WATER AVAILABILITY MODEL FOR THE
SAN ANTONIO-NUECES COASTAL BASIN

Document No. 010421
PBS&J Job No. 440719

WATER AVAILABILITY MODEL
FOR THE
SAN ANTONIO-NUECES COASTAL BASIN

Prepared for:

Texas Natural Resource Conservation Commission
P.O. Box 13087
Austin, Texas 78711-3087

Prepared by:

PBS&J
with
Espey Consultants, Inc.
and
Densmore DuFrain Consulting

March 2002

Printed on recycled paper

0.0 EXECUTIVE SUMMARY

In 1997, the Texas Legislature passed Senate Bill 1, allocating funds to create water availability models for 22 of 23 river basins in Texas. The Water Availability Modeling (WAM) effort aids the Texas Natural Resource Conservation Commission (TNRCC) and other state agencies in sound resource management and planning by determining the amount of water available for each water right and the percentage of time it is available. The models developed by this program are replacing outdated models for eight river basins and creating new models for the remaining river basins in Texas.

PBS&J was selected by TNRCC as the prime contractor of the water availability modeling effort for the San Antonio-Nueces Coastal Basin (SA-N) and Nueces-Rio Grande Coastal Basin (N-RG). This report presents the WAM analyses for the SA-N. The N-RG is addressed in a separate report.

STUDY OBJECTIVES

The overall objective is to develop a numerical model of the basin for the period of record from 1948 to 1998 that can be used to quantify the surface water available under a range of permitting and planning scenarios. The scope of the WAM effort involves the following tasks:

- Development of naturalized monthly streamflows for the latest 50-year analysis period (1948-1998) at key locations such as stream gaging points (called primary control points);
- Distribution of these naturalized flows to ungaged locations of interest including all diversion points and reservoirs authorized under existing water rights (secondary control points); and
- The creation of model input files that contain all relevant information on all existing water rights.

SAN ANTONIO-NUECES

The SA-N is located in south Texas between the San Antonio and Nueces River Basins and is bounded by Copano Bay and Aransas Pass in Goliad, Bee, Refugio and San Patricio Counties (Figure ES-1). The basin has a drainage area of approximately 2,652 square miles (sq mi).

The major elements of the economy of the basin include ranching and oil and gas production (TNRCC, 1996). This basin is sparsely populated; the most significant city is Beeville with a population of 14,000. The SA-N is not characterized by one major stream which discharges to the mouth of the basin, but rather, by three streams (Aransas River, Mission River and Copano Creek) which discharge into Copano Bay and by the area adjacent to the coast that includes a number of smaller streams which drain directly into Copano Bay and the Gulf of Mexico. Many of these streams are intermittent, and historically, there have been relatively few measurements of streamflow.

Figure ES-1, San Antonio-Nueces Coastal Basin

STUDY METHODOLOGY

The methodology for conducting the study of the SA-N WAM project consisted of the following steps:

1. Collection of water right, water use and return flow information for the basin;
2. Development of naturalized streamflows;
3. Incorporation of these data into a computer simulation program and analyzing water availability;
4. Reporting of results; and
5. Providing for public and interagency access to data inputs, outputs, and the models.

Water right, water use and return flow information was collected from various sources, and missing data were interpreted based on similar areas, with available data or projections based on population (in the case of return flows).

Naturalized flows are defined as those flows expected in a water body without human influence or intervention. Naturalized flows are used as a baseline to which different demand scenarios may be compared for permitting and/or planning. Naturalized flows were developed from available streamflow data adjusted to remove the effects of man's activities. For example, wastewater discharges that contributed to streamflow were subtracted while water diversions were added, yielding flow that should have existed naturally.

Over the last several years, the TNRCC has selected and refined a standard WAM approach using the Water Rights Analysis Package (WRAP) computer model (Wurbs, 2001). The WRAP model was originally developed at Texas A&M University for the specific purpose of simulating diversions and reservoir storage for individual water rights in a river basin under the prior appropriation doctrine, subject to specific hydrologic conditions, reservoir operating procedures, and water right provisions. Since then, the WRAP model has been modified in other WAM efforts. This project employs the latest version of WRAP, available at the end of calendar year 2001.

The WRAP model was used to conduct a series of simulations set forth by TNRCC in the WAM Resolved Technical Issues document (TNRCC, 2001). This document identifies nine different simulations designed to provide the necessary information related to water availability and reliability. Due to the nature of the SA-N, only eight of the nine simulation runs were required. The eight modeling scenarios that were completed for the coastal basin included: reuse runs (3), cancellation runs (4), and a current conditions run. The ninth modeling run, the Firm Yield Analysis, did not apply in this WAM study because none of the reservoirs are more than 5,000 acre-feet (ac-ft) in capacity, and they were all considered minor reservoirs (as described in the Project Work Plan).

RESULTS

The eight modeling runs produced results quantifying the reliability of water rights, and the unappropriated and regulated flows for specific points along the tributaries in the system. Tables ES-1, ES-2 and ES-3 show the reliability results for water rights in the SA-N for reuse, cancellation and existing conditions runs, respectively. These tables list all the fresh water rights with authorized diversions in the SA-N. Other information includes the TNRCC water rights identification number, the type of use, and the water body associated with the right. The degree of reliability for the period is represented by the percentage of time for which the demand target is fully met; or equivalently, the probability of the demand being met in any randomly selected month. The volume reliability is the percentage of the total demand that is actually supplied, that is the ratio of water supplied to water demand.

For the flow analyses, regulated and unappropriated flows were determined at the designated control points for each of the three groups of runs. Regulated and unappropriated flows are derived from naturalized flows based on certain use conditions. Regulated and unappropriated streamflows at a control point are of particular interest because these flows may be used to determine the theoretical physical streamflow and the water available for future diversion respectively. To be sure, regulated flow is adjusted to account for both upstream and downstream water rights, reservoir net evaporation-precipitation, and/or reservoir storage. Unappropriated flow is the portions of the naturalized streamflows still remaining after the streamflow depletions are made and return flows are accounted for. For the SA-N models, regulated and unappropriated flow are almost always equal to or within +/- 0.1% of each other. For all 8 model scenarios this occurs because there are relatively minor (between 25 and 52 acre-feet per month [ac-ft/mo]) return flows upstream, and the unappropriated flow is greater than the instream flow requirements at the control point in all cases.

Table ES-5 shows the comparison between the average unappropriated flows for Run 1 through Run 8 for the SA-N. The analysis of the WRAP model was performed primarily for control points 10000 ("catch-all" point), 10047 (downstream end of Mission River), and 10045 (downstream end of Aransas River). These control points are considered significant because they are the most downstream points for their respective watersheds.

There are 16 water rights in the SA-N, however, five are saline and are not modeled since they do not have an effect on water availability. Of the 11 remaining, only 6 are authorized to divert nonsaline or non-interbasin transfer (IBT) water for a total of 1,877 acre-feet per year (ac-ft/yr). Of the six with authorized diversions, only three have diverted in the last 10 years, for a total water use of 1,652 ac-ft/yr under the full cancellation scenario (Runs 4 and 5) and 745 ac-ft/yr under the partial cancellation scenario (Runs 5 and 6). The average period and volume reliability is generally high for the eight modeled scenarios, ranging between 73.2% (period) and 100% (period and volume) for any given water right and scenario. Domestic wastewater return flow is not a significant factor in the availability of water in the

Table ES-1

Table ES-2

Table ES-3

SA-N as there is only a total of 851 ac-ft/yr of water introduced into the SA-N from wastewater discharge introduce downstream of the diversion points. Agricultural return flows are not reported and are not considered to be significant.

Table ES-4 represents all of the water rights included in the WRAP model. The water rights modeled with zero diversion have reservoirs without the right to divert water or have a right of diversion but are modeled with a zero diversion because water is used for industrial purposes without a consumptive use (such as water right ID 12004521401). See Appendix C, Table One, Basin 20 Water Right Issues and Assumptions, for more detail.

The following is a summary of conclusions developed from an analysis of the SA-N WRAP model:

- The reliability of water rights appears unaffected by the influence of domestic wastewater.
- The reliability of existing water rights is generally high for all model runs.
- The effects of return flows are most easily observed in the differences in unappropriated flows between model Run 1 and Run 3.
- Partial cancellation (limiting rights to the maximum use in the last 10 years) with 0% assumed wastewater reuse is 12 to 23% more reliable than the baseline conditions using the full authorized diversion with 0% assumed wastewater reuse.
- Reliability is the same for the total cancellation run with 0% wastewater reuse (Run 4) as it is for total cancellation with 100% wastewater reuse (Run 6).
- Reliability is the same for the partial cancellation run with 0% wastewater reuse (Run 5) as it is for partial cancellation with 100% wastewater reuse (Run 7).
- The current conditions run involving partial cancellation scenario with no wastewater reuse has the highest reliability and most unappropriated flows.

Table ES-4: Summary of Diversion Amount for Each Scenario

				Total Annual Diversions (ac-ft/yr)							
Count	Water Right ID Number*	Owner Name	Control Point	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
1	12004521301	North Shore Golf Partners	10000	557	557	557	557	232	557	232	232
2	12004521401	North Shore Golf Partners	10000	0	0	0	0	0	0	0	0
3	12004547001	E.I. Du Pont de Nemours	10000	0	0	0	0	0	0	0	0
4	12005283001	Stephen Tarlton Dougherty et al.	D10000	150	150	150	0	0	0	0	0
5	12005291001	Mary Claire Harris Ethridge	D10000	60	60	60	0	0	0	0	0
6	12005366401	R&B Welder Wildlife Foundation	10000	1000	1000	1000	1000	496	1000	496	496
7	12005421301	Northshore Golf Partners Ltd.	C10000	0	0	0	0	0	0	0	0
8	62004498301	Mary P. Dougherty et al.	B10000	0	0	0	0	0	0	0	0
9	62004499401	C.W. Marshall	10000	94.9	94.9	94.9	94.9	17	94.9	17	17
10	62004501301	Refugio Co. WCID 2	10000	0	0	0	0	0	0	0	0
11	62004502301	Reynolds Metals Co.	10000	15	15	15	0	0	0	0	0
		SUM		1876.9	1876.9	1876.9	1651.9	745	1651.9	745	745

* See assumptions memo for more detail.

