DRAFT
TECHNICAL MEMORANDUM

DATE: October 30, 2020 **PROJECT #:** 1658.0309

TO: Valerie Swick, US Bureau of Reclamation

CC: Jake Lenderking, Pinal Partnership/Global Water

FROM: Brittney Bates, Juliet McKenna and Hale Barter

PROJECT: Eloy and Maricopa-Stanfield Basin Study, Groundwater Model Development

SUBJECT: Groundwater Model Review

INTRODUCTION

The U.S. Bureau of Reclamation (Reclamation) and the Pinal Partnership are coordinating with other study participants (collectively referred to as "Stakeholders") on the Eloy and Maricopa-Stanfield (EMS) Basin Study. As part of the Basin Study, Montgomery & Associates (M&A) is contracted to review and update the Pinal Active Management Area (AMA) groundwater flow model developed by the Arizona Department of Water Resources (ADWR). The model will serve as a planning tool for the Stakeholders. M&A will use the updated model to simulate future groundwater conditions under various scenarios of projected water supply and demand that are provided by the Study Participants.

The objective of the model review is to confirm adequacy of the model to evaluate Stakeholder alternatives and recommend revisions to the model. This memorandum is completed in accordance with Reclamation contract order #140R3019P0092, line item 52 to document the model review, recommended adjustments to the historical model, and updates through 2018.

GROUNDWATER MODEL EVALUATION AND ADJUSTMENTS

The Pinal model domain is approximately 1,500 square miles and represents most of the Pinal AMA and a small portion of the East Salt River Valley (SRV) subbasin in the Phoenix AMA. The Study Area is the Maricopa-Stanfield and Eloy groundwater subbasins in as shown on Figure 1. The domain includes the incorporated areas for Maricopa, Florence, Coolidge, Eloy, and Casa Grande, part of the Gila River Indian Community (GRIC) and Tohono O'odham Nation, and the Ak-Chin Community. Two ephemeral streams are within the model: the Gila

River and the Santa Cruz River. Land use is dominated by agriculture. Irrigations districts and tribal lands are shown on Figure 2.

Model Versions

ADWR developed a groundwater flow model to simulate future groundwater conditions for the Pinal AMA. The groundwater model is a regulatory tool that is used to evaluate applications to pump groundwater in accordance with the state's Groundwater Management Act, and associated policies and regulations. In 2014, ADWR released a three-layer finite-difference groundwater model of the Pinal AMA (Liu and others, 2014) using the USGS MODFLOW 2005 code (Harbaugh, 2005). The model, referred to as "ADWR 2014", includes a steady-state (1923) and transient period (1923 – 2009) calibration and is divided into annual stress periods.

In October 2019, ADWR released a new version of the model with structural modifications and an extended transient period through 2015. This model is referred to as "ADWR 2019" and is the subject of this model review memorandum.

The updates and adjustments described in this memorandum refer to the "Pinal 2020" version of the model. Table 1 summarizes the adjustments made in Pinal 2020 model. The updates extend the model simulation through 2018. Additional details on various model components were provided at public meetings held on May 15, 2020 and September 29, 2020. The presentations are available from the Pinal Partnership website[1].

Table 1. Summary of Updates and Adjustments to ADWR 2019 Model for Pinal 2020 Model

Model Component	Adjustments from ADWR 2019 Model
Model structure (layers and extent)	None
Hydraulic properties	None
Subsidence	Reduced compressible layer thickness in areas where it exceeded total layer thickness
Groundwater Budget Components	Restored inter-basin boundaries groundwater inflows at dry cell locations
	Small corrections to recharge volumes for underground storage facility (USF) recharge
	Extended all simulated water budget components for the 2016 through 2018 period

