Buckeye/Sun Valley
Area Drainage Master Study
Preliminary Subsidence Engineering Report

June 2004

Flood Control District of Maricopa County

Prepared for

2801 W. Durango Street
Phoenix, Arizona 85009-6399

Prepared by

PBS&J

7310 N. 16th Street
Phoenix, Arizona 85020

Registered Geologist
11889
FRANK S.
TUREK
Date Signed 6/10/04
Arizona, U.S.A.

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Abbreviations

ADWR – Arizona Department of Water Resources
Buckeye/Sun Valley ADMS – Buckeye/Sun Valley Area Drainage Master Study
BIC – Buckeye Irrigation Company
CAP – Central Arizona Project
District – Flood Control District of Maricopa County
InSAR – Interferometric Synthetic Aperture Radar
RID – Roosevelt Irrigation District

1.0 Introduction

1.1 Purpose and Goals

The purpose of this investigation is to complete geologic, hydrogeologic and engineering assessments of available information to develop a preliminary evaluation of regional land subsidence within the Buckeye/Sun Valley Area Drainage Master Study (Buckeye/Sun Valley ADMS) area. Specifically, the goals are to determine whether:

- There is an on-going process of land subsidence and earth fissuring.
- There is no credible evidence of the potential for land subsidence.
- There is a potential for land subsidence and earth fissures to develop in the future in response to large groundwater withdrawals.

1.2 Project Overview

The Buckeye/Sun Valley ADMS study area is located in Maricopa County, Arizona and is defined by surface drainage basin areas. The study area includes portions of the Town of Buckeye. The Buckeye/Sun Valley ADMS study area (Figure 1-1) extends from the north, where the Hassayampa River enters the valley near U.S. Highway 60, south to the Gila River, a distance of about 37 miles. The width of the study area varies from about three miles in the north to about 15 miles in the south.

The Buckeye/Sun Valley ADMS area can be divided into two portions for this subsidence study. The northern part includes the portion of the study area extending from where the Hassayampa River enters the valley, south to the Roosevelt Irrigation District (RID) canal. There is very little development in this portion of the Buckeye/Sun Valley ADMS area and very little groundwater pumping. The southern portion of the study area extends from the RID canal, south to the Gila River. This portion of the area has been developed for irrigated agriculture and there is extensive groundwater pumping. The hydrogeology of the southern portion is very different from the northern portion.

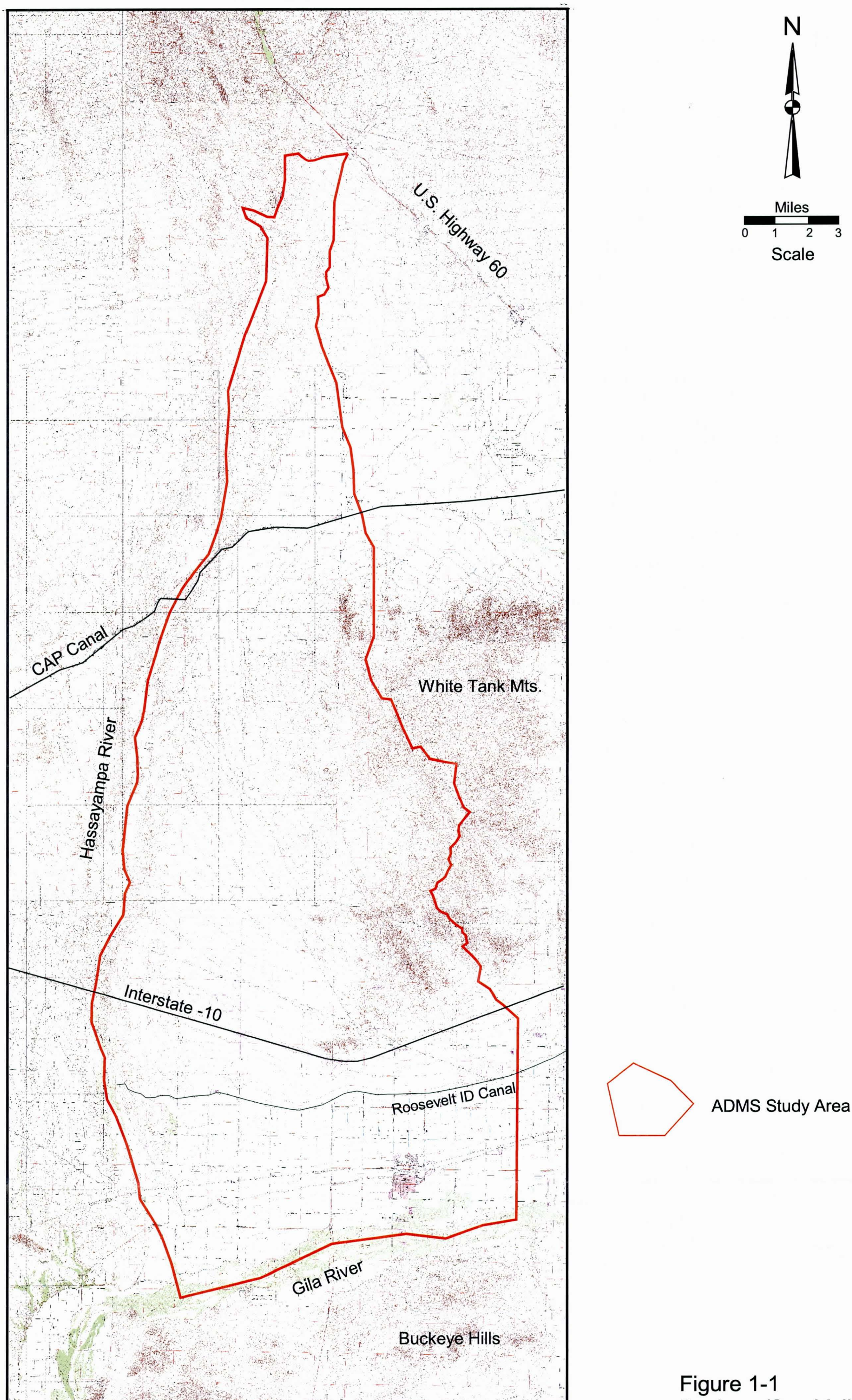

Figure 1-1
Buckeye/Sun Valley
ADMS Study Area

2.0 Land Subsidence

It is necessary to define what regional land subsidence and earth fissuring are before addressing if there is an on-going process of land subsidence in the Buckeye/Sun Valley ADMS area. Land subsidence is a general term that is often used when a decrease in the surface elevation of the land is noted. In some cases, what is called land subsidence is really a local condition that is a result of soil compaction. In other cases the land subsidence is a regional condition that occurs subsequent to the dewatering of an aquifer and can affect a large area. The focus of the Buckeye/Sun Valley ADMS subsidence evaluation is regional land subsidence and the associated earth fissuring..

2.1 Soil Compaction

Soil compaction is a local condition that results in the lowering of the land surface that is often called land subsidence. Soil compaction is commonly observed when a building settles and cracks occur in the foundation or walls of the structure. In other cases, a dip along the top of a long structure such as a canal bank or flood retarding structure berm is noted. Geotechnical investigations are conducted to determine why the local soil conditions changed. Several soil conditions can produce this local lowering of the land surface; including poorly compacted fill, the nature of the minerals of the soil and soil structure.

Poorly compacted fill or soils can often result in soil compaction. Some structures require raising the land surface or installing a building pad. Fill soil materials are imported and compacted to provide a good base for the structure. If the fill is not properly compacted, it can settle over time due to the weight of the structure or due to over-watering of landscaping. In some cases, the fill is properly compacted but the surrounding soil is not. Buildings or structures constructed in agricultural areas may be subjected to soil compaction. Historic agricultural activities disturbed the soils and the weight of the structure and fill can compact the underlying soils. This is a local condition related to the location of the structure and occurs in the top few feet of the soil horizon.

There are locations throughout central Arizona where there are expansive soils. These are also called shrink/swell soils because the clay minerals expand when wet and will shrink or contract when dry. This is because the minerals absorb and lose water molecules in the clay mineral structure and this changes the volume of the minerals. Expansive clay soils can occur over large areas but the soil compaction is noted when it impacts a local structure such as a home, canal, dam or pipeline. Expansive clay soils impacts are a relatively shallow condition because the soil volume changes are related to the depth moisture can penetrate and evaporate in the soil horizon.

There are areas in central Arizona with dispersive soils also called collapsing soils. Dispersive soils are fine-grained soil layers associated with flood deposits on alluvial fans. The soil lattice structure is deposited in a random pattern rather than an aligned pattern where the long axis of the soil particles line up parallel to the land surface. When the dispersive soils are saturated, the soil lattice can compact especially if the weight on the soil is increased by a structure. This type of soil is a concern when it is under a canal or flood retarding structure because percolation from the canal or retained flood water can saturate the soil and the weight of the structure and water can provide the energy to compact the soil. This is a relatively shallow condition that occurs in the soil.

2.2 Regional Land Subsidence

In Arizona, regional land subsidence is associated with groundwater pumping and a regional lowering of the water table. In other parts of the United States, regional land subsidence is associated with groundwater pumping and also the collapse of underground mines and hydrocarbon withdrawals.

In central Arizona, the principal aquifer units are made of unconsolidated or poorly consolidated alluvial sediments that accumulated in the basins over long periods of time. In some locations, these sediments are more than 10,000 feet thick. Groundwater stored in the pore spaces of the alluvium is not compressible and even as the overlying sediments were deposited over time, the groundwater held the pore spaces open. When more groundwater is pumped than is replaced by natural or artificial recharge, the aquifer is overdrafted and the water table declines. Water in the pore spaces is removed and is not replaced. Without the groundwater, the pore spaces are compressed due to the weight of the overlying sediments and there is a regional lowering of the land surface. Regional land subsidence associated with groundwater mining can cover a large area and is deep seated within the stratigraphic sequence.

Several factors influence regional land subsidence, including the amount of water table decline, nature of the sedimentary materials and the amount of time the land has been subsiding.

