moving forward. Therefore, names and locations of faults presented in this report may differ from previously published material.

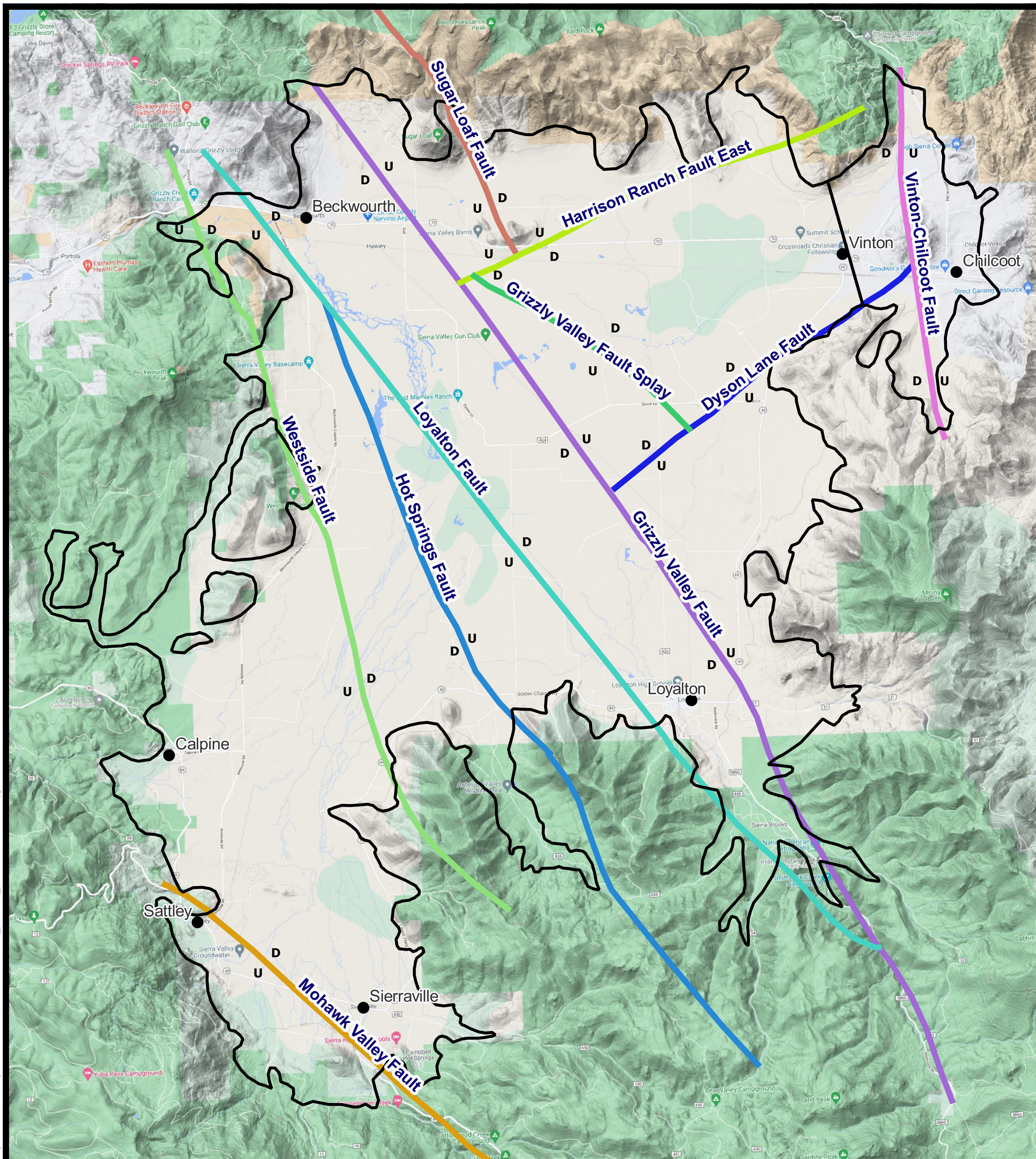
All faults in the model are currently represented as vertical (dip angle of 90°) based on previous descriptions and geophysical surveys. Displacement was generally only provided on a relative basis (upthrown and downthrown sides of the fault indicated). A description of vertical displacement was available from a geologic description of the Mohawk Valley Fault (Sawyer and others, 1995) and for the Grizzly Valley Fault Splay based on seismic reflection data (Gold and others, 2013). Vertical offset for all other faults was estimated by observed bedrock contacts in well logs and professional judgement, which results in a high degree of uncertainty. The USGS is currently conducting a seismic geophysical study of the basin, and an airborne electromagnetic (AEM) survey conducted by DWR is expected in 2022. Results from these studies may provide more information on faults in the basin which could be incorporated into future model updates.

6.1.2 Wells

A total of 439 wells within and immediately adjacent to the groundwater basin boundary (Figure 6-2) were identified from multiple publically available databases (e.g., SGMA Data Viewer, CASGEM, GeoTracker), reports, or provided directly to the project team by SVGMD. A large proportion of the wells identified a location accuracy of approximately 2,640 feet (805 m), as the coordinates reported were the centroid of the section the well is located within as opposed to the actual location of the well. Location data for these wells was refined using the non-redacted information in the well log such as address, parcel number, or driller's map, when available. This typically reduced the location uncertainty to within a few hundred feet, and generally improved representation of the subsurface distribution of sediments.

6.1.3 Bedrock Units and Contacts

Bedrock in SVHSM was defined as the suite of non-sedimentary units present in the basin. This includes the Jurassic metavolcanic and metasedimentary rocks present before the emplacement of the Sierra Nevada batholith, the Cretaceous granitic and granodioritic intrusions of the Sierra Nevada batholith, and the late Tertiary volcanic rocks associated with tectonic extension that formed Sierra Valley. The hydrogeologic conceptual model (HCM) developed for the basin has the late Tertiary volcanics primarily erupting onto the existing granite and granodiorite, as opposed to alluvial and fluvial sediments. While distinct geologically, the non-sedimentary units were assumed to have similar hydrologic properties.



Explanation

Faults
- Dyson Lane Fault
- Grizzly Valley Fault
- Grizzly Valley Fault Splay
- Harrison Ranch Fault East
- Hot Springs Fault
- Loyalton Fault
- Mohawk Valley Fault
- Sugar Loaf Fault
- Vinton-Chilcoot Fault
- Westside Fault
- Groundwater Basin
- City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

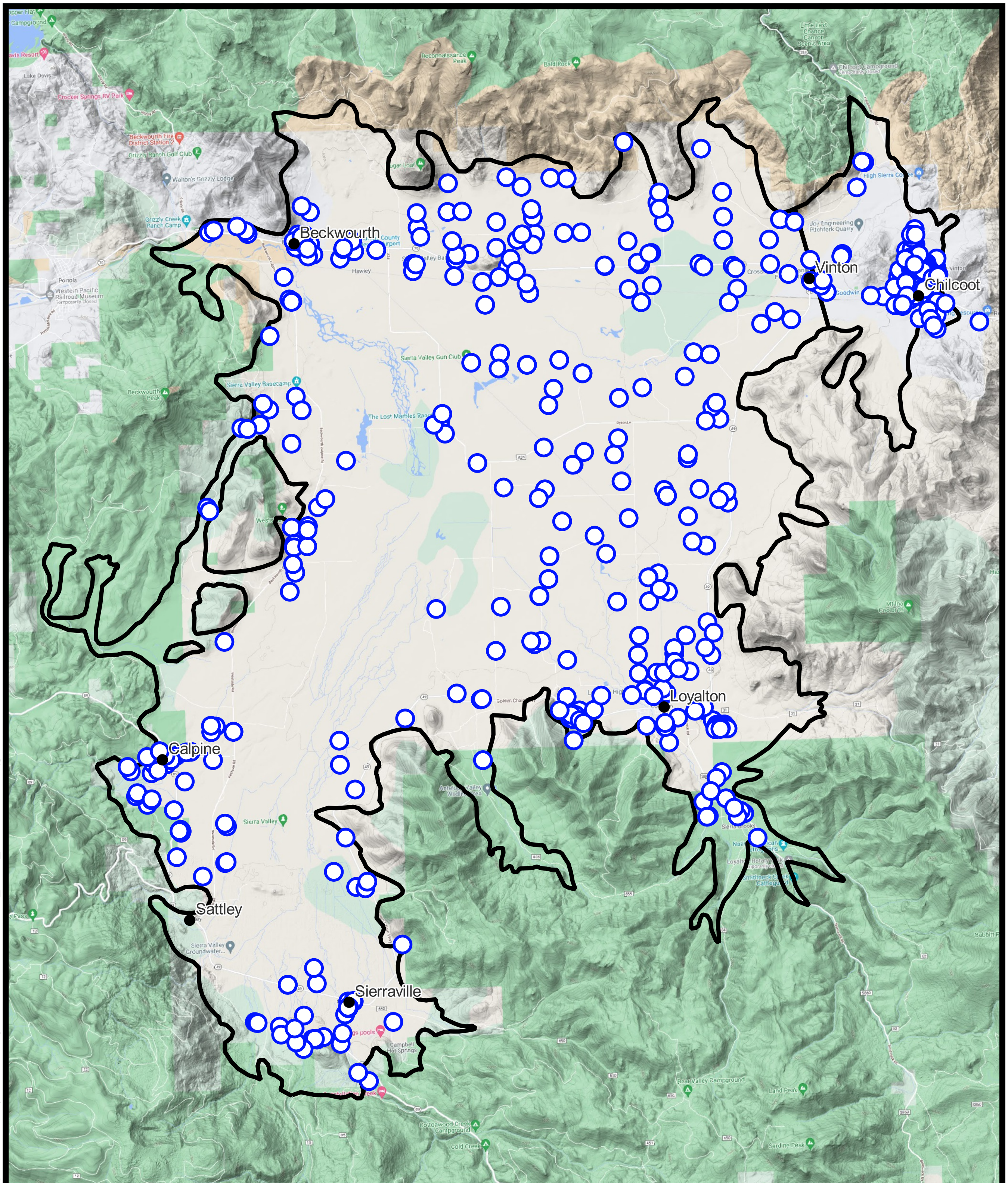
Notes:
1. D and U indicate relative downthrown and upthrown sides of the fault, respectively

SVHSM Documentation
3D Geologic Model Faults

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/10/2021

Figure 6-1



Sources: DWR Well Completion Report Database; CASGEM; GeoTracker; SGMA Data Viewer; SVGMD

Explanation

- Well with Lithology Data
- City or Town
- Groundwater Basin (DWR Bulletin 118)

0 1 2 mi

N

Sierra Valley Groundwater Management District

SVHSM Documentation
Wells with Lithology Data

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

01/08/2022

Figure 6-2

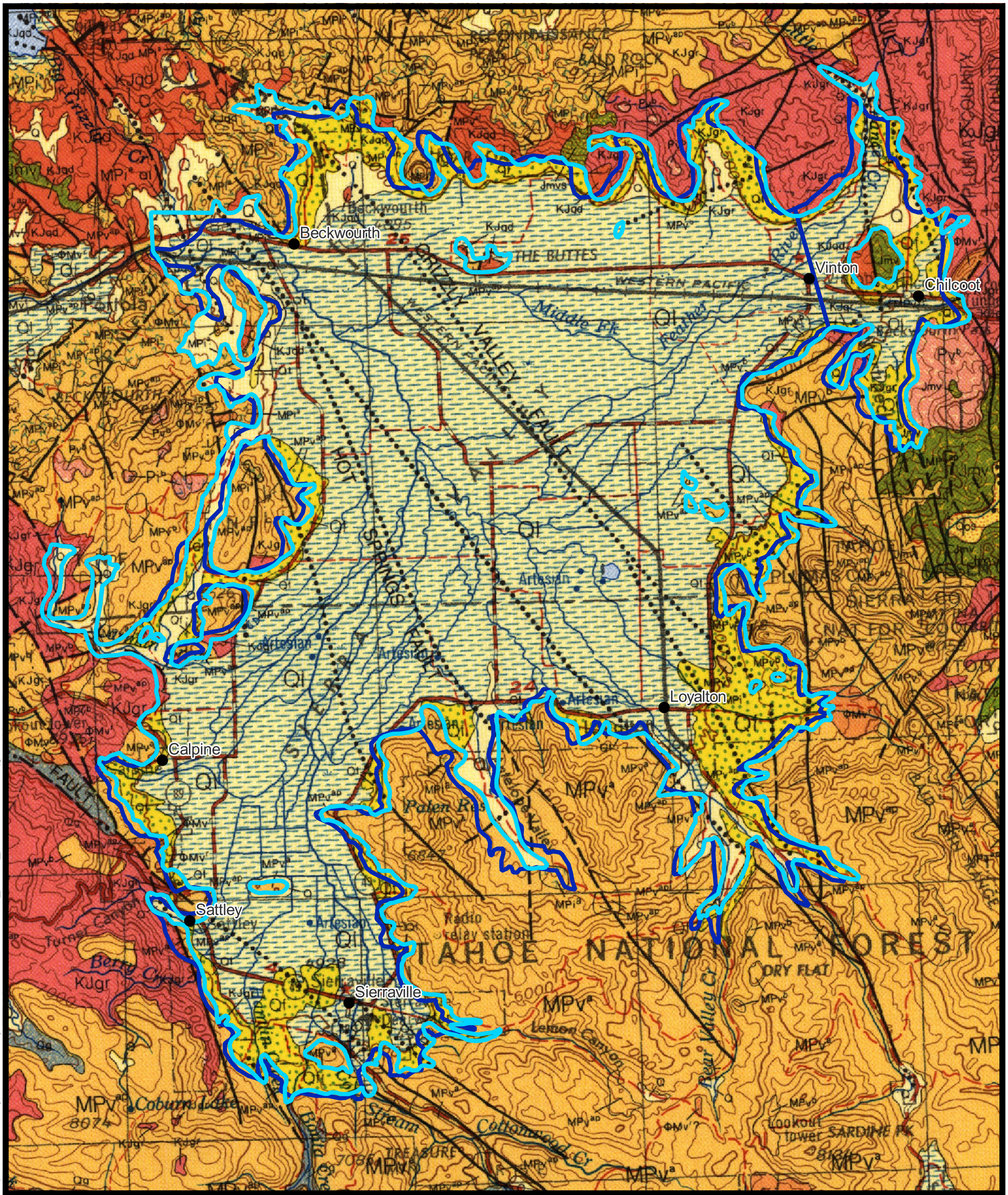
Bedrock contacts within and around the perimeter of the groundwater basin were determined based on the multiple geologic maps available for the basin. Although there is general agreement between the DWR Bulletin 118 groundwater basin boundary and the perimeter of the bedrock contacts used in the 3D geologic model (Figure 6-3), there are some areas where there the two show disagreement (e.g., Antelope Creek canyon in the south and near the northwestboundary of the basin). This indicates that the Sierra Valley groundwater basin could benefit from a basin boundary adjustment in the future to better align the physical and jurisdictional boundaries of the groundwater basin.

Leapfrog Works handles geologic cross-cutting relationships by requiring the user to specify the relative age of each geologic unit and they type of contact surface between them. The contact surface between bedrock and aquifer sediments in SVHSM was represented using the "erosional" contact surface, meaning that sediment volumes took precedence over bedrock volumes. Slope of the bedrock contact into the groundwater basin was assumed to be similar to the topographic slope of the surrounding mountains. This was implemented in the 3D geologic model by adding "structural discs" around the perimeter of the basin. Bedrock contacts were also added manually as needed using "3D polylines" to satisfy geologic principles and interpretations based on well log and geophysical data. These are easily distinguishable within the Leapfrog Works software, and can be modified in the future if more data become available.

6.1.4 Aquifer Units and Contacts

Sedimentary lithology data from well logs was condensed into five hydrogeologic groups: (1) sand and gravel, (2) silty clayey sand and gravel, (3) sandy gravelly silt and clay, (4) silt and clay, and (5) volcanic tuff. The first two groups represent the coarse aquifer units, which make up the most productive portions of the aquifer. The third and fourth groups represent finer-grained sediments that are either poorly productive portions of the aquifer system or act as hydrologic flow barriers (aquitards). The last group was created to account for volcanic tuff that was reported in a few well logs. This classification system resulted in 3,652 geologic intervals that were used to generate contact surfaces and volumes within Leapfrog Works.

Due to the heterogeneous distribution of aquifer sediments in the basin, contacts in the 3D geologic model were represented using the "intrusion" contact surface type in Leapfrog Works. This contact type allows for units that are not laterally continuous across the model domain, which is more consistent with the HCM. Variograms based on well data with each fault block, as well as ellipsoid ratios (relative extent) with values from 60 to 80 in the x and y directions, were applied during the generation of the contact surfaces. Coarser units were defined as being the youngest so they would take precedence over finer units during volume generation. The option to specify a background lithology in Leapfrog Works was not used in order to better comprehend and visualize lithology data gaps. This resulted in the generation of a sixth "Unknown" sedimentary unit.