[1] http://pinalpartnership.com/ems-basin-study/

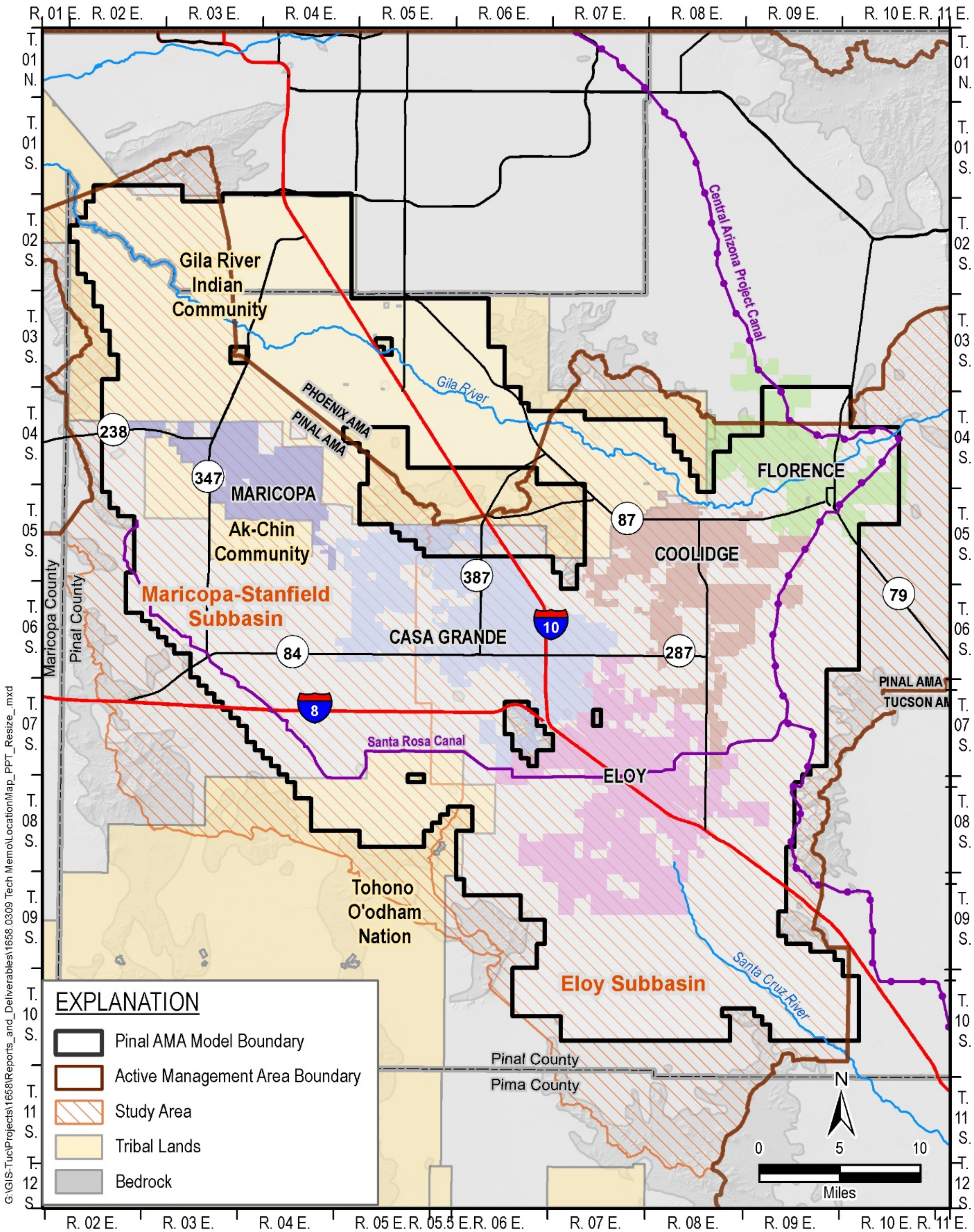

Figure 1. Study Area and Model Extent

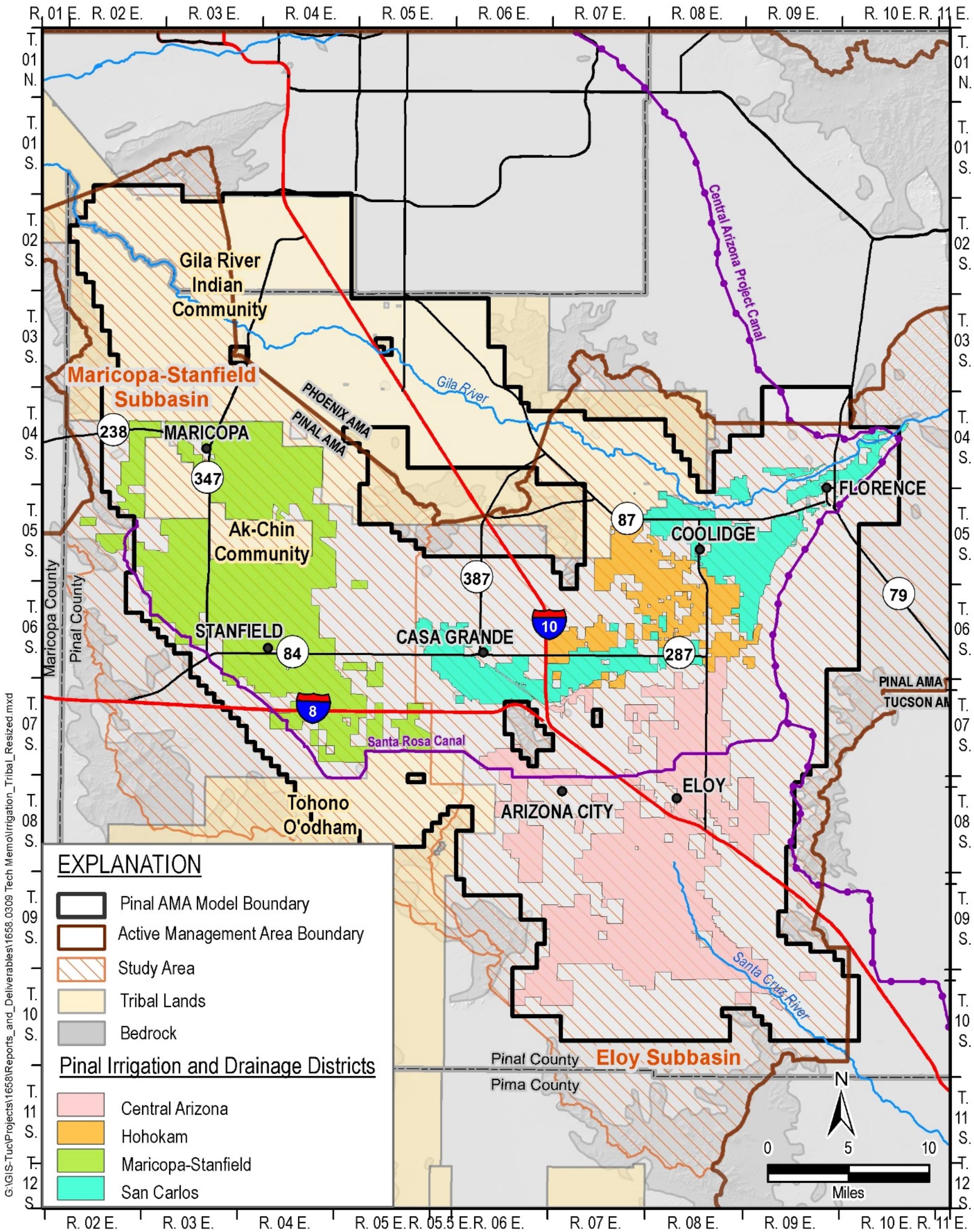

Figure 2. Irrigation Districts

Model Structure

The model area consists of alluvial basins bounded by bedrock mountains. The model area is divided by the Casa Grande Ridge, a buried bedrock ridge that is about 150 feet below land surface (bls) and separates the Maricopa-Stanfield and Eloy subbasins (Lui and others, 2014). The groundwater model is truncated 3,000 feet bls. Alluvial units are water-bearing and bedrock is generally considered to be impermeable, except in certain areas where it is highly fractured around the Casa Grande Ridge.

The model is bounded by no-flow bedrock boundaries or inter-basin flow boundaries, shown in Figure 3. Groundwater flows into the active model area at discrete locations from the west, south, and east, and flows out of the model at the north. The two types of flow boundaries in the groundwater model are constant head and constant flux. Changes to flow boundaries are described in the Groundwater Budget Components section of this memorandum. The extent of the model was not changed from the ADWR 2019 model.

The model is divided into three hydrogeologic units, described in Table 2. No layer changes were made to the ADWR 2019 model. Data acquisition methods and detailed descriptions of the layers are contained in previous ADWR reports (Lui and others, 2014, and references therein).

Table 2. Model Layers

Model Layer	Hydrogeologic Unit	Description
Layer 1	Upper Alluvial Unit (UAU)	Primarily unconsolidated sand and gravel; maximum thickness 450 feet in Eloy subbasin
Layer 2	Middle Silt and Clay Unit (MSCU)	Primarily silt, clay, and sand; does not exist in the Casa Grande Ridge area or along the basin margins, or along the Gila River; several thousand feet thick in Eloy subbasin
Layer 3	Lower Conglomerate Unit (LCU)	Somewhat consolidated coarse sediments such as gravel, sand, and boulders; thickness ranges from 50 to over 8,000 feet

Hydraulic Properties

We reviewed the hydraulic properties of the model, including horizontal and vertical hydraulic conductivity, specific storage, and specific yield. We also reviewed aquifer test data published by ADWR in the model reports and provided by Arizona Water Company and Global Water. We conclude that the hydraulic properties in the ADWR 2019 model are adequate for the study objectives and no adjustments are recommended.

