Groundwater Flow Model of the Willcox Basin

Executive Summary

Due to continuing observations of groundwater level declines in the Willcox Basin, the Arizona Department of Water Resources (ADWR) initiated development of a numerical groundwater flow model in late 2015.

The Willcox Basin covers an area of approximately 1,911 square miles in southeastern Arizona and is essentially a closed basin.

Most surface water flows towards the Willcox Playa, located in the central part of the basin. However, groundwater in the adjacent Aravaipa Creek and Douglas Basins located to the north and south, respectively, are in direct hydraulic connection with the Willcox Basin. Prior to 1940, the groundwater flow system in the Willcox Basin was in a state of approximate equilibration (steady state conditions).

Groundwater pumping - used primarily for agricultural purposes - commenced in the early-1940s. Although water demand has fluctuated over time, in general high rates of groundwater pumping continue to occur and have, consequently, altered the groundwater flow system to a significant extent.

This ADWR model was developed to simulate regional groundwater flow conditions in the Willcox Basin and adjacent portions of the Douglas and Aravaipa Creek Groundwater Basins.

The objectives for developing the model included, primarily, the following:

1. Gaining a better understanding of the regional groundwater flow system and associated parameters, and

2. Using the model as a tool for projecting future groundwater flow conditions.

The model was calibrated to 2,655 observed groundwater levels and four regional-scale flow calibration targets. Due to the inherent uncertainty associated with the groundwater flow system, historical estimates of pumping, as well as past, present *and* future recharge (natural and agricultural recharge), numerous alternative conceptual models (ACMs) were tested. For purposes of this report, results of six plausible ACMs are presented.

Based on the results of the six ACMs, the analysis finds:

- The historic net simulated change-in-storage (water removed from storage) between 1940 and 2015 ranged from 4.9 million to 6.2 million acre-feet
- Estimates of groundwater in storage based on results of the six ACMs presented in this report for 1940, 2015 and 2115 are: 80 – 97 million acre-feet, 73 – 92 million acre-feet and 57 – 78 million acre-feet, respectively. However, it must be noted that much of the remaining groundwater in storage is at significant depth and may not be practical to remove
- The historic and projected net simulated change-in-storage between 1940 and 2115 ranged from 19.8 million to 24 million acre-feet
- For the aquifer system north of the Willcox Playa, the simulated long-term drawdown between 1940 and 2115 ranged from 354 feet to 536 feet
- For the Lower Basin Fill (LBF) aquifer system near Kansas Settlement, the simulated long-term drawdown between 1940 and 2115 ranged from 747 feet to 917 feet
- For the LBF aquifer system near Sunsites, the simulated long-term drawdown between 1940 and 2115 ranged from 496 feet to 636 feet.

The model was developed and calibrated to simulate groundwater flow conditions in the Willcox Basin area during the pre-development era ("steady state**,"** circa 1940) and the "transient period**"** of groundwater development between 1940 and 2015; "seasonality**"** in the model was represented by simulating two stress-periods per year.

"Steady state" represents conditions where groundwater flow rates and directions do not change over time; it is also associated with initial conditions, which typically represent groundwater flow conditions prior to development.

“Transient periods” represent conditions where groundwater flow rates and directions change over time. It also is associated with post-groundwater development conditions where changes in groundwater storage occur over time.

Within the context of the Willcox model, “seasonality” is represented by simulating two independent stress-periods, applied within a single year, based on observed crop/pumping patterns. For example, higher rates of groundwater pumping are generally observed - and simulated - during spring and summer periods, with respect to late-fall and winter period; hence, “seasonality” is reflected in the model.

The model also was used to simulate the long-term projected groundwater flow system, specifically from 2016 to 2115, using pumping and agricultural recharge rates consistent with the last year of the calibration, which occurred in 2015.

This report also provides the following:

1. **Background**

   Background information about the groundwater flow system;

2. **Development**

   An explanation of the model development process, including the testing of alternative conceptual models (ACMs) and associated inversion statistics;

3. **Results**

   Transient model results, including simulated heads, flows, selected water budget information, etc., for six plausible ACM’s from 1940 to 2115; and

4. **Limitations**

   An explanation of model limitations.

Methodology

The Willcox Model was calibrated to available groundwater level (head) data in the Willcox, Aravaipa and Douglas Basins (n=2,655). Groundwater flow also was used as calibration targets, including: 1) groundwater discharge represented by baseflow along Aravaipa Creek; 2) groundwater basin divide “ridges”, which actually represent zones having zero flow groundwater flow (stagnation boundaries) between basins including the

Willcox-Aravaipa Basin divide and the Willcox-Douglas Basin divide; and 3) early-period estimates of groundwater discharge about the Willcox Playa in the form of spring discharge, evaporation/wicking and modest pumping from shallow wells.

Due to the inherent uncertainty associated with the groundwater flow system, historical estimates of pumping and past, present and future recharge (natural; agricultural recharge), a total of six plausible ACMs are presented in this report.

