GROUNDWATER FLOW MODELING AND MULTIPLE SCENARIO ANALYSIS: PRESCOTT ACTIVE MANAGEMENT AREA, YAVAPAI COUNTY, ARIZONA

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ABSTRACT

GROUNDWATER FLOW MODELING AND MULTIPLE SCENARIO ANALYSIS: PRESCOTT ACTIVE MANAGEMENT AREA, YAVAPAI COUNTY, ARIZONA

DANIEL TIMMONS

The Prescott Active Management Area (AMA) in central Arizona is required to achieve a state of safe-yield by 2025. Safe-yield is defined as the condition where long-term groundwater withdrawals do not exceed recharge to the aquifer system of the AMA. This study addresses several of the problems facing water managers and planners in the Prescott Active Management Area. Through further development of an existing numerical groundwater model, the natural hydrologic budget and flow patterns of the area have been quantitatively assessed. Applying the groundwater model to future scenarios, the varying impacts of current and future water management and development decisions have been quantified and assessed. Based on these results, policy recommendations have been made regarding optimal population growth patterns, conservation strategies, and water-supply augmentation policies.

Results indicate that conservation alone is unlikely to allow for the achievement of safe-yield by 2025. Supply augmentation is therefore necessary to bring the Prescott AMA into legal compliance with the safe-yield mandate. Scenario results also indicate that the achievement of safe-yield is possible with projected population growth rates; however, even with effective conservation strategies and the augmentation of existing water supplies, population growth at projected rates is projected to lead to significant impacts on the natural discharges from the groundwater system. Thus, safe-yield can be

achieved, but only by decreasing outflow from Del Rio Springs by an additional 37% and baseflow in the Agua Fria River by 22%. Simulated results also indicate that, under conditions of continued growth at median projected rates, the AMA will likely be unable to maintain a state of compliance with the safe-yield mandate much past 2025.

With coordinated management between the water resources managers and town planners for the various communities, Yavapai County and the Arizona Department of Water Resources, the groundwater resources of the Prescott AMA can be managed in a condition of safe-yield. Through a combination of population growth management, conservation strategies and augmentation of existing supplies, the safe-yield goal for the Prescott AMA can be achieved and maintained through 2025.

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This thesis is dedicated to my family and to the past, present and future students of Abe Springer's Hydro Lab. Your have been my inspiration, encouragement, and incentive along the way. Megan and Steve, you are *real* American heroes.

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CHAPTER ONE: INTRODUCTION AND BACKGROUND

Introduction

Groundwater resources are critical to the future of Arizona and other regions of the U.S. While water management has long been a contentious issue in the arid southwest, other regions are now beginning to realize the limited and fragile nature of their own resources. As future economic development and population growth will place increased stress upon water supplies nationwide, the need for effective water management techniques is greater than ever.

The Prescott Active Management Area (AMA) in central Arizona is one of five Active Management Areas in the state. Established by the Arizona Groundwater Management Act of 1980, the Active Management Areas are regions where groundwater management is needed to address the impacts of large-scale groundwater withdrawals on groundwater resources.

The stated management goal of the Prescott AMA is to achieve “safe-yield” by the year 2025 (Corkhill and Mason, 1995). Safe-yield is defined as the condition where long-term groundwater withdrawals do not exceed recharge to the aquifer system of the AMA. Several management programs have been established by the Arizona Department of Water Resources (ADWR) to achieve the safe-yield goal including “1) groundwater quality assessment and management, 2) agricultural conservation, 3) municipal conservation, 4) industrial conservation, 5) augmentation and reuse” (Corkhill and Mason, 1995).

In 1993, the ADWR began developing a numerical groundwater flow model for the Prescott Active Management Area to assess potential impacts of these various management programs. This model was seen as the first step in a modeling effort that was to be continually revisited and improved as time and new data warranted. The model was subsequently updated based on new data and used to simulate groundwater conditions from 1940 to 1999, as well as to project future groundwater conditions for the years 1999-2025 (Nelson, 2002).

This pre-existing Prescott AMA groundwater model provided the starting point for the research described in this thesis. In 2005, the ADWR contracted with Northern Arizona University to update the model based on newly available data. As part of this research, the active area of the model was expanded, the geologic structure was redefined based on new information, hydraulic parameter values were recalibrated, and the transient simulation was extended to include the years 1999-2004 (Timmons and Springer, 2006). Upon completion of the model update, several future scenarios were then developed in collaboration with the ADWR and the local communities of the Prescott AMA. These scenarios, designed to investigate the impact of population growth, conservation strategies, and alternative water supply importation policies, were simulated with the groundwater model up to the year 2025. Finally, recommendations for water managers and policy makers were made based on the results of these future simulations.

Statement of Problem

The Prescott AMA is legally required to achieve safe-yield status by 2025. For this goal to be reached, however, the ADWR and the water managers of the local communities require a better understanding of the groundwater resources in the area. To plan for the sustainable use of their groundwater resources, they must have a quantitative understanding of the natural hydrologic budget and groundwater flow paths of the AMA.

Planning for the future also requires an assessment of the potential impacts of various development patterns, conservation strategies and augmentation plans. Without an understanding of the natural hydrologic system upon which human development in the Prescott area is based and an awareness of the potential impacts of various planning and management decisions, decision makers will be unable to optimally manage the groundwater resources of the area.

The central research question of this thesis is: *What future impacts will different population growth, water conservation and alternative water supply importation scenarios have on the groundwater resources of the Prescott Active Management Area?*

The hypothesis is that different scenarios will have vastly different impacts on groundwater conditions. Strict conservationist policies combined with development restrictions and importation should allow the aquifers in the AMA to achieve 'safe yield' status, while relaxed conservation policies and unregulated development without importation will likely lead to a rapid depletion of groundwater resources.

This thesis addresses several of the problems facing water managers and planners in the Prescott Active Management Area. Through further development of an existing groundwater model, the natural hydrologic budget and flow patterns of the area have been quantitatively assessed. Applying the groundwater model to future scenarios, the varying impacts of current and future water management and development decisions have been quantified and assessed. Based on these results, policy recommendations have been made regarding optimal population growth patterns, conservation strategies, and alternative water supply importation policies.

Goals and Objectives

The primary goal of the original Prescott AMA groundwater model was defined by the ADWR as the development of an "analytical tool capable of quantifying the effects of various management and conservation programs on the groundwater supplies within the study area" (Corkhill and Mason, 1995). The goal of the model update was thus to refine this analytical tool to more accurately quantify the effects of management and conservation programs. Specific objectives of the model update developed in collaboration with the ADWR included 1) extend the active model area to include the western part of the AMA (referred to as 'the Mint Wash area'), 2) redefine the geologic structure based on newly available data; 3) reevaluate model parameter values based on newly available data and 4) extend the transient simulation to include the years 1999-2004. Additional objectives as part of the multiple scenario analysis process included 5) develop several future scenarios based on population growth, water conservation strategies, and alternative water supply importation policies, 6) simulate the future scenarios with the groundwater model, and 7) provide policy recommendations based on simulation results.

Model Area

The Prescott AMA covers 485 square miles in central Yavapai County, Arizona (Fig. 1). The AMA consists of two ground-water sub-basins, the Little Chino sub-basin (LIC) and the Upper Agua Fria sub-basin (UAF). The modeled area consists of approximately 250 square miles of the groundwater basin, but does not cover the mountainous areas of the AMA. Figure 2 indicates the active model area.

The towns of Chino Valley, Prescott Valley and Dewey-Humboldt are included within the model area. While the City of Prescott is located outside the model area in the bedrock foothills of the Bradshaw Mountains, the City is dependent upon groundwater pumped from the aquifers of the Little Chino sub-basin. In addition, numerous domestic wells provide the primary water supply for several thousand households within the AMA.

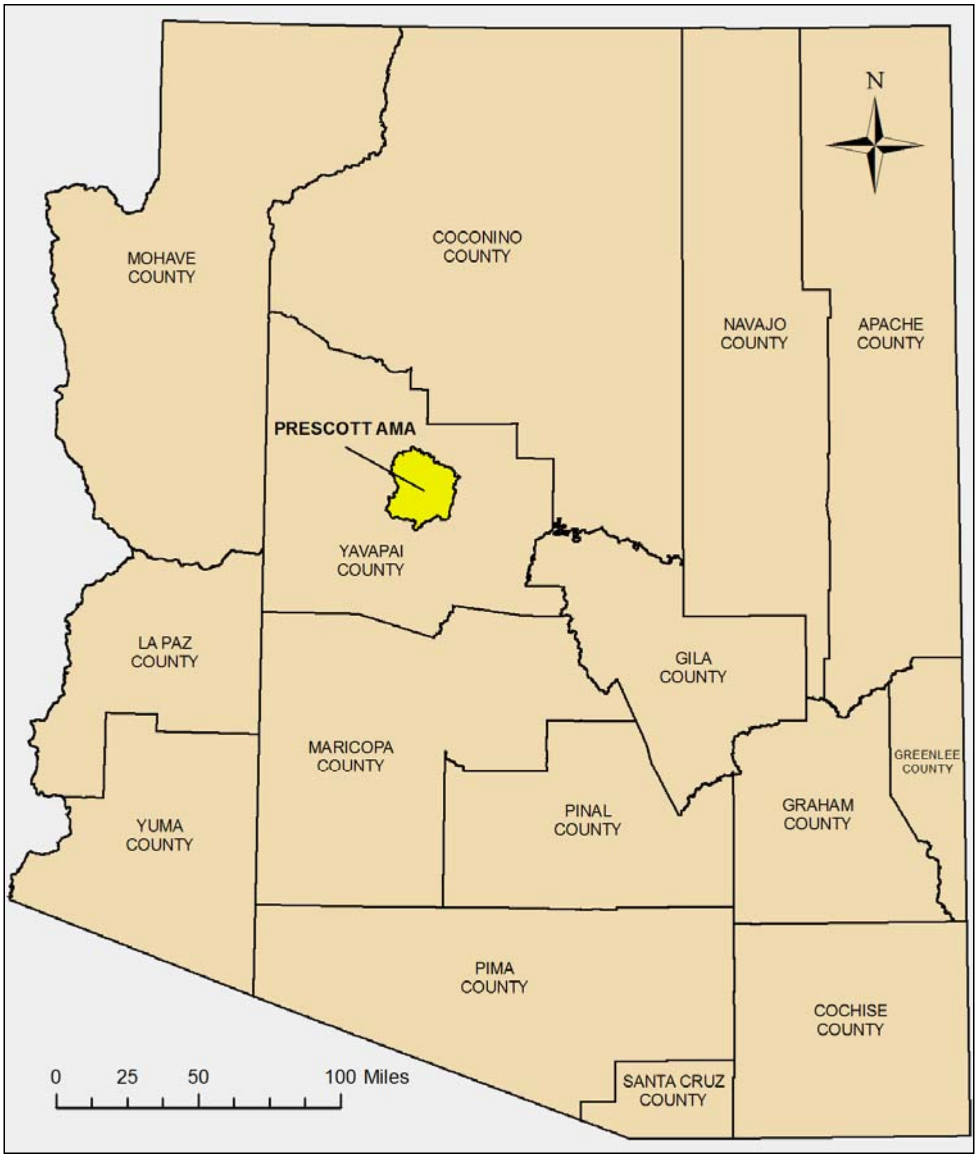

Figure 1. Location of the Prescott Active Management Area, Yavapai County, Arizona.

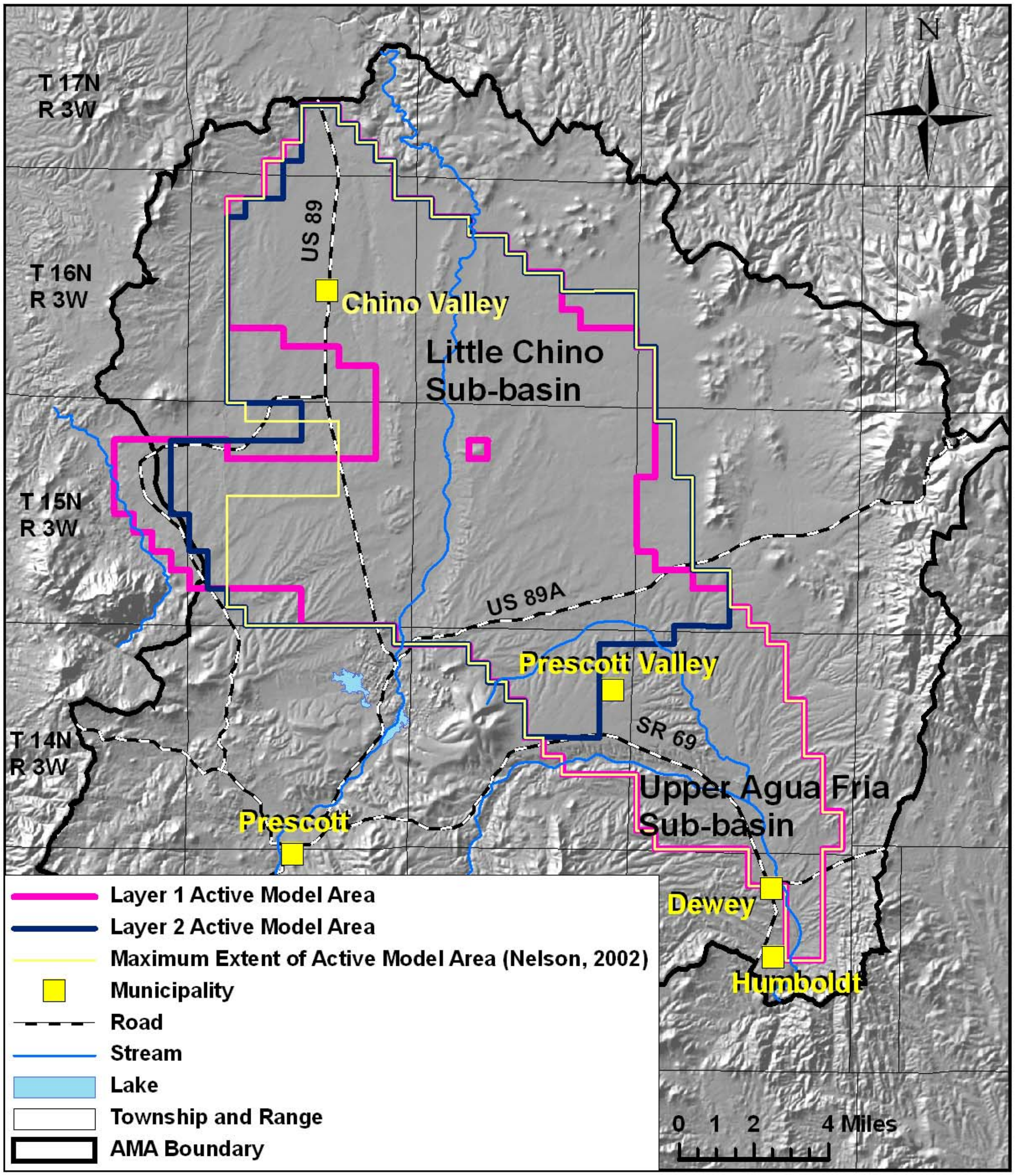

Figure 2. Active model grid of the updated Prescott AMA groundwater flow model.

Previous Investigations

Several geologic mapping studies of Little Chino Valley have been undertaken since the 1960's, the most informative being the United States Geological Survey report provided by Krieger (1965). Krieger (1965) described the stratigraphy and structure of the Prescott and Paulden USGS Topographic Quadrangles. Schwalen (1967) described a groundwater study by the Agricultural Experiment Station at the University of Arizona of the artesian areas of the Little Chino Valley. This report provides descriptions of the geology, hydrology, stream-flow and groundwater development of the Little Chino sub-basin from 1940-1965. Matlock, Davis and Roth (1973) updated this report including groundwater development from 1966-1972.

Wilson's report (1988) described the hydrogeology and water resources of the Upper Agua Fria area, while Navarro's (2002) modeling study characterized the hydrogeology of the Mint Wash and Williamson Valley areas. A recently published USGS report by Wirt, Dewitt and Langenheim (2004) provides a geologic framework, hydrogeologic characterization and geophysical interpretation of the Little Chino sub-basin. Another recent USGS report characterizes the hydrogeology of the entire Upper and Middle Verde watersheds, including the Little Chino sub-basin (Blasch et. al. 2005).

Several groundwater modeling studies have also been conducted for the Prescott AMA. These include Arizona Department of Water Resources' studies by Corkhill and Mason (1995) and Nelson (2002), as well as additional modeling research by Southwest Ground-Water Consultants (1998) and Leon (2005). The groundwater models developed by Corkhill and Mason (1995) and Southwest Ground-Water Consultants (SGWC) (1998) were independently reviewed by William Woessner under contract with ADWR.

This review found that the ADWR model provided a more reasonable representation of the groundwater system of the AMA than the SGWC model (Woessner, 1998). This determination was based on the better supported conceptual model used by ADWR, as well as better model calibration to water levels and discharge values (Woessner, 1998). While Woessner (1998) noted that the ADWR model was more likely to reproduce trends in groundwater levels and discharges than the SGWC, he recommended that the ADWR model be used as an active management tool, with annual re-calibration to new field data. The work by Leon (2005) utilized inverse modeling and sensitivity analysis to refine model parameter values of the ADWR model in the Del Rio Springs area.

The Arizona Department of Water Resources has also published a collection of reports describing the hydrologic conditions of the area. In addition to the groundwater modeling studies discussed previously, annual Hydrologic Monitoring Reports have been published since 2001 (ADWR, 2002, 2003, 2004).

Policy Background

Groundwater in the West was traditionally treated as a common-pool resource with land ownership conveying an unlimited right to pump the underlying water (Holland and Moore, 2002). Under this traditional system, the right of capture defines the right to use. Economic theory predicts that this system will lead to an inefficiently quick pace of mining and rapid resource depletion in arid environments (Holland and Moore, 2002). As competition for groundwater resources increased, the common law of absolute ownership was found to be ill suited to the arid American West, and the majority of states developed groundwater laws based on either the American rule of reasonable use or the doctrine of prior appropriation (Ashley and Smith, 1999).

The American rule of reasonable use is a modification of the common law that limits a landowner's right to groundwater to the amount required for some 'reasonable and beneficial use' on the land above the water (Ashley and Smith, 1999). This essentially prohibits waste of water and the transportation of groundwater to other areas.

The doctrine of prior appropriation has been adopted by most Western states, including Arizona. This doctrine provides that the first appropriator of water has a right to continue that use, providing the use is reasonable and beneficial (Ashley and Smith, 1999). Later appropriators are given junior rights to the senior appropriator.

Except for a brief period in 1952 and 1953, Arizona water law followed the common law doctrine of absolute ownership through the 1970's, with rapid groundwater overdraft as predicted by economic theory (Ashley and Smith, 1999; Holland and Moore, 2002). In the late 1970's and early 1980's, nearly half of all the water consumption in the state was supplied by the depletion of groundwater resources, with an annual overdraft of over 2 million acre-feet (Kyl, 1982). This excessive groundwater pumping was causing declining water levels and attendant problems such as land fissures in the populated areas of the state.

The solution envisioned for these problems was two-fold. First, the Central Arizona Project was developed by the U.S. Bureau of Reclamation to transport Colorado River water over 300 miles from Lake Havasu to the metropolitan areas of Phoenix and Tucson. Second, as a precondition for authorization of the project, the Carter Administration demanded that Arizona reform its groundwater law (Holland and Moore, 2002). To gain necessary federal funding for the Central Arizona Project, the Arizona

State Legislature passed the Arizona Groundwater Management Act of 1980, referred to hereafter as the AGMA.

The AGMA established a Department of Water Resources to administer groundwater law in the state. The Act also created several Active Management Areas and Irrigation Non-Expansion Areas with special restrictions on groundwater use. One of these Active Management Areas is the Prescott Active Management Area.

One of the primary effects of the AGMA was the elimination of most groundwater rights based on the right-of-capture within the AMAs. While “exempt wells” with a maximum capacity of less than 35 gallons per minute remain essentially unrestricted, all other groundwater users must have a right based on historic use, location within a permitted service area, or by special permit (Kyl, 1982).

Finally, the AGMA established a statutory goal of “safe-yield” by 2025 for three of the four initial AMAs, including the Prescott AMA. According to Arizona Revised Statute 45-561-12, “Safe-yield means a groundwater management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of groundwater withdrawn in an active management area and the amount of natural and artificial recharge in the active management area.” This statutory definition does not state explicitly whether natural groundwater discharge is to be counted among groundwater withdrawals, allowing for confusion to persist regarding the actual calculus used to determine safe-yield status.

Prior to the determination of safe-yield status in 1999, it was argued that natural outflows were not to be considered in the safe-yield balance; however, the ADWR has determined that this definition of safe-yield is inconsistent with the legislative intent of the AGMA (Pearson, 1999). If natural discharge is not included in the safe-yield calculation, it is possible for the statutory goal to be achieved while water levels and groundwater in storage continue to decline. Since the intent of the AGMA was to prevent continued declines in water levels, it was determined that natural discharges had to be incorporated into the safe-yield calculation to fulfill the intent of the legislation (Pearson, 1999).

According to the Director of the Prescott AMA, natural discharge is included within the water budget calculations used to determine safe-yield status (G. Wildeman, pers. comm.., 6/5/07). This is calculated based on a ten-year running average of annual change in groundwater storage for each individual AMA. While safe-yield is designed to stabilize water levels, the concept does not differentiate between natural and artificial discharge or take into consideration the level at which groundwater levels will eventually remain balanced. In a simple water budget calculation, natural discharge at springs and as baseflow in perennial streams and rivers is considered in the same discharge category as groundwater pumping. Assuming constant recharge, declining natural discharge allows for increased groundwater pumping under the concept of safe-yield. Thus, an incentive is created to increase pumping and decrease natural discharge prior to the establishment of safe-yield conditions by 2025 (Holland and Moore, 2002).

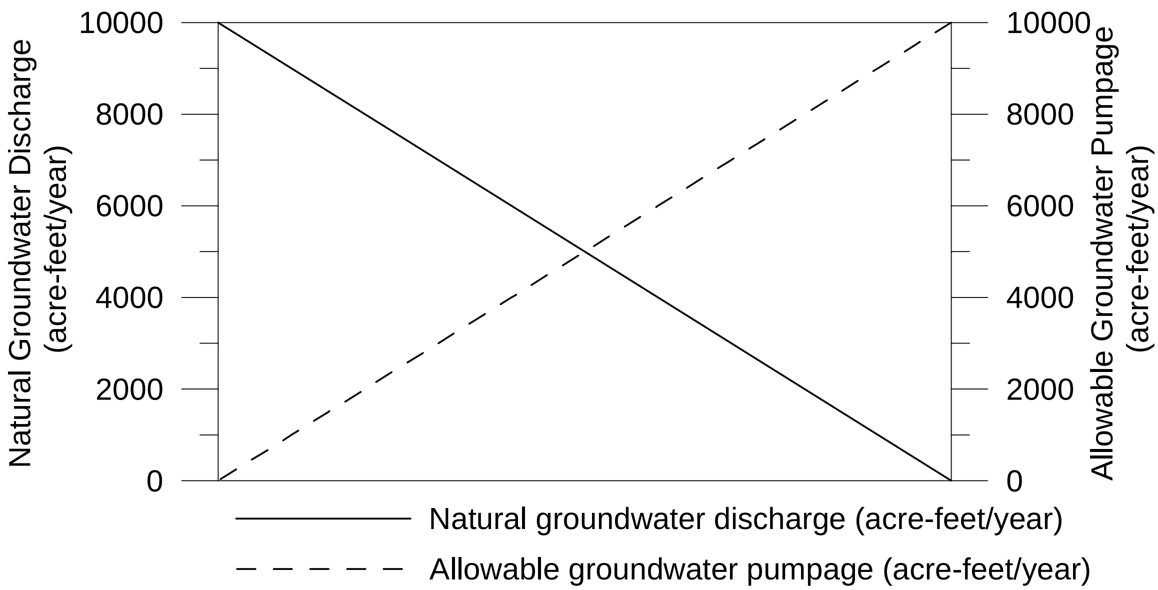

Figure 3. Allowable groundwater pumpage versus natural groundwater discharge under a safe-yield condition, assuming a constant recharge of 10,000 acre-feet per year.

To insure continual progress is made towards the safe-yield goal, the AGMA mandated the development of 10 year management plans for the AMAs. The Prescott AMA is currently operating under the Third Management Plan. This management plan includes specific conservation programs for the agricultural, municipal, and industrial sectors. These conservation programs are discussed further in Chapter 6.

Groundwater use in the Prescott AMA is governed by the provisions of the AGMA. These dictate that the AMA must achieve a state of safe-yield by the year 2025 through various measures including limitations on groundwater pumping rights and the implementation of various conservation and augmentation programs.

CHAPTER TWO: THE HYDROGEOLOGIC SYSTEM

Regional Setting

The Prescott AMA is located in the Transition Zone physiographic province of central Arizona (Fig. 1). Land surface elevations range from about 4,450 feet to 4,900 feet in the basin areas to over 7,000 feet in the Black Hills and Bradshaw Mountains. A topographic boundary creates a surface-water divide that closely corresponds to the groundwater divide between the Little Chino sub-basin and the Upper Agua Fria sub-basin. Runoff and groundwater flow in the Little Chino sub-basin move northward to the Verde River, while runoff and groundwater in the Upper Agua Fria sub-basin flow south to the Agua Fria River (Figure 4).

Geologic Structure

The geologic structure of the model area is defined by a structural trough that trends northwest for a distance of about 25 miles from the southern part of the Upper Agua Fria sub-basin to the northern part of the Little Chino sub-basin near Del Rio Springs. The trough appears to have developed in late Tertiary time (10 Ma to the present) due to crustal extension in central Arizona and in the Basin and Range province to the south (Wirt et. al., 2004). The basin is bounded to the east by the Coyote Fault at the edge of the Black Hills. Vertical offset on the Coyote Fault is estimated by Krieger (1965) to range from 0 feet at Humboldt to about 1,200 feet near the Indian Hills.

The northern end of Little Chino Valley is likely bound by a largely concealed northwest trending normal fault. Displacement across the fault is uncertain, as there are no wells deep enough to penetrate both sediment fill and lati-andesite, but may exceed 600 feet near Del Rio Springs (Wirt et. al, 2004).

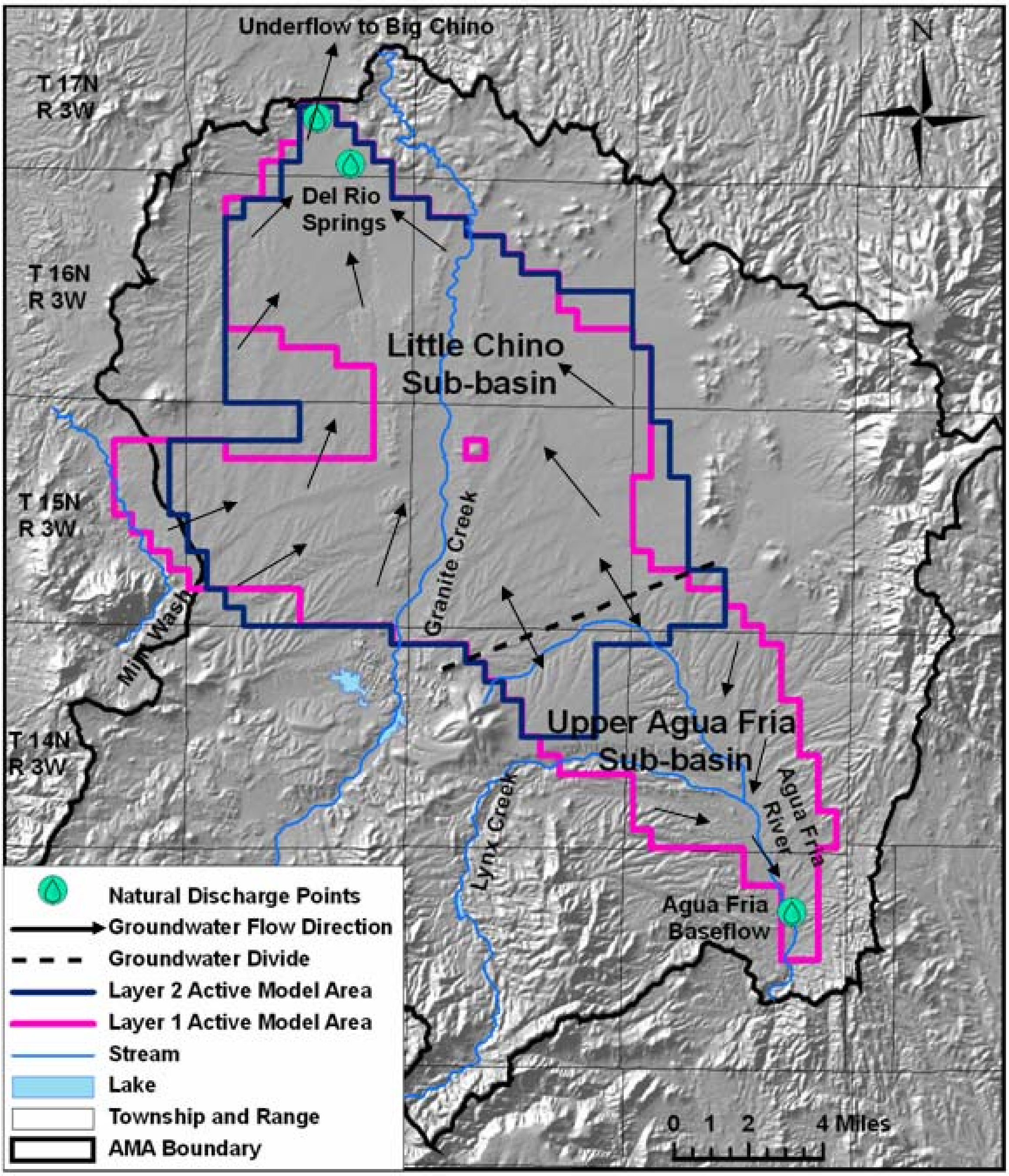

Figure 4. Conceptual model of groundwater flow paths and natural discharge points for the Prescott AMA.

It has previously been suggested that the western side of northern Chino Valley may also be bound by a continuous fault (Ostenaa et. al., 1993). Recent work, however, suggests that this may not be the case. While Big Wash follows a pre-Hickey fault north of Table Mountain, it is unclear whether this fault extends to the northern end of Little Chino Valley (Wirt et. al 2004). Instead, alluvial fans extend away from lati-andesite flows which thicken into Little Chino Valley. While a buried normal fault may be concealed beneath the fans, there are currently no drillhole data to prove the continuity of such a fault.

Modifications to Geologic Structure

In 2001, ADWR drilled several monitoring wells in locations throughout the AMA where the geologic conditions were uncertain (Figure 5). Monitoring Well #1 (55-587403) was drilled in central Little Chino Valley east of Granite Creek near Black Hill (B(15-01-08DAA). Based on previous geologic interpretations of basin depth provided by Krieger (1965) and Oppenheimer and Sumner (1980), it was expected that the drilling would encounter alluvial materials to a depth of around 935 feet, under which several hundred feet of volcanic deposits were believed to exist. However, actual geologic conditions were far different from those expected. Alluvial materials were encountered to a depth of 55 feet, while interbedded volcanic flows and cinders were found between 55 feet and 695 feet below land surface (Corkhill, 2001). Below these volcanic deposits, sands, gravel and conglomerate were found to a depth of around 810 feet before the basement unit was encountered, (Corkhill, 2001).

In addition to this new monitoring well, the USGS report *Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona* includes a cross-section that runs through the Black Hill area (Blasch, et. al., 2005). On this cross-section, Black Hill is depicted as an intrusive flow of Tertiary age Hickey basalt cutting through the overlying sediments. Based on these two new pieces of information, Black Hill was conceptualized as an intrusive volcanic feature overlying a granitic pluton.

ADWR Monitor Well #2 (55-587404) was drilled in northeast Lonesome Valley (B(16-01)23ACA) (Figure 5). The drilling of this well revealed thinner alluvial deposits than expected based on previous geologic interpretations of the area and the Upper Alluvial Unit was unsaturated at this location. Thus, the conceptualization of the extent of the saturated Upper Alluvial Unit was modified in northeast Lonesome Valley.

Based on the drilling log from ADWR Monitor Well #3 (55-588619), an alluvial depression was conceptualized to exist in the newly active area to the northwest of the City of Prescott (B(15-02)22AAB) (Figure 5). While previous geophysical studies (Cunion, 1985) have suggested this area was the center of an intrusive pluton, others have also interpreted the gravity anomaly in the area as a deep pocket of alluvium (Oppenheimer and Sumner, 1980). The driller's log of Monitor Well #3 indicates approximately 1,200 feet of sand, gravel, clay and mudstone overlying granitic bedrock. Thus, the gravity anomaly observed in the area is likely the result of the substantially deeper bedrock in the area.

In 2001, several wells were drilled in the area immediately south of Del Rio Springs (Allen, Stephenson & Associates 2001). These logs provided a more detailed and accurate description of the subsurface in this area. Based on the logs of these wells, the Upper Alluvial Unit was determined to be thicker in some areas than previously believed (Figures 5 and 6).

While previous numerical models developed by ADWR did not include the westernmost portion of the AMA, rapid development in the Mint Wash area over the past 10 years has caused rapid declines in water levels measured in several wells in the area. Due to these increasing impacts on the groundwater resources of this area, it was determined that the model update would extend the active area of the model to include Mint Wash and surrounding areas (Figure 2). Numerous well logs were interpreted to define the geologic structure in this area.

As part of the reevaluation of geologic structure in the area, several well logs from the Prescott Valley North Wellfield were also reviewed to determine whether structural changes were warranted in this area (Figure 5). Based on this review, it was found that the actual thickness of the Upper Alluvial Unit was well approximated by the original model. While well logs indicate that the Lower Volcanic Unit is thicker than 200 feet in localized areas in and around the Prescott Valley North Wellfield, there is currently insufficient data regarding the areal extent of these thicker deposits to warrant structural changes to the model in this area. As new drill log or other data becomes available, the geologic structure in this area should be reevaluated to determine whether structural changes to the model are required.

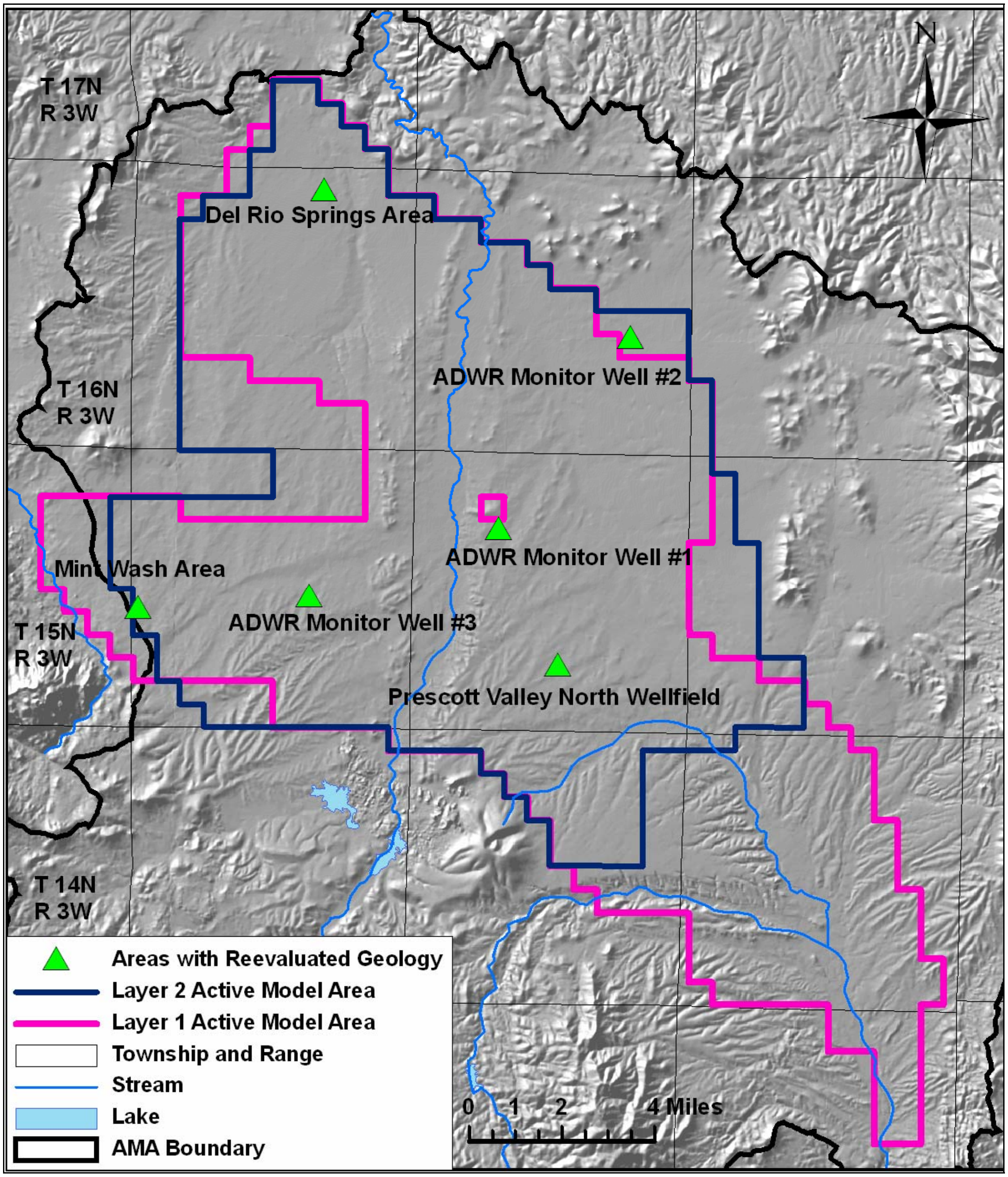

Figure 5. Areas of reevaluated geology in the Prescott AMA.

Hydrostratigraphic Units

While a wide variety of rock types are found in the model area, these rock types have been grouped into three hydro-stratigraphic units with similar hydrologic properties (Corkhill and Mason, 1995). From oldest to youngest, these units are the Basement Unit, the Lower Volcanic Unit (LVU), and the Upper Alluvial Unit (UAU). The Basement Unit consists of a variety of igneous and metamorphic rocks that are generally dense, nonporous and nearly impermeable (Wilson, 1988). The Basement Unit forms the floor and sides of the groundwater basins and is not considered an aquifer for the purposes of this modeling study although it does serve as the primary aquifer for small private wells in some upland areas of the AMA. Magnetic and gravity data suggest that the basement unit underlying much of Little Chino Valley may be Prescott Granodiorite (Wirt et. al. 2004). In several areas, this Prescott Granodiorite appears to exist as a plutonic unit, cutting through overlying rock units.

The Lower Volcanic Unit is generally composed of a sequence of Tertiary age basaltic and andesitic lava flows interbedded with layers of pyroclastic and alluvial material (Corkhill and Mason, 1995). In the area northeast of Granite Mountain near Mint Wash, fractured and decomposed granite is included within the Lower Volcanic Unit. This Lower Volcanic Unit is modeled throughout the Little Chino sub-basin and a small area of the Upper Agua Fria sub-basin near the Town of Prescott Valley. In some areas, the Lower Volcanic Unit aquifer exists in confined artesian conditions.

The Upper Alluvial Unit consists of a wide variety of sedimentary, volcanic and younger alluvial rocks. This unit forms an unconfined aquifer which is distributed throughout the basins of the Prescott AMA.

CHAPTER THREE: THE CONCEPTUAL MODEL

The Aquifer System

The groundwater flow system in the Prescott AMA consists of two distinct sub-basins: the Little Chino sub-basin and the Upper Agua Fria sub-basin (Figure 4). The Little Chino sub-basin consists of an Upper Alluvial Unit aquifer and a Lower Volcanic Unit aquifer. In the Upper Agua Fria Sub-basin, however, the Lower Volcanic Unit is only present in the Prescott Valley area, while the Upper Alluvial Unit extends throughout the sub-basin. The groundwater divide between the two sub-basins generally corresponds with the surface-water divide and loosely follows US 89A from the Indian Hills to Glassford Hill (Figure 4). Surface runoff and groundwater flow in the Little Chino sub-basin move northward towards the Verde River, while runoff and groundwater in the Upper Agua Fria sub-basin flow south to the Agua Fria River.

Hydrostratigraphic Units

For the purposes of the numerical model, the complex geology of the Prescott AMA has been simplified into two hydrostratigraphic units: an Upper Alluvial Unit aquifer and a Lower Volcanic Unit aquifer.

The Upper Alluvial Unit Aquifer

The Upper Alluvial Unit aquifer consists primarily of the saturated alluvial and volcanic deposits that fill the structural trough that trends northwest across the Little Chino and Upper Agua Fria sub-basins. It extends to the west between Granite Mountain and Table Mountain terminating at Mint Wash. The deep structural pocket identified by Oppenheimer and Sumner (1980) in Township 15N 2W is filled with alluvial deposits of the Upper Alluvial Unit aquifer (Figure 5).

The saturated Upper Alluvial Unit forms the main unconfined aquifer throughout the model area. Natural recharge to the Upper Alluvial Aquifer occurs primarily through infiltration along the mountain fronts of the model area and in ephemeral stream channels. Infiltration from canals and excess irrigation water also contributes recharge to the Upper Alluvial Unit aquifer in agricultural areas. In addition, the City of Prescott, the Town of Prescott Valley and the Town of Chino Valley have developed artificial recharge facilities that allow for the infiltration of treated effluent and surface water supplies into the Upper Alluvial Unit Aquifer.

Natural discharge occurs at three locations in the model area. Groundwater is discharged from the Little Chino sub-basin as both spring flow at Del Rio Springs and as subsurface flow out of the model area to the northwest of Del Rio Springs (Figure 4). It is believed this subsurface flow heads northeast through faulted lower Paleozoic-age sedimentary rocks and lati-andesite volcanic rocks towards spring-fed Stillman Lake and Lower Granite Spring (Wirt et. al., 2004). In the Upper Agua Fria sub-basin, discharge occurs as baseflow in the perennial reach of the Upper Agua Fria River near Humboldt.

Evapotranspiration from small riparian areas at Del Rio Springs and along the Agua Fria River near Humboldt also accounts for comparatively minor groundwater discharge from the Upper Alluvial Unit in the model area. For modeling purposes, however, groundwater consumption by evapotranspiration was undifferentiated from the groundwater discharge that also occurs in these locations.

Additional discharge from the Upper Alluvial Unit comes from groundwater pumpage. Numerous small-capacity domestic wells tap into the Upper Alluvial Unit aquifer throughout the model area, while large capacity agricultural and municipal wells in the Upper Agua Fria sub-basin also pump from the Upper Alluvial Unit aquifer.

The Lower Volcanic Unit Aquifer

In much of the Little Chino sub-basin, a thick unit of vesicular volcanic flows interbedded with cinders, tuff and alluvial materials underlies the Upper Alluvial Unit aquifer. These materials are the same as the "artesian" aquifer described by Schwalen (1967) and are designated the Lower Volcanic Unit aquifer. Northeast of Granite Mountain near Mint Wash, fractured and decomposed granite underlie the conglomerate of the Upper Alluvial Unit aquifer and are included within the Lower Volcanic Unit aquifer. The Lower Volcanic Unit extends into the Upper Agua Fria Sub-basin in the vicinity of the Town of Prescott Valley.

Natural discharge from the Lower Volcanic Unit occurs as spring flow at Del Rio Springs and as subsurface flow out of the model domain to the northwest of the springs. This subsurface flow heads northeast towards Stillman Lake and Lower Granite Springs, eventually emerging as baseflow in the Verde River (Wirt et. al, 2004).

Since the 1940's groundwater withdrawal from wells has been the major source of discharge from the Lower Volcanic Unit aquifer. The Lower Volcanic Unit aquifer has provided most of the irrigation and municipal water that has been pumped within the model area. Significant pumpage from the Lower Volcanic Unit aquifer has occurred throughout the Little Chino Sub-basin and in the Town of Prescott Valley's Santa Fe Wellfield in the Upper Agua Fria Sub-basin.

The Predevelopment Hydrologic System

Prior to the initiation of large-scale agricultural and municipal groundwater pumping from the Little Chino sub-basin, steady-state conditions are assumed to have characterized the groundwater flow system of the model area (Corkhill and Mason, 1995; Schwalen, 1967). In the steady-state, a long-term equilibrium between groundwater inflow and groundwater outflow was established and groundwater levels remained relatively constant with time. It should be noted that this steady-state condition was not a natural equilibrium, but included discharge from groundwater pumpage and recharge from excess irrigation water and canal seepage. However, it is believed that the simulated groundwater pumpage rate represents a limited stress on the system, which had not experienced a significant loss of storage prior to 1940 (Nelson, 2002). Therefore, the period of time before 1940 is referred to as 'pre-development.' Substantial groundwater development did not begin in the Upper Agua Fria sub-basin until the 1960's; therefore, near-equilibrium conditions in the Upper Agua Fria sub-basin are believed to have persisted for several decades longer than in the Little Chino sub-basin.

Natural Groundwater Discharge

In the Little Chino sub-basin, natural groundwater discharge occurred at two places during the steady-state period, as surface flow at Del Rio Springs and as subsurface flow out of the model area to the northwest of Del Rio Springs (Figure 4). Conceptual estimates for the groundwater discharge flow rate at Del Rio Springs range from 2,700 acre-feet/year (af/yr) to 3,800 af/yr (Foster, 2001) (Table 1). An acre-foot is the volume of water necessary to cover one acre of land to a depth of one foot and is equivalent to 325,851 gallons. These estimates for groundwater discharge are based on the maximum and minimum annual surface-water measurements reported from Del Rio Springs for the period 1940-1945 (Schwalen, 1967) plus an estimated 400 af/yr of evapotranspiration and unreported diversions upstream of the gauge (Foster 2001). Conceptual estimates for subsurface flow are even more uncertain, ranging from 2,000 af/yr (Corkhill and Mason 1995) to 5,600 af/yr (SRP, 2000) (Table 1).

In the Upper Agua Fria sub-basin, natural groundwater discharge occurred as perennial baseflow in the Agua Fria River near Humboldt (Figure 4). Conceptual estimates for Agua Fria River baseflow range from 1,500 af/yr to 2,500 af/yr (Corkhill and Mason, 1995) (Table 1).

Groundwater Pumpage

Groundwater pumpage in the steady-state simulation totaled approximately 1,500 af/simulation, exclusively in the Little Chino sub-basin (Table 1). This rate is consistent with the pumpage used by Nelson (2002) and is based on approximately 50% of estimated agricultural demand for 1937-1939. Pumpage for agricultural use was distributed vertically between the Lower Volcanic Unit and the Upper Alluvial Unit at a ratio of 3:1.

Groundwater Recharge

Recharge in the steady-state simulation also followed the conceptual model of Nelson (2002). While recharge was spatially redistributed to allow for recharge along Mint Wash, the total mountain front recharge rate of 4,000 af /simulation (7,000 af/yr) was kept the same (Table 1). Incidental agricultural recharge was applied at a rate of 50% of both groundwater pumpage and surface-water deliveries in agricultural areas for a total of 2,200 af/simulation (Nelson 2002). Canal recharge from the Chino Valley Irrigation Ditch (CVID) was estimated at about 950 af/simulation (Nelson 2002).

Table 1. Conceptual water budget for the steady-state simulation of the updated Prescott AMA groundwater flow model.

Inflow	**Conceptual Water Budget acre-feet/simulation[1] (af/yr)**
Mountain Front and Granite Creek Recharge	3,900 (6,800 af/yr)
Agricultural Recharge	2,200
Canal Recharge	950
Total Inflow	**7,050**
Outflow	**Conceptual Water Budget**
Groundwater Pumpage	1,500
Groundwater Discharge Del Rio Springs	1,300-2,000 (2,300 -3,400 af/yr)[2] (2,700 - 3,800 af/yr)[2a]
Groundwater Discharge Agua Fria River	900-1,400 (1,500 - 2,500 af/yr)[3]
Groundwater Discharge Subsurface Flow	1,300-2,600 (2,200 -4,500 af/yr)[4] (5,600 af/yr)[5] (2,000 af/yr)[6]
Total Outflow	**5,000 - 7,500**

[1] The steady-state model simulated the 210 day agricultural season for 1939. The water budgets are the totals for this 210 day simulation while figures in parentheses are annualized totals for 1939.

[2] Max and min annual surface-water measurements at Del Rio Springs 1940-1945 (Schwalen, 1967).

[2a] Surface-water measurements plus estimated 400 AF/YR for ET demand and unreported surface-water diversions upstream of gauge (Foster, 2001)

[3] Corkhill and Mason, 1995

[4] Darcy strip analysis (Nelson, 2002)

[5] Groundwater discharge as subsurface flow based on confined well steady-state equation (SRP, 2000)

[6] Corkhill and Mason, 1995 (Note: UAU aquifer only)

The Developed Hydrologic System

Minimal changes from Nelson (2002) were made to stresses applied to the model for the period 1939-1999. The expanded model area required that changes be made to groundwater pumpage, mountain-front recharge and flood recharge. From 1999-2005, new stress values were included based on previously used methodology (Corkhill and Mason, 1995; Nelson, 2002).

Natural Groundwater Discharge

Limited measurements exist of naturally occurring groundwater discharge as spring flow at Del Rio Springs and baseflow in the Agua Fria River. Annual maximum and minimum discharge at Del Rio Springs from 1940 to 1945 were reported by Schwalen (1967). Matlock et. al (1973) published average discharge rates for the period 1965 to 1972, while average rates for the period 1984 to 1989 were published by Corkhill and Mason (1995). Since 1997, a USGS gauge has been operational at Del Rio Springs (USGS, 2006a) and provides a continuous data stream for groundwater discharge at the springs (Appendix IV). Conceptual estimates for pre-development groundwater discharge from 2,700 to 3,800 af/yr, including approximately 400 af/yr for evapotranspiration and unreported upstream diversions (Table 1) (Foster 2001). The USGS gauge at Del Rio Springs measured approximately 950 acre-feet of flow for 2004 (Appendix IV). Conceptual estimates of groundwater discharge at Del Rio Springs for 2004 range from 950 af/yr to 1,350 af/yr (Table 2). Thus, according to conceptual estimates, groundwater discharge at Del Rio Springs has declined between 1,750 af/yr and 2,850 af/yr over the time period of 1940 to 2004.

Estimates of pre-development subsurface flow from the model area to the north range from 2,000 af/yr (Corkhill and Mason, 1995) to 5,600 af/yr (SRP, 2000). In 2004, the USGS estimated that the Little Chino sub-basin contributes 13.8± 0.7% of the baseflow of the Verde River at Stewart Ranch (Wirt et. al., 2004). For 2004, this equates to approximately 1,900 to 2,000 af/yr. This contribution to the Verde River is conceptualized as coming from the subsurface flow leaving the model area to the northwest of Del Rio Springs.

Pre-development groundwater discharge as baseflow in the Upper Agua Fria River was estimated as 1,500 to 2,500 af/yr for 1940 (Table 1) (Corkhill and Mason, 1995). While a USGS gauge has been operational at Humboldt since 2001 (USGS, 2006b), the gauge captures a great deal of surface runoff that makes baseflow separation techniques difficult (Appendix IV). For 2003, however, ADWR estimated groundwater discharge as baseflow in the Agua Fria River as approximately 1,300 af/yr (ADWR, 2004). Thus, according to conceptual estimates, natural groundwater discharge from the Upper Agua Fria sub-basin has declined between 200 af/yr and 1,200 af/yr over the time period of 1940 to 2003 (Tables 1 and 2).

Table 2. Conceptual water budgets for the Prescott AMA (1940 and 2004). (All figures in af/yr)

Inflow	**1940 Conceptual Water Budget**	**2004 Conceptual Water Budget**
Natural Recharge	5,800	5,800
Recharge: Incidental and Artificial Recharge	4,100	7,600
Flood Recharge	0	21,700 [1]
Total Inflow	**9,900**	**35,100**
Outflow		
Pumpage	4,600	23,800
Groundwater Discharge	2,300 -3,400 [2]	1,000 [3]
at Del Rio Springs (LIC)	2,700 - 3,800 [2a]	1,400 [3a]
Groundwater Discharge at the Agua Fria River (UAF)	1,500 - 2,500 [4]	1,300 [5]
Subsurface Flow (LIC)	2,200 - 4,500 [6]	1,900-2,000 [9]
	5,600 [7]	1,200-2,000 [10]
	2,000 [8]	
Total Outflow	**13,800**	**26,500 – 28,200**
Change in Storage	**-3,900**	**6,900 – 8,600**

[1] Flood recharge includes flooding from January - March 2005.
[2] Max and min annual surface-water measurements at Del Rio Springs 1940-1945 (Schwalen, 1967)
[2a] Surface-water measurements plus estimated 400 AF/YR for ET demand and unreported surface-water diversions upstream of gauge (Foster, 2001)
[3] Surface-water measurements (mean) at Del Rio Springs (2004) (USGS, 2004). (Does not reflect estimated ET demand of 100 af/yr)
[3a] Surface-water measurements at Del Rio Springs (2004) plus 400 AF/YR for ET demand and surface-water diversions upstream of gauge (Foster, 2001)
[4] Contains an undifferentiated ET component estimated at 200 af/yr
[5] Median surface-water measurements at Agua Fria River (2004) plus 200 af/yr for estimated ET demand upstream of gauge
[6] Darcy strip analysis (Nelson, 2002)
[7] Groundwater discharge as subsurface flow based on confined well steady-state equation (SRP, 2000)
[8] Corkhill and Mason, 1995 (Note: UAU aquifer only)
[9] Results of USGS tracer dilution study (Wirt et. al, 2004)
[10] Darcy strip analysis (Nelson, 2002)

Groundwater Pumpage

Groundwater pumpage for agricultural purposes from 1939-1983 was applied to the Little Chino sub-basin based on previously estimated irrigated acreage, areal distribution of historic irrigation rights, estimated consumptive crop use, an estimated irrigation efficiency of 50% and a vertical pumpage distribution of 3:1 LVU to UAU (Nelson, 2002). After 1983, groundwater withdrawal rates for agricultural, municipal and industrial uses were based on annual reports provided by groundwater users in the Prescott AMA (Table 3). Domestic pumpage rates were applied based on estimates provided in ADWR Hydrologic Monitoring Reports. Agricultural and turf-related pumpage were applied only during irrigation stress periods from April through October, while other pumpage was applied uniformly throughout the year (Nelson, 2002).

Approximately four square miles of the added Mint Wash area are outside of the Prescott AMA boundaries (Figure 2). In this area, groundwater pumpage rates are not reported to ADWR. Groundwater pumpage for the American Ranch development was based on the estimated water demand prepared by Clear Creek Associates (2001). Pumpage for the American Ranch development was applied at a rate of 150 af/yr for 2002, and 126.4 af/yr for 2003 and 2004. In addition, approximately 350 domestic wells are located in the active model area, but outside the AMA. Pumpage from these wells was estimated based on an average pumpage rate of 0.33 af/yr per well (ADWR, 2002). Based on this formula, non-AMA domestic pumpage within the active model area was estimated at 115 af/yr for 2004. As development in this area has largely occurred since 1980, no non-AMA domestic pumpage was applied for the years 1939-1979. Domestic well pumpage rates were linearly interpolated between 1980 and 2004 (Table 4).

Table 3. Simulated pumpage applied to the updated Prescott AMA groundwater flow model (1999 – 2004). (All figures rounded to the nearest 5 acre-feet)

AMA Pumpage	1999	2000	2001	2002	2003	2004
City of Prescott[1]	6,750	7,515	7,650	8,320	8,150	8,150
Prescott Valley[1]	3,780	4,090	4,335	4,820	4,870	5,370
Agricultural Users[1]	5,160	6,620	5,850	6,760	4,365	5,290
Non-irrigation Users[1]	6,20	485	1,050	1,190	1,240	1,230
Small Providers[1]	510	460	565	705	825	745
Exempt[2]	1,200	1,365	1,535	1,700	1,830	2,000
Non-AMA Pumpage[3]	90	95	100	255	235	240
Total Pumpage	**18,110**	**20,630**	**21,085**	**23,750**	**21,515**	**23,025**

[1] ADWR, 2005

[2] Estimated domestic and exempt well pumpage in Prescott AMA groundwater basin Area only. See pumpage section of this report for further details.

[3] Estimated non-AMA pumpage from domestic wells and the American Ranch development in the Mint Wash area. See Table 4 and the pumpage section of this report for further details.

Table 4. Non-AMA pumpage applied in the Mint Wash area to the transient simulation of the updated Prescott AMA groundwater flow model. (All figures in af/yr)

Year	Domestic Pumpage	American Ranch Pumpage
2004	115	126
2003	110.4	126
2002	105.8	150
2001	101.2	0
2000	96.6	0
1999	92	0
1998	87.4	0
1997	82.8	0
1996	78.2	0
1995	73.6	0
1994	69	0
1993	64.4	0
1992	59.8	0
1991	55.2	0
1990	50.6	0
1989	46	0
1988	41.4	0
1987	36.8	0
1986	32.2	0
1985	27.6	0
1984	23	0
1983	18.4	0
1982	13.8	0
1981	9.2	0
1980	4.6	0
1939-1979	0	0
Total	**1495**	**402**

Groundwater Recharge

Incidental agricultural recharge was estimated at 50% of agricultural groundwater pumpage and 50% of surface-water deliveries (Nelson 2002). Seepage along the CVID canal was estimated at approximately 40% of surface water deliveries, for a total canal seepage recharge over the transient simulation from 1939 – 2005 of about 62,000 acre-feet (Nelson 2002). Mountain-front recharge was applied at a uniform rate of 5,750 af/yr.

Flood recharge along Granite Creek and the Lynx Creek/Agua Fria River drainage was applied based on the wetted area approach used by Nelson (2002) (Table 5). Flood recharge along Mint Wash was assigned to 12 cells based on an estimated channel width of 30 feet/cell, channel length of 2640 feet/cell, and an estimated recharge rate of 0.25 feet/day. Based on this methodology, the 2004-2005 flood event lasted for an estimated 34 days on all three drainages and contributed a total flood recharge of 21,725 acre-feet to the groundwater system of the Prescott AMA.

Artificial recharge of effluent and surface water was applied at the City of Prescott's Airport Recharge Facility and along the channel of the Agua Fria River near Prescott Valley's Wastewater Treatment Facility based on annual reports provided to ADWR and information provided by the Town of Prescott Valley (Table 6).

Table 5. Simulated flood recharge applied to the transient simulation of the updated Prescott AMA groundwater flow model.

Event Year	Number of Days per Event	Granite Creek (acre-feet/event)	Lynx Creek (acre-feet/event)	Mint Wash (acre-feet/event)
1978	9	4,320	780	49
1980	13	6,240	1,120	71
1983	4	1,920	350	22
1993	39	18,720	3,370	213
1995	9	4,320	780	49
2003		850*	0	0
2004	34	18,690	2,850	185
Total	**108**	**55,060**	**9,250**	**589**

* The 2003 flood event was simulated based on a release from Watson Lake into Granite Creek. Other drainages were not affected.

Table 6. Simulated artificial recharge applied to the transient simulation of the updated Prescott AMA groundwater flow model. (Figures to nearest 10 acre-feet)

Year	Prescott (af/yr)	Prescott Valley (af/yr)
1988	1,100	0
1989-1993	2,100	0
1994	2,100	500
1995	2,100	800
1996	2,100	1,250
1997	2,100	1,400
1998	2,750	1,600
1999	2,080	1,360
2000	2,830	1,630
2001	2,890	1,570
2002	1,680	1,300
2003	3,330	1,640
2004	3,140	1,840
Total	**30,300**	**14,890**

CHAPTER FOUR: THE NUMERICAL GROUNDWATER MODEL

The Prescott AMA groundwater model simulates the steady-state groundwater conditions that characterized the groundwater flow system circa 1939, as well as the transient-state conditions of the period of large-scale groundwater development from 1940 to 2005.

