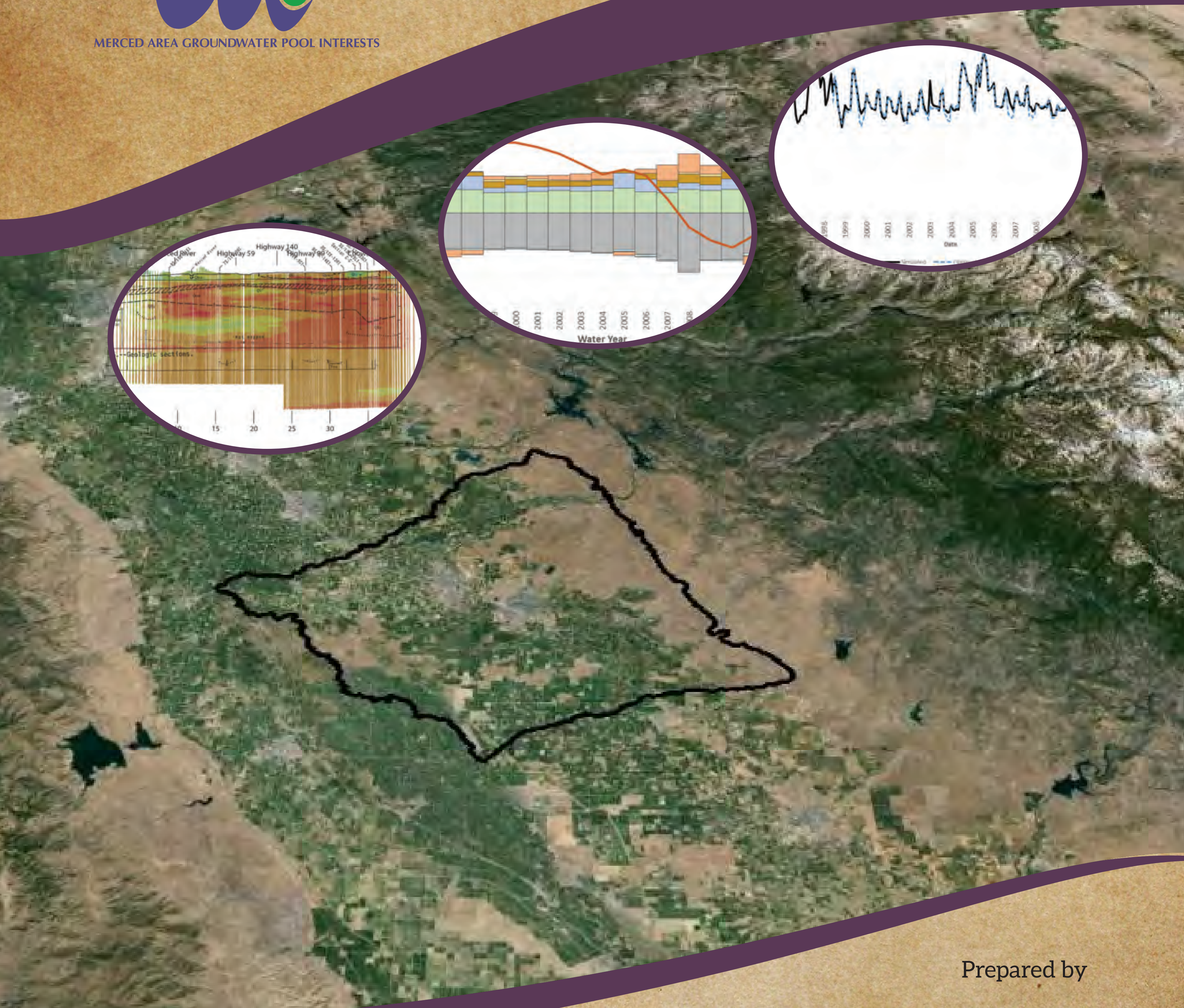
Merced Water Resources Model (Merced WRM)

MERCED AREA GROUNDWATER POOL INTERESTS



Prepared by

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September 2019

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GROUNDWATER POOL INTERESTS

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September 2019

Table of Contents

List of Tables & Diagrams

List of Figures

Appendices

List of Abbreviations

AF	Acre-Feet
AFY	Acre-Feet per Year
C2VSim	California Central Valley Groundwater-Surface Water Simulation Model
CADs	Cowell Agreement Diverters
CALSIMETAW	California Simulation of Evapotranspiration of Applied Water
CDEC	California Data Exchange Center
CDL	Cropland Data Layers from US Department of Agriculture
CFS	Cubic Feet per Second
CVHM	Central Valley Hydrologic Model
CWD	Chowchilla Water District
DEM	Digital Elevation Model
DWR	Department of Water Resources, State of California
ET	Evapotranspiration
GWMP	Groundwater Management Plan
GSE	Ground Surface Elevation
GSP	Groundwater Sustainability Plan
GW	Ground Water
IDC	IWFM Demand Calculator
IGSM	Integrated Groundwater Surface Water Model
ITRC	Irrigation Training and Research Center
IWFM	Integrated Water Flow Model
IRWMP	Integrated Regional Water Management Plans
MAGPI	Merced Area Groundwater Pool Interests
MercedWRM	Merced Water Resources Model
METRIC	Mapping Evapotranspiration at High Resolution with Internalized Calibration
MID	Merced Irrigation District
MID-WBM	Merced Irrigation District Water Balance Model
NASS	National Agricultural Statistics Service
NRCS	Natural Resource Conservation Service
PRISM	Precipitation-Elevation Regressions on Independent Slopes Model
PSDI	Pore Size Distribution Index
SGMA	Sustainable Groundwater Management Act
SW	Surface Water
SWD	Stevenson Water District
TAF	Thousand Acre-Feet
TDS	Total Dissolved Solids
TWG	Technical Work Group
TID	Turlock Irrigation District
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WDL	Water Data Library

Acknowledgements

The Merced Water Resources Model (MercedWRM) was developed by Woodard & Curran with funding contributions and technical support from the Merced Area Groundwater Pool Interests (MAGPI) and the California Department of Water Resources (DWR).

A Technical Work Group (TWG) was formed to provide quality assurance and technical support throughout the project, resulting in a groundwater model widely accepted by local shareholders and public agencies. The workgroup consisted of representatives from the Department of Water Resources (DWR), the United States Geological Survey (USGS), and several of the MAGPI member agencies.

The Project Team included:

- **Merced Irrigation District**
  - Hicham ElTal, Project Manager
  - Marco Bell, Project Engineer
- **Merced County**
  - Ron Rowe
- **City of Merced**
  - Ken Elwin
- **Technical Work Group**
  - Tariq Kadir, DWR
  - Steven Phillips, USGS
  - Hicham ElTal, Merced Irrigation District
  - Marco Bell, Merced Irrigation District
  - Ron Rowe, Merced County
  - Ken Elwin[1], City of Merced
  - Bob Kelly, Stevenson Water District
- **Consultant: Woodard & Curran**
  - Ali Taghavi, Project Manager
  - Dominick Amador, Project Engineer
  - Jim Blanke, Project Hydrogeologist
- **Department of Water Resources Representative**
  - Jason Preece

[1] Prior to Ken Elwin's involvement, Mike Wegley represented the City of Merced in the Technical Work Group

Chapter 1 Introduction

The Merced Water Resources Model (MercedWRM or Model) is a fully integrated surface and groundwater flow model covering approximately 1,500 square miles of the Merced Groundwater Region (Region). The MercedWRM, a quasi-three-dimensional finite element model, was developed using the Integrated Water Flow Model (IWFM) 2015 software package to simulate the relevant hydrologic processes prevailing in the Region. The Model integrates groundwater aquifers with the surface hydrologic system, land surface processes, and water operations. Using data from Federal, State, and local resources, the MercedWRM is calibrated for the hydrologic period of October 1996 through September 2015, by comparing simulated evapotranspiration, groundwater levels, and streamflow records with historical observed records.

Development of the Model includes the study and analysis of technical data and information that have (a) assisted in the understanding the hydrologic, hydrogeologic, water demand, groundwater, and water supply conditions within the Region; and (b) provided the basis for development and analysis of alternative water management scenarios. The results of this study include groundwater analysis suitable to assist the Sustainable Groundwater Management Act (SGMA) program in the Merced groundwater basin. This analysis includes:

- Hydrogeologic conditions –This study was used in the establishment of the basin's simulated conditions and to aid in model development. Information was collected from existing models, reports, and previous hydrogeologic studies that include, well logs, pump tests, and aquifer parameter data. The examination of this data led to the development of geologic cross sections, geologic zones, and water management subareas used to develop water budgets.
- Agricultural and urban water demands - Thorough analysis of the land and water use for the Region was completed using census data, land use surveys, historical crop acreage reports, and referenced standards for evapotranspiration and consumptive use fraction.
- Agricultural and urban water supplies - Detailed accounting of water sources for the Region were linked to the proper users. Extensive coordination between the local water purveyors was undertaken to collect and process available data. To this end, a detailed accounting of the various sources of water supplies (groundwater and surface water) for each user type and category was developed.
- Evaluation of regional water quality conditions – Water quality data for both Total Dissolved Solids (TDS) ad Nitrate (as NO3) was used to develop maps of TDS and NO3 distribution trends .Data collection efforts included loading of TDS and NO3 for various components such as applied water, irrigation canal water, and streamflow. .

1.1 Goals of Model Development

The goal of this project is to develop a comprehensive numerical integrated surface water and groundwater model that will help manage the water resources of the Merced Region at a localized scale. This model is to serve as a robust, defensible, established, publicly accepted analytical tool. This model would be used for analysis of water resources of the Region to evaluate the historical operations and hydrology of the Region, as well as support evaluation of water resources programs and water supply projects under baseline conditions reflecting the existing and future conditions in the Region.

As such, the model has been developed in an open and transparent process, with frequent workshops with the MAGPI members to review model data and assumptions, modeling process, as well as model results. In addition, a Technical Workgroup consistent of representatives of the Department of Water Resources, the US Geological Survey, and local agencies was formed to oversee the details of the model development and calibration process.

It is noteworthy that the Region is covered by the DWR's Central Valley Groundwater and Surface water Model (C2VSim), which can be used for simulation of the groundwater and surface water conditions at a much higher level, and evaluation of the interbasin flows across the model and the Region's boundaries. However, in order to evaluate the water resources conditions in the Region at a local scale, which reflects the details of the operations of the local Region, a detailed integrated hydrologic model is essential.

The specific objectives of development of the Merced Water Resources Model are:

Evaluate the Groundwater Region's Characteristics using the Model to:

- Assess historical and projected characteristics and behavior of the integrated SW & GW resources
- A robust and defensible analytical tool to support development of the Groundwater Sustainability Plan (GSP) for the basin
- Estimate historical water budgets for the basin
- Identify effects of historical operations of the basin on the groundwater resources and interaction of surface water and groundwater
- Estimate sustainable yield of the basin under historical, current, and projected land and water use conditions
- Evaluate interbasin flows across basin boundaries with the neighboring basins
- Evaluate the feasibility of conjunctive use management programs
- Assess natural recharge conditions
- Explore the nature of interaction of stream and aquifer system in various areas of the Region
- Estimate boundary flows between the Region and neighboring groundwater basins
- Assess the nature of operation of unlined canals and their interactions with the aquifer system
- Evaluate the effects of operation of upstream reservoir on the surface water supplies and groundwater system

Appraise Conditions of the Groundwater and Surface Water System Under Project Settings

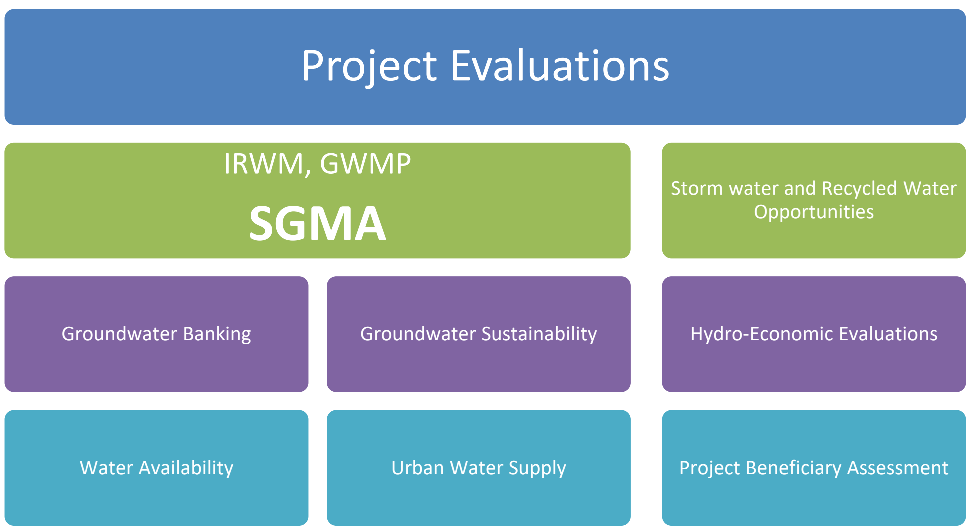
- Evaluate the basin operations under sustainable groundwater management conditions
- Estimate effects of demand side and supply side actions and plans for sustainable management of the basin
- Measures of assessing effects programs and projects considered under the Groundwater Sustainability Plan (GSP), Groundwater Management Plan (GWMP) and Integrated Regional Water Management Plans (IRWMP)
- Evaluate the effects of use of storm water and recycled water in the Region
- Assess effectiveness of groundwater storage and banking operations
- Estimate feasibility of surface water systems re-operations
- Evaluate GW & SW system responses to different pumping and recharge programs
- Estimate impacts of land use and water supply strategies on GW & SW systems
- Evaluate effects of urban growth on SW & GW systems
- Assess effect of basin operations on GW quality conditions
- Appraise benefits and costs for proposed project and programs
- Determine the effects of climate change on groundwater and surface water supplies and resources in the Region

Utilization of this model will provide MAGPI and other stakeholders with the ability to develop accurate analysis of the surface water and groundwater conditions in the Region. The model can evaluate the effects of changes in the land and water use, operations, irrigation practices, climate, water supply availability, conjunctive use, recharge, and other projects and operations on the groundwater and surface water resources in the Region.

It is anticipated the MercedWRM will be used in the evaluation of a variety of projects that include the evaluation of land and water use plans, water supply alternatives, recharge projects, conjunctive use options, water quality conditions, and many other surface and groundwater planning scenarios.

Although, the model development process began a few years prior to the 2014 passage of SGMA, the model, with some refinements and enhancements, is a well-established and defensible analytical tool to be used to support the development of the Groundwater Sustainability Plan (GSP) that will be undertaken in 2018-2019, due to the DWR by January 2020.

Diagram 1 Model Application Areas



1.2 Merced Groundwater Region

The Merced Groundwater Region (Figure 1) is primarily defined by the 491,000-acre Merced Groundwater Subbasin (Merced Subbasin), but it also includes portions of the Chowchilla Groundwater Subbasin to the south and the Turlock Groundwater Subbasin to the north, totaling approximately 608,000 acres. Its boundaries are defined to be the crystalline basement rock of the Sierra Nevada foothills on the east and the San Joaquin River to the west. The northern boundary is set at the northern edge of the Dry Creek Watershed and the southern boundary is formed by the Chowchilla River. The regional streams defining the north, west, and southern boundaries are recognized by the Department of Water Resources (DWR) through the Region Acceptance Process (RAP) as critical hydrological features distinguishing the Region from its neighbors.

Merced County is one of the top 5 agricultural producing counties in the state. In 2013, the County generated a gross of nearly 3.8 billion dollars[2] in commodities, much of which was produced on irrigated farmland. Land and water use in the Merced Region is dominated by agricultural uses, including animal confinement (dairy and poultry), grazing, forage, row crops, and fruit and nut trees. These uses rely heavily on surface water supply and private groundwater wells. Due to economic conditions and a strongly water-dependent

[2] 2013 Merced County Department of Agriculture Report on Agriculture

agricultural economy, water issues in the Region are well-understood and treated as high priority within the Region. Since the Merced Region plays a vital part in the economic future of California, managing the water resources of the Region is both a unique and challenging endeavor.

Furthermore, the Region is marked by a network of streams that are used for both conveyance and flood control. The Region's commitment to proper water resources management is evident by its long history of proactive management. In 1997, most of the Region's water agencies and purveyors formed the Merced Area Groundwater Pool Interests (MAGPI) to share technical data, encourage cooperative planning, and develop management strategies to improve the groundwater basin. Since then, MAGPI has played an active role in management of the groundwater resources in the Region.

1.3 Model Development Partners and the Technical Work Group

The development of the MercedWRM was overseen by the MAGPI board of directors and representative member agencies. The development environment was an open and transparent process, with public workshops during the project to review and reflect upon the data and assumptions used in the model, and to review the model results.

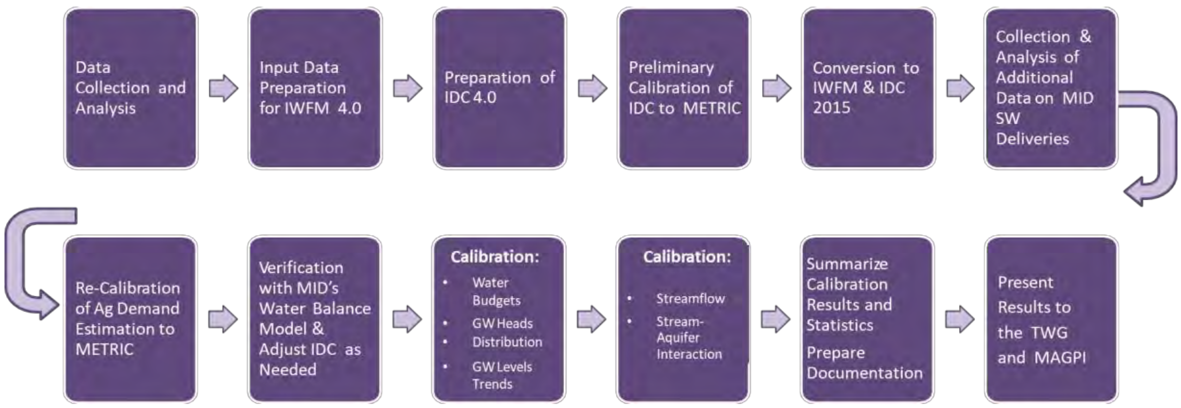
The Model was developed by financial contributions from the Merced Irrigation District, City of Merced, County of Merced, as well as a grant from the California Department of Water Resources.

A Technical Workgroup (TWG) was assigned to meet and oversee the details of the data, information and assumptions that are used in the Model development. This TWG consisted of representatives from the DWR, USGS, MID, Merced County, the City of Merced, and Stevinson Water District (SWD).

Chapter 2 Model Development

This section presents the data and analysis of input information undertaken during the development of the MercedWRM. It includes the spatial and temporal information regarding hydrologic and hydrogeologic data sets included in the model.

Diagram 2 - Model Development Process



2.1 Model Input Data

IWFM model files and associated Microsoft Excel worksheets are referenced below in Table 1.

Table 1: Merced Water Resources Model - Input Data

Major Data Category	Minor Data Category	Data Source	Report Section
Hydrogeological Data	Geologic Stratification	USGS Texture Model	2.8.2
		USGS Geospatial Database	2.8.2
		USGS Reports	2.8.2
	Aquifer Parameters	C2VSim	4.7
Hydrological Data	Stream Configuration	Merced Irrigation District	2.4
	Stream Inflow	USGS & CDEC Stream Gauges	2.4
	Calibration Gauges	USGS & CDEC Stream Gauges	4.3
	Precipitation	PRISM & CalSIMETAW	2.3
Agricultural Water Demand	Land Use	DWR	2.6
		CropScape	2.6
		Ag. Commissioner's Report	2.6
		MID-WBM	4.4.1
	Evapotranspiration	C2VSim	3.1
		METRIC	3.1
	Soil Properties	NASS Web Soil Survey	2.5
Agricultural Water Supply	Groundwater Pumping	Agency Well Locations	3.1.4
		Agency Well Production	3.1.4
		Private Well Production	3.1.5
	Surface Water Deliveries	Merced ID	3.1.3
		Stevinson WD	3.1.3
		Merquin County WD	3.1.3
		Turner Island WD	3.1.3
		Lone-Tree MWC	3.1.3
		Turlock ID	3.1.3
		Chowchilla WD	3.1.3
Urban Water Demand	Population	U.S. Census Bureau	3.2
	Per Capita Water Use	Merced UWMP	3.2
Urban Water Supply	Groundwater Pumping	Municipal Well Locations	3.2
		Municipal Well Production	3.2
Other	Boundary Conditions	DWR	2.10
	Initial Conditions	DWR	2.11
	Small Watersheds	MID	2.9
	Calibration Wells	Merced HydroDMS	4.5

2.2 Model Grid and Subregions

The MercedWRM is based around a two-dimensional finite element grid covering both the 950-square mile (608,000 acres) Region and a 550-square mile buffer zone (Figure 2). The grid consists of 17,696 nodes and 19,563 elements and is defined based on quarter mile discretization on all major hydrologic features while maintaining ½ mile discretization on district and city boundaries. Under this delineation, Model elements within the MAGPI subregions maintain an average area of 24 acres and follow the distribution shown in Figure 3. High grid resolution, along with the incorporation of fine data, makes it possible to provide detailed model results to support future hydrologic analysis of potential scenario runs.

The Region supports nine independently operating agricultural water purveyors and three major municipalities. Each of these agencies, in addition to the many unincorporated areas, have varying water resource practices and unique impacts on the groundwater hydrology. The MercedWRM is subdivided into 37 distinct subregions (Figure 4), 34 of which make up the Merced Groundwater Region, and 3 boundary zones. Delineating subregions help incorporate this variability and facilitate the zonal analysis of water budgets and hydrologic conditions.

2.3 Regional Hydrology

The development of the MercedWRM requires rainfall data for every model element. Rainfall data for the Region is derived from the PRISM (Precipitation-Elevation Regressions on Independent Slopes Model) dataset of the DWR's CALSIMETAW (California Simulation of Evapotranspiration of Applied Water) model. Daily precipitation data is available from October 1, 1921 on a 4-kilometer grid throughout the Region (Figure 5). The spatial distribution of precipitation data, to the model grid, was developed by mapping each of the model elements to the nearest of 621 available reference nodes, uniformly distributed across the model domain. The spatial intensity of the Region's precipitation is shown in Figure 8.

From the PRISM nodes within the Region, average annual rainfall and cumulative departure from the monthly mean is presented for the entire period of record in Figure 6 and for the current hydrological period (1970+) in Figure 7. Additional precipitation statistics are available in Table 2.

Table 2: PRISM Precipitation Statistics within the MercedWRM

	Long Term (1922-2015)		Hydrological Period (1970-2015)		Simulation Period (1996-2015)	
	Year	Precip (in)	Year	Precip (in)	Year	Precip (in)
Minimum	1977	4.90	1977	4.90	2007	6.29
Mean		11.94		11.95		12.52
Maximum	1958	25.59	1983	24.56	1998	23.16

2.4 Stream Configuration and Stream Flow Data

The surface water features of the MercedWRM, shown in Figure 9, include the 12 dynamically simulated streams (Table 3) divided into 71 distinct reaches for budgetary purposes. The streams and creeks listed below are represented in the model by 1548 stream nodes (Figure 10) on a quarter-mile interval. The high number of stream nodes and resolution provide increased accuracy when depicting the stream-groundwater interaction. Physical statistics, including the stream invert elevation, channel width, and a stream flow rating table, were provided by MID surveyed cross sections and USGS Digital Elevations Models (DEM).

Table 3 MercedWRM Simulated Streams

Major Streams within the Merced Region		
Merced River	Owens Creek	Dutchman Creek
Black Rascal Creek	Mariposa Creek	Chowchilla River
Bear Creek	Duck Slough	East Side Canal
Miles Creek	Deadman Creek	San Joaquin River

Metered streamflow data is available from 16 gauging stations that are reported by the USGS, the California Data Exchange Center (CDEC), and MID. Due to the availability of streamflow records, a few of the flow time series datasets were historically extrapolated to estimate flows in periods without recorded data. This process was completed by using the average monthly flow based on the DWR water year index. A detailed table of stream input data and a map of available stream gauge locations are found in Table 4 and Figure 11 respectively.

Table 4: Summary of MercedWRM Streamflow Data

Stream	Stream Node	Reporting Agency	Gauge Name	Period of Record
Merced River	1	USGS	Merced River at Northside Canal	October 1969 to September 2013
Merced River	35	CDEC	Merced River Near Snelling	March 1999 to September 2015
Merced River	85	USGS	Merced River at Shaffer Bridge	January 1970 to September 2015*
Merced River	103	CDEC	Merced River near Cressey	March 1999 to September 2015
Merced River	1127	USGS	Merced River at Stevinson	October 1969 to September 2015*
Bear Creek	225	CDEC	Bear Creek	October 1993 to September 2015
Owens Creek	450	CDEC	Owens Creek Dam	October 1993 to September 2015
Mariposa Creek	598	CDEC	Mariposa Creek Dam	July 1994 to September 2015
Chowchilla River	957	USGS	Chowchilla River at Buchanan	October 1969 to September 1990
San Joaquin River	1311	CDEC	San Joaquin River at Mendota Pool	December 1999 to September 2013

* Includes long periods without data.

2.5 Soils

IWFM, as an integrated surface water and groundwater model, simulates the interaction between surface features and the underlying aquifer system.

The soil types identified within the survey data are associated with one of four hydrological soil groups. Each soil group is categorized according to their runoff potential and infiltration characteristics. The Natural Resource Conservation Service (NRCS) defines these hydrological soil groups as follows:

> **Group A** – Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravelly or sandy textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

> **Group B** – Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group C – Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group D – Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential.

Hydrologic data, collected from the Natural Resource Conservation Service's (NRCS) Web Soil Survey (WSS), was used to develop hydrologic soil types and root zone parameters for each element within the model area (Figure 12).

2.6 Land Use and Cropping Patterns

The MercedWRM uses annual land use distribution by element. The model divides all land use types into four classifications: native, non-ponded, ponded and urban. For each element, an aerial percentage ratio is given to each of 11 agricultural categories, and each of the non-agricultural categories, which are urban, native, riparian, or wetlands. The total of the ratios among categories for each individual element must add up to one.

Land use classifications stem from two primary sources, the DWR Land Use Survey and the USDA CropScape Program. DWR conducts land use surveys by county approximately every seven to ten years to estimate changing land and water use patterns. DWR's Merced County Land Use Survey data, available in 1995, 2002, and 2012, is available on a parcel level and has been mapped to the MercedWRM grid. In addition to DWR land use surveys, the United States Department of Agriculture's National Agricultural Statistics Service (NASS) provides geospatial satellite data, known as cropland data layers (CDL), on an annual basis since 2007. Each CDL has a ground resolution of 30 meters (Figure 13), and the USDA reports an 85% to 95% classification accuracy of the CropScape datasets for major crop-specific land cover categories.

Due to the nature of the CropScape datasets and remote sensing in general, there is some deviation in the total agricultural acreage across the district. In order to minimize error and ensure the quality of the data, the 2012 CropScape was compared to both the 2012 DWR Land Use Survey and the 2012 Merced County Ag Commissioner's report. While all datasets demonstrated some variance at high resolution, subregional aggregation offered a comparable distribution leading to the acceptance of the CropScape datasets and methodology. Accuracy was further enforced through a series of manual detailed analysis, where ground truthing was performed in hydrologically critical areas by inspection of historic areal imagery. These adjustments are further documented within the corresponding land use Excel file.

Due to the discontinuous nature of the available land use data, linear interpolation was completed to connect the 1995 to 2002 DWR Land Use Surveys, and again to connect the 2002 DWR Land Use Survey with the 2007 CropScape data. The annual distribution of crop categories and acreages across the entire Model is available in Figure 14.

Land use trends from 1995 through 2015 show significant increases in total and irrigated agricultural acreage, with 290,000 irrigated acres at the beginning of simulation and 325,000 acres in production by 2015. This change from native to agricultural area brings additional stresses on the hydrological system, particularly as the majority of this increase comes from the increased popularity of permanent crops, specifically vineyards, almonds, and walnuts.

2.7 Drainage

Surface drainage patterns define how runoff from rainfall and applied water is processed within the model framework. As a majority of the model area is either urban or developed agriculture, drainage within the system is largely a factor of infrastructure and does not rely specifically on ground surface elevation and natural flow patterns. Due to this, delineation of small drainage watersheds, as defined by MID (Figure 15), was integrated into the model. Each drainage watershed was assigned a stream node to discharge. All elements in the watershed were assign their specific watershed discharge stream node. As improved surface watershed models of the basin are developed, Merced WRM can spatially be re-delineated so that the watersheds match the updated sub-basin definitions.

2.8 Geologic Structure and Model Layering

The following section highlights the hydrogeologic analysis of the Merced Region and the resulting stratigraphic layering of the MercedWRM.

2.8.1 Conceptual Aquifer Systems

The Merced Groundwater Management Plan (MAGPI 2006) provided a basis for understanding of hydrogeologic conditions in the Merced area. This document identified six aquifer systems, as described below.

Fractured Bedrock - Along the eastern edge of the Merced Subbasin, wells have been completed within the Valley Springs and lone Formations (Page and Balding 1973, Page 1977). These wells appear to be completed in fractured bedrock with limited and variable yields. Because of the limited extent and poor yields of the fractured bedrock aquifer, the fractured aquifer is not a significant source of water in the Merced Subbasin.

The Mehrten Formation - The Mehrten Formation outcrops over a large area in the Merced Subbasin. Many water supply wells in the eastern portion of the Merced Subbasin penetrate the formation, and the formation is a significant source of groundwater. The Mehrten is considered a confined aquifer where it occurs beneath the Corcoran Clay. There is insufficient data to determine the degree of confinement of the formation where the Mehrten does not underlie the Corcoran Clay.

Confined Aquifer- The confined aquifer occurs in older alluvium (and Mehrten Formation) deposits that underlie the Corcoran Clay. Many water supply wells in the western portion of the MGWB penetrate the Corcoran Clay into the confined aquifer, and the confined aquifer is a significant source of groundwater.

Intermediate Leaky Aquifer - The intermediate leaky aquifer occurs in older alluvium deposits that overlie the Corcoran Clay or are east of the Corcoran Clay. Where the Corcoran Clay is absent, the intermediate aquifer extends to the Mehrten Formation. In the eastern portion of the Merced Subbasin the intermediate aquifer consists of a series of interbedded coarse-grained layers (gravel and sand) separated by fine-grained layers (silt and clay). The fine-grained layers inhibit, but do not prevent vertical groundwater flow between layers and thus form a leaky-aquifer system. Many water supply wells in the Merced Subbasin are completed in the intermediate leaky-aquifer and it is a significant source of groundwater.

The Intermediate leaky-aquifer is the most extensively developed aquifer in Merced Subbasin. Measured well yields within the Merced Subbasin range from 670 to 4000 gallons per minute (gpm) (Page and Balding, 1973). Estimates of specific capacity of supply wells throughout the Merced Subbasin range from about 20 to 40 gallons per minute per foot of drawdown and indicate that the specific capacity increases from east to west.

Shallow Unconfined Aquifer - The shallow unconfined aquifer occurs in older and younger alluvium deposited above the shallow clay bed. Because of its shallow depth, few water supply wells are completed in the shallow unconfined aquifer. Where water levels in the intermediate leaky aquifer fall below the base of the shallow clay bed, groundwater in the intermediate aquifer becomes unconfined and water in the overlying shallow aquifer becomes perched. (MAGPI 2006)

2.8.2 Data Sources

Model stratigraphy was developed through a thorough analysis of local and regional datasets, including published geological reports and existing models. The analysis utilized the conceptual understanding of the aquifer system described in the Merced Groundwater Management Plan (MAGPI 2006). This conceptualization was based in part on existing reports, notably by Page and Balding (1973) and Page (1977). The source documents and models were used to define the depth, thickness, and extent of the major geologic units associated with the aquifer systems described by in the Merced Groundwater Management Plan. More recent data was incorporated into the analysis by utilizing textural data from the USGS (2010), completed as part of the development of the Central Valley Hydrologic Model (CVHM). Localized data sets and regional surficial geology provided additional details to identify the extent of certain layers. A summary of hydrogeologic data used in the development of the MercedWRM layering is shown in Table 5.

Table 5: Model Hydrogeologic data

Data Source	Authors	Date
Geology and Quality of Water in the Modesto-Merced Area, San Joaquin, California	R.W. Page and G.O. Balding	1973
Appraisal of Groundwater Conditions in Merced California and Vicinity	R.W. Page	1977
Geologic Map of the San Francisco-San Jose Quadrangle, California	D.L. Wagner, E.J. Bortugno, and R.D. McJunkin	1991
Central California Valley Groundwater-Surface Water Simulation Model	California Department of Water Resources	2013
Central Valley Hydrologic Model Texture Model	United States Geological Survey	2010
Merced Groundwater Basin Groundwater Management Plan	AMEC Geomatrix	2008

Published Cross Sections – The basis for much of the definition of the aquifer systems in the Merced Groundwater Management Plan is Page and Balding (1973) and Page (1977). Among other information, these USGS source documents provide cross sections defining the major stratigraphic units, which allows for definition of the extent, depth, and thickness. Units include:

- Unconsolidated deposits
    - Flood basin deposits and younger alluvium
    - Older alluvium
    - Continental deposits
- Consolidated rocks

- Mehrten Formation
- Valley Springs Formation
- Ione Formation
- Basement complex

Locations of cross sections from Page and Balding (1973) are shown in Figure 16, with the associated cross sections in Figure 17. Similarly, locations of cross sections from Page (1977) are shown in Figure 18, with the associated cross sections in Figure 19. Page and Balding (1973) was used for cross section development as these sections are more regional in nature. Page (1977) contained some additional detail, notably the presence of a shallow clay, which was incorporated into the layering.

The cross sections show units dipping to the west-southwest with steeper dips in the older units and gently dipping recent units. The cross sections show the Corcoran Clay as a regionally extensive unit across the western portion of the model area and a shallower clay unit present in much of the central portion of the area.

USGS CVHM Texture Model – The USGS CVHM texture model of the Central Valley was used to augment the information contained in the published cross sections, as the published cross sections did not incorporate more recent boring log data and were not spaced closely enough to allow for suitable interpolation. The USGS CVHM texture model is a three-dimensional model of sedimentary texture deposited within California's Central Valley. Originally compiled in 2004, the model was developed by analyzing over 150,000 drillers' logs describing lithologies up to 950 meters deep. After a subset of 8,500 boreholes was selected, a form of kriging geostatistical analysis was performed to determine the percentage of coarse-grained deposits over each 15-meter composite interval. (Faunt, Belitz, and Hanson 2009). For use within the MercedWRM, coordination with USGS staff members provided refined textural data at each model node on a 10-foot vertical interval.

The CVHM texture model generally shows coarser materials near the Merced River and above the continental deposits, both above and below the Corcoran Clay. Materials generally become more fine-grained with depth and with distance to the south-southeast.

Additional Data Sources – Additional data sources were used to define the surficial extent of layers, the base of the model, and the extent of shallow clays.

- The ground surface elevation was defined by the USGS Digital Elevation Model was available on a 1/3 arc-second (approximately 33 feet) level of discretization and is shown in Figure 20. The horizontal data is in North American Datum of 1983 (NAD 83) and the vertical data is North American Vertical Datum of 1988 (NAVD 88).
- The location where layers are present at the surface (outcrop) was refined based on the surficial geologic map developed by Wagner, Bortugno, and McJunkin (1991). This map, shown in Figure 21, assisted in further refining the interpolation between cross sections and further improving correlation between texture information and stratigraphic units. Presence of Mehrten Formation, Valley Spring Formation, and alluvium were used to constrain the extent of the layers in the cross sections.
- The extent of shallow clays was established using records of historical perched aquifer conditions provided by Merced ID. Presence of perched aquifer conditions in the local data were combined with the extent of shallow clays shown in the spatially limited Page (1977) cross sections to define the extent of shallow clays.
- Regional extent, depth, and thickness of the Corcoran Clay Member of the Tulare Formation is available on the USGS Central Valley Spatial Database. This digital dataset, (Figure 22 and Figure

23) was directly implemented into the Model layer definition for Aquitard 2, as an extensive impermeable, lacustrine deposit.

- The base of fresh water as defined by the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim-2015) as enhanced by the DWR in 2017, was used to define the maximum thickness of the fresh water aquifer, shown in in Figure 25.
-
- The extent of the MercedWRM is bounded in the vertical direction by the base of the continental deposit as defined by C2VSim-2015, whose elevation is shown in Figure 26.

2.8.3 Model Layer Development and Approach

The texture data was analyzed on a three-dimensional grid and incorporated into the layering analysis by developing cross sections aligned with published cross sections from the Page and Balding (1973) and Page (1977) reports and tying together with surficial geology information in Wagner, Bortugno, and McJunkin (1991). Texture model cross sections were developed at regular intervals aligned with the MercedWRM grid, as shown in Figure 24. This analysis allowed for refinement of the published cross sections with the newer textural data, with care taken to adjust for interpolation within the texture model that prefers the horizontal plane, rather than a dipping plane. The analysis also allowed for improved interpolation in areas without existing published cross sections, using the spatially continuous texture data. Geospatial overlays of the published reports with the texture model are available in Figure 27 though Figure 29, as listed in Table 6.

Table 6: Reference Table of the Hydrogeological Cross-Sectional Overlay

Figure	Page and Balding 1973	Texture Model
27	Cross Section B-B'	Cross Section A-A'
28	Cross Section C-C'	Cross Section F-F'
29	Cross Section D-D'	Cross Section J-J'

These overlays were combined with the other collected information to finalize the layers, as described below.

2.8.4 Model Layer Definition

The MercedWRM is divided into five distinct freshwater aquifers, one saline aquifer, and two confining units. Descriptions of each of the model layers are listed below, from top to bottom.

Layer 1 The ground surface elevation (GSE), or the top Layer 1, maintains an upper bound set by the USGS Digital Elevation Model (DEM) at a resolution of 1/3 arc-seconds, or approximately 33 feet. The layer thickness is limited by the greater of the two bounding factors subsequently listed. The primary element, from within the IWFM framework, maintains that localized stream invert constraints force the top layer to be no thinner than 25 feet thick. Additionally, within the Region, there is a shallow clay unit that covers the valley floor. This clay, described as Aquitard 1 below, is observed at ranges between 20 and 70 feet below the ground surface and, when present, defines the bottom of the first layer. Layer 1 is equivalent to the Shallow Unconfined Aquifer described in the Merced Groundwater Management Plan (http://magpi-gw.org/index.cfm/groundwater-management-plan/).

Aquitard 1 Throughout the central area of the Merced Groundwater Basin there is a shallow confining clay unit that ranges in thickness up to 20 feet thick and primarily lies at a depth of 1/3 of the distance between the ground surface and the top of the Corcoran clay.

Layer 2 Layer 2 is principally bounded by the previously defined confining shallow clay unit, Aquitard 1, and the Corcoran Clay deposit, Aquitard 2. Additionally, a minimum thickness of 25 feet is set wherever Layer 2 exists, to meet suggested convergence constraining factors within IWFM. Layer 2 is equivalent to the Intermediate Leaky aquifer system described in the Merced Groundwater Management Plan.

Aquitard 2 Equivalent to the Corcoran Clay or E Clay, Aquitard 2 within the MercedWRM is a regionally extensive confining unit. Digital shapefiles of the extent, thickness (Figure 22) and depth (Figure 23), of the Corcoran Clay are available from the CVHM Central Valley Spatial Database. The MercedWRM uses these shapefiles to define Aquitard 2.

Layer 3 Layer 3 consists of the older alluvium below the Corcoran Clay, as defined in Aquitard 2, to the top of the continental deposits in Layer 4, defined using cross sections from Page and Balding (1973) in combination with the USGS CVHM textural model, surficial geology, and a maximum depth defined by the C2VSim base of fresh water. Where the Corcoran Clay is present, Layer 3 and Layer 4 are equivalent to the Confined Aquifer described in the Merced Groundwater Management Plan.

Layer 4 Below the older alluvium, as defined in Layer 3, are continental deposits with a base defined in the same manner as above: cross sections from Page and Balding (1973) in combination with the USGS CVHM textural model, surficial geology, and a maximum depth defined by the C2VSim base of fresh water. Where below the Corcoran Clay, Layer 3 and Layer 4 are equivalent to the Confined Aquifer described in the Merced Groundwater Management Plan

Layer 5 The Mehrten Formation is composed of consolidated rock - sandstone, breccia, conglomerate, tuff, siltstone, and claystone - and is an important water supply aquifer. The bottom of the Mehrten, as with layers above, is defined through cross sections from Page and Balding (1973) in combination with the USGS CVHM textural model, surficial geology, and a maximum depth defined by the C2VSim base of fresh water. The Valley Springs Formation underlies the Mehrten on the eastern side of the Merced Groundwater Basin and is not considered a significant source of water due to a matrix of clay and fine ash. This layer is equivalent to the Mehrten Formation described in the Merced Groundwater Management Plan, with the underlying Valley Spring Formation part of the Fractured Bedrock aquifer system from the same document.

Layer 6 Layer 6 consists of the saline water ranging from the base of fresh water to the base of continental deposits as defined by the fourth layer of C2VSim-2015 (equivalent to the base of the Fractured Bedrock as defined in the Groundwater Management Plan). A non-production zone, this layer was implemented as a refinement to the water quality model and for the potential use of scenario development for the simulation of deep well production.

Finalized cross sections of the model layering, shown in v Figure 30 through Figure 42.

2.9 Small-Stream Watersheds

Watersheds defined by both the California Department of Conservation through the California Watershed Portal and the U.S. Geological Survey Watershed Boundary Dataset were reviewed in defining the watersheds of the Merced Region. The USGS Watershed Boundary Dataset classifications were selected as more representative of the Merced Region because its watershed boundaries are determined solely upon hydrologic principles and do not favor any administrative boundaries.

The spatial delineation of the watersheds within the MercedWRM is highlighted in Figure 44 and are listed from north to south in Table 7. The IWFM small watershed package is used to simulate both surface and subsurface flows entering the model's eastern boundary. Though this package, hydrologic conditions are simulated based on site-specific parameters and calculated flow rates are attributed to boundary nodes. Each intersecting groundwater node receives equivalent flow relating to its specific watershed. Since most of the streams entering the Basin are regulated, and IWFM simulates unimpaired flows, stream inflow is superseded whenever gauged inflow is available.

Table 7: Small Stream Watersheds

Small-Stream Watershed	Area (acres)
Bear Creek	46,097
Burns Creek	34,375
Deadman Creek	17,588
Dutchman Creek	10,998
Mariposa Creek	32,340
Merced River	50,762
Miles Creek	9,301
Owens Creek	17,462

2.10 Boundary Conditions

Time series general head boundary conditions were defined for the MercedWRM for all boundary nodes on the northern, western and southern limits (Figure 45), while the Model's eastern boundary is controlled by the small watersheds. These boundary conditions were developed using the DWR's Water Data Library (WDL) and annual groundwater level contours available from the DWR South-Central Region.

2.11 Initial Conditions

Similar to the boundary conditions, groundwater heads for each model node at the beginning of the simulation were developed using the DWR's WDL. As it is not possible to determine perforation interval of the observation wells, the heads were averaged across all layers. Because of this, the initial conditions for the MercedWRM were based on observed fall 1993 water level data (Figure 46), corresponding to a simulation beginning with the start of the 1994 water year. It should be noted that, while the simulation begins with the start of the 1994 water year, the calibration period begins in 1995 with the realization that an initial period is necessary for hydraulic stabilization across the model layering.

Chapter 3 Water Supply and Demand Data

The following sections describe the development process of the MercedWRM water demand and supply calculations.

3.1 Agricultural Water Demand

Agricultural water demand within the MercedWRM is dynamically calculated every month for each model element using consumptive use methodology. The consumptive use analysis within the Region was performed using the IWFM Demand Calculator (IDC) in conjunction with the remote sensing technology Mapping Evapotranspiration at High Resolution and Internalized Calibration (METRIC), which was used to verify the consumptive use demand by the IDC. The investigation of water demand under both methods offered distinct but parallel results, emphasized in the following sections.

3.1.1 Evapotranspiration (METRIC Remote Sensing)

Developed by the University of Idaho in 2000, METRIC is the process of using LandSAT Thematic Mapper data to directly compute the actual evapotranspiration (ET_C) of vegetation as a residual to the surface energy balance. For use in the MercedWRM, the Irrigation Training and Research Center (ITRC) used a modified METRIC procedure to develop the nine years of evapotranspiration data, distributed between 1989 and 2013, and shown in Table 8. The following years of analysis were selected to cover a variety of hydrological year types, cropping patters, and the availability of LandSAT images.

Table 8: METRIC Datasets within the MercedWRM

Available METRIC Data					
Calendar Year	Hydrologic Classification	Calendar Year	Hydrologic Classification	Calendar Year	Hydrologic Classification
1989	Critical	2000	Above Normal	2008	Critical
1997	Wet	2001	Dry	2010	Above Normal
1998	Wet	2002	Dry	2013	Critical

A detailed explanation of the METRIC process and how it was directly applied to the Merced Region is available in Appendix B of this report. The utilized data is a series of monthly rasters exhibiting actual ET_C on a 30-meter spatial discretization.

As remote sensing data is not available on a continuous basis, the dataset was employed as a calibration tool rather than a direct method of demand measurement. The analysis of this dataset, along with other observed parameters were used as a calibration tool for the IDC during Model development and are covered in further detail in the calibration section of this report.

For additional details on the implementation of the METRIC datasets, please reference Section 4.2, Calibration of the IDC and Root-Zone Parameters.

3.1.2 Evapotranspiration (IWFM Demand Calculator)

Agricultural water demand is the amount of irrigation water that is required to satisfy the crops potential evapotranspiration requirement. The IWFM Demand Calculator (IDC) is designed to estimate the agricultural water demand for each element within the model area through consumptive use methodology, based on historical crop acreage, soil moisture requirements, effective rainfall (the portion of rainfall available for crop consumptive use), potential evapotranspiration, and localized soil parameters.

The IDC applied to the MercedWRM is a soil moisture routing simulation integrated with the groundwater model. Figure 47, from the IDC user's manual, highlights the simulated flow processes applied to the Merced Region. Within this framework, a base demand, or the potential evapotranspiration (ET_P) shown in Figure 48, can be employed to either fixed or adjustable water consumption. Due to the nature of private groundwater production in the Central Valley, all elements with irrigated agriculture are set to pump groundwater to meet all demands not met by surface water deliveries.

3.1.3 Surface Water Diversions

Major water purveyors within the model domain provided surface water delivery data for study and model implementation. Figure 49 displays the elements receiving surface water for agricultural use within the Region and Table 9 highlights the spatial and temporal discretization of available data across the entire model. Since complete monthly records are not available for all water purveyors, an analysis of available data was preformed and refined as follows:

Period of Record - The MercedWRM simulation period begins in October 1993 and ends in September 2015. When unavailable, estimations are made to approximate the surface water deliveries applied within the unknown time period. This process is completed by using the average monthly value for that district, according to the respective water year index.

Spatial Discretization – Surface water deliveries within IWFM require the user to specify the surface water destination to be an element, a group of elements within a single subregion, or a specific subregion. As high-resolution delivery data may not be available, and data may span multiple subregions, district and service area deliveries may be divided based on the agriculture area within a sub-section. Since IWFM has the capability to apply surface water deliveries to the element level, future model updates can benefit from enhanced applied water data, including data spatial discretization, quantity and timing.

Time Step Adjustments – The MercedWRM is run on a monthly time step and requires monthly data as input. While monthly data is available from MID, records with such delineation were not presented for use from Stevinson, Merquin County, Turner Island, or Chowchilla Water Districts. Because of this, monthly delivery data is estimated by applying the fraction of monthly versus annual stream diversions by MID off the Merced River.

Table 9: MercedWRM Surface Water Delivery Data

Agency	Period of Record	Resolution	Time-Step
Merced Irrigation District	Oct 1993 - Sept 2015	Parcel / Element	Monthly
Stevinson Water District	Oct 2000 - Sept 2013	District Total	Annual
Merquin County	Oct 2000 - Sept 2013	District Total	Annual
Turner Island Water District	Oct 2003 - Sept 2015	District Total	Annual
Chowchilla Water District	Oct 1993 - Sept 2013	District Total	Annual
Merquin County	Oct 2000 - Sept 2013	District Total	Annual
Turlock Irrigation District	Jan 1991 - Dec 2012	Service Area	Monthly

In conjunction with surface water deliveries used to meet agricultural water demand, the Region benefits from significant recharge as a result of local management practices, particularly the 563 miles of unlined canals operated by MID. Recharge from these and other surface water purveyors provided approximately 114,000 AF per year during 1996-2005 and increased to approximately 141,000 AF per year during 2006-2015 decade to reflect the consolidation of El Nido Water District into the MID service area.

It should be noted that any limitations in available data may lead to relative weaknesses in calibration at both the local and regional level. Additional coordination efforts through the SGMA process will aid in future refinement of MercedWRM.

3.1.4 Agricultural Groundwater Production (Agencies)

Groundwater pumping within the MercedWRM is separated into well and element-based pumping, the former of which is primarily comprised of Merced Irrigation District operated wells that feed into the surface water supply network. District pumping is available annually throughout the simulation period, with well specific data available within the 2007-2012 calendar years. To estimate historical pumping on a per-well basis, prior to 2007 and after 2012, the monthly distribution of annual pumping was developed based on water year type. This index was applied on the monthly timestep for each operational well. Figure 50 and Figure 51 respectively demonstrate the spatial distribution of MID wells and the historical annual pumping used within the model.

In addition to MID, several local water districts, provided annual pumping volumes for implementation within the model. District pumping within Stevinson, Merquin County, and Turner Island Water Districts were accounted for using element pumping in conjunction with private pumping.

3.1.5 Agricultural Groundwater Production (Private)

Private agricultural pumping is estimated by the agricultural demand in each element minus any surface water deliveries. Since no site-specific information is known for private agricultural wells, IWFM averages pumping across the element nodes. Element pumping within the IWFM framework also requires the vertical distribution pumping to be defined in each layer. Estimations for this delineation were made through analysis of the over 5,000 well depth records digitally available within the Merced County Well Database (Figure 53).

The County's database includes maximum well depth, and from this we can see that the majority of wells in the Region are pumping from within the top 500 feet of the surface (Figure 52). Since perforation information is unavailable, assumptions must be made on where groundwater is being extracted from. Through analysis of the wells within this database, it is assumed that the layer pumping distribution is taken from between the 25th and 75th percentile of total well depth (Figure 54 and Figure 55, respectively).

3.2 Urban Water Use

Total urban water demand is the sum of municipal and rural domestic groundwater extraction within the Merced Groundwater Basin. The population, and subsequent water use characteristics, of Merced County are extremely diverse, with approximately half of its population operating private groundwater wells outside of the urban centers.

Municipal pumping data for MAGPI member agencies, which includes the location and monthly pumping rates were analyzed and implemented into the MercedWRM. Figure 56 shows the spatial location of the wells by operating agency.

Population and per capita consumption, the factors IWFM uses to calculate urban demand, are available from a mix of sources that include:

- Local Urban Water Management Plans
- Local Groundwater Pumping Records
- United States Census Bureau

Monthly pumping records from MAGPI member agencies are directly inputted as part of the time-series pumping file. To ensure these records are equal to demands of the system, reflect the historical trends, and are able to project water consumption, the data was compared to population values from the US Census Bureau and the reported values for per capita water use from local Urban Water Management Plans.

Surveyed population data from the US Census Bureau, available on the tract level, is taken every ten years, but annual estimates are also available from the agency and were implemented in the MercedWRM. Census tracts within the model boundaries were incorporated directly, whereas the tracts near the boundary, with only a fraction in the Merced Region, were adjusted according to the participating land use fraction. Summarized between major member agency and rural domestic users, the population of the Merced Region is represented in Figure 57.

Records of urban water consumption are available for municipalities within the Region (Table 10). To estimate the per capita water uses of rural domestic water users, an average of the three major municipalities were used and applied to the corresponding population. Additionally, as pumping data is only available post-1998, historic trends of GPCD were extrapolated from the existing records based on the most senior data available.

Since complete records are not available for all water purveyors, an analysis of available data was preformed and refined as follows:

Period of Record - The MercedWRM simulation period begins in October 1993 and ends in September 2015. When unavailable, estimations are made to approximate groundwater production within the unknown time period. This process is completed by using the average monthly value for that agency. When volumetric data is not available, the IWFM Demand Calculator (IDC) was utilized to estimate demand based on the regional average consumptive use.

Spatial Discretization – Municipal providers within the Region use groundwater wells as their source of supplied water. Due to the lack of well perforation data available, groundwater production is simulated with elemental pumping within estimated layers.

Table 10: MercedWRM Pumping Data

Agency	Period of Record	Resolution	Time-Step
Atwater	Jan 1998 – Feb 2012	Well location	Monthly
Black Rascal	Jan 1998 – Oct 2012	Well location	Monthly
Le Grand	Jan 1998 – Dec 2012	Well location	Monthly
Livingston	Feb 1998 – Dec 2013	Agency	Monthly
Meadowbrook	Jan 1998 – Nov 2012	Well location	Monthly
Merced	Jan 1998 – Jan 2014	Well location	Monthly
Planada	Jan 1998 – Dec 2013	Well location	Monthly
Winton	Jan 1998 – Jan 2014	Well location	Monthly

The City of Merced provided urban consumptive use data through 2015, which was used to calculate GPCD, that was incorporated into the model. Such data has not been provided to date by the cities of Livingston and Atwater and therefore only calculated estimates were incorporated into the model. These estimations are shown at the annual and monthly time scale, in Figure 58 and Figure 59 respectively, while total urban groundwater pumping within the model is shown in Figure 60.

Chapter 4 Model Calibration

The objectives of model calibration are (1) to achieve a reasonable water budget for each component of the hydrologic cycle modeled (i.e., land and water use, soil moisture, stream flow, and groundwater budgets) and (2) to maximize the agreement between simulated results and observed values for groundwater levels at selected well locations and (3) streamflow hydrographs at selected gauging stations. These objectives are achieved through careful review of the model input and adjusted model parameters. The model results also provide insight to key components of the groundwater basin including historical recharge, subsurface flows, and changes in groundwater storage.

The model calibration period for the MercedWRM is October 1996 through September 2015.

4.1 Model Calibration

Model calibration begins after the data analysis and input data file development is complete. The calibration effort can be broken down into subsets that align with multiple packages within the IWFM platform. As an integrated groundwater model, the results of each part of the simulation are dependent on one another. The model calibration can be considered a systematic process that includes the following activities:

- Calibrate hydrologic demand,
- Calibrate Surface Water Features,
- Calibrate overall water budgets for the model area,
- Calibrate simulated groundwater levels to observed groundwater levels,
- Compare calibration performance with the calibration targets, and
- Conduct additional refinements to model as necessary.

4.2 Calibration of the IDC and Root-Zone Parameters

The goal of the IDC calibration process is to align the multiple references for local ET, determine agricultural demand, and develop the corresponding components of a balanced root zone budget. Calibration of these surface features are the foundation of the greater model processes as they are the primary stresses on the groundwater system. This part of the calibration effort was primary focused on refining the following budget items while ensuring accuracy in and maintaining reasonable parameters.

Land Use – As the foundation of consumptive use analysis, land use across the model domain was extensively investigated and ground-truthed adjustments were made when necessary. Beyond the initial land use modifications mentioned in Section 2.6, Land Use and Cropping Patterns, MID cropping patterns underwent further analysis and the CropScape datasets were evaluated alongside the distribution developed as a part of the Merced Irrigation District Water Balance Model (MID-WBM), which uses land use data available through the MID accounting records. This comparison was performed across the MID subregions for 2010 and 2013, and results are shown in Table 11.

Table 11: Land use comparison between the MercedWRM and the MID-BWM (acres)

Land Use Classification	MID-WBM 2010	MID-WBM 2013	MercedWRM 2010	MercedWRM 2013
Orchards	45,914	51,685	40,167	50,189
Pasture	14,310	13,736	12,735	13,251
Alfalfa	17,416	7,985	25,227	13,556
Field Crops	20,003	23,307	15,408	17,485
Truck Crops	11,743	11,503	9,763	7,614
Grains	13,899	7,667	14,625	13,163
Vineyards	226	2,025	3,406	4,892
Rice	2,124	1,721	2,143	1,306
Cotton	0	0	6,074	4,525
Citrus	0	0	30	15
Idle	2,020	5,044	0	0
Total	**127,655**	**124,673**	**129,579**	**125,996**

The variance within the two models, while significant, is due to the differing model framework and consequent definition of the MID boundaries. These boundaries cause IWFM subregional budgets to include some acreage not within the bounds of MID, as IWFM regions must be contiguous and follow the finite element grid, while the WBM is founded on parcel level analysis. These areas of difference are highlighted in Figure 61.

Consumptive Use - IWFM recognizes monthly potential evapotranspiration (ET_P) as a model input for each defined crop category. Initial values were taken from the California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) and were calibrated using the localized data available from the following three sources:

- ET_0 from the California Irrigation Management and Information System (CIMIS).
  - ET_0 is the grass-based reference evapotranspiration and is used as a standardized reflection of the energy available to transport the water vapor from the ground up into the lower atmosphere.
- ET_C from the Irrigation Training and Research Center (ITRC).
  - ET_C is the crop-specific evapotranspiration under standard growing conditions and assumes optimum growing conditions devoid of production limiters such as nutrient and moisture availability, crop diseases and pests.
- ET_A from Mapping Evapotranspiration at High Resolution and Internalized Calibration (METRIC) datasets.
  - ET_A is the actual evapotranspiration as measured from LandSAT images and is calculated as the residual of the difference between the net radiation to the land surface and a combination of sensible and ground heat fluxes.

Each of these sources were reviewed during the calibration process, at which point the original IDC referenced ET_P were adjusted to meet trends highlighted in the METRIC dataset for actual ET_C. Calibration results can be seen in the comparative charts, Figure 62 and Figure 63 , which show ET_C for the model domain and the MID subregions respectively. Post-Calibration ET_P values were calibrated to within an average of 5% of the referenced METRIC datasets.

Consumptive Use and Agricultural Demand – Whereas evapotranspiration makes up the majority of the agricultural demand, it is important to recognize and account for other water uses within a system. Non-consumptive uses including deep percolation, return flow, frost protection, leaching of the root zone, and other beneficial uses, can all add stress to the groundwater system by significantly increasing agricultural water demand. The ratio of evapotranspiration to the total applied water is known as the consumptive use fraction (CUF).

$$Consumptive\ Use\ Fraction\ (CUF) = \frac{Evapotranpiration\ of\ Applied\ Water}{Applied\ Water}$$

To determine the regional CUF, there was extensive coordination between the MercedWRM and the Merced Irrigation District Water Balance Model (MID-WBM) development teams. With data on elemental root zone parameters, research into published reports, and discussions with local growers on their irrigation practices, both models concluded that an average consumptive use fraction, considering all crop types and management practices, of 65% is representative of the Merced Region, with various subregions reaching the upper-70s.

To facilitate this relationship, evapotranspiration and root-zone parameters, particularly the soil hydraulic conductivity and the pore size distribution index, were adjusted in accordance with their hydrologic soil group and subregion. Spatial reference of these calibrated parameters is available from Figure 64 though Figure 68.

4.3 Calibration of Surface Water Features

The MercedWRM simulates streamflow in eight small-stream watersheds and several major rivers and creeks across the model domain. Streamflow calibration is performed by comparing the simulated streamflow with local data from the eight stream gauges in the Region (Figure 11).

Small Stream Watersheds – Calibration of small-stream watersheds was performed by comparing the simulated stream flow of the watersheds with the available gauged data from the Merced River, Bear Creek, Owens Creek, Duck Slough and the Chowchilla River. Since most of the larger, gauged streams are impaired with local reservoirs, their inflows overwritten with historical data. Prior to the flow adjustment, annual volumes were analyzed for potential refinement to the nearby, ungauged watersheds. Parameter adjustments, including watershed size and evapotranspiration, were implemented across the smaller watersheds without flow data.

Merced River – The Merced River is the only stream in the model area with detailed flow records for calibration analysis. The Merced River stream inflow into the model area is based on the USGS stream gauge located at Merced Falls near the Northside Canal and has an average flow of 1450 ft^3/second during the calibration period.

Merced River flowrates are measured at the following gauges:

- USGS – Merced Falls near the Northside Canal
- CDEC – Merced River near Snelling
- USGS – Merced River at Shaffer Bridge
- CDEC – Merced River near Cressey
- USGS – Merced River near Stevinson

Stream flow calibration included refinement of the stream bed hydraulic conductivity and simulated values were compared to observed records, results of which are available in Figure 69 through Figure 73.

4.4 Calibration of Water Budgets

Proper calibration of water budgets within the MercedWRM ensures that the hydrologic characteristics of the groundwater basin are accurately represented. The goal of the water budget analysis is to develop a balanced system between supply and demand, while summarizing the hydrologic flow within the Region, particularly including the movement of all primary sources of water such as rainfall, irrigation, streamflow, and subsurface flows. During the calibration process, model output is reviewed and summarized into monthly and annual budgets referred to as the groundwater budget and the land and water use budget. Key budget components for each of the calibrated water budgets are listed in Table 12.

Table 12: Major Components of Water Budgets

	Groundwater Budget	Land and Water Use Budget
Budget Component	Deep Percolation	Ag. Pumping
	Stream Recharge	Ag. Diversions
	Canal Recharge	Ag. Supply Requirement
	Pumping	Urban Supply Requirement
	Outflow to Root Zone	Urban Pumping
	Subsurface Flow	
	Change in Storage	
	Cumulative Change in Storage	

During this stage of the calibration, key model datasets and parameters have been adjusted. Root zone and aquifer parameters, as well as water use data, including the location, amount, and timing of surface water diversion and groundwater pumping, are particularly important during this stage of calibration.

The MercedWRM results are summarized in the following sections. The model budget tables can be generated in either monthly or annual time steps for the period of simulation.

4.4.1 Land and Water Use Budget

The land and water use budget balances water supply and water demand in the study area. Calculation of this balance ensures that the model is properly representing the key hydrologic components of the study area. This balance includes agricultural and urban land use, agricultural and urban water demand, and overall water supply, consisting of surface water deliveries and groundwater pumping.

The average annual water demand for the Region within the calibration period was 896,000 AF, consisting of 814,000 AF agricultural demand and 82,000 AF of municipal and domestic demand. This demand was met by 329,000 AF of surface water deliveries, and 711,000 AF of groundwater production, 629,000 AF of agricultural and 82,000 AF of municipal and domestic pumping. The annual land and water use budget for the calibration period (water years 1996-2015) are presented in Figure 74.

4.4.2 Groundwater Budget

The major hydrologic processes affecting groundwater flow in the model area are incorporated in the MercedWRM. The primary components of the groundwater budget are:

- Inflows:
    - Deep percolation from rainfall and irrigation-applied water,
    - Recharge due to stream seepage,
    - Recharge from other sources such as irrigation canals and recharge ponds,
    - Boundary inflows from outside the model area, and
    - Subsurface inflows from adjacent subregions.
- Outflows:
    - Groundwater pumping,
    - Outflow to streams and rivers,
    - Subsurface outflows to adjacent subregions, and
    - Boundary outflows.
    - Change in groundwater storage

The groundwater budget (Figure 75) shows that within the calibration period, the primary sources of aquifer recharge are deep percolation and seepage from the surface water features. During the 1996-2015 simulation period, groundwater storage was reduced by an average of 111,000 acre-feet per year. The primary cause for this reduction is the 750,000 acre-feet of pumping, offset by 367,000 acre-feet of deep percolation, a net gain from stream of 148,000 acre-feet, 127,000 acre-feet of canal recharge, and a net boundary flow of 10,000 acre-feet annually.

4.5 Groundwater Level Calibration

The goal of this stage of calibration is to achieve a reasonable agreement between the simulated and observed groundwater levels at the calibration wells. Within the Region, 176 groundwater observation wells were selected from the Merced HydroDMS database to be representative of both the local and regional groundwater trends. The selected calibration wells provide reliable historical data that has served as a fair representation of the long-term conditions of the Basin.

Aquifer parameters, such as hydraulic conductivity, specific storage, and specific yield were modified to achieve calibration targets. The groundwater level calibration is performed in two stages:

- The initial calibration effort is focused on the regional scale to verify hydrogeological assumptions made during development and confirm the accuracy of general groundwater flow vectors. During this iteration, simulated groundwater elevation trends, flow directions, and groundwater gradients generally match the measured data.
- The second stage of calibration of groundwater levels is to compare the simulated and observed groundwater level at each calibration well. This comparison provides information on the overall model performance during the simulation period. The simulated groundwater elevations at the 176 calibration wells (Figure 76) were compared with corresponding observed values for long-term trends as well as seasonal fluctuations.

The results of the groundwater level calibration indicate that the MercedWRM reasonably simulates the long-term hydrologic responses under various hydrologic conditions. Figure 77 and Figure 78 offer a cursory overview of the groundwater level calibration across the model domain, while Appendix A contains groundwater hydrographs at all calibration wells.

4.6 Measurement of Calibration Status

The MercedWRM calibration status was measured using two metrics: simulated and observed groundwater level matching statistics and groundwater trend matching. The statistics were evaluated to meet the

American Standard Testing Method (ATSM). In addition to quantifiable metrics, the MercedWRM calibration was evaluated by generating reasonable regional groundwater flow directions and producing realistic water budgets.

The "Standard Guide for Calibrating a Groundwater Flow Model Application" (ASTM D5981-96) states that "the acceptable residual should be a small fraction of the head difference between the highest and lowest heads across the site." The residual is defined as the simulated head minus the observed heads. An analysis of all calibration wells within the Region indicated the presence of 300+ feet of water level changes. Using 10 percent as the "small fraction", the acceptable residual level would be 30 feet. Calibration goals for the groundwater level residuals were set such that no more than 10 percent of the observed groundwater levels would exceed the acceptable residual level of 30 feet.

- 87.2% of observed groundwater levels are within +/- 20 feet of its respective simulated values
- 97.8% of observed groundwater levels are within +/- 30 feet of its respective simulated values

The residual histogram for the Merced Region is shown in Figure 79. Additionally, a scatter plot of simulated vs observed values is shown in Figure 80.

4.7 Final Calibration Parameters

The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) served as the basis aquifer parameters within the MercedWRM. These parameters were adjusted throughout the calibration process such that hydraulic head of the simulated model was best aligned with the observed data. The parameters resulting from the calibration process are listed in the subsection below.

Horizontal Hydraulic Conductivity – The hydraulic conductivity (K_H) in the MercedWRM varies across the horizontal direction and across model layers. The fully calibrated values remain descriptive of the initial hydrogeologic analysis, range from 4 ft/day to 100ft/day, and the spatial distribution is represented in Figure 81 through Figure 85.

Vertical Hydraulic Conductivity – Primarily a constraining factor across the Corcoran Clay (Aquitard 2), the Vertical Hydraulic Conductivity (K_V) shown in Figure 86 facilitates the separation between the unconfined and confined aquifers within the MercedWRM. The K_V values of the Corcoran aquitard is found to be less than one one-thousandth of the horizontal conductivity of the surrounding aquifer systems.

Specific Storage – Specific Storage (S_S) is used to represent the available storage at nodes in a confined aquifer, where the hydraulic head is above the top of the aquifer. Specific Storage is the unit volume of water released or taken into storage per unit change in head. Calibrated specific storage is shown in Figure 87.

Specific Yield – Specific Yield (S_Y) is representative of the available storage in an unconfined aquifer and defined as the unit volume of volume released from the aquifer per unit change in head due to gravity. Calibrated specific storage is shown in Figure 88.

4.8 Sensitivity Analysis

Sensitivity analysis is an important step in the model development process. It is defined as "the study of distribution of dependent variables (e.g., groundwater elevations in a groundwater model) in response to changes in the distribution of independent variables, initial conditions, boundary conditions, and physical parameters" (AWWA, 2001). In general, a sensitivity analysis of an integrated groundwater and surface water model is performed for the following purposes:

- To test the robustness and stability of the model by establishing tolerance within which the model parameters can vary without significantly changing the model results;
- To understand the impact of inaccuracies in input data on model results (e.g., how model results can change because of a 10% error in the estimation of agricultural pumping); and
- To develop an understanding of the relative sensitivity of the components of the hydrologic cycle and data, so that an effective data collection and monitoring plan can be developed.

4.8.1 Metrics of the Sensitivity Analysis

A sensitivity analysis was performed using the MercedWRM to assess the sensitivity of model results to specific model parameters and input data. Two different metrics were selected to measure the sensitivity of the MercedWRM. A sensitivity metric is a single number derived from the MercedWRM model results and has a unique value for each model run corresponding to a given set of data or parameter value. The sensitivity metrics used here:

- Average groundwater elevation in the study areas, and
- Average root mean square (RMS) error of groundwater elevation aggregated from selected calibration wells.

Average groundwater elevation in the study areas is defined as a three-way average of simulated groundwater elevations at model nodes. The average is taken over:

- Layers,
- Nodes, and
- Time.

This can be mathematically expressed by:

$$\overline{H} = \frac{1}{M}\sum_{K=1}^{M} H_k$$

Such that,

$$H_k = \frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{L}\sum_{j=1}^{L} h_j\right]_i^k$$

Where,

M	total number of simulation time steps,
H_k	average head in the model area at k-th time step,
N	number of model nodes,
L	number of model layers in aquifer,
H_j	groundwater elevation at layer j, and
i, j, k	are indices for node, layer, and time, respectively.

The average RMS error at selected calibration wells is defined as the average of individual RMS error at each calibration well. The RMS error at a calibration well is defined as follows:

$$RMS_w = \sqrt{\left\{\frac{1}{N}\sum_{k=1}^{N_0}\left[h_{k,w}^0 - h_{k,w}^s\right]^2\right\}}$$

where,

N_0 is the number of observations at well k,

$h_{k,w}^0$ is the observed groundwater elevation at time step k, at well w,

$h_{k,w}^s$ is the simulated groundwater elevation at time step k, at well w.

4.8.2 Results of the MercedWRM Sensitivity Analysis

Adjustments of aquifer parameters, and the analysis the resulting groundwater head, was performed at all groundwater nodes within the model domain. Sensitivity analyses were performed for the MercedWRM for the following parameters.

- Hydraulic Conductivity (Horizontal)
- Specific Yield
- Specific Storage
- Hydraulic Conductivity (Vertical) of the Corcoran Clay

4.8.3 Hydraulic Conductivity (Horizontal)

The sensitivity of the MercedWRM to changes in hydraulic conductivity are presented in Figure 89 and Figure 90. Reduction of hydraulic conductivity to one fourth of the calibrated value results in 10.31 feet lower groundwater levels in the model, whereas increases to hydraulic conductivity increase the average groundwater levels by 1.67 feet. Changes to hydraulic conductivity have significant impacts to RMS values.

4.8.4 Specific Yield

The sensitivity of the MercedWRM to changes in specific yield are presented in Figure 91 and Figure 92. Reduction of specific yield to one fourth of the calibrated value results in 14.61 feet lower groundwater levels in the model, whereas increases to specific yield increase the average groundwater levels by 7.90 feet. Changes to specific yield have significant impacts to RMS values.

4.8.5 Specific Storage

The sensitivity of the MercedWRM to changes in specific storage are presented in Figure 93 and Figure 94. Reduction of specific storage to one fourth of the calibrated value results in approximately 0.16 feet lower groundwater levels in the model, whereas increases to specific storage increase the average groundwater levels by 0.74 feet. Changes to specific storage have slight impacts to RMS values.

4.8.6 Hydraulic Conductivity (Vertical) of the Corcoran Clay

The sensitivity of the MercedWRM to changes in vertical hydraulic conductivity across the Corcoran Clay are presented in Figure 95 and Figure 96. Reduction of this parameter to one fourth of the calibrated value results in 1.91 feet lower groundwater levels in the model, whereas increases to the vertical hydraulic conductivity increase the average groundwater levels by 7.90 feet.

4.8.7 Summary of Sensitivity Analysis

The results of the sensitivity analysis for the MercedWRM indicate that the model is a stable model and the system responds in the expected manner because of changes in aquifer parameters and input data.

Chapter 5 The Merced Water Quality Model

The Merced Water Quality Model (MercedWQM) was developed to simulate total dissolved solids (TDS) and nitrogen within the Merced Groundwater Region. This module uses the groundwater flow field from the MercedWRM flow module to simulate the transport of water quality constituents in the soil and vadose zones, surface water features, and the groundwater basin aquifers. This chapter describes the assumptions made, calibration process, and hydrologic and water quality results during the calibration period.

5.1 IGSM Code Update

The foundation of the MercedWQM is the water quality module of the Integrated Groundwater Surface Water Model (IGSM). As IGSM is the predecessor of IWFM and an independent framework separate from IWFM, refinements were necessary to allow for cross-platform integration. Extensive collaboration with DWR staff was undertaken to update the IWFM code, verify parameters and water budget components, and ensure the alignment of flow vectors between the IWFM flow module and the IGSM water quality module.

Water quality modeling in IGSM includes simulation of soil zone biochemical processes, transport and decay processes in the vadose zone, and transport and decay processes in the saturated zone. Soil zone biochemical process simulation for nitrogen includes mineralization, immobilization, adsorption, desorption, denitrification and plant uptake. The transport process in the saturated and vadose zones is simulated by IGSM by solving the mathematical equations of transport that include advection, dispersion adsorption, desorption, and decay. Water quality simulation in the stream system is based on mass balance and first order linear decay rate.

5.2 IGSM Processes

The processes modeled for water quality simulation in surface and subsurface systems depend on the quality constituent and hydrologic unit. The water quality module has a separate water quality simulation procedure for each of the hydrologic units simulated in the MercedWRM flow module:

- Soil zone
- Stream system
- Vadose zone
- Groundwater zone

5.2.1 Soil Zone

The following discussion uses nitrogen as an example of constituent being simulated in the MercedWQM.

Nitrogen inflows to the soil zone are of three forms: as ammonia in fertilizers (adsorbed nitrogen); as organic nitrogen in fertilizers and in dairy wastes; and as nitrate (soluble nitrogen) in applied water.

These three forms of nitrogen interact with each other and transform from one form to another due to biochemical processes taking place in the soil zone. Soil physicists and agronomists have formulated differential equations with first order kinetic reaction rates to describe these processes. MercedWQM uses the Runge-Kutta method for solving these ordinary differential equations for nitrogen transformation processes in the soil zone. These equations are solved on an element by element basis at every time step of simulation. The numerical solution scheme used in the soil zone quality submodel of MercedWQM ensures numerical accuracy and stability by allowing for smaller time steps within the monthly time step.

The input data for the soil zone quality simulation includes:

- the time history of applied fertilizer;

- animal waste disposal data;
- concentration of imported water applied on the land;
- concentration of wastewater discharges;
- waste increment due to water use;
- concentration of stormflow recharge;
- concentration of agricultural and urban return flow;
- concentration of rainwater;
- plant uptake rate;
- mineralization/immobilization rates;
- adsorption/desorption rates; leaching fraction; and
- denitrification coefficients.

This submodel of MercedWQM generates the amount of leachate mass from each model element in the underlying vadose zone.

5.2.2 Stream System

Stream system quality is simulated in MercedWQM by solving the mass balance equation at each stream node. Each stream node in assumed to act like a continuous mixed reactor. A user specified loss rate in each stream element defines a first order loss rate for nitrogen losses in the stream system due to biological processes.

The mass balance components of stream quality simulation are:

- constituents mass inflow associated with water inflow at the upstream node of the stream element;
- mass associated with direct runoff and return flow;
- mass associated with wastewater discharges to stream;
- mass leaving with stream diversions;
- mass entering or leaving the stream system due to gain or loss to underlying aquifer; and
- mass loss due to biochemical processes.

The input data for stream quality simulation includes concentration of boundary stream inflows from:

- major streams and mountain watersheds;
- concentration of wastewater discharges to streams;
- concentration of rain runoff; concentration of return flow from urban and agricultural use; and
- nitrogen loss rate at each stream node.

The solution of constituent mass balance equation for a stream element provides the downstream mass outflow for that element. This outflow is used as upstream inflow for the stream element that is downstream of the current stream element.

5.2.3 Vadose Zone

The mass that leaches from the soil zone with percolation water travels through the vadose zone on its way to the saturated zone. For nitrogen simulation, the predominant form of nitrogen that percolates from the soil zone as leachate is nitrate. The vadose zone quality submodel of MercedWQM simulates water quality in the vadose zone by solving the one-dimensional vertical advection-dispersion equation with adsorption, desorption, and decay. The vadose zone quality submodel of MercedWQM has two mass pools to incorporate these process dynamics in the vadose zone. These two mass pools are mobile mass pool and immobile mass pool.

The mobile mass pool represents mass that is associated with mobile water phase; the immobile mass pool includes mass associated with immobile water phase and mass attached with soil particles by ionic bonds. The mass transfer between these two pools is governed by two model assumptions:

- the mobile and immobile phases of water are completely mixed; and
- concentration in both mass pools are equal at the end of each time step.

Decay coefficient defines the mass removal due to denitrification. The denitrification process removes nitrogen from the mobile and immobile pools. The numerical solution of the mathematical equation representing vadose zone quality is obtained by using the results of vadose zone flow simulation. The computations are performed node by node and layer by layer. In addition to a mass balance on water flow, a constituent mass balance is also performed for each layer. The mass exchange between the vadose zone and saturated zone due to water table rise and fall is included in MercedWQM by keeping track of depth to groundwater and corresponding concentrations in unsaturated and saturated zones at the previous time step. The mass outflow from the overlying vadose zone layer becomes the mass inflow to the layer beneath and so on. The mass outflow from the lowest vadose zone layer is the mass inflow to the saturated zone at the corresponding node.

The input data for vadose zone water quality simulation includes:

- thickness of vadose zone layers;
- hydraulic conductivity; dispersivity; distribution coefficient;
- specific retention; and
- denitrification coefficient for each unsaturated zone layer.

5.2.4 Groundwater Zone

Water quality in the groundwater zone is simulated by MercedWQM by solving two-dimensional advection-dispersion with adsorption, desorption, and decay. The flow field generated by the flow module is used to solve this mathematical equation by finite element method. The solution provides the concentration at each groundwater node at each layer. The vertical connection between the aquifer layers is simulated by considering mass exchanges associated with the vertical flow from one layer to another. A user specified decay coefficient accounts for mass removal due to denitrification.

The input data for groundwater zone water quality simulation includes:

- concentration of subsurface inflows at model boundary;
- concentration of injection water;
- longitudinal and transverse dispersivity;
- specific retention; and

- denitrification coefficient; etc.

The flow related parameters are provided in the flow module and are transferred to the water quality module of MercedWRM through the binary output from the flow module.

5.3 Model Input and Assumptions

This section describes the model inputs required to run the MercedWRM water quality module and key assumptions made. Water quality data sufficient to calibrate the MercedWRM water quality module is largely unavailable, and most values are sourced from local knowledge of the basin. Work associated with the development of the Groundwater Sustainability Plan for the Merced Subbasin will involve collection of water quality data and is expected to begin starting in 2018. Due to the lack of data available, a series of assumptions were developed and implemented based on known characteristics of the MercedWRM area.

5.3.1 Model Input

Previously, the focus of the MercedWRM has been on estimating the hydrologic components that drive the water resources of the study area. For water quality modeling, a water quality must be assigned to each hydrologic component. The input data for the MercedWQM can be summarized to include:

- Binary output file from geometry and flow module;
- time series of imported water quality
- the chemical concentration of rainfall, tributary flows, return flows, etc.;
- chemical concentration of subsurface inflow through the model boundary;
- time series of another surface loading features; and
- transport and rate parameters.

Base information was collected from the following sources, from which a series of assumptions were taken to fill in data gaps.

- The Merced Salt and Nutrient Management Plan
- GeoTracker GAMA Online Database
- Local knowledge of farming practices
- UC Davis Cooperative Extension

5.3.2 Model Assumptions

Initial concentrations for the water quality module, adopted from the Merced Subbasin Salt and Nutrient Management Plan (SNMP). This dataset, while maintaining the greatest spatial coverage, was developed without consideration of the vertical extent and is therefore is limited in its implementation though a lack of vertical discretization. These referenced values were applied at each groundwater node for both TDS and Nitrate as shown in Figure 97 and Figure 98.

For other loading parameters, a generalized survey of local knowledge was undertaken as there is a lack of quantifiable water quality data within the Merced Region. The following assumptions, listed in Table 13, were made based on the best available information.

Table 13: Merced Water Quality Model Assumptions

	TDS	Nitrate (as N)

	(mg/L)	(mg/L)
Boundary Conditions		
Northern Boundary	196	6.84
Western Boundary	1,500	1.14
Southern Boundary	209	0.70
Surface Loading		
Agricultural	1,000	1,000
Urban & Municipal	500	500
Stream Quality		
Simulated Streams	35	3.5
Canal System	50	5.0

5.4 Merced Water Quality Model Calibration

The MercedWQM calibration was performed through comparison of observed constituent levels with those of the simulated shallow and deep aquifers. Within the Region, water quality monitoring wells were selected from GeoTracker GAMA Online Database to be representative of both the local and regional water quality. Since perforation intervals of observed monitoring wells were not available, it is important to note that both an average of the shallow aquifers (layers 1-2) and the deeper aquifers (layers 3-5) were considered during calibration.

The goal of this stage of calibration is to achieve a reasonable agreement between the simulated and observed groundwater levels at the calibration wells. The results of the water quality calibration indicate that the MercedWQM reasonably simulates the long-term responses under various hydrologic and loading conditions. Figure 99 and Figure 100 offer a cursory overview of the water quality calibration across the model domain for TDS while Figure 101 and Figure 102 highlight a few of the calibration targets and simulated values for Nitrate.

Chapter 6 Recommendations

The Merced Water Resources Model, in its current state, is a defensible and well-established model for use in assessment of the water resources in the Region under historical and projected conditions. However, the following recommendations are to be considered for further refinement and enhancement of the Model:

- **Boundary Flows**
  - Interbasin boundary conditions - The current boundary flows between the Merced Region and neighboring groundwater basins are developed based on groundwater head simulations within the buffer model zone. It is recommended to use the latest version of the C2VSimFG, as being enhanced by the DWR for SGMA support, in comparing and verifying the groundwater flows across the boundaries with the neighboring basins.
  - Small Watershed - The boundary flows from the foothills have been calibrated with limited data available for the native conditions in the foothills. It is recommended to collect additional data and information on the nature of the grazing and native lands in the foothills and refine the simulation of the overland and groundwater flows from the foothills.
- **Refinement of Consumptive Use**
  - Variability of potential evapotranspiration - The current version of the IDC used for estimation of the consumptive use of crops in the Model uses monthly potential ET values that are the same for all simulation years. Given the annual variability of this data, and potential effects on the annual estimation of crop water demand, it is recommended to use more detailed data from the CIMIS stations to develop annual ETp values for use in the Model.
  - Drought Year ET Representation - The current set of ET maps used for calibration of the IDC ends in 2009. It is recommended to develop similar ET maps for the drought period of 2011-2015 and use the data to calibrate the performance of the IDC during the drought.
- **Implementation of updated datasets**
  - Land use and cropping patterns - The primary source of land use data in the model is the USDA's CropScape, available on the USDA's website. This data has been verified using the local land use and cropping pattern data from the local entities. Additionally, the DWR has recently published a detailed land use and cropping pattern map as developed based on the remote sensing, and verified at the field level, by LandIQ. This data represents the 2014 land use coverage. It is recommended to use this data in the next version of the model and continue using this data as it becomes available by LandIQ and the DWR for next updates to the Model.
  - Review and analysis of private well construction data
- **Linkage to Surface Model-** In order to be able to assess and evaluate effects of changes in operation of surface water resources and groundwater conditions in a dynamic and direct way, it is recommended to link the operations of the Merced River and Exchequer system to the Merced Water Resources Model.
- **C2VSimFG Update Based on MercedWRM for GSP Application**- C2VSimFG is developed to evaluate the integrated surface water and groundwater conditions at a regional scale, whereas, the MercedWRM is capable of evaluation of that integrated system at the local scale. As C2VsimFG may be used by the neighboring basins to evaluate the water resources conditions, and possibly the interbasin flows, it is recommended to work with the DWR to refine and update C2VSimFGto

reflect the local data in the Merced Region, so that the evaluations performed by the neighboring basins reflect the Merced operations properly.

- **Model update schedule-** In order to keep the Model up-to-date and current for analysis of the water resources in the area, it is recommended to update the model every 3-5 years and keep the Model current for evaluation of the GSP progress on path towards groundwater sustainability.

Model Figures

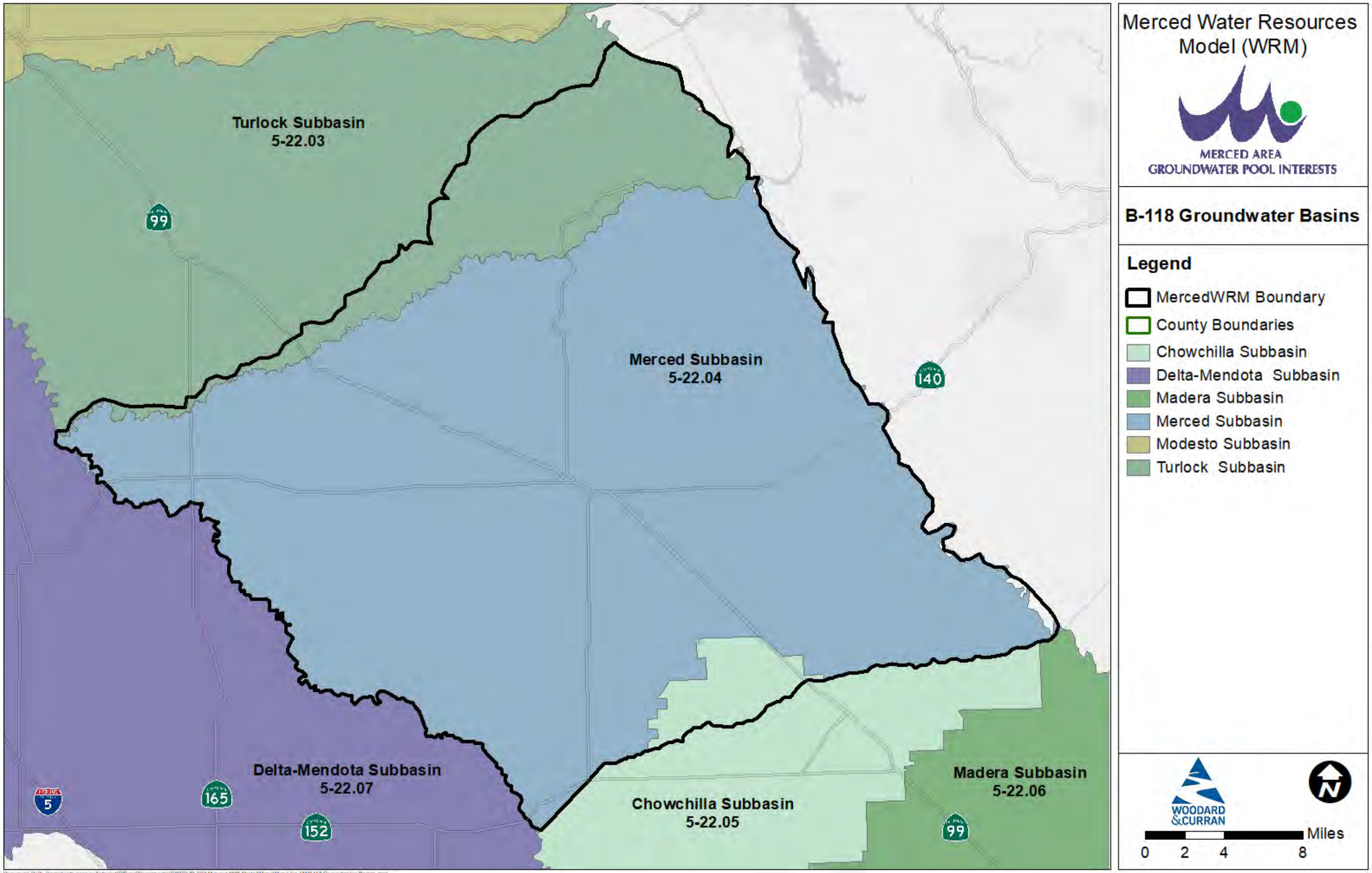


Figure 1: Bulletin 118 Groundwater Basins

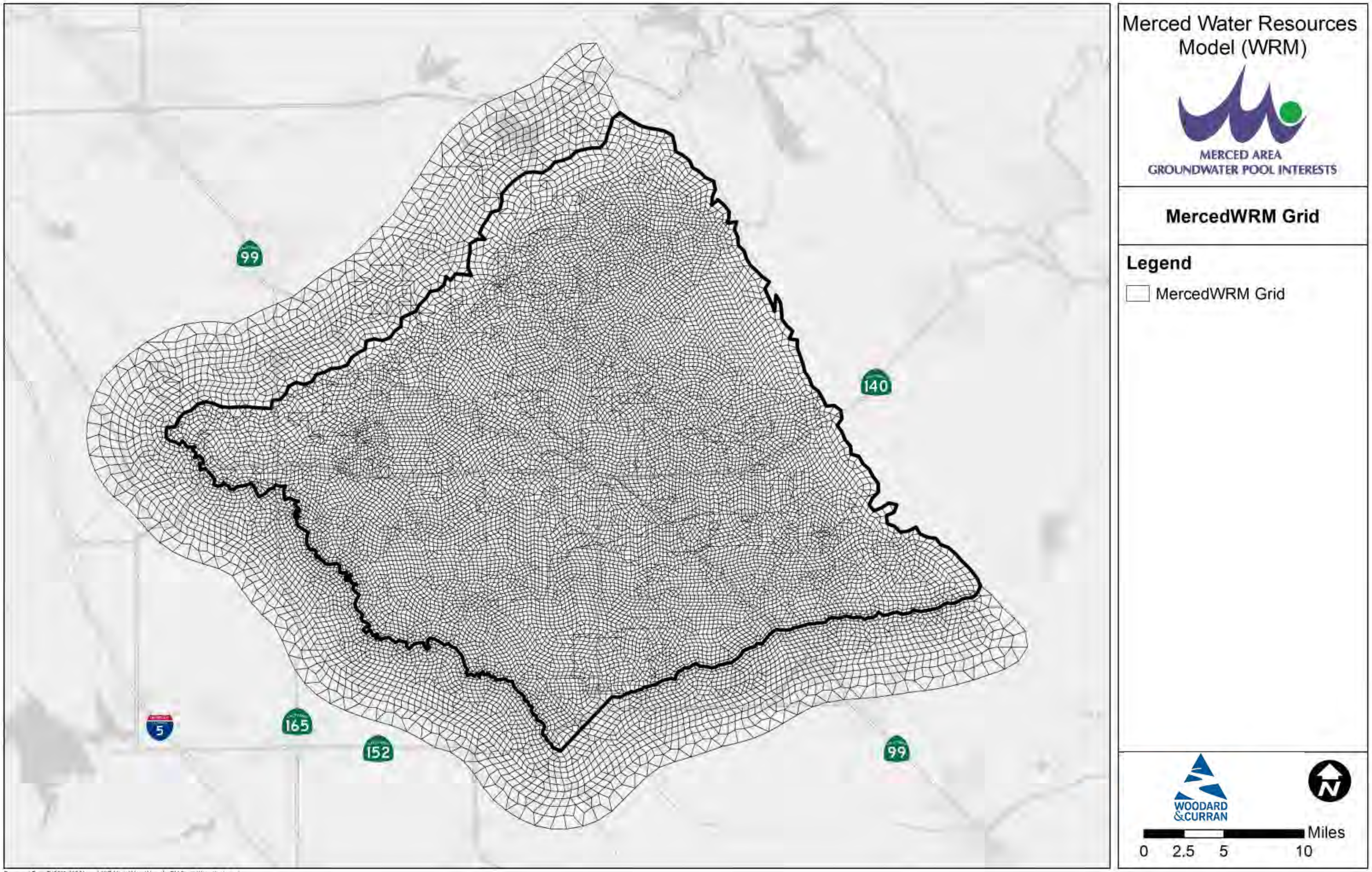


Figure 2: The Merced Water Resources Model Grid

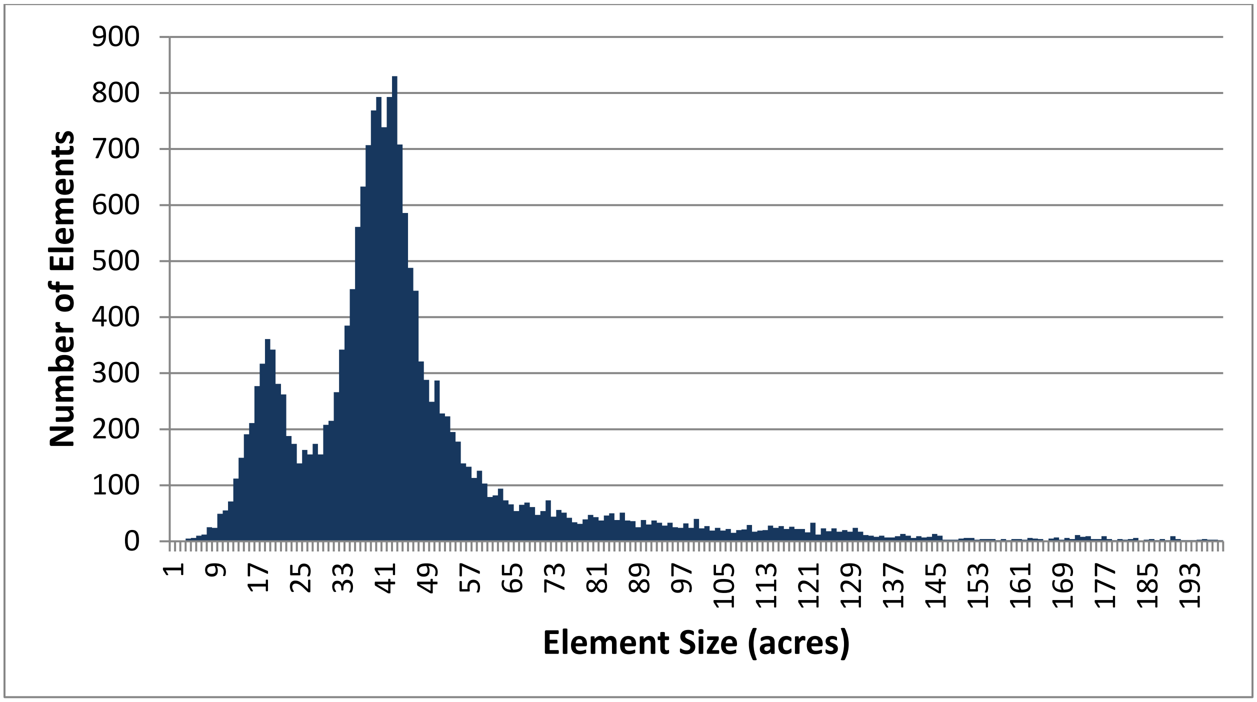


Figure 3: MercedWRM Element Size Distribution

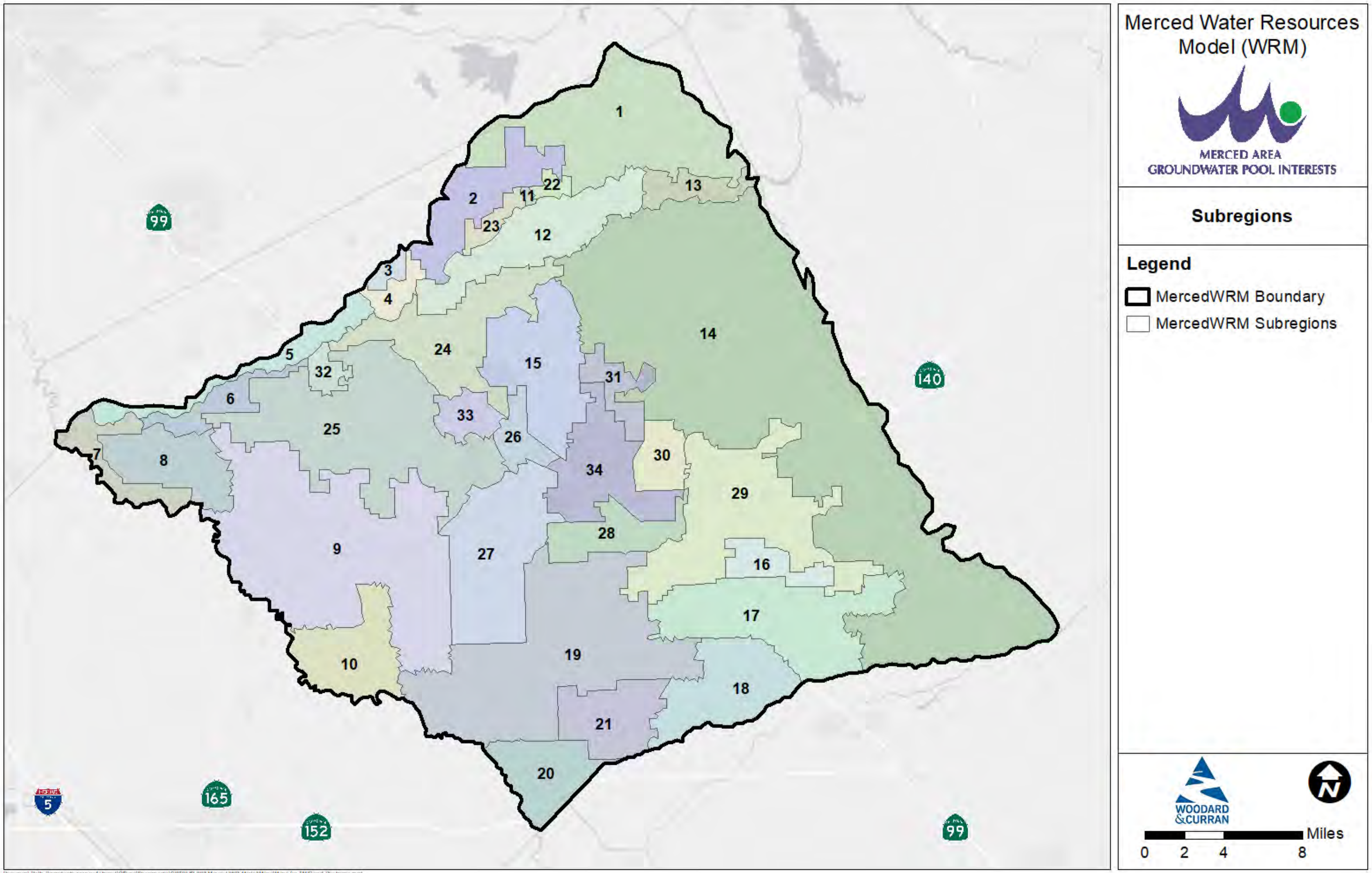


Figure 4: Merced Water Resources Model Subregions

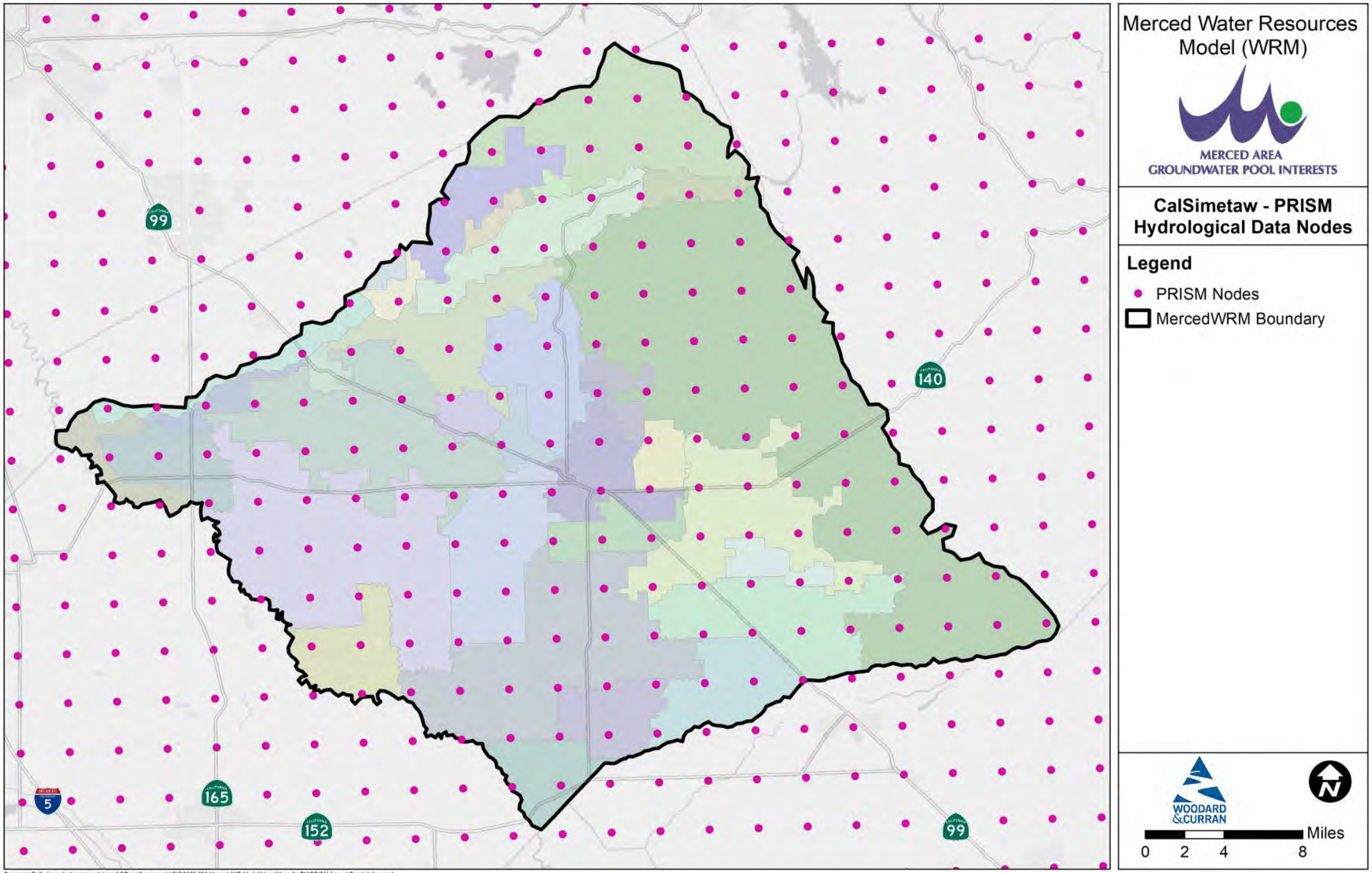


Figure 5: PRISM Grid

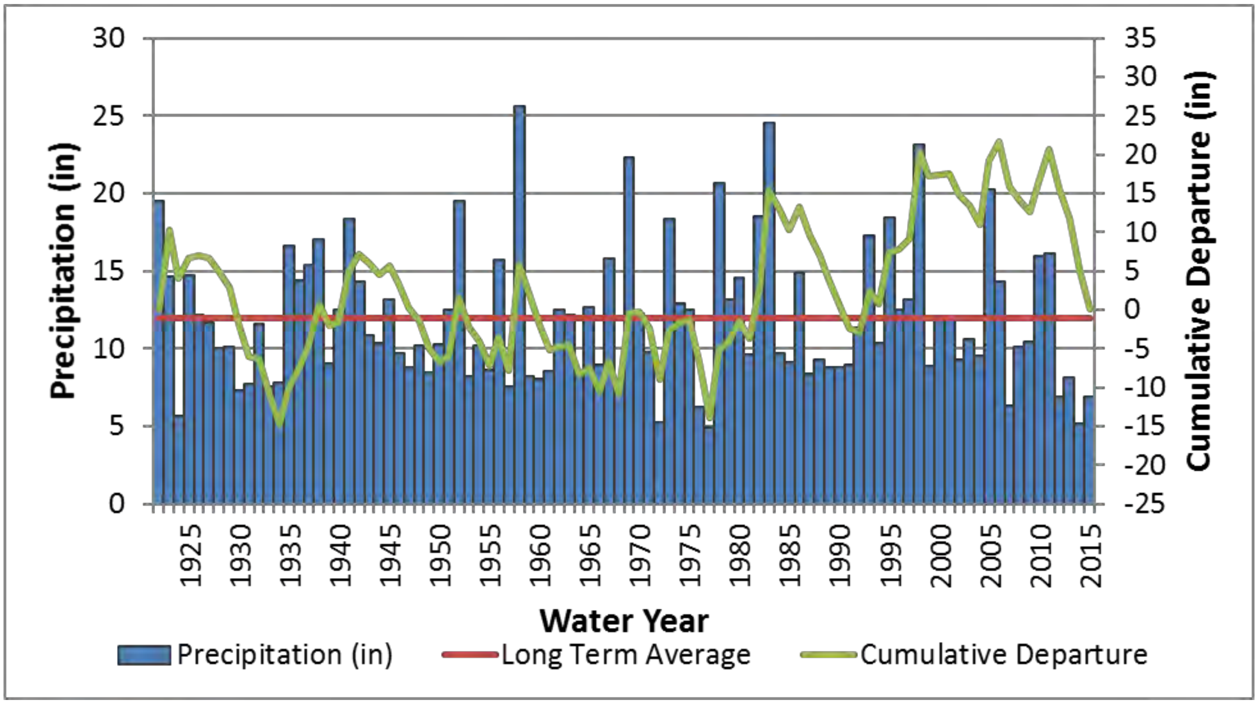


Figure 6: Monthly Precipitation and Cumulative Departure (Long Term: 1922-2015)

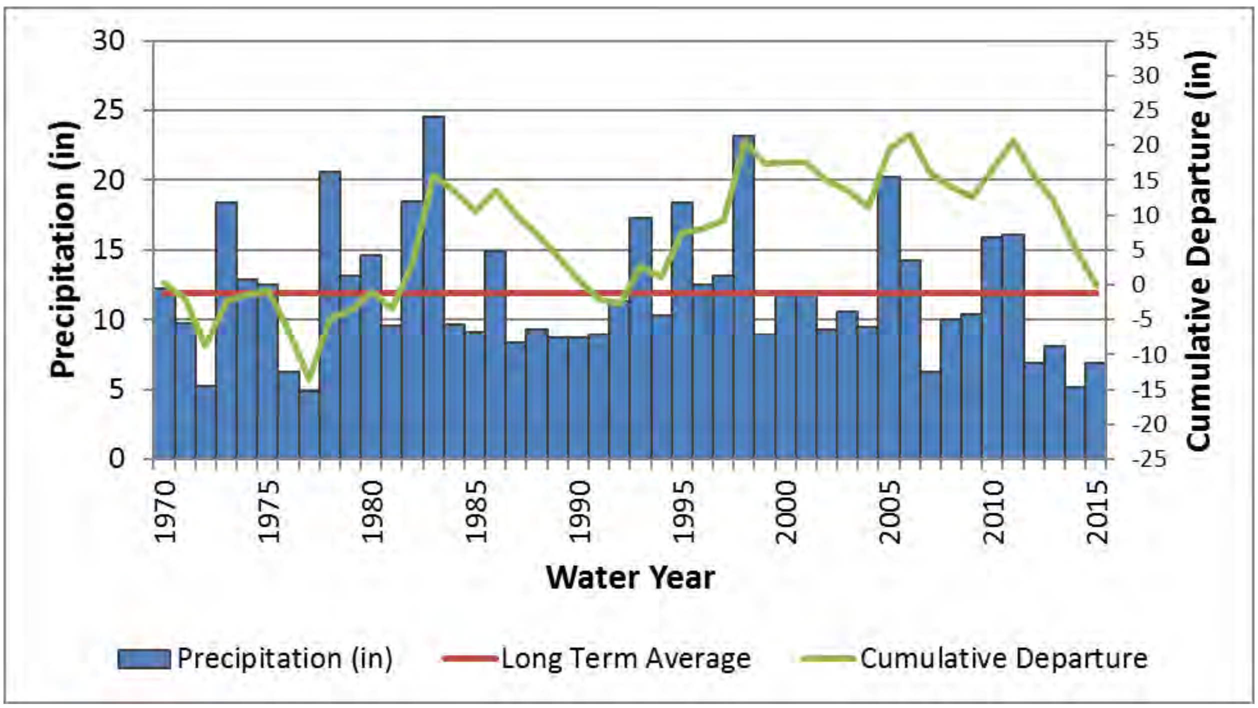


Figure 7: Monthly Precipitation and Cumulative Departure (Hydrologic Period: 1970-2015)

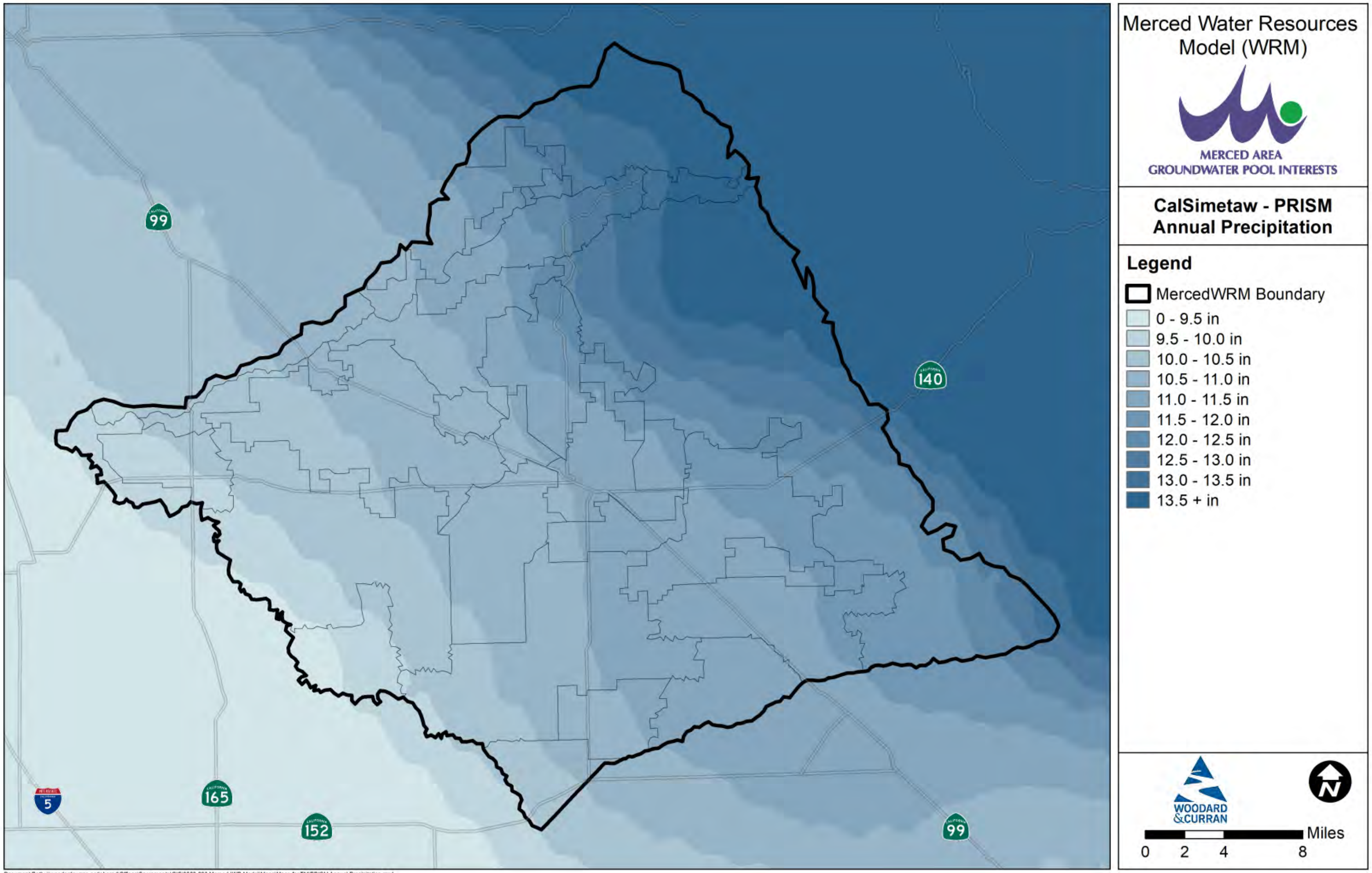


Figure 8: PRISM - Average Annual Rainfall (1970-2015)

