen, cadmium, and Fecal Coliform. Predicted concentrations for phosphorus and nitrogen, when determined with the simulated point sources, match closely with average observed concentrations in the basin. Predicted Fecal Coliform concentrations did not match well with average observed values, but Expected Mean Concentration values for the pollutant were highly variable between land uses and should be investigated further. Insufficient heavy metal measurement data exist to make conclusive assessments of predicted cadmium concentrations.

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1   INTRODUCTION

1.1   Background

In recent years, the contribution that nonpoint sources make to pollution in the United States' surface waters has come under closer scrutiny. Nonpoint source, or diffuse, pollution can be defined as pollution that is not associated with a specific location, pipe effluent discharge, or "point". Duda (1993) lists nonpoint sources of pollution to include agricultural activities, urban and industrial runoff, combined sewer overflows and leaks, hazardous waste dumpsites, septic tank systems, mining and forest harvesting activities, spills, atmospheric deposition, and hydrologic modifications. Intermittent discharges from these sources travel over land in a diffuse manner before reaching surface waters (Rifai et al., 1993).

The relative significance of nonpoint sources in the overall spectrum of pollutants has also been reassessed in recent years. In a national assessment compiled by the U.S. Environmental Protection Agency (EPA) (1992), four times as many waters were found to be polluted by agricultural activities than by municipal point source discharges. Olem (1993) has identified nonpoint source pollution as the main reason that U.S. waters do not meet water quality standards and, in an analysis of nutrient water pollution, Puckett (1995) found that nonpoint sources were the dominant source of nitrogen and phosphorus in the majority of streams studied.

While the Clean Water Act (CWA) of 1972 provided the initial legislative means for restoring the quality of the nation's waters, it was not until section 319 was added in the Water Quality Act of 1987 (PL 100-4) that specific accounting for nonpoint sources of pollution was addressed. Through section 319, titled "Nonpoint Source Management Programs", the legislature required State governors to submit State Assessment Reports identifying significant nonpoint sources of pollution to the States' navigable waters. The Act also required the adoption and implementation of State management programs for controlling pollution added from nonpoint sources to navigable waters (U.S. Congress, 1987).

The Water Quality Act of 1987 also included, as section 320, a provision for the establishment of regional National Estuary Programs (NEP's) to oversee the development of comprehensive estuary management plans. These National Estuary

Programs are administered by the EPA and include representatives from State and local jurisdictional entities, interested Federal agencies, and affected industries and educational institutions. One of the main purposes of each National Estuary Program, in the construction of the management plan, is the development of a relationship between in situ loads and point and nonpoint loadings of pollutants to the estuarine zone (U.S. Congress, 1987). As a result of this focus, much emphasis has been placed on the characterization of water quality, including nonpoint source pollution estimates, in each of the National Estuary Program study areas.

In addition to sections 319 and 320 of the Clean Water Act, section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 requires States to establish coastal nonpoint programs, subject to approval by the EPA and the National Oceanic and Atmospheric Administration (NOAA). The main purpose of section 6217 is to reinforce the interface between Federal and State coastal zone management and water quality programs in order to strengthen regional efforts to manage land use activities that typically degrade coastal waters (USDC-NOAA and USEPA, 1993).

At the Texas State level, the Texas Clean Rivers Act (Senate Bill 818), enacted subsequent to section 319 of the Clean Water Act, requires that biennial water quality assessments be performed for each major basin in the State. The Texas Natural Resource Conservation Commission (TNRCC) is responsible for administering these assessments and relies on regional partner entities, such as river authorities, to organize the assessments for each river basin. For those locations/basins where no river authority exists (such as in coastal areas between river basins), the TNRCC is responsible for producing the assessment report (TNRCC, 1994).

Pursuant to Senate Bill 818, the Texas Clean Rivers Program was created by the TNRCC to be the administering entity for the regional assessments. One of the responsibilities of the Clean Rivers Program is the organization of the assessment report for the San Antonio-Nueces Coastal Basin, which does not fall within the jurisdiction of an existing river authority. The Corpus Christi Bay National Estuary Program (CCBNEP) is also currently being conducted in the region and there is considerable interest in the accurate characterization of pollutant loads to the bay network and estuarine system there.

In support of the TNRCC's water quality assessment of the San Antonio-Nueces basin, a study of pollutant sources is needed. As part of this study, a reliable

method of assessing nonpoint source pollution in the basin is required. This report addresses the need for such a method and takes advantage of the technical opportunity to investigate alternatives for computing nonpoint source loadings on a spatially distributed basis.

1.2   Objectives

A simplified method of nonpoint source pollution assessment is developed using the Arc/Info geographic information system (GIS). This method uses a fine mesh of 1 hectare (ha) cells laid over the landscape, accounting for the pollutant loading and runoff derived from each cell. By tracing the flow of water from cell to cell, the movement of pollution over the landscape and through a stream network is simulated. This method allows for the calculation of average annual nonpoint source pollutant loadings to a regional hydrologic system. In addition, estimates of average expected pollutant concentrations resultant from nonpoint sources are determined.

This research shows that the association of typical pollutant concentrations with land uses in a watershed can provide a reasonably accurate characterization of nonpoint source pollution in the watershed. This method can also be used to identify areas within a basin that may contribute more significantly to nonpoint source pollution. Accordingly, the method is well suited for the selective location of sampling stations in the establishment of local water quality sampling programs.

There are some limitations with the method discussed in this report. First, only average annual assessments are performed, so that runoff and pollutant loads are considered to be steady state parameters from year to year and within any year. Average monthly assessments could be just as easily performed using the same method, but temporal variations in runoff and pollutant loads throughout the basin would need to be correlated with gauged U.S. Geological Survey (USGS) streamflow values and are not considered in this study.

Secondly, pollutant concentration from local runoff is assumed to be directly related to land use in the region and is not considered to vary from event to event or within areas of similar land uses. In particular, a single average estimated pollutant

concentration is assigned to all agricultural land uses instead of considering unique concentrations for different crops, soil types, or activities.

Throughout this study, pollutant transport in streams is considered to be conservative, i.e. no decay of pollutants is examined. This assumption is more legitimate for smaller watersheds, whose times of concentration (Chow et al., 1988) are shorter than the chemical reaction times of pollutant constituents.

Finally, point sources are not initially considered as part of the regional pollution assessment. A separate study, performed in the later stages of the research, investigates a method of estimating and simulating point loads along with the spatially distributed nonpoint loads. However, a preferred method of including point source loads would be through the access of publicly available point source permit documentation.

1.3   Study Area

For this study, the area of interest is the San Antonio-Nueces Coastal Basin, located in south Texas, just north of the city of Corpus Christi. The basin is approximately 7000 square kilometers in size and is bounded by the San Antonio River Basin to the north, the Nueces River Basin to the south and west, and the Texas Intracoastal Waterway, including San Antonio Bay, Aransas Bay, and Corpus Christi Bay, to the south and east. The basin includes two main rivers, the Mission and Aransas Rivers, which both flow to the southeast into Copano Bay and, ultimately, into Aransas Bay. Figure 1.1 shows the location of the San Antonio-Nueces Coastal Basin and Figure 1.2 identifies most of its major hydrologic features.

Topographically, the San Antonio-Nueces Coastal Basin is characterized by fairly distinct variations in elevation in the western part of the basin, away from the coast, and extremely flat terrain in the near-shore portions of the basin, to the south and east. Much of the southern part of the basin is used for agricultural purposes. Major crops and land uses receiving applications of nutrients and chemicals include cotton, corn, grain sorghum, melons, and improved pasture. Soils that support these land uses range from the dark, calcareous Victoria clays in the coastal portions of the basin to the fine sandy loams of the Papalote and Orelia series inland and in the
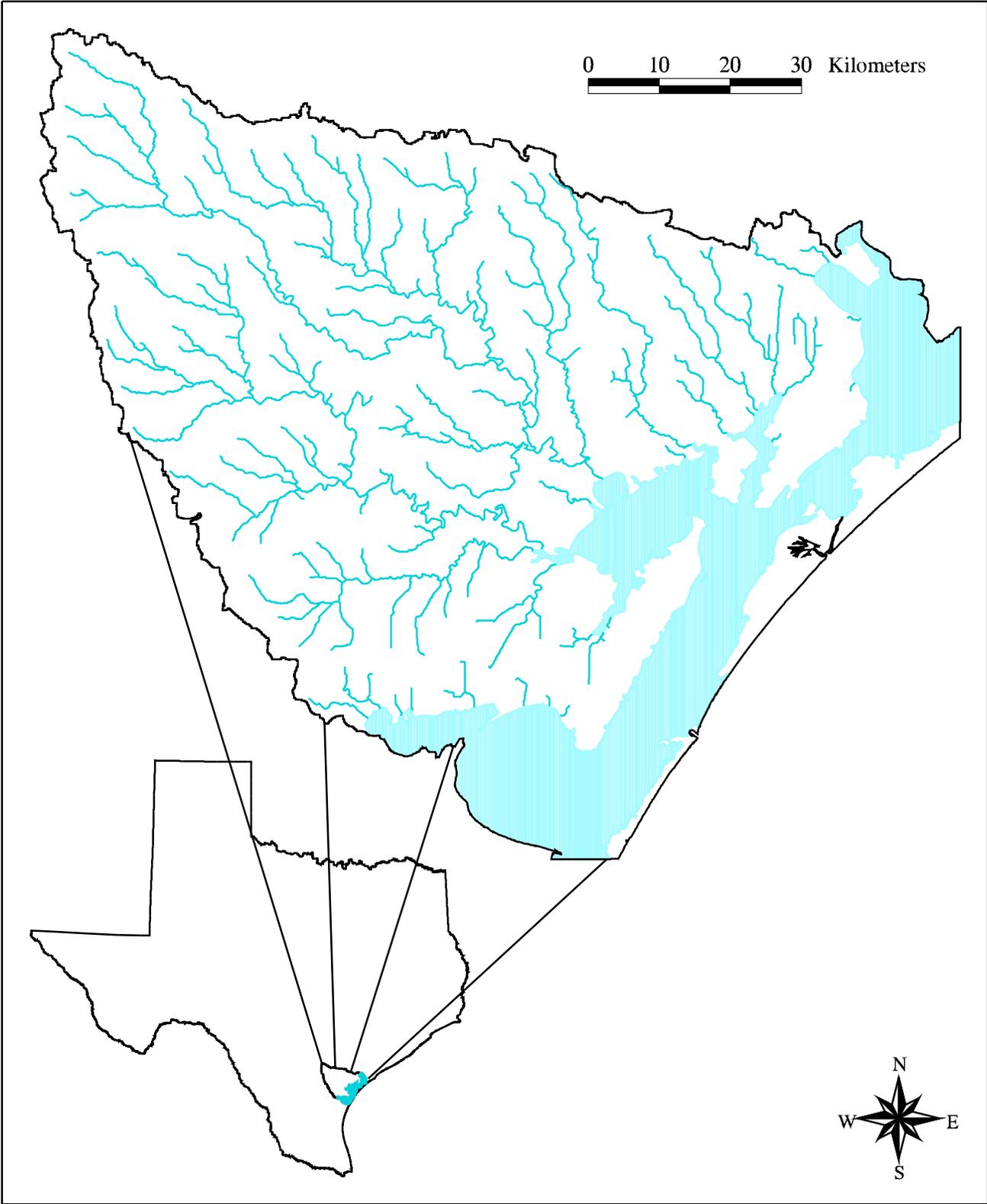
Figure 1.1 : San Antonio - Nueces Coastal Basin
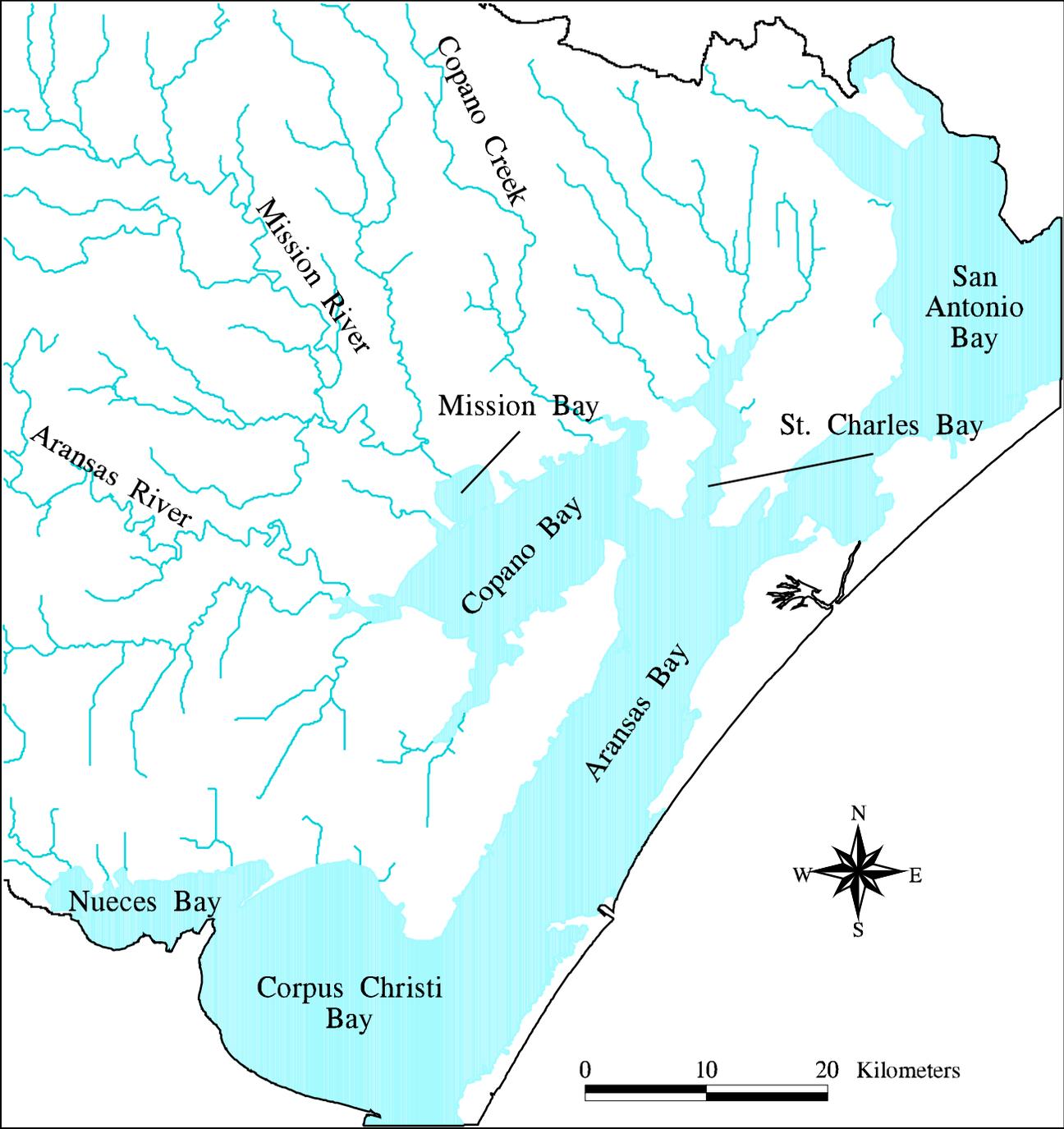
Figure 1.2 : Major Hydrologic Features of the
San Antonio-Nueces Coastal Basin

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southern basin. The shallow, gravelly loams of the Olmos series characterize the western upland portions of the watershed (Baird et al., 1996).

The San Antonio-Nueces Coastal Basin is largely rural, having only a few small cities with populations exceeding 5000. Table 1.1 shows the populations of the larger cities within the watershed.

1.4   Research Approach

This study makes use of Arc/Info version 7.0 with the GRID module installed. Additionally, some steps are performed in the accompanying ArcView 2.0 software. A FORTRAN 77 compiler is also required for the reformat of data acquired over the Internet. The methodology for this study is partitioned into 8 tasks:

(1) A digital database for the study area is established through the assembly of various publicly available physiographic data sets.

(2) The hydrography of the basin is then modeled using Arc/Info GRID manipulations of a digital elevation model. Digital elevation models (DEMs) discretely represent the surface elevations of a region with a fine mesh of equal area (1 hectare) grid cells. The flow of water over this digital elevation surface can be simulated from cell to cell by following the path of steepest descent. As a result, this step produces a digital replica of the basin stream network.

City or Town	County	Population
Beeville	Bee	13,547
Portland	San Patricio	12,224
Aransas Pass	San Patricio	7,180
Ingleside	San Patricio	5,696
Sinton	San Patricio	5,549
Rockport	Aransas	4,753
Refugio	Refugio	3,158

Table 1.1 : Populations of Major Cities within the San Antonio-Nueces Coastal Basin (Baird et al., 1996)

(3) A mathematical relationship between rainfall and runoff in the basin is established by performing a regression analysis of the 30-year average rainfall distribution in the basin and the adjusted 30-year average runoff measured at USGS gauging stations.

(4) Expected Mean Concentration (EMC) values for a number of pollutants are linked with the various land uses in the basin. The values used in this study are published by the U.S. Department of Agriculture Natural Resource Conservation Service (USDA-NRCS).

(5) Annual pollutant loadings throughout the basin and at sub-basin outlet points are estimated by accumulating runoff downstream through the digital stream network.

(6) Estimates of the aerial concentration distribution are calculated for each pollutant constituent by dividing the total annual cumulative load grid by the total annual cumulative runoff grid. These values are compared with average sampled pollutant concentrations at various locations within the basin.

(7) Point loads in the basin are estimated for locations where the average sampled concentration is significantly larger than the calculated concentration.

(8) Finally, in an effort to adjust the literature-based Expected Mean Concentration values, an optimization routine is used to establish values of Expected Mean Concentration from the mass balance equations at a number of constituent sampling locations in the basin.

The process developed here, while specific to the San Antonio-Nueces Coastal Basin, could also be employed for similar nonpoint source pollution assessments in other geographic regions. For this study, only average annual loads and annually averaged concentrations have been considered and estimated. However, average seasonal or average monthly loads and concentrations could also be established by further analysis of the same data sets.

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2   LITERATURE REVIEW

As nonpoint source pollution has garnered more attention in recent years, governmental agencies, academic and research institutions, and commercial consulting firms have developed methods of assessing pollution from nonpoint sources. Many of these methods have involved the development of computer-based models for automated, reliable, and repeatable analyses. More recently, some of these models have been linked with geographic information systems (GIS) for ease of data management or for the apportionment of processing tasks.

This chapter provides a review of some of the more well-known nonpoint source pollution models. An investigation of some of the more recent integrated GIS/nonpoint source modeling efforts is also included. Finally, a discussion is provided of previous water quality analyses performed in the study area.

2.1   Nonpoint Source Pollution Models

Ever since the EPA created the Stormwater Management Model (SWMM) in the early 1970's as the first urban runoff quality model (Donigian and Huber, 1991), researchers worldwide have continued to develop computer-based models to simulate runoff hydraulics and water quality in urban and non-urban environments. The role of GIS in these modeling efforts has also grown from that of a pre-processor for spatially oriented input data (Evans and Miller, 1988) to that of a stand-alone system through which runoff hydraulics and water quality are directly simulated (Newell et al., 1992).
This section describes some of the most commonly used nonpoint source pollution models and some successful GIS links to them. All of the models included in this section are written in standard FORTRAN 77 and are executable under the MS/DOS environment.

HSPF

The Hydrological Simulation Program-FORTRAN (HSPF) was developed by the EPA-Athens laboratory (Johanson et al., 1984). It is executable under either

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DOS-based or VAX VMS systems. HSPF simulates both watershed hydrology and water quality for conventional and toxic organic pollution. The model provides estimates for these parameters on a one-dimensional stream network basis. HSPF is the only water quality model that provides for integrated simulation of land and soil contaminant runoff processes with instream hydraulic and sediment-chemical kinetics (Donigian and Huber, 1991).

HSPF requires continuous rainfall records to drive the agricultural runoff routine embedded in the program. Additionally, records of evapotranspiration, temperature, and solar radiation are input to the model. HSPF simulates the transfer and reaction processes of hydrolysis, oxidation, photolysis, biodegradation, volatilization, and sorption. Settling and resuspension of silts and clays are also modeled (Johanson et al., 1984).

The outputs of the HSPF model include time histories of the runoff flow rate, sediment load, and nutrient and pesticide concentrations. These time histories can be produced for any point in the stream network of a watershed (Donigian and Huber, 1991).

In 1995, Donigian et al. used HSPF, along with its more recently developed Agrichemical (AGCHEM) soil nutrient submodel, to estimate nutrient loadings to Chesapeake Bay. For this study, the AGCHEM modules were used to establish typical nutrient balances for each of the major agricultural crop categories in the Chesapeake Bay watershed. The analysis was the first extension and detailed application of HSPF/AGCHEM on a large (176,000 km^2) drainage area (Donigian et al., 1995).

Also in 1995, Al-Abed and Whiteley used the Arc/Info GIS, along with HSPF, to simulate the effects of changes in land use and in resource management strategies on the quality and quantity of irrigation water in the lower portion of the Grand River watershed, in southwestern Ontario, Canada. In this study, Arc/Info was used to establish watershed segments based on soil classification and land use/crop type. For each segment in the watershed, water holding capacity, soil infiltration capacity, surface slope, and initial soil water storage were calculated and provided as inputs to the HSPF model (Al-Abed and Whiteley, 1995).

CREAMS/GLEAMS

The U.S. Department of Agriculture-Agricultural Research Service developed the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980) to aid in the assessment of agricultural best management practices for pollution control. Like HSPF, CREAMS is a continuous simulation model requiring continuous precipitation data and monthly values of air temperature and solar radiation. Soil and crop type data are also provided as inputs. In order to assess best management practices, the user of CREAMS can simulate various management activities, such as aerial spraying or ground application of pesticides, animal waste management, tillage operations, or terracing (Knisel, 1980).

CREAMS calculates runoff volume, peak flow, infiltration, evapotranspiration, soil water content, and percolation on a daily basis. Daily erosion and sediment yield are also estimated and average concentrations of sediment-associated and solute chemicals are calculated for the runoff, sediment, and percolating water (Knisel, 1980).

By incorporating a component for vertical flux of pesticides in the root zone, the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model (Leonard et al., 1987) was established. GLEAMS is partitioned into three components, namely hydrology, erosion/sediment yield, and pesticides. Rainfall is partitioned into surface runoff and infiltrating water using the Soil Conservation Service (SCS) Curve Number Method (Chow et al., 1988). Soils are divided into multiple layers of varying thickness for water and pesticide routing (Leonard et al., 1987).

A watershed version (Opus) of CREAMS/GLEAMS has also been created. Opus is a comprehensive model that simulates the processes of sediment transport, chemical transport, carbon and nutrient cycles in soil microbial decay, flow of heat in soil, and growth of crops (Smith, 1992). Opus relies heavily on algorithms from other models: weather conditions are simulated by a daily weather generation model (WGEN), daily runoff is calculated from a modified SCS Curve Number approach, and soil erosion is modeled using the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975).

Zhang et al. (1995) used CREAMS-WT, a modified field scale version of CREAMS, for simulating runoff and nutrients under high water table conditions, along with the Enhanced Stream Water Quality Model (QUAL2E) (Brown and Barnwell, 1987) and the GIS-based Lake Okeechobee Agricultural Decision Support System (LOADSS), to simulate phosphorus transport processes in the watersheds draining to Lake Okeechobee in south Florida. For this study, the LOADSS GIS was used to provide spatially distributed land use data to the CREAMS-WT model. Using soils associated data for the land uses, the CREAMS-WT calculates phosphorus concentration values throughout the watershed. This data, along with surface runoff data, is provided to QUAL2E, which simulates the phosphorus transport and retention in wetlands and stream channels. The South Florida Water Management District continues to use this modeling framework for assessment of eutrophication problems in the lake (Zhang et al., 1995).

AGNPS

The Agricultural Nonpoint Source Pollution Model (AGNPS) was created by the U.S. Department of Agriculture-Agricultural Research Service (Young et al., 1986) in order to compare the effects of different watershed pollution control management practices. AGNPS simulates sediment and nutrient loadings from agricultural watersheds for single storm events or for continuous data input. Watersheds in the model are discretized into series of square cells, for which homogeneous characteristic parameters are assigned.

AGNPS is partitioned into two submodels. The erosion portion of the model provides estimates of upland erosion, channel erosion, and sediment yield. The model uses the Modified Universal Soil Loss Equation (Williams, 1975) for soil erosion calculations and distributes predicted erosion into five particle size categories: sand, silt, clay, small aggregates, and large aggregates. The pollutant transport portion of AGNPS is subdivided into one part addressing soluble pollutants and one part handling pollutants adsorbed onto solids. Nitrogen and phosphorus loads are determined using relationships between chemical concentrations, sediment yield, and runoff volume (Young et al., 1986).

Input data for AGNPS are classified into two categories: watershed data and cell data. Watershed data includes information applicable to the entire watershed, while cell data is based on land use practices and soil type data within each cell. Output of the model includes a hydrology component, with runoff volume and peak runoff rate, and a sediment component, which includes the erosion data described above and estimates of pollutant loadings. Volumes and loadings can be determined on a watershed scale or for each receiving cell (Young et al., 1986).

AGNPS has proven to be a quite popular model with researchers and there have been significant numbers of studies coupling AGNPS to other models and GIS. Evans and Miller (1988) used a grid cell-based GIS known as ERDAS (Earth Resources Data Analysis System) integrated with AGNPS. In their study, Evans and Miller used an ERDAS algorithm called AGNPSIN to compute average AGNPS cell values for land slope, channel slope, curve number, roughness coefficient, surface condition constant, soil texture, chemical oxygen demand, and cropping factor. The calculated average cell values were then written to a data file, which supplied direct input to AGNPS during execution of the model.

Vieux and Needham (1993) studied the sensitivity of AGNPS to variations in Arc/Info grid-cell sizes. A 282-hectare agricultural and forested watershed near Morris, Minnesota was used as the test case. By varying the Arc/Info grid-cells between one hectare and 16 hectares, simulated flow path lengths were seen to decrease with increasing grid-cell size. This shortening of flow paths is attributed to stream meander short-circuiting at the larger grid-cell sizes. A corresponding variability in AGNPS sediment yield, which is dependent on flow-path length, was also observed. Sediment delivery ratio, when using the one-hectare grid-cells, was 71% greater than for the 16-hectare grid-cells. This variation was due solely to the cell size selected to represent the watershed. This research showed that cell size selection for a discrete watershed analysis should be based on the scale necessary to capture the spatial variability of parameters in the watershed.

Mitchell et al. (1993) used the Geographic Resources Analysis Support System (GRASS) GIS (U.S. Army, 1987), integrated with AGNPS, to perform a validation of the model for small mild topography watersheds in East Illinois. Using GRASS, all 22 input parameters for the AGNPS model were obtained from just four GIS layers. These input parameters were established either by using internal GRASS routines or

by reclassification of the original GIS layers. For example, the Universal Soil Loss Equation K factor, the percent sand, percent clay, and the hydrologic soil group are AGNPS parameters which are associated with GIS polygons on the soils map. Reclassifications of the soils map with values for these parameters resulted in four input parameter layers for the AGNPS model.

Other AGNPS links with Arc/Info have also been investigated. A study of the impact of changing agricultural management practices on predicted water quality of the 1465 km^2 Bedford-Ouse catchment in England (Morse et al., 1994) showed that AGNPS input parameters could be effectively processed and provided through an interface with Arc/Info. Also, an evaluation of the effectiveness of different management strategies in reducing sediment loads was performed for the 417-hectare Bluegrass watershed in Audubon County, Iowa (Tim and Jolly, 1994). The integrated AGNPS-Arc/Info system proved to be an effective framework for assessing sediment load reductions through the management practices of vegetation filter stripping and contour buffer stripping.

ANSWERS

The ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) model was developed in the Agricultural Engineering Department of Purdue University in the late 1960's. It is a distributed parameter, event-based model for predicting the hydrologic and erosion response of agricultural watersheds. The distributed parameter approach allows the user to account for spatial variability of input variables. ANSWERS also allows for selective evaluation of output within the watershed instead of being limited to the basin outlet (Donigian and Huber, 1991).

Within ANSWERS, an entire watershed is discretized into square cells within which input variables are constant. Principal inputs to the model are the rainfall hyetograph, antecedent soil moisture, and the soil, crop, and physical characteristics of each discrete cell. The model calculates amount of infiltration and then simulates surface storage, surface detention and overland flow. Soil detached from rainfall or runoff is also available for transport by overland flow. ANSWERS outputs an event hydrograph and an event sedimentgraph, from which net sediment yield may be determined (von Euw et al.. 1989).

ANSWERS has been found to be extremely sensitive to rainfall input, indicating that care must be taken for temporally and spatially variable events. The model is also sensitive to infiltration variables for small events (von Euw et al., 1989).

In a comparative study of various water quality models, Engel et al., (1993) used GRASS, linked with ANSWERS, to assess model accuracy of predicted hydrologic responses and sediment loads from single rainfall events in an 830-acre agricultural watershed near West Lafayette, Indiana. GRASS tools, written in the C programming language, were used to calculate flow direction and slope lengths from digital elevation model data, determine SCS curve number values for each ANSWERS cell, and develop soil property data layers from soil series data layers.

For four separate rainfall events, the simulated (ANSWERS) hydrologic responses were found to correlate closely with actual hydrograph responses in the watershed. Predicted sediment loads from ANSWERS, however, were significantly and consistently less than actual measured loads. This research showed that rough estimates for ANSWERS input parameters, as calculated in GRASS, were sufficient for the prediction of hydrologic response, but not for predicting sediment loads (Engel et al., 1993).

SWAT

The Soil Water and Assessment Tool (SWAT; Arnold et al., 1993) was developed as an extension to the Simulator for Water Resources in Rural Basins (SWRRB; Williams et al., 1985) at the Texas Water Resource Institute in College Station, Texas. SWAT is a continuous spatially distributed watershed model operating on a daily time step. It simulates runoff, sediment, nutrient, and pesticide movement through a watershed and aids in assessing water supplies and nonpoint source pollution in large basins (Arnold et al., 1993).

SWAT was one of the nonpoint source pollution water quality models assessed in the comparison of Engel et al. (1993). As with the ANSWERS model, input parameters were calculated in GRASS and provided to the SWAT model. SWAT estimates for total runoff and nutrient and sediment loads were less accurate than the ANSWERS simulated values.

Jacobson et al. (1995) also used a coupling of GRASS and SWAT in their evaluation of water quality impacts of diverse crops and management practices in the Herring Marsh Run Watershed in the North Carolina Coastal Plain. For this study, GRASS was used to input data for the SWAT model. The resultant monthly stream flows predicted by SWAT were seen to be adequate, but nitrate-nitrogen loading values were not.

Other Models

Other water quality models have been coupled with GIS for a variety of purposes. Kern and Stednick (1993) used Arc/Info with a metal speciation model (MINTEQA2) to develop the Chemical-Hydrologic Resource Information System (CHRIS). CHRIS was then used in the Upper Arkansas River catchment to identify heavy metal species concentrations in specified stream reaches and to associate water quality analyses with landscape elements in the basin.

The GRASS GIS has also been used extensively in combination with other water quality models. In an effort to provide for easier assessment of downstream hydrologic and sedimentation impacts, Hodge et al. (1988) linked GRASS with the ARMSED model of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). ARMSED is an adapted version of the Multiple Watershed Sediment Routine (MULTSED) model, which was developed jointly by Colorado State University and New Mexico State University personnel.

Matlock et al. (1995) used GRASS as a data storage and display medium in the development of the Spatially Integrated Model for Phosphorus Loading and Erosion (SIMPLE). SIMPLE was then used to characterize nonpoint source contributions of phosphorus at a watershed scale.

Less recognized GIS programs have also been used for nonpoint source pollution modeling. Klaghofer et al. (1993) linked AGNPS and the Erosion Productivity Impact Calculator (EPIC; Williams et al., 1993) to Clark University's IDRISI GIS (Eastman, 1990) to estimate sediment and nutrient transport resultant from runoff processes. In The Netherlands, Molenaar et al. (1993) used data layers from an unnamed GIS, integrated them into a system called the Integrated River

Information System (IRIS), and used IRIS for the identification and quantification of transboundary pollutant sources and loads.

2.2   GIS-Based Nonpoint Source Pollution Models

In their investigation of alternative management strategies for reduction of sediment pollution using the combined AGNPS-Arc/Info model, Tim and Jolly (1994) refer to three potential levels of integrating GIS with hydrologic/water quality models. For the first level of integration, known as Ad-hoc integration, the GIS and the Model are developed separately and are executed independently. The GIS serves only as a pre-processor of the input data for the model. Most of the studies discussed in section 2.1 fall into this category.

The second level of integration - partial integration - is the result of establishing an interactive interface between the GIS and the model. In this level of integration, the GIS provides input data to the model, but also accepts modeling results from the model for further processing and/or presentation.

The third level of integration is typically referred to as complete integration or "modeling within GIS". For this level of integration, the functionality of the hydrologic/water quality model is implemented or programmed directly into the GIS, so that data pre-processing and analytical functions are performed under the same operating system. This level of integration is technically preferred by most modelers, but is often difficult to implement, due to incompatibilities in the data structures of the model and the GIS, or due to proprietary rights of commercial GIS software limiting the introduction of additional processing routines.

Figure 2.1 shows schematic illustrations of the three potential levels of integration for GIS and hydrologic/water quality models. This section describes some hydrologic and nonpoint source pollution modeling efforts employing either partial or complete integration with a GIS.

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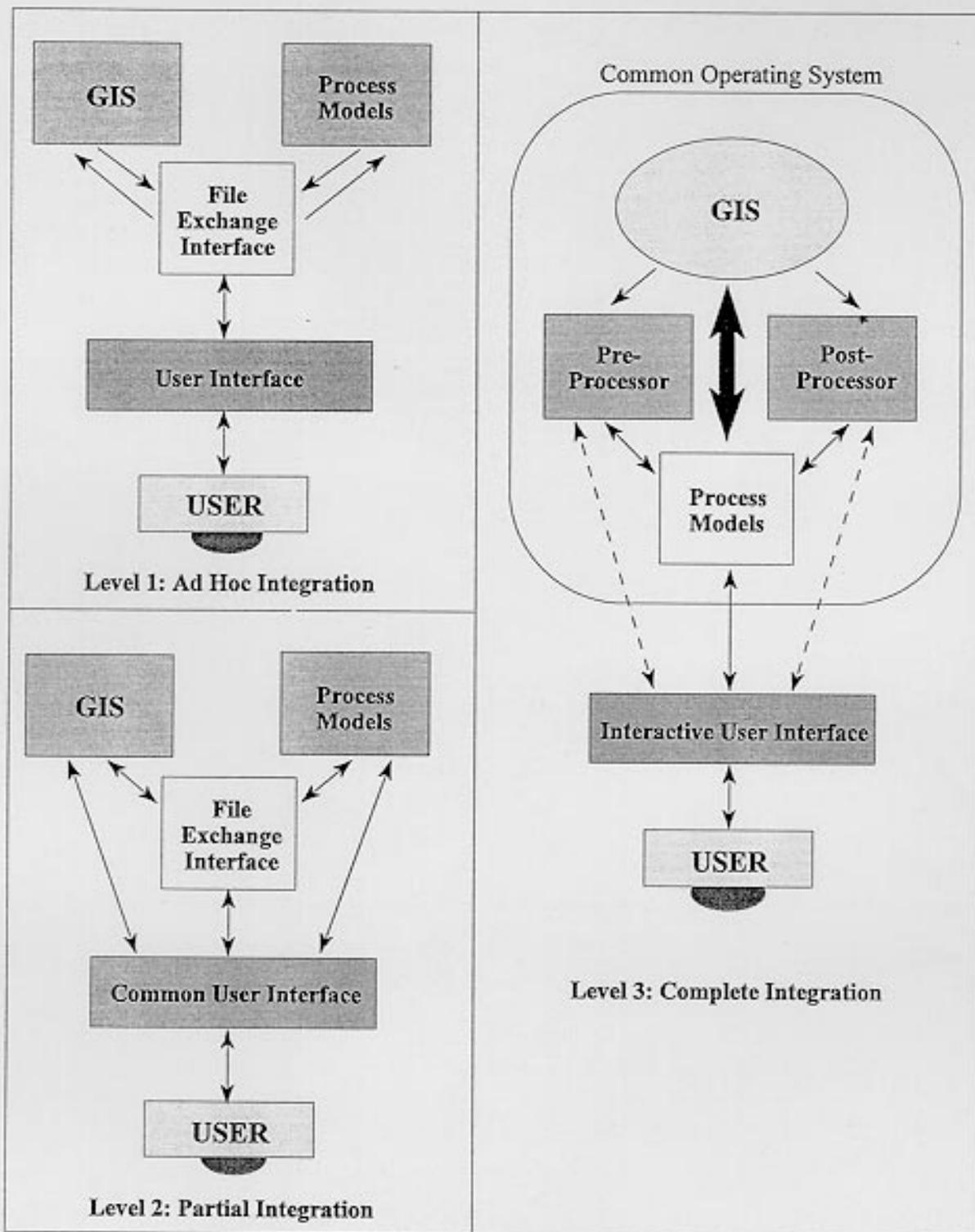
Figure 2.1 : Levels of Integration of GIS and Simulation Models
(Source: Tim and Jolly, 1994)

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Partial Integration

Tim and Jolly (1994) refer to their own investigation as a partial integration of the Arc/Info GIS with AGNPS. For this study, the AGNPS input data was created in Arc/Info through manipulation of topography, hydrography, soil, land cover, land management and climate data coverages. These vector data sets were converted into raster data units corresponding to the AGNPS cell size. Once the data was provided to AGNPS and execution of the model was performed, the output was fed back into Arc/Info for subsequent analysis and presentation.

Kim and Ventura (1993) used an unnamed GIS, along with the Source Loading and Management Model (SLAMM), to identify critical areas of excessive nonpoint source pollutant loadings in the urban portion of southern Milwaukee County, Wisconsin. Contrasting with most of the studies discussed in section 2.1, most of the analytical processing in this study was performed in the GIS, with SLAMM used to estimate runoff volumes and pollutant loadings from individual rainfall events for each land use polygon in the study area. The GIS was then used to accumulate the calculated loads of phosphorus, zinc, copper, lead, cadmium, and sediment for each digitally delineated sewer sub-basin in the watershed.

Complete Integration

Stuebe and Johnston (1990) modeled rainfall runoff directly into the GRASS GIS for six watersheds in Lawrence County, South Dakota. Starting with elevation, soils, and land cover data, GRASS was used to connect the soils and land use data layers to 30-meter resolution raster map layers corresponding to the digital elevation model grid cells. The soils grid was reclassified to create a grid of hydrologic soil group values and the land use grid was reclassified to assign Soil Conservation Service (SCS) curve number values to each discrete 30-meter grid cell.

Then, using the SCS curve number model, map layers of potential abstraction and runoff from each 30-meter grid cell were established. The watersheds of the region were digitally delineated using GRASS's internal Gwatershed program. Finally, the grid cell-based surface runoff values determined from the curve number method

were accumulated throughout the digital basin to establish values of runoff at each watershed outlet point (Stuebe and Johnston, 1990).

Completely integrated GIS models of the Universal Soil Loss Equation (USLE) have also been created. Hession and Shanholtz (1988) created the Virginia Geographic Information System (VirGIS), incorporating the USLE and a sediment delivery ratio, for the estimation of potential sediment loadings to streams from agricultural lands. Separate land use-based map layers were created for rainfall erosivity factor, soil erodibility factor, slope length, cover and management factor, and conservation practice factor. Each of these parameters are components of the USLE, and a value for soil loss per unit area was determined by combining them. Sediment delivery ratio for each land use cell was also determined as a function of the relief and slope in each cell.

Potential sediment loading from each cell was determined as the product of the soil loss per unit area and the delivery ratio. Finally, a Pollution Density Index for each modeled watershed was calculated as the sum of all cell-based potential sediment loadings in the watershed divided by the number of cells there (Hession and Shanholtz, 1988).

Heidtke and Auer (1993) also modeled the USLE in a GIS developed and maintained by the Cayuga County Planning Board in Upstate New York. The GIS was used to build a matrix of land use areas, specified by soil texture and surface slope, for six sub-basins draining to Owasco Lake. The USLE was used, with the appropriate factors indexed by the soil and slope data, to calculate annual soil erosion from each sub-basin. Unit area phosphorus load from each sub-basin was determined by multiplying the annual soil erosion by typical phosphorus concentration values obtained from in situ soil chemistry measurements for each soil type. As a result of this implementation, a simple GIS-based model for prediction of annual phosphorus loads to Owasco Lake was established.

Zollweg et al. (1995) created another GIS-based phosphorus loading model for the 25.7-hectare Brown Watershed near Harrisburg, Pennsylvania. For this study, the Soil Moisture-based Runoff Model (SMoRMod) was rehosted within the GRASS GIS. SMoRMod is an event-based, distributed model of watershed processes, including infiltration, soil moisture redistribution, groundwater flows, and surface runoff. SMoRMod also accounts for variable source areas, which are defined as

runoff contributing regions within a watershed that expand and contract during storm events, providing variable amounts of runoff over the length of the event (Ward, 1984).

Through use of the GRASS GIS, aerial distributions of simulated runoff and phosphorus losses were produced, allowing for the identification of zones of runoff and phosphorus production. The GRASS-hosted SMoRMod algorithm was also modified to implement various land management practices throughout the watershed. This allowed for an assessment of the phosphorus load reducing capabilities of each practice (Zollweg et al., 1995).

Newell et al. (1992) performed an assessment of nonpoint sources and loadings to the Galveston Bay in Texas, as part of a Galveston Bay National Estuary Program study. The assessment was done completely within the Arc/Info GIS and was executed for a list of 15 pollutant constituents, including heavy metals, nutrients, total suspended solids, biochemical oxygen demand, and fecal coliform. For this study, subwatersheds within the study area were manually digitized from USGS 7.5-minute quadrangle maps. Annual runoff values were then established for each subwatershed, using the GIS-modeled SCS curve number method, with precipitation, soil type, land use, and curve number data as inputs to the model. Annual runoff values were calculated for typical wet, average, and dry years.

Typical pollutant constituent loadings for all three categories of runoff were calculated by associating pollutant event mean concentrations with land use polygons in each subwatershed. For each pollutant of interest, an average weighted event mean concentration was established in each subwatershed and multiplied by the annual runoff in that subwatershed to establish total nonpoint source loads of the pollutant (Newell et al., 1992).

The nonpoint source pollution assessment method described by Newell et al. (1992) resembles the method applied in this report more closely than do the approaches of the other studies cited in this section and section 2.1.

2.3   Earlier studies in the San Antonio-Nueces Coastal Basin

The modeling efforts discussed in sections 2.1 and 2.2 represent a diverse cross-section of approaches for simulating hydrologic and water quality parameters. Those investigations also represent a wide variety of study areas where the models have been implemented. These regions are chosen for various reasons, ranging from ease of implementation at the location to availability of an abundance of measurement data with which to compare model results. Frequently, however, study areas are chosen, not for the convenience of model implementation, but because a particular hydrologic or water quality problem exists there.

Complex natural hydrologic systems that are placed under some additional manufactured or man-made burden typically encounter such problems. The Texas Intracoastal Waterway, with its elaborate network of bays, estuaries, marshes, and barrier islands, is a complex hydrologic system made more complicated by the encroachment of industry, agriculture, and shipping throughout its length. In accordance with the greater potential for the occurrence of water quality problems, many hydrologic and water quality analyses have been conducted throughout the waterway. This section focuses on water quality modeling studies that have been performed in close proximity to the San Antonio-Nueces Coastal Basin, particularly in the estuarine regions near Copano Bay, Aransas Bay, and Corpus Christi Bay.

Estuarine water quality modeling of the Corpus Christi Bay dates back to at least the mid 1970's. In 1974, Penumalli et al. applied a model developed by the Texas Water Development Board (TWDB) called the Corpus Christi-Aransas-Copano Bay System Model. This model simulated the aerial shape of the bay network with a series of one square nautical mile grid cells (Figure 2.2). Hydraulic flow throughout the bay network was simulated using a finite difference method to model flow between cells, or segments.

For the same study, a mathematical water quality model was also created to represent conservative constituent transport between grid cells. A finite difference implementation was also employed for this model, accounting for spatial and temporal distributions of the mass concentration of a constituent (Penumalli et al., 1974).

Using these models, with boundary conditions implemented for all boundary cells in the discrete network, simulated phosphorus and nitrogen concentrations were
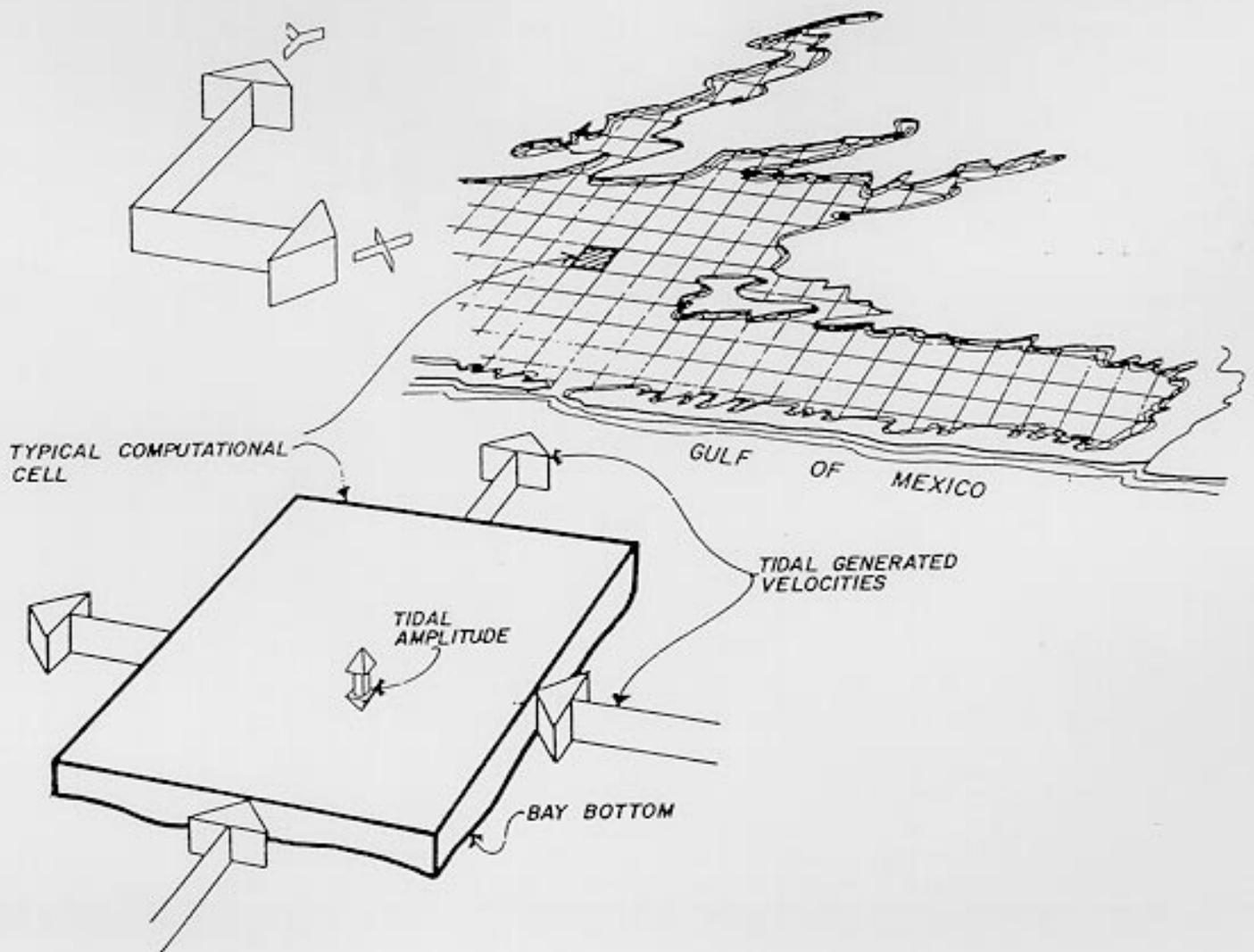
Figure 2.2 : Conceptual Illustration of Discretization of a Bay
(Source: Texas Department of Water Resources, 1981)

established for each grid cell. These concentrations were determined using estimated loadings of the nutrients for the year 1972. The results were compared with observed concentrations measured at various locations throughout the bay network and the models were adjusted for better agreement with the observed measurements. The final adjusted models were used to estimate nitrogen and phosphorus concentration profiles throughout the bay network for the years 1980 and 1990, using anticipated nutrient loadings for those years (Penumalli et al., 1974).

Lambert and Fruh (1976) used a modified version of a hydrodynamic mathematical model called HYDTID, along with a salinity transport model called LOTRAN, to help in the determination of minimum fresh water inflow requirements to Corpus Christi Bay. For the grid-cell representation of the bay, HYDTID and LOTRAN account for hydrodynamic circulation patterns, tidal effects, and vertical mixing, when provided with a varying fresh water inflow profile and a tide cycle period as inputs.

The combined HYDTID/LOTRAN model also accepts, as input parameters, aerial locations and magnitudes of return flows and diversion sources, average rainfall and gross evaporation, average wind speed and direction, aerial locations and magnitudes of excitation tides, and typical boundary condition salinity concentrations. Each of these parameters are provided as average values for a chosen time interval (typically monthly) of the model (Lambert and Fruh, 1976).

For this analysis, various model runs were performed, using monthly values of the input data parameters and fresh water inflow data from the period 1913-1962. By using the historical health profiles of certain aquatic indicator organisms local to Corpus Christi Bay for the same time period, assessments of the adequacy of the documented fresh water inflows were made. Finally, determinations of the minimum fresh water inflows required to maintain organism health were established (Lambert and Fruh, 1976).

Another study of fresh water inflows to the bay network was performed in 1981 by the Texas Department of Water Resources (TDWR). For this analysis, the TDWR used the same hydrodynamic and salinity transport mathematical models to assess the effects of fresh water inflows to the Nueces and Mission-Aransas estuaries. For the purposes of the investigation, this estuary system was defined as the portion of

the Texas Intracoastal Waterway including Nueces Bay, Corpus Christi Bay, Oso Bay, Redfish Bay, Aransas Bay, Copano Bay, and Mission Bay (Figure 2.3).

Annual and monthly average values of fresh water inflows over the period from 1941 to 1976 were used as inputs to the model. Water quality of these inflows was determined by comparison with measured data from USGS gauging stations on Copano Creek, Mission River, Chiltipin Creek, Nueces River, and Oso Creek. As a result of this modeling effort, simulated salinities were generally seen to be within five parts per thousand of observed salinities. Exceedences of this value were consistently seen for the Nueces Bay area, where additional unmodeled industrial brine discharges were suspected of contributing to elevated salinities during periods of low flow (TDWR, 1981).

The TDWR study also included a fresh water inflow/salinity regression analysis in an attempt to determine mathematical relationships applicable at different points within the bay network. The regression analysis resulted in the establishment of two geometric series relationships for monthly average salinity and monthly gauged flow. Using these relationships, salinities were estimated for gauged streamflow into the Nueces Bay and Copano Bay (TDWR, 1981).

The Texas Natural Resource Conservation Commission (TNRCC) published a study of water quality in the Nueces Coastal Basins in 1994. In an effort to identify areas with a high potential risk of nonpoint source loadings, the TNRCC used Arc/Info for the establishment of a nonpoint source pollution potential index. This index was determined by considering components related to soil type, land use, and landscape features such as soil permeability, slope, and soil erodibility.

Components of the nonpoint source pollution potential index are based on the Revised Universal Soil Loss Equation (RUSLE; Renard et al., 1993). For each of the elements of this equation, a separate Arc/Info layer was created with element values assigned to the reclassified polygons from the original source map. For example, values for the soil erodibility an slope steepness layers were assigned to polygons from the initial soils map. In addition to the elements from the RUSLE, the nonpoint source pollution potential index also includes factors accounting for land use potential to permanently degrade receiving waters and land use potential to supply non-sediment related hazardous pollutants, such as pesticides or heavy metals. Separate Arc/Info layers for each of these factors were also created (TNRCC, 1994).
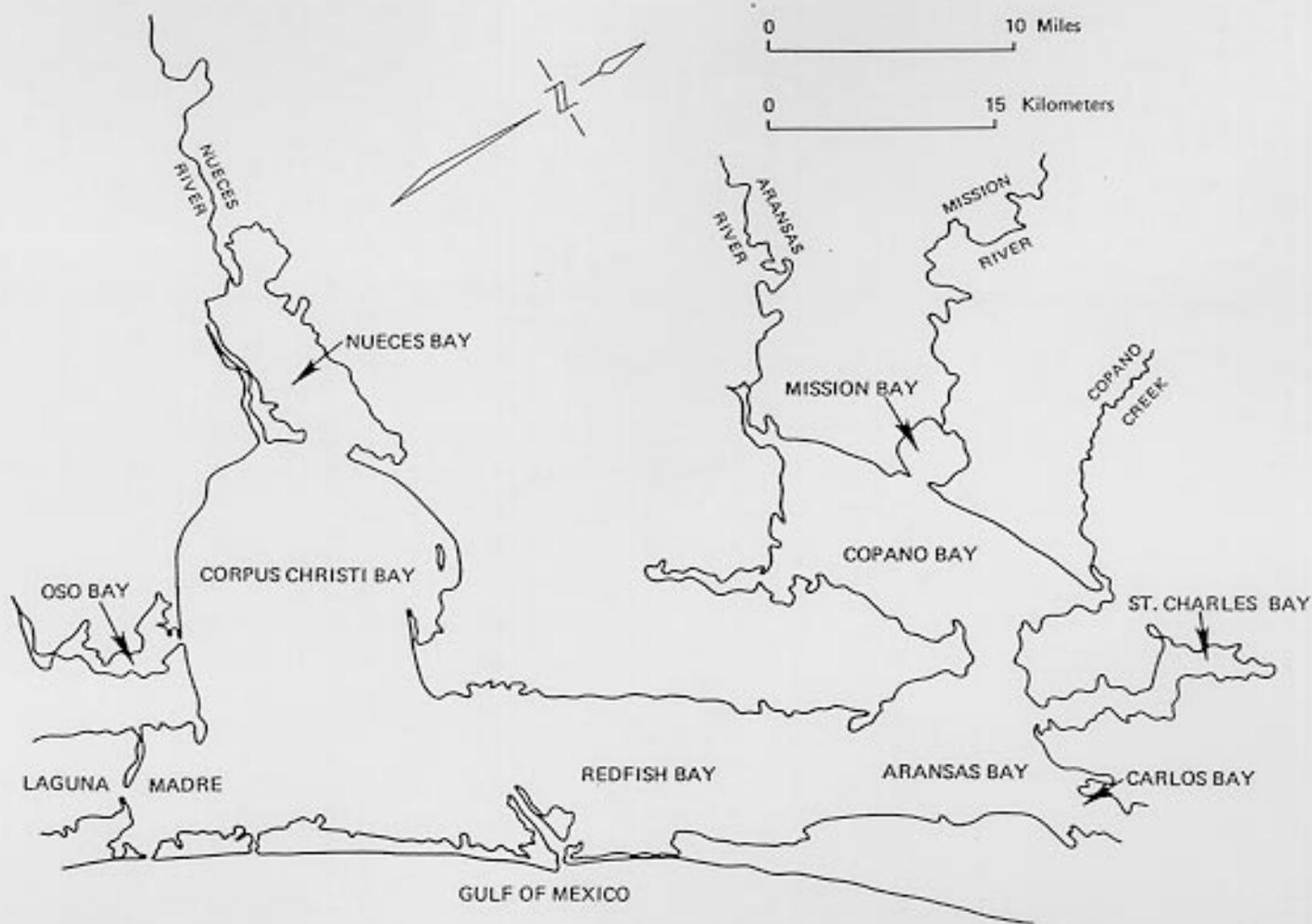
Figure 2.3 : Nueces and Mission-Aransas Estuaries (Source: Texas Department of Water Resources, 1981)

The product of the RUSLE elements and the other factors provided values for the nonpoint source pollution potential index. Through application of this index to the study areas of the San Antonio-Nueces and Nueces-Rio-Grande Coastal Basins, the TNRCC concluded that the region generally had a moderate potential for nonpoint pollutant sources, but that areas of higher potential existed for agricultural land uses in regions of maximum slope and erodible soils (TNRCC, 1994).