Stress Period Setup

The steady-state model simulates the 210 day agricultural pumping season from April through October 1939. The 210 day simulation consists of one stress period and one numerical time step.

The transient model simulates the period from November 1939 through March 2005. Each year is divided into two stress periods, a 210 day irrigation season from April through October and a 155 day non-irrigation season from November through March. Each stress period is further divided into 20 numerical time steps with a time step multiplier of 1.2. The increase in time steps within the stress periods of the updated model was intended to allow for the more accurate simulation of seasonal fluctuations in groundwater levels and discharge.

Code Selection

The original model developed by Corkhill and Mason (1995) utilized the Modular Three-Dimensional Finite-Difference Groundwater Flow Model (MODFLOW) developed by the USGS (McDonald and Harbaugh 1988). For the purposes of this study, MODFLOW-2000 was selected as the model code (Harbaugh et al. 2000). This code is used to solve the following partial-differential equation for groundwater flow simultaneously for each active cell in the model:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

where K_x, K_y, and K_z are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);
H is the potentiometric head (L);
W is a volumetric flux per unit volume representing sources and/or sinks of water, with W<0.0 for flow out of the ground-water system, and W> 0.0 for flow in (T^{-1});
S_s is the specific storage of the porous material (L^{-1}); and
t is time (T). (Harbaugh et. al., 2000)

The selection of MODFLOW-2000 as the model code was based on the following criteria:

1) use of the model code is well-documented in the academic literature,
2) the model code has been widely used by hydrologic professionals and is generally accepted as a valid model for simulating groundwater flow,
3) graphical user interfaces developed for the code allow for relatively simple and efficient adjustment of model parameter values, and
4) the model code allows for automated parameter estimation based on inverse modeling techniques.

The graphical user interface computer program Groundwater Vistas 4.25 was utilized to run MODFLOW-2000 (Environmental Simulations, Reinholds, PA). Groundwater Vistas was chosen as the graphical user interface because the software package incorporates MODFLOW, MODFLOW-2000 and several different parameter estimation packages into a single interface.

Model Assumptions and Limitations

As with all groundwater models, several assumptions have been necessary to allow for numerical modeling of the complex aquifer system of the Prescott Active Management Area. Though necessary, the assumptions do place limitations on the interpretation of model results. Some of the major assumptions of the original model which also apply to this model update include the following:

1) The Prescott AMA groundwater flow model is a regional model which is not intended to provide site-specific determinations of hydrologic conditions.
2) Hydraulic heads computed within each model cell represent the average head within the saturated area of that cell.
3) Simulated recharge is applied directly to the uppermost active model cell.
4) The Lower Volcanic Unit aquifer can be treated as an isotropic, porous medium. Additionally, groundwater flow in the Lower Volcanic Unit aquifer is laminar (that is, non-turbulent) and can be approximated using Darcy's equation (Darcy, 1856). On a regional scale these assumptions are reasonable; however, they may not apply on the local level due to non-laminar and turbulent flow conditions which may occur in fractures and cavities.
5) The available water-level data adequately represent the groundwater flow system within the model area. In most areas this assumption is reasonable, however, there are certain data deficient areas where the assumption is questionable.
6) Recharge from precipitation falling directly on the groundwater basin areas of the model domain is negligible. Because annual precipitation in basin areas averages about 12 to 14 inches per year, and surface-water evaporation rates exceed 60 inches per year. In addition, depth-to-water considerations preclude effective recharge by direct precipitation on the basins.
7) Evaporation of water from the water table is considered negligible. This is due to the fact that the depth-to-water in most parts of the study area is greater than 50 feet.
8) Evapotranspiration losses from riparian vegetation are negligible. This assumption is due to the very limited area of riparian vegetation in the model area. Evapotranspiration losses in those areas are included with the groundwater outflows of the basin. (Corkhill and Mason 1995)

Model Grid

The updated model did not alter the model grid from the original model's 2 layers, 48 rows and 44 columns. Grid cells remain 0.5 miles in length and width. However, the active area of the model was expanded from approximately 220 square miles to nearly 250 square miles, as the active area was extended to include areas in western Little Chino Valley and the Mint Wash area (Figure 2).

Model Layers and Aquifer Conditions

The Prescott AMA model is a two layer model (Figure 2). Layer 1 consists of the unconfined Upper Alluvial Unit aquifer which extends throughout both the Little Chino sub-basin and the Upper Agua Fria sub-basin. Layer 2 consists of the Lower Volcanic Unit aquifer, which is modeled as a convertible confined/unconfined aquifer throughout the northern half of the model area.

The thicknesses of the model layers were assigned based on well log data and gravity data. The thickness of the Upper Alluvial Unit aquifer varied from 0.0 ft. along the margins of the basins to over 1,000 feet in the central trough of the basins and in the alluvial depression northwest of the City of Prescott (Figure 6). In most areas, Layer 2 was assigned a uniform thickness of 200 feet due to sparse geologic data; however, changes to model layer elevations and thicknesses from the original model were made in several areas based on newly available data (Figure 7).

Based on the results of the drilling of ADWR Monitor Well # 1, B(15-01)08DAA (55-587403) and a recently published USGS report (Wirt et. al 2004), Black Hill was interpreted as a local intrusive volcanic center. To simulate this new conceptualization, the Upper Alluvial Unit (Layer 1) was rendered inactive at Black Hill (Row 19, Column 22), while the thickness of the Lower Volcanic Unit (Layer 2) was increased to 800 feet (Figures 6 and 7). The contact between the LVU and the basement unit was elevated from a depth of 1,135 feet below land surface to a depth of 800 feet. The Lower Volcanic Unit in the cells immediately adjacent to Black Hill was thickened to 300 feet, leaving approximately 150 feet of saturated Upper Alluvial Unit above the LVU (Figure 7). As there is no indication of hydrologic disconnection between Black Hill and the

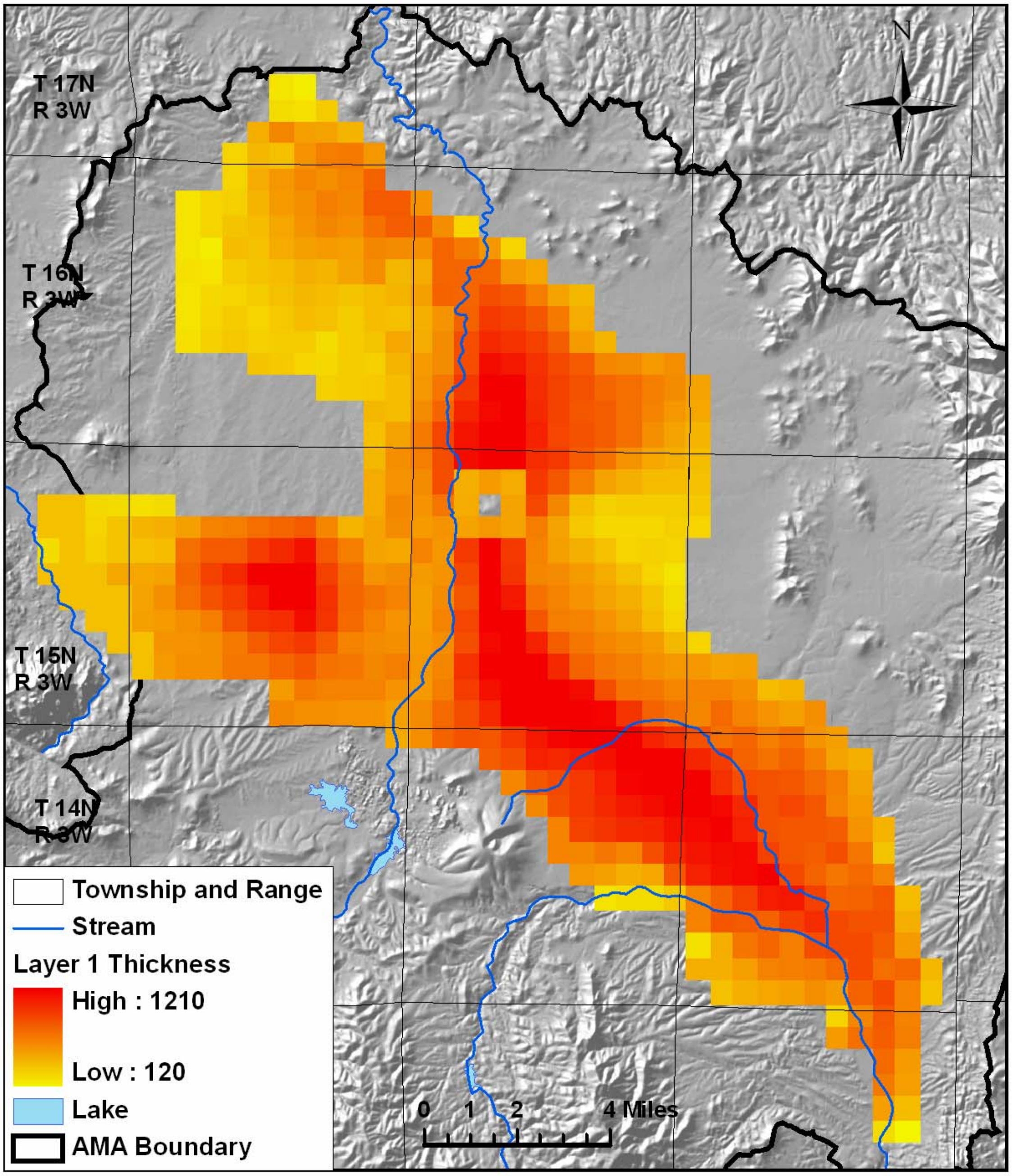

Figure 6. Thickness of Upper Alluvial Unit in the updated Prescott AMA groundwater flow model.

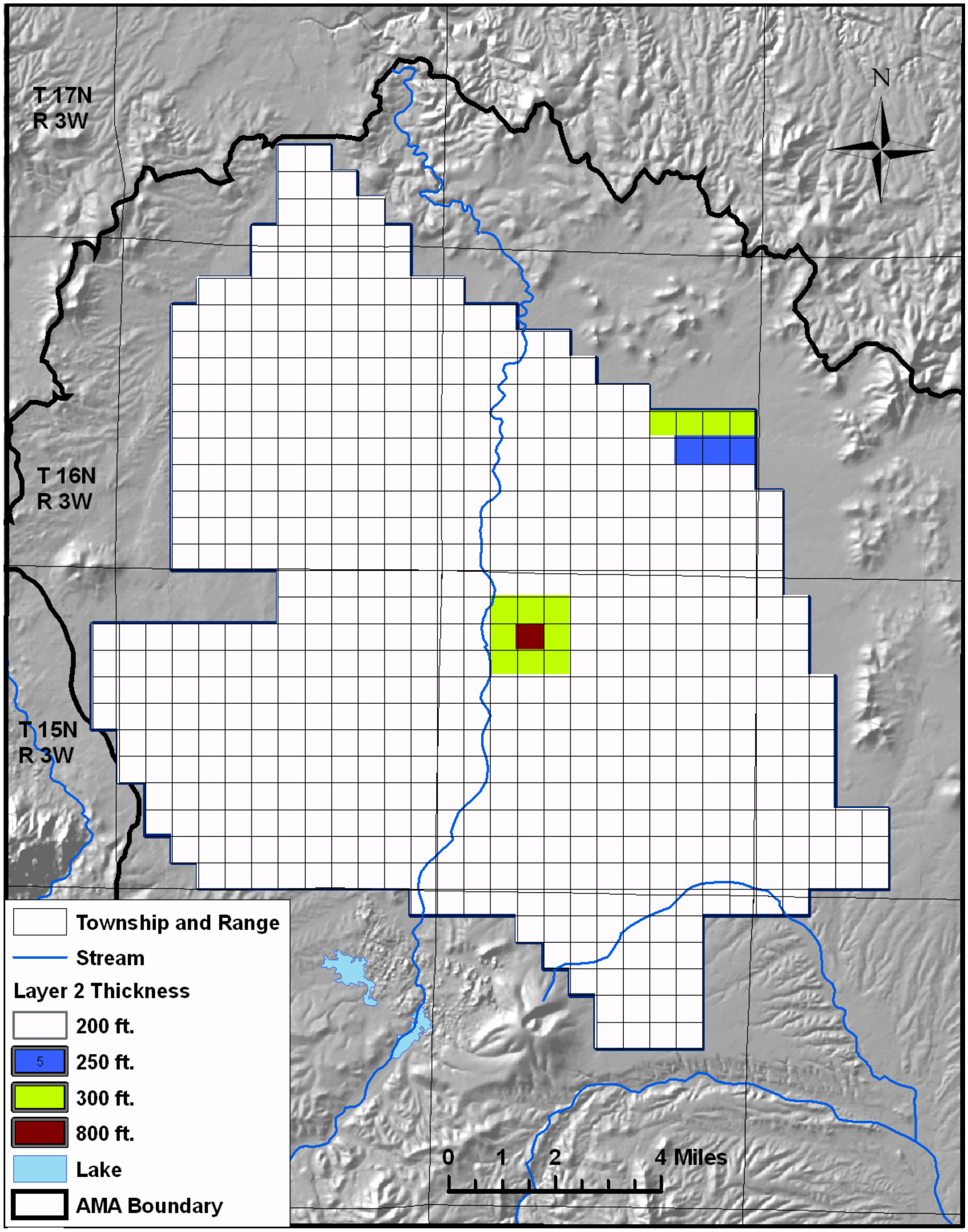

Figure 7. Thickness of Lower Volcanic Unit in the updated Prescott AMA groundwater flow model.

surrounding areas, the hydraulic conductivity of modified cells in the Black Hill area were adjusted to provide similar transmissivity values to unmodified cells in the immediate vicinity of Black Hill.

The drilling of ADWR Monitor Well #2, B(16-01)23ACA (55-587404) also required adjustment of the model layer elevations in the northeast corner of Lonesome Valley. As the Upper Alluvial Unit aquifer was unsaturated at Monitor Well #2, several cells in this area in Layer 1 were rendered inactive. In addition, the top elevation of the Lower Volcanic Unit in several cells was increased to more accurately reflect the drilling data. Finally, the thickness of the Lower Volcanic Unit at several cells was increased from 200 feet to 300 feet to maintain saturated conditions and to correspond with the drilling data (Figure 7).

The drilling of ADWR Monitor Well #3, B(15-02)22AAB (55-588619) revealed a thick pocket of alluvium at least 1,200 feet thick northwest of the City of Prescott (Figure 5). The areal extent of the pocket was estimated based on the depth to basement map prepared by Oppenheimer and Sumner (1980). The model layer elevations and thicknesses in this area were adjusted to reflect these two data sources (Figures 6 and 7).

In 2001, several wells were drilled in the area immediately south of Del Rio Springs (Allen, Stephenson & Associates 2001). Based on the logs of these wells, the thickness of the Upper Alluvial Unit was adjusted in several cells in this area (Figures 5 and 6).

While previous numerical models developed by ADWR did not include the westernmost portion of the AMA, rapid development in the Mint Wash area over the past 10 years has caused rapid declines in water levels measured in several wells in the area

(ADWR, 2004). Due to these increasing impacts on the groundwater resources of this area, it was determined that the model update would extend the active area of the model to include Mint Wash and surrounding areas (Figure 2). This was accomplished by extending the active area of both the Upper Alluvial Unit (Layer 1) and the Lower Volcanic Unit (Layer 2), increasing the number of active model cells from 1,144 to 1,250.

Boundary Conditions

The active model area encompasses the two main groundwater sub-basins of the Prescott AMA. In most locations, the active model area is bounded by impermeable Basement Unit formations that form the "inactive" part of the model. Figure 2 indicates the active model area. The inactive areas were assigned the specified-flux boundary conditions of No Flow to simulate the impermeable Basement Unit. Specified-flux boundary conditions were also used to simulate recharge and groundwater pumpage throughout the model area.

Head-dependent boundaries were used to simulate natural groundwater discharge from the model area. Spring flow at Del Rio Springs, underflow to the Big Chino Valley, and baseflow at the Agua Fria River were all modeled using head-dependent boundary conditions.

MODFLOW-2000 Input Packages

The model was constructed using several modular input packages: 1) the BASIC package, 2) the Layer-Property Flow Package (LPF), 3) the WELL package, 4) the RECHARGE package, 5) the DRAIN package, 6) the General Head Boundary package, and 7) the Pre-conditioned Conjugate-Gradient 2 solver.

The BASIC package in MODFLOW-2000 has been modified from the BASIC package of MODFLOW in several ways to remove parts that have been incorporated into the Global Process Discretization file (Harbaugh et. al 2000). These include the number of layers, rows, and columns in the grid, as well as the number and length of stress periods. The BASIC package in the updated model was used to define active and inactive model cells and to assign starting heads.

The Layer-Property Flow (LPF) package replaced the Block-Centered Flow (BCF) package used in the original model. Similar to the BCF package, the LPF package contained the hydraulic conductivity values used to compute the conductance terms used in the finite-difference equations. However, while the BCF package utilized a leakance coefficient (VCONT) to calculate vertical flow, the LPF package utilizes vertical hydraulic conductivity values to calculate vertical conductance and flow. The LPF package also contains the values for Specific Yield and Specific Storage used to calculate the rate of movement of water into and out of storage. In addition to utilizing specific storage as opposed to storativity, the LPF package differs from the BCF package because it allows for the use of automated parameter estimation techniques.

The WELL and RECHARGE packages were used to simulate specified-flux boundary conditions. The WELL package simulated groundwater pumpage from the aquifer system for agricultural, municipal, industrial and domestic uses. The RECHARGE package simulated groundwater recharge to the aquifer system from various sources including mountain-front recharge, incidental agricultural recharge, flood recharge, artificial recharge, and canal seepage recharge.

The DRAIN and General Head Boundary (GHB) packages were used to simulate head-dependent boundary conditions. The DRAIN package simulated natural groundwater discharge as spring flow at Del Rio Springs and as baseflow along the Agua Fria River. The General Head Boundary (GHB) package was used to simulate underflow from the model area to the northwest of Del Rio Springs.

The PCG2 solver was used to implement the preconditioned conjugate-gradient method to solve the matrix of finite-difference equations by iteration (Hill 1990). This solver utilizes the incomplete Cholesky preconditioning method and was found to provide a more numerically stable solution than the SIP solver used in the original model (Hill, 1990). The solver was set to run for a maximum of 300 outer iterations and 100 inner iterations. The residual criterion for convergence was set to 0.1 ft if met for 100 outer iterations.

Water-Level Data

For the steady-state simulation, static water-level data were needed for initial model inputs, model calibration and statistical analysis of model accuracy. Initially, water-level data were obtained from the ADWR Groundwater Site Inventory (GWSI) database (ADWR, 2005b); however, water-level measurements for the pre-development conditions existing circa 1939 are limited in number and only available for the artesian area of Little Chino Valley. The number of measured values was deemed insufficient for accurate model calibration; thus, estimation techniques were utilized to develop additional head target values. In areas such as the Upper Agua Fria Basin where steady-state conditions are believed to have continued until the 1960's, water-level measurements from later dates were used as the static water level for the predevelopment conditions. In other data deficient areas, target values were assigned based on the potentiometric surface developed by ADWR during the original modeling study (Corkhill and Mason 1995). Appendix B summarizes the water-level data used for calibration targets for the updated model.

Water-level data were also needed for the transient simulation of 1940-2005. Target head values for model calibration and statistical analysis of the transient simulation were taken from the GWSI database. This is discussed further in Chapter 5.

Groundwater Pumpage Data

The steady-state simulation utilized the pumpage data compiled from various sources during the original modeling study. These sources include Schwalen (1967), Matlock, Davis and Roth (1973), Wigal (1988), Foster (1993), City of Prescott (1993), and the ADWR Registry of Grandfathered Rights database (2005a). For the period 1999-2004, pumpage data for municipal, agricultural and industrial purposes uses were obtained from annual values reported to ADWR by individual well owners (ADWR, 2005a). Exempt domestic pumpage was simulated based on estimated values reported in various ADWR reports (ADWR, 2003; ADWR, 2004; Nelson, 2002) (Table 1).

Groundwater Discharge Data

Groundwater discharge data from Del Rio Springs and the perennial reach of the Agua Fria River were used for calibration and statistical analysis. Data from Schwalen (1967), Wilson (1988), and Corkhill and Mason (1995) were used for the period 1940-1993. Data from the USGS gage at Del Rio Springs were used for the period 1997-2004 (USGS, 2006b), while data from ADWR Hydrological Monitoring Reports (2002, 2003, and 2004) and the USGS gage on the Agua Fria River at Humboldt were used for the period 2001-2004 (USGS, 2006b).

Aquifer Parameter Data

Initial aquifer parameter data (hydraulic conductivity, specific yield, and specific storage) were based on the current ADWR model inputs for these parameters that were originally developed from several sources including well logs, pumping tests, specific capacity measurements and others. Changes to hydraulic conductivity values were made in a few locations in the model area.

The distribution of hydraulic conductivity values in the area south of Del Rio Springs was adjusted to reflect results of pumping tests and geophysical studies conducted in the area in 2001 (Allen, Stephenson & Associates, 2001) (Figure 8). These data indicated a northeast trending structural barrier in the Lower Volcanic Unit to the southeast of Del Rio Springs. It is believed this structural barrier serves to funnel groundwater flow in the direction of the springs.

The reach of Granite Creek was also assigned a distinct zone of hydraulic conductivity (Figure 8). The surficial deposits of Granite Creek have been mapped as Quaternary alluvium, while the surrounding basin areas are considered Quaternary sediments (Wirt et. al, 2004). In general, alluvial deposits in intermittent stream channels such as Granite Creek have larger grain sizes and higher hydraulic conductivity values than basin-fill deposits such as those that extend throughout the Little Chino sub-basin (Schwartz and Zhang, 2003). In addition, it was necessary to increase the hydraulic conductivity of the reach of Granite Creek to allow for flood recharge imposed during the transient simulation to effectively disperse throughout the model area.

Several small localized zones of hydraulic conductivity present in the original model were combined into larger areas due to the lack of hydrologic data justifying further discretization (Figure 8 and 9).

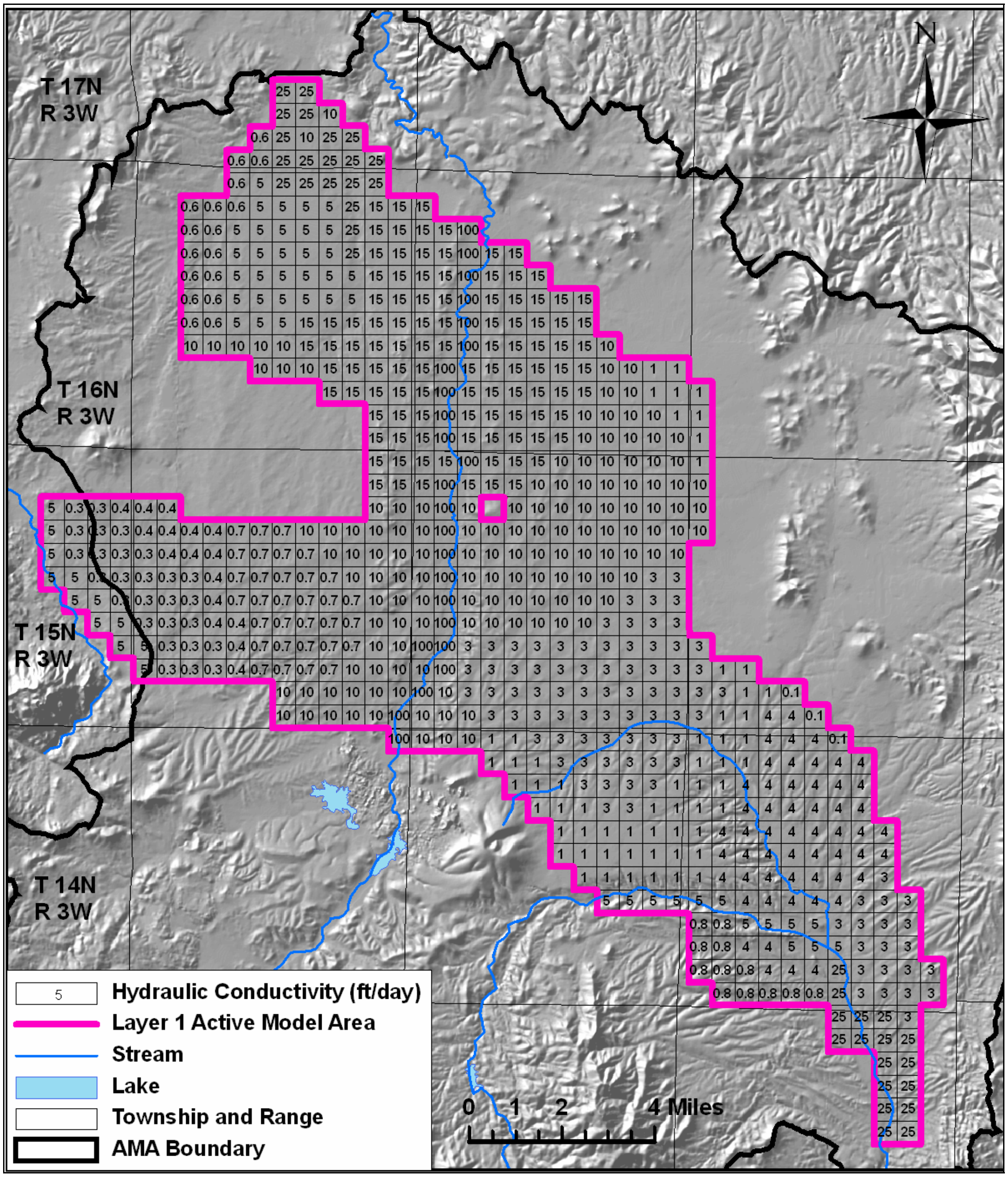

Figure 8. Hydraulic conductivity of the Upper Alluvial Unit in the updated Prescott AMA groundwater flow model.

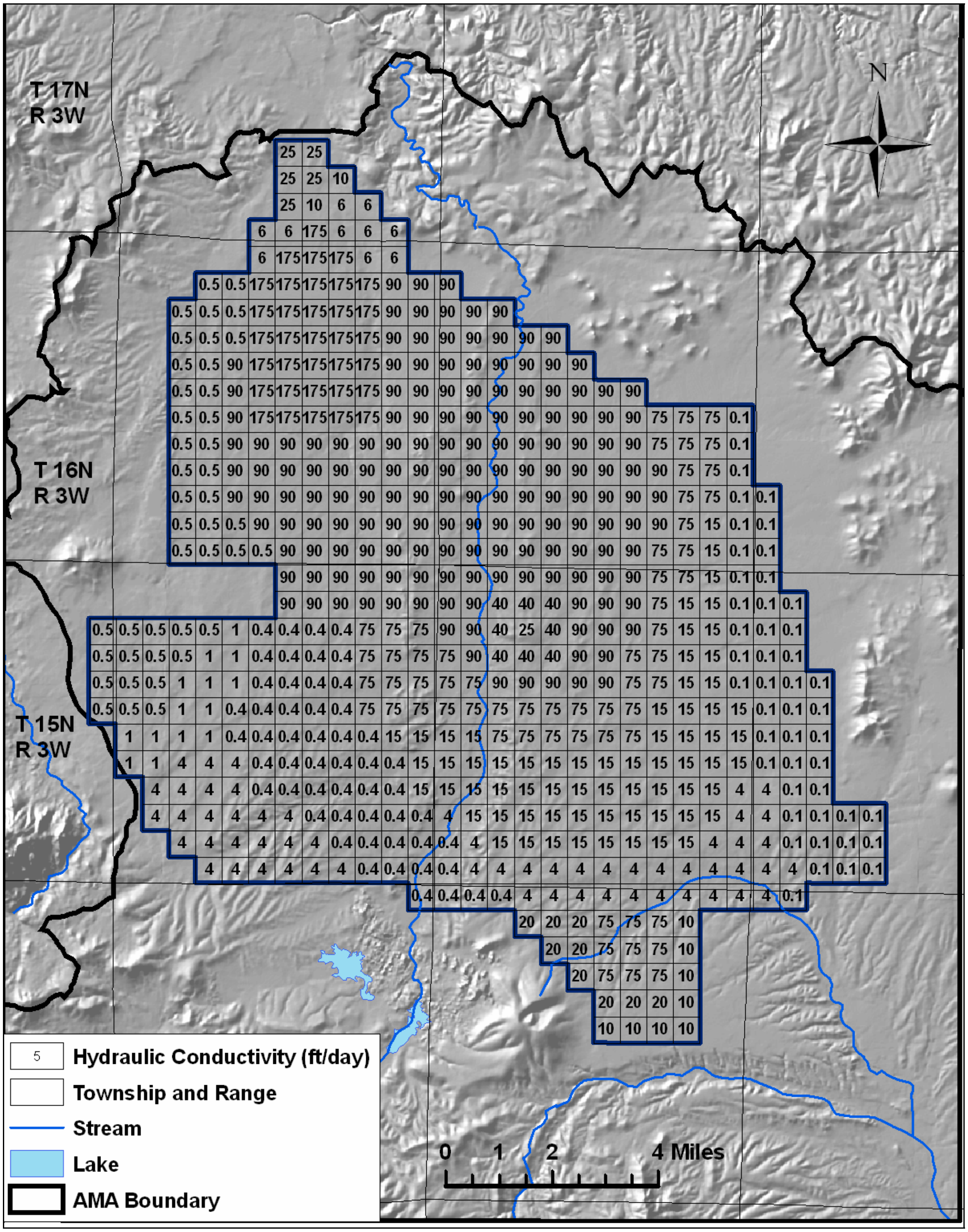

Figure 9. Hydraulic conductivity of the Lower Volcanic Unit in the updated Prescott AMA groundwater flow model.

CHAPTER FIVE: MODEL CALIBRATION

According to Hill (1998), better models have "three attributes: better fit, weighted residuals that are more randomly distributed, and more realistic optimal parameter values." Questions to be asked when evaluating the adequacy of model calibration include the following:

1. Is the conceptual model of the system under investigation reasonable?
2. Are the mathematical representations of the boundary conditions reasonable for the objectives of the study?
3. Does the simulated head and flow distribution mimic the important aspects of the flow system, such as the direction and magnitude of the head contours?
4. Does some quantitative measure of head and flow differences between the simulated and observed values seem reasonable for the objectives of the investigation?
5. Does the distribution of areas where simulated heads are too high and areas where simulated heads are too low seem randomly distributed? If they are not randomly distributed, then is there a hydrogeologic justification to change the model and make the residuals more random areally? (Hill 1998)

Based on these criteria, the Prescott AMA model was effectively calibrated. The conceptual model utilized in this study follows the conceptual model utilized by Corkhill and Mason (1995) and Nelson (2002) in their work for the ADWR. Based on an independent review, the conceptual model used by the ADWR and for this study is believed to be the most accurate conceptual model for the Prescott AMA (Woessner, 1998).

The updated model also followed this previous work in the utilization of both specified flux and head-dependent flux boundary conditions (Nelson, 2002). It is believed that the bedrock outcrops surrounding the groundwater basin areas of the Prescott AMA provide a barrier to groundwater flow. Thus, the specified-flux condition of No Flow has been assigned to these areas. A specified-flux boundary condition has also been used to apply recharge to the model. Because depth to groundwater in most areas of the basin precludes significant groundwater-surface water interaction, it is believed that this boundary condition provides the simplest and most reasonable method for the application of recharge to the model. Finally, groundwater discharge from the model area as spring flow at Del Rio Springs, underflow out of the model area to the north-east, and baseflow at the Agua Fria River are modeled using head-dependent boundary conditions. These boundary conditions most accurately reflect the actual hydrologic conditions in these areas. As water levels in the area drop, discharge declines in both the real world and the simulated hydrologic system.

The model adequately simulates the general trends seen in hydraulic heads and flow directions in the Prescott AMA. The groundwater divide between the Little Chino Sub-basin and the Upper Agua Fria Sub-basin is successfully simulated by the model, though the simulated groundwater divide is located further south than the actual divide. In general, simulated water-level contours and flow directions reflect actual hydrologic conditions.

In addition to these qualitative assessments of the model, the steady-state Prescott AMA model was calibrated to a set of head targets distributed throughout the model area. A goal of 5% error was used to establish calibration adequacy with error defined as the ratio of the root mean squared error or standard deviation to the total head change over the model area (Anderson and Woessner, 1992). This is defined by the following equation:

$$E = \frac{\left[1/n \sum_{i=1}^{n} (h_m - h_s) i^2 \right]^{0.5}}{\Delta H}$$

Where E = error
h_m = Simulated Head Value
h_s = Measured Head Value, and
ΔH = Total head change in the model area

Adapted from Anderson and Woessner, 2002

Based on these criteria, the steady-state model was calibrated to 72 head targets as well as flux targets for discharge at Del Rio Springs and baseflow at the Agua Fria River. There were 25 head targets in the Upper Alluvial Unit (Layer 1) and 47 head targets in the Lower Volcanic Unit (Layer 2) (Figure 10). Twenty-two of the targets in the LVU were used as calibration targets in earlier versions of the Prescott AMA model. Twenty-five targets in the LVU were developed for this model, while the 25 targets in the UAU were all new to this model. Eleven of the UAU targets and one of the LVU targets were taken from the observed potentiometric surface produced by the original modeling study. The remaining 14 UAU targets and 24 LVU targets were taken from the Groundwater Site Inventory database maintained by ADWR (2005b). See Appendix B for a list of steady-state targets.

Based on the same calibration criteria, the transient Prescott AMA model was calibrated to 2324 target values at 113 different wells (Figure 10). 716 target values at 45 wells were located in Layer 1, while 1608 target values at 68 wells were located in Layer 2 (Figure 11). All of the target values were taken from the GWSI database (ADWR, 2005b).

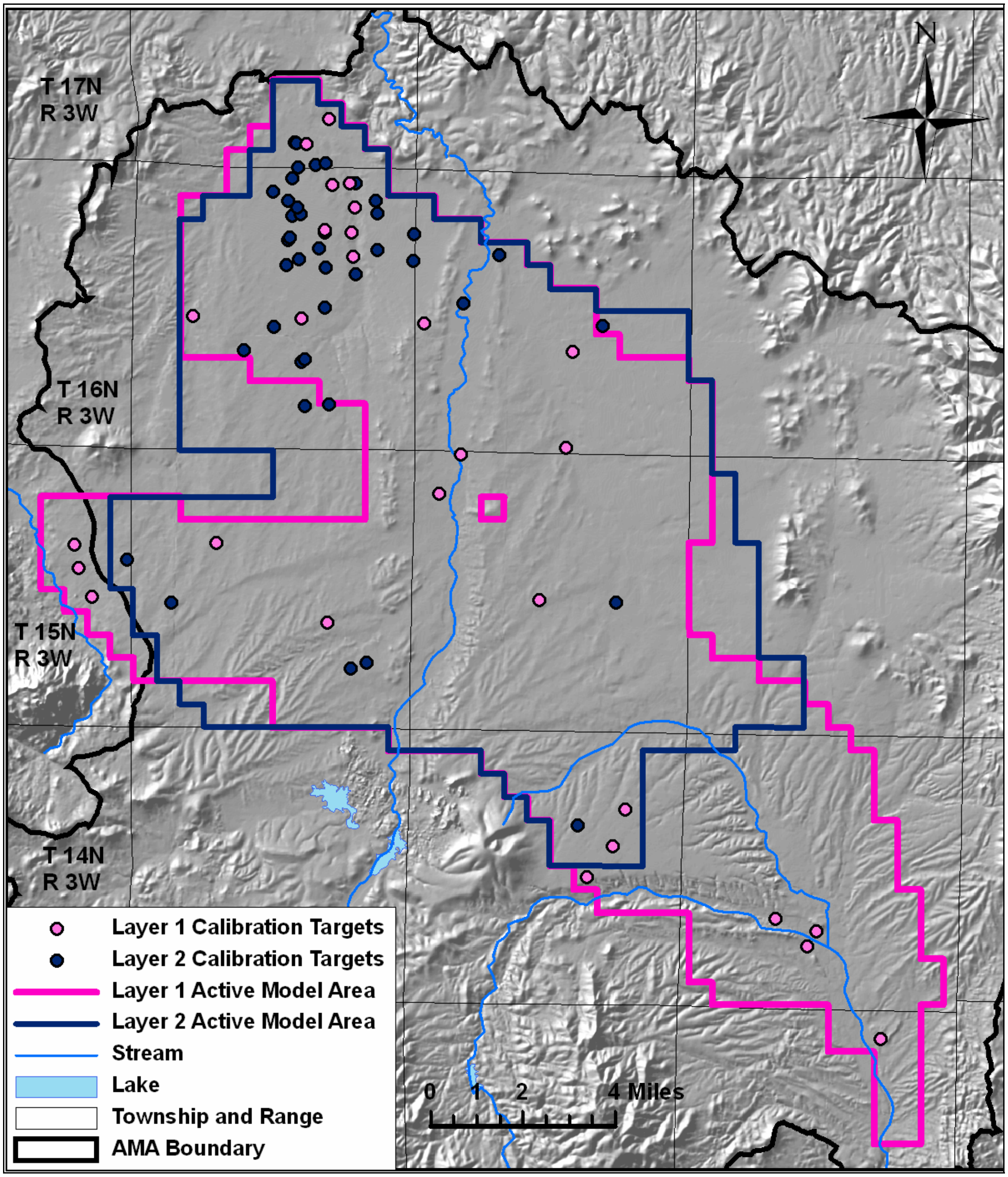

Figure 10. Location of water-level calibration targets for the steady-state simulation of the updated Prescott AMA groundwater flow model.

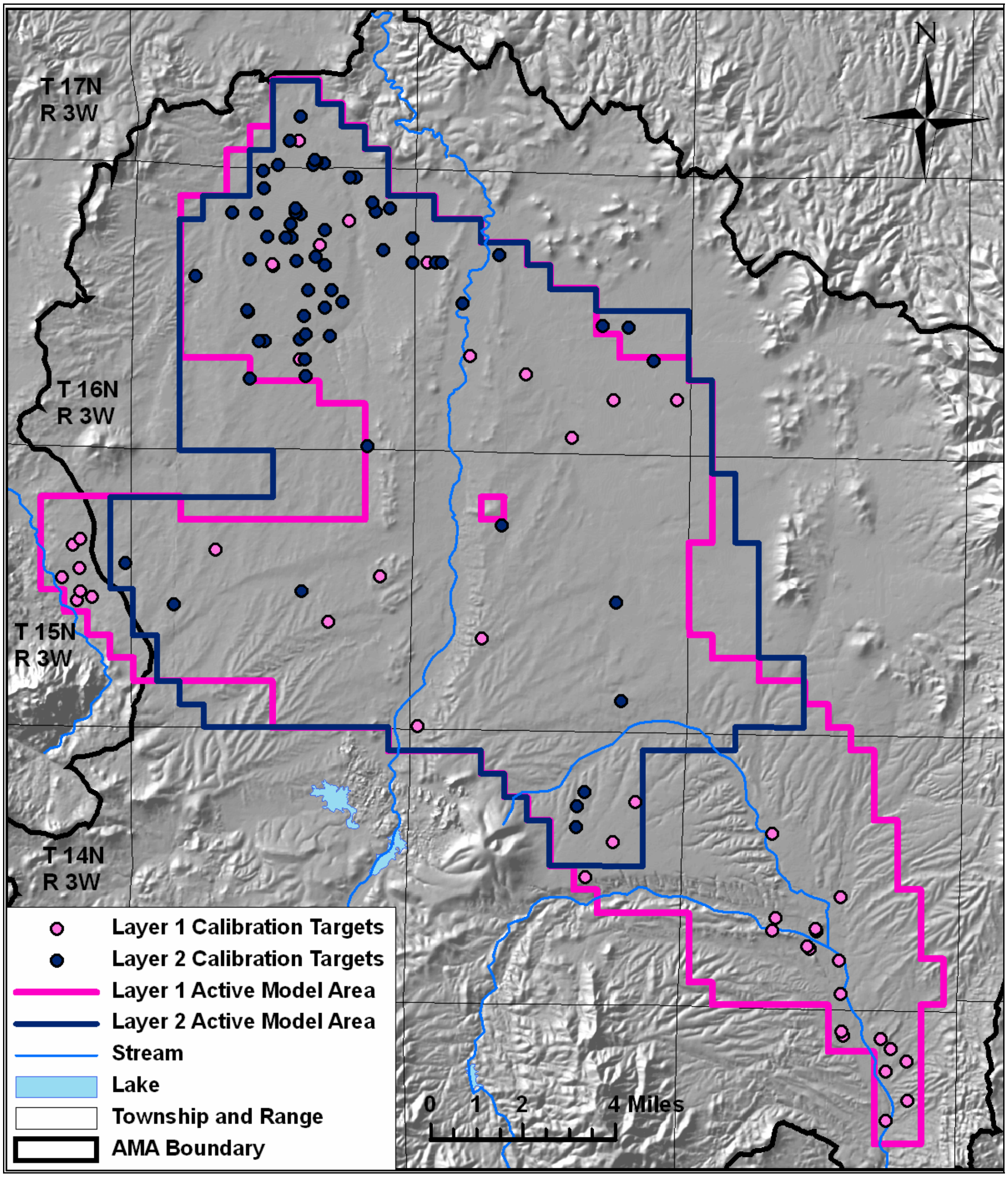

Figure 11. Location of water-level calibration targets for the transient simulation of the updated Prescott AMA groundwater flow model.

Parameter Estimation Techniques

While previous modeling studies of the Prescott AMA relied on trial and error techniques to achieve calibration, automated parameter estimation techniques have since become widely available. This study relied on automated parameter estimation as one of the techniques used for calibration. The computer code PEST was used to perform inverse modeling, posed as a parameter estimation problem (Watermark Numerical Computing, Brisbane). PEST calculates parameter values that minimize a weighted least-squares objective function through non-linear regression using a modified Gauss-Newton method (Hill, 1998). This is an iterative form of non-linear regression that relies on a damping parameter and a Marquadt parameter to function properly. For a more thorough description of inverse modeling and automated calibration, see *PEST: Model-Independent Parameter Estimation* (2002) and Hill (1998).

The use of PEST provided estimated optimal parameter values for horizontal and vertical hydraulic conductivity as well as conductance for the head-dependent boundaries in the model. While utilizing these estimated parameter values in the model minimizes the objective function and provides a close fit between observed and simulated heads and fluxes, inverse modeling does not always provide the most optimal calibration according to Hill's three primary criteria: better fit, random residuals, and realistic parameter values. The optimized parameter values calculated by PEST provide the best fit to observed heads and fluxes; however, the program does not take randomness of residuals and realism of parameter values into consideration. Thus, the results of PEST were used as initial parameter values and subsequently modified by manual techniques to bring model parameter values into closer agreement with pumping test results and to achieve a more random array of head residuals. See Figures 8 and 9 for the final calibrated values of hydraulic conductivity.

Results of the Steady-State Simulation

The results of the steady-state simulation were evaluated by comparing simulated water budgets with conceptual estimates and simulated heads with measured water levels.

Steady-State Water Budget

The results of the steady-state simulation indicate that the simulated water budget compares well with the conceptual water budget (Table 7). Model input values for recharge and groundwater pumpage match conceptual estimates. Model output values for groundwater discharge from Del Rio Springs were at the upper limit of conceptual estimates, while simulated discharge at the Agua Fria River was well within conceptual estimates. Simulated subsurface flow from the Little Chino sub-basin was also within conceptual estimates.

Steady-State Calibration Error Analysis

Simulated heads from the steady-state solution were compared with 50 measured and 22 estimated groundwater levels from the steady-state period (Figures 12 and 13). These include 26 targets in the Upper Alluvial Unit and 46 targets in the Lower Volcanic Unit. See Chapter 4 for a discussion of the target data utilized for the model calibration. Table 8 provides statistical summaries of the calibration error analysis.

Table 7. Simulated and conceptual water budgets for the steady-state simulation of the updated Prescott AMA groundwater flow model.

Inflow	Model Simulation acre-feet/simulation[1] (af/yr)	Conceptual acre-feet/simulation[1] (af/yr)
Mountain Front and Granite Creek Recharge	3,900 (6,800 af/yr)	3,900 (6,800 af/yr)
Agricultural Recharge	2,200	2,200
Canal Recharge	950	950
Total Inflow	**7,050**	**7,050**
Outflow	**Model Simulation**	**Conceptual**
Groundwater Pumpage	1,500	1,500
Groundwater Discharge Del Rio Springs	2,000 (3,500 af/yr)[2]	1,300-2000 (2,300 -3,400 af/yr [3]) (2,700 - 3,800 af/yr [3a])
Groundwater Discharge Agua Fria River	1,200 (2,100af/yr)[4]	900-1,400 (1,500 - 2,500 af/yr [5])
Groundwater Discharge Subsurface Flow	2,350 (4,100 af/yr)	1,300-2,600 (2,200 -4,500 af/yr [6]) (5,600 af/yr [7]) (2,000 af/yr[8])
Total Outflow	**7,050**	**5,000 - 7,500**

[1] The steady-state model simulated the 210 day agricultural season for 1939. The water budget totals are the totals for this 210 day simulation while figures in parentheses are annualized totals for 1939.

[2] Contains an undifferentiated ET component estimated at 100-200 ft/yr (Nelson, 2002)

[3] Max and min annual surface water measurements at Del Rio Springs 1940-1945 (Schwalen, 1967)

[3a] Surface-water measurements plus estimated 400 AF/YR for ET demand and unreported surface-water diversions upstream of gauge (Foster, 2001)

[4] Contains an undifferentiated ET component estimated at 200 af/yr

[5] Corkhill and Mason, 1995

[6] Darcy strip analysis (Nelson, 2002)

[7] Groundwater discharge as subsurface flow based on confined well steady-state equation (SRP, 2000).

[8] Corkhill and Mason, 1995 (Note: UAU aquifer only)

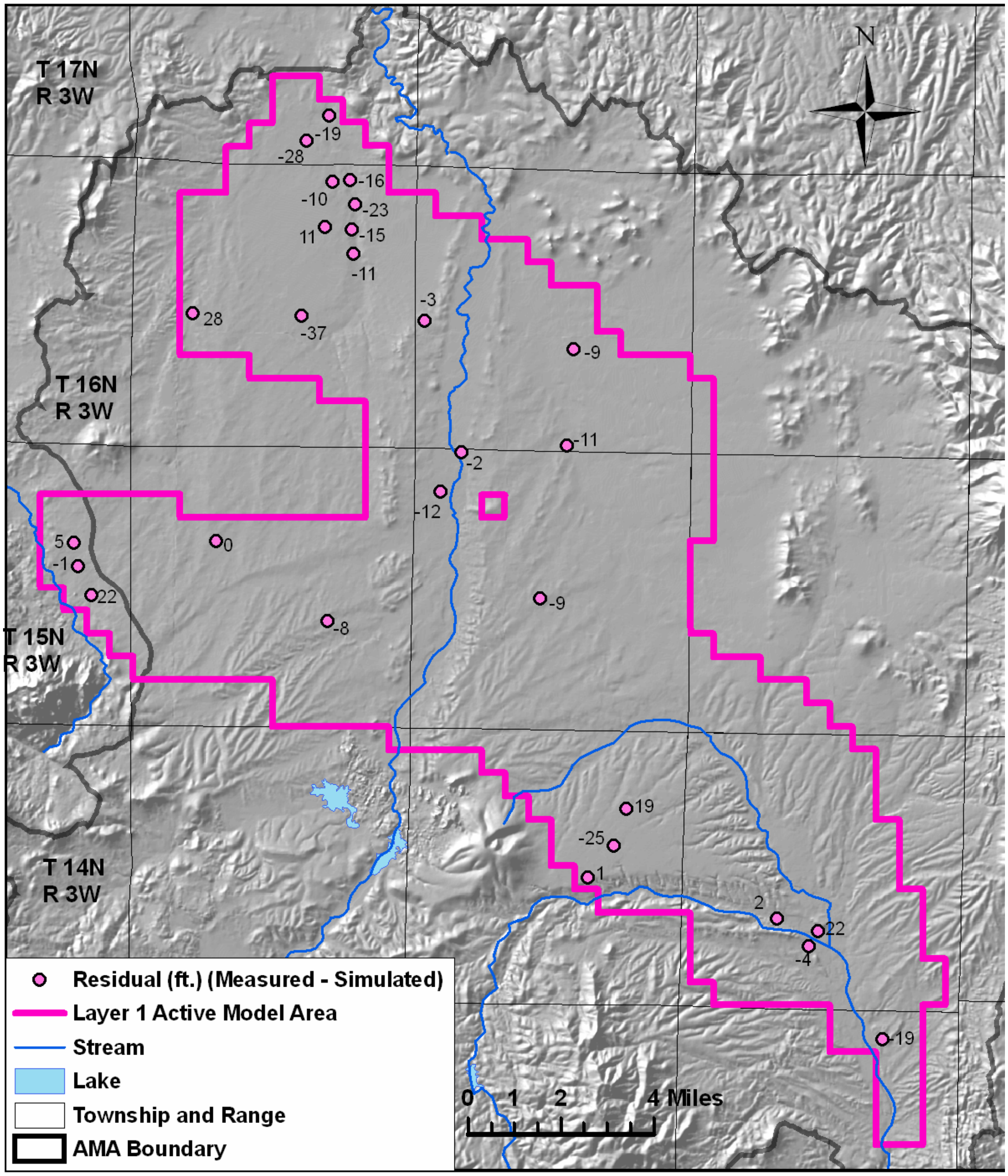

Figure 12. Difference between measured and simulated water levels in the Upper Alluvial Unit for the steady-state simulation of the updated Prescott AMA groundwater flow model.

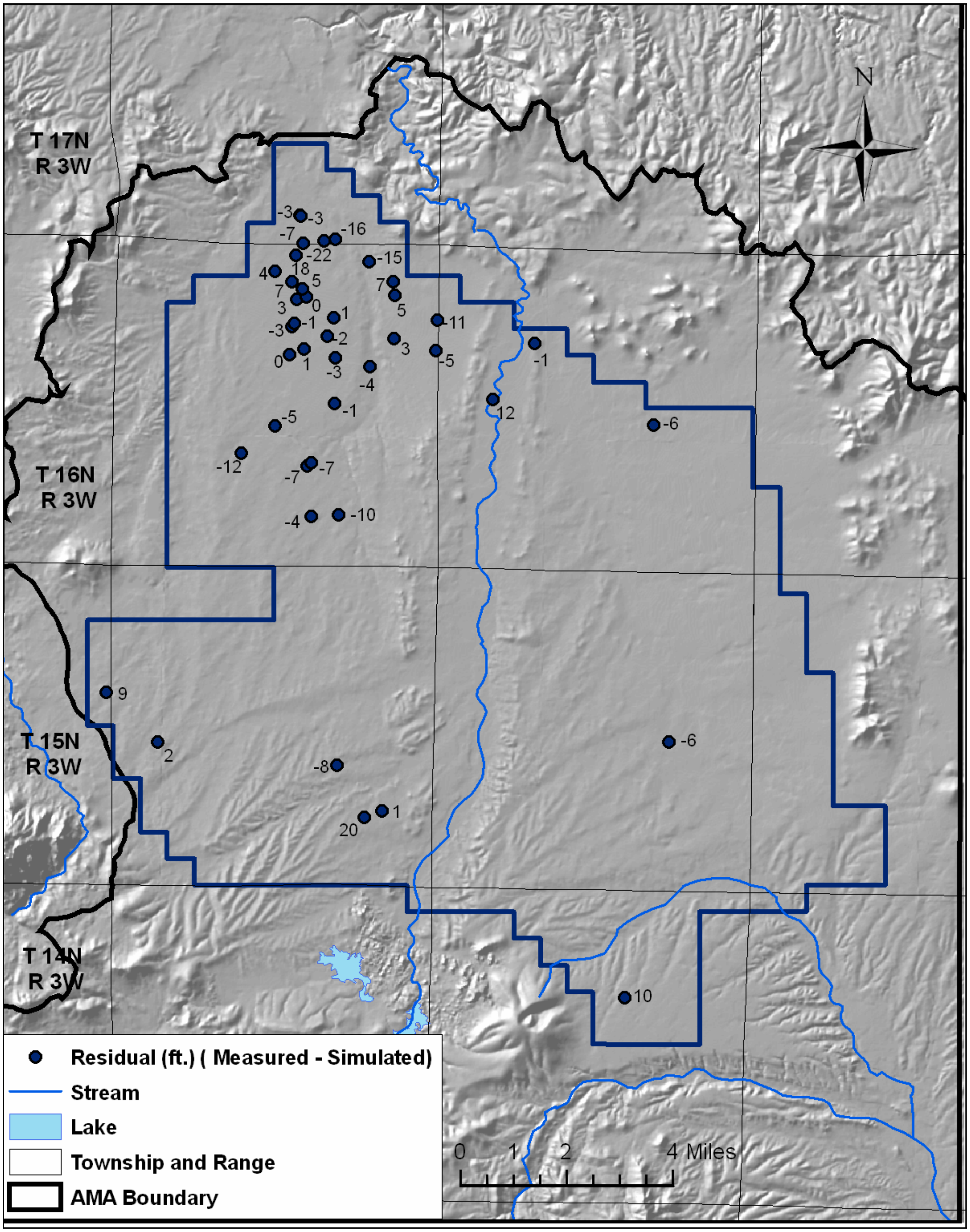

Figure 13. Difference between measured and simulated hydraulic heads in the Lower Volcanic Unit for the steady-state simulation of the updated Prescott AMA groundwater flow model.

Table 8. Statistical summary of error analysis for (A) the combined Upper Alluvial Unit (layer 1) and Lower Volcanic Unit (layer 2), (B) the Upper Alluvial Unit (layer 1), and (C) the Lower Volcanic Unit (layer 2) for the steady-state simulation of the updated Prescott AMA groundwater flow model.
(Residual = measured head value – simulated head value (ft.))

A

Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	E = Standard Deviation / Range in Head
-3.08	9.14	11.78	-37.38	27.66	0.020

B

Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	E = Standard Deviation / Range in Head
-5.42	13.27	15.49	-37.38	27.66	0.026

C

Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	E = Standard Deviation / Range in Head
-1.59	6.51	8.29	-22.19	20.4	0.024

Discussion of Steady-State Simulation Results

The simulated ‘natural’ discharge rate out of the Little Chino sub-basin from groundwater discharge at Del Rio Springs and subsurface flow out of the model area to the north totaled about 7,600 af/yr. The simulated discharge rate for Del Rio Springs was about 3,500 af/yr, which is within conceptual estimates. When compared to previous versions of the model which over-simulated discharge from Del Rio Springs this discharge rate represents an improved correspondence between simulated and conceptual steady-state discharge (Corkhill and Mason 1995) (Nelson 2002).

The simulated subsurface groundwater discharge to the adjoining Big Chino Sub-basin was about 3,900 af/yr. This is also within conceptual estimates; however, it should be noted that considerable uncertainty exists regarding the conceptual subsurface groundwater discharge rate (Table 7). The simulated subsurface discharge rate is also higher than the simulated values of previous models; however, it was expected that reducing discharge from Del Rio Springs to within conceptual estimates would result in greater subsurface flow from the Little Chino Sub-basin.

The simulated groundwater discharge rate in the Upper Agua Fria sub-basin was about 2,025 af/yr. This is within the conceptual estimates of baseflow in the Agua Fria River near Humboldt (Corkhill and Mason 1995).

The error associated with the head residuals was within the calibration goals of the model. Results indicate that the error associated with the residuals was 2.0% of the total head change in the groundwater system (Table 8). This is significantly better than the 5% criterion defined earlier as an indication of a well-calibrated model (Anderson and Woessner 1992).

Qualitative assessment was also required to ensure that the calibration followed the criteria set out by Hill (1998) (Figures 12 and 13). The distribution of residuals in the Upper Agua Fria sub-basin is generally random; that is, there is no clear spatial pattern of simulated heads being too high or too low. Simulated heads in the Little Chino Sub-basin, however, are consistently higher than measured heads. While this bias is undesirable, it represents a reasonable compromise between achieving model-wide calibration acceptability and randomness in the distribution of model residuals. In addition, this bias was necessary to adequately simulate the groundwater discharge rates out of the Little Chino sub-basin and to accurately simulate the groundwater declines observed over the transient period.

Contours of simulated and measured water levels in the Upper Alluvial Unit and the Lower Volcanic Unit were displayed and compared (Figures 14 and 15). These comparisons indicate that the model provides a reasonable approximation of general water-level contours and flow direction.

Finally, proper calibration requires the use of reasonable parameters. While there are limited field data regarding the hydrologic properties of the aquifers in the Prescott AMA, the hydraulic conductivity and storage values used in the model fall within conceptual estimates.