Findings

Pre-development steady state flow estimates (inflow=outflow) for the six ACMs ranged from about 41,600 acre-feet per year (AF/yr) to 54,300 AF/yr, which is consistent with conceptual estimates. For the first ACM, identified as 'ACM1', the natural recharge (inflow) rate was simulated at 43,844 AF/yr while outflow rates consisting of 1) underflow to the north, 2) underflow to the south and 3) groundwater discharge about the Playa that was simulated at 12,740 AF/yr (Aravaipa baseflow 17.6 cfs), 3,048 AF/yr and 28,064 AF/yr, respectively.

In the transient period after 1940, groundwater withdrawals altered the groundwater flow system, resulting in significant cones-of-depressions in many areas within the Willcox Basin. For ACM1, the transient long-term (1940-2015) simulated pumping rate and the net change-in-storage (loss) averaged 136,373 AF/yr and -76,573 AF/yr, respectively. For the same period, incidental agricultural return flow for ACM1 was simulated at about 40,000 AF/yr, or about 30 percent of groundwater withdrawals, consistent with conceptual estimates.

For the six ACMs, between 1940 and 2015, the cumulative volume of water lost from storage ranged from 4.9 million to 6.2 million acre-feet.

The model also was used to project groundwater flow system conditions between 2016 to 2115, using rates assigned/calibrated during 2015. For ACM1, the projected transient-simulated pumping rate and net change-in-storage (loss) averaged 232,614 AF/yr and -148,322 AF/yr, respectively, for the 2016-2115 period. Incidental agricultural return flow rate averaged about 29 percent, or 66,237 AF/yr. Between 1940 and 2115, the cumulative volume of water lost from storage for the six ACMs presented in this report ranged from about 19.8 million to 24 million acre-feet.

Both data and modeling indicate that significant declines in regional groundwater levels continue to occur. For the six ACMs presented in this study, the range of simulated drawdown with respect to steady state conditions vary, depending on location. For the aquifer system north of the Willcox Playa, the projected drawdown between 1940 and 2115 ranged between 376 to 540 feet (95 percent Confidence Interval [CI] ranging from 354 to 536 feet). For the LBF aquifer near Kansas Settlement and Sunsites, the projected drawdown ranged from 747 to 917 feet (95 percent CI, range 734 to 924 feet) at Kansas Settlement, and from 496 to 636 feet (95 percent CI, range 496 to 661 feet) at Sunsites.

North of the Willcox Playa, historic groundwater pumping has effectively resulted in a single, widespread cone-of-depression. The aquifer systems to the south of the Playa show at least three distinctive cones-of-depression associated with the LBF aquifer. South of the Willcox Playa near Kansas Settlement and Sunsites, data show significant vertical gradients - evidence that the fine-grain material (aquitard) limits the rate of groundwater flow between the water table UBF aquifer and the LBF aquifer. Data and modeling indicate that the cones-of-depression associated with the LBF aquifer in the Kansas Settlement and Sunizona areas are generally coalescing into a broader, regional-scale groundwater depression. There are varying degrees of hydraulic connectivity between the aquifers and the aquitards.

This report is intended to make the model development and calibration process transparent to stakeholders. Information contained within this report provides significant detail about the regional hydrology and development of the Groundwater Flow Model of the Willcox Basin. In addition, ADWR had an earlier version of the Groundwater Flow Model of the Willcox Basin independently peer-reviewed by experts in the field of groundwater flow modeling (SSPA, 2016), resulting in a final modeling product, discussed herein.

Questions about the Willcox Basin Groundwater Flow Model should be directed to Keith Nelson, kmnelson@azwater.gov. Media inquiries should be directed to Sally Stewart Lee, sslee@azwater.gov