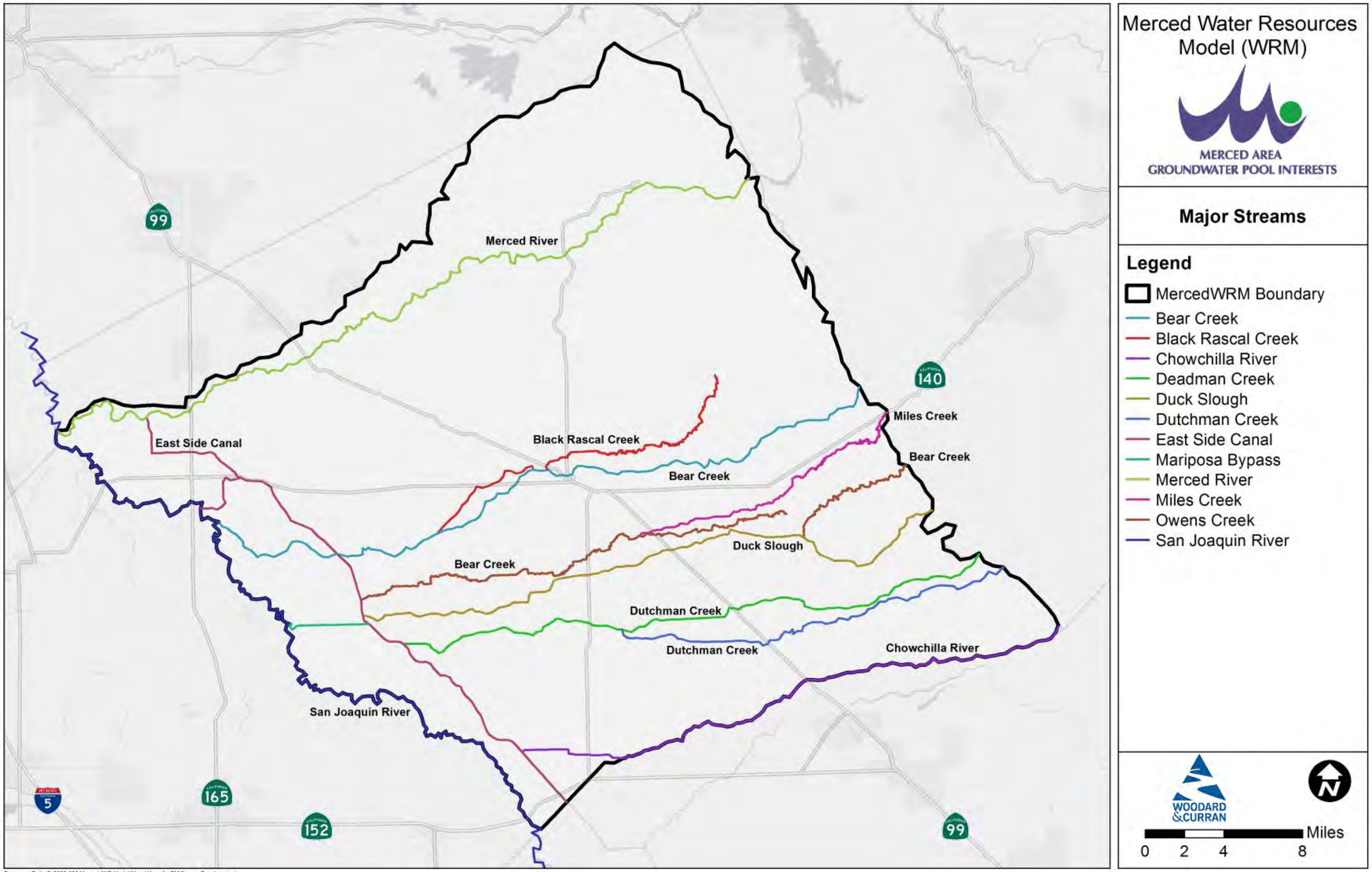


Figure 9: MercedWRM Stream Network

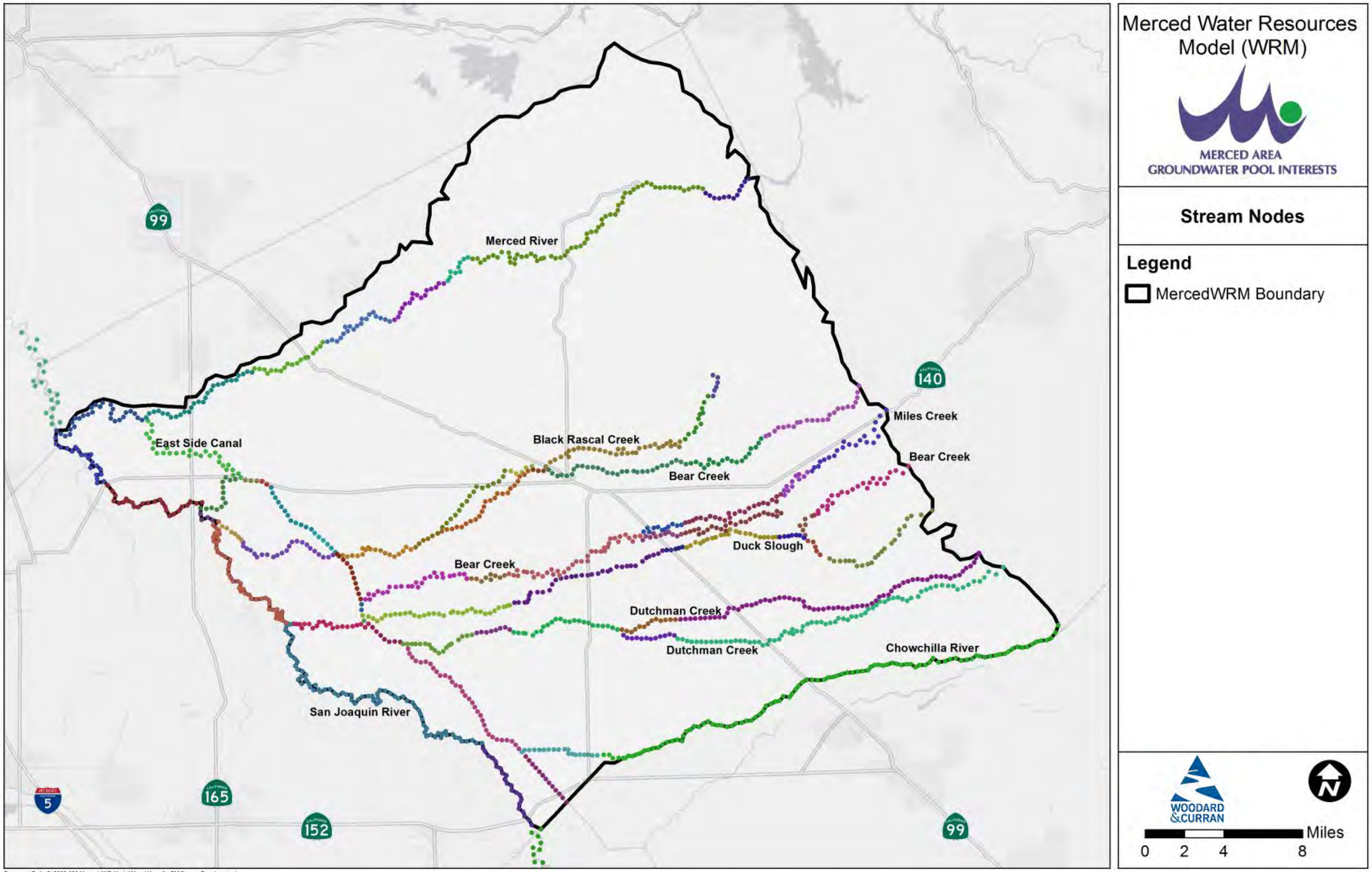


Figure 10: MercedWRM Stream Nodes and Stream Reach Configuration

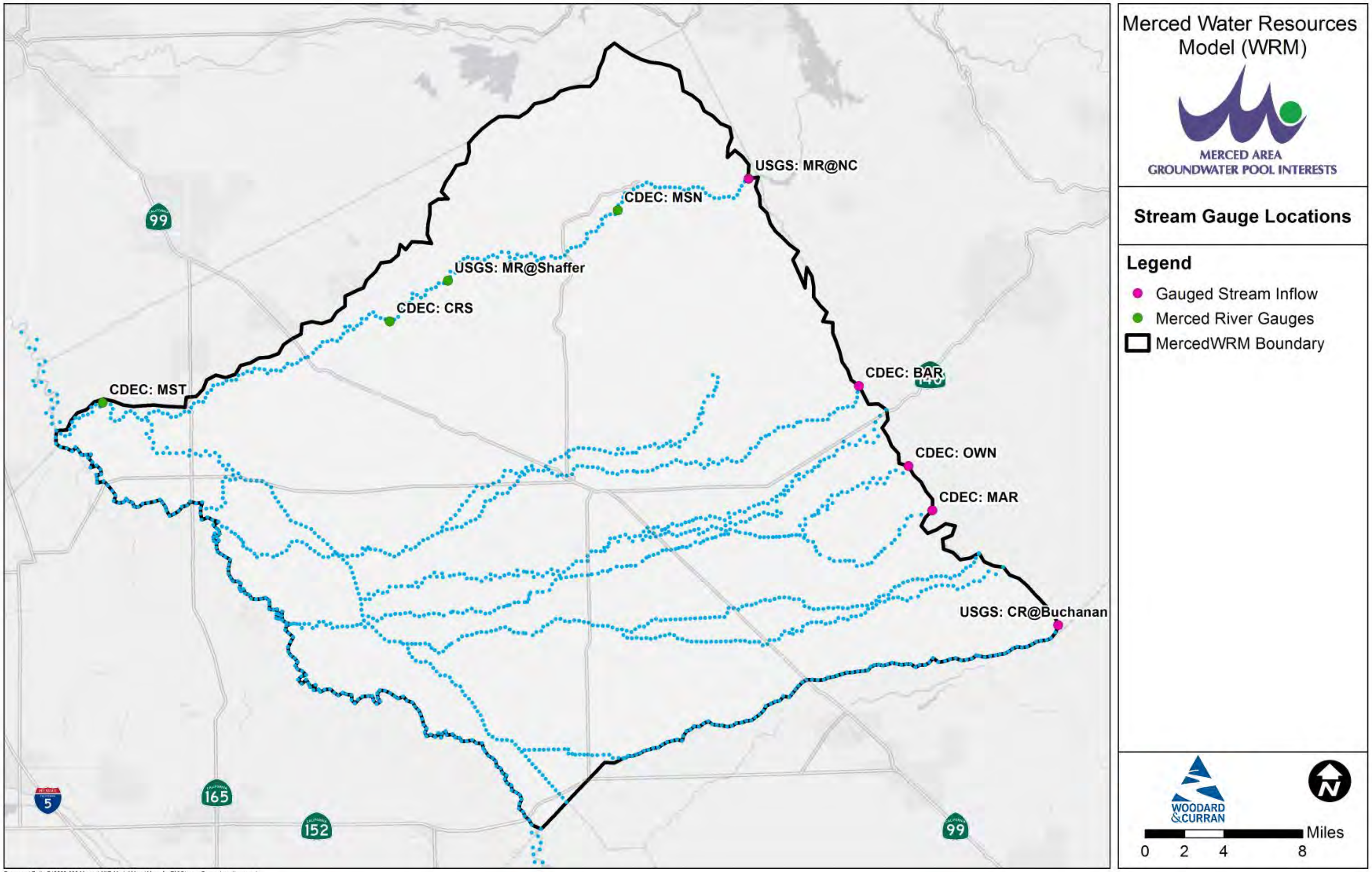


Figure 11: MercedWRM Stream Gauge Locations

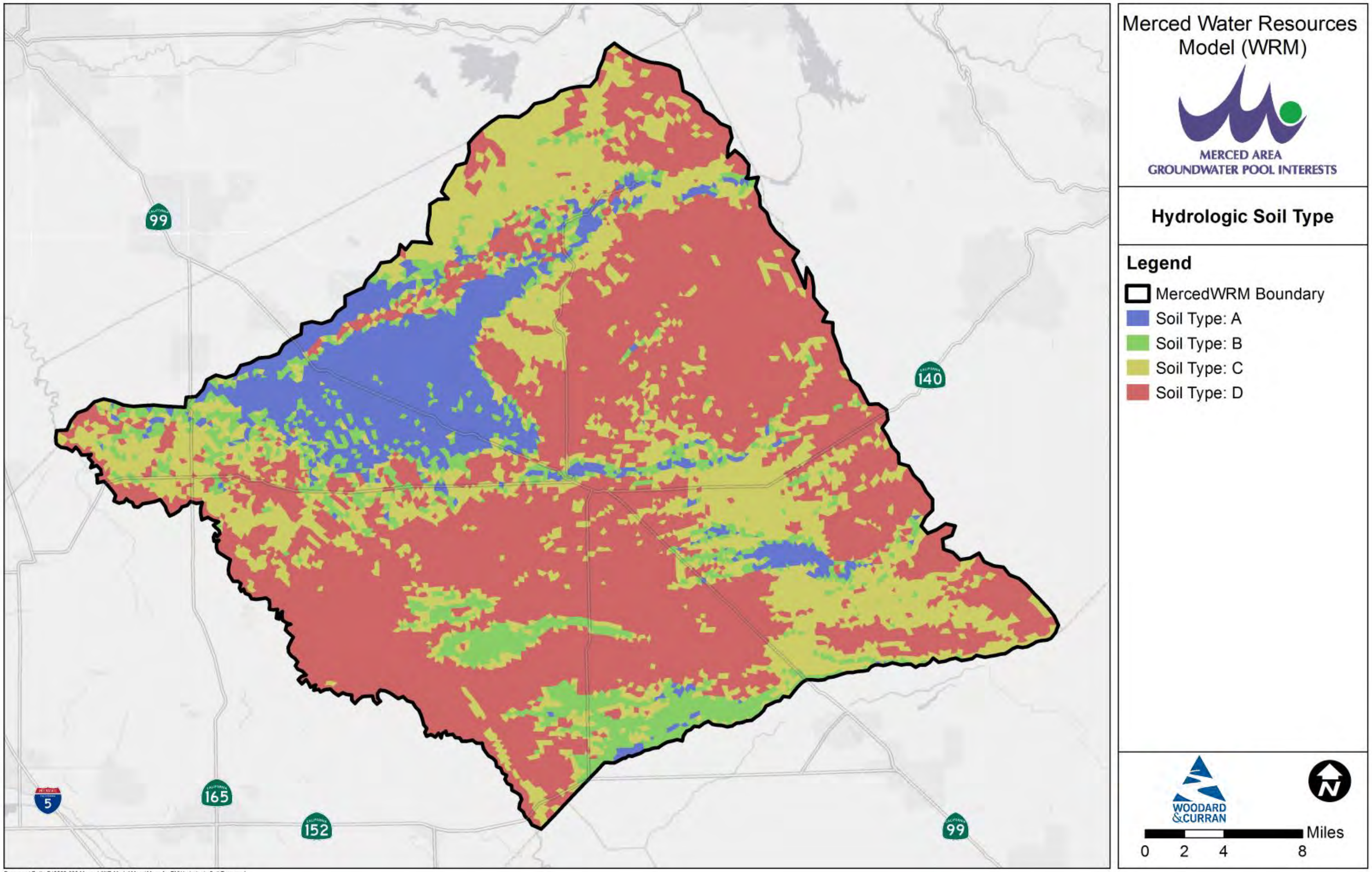


Figure 12: Soil Classifications

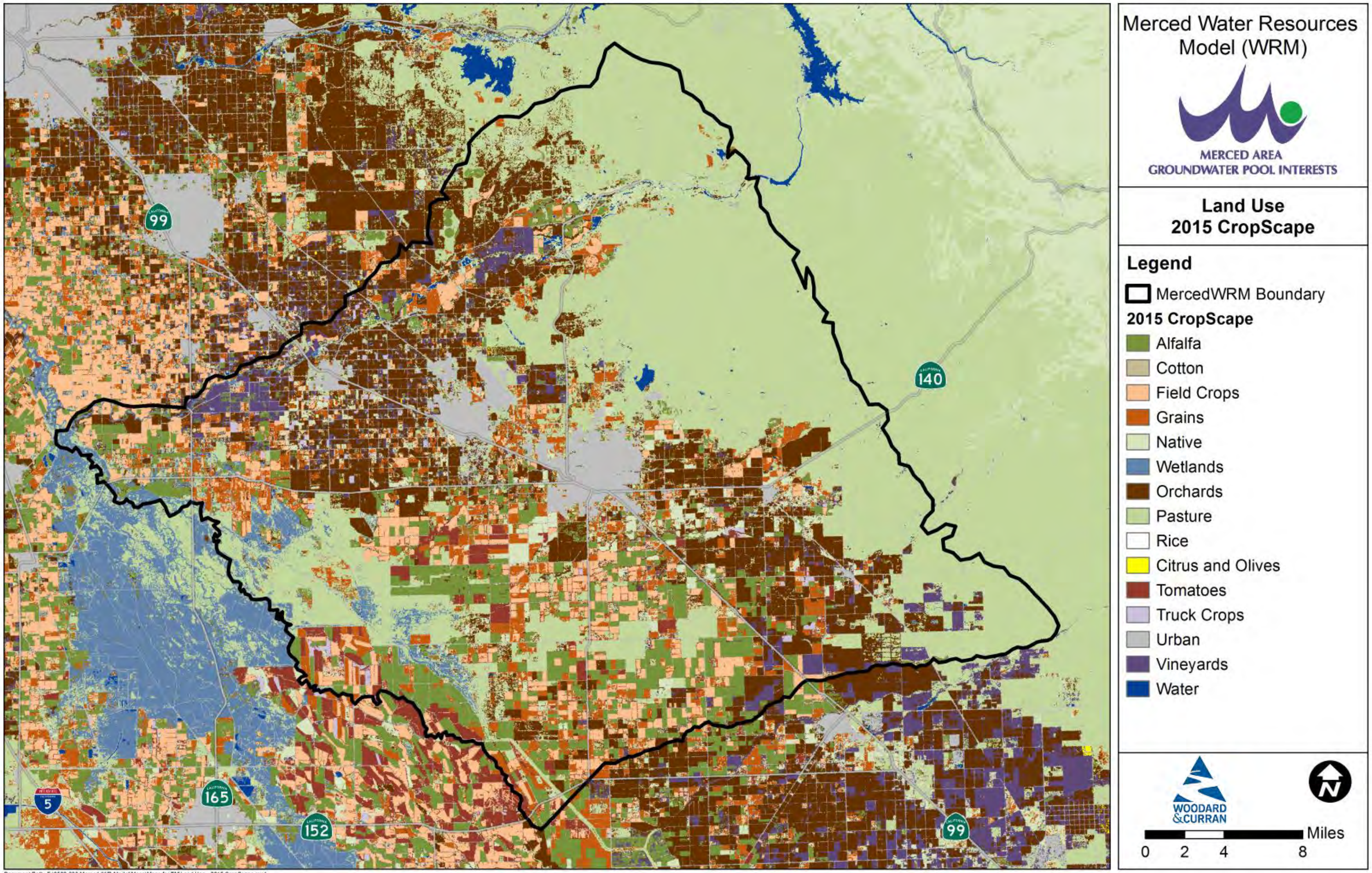


Figure 13: 2015 CropScape Land Use Data

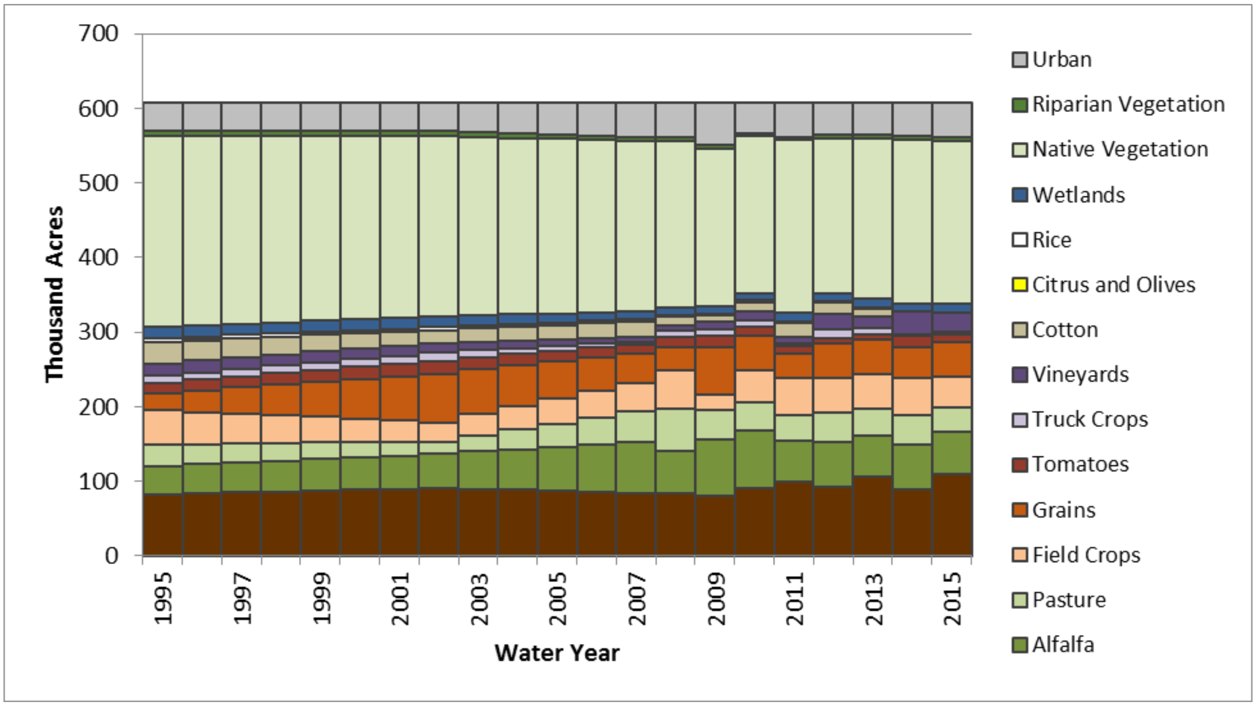


Figure 14: Merced Groundwater Region Annual Land Use Distribution

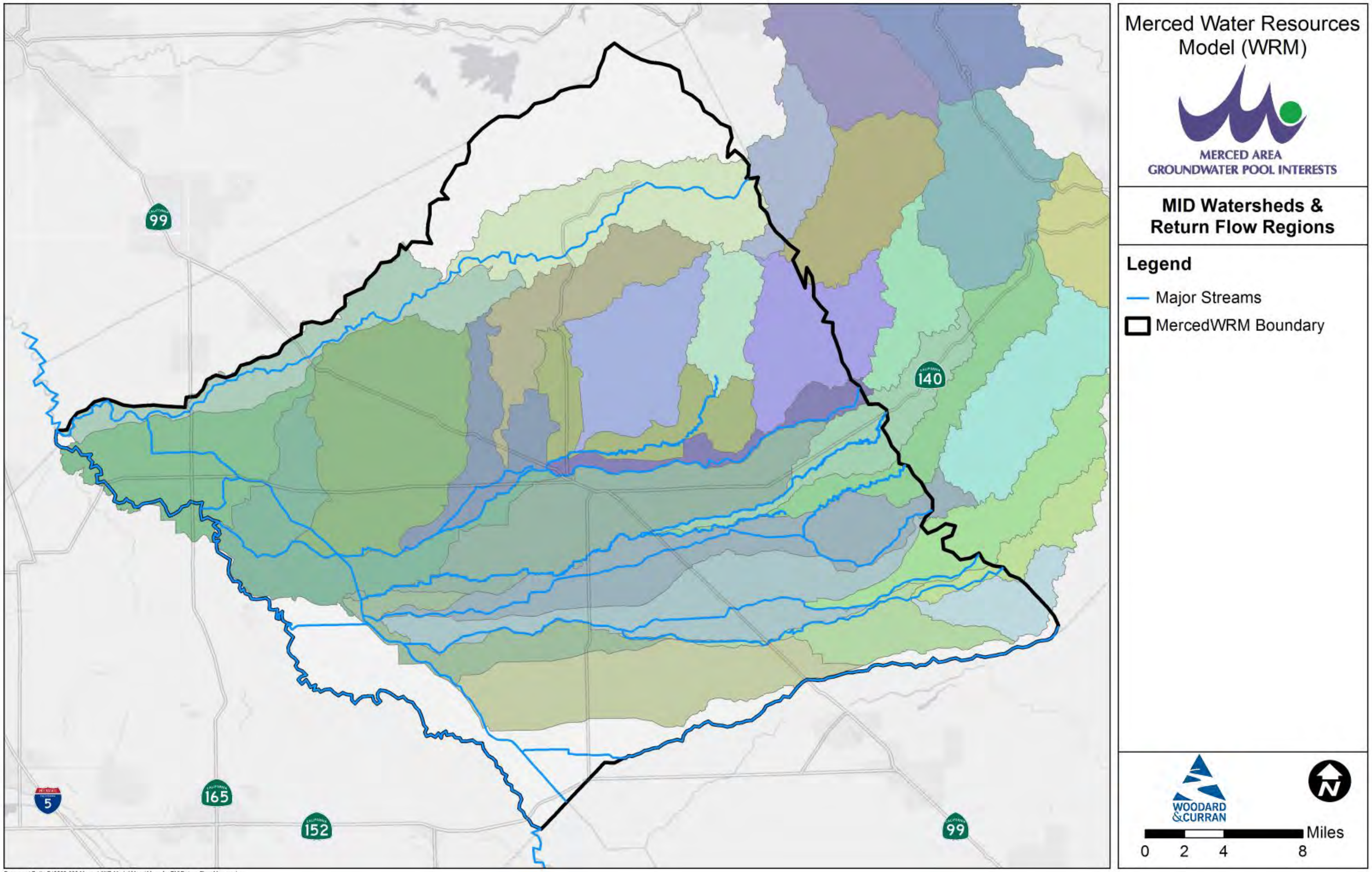


Figure 15: Merced Groundwater Basin Drainage Watersheds

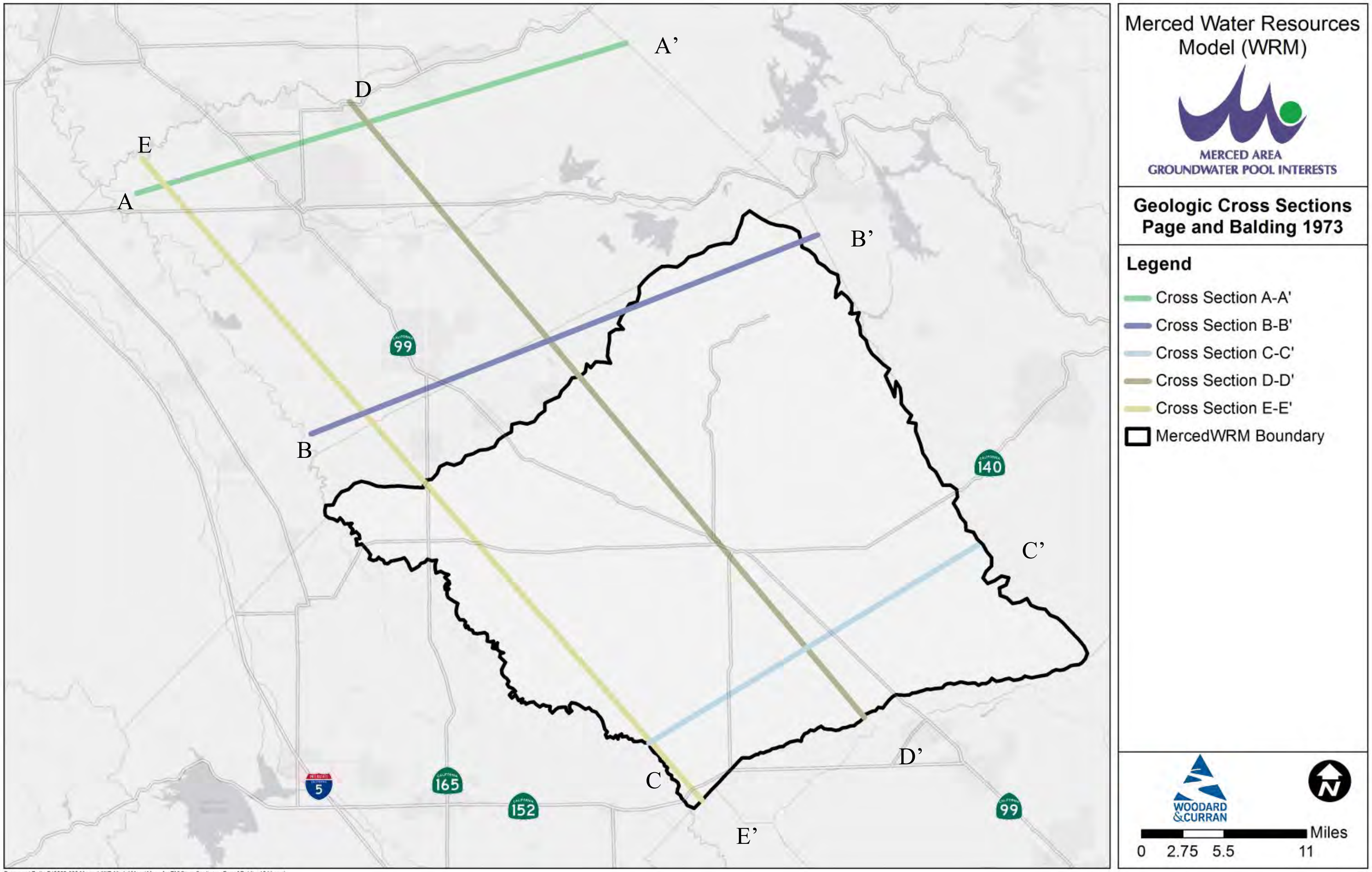


Figure 16: Location of Geologic Cross Sections - Page and Balding 1973

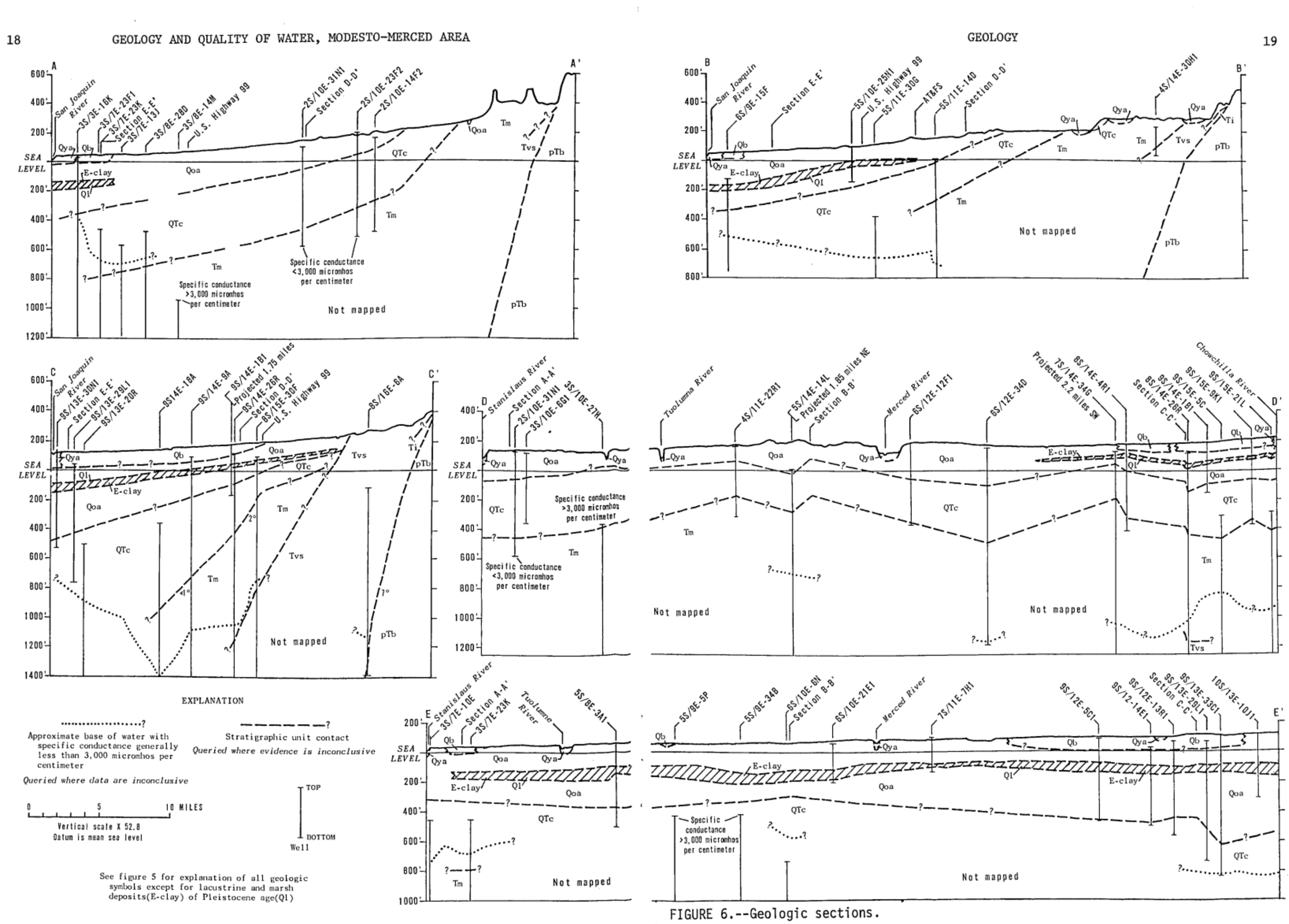


Figure 17: Referenced Cross Sections from Page and Balding 1973

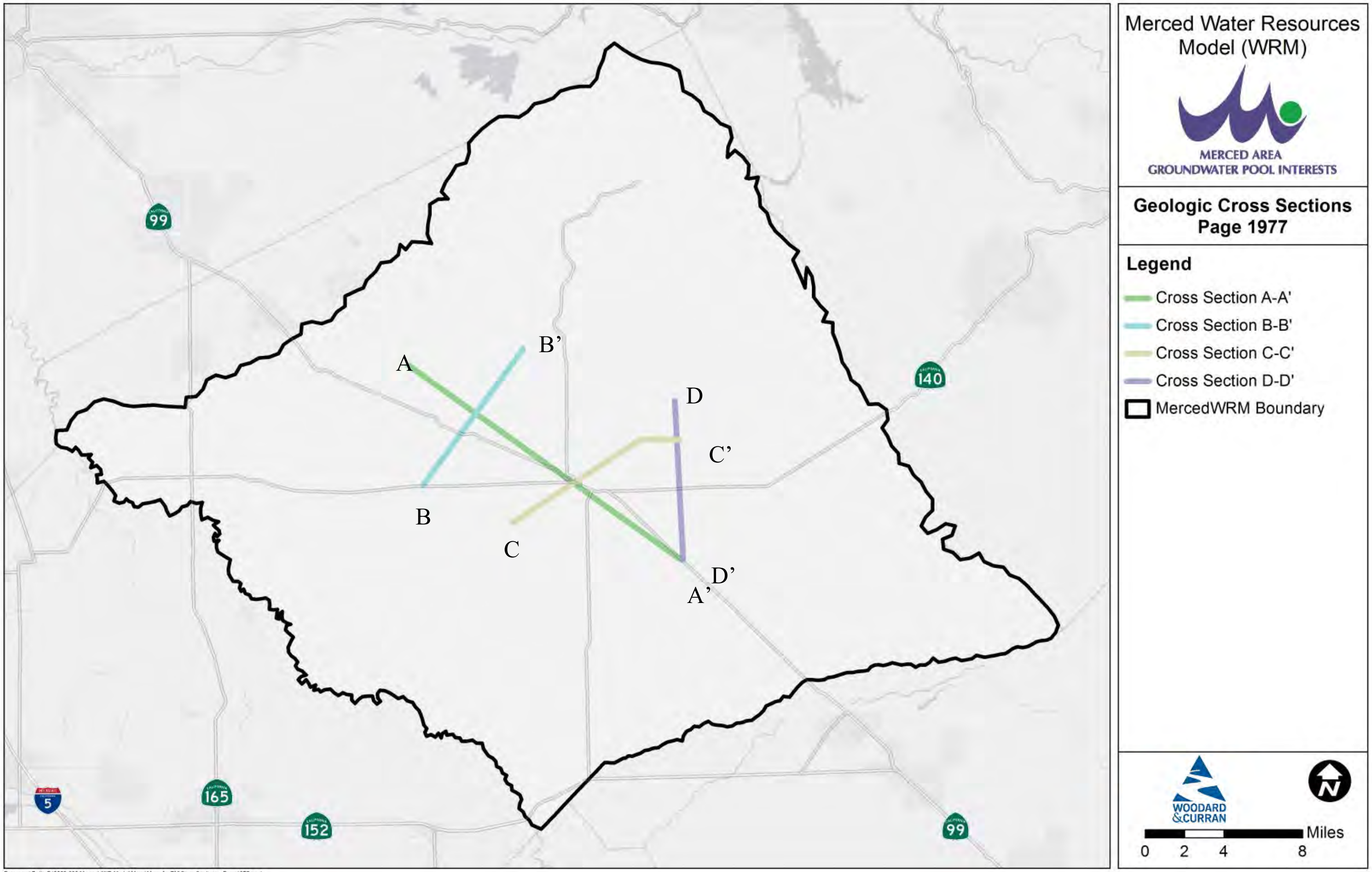


Figure 18: Location of Geologic Cross Sections - Page 1977

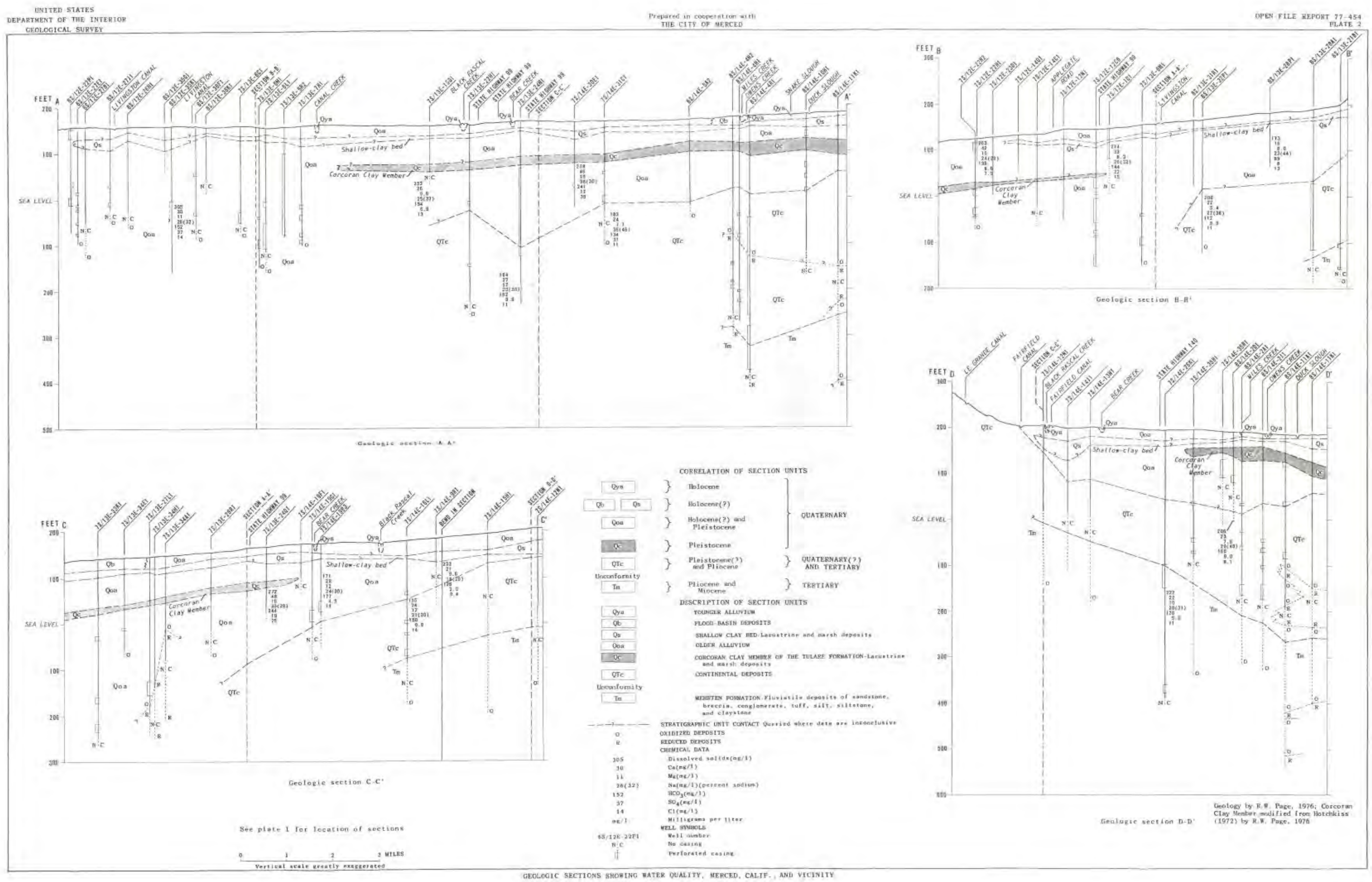


Figure 19: Referenced Cross Sections from Page 1977

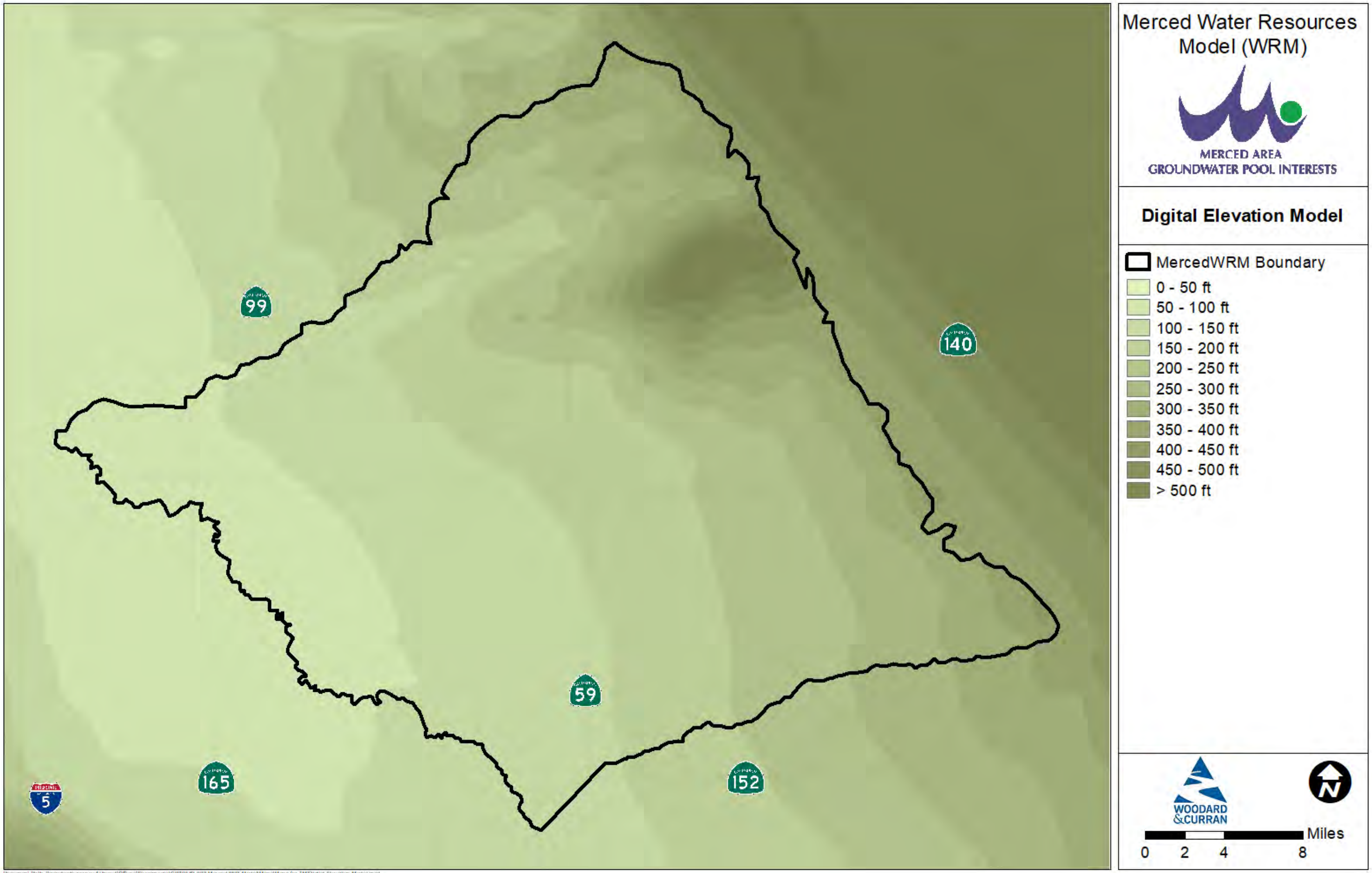


Figure 20: USGS Digital Elevation Model

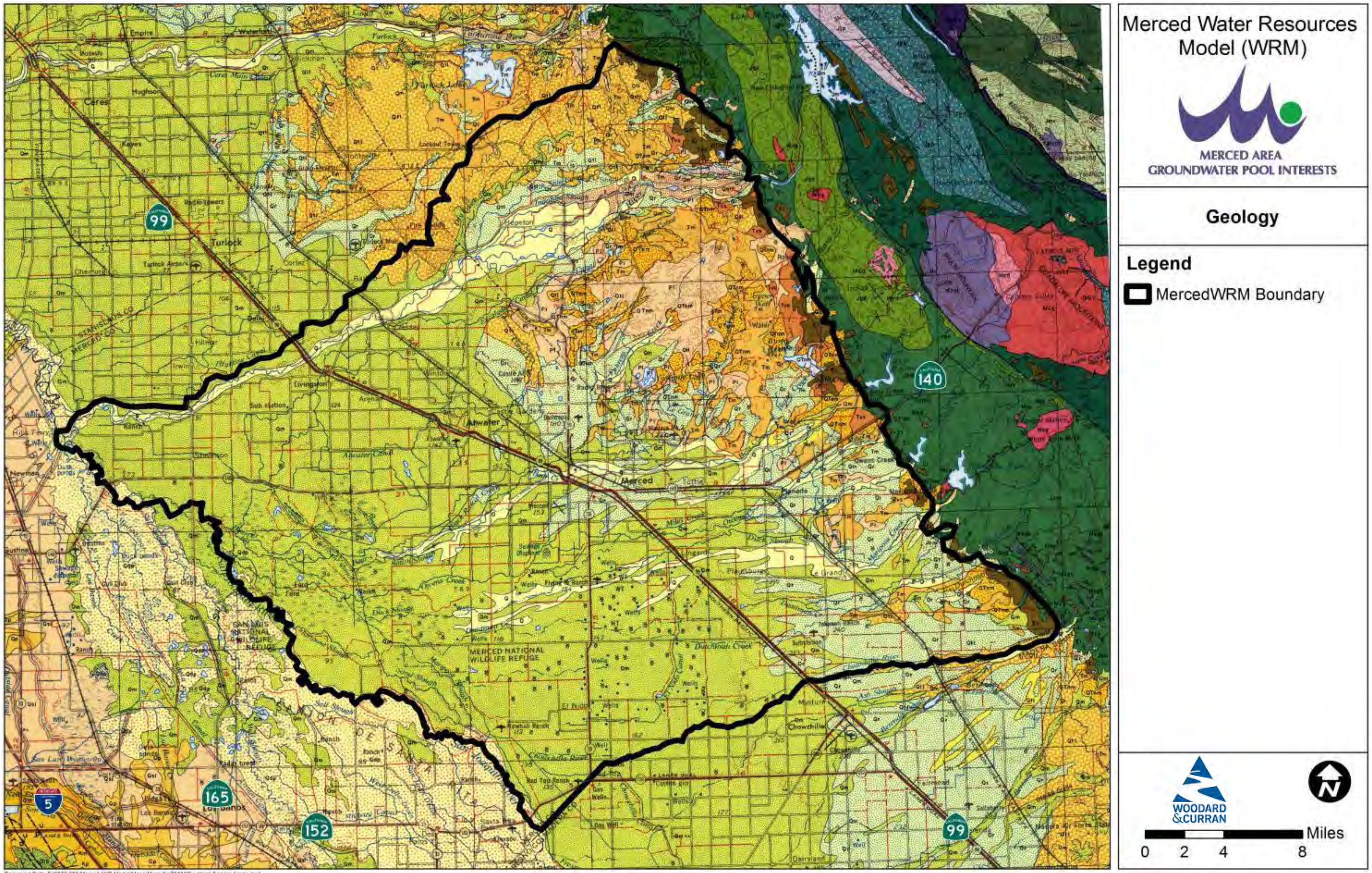


Figure 21: Surficial Geology - Wagner, Bortugno, and McJunkin (1991)

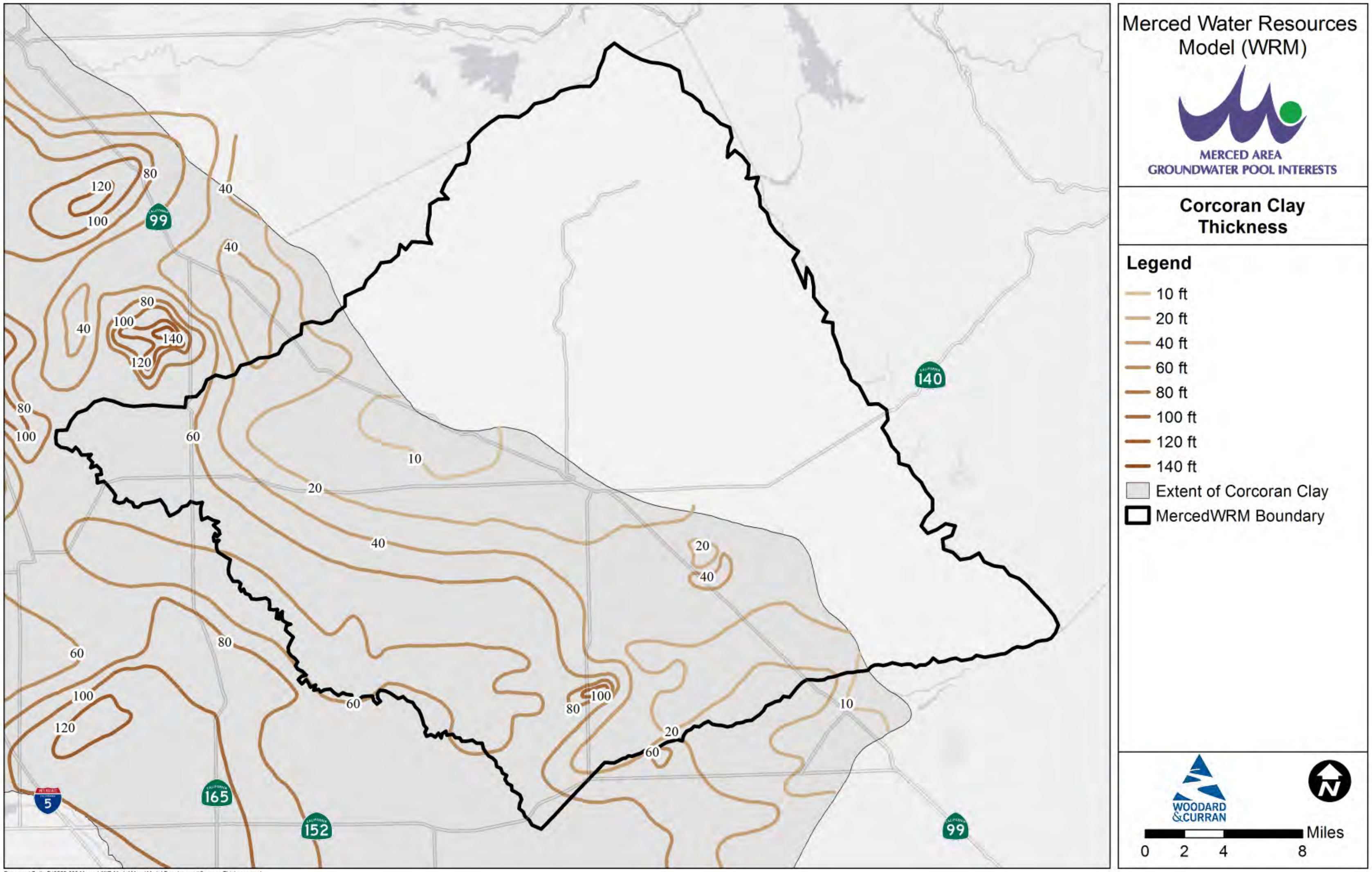


Figure 22: Corcoran Clay Thickness

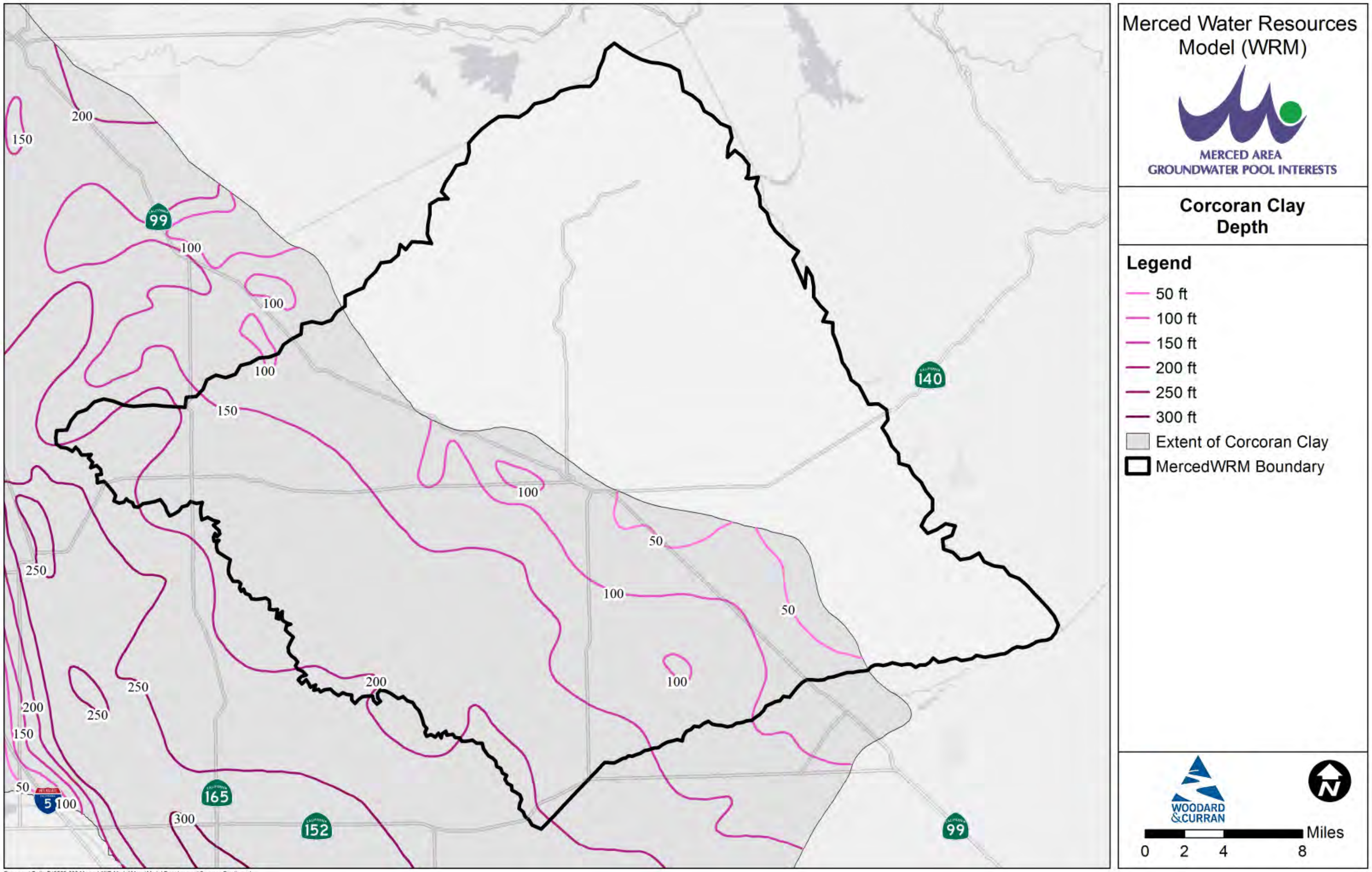


Figure 23: Corcoran Clay Depth

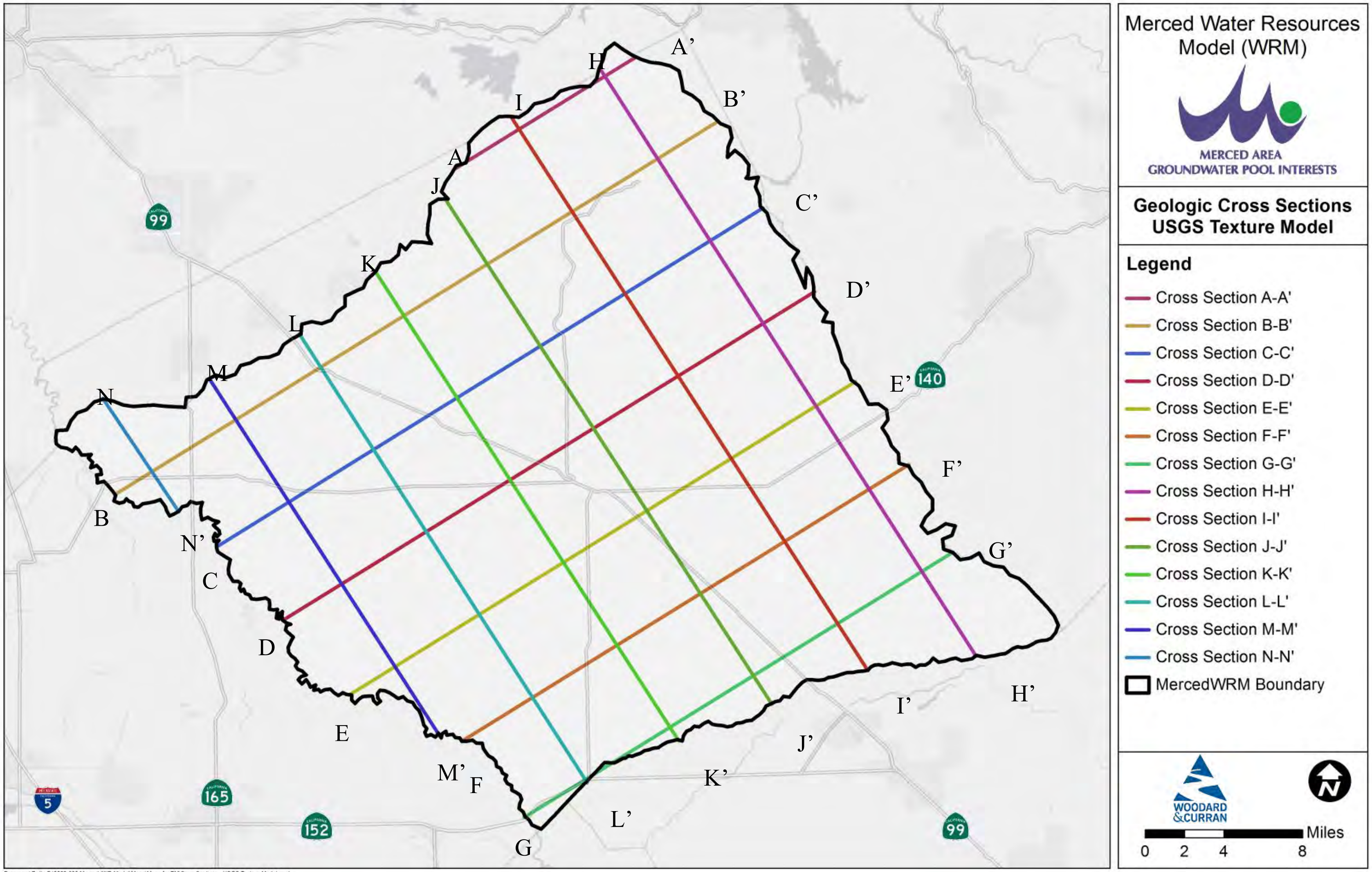


Figure 24: Location of Finalized Geologic Cross Sections

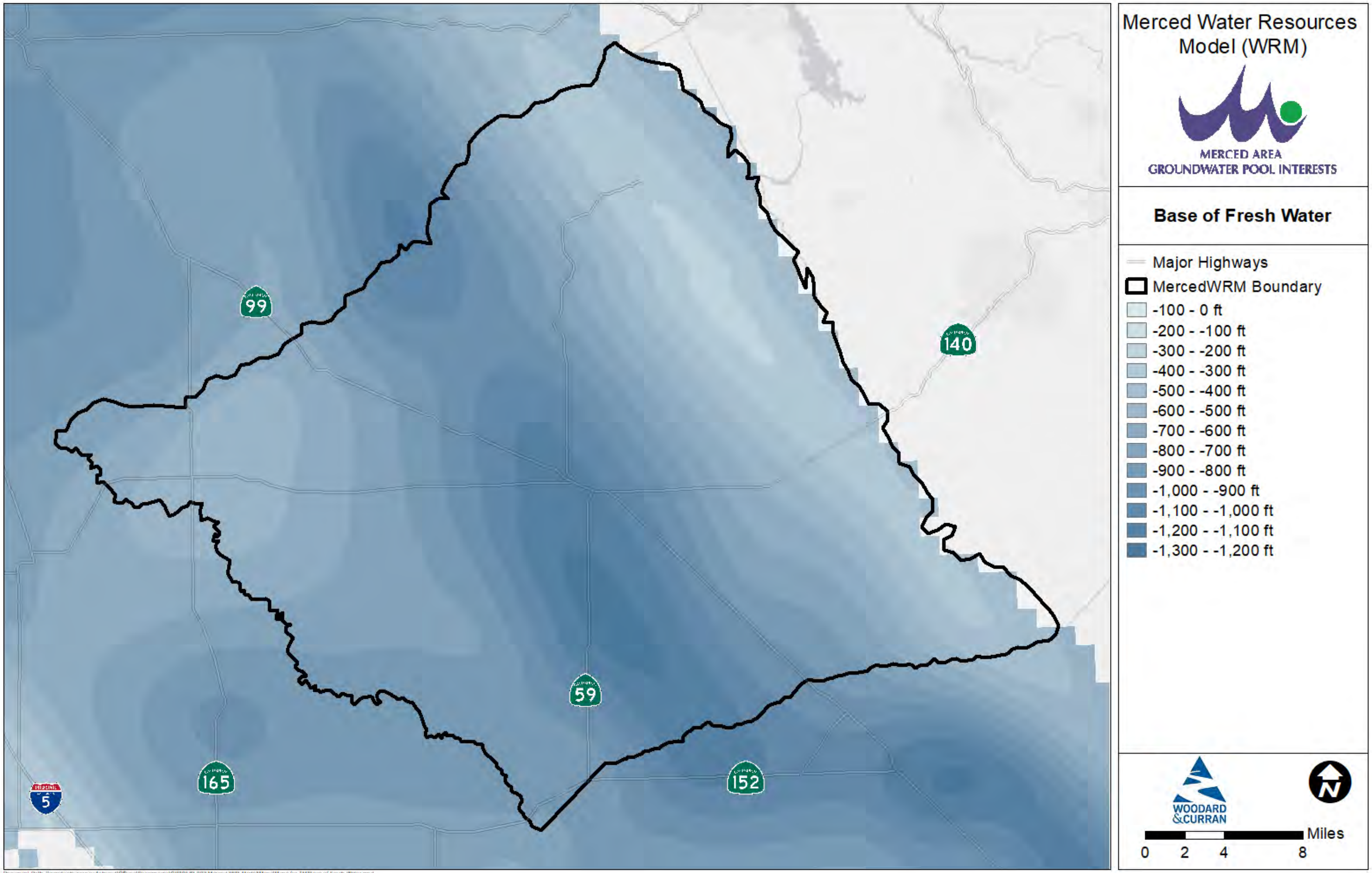


Figure 25: C2VSim Base of Fresh Water

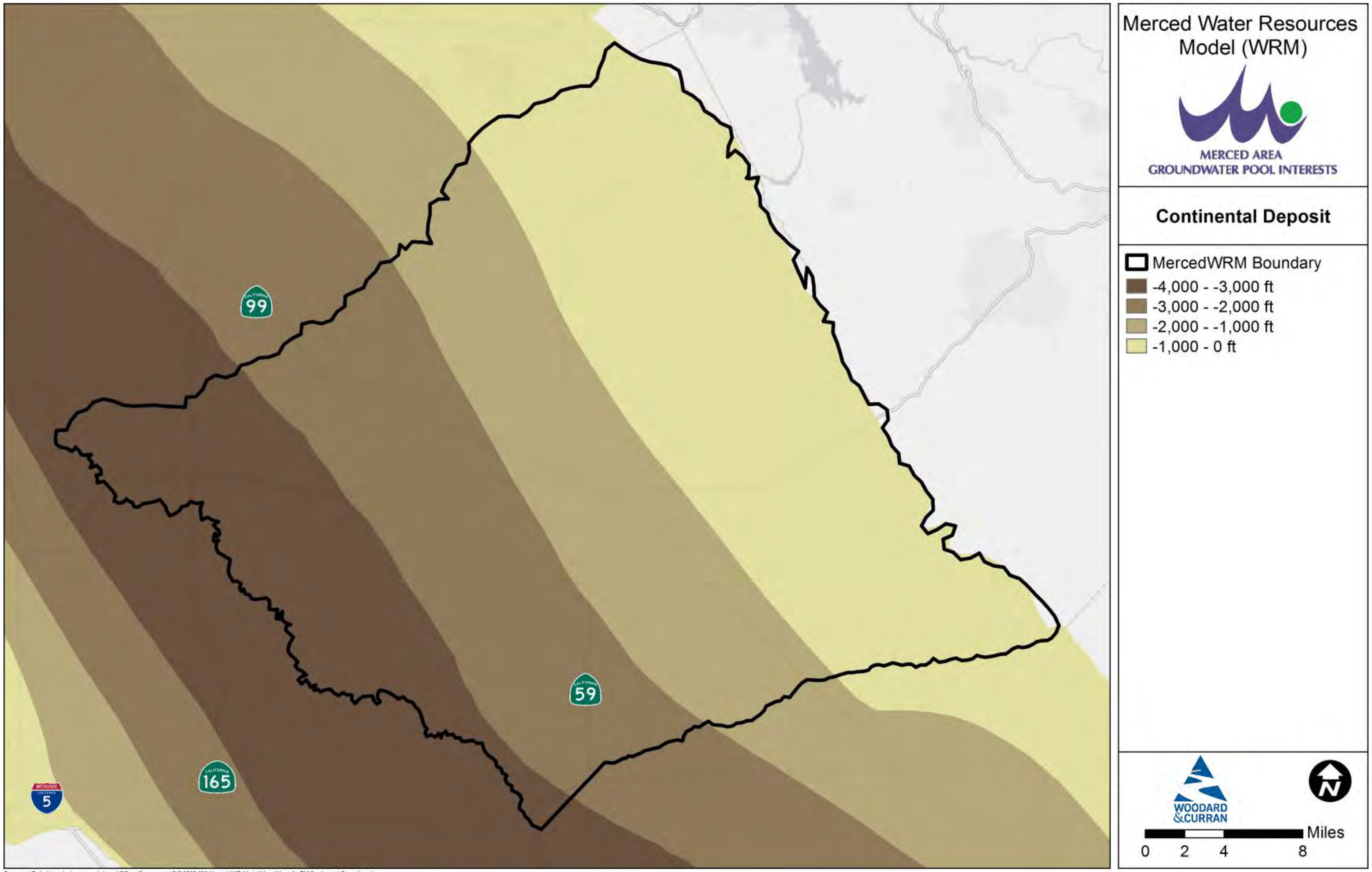


Figure 26: Continental Deposit

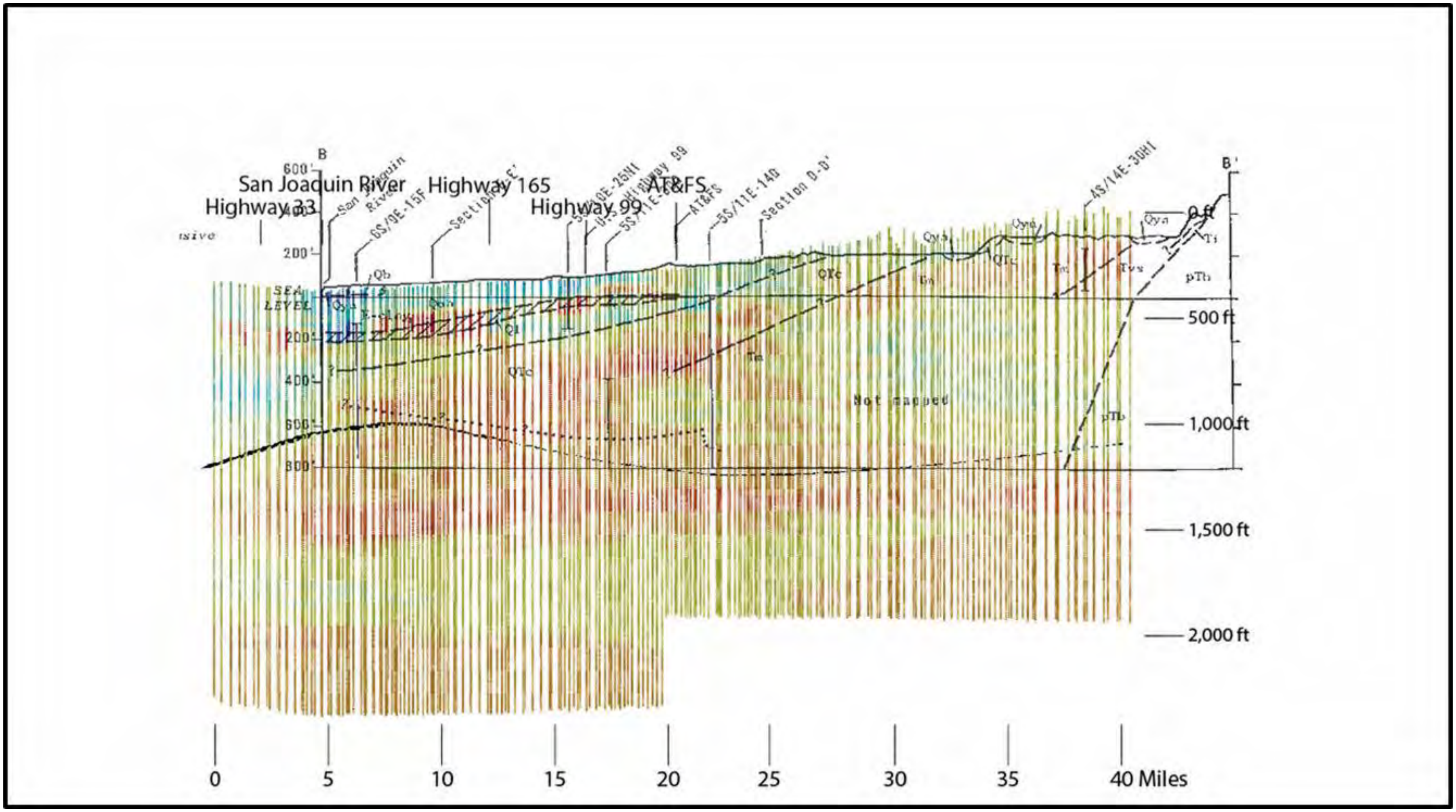


Figure 27: Page and Balding Cross Section B-B' Overlaying the USGS Texture Model Cross Section A-A'

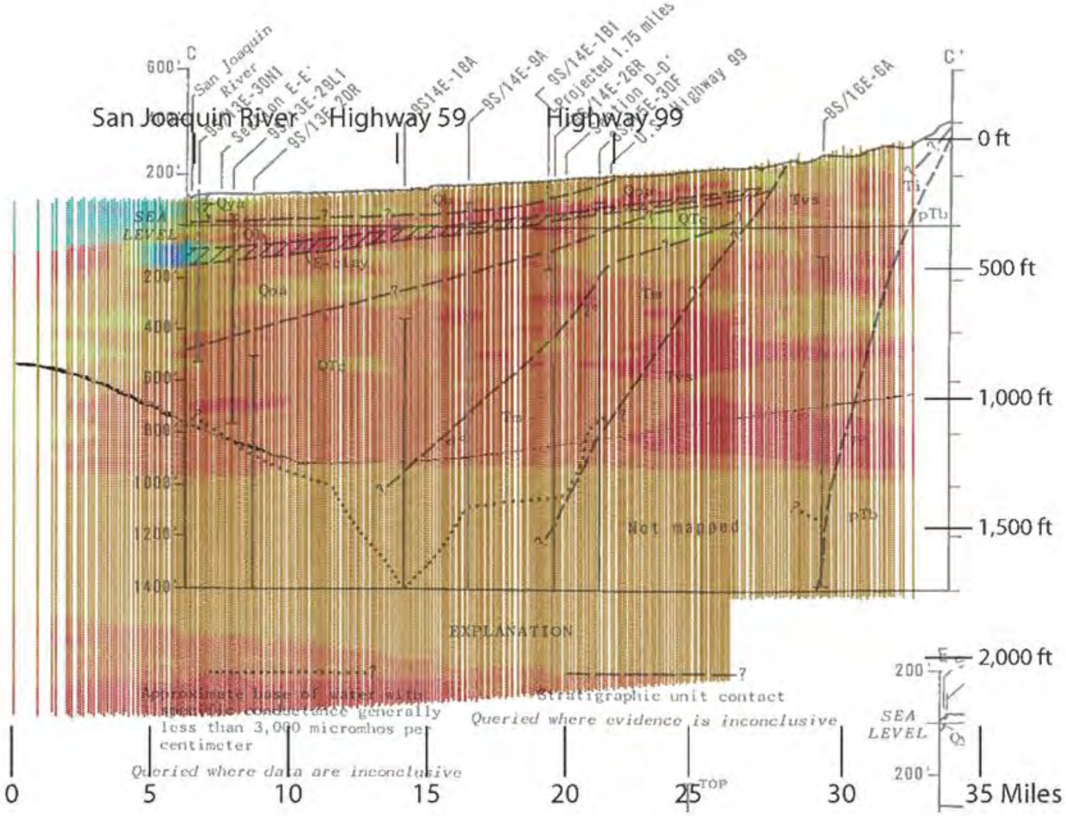


Figure 28: Page and Balding Cross Section C-C' Overlaying the USGS Texture Model Cross Section F-F'

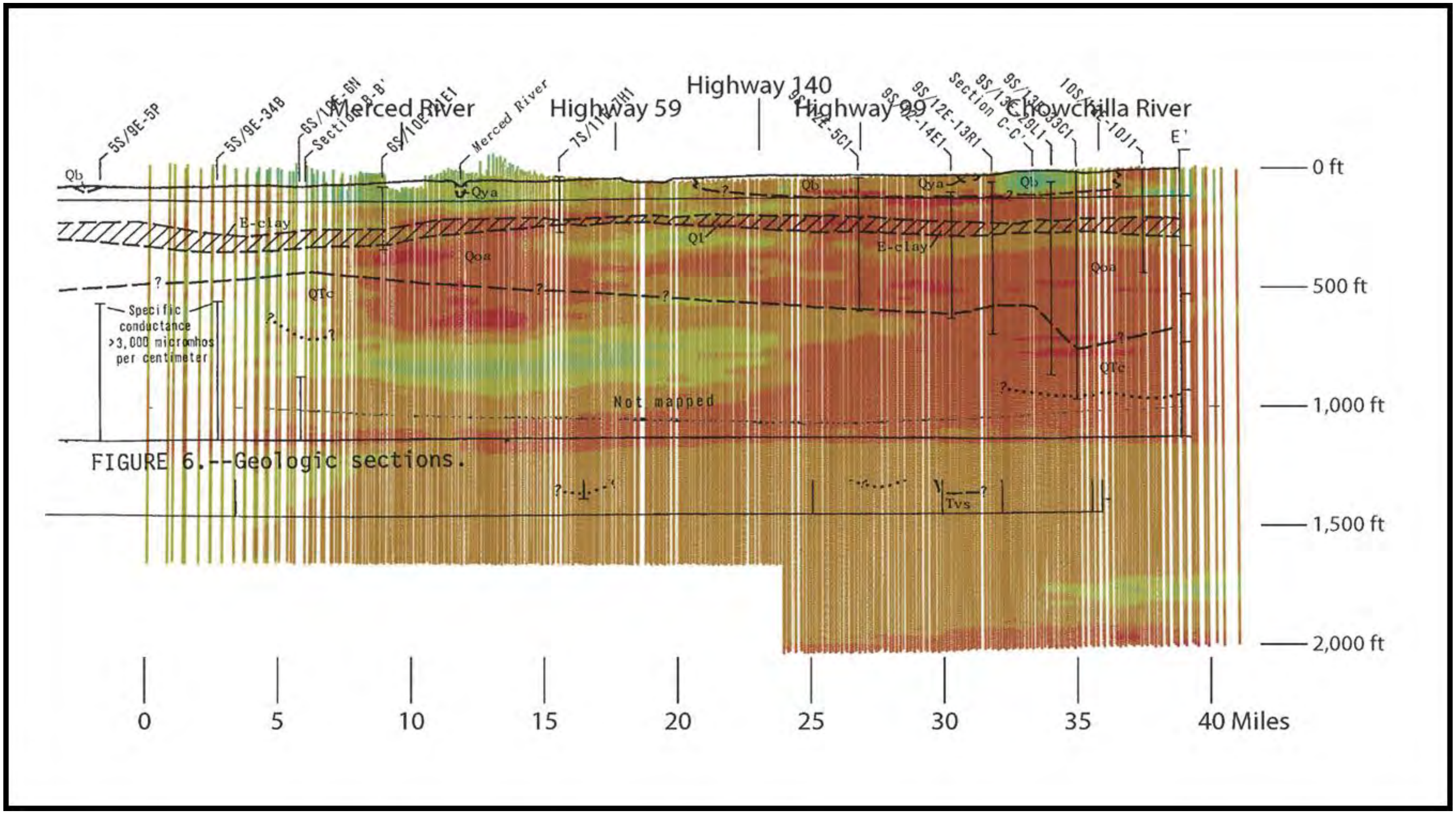


Figure 29: Page and Balding Cross Section D-D' Overlaying the USGS Texture Model Cross Section J-J'

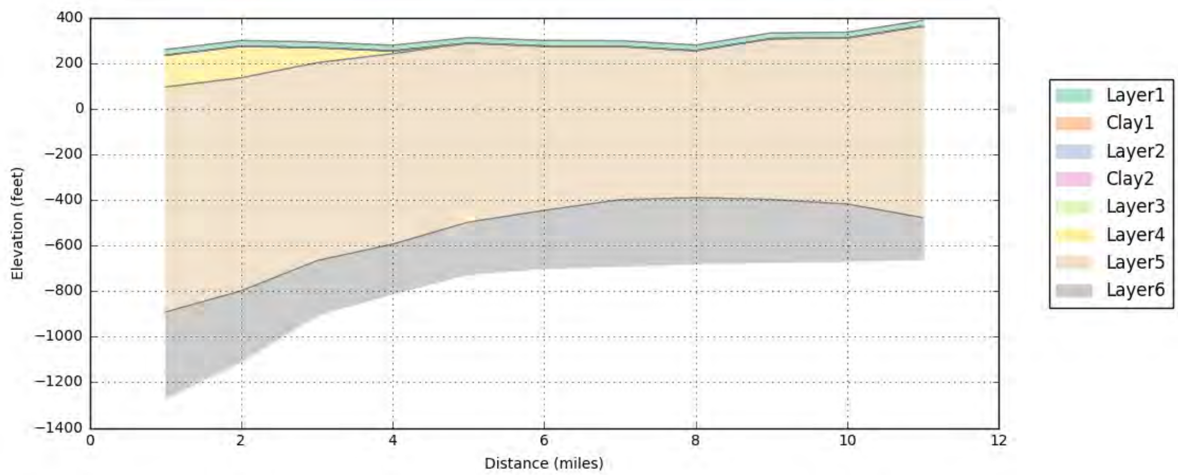


Figure 30: MercedWRM Geologic Cross Section A-A'

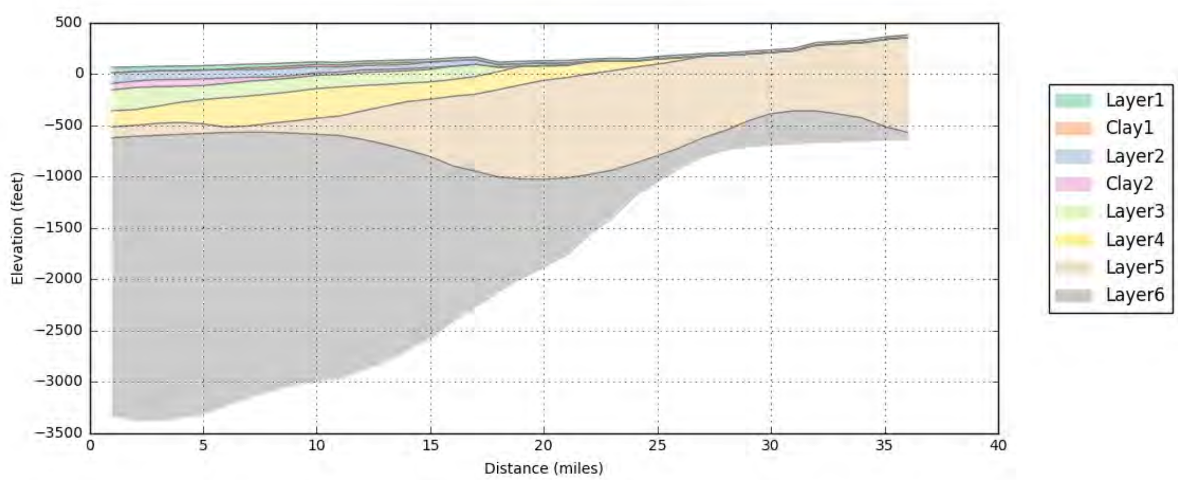


Figure 31: MercedWRM Geologic Cross Section B-B'

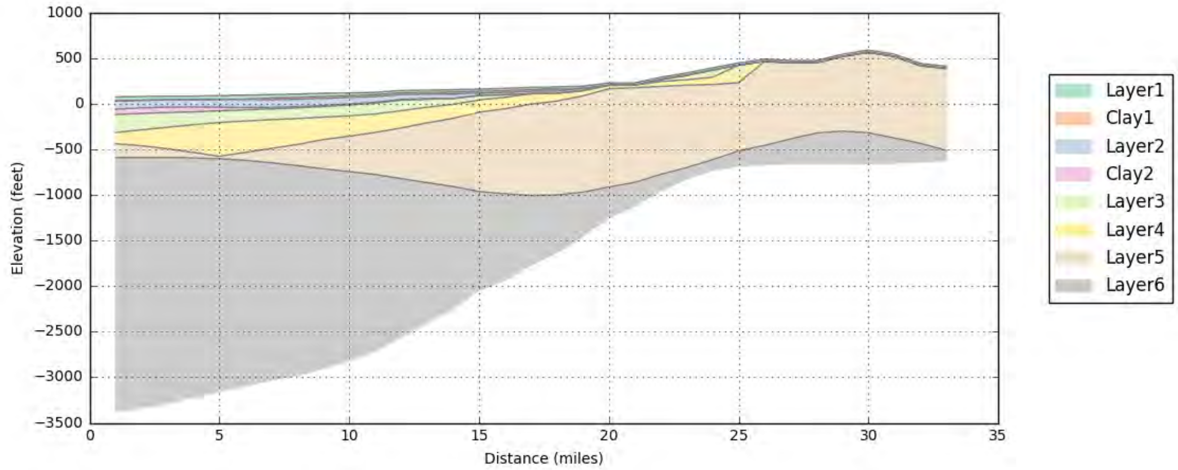


Figure 32: MercedWRM Geologic Cross Section C-C'

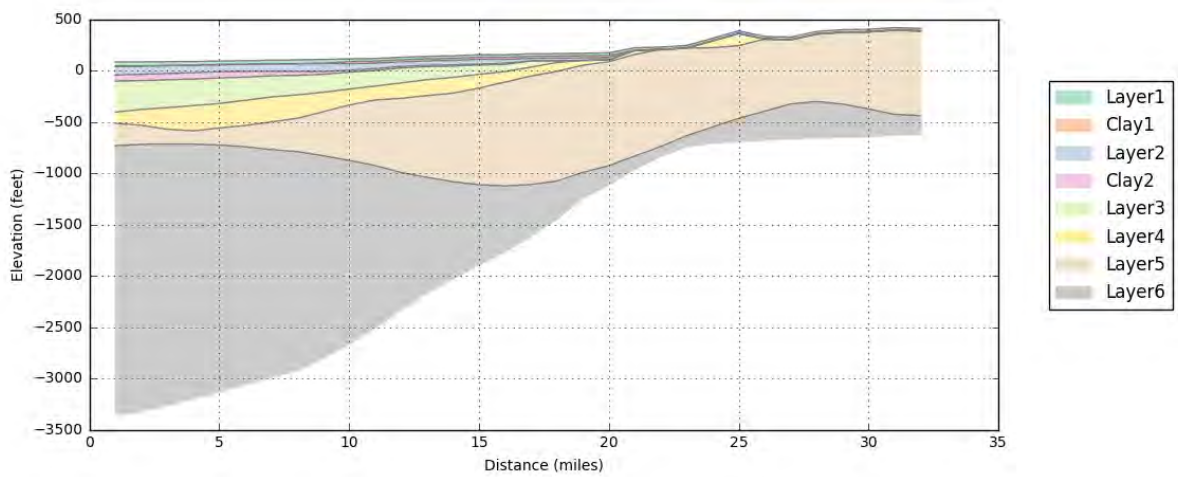


Figure 33: MercedWRM Geologic Cross Section D-D'

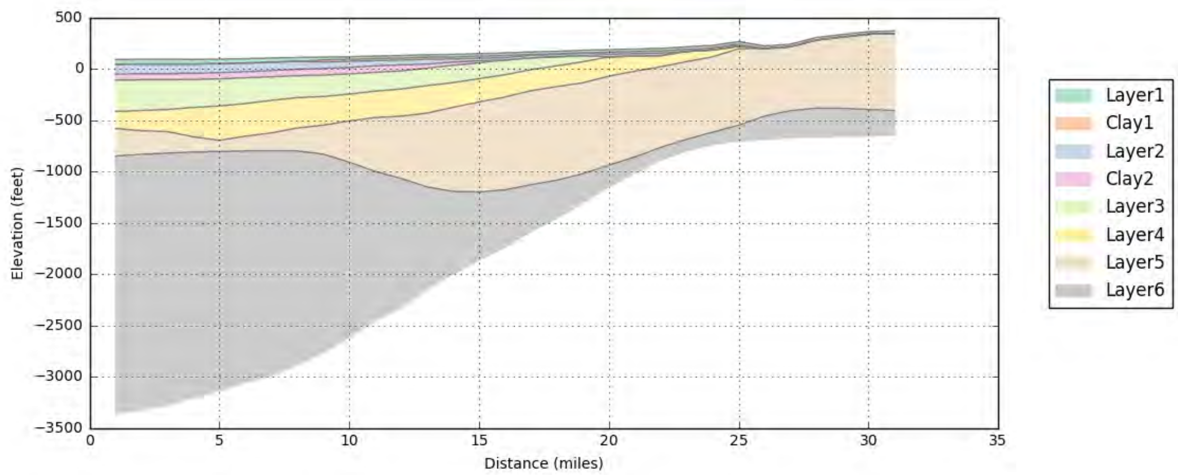


Figure 34: MercedWRM Geologic Cross Section E-E'

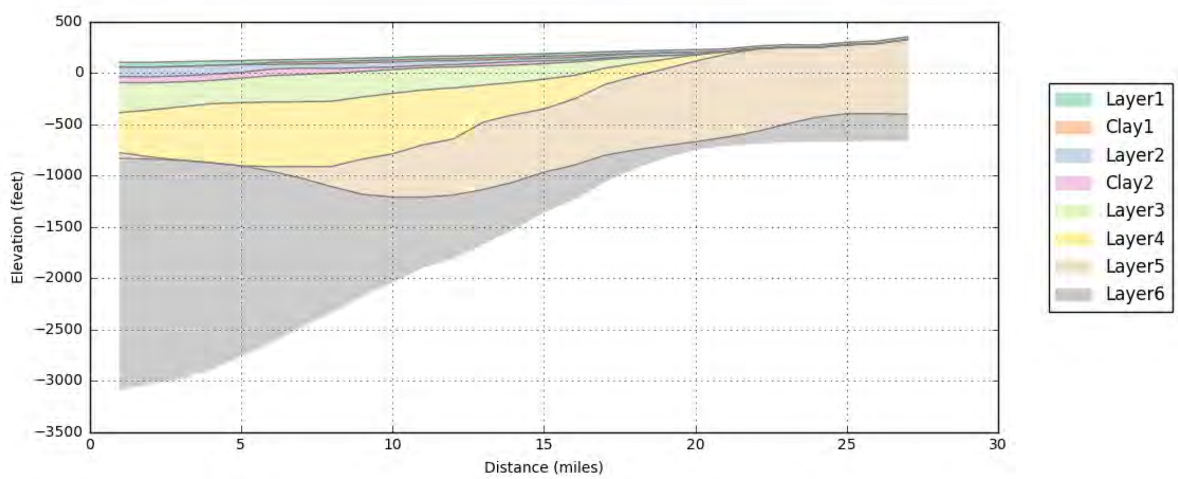


Figure 35: MercedWRM Geologic Cross Section F-F'

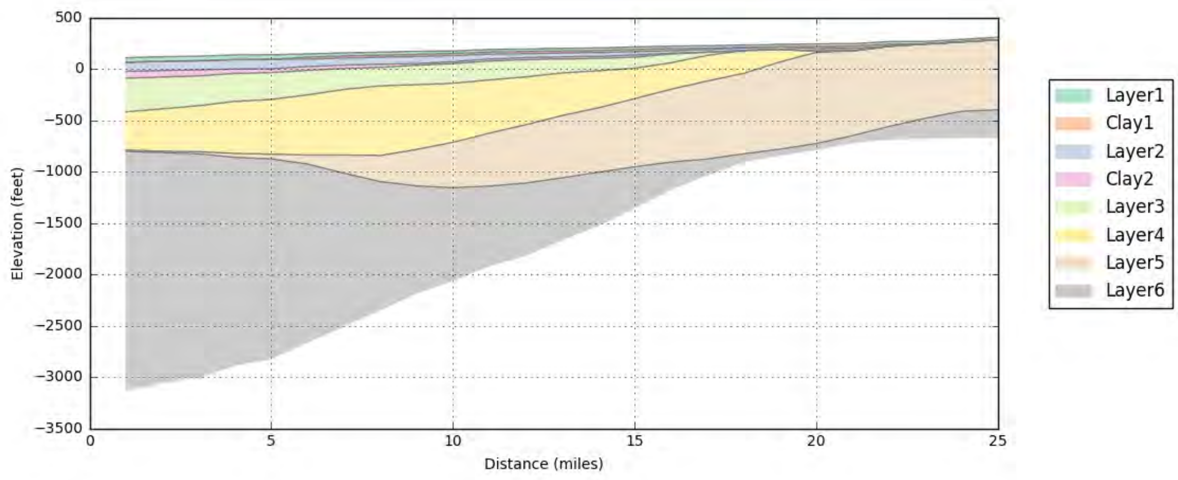


Figure 36: MercedWRM Geologic Cross Section G-G'

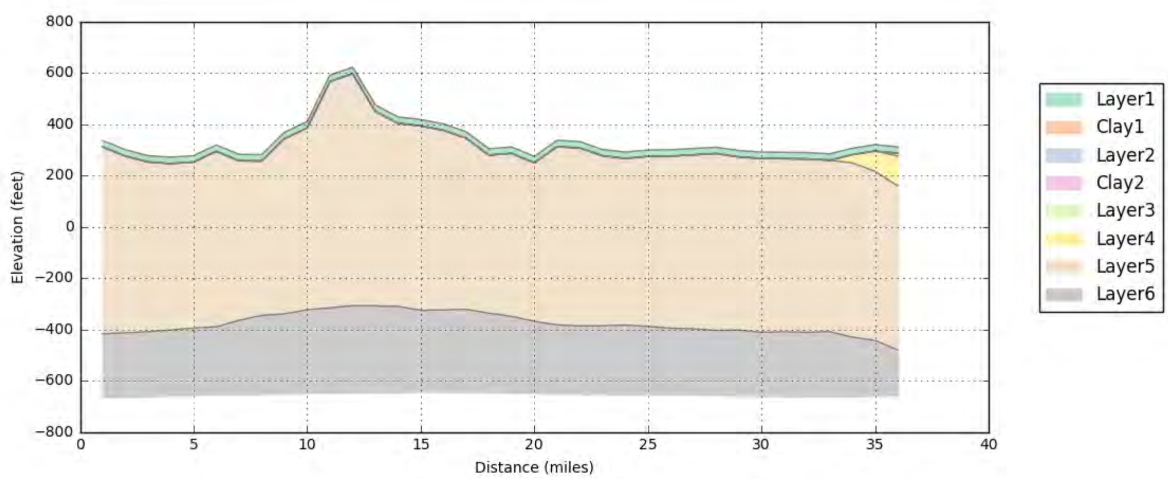


Figure 37: MercedWRM Geologic Cross Section H-H'

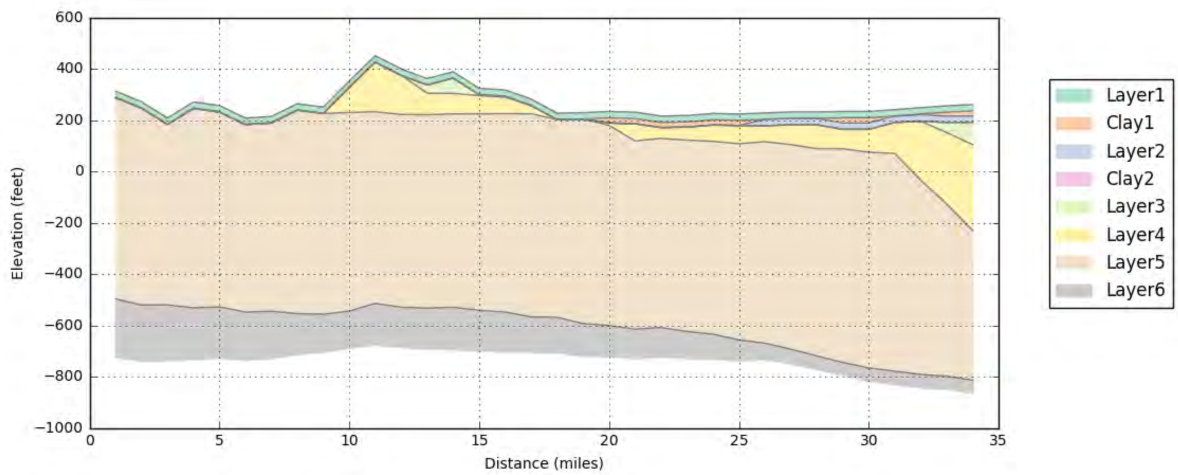


Figure 38: MercedWRM Geologic Cross Section I-I'

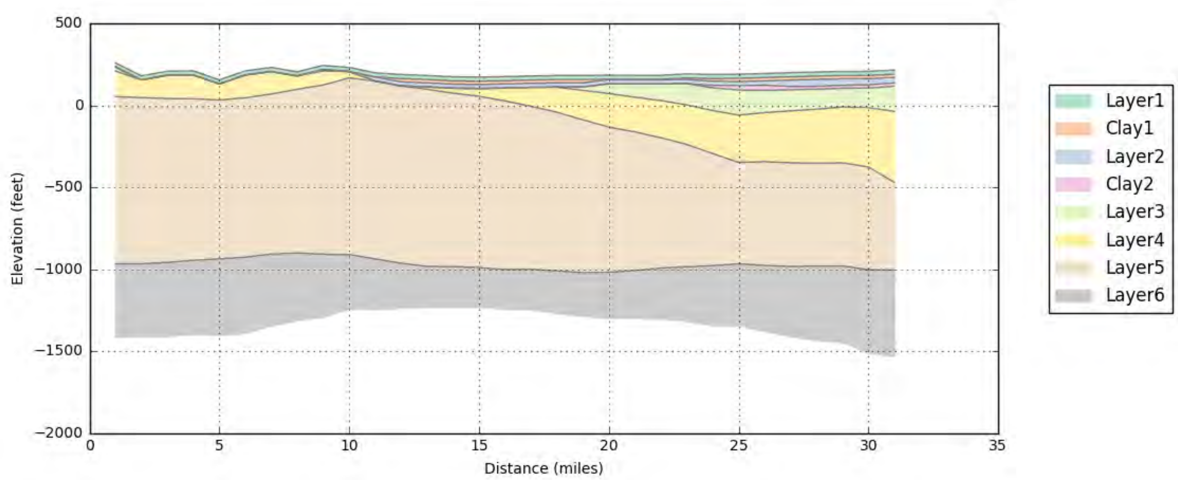


Figure 39: MercedWRM Geologic Cross Section J-J'

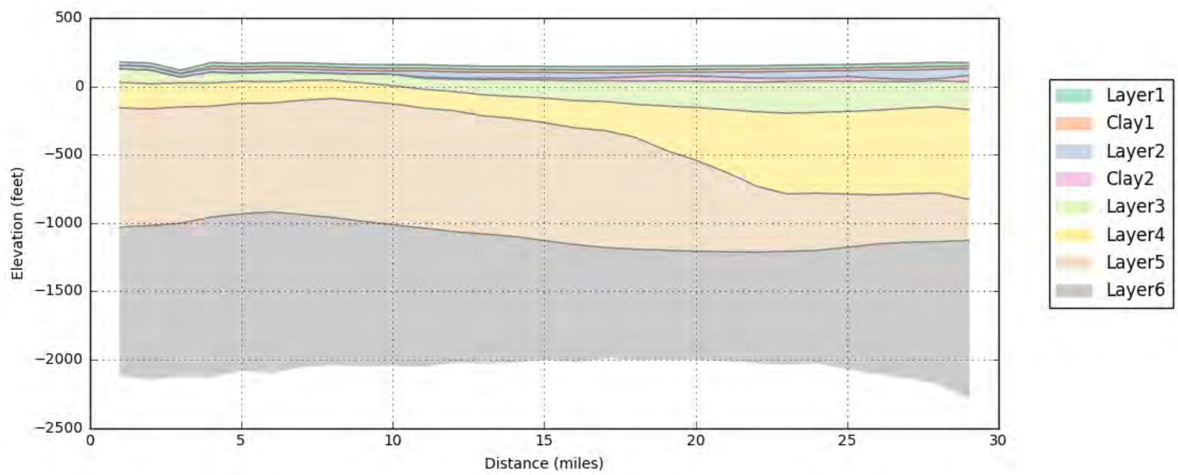


Figure 40: MercedWRM Geologic Cross Section K-K'

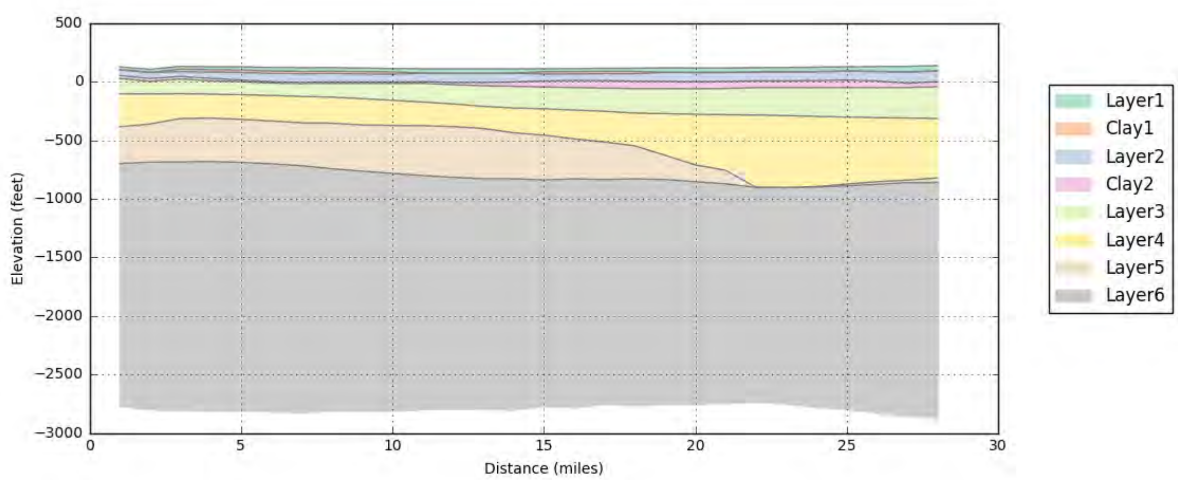


Figure 41: MercedWRM Geologic Cross Section L-L'

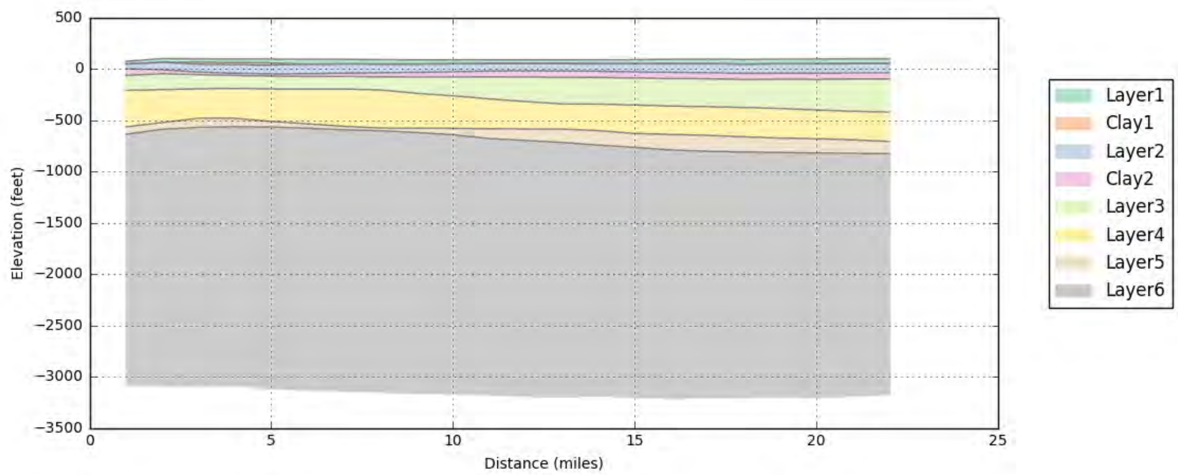


Figure 42: MercedWRM Geologic Cross Section M-M'

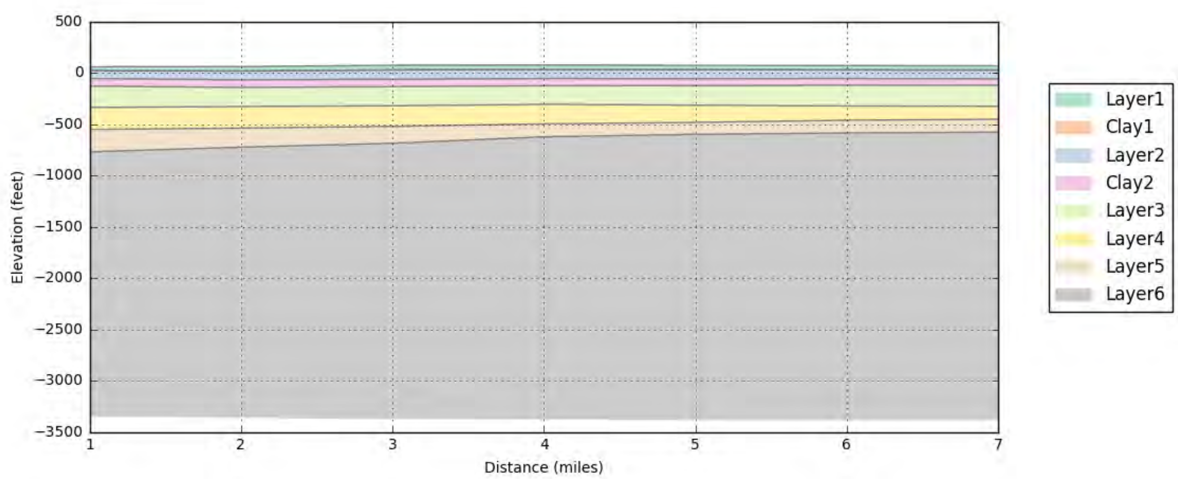


Figure 43: MercedWRM Geologic Cross Section N-N

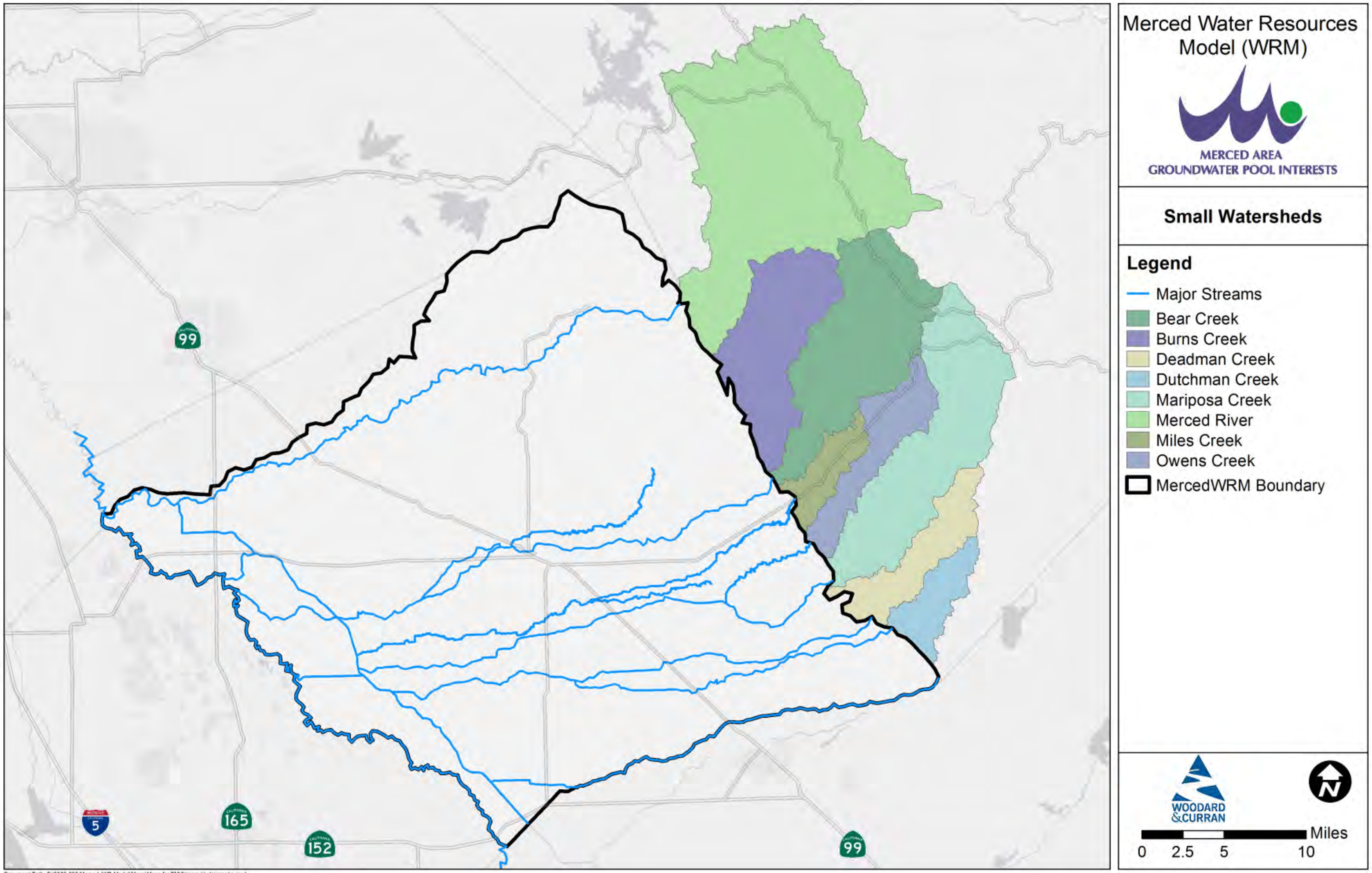


Figure 44: MercedWRM Small Watersheds

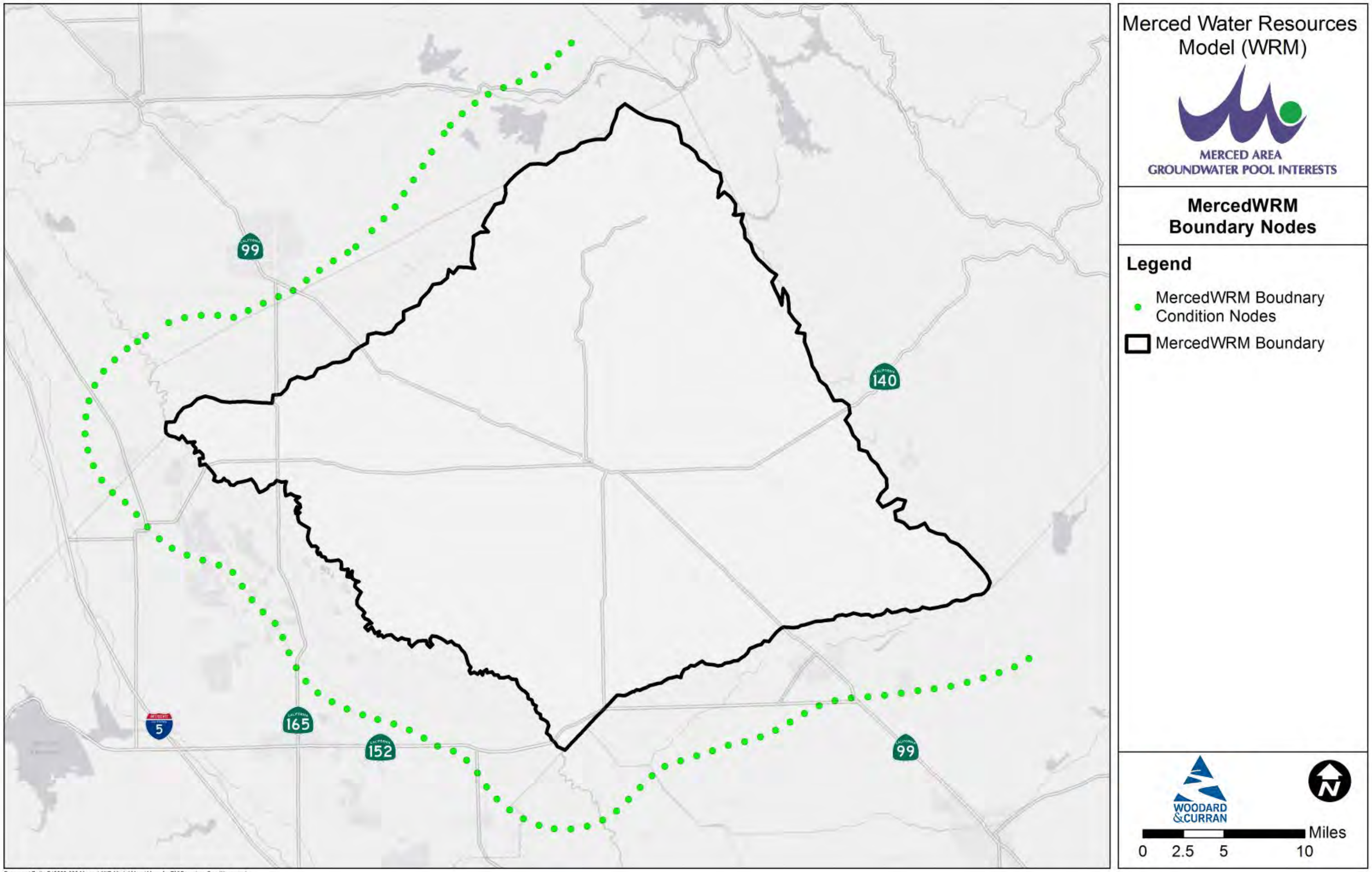


Figure 45: MercedWRM Boundary Nodes

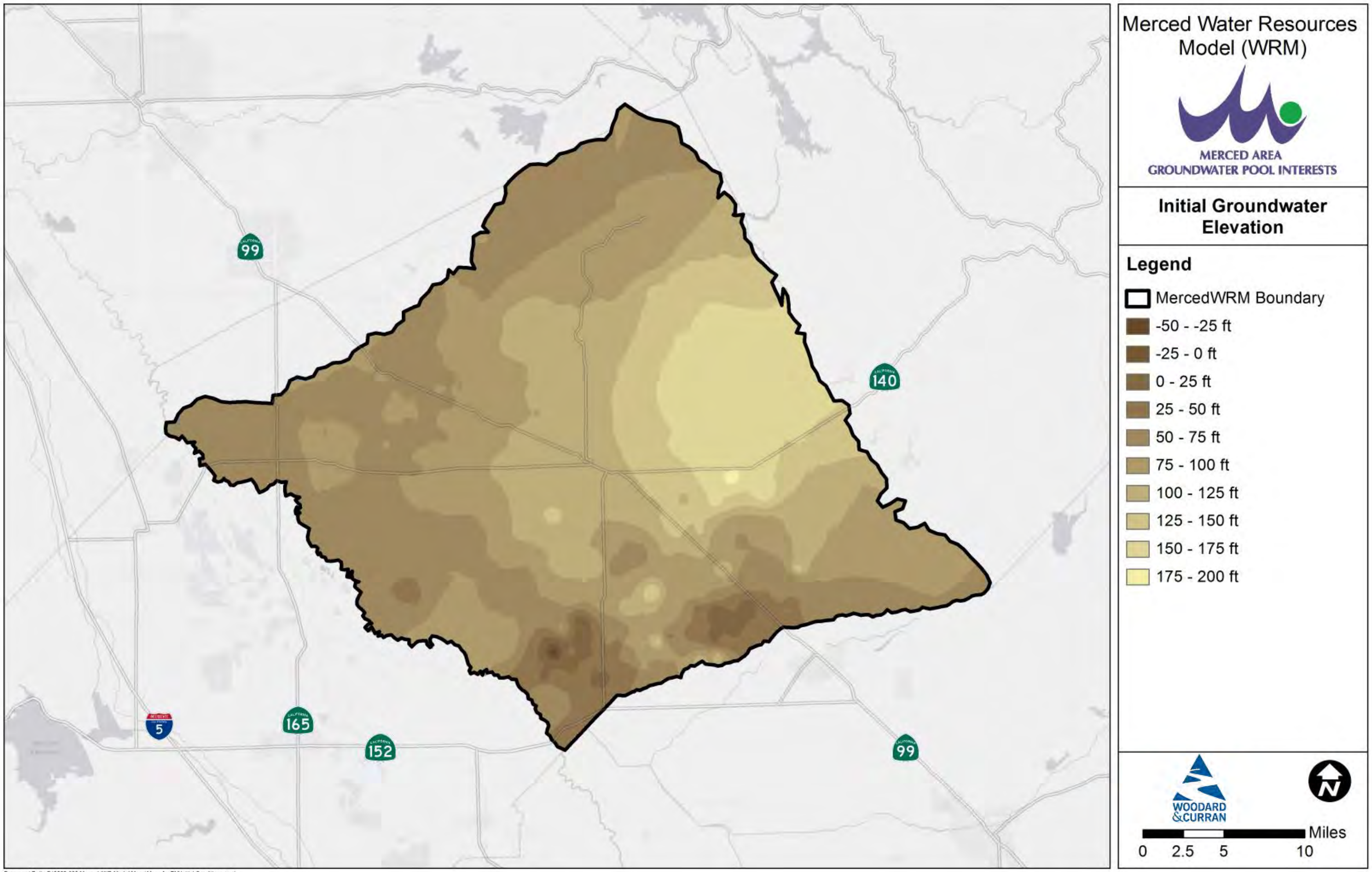


Figure 46: MercedWRM Initial Condition Groundwater Heads

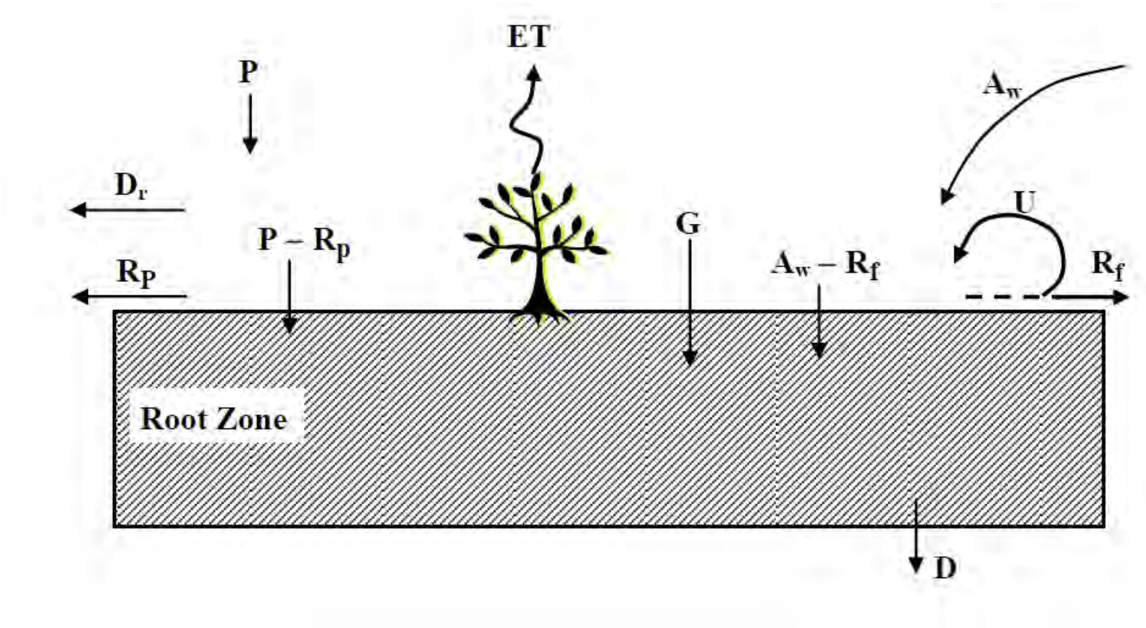


Figure 47: Schematic representation of root zone flow processes simulated by the IDC

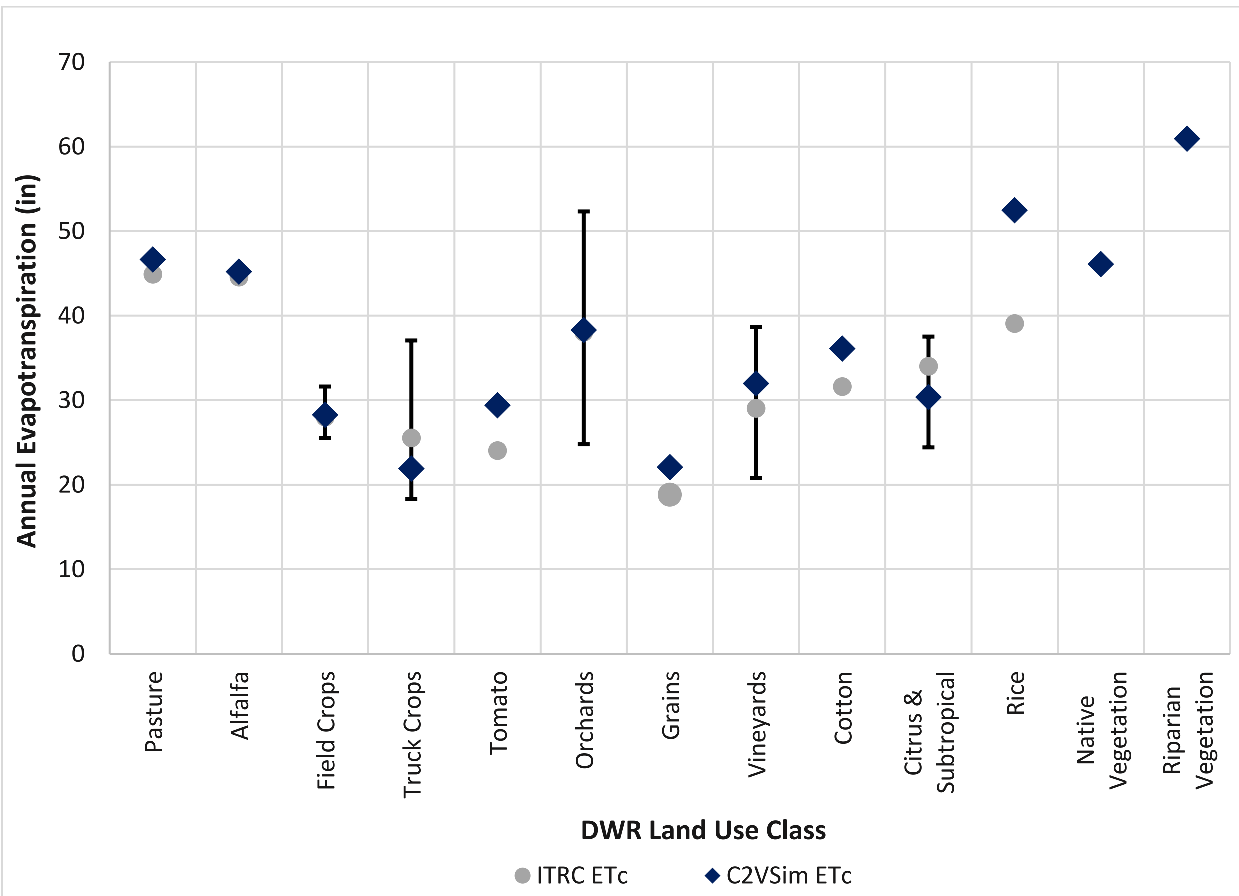


Figure 48: IWFM Demand Calculator Reference Potential Evapotranspiration

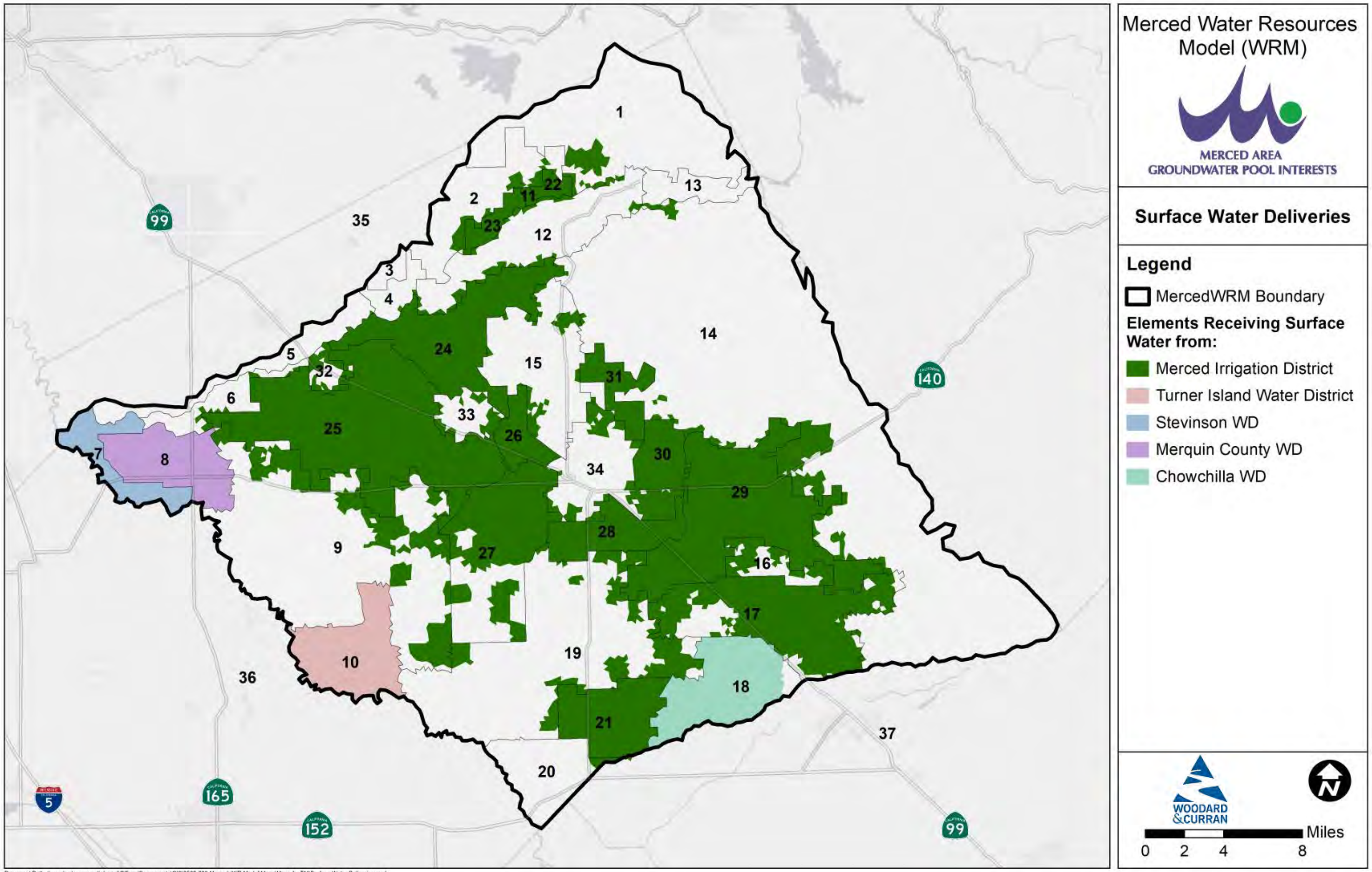


Figure 49: MercedWRM Surface Water Delivery Zones

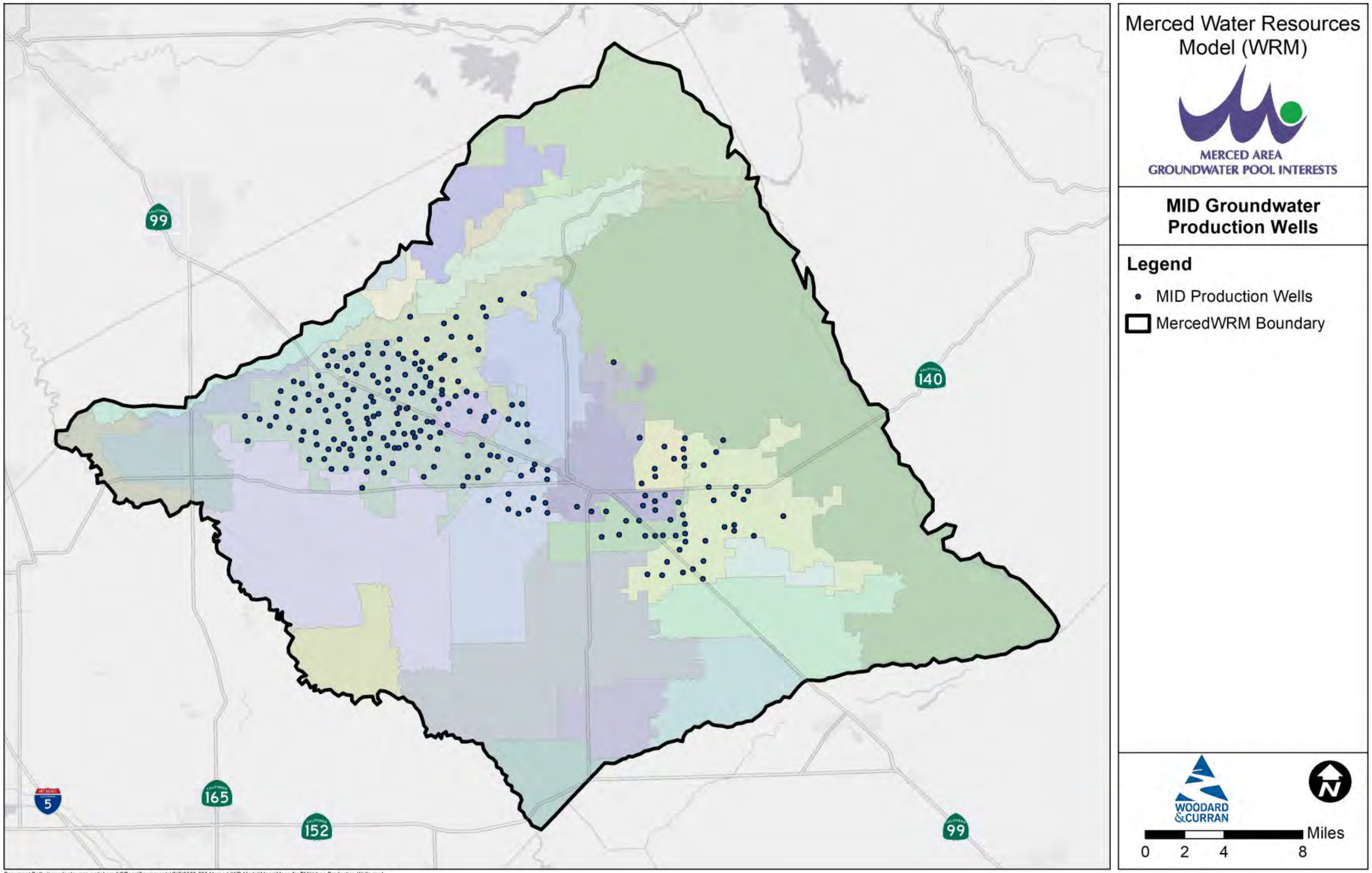


Figure 50: MID Groundwater Production Wells

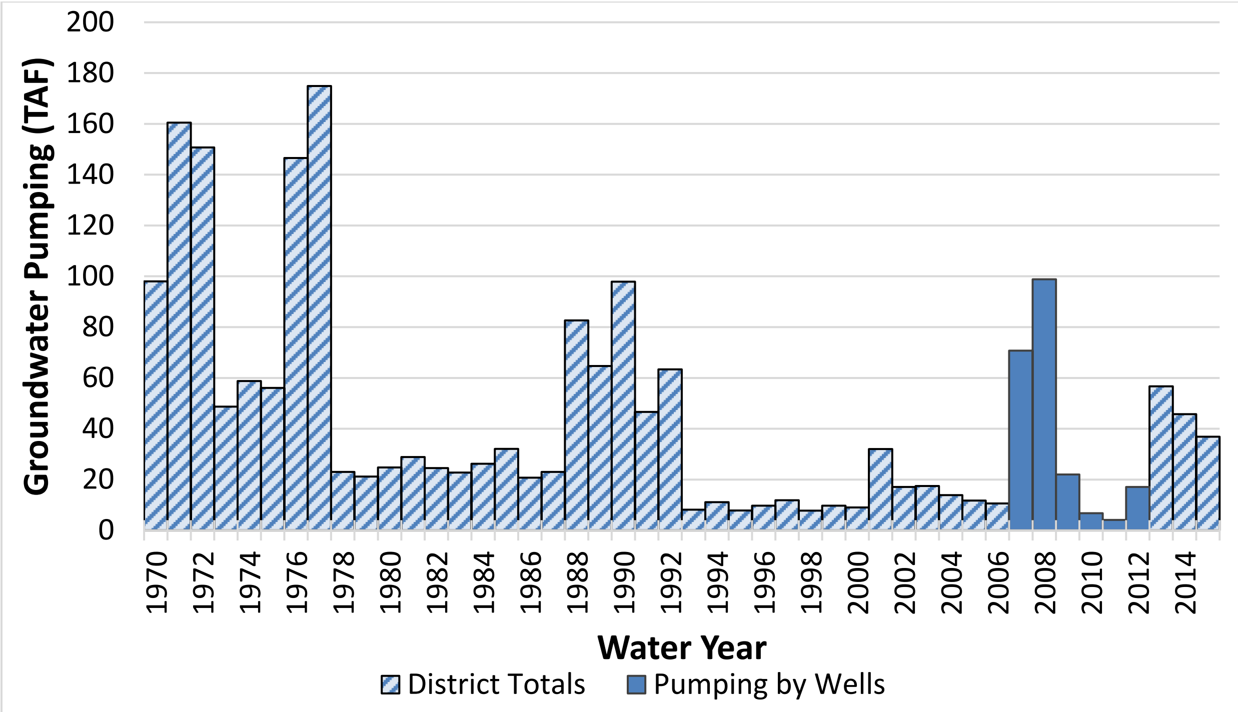


Figure 51: Merced Irrigation District Annual Groundwater Pumping

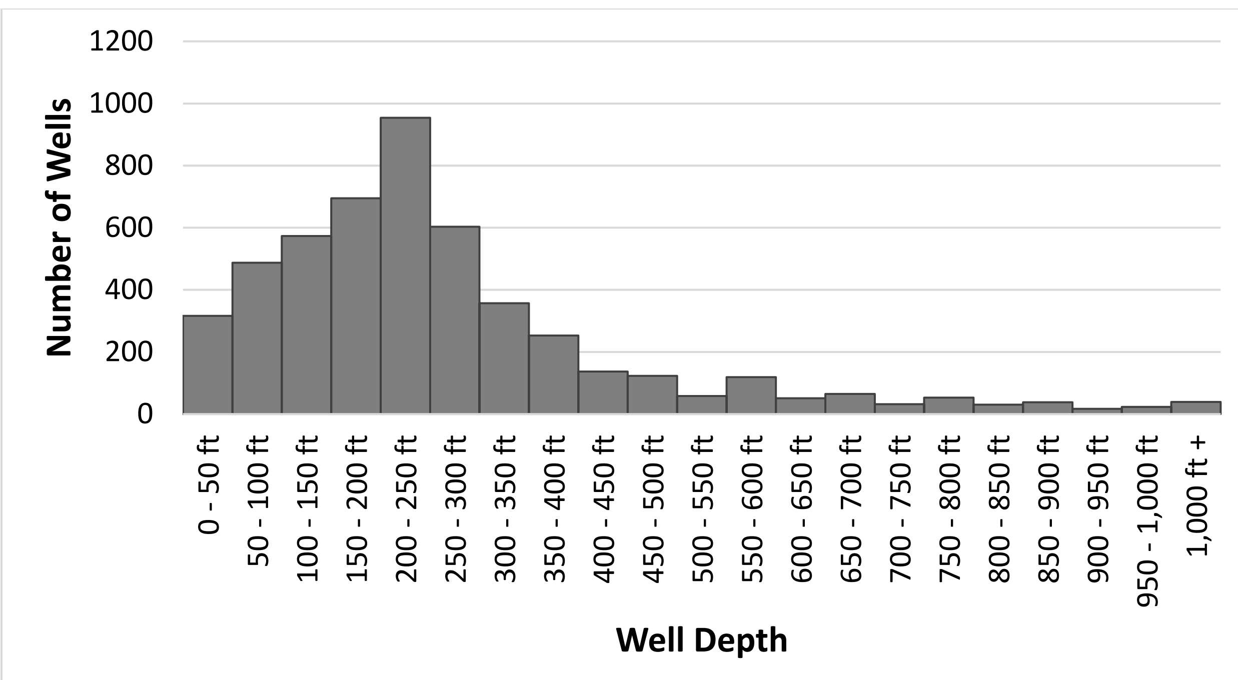


Figure 52: Merced County Database Groundwater Well Depth

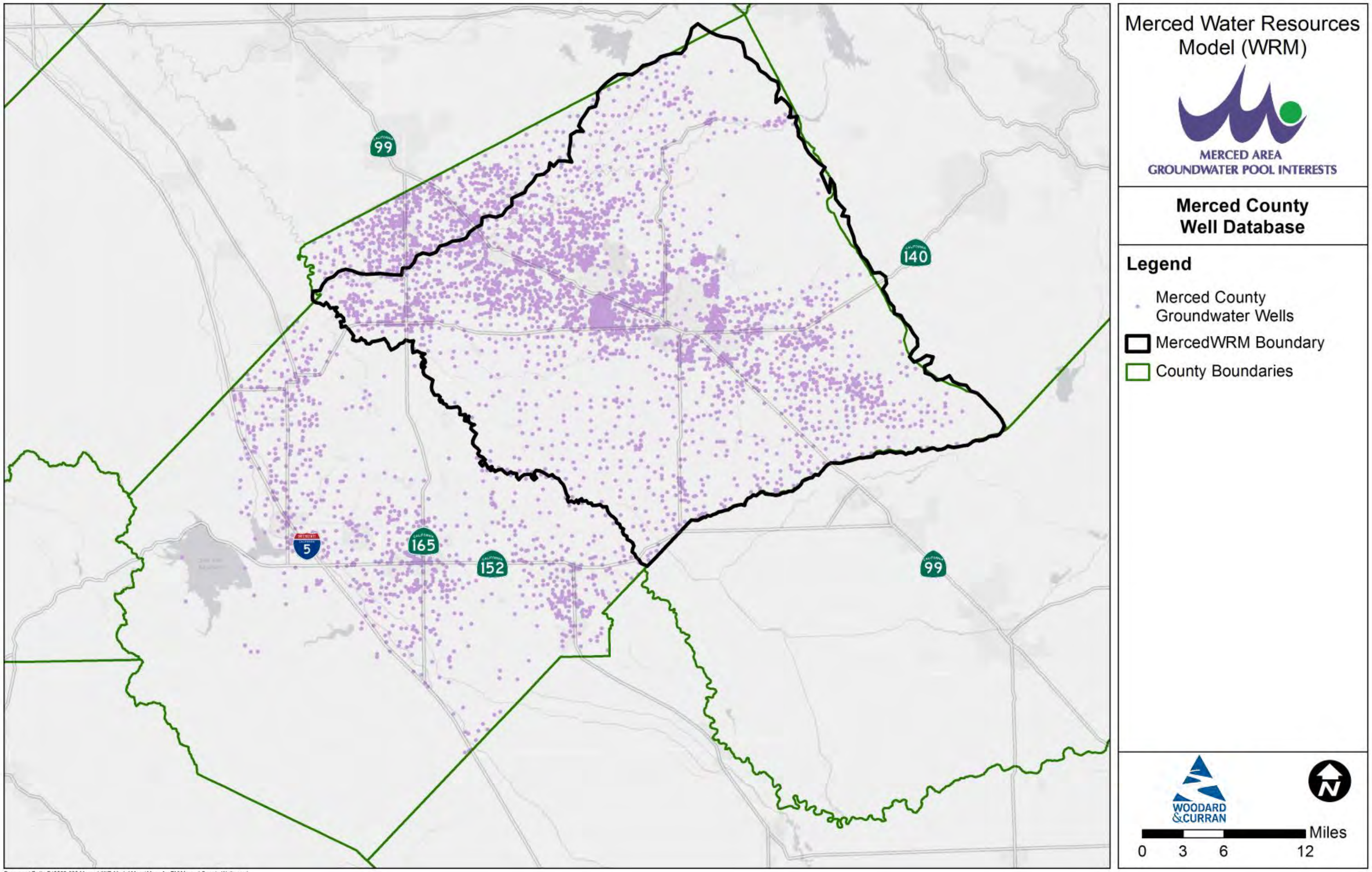


Figure 53: Merced County Groundwater Well Database

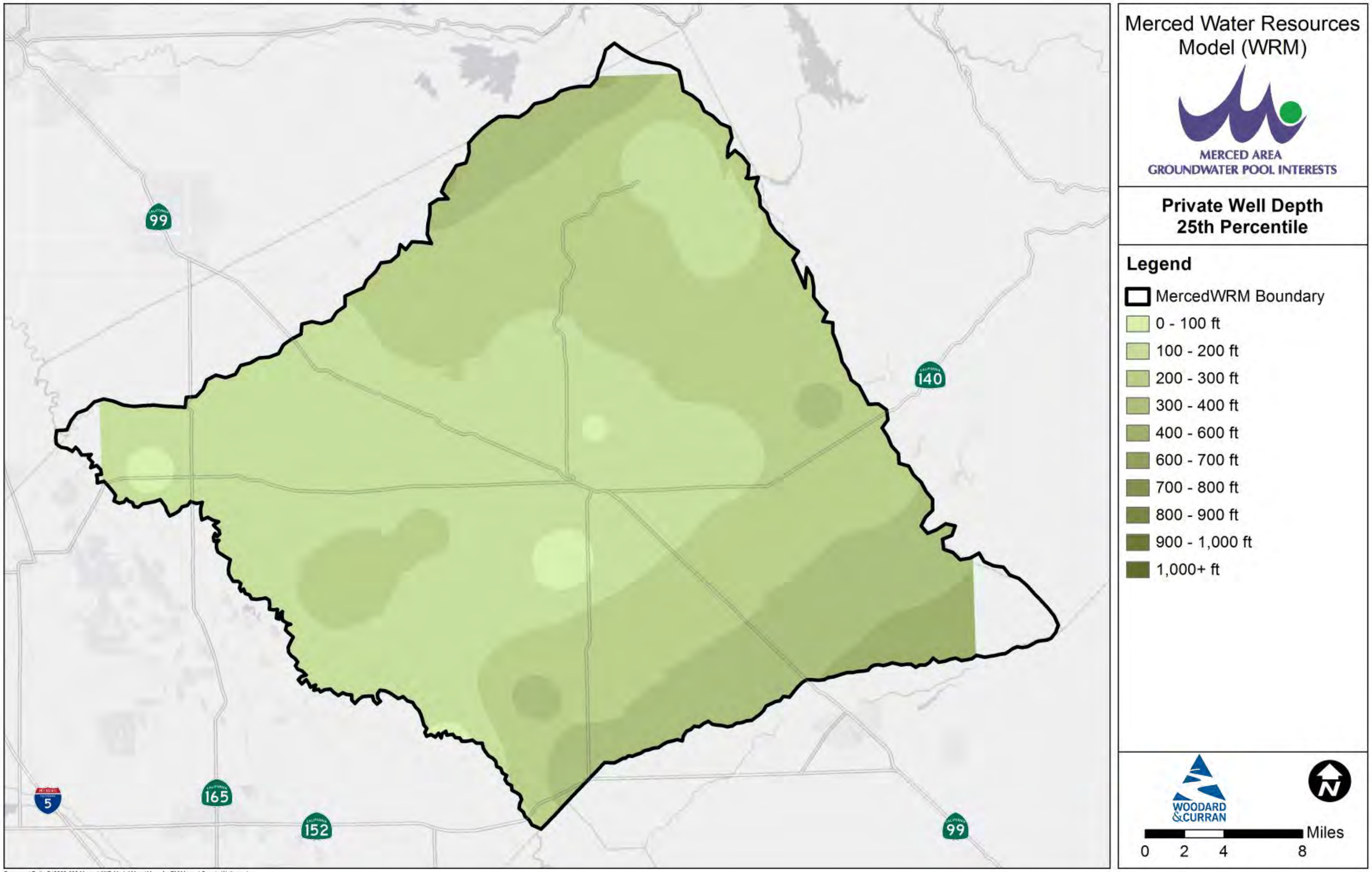


Figure 54: Private Well Depths - 25th Percentile

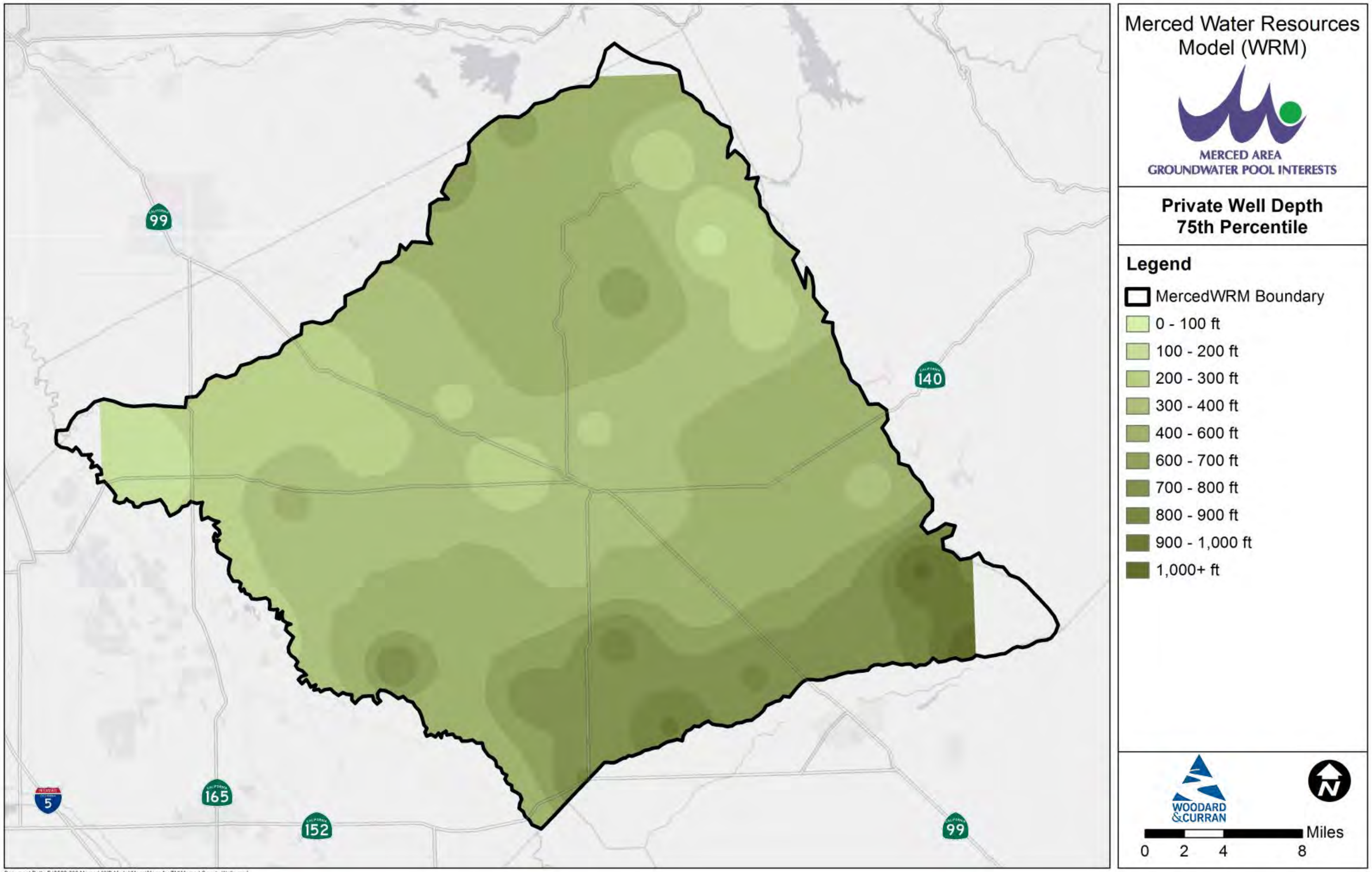


Figure 55: Private Well Depths - 75th Percentile

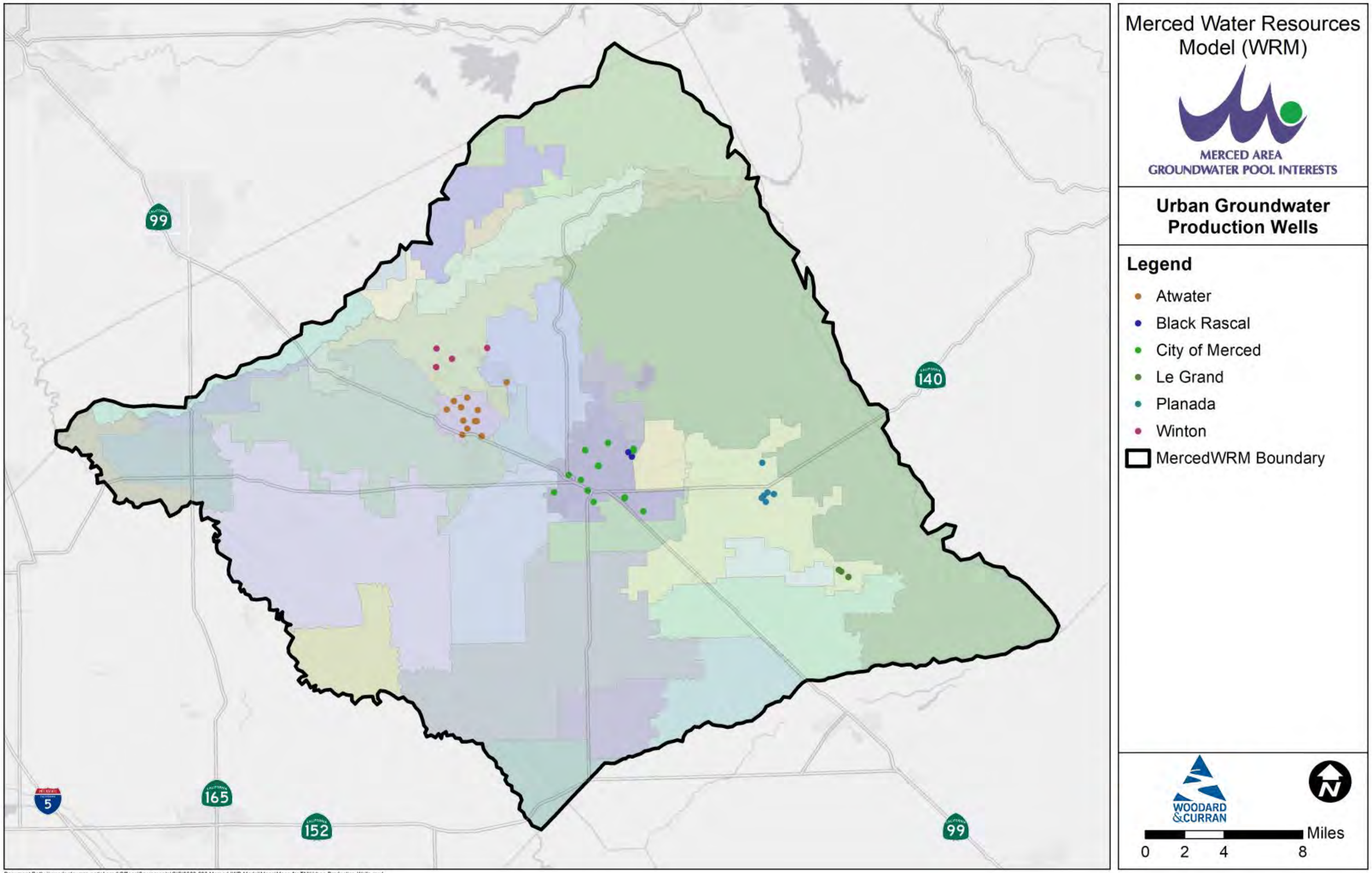
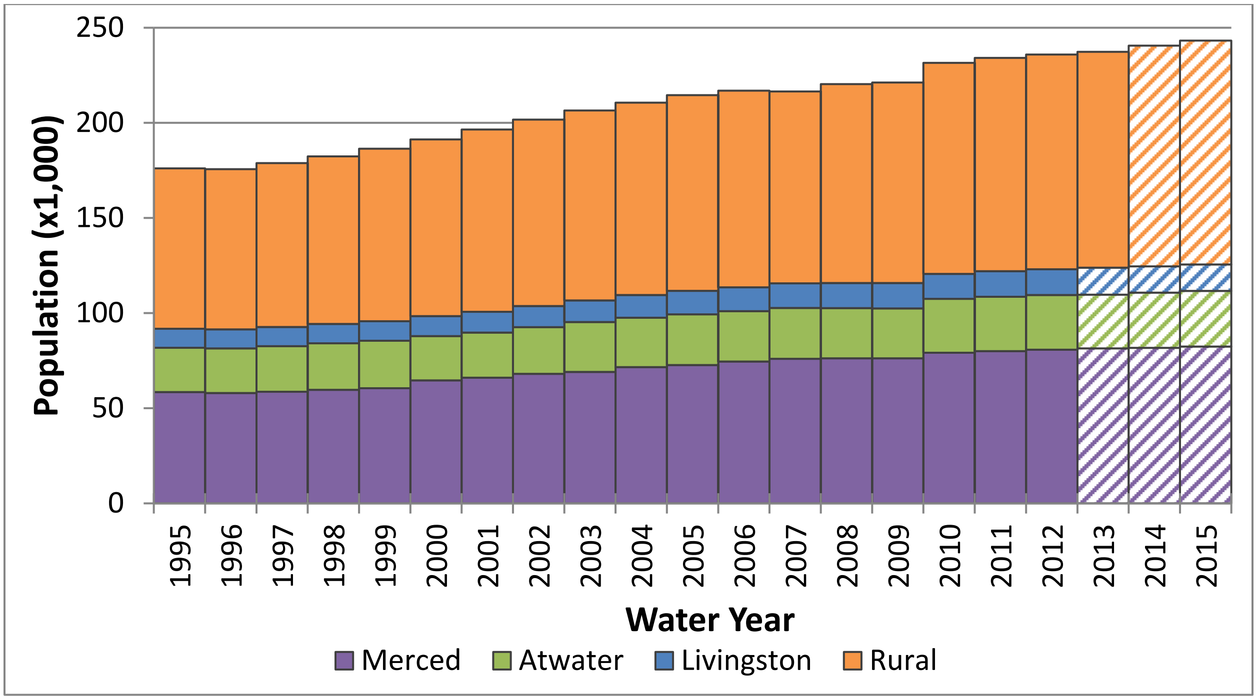
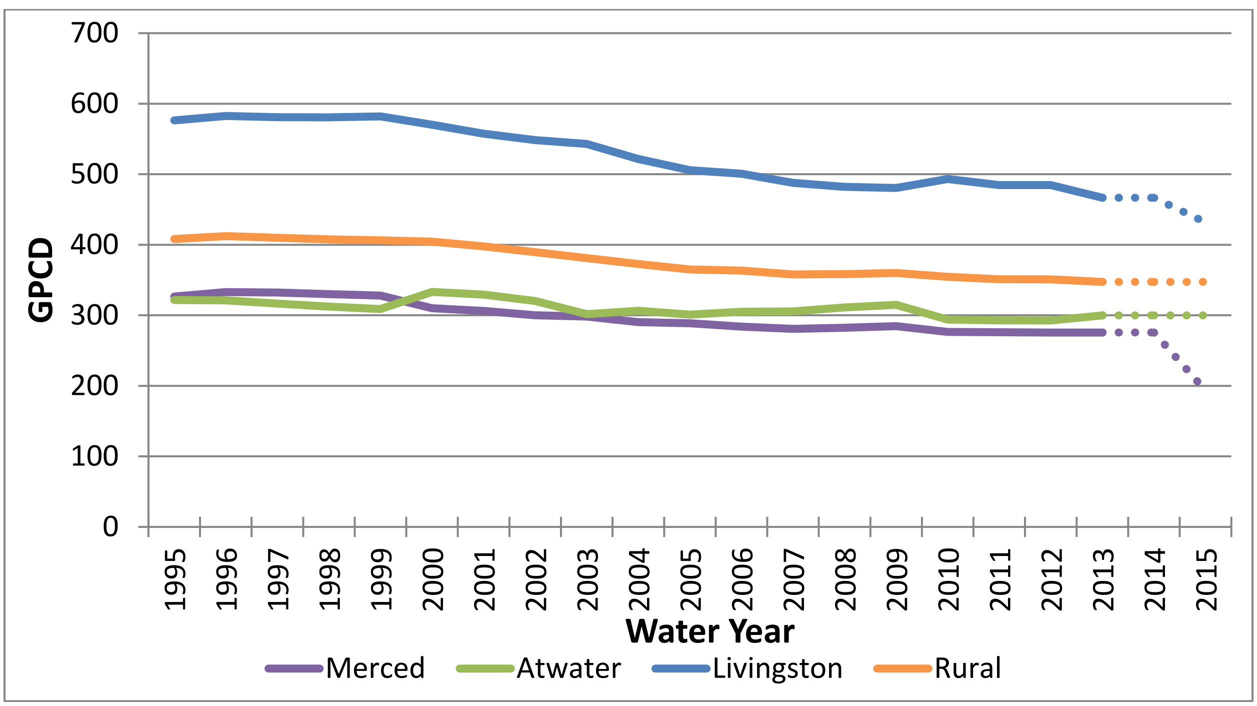