Table ES-5: Comparison of Average Unappropriated Flows (acre-feet/year)

	Reuse			Cancellation				
Outfall	Run 1	Run 2	Run3	Run 4	Run 5	Run 6	Run 7	Run 8
	0% Reuse Auth Diversion	50% Reuse Auth Diversion	100% Reuse Auth Diversion	0% Reuse Full Canc	0% Reuse Partial Canc	100% Reuse Full Canc	100% Reuse Partial Canc	0% Reuse Auth Diversion
Mission River	323,721	323,554	323,385	323,721	323,756	323,385	323,420	323,756
Aransas River	282,066	281,860	281,653	282,191	282,504	281,779	282,091	282,504
Catch-all point	564,019	563,645	563,271	564,158	564,761	563,409	564,012	564,761

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS USED

ac-ft	acre-feet
ac-ft/yr, ac-ft/mo	acre-feet per year, acre-feet per month
CA	Certificate of Adjudication
CI	constant inflow
CN	curve number
CP	control point
CRWR	Center for Research and Water Resources
HSPF	Hydrologic Simulation Program, Fortran
IBT	Interbasin Transfer
NOAA	National Oceanic and Atmospheric Administration
N-RG	Nueces-Rio Grande Coastal Basin
SA-N	San Antonio-Nueces Coastal Basin
SWAT	Soil and Water Assessment Tool
TMDL	Total Maximum Daily Load
TNRCC	Texas Natural Resource Conservation Commission
TWDB	Texas Water Development Board
USGS	U.S. Geological Survey
WAM	Water Availability Modeling
WR	water rights
WRAP	Water Rights Analysis Package

1.0 INTRODUCTION

In 1997, the Texas Legislature passed Senate Bill 1, allocating funds to create water availability models for 22 of 23 river basins in Texas. The Water Availability Modeling (WAM) effort aids the Texas Natural Resource Conservation Commission (TNRCC) and other state agencies in sound resource management and planning by determining the amount of water available for each water right and the percentage of time it is available. The models developed by this program are replacing outdated models for eight river basins and creating new models for the remaining river basins in Texas.

PBS&J was selected by TNRCC as the prime contractor of the water availability modeling effort for the San Antonio-Nueces Coastal Basin (SA-N) and Nueces-Rio Grande Coastal Basin (N-RG). This report presents the WAM analyses for the SA-N. The N-RG is addressed in a separate report.

1.1 DESCRIPTION OF THE BASIN

The SA-N has a drainage area of approximately 2,652 square miles (sq mi) and extends from the rolling hills in south central Texas to the Gulf of Mexico. The downstream end of the basin is crescent-shaped and follows the contour created by the Gulf of Mexico.

The primary groundwater source in the basin is the Gulf Coastal Aquifer. The Gulf Coast aquifer forms a wide belt along the Gulf of Mexico from Florida to Mexico. The aquifer consists of complex interbedded clays, silts, sands, and gravels of Cenozoic age, which are hydrologically connected to form a large, leaky artesian aquifer system. Maximum total sand thickness ranges from 700 feet in the south to 1,300 feet in the northern extent. Recharge to this aquifer occurs throughout the basin.

The area near the coast includes wetlands, land used for dry-land farming, and some petrochemical industries. It is sparsely populated with several small towns with populations under 10,000. Beeville, the county seat of Bee County, has a population over 14,000. The major rivers and their upstream tributaries are the Aransas River, Mission River and Copano Creek. The study area is shown in Figure 1-1.

1.2 STUDY OBJECTIVES

The overall objective is to develop a numerical model of the basin for the period of record from 1948 to 1998 that can be used to quantify the surface water available under a range of permitting and planning scenarios. The scope of the WAM effort involves the following tasks:

- Development of naturalized monthly streamflows for the latest 50-year analysis period (1948-1998) at key locations such as stream gaging points (called primary control points);
- Distribution of these naturalized flows to ungaged locations of interest including all diversion points and reservoirs authorized under existing water rights (secondary control points); and

Figure 1-1, San Antonio-Nueces WAM Study Area

- The creation of model input files that contain all relevant information on all existing water rights.

Operation of the model to simulate quantities of water available for diversion or storage by existing and future water rights under eight specified scenarios.

1.3 STUDY APPROACH

Over the last several years, the TNRCC has selected and refined a standard WAM approach using the Water Rights Analysis Package (WRAP) computer program (Wurbs, 2001). The WRAP program was originally developed at Texas A&M University for the specific purpose of simulating diversions and reservoir storage for individual water rights in a river basin under the prior appropriation doctrine, subject to specific hydrologic conditions, reservoir operating procedures, and water right provisions. Since then, the WRAP computer model has been modified in other WAM efforts. This project employs the latest version of WRAP, available at the end of calendar year 2001.

This report is organized into six sections. The second section, following this introduction, describes the existing data available for determining water supplies. The third section describes the method and results obtained for determining naturalized flows. The fourth section describes the WRAP model and its application to the SA-N. The fifth section presents the results of the water availability modeling using WRAP for a range of future assumed conditions. The sixth section presents the overall summary and conclusions.

2.0 EXISTING WATER AVAILABILITY INFORMATION

Data necessary for the streamflow naturalization process include historical gaged streamflows, historical diversions, return flows, reservoir storage change and evaporation data. This study uses existing U.S. Geological Survey (USGS) gaged streamflow data, which are available at several locations. However, the majority of the basin consists of small, ungaged areas. Diversion and return flow data were obtained through the TNRCC's database. Reservoir information and evaporation data were obtained from the Texas Water Development Board (TWDB). Streamflow information was obtained from USGS gages that are described in more detail in Section 3.0. The following sections describe the data used in the WAM analysis in more detail.

2.1 WATER RIGHTS

In order to develop the WAM model, it is important to know the locations and general characteristics of existing water rights relative to control point locations. The TNRCC provided descriptive water rights information, including the locations of diversion points, the authorized annual use amounts, and priority dates. There are 16 water rights in the SA-N, authorized to divert a total of 33,271 acre-feet per year (ac-ft/yr) fresh plus saline water use. Appendix A lists current TNRCC water rights records for the SA-N, sorted by river order number from upstream to downstream and listings sorted by priority date from the first priority to the most recent. These data were retrieved from TNRCC from the WR Detail file dated October 10, 2000.

A permitted water right may consist of several water right records because of different authorized uses, multiple priority dates, multiple diversion points, and amendments.

2.2 HISTORICAL WATER USE

For development of the naturalized flows, surface water use data (historical diversions) were taken primarily from TNRCC water use records. In the event of incomplete historical data, existing data were used to fill in missing periods in the historical record. Refer to Naturalized Flows for the San Antonio-Nueces and Nueces-Rio Grande Coastal Basins (PBS&J, 2001) for more details. However, there were no reported diversions upstream of the primary control points for the SA-N. Of the four permits in the basin that could affect flows, three reported no diversions, and the fourth (City of Refugio) had not completed construction of diversion facilities.

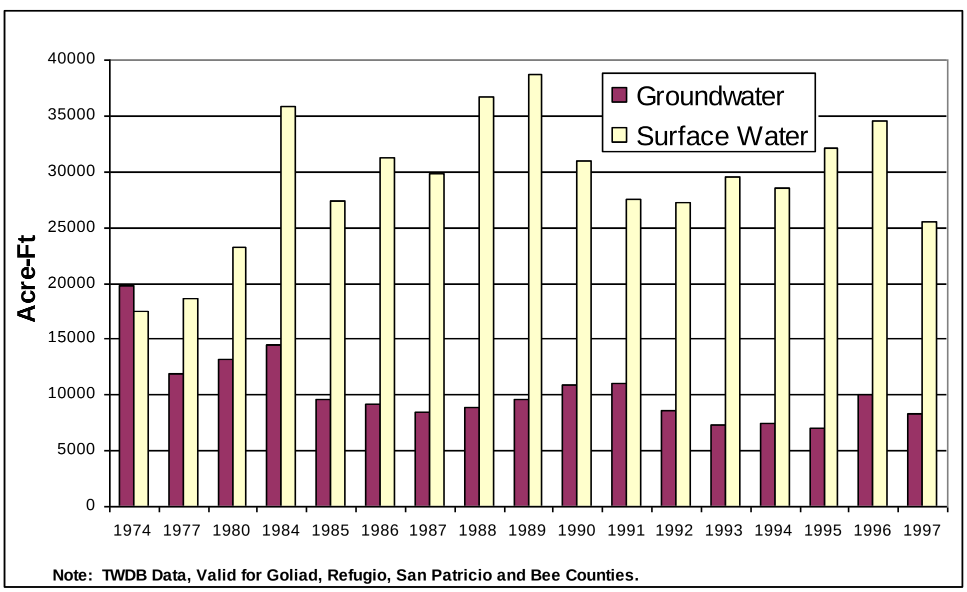
Historical data from wastewater return flows were also used to develop naturalized flows. For municipal uses, correlation with population trends and information from individual water rights holders were incorporated. Similarly, industrial, domestic, commercial and agricultural uses were estimated when records were not available, based on historical patterns in similar areas with historical data. Where historical water use could not be determined or estimated, the values were assumed to be zero. This is the most conservative approach since historical diversions are added to streamflow values in the naturalization process.

