Study 2
Groundwater Availability Model of the Edwards-Trinity (Plateau) and Dockum Aquifer in Western Nolan and Eastern Mitchell Counties, Texas

Prepared for:

BRAZOS G
WATER PLANNING GROUP

Prepared by:

HDR | ONE COMPANY
Many Solutions℠

With administration by:

Brazos River Authority

April 2009

Study 2
Groundwater Availability Model of the Edwards-Trinity (Plateau) and Dockum Aquifer in Western Nolan and Eastern Mitchell Counties, Texas

STATE OF TEXAS
DAVID D. DUNN
82630
REGISTERED
PROFESSIONAL ENGINEER

4-28-2009

David D. Dunn, P.E.

STATE OF TEXAS
LARRY F. LAND
31380
REGISTERED
PROFESSIONAL ENGINEER

Apr 28, 2009

Larry F. Land, P.E.

Table of Contents

Table of Contents (Concluded)

Section **Page**

List of Figures

List of Figures (Continued)

List of Figures (Concluded)

List of Tables

Executive Summary

ES.1 Introduction and Setting

The Brazos G Regional Water Planning Group is conducting a re-evaluation on the City of Sweetwater's Champion Wellfield as a long-term water management strategy. This re-evaluation involves the development of a local scale groundwater availability model to be used as a tool to evaluate groundwater supplies in western Nolan and eastern Mitchell Counties (Figure ES-1). The model is centered on the Champion Wellfield. The major and minor aquifers in the area are the Edwards-Trinity (Plateau), called Edwards-Trinity in this report, and the Dockum. The wells in the Champion Wellfield are screened in the Dockum.

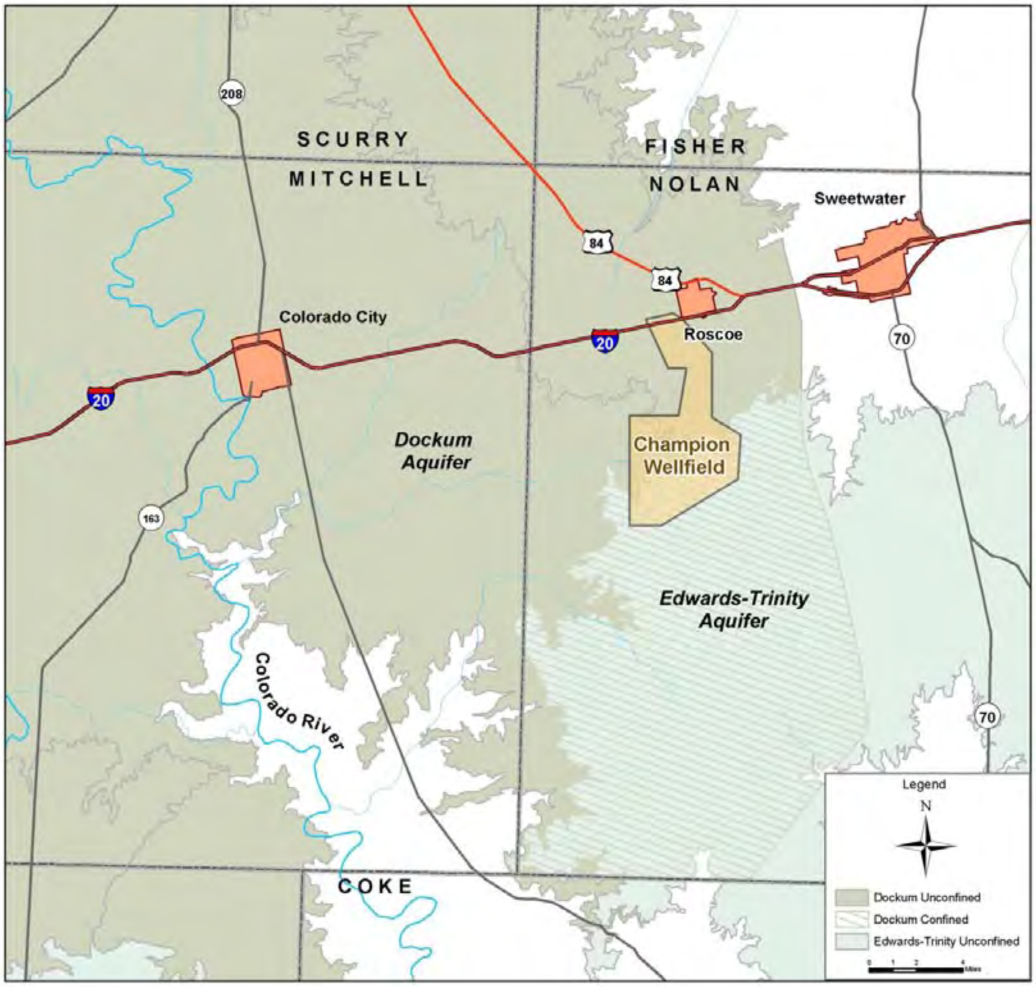


Figure ES-1. Location of Study Area and Major and Minor Aquifers and Champion Wellfield

The general approach for this re-evaluation is the development, calibration, application, and documentation of the groundwater model. The development consists of: (1) compiling and studying data on features and properties of the aquifers; (2) formulating a conceptual model for representation of the aquifer system; and (3) constructing the groundwater model. Calibration consists of two phases, including: (1) steady-state (1990) and (2) transient (1990-2007). Initial application consists of making predictive simulations with Brazos G water management strategies from 2008 to 2060.

The study area is in the Great Plains area of Texas where the topography generally ranges from flat to rolling hills. This area is mostly ranch and farm land. Between the towns of Roscoe and Colorado City, the land is relatively flat, is heavily farmed, and drains to the Colorado River.

The geologic setting consists of the Trinity and Fredericksburg Groups of Cretaceous age, Dockum Group of Triassic age, and the Whitehorse/Pease River Group Undifferentiated of Permian age. The Trinity Group generally occurs underneath Cretaceous limestone or Tertiary and Quaternary sediments. Its water-bearing zones form the Trinity Aquifer, which is classified as a major aquifer. The Dockum Group is the greatest water bearing unit in the study area. The Dockum Aquifer is classified as a minor aquifer. The Whitehorse/Pease River Groups Undifferentiated (Whitehorse) are of late Permian age. They outcrop in the southeast part of the study area or are covered by younger geologic units in other areas. It is rather poorly permeable and yields mostly brackish water to wells.

The climatic setting in the study area borders between semiarid to the west and subhumid to the east. It is characterized by long, hot summers and moderate winters. The average annual precipitation since 1940 is about 23 inches. The driest year was 2000 with rainfall of about 11.3 inches. The longest lasting drought was from 1946 to 1956 when the annual average precipitation was about 17.4 inches. In 1986 and 2004, the annual precipitation was about 35 inches.

The Edwards-Trinity Aquifer consists of lower Cretaceous age Trinity Group formations and overlying limestones and dolomites of the Comanche Peak, Edwards, and Georgetown formations. In the study area, the Antlers Sand is the primary water-bearing unit of the Trinity. The median specific capacity for the few Edwards-Trinity wells with data was about 2.2 gal/min/ft. The base of the Edwards-Trinity is very flat. Generally, the aquifer is considered to be under water table conditions. Recharge is primarily from precipitation. Groundwater levels in the Edwards-Trinity are relatively flat surface on a regional scale. Some of the data show little or no long-term changes, while others show modest rises since the 1960s. Groundwater discharge is mostly to wells for domestic and livestock use and leakage to underlying formations. The water is considered to be fresh and suitable for most uses. The Edwards-Trinity in Nolan and Taylor Counties is hydrologically isolated from the main body of the aquifer which lies to the southwest.

The Dockum Aquifer consists of sand and conglomerate interbedded with layers of silt and shale. In the study area, the aquifer is considered to be under water table conditions, except where confined by the Edwards-Trinity. However, the aquifer in the outcrop area may function as being confined because shales and clays overlie the water-bearing sands and conglomerate. The median specific capacity for the Dockum is about 2.0 gal/min/ft. Recharge to the Dockum is from direct infiltration from precipitation, seepage from tributaries during flood events, and leakage from the Edwards-Trinity. The aquifer pinches out in the subsurface to the east and generally dips toward the west at about 15-20 ft per mile. The highest groundwater level elevations are in the elevated part of the aquifer, which is generally south of Roscoe, and the lowest elevations are along the Colorado River. These data show a strong general trend of rising groundwater levels from the 1960s to about 1990. Since 1990, the water levels have generally stabilized or declined. Groundwater discharge is mostly to wells for irrigation, with some use for domestic, livestock, municipal, and mining supplies and to the Colorado River. Generally, the water has a total dissolved solids concentration of less than 500 milligrams per liter.

The Whitehorse underlies the Dockum. The primary purpose of including the Whitehorse in this study is to provide a hydrogeologic continuity between upland recharge areas in southeastern Mitchell and southwestern Nolan Counties with low lying discharges areas along the Colorado River. In this area, the Edwards-Trinity and Dockum have been eroded away.

ES.2 Groundwater Model

The design of the MODFLOW groundwater model for the Edwards-Trinity and Dockum Aquifers in Nolan and Mitchell Counties extends to the north and south boundaries of the two counties, to the Colorado River to the west, and to either the extent of the aquifer or a relatively narrow, north-south section of the Edwards-Trinity, as defined by Sweetwater Creek flowing to the north and Oak Creek flowing to the south and to the east. The model is oriented in a north-south direction. Cells are square and have a lateral dimension of 0.25 miles. The model has 129 rows and 149 columns. The model's vertical dimension is subdivided into three layers, one for each of the aquifers. Recharge to the outcrop of the Edwards-Trinity and the Dockum is a function of annual precipitation. A study of historical groundwater level patterns suggests trends in recharge that are probably related to land use practices. Trends in recharge are estimated from precipitation during the calibration and predictive periods.

Discharge by wells is from estimates provided from TWDB, Sweetwater and regional planning. Recharge for steady-state conditions was determined by calibration. For variability during transient calibration, recharge is related to precipitation and an analogy of recharge following the same pattern as runoff from a relatively small watershed. The concept is that on an annual basis, there exists a threshold amount of precipitation that is needed to produce runoff and recharge and for simplicity, the amount of recharge increases linearly with annual precipitation above the threshold.

Underflow from parts of the aquifer system outside the model is calculated by the General Head Boundaries (GHB) around the model's edge where the aquifers extend beyond the study area. Discharge to streams is represented by the DRAIN Package.

The simulation periods are based on hydrologic data and the aquifer conditions. The initial steady-state calibration period was selected to be 1990 because water levels were generally stable. Transient calibration is from 1990 to 2007. Model simulations to estimate groundwater availability are from 2008 to 2060.

The model calibration used in this study is an iterative, trial and error process of minimizing the difference between the modeled and measured water levels. The most sensitive and poorly defined parameters are adjusted first. In the latter stages of calibration, adjustments to the other parameters are also tested in an attempt to minimize the calibration errors. For this setting and the model's design, the most sensitive parameters are expected to be recharge, hydraulic conductivity, and storage coefficient. Hydraulic conductivity values are fairly well constrained with aquifer test data for the Dockum Aquifer and to a much lesser amount for the Edwards-Trinity Aquifer. Data on recharge and storage coefficient places little constraint on these parameters. The next tier of parameter sensitivity is expected to be the GHB along the northern edge of the model and the conductivity associated with DRAINS. The vertical hydraulic conductivity is expected to have little sensitivity because the aquifer units are relatively thin, the time steps relatively long, and water levels have a limited range in fluctuations.

The steady-state calibration for 1990 conditions was evaluated by: (1) comparing the difference (residual) between the measured and modeled values by posting the residuals on the map to illustrate their magnitude and location and (2) graphing the measured and modeled values. The success of the calibration for the Edwards-Trinity (layer 1) is difficult to judge because of few values (four), substantial difference in water levels in two relatively close wells, and the locations of the other two wells are very near model boundaries. These results show the modeled stage in the Edwards-Trinity is higher than the observed stage in three of the wells, but approximately split the two water level targets in the main part of the aquifer. The Dockum calibration shows a Root Mean Square Error (RMSE) of about 16 ft. Residuals show little or no bias of the modeled stage and the observed groundwater levels being too high or too low. The range in water levels across the model area was about 250 ft. More than half of the modeled values were within 10 ft of the measured values. A water budget shows the total recharge to the model is about 22,500 acft/yr and total pumping to be about 4,800 acft/yr. Vertical flow between layers is consistently downward, from the Edwards-Trinity to the Dockum and from the Dockum to the Whitehorse; recharge is highest in the Edwards-Trinity; and pumping is highest in the Dockum.

The transient calibration period is from 1990 to 2007 with annual stress periods. The transient calibration data set includes 271 water level measurements in 31 wells. Four of the wells were in the Edwards-Trinity; and, 27 wells were in the Dockum. Calculated water levels reasonably depict the declining water levels that have been observed in the Dockum since 1990. The water levels for the two wells in the main part of the Edwards-Trinity show substantial differences in measured water levels in two relatively close wells, thus, the measured and modeled values are a poor match. The RMSE for the target wells in the Dockum is 14 ft. The RMSE for representative wells in each of the Sweetwater wellfields is 13 ft. These results show little or no bias of the modeled stage and measured groundwater levels being too high or too low in the Dockum Aquifer. From 1990 to 2007, the model calculated drawdowns in the Dockum that typically range from 5-20 feet in the Champion Wellfield and 5-15 ft to the west. A water budget for 2000 shows the total recharge to the model is about 28,200 acft/yr and total pumping to be about 13,000 acft/yr. The increase in Dockum pumping has caused less discharge to the Colorado River and tributaries and a reduction in groundwater storage (lowering of water levels).

The first predictive application of the groundwater model is to assist the City of Sweetwater and Brazos G in assessing the potential long-term supply of water from the Champion Wellfield as a long-term water management strategy. The general approach for this assessment is to make predictive simulations for several wellfield scenarios from 2008 to 2060 and to consider regional groundwater levels, drawdown in groundwater levels, saturated thickness maps and trends in water levels to determine the most suitable water management strategy. Preparation of the model for the predictive simulations included developing long-term estimates of recharge and pumping. Other parameters such as stage for MODFLOW's RIVER, DRAIN, and GHB cells were held constant at 2007 values. The predictive pumping rates are based on water demands that are based on projections in the 2006 Brazos G and Region F Regional Water Plans. A separate accounting of predictive pumping was made for Sweetwater, which ranges from about 3,900 acft/yr in 2008 to about 3,500 acft/yr in 2060. Annual recharge was calculated from historical precipitation and used 1948-2000 as representative of the 2008-2060 predictive period.

ES.3 Results

The selection of locations for prospective Sweetwater wellfields for re-evaluation as a groundwater management strategy considered recharge rates, aquifer thickness, hydraulic conductivity, and proximity to the Champion Wellfield and irrigation area. The irrigation area was avoided as a prospective wellfield because of concern from potential groundwater contamination from fertilizers and pesticides and interference with and from existing irrigation wells. Areas to the east and north of Champion are considered to be undesirable because the aquifer is rather thin and near the updip limit of the Dockum, which limits the groundwater capture zone of the wellfield. With these restraints, the areas to the south and west of the current Champion Wellfield were considered to be the best candidates.

Four test scenarios were selected for development. They include:

- Continuing to utilize the existing Champion Wellfield (Champion Wellfield Scenario),

- Adding to the southwest of the Champion Wellfield that has the same number of wells as the Champion Wellfield (Scenario A),
- Adding a wellfield to the west of the Champion Wellfield that has the same number of wells as the Champion Wellfield (Scenario B), and
- Adding a wellfield in areas to the west and southwest of the Champion Wellfield that has twice the number of wells as the Champion Wellfield (Scenario C),

In each of the scenarios, the existing Champion Wellfield was continued to be used and the individual well pumping was set equal among all the wells. The wells in the prospective wellfields were spaced at half mile intervals.

The Champion Wellfield Scenario is a continued utilization of the existing 45 wells in the Champion Wellfield for all of Sweetwater's future demands. The average annual pumping rate was 54 gpm in 2008 and gradually decreased to 48 gpm in 2060. These results show: (1) a 2008-2060 drawdown in the center of the cone of depression to be between 30-40 ft, (2) the southern wellfield to have a saturated thickness of less than 75 ft and the middle wellfield thickness to be a minimum of about 40 ft, and (3) a continual decline in groundwater levels in all of Sweetwater's wellfields, which indicates that the cone of depression from the wellfield has not expanded to the point of capturing sufficient water to satisfy the pumping. As a result, much of the water is coming from storage.

Scenario A models the continued utilization of existing wells in the Champion Wellfield and adds a wellfield to the south with 45 wells, which is the same number of wells as the Champion Wellfield. This scenario doubles the number of wells in the model to 90 wells and cuts the pumping rate for each well by a half. The intent of this scenario is to test the continued use of the existing Champion Wellfield and the benefit of spreading out the total pumping in the southern direction where there appears to be higher recharge in the Edwards-Trinity that would percolate into the underlying Dockum. These results show a 2008-2060 drawdown in the center of the cone of depression to be slightly more than 30 ft in the prospective wellfield and less than 22 ft in the existing Champion Wellfield. The saturated thickness in 2060 was calculated to be between 125-150 ft. Overall, the minimum saturated thickness continues to be less than 50 ft in the central wellfield. These graphs show a substantially lower rate of decline in groundwater levels in the Champion Wellfield.

Scenario B tests the continued utilization of the existing wells in the Champion Wellfield and adding a wellfield of equal size to the west of the Champion Wellfield. Like Scenario A, this scenario doubles the number of wells and cuts in half the pumping rate for each well. The intent of this scenario is to test the benefit of a more widely distribution of pumping in the western direction where the saturated thickness of the Dockum appears to be relatively thick. The 2008-2060 drawdown in the center of cone of the depression was calculated to be slightly more than 40 ft in the prospective wellfield, which is higher in the prospective wellfield than in the existing Champion Wellfield. These results show much of the prospective wellfield to have a saturated thickness between 75 and 100 ft. This wellfield configuration shows a more modest decline in groundwater levels in all of the Champion Wellfields.

Scenario C was formulated in an attempt to lessen the overall drawdown to a great extent. The approach was to add a prospective wellfield that has twice the number of wells as the existing Champion Wellfield. The Champion Wellfield has 45 wells and Scenario C has an additional 90 wells. The prospective wellfield is partly south and west of the existing wellfield. This cuts the overall pumping rate of a well by one-third and spreads pumping over a larger area. The intent of scenario is to evaluate the benefit of spreading out the pumping over a larger area. Drawdown from 2008-2060 shows that much of the drawdown to be slightly more than 30 ft and is reasonably uniform over a relativly larger area. The saturated thickness in 2060 in much of the prospective wellfield ranges from 75 to 150 ft. By 2060, water levels have nearly stabilized in the southern part of the combined wellfields and are declining at a rather modest rate in other parts of the wellfields.

A well performance study was undertaken to further evaluate the long-term viability of Sweetwater's Champion Wellfield by considering the performance of existing wells. This assessment utilizes information from the construction and testing of new wells in the Champion Wellfield and data provided by Sweetwater. Performance information of key interest are the well's drawdown, the position of the water surface in relation to the bottom of the well screen during pumping, and trends in groundwater levels. These data show an average drawdown of about 85 ft for the 29 wells with data. Of these wells, 9 of the wells have pumping levels below the bottom of the well screen for October 2006 static water level conditions. Nineteen of the wells have the water levels lower than 10 ft above the bottom of the well screens. These data also show a declining trend in water levels with an average of about 3.25 ft from October 2006 to

January 2008. If this trend continued, the drawdown over a 50-year planning period would be more than 70 ft. Any lowering of water levels would reduce the potential yield of most of the wells because drawdown is at are near the maximum amount for October 2006 conditions. In other words, the capacity for about two-thirds of the wells is at or near a maximum for 2006 conditions and will be reduced if there is an additional decline in water levels.

If a groundwater only strategy is considered, the performance of the current Champion Well Field from 2001-2007 and the groundwater modeling suggests that the Edwards-Trinity and Dockum Aquifers could meet this average demand, which was about 2,850 acft/yr. If the well field was substantially expanded to the south-southwest, the modeling analysis suggests that it could meet the projected demand of 3,900 acft/yr for the planning period.

ES.4 Water Management Strategy for Sweetwater

An evaluation of continued use of groundwater by the City of Sweetwater considers the results of the four wellfield scenarios that were tested with the new groundwater model and an analysis of well performance data from the Champion Wellfield. A major concern in the evaluation is based on the well performance data. As stated earlier, about half of the wells with data show the wells are being used at maximum rates, and these yields would become smaller as water levels declined. On the other hand, a re-distribution of the pumping to include nearby areas shows future groundwater declines to be substantially moderated and the aquifer's saturated thickness to experience rather modest changes. Based on these findings, the recommended water management strategy for Sweetwater is to continue to rely on a conjunctive management practice where they utilize water from Oak Creek Reservoir when surface water is available and to utilize groundwater during droughts. This would reduce the long-term withdrawals from the wells and lessen the magnitude of declining water levels. If there becomes a time when there is a need for more groundwater than can be supplied by wells currently in the Champion Wellfield, the most favorable areas for expansion are to the south-southwest. This is attributed to spreading out the wells as much as possible and moving toward an area where the Dockum appears to be thicker and there appears to be more recharge from the overlying Edwards-Trinity.

(This page intentionally left blank.)

1.0 Introduction

The Brazos G Regional Water Planning Group recommended and approved a re-evaluation of water management strategies for the Nolan County area. The re-evaluation focuses on the City of Sweetwater's Champion Wellfield and involves the development of a local scale groundwater availability model to be used as a tool to evaluate groundwater supplies in western Nolan and eastern Mitchell Counties (Figure 1-1). The model is centered on the Champion Wellfield. The major and minor aquifers in the area are the Edwards-Trinity (Plateau), called Edwards-Trinity in this report, and the Dockum Aquifer. The wells in the Champion Wellfield are screened in the Dockum. The initial uses of the model will be to assist the City of Sweetwater and Brazos G in assessing the potential long-term supply of water from their wellfields as a long-term water management strategy.

The general approach for this re-evaluation is the development, calibration, application, and documentation of the groundwater model. The development consists of: (1) compiling and studying data on features and properties of the aquifers; (2) formulating a conceptual model for representation of the aquifer system; and (3) constructing the groundwater model. Calibration consists of two phases, including: (1) steady-state (1990) and (2) transient (1990-2007). Initial application consists of making predictive simulations with Brazos G water management strategies from 2008-2060. This report provides documentation on the model's development, calibration, and Brazos G applications.

1.1 Physiographic Setting

The study area is in Great Plains area of Texas where the topography generally ranges from flat to rolling[1] (Figure 1-2). Along the drainage divide area between the Colorado and Brazos Rivers, the area is a plateau with incised stream channels along the perimeter. This area is mostly ranch and farm land. Between the towns of Roscoe and Colorado City, the land is relatively flat, is heavily farmed, and drains to the Colorado River. In the southern part of the study area, the topography is gently rolling to moderately rugged, especially in the vicinity of the Colorado River and major creeks. The Colorado River and its tributaries drain the study area

[1] Shamburger, V.M., Jr., 1967, Ground-water resources of Mitchell and western Nolan Counties, Texas: Texas Water Development Board Report 50.

except in the vicinity of Sweetwater where the drainage is to the Clear Fork of the Brazos River. All of the tributaries in the area are intermittent and few springs exist in the area.

Soils in Mitchell County are of quartzitic, upland type. Soils in the uplands area of Nolan County are loamy and calcareous, derived from calcareous alluvial sediments or limestone. Soils along the western slope of Nolan County are generally sandy and occasionally loamy.

Land resource classifications are based on properties that are judged to be the most significant in its potential land use. Kier and others (1977) [2] classify land resources in Texas into about eight characteristics (categories) and 71 units. Figure 1-3 shows the land resource units for the study area. The major units are listed in Table 1-1 along with a qualitative description of their infiltration capacity.

Table 1-1.
Land Resource Units

Unit Code	*Unit Name*	*Characteristic*	*Infiltration Capacity*
A-1	Recharge Sand	Geohydrologic	High
B-1	Massive Limestone	Mineral	Low to High, Possibly Fracture Controlled
B-12	Limestone, Sand, and Gravel	Mineral	High
D-5	Severely Eroded Land	Geomorphic	Low
D-6	Undissected Red Beds	Geomorphic	Low to Moderate
D-7	Dissected Red Beds	Geomorphic	Moderate to Low
D-8	Stairstep Topography	Geomorphic	Variable

1.2 Geologic Setting

The geologic setting of interest to this study consists of the Trinity and Fredericksburg Groups of Cretaceous age, Dockum Group of Triassic age, and the Whitehorse/Pease River Group Undifferentiated of Permian age (Figure 1-4). The Ogallala Formation of tertiary age occurs in northern Nolan and Mitchell Counties, but is either unsaturated or too thin to be a major water-bearing unit. All of these formations crop out in the study area. A stratigraphic chart is presented in Table 1-2.

[2] Kier, R.S., Garner, L.E., and Brown, Jr., L.F., 1977, Land resources of Texas, Bureau of Economic Geology, The University of Texas at Austin, Land Resources Laboratory Series.

Table 1-2.
Geologic Units and Water-Bearing Characteristics

System	Series	Group	Formation	Approximate Thickness (feet)	Lithology	Water-Bearing Characteristics
Quaternary	Pleistocene and Recent		Alluvium	0-100	Fine to coarse sand and small to large gravel with occasional clay and caliche beds.	Usually dry
Tertiary	Pilocene		Ogallala	0-100	Fine to coarse sand, gravel, caliche, and zones of clay.	Usually dry
Cretaceous	Comanche	Fredericksburg		0-220	Predominantly limestone with 25 feet of sand marl at base. Very dense, massive, fossiliferous limestone in the upper part.	Upper limestone may contain small to moderate supplies of fresh water in solutional openings.
		Trinity		0-100	Quartz sand, fine to medium grained, moderately to loosely consolidated, with occasional lenses of quartz gravel at the base.	Yields small to large quantities of fresh water. Well yield depends on saturated thickness.
Triassic		Dockum	Santa Rosa	0-330	Basal conglomerate overlain by cross-bedded sand alternating with beds of clay.	Sands and gravels contain moderate to large quantities of fresh water.
Permain	Guadalupe and Ochoa	Whitehorse/Pease River Groups Undifferentiated		1,900	Fine-grained sandstone; dense red silty shale with occasional gypsum of anhydrite beds.	May contain small quantities of moderately to highly mineralized water.

Modified from Shamburger (1967)

The Fredericksburg Group overlies the Trinity Group except along the margins of the plateau. This formation is composed of calcareous sediments, mostly limestone. Occasionally, solutional openings of the Edwards Limestone yield small quantities of water to wells. According to Shamburger (1967), solution features form interior drainage, or sinks, for recharge to Trinity sands.

The Trinity Group is of epicontinental origin. The Trinity Group generally occurs underneath Cretaceous limestone or Tertiary and Quaternary sediments. According to Shamburger (1967), the Trinity sands principally consist of white to purplish, loosely to moderately compacted, and fine- to coarse-grained quartz sand. The Trinity Group ranges in thickness from 60 to 100 ft. The regional dip of the Trinity is to the southeast at a very low angle, with local variability. The Dockum and Whitehorse are underneath most of the Trinity in the study area. The Dockum and Whitehorse eventually pinch out in Nolan County.

The Dockum Group is of continental origin and is the greatest water bearing unit in the study area. According to Shamburger (1967), the sediments east of the Colorado River generally consist of up to 30 ft of hard, coarse-gravel conglomerate at the base of the formation, succeeded upward by alternating red and gray micaceous shale, clay, and sand or gravel. Sand and gravel generally dominate in the lower 100 ft of the formation. Sand and clay beds are highly lenticular, grading both vertically and horizontally from one to the other over short distances. The thickness ranges up to 300 ft. Its regional slope is to the west. Underneath the Dockum is the Whitehorse which has little permeability.

The Whitehorse/Pease River Groups Undifferentiated (Whitehorse) are of late Permian age and either outcrop or are covered by younger geologic units in all but the southeast part of the study area[3]. This group of geologic units consists of shale, anhydrite, gypsum, limestone, dolomite, and sandstone and is about 2,000 ft thick. In the study area, Shamburger (1967) has mapped a Permian marker bed about 200 ft below the base of the Dockum. For purposes of this report, it is considered the base of the Whitehorse.

[3] Duffin, G.L., and Beynon, B.E., May 1992, Evaluation of water resources in parts of the Rolling Prairies Region of North-Central Texas, Texas Water Development Board Report 337.

1.3 Climatic Setting

The climatic setting in the study area borders between semiarid to the west and subhumid to the east. It is characterized by long, hot summers and moderate winters.

The average annual precipitation since 1940 is about 23 inches (Figure 1-5). The driest year was 2000 with rainfall of about 11.3 inches. The longest lasting drought was from 1946 to 1956 when the annual average precipitation was about 17.4 inches. In 1986 and 2004, the annual precipitation was about 35 inches.

During the year, the lowest monthly precipitation is generally from November to February, and the highest is generally between May and September. Occasional tropical disturbances produce large amounts of storm rainfall during summer and fall.

The average annual evaporation of the area from 1954-2004 is about 63 inches per year. It has ranged from a low of about 50 inches in 2002 to about 77 inches in 1956.

2.0 Hydrogeologic Setting

The Edwards-Trinity and Dockum are the only hydrogeologic units in the study area capable of producing moderate quantities of groundwater (Shamburger, 1967). The Edwards-Trinity (Plateau) has been classified by the TWDB as a major aquifer and the Dockum has been classified as a minor aquifer. The Whitehorse is not classified as an aquifer, but is known to yield small quantities of water that are usually brackish to saline.

The Edwards-Trinity consists of lower Cretaceous age Trinity Group formations and overlying limestones and dolomites of the Comanche Peak, Edwards, and Georgetown formations. In the study area, the Antlers Sand is the primary water-bearing unit of the Trinity. Generally, the aquifer is considered to be under water table conditions, however, during short term pumping, the drawdown pattern is typical of a confined aquifer. Water development from the aquifer is generally limited to domestic and livestock use. In the past and at a few locations, the aquifer has been pumped for municipal, irrigation, commercial, livestock, and domestic purposes. The water is considered to be fresh and suitable for most uses. The Edwards-Trinity in Nolan and Taylor Counties is hydrologically isolated from the main body of the aquifer which lies to the southwest.

The Dockum is commonly referred to as the "red bed." Its major water-bearing unit is the Santa Rosa formation, which consists of sand and conglomerate interbedded with layers of silt and shale. In the study area, the aquifer is considered to be under water table conditions, except where confined by the Edwards-Trinity. However, in the outcrop area, it may function as being confined because shales and clays overlie the water-bearing sands and conglomerate. This is illustrated during aquifer tests with a pumping well where the drawdown pattern is typical of a confined aquifer. The primary use of the water is for irrigation, with some use for domestic, livestock, municipal, and mining supplies. Generally, the water has a total dissolved solids concentration of less than 500 milligrams per liter.

The Whitehorse underlies the Dockum. The primary purpose of including the Whitehorse in this study is to provide a hydrogeologic continuity between upland recharge areas in southeastern Mitchell and southwestern Nolan Counties with low lying discharges areas along the Colorado River. In this area, the Edwards-Trinity and Dockum have been eroded away.

An east-west hydrogeologic cross section is provided in Figure 2-1 to illustrate the physical setting of these hydrogeologic units.

2.1 Geologic Structure

The geologic structure in the study area is relatively flat or gently sloping. Geologic maps[4] (Figure 1-4) do not show any faults. Most of the geologic structural features are expressed by erosional features of the land surface.

The base of the Edwards-Trinity (Plateau) Aquifer in the study area is very flat, as shown in Figure 2-2. Control for this map is from contact of the Antlers Sand with the underlying formation along the perimeter of the aquifer, which was developed by the TWDB for the Edwards-Trinity (Plateau) and Cenozoic Pecos Alluvium Groundwater Availability Model,[5] and well data in TWDB's well database. The wells used for control were the result of a substantial screening to eliminate wells that appeared to stop at the first suitable water-bearing zone or were drilled passed the Antler Sand in hopes of finding a better water-bearing zone. This map shows a

[4] Bureau of Economic Geology, 1974, Geologic Atlas of Texas, Big Spring Sheet, Scale 1:250,000: The University of Texas at Austin.
[5] Anaya, R., and Jones, I., 2004, Groundwater Availability Model for the Edwards-Trinity (Plateau) and Cenozoic Pecos Alluvium Aquifer Systems, Texas: Texas Water Development Board GAM report.

very slight ridge trending from the south-southwest to the north-northeast in western Nolan County.

The base of the Dockum Aquifer was mapped by Shamburger (1967). This map is presented in Figure 2-3. The location where the aquifer pinches out in the subsurface to the east is approximated. The base of the Dockum generally dips toward the west at about 15 to 20 ft per mile.

For purposes of this study, Whitehorse is considered to be the geologic unit between the top of the Permian and the Permian Marker Red Bed, as defined by Shamburger (1967). At full thickness, this unit is about 200 ft thick. The base of the Permian Marker Red Bed (Whitehorse) is shown in Figure 2-4.

2.2 Water Levels and Groundwater Flow

A general description of the hydrologic conditions and pattern of groundwater movement was developed from a compilation and analysis of groundwater level data from the TWDB's well database for Nolan and Mitchell Counties. The water level data were grouped into the Edwards-Trinity and the Dockum. For the Edwards-Trinity, water level data are rather sparse since a groundwater study in the early 1960s. In an attempt to illustrate the regional groundwater conditions and movement in the Edwards-Trinity, a map was prepared with 1963 data (Figure 2-5). Hydrographs of wells with the longest and most extensive period of record are presented in Figure 2-6. For the Dockum, a water level map was prepared for the winter of 1990 (Figure 2-7). Hydrographs for wells with a rather extensive history of water level data are presented in Figure 2-8. No wells were identified as being in the Whitehorse.

Groundwater data in the Edwards-Trinity Aquifer, as interpreted from the 1963 water level map, indicates a relatively flat surface on a regional scale. Some of the groundwater level hydrographs show little or no long-term changes, while others show modest rises since the 1960s.

Groundwater flow in the Dockum appears to be uninterrupted by any hydrogeologic barrier. The highest groundwater level elevations are in the elevated part of the aquifer, which is generally south of Roscoe and the lowest elevations are along the Colorado River. Groundwater flow in northern Mitchell County tends to flow to the south, then to the southwest. Groundwater appears to flow approximately parallel along IH-20 from Roscoe to the Colorado River with a hydraulic gradient is about 13-15 ft/mi. The steepest gradient appears to be in the west-central part of Nolan County to the Colorado River. There is a considerable amount of water level data to characterize the hydrologic conditions since the late 1950s in the northern part of the two counties, which coincides with the farming area. These data show a strong general trend of rising groundwater levels from the 1960s to about 1990. Since 1990, the water levels have generally stabilized or declined. The cause in the rise in water levels from the 1960s to 1990 is most likely attributed to a severe drought of the early and mid-1950s, which was followed by generally above average rainfall in the 1960s to 1980s, a change in land management practices, and a change from intense irrigation in the 1950s and 1960s to considerably less irrigation in the 1980s and 1990s. A study of Dockum water levels in Scurry and Fisher Counties showed a strong break in regional patterns that was in the vicinity of the Mitchell-Nolan and Scurry-Fisher County line. The data indicated that water levels were about 100 ft higher in Scurry and Fisher Counties than in nearby wells in Mitchell and Nolan Counties. A study of aerial images for Scurry and Fisher Counties shows a great amount of cultivated farming, extensive terracing, farm ponds, playa lakes, and essentially no irrigation wells. This suggests that: (1) land use practices has contributed to much higher rates of recharge, (2) there is probably little or no water discharge to irrigation wells, and (3) the Dockum is not nearly as permeable in this part of Scurry and Fisher Counties as in the northern parts of Mitchell and Nolan Counties.

Groundwater flow in the Whitehorse is expected to generally follow the regional land surface topography of the area.

2.3 Hydraulic Properties

The water-bearing units of the Edwards-Trinity (Plateau) and the Dockum Aquifers are primarily layers of sand that may be cemented and locally confined by clays, silts and shale. In the long-term, the aquifer functions as being under water table or semi-confined conditions; however, in the short-term, the response from a pumping well will be consistent with a confined hydrogeologic setting.

A search for aquifer test data resulted in documentation for several analyzes in the City of Sweetwater's wellfields and in central and eastern Mitchell County. A Sweetwater consultant's report documents eleven aquifer tests and shows transmissivity to range between 3,600 and 12,200 gal/day/ft. Most values were between 5,000 and 6,000 gal/day/ft. The storage coefficient ranged between 0.00004 and 0.00007. In central and eastern Mitchell County, Shamburger (1967) lists four Dockum aquifer tests. The transmissivity calculated from these tests ranged between about 5,900 and 12,300 gal/day/ft and the storage coefficient ranged from about 0.0001 to 0.0004.

A compilation of data on well yield and drawdown from the TWDB's well database was used to calculate a well's specific capacity and the hydraulic conductivity of the aquifer. This compilation resulted in two values for the Edwards-Trinity (Plateau) and about 25 values for the Dockum. The specific capacity results are presented in Figure 2-9. The hydraulic conductivity estimates for the screened section of the aquifer are presented in Figure 2-10.

Another data set that is available to calculate specific capacity and hydraulic conductivity is driller's reports for the Sweetwater wells. The results of the calculations of these data for specific capacity and estimated hydraulic conductivity are presented in Figures 2-11 and 2-12, respectively.

The median specific capacity for the Edwards-Trinity wells was about 2.2 gal/min/ft and the median specific capacity for the Dockum was 2.0 gal/min/ft. The estimated median hydraulic conductivity is about 8.1 ft/day for the Edwards-Trinity and 7.3 ft/day for the Dockum. Calibration of the Dockum GAM[6] resulted in an estimate of hydraulic conductivity ranging from 0.1 to 1.0 in the study area. They estimated specific storage to range from 0.0003 to 0.003 per ft and specific yield to be 0.15.

Estimates of transmissivity and hydraulic conductivity are considered to be representative of the well's screen section, which probably includes the best water-bearing zone(s). When considering the entire thickness of the aquifer, these estimates probably will be somewhat low.

2.4 Recharge

Recharge to the outcrop of the Edwards-Trinity and the Dockum in the study area is greatly dependent on the amount of precipitation and varies locally on the basis of soils,

[6] Ewing, J.E. and others, 2008, Groundwater Availability Model for the Dockum Aquifer, prepared for Texas Water Development Board.

topography, vegetation and land use. The most effective recharge events occur when the soil's moisture content is high, rains have persisted for a relatively long-time, and evapotranspiration rates are low.

