Arizona Department of Water Resources
Hydrology Division

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Application of the Prescott Active Management Area Groundwater Flow Model Planning Scenario 1999-2025

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By

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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 groundwater pumpage and recharge in the Prescott Active Management Area (Corkhill and Mason, 1995). The model has been updated with new hydrogeologic data and revised estimates of historical water-use and recharge. The updated model was calibrated to measured groundwater level and natural groundwater discharge targets, and was evaluated by a sensitivity analysis for steady state and transient simulations (1939-1999). In addition, the model was used to simulate *projected* hydrologic conditions, including groundwater levels and natural groundwater discharge, between 1999 and 2025.

The ADWR's Prescott Active Management Area includes 485 square miles in central Yavapia County and includes the Little Chino and Upper Agua Fria sub-basins which discharge groundwater to the Verde and Agua Fria Rivers, respectively. The model area covers about 220 square miles of the Upper Agua Fria and Little Chino sub-basins and includes the areas where most of the groundwater pumpage and recharge occur. Historical groundwater pumpage has reduced groundwater levels in most parts of the Upper Alluvial Unit and Lower Volcanic Unit aquifers, and has modified natural groundwater discharge out of the sub-basins. Model simulations have approximately replicated observed groundwater levels and natural groundwater discharge through the transient simulation (1939 to 1999) and through the beginning of the planning scenario (1999 to 2002).

One planning scenario was simulated from 1999 to 2053 to assess the hydrologic impacts of *projected* groundwater withdrawals and recharge. However, *projection* results were only assessed through the year 2025, because of an increasing number of dry model cells encountered halfway through the planning simulation. In the planning scenario, groundwater pumpage for municipal, industrial and domestic demands was *projected* to increase from about 14,000 acre-feet/year in 1999 to about 24,500 acre-feet/year by 2025; agriculture demand was *projected* to decrease from about 4,000 acre-feet/year in 1999 to about 2,100 acre-feet/year by 2025. Model *projection* results through 2025 show that continued groundwater pumpage will further exacerbate groundwater level declines in most parts of the model area and that the groundwater discharge rate near Del Rio Springs (spring flow at the surface and subsurface flow) will continue to decrease over time. However, groundwater levels are *projected* to rise in the southern portion of the Upper Agua Fria sub-basin and result in a gradual increase in groundwater

discharge at the Agua Fria River if the *projected* effluent recharge and long-term natural recharge rates hold true.

Model results demonstrate that except for years of significant precipitation and associated flood recharge, the Prescott AMA on a regional scale will continue to experience a net loss of groundwater storage.

ACKNOWLEDGEMENTS

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Chapter 1 Introduction and Background

1.1. Introduction

The Arizona Department of Water Resources (ADWR) has developed a Regional Groundwater Flow Model (model) for the Prescott Active Management Area (AMA). The model development and calibration process is documented in the *Hydrogeology and Simulation of Groundwater Flow Prescott Active Management Area Yavapai County, Arizona* report (Corkhill and Mason, 1995). The model has been modified, updated and recalibrated to include new hydrogeologic and water use information. In addition, the model has been utilized to simulate one planning scenario of future water use in the Prescott AMA. This report documents model updates and modifications and discusses results of the model simulations. [Note: A draft version of the updated model report was released in May 2001 for general public review and comment (Nelson, 2001). The numerical MODFLOW model has not been modified since the release of the draft report; however, this final report contains clarifications, recent and additional observation data, and other relevant information and references relating to the model.]

1.2. Objectives, Scope, Goals

The objective of the model simulations is to provide quantitative estimates of the impacts of potential groundwater pumpage and recharge to the Upper Alluvial Unit (UAU) and Lower Volcanic Unit (LVU) aquifers in the Prescott AMA. The scope of the predictive simulation is limited to portions of the Little Chino (LIC) and Upper Agua Fria (UAF) sub-basins within the Prescott AMA, and temporally to the time period 1999-2053. The goal of the modeling effort is to provide useful hydrologic projections which will aid the Prescott AMA in testing and refining its groundwater management strategies.

The goal of the model calibration was to:

- Obtain model solutions where simulated water budgets are within conceptual estimates for the steady state and transient simulations.
- Use bilinear interpolation to calculate the difference between measured heads and model simulated heads for the steady state simulation (circa 1939) and the transient simulation for 1950, 1960, 1970, 1982, 1994 and 1999. The calibration target for the absolute mean and standard deviation (RMS) of the residuals associated with the UAU and LVU aquifers was 20 feet or less than 5% of the system head loss. This is considered a small ratio of RMS error to the total head loss of the system given the heterogeneous nature of the aquifer systems (Anderson and Woessner, 1992).

- Develop and assess a sensitivity analysis.

Since the release of the *Draft* version of this report in May 2001, there has been considerable interest regarding the groundwater discharge points at Del Rio Springs and baseflow associated with the Agua Fria River (See Figures 13 and 14). These hydrologic features are not only important in their own right but also serve as valuable flux calibration targets for the model. Regarding the significance of applying sub-basin groundwater discharge as flux calibration targets it has been noted that, "…it is important to augment commonly available hydraulic head observations with flow observations. The latter serve to constrain solutions much more than the relatively easy to fit hydraulic head and therefore, using observations that reflect the rate and (or) direction of ground-water tends to promote the development of more accurate models" (Hill, 1998). Thus, an important goal of the model calibration was to honor groundwater discharge rates observed at Del Rio Springs and the Agua Fria River (see Hydrographs 7 and 8), as well as, the hydraulic heads associated with the Little Chino and Upper Agua Fria Sub-basins.

1.3. Prescott Model Area

The Prescott AMA is approximately 485 square miles in size and includes the LIC and UAF sub-basins. The model area is about 220 square miles and includes significant portions of both the LIC and the UAF sub-basins. It should be noted that most of the groundwater in storage, groundwater pumpage and recharge within the Prescott AMA exists within the model area (Figure 1).

1.4. Factors Which May Effect Model Results

The model results from the planning scenario represent an informed estimate of future groundwater conditions in the Prescott AMA. Results of the deterministic model simulation should not be accepted as an absolute prediction of future hydrologic conditions. The model scenario is based on *projections* including population, water demand and supply and it is unreasonable to assume that all *projections* will meet actual future conditions. Several important factors may change the *projected* conditions of water demand and supply including: 1) Utilization of groundwater sources from the Big Chino sub-basin (or other sources outside the AMA) for the City of Prescott (COP), Prescott Valley Water District (PV) and Chino Valley (CV); 2) alternative locations of groundwater withdrawal for the COP, PV and CV within the AMA; 3) rate of conversion from agricultural water use to municipal and industrial use; 4) changes in groundwater and surface water usage due to new rules and programs; 5) long-term weather changes which may effect surface water availability and mountain front recharge; 6) magnitude and frequency-of-occurrence of flood-induced recharge particularly along Granite Creek, Lynx Creek and the Agua Fria River; and 7) application rate of effluent recharge for COP, PV and CV.

The model results are also affected by the ability of the model to simulate certain types of groundwater flow conditions. The model is only an approximate representation of a complex, **regional** groundwater flow system, and it was necessary to make generalizations and simplifications in order to develop and calibrate the model. Thus, it is recommended that the readers view the model results in the context of the underlying assumptions and limitations.

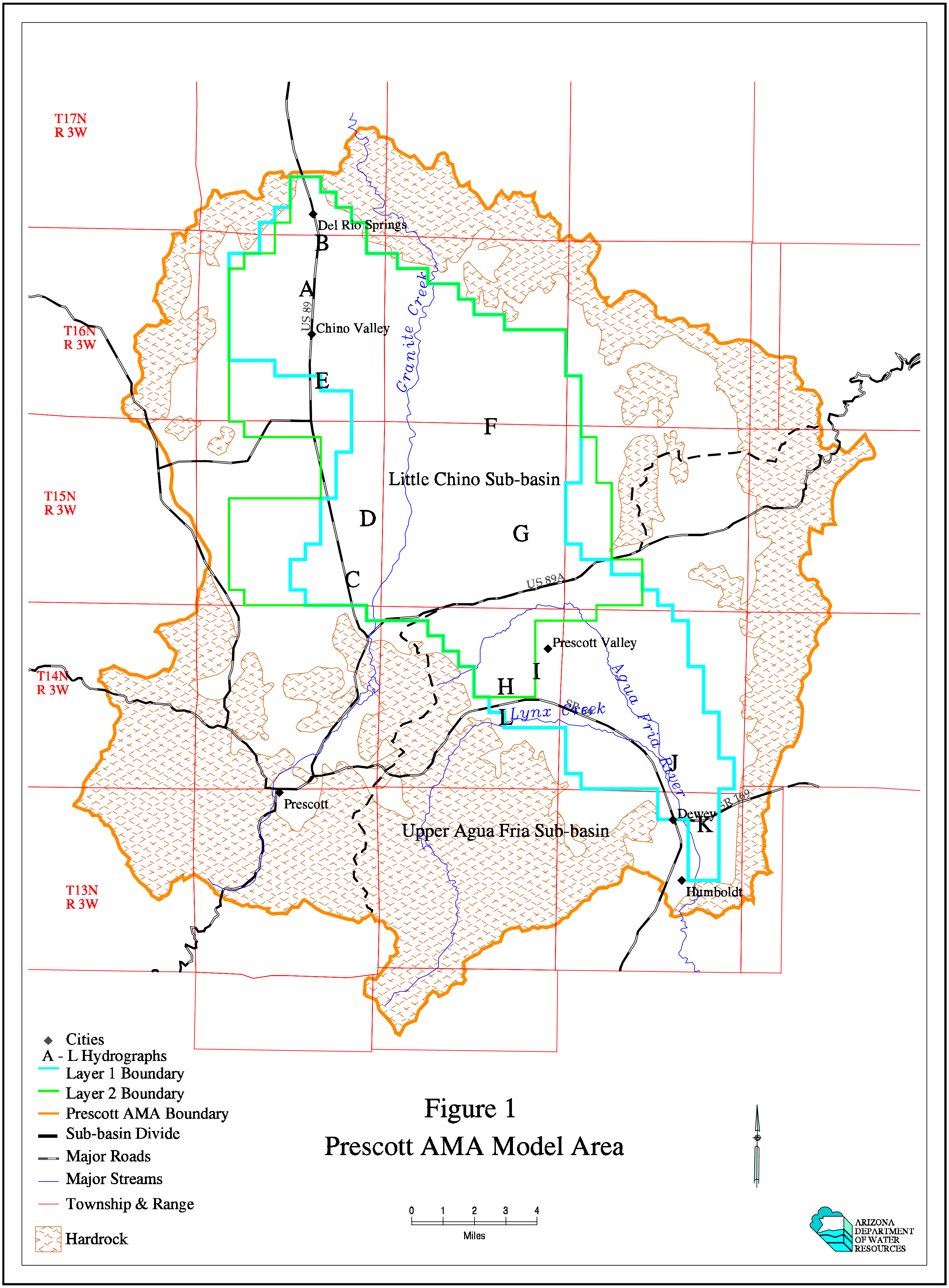


Figure 1
Prescott AMA Model Area

Chapter 2 Modifications to the Prescott AMA Model

Layer 1 (UAU)

In general, the hydraulic conductivity value of model cells located in the southern portion of UAU in the UAF sub-basin were increased with respect to the original model. Model cells located along Lynx Creek and portions of the Agua Fria River were adjusted to reflect the relatively high permeability of alluvial materials adjacent to the stream channels (Wilson, 1988; SFC, 1994). Furthermore, the hydraulic conductivity value associated with some model cells was necessarily increased during the calibration process to accommodate additional recharge imposed on the hydrologic system in order to achieve the model calibration goals (Also see Chapter 3 for recharge details). It should be noted that simply adding extra recharge to the original model parameters would have resulted in an unrealistic distribution of model heads in the UAU aquifer. Therefore in the model update, a reasonably realistic distribution of hydraulic head over space (hydraulic gradient), and parameters that provide acceptable rates of groundwater flow through porous media (represented by the hydraulic conductivity and saturated thickness) were required for the model calibration on a sub-basin scale; this is consistent with Darcy's Law as formulated by the numerical model, MODFLOW (McDonald Harbaugh, 1988). Also, see Hydrographs 1-8.

In the northwestern portion of the UAF sub-basin, the hydraulic conductivity values assigned to model cells representing the UAU aquifer were systematically adjusted while generally honoring aquifer test data at Prescott Valley's Lake Recharge site (SWMR, 1998). For the areal distribution of hydraulic conductivity assigned to model cells in the UAU, see Figure 2. The specific yield values of model cells in the northwestern portion of the LIC were generally increased from 7% to 10% during the calibration process to improve transient simulated heads in that area.

Layer 2 (LVU)

Model cells representing the LVU aquifer were extended south (to row 34) into the Santa Fe well field within the UAF sub-basin. This modification was based on recent drilling and aquifer testing in the Santa Fe well field. The transmissivity (product of hydraulic conductivity and aquifer-unit thickness) assigned to model cells in the immediate vicinity of the Santa Fe well field reflect data obtained during aquifer testing (CH2M HILL, 1999). The transmissivity values assigned in the vicinity of the surface water divide and surrounding the Santa Fe well field were systematically reduced during the calibration process to reflect the observed decline rate over the last couple decades. However, the transmissivity value from aquifer tests conducted at the Viewpoint wells (B-15-1) 26cbc was generally honored (SWMR, 1995).

Model cells representing a 'geologic barrier' (associated with a decrease in horizontal permeability adjacent to Del Rio Springs – see Schwalen, 1967) at the northern end of the artesian area in the LIC sub-basin were relocated one-half mile north (from row 5 to row 4) during the calibration process. This change was made to improve simulated heads and groundwater discharge rates. In addition, hydraulic conductivity values assigned to some model cells along the western and eastern boundaries were adjusted during the calibration process. For the areal distribution of hydraulic conductivity assigned to model cells in the LVU, see Figure 3.

Elevations of model cells representing the LVU and UAU were updated based on recent well drilling data in portions of the model area. As with the original model, the LVU was assigned a uniform thickness of 200 feet throughout the model area. The storage properties of the LVU aquifer were not modified.

Vertical Connection between Layer 1 (UAU) and Layer 2 (LVU)

The vertical conductance in the vicinity of the Santa Fe well field was assigned a value of zero reflecting the hydrologic isolation between the UAU and LVU aquifer systems as determined by aquifer testing (CH2MHILL, 1999). Furthermore, the groundwater level response between the UAU aquifer and LVU aquifer near the Santa Fe well field show dissimilar historical trends (ADWR, 2000b).

Boundary Conditions

To simulate subsurface flow in the UAU aquifer from the LIC to the Big Chino sub-basin, general head boundaries (GHB) replaced the constant head boundaries assigned in the original model in row 1 (McDonald and Harbaugh, 1988). The GHB enable variable boundary fluxes to be applied directly to variable-head model cells and do not act as infinite sources, or sinks, of water. General head boundaries were also assigned to simulate subsurface flow in the LVU aquifer from the LIC sub-basin into the Big Chino sub-basin. The application of GHB to the LVU aquifer had the effect of constraining the heads in the LVU aquifer, thus offsetting the generalized increase in recharge applied to the LIC sub-basin.

The two drain cells simulating groundwater discharge conditions at the Agua Fria River were relocated one-half mile to the west (from column 40 to 39) to reflect the geographic location of the river with respect to the model.

Chapter 3 Steady State Simulation of the Prescott AMA Model

The steady state simulation for the Prescott AMA Groundwater Model has been conceptually modified. An approximate equilibrium is believed to have been established in the LIC sub-basin by approximately 1937 (Schwalen, 1967). Since 1915, a significant portion of natural Granite Creek recharge was impounded and 'transferred' to incidental agricultural recharge within the Chino Valley Irrigation District (CVID), and to recharge along the CVID main canal. In addition, agricultural-related groundwater pumpage within the LIC sub-basin commenced in 1937 (Schwalen, 1967). Thus, natural and agricultural-related incidental recharge, as well as, limited rates of groundwater pumpage in the LIC sub-basin were necessarily imposed on the simulation to reflect the quasi-steady condition of the hydrologic system in the late 1930's. The steady state simulation represents the period of approximate hydrologic equilibrium from April 1939 through October 1939, and also represents the first time period when widespread, water level measurements (head calibration targets) in the LIC sub-basin were recorded (ADWR, 2000b).

3.1. Steady State Simulation: Groundwater Pumpage

The groundwater withdrawal rate applied to the steady state simulation in the LIC sub-basin was about 1,500 acre-feet/simulation. The groundwater demand rate represented a limited stress to the groundwater system, which, prior to 1940, had not experienced a significant loss of storage. The magnitude and distribution of steady state groundwater pumpage in the LIC is based on:

- Areal distribution of historical irrigation rights proportioned to approximately 50% agricultural demand estimated for 1937-39 (average)
- Vertical distribution pumpage ratio (LVU:UAU) of 3:1

The groundwater withdrawal rate was reduced by 50% if agriculture land was located within the CVID reflecting the application of CVID surface water and the reduced need for groundwater pumpage. No groundwater pumpage was applied to the UAF sub-basin over the steady state simulations.