Figure 2-1 shows TWDB (2002) surface and groundwater use for four counties (Goliad, Refugio, San Patricio and Bee) that approximate the SA-N study area. It can be seen that groundwater is the larger supplier of the area. The distribution of uses in the four counties are:

	Use Percentage	
	Groundwater	Surface Water
Municipal	60.5%	25.6%
Manufacturing	0.4%	32.4%
Power	1.1%	30.3%
Irrigation	30.0%	1.5%
Mining	3.0%	0.2%
Stock	5.1%	9.9%
Total	100.0%	100.0%

Note that since the study area boundary is somewhat different from that of the four counties, these water use data will not match exactly with the records and analysis in the rest of the report. They are provided for insight into the general patterns of water use in the region.

Figure 2-1: Texas Water Development Board Water Use Data



2.3 HISTORICAL RETURN FLOWS AND TREATED WASTEWATER EFFLUENT DISCHARGE

TNRCC wastewater discharge permit self-reporting records were used to estimate return flows in the WAM process. This permit information covers industrial and municipal wastewater discharges provided in the TNRCC wastewater discharge self-reporting data. Table 2-1 provides a summary of wastewater discharge permits and their flow limits for dischargers. Self-reporting records were obtained for available data for the period of record that the discharge has been active. These flow records are also used to estimate return flows from earlier periods. Missing information was estimated using historical water use and population data. Individual entities were contacted to enable determination of the historical effects of return flows on the gaged streamflow records.

Return flows from irrigated lands are part of historical streamflows. A portion of the irrigation return flows comes from irrigation water diverted from surface streams, and a portion of the water is obtained from groundwater pumping. However, only limited data are available for irrigation return flows. While there may be some contribution from irrigation return flows to basin streams, no reliable estimates were found to document the source in this basin. This return flow would undoubtedly be a very small contribution due to the aridity of the area and the soil permeability. Accordingly, irrigation return flows were not quantified in the SA-N. Consequently, the naturalized flow process may have reported less water than is actually available. Figure 2-2 shows the locations of return flow points.

Only two return flow points are modeled, which add a total of 851 ac-ft/yr of groundwater into the SA-N from the wastewater treatment plants for the Cities of Refugio and Sinton.

2.4 PREVIOUS WATER AVAILABILITY AND PLANNING STUDIES

While there have been evaluations of water quality in the basin (e.g., the TNRCC 305(b) report, 2002), a previous water availability study for the basin was not located.

2.5 SIGNIFICANT CONSIDERATIONS AFFECTING WATER AVAILABILITY IN THE BASIN

No special considerations regarding water availability have been identified for the SA-N.

Table 2-1, Wastewater Discharges, San Antonio-Nueces Coastal Basin

Figure 2-2

3.0 DEVELOPMENT OF NATURALIZED STREAMFLOWS

This section presents the methodology and results of the streamflow naturalization process.

3.1 STREAMFLOW NATURALIZATION METHODOLOGY

Naturalized flow development was presented in the report, Naturalized Flows for the San Antonio-Nueces and Nueces-Rio Grande Coastal Basins (PBS&J, 2001), intended to be used as a reference to this document. The following paragraphs briefly summarize how naturalized flows are defined.

Naturalized flows are defined as those flows expected in a water body without human influence or intervention. Naturalized flows are used as a baseline to which different demand scenarios may be compared for permitting and/or planning. For permitting purposes, the full paper water rights are used, and for planning purposes, the demands are varied depending on the conditions to be evaluated.

For basins such as the SA-N where gaged streamflows are used, the general equation for calculating naturalized flows is:

$$NF = GF_h + D_h - Rf_h + S_h + E_h$$

Where:

NF	=	Naturalized Flow (ac-ft)
GF_h	=	Historical Gaged Flows (ac-ft)
D_h	=	Historical Diversion (ac-ft)
RF_h	=	Historical Return Flows (ac-ft)
S_h	=	Historical Storage Change in Reservoir (ac-ft)
E_h	=	Adjusted Net Reservoir Evaporation Loss (ac-ft)

Essentially, creating naturalized flows from gaged records is a process of systemically removing the influence of man from the records. This process was followed in the SA-N.

Control points were assigned at the five USGS gaging stations. Table 3-1 provides details on the five gages, and Figure 3-1 shows the relative location of the gages. Gage 08189500 (Control Point MR_RE) has been monitoring the flow during the complete period to be used in the WAM modeling effort.

Table 3-1: USGS Gaging Stations Used as Control Points

Gage	Name	Period of Record	Drainage Area	ID
08189200	Copano Creek near Refugio	July 1970 - December 1998	87.8 mi	CC_RE
08189300	Medio Creek near Beeville	March 1962 - September 1977	204 mi	MC_BE
08189500	Mission River at Refugio	July 1939 - December 1998	690 mi	MR_RE
08189700	Aransas River near Skidmore	April 1964 - December 1998	247 mi	AR_SK
08189800	Chiltipin Creek at Sinton	August 1970 - September 1991	128 mi	CC_SI

Figure 3-1, Study Area for the SA-N Coastal Basin

3.2 ADJUSTMENTS TO FLOWS AT GAGES

Return flows from irrigated lands are a part of historical streamflows. However, this does not appear to be a significant component of the flows in the SA-N.

Another factor in producing naturalized flows is accounting for the effects of reservoirs. There is only one small reservoir located above the assigned control points. With 240 ac-ft of storage capacity, this reservoir would have no significant impact on the flows in the basin.

Another major part of producing naturalized flows is estimating the values for missing flow records based on best available data. Typically, this involves using flow data from nearby gages adjusted for watershed conditions. Where data are filled, they are shaded to ensure that the user of the information is aware of the source, and the correlation with the nearby gage is presented to indicate goodness of fit.

The following sections describe the adjustments made in the flow records to obtain naturalized flows for the SA-N. For more detail on the methodology, refer to Naturalized Flows for the San Antonio-Nueces and Nueces-Rio Grande Coastal Basins (PBS&J, 2001).

CC_RE – Gage 08189200, Copano Creek near Refugio (1970-1998)

There are no diversions or wastewater discharges above this control point. The flows at the gage are thus the natural flow. Gage 08189200 has a period of record from 1970 through 1998. The period of record was extended using a relationship between the natural flows at nearby gage 08189500, Mission River at Refugio. The correlation between the two gages during the period 1970-1998 had an r-square of 0.7592. Appendix B, Table B-2, shows the filled natural flows at gage 08189200.

MC_BE – Gage 08189300, Medio Creek near Beeville (1962-1977)

Water Right 4498 (Appendix A) is located above gage 08189300 but TNRCC records indicate the water right holder has not reported any diversions for this water right. The City of Pettus discharges wastewater above the gage and records of the discharges are available starting in 1977. Table B-3 (Appendix B) contains the self-reported discharges for the City of Pettus, converted from million gallons per day (MGD) to acre-feet per month (ac-ft/mo).

The period of record for gage 08189300 is 1962 through 1977. The records were expanded by filling in the missing periods using the ratio of the total flow for the period 1962 through 1977 for gage 08189300 to the total flow at gage 08189500 for the same period. The r-squared value between the two gages during that period was 0.70562. Table B-4 (Appendix B) is the resulting naturalized flows for the period 1940 through 1998.

MR_RE – Gage 08189500, Mission River at Refugio (1939-1998)

Gage 08189500, Mission River at Refugio, has two water rights and two wastewater discharges above this control point (see Figure 3-1). Records of the TNRCC indicate that no diversion occurred above the control point MR_RE during the period 1940 through 1998. The City of Refugio has operated a wastewater treatment plant above the gage site since 1954, and the City of Pettus has operated a plant since the late 1970s. Both cities rely on groundwater to meet their municipal needs, and thus, the discharges should be considered to be from a groundwater source. Table B-5 (Appendix B) shows the total discharges above the Refugio control point. Table B-6 (Appendix B) shows the resulting naturalized flows when the reported diversions are added and the wastewater discharges are removed from the gage flows. In 1989 for several months, the reported wastewater discharges were greater than the measured flow at this location. Therefore, the small volumes of negative flows were adjusted to zero for use in the WAM model for the basin.

AR_SK – Gage 08189700, Aransas River near Skidmore (1964-1998)

Gage 08189700 has a period of record from 1964 through 1998. There are two water rights above the gage. The water rights holders have reported no diversions to the TNRCC. Above the AR_SK control point, the City of Beeville discharges wastewater from its treatment plants with at least one plant in operation since 1940. Table B-7 (Appendix B) shows the estimated and reported discharges for the Beeville plants. When naturalizing the flows, a number of negative flows resulted, which could be from over estimation of the discharges when no data were available. Where the results were negative the flows are set to zero for use in the WAM model of the basin. The naturalized records were extended using statistical relationships between the natural flows at gage 08189500 and this gage. The correlation between the two gages for the period 1964-98 had an r-square of 0.8048. Table B-8 (Appendix B) displays the resulting naturalized flows.

CC_SI – Gage 08189800, Chiltipin Creek near Sinton (1970-1991)

There are no diversions above gage 08189800 near Sinton. While the community of Saint Paul's wastewater treatment plant discharges would flow past the gage, there were no reported discharges from the plant. The operator confirmed that there had been no discharges because the combination of infiltration and evaporation exceeds the wastewater flow. The flows at the gage could be considered natural. The period of record for the gage is 1970 through 1991. The flow records were extended using statistical relationships between the flows at gage 08189500 and the flows at gage 08189800. The correlation between the flows at the two gages had an r-square of 0.61. Table B-9 (Appendix B) displays the naturalized flows for gage 08189800.