The depth to groundwater varies throughout central Arizona from just below the surface along the Gila River near Buckeye to more than 600 feet below the surface in north Scottsdale. The trigger mechanism for land subsidence is not the depth to groundwater but rather the distance that the water table has declined. Studies have demonstrated that land subsidence is likely to occur in unconsolidated sedimentary materials if the water table has declined more than 100 feet (Gelt, 1992).

The nature of the sedimentary material influences the amount of land subsidence. Silt and clay sediments have a porosity that averages about 40 percent while sand has an average porosity of 30 percent and sand and gravel mixes has a porosity of about 20 percent (Driscoll, 1986). At first this may seem reversed because sand and gravel has large pore spaces that can easily be seen while silt and clay appear to be a solid mass. However, silt and clay have many small pores between the sediment grains and these total a large portion of the volume of the sediments. When the water table declines, sediments with the greatest amount of pore space are the most susceptible to compaction and most likely to produce land subsidence. In central Arizona where there has been significant water table decline and where there is a substantial thickness of fine-grained silt and clay sediments, a large amount of land subsidence has been recorded. In the area east of the White Tank Mountains in the Agua Fria River basin, the land has subsided about 18 feet (Leake, 1997).

The period of time the land has been subsiding will influence the total amount of land subsidence. Regional groundwater pumping can lower the water table five to 10 feet per year. This can produce a large change in the water table depth in a relatively short period of time. Land subsidence is a slow process and the land surface changes will occur over a long period of time once subsidence begins. Land subsidence is a process that is not easily slowed or reversed. Once the water table is lowered and compaction is initiated, the pore space is lost. Recharge can not cause the sediments to swell and recover the pore space. Recharge can reduce or eliminate water table decline and this can reduce the amount of land subsidence that may occur in the future but once the land surface has been lowered it will remain lowered.

Land subsidence is a geologic hazard and can cause many problems particularly in facilities designed to function under gravity flow conditions such as storm drains and sanitary sewers. Land subsidence can lower the hydraulic gradient and reduce the conveyance capacity. Subsidence can also increase the gradient and produce flow velocities in pipelines and channels that exceed the recommended velocity. Land surveys are often impacted by land subsidence because the bench mark level stations used in topographic or elevation surveys will change and old surveys rapidly become obsolete. Land subsidence can impact flood control structures including flood control dams, basins, channels and floodways

2.3 Earth Fissuring

Earth fissures are a geologic hazard associated with land subsidence. Earth fissures are not the desiccation cracks that form in mud when it dries. Earth fissures are large, deep structural features. Commonly what is called an earth fissure is really a fissure gully, the erosion remnants of an earth fissure. When an earth fissure forms, it can be one inch wide but very long and extend several hundred feet below the surface. If the fissure intersects a surface drainage channel, storm water will flow into the fissure and erode it. The result is the large fissure gully shown in most photographs.

Earth fissures form due to horizontal and vertical stresses that occur in the sediments as a result of land subsidence. Land subsidence does not occur equally over the large area. The character of the subsurface sedimentary material changes from coarser near the mountains to finer toward the center of the basin. Finer materials have greater pore space and will compact more than the coarser materials. Consequently, the materials in the center of the basin will subside more than the edges of the basin with an equal amount of water table decline.

Another factor is the total water table decline because the amount of water table decline is greatest near the center of the concentration of pumping. Land subsidence will be initiated closer to the center of the decline and will have continued for a longer period than the land around the periphery of the water table decline. These conditions produce differential compaction and this causes a horizontal component of stress in the sediments. Buried bedrock ridges or structures such as the Luke Salt Dome in the West Salt River Valley will also produce differential compaction because the thickness of sediments that overlies these structures is less than the thickness of the sediments that surrounds them. The horizontal stress builds until the earth fissure forms, extending from several hundred feet underground to the surface.

Very few earth fissures have a vertical movement component. An example of a fissure with vertical movement is the Picacho fissure east of Eloy (Holtzer, 1984). The vertical impacts can be seen where the fissure crosses Interstate 10. Most of the earth fissures in the Phoenix area do not have a vertical component.

Earth fissures can impact a wide range of structures, especially if they erode into fissure gullies. Fissures and fissure gullies can crack water features such as canals, drainage channels and flood retarding structures causing them to leak. Fissures can provide a path for surface pollution to reach groundwater and can lead to contamination of water resources.

If an earth fissure forms it does not mean the land can not be used. The general design procedure to mitigate earth fissure impacts includes over excavation of the fissure area, installing a geofabric liner to prevent erosion of soils down the fissure, filling the excavation with a compacted engineered fill and designing the area so drainage flows away from the fissure area to prevent the formation of a fissure gully. Construction of storm water detention or retention structures should be avoided above an earth fissure. Conveyance channels can be constructed if sealed to prevent seepage into the engineered fill.

3.0 Information Sources

Existing records and published reports provided the foundation for these regional land subsidence analyses. The following is a summary of the information sources researched.

3.1 Study Area Wells

The Arizona Department of Water Resources (ADWR) maintains the well registration database and water level measurement information for Arizona. The well investigations included research of the ADWR well database records updated in June 2003 (ADWR, 2003). The well registration database includes the well location, registration number, owner, depth drilled, water production, well construction data and if there is a driller's log on file.

Figure 3-1 shows the Townships and Ranges in the study area. Using this map as the well location key, the ADWR records show that there are 1,175 registered wells in and around the Buckeye/ Sun Valley ADMS study area (Table 3-1). The records show 1,013 wells are located in the southern portion of the study area in the Ranges in Townships 1 North and 1 South, the agricultural area. The 162 other wells are located in the Ranges in Townships 2 through 6 North in the relatively undeveloped northern portion of the study area.

Registration records were used to identify the deepest wells with driller's logs. Information contained on the logs included a record of the subsurface materials penetrated during well drilling. This was used to interpret the character of the subsurface materials in the area, thickness of the sediments and depth to bedrock. ADWR records were researched to obtain groundwater table information. ADWR periodically measures the depth to water in different regions of Arizona.

3.2 Interferograms

Interferograms are images produced by interpreting two Interferometric Synthetic Aperture Radar (InSAR) satellite images. InSAR is capable of remotely sensing small changes in the elevation of the land surface. Interferograms can show vertical changes in the land surface as small as 3.0 centimeters (about 1.2 inches). The period between InSAR images can be a few weeks or a few months. A longer period between images has the greatest potential to show land subsidence impacts.

While interferograms are a powerful new tool to identify areas of land subsidence, they do have limitations. The area included in a single pixel or picture element on an InSAR image may be as small as tens of thousands of square feet. An area of 10,000 square feet is equal to about 0.22 acres. This means interferograms are useful tools to identify large areas where land subsidence may be occurring.

Another consideration is that InSAR images are collected from space and atmospheric interference can influence the image and the interferogram produced using the image. Atmospheric interference can produce conditions that resemble land subsidence in the interferogram. This is why a single interferogram should not be used as the sole source of information to identify potential land subsidence. Additional interferograms, preferably with longer periods between InSAR images than the period in the interferogram with the suspected land subsidence, should be viewed to verify land