Most recently, Baird et al., (1996) used SWAT and HSPF in a comparison of each model's effectiveness in the assessment of nonpoint source pollution. This comparison was performed on the Oso Creek watershed in southern Nueces County, as part of a Corpus Christi Bay National Estuary Program study. Both models were calibrated for the period of 1987 through 1992, using rainfall data from three gauges in the watershed and streamflow data from the USGS Oso Creek gauge, which drains the upper 39% of the watershed.

The SWAT model was used to simulate streamflow at the Oso Creek gauge, with rainfall data from two of the three precipitation gauges used as input. Agricultural cropping profiles, along with tillage management practices for the fallow period, were also applied as inputs. As a result of this modeling effort, average annual predicted streamflow was determined to be approximately 10% less than the average observed streamflow over the period between 1987 and 1992. Predicted streamflow values for each individual year between 1986 and 1993 showed errors in excess of 80%, when compared with observed annual streamflow values (Baird et al., 1996).

HSPF was used to model both streamflow and loadings of nutrients and sediments. Model parameters were calibrated for the upper portion of the watershed and then applied to the entire watershed for the estimation of runoff and loadings to Corpus Christi Bay. Rainfall data from the most central of the three precipitation gauges was applied across the watershed. The average annual predicted streamflow calculated by HSPF was within 0.4% of the average observed value over the period from 1987 to 1992. As with the SWAT model, however, predicted stream flow values for individual years showed more significant errors of up to 68% (Baird et al., 1996).

Nutrient and sediment loadings were predicted by the HSPF model by applying expected mean concentration values to land uses in the Oso Creek watershed, determining the percentage of each land use within the watershed, calculating the

corresponding percentages of the total runoff from each land use type, and multiplying the pollutant expected mean concentration values by the land use-based runoff values. This process resulted in sets of land use-based loads for each month in the eight year modeling period. Summation of the land use-based loads resulted in a total load of pollutant from the watershed. Variability of the loadings from year to year naturally corresponded to the observed variability of streamflows from year to year (Baird et al., 1996). Overall, the HSPF model was seen to be more robust and to provide more accurate results than the SWAT model.

3   DATA DESCRIPTION

This study uses raster and vector data sets that are publicly available from a variety of sources. Raster data sets have values stored in a uniform rectangular array and are typically referred to as grids. A digital elevation model is an example of a raster data set. Vector data sets include points, lines, and/or polygons and are typically referred to as coverages. A point coverage includes data represented by single coordinate values, such as locations of streamflow gauges. Line coverages, such as stream networks, are defined by series of points, with nodes specified as the starting and ending points of each line. Polygon coverages, such as watershed boundaries, are made up of connected sequences of lines. Vector data sets also have associated tables of values that describe the geographic features they represent. (Environmental Systems Research Institute, 1990).

Vector data layers can be converted into raster data layers (and vice versa) by using the conventions that a point may be represented as a single grid cell, a line may be represented as a string of grid cells, and a polygon may be represented as a zone of cells. The Arc/Info GIS supports the transformations between these raster and vector data sets.

3.1   Map Projection

A standard map projection is needed for any study where the superposition and spatial analysis of geographic data from different sources is performed. Spatial data sets are typically available at various map scales and in different coordinate systems. Arc/Info GIS allows for the successful adjoining of spatial data, even if the data are of different spatial scales, as long as that data have common datum and map projections. Arc/Info also allows for conversion from one map projection to another.

The Texas State Mapping System, which is sometimes referred to as the Shackleford State Mapping System, is defined using a Lambert conformal conic projection, which preserves shapes on a map. For this study, a map projection that preserves area, such as the Albers equal-area conic projection, is preferred to the Lambert projection because it simplifies computations of water and mass balances

over a region (Snyder, 1987). Thus, a hybrid map projection is used for the study, called the Texas State Mapping System-Albers (TSMS-Albers) projection. A list of the TSMS-Albers projection parameters is shown in Table 3.1.

The North American Datum of 1983 (NAD83) uses the Geodetic Reference System of 1980 (GRS80) ellipsoid as a reference ellipsoid defining orientation relative to the geoid of Earth. The Texas State Mapping System projection uses this datum instead of the North American Datum of 1927 (NAD27), which uses the older Clarke (1866) ellipsoid as a reference (Snyder, 1987).

3.2 Establishing a Digital Database

The establishment of a watershed digital description involves the assembly of the data that is ultimately used for each of the subsequent steps of the assessment. Table 3.2 summarizes the data sources used in this study and provides Internet addresses for obtaining the data. Procedures for accessing this data can be obtained from the University of Texas at Austin GIS Hydrologic Modeling World Wide Web site at http://civil.ce.utexas.edu/prof/maidment/gishydro/.

This section describes each of the data sets and provides a discussion of how they are managed in order to extract the data specific to the San Antonio-Nueces Coastal Basin.   A running narrative of the steps performed is provided along with the

Projection:	Albers
Datum:	NAD83
Units:	meters
Spheroid:	GRS1980
1st Standard Parallel:	27 25 0.00
2nd Standard Parallel:	34 55 0.00
Central Meridian	-100 0 0.00
Latitude of Origin:	31 10 0.00
False Easting (m):	1,000,000
False Northing (m):	1,000,000

Table 3.1 : Texas State Mapping System-Albers Projection Parameters

DATA SOURCE	INTERNET ADDRESS
Digital Elevation Models (DEMs)	http://sun1.cr.usgs.gov/eros-home.html
Hydrography Digital Line Graphs	http://sun1.cr.usgs.gov/eros-home.html
Hydrologic Unit Codes (HUCs)	http://h2o.er.usgs.gov/nsdi/wais/water/huc250.HTML
Land Use/Land Cover (LULC) Files	http://www.epa.gov/epahome/search.html
USGS Daily Discharge Values	http://txwww.cr.usgs.gov/cgi-bin/nwis1_server
USGS Stream Gauge Locations	http://txwww.cr.usgs.gov/cgi-bin/nwis1_server
Precipitation Grids	fsl.orst.edu (anonymous ftp site)
Expected Mean Concentration values	CCBNEP (not available via Internet)
Water Quality Measurement Data	tnris.twdb.state.tx.us (anonymous ftp site)

Table 3.2 : Internet Addresses for Data Sources

actual Arc/Info and UNIX commands. This format provides the reader insight into
the specific steps performed and describes the theoretical bases for each procedure.
In addition, some of the steps in this chapter are more efficiently performed via
automated Arc Macro Language (AML) scripts. Where appropriate, these AMLs are
referenced and included in Appendix B.

Hydrologic Unit Codes (HUCs)

Watersheds typically define the boundaries of a hydrologic study. Reasonable
approximations of the drainage basin boundaries in the United States are available
through the USGS 1:250,000-scale Hydrologic Unit Codes (HUCs). This data was
created through digitization of a combination of 1:250,000-, 1:100,000-, and
1:2,000,000-scale Hydrologic Unit Maps, which divide the United States into 21 major
hydrologic regions and further subdivide the regions into subregions, accounting units,
and cataloging units. Each of these subdivisions are uniquely identified by two-digit
fields contained within an eight-digit attribute code referred to as the Hydrologic Unit
Code. The first two digits in the code identify water resources region; the first four
digits identify subregion; the first six digits identify accounting unit; and the whole
eight-digit code identifies the cataloging unit (Steeves and Nebert, 1994).

The Hydrologic Unit Codes are available on Internet from the USGS in an
Albers equal area conical projection (see Table 3.2 for address). The San Antonio-
Nueces Coastal Basin HUCs are not specifically required data for the nonpoint source

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pollution assessment, but they do provide a useful frame of reference for comparison with the digitally delineated versions of the basin and subwatersheds (see Figure 3.1).

The Hydrologic Unit Codes start as Arc/Info interchange files (denoted by a file extension of .e00). A coverage is created from the interchange file through use of the Arc/Info Import command:

Arc: **import cover huc250.e00 huc250**

The huc250 coverage is displayed in the ArcView 2.0 program and the regional location of the San Antonio-Nueces coastal basin is magnified. Through use of the ArcView query builder, five polygons that approximate the basin are identified. Using ArcView Tables, the eight-digit Hydrologic Unit Code for each of the polygons is determined and recorded. Table 3.3 lists the five Hydrologic Unit Codes that approximate the San Antonio-Nueces coastal basin.

To create a new Hydrologic Unit Code coverage including only the five San Antonio-Nueces polygons, the Arc/Info Reselect command is invoked. Through use of the re-select and add-select features of the command, the HUCs with values between 12100404 and 12100407 are chosen and then appended with the code of 12110201. The new coverage is then converted into the desired TSMS-Albers projection and polygon topology is restored with the Arc/Info Clean command:

```
Arc:  reselect huc250 hucs
>:  res huc >= 12100404
>:  ~    <return>
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
>:  asel huc = 12110201
>:  ~
Do you wish to re-enter expression?(Y/N):  n
Do you wish to enter another expression? (Y/N):  n
          5 features out of 2157 selected
Arc:  project cover hucs hucsan alb-tsms.prj
Arc:  clean hucsan sanhucs
```

Huc	Name
12100406	MISSION
12100405	ARANSAS BAY
12100404	WEST SAN ANTONIO BAY
12100407	ARANSAS
12110201	NORTH CORPUS CHRISTI BAY
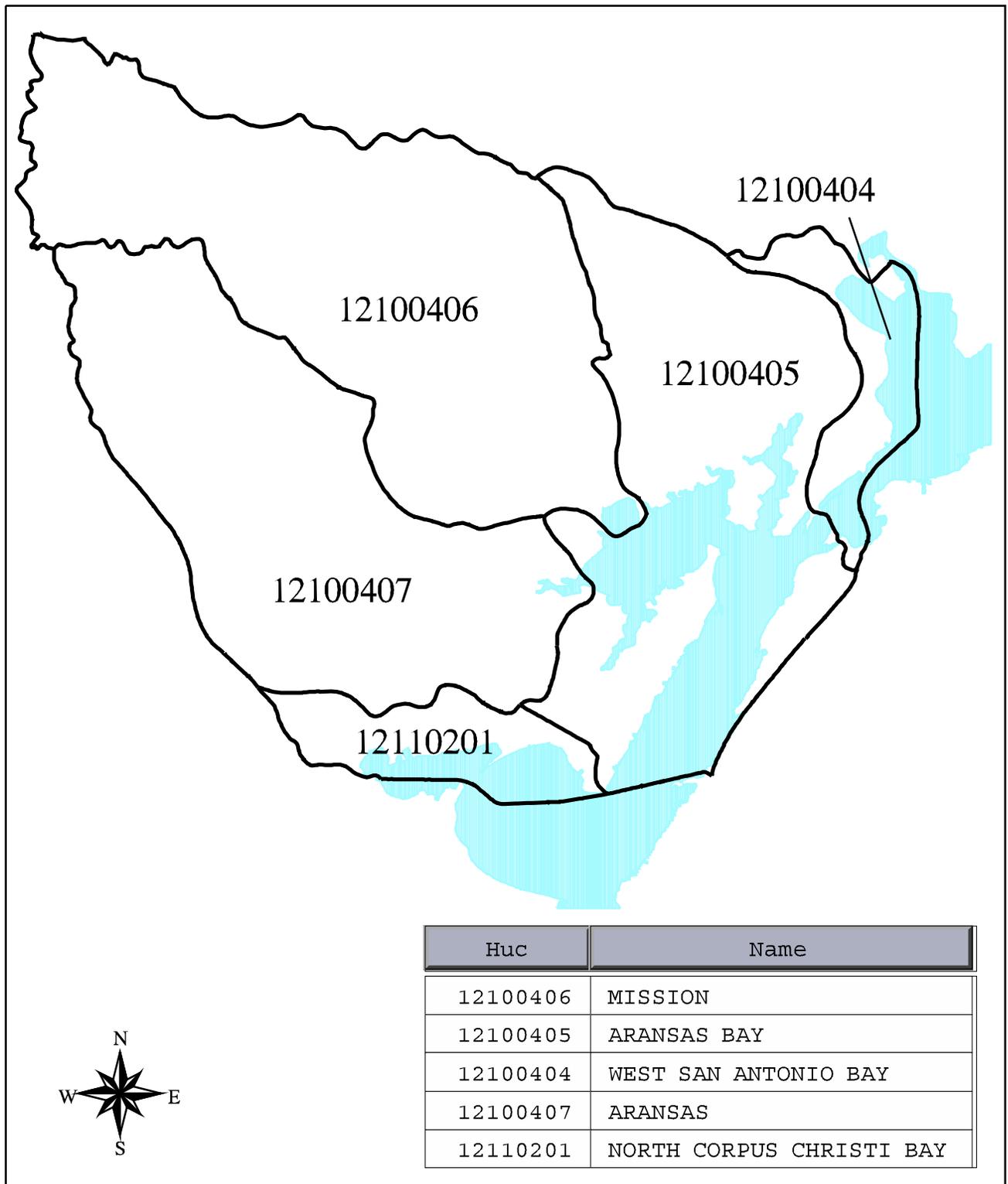
Figure 3.1 : Hydrologic Unit Codes of the
San Antonio-Nueces Coastal Basin

Hydrologic Unit Code	Name
12100404	West San Antonio Bay
12100405	Aransas Bay
12100406	Mission River
12100407	Aransas River
12110201	North Corpus Christi Bay

**Table 3.3 : Hydrologic Unit Codes Approximating the
San Antonio-Nueces Coastal Basin**

The above Project command makes use of a projection file (alb-tsms.prj) that specifies conversion from the national Albers projection to TSMS-Albers parameters. This projection file is included in Appendix B. The sanhucs coverage provides an initial approximation of the San Antonio-Nueces coastal basin boundaries. The sanhucs polygons and corresponding Hydrologic Unit Code values are displayed in Figure 3.1.

Hydrography Digital Line Graphs (DLGs)

The 1:100,000-scale Hydrography Digital Line Graph (DLG) data files are derived from USGS 30 x 60 minute quadrangle topographic maps and include stream networks, standing water, and coastlines as hydrographic features. These graphs are distributed in groups of files that cover a 30 x 30 minute area (the east or west half of the 1:100,000-scale source map). Typically, each 30-minute area is represented by four 15-minute files. Thus, each 30 x 60 minute quadrangle is represented by eight 15-minute files (USGS, 1989).

The 1:100,000 digital line graphs are available in either standard or optional format. The standard format has a larger logical record length (144 bytes) than the optional format (80 bytes), but is projected in an internal file coordinate system (thousandths of a map inch) that is not as easy to work with as the Universal Transverse Mercator (UTM) projection of the optional format (USGS, 1989). For this reason, the optional format hydrography digital line graphs are used in the San Antonio-Nueces Coastal Basin study.

In addition to hydrography, the USGS distributes 1:100,000-scale digital line graphs for roads, rail lines, and pipelines. These are all available publicly via the Internet address in Table 3.2. Alternatively, digital line graph files for the United States are available (in optional format) from the USGS Earth Science Information Center in a 14-volume Compact Disc-Read Only Memory (CD-ROM) set. For this analysis, the required hydrography 15-minute files were accessed and downloaded from Volume 8 (Texas and Oklahoma) of the CD-ROM series (USGS, 1993).

The Hydrography files for Texas are located in the 100k_dlg directory of the USGS 1:100,000-Scale Digital Line Graph Data CD-ROM (USGS, 1993). This directory contains separate subdirectories for each of the 1:100,000-scale USGS mapsheets (60' x 30') in Texas and Oklahoma. By cross-referencing the 1:100,000-Scale Digital Line Graph Index Map at the USGS EROS Data Center Internet World Wide Web site (Table 3.2) with a map of delineated watershed boundaries in Texas (USGS, 1985), five 1:100,000-scale mapsheets that completely overlay the watershed are identified (Figure 3.2). These mapsheets are: Beeville, Goliad, San Antonio Bay, Corpus Christi, and Allyns' Bight.

The hydrography files from each of the five mapsheet subdirectories are copied from the CD-ROM into a local UNIX workspace:

```
$:  cp /cdrom/100k_dlg/beeville/be3hydro.zip ./
$:  cp /cdrom/100k_dlg/sananbay/be4hydro.zip ./
$:  cp /cdrom/100k_dlg/goliad/be1hydro.zip ./
$:  cp /cdrom/100k_dlg/corpus_c/cc1hydro.zip ./
$:  cp /cdrom/100k_dlg/allyns/cc2hydro.zip ./
```

Each of these files exist in a compressed (zipped) format. Uncompressing them creates eight 15-minute (1:62,500-scale) coverages, arranged in a 2-row by 4-column format. For example:

```
$:  unzip be3hydro.zip
Exploding:  be3hyf01
Exploding:  be3hyf02
         :          :
Exploding:  be3hyf08
```

Once all five hydrography files are unzipped, forty separate 15-minute map coverages exist. Through consultation with an atlas (USGS, 1970), the number of
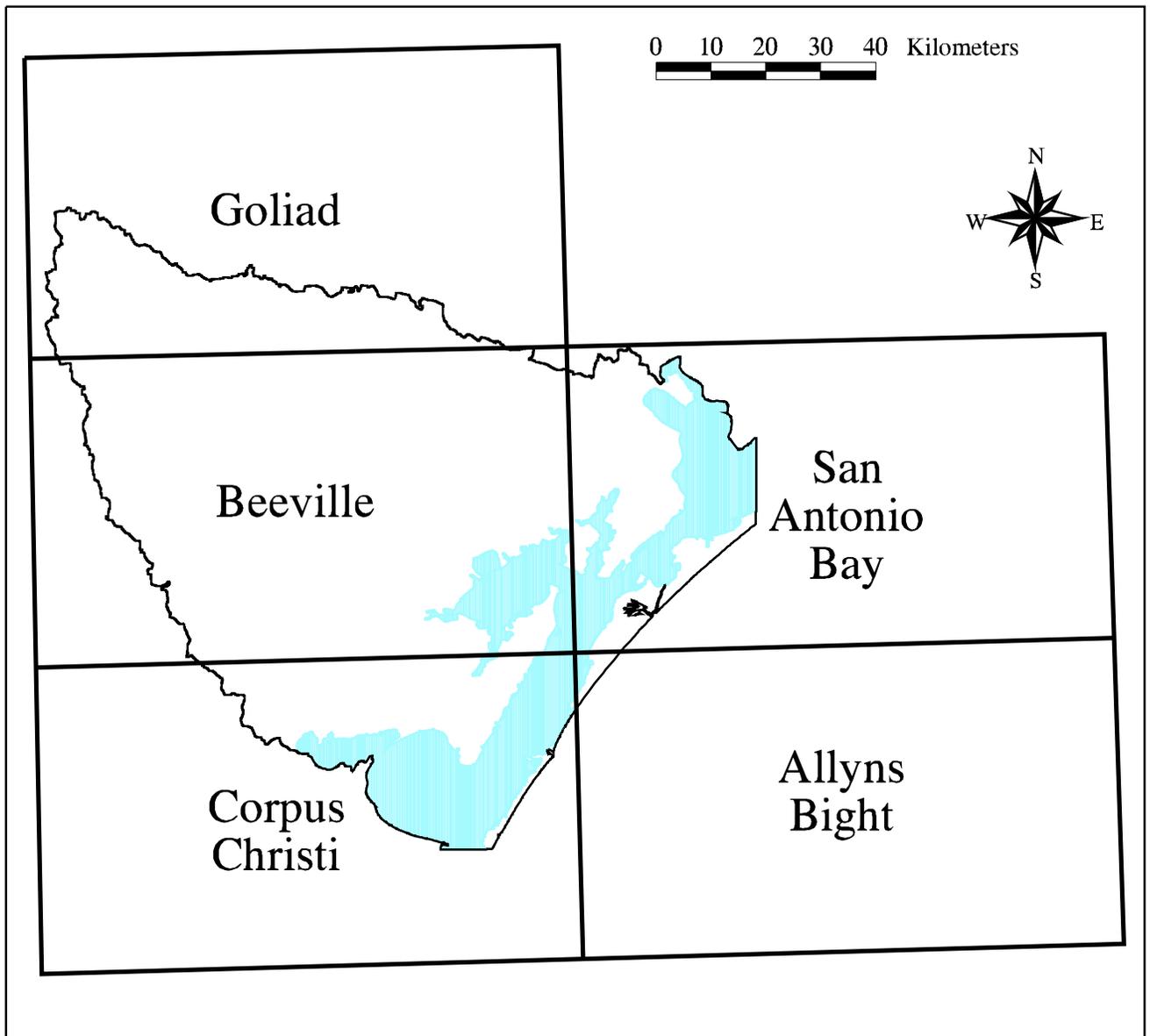
Figure 3.2 : USGS 1:100,000-Scale Mapsheets Covering the
San Antonio-Nueces Coastal Basin

these coverages required to completely overlay the San Antonio-Nueces Coastal Basin is determined as eighteen. These map coverages include all 8 associated with the Beeville mapsheet, maps 5-8 from the Goliad mapsheet, maps 2-4 from the Corpus Christi mapsheet, maps 1 & 5 from San Antonio Bay, and map 1 from Allyns' Bight.

Before manipulation of the hydrography coverages can be performed, each of the 18 maps must be converted from its digital line graph format to an Arc/Info format. The Dlgarc command, with the optional format argument specified, is used for this purpose. Once converted, line topology is restored to each new Arc/Info coverage through application of the Build command. For example, conversion of the first Beeville 15-minute coverage is performed as:

Arc: **dlgarc optional be3hyf01 beef01**
Arc: **build beef01 line**

Each of the 15-minute hydrography coverages contain lines representing the streams, lakes, and coastlines associated with a particular map. A border around each coverage, representing 15-minute meridians and parallels, is also included. If all of these maps were merged together into a single coverage of the basin hydrography, the 15-minute meridians and parallels would be included. Alternatively, these border lines may be removed. This is performed by acknowledging that all arcs in a line coverage have a left polygon number and right polygon number field associated with them and that the value of the exterior polygon in a coverage is always defined as one. Using this information, the meridians and parallels can be trimmed away from each coverage through use of the Reselect command. Using the first Beeville 15-minute coverage as an example:

Arc: **reselect beef01 bee1 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**
        187 features out of 240 selected

Once the meridian/parallel removal process is performed on all 18 hydrography coverages, they can be joined together using the Append command. Line topology is added with the Build command and the appended coverage is then converted from its initial Universal Transverse Mercator projection to TSMS-Albers parameters using the projection file, utmtsms.prj (included in Appendix B).

```
Arc:  append sanutm
Enter the 1st coverage:  bee1
Enter the 2nd coverage:  bee2
         :         :
Enter the 18th coverage:  allyn1
Enter the 19th coverage:  ~
Done entering coverage names (Y/N)?  y
Do you wish to use the above coverages (Y/N)?  y

Appending coverages.....
Arc:  build sanutm line
Arc:  project cover sanutm sanhydro utmtsms.prj
```

This procedure is much more efficiently performed using an AML. Dlgmerge.aml, is used to convert individual files from the 30' x 60' mapsheet subdirectories into a single coverage and is inlcuded in Appendix B. Figure 3.3 shows the final hydrography coverage, sanhydro, as clipped by a coverage of the basin boundary, which is created as per discussion in Chapter 4.

Digital Elevation Models (DEMs)

Three-arc second (3") digital elevation models (DEMs) are created by the Defense Mapping Agency by first digitizing cartographic maps ranging in scale from 1:24,000 to 1:250,000, and then processing elevation data from these digitized maps into a rectangular matrix format. The USGS distributes digital elevation models (via the Internet site noted in Table 3.2) in 1° x 1° blocks that correspond to either the eastern or western half of a USGS 1:250,000-scale map sheet. The models contain elevation data points at 3" intervals, or 20 elevation data points per minute. With 60 minutes per degree, each digital elevation model contains 1201 rows and 1201 columns of data (including the data points on the whole degree latitudes and longitudes, which are repeated in adjacent 1° x 1° grids) (USGS, 1990).
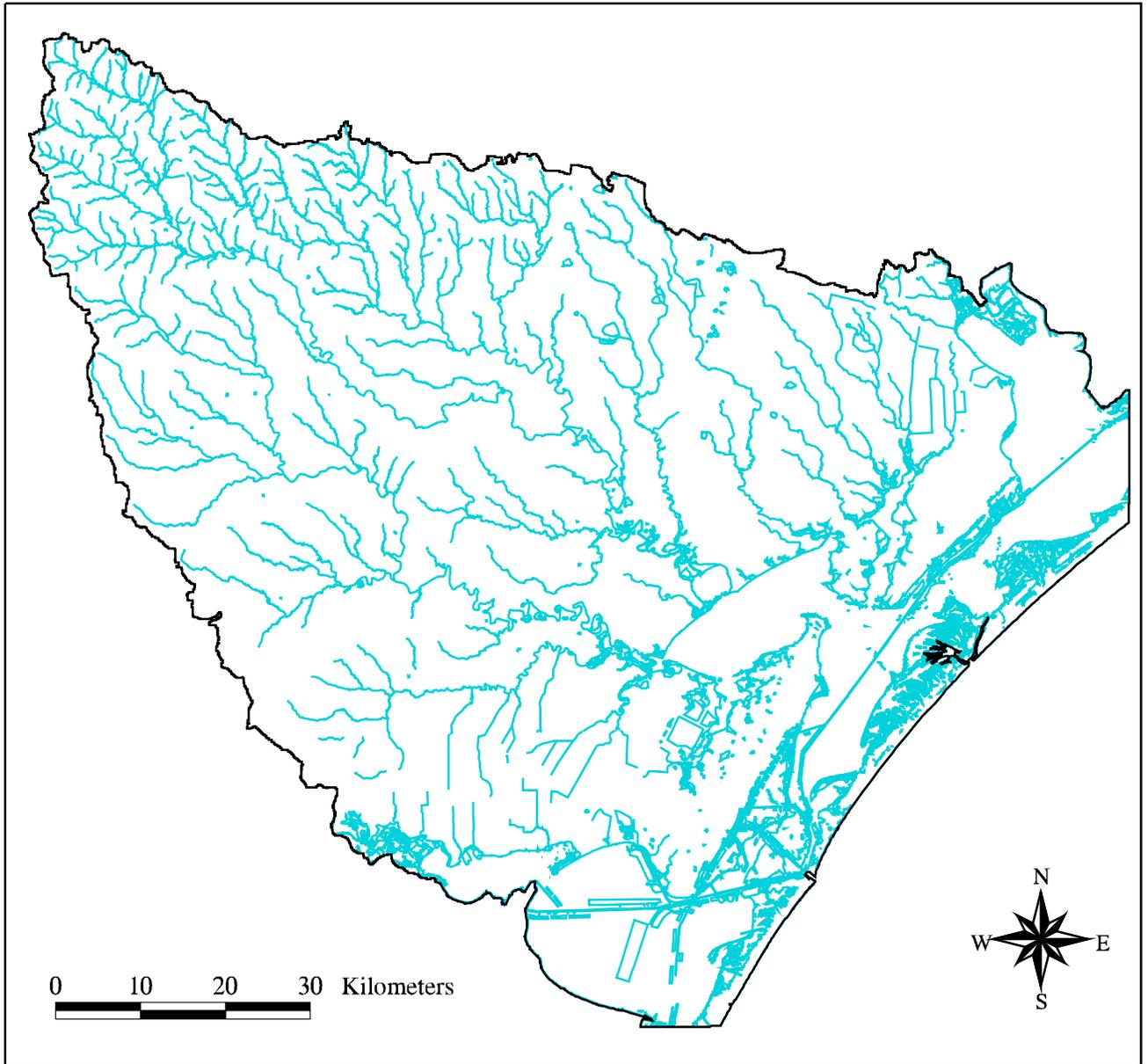
Figure 3.3 : 1-100,000-Scale Hydrography Digital Line Graphs
of the San Antonio-Nueces Coastal Basin

Because the meridians of longitude converge at the poles, the latitudinal distance between 3" data points decreases as one moves north or south away from the equator. The distance along the surface of the earth at a specific radian of latitude ($L\lambda$) can be calculated as $L\lambda = R\cos\phi$, where R (Earth's radius) = 6371.2 km and ϕ = latitude. The distance between 3" elevation points at that latitude can then be calculated as ($L\lambda * \pi/180°$)/1200 (Reed and Maidment, 1995). For the San Antonio-Nueces Coastal Basin, which is bisected by the 28° North parallel, the latitudinal distance between elevation points is

$$[6371.2 \text{ m} * \cos(28°) * \pi/180°]/1200 = 81.8 \text{ meters} \tag{3-1}$$

and the longitudinal distance between points is

$$(6371.2 \text{ m} * \pi/180°)/1200 = 92.67 \text{ meters}. \tag{3-2}$$

For use in a hydrologic analysis, digital elevation model data is first reprojected from geographic coordinates to a flat map coordinate system, in which horizontal dimensions can be measured in units of length and slopes can then be calculated by comparison with elevation values, also in units of length. When the digital elevation model is reprojected, a new grid is created by resampling the data at uniform intervals in the new projection. For example, a 3" x 3" geographic grid cell size is typically converted into a 100 m x 100 m flat map grid cell size.

Three arc-second (3") digital elevation models are available via the US Geodata section of the USGS EROS Data Center Internet World Wide Web site specified in Table 3.2. Each 1° x 1° model is identified by the east or west half of a 1:250,000-scale Index Map. For the San Antonio-Nueces basin, four digital elevation models (Beeville East/West and Corpus Christi East/West) are required to completely cover the watershed.

When accessing compressed versions of the digital elevation models, the local UNIX file extension should be defined to show that the file is compressed (.gz). Compressed files can be uncompressed using the UNIX gunzip utility. These files must then have their record lengths modified to a format that Arc/Info can recognize. The UNIX dd command adds a carriage return at the end of every 1024 bytes. For

example, these steps, as performed on the Beeville East digital elevation model appear as:

```
$: gunzip beevillee.dem.gz
$: dd if=beevillee.dem of=beeve cbs=1024 conv=unblock
```

where if = input file name, of = output file name, cbs = conversion buffer size, and "conv=unblock" specifies to allow for variable sized record lengths. Once these commands are performed for all four digital elevation models, the unblocked files can be converted into Arc/Info grids by using the Arc/Info Demlattice command:

```
Arc: demlattice beeve beedeme usgs
```

This creates a grid called beedeme from the input digital elevation model beeve, which is specified as existing in a standard USGS format.

After the four four grids are created, they are combined into one large digital elevation model using the Arc/Info Grid Merge function. The large digital elevation model is then converted from its initial geographic projection into the desired TSMS-Albers using the projection file al72tsms.prj (included in Appendix B), and specifying a grid cell size of 100 m.

A smaller digital elevation model that contains just the area corresponding to the San Antonio-Nueces Coastal Basin is created by using the previously created sanhucs coverage. A five-kilometer buffer is first established around the sanhucs boundary through use of the Arc/Info Buffer command. Then the Grid Setwindow command is used to reduce the analysis window to the mapextent of the buffered sanhucs coverage. Once this analysis window has been reduced, a new digital elevation model (sndemalb) is defined that contains the values of the larger model within the analysis window.

```
Arc: grid
Grid: bcdem = merge(beedeme,beedemw,corpdeme,corpdemw)
Grid: bcdemalb = project(bcdem,al72tsms.prj,#,100)
Grid: quit
Arc: buffer sanhucs hucbuff # # 5000
Arc: grid
Grid: setwindow hucbuff bcdemalb
Grid: sndemalb = bcdemalb
```

Figure 3.4 shows the gray-shaded digital elevation model overlayed with the USGS Hydrologic Unit Codes, the major streams from the 1:100,000-scale hydrography digital line graphs, and a coverage of the intracoastal waterway features near the basin.

Land Use/Land Cover (LULC) Files

The 1:250,000-scale Land Use/Land Cover (LULC) data files are GIS polygon coverages and were created by the USGS through manual interpretation of aerial photographs acquired from NASA high-altitude missions in the late 1970's. Digitization of the land use maps resulted in the creation of the Geographic Information Retrieval Analysis System (GIRAS) (USGS, 1986). The land use files are available electronically from the USGS (conforming to an Universal Transverse Mercator projection) and the EPA (conforming to an Albers equal area projection). For this study, the land use files are downloaded from the EPA Internet World Wide Web site. Procedures for accessing this data can be obtained from the University of Texas at Austin GIS Hydrologic Modeling World Wide Web site at http://civil.ce.utexas.edu/prof/maidment/gishydro/.

The land use files employ the Anderson Land Use Classification System, which identifies two-digit subcategories within the categories of urban, agricultural, range, forest, water, wetland, barren, tundra, and snowfield land uses (Anderson et al., 1976). While widely available and frequently used, this data set is significantly dated and is considered out of date by many municipalities conducting urban assessments. However, this data set is still considered to be fairly accurate for the San Antonio-Nueces Coastal Basin, which is largely rural.

The land use files are organized and accessible by their associated 1:250,000-scale USGS mapsheet name. Starting at the EPA Internet site identified in Table 3.2, the user performs a query on "land use". This query results in the display of the EPA WAIS Gateway page, where the user selects the EPA EPAGIRAS (HTML) link. Finally, at the EPAGIRAS Data Sets page, the user performs queries on the 1:250,000-scale mapsheet names of interest. Only two land use files (corresponding to the Beeville and Corpus Christi mapsheets) are required to cover the San Antonio-Nueces Coastal Basin. These files are downloaded as compressed Arc/Info interchange files and have extensions of .e00.gz.

Legend

- **USGS HUCs**
- **Digital Line Graph Streams**
- **Bay Network**

N

0   10   20   30   Kilometers
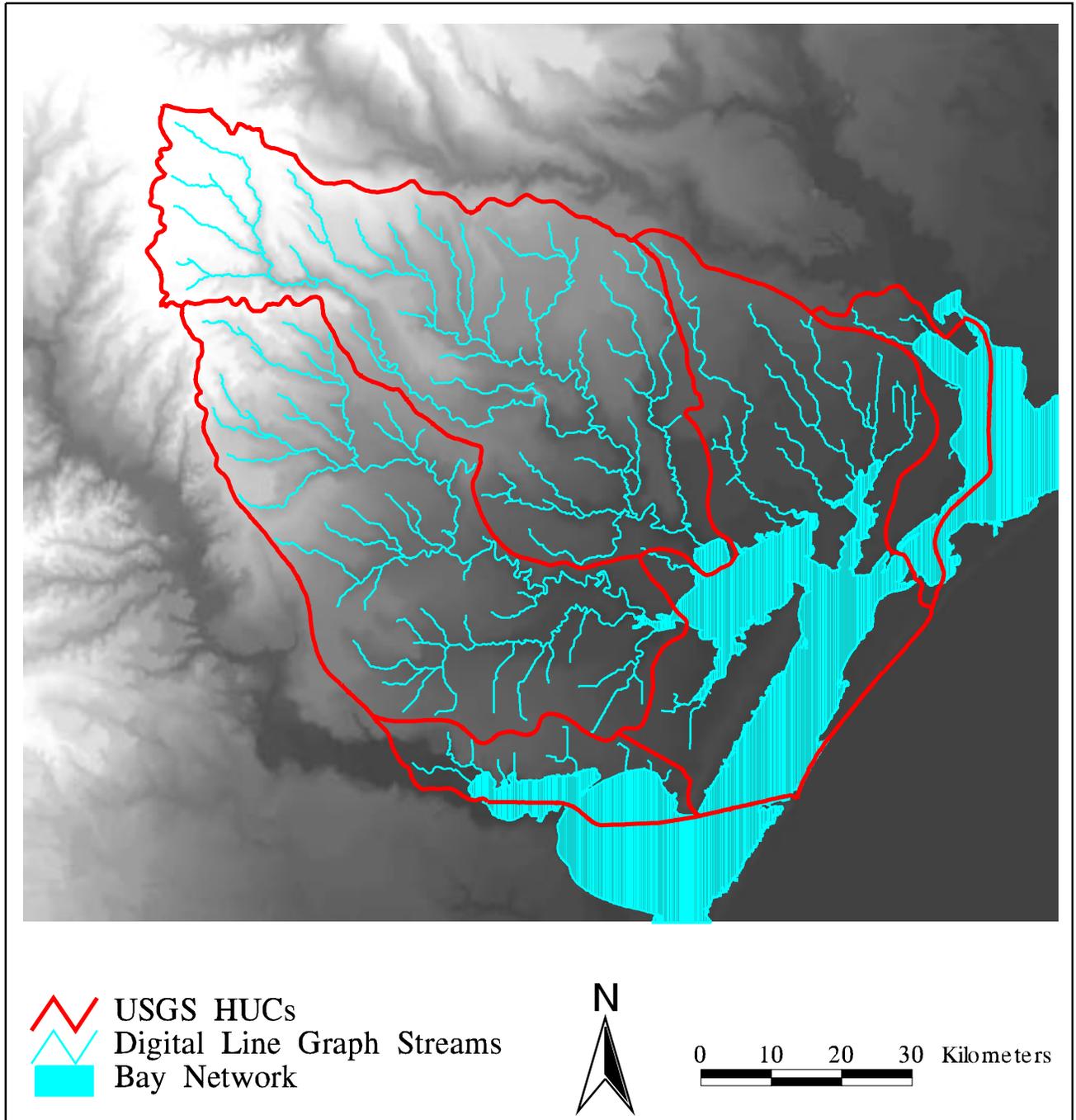
Figure 3.4 :   Digital Elevation Model of the
San Antonio-Nueces Coastal Basin

The land use files are first uncompressed, imported, and cleaned as per the previous discussions. Using the Beeville land use file (lbe28096.e00.gz) as an example:

```
$:  gunzip lbe28096.e00.gz
Arc:  import cover lbe28096.e00 lbe28096
Arc:  clean lbe28096 beelu
```

Once both land use coverages have been created, they are appended together and converted into the TSMS-Albers projection using the alb-tsms.prj file. The parallel line between the two mapsheets is removed using the Arc/Info Dissolve command. This command eliminates arcs between polygons that have the same value for a specified attribute, or "dissolve item". The attribute lanuse-id contains the value of the Anderson land use code for each polygon. By selecting lanuse-id as the dissolve item, any arcs between polygons of the same land use are eliminated.

```
Arc:  mapjoin landuse
Enter the 1st coverage:  beelu
Enter the 2nd coverage:  cclu
Enter the 3rd coverage:  ~
Done entering coverage names (Y/N)?  y
Do you wish to use the above coverages (Y/N)?  y

Appending coverages.....
Arc:  project cover landuse lanuse alb-tsms.prj
Arc:  dissolve lanuse luse lanuse-id poly
```

Using ArcView 2.0 to inspect the luse coverage and selecting lanuse-id as the field through which to display shows that most of the polygons have values reflective of the Anderson land use codes. However, one polygon has a lanuse-id value of 200000. Upon further inspection in ArcView, this anomaly is identified as the lanuse-id for the Gulf of Mexico. By performing a Reselect on the luse coverage, the anomalous polygon is removed:

```
Arc:  reselect luse sanlus
>:  res lanuse-id < 100
>:  ~
Do you wish to re-enter expression?(Y/N):  n
Do you wish to enter another expression? (Y/N):  n
        6513 features out of 6514 selected
```

Figure 3.5 shows the final land use coverage, sanlus, as clipped by a coverage of the basin boundary, which is created as per discussion in Chapter 4.

USGS Daily Discharge Values

Daily average discharge values (in units of cubic feet per second) are available for all active and inactive USGS streamflow gauges in Texas from the Texas Surface Water Database section of the USGS-Austin, TX World Wide Web site listed in Table 3.2. For the San Antonio-Nueces Coastal Basin, five streamflow gauges (three active, two inactive) exist. Table 3.4 identifies the periods of record for each gauge.

The discharge values recorded by each USGS gauge represent average streamflow at the gauge for that particular day. Daily, monthly, and annual streamflow volumes are calculated by processing the raw discharge data through the FORTRAN algorithm montflow.f (included in Appendix B).

USGS Stream Gauge Locations

Geographic locations (in degrees, minutes, and seconds) of the USGS streamflow gauges cited above are available from the same section of the USGS-Austin, TX World Wide Web site. Table 3.4 shows the latitudes and longitudes for each of the five San Antonio-Nueces coastal basin streamflow gauges.

In order to create a GIS coverage of these stations, the latitudes and longitudes are first converted into decimal degrees via the relationship,

$$DD = D + MIN/60 + SEC/3600 \tag{3-3}$$

where DD = decimal degrees, D = degrees, MIN = minutes, and SEC = seconds. A raw data file of the digital coordinates (longitude listed first) is then built in a UNIX text editor window and named lonlat.dat. A copy of this raw data file, constructed by increasing USGS gauge number, is shown in Figure 3.6. Note that West longitude is treated as negative in decimal degrees.

Anderson Land Uses

■ Urban Residential
■ Urban Commercial
■ Urban Industrial
■ Urban Transportation
■ Mixed Urban
■ Other Urban
■ Agriculture
■ Rangeland
■ Forest Land
■ Water Bodies
■ Wetlands
■ Barren/Beaches
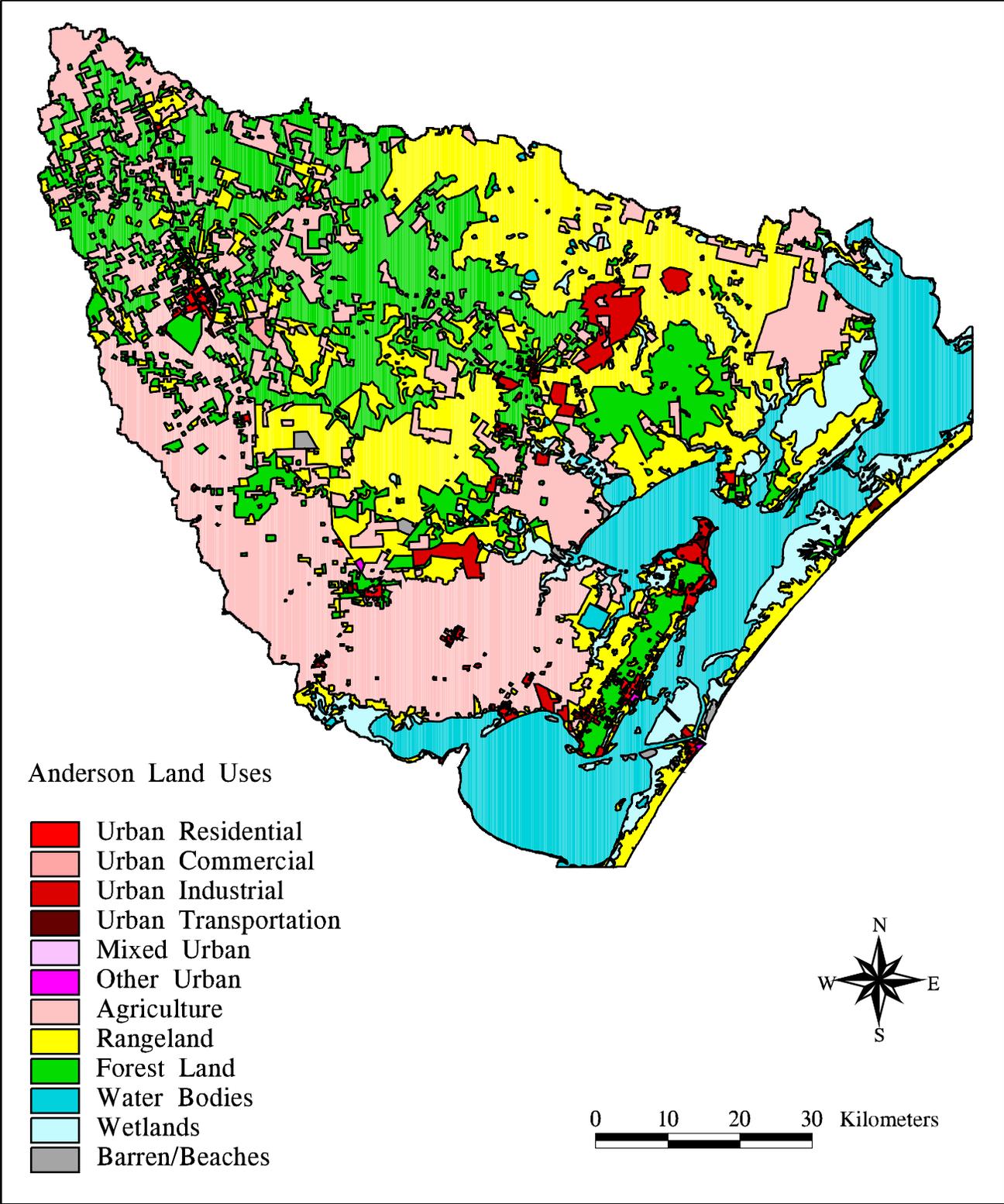
Figure 3.5 : Land Uses in the San Antonio-Nueces Coastal Basin

USGS Gauge	Gauge Description	Period of Operation	Latitude (N)	Longitude (W)
08189200	Copano Creek near Refugio, TX	6/17/1970 - present	28º 18' 12"	97º 06' 44"
08189300	Medio Creek near Beeville, TX	3/1/1962 - 10/17/1977	28º 28' 58"	97º 39' 23"
08189500	Mission River at Refugio, TX	7/1/1939 - present	28º 17' 30"	97º 16' 44"
08189700	Aransas River near Skidmore, TX	4/1/1964 - present	28º 16' 56"	97º 37' 14"
08189800	Chiltipin Creek at Sinton, TX	7/23/1970 - 4/6/1987, 8/4/1987 - 9/30/1991	28º 02' 48"	97º 30' 13"

Table 3.4 : USGS Streamflow Gauge Information

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

```
Arc:  generate stations
Generate:  input lonlat.dat
Generate:  points
          Creating points with coordinates loaded from lonlat.dat
Generate:  quit
          Externalling BND and TIC...
Arc:  build stations points
          Building points...
Arc:  addxy stations
```

```
1    -97.1122    28.3033
2    -97.6564    28.4828
3    -97.2789    28.2917
4    -97.6206    28.2822
5    -97.5036    28.0467
end
```

**Figure 3.6 : Digital Coordinate Data File for
San Antonio-Nueces Stream Gauges**

```
1      08189200     Copano
2      08189300     Medio
3      08189500     Mission
4      08189700     Aransas
5      08189800     Chiltipin
end
```

**Figure 3.7 : Gauge Number and Name Data File for
San Antonio-Nueces Stream Gauges**

A second data file, called statname.dat, is then created as per Figure 3.7. This file includes the gauge-id's and names listed in order. The shell of an attribute data file, called attribut.dat, is then built through use of the Arc/Info Tables function. Attribute field names and formats are defined for each of the items in the statname.dat file, making sure to define the first item, stations-id, to be in the same format as the stations-id field in the stations coverage. The data from statname.dat is used to fill in the formatted attribut.dat file, using the Tables "add from" command. The attribute data is then appended to the stations point attribute table (pat) through use of the Arc/Info Joinitem command. This command links data from two tables through the use of a common relate item. In this case, the station-id field is used as the relate item. Finally, the stream gauge coverage is converted from geographic to the required TSMS-Albers projection, using the geotsms.prj file:

```
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
```

```
Item Output Width:  15
Item Type:  c
Item Name:  ~
Enter Command:  add from statname.dat
Enter Command:  quit
Arc:  joinitem stations.pat attribut.dat stations.pat stations-id stations-id
Arc:  project cover stations sangages geotsms.prj
```

The resultant sangages coverage, shown in Figure 3.8, identifies the locations of each USGS stream gauge in the San Antonio-Nueces Coastal Basin and is used to define outlet points from which subwatersheds can be delineated for hydrologic analysis.

Precipitation Grids

Rainfall data typically provide a prime input to any nonpoint source pollution model. Much has been written about the importance of establishing definitive rainfall inputs for nonpoint source pollution load estimation. Collins and Dickey (1989) employed a stepwise least squares optimization procedure in the development of a stochastic model for simulating individual rainfall-runoff events and performing nonpoint source pollutant load assessments. Rudra et al. (1993) have identified that, for some nonpoint source pollution models that accept non-steady state rainfall inputs, variations in the selected rainfall time step interval can significantly affect estimates of runoff, sediment yield, and erosion characteristics.

This study considers precipitation as a steady state quantity averaged over an extended (30 year) time period. As a result, nonpoint source loads are also estimated as static quantities and concerns about temporal variations in rainfall inputs are somewhat mitigated. Precipitation data for the San Antonio-Nueces coastal basin is extracted from a set of grids developed at the Oregon State University Forestry Sciences Laboratory. These grids are part of the Parameter-elevation Regressions on Independent Slopes Model (PRISM) and cover the conterminous United States. PRISM is an analytical model that uses precipitation data measured at over 7000 National Weather Service and cooperator stations, 500 SNOTEL stations, and some selected State network stations (Daly et al., 1994).

Sangages-id	Stat-num	Stat-name	X-coord	Y-coord
1	08189200	Copano	-97.112	28.303
2	08189300	Medio	-97.656	28.483
3	08189500	Mission	-97.279	28.292
4	08189700	Aransas	-97.621	28.282
5	08189800	Chiltipin	-97.504	28.047
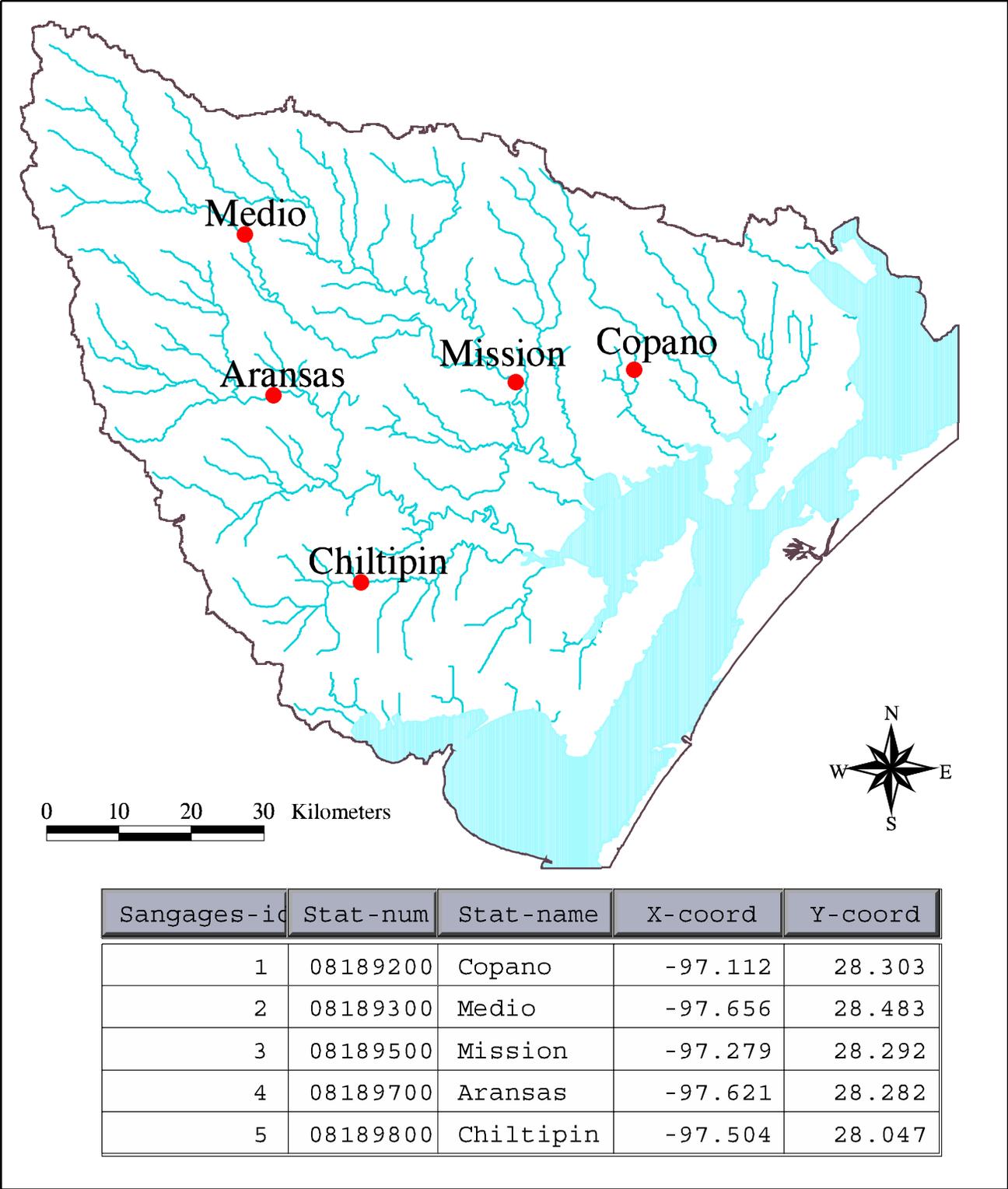
Figure 3.8 : USGS Stream Gauges in the
San Antonio-Nueces Coastal Basin

GRASS Format		Arc/Info Format	
north:	50:01:15 N	ncols	1465
south:	24:03:45 N	nrows	623
east:	64:58:45 W	xllcorner	-126.020833333
west:	126:01:15 W	yllcorner	24.0625
rows:	623	cellsize	0.041666667
cols:	1465	nodata_value	-9

**Table 3.5 : ASCII Header Formats for PRISM files
in GRASS and Arc/Info**

Estimated precipitation values are established for intermediate grid-cells through the use of a regression function, considering the measured precipitation point data along with digital elevation model data to account for orographic effects (Daly et al., 1994). The result of this process is a completely gridded surface of average precipitation across the nation. Average monthly (January-December) and average annual precipitation grids for the period between 1961 and 1990 are available.

The PRISM grids exist as compressed Geographical Resource Analysis Support System (GRASS) ASCII files at the ftp site noted in Table 3.2. For this study, only average annual precipitation data is required and is downloaded from the ftp site as the prism_us.ann.Z ASCII file. In order to uncompress the file, the file extension is changed from .Z to .gz and the gunzip utility is invoked:

$: **mv prism_us.ann.Z prism_us.ann.gz**
$: **gunzip prism_us.ann.gz**

GRASS is a different GIS than Arc/Info, and there are some file format differences. The prism_us.ann ASCII file is compatible for immediate conversion to a GRASS GIS grid, but must have some modification to its' header before conversion to an Arc/Info grid. Table 3.5 shows the ASCII header formats that both GRASS and Arc/Info recognize. To create Arc/Info header information, (1) the nrows and ncols fields are directly transferrable from the GRASS rows and cols fields. (2) The xllcorner and yllcorner fields are just digital degree representations of the GRASS west and south fields. (3) Cellsize is calculated as the decimal degree difference

between the GRASS east and west coordinates, divided by the number of columns. (4) Finally, nodata_value is specified as the value that GRASS uses to represent NODATA cells, -9 in this case.

Once the ASCII header information is modified from the GRASS format, the Arc/Info Asciigrid command is used to convert the ASCII file into an Arc/Info grid:

```
Arc:  asciigrid  prism_us.ann  p_ann
Arc:  describe p_ann
                  Description of Grid P_ANN
```

Cell Size =	0.042	Data Type:	Integer
Number of Rows =	623	Number of Values =	3470
Number of Columns =	1465	Attribute Data (bytes) =	8

BOUNDARY		STATISTICS	
Xmin =	-126.021	Minimum Value =	36.000
Xmax =	-64.979	Maximum Value =	6539.000
Ymin =	24.063	Mean =	771.181
Ymax =	50.021	Standard Deviation =	441.307

NO COORDINATE SYSTEM DEFINED

The Arc/Info Describe command is used to obtain projection and statistical information about the p_ann grid. This description shows that, while no coordinate system is defined for the grid, the X and Y boundary values are digital representations of the original GRASS coordinates, indicating that the grid is in a geographic projection with decimal degrees specified as the units of measure. For projection definition purposes, this information can be used, along with the datum and spheroid information (NAD83, GRS1980) of the TSMS-Albers projection.