Initial recharge estimates to the Edwards-Trinity and Dockum for the selected modeling period are based on past studies and hydrogeologic concepts. The GAM for the Edwards-Trinity (Plateau) Aquifer[7] estimated recharge to the Edwards-Trinity to be 2 percent of annual precipitation. On a long-term average annual basis, this is about 0.46 in/yr. The GAM for the Dockum, divides estimates of recharge in our study area into predevelopment conditions and current (1950-1997). Their estimates of current recharge are between 0.3 and 1.0 inches per year.

The Seymour Aquifer is within the region and in a similar setting. Scanlon and Dutton[8] compiled findings for the Seymour from several studies showed that recharge ranged from 1.0 to 2.6 in/yr, with an average of about 2.0 in/yr. Ewing, Jones, and Pickens[9] cites other estimates that range from 0.2 to 1.18 in/yr. Ewing and others (2004) determined the recharge from calibration of the steady-state Seymour Aquifer GAM which averaged from 0.8 to 2.5 in/yr. They developed a recharge function from annual precipitation on the basis of deep percolation from a SWAT watershed model. This function maintained the average recharge determined by the Seymour Aquifer GAM steady-state model. Their calculated range in annual recharge to the Seymour was near 0 to over 18 in/yr.

A study of the long-term water level hydrographs from wells suggests recharge has varied substantially in modern times. In the farming area in northwest Nolan County and northeast Mitchell County groundwater levels appeared to be relatively stable until the 1960s, rose several tens of feet by about 1990, and generally have declined since. The rise in water levels from about 1960 to 1990 cannot be explained by a change in pumpage, which is mostly for irrigation. An analysis of several of the water level hydrographs suggest that the net pumping/recharge (total recharge less pumping effects and assuming other factors are insignificant) rate from 1960 to 1990 to be about 3.5 in/yr if one assumes a specific yield of 0.1,

---

[7] Anaya, R. and Jones, I, 2004, Groundwater Availability Model for the Edwards-Trinity (Plateau) and Cenozic Pecos Alluvium Aquifer System, Texas, Texas Water Development Board.

[8] Scanlon, B.R. and Dutton, A, 2002, Groundwater recharge in Texas: University of Texas at Austin, Bureau of Economic Geology, contract report for Texas Water Development Board. http://www.twdb.state.tx.us/gam/resources/RechRept.pdf

[9] Ewing, J.E, Jones, T.L., and Pickens, J.F., 2004, Groundwater availability model for the Seymour Aquifer, prepared for Texas Water Development Board.

which is about 15 percent of the annual rainfall. This seems unreasonably high, which suggests that the specific yield may be considerably lower than 0.1. Another explanation is that the aquifer is functioning as a confined system which has a much lower storativity than a water table system. Since 1990, the same analysis suggests the net pumping/recharge value to be about minus 0.8 in/yr.

Based on similarity of physiographic settings, the concept for this study will be similar to the Seymour Aquifer GAM where an estimate a long-term average recharge will be developed by calibration for steady state conditions. However, for variability related to precipitation during transient calibration, an analogy is made with runoff from a relatively small watershed. The concept is that on an annual basis a threshold amount of precipitation is needed to produce runoff and recharge. For simplicity, the amount of recharge increases linearly with annual precipitation above the threshold. The runoff data used in the development of this concept is from the USGS streamflow gaging station 08120500 Deep Creek nr Dunn, Texas. The station's drainage area is about 198 square miles. Daily data are available from 1954-2004. Annual precipitation data are from the TWDB database for grid 507. A scatter plot of the annual precipitation and annual runoff is shown in Figure 2-13. A linear regression line shows an intercept of zero runoff at an annual precipitation of about 10 inches. Depending on the amount of steady state recharge, the regression line would be adjusted by a multiplier that is the ratio of the steady state recharge to average runoff. For example, if the steady state recharge is 1.5 in and the average runoff is 0.75 in, as shown in Figure 2-13, then the slope of the runoff regression curve would be adjusted upward by a factor of 2 to represent recharge as a function of precipitation.

As mentioned earlier, additional recharge is likely to occur in irrigated areas. Based on a study by the State of Nebraska's consultants for the Republican River Compact groundwater model in the High Plains Aquifer in southwest Nebraska,[10,11] about 20 percent of the irrigation water in fully irrigated fields becomes deep percolation and recharges the aquifer. The aquifer, soils and topography of the two groundwater models are reasonably similar. However, the irrigation practices appear to be quite different in that the Nebraska farmers tend to fully meet the crop's water requirements and the Mitchell and Nolan County farmers only provide supplemental water for their crops. As a result, there is no excess irrigation water to return to the

[10] Republican River Compact. http://www.republicanrivercompact.org/v12p/RRCAModelDocumentation.pdf
[11] Marc Groff, 2008, Personal Communications: Flatwater Group, Lincoln, Nebraska

aquifer in the form of recharge. As a result, it is assumed that recharge from irrigation water is insignificant in our study area.

2.5 Pumping

Ground water pumping data are derived from TWDB water use surveys that began in 1980 and are annual values between 1984 and 2003. Categories in these data sets include municipal, manufacturing, steam-electric, irrigation, mining, and livestock. Pumping estimates for Nolan County are summarized in Appendix A (Table A-1). These data show the 2003 total Edwards-Trinity pumping in Nolan County to be 320 acft. However, these data show considerable inconsistencies in that municipal pumpage declined from 1,019 acft in 1990 to 64 acft in 1997, and that irrigation abruptly went from about 250 acft/yr until 1993 to zero since 1993. Pumping estimates for the Dockum in Mitchell County are also summarized in Appendix A. The data indicate that the total pumping from the Dockum is highly variable, ranging from about 2,400 acft/yr in 1995 to about 12,000 acft/yr in 2000. Much of the variability is related to irrigation and a substantial increase in municipal pumpage in 2000. There also appears to be at least some misclassification of municipal pumping in Nolan County where the pumping is assigned to the Edwards-Trinity Aquifer instead of the Dockum Aquifer. These wells probably were in the outcrop of the Edwards-Trinity, but were screened in the underlying Dockum. In this area, the TWDB aquifer maps do not show the existence of the Dockum. Pumping estimates for Mithcell County are summarized in Appendix A (Table A-2). These data show irrigation to be the dominate use of groundwater.

Pumpage in the categories of manufacturing, steam-electric, and mining did not exist or was relatively small and were assigned to municipal category. Rural domestic pumping was estimated from regional planning data sets.

The TWDB also compiles detailed water use data by municipal and industrial user and identifies the water source from surveys. A summary of groundwater pumpage for 1990-2005 is presented in Appendix A (Table A-3). These data show about 4,300 acft of municipal pumpage in year 2005, which is all from the Dockum. The industrial pumpage is shown to be less than 80 acft/yr since 1990, and all from the Edwards-Trinity.

A separate accounting is made for pumpage by the Sweetwater in the Champion Wellfield, which were constructed in 2001 and 2002. A summary of these data are listed in

Appendix A (Table A-4). The pumpage from 2001 to 2007 averaged about 2,850 acft/yr, with the greatest amount being about 3,820 acft in 2003.

With the calibration period extending through 2007, pumping estimates were required for the latter years. Irrigation pumpage from 2004-2006 were estimated on the basis of the average pumping per irrigated acre for 1993-2003, as determined from TWDB irrigation pumpage and irrigated acreage from National Agricultural Statistics Service (NASS)[12]. These data show annual irrigation pumping in Mitchell and Nolan Counties ranged from 7.2 to 21.6 inches per year and averaged 13.9 inches per year. From 1992-2006, irrigated area in the two counties ranged from a low of 2,300 acres in 1999 to 8,900 acres in 2006. The acreage was about evenly split between the two counties. For the other water use categories, pumping in the latter years was assumed to be equal to pumping in the most recent year.

With the groundwater model not including the entire counties, the county-wide pumping is prorated to the model area on the basis of the total number of wells in each county to the number within the model area and that county that were in TWDB's database. Pumping within each category is assigned to the matching category of wells on an equal basis, within that county.

2.6 Natural Groundwater Discharge

The natural groundwater discharge in the vicinity of the study area is along the Colorado River, which is along the western edge of the study area. The TWDB well database lists only one spring in the study area. It discharges from the Dockum at a reported yield of 5 gallons per minute. It is located about 5 miles south of Loraine. Aerial images shows considerable riparian vegetation along the lower reaches of major creeks and the Colorado River, which suggests a shallow water table and possibly baseflow in streams, especially during the winter. A compilation of the streamflow at USGS streamflow gaging station 08121000 Colorado River at Colorado City from 1980-2007 shows a median streamflow of 0.41 cfs. The next downstream station 08123850 Colorado River at Silver shows a median streamflow for the same period to be 7.1 cfs. This statistic indicates a gaining stream in this reach, which implies groundwater discharge from our study area. Actual baseflow estimates would require an accounting of diversions and return flows and inflow from the west side of the river.

[12] National Agricultural Statistics Service, U.S. Department of Agriculture http://www.nass.usda.gov/Data_and_Statistics/index.asp

3.0 Conceptual Model of the Aquifer System

The lateral extent of the groundwater model (Figure 3-1) is based on the location of the Champion Wellfield, the hydrogeology of the area, and the scope of the study. The boundaries for the lateral extent of the model are:

- The northern boundary of the model is in the vicinity of the northern edge of Nolan-Mitchell Counties. A General Head Boundary (GHB) is used to represent a continuation of the Dockum and the Whitehorse into Scurry and Fisher Counties. The Edwards-Trinity does not exist in this vicinity.
- The eastern boundary is beyond the extent of the Dockum. The Whitehorse beyond this area is considered to be hydrogeologically insignificant. For the Edwards-Trinity, the eastern boundary is along a relatively narrow, north-south section, as defined by Sweetwater Creek flowing to the north and Oak Creek flowing to the south. A GHB represents the area where the Edwards-Trinity is continuous.
- The southern boundary of the model is in the vicinity of the southern edge of Nolan-Mitchell Counties except for two relatively narrow peninsulas of the Edwards-Trinity. This is the approximate southern extent of the Edwards-Trinity and Dockum Aquifers. The Dockum and Whitehorse are represented with no-flow boundaries because the aquifers are believed to be poorly permeable in the area and lack of hydrogeological significance to the Champion Wellfield.
- The western boundary is along the Colorado River and is represented by MODFLOW's RIVER package.

Hydrogeologic features that influence groundwater flow and water balance are: hydraulic properties of the aquifers; recharge from precipitation; discharge to wells, tributaries, and riparian vegetation; and underflow. The Whitehorse is generally considered to be insignificant in terms the overall water budget. However, it is included for completeness and for hydrologic connectivity to the Colorado River in the southwestern part of the model area. A schematic showing an east-west cross section of the Edwards-Trinity, Dockum, and Whitehorse Aquifers through the center of the counties and the corresponding conceptual model is shown in Figure 3-2.

The conceptual model represents the aquifer system with three layers, one for each of the aquifers. A single layer for each aquifer is considered to be of sufficient detail because each are relatively thin (generally less than 200 ft of saturated thickness). As illustrated in Figure 3-2, the three aquifer overlap in the southeastern part of the model area. However, to the north, the Edwards-Trinity is absent, and to the southwest, the Edwards-Trinity and Dockum are absent. The aquifer system is underlain by deeper geologic units of the Permian System, which for purposes of this model, is considered to by impermeable and a no-flow boundary.

Recharge to the outcrop of the Edwards-Trinity and the Dockum is a function of annual precipitation. A study of historical groundwater level patterns suggests trends in recharge that are probably related to land use practices. Trends in recharge are represented only by precipitation.

Discharge by wells is from estimates provided from TWDB, Sweetwater and regional planning. Pumpage in each category will be distributed equally among wells within a county in the same category of use.

Aquifer gains and losses to underflow from boundaries and streams are calculated by the model. Underflow will be calculated by the General Head Boundaries (GHB) around the model's edge where the aquifers extend beyond the study area. Discharge to streams will be represented by the DRAIN Package. The ET Package was considered, but eliminated because: (1) the confining nature of the shales and clays over the water-bearing sands and conglomerate, and (2) ET is likely to only occur where there is either a Drain or River cell.

A preliminary review of very limited water level data for Edwards-Trinity wells shows some wells with little or no long-term changes and others with modest rises since the 1960s. For the Dockum, there is a considerable amount of water level data to characterize the hydrologic conditions since the late 1950s. These data show a strong general trend of rising groundwater levels from the 1960s to about 1990. Since 1990, the water levels have tended to stabilize or decline slightly. The cause in the rise in water levels from the 1960s to 1990 is attributed to land management practices, a severe drought of the early and mid-1950s that followed by generally above average rainfall, and a change from intense irrigation in the 1950s and 1960s to considerably less irrigation in the 1990s. Since 2000, irrigation has increased to approximate levels in the early 1980s.

The source of groundwater for pumping in the study area is derived mostly from storage, capture of underflow, recharge, and reduction of baseflow to the Colorado River.

Based on a study of the hydrologic data, the aquifer conditions in 1990 are reasonably stable, as indicated by groundwater level hydrographs and are considered to be suitable for steady-state calibration. Transient calibration is from 1990 to 2007. Model simulations to estimate groundwater availability are from 2008 to 2060.

4.0 Groundwater Model

The design of the MODFLOW groundwater model for the Edwards-Trinity and Dockum Aquifers and the Whitehorse geologic unit in Nolan and Mitchell Counties considers the hydrogeology of the study area and the initial use of the model. The lateral extent of the groundwater model is based on the location of the Champion Wellfield. With this in mind, the model extends to the north and south boundaries of the two counties, to the Colorado River to the west, and to either the extent of the aquifer or a relatively narrow, north-south section of the Edwards-Trinity, as defined by Sweetwater Creek flowing to the north and Oak Creek flowing to the south. The model is oriented in a north-south direction. Cells are square and have a lateral dimension of 0.25 miles. The model has 129 rows and 149 columns. The model's vertical dimension is subdivided into three layers. The world coordinates of the model origin are X: 119177.040236 and Y: 6715667.966962. The aerial extent of the groundwater model was shown earlier in Figure 3-1 along with several of the model's features.

4.1 Calibration Periods

The selection of calibration periods is based on hydrologic considerations along with constraints on funding and time. The most rigorous approach to calibration is: (1) having the boundary of the model extend to natural boundaries of the aquifers or with a sufficient distance where the effects of the project pumping are negligible and (2) starting the model with a steady-state representation of nearly predevelopment conditions, which would probably be the 1940s and (3) conducting a transient simulation from predevelopment to 2007. Associated with this representation would be the requirement to account for the apparent changes in land use in much of the area and the resulting changes in recharge and pumpage. Considering the scope and funding of this study, the selected alternative is starting the calibration period in 1990 by assuming the aquifer was in approximate steady-state conditions when many of the water levels hydrographs showed a gradual transition from a rising limb to stable levels or to a slightly declining limb. Accordingly, the model calibration strategy was to conduct a steady-state calibration for 1990 conditions and a transient calibration from 1990-2007. The stress periods were one year with ten time steps for each year for computational purposes. These time periods are considered to be reasonable for the sluggish response of the aquifer system, detail of the calibration data, and planned use of the model.

4.2 Boundaries

The boundary representation along the northern, eastern, and southern sides of the model uses either MODFLOW's General Head Boundary where the aquifer is continuous or no-flow where the aquifer did not extend to the side of the model. For this boundary, the initial GHB values are: thickness, set to approximately equal a typical saturated thickness of the layer in the area; width, the width of the model cell; hydraulic conductivity, approximate value of adjacent model cells; distance, set to two miles; and stage, based on groundwater level data. For transient simulations, the stage along the northern boundary varied with historical records. The GHB stage at the other boundaries was held constant on the basis of very limited data and little or no indication of time trends.

Along the western boundary, the model is defined by the MODFLOW's RIVER Package which represents the Colorado River.

4.3 Streams

In the study area, two types of streams are used. One is the intermittent streams, such as North Fork Champion Creek and South Fork Champion Creek, which is typical of creeks in the area. For these streams, the DRAIN Package was selected. This representation in MODFLOW allows water to discharge from the aquifer if the groundwater level is higher than the stream's stage and makes the stream inactive if the groundwater level is below the stream's stage. The second type of stream is for a perennial stream (Colorado River), which is represented by the RIVER Package. This representation allows as much water to flow into or out of a stream, as dictated by the model scenario.

From an aquifer's perspective in this setting, the dynamics of the stream's stage of the tributaries and the Colorado River is very minor. Therefore, it is set to a constant value for all model simulations. Because streamflow in the Colorado River in this reach is typically only a few cubic feet per second (cfs) or less, stream stage is set to approximately equal the land surface elevation.

4.4 Pumping

Pumping estimates for the model are based on information obtained from the TWDB, Sweetwater, and regional water plans. The pumpage information from the TWDB consisted of: (1) groundwater withdrawal summaries by county, aquifer, and major category (municipal, manufacturing, steam electric, irrigation, mining and livestock) and (2) compilation and analysis of municipal and industrial water use surveys, and rural-domestic pumping from regional water plans.

The period of TWDB summarized water use data was 1980 and 1984-2003; and, the period of water use survey data extended thru 2005. Pumpage from the City of Sweetwater's Champion wellfields was from 2001-2007. Missing irrigation pumpage was estimated with NESS irrigated acreage data. Other pumping estimates are equal to the most recent data. Lacking a reasonably good inventory and location of wells other than the Sweetwater wells, the pumping from all categories was assigned on an equal basis to wells in the TWDB's database that were in a matching category. For Sweetwater's pumping prior to 1997, pumpage was prorated among their wells that were believed to be in operation at the time. Since 1997, reported pumpage from Sweetwater wells was assigned to individual wells.

4.5 Recharge

Estimates of recharge rates are based on calibration, with consideration given to previous modeling studies, precipitation, soils, land use, response of groundwater levels, and the infiltration characteristics provided by Kier and others (1977), which will provide the initial spatial distribution and relative rates of recharge (Figure 1-3). In the study area, water levels are relatively insensitive to a common adjustment in recharge and hydraulic conductivity. In other words, if the recharge and the hydraulic conductivity are doubled, the resulting water levels are not substantially different from the original water levels in much of the area. Also, using baseflow as a restraint on recharge is not available because: (1) an inability to partition aquifer discharge between baseflow and evapotranspiration, (2) a lack of tributary streamflow data, and (3) baseflow in the Colorado River also comes from the west side of the river and is affected by miscellaneous diversions and return flows. As a result, the calibration of recharge emphasizes: (1) establishing zones where recharge is likely to be unique, (2) adjusting the recharge of the zones and the hydraulic conductivity of the aquifer within limits supported by data and technical studies, and (3) hydrogeologic reasonableness. As discussed earlier, there appears to be great variability in recharge over time, and that the recharge during the selected steady-state period (1990) is in a transition from relatively high rates from about 1960 to 1990 and possibly relatively normal or low rates since 1990. Recharge during the transient period is adjusted on a sliding scale of zero recharge during a very dry year and average steady-state recharge during a year with average precipitation.

5.0 Calibration

The model calibration used in this study is an iterative, trial and error process of minimizing the difference between the modeled and measured water levels. The most sensitive and poorly defined parameters are adjusted first. In the latter stages of calibration, adjustments to the other parameters are also tested in an attempt to minimize the calibration errors. For this setting and the model's design, the most sensitive parameters are expected to be recharge, hydraulic conductivity, and storage coefficient. Horizontal hydraulic conductivity values are fairly well constrained with aquifer test data for the Dockum and to a much lesser amount for the Edwards-Trinity. Data on recharge and storage coefficient places a limited constraint on these parameters. The next tier of parameter sensitivity is expected to be the GHB along the northern edge of the model and the conductivity associated with DRAINS. The vertical hydraulic conductivity between model layers is expected to have little sensitivity because the aquifer units are relatively thin, the time steps relatively long, and water levels have a limited range in fluctuations. Also, there is no water level data to verify a difference in water levels within the geologic units at given locations. Early stages of the calibration were spent on verifying or refining the relative sensitivity of the parameters described above.

As stated earlier, the primary criteria for evaluating the model's calibration were matching modeled and measured water levels. Emphasis was placed on matching both the water level values and shape of the hydrographs. Other considerations include achieving a relatively uniform scatter of measured and modeled water levels along a line of equal values and a review of the root-mean-square error (RSME) to get an indication of any skew in calibration and the overall magnitude of the error. Finally, consideration was given to achieving a water balance among the many water budget components that seemed to be most reasonable.

In the calibration process, local adjustments to model parameters were constrained to maintain regional patterns that were realistic and had somewhat gradual transitions. The lure of 'over calibrating' the model by creating local zones of very high and/or very low values was rejected on the basis of a strong preference for regional characterization. There appears to be substantial variability in the hydraulic properties of aquifers, but there is not sufficient data or detailed model delineation to locally define this variability throughout the model area. This is noted along the northern boundary of the model where groundwater levels north of the model boundary are substantially higher than in the adjacent area within the model. There is also a contrast in the number irrigation wells in the model area and essentially none immediately to the north. This indicates that the Dockum is considerable more permeable in the vicinity the irrigated area.

5.1 Steady-State

The first attempt for a steady-state simulation with 1990 hydrologic conditions was to set the storage coefficient to zero and the initial heads at an arbitrary level above the highest land surface elevation in the model area. However, the model solution either did not converge or produced dry cells over large areas. As an alternative, a steady-state simulation with the initial heads set at land surface, a single stress period of 100,000 days and a rather low storage was tested along with several numerical solvers. GMG solver generally provided superior computational speed and lower mass balance errors. During the calibration process, some of the fringe area of the Edwards-Trinity and Dockum would not remain saturated with reasonable recharge and hydraulic conductivity values. To eliminate the potential modeling difficulties with dry cells in this area, the thin sections along the western fringe of the outcrop area were reclassified to 'inactive.'

The measured and modeled water levels of the selected simulation were evaluated by: (1) comparing the difference (residual) between the measured and modeled values by posting the residuals on the map to illustrate their magnitude and location and (2) graphing the measured and modeled values. The variation of the residuals across the model is shown in Figure 5-1. A scatter plot of the residuals is shown in Figure 5-2. The success of the calibration for the Edwards-

Trinity (layer 1) is difficult to judge because of few values (four), substantial difference in water levels in two relatively close wells, and the locations of the other two wells are very near model boundaries. These results show the modeled stage in the Edwards-Trinity is higher than the observed stage in three of the wells, but approximately split the two water level targets in the main part of the aquifer. The Dockum residuals show little or no bias of the modeled stage and the observed groundwater levels being too high or too low. The RMSE for the Dockum wells is about 16 ft. The range in water levels across the model area was about 250 ft. More that half of the modeled values were within 10 ft of the measured values. Water level data are not available to evaluate the model's accuracy in representing the Whitehorse layer. Modeled water levels for Edwards-Trinity and Dockum are shown in Figures 5-3a and 5-3b, respectively. The maps show that the highest groundwater levels are in the central area of the Edwards-Trinity and the lowest water levels are along the Colorado River. Maps of the saturated thicknesses of the Edwards-Trinity and Dockum are shown in Figures 5-4a and 5-4b, respectively. The saturated thickness of the Edward-Trinity ranges from 25 to 125 ft and the saturated thickness of the Dockum ranges from 25 ft near the Colorado River to over 200 ft in the north-central part of the model.

A water budget for the steady-state calibration is given in Table 5-1. It shows the total recharge to the model is about 22,500 acft/yr and total pumping to be about 4,800 acft/yr. Vertical flow between layers is consistently downward, from the Edwards-Trinity to the Dockum and from the Dockum to the Whitehorse; recharge is highest in the Edwards-Trinity; and pumping is highest in the Dockum.

5.2 Transient

The transient calibration period is from 1990 to 2007 with annual stress periods. The initial heads for this simulation are the water levels that resulted from the 1990 steady-state simulation. The conversion of the model from a steady-state simulation to a transient simulation required estimating storage coefficients, annual pumping and recharge, and adjusting the stage values of the northern GHB.

Table 5-1.
Modeled Water Budget for Steady-State Conditions (1990)

Layer 1 - Edwards-Trinity

Outflow			Inflow	
-129	Wells		Recharge	14,013
0	Stream		Storage	0
0	ET		GHB	0
-1,070	GHB		Stream	0
-5,049	Drains		Rivers	0
0	Storage			
0	Rivers			

Flow from Layer 1 to Layer 2: 7,765

Layer 2 - Dockum

Outflow			Inflow	
-4,663	Wells		Recharge	6,640
0	Stream		Storage	0
0	ET		GHB	877
0	GHB		Stream	0
-5,272	Drains		Rivers	0
	Storage			
-3,225	Rivers			

Flow from Layer 2 to Layer 3: 2,133

Layer 3 - Whitehorse

Outflow			Inflow	
0	Wells		Recharge	1,808
0	Stream		Storage	0
0	ET		GHB	0
-50	GHB		Stream	0
-2,995	Drains		Rivers	0
0	Storage		Constant Head	0
-902	Rivers			

All Values in acft/year

Calibration targets and hydrographs were used to evaluate the transient model. Water level data were reviewed to find wells with multiple years of data throughout the 17-year simulation period. Wells were selected as calibration targets on the basis of number of observations and spatial distribution. The transient calibration data set includes 271 water level measurements in a total of 31 wells. Four of the wells were in the Edwards-Trinity; and, 27 wells were in the Dockum.

Like the steady-state calibration, the transient calibration is evaluated on the basis of the modeled and measured groundwater levels. Figure 5-5 presents hydrographs of measured and modeled water levels at selected well targets. Calculated water levels reasonably depict the water levels trends that have been observed in the Dockum since 1990. The water levels for the two wells in the main part of the Edwards-Trinity show substantial differences in measured water levels in two relatively close wells, thus, the measured and modeled values are a poor match.

A scatter plot of the values for the Edwards-Trinity and the Dockum are shown in Figure 5-6. The RMSE for transient target wells in the Dockum is 14 ft. The RMSE for a representative well in each of the Sweetwater wellfields is 13 ft. These results show little or no bias of the modeled stage and measured groundwater levels being too high or too low in the

Dockum. In the Edwards-Trinity, the modeled stage for the two wells in the main body of the aquifer is approximately evenly split between the two wells.

Maps of 2007 modeled water levels for the Edwards-Trinity, Dockum, and Whitehorse aquifers are presented in Figures 5-7 a, b, and c, respectively. The Whitehorse water levels show the influence of the tributaries.

The Edwards-Trinity and Dockum drawdown from 1990 to 2007 is shown in Figures 5-8a and 5-8b, respectively. There is minimal drawdown in the Edwards-Trinity and the water level is rebounding in both the Edwards-Trinity and the Dockum due to decreased pumping from steady-state conditions in some Sweetwater wells. Drawdowns in the Dockum range from 5 to 20 feet in the Champion Wellfield and 5 to 15 ft to the west.

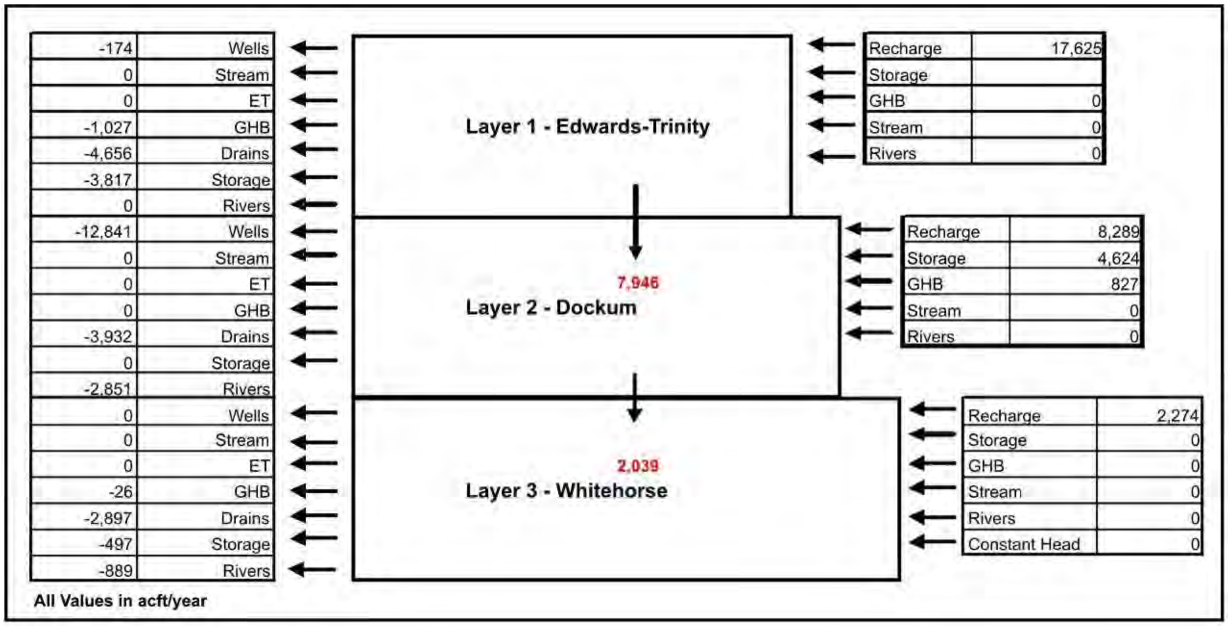
A water budget for the last year (2007) of the transient calibration is shown in Table 5-2. It shows the total recharge to the model in 2007 is about 28,400 acft/yr and total pumping to be about 13,000 acft/yr. The increase in Dockum pumping has caused less discharge to the Colorado River and tributaries and a reduction in groundwater storage (lowering of water levels).

5.2.1 Aquifer Properties

In the calibration process, aquifer properties were adjusted within reasonable limits to achieve a suitable match of measured and modeled groundwater levels. The initial results for all the aquifer parameters except the storage coefficient were obtained from the steady-state calibration. Estimates of storage coefficients were obtained from the transient calibration.

Estimates of the horizontal hydraulic conductivity of the Edwards-Trinity and Dockum are shown in Figures 5-9a and 5-9b, respectively. With no water level data from wells in the Whitehorse, the value was estimated on a relative comparison with the Edwards-Trinity and Dockum, which was 0.5 ft/day. The range of values tested in the calibration were constrained by the data and analysis presented in Section 2. The highest horizontal conductivity is in the Dockum and in the area where there are a relatively large number of irrigation wells. In this hydrogeologic setting, the water-bearing zone is relatively thin and near or at the bottom of the Dockum and is confined by shale and clay layers. However, MODFLOW considers the entire layer to be uniform and calculates the aquifer’s transmissivity from the saturated thickness. With the aquifer dipping to the west at a slightly greater rate than the groundwater levels, MODFLOW will calculate an increasing trend in transmissivity for a uniform horizontal hydraulic conductivity. To compensate for this trend, the hydraulic conductivity of the Dockum, as determined by calibration, tends to decrease from east to west.

Table 5-2.
Modeled Water Budget for Last Year (2007) for
Transient Simulations



For purposes of this model, the vertical hydraulic conductivity is set at 0.01 ft/day. Attempts to substantially decrease the value during sensitivity tests caused numerical convergence problems in MODFLOW that could not be overcome with different solvers and various solver parameters. Considering the hydrogeologic setting and the model design with annual time steps, this parameter was judged to be insensitive for purposes of the model.

The specific storage value was estimated to be a uniform 0.00001 in all layers of the model. The specific yield was estimated to be 0.15 for the Edwards-Trinity and 0.10 for the Whitehorse. However for the Dockum, the specific yield for the Dockum varied from 0.18 in the northeastern (updip) part of the model area to 0.001 in the western (downdip) part, as shown in Figure 5-10. The 0.18 value is rather typical for a sand aquifer, while the 0.001 value is unusually low. In this setting, the water-bearing zone is near or at the bottom of the Dockum and is confined by shale and clay layers. Hydrogeologically, the updip part of the Dockum is under true water table conditions and the middle and lower parts of the Dockum are actually under confined conditions. This is illustrated in Figure 5-11. Because the model design defines the land surface as the top of the aquifer instead of the top of the water-bearing zone, MODFLOW does not recognize the middle and western part of the Dockum as being under confined conditions. To compensate for this detail, the specific yield is set to a value that is consistent with a storage coefficient (0.001) that is typical of a shallow and thin confined aquifer system.

Tests with various conductance values for DRAINS showed them to be relatively sensitive where they are active. As determined by calibration, the conductance values varied from 600 ft^2/day in the east to 200 ft^2/day in the western portion of the model, as shown in Figure 5-12. A river conductance value of about 170,000 ft^2/day was used for the Colorado River. The hydraulic conductivity and thickness of the GHBs were similar to nearby values of the model.

5.2.2 Recharge

In the calibration process, initial recharge zones and relative rates of recharge were based on the land resource characteristics presented in Section 2-4. In the calibration process, these zones and rates were extensively modified along with other aquifer parameters to improve the match between measured and modeled water levels. The resulting recharge for steady-state conditions are presented in Figure 5-13. The lowest rate is 0.13 in/yr and occurs in much of the irrigation area and is equivalent to about 0.6 percent of average annual rainfall. The highest rate is 1.31 in/yr and occurs in the Edwards-Trinity Aquifer area and is equivalent to about 6 percent of average annual rainfall. For the transient simulation, annual recharge is adjusted on the basis of annual precipitation, as discussed earlier. The annual recharge rates for all recharge zones are shown in Figure 5-14; the zone numbers are shown on Figure 5-13. The transient recharge for the lowest zone (zone 2) ranges from 0.03 in/yr to 0.19 in/yr. Likewise, recharge in the highest zone (zone 8) ranges from 0.26 in/yr to 1.93 in/yr.

6.0 Predictive

The initial application of Champion Wellfield groundwater model is to assist the City of Sweetwater and Brazos G in assessing the potential long-term supply of water from the Champion Wellfield as a long-term water management strategy. The general approach for this assessment is to make predictive simulations for several wellfield scenarios from 2008 to 2060 and to consider regional groundwater levels, drawdown in groundwater levels, saturated thickness maps and trends in water levels to determine the most suitable water management strategy.

Preparation of the model for the predictive simulations included developing long-term estimates of recharge and pumping. Other parameters such as stage for the RIVER, DRAIN, and GHB cells were held constant at 2007 values.

6.1 Recharge

The selected approach for estimating recharge assumes: (1) annual rainfall from 1948 to 2000 would be repeated from 2008 to 2060 and (2) recharge could be calculated from annual precipitation with the same method used for the transient calibration. The method used to estimate annual recharge from annual precipitation was described in Section 2.4 and included calculating a recharge factor for each year and multiplying this factor by the steady-state recharge. A plot of the historical annual precipitation is provided in Figure 6-1. A plot of the annual recharge for each of the recharge zones is shown in Figure 6-2. These plots show the period of lowest precipitation and recharge occurred in the first few years of the predictive simulations which corresponded to the 1950s drought. The greatest precipitation and recharge occurred in 2046, which is equivalent to 1986. Recharge for the Edwards-Trinity layer averaged about 1.29 in/yr. Recharge for the Dockum averaged about 0.25 in/yr.

6.2 Pumping

The predictive pumping rates are based on water demands that are based on projections in the 2006 Brazos G and Region F Regional Water Management Plans and estimates of demand from Sweetwater. Nolan and Mitchell Counties are located in Regions G and F, respectively. These plans provided total demand (surface water and groundwater) estimates for each decade. Categories in these data sets include: municipal, manufacturing, steam-electric, irrigation, mining and livestock in both plans and county-other and rural domestic in Brazos G. Adjustments were made by dividing the water use between surface water and groundwater, accounting for parts of the counties that were outside the model and removing Sweetwater's pumping from the municipal category. These adjustments followed the same general procedure that was used for the calibration period. Pumping was interpolated between decades. Because the pumping in all the categories had common trends, the selected approach in making special and temporal distributions of background pumping was to use the 2007 background pumping for spatial distribution and an annual factor that adjusted the 2007 pumping to a given year based on the Regional Water Plan estimates. Figure 6-3 shows the total background pumping (excluding Sweetwater) that was used in each of the scenarios.

A separate accounting of predictive pumping was made for Sweetwater. Considering Sweetwater's supply of water from Oak Creek Reservoir and several contractual obligations to deliver water to other entities, the selected annual demands range from about 3,900 acft/yr in 2008 to about 3,500 acft/yr in 2060 (Figure 6-3). The trend is based on the 2006 Brazos G Water Plan.

6.3 Predictive Scenarios

The selection of locations for prospective Sweetwater wellfields for re-evaluation of this 2006 Brazos G water management strategy considered recharge rates, aquifer thickness, hydraulic conductivity, and proximity to the Champion Wellfield and irrigation area. Water quality in areas selected for prospective wellfields is generally expected to be good, as no previous studies have identified water quality concerns in this area of the Dockum Aquifer. However, the irrigation area was avoided as a prospective wellfield because of concern from potential groundwater contamination from fertilizers and pesticides. Avoidance of this area will also minimize interference with and from existing irrigation wells. Areas to the east and north of Champion are considered to be undesirable because the aquifer is rather thin and near the updip limit of the Dockum, which limits the groundwater capture zone of the wellfield. With these restraints, the areas to the south and west of the current Champion Wellfield were considered to be the best candidates.

Four test scenarios were selected for development. They include:

- Continuing to utilize the existing Champion Wellfield (Champion Wellfield scenario),
- Adding a wellfield to the southwest of the Champion Wellfield that has the same number of wells as the Champion Wellfield (Scenario A),
- Adding a wellfield to the west of the Champion Wellfield that has the same number of wells as the Champion Wellfield (Scenario B), and
- Adding a wellfield in areas to the west and southwest of the Champion Wellfield that has twice the number of wells as the Champion Wellfield (Scenario C).

In each of the scenarios, the existing Champion Wellfield was continually used and the individual well pumping was set equal among all the wells. The wells in the prospective wellfields were spaced at half mile intervals. The conceptual wellfields for these scenarios are shown in Figure 6-4; and, a summary of the number of wells and pumping rates are shown in Table 6-1.

Table 6-1.
Well Summary for Scenarios

	Champion Wellfield		***Additional Wellfield(s)***	
Scenario	***Number of Wells***	***Pumping Rate per Well in 2060 (gpm)***	***Number of Wells***	***Pumping Rate per Well (gpm)***
Champion	45	48	0	0
Scenario A	45	24	45	24
Scenario B	45	24	45	24
Scenario C	45	16	90	16

6.3.1 Champion Wellfield Scenario

The Champion Wellfield Scenario is a continued utilization of existing 45 wells in the Champion Wellfield for much of Sweetwater’s future demands. The average annual pumping rate ranged from 54 gpm in 2008 to 48 gpm in 2060. Figures 6-5 and 6-6 show the modeled water levels in the Dockum for 2060 and drawdown from 2008 to 2060, respectively. These results show a drawdown in the center of the cone of depression to be between 30-40 ft. Figure 6-7 shows the saturated thickness in 2060. These results show much of the southern wellfield to have a saturated thickness of less than 75 ft and the middle wellfield thickness to be a minimum of about 40 ft. Hydrographs for selected monitoring sites are shown in Figure 6-8. The annual variation in the water level hydrographs is in response to varying recharge. These graphs shows a continual decline in groundwater levels in all of Sweetwater's wellfields, which indicates that the cone of depression from the wellfield has not expanded to the point of capturing sufficient water to satisfy the pumping. As a result, much of the water is coming from storage, which causes a continued decline in water levels.