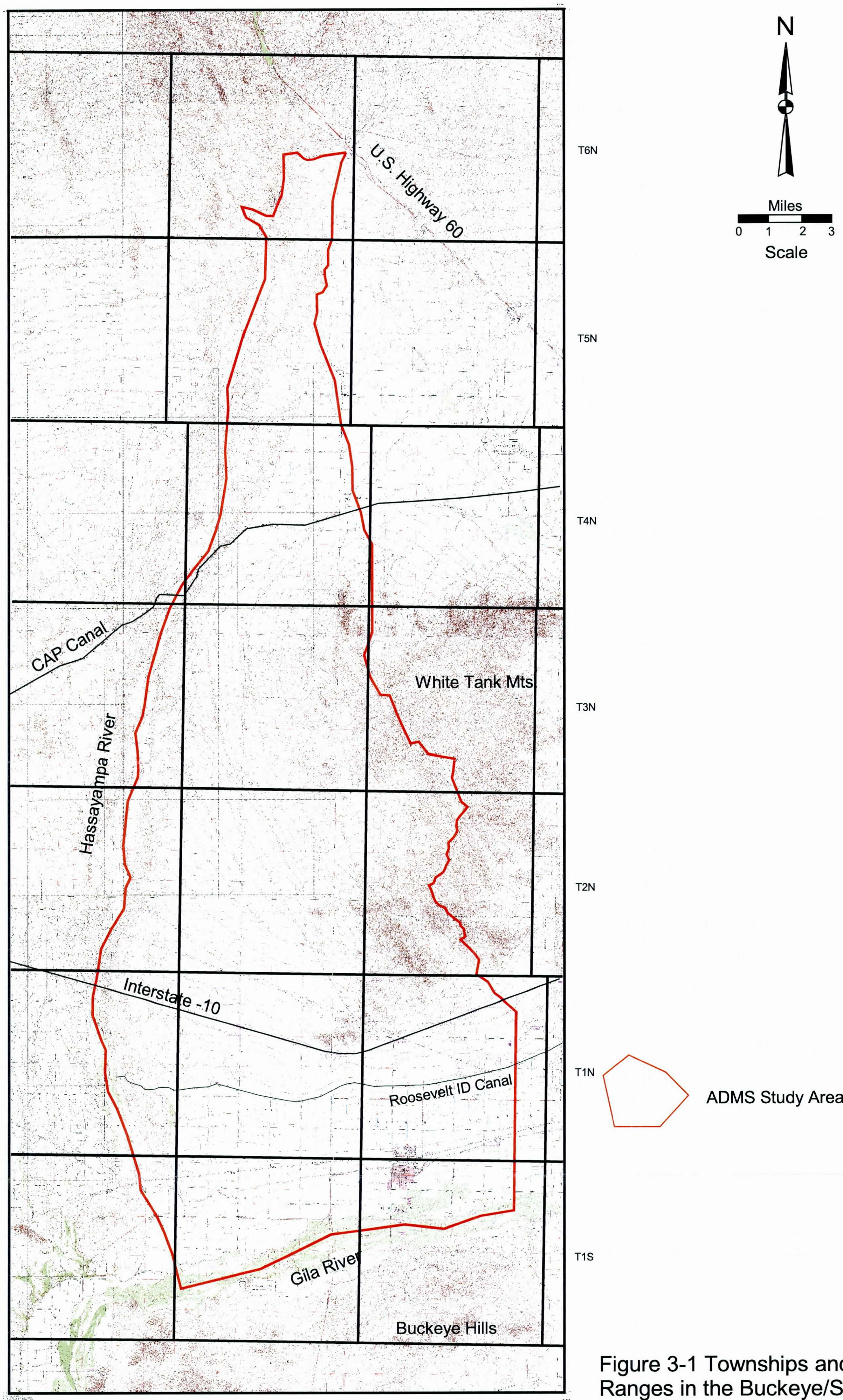

Figure 3-1 Townships and Ranges in the Buckeye/Sun Valley ADMS Study Area

Table 3-1 Study Area Well Summary

Township and Range	Domestic or Public Supply	Irrigation	Stock	Piezometer or Monitoring	Geotech Mineral Cathodic	Drainage	Abandoned	Total Registered Wells
T1S, R3W	63	13	11	68	12	13	12	192
T1S, R4W	124	29	13	32	11	7	9	225
T1S, R5W	27	13	0	39	4	1	8	92
T1N, R3W	115	29	5	17	8	0	5	179
T1N, R4W	118	65	8	4	1	0	2	198
T1N, R5W	70	46	4	1	0	0	6	127
T2N, R3W	0	0	0	0	0	0	0	0
T2N, R4W	5	1	1	2	0	0	3	12
T2N, R5W	14	0	1	0	0	0	0	15
T3N, R3W	0	0	0	0	0	0	0	0
T3N, R4W	4	0	2	2	0	0	1	9
T3N, R5W	1	2	1	1	0	0	0	5
T4N, R3W	0	0	0	0	0	0	0	0
T4N, R4W	6	1	7	2	2	0	3	21
T4N, R5W	0	0	0	0	0	0	0	0
T5N, R4W	6	0	0	0	0	0	2	8
T6N, R4W	62	7	6	4	12	0	1	92
					Total wells in study area =			1,175

subsidence. It is also essential to verify if regional water table decline conditions exist that could be producing land subsidence.

Interferograms used in this Buckeye/Sun Valley ADMS subsidence evaluation were provided by ADWR. Dr. Sean Buckley of the University of Texas - Austin produced the interferograms for ADWR. The four images used in this evaluation are:

- Figure 5-2 June 8, 1998 to May 8, 2000, a 700-day interferogram
- Figure 5-3 December 30, 1996 to November 30, 1998, a 700-day interferogram
- Figure 5-4 December 30, 1996 to December 20, 1999, a 1,085-day interferogram
- Figure 5-5 March 10, 1997 to October 30, 2000, a 1,330-day interferogram

Disturbed ground with an uneven surface is shown as a fine-grained multi-colored area on the four interferograms. The Hassayampa River is not a smooth even surface and is a very distinct disturbed ground pattern on the four interferograms. Agricultural areas are also disturbed ground and the farmed lands in the RID, Buckeye Irrigation Company (BIC) and other irrigation districts along the Gila River can be readily identified in the four interferograms. ADWR added bedrock areas to the interferograms and these are represented by the stippled pattern on Figures 3-2 to 3-5.

3.3 Previous Hydrogeologic Reports and Subsidence Studies

The amount of geologic, hydrologic and groundwater information available for the Buckeye/Sun Valley ADMS area varies greatly. In the southern portion of the Buckeye/Sun Valley ADMS area, south of the RID canal, there are many wells, groundwater level measurements and studies that have defined the surface and subsurface geology. ADWR has a groundwater model that projects the future water table impacts in this area.

There is very little information available for northern part of the Buckeye/Sun Valley ADMS area. Very few wells exist and only a few studies have been completed. These studies were done to identify the water resources that may be available to support future land development projects. ADWR, the Town of Buckeye and the major landowners in this northern area are teaming to develop a groundwater model that ADWR will use to predict future water table changes and areas where the potential changes may produce the conditions that could result in land subsidence. This groundwater model may not be completed until Spring 2005. ADWR has collected the geologic and hydrologic studies that contain information that can be used in the proposed groundwater model. These studies were reviewed as a part of the data collection for this Buckeye/Sun Valley ADMS subsidence evaluation.