Source: California Geological Survey (1992)

Explanation

- Modeled Bedrock Contact
- Groundwater Basin (DWR Bulletin 118)
- City or Town

Notes:
1. Bedrock contacts based on multiple data sources

0 1 2 mi

N

Sierra Valley Groundwater Management District

SVHSM Documentation

3D Geologic Model Bedrock Contacts

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/13/2021

Figure 6-3

6.2 Outputs

Outputs from the 3D geologic model are contact surfaces between each of the simulated units and resulting volumes. The hydrogeology extension provides the ability to map the categorical aquifer sediments onto the MODFLOW grid. Parameter values required by MODFLOW such as hydraulic conductivity, storage coefficients, etc., can then be assigned to the aquifer sediment categories. This allows for heterogeneity to be accounted for without over parameterizing the model.

6.2.1 Bedrock Surface

Figure 6-4 shows the bedrock surface geometry used in SVHSM. Depth to bedrock is generally shallowest along the margins of the valley and greatest near the center. Maximum depth to bedrock in SVHSM is estimated to be about 1,530 feet (466 m) near the Lost Marbles Ranch (intersection of Dyson Lane and Marble Hot Spring road) based on geophysical data (Gold and others, 2013). Bedrock outcrops within the valley are present at various locations and are likely remnant topographic highs or volcanic features.

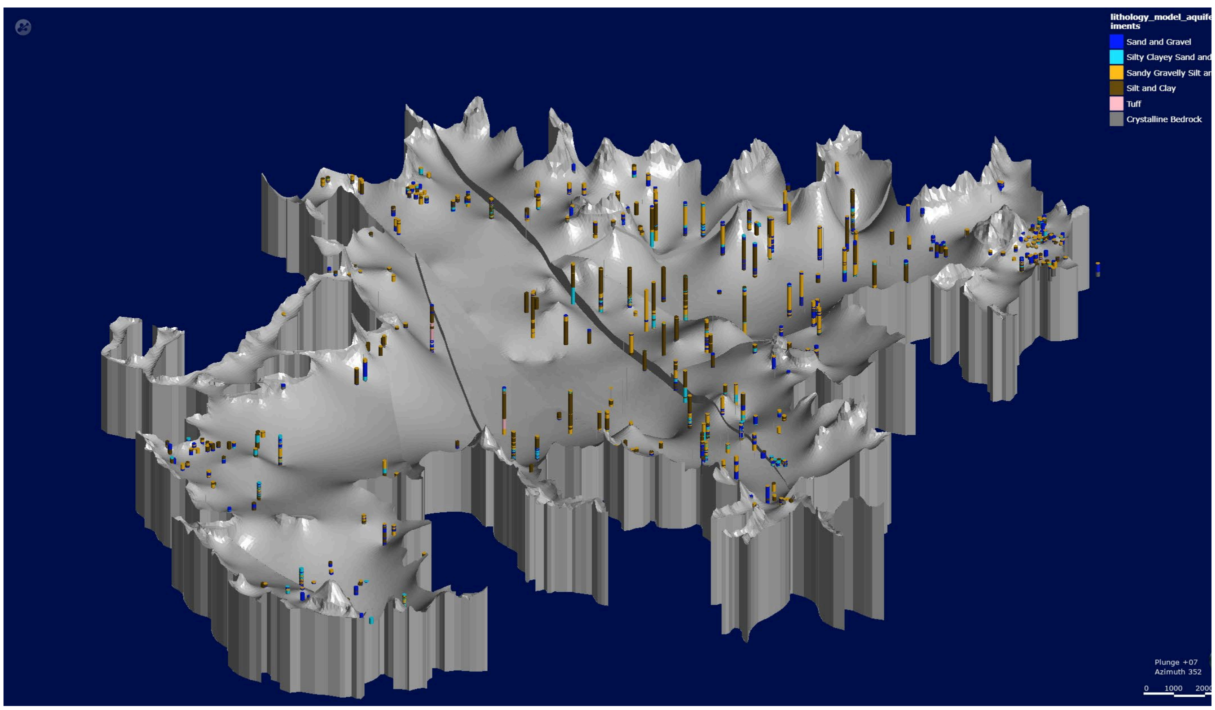


Figure 6-4. Exported image (looking north) of bedrock contact surface and volume simulated in SVHSM . Cylinders show wells with colors representing lithologic units. 5x vertical exaggeration.

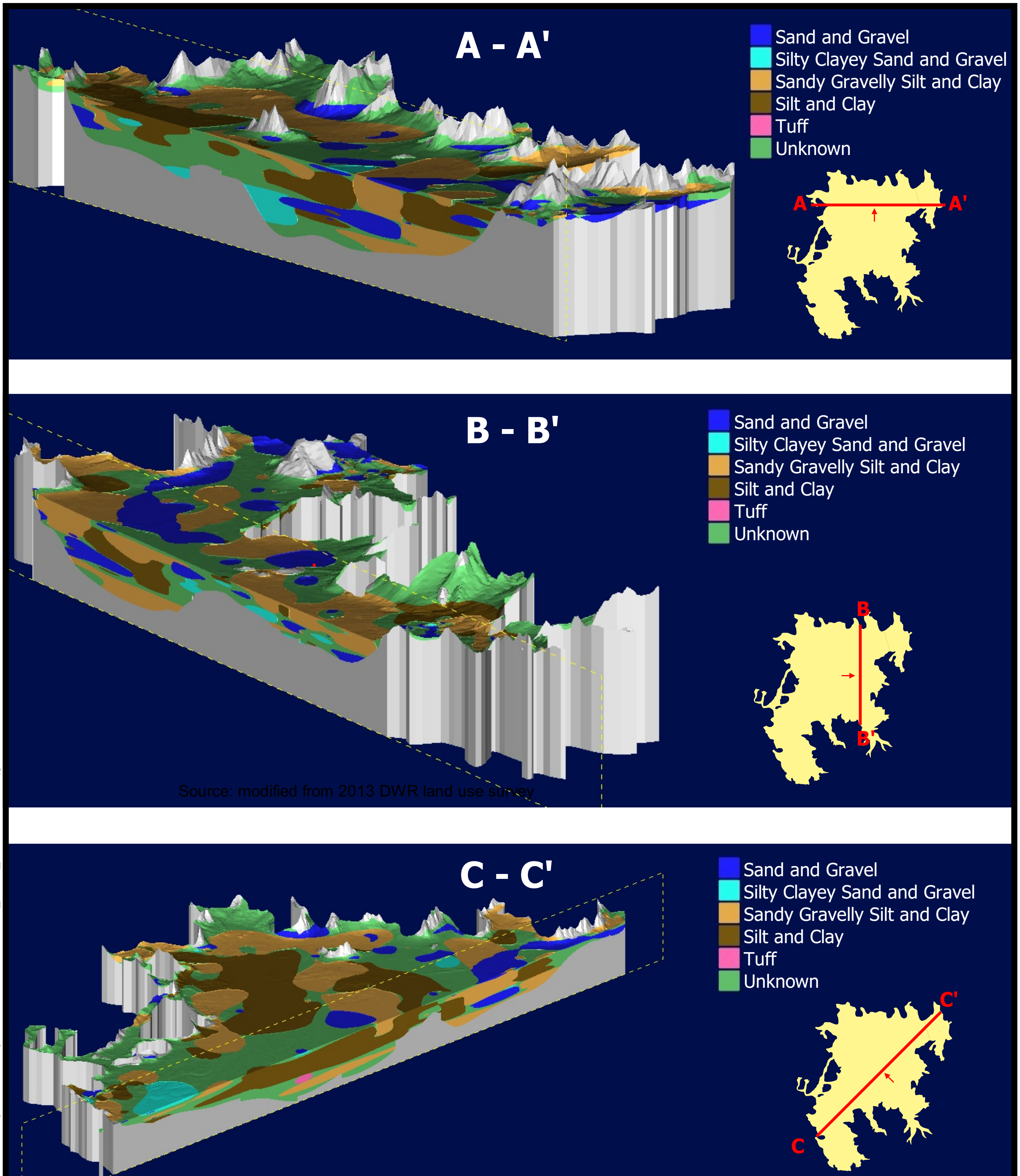
6.2.2 Sediment Volumes and Principal Aquifers

Fine-grained units dominate in the model, with coarse units (lithology groups 1 and 2) comprising only about 10 to 15% of the total sediment volume (Table 6-1). This is consistent with the conceptual model for the basin where lacustrine conditions were prevalent for a large portion of the depositional history. The unknown volume makes up over one-third of the total model volume, indicating that some areas of the model have significant data gaps.

Table 6-1. SVHSM 3D geologic model lithology unit volumes.

ID	Lithology	Volume			Percentage (%)
		m^3	mi^3	km^3	
1	Sand and Gravel	5.80E+09	1.4	5.8	7%
2	Silty Clayey Sand and Gravel	3.69E+09	0.9	3.7	4%
3	Sandy Gravelly Silt and Clay	1.78E+10	4.3	17.8	20%
4	Silt and Clay	3.06E+10	7.3	30.6	35%
5	Tuff	1.76E+08	0	0.2	0%
6	Unknown	3.01E+10	7.2	30.1	34%
	Total	*8.81E+10*	*21.1*	*88.1*	*100%*

Several cross sections of the 3D model as various angles are shown in Figure 6-5. In general, there is much better subsurface characterization on the east side of the basin compared to the west side, largely due to the limited number and shallower depth of wells found on the west side. The model indicates the presence of a shallow unconfined aquifer and a deep confined aquifer on the northeastern portion of the basin in the vicinity of most of the agricultural production wells. Water levels in the area also indicate the presence of an upper and lower aquifer. Although a laterally continuous confining layer has not been observed, silt and clay units in some areas are estimated to be up to about 860 feet (262 m) thick and laterally extensive enough to provide confining conditions. Water levels collected from multiple depth completion wells (e.g., DMW 2 and DMW 3) indicate that the hydrologic connection between the upper and lower aquifer units on the west side of the basin may vary spatially, but cannot be confirmed in the 3D geologic model due to data sparsity in that area.



Notes:
1. Arrows indicate viewing direction
2. Vertical exaggeration = 5x
3. Faults and wells not shown

Sierra Valley Groundwater Management District

SVHSM Documentation
3D Geologic Model Cross Sections

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12/14/2021

Figure 6-5

7.0 Groundwater-Surface-Water Model (MODFLOW)

Groundwater heads and streamflow within the groundwater basin are simulated using the USGS 3D finite-difference code MODFLOW (Harbaugh, 2005). The Newton formulation (MODFLOW-NWT) (Niswonger and others, 2011) is used, as it better handles drying and rewetting of model cells compared to other versions. The MODFLOW One-Water Hydrologic Flow Model (MF-OWHM v2.0) (Boyce and others, 2020) executable was used to run MODFLOW-NWT as improvements were made to the underlying code that improved run times and output formatting.

The MODFLOW model domain (Figure 7-1) is 216 rows, 243 columns, and 12 layers rotated by 35 degrees counter clockwise around 727096.781207E, 4368418.236840N (NAD 83 UTM Zone 10 N). The grid rotation was to align the principal axes in the groundwater model with the Loyalton and Grizzly Valley faults. Horizontal discretization is 150 m the x and y directions and 37 to 69 m in the y direction, for a total of 105,929 active model cells.

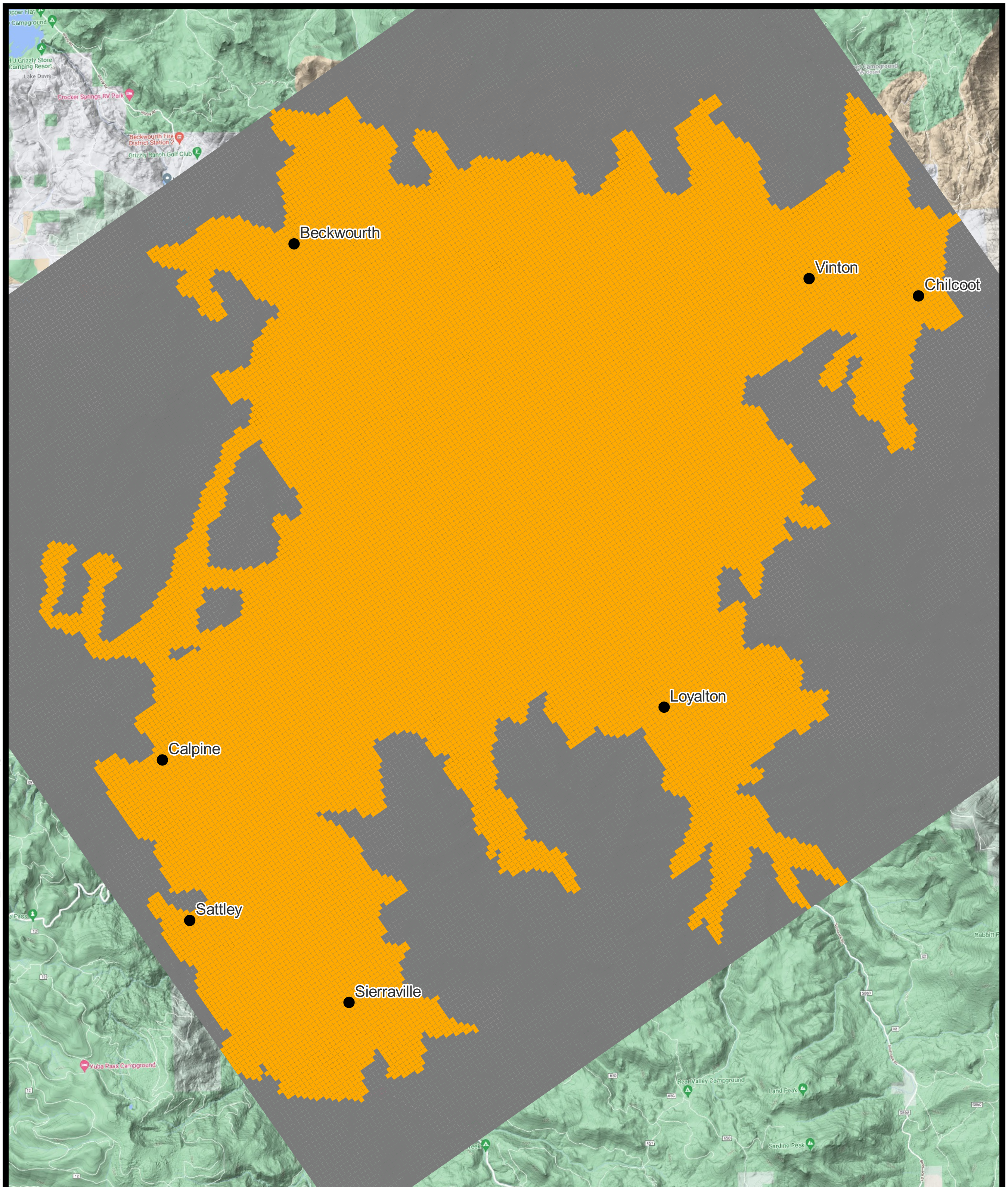
MODFLOW uses a stress period and time step scheme for solving conditions that change with time (transient model). Stress periods are intervals for which boundary conditions (i.e., things that "drive" the model) are specified. Time steps define the interval over which the numerical solution takes place and are always equal to or less than stress periods. SVHSM uses monthly stress periods and daily time steps. This means that boundary conditions (e.g., recharge, pumping, stream inflow) are specified using monthly average values, with groundwater elevations (heads) and streamflow calculated on a daily basis. The historical simulation period is from October 1, 1999 through September 30, 2020.

7.1 MODFLOW Inputs

Inputs to the MODFLOW submodel of SVHSM are specified on a monthly basis, with many inputs being outputs from the other submodels discussed above. Required input files that are not directly written by other submodels or need modifications are generated using a pre-processing script developed in R. This documents a large portion of the workflow for converting the conceptual model of the aquifer system into a numerical simulation, and decreases the time required to update the model in the future.

7.1.1 Hydraulic Properties

The 3D geologic model (see Section 6) was used to define the distribution of hydraulic property zones in the model. Figures 7-2a through 7-2l show the distribution of hydraulic property zones for each model layer. Zones 1 through 6 corresponded with the lithologies represented in the 3D geology model. Zones 7 and 8 are used to represent alteration zones caused by movement of the Loyalton Fault and Grizzly Valley Fault, respectively. These two fault zones are only present in layers 4 through 12, and do not extend to the surface. This was done to reflect the limited movement along the fault the upper sediments have experienced compared to the lower sediments, as the lower sediments were deposited earlier and have more time to accumulate displacement.