Discussion of Naturalized Flow Results

Table B-10 (Appendix B) presents a side-by-side comparison of the original gaged records with the naturalized flow records at the 10th, 25th, 50th, 75th and 90th percentile values and the maximum value for each month. A description of the comparative differences follows.

The Mission River at Refugio (08189500) has a complete period of record with only minor changes due to return flows and diversions. As a result, the gaged and naturalized percentile flow values are nearly identical. For several of the other gages with no discharges or diversions, the main source of difference was due to ungaged years that were filled in using a ratio of data from the Mission River at Refugio gage. This results in some differences particularly at the lower percentile values, primarily because many of the smaller gages have zero flows, while the Mission River generally does not. In marked contrast, is gage 08189700, Aransas River near Skidmore, where the gaged flows at the 10th and 25th percentiles are higher than the naturalized values. This appears to be the result of removing wastewater from the record that produced very low or zero naturalized flows. Overall, the differences between gaged and naturalized flows appear to be within the range of expected values.

3.3 DELIVERY FACTORS AND CHANNEL LOSS RATES

Early on, it was recognized that in a coastal basin with relatively sandy soils and high evaporation rates, it would not be uncommon to have streamflows diminish rapidly during dry periods. However, it was recognized that this process is highly variable both spatially and temporally. An analysis was performed to determine the different soil types and curve number (CN) values that could approximate the variances. This is presented in the Channel Loss Memorandum in Appendix C.

To calculate the delivery factor, the channel loss percentage was applied to the longest stream segment provided in the CRWR ArcView® coverage of the SA-N. This produced a percent loss per mile, which was then applied to each incremental stream segment in the basin. This analysis produced a channel loss factor of 0.48% per mile.

3.4 STATISTICAL ASSESSMENT OF TRENDS IN STREAMFLOW

Because streamflows are measured in only a few locations, the trend analysis was centered on the available flow data. Figure 3-2 shows the historical annual average flows for each of the gages employed. From this figure, it is clear that there are substantial differences year to year in all gage records, with prolonged lower amounts in the mid-1950s and 1960s. A statistical test was performed to see if there was a long-term trend in the data that was significant at the 5% level. For all gages, it was impossible to reject the null hypothesis that there was no long-term trend at the 5% level. Stated in less statistical terms, there is no long-term trend to a 95% certainty.

Figure 3-2

3.5 NATURAL STREAMFLOW AT UNGAGED LOCATIONS

Flows at locations downstream of the most downstream control points were estimated based on the flows at gage 08189200, Copano Creek near Refugio. The flows at this gage were considered to be natural flows since there were no diversions or wastewater discharges above this point. Flows from this gage were adjusted for watershed area and applied to estimate the flow at the ungaged locations in this basin. This gage was selected because it was the closest geographically and because it had the smallest area that was most like the small areas near the bays.

3.6 NET RESERVOIR EVAPORATION

The adjusted net evaporation for a particular reservoir can be determined using known USGS quadrangle gross evaporation amounts and monthly precipitation amounts obtained from the TWDB, such that:

$$\text{Adjusted Net Evaporation}_{quad} = \text{Gross Evaporation}_{quad} - \text{Monthly Precipitation}_{quad}$$

The monthly amount of evaporation applied to a given reservoir is then determined by multiplying the adjusted net evaporation amount by the surface area for each month.

In the SA-N there are nine permitted reservoirs, all of which are relatively small. There are no reservoirs in the SA-N with a capacity larger than 5,000 acre-feet, the minimum size criteria for detailed analysis in this WAM study. Thus, adjusted net evaporation was not required in this WAM study.

3.7 MINOR RESERVOIR COEFFICIENTS

Standard elevation-area-capacity relationships have been used in the water availability analyses for small reservoirs with less than 5,000 ac-ft of storage. The Soil Conservation Service (SCS), now the Natural Resource Conservation Service (NRCS), was involved in the design and construction of many similar impoundments within the SA-N, and area-capacity curves for these impoundments were obtained from the NRCS office in Temple, Texas. The TNRCC dam safety files and water rights files were examined to locate additional area-capacity curves for small impoundments within the SA-N.

For small reservoirs, standardized area-capacity curves have been generated using an equation of the form:

$$\text{Area} = a(\text{Capacity})^b + c$$

This form of equation, known as a power function, is the only equation form available to represent area-capacity relationships in WRAP. To obtain the coefficients a, b, and c, regression analyses of available area-capacity data for existing small reservoirs have been conducted. All available area-capacity curves for the small reservoirs in the SA-N were plotted, and power function regression analyses were used to obtain the best-fit equation, as outlined in the WRAP manual. The data were plotted based on area and capacity values obtained for the reservoirs. Area values were plotted in acres and storage in acre-feet. After plotting the points, an equation was obtained to best represent the data relationship with the following coefficients, including the r-square (R^2) for the best-fit line.

$$a = 1.3317 \qquad b = 0.7536 \qquad c = 000 \qquad R^2 = 0.9199$$

The graphs for the equation shown above and the original data points are shown in Figure 3-3. The area-capacity relationship developed for small reservoirs with capacities less than 5,000 ac-ft is:

$$\mathit{Area} = 1.3317(\mathit{Capacity})^{0.7536} + 0.00$$

These coefficients are then used by WRAP to determine the area of each reservoir for a given month.

3.8 AQUIFER RECHARGE

The primary groundwater source in the basin is the Gulf Coastal Aquifer. The Gulf Coast Aquifer forms a wide belt along the Gulf of Mexico from Florida to Mexico. The aquifer consists of complex interbedded clays, silts, sands, and gravels of Cenozoic age, which are hydrologically connected to form a large, leaky artesian aquifer system. Maximum total sand thickness ranges from 700 feet in the south to 1,300 feet in the northern extent. Recharge to this aquifer occurs throughout the basin and is accounted for in the WAM process through channel losses, as described in Section 3.3.

Figure 3-3, Standard Area-Capacity Curve for Reservoirs Less Than 5,000 Acre-Feet

4.0 WATER AVAILABILITY MODEL OF THE BASIN

4.1 DESCRIPTION OF WRAP MODEL

The WRAP computer model simulates water quantity in a river basin under a priority-based water allocation system. The WRAP model facilitates assessment of water availability and reliability for existing and proposed water rights. Basin-wide impacts of water resources development projects and management strategies may be evaluated based on this information. Model results may also be used to analyze a river basin's capacity to satisfy existing water use requirements and the potential for additional water right applications. Basin-wide impacts of changes in water use may also be assessed. Reservoir system simulation studies can be performed to evaluate alternative operating policies for existing facilities or the impacts of constructing new projects.

The generalized computer model provides capabilities for simulating a stream/reservoir/use system involving essentially any stream tributary configuration based on specified priorities. The model is designed to analyze river basins that may have hundreds of reservoirs, hundreds of water supply diversions, complex water use requirements, and complex water management practices. However, it is applicable to relatively simple systems as well. Water management/use may involve reservoir storage, water supply diversions, return flows, environmental instream flow requirements, and hydroelectric power generation, including multiple-reservoir system operations. Flexibility is provided for modeling the various rules specified in water rights permits governing water allocation and management.

4.2 DEVELOPMENT OF WRAP WATER RIGHTS INPUT FILE

A typical WRAP simulation involves assessing capabilities for meeting specified water management/use requirements during a hypothetical repetition of historical hydrology. WRAP uses a monthly time step with no limit on the number of years in the hydrologic period-of-analysis. Annual water use targets, with seasonal use variations over the 12 months of the year, are combined with sequences of naturalized streamflows and reservoir net evaporation-precipitation rates representing basin hydrology. Volume accounting computations associated with meeting the water rights requirements are performed sequentially for each month of the hydrologic period-of-analysis. The simulation results provide information regarding regulated flows, unappropriated flows, reservoir storage levels, and reliability indices for meeting water use requirements.

Water rights, input files, and river basin control point schematic were created using the revised TNRCC master water rights list, the written certificates of adjudication and water rights permits, TNRCC adjudication maps, and geo-referenced data from the TNRCC (obtained from the CRWR). The basic steps included in creating the water right input card include:

- Identifying primary and secondary control points (as described in Section 4.2.1);
- Obtaining all water right diversion locations from TNRCC;
- Determining diversion amounts, use types, and priority dates for all water rights within the basin;
- Determining impoundment amounts for water rights, storage, and reservoir information (input in the WS card);
- Compiling and computing return flows for all industrial and municipal water right diversions including interbasin transfers (IBT);
- Computing monthly distribution factors to distribute annual diversion amounts;
- Creating a control point schematic; and
- Inputing naturalized streamflow and evaporation data.

Each task methodology is described in the following sections.

4.2.1 Control Points

Control points are used in the WRAP program as a means of spatially referencing the position of all inflows and outflows in a river basin. The actual formulation of the basin schematic used for the WRAP program is done in the CP record. The CP record lists control points and their immediately downstream counterparts. The river layout is reproduced in the CP record by listing each control point and following it with the next downstream control point. Appendix D contains the control point characteristics table, which provides further information related to control points such as drainage area, curve number and precipitation. Water right identification numbers are correlated with control points in Section 5. In the SA-N WAM, control points were segregated into two distinct types:

- Primary control points – five points located at USGS streamflow gage locations, and
- Secondary control points – points located at water right diversions or impoundments, water import locations, groundwater return flow sites, return flow sites, and classified water quality stream segments that are not primary control points.

Naturalized streamflow is distributed by WRAP to these secondary control points. In this case, distribution was based on the drainage area ratio with channel loss (INMETHOD 6). Table 3-1 lists the primary control points for the basin. These primary control points were selected using the following general criteria:

- Streamflow gages with over 20 years of record and drainage areas over 100 sq mi;
- Spatial distribution of primary control points throughout the basin; and
- Reservoir control points were avoided if possible due to the difficulty in obtaining accurate information on reservoir discharges.