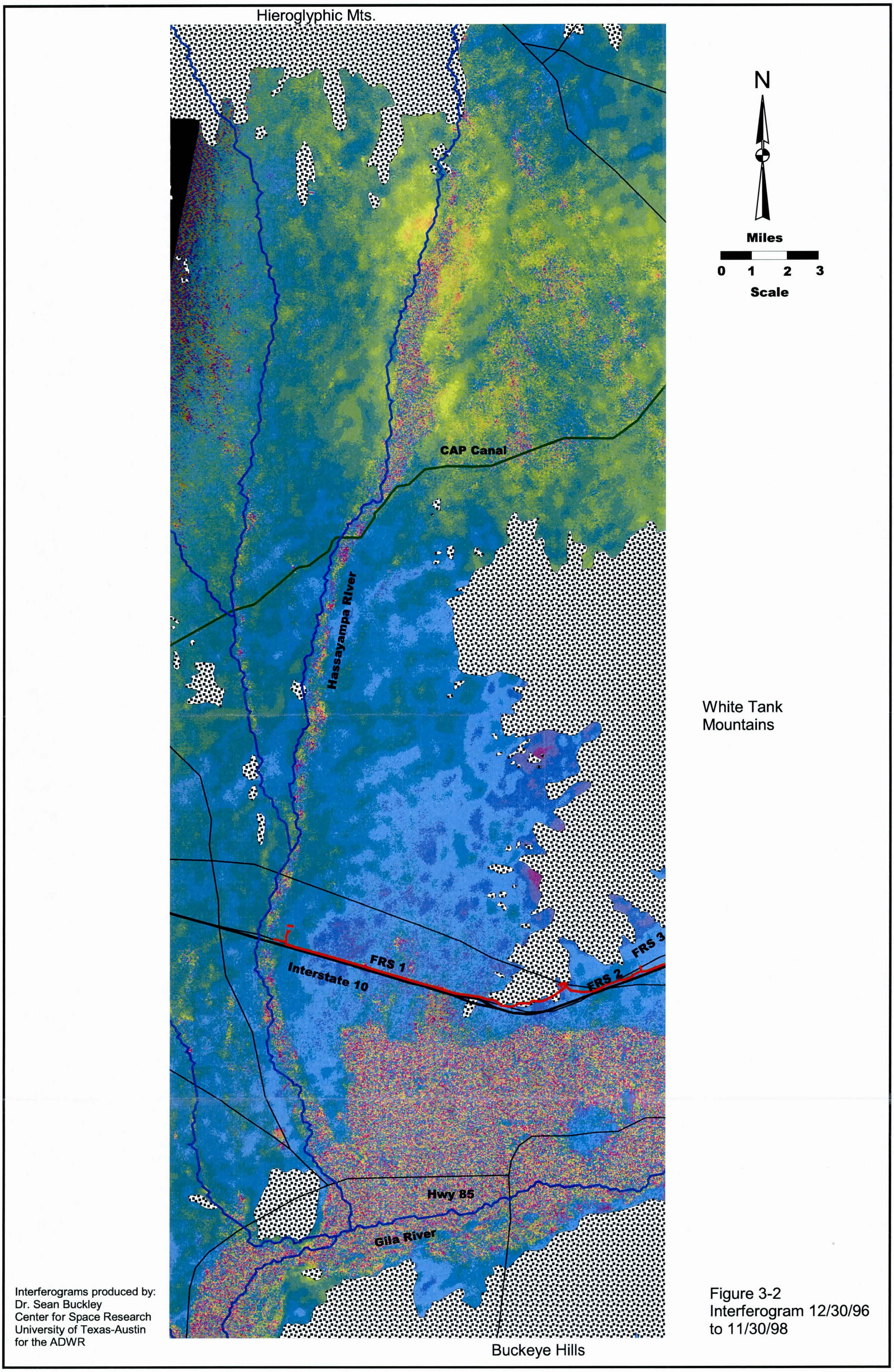

Figure 3-2
Interferogram 12/30/96 to 11/30/98

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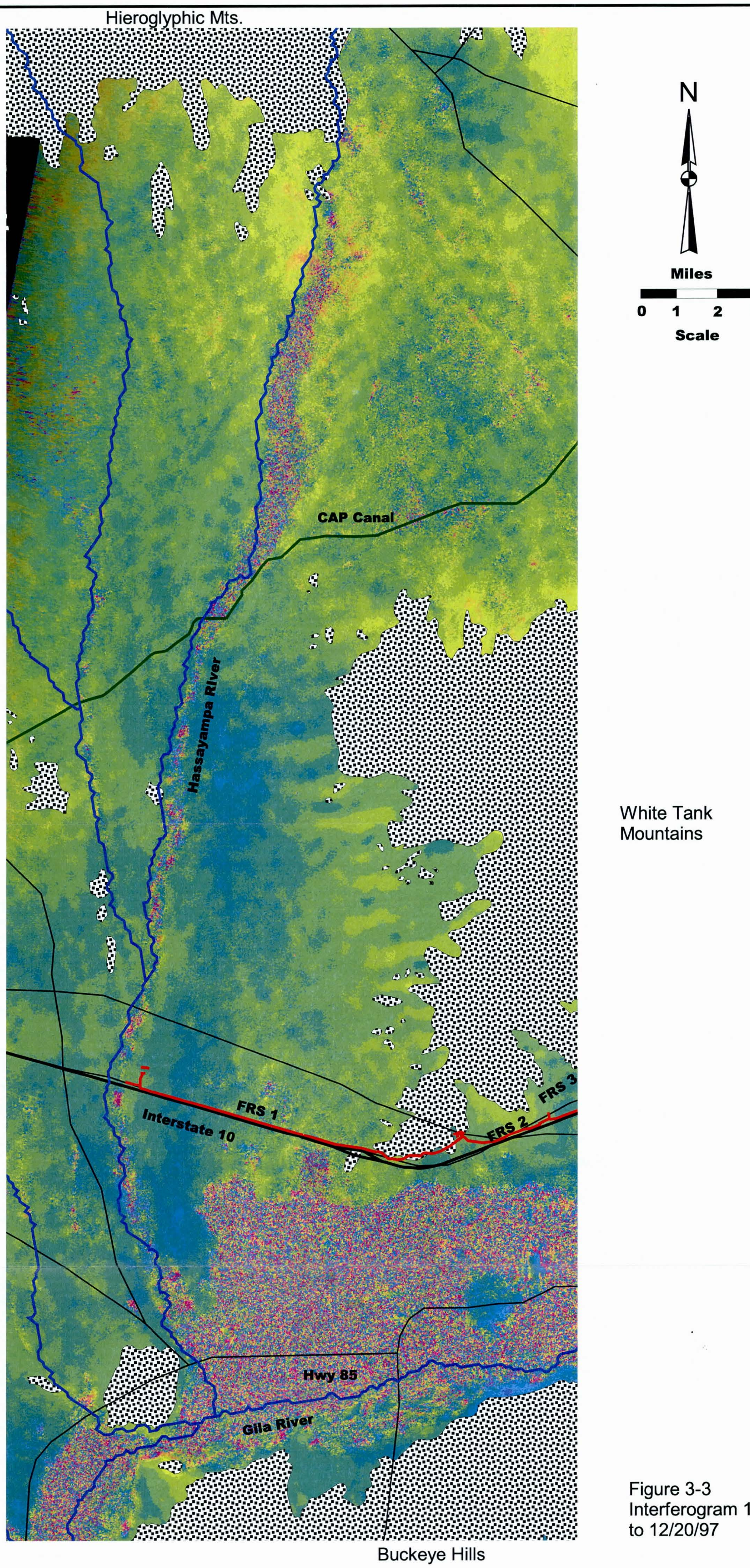

Interferograms produced by:
Dr. Sean Buckley
Center for Space Research
University of Texas-Austin
for the ADWR

Figure 3-3
Interferogram 12/30/96
to 12/20/97

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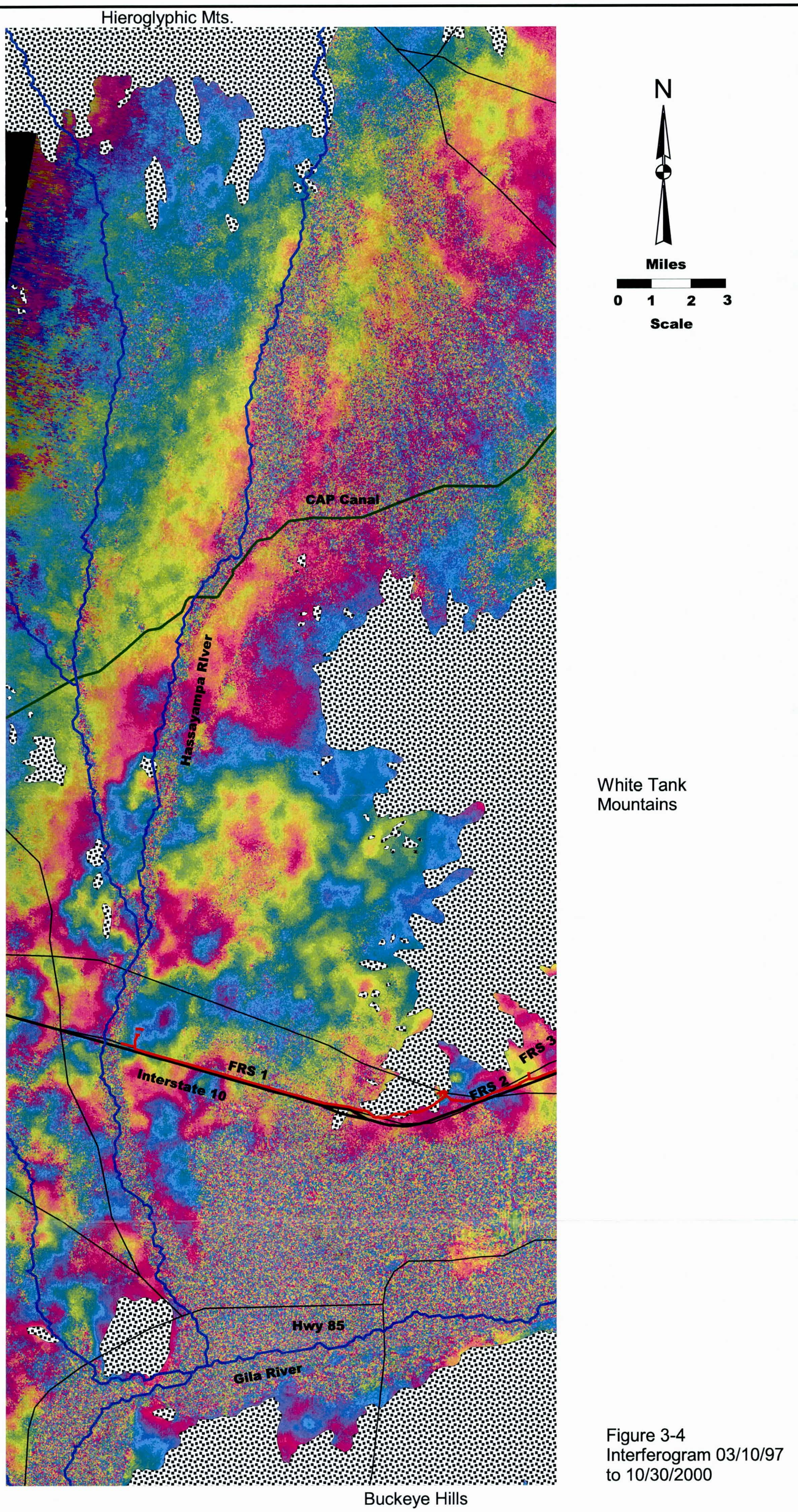

Interferograms produced by:
Dr. Sean Buckley
Center for Space Research
University of Texas-Austin
for the ADWR

Figure 3-4
Interferogram 03/10/97
to 10/30/2000

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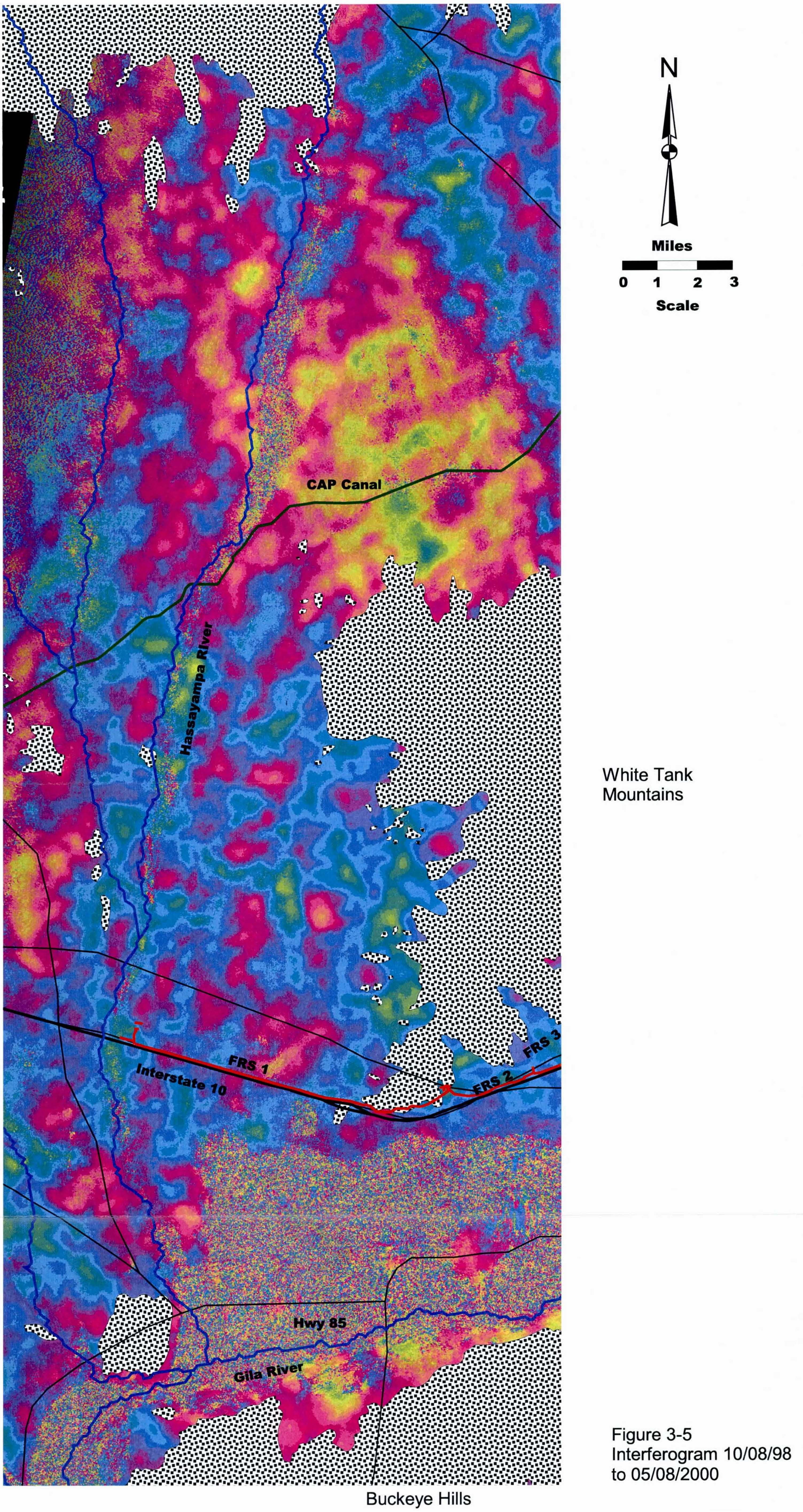

Interferograms produced by:
Dr. Sean Buckley
Center for Space Research
University of Texas-Austin
for the ADWR

Figure 3-5
Interferogram 10/08/98
to 05/08/2000

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4.0 Regional Geology

Regional geologic interpretations are needed to evaluate if there is an on-going process of land subsidence and if there is a potential for land subsidence and earth fissures to develop in the future in response to a significant water table decline.