Figure 56: Location of Municipal Groundwater Production Well



*Hatched fill indicates estimated values

Figure 57: Merced Groundwater Region Urban Population Growth



*Dotted line indicates estimated values

Figure 58: Annual Average Urban Consumptive Use (Gallons per Capita per Day)

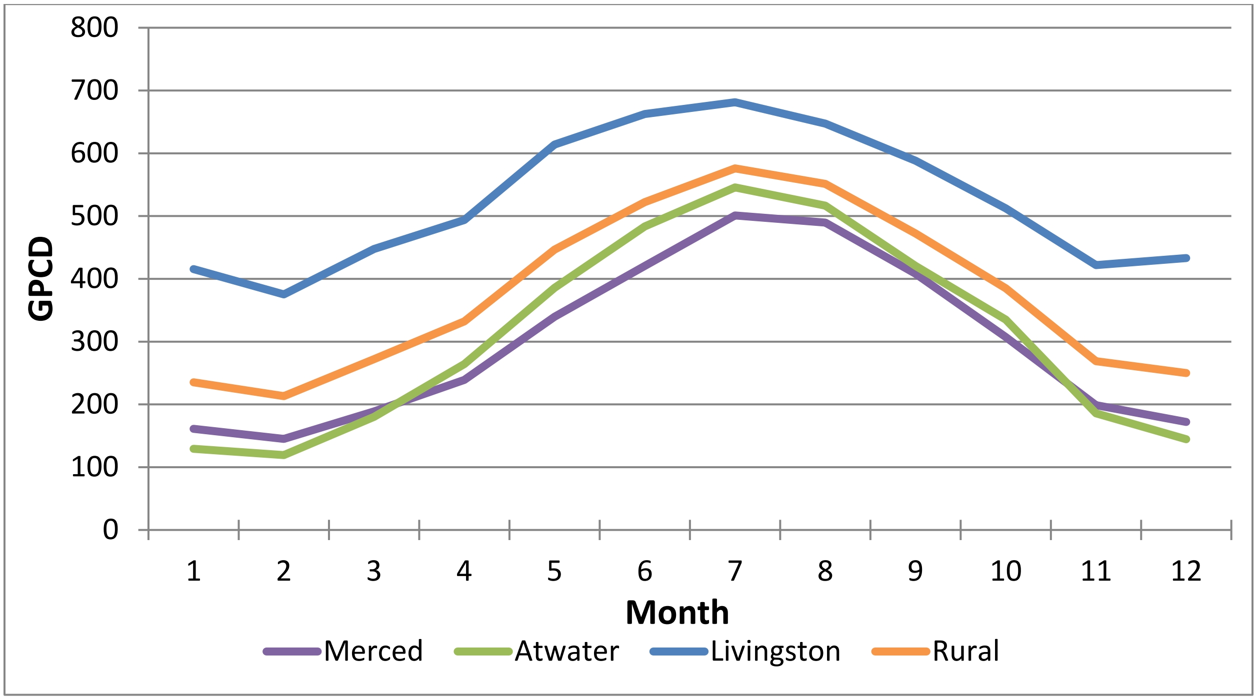
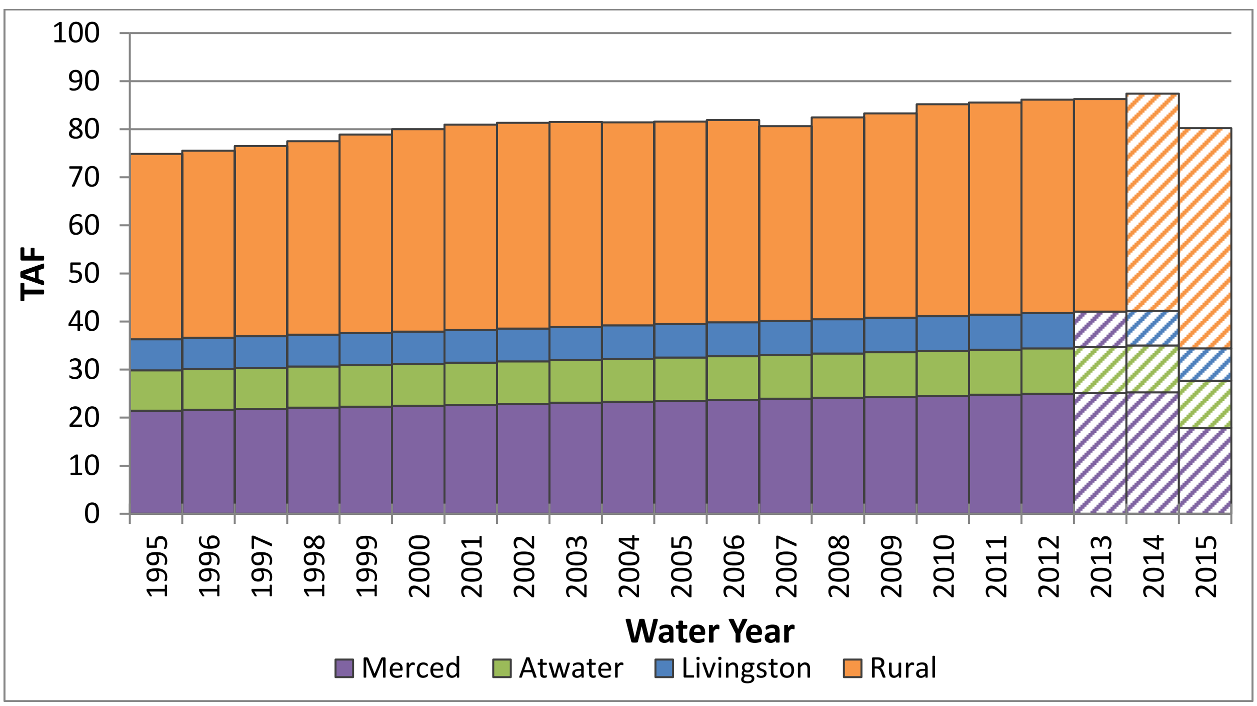


Figure 59: Monthly Average Urban Consumptive Use (Gallons per Capita per Day)



*Hatched fill indicates estimated values

Figure 60: Annual Urban Consumptive Use

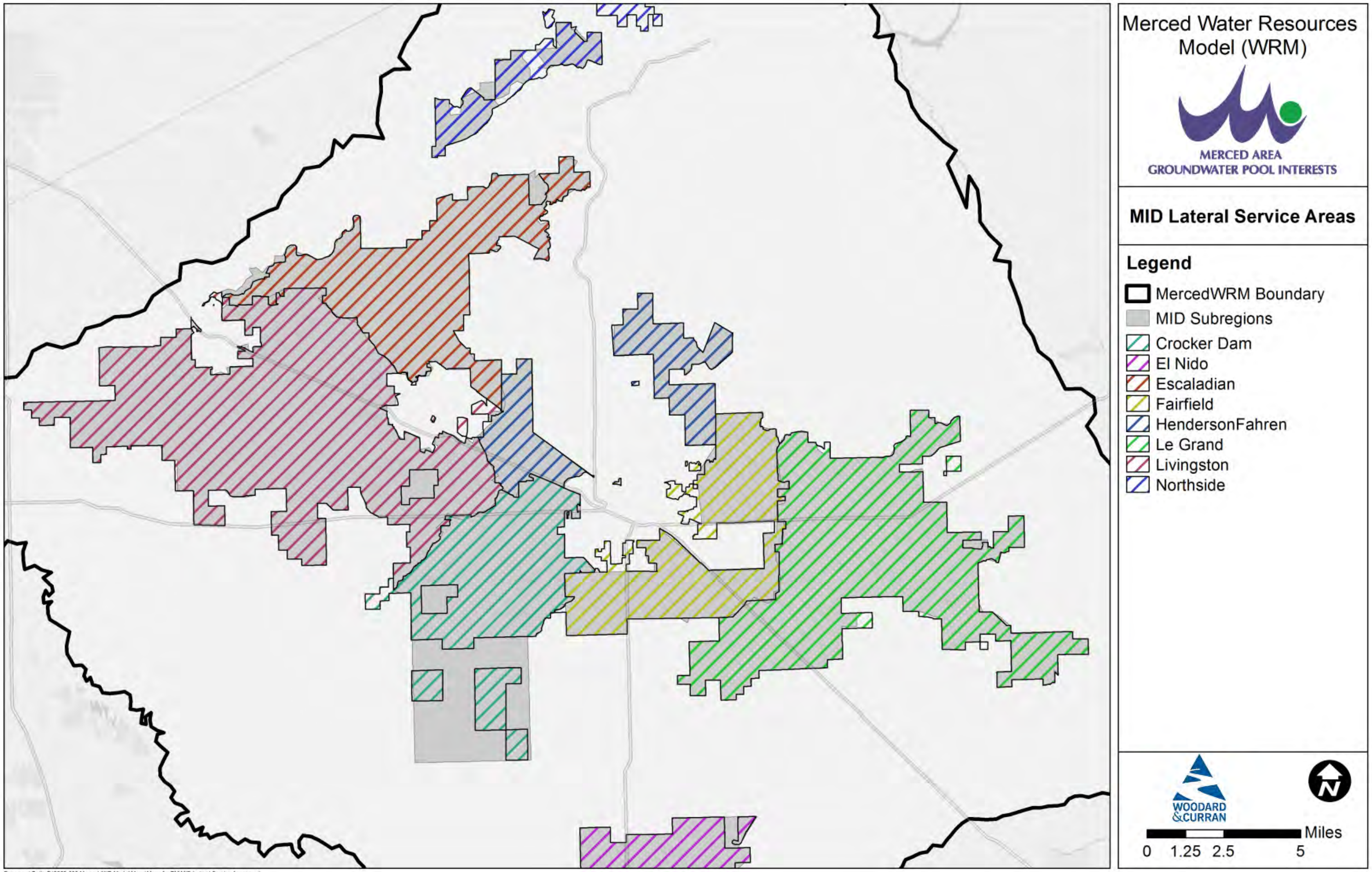


Figure 61: MercedWRM v MID-WBM Surface Budget Areas

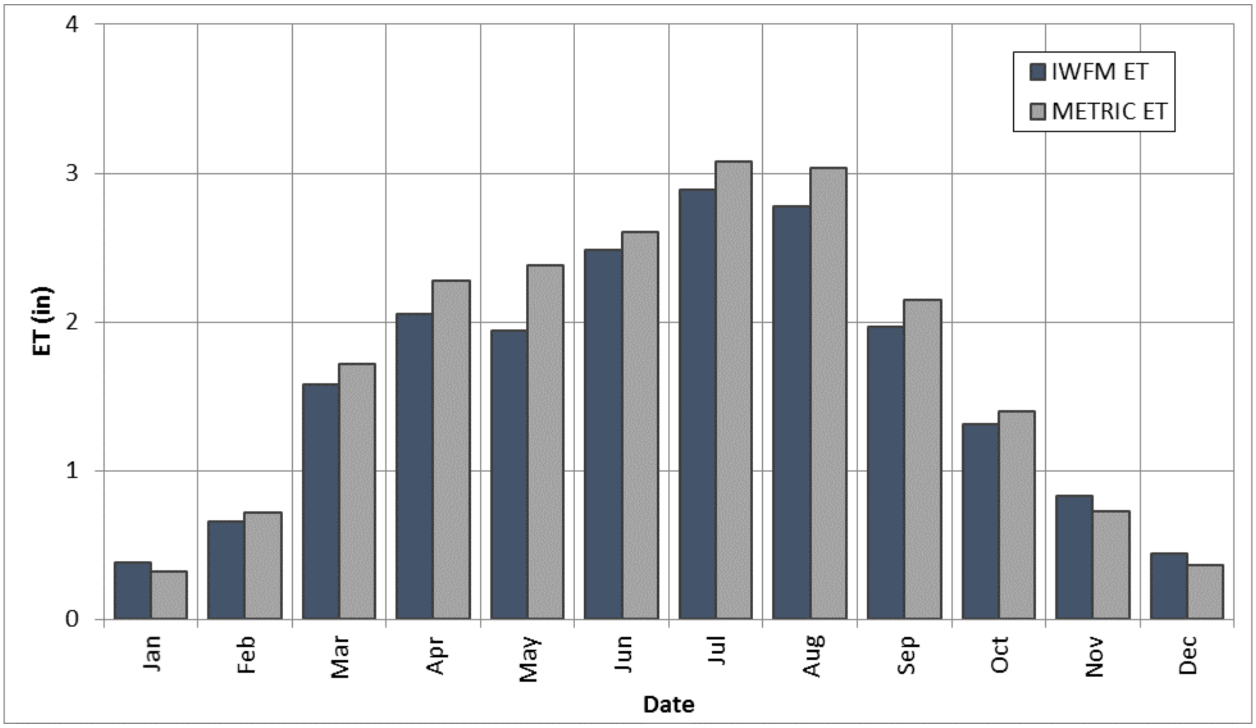


Figure 62: Monthly IWFM-METRIC ET of MercedWRM area during the calibration period

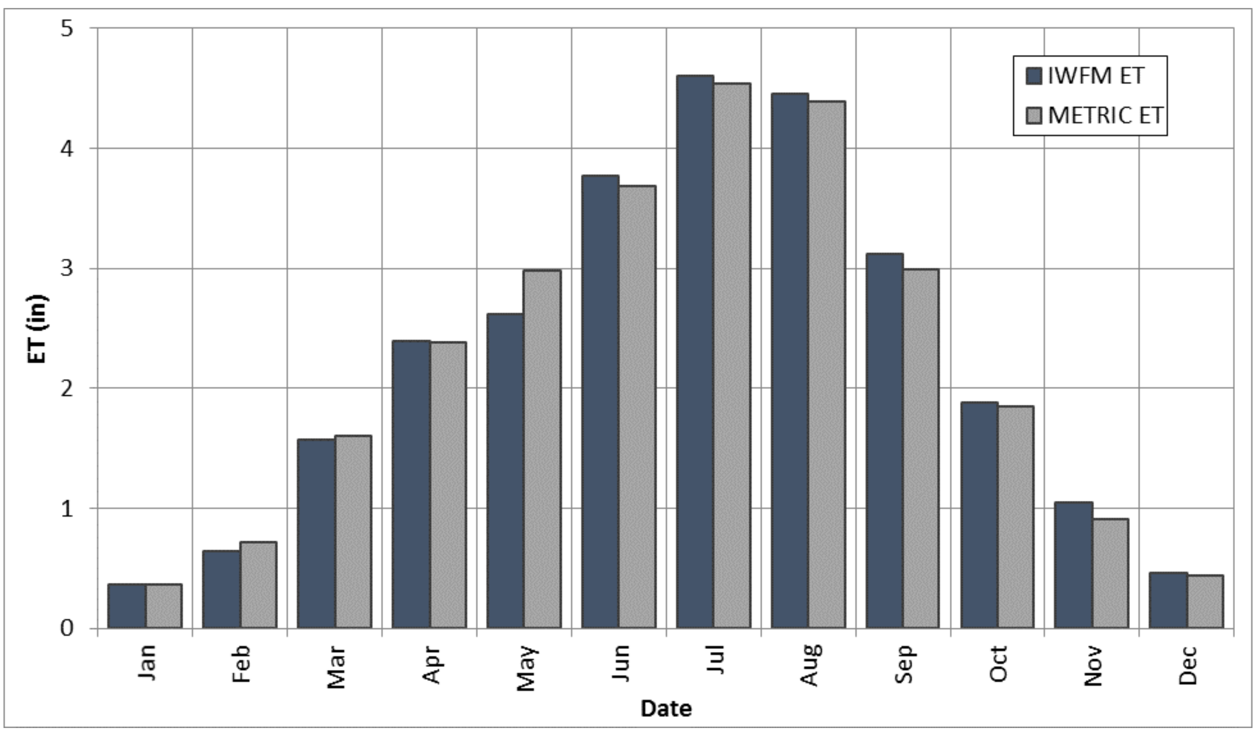


Figure 63: Monthly IWFM-METRIC ET of MID Subregions during the calibration period

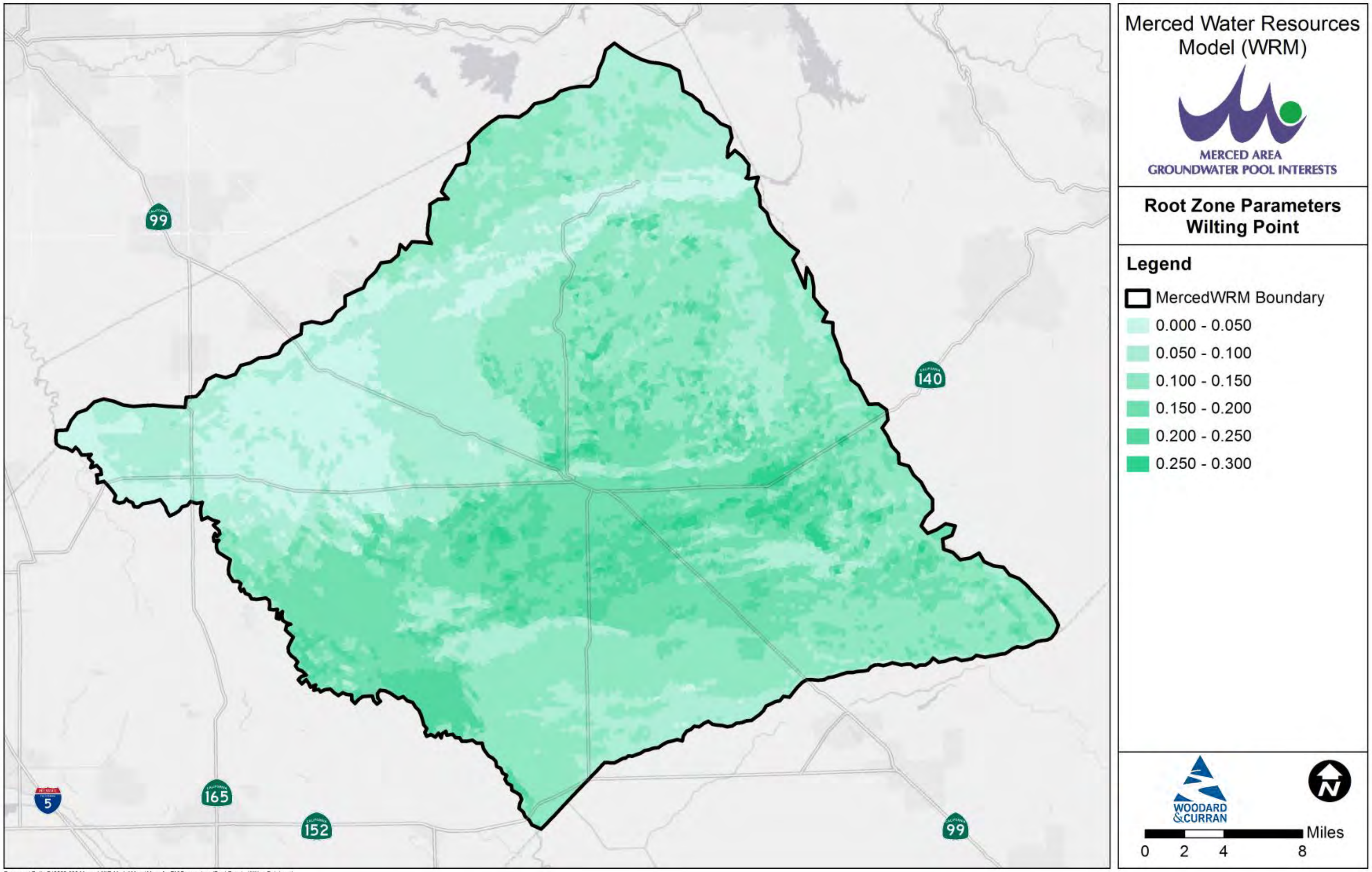


Figure 64: MercedWRM Root Zone Parameters - Wilting Point

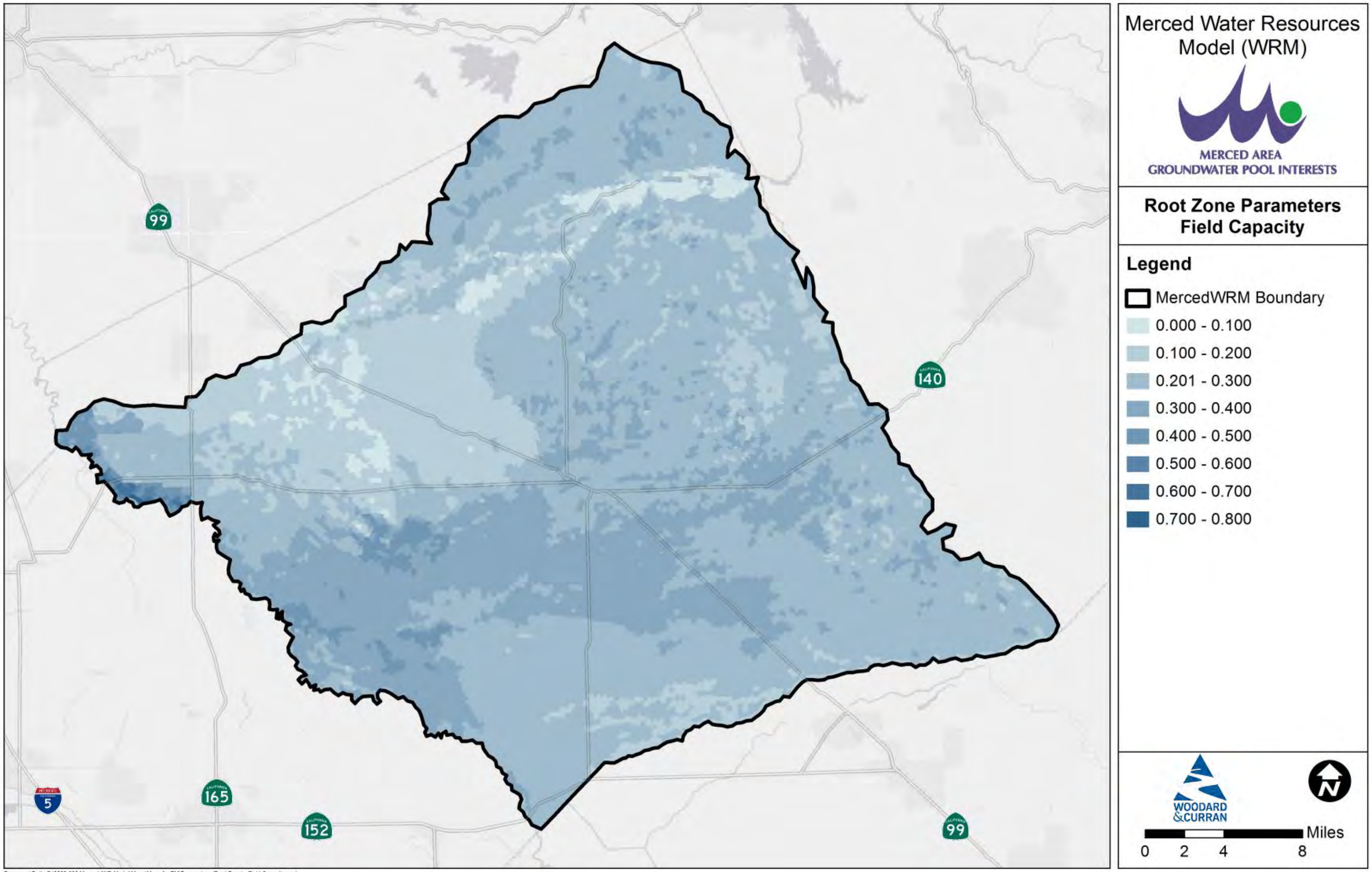


Figure 65: MercedWRM Root Zone Parameters - Field Capacity

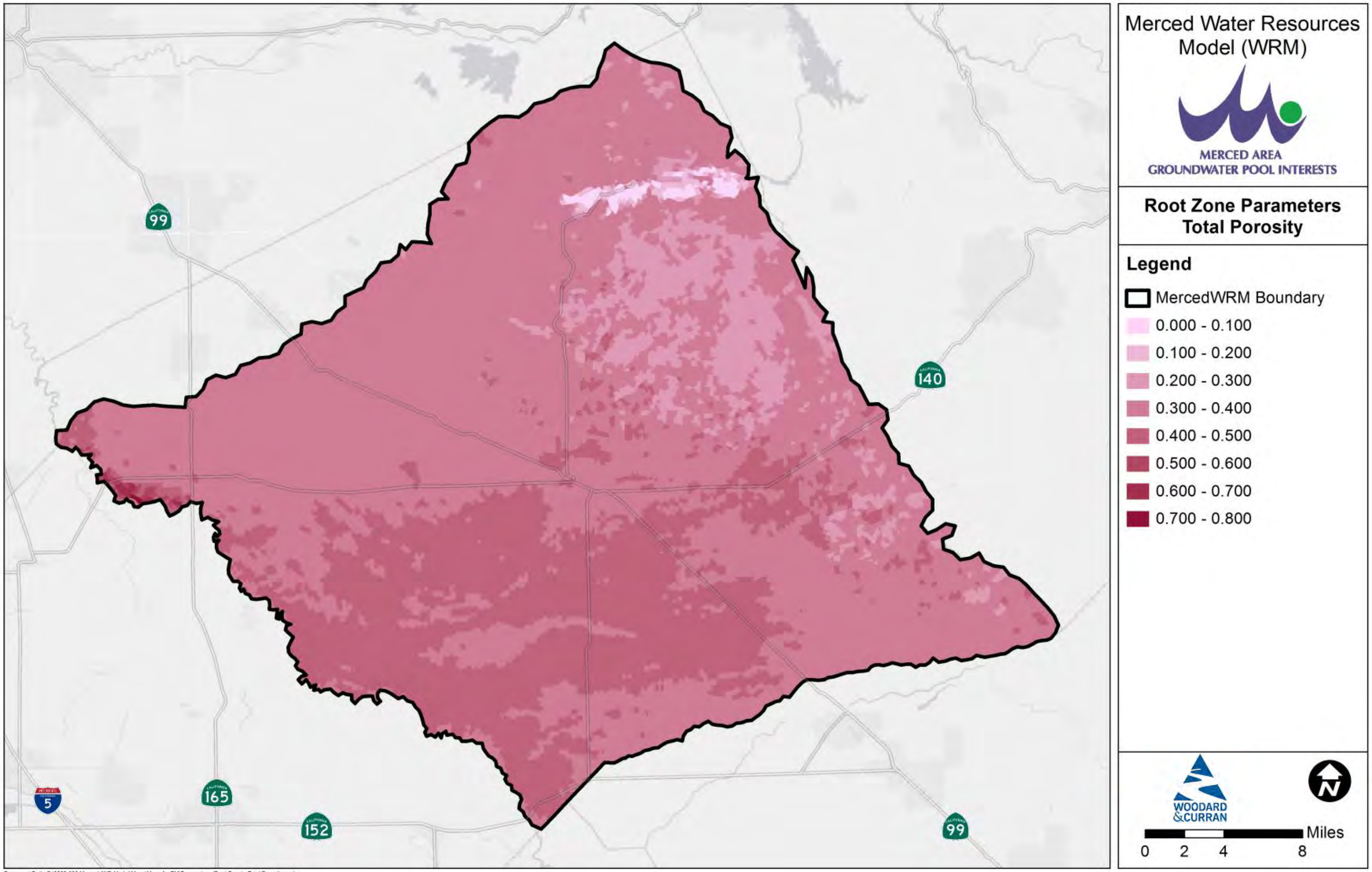


Figure 66: MercedWRM Root Zone Parameters - Total Porosity

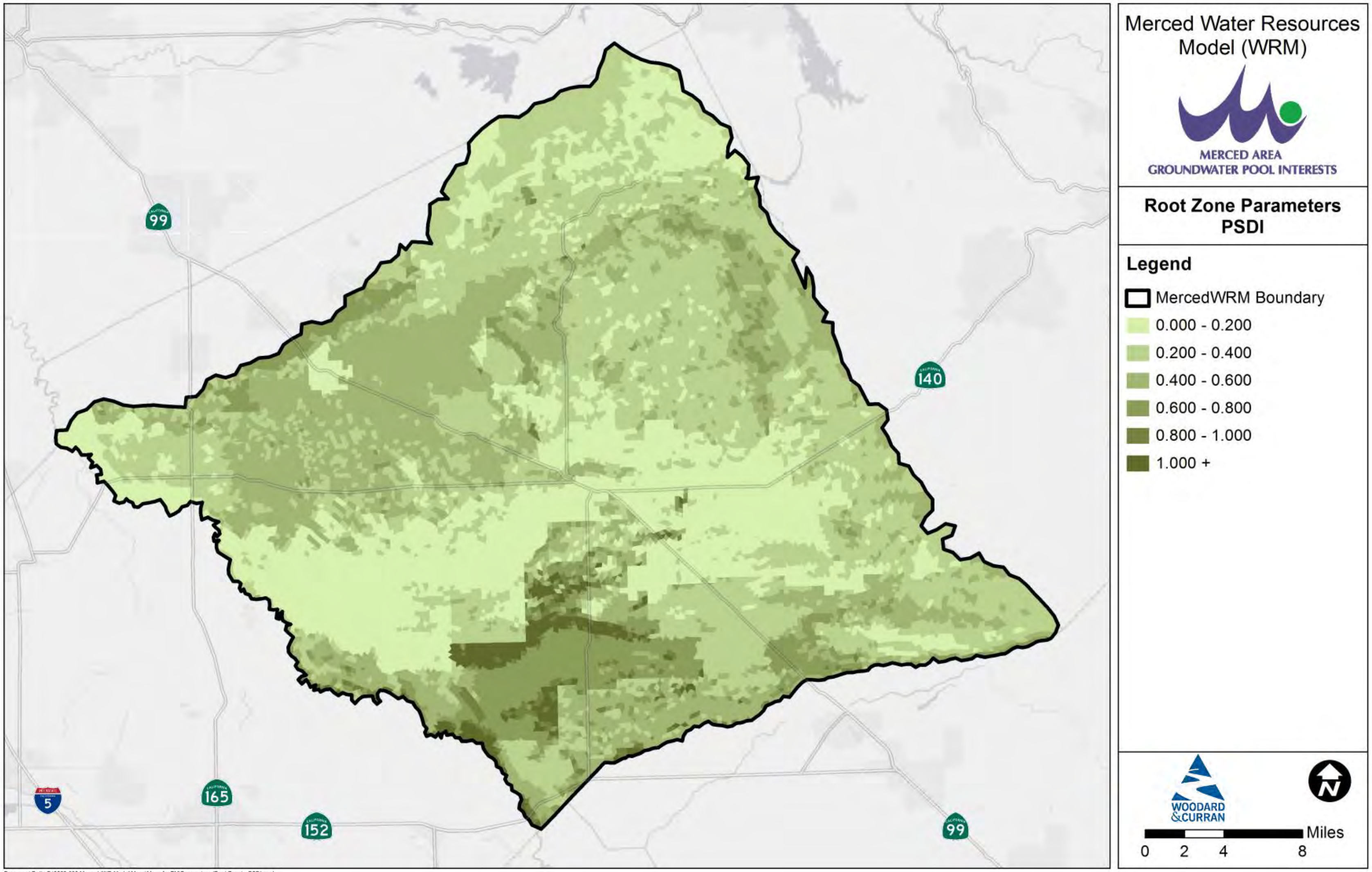


Figure 67: MercedWRM Root Zone Parameters - Pore Size Distribution Index

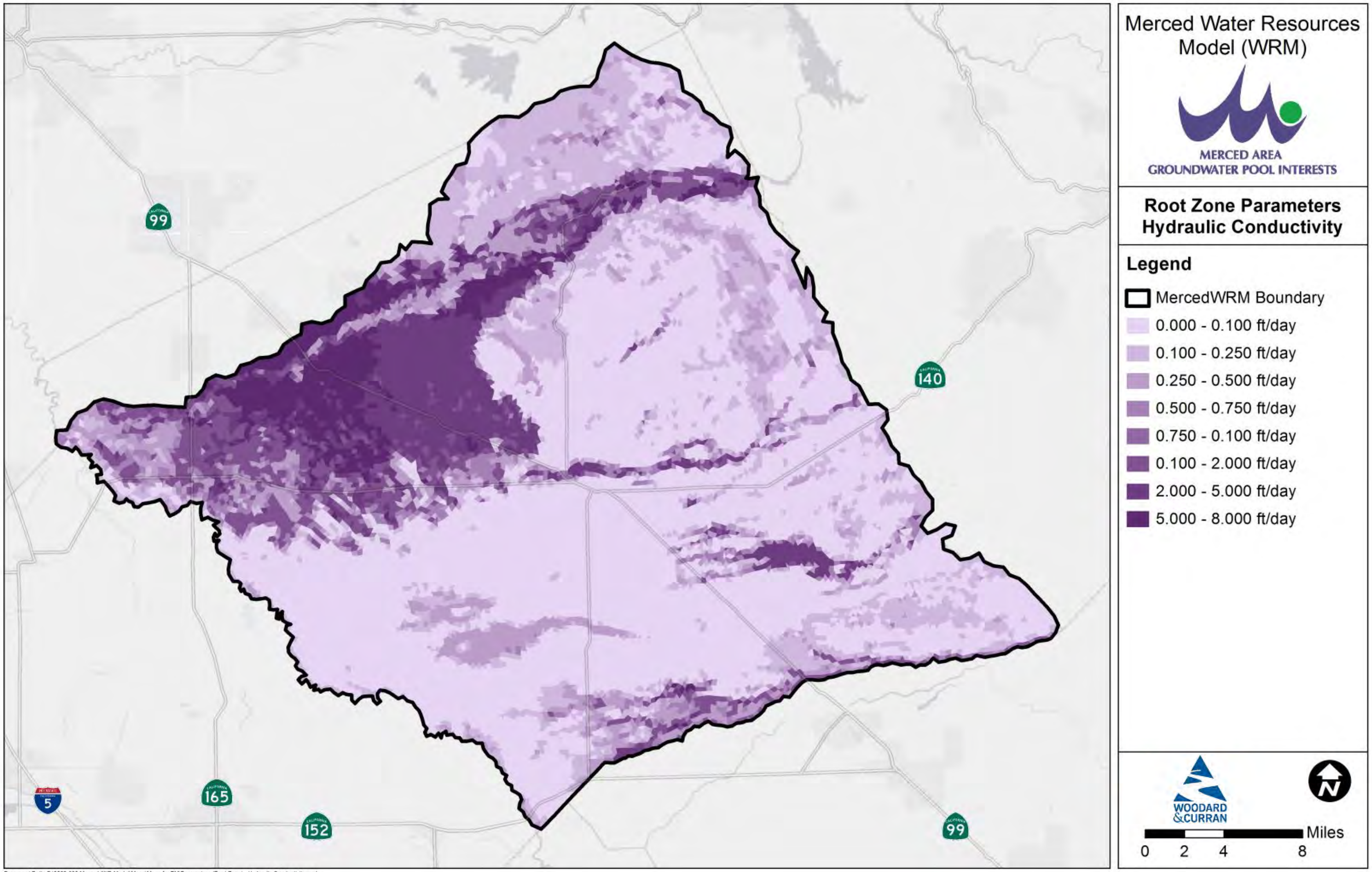


Figure 68: MercedWRM Root Zone Parameters - Hydraulic Conductivity

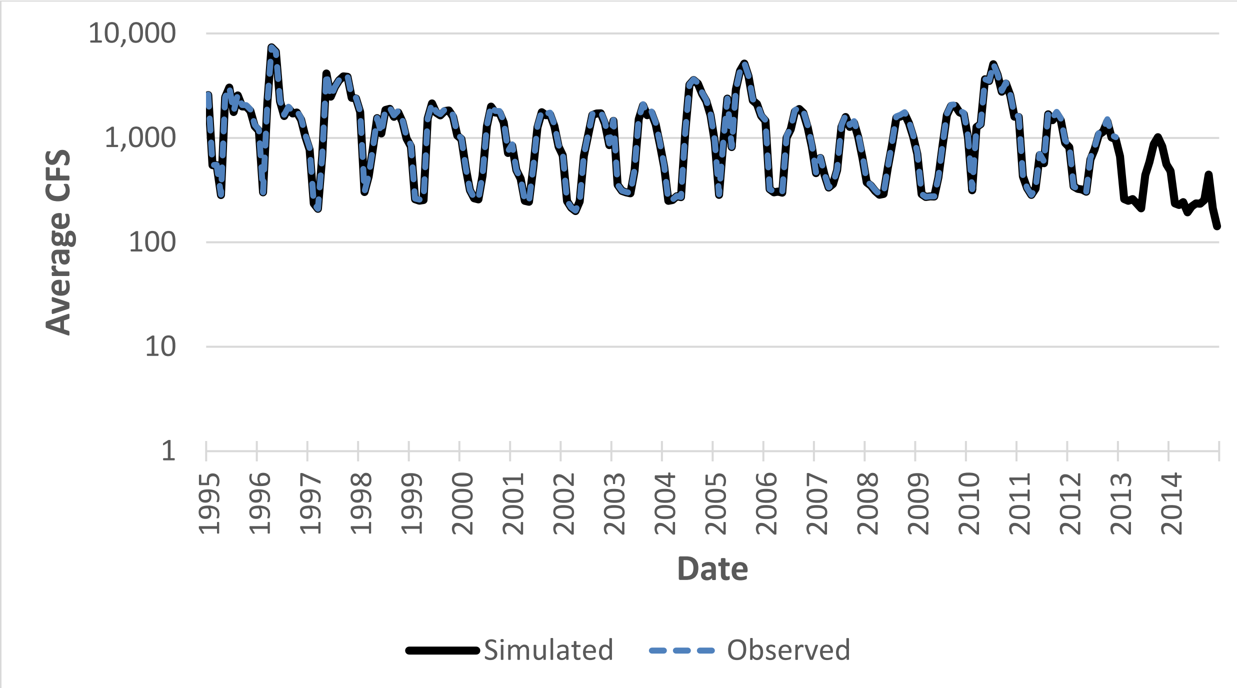


Figure 69: Observed vs Simulated Stream Flow (Merced Falls near the Northside Canal)

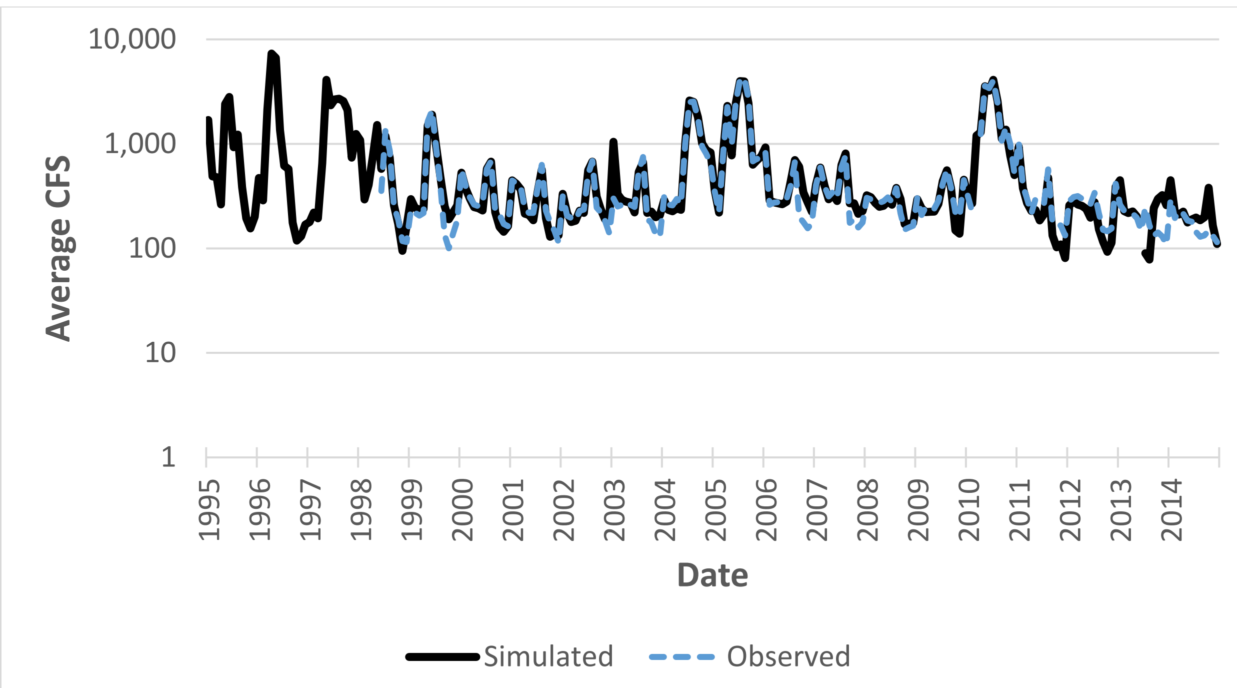


Figure 70: Observed vs Simulated Stream Flow (Merced River near Snelling)

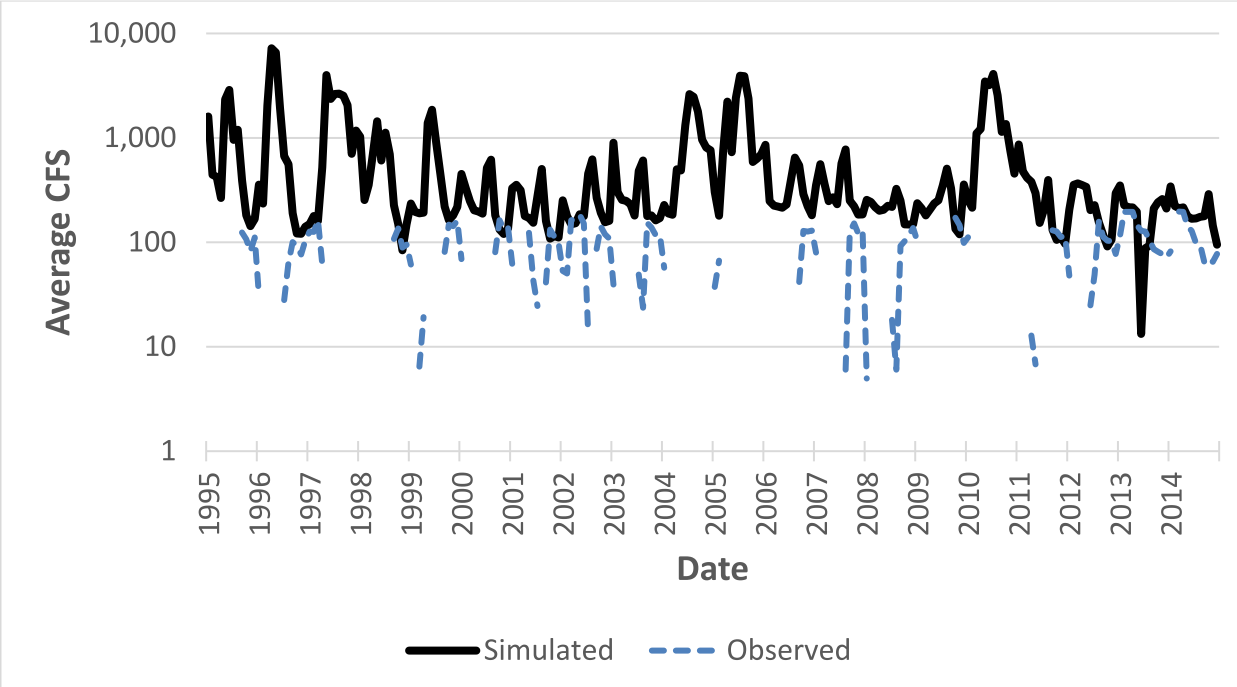


Figure 71: Observed vs Simulated Stream Flow (Merced River at Shaffer Bridge)

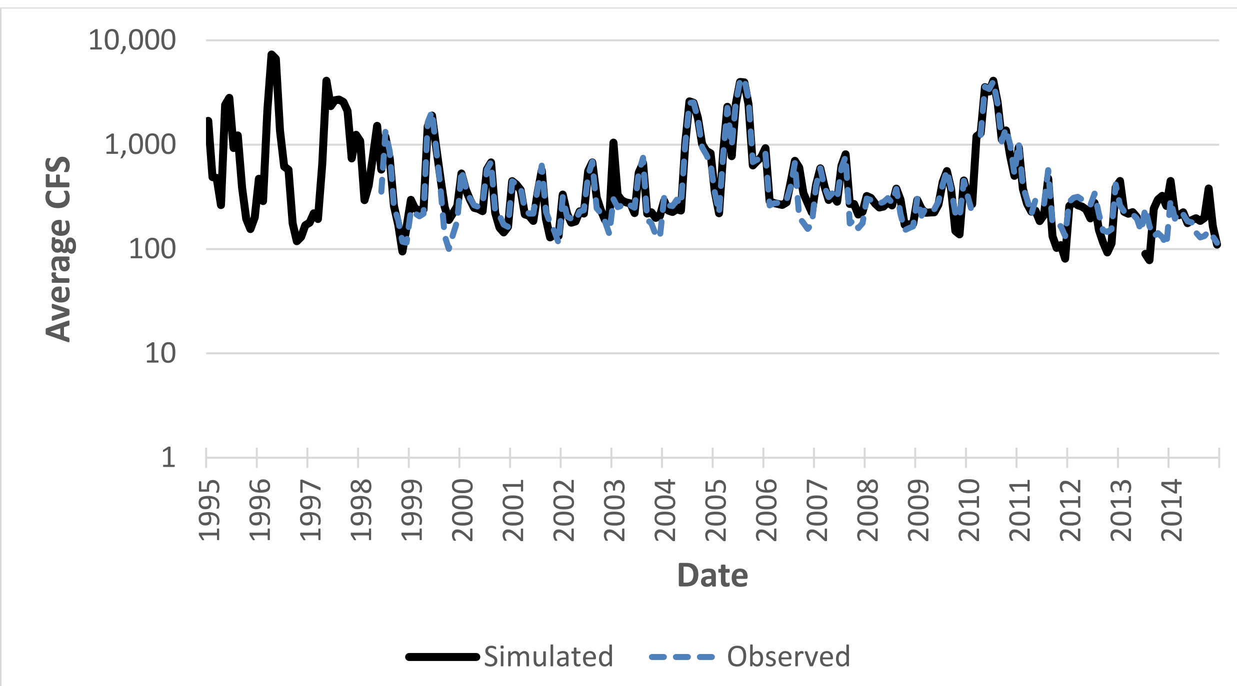


Figure 72: Observed vs Simulated Stream Flow (Merced River near Cressey)

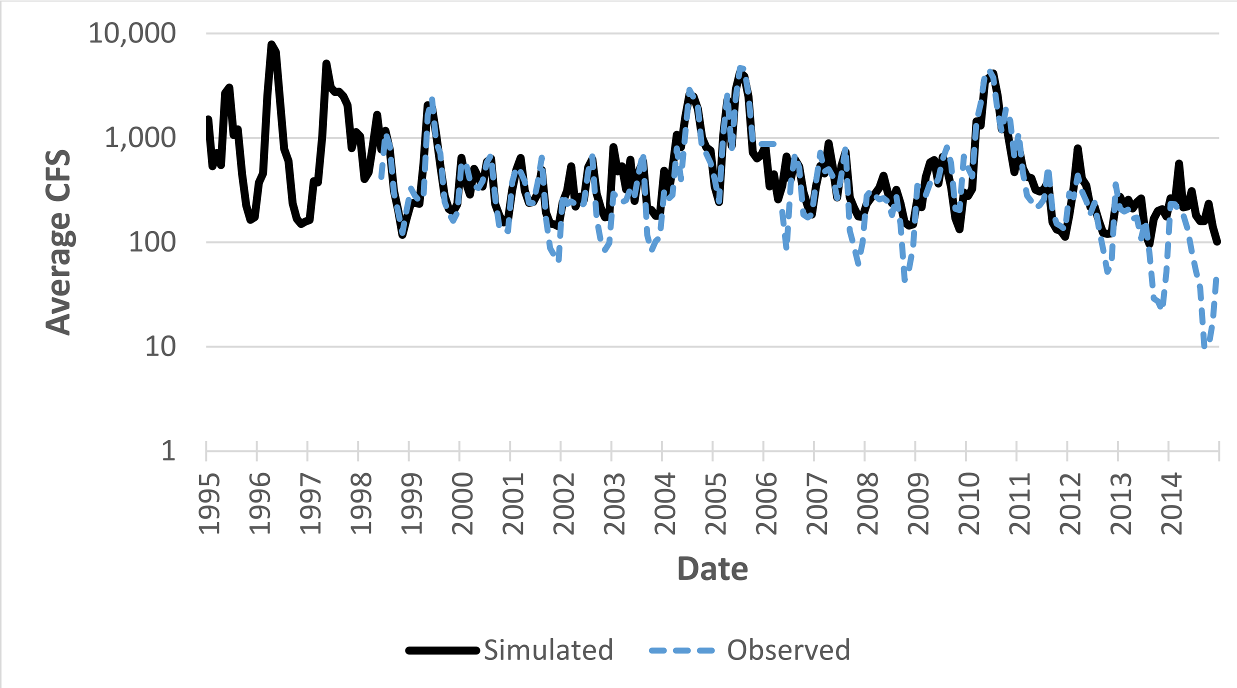


Figure 73: Observed vs Simulated Stream Flow (Merced River near Stevinson

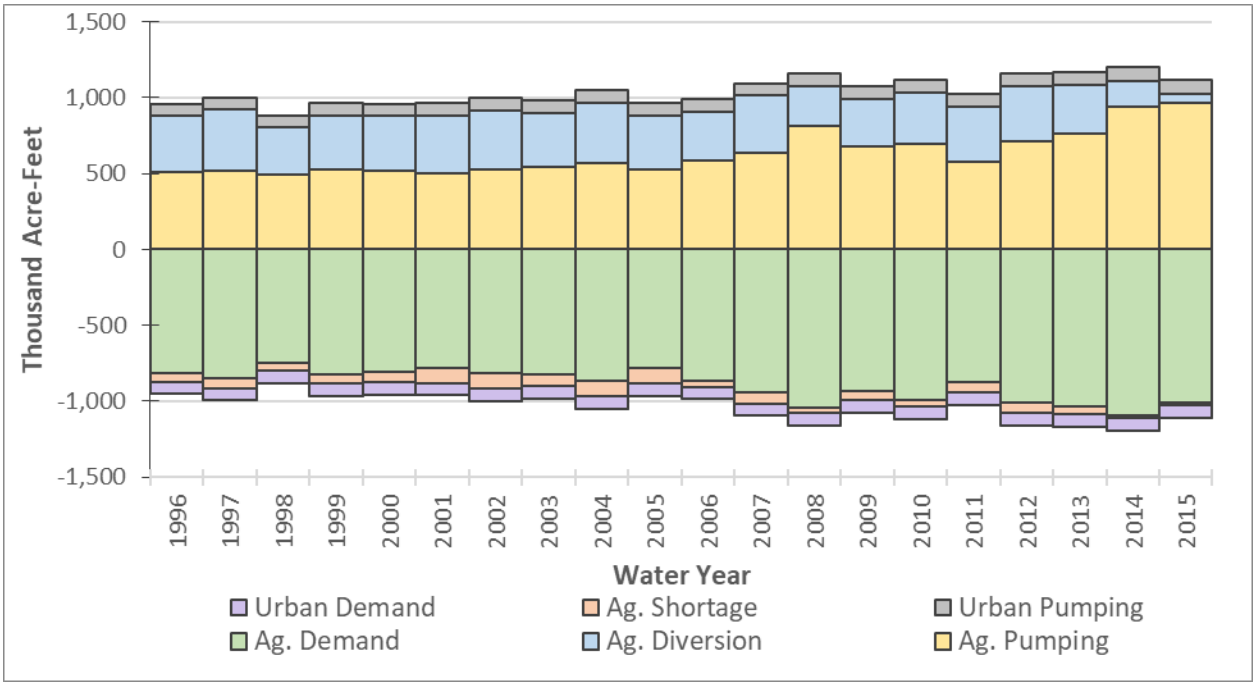


Figure 74: Land and Water Use - Merced Region

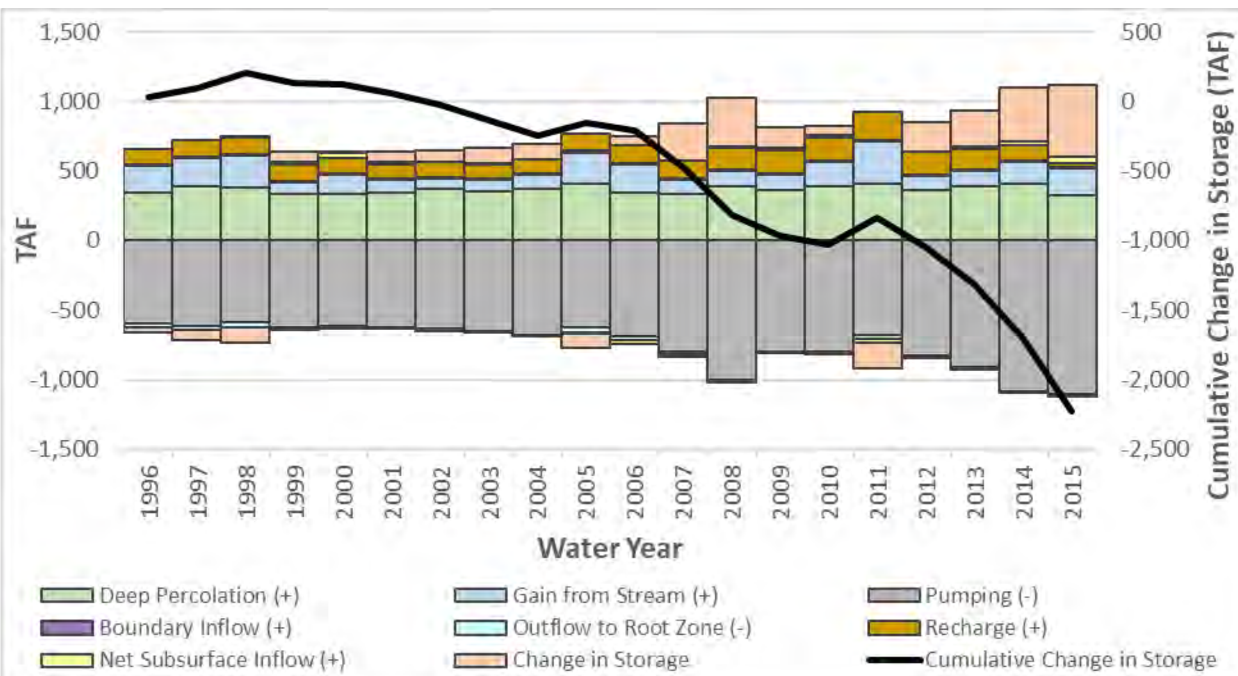


Figure 75: Groundwater Budget - Merced Region

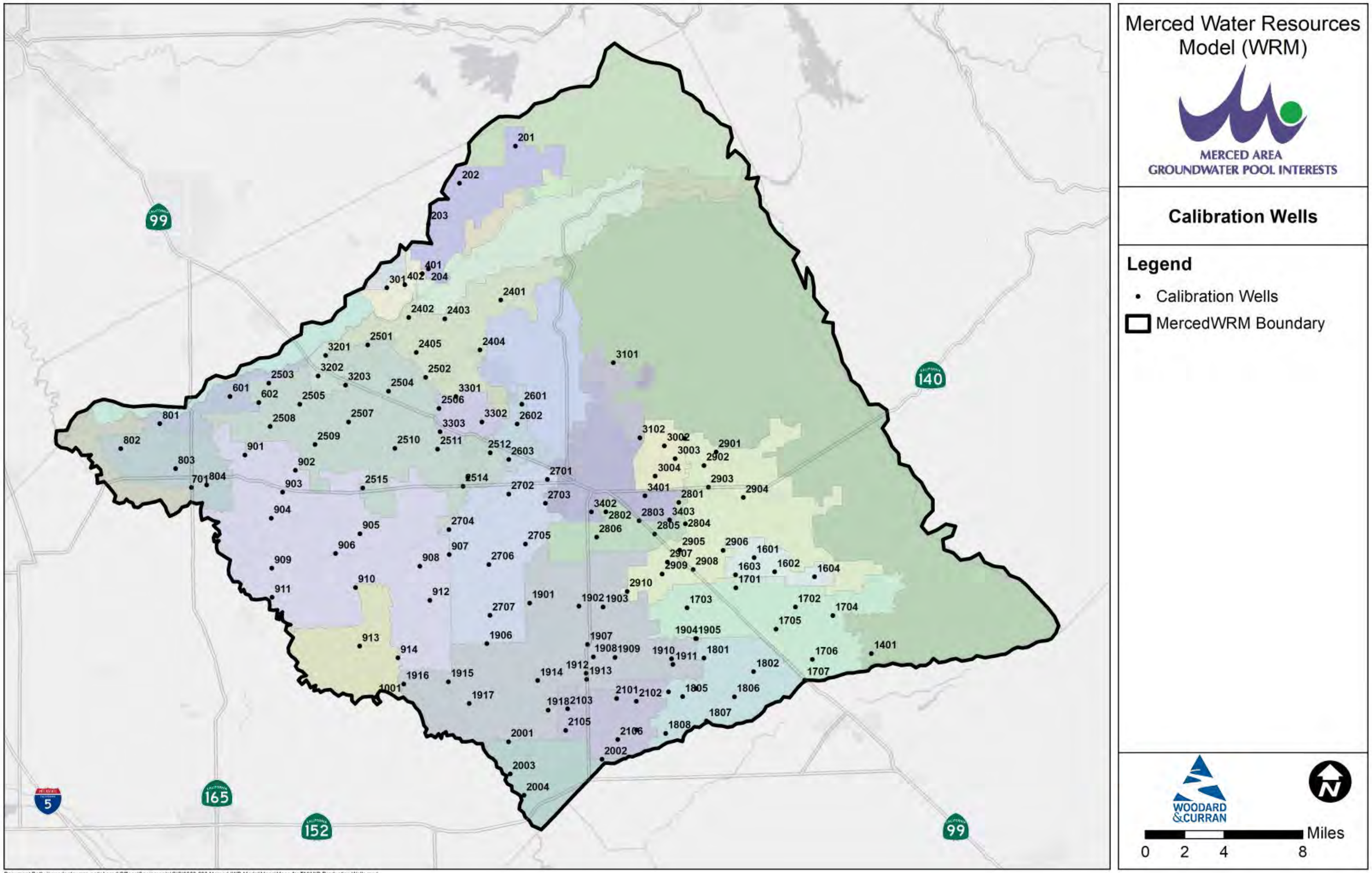


Figure 76: MercedWRM Groundwater Observation Wells

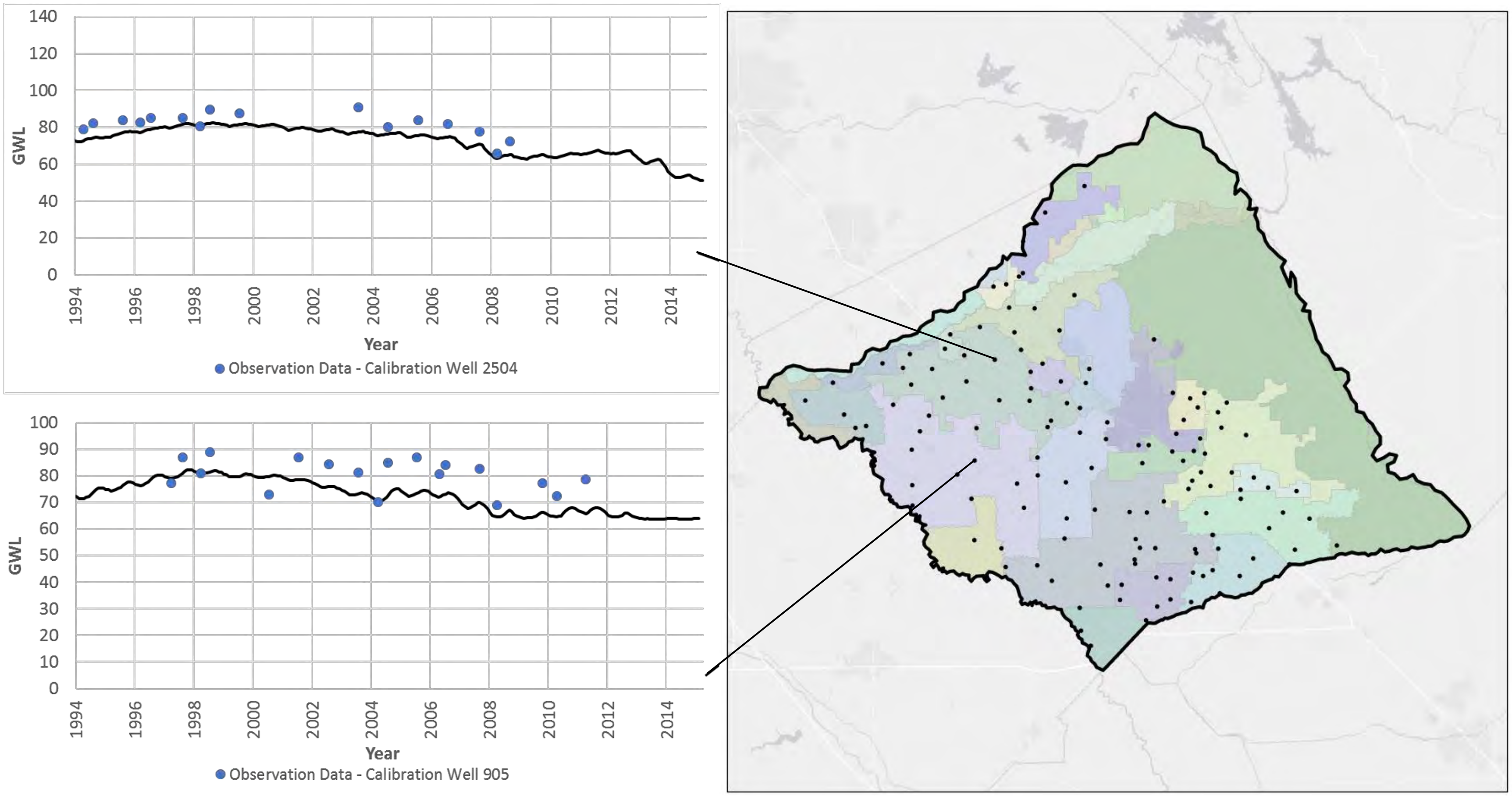


Figure 77: Sample Groundwater Calibration Hydrographs

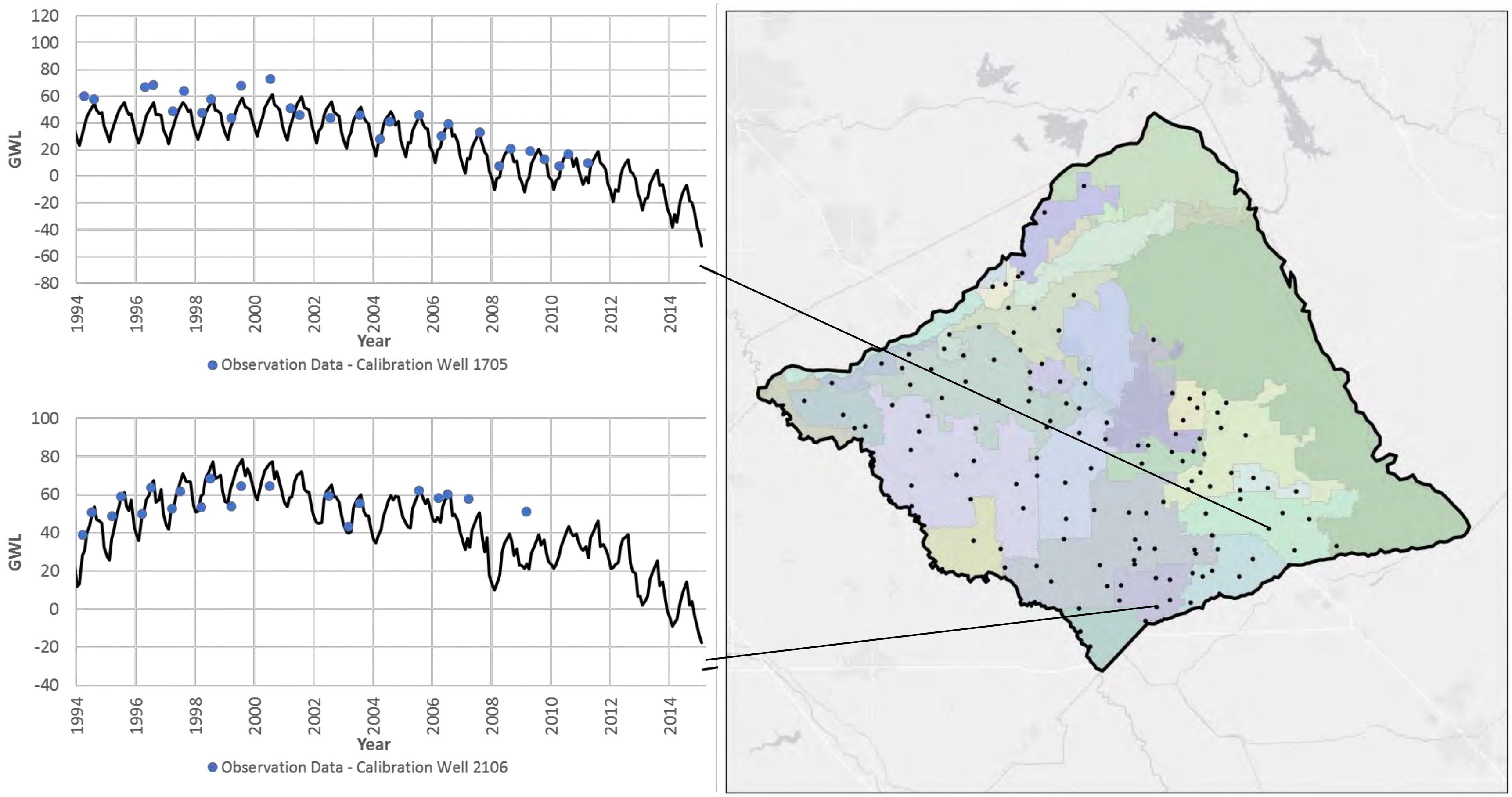


Figure 78: Sample Groundwater Calibration Hydrographs

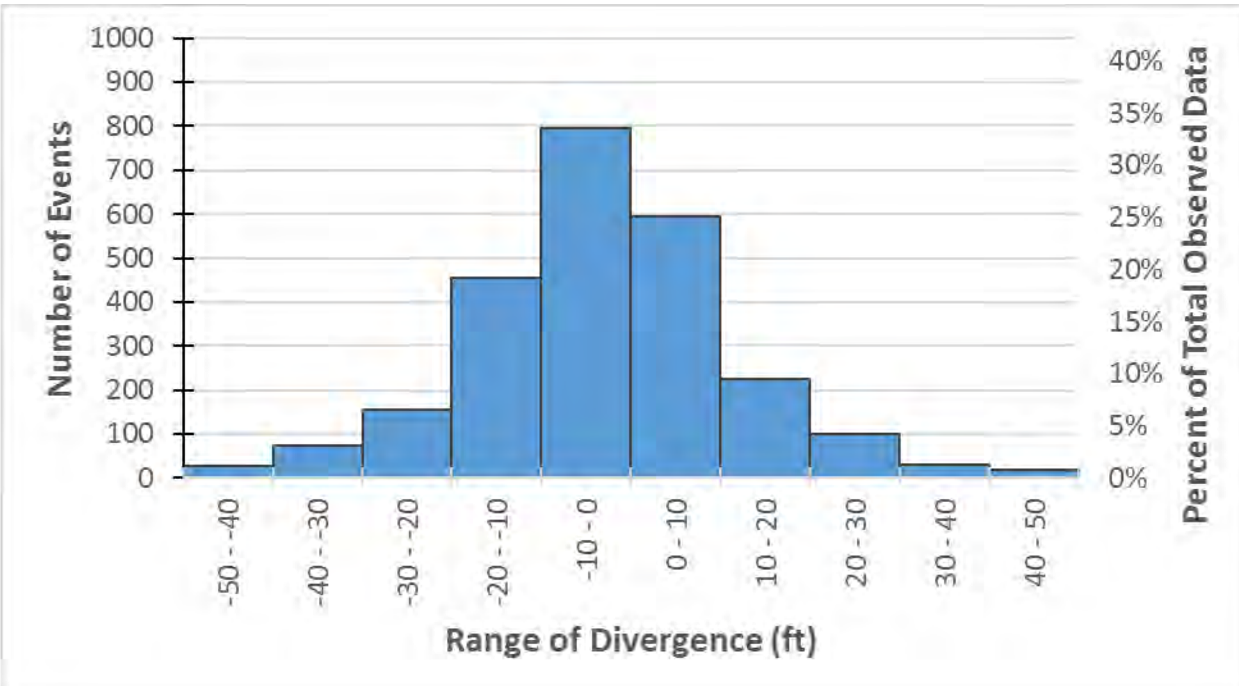


Figure 79: Residual Histogram - Merced Region

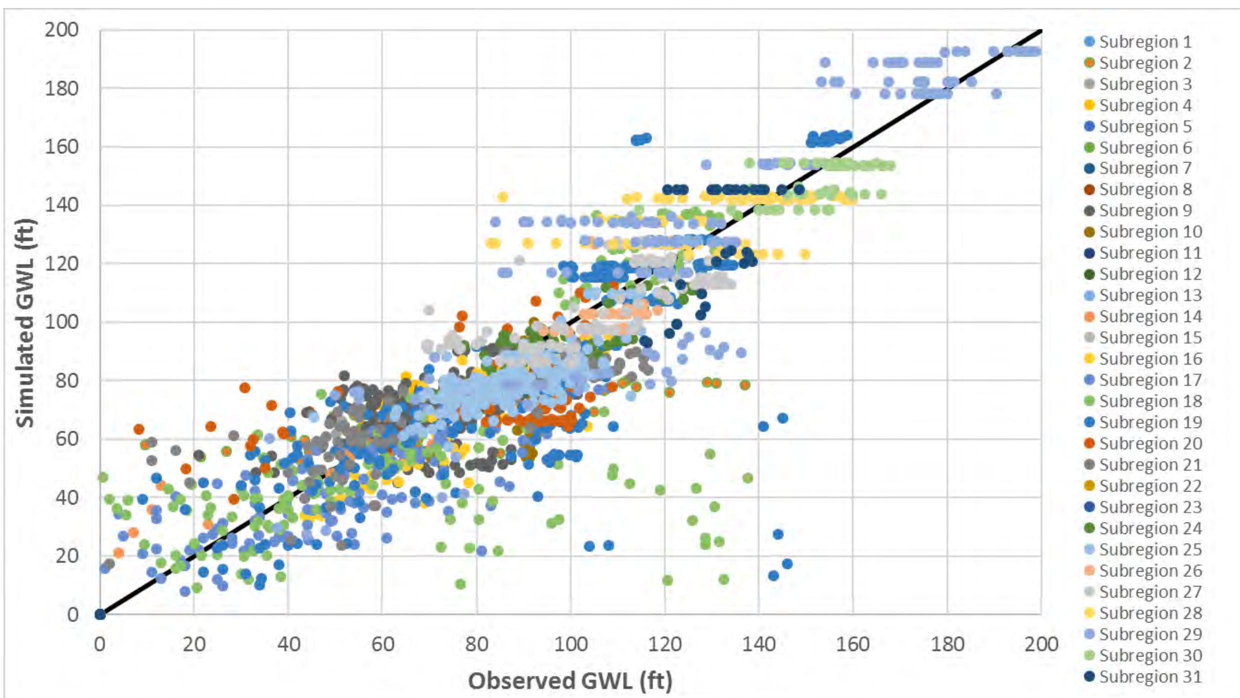


Figure 80: Simulated vs Observed Groundwater Levels By Subregion - Merced Region

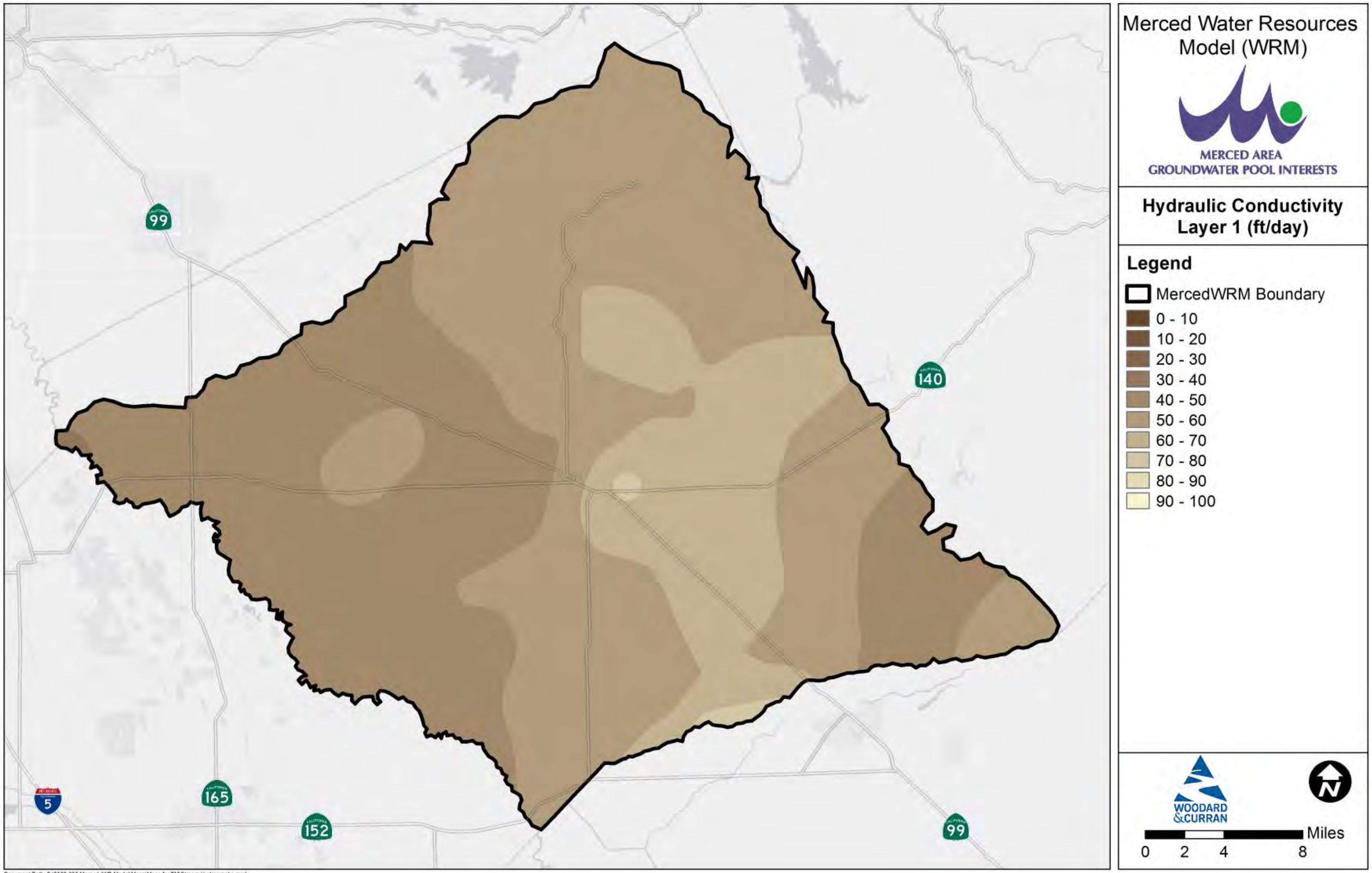


Figure 81: Aquifer Parameters - Hydraulic Conductivity (Layer 1)

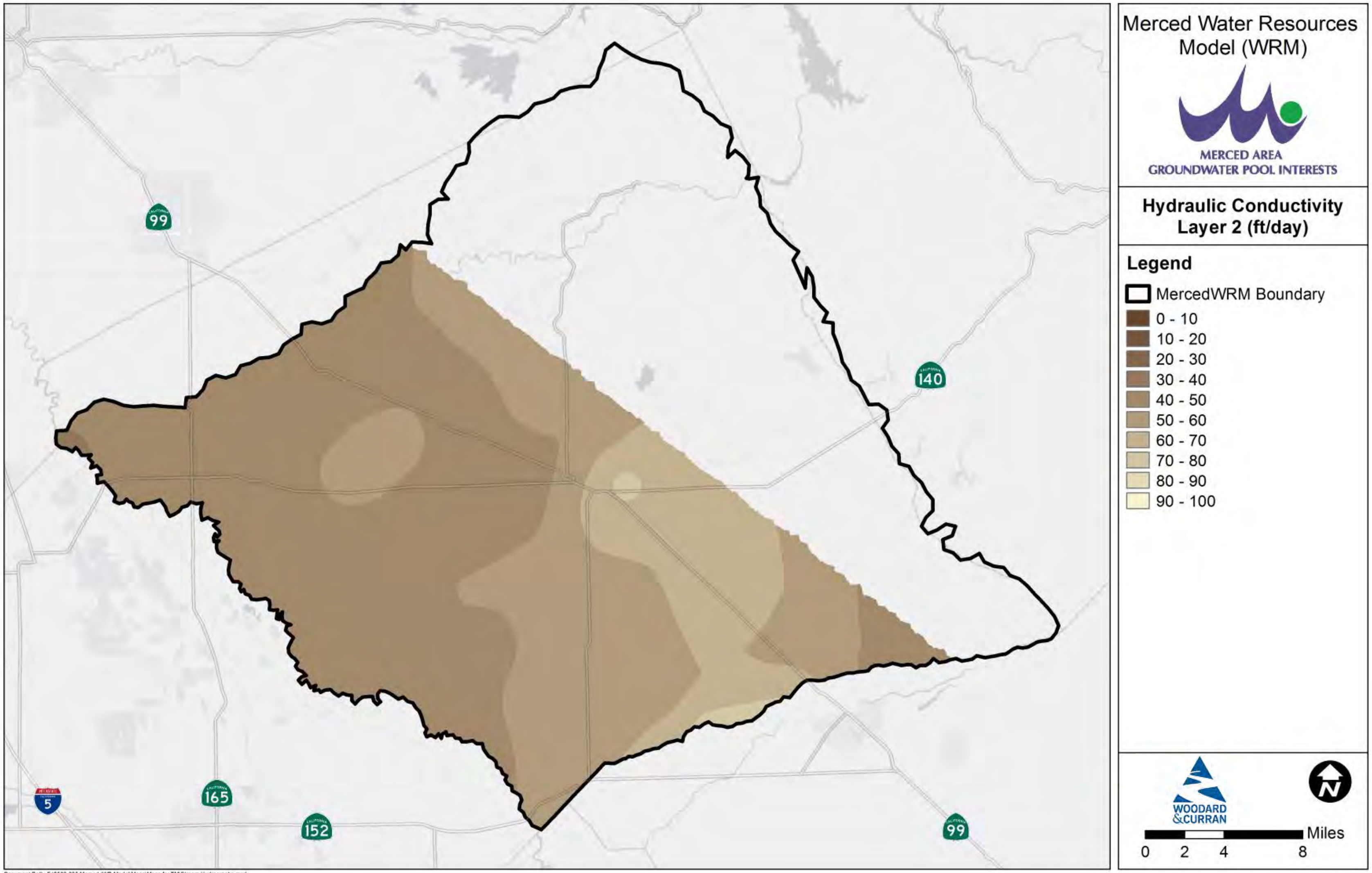


Figure 82: Aquifer Parameters - Hydraulic Conductivity (Layer 2)

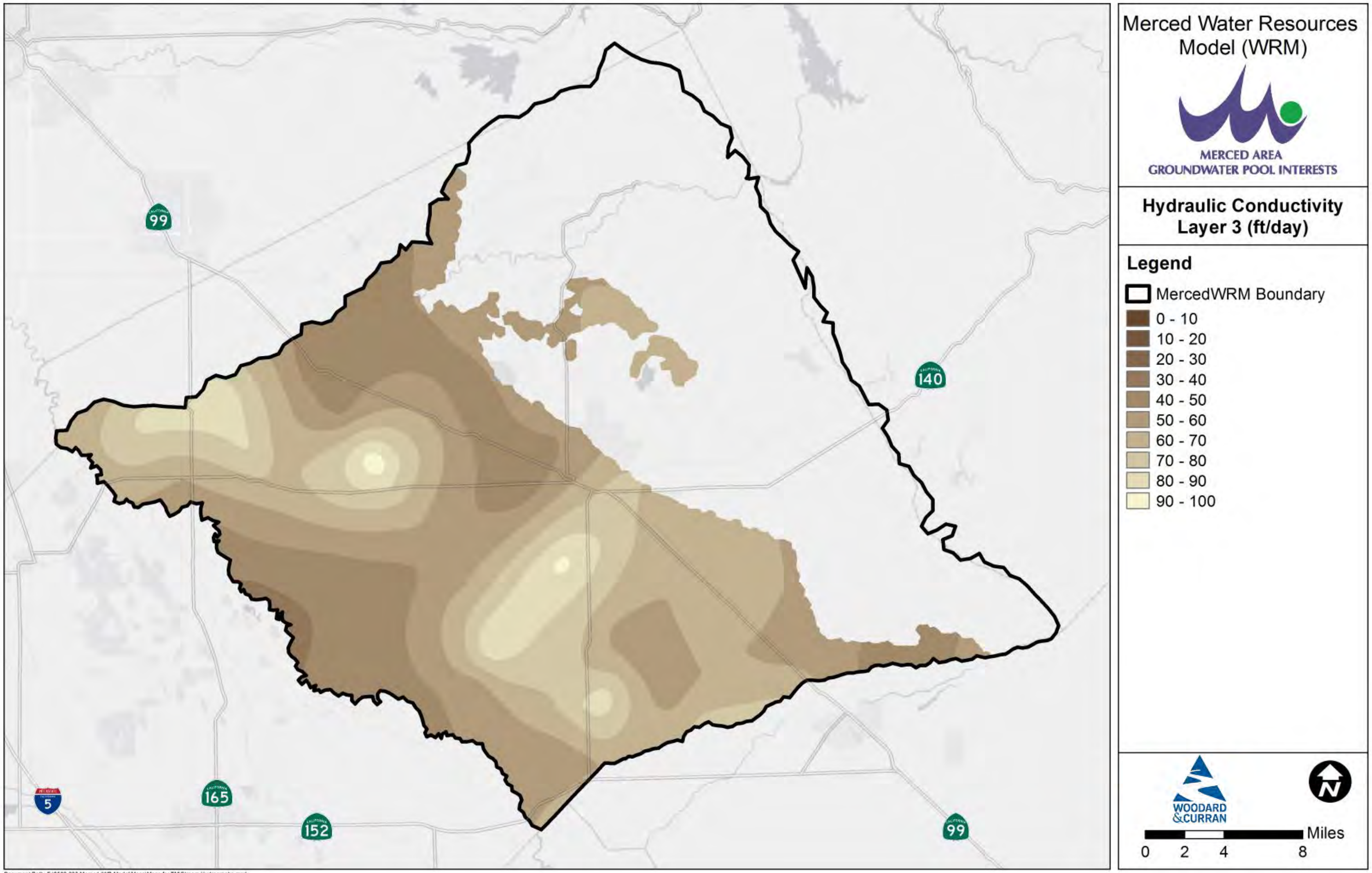


Figure 83: Aquifer Parameters - Hydraulic Conductivity (Layer 3)

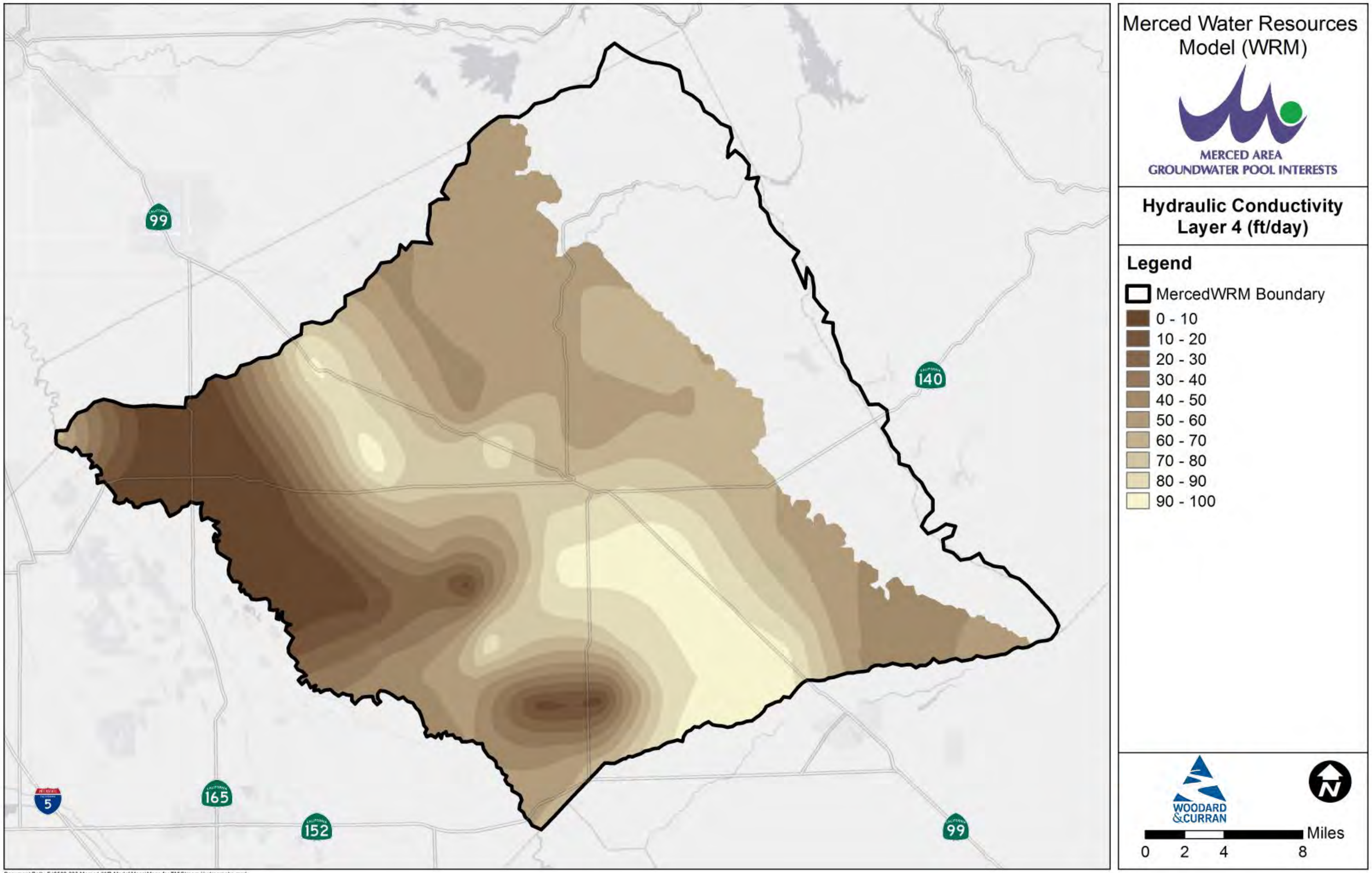


Figure 84: Aquifer Parameters - Hydraulic Conductivity (Layer 4)

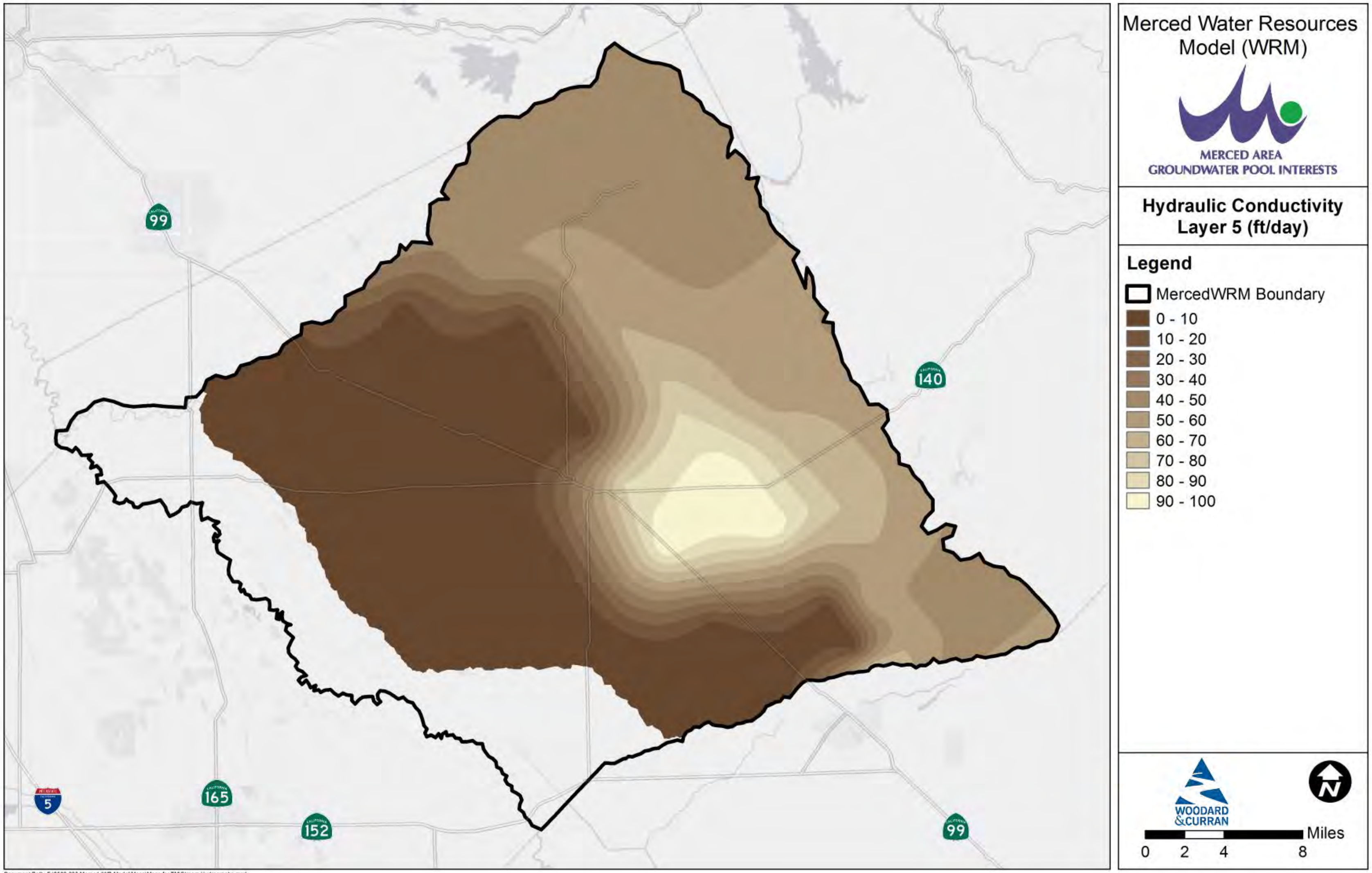


Figure 85: Aquifer Parameters - Hydraulic Conductivity (Layer 5)

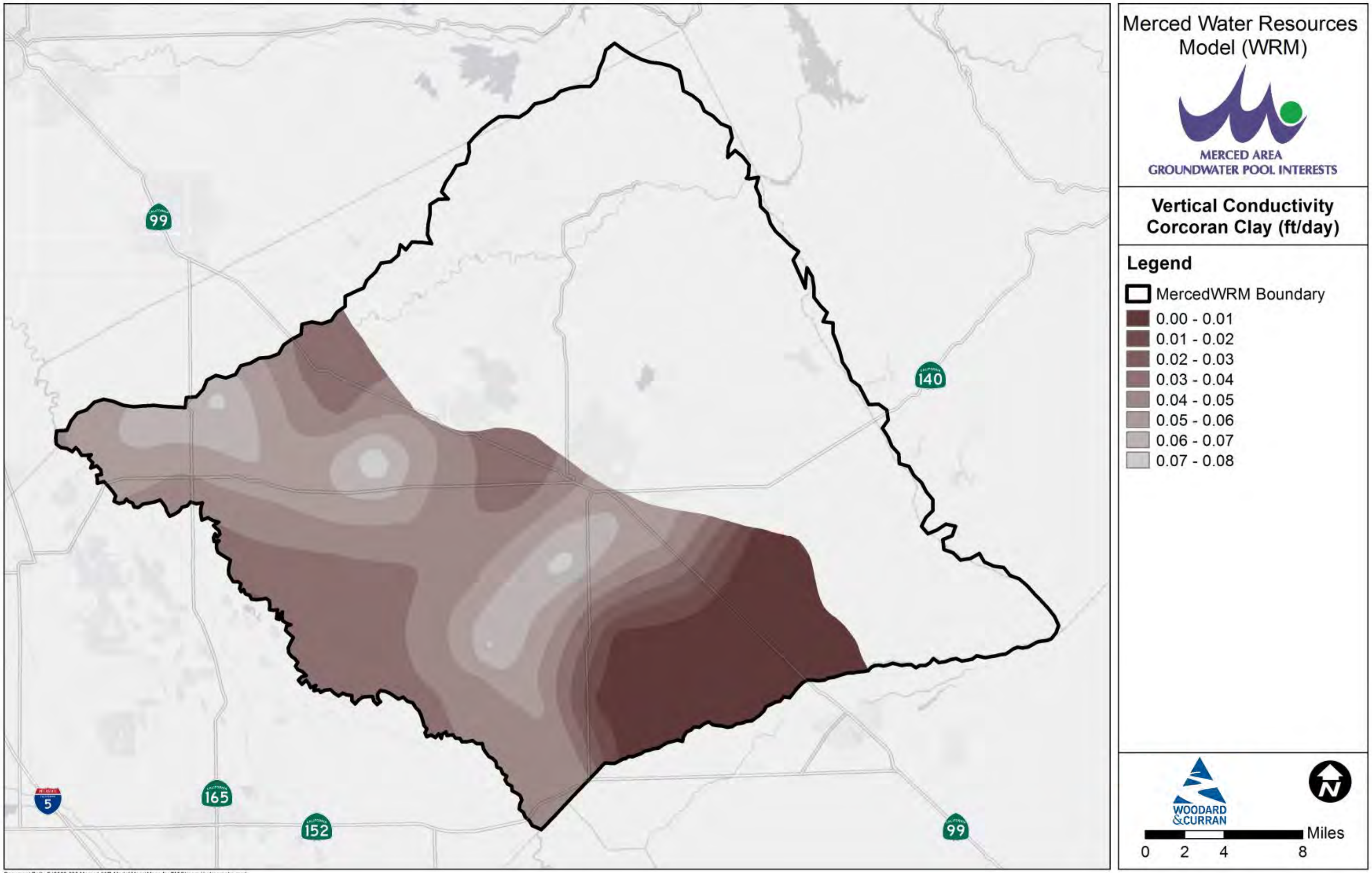


Figure 86: Aquifer Parameters - Vertical Hydraulic Conductivity of the Corcoran Clay

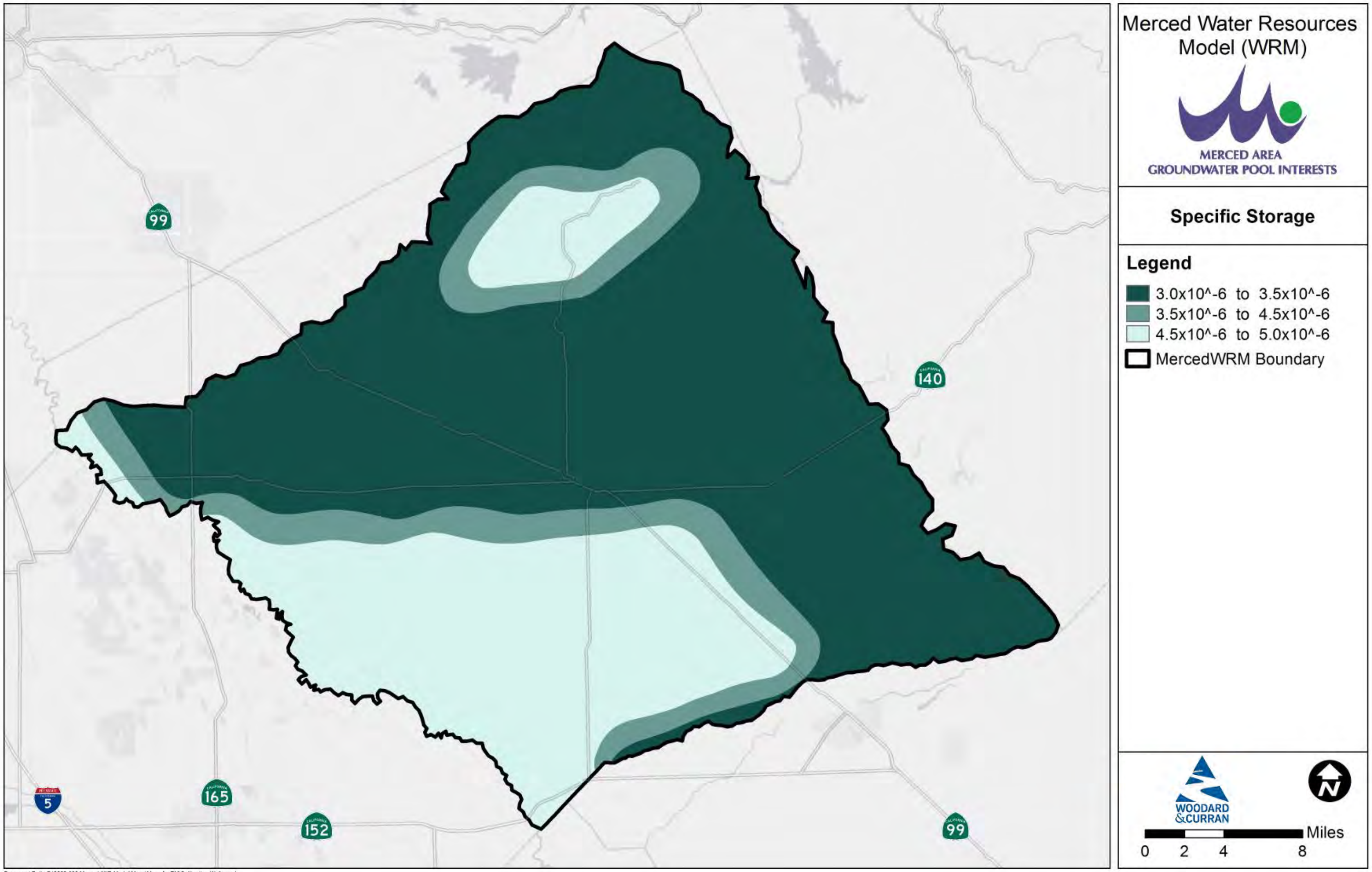


Figure 87: Aquifer Parameters - Specific Storage

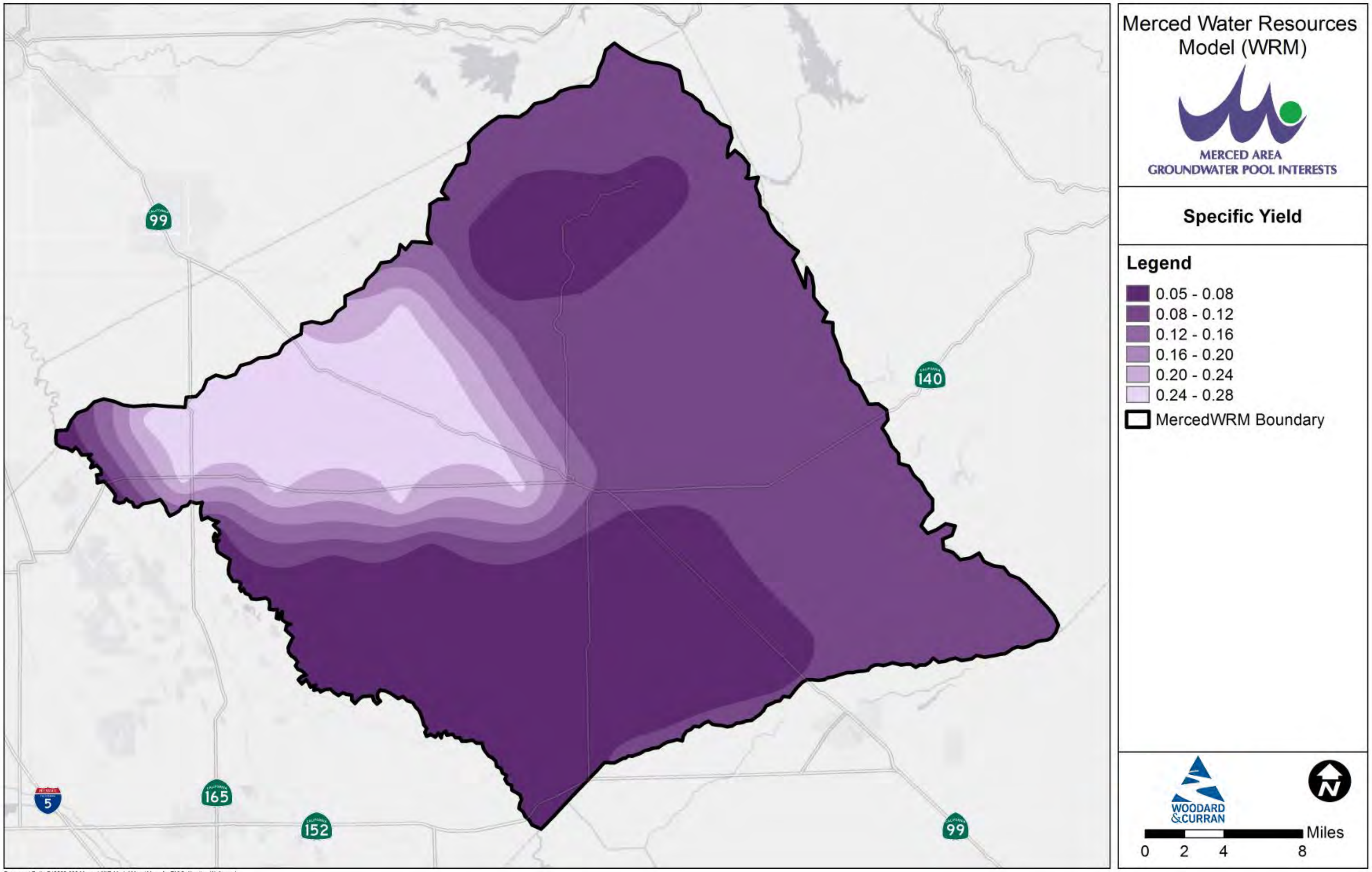


Figure 88: Aquifer Parameters - Specific Yield

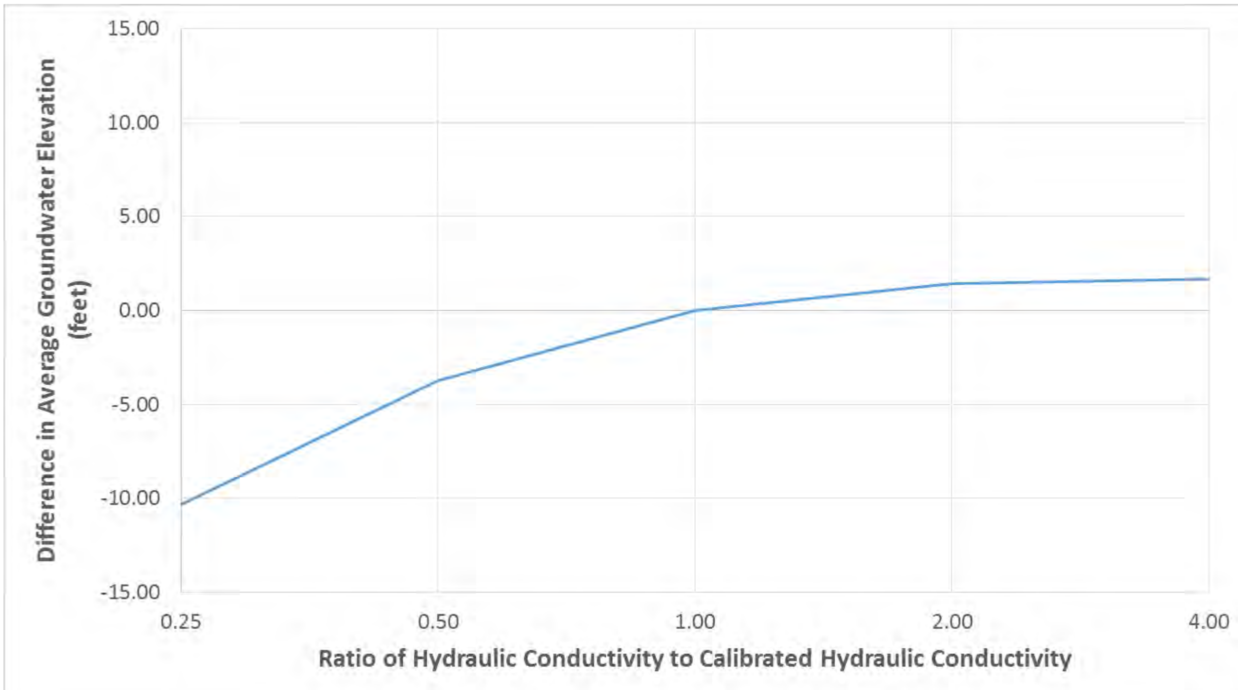


Figure 89: Sensitivity Analysis of Hydraulic Conductivity - Difference in Average Groundwater Elevation (feet)

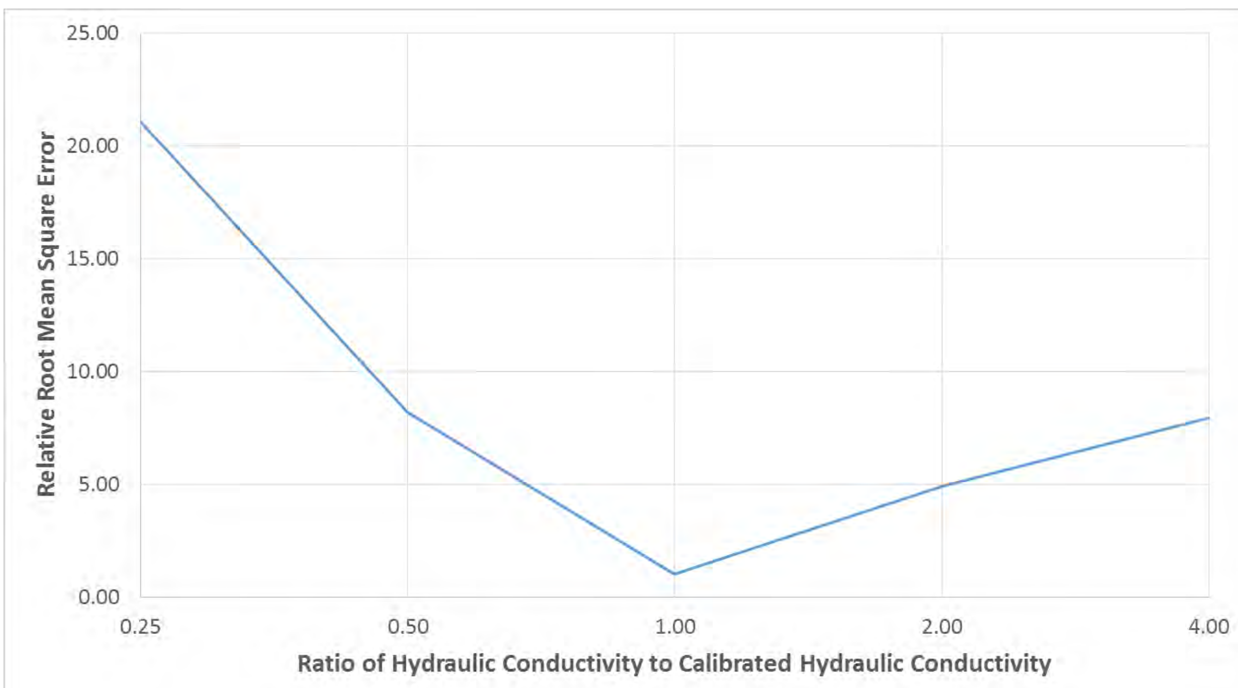


Figure 90: Sensitivity Analysis of Hydraulic Conductivity - Relative Root Mean Square Error

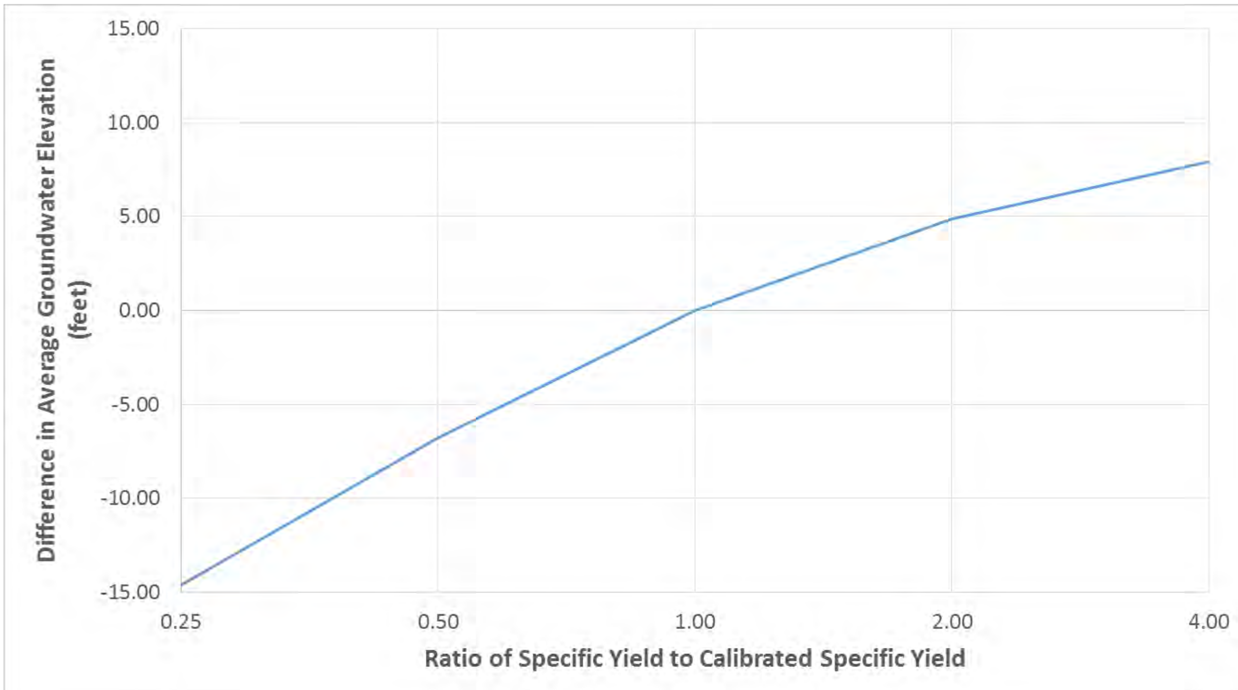


Figure 91: Sensitivity Analysis of Specific Yield - Difference in Average Groundwater Elevation (feet)

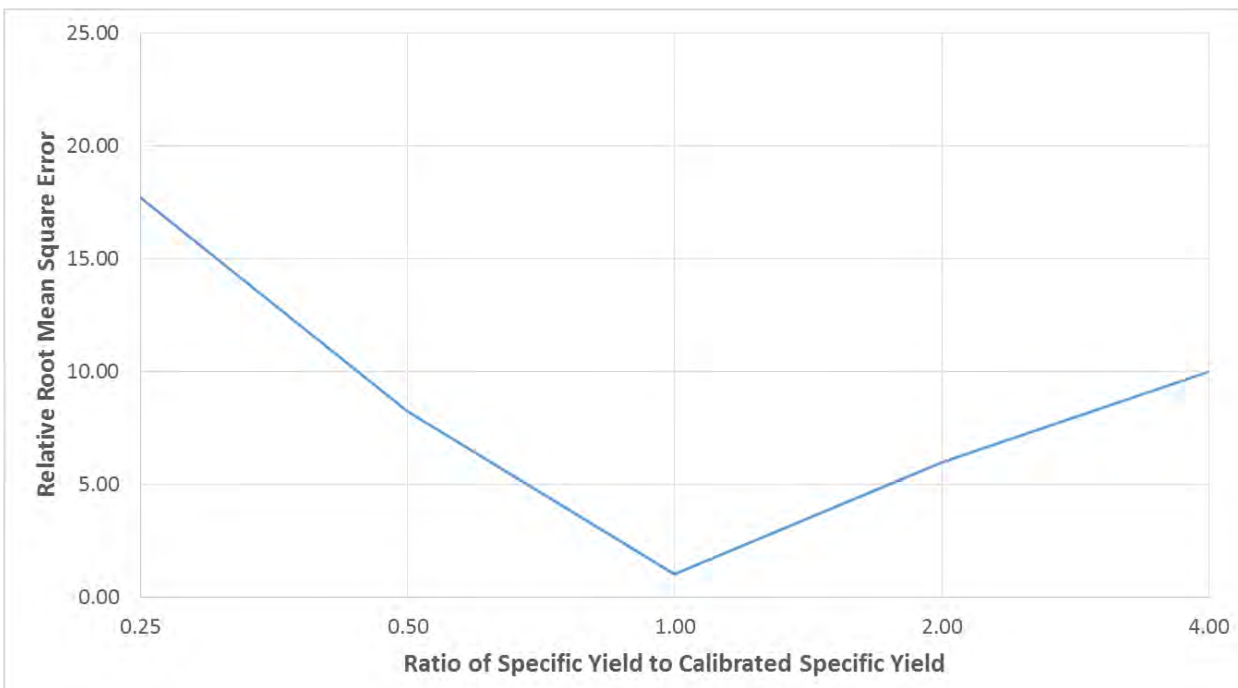


Figure 92: Sensitivity Analysis of Specific Yield - Relative Root Mean Square Error

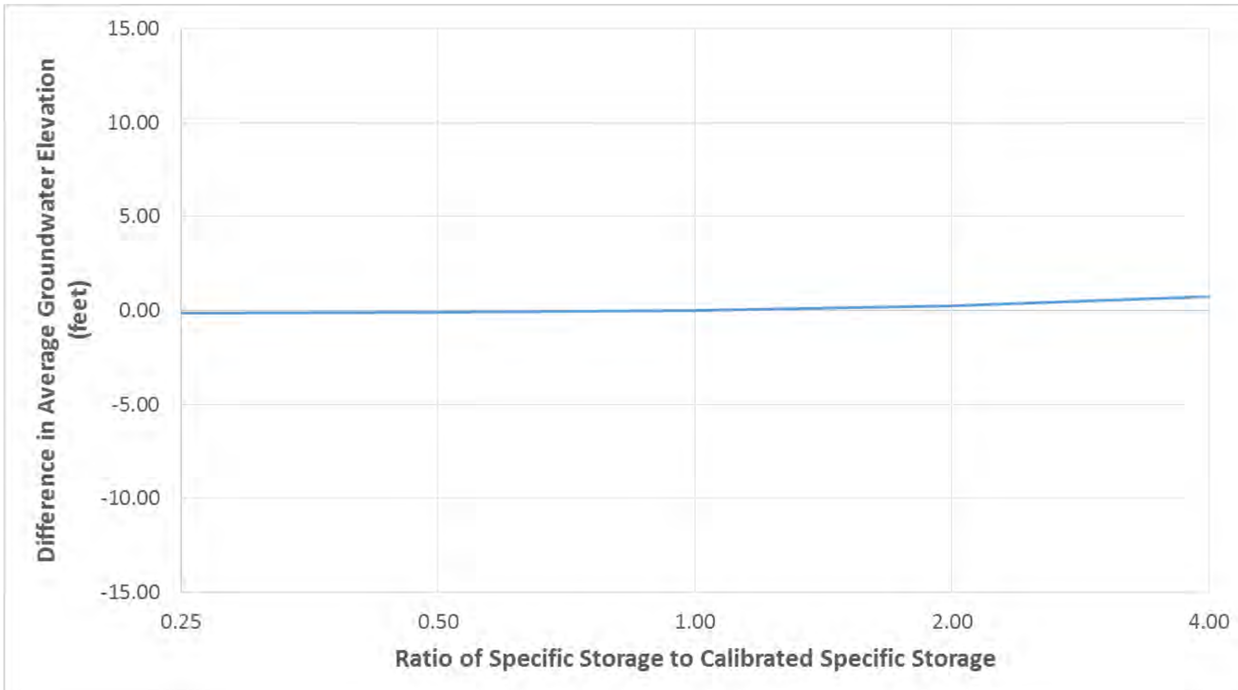


Figure 93: Sensitivity Analysis of Specific Storage - Difference in Average Groundwater Elevation (feet)

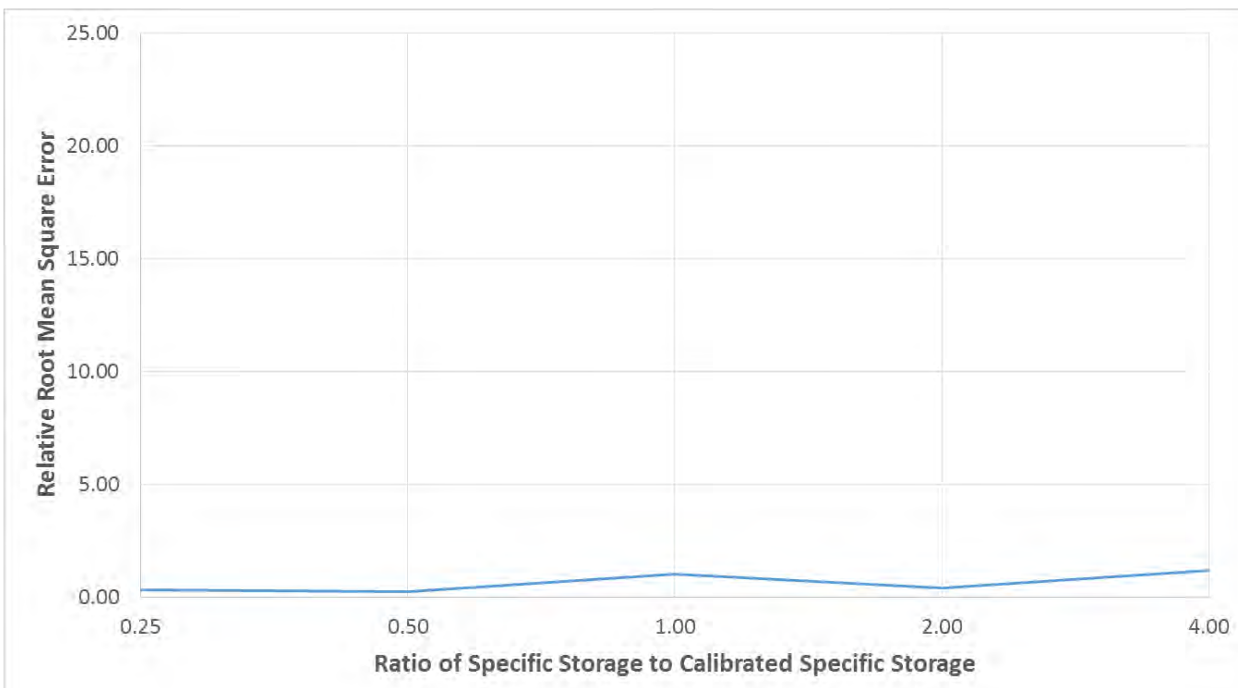


Figure 94: Sensitivity Analysis of Specific Storage - Relative Root Mean Square Error

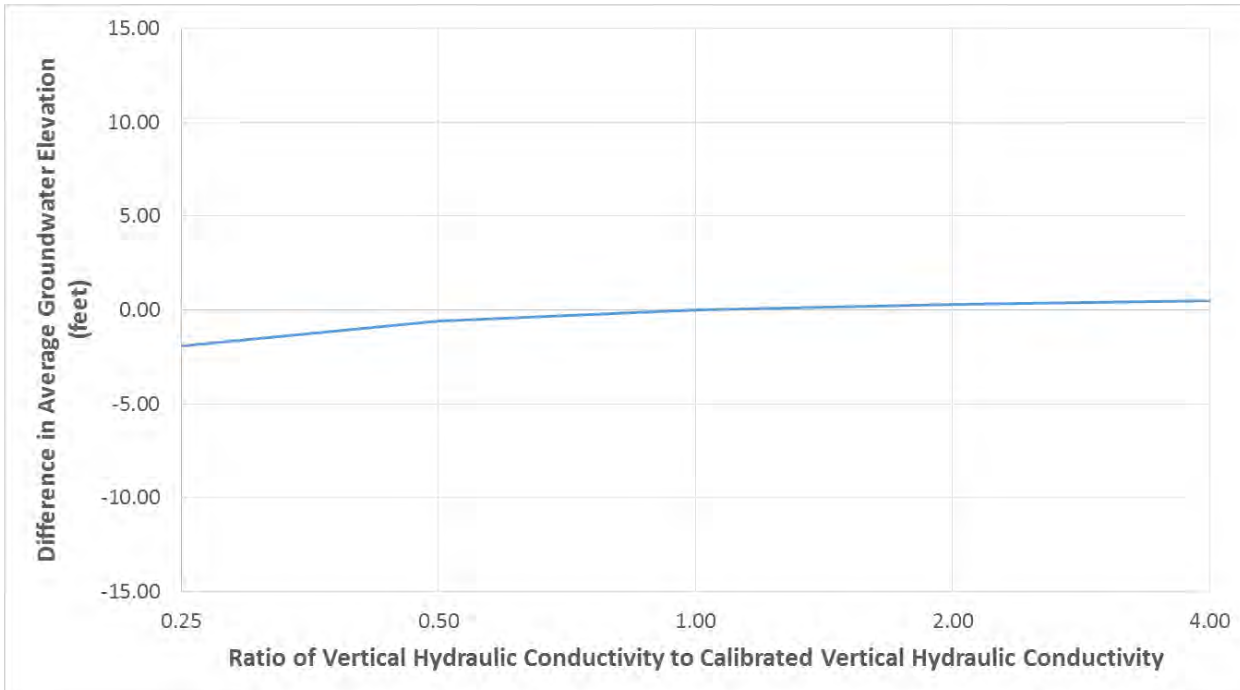


Figure 95: Sensitivity Analysis of Vertical Hydraulic Conductivity of the Corcoran Clay - Difference in Average Groundwater Elevation (feet)

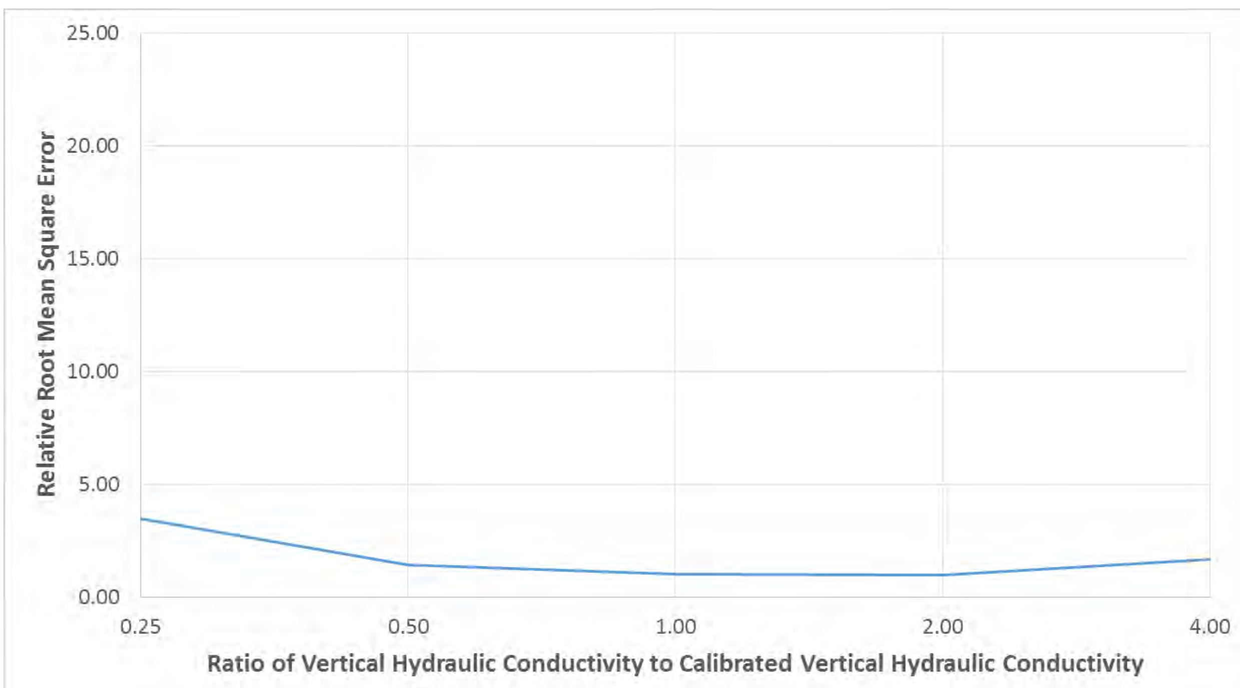


Figure 96: Sensitivity Analysis Vertical Hydraulic Conductivity of the Corcoran Clay - Relative Root Mean Square Error

