Prescott AMA Groundwater Flow Model Update Report

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Executive Summary

In 1995, the Arizona Department of Water Resources developed a regional groundwater flow model to quantify the impacts of various management programs on the groundwater resources of the area. The Prescott AMA groundwater flow model has been updated with new geologic and hydrogeologic data and the active model area has been expanded from approximately 220 square miles to 250 square miles. The model has also been calibrated to an expanded database of measured groundwater levels and discharge targets from 1939 to 2004.

The results of the transient simulation indicate that the groundwater resources of the Prescott AMA continue to be depleted on a regional basis. This has resulted in decreased groundwater storage in the aquifers of the area. In addition, natural groundwater discharge from the area has decreased with potential impacts on riparian areas and downstream users.

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Chapter 1: Introduction and Background

Introduction

The Prescott Active Management Area (AMA) in Central Arizona is one of five AMAs in the State of Arizona. Established by the Groundwater Management Act of 1980, the Active Management Areas are areas 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 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 Arizona Department of Water Resources began developing a groundwater flow model for the Prescott Active Management Area in order 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 and used to simulate groundwater conditions from 1940 to 1999, as well as to predict future groundwater conditions for the years 1999-2025 (Nelson, 2002).

In 2005, the Arizona Department of Water Resources contracted with Northern Arizona University to further update the model based on newly available data. This report documents the model update.

Goals and Objectives

The primary goal of the original Prescott AMA groundwater model was defined by 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 in order to more accurately quantify the effects of management and conservation programs. 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.

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.

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 Togographic 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, streamflow 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).

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 by Corkhill and Mason (1995) and Nelson (2002), annual Hydrologic Monitoring Reports have been published since 2001 (ADWR, 2002, 2003, 2004).

Chapter 2: 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 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.

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 180 m near Del Rio Springs (Wirt et. al, 2004).

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 is 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. 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. Less than 100 feet of alluvial materials were found, while interbedded volcanics flows and cinders were encountered between 55 feet and 695 feet below land surface. 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. 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 center overlying a granitic pluton.

ADWR Monitor Well #2 (55-587404) was drilled in northeast Lonesome Valley (B(16-01)23ACA). The drilling of this well revealed thinner alluvial deposits than expected based on previous geologic interpretations of the area. In addition, 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 of Layer 1 to the northwest of the City of Prescott (B(15-02)22AAB). 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 existing in the area.

Several well logs from the Prescott Valley North Wellfield were reviewed in order to determine whether structural changes were warranted in this area. 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.

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. 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 in the Little Chino sub-basin and the northwest portion of the Upper Agua Fria sub-basin in the area of the Prescott Valley Santa Fe well field. The Lower Volcanic Unit aquifer exists in confined artesian conditions in northern Little Chino Valley and in the Santa Fe well field area.

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

Chapter 3: 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. The Little Chino sub-basin consists of an Upper Alluvial Unit aquifer and a Lower Volcanic Unit aquifer; however, only the Upper Alluvial Unit aquifer is present in the Upper Agua Fria 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. 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. In addition, the Upper Alluvial Unit aquifer 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.

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 contributes recharge to the Upper Alluvial Unit aquifer in agricultural areas. The City of Prescott and the Town of Prescott Valley have also 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 spring flow at Del Rio Springs and subsurface flow out of the model area to the northwest of Del Rio Springs. It is believed this subsurface flow heads northeast through faulted Paleozoic rocks and lati-andesite 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.

Discharge from the Upper Alluvial Unit also 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 "artestian" 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.

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).

Groundwater pumpage has been the major source of discharge from the Lower Volcanic Unit aquifer since the 1940's. The Lower Volcanic Unit aquifer of the Little Chino sub-basin has provided most of the irrigation and municipal water that has been pumped within the model area.

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 largely 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). 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. Conceptual estimates for the groundwater discharge flow rate at Del Rio Springs range from 2,700 acre-feet/year to 3,800 acre-feet/year (Foster, 2001) (Table 1). These estimates 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 acre-feet/year of evapotranspiration and unreported diversions upstream of the gauge (Foster 2001). Conceptual estimates for subsurface flow are even more uncertain, ranging from 2,000 acre-feet/year (Corkhill and Mason 1995) to 5,600 acre-feet/year (SRP, 2000).

In the Upper Agua Fria sub-basin, natural groundwater discharge occurred as perennial baseflow in the Agua Fria River near Humboldt. Conceptual estimates for Agua Fria River baseflow range from 1,500 acre-feet/year to 2,500 acre-feet/year (Table 1).

Groundwater Pumpage

Groundwater pumpage in the steady-state simulation totaled approximately 1,500 acre-feet, exclusively in the Little Chino sub-basin. 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 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 acre-feet/simulation (7,000 acre-feet/year) was kept the same. 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 acre-feet (Nelson 2002). Canal recharge from the Chino Valley Irrigation Ditch (CVID) was estimated at about 950 acre-feet (Nelson 2002).

The Developed Hydrologic System

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

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 09502900) and provides a continuous data stream for groundwater discharge at the springs (Appendix IV). Conceptual estimates for groundwater discharge in 1940 range from 2,700 to 3,800 acre-feet per year, including approximately 400 acre-feet/year for evapotranspiration and unreported upstream diversions (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 acre-feet/year to 1,350 acre-feet/year. Thus, conceptual estimates of the decrease in groundwater discharge at Del Rio Springs range between 1,750 acre-feet per year and 2,850 acre-feet/year over the time period from 1940 to 2004.

For 1940, estimates of subsurface flow from the model area to the north range from 2,000 acre-feet/year (Corkhill and Mason, 1995) to 5,600 acre-feet/year (SRP, 2000). In 2004, the USGS estimated that the Little Chino sub-basin contributes approximately 14% 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 acre-feet/year. 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.

Groundwater discharge as baseflow in the Upper Agua Fria River was estimated as 1,500 to 2,500 acre-feet/year for 1940 (Corkhill and Mason, 1995). While a USGS gauge has been operational at Humboldt since 2001 (USGS 09512450), 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 acre-feet/year (ADWR, 2004). Thus, conceptual estimates of the decrease in natural groundwater discharge from the Upper Agua Fria sub-basin range between 200 acre-feet per year and 1,200 acre-feet per year over the period of 1940 to 2003 (Tables 1 and 7).

Groundwater Pumpage

Groundwater pumpage for agricultural purposes from 1939-1983 was applied to the Little Chino sub-basin based on 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 2). 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. 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 acre-feet/year for 2002, and 126.4 acre-feet/year 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 acre-feet per year per well (ADWR, 2002). Based on this formula, non-AMA domestic pumpage within the active model area was estimated at 115 acre-feet/year 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 3).

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 acre-feet per year.

Flood recharge was applied based on the wetted area approach used by Nelson (2002) (Table 4). In addition to flood recharge along Granite Creek and the Lynx Creek/Agua Fria River drainage, 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.

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 5).

Chapter 4: 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 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 time steps with a time step multiplier of 1.2. The increase in time steps within the stress periods of the updated model enabled the seasonal variation in groundwater conditions to be more accurately simulated by the model than by previous versions of the Prescott AMA model.

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). 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 program Groundwater Vistas 4.21 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 a half mile 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 feet along the margins of the basins to over 1000 feet in the central trough of the basins and in the alluvial depression northwest of the City of Prescott. 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 (Figures 3 and 4).

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 (Figure 6). The contact between the LVU and the basement unit was elevated from a depth of 1135 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 400 feet, leaving approximately 100 feet of saturated Upper Alluvial Unit above the LVU. As there is no indication of hydrologic disconnection between Black Hill and the 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 several cells in the Lower Volcanic Unit 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 in order to maintain saturated conditions and to correspond with the drilling data (Figure 4).

The drilling of ADWR Monitor Well #3, B(15-02)22AAB (55-588619) revealed a thick pocket of alluvium approximately 1200 feet thick northwest of the City of Prescott. 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 in this area were adjusted to reflect these two data sources (Figures 3 and 4).

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.

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. 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 1144 to 1258.

Boundary Conditions

The active model area encompasses the main groundwater basin area 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 constant flux boundary conditions of No-Flow to simulate the impermeable Basement Unit.

Constant 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 Congugate-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 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 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 provided a more numerically stable solution that the SIP solver used in the original model.

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; 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 were 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 V 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.

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), Prescott (1993), and the ADWR-ROGR database. 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. Exempt domestic pumpage was simulated based on estimated values reported in various ADWR reports including ADWR (2003), ADWR (2004) and Nelson (2002).

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 ADWR (1994d) were used for the period 1940-1993. Data from the USGS gage at Del Rio Springs were used for the period 1997-2004, 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.

Aquifer Parameter Data

Initial aquifer parameter data (hydraulic conductivity, specific yield, 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 the distribution of hydraulic conductivity values were made in a few locations in the model area.

The distribution of hydraulic conductivity 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). 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. The surficial deposits of Granite Creek have been mapped as Quaternary alluvium, while the surrounding basin areas are considered Quaternary sediments (Wirt et. al). In general, alluvial deposits in intermittent stream channels such as Granite Creek have larger grain sizes and higher hydraulic conductivity values than basin-fill deposts 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 in order to allow for flood recharge imposed during the transient simulation to effectively disperse throughout the model area.

In addition, 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.

Chapter 5: Model Calibration

According to Hill (1998), better models will 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)

The steady-state Prescott AMA 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 26 head targets in the Upper Alluvial Unit (Layer 1) and 46 head targets in the Lower Volcanic Unit (Layer 2) (Figures 6 and 8). Twenty-two of the targets in the LVU were used as calibration targets in earlier versions of the Prescott AMA model. Twenty-three of the targets in the LVU were developed for this model, while all 26 targets in the UAU were 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 fifteen UAU targets and twenty-one LVU targets were taken from the GWSI database maintained by ADWR. See Appendix V for a list of steady-state targets.

The transient Prescott AMA model was calibrated to 2324 target values at 113 different wells. 716 target values at 45 wells were located in Layer 1, while 1608 target values at 68 wells were located in Layer 2 (Figure 9). All of the target values were taken from the GWSI database.

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 in order to bring model parameter values into closer agreement with pumping test results and to achieve a more random array of head residuals. See Figures 12 and 13 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 model heads with measured water levels.

Steady-State Water Budget

The results of the steady-state indicate that the simulated water budget compares well with the conceptual water budget (Table 1). 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. 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. Tables 6 6a and 6b provide statistical summaries of the calibration error analysis.

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 acre-feet per year. The simulated discharge rate for Del Rio Springs was about 3,500 acre-feet per year, which is within conceptual estimates. This discharge rate represents an improved correspondence between simulated and conceptual steady-state discharge from Del Rio Springs when compared to previous versions of the model which over-simulated discharge from Del Rio Springs (Corkhill and Mason 1995) (Nelson 2002).

The simulated subsurface groundwater discharge was about 3,900 acre-feet per year. This is also within conceptual estimates; however, it should be noted that considerable uncertainty exists regarding the conceptual subsurface groundwater discharge rate (Table 1). 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 acre-feet per year. 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. This is significantly better than the 5% criterion often used to define an acceptable model (Anderson and Woessner 2002).

In addition to the statistical analysis, qualitative assessment was also required to ensure that the calibration followed the criteria set out by Hill (1998). Figures 6 and 8 indicate the spatially distributed residuals. The distribution of residuals in the Upper Agua Fria sub-basin are 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 in order 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.

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.

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. See Hydrographs 1-20 for groundwater level changes in twenty separate wells over the transient simulation (1939-2004).

Transient Water Budget

Table 7 shows model simulated water budgets for 1940 and 2004. 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 were seen compared to earlier versions of the model;

however simulated values were all within conceptual estimates. For 2004, model 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). A total of 2,324 target values at 113 different wells were used for statistical error analysis, including 716 target values in the Upper Alluvial Unit aquifer and 1,608 targets in the Lower Volcanic Unit aquifer. See Tables 8a, 8b, and 8c for the summary of the results of the statistical error analysis.

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, groundwater 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 acre-feet/year to around 2,700 acre-feet per year, a decline of 4,900 acre-feet/year. Discharge from the Upper Agua Fria sub-basin as baseflow in the Agua Fria River also declined approximately 700 acre-feet/year over the period 1940-2004. Over the period from 1939-2004, simulated groundwater storage in the Upper Alluvial Unit aquifer and Lower Volcanic Unit aquifer has declined by approximately 500,000 acre-feet.

The results from the transient simulation residual error analysis were within the calibration goals (Table 8, 8a, and 8b).

Hydrograph 13 indicates stable simulated water levels in the Mint Wash area from 1940 until the 1980’s and 1990’s. This follows the conceptual understanding of the area as hydrologically disconnected from the main agricultural and municipal pumping center in the Little Chino sub-basin, which showed steep groundwater declines from the beginning of the transient simulation.

In addition, 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, 1400 acre-feet per year, is within 30% of the estimated values (Wirt et al, 2004).

Chapter 6: Conclusions

The Prescott AMA Groundwater Flow Model was updated with new geologic and hydrogeologic data. The model area was extended to include the rapidly developing area near Granite Mountain and Mint Wash. Automated parameter estimation techniques were utilized to provide initial parameter values which were subsequently manipulated through trial-and-error to achieve a better calibration based on the criteria set out by Hill (1998). The model was calibrated to the quasi-steady state conditions of 1939 and to the transient conditions of 1939 through 2004.

The Prescott AMA Groundwater Flow Model indicates that the groundwater system of the Prescott AMA has experienced a net loss in groundwater storage and natural groundwater discharge since 1940.

Additional 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 the following 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.

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 is unavailable and was 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. This data should be collected when new well pump 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 and incidental agricultural recharge would be useful for improving the model calibration. Geochemical studies could potentially be used to better quantify the amounts of recharge from these two sources. In addition, future modeling studies would ideally employ inverse modeling techniques to investigate the relative rates of these different sources of groundwater recharge.

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Appendix I: Tables

Table 1
Simulated and Conceptual Steady-State Water Budgets for the Updated Prescott AMA Groundwater Flow Model[1]
(Figures Rounded to Nearest 50 acre-feet)

Inflow	Model Simulation acre-feet/simulation (acre-feet/year)	Conceptual acre-feet/simulation (acre-feet/year)
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 (3,500AF/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 acre-feet/year
[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)

Table 2 Simulated Pumpage Applied to the Updated Prescott AMA Groundwater Flow Model (1999-2004) (Figures Rounded to the Nearest 5 acre-feet)						
AMA Pumpage	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
City of Prescott[1]	6750	7515	7650	8320	8150	8150
Prescott Valley[1]	3780	4090	4335	4820	4870	5370
Agricultural Users[1]	5160	6620	5850	6760	4365	5290
Non-irrigation Users[1]	620	485	1050	1190	1240	1230
Small Providers[1]	510	460	565	705	825	745
Exempt[2]	1200	1365	1535	1700	1830	2000
Non-AMA Pumpage[3]	90	95	100	255	235	240
Total Pumpage	**18110**	**20630**	**21085**	**23750**	**21515**	**23025**

[1] ADWR Registry of Groundwater Rights Database

[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 2 and the pumpage section of this report for further details.

Table 3 Non-AMA Pumpage Applied in the Mint Wash Area to the Updated Prescott AMA Groundwater Flow Model		
Year	**Domestic (acre-feet/year)**	**American Ranch (acre-feet/year)**
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**

Table 4
Simulated Flood Recharge Applied to 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	4320	780	49
1980	13	6240	1120	71
1983	4	1920	350	22
1993	39	18720	3370	213
1995	9	4320	780	49
2003		850*	0	0
2004	34	18690	2850	185
Total	**108**	**55060**	**9250**	**589**

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

Table 5 **Simulated Artificial Recharge Applied to the Updated Prescott AMA Groundwater Flow Model** **(Figures to nearest 10 acre-feet)**		
Event Year	**Prescott (acre-feet/year)**	**Prescott Valley (acre-feet/year)**
1988	1100	0
1989-1993	2100	0
1994	2100	500
1995	2100	800
1996	2100	1250
1997	2100	1400
1998	2750	1600
1999	2080	1360
2000	2830	1630
2001	2890	1570
2002	1680	1300
2003	3330	1640
2004	3140	1840
Total	**30300**	**14890**

Table 6 Combined Statistical Summary of Steady State Error Analysis for the UAU (Layer 1) and LVU (Layer 2)					
Residual = Measured - Simulated (feet)					
Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	Residual Standard Deviation / Range in Head
-3.08	9.14	11.78	-37.38	27.66	0.020

Table 6a Statistical Summary of Steady State Error Analysis for the UAU (Layer 1)					
Residual = Measured - Simulated (feet)					
Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	Residual Standard Deviation / Range in Head
-5.42	13.27	15.49	-37.38	27.66	0.026

Table 6b Statistical Summary of Steady State Error Analysis for the LVU (Layer 2)					
Residual = Measured - Simulated (feet)					
Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	Residual Standard Deviation / Range in Head
-1.59	6.51	8.29	-22.19	20.4	0.024

Table 7
Simulated and Conceptual Transient Water Budgets (1940 and 2004)
Prescott AMA Groundwater Flow Model
(Figures rounded to the Nearest 100 acre-feet)

Inflow	**Simulated 1940 acre-feet/year**	**Simulated 2004 acre-feet/year**	**Conceptual 2004 acre-feet/year**
Natural Recharge	5800	5800	5800
Recharge: Incidental and Artificial Recharge	4100	7600	7600
Flood Recharge	0	21700 [7]	21700
Total Inflow	**9900**	**35100**	**35100**
Outflow	**Simulated 1940**	**Simulated 2004**	**Conceptual 2004**
Pumpage	4600	23000	23800
Groundwater Discharge Del Rio Springs (LIC)	3600 [1]	1300 [1]	1000 [2] 1400 [2a]
Groundwater Discharge Agua Fria River (UAF)	2100 [3]	1400 [3]	1300 [4]
Subsurface Flow (LIC)	3500	1400	1900-2000 [5] 1200-2000 [6]
Total Outflow	**13800**	**27100**	**26500 - 28200**
Change in Storage	**-3900**	**8000**	**6900 - 8600**

[1] Contains and undifferentiated ET component estimated at 100-200 acre-feet/year

[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 acre-feet/year.
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 acre-feet/year

[4] Median surface water measurements at Agua Fria River (2004) plus 200 acre-feet/year for estimated ET demand upstream of gauge
Watson Lake into Granite Creek (ADWR 2004). Other drainages were not affected.

[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 8 Combined Statistical Summary of Transient Error Analysis for the UAU (Layer 1) and LVU (Layer 2)					
Residual = Measured - Simulated (feet)					
Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	Residual Standard Deviation / Range in Head
10.8	17.96	21.85	-89.56	146.95	0.029

Table 8a Statistical Summary of Transient Error Analysis for the UAU (Layer 1)					
Residual = Measured - Simulated (feet)					
Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	Residual Standard Deviation / Range in Head
16.04	22.87	24.2	-48.55	71.19	0.041

Table 8b Statistical Summary of Transient Error Analysis for the LVU (Layer 2)					
Residual = Measured - Simulated (feet)					
Residual Mean	Absolute Residual Mean	Residual Standard Deviation	Minimum Residual	Maximum Residual	Residual Standard Deviation / Range in Head
8.16	15.47	20.05	-89.56	146.95	0.033

Table 9 **Simulated Transient Water Budget for the Updated Prescott AMA Groundwater Flow Model (1939-1998)*** **(Figures rounded to the nearest 1,000 acre-feet)**	
Inflow	Simulated Totals (1939-1998)
Mountain Front Recharge	340000
Other Recharge	575000
Released from Storage	850000
Total Inflow	**1765000**
Outflow	
Pumpage	920000
Del Rio Springs	195000
Agua Fria River	100000
Subsurface Flow	140000
Taken Into Storage	405000
Total Outflow	**1760000**
Change in Storage	**-445000**

*All figures are cumulative totals for the period 1939-1998.

Table 10 Simulated Transient Water Budgets for the Updated Prescott AMA Groundwater Flow Model (1999-2004) (Figures rounded to the Nearest 100 acre-feet)						
Inflow	**Simulated 1999 AF/YR**	**Simulated 2000 AF/YR**	**Simulated 2001 AF/YR**	**Simulated 2002 AF/YR**	**Simulated 2003 AF/YR**	**Simulated 2004 AF/YR**
Natural Recharge[1]	5,800	5,800	5,800	5,800	5,800	5,800
Recharge: Incidental and Artificial Recharge[2,3,4]	6,000	7,800	7,400	6,400	7,200	7,600
Flood Recharge[5]	0	0	0	0	900	21,700
Total Inflow	**11,800**	**13,600**	**13,200**	**12,200**	**13,900**	**35,100**
Outflow	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Pumpage[6]	18,100	20,600	21,100	23,800	21,500	23,000
Del Rio Springs (LIC)[7]	1,700	1,700	1,600	1,500	1,400	1,300
Agua Fria River (UAF)[7]	1,300	1,300	1,300	1,200	1,200	1,400
Subsurface Flow (LIC)[7]	1,700	1,500	1,500	1,400	1,600	1,400
Total Outflow	**22,800**	**25,100**	**25,500**	**27,900**	**25,700**	**27,100**
Change in Storage	**-11,000**	**-11,500**	**-12,300**	**-15,700**	**-11,800**	**8,000**

[1] Estimates for long-term average mountain front recharge (Nelson, 2002). Actual annual volumes may vary significantly from the long-term average.

[2] Incidental agriculture recharge estimated at 50% of agricultural water use. (Corkhill and Mason 1995) (Nelson 2002).

[3] City of Prescott artificial recharge includes treated effluent and surface water. City of Prescott Annual Underground Storage Facility Reports - Schedule 71.

[4] Town of Prescott Valley artifical recharge data provided by John Munderloh - Town of Prescott Valley (09/27/2006)

[5] Flood recharge for Granite Creek, Lynx Creek and Mint Wash estimated based on wetted-area approach (Nelson 2002). Flood recharge for 2003 was simulated based on a release from Watson Lake into Granite Creek (ADWR 2004). Other drainages were not affected.

[6] Pumpage includes reported pumpage from ADWR Registry of Groundwater Rights Database as well as estimated domestic and exempt well pumpage for the active model area. See pumpage section of this report for further details.

[7] Model simulated discharge.