4.1 Physiography

The major physiographic features in the Buckeye/Sun Valley ADMS area include the White Tank Mountains and the Hieroglyphic Mountains forming the topographic high areas and the Hassayampa and Gila Rivers that form the major drainage channels (Figure 4-1).

The regional land slope in the Buckeye/Sun Valley ADMS area is from the north to the south. The land surface elevation of the basin ranges from an elevation of 1,900 feet where the Hassayampa River enters the study area to about 800 feet where the Hassayampa River joins the Gila River. This slope averages about 30 feet per mile. In the central part of the Buckeye/Sun Valley ADMS area, the land slopes west from the White Tank Mountains toward the Hassayampa River and the cross slope averages about 75 feet per mile.

The portion of the Buckeye/Sun Valley ADMS area that extends from the east boundary of the Buckeye/Sun Valley ADMS area west to the Hassayampa River and extends from the White Tank Mountains south to the Gila River has a land slope that follows the Gila River from the east to the west. The land slope averages about 6 feet per mile. The cross slope from the White Tank Mountains south to the Gila River averages about 30 feet per mile.

This information shows that the regional and local land slopes in southern area are much more level than the northern area.

The physiography of the area and information shown on U.S. Geological Survey 7.5 Minute Quadrangle maps can not be used to identify areas where there may be land subsidence. However, in some instances the topography can provide information to infer where there are buried structures that could lead to the formation of earth fissures. An example is the small hills between Luke Air Force Base and the Agua Fria River in the West Salt River Valley. These hills would normally not occur in the middle of an alluvial plain but they are a result of the buried Luke Salt Dome and the hills infer where the top of the salt dome is located. This buried structure in the West Salt River Valley land subsidence area has resulted in the formation of earth fissures. There are no topographic or physiographic surface features in the Buckeye/Sun Valley ADMS area that infer that there are buried bedrock features or other structures that could lead to the formation of earth fissures should regional land subsidence occur.

4.2 Bedrock Geology

Locations where bedrock is exposed at the surface in the Buckeye/Sun Valley ADMS area are shown on Figure 4-1. This bedrock is composed of metamorphic and igneous rocks (Wilson, et. al., 1957). Bedrock is hard and stable; it does not have pore spaces that can be compressed and contains very little groundwater except where the water can gather in fractures in the rock. Surface exposures of

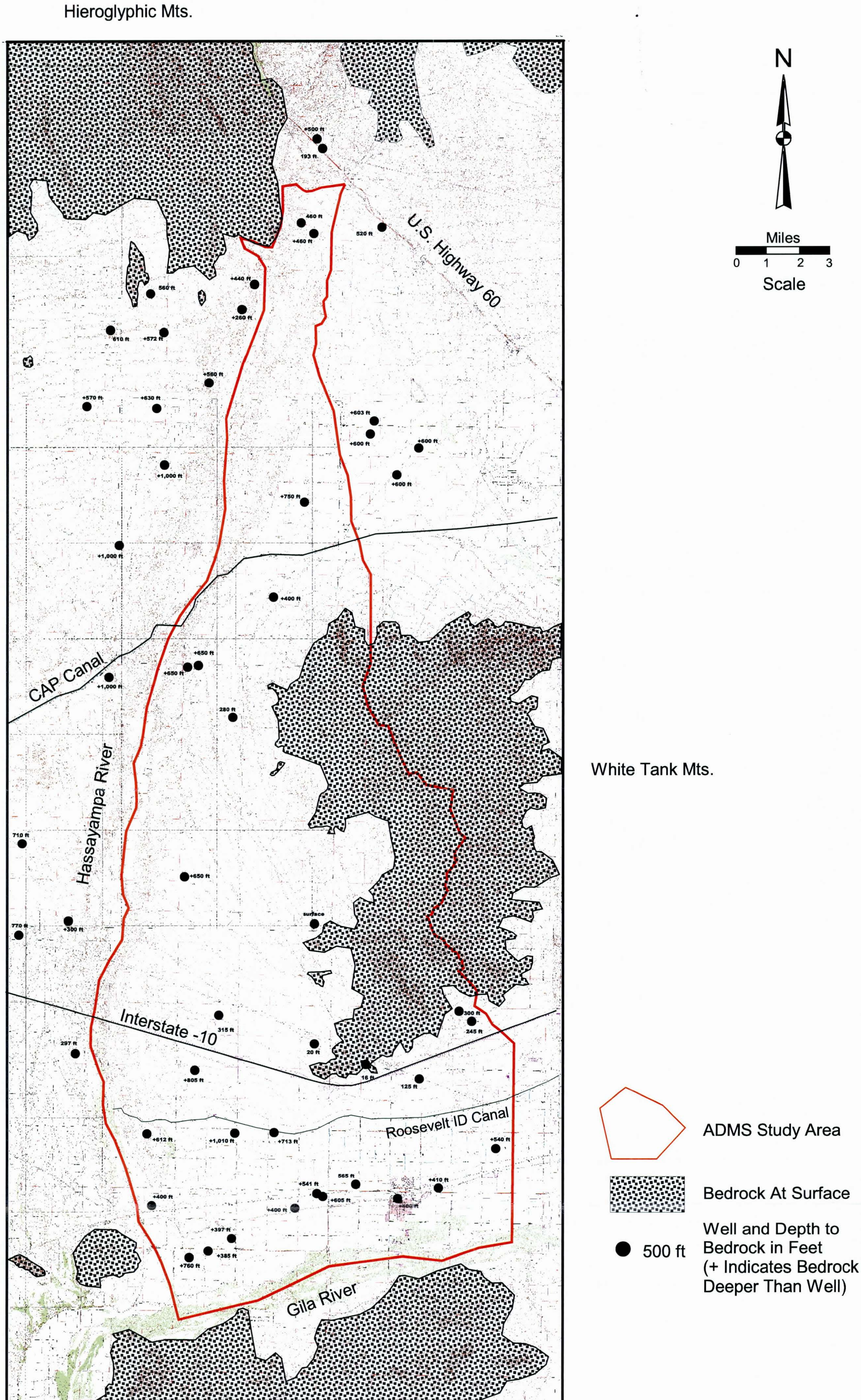

Figure 4-1
Bedrock Geology

bedrock represent locations where land subsidence and earth fissures will not occur now or in the future.

The non-shaded portions of Figure 4-1 are where the sedimentary materials cover the bedrock. ADWR well records were researched to identify the wells with driller's logs on file. However, most of the wells in the Buckeye/Sun Valley ADMS study area do not have driller's logs on file. The available logs were reviewed to verify if the well was drilled to bedrock and the depth where bedrock was encountered. The well data on Figure 4-1 shows the depth to bedrock. A "+" is used to indicate wells that were not drilled deep enough to encounter bedrock and, therefore, the depth to bedrock is greater than the recorded depth of the well.

The driller's log data shows the depth to bedrock in the southern portion of the Buckeye/Sun Valley ADMS study area is deeper than 500 feet. ADWR projects that the depth to bedrock in the southern portion is more than 1,000 feet (Corkhill, et. al., 1993).

The depth to bedrock in the northern portion of the Buckeye/Sun Valley ADMS area is greater than in the southern portion. West of the Hassayampa River there is a well 1,000 feet deep that did not encounter bedrock. In the area between the White Tank Mountains and the Hieroglyphic Mountains, there are wells drilled to more than 700 feet deep and did not encounter bedrock. Other estimates place bedrock between 1,200 and 1,600 feet below the surface (WRA, 1991). There is limited geologic information available for this northern portion of the Buckeye/Sun Valley ADMS area to verify the depth to bedrock. A goal of the proposed ADWR groundwater model is to develop the information needed to better define the depth to bedrock.

Knowledge of the depth to bedrock is important because it defines the thickness of sedimentary materials in an area that could be dewatered and subjected to land subsidence. In central Arizona it has been observed that earth fissures often form where the depth to bedrock is less than 1,200 feet. Based on the existing information, it appears that the majority of the Buckeye/Sun Valley ADMS study area overlies regions where the bedrock is less than 1,200 feet beneath the surface.

The buried bedrock is not a smooth surface, it more resembles the general shape of the mountains with peaks, ridges and valleys and has a basin border fault where the alluvium depth to bedrock increases rapidly. In areas where there is a substantial amount of land subsidence, buried bedrock features can provide the conditions required for earth fissures to form. Geophysical and gravity investigations can be used to identify structural features on the buried bedrock surface. However, there is insufficient information available at the present time to accurately predict the configuration of the buried bedrock surface in the Buckeye/Sun Valley ADMS area.

4.3 Sedimentary Geologic Units

The size and shape of the sediments that form the sedimentary geologic units are dependent on the conditions at the time the sediments were eroded and transported to the location where they are deposited. Sedimentary materials in the southern part of the Buckeye/Sun Valley ADMS study area were transported over geologic time from the east. Most of these materials were transported long distances and in an environment that allowed medium and fine-grained sediments to be deposited.

Sediments in the northern portion of the Buckeye/Sun Valley ADMS study area were transported a shorter distance and are generally coarser grained than those in the southern part.

Table 3-1 shows there are about 1,013 wells in the southern portion of the Buckeye/Sun Valley ADMS study area and the information contained in the driller's logs helps to define the subsurface geology. In addition, several reports help to define the geology and hydrology in this portion of the study area. The sediments in the southern portion of the Buckeye/Sun Valley ADMS area are divided into three units based on the average size of the sediments (Montgomery, 1988); Upper Alluvial Unit, Middle Alluvial Unit and Lower Alluvial Unit. These three units occur throughout the basins in the central Arizona area including the Agua Fria basin east of the White Tank Mountains, the Scottsdale area in the Paradise Valley Basin and in the Mesa-Chandler-Gilbert area of the East Salt River Valley. The sedimentary and hydrologic characteristics of these three units are well documented.