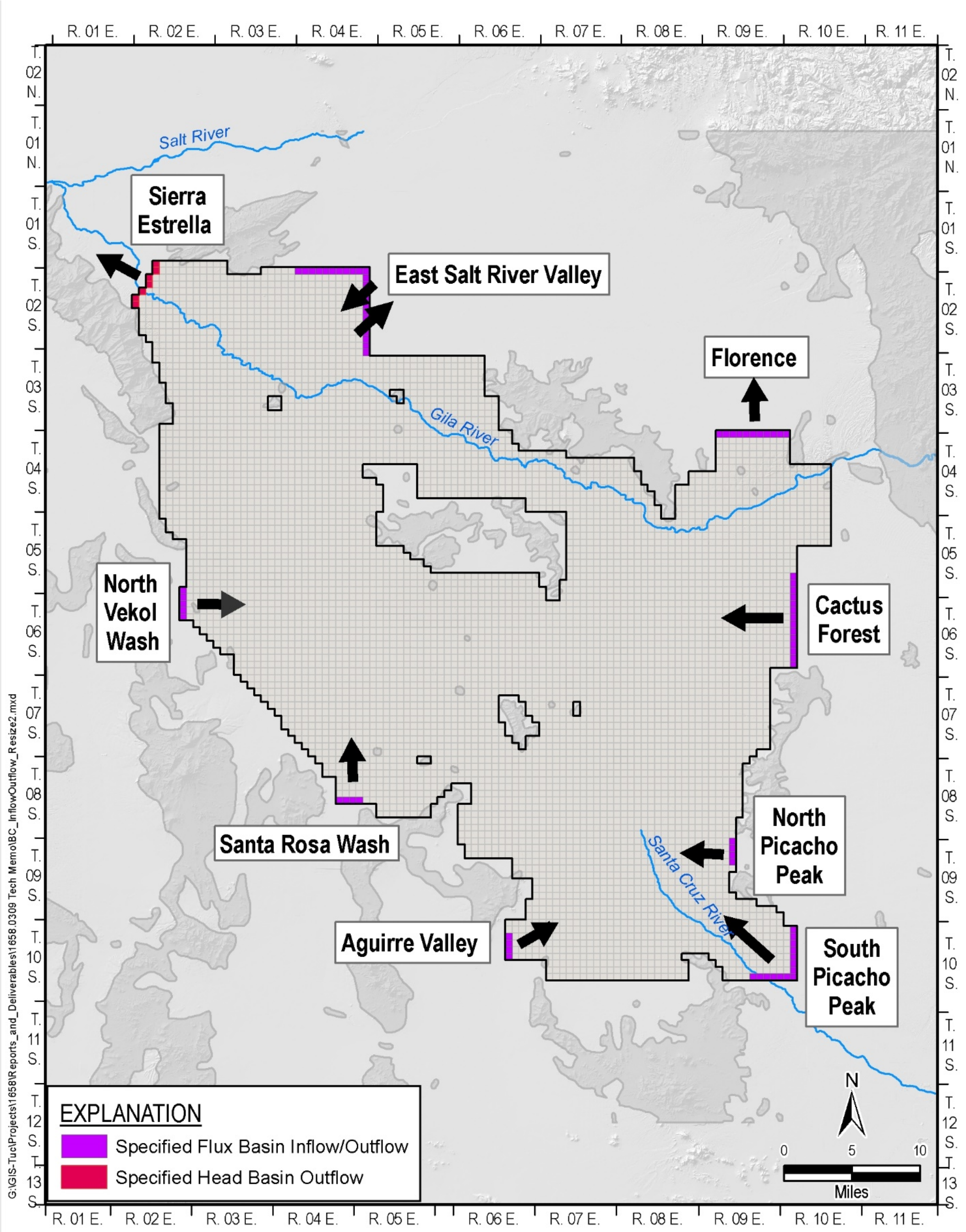

Figure 3. Model Boundary Conditions

Subsidence

Subsidence is well-documented in the Pinal model area as a result of intensive groundwater pumping for agriculture (Lui and others, 2014). Land subsidence occurs when fine-grained aquifer materials with a high percentage of clays are dewatered and collapse, lowering the elevation of the land surface. The compaction is generally irreversible and may result in a permanent loss of groundwater storage and reduced hydraulic conductivity.

The ADWR 2019 model uses the MODFLOW Subsidence and Aquifer-System Compaction Package or “SWT” package. Numerical representation using the SWT package requires estimation of a complex set of hydraulic and soil parameters. ADWR identified that there is substantial uncertainty about specific subsidence parameters in the Pinal area. For the 2014 and 2019 models, ADWR followed a simplifying principal of “parsimony” in their approach for estimating and varying subsidence parameters to reproduce observed subsidence in the Pinal area.

Our review focused on inelastic and elastic specific storage properties in the compressible sediments, compressible sediment thickness, and the model’s ability to reproduce measured subsidence. In some areas, the ADWR 2019 model specified compressible sediment thicknesses in excess of the layer thickness. In these areas, we reduced the compressible thickness to equal model layer thickness, as shown in Figure 4.

We conclude that overall storage representation in the model and in the compressible sediments was acceptable and that the ADWR approach for representing subsidence is generally acceptable for study purposes.

For the model review and update, we used previously published data by Laney et al (1978) and obtained additional subsidence measurements from ADWR (Public Records Request for Historical Land Pinal Subsidence maps, created on 6/9/2019). Figure 5 shows the measured and simulated subsidence using the 2020 Pinal model. The model provides a reasonable match to measured subsidence data, and we conclude and that the model adequately simulates subsidence for purposes of this study.