[8] Flood recharge includes flooding from January - March 2005

Appendix II: Figures

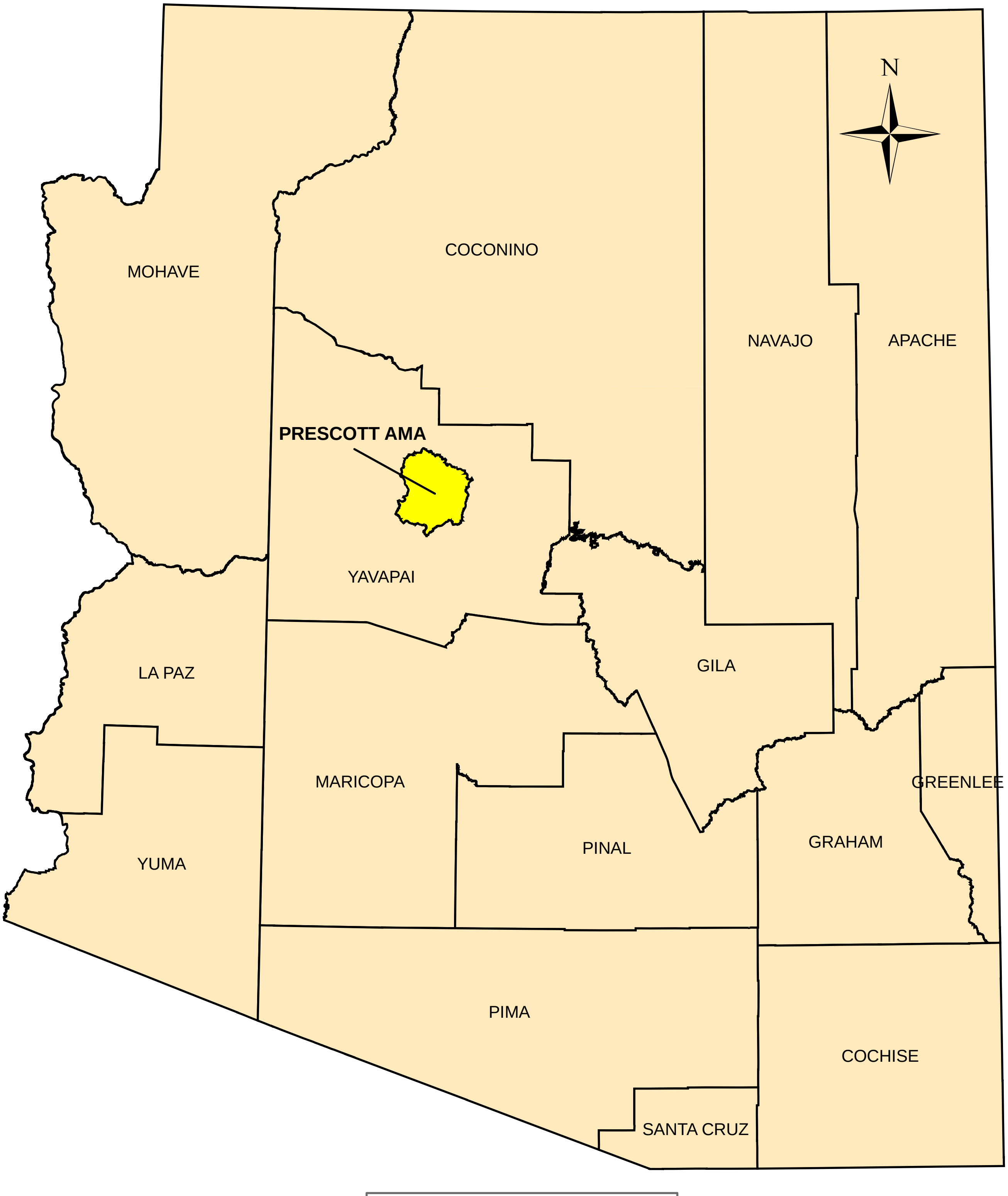


Figure 1
Location of the Prescott
Active Management Area,
Yavapai County, Arizona.

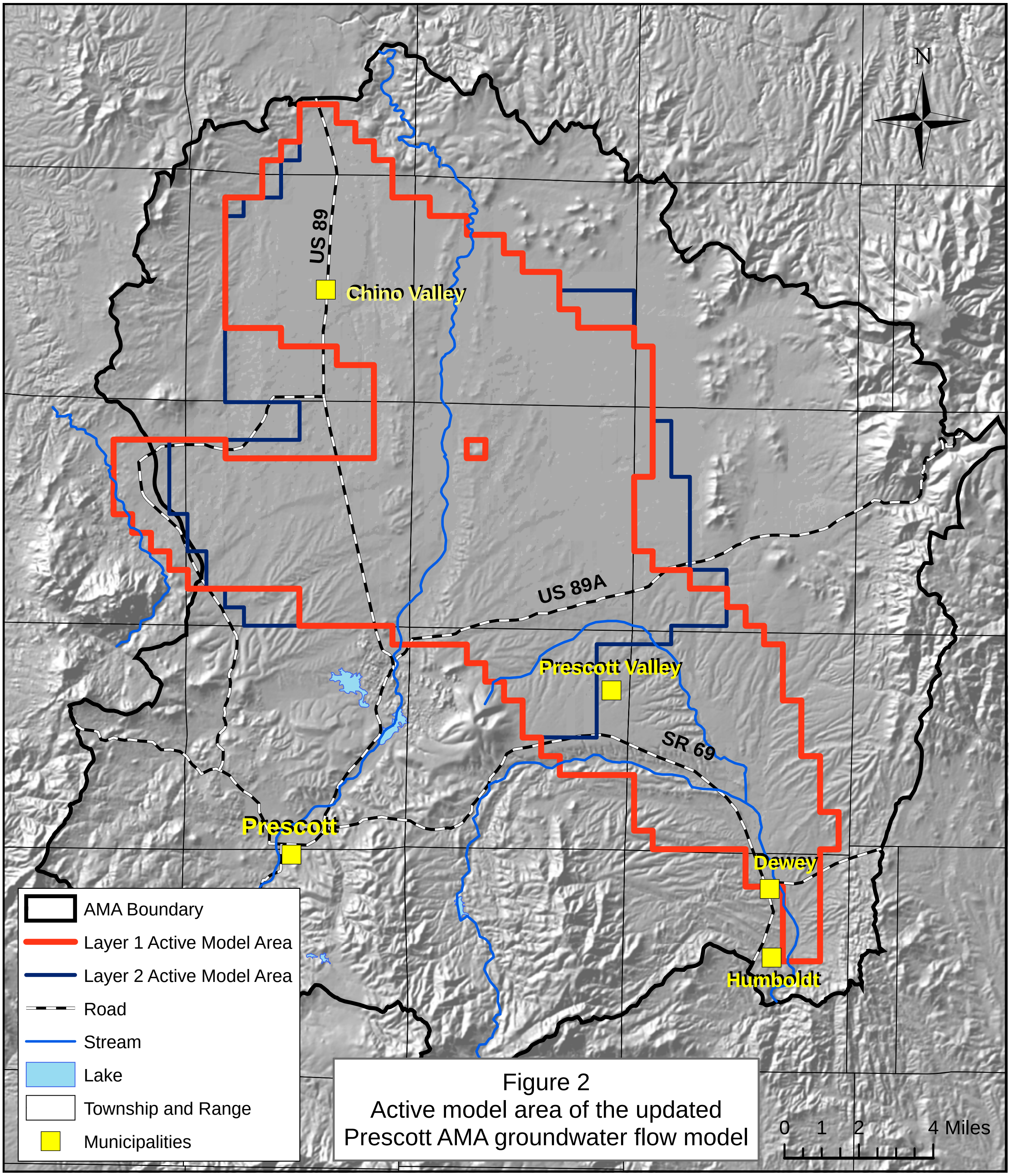


Figure 2
Active model area of the updated
Prescott AMA groundwater flow model

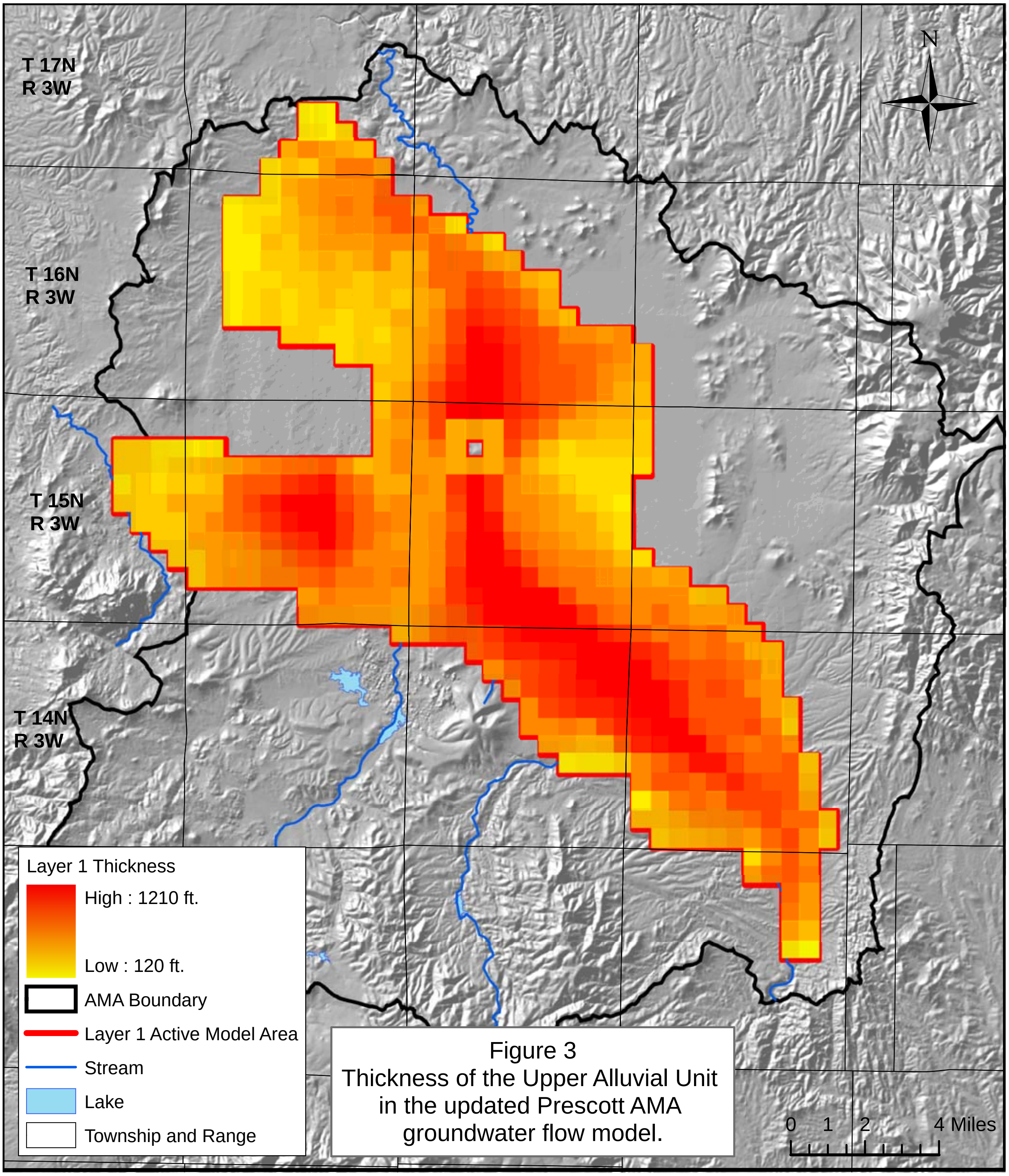


Figure 3
Thickness of the Upper Alluvial Unit in the updated Prescott AMA groundwater flow model.

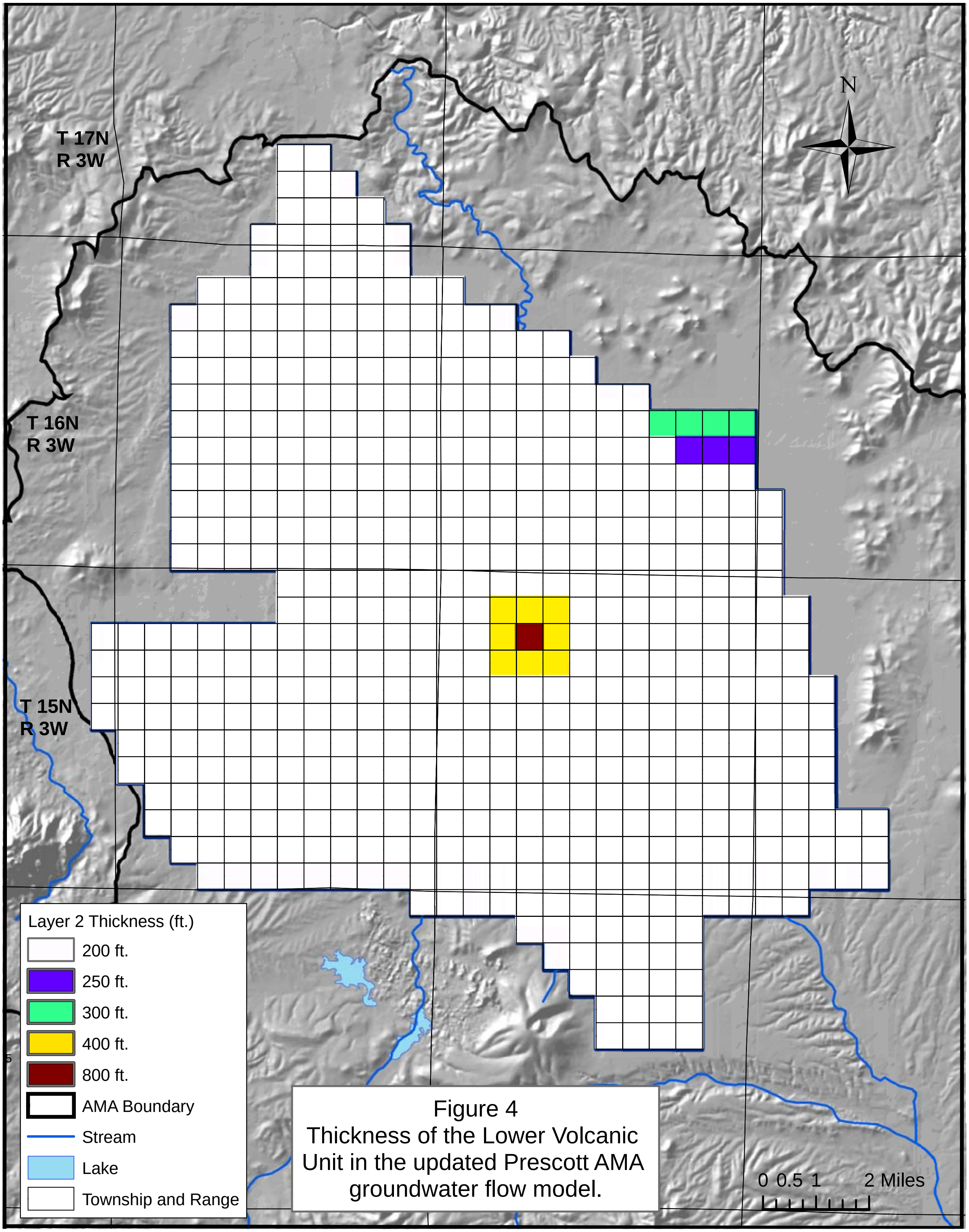


Figure 4
Thickness of the Lower Volcanic Unit in the updated Prescott AMA groundwater flow model.

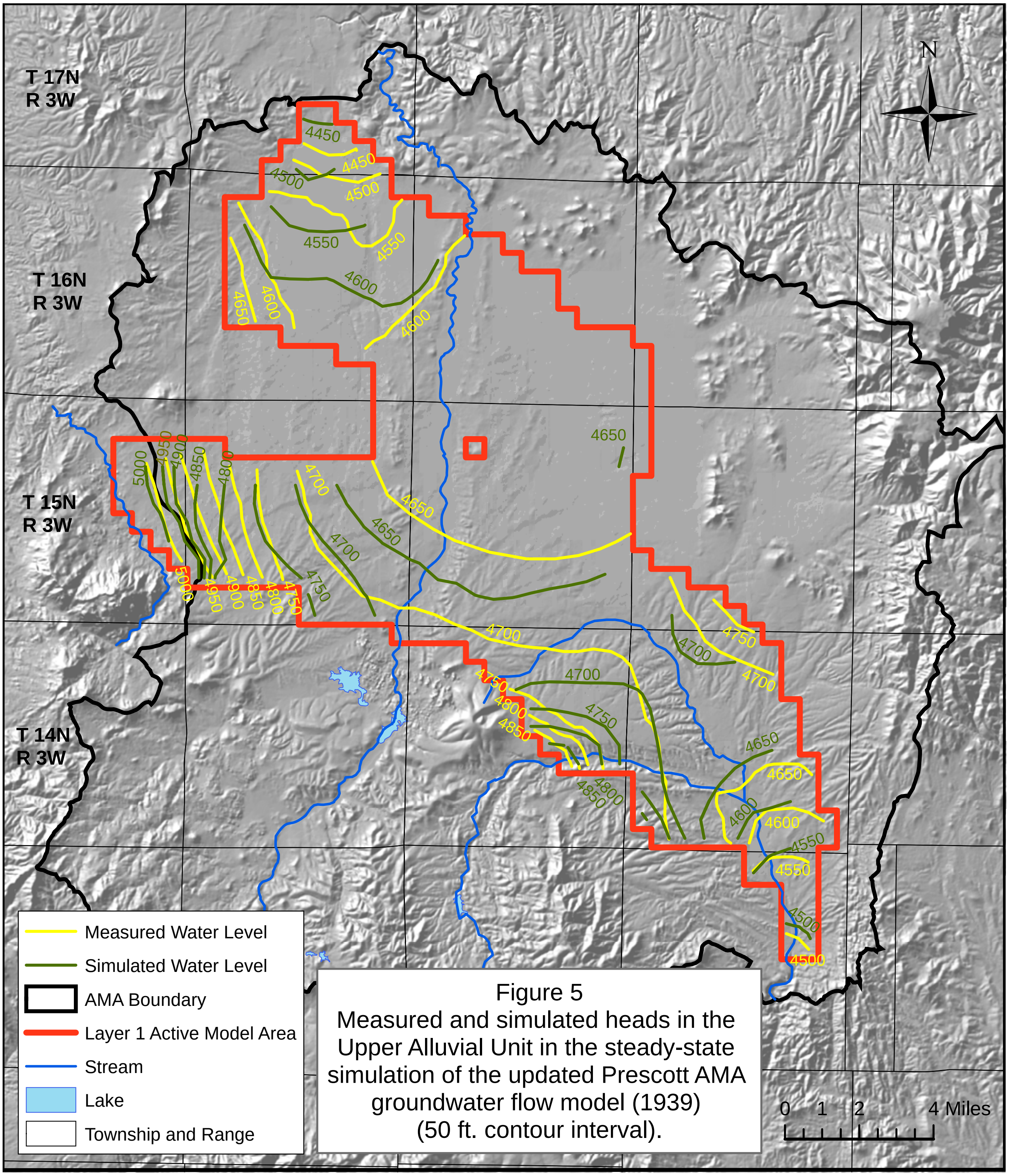


Figure 5
Measured and simulated heads in the Upper Alluvial Unit in the steady-state simulation of the updated Prescott AMA groundwater flow model (1939)
(50 ft. contour interval).

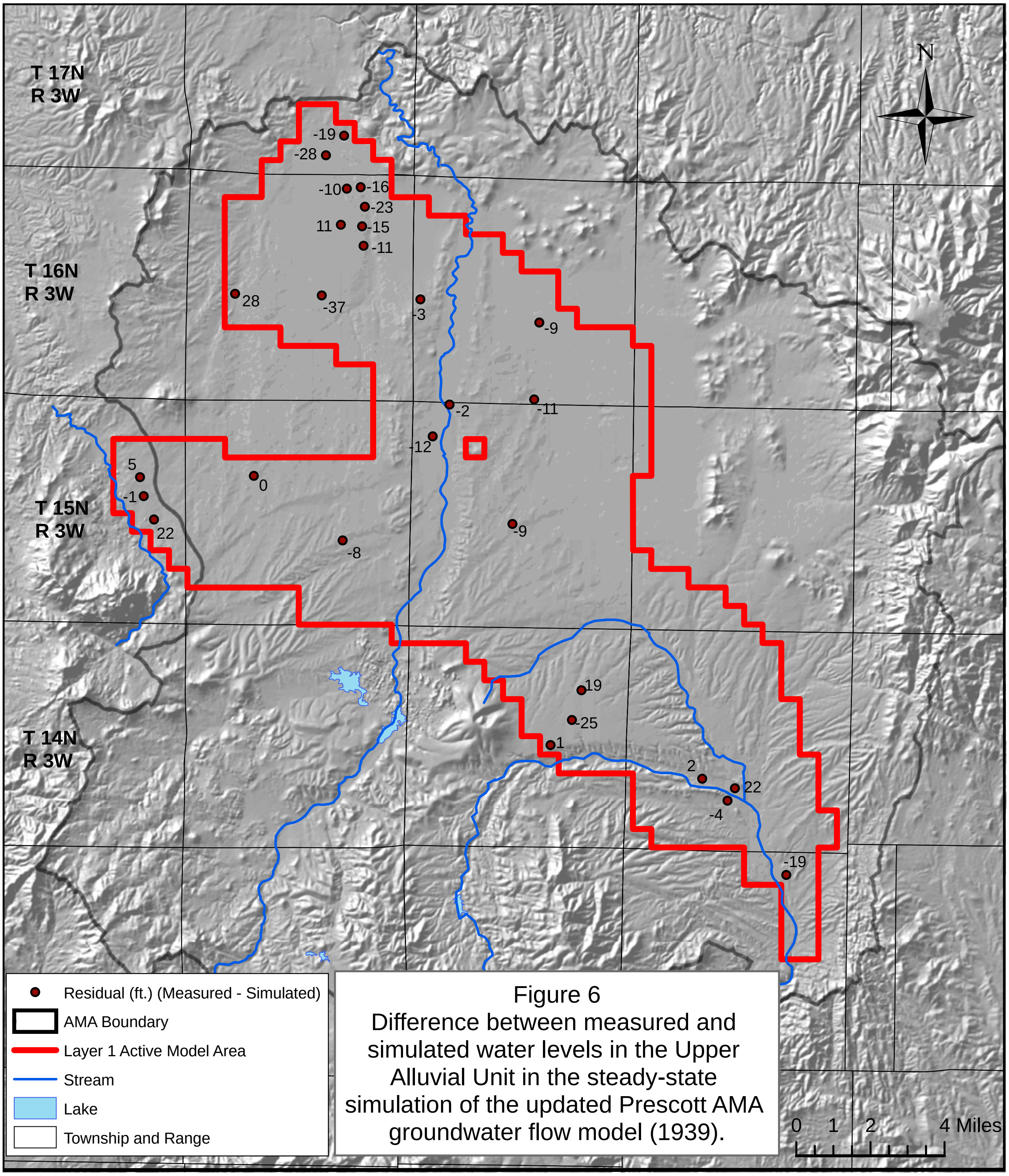


Figure 6
Difference between measured and simulated water levels in the Upper Alluvial Unit in the steady-state simulation of the updated Prescott AMA groundwater flow model (1939).