There was one exception to the above criteria. One primary control point was developed to define the incremental watershed of the SA-N below the five gaged control points. This control point (10000) was created at a location where there was no USGS gage. Therefore, incremental flows were calculated by using a representative gage with a complete period of record and applying the drainage area ratio.

The control points with calculated flows (primary) are discernable from control points with estimated flow (secondary) by the alphanumeric nomenclature assigned to the control point. Also, the two types of control points were labeled in different manners in the model. Primary control points were labeled using an numeric six-digit code that represents the name of the USGS gage (e.g., CC_RE, Copano Creek near Refugio, was labeled as A10000). All primary control points were labeled as a letter of the alphabet with the number 10000. Secondary control points were also labeled using an alphanumeric six-digit code. Their code corresponds to the next primary control point downstream. The secondary control points were coded downstream to upstream. For example, the first point upstream of the primary control point was labeled A10010.

The six-digit code is in the form: AXXXXX, and is defined below:

- A identifies the primary control point, and
- XXXXX represents the relative location to the primary control point.

The water quality stream segment control points were identified as part of the CRWR dataset and used as secondary control points with no diversions at the points. The water quality stream segments were also numbered with the six-digit code. Again, the letter in the first character of the name identifies which primary control point the water quality stream segment is associated with.

4.2.2 Water Rights

Water rights are defined in the WRAP model with parameters for permitted diversions, priority, and reservoir storage. This is accomplished in the WR records of WRAP, which formulate the manner in which a particular water right is configured. In the WR records, a permitted diversion is defined by one or several WR cards based on the language of the Permit or Certificate of Adjudication (CA). For example, a water right with more than one diversion point, or having multiple uses will have more than one WR record to represent the permit in the model.

Water rights are identified using an eleven digit numeric code in the form of TBBWWWWWFFF, as defined below:

- T represents the type of water right, where:
  - 6 is for Certificate of Adjudication, and
  - 1 is for an Application.
- BB represents the Basin Number.
- WWWWW represents the Water Right Number.

- FFF represents the Diversion Point Numbers, where:
  - 001-100 diversion point;
  - 101-200 downstream boundary of diversion area;
  - 201-300 upstream boundary of diversion area;
  - 301-400 on-channel reservoir;
  - 401-500 off-channel reservoir;
  - 501-600 return flow points;
  - 601-700 off-channel diversion point; and
  - 901-999 other.

Water rights in the SA-N for Scenario 1 are listed in Appendix A. This table gives each water right location, permitted diversion amount, use type, priority date, and how each water right permit was segregated into multiple parts.

4.2.2.1 Monthly Demand Distribution Factors

Diversion amounts associated with each water right were input into the WR record in WRAP (version 11/01) as an annual amount in ac-ft/yr. The annual values are then distributed by the monthly distribution factors for each use type as specified in the UC record in WRAP. Seasonal use (demand) patterns were determined from historical consumption data submitted annually to the TNRCC by the water right holders. No significant trend of water demand pattern was indicated from one region to another in the SA-N. Therefore, only one set of use data for each type of water use for the entire basin was used.

4.2.2.2 Priority Dates

Priority dates were derived directly from hard copies of water rights obtained from the TNRCC. While most water rights have only one priority date, some have multiple priority dates. Multiple priority dates may be found on water rights with multiple diversions, with multiple reservoir impoundments, or in amended water rights.

Some water rights were characterized by multiple entries based on priority dates for storage, use types, as well as diversion locations. The format of the priority dates is YYYYMMDD, defined as:

- YYYY represents the four-digit year for Y2K compliance;
- MM represents the month by the two-digit code; and
- DD represents the day of the month in a two–digit code.

4.2.2.3 Treatment of Reservoir Storage

The maximum storage for a reservoir is specified in the TNRCC water right permit or certificate of adjudication. For reservoirs having multiple priority dates for storage, WRAP requires multiple WR and

WS records to represent the different priority dates assigned to reservoir storage. Storage in a reservoir is filled only after meeting the needs of senior water rights. Incorporating these different reservoir storage levels by priority date allows the WRAP (version 11/01) model to fill a reservoir only when flow is available based on the specific priority date.

4.2.2.4 Return Flows

Return flow in the SA-N associated with water right diversions and groundwater use were input into WRAP as a constant monthly amount. All groundwater return flows were modeled using the constant inflow (CI) record to provide continuous return flows throughout the simulation period.

For this study, the CI records are used for wastewater discharge facilities that discharge groundwater only. Groundwater return flow input into the CI record is the minimum return flow amount for each facility over the last five (5) years of the period of record (1994 to 1998). The underlying assumption used for the CI record is that municipal use will be continuous throughout the period of record and this water will always be returned. The amount returned is only a function of the return flow percentage (100%, 50%, 0%), depending on the individual modeling scenarios amount of groundwater.

Return flow from irrigation water rights are assumed to be insignificant, and are not modeled. Industrial and municipal water rights were assigned return flow percentages as described in the following discussion.

There were two wastewater treatment return flows included in the modeling of the basin, City of Refugio and City of Sinton. These return flows were less than 1 MGD, but were the only flows that could impact some water rights' reliabilities. The water supply for both of these return flows was determined to be groundwater. All remaining return flows which originated from groundwater supplies had small discharge amounts and were therefore not modeled. No return flows were distributed in the surface water portion of the model through the WR Record.

4.2.2.5 Multiple Diversion Locations

Water rights containing multiple diversion locations in the SA-N are Permit 5024, Reynolds Metal Company is a saline water right and is not modeled, and Permit 5366, Welder Wildlife Foundation is modeled with a 1,000-ac-ft/yr diversion.

4.2.2.6 Saline Water Rights

Saline water rights in the SA-N are listed below:

- CA 4503, Texas A&M University;
- Permit 4415, H.J. Ewald, Jr.;

- Permit 5024, Reynolds Metal Company; and
- Permit 5100, J.T. Stellman.

Saline rights were included in the model as control points but were excluded from the flow calculations. This was handled by "commenting out" the saline right control points.

4.2.2.7 Rights Requiring Special Consideration

There are two IBTs that are permitted to discharge water into the SA-N: CA 14-5434 (from the Colorado River Basin) and CA 16-2095 (from the Lavaca-Navidad Coastal Basin). Neither of these rights were included in the SA-N model. CA-5434 was not included because there is no pipeline built and no current plans to deliver water from the Colorado River to the SA-N. In CA 16-2095, the IBT is permitted to go to numerous basins; however, in reality, the water does not go to the SA-N. CA 16-2095 provides water to the City of Corpus Christi and returns the flow through the city's wastewater treatment plants. CA 16-2095 was not included in the model because these wastewater treatment plants do not discharge into the SA-N.

Appendix C contains a brief discussion of the assumptions utilized in representing selected water rights in WRAP.

4.2.3 Data for Basin-Specific Features Added to WRAP (Version 11/01)

There were no basin specific modifications made to WRAP for the SA-N WAM (as noted in Appendix H).

4.3 SIGNIFICANT ASSUMPTIONS AFFECTING WATER AVAILABILITY MODELING

The single most significant assumption in this study regarding water availability is the manner in which naturalized flows are distributed from gaged to ungaged sites. The key assumptions in this case are the parameters which are used to distribute the flows, mainly the drainage area ratio with channel loss. Additional modeling assumptions, which have a significant impact on water availability, are described in the following sections. A list of modeling assumptions for each water right is in Appendix C. The modified curve number method was not used because of problems with the routine used in WRAP to distribute the incremental flows. At the time of the development of this report the curve number routine may have a tendency to calculate curve numbers greater than 100 or negative curve numbers. However, the CRWR supplied average curve numbers are included in the WRAP-HYD, *.DIS input deck for use when the curve number, flow distribution method is resolved.

4.3.1 Reuse

Wastewater reuse in the model was formulated for 100%, 50%, and 0% reuse of return flows. Reuse data were provided by TNRCC, and it was assumed that all existing reuse projects are included in the historical return flow data obtained from the TNRCC. This data was analyzed for the past 5 years for all water rights with permitted diversions.

4.3.2 Return Flow/Constant Inflow Assumptions

The CI record can be utilized by the WRAP (version 11/01) model to account for inflow of groundwater and/or surface water from other basins. In this study, the CI record was used to incorporate inflows from groundwater only. There were only two groundwater CI records used in the SA-N: at 10020, representing a wastewater treatment plant for the City of Refugio, and 10310, representing a wastewater treatment plant for the City of Sinton. TNRCC wastewater discharge permit records were used to estimate return flows. Missing information was estimated using historical discharges and population data.

4.3.3 Off-Channel Reservoirs

There are numerous off-channel reservoirs in the SA-N. Generally, for those water rights with multiple off-channel reservoirs, a single reservoir representing the sum total of all capacities was simulated. With this combination, a total of seven off-channel reservoirs were modeled in the SA-N. WRAP simulates off-channel reservoirs by limiting the streamflow depletions which are made to meet diversions and refill storage. These constraints are defined as annual limits, which limits the cumulative annual streamflow depletion and a monthly limit, which defines the maximum streamflow depletion for any given month. Water rights with off-channel impoundment and how they were modeled are described in the Modeling Assumptions Memorandum in Appendix C.

4.3.4 Term Permits

Term permits are issued primarily to industrial, mining, and agricultural enterprises, usually for 10 years. The term can be renewed if, after 10 years, water in the basin is still not being used by other water right holders. There are no term permits in the SA-N.