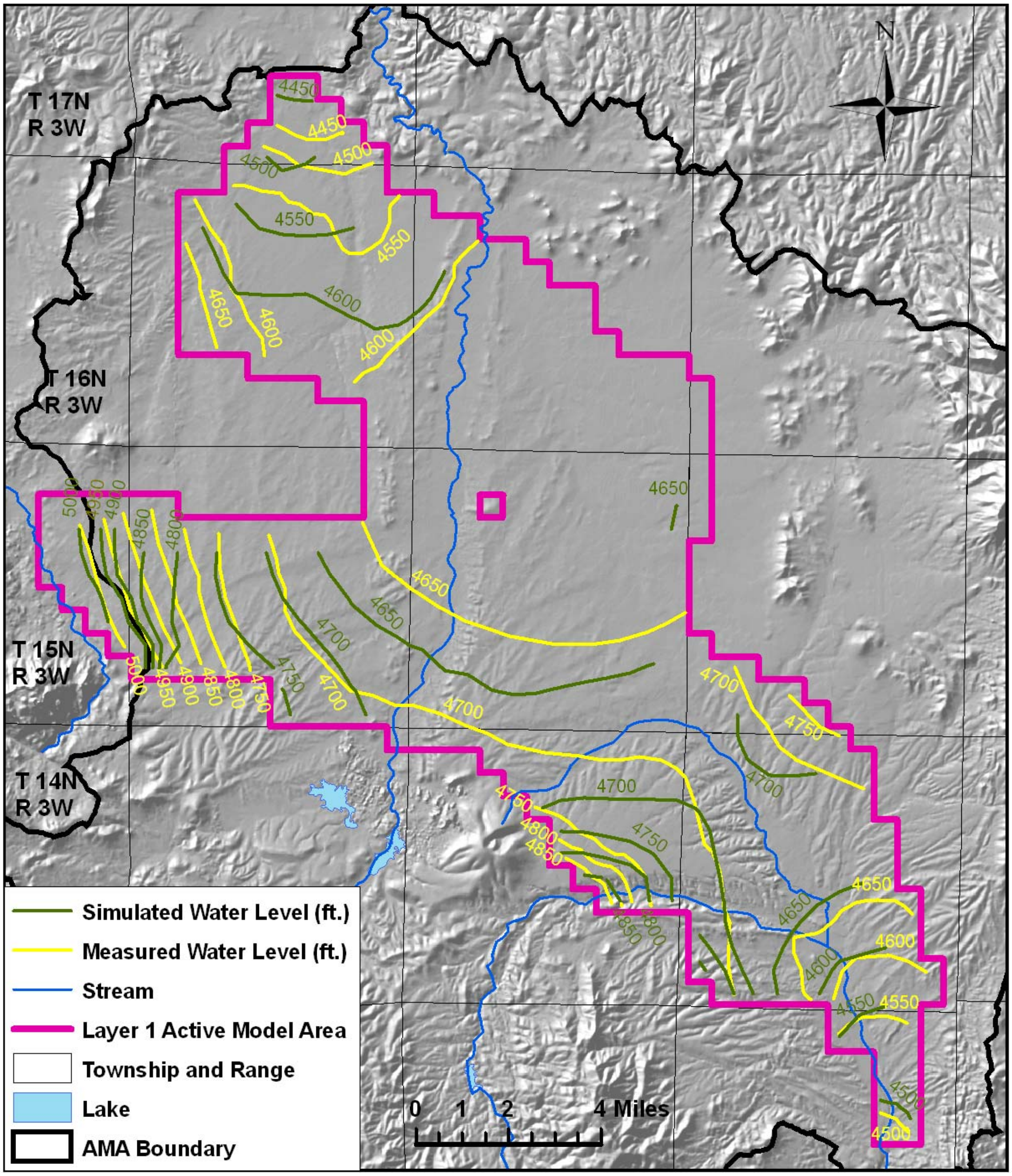

Figure 14. Measured and simulated water-level contours in the Upper Alluvial Unit for the steady-state simulation of the updated Prescott AMA groundwater flow model. (50 ft. contour interval)

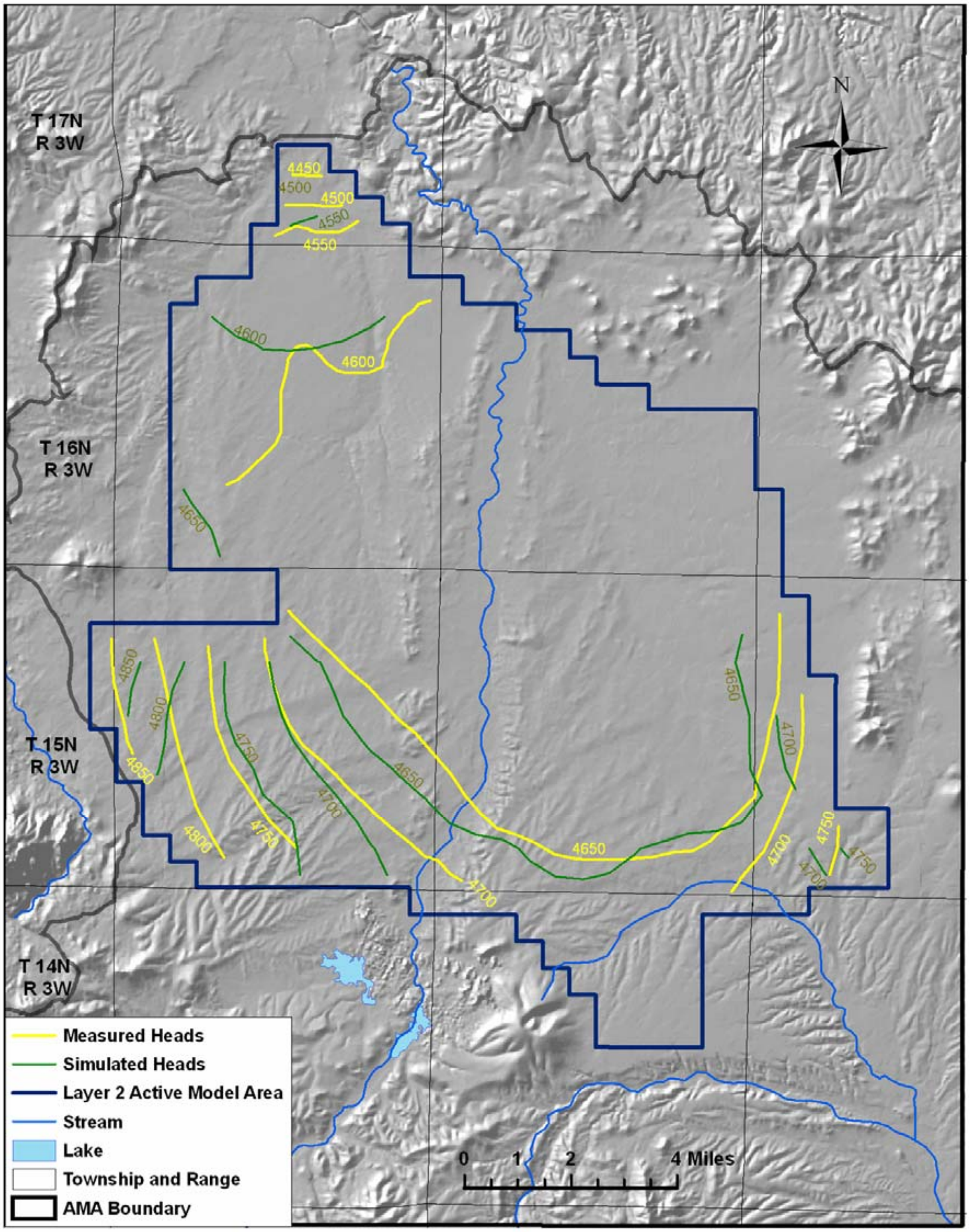

Figure 15. Measured and simulated hydraulic head contours in the Lower Volcanic Unit for the steady-state simulation of the Prescott AMA groundwater flow model. (50 ft. contour interval)

Results of the Transient Simulation

Results of the transient simulation were evaluated by comparing simulated water budgets with conceptual estimates and simulated heads with measured water levels.

Transient Water Budget

Simulated and conceptual water budgets were compared for 1940 and 2004 (Table 9). As expected, the water budget for 1940 shows differences from earlier versions of the model similar to those seen in the steady-state water budget. Decreased discharge from Del Rio Springs and increased subsurface discharge to the north out of the Little Chino Sub-basin were seen compared to earlier versions of the model; however simulated values were all within conceptual estimates. For 2004, simulated results were compared with conceptual estimates.

Transient Calibration Error Analysis

Simulated heads were compared with groundwater levels measured throughout the period of the transient simulation (1940-2004) in a statistical error analysis (Table 10). A total of 2,324 target values at 113 different wells were used for statistical error analysis, including 716 target values at 47 wells in the Upper Alluvial Unit aquifer and 1,608 targets at 66 wells in the Lower Volcanic Unit aquifer.

The results of the statistical analysis indicate that the attransient simulation of the Prescott AMA groundwater flow model was calibrated to within the previously stated calibration goals (Table 10). The combined error for the two model layers was less than 3%, while the error for each of the two layers was less than the calibration goal of 5%. The results indicate that simulated results provide a better fit to measured head values in the Lower Volcanic Unit aquifer than in the Upper Alluvial Unit aquifer. This is possibly due to the larger number of calibration targets used in the LVU for both the steady-state and transient simulations.

Qualitative assessment was used along with the statistical analyses to verify the general pattern of groundwater contours and flow direction (Figures 16 and 17). These figures indicate that the general pattern of groundwater levels and flow directions was effectively simulated by the groundwater flow model.

A series of hydrographs was also produced to compare simulated and measured water levels at individual wells throughout the model area (Figures 18 – 25). These hydrographs indicate that the model was generally effective at reproducing observed water-level trends in all portions of the AMA. There is a large seasonal fluctuation in simulated water levels in the primary agricultural pumping area of Little Chino Valley (Figure 18). While it appears the model may have simulated greater seasonal fluctuations than actually observed, the lack of seasonal observational data makes this determination inconclusive.

In contrast to the trends shown in the northern Little Chino Valley area (Figure 18), a well in the central Little Chino Valley area (Figure 19) indicates that over the past decade the model may actually have simulated *less* seasonal changes than observed. This is likely due to the shift in pumping from agricultural to municipal uses. While agricultural pumping was simulated seasonally, pumpage for municipal purposes was simulated based on average annual rates. Actual pumping rates for municipal uses are, in fact, higher in the summer than in the winter; however, the model failed to account for this seasonal variability. The model effectively reproduced observed water-level trends

Table 9. Simulated and conceptual water budgets (1940 and 2004) for the transient simulation of the updated Prescott AMA Groundwater Flow Model.

Inflow	Simulated 1940 af/yr	Simulated 2004 af/yr	Conceptual 2004 af/yr
Natural Recharge	5,800	5,800	5,800
Recharge: Incidental and Artificial Recharge	4,100	7,600	7,600
Flood Recharge	0	21,700 [7]	21,700
Total Inflow	**9,900**	**35,100**	**35,100**
Outflow	**Simulated 1940**	**Simulated 2004**	**Conceptual 2004**
Pumpage	4,600	23,000	23,800
Groundwater Discharge Del Rio Springs (LIC)	3,600 [1]	1,300 [1]	1,000 [2] 1,400 [2a]
Groundwater Discharge Agua Fria River (UAF)	2,100 [3]	1,400 [3]	1,300 [4]
Subsurface Flow (LIC)	3,500	1,400	1,900-2,000 [5] 1,200-2,000 [6]
Total Outflow	**13,800**	**27,100**	**26,500 – 28,200**
Change in Storage	**-3,900**	**8,000**	**6,900 – 8,600**

[1] Contains and undifferentiated ET component estimated at 100-200 af/yr

[2] Surface water measurements (mean) at Del Rio Springs (2004) (USGS, 2004).
Note: Sub-basin groundwater discharge rate does not reflect estimated ET demand of 100 af/yr upstream of gauge.

[2a] Surface water measurements at Del Rio Springs (2004) plus 400 af/yr for ET demand and surface water diversions upstream of gauge (Foster, 2001)

[3] Contains an undifferentiated ET component estimated at 200 af/yr

[4] Median surface water measurements at Agua Fria River (2004) plus 200 af/yr for estimated ET demand upstream of gauge

[5] Results of USGS tracer dilution study (Wirt et. al, 2004)

[6] Darcy Strip Analysis (Nelson, 2002)

[7] Flood recharge includes flooding from January - March 2005.

Table 10. Statistical summary of error analysis for (A) the combined Upper Alluvial Unit (layer 1) and Lower Volcanic Unit (layer 2), (B) the Upper Alluvial Unit (layer 1), and (C) the Lower Volcanic Unit (layer 2) for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004).
(Residual = measured head value – simulated head value (ft.))

A

Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	E = Standard Deviation / Range in Head
10.8	17.96	21.85	-89.56	146.95	0.029

B

Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	E = Standard Deviation / Range in Head
16.04	22.87	24.2	-48.55	71.19	0.041

C

Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	E = Standard Deviation / Range in Head
8.16	15.47	20.05	-89.56	146.95	0.033

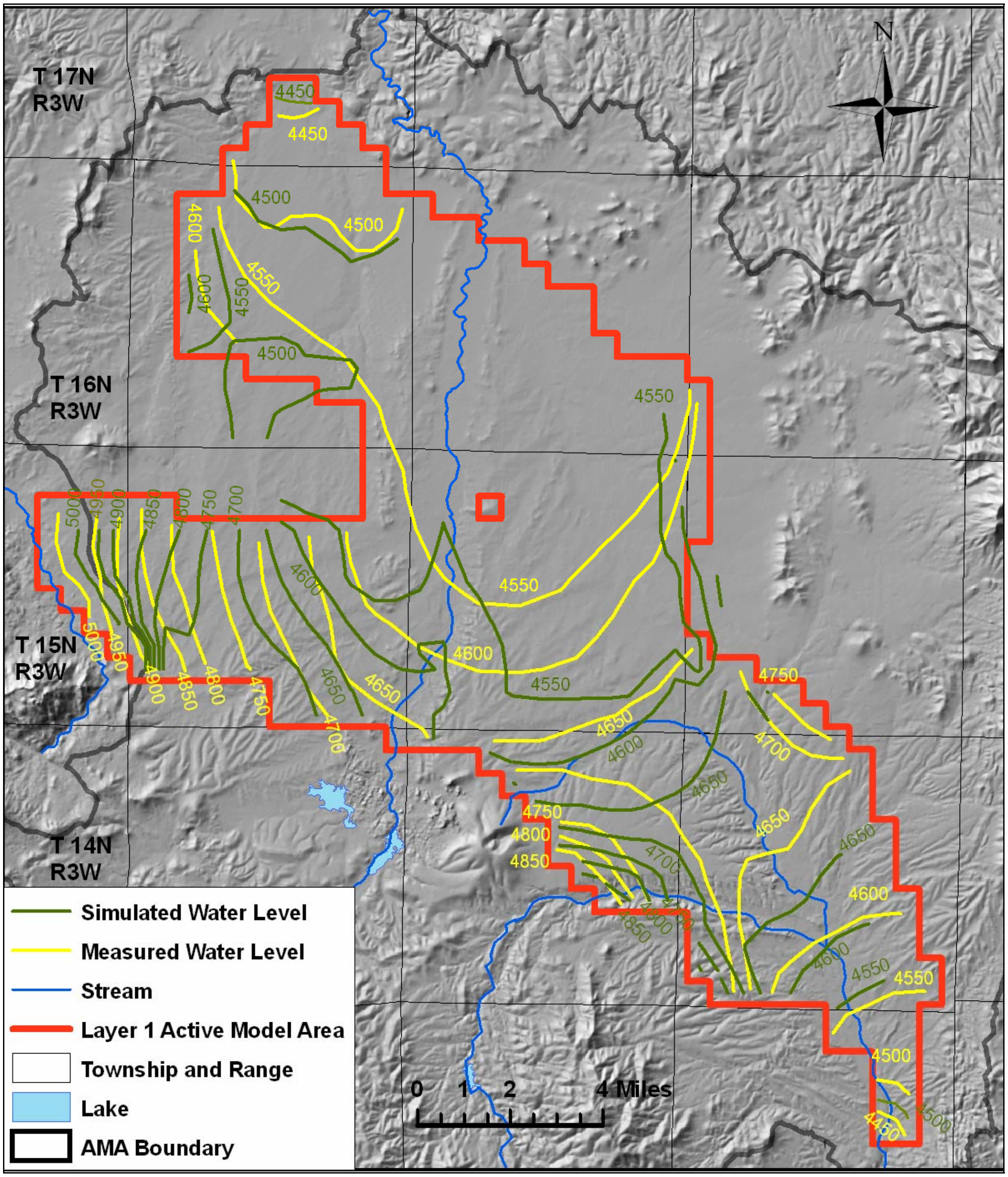

Figure 16. Measured and simulated water levels in the Upper Alluvial Unit at the end of the transient simulation of the updated Prescott AMA groundwater flow model (2005).

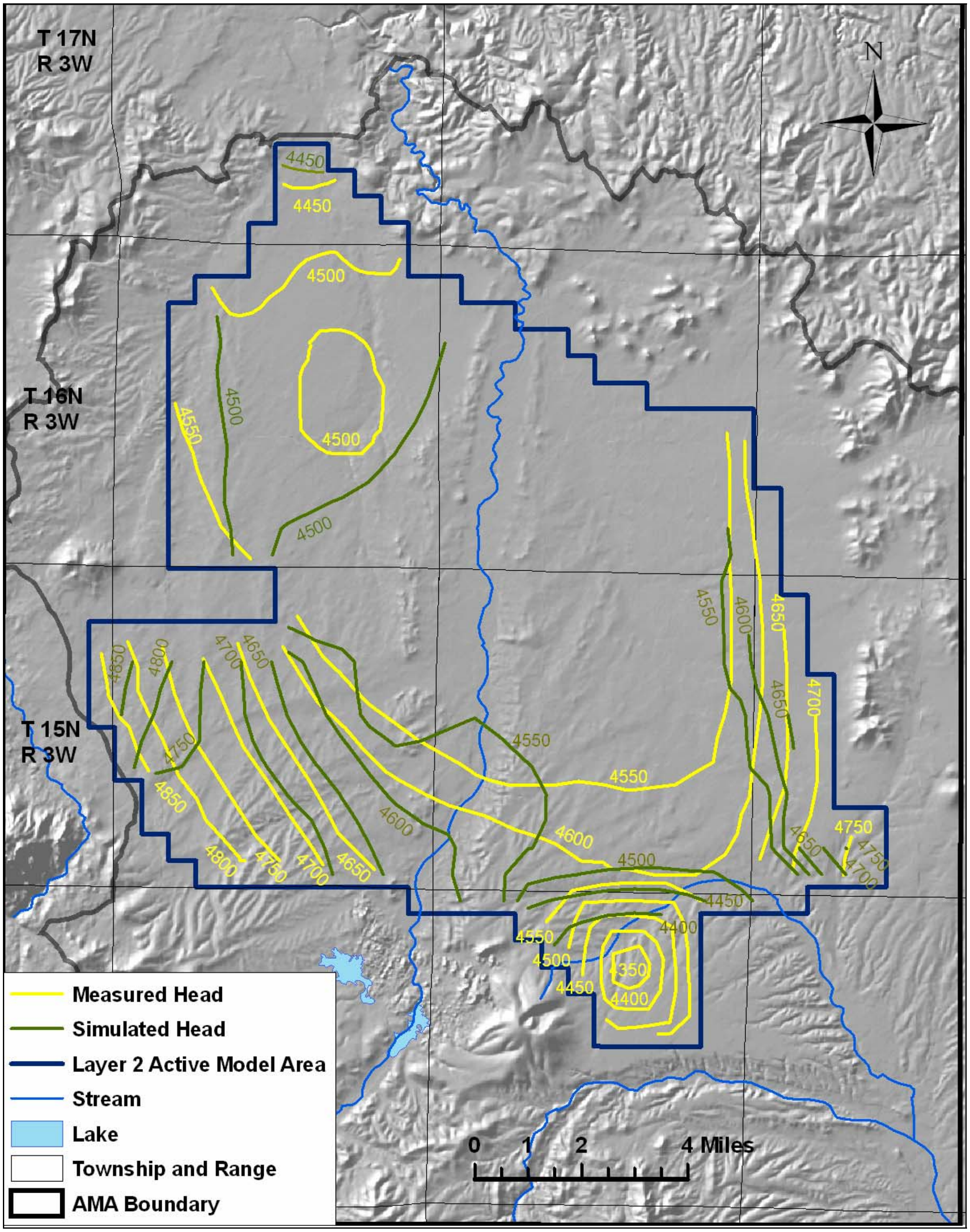

Figure 17. Measured and simulated water levels in the Lower Volcanic Unit at the end of the transient simulation of the updated Prescott AMA groundwater flow model (2005).

in southern Little Chino Valley, northeastern Little Chino Valley area, and Lonesome Valley (Figures 20, 21, and 22).

As significant groundwater development did not occur in the Mint Wash area until the 1980's, it was conceptualized that water levels in this area would have remained generally stable until the 1980's. Simulated water levels in this area follow this conceptual understanding of the area (Figure 23). .

Significant declines in groundwater levels were observed and simulated for the Prescott Valley Santa Fe Wellfield between 1970 and 2004 (Figure 24). The model reproduced this general trend in water levels; however, simulated results do not capture observed seasonal fluctuations possibly due to variations in pumping schedules for the different wells in the area. It should be noted that the development of Prescott Valley's North Wellfield in 2005 has lead to a decrease in pumping from the Santa Fe Wellfield and allowed water levels to rebound in several wells in the area (ADWR GWSI database). Because this model simulation ended prior to this change in pumping, this change is not reflected in this study or model simulations.

There was a strong correspondence between simulated and observed fluctuations in water levels in the Upper Lynx Creek area, likely due to well-simulated flood-induced recharge in the streambed of Lynx Creek (Figure 25).

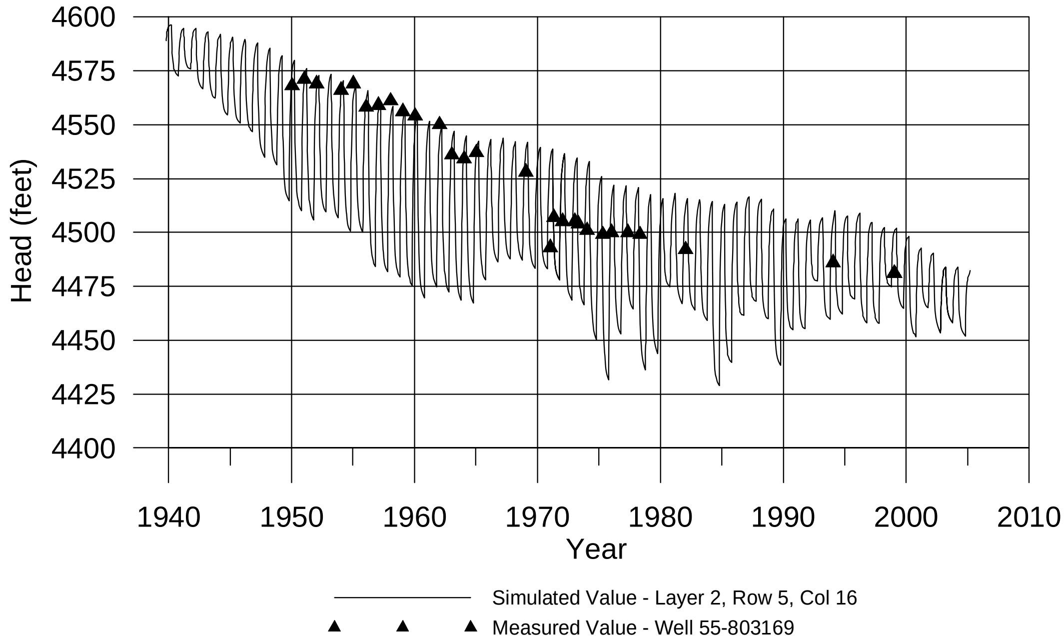

Figure 18. Measured and simulated water levels in the northern Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model.

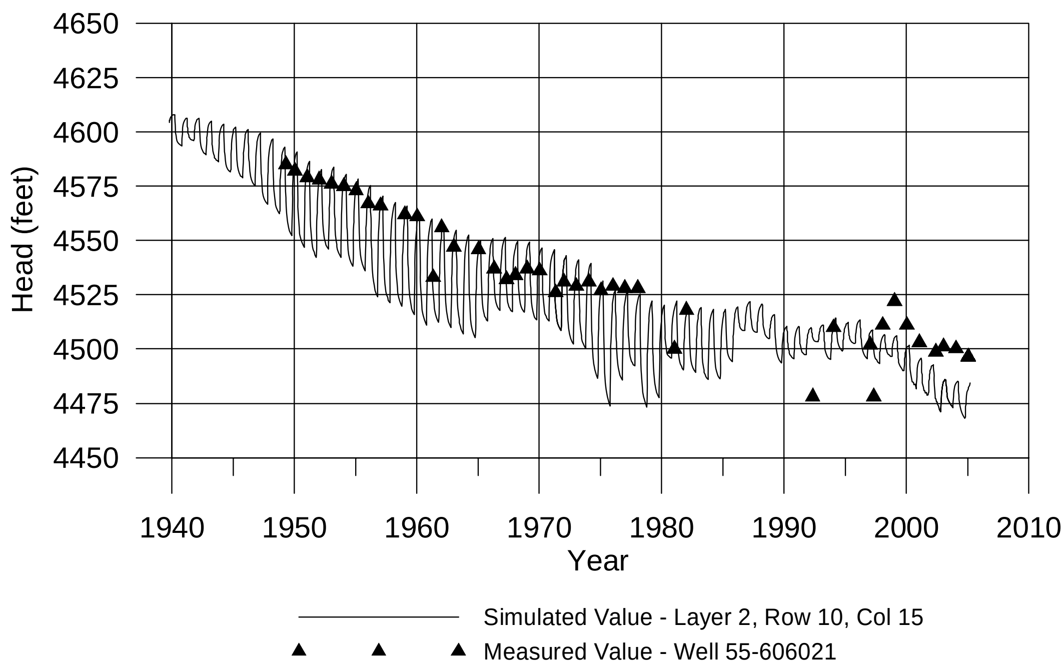

Figure 19. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model.

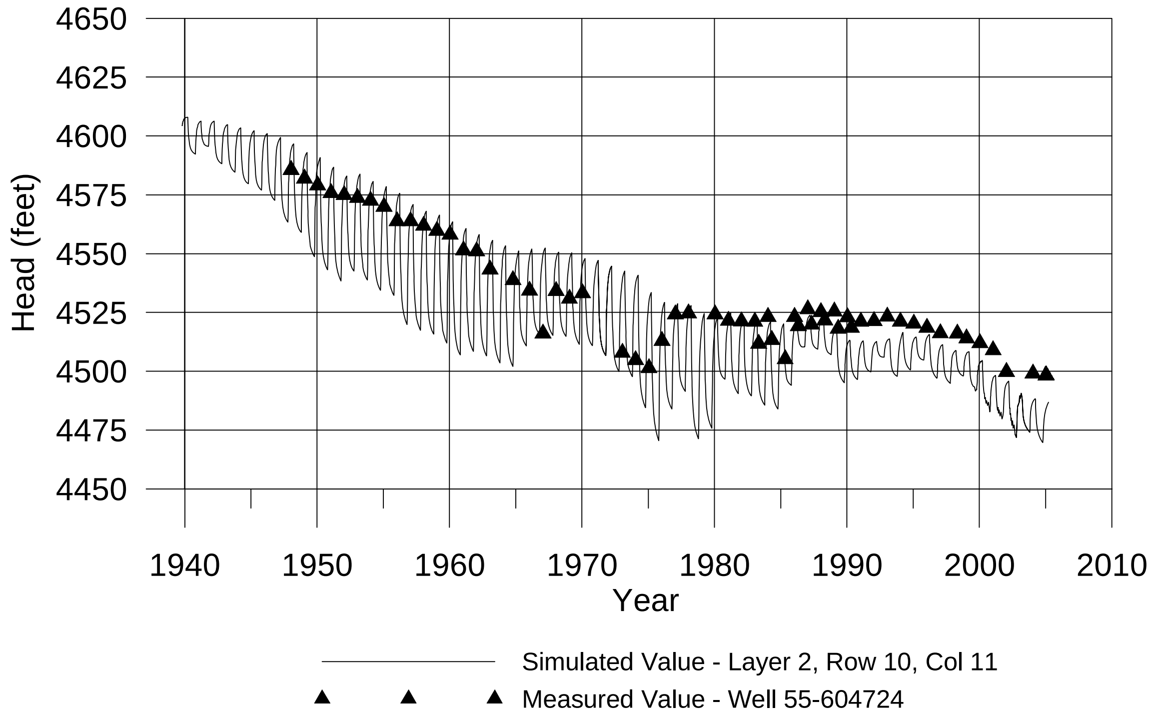

Figure 20. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model.

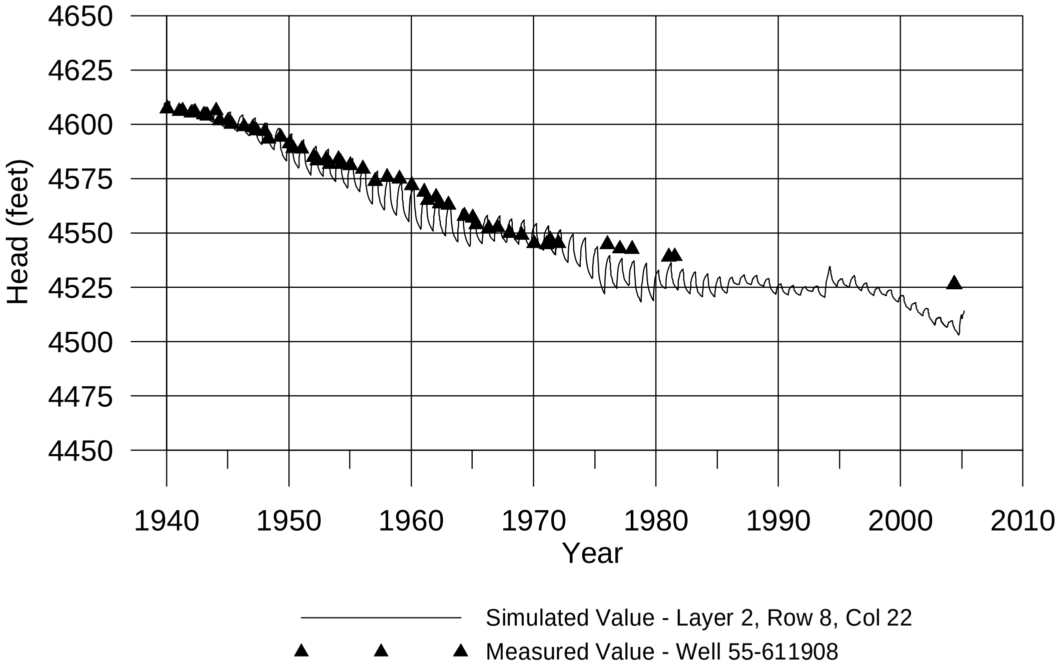

Figure 21. Measured and simulated water levels in the northeast Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model.

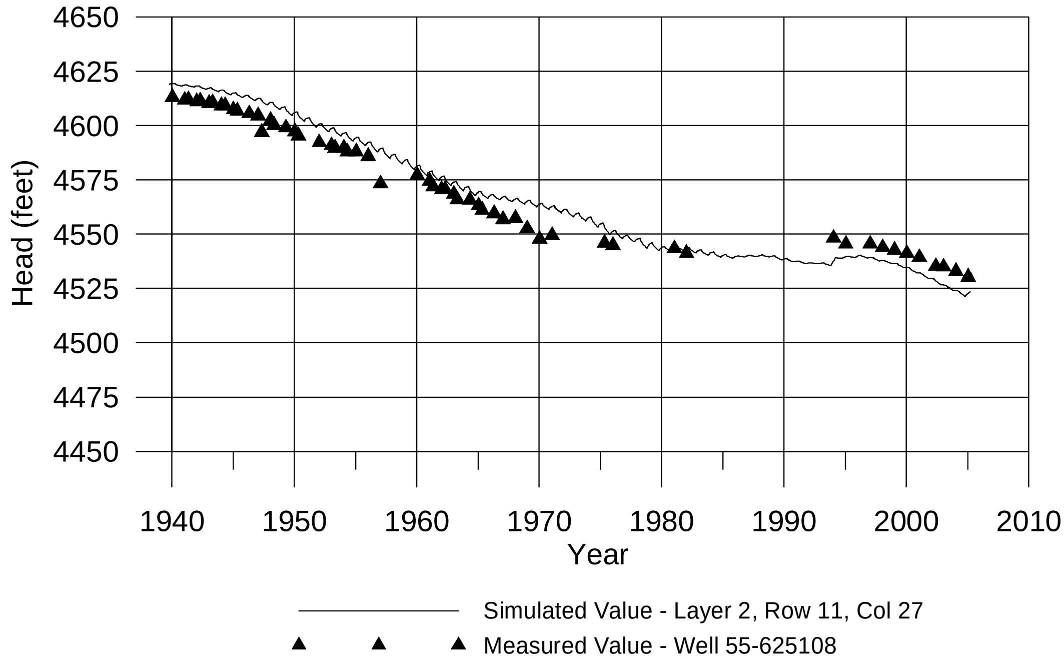

Figure 22. Measured and simulated water levels in the Lonesome Valley area for the transient simulation of the Prescott AMA groundwater flow model.

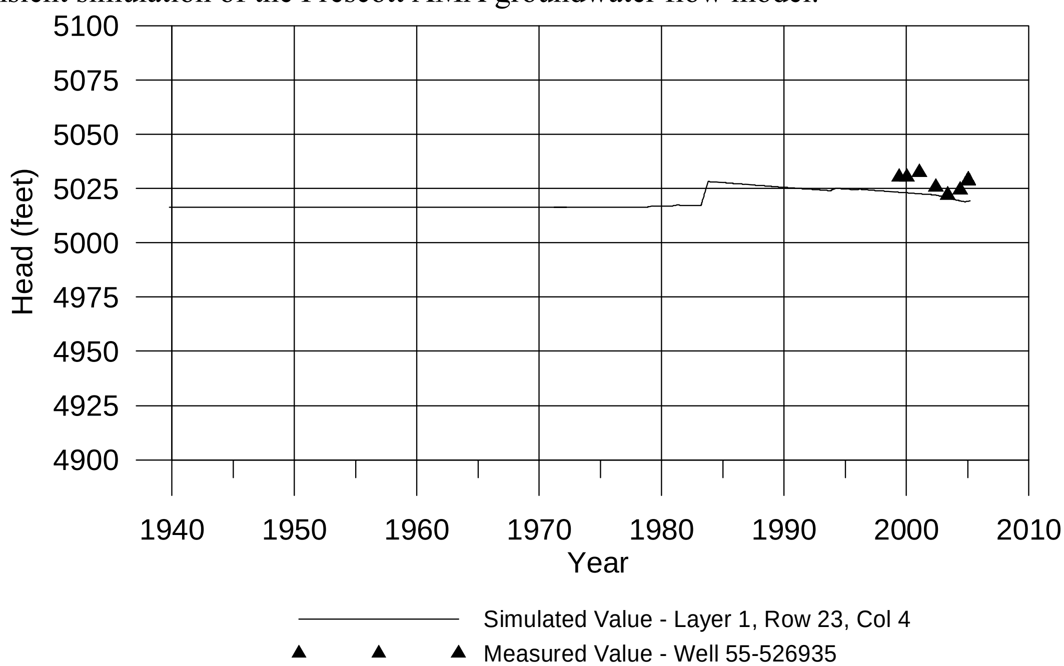

Figure 23. Measured and simulated water levels in the Mint Wash area for the transient simulation of the Prescott AMA groundwater flow model.

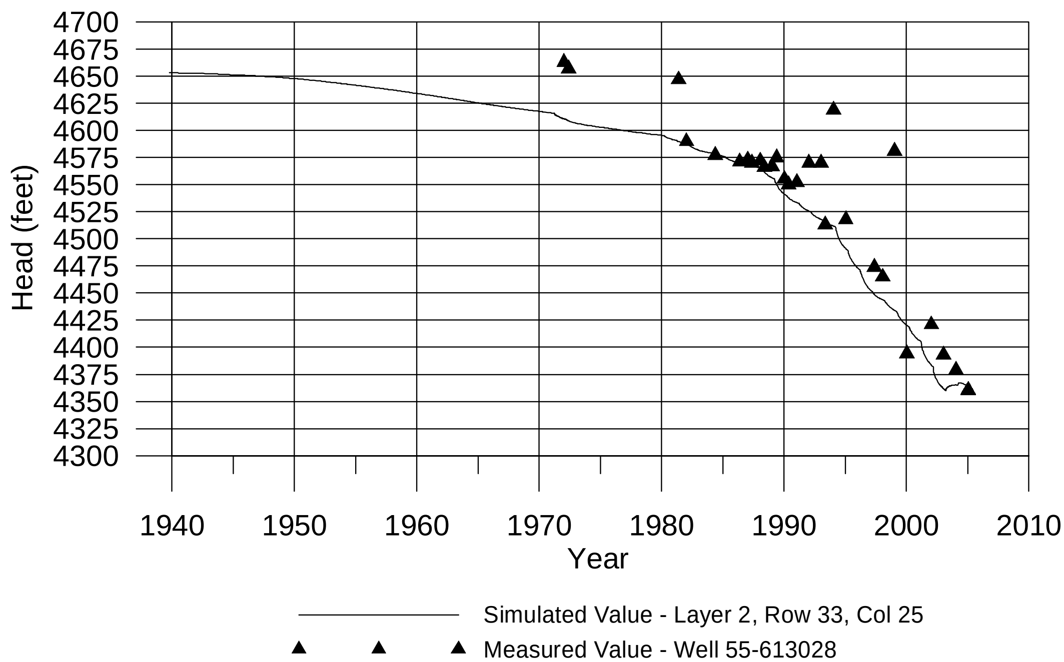

Figure 24. Measured and simulated water levels in the Prescott Valley Santa Fe Wellfield area for the transient simulation of the Prescott AMA groundwater flow model.

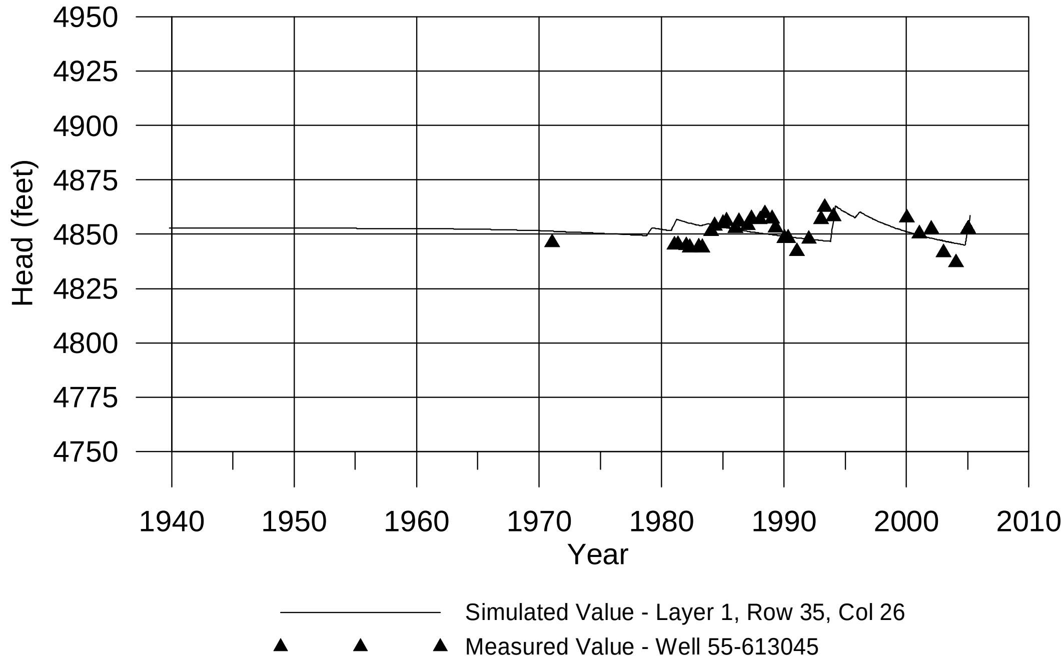

Figure 25. Measured and simulated water levels in the Upper Lynx Creek area for the transient simulation of the Prescott AMA groundwater flow model.

Discussion of Transient Simulation Results

The results of the transient simulation indicate that, overall, the simulated groundwater system experienced a net loss of storage and an increase in capture of groundwater discharge. These results follow conceptual estimates as well as previous modeling results (Corkhill and Mason 1995; Nelson 2002). Over the period from 1940 – 2004, simulated annual groundwater discharge from Del Rio Springs declined from about 3,600 acre-feet to around 1,300 acre-feet, a decline of 2,300 af/yr or 64% (Figure 26, Table 9). Total simulated natural discharge from the Little Chino sub-basin as groundwater discharge at Del Rio Springs and subsurface flow out of the model area has declined from around 7,600 af/yr to around 2,700 af/yr, a decline of 4,900 af/yr or 65%. Over the period from 1940 – 2004, discharge from the Upper Agua Fria sub-basin as baseflow in the Agua Fria River also declined approximately 700 af/yr, or 33%. (Figure 27, Table 9). From 1940 – 2004, annual natural groundwater discharge from the two aquifers declined from 9,200 acre-feet to 4,100 acre-feet, a decrease of 55% (Figure 28, Table 9).

Change in groundwater storage is another indicator of aquifer condition. Model results indicate that over the simulated period from 1939 through 2004, approximately 1,048,000 acre-feet of groundwater was removed from the aquifers of the Prescott AMA through groundwater pumpage (Table 11). Approximately 494,000 acre-feet or 47% of this total pumping was mined from groundwater storage in the aquifers of the Prescott AMA (Table 11, Figure 28).

The results from the transient simulation residual error analysis were within the calibration goals discussed previously (Table 10). Thus, the model provides an acceptable approximation of the groundwater flow system of the Prescott AMA relative to criteria established for calibration. While recent USGS estimates of subsurface flow out of the Little Chino sub-basin were not used as calibration targets, the rate of simulated subsurface flow for 2004, 1,400 af/yr, is within 30% of U.S.G.S. estimates (Wirt et al, 2004).

Table 11. Simulated transient water budget for the updated Prescott AMA groundwater flow model (1939-2004). (Figures rounded to the nearest 1,000 acre-feet)

Inflow	Simulated Totals (1939-2004)*
Mountain Front Recharge	375,000
Other Recharge	640,000
Released from Storage	943,000
Total Inflow	**1,958,000**
Outflow	**Simulated Totals (1939-2004)***
Pumpage	1,048,000
Del Rio Springs	204,000
Agua Fria River	108,000
Subsurface Flow	149,000
Taken Into Storage	444,000
Total Outflow	**1,953,000**
Change in Storage	**-494,000**

*All figures are cumulative totals for the period 1939-2004.

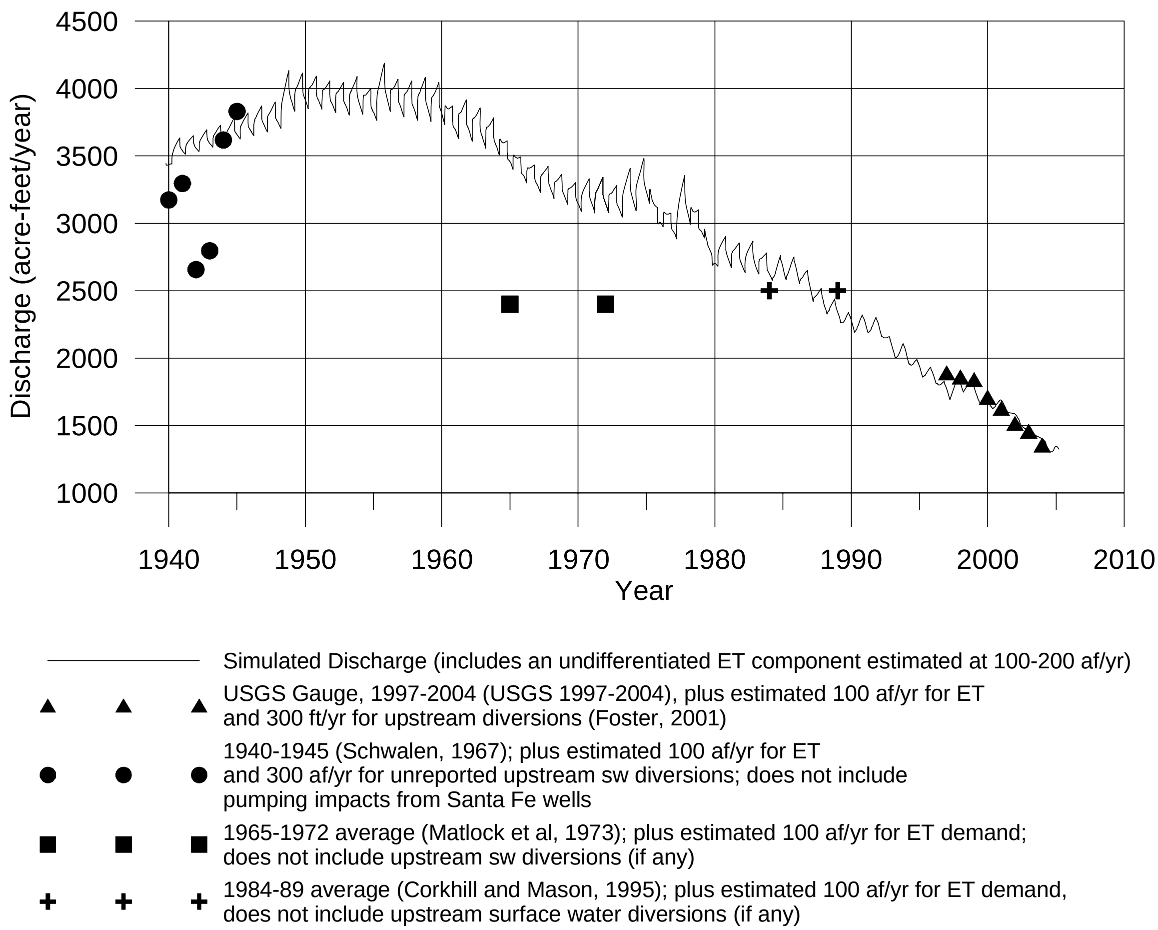

Figure 26. Measured and simulated groundwater discharge at Del Rio Springs for the transient simulation of the Prescott AMA groundwater flow model.

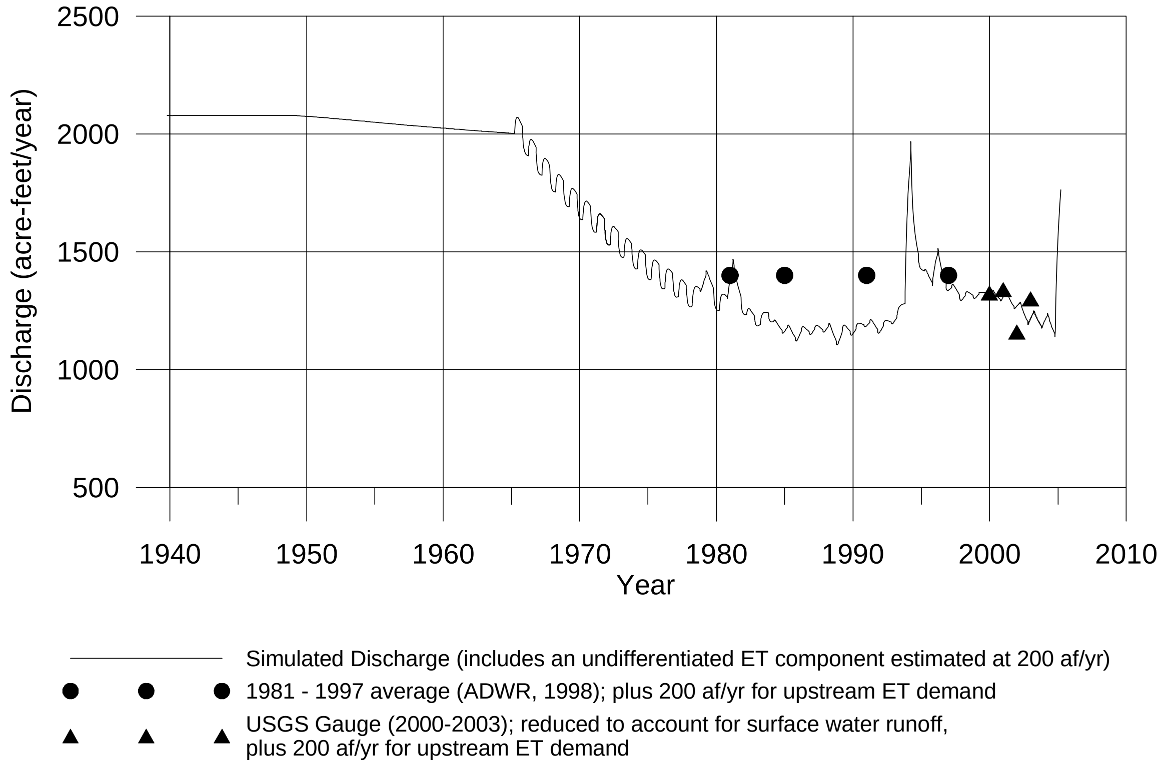

Figure 27. Measured and simulated groundwater discharge as baseflow in the Agua Fria River for the transient simulation of the Prescott AMA groundwater flow model.

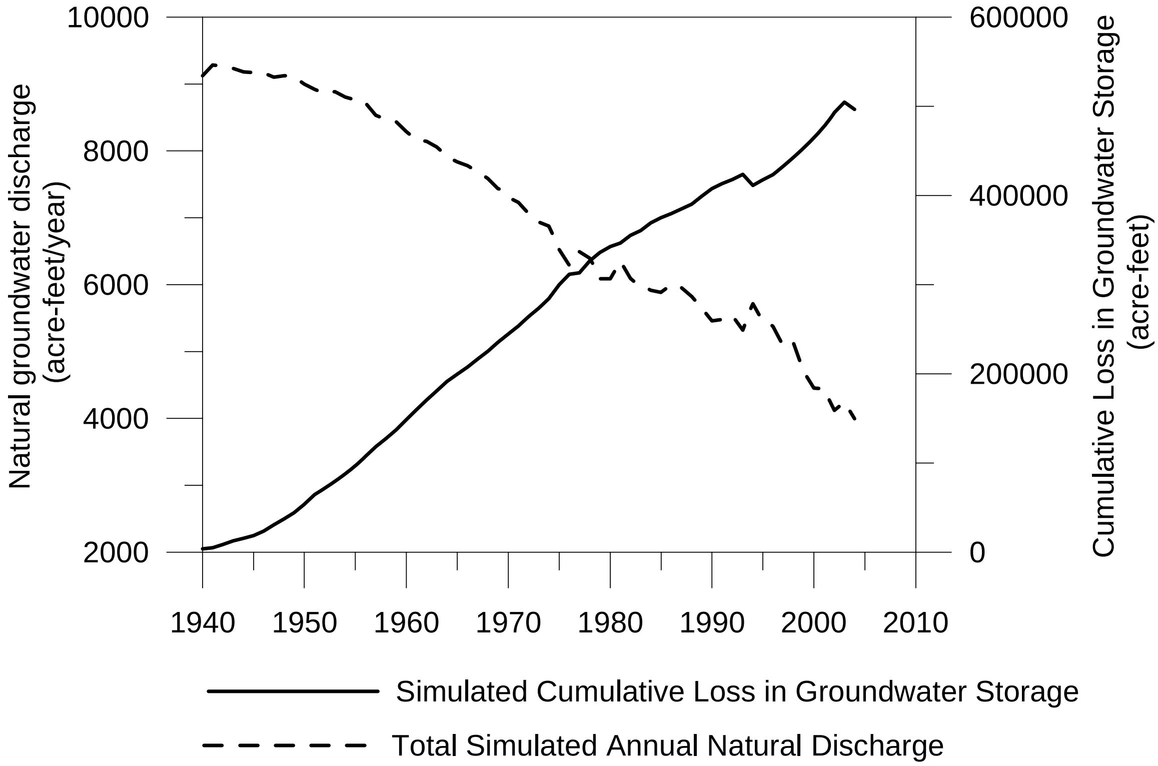

Figure 28. Cumulative loss in groundwater storage and natural groundwater discharge for the transient simulation of the updated Prescott AMA groundwater flow model.

CHAPTER SIX: MULTIPLE SCENARIO ANALYSIS

The updated Prescott AMA groundwater flow model in this study successfully simulated groundwater flow patterns for the period 1939-2004. The model was calibrated according to the criteria previously described by Hill as defining a reasonable model: good fit to head and flux values, randomly distributed residuals and realistic parameter values (1998). Calibration of the model to past conditions was an essential first step in the prediction of future groundwater conditions. Previous work suggests that simulations can be extended into the future up to two times the period of calibration (Faust et. al., 1981). Therefore, since the model was calibrated to an extensive set of groundwater levels and spring discharges over a period of over 60 years, the model should be able to adequately predict future groundwater conditions for 60 to 120 years *if* we are able to accurately predict future stresses to the system. This is, of course, a big *if*. As Wilson (1974) notes, "However good our futures research may be, we shall never be able to escape from the ultimate dilemma that all of our knowledge is about the past, and all of our decisions are about the future." Thus, a technique is needed to incorporate the large uncertainties we have regarding future human activities.

Over the past several decades, multiple scenario analysis has emerged as an effective tool for aiding decision-makers as they plan for the future; however, "in its most rudimentary form, the principle underlying the technique is familiar to all of us" (Heydinger and Zentner, 1983). Sports teams test their strategies against several "what if" situations in practice. Generals use war games or scenarios to test tactics and weapons systems (Heydinger and Zentner, 1983). Large corporations use scenarios to prepare for alternative future marketplaces (Schwartz, 1996). While these activities have been ongoing for centuries, it is only over the past several decades that the techniques for multiple scenario analysis have been codified into a coherent methodology.

According to the International Panel on Climate Change, "scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold" (IPCC, 2000). Scenarios are thus descriptions of distinct visions of the future that encompass a range of possible futures based on a set of clearly defined variables and assumptions.

Use of Multiple Scenario Analysis in Hydrologic Investigations

In addition to applications in many other fields, multiple scenario analysis has been increasingly applied to investigations of future hydrologic conditions. Through the incorporation of future scenarios into groundwater flow models, the impacts of policy decisions can be quantitatively and qualitatively assessed. Groundwater models can be used to investigate the impacts of various development patterns, well locations, conservation strategies, alternative water supplies and climate change on groundwater systems. Multiple scenario analysis has been applied to hydrologic investigations of the Middle Rio Grande Basin in New Mexico, the Eastern Province of Saudi Arabia, and the Nubian Aquifer in Egypt, among others. These three case studies will be used to introduce the concept and practice of multiple scenario analysis.

The Middle Rio Grande Basin, New Mexico

The U.S. Geological Survey used scenario development and groundwater flow modeling to investigate the impacts of three scenarios on the groundwater resources of the Sante Fe Group aquifer system in the Middle Rio Grande Basin, New Mexico

(Bexfield and McAda, 2003). Three groundwater management scenarios were simulated from 2000 to 2040 using a pre-existing USGS groundwater flow model for the area.

Simulation I was a baseline scenario that maintained pumping at constant, year 2000 pumping rates. For simulation II, projected increased water demand was met by increased development of groundwater resources in the area. Simulation III modeled a reduced pumping scenario according to a plan by the City of Albuquerque to use increased amounts of surface water to meet future water demand.

The use of these groundwater management scenarios enabled the USGS to quantitatively and qualitatively assess the impacts of different management options. The scenarios indicated that continued pumping at year 2000 rates would substantially impact groundwater levels both at the water table and in the production zone of the aquifer. In addition, the hydrologic connection between the Rio Grande River and the underlying aquifer would be altered. The model predicted that as groundwater levels decline, leakage from the river would increase.

The results of Simulation II indicate that increased pumping to meet future demand will likely result in even more dramatic declines in groundwater levels. Increased pumping is predicted to result in groundwater declines of over 120 feet between 2000 and 2040. In addition, evapotranspiration from riparian areas is predicted to decrease as groundwater levels drop below the root zone of phreatic plants.

Simulation III indicates that the use of surface water to meet most future municipal demand will allow groundwater levels in many areas to rebound from past declines. While in some areas, groundwater levels continue to decline, other areas see groundwater level rises of greater than fifty feet.

The development and use of these three scenarios allows policy makers to make educated decisions about how best to manage the water resources of the Albuquerque area. While all future predictions come with substantial uncertainty, the scenarios clearly indicate that various management strategies will result in quantitatively different outcomes. In the final analysis, Bexfield and McAda (2003) note that the "simulations indicate that reduced ground-water pumping by the City of Albuquerque through 2040 would have beneficial effects on the regional ground-water system, included substantially reduced water-level declines, increased aquifer storage, and reduced infiltration of surface water from the Rio Grande."

These scenarios have helped to inform the development of a water resources management strategy for the City of Albuquerque that substitutes renewable surface water supplies for mined groundwater. Under the new water resources management plan, the Albuquerque Bernalillo County Water Utility Authority's San Juan-Chama Drinking Water Project will supply up to 70% of the metropolitan area's future water, thus reducing future groundwater pumping (San Juan-Chama Drinking Water Project, 2007). The results of the multiple scenario analysis indicate that this strategy should have positive effects on water levels and groundwater storage throughout the regional groundwater system.

The Eastern Province of Saudi Arabia

While Saudi Arabia has been blessed with abundant oil reserves, the kingdom is less fortunate when it comes to water resources. The country is almost entirely desert and without renewable surface-water supplies. As such, water-resources development over the past several decades has been based almost entirely on fossil groundwater or desalination of sea water (De Jong, et. al, 1989). In the 1980's, a government initiative to achieve self-sufficiency in agricultural products lead to an almost four-fold increase in agricultural water use over the period 1980 – 1985 (De Jong, et. al, 1989). While substantial gains were achieved in agricultural production, the negative impact on groundwater levels was quickly apparent. Declining groundwater levels threatened to jeopardize future generations' access to this precious resource.

To assess the future impacts of continued agricultural and industrial development, the Saudi Arabian government funded a study based on multiple scenario analysis to investigate groundwater impacts under four separate development scenarios (De Jong, et. al, 1989). Researchers used a groundwater flow model to quantify the impacts of the scenarios for the fifteen year planning period 1985-2000 (De Jong, et. al, 1989). These scenarios incorporated municipal and industrial development, agricultural production and conservation strategies as the primary driving forces impacting groundwater abstraction levels. Results indicated that the abstraction levels of 1985 could be sustained without substantial depletion of groundwater resources; however, increased groundwater development associated with industrial and municipal growth would lead to groundwater declines of up to 500 ft. (De Jong, et. al, 1989). The results of this multiple scenario analysis provided clear and quantitative evidence that conservation measures must accompany further agricultural, industrial and municipal development in order to prevent depletion of the groundwater resources of the Eastern Province of Saudi Arabia.

In part based on the results of this multiple scenario analysis, the Saudi Arabian government has introduced several conservation measures over the past 15 years to limit impact on non-renewable groundwater resources. In 1994, a water tariff was established to encourage conservation at the household level (Abderrahman, 2001). Leakage control measures have also been designed to minimize losses from supply networks, while closed water systems have been introduced to industrial plants to reduce industrial demand. Finally, to reduce agricultural use of non-renewable groundwater supplies, pricing supports for wheat production have been reduced and the use of effluent for irrigation has been encouraged (Abderrahman, 2001). Multiple scenario analysis has thus played an important role in the development of a water resources management strategy for Saudi Arabia.

The Nubian Aquifer of Southwestern Egypt

Multiple scenario analysis has also been used to assess potential impacts of groundwater development of the Nubian Aquifer in southwest Egypt (Ebraheem et. al., 2002). The Nubian aquifer is a massive aquifer containing an estimated 6,700 mi^3 of groundwater resources (Ebraheem et. al., 2002). The aquifer covers an area of 150,000 mi^2 across several countries and extends to a depth of over two miles (Ebraheem et. al., 2002). While this makes the Nubian aquifer system one of the largest in the world, only a small amount is currently exploitable.

While it has been recognized since the 1970's that rapid depletion of groundwater resources in southwestern Egypt presents a formidable challenge to sustained economic growth in the region, there is increasing demand for municipal, agricultural and industrial growth in the area (Ebraheem et. al., 2002). Due to these conflicting pressures, multiple scenario analysis has been used in conjunction with a groundwater flow model to assess the impacts of a planned development in an area known as East Oweinat.

The results of the simulations indicated that the planned development at East Oweinat will likely lead to groundwater declines of nearly 350 ft over the next 100 years (Ebraheem et. al., 2002). With such depletion, shallow wells in many areas will dry up and groundwater extraction for agricultural irrigation will become uneconomic (Ebraheem et. al., 2002). These results indicate that economic development based on groundwater exploitation in southwestern Egypt is not without costs. Understanding these costs should allow development planners to make a more educated evaluation of the benefits and costs associated with the proposed development at East Oweinat; however, it is too soon to evaluate any impact of the multiple scenario analysis process on these development plans.

Purpose of Multiple Scenario Analysis in the Prescott AMA

The Prescott AMA has a statutory goal of safe-yield by 2025. To meet this requirement, decision-makers in the area must have an understanding of the hydrologic system in the AMA and of the factors that impact that system. While it is obvious that groundwater development impacts the aquifers of the AMA, the factors that impact the scale and pace of groundwater development are not necessarily immediately apparent. Multiple scenario analysis was chosen as a strategy for investigating future groundwater conditions in the AMA because it allows for the clear elucidation of the important factors that will likely impact these conditions. Identifying these factors thus allows for the recognition of the critical decisions that will most greatly affect future groundwater conditions in the Prescott AMA. Thus, this multiple scenario analysis is proposed as a tool to aid decision-makers as they work towards their safe-yield goal.

The Scenario Development Process

The development of scenarios generally begins with the characterization of the current situation (Gallopin, 2002). This includes the identification of the central issue to be analyzed. The central issue to be addressed in this analysis is the groundwater condition of the Prescott AMA. Current conditions have been characterized quite extensively in the preceding pages of this thesis.