Explanation

MODFLOW Grid
Active
Inactive

● City or Town

0 1 2 mi

N

Notes:
1. Active cells in Layer 1 shown

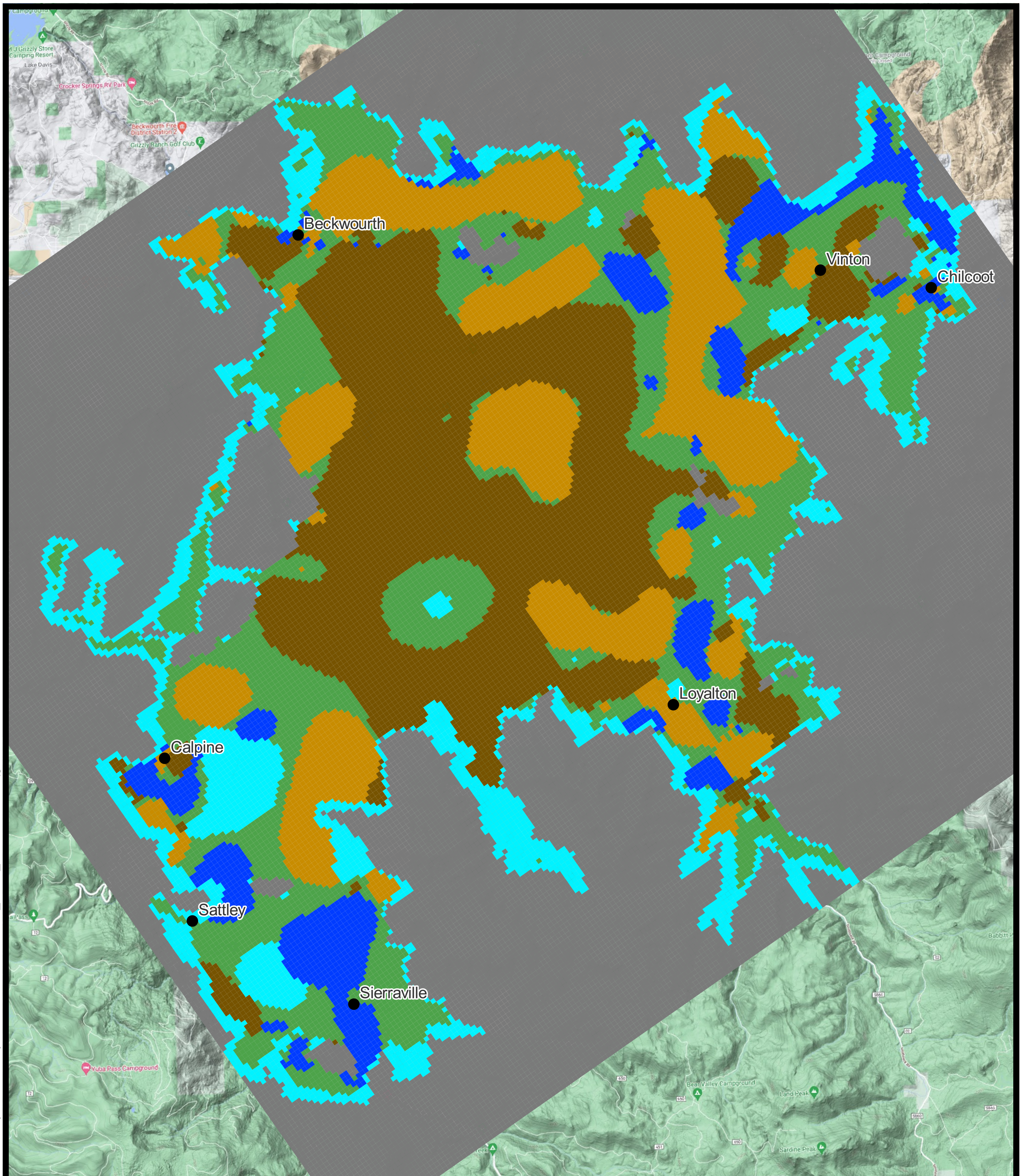
Sierra Valley Groundwater Management District

SVHSM Documentation
MODFLOW Domain

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-1



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 1)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

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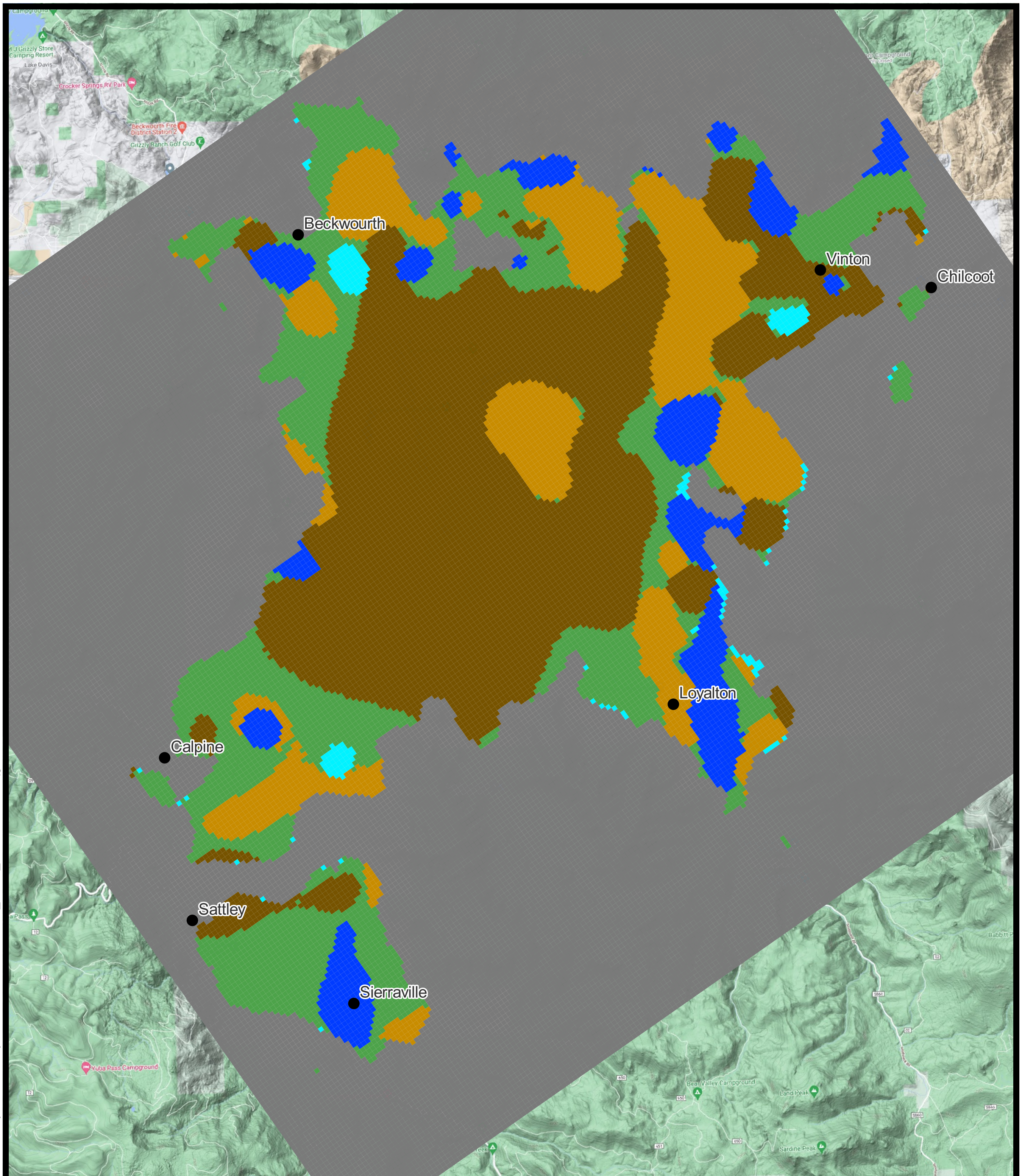
Figure 7-2a



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

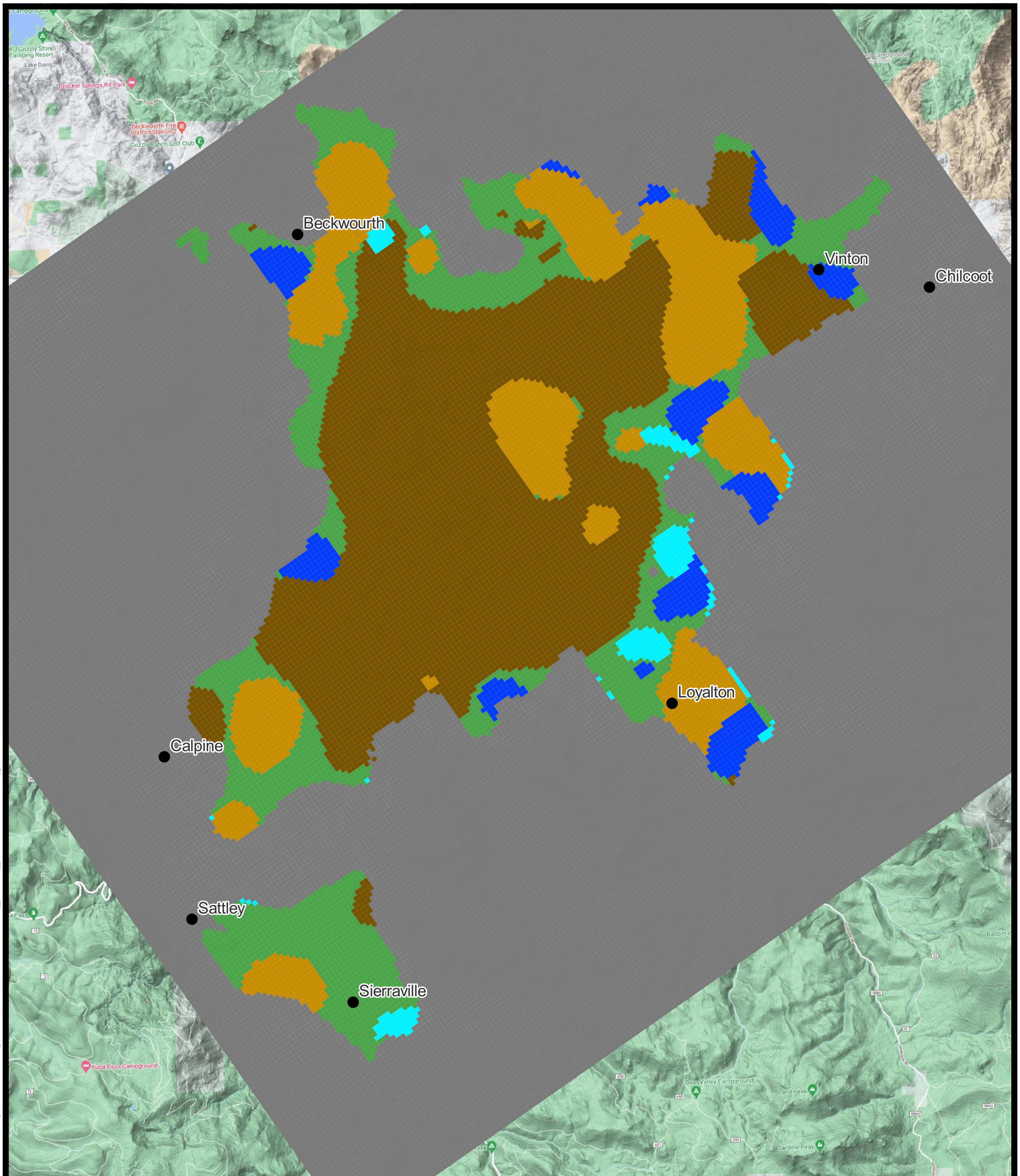
Sierra Valley Groundwater Management District

SVHSM Documentation
MODFLOW Hydraulic Property Zones (Layer 2)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2b



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

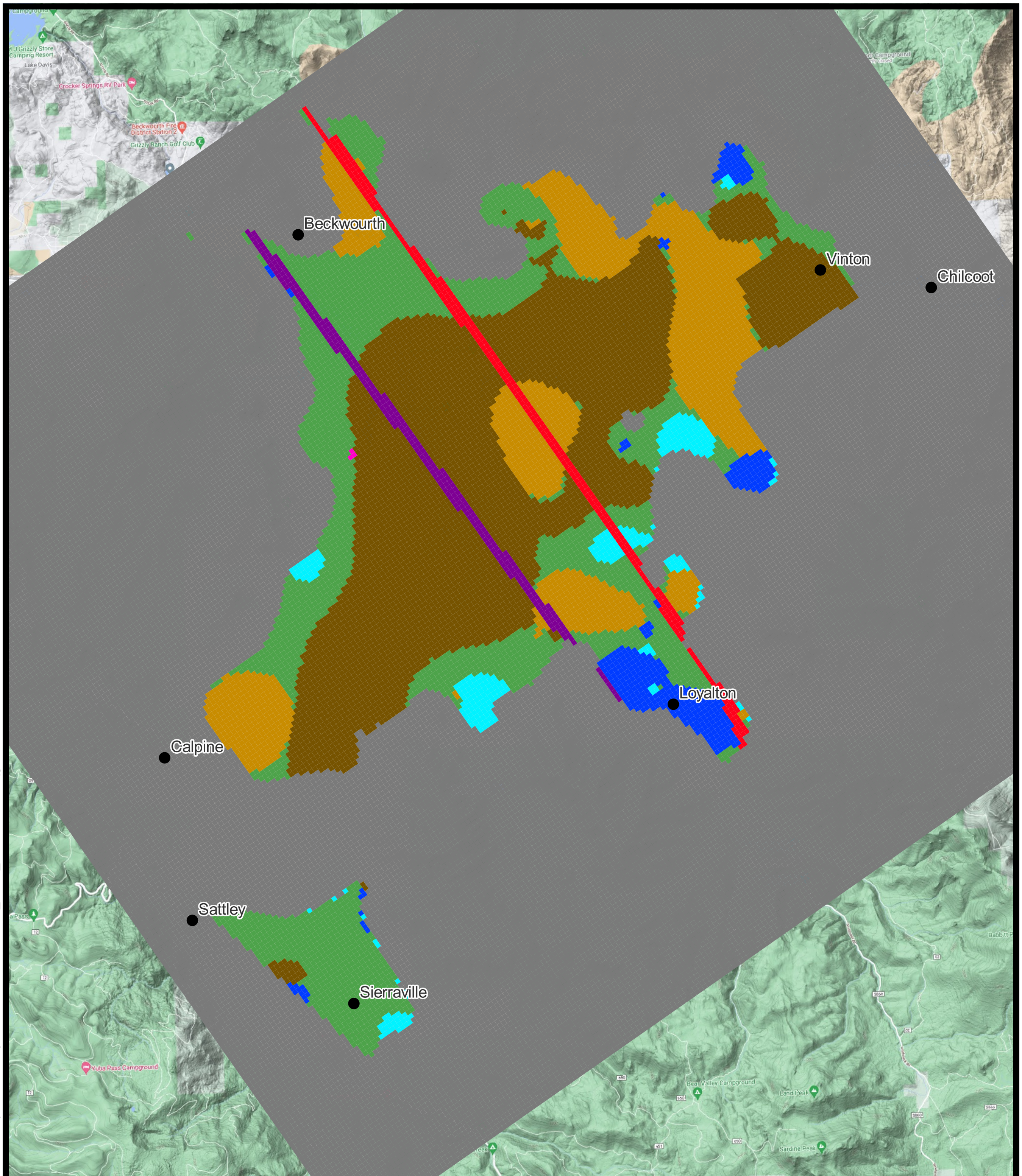
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 3)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2c



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 4)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