3.2. Steady State Simulation: Recharge

Incidental Agriculture Recharge

Incidental recharge was estimated to be 50% of the applied groundwater pumpage or about 750 acre-feet. Incidental surface water recharge to the CVID agriculture land, including ditch and lateral losses, was estimated at 50% of the 1915-1939 average CVID delivery, or 950 acre-feet (Reidhead, 1968). In addition, 300 and 210 acre-feet/simulation of incidental surface water recharge was applied to the Del Rio Ranch and surface water diversions north of Watson

Lake, respectively. Thus, the total incidental agricultural recharge applied to the steady state simulation was 2,210 acre-feet.

CVID Main Canal Recharge

The CVID canal recharge applied to the steady state simulation was estimated to be about 950 acre-feet. This estimate was based on the average CVID delivery from 1915-1939, and an estimated 33% canal-recharge loss (Bureau of Reclamation, 1946). To compute canal recharge for the 26 assigned canal recharge cells a wetted area approach using Manning's Equation was employed**.**

Mountain Front Recharge

The total mountain front recharge (MFR) rate applied to the steady state simulation was about 4,000 acre-feet/simulation (7,000 acre-feet/year). All MFR, except recharge originating from Granite Creek, was increased by 25%, with respect to the original model's areal MFR distribution. The non-Granite Creek MFR rate of 3,300 acre-feet/simulation (5,750 acre-feet/year), was increased to achieve the model calibration goals for hydraulic heads and groundwater discharge within the framework of the modified parameters discussed in Chapter 2. The total MFR rate includes 700 acre-feet/simulation (1,200 acre-feet/year) of spillage and unaccounted-for-releases from Granite Creek was applied to the steady state simulation (Schwalen, 1967).

Chapter 4 Transient Simulation of the Prescott AMA Model (1939-1999)

Hydraulic heads from the steady state solution were applied as the starting heads for the transient simulation. The transient simulation covers 119 stress periods from November 1939 through March 1999. There were two stress periods per water-year including a 210-day irrigation season from April through October and a 155-day, non-irrigation, stress period from November through March.

4.1. Transient Simulation: Groundwater Pumpage

The magnitude and distribution of groundwater pumpage applied to the LIC sub-basin for agricultural purposes from 1939 through 1983, was based on:

- Estimated irrigated acreage per year
- Areal distribution of historical irrigation rights
- Estimated consumptive use of crop
- An estimated irrigation efficiency of 50%
- Vertical distribution pumpage ratio of (LVU to UAU) 3:1

The groundwater withdrawal rate was reduced by 50% if agriculture land was located within the CVID reflecting the application of CVID surface water and the reduced need for groundwater pumpage.

The modifications made to agricultural-related groundwater requirements in the LIC sub-basin from 1939 through 1983 did not significantly change the net groundwater withdrawal volume with respect to the original model. However, the areal distribution of pumpage reflected a reduced groundwater demand in the CVID, and an increased demand in non-CVID areas. All other non agriculture-related pumpage prior to 1984 remained identical to the original model estimates.

As with the original model, after 1983, groundwater withdrawal rates for agricultural, municipal and industrial uses were based on records provided by non-exempt groundwater users in the Prescott AMA (ADWR, 2000a). All agricultural and turf-related groundwater pumpage was applied during irrigation stress periods. All municipal, non-turf industrial and domestic groundwater pumpage was applied at uniform rates throughout the water-year. The total groundwater pumpage imposed over the transient simulation was about 928,000 acre-feet.

4.2. Transient Simulation: Recharge

Incidental Agricultural Recharge

The areal distribution of incidental agriculture recharge from groundwater pumpage was estimated at 50% of groundwater pumpage. Incidental agriculture recharge from surface water and effluent sources was estimated at 50% of the reported surface water applied to the land including ditch losses. Surface water delivery records for the CVID were available from 1915-1967 and from 1980-1998. Surface water delivery for 1968-1979 was estimated at 1,500 acre-feet per stress period. In addition, 300 and 210 acre-feet of incidental agricultural surface water recharge was applied to the Del Rio Ranch and surface water diversions north of Watson Lake, respectively. The model assumes that no time lag is associated with the downward percolation of recharge water through the vadose zone. Therefore, agriculture recharge is assumed to reach the water table instantaneously. The total agricultural-related recharge imposed over the transient simulation was about 445,000 acre-feet, including groundwater and surface water sources.

CVID Main Canal Recharge

Seepage along the main CVID canal was estimated at 33% based on extensive canal seepage-loss measurements conducted in 1940's (Bureau of Reclamation, 1946). Because records and estimations for CVID delivery were available throughout the transient simulation time period, the main canal losses could be computed between the diversion point near Watson Lake and the CVID agriculture land. However, during the transient calibration the canal recharge was increased by 25% to improve simulated heads in the UAU aquifer. The increase in canal recharge over time may reflect a generalized decrease in canal and lateral-conveyance efficiency over time. The total CVID canal-seepage recharge imposed over the transient simulation was about 62,000 acre-feet.

Mountain Front Recharge

As mentioned in Chapter 3, the MFR rate, excluding recharge assigned to Granite Creek, assigned over the transient simulation was increased by 25%, with respect to the original model's MFR areal distribution to provide acceptable solutions for model heads and groundwater discharge rates over the steady state and transient simulations. As with the original model, recharge for the Willow Creek drainage was applied over the transient simulation in order to account for spills from either Willow Creek or Granite Creek. Thus, a uniform, model-calibrated MFR rate of 5,750 acre-feet/year was assigned over the transient simulation totaling about 342,000 acre-feet over the transient simulation. Although the *actual* natural recharge rate into the model area obviously varies from year to year (depending on weather factors), it should be noted that cyclical recharge pulses naturally dampen – from source locations - in porous media over space and time (See Maddock et al., 1996). Because the location of the majority of model cells representing MFR are at sub-basin scale distances to most areas of interest within the regional model domain, the MFR was assigned at a uniform rate to reflect long-term averages.

Flood Recharge

Flood recharge was estimated using a wetted area approach at times when significant flood events occurred on the Granite Creek watershed. Flood recharge to Granite Creek was assigned to 24 cells and was based on an estimated channel width of 1,320 feet/cell, a channel length of 2,640 feet/cell and an estimated recharge rate of 0.25 feet/day (Corkhill and Mason, 1995). Although not included in the original model, flood recharge was also applied on portions of Lynx Creek and the Agua Fria River drainage at times when significant flood events also occurred on the Granite Creek watershed. Flood recharge to the Lynx Creek and Agua Fria River drainage was assigned to 19 cells and was based on an estimated channel width of 75 feet/cell, channel length of 2,640 feet/cell, and an estimated recharge rate of 1.0 feet/day. The total flood-induced recharge imposed over the transient simulation was about 41,920 acre-feet (See Table 1). It should be noted that less significant flood recharge periods are aggregated components of the annualized MFR rate.

Table 1
Flood Recharge Applied to the Prescott AMA Groundwater Model

Event Year	Number of Days per Event	Granite Creek (acre-feet/event)	Lynx Creek/Agua Fria River (acre-feet/event)
1978	9	4,320	780
1980	13	6,240	1,120
1983	4	1,920	350
1993	39	18,720	3,370
1995	9	4,320	780
Total	**74**	**35,520**	**6,400**

Effluent Recharge

Effluent recharge was applied at the City of Prescott's Airport Recharge Facility and Prescott Valley's Wastewater Treatment Plant site near the Agua Fria River. Total effluent recharge imposed over the transient simulation was about 28,300 acre-feet. See Table 2.

Table 2
Effluent Recharge Applied to the Prescott AMA Groundwater Model

Year	Prescott (acre-feet/year)	Prescott Valley (acre-feet/year)
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
Total	**22,750**	**5,550**

Chapter 5 Results of the Steady State Simulation

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

Steady State Water Budget

Table 3 shows the water budget results of the steady state simulation.

Table 3
Simulated and Conceptual Steady State Water Budgets
(Figures Rounded to Nearest 100 acre-feet)

Inflow	**Model Simulation acre-feet/simulation (acre-feet/year)**	**Conceptual acre-feet/simulation (acre-feet/year)**
Mountain Front and Granite Creek Recharge	4,000 (7,000 AF/YR)	4,000 (7,000 AF/YR)
Agricultural Recharge	2,200	2,200
Canal Recharge	900	900
Total Inflow	**7,100**	**7,100**
Outflow	**Model Simulation**	**Conceptual**
Groundwater Pumpage	1,500	1,500
Groundwater Discharge Del Rio Springs (LIC)	2,500 (4,400 AF/YR[1])	1,300–2,000 (2,300–3,400 AF/YR[2]) (2,700–3,800 AF/YR[2a])
Groundwater Discharge Agua Fria River (UAF)	1,300 (2,400 AF/YR[3])	900–1,400 (1,500–2,500 AF/YR[4])
Groundwater Discharge Subsurface flow (LIC)	1,800 (3,100 AF/YR)	1,300-2,600 (2,200-4,500 AF/YR[5]) (5,600 AF/YR[6]) (2,000 AF/YR[7])
Total Outflow	**7,100**	**5,000 – 7,500**

[1] Contains an undifferentiated ET component estimated at 100-200 acre-feet/year
[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] Contains an undifferentiated ET component estimated at 200 acre-feet/year
[4] Corkhill and Mason, 1995
[5] Darcy Strip Analysis: Q_x=KA dh/dx. Estimates for the LVU: $K_{\text{high est}}$=25 feet/day; $K_{\text{low est}}$=5 feet/day, A= 840,000 feet^2 (4,200 feet by 200 feet); dh/dx = 0.022 based on potentiometric heads in 1938 (B-17-02) 35CCC1 and (B-17-02) 26CCA (ADWR 2000b); $K_{\text{UAU est}}$=10feet/day; A=840,000 feet^2; dh/dx = 0.01.
[6] Groundwater discharge as subsurface flow based on confined well steady state equation (SRP, 2000)
[7] Corkhill and Mason, 1995 (Note: UAU aquifer only)

Steady State Calibration Error Analysis

Simulated heads from the steady state solution were compared using bilinear interpolation with 29 groundwater levels measured over the quasi-steady time period in the LVU aquifer (ADWR, 2000b). See Table 4 for a summary of the statistics regarding the calibration analysis.

Table 4
Statistical Summary of Steady State Error Analysis for LVU (Layer 2)

Raw: Measured minus Simulated (feet)			**Absolute: Measured minus Simulated (feet)**		
Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
-1.2	13.9	0	9.0	10.4	5

Discussion of Steady State Simulation Results

The total simulated steady state ‘natural’ groundwater discharge rate out of the LIC sub-basin (representing groundwater discharge at Del Rio Springs and subsurface flow) was about 7,400 acre-feet/year. The simulated steady state groundwater discharge rate representing Del Rio Springs, 4,400 acre-feet/year, exceeds conceptual estimates. However, within the framework of the model, the initial groundwater discharge rate at Del Rio Springs (>4,000 acre-feet/year) was required in order to achieve the calibration goals (flux targets) over the transient simulation. It should be noted that the conceptual/measured spring discharge listed in Table 3 represents a time period where spring discharge was measured immediately adjacent to high production supply wells (i.e. Santa Fe wells – see Schwalen, 1967). In addition, there is uncertainty regarding the quantity of unreported surface water diversions for agricultural and/or municipal purposes above the gauge during the steady state time period. Surface water diversions above the gauge would have caused the amount of water measured at the gauge to under-report the actual groundwater discharge from the collective spring and cienega system. Thus, it is conceivable that the pre-development groundwater discharge at Del Rio Springs (as surface water) approached or even exceeded 4,000 acre-feet/year. The steady state simulated groundwater discharge rate as subsurface flow was about 3,100 acre-feet/year, which is within conceptual estimates. However, there exists uncertainty regarding the conceptual subsurface groundwater discharge flow rate - as reflected in Table 3.

Model-simulated groundwater discharge in the UAF sub-basin was about 2,300 acre-feet/year, which is within the conceptual estimates of baseflow in the Agua Fria River near Humboldt.

The error associated with residuals (see Table 4) were within the calibration goals of the model. Results of the bilinear interpolation indicate the error associated with the residuals was less than 2.5% of total system head loss. However, it should be noted that most of the measured water levels over the steady state calibration time period were limited to the LIC sub-basin agriculture area. Therefore, the assessment of steady state error analysis should be reviewed within that context.

Chapter 6 Results of the Transient Simulation

Results of the transient simulation were evaluated by comparing model-simulated water budgets with conceptual estimates and model-simulated heads with measured water levels. Also, see Hydrographs 1-8 for groundwater level changes over the transient simulation (1939-1999) and the Planning Scenario (1999-2025).

Transient Water Budget

Table 5 shows model simulated water budgets for 1940 and 1999. In addition, model simulated results were compared with conceptual estimates for 1999.

Table 5
Simulated and Conceptual Transient Water Budgets (1940 and 1999)
(Figures Rounded to the Nearest 100 acre-feet)

Inflow	**Simulated 1940 Acre-feet/year**	**Simulated 1999 Acre-feet/year**	**Conceptual 1999 Acre-feet/year**
Mountain Front Recharge	5,800	5,800	5,800
Recharge: Incidental Agriculture & CVID Canal, Effluent	4,100	6,900	6,900
Released from Storage	5,200	10,800	N/A
Total Inflow	**15,100**	**23,500**	**N/A**
Outflow	**Simulated 1940**	**Simulated 1999**	**Conceptual 1999**
Groundwater Pumpage	4,600	16,200	16,200
Groundwater Discharge Del Rio Springs (LIC)	4,300[1]	1,800[1]	1,400[2] 1,800[2a]
Groundwater Discharge Agua Fria River (UAF)	2,400[3]	1,400[3]	1,300[4] 1,600[4a]
Groundwater Discharge Subsurface flow (LIC)	2,800	1,800	1,200-2,100[5] 1,500-2,000[6]
Taken into Storage	1,000	2,300	N/A
Total Outflow	**15,100**	**23,500**	**N/A**
Change-in-Storage	**-4,200**	**-8,500**	**N/A**

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

[2] Surface water measurements (median) at Del Rio Springs 1999 (USGS, 1998, 1999, 2000) 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 1999 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] Manual surface water measurements (1981-1997 average; ADWR, 1998) Note: Sub-basin groundwater discharge rate does not reflect the estimated ET demand of 200 acre-feet/year upstream from measurement site.

[4a] Median surface water measurements at Agua Fria River 2000 (USGS, 2000) Note: Sub-basin groundwater discharge rate does not reflect estimated ET demand of 200 acre-feet/year upstream of gauge.

[5] Darcy Strip Analysis: Q_x=KA dh/dx. Estimates for the LVU: $K_{high\ est}$=25 feet/day; $K_{low\ est}$=5 feet/day, A= 840,000 feet^2 (4,200 feet by 200 feet); dh/dx =0.0083 based on potentiometric heads in 1999 (B-17-02) 34DDD and (B-17-02) 27DCC (ADWR, 2000b); $K_{UAU\ est}$ = 10feet/day; A=840,000 feet^2; dh/dx = 0.01.

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

[It should be noted in Table 5 (and Table 9 of Chapter 10) there exist MODFLOW accounting terms, including “Released from Storage”, “Taken into Storage” and “Changes in Storage”, that quantify changes in water volume over time. The “Released from Storage” term quantifies how much water from storage was required to balance the transient groundwater system as defined by model parameters, and formulated and solved by MODFLOW. The “Released from Storage” term actually reflects a decrease in groundwater storage and is thus associated with a lowering of the hydraulic head. Conversely, “Taken in Storage” reflects an increase in groundwater storage and is thus associated with an increase in head. In the Transient Water Budget the “Change in Storage” term is equal to “Taken into Storage” minus “Released from Storage”.]

Transient Calibration Error Analysis

Layer 1 and 2 heads were compared, using bilinear interpolation, with groundwater levels measured in 1950, 1960, 1970, 1982, 1994 and 1999 to assess the transient calibration. A total of 391 (130 and 261 for the UAU and LVU aquifers, respectively) measured water levels were obtained from ADWR’s GWSI database (ADWR, 2000b) and used in the analysis. See Tables 6, 6a, and 6b for the statistical error analysis summary of the statistics.

Table 6
Combined Statistical Summary of Transient Simulation Error Analysis for the UAU (Layer 1) and LVU (Layer 2)

Raw: Measured minus Simulated (feet)			**Absolute: Measured minus Simulated (feet)**		
Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
-1.0	24.4	-3	17.5	17.0	12

Table 6a
Statistical Summary of Transient Simulation Error Analysis for the UAU (Layer 1)

Raw: Measured minus Simulated (feet)			**Absolute: Measured minus Simulated (feet)**		
Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
6.9	31.2	12.5	26.6	17.5	22

Table 6b
Statistical Summary of Transient Simulation Error Analysis for the LVU (Layer 2)

Raw: Measured minus Simulated (feet)			**Absolute: Measured minus Simulated (feet)**		
Mean	Standard Deviation	Median	Mean	Standard Deviation	Median
-4.9	19.0	-4	13.0	14.8	8

Discussion of Transient Simulation (1939-99) Results

An important goal of the transient model calibration was to simulate the:

- Hydraulic heads in the UAU and LVU aquifers that approximate observed heads over space and time (See Tables 6, 6a and 6b; and Hydrographs 1-6; Figure 8)
- Groundwater discharge rates for the LIC and UAF sub-basins that approximate observed groundwater discharge rates over time at Del Rio Springs and baseflow in the Agua Fria River (See Table 5 and Hydrographs 7 and 8).