The Upper Alluvial Unit is a mixture of sediments that range in size from gravel to clay. ADWR (Corkhill, et. al., 1993) projects this unit is about 100 to 200 feet thick. The Middle Alluvial Unit lies beneath the Upper Unit. ADWR projects the Middle Unit is unit ranges from 200 to 400 feet thick. Driller's logs show the Middle Alluvial Unit contains fine-grained sediments with the majority of sediments classified as clay to fine sand. In some reports the Middle Alluvial Unit is called the Middle Fine-Grained Unit due to the nature of the sediments. The Lower Alluvial Unit is beneath the Middle Alluvial Unit and the bottom of the Lower Alluvial Unit rests on bedrock. The Lower Alluvial Unit is coarse-grained and contains primarily sand and gravel sized sediments. ADWR projects the Lower Alluvial Unit is about 500 feet thick in the southern part of the study area.

The sedimentary sequence in the northern part of the Buckeye/Sun Valley ADMS area is generally coarser grained than in the southern portion of the area. The sediments were classified as a rubble zone of poorly sorted conglomerate (WRA, 1991) and coarse grained sand (Halpenny, 1998). The differentiation between sedimentary layers is less defined in the northern portion than in the southern portion where there are three sedimentary units. Halpenny (1988) said both the older and younger sediment layers are comprised of the coarse-grained sand.

4.4 Geologic Summary

The following is a summary of the regional geology as related to the potential for land subsidence and earth fissures:

- Surface exposures of bedrock represent areas where land subsidence and earth fissures will not occur.
- The physiography of the land surface and available subsurface information does not indicate if the buried bedrock surface is irregular and could induce earth fissure formation if significant land subsidence occurs.
- The sediments in the southern portion of the Buckeye/Sun Valley ADMS area contain fine-grained materials that could be subject to compaction if there is a significant water table decline.
- The sediments in the northern portion of the Buckeye/Sun Valley ADMS area are generally coarse-grained and while they could be subject to compaction if there is a significant amount

of water table decline, the low pore space volume in these sediments would result in less land subsidence than if fine-grained sediments were present.

5.0 Groundwater Hydrology

The groundwater hydrology of an area is the controlling factor in land subsidence because the water table must be declining and have declined at least 100 feet to initiate land subsidence (Gelt, 1992). Figure 5-1 presents water level data throughout the Buckeye/Sun Valley ADMS area. These wells were selected because they have recent water level measurements collected in 2001 and have a history of water level measurements.

5.1 Water Table Conditions

The southern portion of the Buckeye/Sun Valley ADMS area is called a "water logged area" because the groundwater table is very close to the land surface (Montgomery, 1988). There are 13 dewatering wells in this area that pump groundwater, not for irrigation but to lower the water table to prevent the shallow groundwater from impacting the roots of crops. Figure 5-1 shows that the depth to the water table in the southern area ranges from 138.5 feet near the White Tank Mountains to 16.25 feet near the Gila River. The channel of the Gila River is lower than the banks and the water table is at the surface in the channel.

Several geologic and hydrologic factors produce the shallow groundwater and water logging. There is a narrow gap between the White Tank Mountains and the Buckeye Hills (Figure 5-1) and in this narrows area, bedrock is closer to the surface. All the groundwater moving down gradient from the entire Salt River Valley exits the basin at this point as does all the groundwater from the Gila River basin. The narrow area restricts the cross-section of sediments through which groundwater can flow, forcing the groundwater closer to the surface. Additional water is added to the system by the RID and BIC crop irrigation. The RID imports effluent from the 23rd Avenue Wastewater Treatment Plant and from wells located east of the Agua Fria River. The BIC imports water provided by Salt River Project and effluent purchased from the 91st Avenue Wastewater Treatment Plant. Most of this imported water is used by the crops but a portion sinks into the ground and adds to the water logging condition. Sediments in this area are fine-grained and this restricts the movement of groundwater through the sediments so the area can not readily drain. The slope of the land and the water table are relatively flat in this area and this reduces the speed that groundwater can travel through the sediments.

In the northern portion of the Buckeye/Sun Valley ADMS study area, the water table is much farther beneath the land surface. Depths to groundwater range from 87.2 feet near the Hassayampa River to as much as 414.9 feet north of the White Tank Mountains. There are several factors that result in this deep water table. There is no bedrock restriction or large quantity of groundwater flowing through this area, the sediments are coarse-grained and the water table gradient is steeper than in the southern portion of the area thus groundwater can move faster. The elevation of the land is higher in the northern end and when going from south to north, the land surface elevation increases much faster than the water table elevation. This results in a greater depth to groundwater.

5.2 Historic Water Table Changes

Potential water table changes in the Buckeye/Sun Valley ADMS area were evaluated to verify if the water table has declined 100 feet or more.