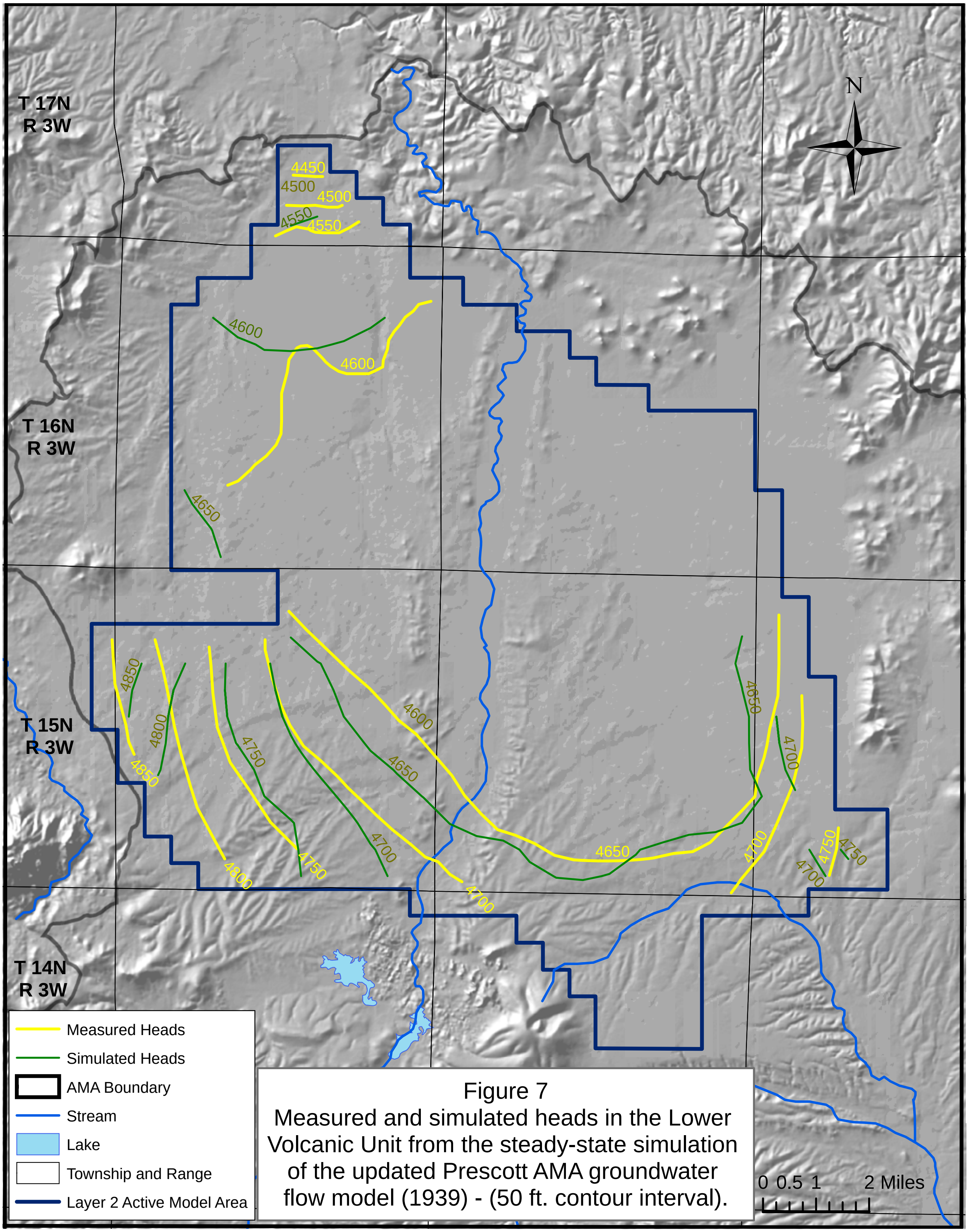


Figure 7
Measured and simulated heads in the Lower Volcanic Unit from the steady-state simulation of the updated Prescott AMA groundwater flow model (1939) - (50 ft. contour interval).

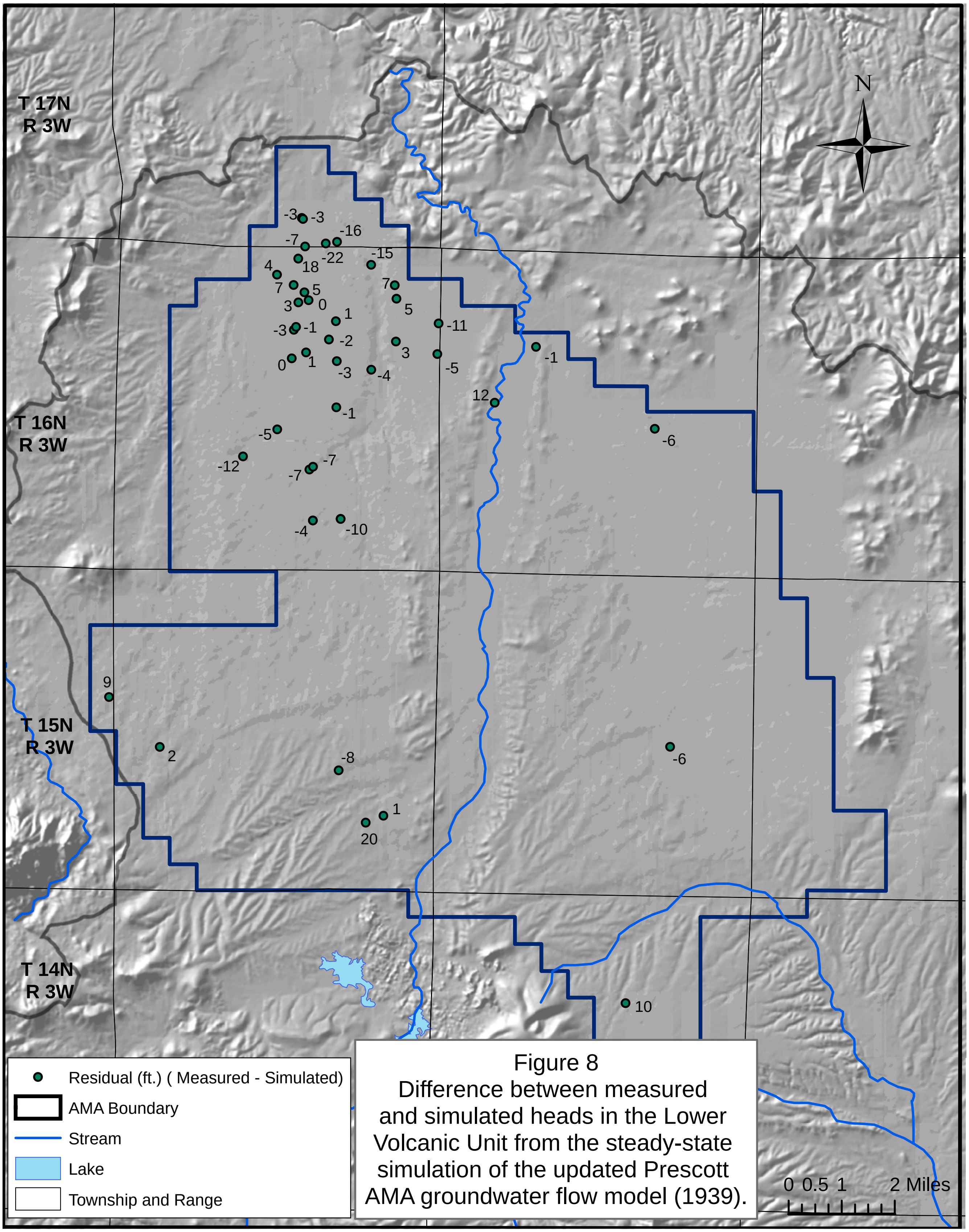


Figure 8
Difference between measured and simulated heads in the Lower Volcanic Unit from the steady-state simulation of the updated Prescott AMA groundwater flow model (1939).

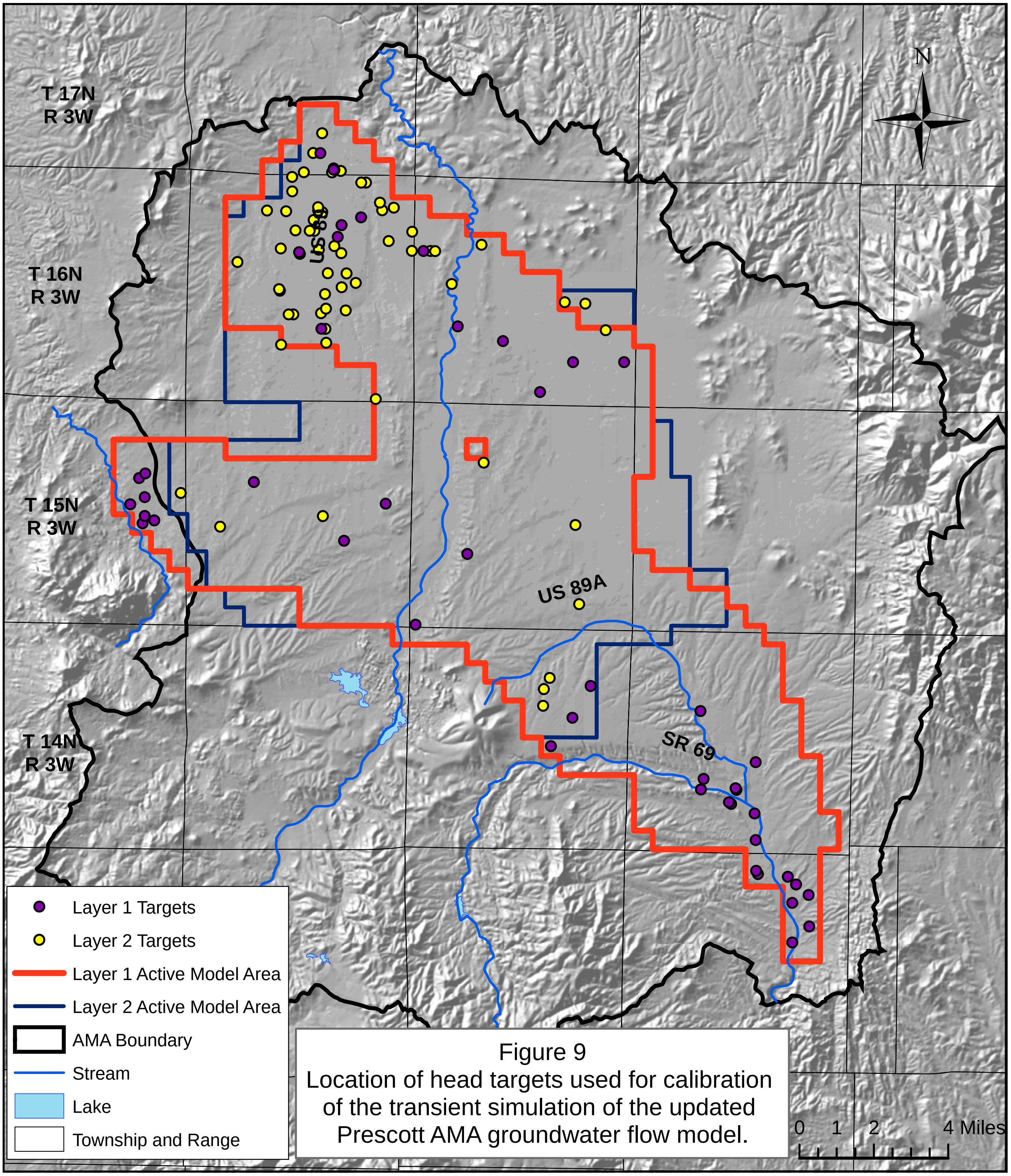


Figure 9
Location of head targets used for calibration of the transient simulation of the updated Prescott AMA groundwater flow model.

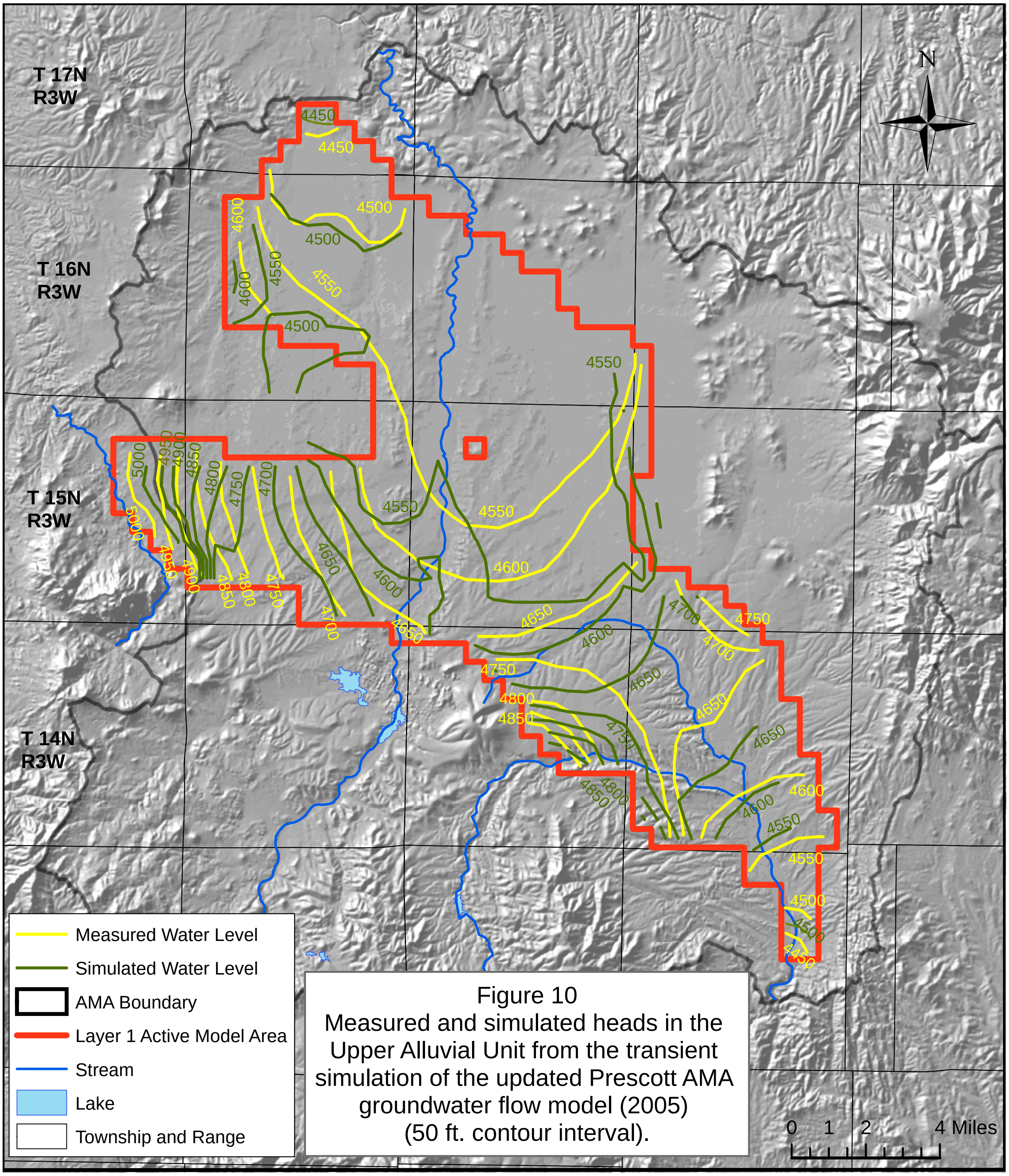


Figure 10
Measured and simulated heads in the Upper Alluvial Unit from the transient simulation of the updated Prescott AMA groundwater flow model (2005) (50 ft. contour interval).

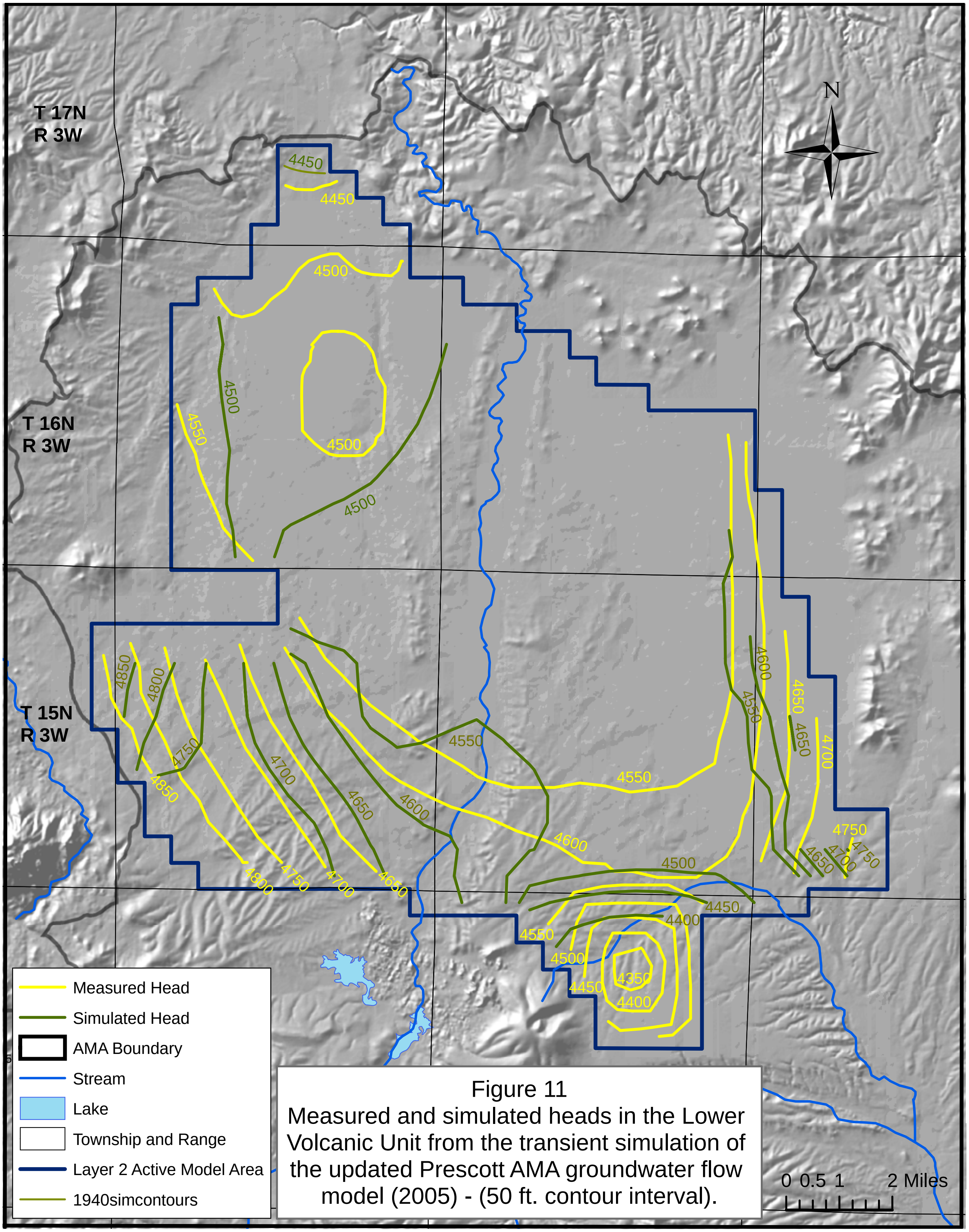


Figure 11
Measured and simulated heads in the Lower Volcanic Unit from the transient simulation of the updated Prescott AMA groundwater flow model (2005) - (50 ft. contour interval).

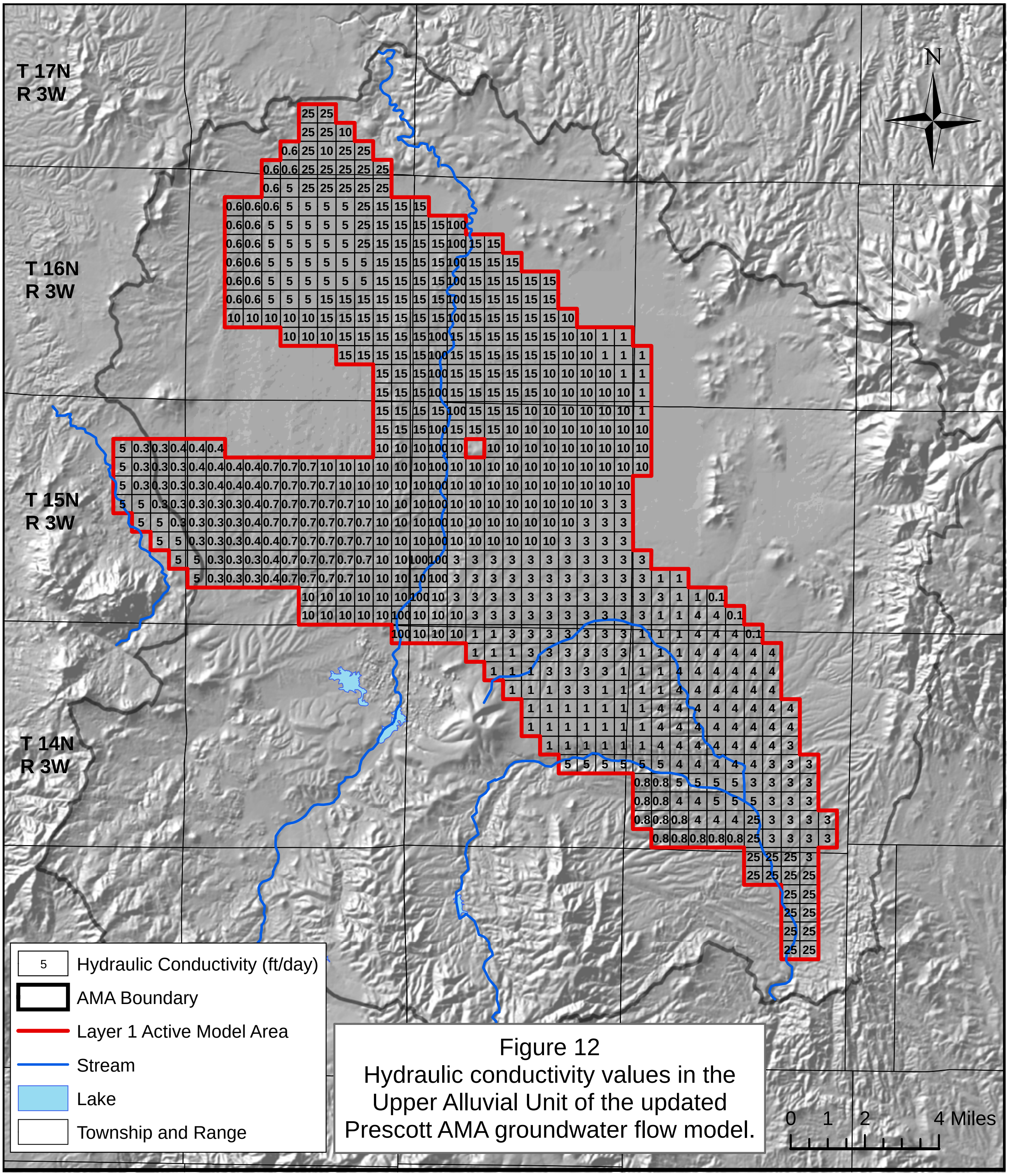


Figure 12
Hydraulic conductivity values in the Upper Alluvial Unit of the updated Prescott AMA groundwater flow model.