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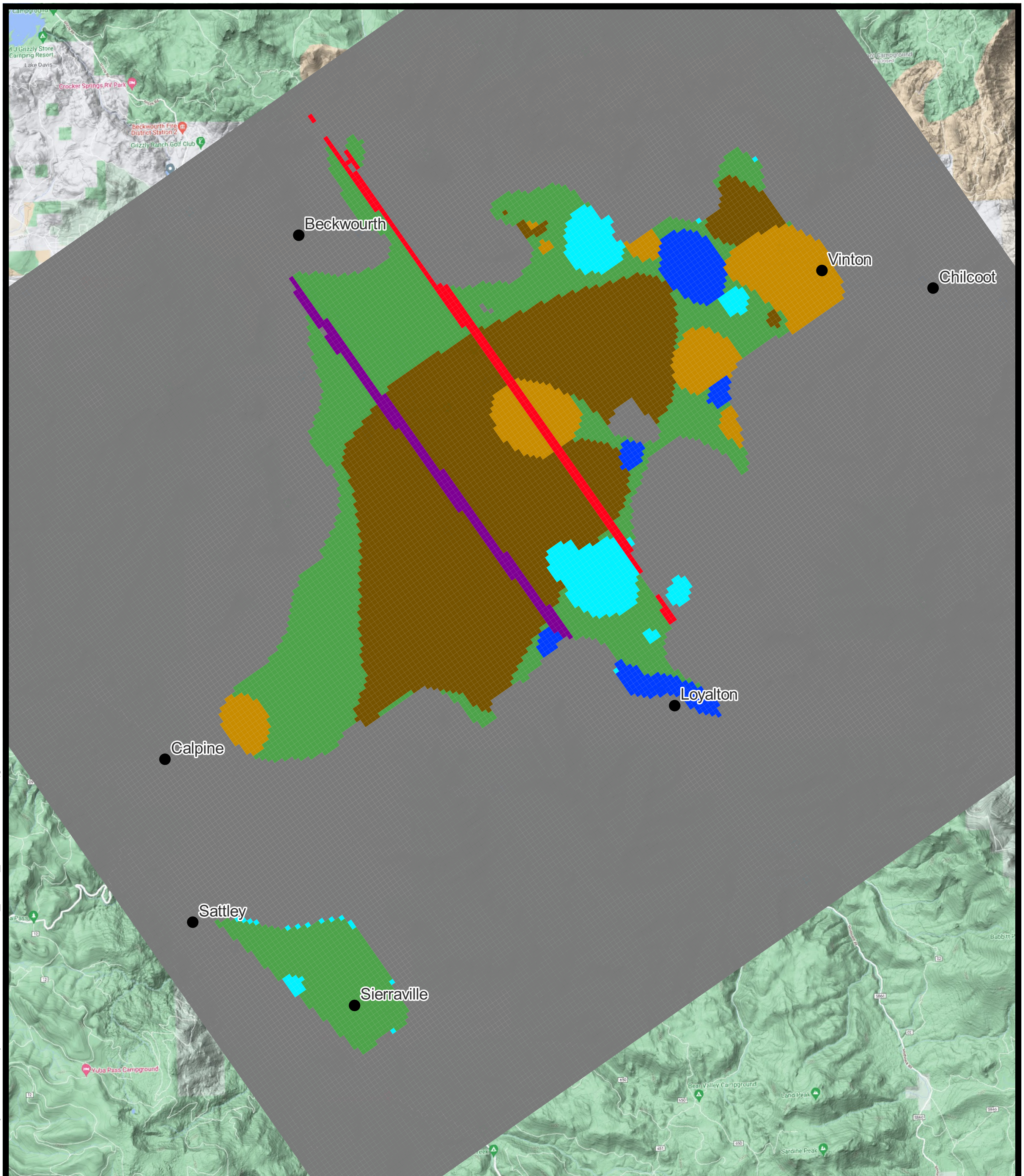
Figure 7-2d



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

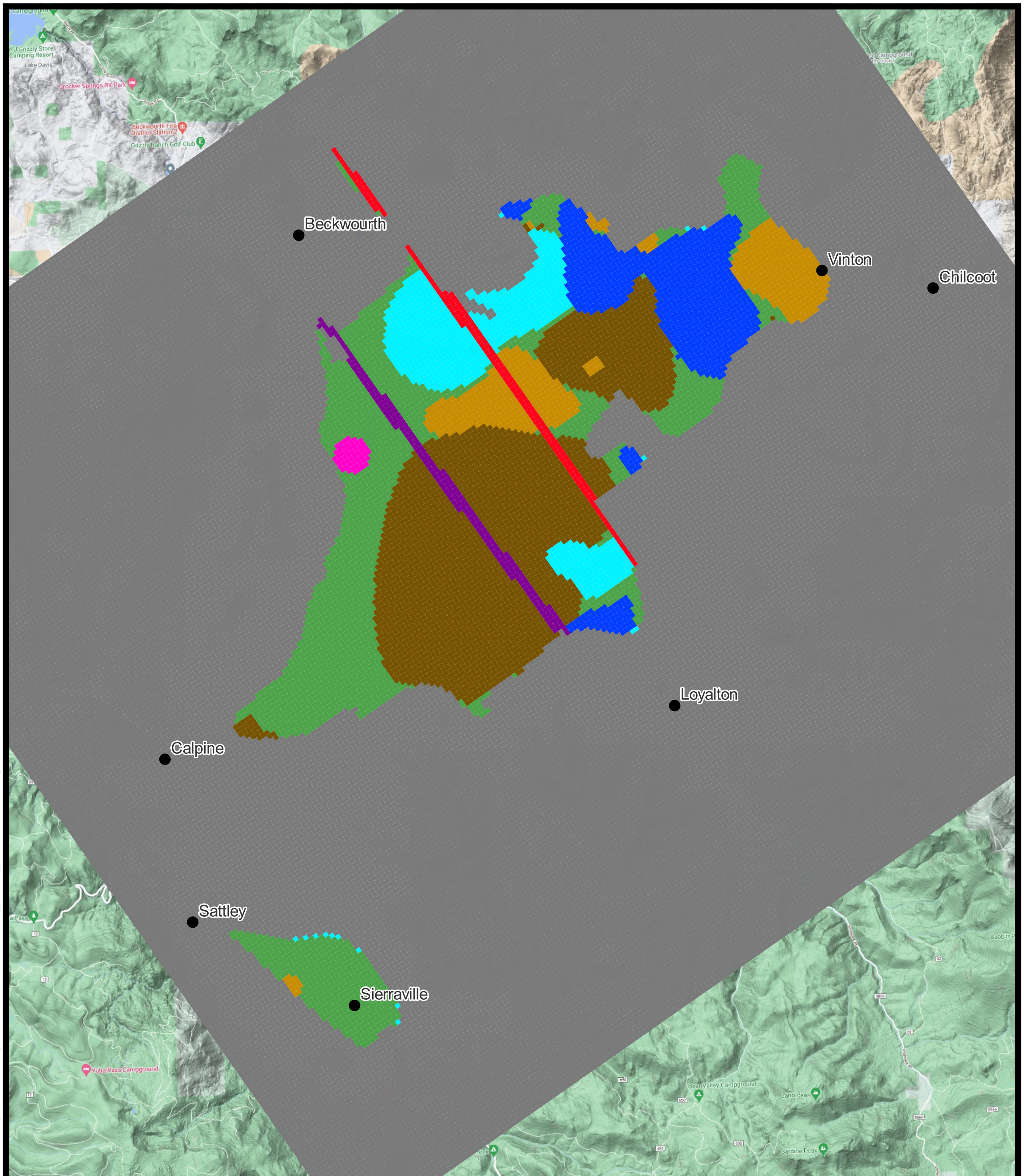
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 5)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2e



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

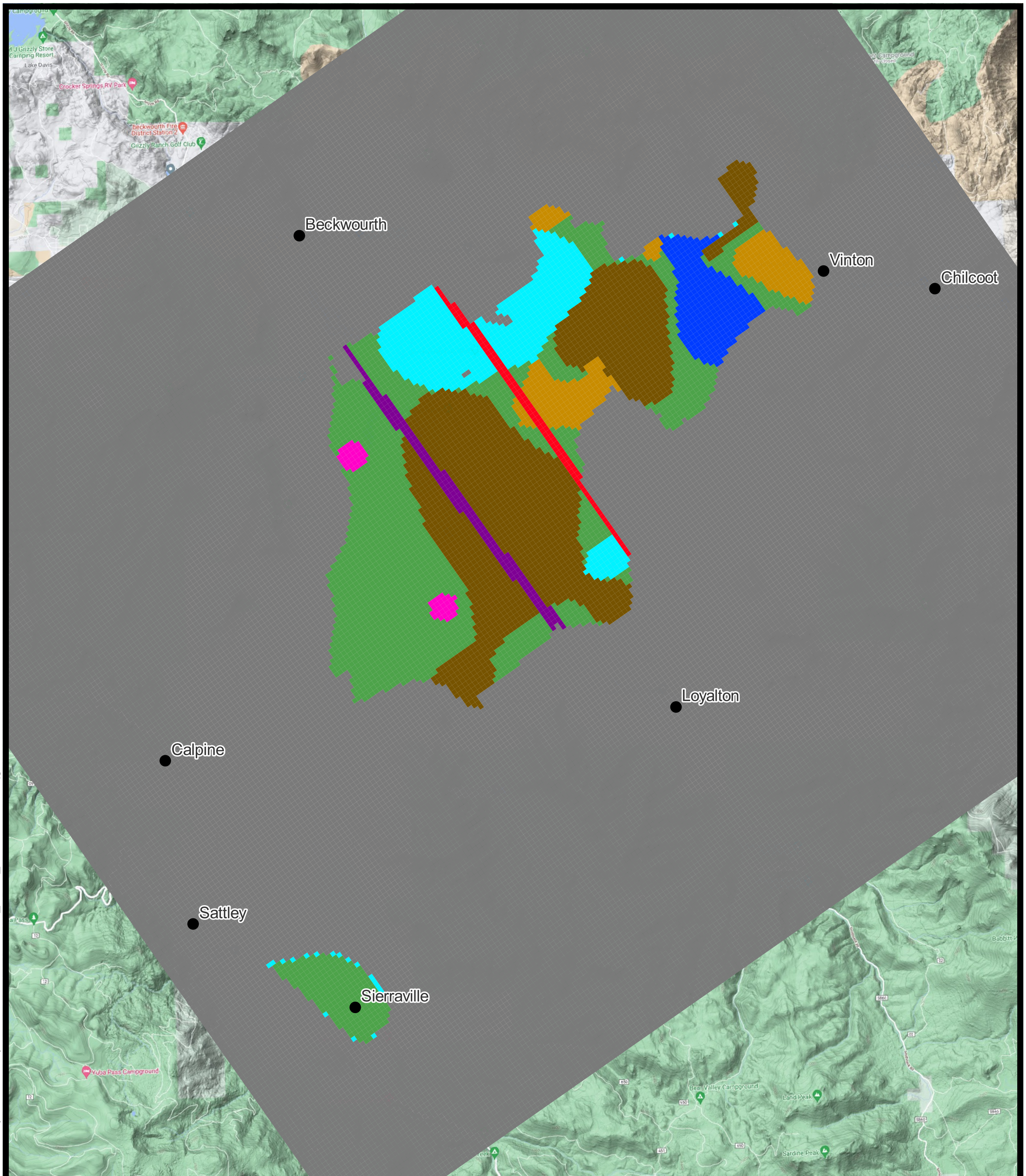
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 6)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2f



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

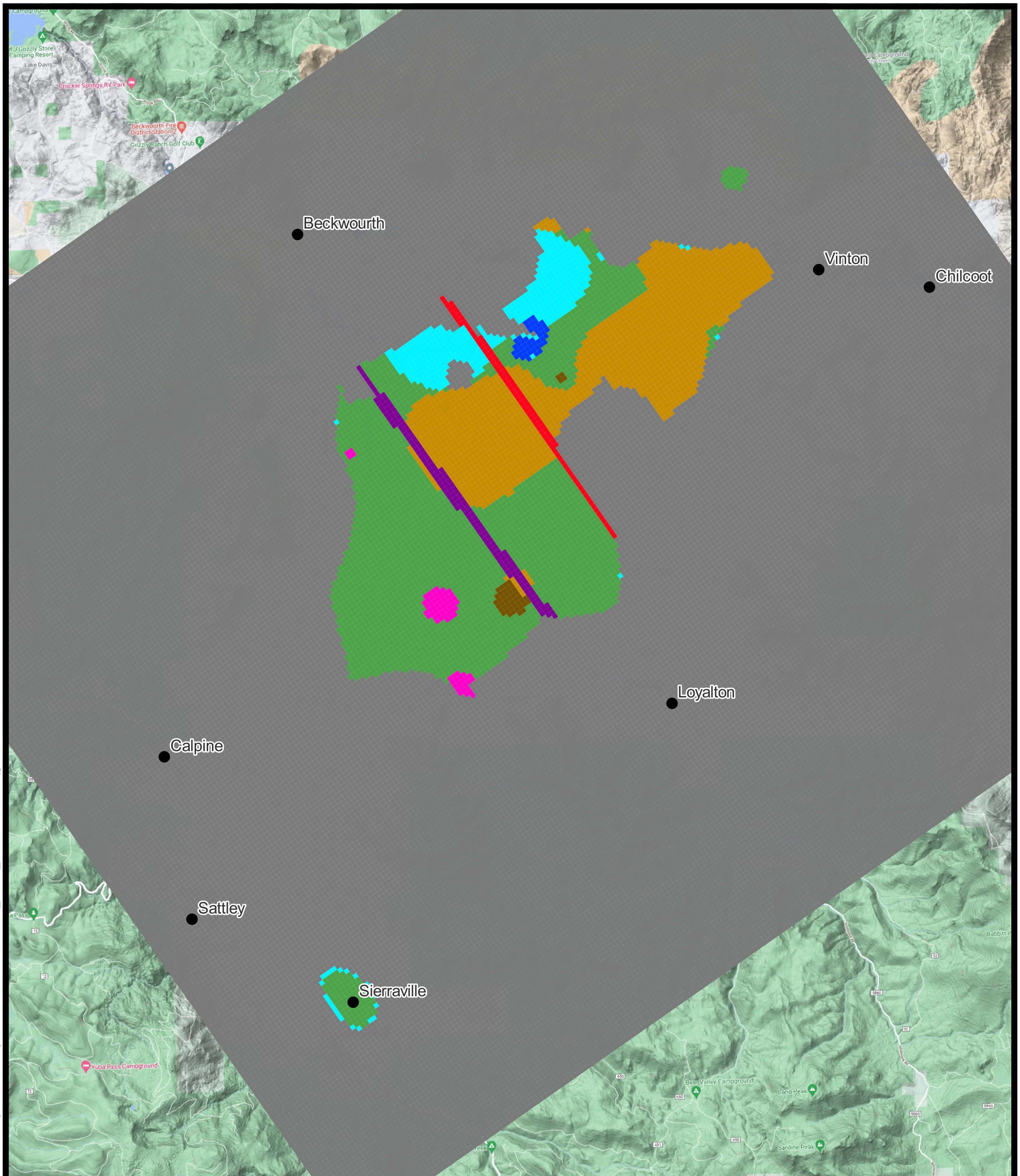
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 7)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2g



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

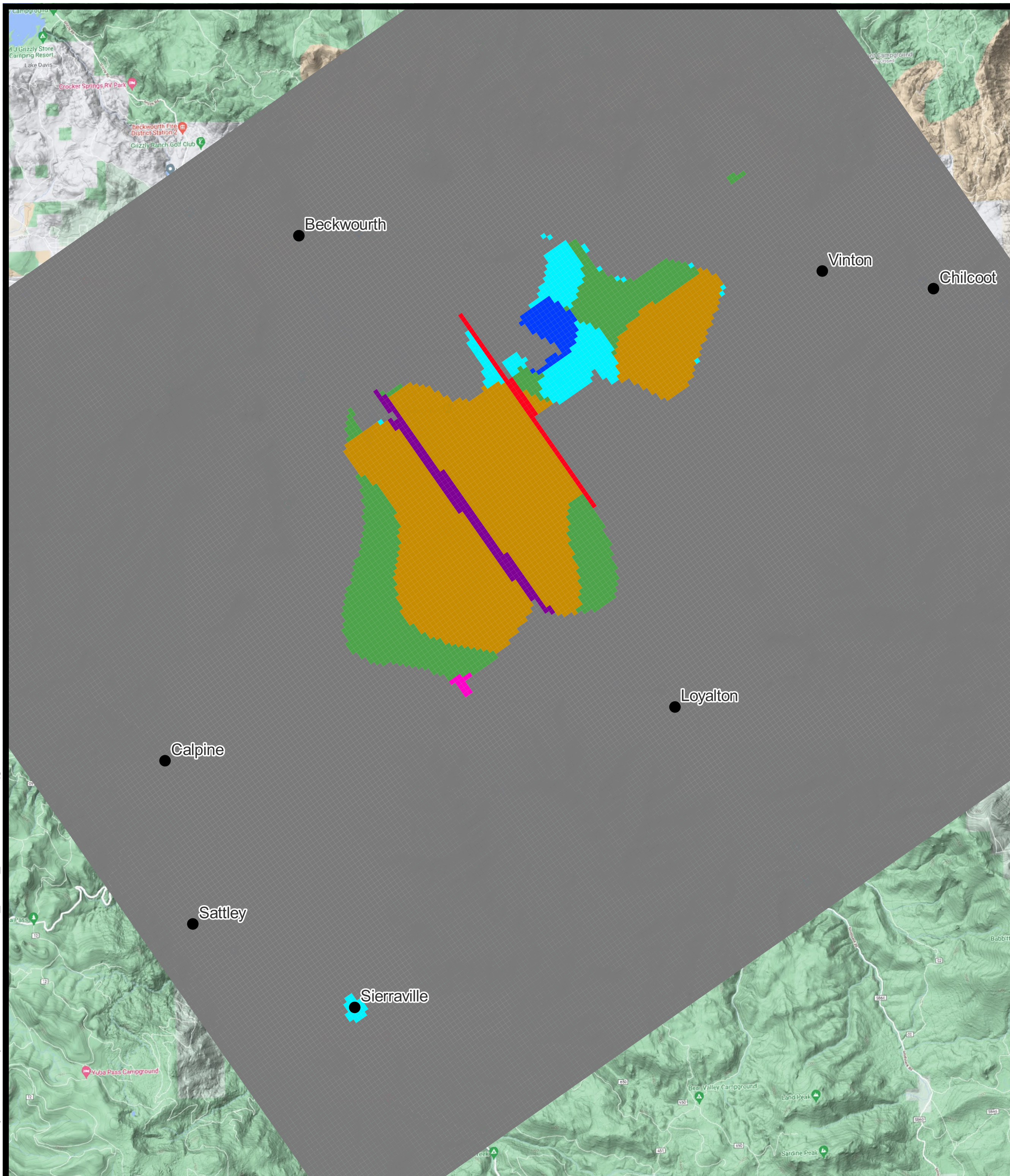
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 8)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2h