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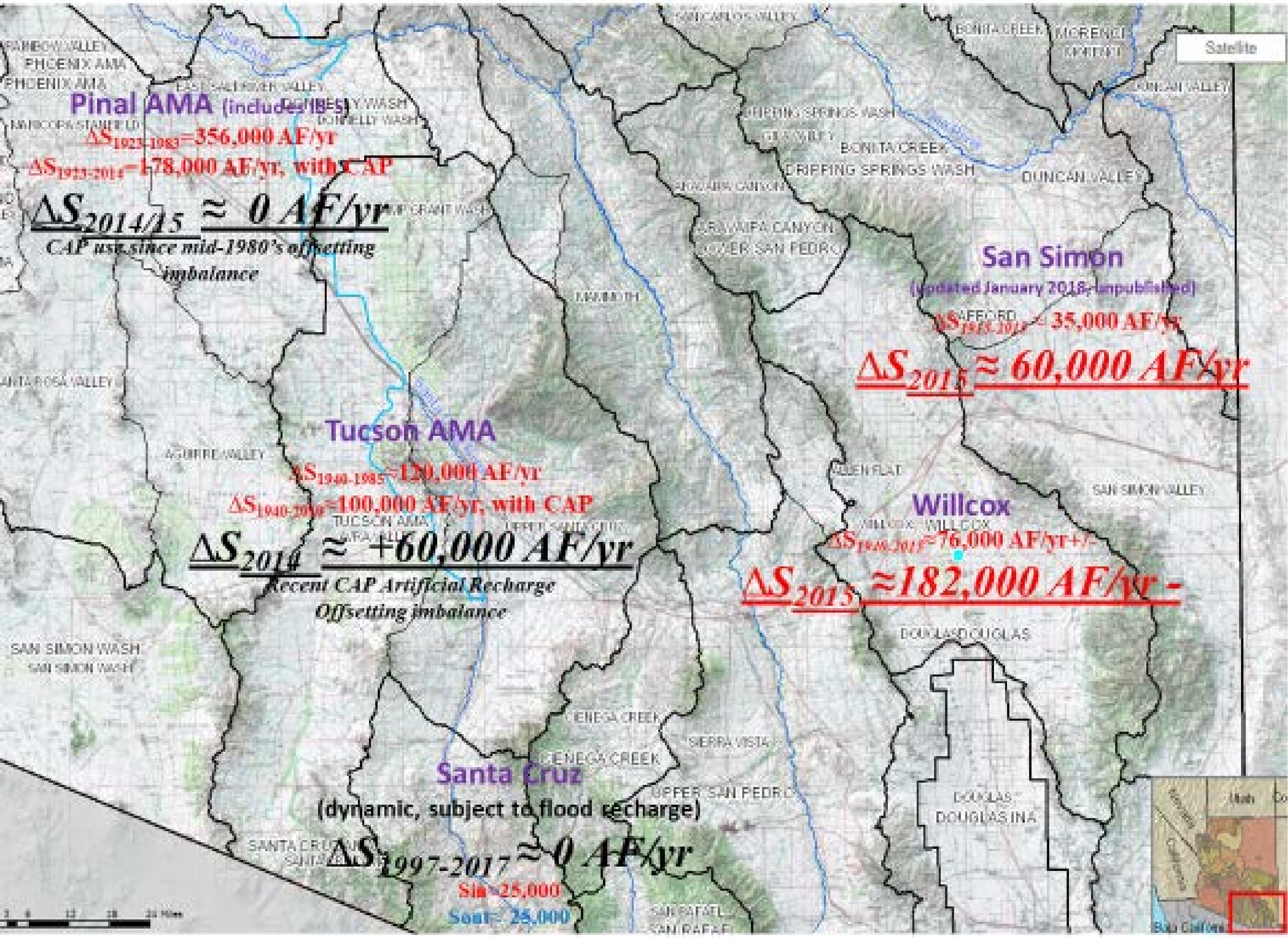
DRAFT Transient *Annualized* ΔS Rates, ADWR Models



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Agricultural Well, Willcox Basin

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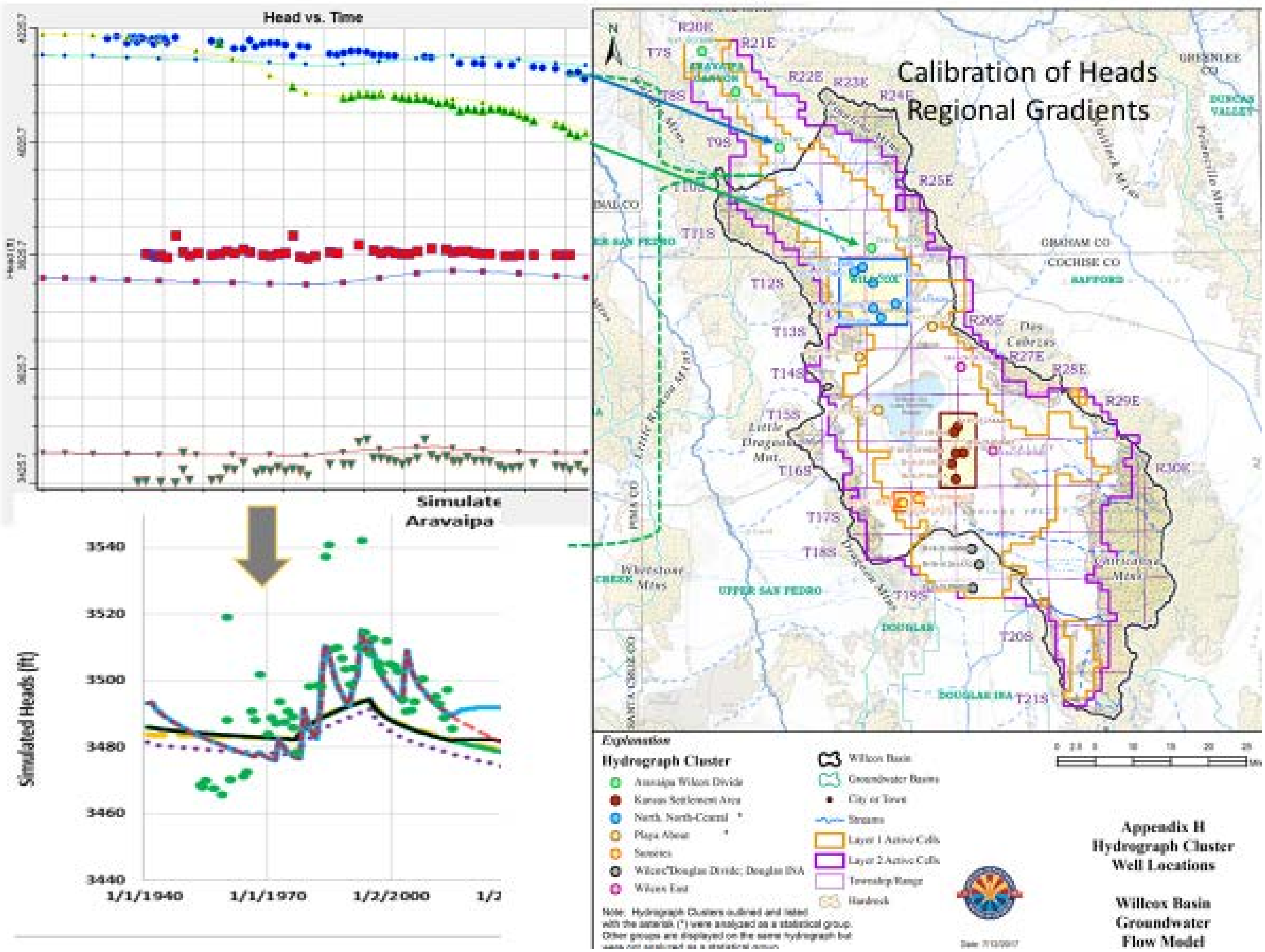