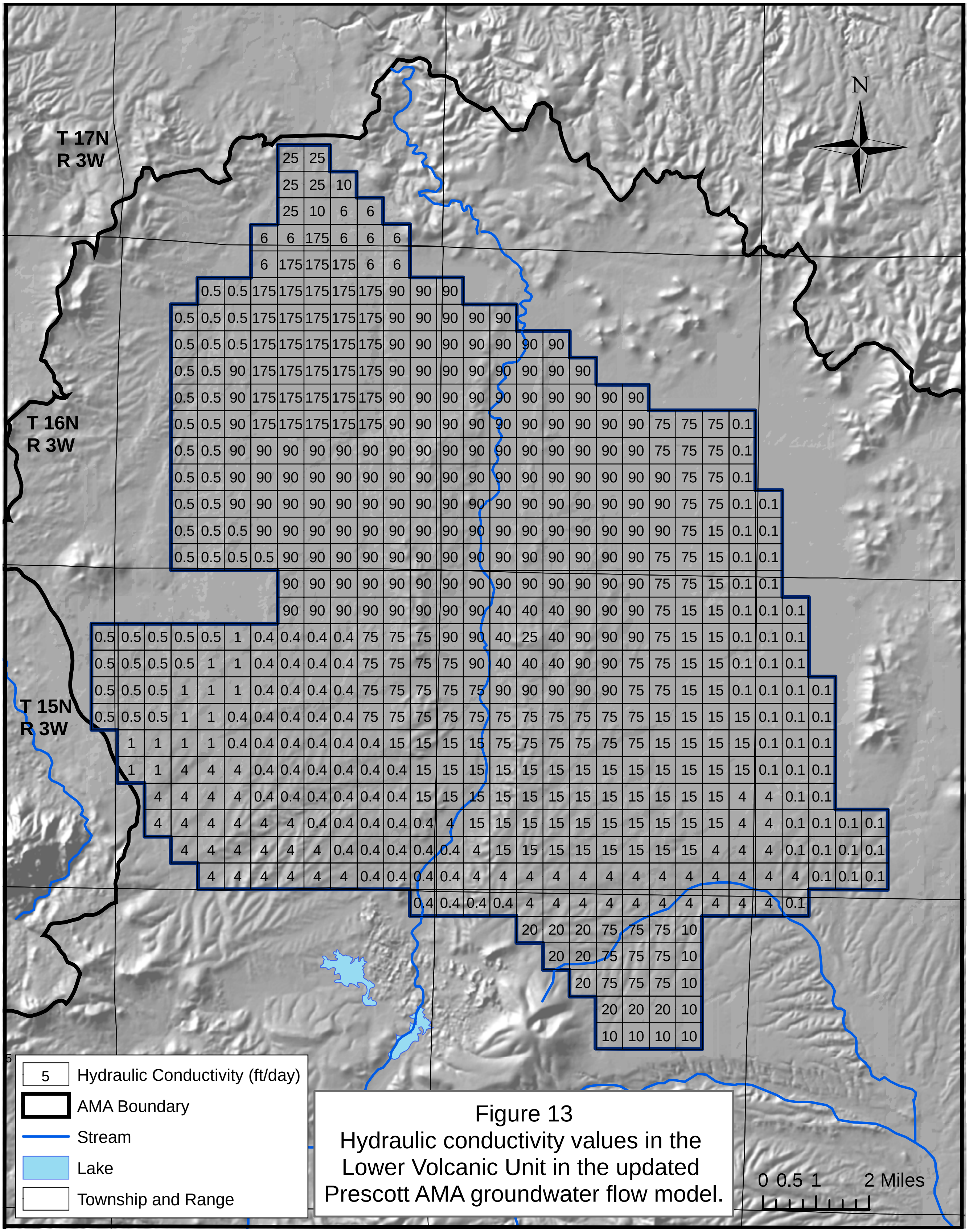


Figure 13
Hydraulic conductivity values in the Lower Volcanic Unit in the updated Prescott AMA groundwater flow model.

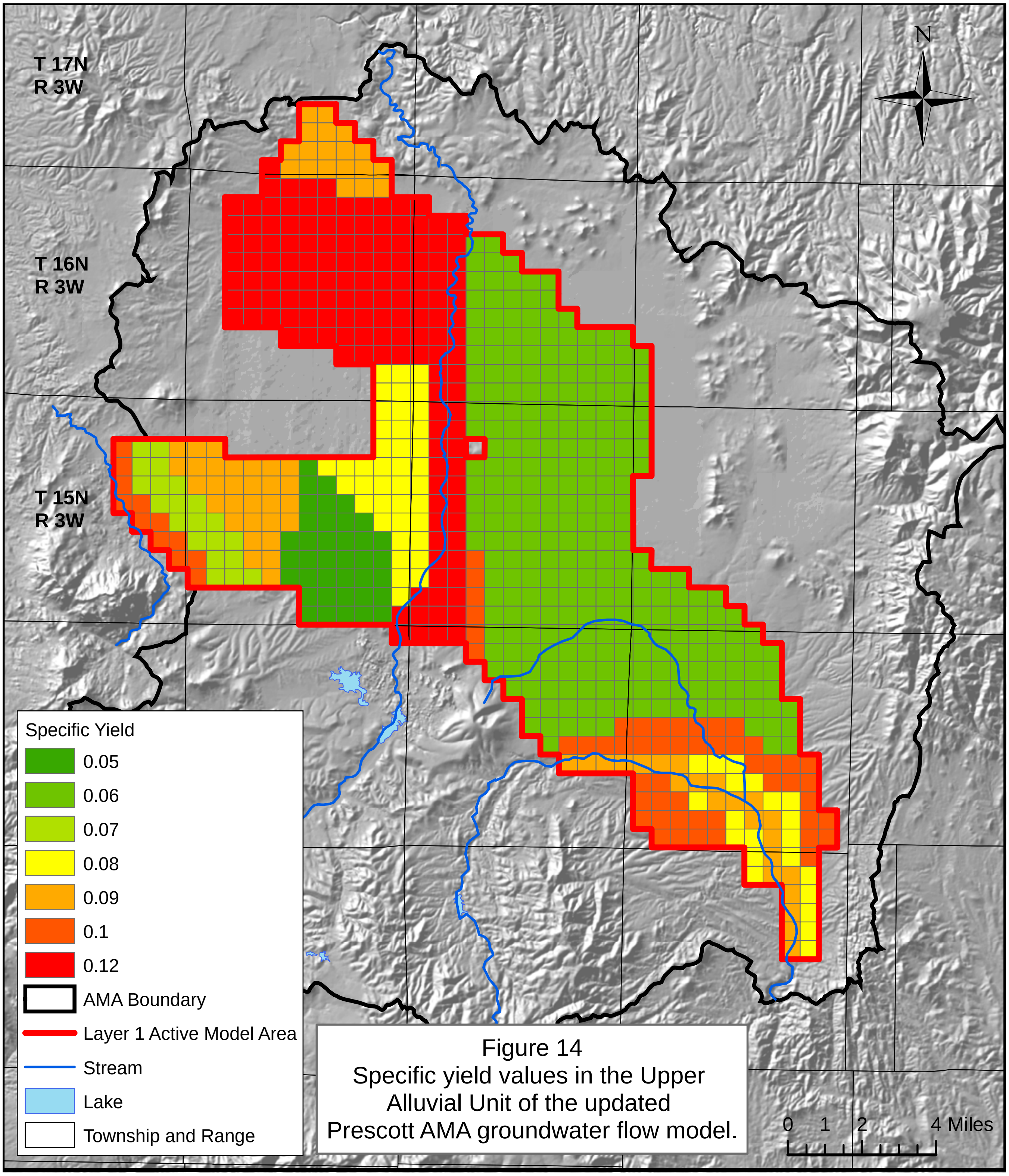


Figure 14
Specific yield values in the Upper Alluvial Unit of the updated Prescott AMA groundwater flow model.

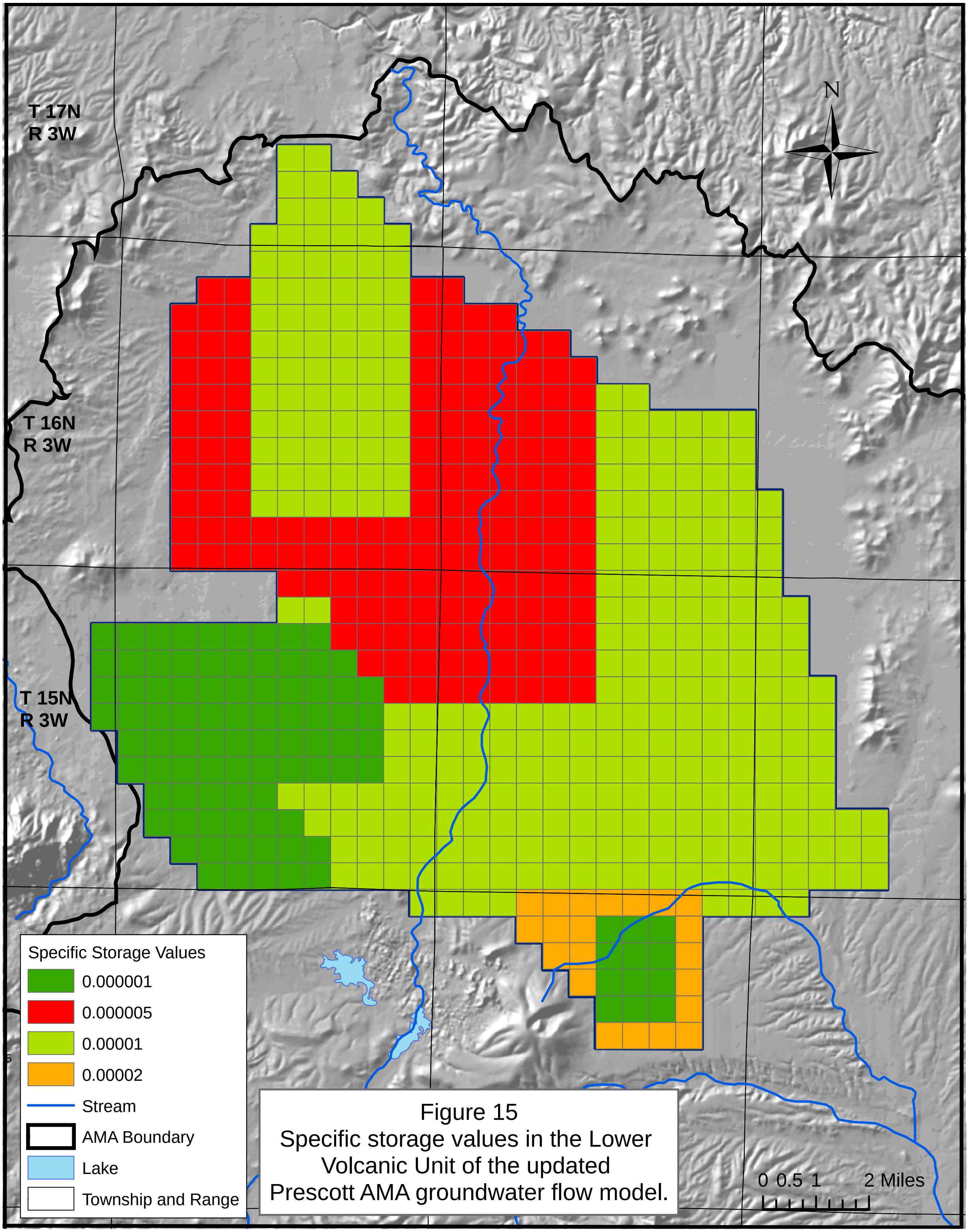
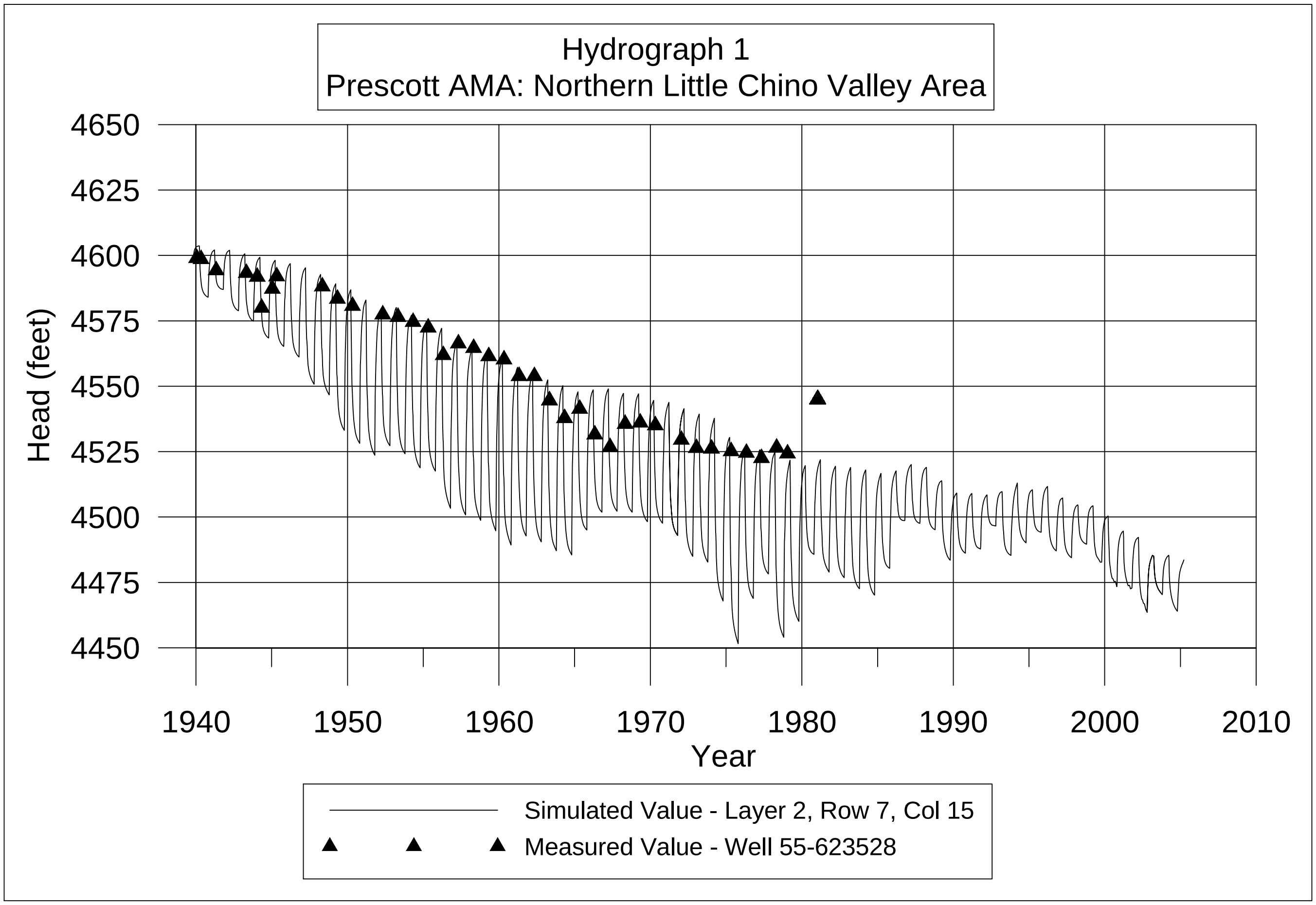
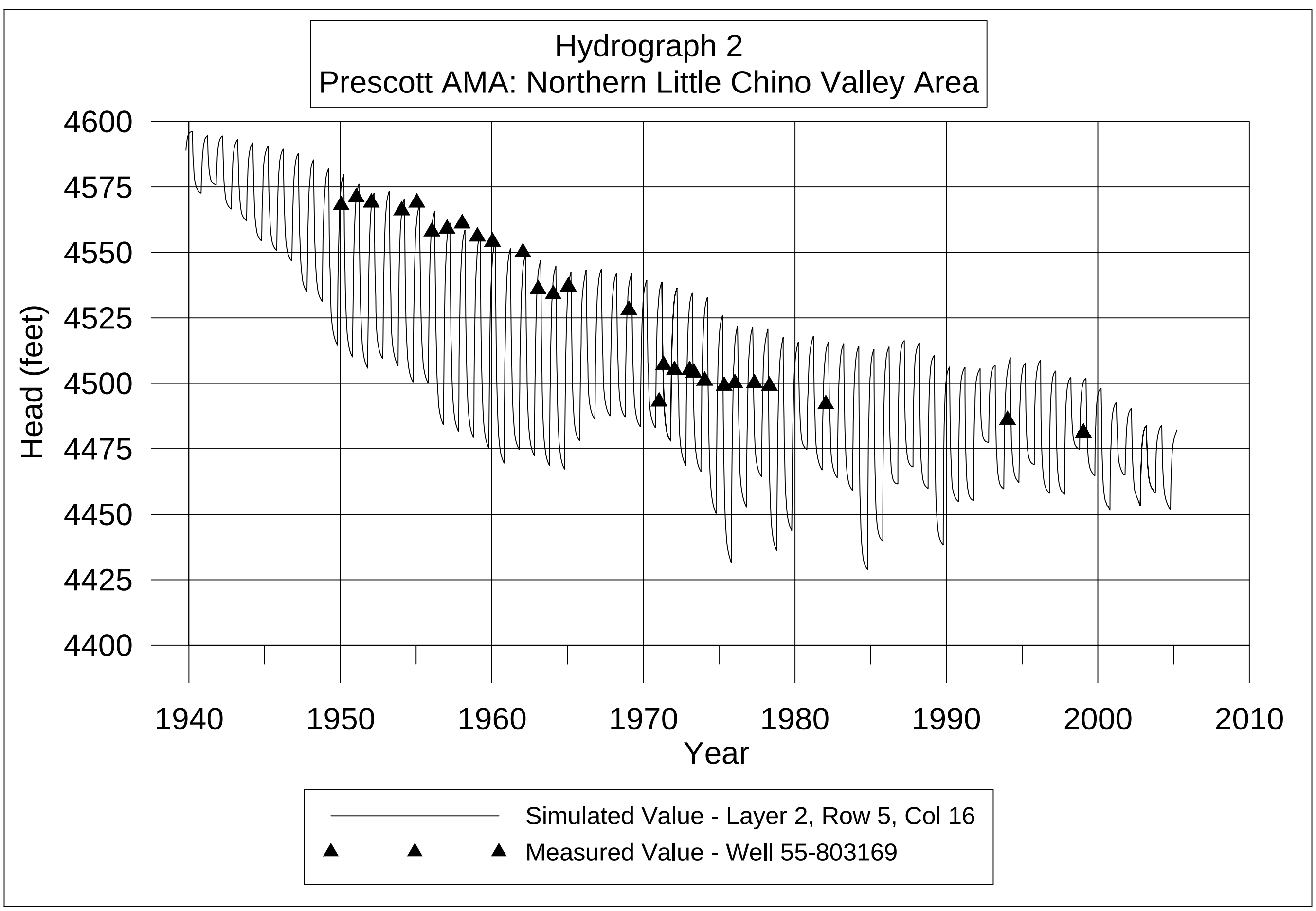
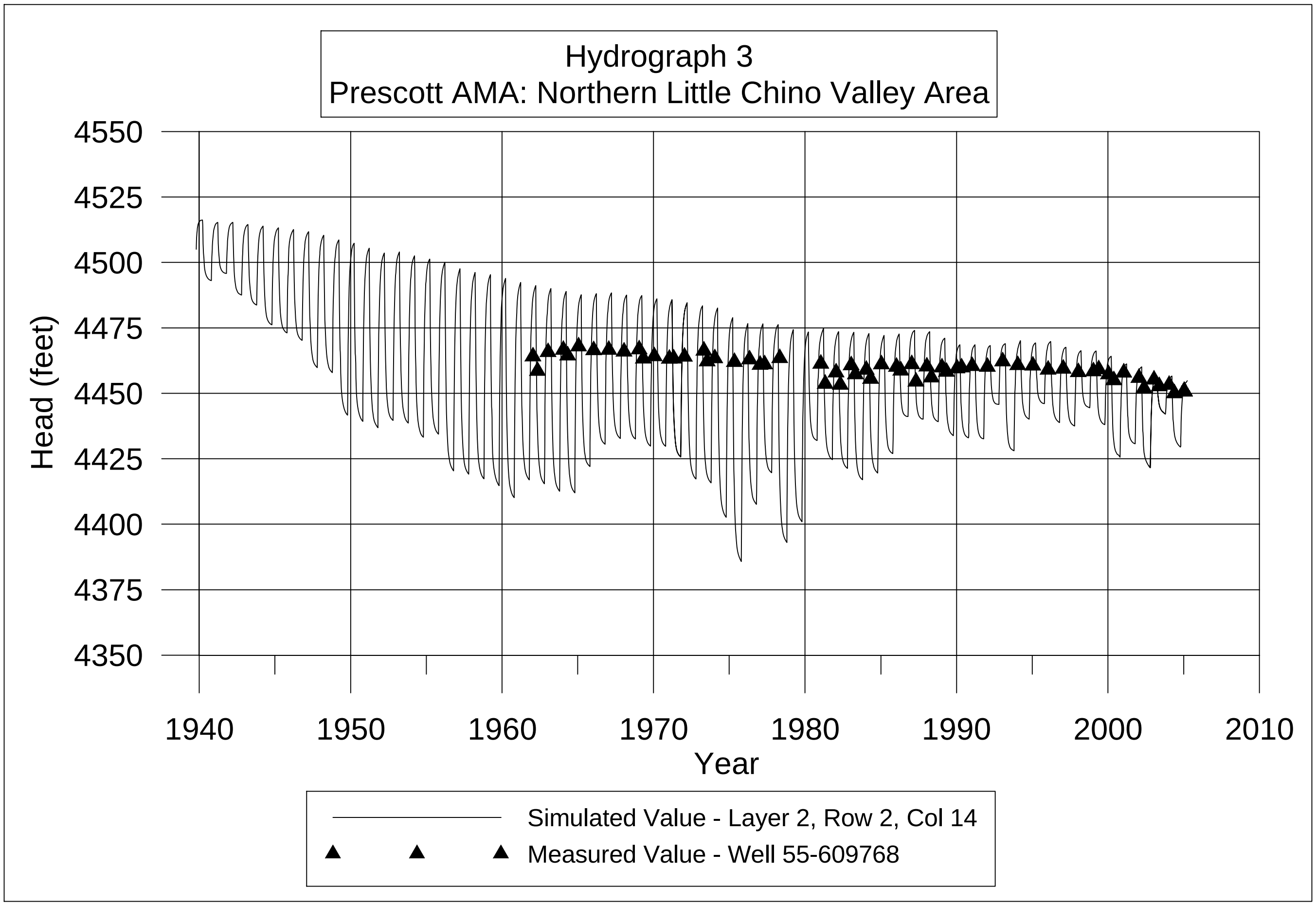