Inspection of Table 5 and Hydrograph 9 show that, overall, the simulated groundwater system experienced a net loss of storage and an increase in capture of groundwater discharge. Model simulations show that the groundwater discharge rate (as surface water flow at Del Rio

Springs and subsurface flow) out of the LIC sub-basin has been reduced by a rate of about 3,500 acre-feet/year (approximately 5 ft^3/s) since the beginning of the transient simulation. The cumulative change-in-storage in the model area over the transient simulation was about -425,000 acre-feet.

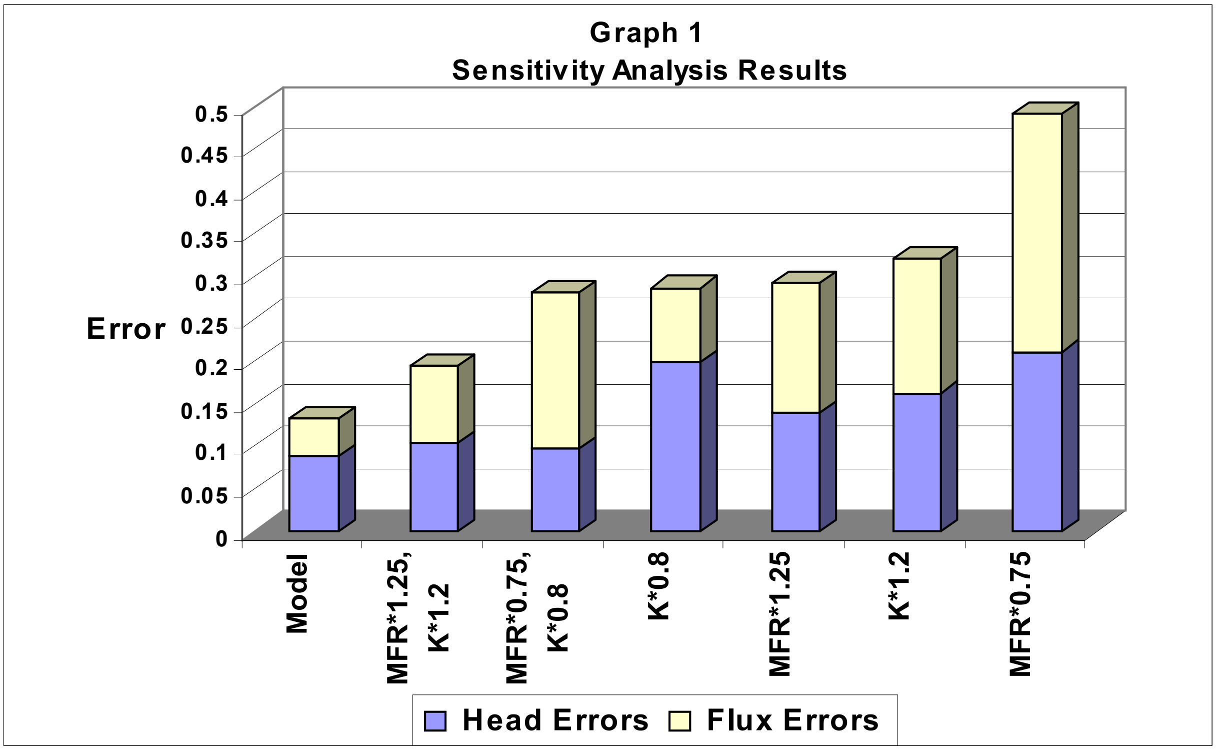
Results from the transient simulation residual error analysis for the absolute mean and standard deviation was 17.5 and 17, respectively, which is within the calibration goal (for the UAU and LVU aquifers). See Figure 8 for the difference between measured and simulated water levels at the end of the transient simulation (1999). [It should be noted that some errors associated with residuals, including those in the Santa Fe well field, reflect a dichotomy between model simulated heads influenced by continuous groundwater pumping demands (as assigned in the model) and observed heads - generally measured during non-pumping, recovering periods. (Also see Appendix A, (B-14-01) 10adba PZ1 in ADWR, 2002).]

Hydrographs 1-3 show decreasing groundwater-level decline rates in the LIC sub-basin between the mid-1970's and the mid-1990's, which can be attributed to a general reduction in agricultural groundwater pumpage and an increase in flood-induced recharge since the mid-1970's. Furthermore, decreasing groundwater-level decline rates during this period also reflect an outward expansion of the cone of depression (hydraulic gradients) from the general Chino Valley pumping center.

Chapter 7 Sensitivity Analysis

A limited sensitivity analysis for the transient and steady state simulations was conducted to determine the relative sensitivity of the final model solution. The sensitivity analysis focused on the hydraulic conductivity and mountain front recharge because those were found to be among the most sensitive in the original model (Corkhill and Mason, 1995). The hydraulic conductivity and mountain front recharge were uniformly changed by factors of +/- 20% and +/- 25%, respectively. In addition, two other sensitivity analyses were conducted in which the hydraulic conductivity and mountain front recharge were simultaneously modified +/- 20% and +/- 25%, respectively. See Table 7 for results of the sensitivity analysis.

Graph 1, was created to better visualize the results of the sensitivity analysis. The Error on the vertical axis was compiled using two components: the residual head error and the deviations from flux targets. The flux error component consisted of the groundwater discharge at the Agua Fria River and at Del Rio Springs for the steady state and transient simulations (1999). The subsurface flow at the northern border near Del Rio was omitted because of uncertainty in conceptual estimates. The head error component consisted of results from the bilinear interpolation for steady state and transient simulations (1999). All component errors were assigned weights of 1.0 except for the steady state groundwater discharge errors, which were assigned weights of 0.5 due to the uncertainty of pre-development measurements.



The flux error component in Graph 1 consisted of evaluating the absolute difference between the sensitivity analysis results and the calibration target value (see Table 7). The flux error for each sensitivity analysis was then divided by the total summed flux error for all seven simulations (six sensitivity simulations and the model simulation) to yield the relative error for each simulation. Similarly, the head error component consisted of dividing the absolute mean residual of each simulation by the total summed residual error for all seven simulations to yield the relative head error for each simulation. The error components were then proportionately scaled such that summed total for both the flux and head errors were equal to one so that the head and flux errors could be treated equally in the graph.

Table 7
Sensitivity Analysis Results
(Flux values rounded to 100 acre-feet)

Parameter	Change Factor	Groundwater Discharge at the Agua Fria Steady State (AF/Year)	Groundwater Discharge at Del Rio Springs Steady State (AF/Year)	Groundwater Discharge at the Agua Fria 1999 (AF/Year)	Groundwater Discharge at Del Rio Springs 1999(AF/Year)	Bilinear Interpolation Absolute value of mean residuals: Steady State LVU (ft)	Bilinear Interpolation Absolute value of mean residuals: 1999 UAU and the LVU (ft)
Target Value	N/A	2,500	3,500	1,500	1,800	0	0
Model	N/A	2,400	4,400	1,400	1,800	9	20
MFR	1.25 X	2,900	4,700	1,900	2,200	17	27
MFR	0.75X	1,400	3,400	500	900	28	38
K	1.2X	2,100	4,200	1000	1,300	21	30
K	0.8X	2,400	4,600	1,500	2,200	33	26
MFR, K	1.25, 1.2 X	2,900	4,700	1,800	1,800	12	21
MFR, K	0.75, 0.8 X	1,700	3,600	800	1,300	9	23

Discussion of Sensitivity Analysis Results

Table 7 and Graph 1 show the results of the sensitivity analysis. Results indicate that the model provides solutions that result in less error than those associated with other defined change factor errors. However, the simultaneous adjustment of hydraulic conductivity and mountain front recharge by factors of 1.2X and 1.25X, respectively, also resulted in a relatively small error compared with the other change factors. On a related note, recently conducted drilling and aquifer testing has shown that a highly permeable zone of the LVU aquifer exists below the origination of Del Rio Springs (ASA, 2002). The existence of a highly permeable zone of LVU aquifer (which appears to taper to the north - with an unknown termination point) along with the hydraulic gradient associated with area, suggest that there may be a more significant subsurface groundwater discharge flow component out of the LIC sub-basin than originally conceptualized.

The independent adjustment of model parameters and/or imposed stresses to hydrologically distinct zones, as opposed to uniform-wide model adjustments, as well as inclusion of the subsurface flow component (omitted because of uncertainty) in the error analysis, may reveal more optimal model conditions than which currently exist. At this time, however, results of a more refined sensitivity analysis would probably yield uncertain results without additional, widespread hydrogeologic information.

Chapter 8 Groundwater Conditions in 1999

Model-simulated groundwater conditions for the Prescott AMA in the spring of 1999 are shown in Figures 4 through 7.

The model-simulated heads and depth-to-water (DTW) in the UAU aquifer are shown in Figures 4 and 5, respectively. The DTW ranges from land surface elevation, near Del Rio Springs and the Agua Fria River near Humboldt, to over 560 feet near Prescott Valley's Santa Fe well field. The water level change in the UAU aquifer over the transient simulation ranged from an increase of 40 feet, at the City of Prescott's Airport Recharge Site, to declines exceeding 70 feet throughout the Lonesome Valley area. A total of 14 cells, located mainly along the eastern and western UAU boundaries, went dry over the transient simulation. [Note: Some layer 1 model cells were already de-watered from the steady state simulation along some Layer 1 boundary margins; the original model UAU aquifer boundary, however, was preserved.]

The model-simulated heads and DTW in the LVU aquifer are shown in Figures 6 and 7. The DTW ranges from about land surface elevation, near the Del Rio Springs area, to over 600 feet in the Santa Fe well field. The water level change over the transient simulation ranged from an increase of about 20 feet at the City of Prescott's Airport Recharge Site to a decline of 170 feet in the Santa Fe well field. Three model cells in the LVU went dry over the transient simulation.

Because, in part, of model resolution limitations in the vicinity of the Santa Fe well field, the model underestimated the drawdown in some cells by almost 100 feet with respect to measured, non-pumping water levels (ADWR, 2000b). Thus, it should be noted that the starting heads for the planning simulations around the Santa Fe well field are based on this model reference. [Also, see page 16 of this report].

The total simulated 'natural' groundwater discharge out the LIC sub-basin in 1999 was about 3,600 acre-feet/year. Simulated and observed/conceptual groundwater discharge, representing surface water at Del Rio Springs in 1999, was about 1,800 acre-feet/year. The simulated groundwater discharge representing subsurface flow out of the LIC sub-basin was about 1,800 acre-feet/year. The simulated and observed groundwater discharge at the Agua Fria River near Humboldt in 1999 was about 1,400 and 1,600 acre-feet/year, respectively. [Note: Simulated groundwater discharge at Del Rio Springs and the Agua Fria River contains an undifferentiated ET component, which, if included in the model, would further reduce the simulated groundwater discharge rate; see Table 5 and Hydrographs 7 and 8.]

Chapter 9 Planning Scenario 1 (1999-2053)

This chapter describes the stresses imposed on groundwater model simulation, Planning Scenario 1 (PS1). Simulated heads from the end of the transient simulation were applied as the starting heads for PS1. See Chapter 8 for information regarding the groundwater conditions in 1999.

9.1. Groundwater Pumpage

See Table 8 for PS1 pumping schedule. Agricultural groundwater demand rates were scaled proportionally to the magnitude and distribution of IGFR wells recorded in ROGR records in 1998 (ADWR, 2000a). The total IGFR pumpage was ramped down linearly from approximately 4,000 acre-feet/year in 1999 to 0 acre-feet/year by 2053. All agricultural-related groundwater pumpage was applied during irrigation stress periods.

City of Prescott: The groundwater withdrawal rates *projected* for the City of Prescott (COP) were based directly on the COP's Overall Water Planning and Management Program, Table III, Groundwater Demand column (COP, 1998). The distribution of *projected* withdrawals was adjusted in proportion to the recorded magnitude of withdrawals of the five productions well listed in ROGR in 1998. After 2005, the *projected* groundwater demand assigned to the service well located at (B-16-02) 14CBA (row 9 column 15) was distributed so that 50% of the *projected* pumpage was imposed on the model cell located at row 10, column 12 (effluent recovery well). For PS1, the total groundwater demand for the COP in 1999 was 6,798 acre-feet/year and was *projected* to increase by 86 acre-feet/year to 9,034 acre-feet/year by 2025 and was maintained at this rate until the end of the simulation.

Prescott Valley: The groundwater withdrawal rates *projected* for Prescott Valley were based approximately on the disaggregated demand projections listed in Table 11-5 of the Prescott AMA Third Management Plan (ADWR, 1999). The areal distribution of *projected* withdrawals was based on current service wells and *projected* locations. For PS1, the total groundwater demand for Prescott Valley in 1999 was estimated at 3,811 acre-feet/year and was *projected* to increase to 10,000 acre-feet/year by 2025 and remain at that rate until 2053. After 2000, the *projected* groundwater withdrawal assigned to the existing service wells, located primarily in the Santa Fe well field, was held at 4,000 acre-feet/year.

After 2000, *projected* pumpage was assigned to Viewpoint (model location row 26, column 27) and Antelope Hills (model location row 27 and column 28) and was increased at a rate of 120 acre-feet/year until 2015 where this rate was held until the end of the simulation. The maximum combined pumpage at this location was *projected* to be 3,600 acre-feet/year from 2015 to 2053.

After 2015, pumpage was assigned to an area east of the Prescott Airport (model location row 23, column 22) and was increased at a rate of 240 acre-feet/year until 2020. The maximum pumpage at this site was *projected* to be 1,200 acre-feet/year from 2020 to 2053.

After 2020, pumpage was assigned to an area near Prescott Valley's current effluent discharge site (model location row 38, column 36) and was increased at a rate of 240 acre-feet/year until 2025. The maximum pumpage at this site was *projected* to be 1,200 acre-feet/year from 2025 to 2053.

Chino Valley: Groundwater pumping demand *projections* for the Town of Chino Valley were based on estimations provided by the Town of Chino Valley (Chino Valley, 2001). This was based on the assumption that the Town of Chino Valley will become a water provider in the near future. The pumping demand rate was *projected* to ramp from 500 acre-feet/year in 2003 to 2,500 acre-feet/year by the year 2007. Extraction sites included row 8, column 18 (32%), row 8, column 15 (28%), and row 11 column 12 (32%).

Small Providers: The groundwater withdrawal rates *projected* for Small Providers in the Prescott AMA were based on demand projections listed in Table 11-5 of the TMP (ADWR, 1999). The areal distribution of *projected* withdrawals were based on current service wells listed in ROGR. The annual groundwater withdrawal increase for small providers is projected to be approximately 2.8%. For PS1, the total groundwater demand for Small Providers in 1999 was estimated at 460 acre-feet/year and is *projected* to increase to 613 acre-feet/year by 2010 and remain at that rate to 2025.

Domestic Wells: Demand for exempt wells is projected to be about 1,200 acre-feet/year within the model area. The magnitude and distribution of the *projected* domestic demand was based approximately on domestic demand rates assigned towards the end of the transient simulation. The domestic demand estimates also reflect TMP projections (ADWR, 1999).

Industrial Groundwater pumpage: Groundwater demands for non-turf Industrial use is based on TMP *projections*. Distribution of industrial groundwater demand is based on recorded pumpage 1998 (ADWR, 2000a). Non-turf industrial use in 1998 was about 300 acre-feet/year and was maintained at that rate throughout PS1.

Groundwater demand and distribution for turf-related industrial use is based on recorded pumpage in 1998 (ADWR, 2000a). Turf-related industrial use in 1998 was about 900 acre-feet/year and was maintained at that rate throughout PS1. All turf-related groundwater pumpage was applied during irrigation stress periods.

9.2. Groundwater Recharge

Incidental Agriculture Recharge: Incidental agricultural recharge was *projected* to equal 50% of the agricultural-related groundwater pumpage as described in 8.1. Thus, the total agricultural recharge from groundwater pumpage was linearly decreased from approximately 2,000 acre-feet/year in 1999 to 0 acre-feet/year by 2053. In addition, 300 and 210 acre-feet/year of incidental surface water (or effluent) recharge, was applied to Del Rio and surface water diversions north of Watson Lake, respectively. There was no CVID-related surface water delivery to agricultural lands or CVID canal recharge applied in PS1. All agricultural-related groundwater pumpage was applied during irrigation stress periods.