6.3.2 Scenario A

Scenario A models the continued utilization of existing wells in the Champion Wellfield and adds a wellfield to the south with the same number of wells as the Champion Wellfield. This scenario doubles the number of wells in the model to 90 wells and cuts the pumping rate for each well by half. The average annual pumping rate for each well is 27 gpm in 2008 and decreases to 24 gpm in 2060. The intent of this scenario is to test the continued use of the existing Champion Wellfield and the benefit of spreading out the total pumping in the southern direction where there appears to be higher recharge in the Edwards-Trinity that would percolate into the underlying Dockum. Figures 6-9 and 6-10 show the modeled water levels for 2060 and drawdown from 2008 to 2060, respectively. These results show a drawdown in the center of the cone of depression to be slightly more than 30 ft in the prospective wellfield and less than about 22 ft in the existing Champion Wellfield. Figure 6-11 shows the saturated thickness in 2060. These results show the prospective wellfield to have a saturated thickness between 125-150 ft. Overall, the minimum saturated thickness continues to be less than 50 ft in the central wellfield. Hydrographs for selected monitoring sites are shown in Figure 6-8. These graphs show a substantially lower rate of decline in groundwater levels in the Champion Wellfields.

6.3.3 Scenario B

Scenario B tests the continued utilization of existing wells in the Champion Wellfield and adding a wellfield of equal size to the west of the southern part of the Champion Wellfield. Like Scenario A, this scenario doubles the number of wells and cuts in half the pumping rate for each well. The intent of this scenario is to test the benefit of spreading out the pumping in the western direction where the saturated thickness of the Dockum appears to be relatively thick. Figures 6-12 and 6-13 show the modeled water levels for 2060 and drawdown from 2008 to

2060, respectively. These results show a drawdown in the center of the cone of depression was calculated to be slightly more than 40 ft in the prospective wellfield, which is higher in the prospective wellfield than in the existing Champion Wellfield. Figure 6-14 shows the saturated thickness in 2060. These results show much of the prospective wellfield to have a saturated thickness between 75 and 100 ft. Hydrographs for selected monitoring sites are shown in Figure 6-8. These graphs show a more modest decline in groundwater levels in all of the Champion Wellfields.

6.3.4 Scenario C

In consideration of the results from the Champion Wellfield Scenario, Scenarios A and B, Scenario C was formulated to lower the overall drawdown and to keep the saturated thickness as great as possible. The approach was to add a prospective wellfield that has twice the number of wells as the existing Champion Wellfield. The Champion Wellfield has 45 wells and Scenario C has an additional 90 wells. The prospective wellfield is partly south and west of the existing wellfield. This cuts the overall pumping rate of a well by one-third and spreads pumping over a larger area. Figures 6-15 and 6-16 show the modeled water levels for 2060 and drawdown from 2008 to 2060, respectively. These results show that much of the drawdown to be slightly more than 30 ft and is reasonably uniform over a relative large area. Figure 6-18 shows the saturated thickness in 2060. These results show much of the prospective wellfield to have a saturated thickness ranging from 75 to 150 ft. Hydrographs for selected monitoring sites are shown in Figure 6-8. These graphs show that the water levels have nearly stabilized by 2060 in the southern part of the combined wellfields and are declining at a rather modest rate in other parts of the wellfields.

6.4 Well Performance

The long-term viability of Sweetwater's Champion Wellfield is also assessed by considering the recent performance of existing wells. This assessment utilizes information provided by Sweetwater and found in driller's reports that document the construction and testing of new wells in the Champion Wellfield. A statistical summary of the assessment is provided in Table 6-2. The detailed assessment for each well is provided in Appendix B (Table B-1). Performance information of key interest includes the well's drawdown, the position of the water surface in relation to the bottom of the well screen during pumping, and trends in groundwater levels. These data show an average drawdown of about 85 ft for the 29 wells with data. Of these wells, 9 of the wells have pumping levels below the bottom of the well screen for October 2006 static water level conditions. Nineteen of the wells have the water levels less than 10 ft above the bottom of the well screens. These data and analysis indicate most of the wells are operating at or very near maximum capacity. It is also important to note that the pump must be set several feet below the water level during pumping to allow for pump submergence. These data also show a declining trend in water levels with an average of about 3.25 ft from October 2006 to January 2008. If this trend continued, the drawdown over a 50 year planning period would be more than 70 ft. Any lowering of water levels would reduce the potential yield of most of the wells because drawdown is at are near the maximum amount for October 2006 conditions. In other words, the capacity for about half of the wells is at or near a maximum for 2006 conditions and will be smaller if there is an additional decline in water levels.

Table 6-2.
Summary of Well Performance Data in the Champion Wellfield

Parameter	***Statistics***				
	Minimum	***25th Percentile***	***Median***	***75th Percentile***	***Maximum***
Well Yield (gallons per minute)	20	50	80	130	225
Well Depth (ft)	160	185	210	250	322
Depth to Bottom of Screen (ft)	145	175	200	240	312
Drawdown during Pump Test (ft)	47	72	82	99	114
Saturated Thickness above Bottom of Screen during Static Conditions (ft) January 2006	64	87	102	122	183
Saturated Thickness above Bottom of Screen during Pumping (ft) January 2008	-24	-4	6	27	44

7.0 Water Management Strategy for Sweetwater

An evaluation of continued use of groundwater by the City of Sweetwater considers the results of the four wellfield scenarios that were tested with the new groundwater model and an analysis of well performance data from the Champion Wellfield. A major concern in the evaluation is based on the well performance data. As stated earlier, about half of the wells with data show the wells are being used at maximum rates, and these yields would become smaller as water levels declined. On the other hand, distributing pumping to nearby areas shows future groundwater declines to be substantially moderated and the aquifer's saturated thickness to experience rather modest changes. Based on these findings, the recommended water management strategy for the Sweetwater is to continue to rely on a conjunctive management practice where they utilize water from Oak Creek Reservoir when surface water is available and to utilize groundwater during droughts. This would reduce the long-term withdrawals from the wells and lessen the magnitude of declining water levels. If there becomes a time when there is a need for more groundwater than can be supplied by wells currently in the Champion Wellfield, the most favorable areas for expansion are to the south-southwest. This is attributed to spreading out the wells as much as possible and moving toward an area where the Dockum appears to be thicker and there appears to be more recharge from the overlying Edwards-Trinity.

The 2006 Brazos G Regional Water Plan assumes a zero yield from Oak Creek Reservoir (Oak Creek) to supply Sweetwater. However, the Region F and Region K Water Planning Groups have noted that with subordination of downstream rights to Oak Creek Reservoir in the Colorado River Basin, the yield available to Sweetwater would be increased to approximately 1,550 acft/yr (Year 2030 sedimentation conditions). This is identified as a water management strategy for the City of Sweetwater in the 2006 Brazos G Plan and for other users of Oak Creek Reservoir in the 2006 Region K and Region F Plans. Diverting this yield from Oak Creek and meeting the remainder of Sweetwater's demands (3,900 acft/yr) from the Champion Wellfield would continue to overtax the wells. A preferable alternative strategy that should be explored for inclusion in the 2011 Brazos G Regional Water Plan would be to overdraft Oak Creek when water is available, and to only utilize the Champion Wellfield when Oak Creek supplies would become depleted during extended droughts. This would provide time during relatively wet hydrologic periods for groundwater levels to rebound. This type of conjunctive use operation should be evaluated as a water management strategy for Sweetwater as the 2011 Brazos G Water Plan is developed.

If a groundwater only strategy is considered, the performance of the current Champion Well Field from 2001-2007 and the groundwater modeling suggests that the Edwards-Trinity and Dockum Aquifers could meet this average demand, which was about 2,850 acft/yr. If the well field was substantially expanded to the south-southwest, the modeling analysis suggests that it could meet the projected demand of 3,900 acft/yr for the planning period.

8.0 Limitations of Model

MODFLOW is a simplified, mathematical representation of a very complex aquifer system. As a result, there are a number of limitations in the design and use of the model.

Major design limitations include:

- The model focuses on representing wellfields in the vicinity of Sweetwater's Champion Wellfield.
- The model covers the western part of Nolan County and the eastern part of Mitchell County. It is considered to be most suitable in the vicinity of the Champion Wellfield, and becomes less and less reliable for evaluation of wellfields as one nears the edge of the model.
- To the east, south, and west, the model's boundaries were at or near natural boundaries. However, to the north, the Dockum continues as part of a regional aquifer system. MODFLOW's general head boundary was used to represent this extension; however, data suggest a very substantial and rapid transition to the north. This transition cannot be represented in detail with the General Head Boundary.
- The spatial gridding is adequate for a wellfield assessment. However, it is not considered to be adequate for an evaluation of an individual well.
- The vertical layering assigns a single layer to each of the three aquifers. A single layer for the Edwards-Trinity is expected to be adequate if future pumping is low. However, the representation of the Dockum as a single layer cannot capture the actual stratification of the aquifer. The averaging of the stratification has an unknown effect on the representation the aquifer's actual transmissivity and storage properties. The Whitehorse formation is assumed to be sufficient to represent the very thick Permian and is suitable in an assessment of the Dockum.
- The calibration of the model with 1990-2007 data is considered to be adequate; however, it most likely would have been improved with a calibration period that extended from predevelopment (1940s) to the current period. The calibration is also limited by not having suitable baseflow data to define natural discharge from the aquifers.

Major data limitations include:

- Water level and aquifer hydraulic data are not available to quantify cross-formational flow between the aquifers. For purposes of this model, the vertical hydraulic properties are between one hundredth and one thousandth of the horizontal value.
- The hydrologic connection to the Colorado River and tributaries is controlled by parameters in the RIVER and DRAIN boundaries. The vertical hydraulic conductivity cannot be defined with existing data and may be somewhat important in some areas.
- There are considerable well data in the irrigated area of the Dockum, that indicate a substantial variability in aquifer properties. This variability has not been mapped and cannot be captured by a groundwater model at this scale.
- Well data suitable for developing a groundwater model are very sparse in the Edwards-Trinity and essentially nonexistent in the Whitehorse.
- The values of aquifer parameters are generalized and primarily defined by calibration. These values should not be considered as a substitute for actual field and test drilling data in siting a well or wellfield.

9.0 Conclusions

An assessment of the long-term groundwater supplies for Sweetwater from the Dockum considers the results of the groundwater modeling and the performance of Sweetwater's wells. About two-thirds of the wells in the Champion Wellfield with data show the wells are being used at maximum rates and these yields would become smaller if the declining trend in water levels continues. On the other hand, distributing the pumping to nearby areas shows future groundwater declines to be substantially moderated and the aquifer's saturated thickness to experience rather modest changes. Based on these findings, the recommended water management strategy for the City of Sweetwater is to continue to rely on a conjunctive management practice where they utilize water from Oak Creek Reservoir when surface water is available and utilize groundwater during droughts. This would reduce the long-term withdrawals from the wells and lessen the magnitude of water level declines. If there becomes a time when there is a need for more groundwater than can be supplied by wells currently in the Champion Wellfield, the most favorable areas for expansion are to the south-southwest of the existing wellfield. This is attributed to spreading out the wells as much as possible and moving toward an area where the Dockum appears to be thicker and there appears to be more recharge from the overlying Edwards-Trinity. If a groundwater only strategy is considered, the analysis suggests that the aquifers could meet 2001-2007 average demand of about 2,850 acft/yr. If the well field was substantially expanded to the south-southwest, the analysis suggests that the projected demand of 3,900 acft/yr for the planning period could be met.

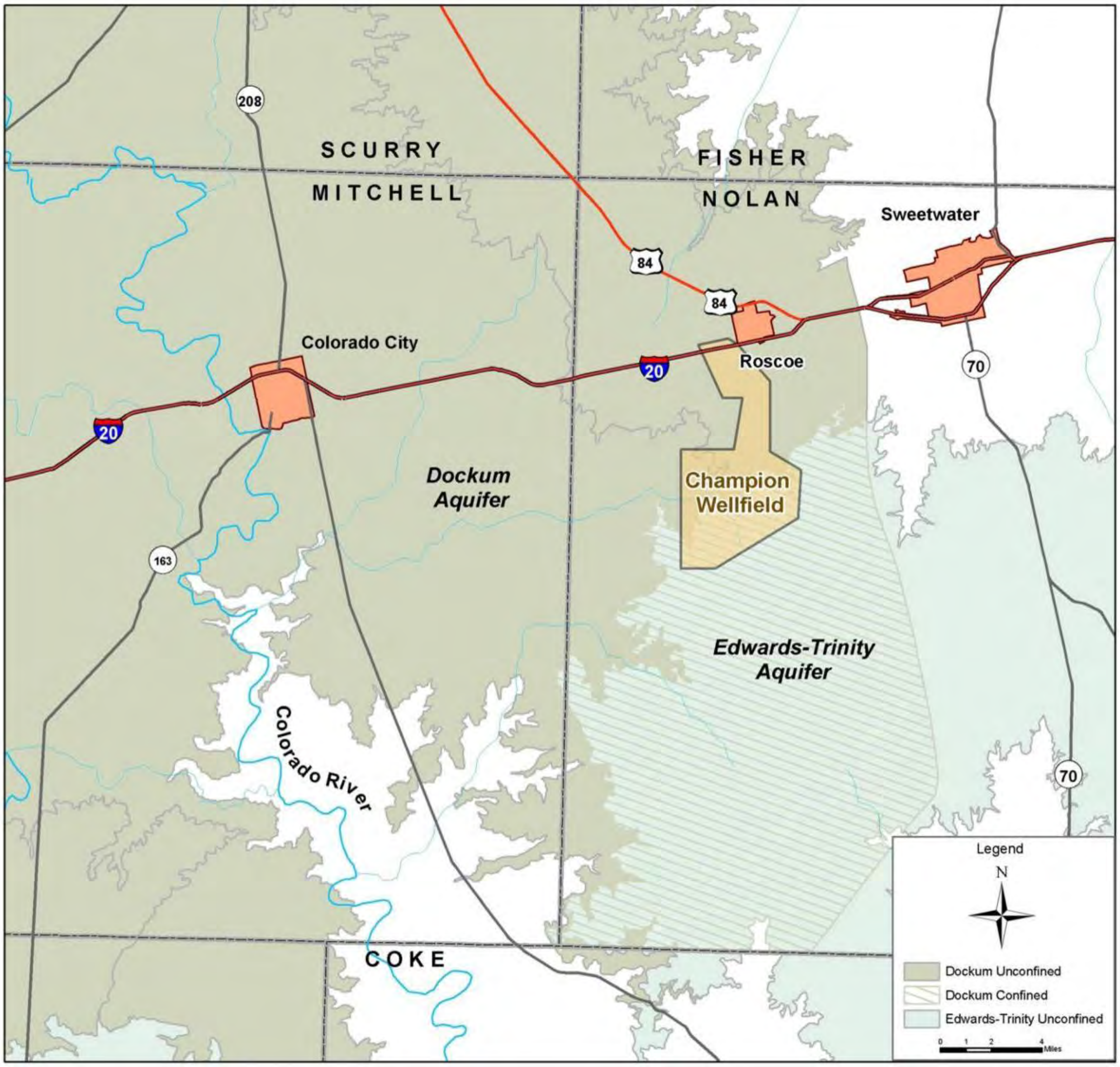


Figure 1-1. Location of Study Area, Major and Minor Aquifers, and Champion Wellfield

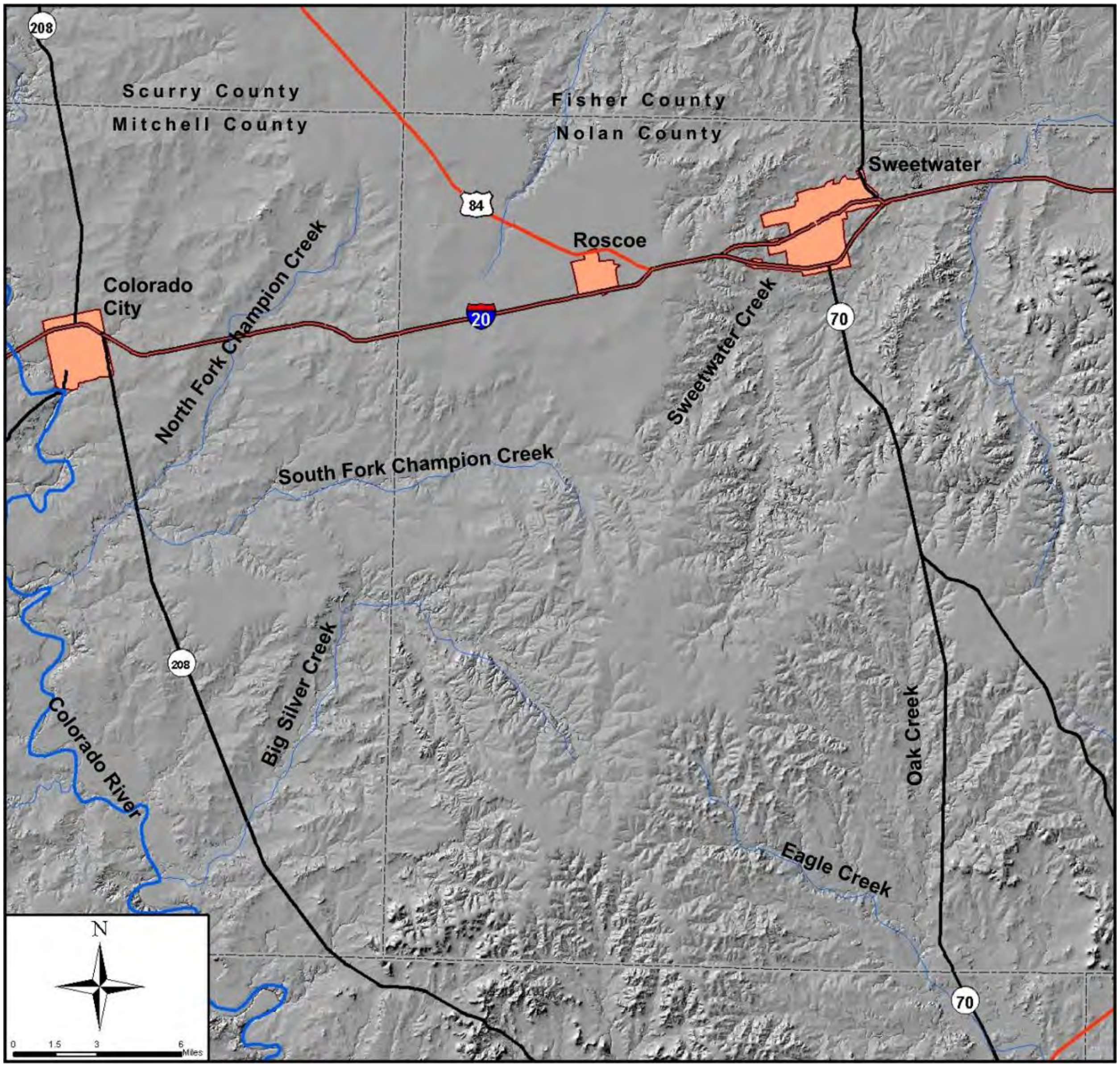


Figure 1-2. Topography of the Study Area

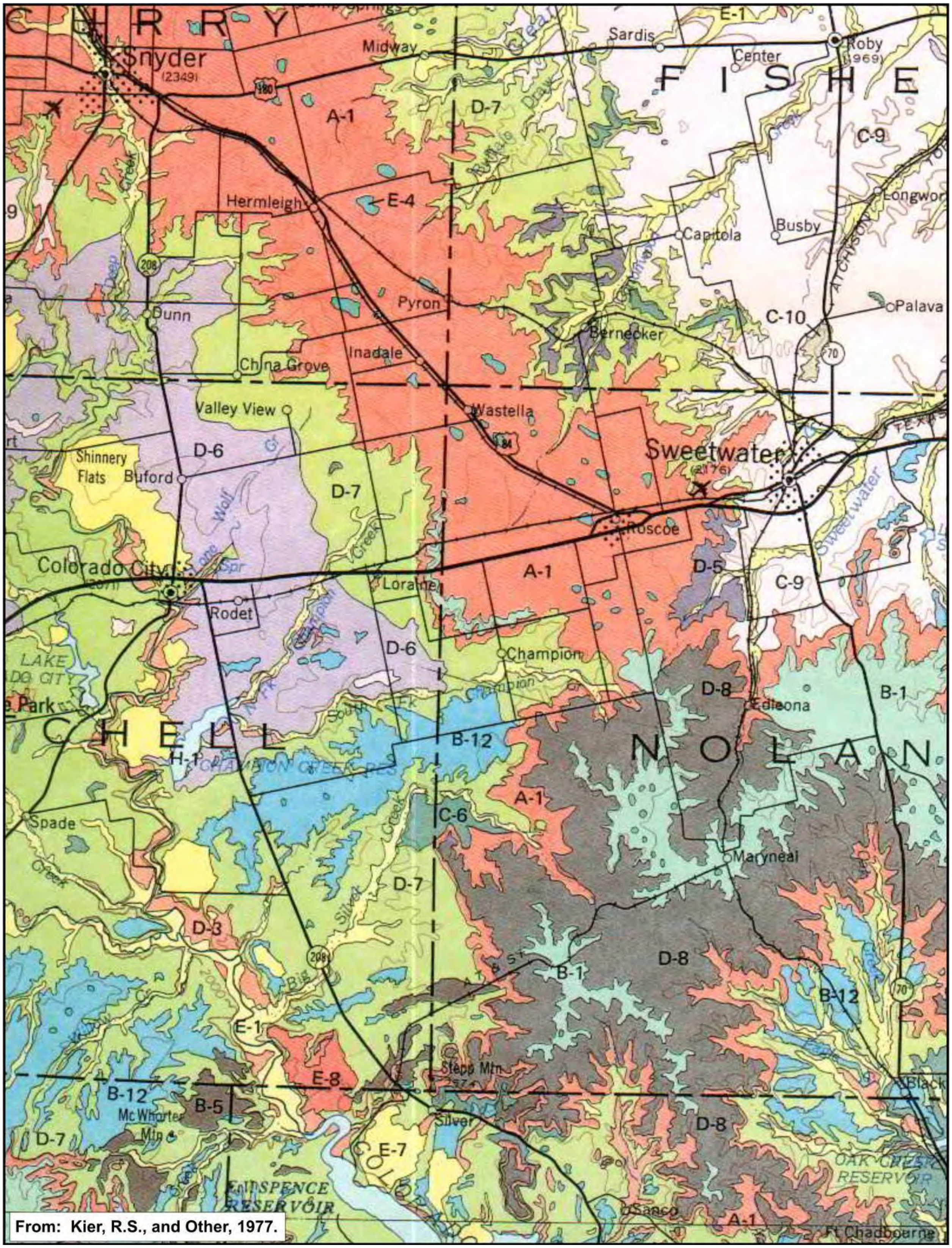


Figure 1-3. Land Resource Units

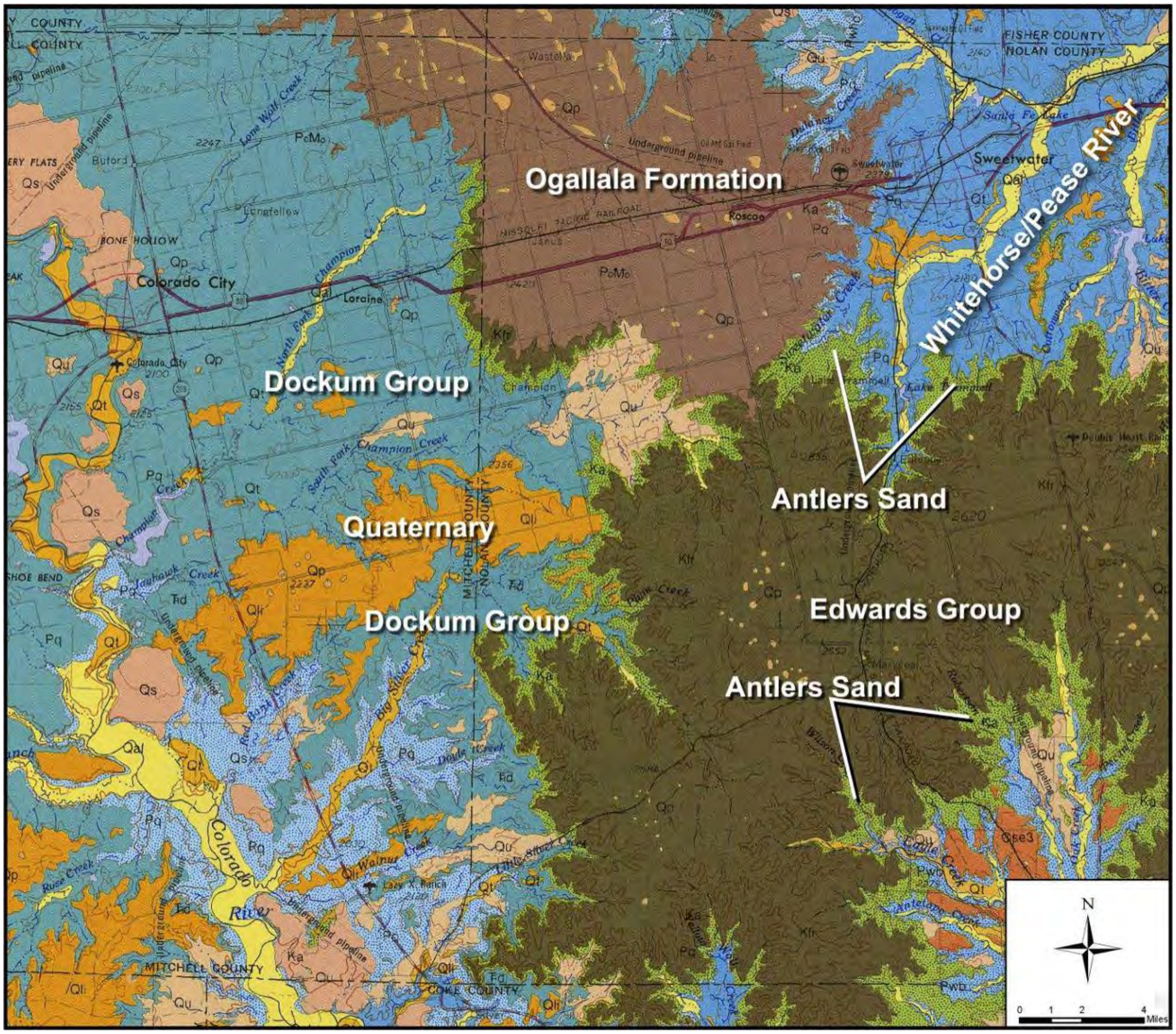


Figure 1-4. Surface Geology

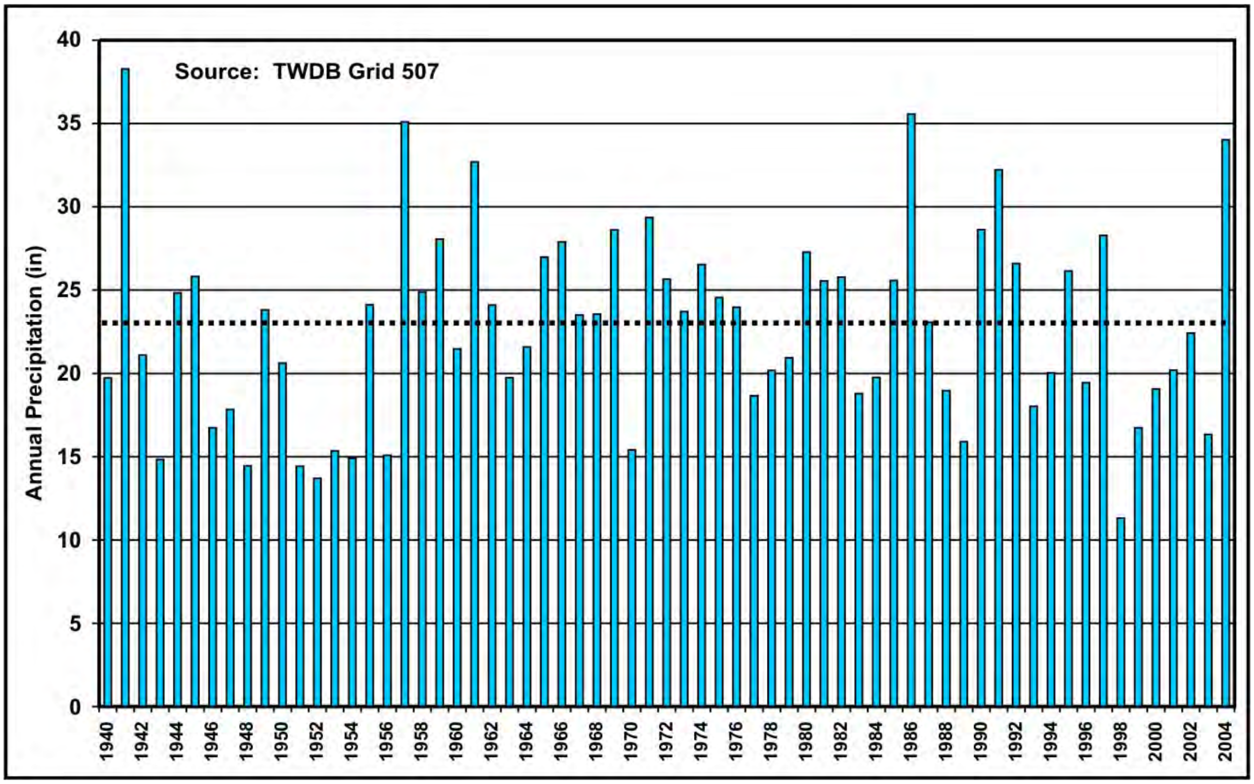


Figure 1-5. Annual Precipitation

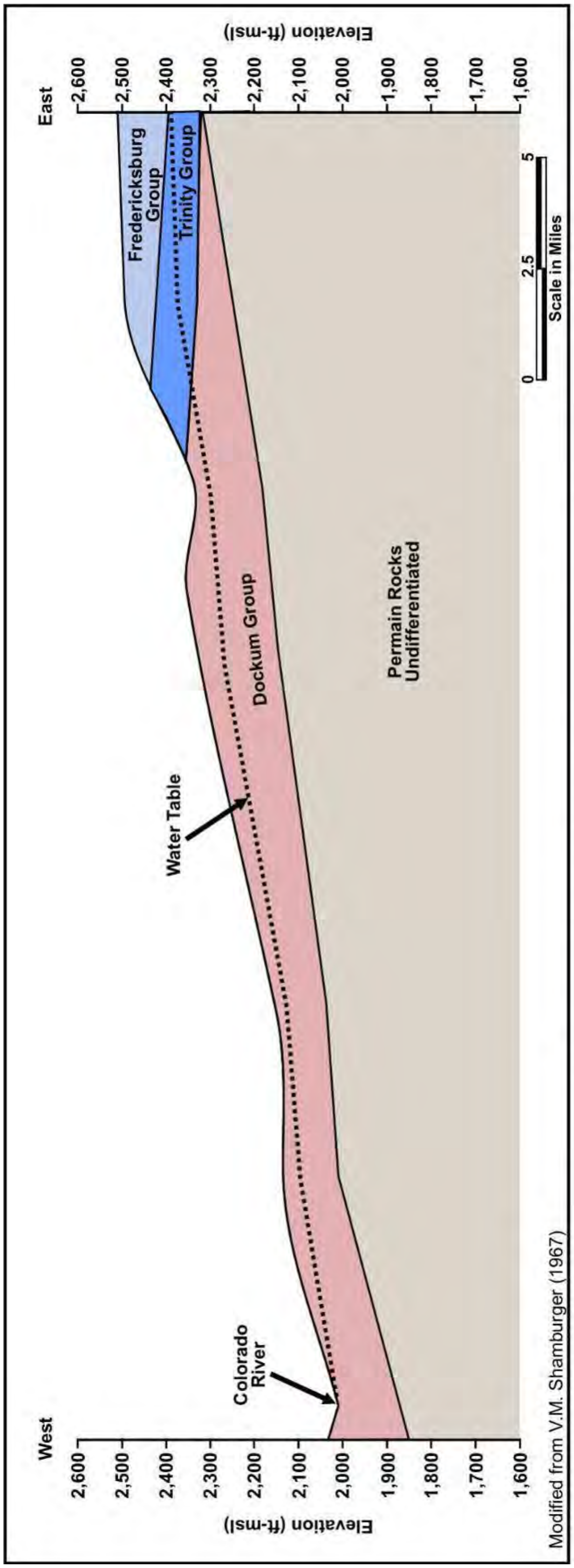


Figure 2-1. Generalized East-West Hydrogeologic Cross-Section

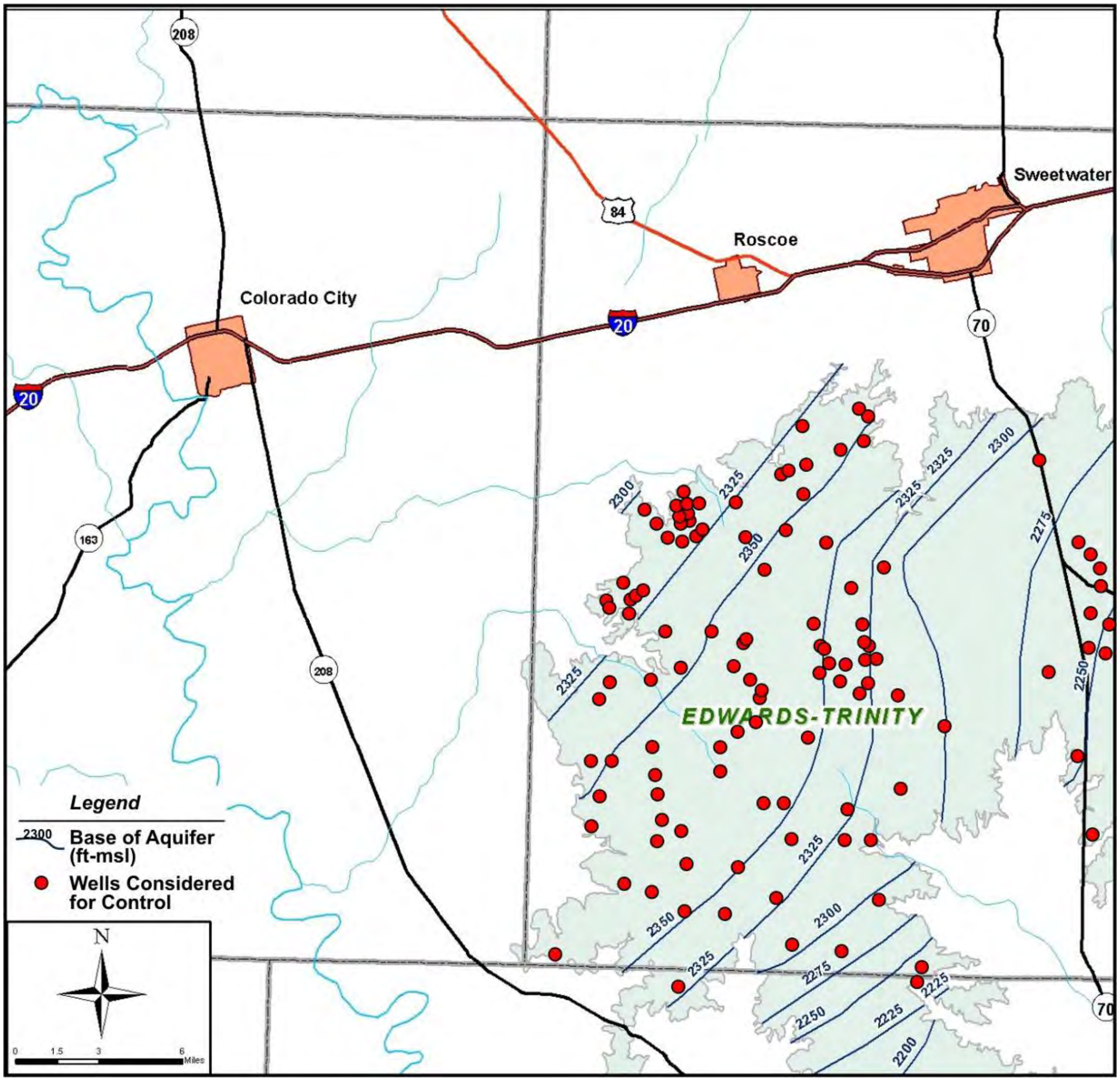


Figure 2-2. Base of Edwards-Trinity (Plateau) Aquifer

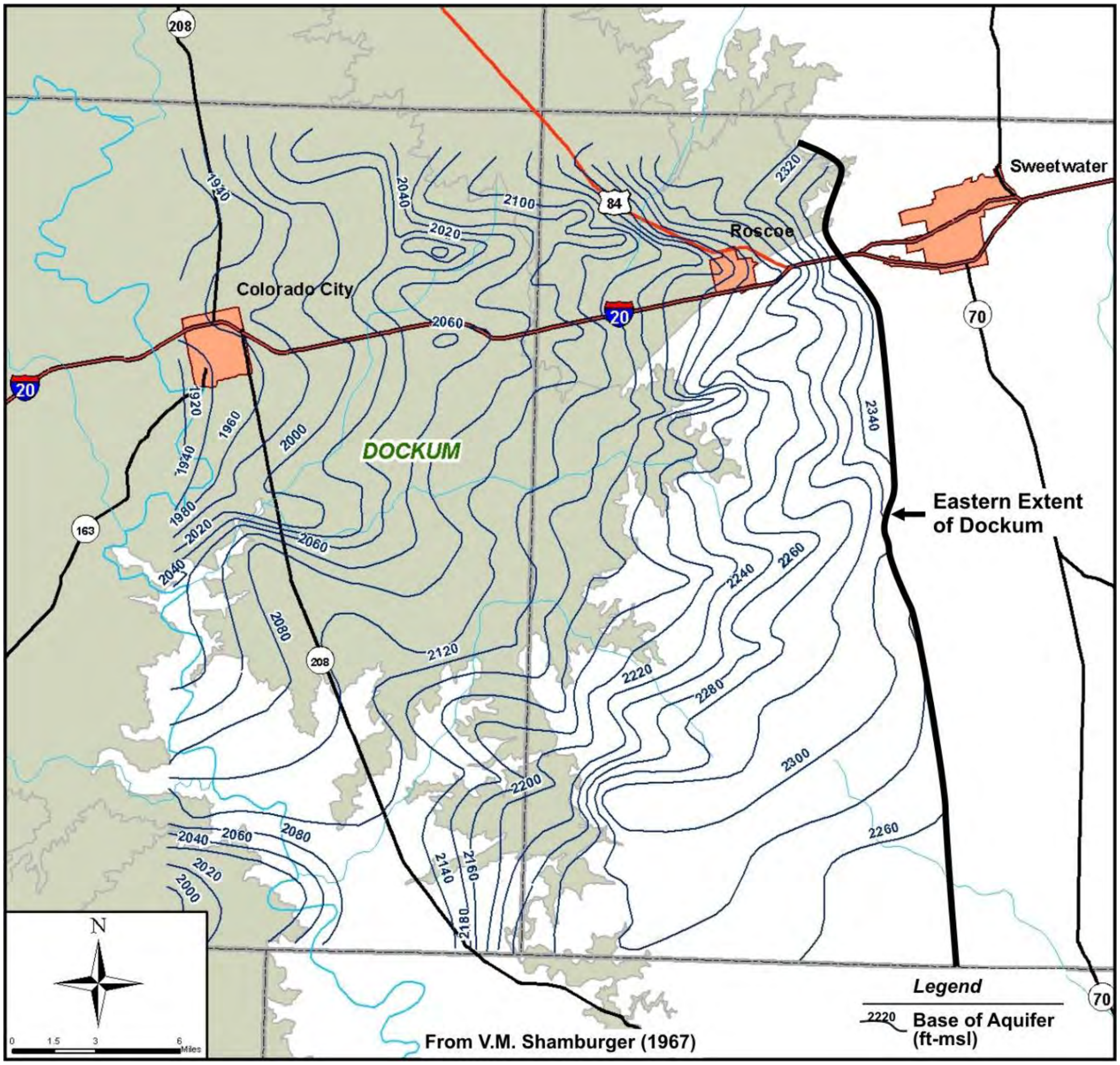


Figure 2-3. Base of Dockum Aquifer

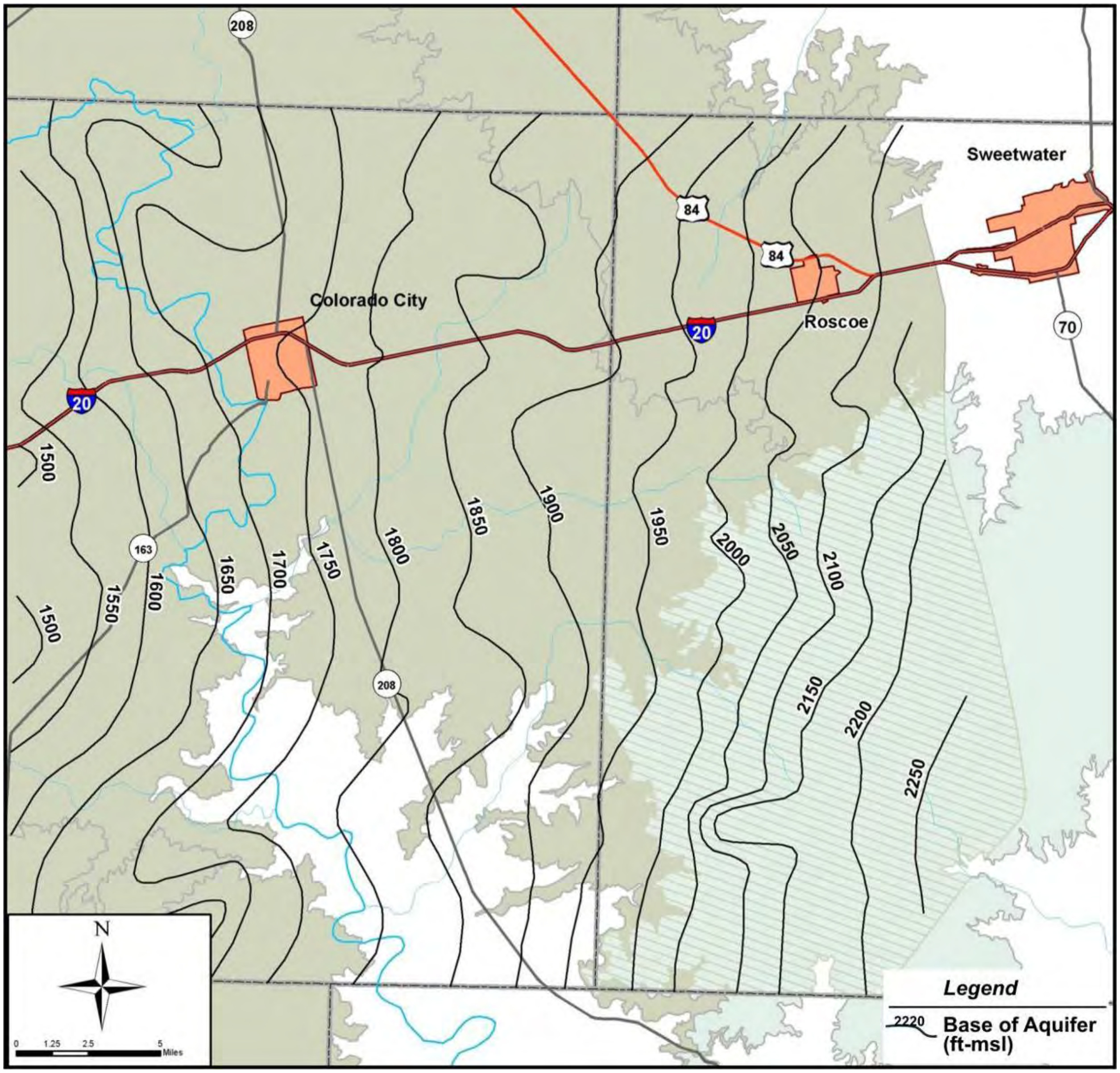


Figure 2-4. Top of Permian Marker Red Bed (Base of Whitehorse)