The next step is to identify the major driving forces (Gallopin, 2002). These are the key factors, trends, and processes that influence the central issue being examined. For the Prescott AMA, population growth is a key driving force because it is clear that population growth will determine in large part future human impacts on the groundwater system of the Prescott AMA. Conservation strategies represent another major driving force in influencing future groundwater conditions. These include education campaigns, conservation incentives, water pricing and water-use restrictions. Effective conservation strategies require the establishment of conservation as a key policy goal as well as public awareness and involvement in creating a conservation ethic. The final driving force identified for the Prescott AMA is potential water importation from outside the AMA. The communities within the AMA are preparing to import water from outside the AMA in the adjoining Big Chino sub-basin of the Verde River groundwater system. This augmentation has the potential to significantly reduce human impacts on the groundwater system within the AMA and is therefore a critical driving force.

These driving forces are often the source of major uncertainties (Gallopin, 2002). For example, while we know that population growth will impact the groundwater system of the Prescott AMA, we do not know what the population growth will be. We do not know how effective conservation strategies will be. Despite clear plans to import water, potential financial and legal hurdles make the outcome of these plans uncertain.

It is these critical uncertainties that mandate the use of multiple scenarios to investigate the future. If population growth, conservation strategies and importation schemes for the Prescott AMA were all known quantities, we would only need one scenario; however, since these are unknown quantities, we must develop several alternative scenarios that incorporate a range of potential outcomes.

Methods for Scenario Development

The Prescott AMA scenarios were developed based on several sources. First, community plans for the City of Prescott, Town of Prescott Valley, and Town of Chino Valley were used to project annual rates of population growth for these areas. Population projections from the Arizona Department of Economic Security were used to determine growth rates for the unincorporated areas dominated by domestic exempt wells. Several meetings were conducted with the water resource managers from the individual communities, the Coordinator for the Yavapai County Water Advisory Committee and Prescott AMA staff to allow for constructive feedback from these individuals and organizations. Finally, a meeting was organized with the Yavapai County Water Advisory Committee Coordinator, the Director of the Prescott AMA and the water resource managers from the Town of Prescott Valley and the Town of Chino Valley. The water resources manager for the City of Prescott was invited, but was unable to attend. The purpose of this meeting was to determine the critical driving forces to be incorporated within the multiple scenario analysis and to discuss which scenarios would be most useful to these interested parties.

Driving Forces for the Prescott AMA

The three driving forces the stakeholder group identified as critical to developing scenarios relevant to the groundwater resources of the Prescott AMA are population growth, conservation strategies and importation of additional water supplies. While these three factors cannot account for all of the potential variability in future groundwater use, they are believed to be the factors that will impact groundwater conditions most substantially over the next 20 years. An additional driving force that is not considered in this analysis is climate change. This omission is due to the large uncertainty regarding regional impacts of climate change and the limited time frame being investigated. The critical driving forces impacting groundwater conditions in the Prescott AMA included in the multiple scenario analysis are explained in the following sections.

Population Growth

Recently, Arizona surpassed Nevada as the fastest growing state in the country (Bernstein, 2006). While growth in the major metropolitan areas of Phoenix and Tucson garners most of the media attention, smaller towns and rural areas in Arizona also face tremendous demographic pressures. The communities within the Prescott AMA are no exception. According to the Arizona Department of Economic Security (ADES), between April 1, 2000 and July 1, 2006, the population of the Town of Chino Valley grew by 62.1%, the City of Prescott grew by 24.0% and the Town of Prescott Valley grew by 51.9% (2006a). Overall, Yavapai County as a whole expanded by 27.3% over this period, making it the third fastest growing county in the state (ADES, 2006a) (Table 12).

Table 12. Past and projected annual population growth rates for the City of Prescott, Town of Prescott Valley, Town of Chino Valley and Yavapai County.

	Population growth rates		
Community	4/1/90 - 4/1/00 [1]	4/1/00 - 7/1/05 [2]	2005 - 2025
City of Prescott	2.1%	3.5%	2.0 - 3.0 % [3]
Town of Prescott Valley	10.2%	6.9%	3.5% - 5.5% [4]
Town of Chino Valley	5.0%	8.0%	4.0% - 10.0% [5]
Yavapai County	4.5%	3.9%	2.2% [6]

[1] ADES, 2000

[2] ADES, 2006a

[3] City of Prescott, 2004

[4] Projected annual growth rates through 2020. (Town of Prescott Valley, 2001)

[5] Town of Chino Valley, 2007

[6] ADES, 2006b

Rapid population growth is expected to continue into the near future. The ADES projects that the population of Yavapai County will continue to expand, growing from 212,722 in 2005 to 332,172 residents in 2025 (2006b). While an influx of an additional 120,000 residents to Yavapai County in the next 20 years seems dramatic, actual numbers may even be significantly higher. These ADES projections assume that the annual rate of population growth will decline from 3.5% in 2005 to less than 1.6% in 2025; however, the management plans of the communities in the Prescott AMA are based upon maintaining significantly higher growth rates than those projected by the ADES. Historical rates of growth have outpaced ADES projections in the past and may do so in the future (2006b).

Several additional statistics serve to illustrate the incredibly rapid population growth seen in the Prescott AMA over the past several decades. Between April 1, 1990 and April 1, 2000, the population of Prescott Valley grew by 164.3%, an annual growth rate of over 10% (ADES, 2000). Chino Valley grew by 62 % over this time, a rate of about 5% annually, while the City of Prescott grew by 22.7%, an annual rate of over 2% (ADES, 2000). The County as a whole grew by 55%, an annual rate of 4.5% (ADES 2000). Thus, while the City of Prescott has grown at a slower pace than the rest of Yavapai County, the Town of Chino Valley and the Town of Prescott Valley have significantly outpaced the county as a whole.

These local communities are also planning for continued growth at higher rates than projected by ADES, as indicated by their community plans. The City of Prescott's general plan assumes a growth rate of between 2% and 3% over the next 20 years (City of Prescott, 2004). As part of its general plan, Prescott Valley developed a series of three population growth scenarios. These scenarios were based on annual population growth rates of 3.5%, 4.5% and 5.5% continuing out through the year 2020 (Town of Prescott Valley, 2001). Projections from the Town of Chino Valley range as high as 10% annual growth through the year 2020 (Town of Chino Valley, 2007). Since all future development requires a dependable water supply, it is clear that population growth will be one of the major driving forces impacting future groundwater conditions in the Prescott AMA.

Population growth in the Prescott AMA for the past decade has been largely driven by immigration, not by an excess of births over deaths. In fact, more deaths than births are projected for Yavapai County each year through 2055 (ADES, 2006b). Thus, essentially all of the growth in Yavapai County is projected to come from immigration.

Driven by immigration, population growth in the Prescott AMA can be affected by policies that alter the pace and scale of new development. Land use planning and local development policies in the Prescott AMA will be a major factor influencing future population growth in the area. Land use policies that limit the amount of land devoted to new development will serve to limit population growth, while policies that increase the amount of land available for development will likely increase population growth.

Conservation Strategies

In addition to population growth, conservation strategies will be an important factor impacting groundwater conditions in the future. With surface-water and groundwater supplies already allocated or over-allocated, conservation represents an obvious source of future supply; however, it is unclear how important conservation will be as a source of future water supply in the Prescott AMA. The wide range of outcomes of various conservation programs across the country indicates that not all conservation programs are created equal. In fact, careful planning, implementation and monitoring will be necessary to ensure that conservation in the AMA is effective and optimal.

Overview of conservation strategies

Conservation strategies can be generally divided into four main categories: education, incentives, restrictions and pricing. Education is most often focused on raising awareness of simple practices that the general public can use to reduce water use and of potential consequences of unsustainable water use. Incentives provide rebates or other financial incentives for the adoption of conservation practices or the purchase of conservation equipment. Restrictions simply place legal limits on water use, while pricing strategies use rate structures to encourage conservation. The most successful conservation plans embrace elements from each of these types of strategies.

Education

Educational programs to promote conservation awareness are a central component of almost all water conservation programs. Education is widely seen as a cost-effective strategy for influencing consumer attitudes and behavior (Michelsen et. al., 1999). While studies have indicated that education can be an effective way of influencing attitudes towards water conservation (Birch and Schwaab, 1983), it is generally more difficult to quantify the impact of educational programs in influencing consumer behavior. In fact, there is currently no universally accepted empirical method for estimating the effectiveness of educational programs (Heath and Mitchell, 2002). This is in part due to the fact that educational programs are often instituted as part of a broader conservation program that makes isolating the impacts of any one component highly problematic.

It has only been in recent years that researchers have attempted to quantify the impacts of various educational campaigns. The results of these studies indicate that educational campaigns vary widely in their level of success. The Water Use Index developed by the Region of Waterloo, Canada utilized a pictorial depiction of the area's water use in a major regional newspaper to deliver water-supply information and to encourage the general public to modify its own water use (Heath and Mitchell, 2002). Study results indicated that the index was ineffective in modifying consumer behavior. Similarly, an education campaign in the Kingdom of Jordan was quite successful in spreading knowledge regarding water issues; however, the program was less successful in influencing attitudes and behavioral changes (Abu-Taleb and Murad 1999). Alternatively, a 1984 campaign in San Antonio, Texas to educate the public and promote voluntary conservation measures was successful both in providing knowledge of water issues and in influencing consumer behavior (Highstreet and Olsen, 1987). The program resulted in a water-use reduction estimated at 8% (Highstreet and Olsen, 1987).

Based on an extensive review of water conservation education programs, Heath and Mitchell (2002) note that "a major challenge facing water resource educators is to develop a program strategy that goes beyond raising general awareness to stimulating behavioural changes within the target population." While increasing public knowledge and influencing attitudes towards water conservation is an essential part of any educational campaign, influencing consumer behavior should be the ultimate goal of any educational program. With this in mind, Heath and Mitchell (2004) summarize the key components of successful educational strategies:

1. Make commitments of time, money and energy to the program;
2. Identify the objective(s);
3. Identify the target audience(s) and understand their needs;
4. Determine the appropriate measures to implement and how to implement them, including a long-term implementation and evaluation schedule; and
5. Evaluate and adapt the program accordingly.

Along these lines, Michelsen et. al, (1999) discuss detailed documentation and monitoring as an essential component of successful conservation programs. Successful education programs have been shown to achieve up to a 10% reduction in water demand (Heath and Mitchell, 2004).

Incentives

Conservation incentives are another component of many water conservation programs. These can take the form of distribution, installation and rebates for water-saving devices to physically reduce water use (Michelsen et. al., 1999). Examples of such incentives include rebates for low-flow toilets, showerheads and washing machines.

Estimates of the efficacy of these types of programs are generally based on an engineering approach that multiplies the estimated savings of each device distributed multiplied by the number of devices distributed (Loaiciga and Renehan, 1997).

Based on this approach, incentive programs have been shown to be effective demand management tools. For example, a toilet flapper rebate program offered by the Town of Cary, North Carolina offered a financial incentive to utility customers to purchase early-closing toilet flappers, which can save up to 1.3 gallons per flush (Platt and Delforge, 2001). Not only has this program saved several million gallons of water, it has done so at a minimal cost of only $0.005/gallon (Platt and Delforge, 2001). Through a popular rebate program that began in 1993, the Los Angeles Department of Water and Power has also replaced over 1.3 million high capacity toilets with low-flow models expected to save nearly 850,000 acre-feet of water over 20 years at a cost of less than $200 an acre-foot. (Dickinson, 2000). In addition to rebates for conservation devices, incentives can be used to encourage other conservation practices such as landscape conversion to replace turf with low water use plants.

While conservation incentives can be part of an effective demand management strategy, the results of the ECoBA (Evaluation and Cost-Benefit Analysis) Project indicate that they are not always cost-effective (Little, 2006). In fact, the Project noted that the economic costs and actual water savings of several types of programs were so variable that they recommend program managers to be particularly cautious in structuring these programs. In particular, they cited landscape conversion programs as having highly variable results. In addition, washing machine rebates and device giveaways were found to actually *increase* participant water use in some instances (Little, 2006). Based on these results, specific recommendations to utilities include:

- *Initiate detailed tracking* of program participation, including water consumption for participants and similar non-participating households, as well as for the whole customer class;
- *Evaluate programs.* Be willing to change direction, doing more of what is working and less of what is not; and
- *Improve communication* between conservation staff and the rest of the water resource management team, particularly data managers. (Little, 2006)

Restrictions

Restrictions place mandatory limits on the use of water either by directly limiting the use of water or by indirectly limiting water use through revised plumbing and building codes that require installation of water-saving appliances. Water restrictions are often put in place by a municipality and can be temporary or permanent.

As part of its overall conservation strategy, the Town of Cary, North Carolina enacted landscape and irrigation ordinances designed to limit outdoor water use. This system relies on a three-stage system of restrictions with Stage 1 mandating odd/even day outdoor watering, Stage 2 mandating limited odd/even day watering and Stage 3 imposing a total ban on turf watering (Platt and Delforge, 2001). These restrictions are imposed primarily to reduce peak summer demand and have proven quite effective. In 1999, Stage 1 restrictions were found to reduce irrigation use by almost 10%, while Stage 3 restrictions yielded an average savings of approximately 22% (Platt and Delforge, 2001). In addition to these temporary restrictions, Cary has instituted permanent ordinances that require a rain sensor on all automatic irrigation systems, restrict runoff due to over-watering and limit the watering of hardscapes such as driveways (Platt and Delforge, 2001).

The effectiveness of the Cary conservation restrictions can be attributed in part to active enforcement of the restrictions. In 2000, town staff issued more than 500 notices of violations; however, the number of violations decreased each month, indicating that visible enforcement was influencing consumer behavior and encouraging compliance (Platt and Delforge, 2001).

Pricing

Economic theory dictates that as the price of a good increases, demand for the good decreases. Based on this premise, various pricing strategies have been devised to limit the demand for water. The most common form of conservation pricing strategy is the inverted block rate structure. Under this pricing structure, small amounts of water use are charged a low rate, but as usage increases, so too does the unit price. The inverted block rate structure allows for a minimal charge for essential water use, but punishes inefficient users by charging a higher rate for excessive use.

While raising the price of water does lead to a decrease in water demand, water is generally price inelastic. This means that the ratio of the reduction in demand to the increase in price is less than 1:1. In fact, a literature review of econometric studies have shown the price elasticity of residential water demand to vary between -0.23 and -0.75 (Michelsen et. al., 1999). The price elasticity for metered Colorado utilities has been estimated to range between -0.33 and -0.46 (Walters and Young, 1994). A study of seven cities in the American West found an average price elasticity of -0.23 (Michelsen et. al, 1999). This means that for every 10% increase in price, water use is reduced on average by only 2.3%.

The inelasticity of water demand means that large price increases are generally needed to effectively reduce water use. As these large price increases are generally politically unpalatable, pricing is not often a preferred method of encouraging conservation (Michelsen et. al, 1999). However, the price inelasticity of water demand also means that raising water rates generally increases revenue for the water provider.

The example of Tucson, Arizona indicates the difficulties of utilizing price as a conservation tool. While econometric analyses have indicated that urban water demand is inelastic, with price elasticity in the range of -0.26 to -0.70, other variables including per capita income and weather have proven equally important factors in impacting water demand (Martin and Kulakowski, 1991). While Tucson's city council passed annual water rate increases throughout the 1980's, per capita use did not decline as expected. In fact, weather patterns and per capita income were shown to have equally important affects on demand as price (Martin and Kulakowski, 1991). The case of Tucson illustrates that for pricing to be an effective demand management tool, significant price increases well in excess of 10% are required (Martin and Kulakowski, 1991). In fact, nominal water price must be increased each year by the rate of inflation plus approximately the rate of change in real income simply to maintain constant and not increasing water use (Martin and Kulakowski, 1991).

Current Conservation Strategies

There are several current conservation programs in the Prescott AMA under the direction of several different authorities. Under the authority of the AGMA, the Arizona

Department of Water Resources has established conservation programs for the agricultural, municipal and industrial sectors that include education and restrictions (ADWR, 1999). The City of Prescott has utilized education, incentives, restrictions and pricing as part of its conservation strategy, while the Town of Prescott Valley has a conservation program that includes education, restrictions and pricing (City of Prescott, 2006; YC WAC, 2006). The Town of Chino Valley currently has no established water conservation program (Mark Holmes, pers. Comm., 12/7/2007).

Education

Water conservation education is part of the conservation strategies being pursued by the ADWR, the City of Prescott, and the Town of Prescott Valley. The ADWR has developed and distributed a "Low Water Use Plant List" intended to educate homeowners regarding the water conservation potential of landscaping with these types of plants (ADWR, 2006). According to the Prescott AMA Third Management Plan, the AMA office is responsible for "developing water conservation information materials, educational curricula and displays" through the Water Management Assistance Program (ADWR, 1999). Such materials have been developed and utilized in local schools and at public events such as Earth Day festivities.

The City of Prescott has also developed a conservation plan that utilizes education to encourage water conservation among municipal users. In 2004, a Water Conservation Committee was established and a Conservation Coordinator was hired with the purpose of making recommendations to the City Council regarding amendments to the City of Prescott Water Conservation Code (City of Prescott, 2007). One of the Committee's strategies for 2006 has been a public education campaign designed to "establish a water conservation culture through a series of continuous public awareness and educational programs" (City of Prescott, 2007). Specific programs include media campaigns, promotional items, printed materials, and school programs (City of Prescott, 2007). While the impacts of educational campaigns are difficult to assess, there is some evidence that education programs can be successful at reducing water demands, especially in the agricultural and domestic sectors (Water Use it Wisely, 2007).

The Town of Prescott Valley has partnered with the national program "Water Use it Wisely" to educate its citizens about water conservation (YC WAC, 2006). The "Water Use it Wisely" program includes educational materials and programs such as a Low Water Use Plant List, Landscape Watering Guide, Home Water Audit, as well as online educational games relating to water conservation (Water Use it Wisely, 2007).

Incentives

The City of Prescott has developed a set of incentives designed to encourage water conservation in both residential and commercial settings. These incentives provide monetary rebates for the purchase of water efficient washing machines, toilets and urinals, showerheads and hot water circulators (City of Prescott, 2006a). In addition, financial incentives are currently being used to encourage landscape conversion to automatic drip irrigation and removal of turf. Since these incentives have been in place for less than two years, there are little data to indicate the effectiveness of these programs; however, the City maintains that approximately 1,400 acre-feet of annual water savings would be possible if the incentives program were to be universally adopted (City of Prescott, 2006a)

Restrictions

Water-use restrictions are the dominant form of conservation program in the Prescott AMA. Restrictions on water use have been separately enacted by the ADWR, the City of Prescott, and the Town of Prescott Valley to reduce water use in the AMA. As the regulatory agency in charge of managing the groundwater resources of the Prescott AMA, the ADWR maintains the most comprehensive set of water-use restrictions in the area. These include restrictions on agricultural, municipal and industrial uses.

One of the provisions of the AGMA was the prohibition of all newly irrigated lands (ADWR, 1999). By law, only lands that were legally irrigated between January 1, 1975 and January 1, 1980 may currently be irrigated. These legally irrigated lands have been assigned an Irrigation Grandfather Right (IGFR) that establishes a maximum groundwater allotment based on historically irrigated acreage, crop consumptive use and irrigation efficiency (ADWR, 1999). The prohibition of newly irrigated acreage and establishment of maximum water allotments for agricultural purposes are clear restrictions on water use.

ADWR restrictions on municipal water use come primarily in the form of per capita water-use requirements for large municipal providers. Charged by the AGMA of 1980 to require reasonable reductions in per capita use, the ADWR developed the Total Gallons per Capita per Day Program (Total GPCD Program) (ADWR, 1999). This program establishes maximum per capita per day water usage for large municipal providers.

In addition to the Total GPCD Program, the ADWR also requires all new subdivisions demonstrate an assured water supply prior to sale of the lands for residential development. "Assured water supply" means that

> "sufficient water of adequate quality will be continuously available to meet the water needs of the proposed use for at least 100 years; that the project use is consistent with the management plan…and achievement of the safe yield management goal for the AMA; and that the financial capability has been demonstrated to construct the water facilities necessary" (ADWR, 1999)

Since the 1999 declaration that the AMA is out of safe-yield status, the assured water supply is required to come in the form of renewable water supplies as opposed to mined groundwater.

In addition to these restrictions for the municipal and agricultural sectors, restrictions for the industrial sector include a requirement to "avoid waste" and to landscape with plants from the established Low Water Use Plant List (ADWR, 1999). Restrictions on water use are thus an important part of the ADWR's conservation strategy for the Prescott AMA.

The City of Prescott has adopted outdoor watering restrictions that limit outdoor spray irrigation and airborne watering to between 8:00 pm and 8:00 am between April 15th and November 1st (City of Prescott, 2007). The City of Prescott also periodically adopts voluntary restrictions during summer months to reduce peak demand. In addition, the City of Prescott and the Town of Prescott Valley currently require the use of reclaimed water on all new golf courses built in either community (YC WAC, 2006).

Pricing

The City of Prescott and the Town of Prescott Valley have each adopted inverted rate structures as part of their conservation strategies. These rate structures are designed to encourage conservation by applying a higher marginal price as water use increases above certain thresholds. For example, the City of Prescott charges residential customers \$1.66 per 1,000 gallons for the first 3,000 gallons of monthly use; however, use over 20,000 gallons is charged a rate of \$7.48 per 1,000 gallons (City of Prescott, 2006b). The Town of Prescott Valley maintains a less-inverted structure; however, the marginal price does increase from \$2.90 per thousand gallons for the first 8,000 gallons of monthly use to \$4.52 per thousand gallons for use over 20,000 gallons (Prescott Valley Water District, 2006).

Potential Conservation Strategies

A 1982 report by the Environmental Policy Institute recommends a 13 point model for municipal water conservation based on elementary techniques and programs that have been shown to reduce water use (Blackwelder and Carlson, 1982).

1. Plumbing code changes to require low-flow fixtures and appliances and insulation of hot water pipes.
2. Retrofit of existing buildings and homes with low-water use fixtures.
3. Leak repair within buildings and homes.
4. Leak repair in the water distribution system.
5. Metering of all areas and checking of meters for accuracy.
6. Revision of rate structure.
7. Public education program.
8. Outdoor water use codes.
9. Drought contingency plan.
10. Program for recycling and reuse.
11. Pressure reducing valves.
12. Watershed protection and planning.
13. Selected changes in personal habits.

While the communities of the Prescott AMA have conservation strategies that already incorporate many of these elements, further conservation is still possible.

Education

The ADWR, the City of Prescott and the Town of Prescott Valley have all utilized education programs as part of their conservation strategies. While these educational programs are designed to reach a wide audience throughout the Prescott AMA, it is unclear how effective any of these programs have been due to the lack of detailed tracking and monitoring of conservation success. Future educational programs should include this type of monitoring and follow-up to allow for the quantitative evaluation of different programs. With such data, limited funds can be allocated to the most effective education programs.

Incentives

The incentives program currently operated by the City of Prescott is quite comprehensive, providing financial encouragement for the adoption of water saving technologies and landscape practices. The Town of Prescott Valley and Town of Chino Valley could also adopt similar ordinances; however, it is unclear how substantial water savings would be in these communities. Since most of the development in Prescott Valley and Chino Valley has occurred recently and under the current Arizona plumbing code, there are not likely significant numbers of high flow appliances in these communities. Thus, water savings from device incentives are likely to be minimal in Prescott Valley and Chino Valley alone. If applied by the ADWR to the entire AMA, however, incentives could provide significant water savings. These incentives would likely need to be applied to water users outside of municipal service areas served by domestic wells to achieve significant conservation.

In addition to the device rebates, turf removal and drip irrigation incentives, the ADWR could provide rebates for the purchase of rainwater harvesting devices in the AMA. Since outdoor water use for landscaping is the largest component of residential water demand in the AMA, the potential for savings from such an incentive program is quite significant (ADWR, 1999). However, previous experience indicates that careful planning and implementation is required for such incentive programs to be effective (Little, 2006).

In addition, the AGMA allows for the purchase of Irrigation Grandfathered Rights (IGFRs) by order of the Director of the Prescott AMA for the purpose of retiring these rights. The high cost of such a strategy has thus far prevented serious consideration of such purchases; however, as the cost of other conservation measures increases, this may become a more viable and necessary option.

To reduce the cost of purchasing and retiring IGFRs, the ADWR could investigate potential options for purchasing and retiring IGFRs without purchasing the land associated with the IGFRs. This option would allow for the purchase of water rights at a fraction of the cost of purchasing the land. In addition, the ADWR could investigate options for partnering with private conservation organizations such as the Nature Conservancy and the Trust for Public Lands. It is possible that these organizations could partner with the ADWR to purchase and retire IGFRs and to preserve agricultural land as open space. . An exploratory investigation of the possibility of such a partnership is certainly worth pursuing.

The Prescott Country Club is currently the only golf course in the AMA with a grandfathered pumping right. These water rights could be extinguished by the ADWR as part of an agreement to provide treated effluent to the golf course. Such an agreement could potentially reduce groundwater pumping by more than 450 acre-feet annually.

Restrictions

The achievement of maximum conservation potential in the Prescott AMA will almost certainly require increased restrictions on water use in the area. These restrictions could be imposed on the community level; however, regulations imposed by the ADWR that apply to the entire AMA would likely be most effective. The outdoor watering restrictions adopted by the City of Prescott could easily be extended to the entire AMA, though such a restriction would likely face enforcement difficulties in the more rural parts of the AMA.

Significant water savings could also be realized by imposing further restrictions on landscaping in new residential and commercial developments. Limitations on allowable turf size, requirements for the installation of modern drip irrigation systems and hot water recirculators would significantly reduce the amount of potable water required to support future development. In addition to these restrictions, new commercial developments could also be required to install waterless urinals in public restrooms.

One of the more promising avenues for further regulation regards the use of reclaimed effluent. All new golf courses and large commercial developments could be required to use treated effluent for irrigation throughout the AMA. While the City of Prescott and Town of Prescott Valley have comparable restrictions, these restrictions could be universally applied throughout the AMA. Irrigation for municipal parks and other municipal landscaping needs could also be converted to use treated effluent. While the capital costs for expanding the infrastructure required for effluent delivery would be significant, the potential for water savings is also substantial. Such a requirement would, however, likely face opposition from municipalities due to cost considerations.

Pricing

The adoption of inverted rate structures by the City of Prescott and Town of Prescott Valley are an important step towards rational pricing of water in the Prescott AMA. According to the Town of Prescott Valley, per capita water use in the town dropped from 125 GPCD to 116 GPCD after the introduction of the inverted rates (Town of Prescott Valley, 2007). The Town of Chino Valley could also adopt an inverted rate structure to encourage conservation among its customers. While the Town of Chino Valley currently has a small municipal water system, as the Town's water service area expands, the potential for conservation savings will be significantly increased. The introduction of an inverted rate structure would likely increase town revenue which could be used to fund additional conservation programs.

Under the provisions of the Groundwater Management Act, the ADWR has a right to levy a groundwater withdrawal fee from all non-exempt groundwater users in the AMA. This fee is currently set at $2.00 per acre-foot; however, the statutory limit for the fee is $5.00 (Gerry Wildeman, pers. comm.., 5/9/2007). This fee could be raised to this statutory maximum. While such a fee is insignificant for the purpose of encouraging conservation through pricing, the fee provides a mechanism for the ADWR to raise money for the purpose of developing, operating and monitoring conservation programs in the AMA, including the purchase and extinguishment of irrigation grandfathered rights.

Importation of Alternative Water Supplies

The final driving force that will critically impact the groundwater resources of the Prescott AMA is the potential importation of alternative water supplies. While the withdrawal and transportation of groundwater across sub-basins is generally prohibited by the Arizona Groundwater Transportation Act (ARS 45-5551), there are two statutory exceptions to this rule for communities in the Prescott AMA (ARS 45-5555). The first exception allows for any city or town in the AMA to purchase and retire historically irrigated acreage overlying the Big Chino Sub-basin and to then withdraw and transport up to 3 acre-feet per retired acre per year of Big Chino groundwater into the AMA (ADWR, 1999; McCormack, et. al, 2006) (Figure 29). A second exception allows for the City of Prescott to withdraw up to 14,000 af/yr from the Big Chino Sub-basin for transport to the AMA "to the extent that the groundwater replaces CAP allocations in the AMA or Verde River groundwater basin, or facilitates certain Indian water rights settlements" (ADWR, 1999). The ADWR has determined that the City currently qualifies for up to 8,717 feet of Big Chino groundwater under this exception (ADWR, 1999).

In December 2004, the City of Prescott, in partnership with the Town of Prescott Valley, purchased over 6,500 acres in the Big Chino Sub-basin as the first step towards importing Big Chino groundwater (Figure 29) (City of Prescott, 2006c). The Prescott City Council has already approved funding for engineering and design for a pipeline to transport water from the Big Chino Water Ranch (Barks, 2006a). The communities intend to develop the infrastructure necessary to begin importation by July 2009 (City of Prescott, 2006c).

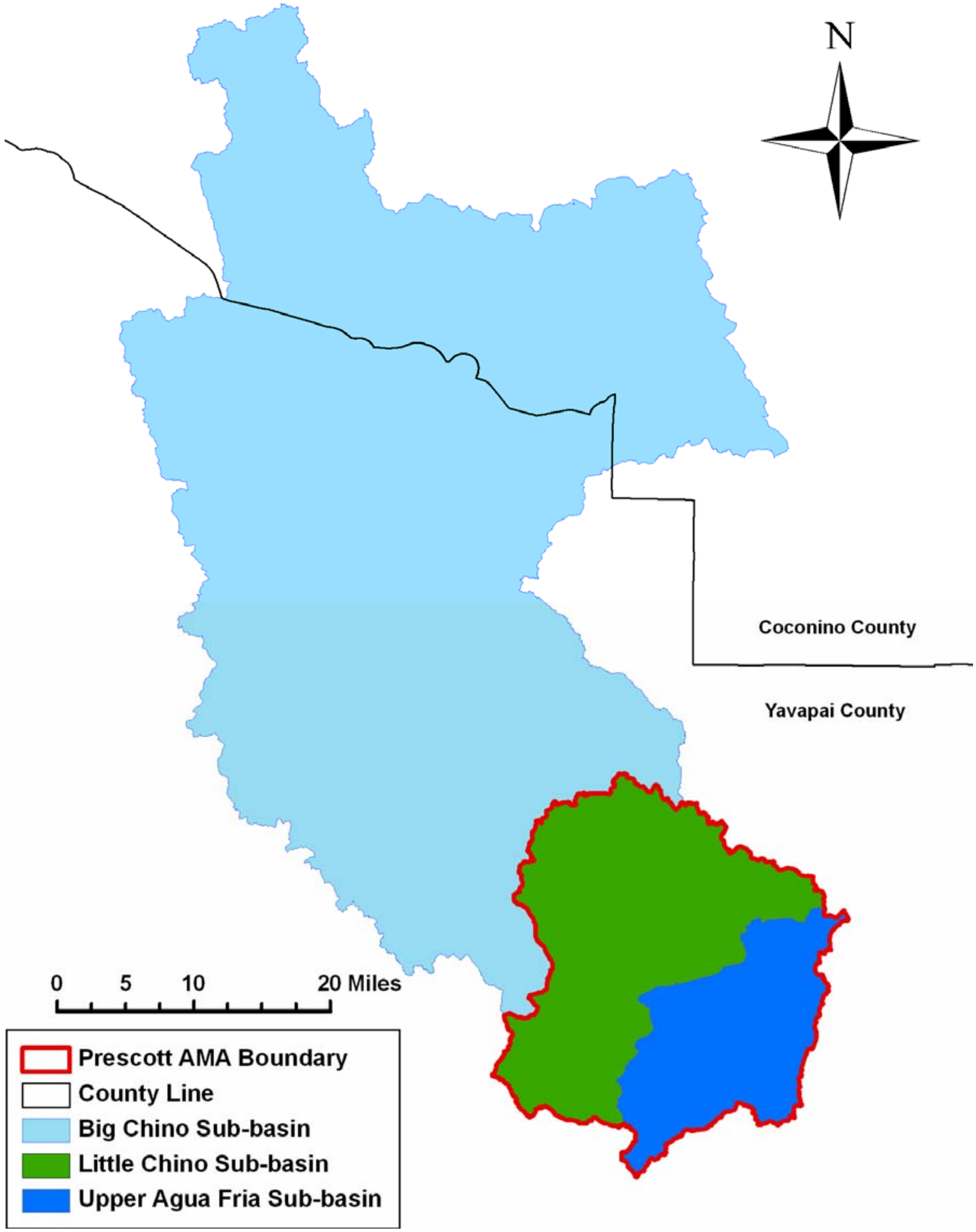

Figure 29. Map showing location of Big Chino Sub-basin in relation to the Prescott AMA.

The Town of Chino Valley has purchased additional lands and water rights in the Paulden area of the Big Chino Sub-Basin just north of the Prescott AMA (Figure 29). Currently, the town owns approximately 230 acres of land; however, the town expects to purchase additional lands up to a total of approximately 600 acres. Upon full development of the importation scheme, these lands are expected to provide approximately 1,800 af/yr of additional water supply. The town expects to begin importation in the next two years (Mark Holmes, pers. comm., 12/7/2006).

While the communities of the Prescott AMA have a current legal right to import groundwater from the Big Chino Sub-Basin of the Verde Groundwater Basin, several obstacles remain that must be overcome before importation can begin. The development of the infrastructure including wells and a thirty-mile long pipeline is projected to cost approximately $170 million (Barks, 2006a). This equates to approximately $20,000 per acre-foot of annual importation. Given the current economic outlook, this cost is reasonable and could be recovered by selling the rights to the water to developers; however, a continued slowdown in the housing market could redefine the price ceiling for Assured Water Supply credits.

While these financial hurdles are currently unlikely to impede the progress of the Big Chino Ranch project, legal challenges potentially threaten the proposed timetable for the project. In late 2004, the Center for Biological Diversity filed a notice of intent to sue Prescott and Prescott Valley over the project arguing the project would "condemn the Upper Verde to death" (Barks, 2006b). This challenge is based on the role of the Big Chino in supplying the baseflow of the Verde River, one of the last perennial rivers in Arizona. Several recent U.S. Geological Survey reports have proposed that the Big

Chino sub-basin contributes approximately 80% of the base flow to the Upper Verde springs (Wirt, et al., 2004). The Verde River is not only important habitat for several endangered species, but it is also an important source of water supply for the Salt River Project and the citizens of Phoenix (Dodder, 2006).

While the communities within the Prescott AMA have a clearly defined right to import water from the Big Chino sub-basin under Arizona law, a suit under the Endangered Species Act would bring the issue into the federal courts. While it will be difficult to quantify the impact pumping in the Big Chino will have on the flow of the Verde River, litigation could potentially delay all importation plans until a final settlement or court decision is reached. Such a final court decision could limit or even prohibit the transportation of Big Chino groundwater into the Prescott AMA.

The potential importation of Big Chino groundwater or other alternative water supplies is clearly an important driving force that will impact groundwater conditions in the Prescott AMA. While the communities of the AMA are pursuing importation as a central component of their water resource management plans, significant opposition to these plans remains. Due to the current uncertainty surrounding the implementation of these importation projects, importation must be considered one of the driving forces that will impact groundwater resources in the Prescott AMA.

Discussion of the Scenarios

Seven scenarios were developed for the Prescott Active Management Area to assess the impacts of population growth, conservation strategies and development of alternative water supplies on the groundwater system of the area. These scenarios are discussed as the Baseline Scenario, Projected Growth Scenario, Projected Growth with

Conservation Scenario, Projected Growth with Conservation and Augmentation Scenario, Low Growth Scenario, Low Growth with Conservation Scenario, and Low Growth with Conservation and Augmentation Scenario. Table 13 provides a summary of the main differences among the scenarios.

Four of these scenarios were simulated with the Prescott AMA groundwater flow model from 2005 to 2025. These four scenarios are the Baseline Scenario, the Projected Growth with Conservation Scenario, the Projected Growth with Conservation and Augmentation Scenario, and the Low Growth with Conservation and Augmentation Scenario. The results of these simulations are discussed in Chapter 7.

Table 13. Summary of major differences among the seven future scenarios for the Prescott AMA.

		Future scenarios						
		Baseline [1]	**PG [2]**	**PGCon [3]**	**PGConAug [4]**	**LG [5]**	**LGCon [6]**	**LGConAug [7]**
Population Growth	**City of Prescott**	0	2.5%	2.5%	2.5%	2.0%	2.0%	2.0%
	Town of Prescott Valley	0	4.5%	4.5%	4.5%	3.5%	3.5%	3.5%
	Town of Chino Valley	0	7.0%	7.0%	7.0%	5.0%	5.0%	5.0%
	Domestic Well Owners	0	5.0%	5.0%	5.0%	3.0%	3.0%	3.0%
Conservation Factor	**2010-2015**	0	0	10%	10%	0	10%	10%
	2015-2020	0	0	15%	15%	0	15%	15%
	2020-2025	0	0	20%	20%	0	20%	20%
Maximum Water Importation Rate (acre-feet/year)	**City of Prescott**	0	0	0	4717	0	0	4717
	Town of Prescott Valley	0	0	0	4000	0	0	4000
	Town of Chino Valley	0	0	0	1800	0	0	1800

[1] Baseline Scenario

[2] Projected Growth Scenario

[3] Projected Growth with Conservation Scenario

[4] Projected Growth with Conservation and Augmentation Scenario

[5] Low Growth Scenario

[6] Low Growth with Conservation Scenario

[7] Low Growth with Conservation and Augmentation Scenario

Baseline Scenario

The Baseline Scenario maintains 2005 pumping conditions through 2024 (Table 14). In addition, mountain front recharge, incidental agricultural recharge and artificial recharge are applied at 2005 rates throughout the period of simulation. Flood recharge is simulated during the winters of 2009-2010 and 2019-2020 based on the average flood recharge rates used by Nelson (2002) and a historic average recurrence interval of 10 years. The purpose of the Baseline Scenario is to assess the impacts of continuing current management practices into the future. Thus, the scenario serves as a baseline for comparison with the other four scenarios.

Projected Growth Scenario

The Projected Growth Scenario simulates increased groundwater pumping to meet water demands due to the rapid population growth that is projected for the Prescott AMA (Table 15). Growth in municipal demand was simulated based on population growth estimates provided by the major municipalities in the area. Water demand was assumed to increase directly with population growth.

The City of Prescott

Growth in the City of Prescott water service area was based on projections found in two primary reports produced by the City, the “City of Prescott Water Management Policy: 2005-2010” (2005) and in the “2003 City of Prescott General Plan: A Community Vision” (2004). These documents forecast a 2.0% - 2.5% annual rate of growth for the City and the City’s water service area. Total simulated water demand for 2005 is 9,700 acre-feet, based on the reported pumpage value for 2005 (ADWR, 2004) and an estimated 1,600 acre-feet of direct effluent use (City of Prescott, 2005). This water demand is then projected to grow by 2.5% per year from 2005 – 2024 (Table 15).

Effluent is projected to be generated at a rate of 50% of municipal use for the City of Prescott. This represents a median value between the 44% rate used by Nelson and the 54% rate estimated by the City of Prescott (Nelson, 2002, City of Prescott, 2005). Direct use of the City of Prescott's effluent is projected to remain constant throughout the simulated period at the 1999-2004 average rate of 1,600 af/yr. This is due to the City's decision to not allocate more effluent for the irrigation of golf courses, the primary source of current effluent use (City of Prescott, 2005). In addition, while one of the City's 1999 Water Management Policy goals was to convert existing parks and large turf areas from potable use to effluent, this goal has not been achieved due to inadequate availability of effluent and the cost of infrastructure (City of Prescott, 2005). While the level of available effluent is projected to increase in the future, it is unclear whether the City will be able to develop the infrastructure needed to increase direct effluent reuse. Thus, all available effluent in excess of the 1,600 af/yr allocated for direct use will be recharged at the City of Prescott's artificial recharge facility (Figure 30). In addition, 1,500 acre-feet of surface water from Watson and Willow Lakes will be recharged annually; however, the CVID will maintain its rights to this recharged surface water until 2020.

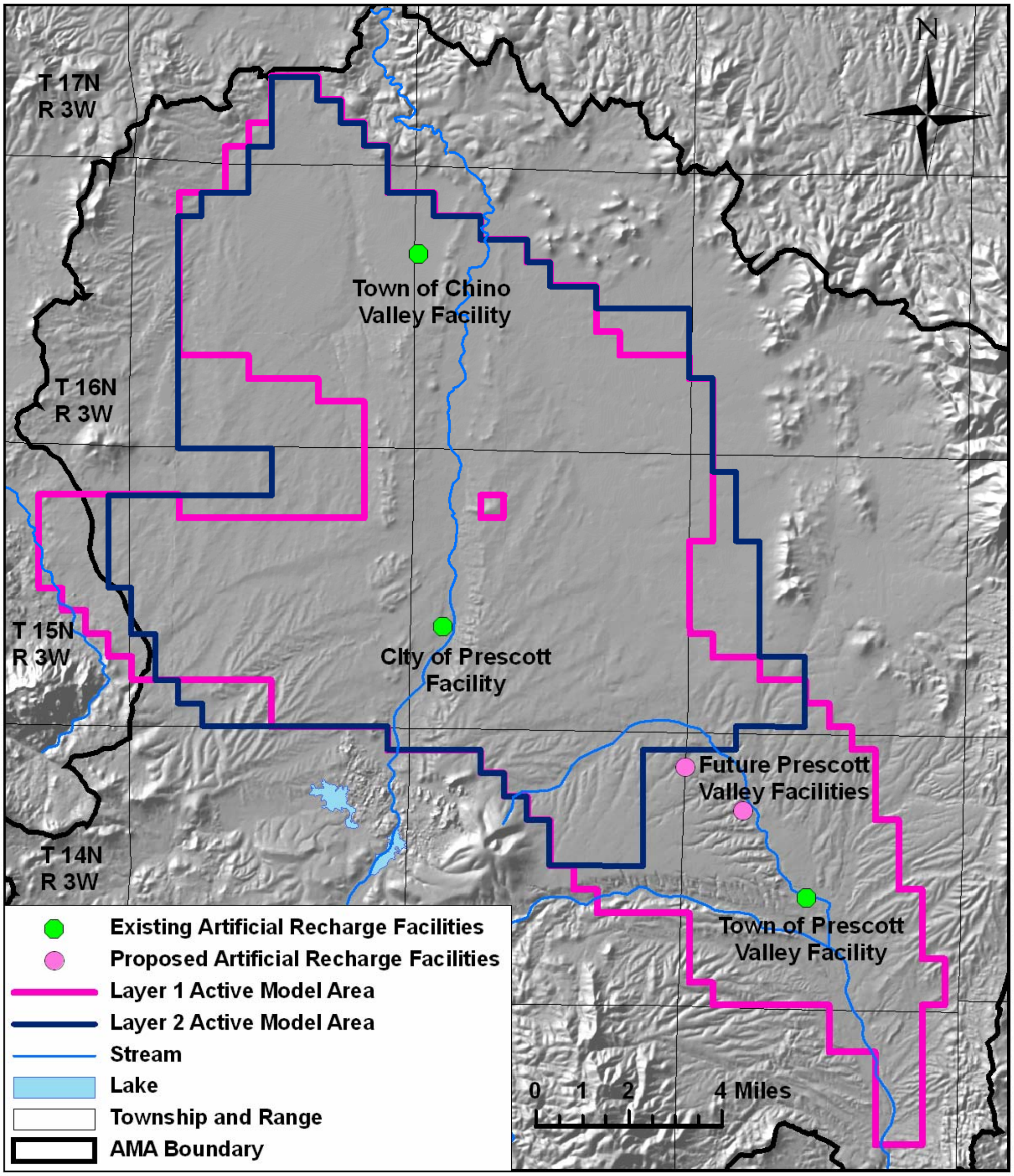

Figure 30. Location map of existing and proposed artificial recharge facilities in the Prescott AMA.

The Town of Prescott Valley

The Town of Prescott Valley developed three alternative growth scenarios as part of its "Prescott Valley General Plan 2020: A Community Blueprint for the Future" (2001). The three scenarios developed by the Town envision Prescott Valley growing from 23,535 residents in 2000 to between 46,365 and 69,780 residents in 2020 (Prescott Valley, 2001). This represents an annual growth rate of between 3.5 and 5.5%. While this is certainly a rapid pace of growth, it is not unreasonable given the astonishing rate of growth experienced by Prescott Valley over the past decade.

The Projected Growth Scenario for the Prescott AMA model utilizes the Town of Prescott Valley's median growth scenario as the basis for water demand projections. This scenario anticipates population growth in Prescott Valley proceeding at around 4.5% per year. Municipal water demand is projected to grow at a commensurate 4.5% annually (Table 15).

Effluent in the Town of Prescott Valley is projected to be generated based on rates provided by the Town (Munderloh, pers. comm., 11/27/2007). Effluent recovery is projected to rise from 48.0% to 52.7% of municipal water use over the simulated period (Munderloh, pers. comm., 11/27/2007). Currently, there are several neighborhoods served by the Prescott Valley water system that are not connected to the municipal sewer system. As all future development in the town will be required to connect to municipal water and sewer systems, new growth will decrease the proportion of unsewered homes, thus raising the effluent recovery rate. Direct use of effluent is projected to be maintained at 2005 levels through the simulated period. This is because Prescott Valley intends to use effluent generated in the future as the basis for future residential growth.

Effluent will be recharged into the alluvial aquifer of the Upper Agua Fria sub-basin and withdrawn from recovery wells as a potable supply. While an initial attempt was unsuccessful, Prescott Valley intends to auction off these effluent recovery rights to the highest bidder (McKinnon, 2006). Thus, all available effluent in excess of 800 af/yr will be recharged at the Town's Agua Fria River underground storage facility and two planned facilities scheduled to open in 2010 (Figure 30) (Munderloh, pers. comm., 11/27/2007).

The Town of Chino Valley

Over the past few years, the population of the Town of Chino Valley has expanded at an extremely rapid pace, with a growth rate exceeding 15% in some years (Mark Holmes, pers. comm.., 12/7/2006). While this extreme growth is not expected to continue, high growth rates are projected for the town. Alternate planning scenarios developed by the town anticipate growth proceeding at an annual rate between 4% and 10% over the next 25 years (Mark Holmes, pers. comm.., 12/7/2006). For the purposes of this scenario, the median annual growth rate of 7% is used. This is not unreasonable given the large subdivisions already planned for the future. The Bright Star subdivision and the Del Rio Ranch subdivision are expected to contribute an additional 5,063 residential units to the existing housing base, more than doubling the town's current population (Town of Chino Valley, 2003). The town is developing a master plan for a town center including increased commercial, industrial and residential development (Mark Holmes, pers. comm.., 12/7/2006). With the anticipated annual growth rate of 7%, the population of the town is expected to grow from less than 10,000 residents in 2004 to nearly 40,000 in 2025.

The structure of the water supply system in the Town of Chino Valley is expected to change greatly over the next twenty years with the rapid population growth. Currently, domestic exempt wells and small providers provide the primary water supply for most of the town's population while septic tanks are the predominant form of wastewater treatment. The town is extending sewer lines to all town residents to provide centralized wastewater treatment. It is expected that this will be completed by 2025 (Mark Holmes, pers. comm.., 12/7/2006). The town also has plans to extend water service to all residents, purchasing existing all small providers and exempt domestic wells within the town limits. The town also has plans to extend sewer lines to the Paulden area of the Big Chino Sub-basin to capture effluent generated from areas now currently served by septic systems (Mark Holmes, pers. comm.., 12/7/2006). As wastewater collection increases, the town plans to utilize its effluent to recharge the underlying groundwater system.

For the purposes of this scenario, we assume that the Town of Chino Valley will purchase all existing water companies within the town limits by 2010. Growth of exempt wells within the town limits will proceed at a growth rate of 5% per year until 2010, when exempt well development will cease (Table 15). Between 2010 and 2025, all exempt wells in the town limits will be converted in a linear fashion to municipal supply. The extension of sewer lines and the collection of wastewater will also proceed in a linear fashion from 2005 to 2025. Artificial recharge will occur at a rate of 50% of groundwater pumping by the town and exempt wells serviced by the municipal sewer system (Figure 30). Effluent generated in the Paulden area will be imported and recharged based on projected values provided by the Town of Chino Valley (Mark Holmes, pers. comm.., 12/7/2006).

Agriculture

Agricultural water use has declined dramatically over the past two decades from over 18,000 acre-feet in 1985 to an average of approximately 8,000 af/yr between 1999 and 2004 (ADWR, 2005). Agricultural water use in 2004 totaled 5,300 acre-feet, including 3800 acre-feet of IGFR's and 1,500 acre feet of CVID effluent recovery. Agricultural water use is projected to continue to decline over the coming decades. The Growth Scenario simulates agricultural water use based on IGFRs declining linearly by 115 af/yr through 2024 (Table 15). The CVID is projected to utilize its entire allotment of 1,500 af/yr of recovered effluent through 2020 when its contract with the City of Prescott expires. Based on this formula, agricultural water use will equal 500 acre-feet in 2024 (Table 15).

Other Water Users

Water demand from small providers and exempt domestic wells is projected to increase by an annual rate of 5% between 2005 and 2024, while demand from non-turf industrial users is projected to increase by an annual rate of 3% (Table 15).

Projected Growth with Conservation Scenario

The Conservation Scenario envisions population growth occurring along similar lines of the Projected Growth Scenario; however, conservation measures are utilized to reduce per capita water use over the length of the simulation. The Conservation Scenario projects that water use during the Fourth Management Period between 2010 and 2015 by municipal users, small providers, industrial users and exempt domestic wells will be reduced by 10% compared to the projections of the Projected Growth Scenario (Table 16). Further conservation measures will reduce water use from 2015 to 2020 by these sectors 15% compared to the Projected Growth Scenario, while the period from 2020-2025 will see water demand reduced by 20%. Economic pressure is expected to lead to continued reductions in agricultural water use over the simulated period (Table 16). This is the same reduction as seen in the Projected Growth Scenario.

The Conservation Scenario provides a framework to evaluate how reducing per capita water usage may impact the groundwater resources of the AMA; however, it does not establish a specific strategy of conservation programs that will reduce usage by the projected amounts. There are many various conservation strategies and programs that could potentially reduce water demand in the municipal, industrial, domestic and agricultural sectors. Many of these potential strategies have been discussed previously. This scenario simply assumes that conservation programs are enacted that reduce per capita water use by the above mentioned amounts (Table 16).

Projected Growth with Conservation and Augmentation Scenario

The Conservation and Augmentation Scenario assumes that water demand will be the same as for the Conservation Scenario. Thus, conservation measures will be used to help reduce the increased water demand due to population growth. However, the Conservation and Augmentation Scenario assumes the communities of the AMA will successfully augment their existing water supply through importation of additional water.

The Conservation and Augmentation Scenario is based on the existing plans of the communities in the area to import groundwater from the Big Chino Sub-basin of the Verde River Groundwater Basin. The Conservation and Augmentation Scenario assumes that the City of Prescott and the Town of Prescott Valley will begin importation in 2010 at a rate of 8,717 af/yr (Table 17). This supply will be divided according to the partnership agreement, with the City receiving 55% of water deliveries and the Town receiving 45%. Importation will continue through 2024.

The Scenario also assumes that the Town of Chino Valley will begin importation of Big Chino water in 2010 at a rate of 600 af/yr (Table 17). This rate will increase by a rate of 120 af/yr until 2020 when importation will reach a maximum annual rate of 1,800 acre-feet. This rate will be continued through 2024.

Low Growth Scenario

The Low Growth Scenario assumes that population growth and development in the Prescott AMA will proceed at the low end of projected rates. Growth in the City of Prescott will proceed at a rate of 2.0 %. Prescott Valley will grow at 3.5% and Chino Valley will grow at 5%. Population growth in the unincorporated areas served by small providers and exempt domestic wells will proceed at 3% annually, while water demand in these areas will grow at commensurate rates. Agricultural and industrial demand will remain the same as the demand seen in the Projected Growth Scenario (Table 18).

Low Growth with Conservation Scenario

The Low Growth with Conservation Scenario envisions growth proceeding along the lines of the Low Growth Scenario; however, conservation measures will be used to reduce actual water demand from municipal and industrial sources. Conservation will reduce water demand by 10% from 2010 – 2015, 15% from 2015 – 2020 and 20% from 2020-2024 when compared with the Low Growth Scenario (Table 19). The conservation strategies discussed previously provide a model for the types of conservation programs that could be used to achieve these levels of conservation; however, it is beyond the scope of this work to discuss a specific set of programs predicted to yield specific conservation results. Agricultural demand will remain the same as for the Projected Growth Scenario.

Low Growth with Conservation and Augmentation Scenario

Water demand in the Low Growth with Conservation and Augmentation Scenario remains the same as demand in the Low Growth with Conservation Scenario; however, in this scenario, imported supplies will be available to reduce groundwater demand within the AMA. In this scenario, 8717 af/yr will be imported by Prescott and Prescott Valley beginning in 2010 (Table 20). This water will be apportioned 55% to the City of Prescott and 45% to the Town of Prescott Valley. Importation will also begin for the Town of Chino Valley in 2010 at a rate of 600 af/yr. This rate will increase to 1800 af/yr by 2020 (Table 20).