In order to select the portion of the precipitation grid applicable to the San Antonio-Nueces Coastal Basin, a copy of the buffered Hydrologic Unit Code coverage (hucbuff) is first reprojected from TSMS-Albers to a Geographic coordinate system, using the tsmsgeo.prj file, included in Appendix B. The Grid Setwindow command is then used to reduce the analysis window to the mapextent of the new geobuff coverage. Once this analysis window has been reduced, a smaller precipitation grid (p_ann2) is defined that contains the values of p_ann within the analysis window. The

smaller precipitation grid is then projected to the TSMS-Albers projection using the geotsms.prj file and specifying a grid cell size of 100 meters:

```
Arc:   project cover hucbuff geobuff tsmsgeo.prj
Arc:   grid
Grid:  setwindow geobuff  p_ann
Grid:  p_ann2 = p_ann
Grid:  rainbuff = project(p_ann2,geotsms.prj,#,100)
Grid:  rainbfcv = gridpoly(rainbuff)
```

A vector representation of the rainbuff grid is created using the Arc/Info Gridpoly command. When this command is invoked, each feature of the resulting coverage is assigned an attribute field called Grid-Code that contains the value of the corresponding grid cell. Figure 3.9 shows this precipitation coverage, as clipped by a coverage of the basin boundary, which is created as per discussion in Chapter 4.

Expected Mean Concentration Values

In order to calculate loadings of pollutants from each grid cell in the San Antonio-Nueces basin, pollutant concentration values need to be associated with the cells. Using literature-based expected mean concentration (EMC) values associated with land use is one way to spatially assign average pollutant concentrations. For this study, a set of expected mean concentration values used in a previous Corpus Christi Bay National Estuary Program analysis (Baird et al., 1996) was applied to the land uses in the basin. These expected mean concentrations were developed from water quality analyses performed at the Oso Creek and Seco Creek USGS stream gauges in south Texas. The Oso Creek stream gauge is located just west of Corpus Christi and represents the outlet of a predominantly agricultural subwatershed. The Seco Creek gauges are northwest of Hondo, Texas and represent drainage of rangeland (Baird et al., 1996). Expected mean concentration values for eighteen pollutants were used during this study and are included in Table 3.6.
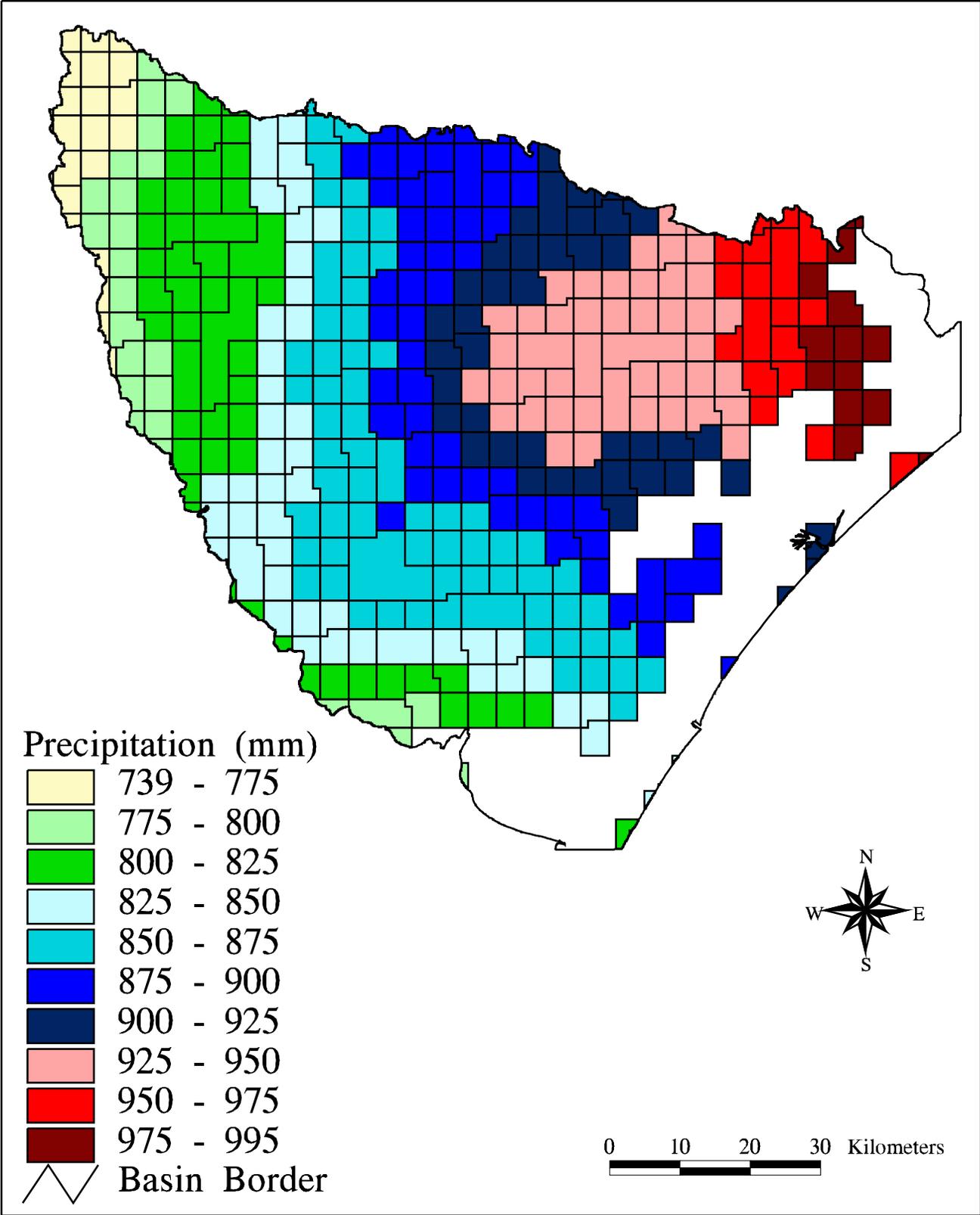
Figure 3.9 : Average Annual Precipitation in the
San Antonio-Nueces Coastal Basin

Constituent	Urban Res 11	Urban Comm 12	Urban Ind 13	Urban Trans 14	Urban 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 N. (mg/L)	1.5	1.1	1	1.5	1.25	1.7	0.2	0.96
Nitrate + Nitrite (mg/L as N)	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 Phos (mg/L)	0.48	0.11	0.22	0.1	0.23			0.03
Suspended Solids (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	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	0.5	
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			
Fec Coliform (col./100 ml)**	20,000	6,900	9,700	53,000	22,400		200	
Fecal Strep (col./100 ml)**	56,000	18,000	6,100	26,000	26,525			

calculated as avg of land uses 11-14

* applied to all subcategories within the land use type

**average concentrations base on instantaneous rather than flow-averaged samples

Table 3.6 : Relationship Between Land Use and Expected Pollutant Concentrations

Water Quality Measurement Data

Once estimated average pollutant loads and concentrations have been established, they need to be compared with sampled data to validate the analysis. In support of this, a ten-year period (1982-1992) of water quality data measured in the region is used. This data set was previously used for the screening analysis portion of the 1994 Regional Assessment of Water Quality in the Nueces Coastal Basins (TNRCC, 1994) and was made available by the Texas Surface Water Quality Monitoring (SWQM) Program, managed by the Watershed Management Division of the TNRCC.

The Surface Water Quality Monitoring data available for the Nueces Coastal Basins (both San Antonio-Nueces and Nueces-Rio Grande basins) include 37 fixed monitoring stations measuring various combinations of 107 different water quality parameters. The parameters typically fall into three classes: (1) conventional parameters, such as pH, dissolved oxygen, and temperature, (2) nutrients (e.g. nitrogen and phosphorus), and (3) toxics (e.g. metals and pesticides). As the coordinating agency, TNRCC oversees and collects sampling data from other various Federal, State, and local agencies that perform the sampling (TNRCC, 1994).

The water quality data is provided, via the TNRCC ftp site identified in Table 3.2, as one compressed GIS point coverage identifying the sampling locations and two database (.dbf) files: one specifying each of the available water quality parameters in the EPA's standard STORET code format, and the other providing the actual time-tagged measurement values. Once the three files are accessed from the ftp site, the station location point coverage is imported and reprojected using the wqtsms.prj file in Appendix B. The .dbf files are converted to INFO files using the Dbaseinfo command;

```
Arc:  import cover snwqsites.e00 wqsites
Arc:  project cover wqsites sanwq wqtsms.prj
Arc:  build sanwq points
Arc:  dbaseinfo value.dbf  value
Arc:  dbaseinfo storet.dbf  storet
```

Figure 3.10 shows the TNRCC water quality measurement points in the San Antonio-Nueces Coastal Basin.
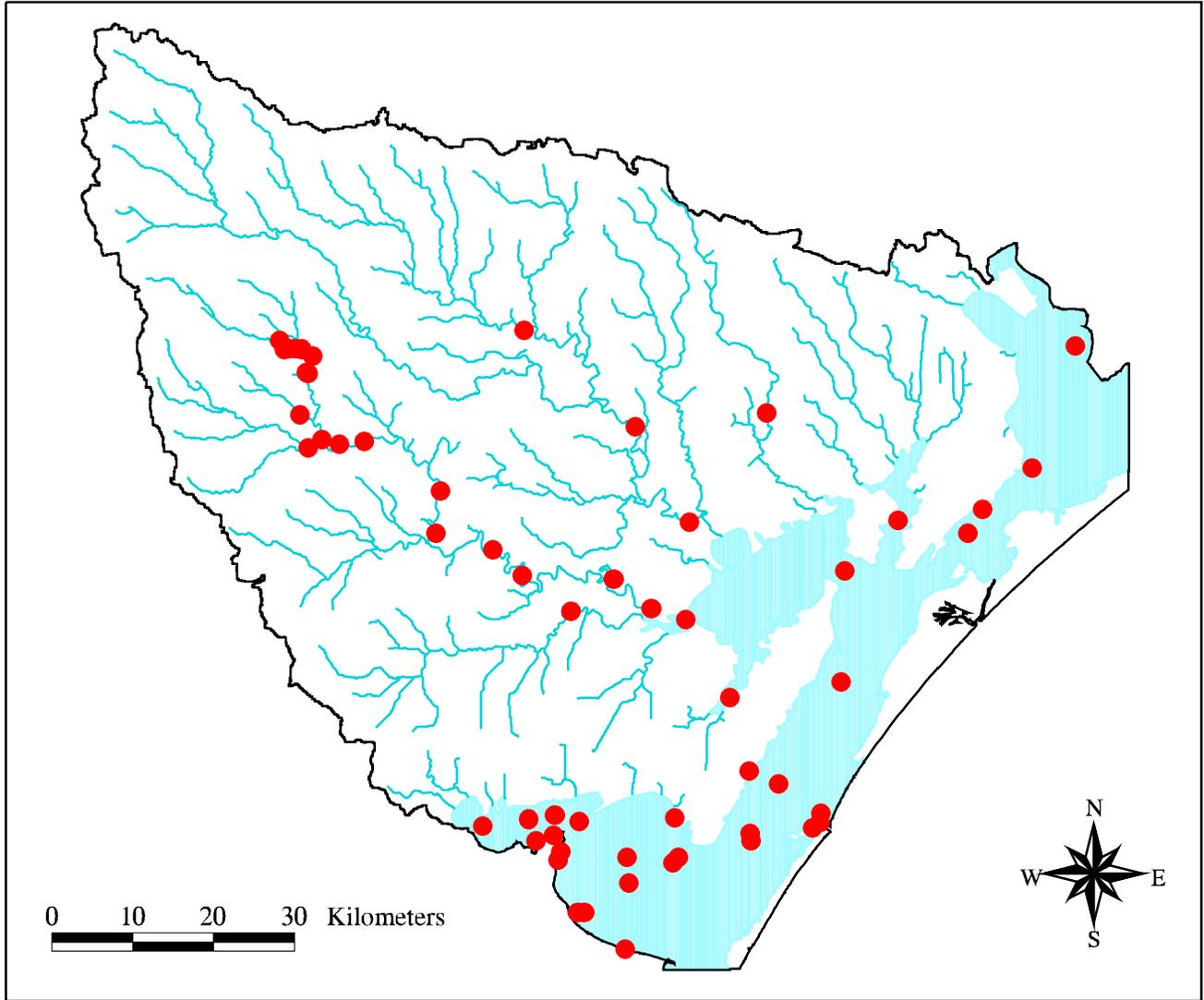
Figure 3.10 : TNRCC Water Quality Measurement Locations
in the San Antonio-Nueces Coastal Basin

In order to link specific concentration values from the value table to stations in the sanwq coverage, a common linkage item must be identifed between the value table and the point attribute table (pat) of the coverage. A review of the two tables shows that the sanwq-id field in the pat contains the same data as the station-id field in the value table. However, the two fields are in different formats and must be in a common format in order to be linkable. This problem is resolved by adding a station-id field to the pat of the coverage, filling in the field with values from the sanwq-id field, and then changing the format of the new station-id field from integer to character type, using the Arc/Info Tables Alter feature:

```
Arc:  additem sanwq.pat sanwq.pat station-id 5 5 i
          Adding station-id to sanwq.pat to produce sanwq.pat.
Arc:  tables
Enter Command:  sel sanwq.pat
          105 Records Selected
Enter Command:  calc station-id = wqsites-id
Enter Command:  alter
Enter item name:  station-id
COLUMN  ITEM NAME  WIDTH  OUTPUT  TYPE  N.DEC  ALTERNATE NAME
     17     STATION-ID      5        5         I       -
Item name:  station-id
Item output width:  5
Item type:  c
Alternate item name:  ~
COLUMN  ITEM NAME  WIDTH  OUTPUT  TYPE  N.DEC  ALTERNATE NAME
     17     STATION-ID      5        5         C       -
Enter item name:  ~
```

Using ArcView 2.0, the sanwq point attribute table and the value table are linked through their station-id fields and the storet table is linked to the value table through their respective param-id and storetcode fields. Figure 3.11 shows portions of the three linked tables and demonstrates how selection of a pollutant constituent in the storet table identifies the sanwq locations where that pollutant is measured and the values of those concentration measurements in the value table.

Param_id	Long_desc	Short1_des	Short2_des
01034	CHROMIUM, TOTAL (UG/L AS CR)	CHROMIUM	CR,TOT
01040	COPPER, DISSOLVED (UG/L AS CU)	COPPER	CU,DISS
01042	COPPER, TOTAL (UG/L AS CU)	COPPER	CU,TOT
01043	COPPER IN BOTTOM DEPOSITS (MG/KG AS CU DRY WGT	CU MUD	DRY WGT
01045	IRON, TOTAL (UG/L AS FE)	IRON	TOTAL
01046	IRON, DISSOLVED (UG/L)	IRON	FE,DISS
01049	LEAD, DISSOLVED (UG/L AS PB)	LEAD	PB,DISS

storet.dbf

Station_i	On_seg_fl	Seg_id	Enddate	Tag	Storetcode	Gtlt	Value
12943	1	2001.0000	08/24/1983	Z195629	01042		16.0000
12944	1	2002.0000	02/10/1982	U009065	01042		10.0000
12944	1	2002.0000	05/04/1982	U009067	01042		3.0000
12944	1	2002.0000	08/31/1982	U009069	01042	<	1.0000
12944	1	2002.0000	11/19/1981	U009064	01042		5.0000
12945	1	2003.0000	08/24/1983	Z195890	01042	<	10.0000
12948	1	2004.0000	08/24/1983	Z196056	01042		13.0000
13074	1	2202.0000	05/31/1989	Z203336	01042		11.0000
13074	1	2202.0000	07/14/1986	Z203318	01042		4.0000
13074	1	2202.0000	07/20/1987	Z203325	01042		5.0000
13074	1	2202.0000	07/28/1988	Z203332	01042	<	20.0000
13074	1	2202.0000	08/07/1985	Z203309	01042	<	20.0000
13091	1	2203.0000	08/20/1982	Z203549	01042		11.0000
13093	1	2204.0000	08/19/1982	Z203616	01042		11.0000
13094	1	2204.0000	08/19/1982	Z203625	01042		18.0000
13096	1	2204.0000	08/19/1982	Z203642	01042		47.0000
13098	1	2204.0000	08/19/1982	Z203646	01042	<	10.0000
12931	0	2004.0000	01/04/1982	Z194514	00011		67.0000
12931	0	2004.0000	01/04/1982	Z194514	00300		7.4000
12931	0	2004.0000	01/04/1982	Z194514	00400		7.7000
12931	0	2004.0000	01/09/1989	Z194589	00011		61.0000

value.dbf

Shape	Area	Perimeter	Sanwq#	Sanwq-id	Station_i	Wqsites#
Point	0.000	0.000	14	12943	12943	14
Point	0.000	0.000	15	12944	12944	15
Point	0.000	0.000	16	12945	12945	16
Point	0.000	0.000	19	12948	12948	19
Point	0.000	0.000	35	13091	13091	35
Point	0.000	0.000	37	13093	13093	37
Point	0.000	0.000	38	13094	13094	38
Point	0.000	0.000	40	13096	13096	40
Point	0.000	0.000	42	13098	13098	42
Point	0.000	0.000	1	12930	12930	1
Point	0.000	0.000	2	12931	12931	2
Point	0.000	0.000	3	12932	12932	3
Point	0.000	0.000	4	12933	12933	4
Point	0.000	0.000	5	12934	12934	5
Point	0.000	0.000	6	12935	12935	6
Point	0.000	0.000	7	12936	12936	7
Point	0.000	0.000	8	12937	12937	8

sanwq.pat

Figure 3.11 : Linking Water Quality Measurement Data Files

3.3   Scales of Analysis

For this study, there are four spatial scales at which hydrologic and loadings analysis can be performed: (1) the 100 m digital elevation model grid cell (0.01 km^2 in area), (2) the PRISM 20 km^2 rainfall grid cell, (3) the subwatersheds defined by drainage area to the USGS streamflow gauges (average area = 650 km^2), and (4) the coastal basin (7235 km^2) taken as a whole. Figure 3.12 demonstrates the relationships between these scales of analysis.

Processes in this study are performed using the 100 m x 100 m (1 hectare) digital elevation model grid cell as the analysis unit. This is the only reasonable scale to use for the watershed modeling step, since an accurate replica of the stream network in the basin is required. Even at this scale, the resultant digital streams are all of a uniform 100 m width (or 141 m when flowing to diagonally adjacent cells).

For calculations performed using the PRISM rainfall data, each 20 km^2 cell is discretized into approximately 2000 grid cells corresponding to the digital elevation model cells. One may note, from Figure 3.12, that a number of the rainfall cells are irregular in shape. This is the result of (1) the reprojection of the grid from its initial geographic map projection and (2) the discretization process performed on each rainfall cell.

While the digital elevation model grid cell is used as the analysis unit for determination of loadings from each subwatershed, these loadings are also accumulated and reported on a subwatershed basis. Finally, the coastal basin scale is not used at all for this study. Coastal basins differ from river basins in that there are multiple outlets versus just one. For river basins, characteristic parameters such as runoff or load that are determined on a subwatershed basis can be lumped into single values associated with the outlet point of the basin. To perform the same accumulations for a coastal basin would leave the false impression that these quantities might be measurable at a specific point. For this reason, analysis on the coastal basin scale is avoided.
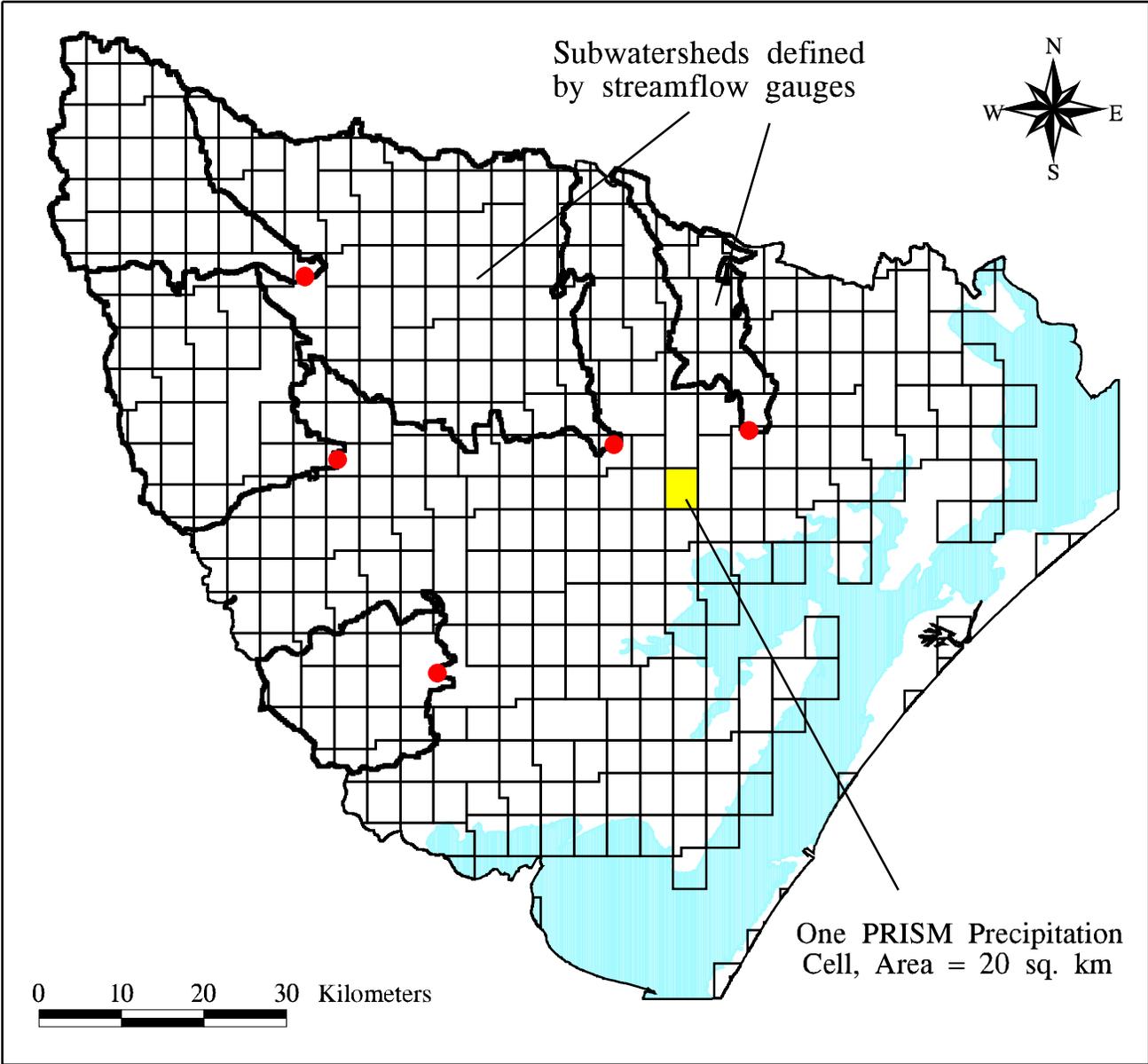
Figure 3.12 : Scales of Analysis

4   METHODOLOGY

As discussed in section 1.4, the methodology followed in this study is partitioned into eight major tasks: (1) Establishment of a digital database, (2) digital modeling of the watershed, (3) definition of a rainfall/streamflow relationship, (4) linking expected mean concentration of pollutants to land use, (5) calculation of pollutant loadings in the watershed, (6) predicting the aerial distribution of pollutant concentrations, (7) simulation of point sources, and (8) estimating EMC values.

Chapter 3 discussed the establishment and preparation of digital data sets for the nonpoint source pollution assessment. In the discussion of the remaining tasks, this chapter is similarly formatted to provide a descriptive narrative of the steps performed along with the actual Arc/Info and UNIX commands executed. This format provides the reader insight into the specific steps performed and describes the theoretical bases for each procedure. As in Chapter 3, automated Arc Macro Language (AML) scripts are referenced where appropriate.

4.1 Grid-Based Watershed Modeling Using Digital Elevation Data

The process of digitally simulating a watershed starts with the digital elevation model of the basin. The fine mesh of 1 hectare cells laid out over the basin is simply represented by a rectangular array, or grid. For the San Antonio-Nueces region, the total number of cells in this array is approximately 1.87 million. Processing of this digital basin relies heavily on the Arc/Info version 7.0 GRID module.

Establishing a Digital Stream Network

Before digitally simulated stream networks and subwatersheds can be created, the raw USGS digital elevation model accessed from the Internet must be corrected for data errors that exist in the original data file or are introduced as a result of reprojection to a different coordinate system. In particular, raw digital elevation models downloaded from Internet may contain many sinks. Sinks are single grid cells or groups of cells surrounded by cells of higher elevation. In order to create a

"hydrologic DEM" (Reed and Maidment, 1995), all of the sinks in the digital elevation model must be removed. This is accomplished through use of the Fill command. The Fill command redefines the elevations of each of the sink points to be equal to that of its lowest elevation neighbor. This smoothing process should always be used on a digital elevation model after reprojection because the data resampling that occurs during reprojection often creates artificial holes, or sinks, in the grid.

        Grid: **fill sndemalb sanfil SINK**

Once the filled hydrologic digital elevation model has been created, it can be processed to determine the direction of the flow of water from cell to cell and to determine, for each cell in the grid, the number of cells that are upstream. The Flowdirection and Flowaccumulation commands are used for these purposes. The conceptual basis for this process relies on the 8-direction pour point model (Figure 4.1a). This model represents a cell surrounded by its eight neighbors. Drainage passes from each cell to only one of its neighbors in the direction of steepest descent, as defined by the filled digital elevation model (Figure 4.1b). By tracing these cell to cell drainage connections downstream, a flow direction network for a complete basin is established (Figure 4.1c).   By counting the number of cells that occur upstream of each particular cell, a flow accumulation grid (Figure 4.1d) is established (Maidment, 1993).

        Grid: **sanfdr = flowdirection(sanfil)**
        Grid: **sanfac = flowaccumulation(sanfdr)**

A digital representation of the stream network in the basin is established by acknowledging that, just as surface runoff accumulates in creeks and streams, flow accumulation values along the digital streams should be greatest. The Conditional (Con) function is used to extract the flow accumulation cells that have value greater than a certain threshold (in this case, 1000). The resulting grid (str1) and equivalent coverage (covstr) actually reflect strings of cells whose flow accumulation values are greater than 1000.

        Grid: **str1 = con(sanfac > 1000,1)**
        Grid: **covstr = gridline(str1)**
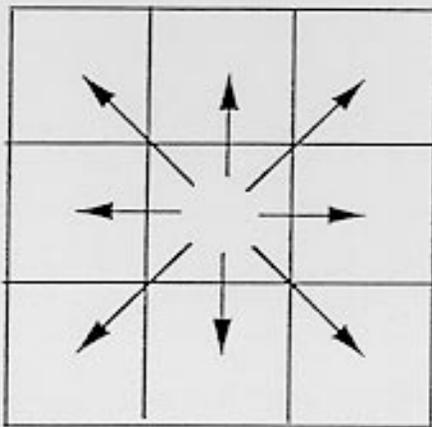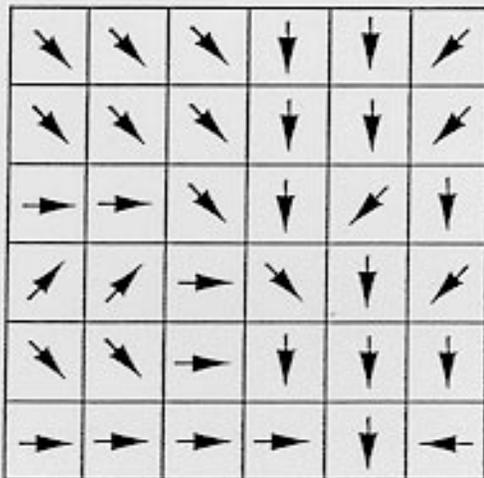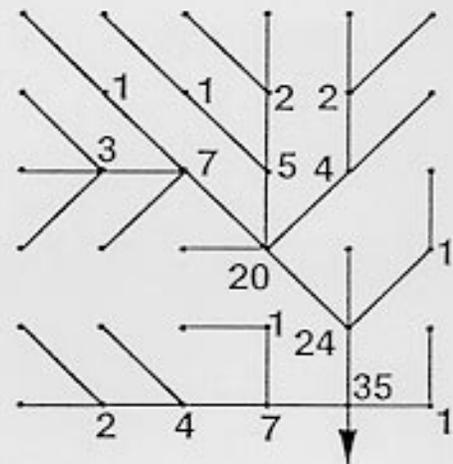
Figure 4.1 : Processing of Digital Elevation Data.
(a) the 8-direction pour point model; (b) a grid of elevation values; (c) flow
direction grid; (d) flow accumulation grid. (Source: Maidment, 1993)

Figure 4.2 shows a comparison of the digitally delineated stream network (covstr) and the 1:100,000-scale hydrography digital line graph representation of the basin streams (Saunders and Maidment, 1995). As can be seen in the figure, the delineated streams in the inland portions of the basin match quite closely with the digital line graphs. However, closer to the coast, the differences between the Grid-delineated and digital line graph streams are much more apparent. This is expected, as slopes in this region of the San Antonio-Nueces coastal basin are generally flat. Elevations in this region do not change as significantly (or at all) from cell to cell and flow directions must be determined over larger areas of equal elevation.

Burning Digital Line Graph Streams into the Digital Elevation Model

The digital stream network established in the above procedure is derived using pure elevation data. However, the poor match that exists with the digital line graphs in the near-shore portions of the watershed is of concern. These digital line graphs are the result of manual digitizations of USGS 1:100,000-scale maps of the region and are considered to be fairly accurate. A review of the digital line graph coverage indicates many straight constructed channels in the region. Elevations of these channel beds may not be accounted for in the digital elevation model. In order to correct for this inconsistency, and to ensure that all digitally derived drainage paths adhere to the accepted stream networks reflected in the digital line graphs, a process of "burning" the digital line graphs into the digital elevation model is performed (Maidment and Saunders, 1996).

As can be seen from Figure 3.3, the hydrography digital line graphs of the San Antonio-Nueces coastal basin include lakes, in-stream lakes, coastlines, and "disappearing" streams in addition to the streams that flow to the bay network. The first step in preparing the digital line graph coverage for the "burn-in" process is to remove all of the features that do not contribute to providing contiguous drainage paths throughout the basin. The Arc/Info ArcEdit module is used for this purpose. In ArcEdit, each stand-alone lake and "disappearing" stream is removed. All in-stream lakes are replaced with arc segments that would otherwise bisect the lakes. Additionally, in the deltas of the Nueces and San Antonio Rivers, where the braiding effects of bifurcating and distributary streams occur, a main channel is identified

65
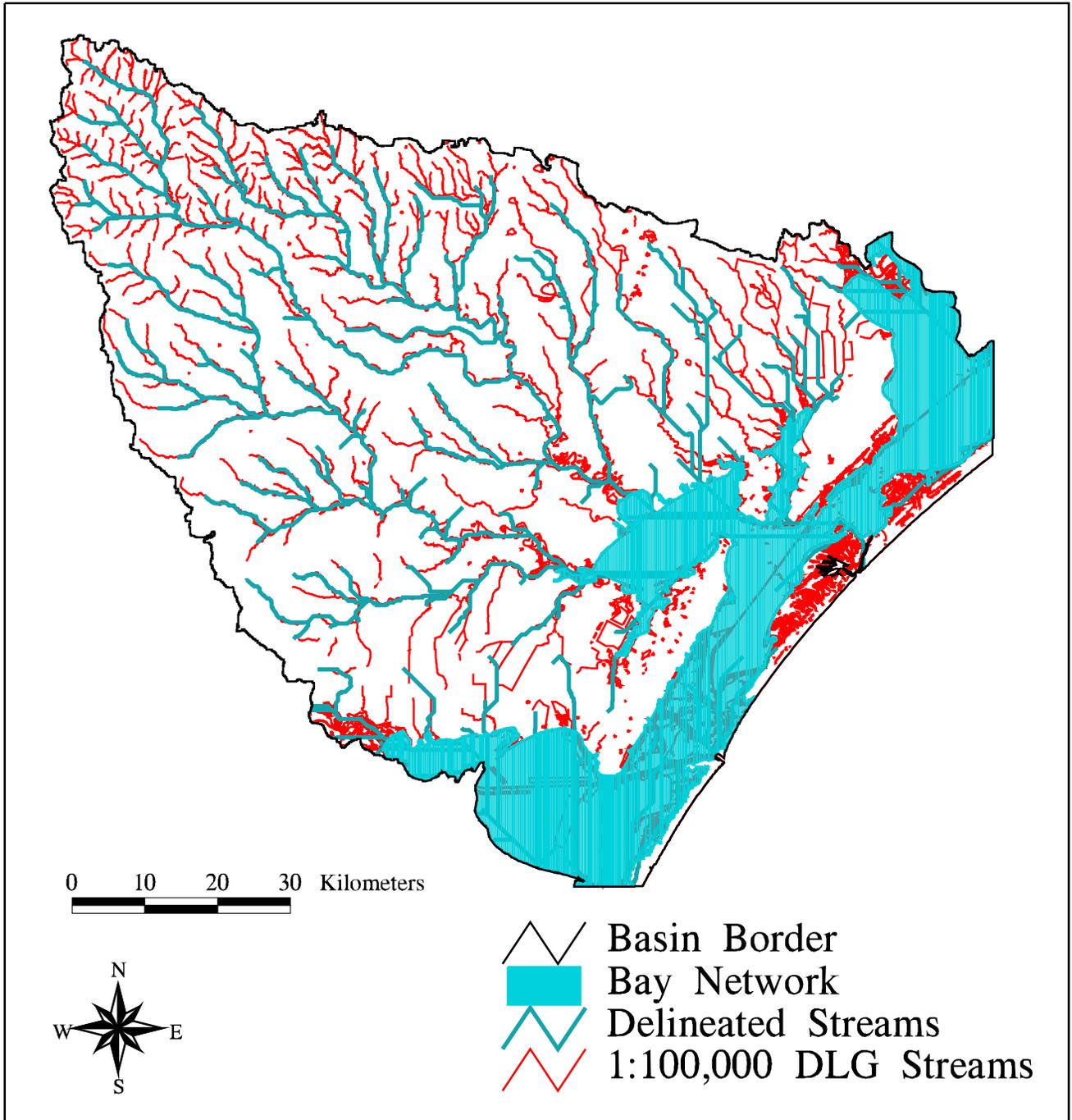
Figure 4.2 : Comparison of GRID-Delineated Streams with
1:100,000-Scale Hydrography Digital Line Graphs

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through the delta and all other split channels and sinuous side channels are removed. This maintains one and only one drainage path for each upstream cell.

Other editing performed on the digital line graph coverage includes the removal of marsh channels throughout the barrier islands, removal of pipelines, shipping lanes, and islands within the Intracoastal Waterway, and the addition of arc segments to bound the Intracoastal Waterway between Corpus Christi Bay and San Antonio Bay. The final edited coverage, defined as sanrivs4, is shown in Figure 4.3.

Polygons are established from this line coverage by using the Arc/Info Clean command to create the sanpolys coverage. When all of the edits have been implemented correctly, the only polygons produced are those of the Intracoastal Waterway and the barrier islands. Unique polygon coverages of the Intracoastal Waterway and barrier islands are created by displaying sanpolys in ArcView 2.0, selecting the appropriate polygons, and converting them into shape files (bays.shp and barriers.shp). The Arc/Info Shapearc command is then used to build coverages from these shape files:

```
Arc:  clean sanrivs4 sanpolys
Arc:  shapearc bays bays
Arc:  build bays poly
Arc:  shapearc barriers barriers
Arc:  build barriers poly
```

The bays coverage is buffered by 100 meters (one cell width) to create an approximate bay network coverage that can be used to remove coastlines from the edited digital line graph coverage. First a rectangular coverage spanning the extent of the filled digital elevation model is created through use of the Con and Gridpoly commands. The buffered bay coverage is then combined with this rectangle through the Arc Union command. The resulting coverage is converted back into 100 m grid cell format, using Polygrid:

```
Arc:  buffer bays baybuff # # 100 # poly
Grid: sqgrid = int(con(sanfil,1,1))
Grid: sqcov = gridpoly(sqgrid)
Arc:  union sqcov baybuff baycov
Grid: baygrid = polygrid(baycov,#,#,#,100)
```
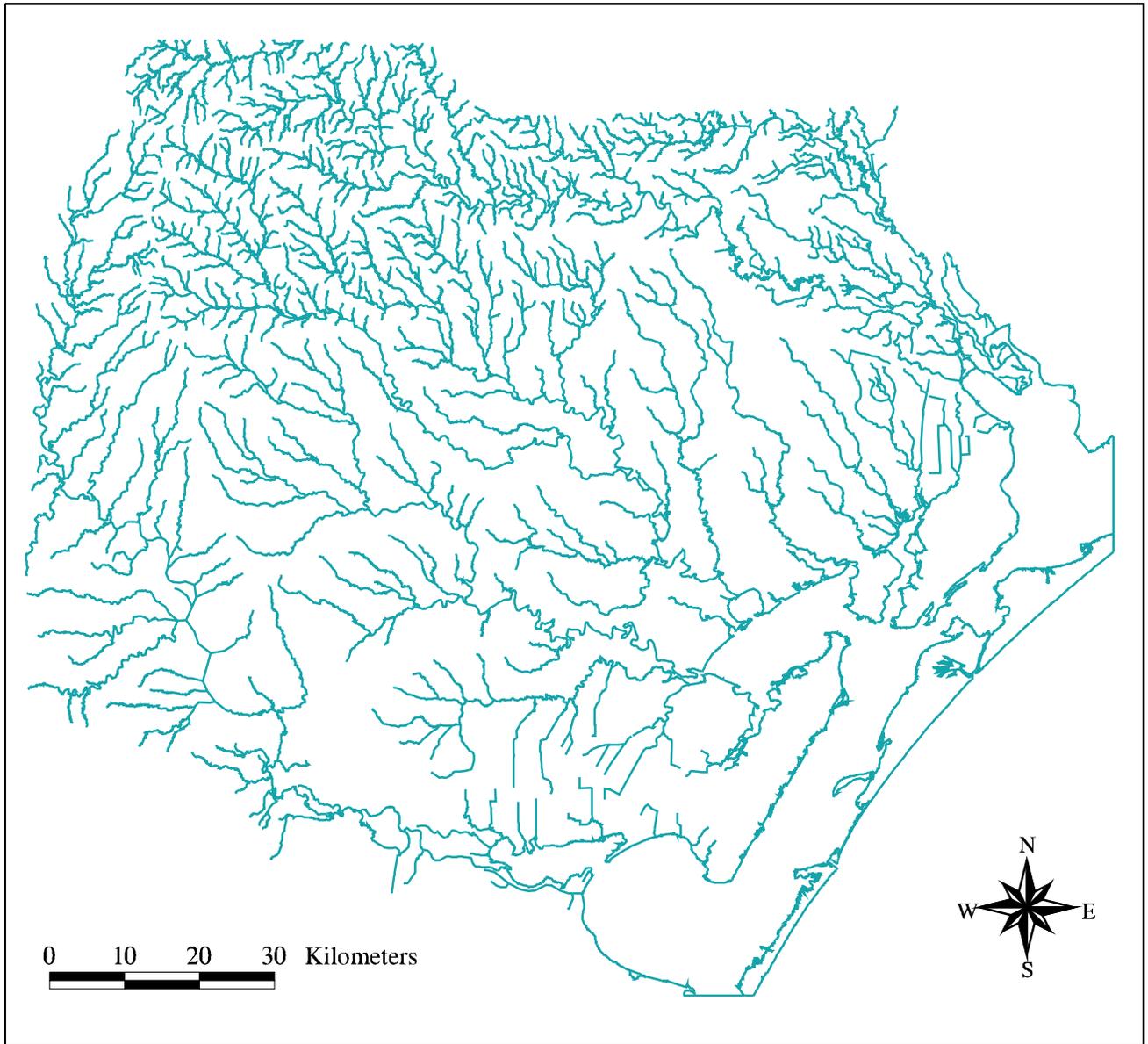
Figure 4.3 : Final Edited Digital Line Graph Stream Coverage
for the San Antonio-Nueces Coastal Basin

The grid analysis window is then set to the size of the digital elevation model. An equivalent grid of the edited stream coverage is created, using the Linegrid command. The coastlines of the stream grid are removed with the Con statement, by selecting only the cells that correspond to the mainland portion of baygrid (i.e. baygrid cell value = 2). In effect, this step reduces all subsequent analyses to the mainland portion of the basin, as all other grid cells (bay network and barrier islands) are represented by NODATA, or null values.

Grid: **setwindow sanfil**
Grid: **strgrid = linegrid(sanrivs4,#,#,#,100,zero)**
Grid: **strmgrid = con(baygrid == 2,strgrid)**

Strmgrid is "burned" into the digital elevation model with the Con statement by artificially raising the elevation of all off-stream grid cells by five meters while holding the in-stream grid cells to a value of zero elevation. This creates a new digital elevation model with which to restart the digital stream delineation process.

Grid: **ditstrm = con(strmgrid > 0,0,sanfil + 5)**

After the new digital elevation model is filled, the bay network region is redefined with values of zero elevation in place of the NODATA values, using baygrid and the Con statement. This is required in order to avoid erroneous flow direction computations in the subsequent steps. A flow direction grid is established from the updated bayfil grid, and then NODATA values are reinserted into the bay network, so that subsequent analyses will be specific to the mainland region, only. This last step is accomplished by using baygrid and the Con statement to isolate the flow direction cells specific to the mainland:

Grid: **fill ditstrm ditfil SINK**
Grid: **bayfil = con(baygrid == 2,ditfil,0)**
Grid: **ditfdr = flowdirection(bayfil)**
Grid: **clipfdr = con(baygrid == 2,ditfdr)**

A flow accumulation grid is created and, as before, flow accumulation cells with a value greater than 1000 are extracted to define the locations of the digitally simulated streams:

Grid: **ditfac = flowaccumulation(clipfdr)**

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Grid: **ditstr1 = con(ditfac > 1000,1)**
Grid: **covstr1 = gridline(ditstr1)**

Figure 4.4 shows the new digital streams, as burned into the digital elevation model and superimposed over the 1:100,000-Scale hydrography digital line graph files of the basin.

Digital Delineation of Subwatershed Drainage Areas from USGS Flow Gauges

In order to provide a more quantitative check on the accuracy of the digitally derived basin, drainage areas from the existing USGS flow gauges in the basin are determined from the flow accumulation grid, using an overlay of the sangages coverage created in section 3.2. These digitally delineated subwatershed drainage areas are then compared with values provided through the USGS-Texas Internet site identified in Table 3.2.

In order to digitally delineate drainage areas, outlet cells for each particular area must first be established. This is accomplished through the Arc/Info Grid module, by displaying the flow accumulation grid, overlaying the sangages coverage, and selecting each gauge location along a flow accumulation string. The fact that each of the stream gauges in the coverage fall exactly on the flow accumulation network is a testament to the accuracy of the "burn-in" process used above. The Selectpoint command allows the user to interactively define each outlet point. Once the outlet cell grid is defined, the Watershed function uses it, along with the flow direction grid, to define the area draining to the selected cell. An equivalent coverage of the drainage area is then created using the Gridpoly command. This process is performed for all five USGS gauges in the coastal basin. For example, the commands for delineating drainage area to the Aransas River gauge are:

Grid: **drainpt1 = selectpoint(ditfac,*)**
Grid: **aranarea = watershed(clipfdr,drainpt1)**
Grid: **arancov = gridpoly(aranarea)**
Grid: **list aranarea.vat**

Record	Value	Count
1	56	63291

70
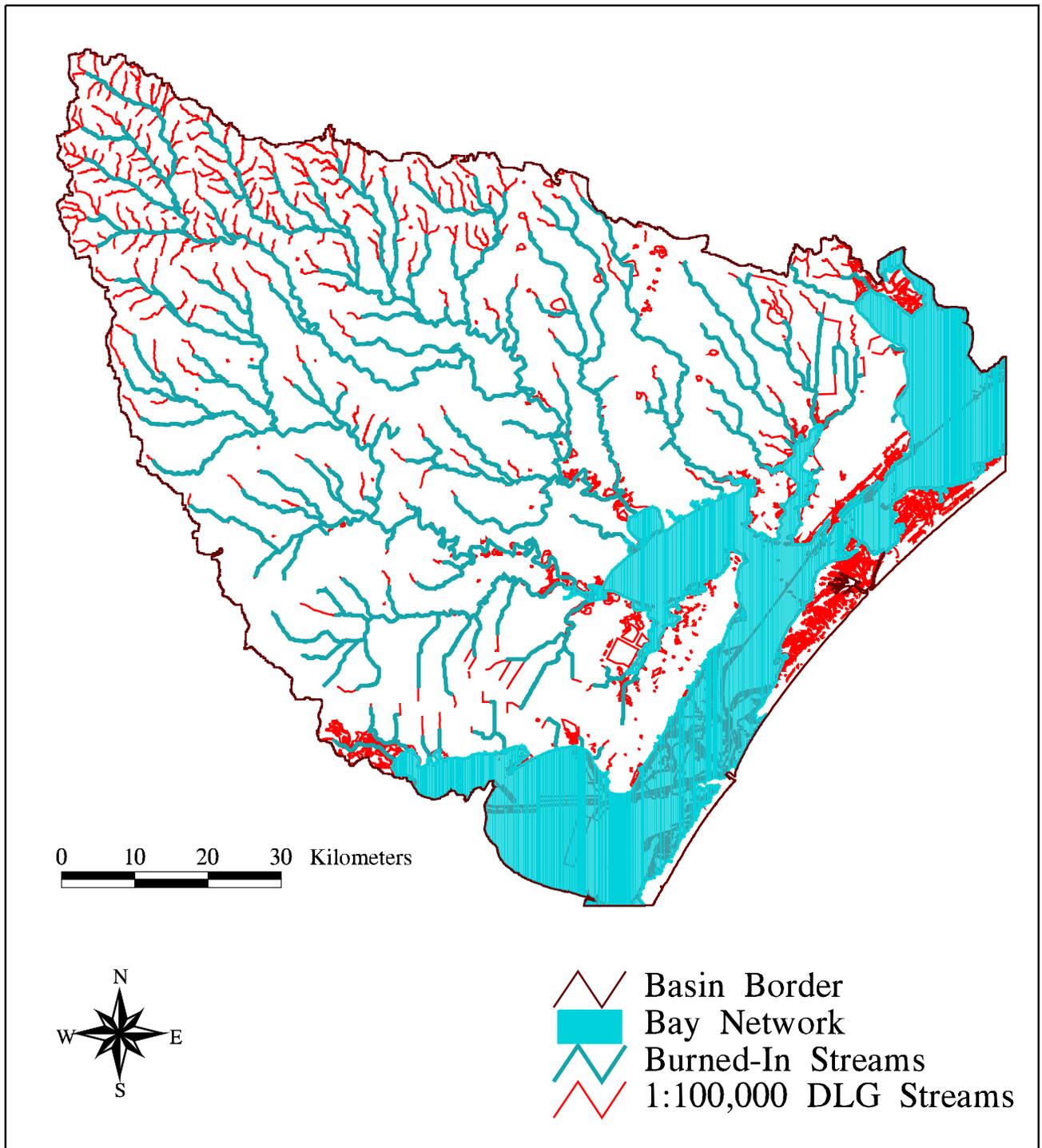
Figure 4.4 : Comparison of Burned-In Streams with
1:100,000-Scale Hydrography Digital Line Graphs

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By displaying the value attribute tables (vat's) for each of the five drainage area grids, a count of the number of cells simulating each drainage area is obtained. Since it is known that each cell has area of 1 hectare = 10,000 m^2, the area in square kilometers is established by dividing the number of cells by 100. These areas, converted to square miles, are then compared with the USGS drainage areas obtained from the Internet site. Table 4.1 shows the comparison of the digitally delineated drainage areas with USGS drainage areas and Figure 4.5 shows the digital drainage areas as they exist within the basin.

Percent errors from Table 4.1 indicate that the digitally delineated drainage areas match the USGS areas fairly accurately. The largest errors, 8.89% for the Copano Creek drainage and 2.85% for the Chiltipin Creek drainage, occur in the flattest portions of the basin, which are also closest to the coast. The smallest error, 0.32% for the Medio Creek drainage, occurs for the furthest inland area.

Figure 4.6 shows a close-up of the Copano Creek drainage area and one potential contributing factor to the errors occurring in the digital delineation. The sinuous nature of the digital subwatershed boundary results when using the "burn-in" process for establishing the digital elevation model. While the actual cause of this anomaly is unknown, it is suspected that the flow direction grid is affected by the sharp drops in elevation to the burned-in streams. Even with these boundary anomalies, the percent errors for the delineated drainage errors are considered to be acceptable.

USGS GAGE #	STREAM	# CELLS	DELINEATED DRAINAGE AREA (km^2)	(mi^2)	ACTUAL USGS DRAINAGE (mi^2)	% ERROR
08189200	COPANO	20,782	207.82	80.2	88	8.89
08189300	MEDIO	52,708	527.08	203.3	204	0.32
08189500	MISSION	176,619	1766.19	681.4	690	1.25
08189700	ARANSAS	63,291	632.91	244.2	247	1.15
08189800	CHILTIPIN	32,233	322.33	124.4	128	2.85

Table 4.1 : Comparison of Digitally Delineated and USGS Drainage Areas

203.3 sq. mi.

681.4 sq. mi.

80.2 sq. mi.

244.2 sq. mi.

124.4 sq. mi.

0   10   20   30   Kilometers

N
W   E
S

- USGS Gauges
Burned-In Streams
Basin Border
Medio Drainage
Mission Drainage
Copano Drainage
Chiltipin Drainage
Aransas Drainage
Bay Network
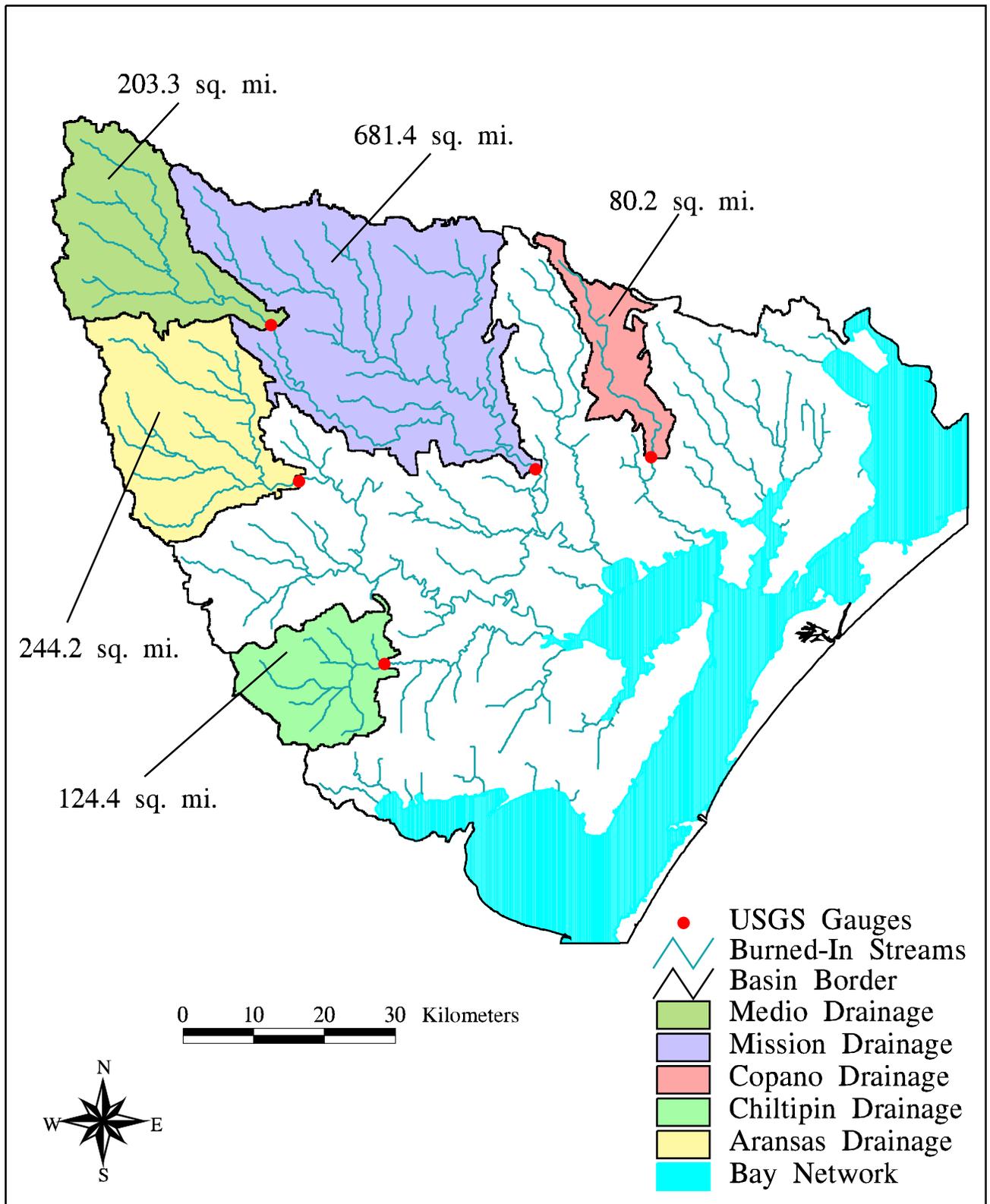
Figure 4.5 :   Digital Drainage Areas Delineated from
USGS Streamflow Gauges
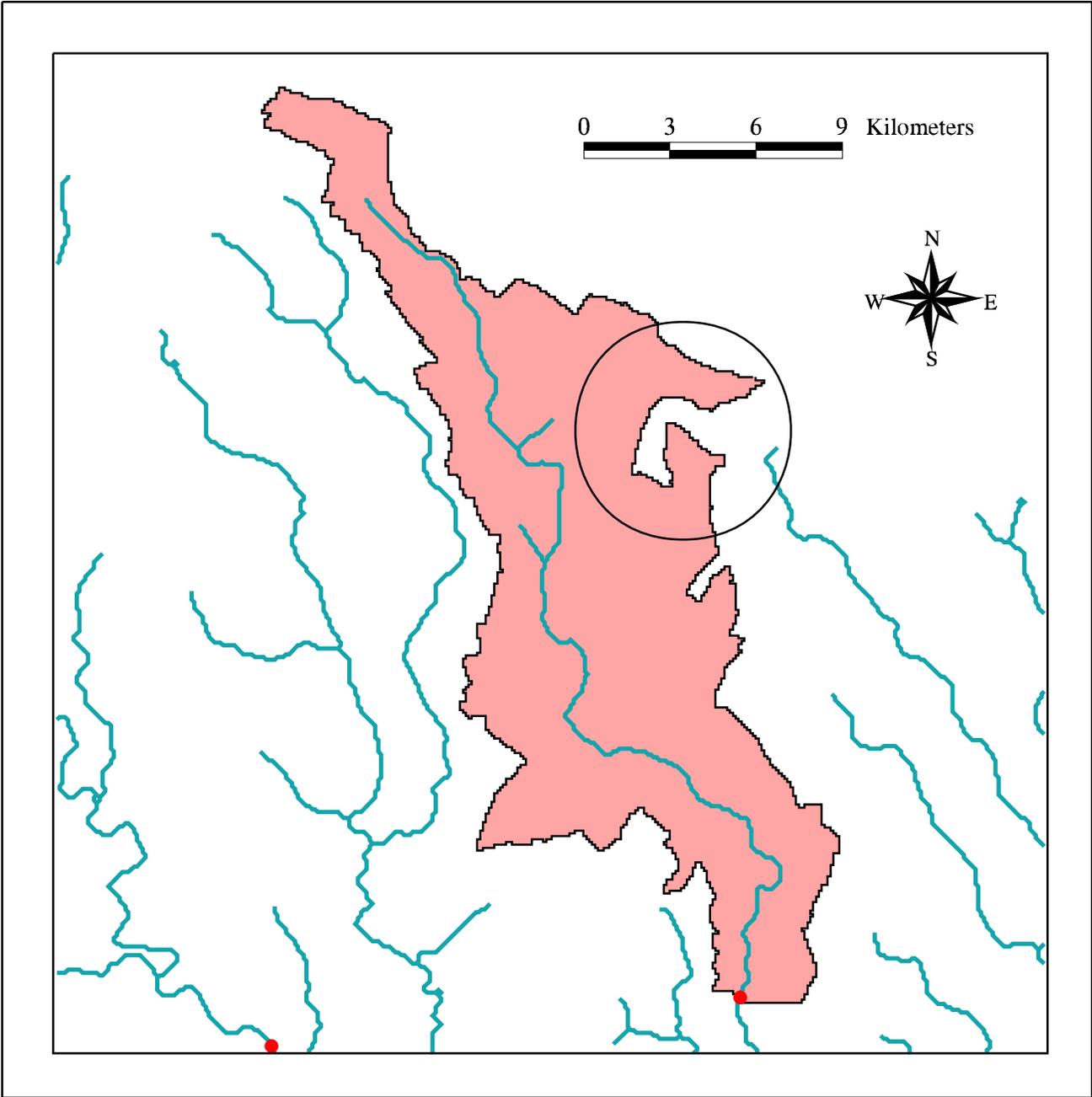
Figure 4.6 : Drainage Area Delineated from the
Copano Creek USGS Stream Gauge

Defining the Coastal Basin Boundary

For many of the figures in section 3.2, a coverage of the San Antonio-Nueces coastal basin boundary is used to clip out the particular features of the display. This boundary is created to facilitate watershed-level analyses of the respective spatial parameters. Both Arc/Info version 7.0 and ArcView 2.0 are used in the establishment of this border.