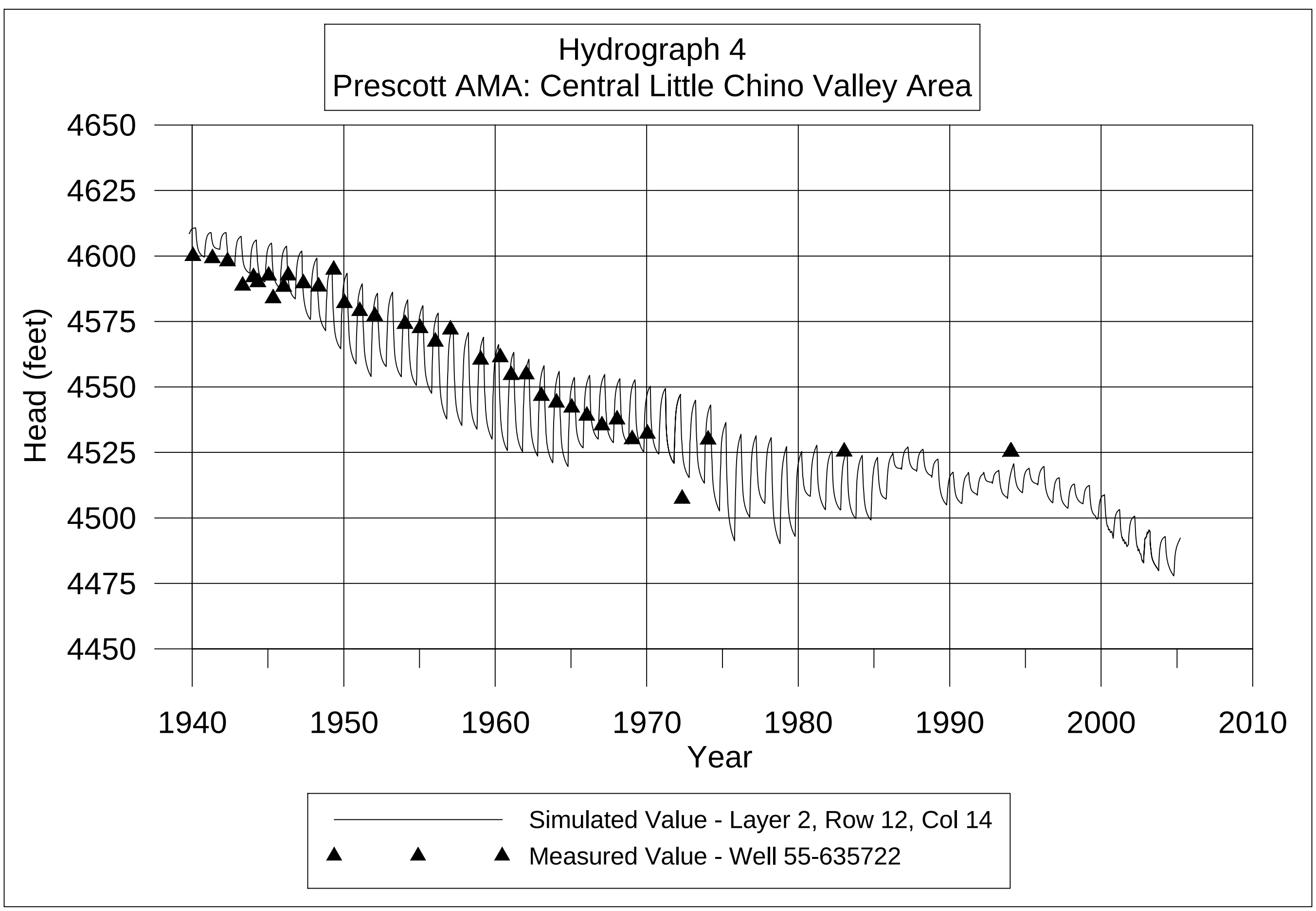
Figure 15
Specific storage values in the Lower Volcanic Unit of the updated Prescott AMA groundwater flow model.

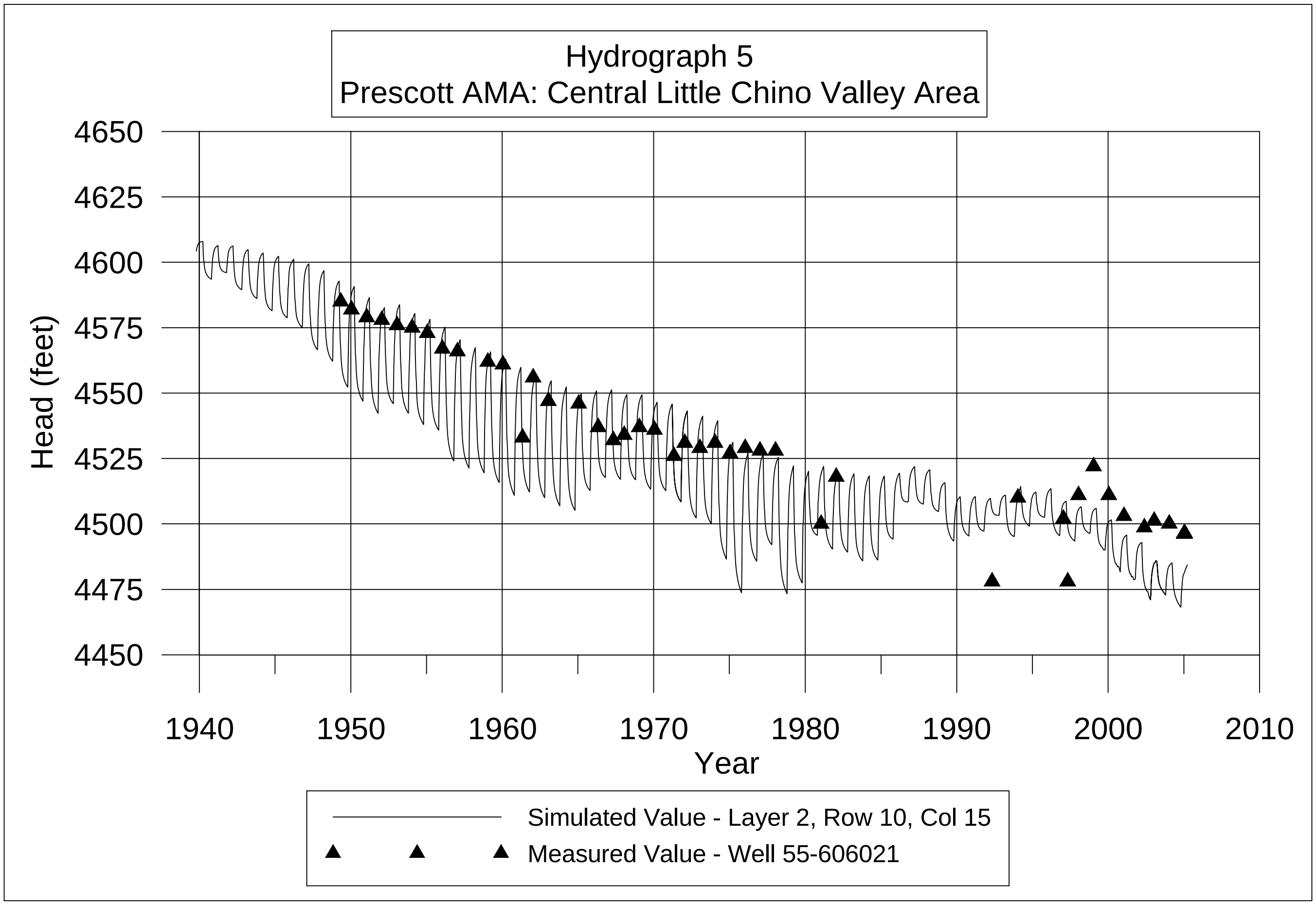
Appendix III: Hydrographs

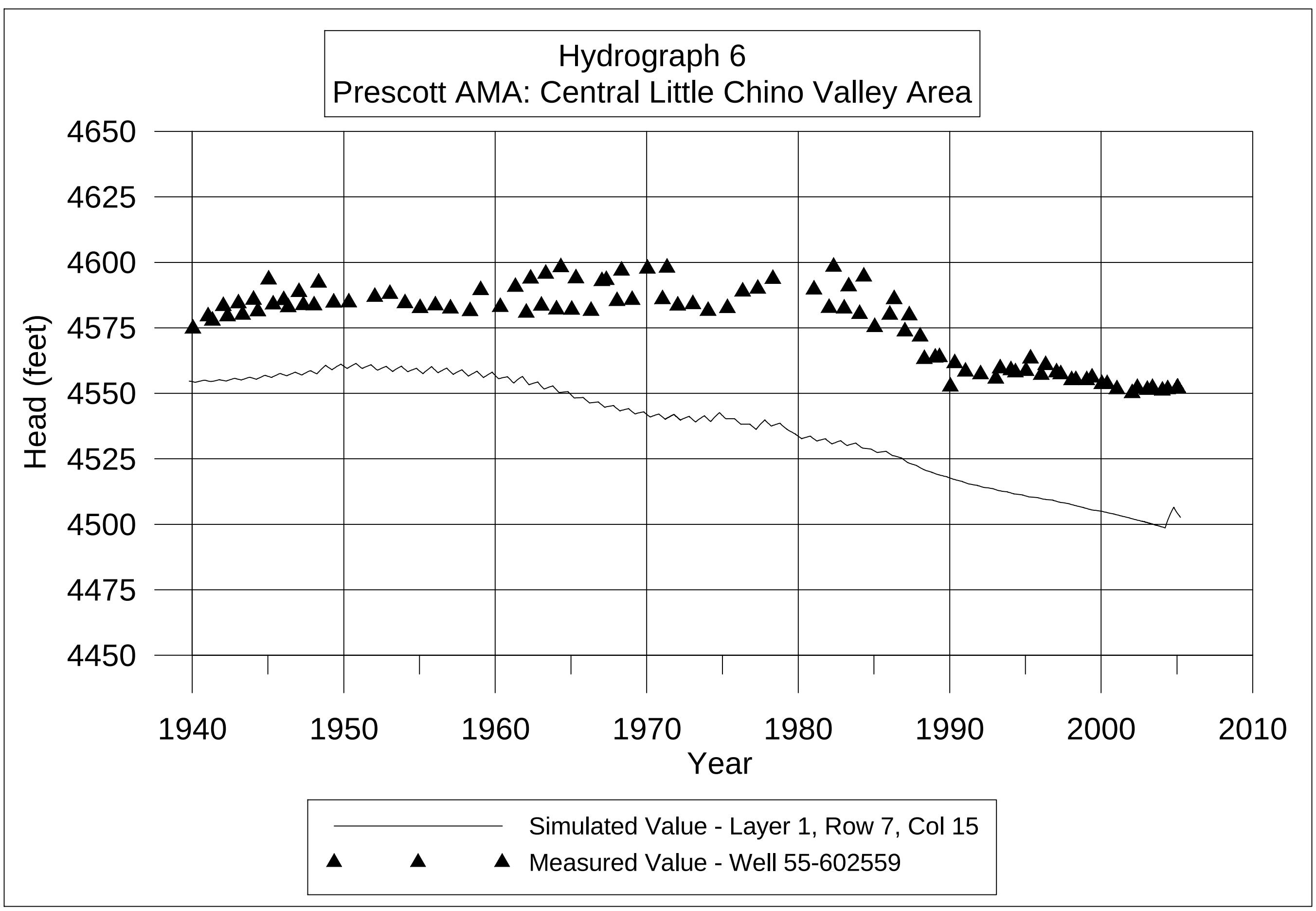

Hydrograph 1
Prescott AMA: Northern Little Chino Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 7, Col 15
Measured Value - Well 55-623528

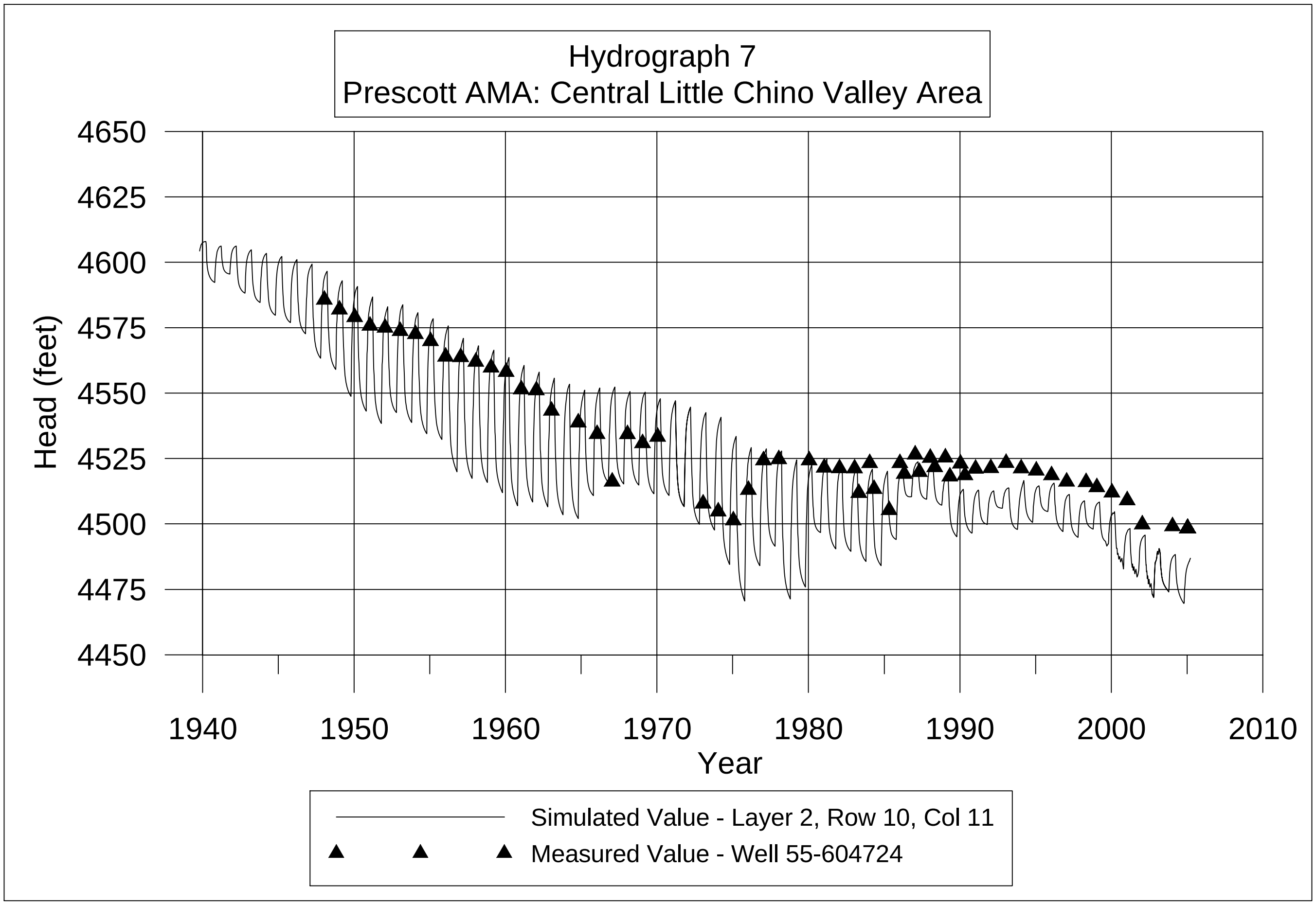

Hydrograph 2
Prescott AMA: Northern Little Chino Valley Area
4600
4575
4550
4525
4500
4475
4450
4425
4400
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 5, Col 16
Measured Value - Well 55-803169

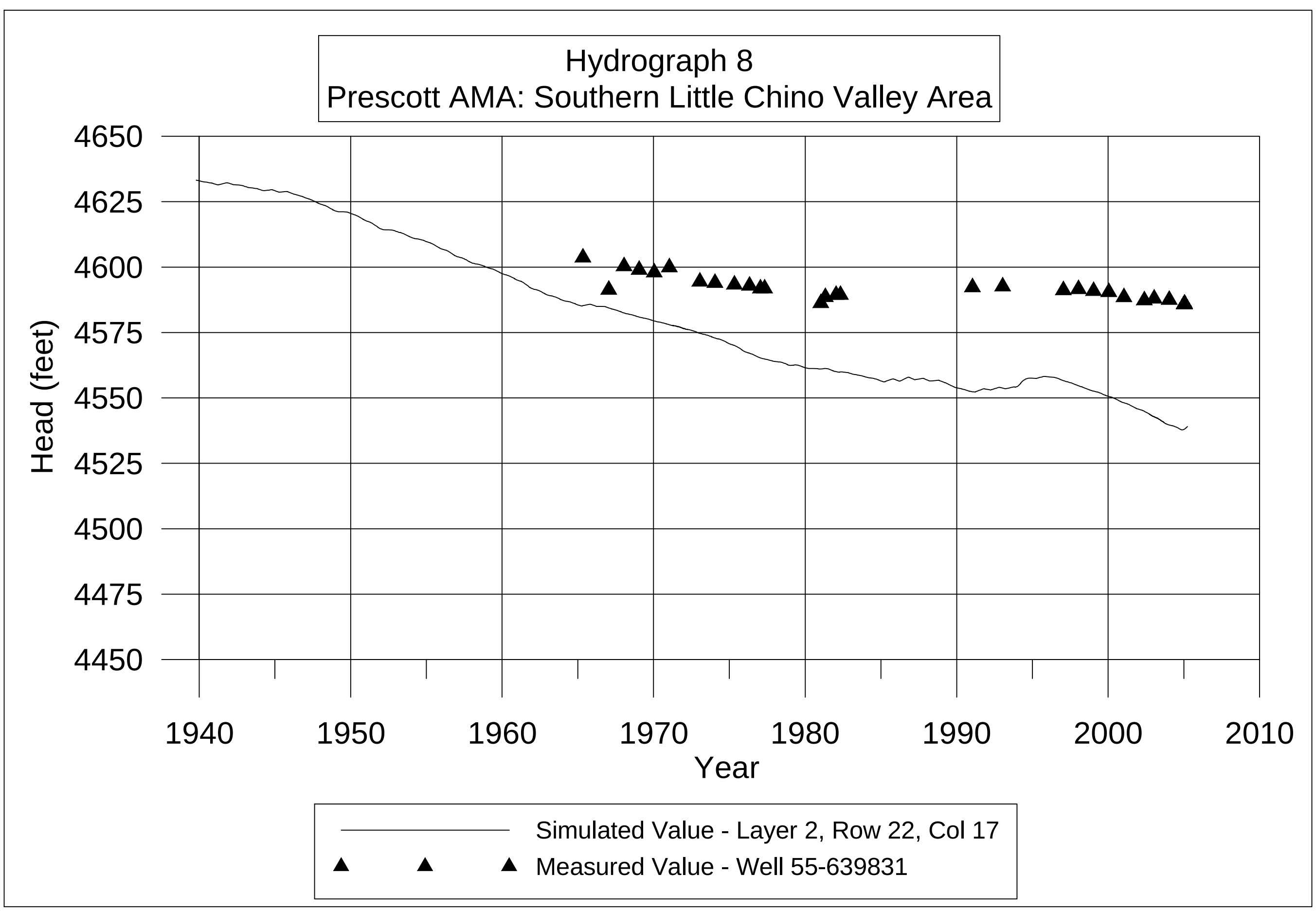

Hydrograph 3
Prescott AMA: Northern Little Chino Valley Area
4550
4525
4500
4475
4450
4425
4400
4375
4350
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 2, Col 14
Measured Value - Well 55-609768