Table 14. Conceptual Water Budget Components for the Baseline Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700	9700
Potable Water Demand	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900	7900
Effluent Generated	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950	3950
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350	2350
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570	1570
Effluent Remaining	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780
Surface Water Recovery																				
Importation																				
Groundwater Pumpage	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330	6330
Town of Prescott Valley																				
Total Water Demand	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405	5405
Potable Water Demand	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072
Effluent Recovery %	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%	48.0%
Effluent Generated	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328	2328
Effluent Direct Use	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333	333
Incidental Recharge	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33	33
Effluent Recharge	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995
Effluent Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Effluent Remaining	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995
Importation																				
Groundwater Pumpage	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072	5072
Town of Chino Valley																				
Total Water Demand	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332	1332
Municipal Demand	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
Small Water Providers	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310
Exempt Wells	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Exempt/ SP Sewered	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SP/Exempt Effluent Generated	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Effluent Generated	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Imported Effluent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Effluent Recharged	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Effluent Recovery	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Effluent Remaining in Aquifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Imported Potable Water																				
Municipal Groundwater Pumpage	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Agricultural Users																				
CVID	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200
IGFR's and Irrigation Use	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650
Incidental Recharge	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925	1925
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325	325
Industrial Use																				
Non-turf pumpage	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310	310
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Non-AMA Pumpage	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge					8470										8470					
Total Pumpage	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494	20494
Total Recharge	15227	15227	15227	15227	23697	15227	15227	15227	15227	15227	15227	15227	15227	15227	23697	15227	15227	15227	15227	15227

Table 15. Conceptual Water Budget Components for the Projected Growth Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9500	9738	9981	10230	10486	9674	9915	10163	10417	10678	10337	10595	10860	11131	11410	11007	11282	11564	11853	12150
Potable Water Demand	7900	8138	8381	8630	8886	8074	8315	8563	8817	9078	8737	8995	9260	9531	9810	9407	9682	9964	10253	10550
Effluent Generated	4050	4171	4296	4423	4553	4687	4825	4965	5109	5257	5408	5564	5723	5886	6053	6224	6400	6580	6764	6953
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2571	2696	2823	2953	3087	3225	3365	3509	3657	3808	3964	4123	4286	4453	4624	4800	4980	5164	5353
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	2571	2696	2823	2953	3087	3225	3365	3509	3657	3808	3964	4123	4286	4453	4624	4800	4980	5164	5353
Effluent Remaining	780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Water Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	1500	1500	1500
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Groundwater Pumpage	6330	5566	5685	5808	5933	4986	5091	5198	5308	5421	4928	5031	5137	5246	5357	4783	3382	3484	3589	3696
Town of Prescott Valley																				
Total Water Demand	5405	5648	5902	6168	6446	6062	6335	6620	6918	7229	7135	7456	7791	8142	8508	8368	8745	9138	9549	9979
Potable Water Demand	5072	5298	5552	5818	6096	5712	5985	6270	6568	6879	6785	7106	7441	7792	8158	8018	8395	8788	9199	9629
Effluent Recovery %	48.0%	48.4%	48.9%	49.3%	49.7%	49.1%	49.5%	49.9%	50.3%	50.6%	50.5%	50.9%	51.2%	51.5%	51.8%	51.7%	52.0%	52.2%	52.5%	52.7%
Effluent Generated	2328	2566	2713	2867	3028	2806	2964	3129	3302	3483	3428	3614	3809	4012	4225	4143	4362	4590	4828	5078
Effluent Direct Use	333	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Incidental Recharge	33	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Effluent Recharge	1995	2216	2363	2517	2678	2456	2614	2779	2952	3133	3078	3264	3459	3662	3875	3793	4012	4240	4478	4728
Effluent Recovery	0	0	0	0	100	400	700	1000	1300	1600	1900	2200	2400	2600	2724	2724	2724	2724	2724	2724
Effluent Remaining	1995	2216	2363	2517	2578	2056	1914	1779	1652	1533	1178	1064	1059	1062	1151	1069	1288	1516	1754	2004
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	5072	5298	5552	5818	5996	5312	5285	5270	5268	5279	4885	4906	5041	5192	5434	5294	5671	6064	6475	6905
Town of Chino Valley																				
Total Water Demand	1332	1425	1525	1632	1746	1868	1999	2139	2289	2449	2620	2804	3000	3210	3435	3675	3932	4208	4502	4817
Municipal Demand	22	115	228	344	465	720	879	1099	1329	1569	1820	2084	2360	2650	2955	3275	3612	3968	4342	4737
Small Water Providers	310	260	195	130	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exempt Wells	1000	1050	1103	1158	1216	1149	1120	1040	960	880	800	720	640	560	480	400	320	240	160	80
Exempt/ SP Sewered	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%
SP/Exempt Effluent Generated	0	65	130	193	256	287	336	364	384	396	400	396	384	364	336	300	256	204	144	76
Total Effluent Generated	7	123	244	365	489	647	775	913	1048	1180	1310	1438	1564	1689	1813	1938	2062	2188	2315	2445
Imported Effluent	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Effluent Recharged	7	115	244	365	489	647	775	913	1048	1180	1310	1438	1564	1689	1813	1938	2062	2188	2315	2445
Effluent Recovery	7	115	228	344	465	533	775	913	1048	1180	1310	1438	1564	1689	1813	1938	2062	2188	2315	2445
Effluent Remaining in Aquifer	0	0	16	21	24	114	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Imported Potable Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Municipal Groundwater Pumpage	15	0	0	0	0	0	103	185	280	388	510	646	796	961	1141	1338	1550	1780	2027	2293
Agricultural Users																				
CVID	1200	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	0	0	0
IGFR's and Irrigation Use	2650	2535	2420	2305	2190	2075	1960	1845	1730	1615	1500	1385	1270	1155	1040	925	810	695	580	500
Incidental Recharge	1925	2018	1960	1903	1845	1788	1730	1673	1615	1558	1500	1443	1385	1328	1270	1213	405	348	290	250
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	341	358	376	395	373	392	412	432	454	450	472	496	521	547	541	568	596	626	657
Industrial Use																				
Non-turf pumpage	310	319	329	339	349	323	333	343	353	364	354	365	376	387	399	386	398	410	422	435
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1030	1061	1093	1126	1159	1194	1230	1267	1305	1344	1384	1426	1469	1513	1558	1605	1653	1702	1754
Non-AMA Pumpage	240	252	265	278	292	306	322	338	355	372	391	410	431	453	475	499	524	550	578	606
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge						8470										8470				
Total Pumpage	20494	21304	21857	22436	23043	21670	22465	23104	23776	24481	24146	24886	25665	26482	27341	26974	26378	27329	28328	29413
Total Recharge	15227	15871	16214	16559	16917	25399	17296	17682	18076	18479	18648	19060	19482	19916	20362	28989	20230	20707	21199	21727

Table 16. Conceptual Water Budget Components for the Projected Growth with Conservation Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9500	9738	9981	10230	10486	9674	9915	10163	10417	10678	10337	10595	10860	11131	11410	11007	11282	11564	11853	12150
Potable Water Demand	7900	8138	8381	8630	8886	8074	8315	8563	8817	9078	8737	8995	9260	9531	9810	9407	9682	9964	10253	10550
Effluent Generated	3950	4069	4190	4315	4443	4037	4158	4282	4409	4539	4368	4498	4630	4766	4905	4704	4841	4982	5127	5275
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2469	2590	2715	2843	2437	2558	2682	2809	2939	2768	2898	3030	3166	3305	3104	3241	3382	3527	3675
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	2469	2590	2715	2843	2437	2558	2682	2809	2939	2768	2898	3030	3166	3305	3104	3241	3382	3527	3675
Effluent Remaining	780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Water Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	1500	1500	1500
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	6330	5669	5790	5915	6043	5637	5758	5882	6009	6139	5968	6098	6230	6366	6505	6304	4941	5082	5227	5375
Town of Prescott Valley																				
Total Water Demand	5405	5648	5902	6168	6446	6062	6335	6620	6918	7229	7135	7456	7791	8142	8508	8368	8745	9138	9549	9979
Potable Water Demand	5072	5298	5552	5818	6096	5712	5985	6270	6568	6879	6785	7106	7441	7792	8158	8018	8395	8788	9199	9629
Effluent Recovery %	48.0%	48.4%	48.9%	49.3%	49.7%	49.1%	49.5%	49.9%	50.3%	50.6%	50.5%	50.9%	51.2%	51.5%	51.8%	51.7%	52.0%	52.2%	52.5%	52.7%
Effluent Generated	2328	2566	2713	2867	3028	2806	2964	3129	3302	3483	3428	3614	3809	4012	4225	4143	4362	4590	4828	5078
Effluent Direct Use	333	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Incidental Recharge	33	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Effluent Recharge	1995	2216	2363	2517	2678	2456	2614	2779	2952	3133	3078	3264	3459	3662	3875	3793	4012	4240	4478	4728
Effluent Recovery	0	0	0	0	100	400	700	1000	1300	1600	1900	2200	2400	2600	2724	2724	2724	2724	2724	2724
Effluent Remaining	1995	2216	2363	2517	2578	2056	1914	1779	1652	1533	1178	1064	1059	1062	1151	1069	1288	1516	1754	2004
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	5072	5298	5552	5818	5996	5312	5285	5270	5268	5279	4885	4906	5041	5192	5434	5294	5671	6064	6475	6905
Town of Chino Valley																				
Total Water Demand	1332	1425	1525	1632	1746	1681	1799	1925	2060	2204	2227	2383	2550	2728	2919	2940	3146	3366	3602	3854
Municipal Demand	22	115	228	344	465	533	679	885	1100	1324	1427	1663	1910	2168	2439	2540	2826	3126	3442	3774
Small Water Providers	310	260	195	130	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exempt Wells	1000	1050	1103	1158	1216	1149	1120	1040	960	880	800	720	640	560	480	400	320	240	160	80
Exempt/ SP Sewered	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%
SP/Exempt Effluent Generated	0	33	65	97	128	144	168	182	192	198	200	198	192	182	168	150	128	102	72	38
Total Effluent Generated	7	90	179	269	361	410	508	625	742	860	914	1030	1147	1266	1388	1420	1541	1665	1793	1925
Imported Effluent	0	0	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Effluent Recharged	7	90	179	319	461	560	708	875	1042	1210	1314	1480	1647	1816	1988	2070	2241	2415	2593	2775
Effluent Recovery	7	90	179	319	461	533	679	875	1042	1210	1314	1480	1647	1816	1988	2070	2241	2415	2593	2775
Effluent Remaining in Aquifer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Imported Potable Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Municipal Groundwater Pumpage	15	25	49	25	5	0	0	11	58	114	114	184	263	352	452	470	585	711	849	999
Agricultural Users																				
CVID	1200	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500				
IGFR's and Irrigation Use	2650	2535	2420	2305	2190	2075	1960	1845	1730	1615	1500	1385	1270	1155	1040	925	810	695	580	500
Incidental Recharge	1925	2018	1960	1903	1845	1788	1730	1673	1615	1558	1500	1443	1385	1328	1270	1213	405	348	290	250
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	341	358	376	395	373	392	412	432	454	450	472	496	521	547	541	568	596	626	657
Industrial Use																				
Non-turf pumpage	310	319	329	339	349	323	333	343	353	364	354	365	376	387	399	386	398	410	422	435
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1050	1103	1158	1216	1149	1206	1266	1330	1396	1385	1454	1526	1603	1683	1663	1746	1834	1925	2022
Non-AMA Pumpage	240	252	265	278	292	306	322	338	355	372	391	410	431	453	475	499	524	550	578	606
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge					8470										8470					
Total Pumpage	20494	21324	21898	22501	23134	21659	22277	22927	23610	24327	23793	24536	25315	26135	26996	26344	25733	26668	27650	28718
Total Recharge	15227	15744	16044	16405	25249	16192	16561	16959	17369	17791	17611	18035	18472	18923	27859	19131	18850	19336	19840	20379

Table 17. Conceptual Water Budget Components for the Projected Growth with Conservation and Augmentation Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9500	9738	9981	10230	10486	9674	9915	10163	10417	10678	10337	10595	10860	11131	11410	11007	11282	11564	11853	12150
Potable Water Demand	7900	8138	8381	8630	8886	8074	8315	8563	8817	9078	8737	8995	9260	9531	9810	9407	9682	9964	10253	10550
Effluent Generated	3950	4069	4190	4315	4443	4037	4158	4282	4409	4539	4368	4498	4630	4766	4905	4704	4841	4982	5127	5275
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2469	2590	2715	2843	2437	2558	2682	2809	2939	2768	2898	3030	3166	3305	3104	3241	3382	3527	3675
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	2469	2590	2715	2843	2437	2558	2682	2809	2939	2768	2898	3030	3166	3305	3104	3241	3382	3527	3675
Effluent Remaining	780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Water Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	1500	1500	1500
Importation	0	0	0	0	0	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717
Groundwater Pumpage	6330	5669	5790	5915	6043	920	1041	1165	1292	1422	1251	1381	1513	1649	1788	1587	224	365	510	658
Town of Prescott Valley																				
Total Water Demand	5405	5648	5902	6168	6446	6062	6335	6620	6918	7229	7135	7456	7791	8142	8508	8368	8745	9138	9549	9979
Potable Water Demand	5072	5298	5552	5818	6096	5712	5985	6270	6568	6879	6785	7106	7441	7792	8158	8018	8395	8788	9199	9629
Effluent Recovery %	48.0%	48.4%	48.9%	49.3%	49.7%	49.1%	49.5%	49.9%	50.3%	50.6%	50.5%	50.9%	51.2%	51.5%	51.8%	51.7%	52.0%	52.2%	52.5%	52.7%
Effluent Generated	2328	2566	2713	2867	3028	2806	2964	3129	3302	3483	3428	3614	3809	4012	4225	4143	4362	4590	4828	5078
Effluent Direct Use	333	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Incidental Recharge	33	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Effluent Recharge	1995	2216	2363	2517	2678	2456	2614	2779	2952	3133	3078	3264	3459	3662	3875	3793	4012	4240	4478	4728
Effluent Recovery	0	0	0	0	100	400	700	1000	1300	1600	1900	2200	2400	2600	2724	2724	2724	2724	2724	2724
Effluent Remaining	1995	2216	2363	2517	2578	2056	1914	1779	1652	1533	1178	1064	1059	1062	1151	1069	1288	1516	1754	2004
Importation	0	0	0	0	0	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
Groundwater Pumped	5072	5298	5552	5818	5996	1312	1285	1270	1268	1279	885	906	1041	1192	1434	1294	1671	2064	2475	2905
Town of Chino Valley																				
Total Water Demand	1332	1425	1525	1632	1746	1681	1799	1925	2060	2204	2227	2383	2550	2728	2919	2940	3146	3366	3602	3854
Municipal Demand	22	115	228	344	465	533	679	885	1100	1324	1427	1663	1910	2168	2439	2540	2826	3126	3442	3774
Small Water Providers	310	260	195	130	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exempt Wells	1000	1050	1103	1158	1216	1149	1120	1040	960	880	800	720	640	560	480	400	320	240	160	80
Exempt/ SP Sewered	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%
SP/Exempt Effluent Generated	0	33	64	94	123	150	168	182	192	198	200	198	192	182	168	150	128	102	72	38
Total Effluent Generated	7	91	178	266	355	416	508	625	742	860	914	1030	1147	1266	1388	1420	1541	1665	1793	1925
Imported Effluent	0	0	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Effluent Recharged	7	91	178	316	455	566	708	875	1042	1210	1314	1480	1647	1816	1988	2070	2241	2415	2593	2775
Effluent Recovery	7	91	178	316	0	0	0	0	0	0	0	0	110	368	639	740	1026	1326	1642	1974
Effluent Remaining in Aquifer	0	0	0	0	455	566	708	875	1042	1210	1314	1480	1537	1448	1349	1330	1215	1089	951	801
Imported Potable Water	0	0	0	0	600	840	1080	1320	1560	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Municipal Groundwater Pumpage	15	25	50	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agricultural Users																				
CVID	1200	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	0	0	0
IGFR's and Irrigation Use	2650	2535	2420	2305	2190	2075	1960	1845	1730	1615	1500	1385	1270	1155	1040	925	810	695	580	500
Incidental Recharge	1925	2018	1960	1903	1845	1788	1730	1673	1615	1558	1500	1443	1385	1328	1270	1213	405	348	290	250
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	341	358	376	395	373	392	412	432	454	450	472	496	521	547	541	568	596	626	657
Industrial Use																				
Non-turf pumpage	310	319	329	339	349	323	333	343	353	364	354	365	376	387	399	386	398	410	422	435
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1050	1103	1158	1216	1149	1206	1266	1330	1396	1385	1454	1526	1603	1683	1663	1746	1834	1925	2022
Non-AMA Pumpage	240	252	265	278	292	306	322	338	355	372	391	410	431	453	475	499	524	550	578	606
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge					8470	0									8470	0				
Total Pumpage	20494	21324	21898	22501	22668	12409	12881	13325	13793	14286	13649	14155	14799	15618	16479	15827	15217	16151	17134	18201
Total Recharge	15227	15744	16043	16403	25243	16198	16561	16959	17369	17791	17611	18035	18472	18923	27859	19131	18850	19336	19840	20379

Table 18. Conceptual Water Budget Components for the Low Growth Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9500	9690	9884	10081	10283	10489	10699	10913	11131	11353	11580	11812	12048	12289	12535	12786	13041	13302	13568	13840
Potable Water Demand	7900	8090	8284	8481	8683	8889	9099	9313	9531	9753	9980	10212	10448	10689	10935	11186	11441	11702	11968	12240
Effluent Generated	3950	4045	4142	4241	4342	4444	4549	4656	4765	4877	4990	5106	5224	5345	5468	5593	5721	5851	5984	6120
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2445	2542	2641	2742	2844	2949	3056	3165	3277	3390	3506	3624	3745	3868	3993	4121	4251	4384	4520
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	2445	2542	2641	2742	2844	2949	3056	3165	3277	3390	3506	3624	3745	3868	3993	4121	4251	4384	4520
Effluent Remaining	780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Water Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	1500	1500	1500
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	6330	5645	5742	5841	5942	6044	6149	6256	6365	6477	6590	6706	6824	6945	7068	7193	5821	5951	6084	6220
Town of Prescott Valley																				
Total Water Demand	5405	5594	5790	5993	6202	6419	6644	6877	7117	7366	7624	7891	8167	8453	8749	9055	9372	9700	10040	10391
Potable Water Demand	5072	5244	5440	5643	5852	6069	6294	6527	6767	7016	7274	7541	7817	8103	8399	8705	9022	9350	9690	10041
Effluent Recovery %	48.0%	48.4%	48.9%	49.3%	49.7%	49.1%	49.5%	49.9%	50.3%	50.6%	50.5%	50.9%	51.2%	51.5%	51.8%	51.7%	52.0%	52.2%	52.5%	52.7%
Effluent Generated	2435	2540	2658	2781	2907	2981	3117	3257	3402	3552	3675	3836	4001	4172	4349	4498	4688	4883	5086	5295
Effluent Direct Use	333	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Incidental Recharge	33	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Effluent Recharge	1995	2190	2308	2431	2557	2631	2767	2907	3052	3202	3325	3486	3651	3822	3999	4148	4338	4533	4736	4945
Effluent Recovery	0	0	0	0	100	400	700	1000	1300	1600	1900	2200	2400	2600	2724	2724	2724	2724	2724	2724
Effluent Remaining	1995	2190	2308	2431	2457	2231	2067	1907	1752	1602	1425	1286	1251	1222	1275	1424	1614	1809	2012	2221
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	5072	5244	5440	5643	5752	5669	5594	5527	5467	5416	5374	5341	5417	5503	5675	5981	6298	6626	6966	7317
Town of Chino Valley																				
Total Water Demand	1332	1399	1469	1542	1619	1700	1785	1874	1968	2066	2170	2278	2392	2512	2637	2769	2908	3053	3206	3366
Municipal Demand	22	89	171	254	339	551	665	834	1008	1186	1370	1558	1752	1952	2157	2369	2588	2813	3046	3286
Small Water Providers	310	260	195	130	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exempt Wells	1000	1050	1103	1158	1216	1149	1120	1040	960	880	800	720	640	560	480	400	320	240	160	80
Exempt/ SP Sewered	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%
SP/Exempt Effluent Generated	0	26	55	87	122	144	168	182	192	198	200	198	192	182	168	150	128	102	72	38
Total Effluent Generated	7	71	141	214	291	419	501	599	696	791	885	977	1068	1158	1247	1335	1422	1508	1595	1681
Imported Effluent	0	0	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Effluent Recharged	7	71	141	264	391	569	701	849	996	1141	1285	1427	1568	1708	1847	1985	2122	2258	2395	2531
Effluent Recovery	7	71	141	254	0	0	0	0	0	0	0	0	0	152	357	569	788	1013	1246	1486
Effluent Remaining in Aquifer	0	0	0	10	391	569	701	849	996	1141	1285	1427	1568	1556	1490	1416	1334	1245	1149	1045
Imported Potable Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Municipal Groundwater Pumpage	15	18	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agricultural Users																				
CVID	1200	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	0	0	0
IGFR's and Irrigation Use	2650	2535	2420	2305	2190	2075	1960	1845	1730	1615	1500	1385	1270	1155	1040	925	810	695	580	500
Incidental Recharge	1925	2018	1960	1903	1845	1788	1730	1673	1615	1558	1500	1443	1385	1328	1270	1213	405	348	290	250
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	335	345	355	366	377	388	400	412	424	437	450	463	477	492	506	522	537	553	570
Industrial Use																				
Non-turf pumpage	310	319	329	339	349	359	370	381	393	404	417	429	442	455	469	483	497	512	528	544
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1030	1061	1093	1126	1159	1194	1230	1267	1305	1344	1384	1426	1469	1513	1558	1605	1653	1702	1754
Non-AMA Pumpage	240	247	255	262	270	278	287	295	304	313	323	332	342	352	363	374	385	397	409	421
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge	0	0	0	0	8470	0	0	0	0	0	0	0	0	0	8470	0	0	0	0	0
Total Pumpage	20494	21164	21566	21985	22081	22321	22677	22995	23328	23676	24040	24419	24814	25378	26012	26671	25855	26565	27301	28100
Total Recharge	15227	15674	15902	16190	24956	16784	17098	17437	17780	18129	18452	18813	19180	19554	28405	20290	19937	20342	20756	21197

Table 19. Conceptual Water Budget Components for the Low Growth with Conservation Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9500	9690	9884	10081	10283	9440	9629	9821	10018	10218	9843	10040	10241	10446	10655	10229	10433	10642	10855	11072
Potable Water Demand	7900	8090	8284	8481	8683	7840	8029	8221	8418	8618	8243	8440	8641	8846	9055	8629	8833	9042	9255	9472
Effluent Generated	3950	4045	4142	4241	4342	3920	4014	4111	4209	4309	4122	4220	4321	4423	4527	4314	4417	4521	4627	4736
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2445	2542	2641	2742	2320	2414	2511	2609	2709	2522	2620	2721	2823	2927	2714	2817	2921	3027	3136
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	2445	2542	2641	2742	2320	2414	2511	2609	2709	2522	2620	2721	2823	2927	2714	2817	2921	3027	3136
Effluent Remaining	780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Water Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	1500	1500	1500
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	6330	5645	5742	5841	5942	5520	5614	5711	5809	5909	5722	5820	5921	6023	6127	5914	4517	4621	4727	4836
Town of Prescott Valley																				
Total Water Demand	5405	5594	5790	5993	6202	5778	5980	6189	6406	6630	6481	6707	6942	7185	7437	7244	7498	7760	8032	8313
Potable Water Demand	5072	5244	5440	5643	5852	5428	5630	5839	6056	6280	6131	6357	6592	6835	7087	6894	7148	7410	7682	7963
Effluent Recovery %	48.0%	48.4%	48.9%	49.3%	49.7%	49.1%	49.5%	49.9%	50.3%	50.6%	50.5%	50.9%	51.2%	51.5%	51.8%	51.7%	52.0%	52.2%	52.5%	52.7%
Effluent Generated	2435	2540	2658	2781	2907	2666	2788	2914	3045	3179	3097	3234	3374	3519	3670	3563	3714	3870	4032	4199
Effluent Direct Use	333	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Incidental Recharge	33	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Effluent Recharge	1995	2190	2308	2431	2557	2316	2438	2564	2695	2829	2747	2884	3024	3169	3320	3213	3364	3520	3682	3849
Effluent Recovery	0	0	0	0	100	400	700	1000	1300	1600	1900	2200	2400	2600	2724	2724	2724	2724	2724	2724
Effluent Remaining	1995	2190	2308	2431	2457	1916	1738	1564	1395	1229	847	684	624	569	596	489	640	796	958	1125
Importation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Groundwater Pumpage	5072	5244	5440	5643	5752	5028	4930	4839	4756	4680	4231	4157	4192	4235	4363	4170	4424	4686	4958	5239
Town of Chino Valley																				
Total Water Demand	1332	1399	1469	1542	1619	1530	1607	1687	1771	1860	1844	1936	2033	2135	2242	2215	2326	2442	2564	2693
Municipal Demand	22	89	171	254	339	381	487	647	811	980	1044	1216	1393	1575	1762	1815	2006	2202	2404	2613
Small Water Providers	310	260	195	130	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exempt Wells	1000	1050	1103	1158	1216	1149	1120	1040	960	880	800	720	640	560	480	400	320	240	160	80
Exempt/ SP Sewered	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%
SP/Exempt Effluent Generated	0	26	55	87	122	144	168	182	192	198	200	198	192	182	168	150	128	102	72	38
Total Effluent Generated	7	71	141	214	291	334	411	505	598	688	722	806	889	969	1049	1058	1131	1203	1274	1344
Imported Effluent	0	0	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Effluent Recharged	7	71	141	264	391	484	611	755	898	1038	1122	1256	1389	1519	1649	1708	1831	1953	2074	2194
Effluent Recovery	7	71	141	254	0	0	0	0	0	0	0	0	0	0	0	16	206	402	604	812
Effluent Remaining in Aquifer	0	0	0	10	391	484	611	755	898	1038	1122	1256	1389	1519	1649	1692	1625	1551	1470	1382
Imported Potable Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Municipal Groundwater Pumpage	15	18	30	0	339	381	487	647	811	980	1044	1216	1393	1575	1762	1799	1800	1800	1800	1801
Agricultural Users																				
CVID	1200	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	0	0	0
IGFR's and Irrigation Use	2650	2535	2420	2305	2190	2075	1960	1845	1730	1615	1500	1385	1270	1155	1040	925	810	695	580	500
Incidental Recharge	1925	2018	1960	1903	1845	1788	1730	1673	1615	1558	1500	1443	1385	1328	1270	1213	405	348	290	250
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	335	345	355	366	339	349	360	371	382	371	382	394	406	418	405	417	430	443	456
Industrial Use																				
Non-turf pumpage	310	319	329	339	349	323	333	343	353	364	354	365	376	387	399	386	398	410	422	435
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1030	1061	1093	1126	1043	1075	1107	1140	1174	1142	1177	1212	1248	1286	1246	1284	1322	1362	1403
Non-AMA Pumpage	240	247	255	262	270	278	287	295	304	313	323	332	342	352	363	374	385	397	409	421
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge	0	0	0	0	8470	0	0	0	0	0	0	0	0	0	8470	0	0	0	0	0
Total Pumpage	20494	21164	21566	21985	22420	20821	21234	21662	22108	22571	21873	22340	22825	23329	23853	23040	22066	22613	23181	23807
Total Recharge	15227	15674	15902	16190	24956	15859	16145	16454	16768	17085	16843	17154	17470	17791	26587	17798	17368	17693	18025	18381

Table 20. Conceptual Water Budget Components for the Low Growth with Conservation and Augmentation Scenario for the Prescott AMA.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
City of Prescott																				
Total Water Demand	9500	9690	9884	10081	10283	9440	9629	9821	10018	10218	9843	10040	10241	10446	10655	10229	10433	10642	10855	11072
Potable Water Demand	7900	8090	8284	8481	8683	7840	8029	8221	8418	8618	8243	8440	8641	8846	9055	8629	8833	9042	9255	9472
Effluent Generated	3950	4045	4142	4241	4342	3920	4014	4111	4209	4309	4122	4220	4321	4423	4527	4314	4417	4521	4627	4736
Effluent Direct Use	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600	1600
Incidental Recharge	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120
Effluent Recharge	2350	2445	2542	2641	2742	2320	2414	2511	2609	2709	2522	2620	2721	2823	2927	2714	2817	2921	3027	3136
Surface Water Recharge	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Effluent Recovery	1570	2445	2542	2641	2742	2320	2414	2511	2609	2709	2522	2620	2721	2823	2927	2714	2817	2921	3027	3136
Effluent Remaining	780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Surface Water Recovery	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1500	1500	1500	1500
Importation	0	0	0	0	0	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717	4717
Groundwater Pumpage	6330	5645	5742	5841	5942	803	897	994	1092	1192	1005	1103	1204	1306	1410	1197	-200	-96	10	119
Town of Prescott Valley																				
Total Water Demand	5405	5594	5790	5993	6202	5778	5980	6189	6406	6630	6481	6707	6942	7185	7437	7244	7498	7760	8032	8313
Potable Water Demand	5072	5244	5440	5643	5852	5428	5630	5839	6056	6280	6131	6357	6592	6835	7087	6894	7148	7410	7682	7963
Effluent Recovery %	48.0%	48.4%	48.9%	49.3%	49.7%	49.1%	49.5%	49.9%	50.3%	50.6%	50.5%	50.9%	51.2%	51.5%	51.8%	51.7%	52.0%	52.2%	52.5%	52.7%
Effluent Generated	2435	2540	2658	2781	2907	2666	2788	2914	3045	3179	3097	3234	3374	3519	3670	3563	3714	3870	4032	4199
Effluent Direct Use	333	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Incidental Recharge	33	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Effluent Recharge	1995	2190	2308	2431	2557	2316	2438	2564	2695	2829	2747	2884	3024	3169	3320	3213	3364	3520	3682	3849
Effluent Recovery	0	0	0	0	100	400	700	1000	1300	1600	1900	2200	2400	2600	2724	2724	2724	2724	2724	2724
Effluent Remaining	1995	2190	2308	2431	2457	1916	1738	1564	1395	1229	847	684	624	569	596	489	640	796	958	1125
Importation	0	0	0	0	0	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
Groundwater Pumpage	5072	5244	5440	5643	5752	1028	930	839	756	680	231	157	192	235	363	170	424	686	958	1239
Town of Chino Valley																				
Total Water Demand	1332	1399	1469	1542	1619	1530	1607	1687	1771	1860	1844	1936	2033	2135	2242	2215	2326	2442	2564	2693
Municipal Demand	22	89	171	254	339	381	487	647	811	980	1044	1216	1393	1575	1762	1815	2006	2202	2404	2613
Small Water Providers	310	260	195	130	65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Exempt Wells	1000	1050	1103	1158	1216	1149	1120	1040	960	880	800	720	640	560	480	400	320	240	160	80
Exempt/ SP Sewered	0.0%	5.0%	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%	95.0%
SP/Exempt Effluent Generated	0	26	55	87	122	144	168	182	192	198	200	198	192	182	168	150	128	102	72	38
Total Effluent Generated	7	71	141	214	291	334	411	505	598	688	722	806	889	969	1049	1058	1131	1203	1274	1344
Imported Effluent				50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850
Effluent Recharged	7	71	141	264	391	484	611	755	898	1038	1122	1256	1389	1519	1649	1708	1831	1953	2074	2194
Effluent Recovery	7	71	141	254	0	0	0	0	0	0	0	0	0	0	0	15	206	402	604	812
Effluent Remaining in Aquifer	0	0	0	10	391	484	611	755	898	1038	1122	1256	1389	1519	1649	1693	1625	1551	1470	1382
Imported Potable Water	0	0	0	0	600	840	1080	1320	1560	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
Municipal Groundwater Pumpage	15	18	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Agricultural Users																				
CVID	1200	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	0	0	0	0
IGFR's and Irrigation Use	2650	2535	2420	2305	2190	2075	1960	1845	1730	1615	1500	1385	1270	1155	1040	925	810	695	580	500
Incidental Recharge	1925	2018	1960	1903	1845	1788	1730	1673	1615	1558	1500	1443	1385	1328	1270	1213	405	348	290	250
Non Chino Valley Small Providers																				
Groundwater Pumpage	325	335	345	355	366	339	349	360	371	382	371	382	394	406	418	405	417	430	443	456
Industrial Use																				
Non-turf pumpage	310	319	329	339	349	323	333	343	353	364	354	365	376	387	399	386	398	410	422	435
Turf pumpage	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465	465
Incidental recharge	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47	47
Non Chino Valley Exempt Wells																				
Groundwater Pumpage	1000	1030	1061	1093	1126	1043	1075	1107	1140	1174	1142	1177	1212	1248	1286	1246	1284	1322	1362	1403
Non-AMA Pumpage	240	247	255	262	270	278	287	295	304	313	323	332	342	352	363	374	385	397	409	421
Other Recharge																				
Mountain Front Recharge	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750	5750
Granite Creek Conveyance	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Flood Recharge	0	0	0	0	8470	0	0	0	0	0	0	0	0	0	8470	0	0	0	0	0
Total Pumpage	20494	21164	21566	21985	22081	11723	12030	12298	12579	12874	12112	12407	12715	13037	13375	12523	11549	12096	12664	13289
Total Recharge	15227	15674	15902	16190	24956	15859	16145	16454	16768	17085	16843	17154	17470	17791	26587	17798	17368	17693	18025	18381

Climate Change

One of the most important variables that was not included within the four scenarios is global climate change. This is due to two primary reasons. First, there exists great uncertainty regarding any application of global climate models to regional and localized conditions. Second, the time period under investigation from 2005 to 2024 is not long enough to see the full effects of global climate change as an important factor that will influence future water supply and demand in the area.

In spite of the uncertainty regarding the extension of global climate models to regional patterns, there are indications that global climate change may have significant impacts on the water resources of the American Southwest. In particular, several studies have investigated potential impacts on the hydrology of the Colorado River Basin, which includes the Prescott AMA.

Christensen et. al (2004) assessed the potential effects of climate change on the Colorado River Basin by comparing simulated hydrologic and water resources scenarios derived from downscaled climate simulations of the U.S. Department of Energy/National Center for Atmospheric Research Parallel Climate Model (PCM) to scenarios driven by observed historical (1950-1999) climate. Downscaled temperature and precipitation sequences were extracted from PCM sequences and used to drive a Variable Infiltration Capacity (VIC) hydrology model to produce projected stream-flow sequences. While the scenarios were used to investigate potential impacts on the surface-water resources of the Colorado River Basin, primarily the availability of water and hydropower from the major reservoirs of the basin, the results also have implications for groundwater resources.

Christensen et. al. (2004) indicate that average annual temperatures in the Colorado River Basin will be up to 2.4° C warmer in 2100 compared to the historical average. Compared to other model projections, this is in fact a conservative estimate of temperature change (Barnett et. al., 2004). Thus, the predicted impacts could be considered a "'best-case' future scenario" (Barnett, et al., 2004).

In addition, precipitation in the region is projected to decline by between 3 and 6% (Christensen, 2004). These conditions are predicted to reduce annual runoff up to 18% from historical averages (Christensen, 2004). In addition, spring snowmelt runoff is projected to occur earlier in the year due to increased spring temperatures, while peak runoff events are projected to decrease. In fact, a trend towards earlier snowmelt runoff due primarily to increased winter temperatures has already been detected for several major river systems in California (Dettinger, 1994).

Evapotranspiration rates are also predicted to be altered by climate change. Increased temperatures in the spring and fall are projected to lengthen the growing season for vegetation in temperate regions, increasing total annual evapotranspiration (Huntington, 2006). Several studies have inferred increasing rates of evapotranspiration over the period 1950 – 1990 from observed continental scale increases in precipitation much greater than observed increases in runoff rates (Milly and Dunne, 2001; Walter, et. al., 2004). Increased evapotranspiration rates can be reasonably assumed to reduce groundwater discharge as spring flow in areas where phreatophytes utilize shallow groundwater.

While it is not possible to extend these predictions into quantitative predictions for the water resources of the Prescott AMA, several interpretations can be made. Since much of the natural recharge in the Prescott AMA is due to infiltration in ephemeral stream channels such as Lynx Creek and Mint Wash, decreased runoff and stream-flow will almost certainly lead to decreased groundwater recharge in these areas. In addition, decreased runoff in the Granite Creek drainage may lead to decreased storage in Watson and Willow Lakes which could consequently impact the amount of surface water available to recharge the groundwater system. Decreased peak stormflow may also reduce the amount of flood recharge that occurs along Granite Creek, Lynx Creek, the Agua Fria River and Mint Wash. Increased evapotranspiration is also expected to contribute to reduce discharge as surface flow at Del Rio Springs and baseflow in the Agua Fria River.

In addition to these potential impacts upon the water supply of the Prescott AMA, increased temperature and precipitation is likely to have impacts on water demand as well. With a significant portion of residential water demand attributed to outdoor landscaping, changes in temperature and precipitation patterns will impact this important segment of water demand.

As regional climate models improve and more accurate forecasting becomes possible, the Prescott AMA groundwater model should be updated to incorporate these new data. Future scenario modeling should incorporate climate as one of the driving forces that is expected to influence future groundwater conditions in the Prescott AMA.

CHAPTER SEVEN: RESULTS OF THE MULTIPLE SCENARIO ANALYSIS

The Prescott AMA groundwater model was utilized to investigate four of the previously discussed scenarios in further detail. These scenarios were the Baseline Scenario, Projected Growth with Conservation Scenario, Projected Growth with Conservation and Augmentation Scenario, and the Low Growth with Conservation and Augmentation Scenario. These four scenarios were chosen for further investigation in consultation with the water resources managers from the involved communities, the Coordinator for the Yavapai County Water Advisory Committee, and the Director of the Prescott AMA.

The four scenarios were chosen to represent a broad spectrum of possible futures; however, it should be noted that the scenarios do not represent the full range of possibilities expressed by the seven scenarios. In particular, the Projected Growth Scenario represents future conditions that are likely to have the most impact upon the groundwater resources of the area. However, existing conservation plans for the City of Prescott and Town of Prescott Valley make the assumption of equivalent growth in population and water demand used for this scenario questionable. Past experience indicates that technological advancement is likely to lead to a reduction in per capita water consumption in the future. It was also believed that the groundwater model would be incapable of effectively simulating the impacts under this scenario, as increasing numbers of dry cells would make results questionable and difficult to interpret.

Dry cells develop when the simulated water table drops below the bottom of the model layer. While this may reflect actual drying of the aquifer, dry cells present several problems for numerical models. When a model cell goes dry, it is deactivated and model-imposed stresses cannot be applied. Any pumpage applied to a dry cell is not simulated, while recharge applied to a dry cell is applied to a lower layer if saturated conditions exist. Thus, for the Prescott AMA model, recharge applied to dry cells in Layer 1 is applied to Layer 2, assuming Layer 2 exists in the area and is saturated.

Previous attempts to investigate groundwater conditions in the Prescott AMA past 2025 have been unsuccessful due to increasing numbers of dry cells, especially in Layer 1 (Nelson, 2002). This was considered in the decision to simulate future conditions through the year 2025. Dry cells did in fact become a problem for several of the scenarios simulated with the groundwater model. In particular, the Baseline Scenario and the Projected Growth with Conservation Scenario developed significant numbers of dry cells before the end of the simulation (Table 21).

For the Baseline Scenario, these dry cells deactivated up to 300 af/yr of simulated pumping primarily in the Lonesome Valley area (Table 22). To prevent this problem in the other scenarios, pumpage in this area was applied to Layer 2. This was based on the assumption that wells going dry in this area would be deepened to exploit the deeper Lower Volcanic Unit aquifer.

While dry cells were present in all of the scenarios simulated with the Prescott AMA groundwater flow model, it should be noted that dry cells in the model are not numerical anomalies caused by the iterative process of calculation. The Prescott AMA groundwater flow model utilizes the Re-Wetting option in MODFLOW-2000. Thus, a cell that goes dry is not permanently deactivated, but is reactivated if the simulated water level rises below the bottom of the layer. Dry cells are not believed to have significantly impacted the effective simulation of future groundwater conditions in the Prescott AMA and should not impact future simulations as long as the Re-Wetting option is used.

Table 21. Dry cells as percentage of the active model area for the various simulations of the Prescott AMA groundwater flow model.

	Number of Dry Cells	Percentage of Active Model Area
Steady-State Simulation (1939)	16	1.3%
Transient Simulation (2004)	65	5.2%
Baseline Scenario (2025)	112	9.0%
Projected Growth with Conservation Scenario (2025)	120	9.6%
Projected Growth with Conservation and Augmentation Scenario (2025)	71	5.7%
Low Growth with Conservation and Augmentation Scenario (2025)	62	5.0%

The four scenarios simulated with the groundwater flow model lead to a wide range of outcomes related to groundwater conditions in 2024. Two of the scenarios failed to bring the AMA into compliance with safe-yield, while the other two scenarios allowed the AMA to return to a safe-yield condition by 2025. In addition, water levels and natural discharge from the model varied widely among the scenarios. This chapter discusses the results of the four scenarios simulated with the Prescott AMA groundwater model.

Results of the Baseline Scenario

As discussed in Chapter 6, the Baseline Scenario simulated a continuation of 2005 pumping and recharge conditions through 2024. This scenario was designed to investigate the long-term impacts of continuing current activities. The results of this simulation continue to indicate that the groundwater system of the Prescott AMA is not in a safe-yield condition and that current practices are depleting the groundwater resources of the AMA. These results are consistent with previous assessments of groundwater conditions in the AMA (Corkhill and Mason, 1995; Nelson, 2002; ADWR, 2002, 2003, 2004).

The results of the Baseline Scenario indicate that continued groundwater pumpage at current levels is projected to lead to continued declines in groundwater levels throughout the Little Chino Sub-basin (Figures 31 – 36). Annual discharge from the Little Chino Sub-basin at Del Rio Springs is projected to decline from approximately 1,350 acre-feet to less than 450 acre-feet by 2024, reducing the flow in this important riparian area by two-thirds from 2005 conditions and over 85% from historical pre-development conditions (Figure 37) (Table 22). Annual discharge from the Little Chino Sub-basin as underflow is also projected to decline from approximately 1,600 acre-feet in 2005 to 1,050 acre-feet by 2024 (Table 22). Natural discharge from the Little Chino Sub-basin as surface flow at Del Rio Springs and as subsurface flow out of the sub-basin is projected to decline from approximately 2,950 acre-feet in 2005 to approximately 1,450 acre-feet in 2024, a reduction of over 50% (Table 22).

According to the Baseline Scenario, water levels in the Upper Agua Fria Sub-basin are projected to fall in some areas and rise in others. The brief rise in water levels indicated by Figure 38 reflects a rebound in pressure head in the confined Lower Volcanic Unit aquifer at Prescott Valley's Santa Fe Wellfield as pumping switched to the town's North Wellfield in 2005. Water levels in the Upper Lynx Creek area are projected to generally decline over time, though this trend is punctuated by water-level increases due to flood pulse recharge (Figure 39).

Groundwater discharge as baseflow in the Agua Fria River is projected to increase slightly over the simulated period, punctuated by high flow years in 2009 and 2019 attributable to simulated flood recharge (Figure 40). This increase in baseflow is likely due to artificial recharge at Prescott Valley's current artificial recharge site in the stream-bed of the Agua Fria River (Figure 30). While the Town of Prescott Valley's North Wellfield is located in the Little Chino Sub-basin north of the groundwater divide between the Little Chino Sub-basin and the Upper Agua Fria Sub-basin, effluent recovered from this groundwater is recharged south of the divide in the Upper Agua Fria Sub-basin. It appears that the model may be simulating the groundwater divide further south than the actual divide; however, there are insufficient water-level data in the area to determine the exact location of the divide.

The results of the Baseline Scenario indicate that continuing current activities into the future is likely to lead to continued groundwater mining in the area. Between 2005 and 2024, average water levels for 22 wells in the model area are projected to decline approximately 22.3 ft., while natural groundwater discharge is projected to decrease by 35% (Figure 41, Table 22). Groundwater storage in the groundwater basins of the Prescott AMA is projected to decrease by more than 150,000 acre-feet over the period of simulation, an average annual storage loss of over 7,500 acre-feet (Figure 41). Thus, while certain areas experience steady or rising groundwater levels during the Baseline Scenario, the groundwater conditions of the Prescott AMA as a whole are projected to be impacted under this scenario. Under the Baseline Scenario, the Prescott AMA is not projected to reach a safe-yield condition by 2025 (Figure 42).

Table 22. Conceptual and simulated annual water budgets for the Baseline Scenario for the Prescott AMA (2005 – 2024). (All figures to the nearest 50 acre-feet/year)

Year	Recharge			Pumpage			Del Rio	Agua Fria	Underflow	Change in
	Conceptual	Simulated	Sim/Con [1]	Conceptual	Simulated	Sim/Con [2]	Springs	Baseflow		Storage
2005	15250	15250	100.0%	20500	20500	100.0%	1350	1350	1600	-9550
2006	15250	15250	100.0%	20500	20450	99.8%	1300	1300	1600	-9400
2007	15250	15250	100.0%	20500	20400	99.5%	1250	1250	1550	-9200
2008	15250	15250	100.0%	20500	20300	99.0%	1200	1250	1500	-9000
2009	23700	23500	99.2%	20500	20350	99.3%	1150	1350	1500	-850
2010	15250	15250	100.0%	20500	20300	99.0%	1100	1300	1450	-8900
2011	15250	15250	100.0%	20500	20350	99.3%	1000	1300	1400	-8800
2012	15250	15250	100.0%	20500	20300	99.0%	950	1300	1400	-8700
2013	15250	15250	100.0%	20500	20300	99.0%	900	1300	1350	-8600
2014	15250	15250	100.0%	20500	20200	98.5%	850	1300	1300	-8400
2015	15250	15250	100.0%	20500	20200	98.5%	800	1300	1300	-8350
2016	15250	15250	100.0%	20500	20250	98.8%	750	1300	1250	-8300
2017	15250	15250	100.0%	20500	20200	98.5%	700	1300	1200	-8150
2018	15250	15250	100.0%	20500	20200	98.5%	700	1300	1200	-8150
2019	23700	23500	99.2%	20500	20200	98.5%	650	1400	1200	50
2020	15250	15250	100.0%	20500	20200	98.5%	600	1400	1150	-8100
2021	15250	15250	100.0%	20500	20250	98.8%	550	1350	1150	-8050
2022	15250	15250	100.0%	20500	20250	98.8%	500	1350	1100	-7950
2023	15250	15250	100.0%	20500	20250	98.8%	450	1350	1050	-7850
2024	15250	15250	100.0%	20500	20200	98.5%	450	1350	1050	-7800
Total	**321900**	**321500**	**99.9%**	**410000**	**405650**	**98.9%**	**17200**	**26400**	**26300**	**-154050**

[1] Simulated recharge / conceptual recharge

[2] Simulated pumpage / conceptual pumpage

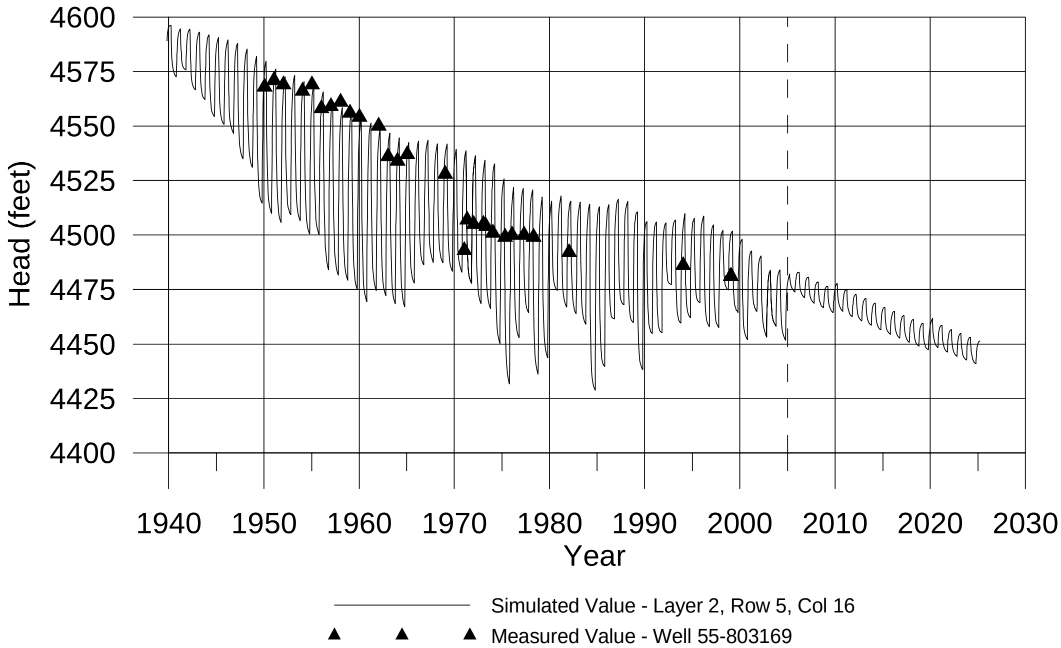

Figure 31. Measured and simulated water levels in the northern Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

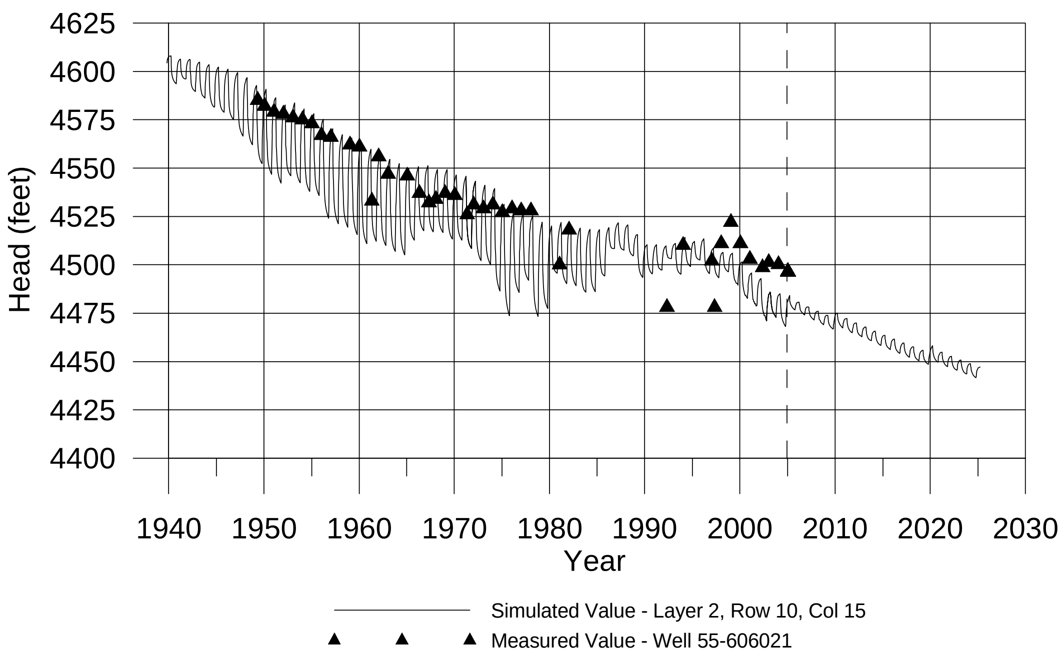

Figure 32. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

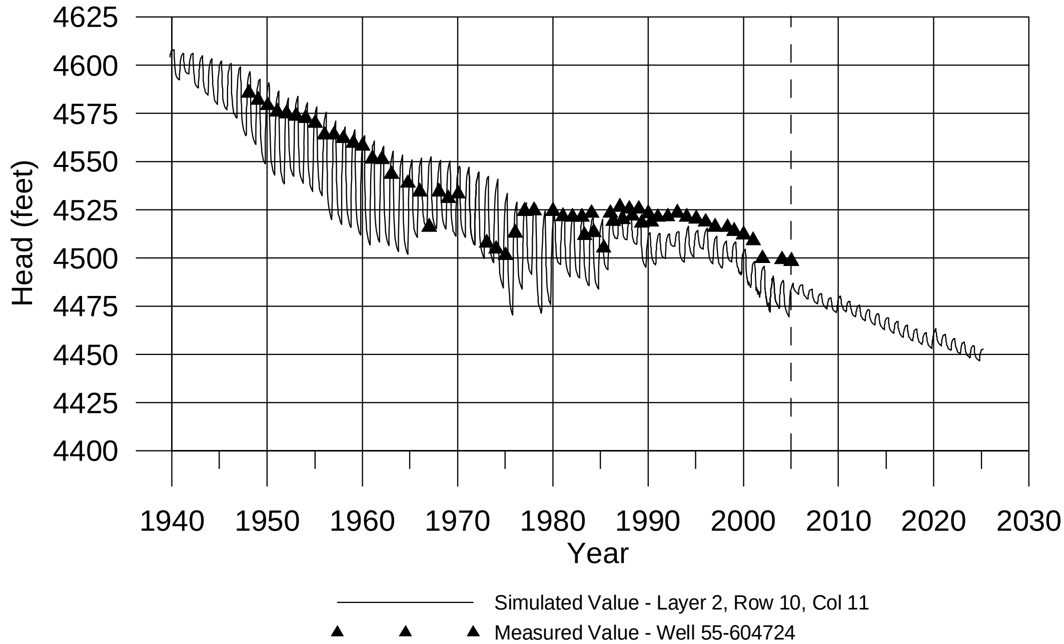

Figure 33. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

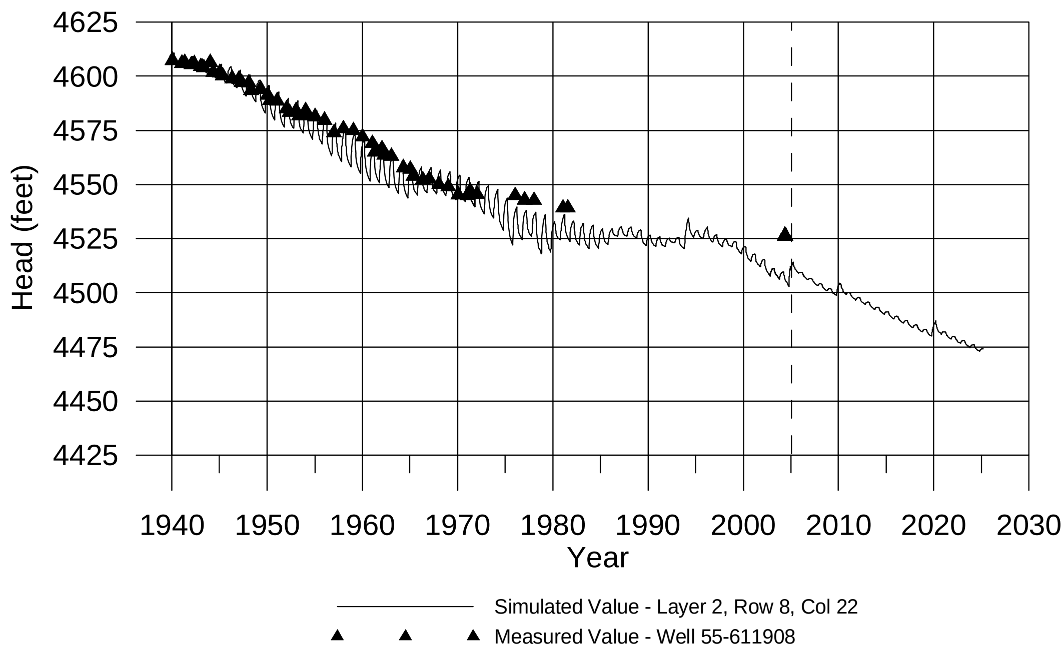

Figure 34. Measured and simulated water levels in the northeast Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

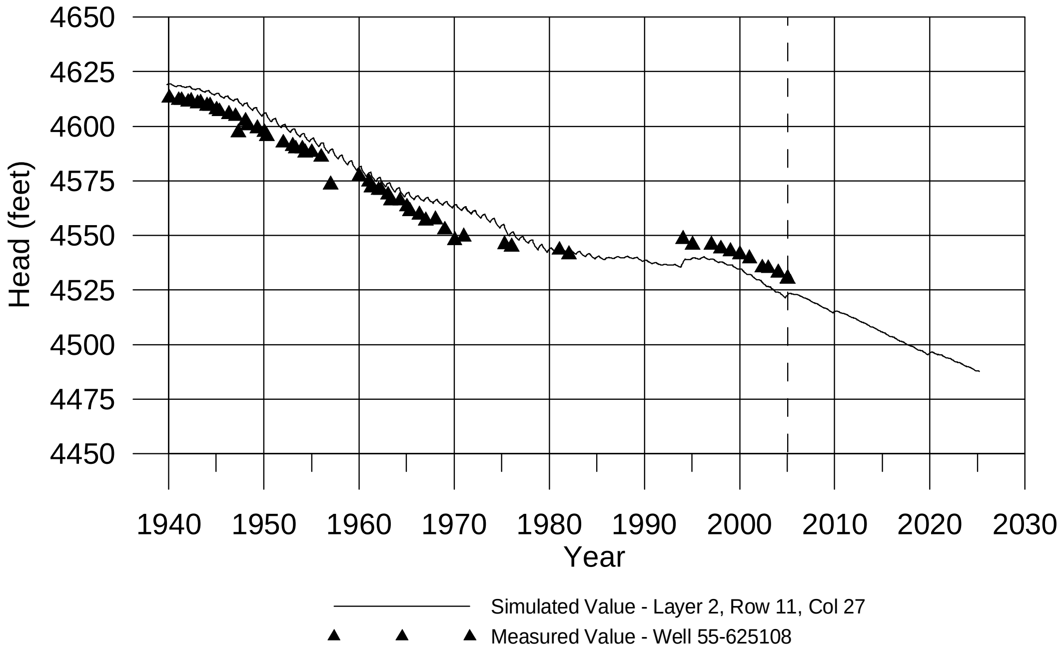

Figure 35. Measured and simulated water levels in the Lonesome Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

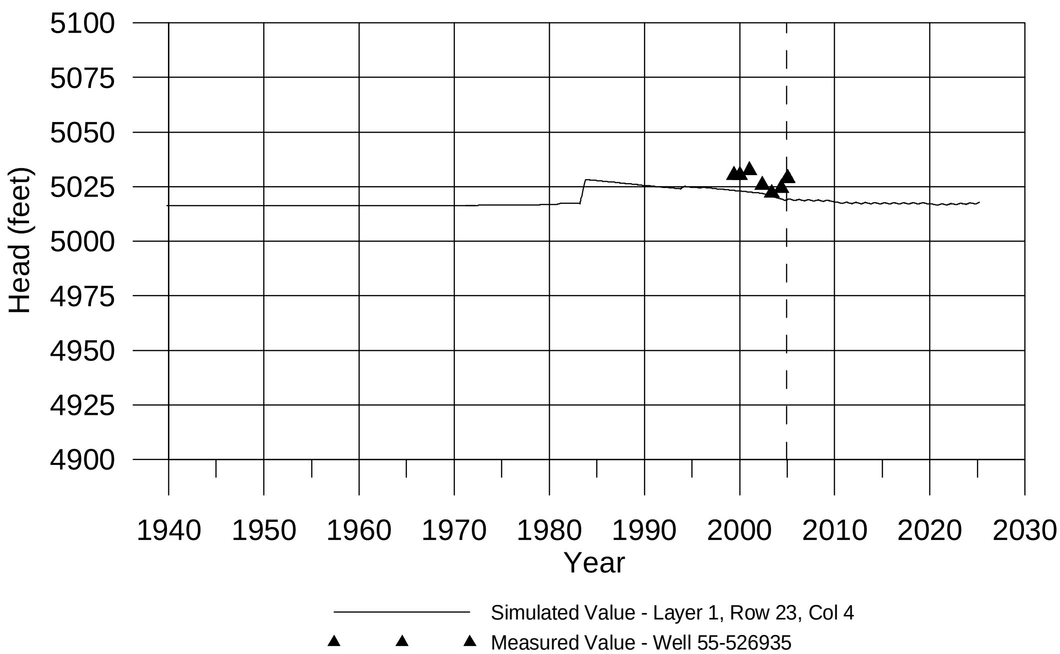

Figure 36. Measured and simulated water levels in the Mint Wash area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

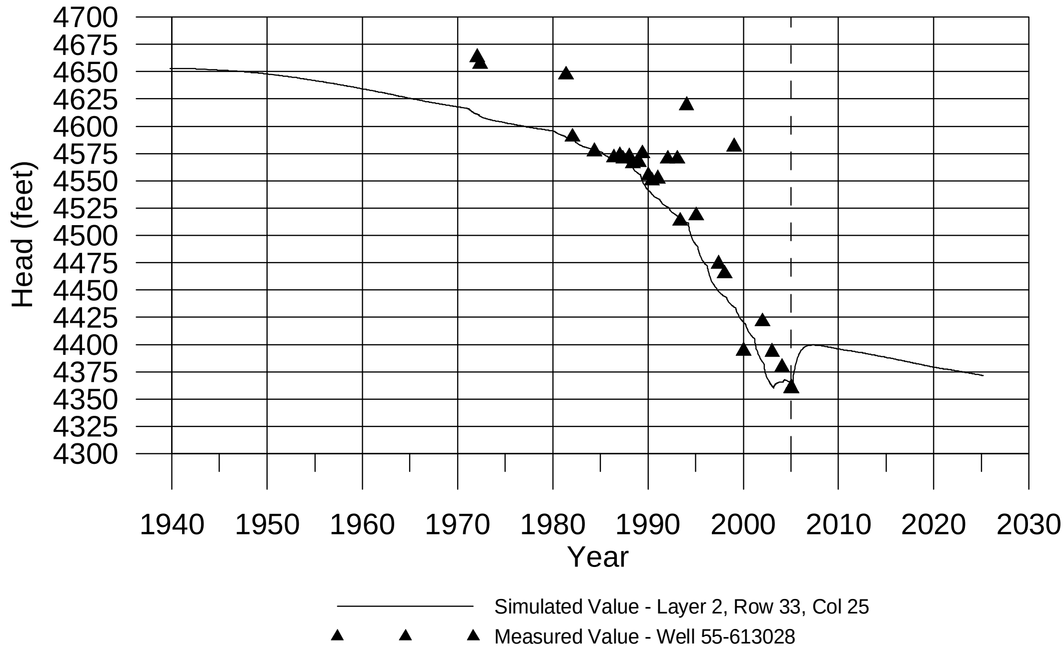

Figure 37. Measured and simulated water levels in the Santa Fe Wellfield area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

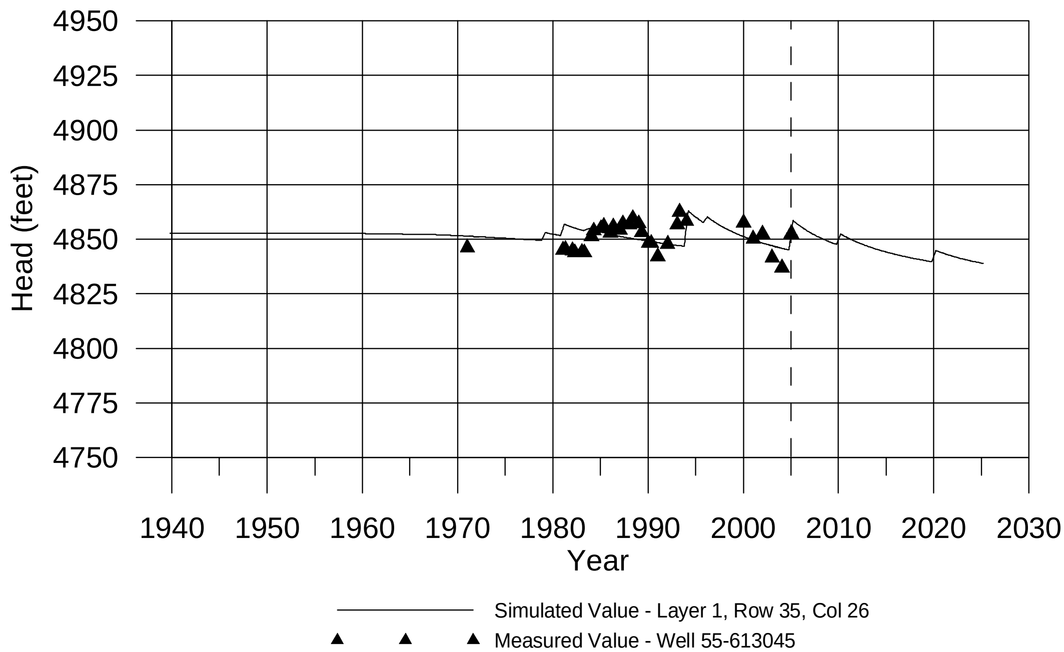

Figure 38. Measured and simulated water levels in the Upper Lynx Creek area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Baseline Scenario (2005 – 2024).