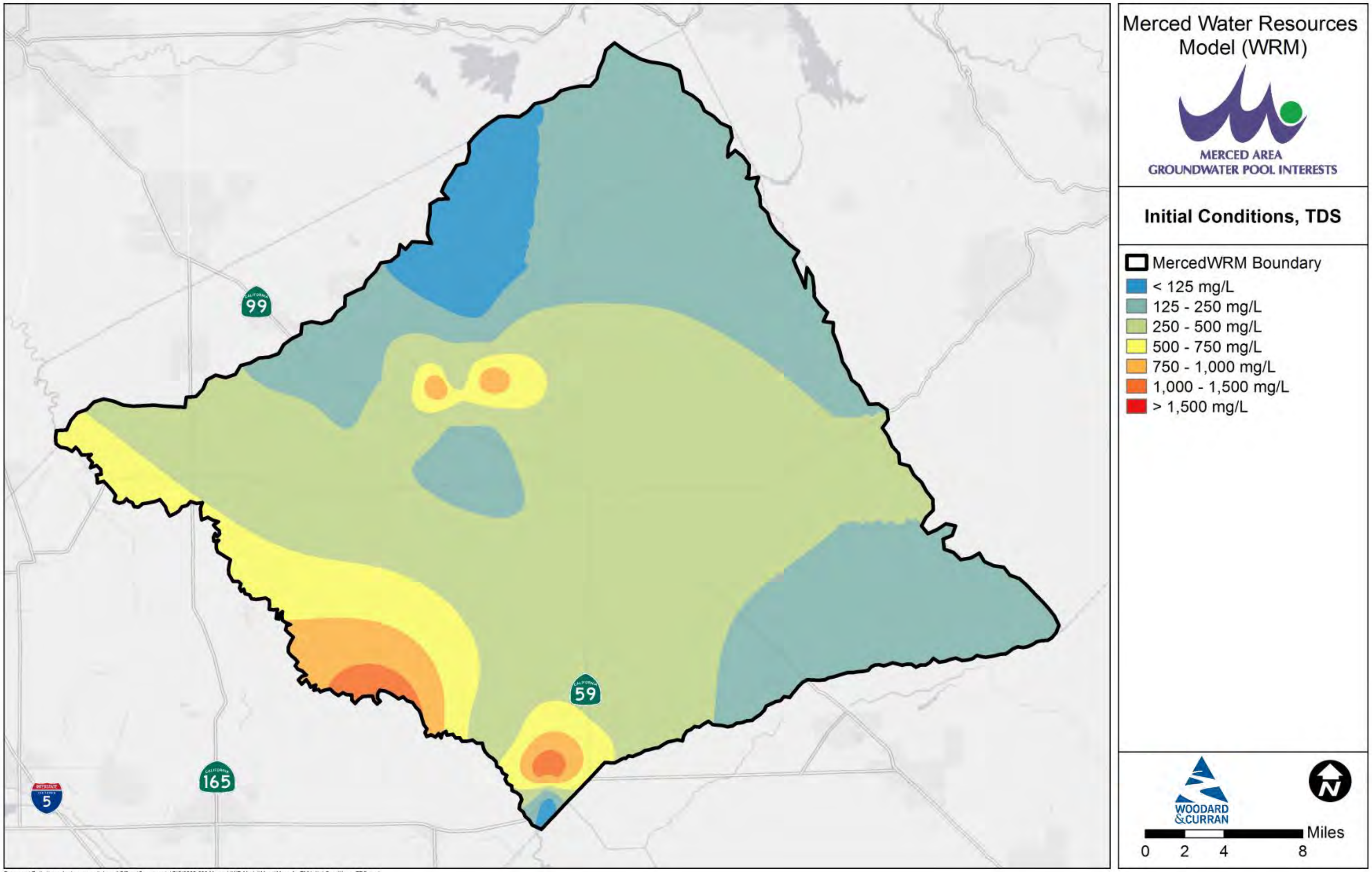


Figure 97: Initial Conditions, TDS

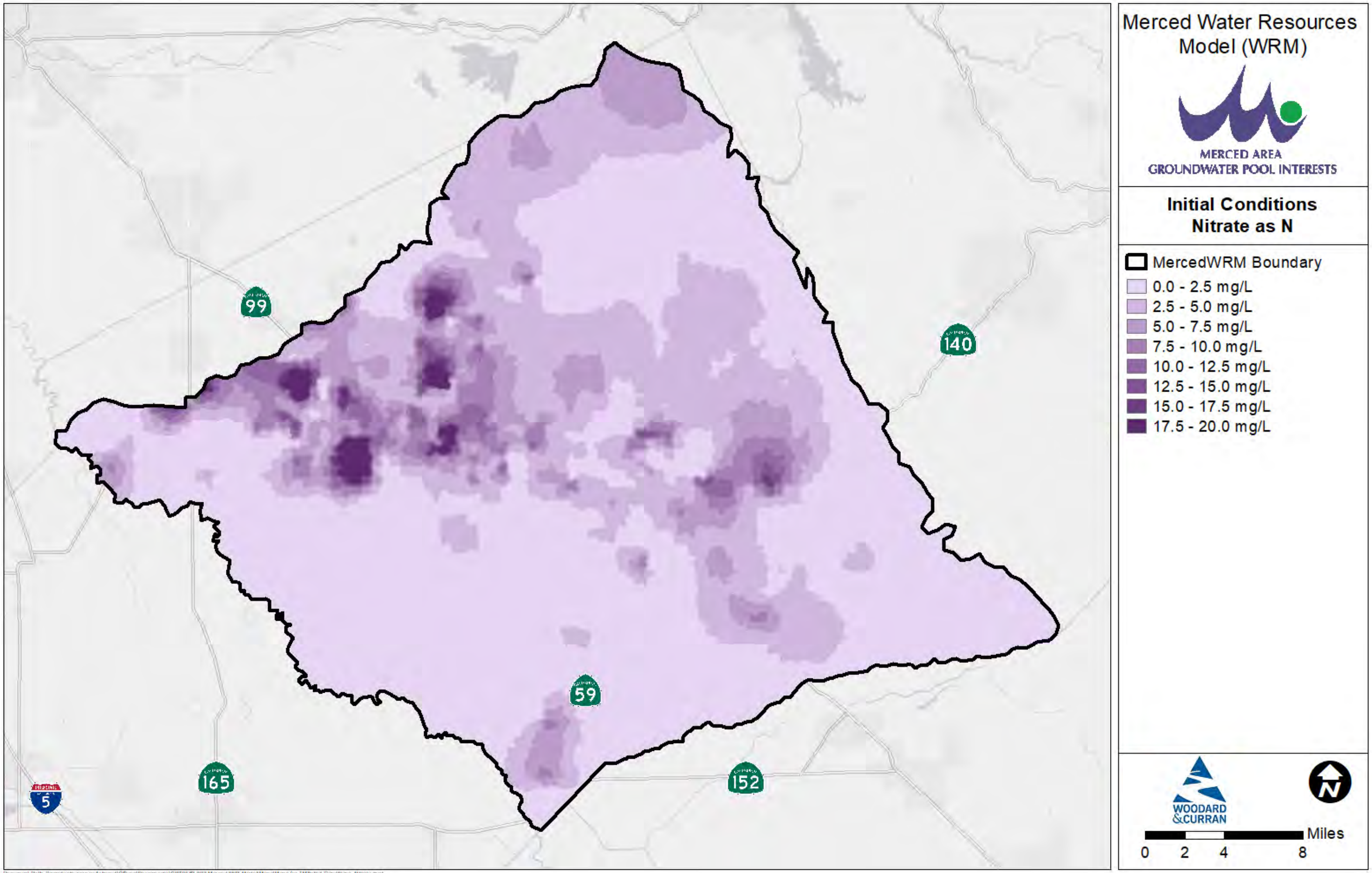


Figure 98: Initial Conditions, Nitrate as N

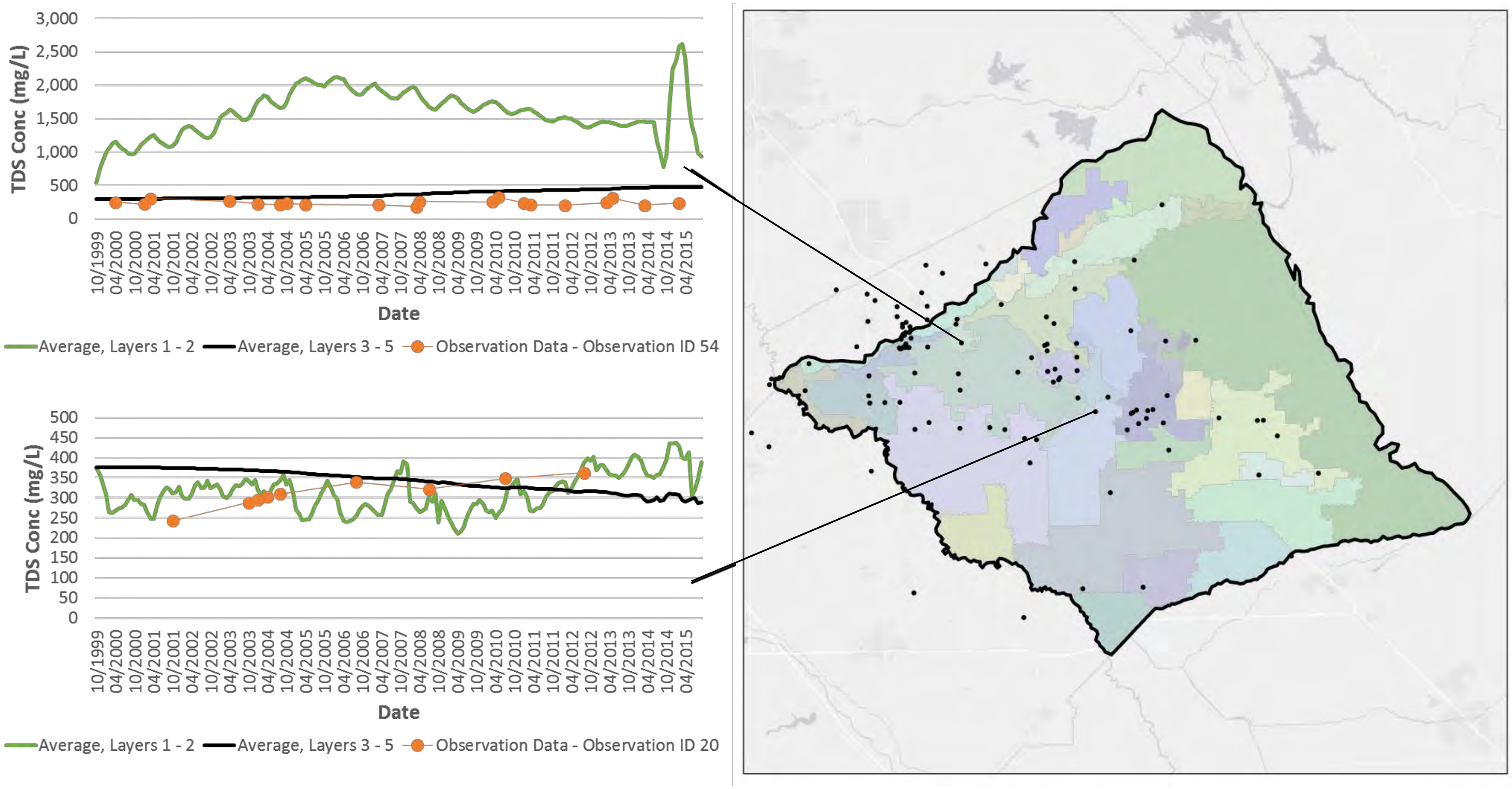


Figure 99: Sample TDS Concentration

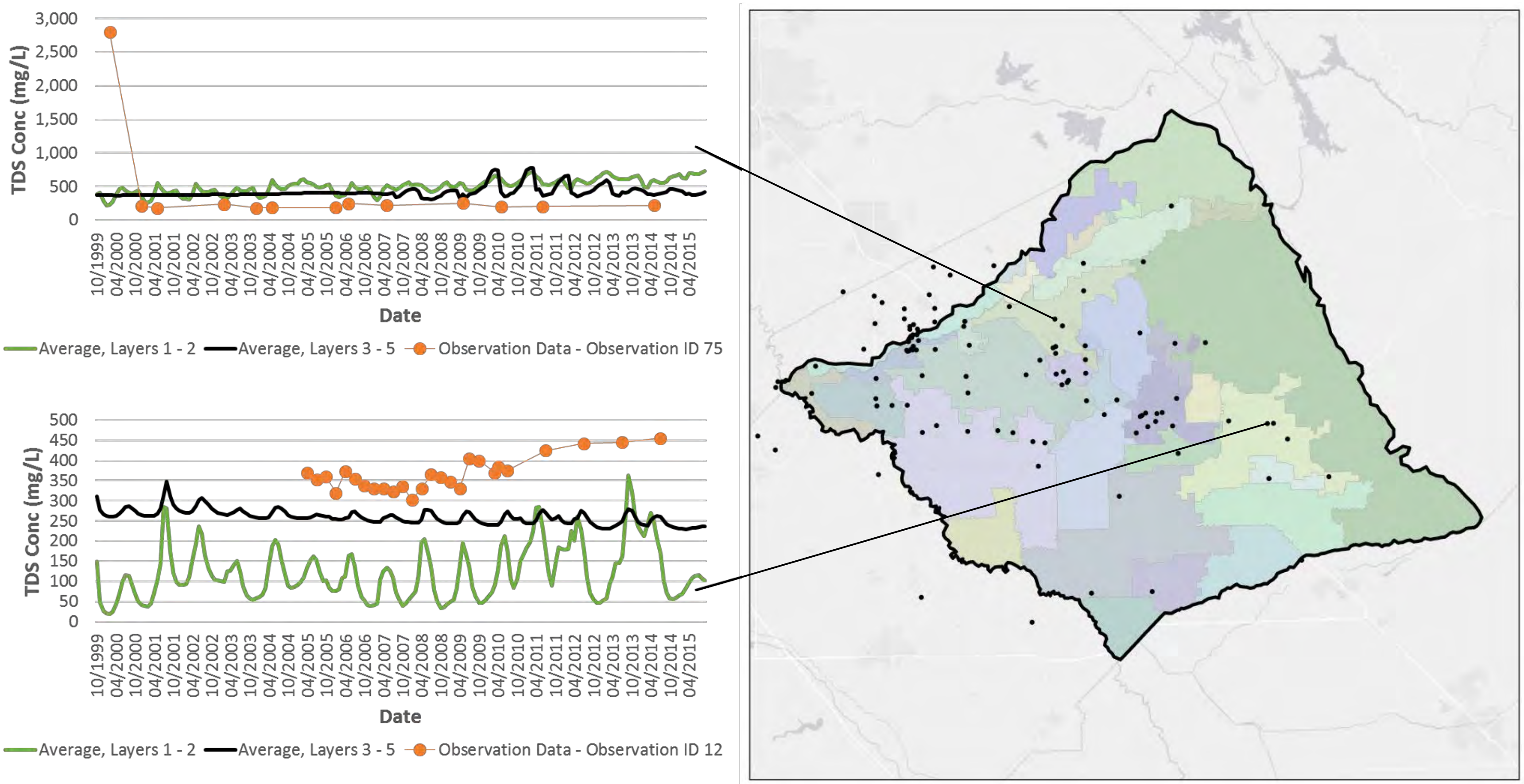


Figure 100: Sample TDS Concentration

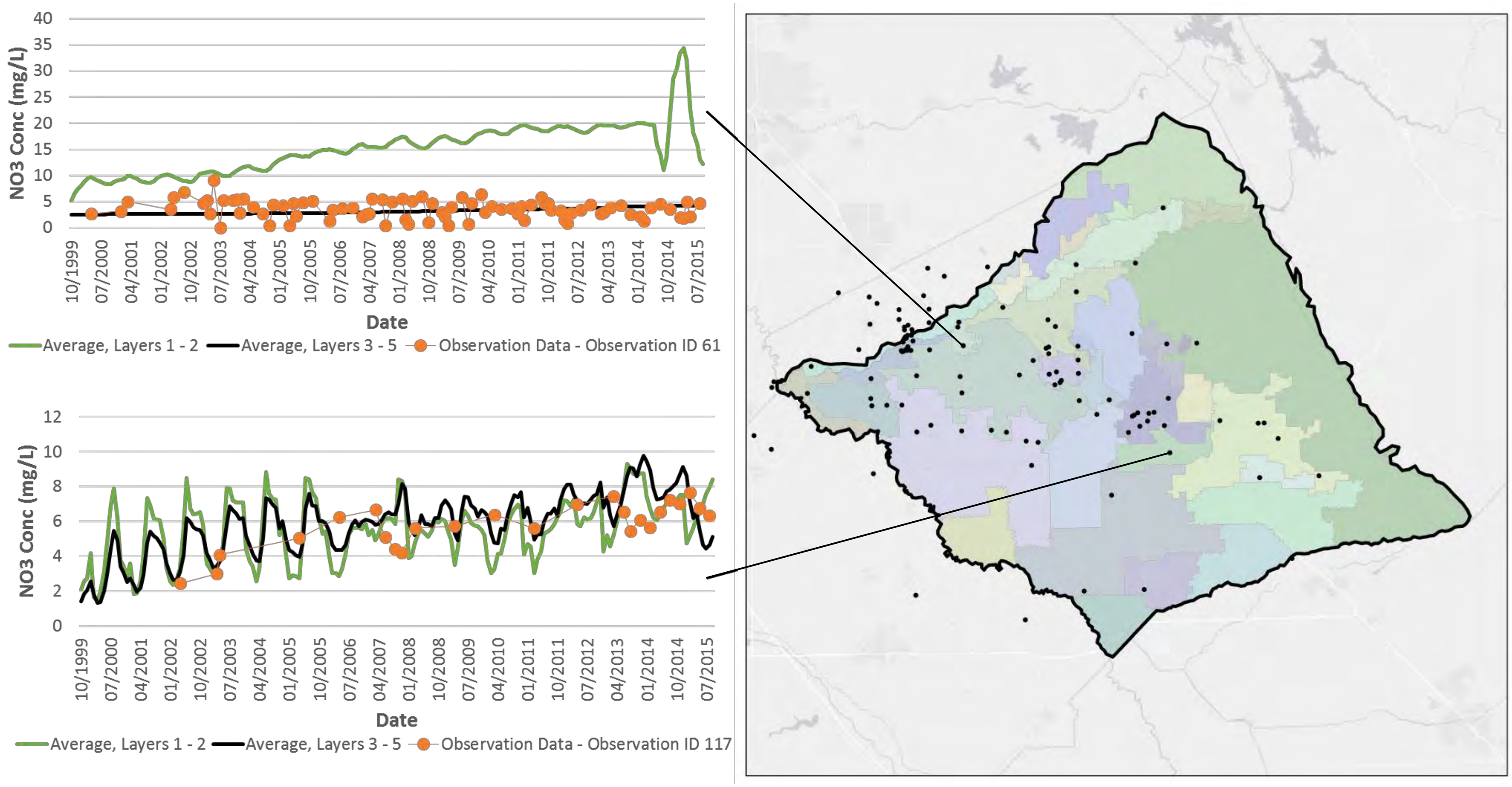


Figure 101: Sample Nitrate Concentration

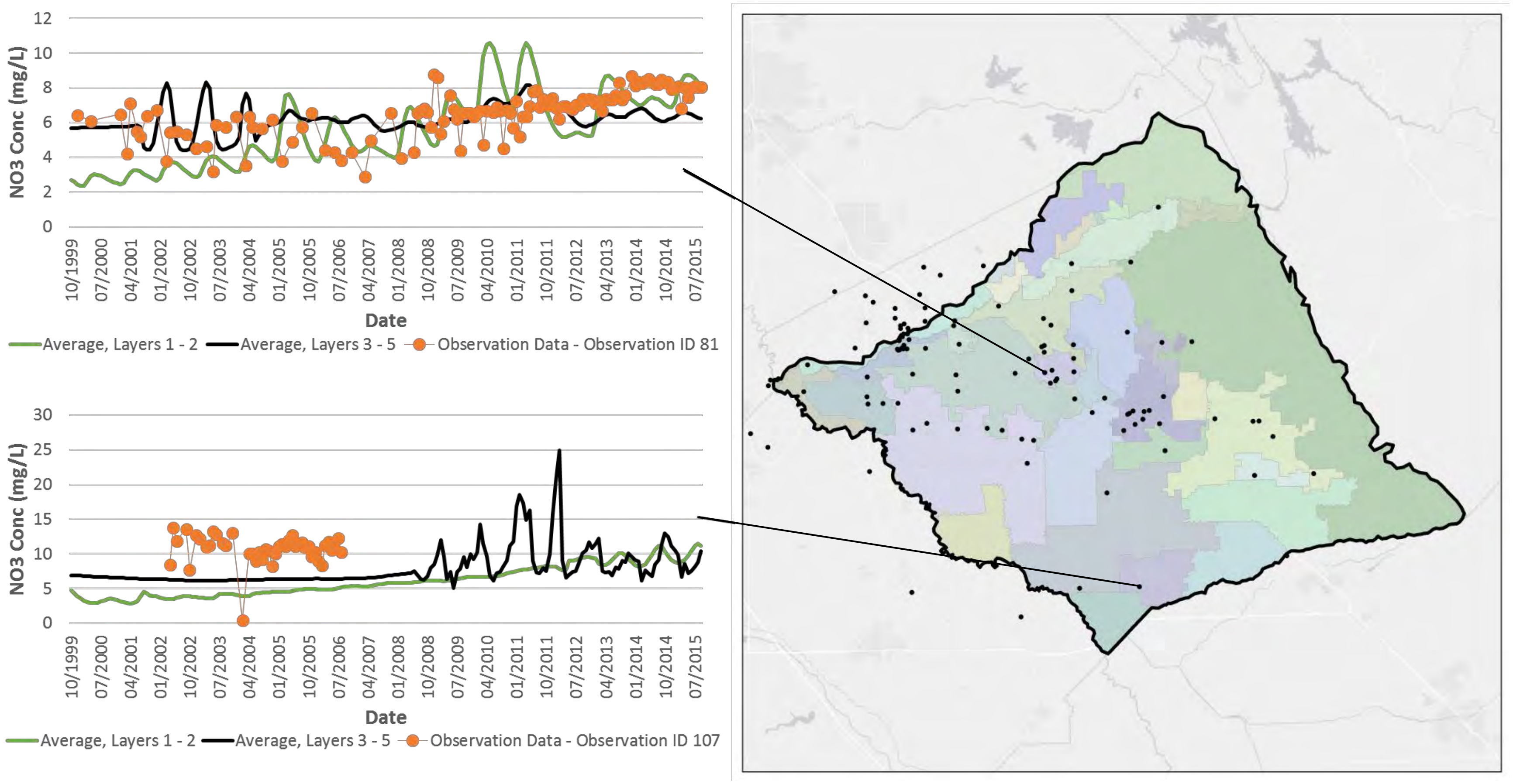
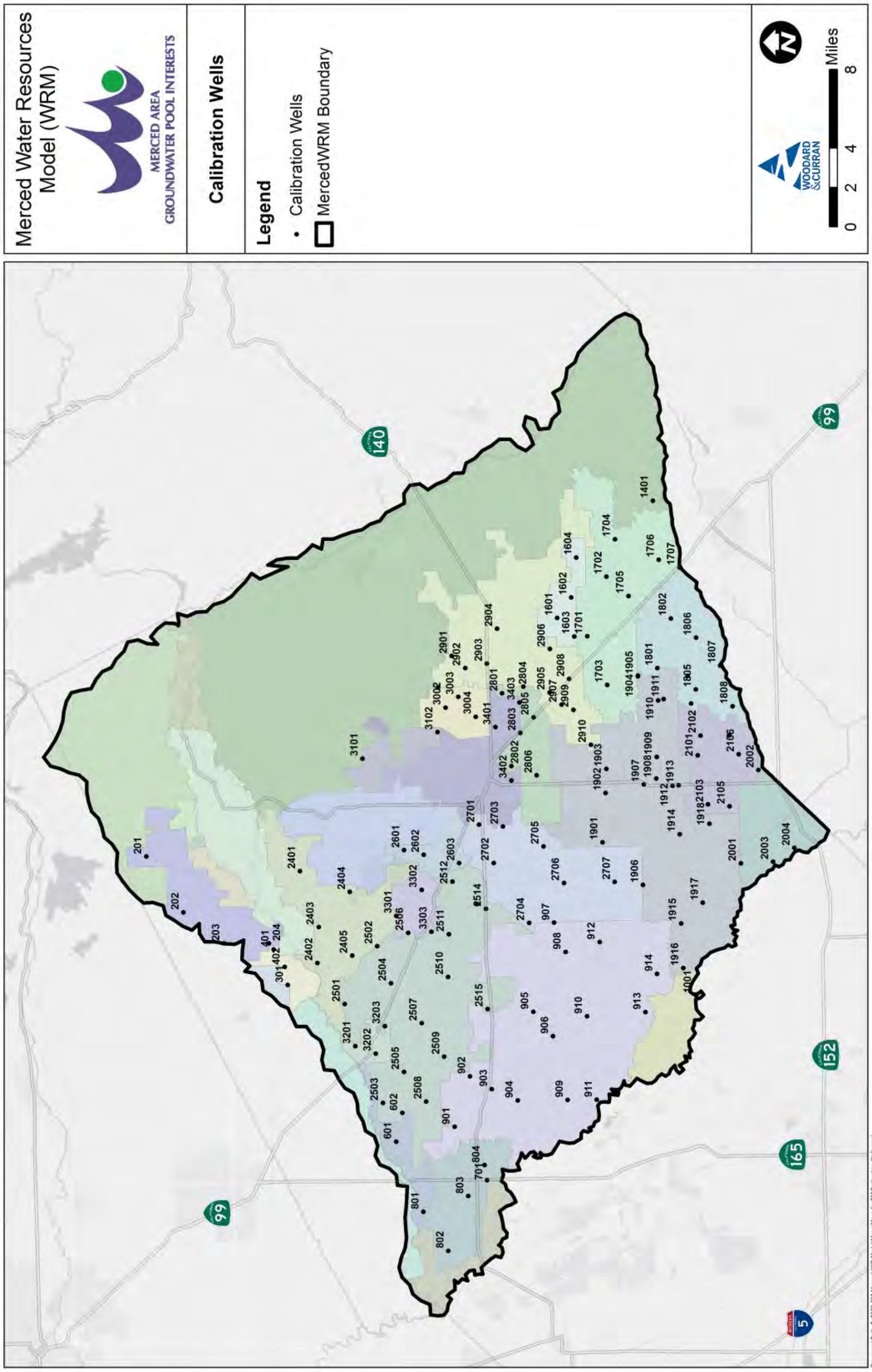


Figure 102: Sample Nitrate Concentration

Appendix A - Groundwater Hydrographs


Merced Water Resources Model (WRM)
MERCED AREA GROUNDWATER POOL INTERESTS
Calibration Wells
Legend
Calibration Wells
MercedWRM Boundary
WOODARD & CURRAN
0 2 4 8
Miles