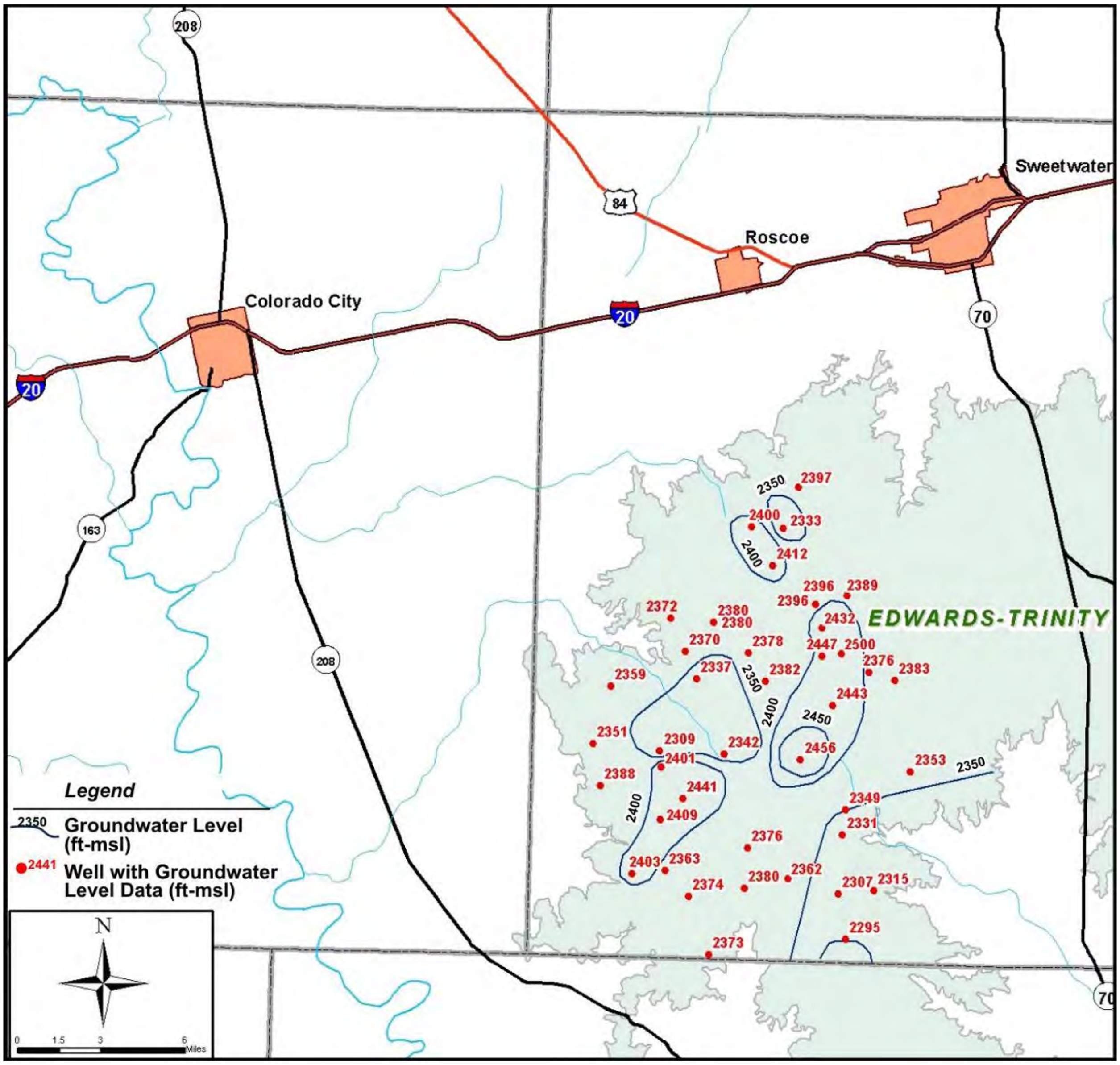


Figure 2-5. Groundwater Levels in the Edwards-Trinity (1963)

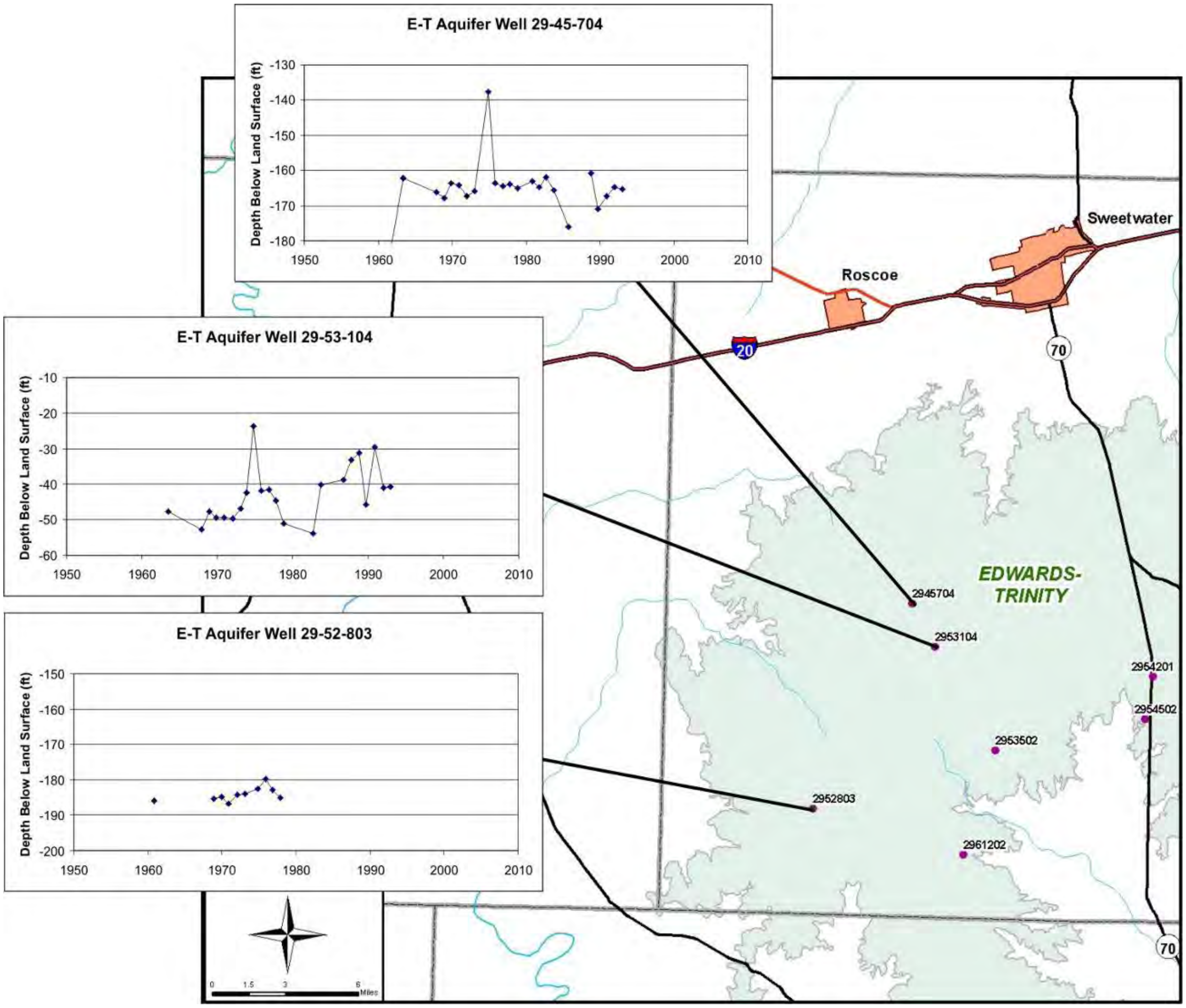


Figure 2-6. Groundwater Level Hydrographs for Selected Edwards-Trinity Wells (page 1 of 2)

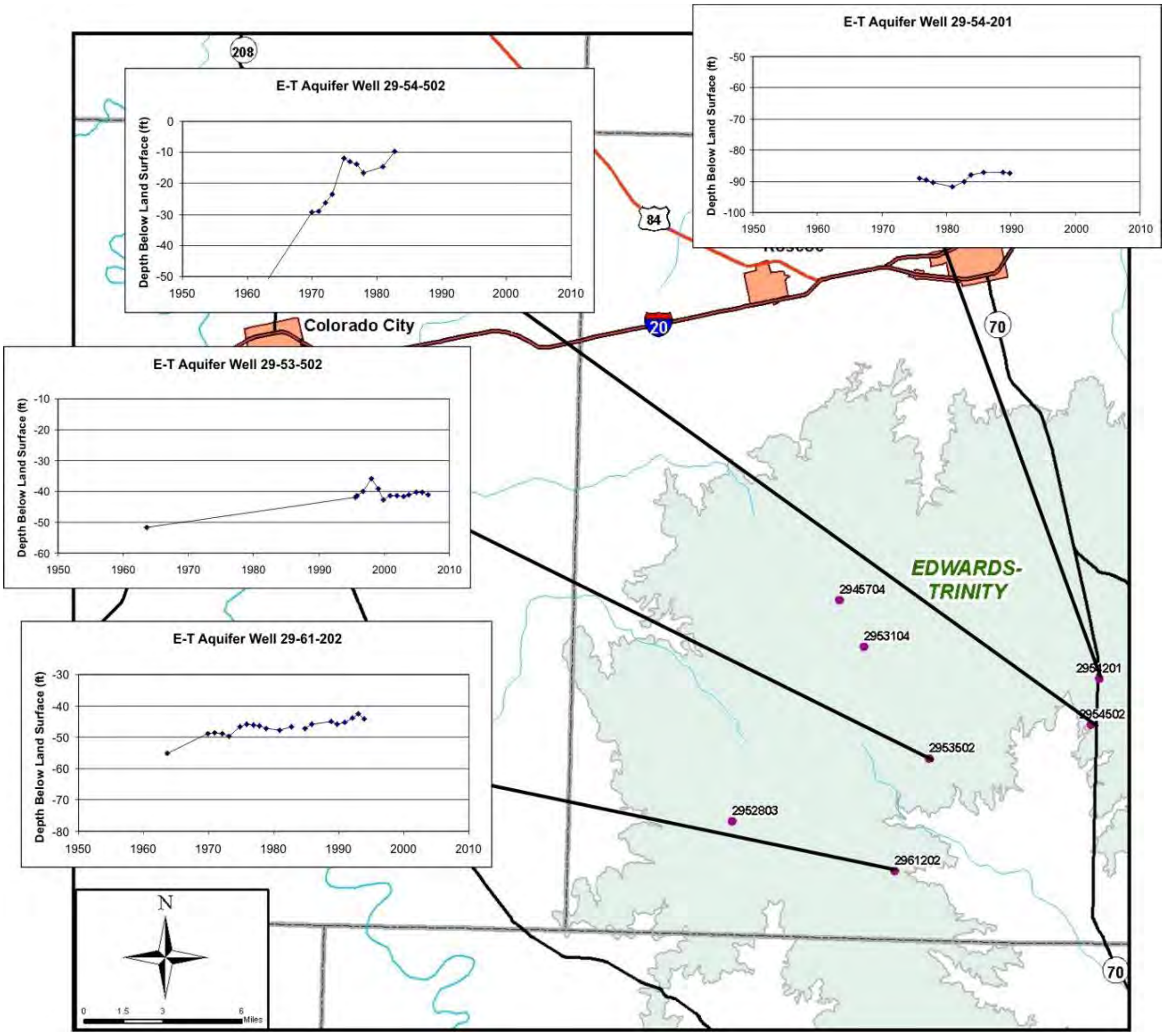


Figure 2-6. Groundwater Level Hydrographs for Selected Edwards-Trinity Wells (page 2 of 2)

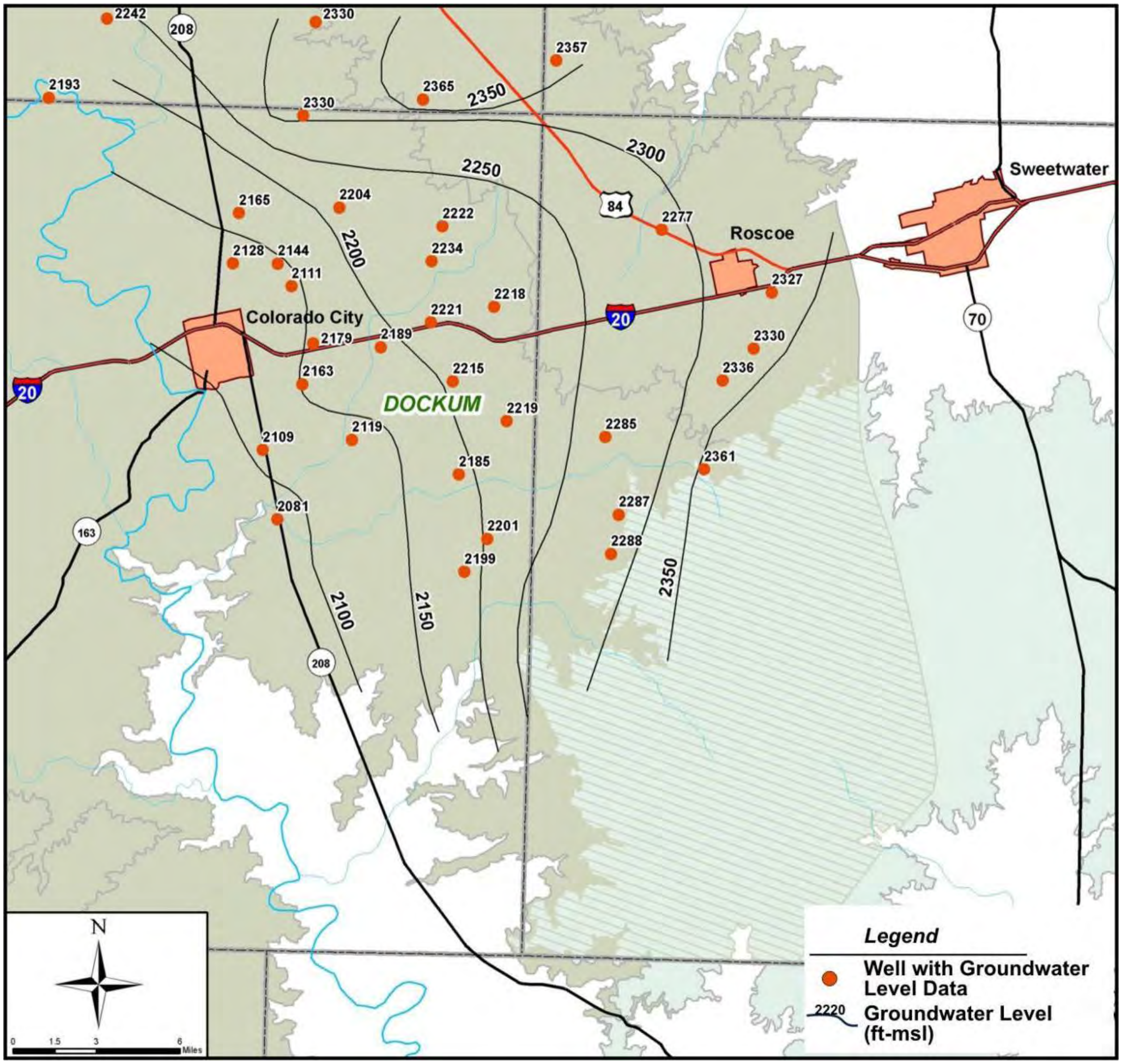


Figure 2-7. Groundwater Levels in the Dockum (1990)

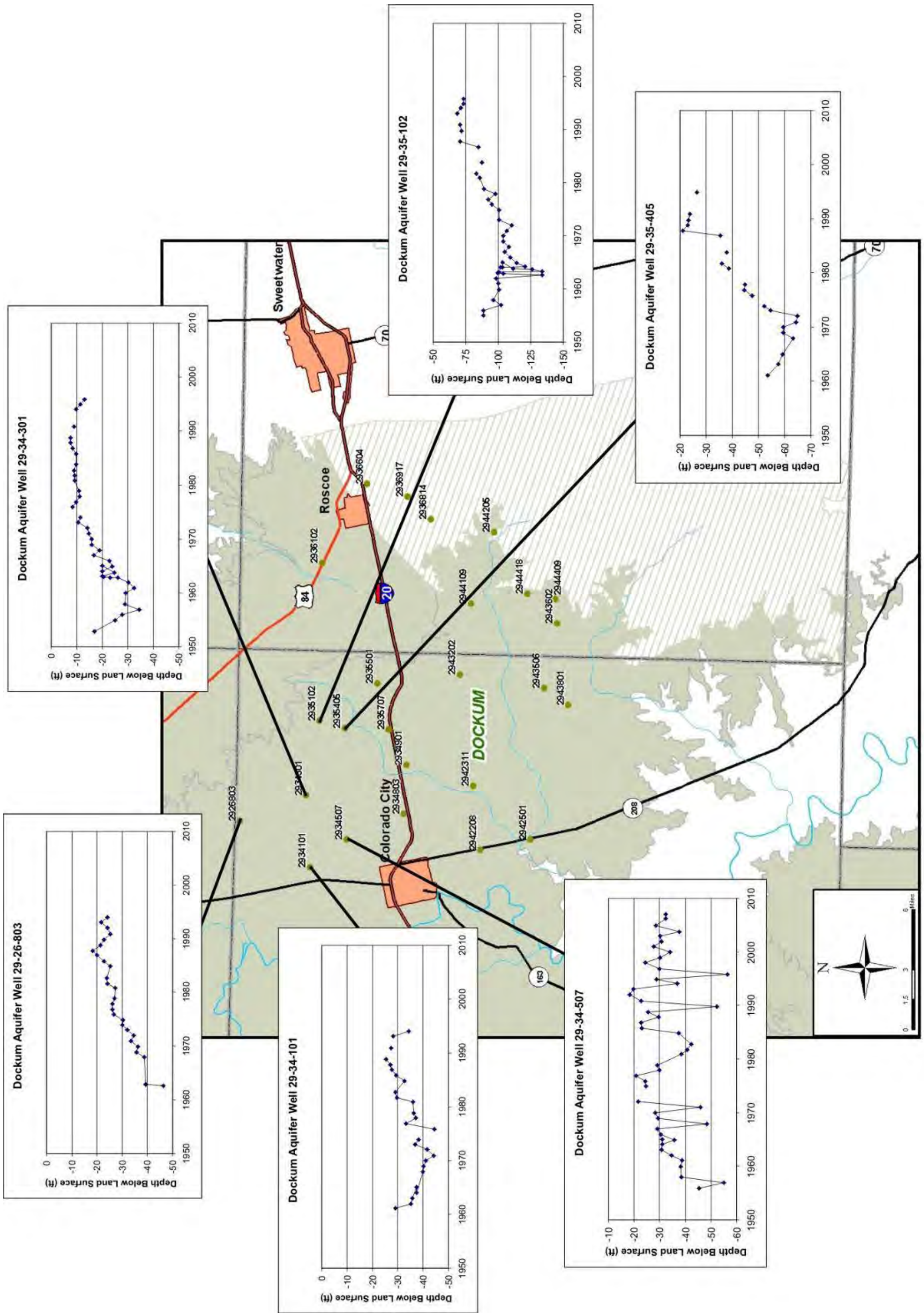


Figure 2-8. Groundwater Level Hydrographs for Selected Dockum Wells (page 1 of 4)

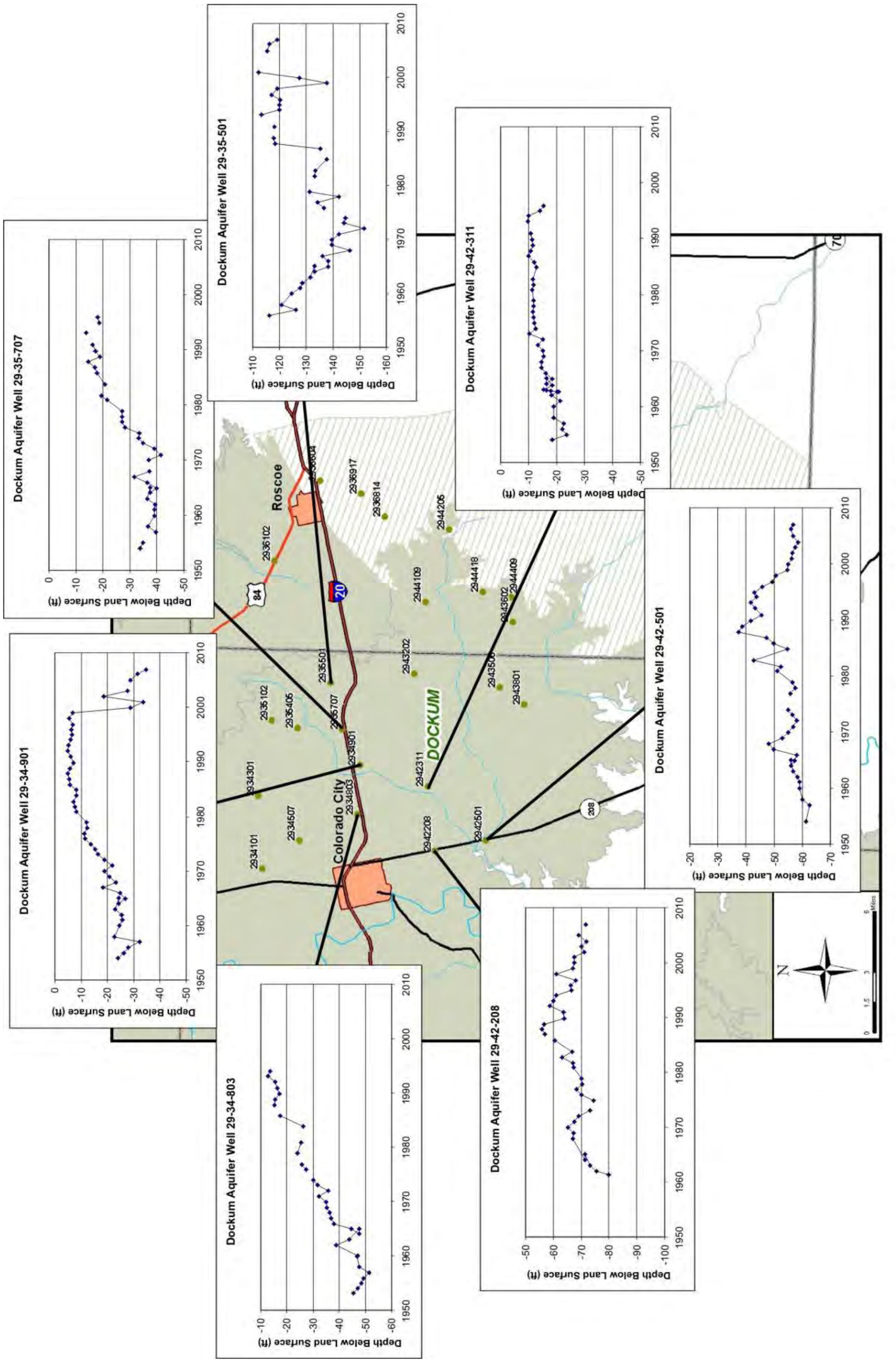


Figure 2-8. Groundwater Level Hydrographs for Selected Dockum Wells (page 2 of 4)

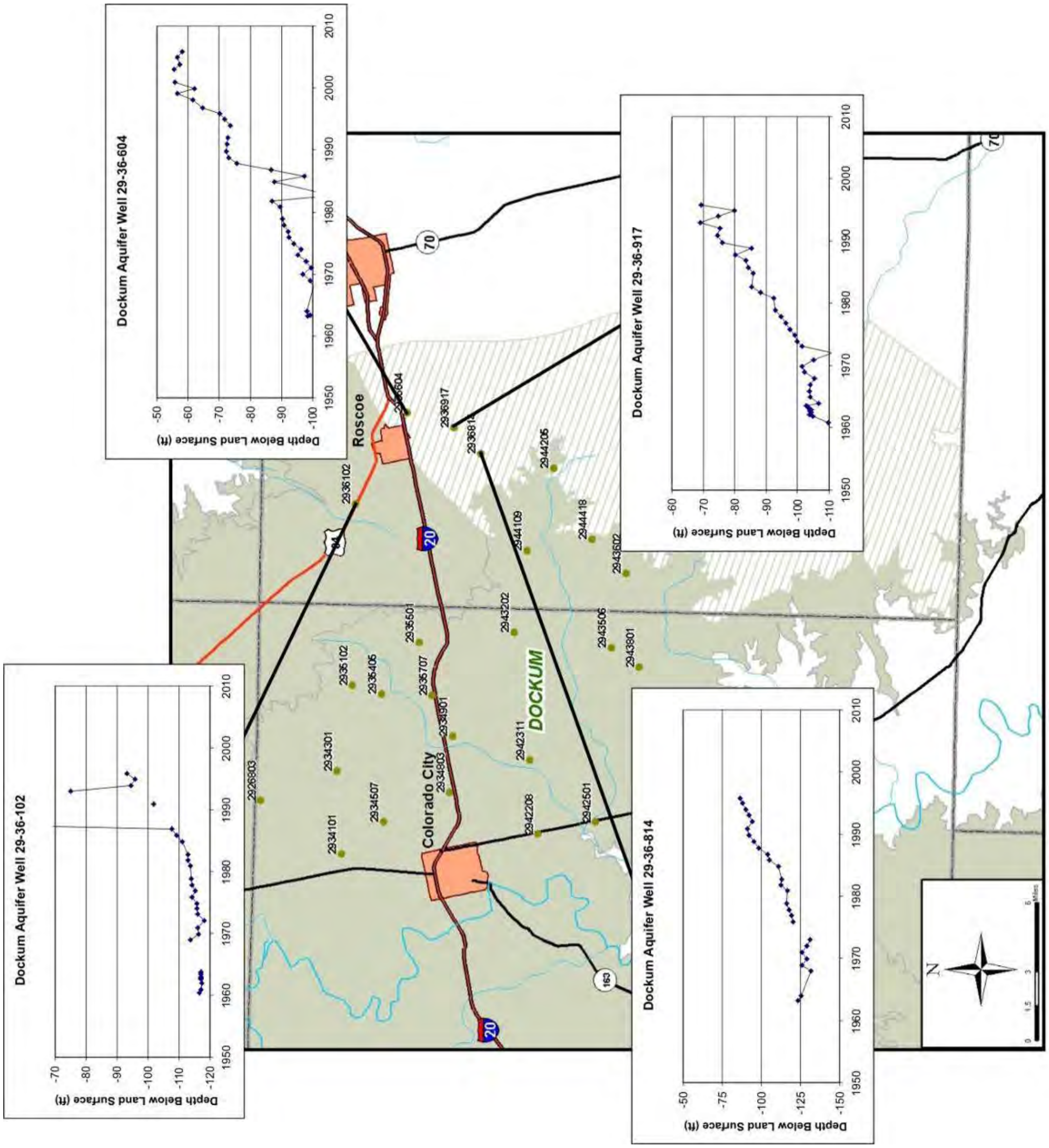


Figure 2-8. Groundwater Level Hydrographs for Selected Dockum Wells (page 3 of 4)

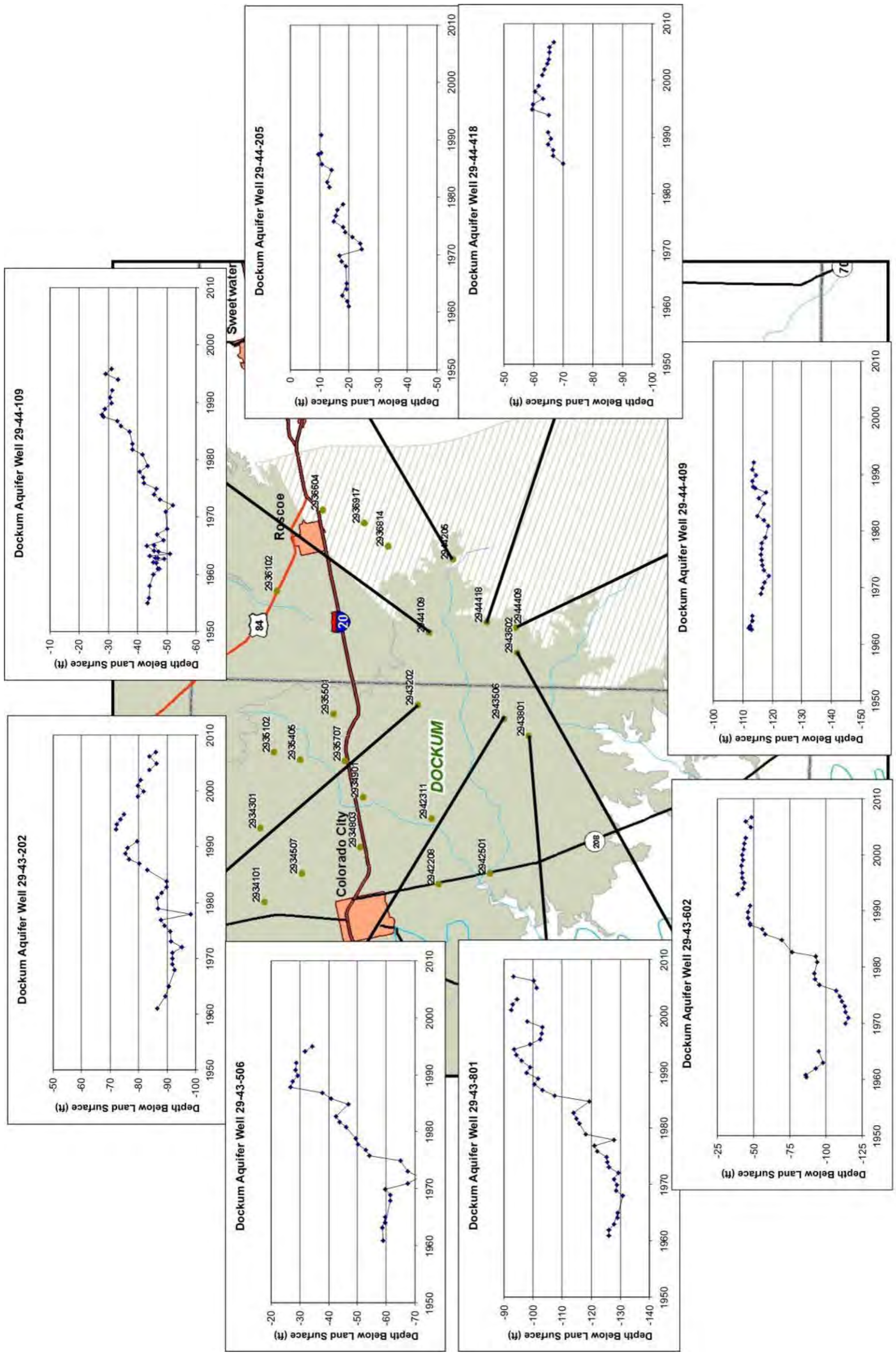


Figure 2-8. Groundwater Level Hydrographs for Selected Dockum Wells (page 4 of 4)