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

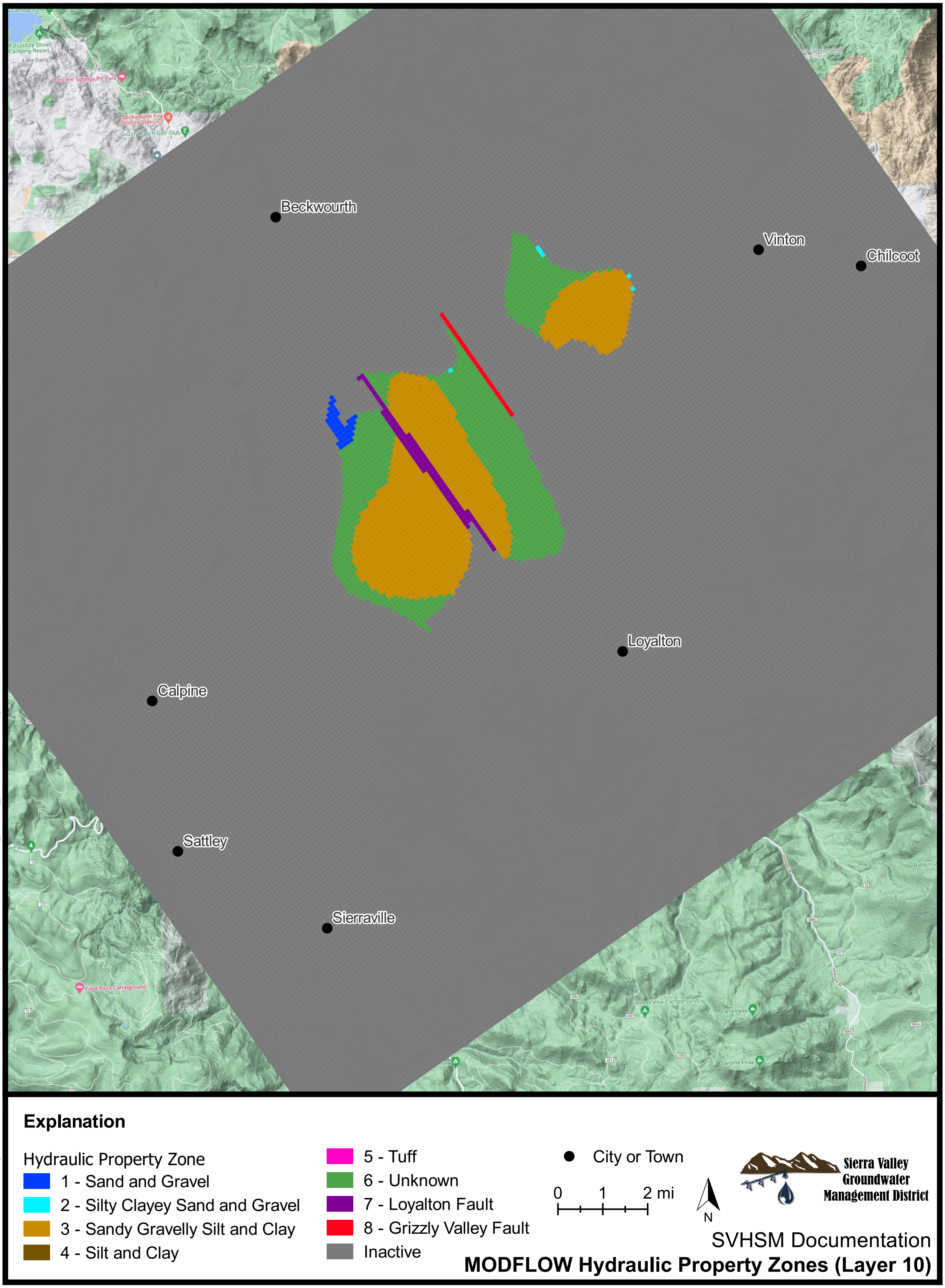
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 9)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2i



SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 10)

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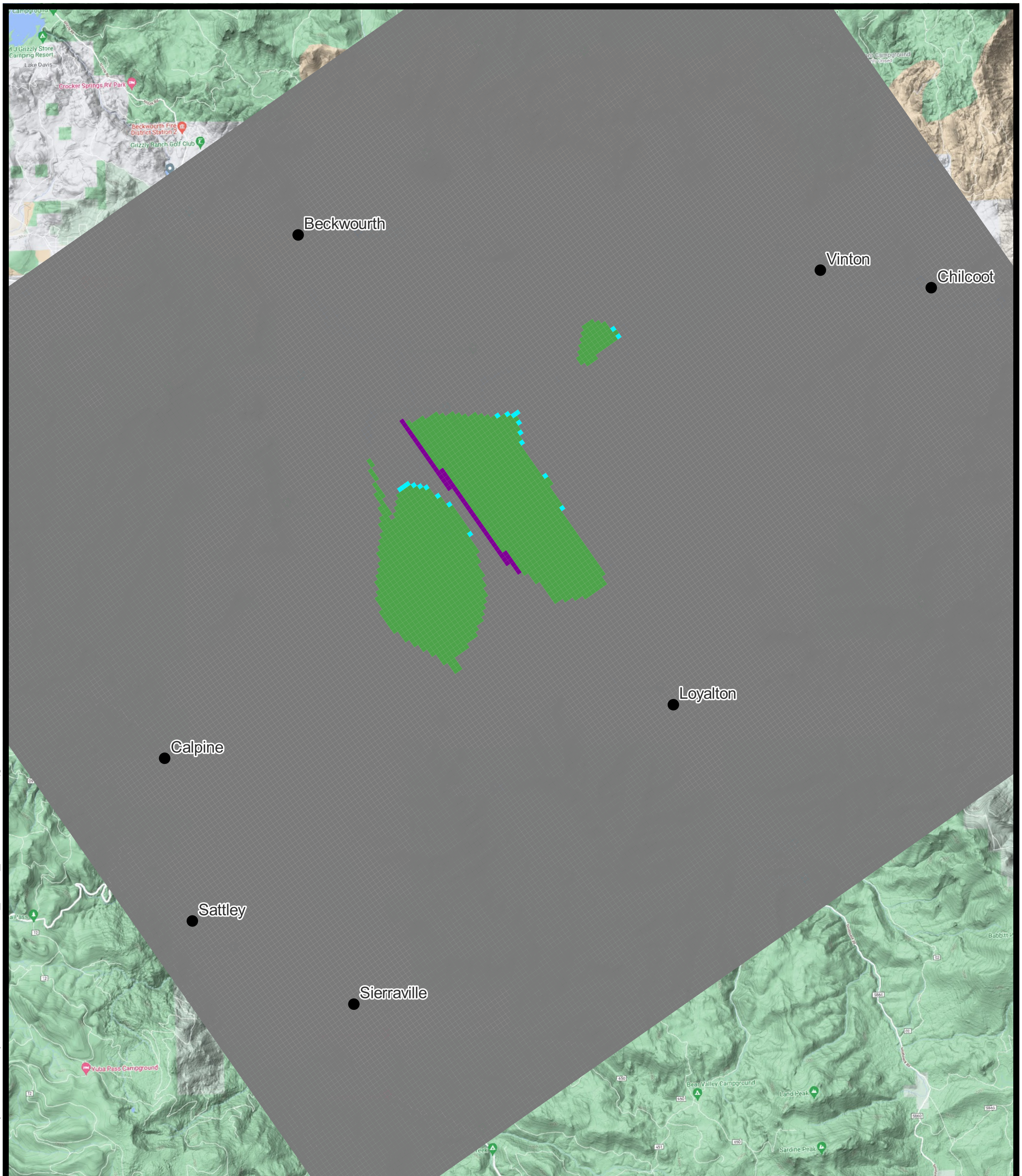
12/14/2021

Figure 7-2j



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

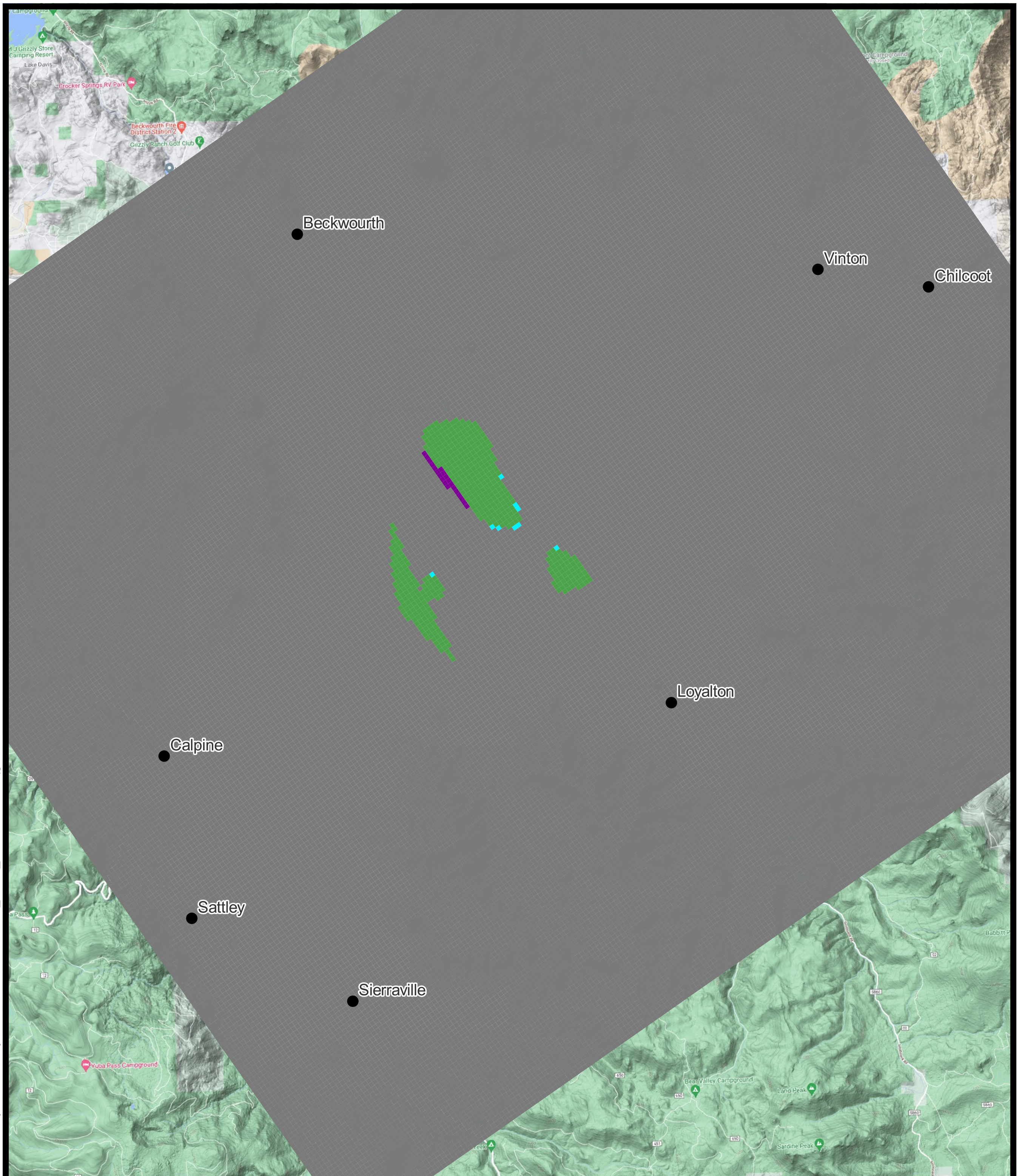
SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 11)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2k



Explanation

Hydraulic Property Zone
- 1 - Sand and Gravel
- 2 - Silty Clayey Sand and Gravel
- 3 - Sandy Gravelly Silt and Clay
- 4 - Silt and Clay
- 5 - Tuff
- 6 - Unknown
- 7 - Loyalton Fault
- 8 - Grizzly Valley Fault
- Inactive

● City or Town

0 1 2 mi

N

Sierra Valley Groundwater Management District

SVHSM Documentation

MODFLOW Hydraulic Property Zones (Layer 12)

C:\Users\500\Sierra Valley GSP Dropbox\Gus Tolley\Sierra Valley GSP\GIS\QGZs\SVHSM_Model_Documentation.qgz

12/14/2021

Figure 7-2l

The hydraulic property zones are used to assign numerical values for horizontal hydraulic conductivity (*HK*), horizontal anisotropy (*HANI*), vertical anisotropy (*VANI*), specific yield (*SY*), and specific storage (*SS*). These parameters control groundwater flow and storage in the MOFLOW model. Calibrated parameter values for each zone can be found in Section 8.XX.X.

The upper three layers of the model are specified as convertible layer types (*LAYTYP*), which represent the upper aquifer as unconfined (). The remaining model layers (4 through 12) are specified as confined. A “Quasi-Three-Dimensional” (Quasi-3D) confining bed was placed between the third and fourth layers of the model in order to better match observed heads and head differences between the upper and lower aquifers. This confining bed restricts vertical flow between layers, and allows for thin aquitards to be represented without adding additional layers (computational expense).

7.1.2 Groundwater Pumping

Agricultural and municipal groundwater pumping in SVHSM is simulated using the multi-node well (MNW2) (Konikow and others, 2010) package due to the presence of long screen intervals for agricultural irrigation wells that spanned multiple model layers. Wells without screen information were assumed to be screened from 10 feet below ground surface to the total well depth. If well depth was unknown, then it was assumed to be 800 feet. Total well depth is missing from about 28% of simulated wells, and screen depth information is missing from about 51% of high capacity pumping wells. Assumptions made in the absence of this data are more likely to bias well and screen depths shallow.

Groundwater inputs to the MODFLOW submodel are estimated by the SWBM or specified by the user. For more details, see Section 5.

7.1.3 Evapotranspiration (ET)

The majority of ET simulated in SVHSM is handled by the SWBM submodel. However, the current version of the SWBM does not simulate direct uptake from shallow groundwater by vegetation. Due to prevalence of wetlands and shallow depth to water in some areas of the groundwater basin, representation of ET directly from the shallow groundwater aquifer was desired. The evapotranspiration segments (ETS) (Banta, 2000) package was used to simulate ET losses from the shallow aquifer. Groundwater that comes within a specified distance of the land surface, referred to as the extinction depth (*ETSX*) is subject to ET in SVHSM. A maximum flux rate (*ETSR*) is specified at the land surface, which decreases linearly to a value of zero at the extinction depth. For example, if the groundwater elevation in a model cell is halfway between the land surface and the extinction depth, then the ET rate at that cell for that time step is 50% of the specified maximum rate.

7.1.4 Mountain Front Recharge (MFR)

Mountain front recharge (MFR) is represented in the groundwater-surface-water submodel using a specified flux boundary applied to selected cells in layers 1-10. Model cells along the perimeter of the active area in each of these layers were chosen and assigned to one of six MFR segments (Figure 7-3). The MFR parameters found in the **SVHSM.pval** input file (e.g., *MFR_1*) represent the total volumetric flux (units of m^3/day) that enters the model across each MFR segment boundary. This flux is distributed between the selected model cells based on lithology. Currently, the MFR flux is constant for each stress period and distributed equally to cells with coarser lithologies (hydraulic property zones 1, 2, 6 ,7, and 8); cells with lower conductivities (hydraulic property zones 1, 2, and 5) are excluded from MFR.