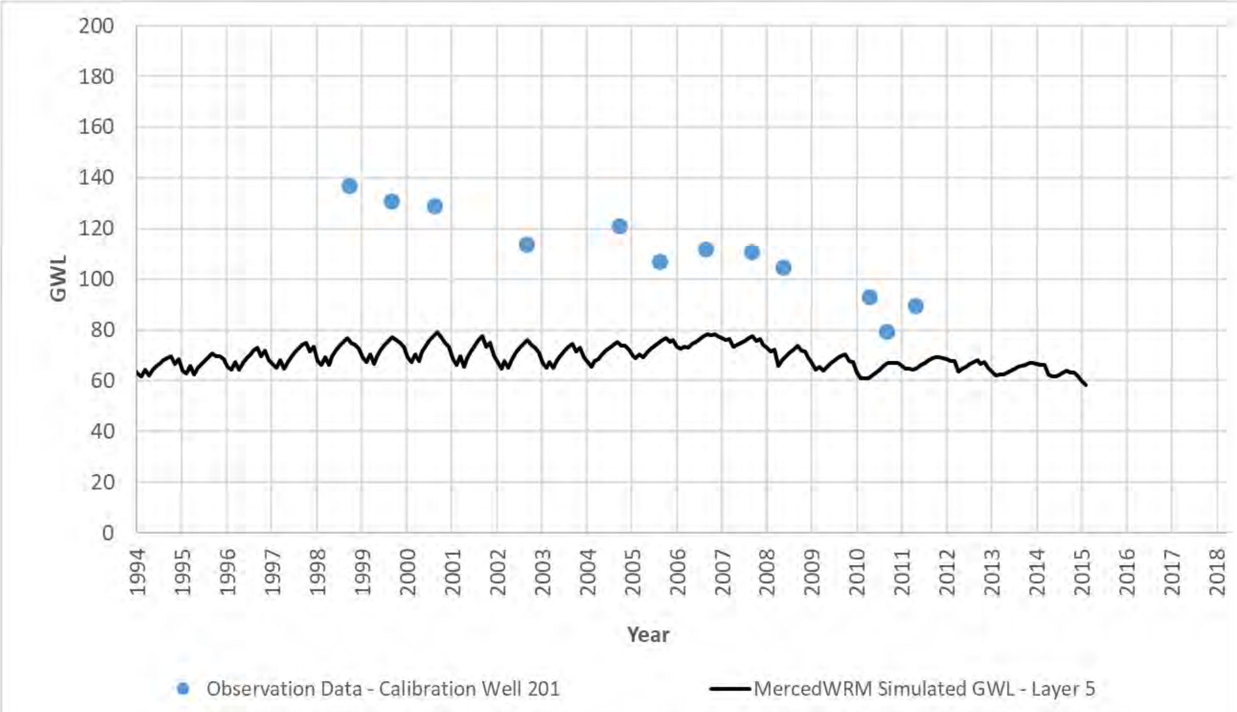


Figure A1: Calibration Well 201

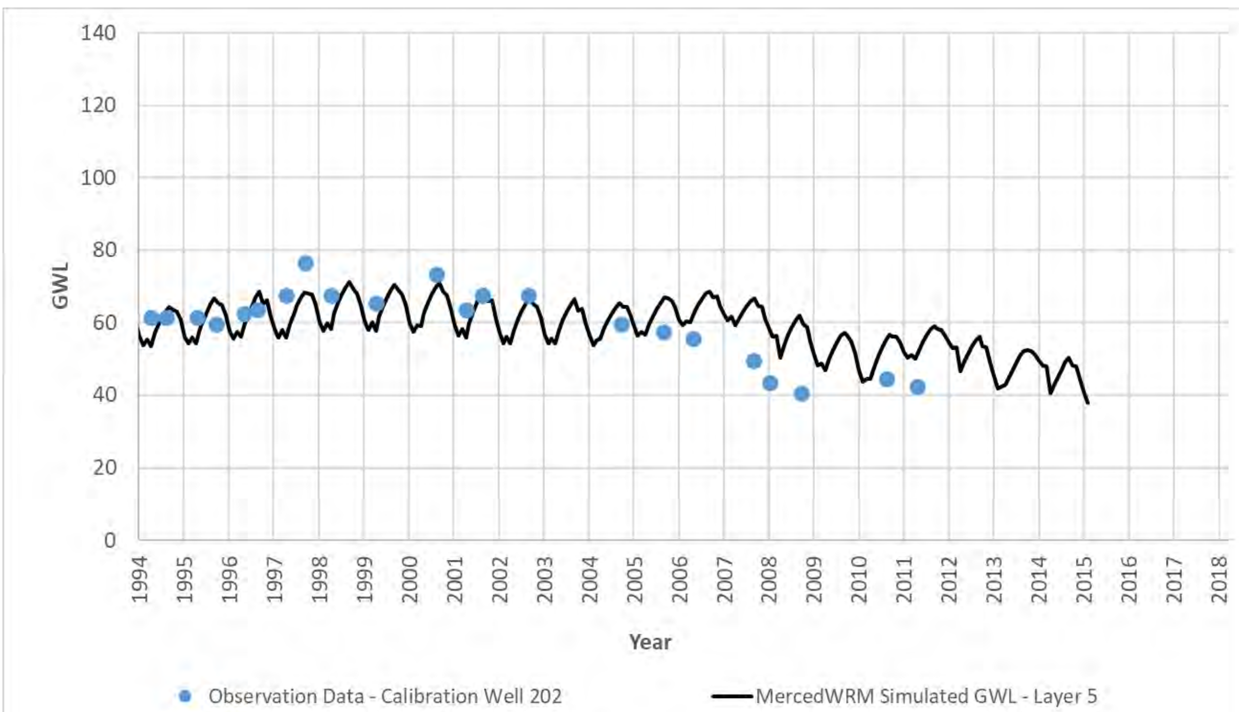


Figure A2: Calibration Well 202

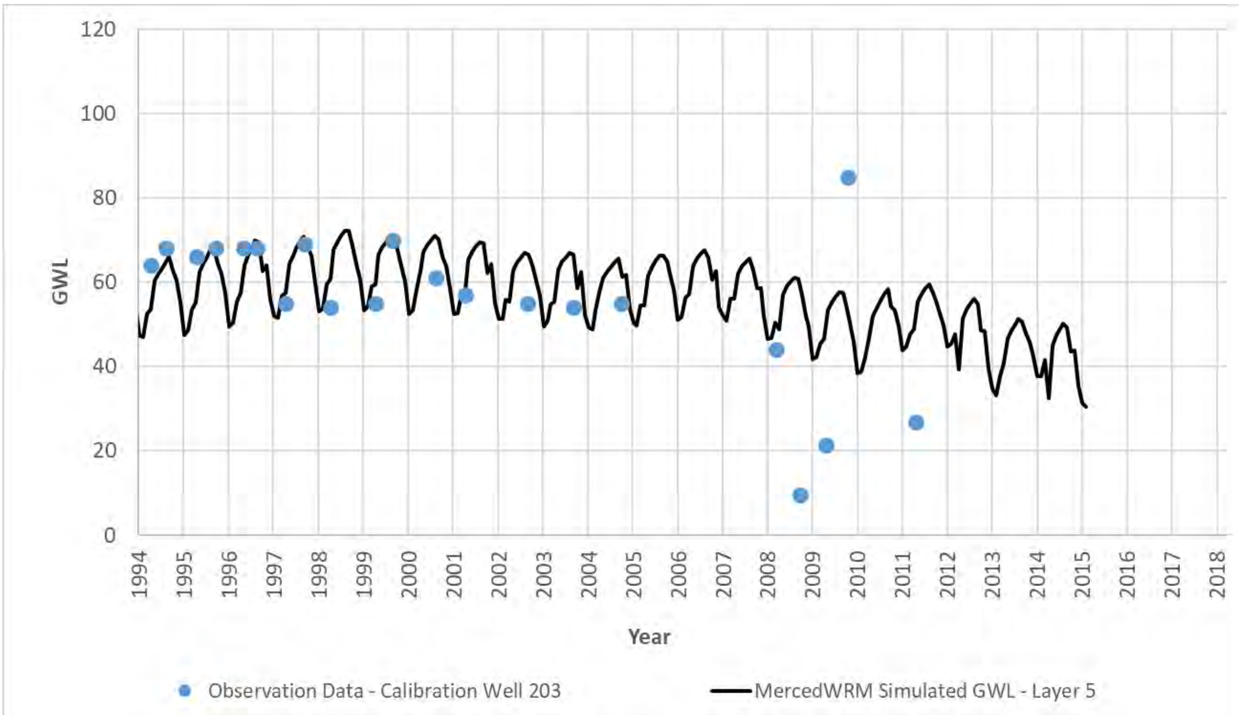


Figure A3: Calibration Well 203

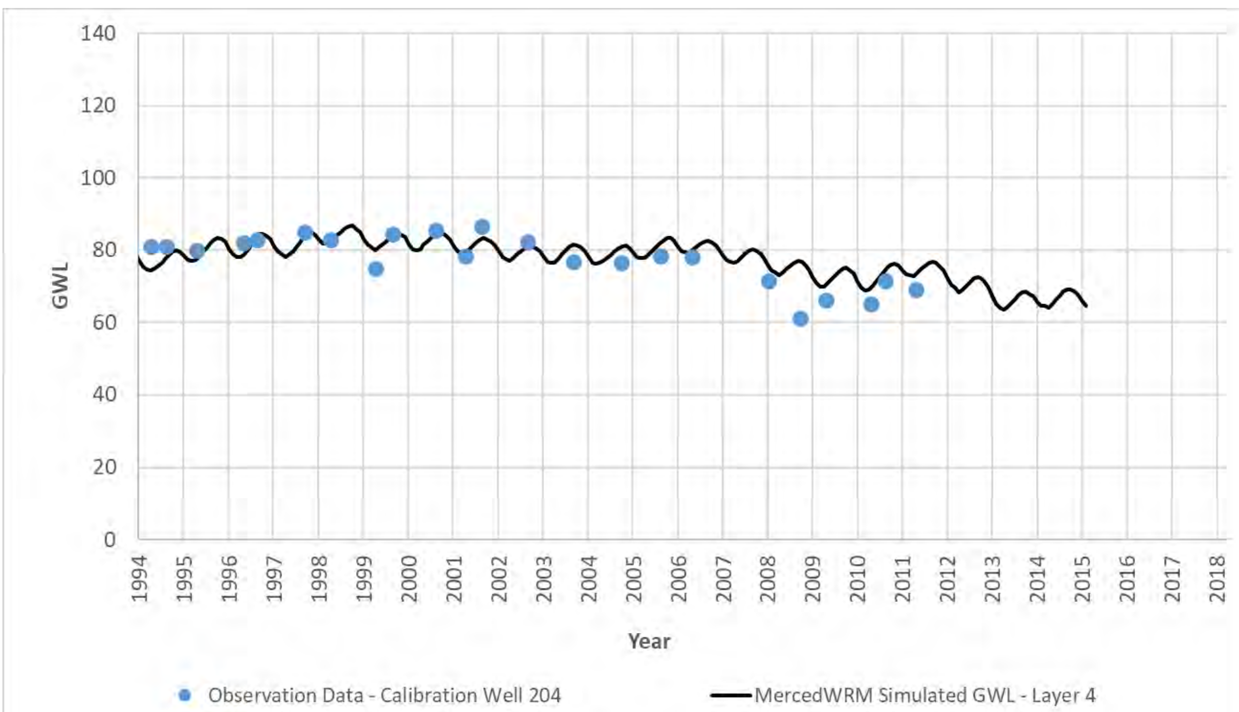


Figure A4: Calibration Well 204

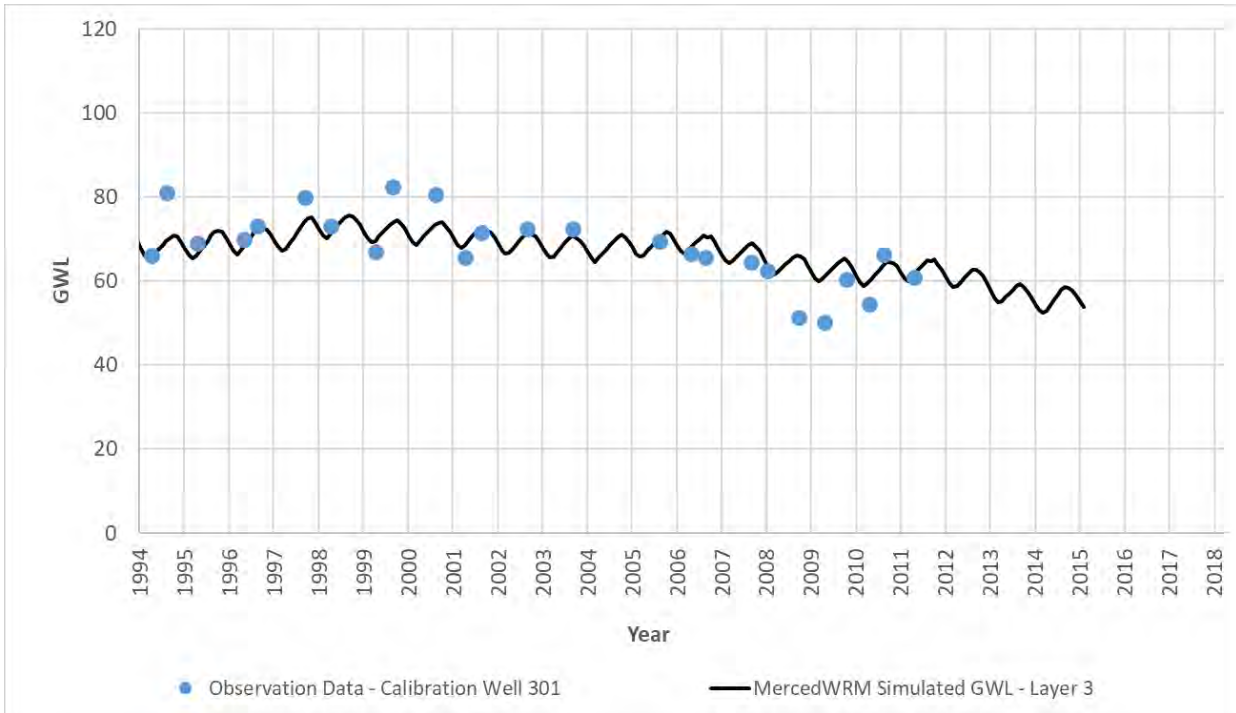


Figure A5: Calibration Well 301

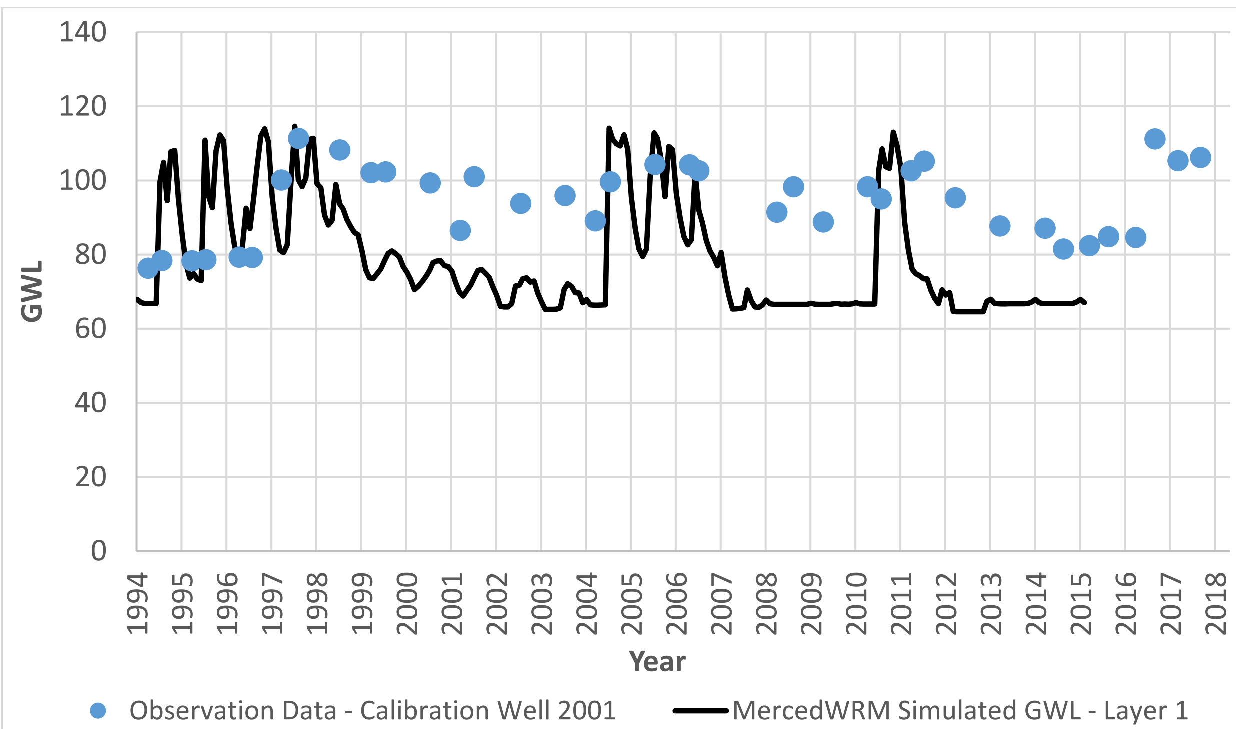


Figure A 6: Calibration Well 401

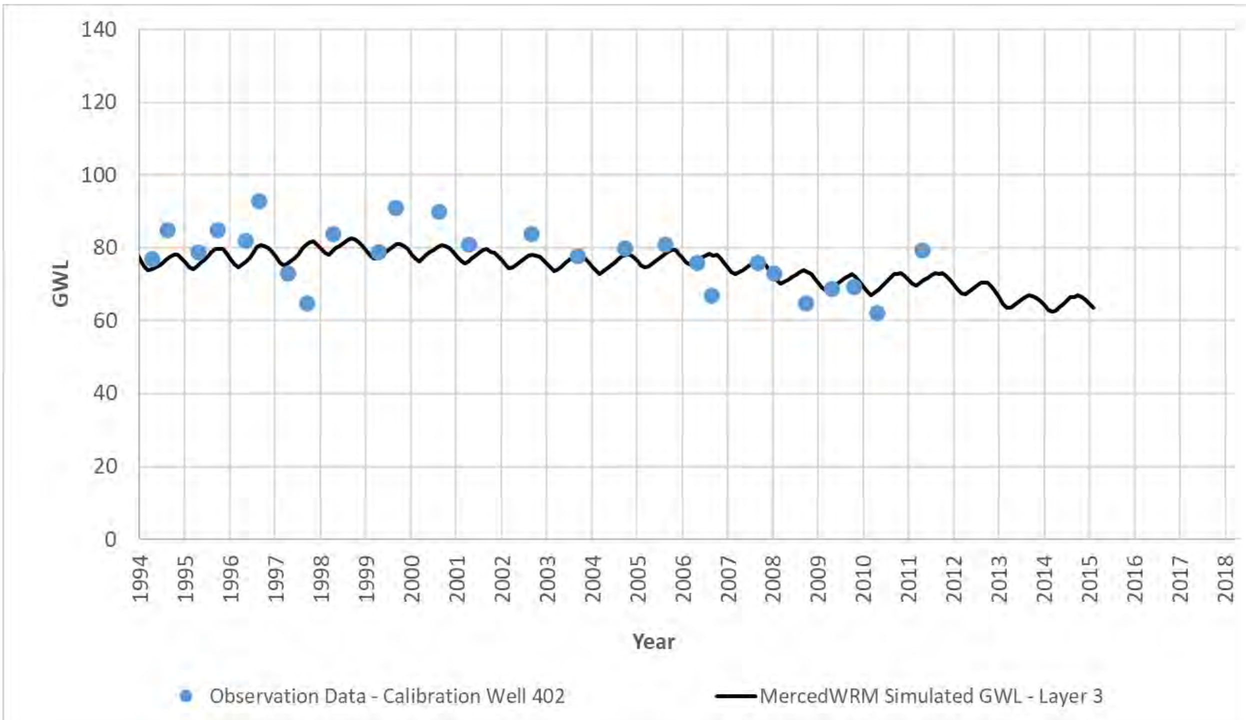


Figure A 7: Calibration Well 402

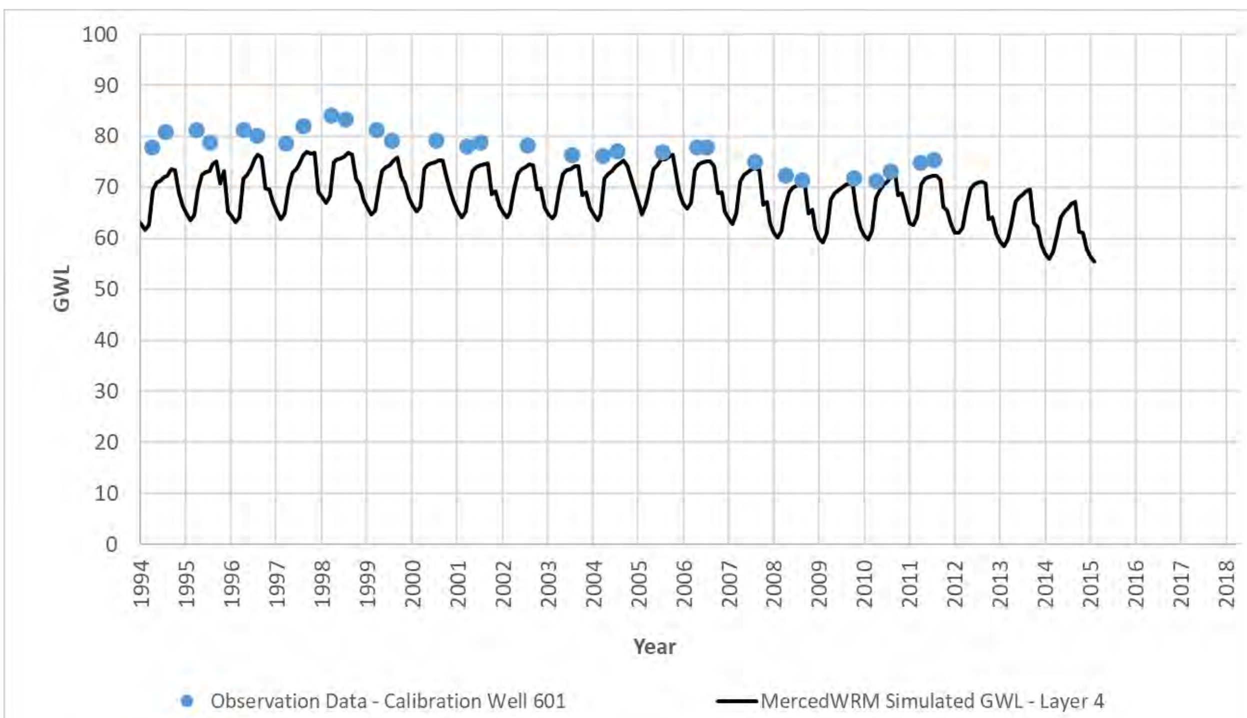


Figure A 8: Calibration Well 601

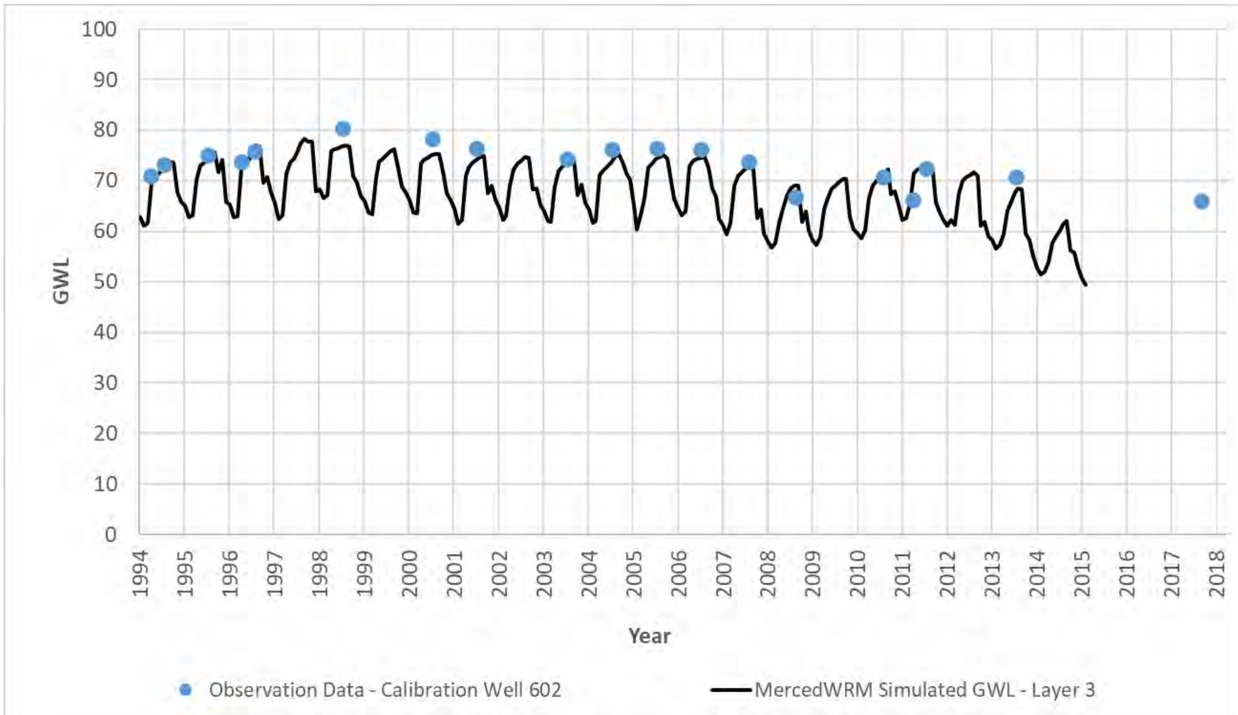


Figure A 9: Calibration Well 602

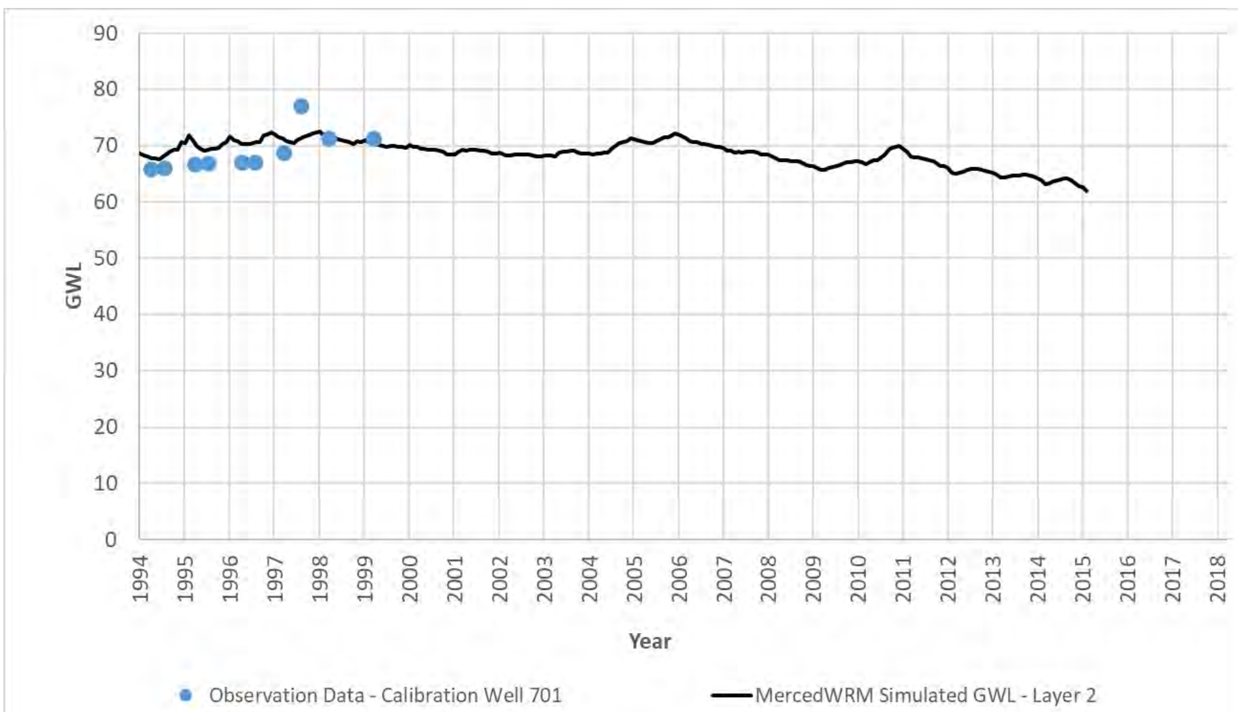


Figure A 10: Calibration Well 701

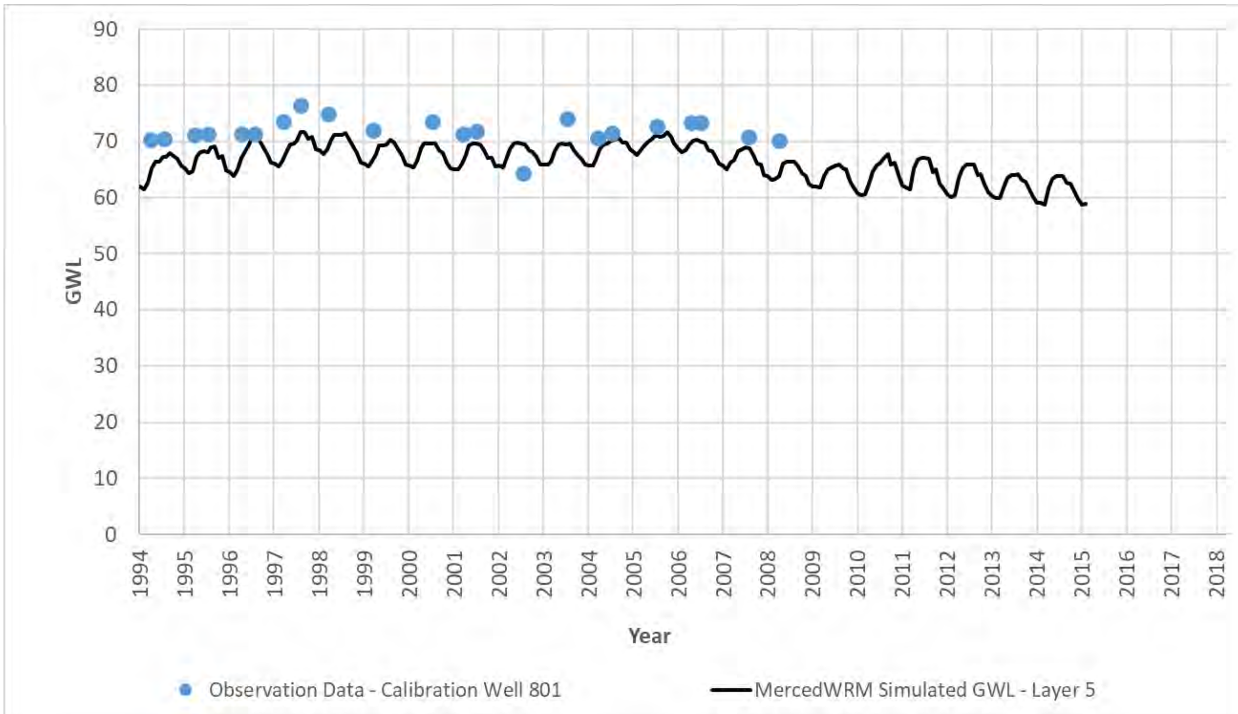


Figure A 11: Calibration Well 801

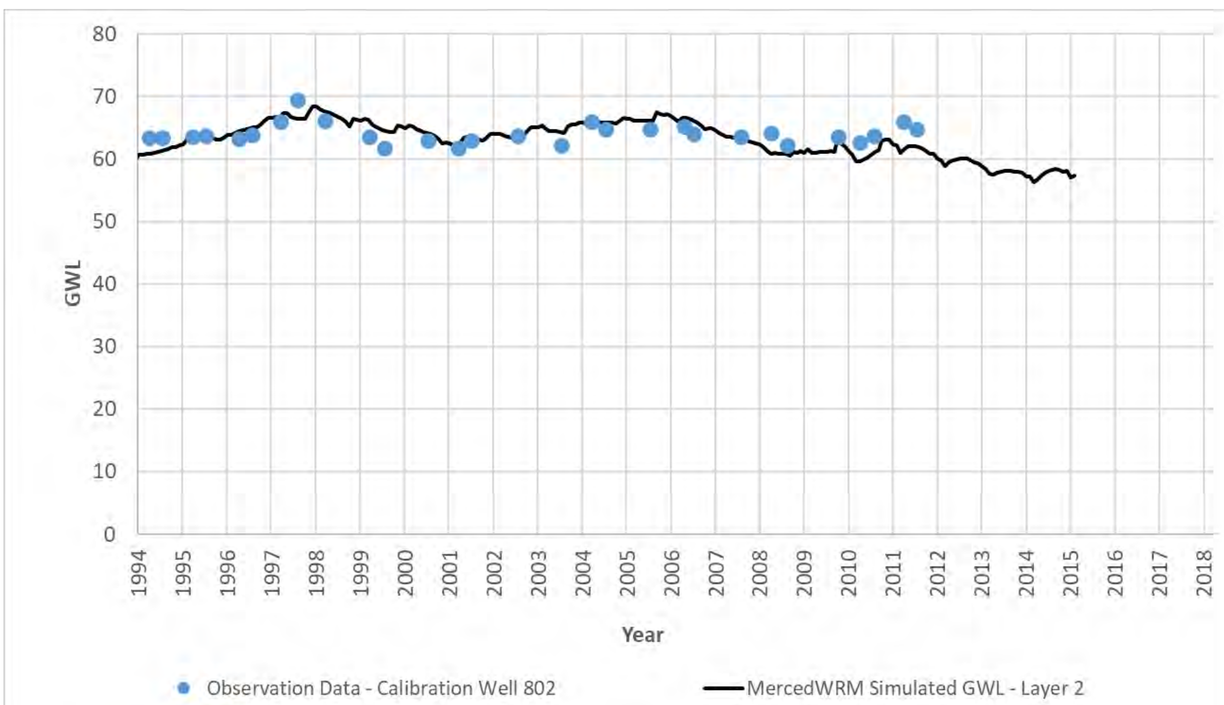


Figure A 12: Calibration Well 802

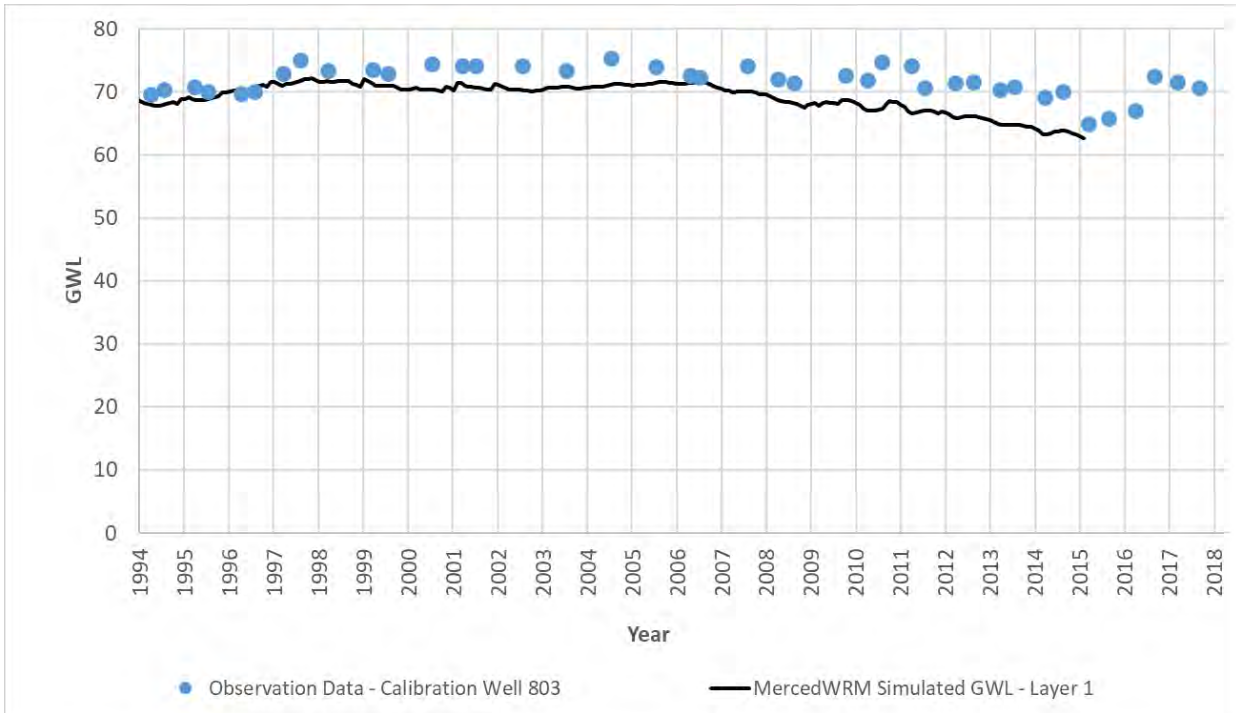


Figure A 13: Calibration Well 803

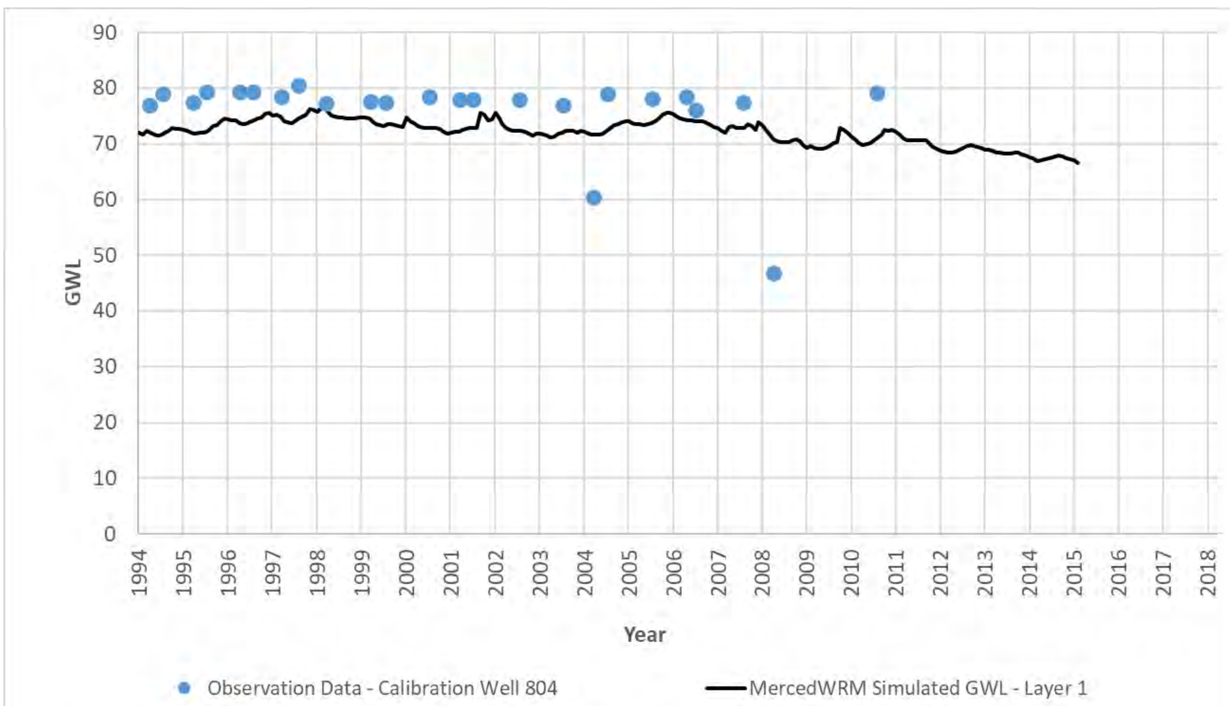


Figure A 14: Calibration Well 804

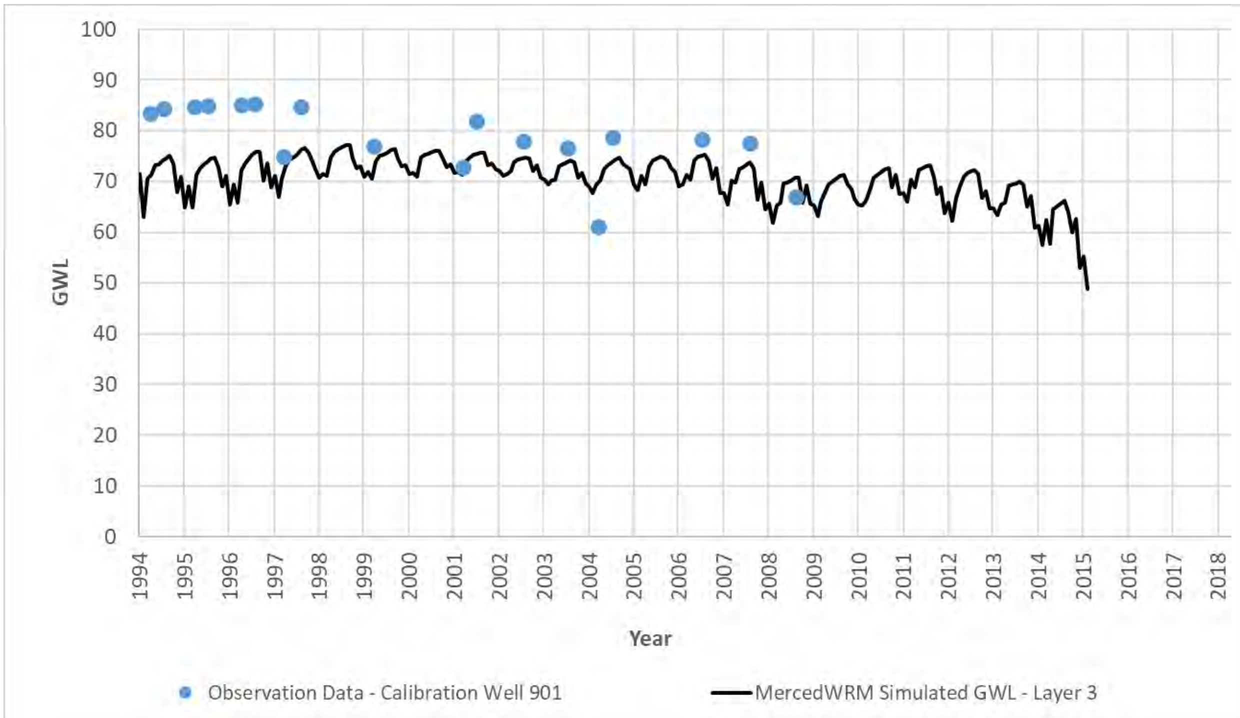


Figure A 15: Calibration Well 901

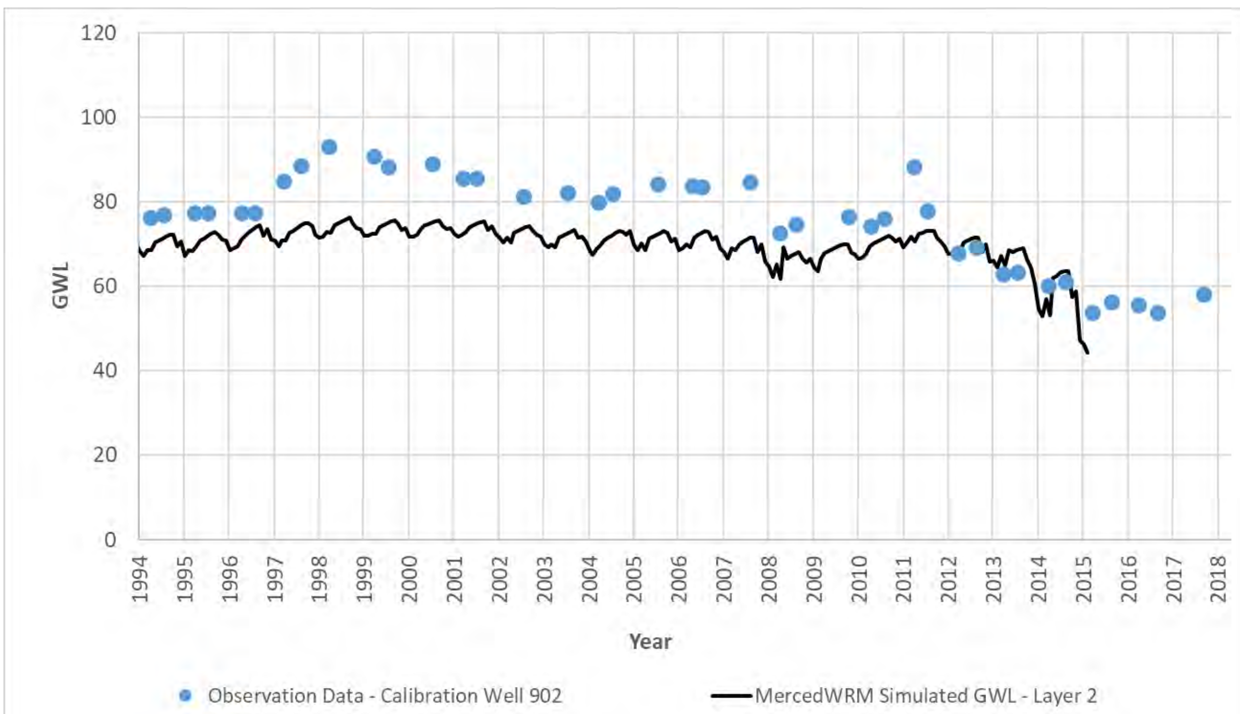


Figure A 16: Calibration Well 902

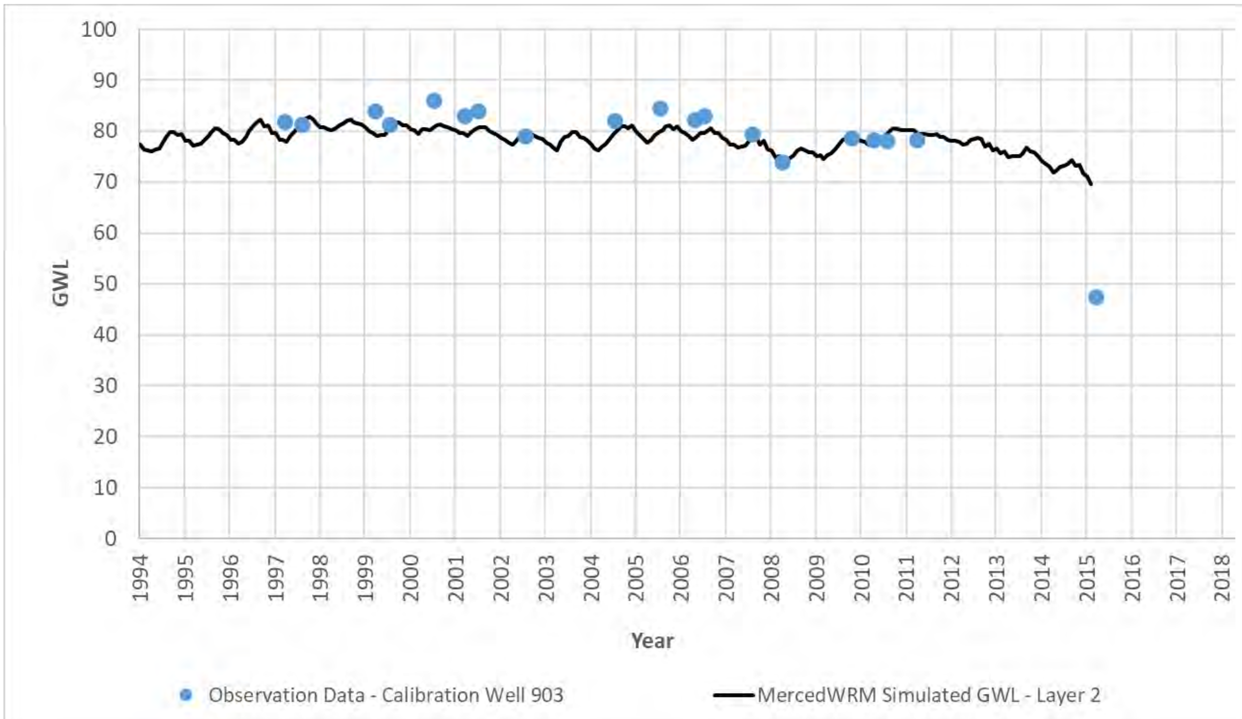


Figure A 17: Calibration Well 903

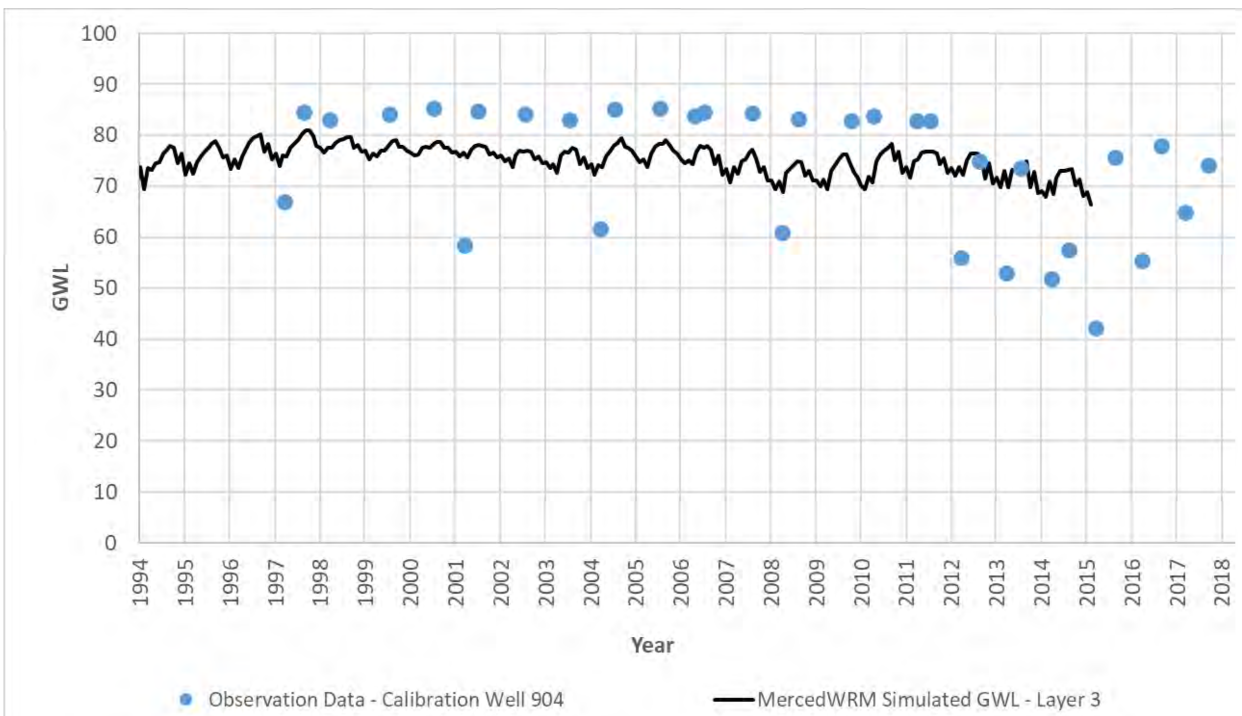


Figure A 18: Calibration Well 904

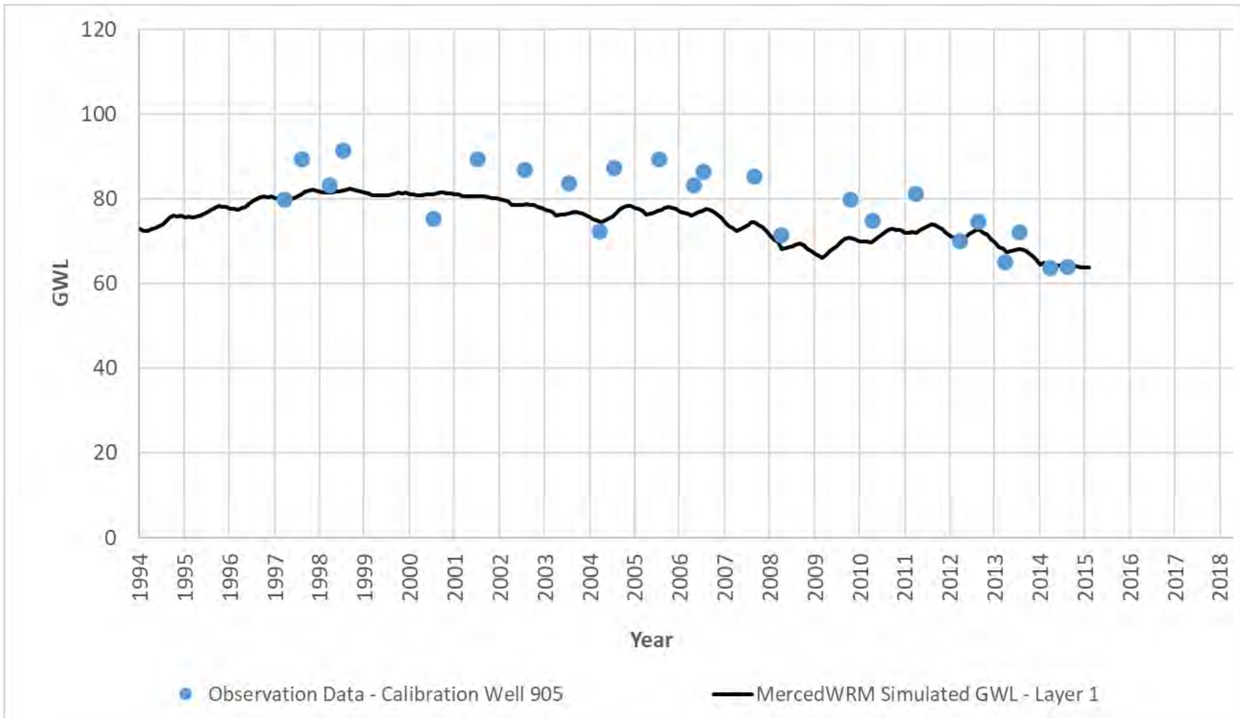


Figure A 19: Calibration Well 905

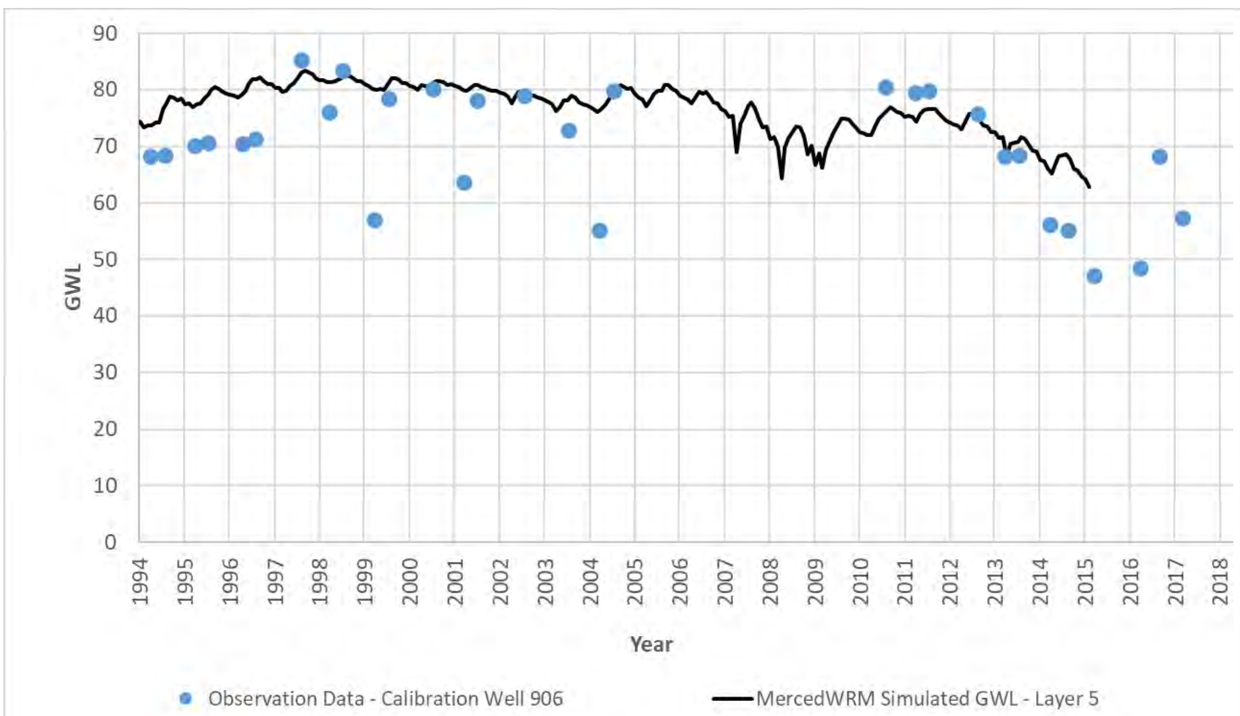


Figure A 20: Calibration Well 906

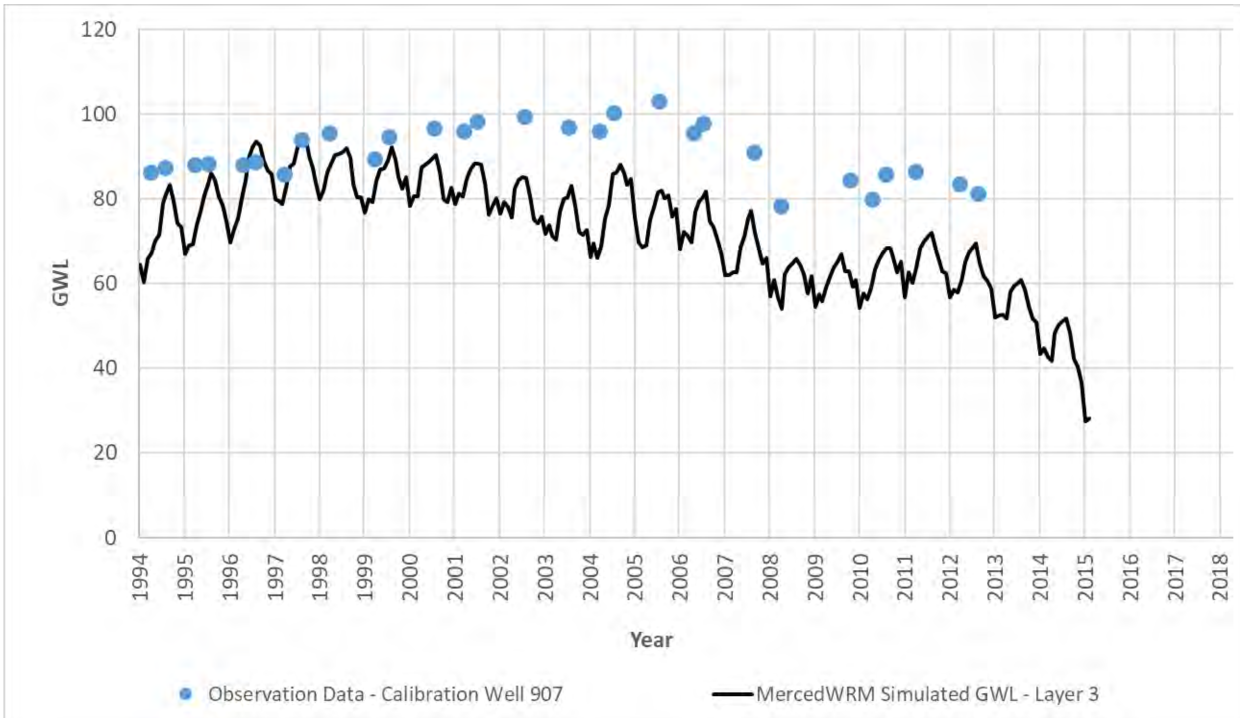


Figure A 21: Calibration Well 907

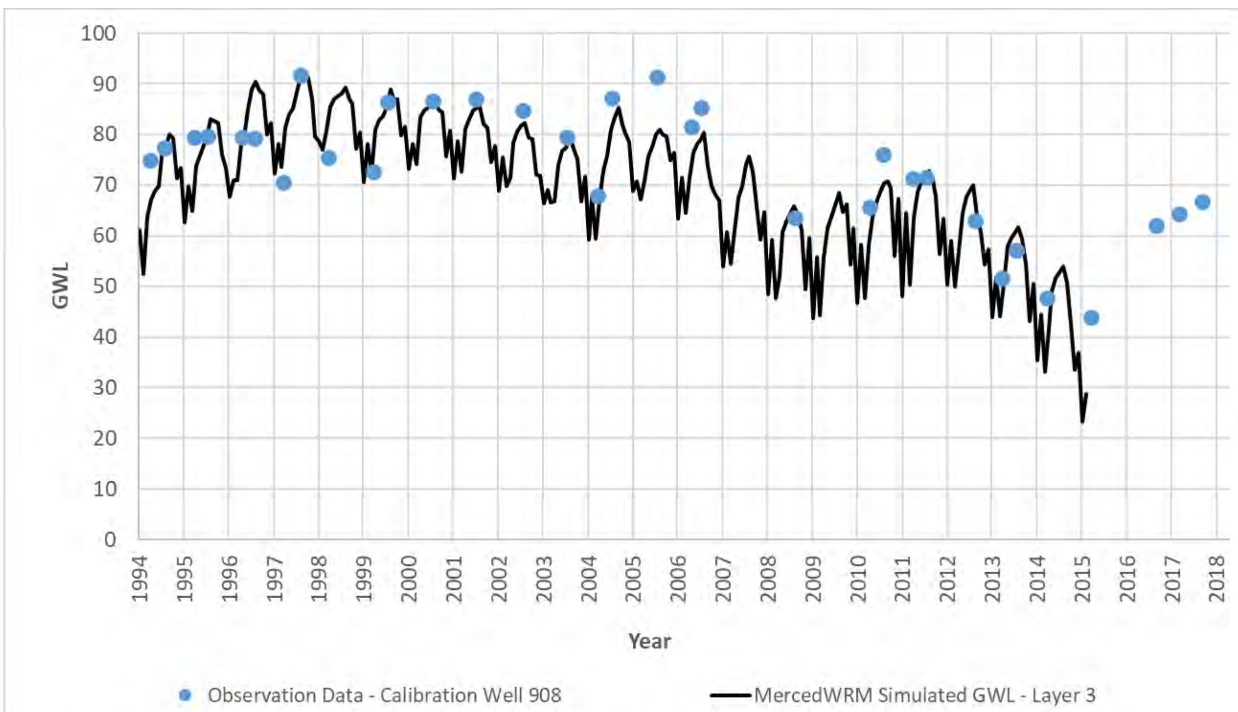


Figure A 22: Calibration Well 908

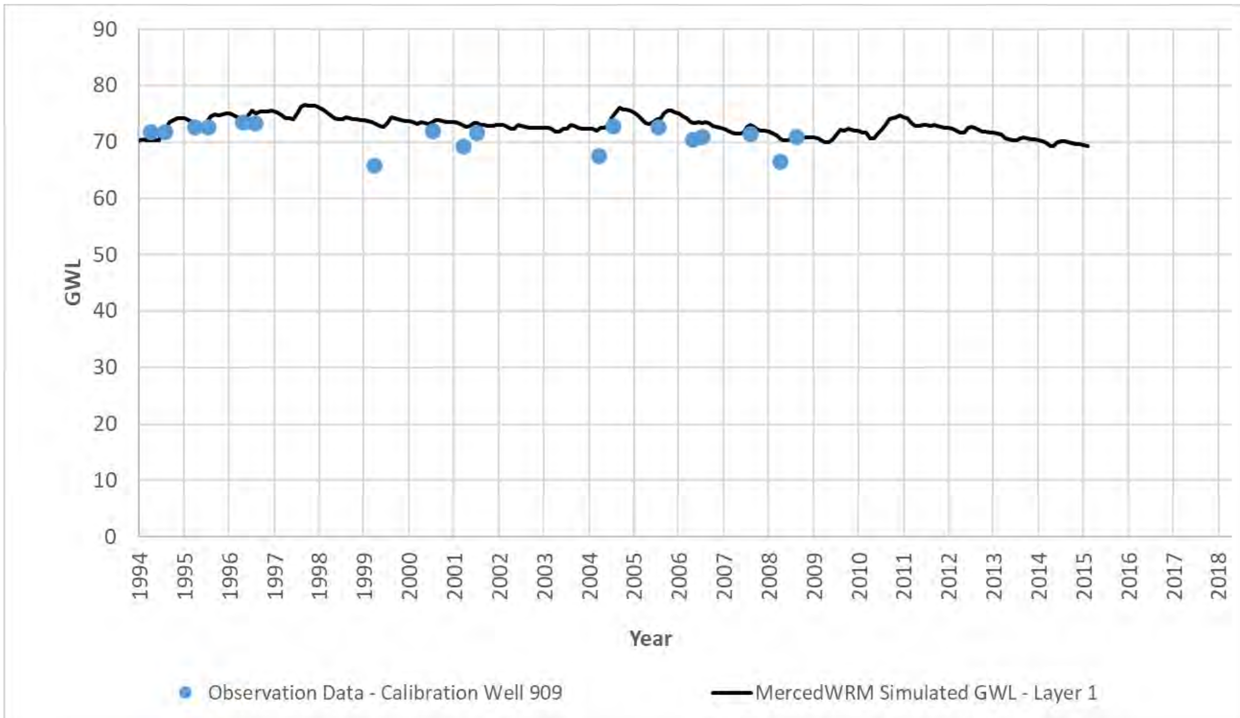


Figure A 23: Calibration Well 909

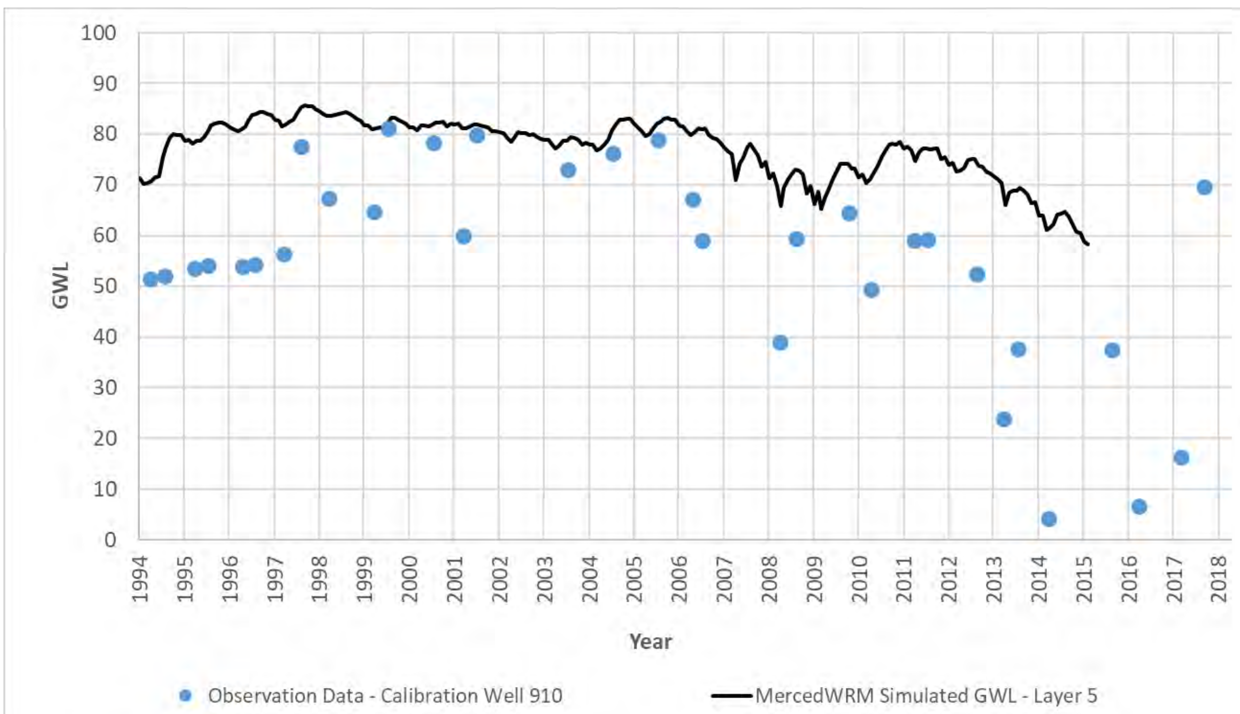


Figure A 24: Calibration Well 910

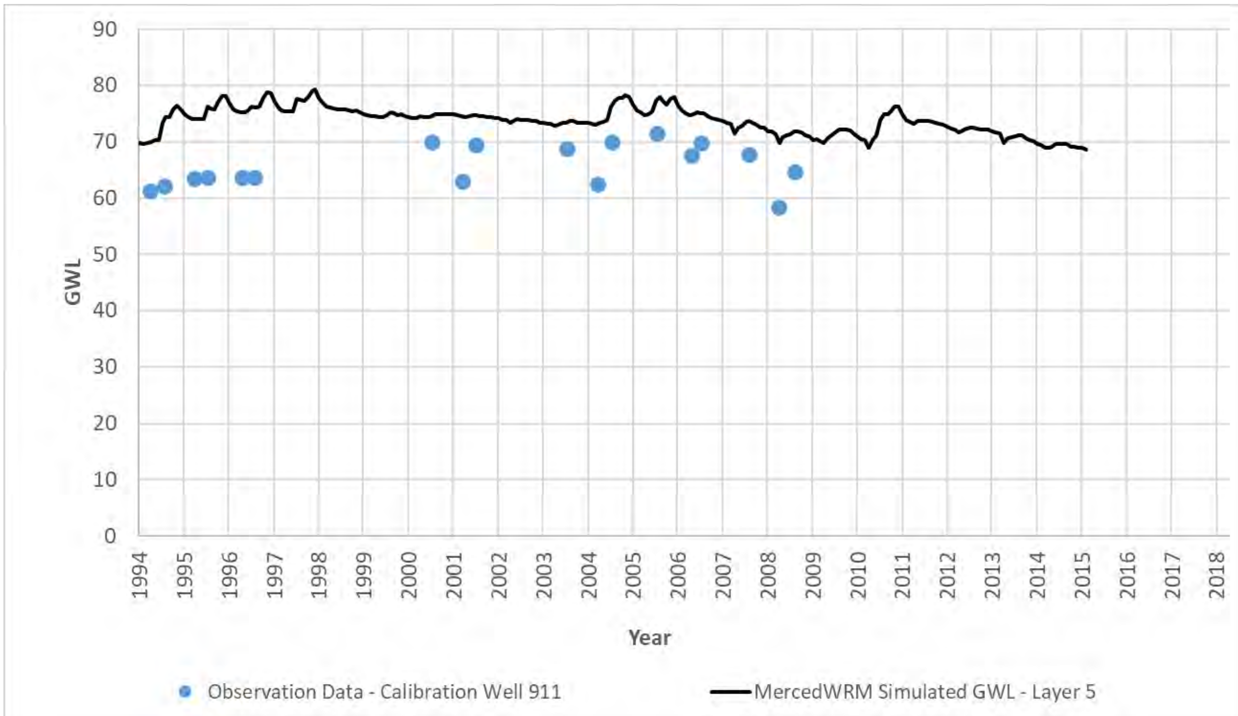


Figure A 25: Calibration Well 911

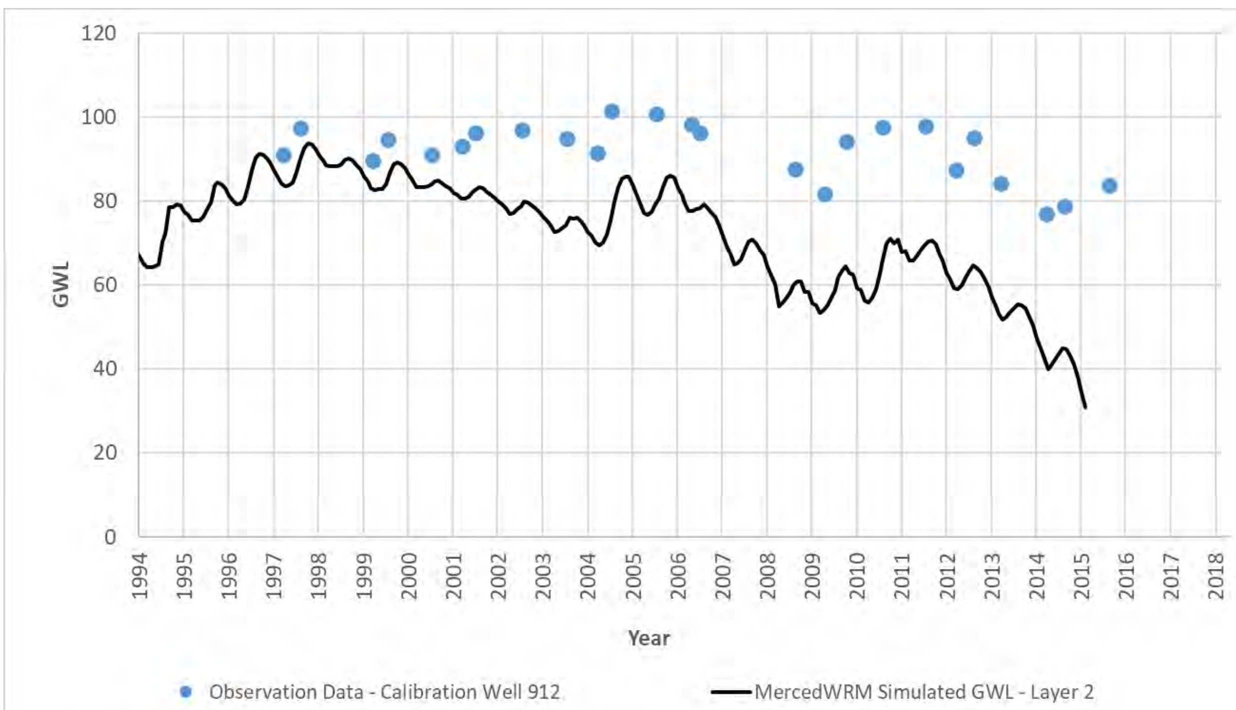


Figure A 26: Calibration Well 912

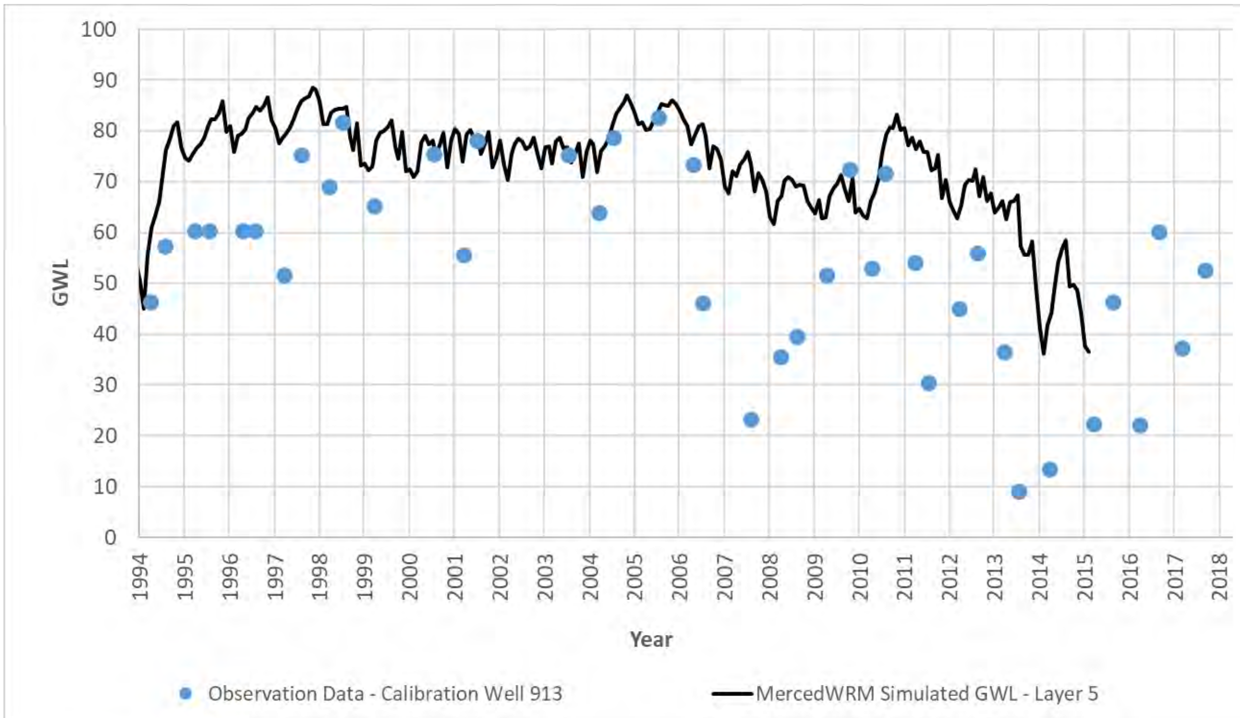


Figure A 27: Calibration Well 913

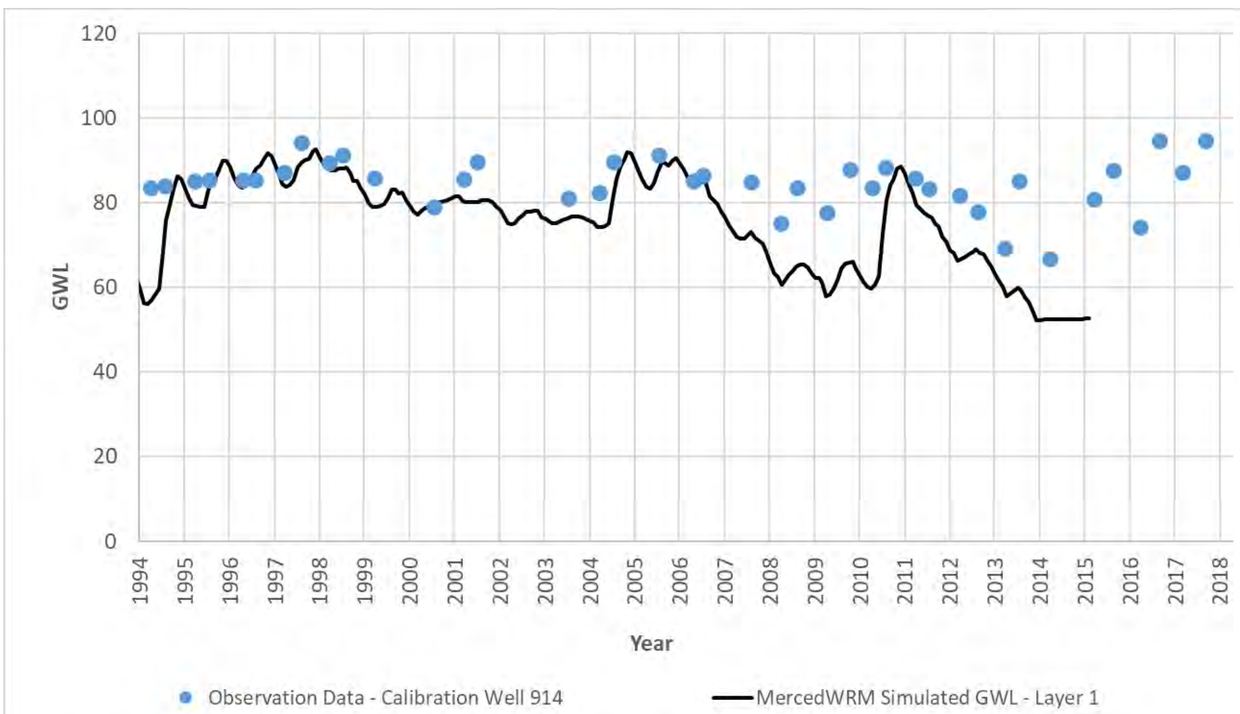


Figure A 28: Calibration Well 914

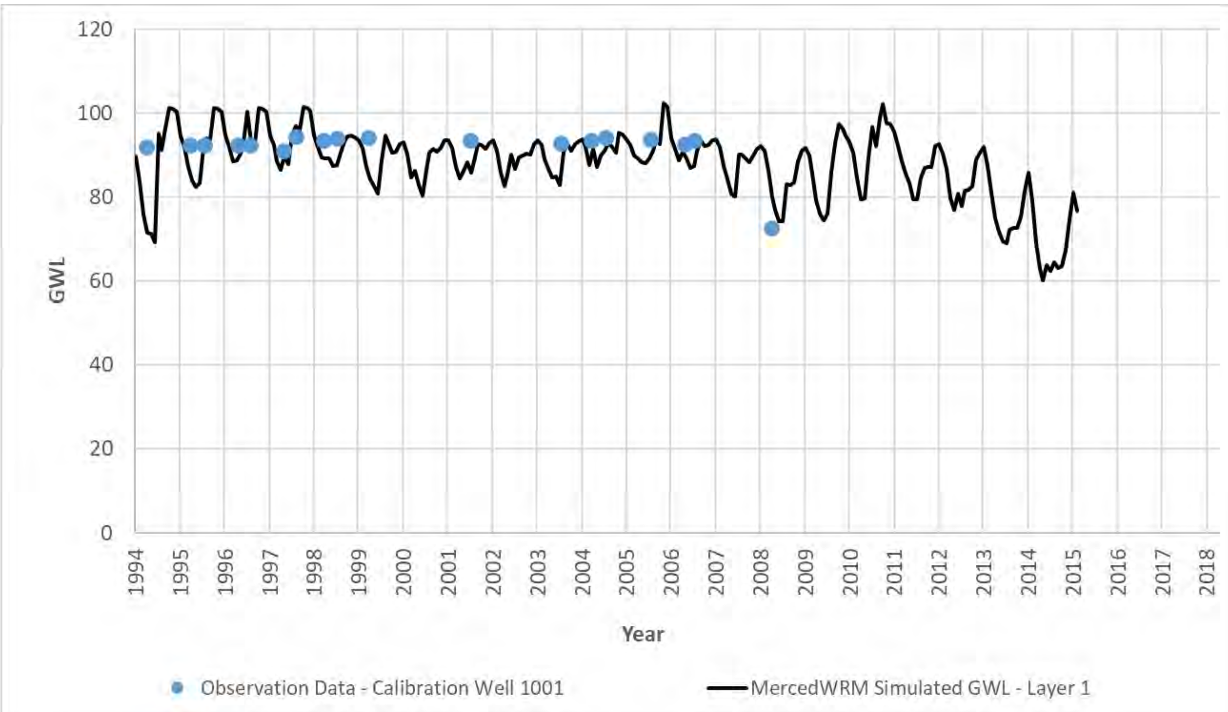


Figure A 29: Calibration Well 1001

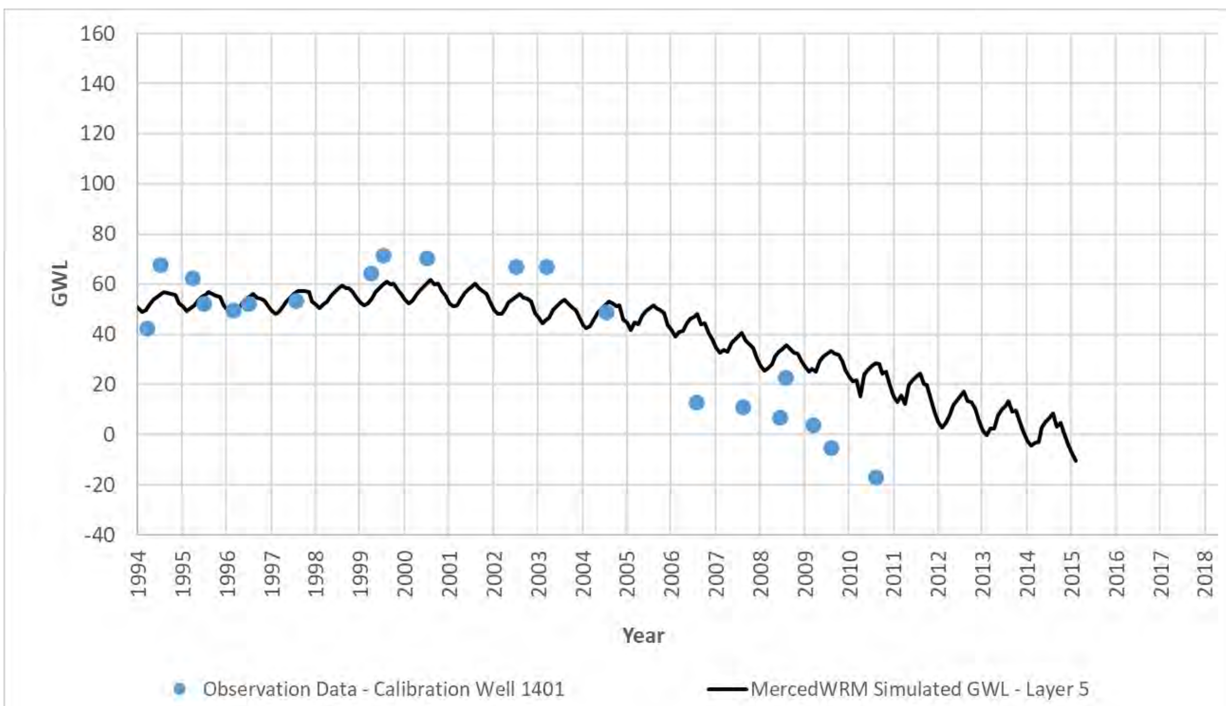


Figure A 30: Calibration Well 1401

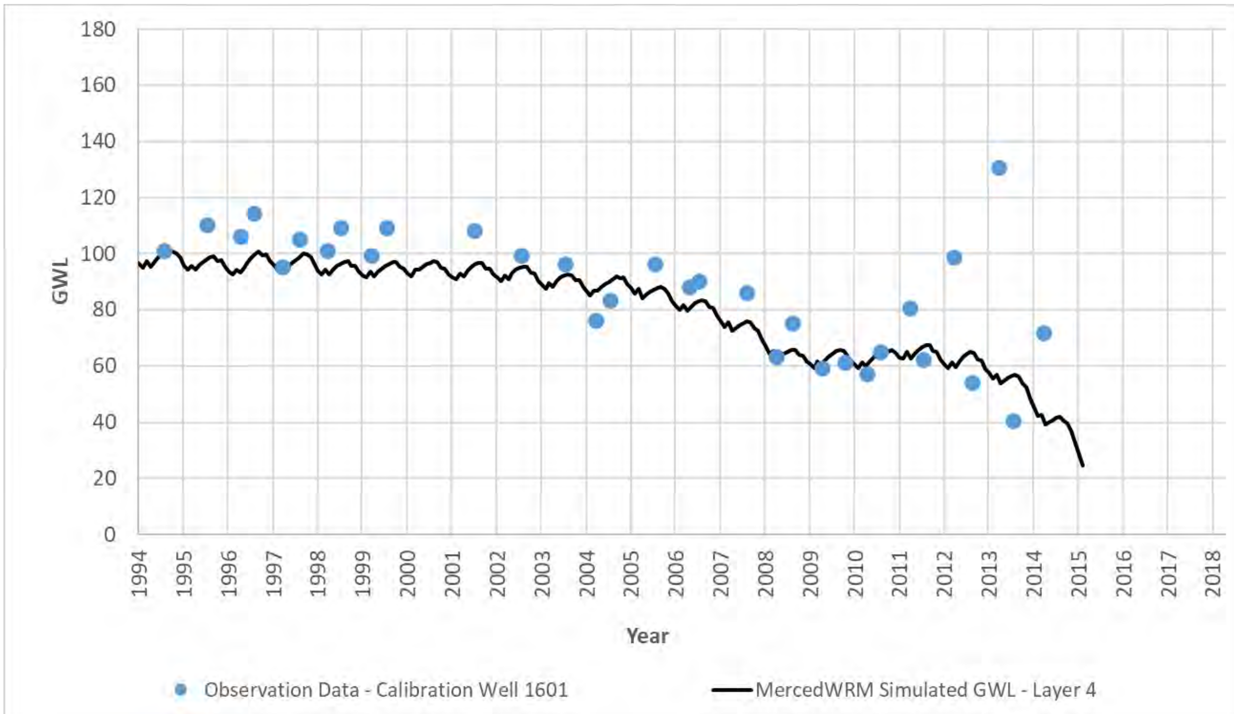


Figure A 31: Calibration Well 1601

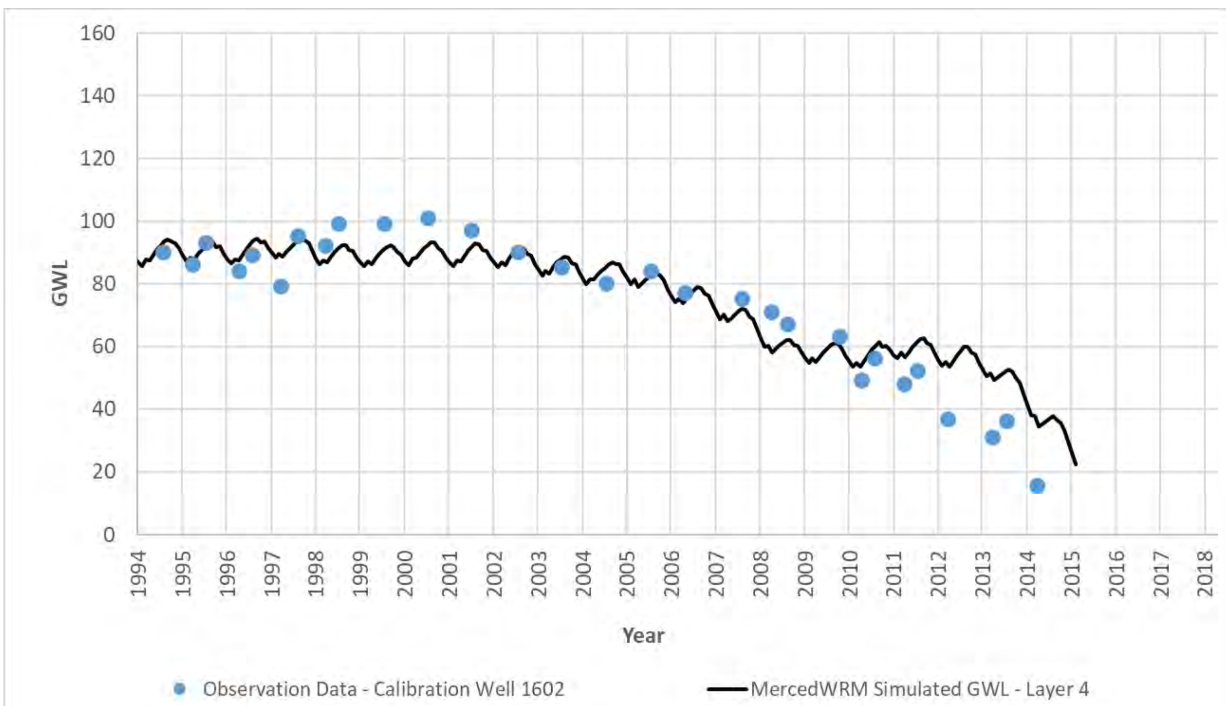


Figure A 32: Calibration Well 1602

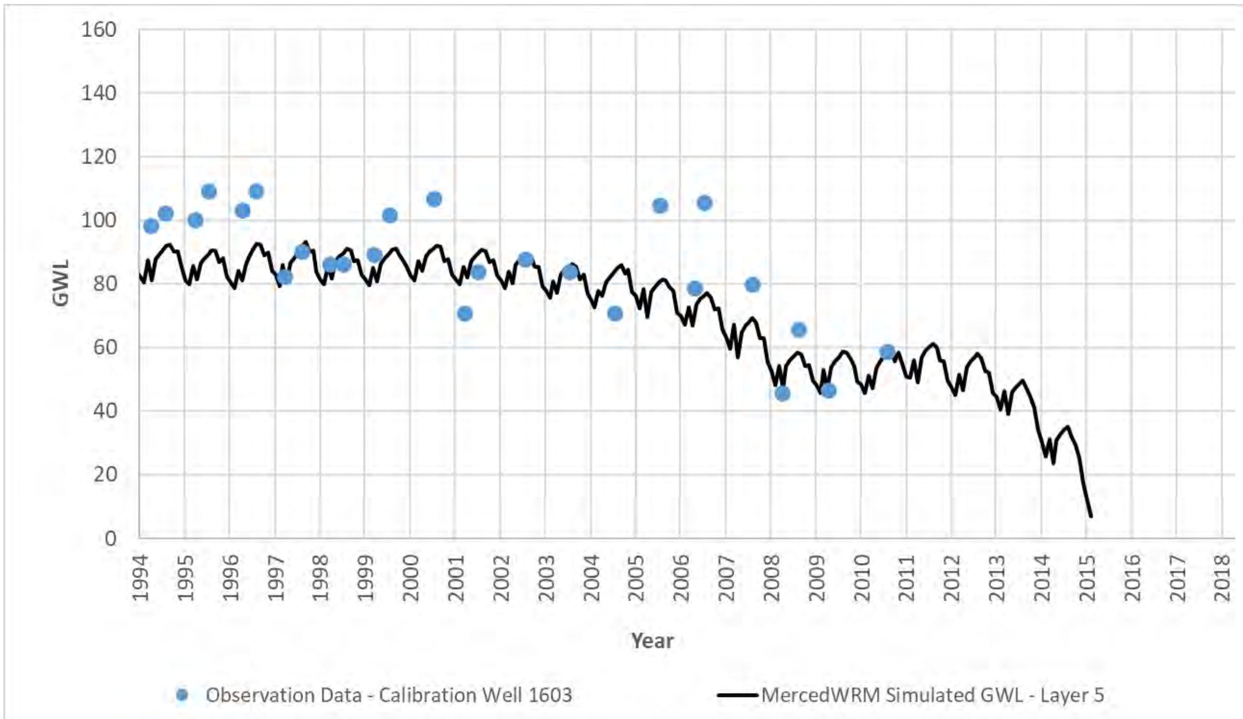


Figure A 33: Calibration Well 1603

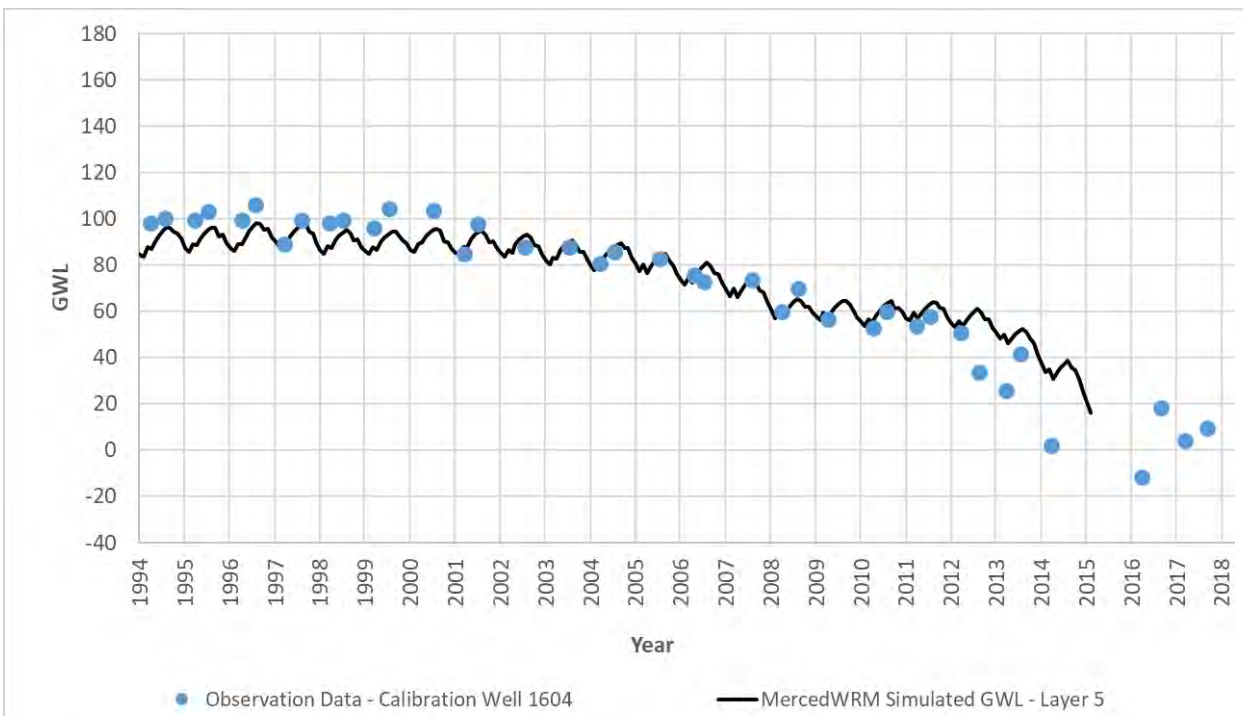


Figure A 34: Calibration Well 1604

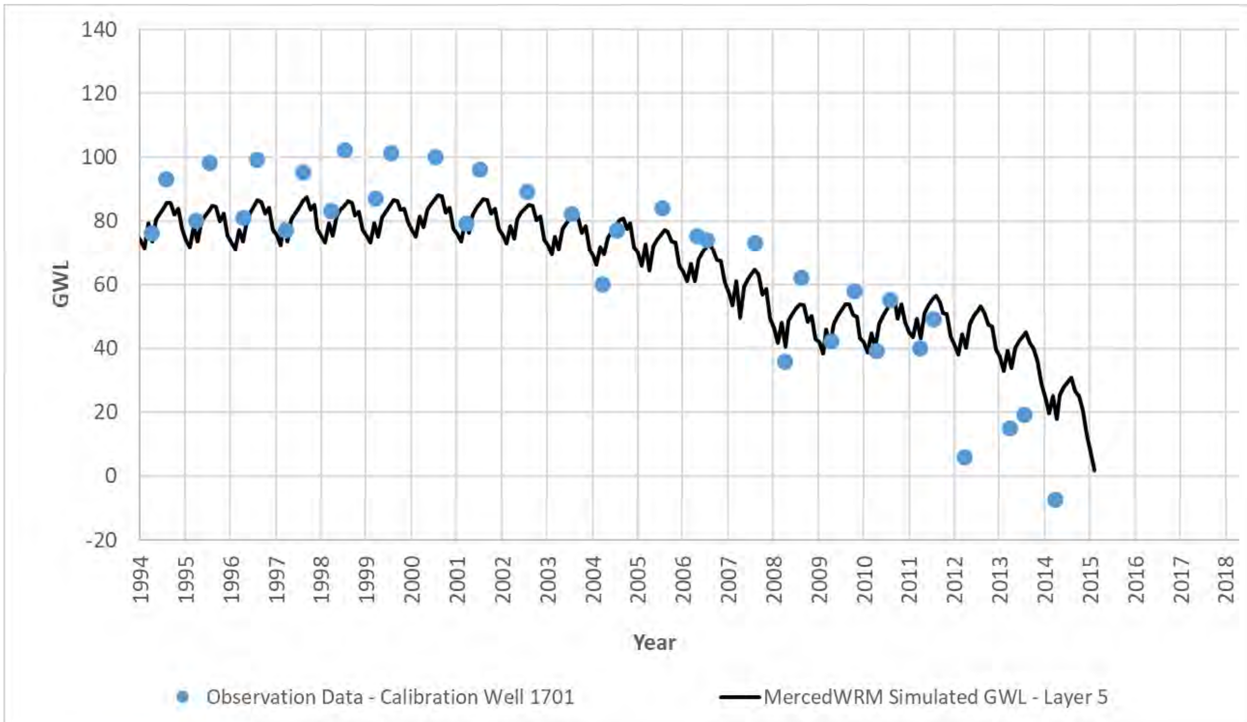


Figure A 35: Calibration Well 1701

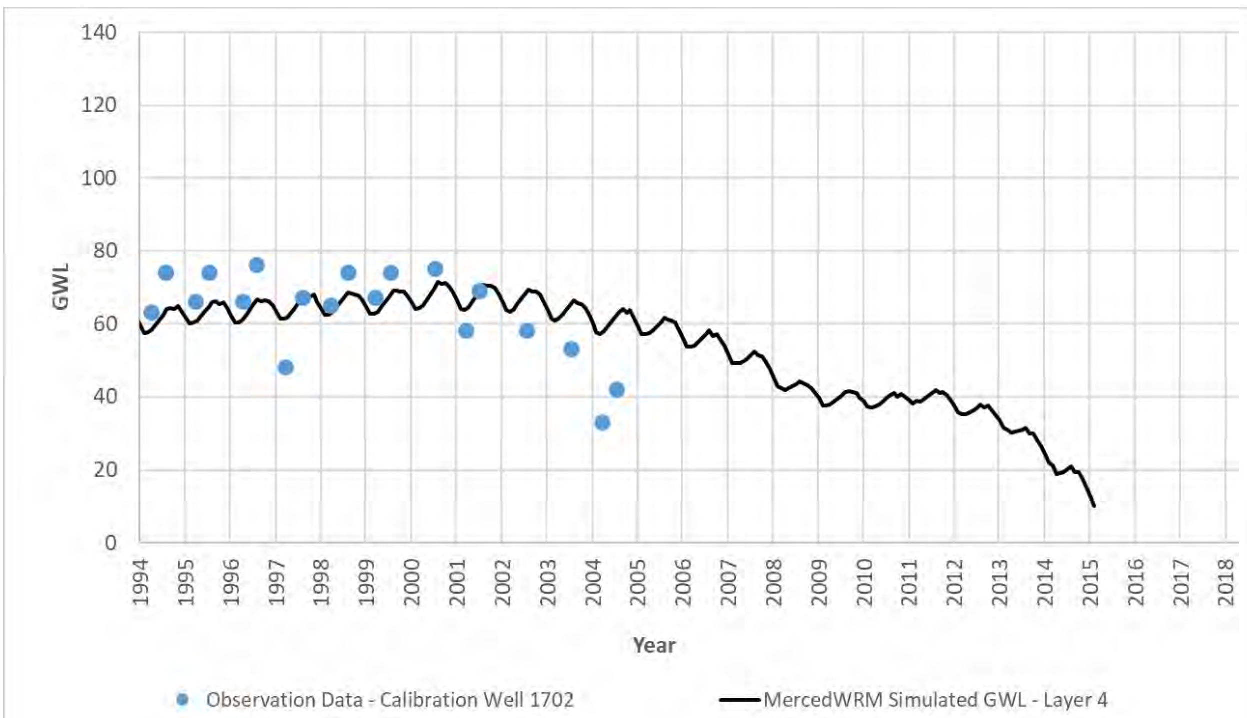


Figure A 36: Calibration Well 1702

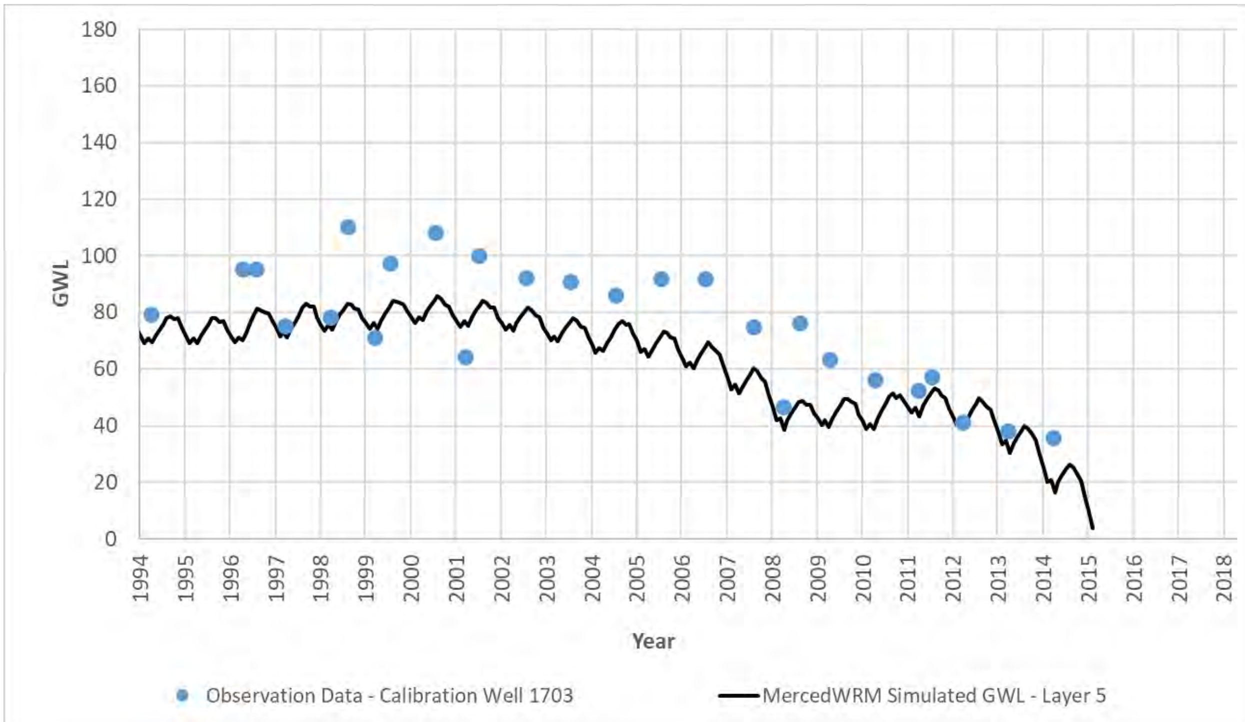


Figure A 37: Calibration Well 1703

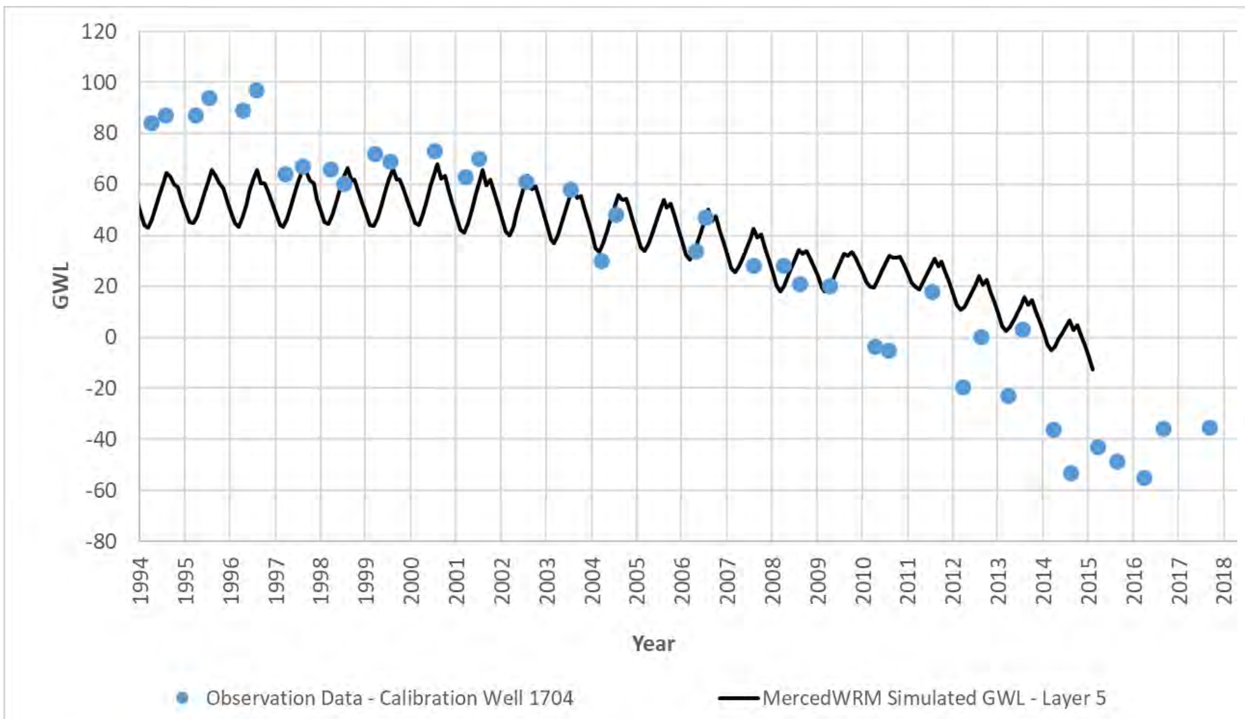


Figure A 38: Calibration Well 1704

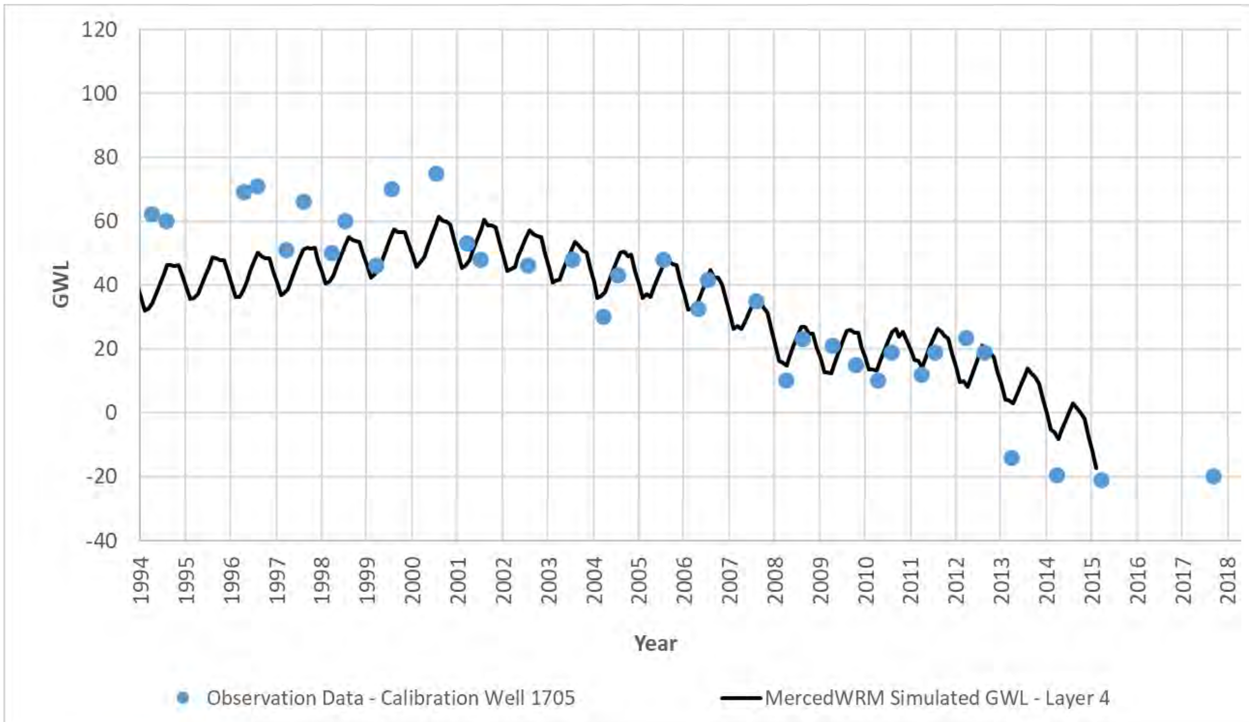


Figure A 39: Calibration Well 1705

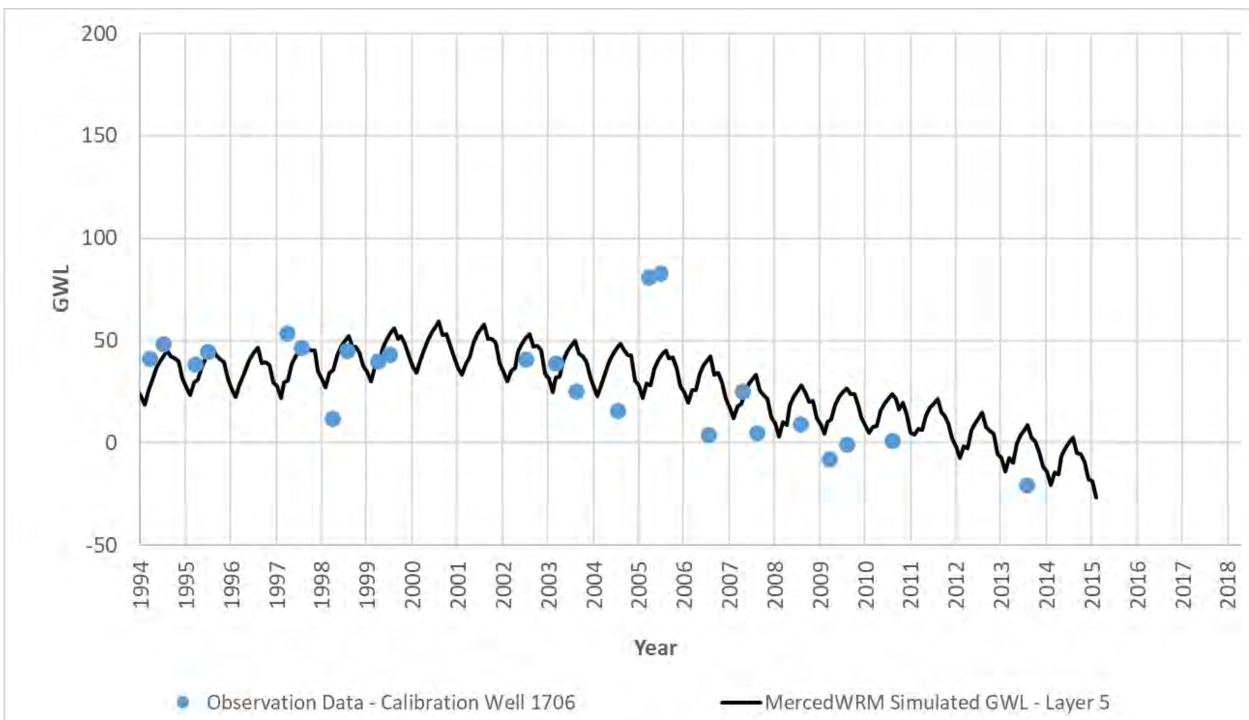


Figure A 40: Calibration Well 1706

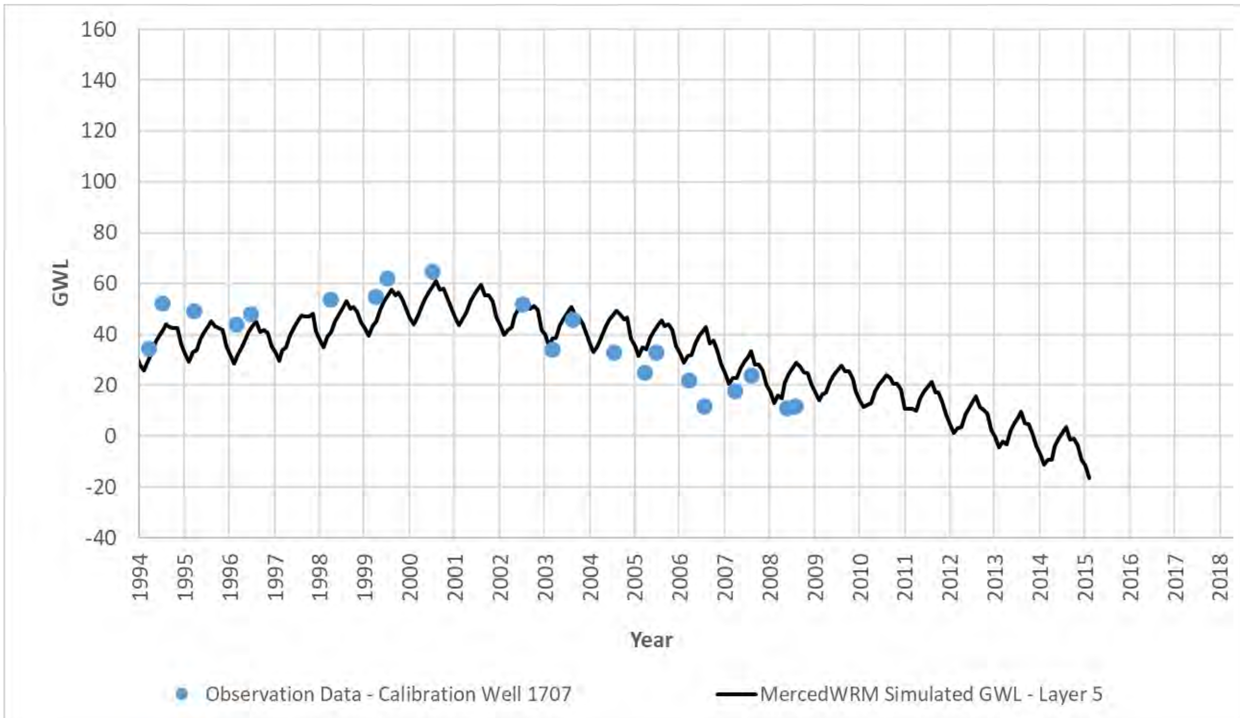


Figure A 41: Calibration Well 1707

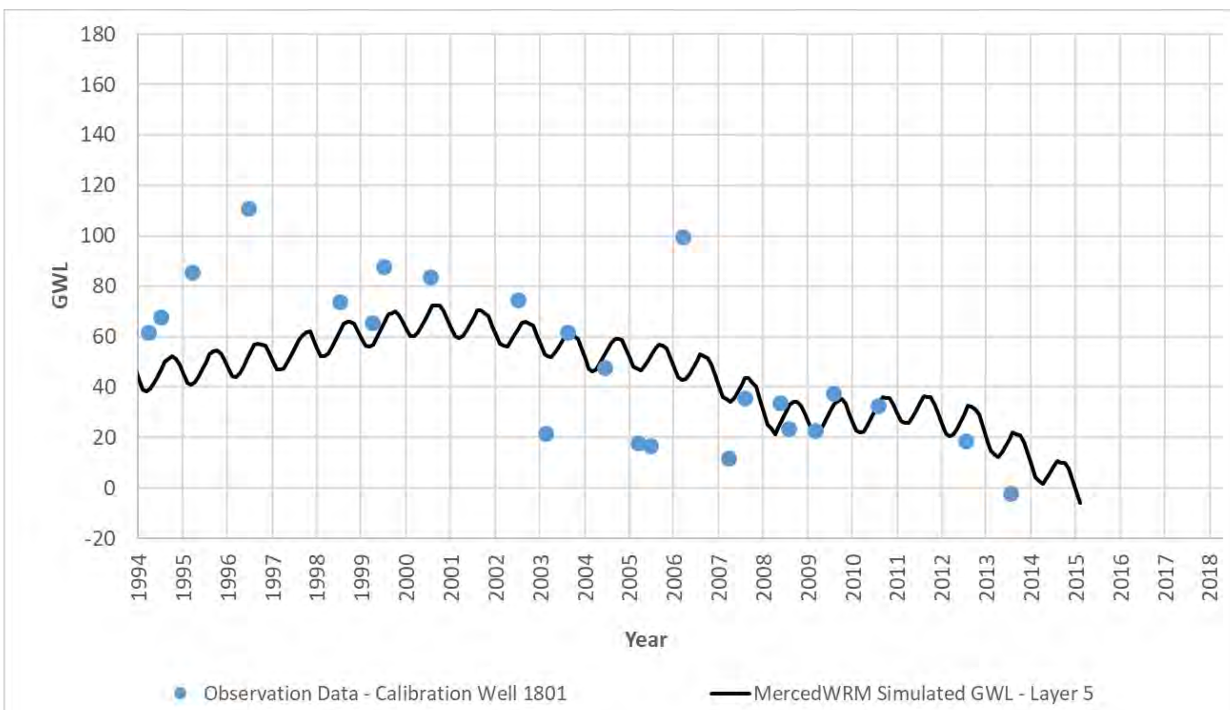


Figure A 42: Calibration Well 1801

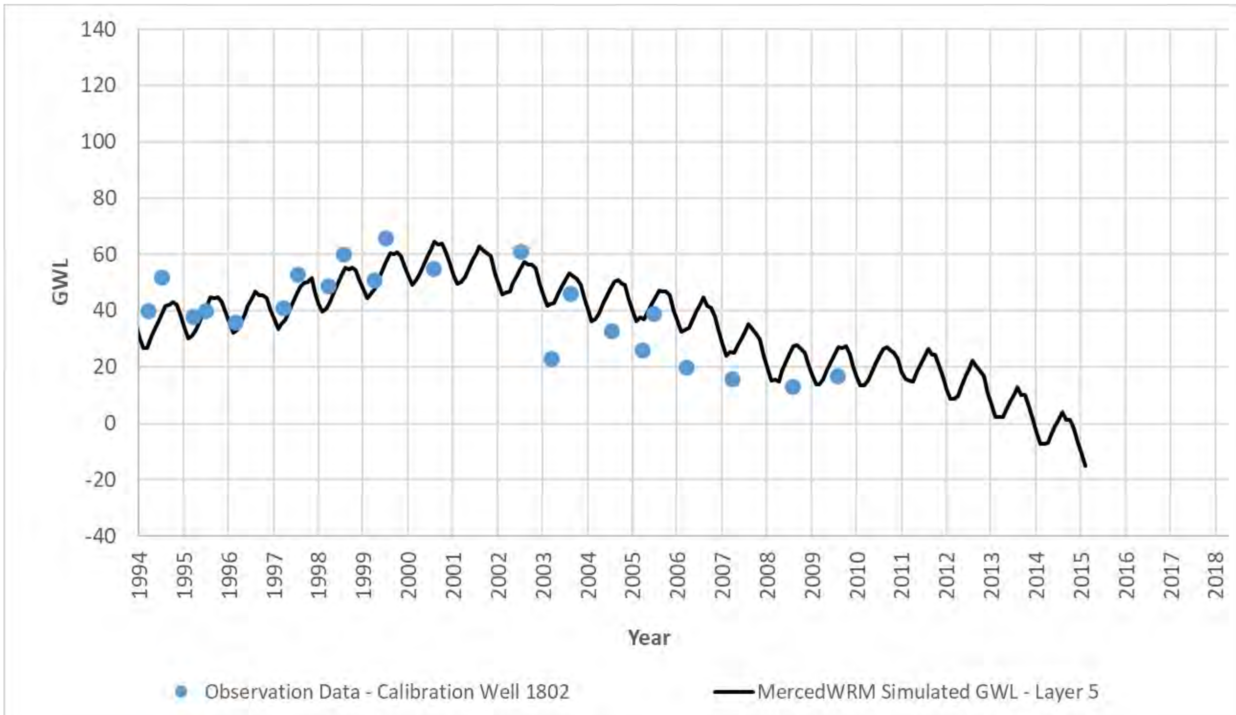


Figure A 43: Calibration Well 1802

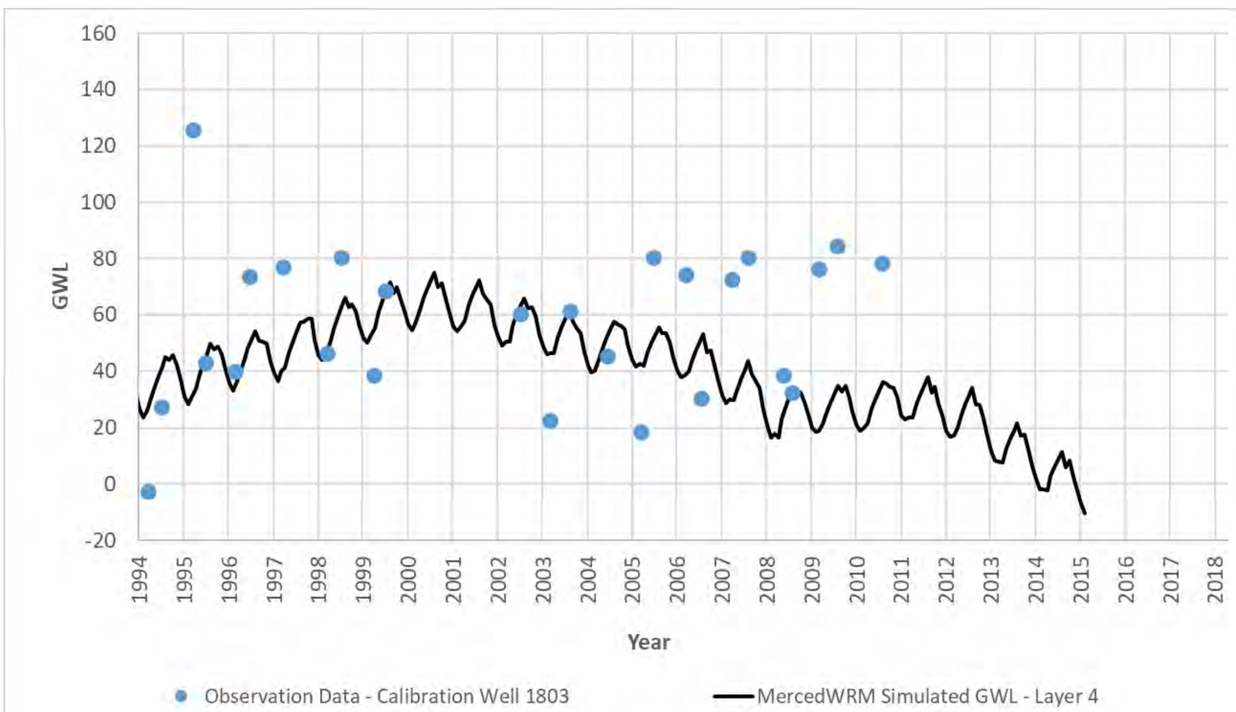


Figure A 44: Calibration Well 1803

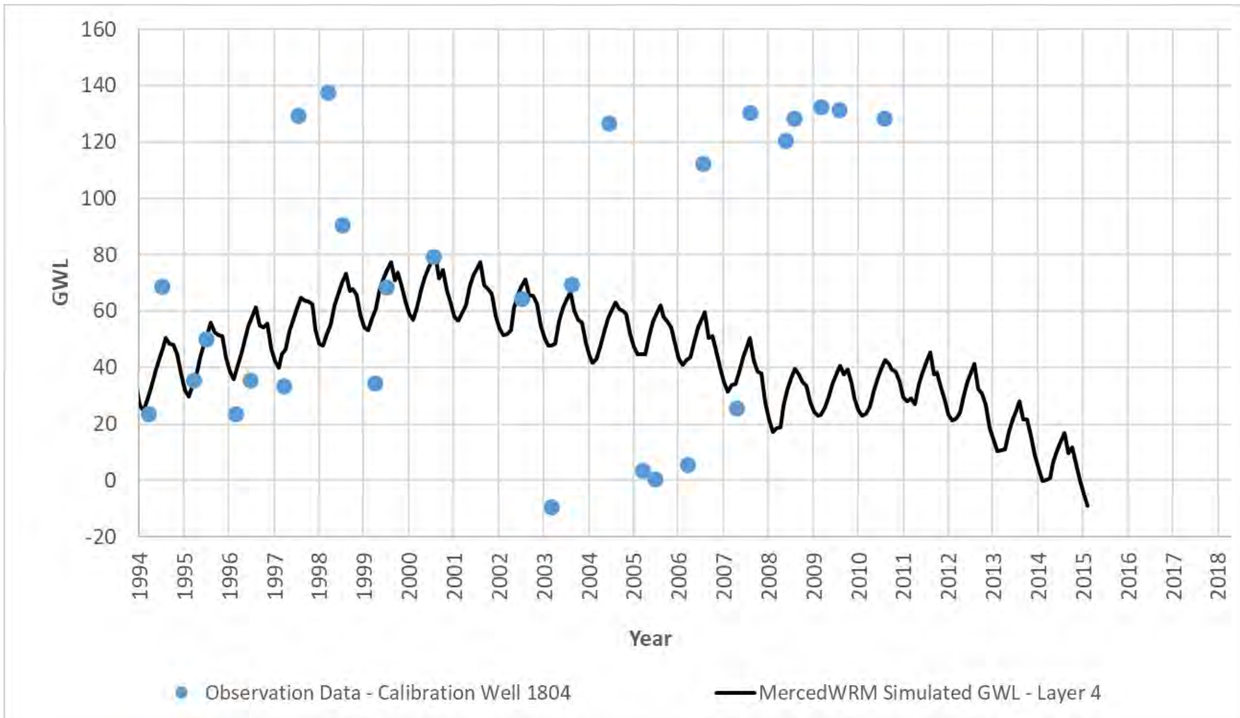


Figure A 45: Calibration Well 1804

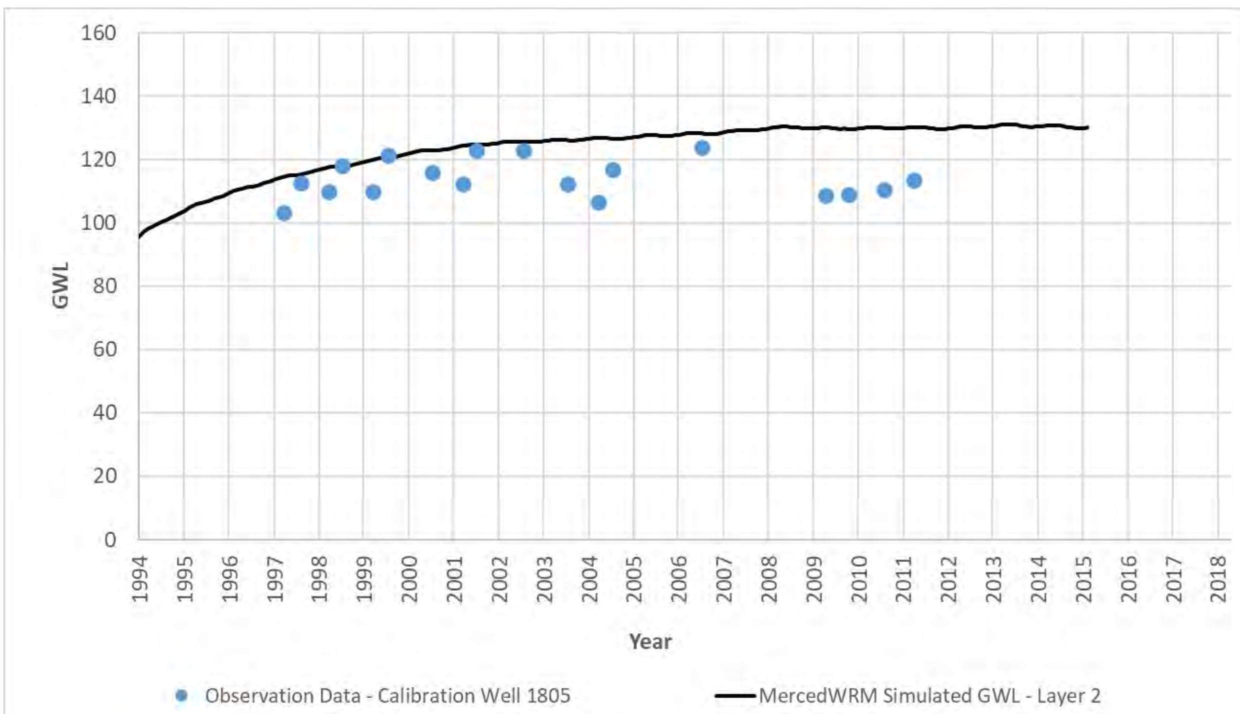


Figure A 46: Calibration Well 1805

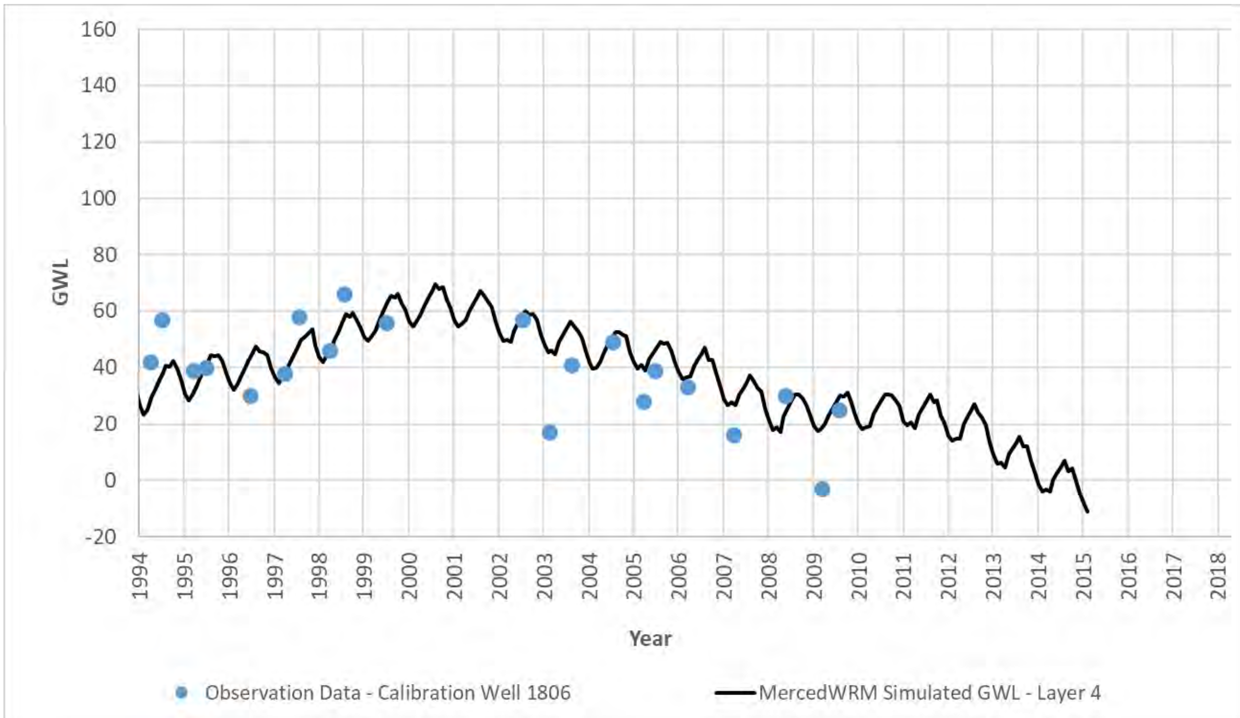


Figure A 47: Calibration Well 1806

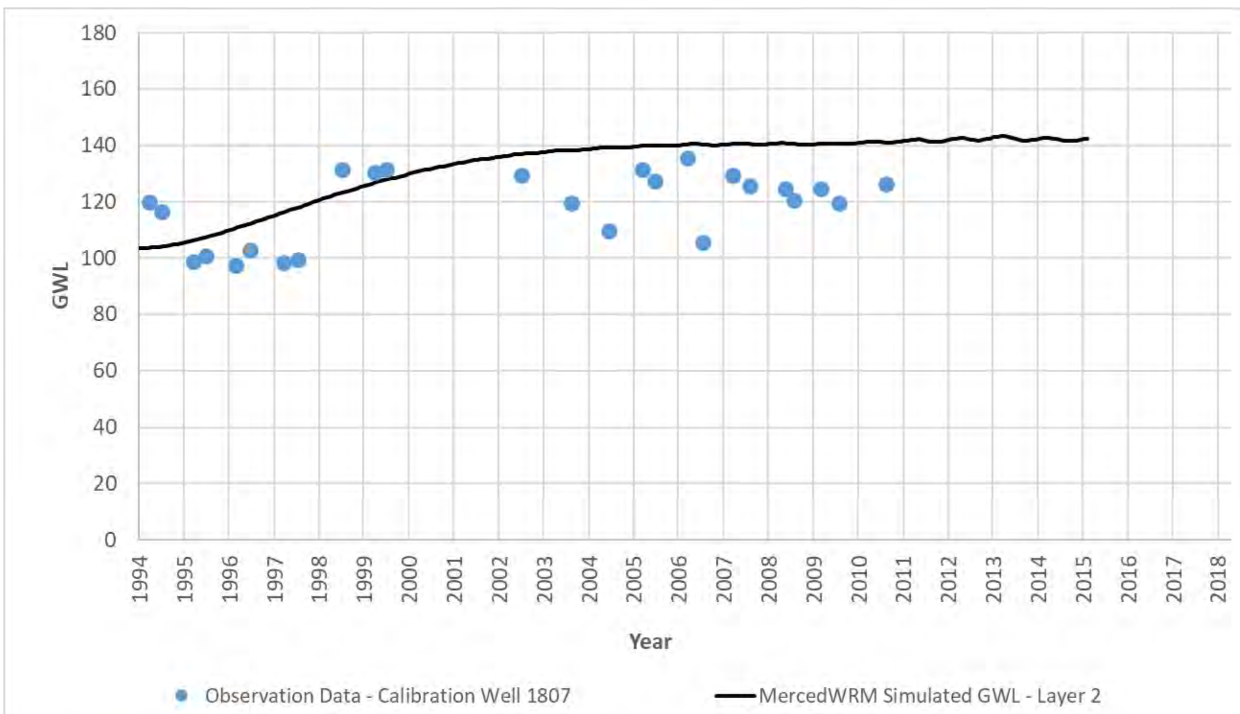


Figure A 48: Calibration Well 1807

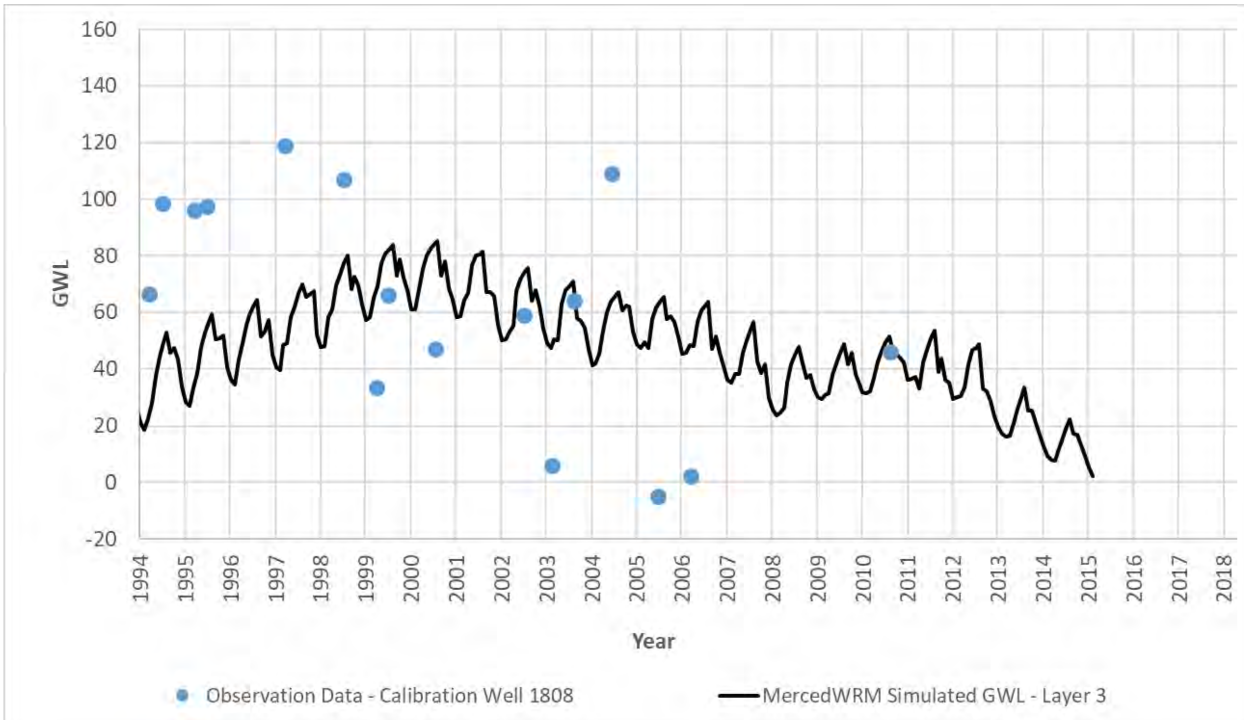


Figure A 49: Calibration Well 1808

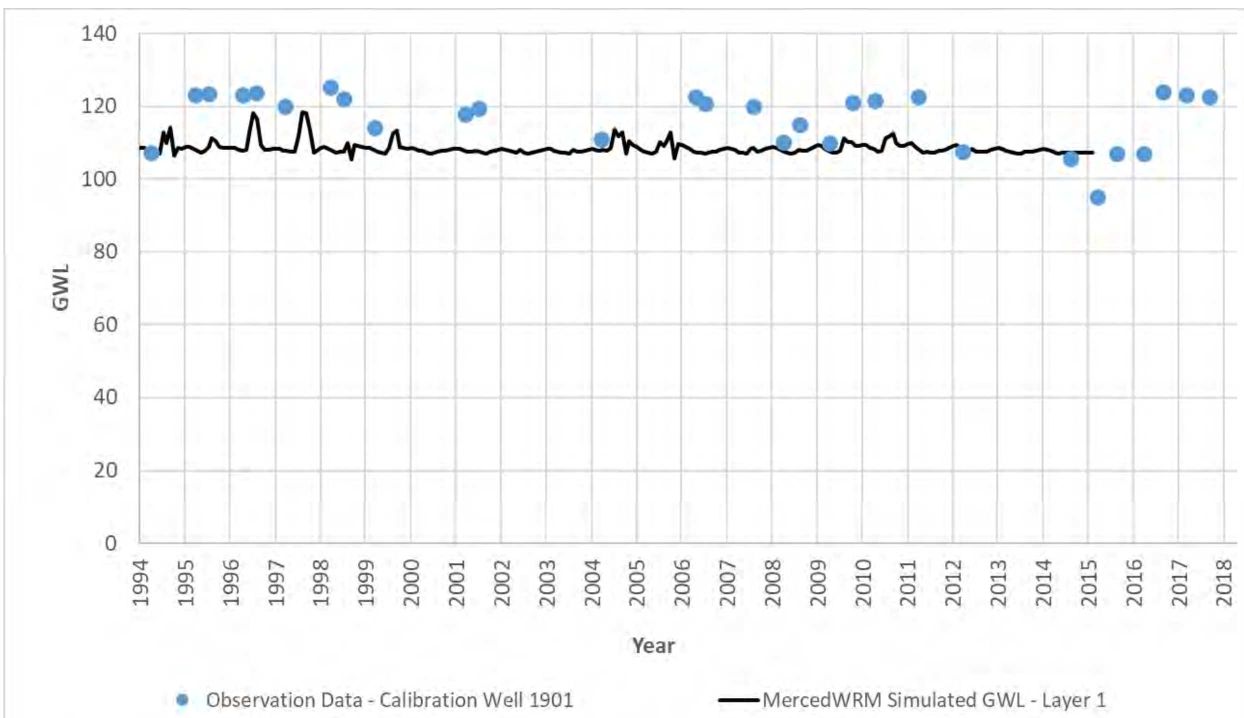


Figure A 50: Calibration Well 1901

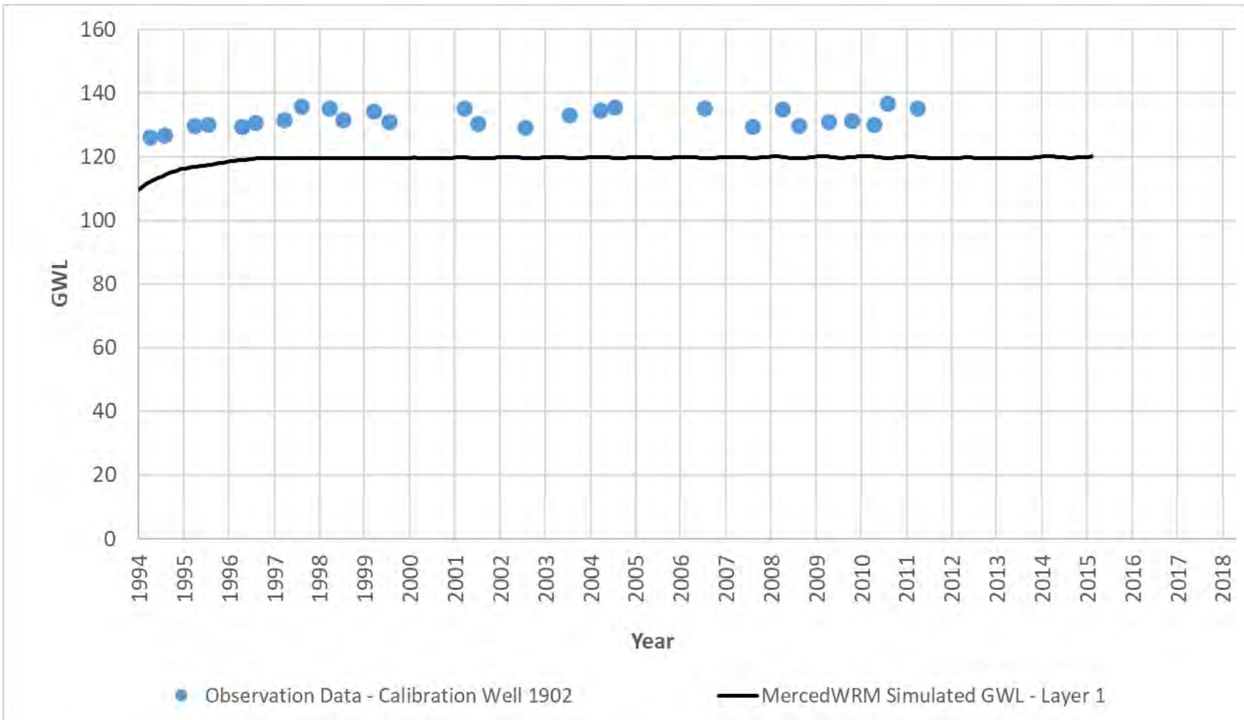


Figure A 51: Calibration Well 1902

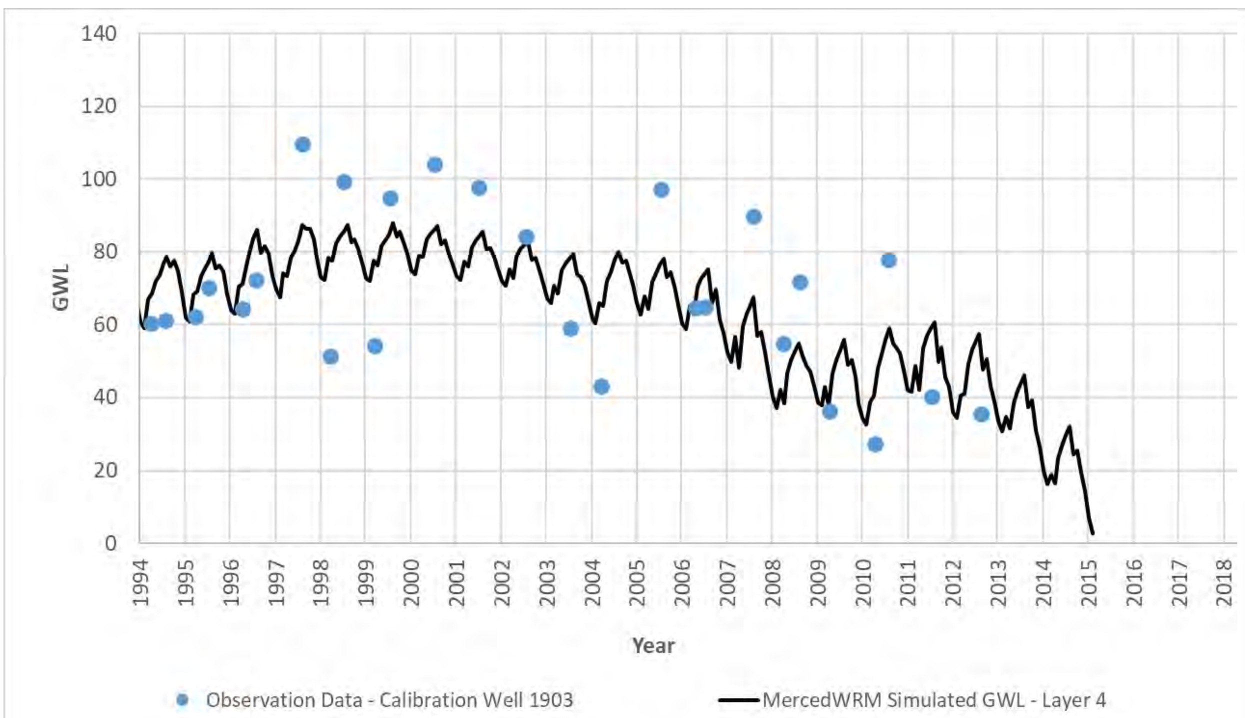


Figure A 52: Calibration Well 1903

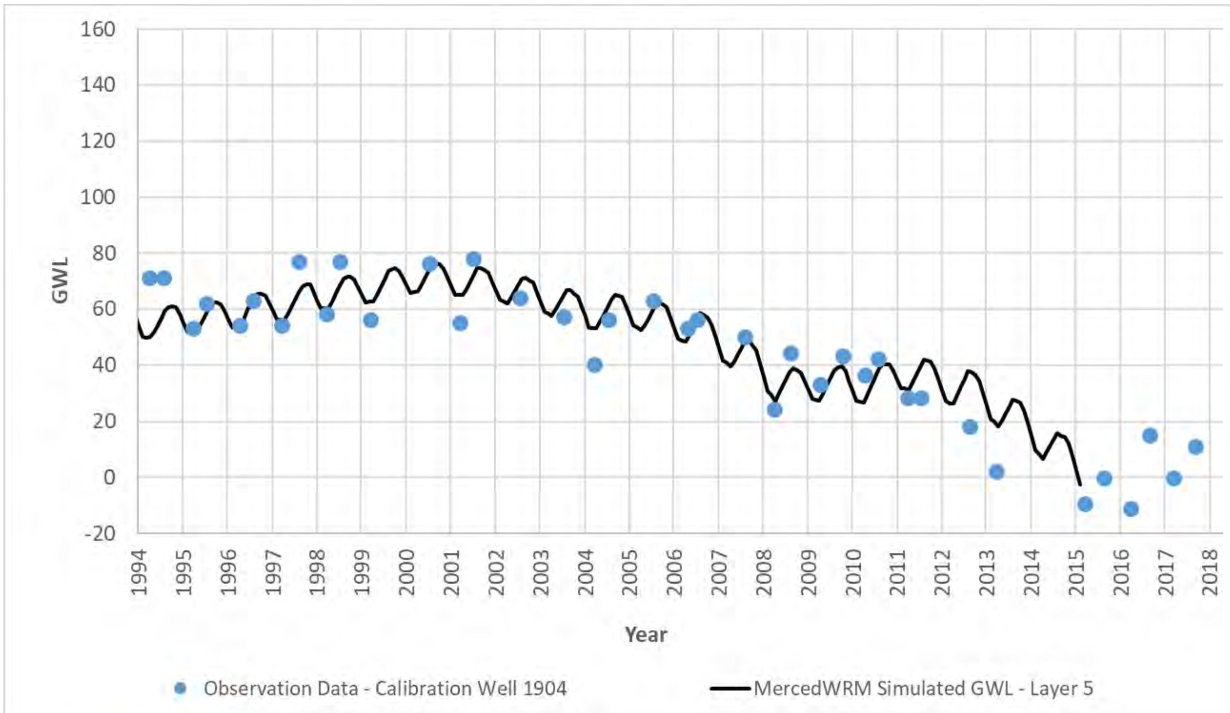


Figure A 53: Calibration Well 1904

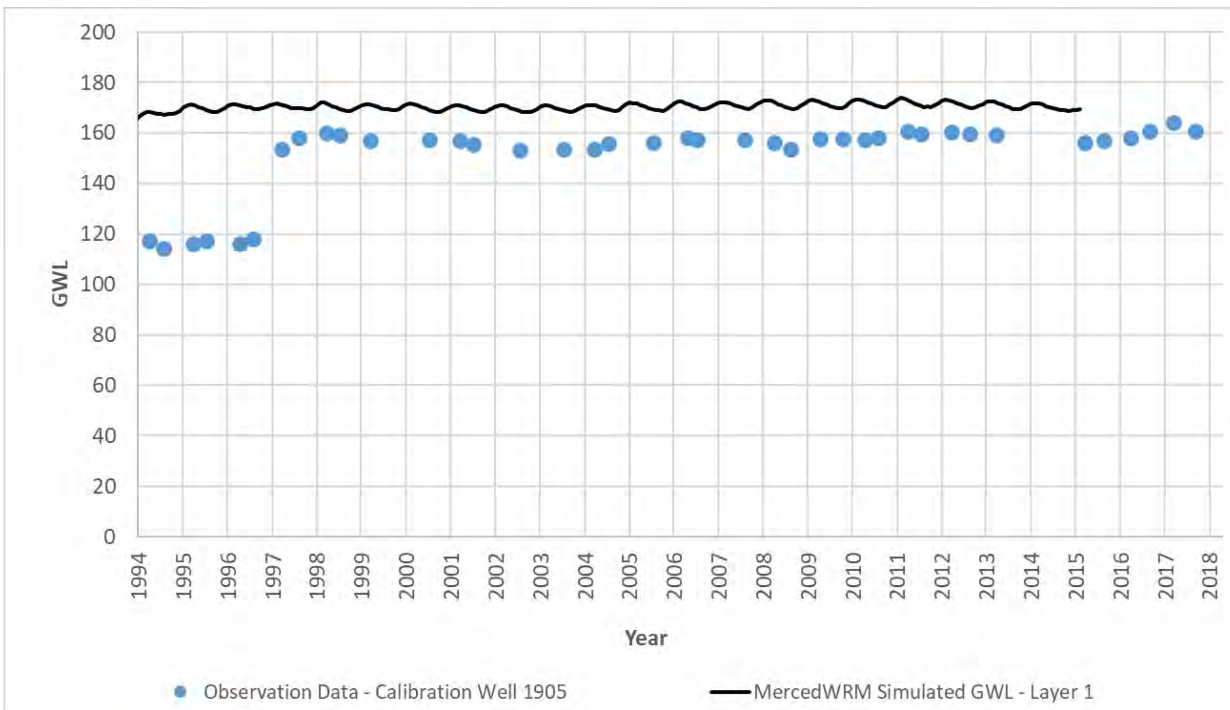


Figure A 54: Calibration Well 1905

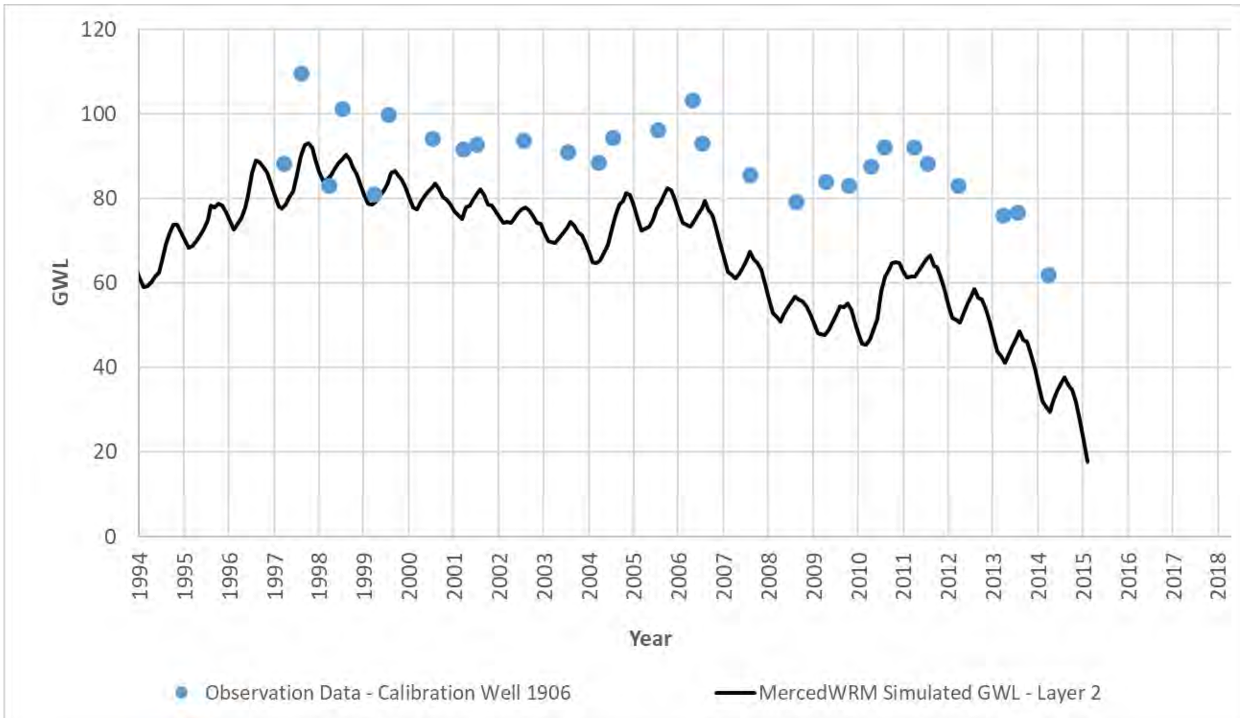


Figure A 55: Calibration Well 1906

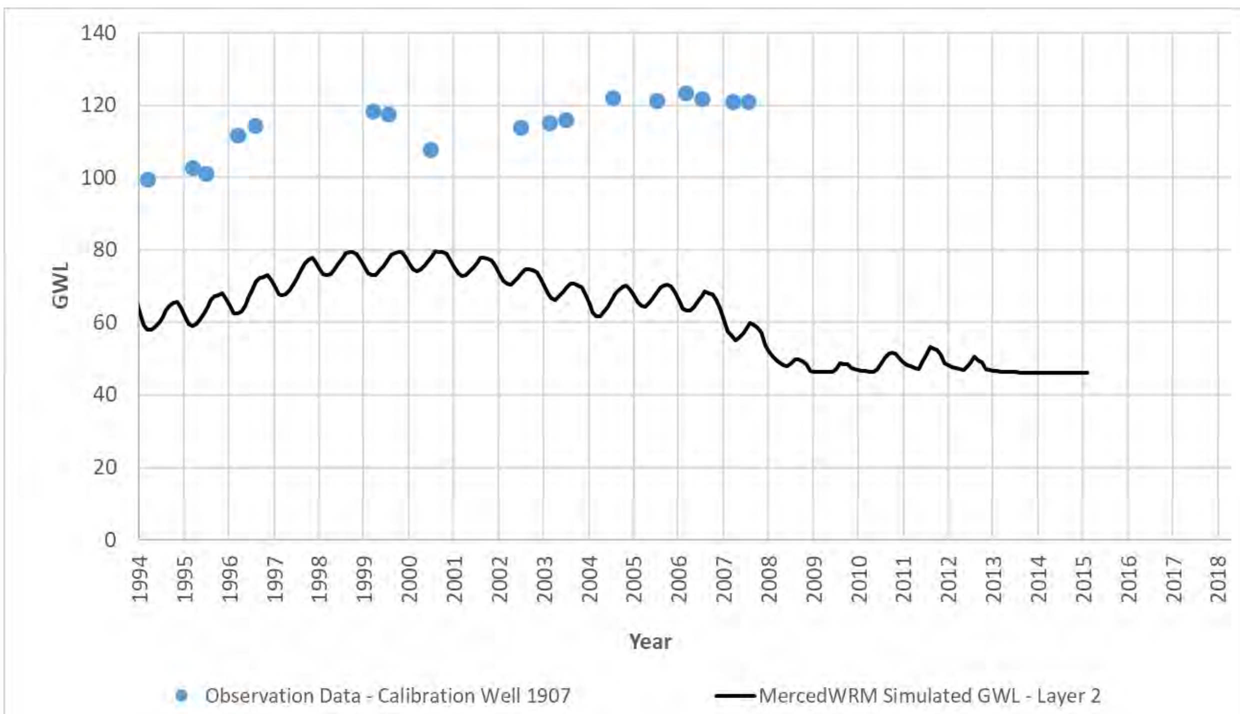


Figure A 56: Calibration Well 1907

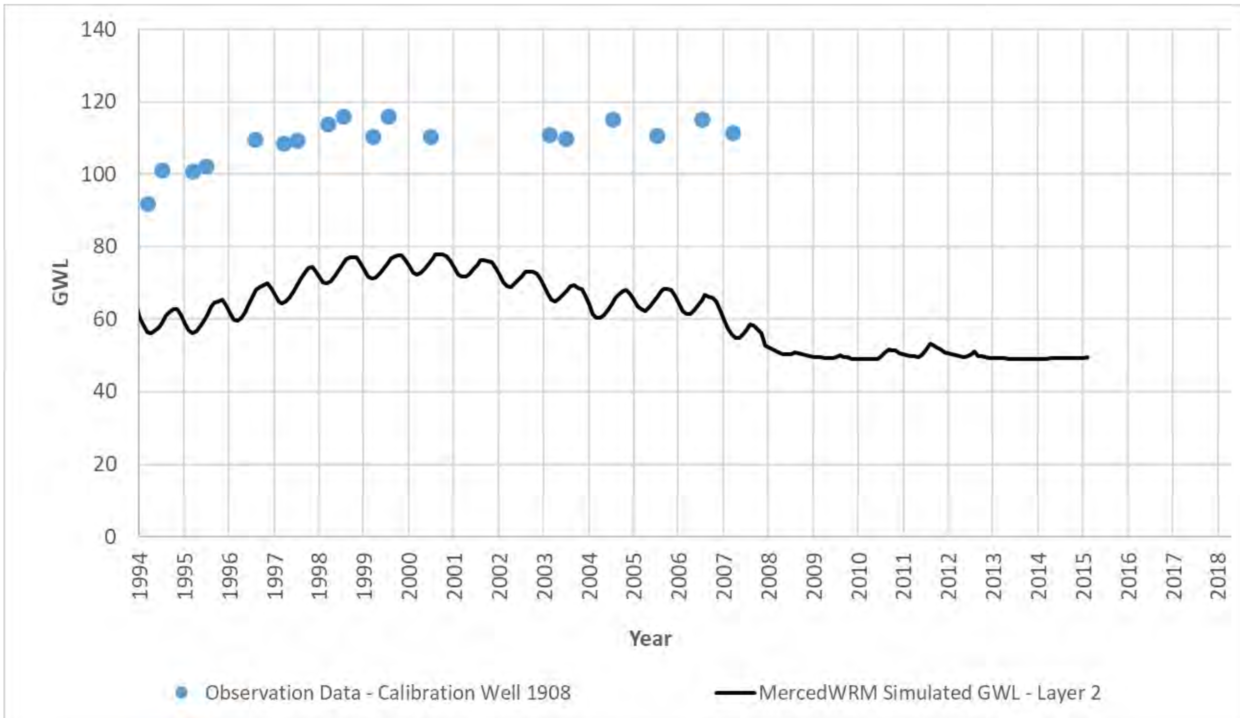


Figure A 57: Calibration Well 1908

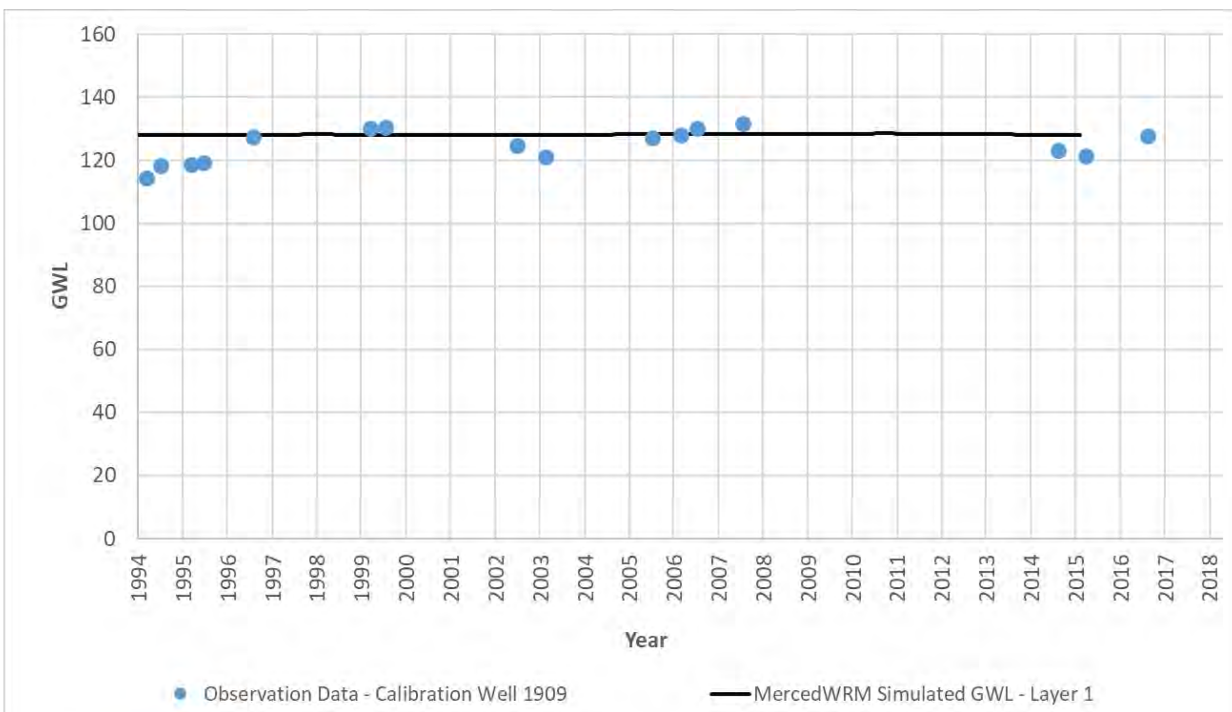


Figure A 58: Calibration Well 1909

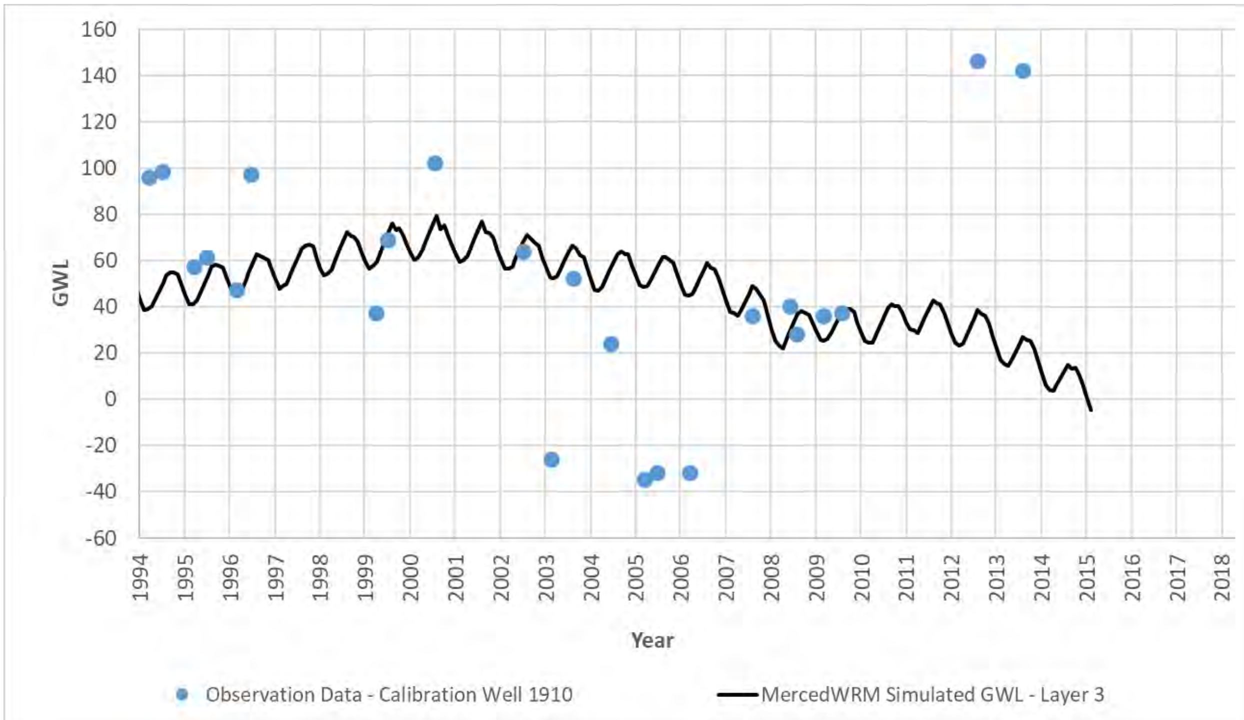


Figure A 59: Calibration Well 1910

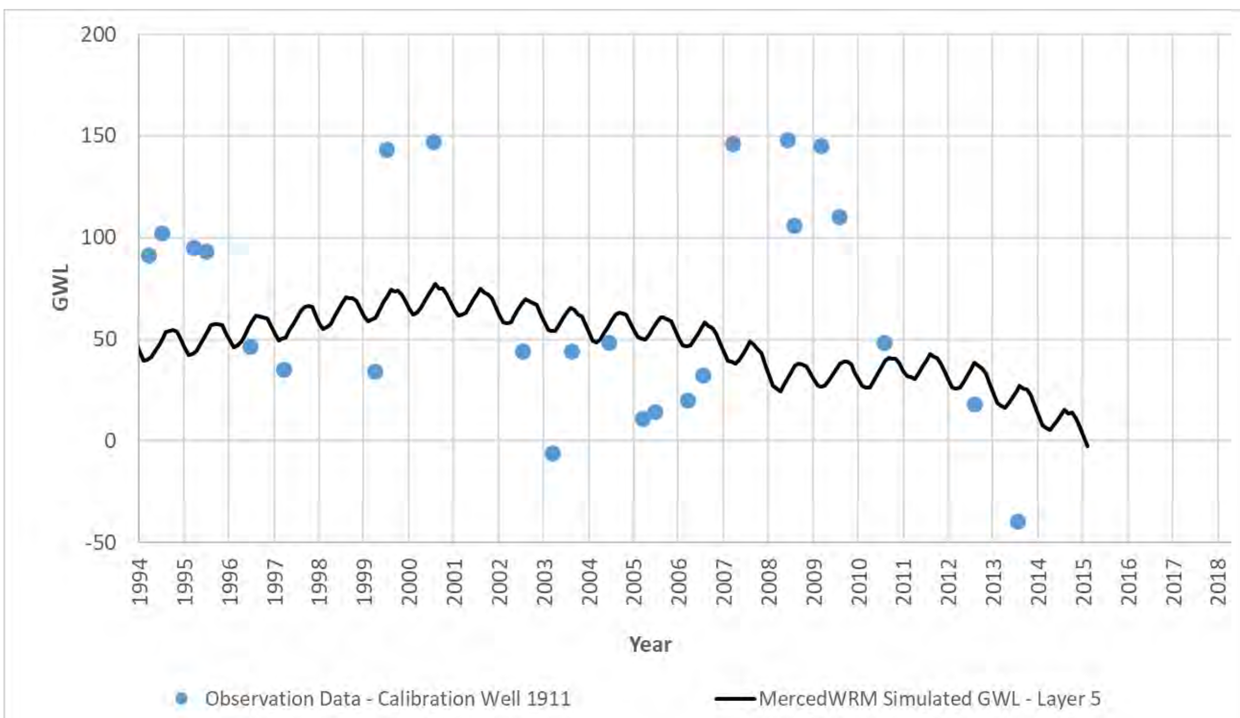


Figure A 60: Calibration Well 1911

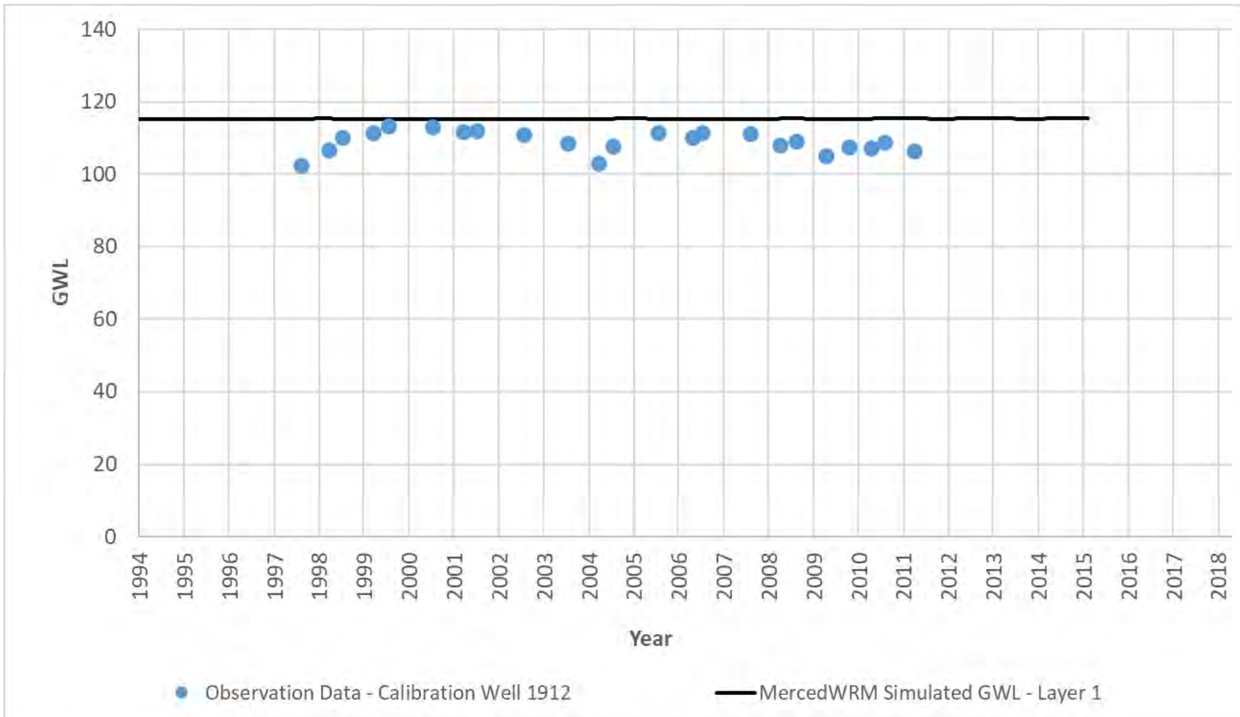


Figure A 61: Calibration Well 1912

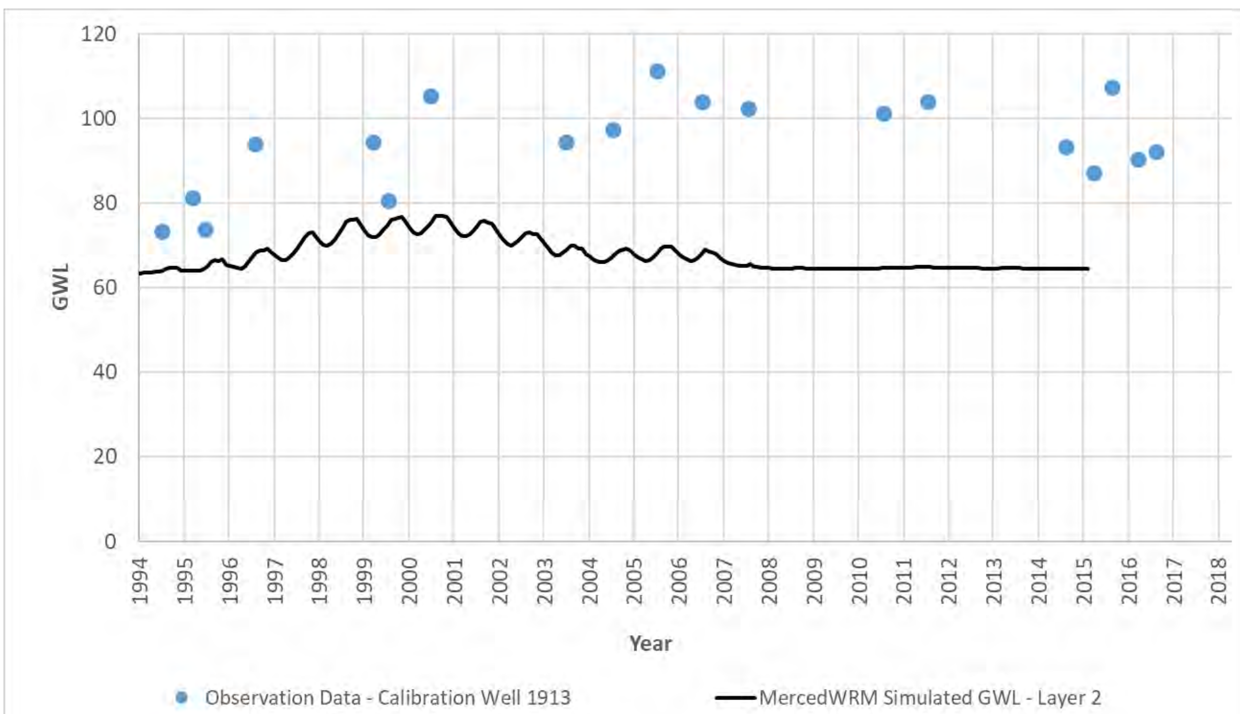


Figure A 62: Calibration Well 1913

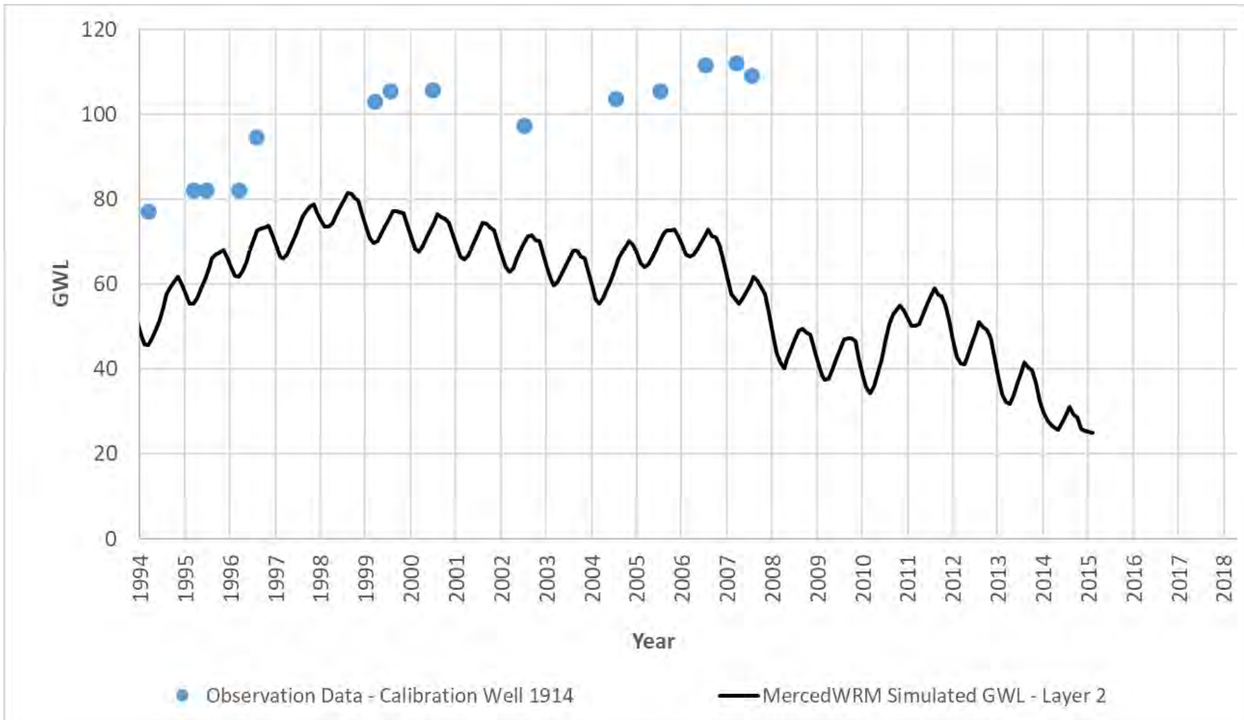


Figure A 63: Calibration Well 1914

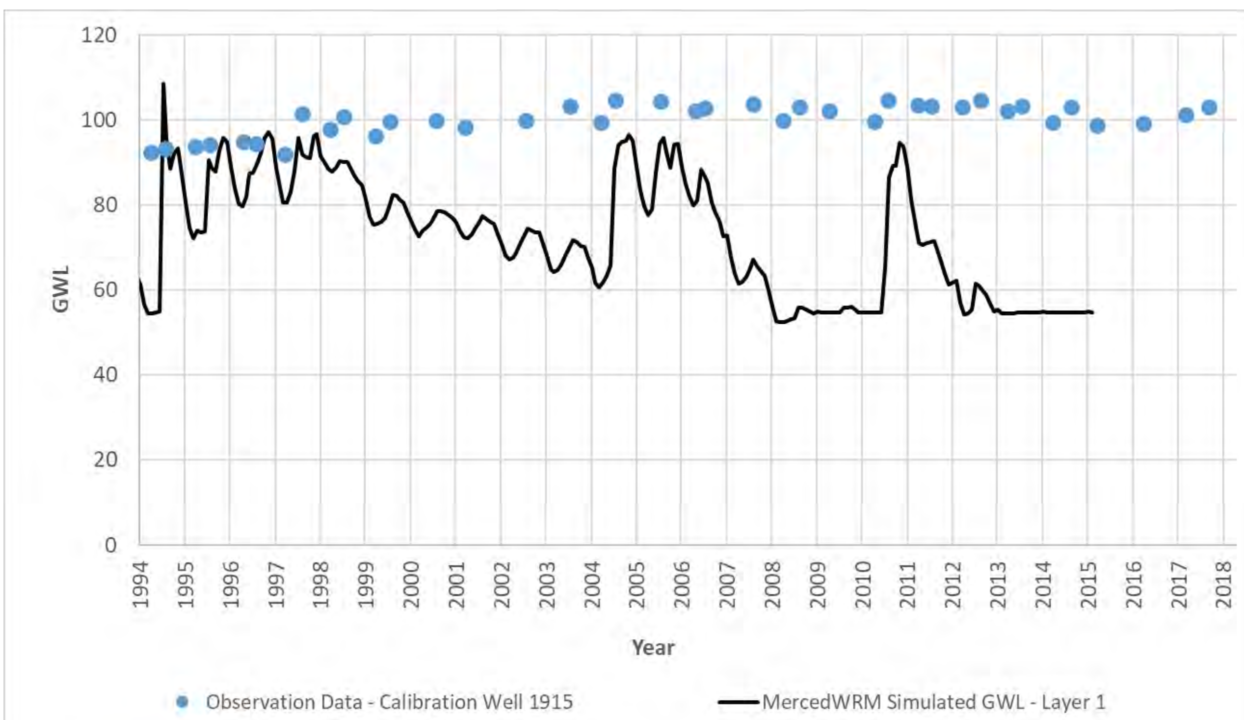


Figure A 64: Calibration Well 1915

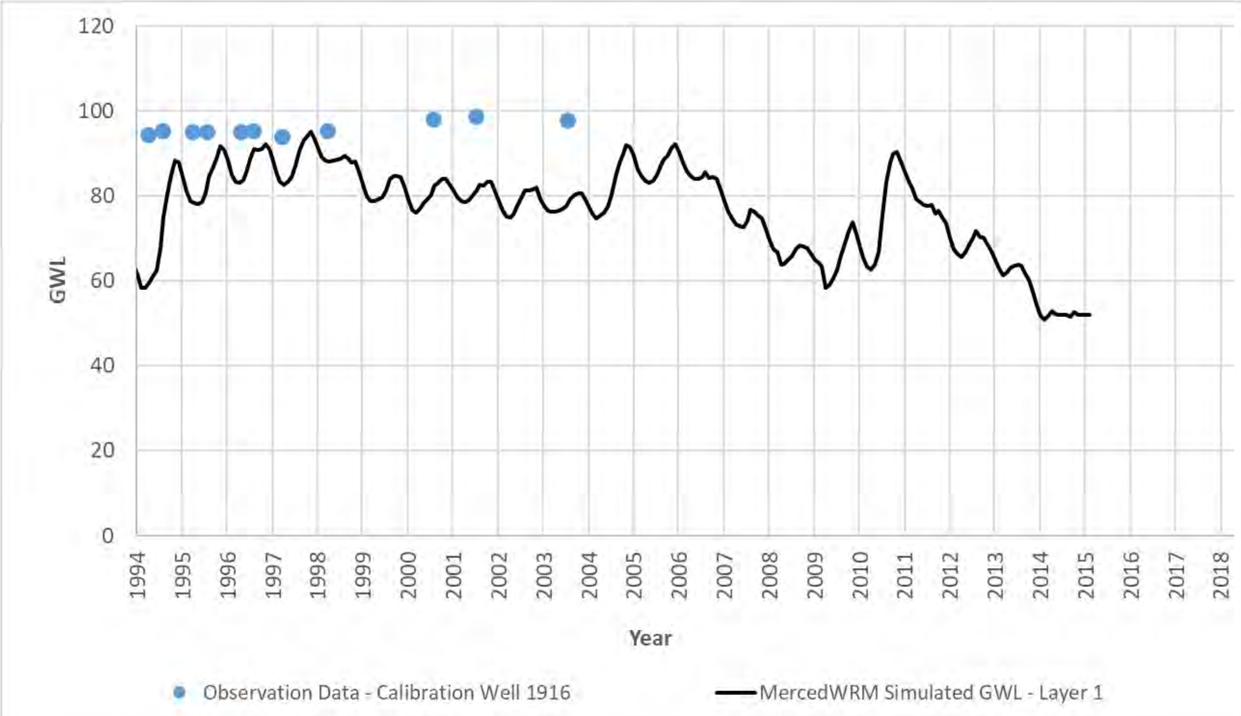


Figure A 65: Calibration Well 1916

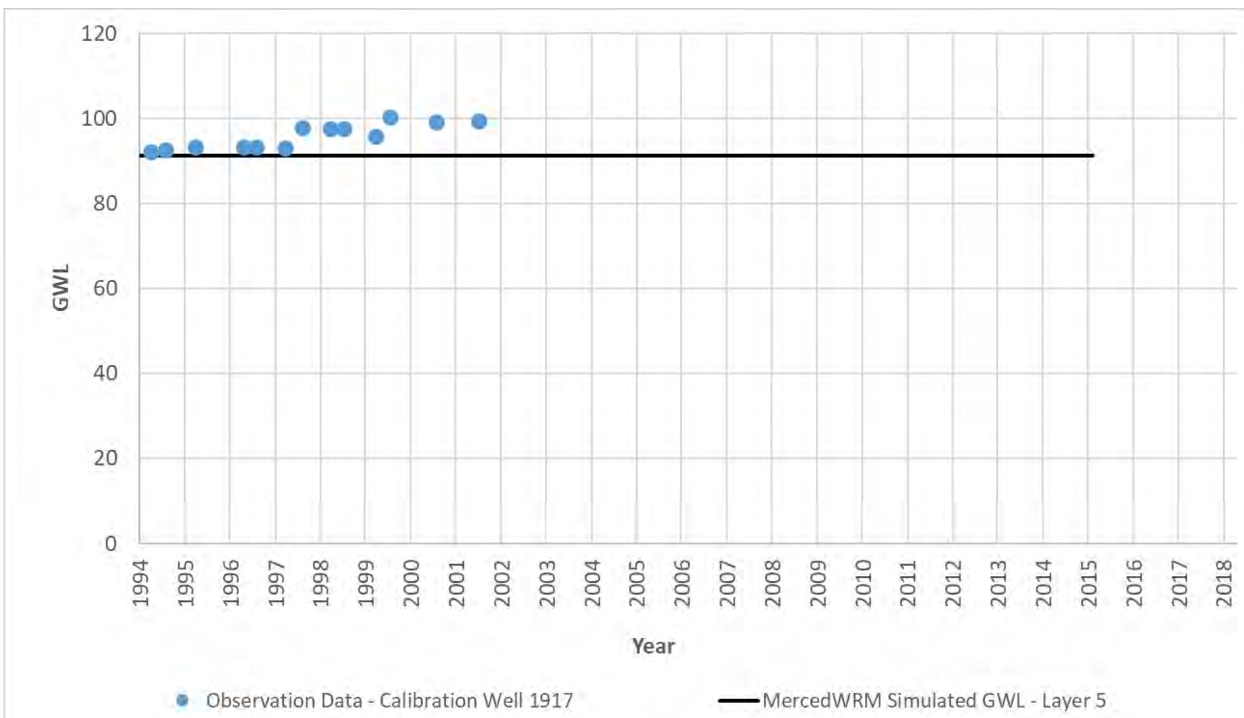


Figure A 66: Calibration Well 1917

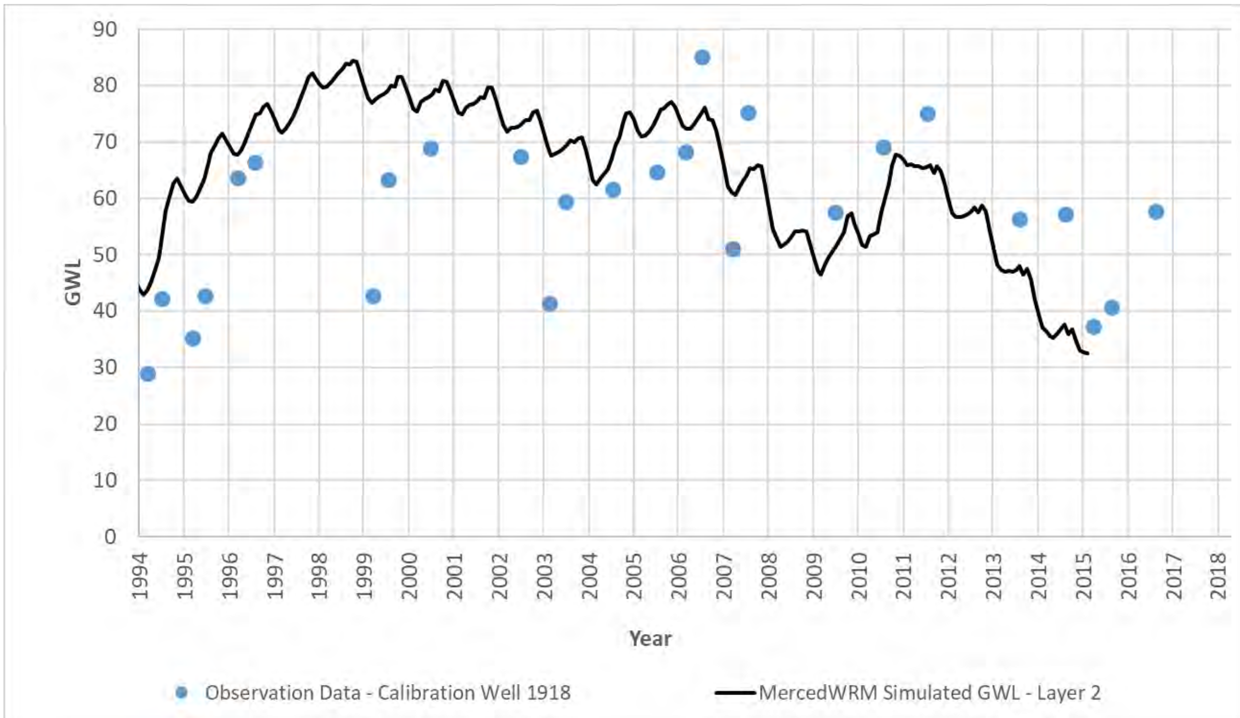


Figure A 67: Calibration Well 1918

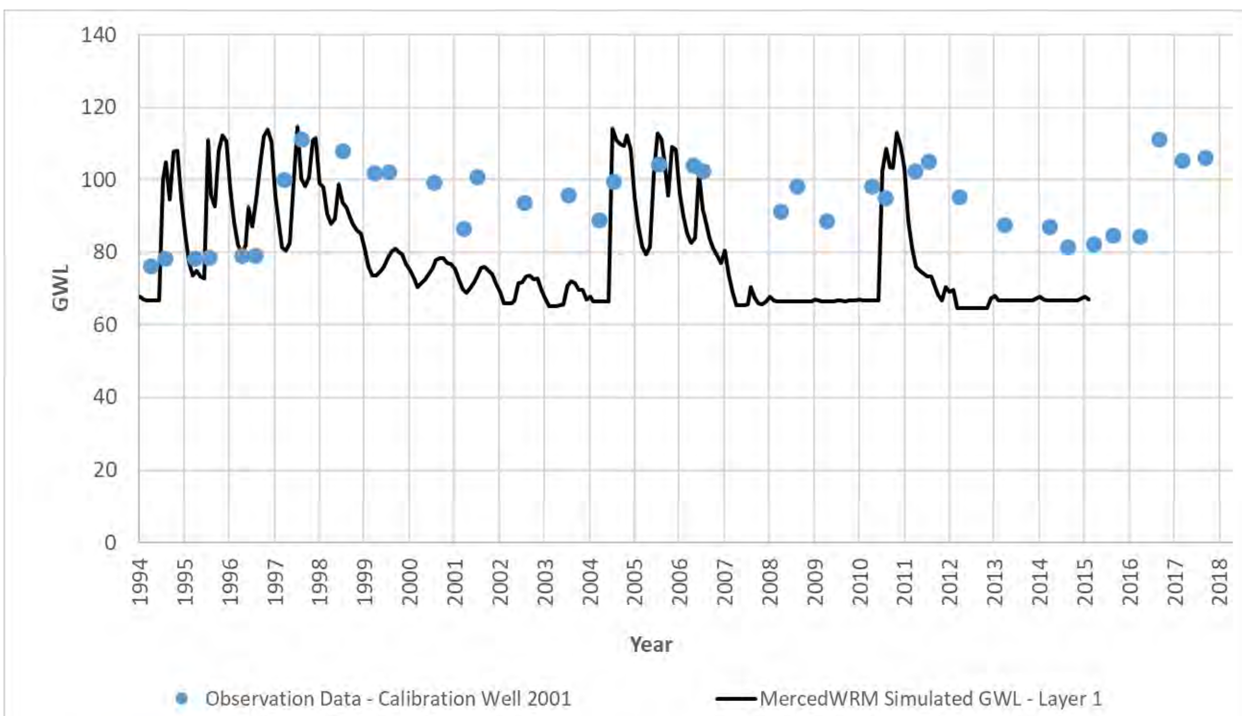


Figure A 68: Calibration Well 2001