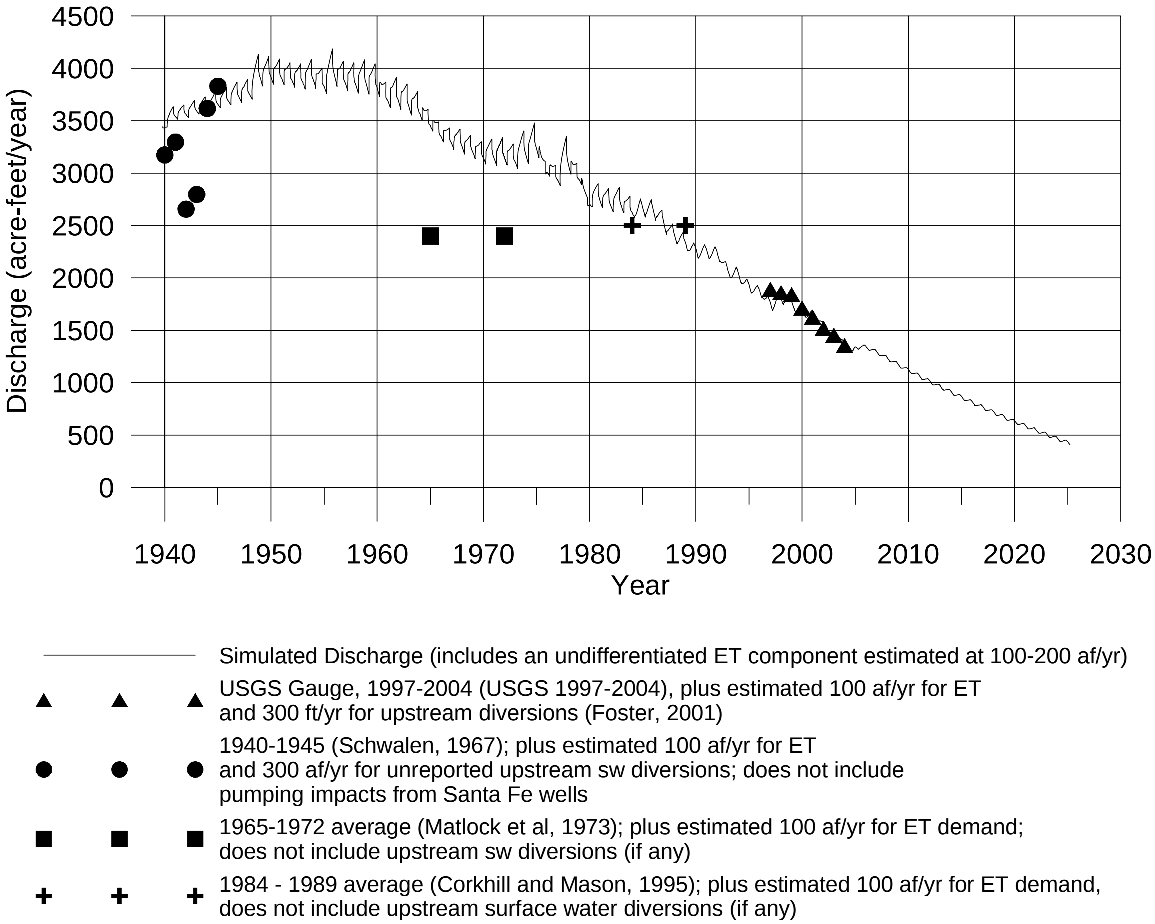

Figure 39. Measured and simulated groundwater discharge at Del Rio Springs for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated groundwater discharge for the Baseline Scenario (2005 – 2024).

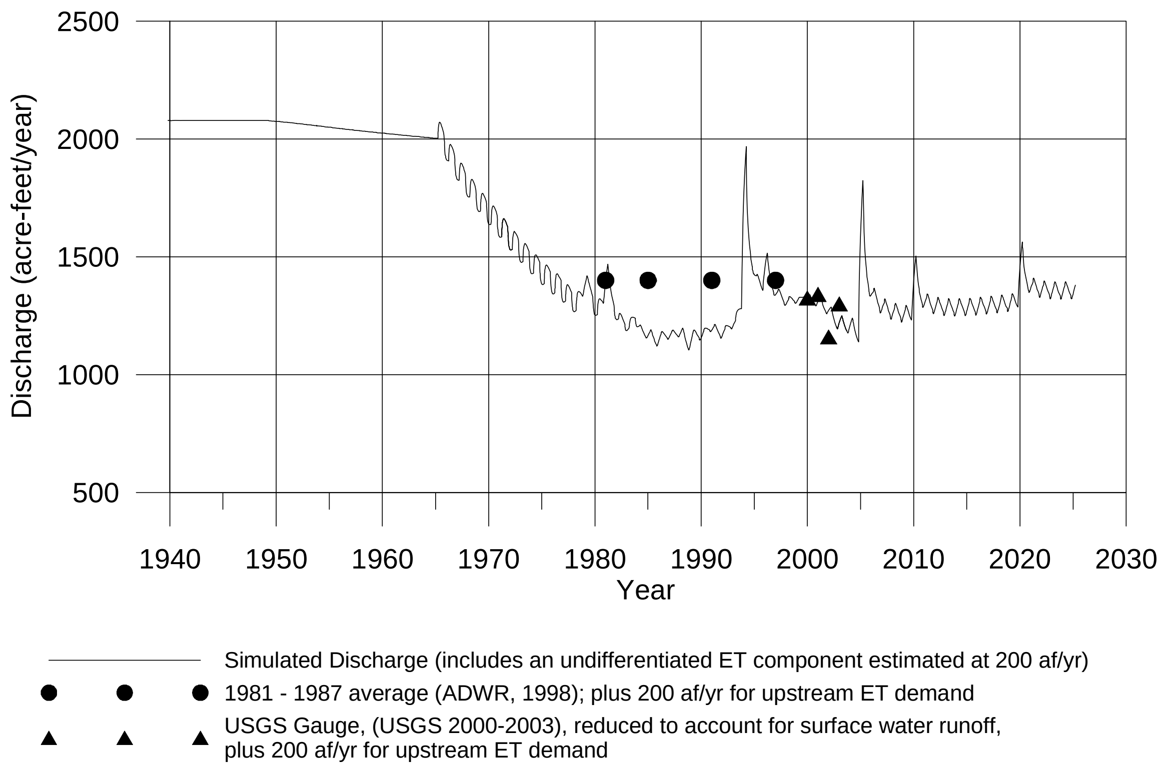

Figure 40. Measured and simulated groundwater discharge as baseflow in the Agua Fria River the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated groundwater discharge for the Baseline Scenario (2005 – 2024).

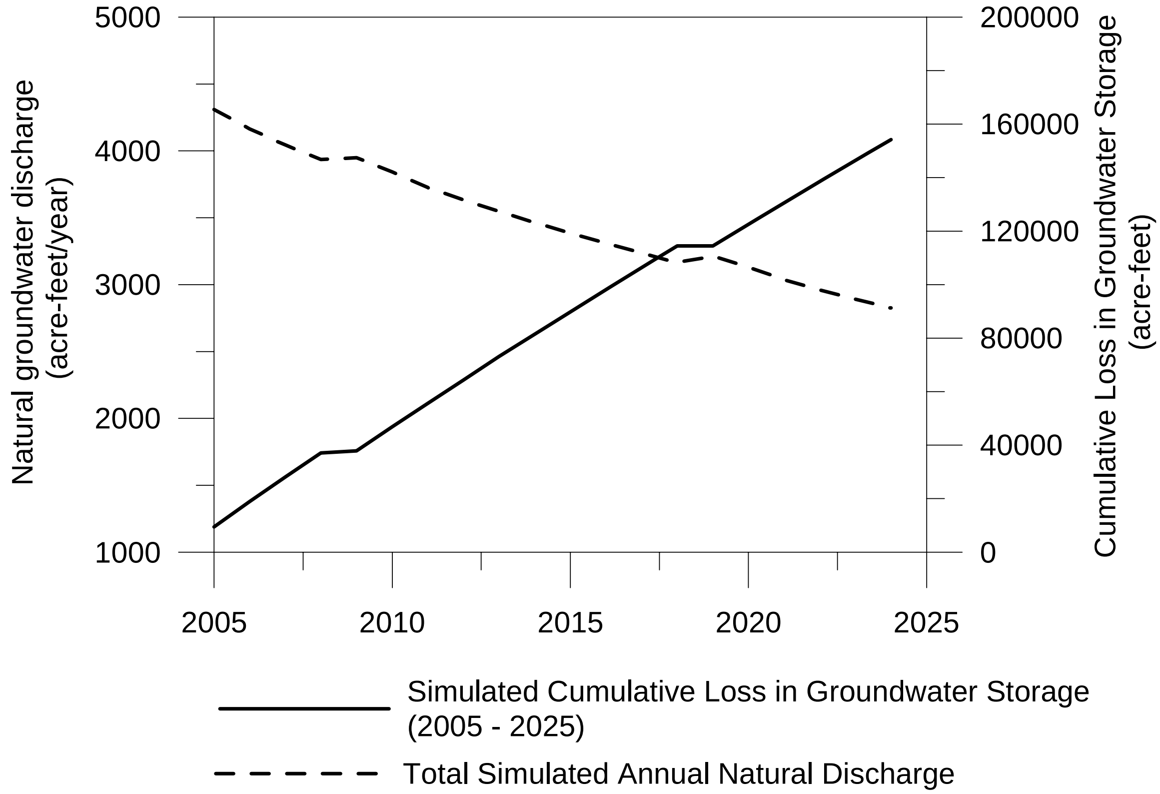

Figure 41. Simulated cumulative loss in groundwater storage and annual natural discharge in the Baseline Scenario (2005 – 2024)

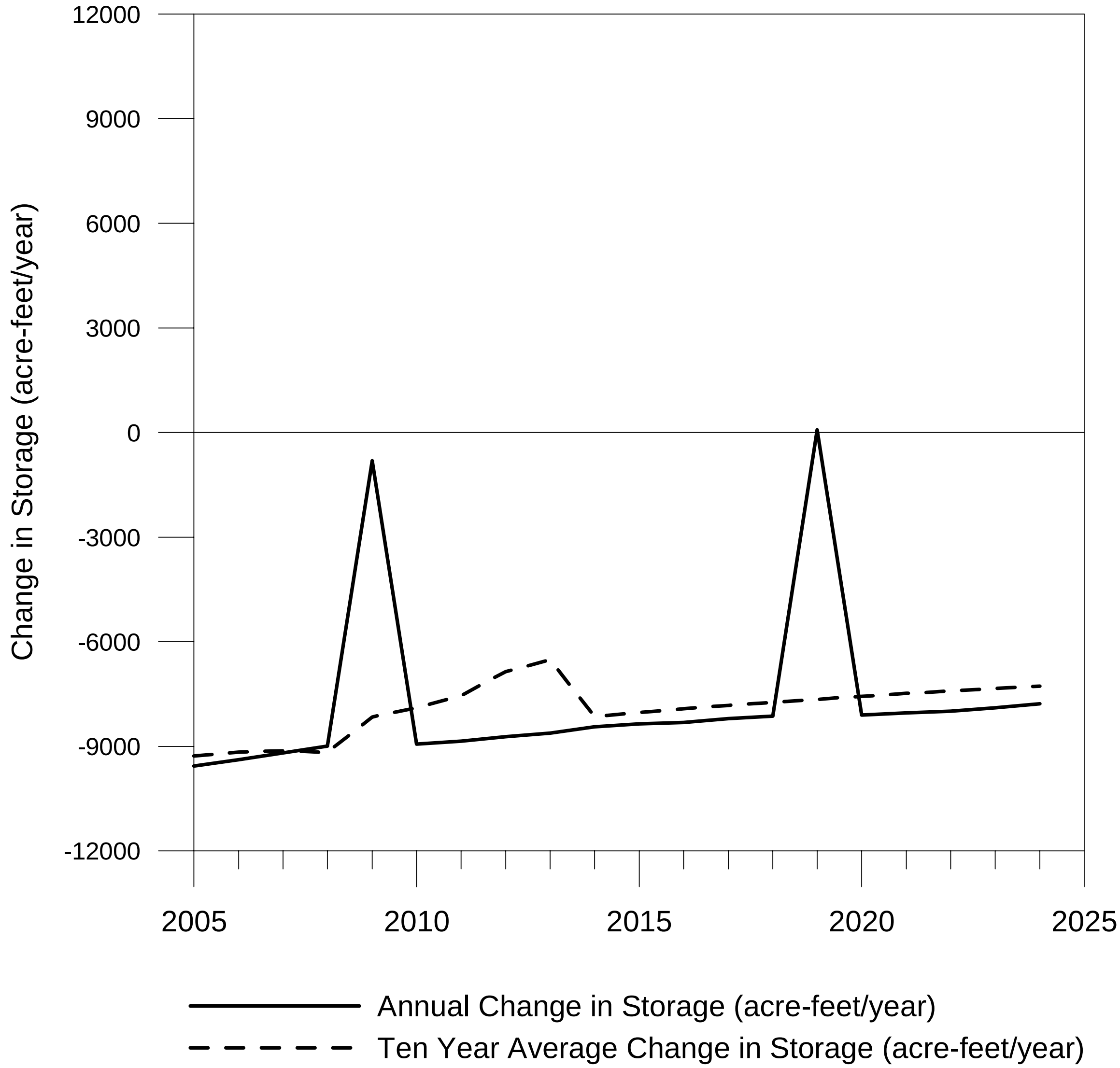

Figure 42. Simulated annual and ten year average change in storage for the Baseline Scenario (2005 – 2024).

Results of the Projected Growth with Conservation Scenario

The Projected Growth with Conservation Scenario simulates a future where water demands of a rapidly growing population are tempered by conservation strategies that effectively limit water demand from municipal, industrial and domestic users. According to simulation results, conservation strategies that achieve 20% conservation by 2024 will be insufficient to bring the Prescott AMA into a safe-yield condition.

The results of the Projected Growth with Conservation Scenario show continued declines in groundwater levels throughout the Little Chino Sub-basin (Figures 43-48). Annual discharge from the Little Chino Sub-basin at Del Rio Springs is projected to decline from approximately 1,250 acre-feet to less than 350 acre-feet by 2024, reducing the flow in this important riparian area by over 70% (Table 23, Figure 49). Annual discharge from the Little Chino Sub-basin as underflow is also projected to decline from approximately 1,600 acre-feet in 2005 to 700 acre-feet by 2024 (Table 23) . Total natural discharge from the Little Chino Sub-basin from these two sources is thus projected to decline from approximately 2,800 acre-feet to approximately 1,050 acre-feet, a reduction of over 60%.

Impacts upon groundwater conditions in the Upper Agua Fria Sub-basin are also projected according to the Projected Growth with Conservation Scenario. While groundwater levels in the immediate vicinity of the Town of Prescott Valley's current and planned artificial recharge facilities are projected to rise, water levels in other parts of the Upper Agua Fria Sub-basin are projected to decline over the period of simulation (Figures 50 and 51). Annual discharge from the aquifer as baseflow in the Agua Fria

River is projected to decline from approximately 1,350 acre-feet in 2005 to approximately 950 acre-feet by 2024, a decline of 30% (Figure 52).

Under the Projected Growth with Conservation Scenario, annual natural groundwater discharge from the Prescott AMA is projected to decline over 2,100 acre-feet, a reduction of over 50% between 2005 and 2024 (Figure 52). Over this period, average water levels measured in 22 observation wells are projected to decline 38.3 ft., with a subsequent loss in groundwater storage of nearly 175,000 acre-feet (Table 23, Figure 53). This equates to a storage loss rate of 8,600 af/yr (Figure 53). Under this scenario, the Prescott AMA is not projected to reach safe-yield by 2024 (Figure 54).

Table 23. Conceptual and simulated annual water budgets for the Projected Growth with Conservation Scenario for the Prescott AMA. (All figure to the nearest 50 acre-feet/year)

Year	Recharge			Pumpage			Del Rio	Agua Fria	Underflow	Change in
	Conceptual	Simulated	Sim/Con [1]	Conceptual	Simulated	Sim/Con [2]	Springs	Baseflow		Storage
2005	15250	15250	100.0%	20500	20500	100.0%	1250	1350	1550	-9400
2006	15750	15750	100.0%	21300	21300	100.0%	1150	1300	1450	-9450
2007	16050	16050	100.0%	21900	21850	99.8%	1100	1250	1400	-9450
2008	16400	16400	100.0%	22550	22500	99.8%	1150	1300	1350	-9400
2009	25250	25250	100.0%	23200	23200	100.0%	950	1350	1300	-1550
2010	16150	16150	100.0%	21600	21550	99.8%	900	1300	1300	-8900
2011	16550	16550	100.0%	22300	22250	99.8%	850	1300	1250	-9100
2012	16950	16950	100.0%	22900	22900	100.0%	800	1250	1200	-9250
2013	17350	17350	100.0%	23600	23550	99.8%	750	1300	1150	-9400
2014	17800	17800	100.0%	24350	24300	99.8%	700	1250	1100	-9550
2015	17600	17600	100.0%	23800	23750	99.8%	650	1250	1100	-9100
2016	18050	18050	100.0%	24550	24550	100.0%	600	1250	1000	-9350
2017	18450	18500	100.3%	25300	25300	100.0%	550	1200	1000	-9550
2018	18900	18900	100.0%	26150	26100	99.8%	500	1150	950	-9800
2019	27850	27850	100.0%	27000	26950	99.8%	500	1200	900	-1700
2020	19150	19150	100.0%	26350	26350	100.0%	450	1150	900	-9700
2021	18850	18900	100.3%	25750	25650	99.6%	450	1100	900	-9150
2022	19350	19350	100.0%	26650	26650	100.0%	400	1050	800	-9600
2023	19850	19850	100.0%	27650	27650	100.0%	350	1000	750	-9900
2024	20400	20400	100.0%	28700	28650	99.8%	350	950	700	-10250
Total	**371950**	**372050**	**100.0%**	**486100**	**485500**	**99.9%**	**14400**	**24250**	**22050**	**-173550**

[1] Simulated recharge / conceptual recharge

[2] Simulated pumpage / conceptual pumpage

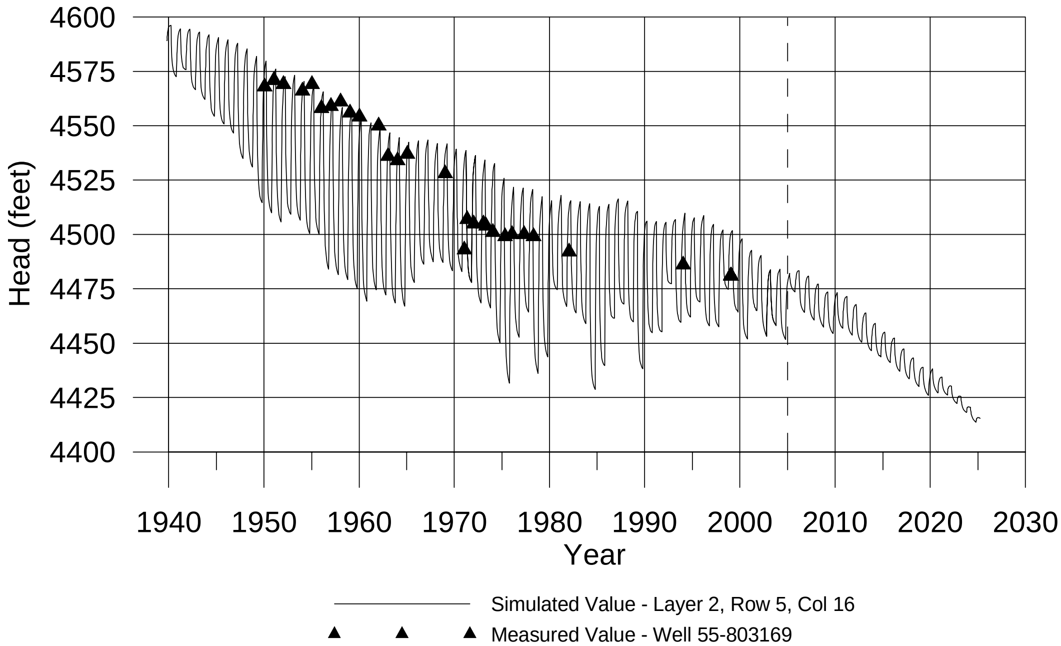

Figure 43. Measured and simulated water levels in the northern Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

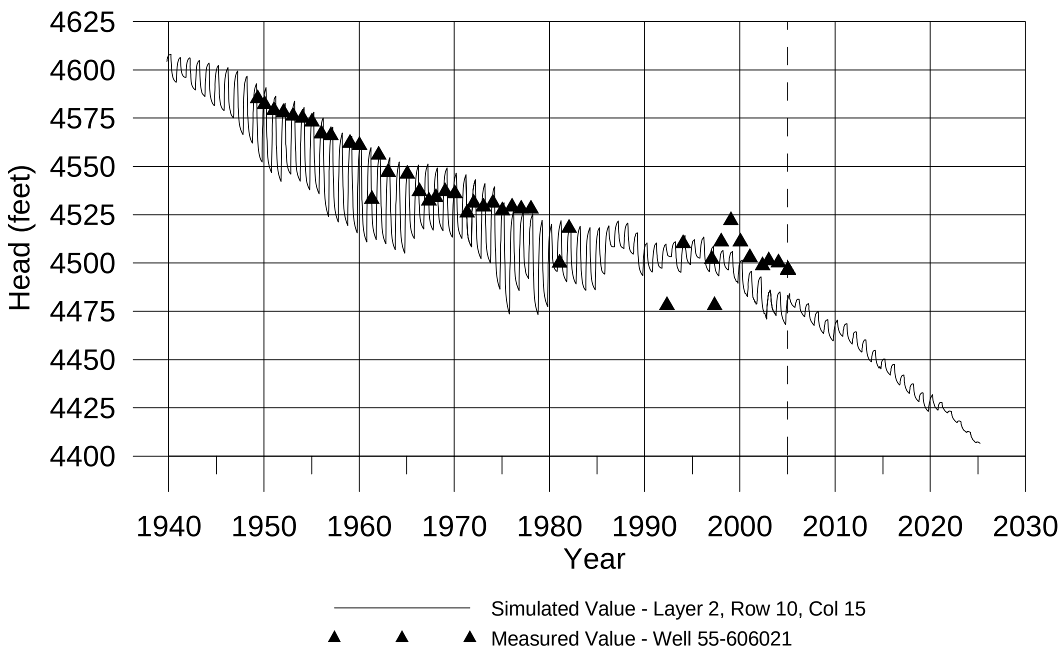

Figure 44. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

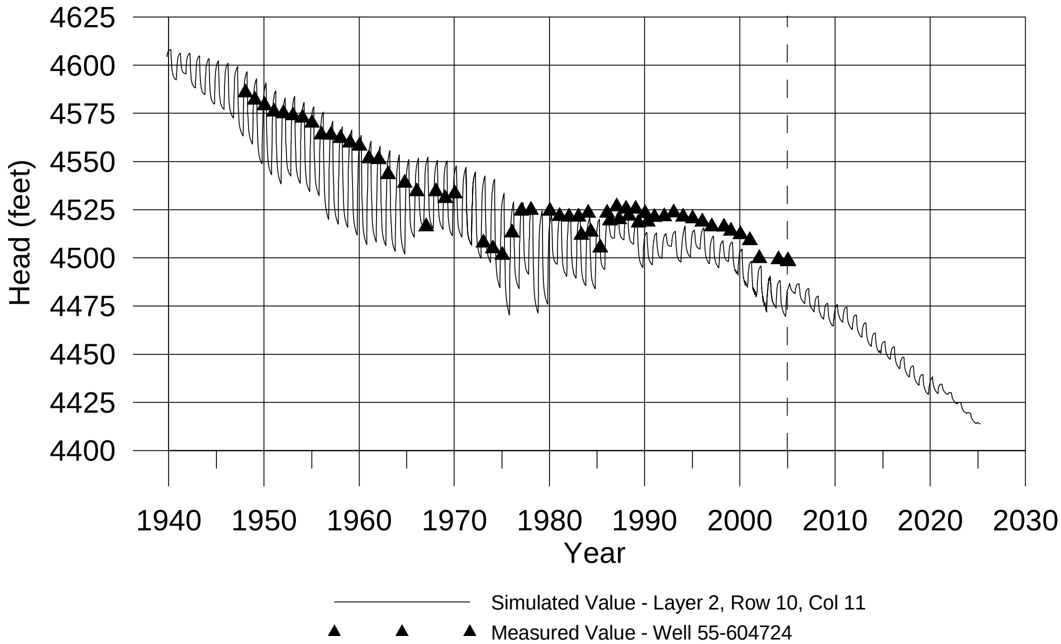

Figure 45. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

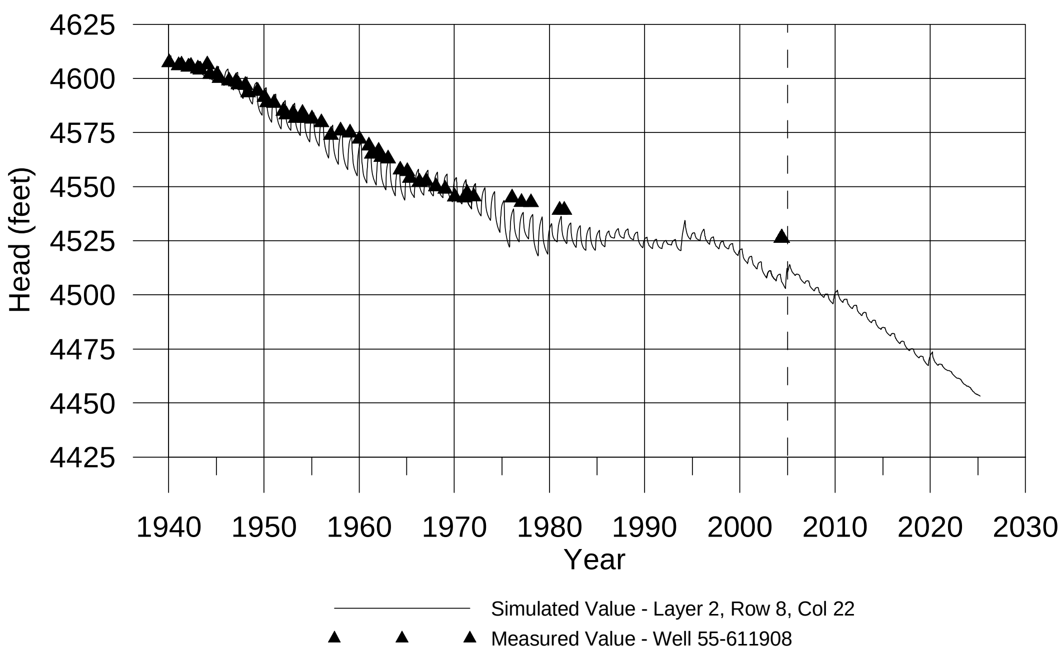

Figure 46. Measured and simulated water levels in the northeast Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

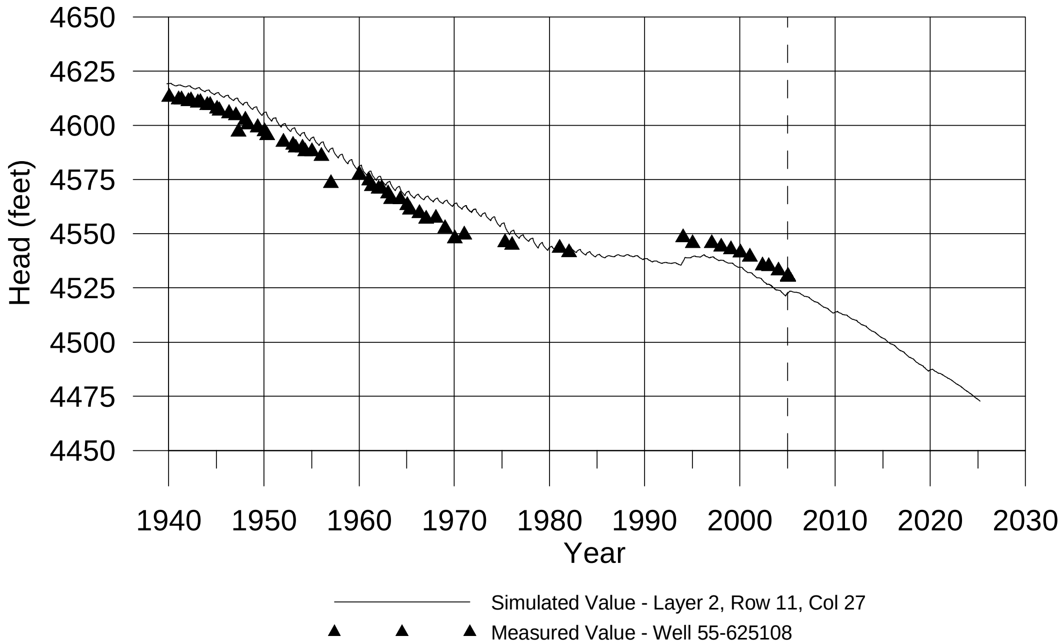

Figure 47. Measured and simulated water levels in the Lonesome Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

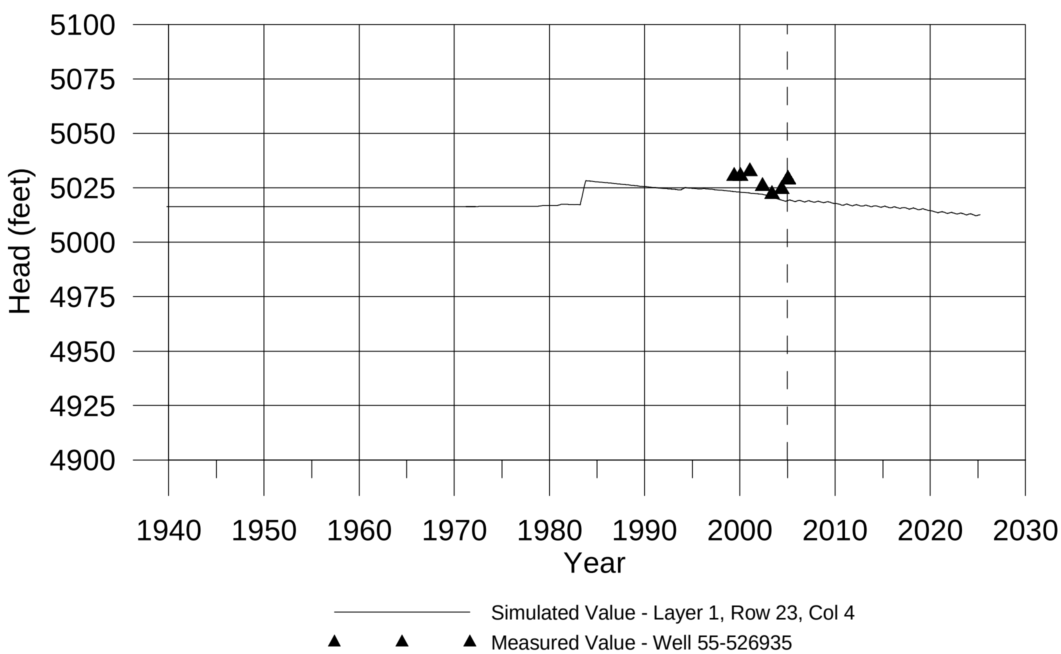

Figure 48. Measured and simulated water levels in the Mint Wash area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

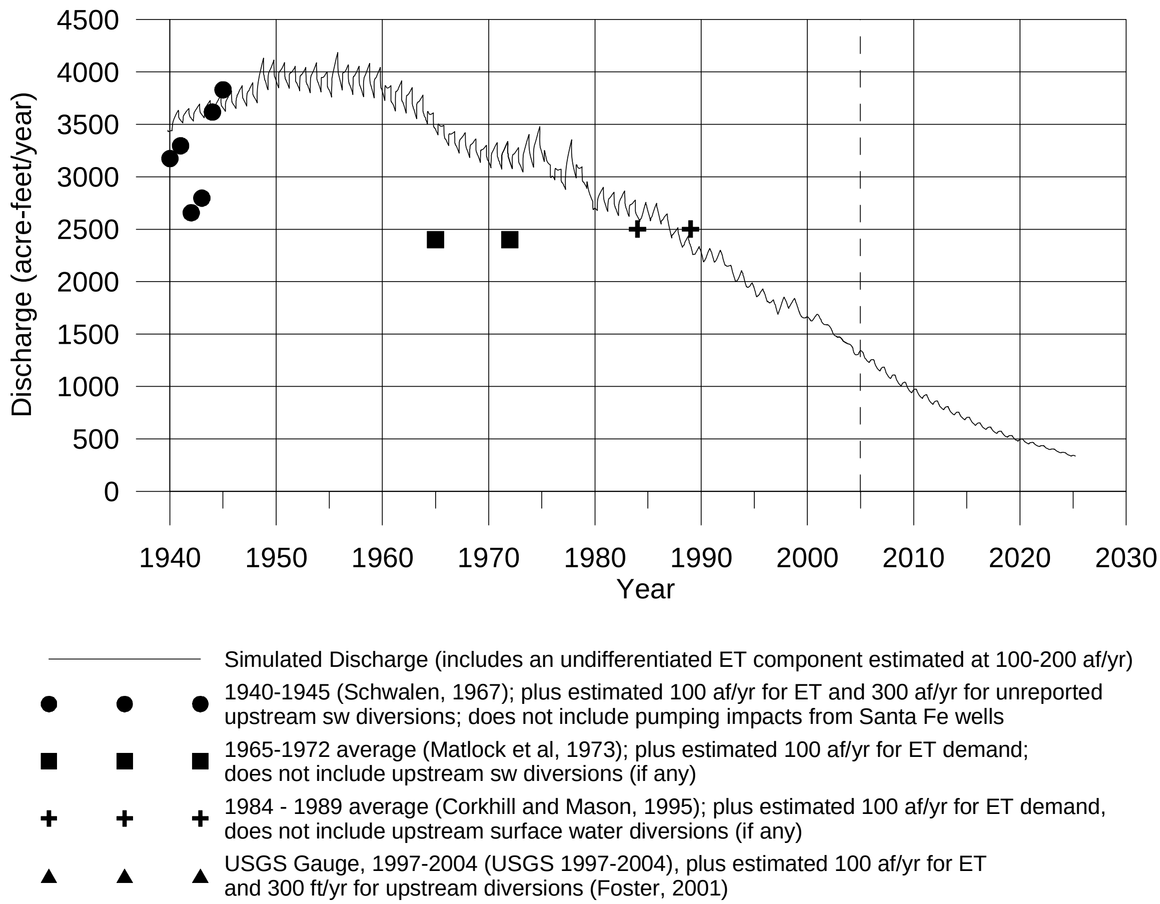

Figure 49. Measured and simulated groundwater discharge at Del Rio Springs for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated groundwater discharge for the Projected Growth with Conservation Scenario (2005 – 2024).

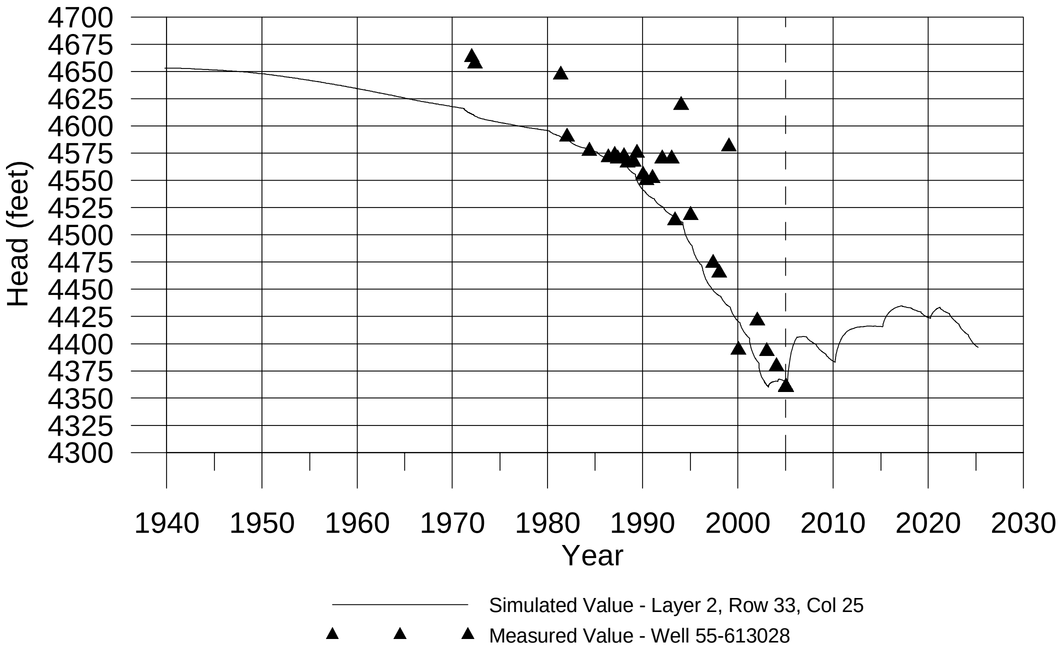

Figure 50. Measured and simulated water levels in the Santa Fe Wellfield area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

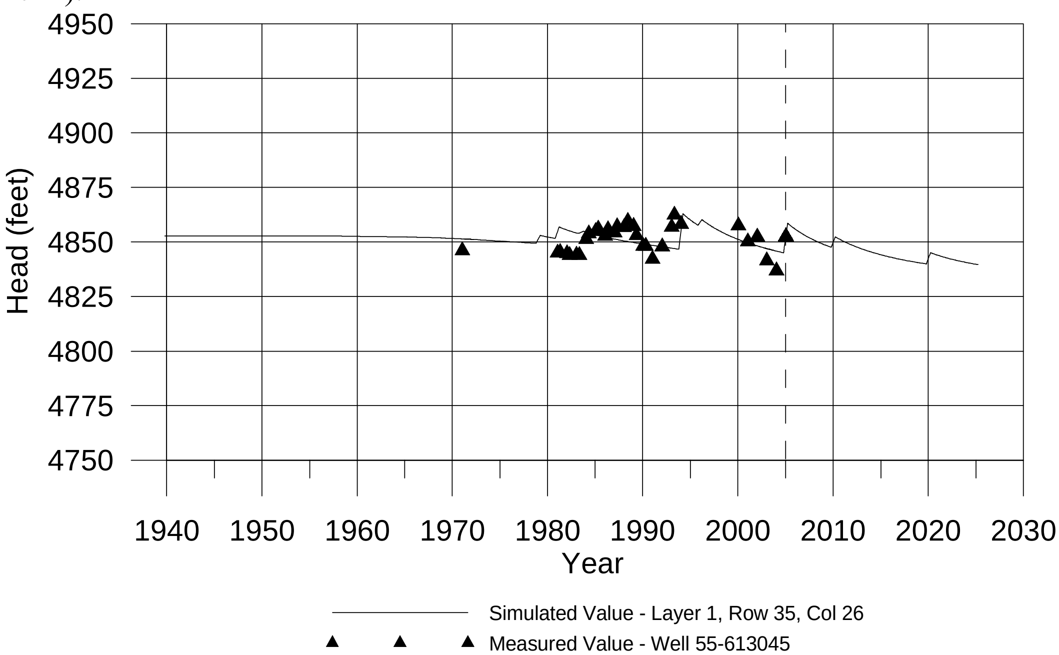

Figure 51. Measured and simulated water levels in the Upper Lynx Creek area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation Scenario (2005 – 2024).

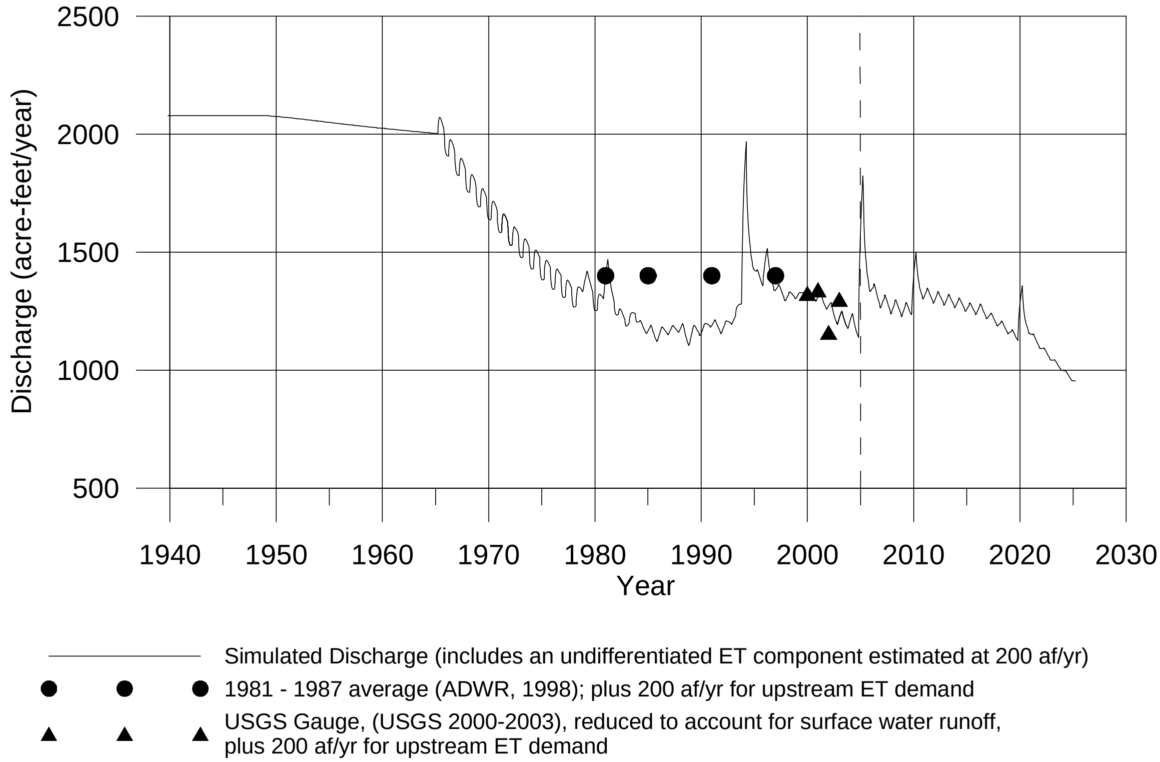

Figure 52. Measured and simulated groundwater discharge as baseflow in the Agua Fria River for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated groundwater discharge for the Projected Growth with Conservation Scenario (2005 – 2024).

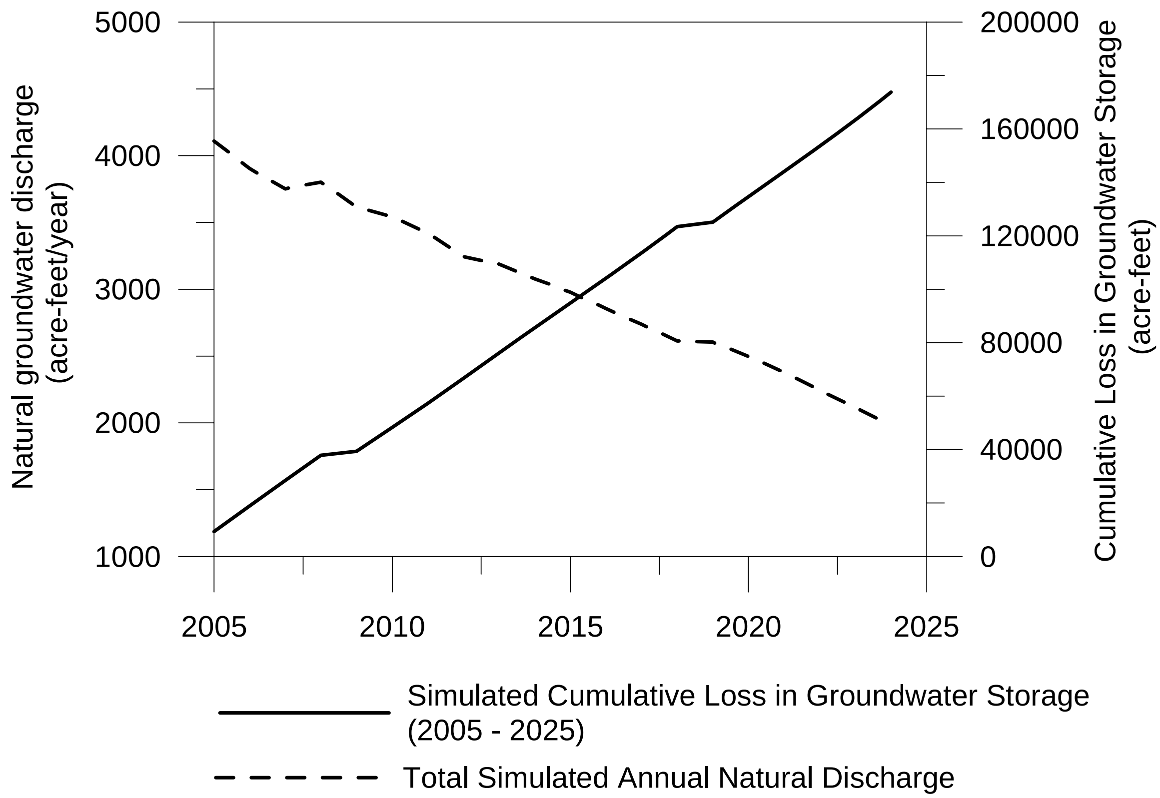

Figure 53. Cumulative loss in groundwater storage and natural groundwater discharge for the Projected Growth with Conservation Scenario of the updated Prescott AMA groundwater flow model (2005 – 2024).

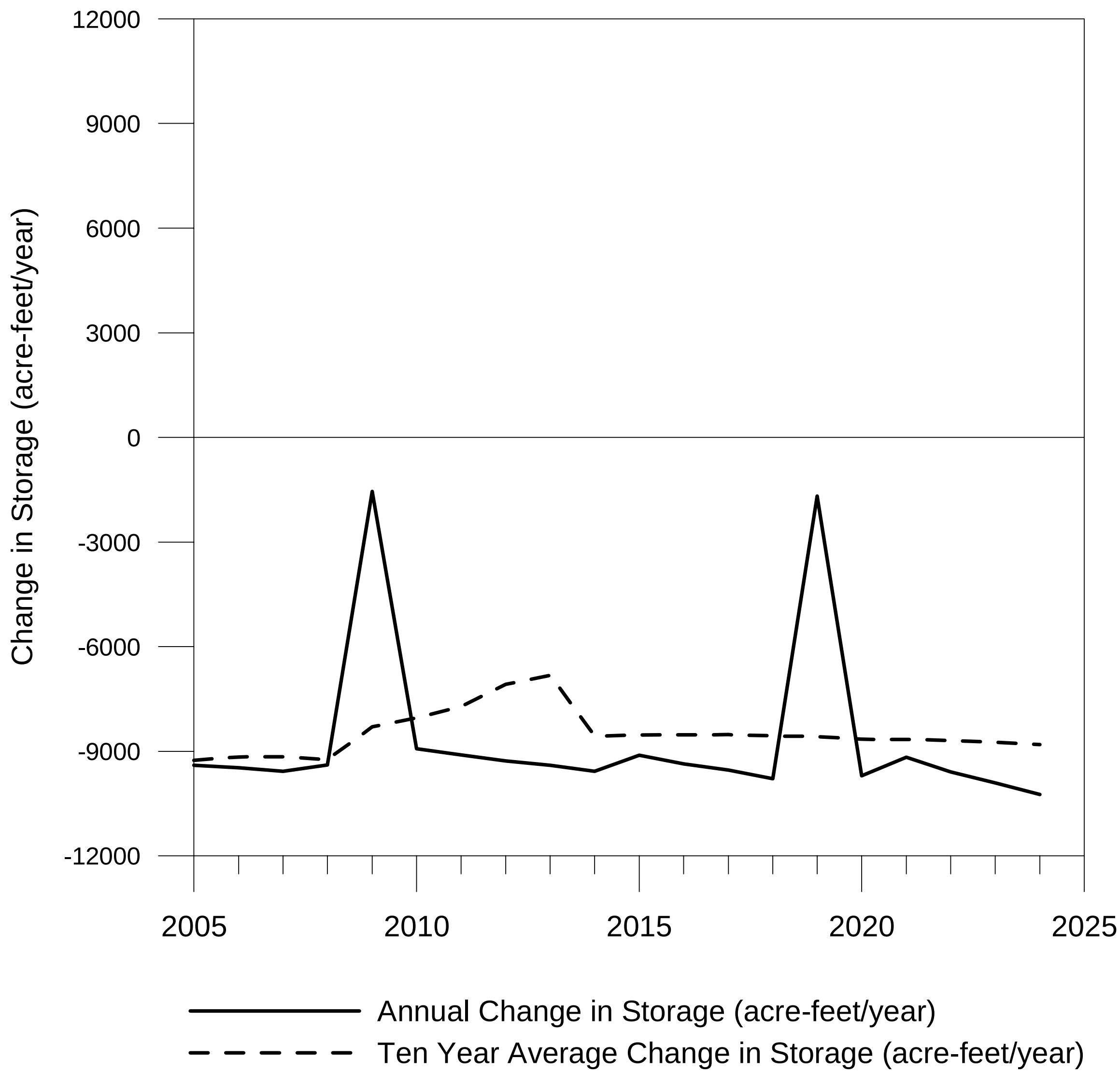

Figure 54. Simulated annual and ten year average change in storage for the Projected Growth with Conservation Scenario (2005 – 2024).

Results of the Projected Growth with Conservation and Augmentation Scenario

The Projected Growth with Conservation and Augmentation Scenario simulates a future where the increasing water demands of a rapidly rising population are met by a combination of conservation and augmentation strategies. Under this scenario, the Prescott AMA is able to reach its statutory safe-yield goal before 2025, though not without impacts to the overall groundwater system.

The results of the Projected Growth with Conservation and Augmentation Scenario project steep declines in groundwater levels throughout the Little Chino Sub-basin until the importation of Big Chino groundwater by the City of Prescott and Town of Prescott Valley begins in 2010 (Table 24). With this additional supply, groundwater pumping in the AMA is sharply reduced, allowing groundwater levels to quickly rebound in heavily pumped areas. After this initial spike, however, groundwater levels are projected to revert to a state of decline, as groundwater pumping is increased to meet increasing demand (Figures 55-61). Annual discharge from the Little Chino Sub-basin at Del Rio Springs is projected to decline from approximately 1,350 acre-feet in 2005 to approximately 850 acre-feet by 2024, a reduction in flow of over 35% (Figure 62). Annual discharge from the Little Chino Sub-basin as underflow is projected to decline slightly from approximately 1,600 acre-feet in 2005 to 1,550 acre-feet by 2024 (Table 24). Total natural discharge from the Little Chino Sub-basin from these two sources is thus projected to decline from approximately 2,950 acre-feet to approximately 2,400 acre-feet, a reduction of 19%.

Groundwater impacts are also projected for the Upper Agua Fria Sub-basin. While groundwater levels in the vicinity of the Town of Prescott Valley's recharge facilities are projected to increase, groundwater levels elsewhere in the Sub-basin are projected to decline (Figures 63 and 64). Natural groundwater discharge as baseflow in the Agua Fria River is also projected to decline from an annual rate of 1,350 acre-feet to 1,050 acre-feet, a reduction of over 20% (Table 24, Figure 65).

Under the Projected Growth with Conservation and Augmentation Scenario, annual natural discharge from the Prescott AMA is projected to decline approximately 850 acre-feet, while water levels in 109 observation wells are projected to decline by an average of 6.3 ft. Total groundwater storage is projected to decrease by 36,750 acre-feet over the simulated period of 2005-2024 (Figure 66). While the Prescott AMA is able to achieve its statutory goal of safe-yield, this is achieved in part due to the reduction in natural discharge from the system (Figure 66 and 67). As discussed earlier, the legal concept of safe-yield is based upon a water budget balance between all inflows and all outflows, natural and anthropogenic. Thus, the decline in natural groundwater discharge allows for increased groundwater pumpage in a safe-yield condition (Figure 3).

It is also important to note the trend in the safe-yield budget (Figure 66). While a positive 10 year safe-yield balance of over 600 acre-feet is shown for 2019, increasing water demand reduces this positive balance to less than 500 acre-feet for 2024. In fact, each of the years from 2022 – 2024 show an increasingly negative change in storage, as groundwater is mined from the aquifers of the AMA. Over 1,250 acre-feet of groundwater are removed from storage in the year 2024 (Table 24). While this scenario has not been simulated past 2024, the trend from 2020-2024 indicates that the Prescott

AMA will likely return to a state of non-compliance with safe-yield sometime after 2025. Thus, while the Projected Growth with Conservation and Augmentation Scenario allows for the Prescott AMA to reach its safe-yield goal, it does so only temporarily and by negatively impacting natural groundwater discharge. The apparent contradictions evidenced by this scenario illustrate that the concept of safe-yield is not the same as sustainability.