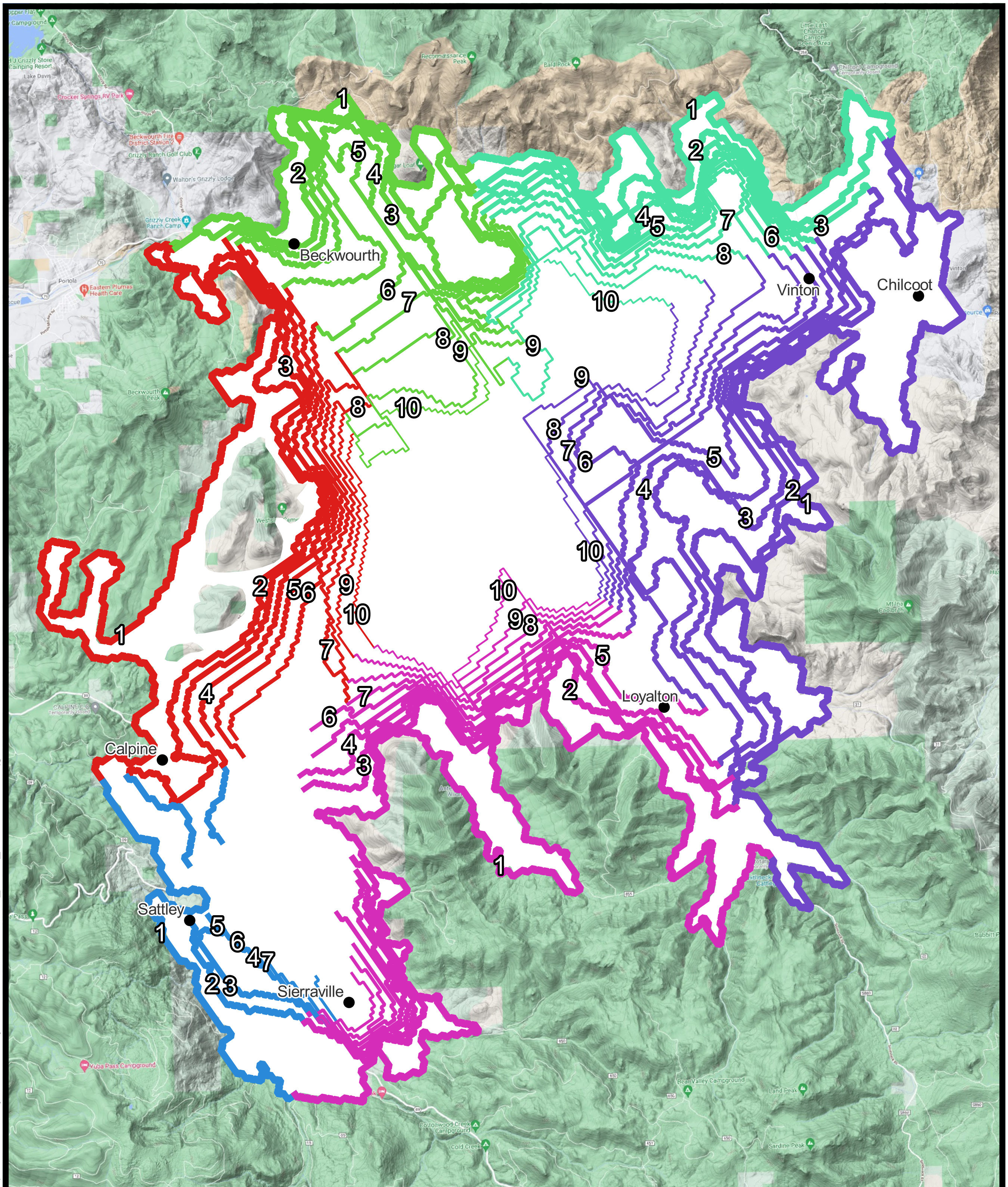
The model development timeline only allowed for limited model calibration, so a detailed evaluation of different representations of MFR could not be completed. For example, MFR may vary intra-annually, inter-annually, or experience a time-lagged cross correlation with recharge in the upper watershed estimated by the PRMS submodel. Evaluation of these conceptualizations would require much more detailed parameterization, computational expense, and analysis, but may ultimately provide greater understanding of watershed-scale recharge processes operating in the basin.

7.1.5 Surface Water

The streamflow routing (SFR2) (Niswonger and Prudic, 2005) package is used to represent surface water flow and interactions between surface water and groundwater within the groundwater basin boundary. The SFR package uses a segment and reach classification system, where reaches are the portion of a stream contained within a given model cell and segments are continuous collections of reaches that define how flow is routed through the system. Physical properties of the streambed can be defined for each specific reach, or be linear interpolated along the segment using specified values for the beginning and end. Typically, segments are defined by the intersection of streams with the model boundary or other surface water features (e.g., confluence of two streams).

Flow rates are specified for each stress period at the margin of the basin where streams enter Sierra Valley. The flows are routed through a stream network specified by the user using one of several available methods. Exchanges between groundwater and surface water are treated as either a general head boundary (i.e., flux is dependent on water levels) or a constant flux boundary if groundwater levels drop below the bottom of the streambed in that model cell.

The surface-water network in the Sierra Valley is a complex system of low-gradient, interconnected natural stream channels and unlined canals. This complex network was condensed into 51 stream segments based on available data and stakeholder feedback that represent the major surface water features in the valley. From a modeling perspective, groundwater-surface-water exchange processes are the same for a natural streambed as an unlined canal, so no differentiation was made between the two in the model (Figure 7-4). Specification of diversion information is required at seven locations where a stream segment splits (bifurcates) into two downstream segments.



Explanation

MFR Segment
- MFR 1
- MFR 2
- MFR 3
- MFR 4
- MFR 5
- MFR 6

● City or Town

0 1 2 mi

N

Notes:
1. Annotations indicate model layer
2. Thinner lines denote deeper model layers

Sierra Valley Groundwater Management District

SVHSM Documentation
MODFLOW Mountain Front Recharge

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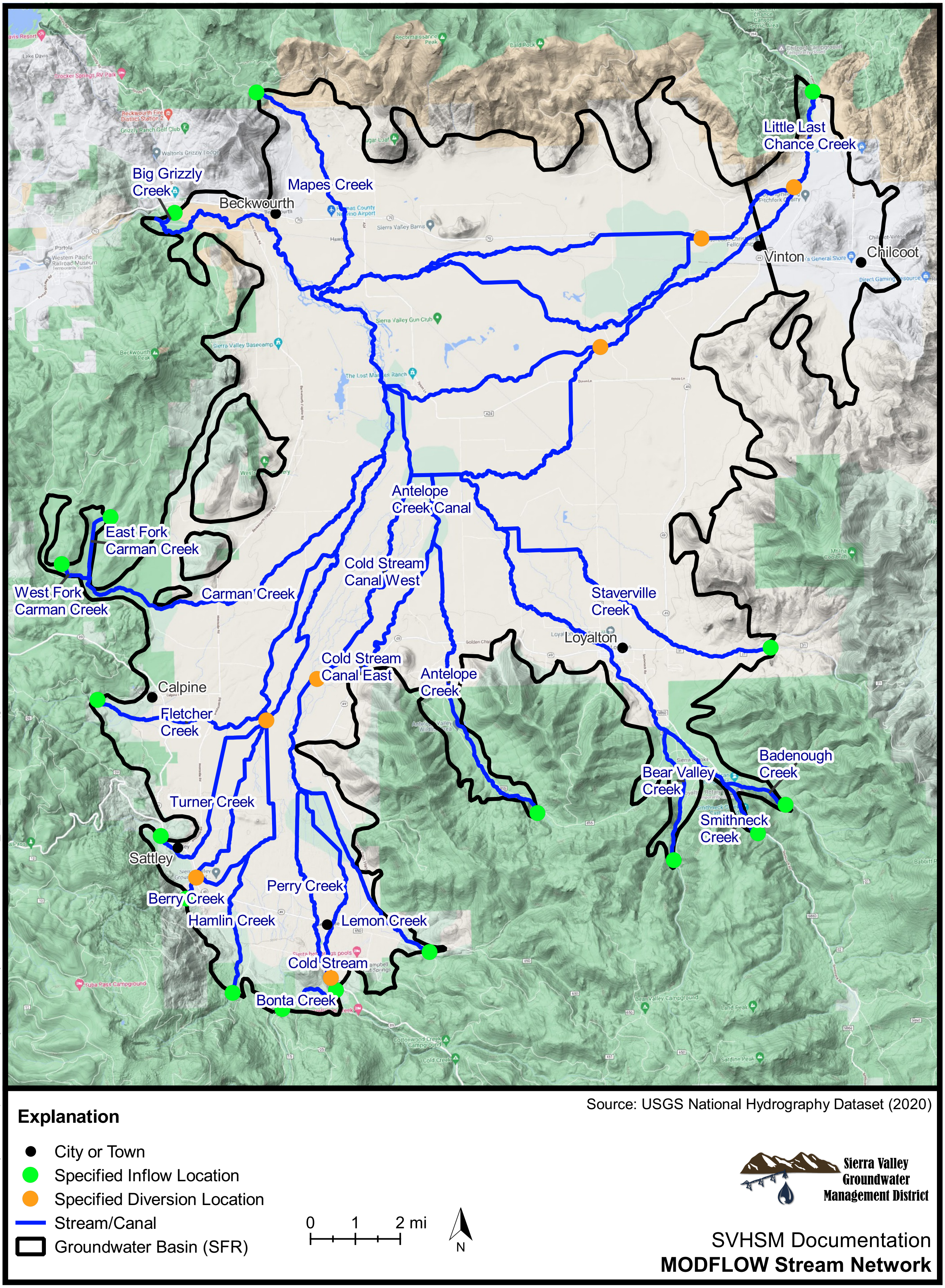
Figure 7-3



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SVHSM Documentation
MODFLOW Stream Network

12/17/2021

Figure 7-4

Due to a lack of detailed diversion information within the valley, flow from the upstream segment was evenly split between the two downstream segments.

Flows are routed through the network using Manning's equation. Solution of this equation requires physical parameters related to the slope, geometry, and roughness of the streambed for be specified for every reach in the segment, as well as a numerical boundary condition for the stream segment itself. Streambed slope was calculated for each reach using elevations extracted from the digital elevation model (DEM) at the centroids of each reach and the distance between them along the stream channel. Channel geometry is assumed to be rectangular with stream widths defined using aerial imagery. Channel roughness for all segments was set to 0.035, which is appropriate for cultivated areas with mature field crops (Chow, 2009). Inflow rates are specified for each stream where it enters the groundwater basin for every stress period (month) during the simulation to satisfy the numerical boundary condition requirement. Stream inflows to SFR are those input to the SWBM minus any surface water irrigation.

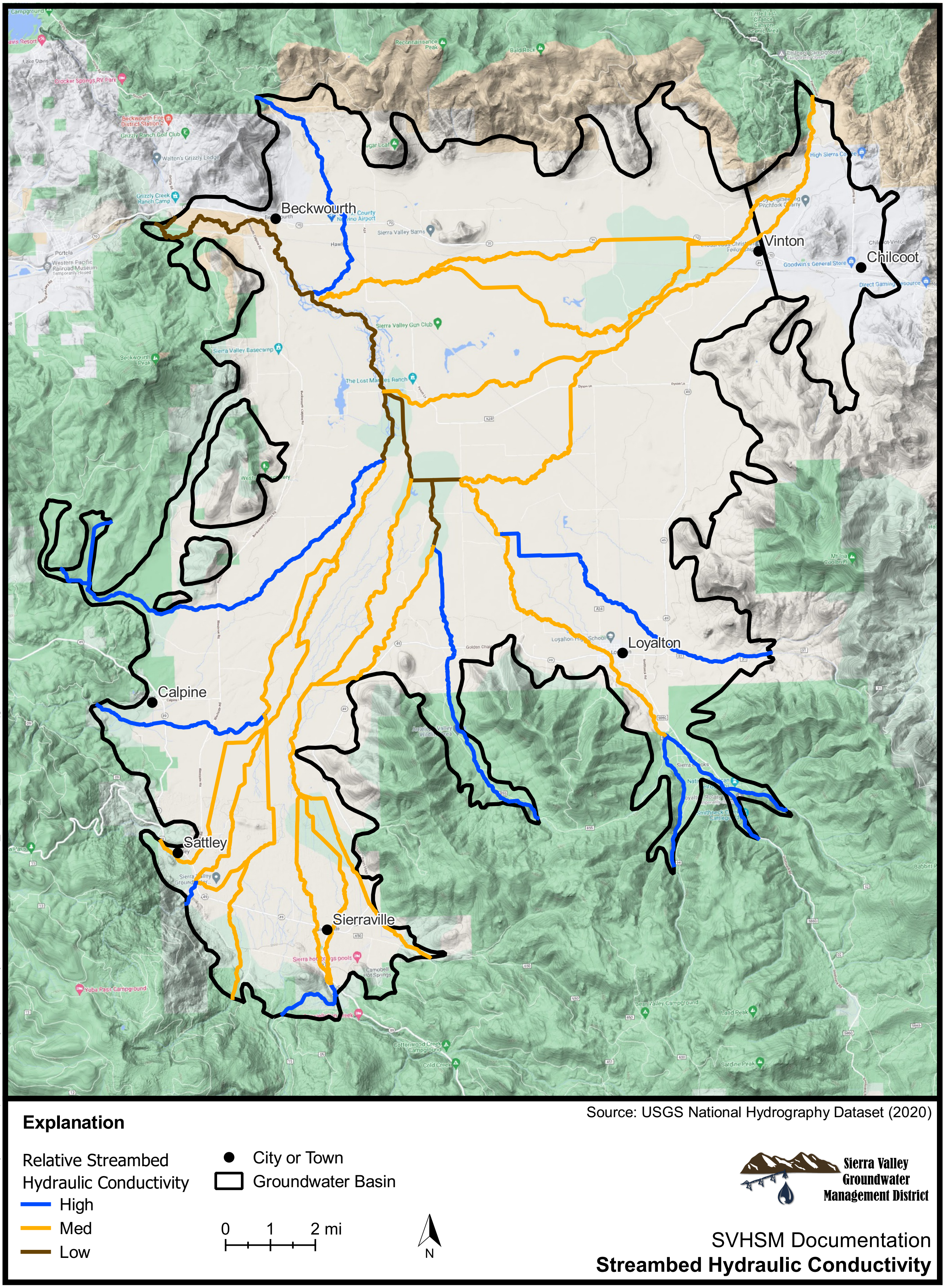
Relative streambed hydraulic conductivities were assigned to each reach (Figure 7-5) that, together with stream and groundwater elevations, control groundwater-surface water exchanges. High streambed conductivity results in strong communication between the groundwater and surface water system, while low streambed conductivity restricts exchanges between the two. Generally, streambed hydraulic conductivity is highest along the margins of the valley and decreases toward the center and outlet of the valley.

7.2 MODFLOW Outputs

Outputs from the MODFLOW submodel of SVHSM include detailed water budget, groundwater elevation, and streamflow data. Frequency of MODFLOW simulation output is specified by the user in the output control file (**SVHSM.oc**); it can vary depending on the output data type and be as detailed as every time step or as coarse as a summary of the entire simulation. Simulated output in SVHSM is generally saved at the end of each month (stress period), except for streamflow data at specified gage locations where output is saved on a daily basis. This frequency was chosen as it allows for evaluation of intra-annual changes while keeping output files to a manageable size.

7.2.1 Groundwater Elevations

Groundwater elevations, also referred to as groundwater heads, are saved at every active cell in the model domain at intervals specified by the user in the output control file. In SVHSM, heads are printed at the end of every stress period (month). Due to the large number of active model cells and stress periods, this file (**SVHSM.hds**) is written into a binary format to reduce the file size and therefore cannot be viewed in a text editor directly like most of the other model input and output files. The file **Read_MODFLOW_heads.R** included in the model post processing R script library on the project repository (https://github.com/gustolley/SVHSM) can be used to translate the binary file into an ASCII format that can be read by standard text editors.



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12/17/2021

Figure 7-5

Groundwater elevations can be extracted for the entire model domain for a specific stress period, or as a time series for all layers at a specific row-column location. Other freely available options for reading the groundwater elevation data include the USGS software ModelMuse (https://www.usgs.gov/software/modelmuse-graphical-user-interface-groundwater-models), Python scripts (https://github.com/modflowpy/flopy), or other R scripts (https://rdrr.io/cran/inlmisc/).

The other location groundwater heads in the model are saved is the head observation (HOBS) package output file (**SVHSM_HOB_out.dat**). Data written to this file are simulated and observed groundwater elevations at the corresponding location and time of observations provided in the HOBS input file (SVHSM.hob) and are used to evaluate model performance (see Section 8). The file can be viewed with a standard text editor.