Observed and Simulated Groundwater Levels in the Willcox Basin and Aravaipa Creek Basins

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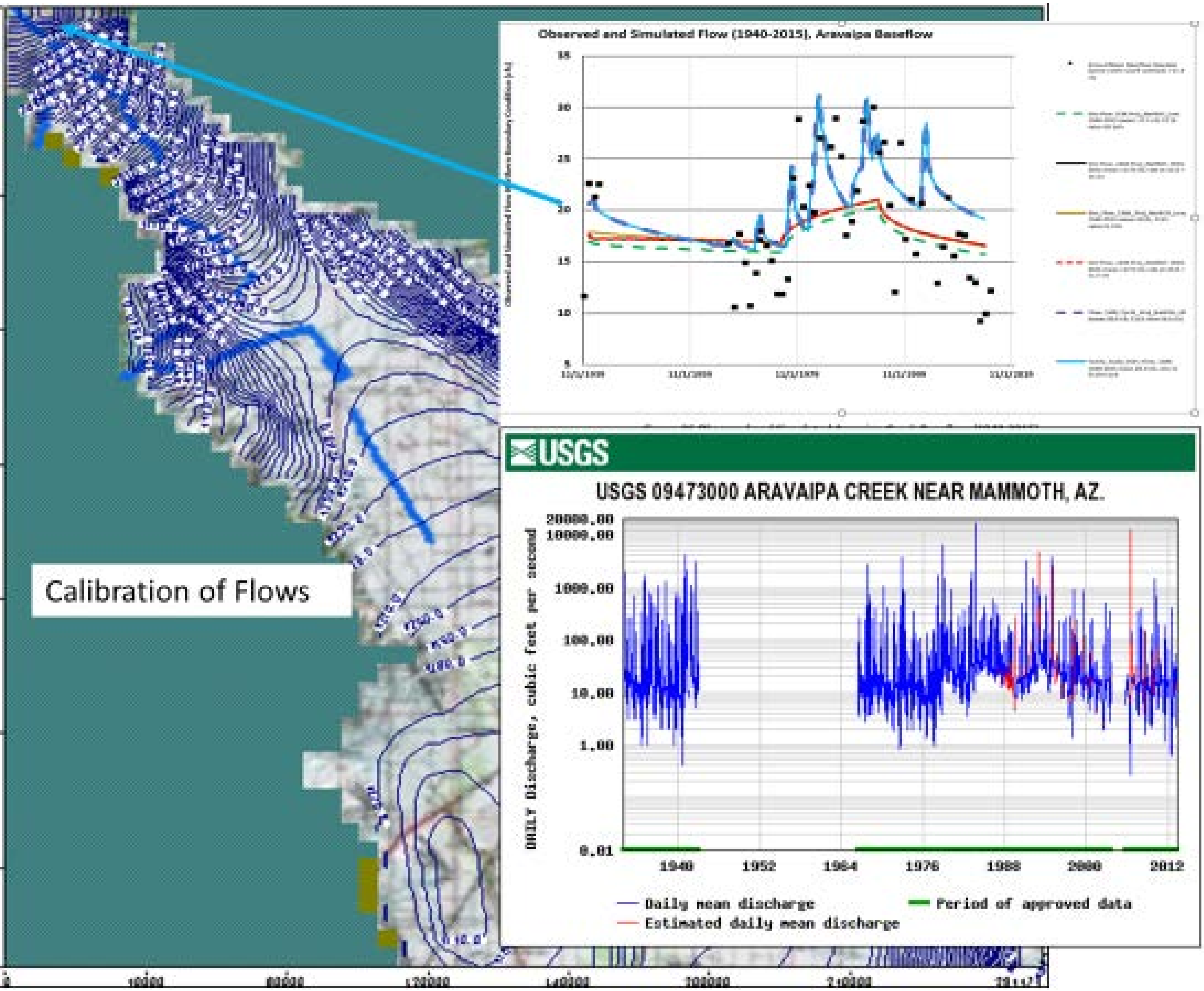