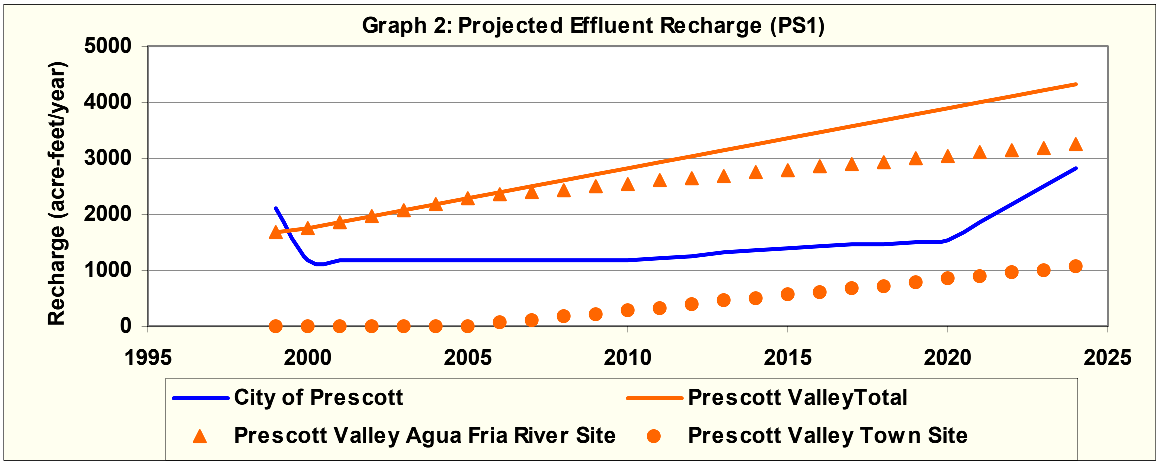
Mountain Front Recharge: Mountain front recharge was applied to PS1 at a rate of 5,750 acre-feet/year; this represents the same MFR rate (magnitude and distribution) assigned in the transient simulation. In addition, a uniform recharge rate of 1,500 acre-feet/year was assigned to cells on Granite Creek downstream from the CVID diversion point. This value represents spills and releases from Watson Lake, and conveyance leakage to the COP recharge site. Thus the total natural recharge was *projected* to be 7,250 acre-feet/year.

Flood recharge: There is a significant amount of uncertainty regarding flood recharge *projections*. Despite the uncertainty, *projected* flood-induced recharge rates of 7,100 and 1,300 acre-feet per event were applied to Granite Creek and portions of Lynx Creek and Aqua Fria River, respectively. The *projected* recharge rates represent the average flood recharge rates assigned periodically over the transient simulation. Flood recharge was applied at 5 different times over PS1 including years 2010, 2020, 2030, 2040 and 2050 and approximately represents the frequency of occurrence of assigned flood imposed over the transient model simulation.

Effluent Recharge: Annual effluent recharge rates for the City of Prescott were based directly on the COP's Overall Water Planning and Management Program, Table III, Groundwater Demand column (COP, 1998). Annual effluent recharge rates for Prescott Valley were *projected* using an effluent discharge-to-groundwater pumpage ratio of 44%. All effluent recharge for Prescott Valley was applied to the Agua Fria River site until the planning simulation year 2006. After 2005, an increasing component of effluent recharge of about 50 acre-feet/year was applied to the Prescott Valley Lake Recharge Site. See Graph 2 below for projected effluent recharge. All effluent for Chino Valley was *projected* to be directly used.

Table 8
***Projected* Groundwater Pumping Demands for PS1**
(all units in acre-feet/year)

Sector or Provider	**Location**	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2053**
Agriculture	~ Proportional to 1998 IGFR Distribution	4,000	3,645	3,270	2,895	2,520	2,145	0
City of Prescott	~ Proportional to 1998 Distribution (See text)	7,000	7,300	7,744	8,174	8,604	9,034	9,034
Prescott Valley	Total	4,000	5,200	6,400	7,600	8,800	10,000	10,000
	~ Proportional to 1998 Distribution	4,000	4,000	4,000	4,000	4,000	4,000	4,000
	Viewpoint Site: row26, col 27; Antelope Hills: row 27, 28	0	1,200	2,400	3,600	3,600	3,600	3,600
	Airport Site: row 23, col 22	0	0	0	0	1,200	1,200	1,200
	Near Agua Fria Effluent recharge site Row 38, col 36	0	0	0	0	0	1,200	1,200
Chino Valley	Row 8, col 18; Row 9, col 15; Row 11, col 15;	0	1,500	2,500	2,500	2,500	2,500	2,500
Small Providers	Proportional to 1998 Distribution	460	460	600	600	600	600	600
Industrial	Turf: Proportional to 1998 Distribution	900	900	900	900	900	900	900
	Non-Turf: Proportional to 1998 Distribution	300	300	300	300	300	300	300
Domestic	Wells 55 estimations	1,200	1,200	1,200	1,200	1,200	1,200	1,200
Total PS1		**17,860**	**20,505**	**22,914**	**24,169**	**25,424**	**26,679**	**24,534**



Graph 2: Projected Effluent Recharge (PS1)

Chapter 10 Results of PS1 Simulation

PS1 Water Budget

Table 9 shows the *projected* model simulated water budget for the simulation years 2005, 2015 and 2025. Hydrographs 1-6 show *projected* water-level changes over time for selected wells. Water budgets and hydrographs are only shown through projected simulation year 2025. This is because after 2025, many model cells – especially those in the UAU (layer 1) - begin to go dry, thus deactivating model-imposed stresses including pumpage and recharge. In addition, there is an increasing degree of uncertainty in *projection* demand and water uses as time goes on in any planning scenario. See Figures 9-12 for simulated heads and simulated depth-to-water for PS1.

Discussion of PS1 Simulation Results

Inspection of Table 10 and Hydrograph 9 shows that the collective groundwater system is *projected* to experience a further net loss of storage and an increase in capture of groundwater discharge over time. The cumulative change-in-storage over the PS1 simulation (1999-2025) is *projected* to be about –290,400 acre-feet by 2025. The total cumulative change-in-storage over the transient and PS1 simulations (1939-2025) is *projected* to be about –700,000 acre-feet by 2025.

Projections indicate that groundwater levels will decline significantly in the Prescott Valley area and more gradually elsewhere. Concentrated declines of over 100 feet are *projected* in the immediate vicinity of the View Point, Antelope Hills and Santa Fe well fields - based on the magnitude of the assigned, *projected* groundwater demands. Model results from PS1 show that the general area near the City of Prescott well field will continue to experience slow steady water level declines in the LVU aquifer, with larger declines in the UAU aquifer.

Model *projections*, as well as empirical data, show that groundwater-level decline rates start to increase throughout much of the LIC sub-basin early into PS1 (See Hydrographs 1-3). The changing groundwater level decline rates over time (inflection) in the LIC sub-basin reflect the generalized groundwater demand in the LIC sub-basin and a reduction in agricultural-related incidental recharge. In addition, the regional impact of the inflection may also suggest that the expansion of the LIC sub-basin cone-of-depression has propagated outward to less permeable zones, or boundaries, surrounding the LVU and UAU aquifers.

It should be noted that in 2001, the Arizona Department of Water Resources drilled three monitor wells in data-deficient areas within the Prescott AMA. The monitor wells are located at (B-15-01) 08daa, MW #1; (B-16-01) 23aca, MW #2; and (B-15-02) 22aab, MW #3 (See ADWR, 2002). The difference between measured minus simulated (layer 2) groundwater levels in 2002 at MW # 1, MW #2 and MW #3 was –14 feet, - 13 feet and 0 feet, respectively.

Groundwater discharge in the LIC sub-basin, including sub-surface and surface water flow near Del Rio Springs, is *projected* to be further reduced over time. However, in the southeastern portion of the UAF sub-basin, groundwater levels and the groundwater discharge rate are *projected* to gradually increase primarily due to *projected* effluent recharge rates (See hydrographs 7 and 8). However, if the effluent recharge rates assigned in the planning scenario prove to be less than the *projections*, or if effluent groundwater recharge is intercepted by recovery wells, then the *projected* groundwater discharge rate out of the UAF sub-basin would consequently be reduced. [Note: Inspection of Hydrograph 5 (J) shows the *projected* impact of assigned groundwater pumpage on groundwater levels near the current effluent recharge site after the projection year 2020 (also see Table 8).]

Table 9
***Projected* Simulated Water Budget for PS1 (2005, 2015 and 2025)**
(Figures Rounded to the Nearest 100 acre-feet)

Inflow	**Simulated 2005 Acre-feet/year**	**Simulated 2015 Acre-feet/year**	**Simulated 2025 Acre-feet/year**
Mountain Front Recharge	5,800	5,800	5,800
Recharge: Conveyance, Spills	1,500	1,500	1,500
Recharge: Incidental Agriculture and Effluent Recharge	5,800	6,700	9,100
Released from Storage	13,400	14,300	13,300
Total Inflow	**26,500**	**28,300**	**29,800**
Outflow	**Simulated 2005**	**Simulated 2015**	**Simulated 2025**
Groundwater Pumpage	19,900	22,200	24,500
Groundwater Discharge Del Rio Springs (LIC)	1,300[1]	500[1]	0
Groundwater Discharge Agua Fria River (UAF)	1,500[2]	1,900[2]	2,200[2]
Net Groundwater Discharge Subsurface flow (LIC)	1,600	1,400	1,100
Taken into storage	2,200	2,300	1,900
Total Outflow	**26,500**	**28,300**	**29,800**
Change-in-Storage	**-11,200**	**-12,000**	**-11,400**

[1] Projected to contain an undifferentiated ET component estimated at 100-200 acre-feet/year

[2] Projected to contain an undifferentiated ET component estimated at 200-300 acre-feet/year

Chapter 11 Conclusions

The Prescott AMA Groundwater Flow Model was updated with new hydrogeologic data and revised estimates of historical water-use, recharge and natural discharge. The model was calibrated to measured groundwater level and natural discharge targets from 1939 through 1999. Results show that the model generally achieves the goals outlined in Chapter 1, and provides acceptable solutions for hydraulic head and groundwater discharge over time (1939-2002) in the UAU and LVU aquifers associated with the LIC and UAF sub-basins.

This model was applied as a *predictive* tool to examine one planning scenario. Results of the planning scenario indicate that most locations within the model area of the LIC sub-basin (UAU and LVU) will continue to experience long-term declines. The generalized decrease in hydraulic head throughout the LIC sub-basin is *projected* to further decrease the groundwater discharge rate near Del Rio Springs (spring flow at the surface and subsurface flow). Groundwater levels are *projected* to rise in the southern portion of the Upper Agua Fria sub-basin and result in a gradual increase in the groundwater discharge rate at the Agua Fria River if the *projected* effluent recharge and long-term natural recharge rates hold true. However, if effluent recharge rates assigned in the planning scenario prove to be less than the *projections*, or if effluent groundwater recharge is intercepted by recovery wells, then the *projected* groundwater discharge rate out of the UAF sub-basin would consequently be reduced.

Model results demonstrate that except for years of significant precipitation and associated flood recharge, the Prescott AMA on a regional scale will continue to experience a net loss of groundwater storage.

Woessner (1998), in his review of the ADWR Prescott AMA Groundwater Model (Corkhill and Mason, 1995), suggested that model "…be updated with new drilling, pumping and well log data, and re-calibrated annually". Since the release of the Draft model report in May 2001, additional hydrologic and geo-technical investigations have been conducted in the model area (see ADWR 2002; ASA, 2002). Data from these investigations, and potentially many future sources, will be incorporated into future model updates, accordingly. However, because the current version of the updated Prescott model provides solutions that continue to be in close agreement with observational data on a sub-basin scale through the early portion of PS1 (into 2002), its use as a **regional**, groundwater management tool is considered applicable.