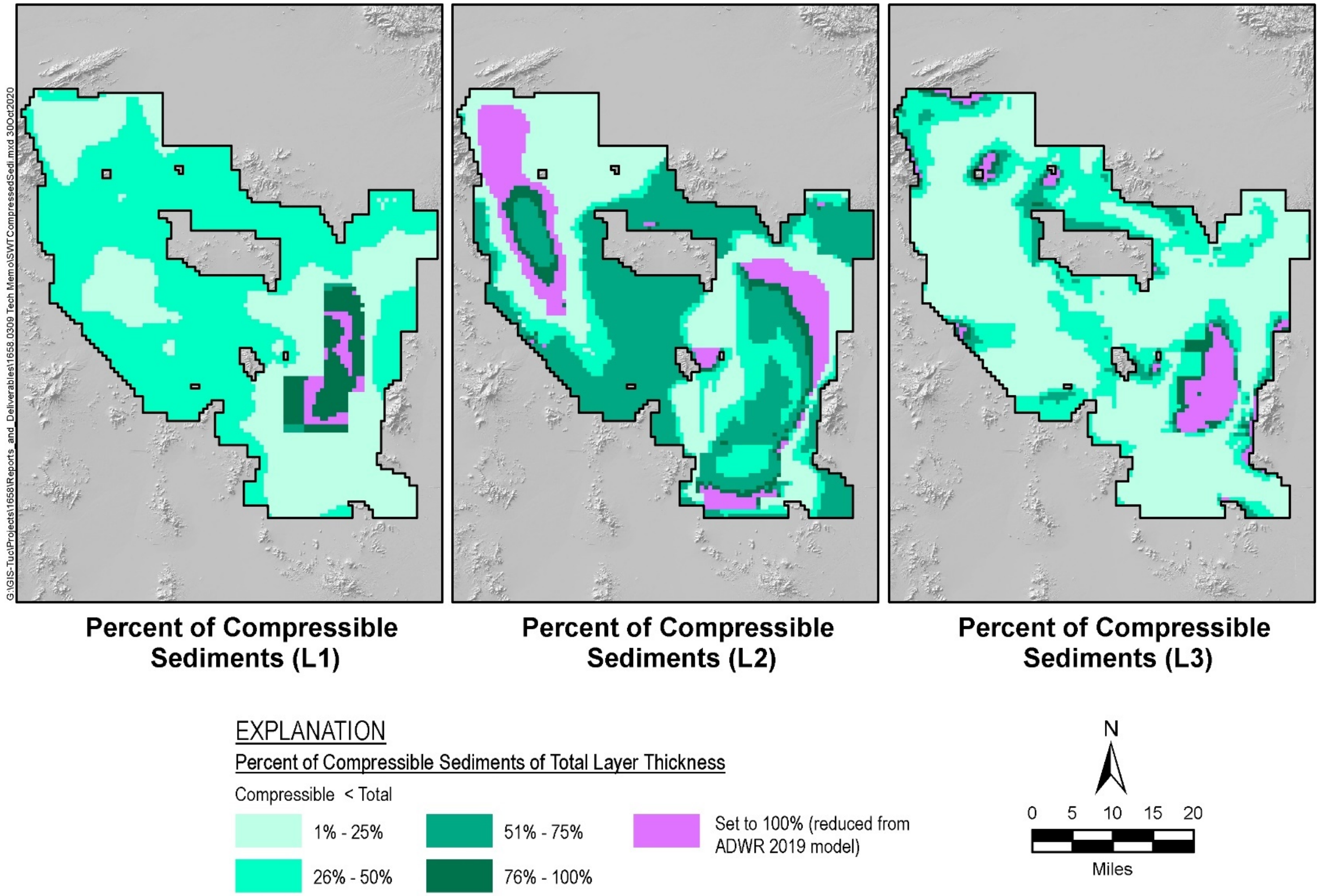

Figure 4. Compressible Sediment Thickness and Areas of Adjustments in Model Layers 1, 2, and 3

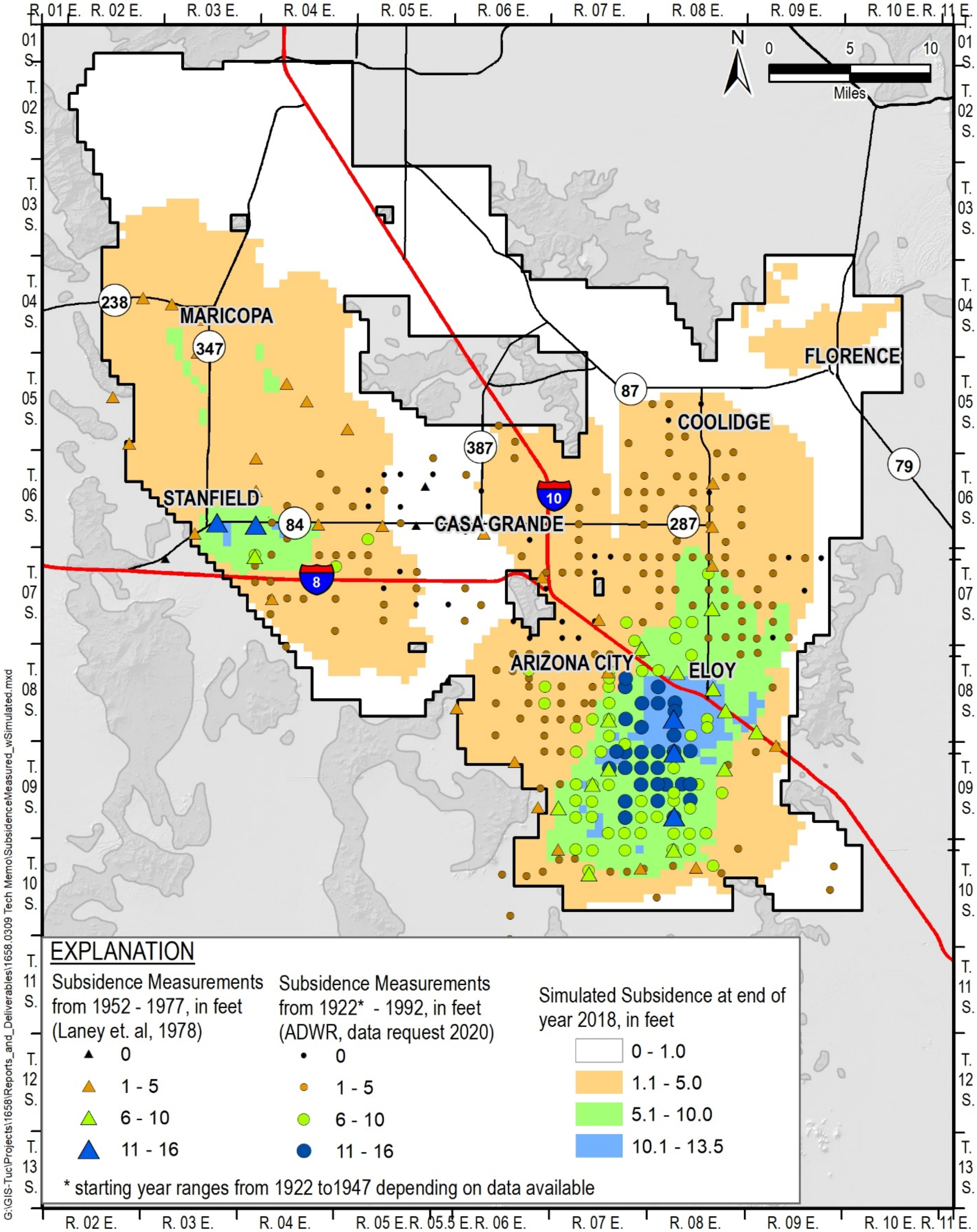

Figure 5. Measured and Simulated Subsidence

Water Budget Components

Simulated water budget components are shown in Figure 6. We reviewed the following simulated water budget components:

- Inflow - recharge from agricultural return flows, canal and Picacho Reservoir seepage, stream recharge, inter-basin inflows and other recharge (mountain front, USF, and urban runoff recharge)

- Outflow - groundwater pumping, inter-basin outflows, stream outflow, and evapotranspiration (ET)

We identified dry model cells that reduced specified inter-basin inflows at Santa Rosa Wash, Cactus Forest, and Aguirre Valley (Figure 3). These boundaries were adjusted to restore the specified inflows for the 2020 Pinal model. The total amount restored was 93,000 acre-feet (AF) over the 96-year model transient period. We also made small corrections to the historical USF recharge to match annual volumes reported by ADWR. We conclude other water budget components in the ADWR 2019 model were acceptable for the study purposes.