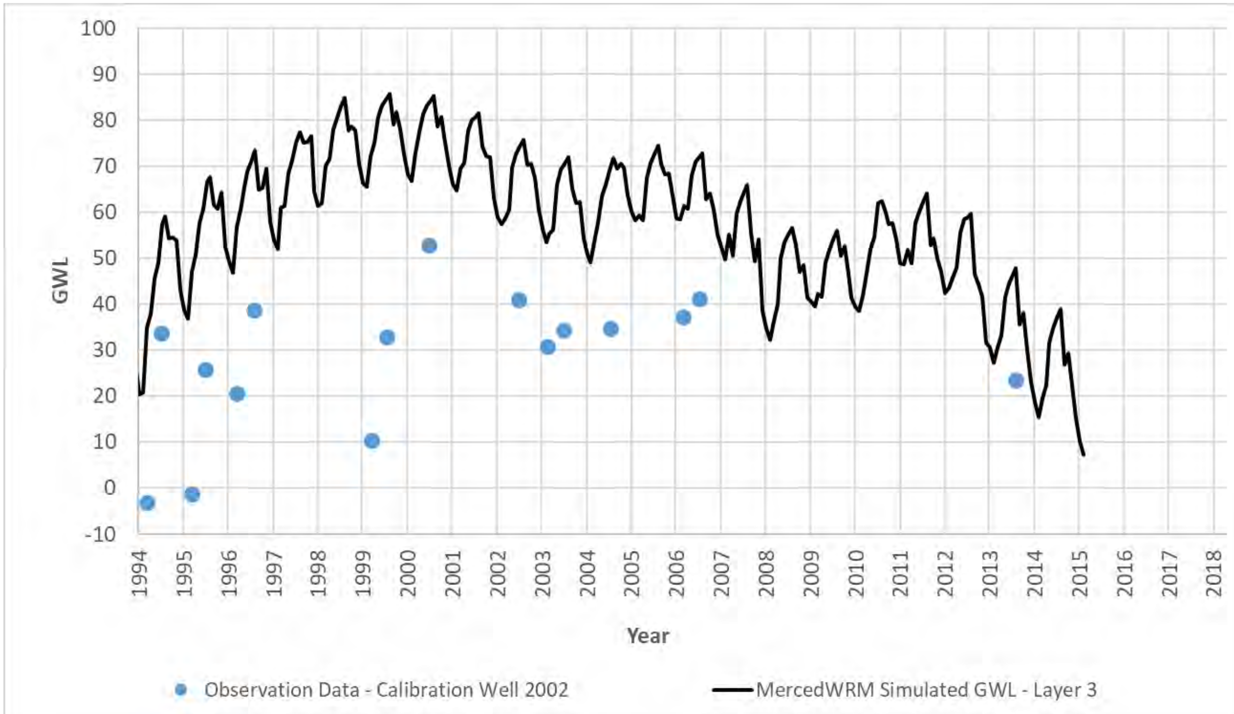


Figure A 69: Calibration Well 2002

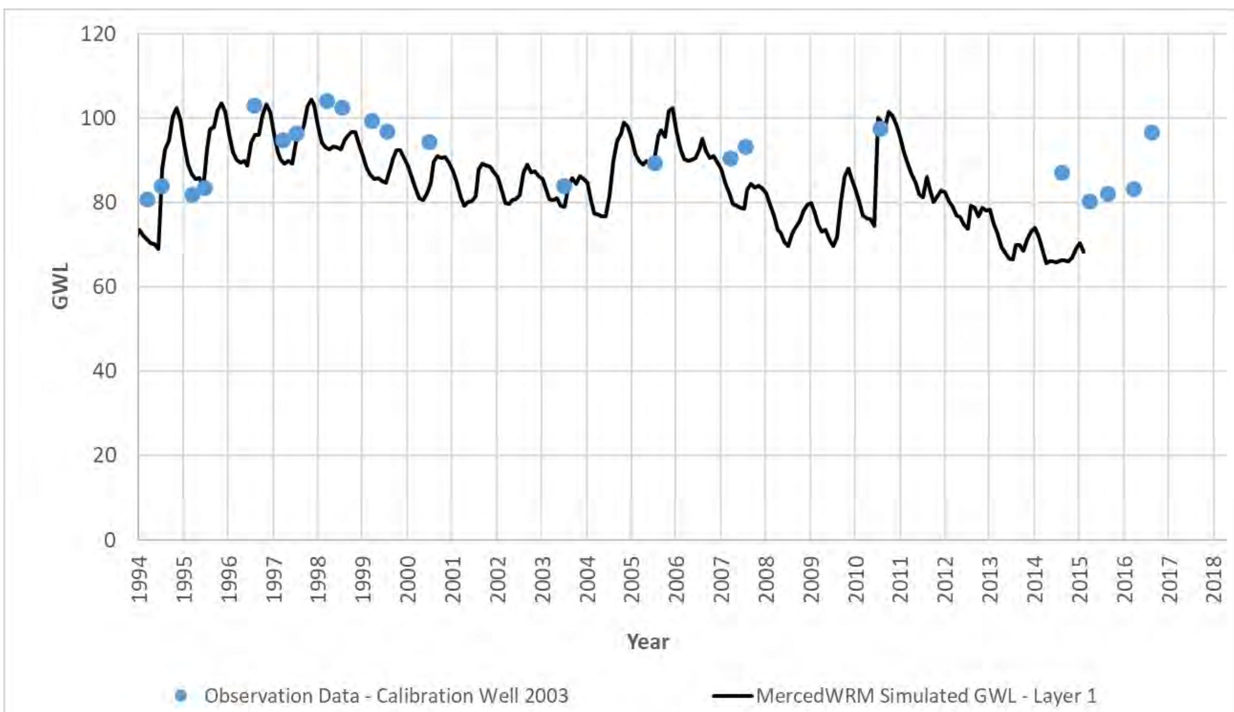


Figure A 70: Calibration Well 2003

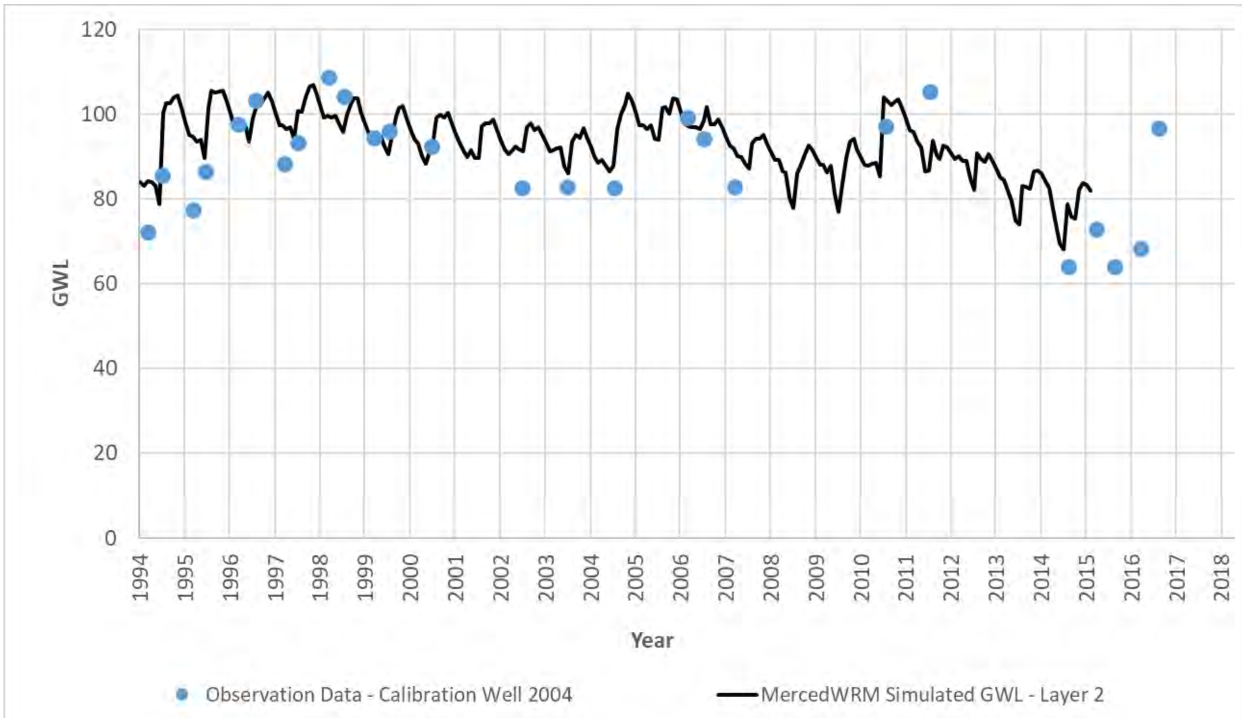


Figure A 71: Calibration Well 2004

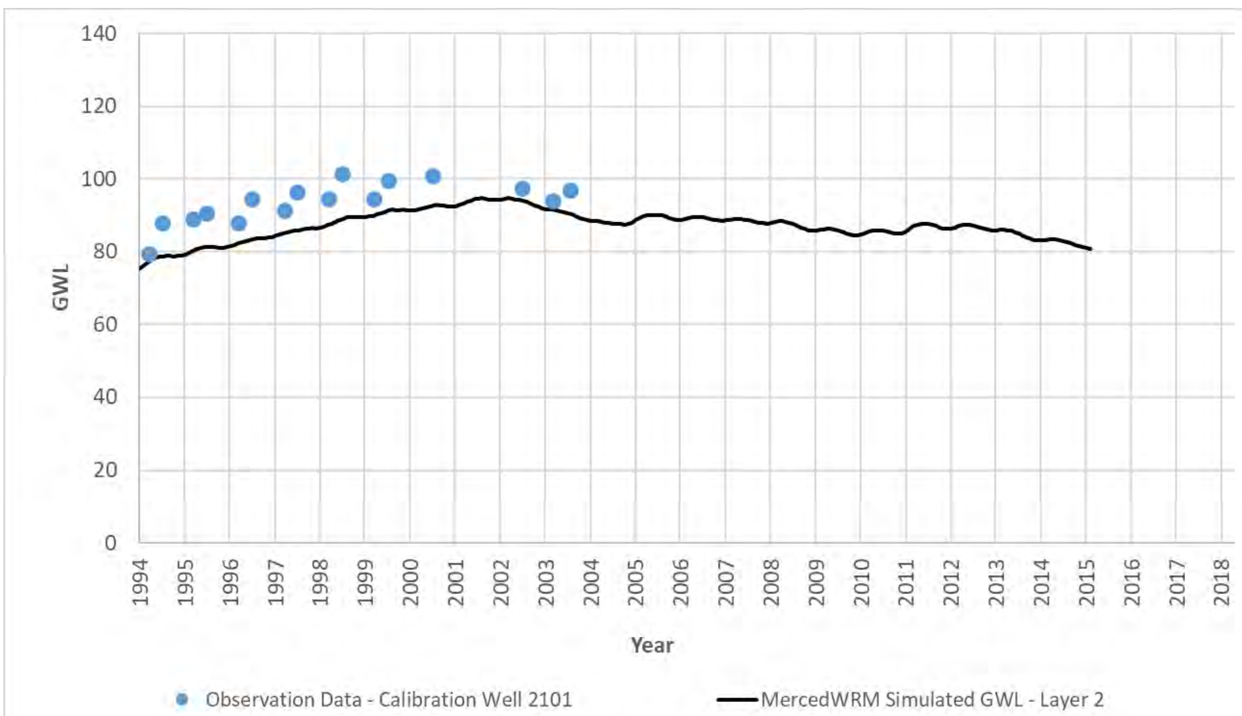


Figure A 72: Calibration Well 2101

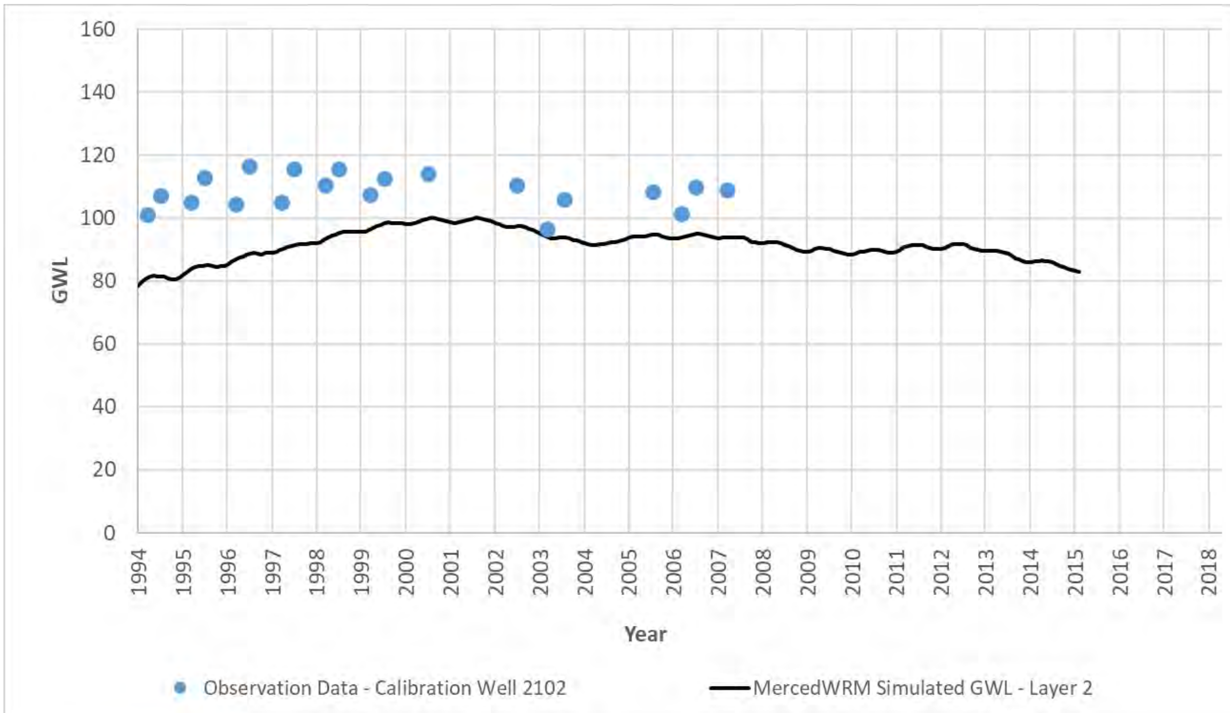


Figure A 73: Calibration Well 2102

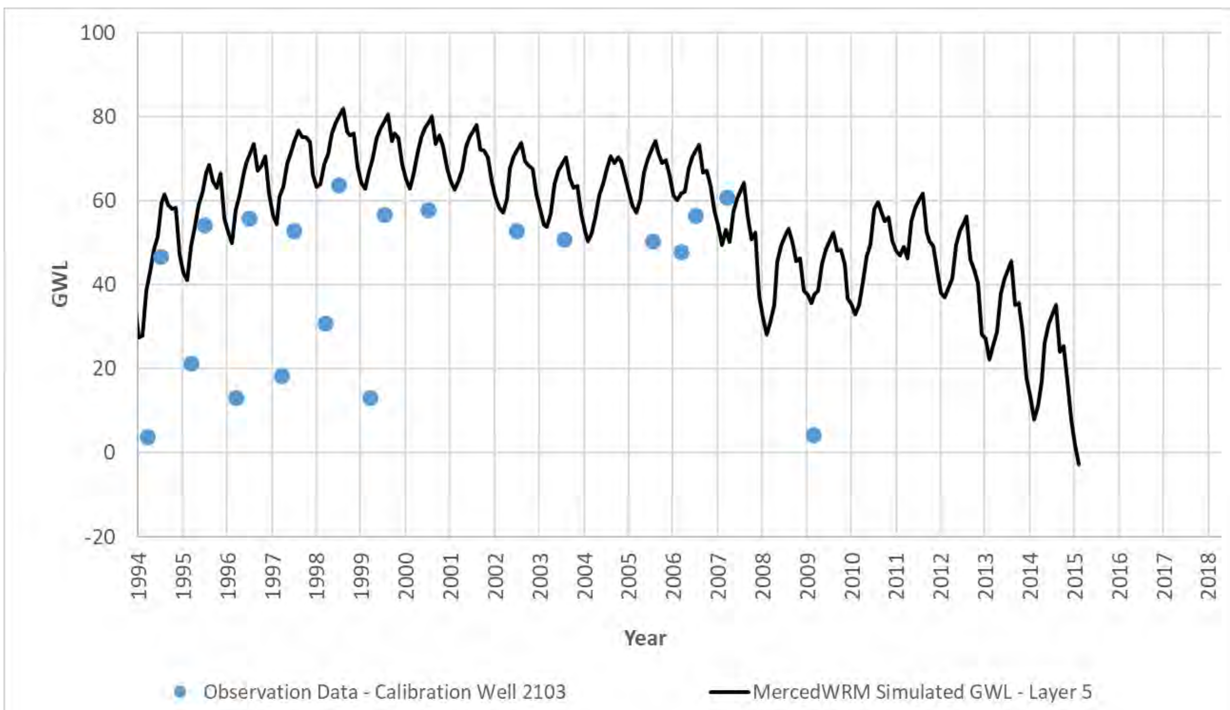


Figure A 74: Calibration Well 2103

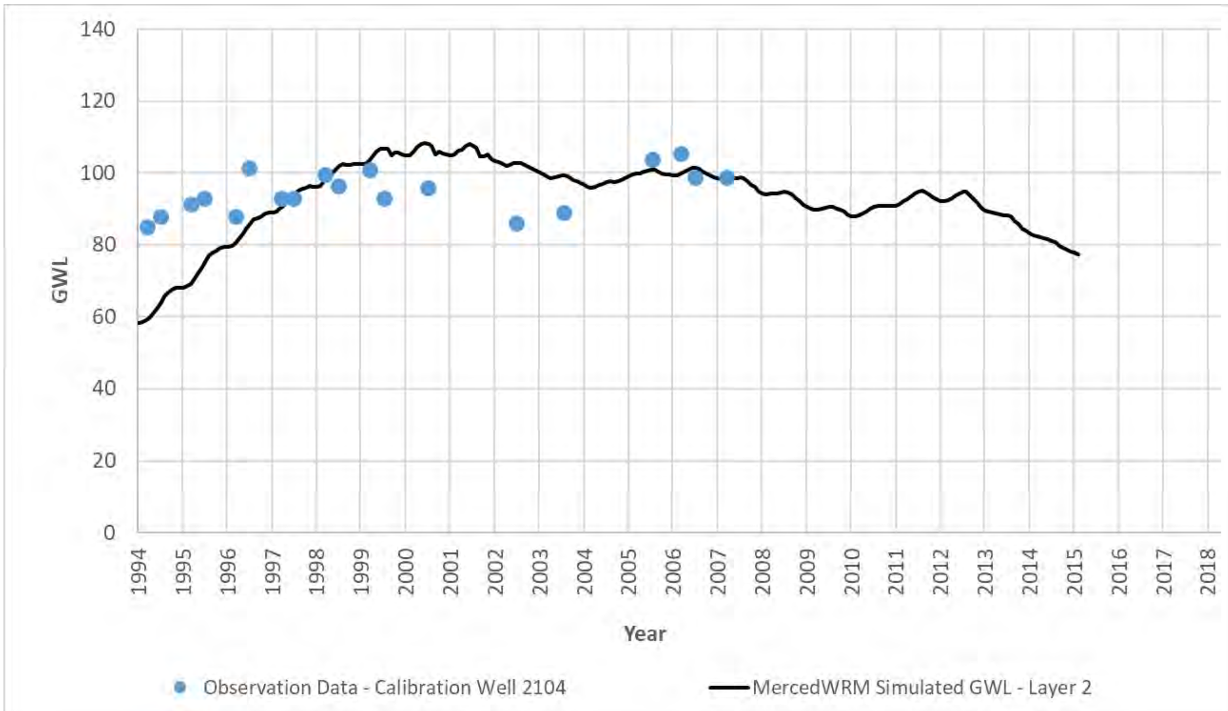


Figure A 75: Calibration Well 2104

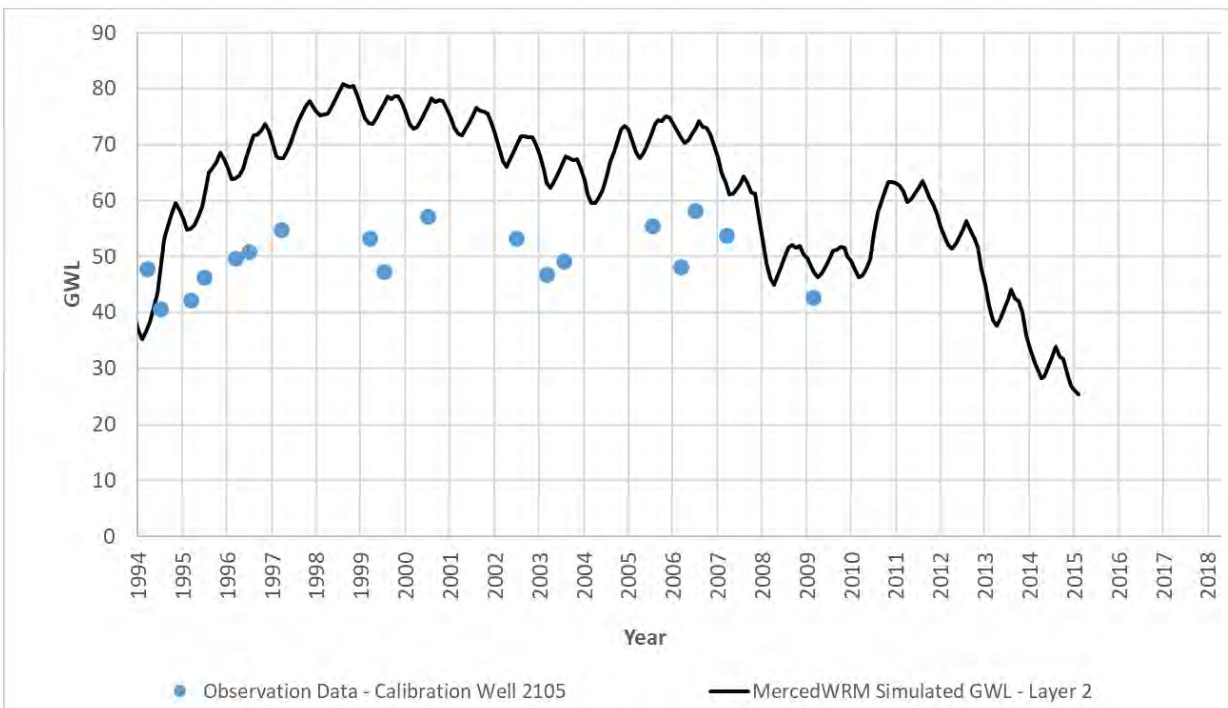


Figure A 76: Calibration Well 2105

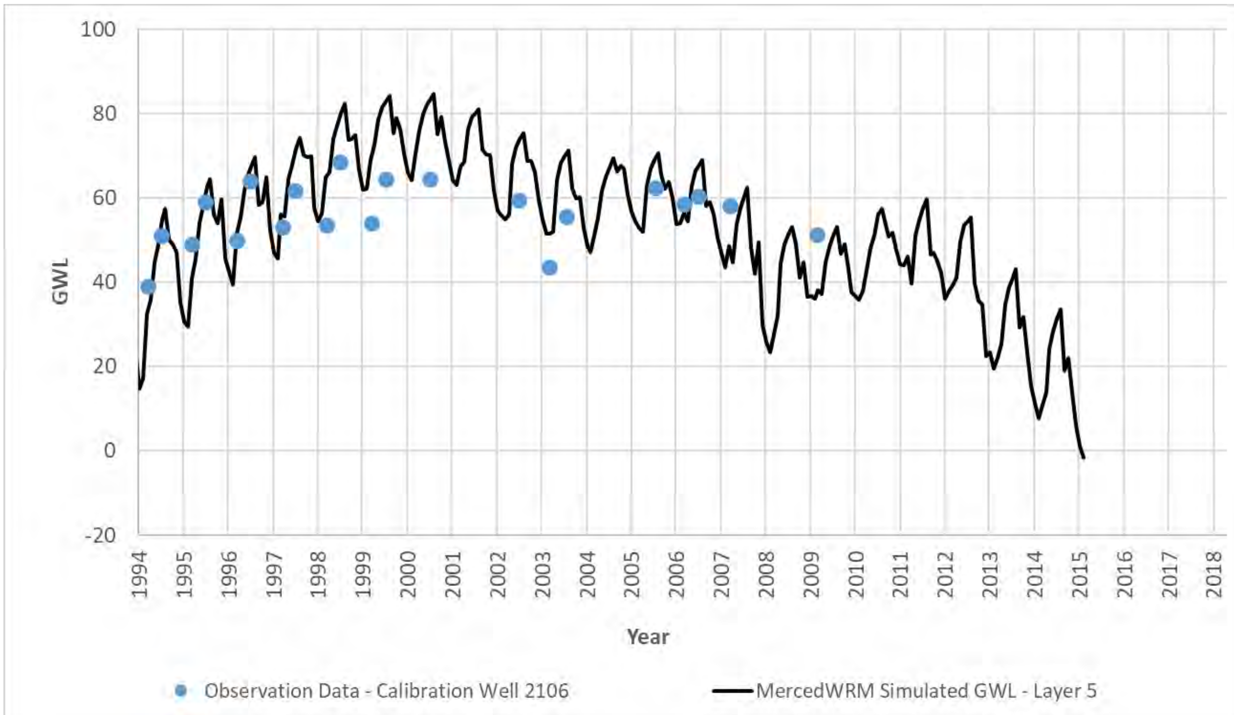


Figure A 77: Calibration Well 2106

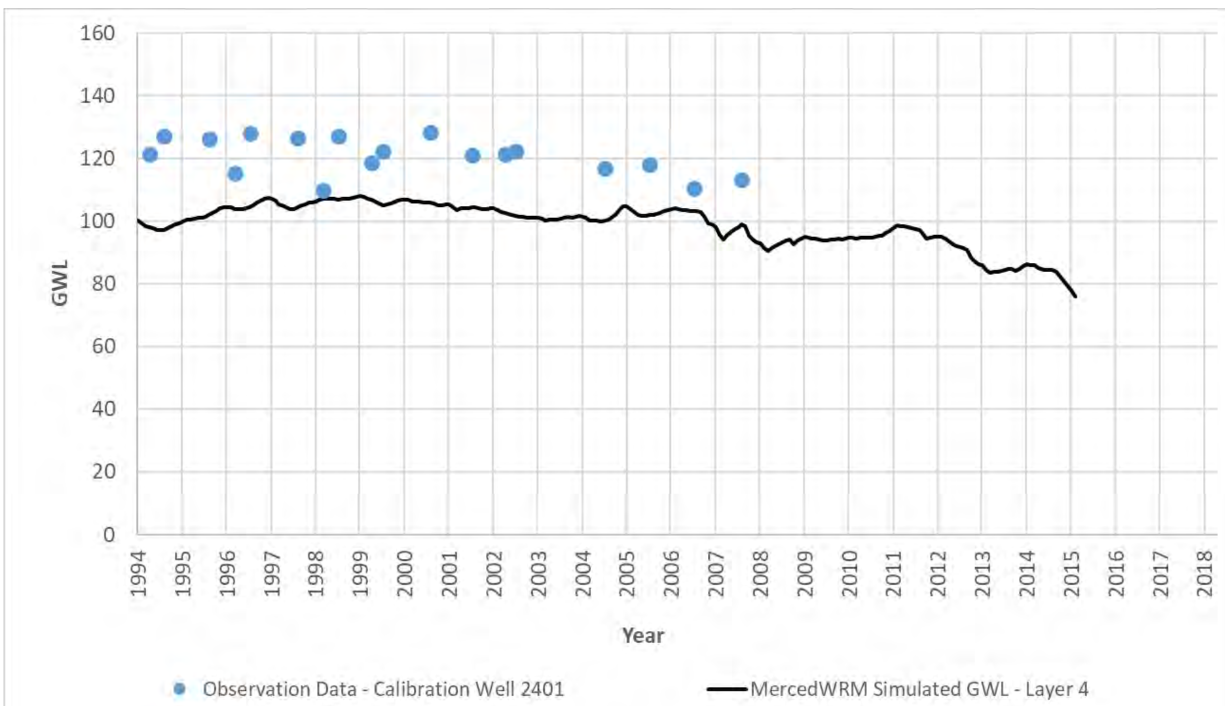


Figure A 78: Calibration Well 2401

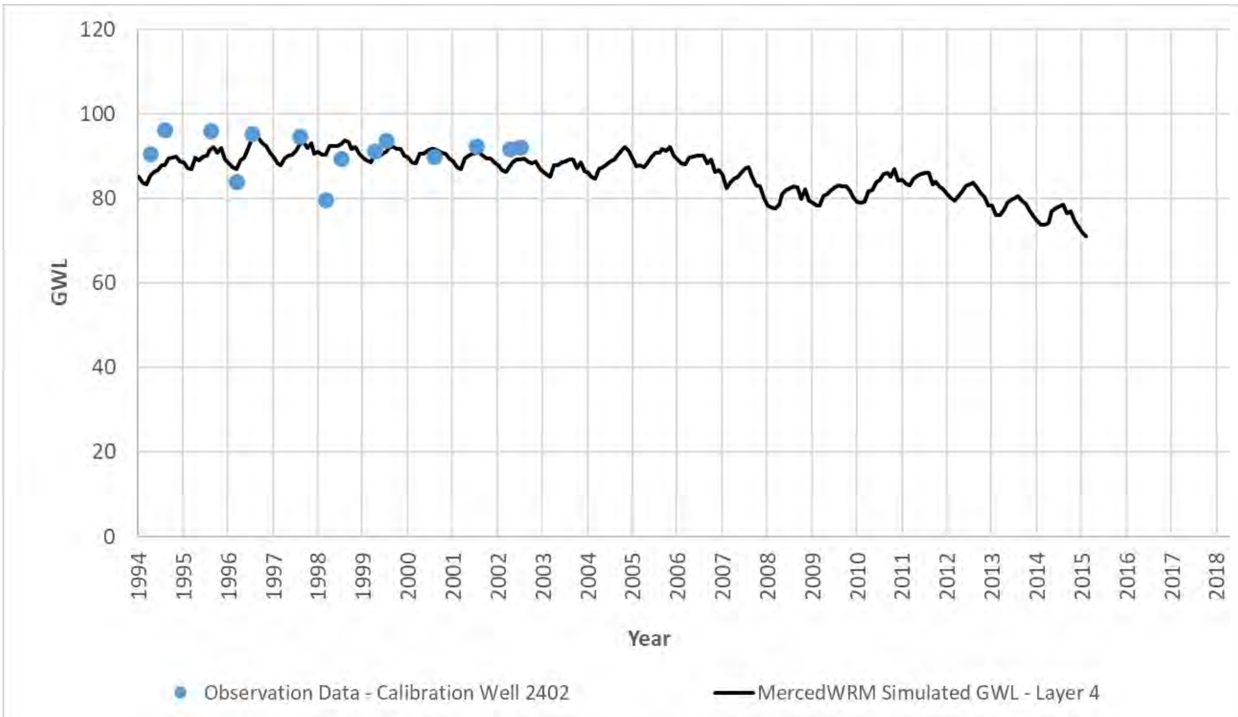


Figure A 79: Calibration Well 2402

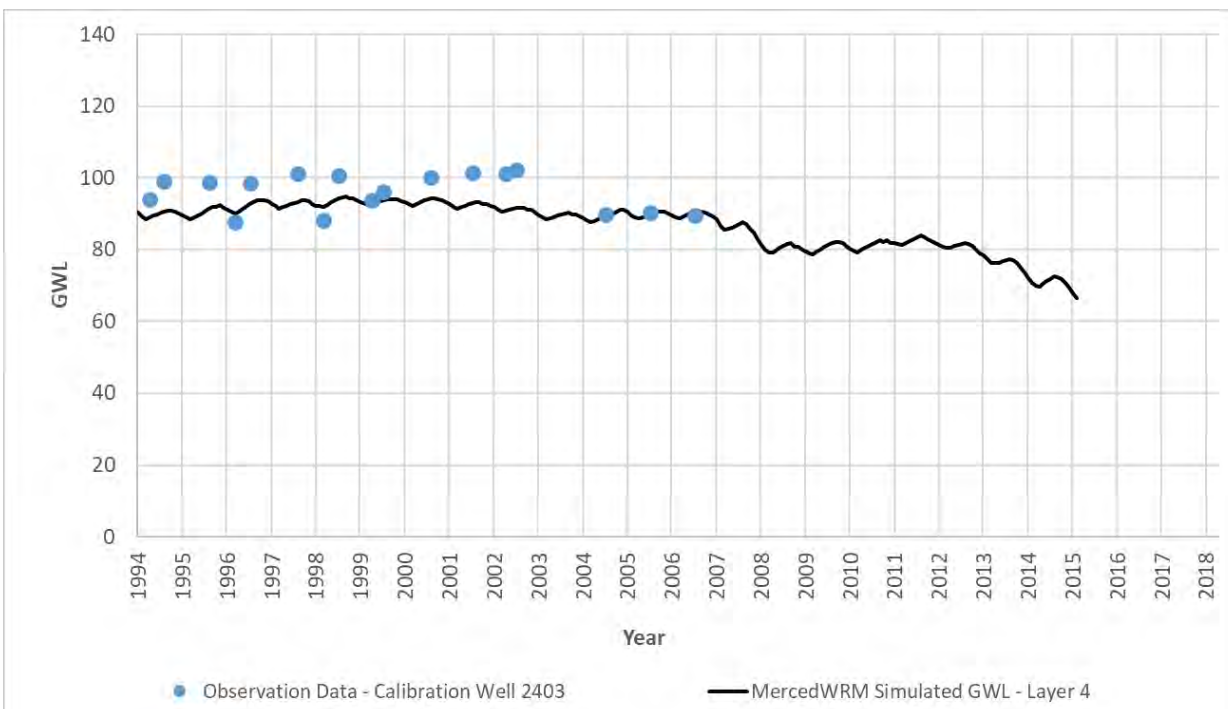


Figure A 80: Calibration Well 2403

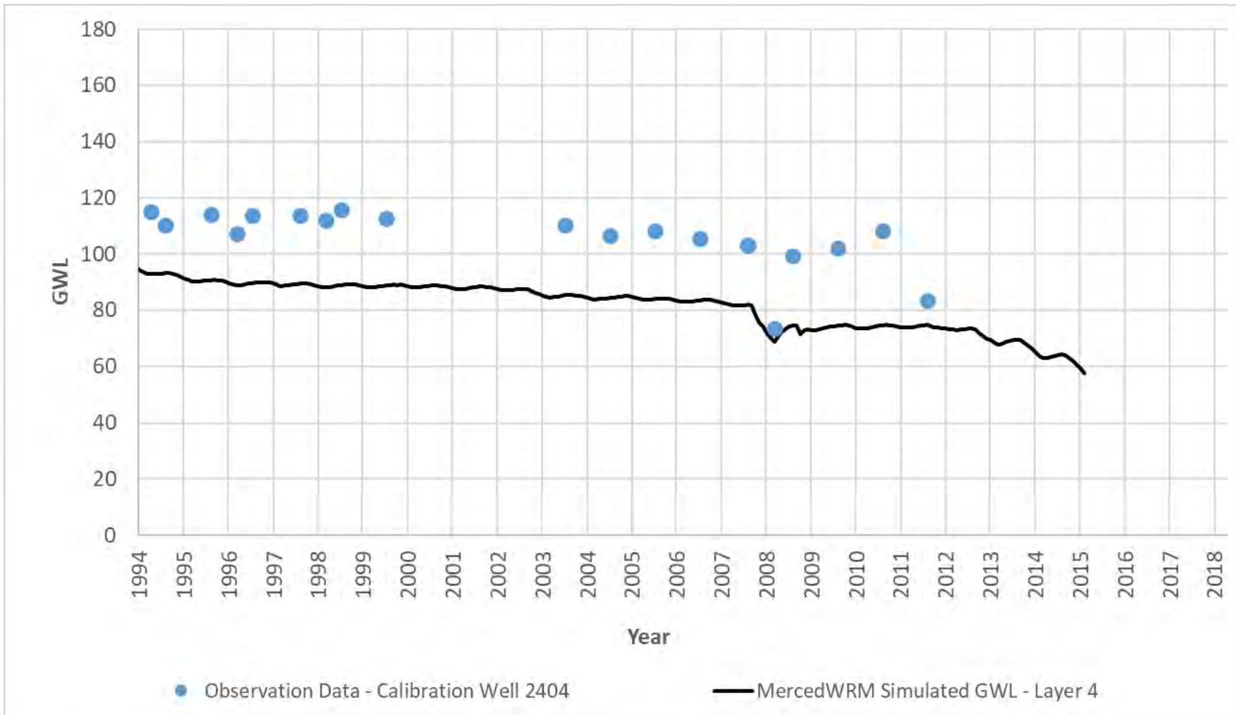


Figure A 81: Calibration Well 2404

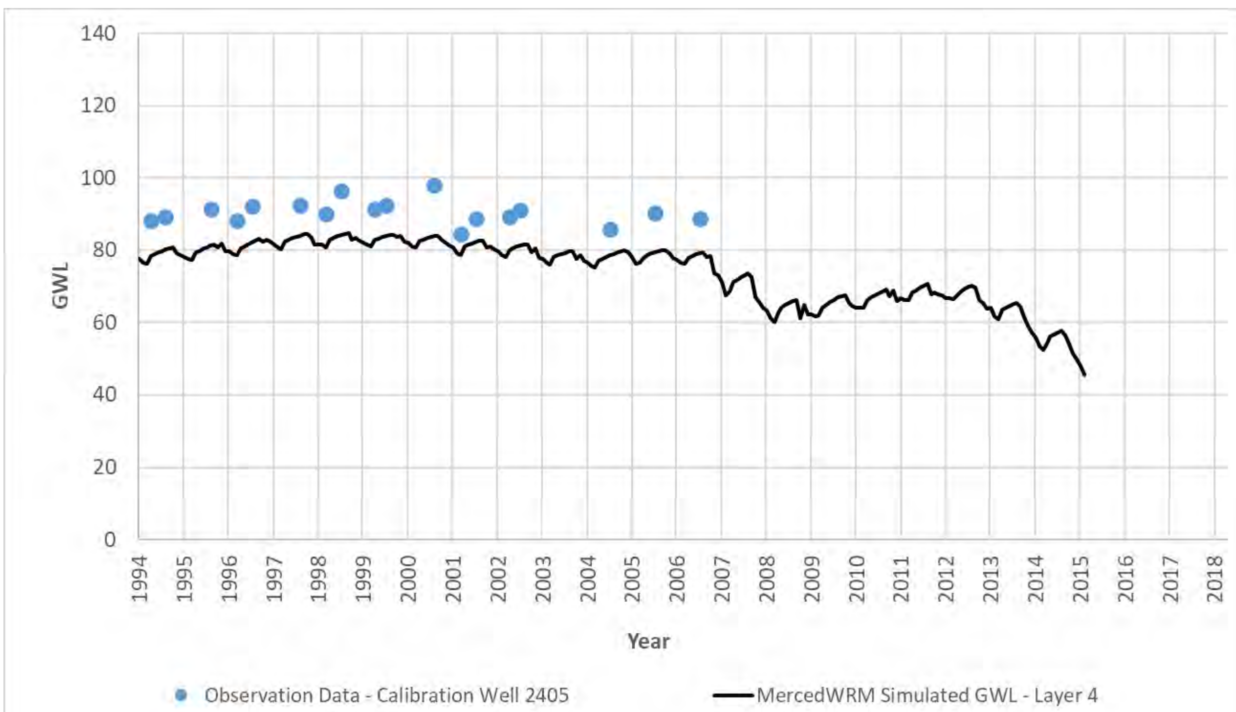


Figure A 82: Calibration Well 2405

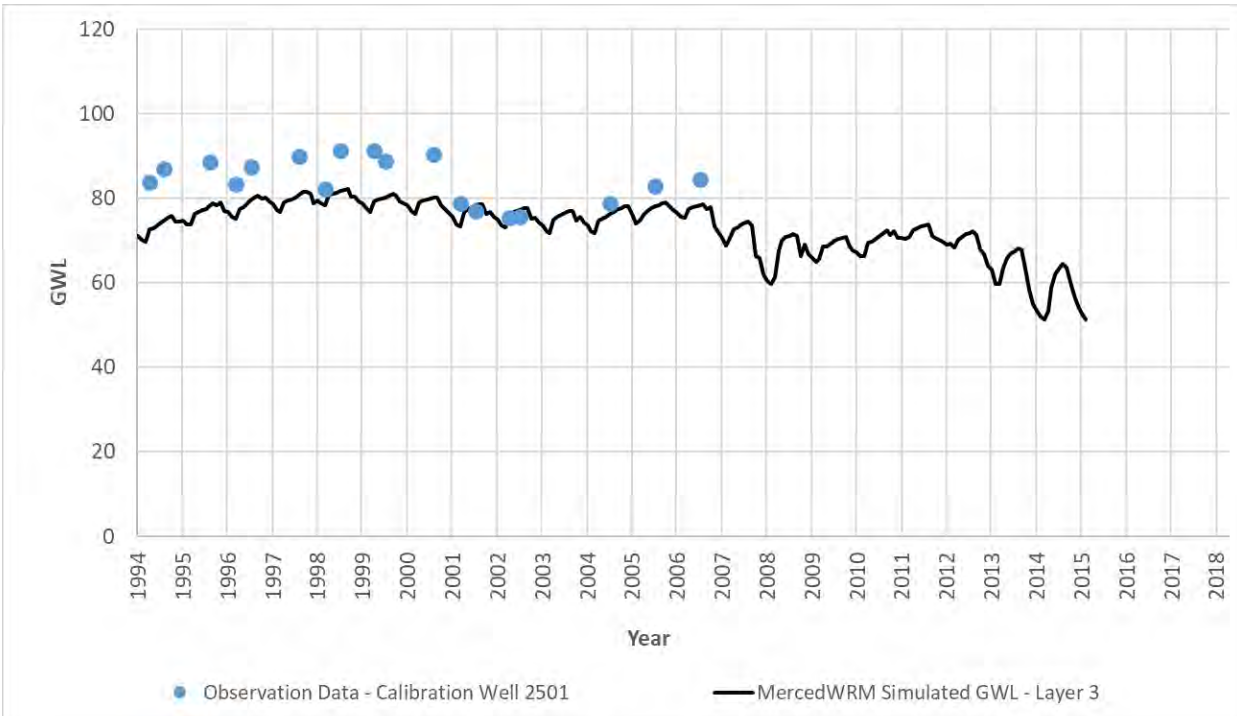


Figure A 83: Calibration Well 2501

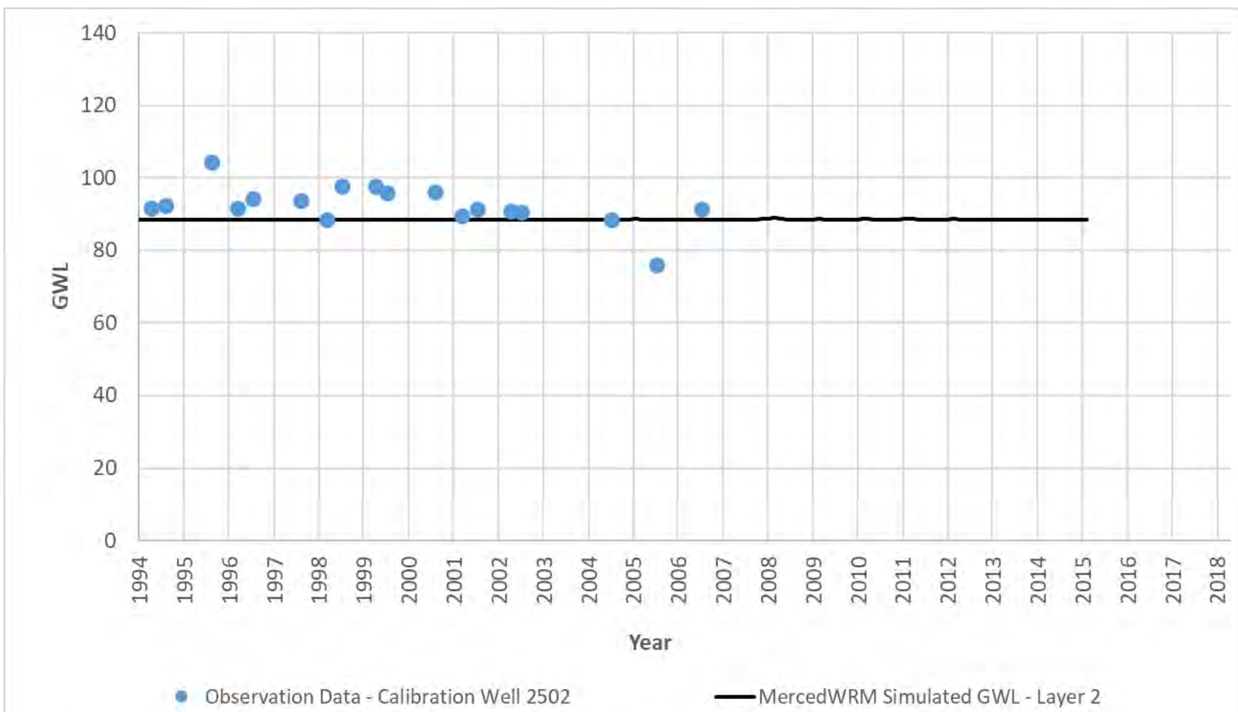


Figure A 84: Calibration Well 2502

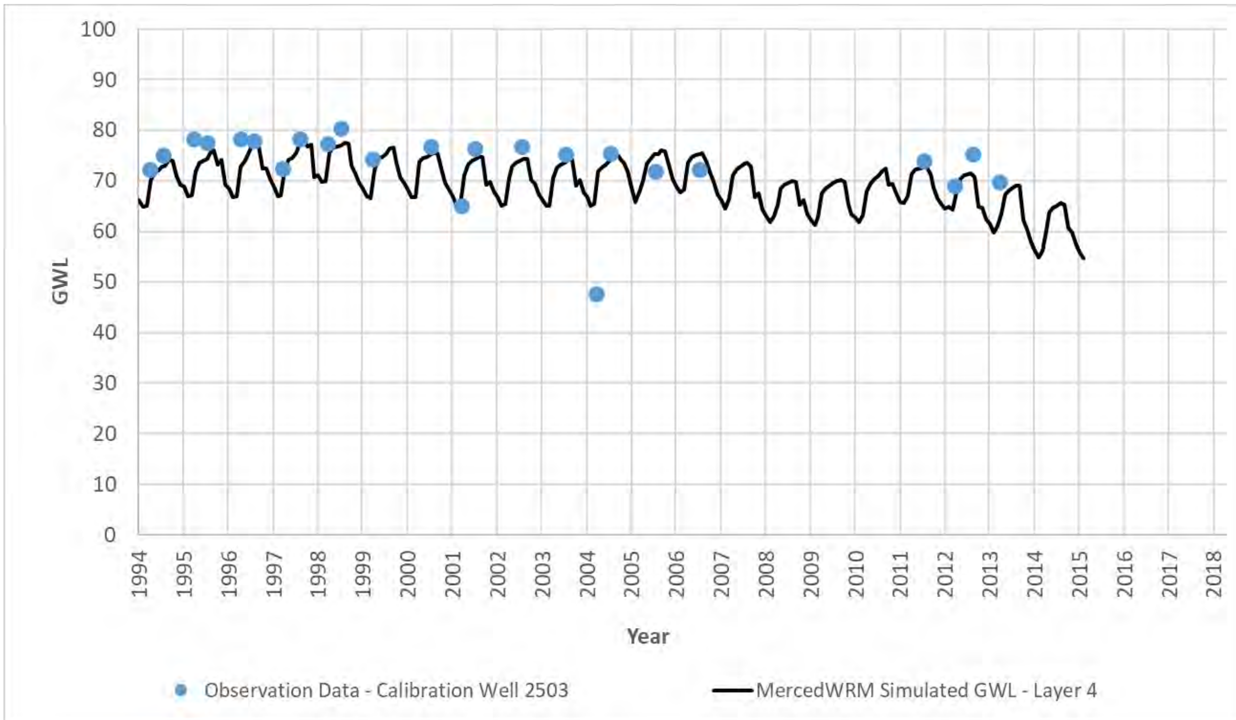


Figure A 85: Calibration Well 2503

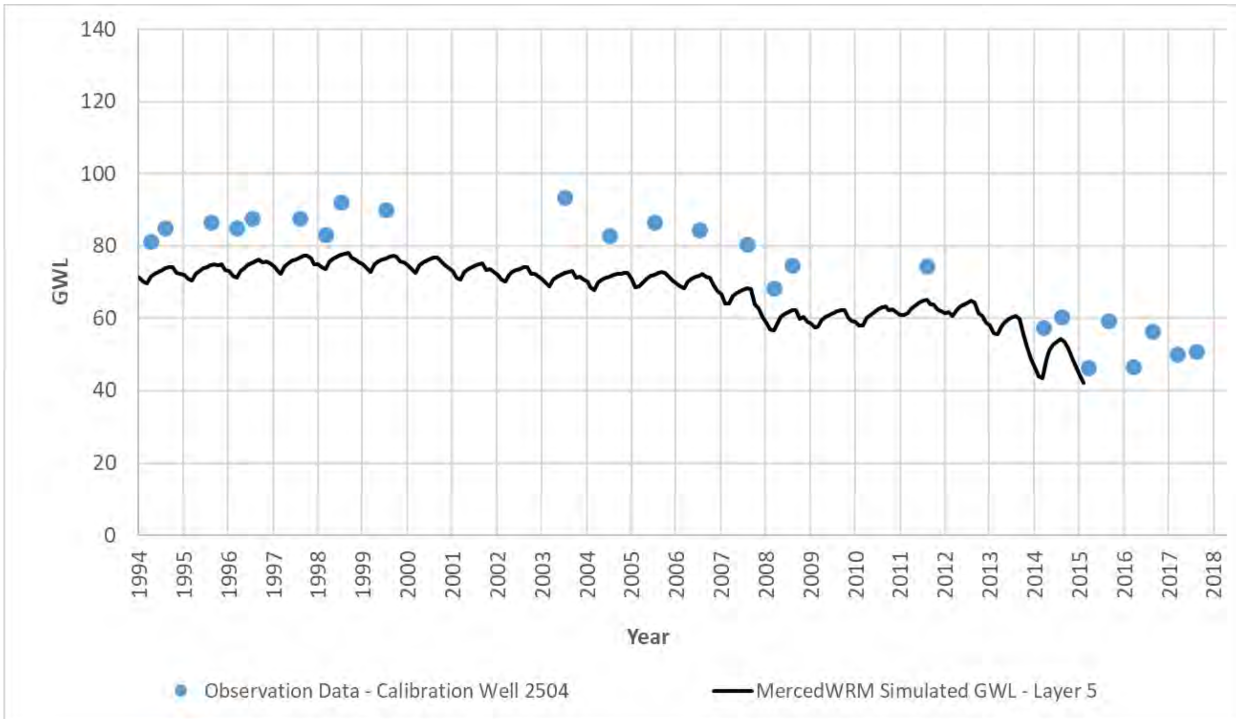


Figure A 86: Calibration Well 2504

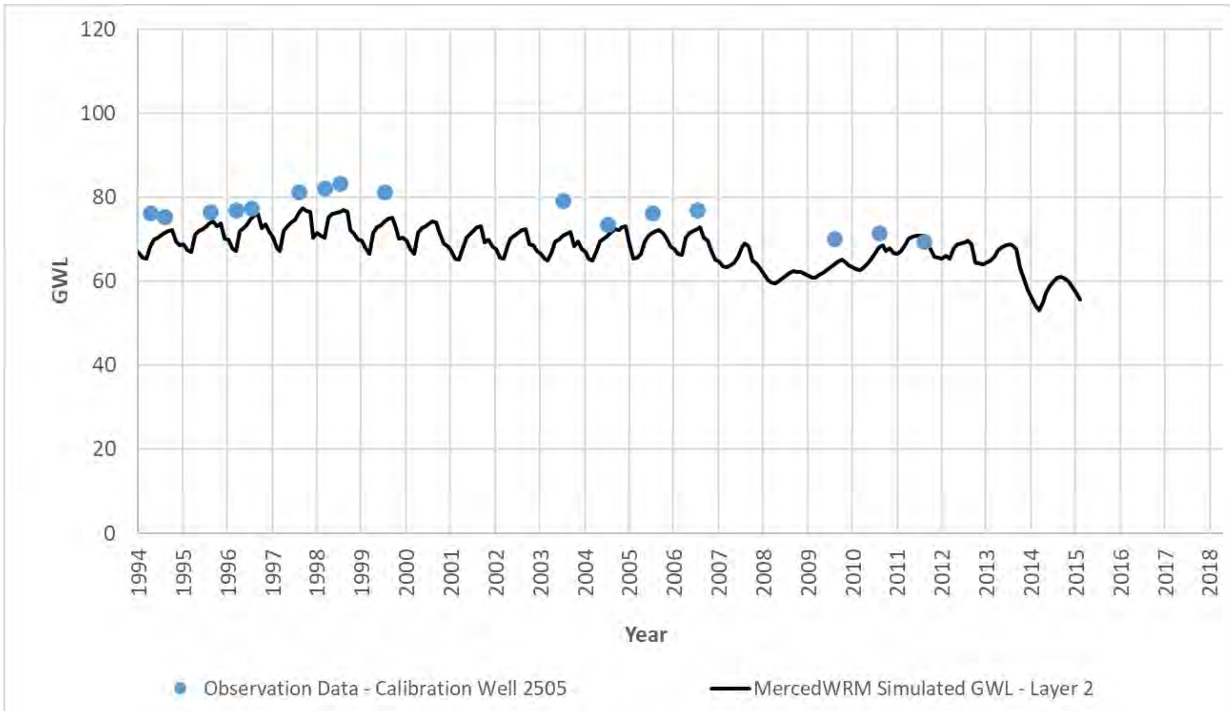


Figure A 87: Calibration Well 2505

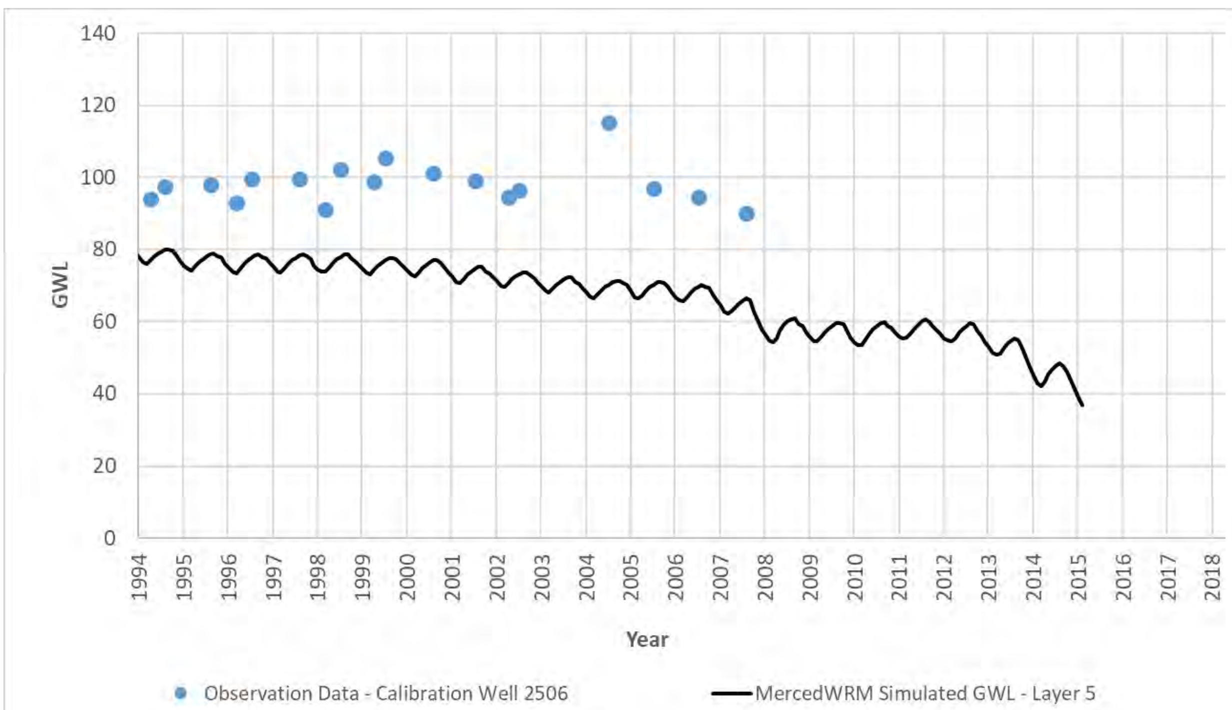


Figure A 88: Calibration Well 2506

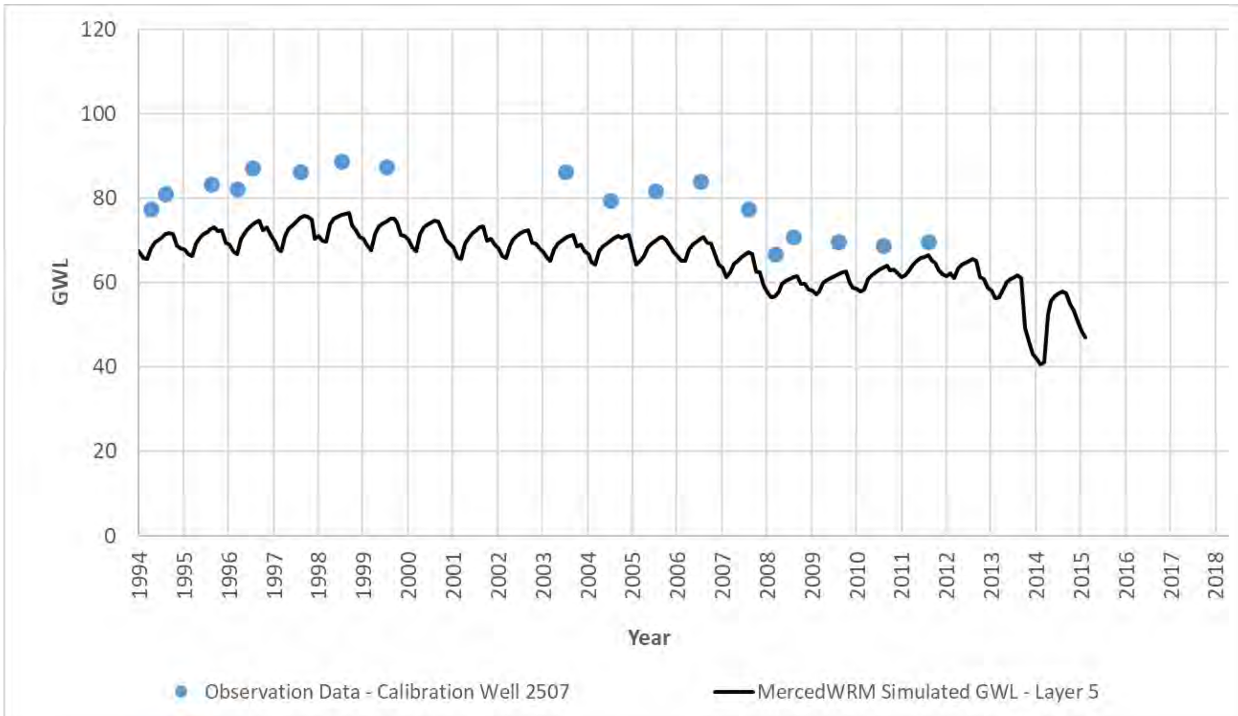


Figure A 89: Calibration Well 2507

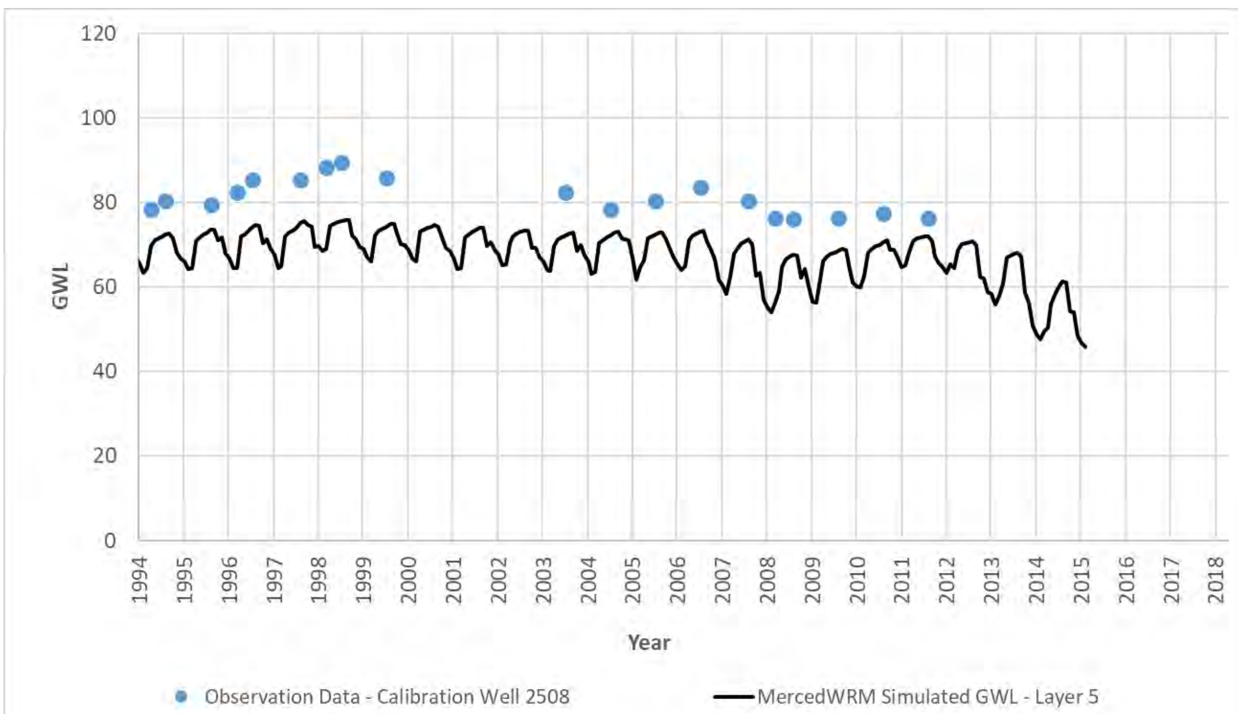


Figure A 90: Calibration Well 2508

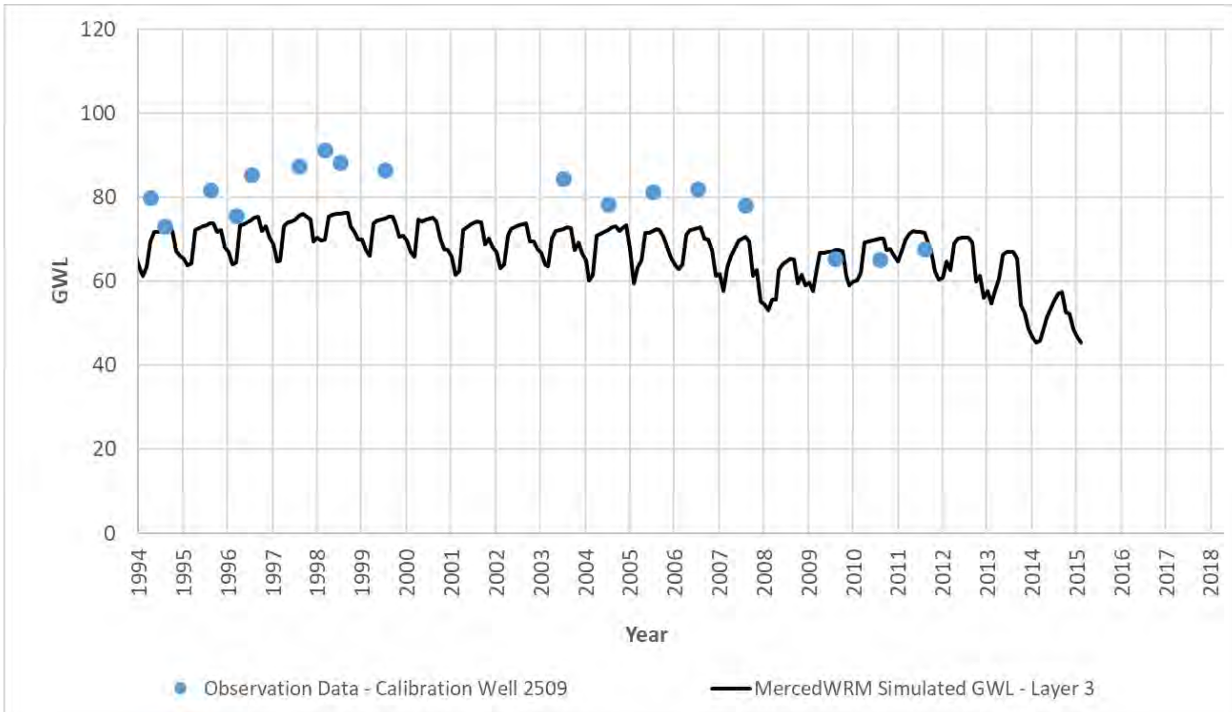


Figure A 91: Calibration Well 2509

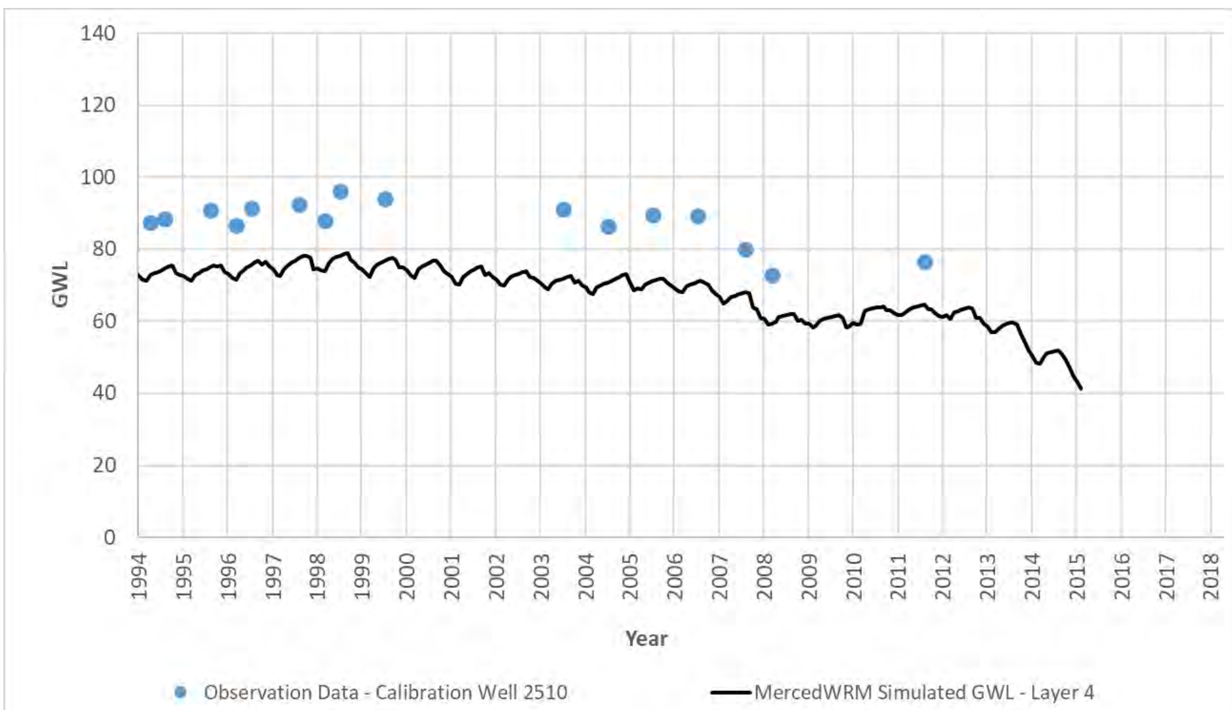


Figure A 92: Calibration Well 2510

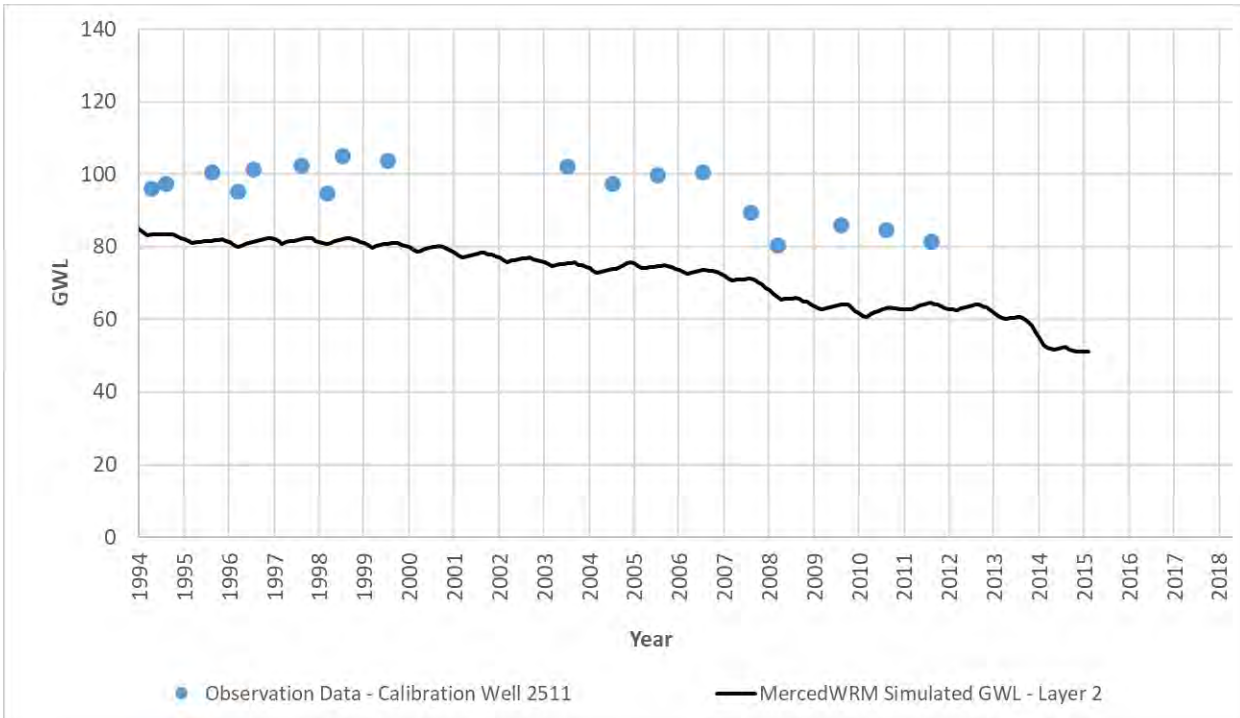


Figure A 93: Calibration Well 2511

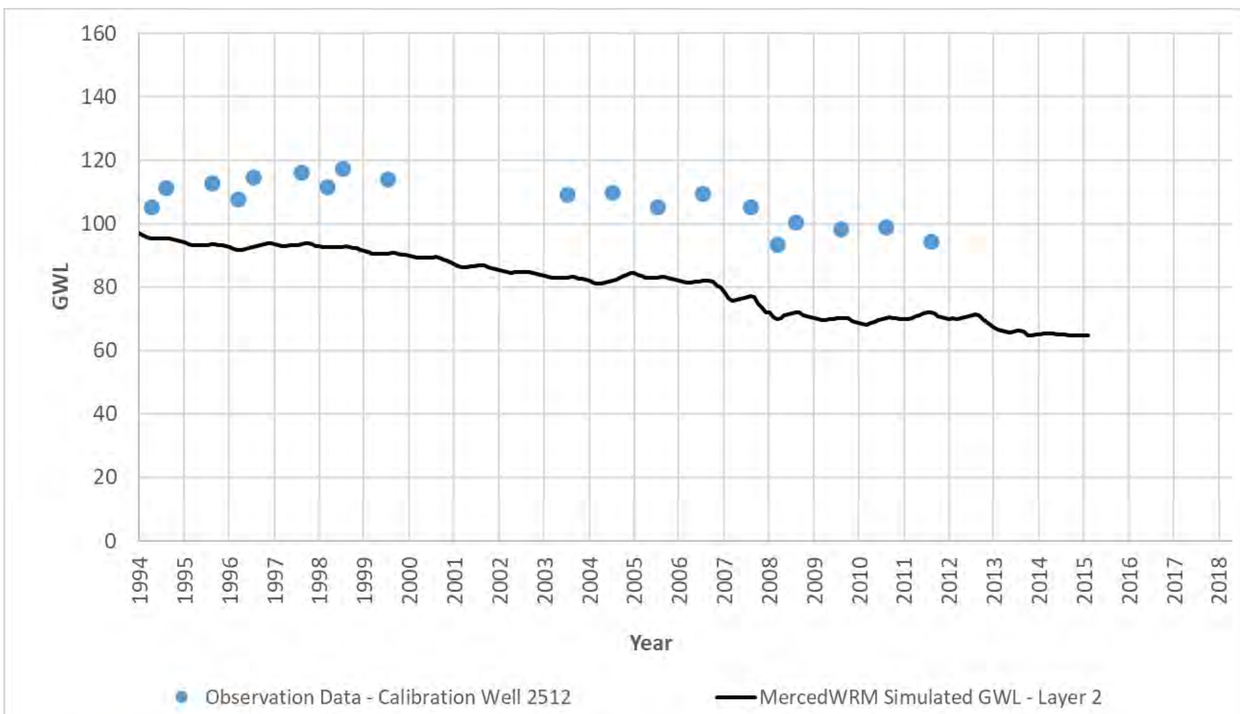


Figure A 94: Calibration Well 2512

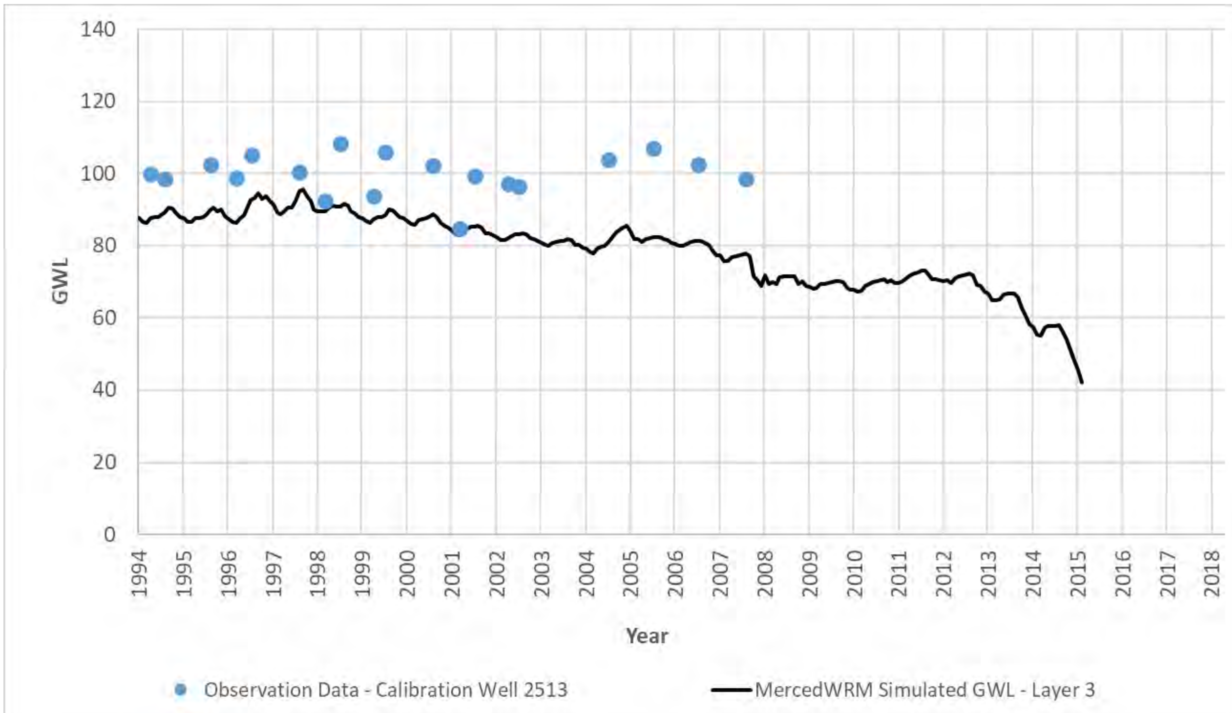


Figure A 95: Calibration Well 2513

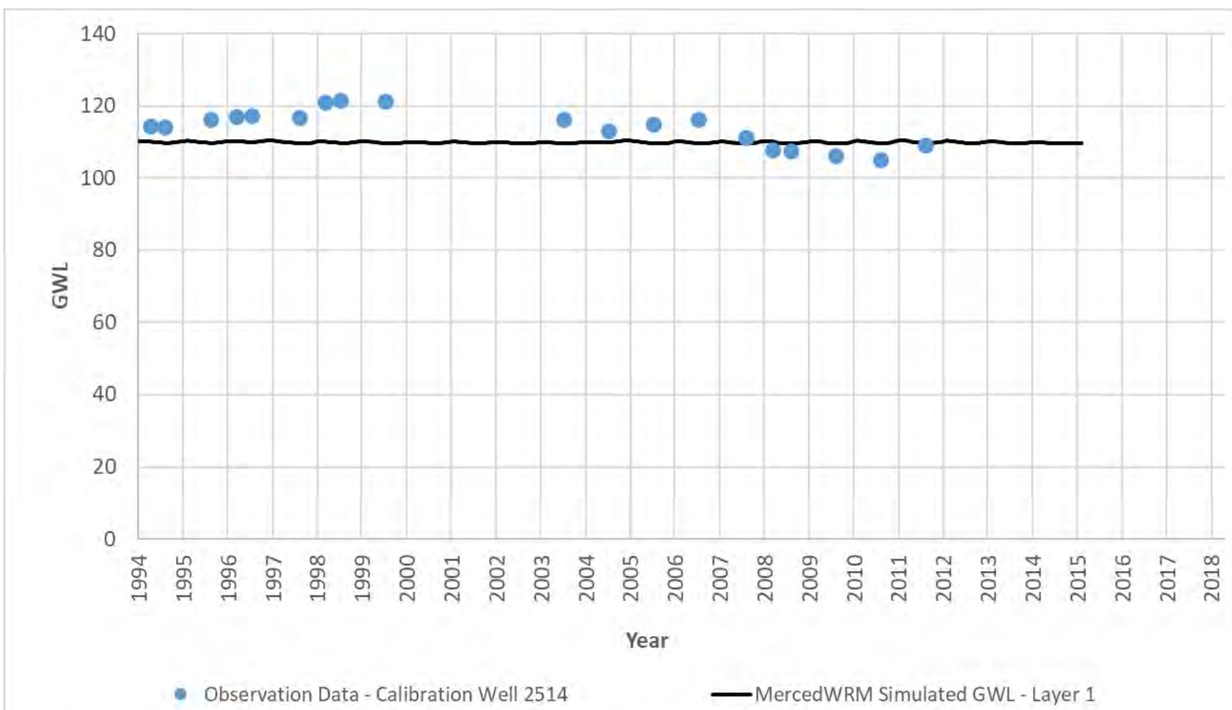


Figure A 96: Calibration Well 2514

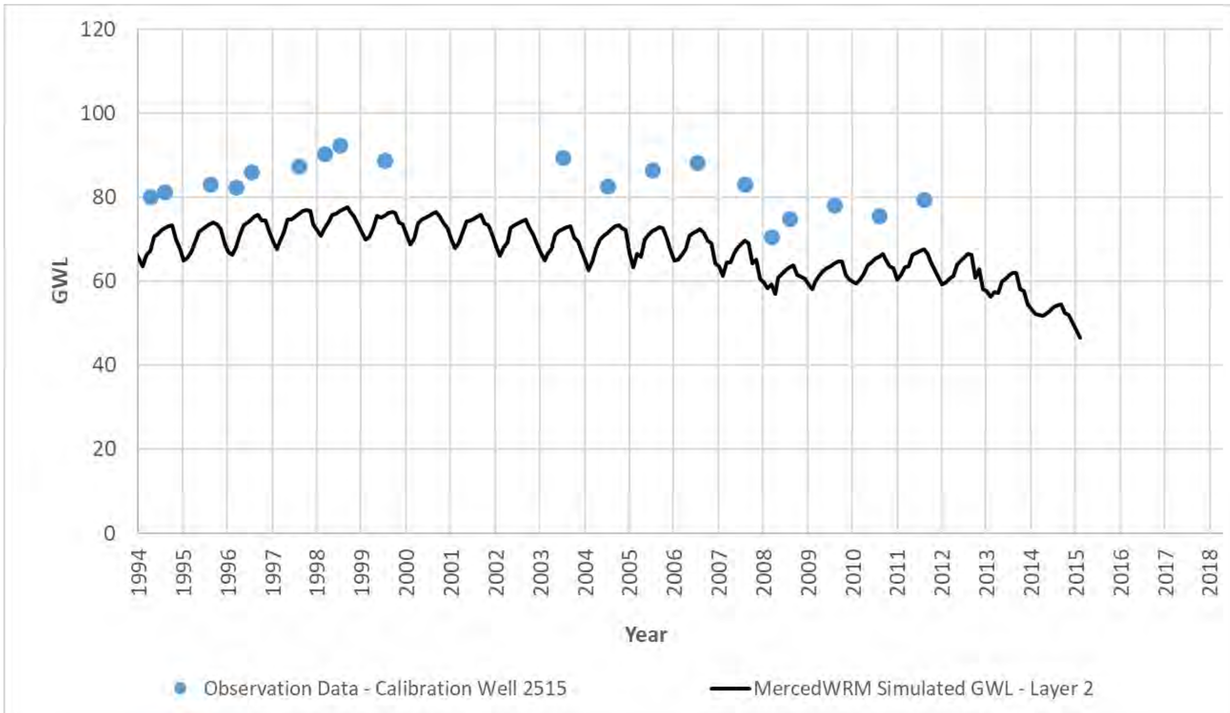


Figure A 97: Calibration Well 2515

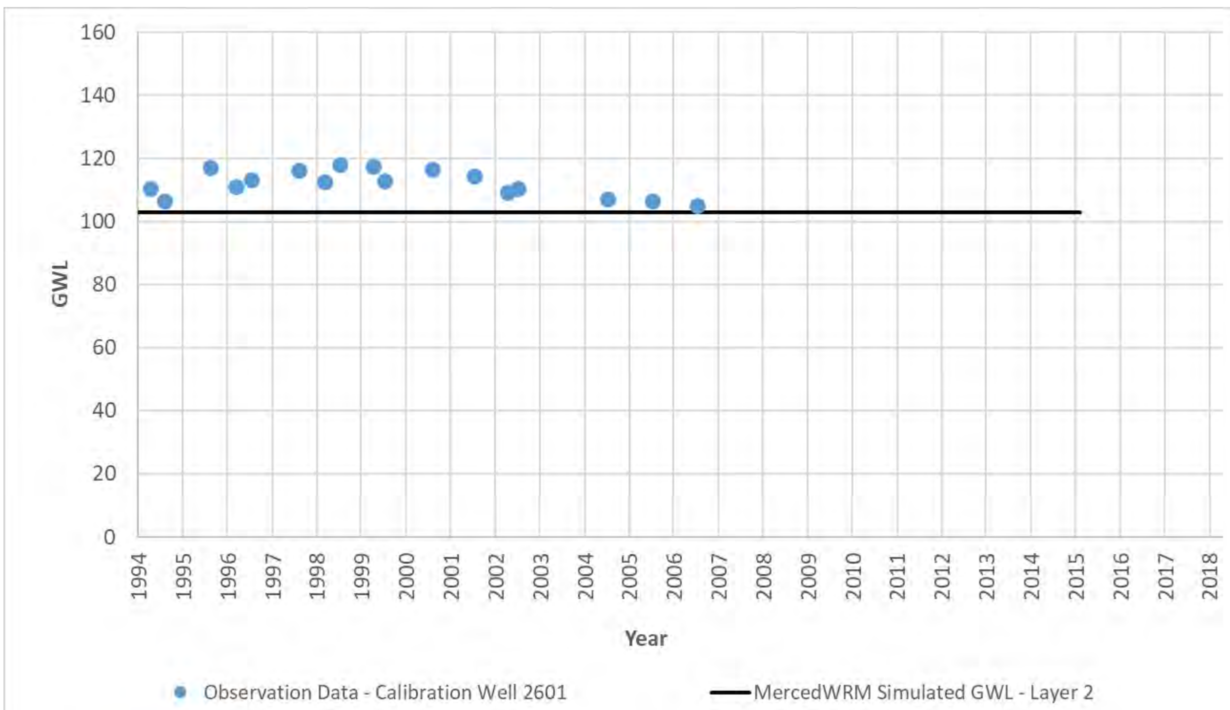


Figure A 98: Calibration Well 2601

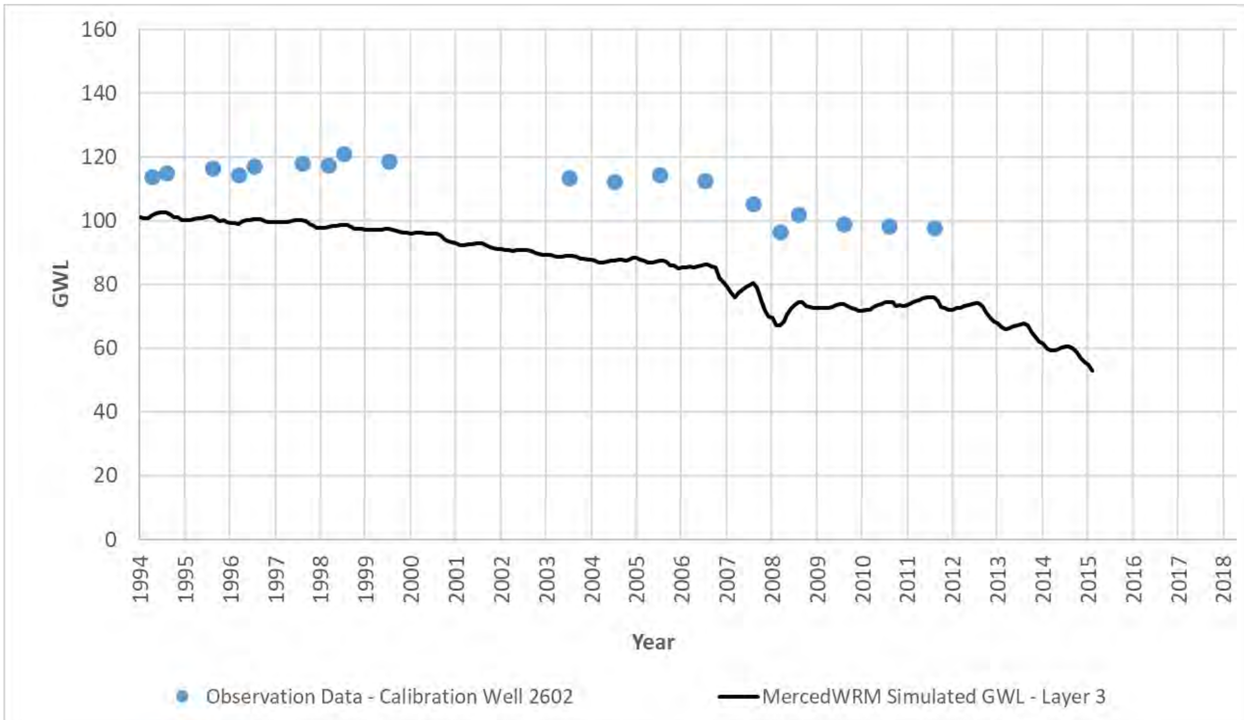


Figure A 99: Calibration Well 2602

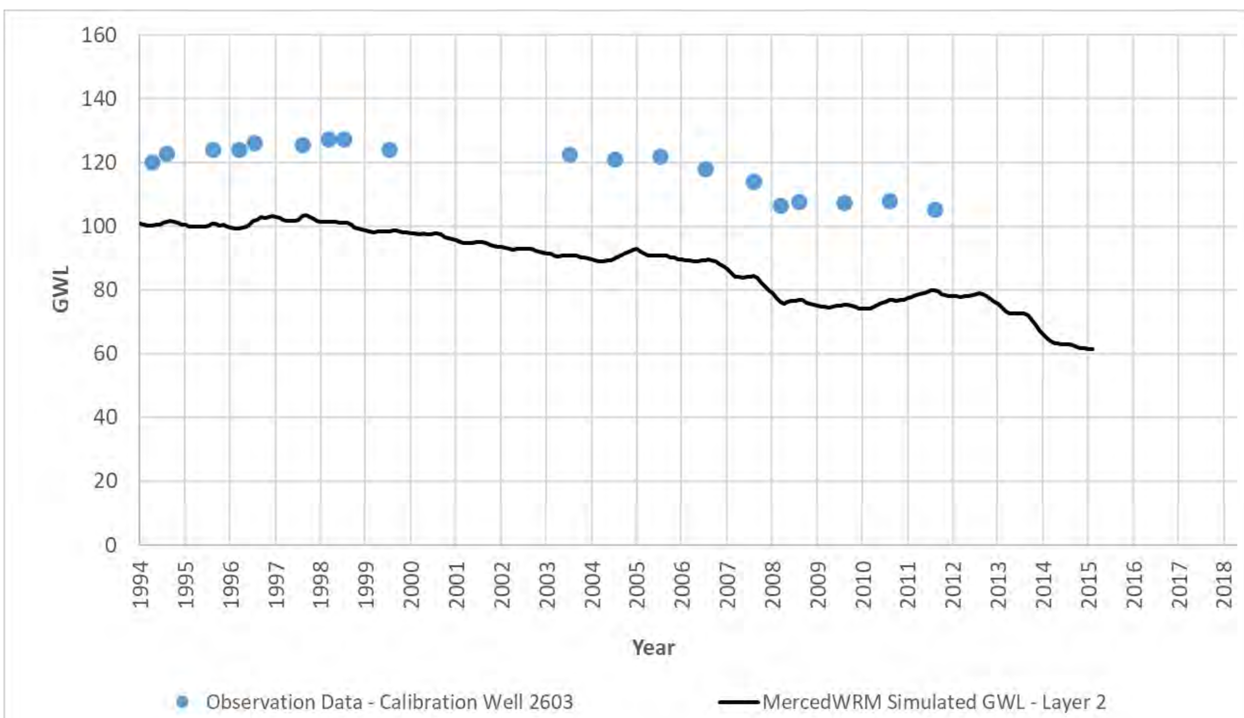


Figure A 100: Calibration Well 2603

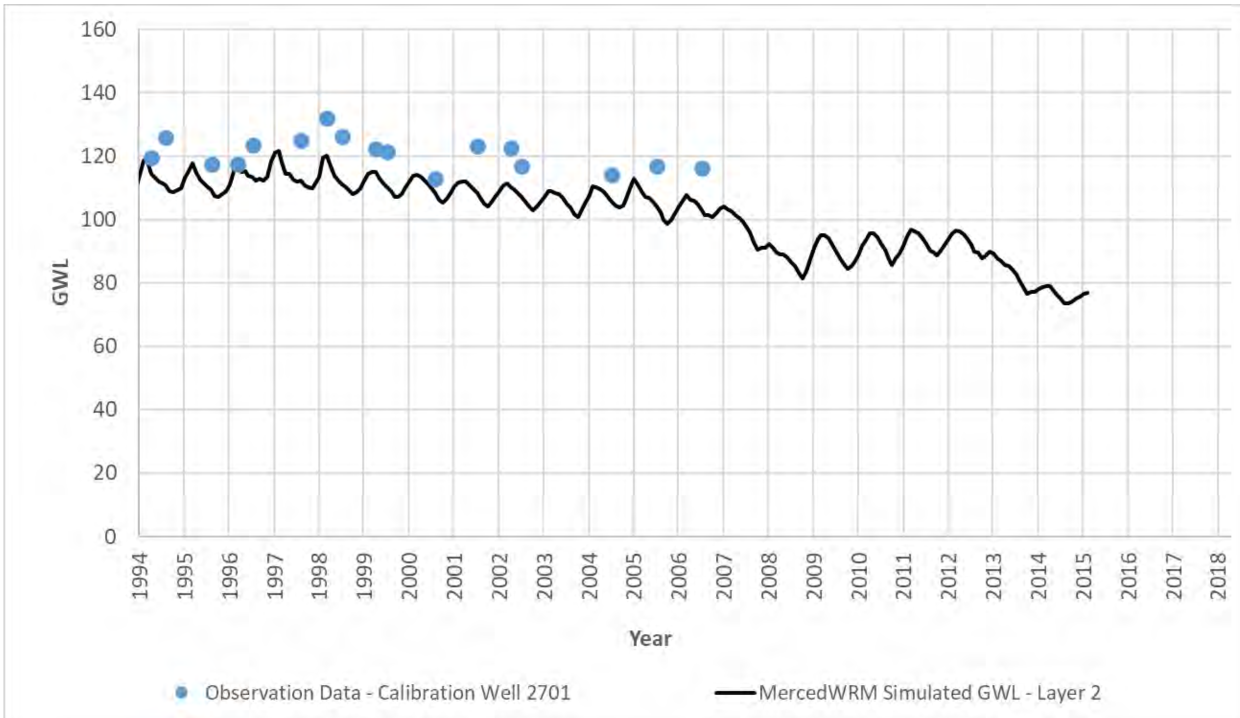


Figure A 101: Calibration Well 2701

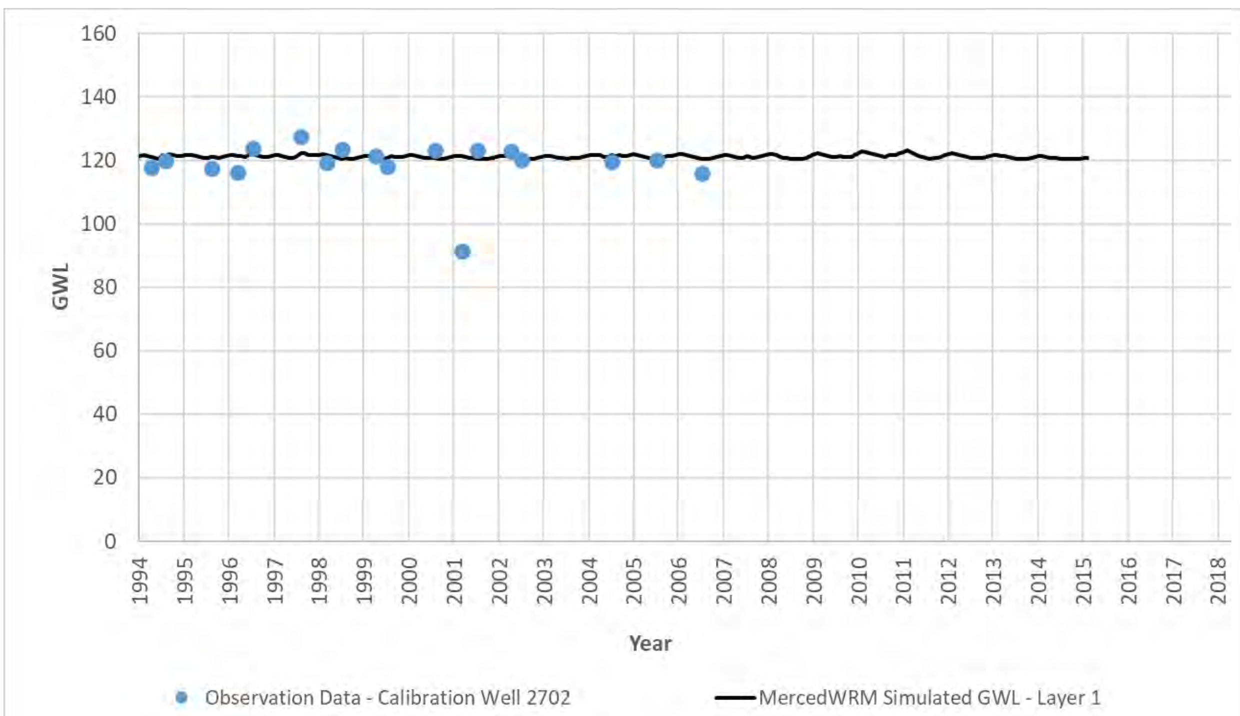


Figure A 102: Calibration Well 2702

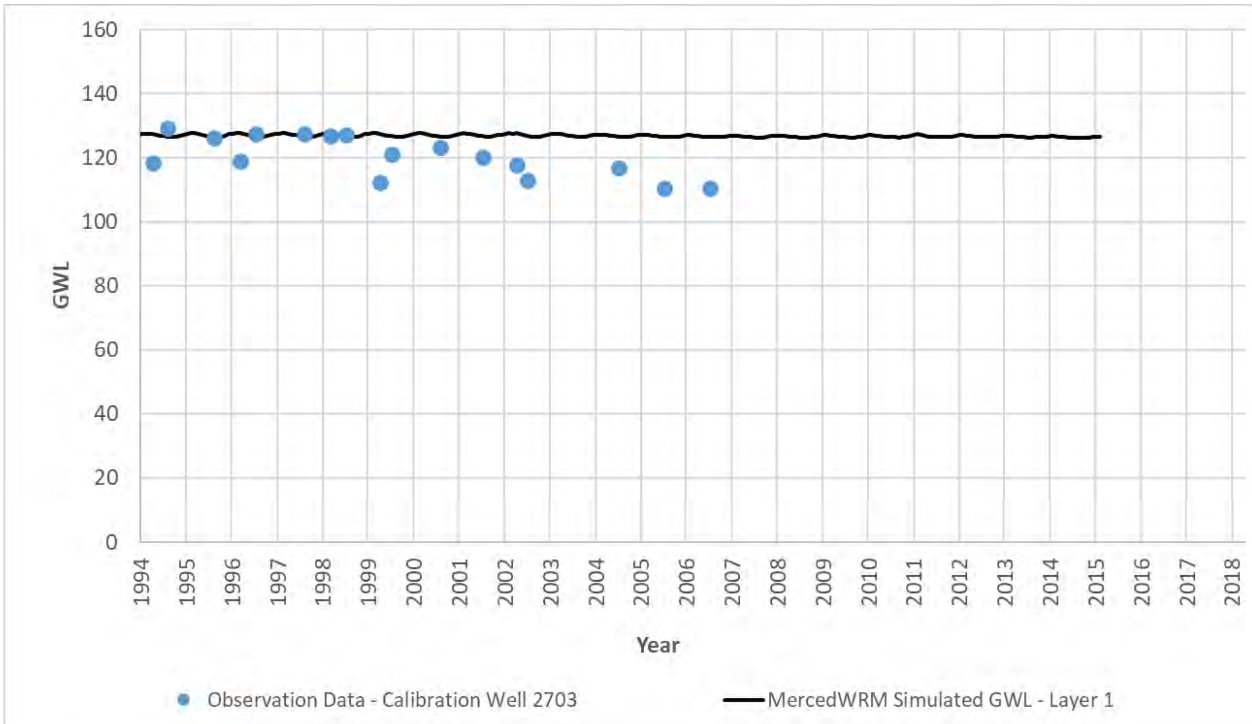


Figure A 103: Calibration Well 2703

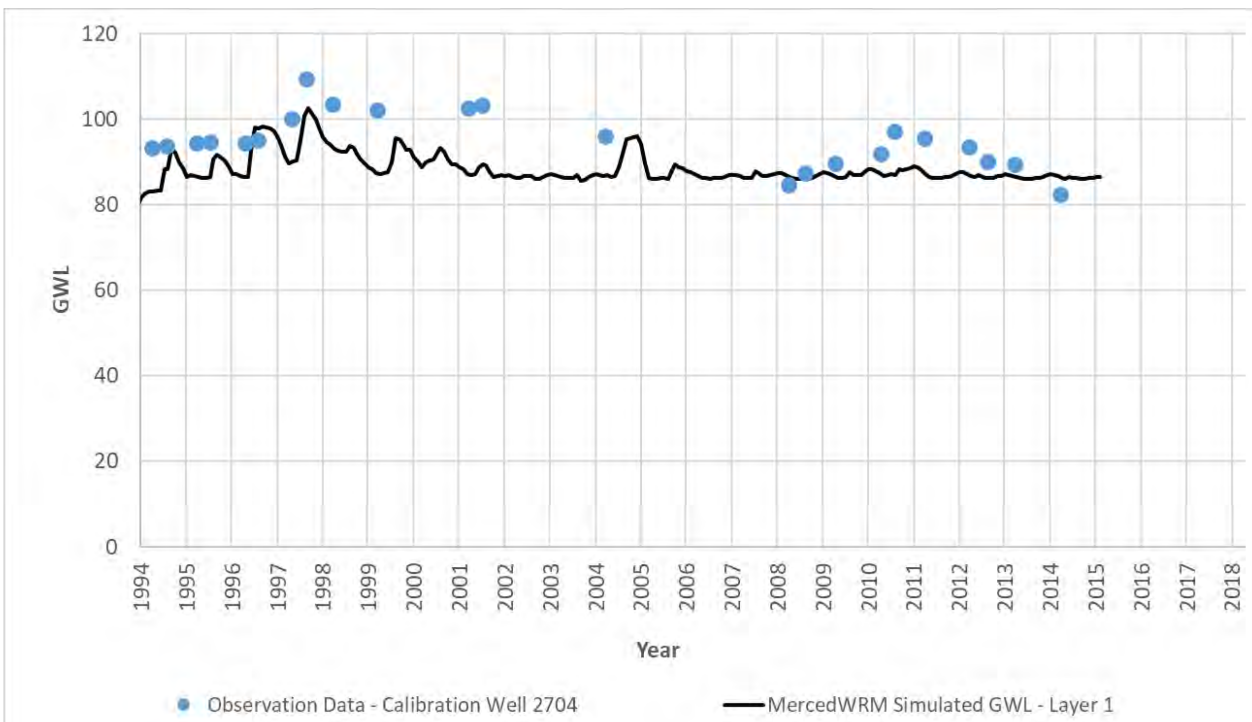


Figure A 104: Calibration Well 2704

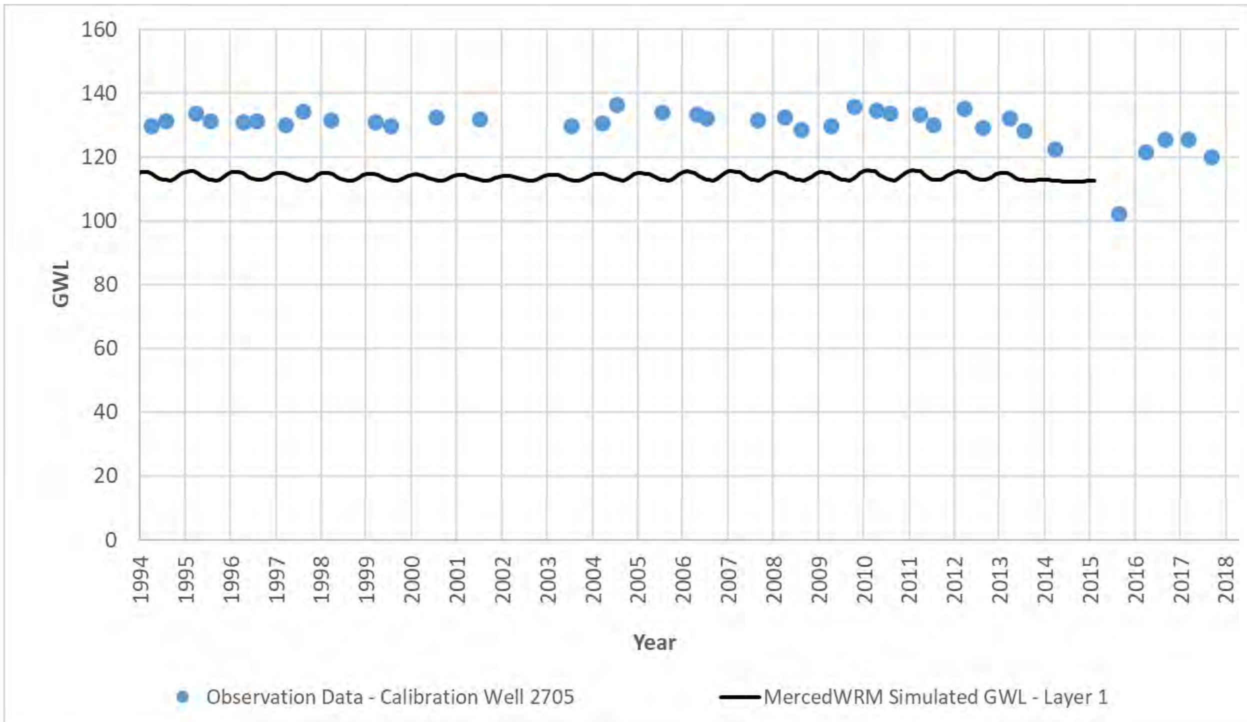


Figure A 105: Calibration Well 2705

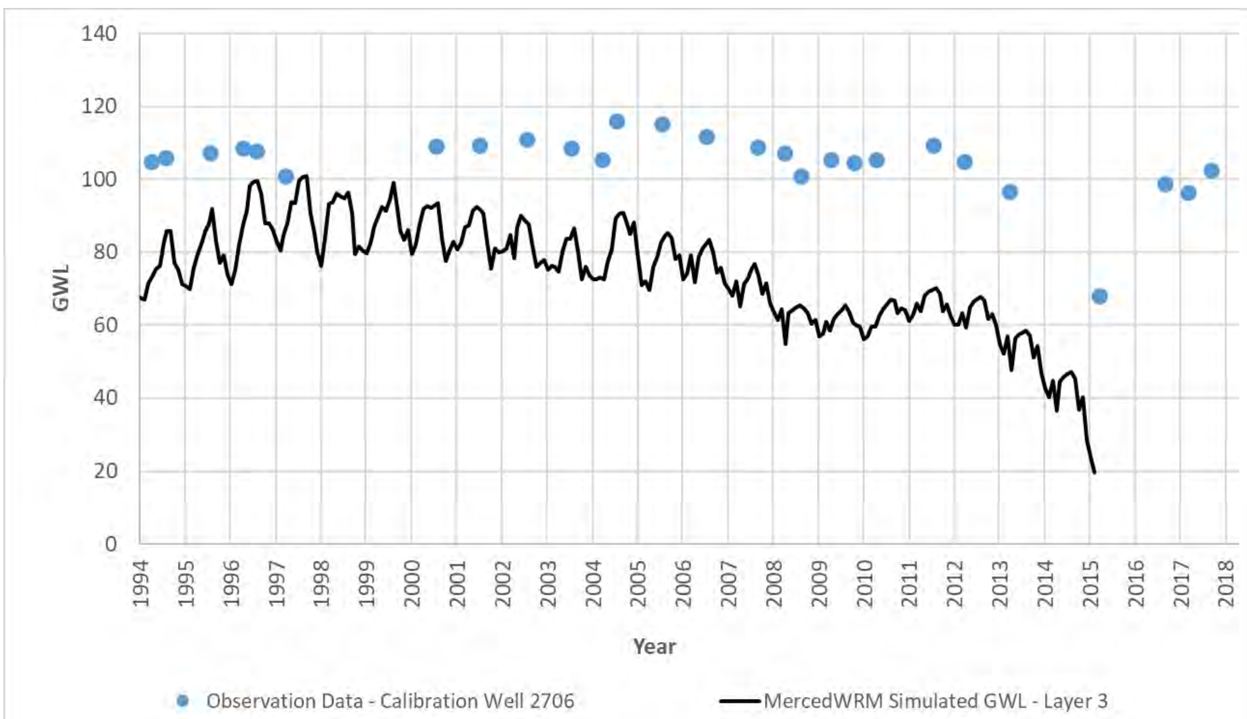


Figure A 106: Calibration Well 2706

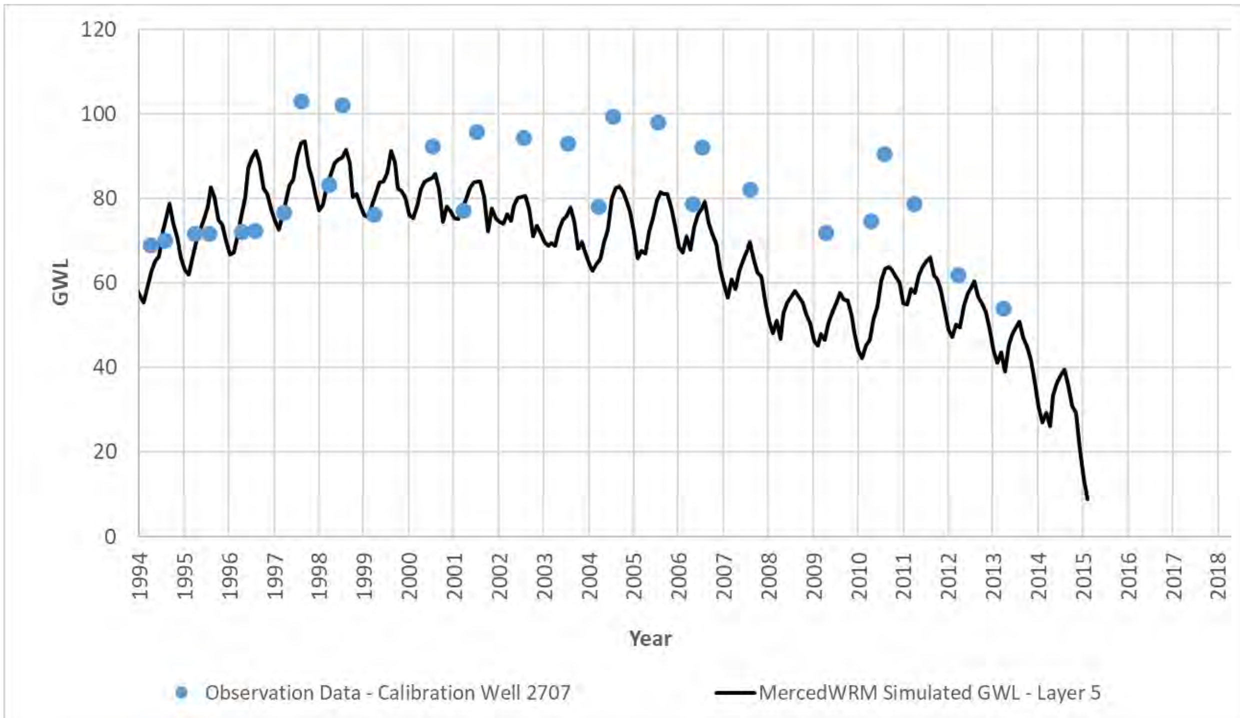


Figure A 107: Calibration Well 2707

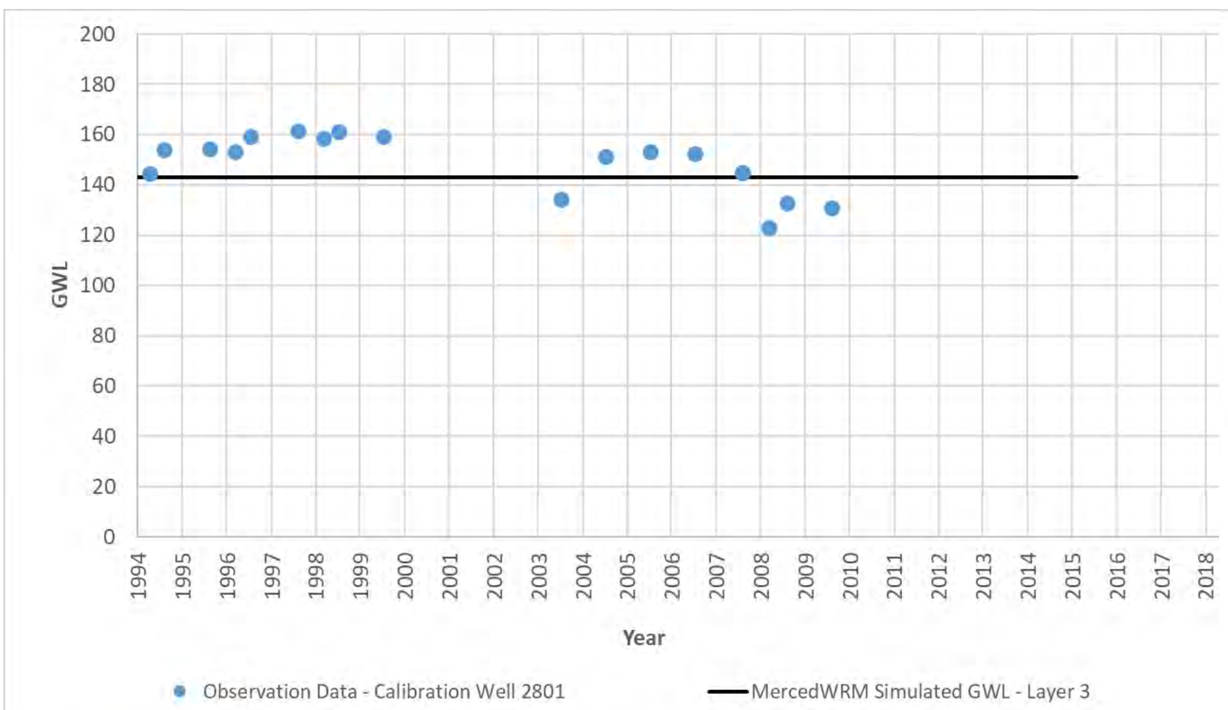


Figure A 108: Calibration Well 2801

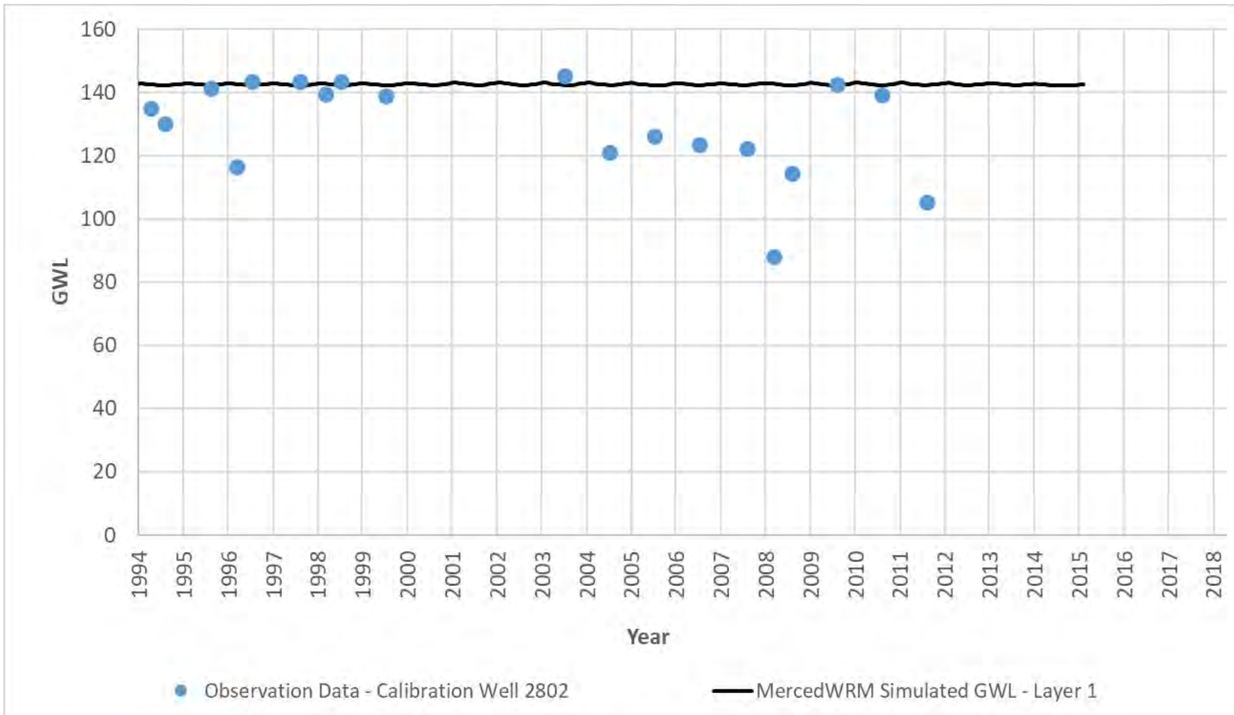


Figure A 109: Calibration Well 2802

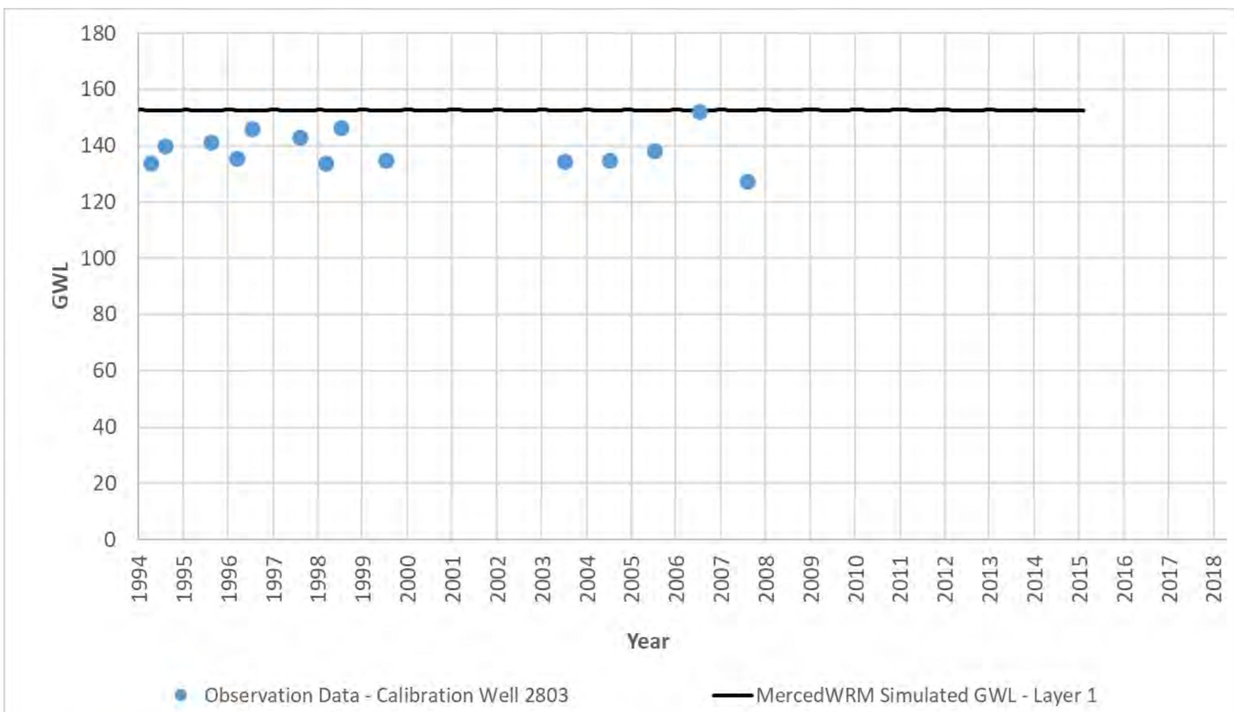


Figure A 110: Calibration Well 2803

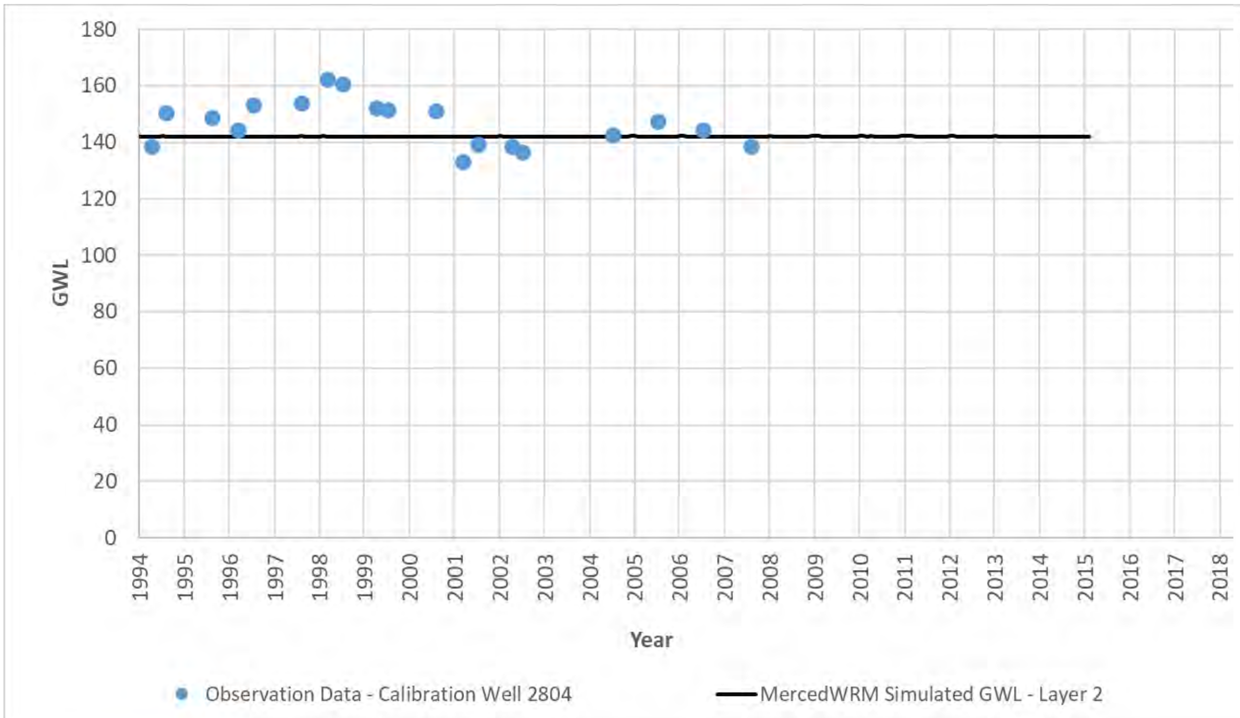


Figure A 111: Calibration Well 2804

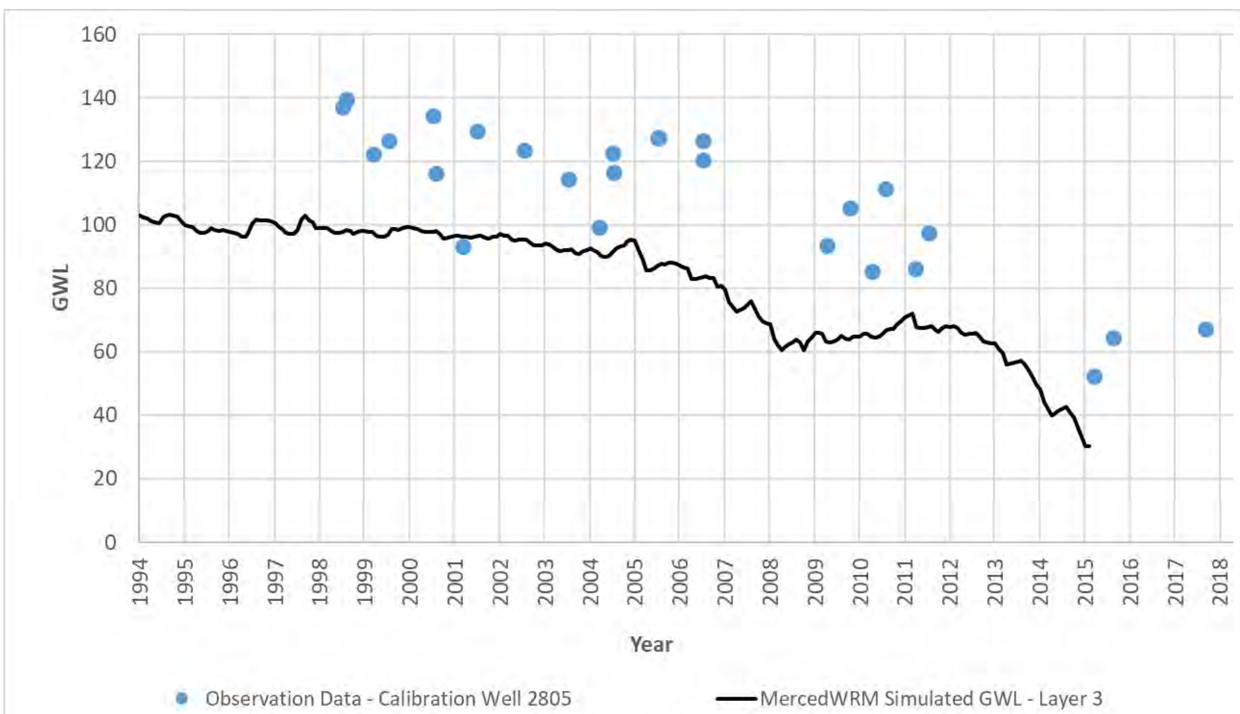


Figure A 112: Calibration Well 2805

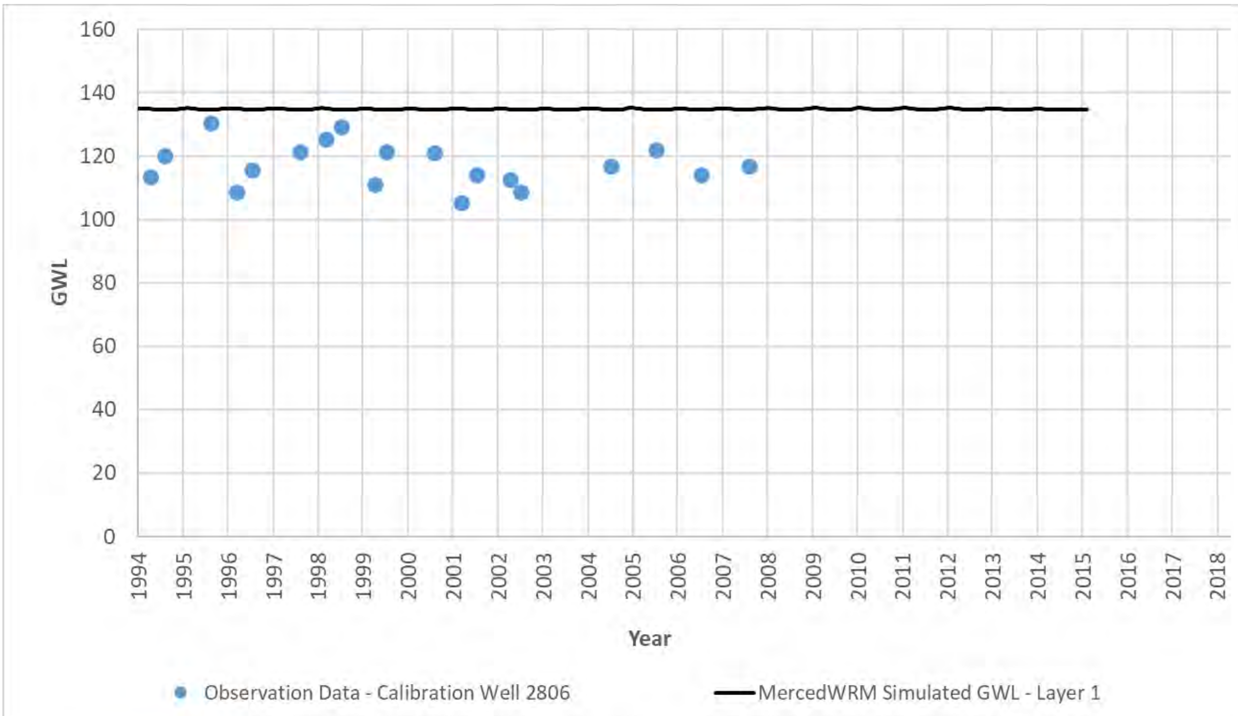


Figure A 113: Calibration Well 2806

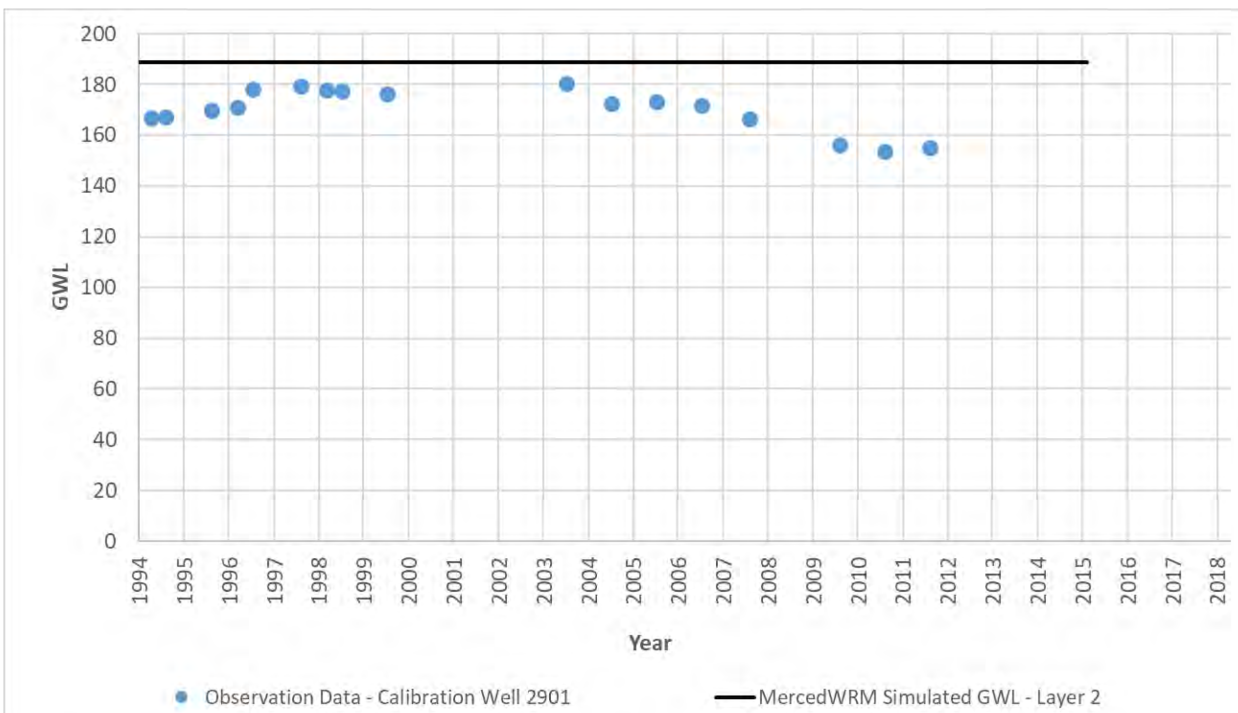


Figure A 114: Calibration Well 2901

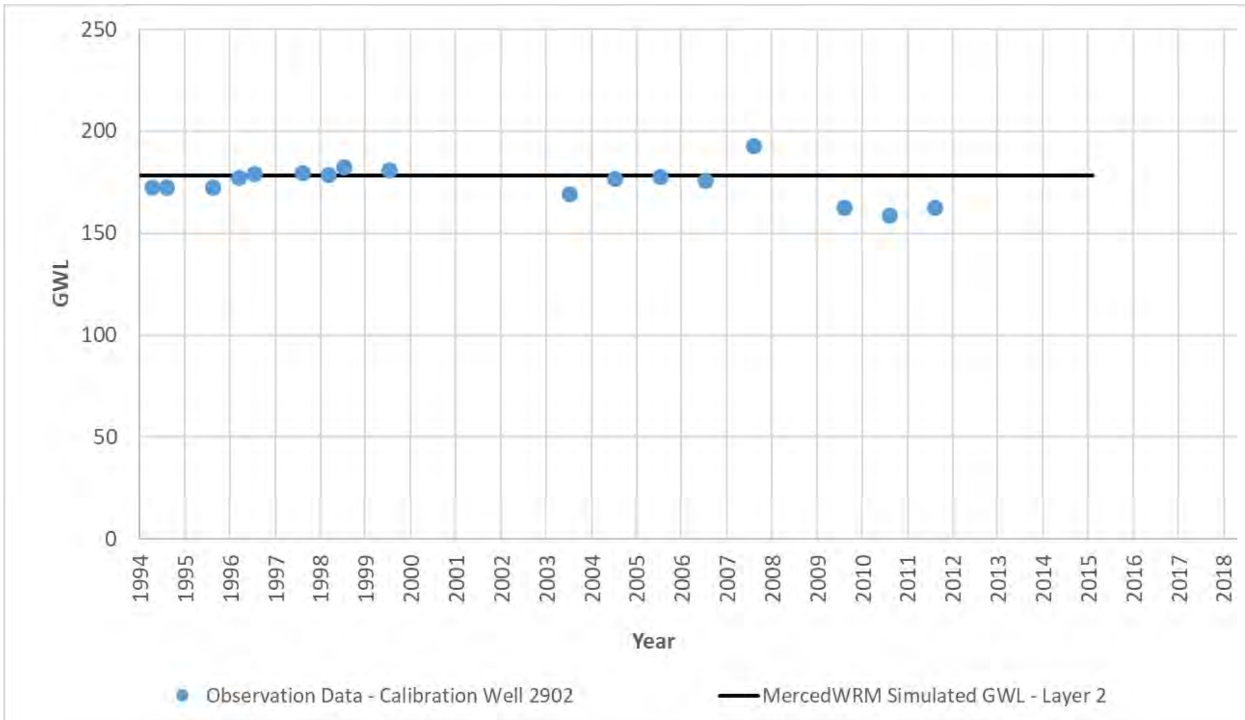


Figure A 115: Calibration Well 2902

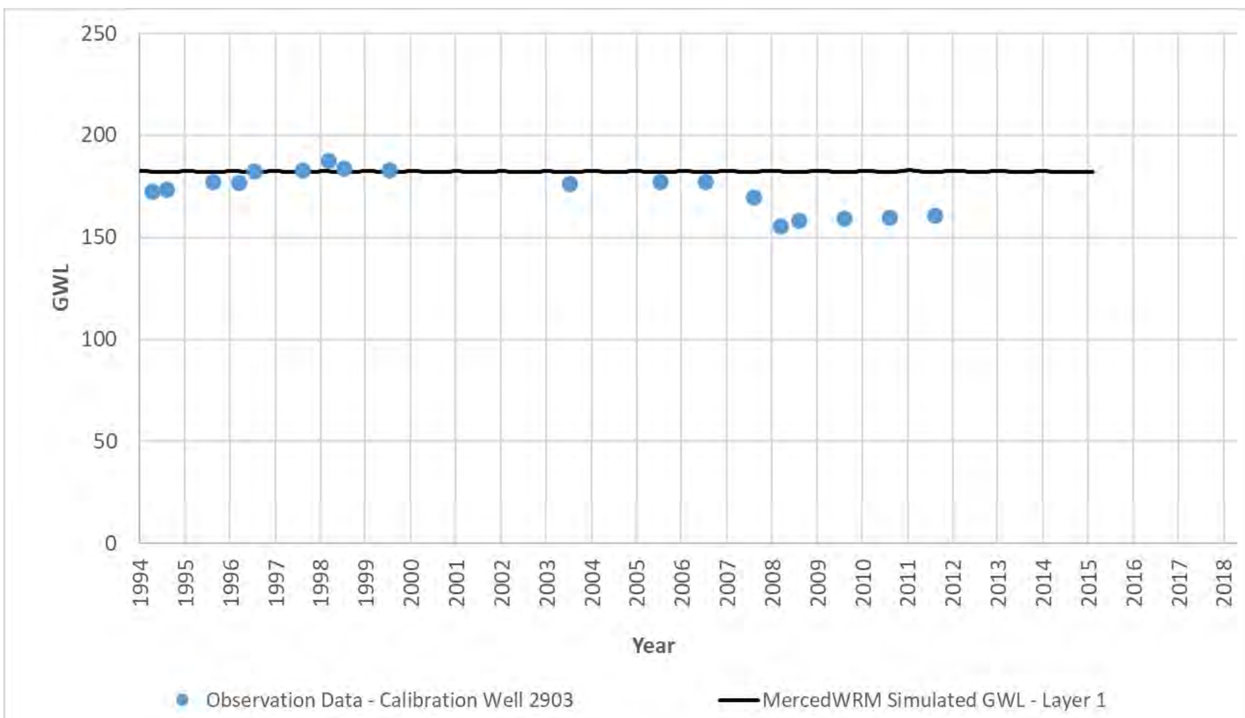


Figure A 116: Calibration Well 2903

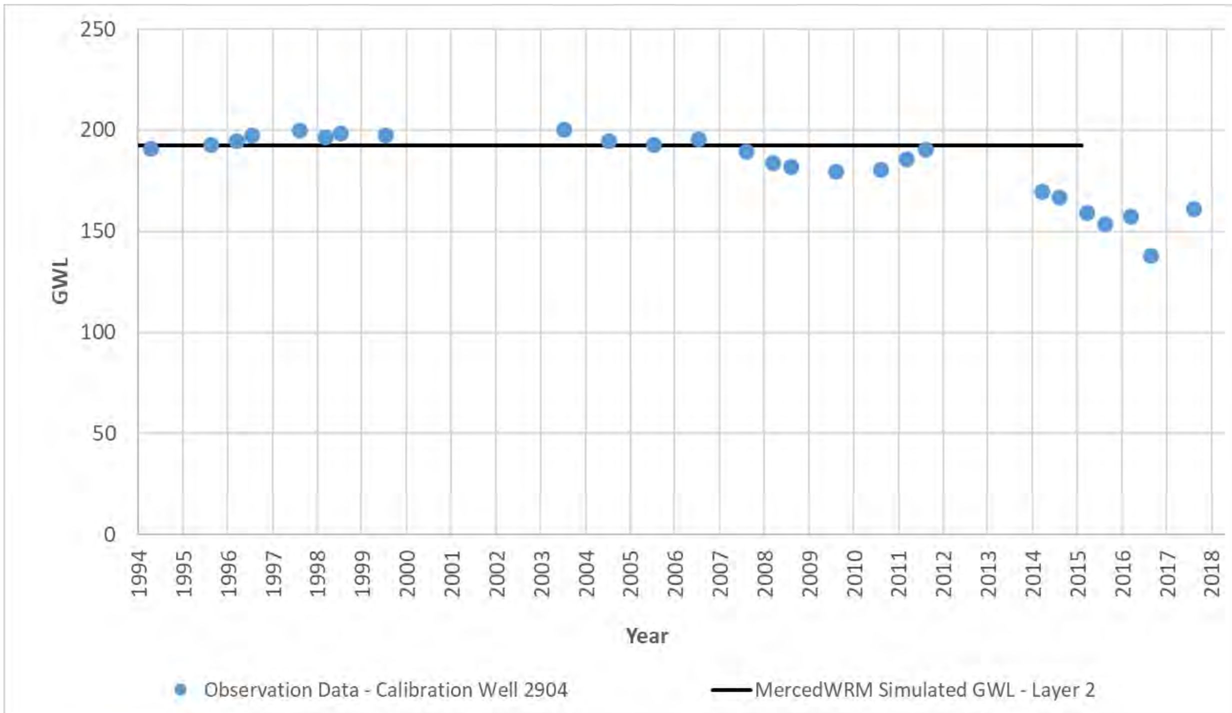


Figure A 117: Calibration Well 2904

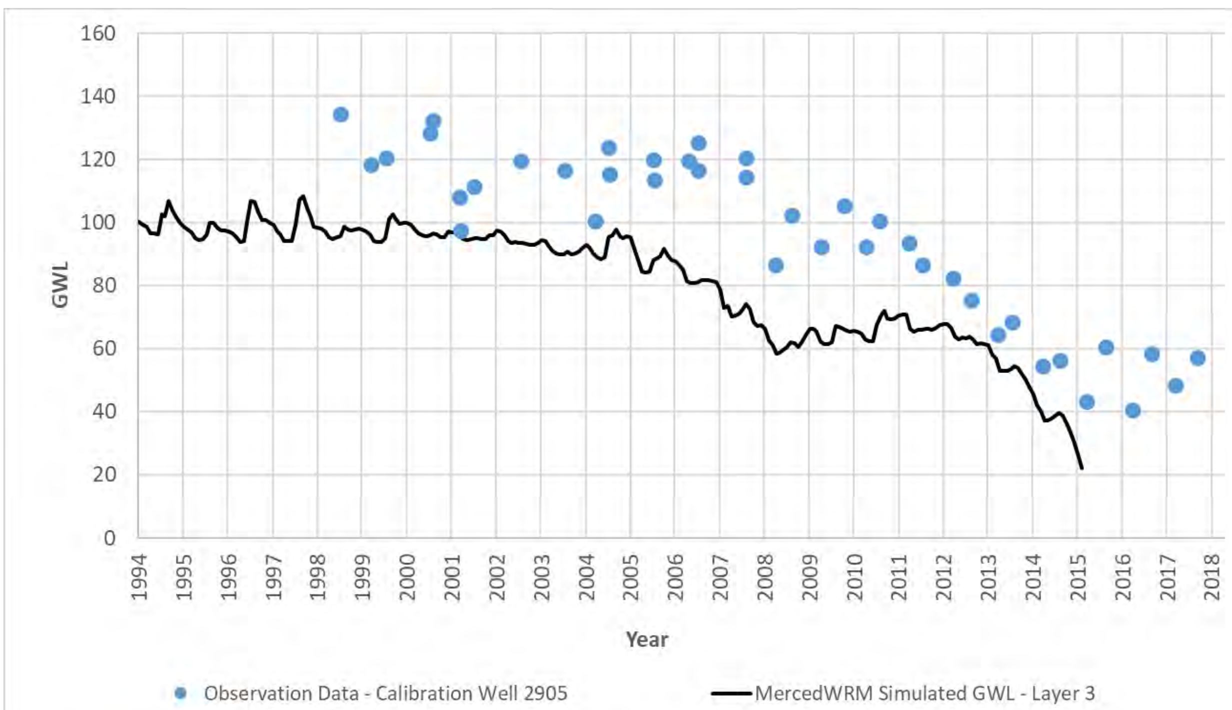


Figure A 118: Calibration Well 2905

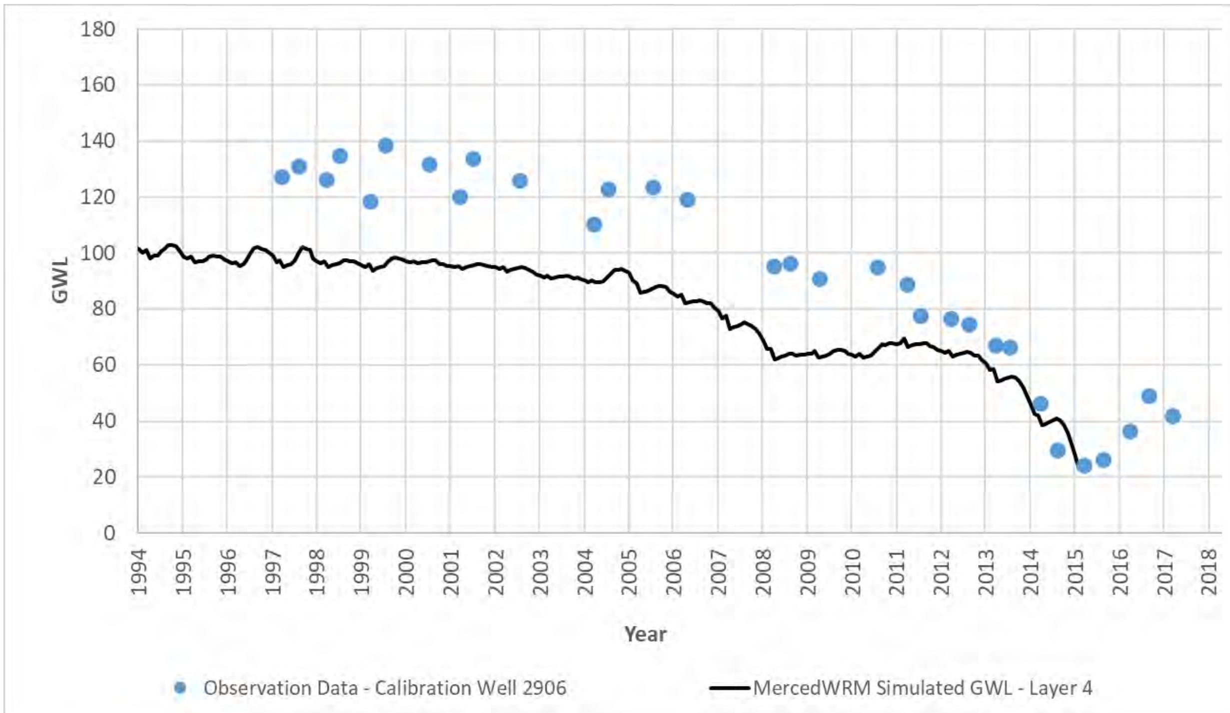


Figure A 119: Calibration Well 2906

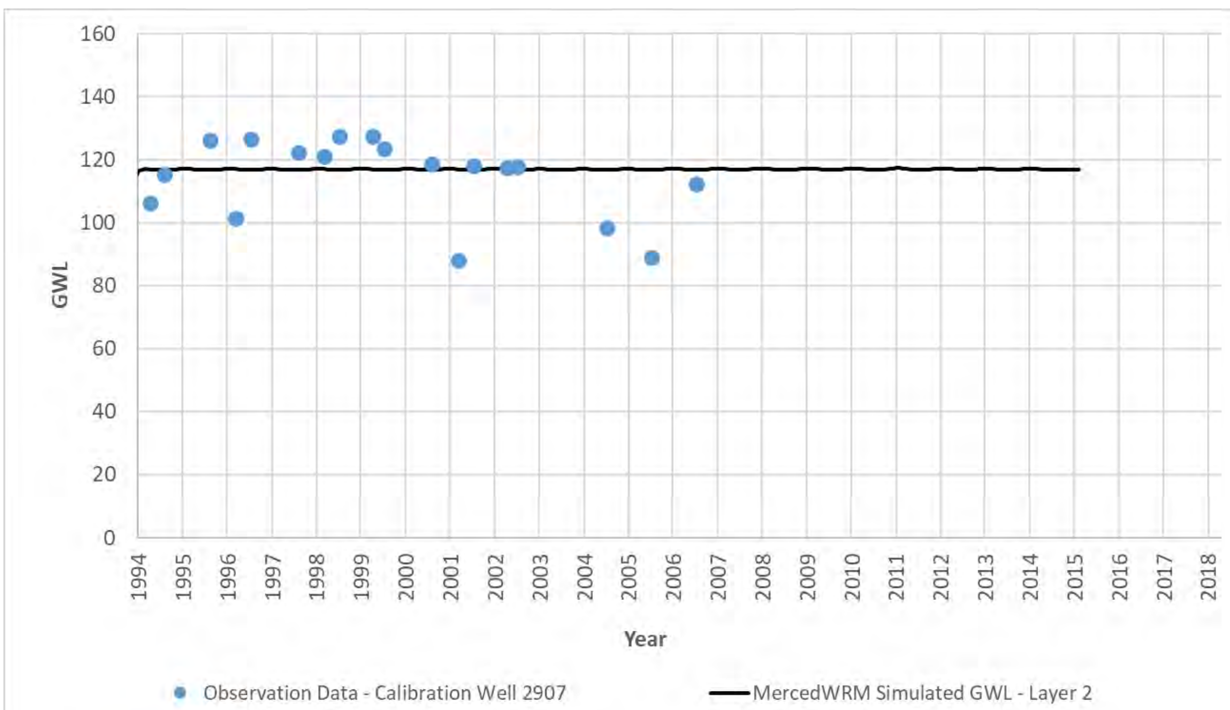


Figure A 120: Calibration Well 2907

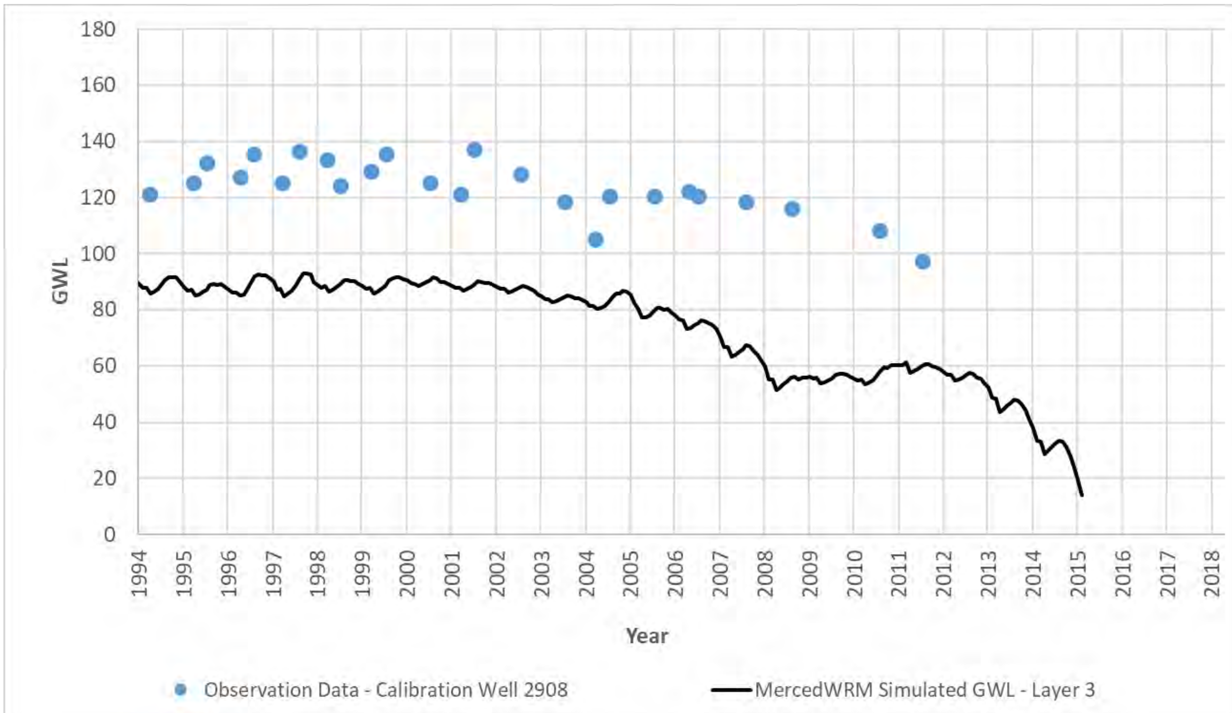


Figure A 121: Calibration Well 2908

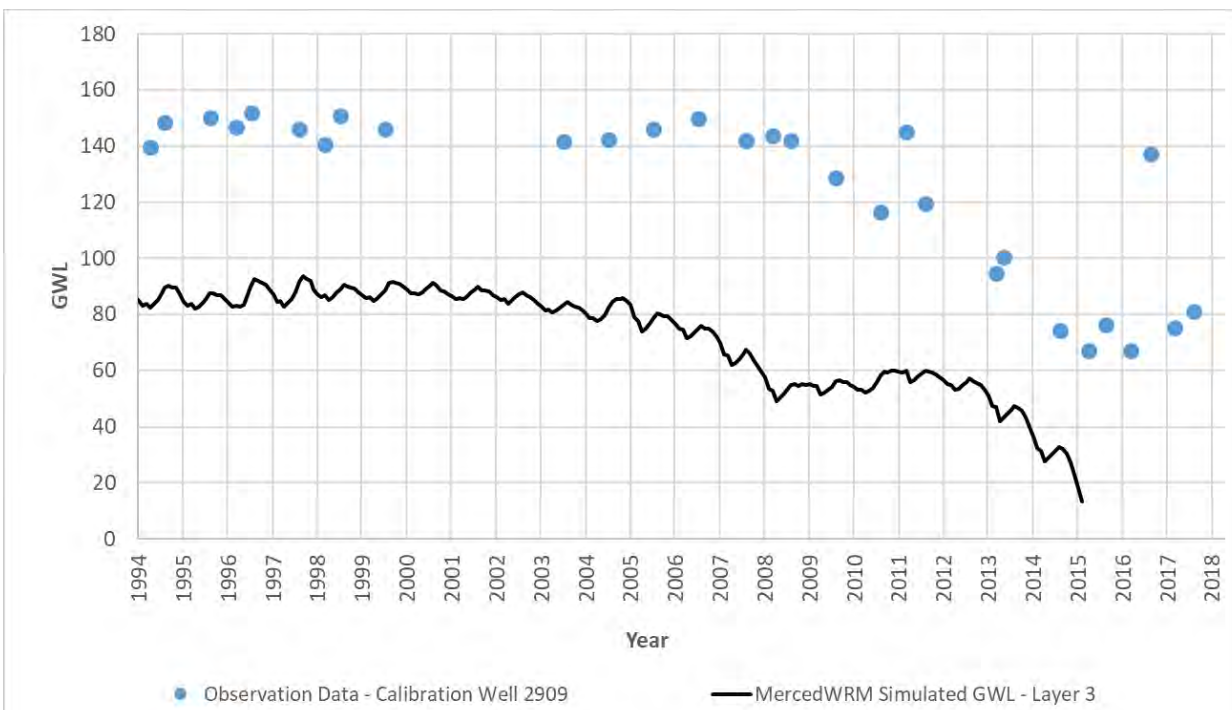
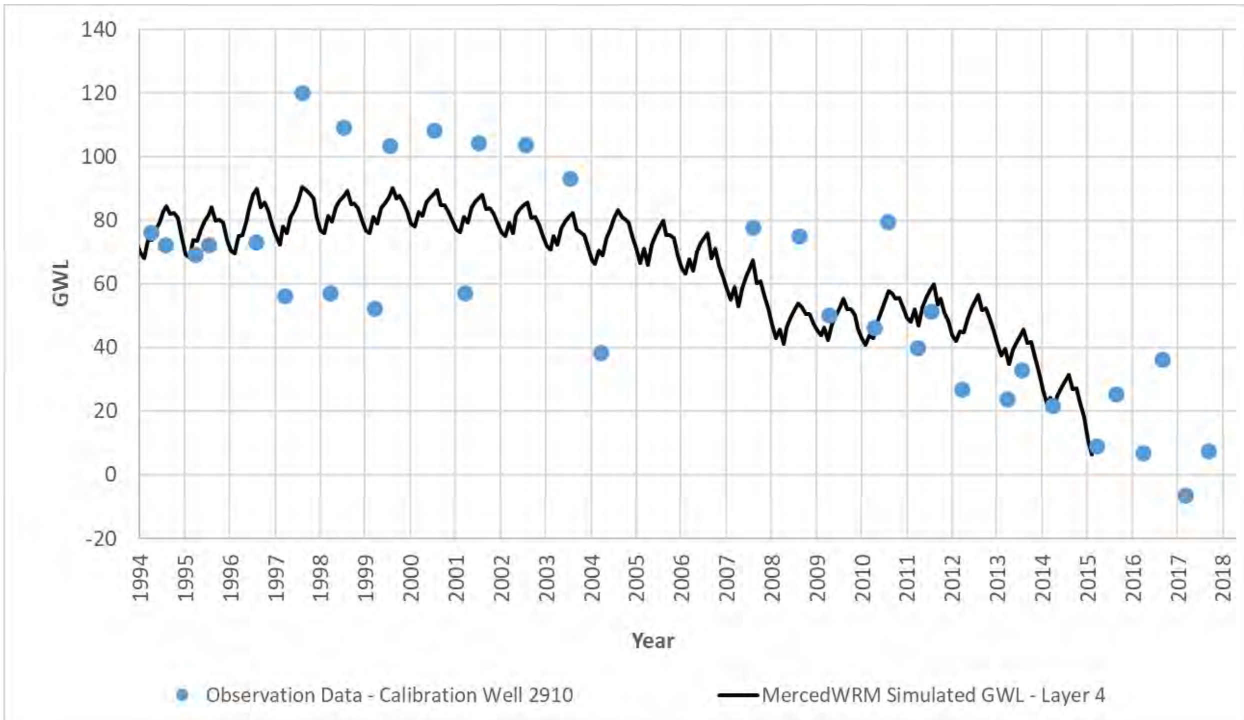


Figure A 122: Calibration Well 2909



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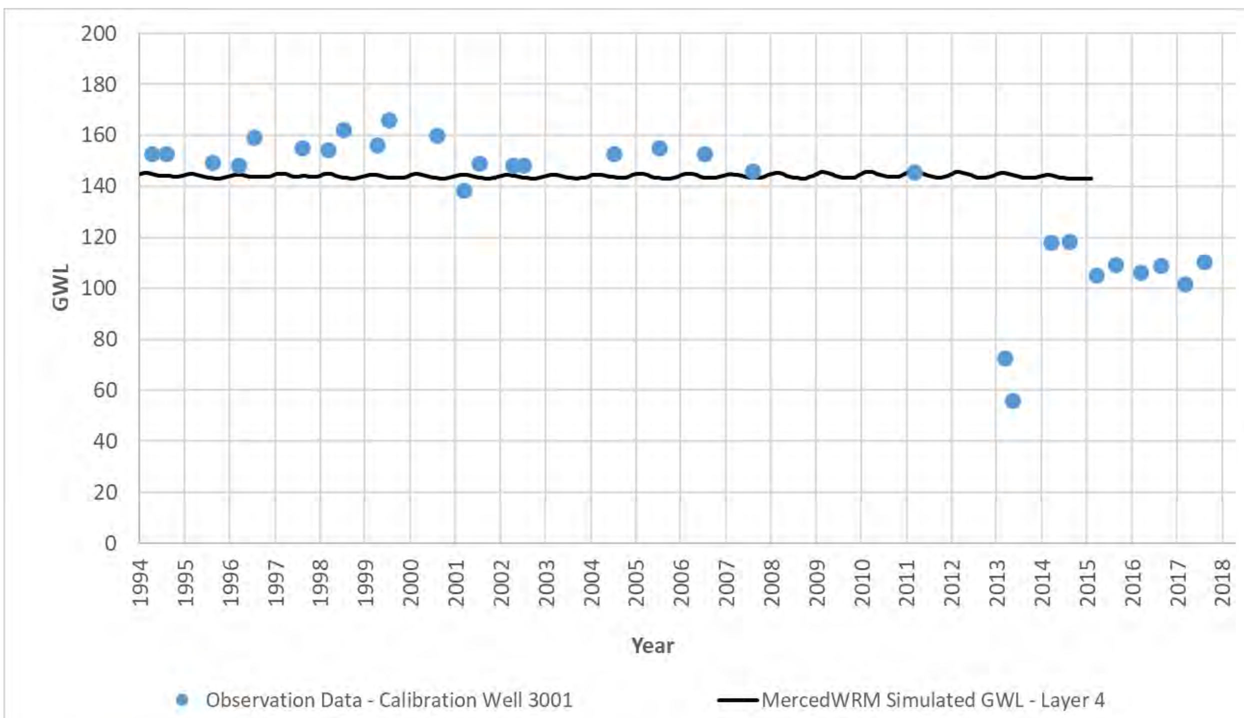

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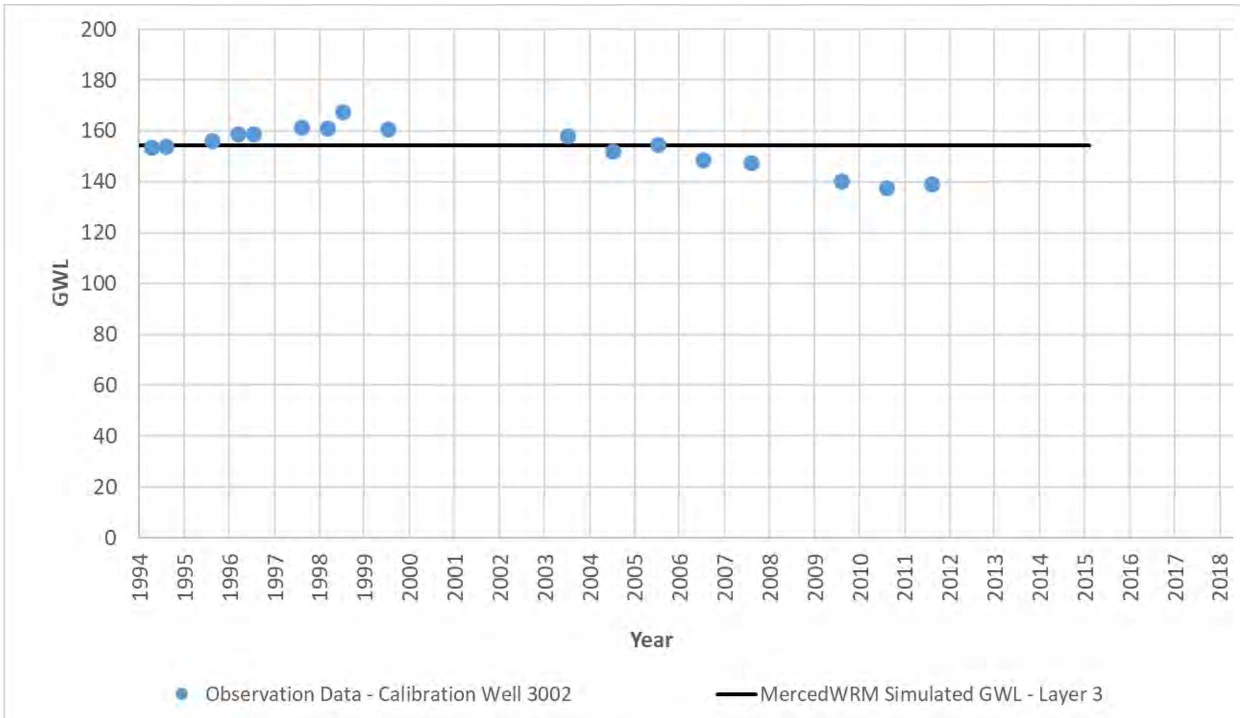

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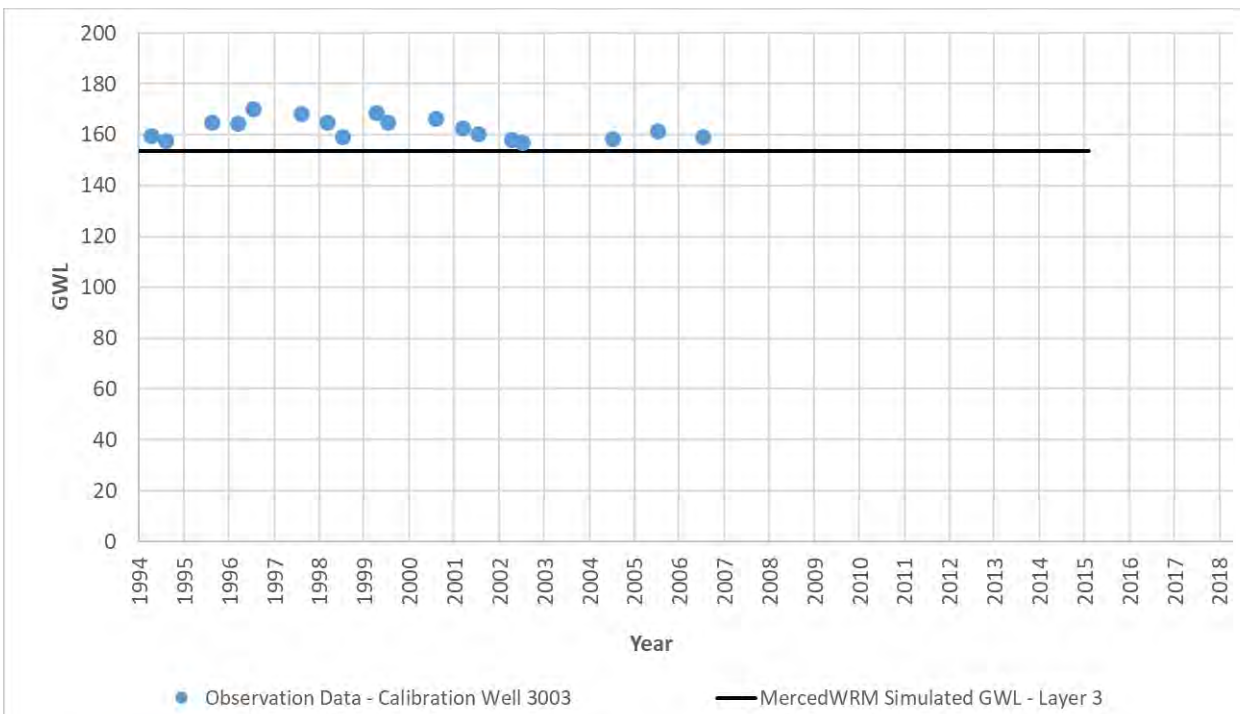
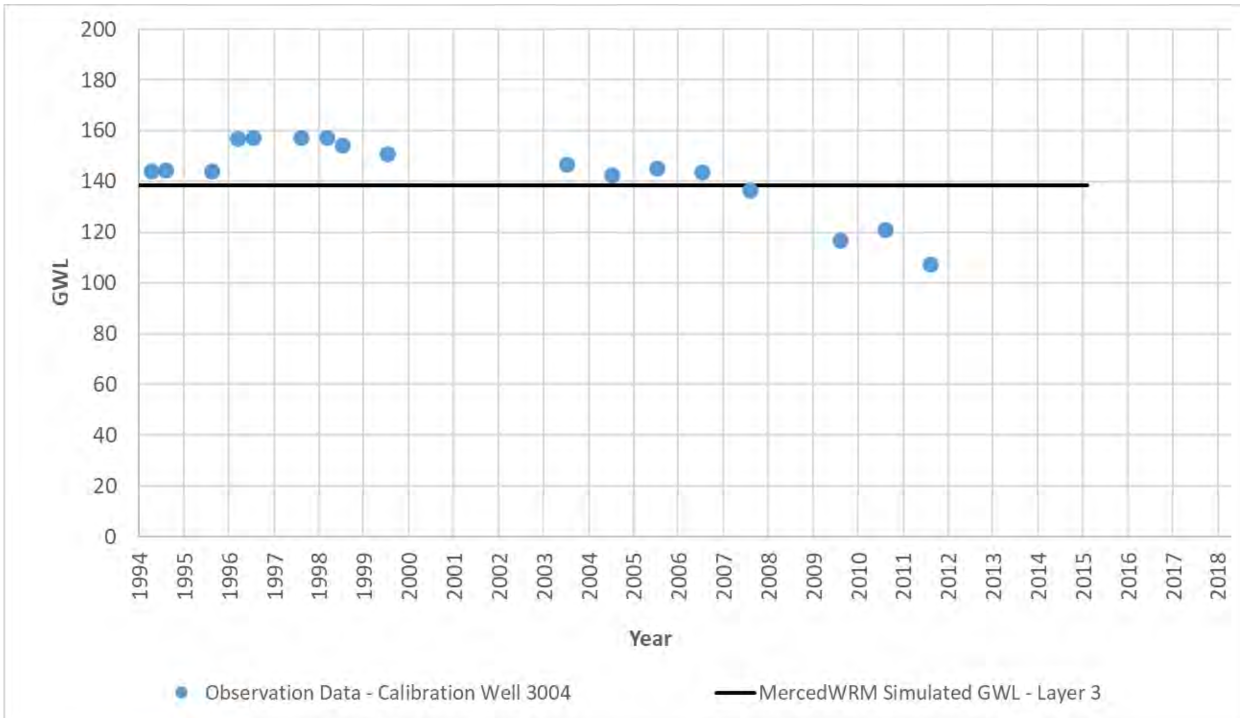


Figure A 126: Calibration Well 3003



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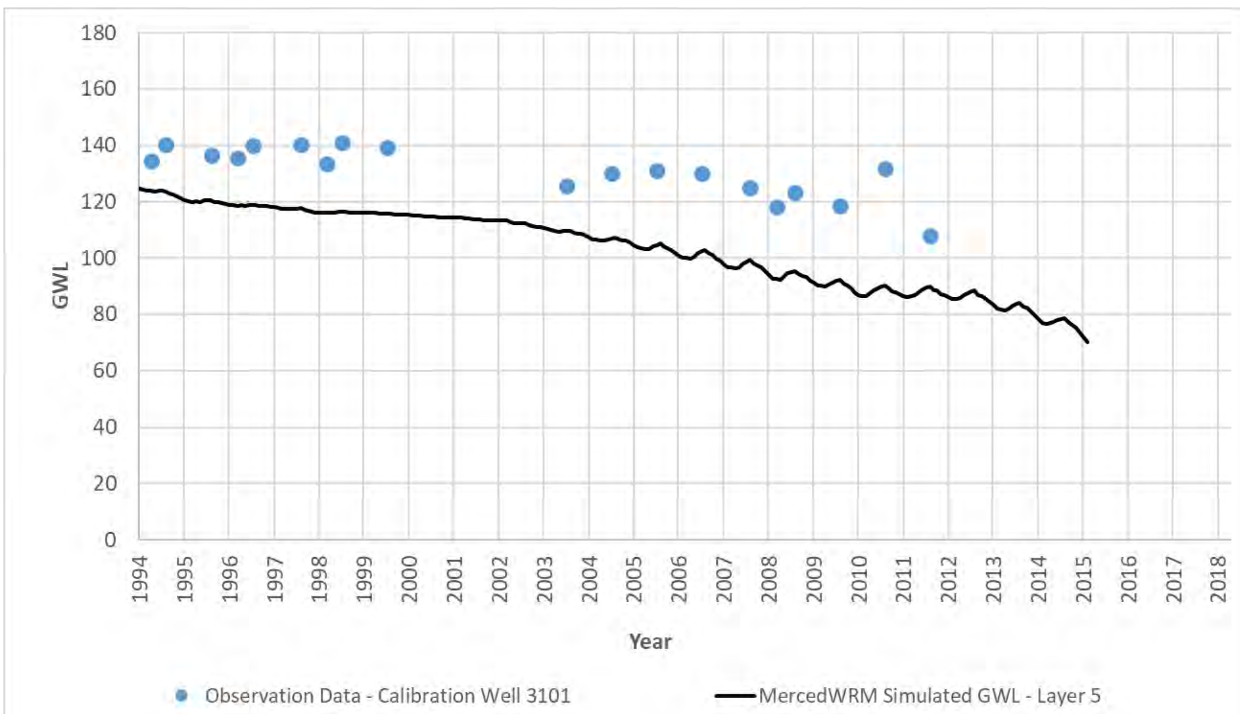

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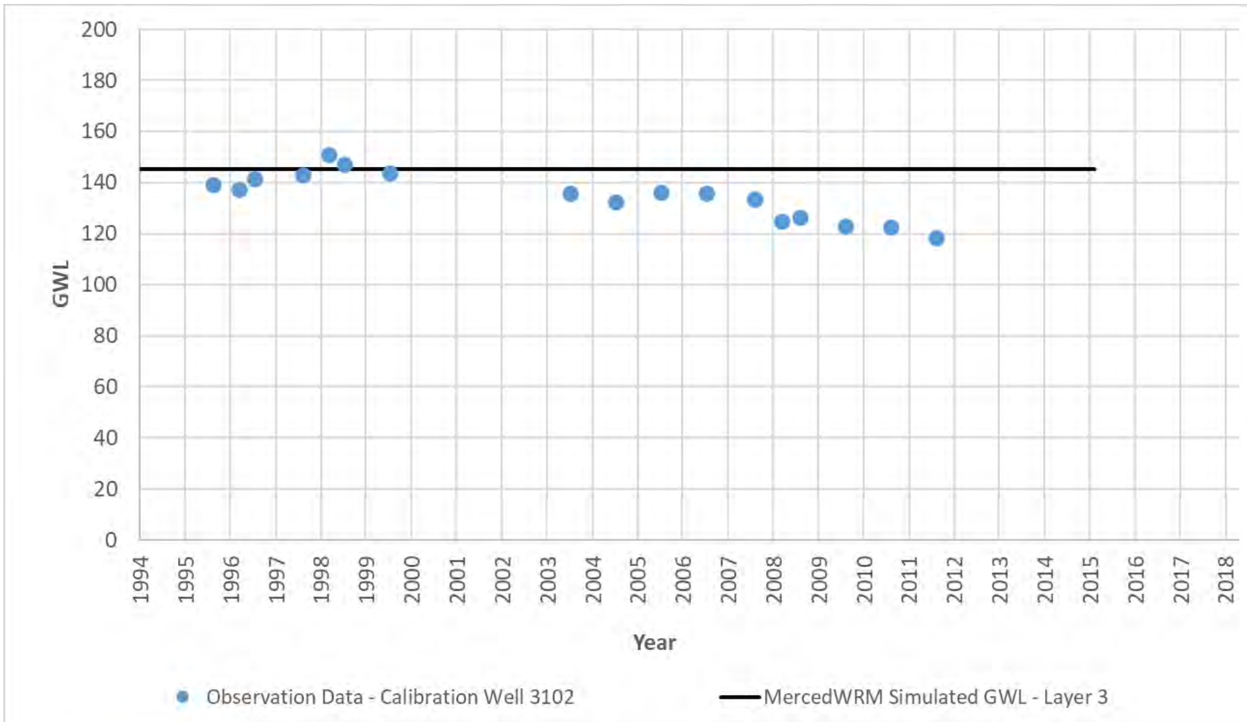

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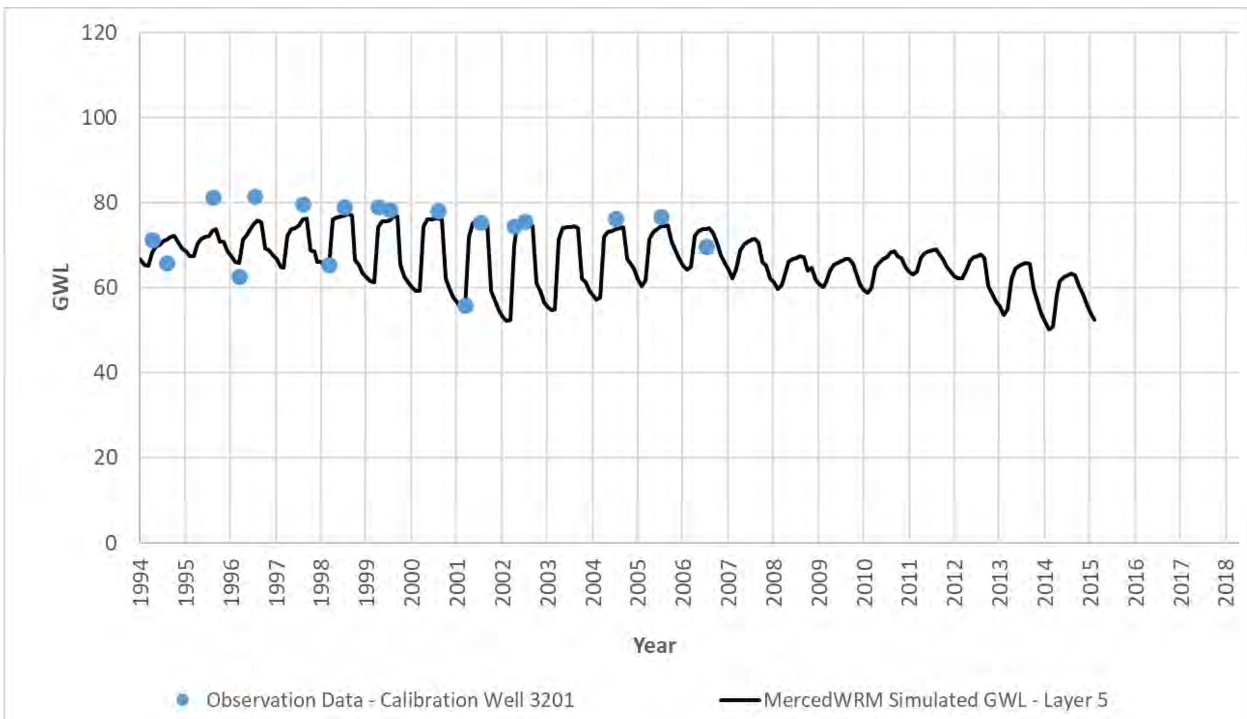

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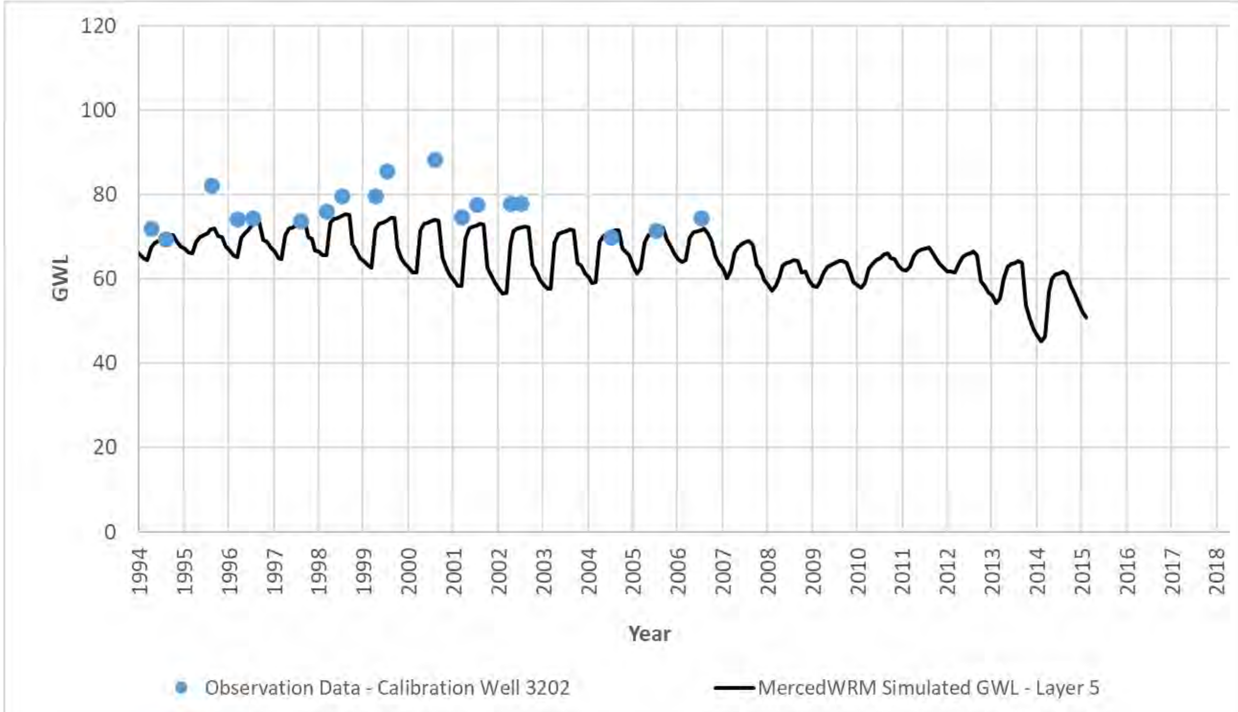

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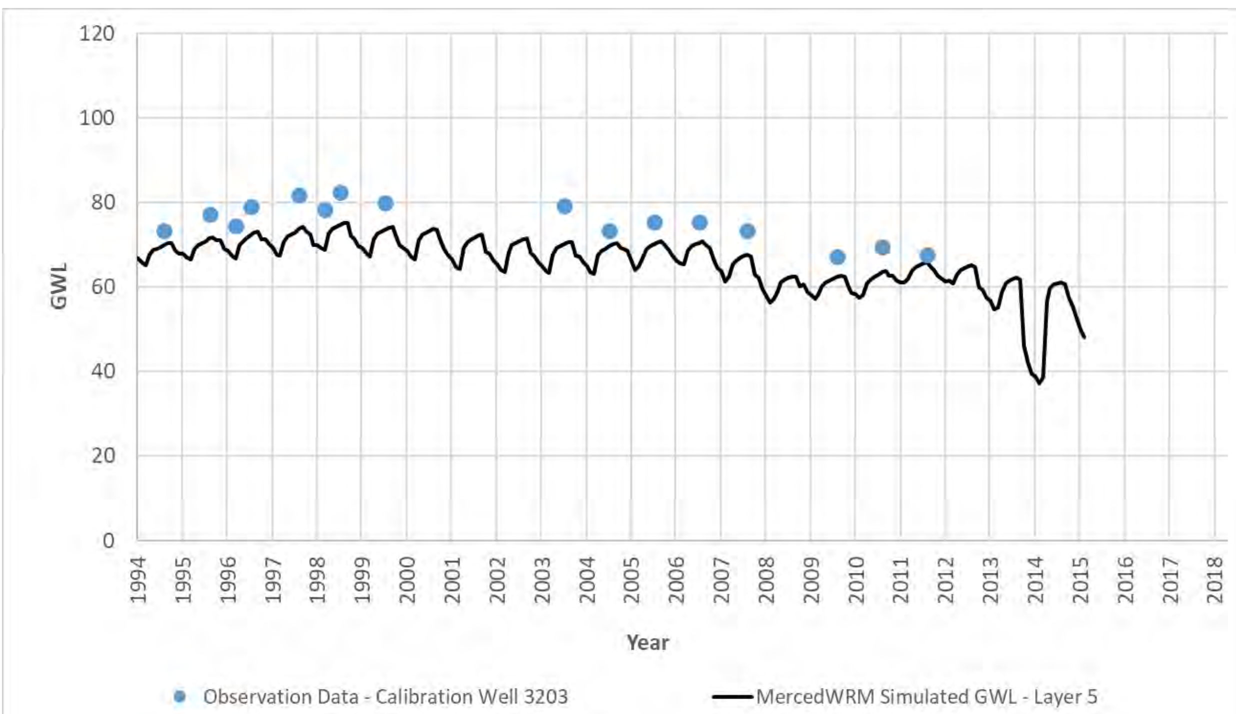

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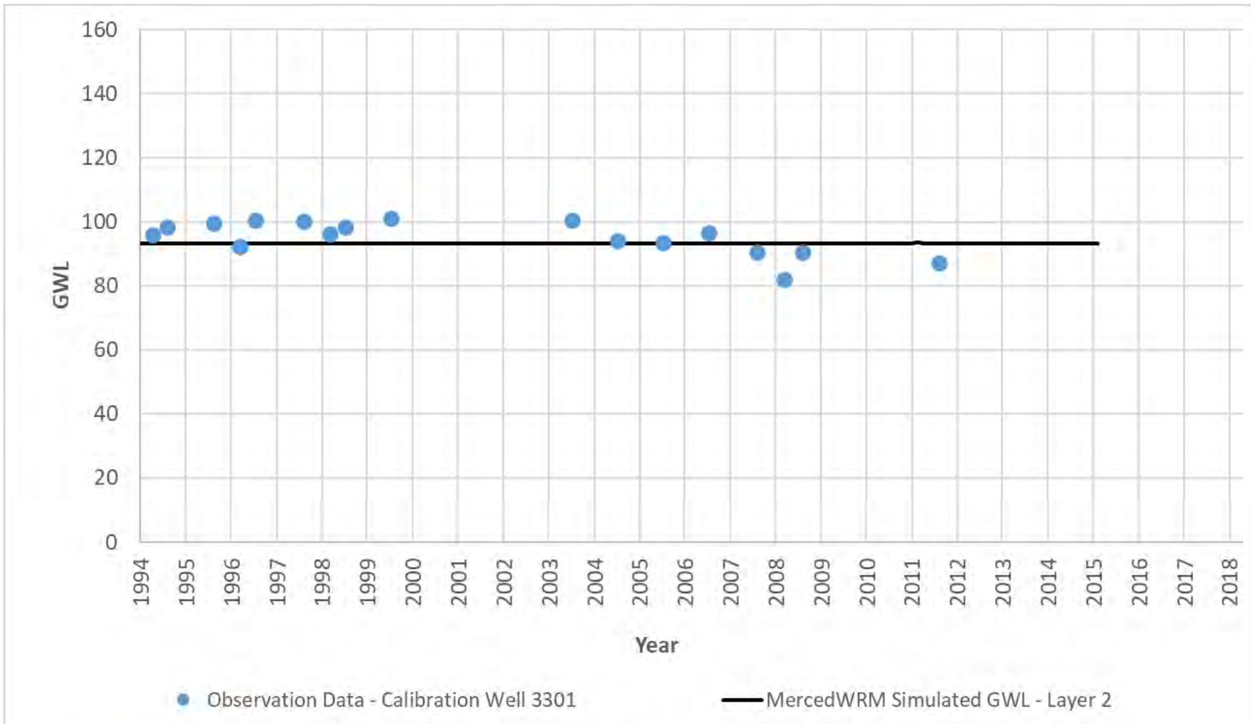

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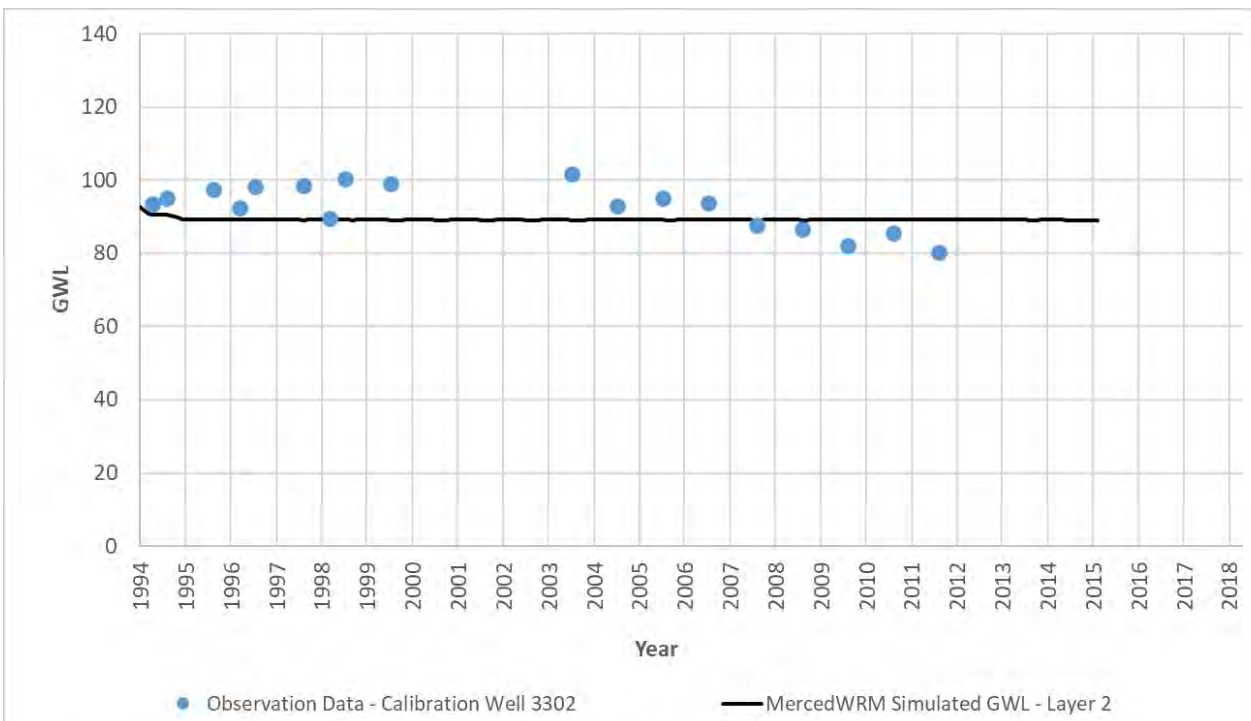