Observed and Simulated Groundwater Discharge as Baseflow associated with Aravaipa Creek (Model Calibration Target)

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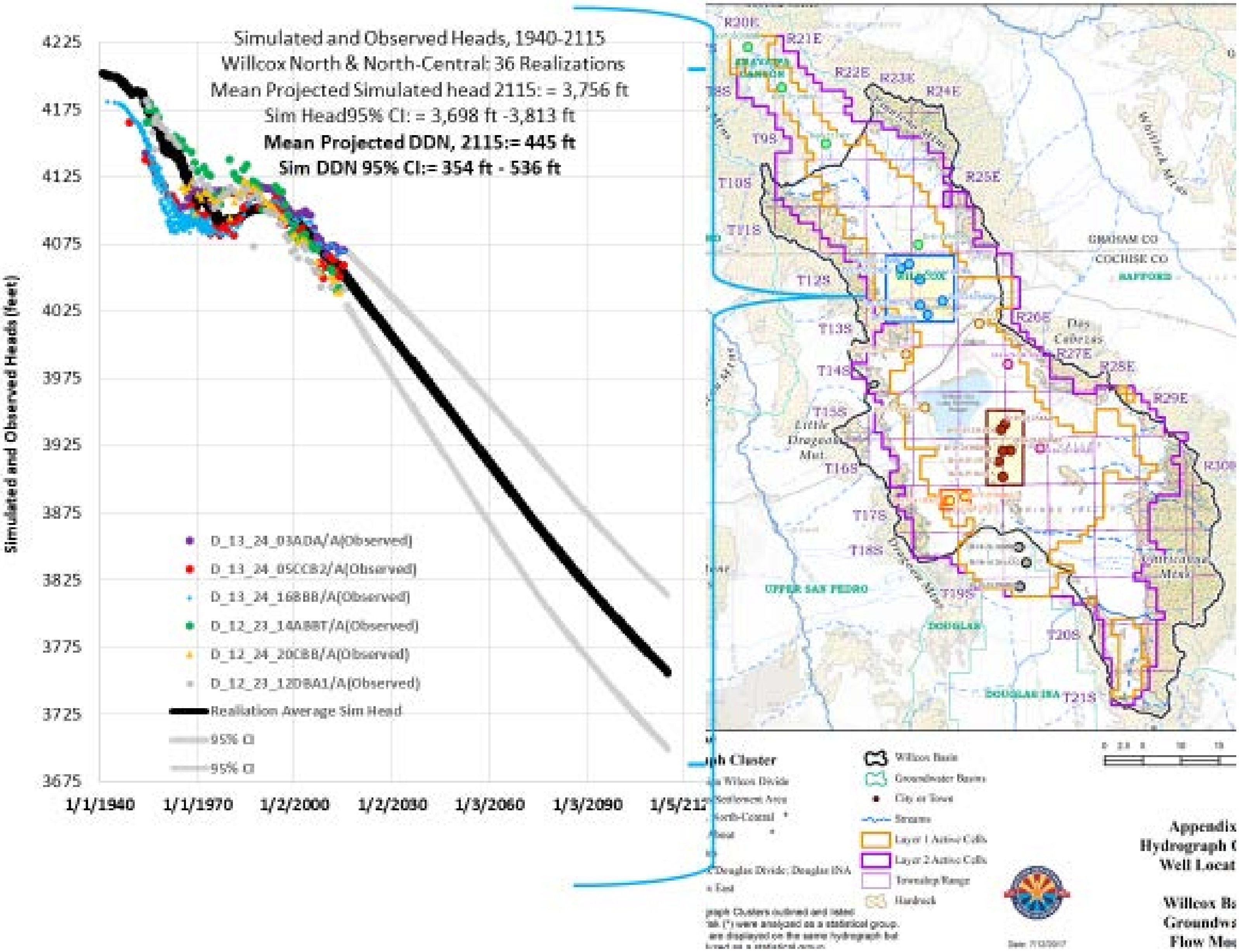

Observed and Simulated Groundwater Levels in the Willcox Basin, North of the Willcox Playa