The Arc/Info Grid module is first employed to delineate subwatersheds within the complete basin. A threshold value (i.e. number of cells) defining the size of subwatersheds to be delineated is specified. This threshold value should be chosen to ensure that the total number of subwatersheds delineated is manageable. The total area of the San Antonio-Nueces coastal basin is known to be approximately 7000 km^2. In order to keep the number of subwatersheds in the basin under 100, a threshold value of 8000 cells (i.e. 80 km^2) is chosen. The Con statement is used to identify all flow accumulation cells in the basin with value greater than the threshold. As discussed previously, this results in strings of grid cells that represent a stream grid of the basin.

The Streamlink command is used to identify specific stream reaches, based on the stream grid and flow direction grids. The Zonalmax command then produces a grid of accumulation zones, using the grid of stream reaches along with the flow accumulation grid. This command stores the maximum value of each of the stream reaches into all cells of the corresponding accumulation zones.

Next, using the Con statement, the outlet cells of each accumulation zone are defined as those cells with identical flow accumulation and accumulation zone grid values. The Watershed function is then used, as before, to delineate the drainage areas to each zonal outlet cell. Finally, an equivalent coverage of the delineated subwatersheds is created through the Gridpoly command:

Grid: **ditstr8 = con(ditfac > 8000,1)**
Grid: **ditlnk8 = streamlink(ditstr8,clipfdr)**
Grid: **ditacc8 = zonalmax(ditlnk8,ditfac)**
Grid: **ditout8 = con(ditacc8 == ditfac, ditlnk8)**
Grid: **ditshd8 = watershed(clipfdr,ditout8)**
Grid: **shed8cov = gridpoly(ditshd8)**

Figure 4.7 shows the digitally delineated subwatersheds of the San Antonio-Nueces coastal basin overlaid with the USGS Hydrologic Unit Codes to provide an estimate of which subwatersheds fall within the basin and which are associated with the Nueces and San Antonio River basins.

Using ArcView 2.0, the subwatersheds coverage (shed8cov) is displayed and each of the polygons that fall within the San Antonio-Nueces basin are selected. Once selected, these polygons are converted into the shapefile, subsheds.shp. As can be seen from Figure 4.7, the complete San Antonio-Nueces basin is not accounted for by the polygons of shed8cov. This occurs because the San Antonio-Nueces basin is a coastal basin and not a river basin. River basins have a single outlet point, but coastal basins drain to the ocean in a more diffuse manner. Since many of the actual drainage areas along the coast are smaller than 80 km^2, they are not included in the subwatersheds coverage.

This problem is resolved by selecting shed8cov polygons that, along with the baybuff coverage and the subsheds shapefile, completely enclose the basin area not accounted for in shed8cov. Only three additional polygons are selected for this purpose and converted into the shapefile, trimshed.shp. Figure 4.8 shows the shapefiles subsheds.shp and trimshed.shp displayed with the baybuff coverage to completely enclose the undelineated area of the coastal basin.

The subsheds and trimshed shapefiles are converted to coverages using the Arc/Info Shapearc command. The coverages are then cleaned to construct polygon topology. This process creates the coverages covsheds and covtrim. The Append command is used to merge the covsheds, covtrim, baybuff, and barriers coverages into one large coverage blanketing the entire coastal basin.

```
Arc:  shapearc subsheds subsheds
Arc:  shapearc trimshed trimshed
Arc:  clean subsheds covsheds
Arc:  clean trimshed covtrim
Arc:  append basin
Enter the 1st coverage:  covsheds
Enter the 2nd coverage:  covtrim
Enter the 3rd coverage:  baybuff
Enter the 4th coverage:  barriers
Enter the 5th coverage:  ~  <return>
Done entering coverage names (Y/N)?  y
Do you wish to use the above coverages (Y/N)?  y
```
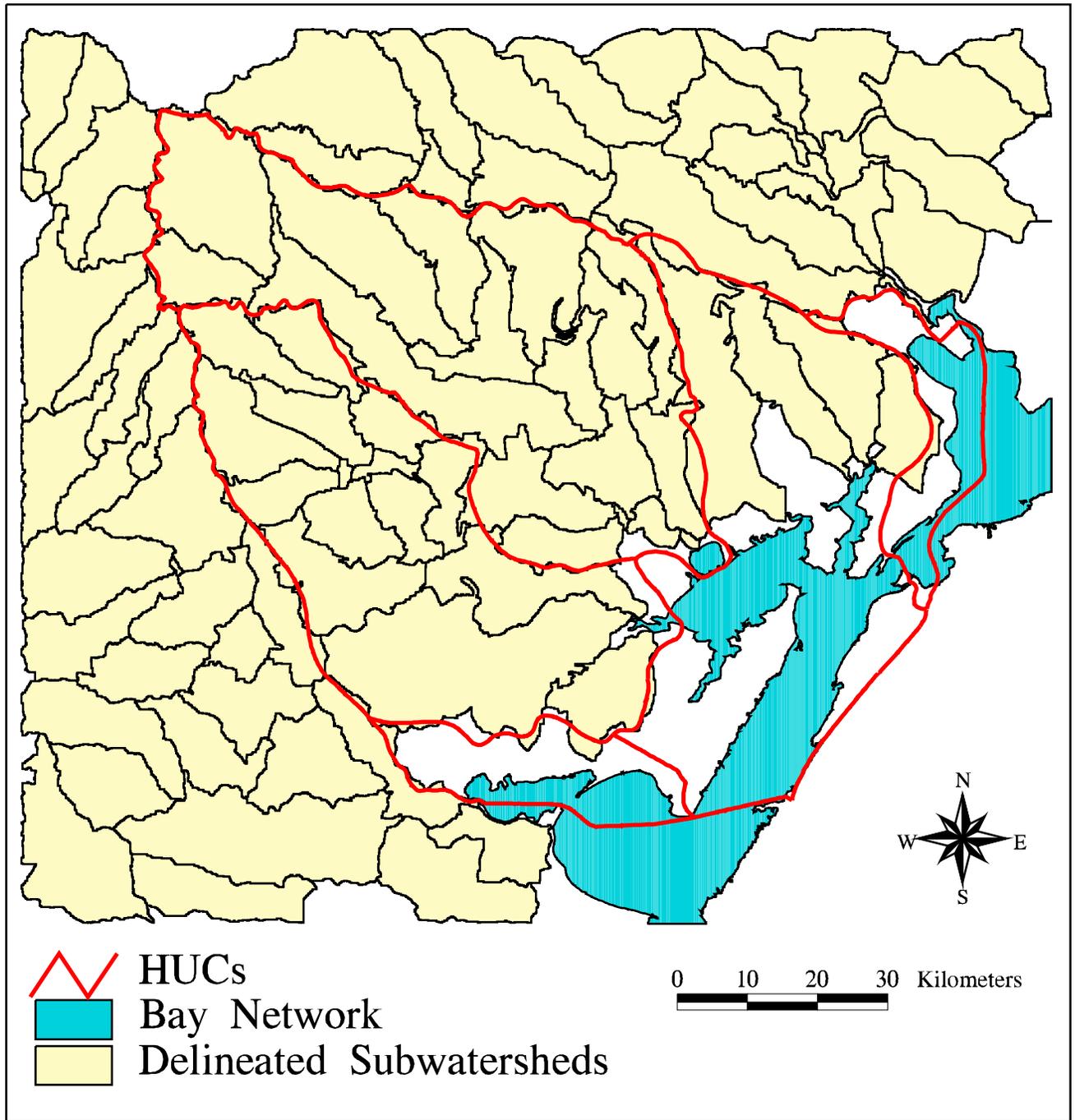
Figure 4.7: Digitally Delineated Subwatersheds of the San Antonio-Nueces Basin Compared with USGS Hydrologic Unit Codes
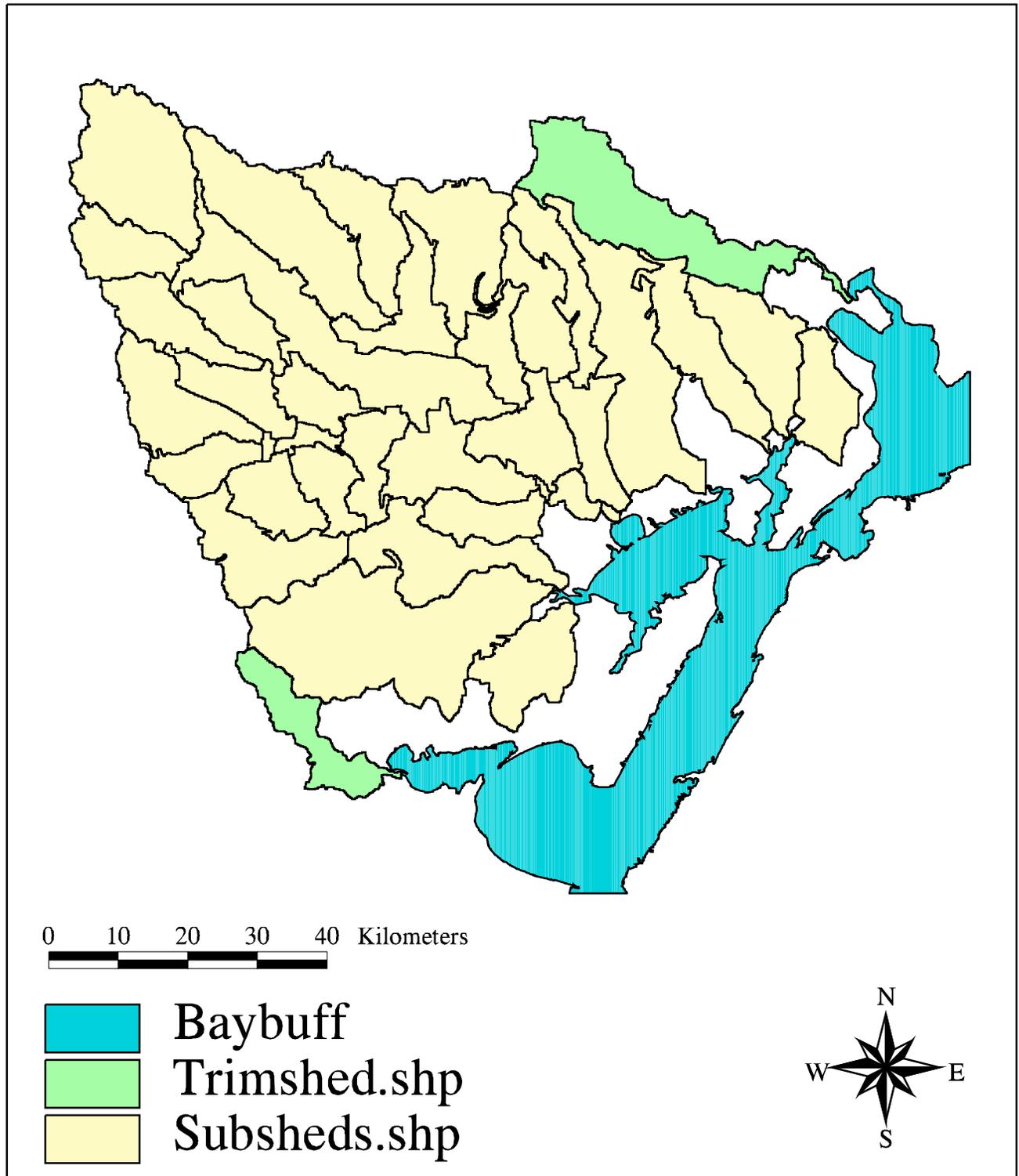
Figure 4.8 : Creating the Basin Boundary
through use of ArcView Shapefiles

```
   Appending coverages....
Arc:  clean basin sanbasin
```

The final cleaned basin coverage, sanbasin, actually contains the three polygons
from the trimshed shapefile. By displaying the sanbasin coverage in ArcView 2.0, all
sanbasin polygons except for those from trimshed are selected and converted to the
shapefile, bord.shp. Once again, the Shapearc and Clean commands are used to create
a border coverage. Finally, the Reselect command is used to select the exterior
polygon of the coverage. This has the effect of removing all of the interior
subwatershed boundaries and leaving only the outline of the basin.

```
Arc:  shapearc bord bord
Arc:  clean bord border
Arc:  reselect bord sanbord
>:  res bord# = 1
>:  ~
Do you wish to re-enter expression (Y/N)?  n
Do you wish to enter another expression (Y/N)?  n
  1 features out of 60 selected
```

The final sanbord coverage is used throughout this project to define the
boundary of the San Antonio-Nueces Coastal Basin. For aesthetics, the complete
bodies of both Corpus Christi Bay and San Antonio Bay are included in the coverage.
The Clip command is used, along with this basin border, to select data specific to the
basin from the data sets described in section 3.2.

```
Arc:  clip sanhydro sanbord sanhyd line
Arc:  clip sanlus sanbord sanlu poly
Arc:  clip rainbfcv sanbord snrainyr poly
```

4.2 Determination of a Rainfall/Runoff Relationship

In order to assess the transport of pollutant loads in a region, an understanding
of the means by which the loads migrate is first required. Nonpoint source pollutants
are carried over land and into the stream networks of a region by direct runoff. This
runoff is largely the result of precipitation over the area, although some runoff may also
be generated by over-irrigation in agricultural areas. For this study, the volume of

runoff from a grid-cell is completely attributed to precipitation over the cell. By comparing average annual stream flows at each of the USGS flow gauges with the average annual precipitation that occurs upstream of those gauges, a mathematical relationship between rainfall and runoff is established.

Determining Average Rainfall for each Delineated Drainage Area

The Parameter-elevation Regressions on Independent Slopes Model (PRISM) discussed in section 3.2 provides the precipitation data used for this study. This data is provided as total annual depth of precipitation (mm) averaged over the 30-year period from 1961 to 1990. Two methods of determining average rainfall for each drainage area are performed and compared in this analysis.

The first method for calculating average rainfall for each drainage area makes use of a process called a weighted flow accumulation. This is an extension of the regular Flowaccumulation command. However, instead of counting the number of cells that occur upstream of each particular grid cell, the weighted Flowaccumulation command uses a second grid, called a weight grid, and sums the weight grid values of the cells that occur upstream. Using the buffered precipitation grid as the weight grid, a grid representing total annual potential runoff is generated:

Grid: **weighfac = flowaccumulation(clipfdr,rainbuff) * 10**

The factor of ten is used in this command to convert from the rainbuff units of depth (mm) to units of volume (m^3), using the knowledge that each cell is equal to 10,000 m^2, or

Volume = Depth (mm) * Area (#cells) * 10,000 m^2/cell * .001 m/mm.   (4-1)

Once the weighted flow accumulation grid is established and displayed, the USGS stream gauge coverage is overlaid and each of the gauge points are queried, using the Cellvalue command, to determine the potential runoff that would occur at each gauge. By dividing these potential runoff values by the delineated drainage areas associated with each gauge (from Table 4.1), the average depth of precipitation is established for each drainage area:

```
Grid:  gridpaint weighfac value linear nowrap gray
Grid:  points sangages
Grid:  cellvalue weighfac *
<9 to END>
The cell containing point (1233178.620,682331.934) has value 510618944.000
The cell containing point (1266688.298,684048.117) has value 1487741184.000
The cell containing point (1282992.941,685733.054) has value 192068960.000
The cell containing point (1229206.739,704427.678) has value 412713952.000
The cell containing point (1245272.269,656404.121) has value 273848544.000
```

A second method of determining average precipitation at each gauge is to create separate precipitation grids corresponding to each subwatershed grid, using the Con statement. Once the localized precipitation grids are created, the Describe command provides the mean value of all cells in the grid as a statistic. Using the Aransas drainage area as an example, this process is performed as:

```
Grid:  aranrain = con(aranarea,rainbuff)
Grid:  describe aranrain
                Description of Grid ARANRAIN

Cell Size =            100.000    Data Type:          Integer
Number of Rows   =      1325       Number of Values =      37
Number of Columns =     1520       Attribute Data (bytes) =    8

        BOUNDARY                   STATISTICS

Xmin =      1180828.125    Minimum Value =      761.000
Xmax =      1332828.125    Maximum Value =      860.000
Ymin =       612183.250    Mean       =        806.792
Ymax =       744683.250    Standard Deviation =     15.708
```

Table 4.2 shows the average annual precipitation values determined by both methods for each gauge. As can be seen from the table, results are consistent for both methods.

A precipitation grid that adheres to the watershed boundary is established by first creating an equivalent grid from the sanbord coverage established in section 4.1. Then, using that grid with the Con statement, the precipitation cells particular to the basin are selected.

```
Grid:  bordgrid = polygrid(sanbord,#,#,#,100)
Grid:  sanpyr = con(bordgrid,rainbuff)
```

	Method #1			Method #2
Drainage Subwatershed	Potential Runoff (m^3)	Drainage Area (km^2)	Precip Depth (mm)	Precip Depth (mm)
Mission	1,487,741,184	1766.19	842.34	842.326
Aransas	510,618,944	632.91	806.78	806.792
Copano	192,068,960	207.82	924.21	924.252
Chiltipin	273,848,544	322.33	849.59	849.618
Medio	412,713,952	527.08	783.02	783.033

Table 4.2 : Comparison of Methods for Determining Average Annual Precipitation for each Gauged San Antonio-Nueces Drainage Area

Determining Average Depth of Runoff at each USGS Gauge

The montflow.f FORTRAN algorithm (Appendix B) calculates values for total monthly, annual, and average annual streamflow volume, given average daily streamflow in cubic feet per second (cfs). Table 4.3 shows the output from this algorithm for each USGS streamflow gauge in the San Antonio-Nueces Coastal Basin, given the raw input data for the years 1961-1990. Table 4.4 shows the equivalent depths of streamflow for those volumes, calculated by dividing each value by the delineated drainage area of the particular gauge (from Table 4.1). Figure 4.9 shows how annual depths of streamflow have varied from the average annual depths at each gauge for the period 1961-1990.

One may note from Tables 4.3 and 4.4 that, of the five USGS gauges in the basin, only the Mission River gauge has recorded streamflow values for the total period of applicable precipitation data. Ideally, for the establishment of a rainfall/runoff relationship, rainfall and streamflow data from the same periods of record should be used. To that end, projected 30-year average annual streamflows at each gauge, Q_g, are estimated using the average annual 1961-1990 streamflow at the Mission gauge, Q_m. These estimates are established 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 over the same time period, or

Year	Mission	Aransas	Chiltipin	Copano	Medio
1961	57,685,664				
1962	40,983,796				
1963	5,693,702				3,769,459
1964	10,694,530				3,144,356
1965	47,063,808	12,482,179			11,207,823
1966	106,309,680	23,827,040			1,432,233
1967	632,705,728	184,715,696			163,328,112
1968	131,968,248	18,562,584			12,908,496
1969	74,330,552	14,724,674			2,892,822
1970	65,834,276	14,914,258			7,378,471
1971	379,032,896	115,493,312	117,657,808	97,337,648	11,217,219
1972	177,693,296	34,983,532	36,046,596	58,093,640	6,511,890
1973	356,130,304	70,796,616	82,647,592	76,333,720	10,388,754
1974	106,735,128	52,987,968	12,367,189	21,977,854	745,549
1975	35,551,872	4,430,039	11,762,097	1,716,429	557,798
1976	253,111,616	30,784,200	59,696,076	42,789,296	18,338,360
1977	117,446,048	16,581,756	26,458,148	14,502,448	
1978	61,703,216	6,657,413	15,928,468	57,803,472	
1979	123,047,520	16,923,788	55,162,504	47,387,740	
1980	114,900,872	21,109,020	57,560,848	10,808,809	
1981	347,880,480	55,757,024	43,350,032	134,456,512	
1982	113,334,800	11,405,166	25,378,954	21,914,878	
1983	164,663,248	26,732,898	46,031,200	84,999,136	
1984	26,053,482	7,954,423	41,102,256	7,781,302	
1985	70,610,344	19,403,550	51,825,828	14,094,454	
1986	39,910,080	3,505,644	775,226	11,878,824	
1987	90,450,640	26,621,798		14,231,760	
1988	8,253,274	9,077,310	3,634,653	0	
1989	1,103,216	2,086,059	419,566	467,225	
1990	179,311,024	50,048,796	1,853,683	32,815,878	
Avg Annual =	131,339,778	32,791,029	42,734,426*	37,569,551	18,130,096

*calculated for 1971-1986 due to break in service in 1987

Table 4.3 : Annual Volume (m^3) of Recorded Streamflow (1961-1990) for the Five USGS Gauges in the San Antonio-Nueces Coastal Basin

Year	Mission	Aransas	Chiltipin	Copano	Medio
1961	32.7				
1962	23.2				
1963	3.2				7.2
1964	6.1				6.0
1965	26.6	19.7			21.3
1966	60.2	37.6			2.7
1967	358.2	291.9			309.9
1968	74.7	29.3			24.5
1969	42.1	23.3			5.5
1970	37.3	23.6			14.0
1971	214.6	182.5	365.0	468.4	21.3
1972	100.6	55.3	111.8	279.5	12.4
1973	201.6	111.9	256.4	367.3	19.7
1974	60.4	83.7	38.4	105.8	1.4
1975	20.1	7.0	36.5	8.3	1.1
1976	143.3	48.6	185.2	205.9	34.8
1977	66.5	26.2	82.1	69.8	
1978	34.9	10.5	49.4	278.1	
1979	69.7	26.7	171.1	228.0	
1980	65.1	33.4	178.6	52.0	
1981	197.0	88.1	134.5	647.0	
1982	64.2	18.0	78.7	105.5	
1983	93.2	42.2	142.8	409.0	
1984	14.8	12.6	127.5	37.4	
1985	40.0	30.7	160.8	67.8	
1986	22.6	5.5	2.4	57.2	
1987	51.2	42.1	-------	68.5	
1988	4.7	14.3	11.3	0.0	
1989	0.6	3.3	1.3	2.2	
1990	101.5	79.1	5.8	157.9	
Avg Annual =	74.4	51.8	132.6*	180.8	34.4

*calculated for 1971-1986 due to break in service in 1987

**Table 4.4 : Equivalent Depth (mm) of Recorded Streamflow (1961-1990) for the
Five USGS Gauges in the San Antonio-Nueces Coastal Basin**
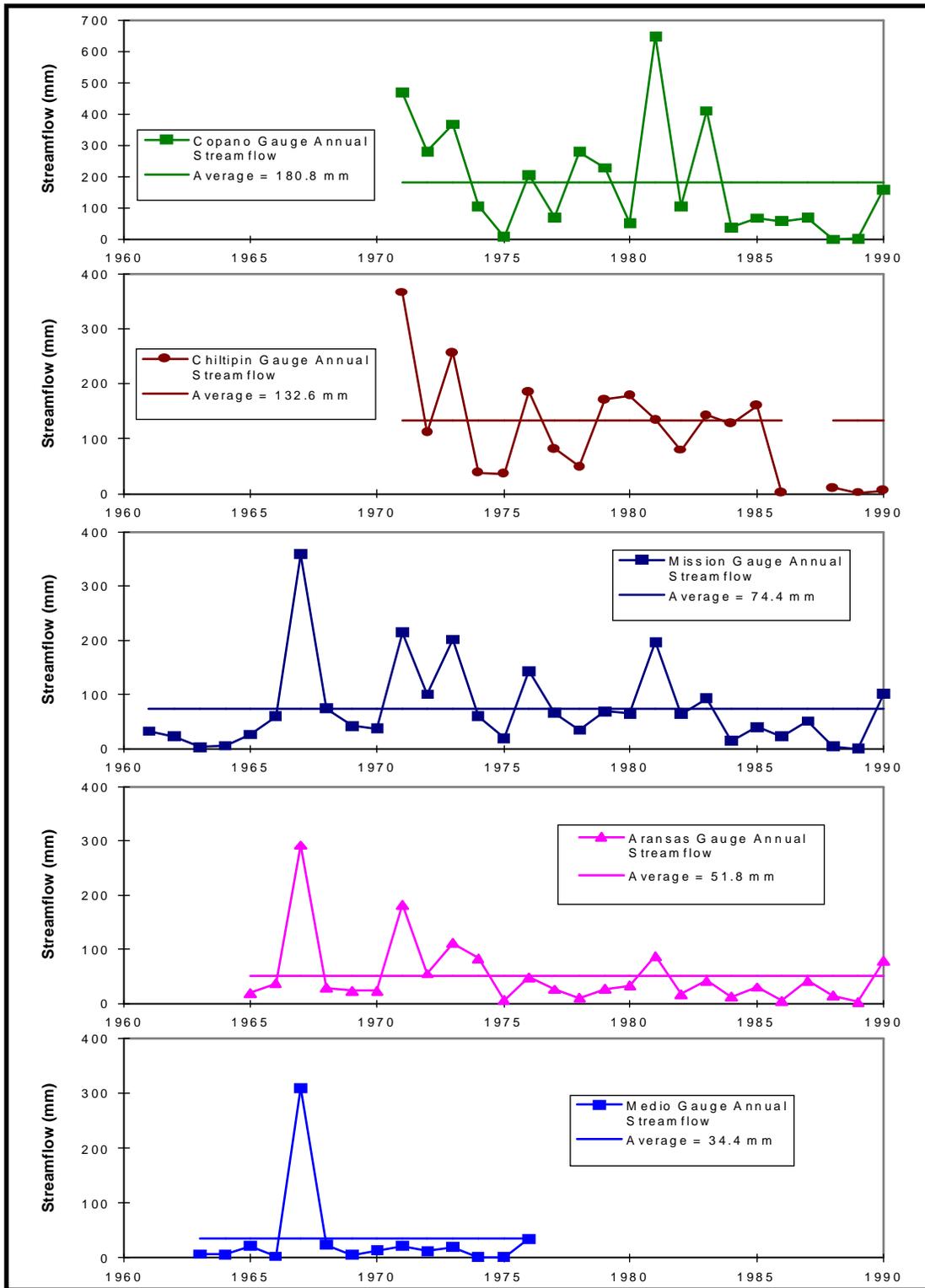
Figure 4.9 : USGS Recorded Annual Streamflows for Five Gauges in the San Antonio-Nueces Basin

85

$$Q_g = Q_m * (q_g/q_m). \tag{4-2}$$

This approach is legitimate for temporally averaged estimates in a region, where variations from year to year generally conform to similar trends. Figure 4.9 illustrates these regional trends with coincident occurrences of local maximum and minimum streamflow values. Table 4.5 shows the projected 30-year average annual depths of streamflow for each of the five USGS gauges.

Establishing a Mathematical Relationship Between Rainfall and Runoff

Using the five values for average annual precipitation along with the five values for projected 30-year average annual depth of streamflow, the Microsoft Excel 5.0 Regression tool is employed to determine the best fit curve between the two data sets. Assessments of the best linear, best quadratic, and best exponential fits show that the linear relationship most accurately reflects runoff in the San Antonio-Nueces coastal basin. Figure 4.10 shows the Microsoft Excel output of the regression for the linear case. This regression run produces a squared multiple correlation coefficient (r^2) value of 0.964, which indicates that the best fit line approximates the actual data well.

Based on the regression output, the linear relationship that best approximates the rainfall/runoff relationship in the San Antonio-Nueces Coastal Basin is

$$Q \text{ (mm)} = 1.0527 * P \text{ (mm)} - 799.37, \tag{4-3}$$

where Q represents depth of streamflow and P represents precipitation.

In order to create an Arc/Info grid of runoff, this relationship would be applied to every cell in the precipitation grid. However, since the precipitation grid has an effective range of values between 739 mm and 985 mm, it is noted that there is a small range of cells (739 - 759 mm) for which the relationship produces negative numbers. In order to avert this irregularity, the rainfall/runoff relationship of equation 4-3 is only applied to precipitation cells with value greater than 759 mm. In other words, the adjusted rainfall/runoff relationship becomes

$$Q \text{ (mm)} = 1.0527 * P \text{ (mm)} - 799.37, \quad P > 759 \text{ mm}$$
$$Q \text{ (mm)} = 0, \quad P \leq 759 \text{ mm}. \tag{4-4}$$

USGS Streamflow Gauge	Average Depth of Streamflow (mm)	Years of Continuous Operation	Avg Mission Depth for those Years (mm)	Projected 30-Year Avg (61-90) (mm)
Mission	74.4	1961-90	74.4	74.4
Aransas	51.8	1965-90	83.3	46.3
Copano	180.8	1971-90	78.3	171.6
Chiltipin	132.6	1971-86	88.1	112.0
Medio	34.4	1963-76	96.7	26.5

Table 4.5 : Projected 30-Year Average Annual Depth of Streamflow for the Five USGS Gauges in the San Antonio-Nueces Basin

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9818
R Square	0.9640
Adjusted R Square	0.9519
Standard Error	12.6196
Observations	5.0000

ANOVA

	df	SS	MS	F	Significance F
Regression	1	12779.4255	12779.4255	80.2450	0.0029
Residual	3	477.7651	159.2550		
Total	4	13257.1906			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	-799.3698	99.0143	-8.0733	0.0040	-1114.4778	-484.2617
X Variable 1	1.0527	0.1175	8.9580	0.0029	0.6787	1.4267

Figure 4.10 : Regression Tool Output for Best Linear Fit Relationship Between Average Annual Precipitation and Depth of Streamflow

The fact that this equation produces values of Q = 0 for precipitation values less than 759 mm is a limitation of the linear modeling function. However, since the region of the San Antonio-Nueces basin that annually receives less than 759 mm of rain is limited to a 78 square kilometer area in the northwest corner of the watershed (approximately one percent of the basin's area), the adjusted linear rainfall/runoff relationship is considered acceptable for the basin. However, it should be stressed that the equation is specific to the San Antonio-Nueces coastal basin and should not be applied outside the watershed. A plot of this adjusted rainfall/runoff relationship is shown in Figure 4.11. The five points denoted on the graph represent the average precipitation and 30-year projected depth of streamflow for each gauge.

While equation 4-4 provides reasonable estimates of runoff for portions of the San Antonio-Nueces basin that drain to gauged locations, a more comprehensive relationship for the basin might be established by considering runoff data from gauges in adjacent basins which receive greater and less precipitation. Consideration of this additional runoff data would extend the range of application of the rainfall/runoff relation and a mathematical form of the relationship could be estimated more accurately.

Using the rainfall/runoff relationship of equation 4-4 in conjunction with the precipitation grid and the Con statement, a grid of runoff is produced. So that subsequent flow accumulations may be performed on this grid without encountering cells of NODATA (null) value, the Isnull command is used with a second Con statement to zero fill all of the null cells resulting from application of the rainfall/runoff relationship. Finally, an equivalent coverage of runoff is created through use of the Gridpoly command. Figure 4.12 shows this runoff coverage, with annual runoff amounts depicted in intervals of 50 mm.

Grid: **runoffeq = con(sanpyr > 759, 1.0527 * sanpyr - 799.37, 0)**
Grid: **runoff = con(isnull(runoffeq),0,runoffeq)**
Grid: **runoffcv = gridpoly(int(runoff))**
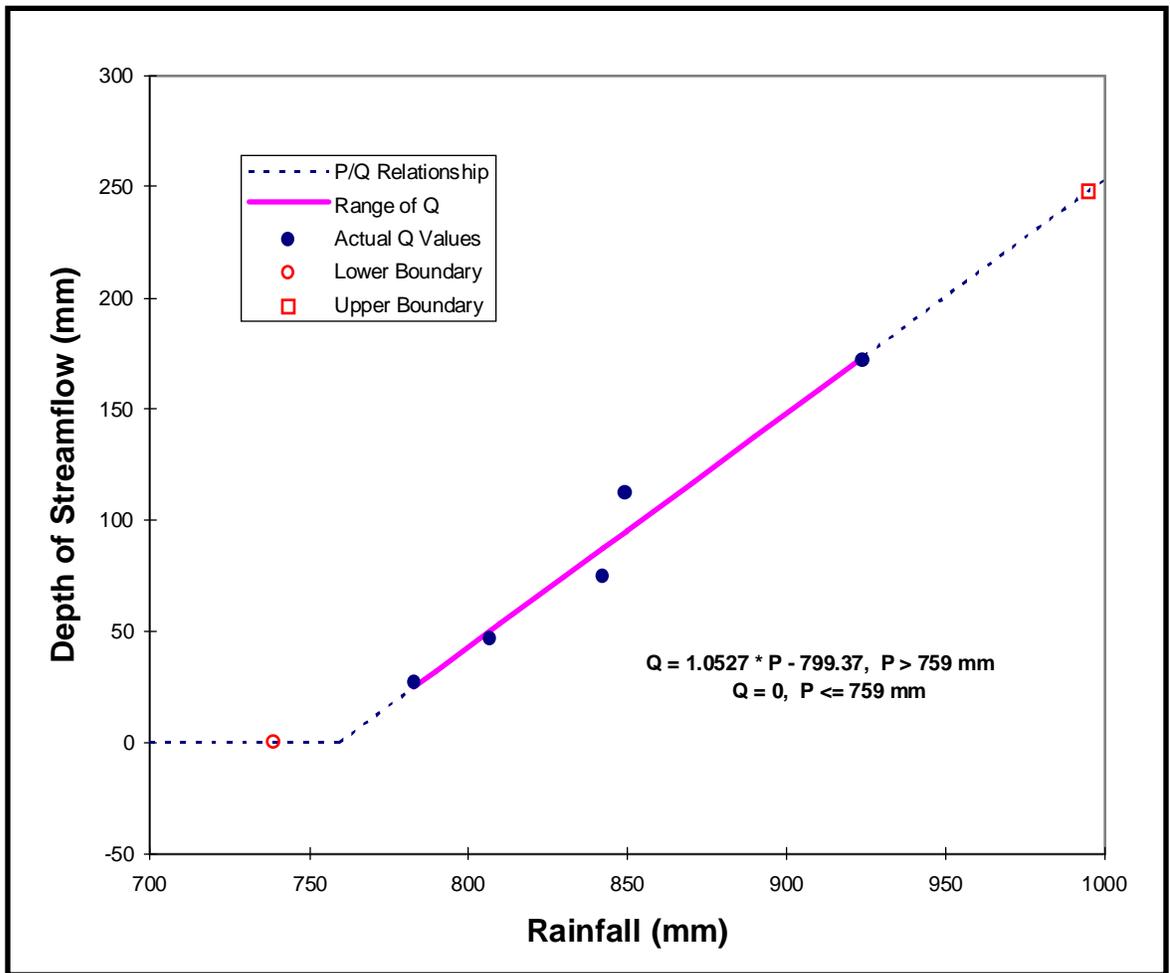
**Figure 4.11 : Realtionship Between Rainfall and Streamflow in the
San Antonio-Nueces Coastal Basin (Linear)**
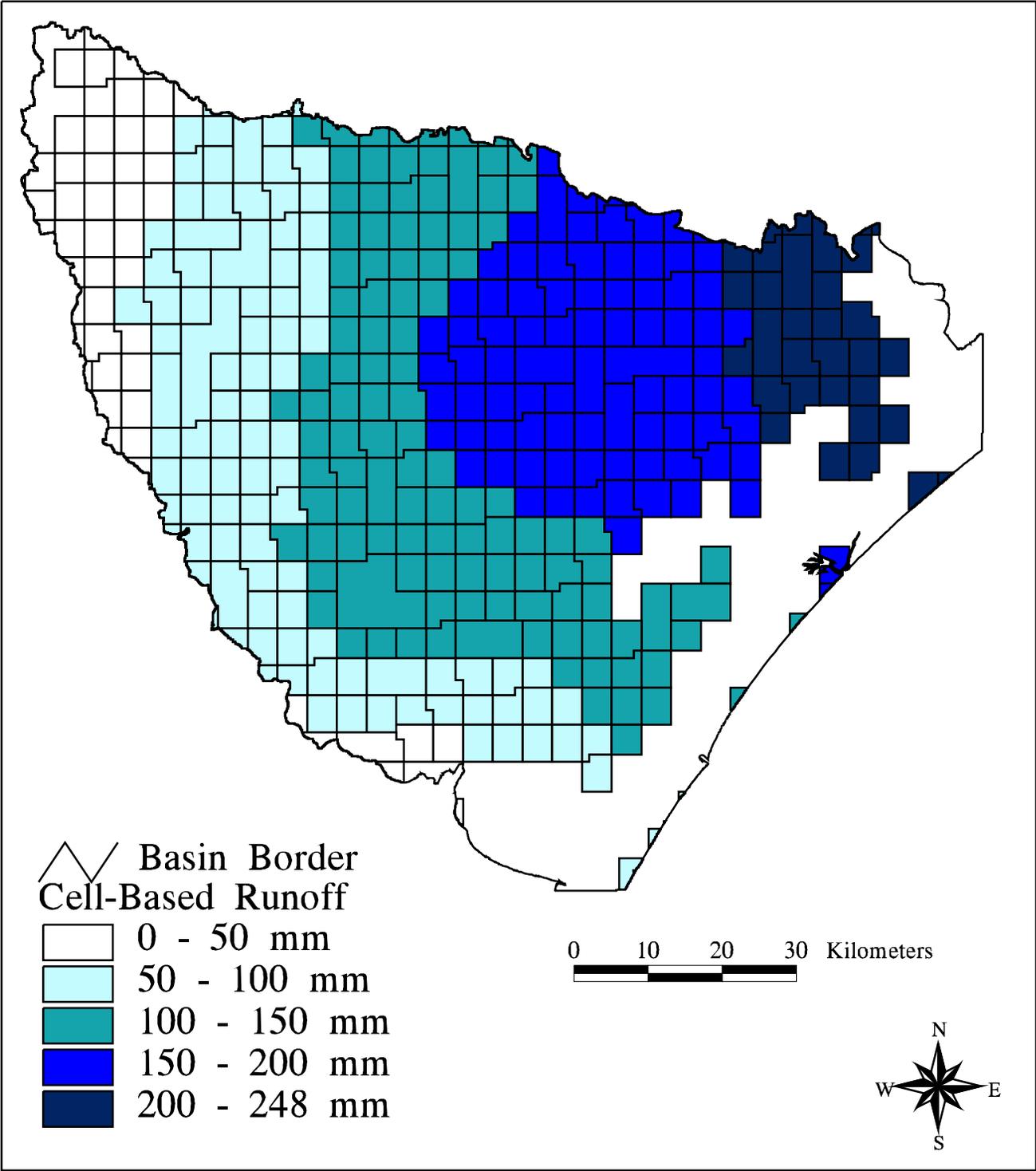
Figure 4.12 : Estimated Runoff in the San Antonio-Nueces Coastal Basin

4.3 Linking Expected Mean Concentration of Pollutants to Land Use

The measure of pollutant level that occurs during a runoff event is the expected mean concentration, or EMC, defined as the mass of pollutant transported per volume of runoff. For this study, it is assumed that expected mean concentrations of various pollutants are directly related to land uses in the drainage areas. In order to associate pollutant expected mean concentrations with land use, the land use coverage shown in Figure 3.5 is used along with the expected mean concentration data from Table 3.6.

Establishing a Link Attribute

A review of the data in Table 3.6 shows that, while expected mean concentration values are included for each subcategory of urban land use, only one value is included for the agricultural, range, and barren land use categories. However, all polygons in the land use coverage are delineated by subcategory. In order to facilitate the assignment of expected mean concentrations to land uses in the region, an additional attribute is first created in the polygon attribute table (pat) of the land use coverage. This new attribute, called lusecat, identifies the unique land use categories to which the expected mean concentrations are assigned.

The Arc/Info Tables tool is used to create the lusecat attribute. The attribute, defined as an integer, is first added to the polygon attribute table, using the Additem command. All land use subcategory polygons for which no unique expected mean concentrations exist are then reselected and the lusecat attribute for these polygons is defined as the truncated lanuse-id field, rounded to the lowest multiple of ten. This has the effect of redefining all agriculture land use subcategories, for example, to one value of land use category. For those land use subcategory polygons which do have corresponding unique expected mean concentrations (i.e. urban land uses), the lusecat attribute is defined as the value of the lanuse-id field. Finally, the Arc/Info Dissolve command is used to create a land use map with distinct category, versus subcategory, polygons.

```
Arc:  tables
Enter Command:  additem sanlu.pat lusecat 8 8 i
Enter Command:  sel sanlu.pat
```

```
Enter Command:  reselect lanuse-id > 19
Enter Command:  calc lusecat = lanuse-id / 10
Enter Command:  sel
   File SANLU.PAT is now closed.
Enter Command:  sel sanlu.pat
Enter Command:  calc lusecat = lusecat * 10
Enter Command:  sel
   File SANLU.PAT is now closed.
Enter Command:  sel sanlu.pat
Enter Command:  reselect lanuse-id < 19
Enter Command:  calc lusecat = lanuse-id
Enter Command:  quit
Arc:  dissolve sanlu sanluse lusecat poly
Arc:  kill sanlu all
Arc:  rename sanluse sanlu
```

Attaching the Expected Mean Concentration Data to Land Use

In order to attach the Expected Mean Concentration data from Table 3.6 to the land use coverage, a separate data table with each of the values listed by land use category must first be created. This data table, called emc3a.dat, is shown in Figure 4.13. Note that land use category appears as the first item in each row of the data and that expected mean concentration values for each pollutant are listed horizontally, in order of their appearance in Table 3.6, for each land use category. It should also be noted that expected mean concentration values for water, wetlands, tundra, and snowfield land uses are assumed to be zero for all pollutants and that the concentration values for range land uses are also applied to forest land uses in the basin. For the creation of this data file, special care must be taken to ensure that items in the file are delimited by single spaces and that the data is followed by an 'end' statement.

Once the raw expected mean concentration data file is created, it is used to fill a formatted data file, called attrib.dat, that is subsequently attached to the polygon attribute table of the land use coverage. Construction of the formatted data file is done with the Tables tool. A field for land use category is defined and then fields for each pollutant expected mean concentration value are defined. This process of defining the formatted data table is cumbersome and the potential for error in data input is significant. The process is more efficiently performed through use of an AML.

```
0 0.0 0.0 0.0 0.0 0.0 0.0 0 0.0 0.0 0 0.0 0.0 0.0 0.0 0.0 0.0 0 0
11 1.82 1.5 0.23 0.57 0.48 41.0 134 9.0 15.0 80 0.75 2.1 5.0 25.5 49.5 1.7 20000 56000
12 1.34 1.1 0.26 0.32 0.11 55.5 185 13.0 14.5 180 0.96 10.0 11.8 23.0 116.0 9.0 6900 18000
13 1.26 1.0 0.3 0.28 0.22 60.5 116 15.0 15.0 245 2.0 7.0 8.3 14.0 45.5 3.0 9700 6100
14 1.86 1.5 0.56 0.22 0.1 73.5 194 11.0 11.0 60 0.5 3.0 4.0 6.4 59.0 0.4 53000 26000
15 1.30 1.05 0.28 0.3 0.17 58.0 151 14.0 14.8 207 1.48 8.5 10.1 18.5 81.0 6.0 8300 12050
16 1.57 1.25 0.34 0.35 0.23 57.9 157 12.0 13.9 141 1.05 5.5 7.3 17.2 67.5 3.5 22400 26525
17 1.57 1.25 0.34 0.35 0.23 57.9 157 12.0 13.9 141 1.05 5.5 7.3 17.2 67.5 3.5 22400 26525
20 4.4 1.7 1.6 1.3 0.0 107.0 1225 1.5 1.5 16 1.0 5.0 0.0 4.0 0.0 0.0 0 0
30 0.7 0.2 0.4 0.0 0.0 1.0 245 5.0 5.0 6 0.5 7.5 0.0 0.5 0.0 0.0 200 0
40 0.7 0.2 0.4 0.0 0.0 1.0 245 5.0 5.0 6 0.5 7.5 0.0 0.5 0.0 0.0 200 0
50 0.0 0.0 0.0 0.0 0.0 0.0 0 0.0 0.0 0 0.0 0.0 0.0 0.0 0.0 0.0 0 0
60 0.0 0.0 0.0 0.0 0.0 0.0 0 0.0 0.0 0 0.0 0.0 0.0 0.0 0.0 0.0 0 0
70 1.5 0.96 0.54 0.12 0.03 70.0 0 1.52 0.0 0 0.0 0.0 0.0 0.0 40.0 0.0 0 0
80 0.0 0.0 0.0 0.0 0.0 0.0 0 0.0 0.0 0 0.0 0.0 0.0 0.0 0.0 0.0 0 0
90 0.0 0.0 0.0 0.0 0.0 0.0 0 0.0 0.0 0 0.0 0.0 0.0 0.0 0.0 0.0 0 0
end
```

Figure 4.13 : Conversion of Tabulated Expected Mean Concentration Values to an Arc/Info Data File

Appendix B includes the attrib.aml file, which is used to define item formats in the attrib.dat file and then fill the formatted file with raw data from the emc3a.dat file.

Finally, the expected mean concentration data is attached to the land use polygon attribute table through use of the Joinitem command, using the lusecat field as the linking item between both tables:

Arc: **joinitem sanlu.pat attrib.dat sanlu.pat lusecat lusecat**

The resulting land use coverage includes 18 new fields identifying pollutant expected mean concentrations for each land use category within the basin. The land use coverage can be used to show how expected mean concentrations for a particular pollutant vary throughout the land use polygons of a particular region. For instance, Figure 4.14 shows expected mean concentrations for total phosphorus, based on the land use polygons within the San Antonio-Nueces Coastal Basin. As expected, the highest concentrations of total phosphorus are identified in the regions where agricultural land uses are predominant.

Figure 4.14 : Expected Mean Concentrations for Total Phosphorus
in the San Antonio-Nueces Coastal Basin

4.4 Estimating Annual Loadings Throughout the Watershed

The pollutant mass contribution that each cell makes to downstream pollutant loading is calculated by taking the product of the expected mean concentration and runoff associated with the cell, or

$$\text{Load (mass/time)} = \text{EMC (mass/volume)} * Q \text{ (volume/time)}. \qquad (4\text{-}5)$$

For load computations in this study, equation 4-5 becomes

$$L = K * Q * EMC * A, \qquad (4\text{-}6)$$

where Q is given in units of mm/year, EMC is given in units of mg/Liter, A is the area of one grid cell (10,000 m^2), and K is a constant to make the units consistent, i.e. K = 10^{-6} kg-m-L/mg-mm-m^3, so that L is determined in units of kg/year. This approach to representation of loadings assumes that the downstream transport process is conservative, i.e. no pollutant decay occurs along the flow paths. This assumption is considered appropriate for the pollutants in Table 3.6 along the short flow paths of the San Antonio-Nueces Basin. Another important point about this relationship is that it applies expected mean concentration, which is typically associated with single runoff events, to mean annual runoff, which generally includes stream base flow as well as runoff from storm events.

Pollutant loadings associated with each grid cell are determined by first converting the expected mean concentration map coverage to a grid, through use of the Polygrid command. For the creation of this grid, cell values are determined from the appropriate concentration attribute of the land use coverage. For the case of total phosphorus, the tp field is specified as the item from which to extract cell values. Once the expected mean concentration grid is created, a cell-based loading grid is established as the product of this grid and the runoff grid.

> Grid: **phosgrid = polygrid(sanlu,tp,#,#,100)**
> Grid: **phosrnof = phosgrid * runoff**

Before a cumulative annual loading grid is created, it is noted that, for display purposes, a representation of cumulative loads in the stream networks is desired. One

way to accomplish this is through the conversion of grid cell strings to an equivalent arc coverage, using the Streamline command. However, arcs created using Streamline start at the geographic center of the endpoint cell, rather than including the full width of the cell. The result of this idiosyncrasy is that the equivalent arc of a gridded stream falls one-half cell short of its expected outlet point.

To correct for this anomaly, the mainland portion of the baycov coverage, created in section 4.1, is isolated using the Reselect command. The new mainland coverage is then buffered by 100 meters and the buffered coverage is converted to an equivalent grid, using Polygrid. Finally, a flow direction grid specific to the buffered mainland coverage is created with the Con statement. This procedure has the effect of creating a flow direction grid that covers the mainland plus a 100-meter boundary extending out into the bay network.

```
Arc:  reselect baycov mainland
>:  res baycov-id = 1
>:  ~
Do you wish to re-enter expression (Y/N)?  n
Do you wish to enter another expression (Y/N)?  n
  1 features out of 30 selected
Arc:  buffer mainland main # # 100
Arc:  grid
Grid:  maingrid = polygrid(main,#,#,#,100)
Grid:  mainfdr = con(maingrid,ditfdr)
```

Cumulative annual loading in the basin is determined by performing a weighted flow accumulation, using the cell-based loading grid as the weight grid and the new buffered mainland flow direction grid. Division by 100 is introduced into this command, as per equation 4-6, to provide the result in units of kg/year.

```
Grid:  phosld = flowaccumulation(mainfdr,phosrnof) / 100
```

In order to facilitate the conversion of the cumulative loading grid to a coverage, an integer grid of cumulative load is first created. Then the Con statement is used with the Streamline command to effectively reselect all grid cells with value greater than or equal to a threshold of 1000. Selection of this threshold value reduces the number of cells to be converted to those that occur at in-stream locations, where accumulated loads are greatest. The specific threshold value is not arbitrary, but

should be selected so as to reflect as much of the known stream network as possible. Finally, the cumulative loadings coverage is clipped with the mainland template, so that the endpoints of the streams occur exactly at the bay network borders.

Grid: **phosload = int(phosld)**
Grid: **tpline = streamline(con(phosload >= 1000,phosload),mainfdr,grid-code)**
Arc: **clip tpline mainland tpload line**

By performing a Describe command on the annual cumulative loading grid (phosload), the maximum value (i.e. load) in the grid can be identified. Also, by querying the various outlet cells to the bay network with the Cellvalue command, annual cumulative loads from each subwatershed in the basin can be established.

Grid: **describe phosload**

Description of Grid PHOSLOAD

Cell Size =	100.000	Data Type:	Integer
Number of Rows =	1325	Number of Values =	4884
Number of Columns =	1520	Attribute Data (bytes) =	8

BOUNDARY   STATISTICS

Xmin =	1180828.125	Minimum Value =	0.000
Xmax =	1332828.125	Maximum Value =	60900.000
Ymin =	612183.250	Mean =	74.213
Ymax =	744683.250	Standard Deviation =	1553.429

Grid: **gridpaint phosload value linear nowrap gray**
Grid: **cellvalue phosload ***
The cell containing point (1267701.191,660318.274) has value 60900

Figure 4.15 shows annual cumulative loads of total phosphorus in the San Antonio-Nueces basin, using the grid-code attribute of the tpload coverage to display aerial distributed values of load greater than thresholds of 1000 kg/yr, 5000 kg/yr, 10,000 kg/yr, and 50,000 kg/yr. Specific load values at five bay network outlet points are identified on the figure. It should be noted that the largest contributions of phosphorus load are seen to be from the agricultural part of the basin in the Aransas subwatershed.
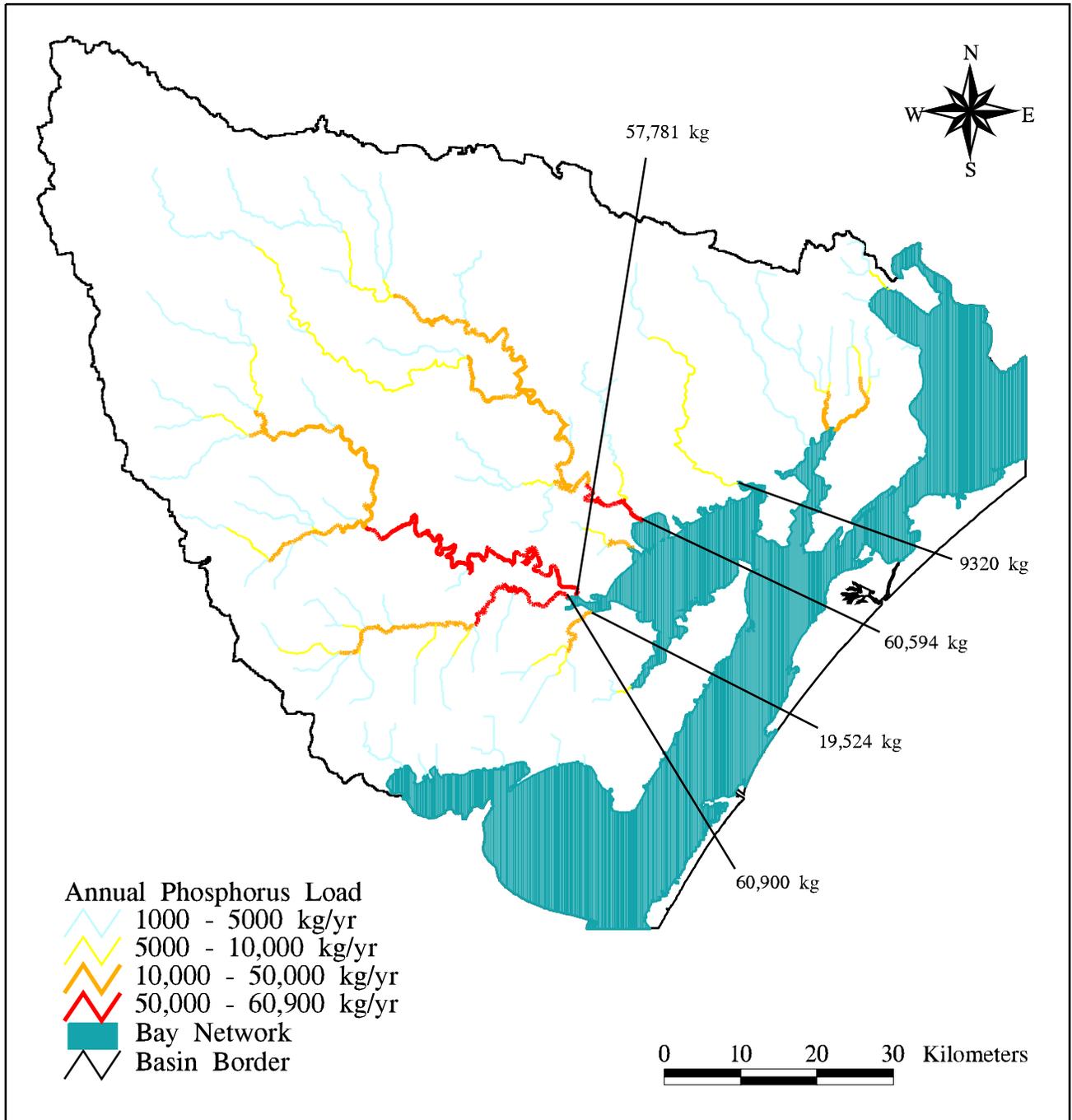
Figure 4.15 : Average Annual Total Phosphorus Loads in the
San Antonio-Nueces Coastal Basin

4.5 Predicting Downstream Pollutant Concentrations in Watershed Stream Networks

Pollutant concentrations that are sampled at various in-stream locations result from the mixing of all pollutant-laden flows draining from upstream of the particular location. For a digitally discretized grid model, this mixing process is approximated by dividing the accumulated load at each cell by the accumulated runoff that also occurs there. Mathematically, this is represented by

$$C_a = L_a / Q_a, \tag{4-7}$$

where L_a is the annual cumulative loading, Q_a is the annual cumulative runoff, and C_a is the average concentration expected at the location.