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APPENDIX I - FIGURES

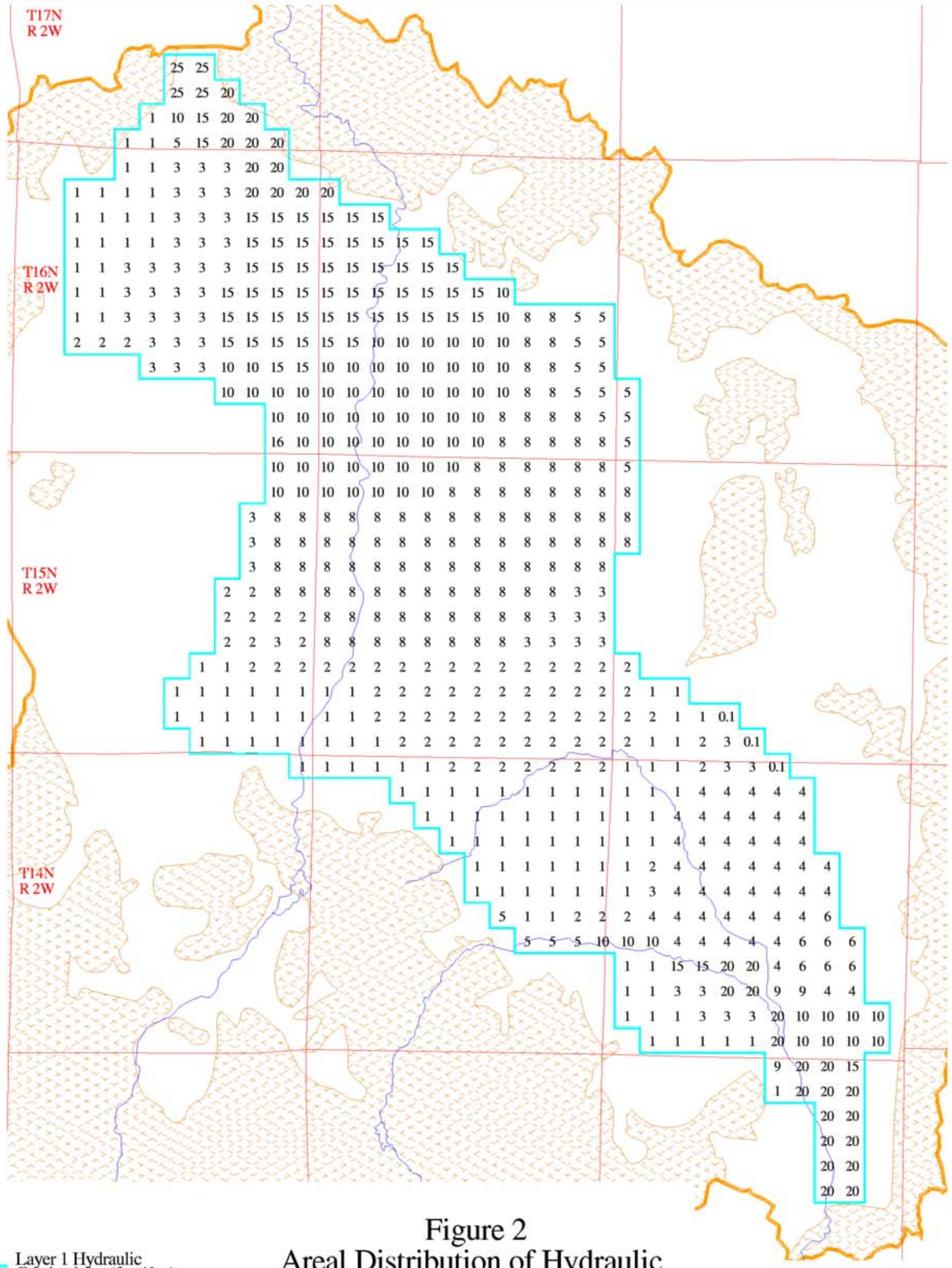


Figure 2
Areal Distribution of Hydraulic Conductivity in the Upper Alluvial Unit

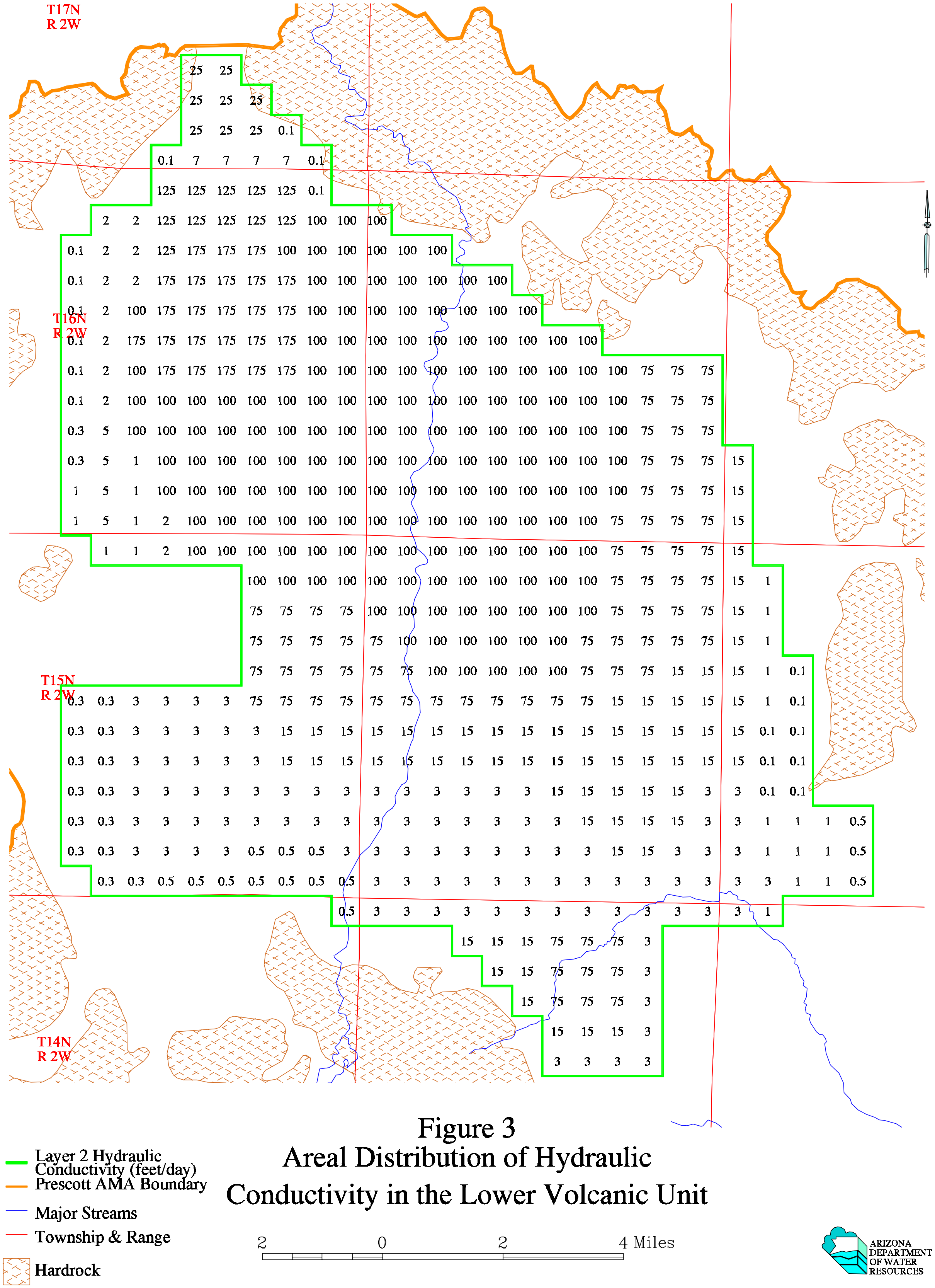


Figure 3
Areal Distribution of Hydraulic Conductivity in the Lower Volcanic Unit

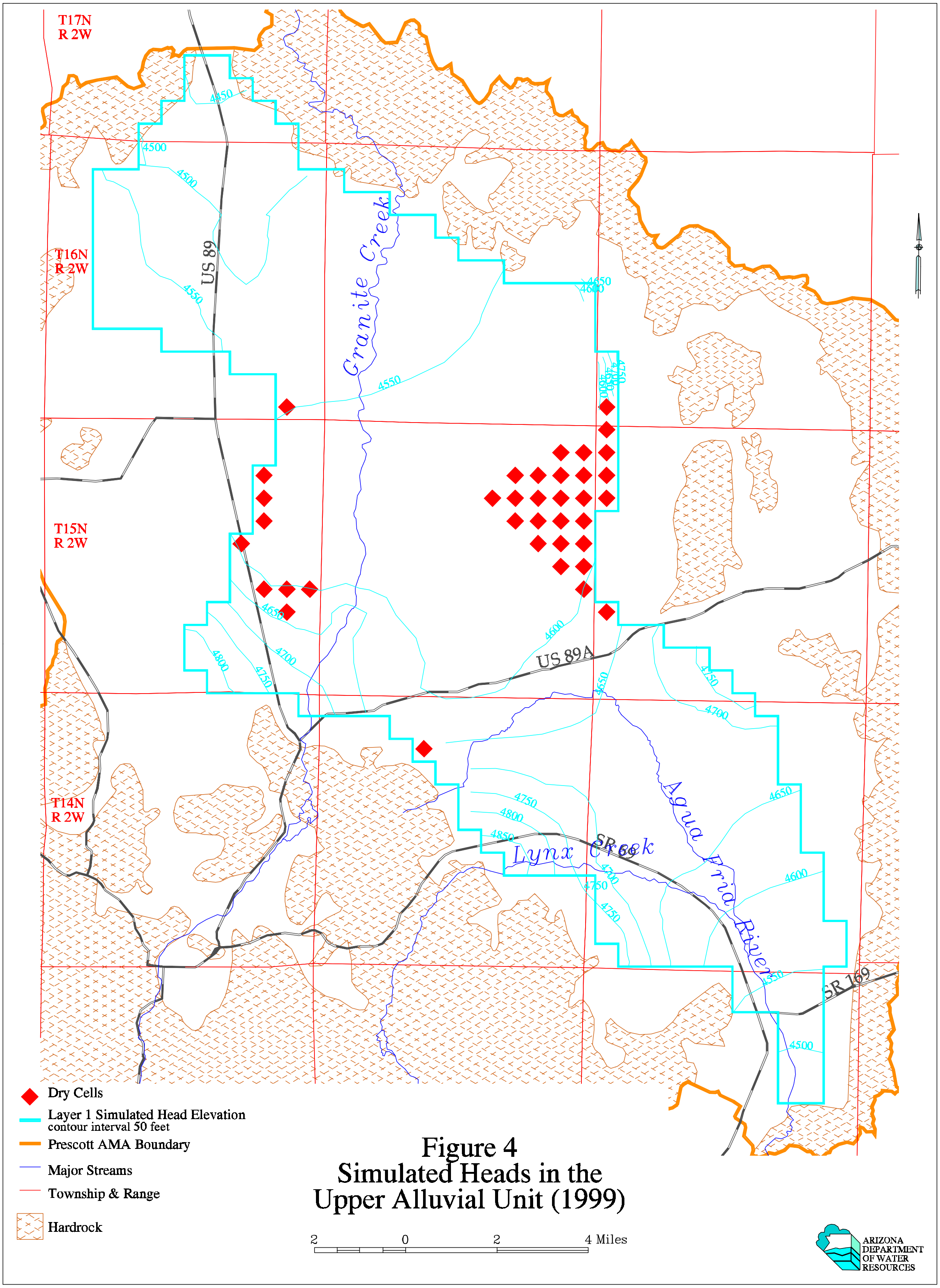


Figure 4
Simulated Heads in the
Upper Alluvial Unit (1999)

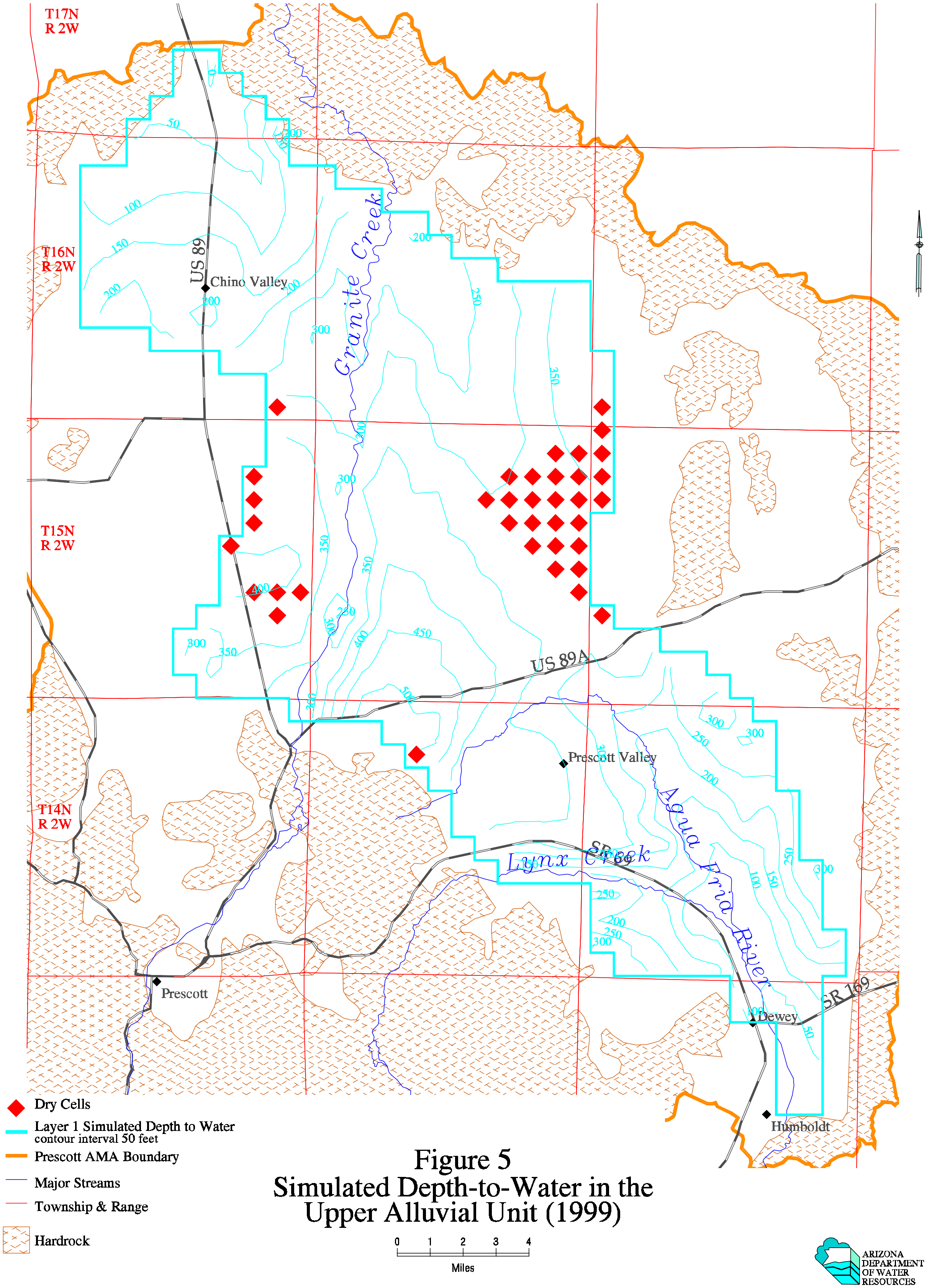


Figure 5
Simulated Depth-to-Water in the Upper Alluvial Unit (1999)

ARIZONA DEPARTMENT OF WATER RESOURCES

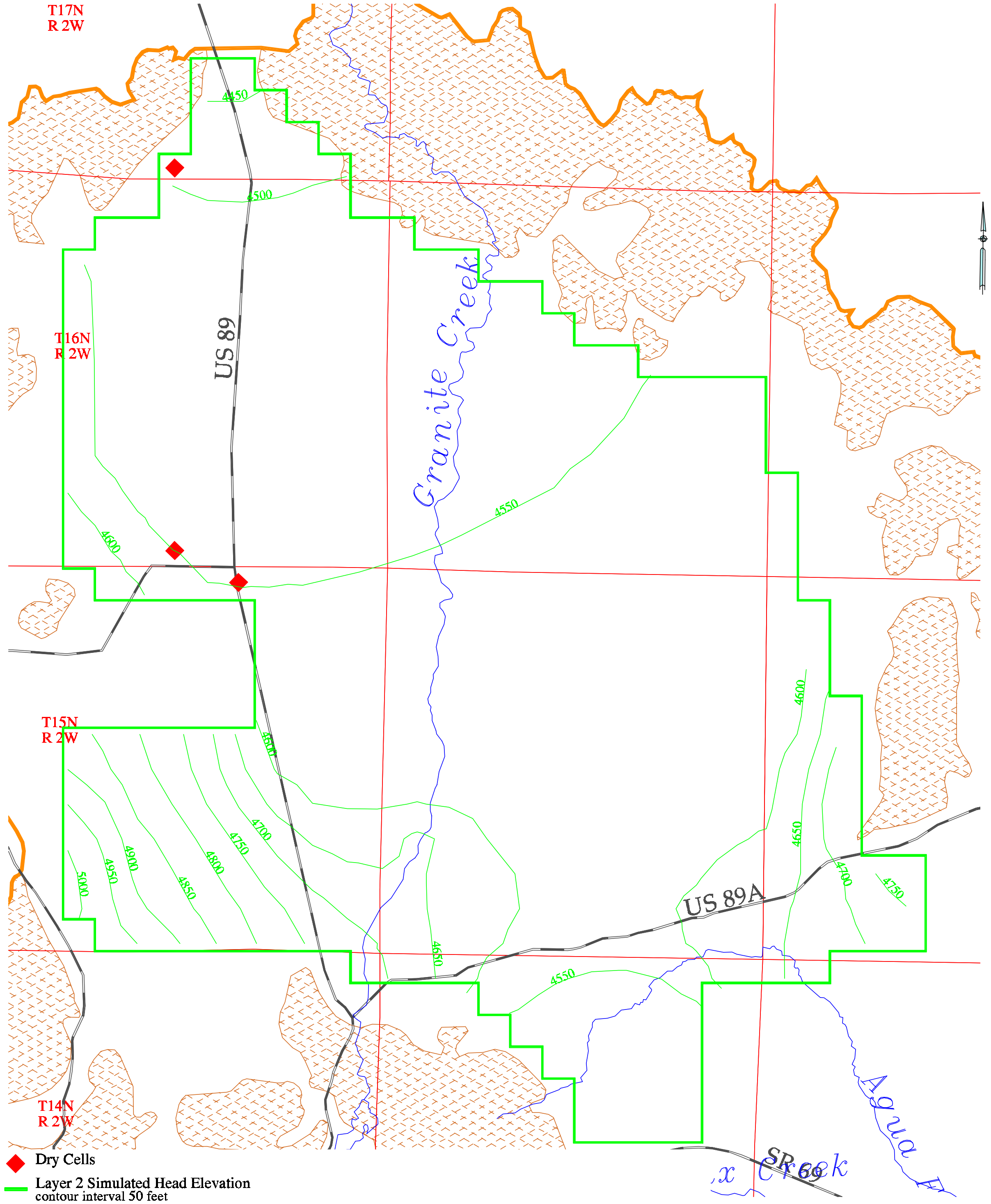


Figure 6
Simulated Water Levels in the Lower Volcanic Unit (1999)