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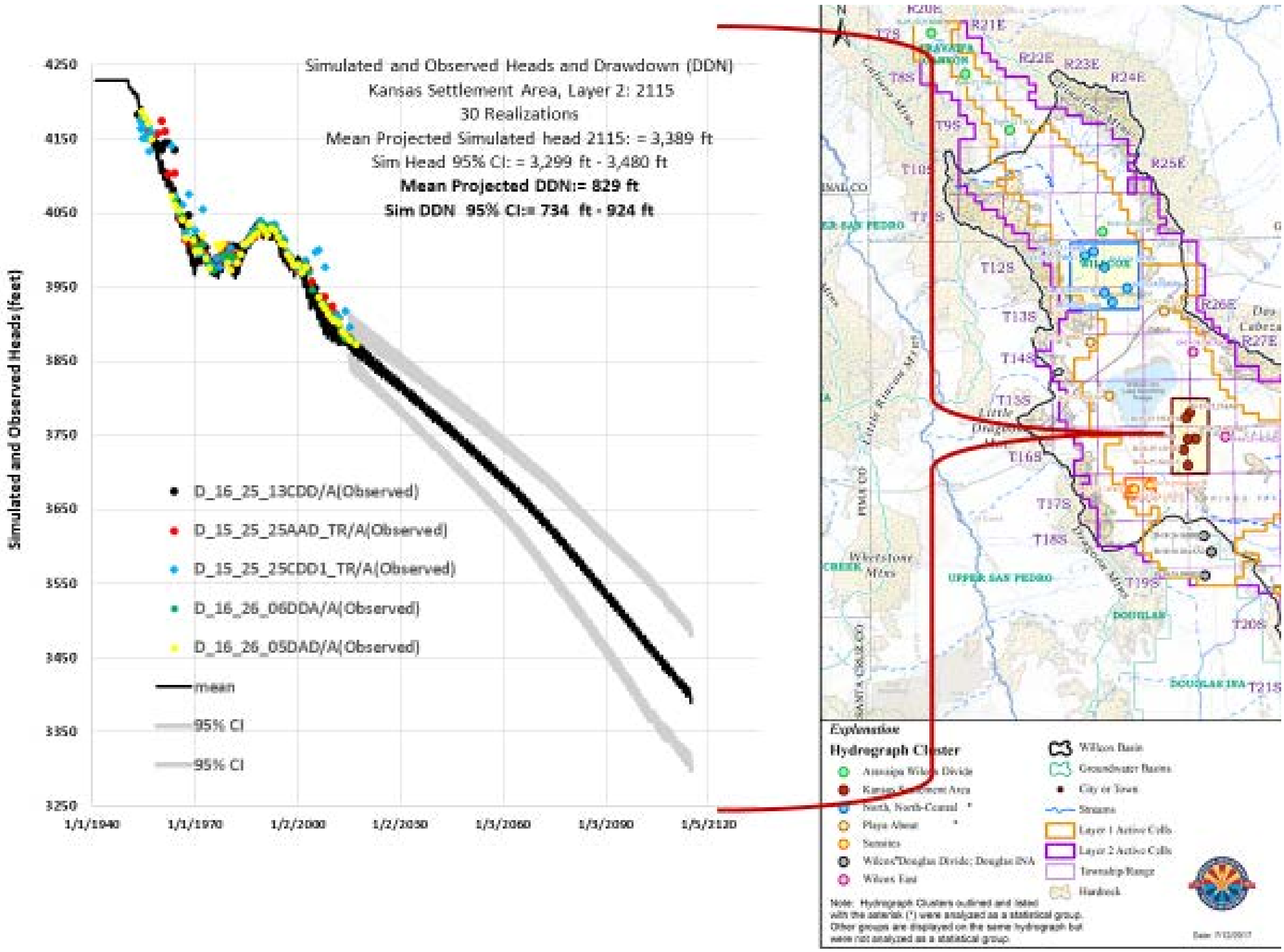

Observed and Simulated Groundwater Levels (LBF Aquifer) in the Willcox Basin, near Kansas Settlement