These predicted concentration values can be compared with measured data from a sampling program in order to assess the accuracy of the predicted values. For this study the water quality measurement data described in section 3.2 are used for comparison. For each sampling location in the data set, the assumption is made that the expected observed concentration is simply the average of all the measurements made there, or

$$C_o = (1/n) * \sum_{i=1}^{n} C_i, \tag{4-8}$$

where C_i is each concentration value measured at a particular sampling location, n is the total number of samples made at that location, and C_o is the average observed concentration.

Estimating Average Concentrations

Before estimated concentrations can be calculated, grids of annual cumulative loading and annual cumulative runoff need to be established. Grids of annual cumulative loading are created as per the procedure in section 4.4. Annual cumulative runoff is created by performing a weighted flow accumulation, using the runoff grid as

the weight grid. The result of the weighted flow accumulation is multiplied by 10 to convert from runoff units of mm/yr to accumulated units of m^3/yr, as in equation 4-1.

> Grid: **runoffac = flowaccumulation(mainfdr,runoff) * 10**
> Grid: **describe runoffac**

By performing a Describe command on the cumulative runoff grid, the maximum value of the grid is determined as more than 290 million m^3/yr. This is the value at the outlet of the Mission River to Mission Bay. The equivalent annual cumulative runoff grid, in units of cubic feet per second (cfs), is calculated by multiplying the runoffac grid by the number of cubic feet per cubic meter and dividing by the number of seconds per year. In these units of measure, the annual cumulative runoff is represented as an average stream flow and is more easily compared with recorded USGS stream flow values. For display purposes, an equivalent coverage of the accumulated runoff grid is created by first converting the real number grid to an integer grid. Then the Streamline command is used, along with the Con statement, to create arcs for all cells having value greater than or equal to a certain threshold value, specified so that only in-stream cells are converted. For this conversion, the threshold value is chosen to be 1 cfs. The cumulative runoff coverage is then clipped with the mainland coverage to create cumulative runoff arcs that end exactly at the boundaries of the bay network. Figure 4.16 shows average stream flows in units of cubic feet per second.

> Grid: **rofaccfs = runoffac * 35.2875 / 31557600**
> Grid: **introfac = int(rofaccfs)**
> Grid: **rofaclin = streamline(con(introfac >= 1,introfac),mainfdr,grid-code)**
> Arc: **clip rofaclin mainland rofaccov line**

Once the annual cumulative runoff grid is created, a grid of predicted pollutant concentration can be created as per equation 4-7. Using total phosphorus as an example pollutant, a grid of predicted concentrations is produced by dividing the annual total phosphorus cumulative load grid by the annual cumulative runoff (m^3/yr) grid. Multiplication of this result by 1000 produces a concentration grid in units of mg/L as per the equation

$$C \text{ (mg/L)} \ = \ L \text{ (kg/yr)} / Q \text{ (m}^3\text{/yr)} * 10^6 \text{ mg/kg} * .001 \text{ m}^3\text{/L.} \tag{4-9}$$

Average Stream Flow

/\/\/ 1 - 25 cfs
/\/\/ 25 - 50 cfs
/\/\/ 50 - 100 cfs
/\/\/ 100 - 200 cfs
/\/\/ 200 - 324 cfs
████ Bay Network
/\/\/ Basin Border

0   10   20   30   Kilometers
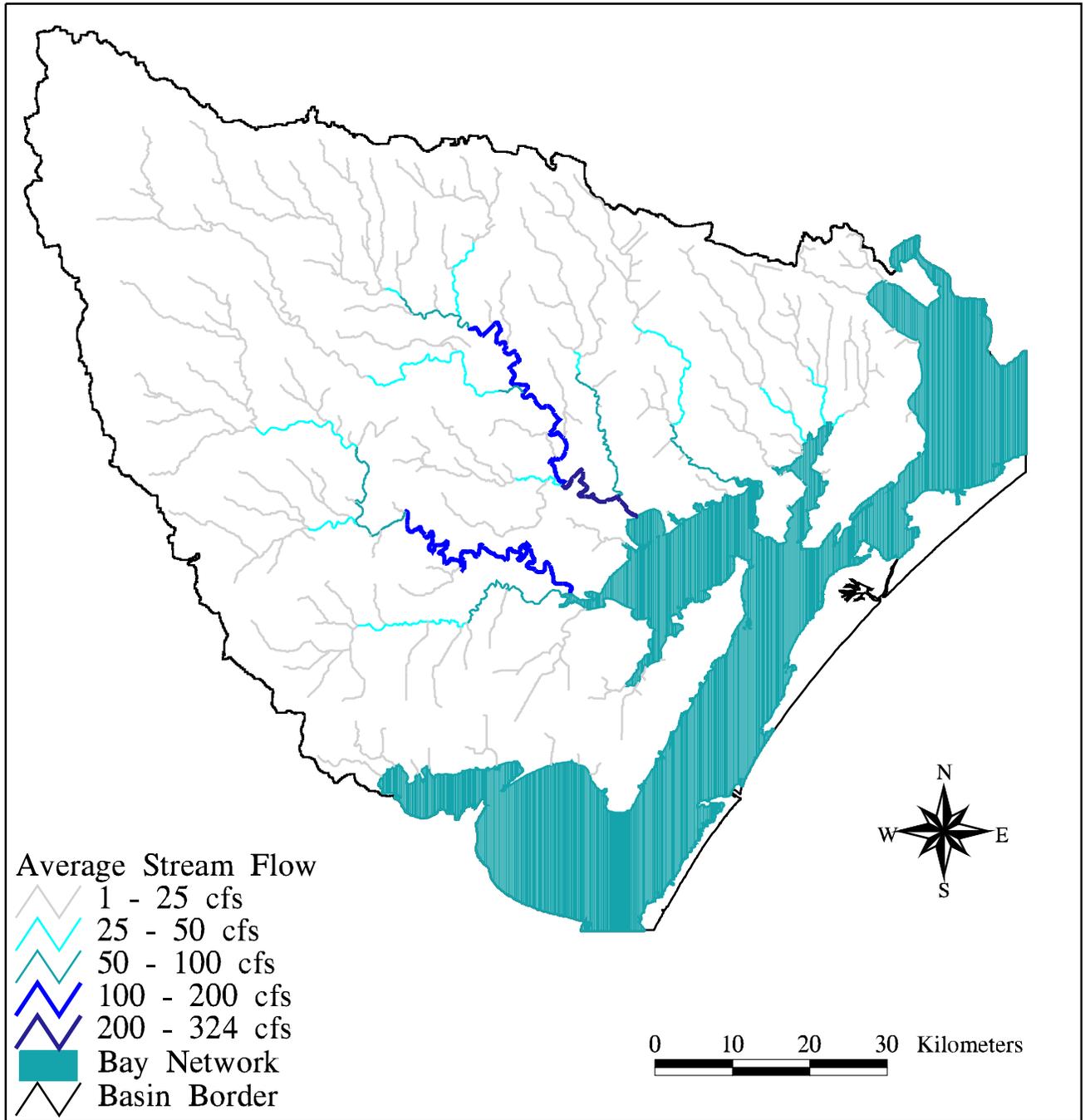
Figure 4.16 :   Average Annual Stream Flows in the
San Antonio-Nueces Coastal Basin

A grid of concentration values specific to the basin stream network is established using the Con statement with the introfac grid created above. Values from the predicted total phosphorus concentration grid are filled into those cells that correspond to locations along the stream networks. Since arc coverages may only be converted from integer value grids, the stream concentration grid is multiplied by 1000 to retain significant figures, the product is truncated to create the integer grid, and the resulting grid is converted to a coverage, using the Streamline command. Finally, the phosphorus concentrations arc coverage is clipped so that the concentration arcs end exactly at the shores of the bay network.

Grid: **phosconc = phosload / runoffac * 1000**
Grid: **phconstr = con(introfac >= 1,phosconc)**
Grid: **phline = streamline(int(phconstr * 1000),mainfdr,grid-code)**
Arc: **clip phline mainland phcon line**

Figure 4.17 shows the predicted concentrations for total phosphorus in the San Antonio-Nueces coastal basin. These predicted concentrations represent the levels of pollution that are attributed to nonpoint source runoff, only. Additional point source pollutant loadings are considered in section 4.6.

Attaching Observed Concentration Data to Measurement Locations

The Surface Water Quality Monitoring (SWQM) data described in section 3.2 are used for comparison with the predicted concentration values. With the data linked in ArcView 2.0 as shown in Figure 3.11, the average measured value of a particular pollutant constituent is established through use of the Summary Statistics tool. First, a pollutant is selected in the storet.dbf table. Then, with the station_id field selected in the value.dbf table, the Summary Statistics tool is invoked. This tool allows the user to sort and manipulate data from the selected table, using the previously selected field to sort by. Using the tool, the Value field is specified as the data to manipulate and the Summary Statistics Averaging function is performed on the data. This process creates a new database file (.dbf) that includes three fields: (1) all station-id's reporting data for the particular pollutant, (2) a field called count that represents the total number of measurements of the pollutant at that station, and (3) a field called ave_value that
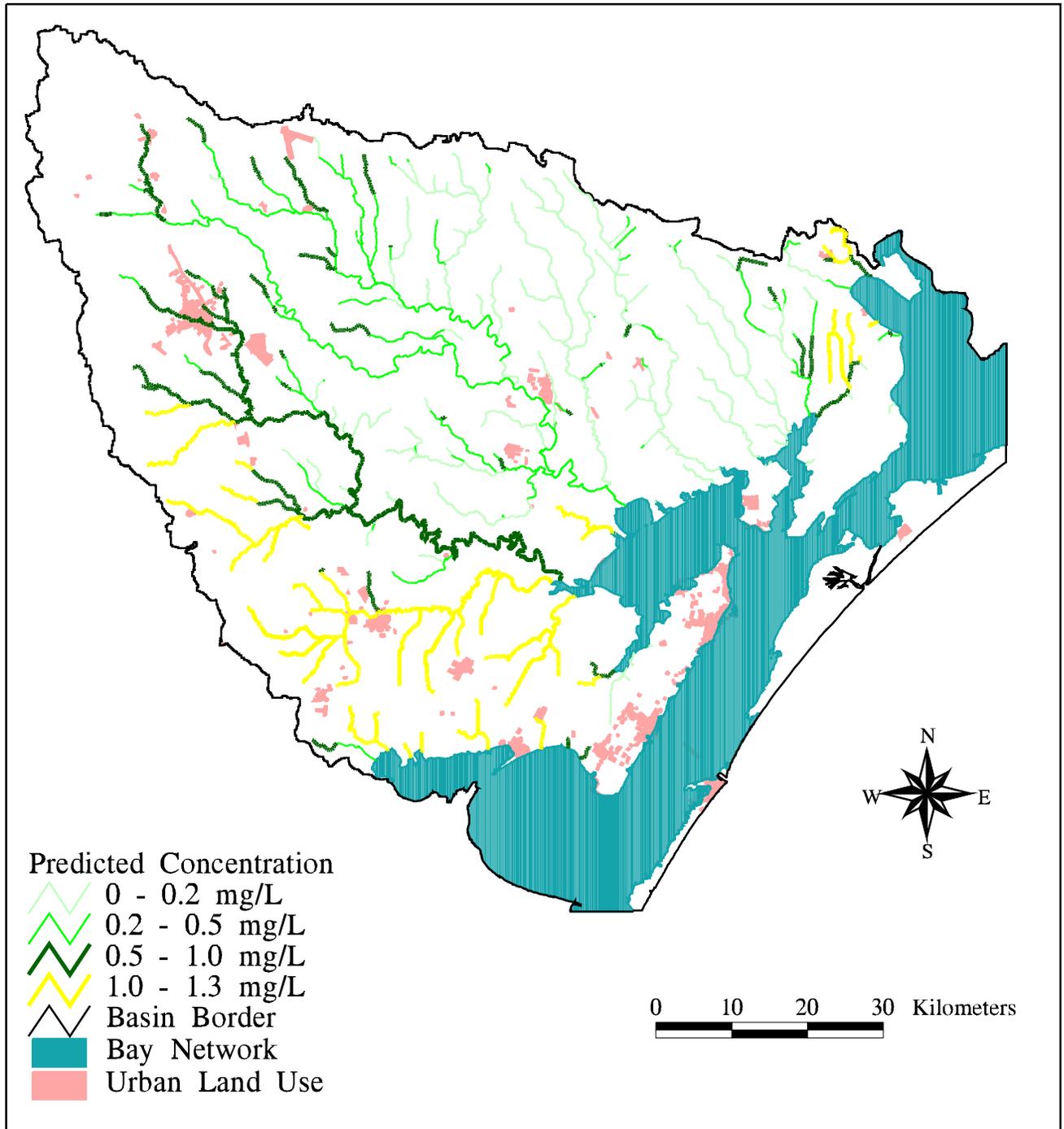
Figure 4.17 :   Estimated Total Phosphorus Concentrations in the
San Antonio-Nueces Coastal Basin

represents the mean value of the specified measurements. Table 4.6 shows a portion of the tp.dbf file identifying all measurement locations where total phosphorus is measured, the number of measurements at each location, and the average concentrations at each location.

The tp.dbf file is attached to the water quality measurement stations point coverage in Arc/Info. First, the file is converted to an Arc/Info Information file (.dat) using the Dbaseinfo command. The new tp.dat file is then attached to the sanwq point attribute table using the Joinitem command with the station_id field specified as the link item. Using the Arc/Info Tables module, the new count and ave_value fields of the sanwq point attribute table are altered to have the more definitive tp_cnt and tp_avg field names.

```
Arc:  dbaseinfo tp.dbf tp.dat
Arc:  joinitem sanwq.pat tp.dat sanwq.pat station_id station_id
Arc:  tables
Enter Command:  sel sanwq.pat
  105 Records selected
Enter Command: alter
Enter item name: count
COLUMN  ITEM NAME       WIDTH OUTPUT  TYPE N.DEC  ALTERNATE NAME
  22            COUNT          8      11      F       0
Item name: tp_cnt
Item output width: 11
Item type: f
Item decimal places: 0
Alternate item name: ~
COLUMN  ITEM NAME       WIDTH OUTPUT  TYPE N.DEC  ALTERNATE NAME
  22            TP_CNT         8      11      F       0
Enter item name: ave_value
COLUMN  ITEM NAME       WIDTH OUTPUT  TYPE N.DEC  ALTERNATE NAME
  30         AVE_VALUE       8      16      F       2
Item name: tp_avg
Item output width: 16
Item type: f
Item decimal places: 2
Alternate item name: ~
COLUMN  ITEM NAME       WIDTH OUTPUT  TYPE N.DEC  ALTERNATE NAME
  30           TP_AVG        8      16      F       2
Enter item name:  ~
Enter Command: quit
```

STATION_ID	COUNT	AVE_VALUE
12932	2	0.61
12933	5	6.60
12934	1	7.36
12935	6	6.28
12937	2	6.61
12938	2	5.94
12939	2	4.26
12940	2	4.22
12941	1	0.25
12942	1	0.16
12943	27	0.15
12944	75	0.06
12945	27	0.14
12946	1	0.28
12947	2	0.50
12948	39	1.09
12949	2	1.73
12950	1	2.19
12951	2	2.91
12952	3	4.47
12953	1	3.01
13030	1	0.14
:	:	:
:	:	:

Table 4.6 : Summary Statistics for Total Phosphorus

The procedure of using the ArcView Summary Statistics tool and attaching average concentration values to the sanwq point attribute table is repeated for each pollutant constituent of interest (i.e. those pollutants identified in Table 3.6). Nitrogen, however, is not sampled and reported as total nitrogen in the Surface Water Quality Monitoring data set. Instead, total kjeldahl nitrogen (organic plus ammonia nitrogen), nitrate nitrogen, and nitrite nitrogen are reported separately. These are the components that total nitrogen is comprised of (American Public Health Association, American Water Works Association and Water Environment Federation, 1992). Each of the three nitrogen components is summarized, averaged, and attached to the sanwq point attribute table along with the other pollutant constituents from Table 3.6. Then two additional fields, tn_cnt and tn_avg, are added to the point attribute table using the Joinitem command. In the Tables module, the number of effective total nitrogen measurements at each location is determined as the average of the number of measurements for each component. The average value for total nitrogen concentration at each location is determined as the sum of the average values for each component. Finally, X- and Y-coordinate values are added to each record in the sanwq point attribute table through use of the Addxy command:

```
Arc:  additem sanwq.pat sanwq.pat tn_cnt 8 8 f 0
Arc:  additem sanwq.pat sanwq.pat tn_avg 8 8 f 2
Arc:  tables
Enter Command:  sel sanwq.pat
  105 Records selected
Enter Command:  calc tn_cnt = ( tkn_cnt + no2_cnt + no3_cnt ) / 3
Enter Command:  calc tn_avg = tkn_avg + no2_avg  + no3_avg
Enter Command:  quit
Arc:  addxy sanwq
```

Analyses of the Surface Water Quality Monitoring data at specific locations and for specific pollutants reveal some interesting points. Figure 4.18 shows all of the total phosphorus measurements taken at station #12948 along the Aransas River about 15 kilometers upstream of Copano Bay. By plotting these concentration levels against the sampling dates, the variations in concentration magnitude are plainly seen. A plot of the average concentration overlaid on the data shows the effect of a few elevated concentration measurements on the average value and suggests that consideration and
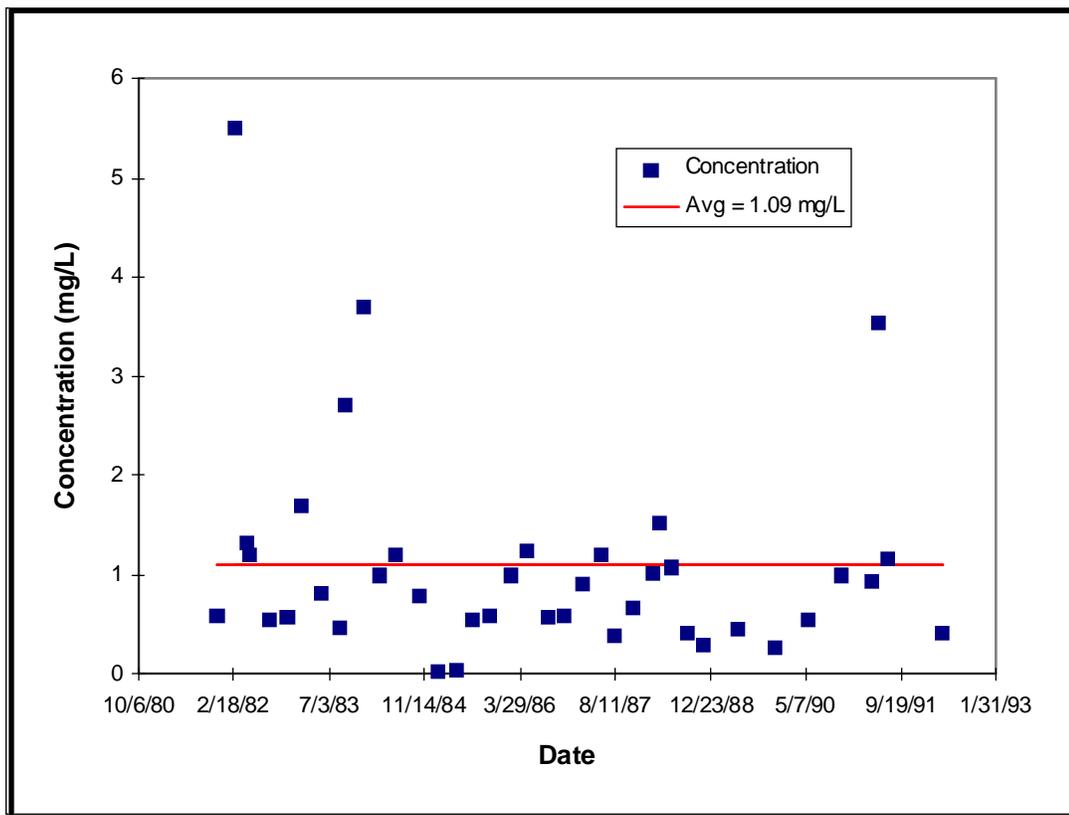
Figure 4.18 : Total Phosphorus Concentration Measurements at TNRCC SWQM Station # 12948 (Aransas River)

possible removal of outlying data points may be appropriate for determination of a revised average.

Figures 4.19 and 4.20 respectively show the nitrogen component measurements made at the Aransas station and at station #12944 along the Mission River about 10 kilometers upstream of Mission Bay. Each of these plots also shows the value for total nitrogen, calculated as the sum of the average total kjeldahl, total nitrate, and total nitrite levels. Values for total kjeldahl and total nitrite nitrogen generally fall into fairly well-bounded ranges, but nitrate nitrogen concentration values, particularly at the Mission River station, show an occasional tendency to vary significantly from the normal range. These atypical measurements have a significant effect on the calculated average total nitrate concentration which, in turn, affects the calculation of average total nitrogen concentration. In fact, the single outlying total nitrate concentration data point observed at the Mission station (Figure 4.20) affects the calculated average total nitrate concentration by almost 200%, increasing it from about 0.077 mg/L to 0.22 mg/L. As a result, average total nitrogen calculated for the station is 18% higher than it would be without inclusion of the anomalous data point. This point emphasizes that outlying data points should be considered when establishing averaged values for pollutant concentration at a particular location.

A second point of interest regarding the Surface Water Quality Measurement nitrogen data is illustrated in Figure 4.21, which shows the percentile distributions, for both the Aransas and Mission stations, of the three components that contribute to the calculated average total nitrogen concentrations. The charts in this figure have been determined using all data points from each of the stations, i.e. without consideration and removal of outlying data points. The chart shows that, for both locations, most of the total nitrogen observed is of an organic nature. The oxidized forms of nitrogen account for only 25-30% of the total observed (before consideration of outlying points). Organic and ammonia nitrogen is typically associated with agricultural land uses and the fact that kjeldahl nitrogen accounts for over 70% of the total nitrogen measured in the two main streams of the basin indicates a significant contribution from the local agricultural lands.
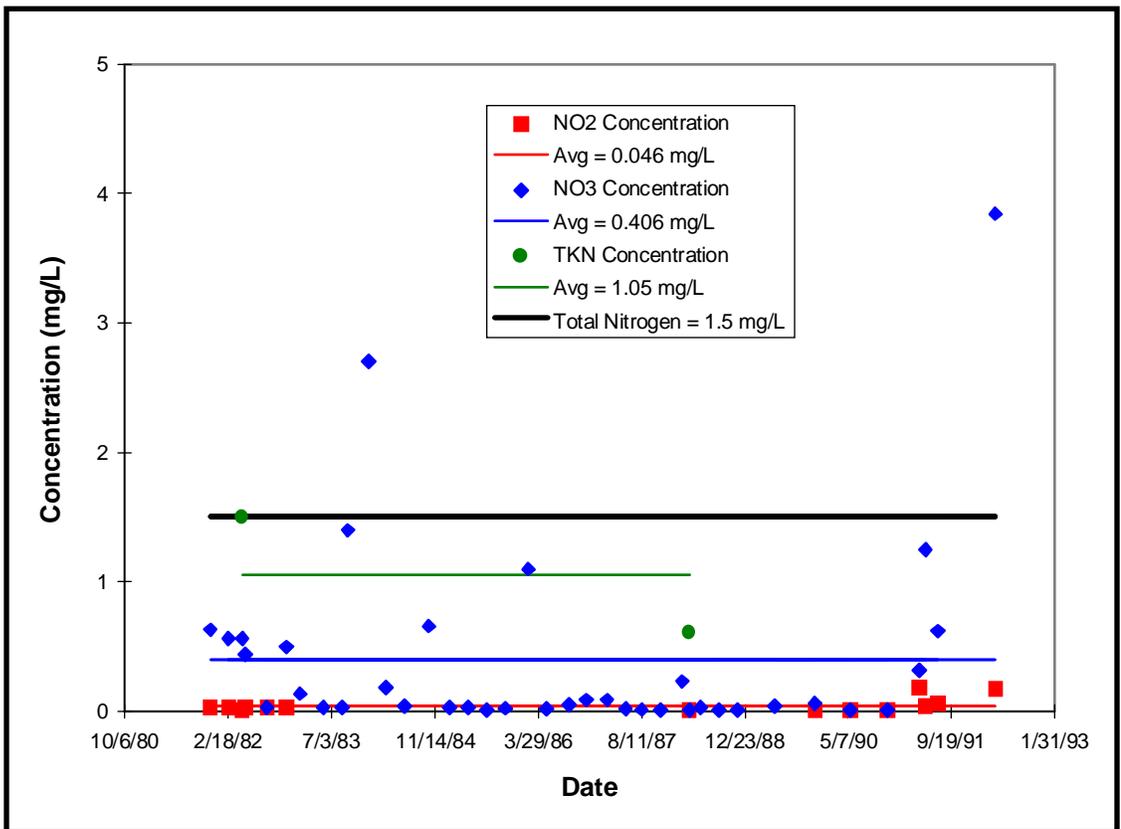
Figure 4.19 : Total Nitrogen Component Concentration Measurements at TNRCC SWQM Station # 12948 (Aransas River)
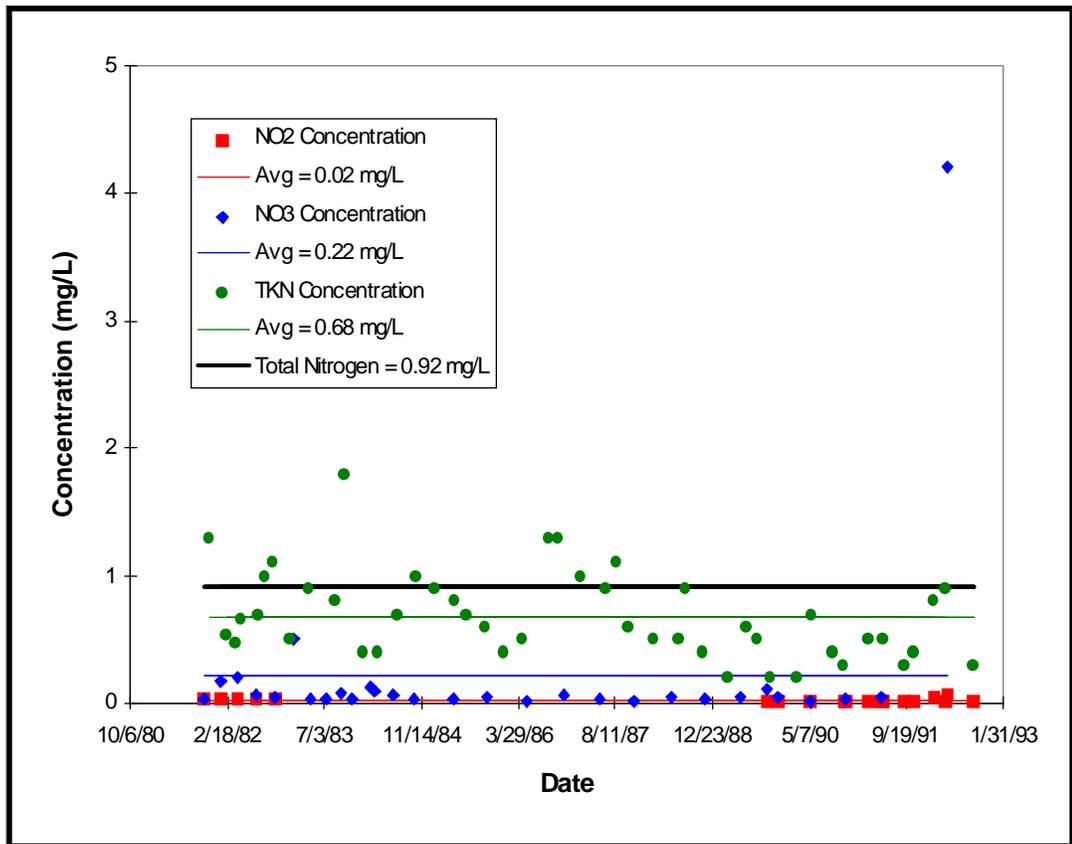
Figure 4.20 : Total Nitrogen Component Concentration Measurements at TNRCC SWQM Station # 12944 (Mission River)
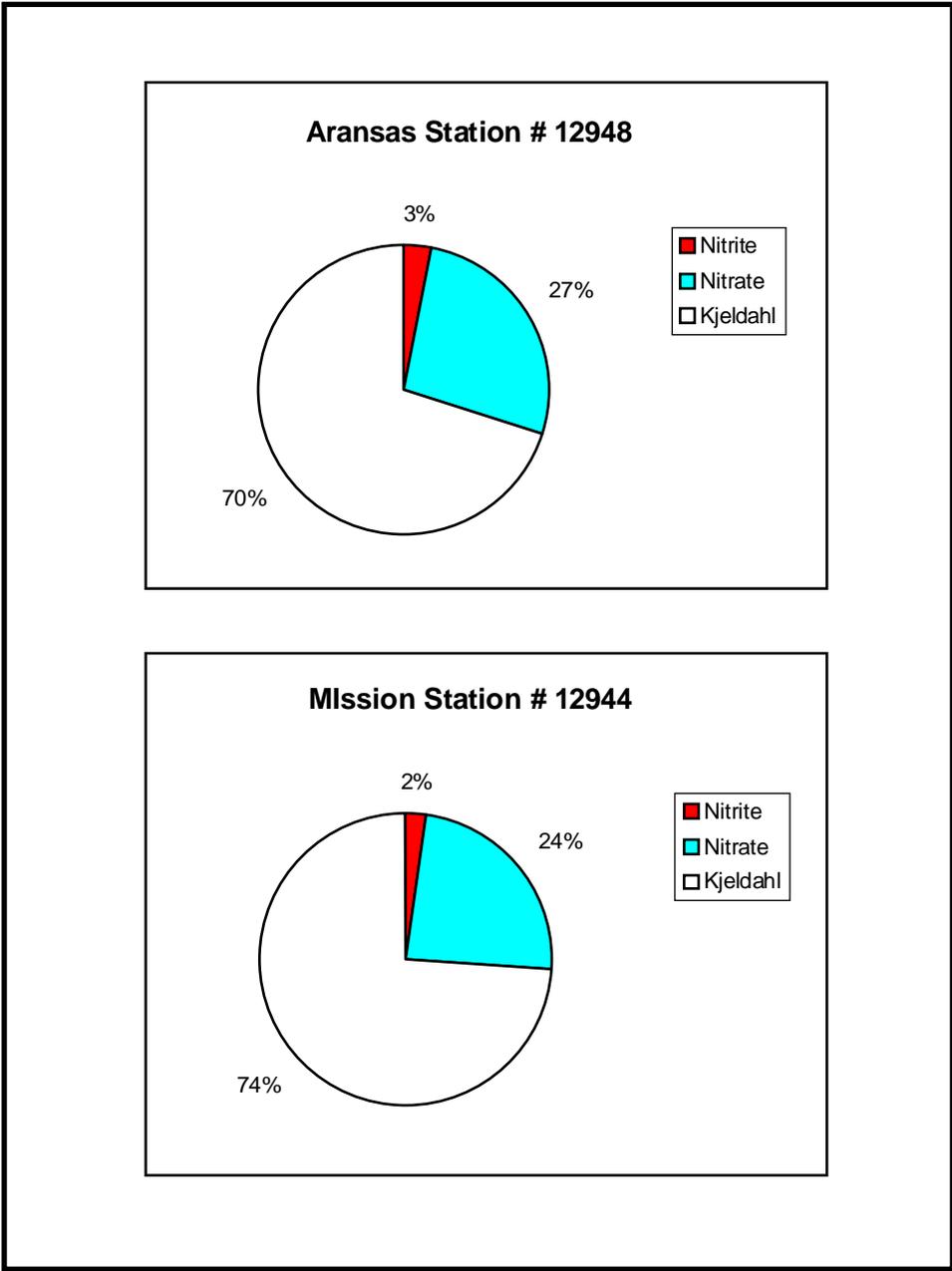
Figure 4.21 : Percentile Distribution of Total Nitrogen Components Measured at Two Locations in the San Antonio-Nueces Basin

Graphically Depicting Variations in the Frequency of Concentration Sampling

The average concentrations that are attached to the water quality measurement points are calculated by averaging various numbers of measurements. In fact, for total phosphorus, Table 4.6 shows one average concentration derived from 75 measurements while a number of locations have only one measurement defining average concentration. One would be correct in placing more statistical validity in those averages derived from larger numbers of measurements.

A method of depicting this variation in the number of concentration measurements is established by converting the water quality measurement point coverage into a polygon coverage of circles, where each circle is centered about the measurement location coordinates and each circle's area is approximately proportional to the number of measurements made at the station. This is done by (1) adding a radius field to each record in the sanwq point attribute table, (2) calculating values for radius based on the number of measurements for the pollutant constituent of interest, (3) creating a text-delimited data file from the station-id, x-coordinate, y-coordinate, and radius fields, (4) generating a polygon coverage from the data file, and (5) attaching the pollutant measurement data to the new polygon coverage.

The first three of these steps are performed in ArcView 2.0: For the case of total phosphorus measurements, the sanwq point attribute table is displayed and the Properties feature in the Table menu is used to deselect all fields except for station_id, x-coord, y-coord, and tp_cnt. The Table menu is used once again to Start Editing of the table. The Add Field feature from the Edit menu is then invoked and the Radius field is defined as an 8-character numeric item.

The Calculate feature of the Field menu is used to specify that values in the Radius field are determined as the truncated square root of the tp_cnt field multiplied by 200 meters, or

$$\text{Radius} = \text{tp\_cnt.sqrt.truncate} * 200. \qquad (4\text{-}10)$$

The value of 200 meters is selected, by trial and error, as the smallest radius that produces a discernible circle for single measurement stations, while maintaining a reasonably sized circle for locations with many measurements. By taking the square

root of the number of pollutant measurements, the area of the circle ($\pi * radius^2$) is made proportional to the number of measurements. Once the values for the Radius field are filled, the Stop Editing feature is selected from the Table menu.

The Properties feature in the Table menu is used to deselect the tp_cnt field from the sanwq point attribute table, leaving only the station-id, x-coord, y-coord, and radius fields displayed, in that order. The Export feature from the File menu is then invoked to create a text-delimited file containing the values of these four fields. A portion of this text-delimited file, called rad.txt, is shown in Figure 4.22.

A raw data file (rad.dat) is created from this text-delimited file by removing the column labels in the header and appending the bottom of the file with an END statement. This raw data file is then used in conjunction with the Arc/Info Generate command to create a coverage of circles at each measurement location. Polygon topology is created through use of the Clean command:

```
Arc:  generate phospts
Generate:  input rad.dat
Generate:  circles
   Creating Circles with coordinates loaded from rad.dat
Generate:  quit
   Externalling BND and TIC.......
Arc:  clean phospts phopts
```

Finally, water quality measurement data is attached to the phopts coverage by adding an integer field called station_id to the phopts polygon attribute table, filling those fields with the values from the phopts-id field, altering the station_id field to character type, and performing a Joinitem command with the tp.dat file, using the station_id field to join the two files.

```
Arc:  additem phopts.pat phopts.pat station_id 5 5 i
Arc:  tables
Enter Command:  sel phopts.pat
    24 Records selected
Enter Command:  calc station_id = phopts-id
Enter Command: alter
Enter item name: station_id
COLUMN   ITEM NAME       WIDTH OUTPUT  TYPE N.DEC  ALTERNATE NAME
  17           STATION_ID          5        5         I       -
Item name: station_id
Item output width: 5
Item type: c
```

```
"Sanwq-id","X-coord","Y-coord","Radius"
12931,1253025.250,696013.875,0
12932,1222723.500,694795.125,200
13399,1321153.000,694116.750,0
12933,1223832.250,693739.500,400
12934,1224645.625,693725.188,200
12936,1223313.875,693697.688,0
12935,1225518.375,693651.250,400
12937,1226820.250,692784.062,200
12939,1226039.375,690734.125,200
12938,1226287.000,690616.125,200
13660,1282946.625,685779.625,800
12942,1225275.500,685540.438,200
12944,1266646.625,684073.938,1600
12940,1227986.625,682454.125,200
12952,1233187.250,682256.125,200
12953,1230096.875,681881.750,200
12941,1226212.125,681493.000,200
13398,1315794.250,678917.375,0
12951,1242619.250,676083.625,200
13401,1309669.875,673810.625,0
13406,1299136.750,672437.562,0
12943,1273454.375,672223.500,1000
13400,1307925.750,670925.375,0
12950,1242018.500,670924.062,200
12949,1249132.375,668866.188,200
13404,1292647.500,666251.562,0
12948,1252749.000,665714.812,1200
         :       :       :       :
         :       :       :       :
         :       :       :       :
```

Figure 4.22 : Text-Delimited File of Water Quality Measurement Radii

```
Alternate item name: ~
COLUMN  ITEM NAME        WIDTH OUTPUT  TYPE N.DEC  ALTERNATE NAME
   17        STATION_ID        5      5      C       -
Enter item name: ~
Enter Command: quit
Arc: joinitem phopts.pat tp.dat phopts.pat station_id station_id
```

This procedure is performed for each pollutant constituent of interest. However, since no .dat file exists for total nitrogen, the polygon attribute table for that coverage of circles is joined with the sanwq point attribute table, which contains the average values for all pollutant constituents of interest. The sanwq point attribute table is actually an alternative source of average concentration data for all of the circle coverages.

Figure 4.23 shows the predicted total phosphorus concentration data overlaid with the phopts polygons. For display purposes, these circles are provided with a label of the average concentration at the location concatenated with the number of total phosphorus measurements. This label is created in ArcView 2.0 by adding a new character field and, using ArcView's internal Avenue programming language, defining the contents of the character string as

$$[pho\_tag] = [tp\_avg].SetFormat(\text{``d.dd''}).AsString ++$$
$$\text{''(`` ++ } [tp\_cnt].AsString ++ \text{'')'',} \qquad (4\text{-}11)$$

where .AsString converts the value of the preceding variable to a character string and .SetFormat("d.dd") specifies a floating point numeric format for the preceding variable.

Figure 4.23 also shows interesting trends in the comparison of predicted and average observed values for total phosphorus concentration. Using the same color coding scheme to represent predicted and observed concentrations, it can be seen that, within the Mission and Copano subwatersheds, estimated concentrations generally match the minimal levels that have historically been recorded there, between 0.1 and 0.3 mg/L. However, in the Aransas subwatershed, observed concentrations significantly exceed predicted levels. In particular, observed concentrations just downstream from the city of Beeville (Figure 4.24) are seen to reach above 7 mg/L, whereas predicted concentrations in the same reaches of the river are less than 1 mg/L.
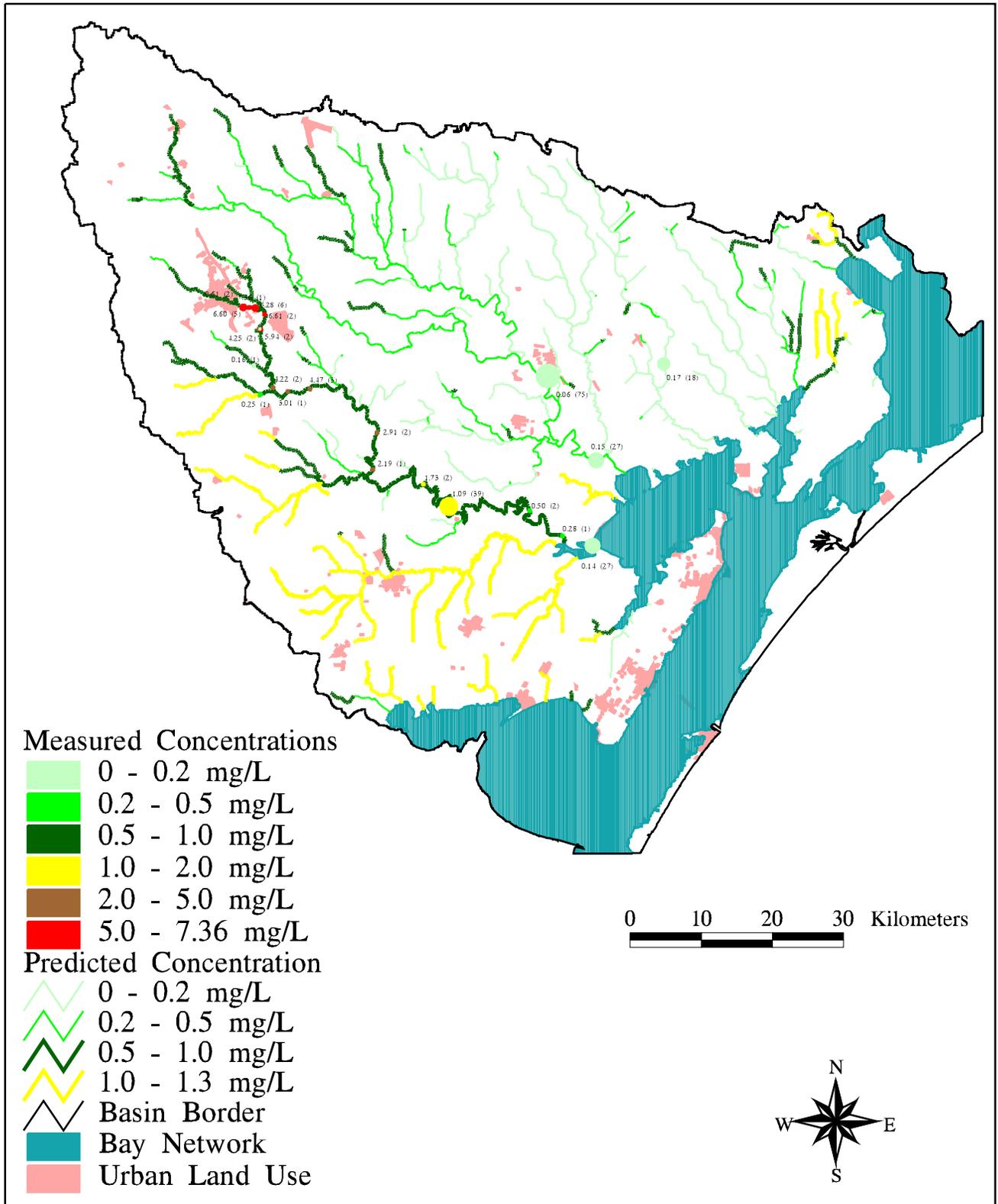
Figure 4.23 : Comparison of Estimated and Average Observed Total Phosphorus Concentrations in the San Antonio-Nueces Coastal Basin
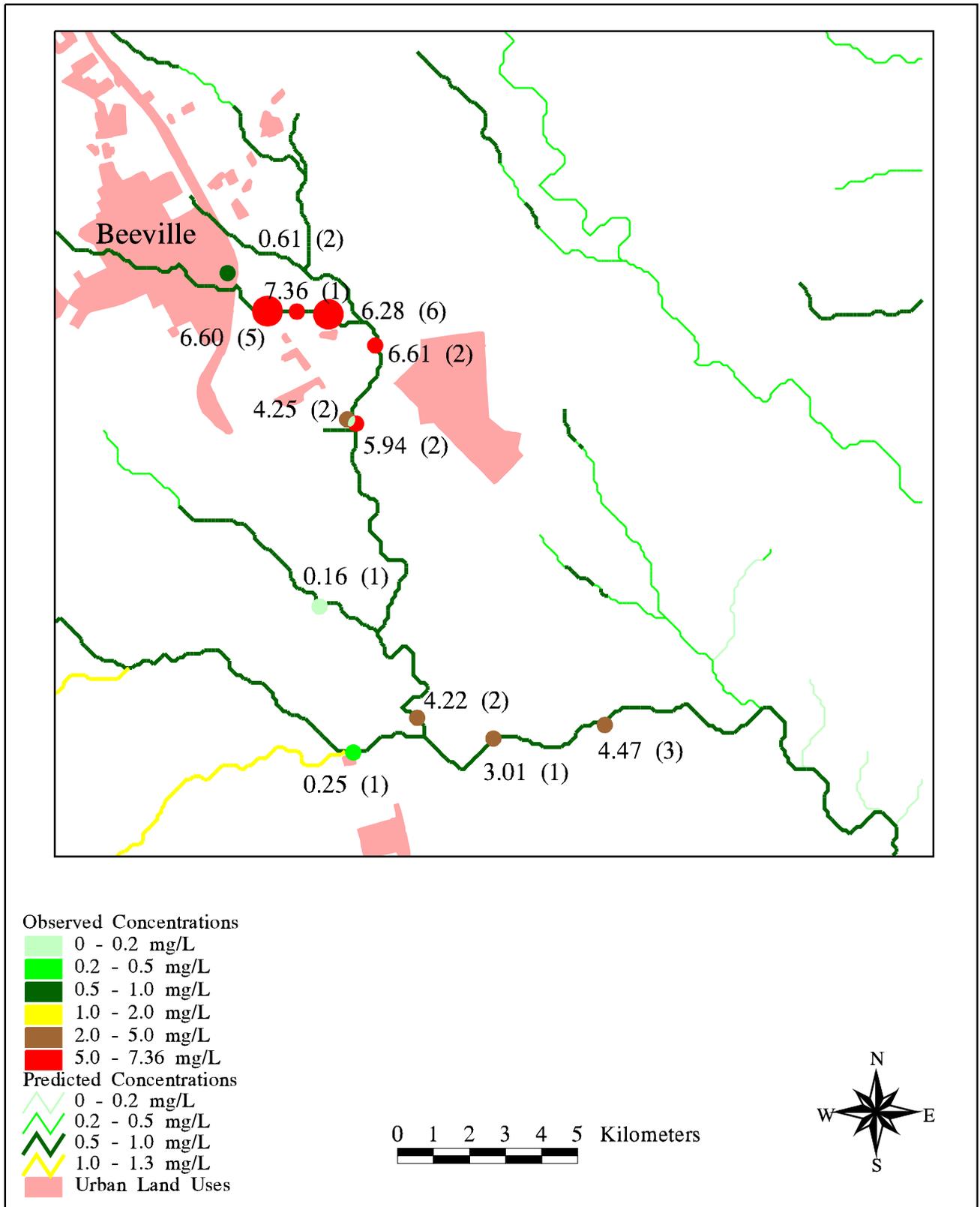
Figure 4.24 : Estimated vs. Observed Total Phosphorus Concentrations
Just Downstream of Beeville, TX

These discrepancies would tend to indicate a significant point source in the area contributing to total phosphorus loads. Consultation with TNRCC personnel have identified that the data points in question were sampled to investigate suspected effluent problems from a wastewater treatment plant in Beeville. However, it should also be noted that most of these measurements were made within a short period in the early 1980's and it is not known whether total phosphorus at the sampling locations has remained at these elevated levels.

4.6 Considering and Simulating Point Sources

As can be seen from section 4.5, the characterization of nonpoint source pollution for a particular region may not provide a complete representation of the pollutant levels in that area. Point sources along stream networks can contribute significantly to the measured pollutant levels. Pollutant level data for point sources in the San Antonio-Nueces Coastal Basin were unavailable at the time of this study. However, a method of simulating point sources is investigated by considering the difference between predicted nonpoint source pollution concentration levels and observed concentration levels at a specific location, and then accounting for the difference with a single point load at the location. The point source pollutant load is then included in every downstream location in the digital basin.

Estimating an Annual Point Load

Figure 4.24 shows a number of measurement points just downstream of Beeville, TX where observed total phosphorus concentrations significantly exceed the values expected from nonpoint sources alone. Assuming that the Beeville wastewater treatment plant effluent enters the Aransas River at the furthest upstream location where a significant concentration discrepancy exists, a point source phosphorus contribution for that location is estimated to account for the discrepancy.

To establish the exact value of estimated nonpoint source total phosphorus concentration at the location, the phosconc grid is displayed in the Grid tool, overlaid with the phopts coverage, and queried at the suspected point source location, using

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the Cellvalue command. Similarly, the annual cumulative runoff grid is displayed and queried to determine cumulative runoff at the point source location. By multiplying the cumulative runoff by the difference between observed and estimated concentrations, the amount of observed annual phosphorus load attributable to the point source is calculated.

Grid: **gridpaint phosconc value linear nowrap gray**
Grid: **polygonshades phopts 2**
Grid: **cellvalue phosconc ***
  The cell containing point (1223830.414,693729.621) has value 0.621
Grid: **gridpaint runoffac value linear nowrap gray**
Grid: **polygonshades phopts 2**
Grid: **cellvalue runoffac ***
  The cell containing point (1223830.414,693729.621) has value 5467914

Noting that the average observed total phosphorus concentration at the point source location is 6.6 mg/L, the amount of this concentration attributed to the point source effluent is calculated as 6.6 mg/L - 0.621 mg/L = 5.979 mg/L. By multiplying this value by the cumulative runoff at the point source, the total annual estimated cumulative phosphorus point load is determined as

$$5.979 \text{ mg/L} * 5{,}467{,}914 \text{ m}^3/\text{yr} * 1000 \text{ L/m}^3 * 10^{-6} \text{ kg/mg} = 32{,}694 \text{ kg/yr}. \qquad (4\text{-}12)$$

This value for estimated load is compared with an algorithm from Thomann and Mueller (1987), where load is calculated as the product of daily per capita municipal flow, population of the municipality, and typical effluent concentration. For Beeville, using the population data from Table 1.1, and Thomann and Mueller's typical average values for per capita flow (125 gallons/capita-day) and total phosphorus municipal effluent concentration (7 mg/L), this algorithm results in an estimate of

$$125 \text{ gcd} * 13547 \text{ pop.} * 365 \text{ d/yr} * 3.785 \text{ L/gal} * 7 \text{ mg/L} * 10^{-6} \text{ kg/mg} = 16{,}376 \text{ kg/yr}. \quad (4\text{-}13)$$

According to the Beeville wastewater treatment plant chief operator, daily flow at the facility, averaged over the year, is approximately 2,000,000 gallons per day (Barrera, 1996). Using this value for flow, instead of Thomann and Mueller's typical daily per capita flow value, estimated total phosphorus load is calculated as

$$2{,}000{,}000 \text{ gal/d} * 365 \text{ d/yr} * 3.785 \text{ L/gal} * 7 \text{ mg/L} * 10^{-6} \text{ kg/mg} = 19{,}341 \text{ kg/yr.} \quad (4\text{-}14)$$

This value represents 58% of the value calculated in equation 4-12. The fact that these other estimates are within the same order of magnitude show that this method of estimating point loads has some validity. However, the other estimates also indicate that the additional phosphorus loads contributing to the measured concentrations at the Beeville location are probably not from the wastewater treatment plant alone.

Considering Point and Nonpoint Sources Together

In order to combine the point source load from equation 4-12 with the nonpoint source load, the point source load value is added to the cell where the observed concentration discrepancy exists. First, the flow accumulation grid is displayed and overlaid with the phosphorus measurement location point coverage. Through visual identification of the discrepant Beeville measurement location and use of the Selectpoint command, a single-cell grid representing the location is established. This grid has values of NODATA in all other cells. So that map algebra may be performed with this grid, the NODATA cells are converted to zero-value cells through use of the Isnull command and the Con statement. The annual point load value is simultaneously stored into the selected cell.

```
Grid: gridpaint ditfac value linear nowrap gray
Grid: points phopts
Grid: beepoint = selectpoint(ditfac,*)
Grid: beeload = con(isnull(beepoint),0,32694)
```

A new cell-based loading grid is established by adding the existing nonpoint source cell-based load grid (phosrnof) and the Beeville point load grid. However, since the Beeville point load grid is in units of kg/yr, it must first be converted to the aerial mg-mm/L-yr units of phornof. As shown in equation 4-15, this is accomplished by multiplying the point load grid by 100.

$$Q * EMC \text{ (mg-mm/L-yr)} = \text{kg/yr} * 10^{6} \text{ mg/kg} * .0001 \text{ cells/m}^{2} * .001 \text{ m}^{3}/\text{L} * 1000 \text{ mm/m} \quad (4\text{-}15)$$

A new total phosphorus load grid is created as the weighted flow accumulation of the new cell-based loading grid divided by 100, as per equation 4-6. The

phosphorus concentration grid is then recalculated as the new total phosphorus load grid divided by the accumulated runoff grid. A factor of 1000 included in this product produces concentration in units of mg/L, as per equation 4-9. As in section 4.5, a grid of concentration values specific to the basin stream network is established using the Con statement with the introfac grid. The stream concentration grid is multiplied by 1000 to retain significant figures, the product is truncated to create the integer grid, and the resulting grid is converted to a coverage, using the Streamline command. The mainland coverage is then used to clip the concentration coverage so that concentration streams end exactly at the shores of the bay network.

> Grid: **beernof = phosrnof + (beeload * 100)**
> Grid: **totpload = flowaccumulation(mainfdr,beernof) / 100**
> Grid: **totpconc = totpload / runoffac * 1000**
> Grid: **tophostr = con(introfac >= 1,totpconc)**
> Grid: **topholin = streamline(int(tophostr * 1000),mainfdr,grid-code)**
> Arc: **clip topholin mainland tophocon line**

Since the beeload point source pollutant grid only affects load values along the Aransas River, the only differences between this new concentration coverage and the one created in section 4.5 occur along the Aransas. Figure 4.25a shows the Beeville portion of the newly calculated concentration coverage with the observed concentration circles overlaid. Likewise, figures 4.25b and 4.25c show portions of the Aransas River between the Beeville area and the Copano Bay outlet. A review of the newly calculated concentrations in these three figures shows better agreement with the average observed concentrations along the length of the Aransas River. However, it should be re-emphasized that this new concentration coverage is derived with the assumption that the Beeville wastewater treatment plant effluent accounts for the difference between observed concentrations and estimated nonpoint source concentrations. In fact, there may be a number of point sources along the Aransas River that contribute to the total phosphorus concentration profile there.