ARIZONA
DEPARTMENT
OF WATER
RESOURCES

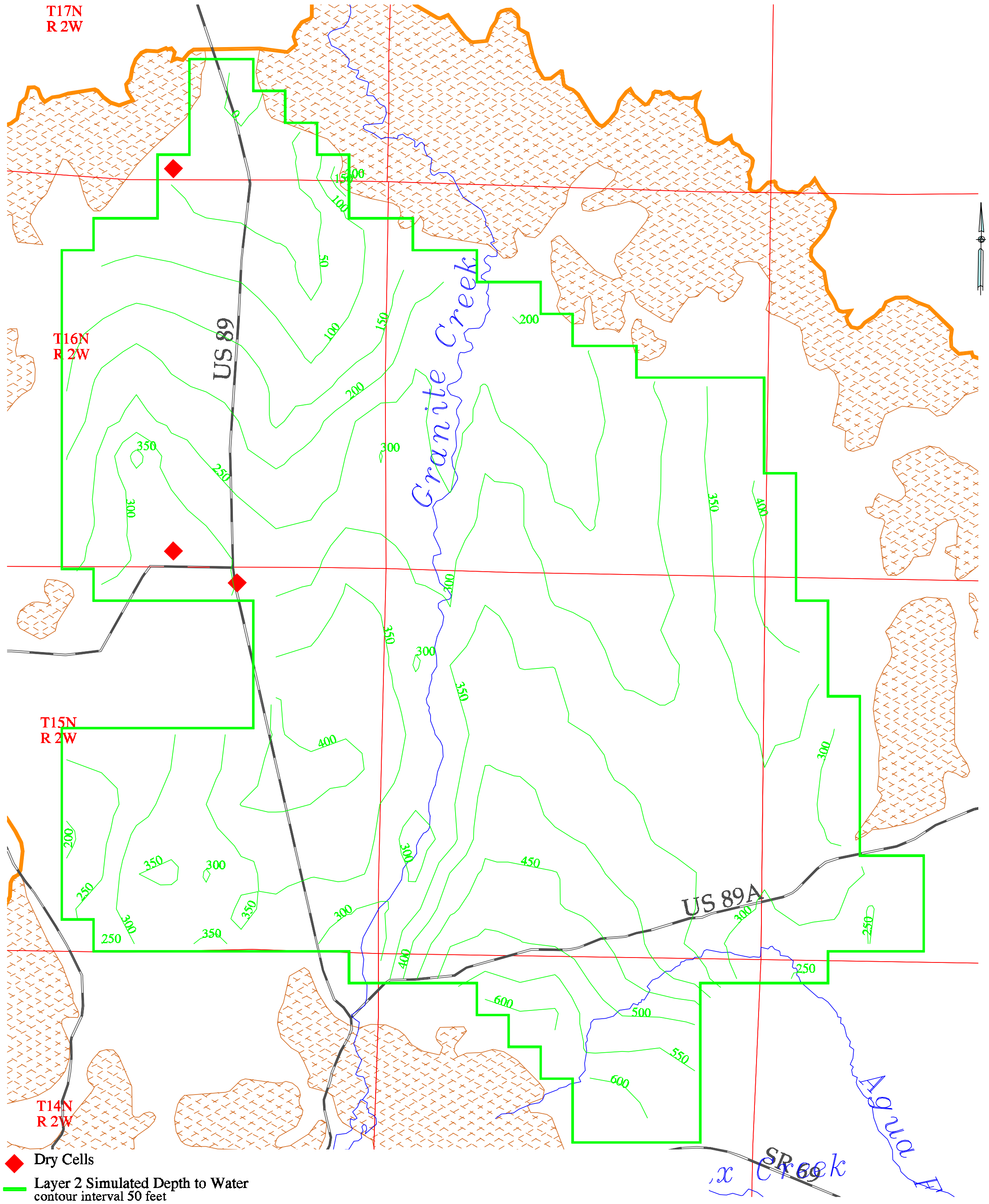
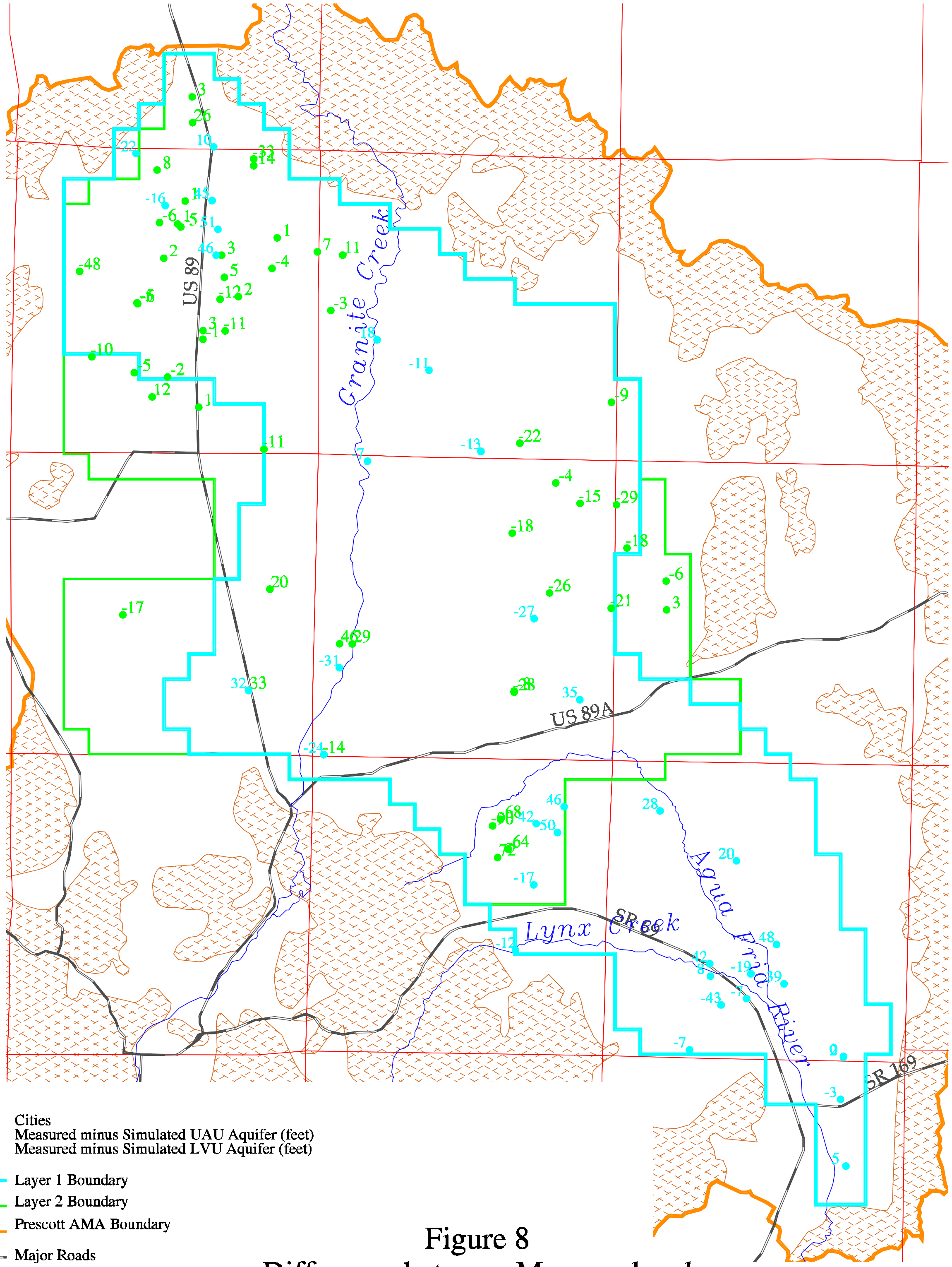


Figure 7
Simulated Depth-to-Water in the Lower Volcanic Unit (1999)

ARIZONA DEPARTMENT OF WATER RESOURCES



◆ Cities
● Measured minus Simulated UAU Aquifer (feet)
● Measured minus Simulated LVU Aquifer (feet)

Layer 1 Boundary
Layer 2 Boundary
Prescott AMA Boundary
Major Roads
Major Streams
Township & Range
▨ Hardrock

Figure 8
Difference between Measured and Simulated Water Level (1999)

2 0 2 4 Miles

ARIZONA DEPARTMENT OF WATER RESOURCES

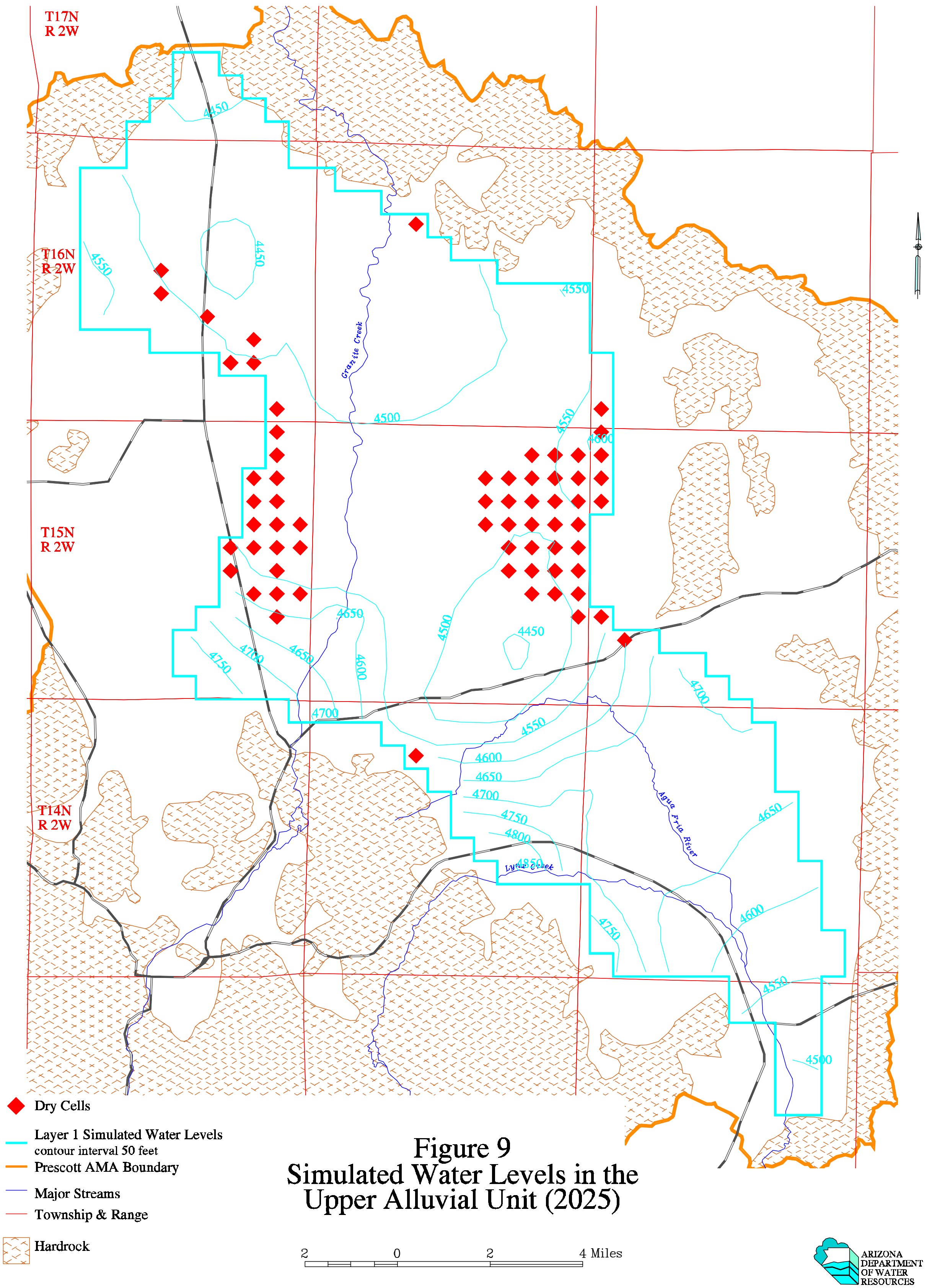


Figure 9
Simulated Water Levels in the
Upper Alluvial Unit (2025)

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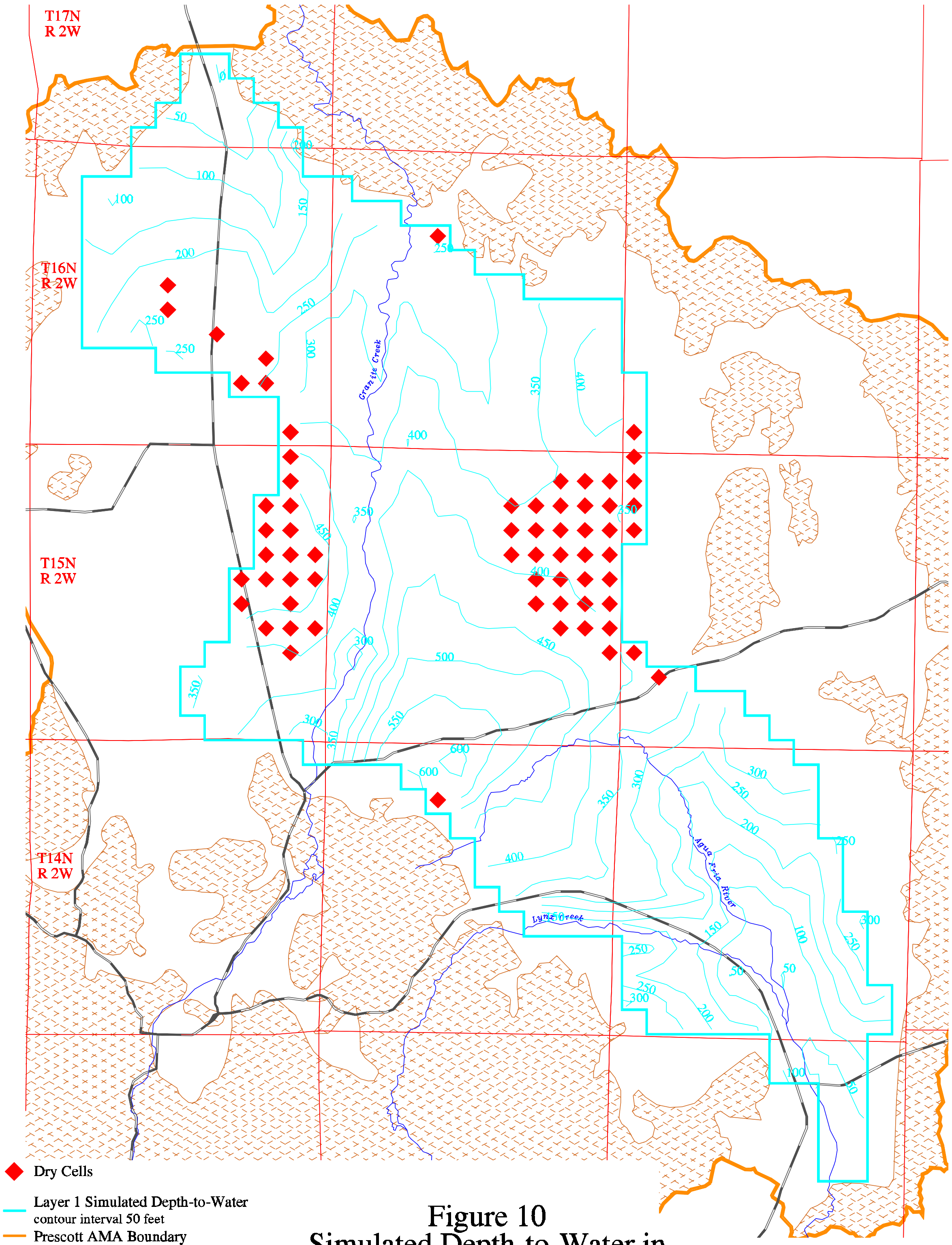

◆ Dry Cells

Layer 1 Simulated Depth-to-Water
contour interval 50 feet

Prescott AMA Boundary

Major Streams

Township & Range

▨ Hardrock

Figure 10
Simulated Depth-to-Water in Upper Alluvial Unit (2025)

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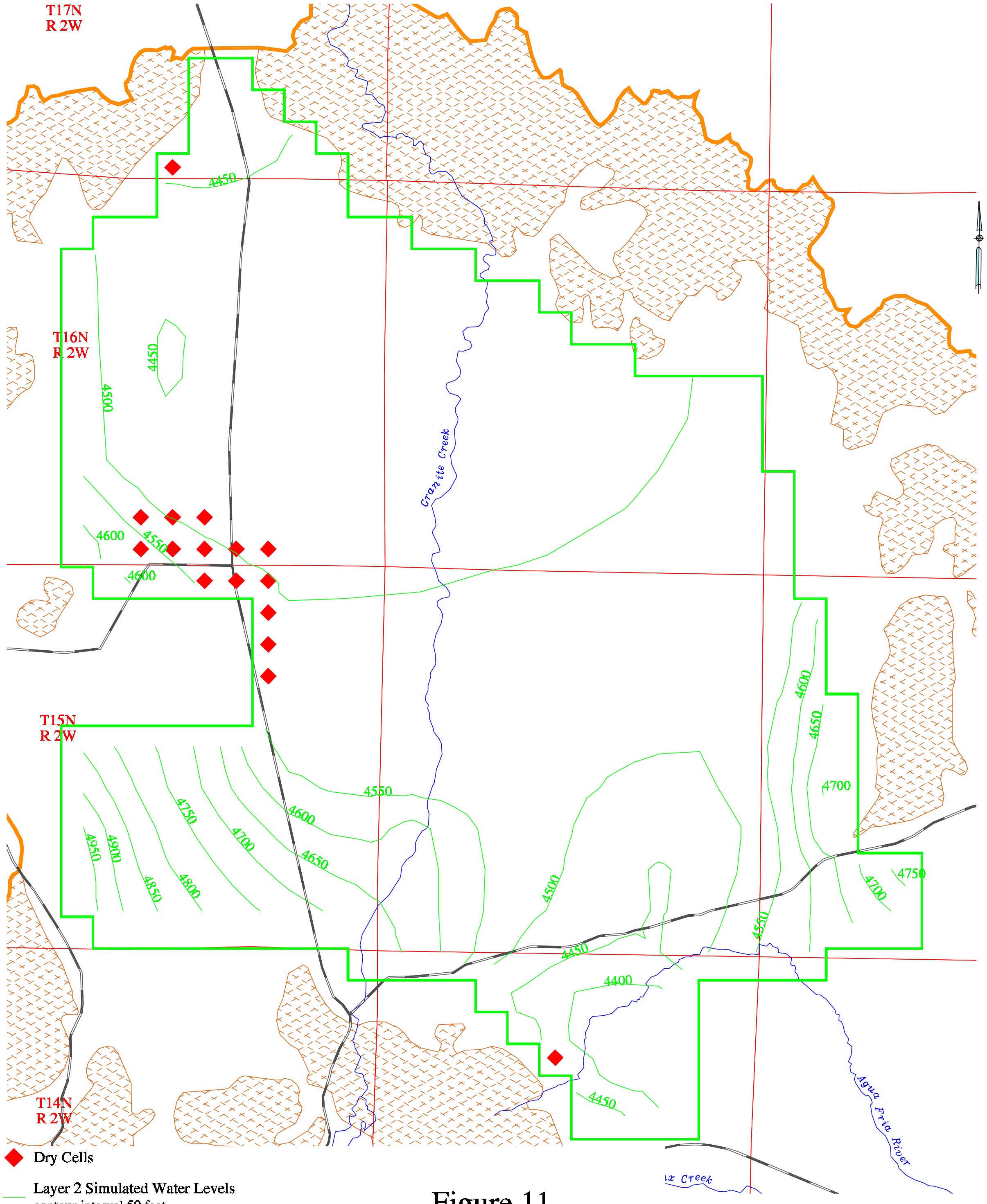

Figure 11
Simulated Water Levels in the
Lower Volcanic Unit (2025)