MODEL UPDATE (2016 – 2018)

M&A extended the simulation period to include 2016 through 2018. The additional three years of simulated water budget components are shown on Figure 6. Methods for each component are described below.

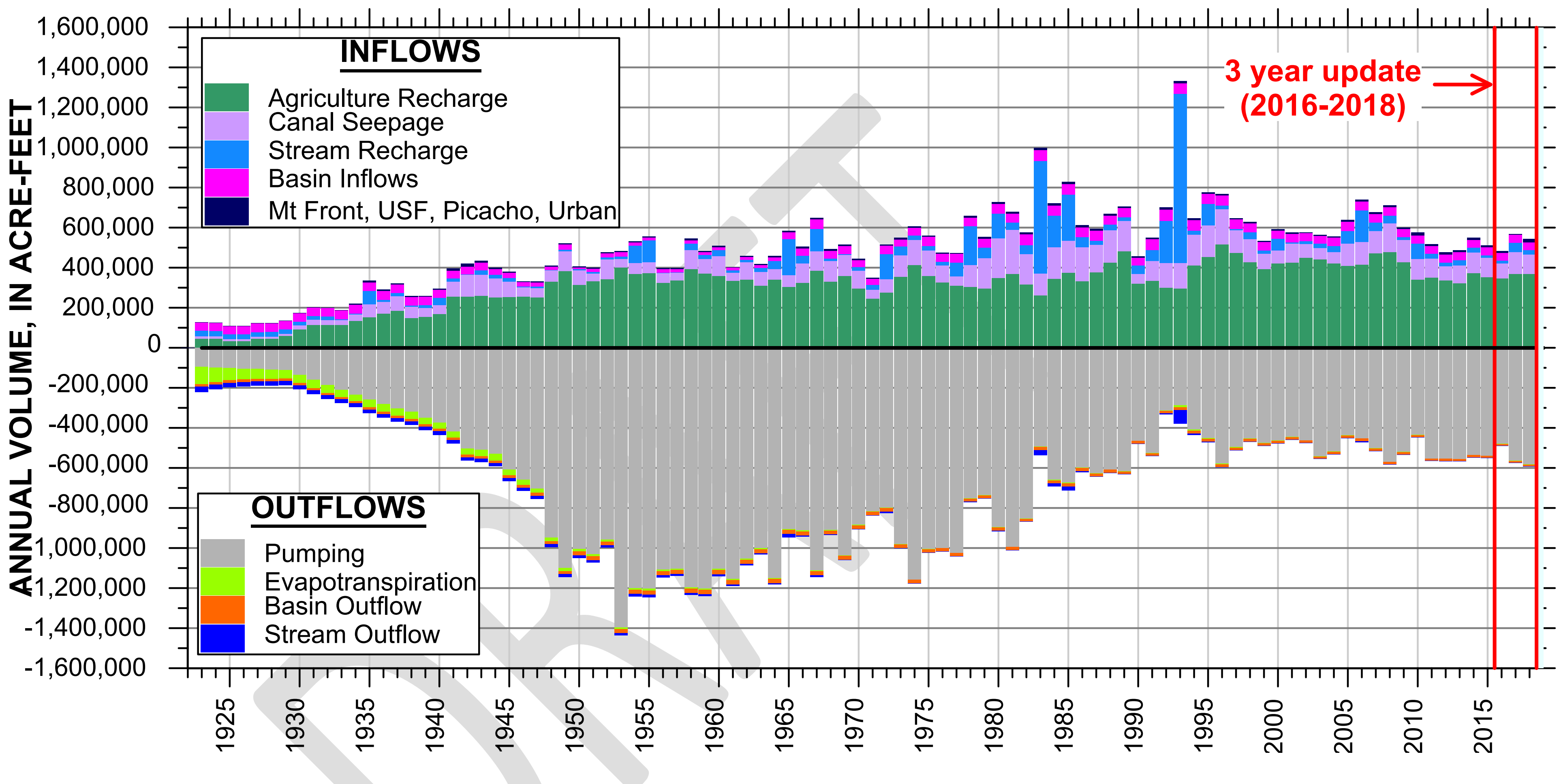

Figure 6. Inflows and outflows in model and 3-year update, 2016-2018.

Inflows

Agricultural Recharge

Agricultural recharge for the period 2016 through 2018 was derived using the same method used for the ADWR 2019 model update. The data sources are USDA cropland raster data sets and irrigation requirements numbers published in the Third Management Plan for Pinal AMA (ADWR, 1999). The estimated farm efficiency was set at 70 percent based on the 2019 ADWR model agricultural recharge totals. Consistent with the ADWR 2019 model for the period 2010 through 2015, we assumed the lag period for annual agricultural return flows to infiltrate to the underlying aquifer remained constant, and the simulated annual agricultural aquifer recharge rates were in equilibrium with the calculated annual agricultural return flows. Simulated annual agricultural recharge to the aquifer for the period 2016 through 2018 is shown on Figure 6.

Stream Recharge

Annual stream flow recharge from the Gila and Santa Cruz Rivers is updated for 2016 through 2018 based on reported stream flow data.

Consistent with the ADWR 2019 model, annual 2016 through 2018 recharge from the Gila River is calculated as the difference between the reported flow in the San Carlos Irrigation Project (SCIP) annual reports at Ashurst-Hayden Dam and the measured flow downstream at the USGS Maricopa stream gage. Annual volume of simulated recharge from calculated Gila River inflows is shown in Table 3. Spatial distribution of annual Gila River recharge mirrors the ADWR 2019 model distribution under baseflow conditions, as shown on Figure 7.

Annual 2016 through 2018 recharge from the Santa Cruz River is based on the measured flows at the USGS Trico Road gage and estimated infiltration losses along the seven mile stretch of river channel between the Trico Gage and the Pinal model boundary. The infiltration losses along the seven-mile stretch were estimated by calculating the daily average infiltration rate between the Trico and Cortaro USGS gages. This method accounts for the increased infiltration due to improved water quality of effluent discharge from Tucson’s wastewater treatment plants (Sonoran Institute, 2019). This method is different from the method used for ADWR 2019 model but yielded comparable results. Annual volume of simulated recharge from calculated Santa Cruz River inflows is shown in Table 3. Spatial distribution of annual Santa Cruz River recharge mirrors ADWR 2019, as shown on Figure 7.