For more accuracy, this method of simulating point sources should be implemented with values of reported annual loads or permitted average concentrations for all of the permitted point source effluents in the basin.
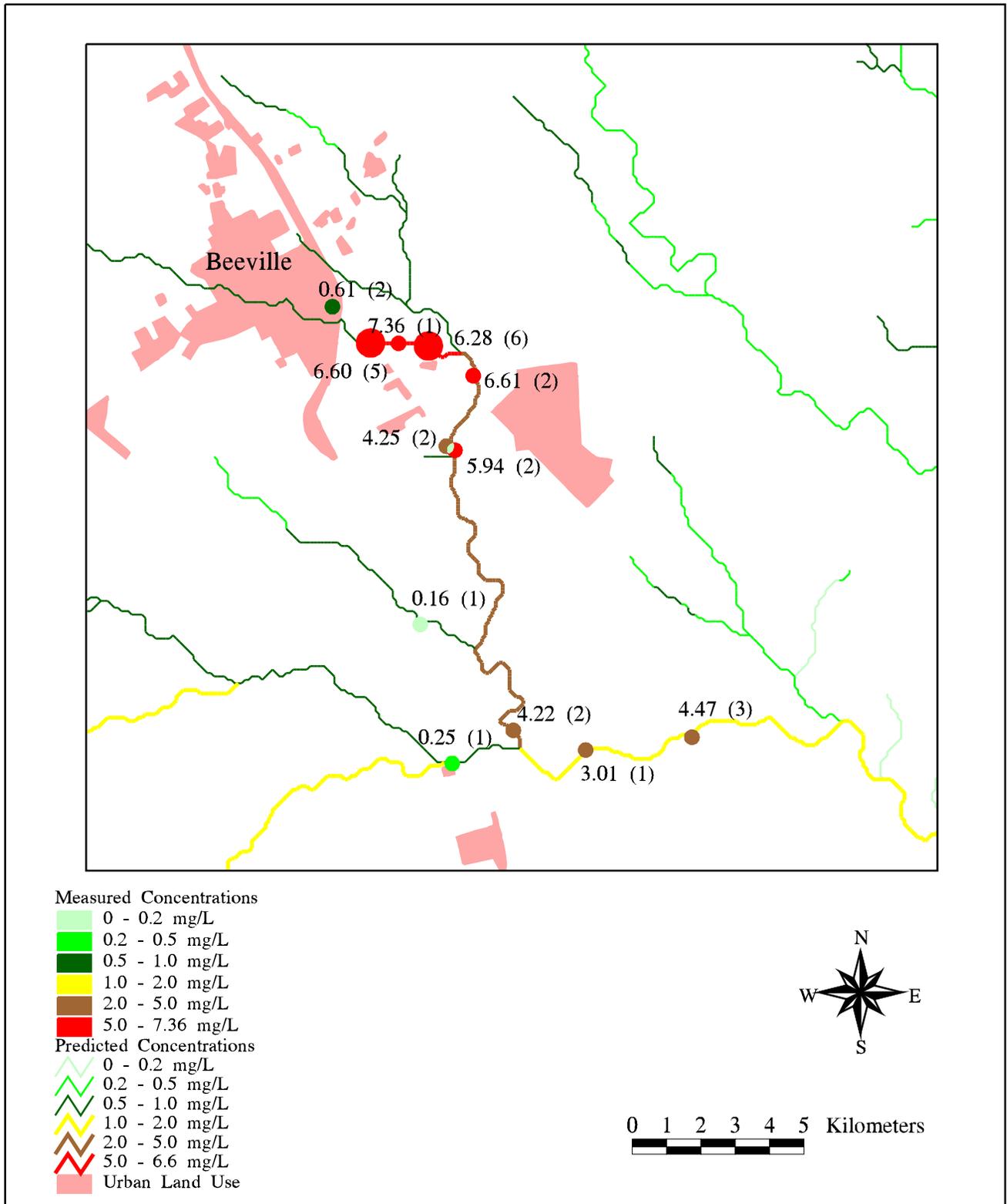
Figure 4.25a : Predicted vs. Measured Total Phosphorus Concentrations (Beeville Point Source Included) Just Downstream of Beeville, TX

Measured Concentrations
- 0 - 0.2 mg/L
- 0.2 - 0.5 mg/L
- 0.5 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 5.0 mg/L
- 5.0 - 7.36 mg/L

Predicted Concentrations
- 0 - 0.2 mg/L
- 0.2 - 0.5 mg/L
- 0.5 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 5.0 mg/L
- 5.0 - 6.6 mg/L
- Urban Land Use

0 1 2 3 4 5 Kilometers
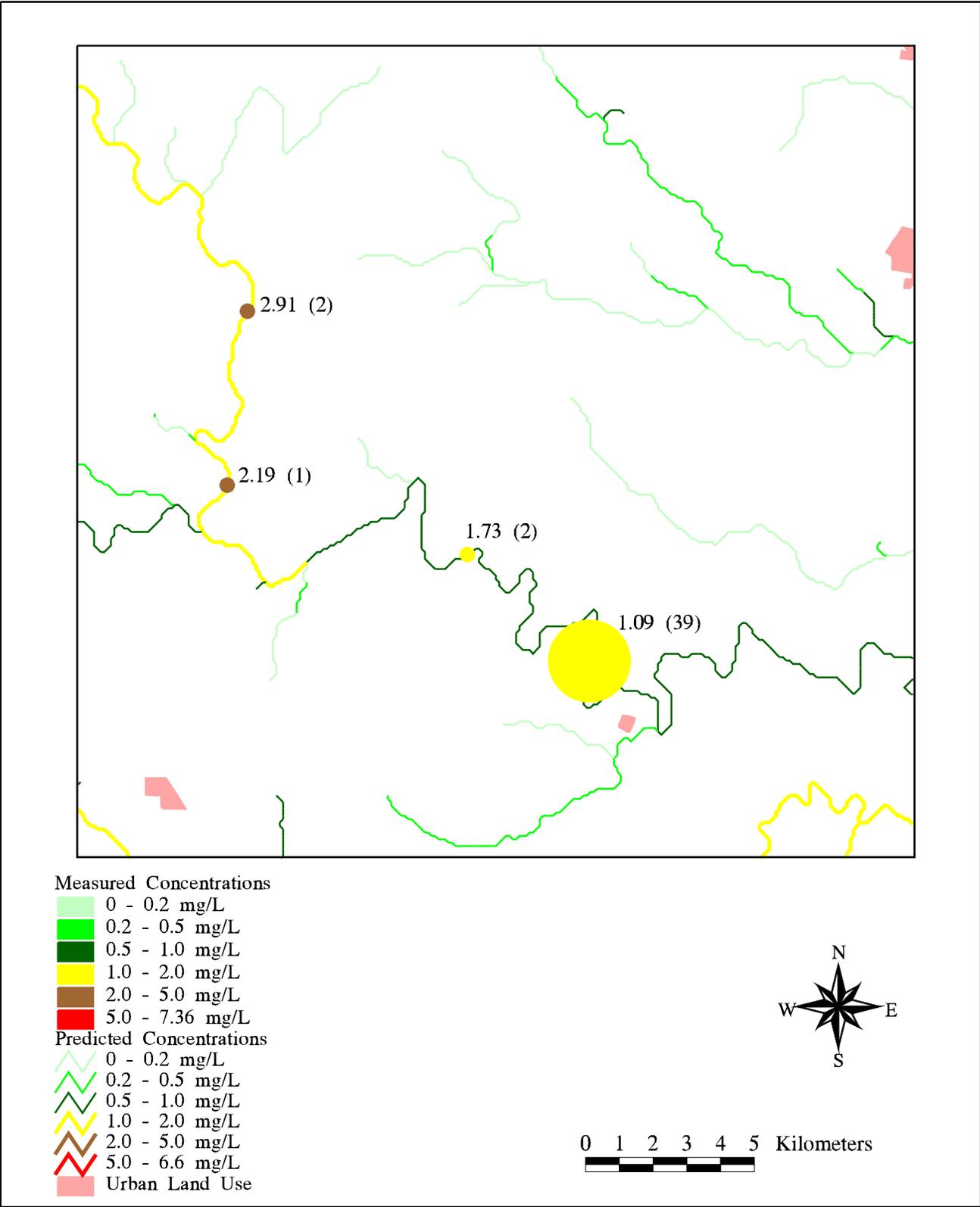
Figure 4.25b : Predicted vs. Measured Total Phosphorus Concentrations (Beeville Point Source Included) for Middle Aransas River

Measured Concentrations
- 0 - 0.2 mg/L
- 0.2 - 0.5 mg/L
- 0.5 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 5.0 mg/L
- 5.0 - 7.36 mg/L

Predicted Concentrations
- 0 - 0.2 mg/L
- 0.2 - 0.5 mg/L
- 0.5 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 5.0 mg/L
- 5.0 - 6.6 mg/L
- Bay Network
- Urban Land Use

0.50 (2)

0.28 (1)

0.14 (27)

0 1 2 3 4 5 Kilometers
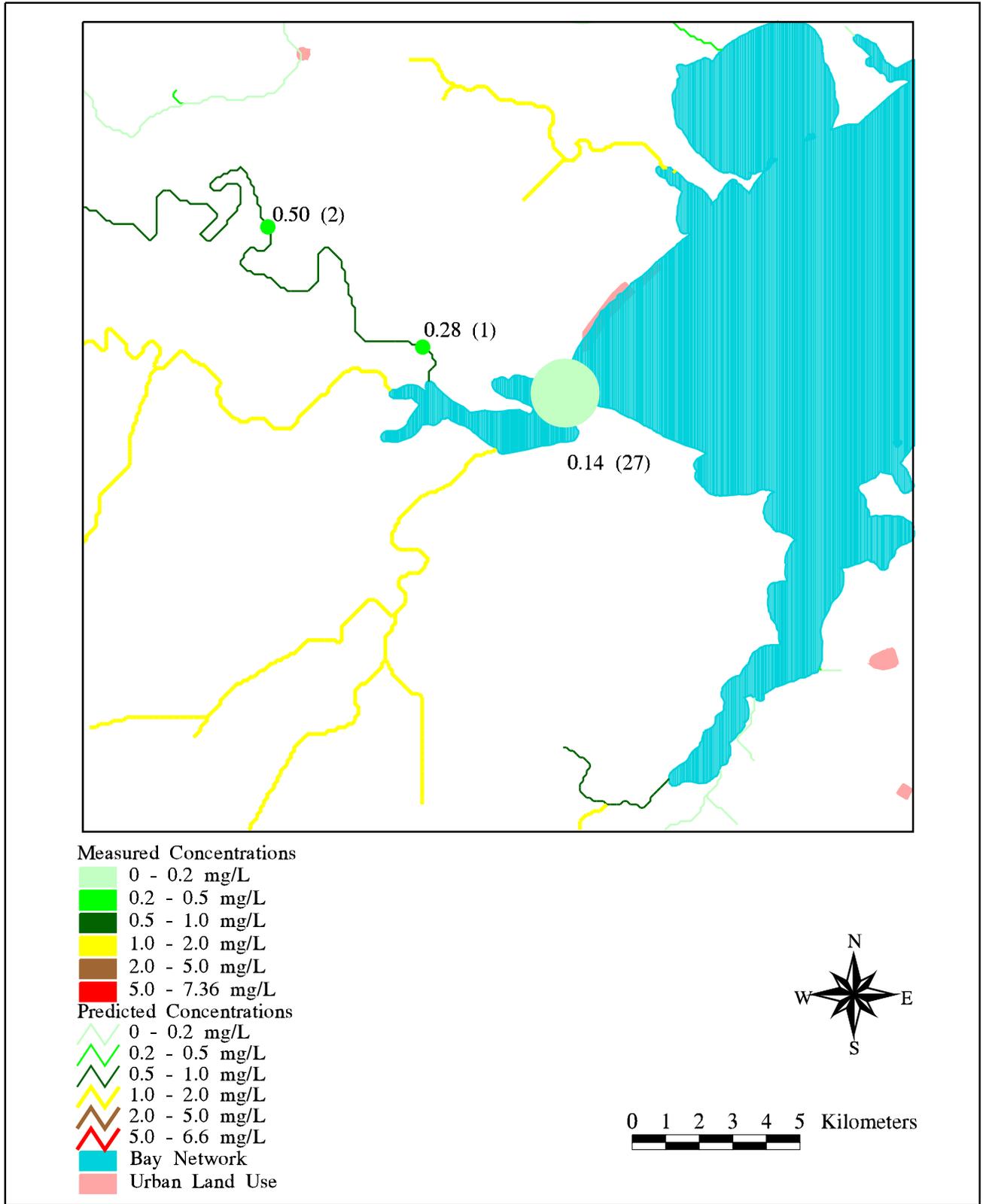
Figure 4.25c :   Predicted vs. Measured Total Phosphorus Concentrations
(Beeville Point Source Included) for Lower Aransas River

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4.7 Using an Optimization Routine to Provide Estimates of EMC Values

The land use expected mean concentration values included in Table 3.6 are integral to this assessment of nonpoint source pollution. As outlined in section 3.2, these data are literature-based values used and published in a previous study (Baird, et al., 1996). Even though the agriculture and rangeland expected mean concentrations in this study were established empirically from measurements made near the San Antonio-Nueces coastal basin, it is desirable to establish a full set of expected mean concentration data that fits local conditions in the basin and does not necessarily rely on literature-based values.

One alternative method of determining expected mean concentration values for each land uses involves the use of a computer-based optimization routine. The input data required for this routine are (1) average observed pollutant concentrations at significant sampling locations, (2) all upstream pollutant point loads, (3) total annual cumulative runoff at the sampling locations, and (4) the annual cumulative runoff occurring from each land use upstream of each sampling location.

Determination of Optimization Routine Inputs

Average observed pollutant concentrations are established from the methods discussed in section 4.5 and upstream point load data should be acquired from reported or permitted values, as identified in section 4.6. However, for this analysis, the total phosphorus point load data estimated in section 4.6 is used.

Total annual cumulative runoff and land use-based cumulative runoff are established for the TNRCC sampling sites where significant numbers (more than 15) of historical phosphorus measurements exist. There are five such locations in the San Antonio-Nueces coastal basin; two along the Aransas River, two on the Mission River, and one on Copano Creek. Upon further review, one of these sampling locations, in Copano Bay a few kilometers east of the Aransas River outlet, is rejected since pollutant transport to the location does not follow a strict linear path along the stream network and is assumed to have a significant dispersion component.

Determination of total annual cumulative runoff is accomplished by displaying the cumulative runoff grid of the basin, overlaying the phosphorus sampling locations,

and querying the locations of significant phosphorus measurements. These steps are performed using the Gridpaint, Points, and Cellvalue commands. For a sampling site along the Aransas River, the procedure is as follows:

> Grid: **gridpaint runoffac value linear nowrap gray**
> Grid: **points phopts**
> Grid: **cellvalue runoffac ***
>> The cell containing point (1252520.808,665484.913) has value 94664336.000

The cumulative runoff values for each land use upstream of a sampling location are determined by first delineating a subwatershed from the sampling site, using the Gridpaint, Points, Selectpoint, and Watershed commands along with the basin flow accumulation grid, flow direction grid, and sampling sites coverage. An equivalent polygon coverage of the subwatershed grid is created, using Gridpoly. The polygon coverage is then used to clip the basin land use coverage, so that only those land uses occurring upstream of the sampling location are retained.

> Grid: **gridpaint ditfac value linear nowrap gray**
> Grid: **points phopts**
> Grid: **aranpt = selectpoint(ditfac,*)**
> Grid: **arptarea = watershed(clipfdr,aranpt)**
> Grid: **araptcov = gridpoly(arptarea)**
> Arc: **clip sanlu araptcov aranlu poly**

The clipped land use coverage is converted back to a grid, using Polygrid. Cells in the land use grid are filled with land use category values (lusecat). Finally, cumulative runoff from each land use is established by using the Zonalsum command with the land use grid and the cell-based runoff grid. This command sums the grid cell values from a target grid (runoff) based on regions of equal value defined in a zone grid (land use category). The result of this Zonalsum is multiplied by 10, as per equation 4-1, in order to convert cumulative runoff to units of m^3/yr. The product is then converted to an integer grid, so that a value attribute table may be subsequently created for the grid.

> Grid: **arlugrid = polygrid(aranlu,lusecat,#,#,100)**
> Grid: **arrunoff = int(zonalsum(arlugrid,runoff) * 10)**

By listing the value attribute tables (vat) of the land use grid and the cumulative runoff grid, cumulative runoff values from each land use category in the subwatershed are established by matching the values from the two tables, based on the count of cells in each grid.

Grid: **list arlugrid.vat**

Record	VALUE	COUNT
1	11	1312
2	12	1229
3	13	6
4	14	437
5	16	25
6	17	30
7	20	65400
8	30	25711
9	40	35419
10	50	19
11	60	97
12	70	866

Grid: **list arrunoff.vat**

Record	VALUE	COUNT
1	6730	6
2	14420	19
3	15100	25
4	18450	30
5	117060	97
6	256980	437
7	752240	866
8	785360	1312
9	906050	1229
10	25114850	25711
11	25536140	35419
12	41141650	65400

Once this procedure is performed for each of the four significant sampling locations in the basin, mass balance equations are set up for each subwatershed. These mass balances equate the total measured load (total cumulative runoff at the sampling location multiplied by the observed concentration) with the sum of the loads from each land use and point source. The loads from each particular land use are denoted by taking the product of the cumulative runoff from that land use and an expected mean concentration variable associated with the land use. Known point sources upstream of

the sampling location are also included in the sum. Mathematically, the mass balance equation for each subwatershed is written as

$$C_o * Q_a \;=\; \sum_{i=1}^{n} (C_i * Q_i) \;+\; \sum_{j=1}^{m} Pt_j \qquad\qquad (4\text{-}16)$$

where C_o is the average observed concentration at the sampling location, Q_a is the total cumulative runoff at the sampling location, n is the number of subwatershed land uses, C_i is the expected mean concentration for each land use, Q_i is the cumulative runoff from each land use, m is the number of subwatershed point sources, and Pt_j is the load from each point source.

Execution of the Optimization Routine

The four mass balance equations are entered into the Microsoft Excel Solver optimization routine and solved simultaneously to establish the best fit values for the land use-based expected mean concentration variables. Initially, the optimization routine does not converge to a solution since, for the four subwatershed mass balance equations, a total of 12 expected mean concentration variables exist. In order to solve for 12 variables in four equations, additional constraints on the variables are introduced. These constraints are derived from observations about the literature-based event mean concentration data in Table 3.6 and are outlined below:

- All phosphorus EMC's are limited to within +/-50% of their initially entered value.
- No pollutant contribution is expected from water and wetland land uses (i.e. phosphorus EMC's for those land uses are set to 0)
- Phosphorus EMC's for mixed urban and other urban land uses are assumed to be equal to the linear average of the phosphorus EMC's for residential, commercial, industrial, and transportation land uses.

The constraints do provide some bounds for the solution of the 12 variables, but still do not amount to 12 unique equations. However, the solution is further constrained by entering the total phosphorus data from Table 3.6 as the initial set of values for the expected mean concentration variables. Unfortunately, this limits the

function of the routine to that of an adjustment algorithm, rather than an independent method of establishing expected mean concentration values.

In order to run the optimization routine, all terms from equation 4-16 are placed on one side of the equation and are divided by total cumulative runoff at the sampling location, Q_a. Mathematically, this manipulation appears as

$$C_o - \left[\sum_{i=1}^{n} (C_i * Q_i) + \sum_{j=1}^{m} Pt_j \right] / Q_a = CB, \qquad (4\text{-}17)$$

where CB is the concentration balance, which should equal zero when the appropriate values for the land use-based expected mean concentrations are entered.

The concentration balances for each subwatershed are established and optimized solutions for the land use expected mean concentrations are calculated in two different ways. First, the sum of the absolute values of the concentration balances for each subwatershed is minimized. This optimization produces the expected mean concentration values shown in the fourth column of Table 4.7. A second optimization of the land use expected mean concentrations is performed by minimizing the maximum absolute value of the concentration balances for each subwatershed. This optimization method results in the recalculated expected mean concentration values shown in the fifth column of Table 4.7. Both of these methods have the effect of minimizing each of the individual subwatershed concentration balance values.

Land Use	Land Use Code	EMC Values (mg/L)		
		From Table 3.6	Minimized Conc Bal SUM	Minimized Conc Bal MAX
Urban Residential	11	0.57	0.332	0.609
Urban Commercial	12	0.32	0.228	0.327
Urban Industrial	13	0.28	0.14	0.269
Urban Transportation	14	0.22	0.33	0.226
Mixed Urban	16	0.35	0.257	0.358
Other Urban	17	0.35	0.257	0.358
Agricultural	20	1.3	1.424	1.306
Range Land	30	0.005	0.0025	0.0047
Forest Land	40	0.005	0.0036	0.0035
Water	50	0	0	0
Wetlands	60	0	0	0
Barren Lands	70	0.12	0.18	0.123

Table 4.7 :   Expected Mean Concentration Values Calculated Using the Microsoft Excel Solver Optimization Routine

5 RESULTS

The nonpoint source pollution methodology outlined in sections 4.1 through 4.5 has been performed for four of the pollutant constituents included in Table 3.6. Results of these analyses are discussed in this section. In addition, the point source simulation discussed in section 4.6 is performed for both phosphorus and nitrogen. Finally, results of the optimization runs for estimation of phosphorus expected mean concentration values are analyzed.

5.1 Nonpoint Source Pollution Assessment

The original intent of this research was to provide an assessment of nonpoint source pollution in the San Antonio-Nueces Coastal Basin, using GIS. The method of associating pollutant expected mean concentrations with land use and accumulating pollutant loads along flow direction paths in the basin shows that, for subbasins where few or no point sources are suspected, predicted pollutant concentrations match well with average measured concentrations. The results of the nonpoint source pollution assessment for total phosphorus, total nitrogen, total cadmium, and fecal coliform are included below.

Total Phosphorus

The aerial distribution of total phosphorus expected mean concentrations in the San Antonio-Nueces basin is shown in Figure 4.14. This map shows that most of the total phosphorus contribution comes from the southern and western portions of the basin, where agricultural land uses are prevalent. The expected mean concentration value for range land uses (from Table 3.6) is <0.01 mg/L, which indicates that all or most of the concentrations observed during the establishment of expected mean concentrations were below the reporting limit for total phosphorus (Baird, et al.. 1996). This entry is interpreted as 0 mg/L for assignment to the range land use polygons. Also, since no expected mean concentration values for forest land uses exist in Table 3.6, the values for range land uses are assigned as approximations. As a

result of these two interpretations, a value of 0 mg/L is assigned to all of the range and forest land use polygons, which occupy a significant portion of the north and central portions of the basin.

The geographic differential between assigned expected mean concentration values also reveals itself through the assessment of annual cumulative loads in the basin, as seen in Figure 4.15. As one might anticipate from the expected mean concentration map, total loads to Copano Bay from stream networks in the southern agricultural part of the basin (Aransas River, Chiltipin Creek, Taft drainage ditch) are significantly greater than loads from the Mission River or Copano Creek. When loads from the three major streams in the southern basin are combined, the total annual phosphorus load is estimated in excess of 138,000 kilograms, more than twice the predicted load from the Mission subbasin. Table 5.1 summarizes the predicted annual loads to Copano Bay for each of the five major stream network outlet points.

Total phosphorus concentrations predicted for the stream networks of the San Antonio-Nueces basin also indicate a heavier contribution of phosphorus from the southern agricultural region, as seen in Figure 4.23. Concentrations throughout the length of Chiltipin Creek, which drains an almost exclusively agricultural area near Sinton, TX, are predicted to be between 1.0 and 1.3 mg/L. For the main stem of the Aransas River, phosphorus concentrations expected from nonpoint sources fall in the range between 0.5 and 1.0 mg/L, and a general dilution effect is expected as tributaries of higher phosphorus concentration mix with the increased flows of the larger stream.

Observed concentrations along the Aransas River are consistently higher than the predicted values but, as is discussed in section 5.2, this is attributed to the additional phosphorus contribution from point sources. The average measured concentrations at two locations along the Mission River (in the 0 - 0.2 mg/L range) are actually lower than the predicted values (between 0.2 and 0.5 mg/L). As most of the upstream phosphorus contributing land uses in this subbasin are also agricultural, this trend indicates that either (a) the expected mean concentration assigned to those specific land use polygons is too high or (b) there is some loss of phosphorus that occurs along the length of the Mission River, possibly as the result of sedimentation or decay.

Stream Outlet Point	Total Phosphorus (kg/yr)	Total Nitrogen (kg/yr)	Total Cadmium (kg/yr)	Fecal Coliform (trillion col./yr)
Copano Creek	9320	67,152	45.4	941
Mission River	60,594	369,122	173.5	1469
Aransas River	57,781	239,843	76.8	550
Chiltipin Creek	60,900	213,314	56.1	506
Taft Drainage	19,524	66,252	15.3	43
Aransas Subbasin	138,205	519,409	148.2	1099
Copano Bay	208,119	955,683	367	3509

Table 5.1 : Predicted Annual Pollutant Loads to Copano Bay

Total Nitrogen

Figure 5.1 shows the expected mean concentration values for total nitrogen assigned to land use polygons in the San Antonio-Nueces basin. As for phosphorus, the highest nonpoint source derived concentrations of total nitrogen (4.4 mg/L) are expected from agricultural land uses. However, the contributions of total nitrogen from range and forest land uses are not negligible (0.7 mg/L).

The average annual cumulative loads of total nitrogen are shown in Figure 5.2. In contrast to the loadings of total phosphorus, the largest single cumulative load of nitrogen in the basin is predicted at the outlet of the Mission River. This is due to the non-zero value of concentration associated with the range and forest land uses in the drainage area and the larger runoff from the subbasin. When the loads from the three major streams in the southern basin are combined, however, the total annual estimated nitrogen load exceeds 519,000 kilograms, which is 41% more than the load estimated from the Mission River subbasin.

In general, annual nonpoint source nutrient loads in the San Antonio-Nueces coastal basin are seen to be predominantly from the agricultural areas there. Even at the Mission River outlet, the predicted loads of phosphorus and nitrogen are strongly influenced by agricultural land uses in that subbasin. Table 5.1 includes the predicted

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Nitrogen EMC's
- 0 mg/L
- 0.7 mg/L
- 1.26 mg/L
- 1.34 mg/L
- 1.5 mg/L
- 1.57 mg/L
- 1.82 mg/L
- 1.86 mg/L
- 4.4 mg/L

0 10 20 30 Kilometers
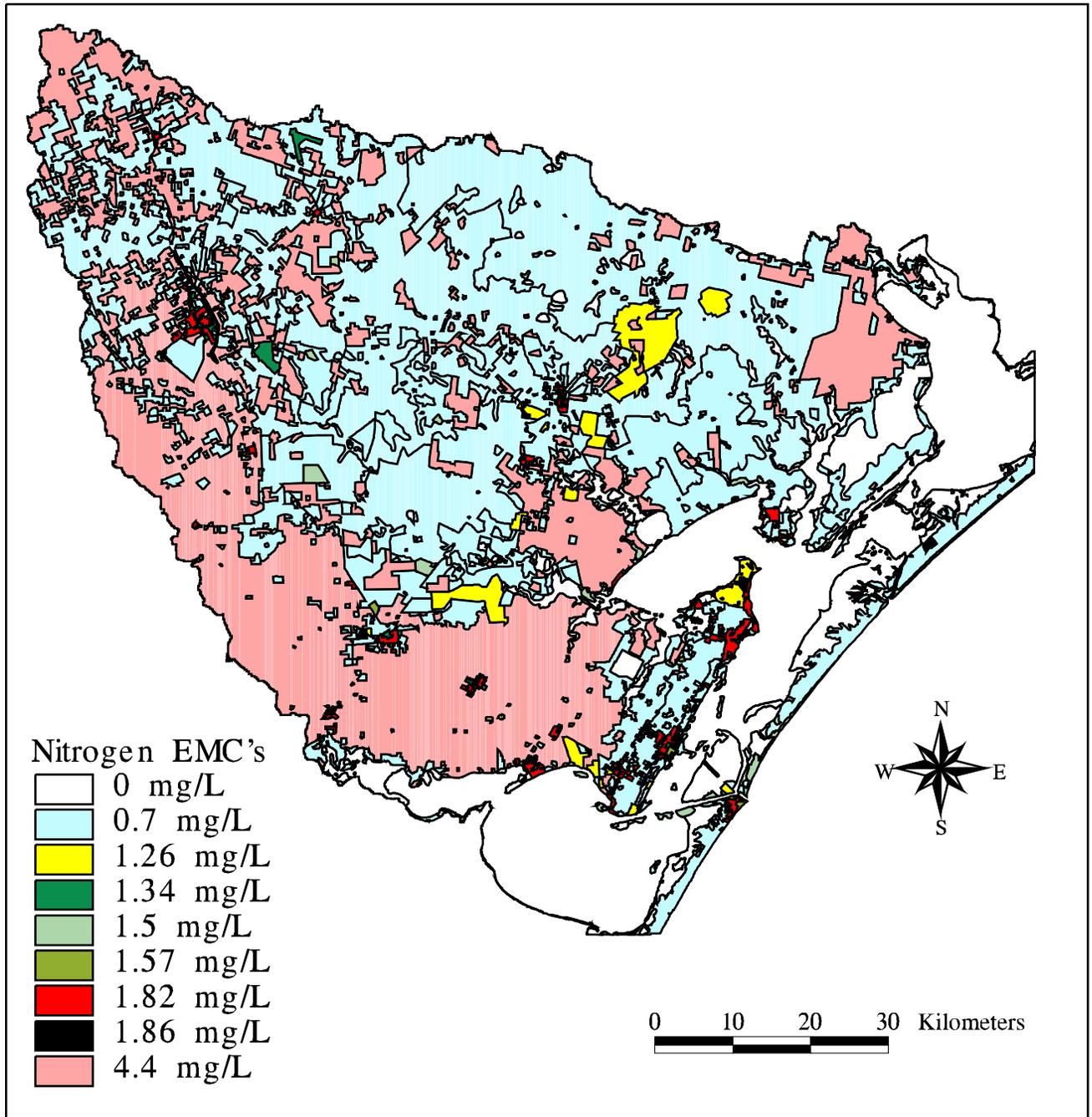
Figure 5.1 : Total Nitrogen Estimated Mean Concentrations in the San Antonio-Nueces Coastal Basin

Annual Nitrogen Load
- 1000 - 5000 kg/yr
- 5000 - 10,000 kg/yr
- 10,000 - 50,000 kg/yr
- 50,000 - 100,000 kg/yr
- 100,000 - 200,000 kg/yr
- 200,000 - 300,000 kg/yr
- 300,000 - 369,000 kg/yr
- Basin Border
- Bay Network

239,843 kg

67,152 kg

369,122 kg

66,252 kg

213,314 kg

0   10   20   30   Kilometers
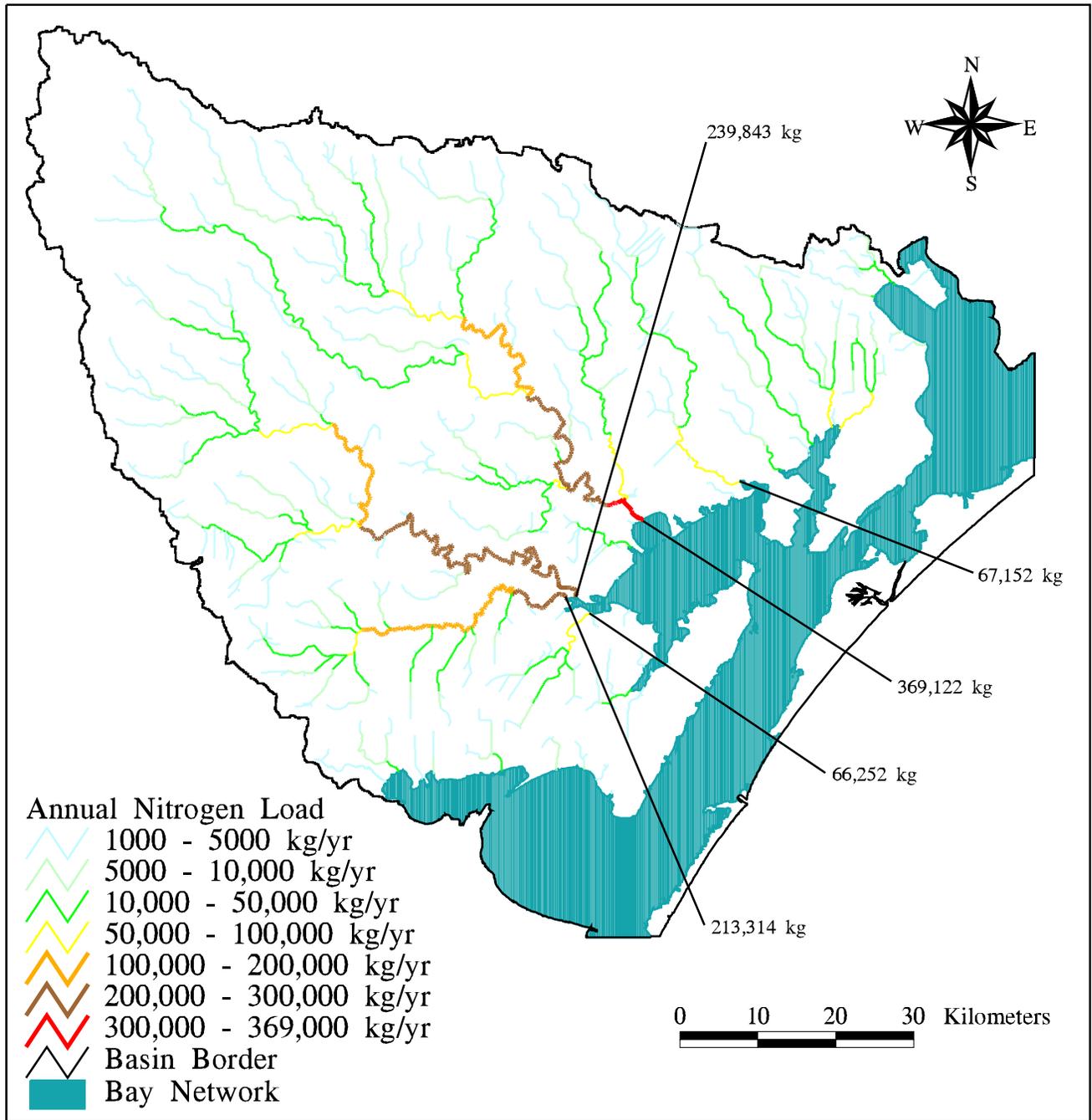
Figure 5.2 :   Average Annual Total Nitrogen Loads in the
San Antonio-Nueces Coastal Basin

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annual nitrogen loads to Copano Bay for each of the five major stream network outlet points.

Figure 5.3 shows the total nitrogen concentrations predicted for the stream networks of the San Antonio-Nueces basin. As for the phosphorus concentrations in Figure 4.23, the highest concentrations of nitrogen are expected from the southern agricultural region of the basin. Concentrations along the main stem of the Aransas River are predicted to be between 2.0 and 4.0 mg/L. Observed concentrations along the river are consistently higher than predicted values. As with the phosphorus concentrations, this is attributed to additional nitrogen loads from point sources along the river.

The average measured nitrogen concentrations at two locations along the Mission River (in the 0 - 1.0 mg/L range) are lower than the predicted values (between 1.0 and 2.0 mg/L). This trend was also observed for phosphorus, but no load contributions from range and forest land uses exist for that nutrient. The lower observed nitrogen concentrations may be due to elevated expected mean concentration values assigned to either the range, forest, or agriculture land uses in the basin. Alternatively, the fact that no loss of pollutant is included in the assessment may account for the elevated predicted concentrations in this subbasin.

Total Cadmium

Table 3.6 includes expected mean concentration data for six heavy metal pollutants. Cadmium is chosen as a representative metal with which to perform the nonpoint source pollution assessment. Figure 5.4 shows the aerial distribution of total cadmium expected mean concentrations in the San Antonio-Nueces coastal basin. Expected mean metal concentrations are three orders of magnitude lower than for the nutrients, and are measured in micrograms per liter (µg/L). Unlike for the nutrient concentrations, the highest levels of cadmium (2.0 µg/L) are expected from urban industrial land uses, rather than agricultural land uses (1.0 µg/L). Cadmium concentrations from range and forest land uses are expected to be 0.5 µg/L. Actual metal contributions from urban industrial land uses are expected to vary with the particular industries that occupy each specific land use area. Closer review of Figure 5.4

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Observed Concentrations
- 0 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 4.0 mg/L
- 4.0 - 8.0 mg/L
- 8.0 - 12.0 mg/L
- 12.0 - 16.0 mg/L

Predicted Concentrations
- 0 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 4.0 mg/L
- 4.0 - 4.4 mg/L
- Basin Border
- Bay Network

Figure 5.3 : Comparison of Estimated and Average Observed Total Nitrogen Concentrations in the San Antonio-Nueces Coastal Basin

Figure 5.4 : Total Cadmium Estimated Mean Concentrations in the San Antonio-Nueces Coastal Basin

shows the largest patch of urban industrial land uses exists in the northern central part of the basin. These areas depict the boundaries of existing oil fields in the region.

Figure 5.5 shows the predicted annual cumulative cadmium loadings to stream networks in the San Antonio-Nueces basin. The largest cumulative cadmium load (173.5 kg/yr) is expected at the outlet of the Mission River subbasin, which drains the largest area in the coastal basin and includes part of the oil field land use area discussed above. The magnitudes of the cumulative loads are significantly smaller than those for the nutrients, as a result of the smaller expected mean concentrations assigned to the land use polygons. Table 5.1 shows that, unlike for the nutrient loads, total annual cumulative cadmium load from the Mission River subbasin exceeds the sum of the loads from the three major streams in the Aransas River subbasin (148.2 kg/yr). This corresponds to a lower relative level of cadmium contribution from agricultural land uses.

A review of the predicted cadmium concentrations from Figure 5.6 shows that concentrations in the San Antonio-Nueces coastal basin are almost universally expected to be in the 0.5 - 1.0 µg/L range. There are a few small tributaries in the Copano and Mission subbasins where concentrations are expected to exceed 1.0 µg/L. These are the tributaries draining the oil fields in the north central part of the basin. One small tributary to Chiltipin Creek that passes through an urban industrial area also includes a reach where concentrations are expected to be higher than 1.0 µg/L. Finally, there are some small reaches in the southern part of the basin that drain agricultural land use regions, only. Concentrations along these reaches are expected to be exactly 1.0 µg/L, but are identified as being in the 1.0 - 2.0 µg/L range. Due to the rounding associated with the division of cumulative load by the integer values of cumulative runoff, the calculated values for predicted cadmium concentration are slightly higher than the expected 1.0 µg/L.

Figure 5.6 also includes four measurement locations where values for observed cadmium concentrations were recorded. A review of the TNRCC Surface Water Quality Monitoring (SWQM) data for these locations shows only one location (Mission River) where more than a single measurement exists. A comparison of the TNRCC recorded concentrations for other heavy metal pollutants with the measurements for cadmium shows that the exact same values are recorded for all heavy metal measurements at each location. This fact leads to the conclusion that the
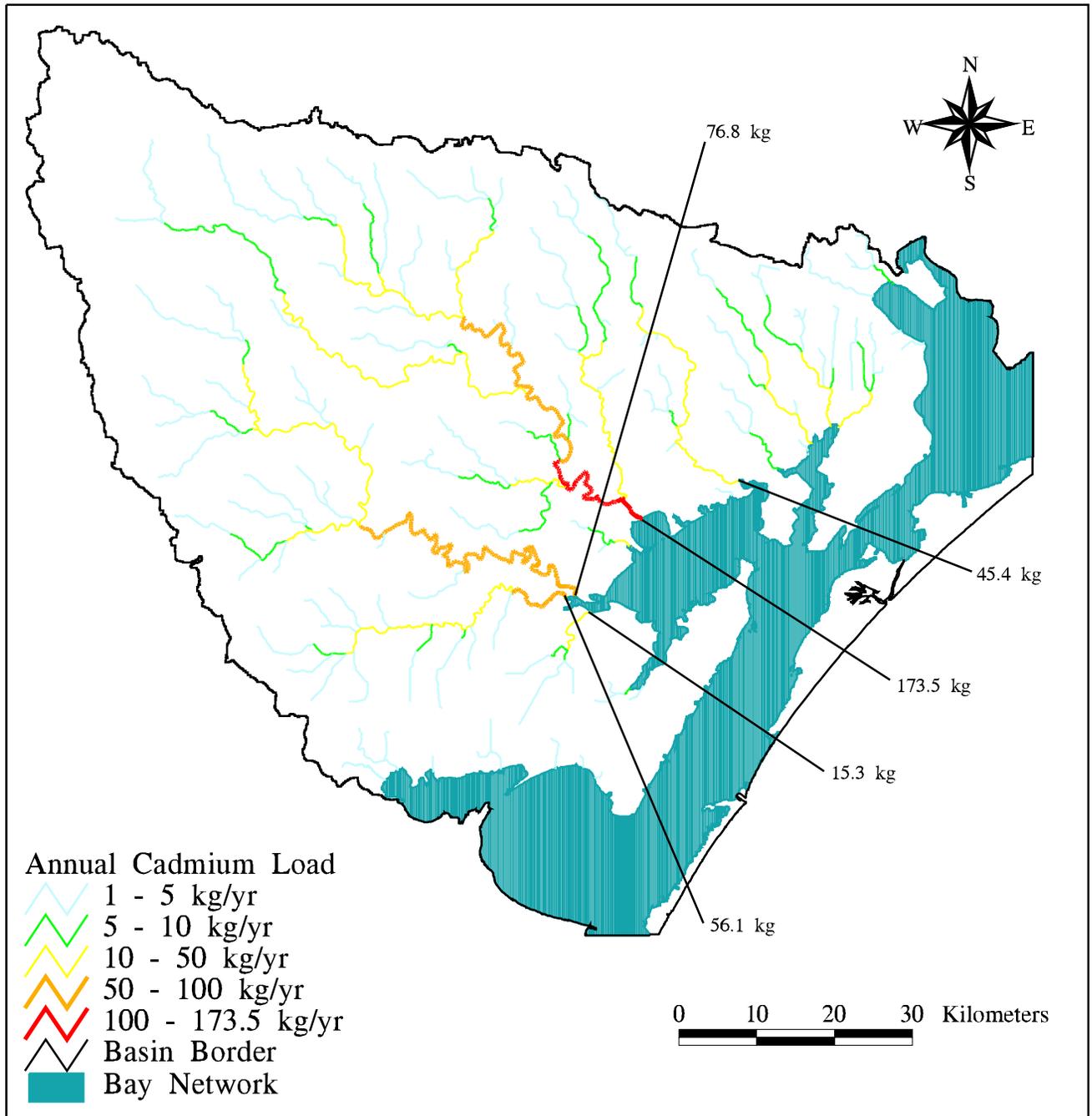
Figure 5.5 :   Average Annual Total Cadmium Loads in the
San Antonio-Nueces Coastal Basin
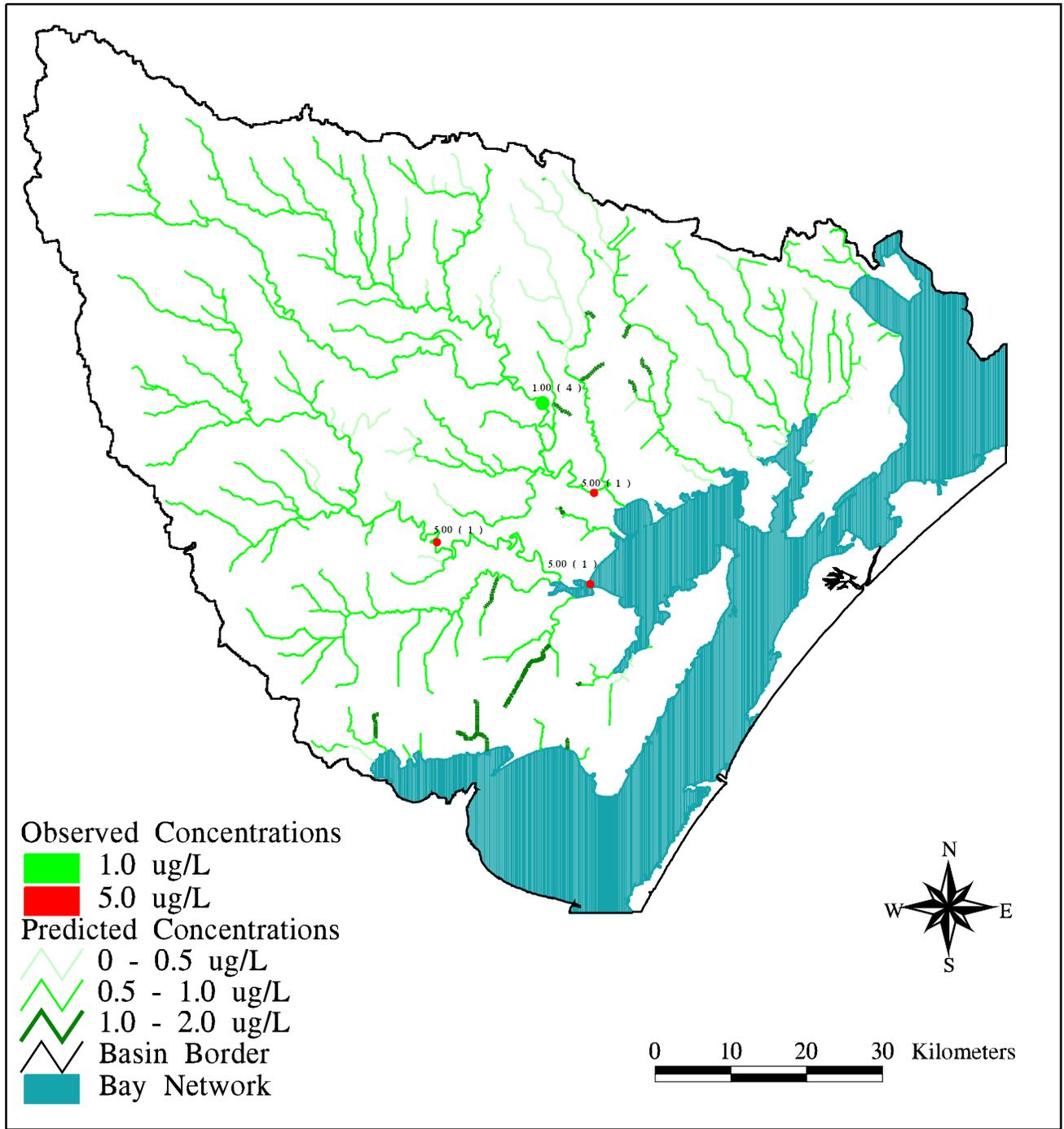
Figure 5.6 : Comparison of Estimated and Average Observed Total Cadmium
Concentrations in the San Antonio-Nueces Coastal Basin

TNRCC SWQM data for heavy metals is questionable and more data are needed to judge the accuracy of the nonpoint source pollution assessment.

Fecal Coliform

Fecal coliform bacteria are present in the feces of warm blooded animals and are indicators of bacteriological water quality. Concentrations of fecal coliform are measured in number of bacteria colonies per 100 milliliter sample. The fecal coliform expected mean concentration data from Table 3.6 only includes values for urban land uses and range/forest land uses. The urban land use concentrations are established from concentrations measured as part of the Dallas-Ft. Worth National Pollutant Discharge Elimination System (NPDES) study and the range land expected mean concentrations are established from measured concentrations at the USGS stream gauge #08201500 on Seco Creek near Utopia, TX (Baird, et al., 1996). No expected mean concentration value for agricultural lands is provided in Table 3.6. Preliminary copies of this table actually included agricultural expected mean concentration values in the range of 20,000 - 30,000 colonies per 100 milliliters but, ultimately, the variability observed in the unpublished editions of the table persuaded the authors to exclude any official value for agricultural lands. In accordance with this lack of actual published data, no fecal coliform concentration is assumed from agricultural land uses.

Figure 5.7 shows the aerial distribution of the available expected mean concentration data in the San Antonio-Nueces coastal basin. As is the case with Table 3.6, the most significant concentration values are associated with urban land uses in the basin. A value of 200 colonies per 100 milliliters is assigned to the range and forest land use regions in the basin.

Average annual fecal coliform loads in the San Antonio-Nueces coastal basin are calculated using the procedure outlined in section 4.5. However, due to the uncommon units of the fecal coliform expected mean concentrations and the magnitude of the cumulative loads, the cumulative load equation for this calculation is modified to

$$L = Q \text{ (mm/yr)} * EMC \text{ (colonies/100 mL)} * A \text{ (10,000 m}^2\text{/cell)} * 10^{-9} \text{ trillion mL-m/mm-m}^3, \quad (5\text{-}1)$$

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Fecal Coliform EMC's

☐	0 colonies/100 mL
(green)	200 colonies/100 mL
(cyan)	6900 colonies/100 mL
(pale yellow)	9700 colonies/100 mL
(orange)	20,000 colonies/100 mL
(red)	22,400 colonies/100 mL
(gray)	53,000 colonies/100 mL
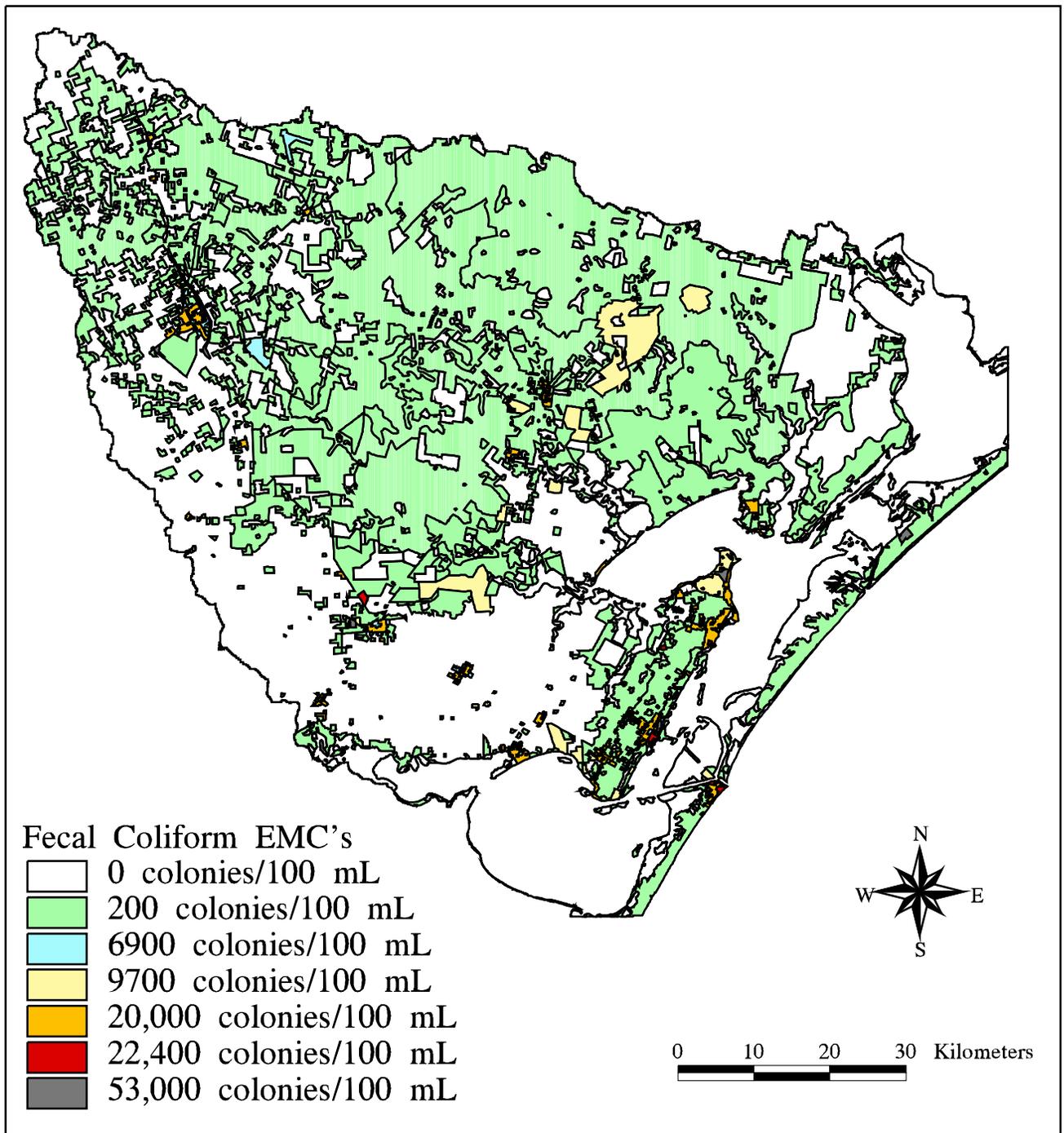
Figure 5.7 : Fecal Coliform Estimated Mean Concentrations in
the San Antonio-Nueces Coastal Basin

where load (L) is determined in units of trillion colonies per year. Figure 5.8 shows the average annual cumulative loadings in the San Antonio-Nueces coastal basin. Due to the zero value of expected mean concentration assigned to the agricultural land use areas, streams that exclusively drain agricultural regions accumulate no loads and, hence, are absent from this figure.

The largest predicted cumulative load in the San Antonio-Nueces basin occurs at the outlet of the Mission River subbasin and is almost 1.47×10^{15} colonies per year. As can be seen from Table 5.1, this value exceeds the sum of the loads from the three major streams of the Aransas River subbasin (1.1×10^{15} colonies per year) and the fecal coliform average annual load from Copano Creek (941×10^{12} colonies).

Figure 5.9 shows predicted fecal coliform concentrations in the San Antonio-Nueces coastal basin stream network. These values range up to almost 9000 colonies/100 milliliter sample. The largest concentrations occur immediately downstream of the locations of various urban land uses in the basin. Average observed fecal coliform concentrations throughout the basin are consistently lower than the predicted values, although, for most of the sampling locations, only one measurement specifies the average observed value. The trend of predicted concentration values exceeding average measured values indicates that the fecal coliform expected mean concentration values assigned to urban land uses are probably too high. Given the magnitudes of these expected mean concentration values and the large degree of variability between measurements, the nonpoint source pollution assessment for this constituent (and fecal streptococci) needs further investigation and data collection to be reliable.