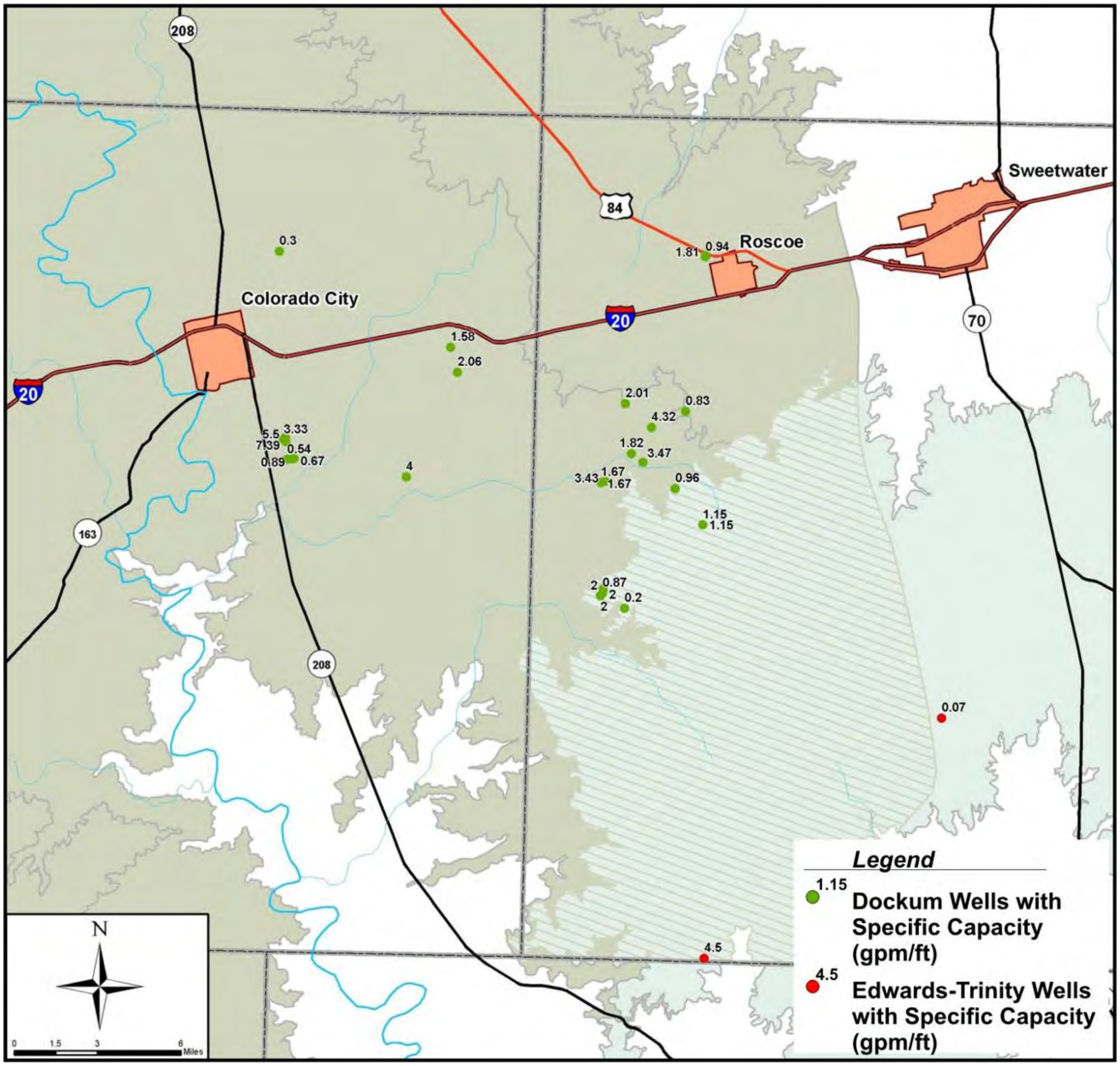


Figure 2-9. Specific Capacity of Wells in TWDB Database

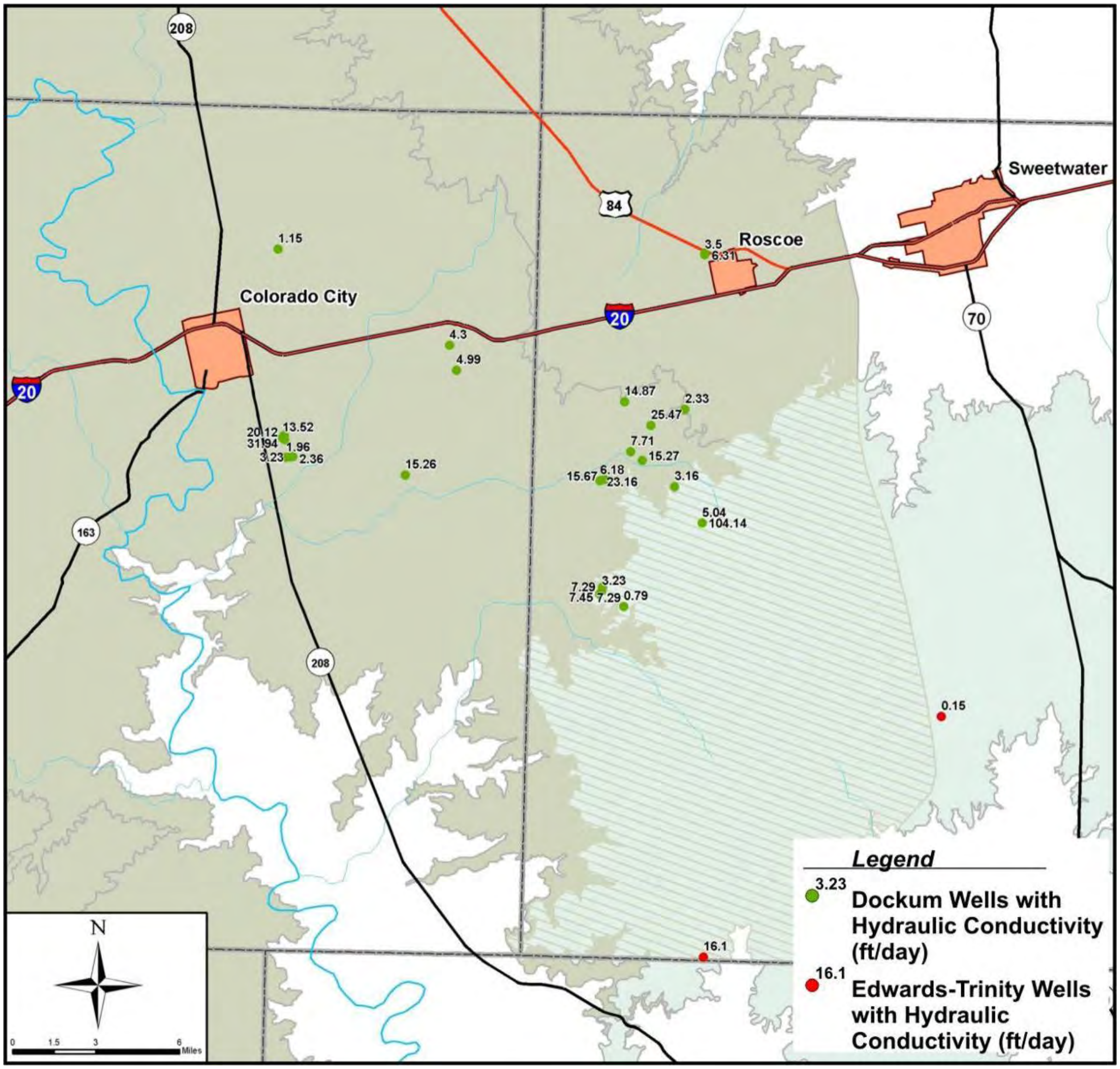


Figure 2-10. Hydraulic Conductivity for Wells in TWDB Database

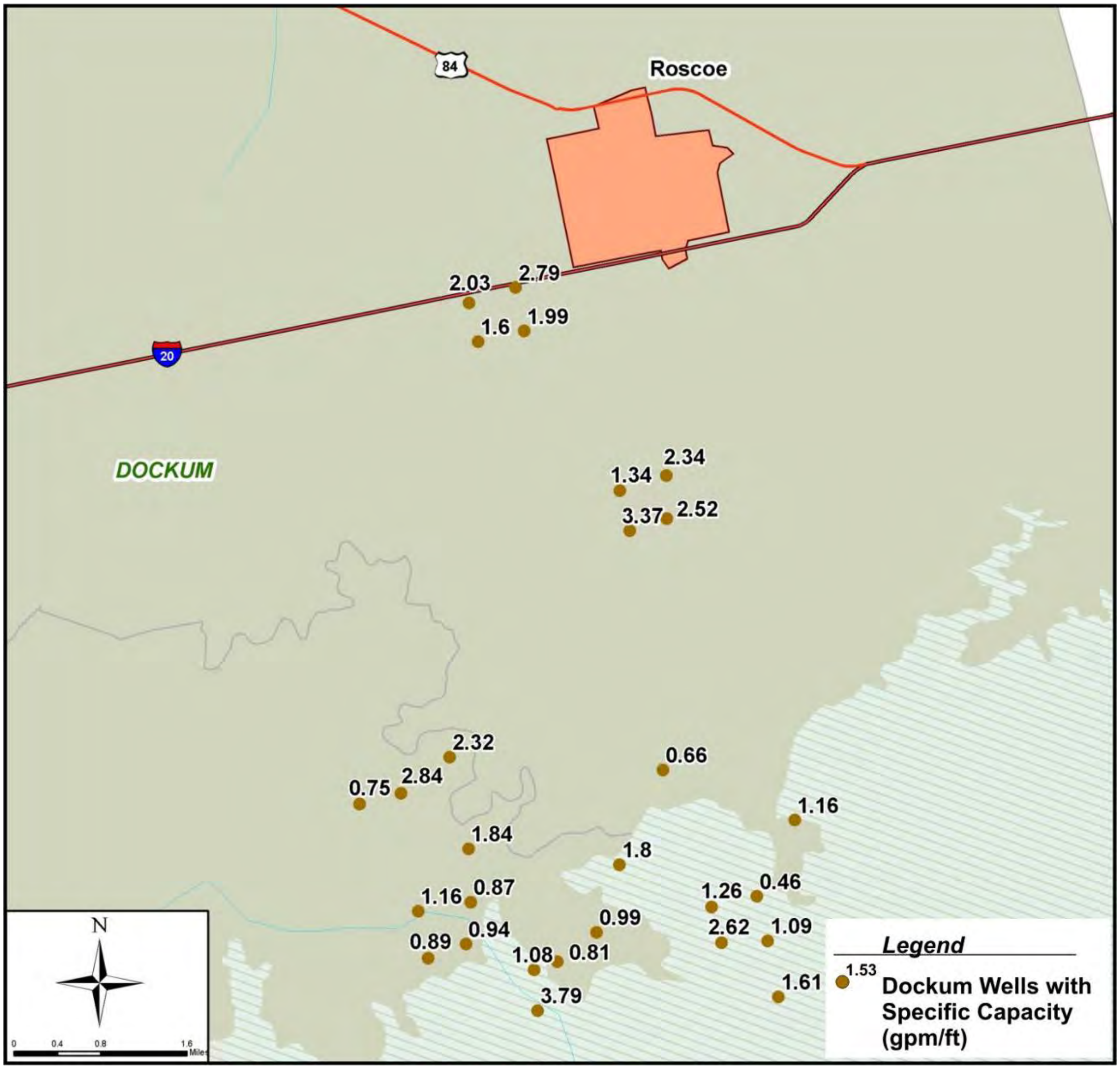


Figure 2-11. Specific Capacity of City of Sweetwater Wells

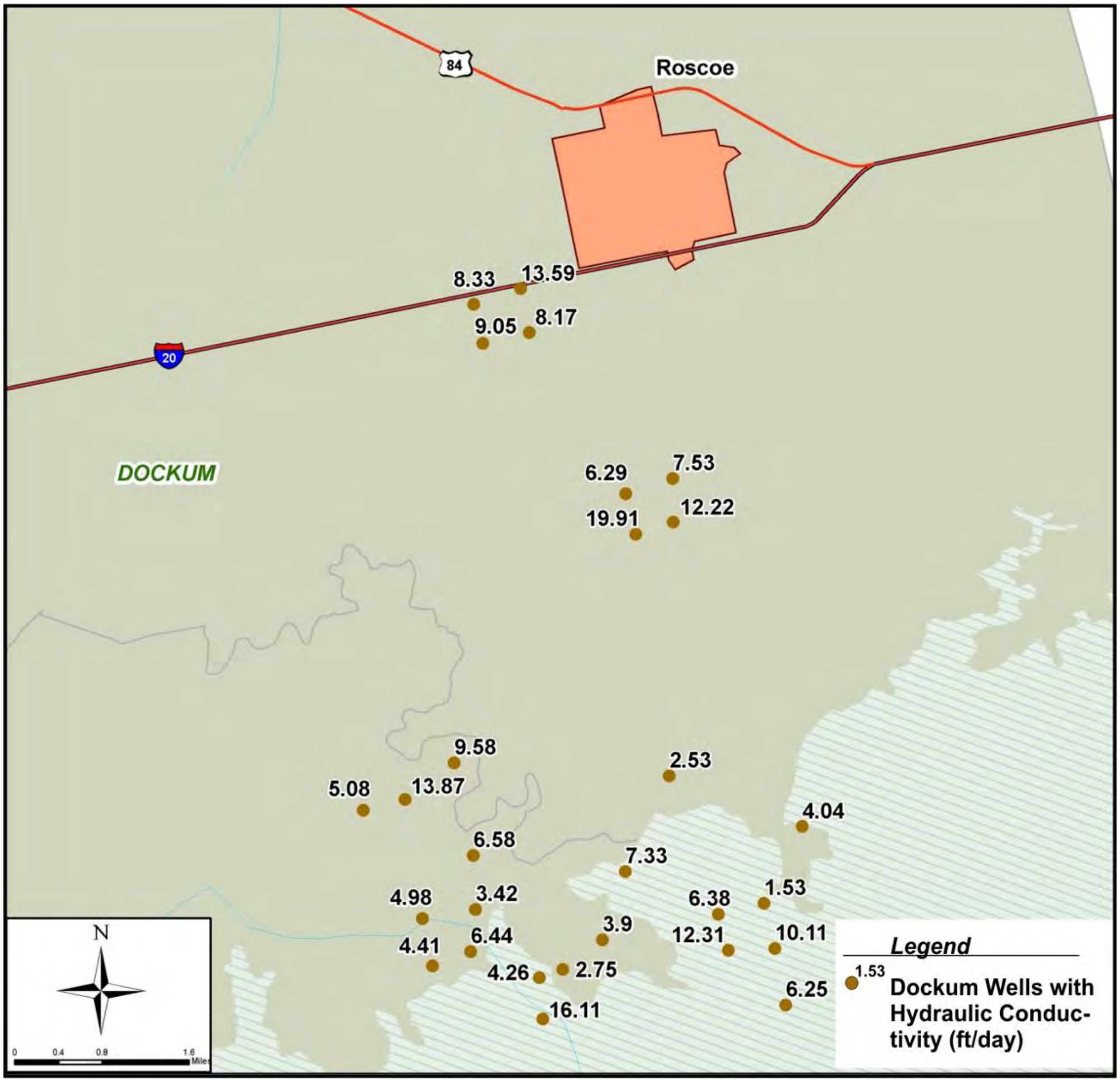


Figure 2-12. Hydraulic Conductivity for City of Sweetwater Wells

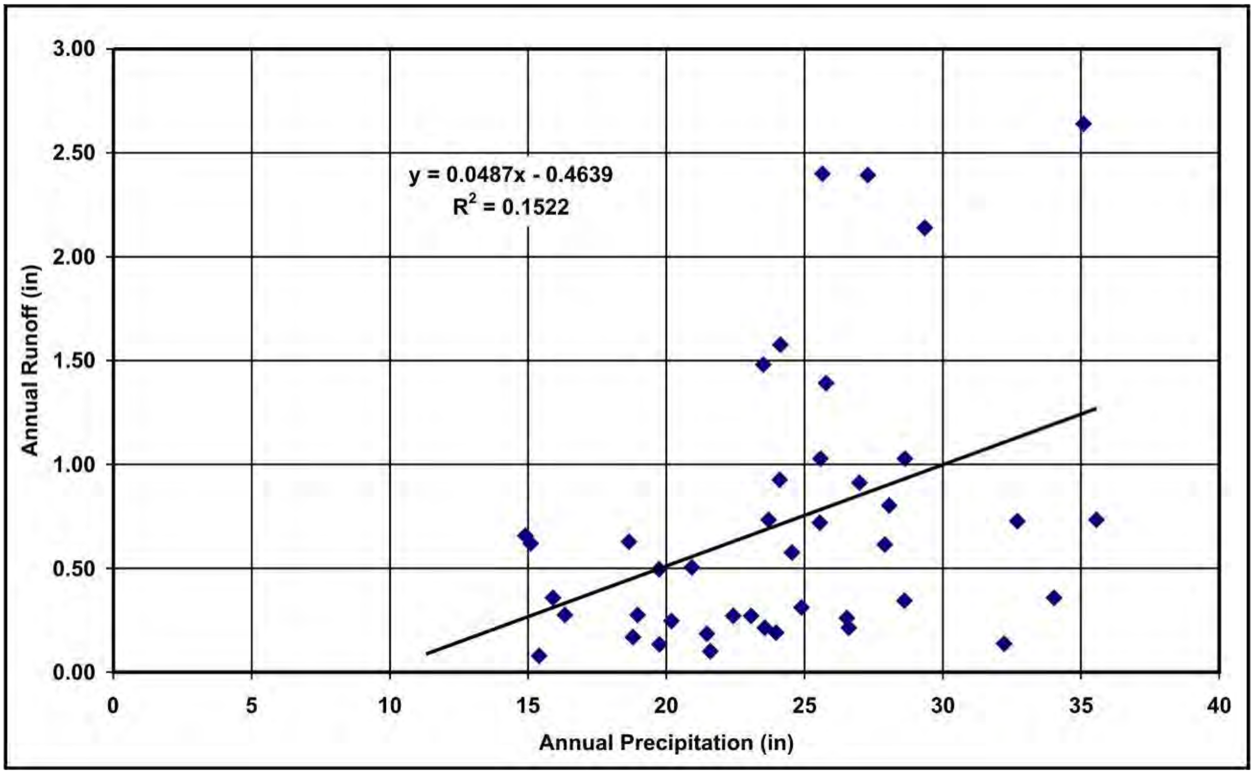


Figure 2-13. Annual Precipitation and Annual Runoff for Deep Creek near Dunn

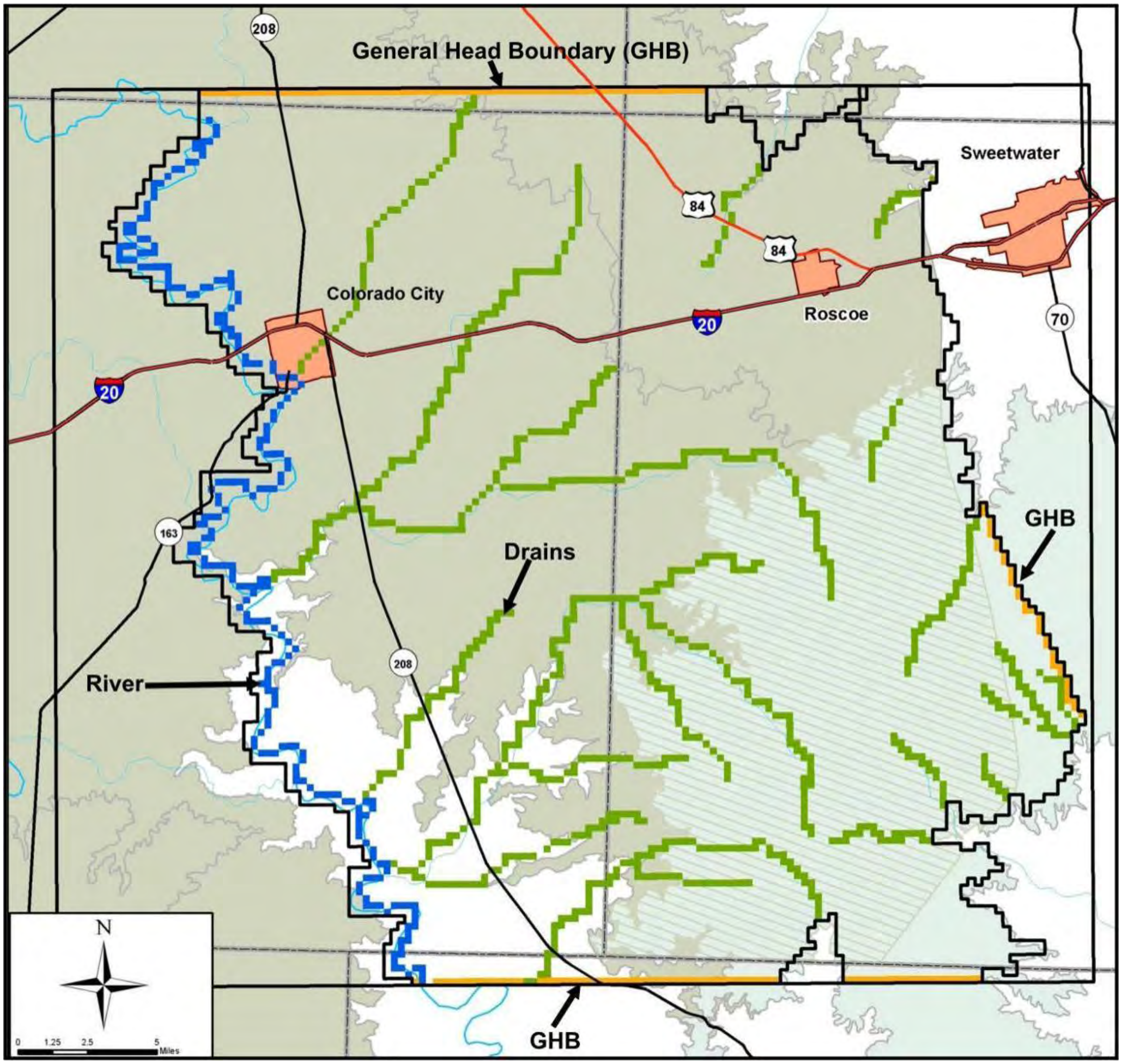


Figure 3-1. Area of Groundwater Model

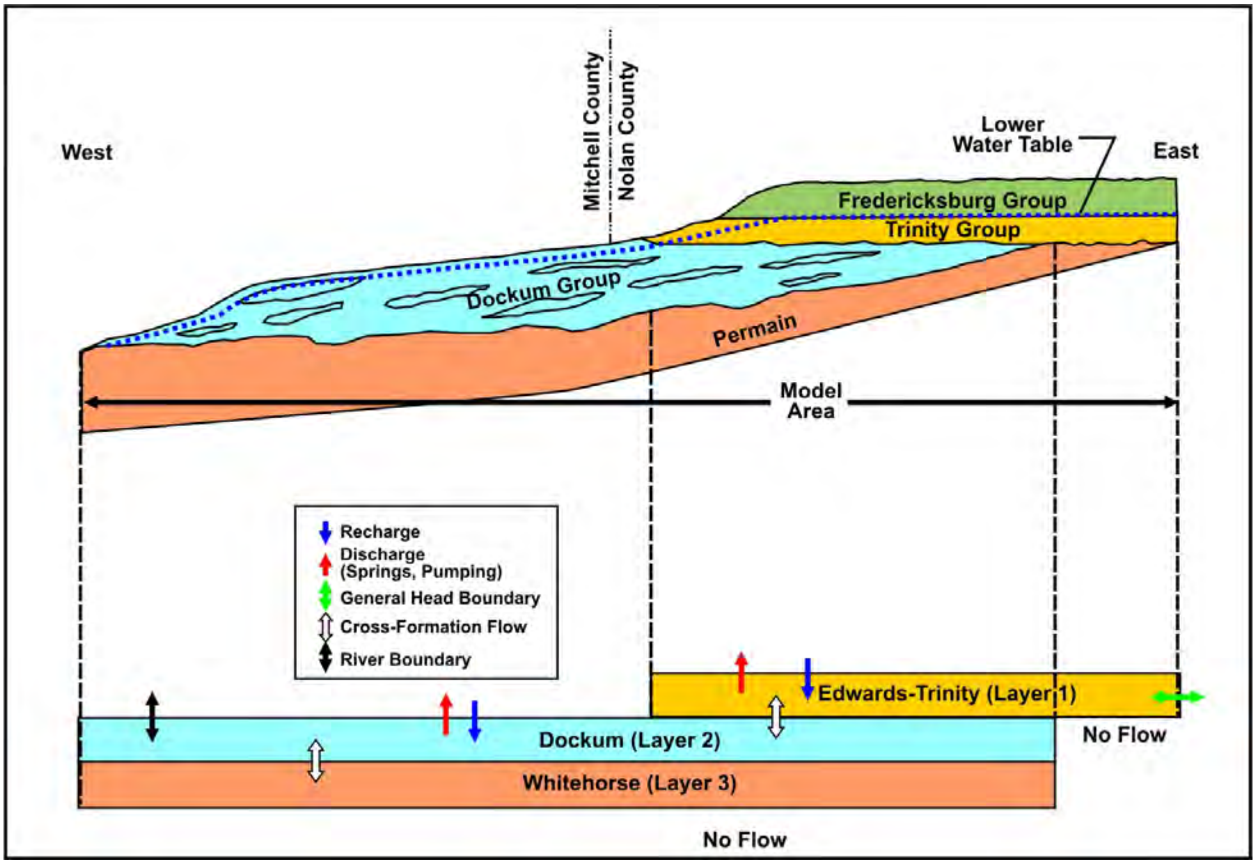


Figure 3-2. Schematic of Cross-Section Showing Conceptualization of the Edwards-Trinity and Dockum in the Study Area

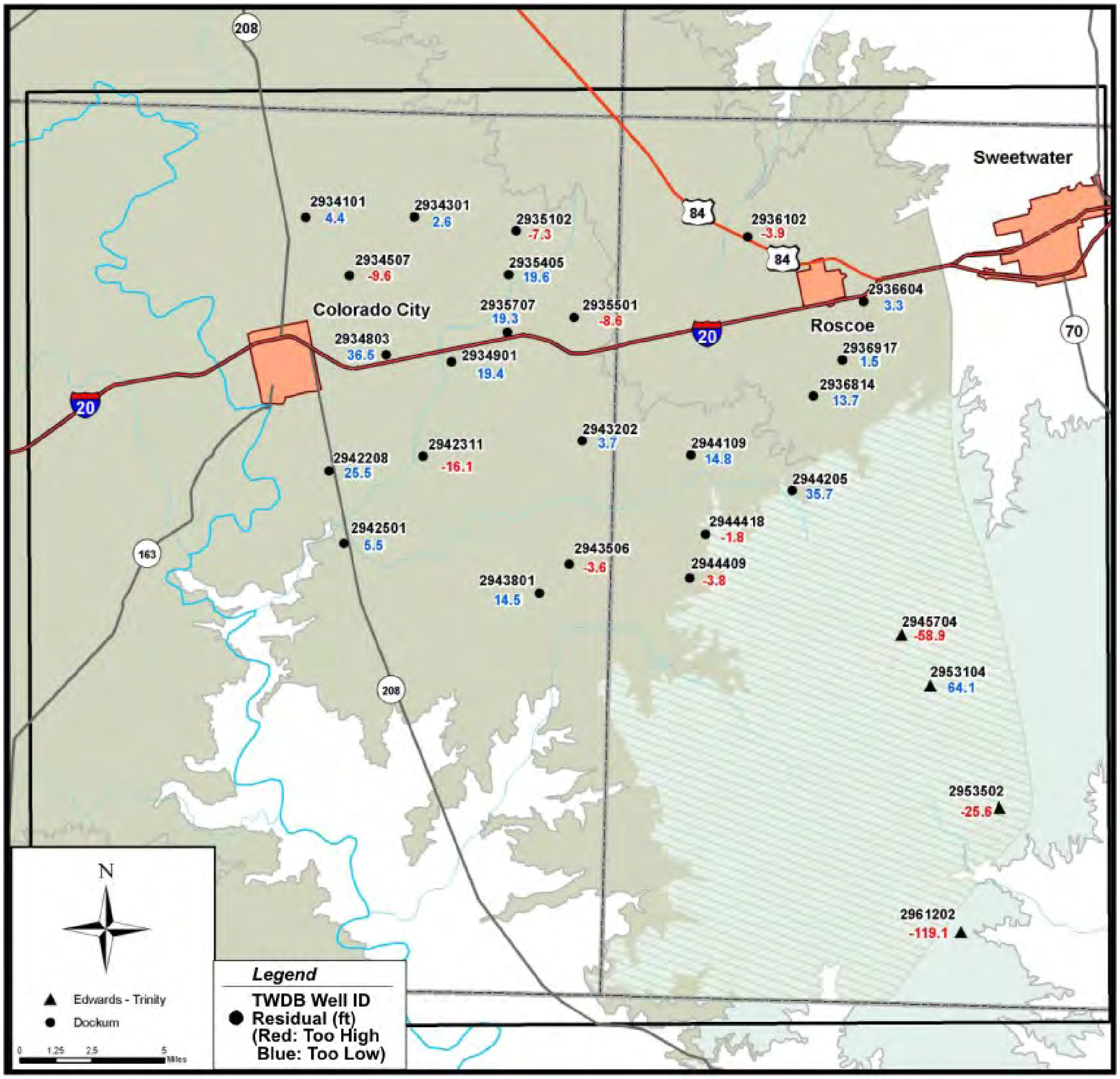


Figure 5-1. Residuals of Measured and Modeled Groundwater Levels for Steady-State Conditions (1990)

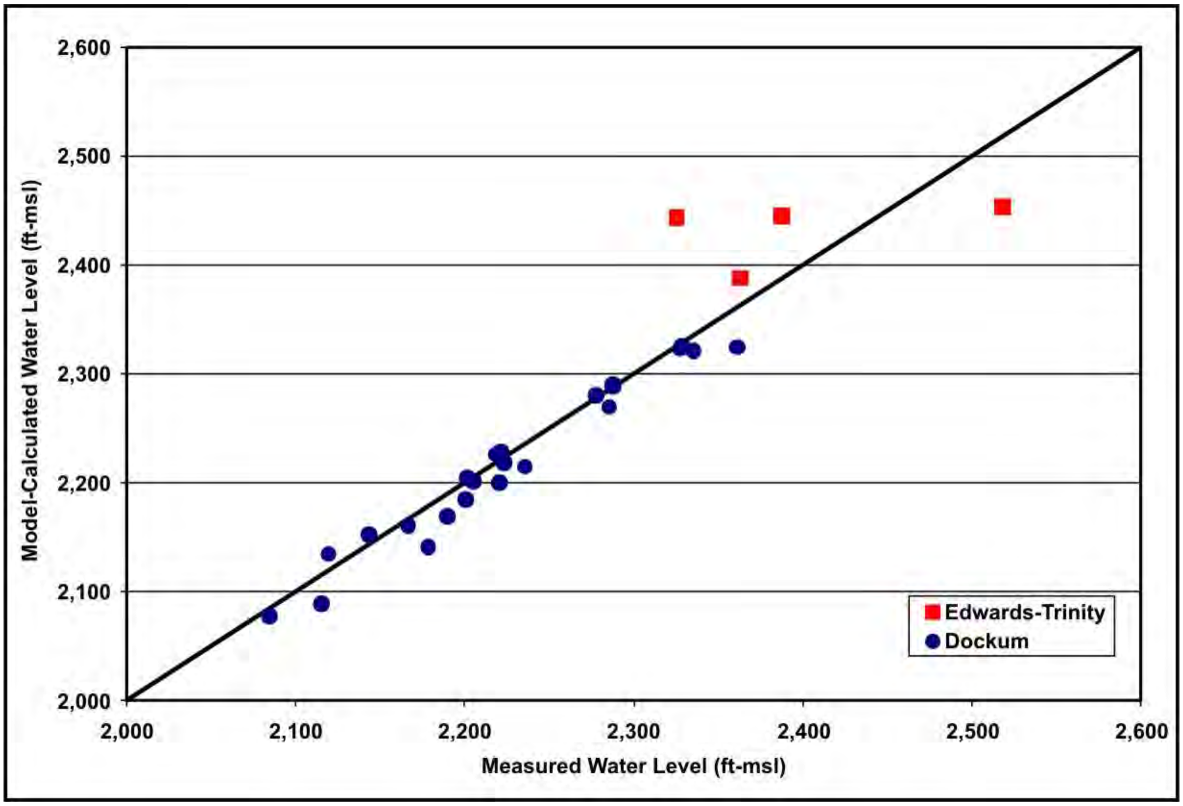
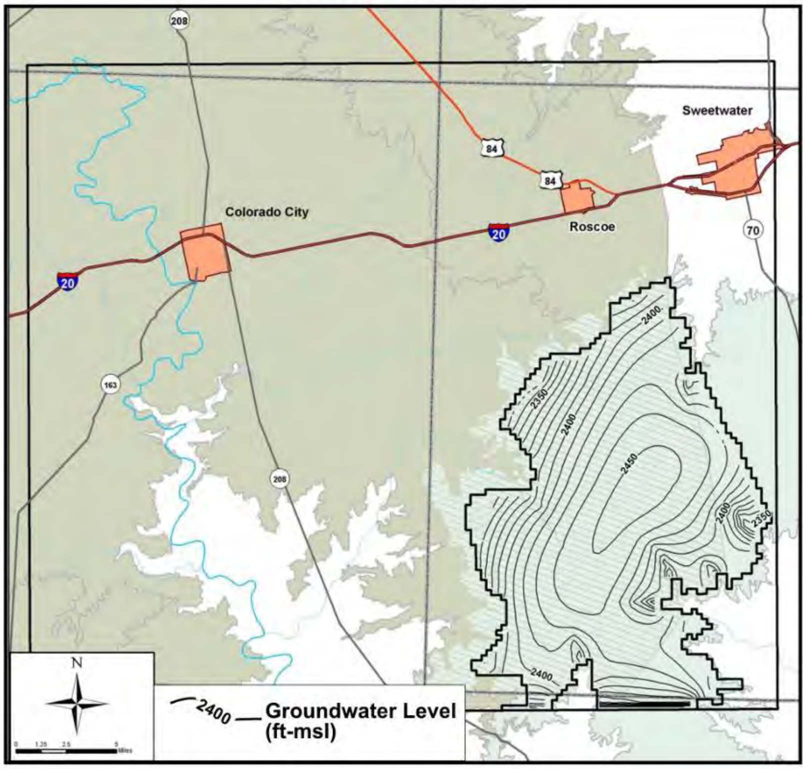


Figure 5-2. Scatterplot of Measured and Modeled Groundwater Levels for Steady-State Conditions (1990)

a. Edwards-Trinity



b. Dockum

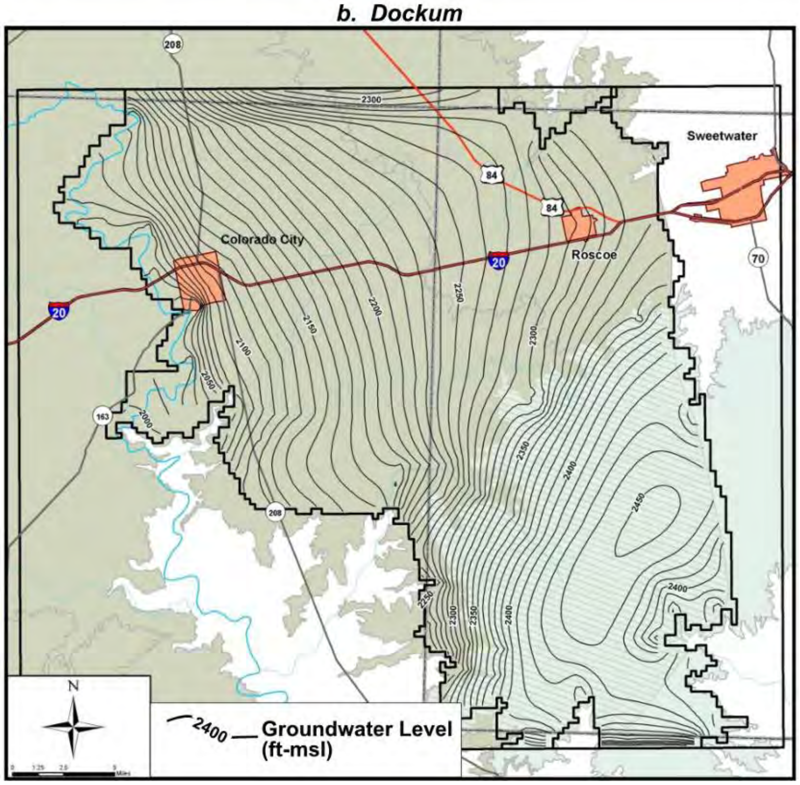


Figure 5-3. Modeled Groundwater Levels for Steady-State Conditions (1990)

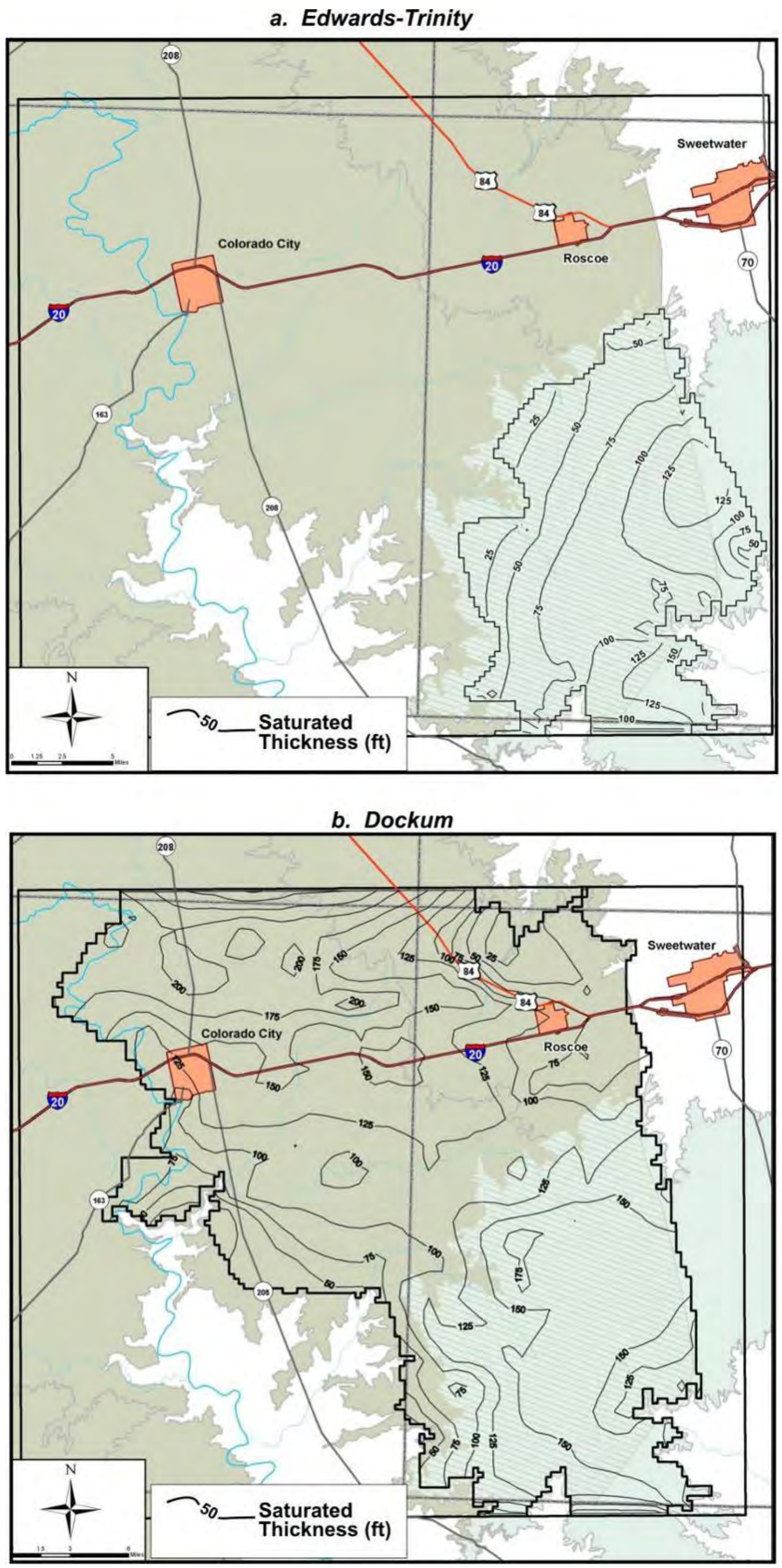


Figure 5-4. Modeled Saturated Thickness for Steady-State Conditions (1990)