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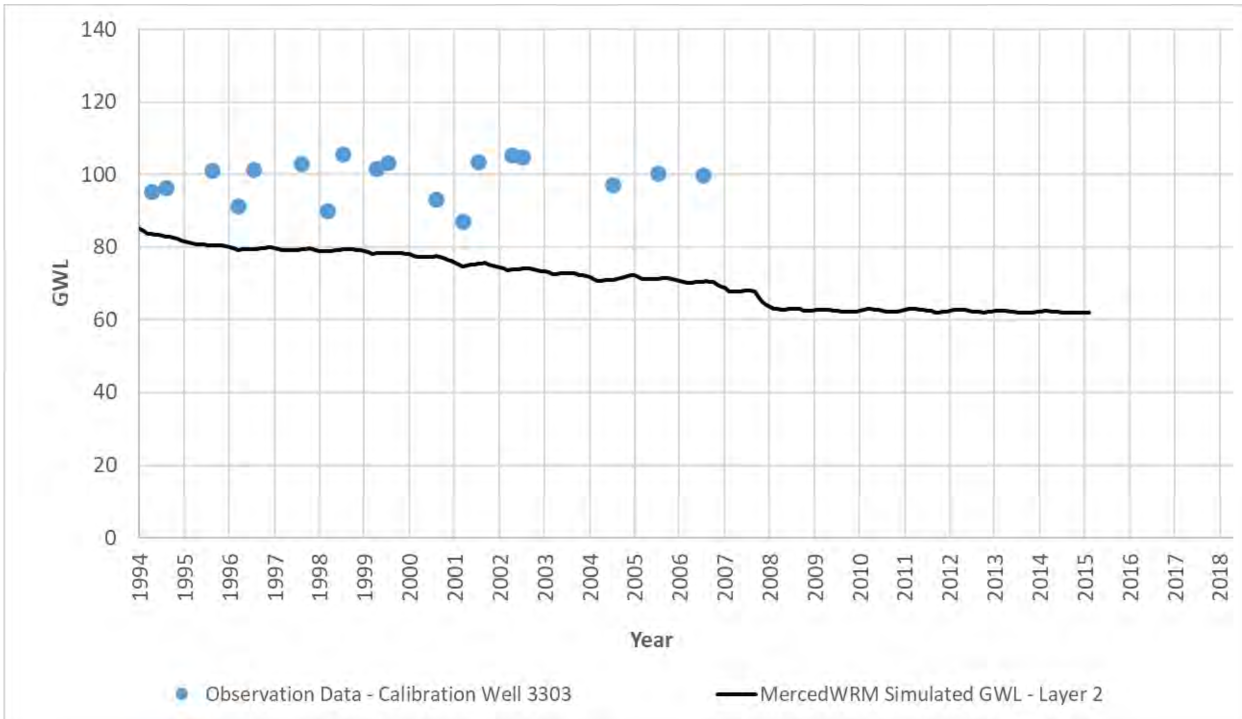

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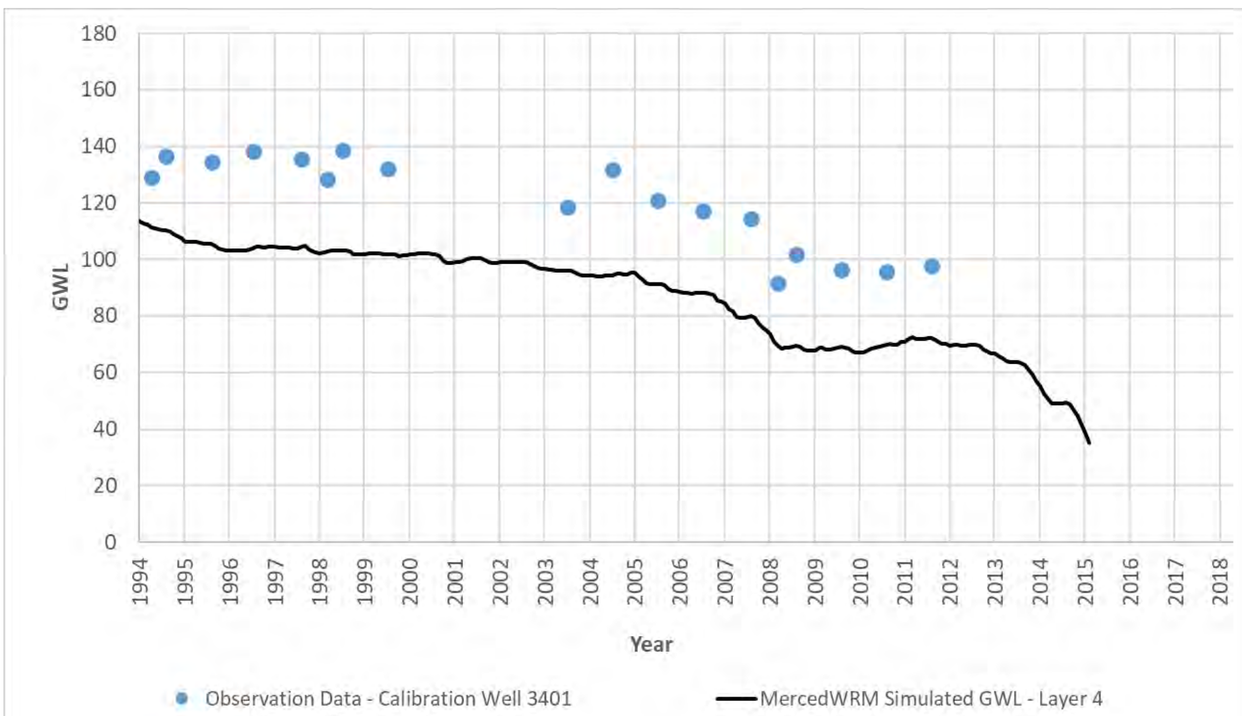

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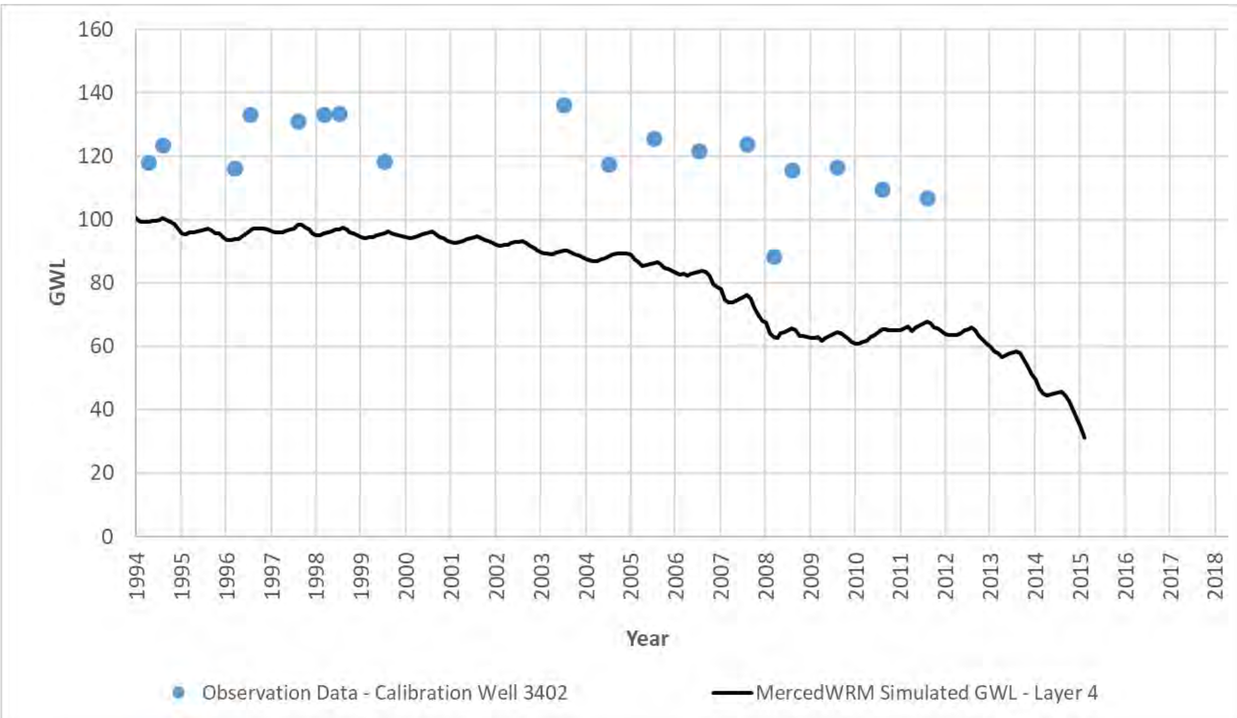

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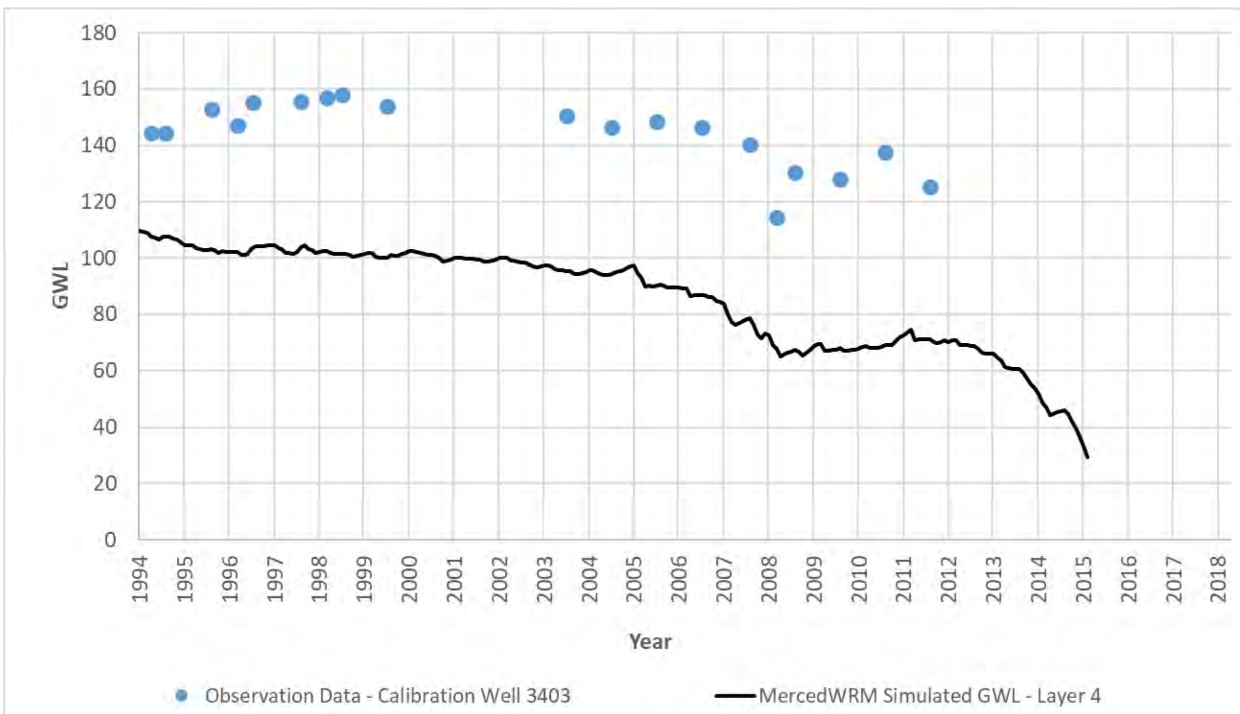

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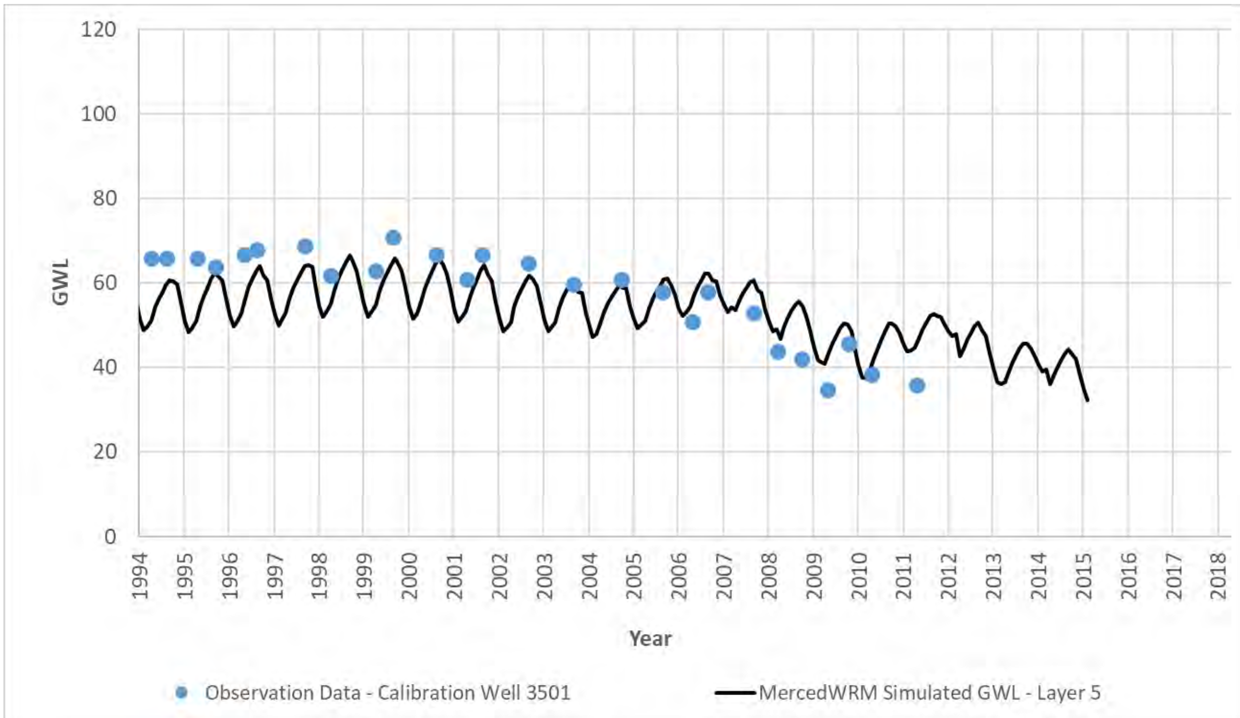

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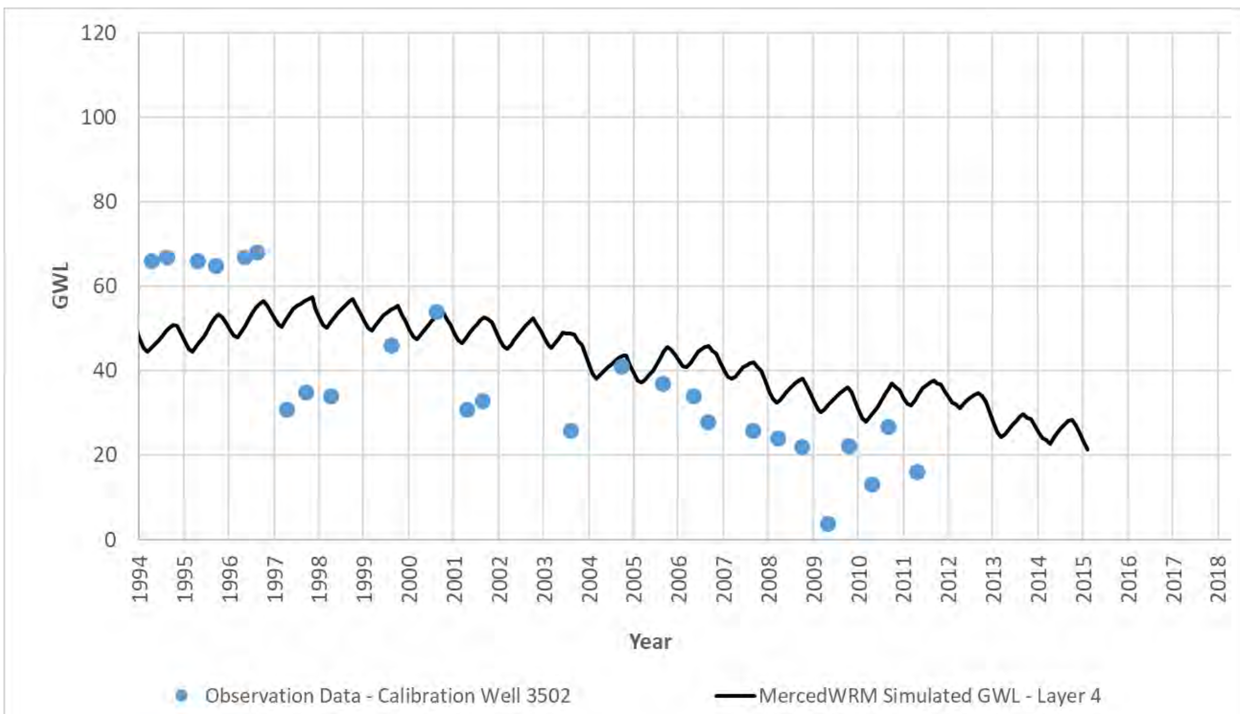

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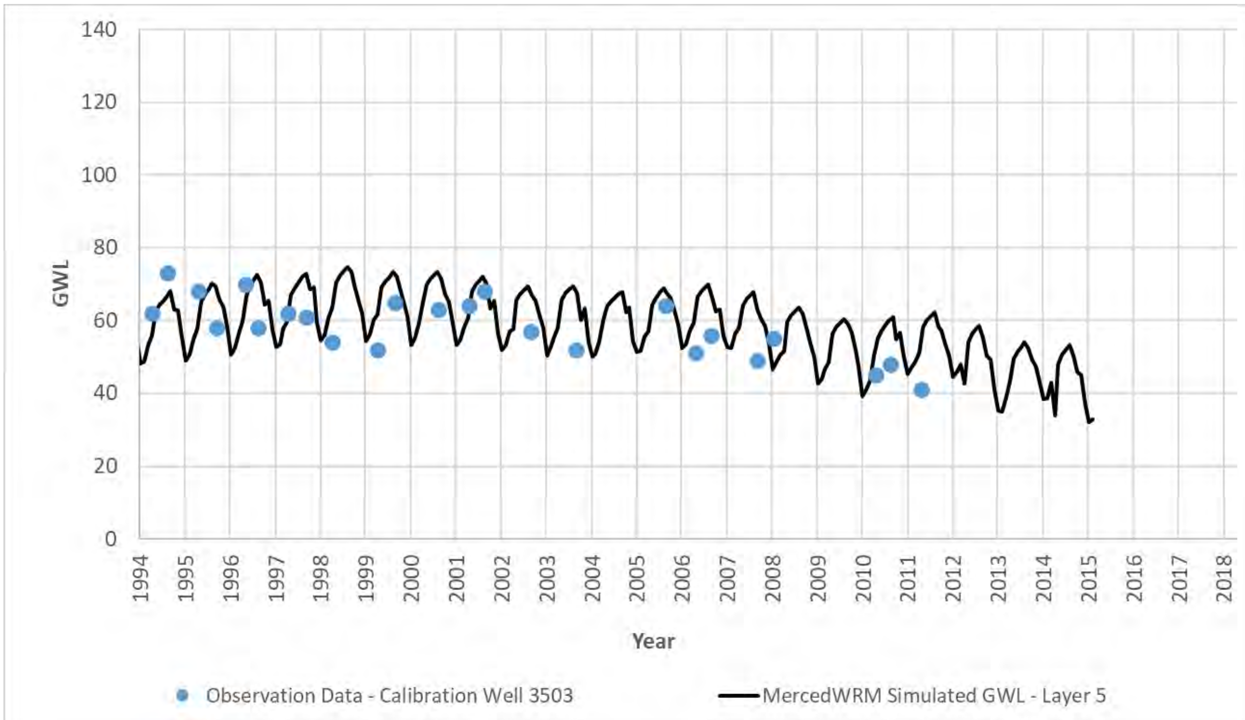

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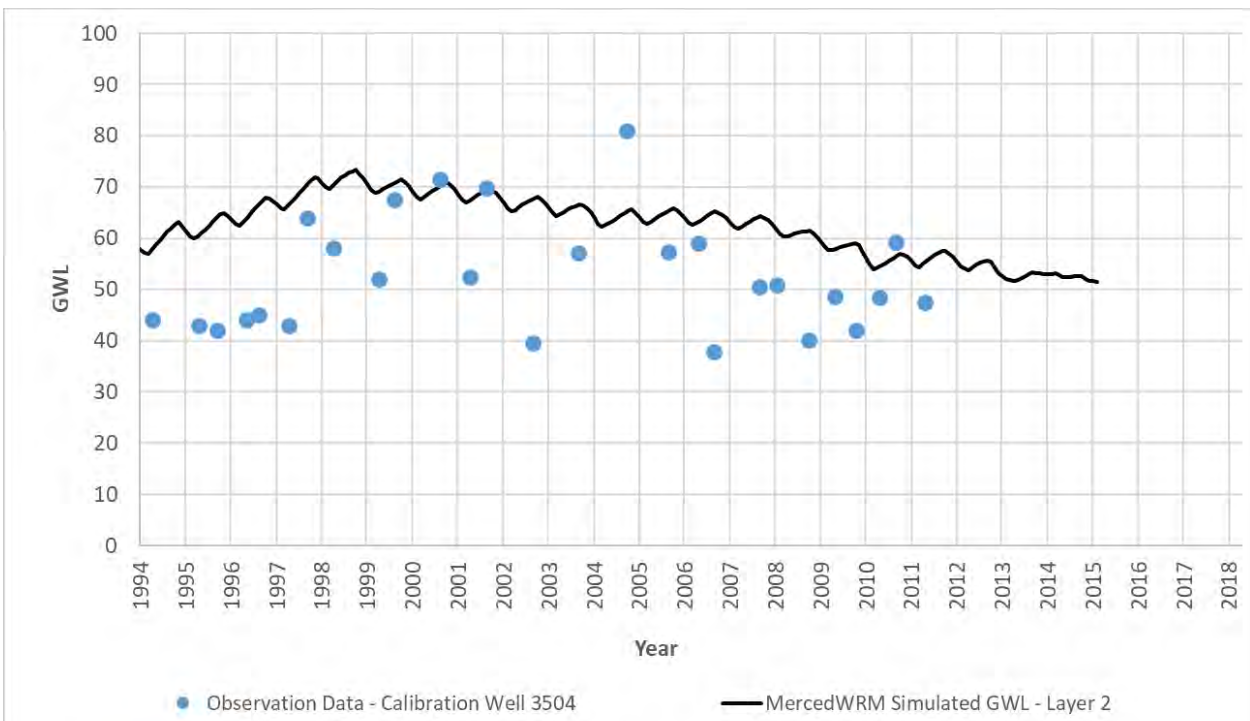

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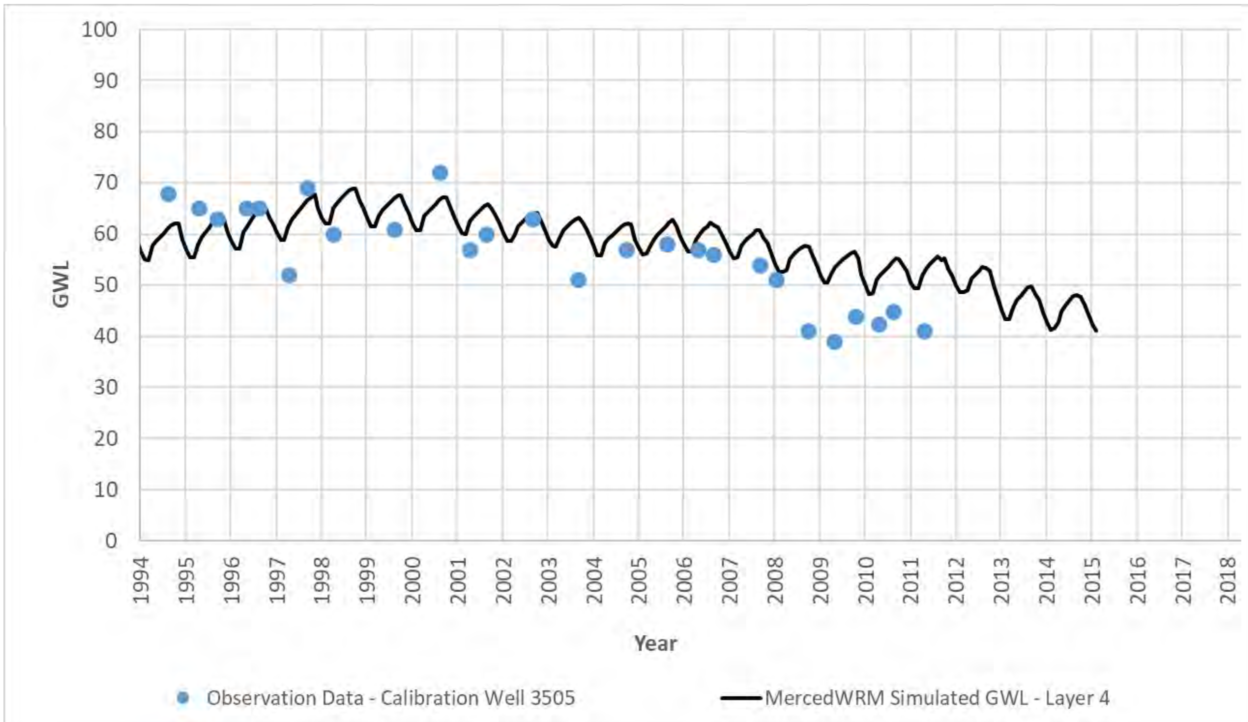

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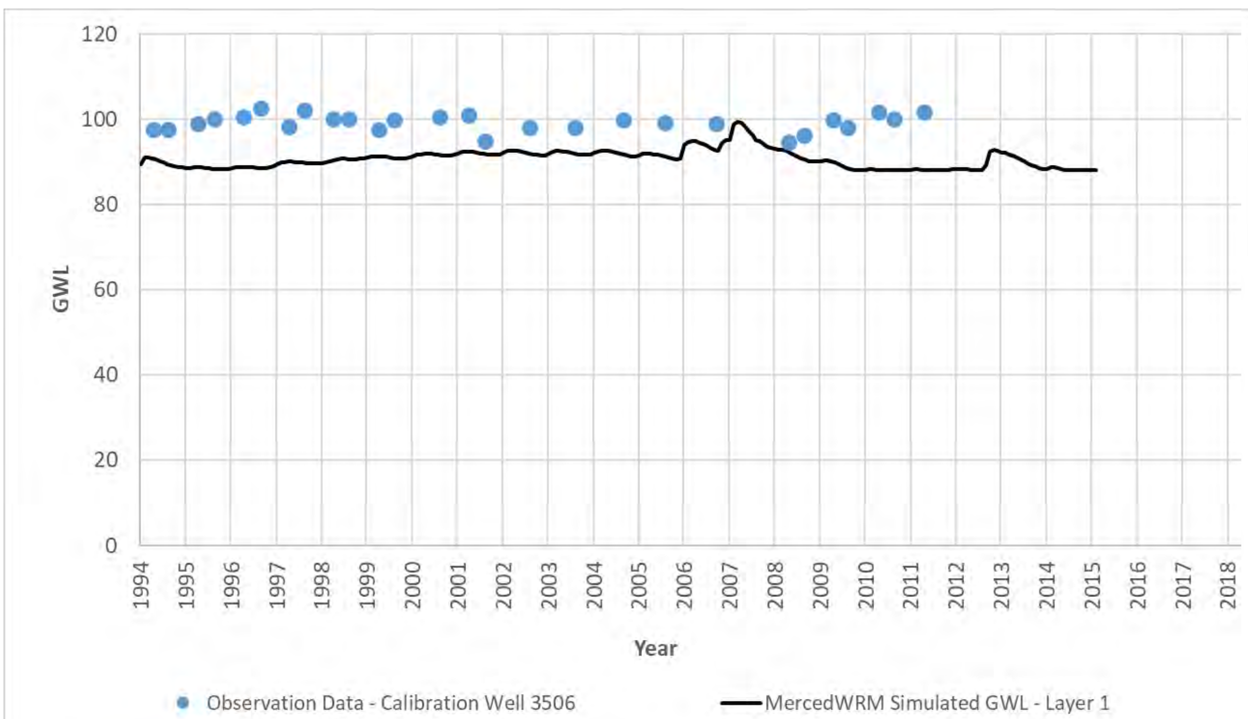

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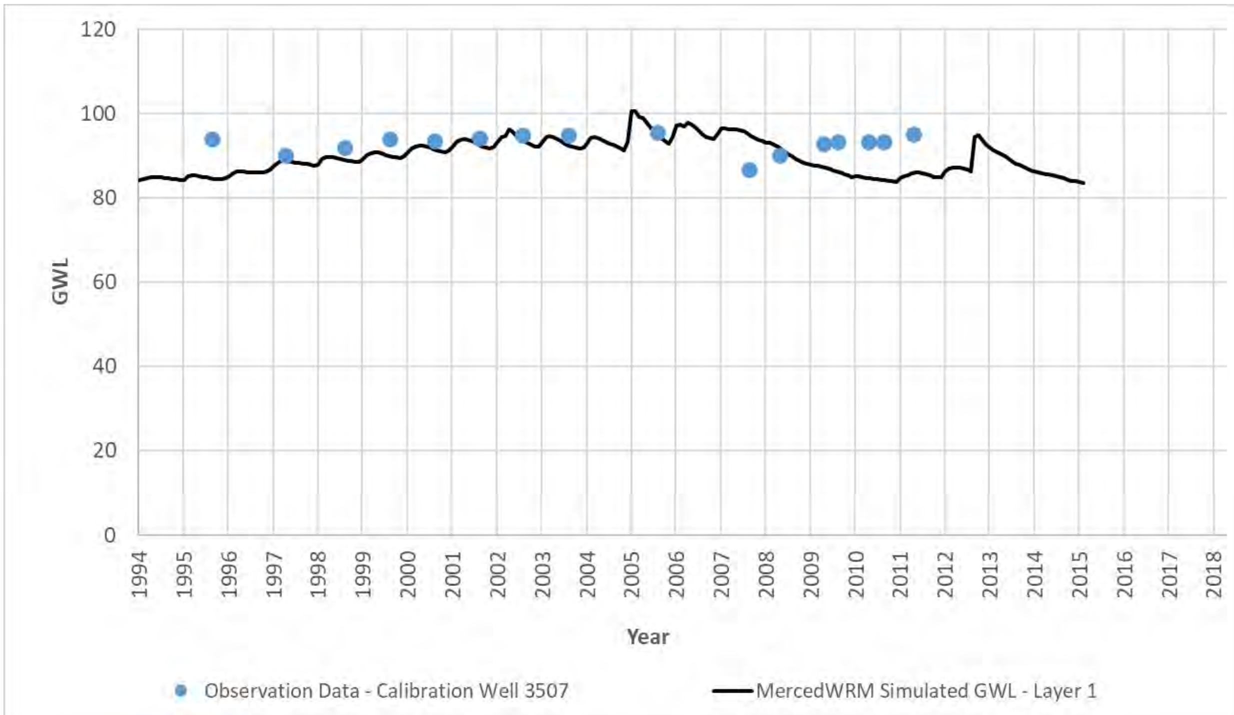

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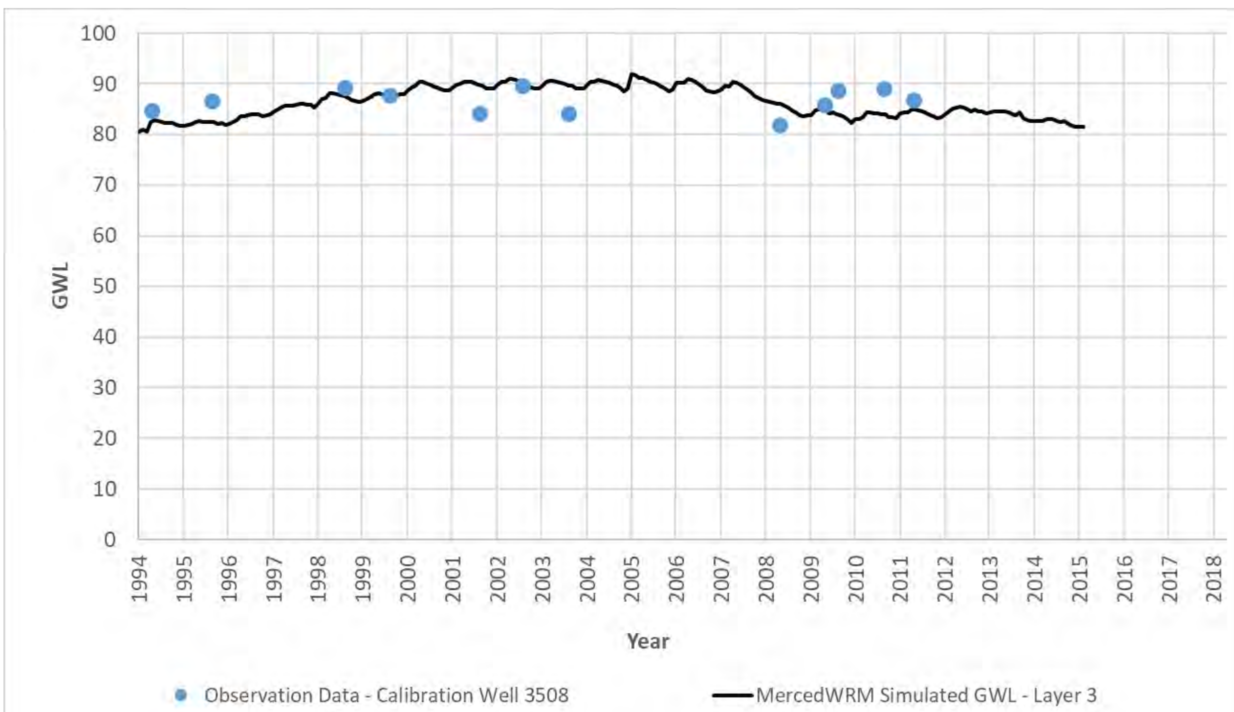

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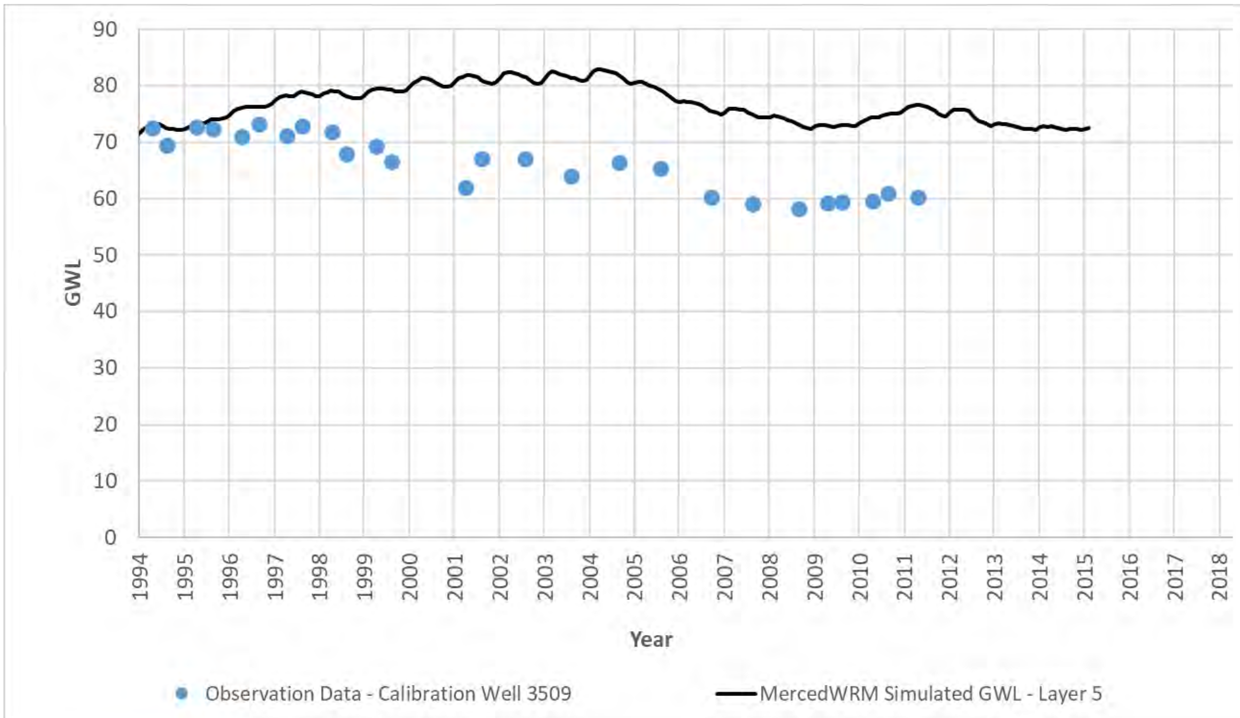

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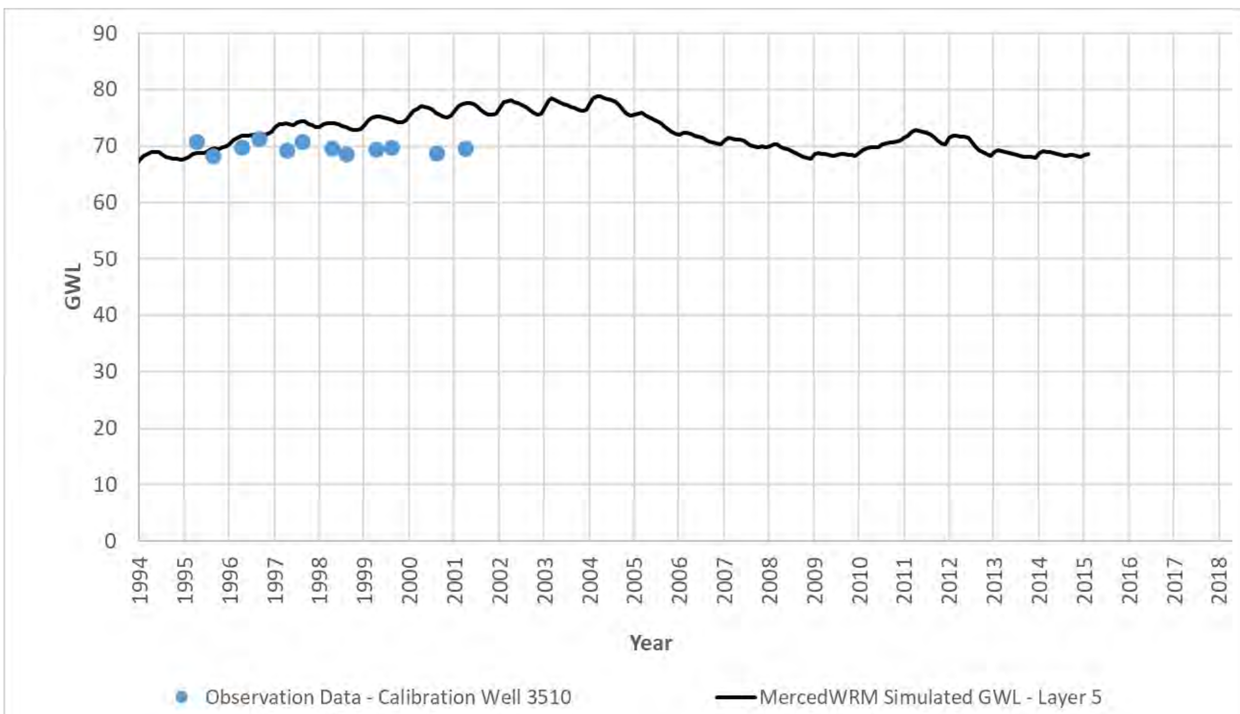
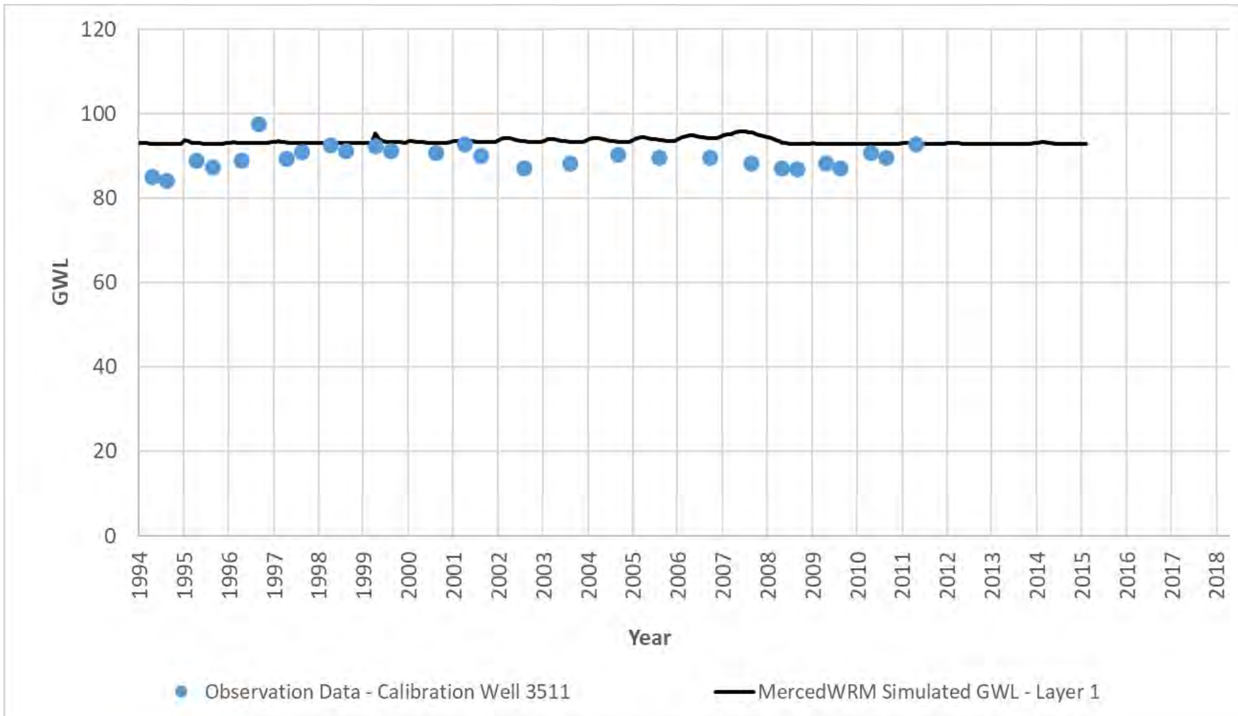


Figure A 148: Calibration Well 3510



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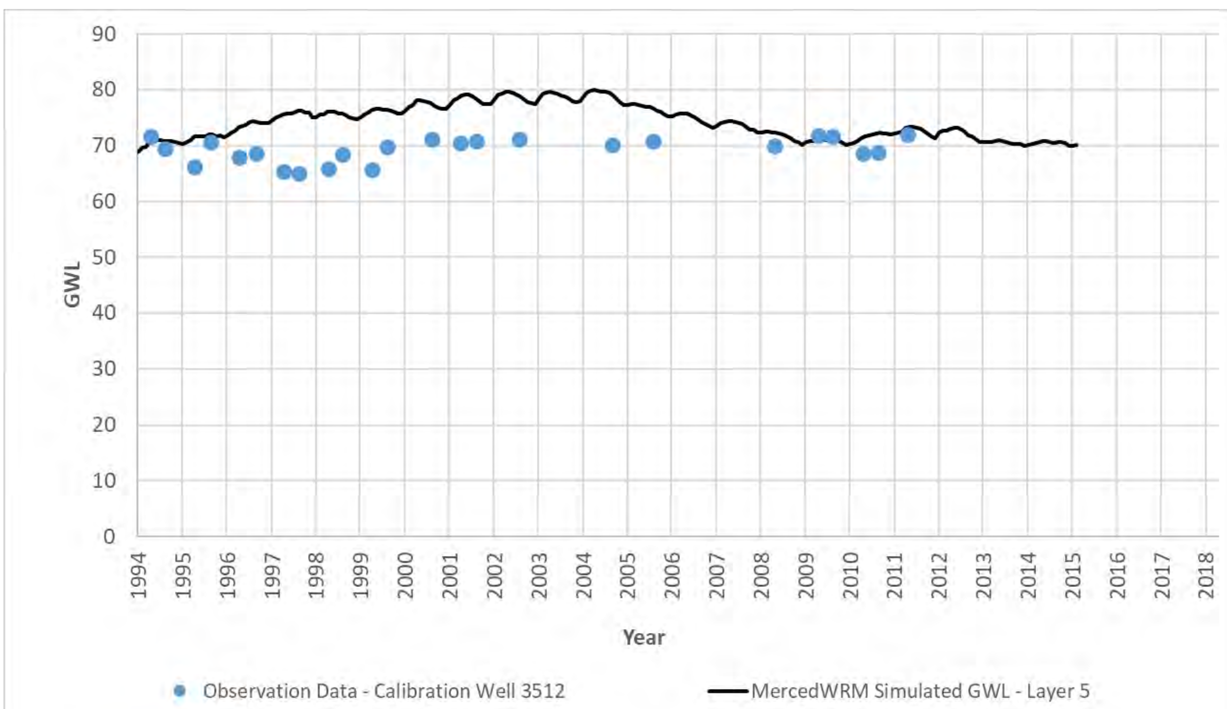

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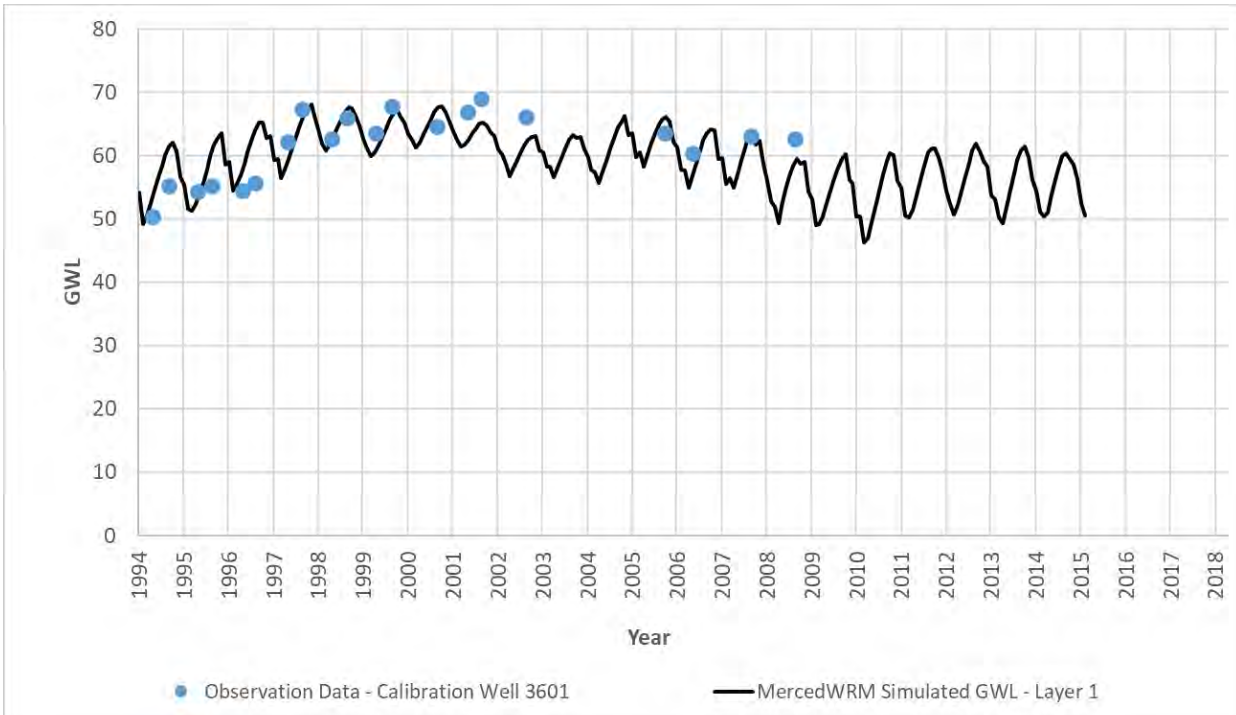

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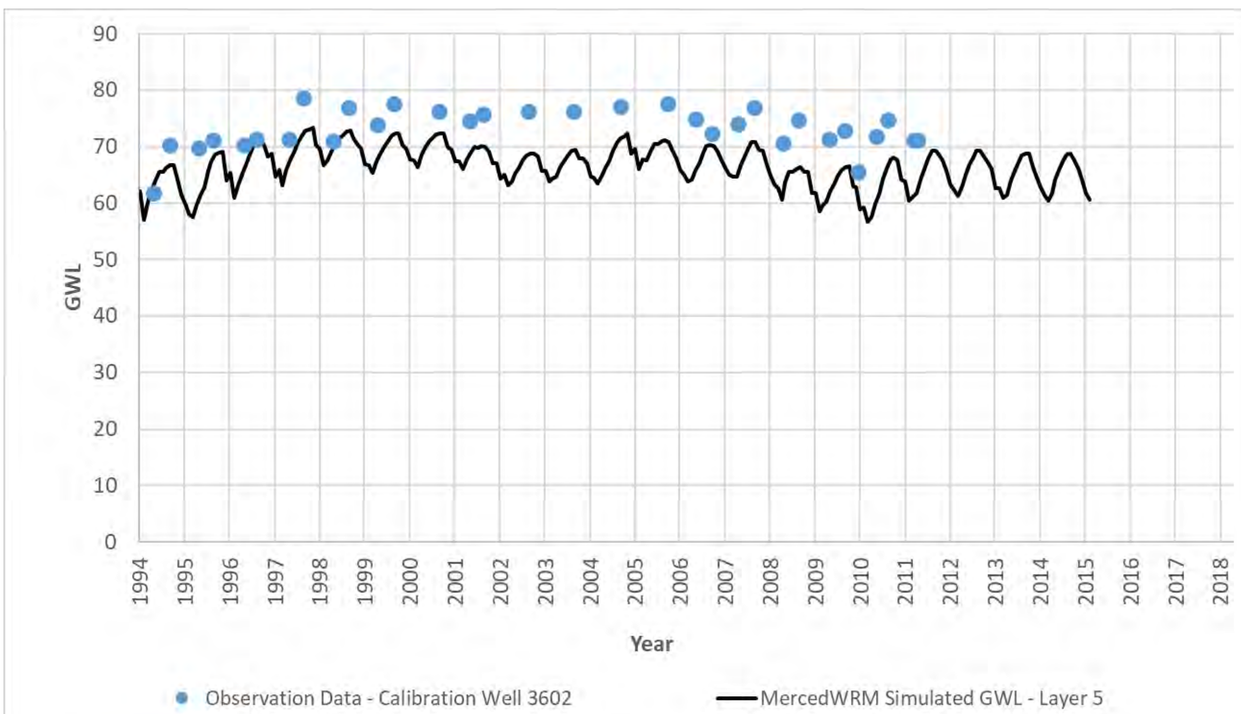

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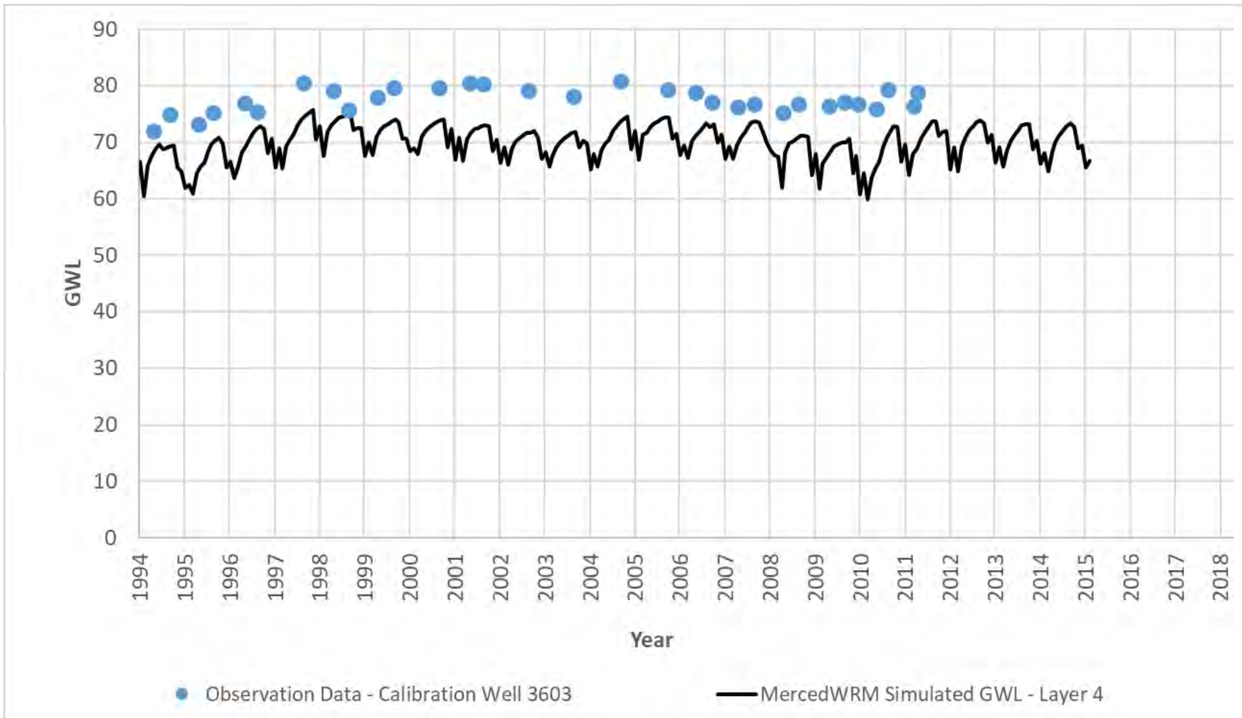

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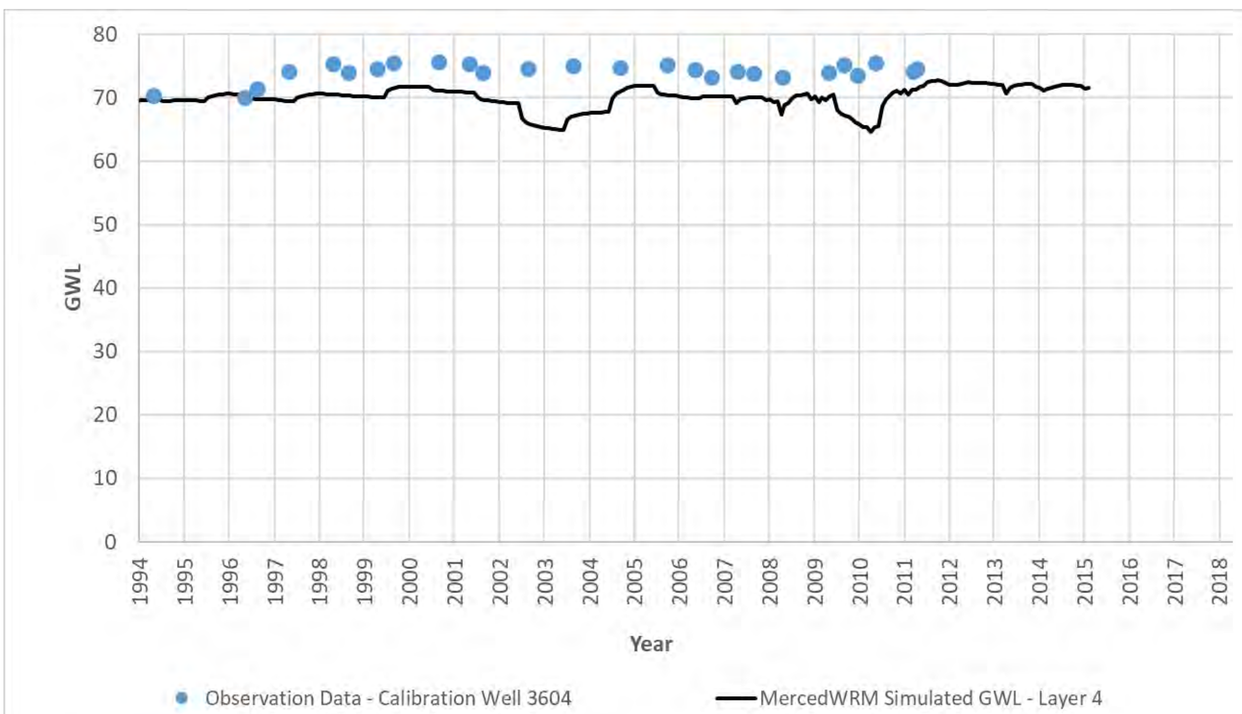

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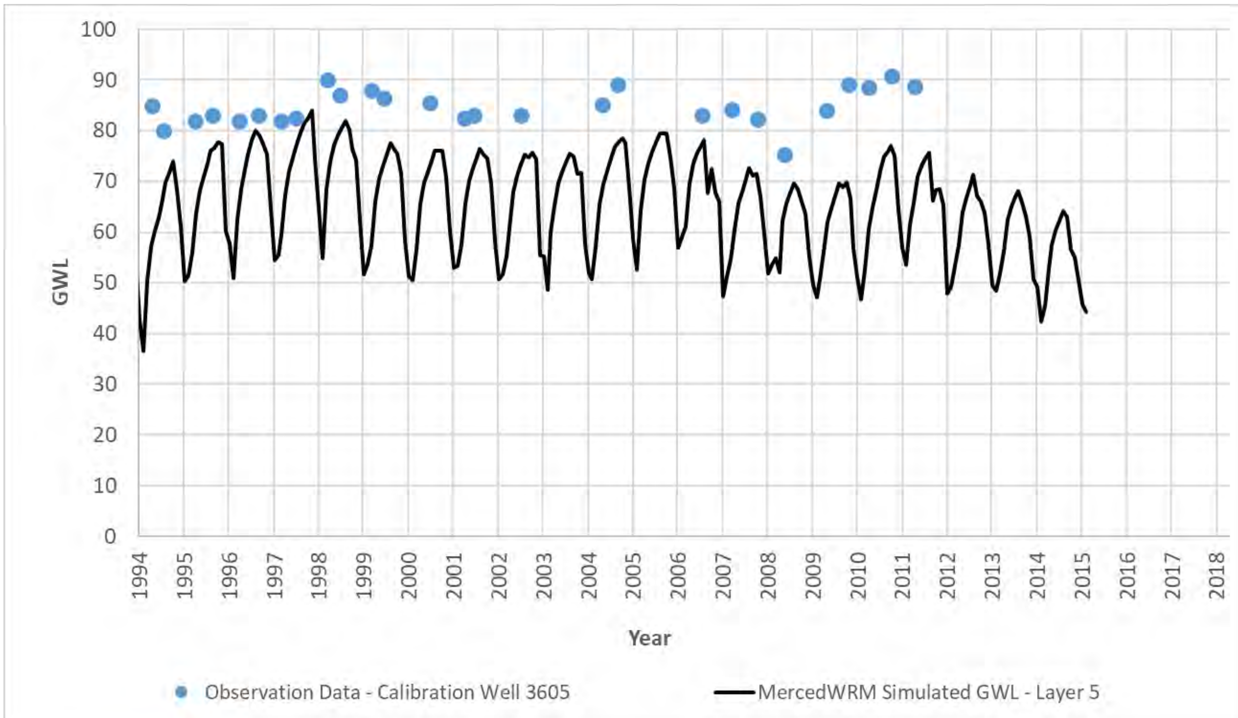

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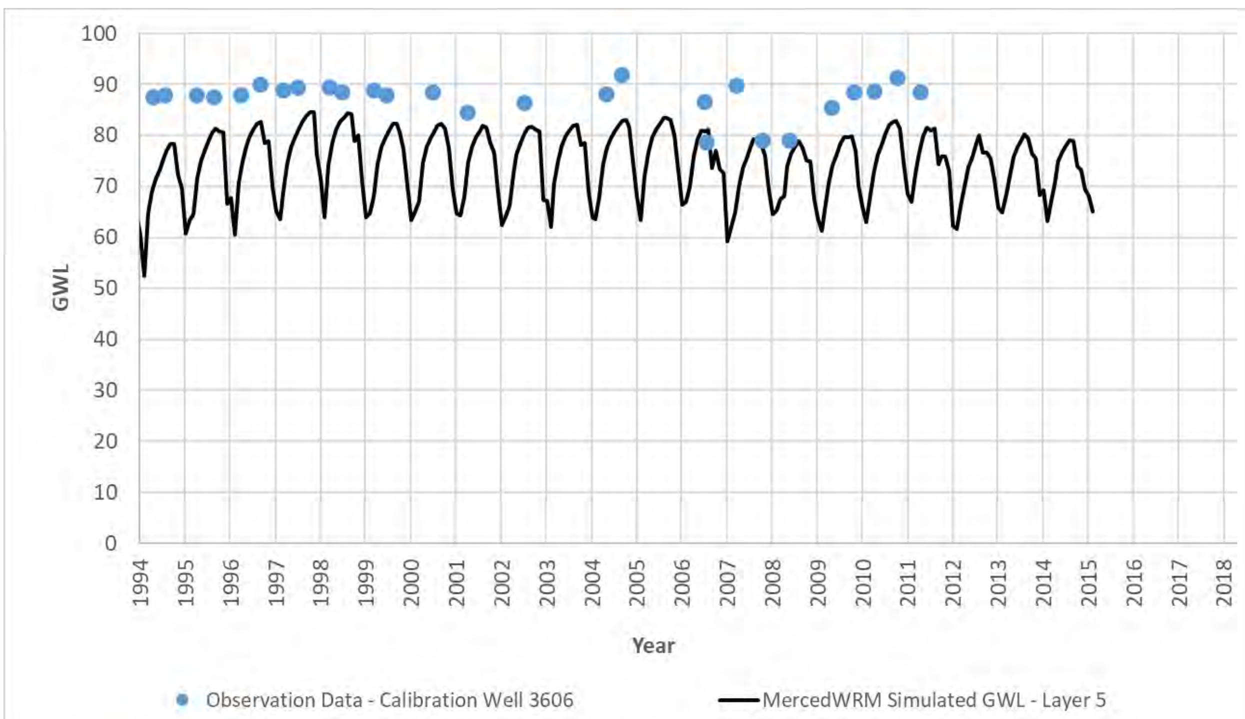

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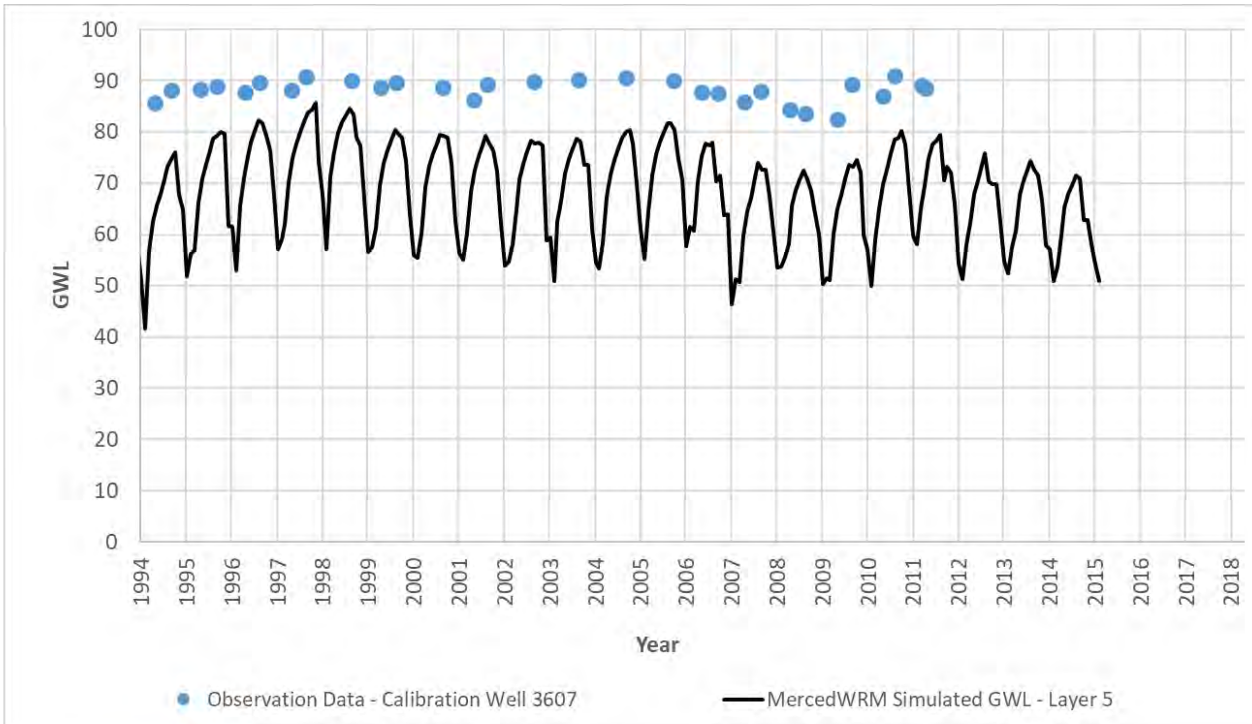

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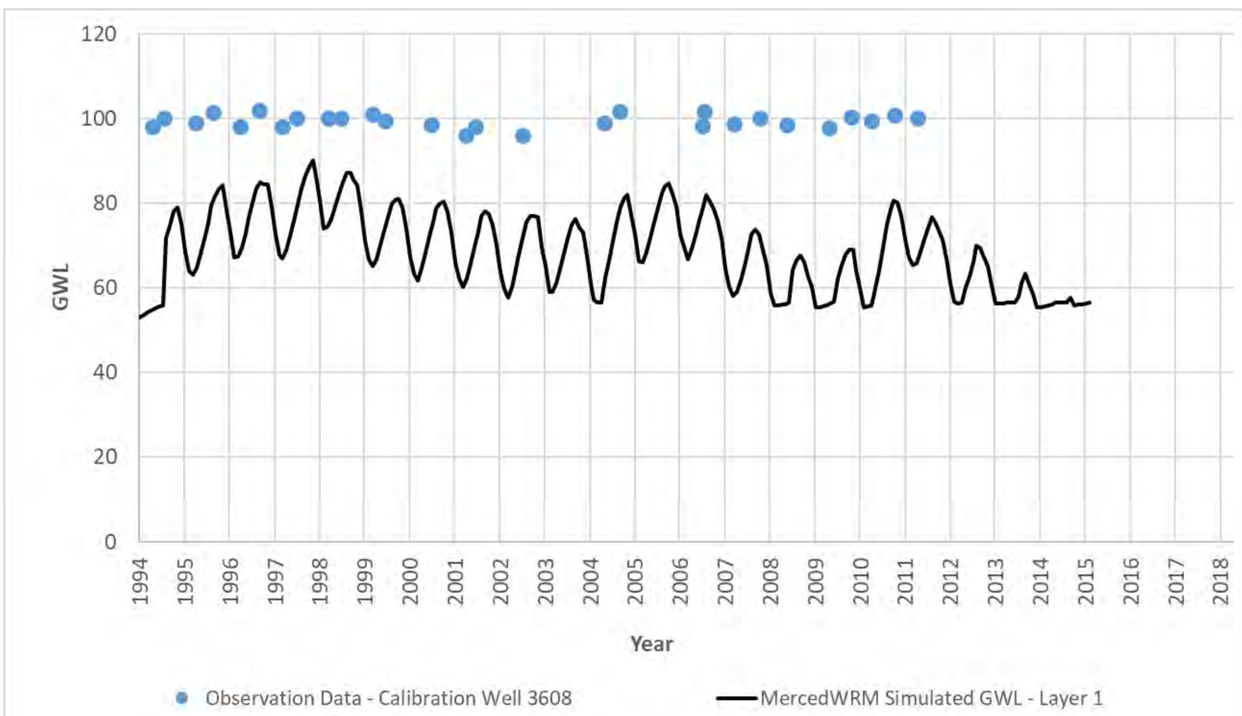

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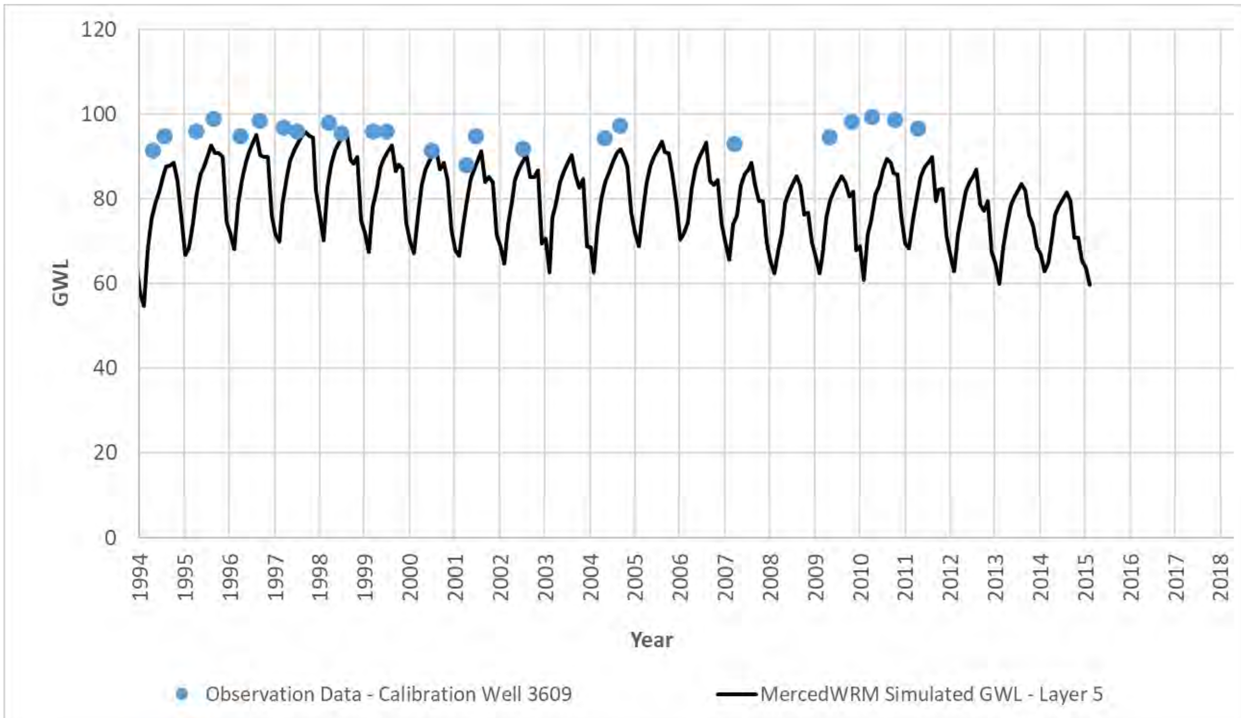


Figure A 159: Calibration Well 3609

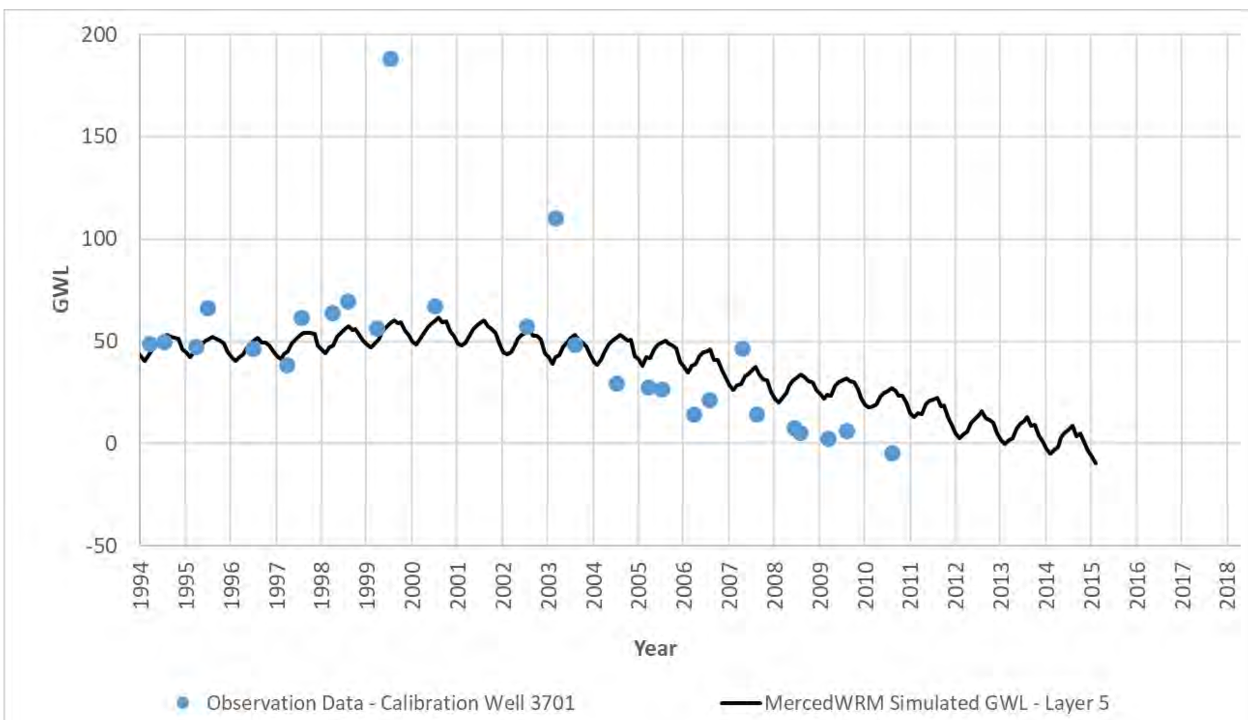


Figure A 160: Calibration Well 3701

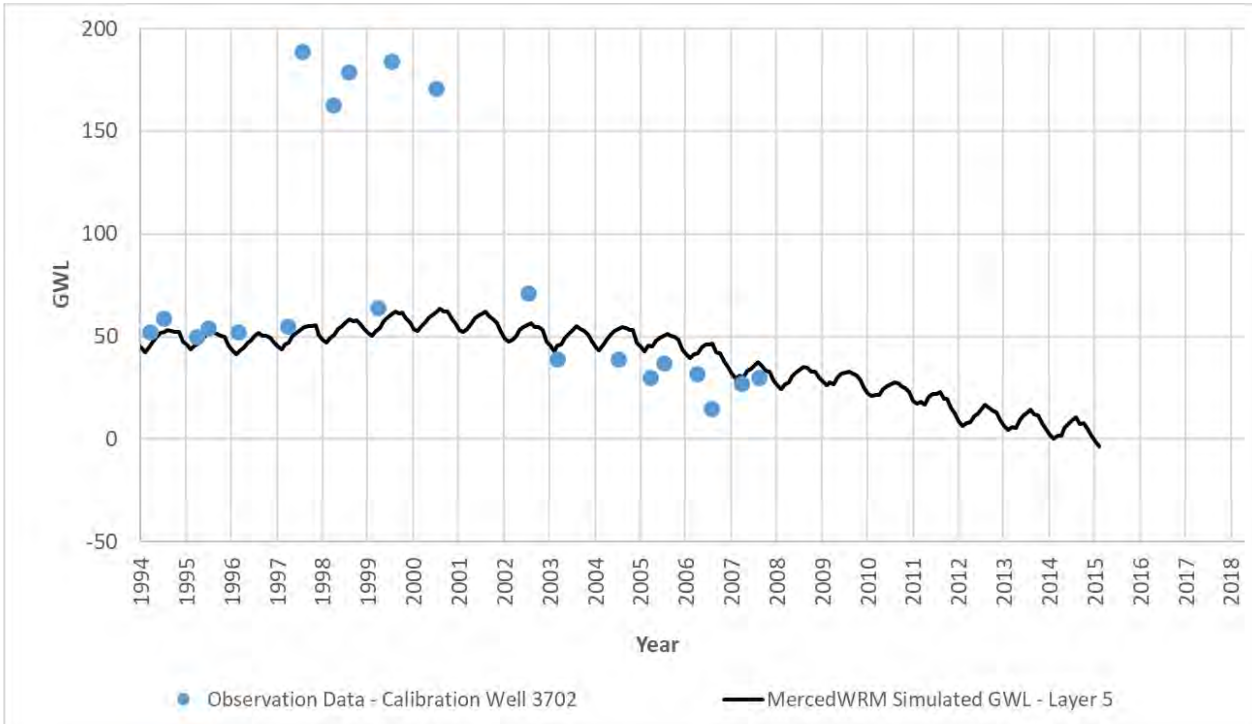


Figure A 161: Calibration Well 3702

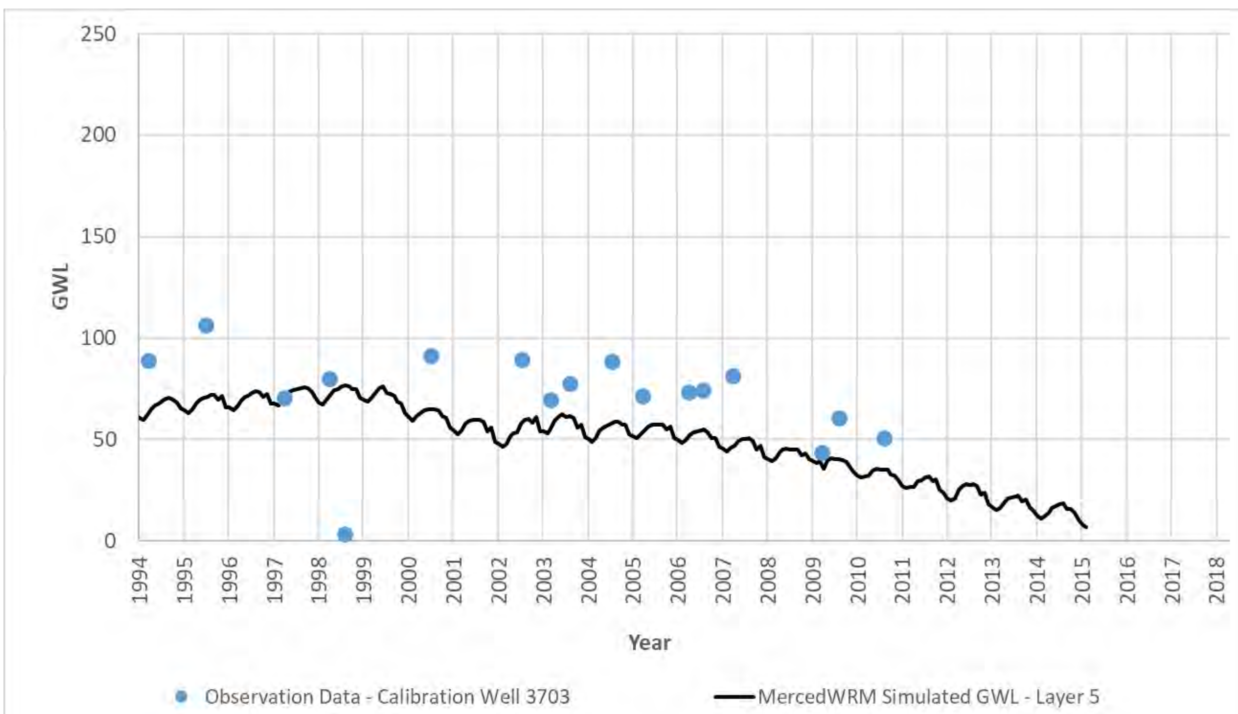
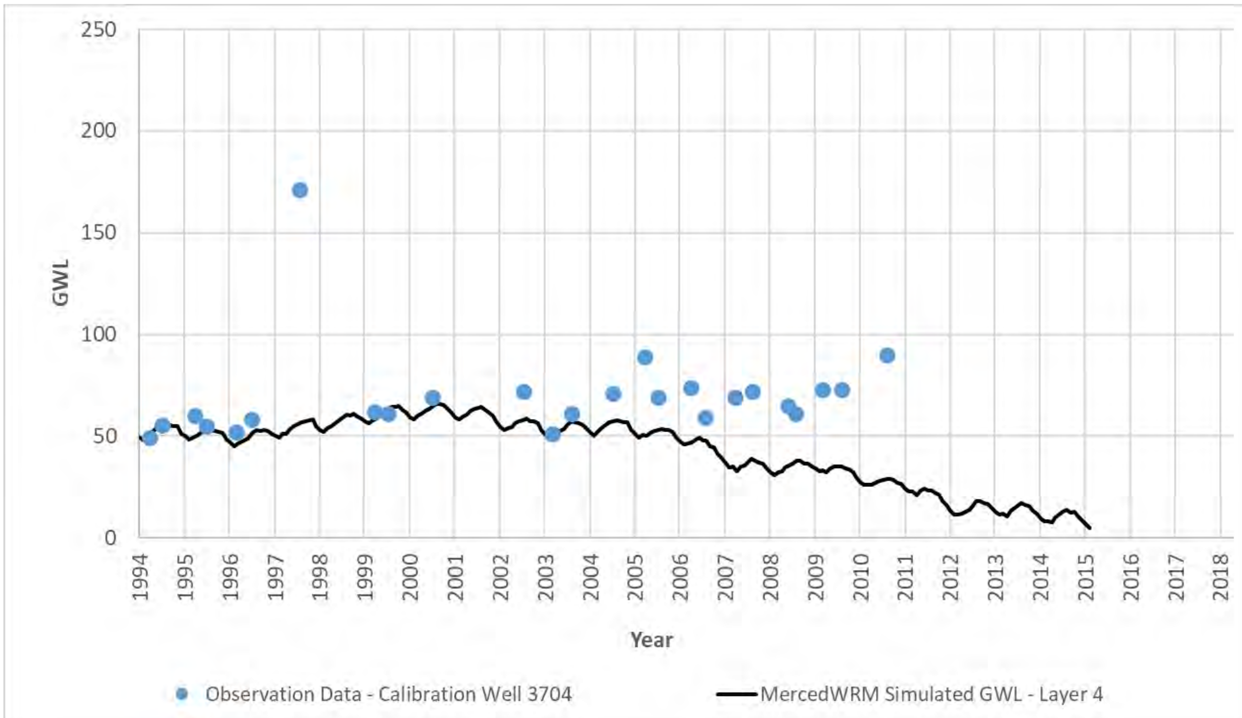


Figure A 162: Calibration Well 3703



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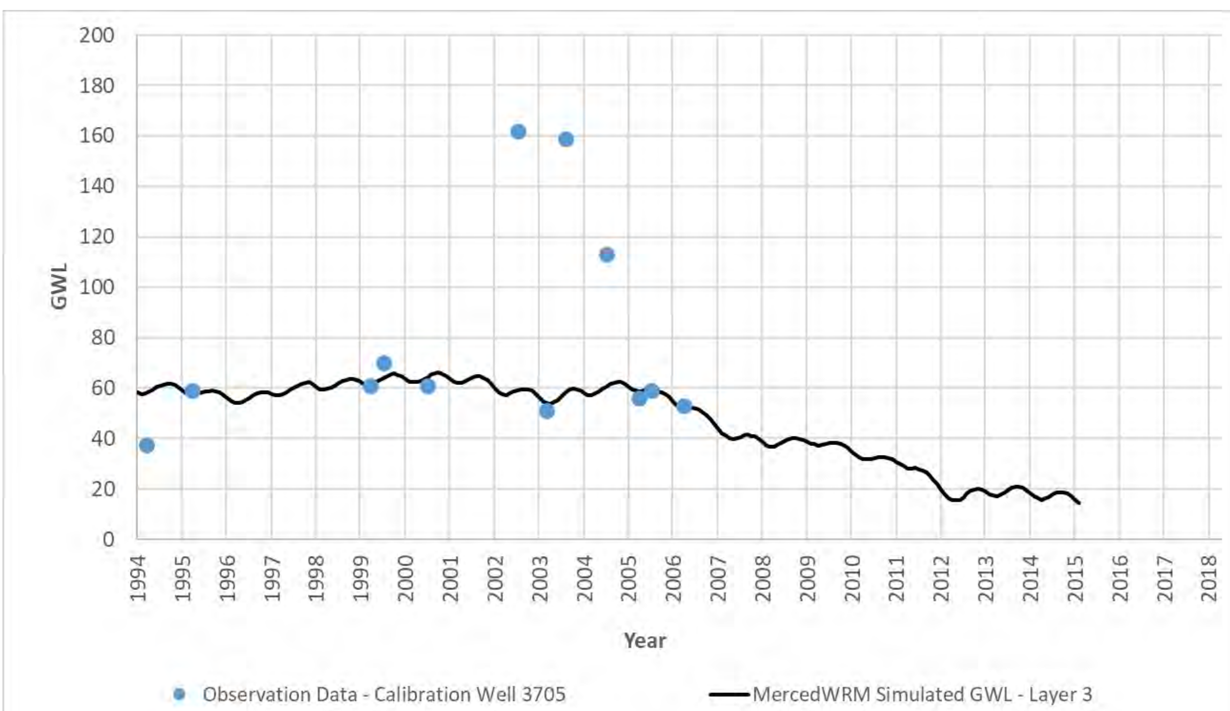

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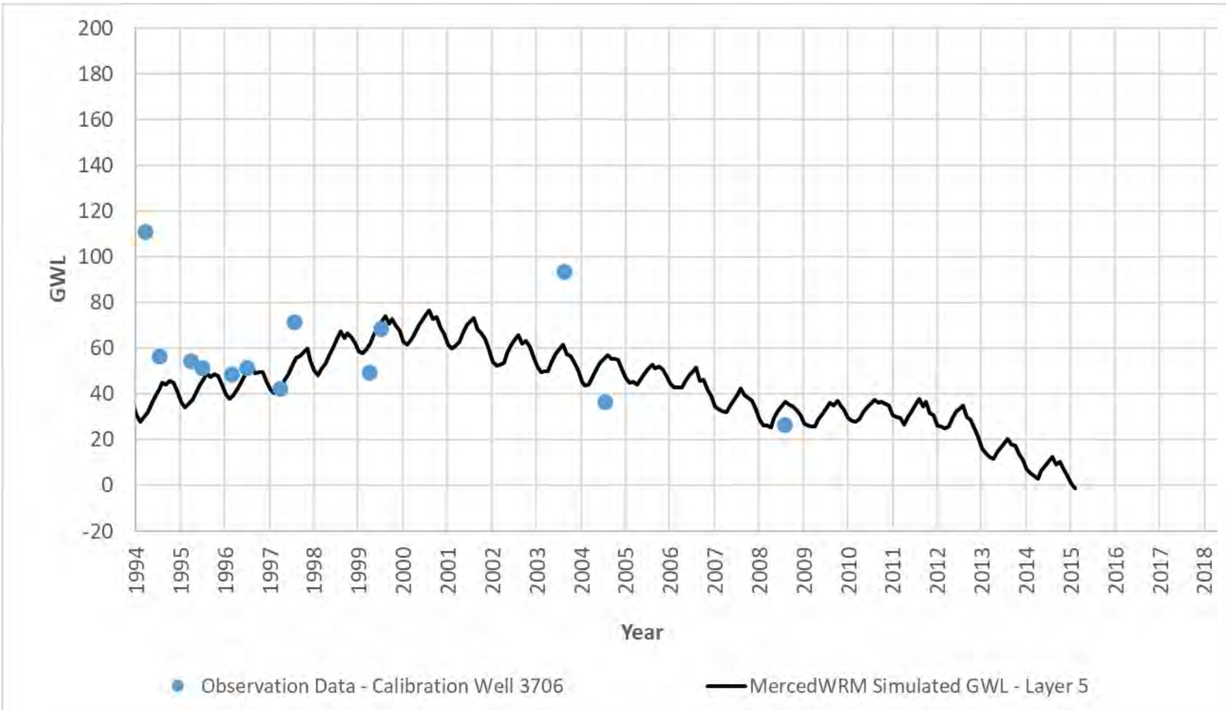

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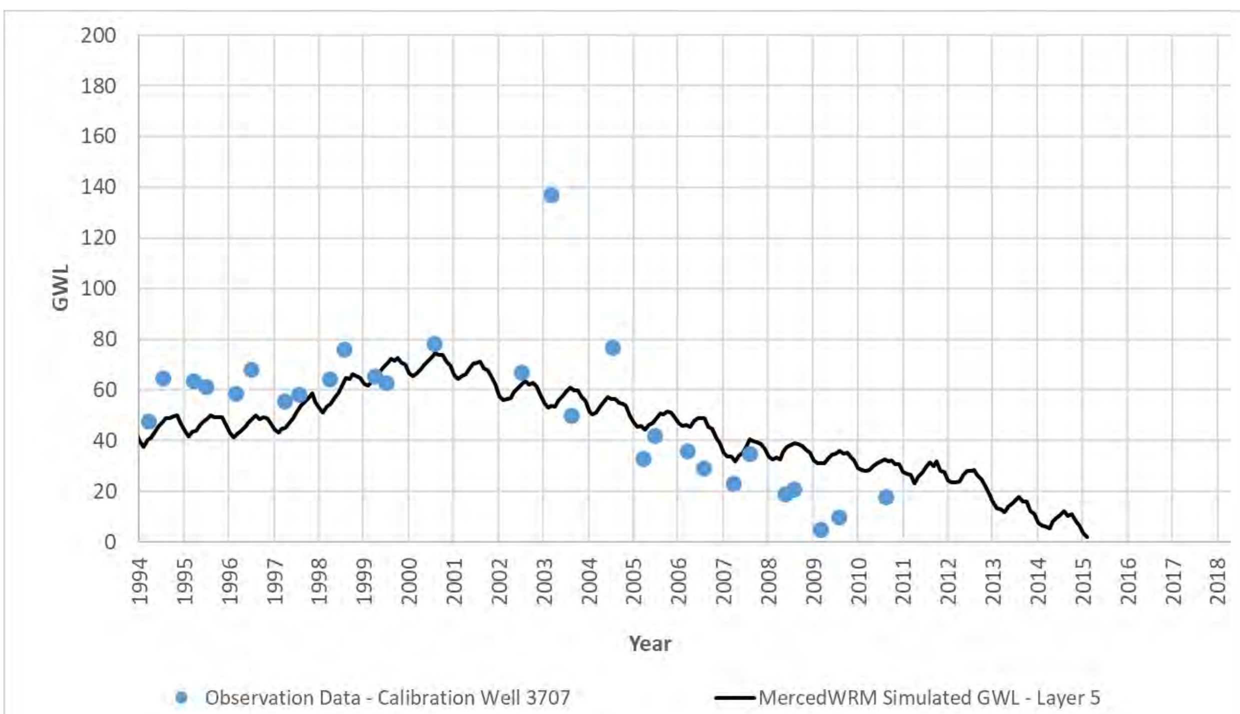

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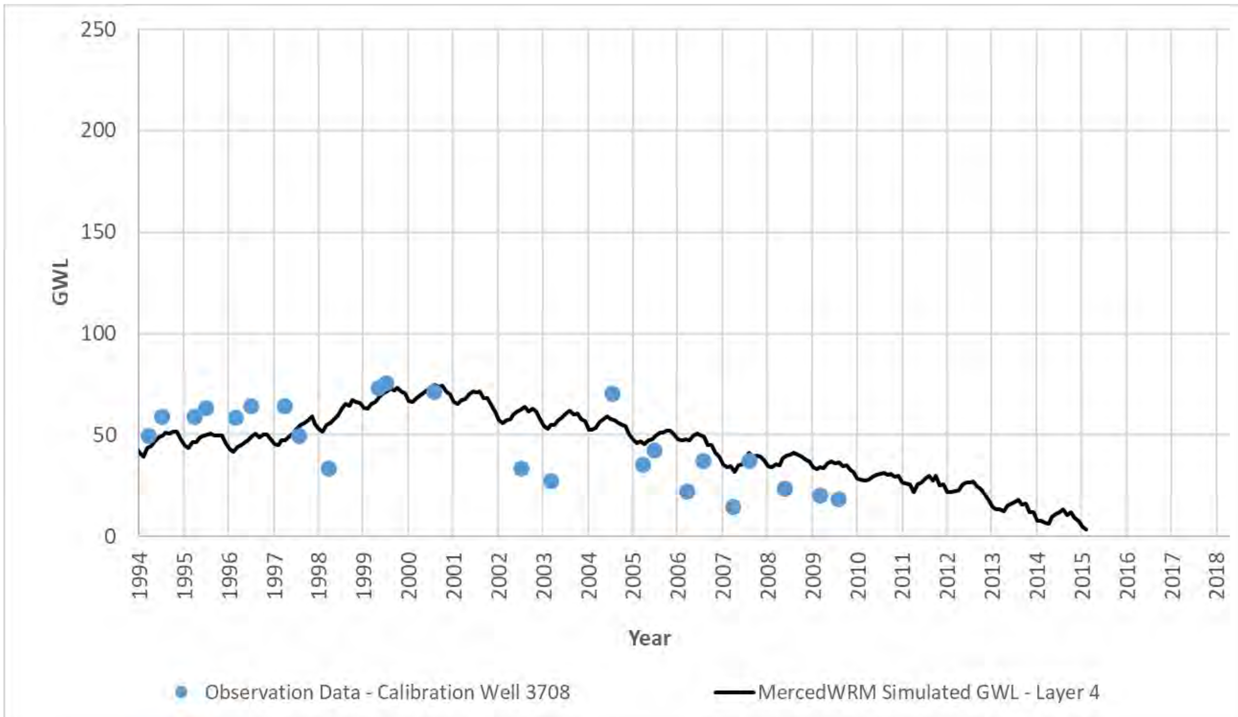

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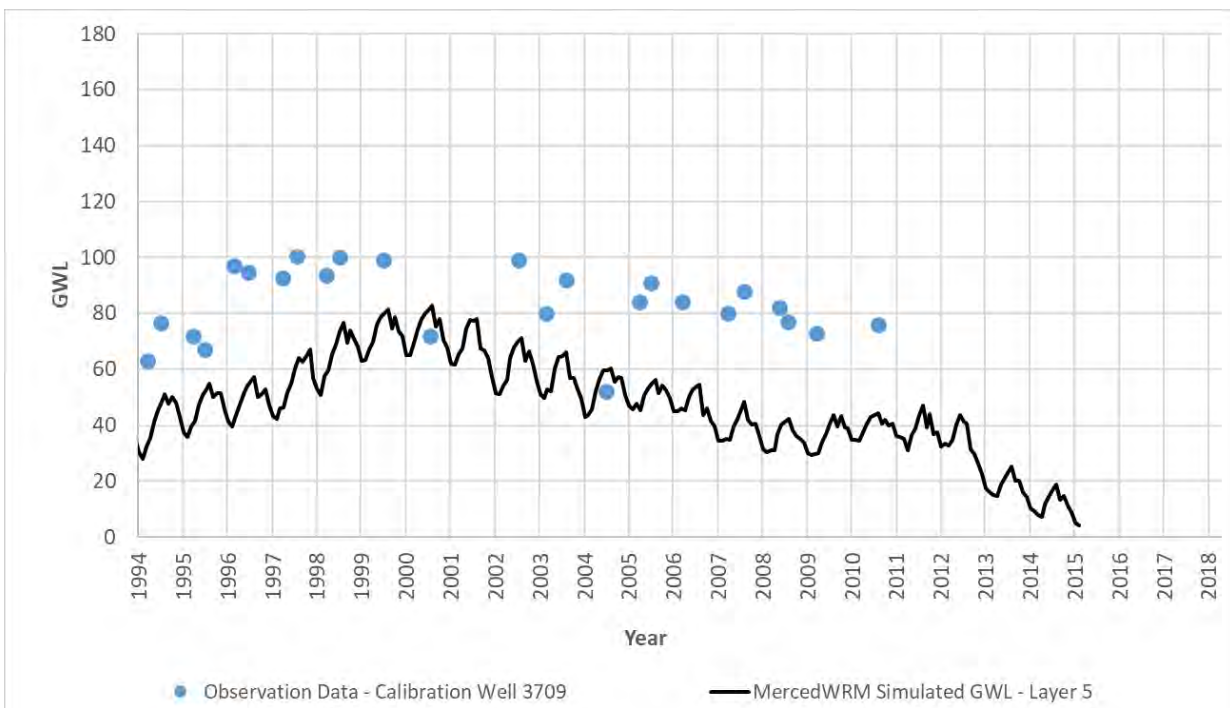

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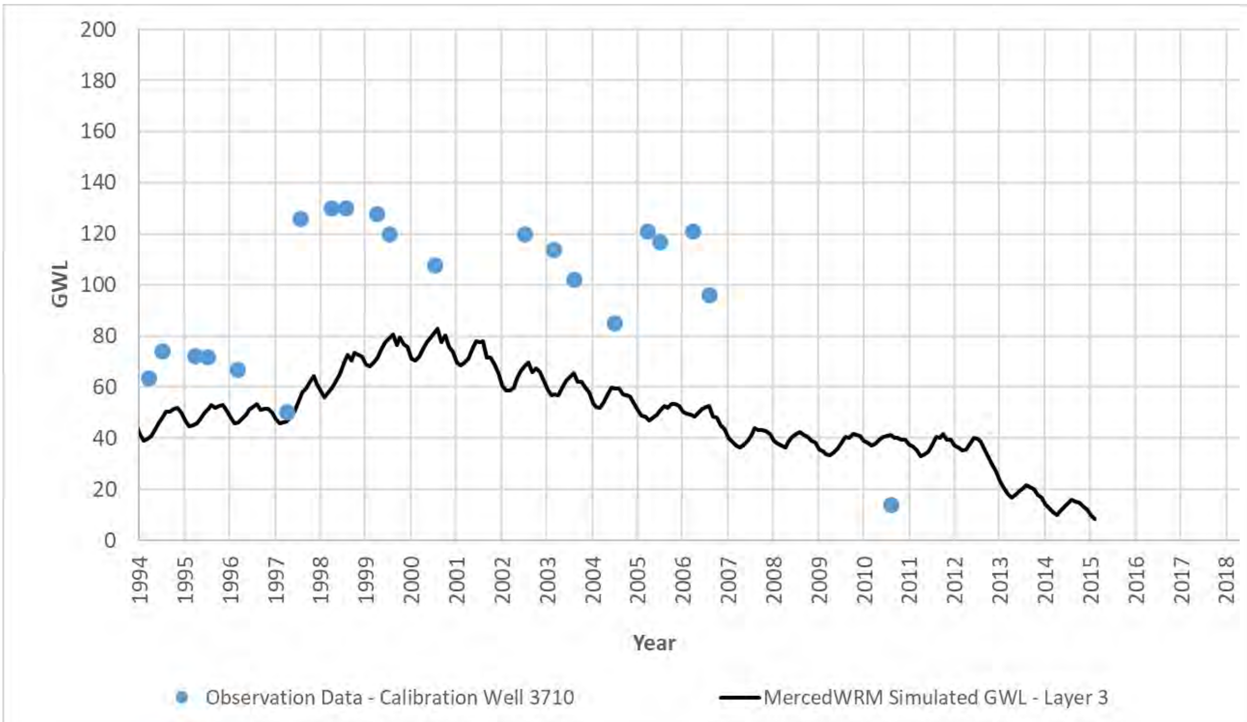

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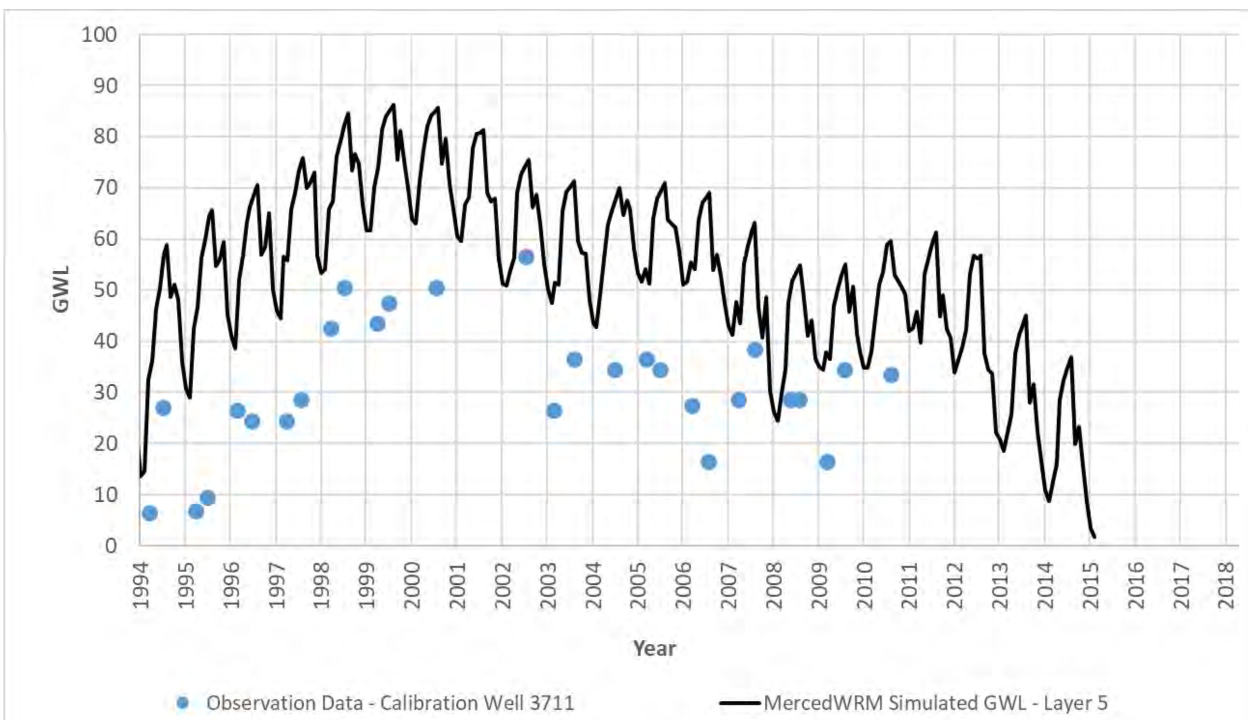

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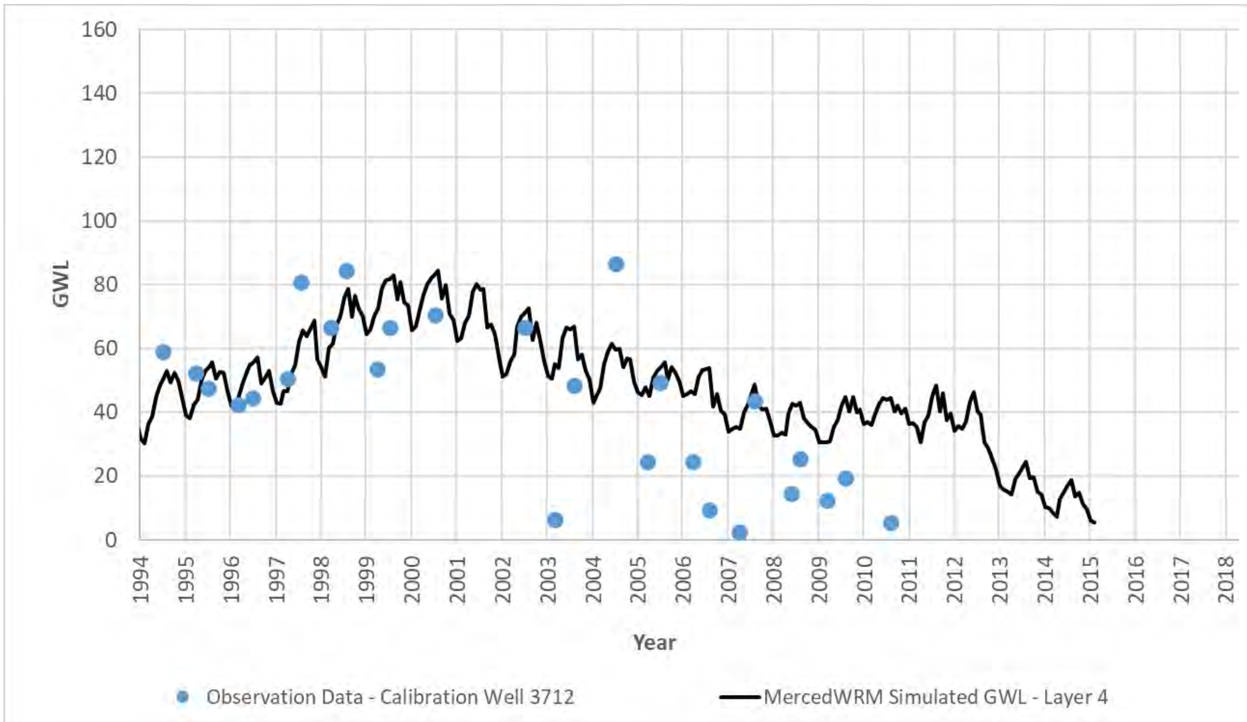


Figure A 171: Calibration Well 3712

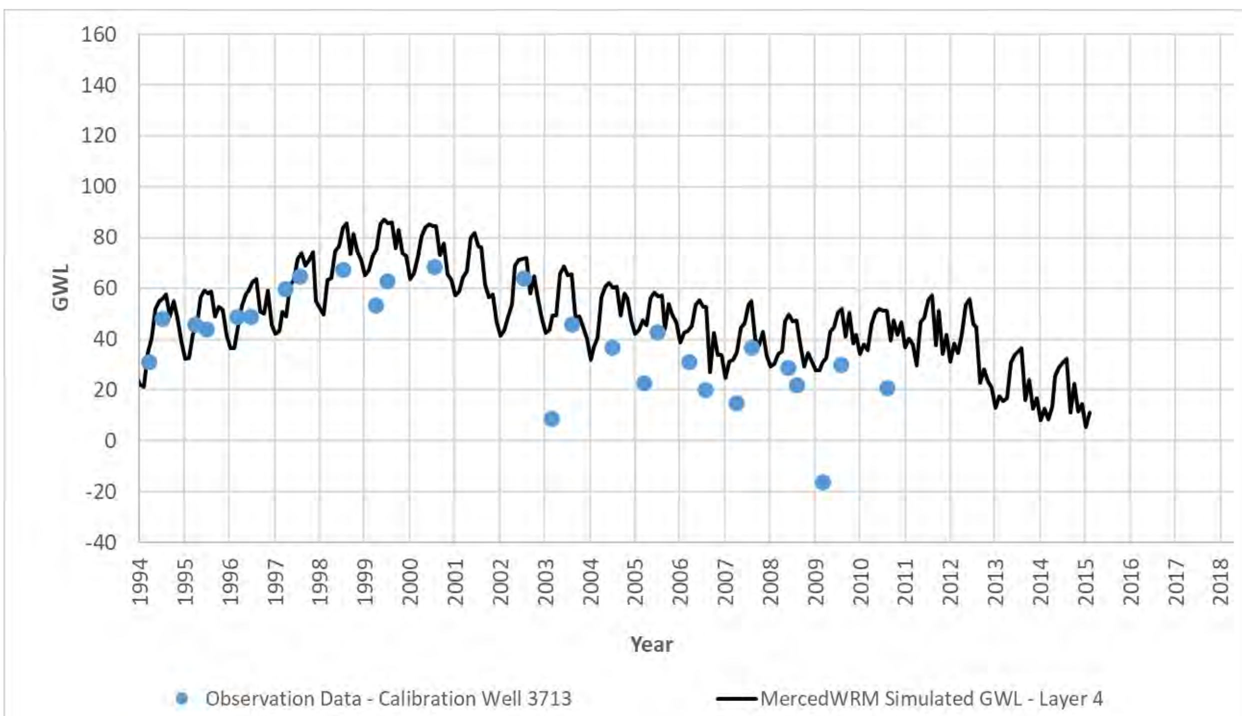


Figure A 172: Calibration Well 3713

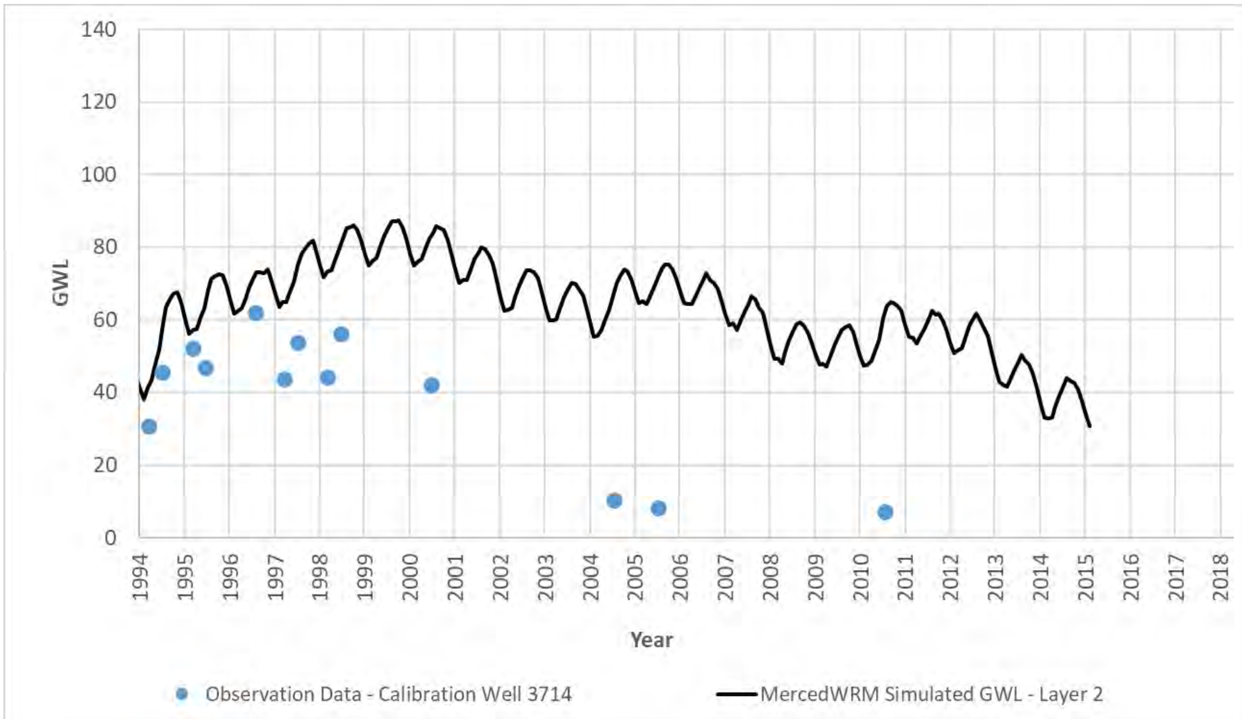
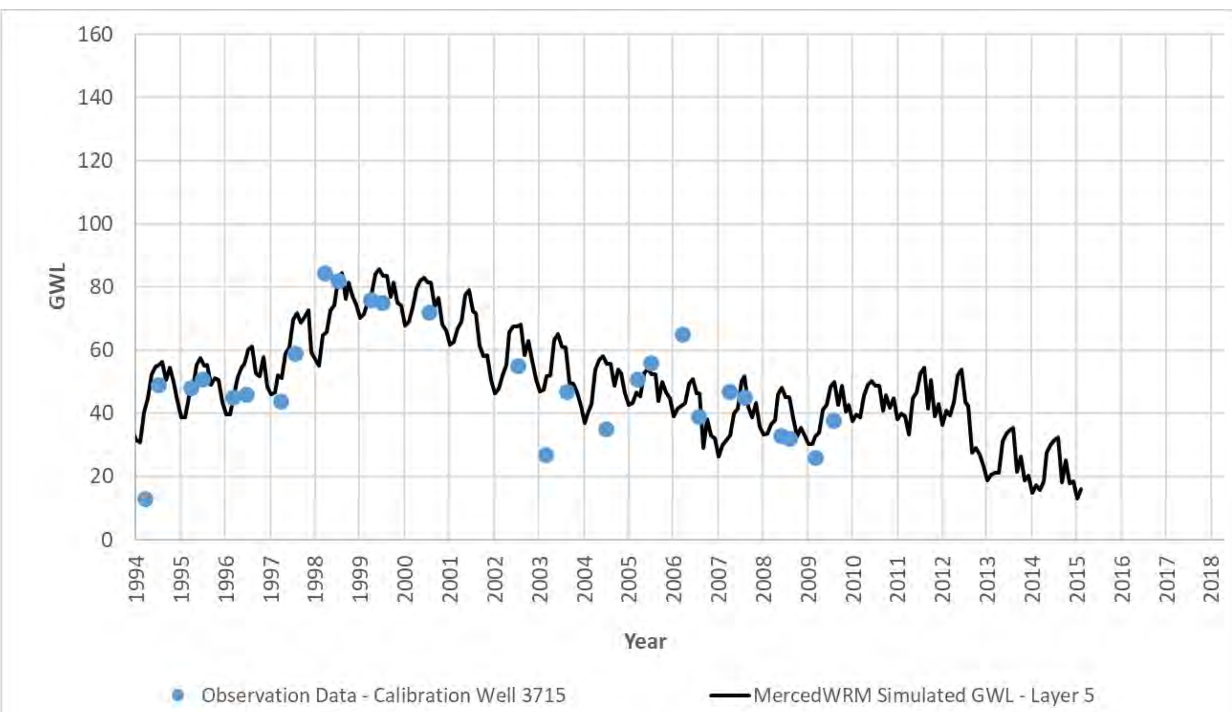


Figure A 173: Calibration Well 3714



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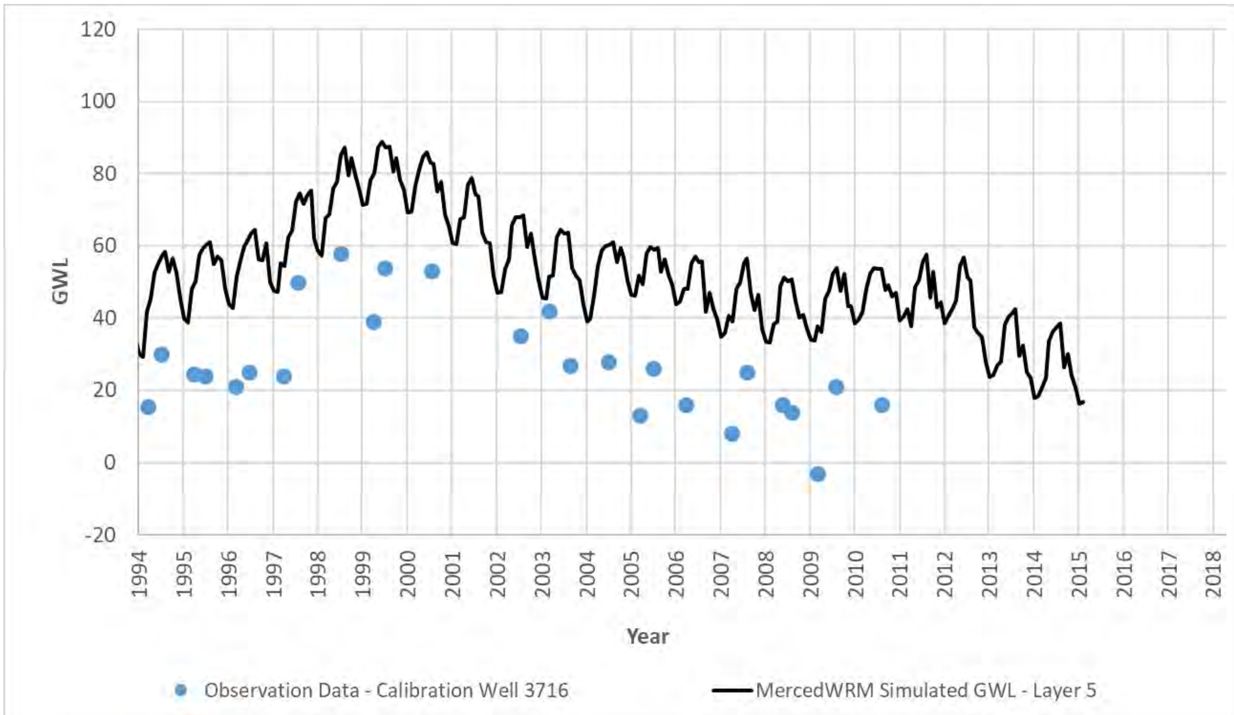


Figure A 175: Calibration Well 3716

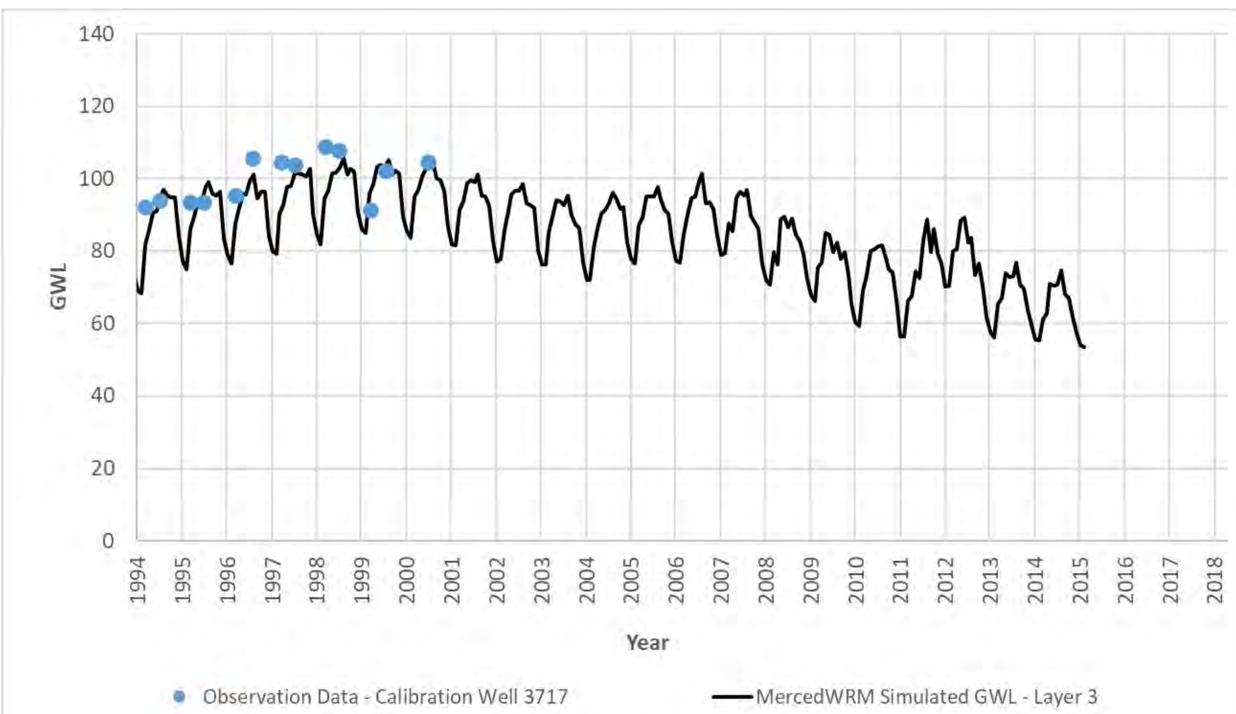


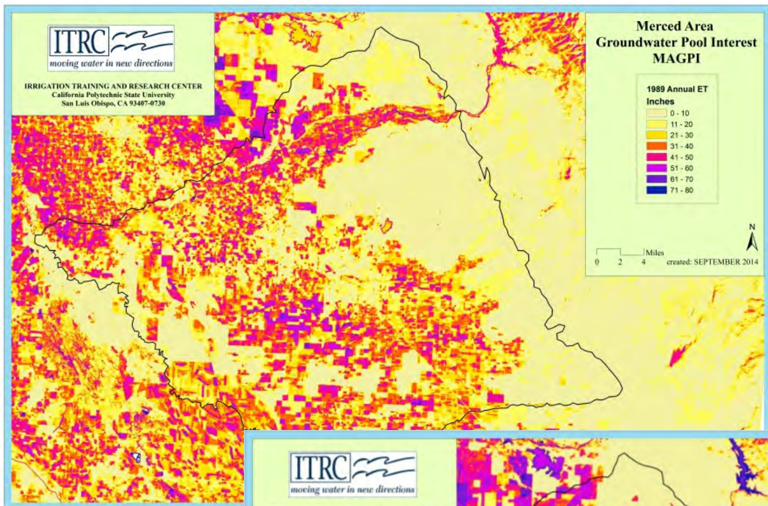
Figure A 176: Calibration Well 3717

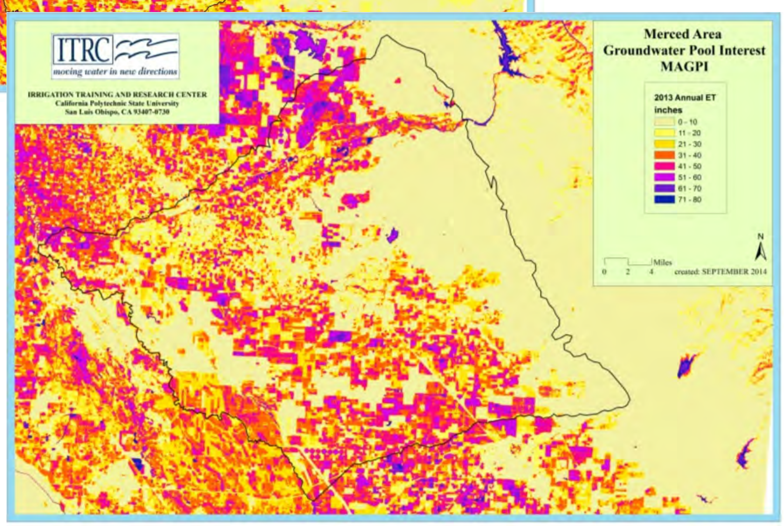
Appendix B - METRIC Project Report

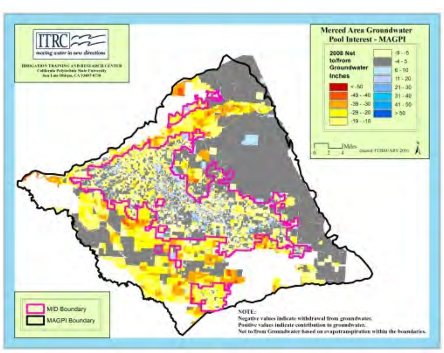
IRRIGATION TRAINING AND RESEARCH CENTER

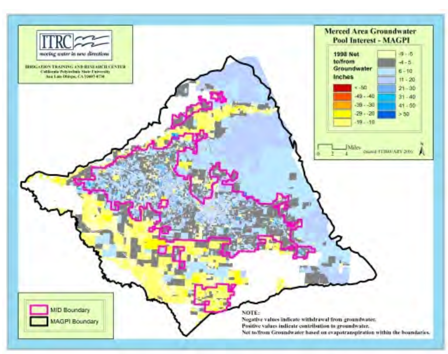
Remote Sensing of Actual Evapotranspiration and Net To and From Groundwater

DRAFT









DRAFT

Merced Area Groundwater Pool Interests (MAGPI)

Updated February 2016

IRRIGATION TRAINING AND RESEARCH CENTER

Prepared by

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Irrigation Training and Research Center
Original September 2014
Updated February 2016

EXECUTIVE SUMMARY

This project was conducted by the Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo, in cooperation with RMC Water & Environmental for the Merced Area Groundwater Pool Interests (MAGPI). The primary objective of this project was to provided actual spatial evapotranspiration information for the MAGPI region to support the groundwater modeling efforts by RMC. ITRC provided monthly ET information for 9 sample years from 1989 through 2013. These years were selected based on different precipitation levels and to account for crop shifts since the late 1980's. The ITRC-METRIC procedure was used to compute the actual evapotranspiration at a 30 meter pixel resolution throughout the study area using LandSAT TM data (LandSATs 5, 7, and 8 were used in this evaluation).

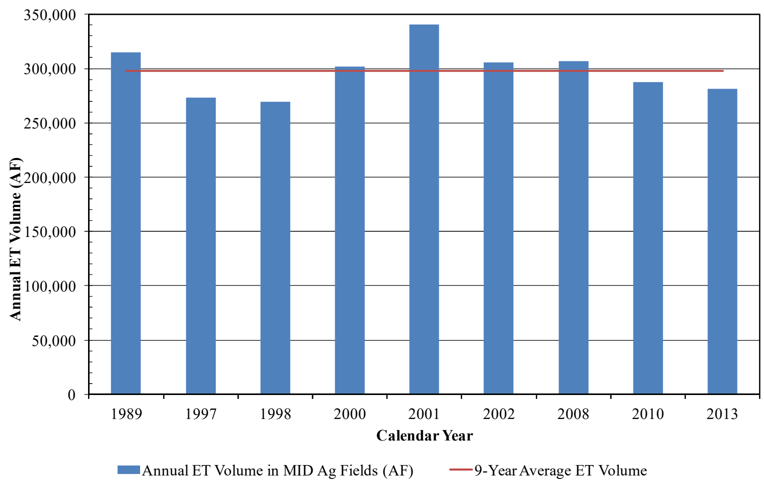


Figure ES-1. Annual volume of crop evapotranspiration within parcels in Merced ID boundaries.

A second objective was to evaluate net amount of water (precipitation and surface irrigation) that taken from or provided to the groundwater from fields throughout the study area. The Net To and From Groundwater (NTFGW) only accounted for water delivered to fields by MID and used in vegetative areas (not canal, drain, river, stream seepage) where surface water delivery information was known. This evaluation required inputs on surface water deliveries, precipitation, evapotranspiration, and estimated runoff (from irrigation and precipitation) spatially throughout the study area. Examples of the results are shown in the following figure for a average (10 inches), wet (19 inches), and a dry (4 inches) precipitation years.

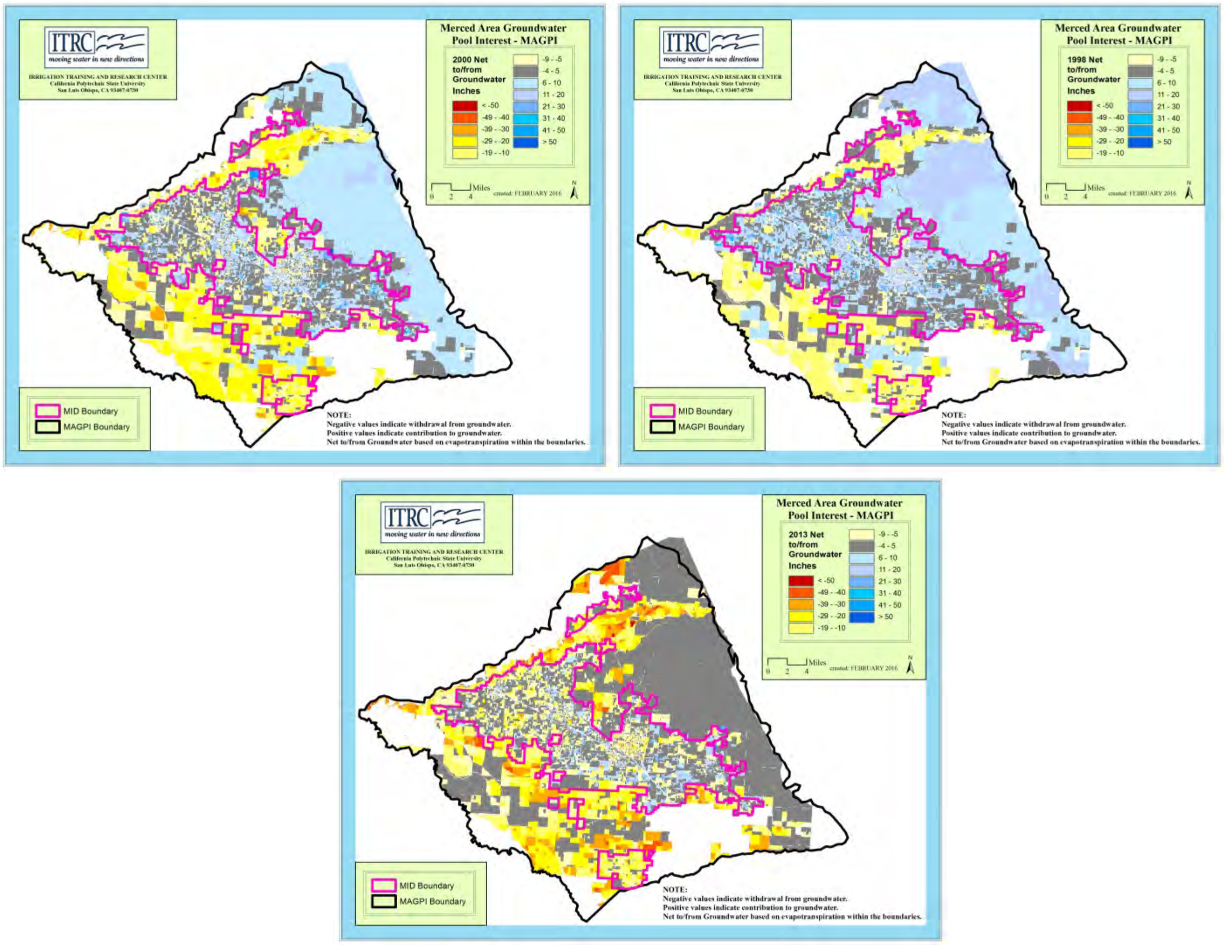


Figure ES-2. Annual net to and from groundwater for vegetative areas in MAGPI area during an AVERAGE (top left), WET (Top right), and DRY (bottom) precipitation year. Negative values (yellow to red) indicate a net from groundwater.

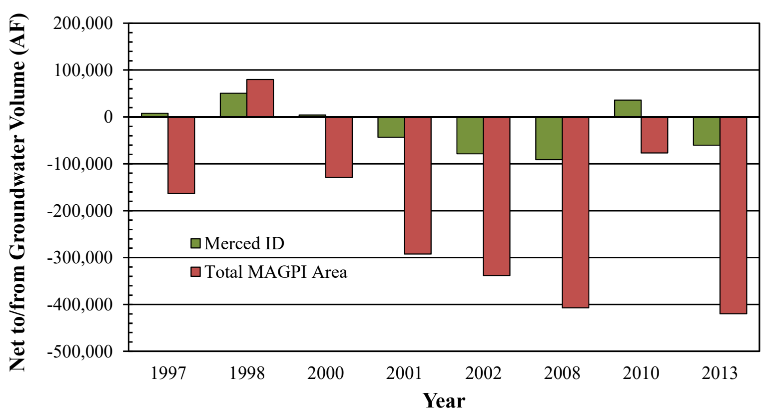


Figure ES-3. Net to/from Groundwater volumes in the Merced ID portion compared to the total MAGPI Area.

Figure ES-3 shows the estimated volume of net to and from groundwater for each year in the study. The volume of groundwater use or recharge is shown within MID boundaries and over the entire MAGPI boundary. It should be noted that surface water deliveries and diversions outside of MID control were requested but not provided as part of this analysis. Therefore the Total MAGPI NTFGW volume is slightly overestimated.

Key Findings

1) Of the years processed, 2001 had the highest ETc in the cropped areas within Merced ID.
2) In normal and wet years, MID users have a net contribution TO the groundwater. This occurs even though most MID users use both surface and groundwater during all years.
3) In dryer years, MID users rely more heavily on groundwater.
4) Except during extremely wet years, the overall MAGPI area has a net FROM (overdraft) which is mitigated by surface water deliveries in MID.

ITRC provided monthly and annual ITRC-METRIC actual ETc images (GIS format) to RMC for the groundwater modeling effort. NTFGW GIS images are also available for RMC to use. The NTFGW should help in the calibrations since one would expect the net groundwater use from the groundwater model to match.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo was subcontracted by RMC Water and Environmental to provide actual evapotranspiration (ETc) from vegetation throughout the Merced Area Groundwater Pool Interests (MAGPI) area for a select number of years. This ETc information will be used by RMC as part of a groundwater modeling study for the region that is being funded by MAGPI.

ITRC uses a modified Mapping of EvapoTranspiration with Internal Calibration (METRIC) procedure to compute actual evapotranspiration using LandSAT Thematic Mapper (LandSAT) data. Three LandSAT satellites were used for this study which covered a timeframe starting in 1985-2013 (several years or portions of years were missing in this timeframe). The MAGPI area is shown in Figure 1.

The second objective of this study was to evaluate the net amount of water that was contributed to or taken from the groundwater for crop use in the MAGPI area. ITRC felt that this information would help RMC calibrate the groundwater model for the years examined. This will be discussed in more detail in the body of this report.

ITRC-METRIC MODELING

Satellite Images

LandSAT 5, LandSAT 7, and LandSAT 8 images available from the United States Geological Survey (USGS) on sixteen-day intervals were used for the MAGPI METRIC process. **Table 1** below shows the time frame of available satellite images for each individual satellite.

Table 1. Time frame of available images for LandSAT 5, 7, and 8

LandSAT 5	LandSAT 7**	LandSAT 8
November 1982-October 2011	June 1999-May 2003	April 2013-Present

**After May 2003, LandSAT 7 began producing images with missing data because of a defective sensor

For all three satellites, the LandSAT image that encompassed the area of interest was located in Path 43 and in Row 34. The project area of interest can be seen in **Figure 1** with the July 30th 2013 LandSAT 8 "natural look" image in the background. **Figure 2** shows the infrared background for the same LandSAT 8 image date.