5.2   Assessment of Basin Pollution Including Point Sources

Section 4.6 describes a method of estimating point source loads by considering the difference between calculated nonpoint source pollution concentration levels and observed concentration levels at a specific location, and then accounting for that difference with a single point load at the location. This method is employed for both total phosphorus and total nitrogen, since nutrients are of particular interest to the TNRCC. Also, since there are significant numbers of TNRCC Surface Water Quality Monitoring data measurements for phosphorus and nitrogen, the average of the

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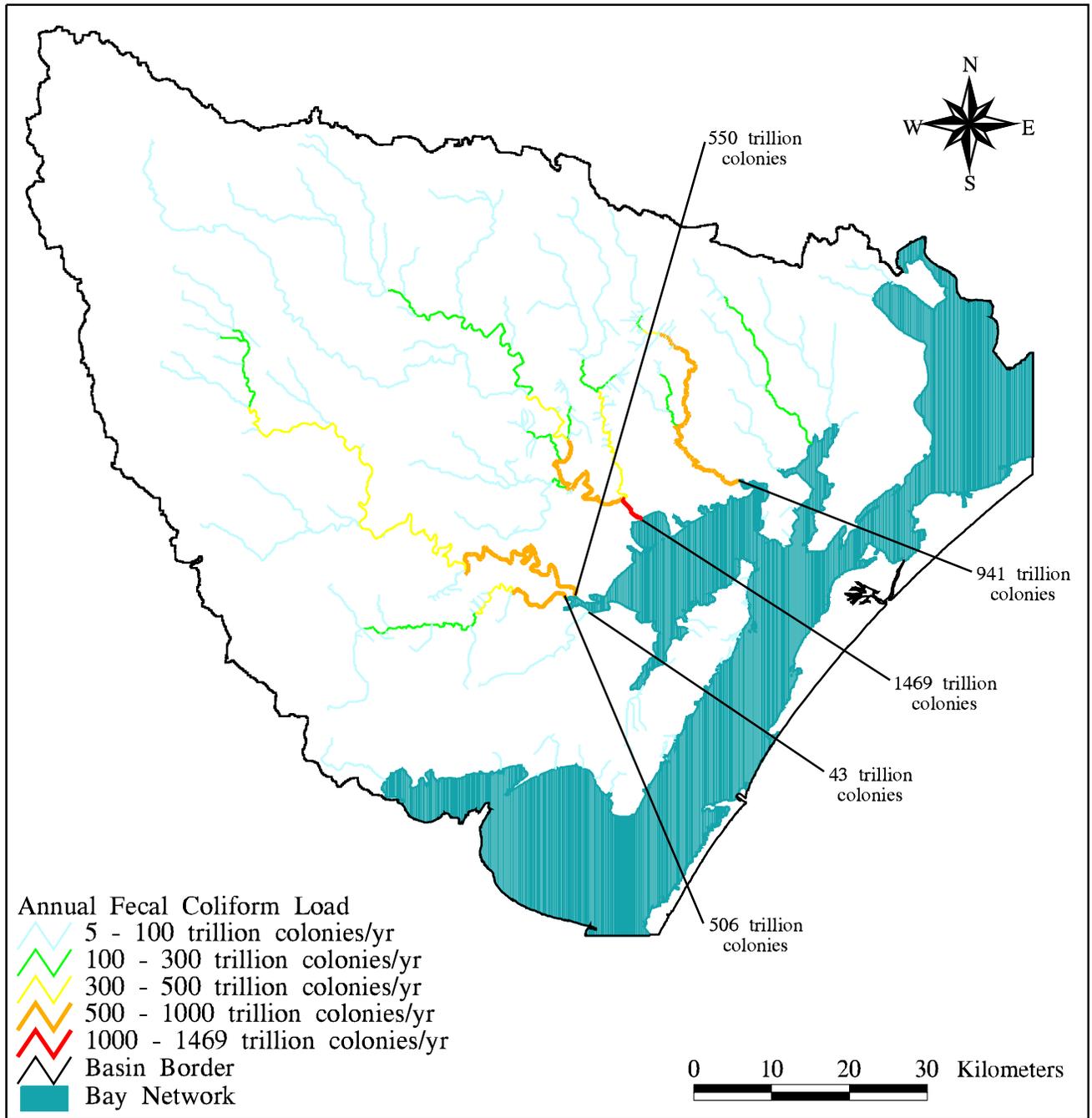
Figure 5.8 :   Average Annual Fecal Coliform Loads in the
San Antonio-Nueces Coastal Basin

Measured Concentrations
- 0 - 200 colonies/100 mL
- 200 - 300 colonies/100 mL
- 300 - 400 colonies/100 mL
- 400 - 462 colonies/100 mL

Predicted Concentrations
- 0 - 200 colonies/100 mL
- 200 - 300 colonies/100 mL
- 300 - 400 colonies/100 mL
- 400 - 500 colonies/100 mL
- 500 - 1000 colonies/100 mL
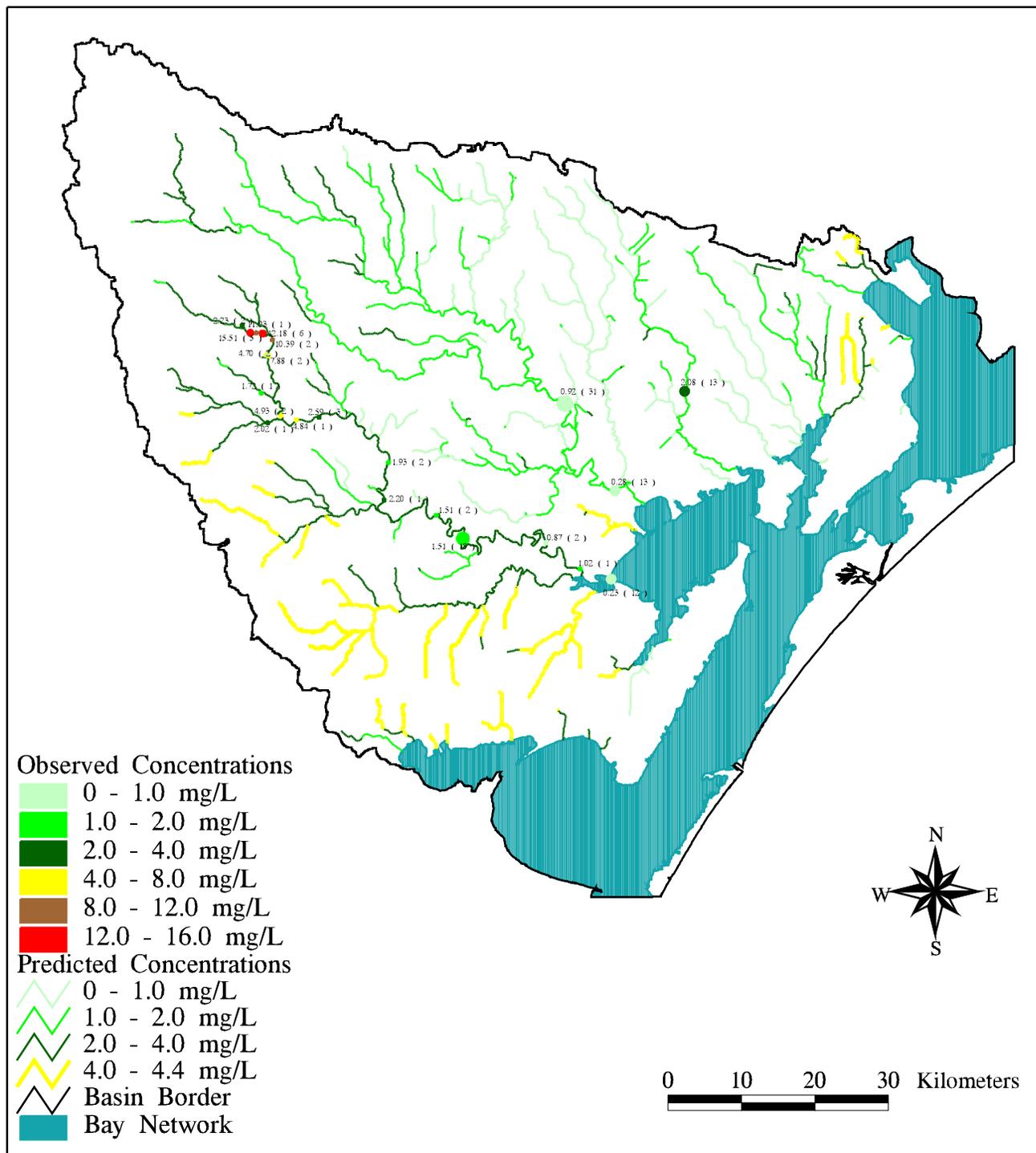- 1000 - 8996 colonies/100 mL
- Basin Border
- Bay Network
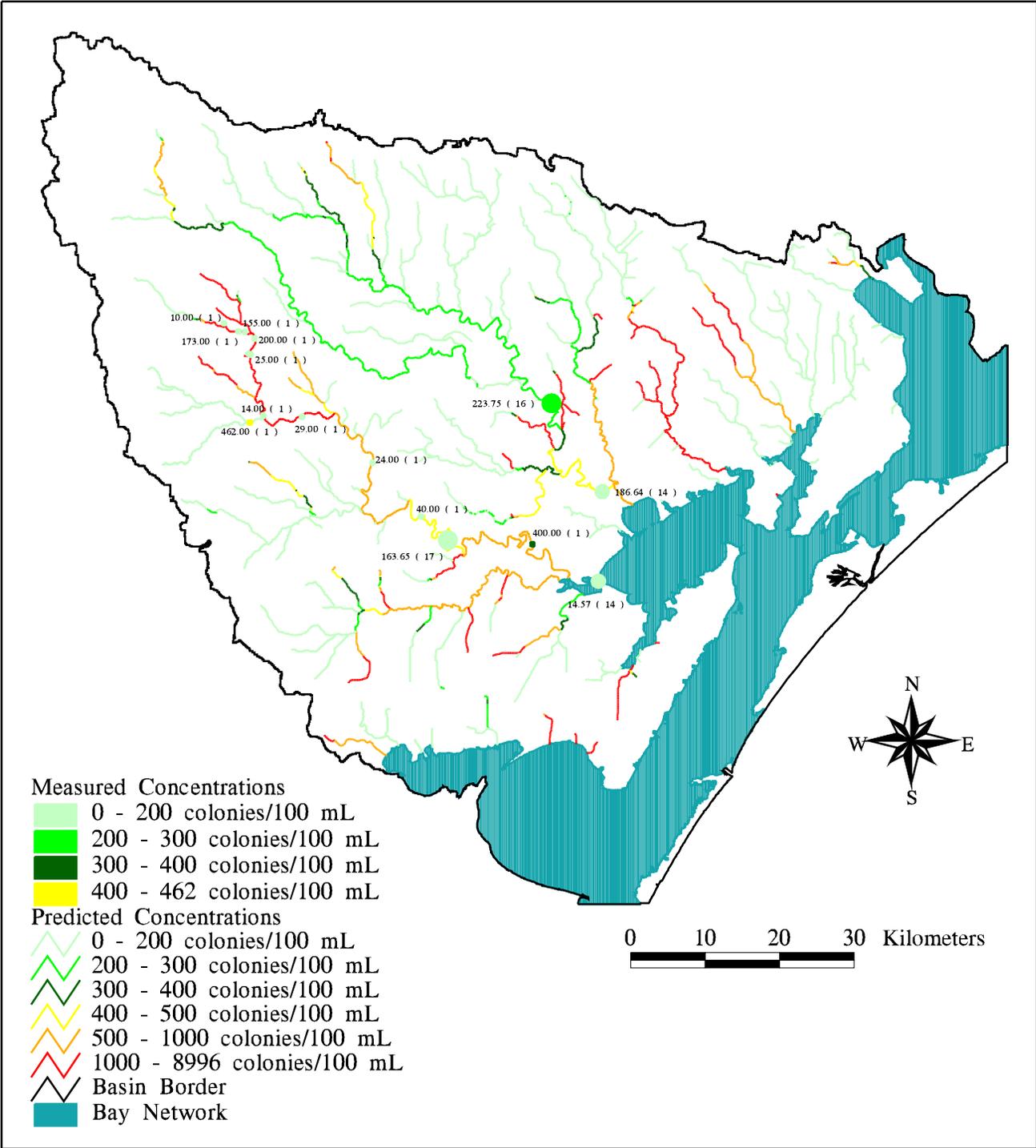
Figure 5.9 :   Comparison of Estimated and Average Observed Fecal Coliform
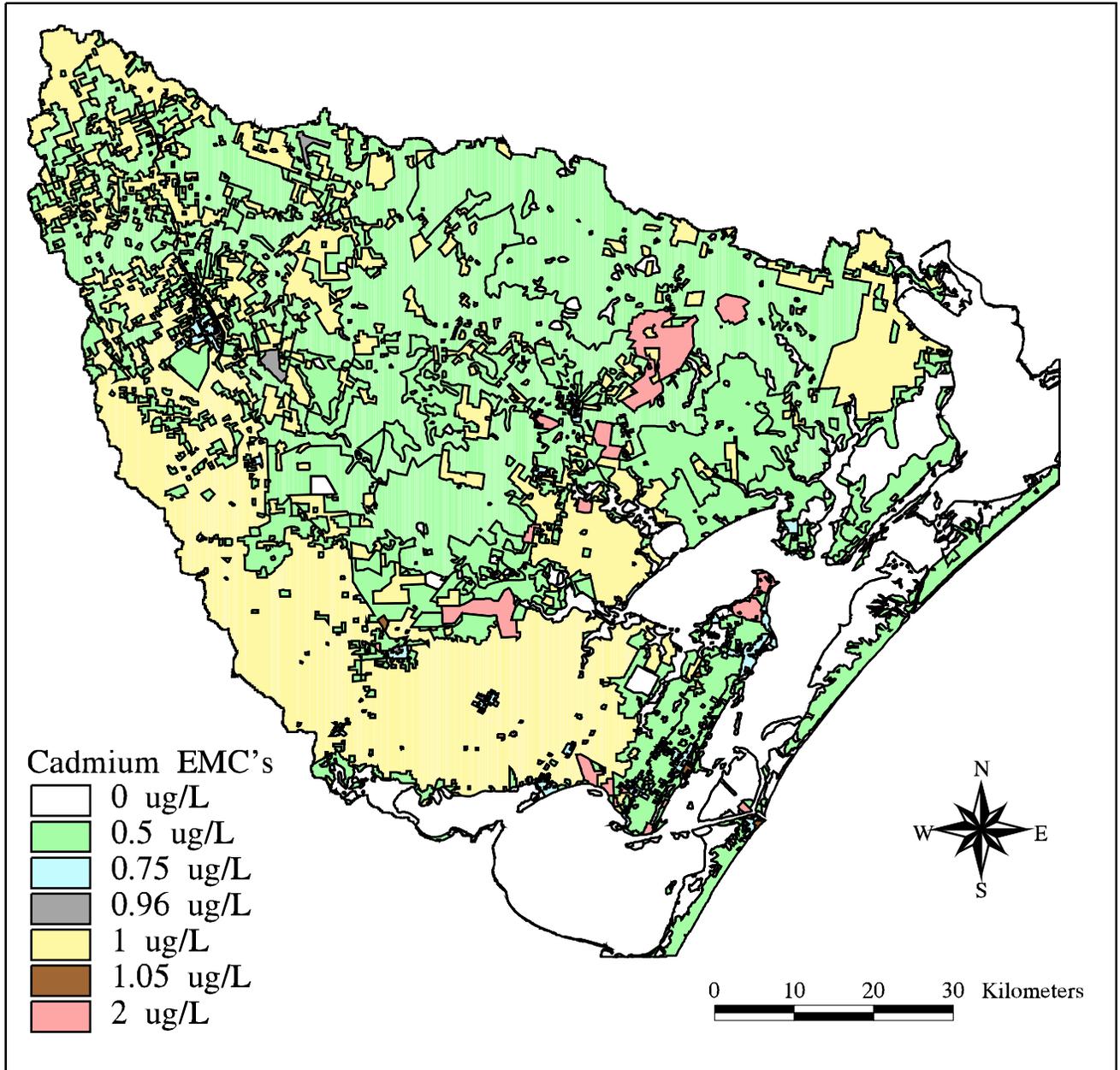Concentrations in the San Antonio-Nueces Coastal Basin

observed concentrations for these pollutants is considered more representative of actual conditions within the stream networks. Hence, comparison of predicted and average observed concentrations is considered more significant for these constituents.

Total Phosphorus

As discussed in section 4.6, the phosphorus point load established by this method, estimated at the furthest upstream location where a significant concentration discrepancy exists, is approximately 100% higher than an equivalent load estimated using the methods of Thomann and Mueller (1987) and approximately 69% higher than a load estimated using the current average daily flow reported by the Beeville wastewater treatment plant (Barrera, 1996).

The discrepancy between the point load estimation and these other methods of calculating point loads could be explained by the existence of additional point sources in close proximity to or somewhere upstream from the location of the Beeville wastewater treatment plant. Alternatively, the effluent phosphorus concentration from the plant may have been higher than Thomann and Mueller's typical estimate of seven mg/L during the period when phosphorus measurements were recorded at the location. Regardless of whether this method accurately represents the phosphorus point load from the Beeville wastewater treatment plant, the method does illustrate a method of simulating a conservative point load and applying the corresponding increase in mass load to all downstream locations.

Figure 4.25 (a-c) shows the modified in-stream phosphorus concentrations compared with the average observed phosphorus concentrations at measurement locations along the Aransas River. As a result of the point source addition at Beeville, the dilution effect of the higher concentration tributaries mixing with the larger flows of the Aransas main stem is more pronounced. Also, while the chosen predicted and observed concentration ranges still do not match up exactly at all downstream locations, the differential at each location is made smaller and, in fact, predicted concentration ranges do match the observed ranges in the lower reaches of the Aransas River (Figure 4.25c).

Total Nitrogen

For total nitrogen, a nonpoint source pollution concentration grid, nitconc, is created as per the procedure outlined in section 4.5. The predicted nonpoint source nitrogen concentration at the point where the Beeville wastewater treatment plant effluent is estimated (from the total phosphorus analysis) is queried, using the Gridpaint and Cellvalue commands, as in section 4.6.

Grid: **gridpaint nitconc value linear nowrap gray**
Grid: **polygonshades nitpts 2**
Grid: **cellvalue nitconc ***
> The cell containing point (1223830.414,693729.621) has value 2.434

Noting that the average observed total nitrogen concentration at the point source location is 15.51 mg/L, the amount of this concentration attributed to the point source effluent is calculated as 15.51 mg/L - 2.434 mg/L $=$ 13.076 mg/L. By multiplying this value by the cumulative runoff at the point source established from the total phosphorus analysis in section 4.6, the total annual estimated cumulative nitrogen point load is determined as

$$13.076 \text{ mg/L} * 5{,}467{,}914 \text{ m}^3/\text{yr} * 1000 \text{ L/m}^3 * 10^{-6} \text{ kg/mg} = 71{,}498 \text{ kg/yr}. \qquad (5\text{-}2)$$

Thomann and Mueller's estimate for a typical mean value of total nitrogen concentration in the effluent of a conventional secondary treatment facility is 18 mg/L (Thomann and Mueller, 1987). Using this value, along with the other parameters from equation 4-13, an alternative value for total nitrogen load is estimated as

$$125 \text{ gcd} * 13547 \text{ pop.} * 365 \text{ d/yr} * 3.785 \text{ L/gal} * 18 \text{ mg/L} * 10^{-6} \text{ kg/mg} = 42{,}110 \text{ kg/yr}. \quad (5\text{-}3)$$

Finally, using the average daily flow from the Beeville wastewater treatment plant to replace the population-derived flow, a third estimate of annual total nitrogen load is calculated as

$$2{,}000{,}000 \text{ gal/d} * 365 \text{ d/yr} * 3.785 \text{ L/gal} * 18 \text{ mg/L} * 10^{-6} \text{ kg/mg} = 49{,}735 \text{ kg/yr}. \qquad (5\text{-}4)$$

The total nitrogen point load calculated in equation 5-2, estimated by accounting for the complete difference in predicted nonpoint source concentration and average observed concentration with a single point source, exceeds the value estimated using Thomann and Mueller's method by approximately 70%. Alternatively, the load of equation 5-2 is only 44% greater than a load calculated using the current average daily flow at the Beeville wastewater treatment plant.

As for the estimate of annual total phosphorus point load, the fact that the estimate from equation 5-2 is within the same order of magnitude as the other estimates is encouraging, but also indicates that there may be additional point sources in close proximity to the location of the Beeville wastewater treatment plant. Alternatively, if the effluent nitrogen concentration from the plant was as high as 26 mg/L during the period when nitrogen measurements were recorded at the location, instead of Thomann and Mueller's typical estimate of 18 mg/L, then the difference between predicted and observed total nitrogen concentrations would be explained by the single point source.

Figure 5.10 (a-c) shows the in-stream predicted total nitrogen concentrations, determined with the point source at Beeville included and compared with the average observed total nitrogen concentrations at measurement locations along the Aransas River. As for the similar total phosphorus comparison in Figure 4.25 (a-c), the predicted and observed concentration ranges do not match exactly throughout the length of the river, but do agree quite well, particularly in the reaches immediately downstream of the suspected point source at Beeville. In the lower reaches of the Aransas River, where the defined concentration ranges are smaller, predicted concentrations typically fall within 1-2 mg/L of the average observed concentrations.

5.3   Expected Mean Concentration Values from the Optimization Routine

Table 4.7 shows the results from the Microsoft Excel Solver optimization program runs. As identified is section 4.7, the original intent of using this routine was to establish a method of estimating pollutant expected mean concentration values rather than having to rely on literature-based values. However, since there are only four useable Surface Water Quality Measurement stations with a significant number of
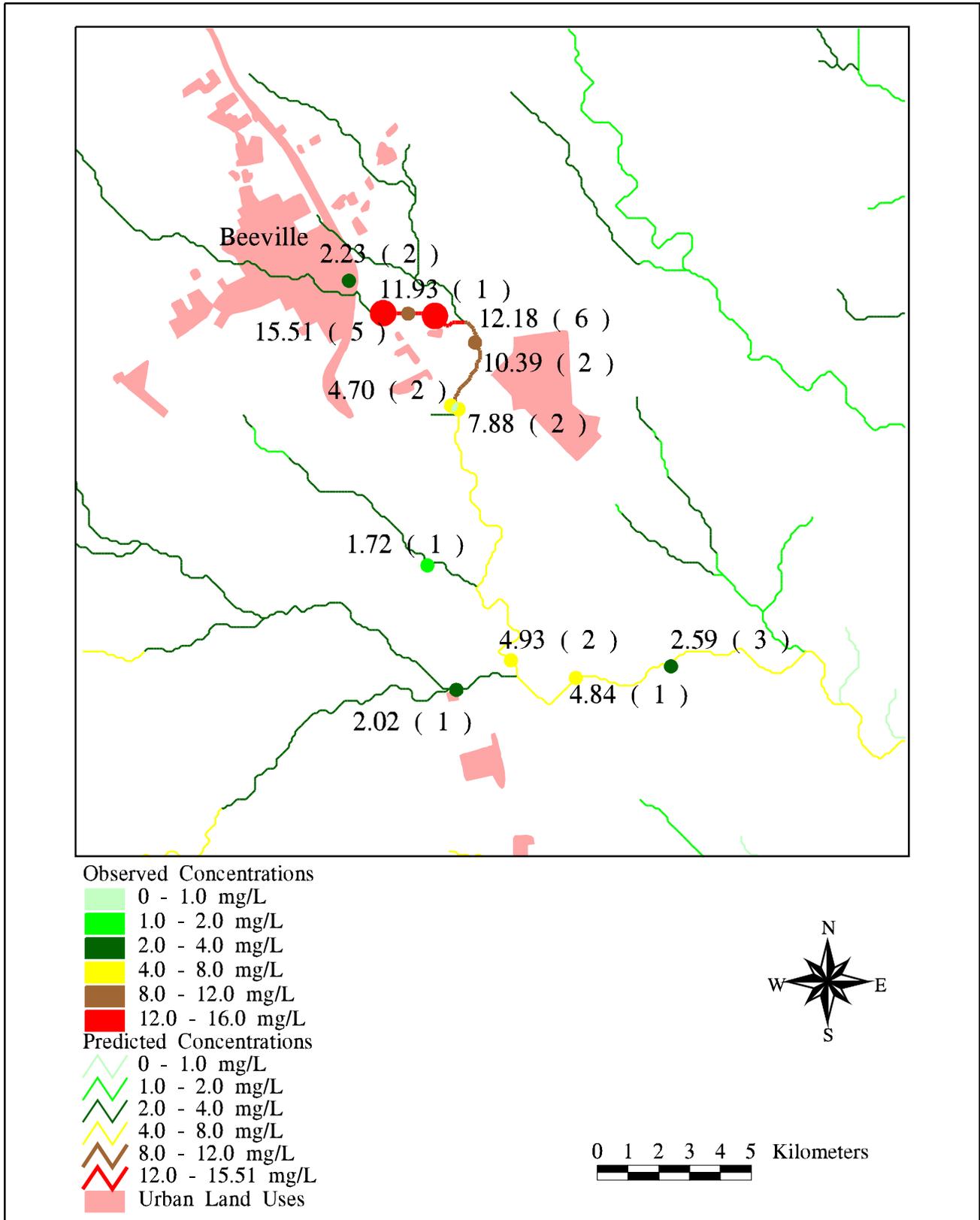
Figure 5.10a : Predicted vs. Observed Total Nitrogen Concentrations
(Beeville Point Source Included) Just Downstream of Beeville, TX

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Observed Concentrations
0 - 1.0 mg/L
1.0 - 2.0 mg/L
2.0 - 4.0 mg/L
4.0 - 8.0 mg/L
8.0 - 12.0 mg/L
12.0 - 16.0 mg/L
Predicted Concentrations
0 - 1.0 mg/L
1.0 - 2.0 mg/L
2.0 - 4.0 mg/L
4.0 - 8.0 mg/L
8.0 - 12.0 mg/L
12.0 - 15.51 mg/L
Urban Land Uses
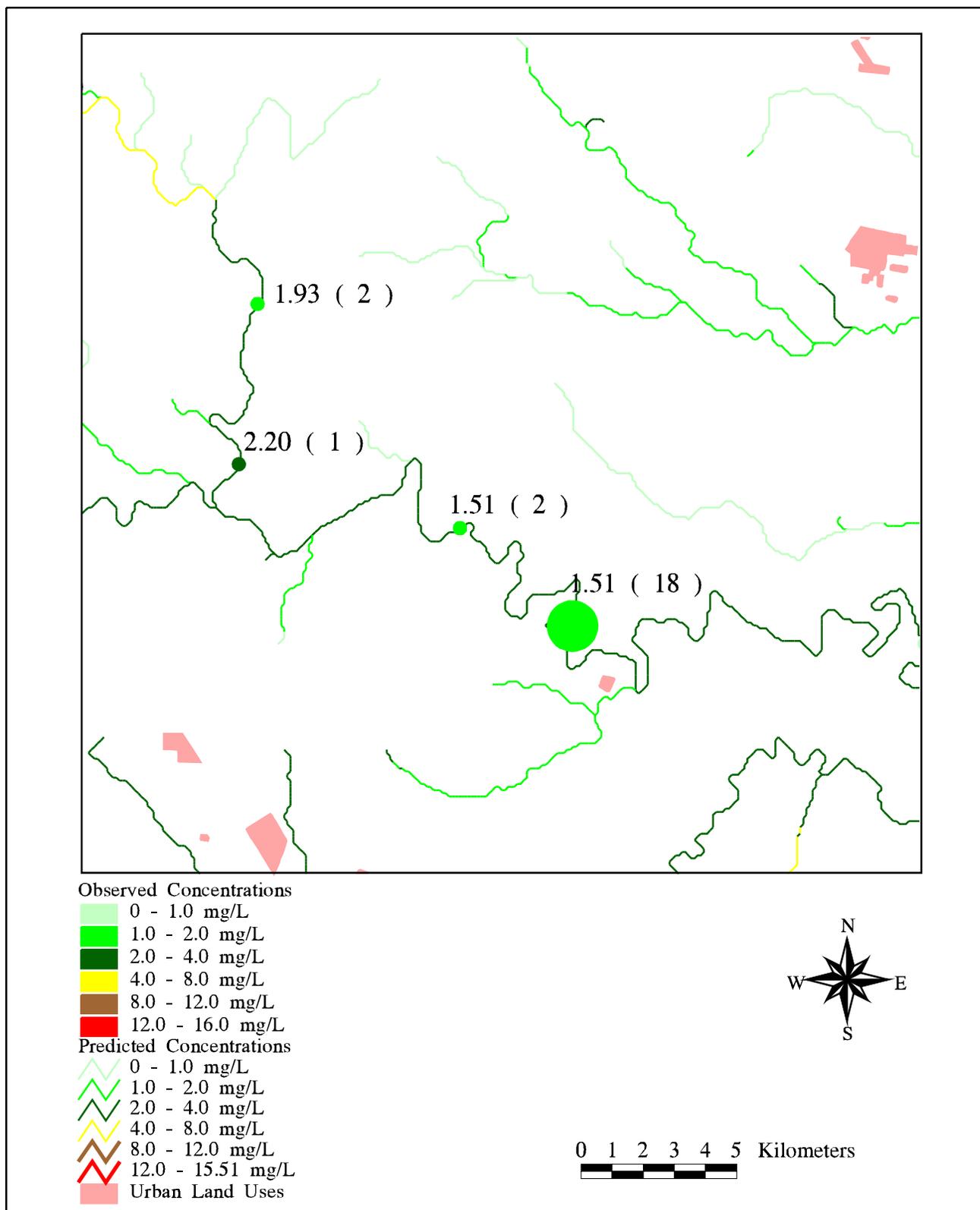
Figure 5.10b : Predicted vs. Observed Total Nitrogen Concentrations
(Beeville Point Source Included) for Middle Aransas River

Observed Concentrations
- 0 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 4.0 mg/L
- 4.0 - 8.0 mg/L
- 8.0 - 12.0 mg/L
- 12.0 - 16.0 mg/L

Predicted Concentrations
- 0 - 1.0 mg/L
- 1.0 - 2.0 mg/L
- 2.0 - 4.0 mg/L
- 4.0 - 8.0 mg/L
- 8.0 - 12.0 mg/L
- 12.0 - 15.51 mg/L
- Bay Network
- Urban Land Uses
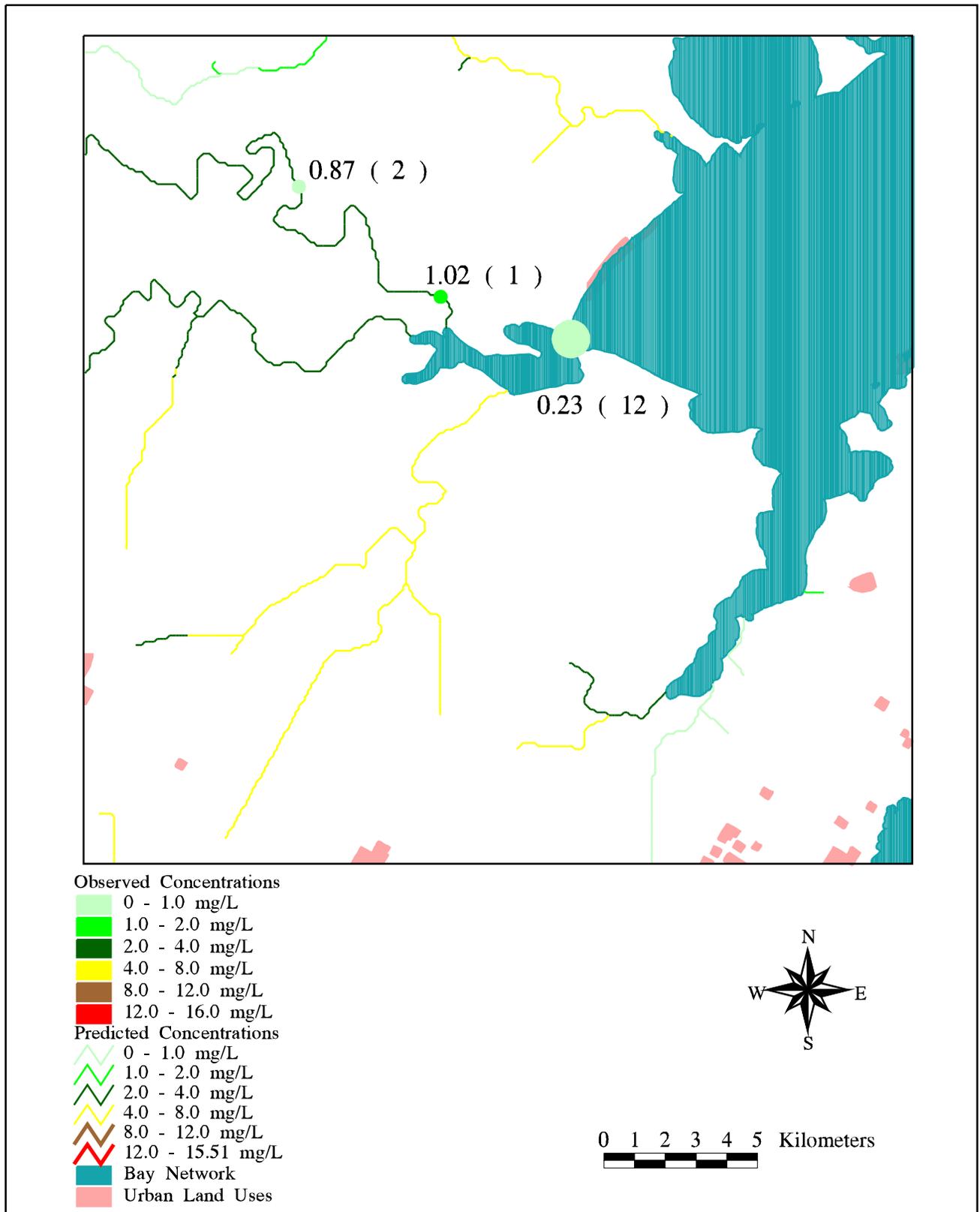
Figure 5.10c : Predicted vs. Observed Total Nitrogen Concentrations (Beeville Point Source Included) for Lower Aransas River

measurements (more than 15) for total phosphorus concentration, only four concentration balance equations are established for those sampling locations. The fact that there are 12 different land uses in the four subbasins draining to these sampling locations necessitates that 12 expected mean concentration variables are included in the four concentration balance equations.

With only four equations and 12 variables, additional constraints on the variables are required to limit the number of possible solutions. By constraining the water and wetland expected mean concentrations to a value of zero and by making the values of other urban and mixed urban expected mean concentrations dependent on the residential, commercial, industrial and transportation expected mean concentration values, the number of variables in the four equations is effectively reduced to eight. However, four equations with eight variables can still be solved with an infinite number of solutions. The initial values entered for each expected mean concentration value have a definite impact on the final values established by the optimization routine. Hence, for these runs, the optimization routine does not provide an independent method of determining expected mean concentration values. Rather, it provides a method of adjusting initial values until a more optimum solution is established.

The two methods used to establish optimum expected mean concentration values for the subbasin land uses are (1) minimization of the sum of the absolute values of each concentration balance and (2) minimization of the maximum concentration balance absolute value. With only four equations and eight effective variables, the concentration balance equations do not converge to zero for either method.

Using the first optimization method, the routine converges to a solution that includes a negative concentration balance of 0.184 mg/L at the Mission River station. This negative value of concentration balance represents an overestimation of the predicted concentration at that location. The same method underestimates the predicted concentration at the Aransas station by 0.117 mg/L. An additional observation with the use of this optimization method is that, for urban industrial, urban transportation, range, and barren land uses, the final optimized expected mean concentrations are equal to the +/- 50% constraint value imposed on each variable. This indicates that the optimization routine stops because it reaches the constraint values and doesn't necessarily find the most optimum solution.

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Minimization of the maximum concentration balance absolute value converges to a solution that overestimates the predicted concentration at the Mission River station by only 0.165 mg/L, but also underestimates the predicted concentration at the Aransas River station by 0.165 mg/L. Interestingly, no constraint value is reached when using this optimization method. In fact, only the optimized expected mean concentration value for forest land is more than 7% greater than the initial value entered from Table 3.6. Since this optimization method produces adjusted results that are closer to the empirically established expected mean concentration values of Table 3.6, and since the optimization converges to a solution without reaching any of the constraint values, this method is preferred to the minimization of the concentration balance sum as the means to adjust expected mean concentration values.

For future investigations, this optimization method may be used to independently establish land use-based expected mean concentration values by including additional measurement locations in or near the basin of interest. For this study, no additional measurement locations with more than six total phosphorus concentration measurements exist in the basin. However, by including additional measurement locations in close proximity to the basin, more concentration balance equations could be added to the optimization without adding more expected mean concentration variables. By simultaneously solving a number of concentration balance equations with the same number of expected mean concentration variables, an unique solution should be achievable.

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6 CONCLUSIONS AND LIMITATIONS

The GIS nonpoint source pollution assessment method discussed in the preceding chapters has been shown to present a viable technique of characterizing the nonpoint source contributions to pollution within a watershed or geographic region. Advantages of the method are outlined below:

- By virtue of the fact that values for predicted and observed concentrations are comparable, the GIS nonpoint source assessment method is seen to provide relatively accurate estimates of pollutant loads and concentrations throughout the stream network of a hydrologic unit. Particularly along smaller streams, where few or no point sources exist (e.g. Copano Creek), concentrations predicted via the assessment method match quite well with average observed concentration values.
- The method also provides an efficient way to identify specific locations or regions where elevated levels of pollutant concentrations may be expected. In particular, this study has shown that the Aransas River watershed, with a large percentage of its area occupied by agricultural lands, includes locations where elevated nutrient levels are expected. More sampling is warranted in this subbasin, particularly downstream from Beeville, where the partitioning between nonpoint and point source nutrient loading is still unclear.
- Use of the GIS nonpoint source pollution assessment method also has some logistical advantages that allow for adaptation to other study areas. This method makes use of all recorded streamflow and pollutant concentration data available in the basin and synthesizes the data in a consistent and logical way across the basin. Most of the data sources used for this study are publicly available in a digital format and the data pertinent to the study area are easily extractable from each database.
- Also, the procedures used for this method employ standard Arc/Info and ArcView GIS commands and routines and the necessity for external programming scripts is limited to data reformatting routines.
- By including estimated point source loads as per the simulation method described in sections 4.6 and 5.2, predicted concentration levels in larger streams, where point sources are known to exist, are more closely correlated with average observed concentrations. The practice of accounting for the full difference between

predicted and observed pollutant concentrations with a single point load, however, is not expected to represent actual conditions in a watershed the size of the San Antonio-Nueces coastal basin. Optimally, point loads should be accounted for with values of reported annual loads or permitted average concentrations for all of the permitted point source effluents within the basin.

- The use of the optimization routine, intended for explicit determination of land use-based expected mean concentration values, became a method of adjusting the literature-based expected mean concentrations, due to the lack of sufficient Surface Water Quality Monitoring stations with significant numbers of pollutant measurements in the basin. For future nonpoint source pollution assessments, an equal number of concentration balance equations and land use expected mean concentration variables are recommended, along with a fully documented set of point source loads.

    While the advantages of the GIS nonpoint source pollution assessment method described in this report are plainly evident, there are also a number of limitations with this application of the method that should be addressed for future assessments:

- Since the assessment is performed for average annual conditions, results are given for mean annual flow and average annual cumulative load. These steady state results do not consider variations within years or from year to year. Figure 4.9 shows that recorded streamflows are highly correlated in space throughout the basin. One way to model temporal variations in flow would be to use the Mission River gauge as an index defining temporal flow variations throughout the basin and use the method illustrated through equation 4-2 to infer temporal flows at other locations in the basin. This would provide approximate flow profiles for other locations and would facilitate the performance of event-based nonpoint source analyses.

- The literature-based expected mean concentrations assume constant values associated with each land use and are not considered to vary from event to event or between different land use subcategories. This assumption might be relaxed by considering constituent event mean concentrations (Huber, 1993) instead of expected mean concentrations. By considering a series of runoff events and the measured pollutant event mean concentrations associated with each event, a distribution of event mean concentrations can be established and a representative concentration can

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be determined and applied to all cells upstream of the particular measurement location. These values could then be used in an event-based nonpoint source pollution assessment.

- Transport of pollutants is considered to be conservative throughout this study, i.e. no loss or decay of pollutants is considered. In the future, this limitation may be addressed through use of a water quality simulation model, such as the EUTRO5 module of WASP5, which includes a kinetics option for the modeling of nutrient concentrations.

- For comparison purposes, representative observed pollutant concentrations are established by averaging all observed pollutant concentrations at a particular sampling location. This averaging is done without consideration of flow conditions at the time each measurement. A more detailed study might classify the observed concentrations according to whether the corresponding streamflow is high, intermediate, or low. In this way, more appropriate values for average observed pollutant concentration can be established for an event-based assessment. Additionally, consideration and exclusion of outlying data points might be included as a method to refine the observed pollutant concentration values.

- The rainfall/runoff relationship established in section 4.2 is determined from the streamflow data of just five gauges. The runoff grid shown in Figure 4.12 represents an extrapolation across the basin of the best linear fit for the five data points. As a result, the rainfall/runoff relationship, while applied to the whole basin, is only valid for the precipitation range between 783 and 924 mm/yr. Actual precipitation in the San Antonio-Nueces coastal basin ranges from 739 to 985 mm/yr. By including additional USGS streamflow gauges in watersheds immediately adjacent to the San Antonio-Nueces basin, a rainfall/runoff relationship can be established for a wider range of precipitation values. By ensuring that two of the additional gauges drain areas receiving less than 739 mm/yr and more than 985 mm/yr of rain, respectively, a rainfall/runoff relationship that is valid for the complete basin can be established. This would also resolve the issue of having to redefine the runoff for cells receiving less than 759 mm of rain per year with values of zero.

The GIS nonpoint source pollution assessment method is a useable, reliable, and repeatable means of establishing nonpoint source pollution estimates in a

watershed or geographic region. Consideration of the above limitations for future applications of the method will provide for a more comprehensive analysis. In time, an equivalent vector-based procedure may be developed completely within the Avenue object-oriented programming environment of ArcView so that a stand-alone model may allow for even wider use of the method.

Appendix A :   Data Dictionary

Data	Feature	Class	Attribute	Value	Description	Page #
allyn1	15-minute Allyns' Bight Digital Line Graph map #1 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
allynf01	Original Arc/Info coverage converted from 15-minute Allyns' Bight Digital Line Graph map #1. UTM projection.	Arc	none			(37)
aranarea	Grid of subwatershed delineated from the Aransas River USGS gauge (drainpt1) using the clipfdr flow direction grid.	Grid	none	integer	63,291 cells	70
arancov	Equivalent polygon coverage of the aranarea grid. Created using gridpoly	Polygon	none			70
aranlu	Land Use coverage specific to the subwatershed delineated from the Aransas River TNRCC SWQM gauge. Created by clipping the sanlu coverage with the araptcov coverage.	Polygon	lusecat	same as lusecat for sanlu coverage.		126
aranpt	Single cell grid identifying the location of the TNRCC SWQM station # 12948 on the Aransas River. All other cells have values of NODATA.	Grid	none			126
aranrain	Precipitation grid specific to the subwatershed delineated from the Aransas River USGS gauge.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 761 - 860 mm/year.	81

* All arc, polygon, and point coverages and all grids are projected in TSMS-Albers coordinates unless otherwise
    specified.

**   The Page # field lists the location within the document where the data layer is first referenced. Page #'s in
     parentheses ( ) indicate that the data are not explicitly called out on the page, but that the process described on
     the page has been performed in the creation of the data layer.

Data	Feature	Class	Attribute	Value	Description	Page #
araptcov	Equivalent polygon coverage of the arptarea grid. Created using the gridpoly command.	Polygon	none			126
arlugrid	Equivalent 100-meter cellsize grid of the aranlu coverage. Created using polygrid with the lusecat attribute specified for grid-cell values.	Grid	land use	varies	between the lusecat 12 values specifed for the sanluse coverage.	126
arptarea	Grid of subwatershed delineated from the Aransas River TNRCC SWQM station (aranpt) using the clipfdr flow direction grid.	Grid	none			126
arrunoff	Grid of cumulative runoff from each land use specified in the arlugrid grid. Created using the zonalsum command, summing values from the runoff grid based on zonal regions specified in arlugrid.	Grid	runoff volume	varies	Cumulative runoff values in each grid-cell are in units of cubic meters / year. 6730 - 41,141,650 cub. meters/yr.	126
attrib.dat	Arc/Info file of expected mean concentration data. Created from the emc3a.dat text file. Used to assign EMC attributes to the land use coverage, sanlu.	INFO	lusecat	same as lusecat for sanluse coverage		93
			tn	0 - 4.4	(mg/L) total nitrogen emc	
			tkn	0 - 1.7	(mg/L) total kjeldahl nitrogen emc	
			nn	0 - 1.6	(mg/L) nitrate + nitrite emc	
			tp	0 - 1.3	(mg/L) total phosphorus emc	
			dp	0 - 0.48	(mg/L) dissolved phosphorus emc	
			ss	0 - 107	(mg/L) total suspended solids emc	
			ds	0 - 1225	(mg/L) total dissolved solids emc	
			pb	0 - 15	(ug/L) total lead emc	
			cu	0 - 15	(ug/L) total copper emc	
			zn	0 - 245	(ug/L) total zinc emc	
			cd	0 - 1.05	(ug/L) total cadmium emc	
			cr	0 - 10	(ug/L) total chromium emc	
			ni	0 - 11.8	(ug/L) total nickel emc	
			bod	0 - 25.5	(mg/L) biological oxygen demand emc	
			cod	0 - 116	(mg/L) chemical oxygen demand emc	
			o&g	0 - 9	(mg/L) oil & grease emc	

Data	Feature	Class	Attribute	Value	Description	Page #
			fcol	0 - 53,000	(col/100 mL) fecal coliform emc	
			fstr	0 - 56,000	(col/100 mL) fecal streptococci emc	
attribut.dat	Arc/Info table, built from a text file, including USGS gauge station-id number and name. Used to add attributes to the stations coverage.	INFO	stations-id	integer	1-5	48
			stat-num	08189200 08189300 08189500 08189700 08189800	USGS stream gauge station identification number.	
			stat-nam	Copano Medio Mission Aransas Chiltipin	Stream or Creek that gauge is located on.	
balugrid	Equivalent 100-meter cellsize grid of the bayptlu coverage. Created using polygrid with the lusecat attribute specified for grid-cell values.	Grid	land use	varies	between the lusecat 12 values specifed for the sanluse coverage.	(126)
barriers	Polygon coverage of the barrier islands included in the final digital line graph hydrography coverage. Converted from ArcView shapefile and sanpolys coverage.	Polygon	none			67
barunoff	Grid of cumulative runoff from each land use specified in the balugrid grid. Created using the zonalsum command, summing values from the runoff grid based on zonal regions specified in balugrid.	Grid	runoff volume	varies	Cumulative runoff values in each grid-cell are in units of cubic meters / year. 35,530 - 106,393,580 cub. meters/yr.	(126)
basin	Appended coverage of the covsheds, covtrim, baybuff, and barriers coverages.	Polygon	none			76
bayarea	Grid of subwatershed delineated from the Copano Bay SWQM station # 12945 (baypt) using the clipfdr flow direction grid.	Grid	none			(126)

Data	Feature	Class	Attribute	Value	Description	Page #
baybuff	One cell (100 meter) buffer around the bays coverage. Used to eliminate shorelines from the final stream hydrography coverage.	Polygon	inside	0 1	outside of buffer boundary insider buffer boundary	67
baycov	Combined (unioned) polygon coverage of the sqcov and baybuff coverage. Used to trim out subsequent coverages local to the bay network.	Polygon	none			67
bayfil	A redefined version of the ditfil DEM with zero values for elevation replacing the NODATA values occuring in the bay network. Required to avoid errors in subsequent flow direction computations.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	69
baygrid	Equivalent 100 meter cell size grid of the baycov coverage. Used to isolate other grid features specific to the bay network.	Grid	none			67
baypt	Single cell grid identifying the location of the TNRCC SWQM station # 12945 in the Copano Bay. All other cells have values of NODATA.	Grid	none			(126)
bayptcov	Equivalent polygon coverage of the bayarea grid. Created using the gridpoly command.	Polygon	none			(126)
bayptlu	Land Use coverage specific to the subwatershed delineated from the Copano Bay SWQM gauge # 12945. Created by clipping the sanlu coverage with the bayptcov coverage.	Polygon	lusecat		same as lusecat for sanlu coverage.	(126)
bays	Polygon coverage of the ICWW bay network included in the final digital line graph hydrography coverage. Converted from ArcView shapefile and sanpolys coverage.	Polygon	none			67

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Data	Feature	Class	Attribute	Value	Description	Page #
bcdem	Merged grid of the the 4 Beeville and Corpus Christi Digital Elevation Model mapsheets. Geographic coordinates	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41
bcdemalb	Reprojected version of the merged Digital Elevation Model .	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41
bee1	15-minute Beeville Digital Line Graph map #1 w/ meridians and parallels removed. UTM projection.	Arc	none			37
bee2	15-minute Beeville Digital Line Graph map #2 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
bee3	15-minute Beeville Digital Line Graph map #3 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
bee4	15-minute Beeville Digital Line Graph map #4 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
bee5	15-minute Beeville Digital Line Graph map #5 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
bee6	15-minute Beeville Digital Line Graph map #6 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
bee7	15-minute Beeville Digital Line Graph map #7 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
bee8	15-minute Beeville Digital Line Graph map #8 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
beedeme	Initial grid created from Beeville East 3" Digital Elevation Model mapsheet. Projected in Geographic coordinates.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41

Data	Feature	Class	Attribute	Value	Description	Page #
beedemw	Initial grid created from Beeville West 3" Digital Elevation Model mapsheet. Projected in Geographic coordinates.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41
beef01	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph map #1. UTM projection.	Arc	none			37
beef02	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #2. UTM projection.	Arc	none			(37)
beef03	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #3. UTM projection.	Arc	none			(37)
beef04	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #4. UTM projection.	Arc	none			(37)
beef05	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #5. UTM projection.	Arc	none			(37)
beef06	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #6. UTM projection.	Arc	none			(37)
beef07	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #7. UTM projection.	Arc	none			(37)
beef08	Original Arc/Info coverage converted from 15-minute Beeville Digital Line Graph. map #8. UTM projection.	Arc	none			(37)
beeload	Point source phosphorus load grid for the Beeville point source identified in the beepoint grid. All other cells have values of zero.	Grid	Load	32,694	Annual Point source phosphorus load at the Beeville location in units of kg/year.	120

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Data	Feature	Class	Attribute	Value	Description	Page #
beelu	Cleaned version of the original Beeville land use coverage. Standard Albers projection.	Polygon	none			44
beenit	Point source nitrogen load grid for the Beeville point source identified in the beepoint grid. All other cells have values of zero.	Grid	Load	71,498	Annual Point source nitrogen load at the Beeville location in units of kg/year.	(120)
beepoint	Single cell grid identifying the presumed location of a Beeville point source along the Aransas River. All other cells have values of NODATA.	Grid	none			120
beernof	Cell-based phosphorus loading grid created by adding the nonpoint source loading grid (phosrnof) and the Beeville point source loading grid (beeload).	Grid	Load	varies	Cell-based load values in each grid cell are in units of mg-mm/L-year. 0 - 3,269,400 mg-mm/L-yr.	121
bord	Border of the digitally delineated San Antonio-Nueces Basin, created from an ArcView shapefile by selecting only those sanbasin polygons corresponding to the basin, i.e. exluding the trimshed polygons.	Arc	none			79
border	Cleaned version of the bord coverage.	Polygon	none			79
bordgrid	Equivalent 100 meter cellsize grid of the sanbord coverage. Created using polygrid.	Grid	none			81
cadconc	Grid of predicted cadmium concentrations due to nonpoint sources. Created by dividing the cumulative cadmium load grid (cadload) by the annual cumulative runoff grid (runoffac).	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of micrograms/Liter. 0 - 2.0 ug/L	(102)
cadgrid	Initial 100-meter cellsize grid of total cadmium EMC values. Created by converting the sanlu coverage (with the cd attribute specified) to a grid using polygrid.	Grid	Cd EMC (ug/L)	0 0.75 0.96 2	Barren/Water/Wetland EMC Urban Residential EMC Urban Commercial EMC Urban Industrial EMC	(95)

Data	Feature	Class	Attribute	Value	Description	Page #
				0.5	Urban Transportation EMC	
				1.05	Mixed/Other Urban EMC	
				1	Agriculture EMC	
				0.5	Range/Forest Land EMC	
cadld	Cummulative annual cadmium load grid created by performing a weighted flow accumulation on the mainfdr grid, using the cadrunof grid as the weight grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of g/year. 0 - 173,535.844 g/yr	(96)
cadline	Equivalent line coverage of the cadload grid. In-stream loads isolated through selection of a load threshold value = 1000 grams. Grid-code integer load values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Cumulative load values along each stream are in units of grams per year. 1000 - 173,535 g/yr	(97)
cadload	Equivalent integer grid of the cadld grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of grams/year. 0 - 173,535 g/yr	(97)
cadpts	Polygon coverage of circles associated with each total cadmium TNRCC SWQM location. Radius of each circle is defined as a function of the square root of the number of cd measurements at the location. Created using the generate command with the cadrad.dat data file.	Polygon	Radius	varies	in increments of 400 between 0 and 800 meters.	(113)
cadrad.dat	Arc/Info data file created from the sanwq point attribute table by defining a sanwq Radius field as a function of the cd_cnt field, and then using the ArcView File Export feature to create a text-delimited data file.	INFO	sanwq-id X-coord Y-coord Radius	varies varies varies varies	5-digit water quality station number TSMS Albers x-coordinate of station TSMS Albers y-coordinate of station in increments of 400 between 0 and 800 meters.	(113)

Data	Feature	Class	Attribute	Value	Description	Page #
cadrunof	Cell-based total cadmium loading grid created by taking the product of the runoff and cadgrid grids.	Grid	Load	varies	Cell-based load values in each grid cell are in units of ug-mm/L-year. 0 - 392.97 ug-mm/L-yr.	(95)
cc2	15-minute Corpus Christi Digital Line Graph map #2 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
cc3	15-minute Corpus Christi Digital Line Graph map #3 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
cc4	15-minute Corpus Christi Digital Line Graph map #4 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
ccf02	Original Arc/Info coverage converted from 15-minute Corpus Christi Digital Line Graph map #2. UTM projection.	Arc	none			(37)
ccf03	Original Arc/Info coverage converted from 15-minute Corpus Christi Digital Line Graph map #3. UTM projection.	Arc	none			(37)
ccf04	Original Arc/Info coverage converted from 15-minute Corpus Christi Digital Line Graph map #4. UTM projection.	Arc	none			(37)
cclu	Cleaned version of the original Corpus Christi land use coverage. Standard Albers projection.	Polygon	none			(44)
cd.dat	Arc/Info data file of total cadmium water quality measurements. Created from cd.dbf using the dbaseinfo command.	INFO	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 4 (# of measurements) between 1 - 5 ug/L	(104)
cd.dbf	Database file of total cadmium water quality measurements. Created from the TNRCC SWQM database using ArcView Summary Statistics tools.	DBF	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 4 (# of measurements) between 1 - 5 ug/L	(104)

Data	Feature	Class	Attribute	Value	Description	Page #
cdcon	Final nonpoint cadmium concentration coverage. Created by clipping the cdline arc coverage with the mainland template.	Arc	grid-code	varies	Concentration values along each stream are in units of ug/L x 1000. 0 - 1770	(102)
cdconstr	Grid of predicted nonpoint cadmium concentrations occuring in the stream network of the basin. Created using the Con statement with the introfac and cadconc grids.	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of micrograms/Liter. 0 - 1.77 ug/L	(102)
cdline	Equivalent line coverage of the cdconstr grid. Concentrations multiplied by 1000 to retain significant figures. Grid-code integer concentration values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Concentration values along each stream are in units of ug/L x 1000. 0 - 1770	(102)
cdload	Final total cadmium cumulative load coverage. Created by clipping the cadline arc coverage with the mainland template.	Arc	grid-code	varies	Cumulative load values along each stream are in units of grams per year. 1000 - 173,535 g/yr	(97)
cdpts	Cleaned version of the cadpts coverage. Joined with data from the cd.dat data file.	Polygon	Radius	varies	in increments of 400 between 0 and 800 meters.	(113)
			station-id	varies	5-digit water quality station number	
			count	varies	between 0 - 4 (# of measurements)	
			ave-value	varies	between 0 - 5 ug/L	
chilarea	Grid of subwatershed delineated from the Chiltipin Creek USGS gauge (drainpt5) using the clipfdr flow direction grid.	Grid	none	integer	32,233 cells	(70)
chilcov	Equivalent polygon coverage of the chilarea grid. Created using the gridpoly command.	Polygon	none			(70)
chilrain	Precipitation grid specific to the subwatershed delineated from the Chiltipin Creek USGS gauge.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 811 - 877 mm/year.	(81)

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Data	Feature	Class	Attribute	Value	Description	Page #
clipfdr	Flow direction grid with ditfdr values assigned to mainland cells and NODATA values assigned to bays and islands.	Grid	direction		same as for the sanfdr grid.	69
colugrid	Equivalent 100-meter cellsize grid of the copalu coverage. Created using polygrid with the lusecat attribute specified for grid-cell values.	Grid	land use	varies	between the lusecat 12 values specifed for the sanluse coverage.	(126)
copacov	Equivalent polygon coverage of the coparea grid. Created using the gridpoly command.	Polygon	none			(70)
copalu	Land Use coverage specific to the subwatershed delineated from the Copano Creek SWQM gauge # 13660 (USGS flow gauge). Created by clipping the sanlu coverage with copacov.	Polygon	lusecat		same as lusecat for sanlu coverage.	(126)
coparain	Precipitation grid specific to the subwatershed delineated from the Copano Creek USGS gauge.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 893 - 938 mm/year.	(81)
coparea	Grid of subwatershed delineated from the Copano Creek USGS gauge (drainpt3) using the clipfdr flow direction grid.	Grid	none	integer	20,782 cells	(70)
corpdeme	Initial grid created from Corpus Christi East 3" Digital Elevation Model mapsheet. Projected in Geographic coordinates.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41
corpdemw	Initial grid created from Corpus Christi West 3" Digital Elevation Model mapsheet. Projected in Geographic coordinates.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41
corunoff	Grid of cumulative runoff from each land use specified in the colugrid grid. Created using the zonalsum command, summing values from the runoff grid based on zonal regions specified in colugrid.	Grid	runoff volume	varies	Cumulative runoff values in each grid-cell are in units of cubic meters / year. 196,200 - 21,440,430 cub. meters/yr.	(126)