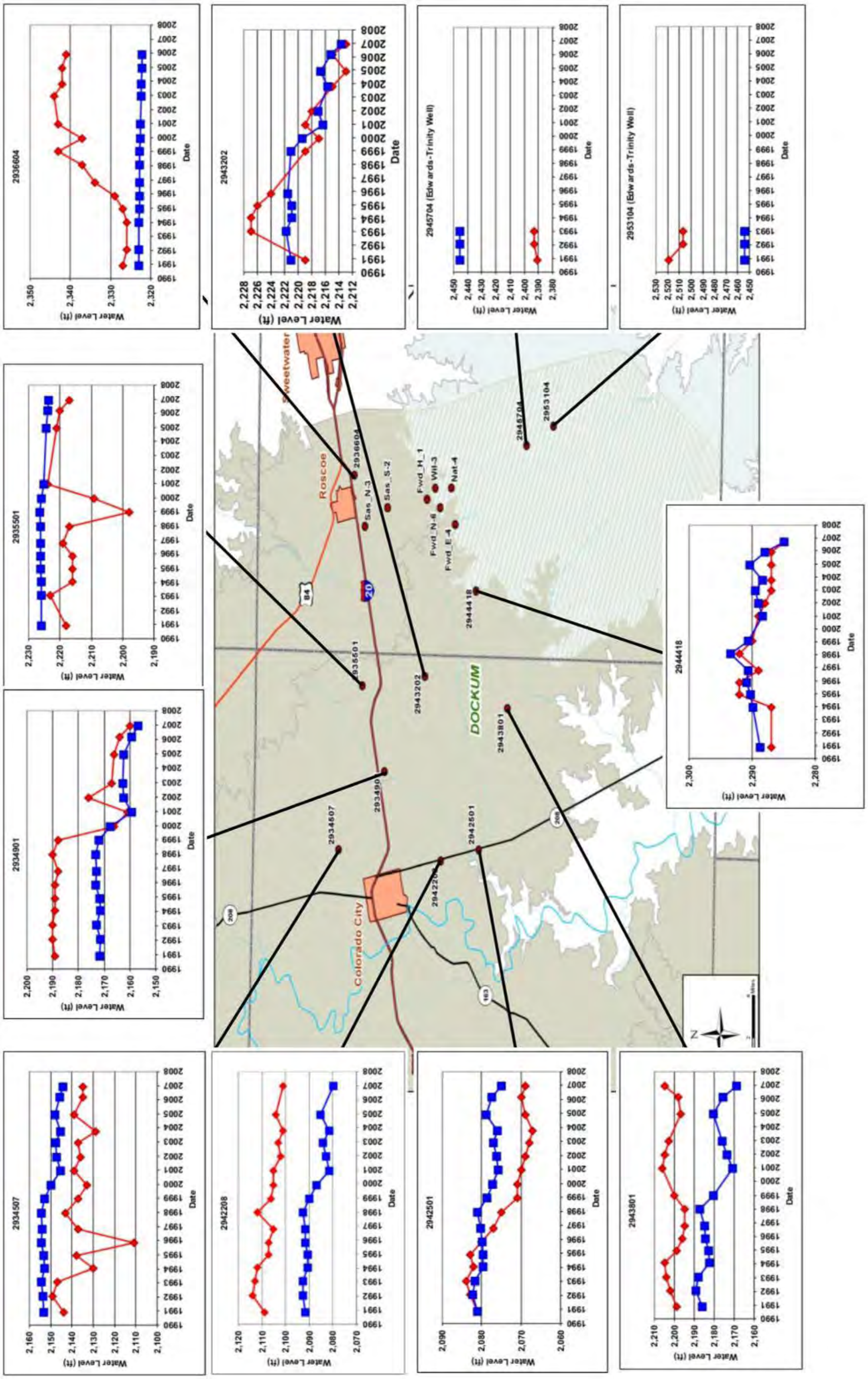


Figure 5-5. Model-Computed and Observed Water Levels for the Transient Calibration Model (page 1 of 2)

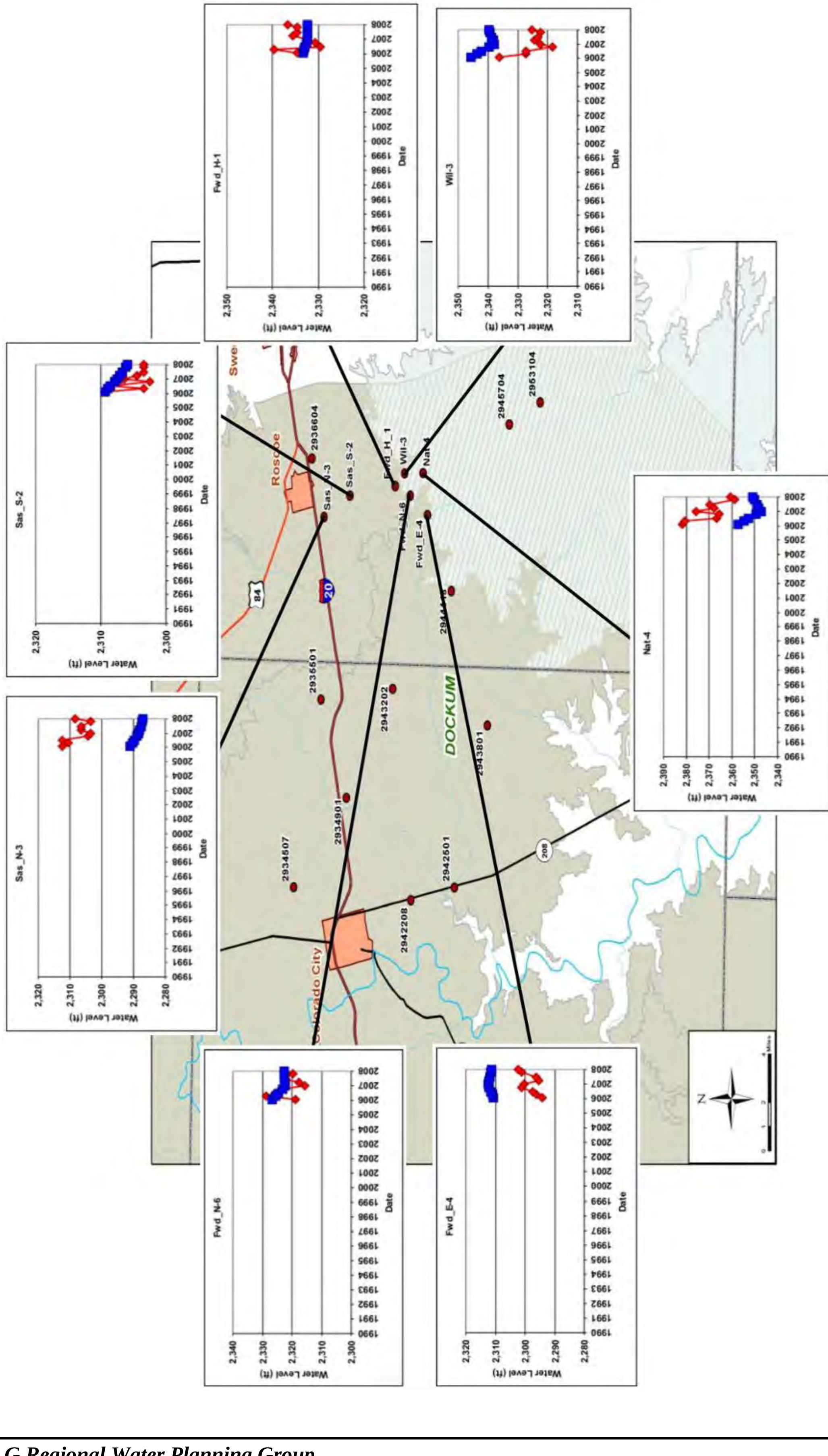


Figure 5-5. Model-Computed and Observed Water Levels for the Transient Calibration Model (page 2 of 2)

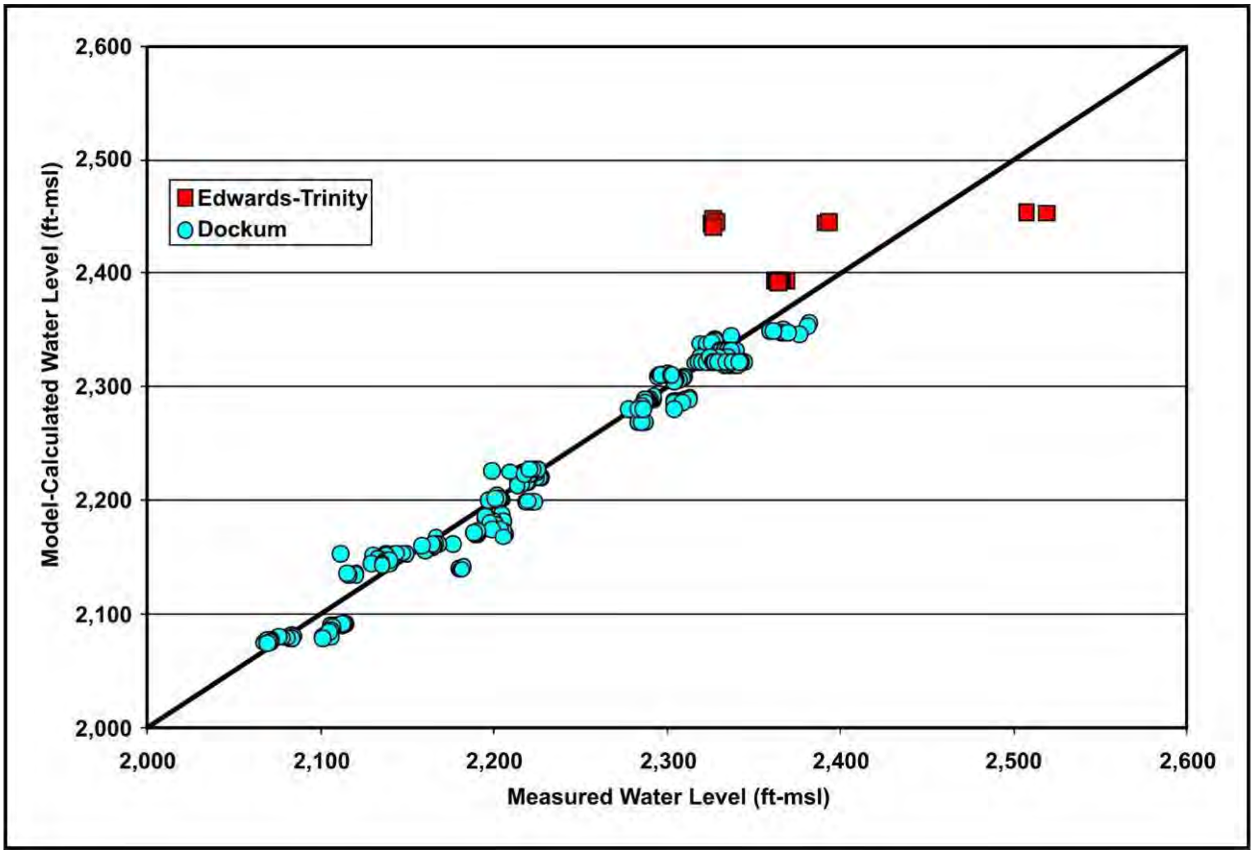


Figure 5-6. Scatterplot of Measured and Modeled Groundwater Levels for Transient Calibration

a. Edwards-Trinity

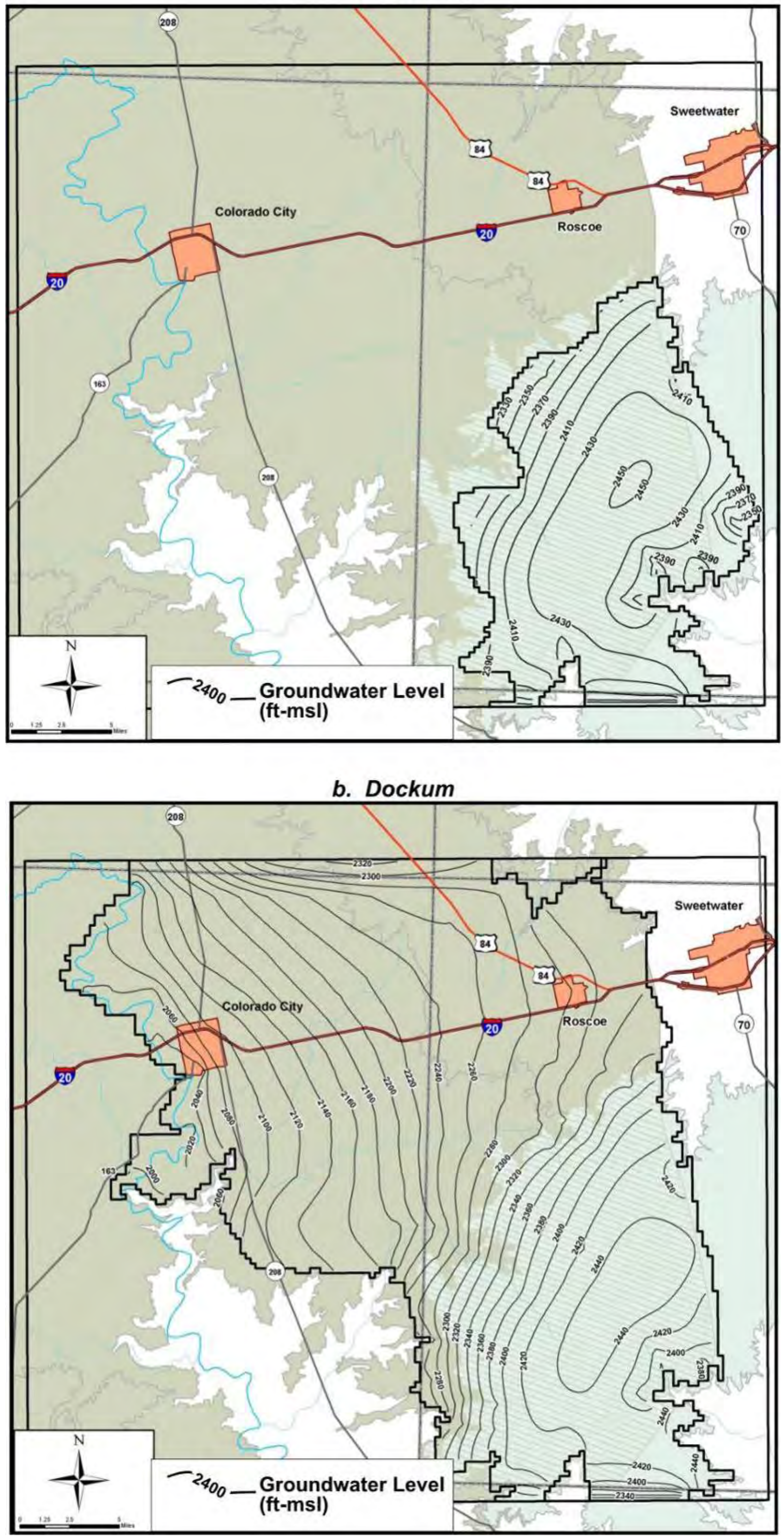


Figure 5-7. Modeled Groundwater Levels for Transient Simulations (2007) (page 1 of 2)

c. Whitehorse

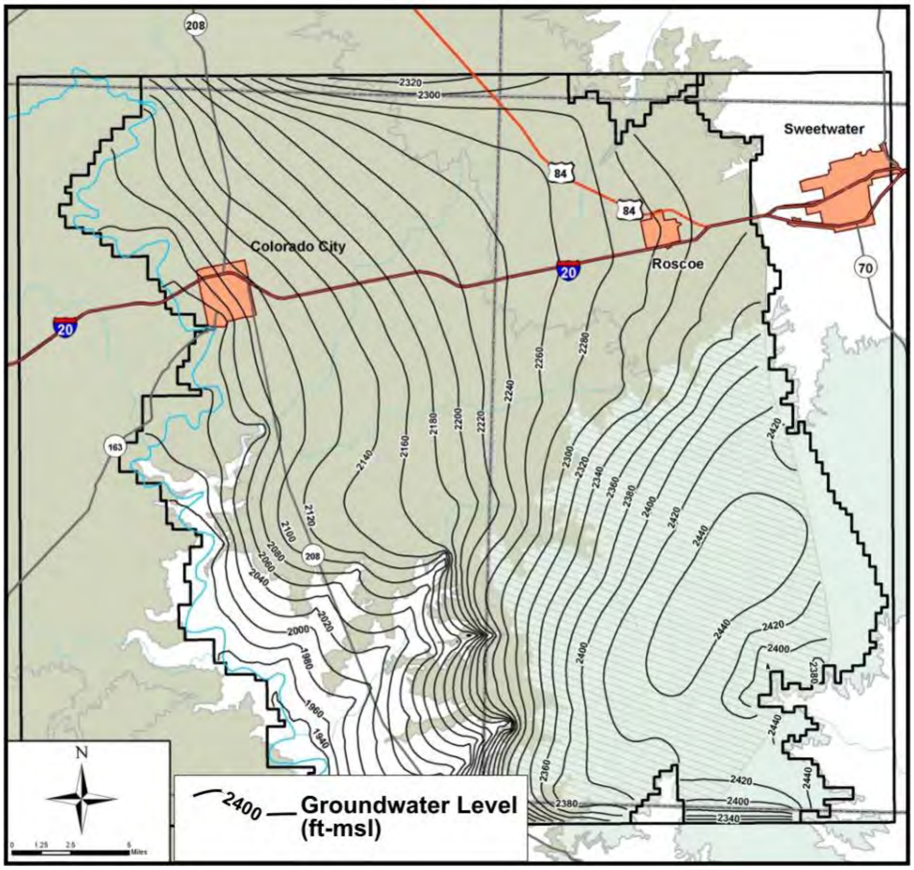


Figure 5-7. Modeled Groundwater Levels for Transient Simulations (2007) (page 2 of 2)

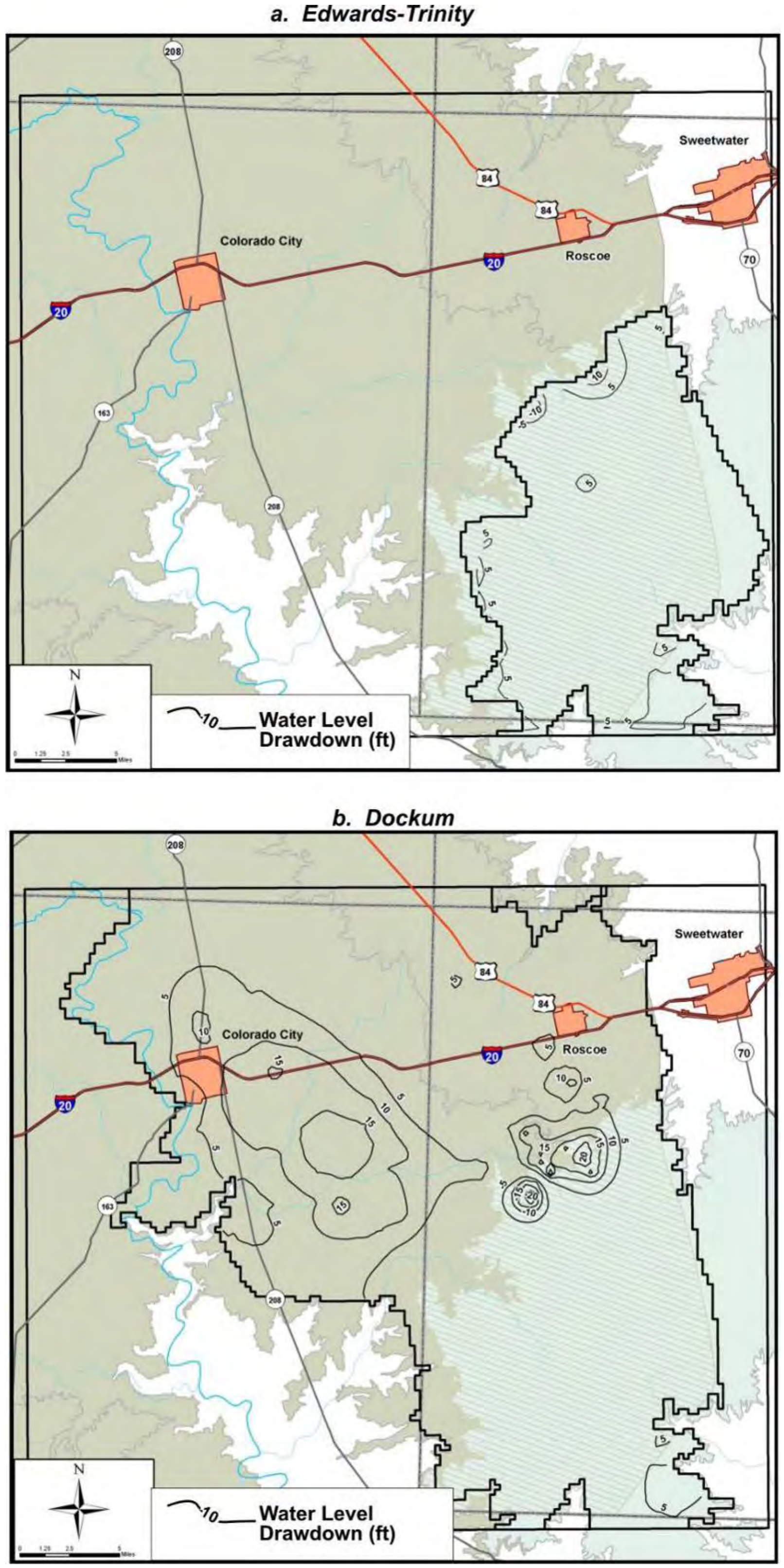


Figure 5-8. Drawdown during Transient Simulations (1990 – 2007)

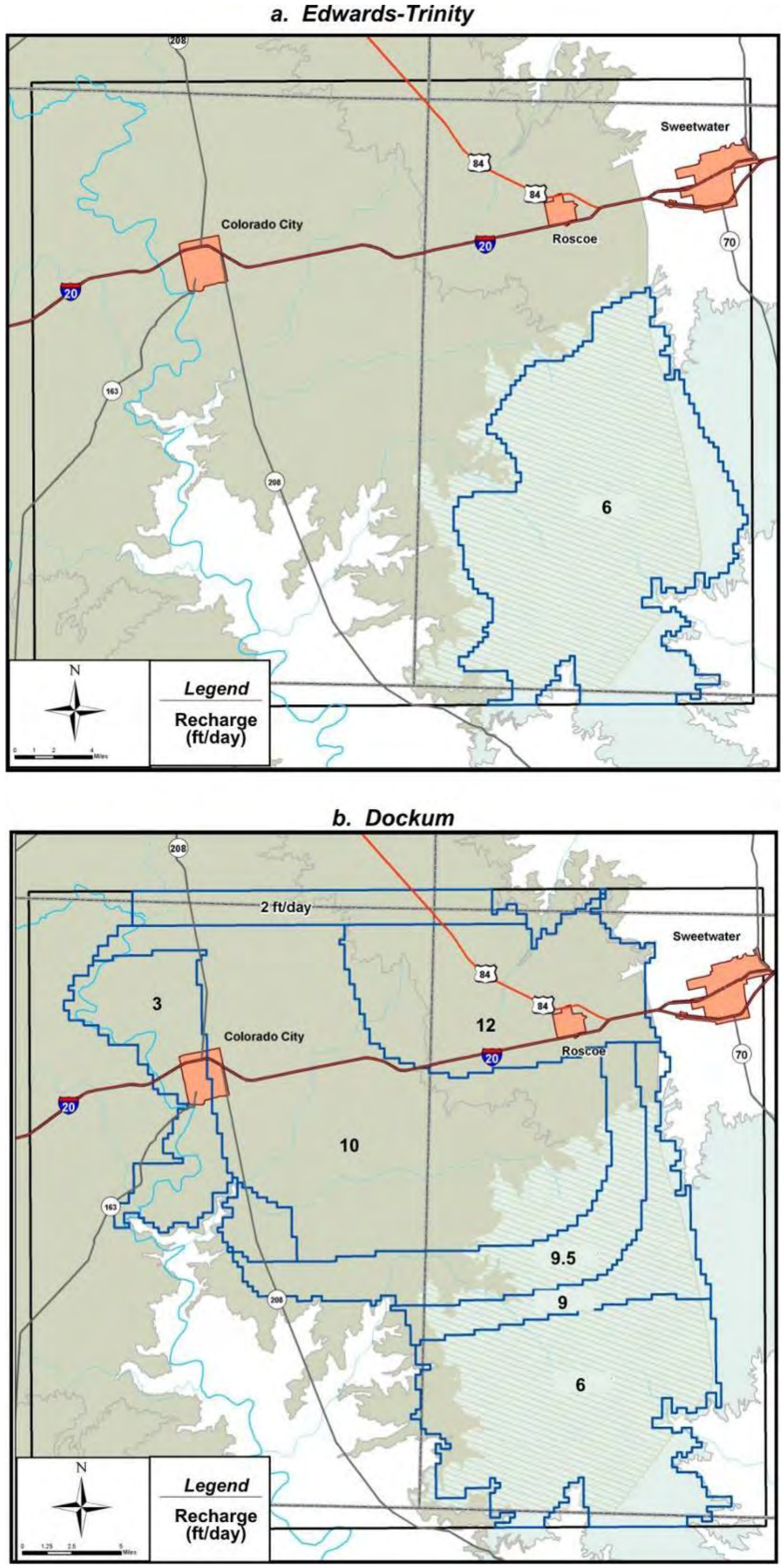


Figure 5-9. Horizontal Hydraulic Conductivity Determined from Calibration

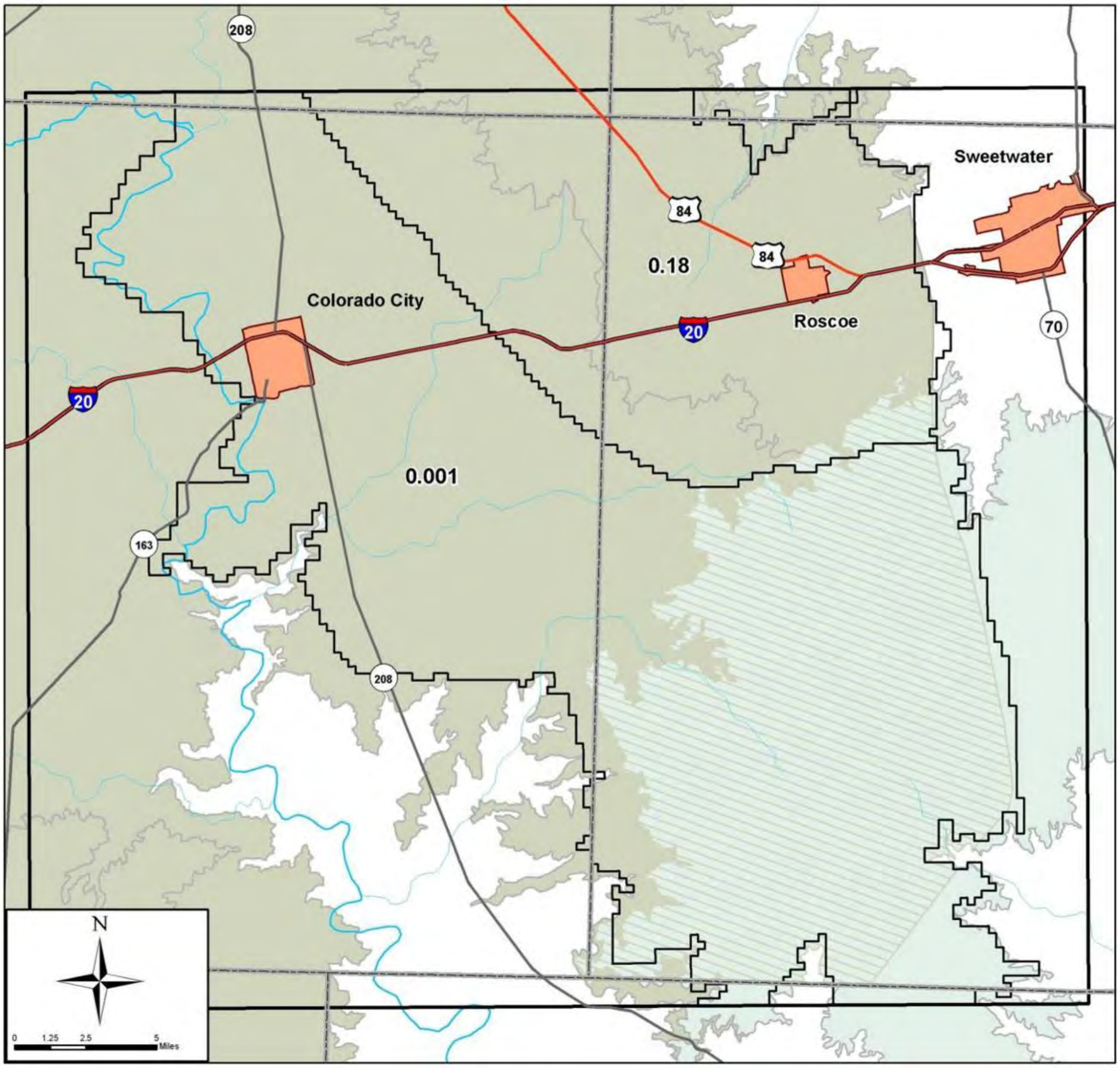


Figure 5-10. Specific Storage for Dockum Determined from Calibration

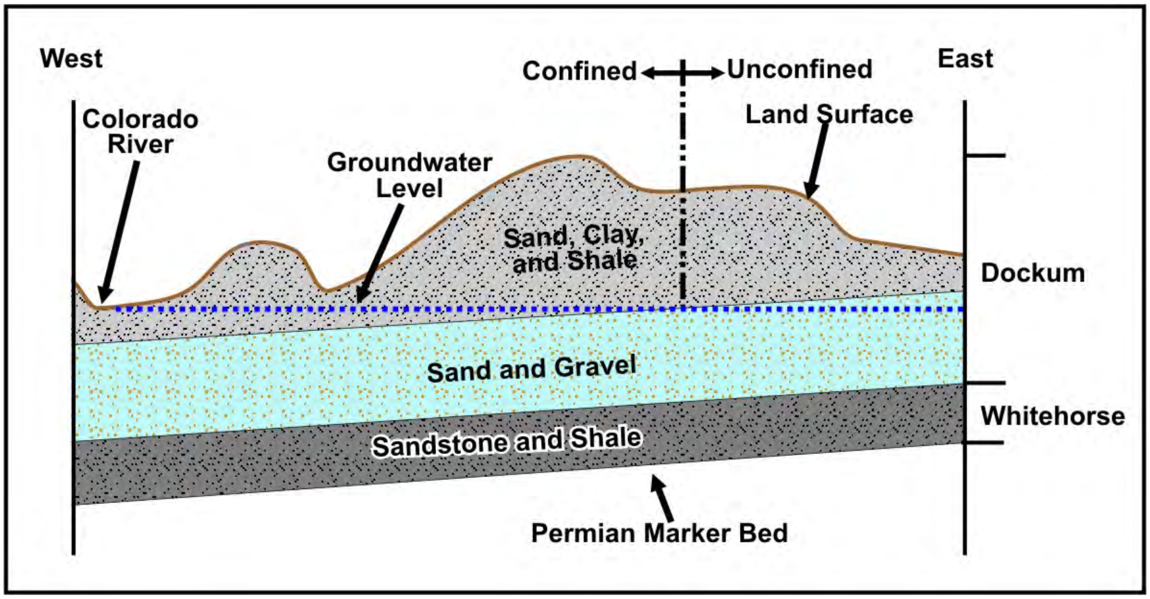


Figure 5-11. Schematic of Cross-Section Showing Dockum Layering and Variation in Location of Groundwater Levels to the Layers

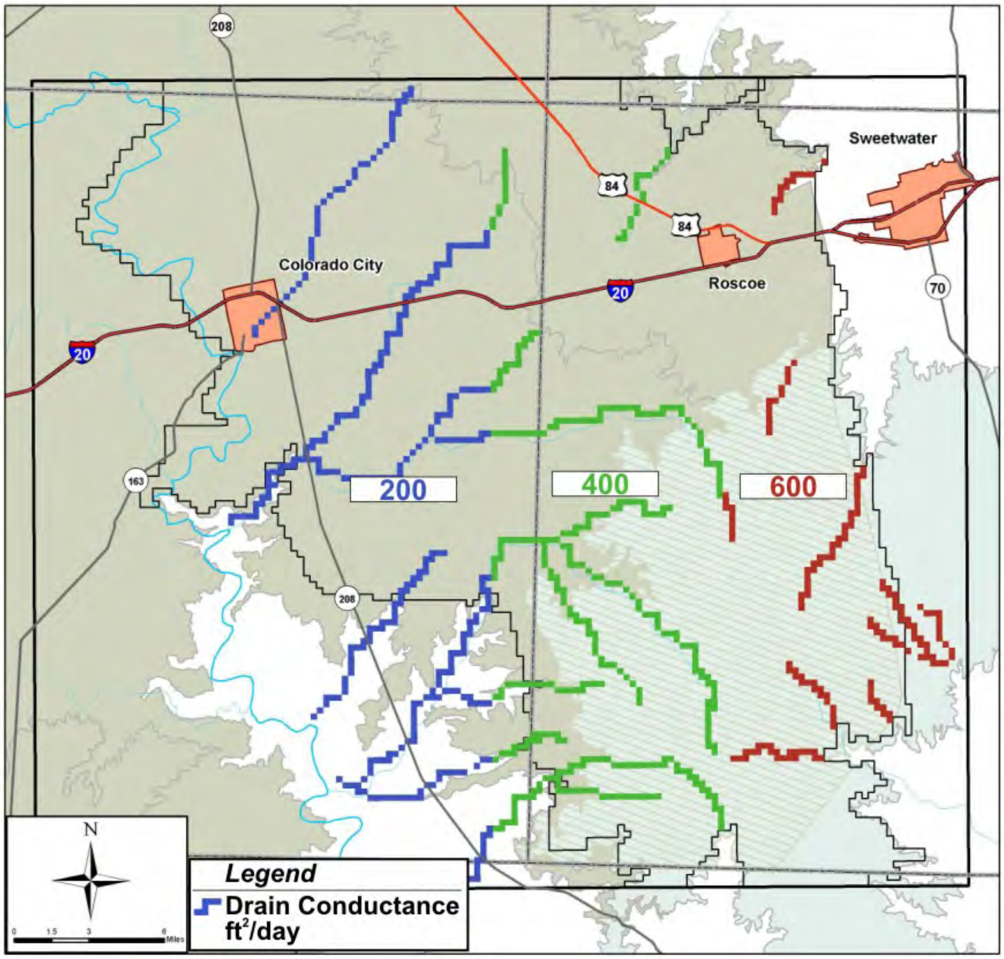


Figure 5-12. Drain Conductance Determined from Calibration

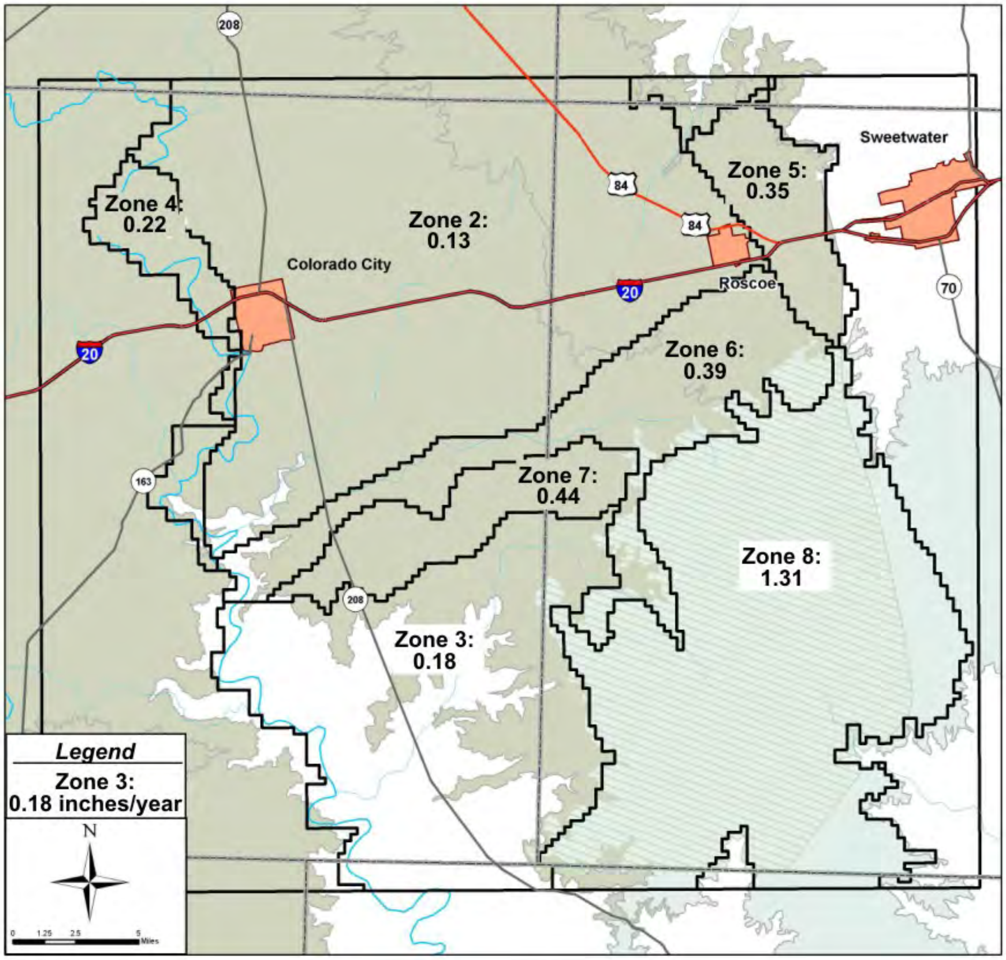


Figure 5-13. Annual Recharge Rates for Steady-State Conditions (1990)