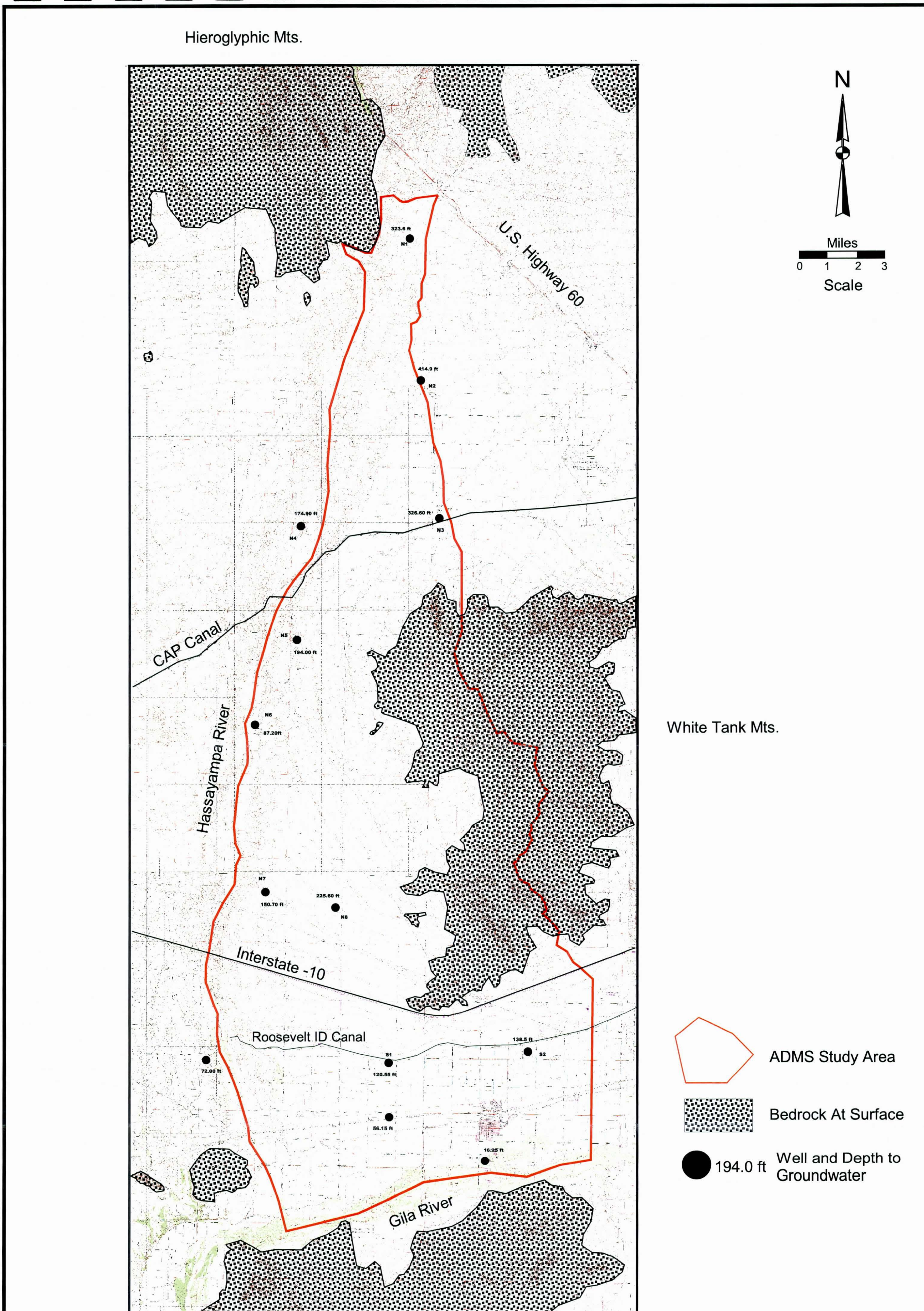

Figure 5-1
2001 Depth to Groundwater

Table 5-1 Southern Area Groundwater History

Well S1 Well B-01-03 21DBB Date	Depth to Water (Feet)	Depth Change (Feet)		Well S2 Well B-01-04 27ABBB Date	Depth to Water (Feet)	Depth Change (Feet)
Jan-56	137.30	0.00		Jan-56	134.39	0.00
Jan-57	138.15	-0.85		Jan-57	131.79	2.60
Jan-58	139.86	-2.56		Jan-58	134.82	-0.43
Feb-59	152.13	-14.83		Feb-59	136.58	-2.19
Feb-60	145.35	-8.05		Feb-60	140.74	-6.35
Mar-61	146.30	-9.00		Mar-61	146.31	-11.92
Jan-62	147.68	-10.38		Jan-62	142.92	-8.53
Jan-64	155.92	-18.62		Feb-63	145.74	-11.35
Feb-65	156.56	-19.26		Jan-64	143.98	-9.59
Jan-66	161.25	-23.95		Feb-65	143.45	-9.06
Feb-67	160.60	-23.30		Jan-66	145.74	-11.35
Jan-68	158.20	-20.90		Feb-67	142.30	-7.91
Jan-69	153.20	-15.90		Jan-68	138.14	-3.75
Jan-70	158.20	-20.90		Jan-70	136.00	-1.61
Feb-71	155.20	-17.90		Jan-72	159.50	-25.11
Feb-72	150.00	-12.70		Feb-73	132.50	1.89
Feb-73	151.80	-14.50		Jan-74	134.30	0.09
Jan-74	147.20	-9.90		Jan-75	139.80	-5.41
Jan-75	152.10	-14.80		Jan-76	139.10	-4.71
Dec-76	164.90	-27.60		Dec-76	137.00	-2.61
Feb-78	156.20	-18.90		Feb-78	136.40	-2.01
Mar-78	165.60	-28.30		Dec-78	135.20	-0.81
May-78	167.00	-29.70		Jan-79	134.20	0.19
Dec-78	165.80	-28.50		Jan-79	132.20	2.19
Jan-79	165.40	-28.10		Feb-79	131.40	2.99
Jan-79	161.60	-24.30		Apr-79	127.80	6.59
Feb-79	162.20	-24.90		Feb-81	133.50	0.89
Jan-80	160.10	-22.80		Jan-82	127.50	6.89
Feb-81	159.50	-22.20		Dec-82	120.30	14.09
Dec-82	159.50	-22.20		Dec-83	121.40	12.99
Dec-83	151.70	-14.40		Dec-84	120.30	14.09
Dec-84	147.40	-10.10		Jun-85	137.50	-3.11
Jun-85	151.20	-13.90		Dec-85	119.70	14.69
Dec-85	148.80	-11.50		Jun-86	125.50	8.89
Jan-86	148.50	-11.20		Dec-86	127.80	6.59
Jun-86	147.70	-10.40		Jun-87	127.70	6.69
Dec-86	148.80	-11.50		Dec-87	125.70	8.69
Jun-87	147.30	-10.00		Jun-88	132.90	1.49
Dec-87	148.30	-11.00		Dec-88	123.80	10.59
Jun-88	148.80	-11.50		Nov-89	129.10	5.29
Dec-88	148.30	-11.00		Nov-90	127.90	6.49
Nov-89	148.50	-11.20		Nov-91	129.70	4.69
Nov-90	147.10	-9.80		Nov-92	127.80	6.59
Dec-91	147.80	-10.50		Dec-93	129.60	4.79
Nov-92	145.70	-8.40		Nov-94	129.40	4.99
Dec-93	144.20	-6.90		Jun-95	157.10	-22.71
Nov-94	146.90	-9.60		Dec-95	126.50	7.89
Dec-95	145.40	-8.10		Oct-96	125.20	9.19
Oct-96	146.10	-8.80		Nov-97	122.30	12.09
Nov-97	139.80	-2.50		Dec-98	120.90	13.49
Dec-98	133.80	3.50		Nov-99	124.40	9.99
Nov-99	135.50	1.80		Nov-00	121.70	12.69
Nov-00	137.20	0.10		Oct-01	120.55	13.84
Oct-01	138.50	-1.20				

Depth change calculated from initial depth to water measurement.

In the southern portion of the study area, Figure 5-1 shows that several of the wells in the water logged area have a depth to water less than 100 feet. These wells are in an area where there is no substantial water table decline that would indicate there is a potential for on-going land subsidence. There are two wells in the southern portion of the study area where the 2001 depth to groundwater is greater than 100 feet. These warranted additional investigation. Table 5-1 presents the 45 years of water table history for these two wells (S1 and S2 on Figure 5-1) obtained from ADWR records. The water table history verifies that in the southern area the water table has been very stable. The water table in these wells fluctuated during this period declining almost 30 feet, but then recovered. These wells define additional areas where there is no substantial water table decline that would be an indicator for on-going land subsidence.

The depth to the water table is much greater in the northern portion of the Buckeye/Sun Valley ADMS area than in the southern portion, but the water table has also been relatively stable. The water table history for eight wells (N1 to N8 Figure 5-1) in the northern portion is presented on Table 5-2. The period of water table records for these wells is generally shorter than for wells in the southern portion of the study area because there has not been very much historic development in the northern portion. Some the wells were drilled during the 1980's as a part of the original Sun Valley development.

The ADWR water table data show the water table was stable or rose in five of the eight wells. There was a slight decline in three wells but the water level depth change was very small, ranging from 4 feet to 11 feet. Well N4 appears to have anomalous data for 1987 and 1988. There is a significant decline in that well in those two years but a similar decline was not measured in N3, the closest well with water level data in the same period. This is decline may not be a change in the water table but rather may be due to a data entry error in the ADWR database. The water table history in the northern portion of the Buckeye/Sun Valley ADMS study area does not show there has been a substantial water table decline that would be an indicator for on-going land subsidence.

5.4 Groundwater Summary

The ADWR water table data verifies the depth to groundwater has been very stable. The water table decline has been very slight and is not in the magnitude that would indicate on-going land subsidence.

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Table 5-2 Northern Area Groundwater History

Well N5 Well B-03-04 07BBB		
Date	Depth to Water (Feet)	Depth Change (Feet)
Nov-91	354.67	0.00
Oct-97	329.30	25.37
Oct-98	350.90	3.77
Nov-99	336.10	18.57
Nov-00	331.50	23.17
Oct-01	327.60	27.07

Well N6 Well B-03-05 26ADD		
Date	Depth to Water (Feet)	Depth Change (Feet)
Dec-86	86.50	0.00
Dec-89	87.00	-0.50
Jan-91	76.70	9.80
Nov-91	87.00	-0.50
Nov-92	87.70	-1.20
Dec-93	83.60	2.90
Dec-94	85.90	0.60
Nov-95	85.20	1.30
Nov-96	86.30	0.20
Oct-97	87.20	-0.70
Oct-98	85.10	1.40
Nov-99	87.10	-0.60
Nov-00	87.20	-0.70
Nov-01	87.20	-0.70

Well N7 Well B-02-05 25BAB		
Date	Depth to Water (Feet)	Depth Change (Feet)
Dec-82	146.60	0.00
Dec-86	148.30	-1.70
Nov-91	149.60	-3.00
Nov-97	149.70	-3.10
Oct-98	149.90	-3.30
Nov-99	150.40	-3.80
Nov-00	150.40	-3.80
Nov-01	150.70	-4.10

Well N8 Well B-02-04 129DCD		
Date	Depth to Water (Feet)	Depth Change (Feet)
Dec-52	216.80	0.00
Jul-63	223.40	-6.60
May-69	219.60	-2.80
Jan-70	218.30	-1.50
Mar-81	222.70	-5.90
Jan-82	223.40	-6.60
Jun-85	223.00	-6.20
Dec-85	226.90	-10.10
Jun-86	223.20	-6.40
Dec-86	224.50	-7.70
Jun-87	223.50	-6.70
Dec-87	223.00	-6.20
Jun-88	223.20	-6.40
Dec-88	223.20	-6.40
Nov-89	223.80	-7.00
Jan-91	223.70	-6.90
Nov-91	223.90	-7.10
Nov-92	224.00	-7.20
Dec-93	224.00	-7.20
Dec-94	223.90	-7.10
Nov-95	223.80	-7.00
Nov-96	223.60	-6.80
Nov-97	223.80	-7.00
Oct-98	223.60	-6.80
Nov-99	223.80	-7.00
Nov-00	223.80	-7.00
Nov-01	225.60	-8.80

Depth change calculated from initial depth to water measurement.

Table 5-2 Northern Area Groundwater History

Well N1 Well B-06-04 26DBC Date	Depth to Water (Feet)	Depth Change (Feet)
Nov-77	354.67	0.00
Jan-88	329.30	25.37
Dec-91	350.90	3.77
Nov-97	336.10	18.57
Dec-98	331.50	23.17
Nov-99	327.60	27.07
Nov-00	323.60	31.07

Well N2 Well B-05-04 24CCD Date	Depth to Water (Feet)	Depth Change (Feet)
Jan-73	440.00	0.00
Jan-74	441.00	-1.00
Feb-75	441.20	-1.20
Feb-76	442.00	-2.00
Jan-77	439.30	0.70
Nov-77	440.20	-0.20
Mar-78	439.70	0.30
Jan-79	441.90	-1.90
Feb-80	445.30	-5.30
Mar-81	427.00	13.00
Jan-82	422.90	17.10
Jan-83	421.10	18.90
Dec-83	417.20	22.80
Dec-84	414.60	25.40
Jun-85	414.10	25.90
Dec-85	414.50	25.50
Jun-86	413.00	27.00
Dec-86	413.40	26.60
Jun-87	413.10	26.90
Dec-87	413.50	26.50
Jun-88	414.30	25.70
Dec-88	414.30	25.70
Nov-89	416.40	23.60
Jan-91	418.30	21.70
Nov-91	419.80	20.20
Nov-92	422.35	17.65
Dec-93	417.10	22.90
Nov-94	413.20	26.80
Nov-95	410.30	29.70
Nov-96	408.30	31.70
Nov-97	408.70	31.30
Oct-98	409.20	30.80
Nov-99	411.20	28.80
Nov-00	412.50	27.50
Oct-01	414.90	25.10

Well N3 Well B-04-04 13CBD Date	Depth to Water (Feet)	Depth Change (Feet)
Apr-46	315.60	0.00
Jul-46	315.50	0.10
Sep-48	315.65	-0.05
Feb-49	315.62	-0.02
Nov-49	322.54	-6.94
Mar-50	315.98	-0.38
Feb-51	316.15	-0.55
Nov-51	316.15	-0.55
Jan-52	316.56	-0.96
Feb-54	322.21	-6.61
Feb-55	317.60	-2.00
Feb-56	318.12	-2.52
Jan-57	320.22	-4.62
Feb-62	321.48	-5.88
Jan-63	322.40	-6.80
Feb-64	322.80	-7.20
Jan-65	323.55	-7.95
Jan-66	322.70	-7.10
Jan-68	328.20	-12.60
Mar-69	328.20	-12.60
Feb-70	330.50	-14.90
Jan-71	327.70	-12.10
Dec-86	329.60	-14.00
Nov-89	328.90	-13.30
Jan-91	329.00	-13.40
Nov-91	329.10	-13.50
Nov-92	329.30	-13.70
Dec-93	328.70	-13.10
Nov-94	328.10	-12.50
Nov-95	327.20	-11.60
Dec-96	326.50	-10.90
Oct-97	326.80	-11.20
Oct-98	326.00	-10.40
Nov-99	326.20	-10.60
Nov-00	326.10	-10.50
Oct-01	326.60	-11.00

Well N4 Well B-04-04 19BAA Date	Depth to Water (Feet)	Depth Change (Feet)
Oct-82	178.30	0.00
Jan-85	178.20	0.10
Jun-85	178.50	-0.20
Dec-86	178.70	-0.40
Jun-87	180.00	-1.70
Dec-87	239.20	-60.90
Jun-88	236.70	-58.40
Dec-88	177.20	1.10
Dec-89	170.10	8.20
Jan-91	178.80	-0.50
Nov-91	178.30	0.00
Dec-93	174.20	4.10
Nov-94	174.20	4.10
Nov-95	172.80	5.50
Dec-96	172.80	5.50
Oct-97	173.60	4.70
Oct-98	173.30	5.00
Nov-99	174.30	4.00
Nov-00	174.60	3.70
Oct-01	174.90	3.40

Depth change calculated from initial depth to water measurement.