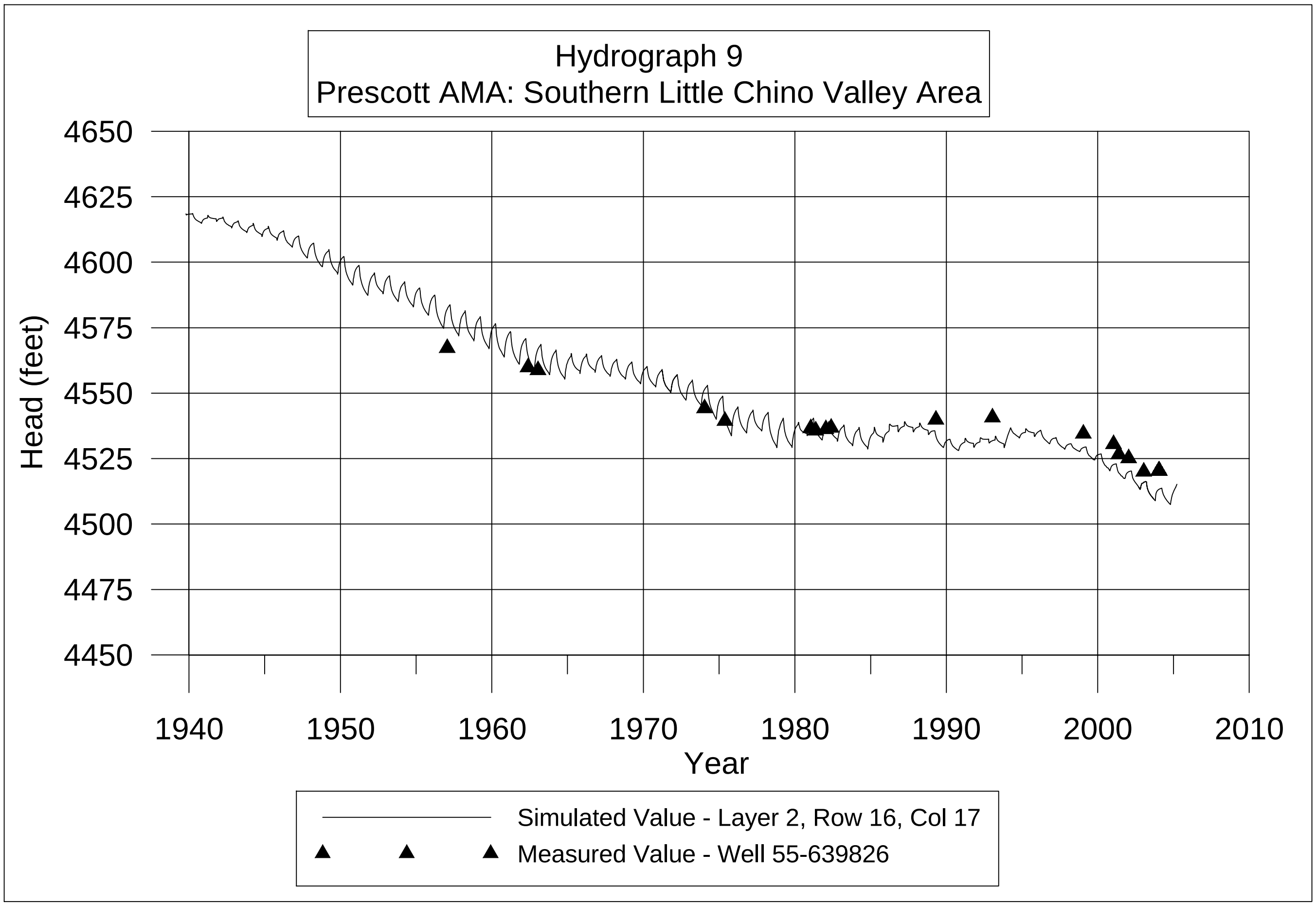

Hydrograph 4
Prescott AMA: Central Little Chino Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 12, Col 14
Measured Value - Well 55-635722

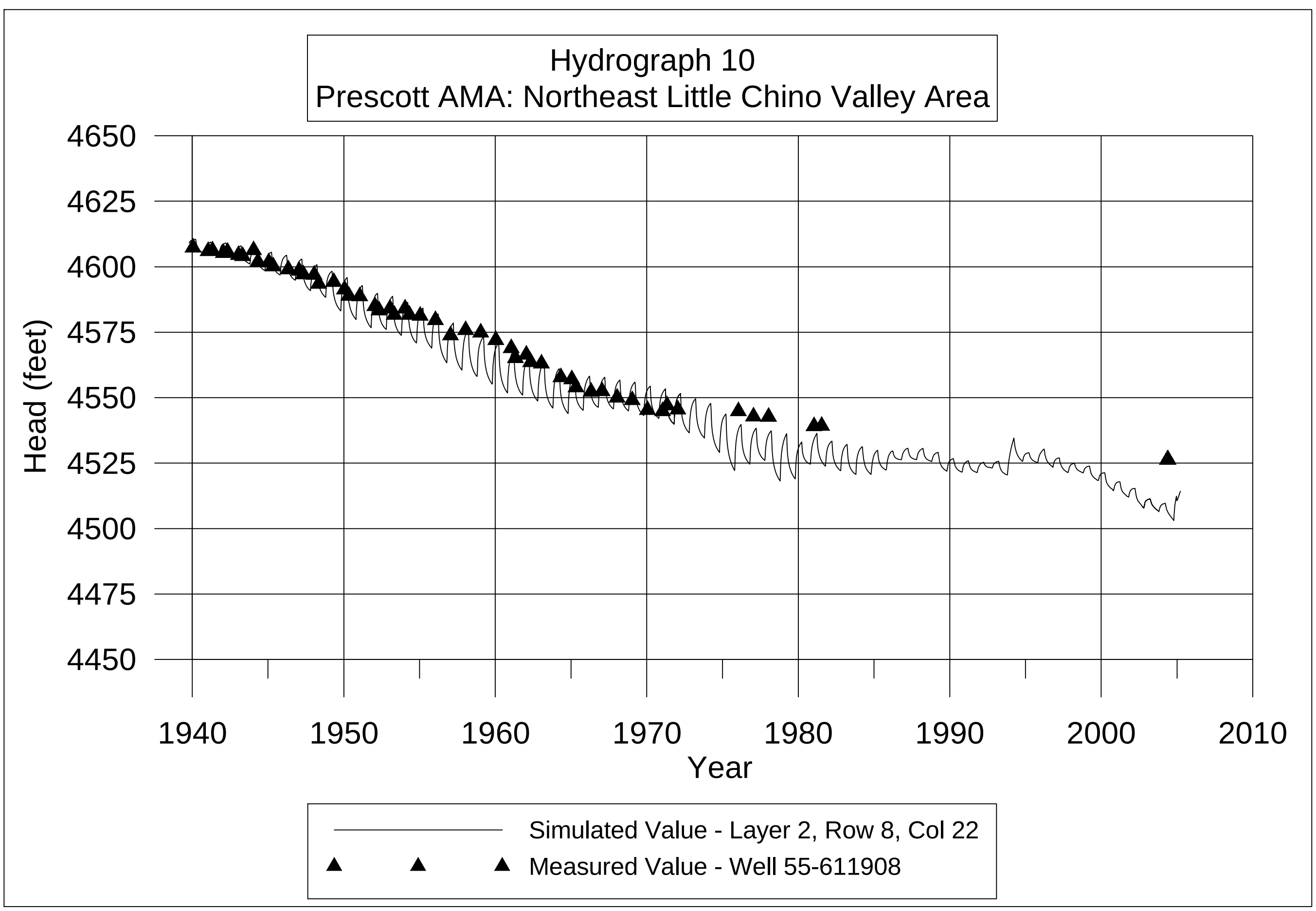

Hydrograph 5
Prescott AMA: Central Little Chino Valley Area
Head (feet)
4650
4625
4600
4575
4550
4525
4500
4475
4450
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 10, Col 15
Measured Value - Well 55-606021

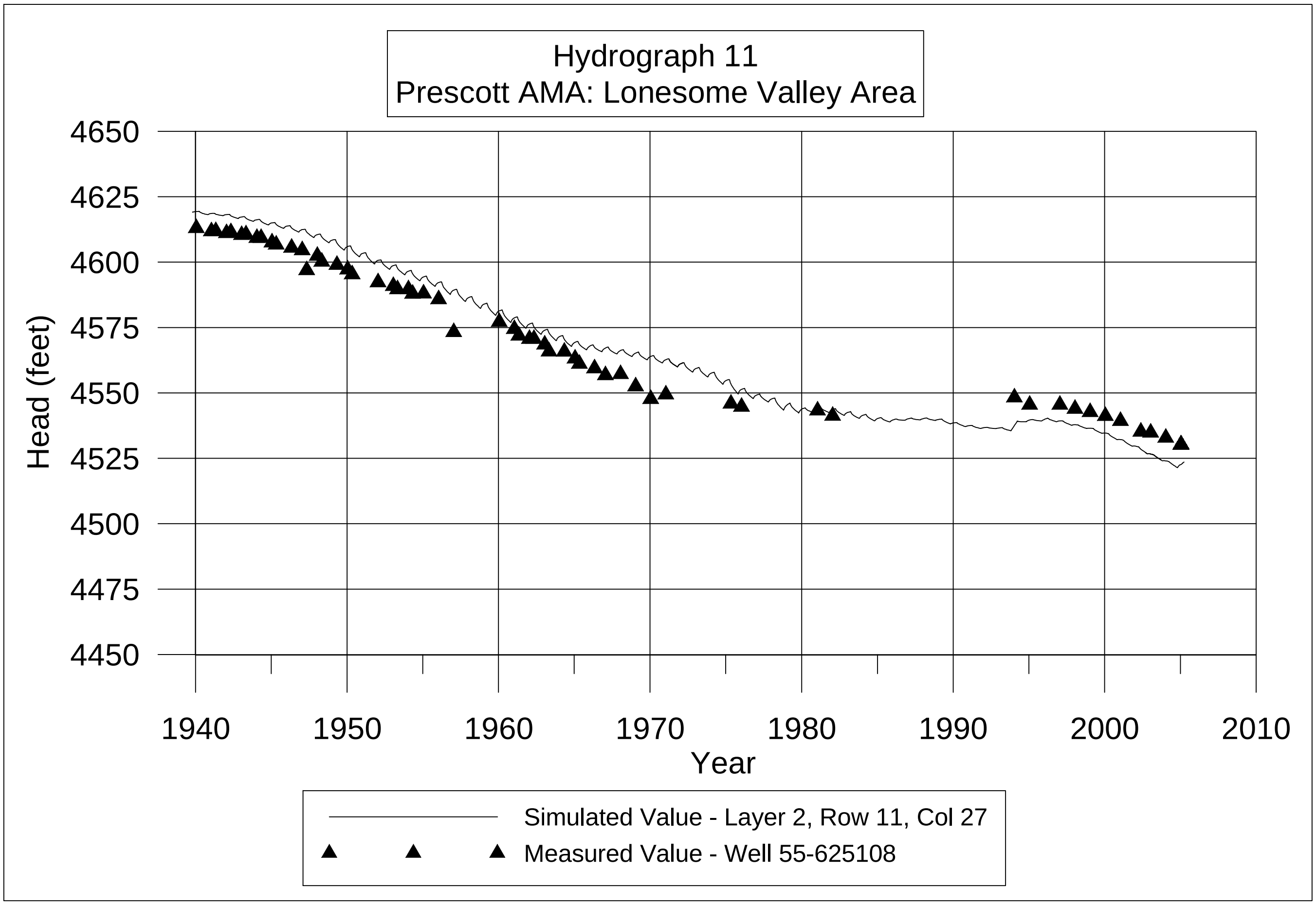

Hydrograph 6
Prescott AMA: Central Little Chino Valley Area
Head (feet)
4650
4625
4600
4575
4550
4525
4500
4475
4450
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 1, Row 7, Col 15
Measured Value - Well 55-602559

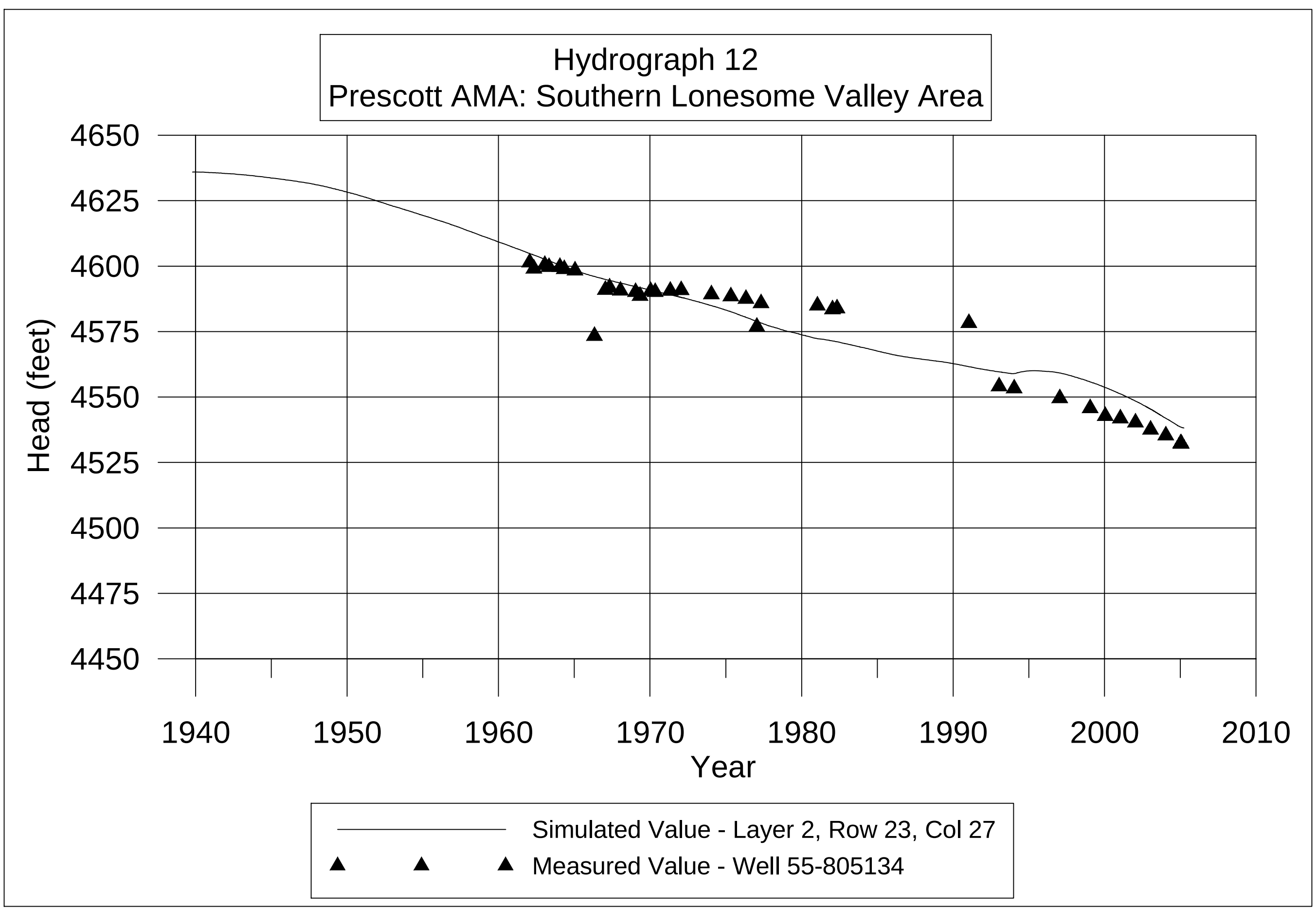

Hydrograph 7
Prescott AMA: Central Little Chino Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 10, Col 11
Measured Value - Well 55-604724

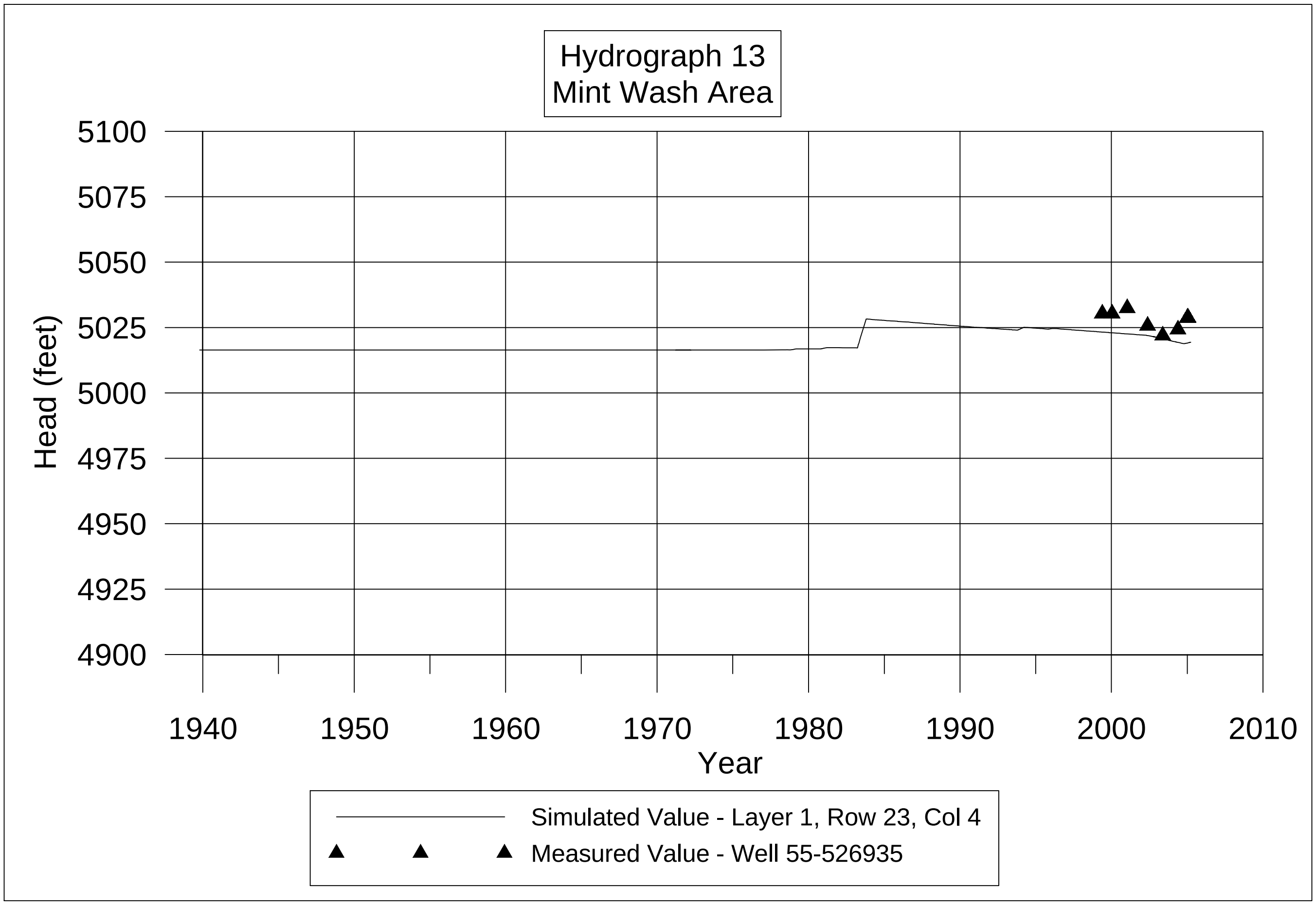

Hydrograph 8
Prescott AMA: Southern Little Chino Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 22, Col 17
Measured Value - Well 55-639831

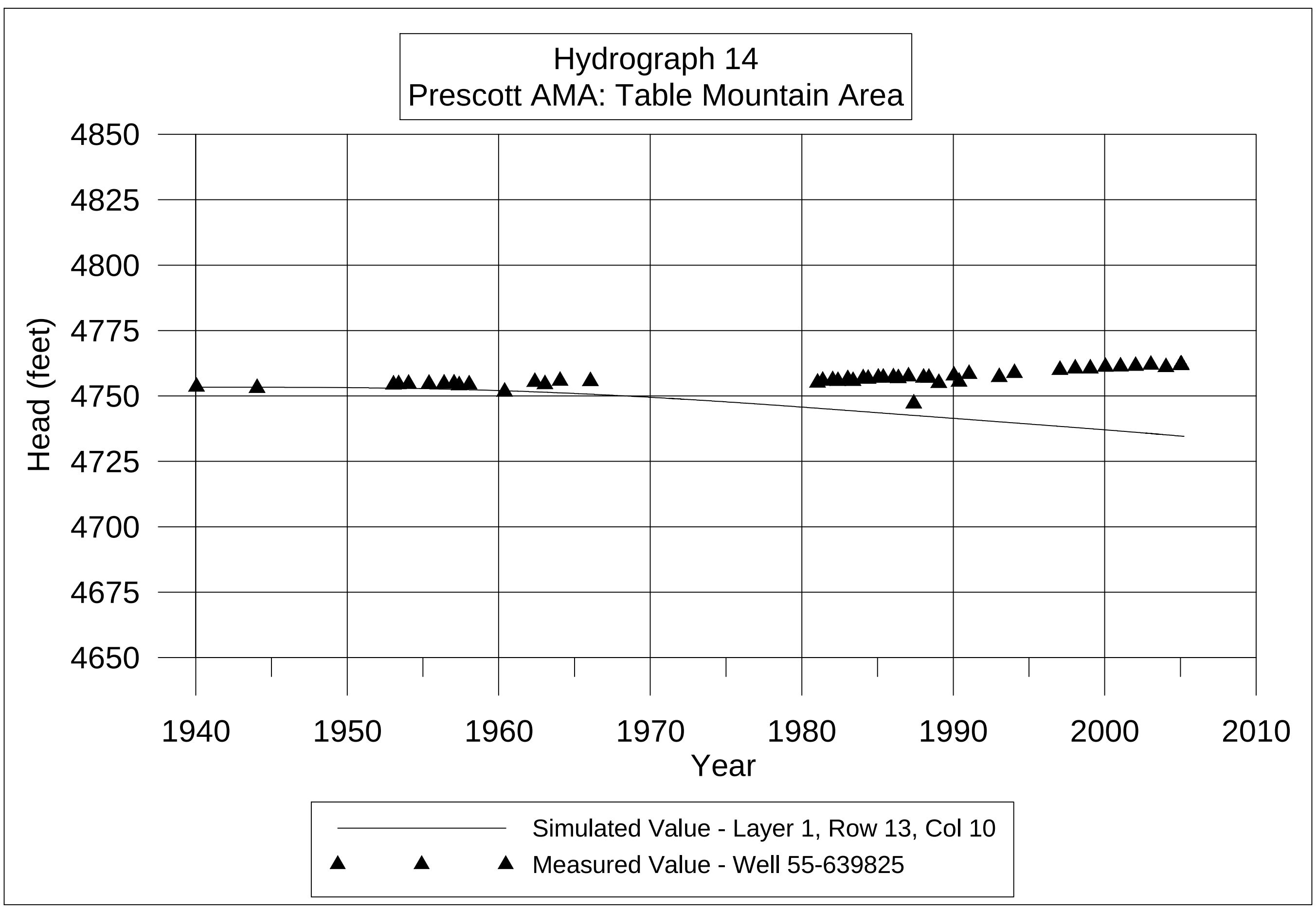

Hydrograph 9
Prescott AMA: Southern Little Chino Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 16, Col 17
Measured Value - Well 55-639826