5.0 WATER AVAILABILITY IN THE BASIN

TNRCC has established guidelines for the modeling scenarios to be employed with each WAM study, as set forth in the WAM Resolved Technical Issues document (TNRCC, 2001). Water availability in the SA-N was analyzed using the WRAP system (Wurbs, 2001) by comparing standard model scenarios. These scenarios may be used to determine the character of water availability in the SA-N based on varying amounts of return flows (wastewater reuse) and the diversion amounts for a range of cancellation scenarios.

There are both fresh surface water rights and saline water rights. The major tributaries in the basin include the Aransas River, Mission River and Copano Creek. The fresh water rights are located in the Aransas and Mission River watersheds. The saline rights are located adjacent to the coastal areas, as shown in Figure 5-1 (see Appendix I, Figure I-1, for a detailed map of SA-N subwatersheds and secondary control points). These saline rights are included in the water availability model as comments and do not have an effect on any of the flow values presented in this report.

5.1 DESCRIPTIONS OF SCENARIOS MODELED

The purpose of the WAM effort is to determine the water available and the reliability of individual water rights. This is accomplished through a series of simulations set forth by TNRCC in the WAM Resolved Technical Issues document (TNRCC, 2001). This document identifies nine different simulations designed to provide the necessary information related to water availability and reliability. Due to the nature of the basin, only eight of the nine simulation runs were required. The eight modeling runs completed for the basin included: reuse runs (3), cancellation runs (4), and a current conditions run. The ninth modeling run, the Firm Yield Analysis, did not apply in this WAM study because all of the reservoirs were considered to be minor and were less than 5,000 ac-ft in capacity. Each of the modeling scenarios is described in Table 5-1, which summarizes the characteristics that vary by run as used for this project.

5.1.1 Reuse Runs

Runs 1, 2 and 3 simulate variations in water availability based on the amount of wastewater return flow reuse. The runs all utilize the authorized diversion amounts and authorized area-capacity parameters. Term water rights are not included in the reuse runs. The runs vary only in the percent of return flows modeled, with Run 1 modeled at 0% reuse, Run 2 at 50% reuse, and Run 3 at 100% reuse. The results are designed to allow analysis of the effects of wastewater return flow on water reliability and availability.

Figure 5-1

Table 5-1: Summary of Simulation Run Characteristics

Run Type	Run #	Diversion Amount	Area-Capacity	Return Flow Amount	Cancellation	Term Water Rights
Reuse	1	Authorized	Authorized	100%	None	No
	2	Authorized	Authorized	50%	None	No
	3	Authorized	Authorized	0%	None	No
Cancellation	4	Authorized	Authorized	100%	Total	No
	5	Maximum in last 10 years	Authorized	100%	Partial	No
	6	Authorized	Authorized	0%	Total	No
	7	Maximum in last 10 years	Authorized	0%	Partial	No
Current Conditions	8	Maximum in last 10 years	Year 2000	100%	Partial	Yes

5.1.2 Cancellation Runs

The next series of runs, Runs 4, 5, 6 and 7, are each designated as cancellation runs. These runs simulate water availability based on partial or full cancellation of water rights. Partial cancellation involves setting the diversion amounts to the maximum reported use in the last 10 years. Total or full cancellation is based on cancelling the rights with zero reported use in the last 10 years and setting those water rights that did divert to their maximum authorized use. Table 5-7 (page 5-15) lists the authorized diversions with their cancellation record during these runs. In addition to cancelling certain water rights, the cancellation runs also vary the level of wastewater reuse. Runs 4 and 5 include full return flows, while Runs 6 and 7 do not include return flows. An additional variation involves the diversion amount. Runs 4 and 6 use authorized diversions, and Runs 5 and 7 use the maximum amount reported in the last 10 years. All of the cancellation runs use the default reservoir authorized area-capacity curves, and no term water rights are included. Note that no irrigation return flows are simulated. The resulting four runs allow comparisons with the reuse runs to determine the effects of partial or total cancellation under different scenarios of diversion amount and return flow.

5.1.3 Current Conditions Run

Run 8 uses the Year 2000 area-capacity parameters, with 0% reuse (normal return flow) and would include the term water rights. The annual diversion amount is set to the maximum for the last 10 years. This simulation allows the comparison of the best representation of current conditions (Run 8) with reuse Run 1. However, since there are no term water rights in the SA-N and all SA-N reservoirs were considered minor, Run 8 is the same as Run 5.

5.2 RESULTS OF WATER AVAILABILITY MODEL RUNS

The WRAP system (Wurbs, 2001) was used to simulate the eight water availability scenarios. The input, inflow, evaporation and flow distribution/watershed parameter files are presented in Appendix E. A diagram depicting the connectivity between the secondary and primary control points modeled is presented in Figure 5-2. A summary of the diversion amounts for the eight modeled runs is given in Table 5-2. The following subsections of Section 5.2 present an analysis of the resulting reliability for all of the water rights, and the regulated and unappropriated flows are presented for all primary control points (A10000, B10000, C10000, D10000, and E10000), the catch-all point, 10000, and selected secondary points, 10047 and 10045. The two secondary control points are chosen because they are the furthest downstream control points on the Mission River (10047) and Aransas River (10045). The rights with zero diversion are either reservoirs with no diversion authorized or have no consumptive use. Emphasis is placed on the control points 10000, 10047 and 10045 because these are the most downstream points of their respective basins. See Figures 5-3, 5-4, and 5-5 for graphs of the calculated unappropriated flows for the period of record.

Table 5-2: Summary of Diversion Amount for Each Model Run

TNRCC ID Number	Control Point	Total Annual Diversions (ac-ft/yr)							
		Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
12004521301	10000	557	557	557	557	232	557	232	232
12004521401	10000	0	0	0	0	0	0	0	0
12004547001	10000	0	0	0	0	0	0	0	0
12005283001	D10000	150	150	150	0	0	0	0	0
12005291001	D10000	60	60	60	0	0	0	0	0
12005366401	10000	1000	1000	1000	1000	496	1000	496	496
12005421301	C10000	0	0	0	0	0	0	0	0
62004498301	B10000	0	0	0	0	0	0	0	0
62004499401	10000	94.9	94.9	94.9	94.9	17	94.9	17	17
62004501301	10000	0	0	0	0	0	0	0	0
62004502301	10000	15	15	15	0	0	0	0	0
	SUM	1876.9	1876.9	1876.9	1651.9	745	1651.9	745	745

The results of the period and volume reliability are given in Table 5-3 for all water rights within the SA-N for each of the eight model scenarios. Additionally, a comparison summary is presented in Appendix F, Tables F-1, F-2 and F-3 for the reuse, cancellation, and current conditions runs, respectively. The period reliability denotes the percentage of time for which the demand target is fully met; or equivalently, the probability of the demand being met in any randomly selected month. The volume reliability is the total volume of actual diversions available during the simulation period of analysis expressed as a percentage of the corresponding total permitted, target diversion.

Figure 5-2

Figure 5-3

Figure 5-4

Figure 5-5

Table 5-3

Table 5-3, 2 of 3

Table 5-3, 3 of 3

Regulated and unappropriated streamflows at a control point are of particular interest, because these flows may be used to compare the total amount of water remaining to the total amount of water available for future diversions. Specifically, the regulated streamflow is the streamflow remaining after all diversions have been made plus the volume of water accounting for instream flow requirements. The unappropriated streamflow is the water remaining after all streamflow depletions and return flows have been made (the water available for future diversions.) A summary and run comparison for the regulated and unappropriated flows are given in Appendix G (Tables G-1, G-2 and G-3) for the reuse, cancellation, and current conditions scenarios. A graphical representation of the unappropriated flow for Run 1 and the difference between Runs 2 through 8 from Run 1 are given in Figures 5-3, 5-4, and 5-5. Regulated streamflows may be equal to unappropriated flows if there are no return flows upstream and the unappropriated flow is greater than the instream flow requirements. For the SA-N models, regulated and unappropriated flow are almost always equal or within +/- 0.1%.

A comparative analysis of reliability, regulated and unappropriated flow was conducted by subtracting Run 1 from Runs 2 through 8, and Run 3 from Runs 6 and 7 for the cancellation scenarios in order to better isolate the effects of cancellation, since Runs 3, 6 and 7 all have 100% reuse. The results of the difference in regulated and unappropriated flow between these runs is presented in Table 5-4 for the primary control points and the most downstream points on Mission River (10047) and Aransas River (10045).

5.2.1 <u>Wastewater Reuse Runs</u>

The details of the reliability analysis and a summary of the difference between Runs 2-Run 1 and Run 3-Run 1 are presented in Appendix F, Table F-1. A summary of the difference between these runs is presented in Table 5-5. In general, the reliability, both in volume and time, of water in the SA-N is high for the six nonsaline water rights authorized to divert water (see Table 5-3). Additionally, the regulated and unappropriated flows do not vary significantly between the wastewater reuse runs. As a result, no water rights are dependent on return flow to achieve targeted diversion amounts.

5.2.1.1 Reliability

The lowest period and volume reliability for water rights in the SAN are 73.2 and 76.9% (Table 5-3). As seen in the difference columns of Appendix F, Table F-1, and summarized in Table 5-5, the three reuse runs have identical reliabilities. This is because the return flows in the SA-N are not very significant. There are only two return flows in the SA-N ranging between 25 and 48 ac-ft/mo with a total annual return flow of 851 ac-ft/yr. The authorized diversions for the SA-N are relatively low. The largest water right modeled is only authorized to divert 1,000 ac-ft (permit #5366), and the remaining water rights are only 15 to a few hundred ac-ft/yr (see Table 5-6). There is no clear trend between the size of the authorized diversion and the reliability for the three reuse runs as seen in Appendix F, Table F-1.