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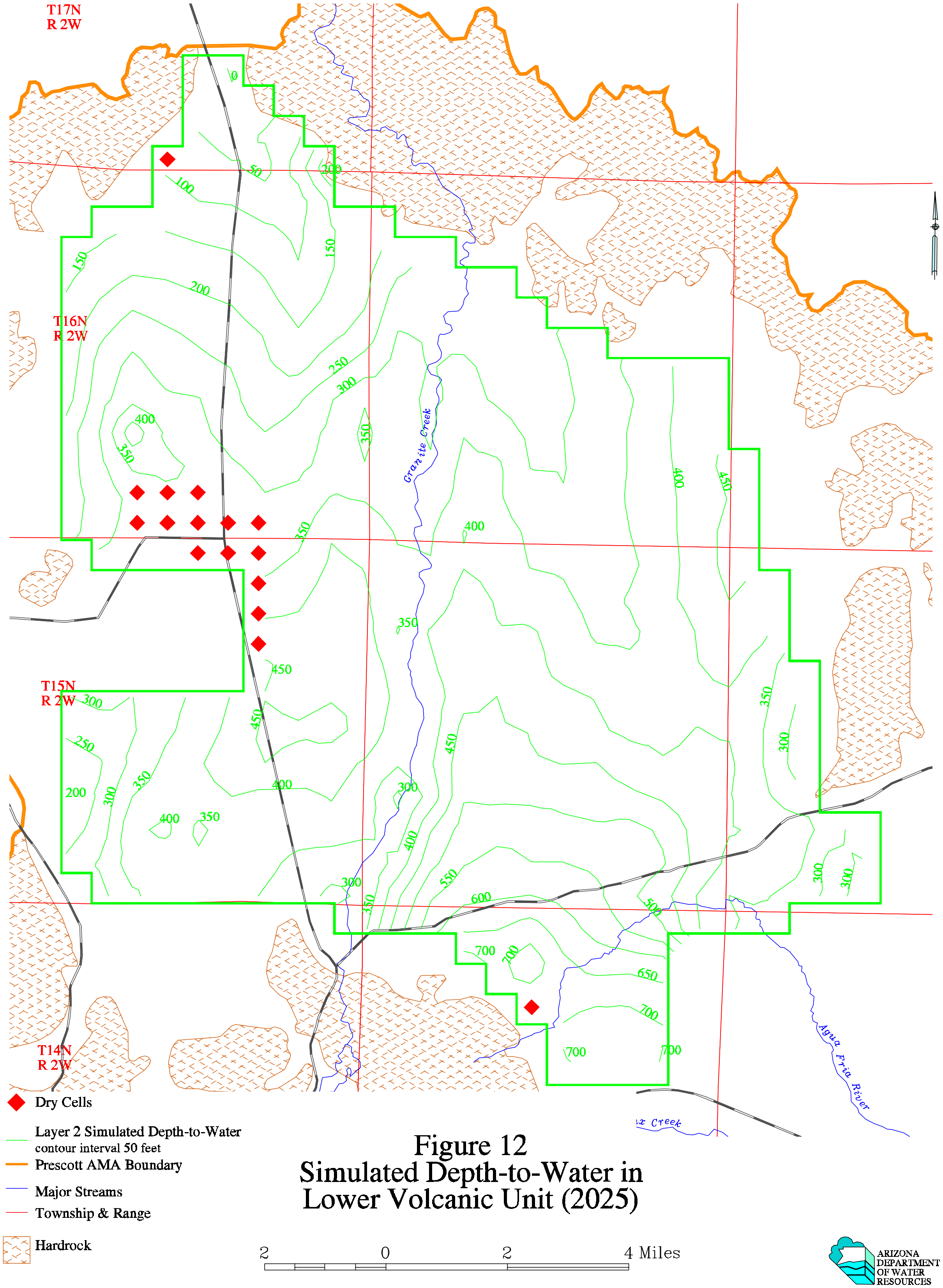
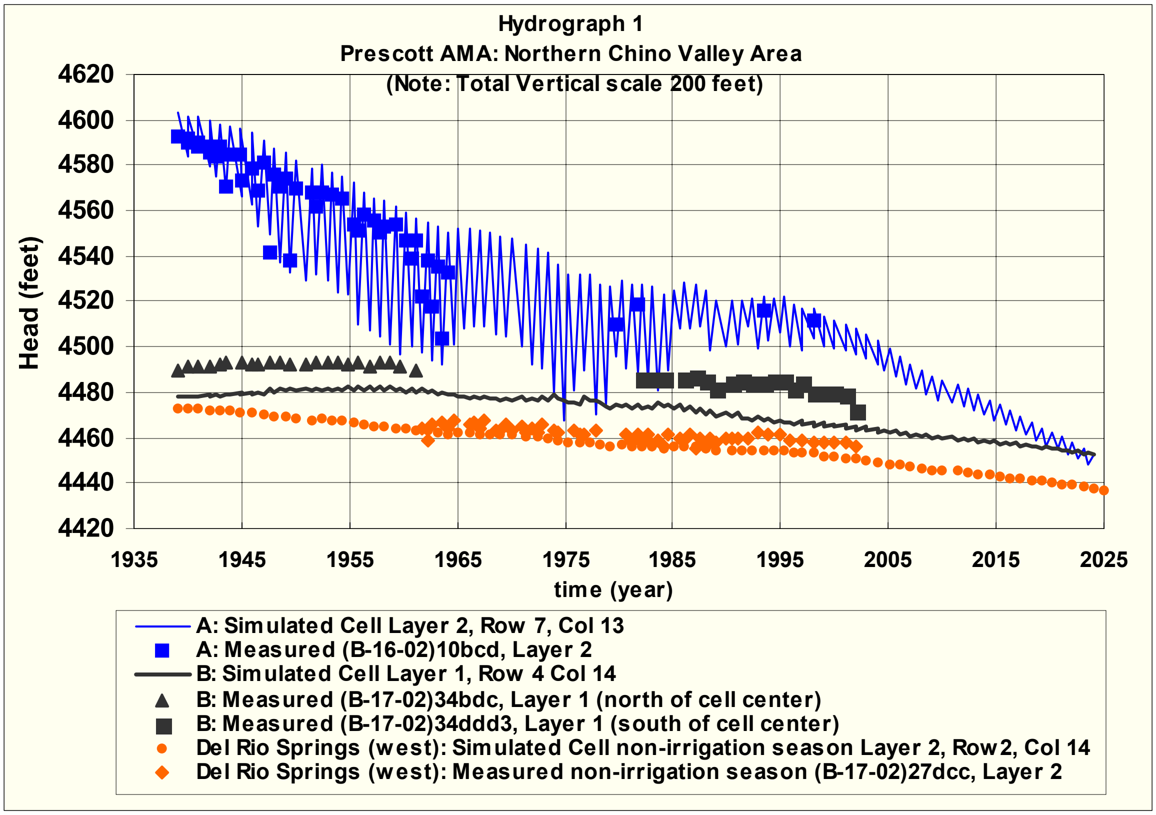
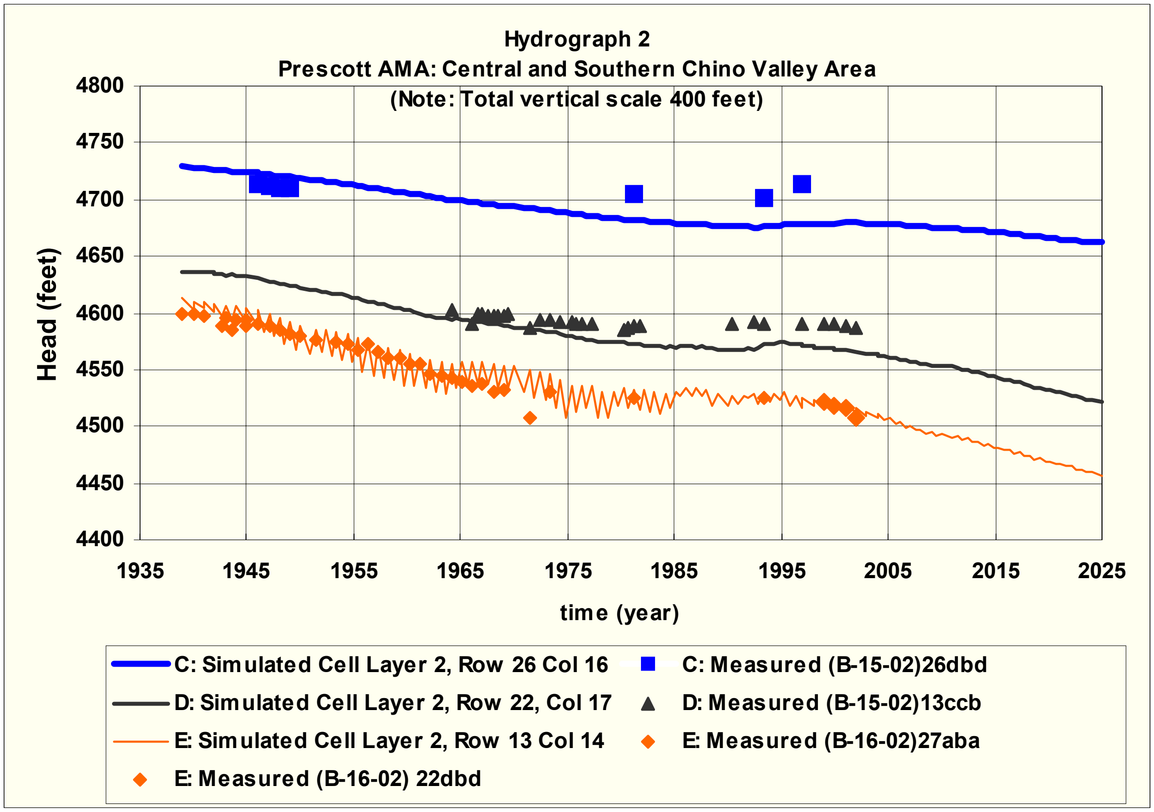
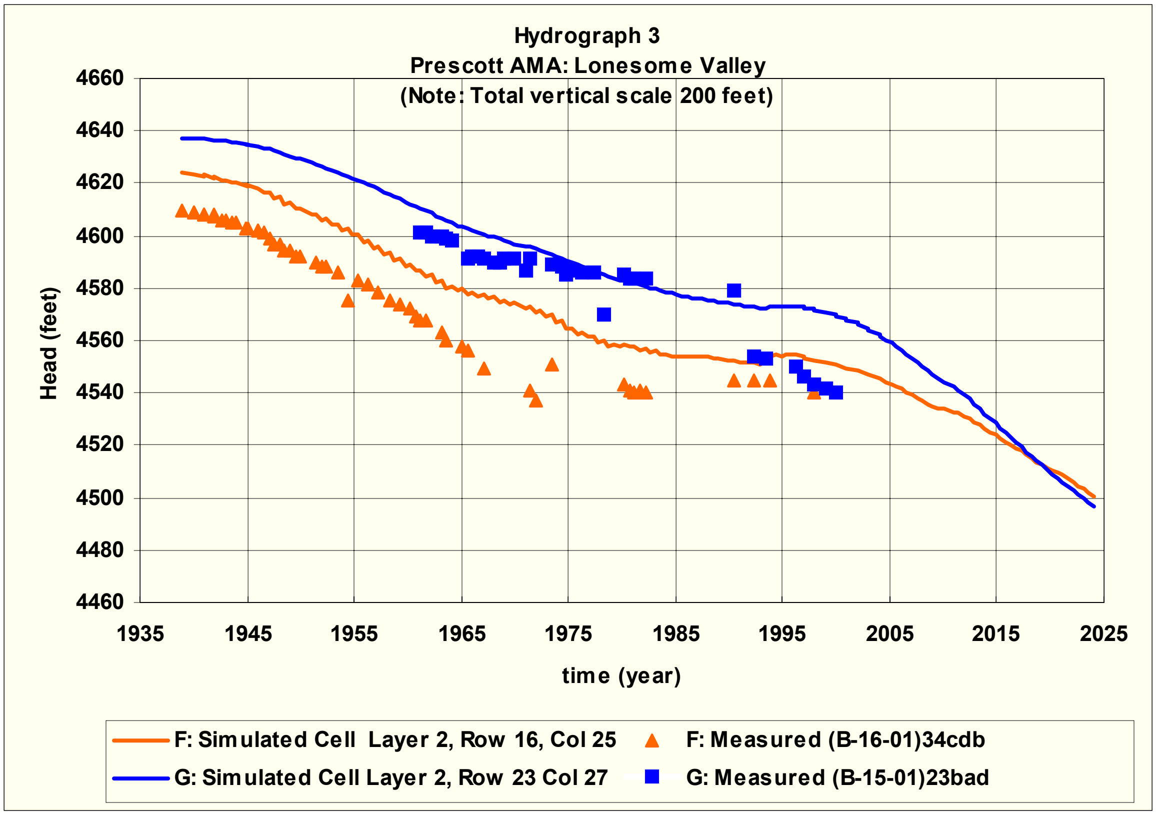


Figure 12
Simulated Depth-to-Water in
Lower Volcanic Unit (2025)

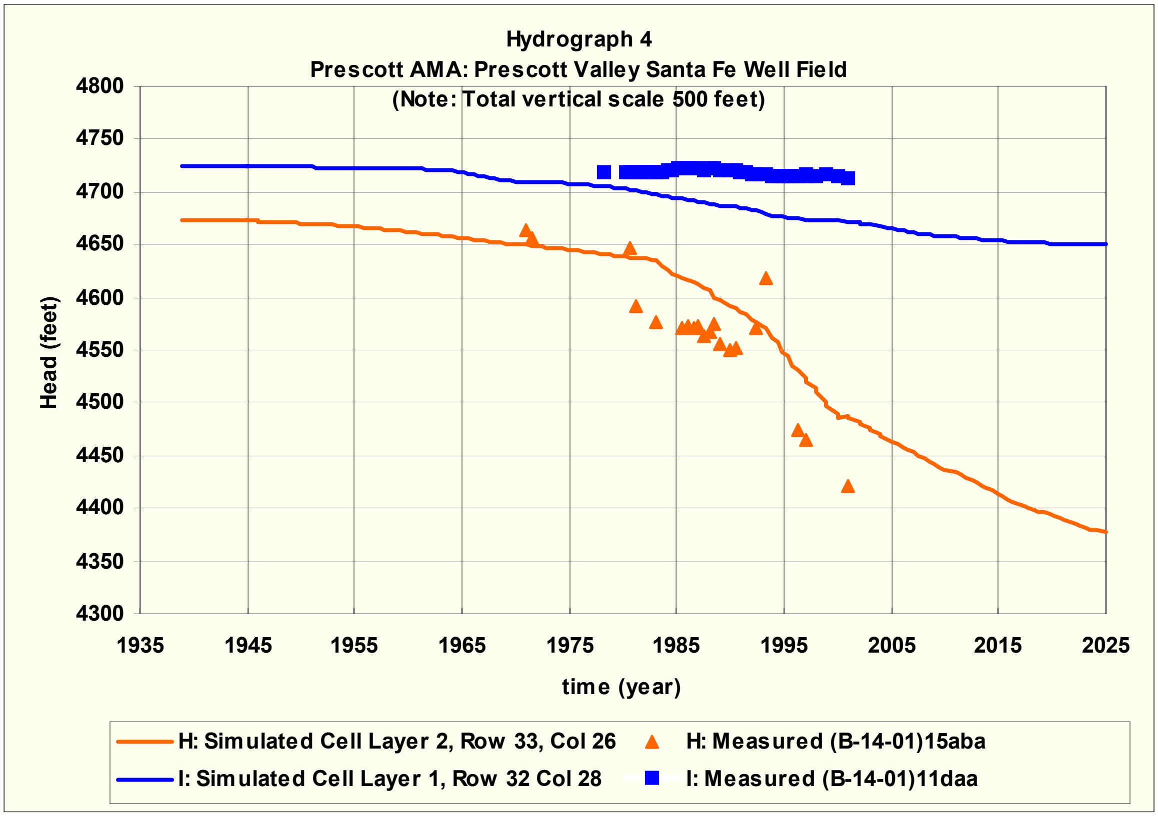
APPENDIX II - HYDROGRAPHS


Hydrograph 1
Prescott AMA: Northern Chino Valley Area
(Note: Total Vertical scale 200 feet)
Head (feet)
4620
4600
4580
4560
4540
4520
4500
4480
4460
4440
4420
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (year)
A: Simulated Cell Layer 2, Row 7, Col 13
A: Measured (B-16-02)10bcd, Layer 2
B: Simulated Cell Layer 1, Row 4 Col 14
B: Measured (B-17-02)34bdc, Layer 1 (north of cell center)
B: Measured (B-17-02)34ddd3, Layer 1 (south of cell center)
Del Rio Springs (west): Simulated Cell non-irrigation season Layer 2, Row2, Col 14
Del Rio Springs (west): Measured non-irrigation season (B-17-02)27dcc, Layer 2