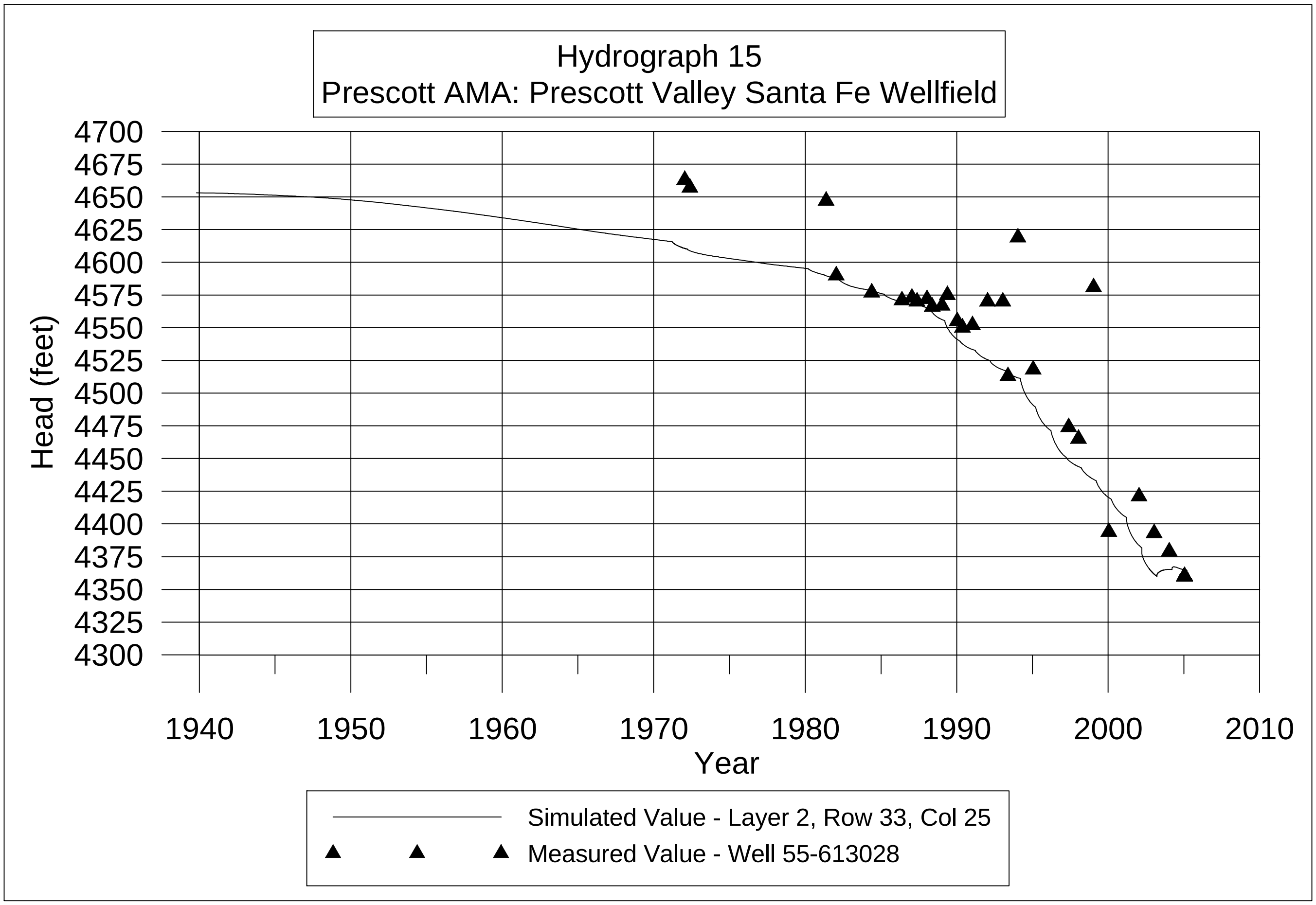

Hydrograph 10
Prescott AMA: Northeast Little Chino Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 8, Col 22
Measured Value - Well 55-611908

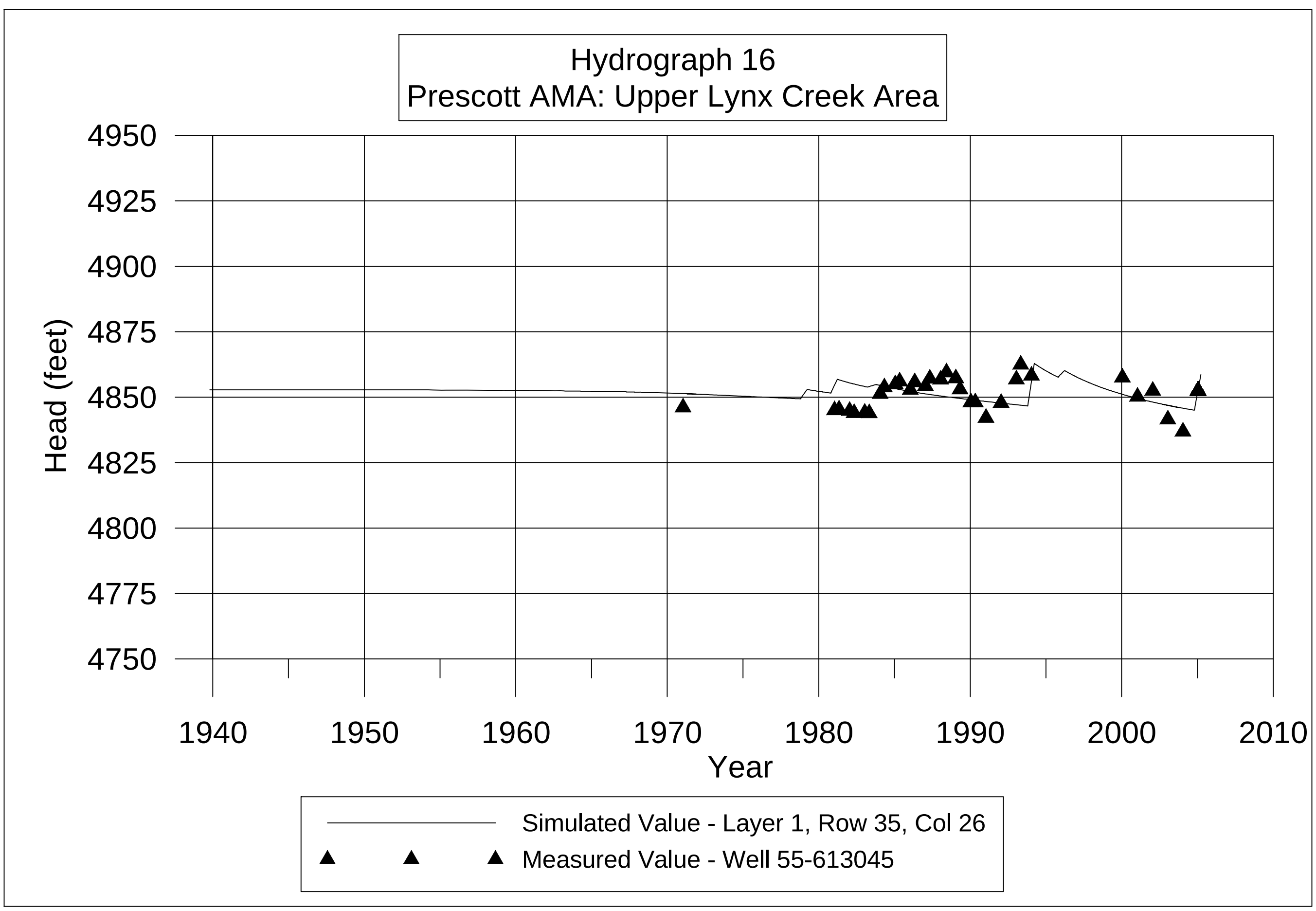

Hydrograph 11
Prescott AMA: Lonesome Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 11, Col 27
Measured Value - Well 55-625108

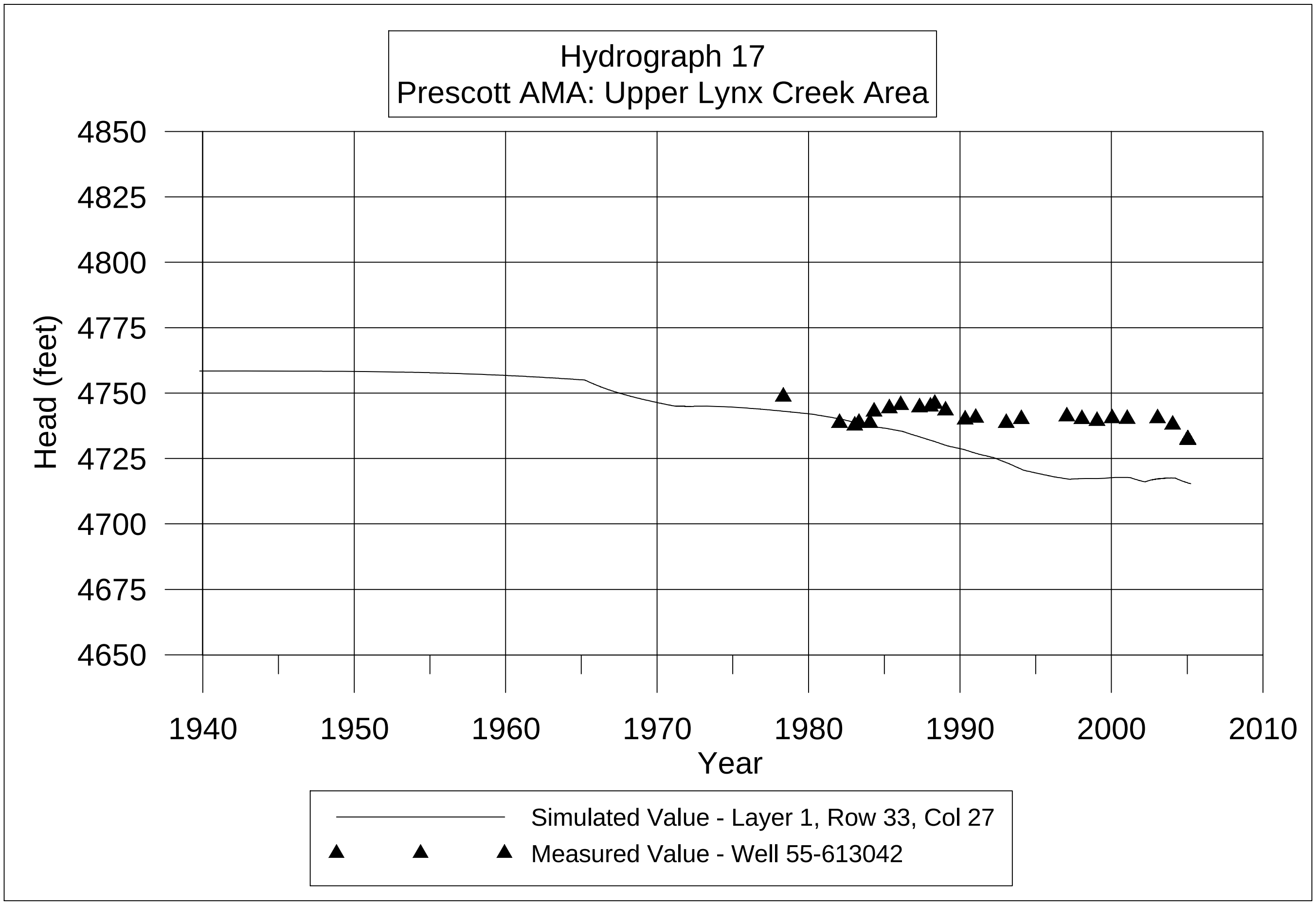

Hydrograph 12
Prescott AMA: Southern Lonesome Valley Area
4650
4625
4600
4575
4550
4525
4500
4475
4450
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 23, Col 27
Measured Value - Well 55-805134

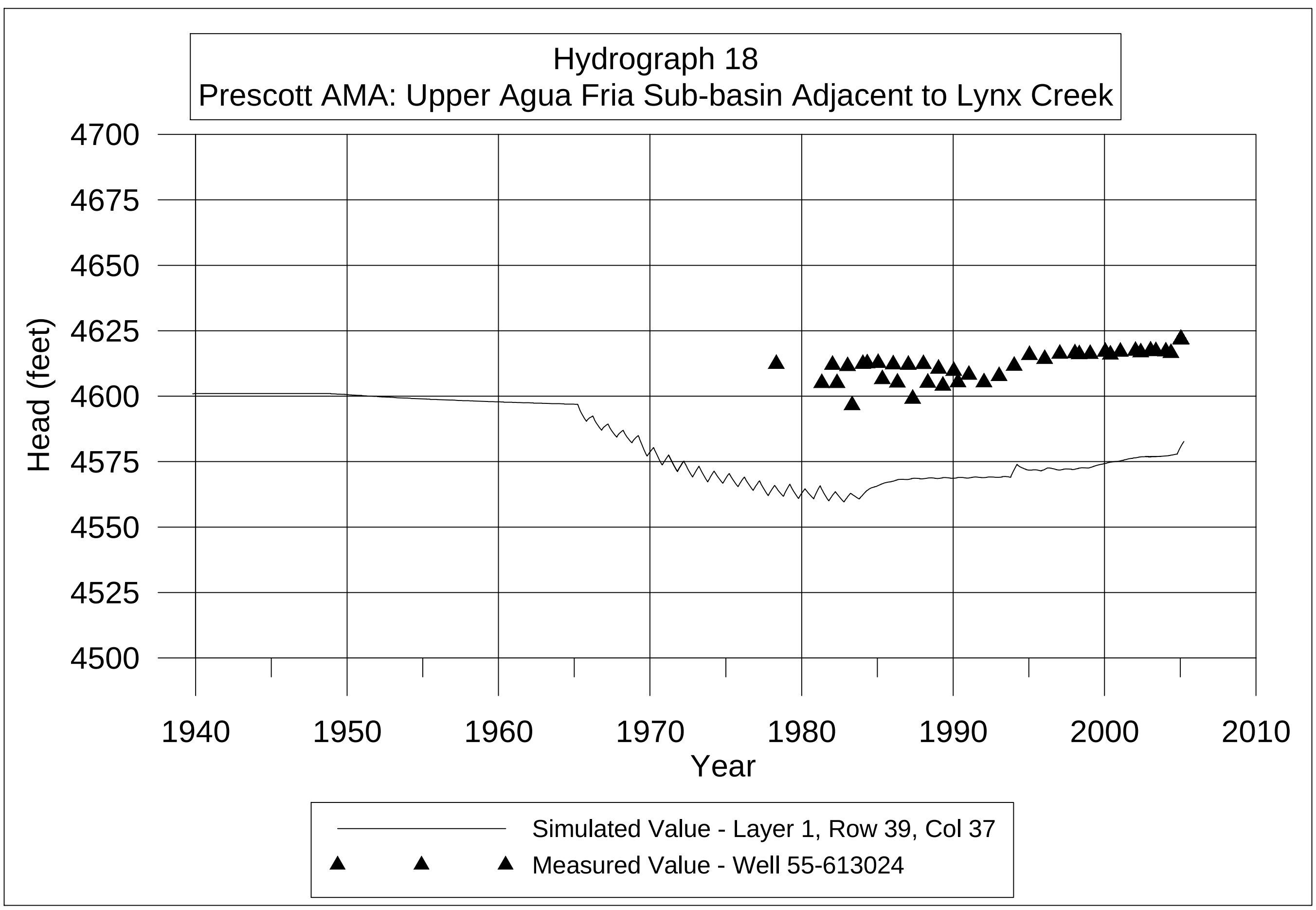

Hydrograph 13
Mint Wash Area
5100
5075
5050
5025
5000
4975
4950
4925
4900
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 1, Row 23, Col 4
Measured Value - Well 55-526935

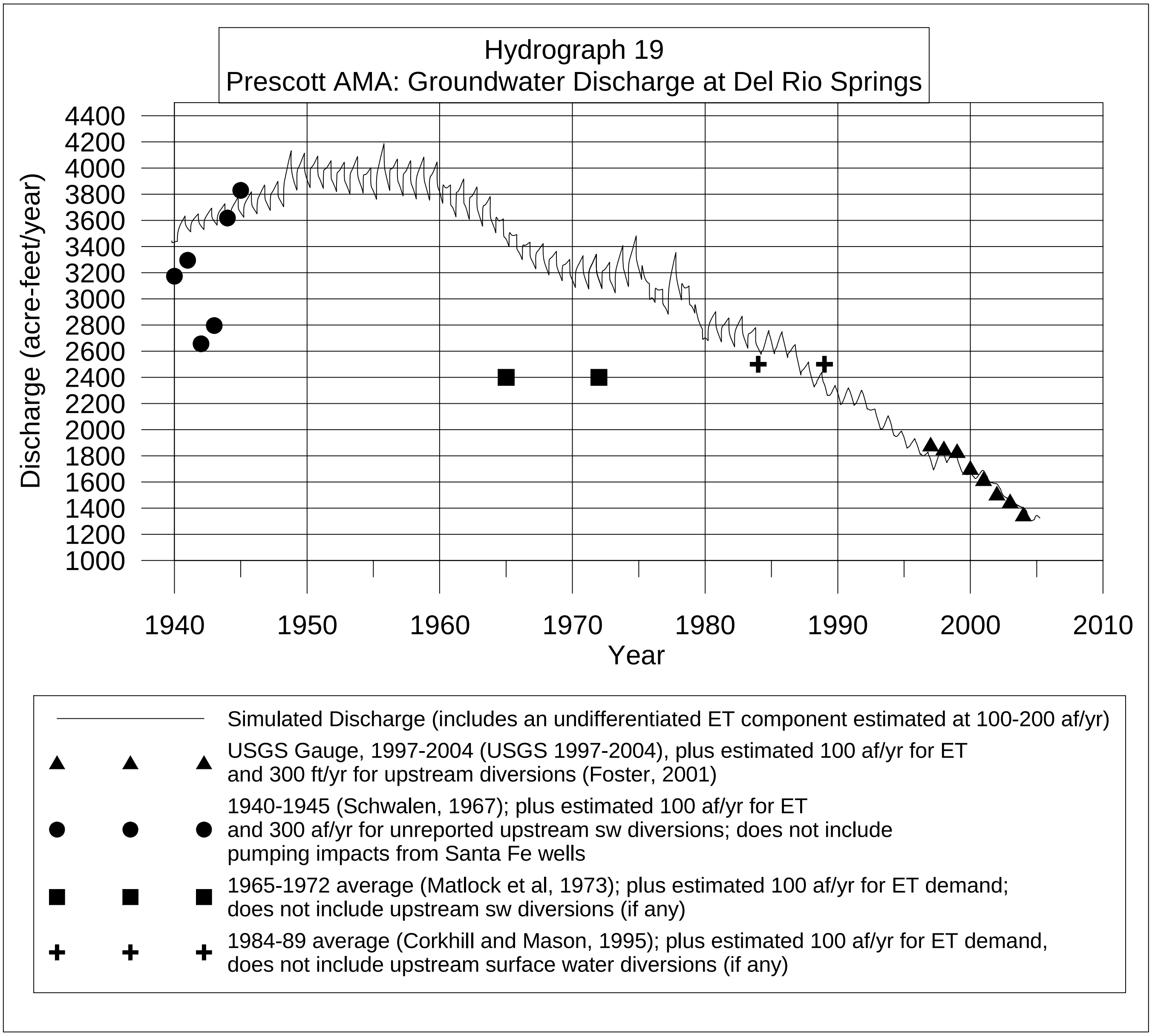

Hydrograph 14
Prescott AMA: Table Mountain Area
4850
4825
4800
4775
4750
4725
4700
4675
4650
Head (feet)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 1, Row 13, Col 10
Measured Value - Well 55-639825

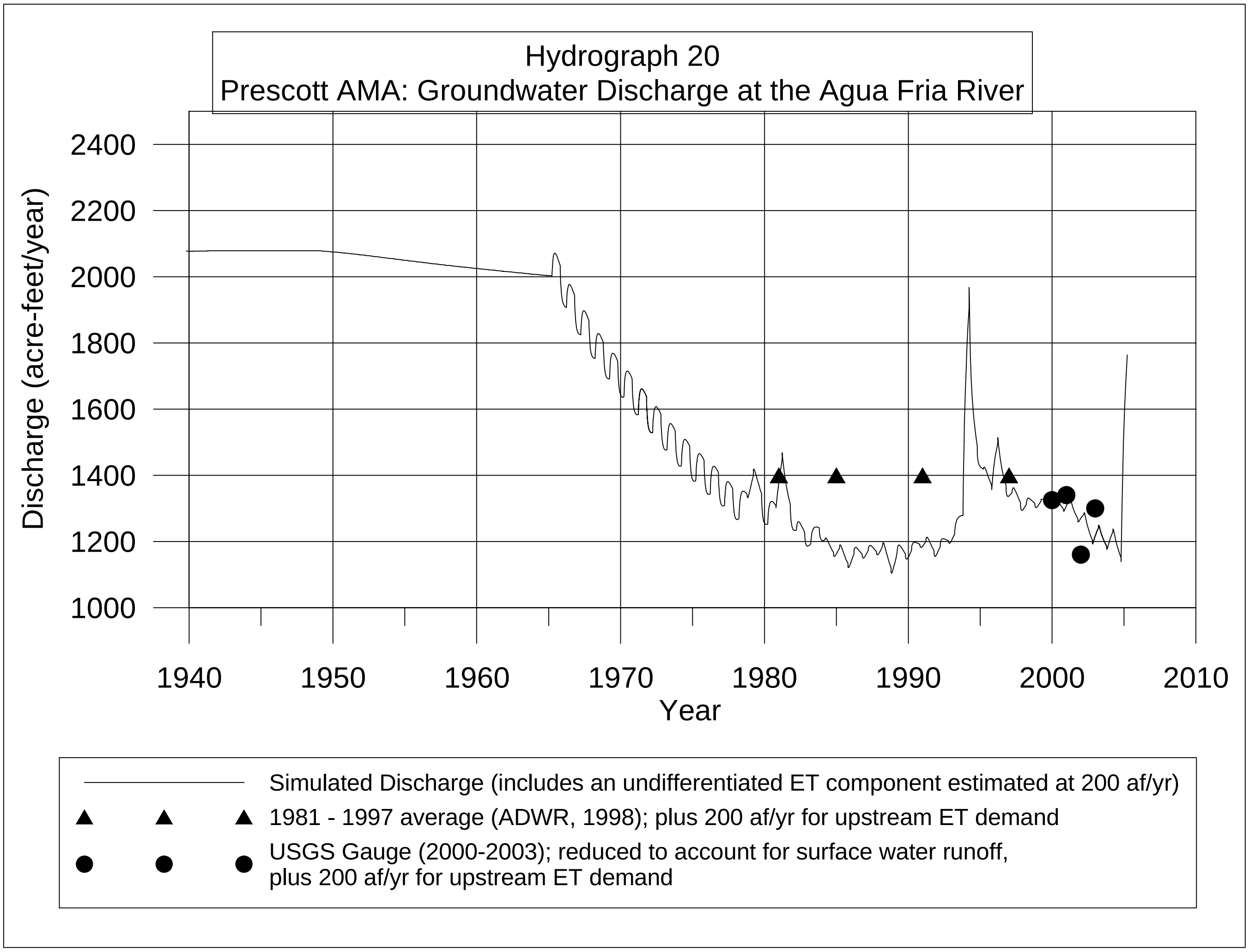

Hydrograph 15
Prescott AMA: Prescott Valley Santa Fe Wellfield
Head (feet)
4700
4675
4650
4625
4600
4575
4550
4525
4500
4475
4450
4425
4400
4375
4350
4325
4300
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 2, Row 33, Col 25
Measured Value - Well 55-613028