Table 5-4: Average Difference in Regulated and Unappropriated Flow Between Model Runs

Control Point	River/Trib	Reuse 2-1	Reuse 3-1	Cancellations 4-1	Cancellations 5-1	Cancellations 6-1	Cancellations 6-3	Cancellations 7-1	Cancellations 7-3	Existing 8-1
Average Flow Difference in Regulated Flow between Runs (ac-ft/yr)										
10000	Catch-all point	-374	-748	139	742	-610	138	-7	742	742
A10000	Copano Creek	0	0	0	0	0	0	0	0	0
10047	Mission River	-168	-336	0	35	-336	0	-301	35	35
C10000	Mission River	0	0	-4	0	0	0	0	0	0
B10000	Medio Creek	0	0	-9	0	0	0	0	0	0
10045	Aransas River	-206	-413	126	438	-287	126	25	438	438
D10000	Aransas River	0	0	78	171	171	171	171	171	171
E10000	Chiltipin Creek	0	0	0	0	0	0	0	0	0
Average Flow Difference in Unappropriated Flow between Runs (ac-ft/yr)										
10000	Catch-all point	0	0	0	0	0	0	0	0	0
A10000	Copano Creek	-168	-336	0	69	-336	0	-268	69	69
10047	Mission River	0	0	0	0	0	0	0	0	0
C10000	Mission River	-206	-413	146	612	-267	146	199	611	612
B10000	Medio Creek	-2	-19	0	0	-19	0	-19	0	0
10045	Aransas River	0	0	199	199	199	199	199	199	199
D10000	Aransas River	0	0	0	0	0	0	0	0	0
E10000	Chiltipin Creek	0	0	0	0	0	0	0	0	0

Table 5-5: Reliability difference for Wastewater Reuse Runs

Type	WR #	Water Right Permitee	Water Right ID No.	Use Type	Difference R2 - R1 Month (%)	Difference R2 - R1 Volume (%)	Difference R3 - R1 Month (%)	Difference R3 - R1 Volume (%)
CA	4502	Reynolds Metals Co.	62004502301	IRR	0	0	0	0
CA	4499	C.W. Marshall	62004499401	REC	0	0	0	0
APP	4521	Northshore Golf Partners, Ltd.	12004521301	IRR	0	0	0	0
APP	5283	Stephen Tarlton Dougherty et al.	12005283001	IRR	0	0	0	0
APP	5291	Mary Claire Harris Ethridge	12005291001	IRR	0	0	0	0
APP	5366	R&B Welder Wildlife Foundation	12005366401	OTHER	0	0	0	0

5.2.1.2 Unappropriated Flows at Selected Locations

The unappropriated flows and the difference between Runs 1, 2 and 3 are reported in Table 5-4 and in detail in Appendix G, Table G-1, for all of the pertinent primary and secondary control points. There is minimal difference in the unappropriated flow between the reuse scenarios due to the minimal return flow upstream of the control points in question. The unappropriated flows are the same for the three reuse runs at control points A10000, B10000, D10000 and E10000 because there is no return flow upstream of these points. Only the control points 10000, 10047, 10045 and C10000 with upstream return flow, have variations in the regulated and unappropriated flows for the reuse runs, as seen in the difference column in Appendix G, Table G-1.

5.2.1.3 Regulated Flows at Selected Locations

The regulated flows and the difference between these flows for Runs 1, 2 and 3 are reported for all of the selected, pertinent control points in Table 5-4 and in detail in Appendix G, Table G-1. Similar to the unappropriated flows, there is minimal difference in the regulated flows for the reuse scenarios. The difference between Run 3 – Run 1 and Run 2 – Run 1 for the regulated flows is identical to the unappropriated flows except control points 10000, 10047, 10045, C10000, and 10045, where there are upstream return flows.

Table 5-6: Average Unappropriated Flow at Major SA-N
Tributary Outfalls with Varying Amounts of Wastewater Reuse (ac-ft/yr)

Tributary System	Control Points	Run 1 0% Reuse	Run 2 50% Reuse	Run3 100% Reuse
Mission River	10047	323,721	323,554	323,385
Aransas River	10045	282,066	281,860	281,653
Catch-all point	10000	564,019	563,645	563,271

5.2.2 Cancellations Runs

There are eleven water rights modeled in the SA-N. Of these, only three nonsaline water rights have reported water usage within the last 10 years (See Table 5-6). For the full cancellation scenarios, Runs 4 and 6, there is a total water usage of 1,652 ac-ft (see Table 5-2). The total, nonsaline, maximum reported water usage within the last 10 years is 745 ac-ft for the partial cancellation scenarios, Runs 5 and 7. A detailed comparative analysis of the cancellation scenarios is presented for the reliability, regulated and unappropriated flows in Appendix F, Table F-2, and Appendix G, Table G-2, respectively, and summarized in Table 5-4. This comparative analysis is performed by subtracting values from each cancellation run from baseline runs. Runs 6 and 7 are subtracted from Run 3 in order to isolate the effects of cancellation, since Runs 3, 6 and 7 all have 100% reuse. All cancellation runs are subtracted from Run 1 for analysis.

5.2.2.1 Reliability Analyses

The reliability of water rights is sensitive to variations in the cancellation diversion amount, but insensitive to the amount of wastewater reuse. As seen in Table 5-8, the reliability remains unchanged between the Run 1, and the full cancellation Runs 4 and 6. However, the reliability for Runs 5 and 7 (partial cancellation) increases significantly over Run 1. This is a result from the authorized diversion equaling nearly twice the maximum 10-year reported use. Given this situation, the partial cancellation scenarios are 12% to 23% more reliable than the Run 1 scenario (for volume). The difference between Runs 6, 7 and Run 3 was calculated to isolate the exclusive effects of cancellation without return flow. This comparison reveals the insensitivity to return flows as seen in the fact that the difference between Runs 6 and 7 and Run 1 is the same as the difference between Runs 6 and 7 and Run 3.

Table 5-7: Cancellation Summary

Water Right Number	Water Right Permitee Name	Control Point	Use Type	Authorized Diversion (ac-ft/yr)	Max Use 10 Years (ac-ft/yr)	Cancel
12004415401 (Saline)	H.J. Ewald Jr.	10100	IND	10	1	No
62004497301 (Saline)	United States Dept. of Interior	10010	REC	7,685	0	Yes
62004499401	C.W. Marshall	10040	REC	95	17	No
62004502301	Reynolds Metals Co.	10070	IRR	15	0	Yes
62004503401 (Saline)	Texas A&M University	10120	IND	1	2	No
12004521301	Northshore Gulf Partners, LTD	10160	IRR	557	232	No
12004547001 (Saline)	E.I. Du Pont de Nemours	10130	IND	4,000	0	Yes
12005024001 (Saline)	Reynolds Metals Co.	10090	IND	6,000	0	Yes
12005024002 (Saline)	Reynolds Metals Co.	10090	IND	6,000	4,081	No
12005100401 (Saline)	J.T. Stellman	10080	IND	6	0	Yes
12005283001	Stephen Tarlton Dougherty et al.	D10010	IRR	150	0	Yes
12005291001	Mary Claire Harris Ethridge	D10020	IRR	60	0	Yes
12005366401	R&B Welder Wildlife Foundation	10060	OTHER	1,000	496	No
			SUM	25,579	4,829	

Table 5-8: Reliability Difference for Cancellation Runs

Type	WR #	Water Right Permitee	Water Right ID No.	Use Type	Difference		Difference		Difference		Difference	
					R4 - R1	R4 - R1	R5 - R1	R5 - R1	R6 - R1	R6 - R1	R7 - R1	R7 - R1
					Month (%)	Volume (%)	Month (%)	Volume (%)	Month (%)	Volume (%)	Month (%)	Volume (%)
CA	4499	C.W. Marshall	62004499401	REC	0	0	26.8	23.06	0	0	26.8	23.06
APP	4521	Northshore Golf Partners, Ltd.	12004521301	IRR	0	0	14.87	11.8	0	0	14.87	11.8
APP	5366	R&B Welder Wildlife Foundation	12005366401	OTHER	0	-0.05	16.34	12.82	0	-0.05	16.34	12.82

Type	WR #	Water Right Permitee	Water Right ID No.	Use Type	Difference		Difference	
					R6 - R3	R6 - R3	R7 - R3	R7 - R3
					Month (%)	Volume (%)	Month (%)	Volume (%)
CA	4499	C.W. Marshall	62004499401	REC	0	0	26.8	23.06
APP	4521	Northshore Golf Partners, Ltd.	12004521301	IRR	0	0	14.87	11.8
APP	5366	R&B Welder Wildlife Foundation	12005366401	OTHER	0	-0.05	16.34	12.82

5.2.2.2 Unappropriated Flows at Selected Locations

The unappropriated flows are presented in Table 5-9 for the pertinent control points, along with difference tables. A comparison of the difference in Appendix G, Table G-2, reveals that the four runs vary significantly depending on the year and control point. Significant differences in unappropriated flow occur at control point 10000, 10047, 10045 and D10000 for the cancellation runs. For control point 10047 (downstream end of Mission River), the difference in unappropriated flow between the cancellation scenarios is affected primarily by return flow, but also by cancellation. The effects of return flow may be seen by the fact that there is no difference between Run 4 (full cancellation, 0% reuse) and Run 1 (total authorized diversion, 0% reuse) or between Run 6 (full cancellation, 100% reuse) and Run 3 (total authorized diversion, 100% reuse); but Run 6 is 336 acre-ft/year less than Run 1. The partial cancellation adds on average 35 ac-ft/yr more unappropriated flow to control point 10047 than the full cancellation scenario (See Table 5-4 and Appendix G, Table G-2).