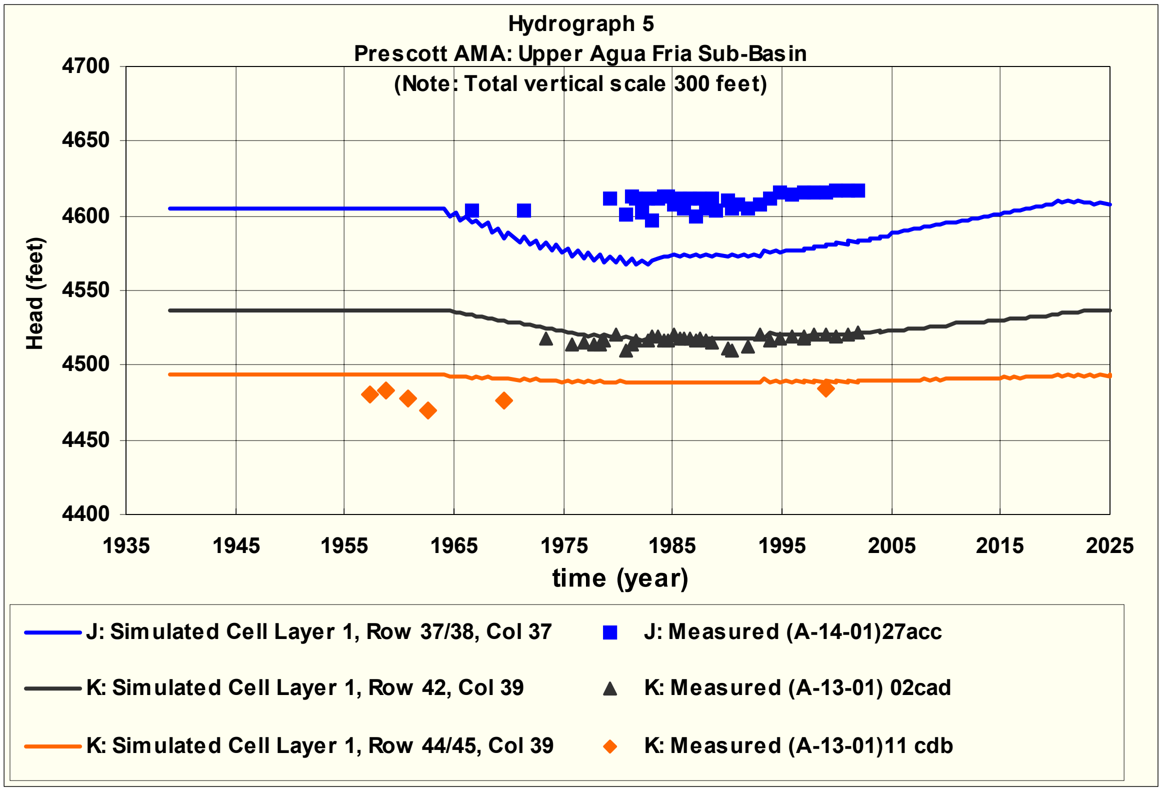

Hydrograph 2
Prescott AMA: Central and Southern Chino Valley Area
(Note: Total vertical scale 400 feet)
Head (feet)
4800
4750
4700
4650
4600
4550
4500
4450
4400
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (year)
C: Simulated Cell Layer 2, Row 26 Col 16
C: Measured (B-15-02)26dbd
D: Simulated Cell Layer 2, Row 22, Col 17
D: Measured (B-15-02)13ccb
E: Simulated Cell Layer 2, Row 13 Col 14
E: Measured (B-16-02)27aba
E: Measured (B-16-02) 22dbd

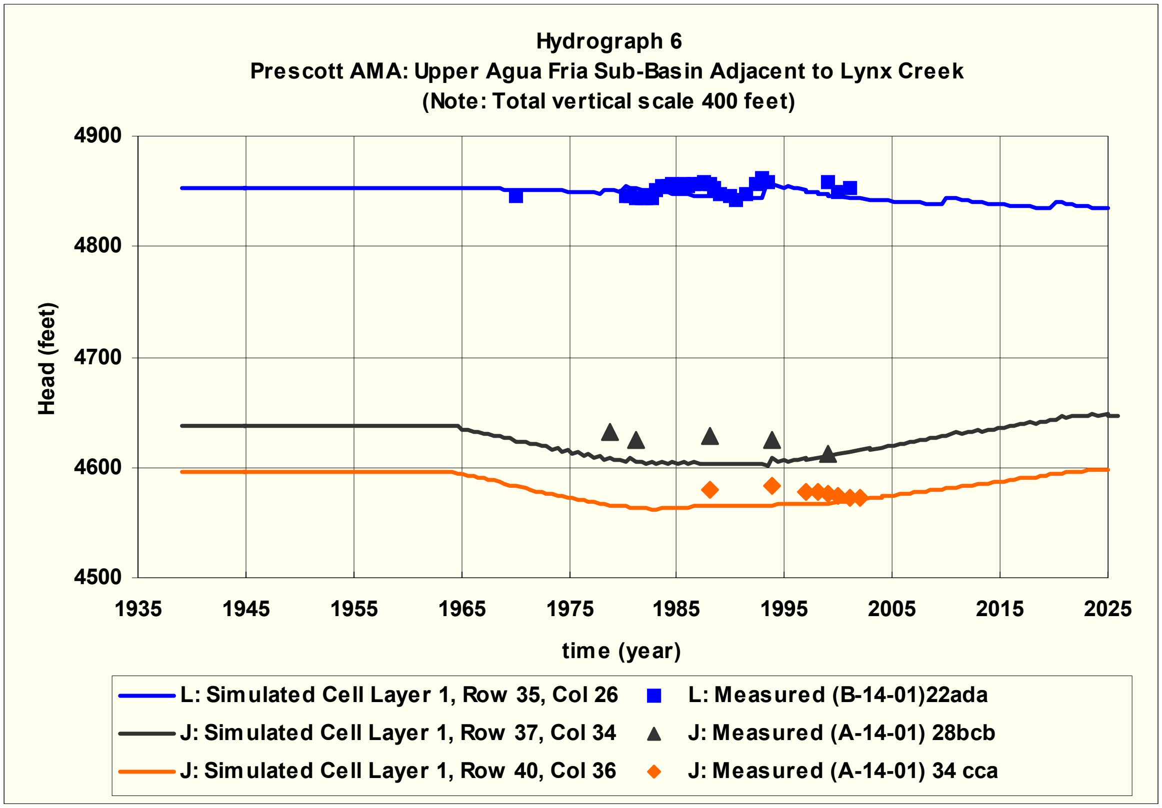


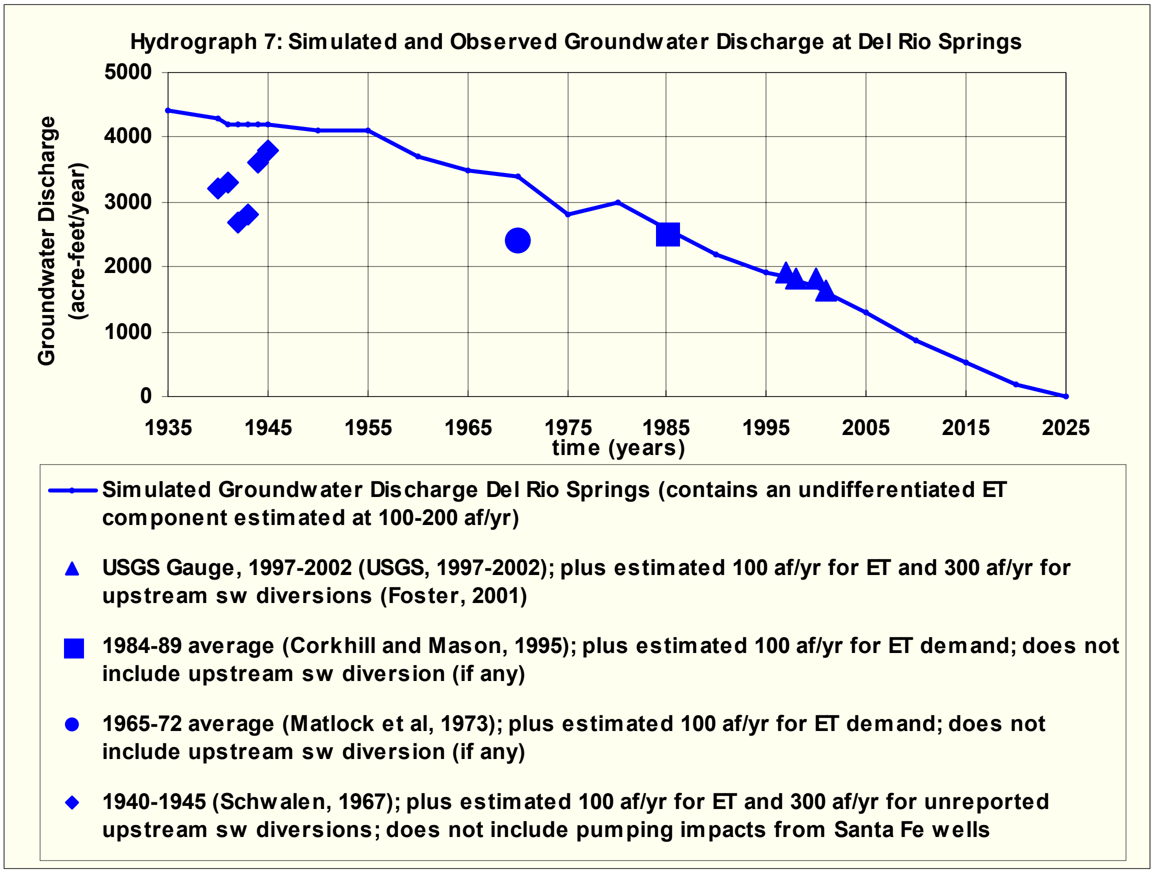
Hydrograph 3
Prescott AMA: Lonesome Valley
(Note: Total vertical scale 200 feet)
Head (feet)
4660
4640
4620
4600
4580
4560
4540
4520
4500
4480
4460
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (year)
F: Simulated Cell Layer 2, Row 16, Col 25
F: Measured (B-16-01)34cdb
G: Simulated Cell Layer 2, Row 23 Col 27
G: Measured (B-15-01)23bad

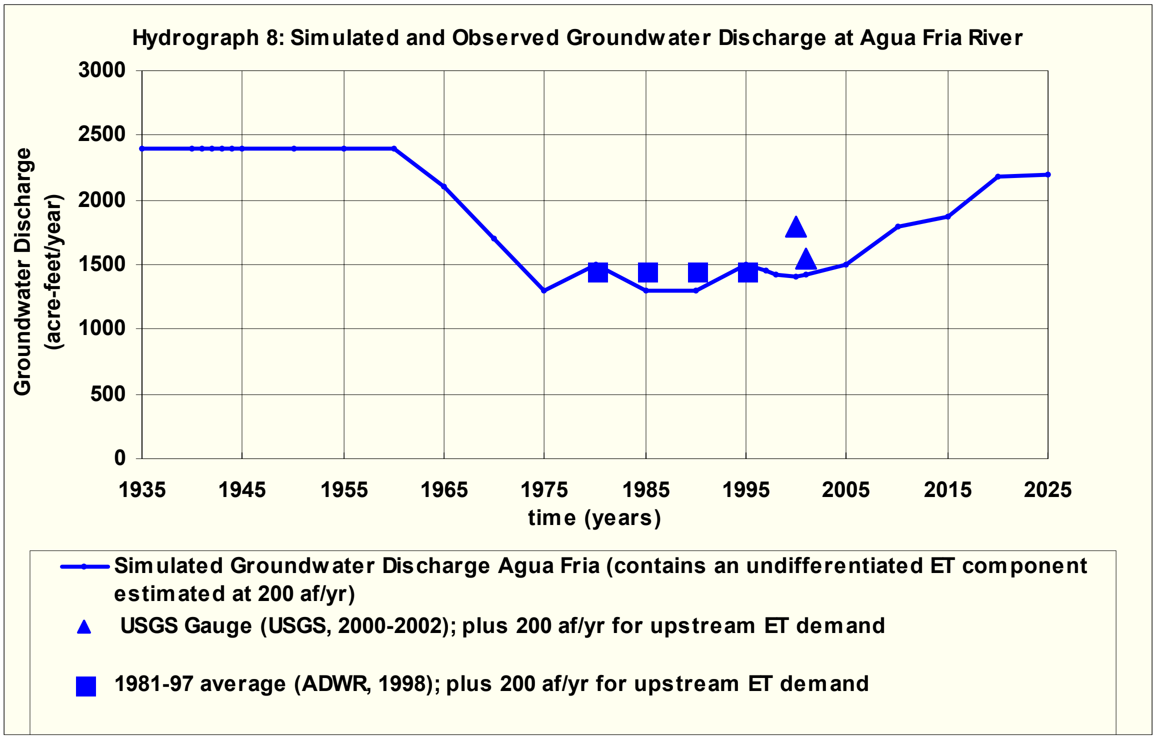


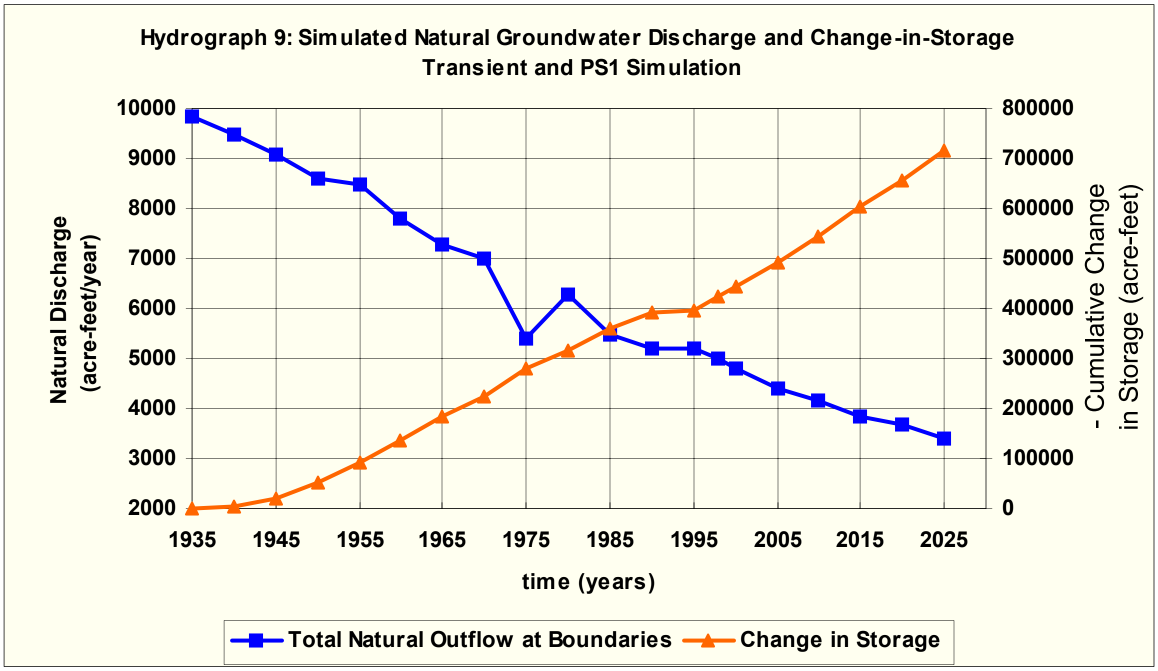
Hydrograph 4
Prescott AMA: Prescott Valley Santa Fe Well Field
(Note: Total vertical scale 500 feet)
Head (feet)
4800
4750
4700
4650
4600
4550
4500
4450
4400
4350
4300
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (year)
H: Simulated Cell Layer 2, Row 33, Col 26
H: Measured (B-14-01)15aba
I: Simulated Cell Layer 1, Row 32 Col 28
I: Measured (B-14-01)11daa


Hydrograph 5
Prescott AMA: Upper Agua Fria Sub-Basin
(Note: Total vertical scale 300 feet)
Head (feet)
4700
4650
4600
4550
4500
4450
4400
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (year)
J: Simulated Cell Layer 1, Row 37/38, Col 37
J: Measured (A-14-01)27acc
K: Simulated Cell Layer 1, Row 42, Col 39
K: Measured (A-13-01) 02cad
K: Simulated Cell Layer 1, Row 44/45, Col 39
K: Measured (A-13-01)11 cdb


Hydrograph 6
Prescott AMA: Upper Agua Fria Sub-Basin Adjacent to Lynx Creek
(Note: Total vertical scale 400 feet)
Head (feet)
4900
4800
4700
4600
4500
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (year)
L: Simulated Cell Layer 1, Row 35, Col 26
L: Measured (B-14-01)22ada
J: Simulated Cell Layer 1, Row 37, Col 34
J: Measured (A-14-01) 28bcb
J: Simulated Cell Layer 1, Row 40, Col 36
J: Measured (A-14-01) 34 cca


Hydrograph 7: Simulated and Observed Groundwater Discharge at Del Rio Springs


Hydrograph 8: Simulated and Observed Groundwater Discharge at Agua Fria River


Hydrograph 9: Simulated Natural Groundwater Discharge and Change-in-Storage
Transient and PS1 Simulation
Natural Discharge (acre-feet/year)
- Cumulative Change in Storage (acre-feet)
10000
9000
8000
7000
6000
5000
4000
3000
2000
800000
700000
600000
500000
400000
300000
200000
100000
0
1935
1945
1955
1965
1975
1985
1995
2005
2015
2025
time (years)
Total Natural Outflow at Boundaries
Change in Storage

APPENDIX III - PICTURES

Figure 13. Groundwater Discharge as baseflow at the Agua Fria River near Humboldt (looking north)

Figure 14. Groundwater Discharge at Del Rio Springs (looking south)

Figure 15. Near the Little Chino and Upper Agua Fria Sub-basin Divide (looking southwest)

Figure 16. Flood Recharge along lower Granite Creek (looking northeast)