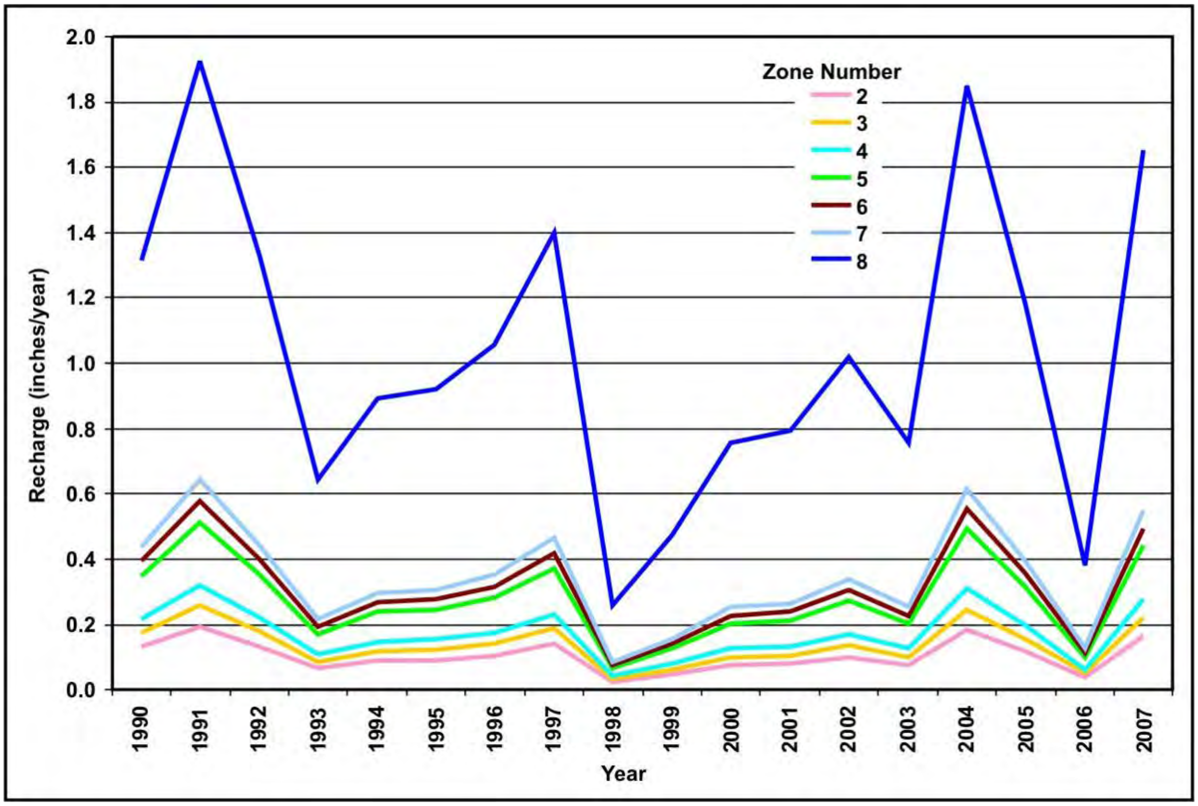


Figure 5-14. Annual Recharge for Transient Conditions Determined from Calibration

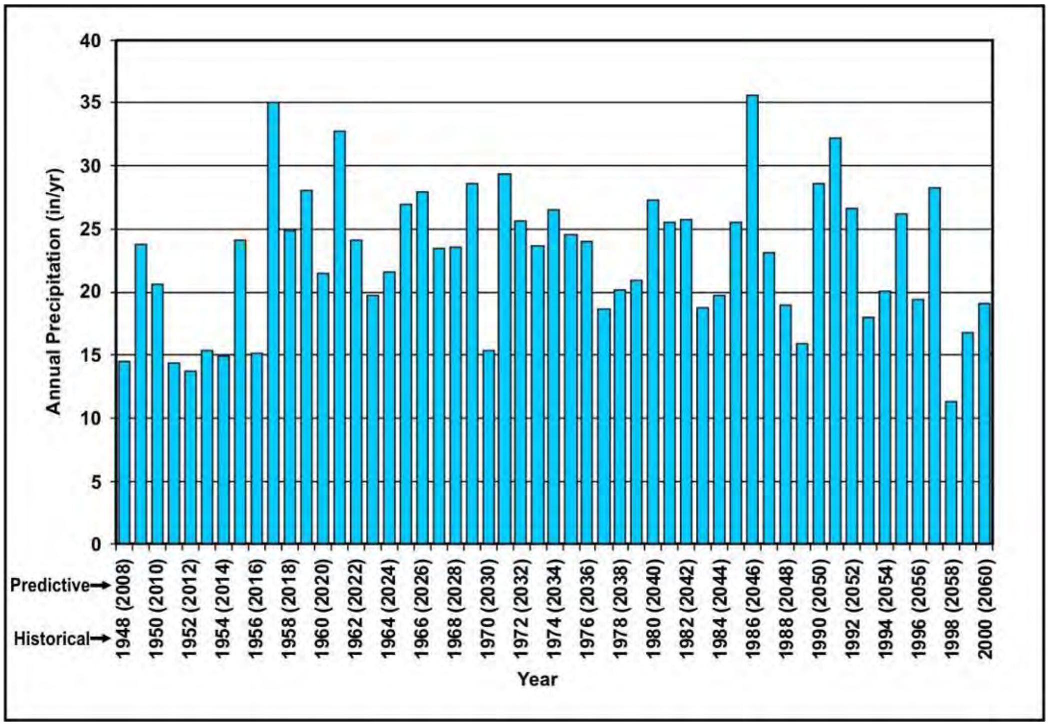


Figure 6-1. Annual Predictive Recharge

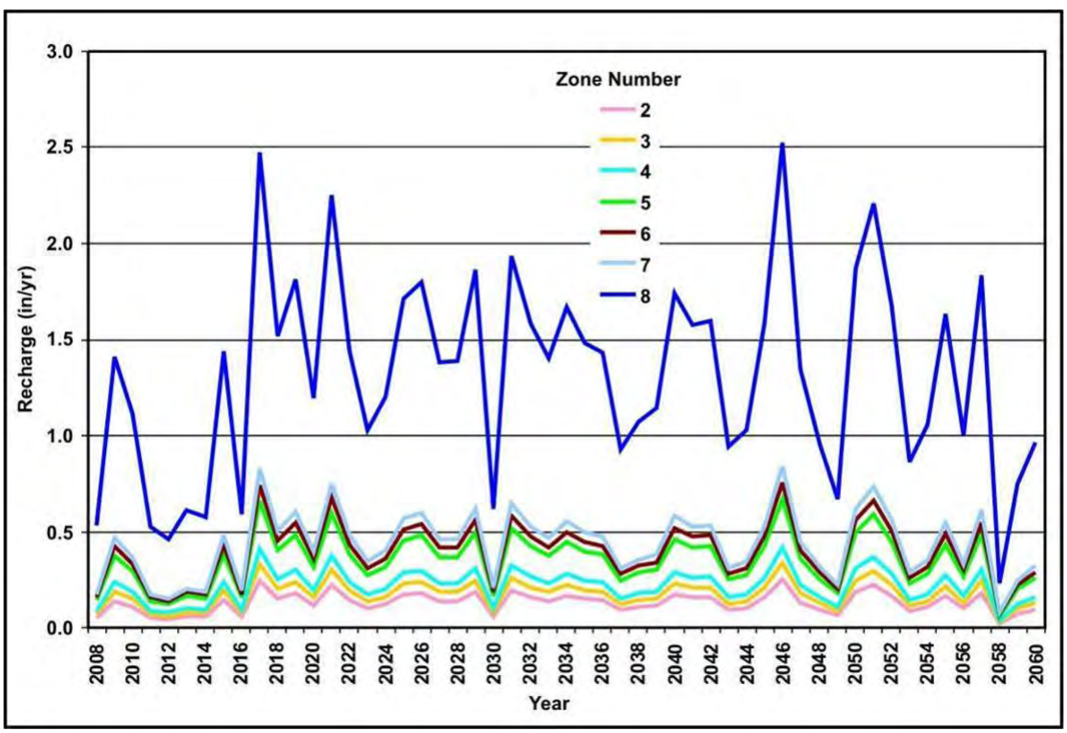


Figure 6-2. Annual Predictive Recharge for Each Recharge Zone

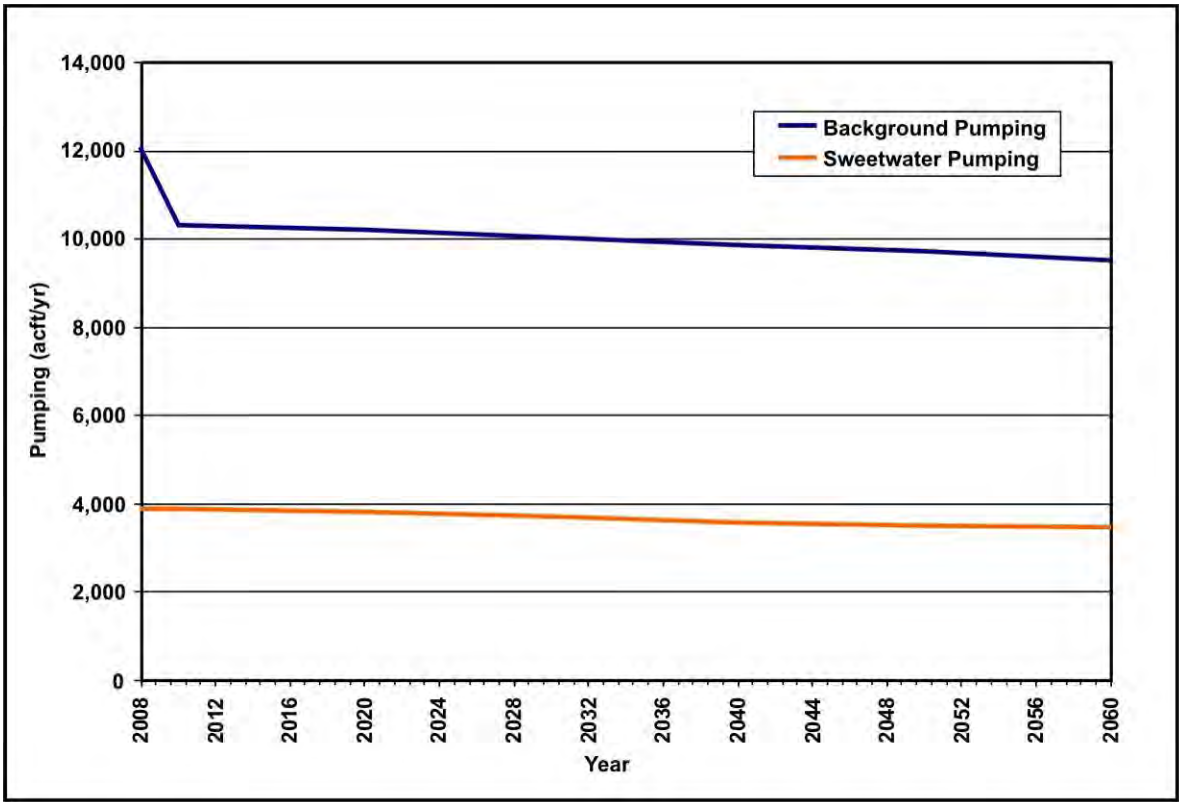


Figure 6-3. Annual Background and Sweetwater Pumping (2008-2060)

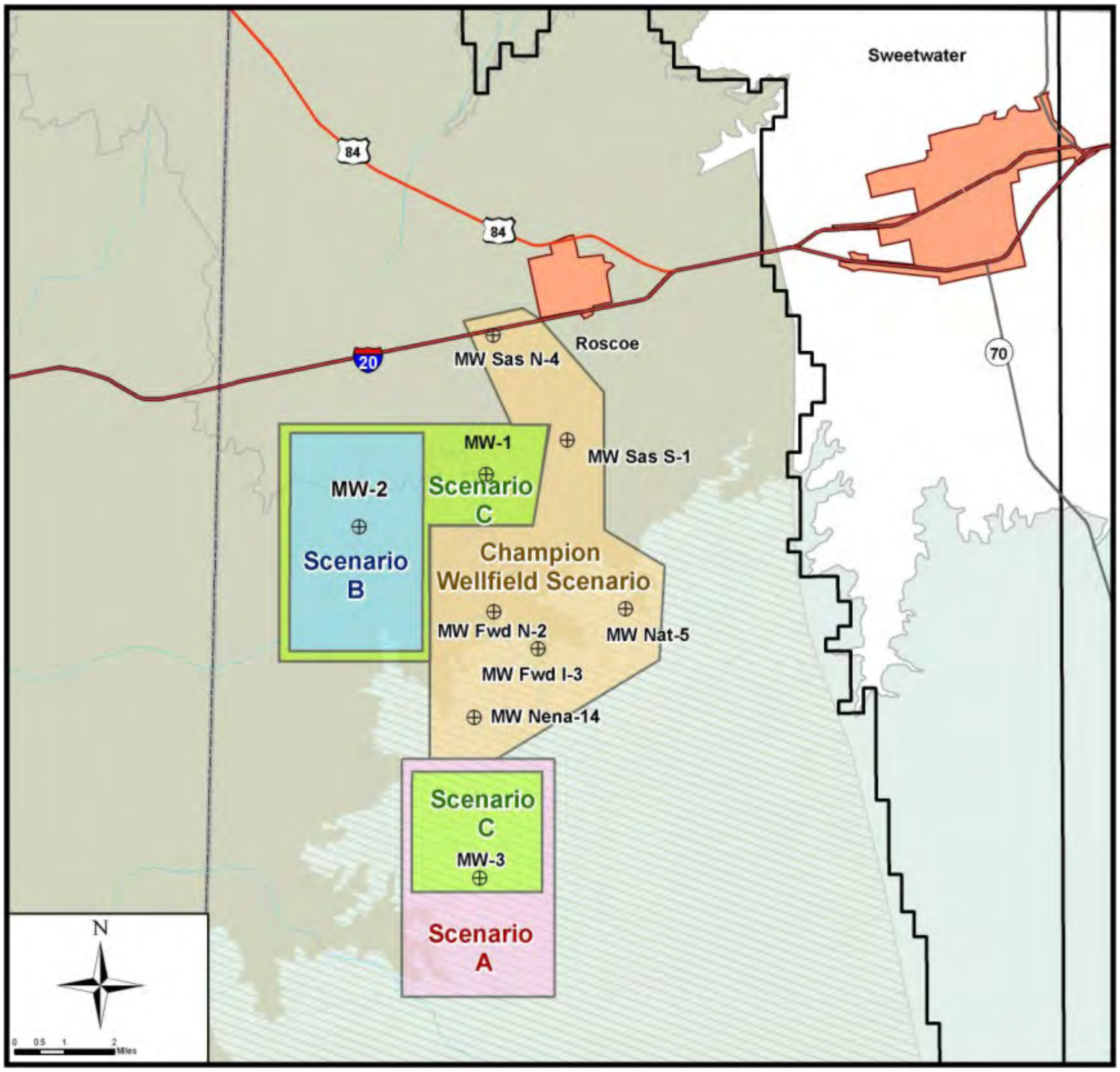


Figure 6-4. Location of Prospective Sweetwater Wellfields

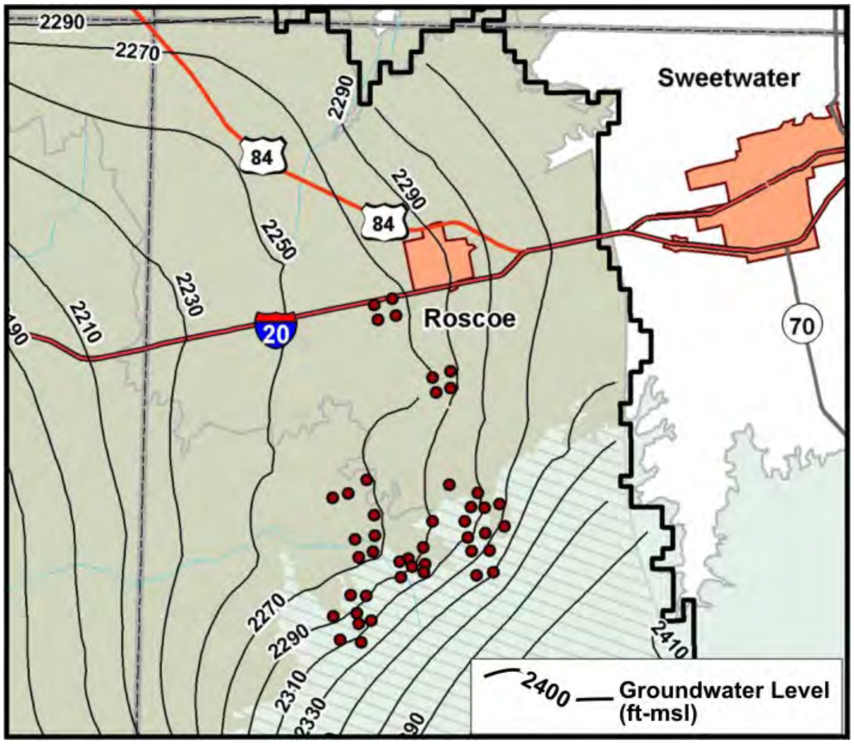


Figure 6-5. Modeled Dockum Water Levels for Champion Wellfield Scenario (2060)

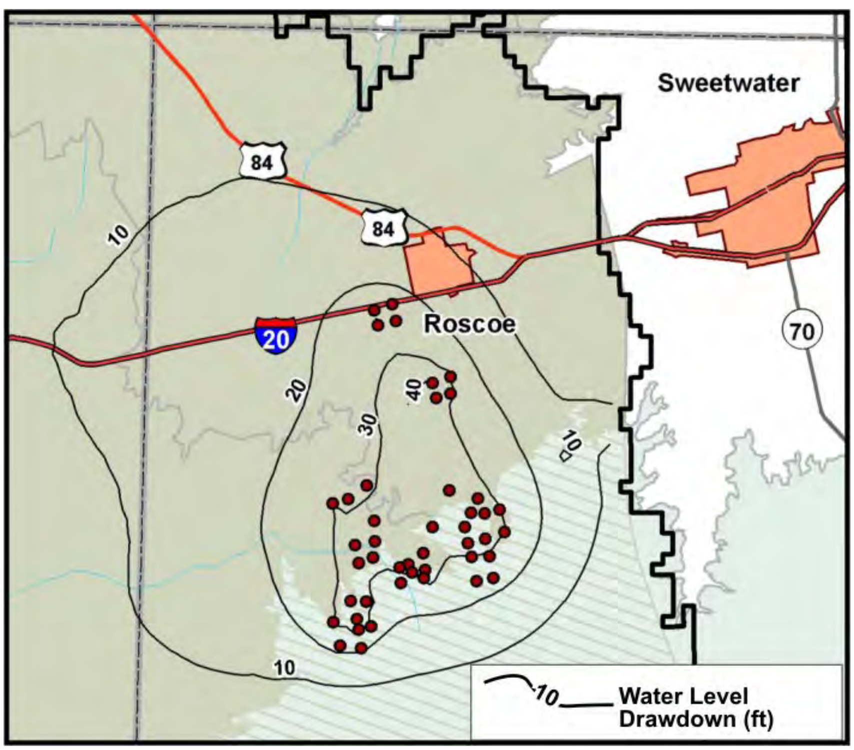


Figure 6-6. Modeled Dockum Drawdown in Water Levels for Champion Wellfield Scenario (2007 – 2060)

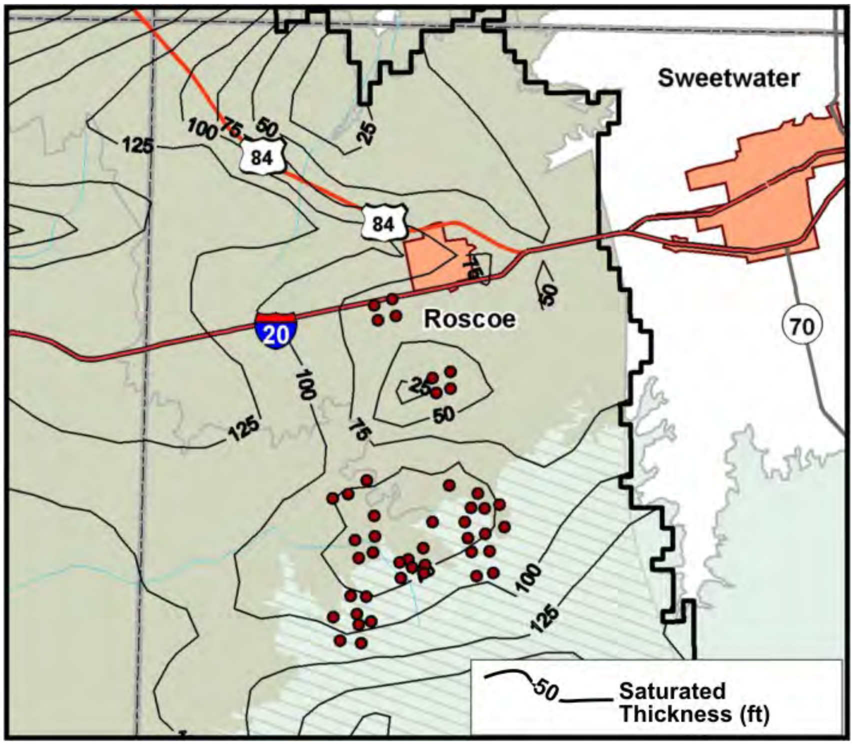


Figure 6-7. Modeled Dockum Saturated Thickness for Champion Wellfield Scenario (2060)

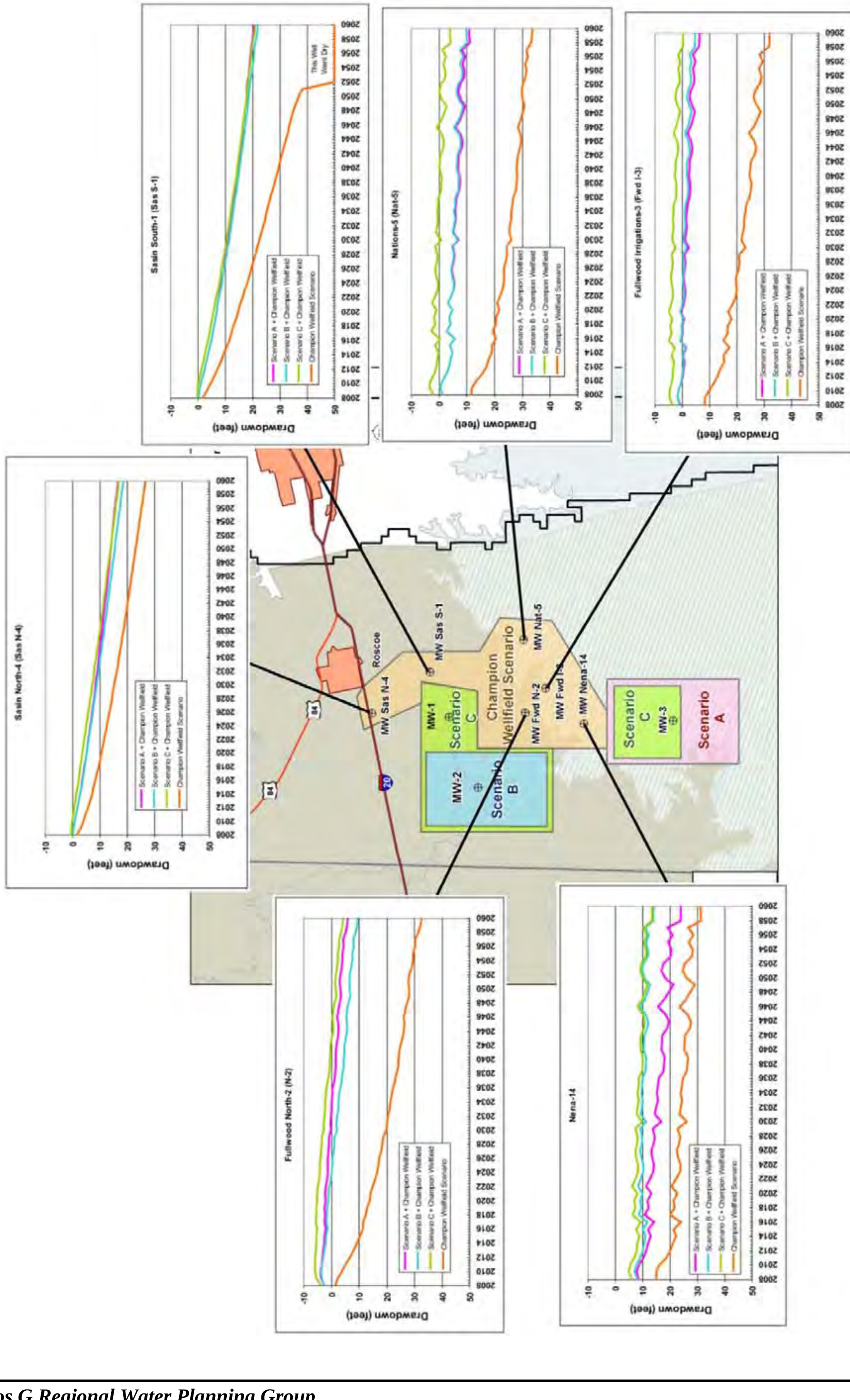


Figure 6-8a. Predictive Scenario Hydrographs (Champion Well Field)

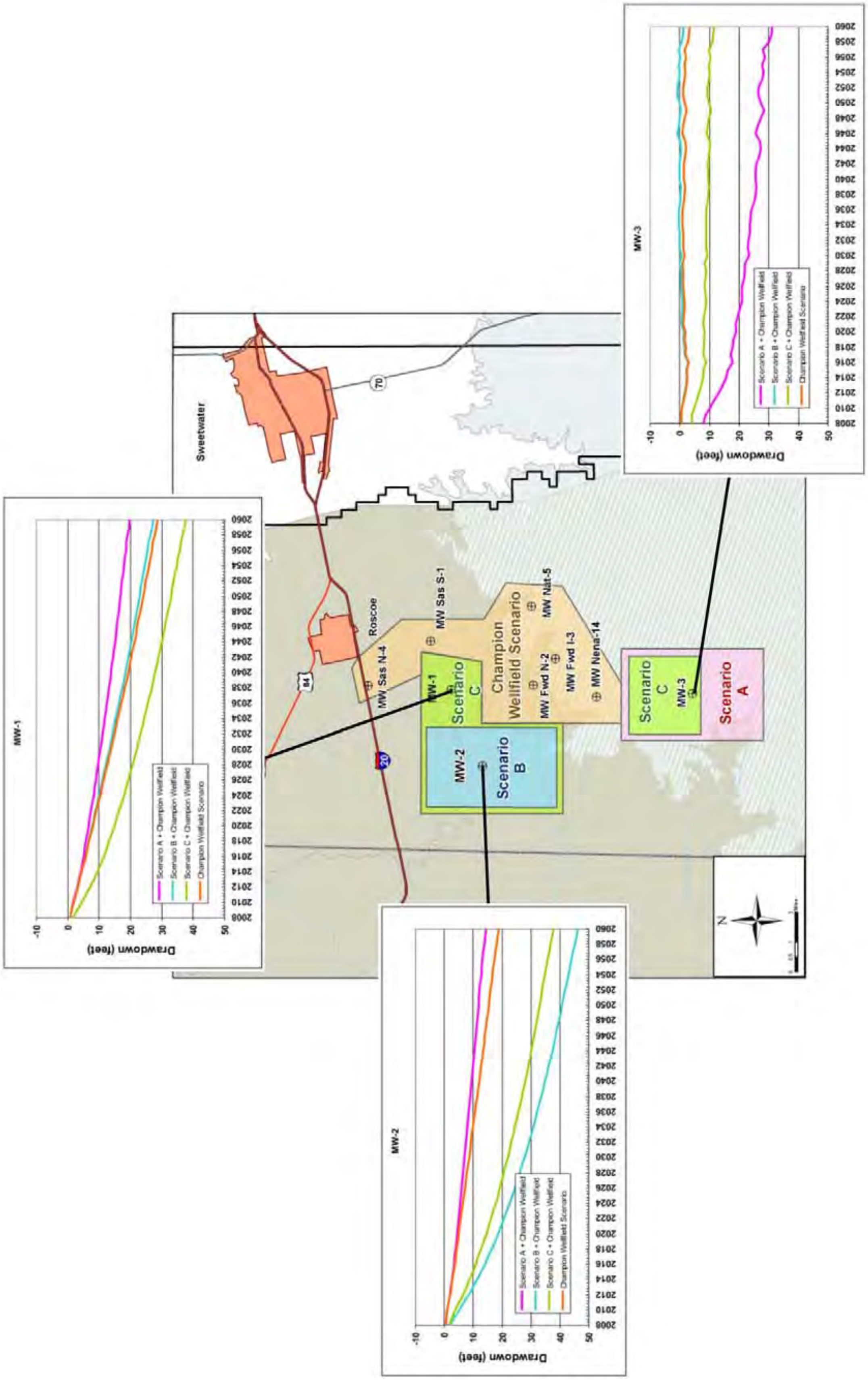


Figure 6-8b. Predictive Scenario Hydrographs (New Well Fields)

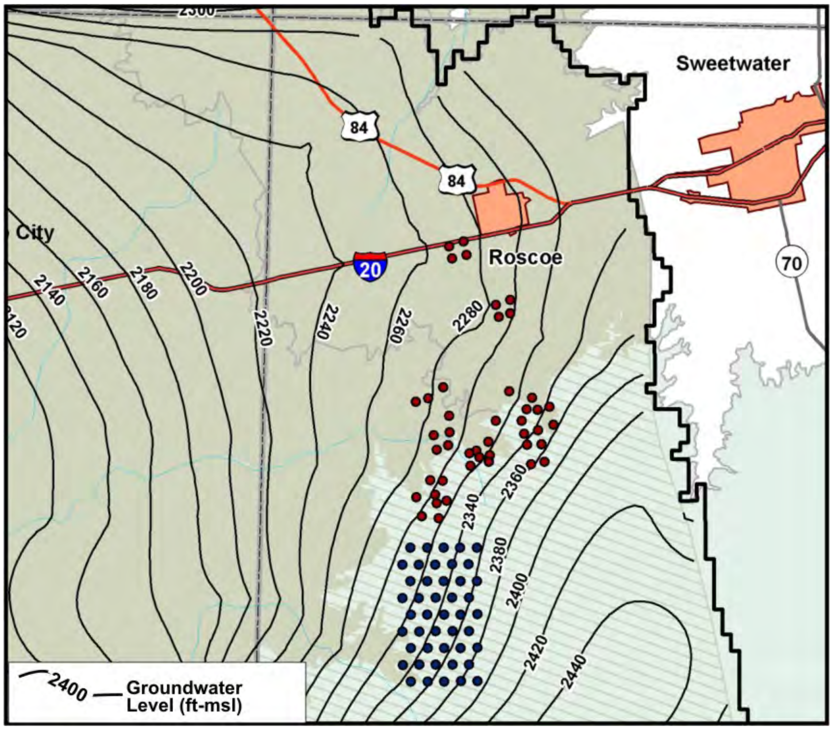


Figure 6-9. Modeled Dockum Water Levels for Scenario A (2060)

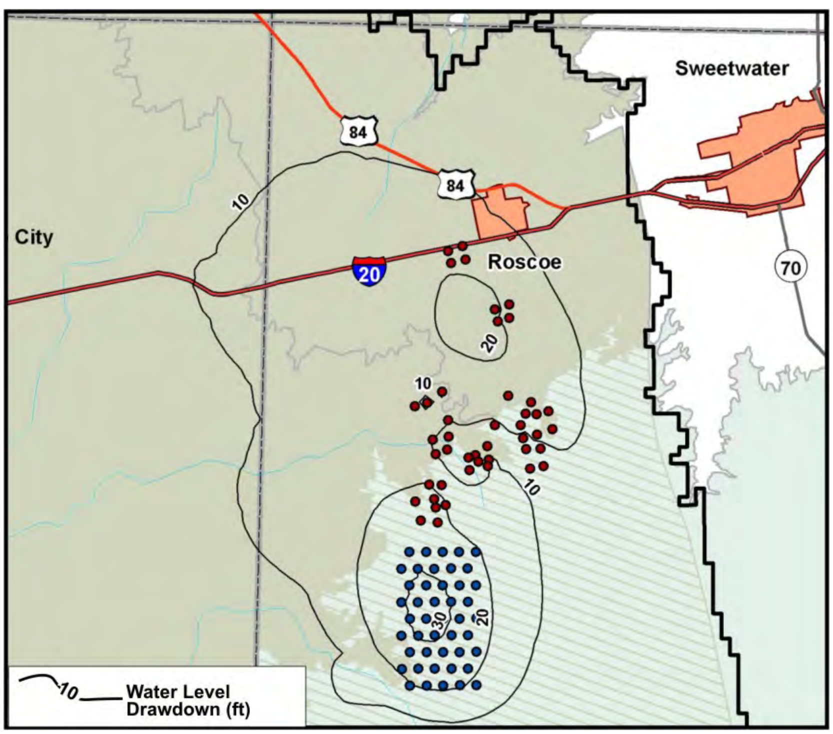


Figure 6-10. Modeled Dockum Drawdown in Water Levels for Scenario A (2007 – 2060)

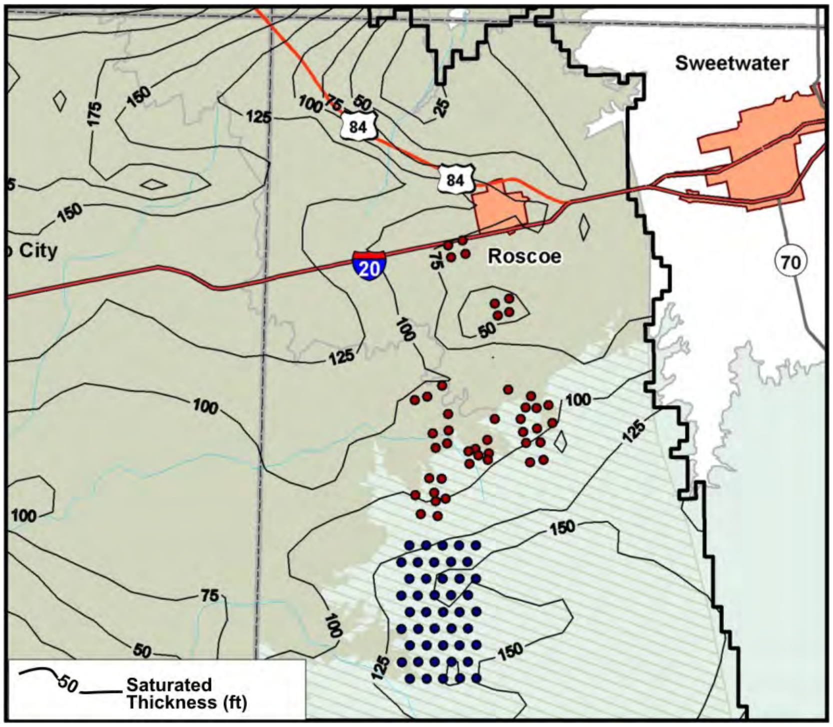


Figure 6-11. Modeled Dockum Saturated Thickness for Scenario A (2060)

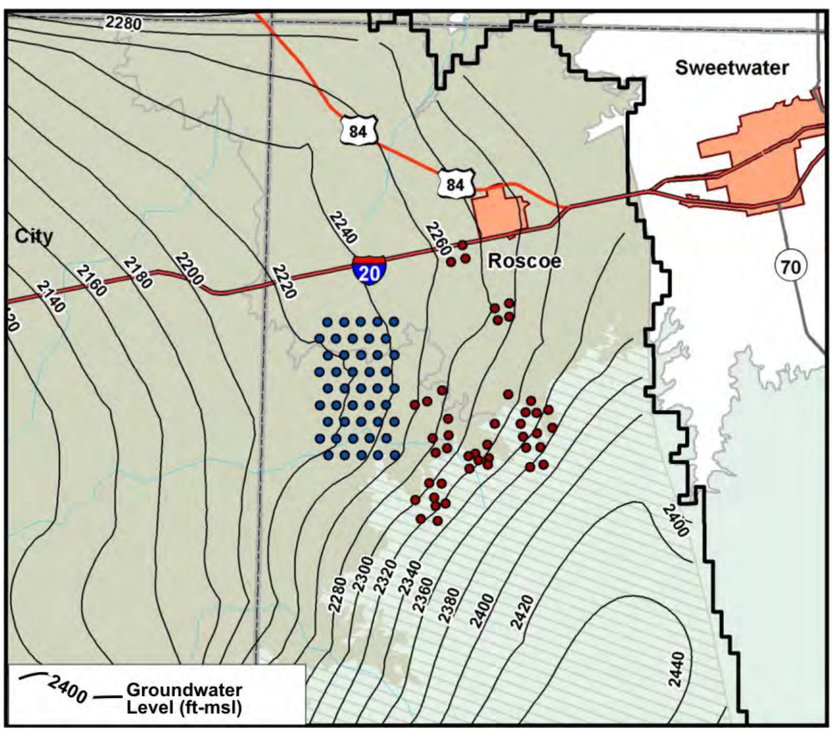


Figure 6-12. Modeled Dockum Water Levels for Scenario B (2060)

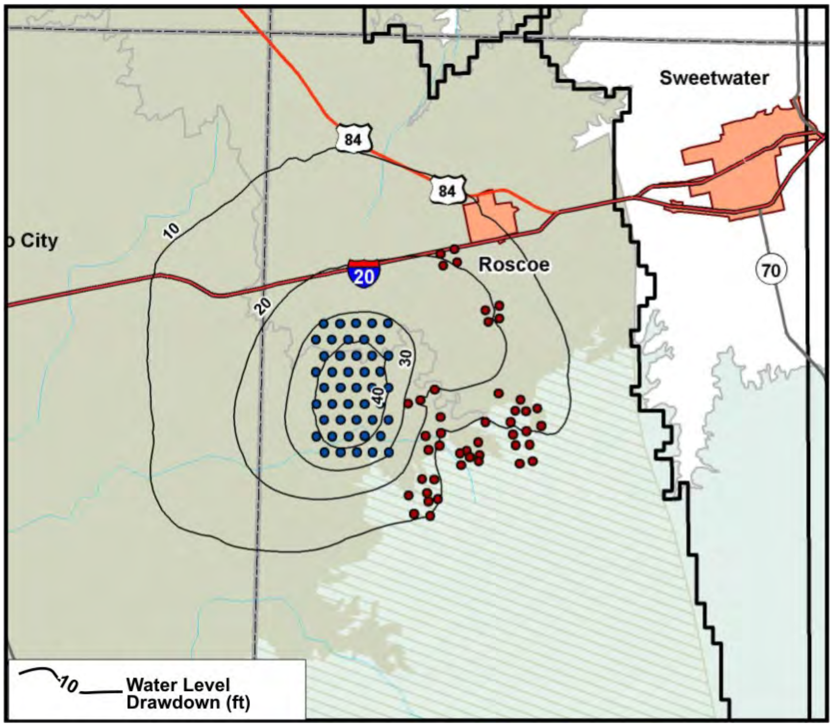


Figure 6-13. Modeled Dockum Drawdown in Water Levels for Scenario B (2007 – 2060)