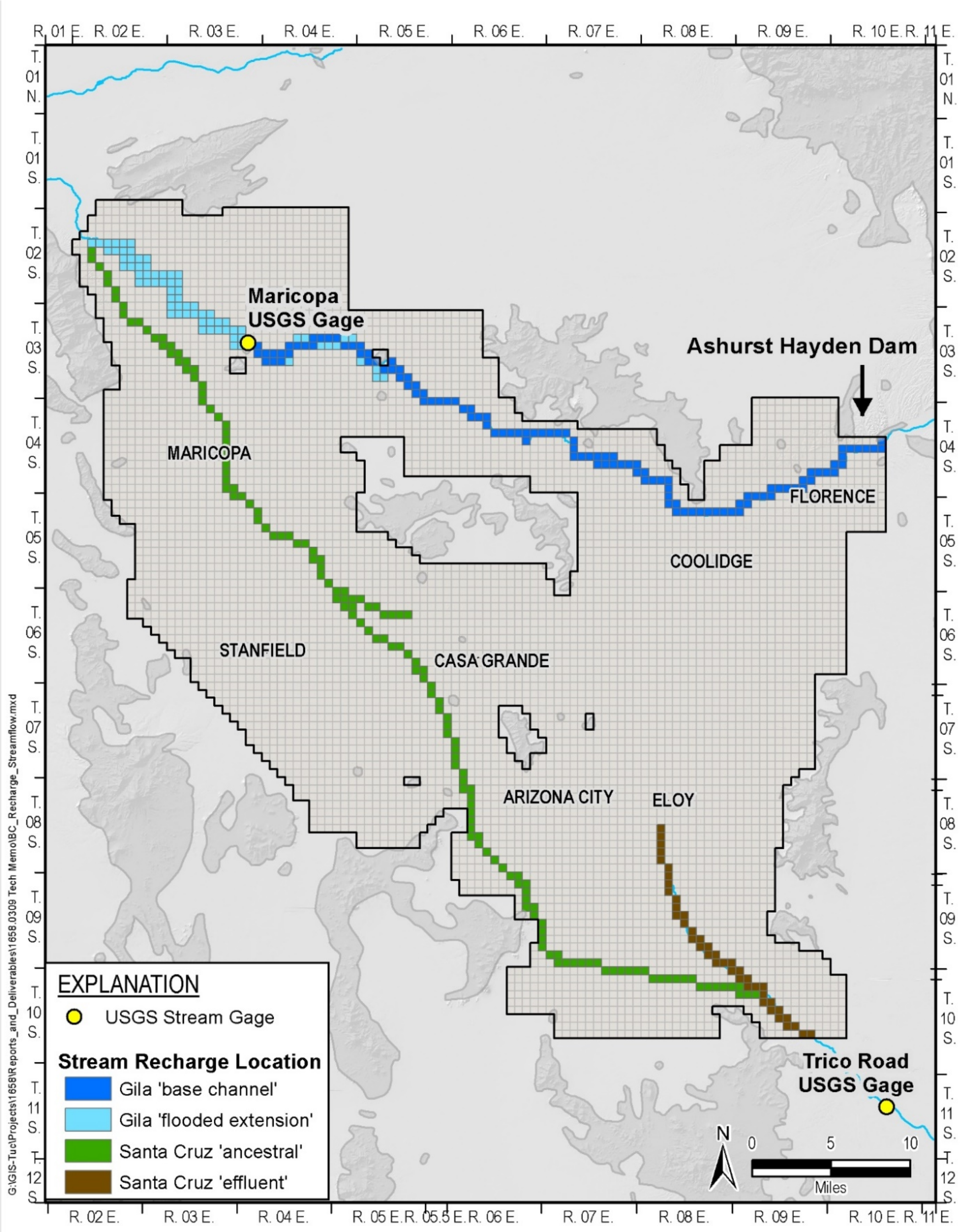

Figure 7. Stream Recharge Distribution and Gaging Points

Table 3. Simulated Stream Recharge for 2016 through 2018

Year	Total Recharge Volume (acre-feet)	
	Gila River	Santa Cruz River
2016	11,584	8,764
2017	33,578	14,474
2018	10,811	5,219

Canal Seepage

Annual volume of simulated canal seepage is shown in Table 4. Central Arizona Project (CAP) Aqueduct recharge from seepage for the period 2016 through 2018 is maintained at the same 1,710 acre-feet per year (AF/yr) annual rate simulated in the ADWR 2019 model for year 2015.

Consistent with ADWR 2019 model, 2016 through 2018 recharge from seepage for the SCIP canals is estimated based on the total canal deliveries sourced from SCIP annual reports. The distribution of seepage recharge is similar to the ADWR 2019 model. We assumed a 37% seepage loss of total SCIP deliveries based on 10-year average seepage loss (2006 through 2015) in ADWR 2019 model.

Recharge for the period 2016 through 2018 from Picacho Reservoir seepage is calculated using the same method used in the ADWR 2019 model. Storage volumes are from SCIP annual reports.

Table 4. Simulated Canal Seepage for 2016 through 2018

Year	Total Seepage Volume (acre-feet)		
	CAP Canal	SCIP Canals	Picacho Reservoir
2016	1,710	72,234	542
2017	1,710	107,298	1062
2018	1,710	95,723	460

Other Recharge

USF recharge for the period 2016 through 2018 was updated based on ADWR records (ADWR data request received on September 11, 2020). The Olberg Dam USF on GRIC began recharging in 2015 and was added to the model.

Recharge from urban runoff for the period 2016 through 2018 is set at the same 3,182 AF/yr rate and location as year 2015 in the ADWR 2019 model.

Mountain-front recharge for the period 2016 through 2018 is set at the same 500 AF/yr locations as year 2015 in the ADWR 2019 model.

Basin Inflows

Inter-basin inflows are set at the same constant rate as published in the ADWR 2019 model report for year 2015, and accordingly restored in the model simulation 2020 Pinal model (previously described in this memorandum).

Outflows

Pumping

Simulated groundwater pumping for the period 2016 through 2018 was obtained from three sources and are shown on Table 5. The majority of annual pumping volumes and locations is sourced from the ADWR public database (ADWR, download from web portal in December 2019). GRIC annual pumping volumes and locations was received from GRIC (P. Mock, personal communication, June 2020). SCIP annual pumping volumes and location information was sourced from the Bureau of Indian Affairs (A. Fisher, personal communication, in June 2020). Pumping distribution between layers was maintained consistent with ADWR 2019 model. Location of specified pumping in year 2018 is shown on Figure 8.

Table 5. Simulated Pumping for 2016 through 2018

Year	Total Pumping Volume (acre-feet)		
	ADWR Wells	GRIC Wells	SCIP Wells
2016	368,296	52,493	57,403
2017	459,361	60,281	43,955
2018	446,776	73,147	61,985

Basin Outflows

Basin outflows are consistent with specifications for year 2015 in the ADWR 2019 model.

Stream Outflow and Evapotranspiration

Stream outflow only occurs from the Gila River as discharge via the last stream cell at northwest corner of the model, shown on Figure 9. Stream package parameters (STR) were unchanged from the ADWR 2019 model, for 2016 through 2018.