Hydrograph 16
Prescott AMA: Upper Lynx Creek Area
Head (feet)
4950
4925
4900
4875
4850
4825
4800
4775
4750
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 1, Row 35, Col 26
Measured Value - Well 55-613045

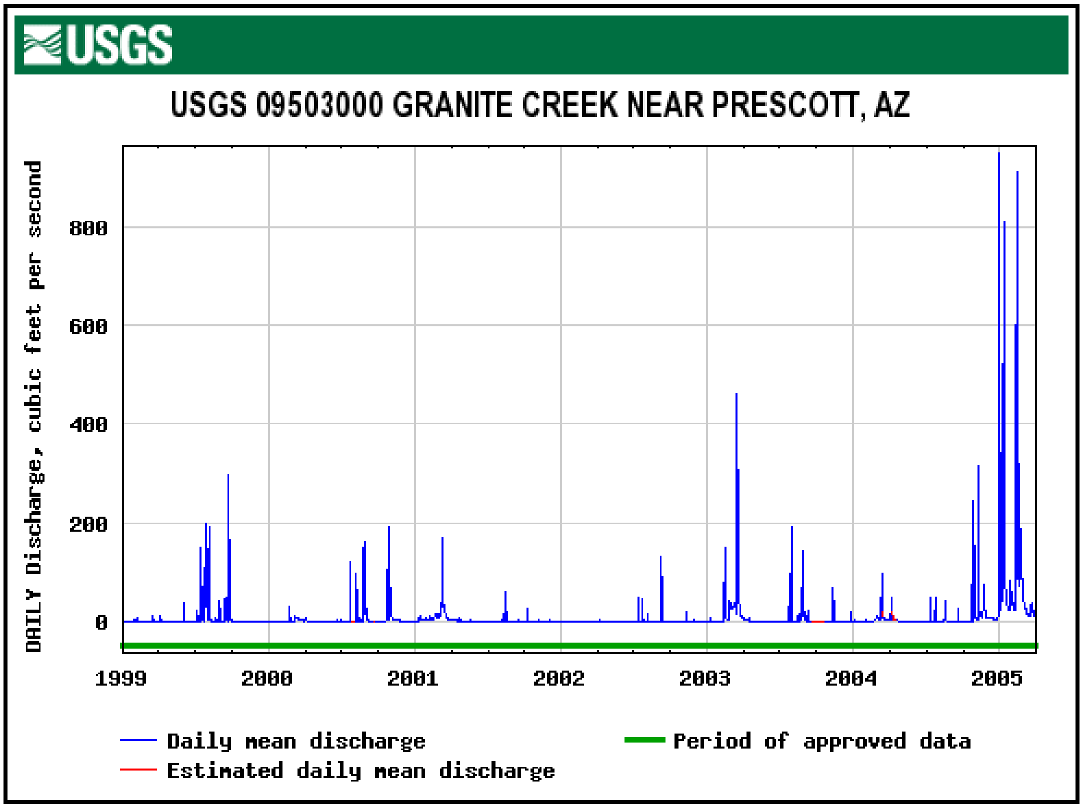

Hydrograph 17
Prescott AMA: Upper Lynx Creek Area
Head (feet)
4850
4825
4800
4775
4750
4725
4700
4675
4650
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 1, Row 33, Col 27
Measured Value - Well 55-613042

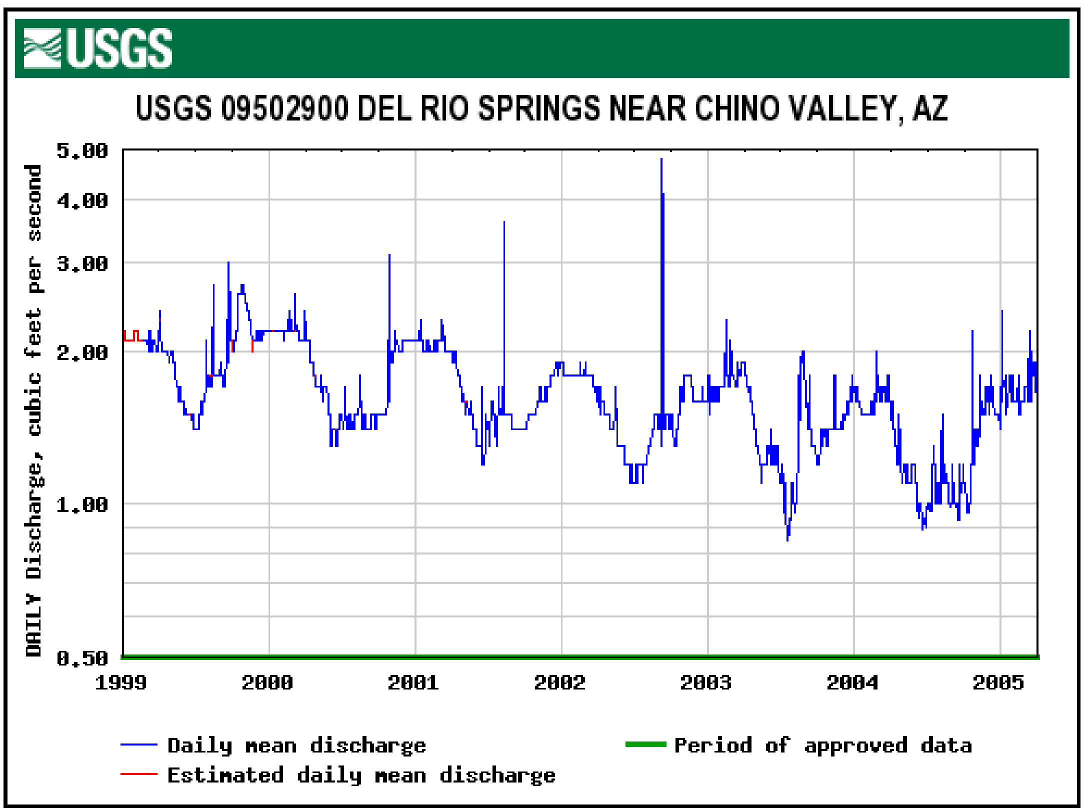

Hydrograph 18
Prescott AMA: Upper Agua Fria Sub-basin Adjacent to Lynx Creek
Head (feet)
4700
4675
4650
4625
4600
4575
4550
4525
4500
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Value - Layer 1, Row 39, Col 37
Measured Value - Well 55-613024

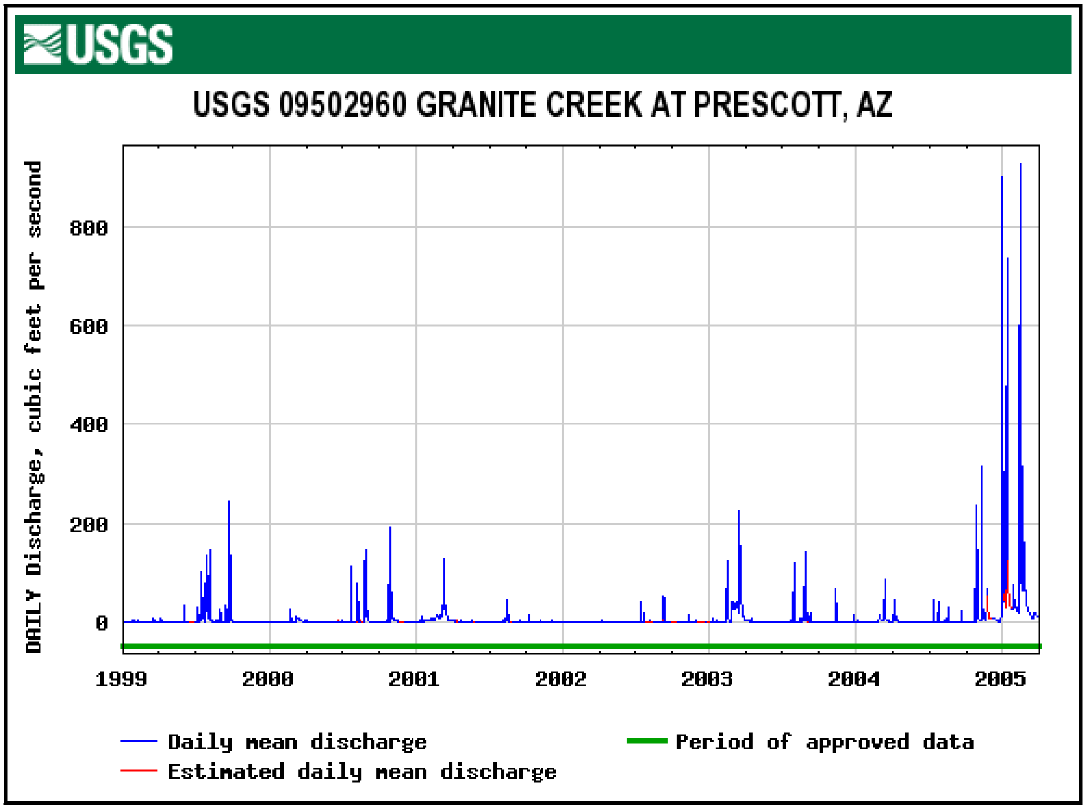

Hydrograph 19
Prescott AMA: Groundwater Discharge at Del Rio Springs
Discharge (acre-feet/year)
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Discharge (includes an undifferentiated ET component estimated at 100-200 af/yr)
USGS Gauge, 1997-2004 (USGS 1997-2004), plus estimated 100 af/yr for ET and 300 ft/yr for upstream diversions (Foster, 2001)
1940-1945 (Schwalen, 1967); plus estimated 100 af/yr for ET and 300 af/yr for unreported upstream sw diversions; does not include pumping impacts from Santa Fe wells
1965-1972 average (Matlock et al, 1973); plus estimated 100 af/yr for ET demand; does not include upstream sw diversions (if any)
1984-89 average (Corkhill and Mason, 1995); plus estimated 100 af/yr for ET demand, does not include upstream surface water diversions (if any)

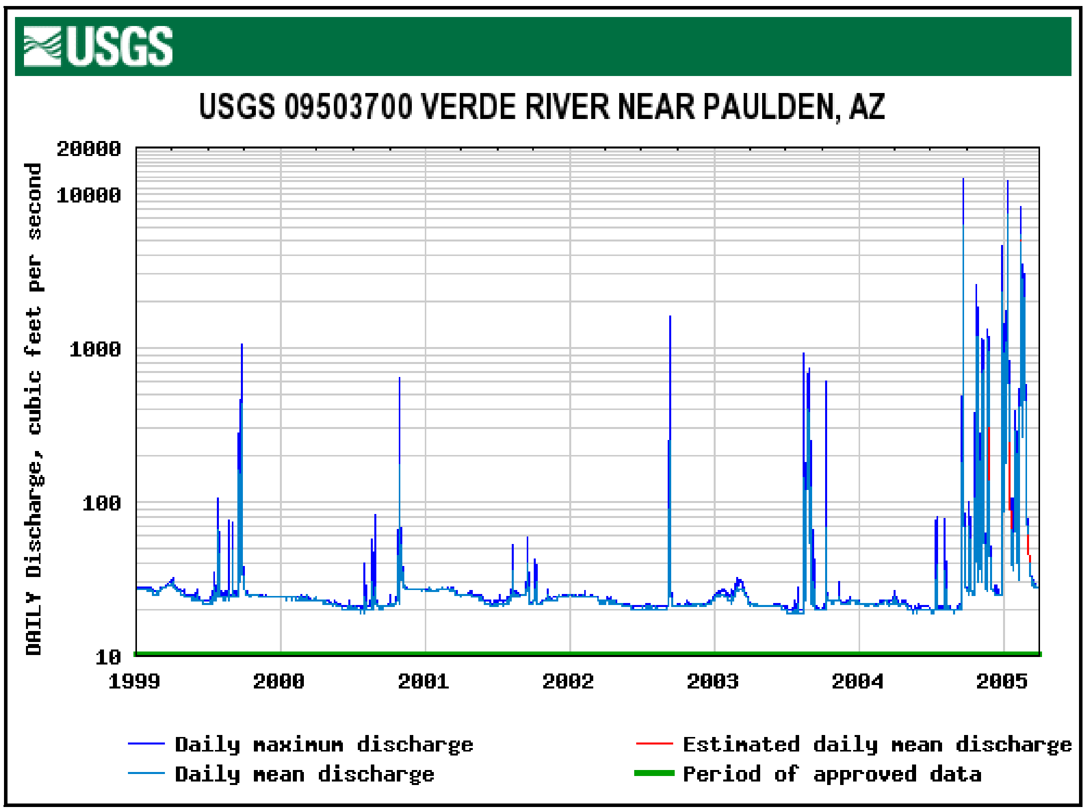

Hydrograph 20
Prescott AMA: Groundwater Discharge at the Agua Fria River
Discharge (acre-feet/year)
2400
2200
2000
1800
1600
1400
1200
1000
1940
1950
1960
1970
1980
1990
2000
2010
Year
Simulated Discharge (includes an undifferentiated ET component estimated at 200 af/yr)
1981 - 1997 average (ADWR, 1998); plus 200 af/yr for upstream ET demand
USGS Gauge (2000-2003); reduced to account for surface water runoff,
plus 200 af/yr for upstream ET demand

Appendix IV: Additional Figures


USGS
USGS 09503000 GRANITE CREEK NEAR PRESCOTT, AZ
DAILY Discharge, cubic feet per second
800
600
400
200
0
1999
2000
2001
2002
2003
2004
2005
Daily mean discharge
Estimated daily mean discharge
Period of approved data


USGS
USGS 09502900 DEL RIO SPRINGS NEAR CHINO VALLEY, AZ
DAILY Discharge, cubic feet per second
5.00
4.00
3.00
2.00
1.00
0.50
1999
2000
2001
2002
2003
2004
2005
Daily mean discharge
Estimated daily mean discharge
Period of approved data


USGS
USGS 09502960 GRANITE CREEK AT PRESCOTT, AZ
DAILY Discharge, cubic feet per second
800
600
400
200
0
1999
2000
2001
2002
2003
2004
2005
Daily mean discharge
Estimated daily mean discharge
Period of approved data


USGS
USGS 09503700 VERDE RIVER NEAR PAULDEN, AZ
DAILY Discharge, cubic feet per second
20000
10000
1000
100
10
1999
2000
2001
2002
2003
2004
2005
Daily maximum discharge
Daily mean discharge
Estimated daily mean discharge
Period of approved data

Appendix V: Steady-State Calibration Targets

Original Steady-State Targets											
Target #	Wells 55 #	Row	Col.	Layer	UTM X	UTM Y	Model X	Model Y	Year Measured	Measured Head	Target Value
1	No Match	26	16	2	368589	3834723	40596.62	59556.4	1947	4713	4713
2	639828	24	15	2	367772	3836306	37916.21	64749.9	1940	4675	4675
3	No Match	23	11	2	364550	3837153	27345.47	67528.7	1940	4756	4756
4	No Match	15	14	2	366990	3843866	35350.62	89552.7	1939	4609	4609
5	No Match	15	15	2	367830	3843915	38106.49	89713.5	1940	4604	4604
6	635722	13	14	2	367014	3845560	35429.36	95110.4	1938	4602	4602
7	606023	10	15	2	367675	3847307	37597.97	100842	1938	4603	4603
8	No Match	9	16	2	368759	3848431	41154.36	104530	1939	4599	4599
9	No Match	8	14	2	366783	3848953	34671.49	106242	1938	4601	4601
10	606300	8	17	2	369509	3849283	43614.96	107325	1941	4605	4605
11	No Match	8	14	2	367476	3849343	36945.09	107522	1940	4597	4597
12	605844	7	13	2	366412	3849636	33454.32	108483	1937	4595	4595
13	623528	7	15	2	367687	3849895	37637.34	109333	1940	4599	4599
14	No Match	6	13	2	366551	3850466	33910.35	111206	1940	4599	4599
15	608276	6	14	2	367087	3850582	35668.86	111587	1937	4596	4596
16	No Match	6	13	2	366500	3850436	33743.03	111108	1938	4599	4599
17	617596	6	14	2	366734	3850772	34510.74	112210	1938	4600	4600
18	No Match	6	13	2	366406	3850992	33434.63	112932	1938	4601	4601
19	No Match	5	16	2	368754	3851605	41137.95	114943	1939	4577	4577
20	No Match	5	13	2	366545	3851791	33890.66	115553	1939	4606	4606
21	No Match	4	15	2	367721	3852298	37748.88	117216	1938	4566	4566
22	No Match	3	14	2	366689	3852991	34363.1	119490	1938	4542	4542

New Steady-State Targets											
Target #	Wells 55 #	Row	Col.	Layer	UTM X	UTM Y	Model X	Model Y	Year Measured	Measured Head	Target Value
From ADWR GWSI Database											
23	802111	8	15	2	367715	3848690	37728.22	105379	1944	4598	4598
24	639828	24	15	1	367772	3836306	37916.21	64749.9	1940	4675	4675
25	623530	7	15	1	367727	3849903	37654.1	109590	1938	4556	4556
26	605843	7	13	2	366516	3849724	33679.1	108773	1935	4597	4597
27	613020	37	34	1	383368	3825994	89083.56	30917.9	1956	4666.5	4666.5
28	613018	37	36	1	384785	3825576	93732.13	29547.5	1969	4659	4659
29	613042	34	27	1	377828	3828666	70906.62	39683.9	1964	4742.2	4742.2
30	No Match	12	11	2	364906	3845745	28512.25	95717.1	1942	4595.46	4595.46
31	No Match	5	12	2	365902	3851307	31782.63	113967	1937	4596.6	4596.6
32	No Match	11	12	2	365910	3846624	31808.67	98600.5	1941	4599.85	4599.85
33	No Match	8	13	2	366349	3848774	33246.24	105656	1942	4600.42	4600.42
34	No Match	3	13	2	366689	3852991	34364.67	119489	1937	4540.3	4540.3
35	No Match	4	14	2	366754	3852158	34575.14	116756	1944	4576.03	4576.03
36	No Match	14	14	2	366990	3843866	35349.12	89552.2	1937	4609.3	4609.3
37	No Match	4	14	2	367415	3852179	36744.2	116826	1943	4562.5	4562.5
38	No Match	8	14	2	367476	3849343	36943.53	107523	1940	4597.21	4597.21
39	No Match	14	15	2	367830	3843915	38105.68	89714.6	1940	4603.97	4603.97
40	No Match	26	17	2	369127	3834931	42361.24	60237.5	1945	4678	4678

New Steady-State Targets (continued)											
Target #	**Wells 55 #**	**Row**	**Col.**	**Layer**	**UTM X**	**UTM Y**	**Model X**	**Model Y**	**Year Measured**	**Measured Head**	**Target Value**
41	No Match	6	17	2	369506	3850917	43606.34	112684	1938	4605.55	4605.55
42	No Match	6	17	2	369527	3850577	43673.93	111571	1938	4605.2	4605.2
43	606294	8	19	2	370735	3848860	47521.73	105938	1947	4599	4599
44	No Match	18	20	1	371679	3840811	50733.14	79528.4	1940	4613.72	4613.7
45	No Match	17	21	1	372410	3842187	53133.31	84044	1940	4618.95	4618.95
46	No Match	16	25	1	376077	3842414	65163.48	84789.5	1939	4611.14	4611.14
47	No Match	12	25	1	376300	3845739	65894.37	95696.8	1941	4609.47	4609.47
48	606295	7	19	2	370749	3849688	47684.46	108653	1948	4592.4	4592.4
49	611908	8	22	2	373755	3849239	57543.59	107182	1939	4608.16	4608.16
50	625108	11	27	2	377355	3847145	69356.11	100310	1940	4613.02	4613
51	613028	33	25	2	376469	3829259	66449	41630.1	1971	4663	4663
52	564575	23	8	2	362439	3837002	20421.01	67033.3	1999	4805.6	4805.6
53	639825	21	10	2	363696	3839033	24542.68	73696	1939	4753.5	4753.5
54	536656	21	6	2	360845	3838454	15190.1	71795.4	1999	4882.6	4885
55	636587	10	21	2	372502	3847431	53433.41	101249	1942	4621.43	4621
56	613043	38	36	1	384558	3824971	92678	27792	1956	4630.5	4630.5
57	638550	42	39	1	386962	3821699	101040.9	17239.2	1973	4617.9	4617.9
58	627588	23	5	1	359586	3837216	11058.92	67735.1	1992	5033	5033
From American Ranch Report (Manera 1999)											
59	573965	21	4	1	358982	3839047	9077.974	73742.2	1999	5019	5019
60	573968	22	4	1	359169	3838224	9690.499	71043.8	1999	5012	5012
From Head Map (Corkhill and Mason 1995)											
61		23	27	2	377819	3837019	70877.75	67089.1			4630
62		5	16	1	368554	3851598	40482.1	114920			4505
63		6	16	1	368735	3850754	41075.5	112151			4515
64		7	16	1	368614	3849910	40679.9	109381			4535
65		11	14	1	366864	3846917	34937.34	99563.8			4575
66		2	15	1	367831	3853829	38108.4	122239			4445
67		11	9	1	363104	3846985	22600	99786.3			4670
68		11	19	1	371145	3846744	48981.4	98994.5			4600
69		23	24	1	375136	3837083	62075.55	67300.4			4625
70		35	26	1	376788	3827445	67495	35677.3			4855
71		32	28	1	378130	3829820	71899.6	43470			4725
72		3	14	1	367047	3852985	35536.9	119470			4450