Table 24. Conceptual and simulated annual water budgets for the Projected Growth with Conservation and Augmentation Scenario for the Prescott AMA (2005- 2024). (All figures to the nearest 50 acre-feet/year)

Year	**Recharge**			**Pumpage**			**Del Rio**	**Agua Fria**	**Underflow**	**Change in**
	Conceptual	**Simulated**	**Sim/Con 1**	**Conceptual**	**Simulated**	**Sim/Con 2**	**Springs**	**Baseflow**		**Storage**
2005	15250	15200	99.7%	20500	20500	100.0%	1250	1350	1600	-9600
2006	15650	15600	99.7%	21150	21100	99.8%	1300	1300	1550	-9600
2007	15850	15750	99.4%	21550	21550	100.0%	1200	1250	1500	-9750
2008	16100	16000	99.4%	22000	21950	99.8%	1150	1250	1450	-9800
2009	25050	24950	99.6%	22100	22000	99.5%	1100	1350	1400	-900
2010	16050	16050	100.0%	11700	11650	99.6%	1050	1350	1650	350
2011	16400	16400	100.0%	12050	11950	99.2%	1000	1300	1650	450
2012	16750	16750	100.0%	12300	12250	99.6%	1000	1300	1650	500
2013	17100	17100	100.0%	12600	12500	99.2%	950	1300	1650	650
2014	17450	17450	100.0%	12900	12800	99.2%	950	1300	1650	700
2015	17150	17100	99.7%	12100	12050	99.6%	900	1300	1650	1150
2016	17400	17350	99.7%	12400	12350	99.6%	900	1300	1650	1150
2017	17600	17600	100.0%	12700	12550	98.8%	900	1300	1650	1150
2018	17850	17800	99.7%	13050	12950	99.2%	900	1250	1650	1050
2019	26550	26500	99.8%	13350	13300	99.6%	900	1350	1650	9250
2020	17700	17700	100.0%	12500	12500	100.0%	900	1300	1700	1300
2021	16900	16900	100.0%	11550	11450	99.1%	900	1250	1750	1550
2022	17250	17200	99.7%	12100	12000	99.2%	900	1200	1750	1350
2023	17550	17550	100.0%	12650	12550	99.2%	900	1150	1750	1200
2024	17900	17900	100.0%	13300	13150	98.9%	900	1100	1750	950
Total	**355500**	**354850**	**99.8%**	**294550**	**293100**	**99.5%**	**19950**	**25550**	**32700**	**-16900**

1 Simulated recharge / conceptual rechage

2 Simulated pumpage / conceptual pumpage

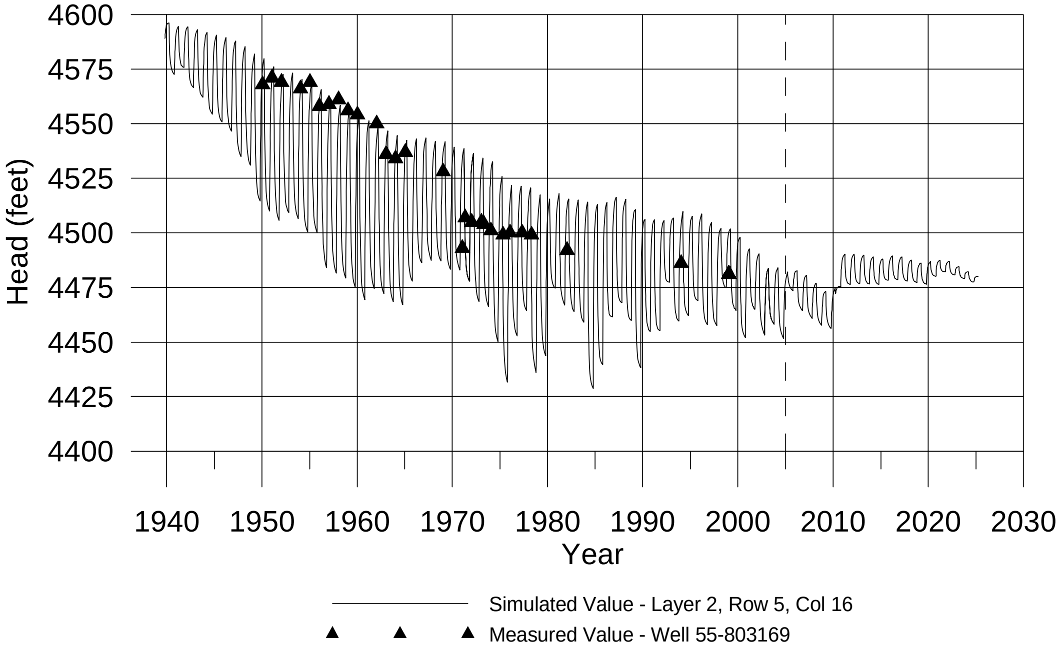

Figure 55. Measured and simulated water levels in the northern Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

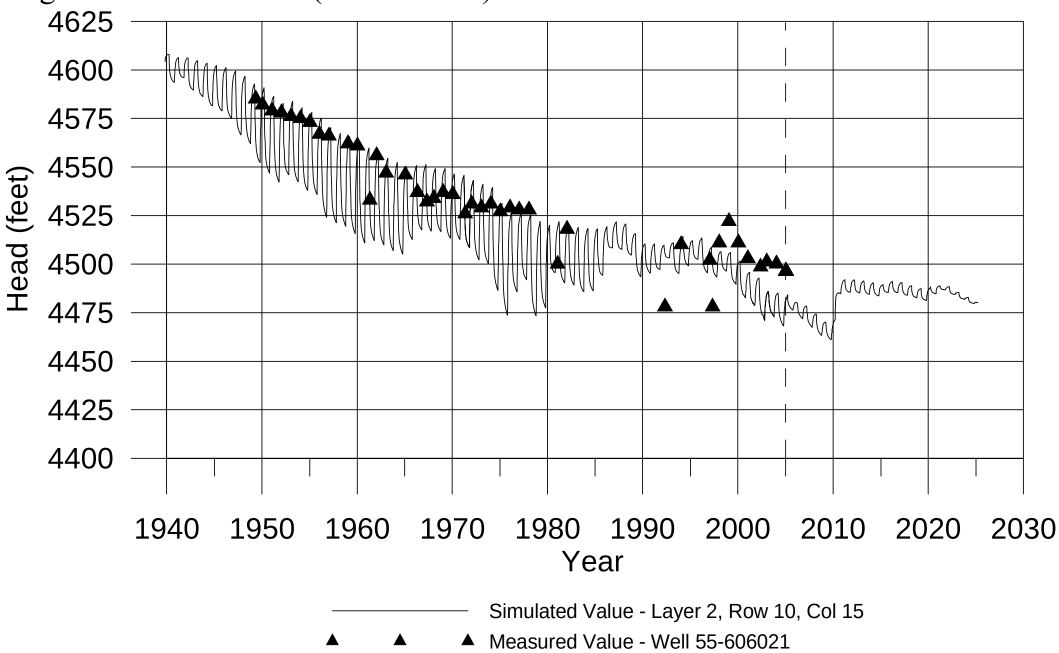

Figure 56. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

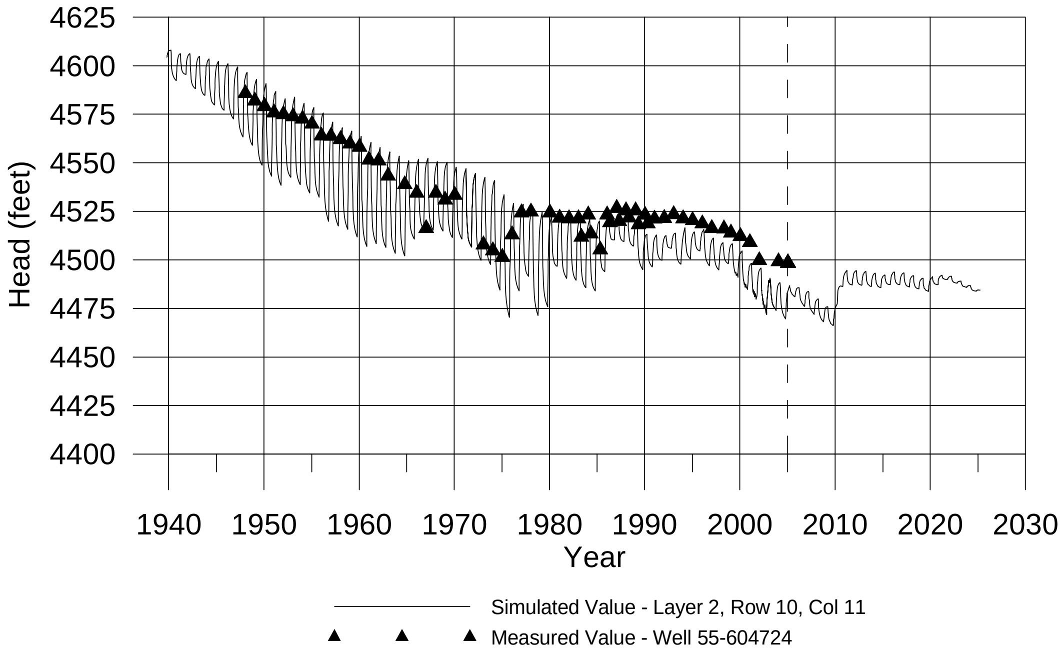

Figure 57. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

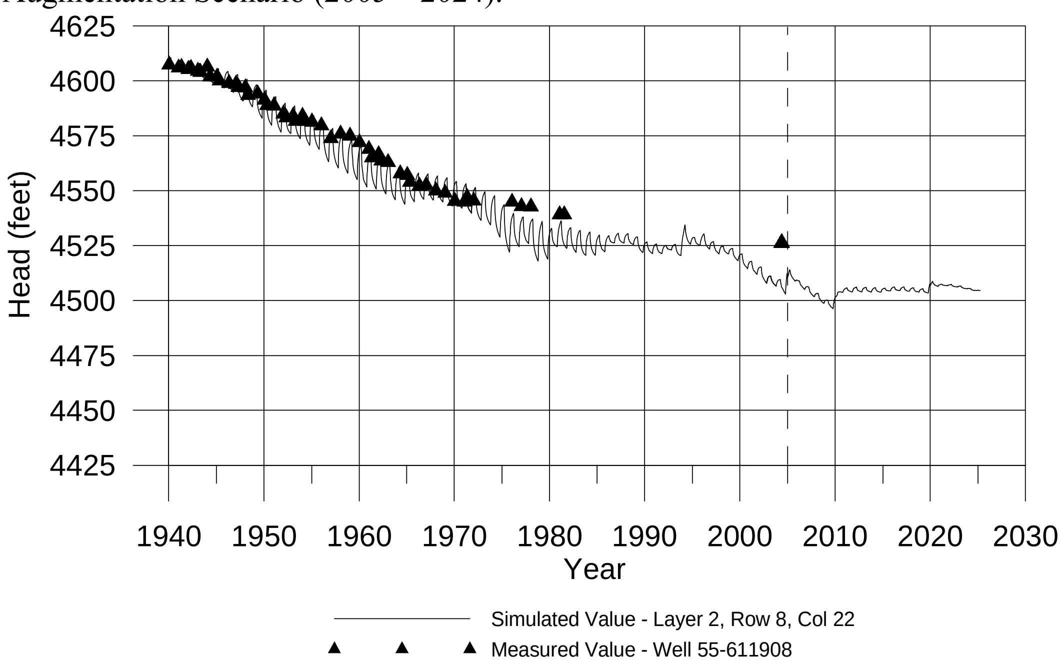

Figure 58. Measured and simulated water levels in the northeast Little Chino Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

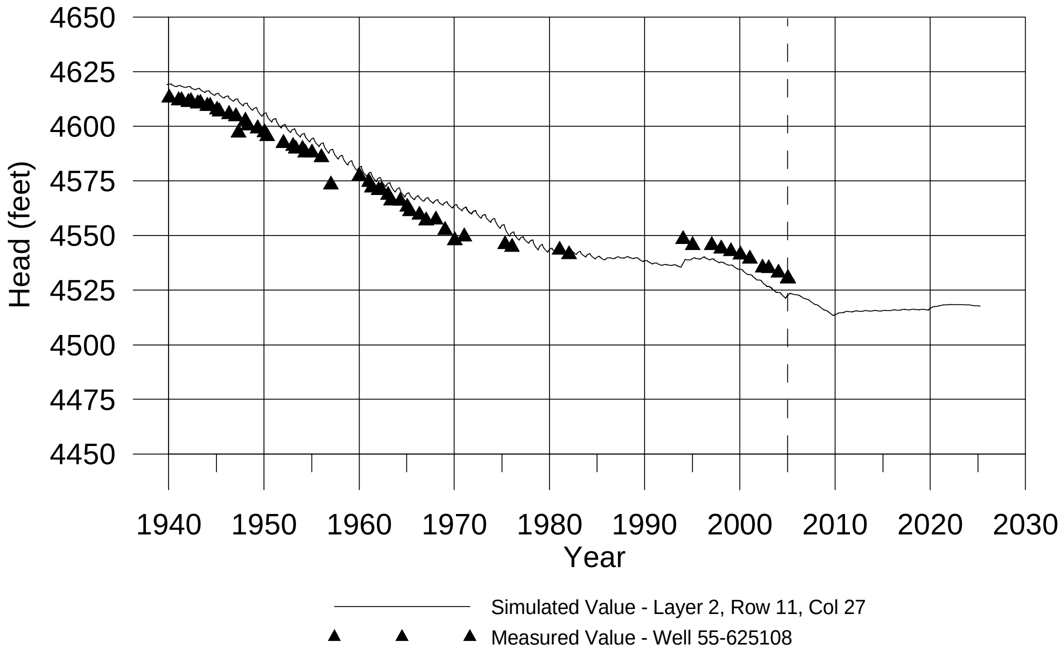

Figure 59. Measured and simulated water levels in the Lonesome Valley area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

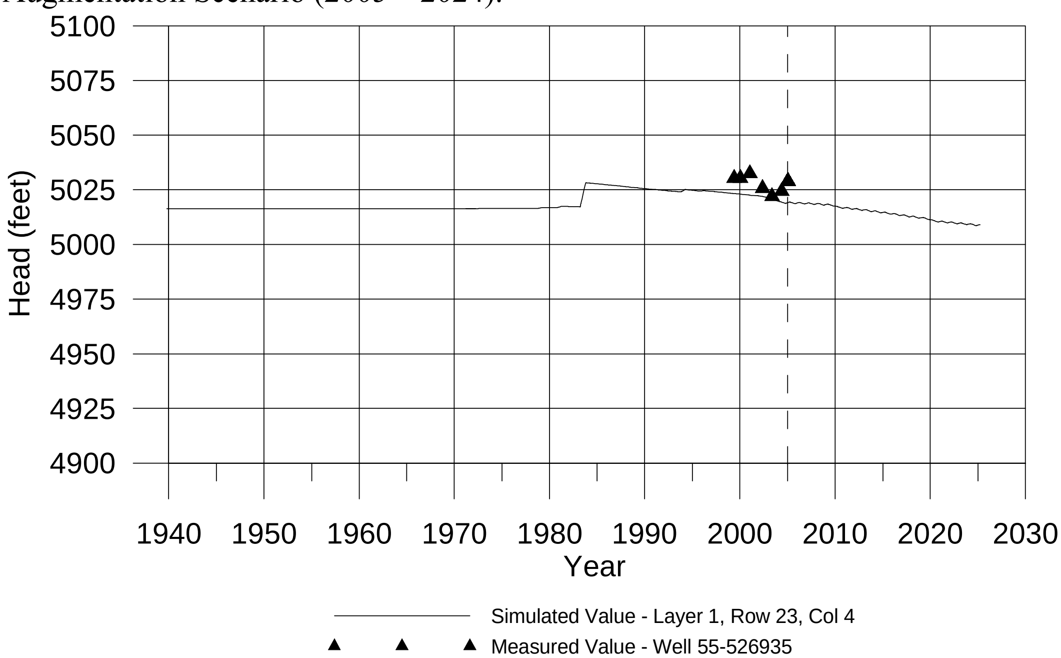

Figure 60. Measured and simulated water levels in the Mint Wash area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

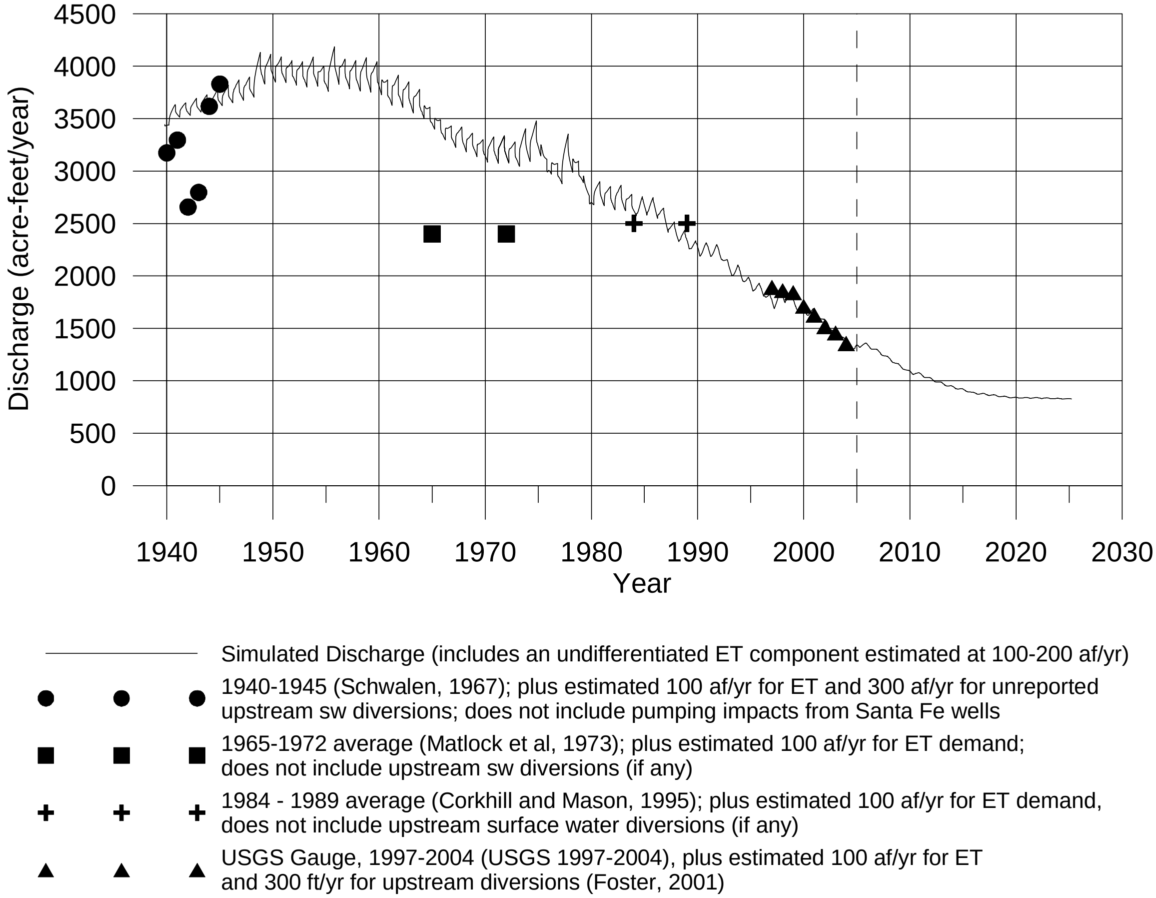

Figure 61. Measured and simulated groundwater discharge at Del Rio Springs for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

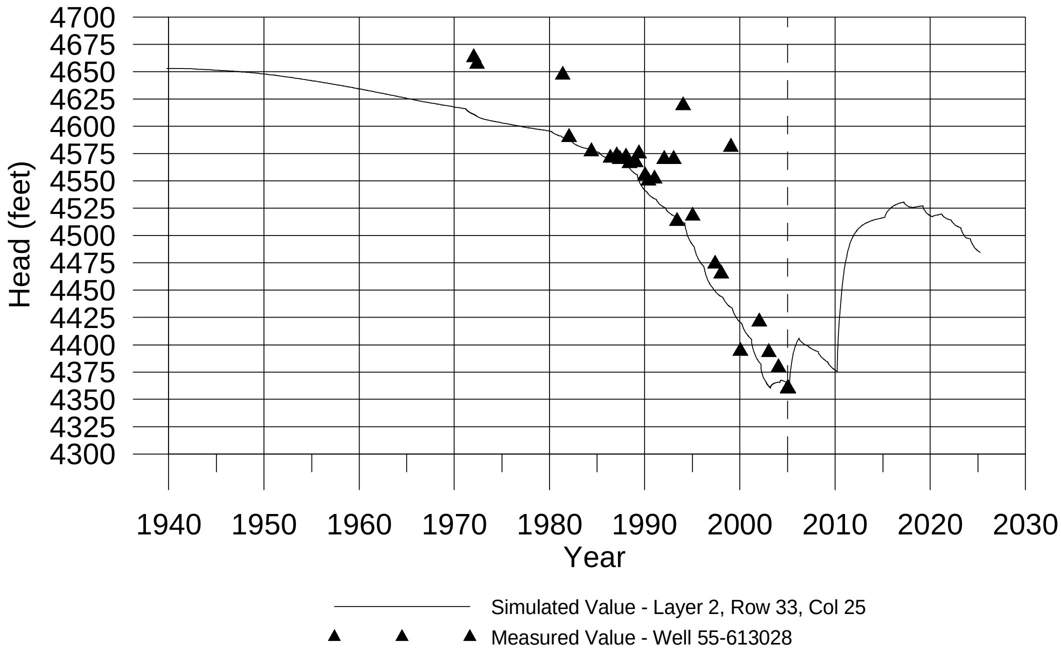

Figure 62. Measured and simulated water levels in the Santa Fe Wellfield area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

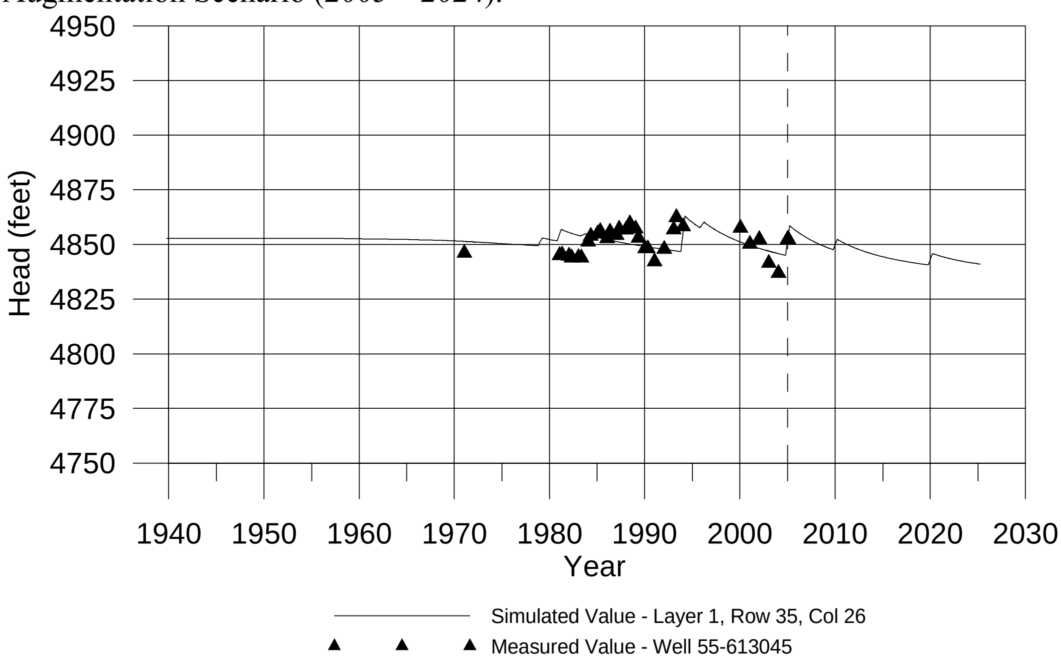

Figure 63. Measured and simulated water levels in the Upper Lynx Creek area for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

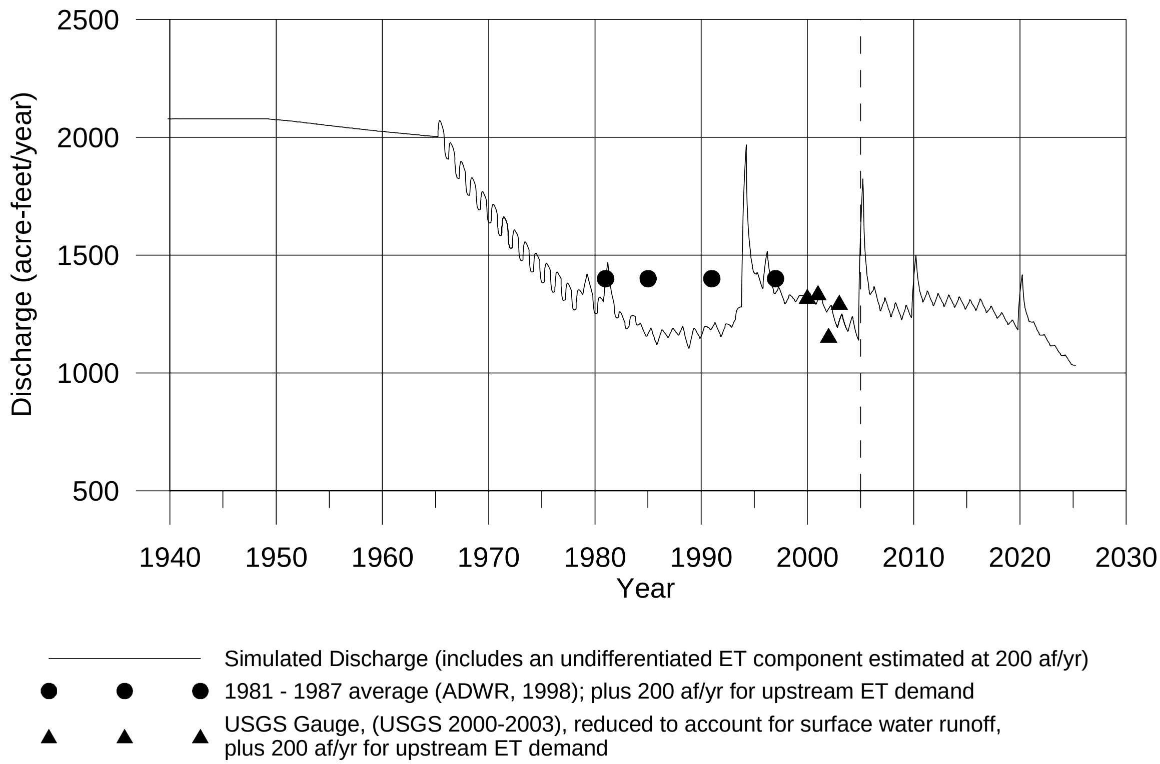

Figure 64. Measured and simulated groundwater discharge as baseflow at the Agua Fria River for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

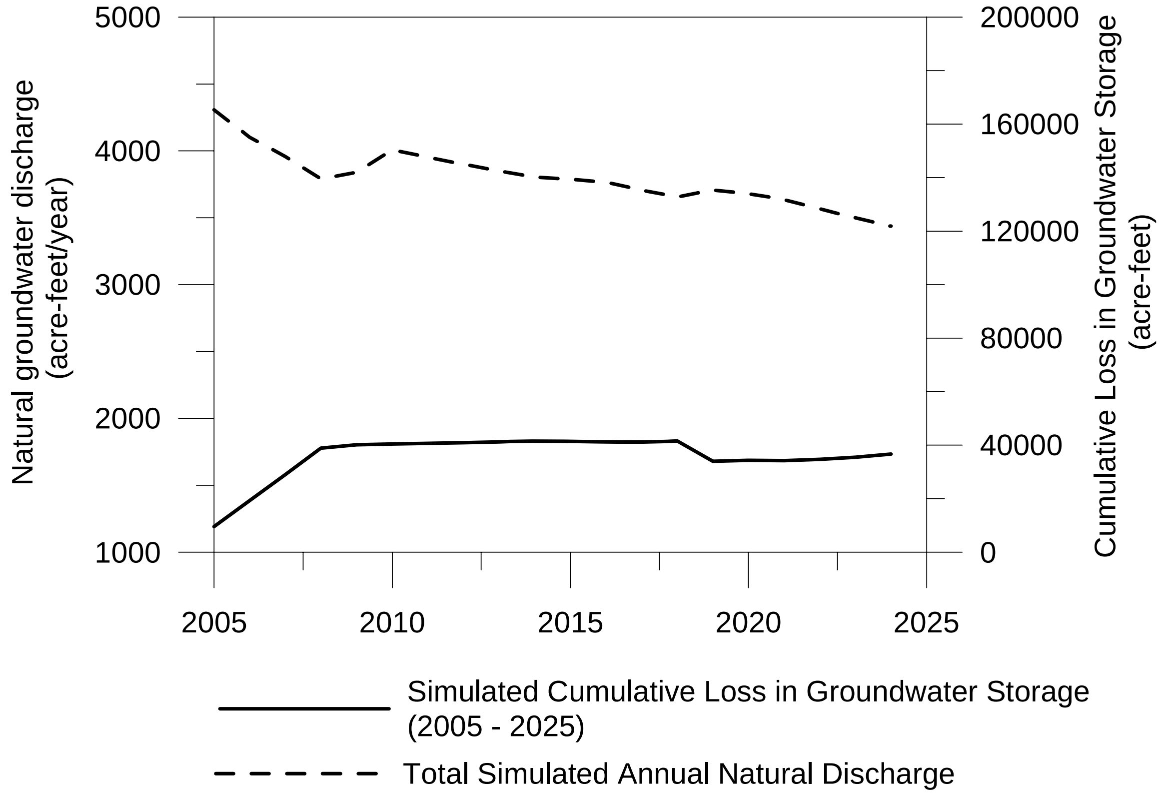

Figure 65. Simulated cumulative loss in groundwater storage and annual natural discharge in the Projected Growth with Conservation and Augmentation Scenario (2005 – 2024).

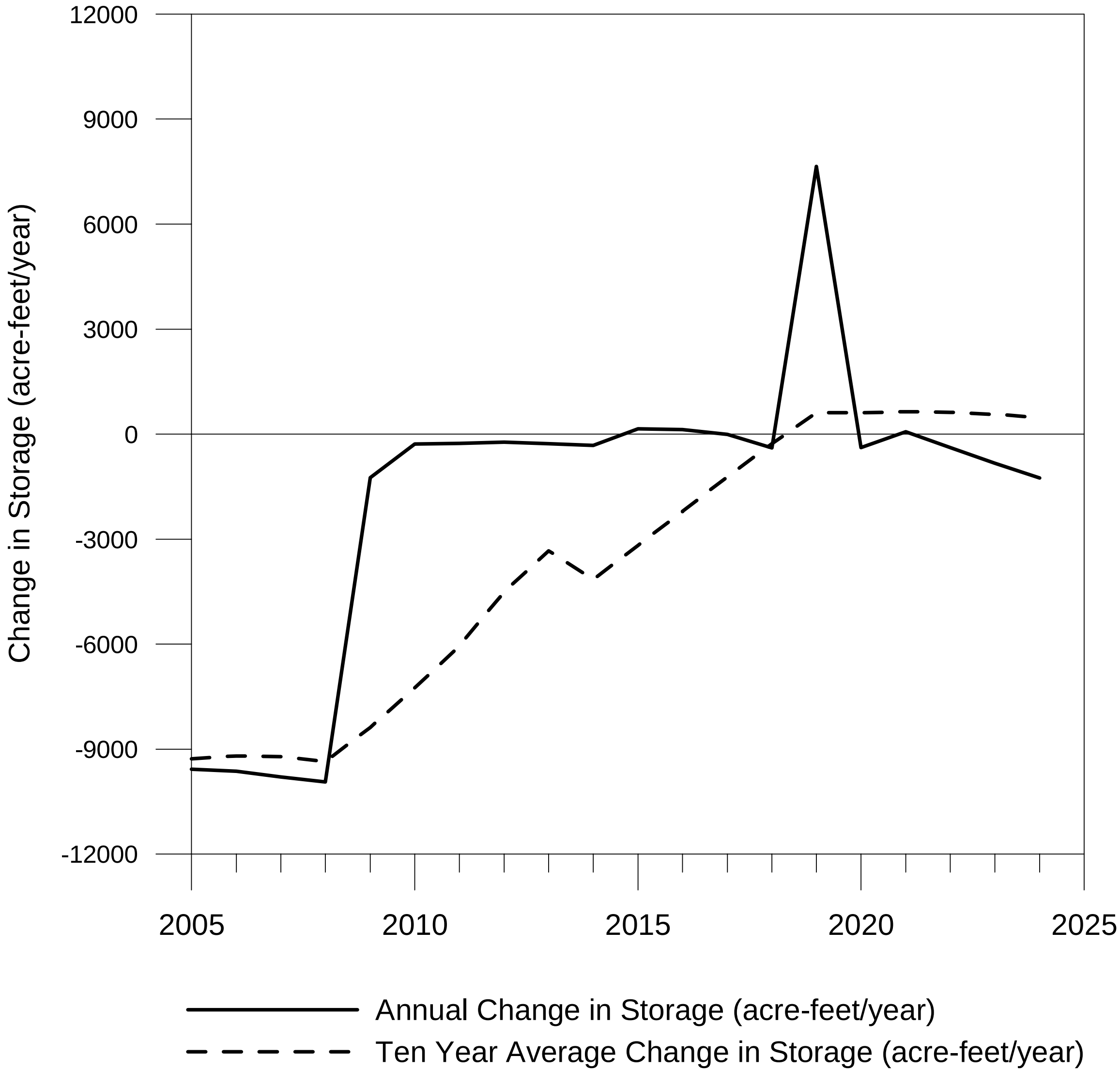

Figure 66. Simulated annual and ten year average change in storage for the Projected Growth with Conservation and Augmentation Scenario.

Results of the Low Growth with Conservation and Augmentation Scenario

In the Low Growth with Conservation and Augmentation Scenario, population and water demand in the Prescott AMA grows at the low end of projected estimates. Conservation programs enacted by the ADWR and the local communities reduce water demand in the area up to 20% by 2020. Proposed water importation projects are developed by the City of Prescott, Town of Prescott Valley, and Town of Chino Valley, providing a source of water in addition to local groundwater. This combination of factors allows the Prescott AMA to reach its safe-yield goal by 2018 while stabilizing natural groundwater discharge from Del Rio Springs (Table 25).

The results of the Low Growth with Conservation and Augmentation Scenario indicate that water levels in the Little Chino Sub-basin are projected to rebound once Big Chino groundwater becomes available as a source of supply (Figures 67-72). The largest water level increases are seen in areas most heavily impacted by earlier groundwater pumping, particularly in the vicinity of the City of Prescott's well field (Figures 68 and 69). After this initial spike in water levels, however, water levels in the Little Chino Sub-basin are projected to stabilize through 2024. Annual discharge from Del Rio Springs is projected to decline from approximately 1200 acre-feet to 900 acre-feet between 2005 and 2024 (Table 25, Figure 73). While this does represent a 25% decrease in discharge over the 20 year period, the discharge appears to be stabilizing at this lower level. Thus, the Low Growth with Conservation and Augmentation Scenario projects that annual discharge from Del Rio Springs will stabilize at approximately 900 acre-feet (Figure 73). Annual discharge from the Little Chino Sub-basin is actually projected to increase over the simulated period from approximately 1,600 acre-feet to nearly 1,750 acre-feet (Table 25).

Groundwater conditions in the Upper Agua Fria Sub-basin are more variably impacted than in the Little Chino Sub-basin. In the vicinity of the Town of Prescott Valley's artificial recharge facilities, groundwater levels are projected to increase over the simulated period; however, water levels in other areas are projected to decline (Figures 74 and 75). Annual groundwater discharge as baseflow in the Upper Agua Fria Sub-basin is also projected to decline from approximately 1,350 acre-feet in 2024 to around 1,100 acre-feet in 2005 (Table 25, Figure 76)

While groundwater conditions in the Upper Agua Fria Sub-basin appear to be impacted by the Low Growth with Conservation and Augmentation Scenario, the groundwater system of the Prescott AMA as a whole is projected to essentially stabilize in a condition of safe-yield. While groundwater storage in the aquifers of the Prescott AMA is projected to decrease by 16,750 acre-feet over the period from 2005 – 2024, all of this storage loss occurs in the early years of the simulation (Figure 77). Over the simulated period, average water level in 22 observation wells is projected to decline 0.5 ft. By 2010, groundwater in storage is projected to stabilize and begin increasing. Based on a ten-year running average of changes in groundwater storage, the AMA reaches its safe-yield goal in 2018 (Figure 78). In addition, this safe-yield state is achieved without dramatic declines in natural discharge from the aquifer system, thus allowing for the preservation of important riparian habitat and moderating impacts on downstream users.

Table 25. Conceptual and simulated annual water budgets for the Low Growth with Conservation and Augmentation Scenario for the Prescott AMA (2005 – 2024). (All figures to the nearest 50 acre-feet)

Year	Recharge			Pumpage			Del Rio	Agua Fria	Underflow	Change in
	Conceptual	Simulated	Sim/Con 1	Conceptual	Simulated	Sim/Con 2	Springs	Baseflow		Storage
2005	15250	15200	99.7%	20500	20500	100.0%	1250	1350	1600	-9600
2006	15650	15600	99.7%	21150	21100	99.8%	1300	1300	1550	-9600
2007	15850	15750	99.4%	21550	21550	100.0%	1200	1250	1500	-9750
2008	16100	16000	99.4%	22000	21950	99.8%	1150	1250	1450	-9800
2009	25050	24950	99.6%	22100	22000	99.5%	1100	1350	1400	-900
2010	16050	16050	100.0%	11700	11650	99.6%	1050	1350	1650	350
2011	16400	16400	100.0%	12050	11950	99.2%	1000	1300	1650	450
2012	16750	16750	100.0%	12300	12250	99.6%	1000	1300	1650	500
2013	17100	17100	100.0%	12600	12500	99.2%	950	1300	1650	650
2014	17450	17450	100.0%	12900	12800	99.2%	950	1300	1650	700
2015	17150	17100	99.7%	12100	12050	99.6%	900	1300	1650	1150
2016	17400	17350	99.7%	12400	12350	99.6%	900	1300	1650	1150
2017	17600	17600	100.0%	12700	12550	98.8%	900	1300	1650	1150
2018	17850	17800	99.7%	13050	12950	99.2%	900	1250	1650	1050
2019	26550	26500	99.8%	13350	13300	99.6%	900	1350	1650	9250
2020	17700	17700	100.0%	12500	12500	100.0%	900	1300	1700	1300
2021	16900	16900	100.0%	11550	11450	99.1%	900	1250	1750	1550
2022	17250	17200	99.7%	12100	12000	99.2%	900	1200	1750	1350
2023	17550	17550	100.0%	12650	12550	99.2%	900	1150	1750	1200
2024	17900	17900	100.0%	13300	13150	98.9%	900	1100	1750	950
Total	**355500**	**354850**	**99.8%**	**294550**	**293100**	**99.5%**	**19950**	**25550**	**32700**	**-16900**

1 Simulated recharge / conceptual rechage

2 Simulated pumpage / conceptual pumpage

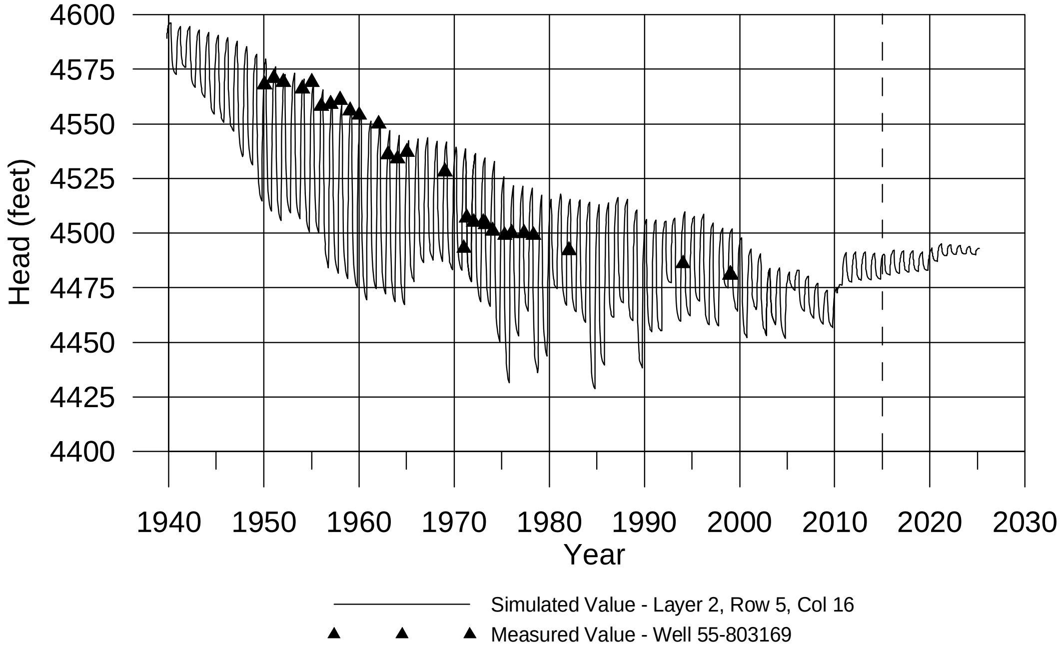

Figure 67. Measured and simulated water levels in the northern Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

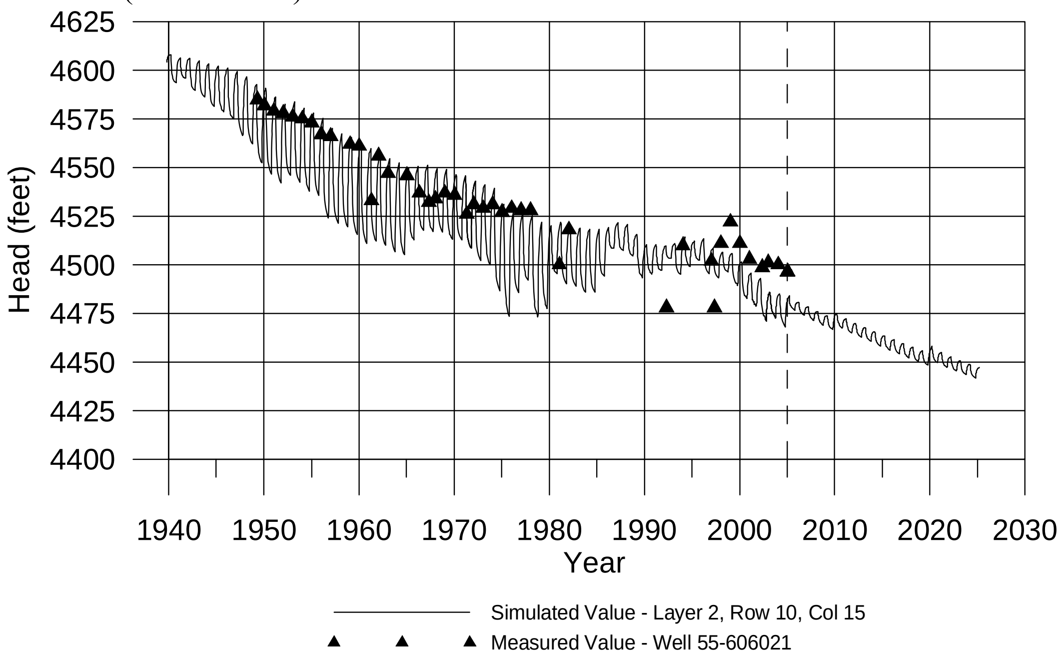

Figure 68. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

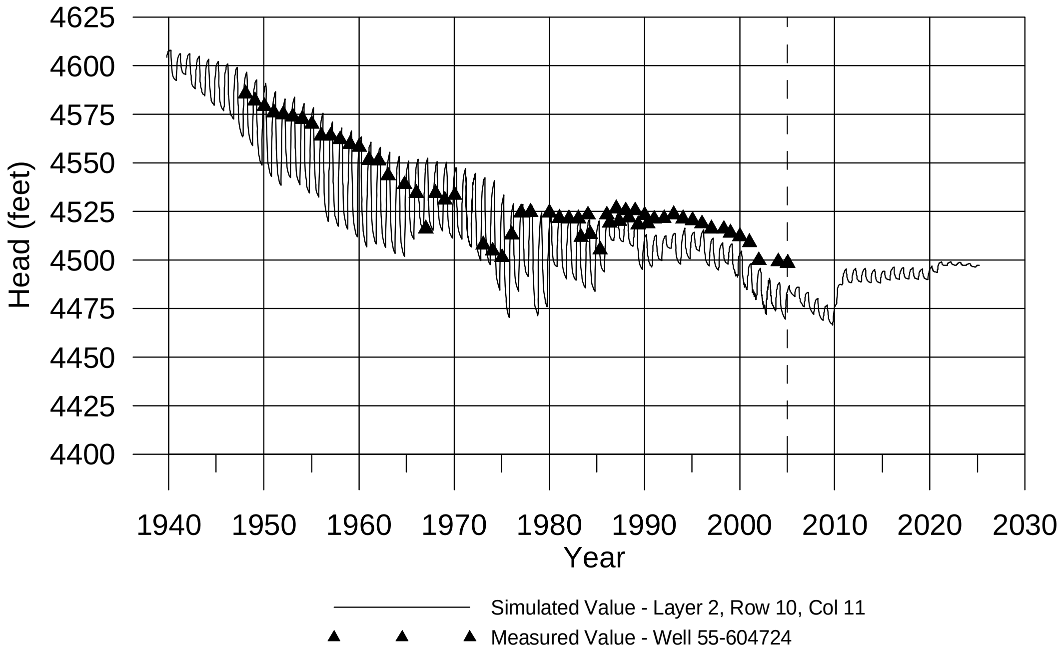

Figure 69. Measured and simulated water levels in the central Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

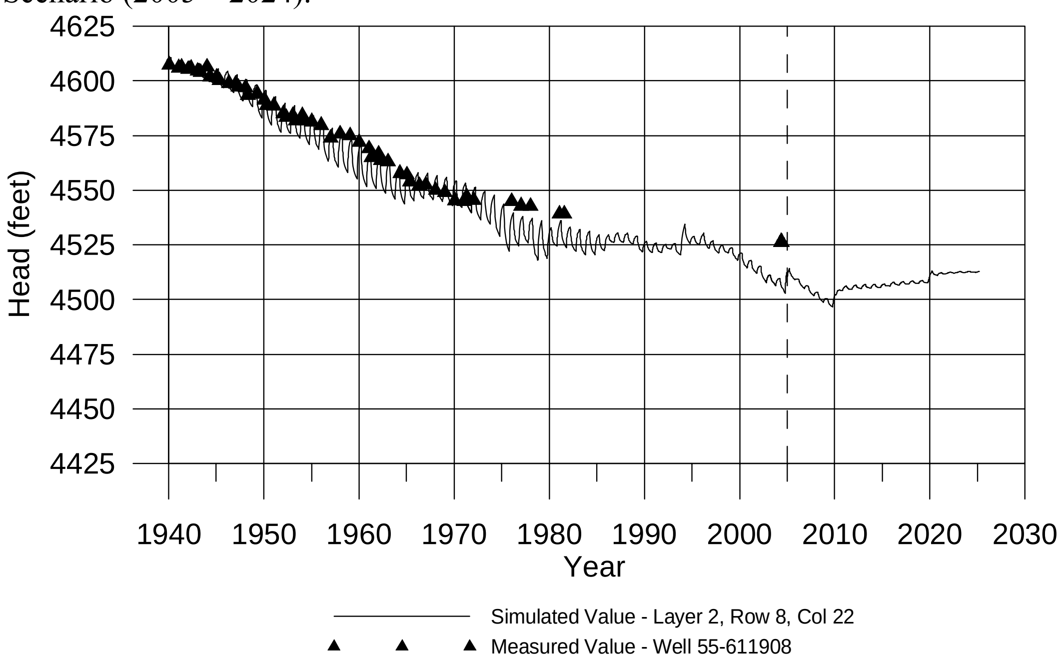

Figure 70. Measured and simulated water levels in the northeast Little Chino Valley area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

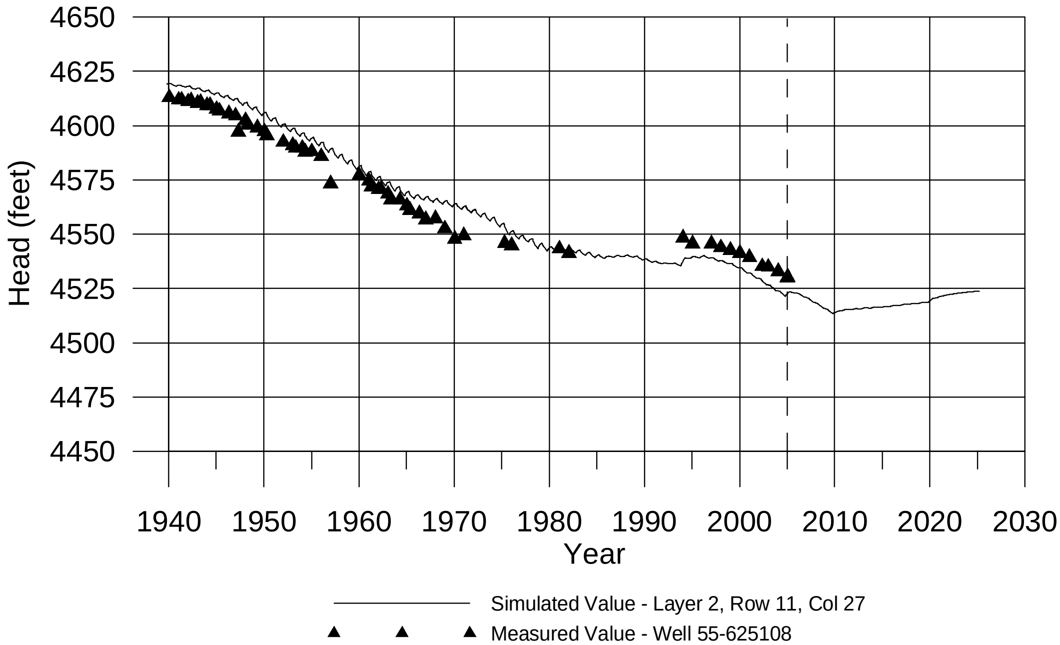

Figure 71. Measured and simulated water levels in the Lonesome Valley area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

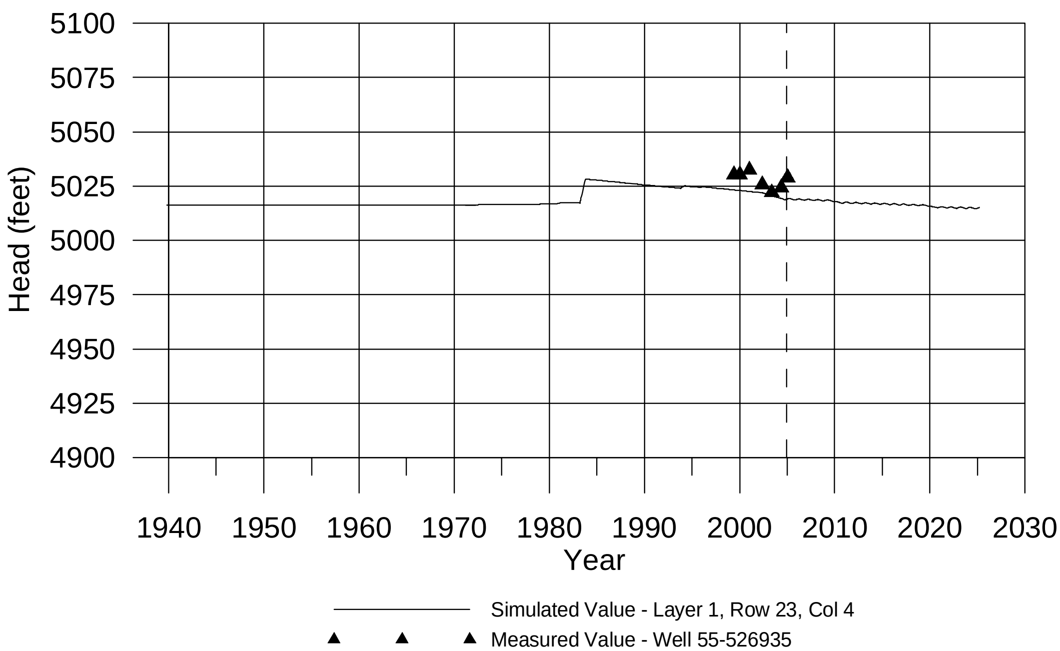

Figure 72. Measured and simulated water levels in the Mint Wash area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

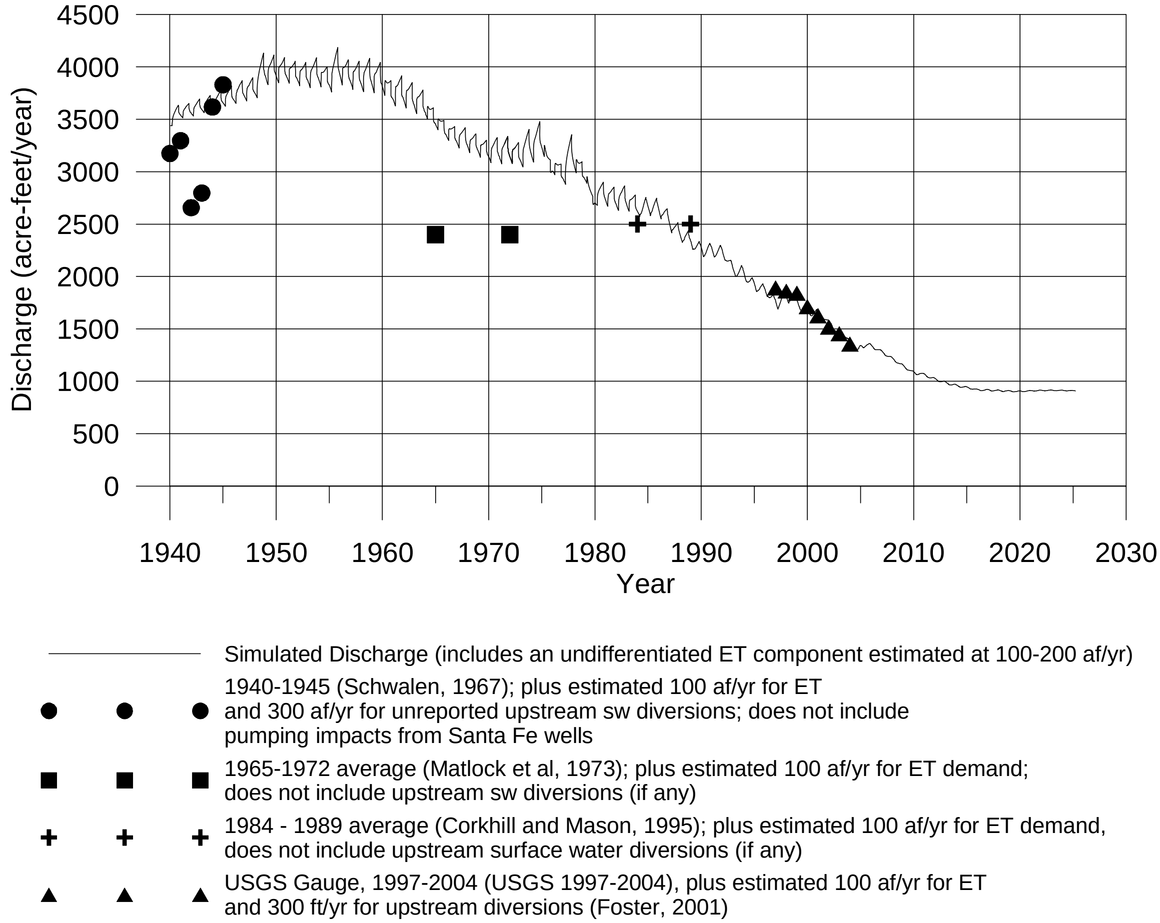

Figure 73. Measured and simulated groundwater discharge at Del Rio Springs for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

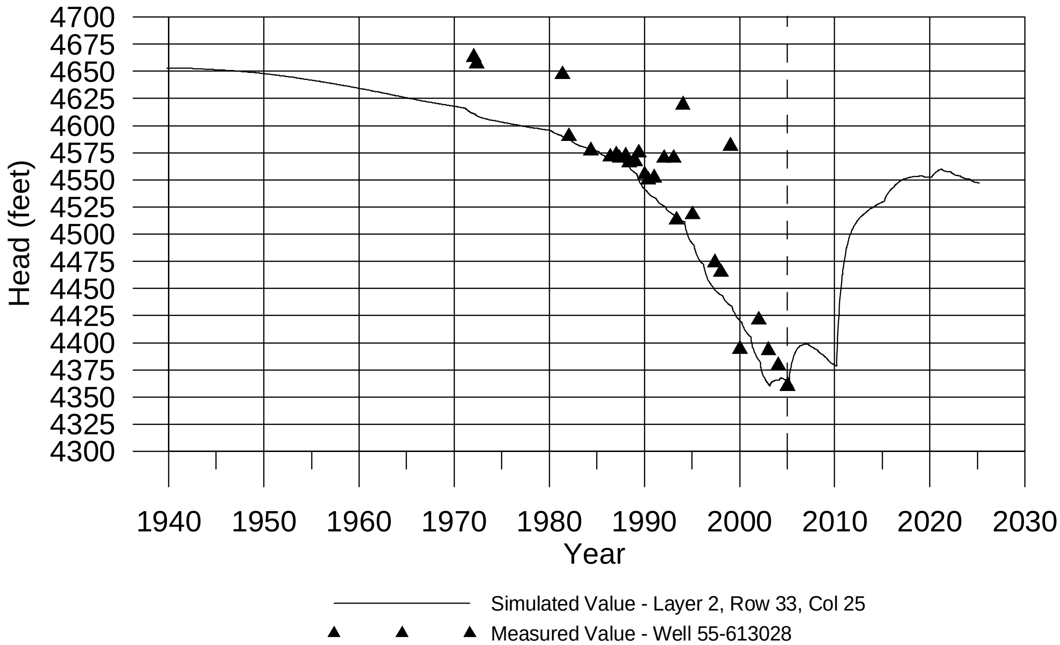

Figure 74. Measured and simulated water levels in the Santa Fe Wellfield area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

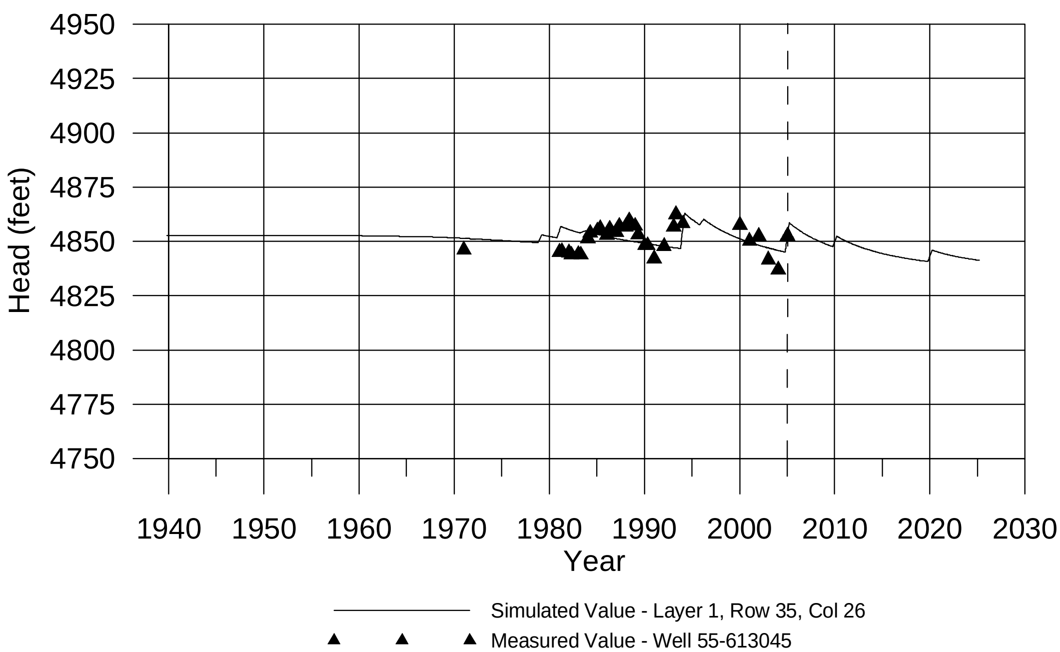

Figure 75. Measured and simulated water levels in the Upper Lynx Creek area for the transient simulation of the Prescott AMA groundwater flow model (1999 – 2004) and simulated water levels for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

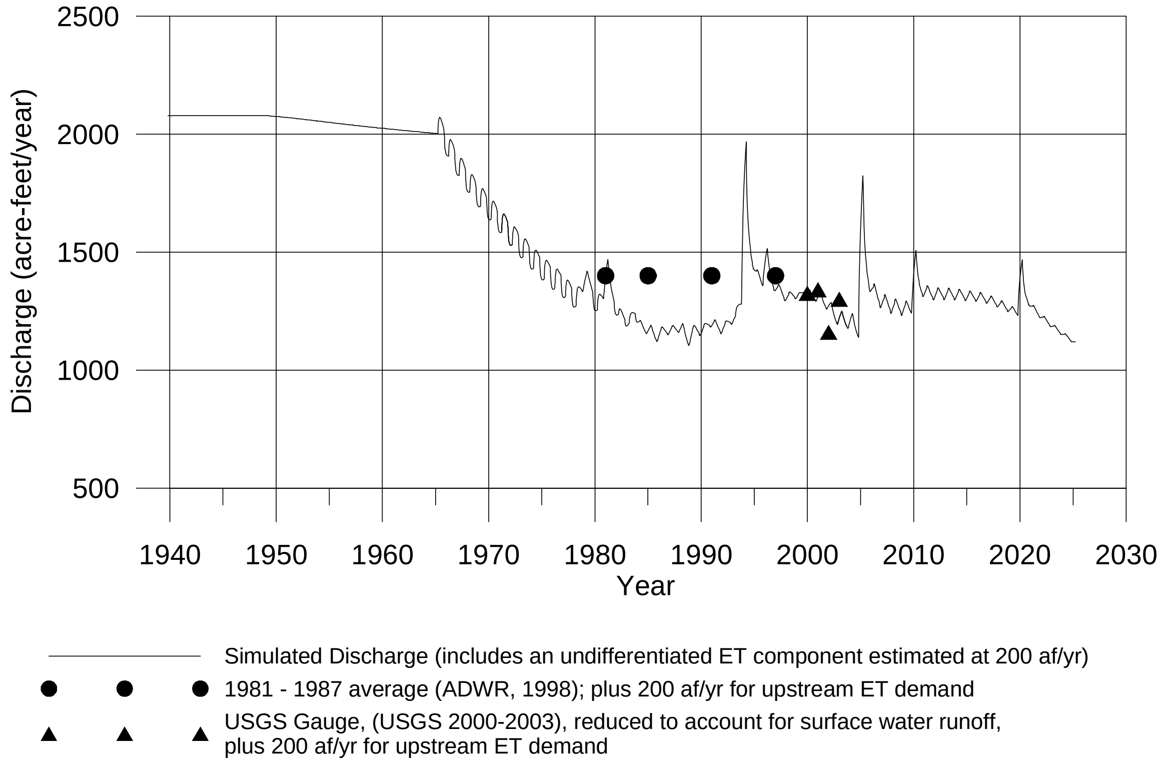

Figure 76. Measured and simulated groundwater discharge as baseflow at the Agua Fria River for the transient simulation of the updated Prescott AMA groundwater flow model (1940 – 2004) and simulated groundwater discharge for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024).

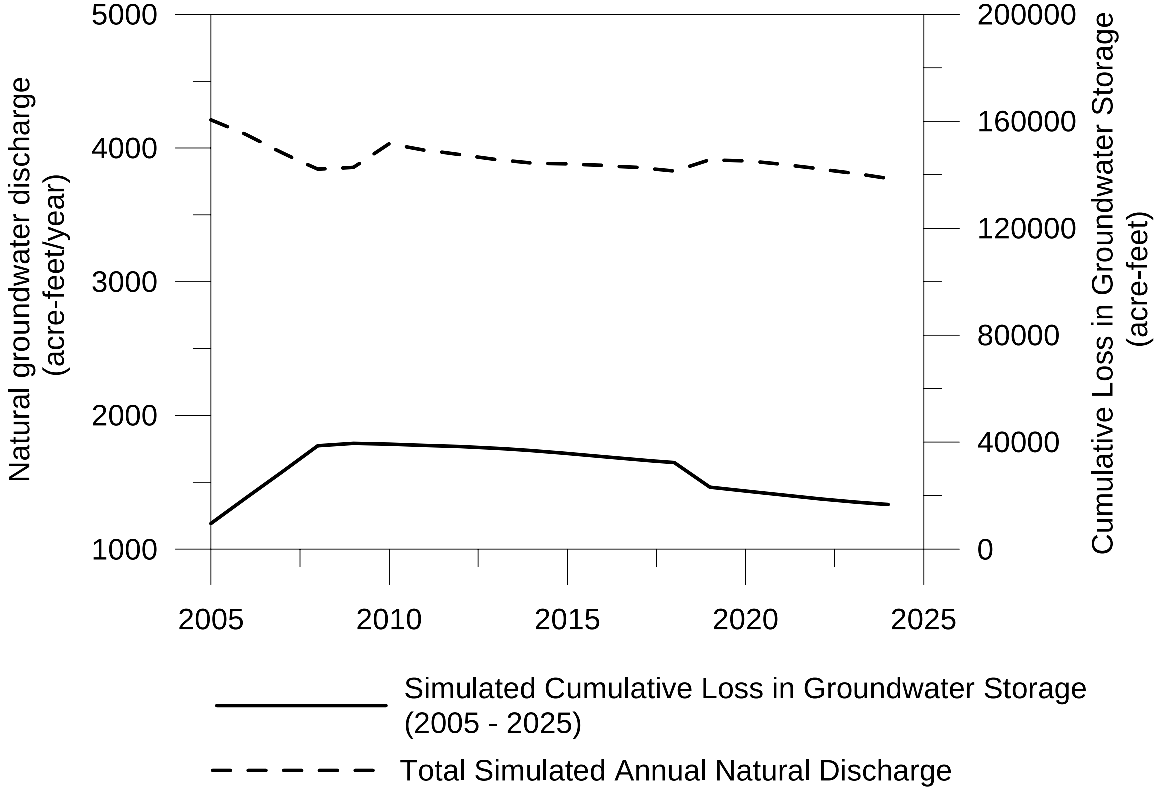

Figure 77. Simulated annual natural groundwater discharge and cumulative loss in groundwater storage for the Low Growth with Conservation and Augmentation Scenario (2005 – 2024) for the Prescott AMA.