ET is specified only along the Gila River in the ADWR 2019 model. ET package (EVT) parameters were unchanged from the ADWR 2019 model, for the 2016 through 2018 period.

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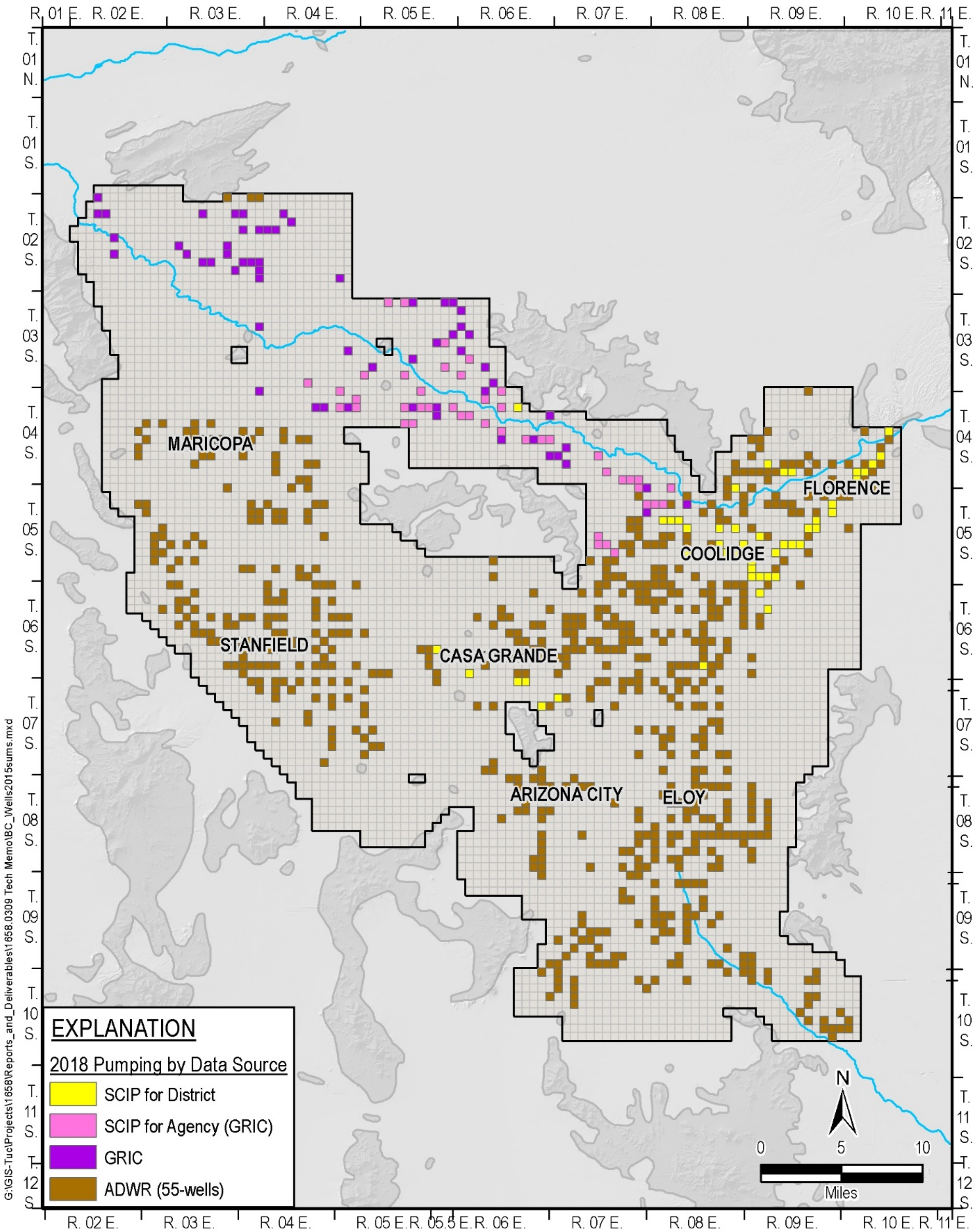