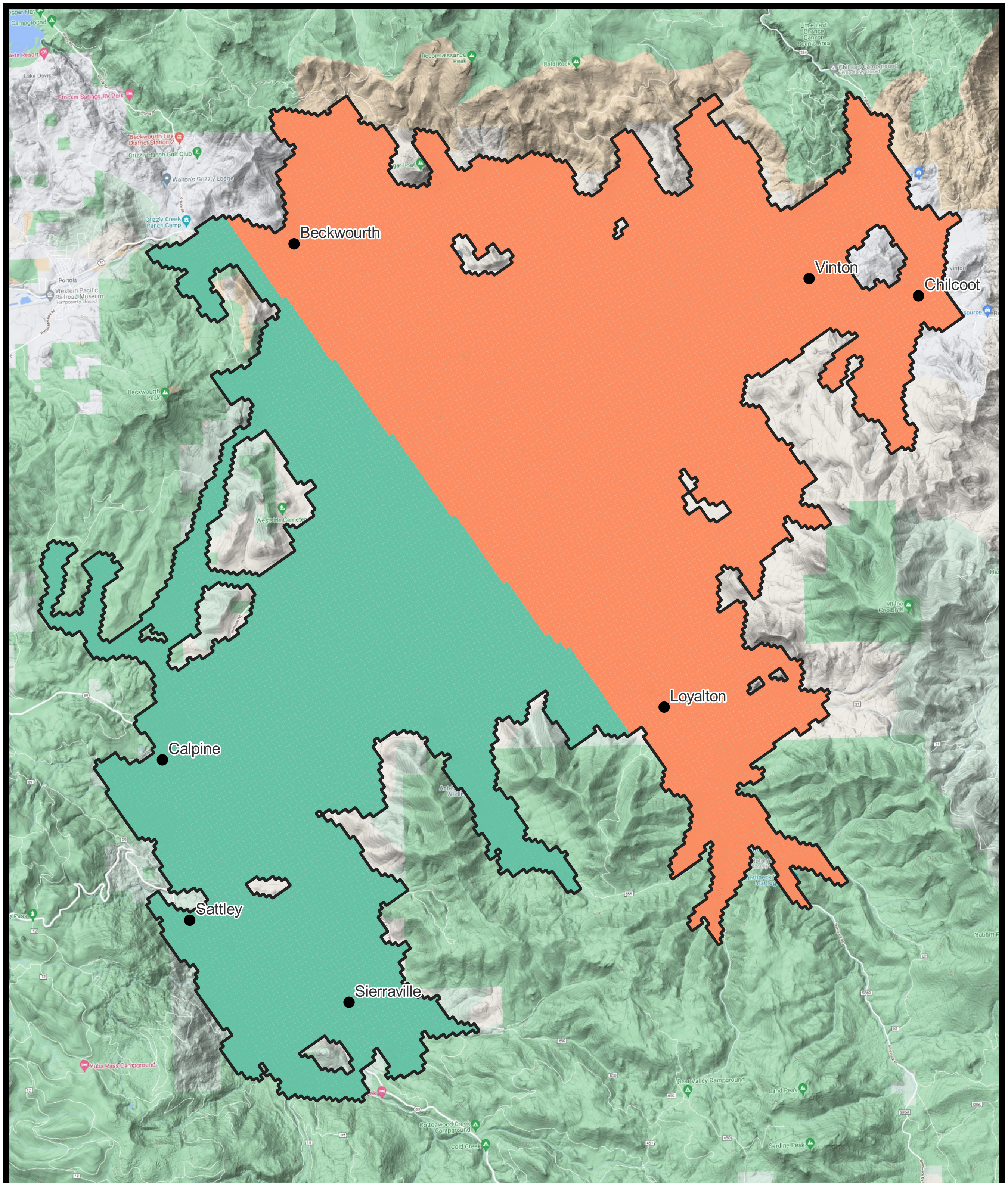
7.2.2 Water Budgets

MODFLOW tracks the movement (flux) of water into, within, and out of the model domain which allows for development of detailed water budgets. Summary water budgets for the entire model are printed at intervals specified by the user in the output control file. Fluxes are grouped according to the physical process represented in the model, such as groundwater pumping, recharge, and change in storage.

Water budgets are printed to several different output files. A model summary of cumulative flux volumes and daily flux rates for the time step specified in the output control file are printed to the listing file (**SVHSM.lst**). For SVHSM, this means that cumulative volumetric water budgets are printed at the end every month along with the flux rates for the last day of each month. A new feature in MF-OWHM v2.0 is the ability to print water budgets for every time step directly to a spreadsheet formatted file. This is done by specifying a filename for the *BUDGETDB* parameter in the options list at the beginning of the basic package (BAS or BAS6) input file (**SVHSM.bas**). In SVHSM, this file is named **MODFLOW_Budget.dat**. Both the listing file and the spreadsheet formatted budget file can be viewed with standard text editors.

Cell-specific fluxes are written to the cell-by-cell budget file (**SVHSM.cbb**) at intervals specified by the user in the output control file. In SVHSM, these fluxes are saved for the last day in each month and can be used to evaluate water budgets for specific portions of the model, as opposed to the summary (global) budgets exported to the listing file and spreadsheet formatted budget file. This is done by specifying zones within the model domain and using the ZONEBUDGET program (https://www.usgs.gov/software/zonebudget-program-computing-subregional-water-budgets-modflow-groundwater-flow-models) to extract the saved flux rates.

Two different zonations were created to evaluate water budgets spatially in SVHSM. The first separates the eastern and western portions of the groundwater basin separated by the Loyalton Fault (Figure 7-6). The second uses the same east-east differentiation but also subdivides the eastern portion of the basin into an upper and lower zone; the upper zone is defined as the top three layers of the model. The values extracted using ZONEBUDGET are flux rates for the time step during which they are printed, as opposed to the volumetric fluxes saved in the global water budgets.



Explanation

Budget Zone
- Eastside
- Westside

- City or Town
- Active MODFLOW Domain Boundary

Notes:
1. Active cells in Layer 1 shown

0 1 2 mi

N

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Water Budget Zones

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Figure 7-6

While most fluxes are generally constant during the stress period (e.g., pumping and recharge), some fluxes are dependent on water levels (e.g., groundwater-surface water exchange and ET), which can change over the stress period. The flux rate for a given budget component saved at the end of the month may not be the same as that at the beginning of the month, which can potentially result in significant extrapolation errors if converted to monthly volumes. Therefore, ZONEBUDGET results are presented with rate units as opposed to volume units used in the global water budgets.

7.2.3 Streamflow

Streamflow simulated using the SFR package in MODFLOW can be exported several different ways. Commonly, time-series data at a specific location are desired in order to compare simulated streamflow with observations from a stream gage. The streamflow gaging (GAGE) package in MODFLOW allows the user to specify SFR reaches where outputs are saved for every time step. The current version of SVHSM only has a single model gage located at the most downstream reach in the surface water network (Figure 7-4), with results saved to **SVHSM_streamflow_MFFR.dat**. This represents the Middle Fork Feather River gage near Portola (MFP) (http://stratus.water.ca.gov/dynamicapp/QueryF?s=MFP) operated by DWR. While the simulated location of the gage is approximately 0.8 mile (1.3 km) upstream of the actual location, streamflow at both locations is assumed to be similar as no tributaries enter between the two and groundwater-surface water exchanges are expected to be minor given the short distance. Files produced by the gage package can be viewed with any standard text editor.

Results for all simulated reaches are also printed at intervals specified by the user in the output control file. In SVHSM, SFR results are printed at the end of every stress period (month) to **SVHSM_Streamflow_Global.dat**. This provides a snapshot in time of conditions for the entire streamflow network. A new feature in MF-OWHM v2.0 is the ability to export detailed streamflow data for the entire surface water network at every time step directly to a spreadsheet formatted file. This is done by specifying a filename for the *DBFILE* parameter in the options list at the beginning of the SFR package input file (**SVHSM.sfr**). In SVHSM, this file is named **SFR_out.dat**. Although both reach budget files can be viewed with a standard text editor, they are they are considerably large (3-6GB file size) and therefore may take considerable time to open.

8.0 Sensitivity Analysis and Calibration

A numerical model can generally be partitioned into two development categories: (1) parameterization and (2) numerical value assignment to the parameterization. Parameterization in the context of integrated hydrologic models is the establishment of the physical framework, or structure, and what/how different real-world hydrologic processes are to be simulated. Structural components of SVHSM are discussed in Sections 4 through 7, and generally include things like how the subsurface sediment distribution is represented, how different boundary conditions (e.g., pumping, streams, MFR) are distributed throughout the model domain, and specific hydrologic processes are represented within the numerical model. Some structural model elements have a relatively high degree of certainty because they can be easily observed (e.g., topography, landcover, stream locations). Others can vary with location due to differences in data density (e.g., subsurface sediment distribution), and some have a high degree of uncertainty because they cannot be directly observed (e.g., MFR).

Once the model parameterization has been prescribed, numerical values for physical properties or boundary condition fluxes must be assigned in order to solve the system of equations posed by the numerical model. For example, eight lithology categories were used to represent the subsurface in SVHSM. The distribution of these categories in each layer is how the model was parameterized, but physical values that represent hydraulic conductivity, anisotropy, and storage must be assigned to each of these categories. Parameter values are rarely a fixed (scalar) number but instead occur over a likely range (distribution). Hydraulic conductivity is commonly used to demonstrate this, as naturally occurring values range over eight orders of magnitude. Additional information such as the sediment type being represented can be used to constrain the range to within a few orders of magnitude, but that still covers a wide range of possible values.

Sensitivity analysis and calibration are two tools that are used to assess model parameterization and define optimum parameter values. Sensitivity analysis is used to evaluate which parameters have the greatest impact on simulated results by comparing changes in simulated output when parameter values are adjusted. Model calibration, also known as inverse modeling, is the process of adjusting parameter values so that the difference between simulated and observed values is minimized. Both methods can inform parameterization and parameter value assignment, and can be performed manually or using automated software.

8.1 Methods

Sensitivity analysis and calibration of SVHSM was performed manually for the PRMS submodel while an automated method was used for the SWBM and MODFLOW submodels. Manual methods were chosen for the PRMS model, as the input file structure makes it difficult to automate with a reasonable number of parameters. In addition, the lack of streamflow data would likely result in what is referred to as an "underdetermined" problem, where the number of knowns (observations) is less than the number of unknowns (parameters). Therefore, the effort required to develop the input files required for PRMS to be evaluated with automated methods was not considered to be an efficient use of the limited time available. This may change in the future if additional observations are collected within the PRMS model domain area.

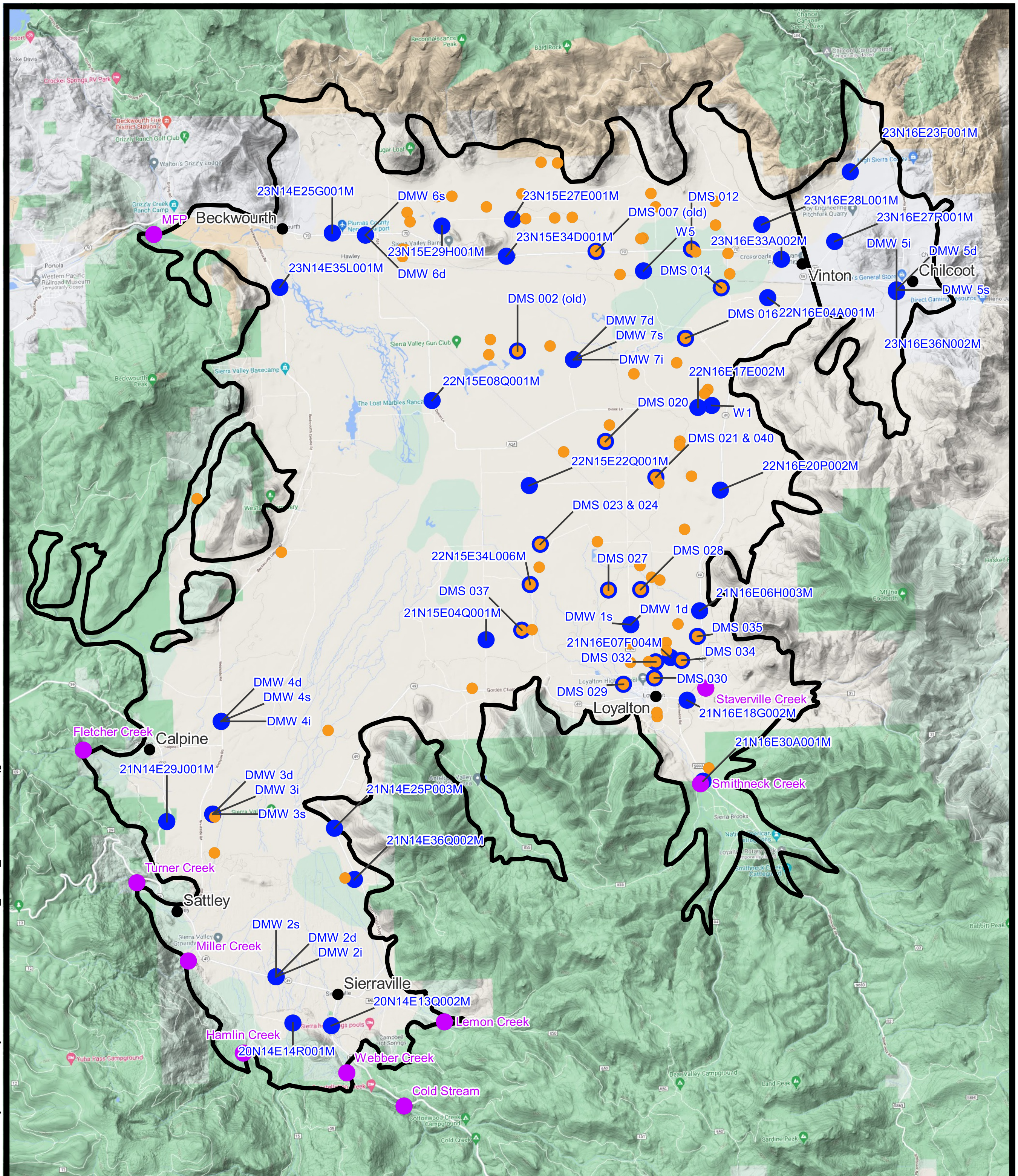
Sensitivity analysis and calibration of the SWBM and MODFLOW submodels of SVHSM was performed using the universal inverse modeling software suite UCODE_2014 (Poeter and others, 2005 and 2014) (https://igwmc.mines.edu/ucode-2/) which compares measured observations (e.g., groundwater elevations, streamflow rates, pumping volumes) with simulated equivalents in the model. Residuals, or the differences between simulated equivalents and measured observations, are aggregated into a single value referred to as the objective function which represents a numerical valuation of the overall mismatch between the two for the entire model. A reduction of the objective function value generally means the model is a better representation of the system, as it is producing similar conditions to those observed. Because most physical aquifer properties do not vary with time, once optimum parameter values for a historical time period have been identified, future conditions can be estimated by altering the model boundary conditions appropriately.

The forward-difference perturbation technique available in UCODE_2014 was used to perform sensitivity analysis on 79 identified parameters. Parameter values were increased one at a time by 1% from their starting values. Initial parameter values where chosen based on previously published values and expert judgement. Parameter sensitivity is fit-independent for linear models, meaning that the same sensitivities are calculated whether or not parameter values are at their optimum value. For highly nonlinear models, parameter sensitivities can change depending on the choice of initial values (Tolley and others, 2019) even when model structure is not altered. Inclusion of groundwater-surface water interactions generally adds nonlinearity to a numerical model. Unfortunately, the project timeline did not allow for evaluation of model nonlinearity so a linear model was assumed. Evaluation of the degree of nonlinearity of SVHSM could be conducted using UCODE_2014 as part of future sensitivity analysis and calibration efforts.

Selected model parameters based on the sensitivity analysis results were then adjusted automatically using the parameter optimization mode in UCODE_2014 in an attempt to minimize the objective function and therefore provide the best match between observed and simulated values. Convergence was met when either parameter values did not vary by more than 1% (*TolPar* = 0.01), or the objective function did not change by more than 1% for three consecutive iterations (*TolSOSC* = 0.01).

8.2 Observations

Observations used to develop the objective function include water levels, streamflow, and annual groundwater pumping (Figure 8-1). Weights are applied to each residual to (1) convert all observations into similar units so they can be squared and summed together and (2) reflect the observation certainty. More accurate observations are given greater weight, which increases their influence on the objective function value.



Explanation

Observation Type

- Annual Extraction Volume
- Groundwater Elevation
- Streamflow

- City or Town
- Groundwater Basin

0 1 2 mi

N

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SVHSM Documentation
Observation Locations

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Figure 8-1

8.2.1 Streamflow

Instantaneous streamflow observations collected intermittently from nine tributaries near the margin of the groundwater basin (Figure 8-1) were used to manually calibrate the PRMS submodel of SVHSM.