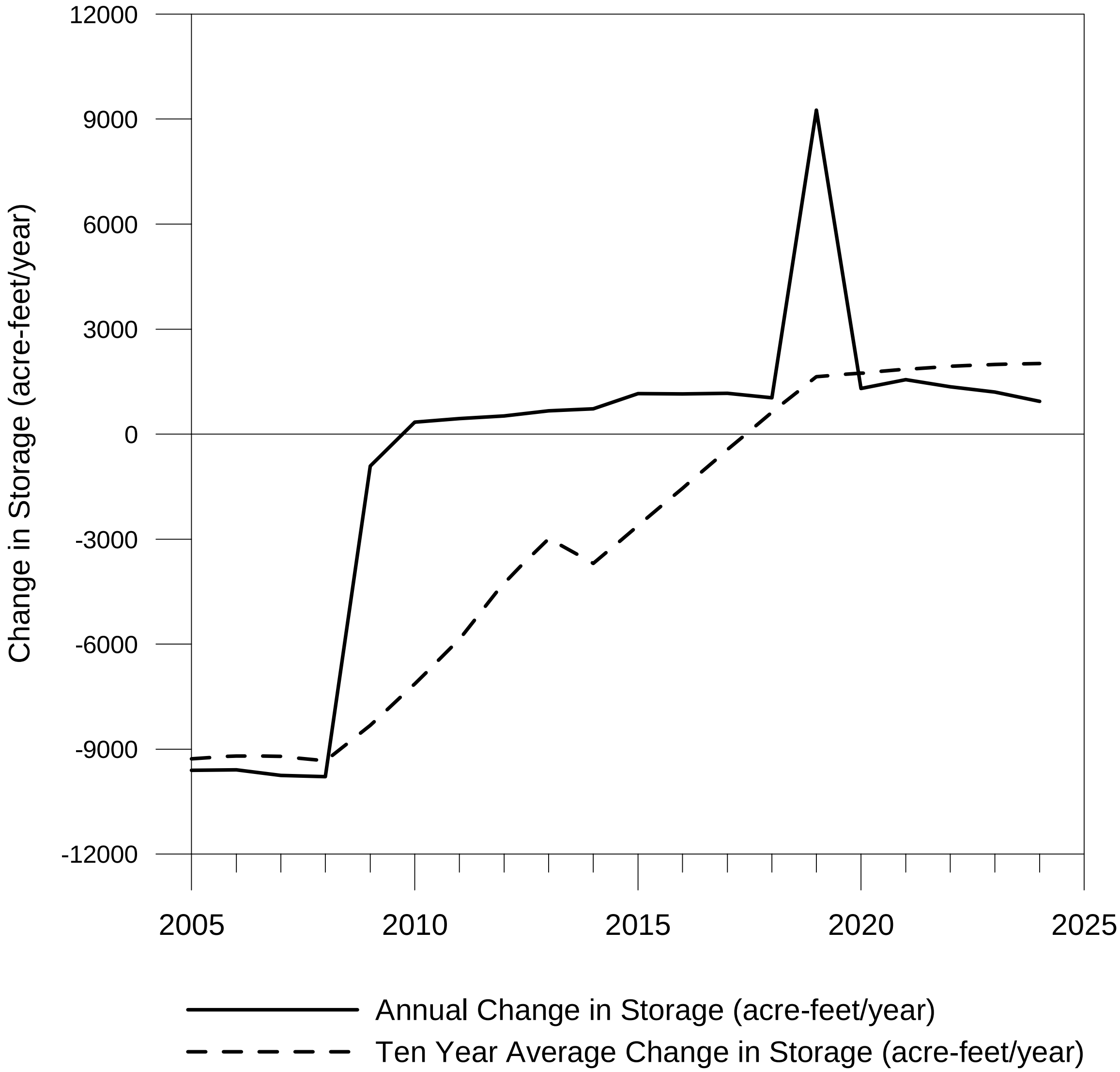

Figure 78. Simulated annual and ten year average change in groundwater storage for the Low Growth with Conservation and Augmentation Scenario for the Prescott AMA (2005 – 2024)

Discussion of Scenario Results

As noted earlier, the central research question addressed by this thesis is: *What future impacts will different population growth, water conservation and alternative water supply importation scenarios have on the groundwater resources of the Prescott Active Management Area?* The original hypothesis was that different scenarios based on these variables would have vastly different impacts on the groundwater resources of the Prescott AMA. The results from the scenario modeling generally support this hypothesis.

Change in water level, natural discharge, and groundwater in storage are variously impacted under the different scenarios (Table 26). Each of these indicators of aquifer condition is most impacted by the Projected Growth with Conservation Scenario, while the Low Growth with Conservation and Augmentation Scenario has the least impact upon the groundwater resources of the Prescott AMA. The Baseline Scenario and the Projected Growth with Conservation and Augmentation Scenario each have intermediate impacts on the future condition of groundwater resources in the area.

Table 26. Summary of results from the four future scenarios simulated with the updated Prescott AMA groundwater flow model.

Scenario	Change in Water Level	Change in Natural Discharge	Change in Storage
Baseline [1]	-22.3 ft	-34%	-154,000 ac-ft
PG Con [2]	-38.3 ft	-52%	-174,000 ac-ft
PG Con Aug [3]	-6.3 ft	-19.70%	-37,000 ac-ft
LG Con Aug [4]	-0.5 ft	-11.90%	-17,000 ac-ft

[1] Baseline Scenario
[2] Projected Growth with Conservation Scenario
[3] Projected Growth with Conservation and Augmentation Scenario
[4] Low Growth with Conservation and Augmentation Scenario

Looking at simulated groundwater storage as an indicator of aquifer condition, the four modeled scenarios had significantly different impacts upon the aquifers of the Prescott AMA (Figure 79). Based on this metric, the Projected Growth with Conservation Scenario had the most impact on the groundwater resources of the Prescott AMA, followed by the Baseline Scenario, the Projected Growth with Conservation and Augmentation Scenario and the Low Growth with Conservation and Augmentation Scenario.

Natural groundwater discharge is another indicator of aquifer condition with particular importance for riparian habitat and downstream users. If simulated natural groundwater discharge is examined, the scenarios fall along the same continuum from most to least impact (Figure 80). Based on these two metrics, it is clear that the impact upon the groundwater resources of the Prescott AMA experienced under the different scenarios varies widely. The Projected Growth with Conservation Scenario leads to the greatest impact on these two indicator metrics, with the Baseline Scenario, the Projected Growth with Conservation Scenario, and the Low Growth with Conservation and Augmentation Scenario leading to lesser and lesser impacts upon the groundwater system of the area.

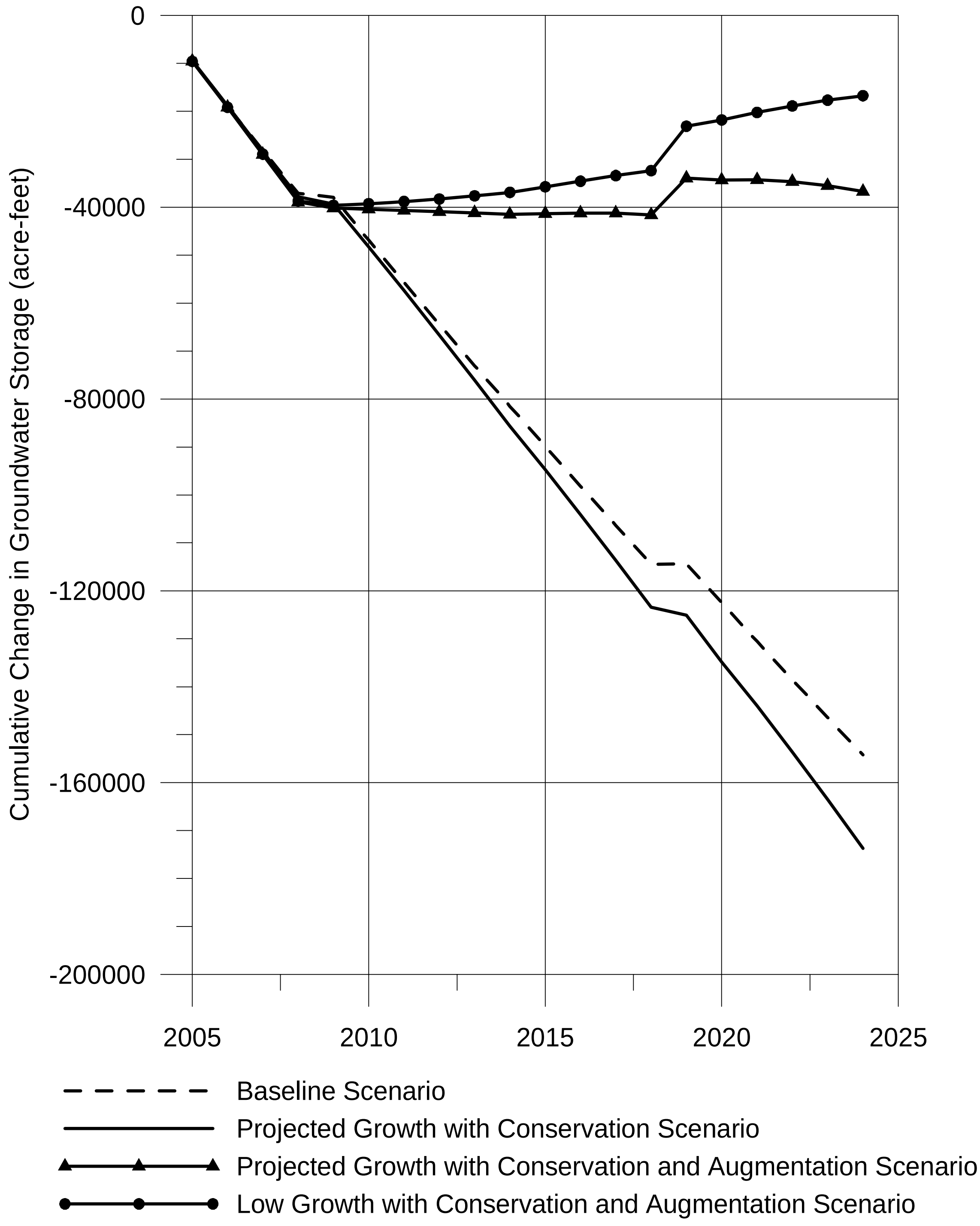

Figure 79. Simulated cumulative change in storage for the Baseline Scenario, Projected Growth with Conservation, Projected Growth with Conservation and Augmentation and Low Growth with Conservation and Augmentation Scenarios for the Prescott AMA (2004 – 2024).

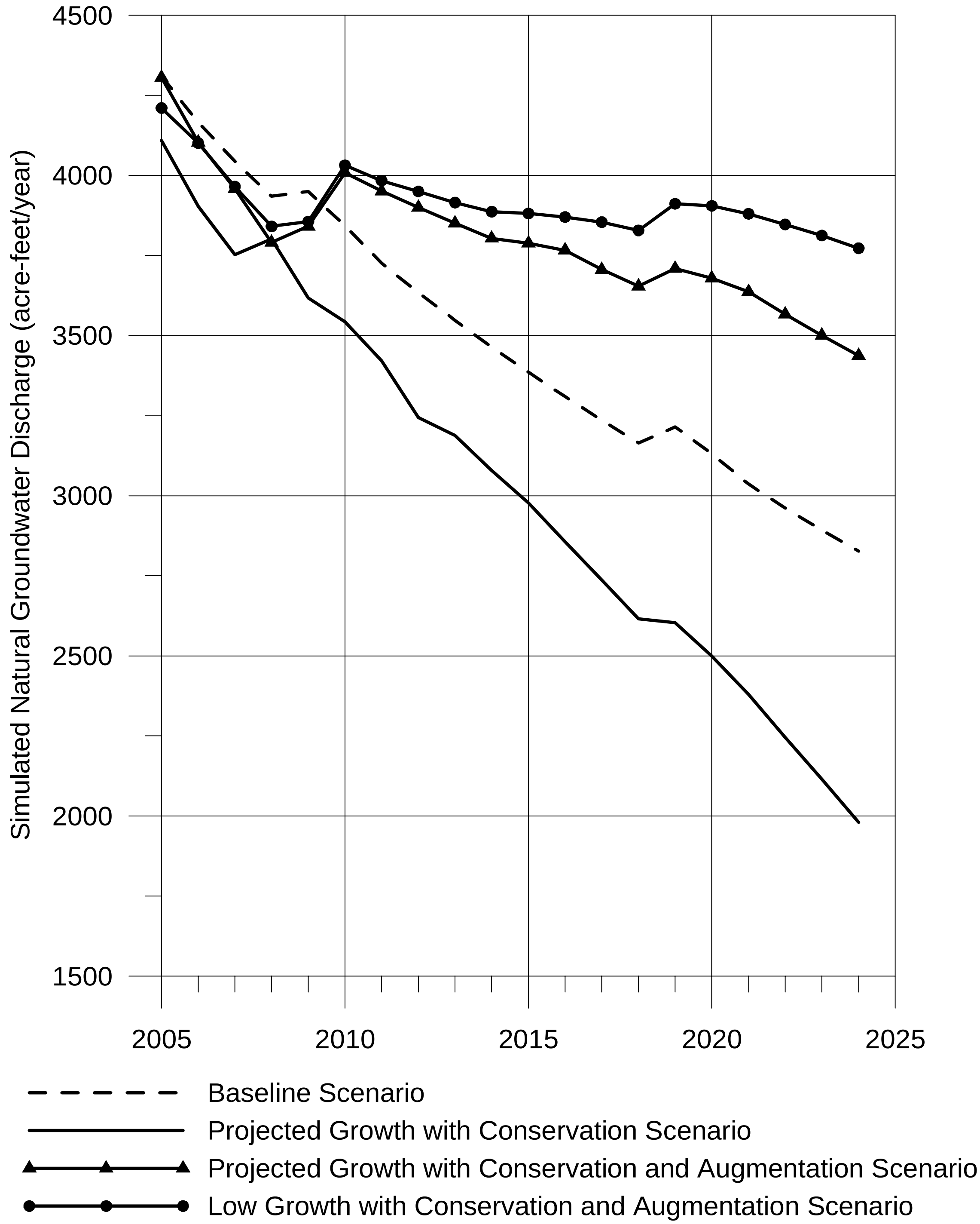

Figure 80. Simulated natural groundwater discharge for the Baseline Scenario, Projected Growth with Conservation, Projected Growth with Conservation and Augmentation and Low Growth with Conservation and Augmentation Scenarios for the Prescott AMA (2004 – 2024).

The use of multiple scenario analysis allows for several important observations. First, conservation alone is unlikely to allow for the achievement of safe-yield by 2025. While the conservation factors utilized in the analysis could be debated within a range, the level of conservation required to bring the AMA into safe-yield without additional supply would be larger than indicated by the current literature. A conservation factor of nearly 50% would be required to bring current demand to within the limits of a safe-yield system. The highest conservation factor found in the literature review for this study was 30% for the Goleta, California, Water District (US EPA, 2002). This high level of conservation was achieved through a combination of education, restrictions, pricing and the distribution of over 15,000 low-flow toilets and over 35,000 low-flow showerheads (US EPA, 2002). In addition, per capita water use in Goleta prior to the development of conservation programs was significantly higher than current water use in the Prescott AMA (ADWR, 1999; US EPA, 2002). Given the already low per capita water usage in the Prescott AMA, it is unlikely that savings of 30% or more could be achieved. Factoring in expected population growth, the level of conservation that would be required to bring the AMA into safe-yield through conservation alone would be impossible with current technology.

Recognizing that conservation alone is insufficient to bring the AMA into safe-yield, it becomes clear that supply augmentation is necessary for the achievement of safe-yield. In this study, it was assumed that additional supply will come from Big Chino groundwater; however, this is not necessarily the only additional supply option. If Big Chino groundwater is not available for importation due to legal or other difficulties, other augmentation options must be pursued to bring the AMA into safe-yield. These additional sources of supply could come from alternate groundwater basins, additional capture of surface runoff from the uplands of the AMA, increased effluent recovery, or weather modification. The extension of sewer lines to capture effluent from residents currently served by individual septic systems has also been suggested as a potential source of additional supply for irrigation use or aquifer recharge (Sonoran Institute, 2007). Regardless of the source, simulation results indicate that additional water supplies will be required for the Prescott AMA to reach its safe-yield mandate.

Finally, scenario results indicate that the achievement of safe-yield is possible with projected population growth rates; however, even with effective conservation strategies and the importation of alternate water supplies, population growth at projected rates leads to impacts on the natural discharges from the groundwater system. Thus, safe-yield can be achieved, but only by decreasing outflow from Del Rio Springs, baseflow in the Agua Fria River, and underflow to the Verde River. Projected rates of population growth make the achievement of safe-yield by 2025 likely only a temporary state of affairs. Simulated results indicate that, under conditions of continued growth at projected rates, the AMA will likely be unable to maintain a state of compliance with the safe-yield mandate much past 2025.

Results of the Scenarios Utilizing Manipulated Natural Recharge

One of the more uncertain components in the water budget for the groundwater system of the Prescott AMA is natural recharge. Both the annualized mountain front recharge and the decadal flood recharge values utilized for the multiple scenario analysis include a large amount of error. Based on previous sensitivity analysis and the work of an independent reviewer, estimates of natural recharge may range by ± 50% (Corkhill and Mason, 1995; Woessner, 1998). While a systematic sensitivity analysis was not completed, a series of additional simulations were used to investigate the impact of varying natural recharge values on the results of the future scenarios.

Each of the four scenarios were simulated twice utilizing different values for natural recharge, including mountain front recharge and flood recharge. Each of the four scenarios were re-simulated utilizing 50% of the estimated mountain front recharge value of 5,750 af/yr, or 2,875 af/yr and 50% of the estimated ten-year flood recharge value of 8,470 af/yr, or 4,235 af/yr. Next, the four scenarios were re-simulated utilizing 150% of the estimated recharge values. For these simulations, a mountain front recharge value of 8,625 af/yr and a ten-year flood recharge value of 12,700 af/yr were used. The altered recharge numbers were utilized for the period 2005 – 2024.

As expected, manipulating the natural recharge values utilized for the future scenarios lead to different water budget outputs. Water levels, total natural discharge, and total change in storage were all altered by the different recharge values (Table 27). In particular, total change in storage was more greatly impacted than total natural discharge (Table 27). This is likely due to several reasons. First, natural discharge is a much smaller component of the overall water budget than change in storage. Second, a considerable lag time was required before the altered natural recharge began to significantly impact the natural discharge from the system. In fact, over a decade was required before the altered recharge values began to impact discharge from Del Rio Springs.

The significant impact that altered natural recharge had on the simulated results for the different future scenarios indicates that further work should be done to better constrain the model input values used for this important component of the water budget for the Prescott AMA groundwater system. The accurate determination of the safe yield for the Prescott AMA requires that all of the water budget components be understood, including natural recharge. Further discussion of this and other research needs is found in the next chapter.

Scenario	Water Level Change	Total Natural Discharge	Percent Difference [3]	Total Change in Storage	Percent Difference [4]
Baseline	-22.3 ft	69800 af	-	-154200 af	-
-50%[1]	-31.3 ft	67600 af	-3.2%	-223600 af	-45.0%
+50%[2]	-15.3 ft	72000 af	3.2%	-95800 af	37.9%
PGCon	-38.3 ft	60700 af	-	-173700 af	-
-50%[1]	-47.6 ft	58400 af	-3.8%	-243700 af	-40.3%
+50%[2]	-30.5 ft	63500 af	4.6%	-103600 af	40.4%
PGConAug	-6.3 ft	76000 af	-	-36700 af	-
-50%[1]	-14.9 ft	74000 af	-2.6%	-105400 af	-187.0%
+50%[2]	1.0 ft	78400 af	3.2%	33400 af	191.0%
LGConAug	-0.5 ft	78400 af	-	-16800 af	-
-50%[1]	-8.8 ft	76400 af	-2.6%	-85800 af	-410.7%
+50%[2]	+6.0 ft	80400 af	2.6%	41800 af	348.9%

[1] Above scenario simulated with 50% estimated mountain front and flood recharge values.
[2] Above scenario simulated with 150% estimated mountain front and flood recharge values.
[3] Percent difference in total natural discharge compared to original scenario results.
[4] Percent difference in total change in storage compared to original scenario results.

Table 27. Results of the future scenarios based on uncertainty in natural recharge values.

CHAPTER EIGHT: CONCLUSIONS

The Prescott Active Management Area was established by the AGMA of 1980 to address the unregulated depletion of the common-pool groundwater resources of the area. The AGMA mandated that the Prescott AMA achieve a state of safe-yield by 2025 through statutory restrictions on groundwater use in the area. Safe-yield is defined as a long-term balance between the amount of groundwater withdrawn and the amount of natural and artificial recharge in the area. The Arizona Department of Water Resources has established several groundwater management programs including conservation, augmentation and reuse designed to help the Prescott AMA reach its safe-yield goal.

To assess potential impacts of these various management programs, the ADWR developed a groundwater flow model for the Prescott AMA (Corkhill and Mason, 1995; Nelson, 2002). This groundwater model served as the basis for the research conducted for this thesis. The primary goal of this research was to revise and update the model to provide a more up-to-date tool for the prediction of future groundwater conditions in the area. The research question being asked was: *What future impacts will different population growth, water conservation and alternative water supply importation scenarios have on the groundwater resources of the Prescott Active Management Area?* The hypothesis being tested was that different scenarios would have vastly different impacts on groundwater conditions.

Specific objectives of the study included: 1) Extend the active model area to include the western part of the AMA (referred to as 'the Mint Wash area'), 2) Redefine the geologic structure based on newly available data; 3) Reevaluate model parameter values based on newly available data and 4) Extend the transient simulation to include the years 1999-2004.

To fulfill these objectives, the active model was extended laterally to include the Mint Wash area and the geologic structure was redefined based on recently published material and the results from the drilling of several ADWR monitoring wells. Model parameter values were reevaluated based on inverse modeling techniques, while the transient simulation was extended to include the years 1999-2004. The groundwater model was calibrated to the steady-state conditions of 1939 and the transient conditions from 1939 – 2004. Statistical and qualitative results indicate that the calibrated model provides a reasonable approximation of the regional groundwater system.

Additional objectives as part of the multiple scenario analysis process included 5) Develop several future scenarios based on population growth, water conservation strategies, and alternative water supply importation policies, 6) Simulate the future scenarios with the groundwater model, and 7) Provide policy recommendations based on simulation results.

In collaboration with the ADWR, water resources managers of the local communities, and other stakeholders, several scenarios were developed to assess the impacts of different population growth rates, conservation strategies, and alternative water-supply augmentation plans on the groundwater resources of the Prescott AMA. Four of the scenarios were then simulated with the updated Prescott AMA groundwater flow model.

The results of the scenario simulations support the original hypothesis. A wide range of impacts on the groundwater system of the AMA are projected by the different scenarios. Based on these results, several conclusions can be drawn. First, conservation alone is likely to be insufficient to bring the Prescott AMA into a safe-yield condition. Second, augmentation of local water supplies is likely to be necessary for the achievement of safe-yield. This may come from Big Chino groundwater; however, other options must be considered if this source is unavailable due to legal or other challenges. Third, while it is possible for the Prescott AMA to achieve safe-yield while maintaining population growth at median projected rates, it will do so at the expense of natural groundwater discharge from the aquifer system of the area. It is also likely that continued population growth at these projected rates will eventually force the AMA out of compliance with its statutory safe-yield mandate.

Public Policy Recommendations

The results of this research are relevant to policymakers at several levels of government. While it has been noted that conservation alone is likely to be insufficient to bring the Prescott AMA into safe-yield, conservation must be a central component of any comprehensive water resources management plan. It is essential, however, that conservation programs be carefully planned, executed and monitored to insure efficacy. Funding for conservation programs should ensure that adequate resources are available to monitor and evaluate program effectiveness. Specific program types that have the potential for substantial impact in the Prescott AMA include incentive programs for turf removal, landscape conversion to drip irrigation, and installation of rainwater harvesting devices (Michelsen et. al., 1999; Platt et. al., 2001). Restrictions on landscape watering schedules could be extended to the entire AMA, while limitations on allowable turf size, and requirements for installation of drip irrigation systems and hot water recirculators could be applied to all new development (Platt, et. al., 2001). Conservation pricing, or the inverted-rate structure, could be adopted by the Town of Chino Valley. While pricing alone is not a particularly efficient way to encourage conservation, pricing strategies allow for increased revenue which can be used to fund additional conservation measures. Pricing has also shown to increase the effectiveness of conservation education campaigns when the two strategies are well coordinated (Michelsen et. al, 1999).

Finally, the ADWR could investigate the possibility of purchasing and retiring existing agricultural groundwater pumping rights. While the water rights market is currently priced out of the range of the ADWR's limited budget, creative solutions may be possible. The ADWR could examine the possibility of partnering with private organizations such as the Trust for Public Lands or Nature Conservancy to purchase and preserve both the groundwater and land resources of the Prescott AMA. If the financial resources of such organizations could be leveraged, it is possible that significant amounts of land and water could be purchased and conserved.

In addition to the importance of conservation, the results of the scenarios indicate that the importation of alternative water supplies will be necessary for the achievement of safe-yield. Current plans to import Big Chino groundwater may provide this source; however, the ADWR and the local communities must begin to investigate alternative supplies to Big Chino groundwater in case legal or other challenges delay or prevent development of this supply. Potential augmentation projects could be designed to increase capture of surface runoff within the AMA, though careful planning would be necessary to avoid legal challenge by downstream surface-water rights holders. In addition, the communities of the Prescott AMA must continue to maximize effluent recovery for direct reuse or aquifer recharge. The communities of the area should be prepared to invest in new technologies that permit increased recovery rates; however, this must be done with careful monitoring of water-quality parameters to insure that groundwater contamination does not occur due to effluent recharge.

The scenario results also indicate that some form of population growth management is needed for the Prescott AMA to maintain safe-yield status. With median projected growth rates, conservation and supply augmentation measures are only able to temporarily bring the AMA into safe-yield. Continued growth at these rates leads to declining amounts of groundwater in storage by the end of the simulated period, indicating a trend away from safe-yield. Growth at the lower end of projected rates allows for safe-yield to be maintained past the end of the simulated period. It is therefore important that local governments manage development and population growth patterns to prevent rapid growth from negating successful conservation and augmentation efforts.

Additional Scientific Data Needs

This project has been greatly aided by data collected by ADWR, other agencies, and private firms over the past five years. Enhanced well monitoring, additional well drilling, and geochemical studies have provided new data that has improved the delineation of the extent of aquifer units and allowed for improved simulation of the ever-changing responses of the aquifer system to new stresses. However, in the course of the model update project, several data deficient areas were identified. Future modeling studies would be improved by further studies or data collection projects in several areas.

Water-Level Data

The calibration of the transient simulation relied on the annual water-level data measured and collected by the ADWR-Basic Data Section. Increasing the number of regularly measured "index" wells would allow for a more accurate calibration. In particular, water-level data in Lonesome Valley and the area between Table Mountain and the Town of Chino Valley would be useful, while data in the area of the groundwater divide between the Little Chino Sub-basin and the Upper Agua Fria Sub-basin would help constrain the model in this area.

Flow Data

The stream flow data from the USGS gages in the AMA has been useful in determining natural groundwater discharge and flood recharge rates. Additional flow data along Lynx Creek, the Agua Fria below the confluence with Lynx Creek and along lower Granite Creek would enable better estimates of recharge along these important drainages.

Aquifer Test Data

In many areas of the model, hydraulic conductivity and storativity data are unavailable and were estimated during the calibration procedure. Additional aquifer test data to provide field-based measurements of these aquifer properties would be useful for future model updates. These data should be collected when new well pumping tests are performed.

Recharge Data

One of the more uncertain parameters in the Prescott AMA groundwater flow model remains recharge. Future investigations of rates of natural recharge, incidental agricultural recharge and septic recharge would be useful for improving the model calibration. Geochemical studies could potentially be used to better quantify the amounts of recharge from these sources, while tracer studies during flood events along Granite Creek and other drainages could be used to quantify infiltration and seepage rates. In addition, future modeling studies would ideally employ inverse modeling techniques to investigate the relative rates of these different sources of groundwater recharge.

Geochemical Data

The collection of geochemical data from Del Rio Springs, baseflow in the Agua Fria River, and wells throughout the area could provide additional insights into the workings of the hydrogeologic system of the AMA. In particular, stable isotopes such as ^{18}O and deuterium (^{2}H) could potentially be used to identify recharge elevation and seasonality. Radioactive isotopes such as ^{14}C or tritium (^{3}H) could be used to provide estimates of residence time. These types of data have already been collected in other locations in the Verde River Basin (Rice, 2007) and could provide interesting comparisons to data collected in the AMA.

This information would also help constrain the groundwater model and provide insight into recharge properties including elevation and seasonality. The data could be used to determine whether the assumption of mountain front and ephemeral stream channel recharge as the primary components of natural recharge is justified. Extended residence times would indicate that additional recharge is occurring as mountain-block recharge in the uplands of the AMA and could potentially justify an expansion of the active model area to include the bedrock uplands of the Prescott AMA.

Exempt Well Pumpage Data

There are currently over 10,000 registered domestic wells in the Prescott AMA (ADWR, 2005b). These wells pump less than 35 gallons per minute and are not required to report annual pumpage to the ADWR. The uncertainty regarding total pumpage from these exempt wells has caused significant political debate and confusion regarding the contribution of these wells to the overdraft of the groundwater resources of the AMA. Research done to better quantify pumpage from exempt wells in the Prescott AMA would be helpful for both scientists and managers as they work to understand and manage the groundwater resources of the area.

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Appendix A:

USGS gauge data for the Prescott AMA and surrounding area

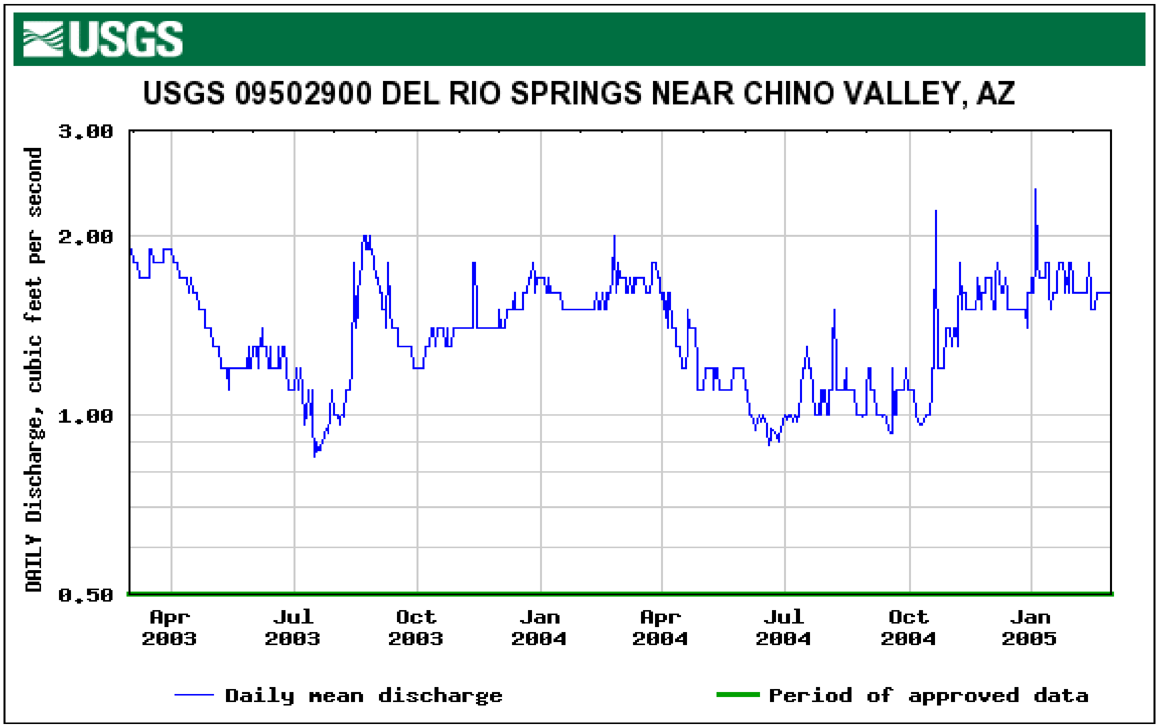

Figure 81. Daily mean discharge measured at the USGS Del Rio springs near Chino Valley, AZ gauge 0902900 (March 2003 – February 2005).

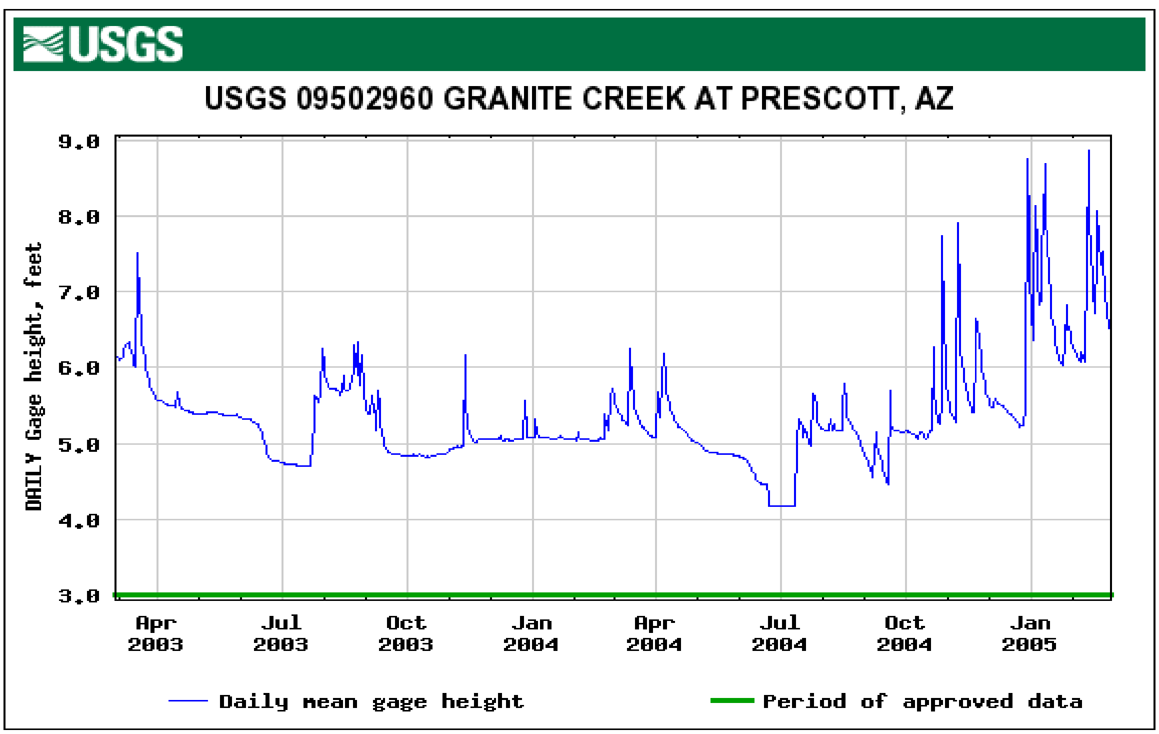

Figure 82. Daily mean discharge measured at the USGS Granite Creek at Prescott, AZ gauge 09502960 (March 2003 – February 2005).

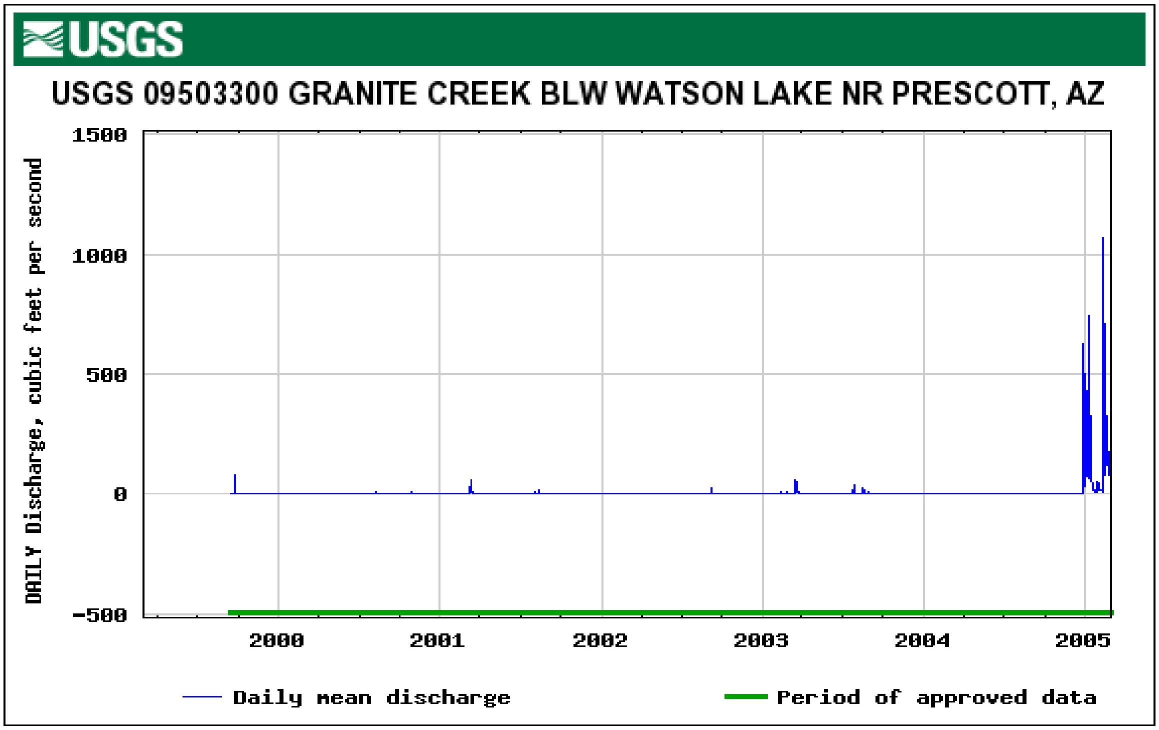

Figure 83. Daily mean discharge measured at the USGS Granite Creek near Prescott, AZ gauge 09503000 (March 2003 – February 2005).

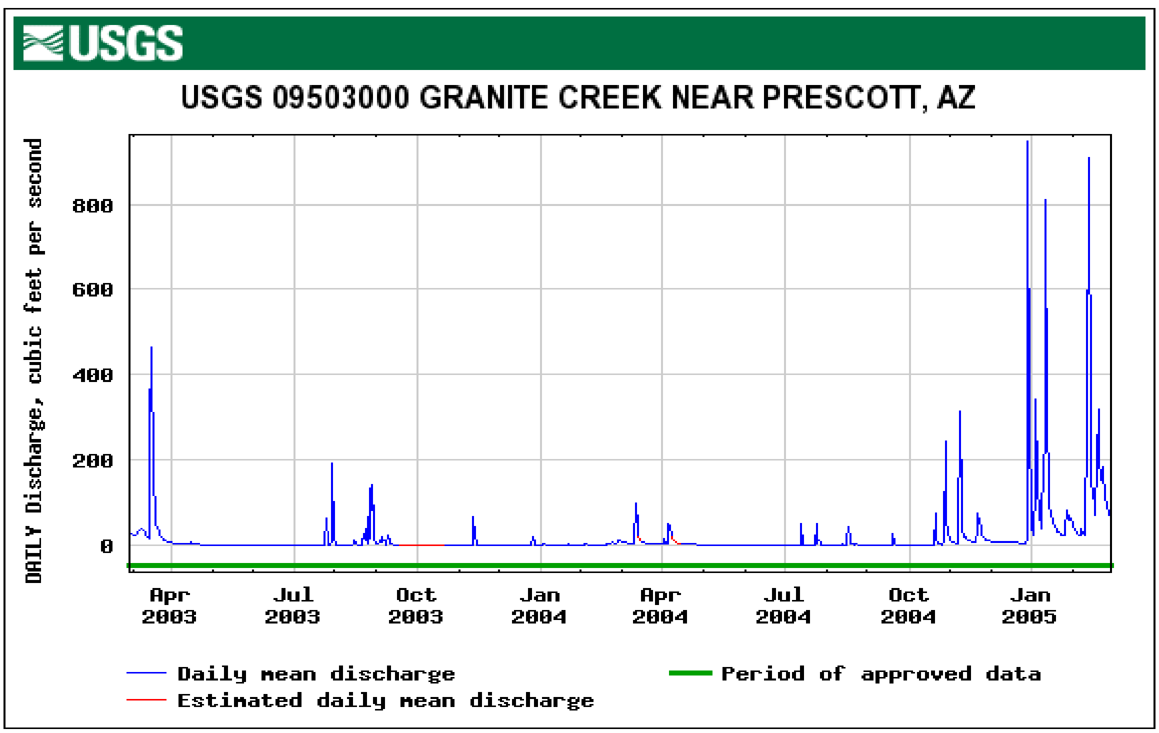

Figure 84. Daily mean discharge measured at the USGS Granite Creek below Watson Lake near Prescott, AZ gauge 09503300 (March 2003 – February 2005).

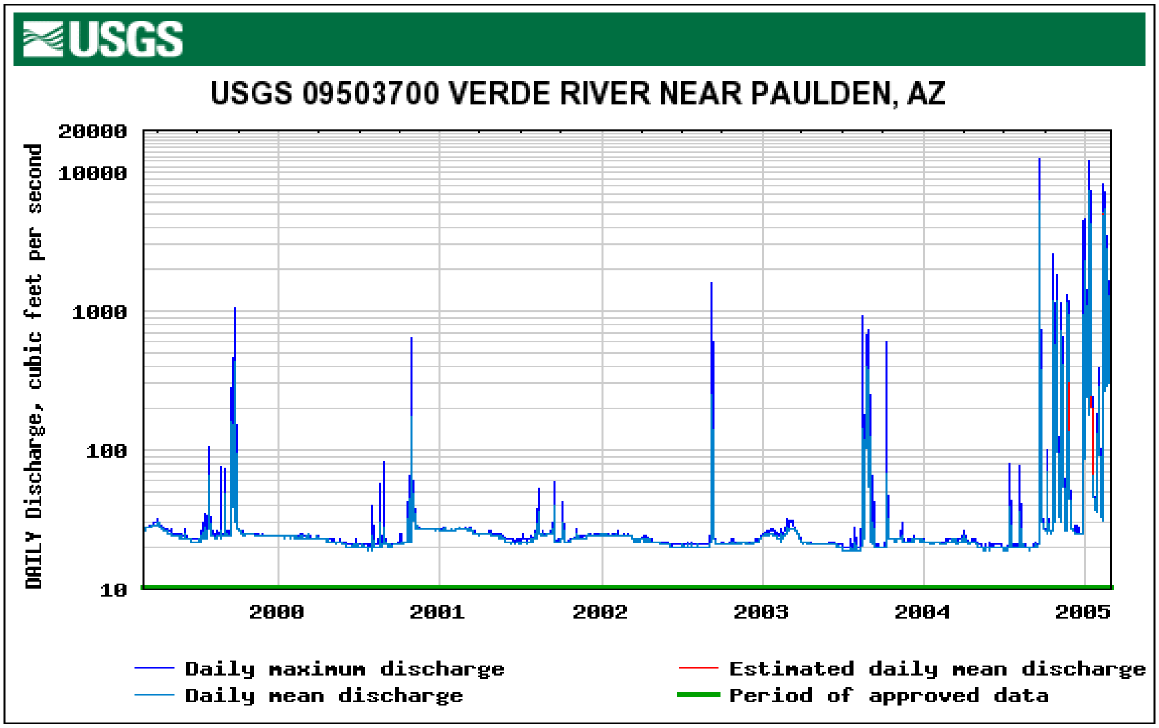

Figure 85. Daily mean discharge measured at the USGS Verde River near Paulden, AZ gauge 09503700 (March 2003 – February 2005).

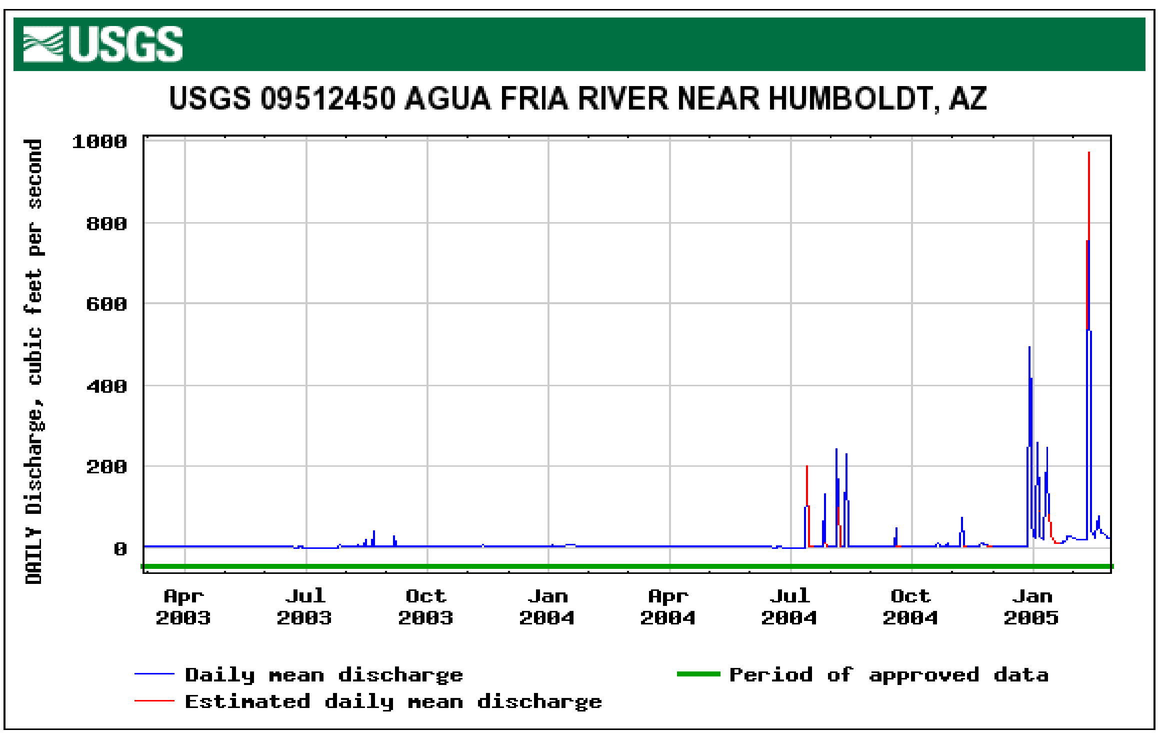

Figure 86. Daily mean discharge measured at the USGS Agua Fria River near Humboldt, AZ gauge 09512450 (March 2003 – February 2005).

Appendix B:

Water-level data used for calibration of the updated Prescott AMA groundwater flow model

Table 28. Head targets used for calibration of the steady-state simulation of the original and updated Prescott AMA groundwater flow model.

Target #	Wells 55 #	Row	Col.	Layer	UTM X	UTM Y	Model X	Model Y	Year Measured	Target Value
1	No Match	26	16	2	368589	3834723	40597	59556	1947	4713
2	639828	24	15	2	367772	3836306	37916	64750	1940	4675
3	No Match	23	11	2	364550	3837153	27345	67529	1940	4756
4	No Match	15	14	2	366990	3843866	35351	89553	1939	4609
5	No Match	15	15	2	367830	3843915	38106	89713	1940	4604
6	635722	13	14	2	367014	3845560	35429	95110	1938	4602
7	606023	10	15	2	367675	3847307	37598	100842	1938	4603
8	No Match	9	16	2	368759	3848431	41154	104530	1939	4599
9	No Match	8	14	2	366783	3848953	34671	106242	1938	4601
10	606300	8	17	2	369509	3849283	43615	107325	1941	4605
11	No Match	8	14	2	367476	3849343	36945	107522	1940	4597
12	605844	7	13	2	366412	3849636	33454	108483	1937	4595
13	623528	7	15	2	367687	3849895	37637	109333	1940	4599
14	No Match	6	13	2	366551	3850466	33910	111206	1940	4599
15	608276	6	14	2	367087	3850582	35669	111587	1937	4596
16	No Match	6	13	2	366500	3850436	33743	111108	1938	4599
17	617596	6	14	2	366734	3850772	34511	112210	1938	4600
18	No Match	6	13	2	366406	3850992	33435	112932	1938	4601
19	No Match	5	16	2	368754	3851605	41138	114943	1939	4577
20	No Match	5	13	2	366545	3851791	33891	115553	1939	4606
21	No Match	4	15	2	367721	3852298	37749	117216	1938	4566
22	No Match	3	14	2	366689	3852991	34363	119490	1938	4542

Table 29. Head targets used for calibration of the steady-state simulation of the updated Prescott AMA groundwater flow model not used for calibration of previous versions of the model.

Target #	Wells 55 #	Row	Col.	Layer	UTM X	UTM Y	Model X	Model Y	Year Measured	Target Value
Targets from ADWR GWSI Database										
23	802111	8	15	2	367715	3848690	37728	105379	1944	4598
24	639828	24	15	1	367772	3836306	37916	64750	1940	4675
25	623530	7	15	1	367727	3849903	37654	109590	1938	4556
26	605843	7	13	2	366516	3849724	33679	108773	1935	4597
27	613020	37	34	1	383368	3825994	89084	30918	1956	4666.5
28	613018	37	36	1	384785	3825576	93732	29548	1969	4659
29	613042	34	27	1	377828	3828666	70907	39684	1964	4742.2
30	No Match	12	11	2	364906	3845745	28512	95717	1942	4595.46
31	No Match	5	12	2	365902	3851307	31783	113967	1937	4596.6
32	No Match	11	12	2	365910	3846624	31809	98600	1941	4599.85
33	No Match	8	13	2	366349	3848774	33246	105656	1942	4600.42
34	No Match	3	13	2	366689	3852991	34365	119489	1937	4540.3
35	No Match	4	14	2	366754	3852158	34575	116756	1944	4576.03
36	No Match	14	14	2	366990	3843866	35349	89552	1937	4609.3
37	No Match	4	14	2	367415	3852179	36744	116826	1943	4562.5
38	No Match	8	14	2	367476	3849343	36944	107523	1940	4597.21
39	No Match	14	15	2	367830	3843915	38106	89715	1940	4603.97
40	No Match	26	17	2	369127	3834931	42361	60238	1945	4678
41	No Match	6	17	2	369506	3850917	43606	112684	1938	4605.55
42	No Match	6	17	2	369527	3850577	43674	111571	1938	4605.2
43	606294	8	19	2	370735	3848860	47522	105938	1947	4599
44	No Match	18	20	1	371679	3840811	50733	79528	1940	4613.7
45	No Match	17	21	1	372410	3842187	53133	84044	1940	4618.95
46	No Match	16	25	1	376077	3842414	65163	84789	1939	4611.14
47	No Match	12	25	1	376300	3845739	65894	95697	1941	4609.47
48	606295	7	19	2	370749	3849688	47684	108653	1948	4592.4
49	611908	8	22	2	373755	3849239	57544	107182	1939	4608.16
50	625108	11	27	2	377355	3847145	69356	100310	1940	4613
51	613028	33	25	2	376469	3829259	66449	41630	1971	4663
52	564575	23	8	2	362439	3837002	20421	67033	1999	4805.6
53	639825	21	10	2	363696	3839033	24543	73696	1939	4753.5
54	536656	21	6	2	360845	3838454	15190	71795	1999	4885
55	636587	10	21	2	372502	3847431	53433	101249	1942	4621
56	613043	38	36	1	384558	3824971	92678	27792	1956	4630.5
57	638550	42	39	1	386962	3821699	101041	17239	1973	4617.9
58	627588	23	5	1	359586	3837216	11059	67735	1992	5033
Targets from American Ranch Report (Manera, 1999)										
59	573965	21	4	1	358982	3839047	9078	73742	1999	5019
60	573968	22	4	1	359169	3838224	9690	71044	1999	5012

Target #	Wells 55 #	Row	Col.	Layer	UTM X	UTM Y	Model X	Model Y	Year Measured	Target Value
Targets from Head Map (Corkhill and Mason, 1995)										
61		23	27	2	377819	3837019	70878	67089		4630
62		5	16	1	368554	3851598	40482	114920		4505
63		6	16	1	368735	3850754	41076	112151		4515
64		7	16	1	368614	3849910	40680	109381		4535
65		11	14	1	366864	3846917	34937	99564		4575
66		2	15	1	367831	3853829	38108	122239		4445
67		11	9	1	363104	3846985	22600	99786		4670
68		11	19	1	371145	3846744	48981	98995		4600
69		23	24	1	375136	3837083	62076	67300		4625
70		35	26	1	376788	3827445	67495	35677		4855
71		32	28	1	378130	3829820	71900	43470		4725
72		3	14	1	367047	3852985	35537	119470		4450

Appendix C:

Aquifer storage parameter values used in the updated Prescott AMA groundwater flow model.

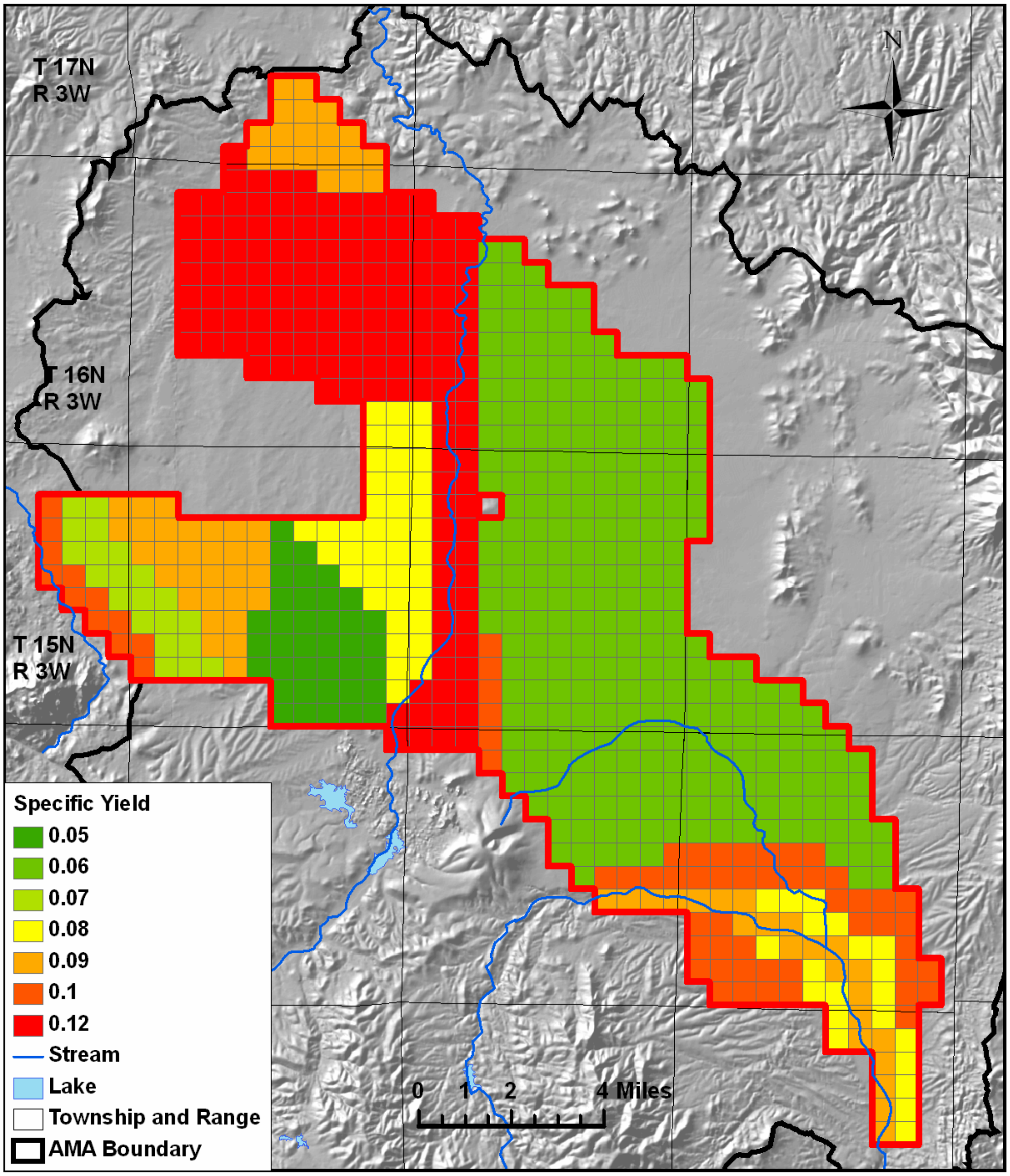

Figure 87. Specific yield values for the Upper Alluvial Unit used in the updated Prescott AMA groundwater flow model.

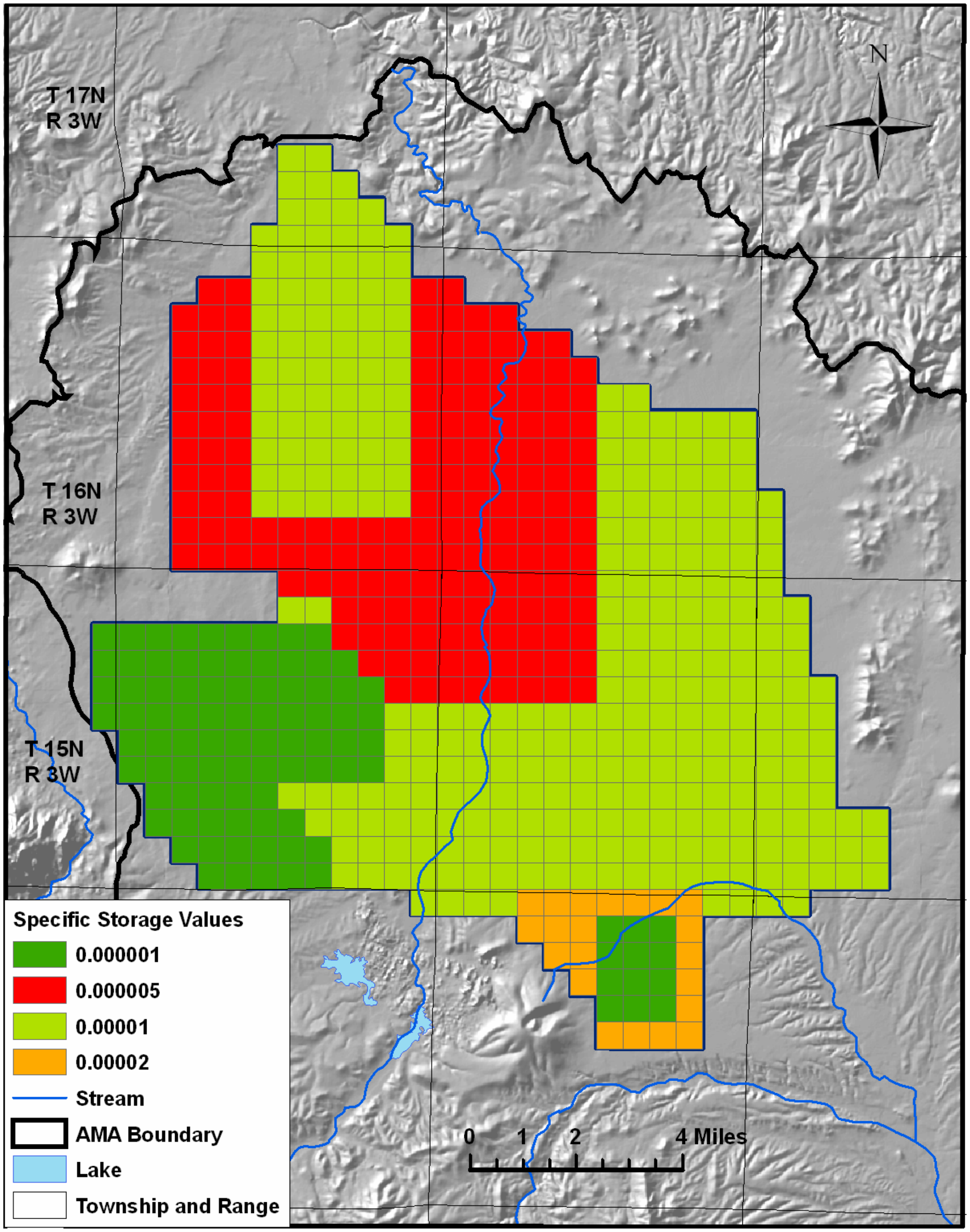

Figure 88. Specific storage values for the Lower Volcanic Unit used in the updated Prescott AMA groundwater flow model.