Figure 8. Pumping Locations in Model Update, 2016-2018

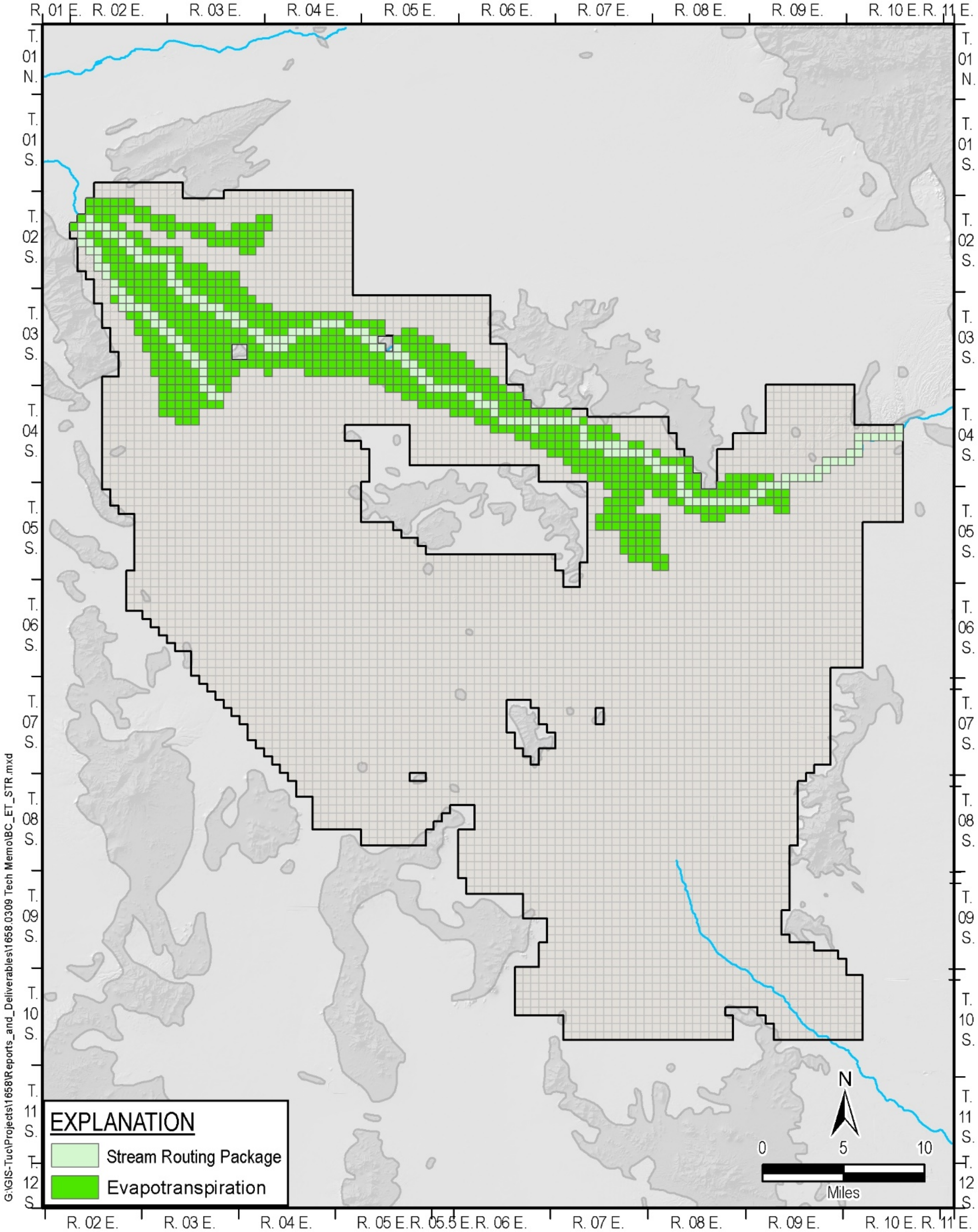

Figure 9. Stream Outflow and Evapotranspiration

Calibration Results

We evaluated the calibration method in the ADWR 2019 model for comparing measured to simulated heads. Substantial vertical gradients exist in the study area due to deeper agricultural pumping, shallow agricultural recharge and small vertical hydraulic conductivities. Heads that are measured in wells screened through multiple aquifer layers represent an average of aquifer heads along the well's vertical screened interval. Due to the steep vertical gradient, these measured water levels and can vary dramatically depending on the depth and length of the well's screened interval. The well screened intervals can span multiple model layers, and often well screened intervals are not known.

Since the model only simulates heads for each layer, it is challenging to compare simulated model layer heads to the corresponding average heads measured in wells.

- The 2014 ADWR model selects the simulated head for the model layer where the well was predominantly screened, for comparison to the measured head in the well.
- The 2019 ADWR model calculates a weighted average of simulated heads from model layers corresponding to the well saturated screened interval, for comparison to the measured head in the well.
- For this current study, we calculated a weighted average of simulated heads from model layers corresponding to the well screened interval, for comparison to the measured head in the well. The difference from the ADWR 2019 method is simulated heads in layers above the measured head in the well are included in the weighted average, whereas they were excluded from the ADWR 2019 method. This change results in a better representation of simulated heads to compare to corresponding measured heads.

Comparison of simulated to measured heads for the entire updated simulation period, 1923 through 2018, is shown on Figure 10. The calibration is very similar to that published for the ADWR 2019 model. Calibration statistics are reasonable, with a scaled residual mean squared error (Scaled RMSE) of 4.4 percent, the same as ADWR 2019 published scaled RMSE. We conclude that the model is sufficiently calibrated for the study objectives.

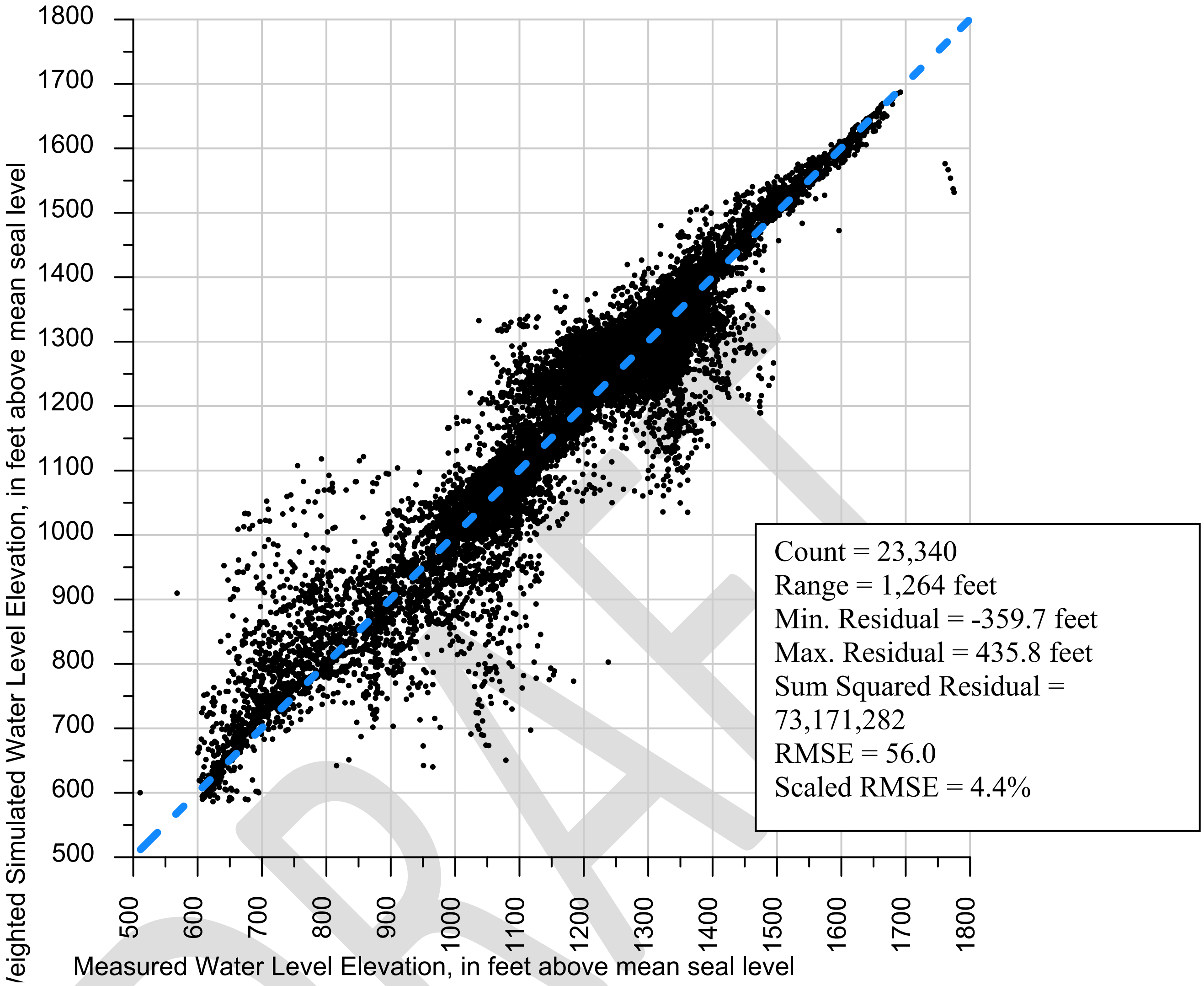

Figure 10. Calibration Statistics for 2020 Pinal Updated Model, 1923 to2018

CONCLUSIONS

The model review and update showed no issues that warranted substantial model modification, other than the minor adjustments noted. The Pinal model is acceptable for the Basin Study objective, which is to evaluate regional water level changes in response to future alternatives scenarios.

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