Control point 10045 (downstream end of Aransas River) is affected by both return flows and cancellation. The full cancellation, 0% reuse (Run 4) scenario provides on average 126 ac-ft/yr more water than Run 1 scenario, while the partial cancellation, 0% reuse scenario (Run 5) adds on average of 438 ac-ft/yr more water. Return flow affects the availability of unappropriated flow more than the effects of cancellation, as seen in the fact that the full cancellation without return flow is on average 287 ac-ft/yr less than the Run 1 scenario. The downstream catch-all control point of 10000 is also affected by both cancellation and return flow. The full cancellation, 0% reuse scenario provides on average 139 ac-ft/yr more water than Run 1, and partial cancellation, 0% reuse adds on average 742 ac-ft/yr. The significance of return flow is seen in the fact that full cancellation without return flow has 610 ac-ft/yr less water than Run 1 while full cancellation with the assumed return flow has 139 ac-ft/yr more water than Run 1 (see Table 5-4 and Appendix G, Table G-2).

5.2.2.3 Regulated Flows at Selected Locations

The regulated flows are of the same magnitude and exhibit nearly identical trends as the unappropriated flows. The regulated flow values for the cancellation runs are presented in Appendix G, Table G-2, for the primary control points.

Table 5-9: The Average Effect of Permit Cancellation Scenarios on Unappropriated Flows at Major Outfall Locations (ac-ft/yr)

Tributary System	Control Point	Run 4	Run 5	Run 6	Run 7
		0% Reuse	0% Reuse	100% Reuse	100% Reuse
		Full Cancellation	Partial Cancellation	Full Cancellation	Partial Cancellation
Mission River	10047	323,721	323,756	323,385	323,420
Aransas River	10045	282,191	282,504	281,779	282,091
Catch-all point	10000	564,158	564,761	563,409	564,012

5.2.3 Current Conditions Run

The results for Run 8, the current conditions scenario, are the same as the results for the Run 5 cancellation scenario (see Table 5-10). There are no major reservoirs upstream of any control point, so the Year 2000 area-capacity relationship is assumed to be equal for all runs, and there are no term water rights. A comparison between Run 1 and Run 8 for reliability and the regulated and unappropriated flows reveals that the current conditions scenario is more reliable, as expected, since the total maximum use for the last 10 years is about one-half of the authorized diversion amount.

5.2.3.1 Reliability

There are only three water rights with reported diversions within the last 10 years for a total annual diversion of 745 ac-ft. These three water rights are nearly 100% reliable. The current conditions reliability is 12% to 23% more reliable than the Run 1 conditions (for volume).

5.2.3.2 Unappropriated Flows at Selected Locations

A summary of the Run 8, unappropriated flows may be found in Appendix G, Table G-3, for all pertinent control points. A comparison of the unappropriated flows for Run 1–Run 8 in Appendix G, Table G-3, reveals that the Run 8 scenario is the same as the Run 1, 0% reuse scenario, for control points A10000, B10000, and E10000 because there are no significant diversions upstream of these control points. The most significant difference between Runs 1 and 8 occurs at the most downstream primary control point 10000 where Run 8 has between 170 to 1,181 acre-ft more water in any given year.

5.2.3.3 Regulated Flows at Selected Locations

Regulated streamflow values are shown in Appendix G, Table G-3, for all of the pertinent control points. Regulated streamflow closely mirrors unappropriated streamflows and are essentially the same.

Table 5-10: Average Current Conditions Unappropriated Flows at Major Outfall Locations (ac-ft/yr)

Tributary System	Run 1	Run 3	Run 5	Run 8
	0% Reuse	100% Reuse	0% Reuse	0% Reuse
	Auth. Diversion	Auth. Diversion	Partial Cancellation	Max. Diversion
Mission River	323,721	323,385	323,756	323,756
Aransas River	282,066	281,653	282,504	282,504
Catch-all point	564,019	563,271	564,761	564,761

5.3 COMPARISON TO EXISTING RIVER BASIN MODEL

There is no existing SA-N WRAP model for comparison.

5.4 FACTORS AFFECTING WATER AVAILABILITY AND MODELING RESULTS

Incremental flows are distributed based on the drainage area without regard to the SCS curve number. Although WRAP allows curve numbers to be used to distribute flows, problems limited this operation in this report. The incremental drainage areas were developed using 30-meter-square terrain representation. Given the relatively low relief on the SA-N, the resolution of the terrain model may not be entirely satisfactory in representing the areas and boundaries.

A final limitation of the analysis is that which is produced from using monthly average values in a relatively small basin. Most of the flows in the basin are associated with rain events whose duration is typically a matter of a few days, with the runoff flows not lasting much longer. When these events are placed in a monthly average context, the true nature of their variation is smoothed. However, the monthly average analysis has been used effectively on larger river basins, and will undoubtedly serve in this basin as well.

5.5 REQUIREMENTS FOR MODEL RERUN AND/OR MODEL UPDATE

WRAP may be run on any standard IBM-compatible computer. Issues that may be evaluated in the future include the use of curve number and precipitation in the flow distribution process. Although INMETHOD 6 was used to distribute flows based on drainage areas with channel loss, curve numbers are reported in the watershed parameters file so that the curve number INMETHOD 4, 5, and 8 may be analyzed at a later date.

6.0 SUMMARY AND CONCLUSIONS

The SA-N is small, with only 16 water rights and a limited set of demands on the water. While the basin is small, there are sufficient flow measurements to allow quantification with conventional methods.

Because the basin is small with streams that typically have little water available, the history that has developed is to place relatively small demands on the water. As a consequence of these small water demands, the existing rights tend to have an acceptable degree of reliability.

Of the 16 water rights in the SA-N, five are saline water rights which are included into the WRAP model as comments and do not affect the model results. For the 11 nonsaline water rights included in the WRAP model, there is a total authorized diversion of 1,877 ac-ft/yr. Only three nonsaline water rights are included in Runs 4, 5, 6 and 7. The maximum 10-year reported water use (partial cancellation) Runs 4 and 6 have a total diversion of 745 ac-ft/yr while the full diversion scenarios, Runs 5 and 6, use 1,652 ac-ft/yr. The average period and volume reliability is generally high for the eight modeled runs, ranging between 73.2% (period) and 100% (period and volume) for any given water right and run. The regulated and unappropriated flows do not vary by more than +/- 0.1% between any given run.

There are two domestic wastewater return flow points ranging between 25 to 48 ac-ft/mo for a total annual return flow of 851 ac-ft/yr. In general, the reliability of water is insensitive to variation in this return flow. However, the effects of return flow may be observed in differences in unappropriated flows for the reuse runs. The effects of the cancellation of water rights are most clearly seen in control points 10047 (downstream end of Mission River), 10045 (downstream end of Aransas River) and 10000 (most downstream catch-all point). For control point 10000, full cancellation, 0% reuse, adds 139 ac-ft/yr of water over Run 1, and partial cancellation, 0% reuse adds 742 ac-ft/yr over Run 1. Furthermore, the significance of return flow is seen in the fact that full cancellation without return flow has 610 ac-ft/yr less water than Run 1 while full cancellation with the assumed return flow has 139 ac-ft/yr more water than Run 1. The results for the Run 8, current conditions scenario are the same as the results for the Run 5 cancellation scenario. The reliability for the three water rights modeled in the current conditions run are nearly 100%.

7.0 REFERENCES

PBS&J. 2001. Naturalized Flows for the San Antonio-Nueces and Nueces-Rio Grande Coastal Basins. Prepared for the Texas Natural Resource Conservation Commission. PBS&J Document No. 010117. July 2001.

Texas Natural Resource Conservation Commission (TNRCC). 1996. Water Quality Inventory, 13th Edition, prepared pursuant to Section 305(b) of the Clean Water Act.

———. 2001. WAM Resolved Technical Issues.

Texas Water Development Board (TWDB). 2002. Water Use Data By County.

Wurbs, R.A. 2001. Reference and Users Manual for the Water Rights Analysis Package (WRAP). Technical Report No. 180, Texas Water Resources Institute, The Texas A&M University System, College Station, Texas. Prepared for the Texas Natural Resource Conservation Commission, Austin, Texas. July 2001.

APPENDIX A

SAN ANTONIO-NUECES COASTAL BASIN ACTIVE WATER RIGHTS

APPENDIX B

SAN ANTONIO-NUECES COASTAL BASIN
NATURALIZED FLOW TABLES

APPENDIX C

MEMORANDUM OF CORRECTIONS TO TNRCC DATABASE

MEMORANDUM OF SALINE WATER RIGHTS

MEMORANDUM OF MODELING ASSUMPTIONS FOR CHANNEL LOSSES AND GROUNDWATER INTERACTION

MEMORANDUM OF MODELING ASSUMPTIONS AND ANY OTHER BASINS' APPLICABLE SYSTEM OPERATION ORDER

APPENDIX D

CONTROL POINT CORRELATION TABLE

APPENDIX E

WATER RIGHT ANALYSIS PACKAGE (WRAP) INPUT

APPENDIX F

RELIABILITY SUMMARY AND COMPARISON TABLE

APPENDIX G

REGULATED AND UNAPPROPRIATED FLOW AND COMPARISON TABLE

APPENDIX H

REQUESTS FOR BASIN-SPECIFIC MODIFICATIONS

APPENDIX I

SAN ANTONIO-NUECES COASTAL BASIN
SUBWATERSHEDS AND SECONDARY CONTROL POINTS

Appendix H
Requests for Basin-Specific Modifications

[Basin-specific modifications are not applicable to this report.]

- Rounded acreages per SuzyRun numbers are capitalized with specific numbers onlyThe full cancellation, 0% reuse (Run 4) scenario provides…"

Submitted to the Texas Water Digital Library on May 15, 2014, by Grant J. Gibson, P.G., Texas Commission on Environmental Quality.