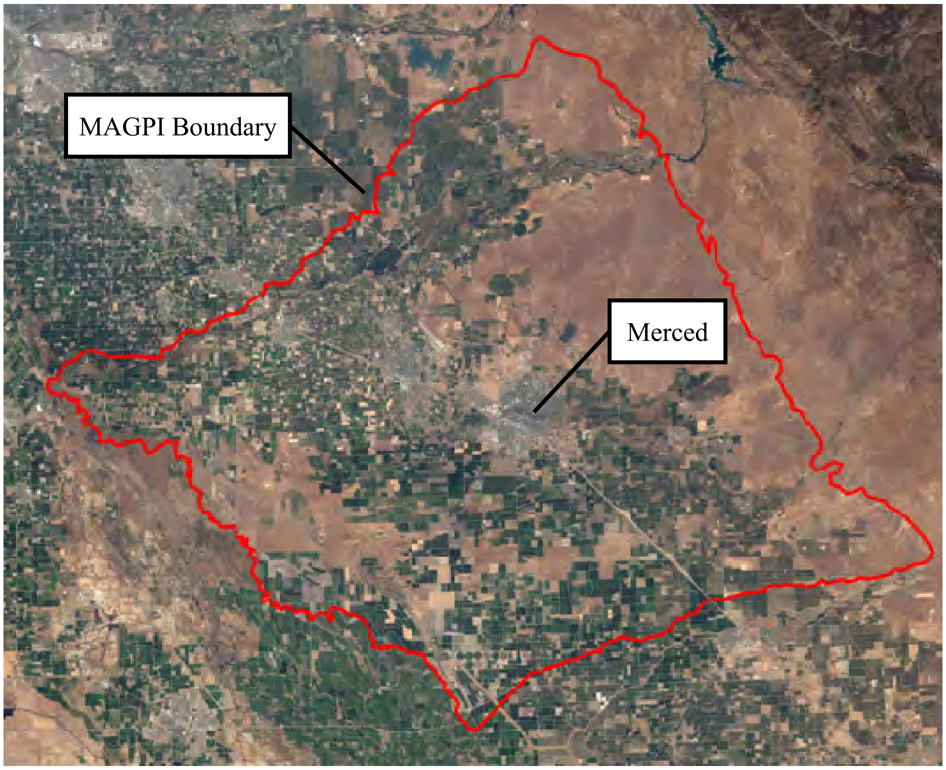


Figure 1. Area of interest with "natural color" image in the background

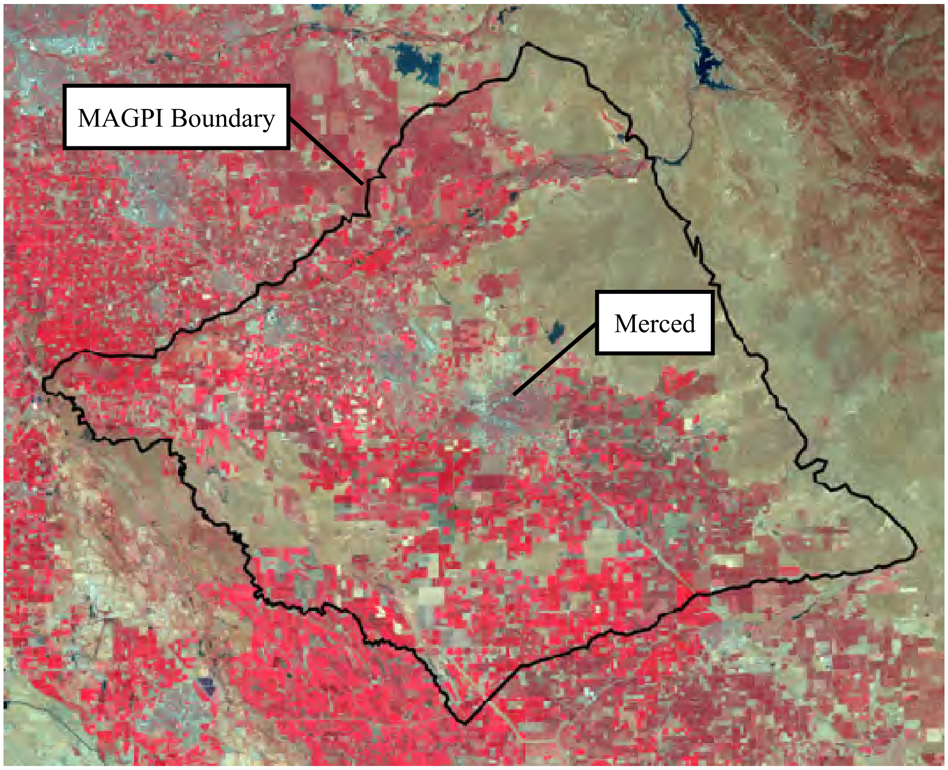


Figure 2. Area of interest with infrared image in the background

A total of nine years were analyzed for the METRIC modeling process. Years were selected so that they covered different precipitation year types (dry, average, or wet water year) and accounted for changes in crop types since the late 1980's. The following years were analyzed for this project:

1. 1989 (Dry water year)
2. 1997 (Average water year)
3. 1998 (Wet water year)
4. 2000 (Average water year)
5. 2001 (Average water year)
6. 2002 (Average/Dry water year)
7. 2008 (Average/Dry water year)
8. 2010 (Wet water year)
9. 2013 (Dry Water Year)

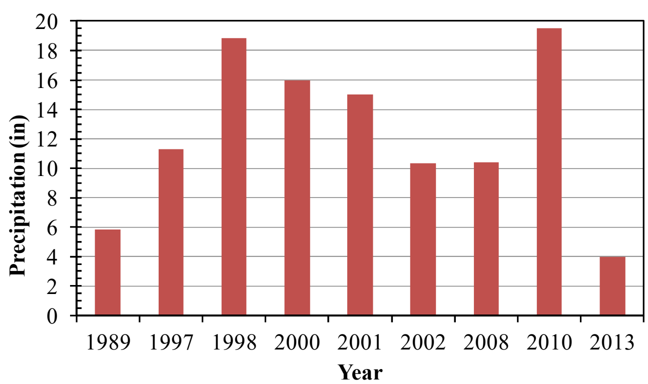


Figure 3. Approximate precipitation amounts in the MAGPI area for the years examined.

In order to obtain reliable results from the METRIC modeling process, daily images need to be free of cloud coverage in the area of interest. **Figure 4** shows the difference between a usable and unusable image for METRIC modeling.

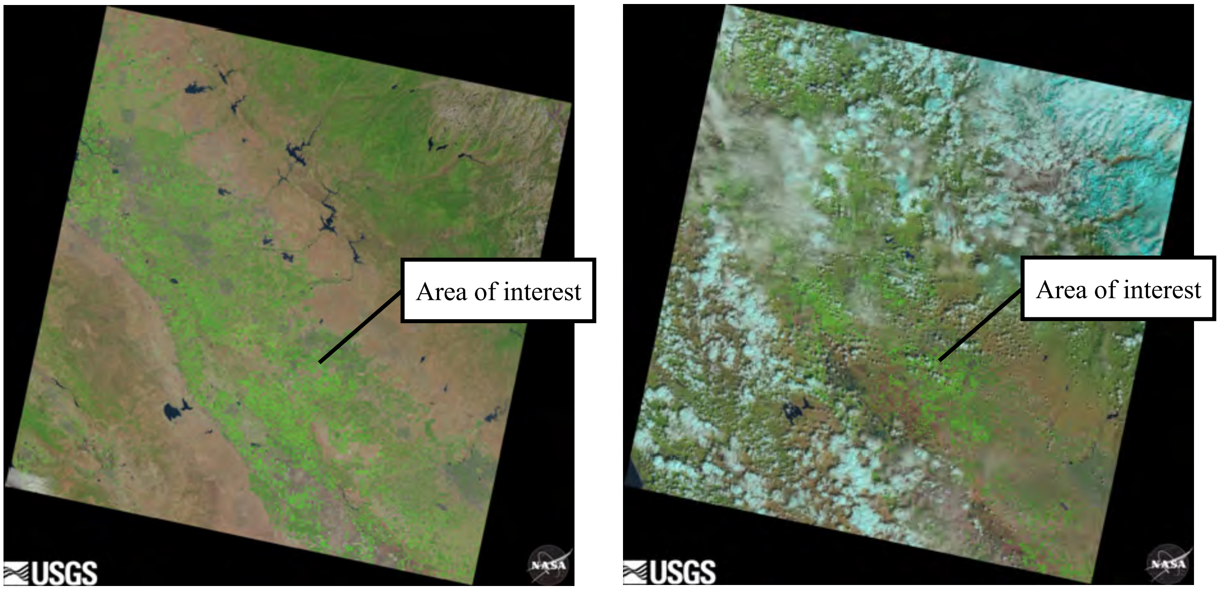


Figure 4. Usable LandSAT image (left image) and an unusable LandSAT image (right image)

All available cloud-free images were used for the modeling process as seen in **Table 2**. A total of 124 images were processed using METRIC.

Table 2. Chosen image dates for MAGPI METRIC Process

Year	1989	1997	1998	2000	2001	2002	2008	2010	2013**
Type	Dry	Average	Wet	Average	Average	Average	Dry	Wet	Dry
Image Dates	1/17	1/7	2/11	2/1	1/18	3/2*	2/7	2/12	4/25
	3/22	2/24	3/15	3/20	2/3	4/3*	3/26	4/1	5/11
	4/7	3/12	4/16	4/29*	3/23	4/19*	4/11	5/35	6/12
	5/25	3/28	5/18	5/31*	4/24	5/5*	4/27	5/19	6/28
	6/10	4/13	6/19	6/16*	5/10	5/13	5/13	6/20	7/14
	7/28	5/15	7/5	6/24	5/26	6/14	5/29	7/6	7/30
	8/13	5/31	7/21	7/2*	6/11	6/30	6/14	7/22	8/15
	8/29	6/16	8/6	7/26	6/19*	7/8*	6/30	8/7	8/31
	9/30	7/2	8/22	8/11	7/13	7/24*	7/16	8/23	9/16
	10/16	7/18	9/7	8/19*	7/29	8/9*	8/1	9/24	10/18
	11/1	8/3	10/9	9/20*	8/14	8/25*	8/17	10/10	12/25
	12/3	9/4	11/26	9/28	8/30	9/10*	9/2	11/11	12/21
		9/20	12/28	10/14	9/15	9/26*	9/18		
		10/22		10/22*	10/1	10/14	10/20		
		11/23		11/17*	11/26*	10/28*			
					12/20				
Total	12	15	13	15	16	15	14	12	12

Notes: * indicates LandSAT 7 and ** indicates LandSAT 8

Weather Data

Daily and hourly weather data for the project time frame were collected from the California Irrigation Management Information System (CIMIS) weather stations located near the project area of interest as seen in **Figure 5**.

Figure 5. Location of agricultural weather stations considered for historical weather data

Two weather stations were considered for the METRIC modeling process:

1. Merced (Source: CIMIS – Station ID: #148 – Available 1/4/1999 to present)
2. Los Banos (Source: CIMIS – Station ID: #56 – Available 6/28/1988)

The Merced weather station data was used for the modeling years 2000 through 2013 because of its location in respect to the majority of the agricultural area within the MAGPI boundary. The Los Banos weather station data was used for the modeling years prior to the year 2000. The weather component data collected from both weather stations are:

1. Solar radiation (W/m^2)
2. Air temperature (ºC)
3. Wind speed (m/s)
4. Precipitation (mm)
5. Relative humidity (%)
6. Dew point temperature (ºC)

The collected weather data went through a quality control check based FAO procedures. A detailed procedure on the quality control conducted can be found in FAO Irrigation and Drainage paper No. 56 (Allen et al., 1998) along with correction procedures. The main correction needed to compute the hourly *ETo* is to the solar radiation. **Figure 6** contains a graph of the corrected solar radiation over the project time frame.

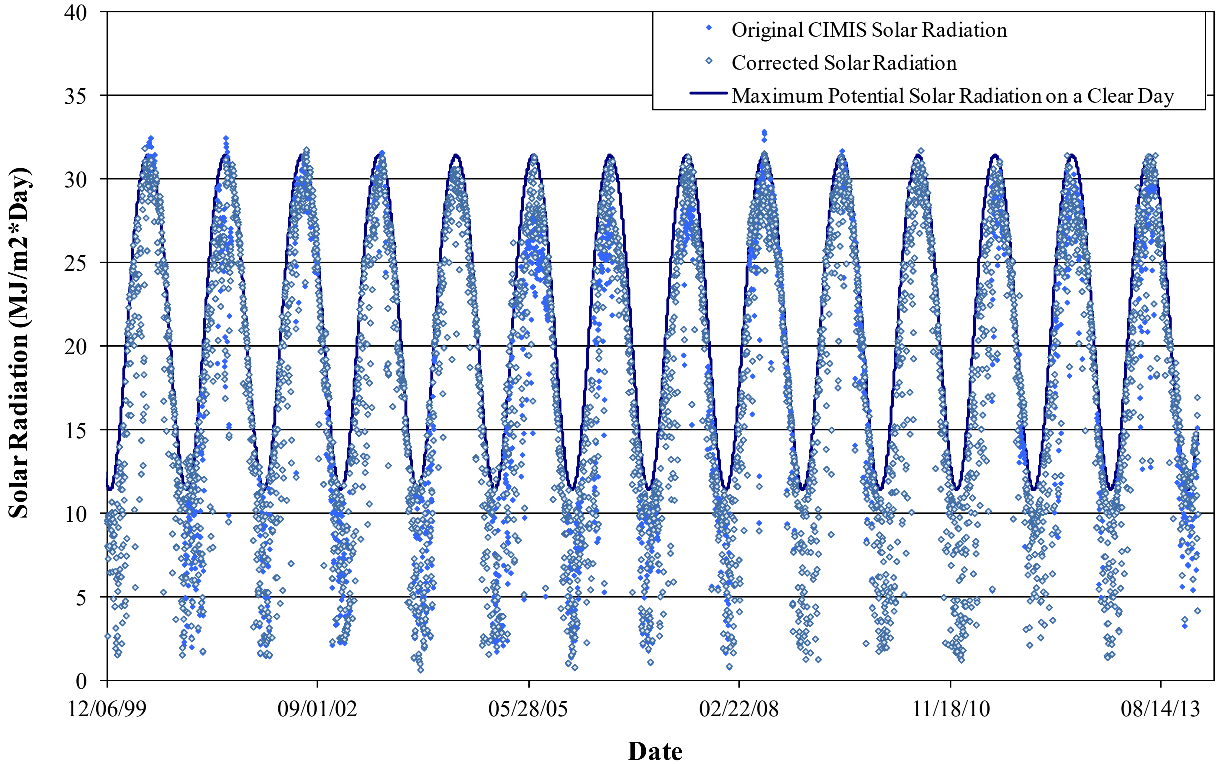


Figure 6. Adjusted solar radiation using FAO 56

Once the solar radiation and any other errors were corrected using the FAO procedures, the *ETo* was computed using the ASCE 2005 Standardized Penman Monteith *ETo* equation. **Figure 7** below shows a monthly comparison of the computed *ETo* for various years of the Merced weather data.

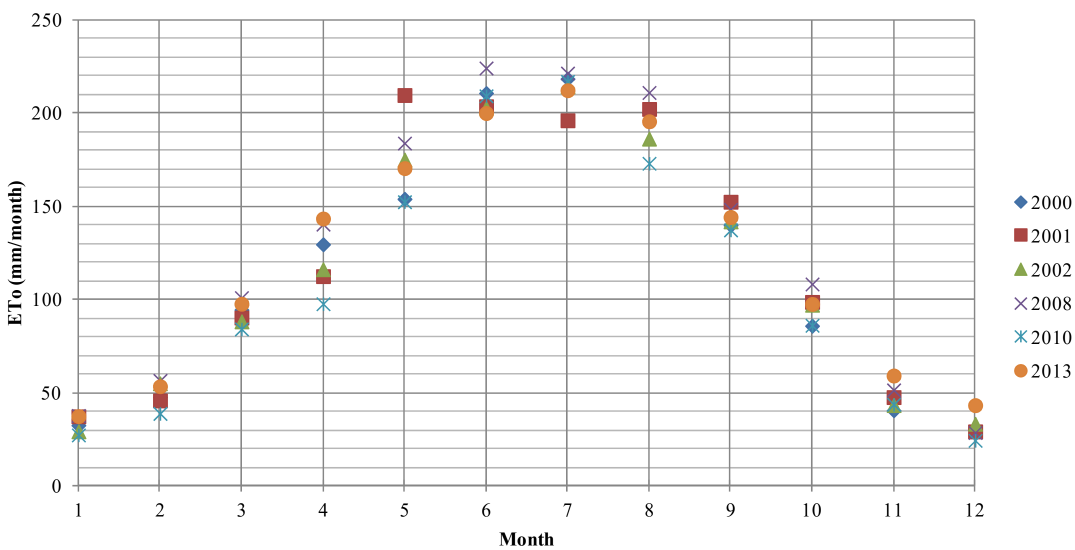


Figure 7. Comparison of monthly ETo computed from the ASCE 2005 Standardized Penman Monteith *ETo* equation using Merced historical weather data

ETo and individual weather data are used within the METRIC process to compute inputs into the software. METRIC computes the instantaneous *ETc* for every pixel within the LandSAT image at the instant the image is taken. Knowing the *ETo* at that instant from the local weather station, a **crop coefficient (*Kc*)** can be computed (*Kc = ETc/ETo*). It has been shown that this instantaneous *Kc* at the time of image acquisition (approximately 11 a.m.) is a very good representation of the *Kc* for that entire day.

Elevation Data

A Digital Elevation Model (DEM) provided by the USGS was used to adjust the model outputs based on the surface elevation through the area of interest. The DEM used had a resolution of 10m (1/3 arc second) which was then re-projected into a 30m x 30m pixel size to match the resolution of the LandSAT images.

Landuse Map

Landuse surveys conducted by the California Department of Water Resources (DWR) on a field by field basis for Merced County in 1995 and 2002 were used as the main source for landuse map in the METRIC modeling process. Additional landuse surveys provided by the DWR for the surrounding counties and annual landuse data provided by the National Agricultural Statistics Service (NASS – an extension of the U.S. Department of Agriculture – USDA) were used to compute the landuse characteristics in the outside areas of Merced County.

All of the landuse maps when through a quality control check to ensure that a single landue value was uniform across an entire field. **Figure 8** shows an example of the Landuse map used for processing the modeling year 2002.

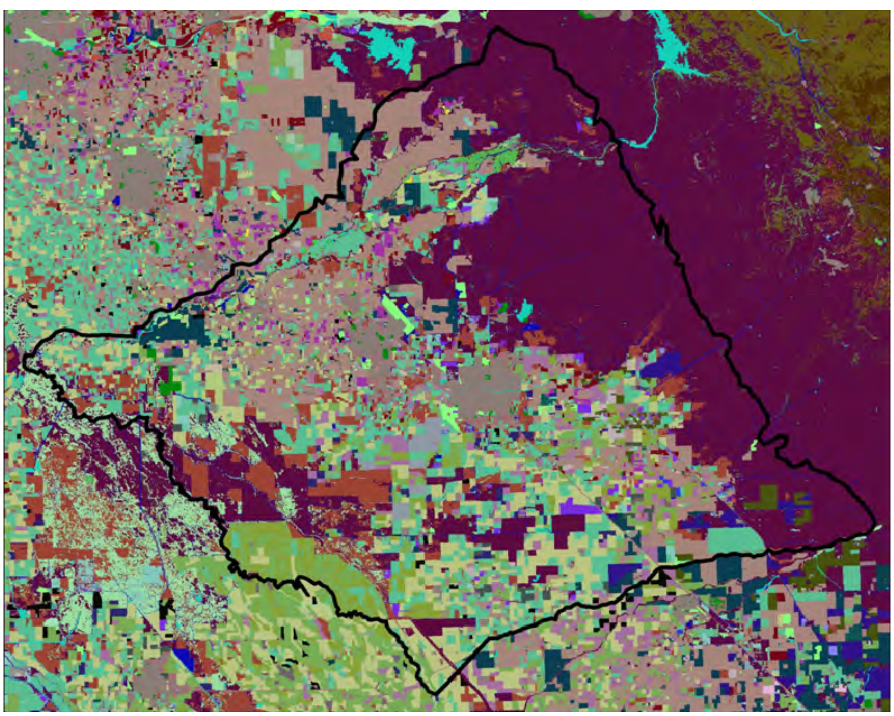


Figure 8. Example of landuse characteristic map used of the METRIC modeling process. Each color identifies a different landuse type (i.e. almonds, alfalfa, developed, etc.)

METRIC Kc Results

Figure 9, **Figure 10**, and **Figure 11** consist of *Kc* results from three different image dates and their ranges of *Kc* values. The lighter the pixel color, such as yellow, the lower the *Kc* value. Conversely, the darker the pixel color, such as blue, the higher the *Kc* value.

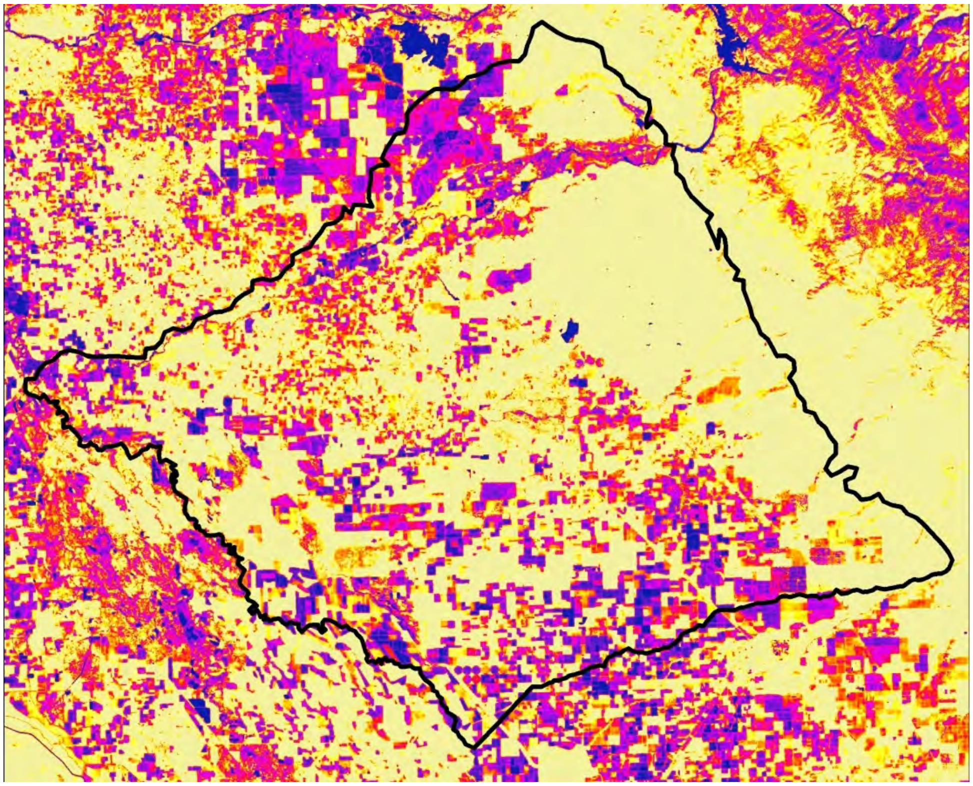


Figure 9. METRIC *Kc* Results for April 25th, 2013

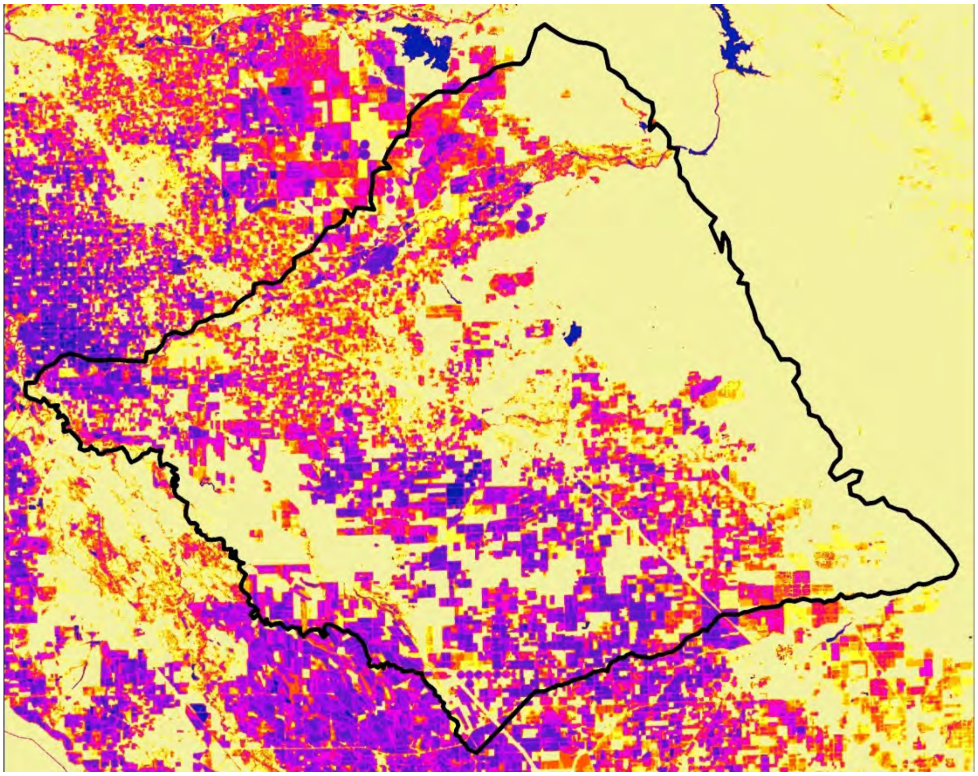


Figure 10. METRIC *Kc* Results for July 30nd, 2013

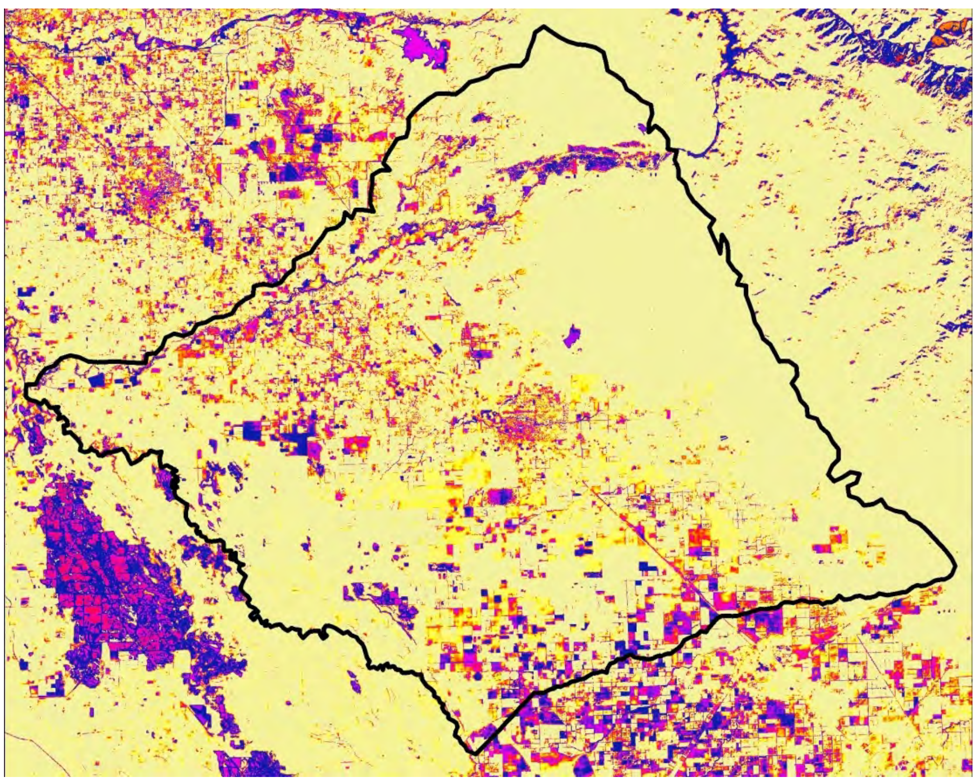


Figure 11. METRIC *Kc* Results for December 21st, 2013

Figure 12 compares the *Kc* values found in individual corn, almond, alfalfa, and peach fields for July 24th, 2002.

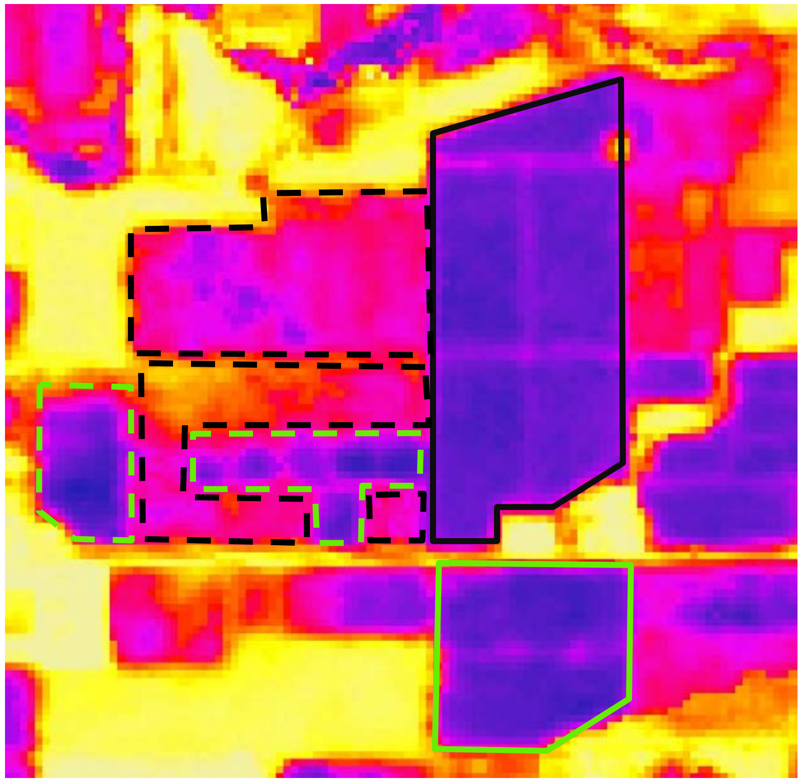


Figure 12. *Kc* color indexing for corn field (solid black border), almond field (dashed black border), alfalfa field (solid green border), and peach field (dashed green boarder) on July 24th, 2002

The *Kc* value ranges for the selected fields in **Figure 12** can be seen in **Table 3** below.

Table 3. Individual Field Kc Values for July 24th, 2002 image (refer to Figure 12)

Individual Field *Kc* Values for July 24th 2002 Image		
Crop	**Border Type/Color**	***Kc* Range**
Corn	Solid Black Line	1.05 – 1.15
Almonds	Dashed Black Line	0.75 – 0.95
Alfalfa	Solid Green Line	1.05 – 1.20
Peaches	Dashed Green Line	1.00 – 1.20

NET TO AND FROM GROUNDWATER MODELING

The other main objective of the ITRC for the MAGPI project besides determining ET for the area of interest was to make monthly estimates of the net amount of water to and from the groundwater for each project year. **Figure 13** shows a simple schematic of the individual components for estimating the *Net To and From Groundwater* (*NTFGW*).

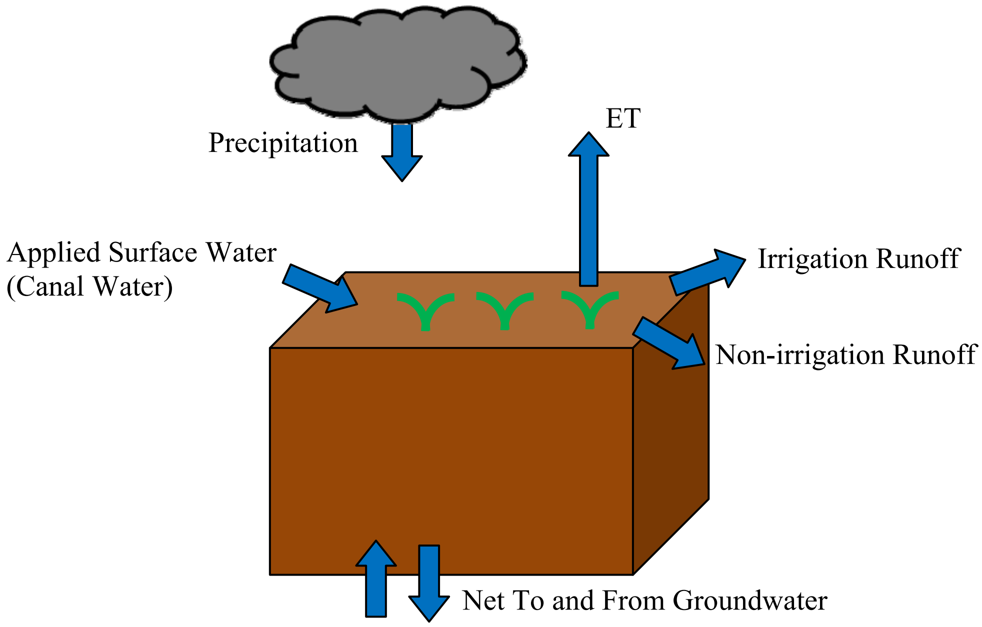


Figure 13. Schematic showing the components for computing the net to and from groundwater

The main components of NTFGW shown in **Figure 13** include:

1. Applied surface water (canal water)
2. Precipitation
3. Evapotranspiration (ET)
4. Irrigation Runoff
5. Non-Irrigation Runoff (precipitation runoff)

The *NTFGW* can be computed using to following equation:

$$NTFGW = Applied\ Water + Precipitation - ET - Irrigation\ Runoff - Non\_Irrigation\ Runoff$$

On a monthly time step, this equation must include the soil moisture depletion (SMD) at the beginning of the month. In order to determine SMD, the soil type and general crop type are needed to determine the soils available water holding capacity in the crops root zone. The initial SMD is estimated based on prior months' (November and December) precipitation amounts. The evaluation of monthly NTFGW requires several checks on Equation 1:

- If Eq. 1NTFGW is positive and is greater than the SMD, the end of the month SMD is assumed to be filled and any additional NTFGW must deep percolate below the root zone (Net to Groundwater).
- If Eq. 1 NTFGW is positive and is less than the SMD, the SMD at the end of the month is equal to the SMD at the beginning plus the Eq 1. NTFGW (no Net to Groundwater).

- If Eq. 1 NTFGW is negative and is less than the water remaining in the soil root zone at the end of the month, SMD at the end of the month is decreased by NTFGW (no Net from Groundwater).
- If Eq. 1 NTFGW is negative and is greater than the water remaining in the soil root zone at the end of the month, the SMD at the end of the month is decreased to the allowable depletion and the remaining NTFGW must be pumped from the groundwater (Net from Groundwater).

The sub-sections below discuss how each parameter of *NTFGW* was computed.

Merced County Parcels

A GIS file containing individual parcel locations in Merced County were obtained from the Merced County website. Output parameters such as ET, applied water, irrigation runoff, etc. were determined on a monthly basis for each individual parcel. **Figure 14** shows all the parcels located in eastern Merced County and within the MAGPI project boundary. **Figure 15** shows an example of an aerial image with individual parcels located just west of Merced.

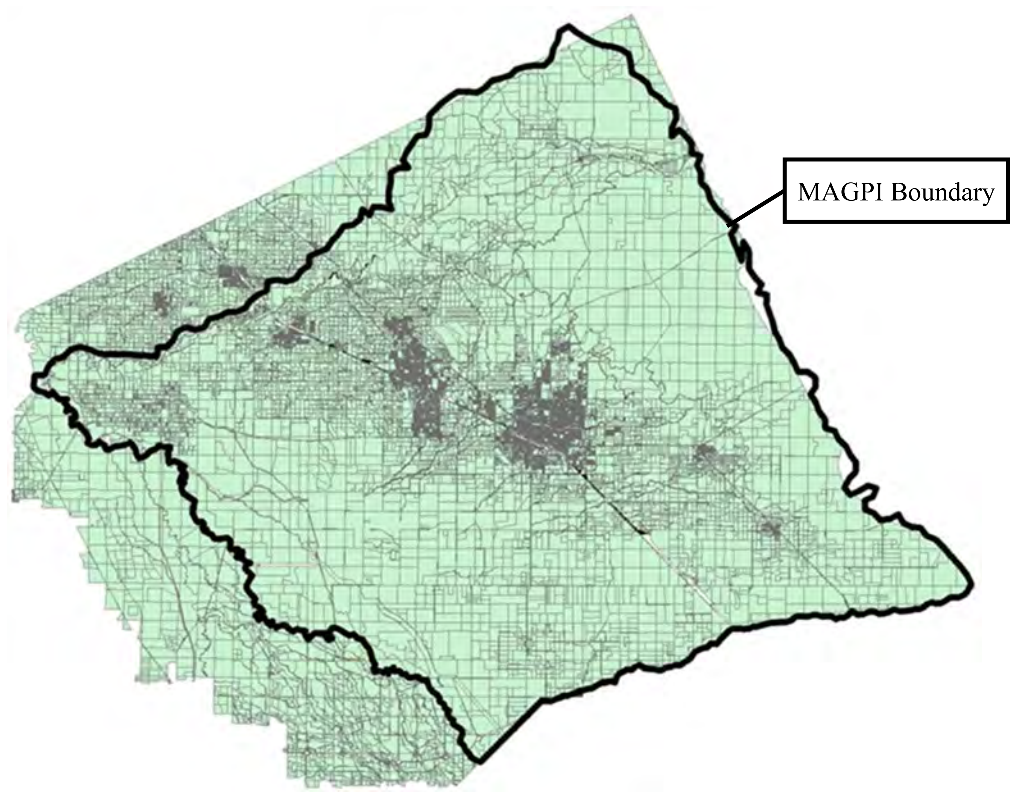


Figure 14. Individual parcels located in eastern Merced County and within the MAGPI project boundary

Figure 15. Aerial image shows individual parcels (outlined with black borders) west of Merced

Applied Surface Water

Surface water delivery events obtained from Merced Irrigation District (MID) from 1992 through 2013 were used to determine the applied water (in acre-feet) for individual water user accounts. The account number for individual surface water users in MID were compared to the known associated parcel numbers. The location of the associated parcel number was compared to the Merced County parcel GIS file to determine the approximate location of the applied water.

With the known approximate acreage of each parcel, the volume of applied water by parcel was converted to applied inches of water on a monthly basis. For simplicity, the applied inches of water were created to be uniform across the entire parcel. Some water accounts had multiple parcels for which the applied water was evenly distributed across all of the parcels under the single account number. A small amount of account numbers did not have an associated parcel number. In this case, the applied water for that account was ignored.

The applied surface water by parcel was averaged over one mile by one mile grid from the Merced County township and sections provided by the Public Land Survey System (PLSS). The reason for averaging the applied water over the quarter mile sub-section was to eliminate field outliers in such cases where small (only a few acres) irrigated fields applying an unrealistic amount of water in a single month. The field outliers were a result of missing parcel numbers for individual accounts that clearly have multiple parcels associated with that account.

An example of the applied water by parcel can be seen in the left image of **Figure 16**. The applied surface water averaged over the one mile grid sections for the same area can be seen in the right image of **Figure 16**. **Figure 17** shows the applied water (one mile resolution) for July 2002 for the entire MAGPI boundary area.

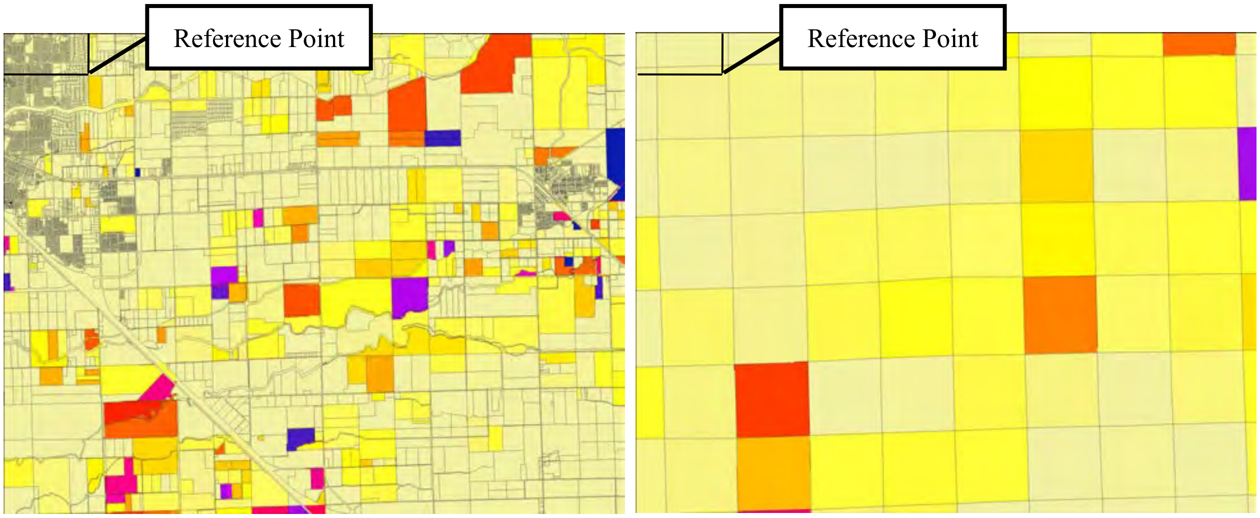


Figure 16. Example of applied water by parcel (left image) compared to applied water over one mile sections (right image) for July 2002. The darker the color the higher the applied surface water.

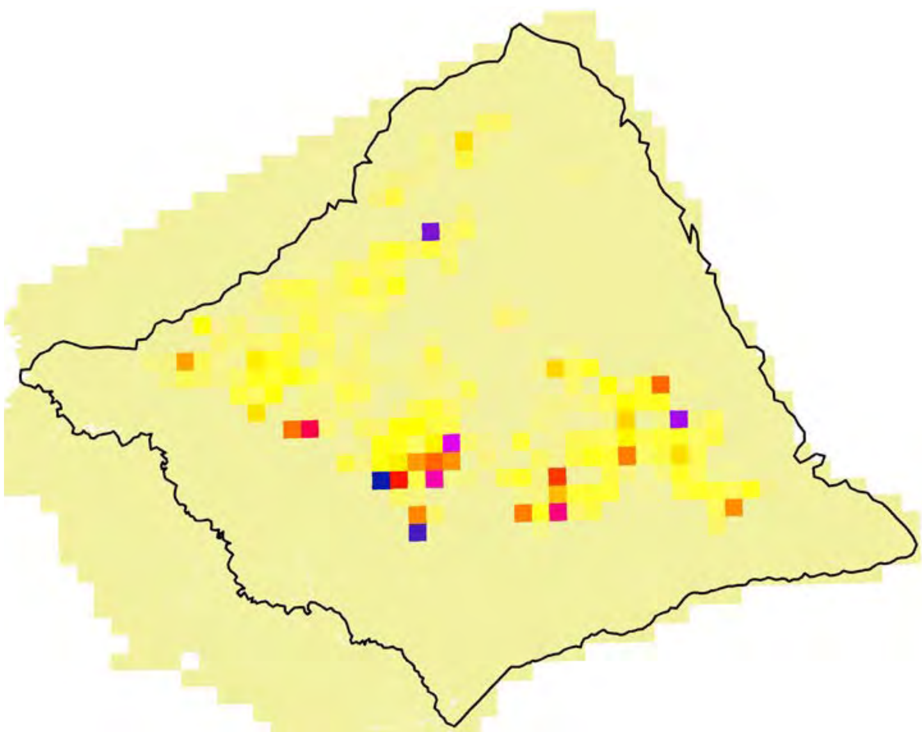


Figure 17. Example of applied surface water on a one mile resolution during July 2002 for the entire MAGPI boundary area

Precipitation

Spatially distributed precipitation maps were downloaded from the PRISM Climate Group of Oregon State University. The raster files displayed monthly precipitation data in millimeters for the entire United States on a 4 km by 4 km resolution.

A sub-set of the original monthly precipitation raster was extracted to be just larger that the project area of interest. The precipitation values of the sub-set precipitation raster were converted from millimeters to inches of precipitation. **Figure 18** shows an example of precipitation raster from PRISM for December 2002. The darker colors indicate a higher monthly total of precipitation.

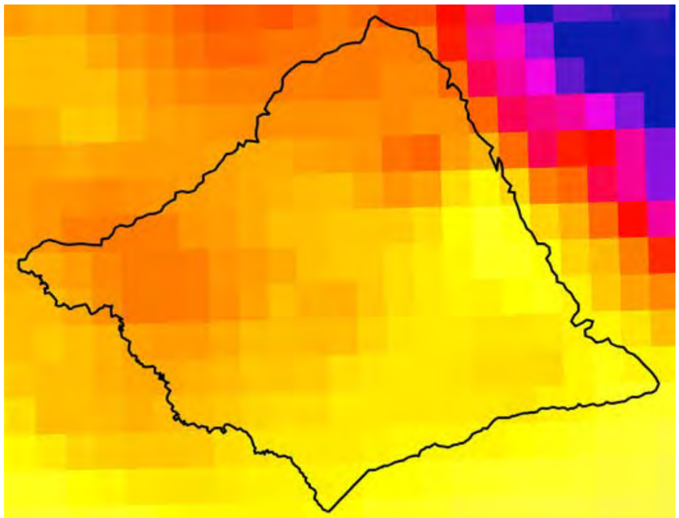


Figure 18. Example of monthly precipitation raster available from PRISM Climate Group for December 2002. The darker colors indicate higher monthly total of precipitation.

ET by Parcel

The average monthly ET per parcel rasters were created from the original 30m by 30 m resolution ET rasters calculated from METRIC. The average monthly ET (in inches) was applied to be uniform across the entire parcel. **Figure 19** shows an example of the average monthly ET by parcel for July 2002 where the dark the colors (blue) indicate a higher the ET value.

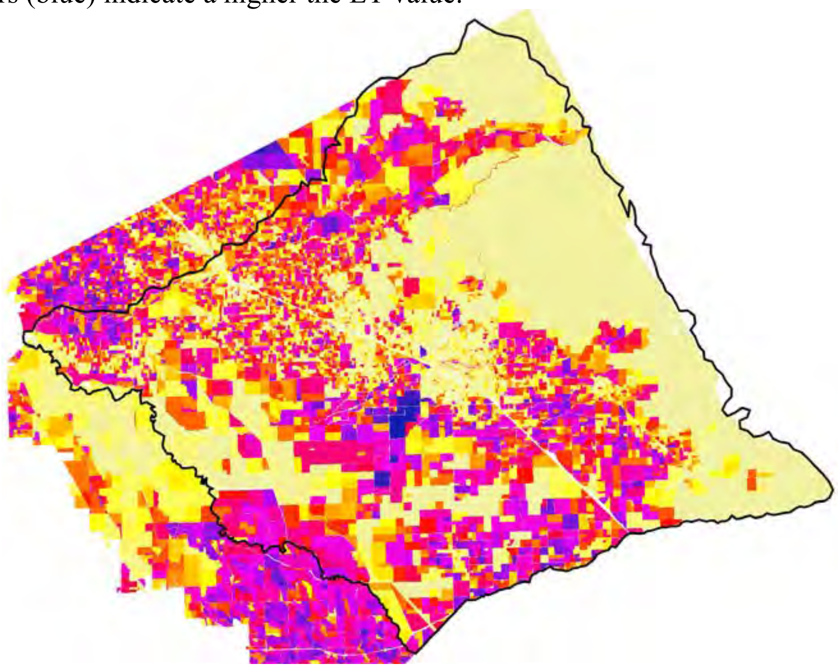


Figure 19. Example of average monthly ET by individual parcel for July 2002. The darker color (blue) indicates a higher ET amount.

Irrigation Runoff

The following process was used to estimate the amount of monthly irrigation runoff from agricultural fields inside the MAGPI project boundary area.

Landuse Type for Determining Irrigation Runoff

Landuse type for each individual parcel was determined using the landuse map created from the DWR land use survey as well as the NASS. Certain crops and landuse types were associated with having no irrigation runoff (refer to **Table 4**). For any orchard or vineyards, it is assumed that drip/microspray irrigation system as used to apply water to the crop and therefore produces no irrigation runoff.

Table 4. Landuse types associated with no irrigation runoff

Landuse Types Associated with No Irrigation Runoff		
Orchards/Vineyards	**Urban**	**Other**
Cherries	Developed – Open Space	Forest
Peaches	Developed – Low Intensity	Shrubland
Apples	Developed – Medium Intensity	Barren
Grapes	Developed – High Intensity	Non-Agriculture
Other Tree Crops		Deciduous Forest
Citrus		Evergreen Forest
Pecans		Mixed Forest
Almonds		Grassland Herbaceous
Walnuts		Fallow/Idle Cropland
Pears		Woody Wetlands
Pistachios		Herbaceous Wetlands
Prunes		
Oranges		
Pomegranates		

Irrigation Method for Determining Irrigation Runoff

The irrigation method for each individual parcel was determined from the DWR land use survey conducted in 2002 for Merced County. The following irrigation methods were assumed to have no irrigation runoff:

- Surface drip irrigation
- Buried drip irrigation (sub-surface drip irrigation)
- Microsprayer irrigation
- Center pivot sprinkler irrigation
- Linear mover sprinkler irrigation
- Non-irrigated fields

Estimated Irrigation Runoff

The following procedure was used to estimate the monthly irrigation runoff for each individual parcel:

1. If a single parcel had either a land use type **or** irrigation method associated with having no irrigation runoff (see previous sections), then it was assumed that no irrigation runoff would occur.

2. If the land use characteristic **<u>or</u>** irrigation method for an individual parcel did not match those stated in the previous sections, then it was assumed that irrigation runoff would occur. For example, a parcel irrigating corn using furrows would be assumed to have some amount of irrigation runoff.
3. For individual parcels assumed to have irrigation runoff occur, the runoff was estimated to be approximately 5% of the average monthly ET computed from METRIC for that specific parcel. For example, if the average monthly ET for a single parcel was 10 inches, the estimated irrigation runoff would be approximately 0.5 inches.

The reasoning behind the 5% of average monthly ET is based on the following reasons:

1. There is not an extensive drainage system throughout the MAGPI boundary to collect tail water runoff.
2. Farmers tend not to have any tail water runoff in their irrigation practices.
3. Some fields throughout the MAGPI boundary utilize tail water recovery systems.

Figure 20 below shows an example of the estimate July 2013 irrigation runoff for each individual parcel. The tan color indicated approximately zero irrigation runoff while the dark colored areas (blue being the darkest) indicating a higher amount of irrigation runoff (up to approximately 0.6 inches for this example).

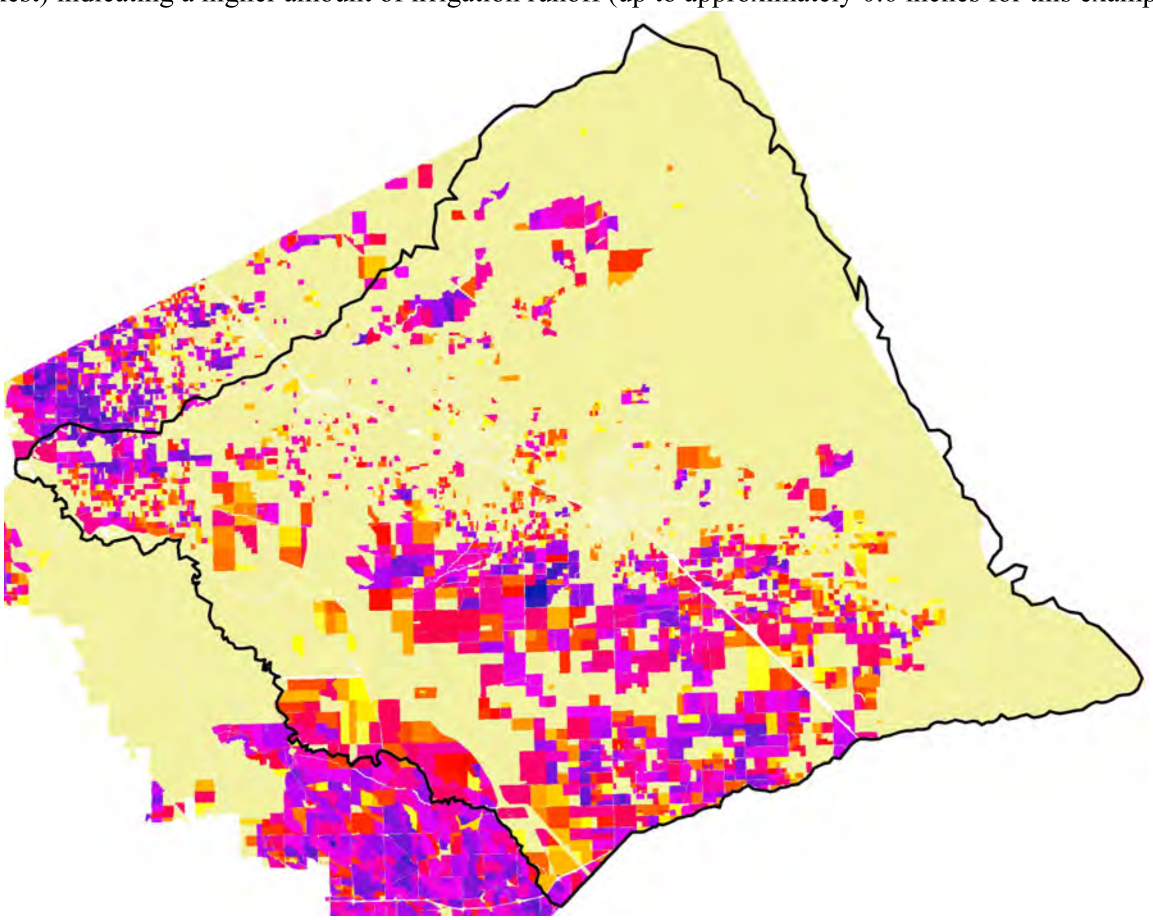


Figure 20. Example of estimate irrigation runoff for individual parcels in July 2013. The darker the color, the higher the irrigation runoff (up to approximately 0.6 inches of irrigation runoff for this example).

Non-Irrigation Runoff

The following procedure was used to estimate the non-irrigation runoff for individual parcels in the agricultural areas within the MAGPI boundary. Precipitation runoff in the urban areas was not considered for this study.

Soil Type Characterization for Individual Parcels

Soil characteristics for Merced County were obtained from the National Resources Conservation Service (NRCS) as seen in **Figure 21**.

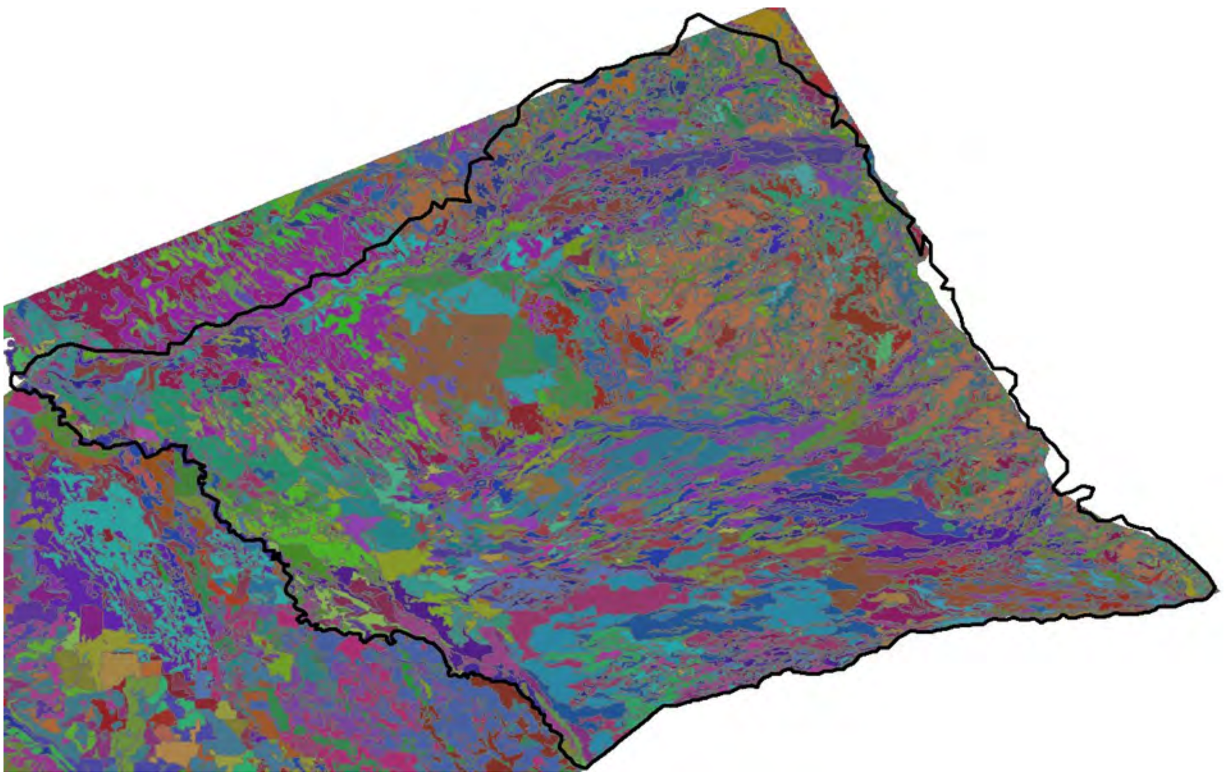


Figure 21. Example of Merced County soil types provided by the NRCS. Each color identifies a separate soil type.

The soil classification provide by the county were assigned a generic soil class types and soil group classification as following:

- Sand – Soil Group A
- Sandy Loam – Soil Group B
- Loam – Soil Group B
- Silt Loam – Soil Group C
- Clay Loam – Soil Group C
- Clay – Soil Group D

The soil types were reclassified for each individual parcel based on the majority of soil type located within each parcel. Each parcel was then assigned a uniform soil type. **Figure 22** shows the uniform soil types reclassified for each parcel to be used for the non-irrigation runoff estimates.

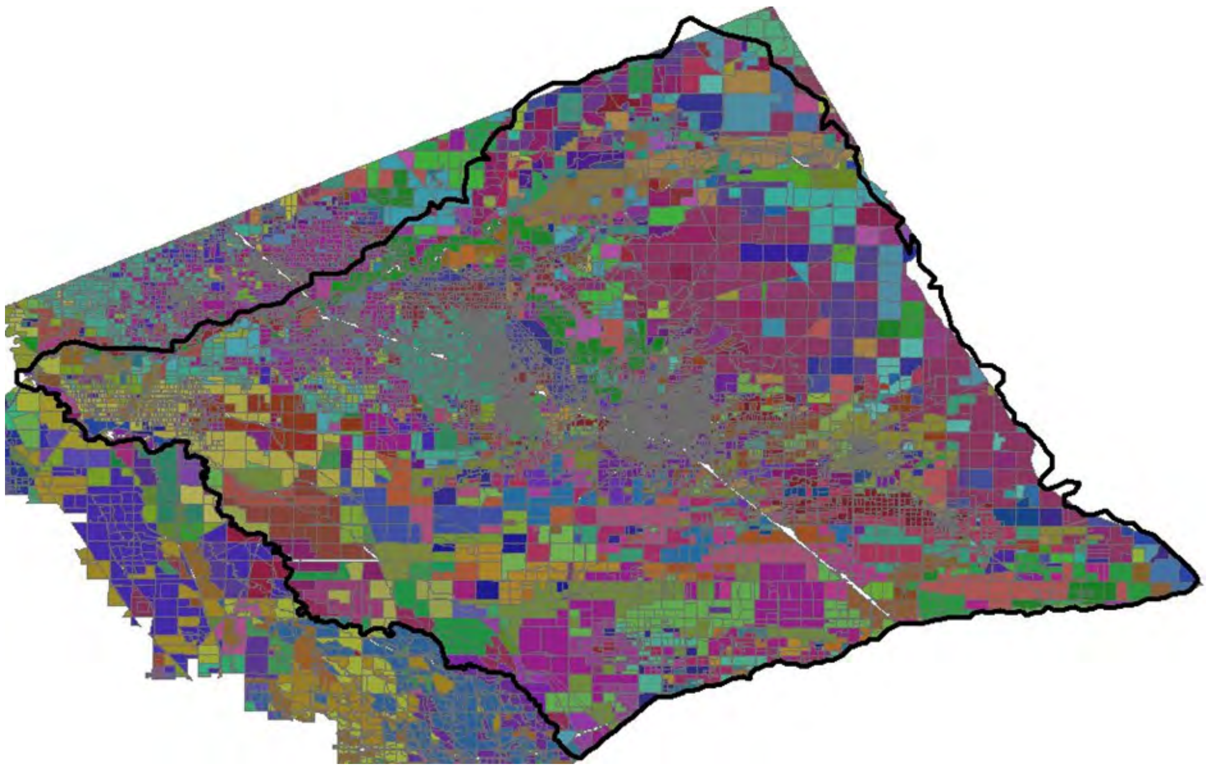


Figure 22. Reclassified soil type by parcel

NRCS (SCS) Rainfall Runoff Procedure for Non-Irrigation Runoff

The NRCS (SCS) rainfall runoff procedure was used to estimate the amount of monthly non-irrigation runoff from agricultural fields inside the MAGPI project boundary area due to precipitation.

Runoff due to precipitation can be estimated using the following equations:

$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$S = \frac{1000}{CN} - 10$$

Where: P_e = direct runoff, inches
P = precipitation, inches
S = potential maximum retention
CN = runoff curve number

The precipitation input in the SCS runoff equation was based on daily precipitation totals from the two CIMIS weather stations. It was assumed that the precipitation totals were uniform across the entire project boundary. The curve number for each parcel was determined based on:

1. Assigned land use description (agricultural crop, fallow land, etc).
2. Hydrological soil group.

Table 5 shows the assigned SCS curve numbers used in the estimation of non-irrigation runoff of individual parcels. Runoff from urban areas was not considered in the estimates.

Table 5. Assigned SCS curve numbers for different land use and soil group descriptions

Assigned Curve Numbers for Different Land Use and Soil Group		
Land Use Description**	Soil Group	Curve Number
All agricultural crops – for cultivated agricultural land, row crops, straight rows, in good condition	A	67
	B	78
	C	85
	D	89
Fallow/idle cropland – for non-cultivated agricultural land, pasture or range, no mechanical treatment, in fair condition	A	49
	B	69
	C	79
	D	84
Grassland herbaceous – for non-cultivated agricultural land, forested, grass, in fair condition	A	44
	B	65
	C	76
	D	82
Shrubland – for non-cultivated land, forested, brush, in poor condition	A	48
	B	67
	C	77
	D	83

** Based on SCS Curve Number Descriptions

For small precipitation events, the SCS runoff equation would produce a runoff value greater than the amount of daily precipitation. The reason for this is because of the empirical characteristics for which the SCS runoff equation was produced. Therefore multiple quality control checks were performed on the calculated non-irrigation runoff estimates. The two quality control checks performed were as follows:

1. If the result of $\left[Precipitation - 0.2 \times \left(\frac{1000}{Curve\ No.} - 10\right)\right]$ is negative, then there is no runoff due to precipitation.
2. The amount of computed $Runoff\ must\ be \leq Precipitation.$

Only significant precipitation event with a total daily precipitation of approximately 0.4 inches or greater would produce any runoff amounts. The SCS runoff equation does take into account that a certain amount of precipitation must percolate into the soil before any runoff can occur. That is why only significant precipitation events produce runoff and account for the soil being fully saturated.

The daily runoff estimates were summarized into monthly runoff totals for each model year. **Figure 23** shows an example of the non-irrigation runoff computed for December 2002. The tan color indicated approximately zero non-irrigation runoff while the dark colored areas (blue being the darkest) indicating a higher amount of non-irrigation runoff (up to approximately 0.8 inches for this example).

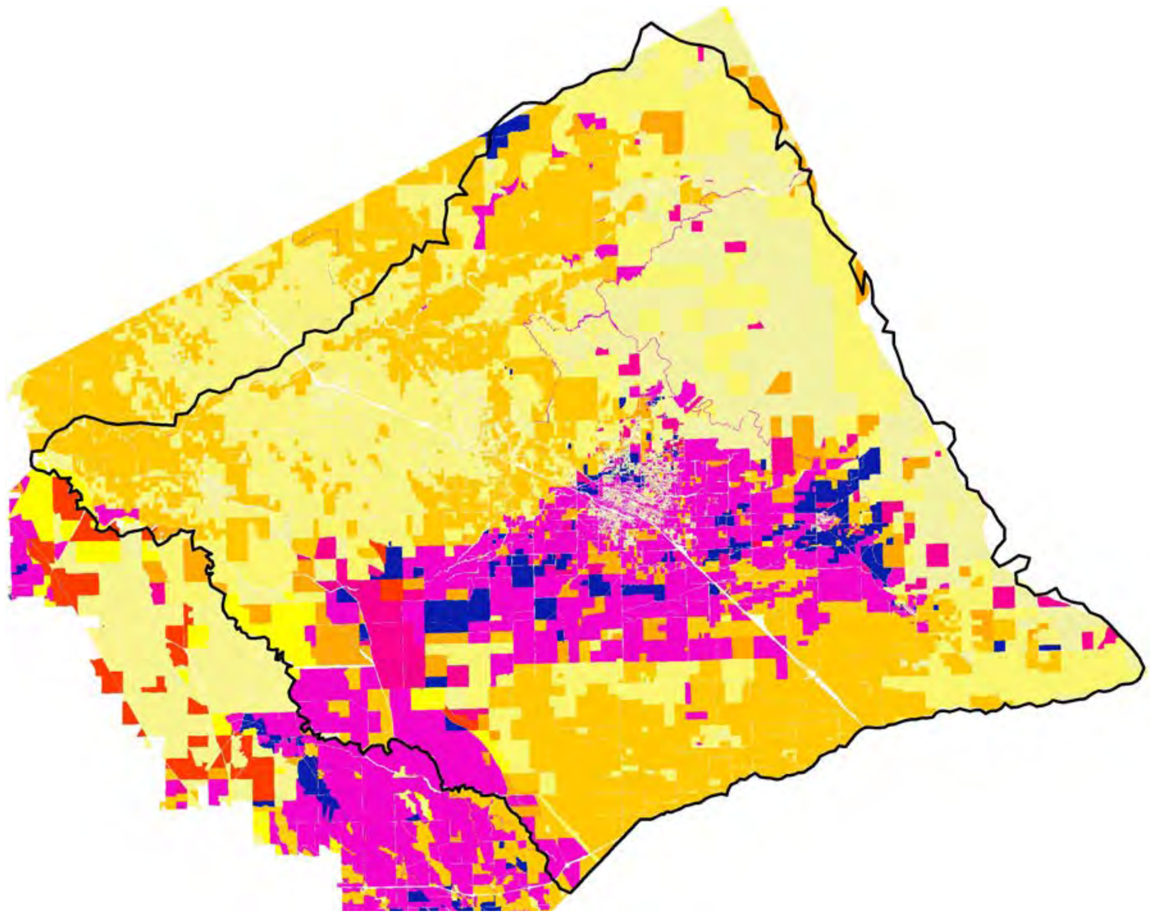


Figure 23. Example of estimate non-irrigation runoff for individual parcels in December 2002. The darker the color, the higher the non-irrigation runoff (up to approximately 0.8 inches of non-irrigation runoff for this example).

Soil Moisture Depletion

The soil's available water holding capacity (AWHC) in the crop root zone is needed to evaluate soil moisture depletion. The NRCS soils map for Merced County provides estimates of AWHC by soil type throughout the area of interest. The AWHC is provided as inches of water held at field capacity per inch of soil (inches/inch) for each soil horizon. A weighted average over the potential root zone was used to determine the root zone AWHC.

Root zones were assumed to be 5 feet for orchards, alfalfa, and vineyards, 3 feet for field crops, and 1.5 feet for natural vegetation. If an orchard or vineyard was irrigated using drip or microspray, the assumed wetted area was 60% of the total area, which reduces the AWHC by 40% for these irrigation methods. There was not a significant amount of buried row crop drip in the region during the analysis period.

The initial soil moisture depletions were estimated based on monthly rainfall in November and December prior to the year being analyzed. ET demand is low during these months and significant precipitation generally occurs in the area between November and February. If there was heavy rainfall during this period the SMD was assumed to be small. If there was little precipitation in the prior month the SMD was assumed to be large (approximately 50%-60% of the root zone AWHC). With average precipitation the SMD was assumed to be 20%-30% of the root zone AWHC.

The soil moisture depletion at the beginning of each month was applied to the procedure for estimating NTFGW as described.

Net To and From Groundwater Results

The resulting monthly *NTFGW* estimates (in inches) were created for each project years. **Figure 24** and **Figure 25** show examples of the computed *NTFGW* for February 2013 and July 2013 respectively.

From summer to fall, the applied water and ET are the driving factors for the *NTFGW* computations. Precipitation, irrigation runoff, and non-irrigation runoff have little to no impact during these months. On the contrary, during late fall through early spring months such as February 2013 (**Figure 24**), the precipitation and non-irrigation runoff become the driving factors. There is very little ET occurring during these months so depending on the monthly precipitation, there should be a slight to a significant contribution to the groundwater.

From the *NTFGW* result for July 2013, there is a apparent withdrawal from the ground water in the outside areas of the MAGPI boundary. No surface water is provided to those outside area and farmers are required to pump groundwater for irrigation. In the same image (**Figure 25**), there also appears to be a slight contribution to the groundwater from agricultural fields located within the MID boundary.

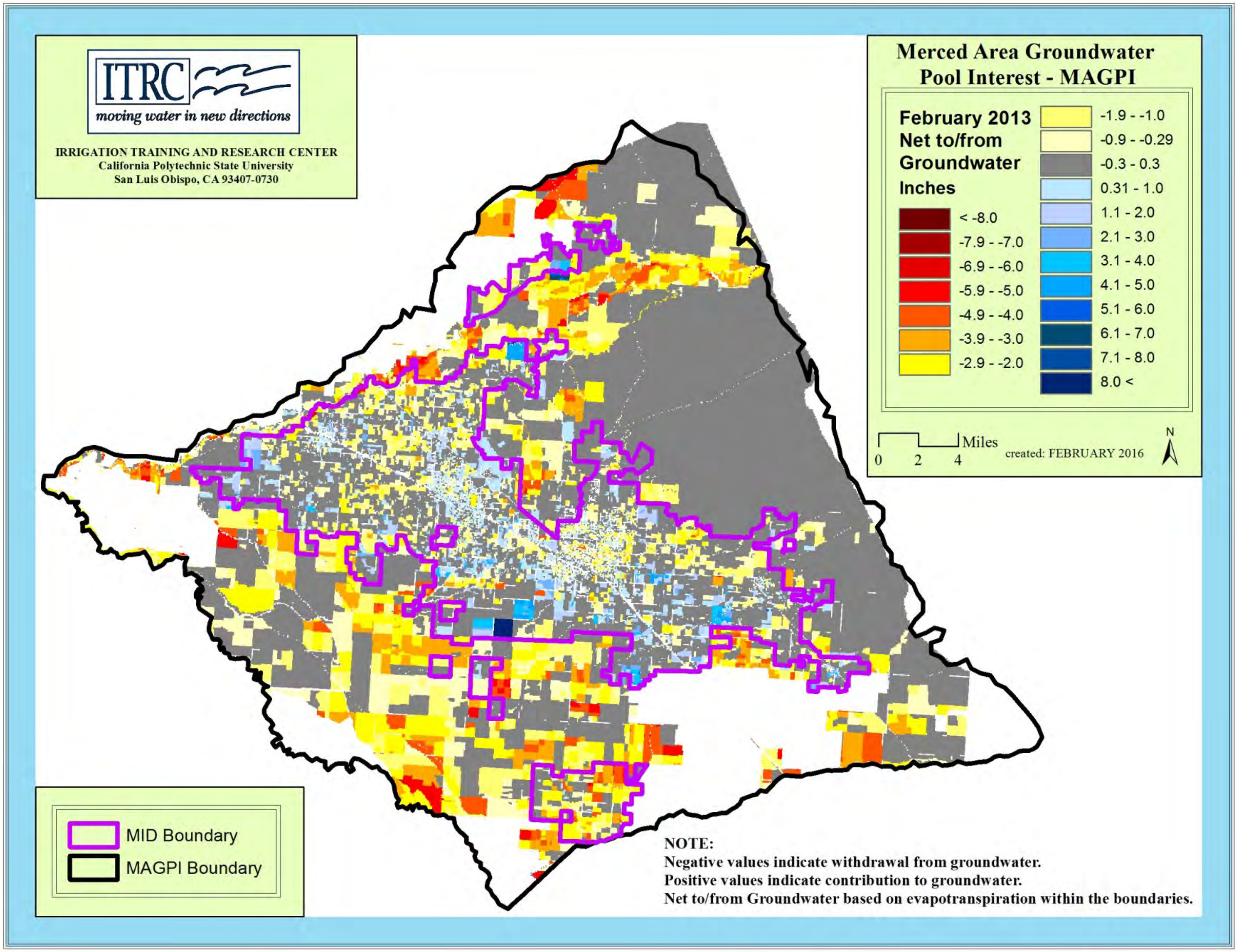


Figure 24. Estimated "Net To and From Groundwater" for February 2013

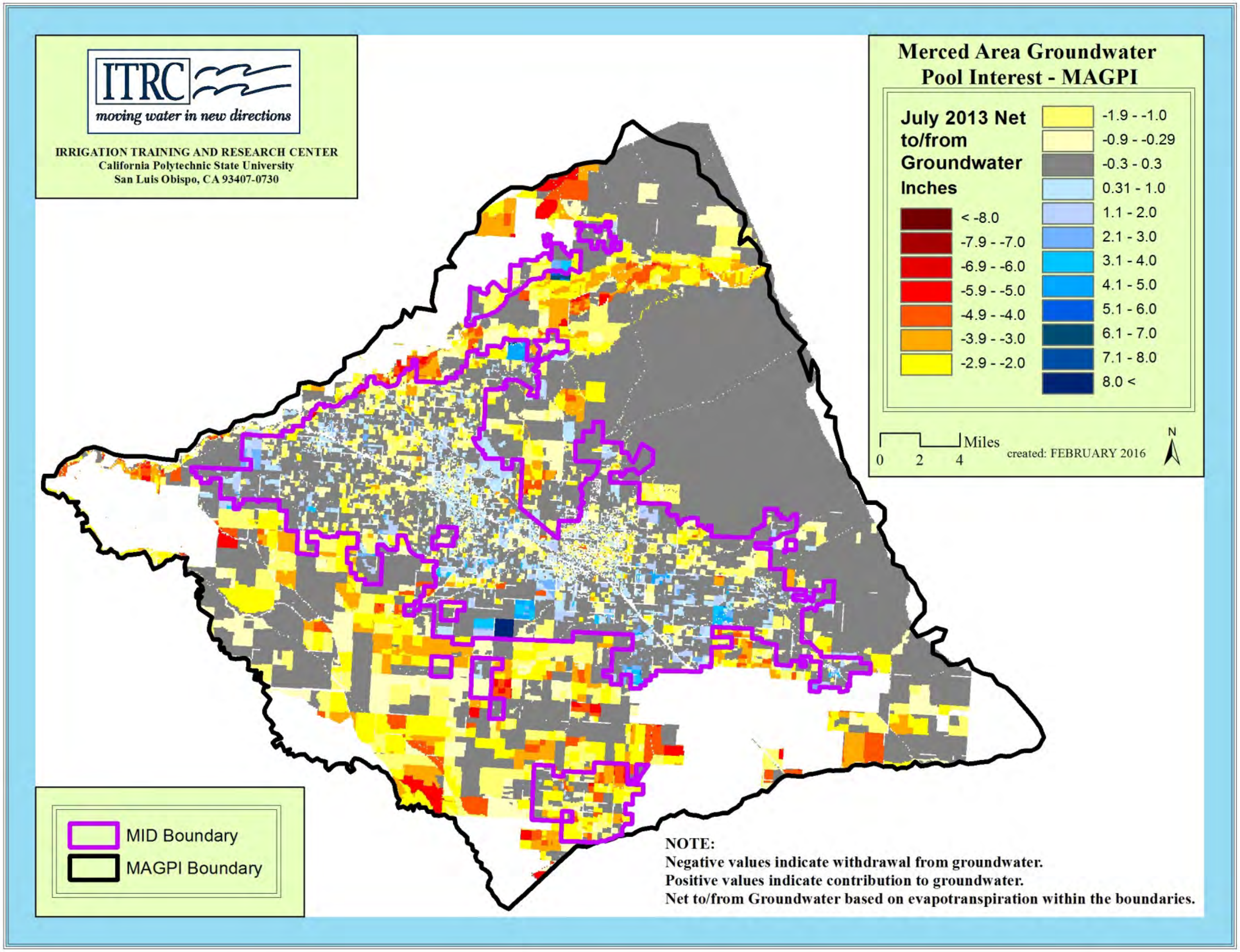


Figure 25. Estimated "Net To and From Groundwater" for July 2013

Missing Surface Water Data for Outside Areas

ITRC was not provided surface water deliveries data made by other irrigation and water districts such as Stevinson Water District or Turner Island Water District. Additionally, ITRC requested but did not receive water diversions from the Merced River north of Merced. Without knowing the amount of applied water in the other water purveyors, the *NTFGW* estimates would be inaccurate. For example, the *NTFGW* estimate would show a significant withdraw in groundwater in those areas when in reality there may only be a small amount of water withdrawn from the groundwater.

Therefore the boundary areas of other water purveyors (see **Figure 26**) were eliminated from the final *NTFGW* estimates.

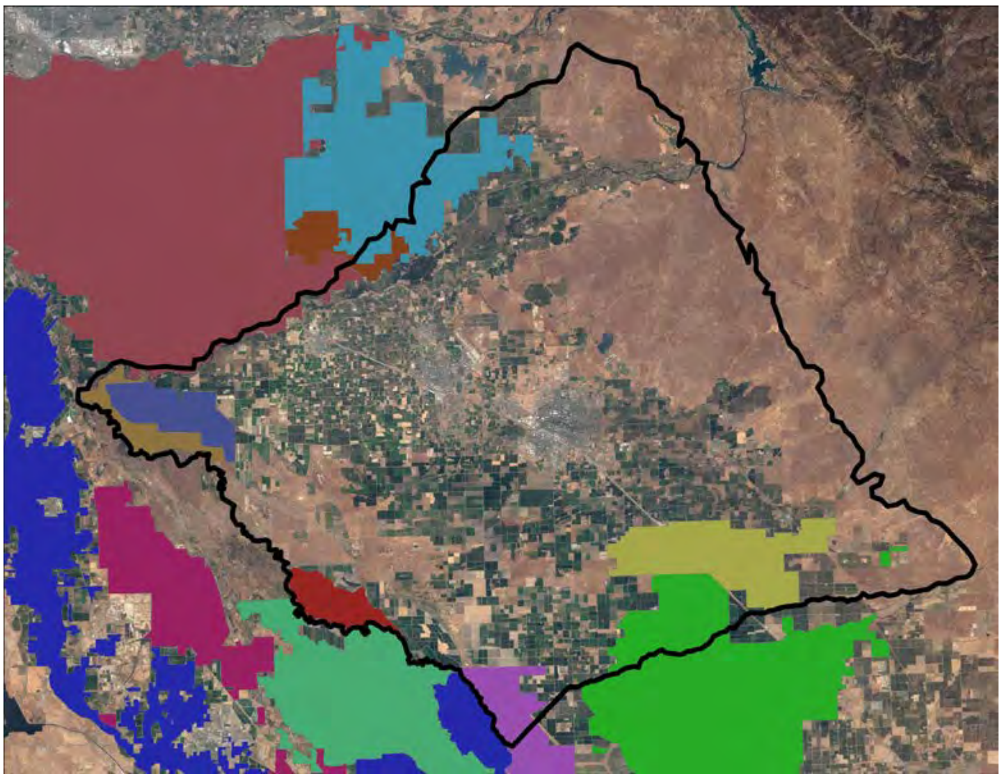
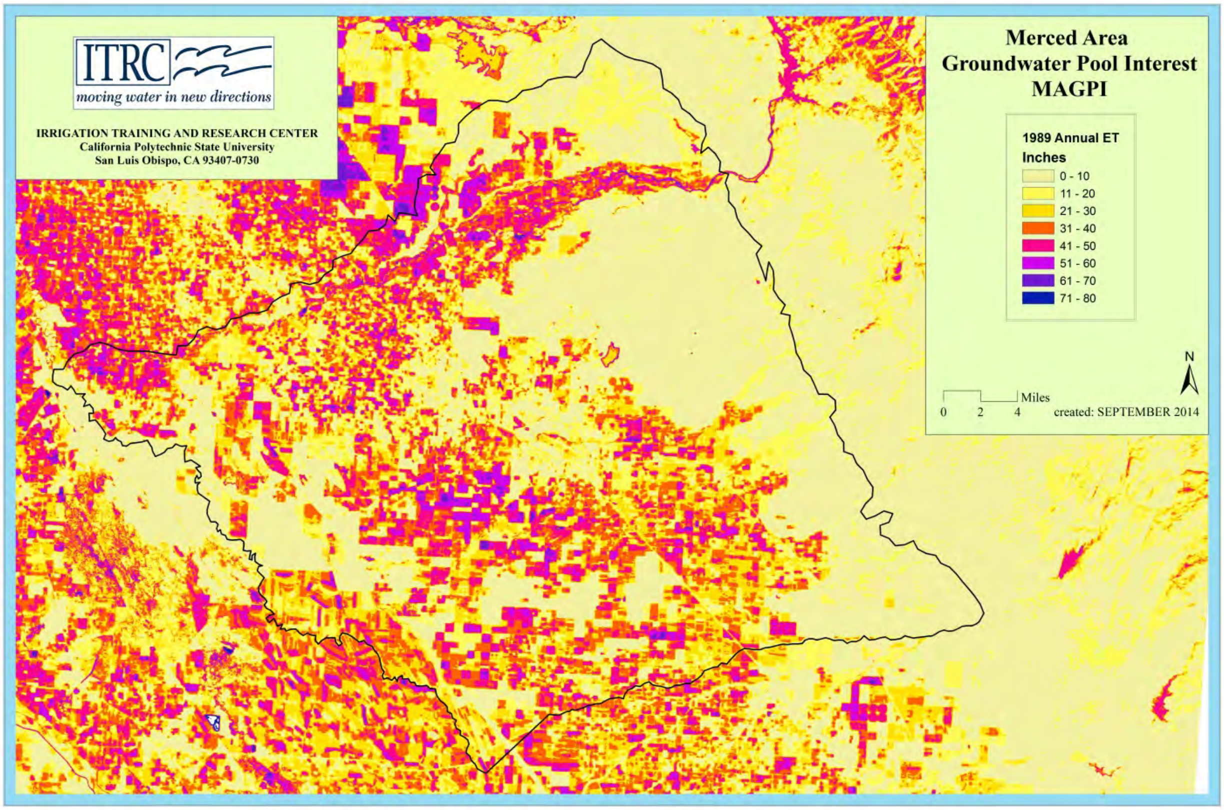
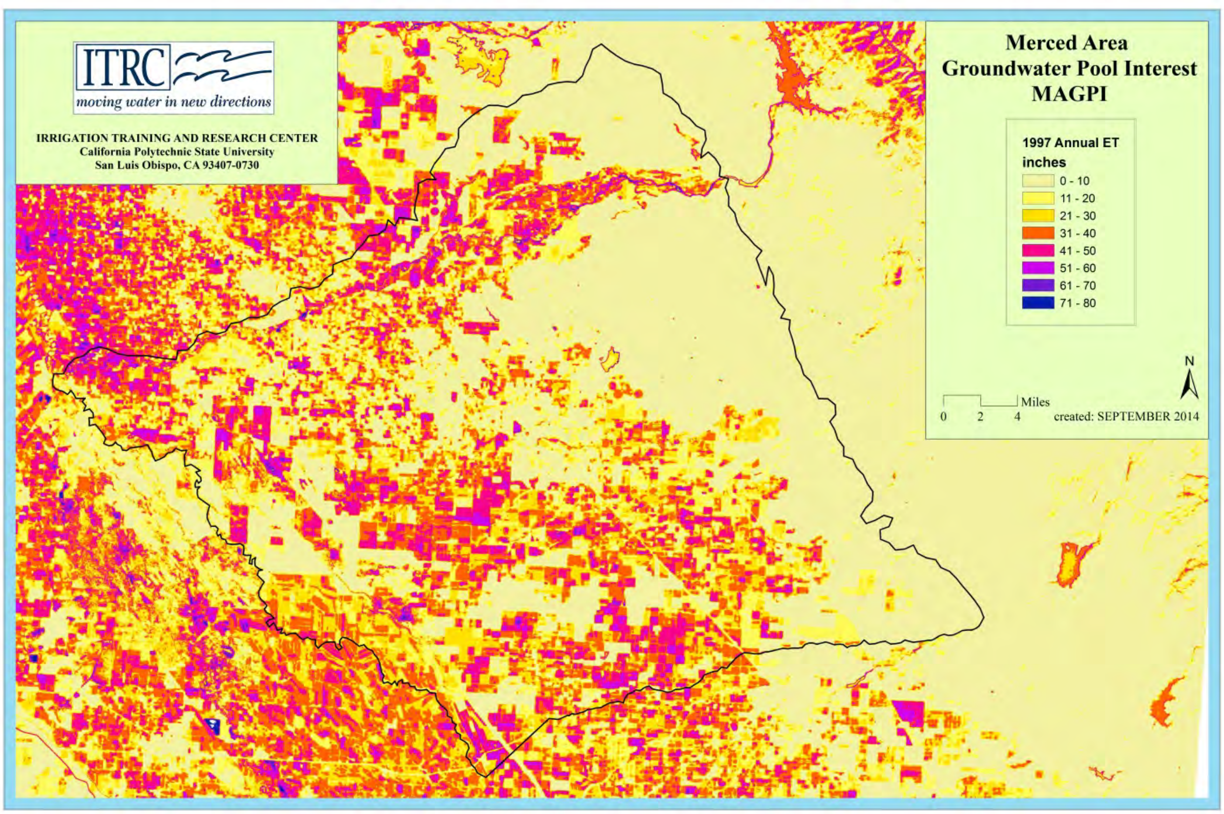
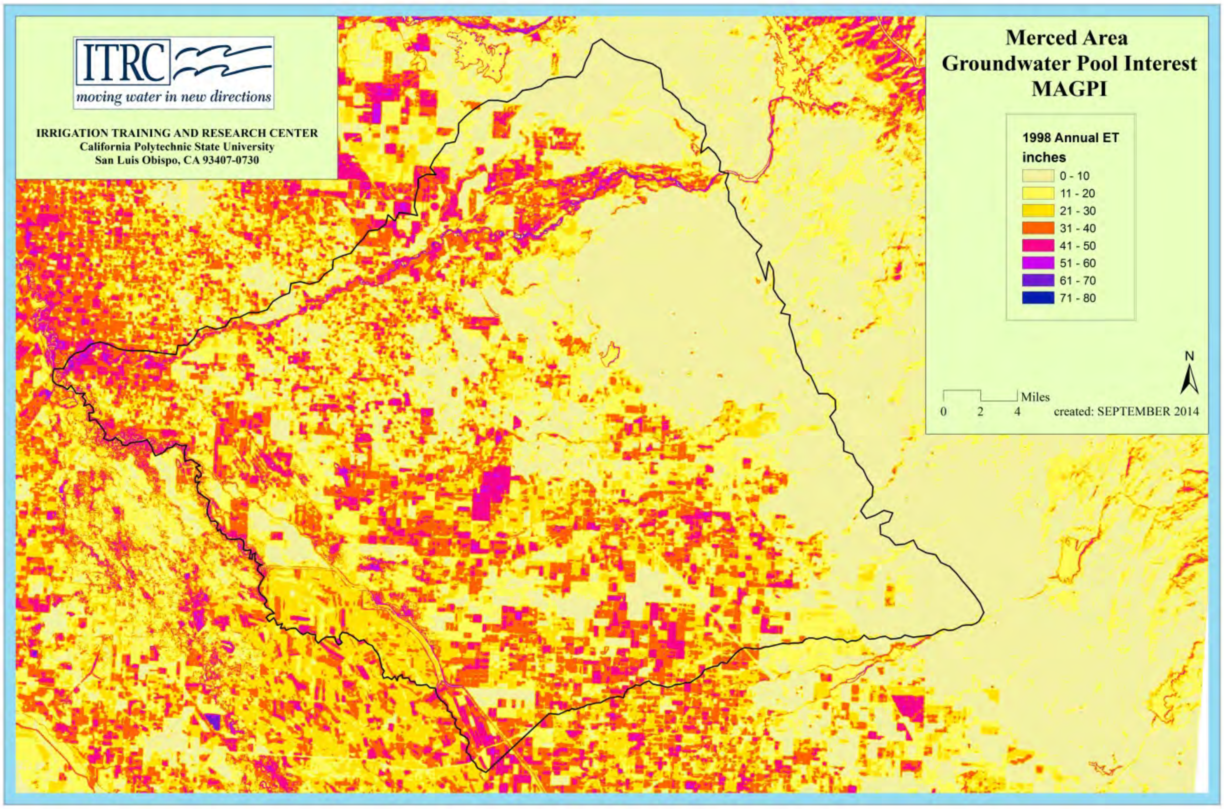


Figure 26. Additional water purveyors in and surrounding the MAGPI boundary for which no surface water data was provided

ATTACHMENT A
ITRC-METRIC Annual ETc Images


ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
1989 Annual ET
Inches
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014


ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
1997 Annual ET
inches
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014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moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
1998 Annual ET
inches
0 - 10
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31 - 40
41 - 50
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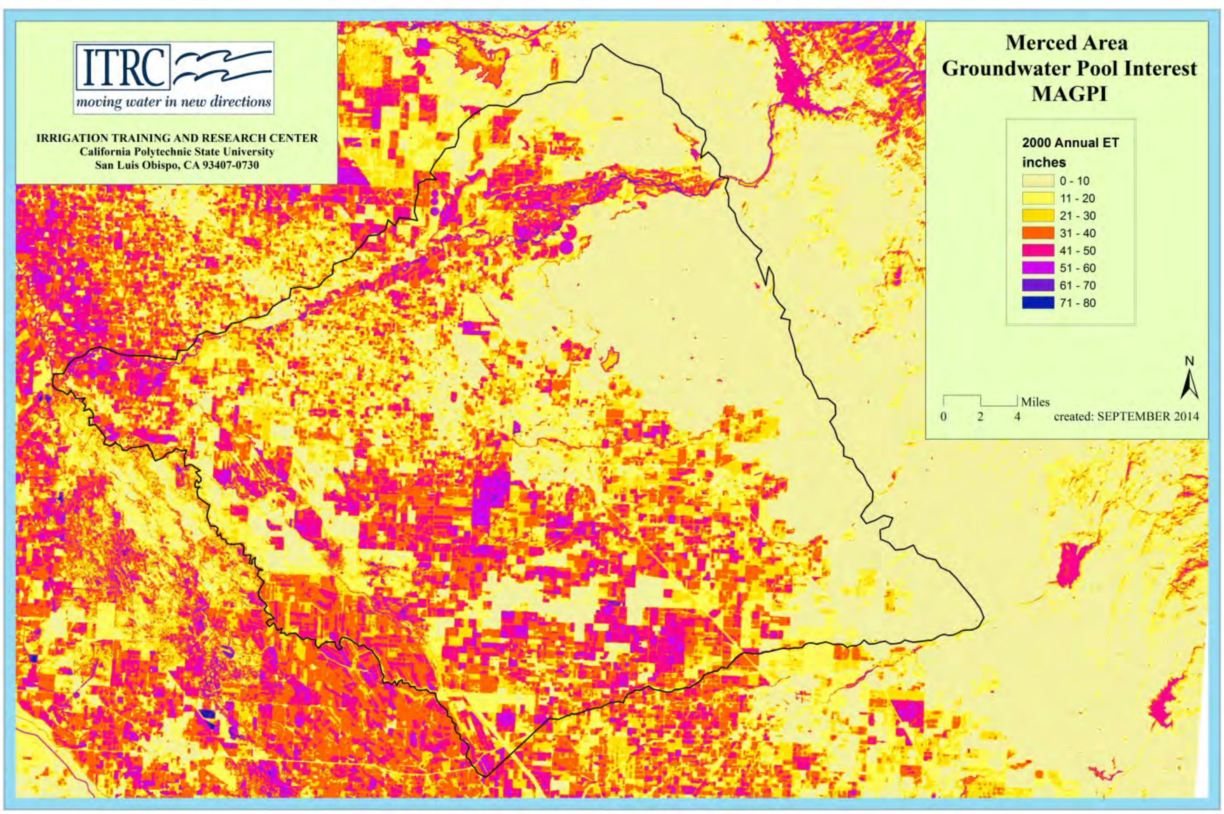
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014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IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
2000 Annual ET
inches
0 - 10
11 - 20
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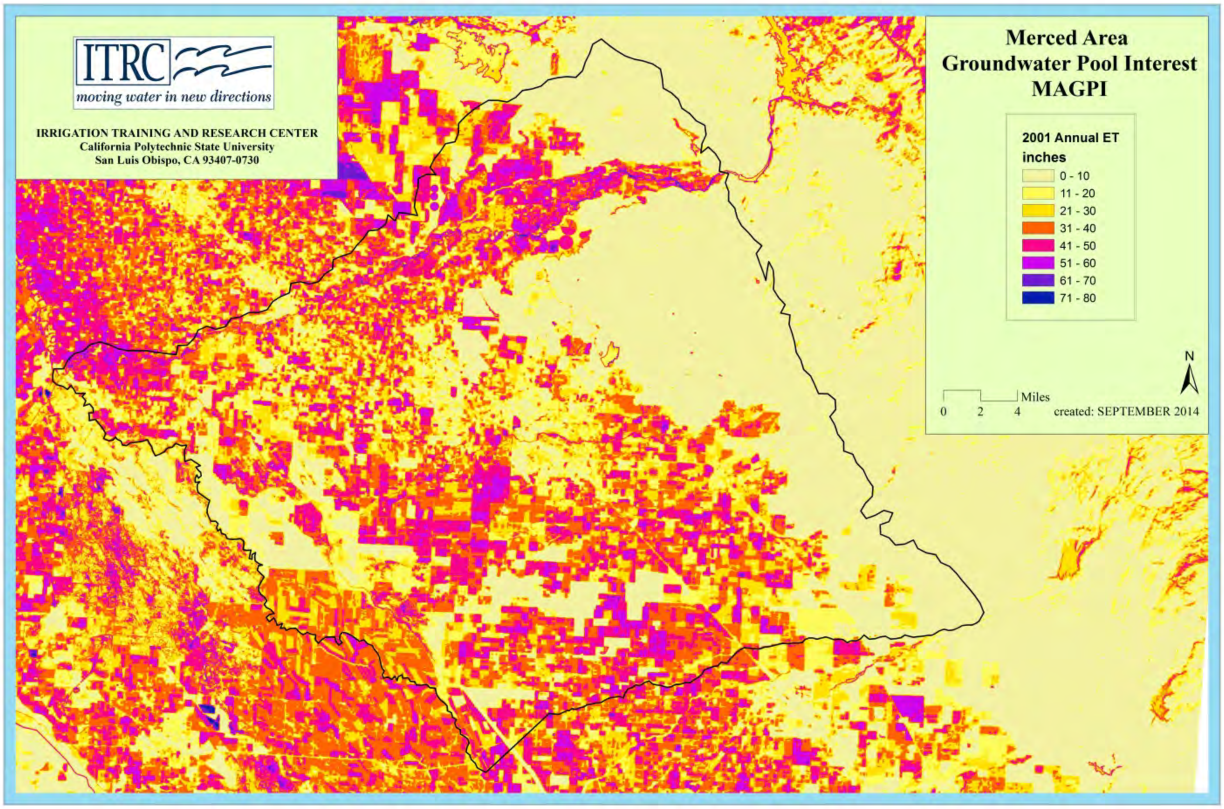
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014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IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
2001 Annual ET
inches
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41 - 50
51 - 60
61 - 70
71 - 80
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Miles
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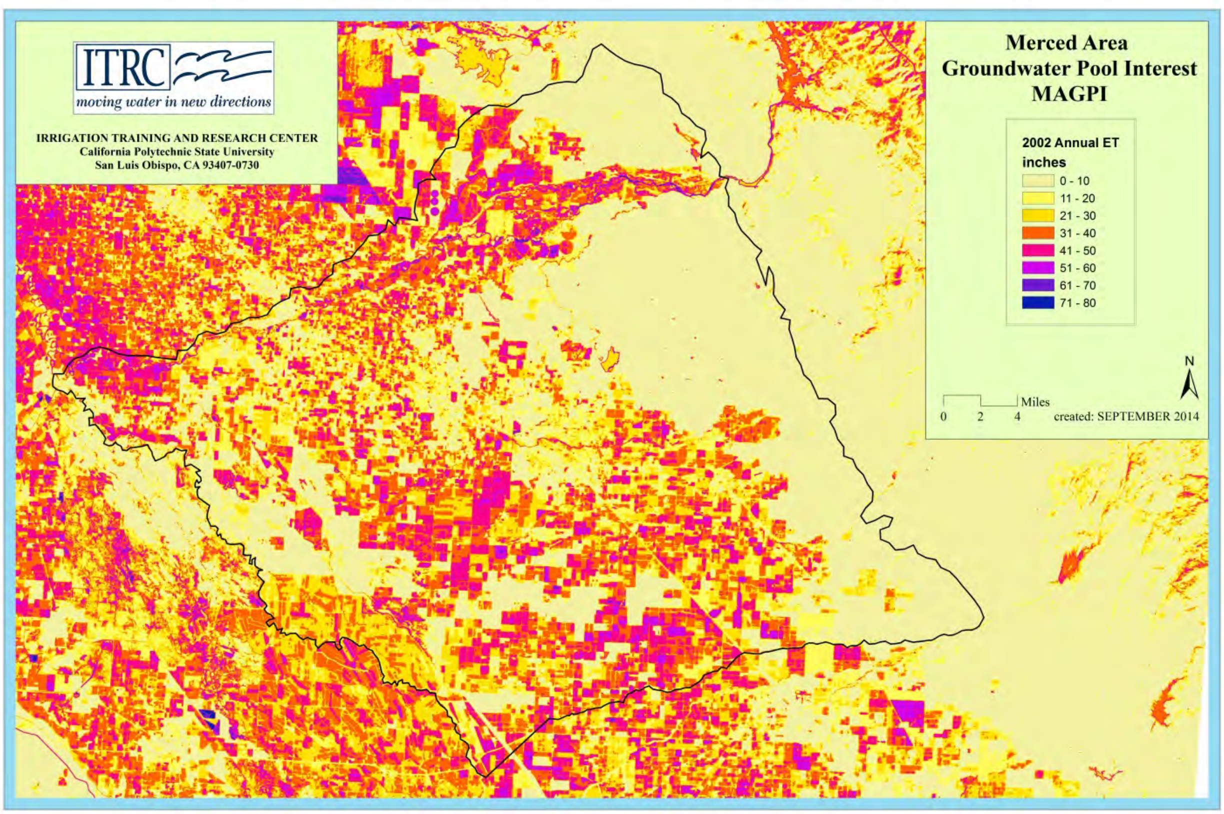
created: SEPTEMBER 2014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IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
2002 Annual ET
inches
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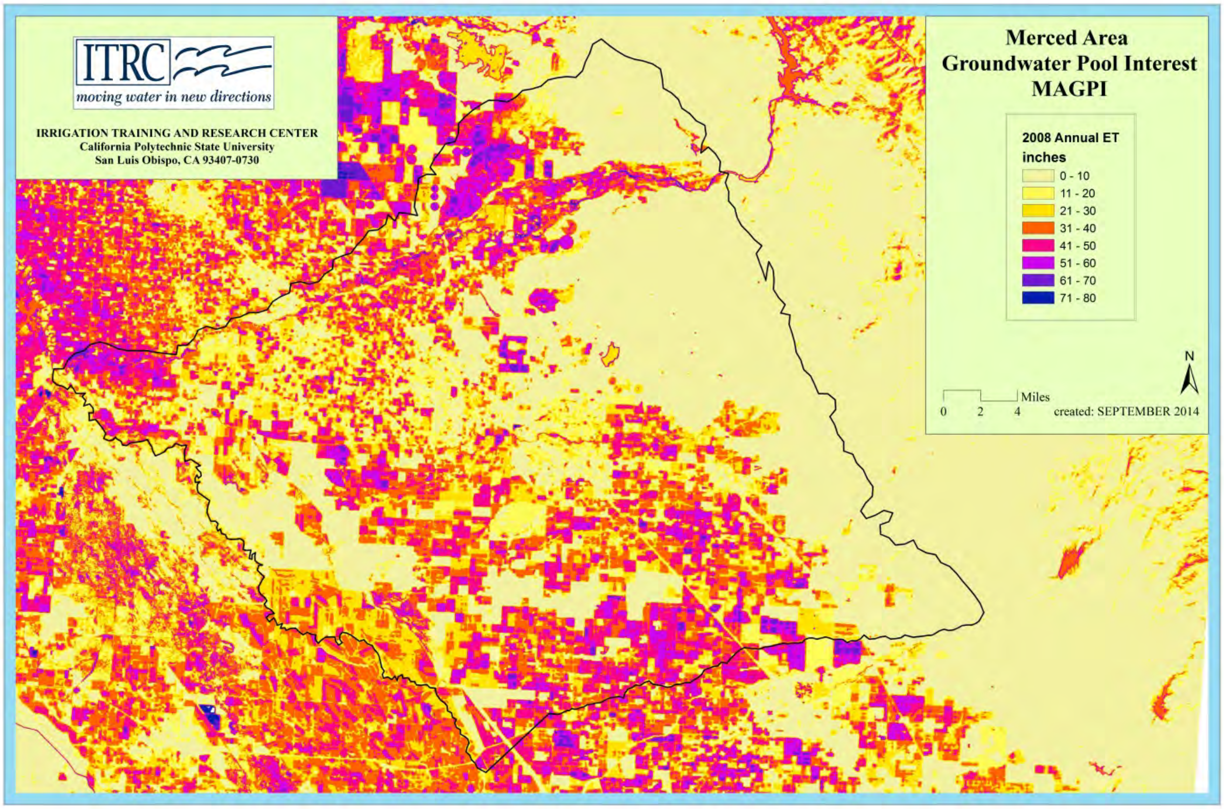
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014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moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
2008 Annual ET
inches
0 - 10
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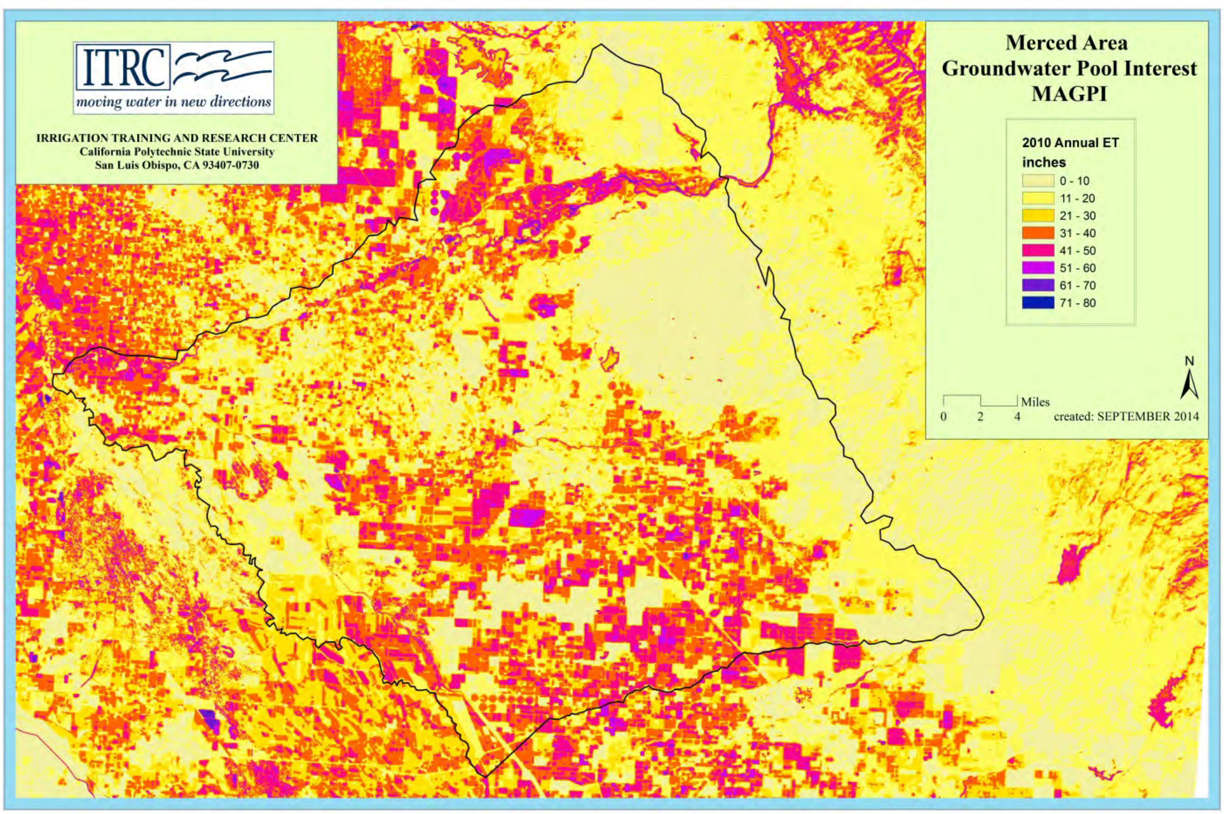
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014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IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
2010 Annual ET
inches
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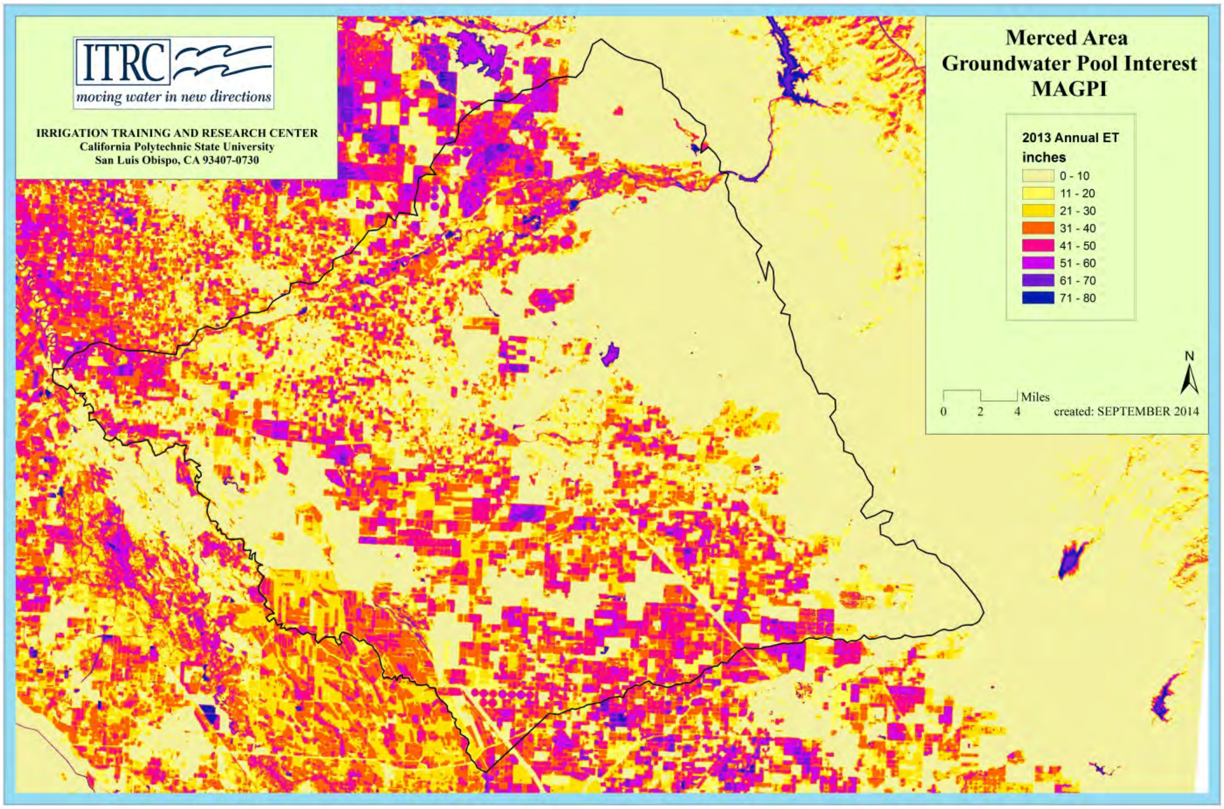
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014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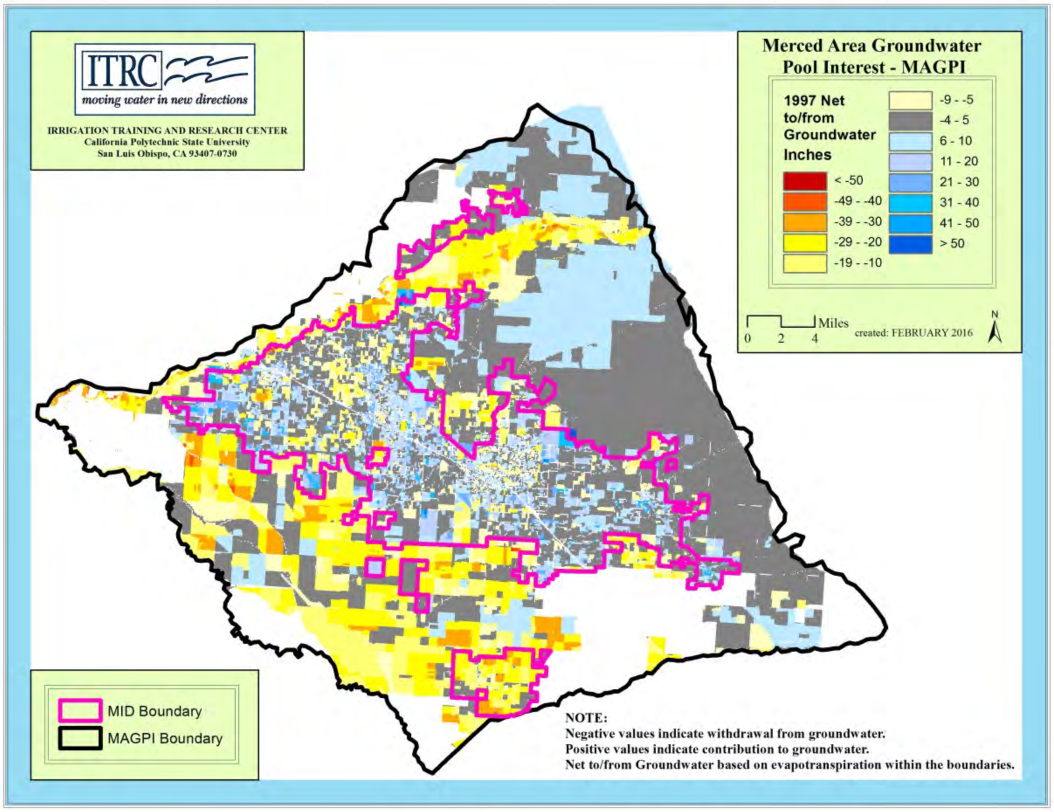
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area
Groundwater Pool Interest
MAGPI
2013 Annual ET
inches
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
N
Miles
0 2 4
created: SEPTEMBER 2014

ATTACHMENT B
NTFGW Annual Maps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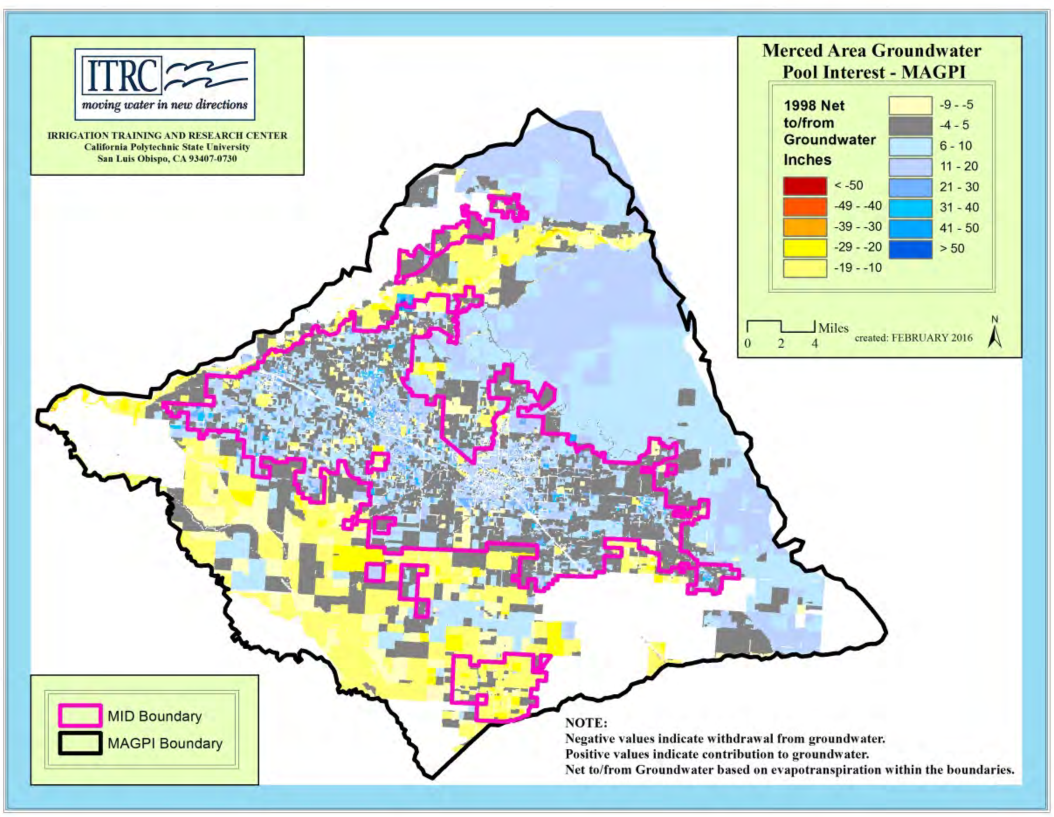
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
1997 Net to/from Groundwater Inches
< -50
-49 - -40
-39 - -30
-29 - -20
-19 - -10
-9 - -5
-4 - 5
6 - 10
11 - 20
21 - 30
31 - 40
41 - 50
> 50
Miles
0 2 4
created: FEBRUARY 2016
N
MID Boundary
MAGPI Boundary
NOTE:
Negative values indicate withdrawal from groundwater.
Positive values indicate contribution to groundwater.
Net to/from Groundwater based on evapotranspiration within the boundaries.


ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
1998 Net to/from Groundwater Inches
< -50
-49 - -40
-39 - -30
-29 - -20
-19 - -10
-9 - -5
-4 - 5
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11 - 20
21 - 30
31 - 40
41 - 50
> 50
Miles
0 2 4
created: FEBRUARY 2016
N
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MAGPI Boundary
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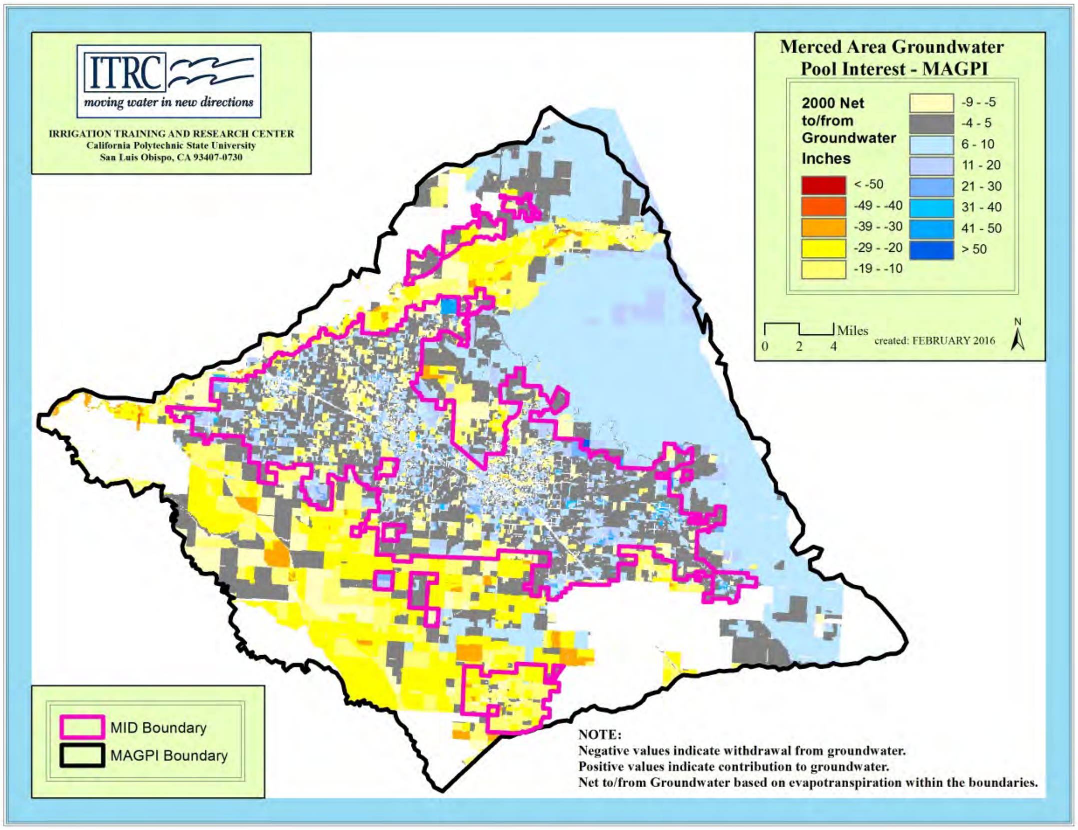
ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
2000 Net to/from Groundwater Inches
< -50
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21 - 30
31 - 40
41 - 50
> 50
0 2 4 Miles
created: FEBRUARY 2016
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MAGPI Boundary
NOTE:
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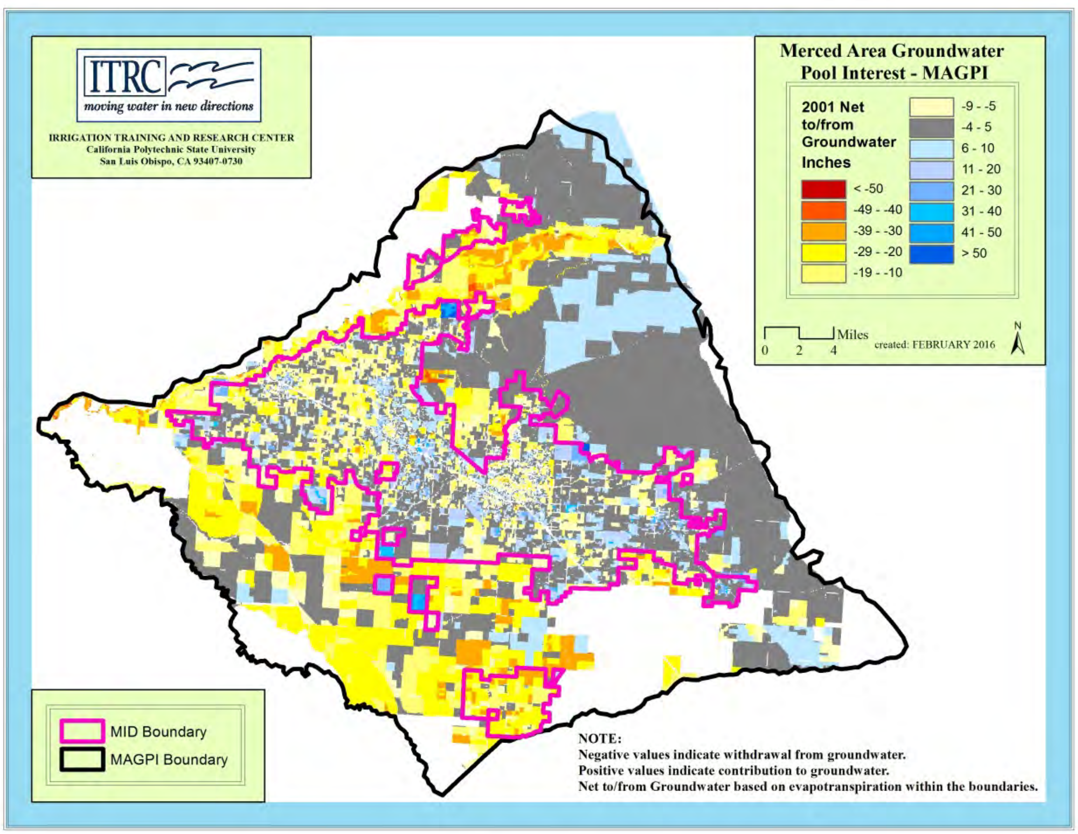
Net to/from Groundwater based on evapotranspiration within the boundaries.


ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
2001 Net to/from Groundwater Inches
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41 - 50
> 50
0 2 4 Miles
created: FEBRUARY 2016
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MAGPI Boundary
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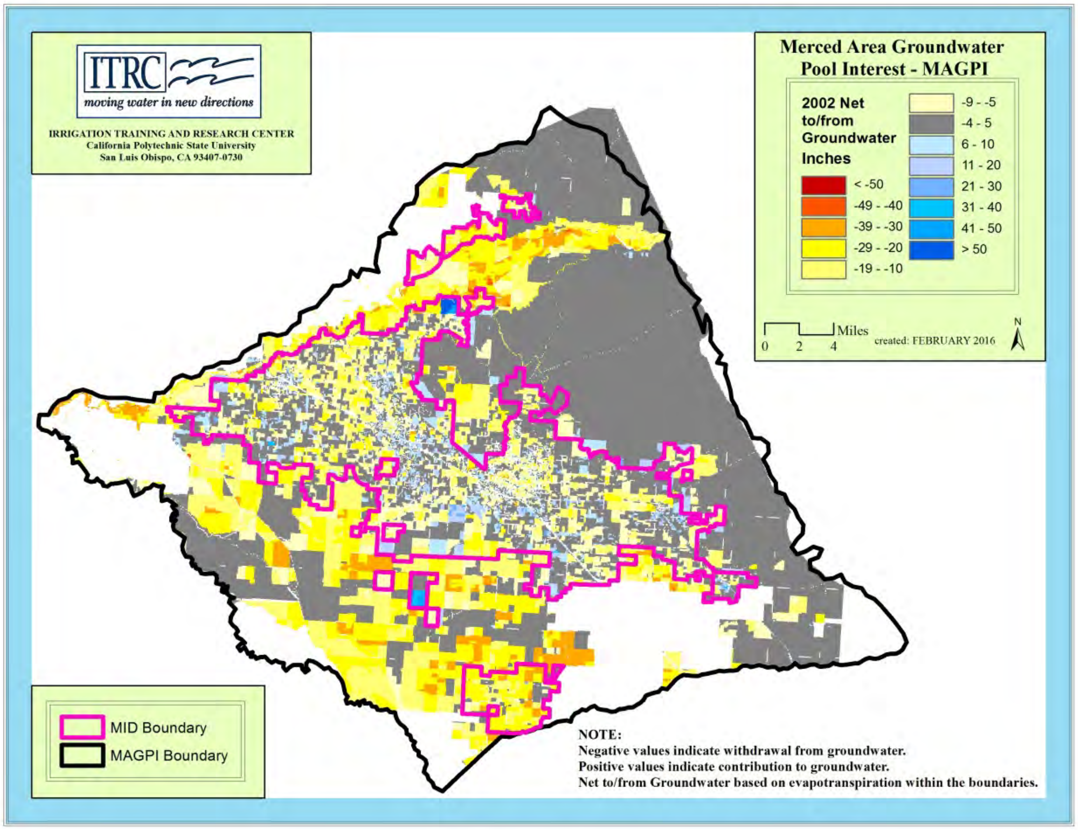
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California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
2002 Net to/from Groundwater Inches
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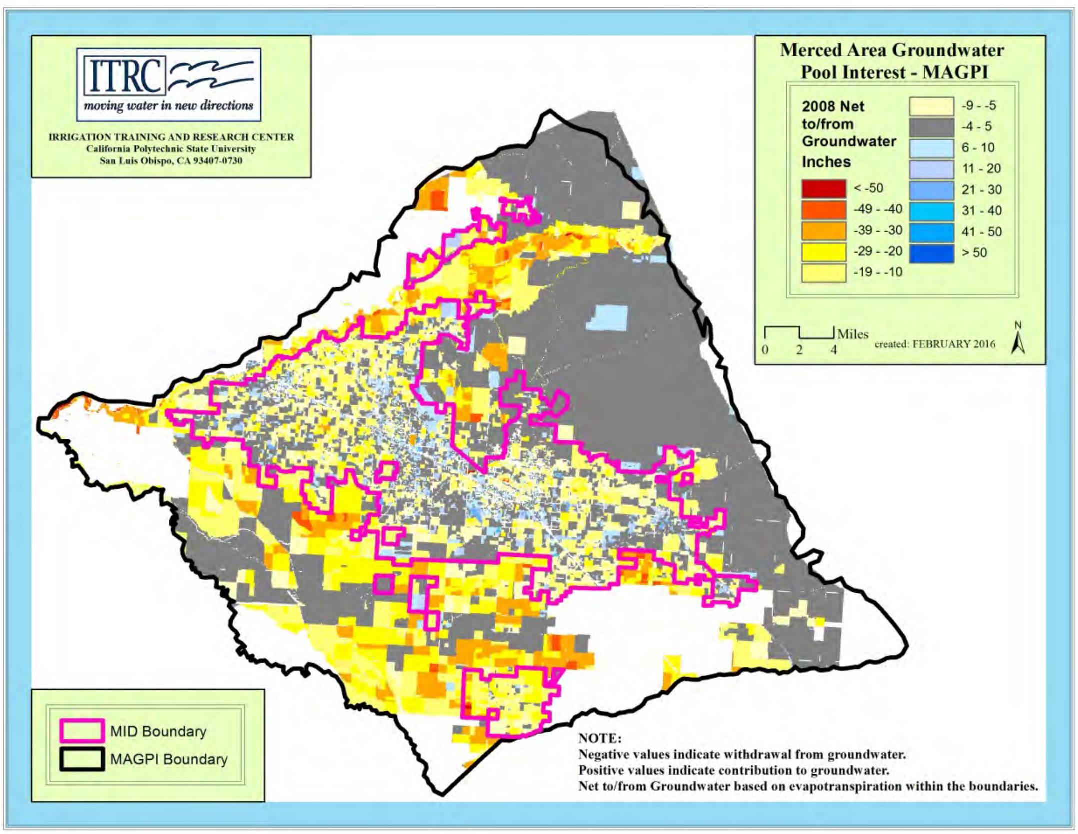
ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
2008 Net to/from Groundwater Inches
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-9 - -5
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Miles
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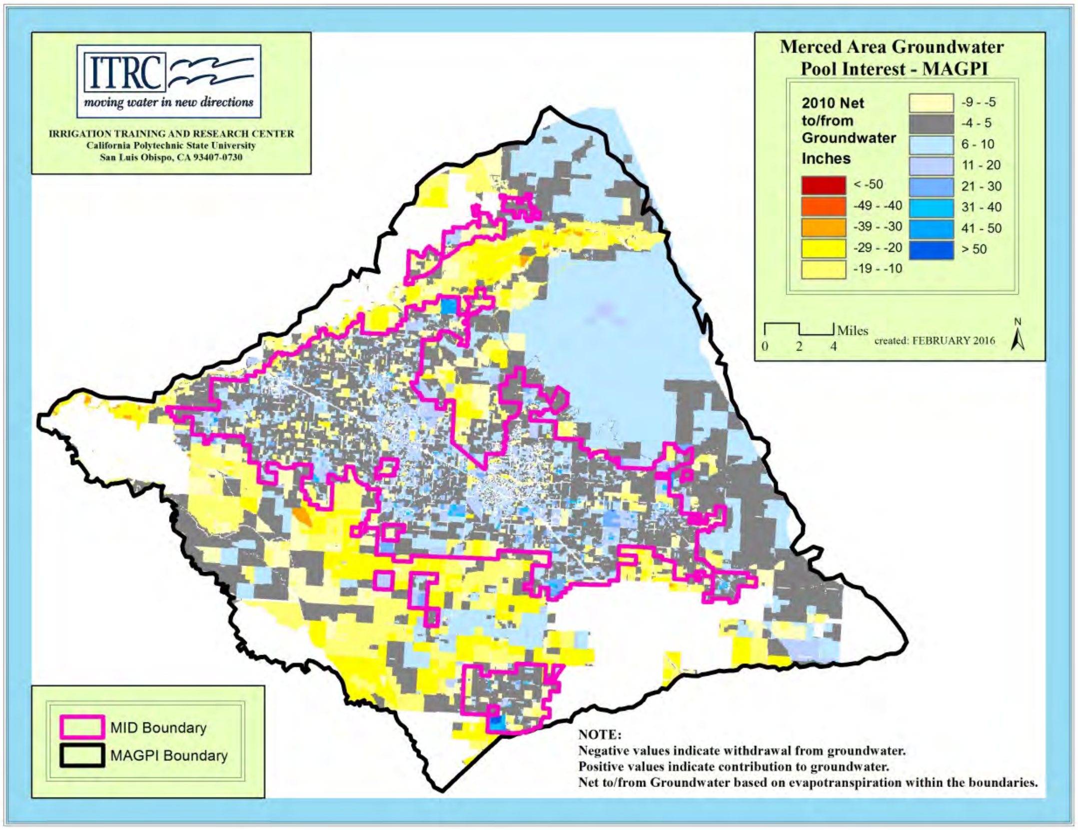
ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
2010 Net to/from Groundwater Inches
< -50
-49 - -40
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21 - 30
31 - 40
41 - 50
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Miles
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NOTE:
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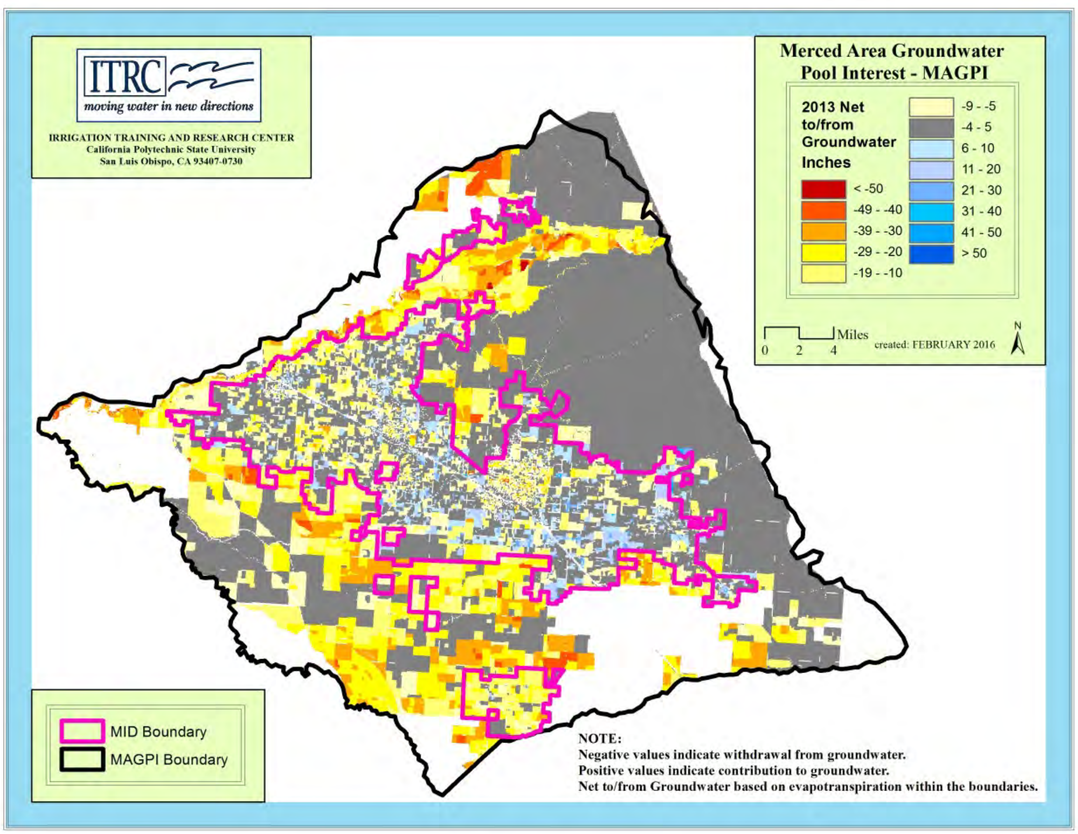
Net to/from Groundwater based on evapotranspiration within the boundaries.


ITRC
moving water in new directions
IRRIGATION TRAINING AND RESEARCH CENTER
California Polytechnic State University
San Luis Obispo, CA 93407-0730
Merced Area Groundwater Pool Interest - MAGPI
2013 Net to/from Groundwater Inches
< -50
-49 - -40
-39 - -30
-29 - -20
-19 - -10
-9 - -5
-4 - 5
6 - 10
11 - 20
21 - 30
31 - 40
41 - 50
> 50
Miles
0 2 4
created: FEBRUARY 2016
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MID Boundary
MAGPI Boundary
NOTE:
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Net to/from Groundwater based on evapotranspiration within the boundaries.

ATTACHMENT C