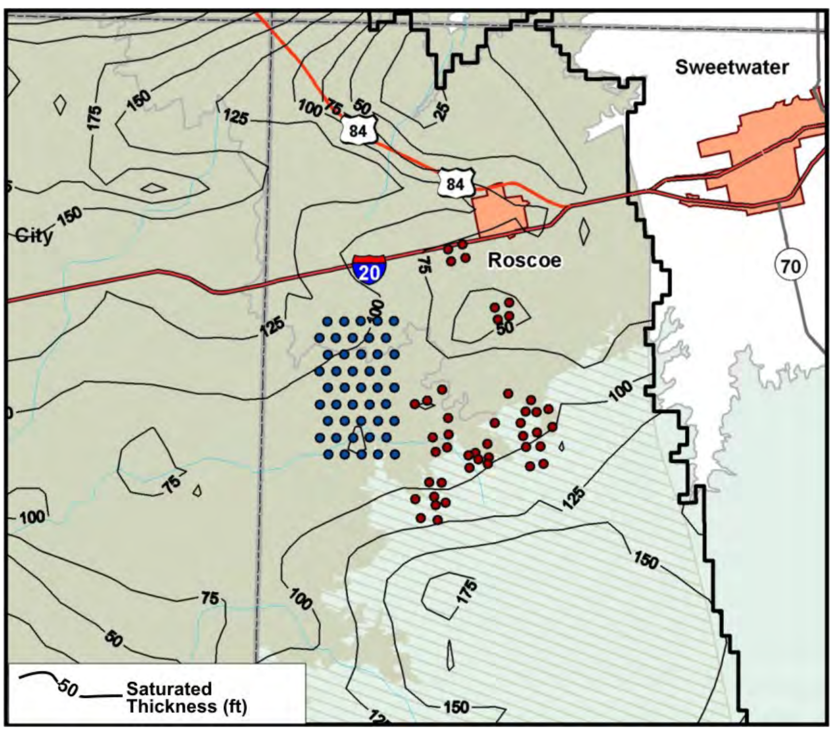


Figure 6-14. Modeled Dockum Saturated Thickness for Scenario B (2060)

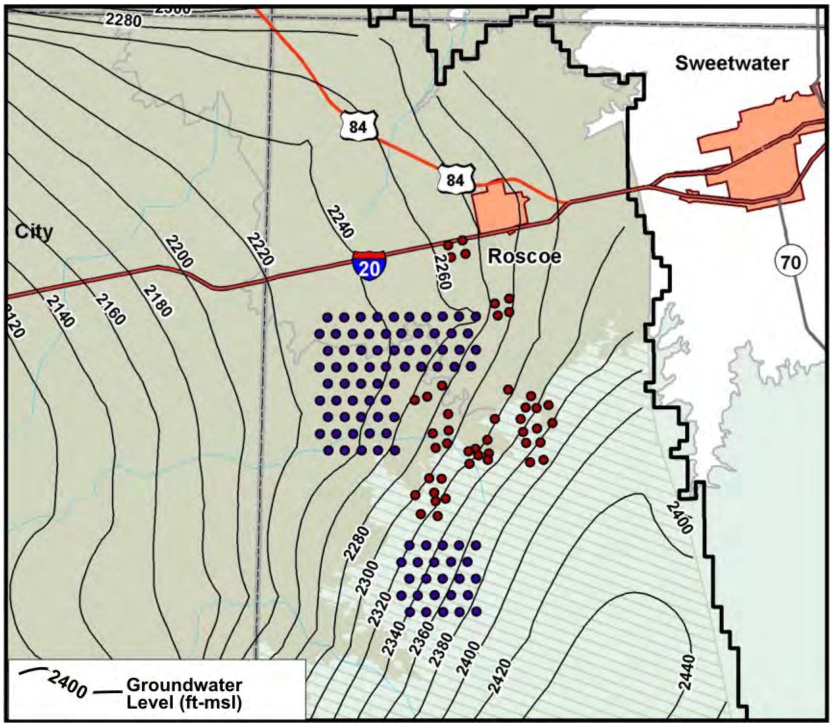


Figure 6-15. Modeled Dockum Water Levels for Scenario C (2060)

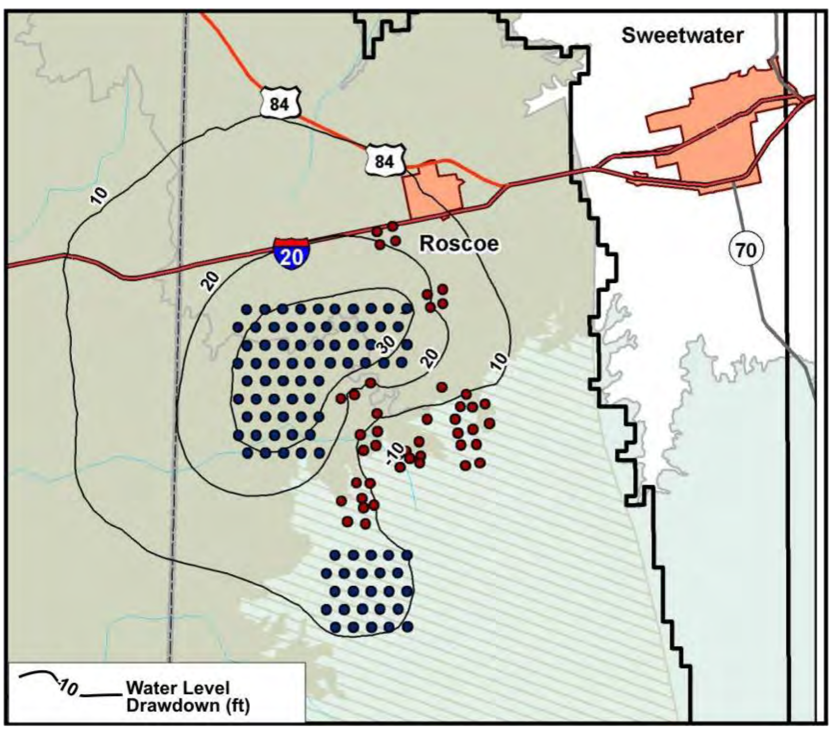


Figure 6-16. Modeled Dockum Drawdown in Water Levels for Scenario C (2007 – 2060)

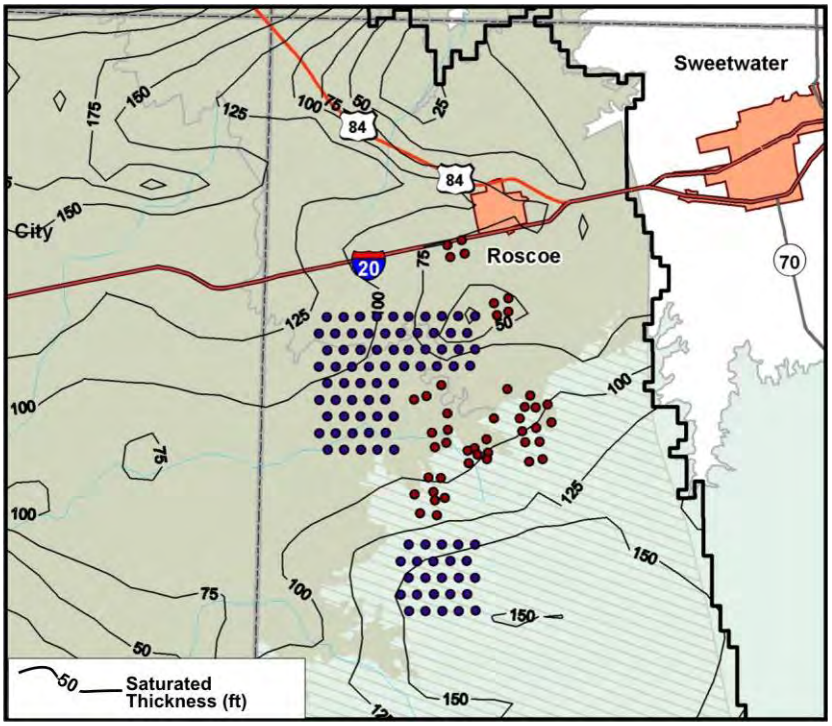


Figure 6-17. Modeled Dockum Saturated Thickness for Scenario C (2060)

Appendix A
Pumping Estimates

Table A-1. Annual Pumping in Nolan County

Nolan County							
Edwards-Trinity (Plateau) Aquifer							
Year	**Municipal**	**Manufacturing**	**Steam Electric**	**Irrigation**	**Mining**	**Livestock**	**Total**
1980	787	45	0	295	62	71	1,260
1984	850	43	0	250	90	40	1,273
1985	717	54	0	278	111	37	1,197
1986	468	44	0	178	106	27	823
1987	26	42	0	151	98	30	347
1988	471	46	0	181	91	29	818
1989	1,002	44	0	295	84	29	1,454
1990	1,019	40	0	254	84	28	1,425
1991	892	28	0	209	94	30	1,253
1992	261	36	0	154	94	42	587
1993	285	48	0	320	94	43	790
1994	260	52	0	0	94	43	449
1995	368	43	0	0	62	51	524
1996	327	28	0	0	62	82	499
1997	64	36	0	0	62	47	209
1998	71	46	0	0	62	35	214
1999	70	46	0	0	62	25	203
2000	114	70	0	0	62	22	268
2001	93	75	0	0	62	20	250
2002	95	78	0	0	62	20	255
2003	93	78	0	0	62	87	320
Dockum Aquifer							
Year	**Municipal**	**Manufacturing**	**Steam Electric**	**Irrigation**	**Mining**	**Livestock**	**Total**
1980	378	0	0	1,498	106	34	2,016
1984	322	0	0	1,360	80	20	1,782
1985	369	0	0	1,515	45	18	1,947
1986	282	0	0	972	43	14	1,311
1987	315	0	0	822	40	14	1,191
1988	510	0	0	988	36	14	1,548
1989	546	0	0	1,566	34	14	2,160
1990	490	0	0	1,382	35	14	1,921
1991	477	0	0	1,138	20	14	1,649
1992	425	0	0	841	19	20	1,305
1993	442	0	0	1,769	19	20	2,250
1994	429	0	0	1,760	19	20	2,228
1995	387	0	0	1,217	19	24	1,647
1996	410	0	0	2,240	19	38	2,707
1997	393	0	0	1,323	19	22	1,757
1998	437	0	0	1,212	19	16	1,684
1999	428	0	0	1,359	19	12	1,818
2000	701	0	0	4,145	19	10	4,875
2001	286	0	0	1,933	19	10	2,248
2002	301	0	0	1,950	19	10	2,280
2003	305	0	0	2,151	19	40	2,515

Table A-2.
Annual Pumping in Mitchell County

Mitchell County							
Dockum Aquifer							
Year	Municipal	Manufacturing	Steam Electric	Irrigation	Mining	Livestock	Total
1980	223	0	0	3,218	116	50	3,607
1984	152	19	0	2,739	620	42	3,572
1985	174	19	0	4,414	621	32	5,260
1986	182	19	0	2,765	586	38	3,590
1987	117	0	0	2,262	551	36	2,966
1988	139	0	0	2,129	518	39	2,825
1989	136	0	0	1,477	483	38	2,134
1990	131	0	0	1,593	483	38	2,245
1991	122	0	0	2,241	252	39	2,654
1992	177	0	0	953	252	42	1,424
1993	193	0	0	1,313	244	49	1,799
1994	199	0	0	1,240	244	44	1,727
1995	198	0	0	410	141	42	791
1996	336	0	0	1,044	141	37	1,558
1997	171	0	0	985	141	39	1,336
1998	353	0	0	809	141	43	1,346
1999	418	0	0	2,776	141	41	3,376
2000	1,369	0	0	5,549	141	42	7,101
2001	1,254	0	0	3,423	141	40	4,858
2002	1,801	0	0	3,670	141	33	5,645
2003	1,531	0	0	5,188	141	90	6,950

Table A-3. Annual Municipal and Industrial Pumping TWDB's Detailed Database

Municipal Pumpage (acft)					
Year	***Dockum***		***Edwards-Trinity***		***All***
	Mitchell	***Nolan***	***Mitchell***	***Nolan***	***Total***
1990	132	1,441	0	0	1,573
1991	121	1,300	0	0	1,421
1992	176	616	0	0	792
1993	192	654	0	0	846
1994	198	619	0	0	817
1995	198	656	0	0	854
1996	336	643	0	0	979
1997	171	362	0	0	533
1998	109	420	0	0	529
1999	219	450	0	0	669
2000	855	1,004	0	0	1,859
2001	1,240	2,866	0	0	4,106
2002	1,780	3,217	0	0	4,997
2003	1,513	3,720	0	0	5,233
2004	1,513	2,788	0	0	4,301
2005	1,513	2,788	0	0	4,301
Industrial Pumpage (acft)					
Year	***Dockum***		***Edwards-Trinity***		***All***
	Mitchell	***Nolan***	***Mitchell***	***Nolan***	***Total***
1990	0	0	0	41	41
1991	0	0	0	28	28
1992	0	0	0	36	36
1993	0	0	0	48	48
1994	0	0	0	52	52
1995	0	0	0	43	43
1996	0	0	0	28	28
1997	0	0	0	36	36
1998	0	0	0	46	46
1999	0	0	0	65	65
2000	0	0	0	70	70
2001	0	0	0	76	76
2002	0	0	0	79	79
2003	0	0	0	79	79
2004	0	0	0	79	79
2005	0	0	0	79	79

Table A-4.
Estimated Water Supplies Used by City of Sweetwater

Year	TWDB Water Use Survey			
	Surface Water (acft/yr)		Groundwater (acft/yr)	
	Oak Creek Reservoir	Nolan County	DUER WAGONER	Champion Wellfield
1971	3,770			
1972	4,171			
1973	4,397			
1974	4,596			
1975	5,946			
1976	5,630			
1977	4,558			
1978	4,550			
1979	4,998	202		
1980	5,125	182	424	
1981	2,043	2,485	1,022	
1982	1,686	3,343	455	
1983	3,473	1,465	840	
1984	2,576	2,398	807	
1985	2,037	1,826	673	
1986	2,460	1,849	448	
1987	2,431	2,066	0	
1988	3,029	1,617	434	
1989	5,383	761	975	
1990	2,278	1,713	975	
1991	4,074	912	848	
1992	4,352	809	216	
1993	3,542	0	238	
1994	3,822	0	215	
1995	2,656	1,042	302	
1996	5,146	21	264	
1997	5,298	85		
1998	5,381	706		
1999	3,735	387		61
2000	3,839	234		616
2001	2,000	361		2,500
2002	1,500	36		2,851
2003	0	10		3,333
2004	0	623		2,401
2005	0	971		2,153

Table A-4.
Pumpage in Champion Wellfield

Wellfield Name	Champion Wellfield Pumpage (acft/yr)						
	2001	2002	2003	2004	2005	2006	2007
Fullwood East	391	555	501	418	528	400	491
Fullwood Home	197	583	589	506	581	358	441
Fullwood Irrigations	173	176	111	73	14	2	0
Fullwood North	388	701	621	541	487	450	586
Nations	194	501	743	560	181	549	476
Nena	434	436	431	420	167	3	0
Sasin North	6	181	124	104	117	374	267
Sasin South	113	273	311	128	114	299	323
Whitfield Irrigations	45	24	0	0	0	0	0
Wilson	0	0	391	135	93	322	256
TOTAL	1,941	3,430	3,822	2,885	2,282	2,757	2,840

(This page intentionally left blank.)

Appendix B
Well Performance in Champion Wellfield

Table B-1.
Well Performance Data in Champion Wellfield (page 1 of 3)

Well ID	Motor Size (HP)	Well Yield (gpm)	Average Pumpage (acft/yr) 2001-2007	Well Depth (ft)	Depth to Top of Screen (ft)	Depth to Bottom of Screen (ft)	Drawdown during Pump Test (ft)	Saturated Thickness above Bottom of Screen during Static Conditions (ft) Jan 2006	Saturated Thickness above Bottom of Screen during Pumping (ft) January 2008	Depth to Water (ft) January 2006	Depth to Water (ft) January 2008	Change in Water Levels (ft) October 2006-January 2008
Nena Wells#2	5	40	39	250		240		148		92		
Nena Wells#4	5	60	43	250		240		130		110		
Nena Wells#7	5	30	12	250		240		112		128		
Nena Wells#8	5	20	23	322		312		138		174		
Nena Wells#9	5	20	22	247		237		155		82		
Nena Wells#10	5	40	38	255		245		100		145		
Nena Wells#12	5	80	60	250		240		82		158		
Nena Wells#14	5	45	34	251		241		99		142		
Nations Wells#1	20	160	93	283	200	273	99	138	41	135	133	2
Nations Wells#2	20	190	122	210	160	200		125		75		
Nations Wells#3	15	105	60	225	185	215	82	114	27	101	106	-5
Nations Wells#4	20	140	100	196	124	186	76	124	27	62	83	-21
Nations Wells#5	5	35	12	250	160	240	75	102	25	138	140	-2
Nations Wells#6	15	110	70	235	170	225	90	103	2	122	133	-11
Fullwood Irrigation#1	25	50	25	225		215		183		32		
Fullwood Irrigation#2	25	80	50	220		210		142		68		
Fullwood Irrigation#3	30	50	4	205		195		121		74		
Fullwood Homeplace#1	10	50	35	230	150	220	114	116	4	104	102	2
Fullwood Homeplace#2	15	70	49	200	160	200	100	101	4	99	96	3
Fullwood Homeplace#3	25	180	182	240	140	230	98	96	3	134	129	5
Fullwood Homeplace#4	30	190	199	200	130	190	102	74	-24	116	112	4

Table B-1.
Well Performance Data in Champion Wellfield (page 2 of 3)

Well ID	Motor Size (HP)	Well Yield (gpm)	Average Pumpage (acft/yr) 2001-2007	Well Depth (ft)	Depth to Top of Screen (ft)	Depth to Bottom of Screen (ft)	Drawdown during Pump Test (ft)	Saturated Thickness above Bottom of Screen during Static Conditions (ft) Jan 2006	Saturated Thickness above Bottom of Screen during Pumping (ft) January 2008	Depth to Water (ft) January 2006	Depth to Water (ft) January 2008	Change in Water Levels (ft) October 2006-January 2008
Fullwood North#1	15	90	77	180	130	170	80	76	2	94	88	6
Fullwood North#2	15	90	90	167	87	157	103	97	-5	60	59	1
Fullwood North#3	20	130	90	160	70	150	76	83	-5	67	79	-12
Fullwood North#4	15	70	64	185	120	175	79	85	8	90	88	2
Fullwood North#5	15	90	112	170	80	145	86	82	-4	63	63	0
Fullwood North#6	25	150	106	170	90	160	89	75	-10	85	81	4
Fullwood East#1	15	90	59	180	100	170	101	109	6	61	63	-2
Fullwood East#2	15	40	46	180	90	170	99	96	-1	74	72	2
Fullwood East#3	30	225	281	240	160	230	72	72	7	158	151	7
Fullwood East#4	15	70	84	174	99	169	93	64	-21	105	97	8
Sasin North#1	15	75	27	200	140	190	47	82	34	108	109	-1
Sasin North#2	25	170	49	210	140	200	61	109	44	91	95	-4
Sasin North#3	20	115	47	205	125	195	58	97	35	98	102	-4
Sasin North#4	20	115	44	200	130	190	57	87	28	103	105	-2
Sasin South#1	30	220	87	180	120	170	65	91	20	79	85	-6
Sasin South#2	15	75	30	190	120	180	58	97	33	83	89	-6
Sasin South#3	25	170	49	175	75	165	73	89	13	76	79	-3
Sasin South#4	30	160	57	175	105	165	69	81	16	84	80	4

Table B-1.
Well Performance Data in Champion Wellfield (page 3 of 3)

Well ID	Motor Size (HP)	Well Yield (gpm)	Average Pumpage (acft/yr) 2001-2007	Well Depth (ft)	Depth to Top of Screen (ft)	Depth to Bottom of Screen (ft)	Drawdown during Pump Test (ft)	Saturated Thickness above Bottom of Screen during Static Conditions (ft) Jan 2006	Saturated Thickness above Bottom of Screen during Pumping (ft) January 2008	Depth to Water (ft) January 2006	Depth to Water (ft) January 2008	Change in Water Levels (ft) October 2006-January 2008
Wilson Wells#1	10	80	20	270	180	260	107	110	-5	150	158	-8
Wilson Wells#2	7.5	65	31	270	180	260		126		134	151	-17
Wilson Wells#3	10	50	32	240	150	230		120		110	121	-11
Wilson Wells#4	10	85	28	210	150	200		122		78	88	-10
Wilson Wells#5	5	45	15	240	150	230		154		76	101	-25
Wilson Wells#6	10	120	45	270	180	260	113	114	-7	146	154	-8

(This page intentionally left blank.)

Appendix C
Comments from the Texas Water Development Board Regarding Phase I Reports and Responses from the Brazos G Regional Water Planning Group

TEXAS WATER DEVELOPMENT BOARD

February 20, 2009

RECEIVED
MAR 2 2009
GENERAL MANAGER

A
copy to
Troy Bumgarner

Mr. Phillip J. Ford
General Manager/CEO
Brazos River Authority
P.O. Box 7555
Waco, Texas 76714-7555

Re: Region G, Region-Specific Studies Contract for Regional Water Planning between the Texas Water Development Board (TWDB) and the Brazos River Authority (BRA), TWDB Contract No. 0704830692, Draft Final Study Report Comments.

Dear Mr. Ford:

Staff members of TWDB have completed a review of the Draft Final Study Report under TWDB Contract No. 0704830692. As stated in the above-referenced contract, BRA will consider incorporating Draft Final Study Report comments, shown in Attachment 1, as well as other comments received, into the Final Study Report. In accordance with paragraph F, Article III, Section II of the contract, a copy of these TWDB Executive Administrator comments as well as a written summary of how the Draft Final Study Report was revised in response must be included in all the Final Study Report documents, for example, as an appendix.

TWDB looks forward to receiving one (1) electronic copy of all files, one electronic copy of each Final Study Report in Portable Document Format (PDF), and nine (9) bound double-sided copies of each Final Study Report to the TWDB Executive Administrator no later than the contract Final Study Report Deadline (April 30, 2009 for most reports). Please also transfer copies of all data and reports generated by the planning process and used in developing the Final Study Report to the TWDB Executive Administrator no later than the contract Final Study Report Deadline.

As a reminder, if any portion of the Final Study Report is to be included in a 2011 regional water plan it will be reviewed as part of the Initially Prepared Plan for meeting all statutory and agency rule requirements regarding the preparation of regional water plans.

If you have any questions concerning this contract, please contact Matt Nelson, TWDB's designated Contract Manager for this study at (512) 936-0829.

Sincerely,

Dan Harden
for Carolyn L. Brittin
Deputy Executive Administrator
Water Resources Planning and Information

Enclosures
Attachment 1

c: Matt Nelson, TWDB

ATTACHMENT 1

TWDB Contract No. 0704830692

Region G, Region-Specific Studies 1-5:

<u>TWDB Comments on Draft Final Region-Specific Study Reports:</u>
1) Updated Drought of Record and Water Quality Implications for Reservoirs Upstream of Possum Kingdom Reservoir

2) Groundwater Availability Model of the Edwards-Trinity (Plateau) and Dockum Aquifer in Western Nolan and Eastern Mitchell Counties, Texas

3) Regionalization Strategies to Assist Small Water Systems in Meeting New SDWA Requirements

4) Brazos G Activities in Support of Region C's Water Supply Study for Ellis, Johnson, Southern Dallas, and Southern Tarrant Counties

5) Updated Water Management Strategies for Water User Groups in McLennan County

Region-Specific Study 1: Updated Drought of Record and Water Quality Implications for Reservoirs Upstream of Possum Kingdom Reservoir

1. Report does not present newly developed model input datasets developed under Task 1, for example, the raw numerical naturalized flow dataset (including from 1998) through June 2008 as used in the model. Please present these data as appendices in report.

2. Page 8, Table 2.1: Please clarify where the rating curves came from for elevation-content calculations.

Region-Specific Study 2: Groundwater Availability Model of the Edwards-Trinity (Plateau) and Dockum Aquifer in Western Nolan and Eastern Mitchell Counties, Texas

1. The data discussed on page 12 does not appear to match the data referred to in Appendix A. In the second to last paragraph, the report refers to the data showing 4,300 acre-feet of municipal pumpage in year 2005. The data in Appendix A do not appear to support this total. Please correct or clarify the basis of the 4,300 reference in the report.

2. Page 12, last paragraph discusses data in Appendix A and states that the total pumping in 2003 was 4,600 acre-feet. The value for 2003 in the Appendix A table however, appears to be 3,823 acre-feet. This paragraph also states the average is 3,240 acft/year, although the data as presented in the Appendix averages 2,851 acre-feet/year. Please correct

reference or clarify how numbers referred to in text were derived. Also, it appears that the totals for years 2001-2004 and 2007 are off by 1 acre-foot.

3. According to Task 1, subtask C in the contract Scope of Work, the report was to "estimate long-term supplies available from the well field." The report does not appear to directly provide estimates of long-term supplies. Please provide information regarding estimated long-term supplies in the report.

Region-Specific Study 3: Regionalization Strategies to Assist Small Water Systems in Meeting New SDWA Requirements

1. Page 58, paragraph 3 states that "the TWDB Regional Water Supply and Wastewater Facilities Planning Program could be used to provide up to 50 % of the cost of a detailed analysis of regionalization opportunities to encourage small water systems to actively consider and begin implementation of a regionalization strategy". Please clarify in the report that "TWDB can pay up to 50% of the study costs (75% in areas which have unemployment rates exceeding the state average by 50% or more and per-capita income is 65% or less than the state average for the last reporting period available)..."

Region-Specific Study 4: Brazos G Activities in Support of Region C's Water Supply Study for Ellis, Johnson, Southern Dallas, and Southern Tarrant Counties

TWDB's acceptance of the final report does not constitute approval of any revised population or water demand projections contained therein. The formal procedure for requesting revised projections is stated in TAC 357.5 (d) (2):

> *"Before requesting a revision to the population and water demand projections, the regional water planning group shall discuss the issue at a public meeting for which notice has been posted pursuant to the Open Meetings Act in addition to being published on the internet and mailed at least 14 days before the meeting to every person or entity that has requested notice of regional water planning group activities. The public will be able to submit oral or written comment at the meeting and written comments for 14 days following the meeting. The regional water planning group will summarize the public comments received in its request for projection revisions. Within 45 days of receipt of a request from a regional water planning group for revision of population or water demand projections, the executive administrator shall consult with the requesting regional water planning group and respond to their request."*

All requested revisions which receive a consensus recommendation from TWDB, the Texas Department of Agriculture, Texas Commission on Environmental Quality, and Texas Parks and Wildlife Department, will then be presented for consideration of Board approval at the next scheduled meeting.

1. Task 1 of the contract Scope of Work refers to reviewing recent studies. Please provide a general summary of findings regarding recent supply studies and activities in the area since the 2006 Brazos G Regional Water Plan was adopted.

2. Tasks 1 and 4 of the contract Scope of Work refer to reviews of studies and reviews of population projection estimates. While Section 1.0 of the report summarizes the associated activities performed by date, it does not provide a general summary of the findings of these reviews or copies of or summaries of the comments that were provided by Region G consultant as a result of these reviews. Please provide a summary of findings or copies of written comments resulting from this work, for example, as an appendix in the report.

3. The report does not include or make specific reference to the raw population/water demand projections that were provided from individual water providers in the regional study area (e.g. Alvarado, Burleson, JCSUD, Mansfield, and Venus). Please provide copies of these water planning projections that are generally greater than TWDB population and/or water demand projections. If this raw data was included in another available report, please provide a reference.

4. Please consider adding clarifying language to the Executive Summary that more clearly sets forth the purpose and content of this specific report and that explains the need for a reader to also review the "Region C Water Supply Study for Johnson, Southern Dallas, and Southern Tarrant Counties". Consider including a copy of the associated Region C study Table of Contents for reference, for example, in an appendix.

5. Page B-3: Table B-2 is missing from report. Please include in final report.

Region-Specific Study 5: Updated Water Management Strategies for Water User Groups in McLennan County

1. Task 3 of the contract scope of work states that the following sections will be included in the draft and final report: "... purpose of study including how the study supports regional water planning, methodology, results, and recommendations, if applicable." These sections are not present in the draft report. Please include them in the final report.

ONE COMPANY
Many Solutions℠

Memo

To:	Brazos G Regional Water Planning Group		
From:	David Dunn, PE	Project:	Brazos G 2011 Regional Water Plan
CC:	Trey Buzbee, Brazos River Authority		
Date:	April 7, 2009	Job No:	00044257-001

RE: Suggested responses to TWDB comments regarding the five Phase I Reports

On December 29, 2008, HDR submitted to the Texas Water Development Board (TWDB) draft copies of the reports summarizing the five Phase I studies completed pursuant to the 2011 Brazos G Regional Water Plan. On February 20, 2009, the TWDB provided review comments on each draft report. Those review comments are repeated in this memorandum, followed by HDR's suggested response to each comment.

HDR recommends that the Brazos G RWPG accept these suggested responses to the TWDB comments, and direct HDR and the Brazos River Authority to incorporate the responses into the final versions of the reports, and submit the final reports to the TWDB prior to the report submission deadline of April 30, 2009. A copy of the TWDB review comments and the planning group's responses will be included as an appendix to each report.

Region-Specific Study 1: Updated Drought of Record and Water Quality Implications for Reservoirs Upstream of Possum Kingdom Reservoir

1. Report does not present newly developed model input datasets developed under Task 1, for example, the raw numerical naturalized flow dataset (including from 1998) through June 2008 as used in the model. Please present these data as appendices in report.

Suggested Response: The newly developed data sets have been printed and included as an appendix to the report.

2. Page 8, Table 2.1: Please clarify where the rating curves came from for elevation-content calculations.

Suggested Response: The reservoir elevation-area-capacity relations were obtained from the most recent bathymetric survey available for each reservoir. The last paragraph on page 7 has been updated to make the source of the data more clear.

Region-Specific Study 2: Groundwater Availability Model of the Edwards-Trinity (Plateau) and Dockum Aquifer in Western Nolan and Eastern Mitchell Counties, Texas

1. The data discussed on page 12 does not appear to match the data referred to in Appendix A. In the second to last paragraph, the report refers to the data showing 4,300 acre-feet of

municipal pumpage in year 2005. The data in Appendix A do not appear to support this total. Please correct or clarify the basis of the 4,300 reference in the report.

Suggested Response: The data shown in Table A-3 of Appendix A have been corrected.

2. Page 12, last paragraph discusses data in Appendix A and states that the total pumping in 2003 was 4,600 acre-feet. The value for 2003 in the Appendix A table however, appears to be 3,823 acre-feet. This paragraph also states the average is 3,240 acft/year, although the data as presented in the Appendix averages 2,851 acre-feet/year. Please correct reference or clarify how numbers referred to in text were derived. Also, it appears that the totals for years 2001-2004 and 2007 are off by 1 acre-foot.

Suggested Response: The numbers in the text have been corrected.

3. According to Task 1, subtask C in the contract Scope of Work, the report was to "estimate long-term supplies available from the well field." The report does not appear to directly provide estimates of long-term supplies. Please provide information regarding estimated long-term supplies in the report.

Suggested Response: The following text has been added to the report as a final paragraph in Section 7 Water Management Strategy for Sweetwater:

"If a groundwater only strategy is considered, the performance of the current Champion Well Field from 2001-2007 and the groundwater modeling suggests that the Edwards-Trinity and Dockum Aquifers could meet this average demand, which was about 2,850 acft/yr. If the well field was substantially expanded to the south-southwest, the modeling analysis suggests that it could meet the projected demand of 3,900 acft/yr for the planning period."

And the following text has been added to Section 9 Conclusions:

"If a groundwater only strategy is considered, the analysis suggests that the aquifers could meet 2001-2007 average demand of about 2,850 acft/yr. If the well field was substantially expanded to the south-southwest, the analysis suggests that the projected demand of 3,900 acft/yr for the planning period could be met."

Region-Specific Study 3: Regionalization Strategies to Assist Small Water Systems in Meeting New SDWA Requirements

1. Page 58, paragraph 3 states that "the TWDB Regional Water Supply and Wastewater Facilities Planning Program could be used to provide up to 50 % of the cost of a detailed analysis of regionalization opportunities to encourage small water systems to actively consider and begin implementation of a regionalization strategy". Please clarify in the report that "TWDB can pay up to 50% of the study costs (75% in areas which have unemployment rates exceeding the state average by 50% or more and per-capita income is 65% or less than the state average for the last reporting period available)..."

Suggested Response: The following text has been added as the second sentence of paragraph 3 on page 58:

"In some instances, the TWDB can pay for more than 50% of the study costs (75% in areas which have unemployment rates exceeding the state average by 50% or more and per-capita income is 65% or less than the state average for the last reporting period available)."

Region-Specific Study 4: Brazos G Activities in Support of Region C's Water Supply Study for Ellis, Johnson, Southern Dallas, and Southern Tarrant Counties

1. Task 1 of the contract Scope of Work refers to reviewing recent studies. Please provide a general summary of findings regarding recent supply studies and activities in the area since the 2006 Brazos G Regional Water Plan was adopted.

Suggested Response: The following text will be added to Section 1.0:

"A review was conducted of recent water supply studies in the four-county area, with a primary emphasis on Johnson County entities. The overall message from the studies indicates that population and water demand projections are increasing at a faster pace than the Texas Water Development Board (TWDB) projections from the 2006 Plan. The City of Cleburne conducted a study[1] in May 2007 that showed that new industrial development and oil and gas exploration in the area have increased rapidly, which has led to increased water requirements. A study conducted by Johnson County Special Utility District (JCSUD)[2] showed substantially higher projected population and water demands in Year 2030 than TWDB estimates. The JCSUD study was used as a basis for recommending population and water demand updates, which show a 37% increase in projected population in Year 2030 and nearly 40% increase in projected Year 2030 water demands as compared to TWDB projections used in the 2006 Brazos G Plan. Since the 2006 Brazos G Plan, Johnson County Fresh Water Supply District No. 1 has merged with JCSUD and is shown accordingly in the Four County Study report. Additional studies in the area were reviewed and considered including: information from the City of Arlington regarding their wholesale water rate study, and a report developed jointly by the Brazos River Authority and Tarrant Regional Water District in April 2004 entitled "Regional Water Supply and Wastewater Service Study for Johnson and Parker County."

2. Tasks 1 and 4 of the contract Scope of Work refer to reviews of studies and reviews of population projection estimates. While Section 1.0 of the report summarizes the associated activities performed by date, it does not provide a general summary of the findings of these reviews or copies of or summaries of the comments that were provided by Region G consultant as a result of these reviews. Please provide a summary of findings or copies of written comments resulting from this work, for example, as an appendix in the report.

---

[1] *City of Cleburne and Freese and Nichols, "Cleburne Long-Range Water Supply Study- Draft," May 2007.*

[2] *Johnson County Special Utility District and HDR Engineering, Inc, "Evaluation of Additional Water Supplies from the Trinity and Brazos River Basins," December 2006.*

Suggested Response: Copies of selected email correspondence with comments provided by Brazos G consultants have been added as Attachment B-1. An interim progress report update with proposed population and water demand projections was provided to the Brazos G RWPG on October 28, 2008 (as described in Section 1.0). A copy of this presentation has been added as Attachment B-2.

In addition, the following text will be added to Section 1:0:

"The population and water demand recommendations were reviewed for consistency with information provided by each of the Johnson County entities. In some cases, historical population and water use information was provided which was used to assess the reasonableness of extrapolating historical trends to future population and water demands projections. Due to the large number of entities over the study area, there were numerous review processes required to ensure that the recommended population and water demand projections used in the study were consistent with current trends that Johnson County entities are experiencing and their local plans. A copy of selected email correspondence from Brazos G consultants with comments and results of their reviews of Region C's interim analyses and reported results is presented in Attachment B-1."

3. The report does not include or make specific reference to the raw population/water demand projections that were provided from individual water providers in the regional study area (e.g. Alvarado, Burleson, JCSUD, Mansfield, and Venus). Please provide copies of these water planning projections that are generally greater than TWDB population and/or water demand projections. If this raw data was included in another available report, please provide a reference.

Suggested Response: The raw population and water demand projections provided by Johnson County water entities will be provided as Attachment A. Text will be added to Section 1.0 to reference Attachment A. For more information regarding how raw population and water demand projections were used to develop recommended projections, please consult Region C's report entitled "Water Supply Study for Ellis County, Johnson County, Southern Dallas County, and Southern Tarrant County."

4. Please consider adding clarifying language to the Executive Summary that more clearly sets forth the purpose and content of this specific report and that explains the need for a reader to also review the "Region C Water Supply Study for Johnson, Southern Dallas, and Southern Tarrant Counties". Consider including a copy of the associated Region C study Table of Contents for reference, for example, in an appendix.

Suggested Response: The purpose and content of the specific report was included in the draft report in the executive summary as follows:

"The purpose of this study is to review recent growth in the study area, make adjustments to population and demand projections to account for the growth, and update the current and future water plans of the water user groups and wholesale water providers in the study area. This study included conducting meetings and compiling survey data provided by water suppliers regarding their current and future water plans, determining revisions to population and demand projections, and developing a water supply plan for the study area. This report describes the

assistance provided by Brazos G to the study effort, and summarizes the information resulting from the study that is pertinent to the Brazos G Area."

The following additional text will be added to the Executive Summary:

"Those reading this summary should also consult the 'Region C Water Supply Study for Ellis County, Johnson County, Southern Dallas County, and Southern Tarrant County,' which provides the full report and results of the Four County study."

5. Page B-3: Table B-2 is missing from report. Please include in final report.

Suggested Response: Table B-2 (which has been relabeled as Table D-2 in response to renumbering attachments) will be included in the final report.

Region-Specific Study 5: Updated Water Management Strategies for Water User Groups in McLennan County

1. Task 3 of the contract scope of work states that the following sections will be included in the draft and final report: "… purpose of study including how the study supports regional water planning, methodology, results, and recommendations, if applicable." These sections are not present in the draft report. Please include them in the final report.

Suggested Response: The organization of the report has been restructured as follows:

Section 1.0 Introduction has been subdivided into Section 1.1 Purpose of Study and Section 1.2 Methodology. The text states how the study supports regional water planning. Sections 2.0 through 5.0 have been made subdivisions 2.1 through 2.4 of a new Section 2.0 Results, while retaining their original text and organization. Section 5.0 Summary has been titled Section 3.0 Summary and Recommendations with two new subdivisions 3.1 Summary and 3.2 Recommendations, while retaining its original text.

(This page intentionally left blank.)