Table 5-2 Northern Area Groundwater History

Well N5 Well B-03-04 07BBB Date	Depth to Water (Feet)	Depth Change (Feet)
Nov-91	354.67	0.00
Oct-97	329.30	25.37
Oct-98	350.90	3.77
Nov-99	336.10	18.57
Nov-00	331.50	23.17
Oct-01	327.60	27.07

Well N6 Well B-03-05 26ADD Date	Depth to Water (Feet)	Depth Change (Feet)
Dec-86	86.50	0.00
Dec-89	87.00	-0.50
Jan-91	76.70	9.80
Nov-91	87.00	-0.50
Nov-92	87.70	-1.20
Dec-93	83.60	2.90
Dec-94	85.90	0.60
Nov-95	85.20	1.30
Nov-96	86.30	0.20
Oct-97	87.20	-0.70
Oct-98	85.10	1.40
Nov-99	87.10	-0.60
Nov-00	87.20	-0.70
Nov-01	87.20	-0.70

Well N7 Well B-02-05 25BAB Date	Depth to Water (Feet)	Depth Change (Feet)
Dec-82	146.60	0.00
Dec-86	148.30	-1.70
Nov-91	149.60	-3.00
Nov-97	149.70	-3.10
Oct-98	149.90	-3.30
Nov-99	150.40	-3.80
Nov-00	150.40	-3.80
Nov-01	150.70	-4.10

Well N8 Well B-02-04 129DCD Date	Depth to Water (Feet)	Depth Change (Feet)
Dec-52	216.80	0.00
Jul-63	223.40	-6.60
May-69	219.60	-2.80
Jan-70	218.30	-1.50
Mar-81	222.70	-5.90
Jan-82	223.40	-6.60
Jun-85	223.00	-6.20
Dec-85	226.90	-10.10
Jun-86	223.20	-6.40
Dec-86	224.50	-7.70
Jun-87	223.50	-6.70
Dec-87	223.00	-6.20
Jun-88	223.20	-6.40
Dec-88	223.20	-6.40
Nov-89	223.80	-7.00
Jan-91	223.70	-6.90
Nov-91	223.90	-7.10
Nov-92	224.00	-7.20
Dec-93	224.00	-7.20
Dec-94	223.90	-7.10
Nov-95	223.80	-7.00
Nov-96	223.60	-6.80
Nov-97	223.80	-7.00
Oct-98	223.60	-6.80
Nov-99	223.80	-7.00
Nov-00	223.80	-7.00
Nov-01	225.60	-8.80

Depth change calculated from initial depth to water measurement.

6.0 Land Subsidence Assessment

The goals of this study are to determine whether:

- There is an on-going process of land subsidence and earth fissuring.
- There is no credible evidence of the potential for land subsidence.
- There is a potential for land subsidence and earth fissures to develop in the future in response to large groundwater withdrawals.

The available geologic, hydrogeologic and hydrologic information was analyzed with respect determining if there is on-going regional land subsidence and earth fissure formation and if there is a potential for these geologic hazards to occur in the future.

6.1 Historic and Present Land Subsidence

The first two goals of this study relate to assessing if there is on-going land subsidence and earth fissuring. The water table information presented in Section 5.0 documents there has not been a significant decline in the water table anywhere in the Buckeye/Sun Valley ADMS study area. This means there is no credible evidence that the conditions are suitable to cause compaction of the sediments and regional land subsidence.

The interferograms (Figures 3-2 to 3-5) were reviewed in consultation with Mr. Maurice Tatlow, the interferogram expert at ADWR. The color shift on an interferogram indicates if there is land subsidence. An example of the shift is if the color goes from blue, through the spectrum and back to blue. This could indicate 3 centimeters of land subsidence. The color shift does not apply to disturbed areas. Figures 3-2 and 3-3 are primarily blue and green and do not exhibit a color shift within the Buckeye/Sun Valley ADMS area.

Figures 3-4 contains a wide range of colors and some of the information could be interpreted as indicating land subsidence. This area was included in a previous study (Tetra Tech, 2003) completed for the Flood Control District of Maricopa County (District). In that study, a suspected occurrence of land subsidence was identified at Buckeye Flood Retarding Structure No. 1 from Station 770+00 to 820+00 on the March 10, 1997 to October 30, 2000 interferogram (included in Figure 3-4). Because there was no evidence of water table decline that could produce this land subsidence, additional investigation of the interferogram was warranted. Mr. Tatlow and Dr. Buckley reviewed the interferogram and weather records. They found that on October 29, 2000 a major rainstorm occurred in the Phoenix area and several other storms had occurred just prior to October 29. They concluded that the weather had produced atmospheric interference that impacted the interferogram and that the suspected land subsidence was an anomaly not regional land subsidence.

Figure 3-5 contains a range of colors but does not have a color shift that would indicate the presence of on-going land subsidence.

Examination of these four interferograms did not indicate that land subsidence is occurring within the Buckeye/Sun Valley ADMS study area. This is additional information to verify that there is no on-going process of land subsidence. Further, if there is no regional land subsidence there is no earth fissuring.

Because there is no credible evidence that there has been a substantial amount of water table decline and the interferograms document confirm there is no on-going land subsidence, it is concluded there is no on-going process of regional land subsidence.

6.2 Future Potential Land Subsidence

The third study goal of the study is to assess if there is a potential for land subsidence and earth fissures to occur in the future. This goal statement relates land subsidence to large scale groundwater withdrawals. However, it must be noted that groundwater withdrawals do not necessarily produce the conditions that can result in land subsidence. Water table decline, produced when pumping exceeds the natural and artificial recharge, can initiate land subsidence. An example of an area where large scale groundwater withdrawals have occurred but did not result in regional land subsidence is the southern portion of the Buckeye/Sun Valley ADMS area. Groundwater pumping for irrigation has been on-going for decades but there has been no water table decline; hence there is no regional land subsidence.

The sedimentary materials within the Buckeye/Sun Valley ADMS could be subjected to compaction if significant water table declines occur in the future. The ADWR Salt River Valley groundwater model does not project significant water table decline will occur within the southern portion of the Buckeye/Sun Valley ADMS study area and this means there is a very small potential for regional land subsidence or earth fissures to occur in this area.

Currently, there is no groundwater model to project future water table conditions in the northern portion of the Buckeye/Sun Valley ADMS study area. ADWR, the Town of Buckeye and the major developers are working to develop a groundwater model but this will not be operational until 2005. The groundwater model will simulate the projected water table impacts that result when development occurs and groundwater is pumped to meet the demands. The groundwater model will also include projections of the impacts that reclaimed water direct use and recharge and Central Arizona Project (CAP) water recharge will have to reduce the amount of water table decline. Another goal of the groundwater modeling project will be to determine if the projected water table declines are sufficient to initiate land subsidence. ADWR will use the groundwater model as the foundation for future regional land subsidence modeling. It is recommended that the District coordinate with ADWR during the groundwater model development phase. Runoff projections developed as a part of the Buckeye/Sun Valley ADMS project can be incorporated into the groundwater model to better define the quantity of natural recharge. ADWR can then provide the District with water table decline and land subsidence projections.

The coarse-grained nature of the sediments in the northern portion of the Buckeye/Sun Valley ADMS study area will influence the amount of regional land subsidence that may occur even if the water table does decline. Coarse-grained sediments have less pore space and will be subjected to less compaction than fine-grained sediments. Land subsidence in the Buckeye/Sun Valley ADMS area would be less severe than that measured on the east side of the White Tank Mountains in the Sun City and Luke Air Force Base areas even with an equal amount of water table decline.

If a significant water table decline occurs in the northern portion of the Buckeye/Sun Valley ADMS area and if significant land subsidence is measured, then there is a potential for earth fissures to form. However, there is not sufficient information available at this time to predict if the fissures will form or where they may occur.

7.0 Conclusions

Based on the review of available geologic, hydrogeologic, and hydrologic information, there is no on-going regional land subsidence or earth fissure formation within the Buckeye/Sun Valley ADMS study area. There does not appear to be a potential for regional land subsidence to occur in the southern portion of the Buckeye/Sun Valley ADMS area in the future. A regional groundwater model proposed by ADWR will provide the information needed to predict if there is a potential for regional land subsidence to occur in the northern portion of the Buckeye/Sun Valley ADMS study area in the future.

8.0 Recommendations

It is recommended the District should coordinate with ADWR during the development of the groundwater model for the Hassayampa River basin. The District can obtain information from the model to identify areas where there may be significant water table decline in the future and where regional land subsidence may occur. ADWR can also provide the District with current well depth to water measurements and if a significant decline in the water table occurs, the District can initiate planning to mitigate the effects on regional land subsidence on District facilities.

It is also recommended that potential future land subsidence and earth fissuring be evaluated in further detail specific to each alternative developed in the future Buckeye Sun Valley Area Drainage Master Plan. As a part of ongoing work under the District's dam safety program, the District has developed a technique to identify "earth fissure risk zones". Such techniques should be applied as needed as part of the Buckeye Sun Valley Area Drainage Master Plan in order to assure future flood control projects avoid or mitigate for potential future earth fissures.

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