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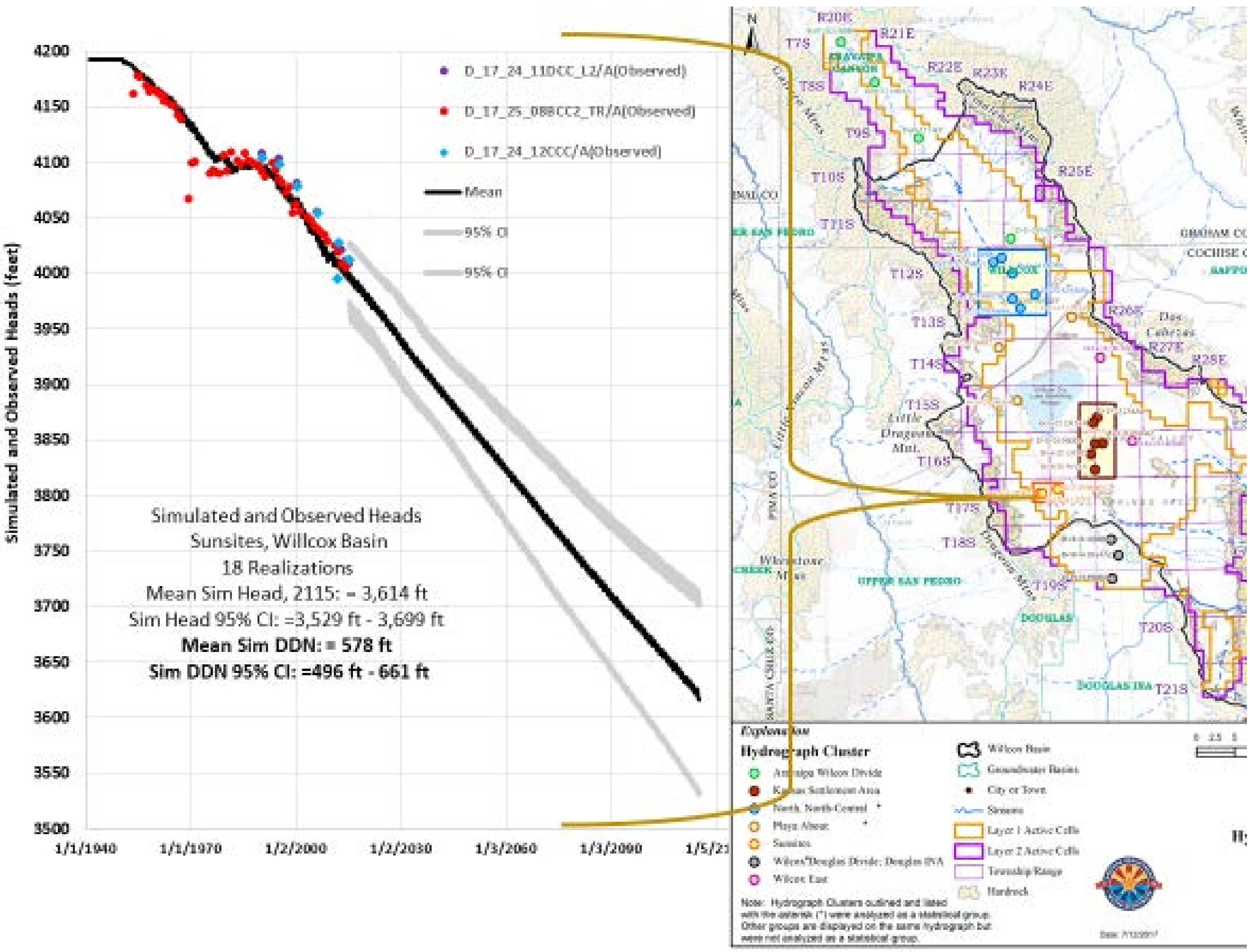

Observed and Simulated Groundwater Levels (LBF Aquifer) in the Willcox Basin, near Sunsites

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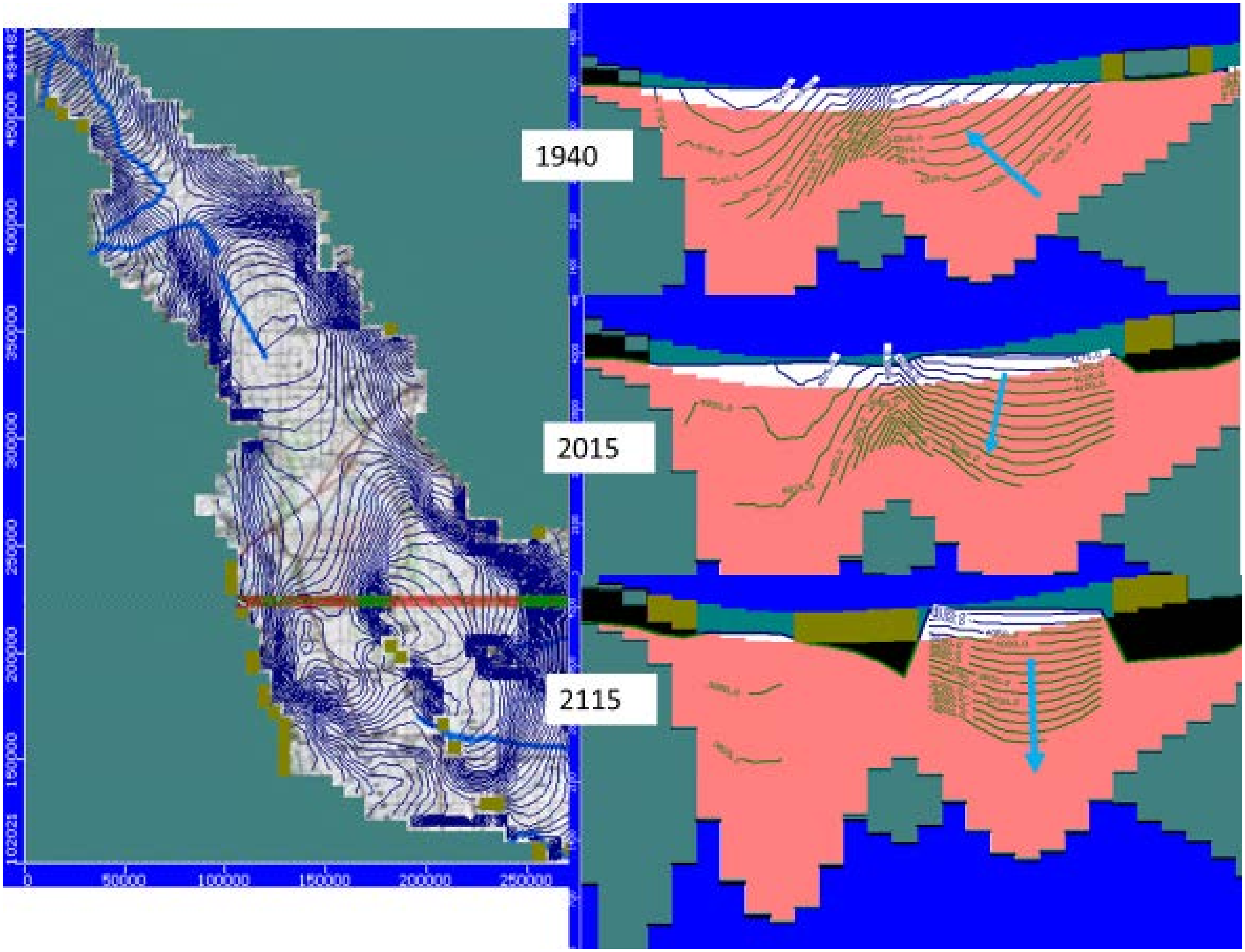