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Data	Feature	Class	Attribute	Value	Description	Page #
covsheds	Cleaned version of the subsheds coverage.	Polygon	none			76
covstr	Equivalent line coverage of the str1 grid. Created using the Gridline command.	Arc	none			63
covstr1	Equivalent line coverage of the ditstr1 grid. Created using the Gridline command.	Arc	none			70
covtrim	Cleaned version of the trimshed coverage.	Polygon	none			76
ditacc8	Grid of accumulation zones in the region. Created using the zonlamax command with the ditfac and ditlnk8 grids. Assigns the values of each ditlnk8 reach to all cells in the associated accumulation zones.	Grid	zone #	same as for the ditlnk8 grid		75
ditfac	Flow accumulation grid created from the clipfdr flow direction grid.	Grid	accumu-lation	varies	integer number of cells that fall upstream of each cell.	69
ditfdr	Flow direction grid built from the "burned in" bayfil DEM.	Grid	direction	same as for the sanfdr grid.		69
ditfil	Processed Digital Elevation Model with all "pits" of the ditstrm DEM filled to the level of the lowest elevation neighboring cell.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	69
ditlnk8	Grid of stream reaches in the San Antonio-Nueces basin region, created using the streamlink command with the clipfdr and ditstr8 grids.	Grid	reach #	varies		75
ditout8	Grid of outlet cells for each accumulation zone in the region. Created using the Con statement with the ditacc8, ditlnk8, and ditfac grids.	Grid	outlet cell #	same as for the ditlnk8 grid		75

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Data	Feature	Class	Attribute	Value	Description	Page #
ditshd8	Grid of subwatersheds in the San Antonio-Nueces region. Based on the selection of 8000 cells for the ditstr8 grid, each of these subwatersheds are at least 80 sq km in area. Created using the watershed command with the clipfdr and ditout8 grids.	Grid	water-shed #	same as for the ditlnk8 grid		75
ditstr1	Grid of flow accumulation cells with value greater than a threshold of 1000. Results in strings of cells that represent the larger streams in the basin.	Grid	accumu-lation	varies	from 1000 to the maximum value of the ditfac grid	70
ditstr8	Grid of flow accumulation cells with value greater than a threshold of 8000. Results in strings of cells that represent the largest streams in the basin.	Grid	accumu-lation	varies	from 8000 to the maximum value of the ditfac grid	75
ditstrm	"Burned-In" Digital Elevation Model created by artificially raising the elevations of all off-stream cells in the strmgrid grid by 5 meters and specifying in-stream grid cells with a zero elevation value.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	69
drainpt1	Single cell grid identifying the location of the USGS Aransas River stream gauge. All other cells have values of NODATA.	Grid	none			70
drainpt2	Single cell grid identifying the location of the USGS Mission River stream gauge. All other cells have values of NODATA.	Grid	none			(70)
drainpt3	Single cell grid identifying the location of the USGS Copano Creek stream gauge. All other cells have values of NODATA.	Grid	none			(70)
drainpt4	Single cell grid identifying the location of the USGS Medio Creek stream gauge. All other cells have values of NODATA.	Grid	none			(70)

Data	Feature	Class	Attribute	Value	Description	Page #
drainpt5	Single cell grid identifying the location of the USGS Chiltipin Creek stream gauge. All other cells have values of NODATA.	Grid	none			(70)
fec_col.dat	Arc/Info data file of fecal coliform water quality measurements. Created from fec_col.dbf using the dbaseinfo command.	INFO	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 17 (# of measurements) between 0 - 462 colonies / 100 mL	(104)
fec_col.dbf	Database file of fecal coliform water quality measurements. Created from the TNRCC SWQM database using ArcView Summary Statistics tools.	DBF	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 17 (# of measurements) between 0 - 462 colonies / 100 mL	(104)
fecalpts	Polygon coverage of circles associated with each fecal coliform TNRCC SWQM location. Radius of each circle is defined as a function of the square root of the number of fec_col measurements at the location. Created using the generate command with the fecrad.dat data file.	Polygon	Radius	varies	in increments of 300 between 0 and 1200 meters.	(113)
feccon	Final nonpoint fecal coliform concentration coverage. Created by clipping the feclin arc coverage with the mainland template.	Arc	grid-code	varies	Concentration values along each stream are in units of colonies per 100 mL. 0 - 8996 colonies / 100 mL	(102)
fecconc	Grid of predicted fecal coliform concentrations due to nonpoint sources. Created by dividing the cumulative fecal coliform load grid (feclload) by the annual cumulative runoff grid (runoffac).	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of colonies per 100 mL. 0 - 8996 colonies/100 mL	(102)
fecld	Cummulative annual fecal coliform load grid created by performing a weighted flow accumulation on the mainfdr grid, using the feclrnof grid as the weight grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of trillion colonies/year. 0 - 1469.786 trillion colonies/year	(96)
feclgrid	Initial 100-meter cellsize grid of fecal coliform EMC values. Created by	Grid	Fecal Coliform	0 20,000	Agricul/Barren/Water/Wetland EMC Urban Residential EMC	(95)

Data	Feature	Class	Attribute	Value	Description	Page #
	converting the sanlu coverage (with the fcol attribute specified) to a grid using polygrid.		EMC (colonies /100 mL)	6,900 9,700 53,000 22,400 200	Urban Commercial EMC Urban Industrial EMC Urban Transportation EMC Mixed/Other Urban EMC Range/Forest Land EMC	
feclin	Equivalent line coverage of the feconstr grid. Grid-code integer concentration values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Concentration values along each stream are in units of colonies per 100 mL. 0 - 8996 colonies/100 mL	(102)
fecline	Equivalent line coverage of the feclload grid. In-stream loads isolated through selection of a load threshold value = 100 trillion colonies. Grid-code integer load values retained in the line coverage thru use of the streamline command.	Arc	grid-code	varies	Cumulative load values along each stream are in units of trillion colonies per year. 100 - 1469 trillion colonies/yr.	(97)
feclload	Equivalent integer grid of the fecld grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of trillion colonies/year. 0 - 1469 trillion colonies/yr	(97)
fecload	Final fecal coliform cumulative load coverage. Created by clipping the fecline arc coverage with the mainland template.	Arc	grid-code	varies	Cumulative load values along each stream are in units of trillion colonies per year. 100 - 1469 trillion colonies/yr.	(97)
feclrnof	Cell-based fecal coliform loading grid created by taking the product of the runoff and feclgrid grids.	Grid	Load	varies	Cell-based load values in each grid cell are in units of col-mm/100 mL-year. 0 - 10,413,663 colony-mm/100 mL-yr.	(95)
feconstr	Grid of predicted nonpoint fecal coliform concentrations occuring in the stream network of the basin. Created using the Con statement with the introfac and fecconc grids.	Grid	Concen- tration	varies	Concentration values in each grid-cell are in units of colonies per 100 mL. 0 - 8996 colonies/100 mL	(102)
fecpts	Cleaned version of the fecalpts coverage. Joined with data from the fec_col.dat data	Polygon	Radius	varies	in increments of 300 between 0 and 1200 meters.	(113)

Data	Feature	Class	Attribute	Value	Description	Page #
	file.		station-id	varies	5-digit water quality station number	
			count	varies	between 0 - 17 (# of measurements)	
			ave-value	varies	between 0 - 462 colonies / 100 mL	
fecrad.dat	Arc/Info data file created from the sanwq point attribute table by defining a sanwq Radius field as a function of the fec_cnt field, and then using the ArcView File Export feature to create a text-delimited data file.	INFO	sanwq-id X-coord Y-coord Radius	varies varies varies varies	5-digit water quality station number TSMS Albers x-coordinate of station TSMS Albers y-coordinate of station in increments of 300 between 0 and 1200 meters.	(113)
geobuff	Equivalent of hucbuff coverage reprojected to Geographic coordinates.	Polygon	inside	0 1	outside of buffer boundary insider buffer boundary	53
goli5	15-minute Goliad Digital Line Graph map #5 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
goli6	15-minute Goliad Digital Line Graph map #6 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
goli7	15-minute Goliad Digital Line Graph map #7 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
goli8	15-minute Goliad Digital Line Graph map #8 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
golif05	Original Arc/Info coverage converted from 15-minute Goliad Digital Line Graph map #5. UTM projection.	Arc	none			(37)
golif06	Original Arc/Info coverage converted from 15-minute Goliad Digital Line Graph map #6. UTM projection.	Arc	none			(37)
golif07	Original Arc/Info coverage converted from 15-minute Goliad Digital Line Graph map #7. UTM projection.	Arc	none			(37)

Data	Feature	Class	Attribute	Value	Description	Page #
golif08	Original Arc/Info coverage converted from 15-minute Goliad Digital Line Graph map #8. UTM projection.	Arc	none			(37)
huc250	Original 1:250,000-scale HUC coverage of the U.S. imported from a .e00 file. Standard Albers projection.	Polygon	huc	varies	8-digit Hydrologic Unit Code identifies water resources region, subregion, accounting unit, and cataloging unit.	32
hucbuff	5 kilometer buffer around the sanhucs coverage. Used as a coarse template to clip other coverages or trim grids.	Polygon	inside	0 1	outside of buffer boundary insider buffer boundary	41
hucs	Intermediate coverage of the 5 HUCs representing the San Antonio-Nueces Basin. Standard Albers projection.	Polygon	huc	12100404 12100405 12100406 12100407 12110201	West San Antonio Bay HUC Aransas Bay HUC Mission HUC Aransas HUC North Corpus Christi Bay HUC	32
hucsan	Intermediate reprojected coverage of the 5 San Antonio-Nueces HUCs	Polygon	huc	same as huc for the hucs coverage		32
introfac	Equivalent integer grid of cumulative runoff in units of cubic feet per second.	Grid	Runoff Flow	varies	Cumulative runoff values in each grid-cell are in units of cubic feet/second. 0 - 324 cfs	100
landuse	Appended land use map of the Beeville and Corpus Christi mapsheets. Anderson Land Use Classification is used to distinguish between land use types. Standard Albers projection.	Polygon	landuse-id	0 11 12 13 14 15 16 17 21 22 23 31 32	Unknown Residential Commercial Services Industrial Transportation, Comunications Industrial and Commercial Mixed Urban or Built-Up Land Other Urban or Built-Up Land Cropland and Pasture Orchards, Groves, Vineyards, Nursery Confined Feeding Operations Herbaceous Rangeland Shrub and Brush Rangeland	44

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Data	Feature	Class	Attribute	Value	Description	Page #
				33	Mixed Rangeland	
				41	Deciduous Forest Land	
				42	Evergreen Forest Land	
				43	MIxed Forest Land	
				51	Streams and Canals	
				52	Lakes	
				53	Reservoirs	
				54	Bays and Estuaries	
				61	Forested Wetlands	
				62	Nonforested Wetlands	
				71	Dry Salt Flats	
				72	Beaches	
				73	Sandy Areas Other Than Beaches	
				74	Bare Exposed Rock	
				75	Strip Mines, Quarries, Gravel Pits	
				76	Transitional Areas	
				77	Mixed Barren Land	
				200000	Unknown	
lanuse	Reprojected version of the appended land use coverage. Includes the full Beeville and Corpus Christi mapsheets.	Polygon	lanuse-id		same as landuse-id for landuse coverage	44
lbe28096	Initial land use coverage of the Beeville 1:250,000-scale mapsheet imported from uncompressed .e00 file. Standard Albers projection.	Polygon	none			44
lco27096	Initial land use coverage of the Corpus Christi 1:250,000-scale mapsheet imported from uncompressed .e00 file. Standard Albers projection.	Polygon	none			(44)
lonlat.dat	Raw data file of longitude and latitude data, in decimal degrees, used to build the stations coverage.	Text	longitude latitude	varies varies	between -97.1122 and -97.6564 betweeen 28.0467 and 28.4828	47

Data	Feature	Class	Attribute	Value	Description	Page #
luse	Dissolved (no boundary lines) land use coverage with Anderson classification.	Polygon	luse-id	same as landuse-id for landuse coverage		44
m2lugrid	Equivalent 100-meter cellsize grid of the mis2lu coverage. Created using polygrid with the lusecat attribute specified for grid-cell values.	Grid	land use	varies	between the lusecat 12 values specifed for the sanluse coverage.	(126)
m2runoff	Grid of cumulative runoff from each land use specified in the m2lugrid grid. Created using the zonalsum command, summing values from the runoff grid based on zonal regions specified in m2lugrid.	Grid	runoff volume	varies	Cumulative runoff values in each grid-cell are in units of cubic meters / year. 31,260 - 109,195,880 cub. meters/yr.	(126)
main	Polygon coverage of the mainland basin region buffered by one cell width (100 meters). Created by buffering the coverage called mainland	Polygon	none			96
mainfdr	Flow direction grid created by storing ditfdr values into the cells of the maingrid grid and storing values of NODATA elsewhere. This grid was created in order to correct for an anomaly with the use of the streamline command, so that arc coverages converted from string grids would extend for the full intended length.	Grid	direction	same as for the sanfdr grid.		96
maingrid	Equivalent 100-meter cellsize grid of the main coverage, created using the polygrid command.	Grid	none			96
mainland	Polygon coverage of the mainland basin region reselected from the baycov coverage.	Polygon	none			96
mediarea	Grid of subwatershed delineated from the Medio Creek USGS gauge (drainpt4) using the clipfdr flow direction grid.	Grid	none	integer	52,708 cells	(70)

Data	Feature	Class	Attribute	Value	Description	Page #
medicov	Equivalent polygon coverage of the mediarea grid. Created using the gridpoly command.	Polygon	none			(70)
medirain	Precipitation grid specific to the subwatershed delineated from the Medio Creek USGS gauge.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 739 - 826 mm/year.	(81)
mi2ptcov	Equivalent polygon coverage of the mis2area grid. Created using the gridpoly command.	Polygon	none			(126)
milugrid	Equivalent 100-meter cellsize grid of the misslu coverage. Created using polygrid with the lusecat attribute specified for grid-cell values.	Grid	land use	varies	between the lusecat 12 values specifed for the sanluse coverage.	(126)
mirunoff	Grid of cumulative runoff from each land use specified in the milugrid grid. Created using the zonalsum command, summing values from the runoff grid based on zonal regions specified in milugrid.	Grid	runoff volume	varies	Cumulative runoff values in each grid-cell are in units of cubic meters / year. 19,330 - 93,565,590 cub. meters/yr.	(126)
mis2area	Grid of subwatershed delineated from the Mission River SWQM station # 12943 (mis2pt) using the clipfdr flow direction grid.	Grid	none			(126)
mis2lu	Land Use coverage specific to the subwatershed delineated from the Mission River SWQM gauge # 12943. Created by clipping the sanlu coverage with the mi2ptcov coverage.	Polygon	lusecat	same as lusecat for sanlu coverage.		(126)
mis2pt	Single cell grid identifying the location of the TNRCC SWQM station # 12943 on the Mission River. All other cells have values of NODATA.	Grid	none			(126)

Data	Feature	Class	Attribute	Value	Description	Page #
missarea	Grid of subwatershed delineated from the Mission Creek USGS gauge (drainpt2) using the clipfdr flow direction grid.	Grid	none	integer	176,619 cells	(70)
misscov	Equivalent polygon coverage of the missarea grid. Created using gridpoly.	Polygon	none			(70)
misslu	Land Use coverage specific to the subwatershed delineated from the Mission River SWQM gauge # 12944 (USGS flow gauge). Created by clipping the sanlu coverage with misscov.	Polygon	lusecat	same as lusecat for sanlu coverage.		(126)
missrain	Precipitation grid specific to the subwatershed delineated from the Mission River USGS gauge.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 739 - 945 mm/year.	(81)
niconstr	Grid of predicted nonpoint nitrogen concentrations occuring in the stream network of the basin. Created using the Con statement with the introfac and nitconc grids.	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 4.4 mg/L	(102)
nitconc	Grid of predicted nitrogen concentrations due to nonpoint sources. Created by dividing the cumulative nitrogen load grid (nitload) by the annual cumulative runoff grid (runoffac).	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 4.4 mg/L	(102)
nitgrid	Initial 100-meter cellsize grid of total nitrogen EMC values. Created by converting the sanlu coverage (with the tn attribute specified) to a grid using polygrid.	Grid	Nitrogen EMC (mg/L)	0 1.82 1.34 1.26 1.86 1.57 4.4 0.7 1.5	Water/Wetland EMC Urban Residential EMC Urban Commercial EMC Urban Industrial EMC Urban Transportation EMC Mixed/Other Urban EMC Agriculture EMC Range/Forest Land EMC Barren Lands EMC	(95)

Data	Feature	Class	Attribute	Value	Description	Page #
nitld	Cummulative annual nitrogen load grid created by performing a weighted flow accumulation on the mainfdr grid, using the nitrunof grid as the weight grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of kg/year. 369,122.406 kg/yr	(96)
nitline	Equivalent line coverage of the nitload grid. In-stream loads isolated through selection of a load threshold value = 1000 kg. Grid-code integer load values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Cumulative load values along each stream are in units of kg/year. 1000 - 369,122 kg/yr	(97)
nitload	Equivalent integer grid of the nitld grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of kg/year. 0 - 369,122 kg/yr	(97)
nitpts	Cleaned version of the nitropts coverage. Joined with data from the sanwq.pat data file.	Polygon	Radius station-id tn_cnt tn_avg	varies	in increments of 200 between 0 and 1000 meters. same as for sanwq coverage same as for sanwq coverage same as for sanwq coverage	(113)
nitrad.dat	Arc/Info data file created from the sanwq point attribute table by defining a sanwq Radius field as a function of the tn_cnt field, and then using the ArcView File Export feature to create a text-delimited data file.	INFO	sanwq-id X-coord Y-coord Radius	varies varies varies varies	5-digit water quality station number TSMS Albers x-coordinate of station TSMS Albers y-coordinate of station in increments of 200 between 0 and 1000 meters.	(113)
nitropts	Polygon coverage of circles associated with each total nitrogen TNRCC SWQM location. Radius of each circle is defined as a function of the square root of the number of measurements at the location. Created using the generate command with the nitrad.dat data file.	Polygon	Radius	varies	in increments of 200 between 0 and 1000 meters.	(113)

Data	Feature	Class	Attribute	Value	Description	Page #
nitrunof	Cell-based total nitrogen loading grid created by taking the product of the runoff and nitgrid grids.	Grid	Load	varies	Cell-based load values in each grid cell are in units of mg-mm/L-year. 0 - 1031.3 mg-mm/L-yr.	(95)
no2.dat	Arc/Info data file of nitrite nitrogen water quality measurements. Created from no2.dbf using the dbaseinfo command.	INFO	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 19 (# of measurements) between 0 - 0.92 mg/L	(104)
no2.dbf	Database file of nitrite nitrogen water quality measurements. Created from the TNRCC SWQM database using ArcView Summary Statistics tools.	DBF	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 19 (# of measurements) between 0 - 0.92 mg/L	(104)
no3.dat	Arc/Info data file of nitrate nitrogen water quality measurements. Created from no3.dbf using the dbaseinfo command.	INFO	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 39 (# of measurements) between 0 - 6.57 mg/L	(104)
no3.dbf	Database file of nitrate nitrogen water quality measurements. Created from the TNRCC SWQM database using ArcView Summary Statistics tools.	DBF	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 39 (# of measurements) between 0 - 6.57 mg/L	(104)
p_ann	Original grid of annual precipitation for the U.S. Converted from the ASCII file prism_us.ann. Geographic coordinates.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year.	52
p_ann2	Precipitation grid for the San Antonio-Nueces basin region. Mapextent reduced from p_ann. Geographic coordinates.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 733 - 1010 mm/year.	53
phcon	Final nonpoint phosphorus concentration coverage. Created by clipping the phline arc coverage with the mainland template.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 1299	102
phconstr	Grid of predicted nonpoint phosphorus concentrations occuring in the stream network of the basin. Created using the Con statement with the introfac and phosconc grids.	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 1.3 mg/L	102

Data	Feature	Class	Attribute	Value	Description	Page #
phline	Equivalent line coverage of the phconstr grid. Concentrations multiplied by 1000 to retain significant figures. Grid-code integer concentration values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 1299	102
phopts	Cleaned version of the phospts coverage. Joined with data from the tp.dat data file.	Polygon	Radius	varies	in increments of 200 between 0 and 1600 meters.	113
			station-id	varies	5-digit water quality station number	
			count	varies	between 0 - 75 (# of measurements)	
			ave-value	varies	between 0 - 7.36 mg/L	
phosconc	Grid of predicted phosphorus concentrations due to nonpoint sources. Created by dividing the cumulative phosphorus load grid (phosload) by the annual cumulative runoff grid (runoffac).	Grid	Concen-tration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 1.3 mg/L	102
phosgrid	Initial 100-meter cellsize grid of total phosphorus EMC values. Created by converting the sanlu coverage (with the tp attribute specified) to a grid using polygrid.	Grid	Phos EMC (mg/L)	0 0.57 0.32 0.28 0.22 0.35 1.3 0.12	Range/Forest/Water/Wetland EMC Urban Residential EMC Urban Commercial EMC Urban Industrial EMC Urban Transportation EMC Mixed/Other Urban EMC Agriculture EMC Barren Lands EMC	95
phosld	Cummulative annual phosphorus load grid created by performing a weighted flow accumulation on the mainfdr grid, using the phosrnof grid as the weight grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of kg/year. 0 - 60,926.4 kg/yr	96
phosload	Equivalent integer grid of the phosld grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of kg/year. 0 - 60,926 kg/yr	97

Data	Feature	Class	Attribute	Value	Description	Page #
phospts	Polygon coverage of circles associated with each total phosphorus TNRCC SWQM location. Radius of each circle is defined as a function of the square root of the number of measurements at the location. Created using the generate command with the rad.dat data file.	Polygon	Radius	varies	in increments of 200 between 0 and 1600 meters.	113
phosrnof	Cell-based total phosphorus loading grid created by taking the product of the runoff and phosgrid grids.	Grid	Load	varies	Cell-based load values in each grid cell are in units of mg-mm/L-year. 0 - 304.7 mg-mm/L-yr.	95
rad.dat	Arc/Info data file created from the sanwq point attribute table by defining a sanwq Radius field as a function of the tp_cnt field, and then using the ArcView File Export feature to create a text-delimited data file.	INFO	sanwq-id X-coord Y-coord Radius	varies varies varies varies	5-digit water quality station number TSMS Albers x-coordinate of station TSMS Albers y-coordinate of station in increments of 200 between 0 and 1600 meters.	113
rainbfcv	Equivalent coverage of the rainbuff grid. Converted using the Gridpoly command.	Polygon	grid-code	varies	Precipitation values in each polygon are in units of millimeters/year. 733 - 1010 mm/year.	53
rainbuff	Final reprojected precipitaton grid. Converted from the p_ann2 grid.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 733 - 1010 mm/year.	53
rofaccfs	Equivalent runoff grid in units of cubic feet per second. Converted from the runoffac grid.	Grid	Runoff Flow	varies	Typical runoff values in each grid-cell are in units of cubic feet/second. 0 - 324.757 cfs	100
rofaccov	Final typical streamflow coverage, created by clipping the rofaclin arc coverage with the mainland template.	Arc	grid-code	varies	Typical flow values along each stream are in units of cubic feet / sec. 1 - 324 cfs.	100
rofaclin	Equivalent line coverage of the introfac grid. In-stream flows isolated through selection of a flow threshold value = 1 cfs. Grid-code integer flow values retained	Arc	grid-code	varies	Typical flow values along each stream are in units of cubic feet / sec. 1 - 324 cfs.	100

Data	Feature	Class	Attribute	Value	Description	Page #
	in the line coverage through use of the streamline command.					
runoff	Final runoff grid created by zero-filling the NODATA grid cells from runoffeq. Created using the isnull command.	Grid	Runoff depth	varies	Runoff values in each grid-cell are in units of millimeters/year. 0 - 248 mm/yr	88
runoffac	Cumulative annual runoff grid. Created by performing a weighted flow accumulation on the mainfdr grid, using runoff as the weight grid.	Grid	Runoff volume	varies	Cumulative runoff values in each grid-cell are in units of cubic meters/year. 0 - 290,430,464 cubic meters/year	100
runoffcv	Equivalent polygon coverage of the runoff grid. Converted using the Gridpoly and int commands.	Polygon	Runoff depth	varies	Runoff values in each polygon are in units of millimeters/year. 0 - 248 mm/yr	88
runoffeq	Original grid of cell-based runoff values created by applying the rainfall/runoff mathematical relationship to the sanpyr precipitation grid.	Grid	Runoff depth	varies	Runoff values in each grid-cell are in units of millimeters/year. 0 - 248 mm/yr	88
sabay1	15-minute San Antonio Bay Digital Line Graph map #1 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
sabay5	15-minute San Antonio Bay Digital Line Graph map #5 w/ meridians and parallels removed. UTM projection.	Arc	none			(37)
sabayf01	Original Arc/Info coverage converted from 15-minute San Antonio Bay Digital Line Graph map #1. UTM projection.	Arc	none			(37)
sabayf05	Original Arc/Info coverage converted from 15-minute San Antonio Bay Digital Line Graph map #5. UTM projection.	Arc	none			(37)
sanbasin	Cleaned version of the basin polygon coverage. Includes all San Antonio-Nueces subwatersheds plus 3 bordering subwatersheds from trimshed.	Polygon	none			79

Data	Feature	Class	Attribute	Value	Description	Page #
sanbord	Final coverage of the San Antonio-Nueces border, created by reselecting only the outside polygon from the border coverage.	Polygon	none			79
sanfac	Initial Flow Accumulation grid for the basin built from the sanfdr grid. Identifies the total number of cells draining to each cell in the grid.	Grid	accumu-lation	varies	integer number of cells that fall upstream of each cell.	63
sanfdr	Initial Flow Direction Grid for the basin built from the sanfil grid identifying the predominant direction of the flow of runoff from each grid cell.	Grid	direction	1 2 4 8 16 32 64 128	East Southeast South Southwest West Northwest North Northeast	63
sanfil	Processed Digital Elevation Model with all "pits" filled to the level of the lowest elevation neighboring grid cell.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	63
sangages	Final reprojected version of the USGS Stream gauge point coverage.	Point	stat-num stat-nam	same as for the stations coverage same as for the stations coverage		49
sanhucs	Final cleaned and reprojected coverage of the 5 San Antonio-Nueces HUCs	Polygon	huc	same as huc for the hucs coverage		32
sanhyd	Final hydrography digital line graph coverage of the San Antonio-Nueces basin, created by clipping the sanhydro coverage with sanbord.	Arc	none			79
sanhydro	Reprojected coverage of the appended Digital Line Graph hydrography maps in the region.	Arc	none			38
sanlu	Final land use coverage of the San Antonio-Nueces basin, created by clipping the sanluse coverage with sanbord.	Polygon	lusecat tn tkn	same as lusecat for sanluse coverage 0 - 4.4 0 - 1.7	(mg/L) total nitrogen emc (mg/L) total kjeldahl nitrogen emc	79

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Data	Feature	Class	Attribute	Value	Description	Page #
			nn	0 - 1.6	(mg/L) nitrate + nitrite emc	
			tp	0 - 1.3	(mg/L) total phosphorus emc	
			dp	0 - 0.48	(mg/L) dissolved phosphorus emc	
			ss	0 - 107	(mg/L) total suspended solids emc	
			ds	0 - 1225	(mg/L) total dissolved solids emc	
			pb	0 - 15	(ug/L) total lead emc	
			cu	0 - 15	(ug/L) total copper emc	
			zn	0 - 245	(ug/L) total zinc emc	
			cd	0 - 1.05	(ug/L) total cadmium emc	
			cr	0 - 10	(ug/L) total chromium emc	
			ni	0 - 11.8	(ug/L) total nickel emc	
			bod	0 - 25.5	(mg/L) biological oxygen demand emc	
			cod	0 - 116	(mg/L) chemical oxygen demand emc	
			o&g	0 - 9	(mg/L) oil & grease emc	
			fcol	0 - 53,000	(col/100 mL) fecal coliform emc	
			fstr	0 - 56,000	(col/100 mL) fecal streptococci emc	
sanlus	Reselected land use coverage to eliminate the unknown category, which was seen to define the Gulf of Mexico.	Polygon	sanlus-id		same as luse-id for luse coverage except no value 200000 is included	44
sanluse	Redefined land use coverage, created by dissolving boundaries between subcategory polygons for Agriulture, Rangeland, Forestland, Water, Wetland, and Barren land use categories of the sanlus coverage.	Polygon	lusecat	0	Unknown	92
				11	Residential	
				12	Commercial Services	
				13	Industrial	
				14	Transportation, Comunications	
				16	Mixed Urban or Built-Up Land	
				17	Other Urban or Built-Up Land	
				20	Agriculture	
				30	Rangeland	
				40	Forest Land	
				50	Water Bodies	
				60	Wetlands	
				70	Barren Land Uses	

Data	Feature	Class	Attribute	Value	Description	Page #
sanpolys	Cleaned polygon coverage of sanrivs4 arc coverage. Performed to isolate the bay network & barrier islands in the coverage.	Polygon	none			67
sanpyr	Precipitation grid specific to the boundary of the San Antonio-Nueces border. Created using the Con statement with the rainbuff and bordgrid grids.	Grid	Precip-depth	varies	Precipitation values in each grid-cell are in units of millimeters/year. 739 - 985 mm/year.	81
sanrivs4	Final edited digital line graph coverage of hydrography in the San Antonio-Nueces basin. Created by using ArcEdit with the sanhydro coverage to eliminate lakes and disappearing streams.	Arc	none			67
sanutm	Appended coverage of 15-minute Digital Line Graph hydrography maps for the San Antonio-Nueces region. UTM projection.	Arc	none			38
sanwq	Final reprojected point coverage of TNRCC SWQM stations. Appended with average concentration values and # of samples for a number of pollutant constituents	Point	station-id	varies	character representation of sanwq-id	56
			tp_cnt	varies	# of total phosphorus measurements between 0 - 75	
			tp_avg	varies	between 0 - 7.36 mg/L	
			tkn_cnt	varies	# of total kjeldahl nitrogen measmts. between 0 - 46	
			tkn_avg	varies	between 0 - 9.90 mg/L	
			no2_cnt	varies	# of total nitrate measurements between 0 - 19	
			no2_avg	varies	between 0 - 0.92 mg/L	
			no3_cnt	varies	# of total nitrite measurements between 0 - 39	
			no3_avg	varies	between 0 - 6.57 mg/L	
			tn_cnt	varies	"calculated" # of tot nitrogen measmts = (tkn_cnt + no2_cnt + no3_cnt) / 3 between 0 - 31	

Data	Feature	Class	Attribute	Value	Description	Page #
			tn_avg	varies	"calculated" tot nitrogen avg conc = tkn_avg + no2_avg + no3_avg between 0 - 15.51 mg/L	
			cd_cnt	varies	# of cadmium measurements between 0 - 4	
			cd_avg	varies	between 0 - 5 ug/L	
			fec_cnt	varies	# of fecal coliform measurements between 0 - 17	
			fec_avg	varies	between 0 - 462 colonies / 100 mL	
			X-coord	varies	TSMS Albers x-coordinate of station	
			Y-coord	varies	TSMS Albers y-coordinate of station	
shed8cov	Equivalent polygon coverage of the ditshd8 grid. Created using the gridpoly command.	Polygon	none			75
sndemalb	Final Digital Elevation Model of the San Antonio-Nueces basin area.	Grid	elevation	varies	elevation values in each grid-cell are in units of meters above sea level.	41
snrainyr	Final precipitation coverage of the San Antonio-Nueces basin, created by clipping the rainbfcv coverage with sanbord.	Polygon	grid-code	varies	Precipitation values in each polygon are in units of millimeters/year. 739 - 985 mm/year.	79
sqcov	Equivalent coverage of the grid sqgrid. Built in order to combine (union) with the baybuff coverage.	Polygon	none			67
sqgrid	A single value grid spanning the extent of the other study area grids, defined by the sanfil grid.	Grid	integer	1		67
stations	Point coverage of USGS Stream Gauges built using the lonlat.dat data file. Geographic Coordinates.	Point	stat-num	08189200 08189300 08189500 08189700 08189800	USGS stream gauge station identification number.	47
			stat-nam	Copano Medio	Stream or Creek that gauge is located on.	

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Data	Feature	Class	Attribute	Value	Description	Page #
				Mission Aransas Chiltipin		
storet.dbf	Database file of TNRCC SWQM pollutant constituent identification codes. Used with the value.dbf and sanwq.pat tables to link water quality measurements to specific locations.	DBF	param-id	varies	identifies the 5-digit numeric code of the pollutant being measured.	56
			long-desc	varies	identifies full ASCII text description of the pollutant being measured.	
			short1-desc	varies	identifies the pollutant element or constituent in one word, typically noun	
			short2-desc	varies	identifies descriptive words regarding the pollutant.	
			short3-desc	varies	identifies units of the pollutant constituent being measured.	
			Group-cd	1.0000		
			Max-val	varies	upper bound on possible values.	
			Min-val	varies	lower bound on possible values.	
str1	Grid of flow accumulation cells with value greater than a threshold of 1000. Results in strings of cells that represent the larger streams in the basin.	Grid	accumu-lation	varies	from 1000 to the maximum value of the sanfac grid	63
strgrid	Equivalent 100 meter cellsize grid of the sanrivs4 hydrography coverage. All off-stream cells have zero value rather than NODATA.	Grid	none			69
strmgrid	Grid of stream hydrography cells particular to the mainland of the region, i.e. excluding cells in the bay network & barrier islands.	Grid	none			69
subsheds	Polygon coverage of the shed8cov subwatersheds that fall within the bounds of the San Antonio-Nueces basin borders. Created from an ArcView shapefile.	Arc	none			76

Data	Feature	Class	Attribute	Value	Description	Page #
tkn.dat	Arc/Info data file of total kjeldahl nitrogen water quality measurements. Created from tkn.dbf using the dbaseinfo command.	INFO	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 46 (# of measurements) between 0 - 9.9 mg/L	(104)
tkn.dbf	Database file of total kjeldahl nitrogen water quality measurements. Created from the TNRCC SWQM database using ArcView Summary Statistics tools.	DBF	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 46 (# of measurements) between 0 - 9.9 mg/L	(104)
tncon	Final nonpoint nitrogen concentration coverage. Created by clipping the tnline arc coverage with the mainland template.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 4400	(102)
tnline	Equivalent line coverage of the niconstr grid. Concentrations multiplied by 1000 to retain significant figures. Grid-code integer concentration values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 4400	(102)
tnload	Final total nitrogen cumulative load coverage. Created by clipping the nitline arc coverage with the mainland template.	Arc	grid-code	varies	Cumulative load values along each stream are in units of kg/year. 1000 - 369,122 kg/yr	(97)
tnrnof	Cell-based nitrogen loading grid created by adding the nonpoint source loading grid (nitrunof) and the Beeville point source loading grid (beenit).	Grid	Load	varies	Cell-based load values in each grid cell are in units of mg-mm/L-year. 0 - 7,149,842.5 mg-mm/L-yr.	(121)
tonitcon	Final point + nonpoint nitrogen concentration coverage. Created by clipping the tonitlin arc coverage with the mainland template.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 15,509	(121)
tonitlin	Equivalent line coverage of the tonitstr grid. Concentrations multiplied by 1000 to retain significant figures. Grid-code integer concentration values retained in the line coverage through use streamline.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 15,509	(121)

Data	Feature	Class	Attribute	Value	Description	Page #
tonitstr	New grid of predicted nonpoint & point nitrogen concentrations occuring in the stream network of the basin. Created using the Con statement with the introfac and totnconc grids.	Grid	Concentration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 15.51 mg/L	(121)
tophocon	Final point + nonpoint phosphorus concentration coverage. Created by clipping the topholin arc coverage with the mainland template.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 6600	121
topholin	Equivalent line coverage of the tophostr grid. Concentrations multiplied by 1000 to retain significant figures. Grid-code integer concentration values retained in the line coverage through use of the streamline command.	Arc	grid-code	varies	Concentration values along each stream are in units of mg/L x 1000. 0 - 6600	121
tophostr	New grid of predicted nonpoint & point phosphorus concentrations occuring in the stream network of the basin. Created using the Con statement with the introfac and totpconc grids.	Grid	Concentration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 6.6 mg/L	121
totnconc	New grid of predicted nitrogen concentrations from both nonpoint and point sources. Created by dividing the new nitrogen load grid (totnload) by the annual cumulative runoff grid (runoffac).	Grid	Concentration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 15.51 mg/L	(121)
totnload	New total nitrogen load grid created by performing a weighted flow accumulation on the mainfdr grid, using tnrnof as the weight grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of kg/year. 0 - 369,122.41 kg/yr	(121)
totpconc	New grid of predicted phosphorus concentrations from both nonpoint and point sources. Created by dividing the new	Grid	Concentration	varies	Concentration values in each grid-cell are in units of milligrams/Liter. 0 - 6.6 mg/L	121

Data	Feature	Class	Attribute	Value	Description	Page #
	phosphorus load grid (totpload) by the annual cumulative runoff grid (runoffac).					
totpload	New total phosphorus load grid created by performing a weighted flow accumulation on the mainfdr grid, using beernof as the weight grid.	Grid	Load	varies	Cumulative load values in each grid cell are in units of kg/year. 0 - 90,479.46 kg/yr	121
tp.dat	Arc/Info data file of total phosphorus water quality measurements. Created from tp.dbf using the dbaseinfo command.	INFO	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 75 (# of measurements) between 0 - 7.36 mg/L	104
tp.dbf	Database file of total phosphorus water quality measurements. Created from the TNRCC SWQM database using ArcView Summary Statistics tools.	DBF	station-id count ave-value	varies varies varies	5-digit water quality station number between 0 - 75 (# of measurements) between 0 - 7.36 mg/L	104
tpline	Equivalent line coverage of the phosload grid. In-stream loads isolated through selection of a load threshold value = 1000 kg. Grid-code integer load values retained in the coverage through use of streamline.	Arc	grid-code	varies	Cumulative load values along each stream are in units of kg/year. 1000 - 60,926 kg/yr	97
tpload	Final total phosphorus cumulative load coverage. Created by clipping the tpline arc coverage with the mainland template.	Arc	grid-code	varies	Cumulative load values along each stream are in units of kg/year. 1000 - 60,900 kg/yr	97
trimshed	Polygon coverage of those shed8cov subwatersheds that, along with subsheds and baybuff, completely enclose the undelineated (near shore) portions of the San Antonio-Nueces Coastal Basin. Created from an ArcView shapefile.	Arc	none			76
value.dbf	Database file of TNRCC SWQM pollutant concentration measurement values. Used with the storet.dbf and sanwq.pat tables to link water quality measurements to specific locations.	DBF	station-id on-seg- flg seg-id	varies 0 1 varies	5-digit water quality station number identifies the 4-digit TNRCC segment where the sample was taken.	56

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Data	Feature	Class	Attribute	Value	Description	Page #
			enddate	varies	identifies last date of a series of measurements	
			tag	varies	7-character id with one letter and 6 numerals	
			storet-code	varies	identifies the 5-digit numeric code of the pollutant being measured.	
			gtlt	< or >	flag that is set when measurement is below or above a threshold value	
			value	varies	the measured value of the pollutant constituent.	
weighfac	Weighted flow accumulation grid representing potential runoff in the basin. Created with the clipfdr and rainbuff grids.	Grid	potential runoff	varies	from 0 - 2,244,562,432 cubic meters per year	80
wqsites	Original point coverage of TNRCC SWQM stations. Imported from the snwqsites.e00 file. Projected in Albers with measurement units of feet specified.	Point	none			56

Appendix B :   Programs/AMLs

Attrib.aml

```
/*    attrib.aml ------ to be run from the Arc prompt, this aml defines items for the
/*    attrib.dat data file and then fills them with raw expected mean concentration
/*    data from the emc3a.dat file.
/*
tables
define attrib.dat
/*
lusecat /*Item Name: land use category
8       /*Item Width: 8
8       /*Item Output Width: 8
i       /*Item Type: integer
/*
tn      /*Item Name: total nitrogen
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
2       /*Item Decimal Places: 2
/*
tkn     /*Item Name: total kjeldahl nitrogen
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
2       /*Item Decimal Places: 2
/*
nn      /*Item Name: nitrate + nitrite (mg/L as N)
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
2       /*Item Decimal Places: 2
/*
tp      /*Item Name: total phosphorus
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
2       /*Item Decimal Places: 2
/*
dp      /*Item Name: dissolved phosphorus
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
2       /*Item Decimal Places: 2
/*
```

196

```
ss      /*Item Name: suspended solids
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
1       /*Item Decimal Places: 1
/*
ds      /*Item Name: dissolved solids
4       /*Item Width: 4
4       /*Item Output Width: 4
i       /*Item Type: integer
/*
pb      /*Item Name: total lead
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
1       /*Item Decimal Places: 1
/*
cu      /*Item Name: total copper
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
1       /*Item Decimal Places: 1
/*
zn      /*Item Name: total zinc
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
1       /*Item Decimal Places: 1
/*
cd      /*Item Name: total cadmium
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
2       /*Item Decimal Places: 2
/*
cr      /*Item Name: total chromium
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
1       /*Item Decimal Places: 1
/*
ni      /*Item Name: total nickel
5       /*Item Width: 5
5       /*Item Output Width: 5
n       /*Item Type: numeric
```

```
1          /*Item Decimal Places: 1
/*
bod        /*Item Name: biological oxygen demand
5          /*Item Width: 5
5          /*Item Output Width: 5
n          /*Item Type: numeric
1          /*Item Decimal Places: 1
/*
cod        /*Item Name: chemical oxygen demand
5          /*Item Width: 5
5          /*Item Output Width: 5
n          /*Item Type: numeric
1          /*Item Decimal Places: 1
/*
o&g        /*Item Name: oil & grease
4          /*Item Width: 4
4          /*Item Output Width: 4
n          /*Item Type: numeric
1          /*Item Decimal Places: 1
/*
fcol       /*Item Name: fecal coliform
7          /*Item Width: 7
7          /*Item Output Width: 7
i          /*Item Type: integer
/*
fstr       /*Item Name: fecal streptococci
7          /*Item Width: 7
7          /*Item Output Width: 7
i          /*Item Type: integer
/*
~          /*Item Name: <return>
/*
add from emc3a.dat
quit
&return
```

Dlgmerge.aml

```
/* An ARC AML FOR PREPARING DLG DATA FOR REGIONAL ANALYSIS
/*
/* prepared by Bill Saunders, University of Texas at Austin
/*                 Center for Research in Water Resources
/*                 GIS in Water Resources Research group
/*
/* AML NAME:  dlgmerge.aml (run from the "Arc" prompt)
/* FUNCTION:  Prepares selected DLG data for analysis with respect to a
/*            particular hydrologic or political region.
/* INPUTS:
/*    -all compressed ("zipped") DLG files corresponding to the region of
/*        interest.  These zipped files are downloaded from the USGS EROS Data
/*        Center at http://sun1.cr.usgs.gov/eros-home.html.  Alternatively the
/*        DLG files can be accessed from US Geodata 1:100,000-Scale DLG Data
/*        Compact Disc (USGS, 1993).
/*    -a projection file that will allow for conversion from utm map
/*        coordinates to whatever projection is desired.
/*    -a polygon coverage delineating the boundary of the hydrologic or
/*        political region of interest.
/*
/*******************************************************************
/* BEGIN AML EXECUTION
/*
/* Assuming that zipped DLG files have been downloaded from CD-ROM (in this
/* case, 5 hydro files using the following commands):
/*
/* cp /cdrom/100k_dlg/beeville/be3hydro.zip ./
/* cp /cdrom/100k_dlg/goliad/be1hydro.zip ./
/* cp /cdrom/100k_dlg/allyns_b/cc2hydro.zip ./
/* cp /cdrom/100k_dlg/corpus_c/cc1hydro.zip ./
/* cp /cdrom/100k_dlg/sananbay/be4hydro.zip ./
/*
/*
/* The first set of commands below MUST ALWAYS BE CHANGED by the user of the
/* AML.  Store the number of zipped DLG files into the variable dlgnum.
/* Then, for each zipped DLG file, define sequential variables called dlg# as
/* the first 3 characters of each of the zipped files.
/* Store the name of your projection file (in this case, utmtsms.prj) into
/* the variable prjfname.
/* Store the name of your hydrologic or political boundary coverage (in this
/* case, sanbord) into the variable border.
/* Finally, specify the type of files that you are using -- the only valid
```

```
/*  entries for this variable (filetype) are hydro, roads, rail, and mtran.
/*
&sv dlgnum = 5
&sv dlg1 = be1
&sv dlg2 = be3
&sv dlg3 = be4
&sv dlg4 = cc1
&sv dlg5 = cc2
&sv prjfname = utmtsms.prj
&sv border = sanbord
&sv filetype = hydro
/*
/*
&if %filetype% eq hydro &then
  &sv abbr = hy
&if %filetype% eq roads &then
  &sv abbr = rd
&if %filetype% eq rail &then
  &sv abbr = rr
&if %filetype% eq mtran &then
  &sv abbr = mt
/*
/*  This part of the AML unzips all of the compressed files to create 15-minute
/*  map files.  Each 15-minute map file is first converted into an Arc/Info
/*  line coverage.  Then, the borders of each of the 15-minute map files are
/*  trimmed away from the coverage so that those 15-minute meridians and
/*  parallels will not appear in the final appended coverage.
/*
&sv count = 1
&do &while %count% le %dlgnum%
  &sv filename = [value dlg%count%]
  &sv count = %count% + 1
  &sys unzip %filename%%filetype%.zip
  &sv count2 = 1
  &do &while %count2% le 8
    &do &while [exists %filename%%abbr%f0%count2% -file]
      dlgarc optional %filename%%abbr%f0%count2% %filename%f0%count2%
      &sv x = [delete %filename%%abbr%f0%count2% -file]
      build %filename%f0%count2% line
      reselect %filename%f0%count2% %filename%0%count2% line # line
      res rpoly# > 1
      ~
      n
      y
      res lpoly# > 1
```

```
      ~
      n
      n
      kill %filename%f0%count2% all
    &end
    &sv count2 = %count2% + 1
  &end
&end
/*
/*  This part of the AML merges, or "appends", all of the 15-minute map file
/*  coverages together and then builds line topology for the resultant coverage,
/*  called "bigmap".
/*
append bigmap
&sv count = 1
&do &while %count% le %dlgnum%
  &sv filename = [value dlg%count%]
  &sv count = %count% + 1
  &sv count2 = 1
  &do &while %count2% le 8
    &do &while [exists %filename%0%count2% -cover]
      %filename%0%count2%
      &sv count2 = %count2% + 1
    &end
  &sv count2 = %count2% + 1
  &end
&end
~
y
y
build bigmap line
/*
/*  Once "bigmap" has been created, each of the coverages that were merged to
/*  build it are no longer necessary.  This part of the AML kills off all of
/*  the intermediate level coverages used to append "bigmap".
/*
&sv count = 1
&do &while %count% le %dlgnum%
  &sv filename = [value dlg%count%]
  &sv count = %count% + 1
  &sv count2 = 1
  &do &while %count2% le 8
    &do &while [exists %filename%0%count2% -cover]
      kill %filename%0%count2% all
      &sv count2 = %count2% + 1
```

```
    &end
  &sv count2 = %count2% + 1
  &end
&end
/*
/*  The "bigmap" coverage is then reprojected to the desired map projection
/*  and coordinates.  The projection file must be located in the same directory
/*  as the coverage being projected.
/*
project cover bigmap bigprj %prjfname%
/*
/*  Finally, a polgyon coverage of the hydrologic or political boundary of
/*  interest is used to "clip" out the hydrologic features specific to that
/*  region.  The final coverage is called "dlgcov".
/*
clip bigprj %border% dlgcov line
kill bigmap all
kill bigprj all
/*
&return
/*****************************end of AML***************************
```

Montflow.f

```fortran
      program monthflow

      character script*13
      integer month,day,year,mon,yr,yer(50)
      real dayflow,volmo,monthflo(12),yrflo(50),totflo,avganl

      open (unit = 20, file = 'chiltip.dat',status = 'old')

c     ** input data file -- CHANGE NAME for new run

      open (unit = 30, file = 'chilvmon.dat',status = 'unknown')

c     ** output data file -- CHANGE NAME for new run

c     ** the following are initial values for month, monthly volume, and
C     ** counters.  CHANGE VALUE of mon to the first month of your data set

      mon = 7
      volmo = 0.0
      i = 1
      k = 1

10    read (20,15) month,day,year,dayflow

c     ** Had to perform  (awk '{print $1,$2}' aransas.gage > arans.dat)
c     ** because date and flow values were seperated by 1 tab and NOT 6
c     ** SPACES.  My format statement originally had 6x for the spaces
c     ** between the year and dayflow.  Resulted in values of 0.0 being
c     ** read in for dayflow!!

15    format (i2,1x,i2,1x,i4,1x,f7.2)

c     ** check for end-of-file

      if (month .ne. 0) then

c     ** when the month of the input data changes, write out the total cum
c     ** volume for the previous month (volmo) and save the value in a matrix
c     ** variable called monthflo(i)

              if (month .ne. mon) then
                      write (30,16) mon,yr,volmo
```

```
16                          format (i2,2x,i4,2x,f11.1)
                            monthflo(i) = volmo
                            i = i + 1

c        ** when mon=12 (i.e. at the end of a year), reset the i counter to 1.
c        ** Also, if the i counter is in sequence with the mon counter, then a
c        ** full year's worth of data has been accumulated, so sum all of the
c        ** 12 values of monthflo and store them in a matrix variable called
c        ** yrflo(k).

                      if (mon .eq. 12) then
                            if (i .eq. 13) then
                                  yrflo(k) = 0
                                  do 17, j = 1,i-1
                                  yer(k) = yr
                                  yrflo(k) = yrflo(k) + monthflo(j)
17                                continue
                                  k = k + 1
                            endif
                            i = 1
                      endif

c        ** set mon = the value of month read in from the input table and define
c        ** the first monthly value of volmo as the measured flow value (cfs)
c        ** multiplied by 86400 sec/day and .028317 cub meters/cub ft.  The
c        ** resulting volume has units of cubic meters.

                      mon = month
                      volmo = dayflow*.028317*86400
                      goto 10
              endif

c        ** when mon = the value of month from the input table, incorporate the
c        ** new value of dayflow into the accumulating value of volmo.

              volmo = volmo+dayflow*.028317*86400
              yr = year
              goto 10
      endif
      write (30,*)

c        ** once all monthly values of volume have been calculated, print out the
c        ** cumulative volumes for each FULL year (i.e. yrflo(l))

      do 20, l = 1,k-1
```

```
        write (30,18) yer(l),yrflo(l)
18      format (i4,2x,f12.1)
        totflo = totflo + yrflo(l)
20      continue

c       ** once all yearly values of volume have been calculated, average them
c       ** over the number of FULL years worth of data accumulated and establish
c       ** an averge annual value for stream volume.

        avganl = totflo / (k-1)
        write (30,*)
        script = 'Avg Annual = '
        write (30,21) script,avganl
21      format (a13,f12.1)
        write (*,*) 'Done'
        stop
        end
```

al72tsms.prj

/* This is a projection file to convert coverages from geographic coordinates (specified in
/* decimal seconds with WGS72 datum) to the TSMS-Albers projection.
/*
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 00
1000000.0
1000000.0
END

alb-tsms.prj

/* This is a projection file to convert coverages from the standard Albers projection to the
/* TSMS-Albers projection.
/*
input
projection albers
units meters
datum NAD27
spheroid CLARKE1866
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
spheroid GRS1980
parameters
27 25 0.000
34 55 0.000
-100 0 0.000
31 10 0.000
1000000.00000
1000000.00000
end

geotsms.prj

/* This is a projection file to convert coverages from geographic coordinates (specified in
/* decimal degrees with NAD83 datum) to the TSMS-Albers projection.
/*
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

tsmsgeo.prj

/* This is a projection file to convert coverages from the TSMS-Albers projection to
/* geographic coordinates (specified in decimal degrees with NAD83 datum).
/*
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
parameters
END

utmtsms.prj

```
/*  This is a projection file to convert coverages from the Universal Transverse Mercator
/*  projection (zone 14) to the TSMS-Albers projection.
/*
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
```

wqtsms.prj

/* This is a projection file written to convert TNRCC SWQM data from an Albers projection
/* specified in units of feet and with specific latitude/longitude parameters to theTSMS-
Albers
/* projection.
/*
input
projection albers
units feet
datum NAD27
spheroid Clarke1866
parameters
25 48 00
37 00 00
-99 00 00
31 24 00
0.0
0.0
/*
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

Appendix C :   List of Acronyms

AGCHEM	Agrichemical Soil Nutrient Model
AGNPS	Agricultural Nonpoint Source Pollution Model
AML	Arc Macro Language
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
ARMSED	U.S. Army Watershed Sediment Routine
CCBNEP	Corpus Christi Bay National Estuary Program
CD-ROM	Compact Disc-Read Only Memory
CHRIS	Chemical-Hydrologic Resource Information System
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
CWA	Clean Water Act
DEM	Digital Elevation Model
DLG	Digital Line Graph
EMC	Expected Mean Concentration
EPA	Environmental Protection Agency
ERDAS	Earth Resources Data Analysis System
EROS	Earth Resources Observation Systems
ESRI	Environmental Systems Research Institute
GBNEP	Galveston Bay National Estuary Program
GIRAS	Geographical Information Retrieval Analysis System
GIS	Geographic Information Systems
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems
GRASS	Geographic Resources Analysis Support System
GRS80	Geodetic Reference System of 1980
HSPF	Hydrological Simulation Program - FORTRAN
HTML	Hyper Text Markup Language
HUC	Hydrologic Unit Code
IRIS	Integrated River Information System
LOADSS	Lake Okeechobee Agricultural Decision Support System
LULC	Land Use/Land Cover
MULTSED	Multiple Watershed Sediment Routine
MUSLE	Modified Universal Soil Loss Equation
NAD27	North American Datum of 1927
NAD83	North American Datum of 1983
NEP	National Estuary Program
NO2	Nitrite Nitrogen
NO3	Nitrate Nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PAT	Point (or Polygon) Attribute Table
PRISM	Parameter-elevation Regressions on Independent Slopes Model
QUAL2E	Enhanced Stream Water Quality Model
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SIMPLE	Spatially Integrated Model for Phosphorus Loading and Erosion
SLAMM	Source Loading and Management Model

SMoRMod	Soil Moisture-based Runoff Model
SNOTEL	Snowpack Telemetry
STORET	Storage and Retrieval of U.S. Waterways Parametric Data
SWAT	Soil Water and Assessment Tool
SWMM	Stormwater Management Model
SWQM	Surface Water Quality Monitoring
SWRRB	Simulator for Water Resources in Rural Basins
TDWR	Texas Department of Water Resources
TKN	Total Kjeldahl Nitrogen
TNRCC	Texas Natural Resource Conservation Commission
TSMS	Texas State Mapping System
TWDB	Texas Water Development Board
USA-CERL	U.S. Army Construction Engineering Research Laboratory
USDA-NRCS	U.S. Department of Agriculture Natural Resource Conservation Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
VAT	Value Attribute Table
VirGIS	Virginia Geographic Information System
WAIS	Wide Area Information Servers
WGEN	Weather Generation Model

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