East-West Cross Section of Simulated Groundwater Levels in the Willcox Basin, South of Willcox Playa

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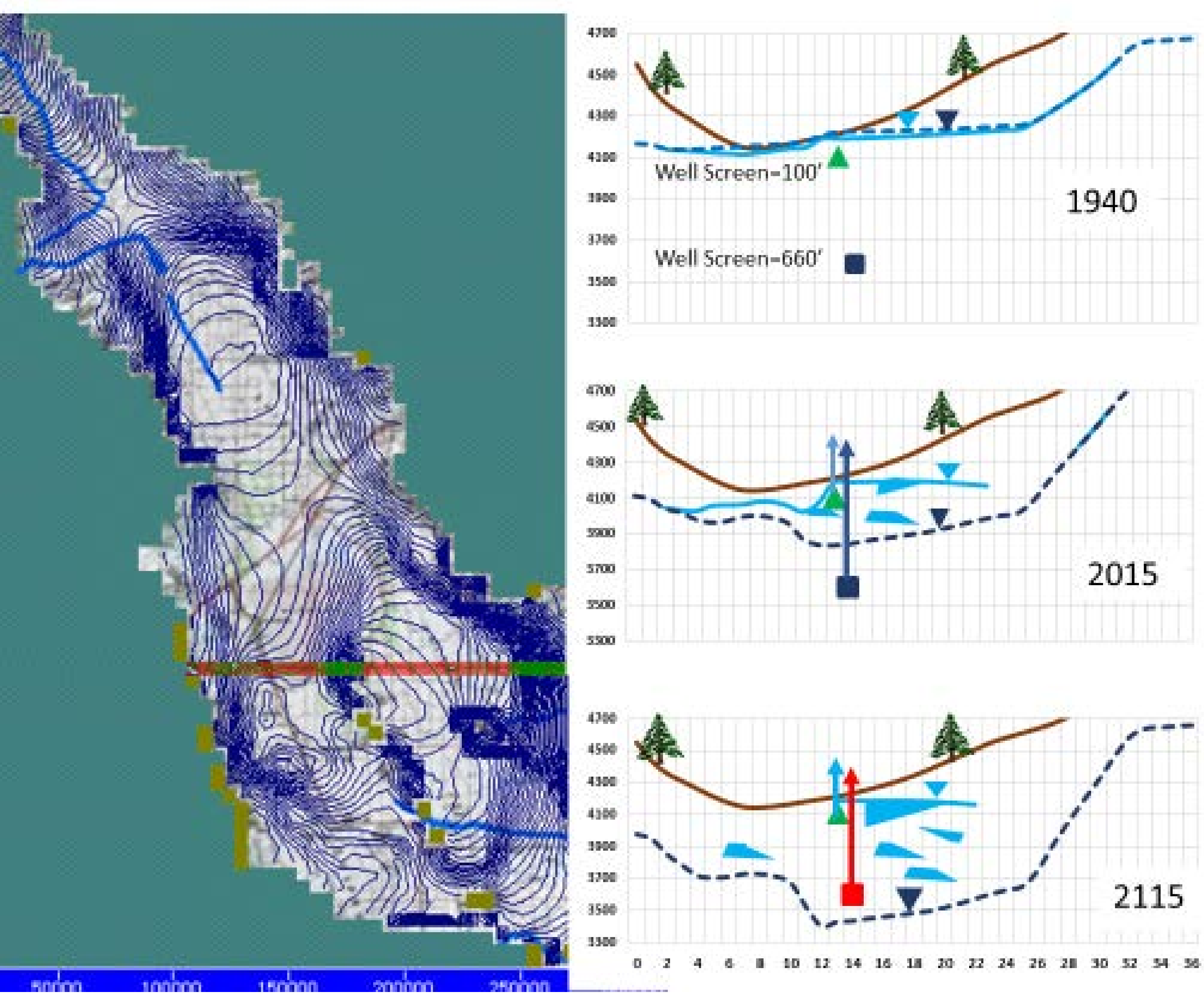

East-West Cross Section of Simulated Groundwater Levels in the Willcox Basin, South of Willcox Playa