Daily streamflow observations from the Middle Fork Feather River near Portola (MFP) (http://cdec4gov.water.ca.gov/dynamicapp/QueryF?s=MFP) gage (Figure 8-1) were used to calibrate the SWBM and MODFLOW submodels of SVHSM. Flow data at this gage were available from September 8, 2006 through October 1, 2018, and represent total surface water outflow from the groundwater basin. A total of 500 streamflow observations were randomly selected from this dataset (Figure 8-2) and grouped into low flow (<10 cfs), medium flow (10 to 100 cfs), and high flow (>100 cfs) categories with 100, 300, and 100 observations, respectively. The selected observations are generally distributed through the entire time period for which data are available.

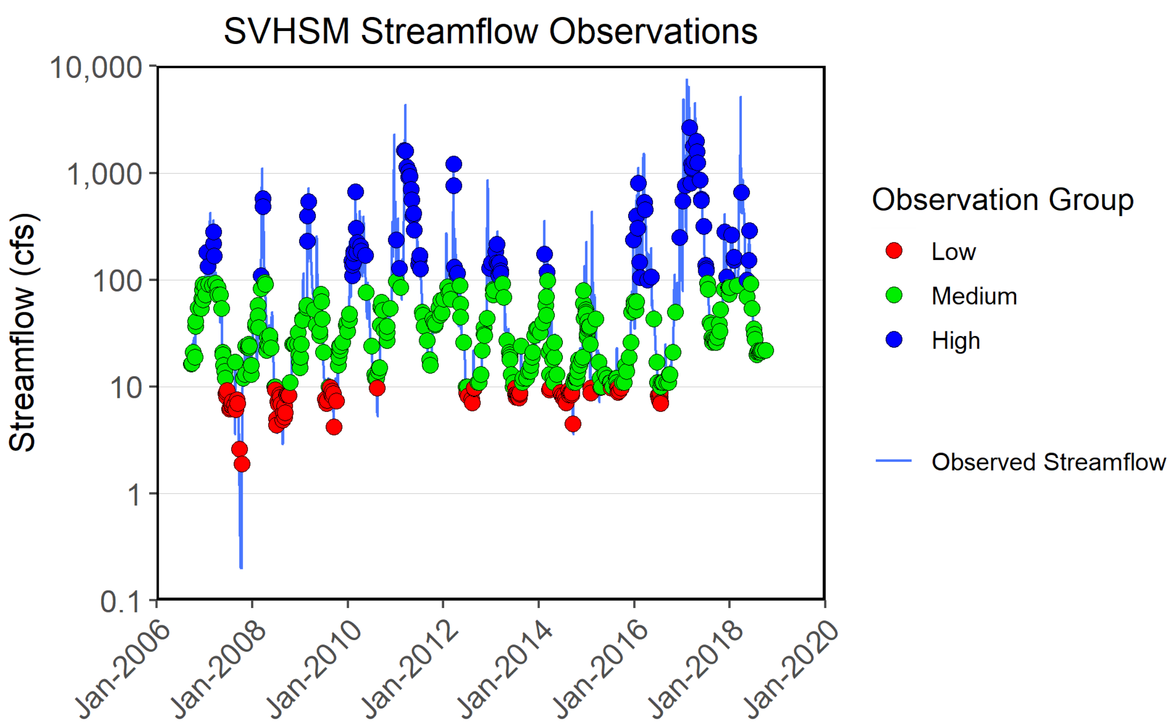


Figure 8-2. Streamflow observations used for sensitivity analysis and calibration.

Streamflow observation weights were determined using the coefficient of variation method, which allows the user to specify a confidence interval for the observation expressed as a percentage. The observation weight is a function of the coefficient of variation and the observation value. A lower coefficient of variation assigned to an observation indicates greater trust in that observation. The low, medium, and high streamflow categories were assigned coefficients of variation equal to 10%, 20%, and 40%, respectively, to reflect increasing uncertainty in estimated streamflow as flow rates increase.

8.2.2 Groundwater Elevations

A total of 4,112 groundwater elevation observations from 63 observation wells (Figure 8-1) were used to calibrate the SWBM and MODFLOW submodels of SVHSM. Based on available well construction information, 24 observation wells (38%) associated with 1,279 observations (31%) were screened in two or more model layers. Head contributions from these multi-layer observations were assumed to be equal, meaning that the average simulated value from all layers the well was screened within was used as the simulated equivalent. Head observation weights were defined using an assumed measurement error variance of 1 m^2. Head observations are contained in the UCODE_2014 input file *SVHSM.headobs*.

8.3 Results

Limited sensitivity analysis and calibration efforts performed due to the accelerated project timeline. Despite this limited effort, results presented below show that the model performs reasonably well. Additional calibration efforts are likely to improve model performance even further.

8.3.1 Sensitivity Analysis

Although a formal sensitivity analysis was not performed on the PRMS submodel of SVHSM, parameter sensitivity was observed during the manual calibration efforts. The parameters related to temperature lapse rates (*tmax_lapse and tmin_lapse*), which control how temperatures are adjusted for elevation, appeared to significantly affect hydrograph timing. The two parameters controlling downslope routing of gravity reservoir storage (*slowcoef_lin and slowcoef_sq*) were also identified as having a significant effect on hydrograph shape and timing. Parameters that represent the groundwater system of the upper watershed and control groundwater-surface water interactions in PRMS such as *gwflow_coef*, *gwsink_coef*, and *gwstor_init* were important for controlling baseflow entering streams. Most of these parameters are applied to the entire basin, or were adjusted uniformly across the basin as part of manual calibration efforts. More detailed evaluation of these parameters at the sub-watershed (stream catchment) scale may improve model representation of streamflows generated from the upper watershed portion of the basin.

Formal sensitivity analysis was performed on 79 parameters (Table 8-1) in the SWBM and MODFLOW submodels of SVHSM using UCODE_2014. Composite scaled sensitivities for the 25 most sensitive parameters are shown in Figure 8-3, with more sensitive parameters indicated by greater value. The most sensitive parameter identified in the analysis was the vertical hydraulic conductivity of the quasi-3D confining bed (*CB_3*) present at the bottom of the third model layer, which means that changes to the value of this parameter results in the greatest change in model results. This parameter affects groundwater heads throughout the model domain, so the high degree of sensitivity is not unexpected.

Table 8-1. Summary of parameters evaluated in SWBM and MODFLOW submodels during sensitvitiy analysis.

SVHSM Submodel	Parameter Type	Parameter Group	Parameter Names	Description
SWBM	Effective Rooting Depth	SWBM	RD_Alf_Irr, RD_Grn_Irr, RD_Pstr_Irr, RD_NatVeg, RD_Barren, RD_Water, RD_Alf_NI, RD_Grn_NI, RD_Pstr_NI	Total depth that plants can access soil moisture from. Accounts for root depth and capillary movement of water into root zone
	Effective Irrigation Efficiency	SWBM	Fld_IE_Alf, Fld_IE_Grn, Fld_IE_Pstr, WL_IE_Alf, WL_IE_Grn, WL_IE_Pstr, CP_IE_Alf, CP_IE_Grn, CP_IE_Pstr	Ratio of crop water uptake to applied water.
	Crop Coefficient (Kc) Scaling Factor	SWBM	KcMltAlfIrr, KcMltGrnIrr, KcMltPstrIrr, KcMltNatVeg, KcMltWater, KcMltAlfNI, KcMltGrnNI, KcMltPstrNI	Scaling factor that allows crop coefficients to be adjusted uniformly. Allows for single parameter to adjust crop coefficients that vary over time.
MODFLOW	Hydraulic Conductivity	Kx	Kx_1, Kx_2, Kx_3, Kx_4, Kx_5, Kx_6, Kx_7, Kx_8	Sediment hydraulic conductivity along rows.
	Horizontal Anisotropy	Hani	HANI_1, HANI_2, HANI_3, HANI_4, HANI_5, HANI_6, HANI_7, HANI_8	Scaling factor that adjusts aquifer hydraulic conductivty along columns based on Kx value.
	Vertial Anisotropy	Kvar	KVAR_1, KVAR_2, KVAR_3, KVAR_4, KVAR_5, KVAR_6, KVAR_7, KVAR_8	Scaling factor that adjusts vertical hydraulic conductivty of aquifer based on Kx value.
	Specific Yield	Sy	Sy_1, Sy_2, Sy_3, Sy_4, Sy_5, Sy_6, Sy_7, Sy_8	Unconfined aquifer storage coefficient
	Specific Storage	Ss	Ss_1, Ss_2, Ss_3, Ss_4, Ss_5, Ss_6, Ss_7, Ss_8	Confined aquifer storage coefficient
	Mountain Front Recharge	MFR	MFR_1, MFR_2, MFR_3, MFR_4, MFR_5, MFR_6	Flux of water into model from surrounding bedrock.
	Quasi-3D Confining Bed	Q3DCB	CB_3	Vertical hydraulic conductivity of Quasi-3D confining layer.
	Streambed Hydraulic Conductivity	SFR	BedK_1, BedK_2, BedK_3	Hydraulic conductivity of sediments in stream channels.
	Manning Roughness Coefficient	SFR	Manning_n_1, Manning_n_2, Manning_n_3	Coefficient that defines how easily water can flow though a channel.

Notes:
1. Alf = alfalfa; Grn = grain hay; Pstr = pasture; NatVeg = native vegetation; IE = irrigation efficiency; Fld = flood irrigated; WL = wheel line irrigated; CP = center pivot irrigated; Irr = Irrigated; NI = non-irrigated
2. Numbers in parameter name indicate property zone (Kx, Hani, Kvar, Sy, and Ss), MFR segment (MFR), model layer (Q3DCB), or streamflow channel property segments (SFR).

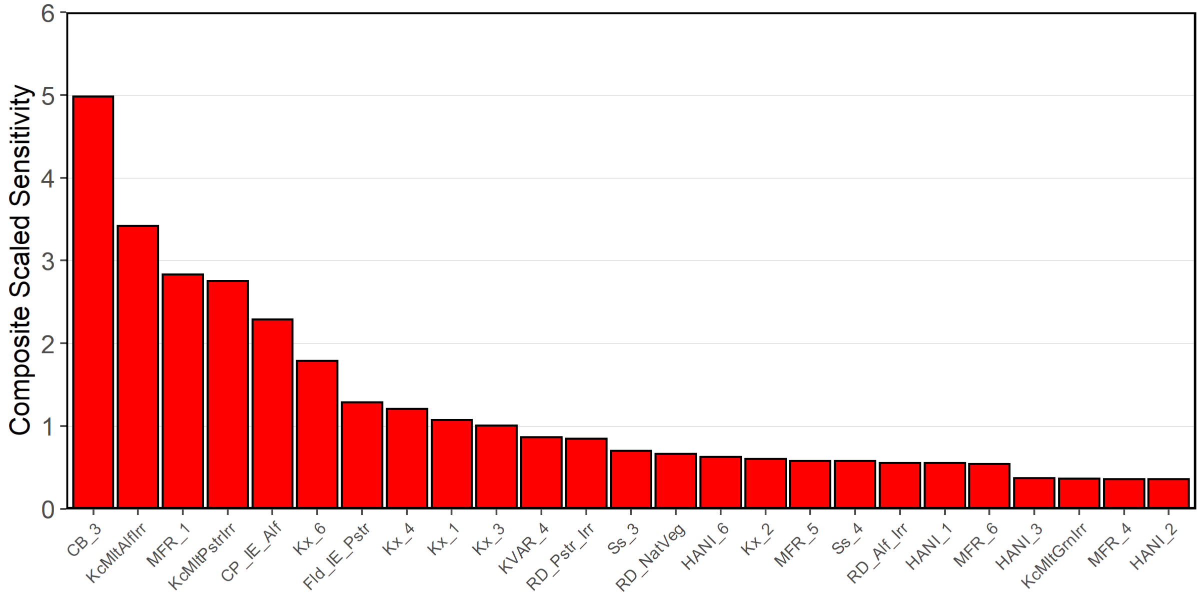
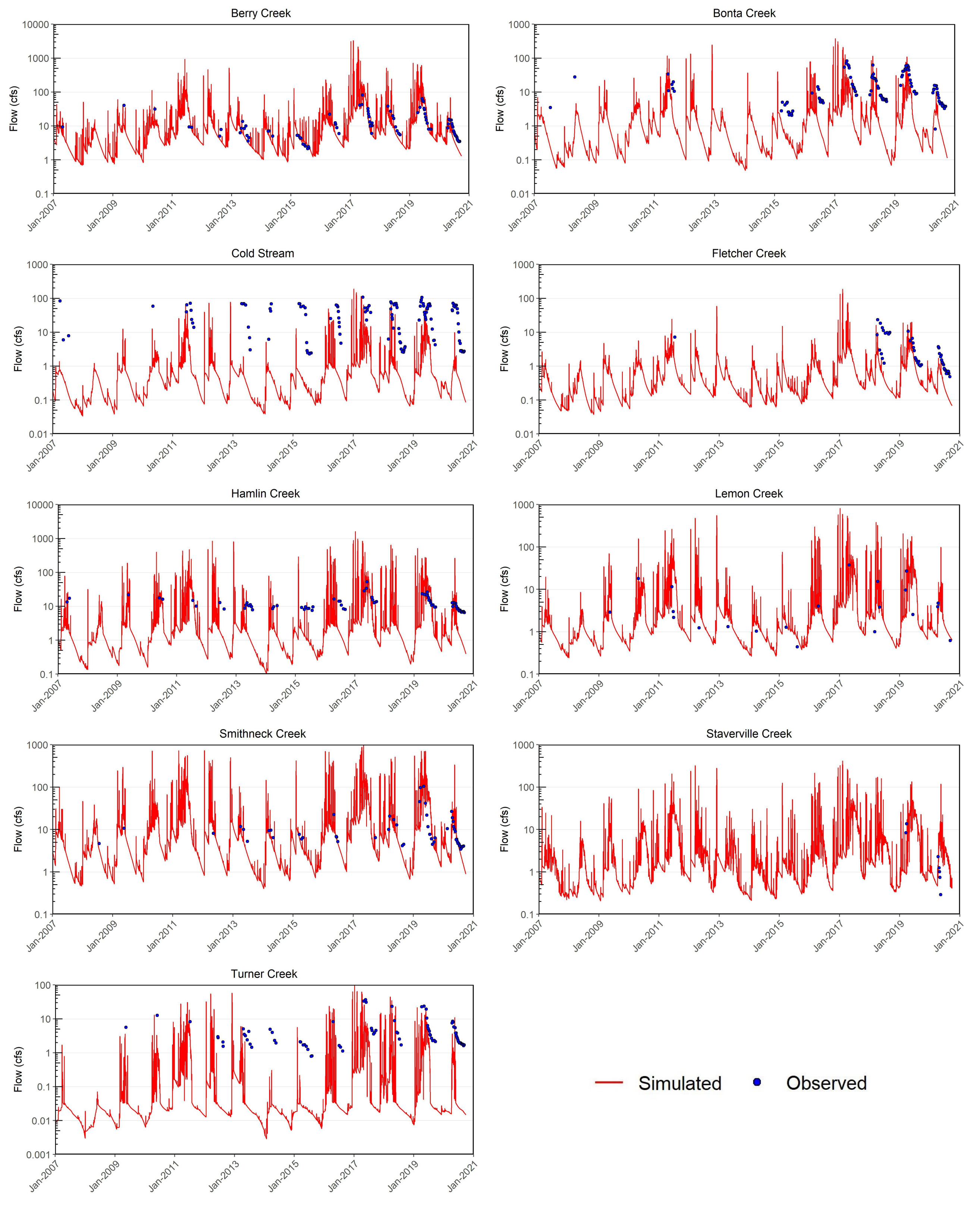


Figure 8-3. Sensitivity analysis results for the 25 most sensitive model parameters in the SWBM and MODFLOW submodels of SVHSM.

Sensitive SVHSM parameters are found in both the SWBM and MODFLOW submodels, indicating that processes represented in each are important for recreating observed groundwater and streamflow conditions. In the SWBM, the crop coefficient factors and irrigation efficiencies for alfalfa (*KcMltAlfIrr* and *CP_IE_Alf*) and pasture (*KcMltPstrIrr* and *Fld_IE_Pstr*) were the most sensitive. Like the MODFLOW quasi-3D confining bed parameter, these SWBM parameters affect a large portion of the model domain and, therefore, multiple observations. Other sensitive MODFLOW parameters include the MFR flux (*MFR_1*) into the southwest portion of the model domain (see Figure 7-3) and the hydraulic conductivity (K_x) for aquifer property zones 6, 4, 1, and 3. Eight parameters (*Sy_5*, *Sy_7*, *Sy_8*, *MFR_2*, *RD_Barren*, *RD_Water*, *Fld_IE_Grn,* and *KcMltWater*) were determined to be insensitive, meaning that changes in their values did not result in changes to the model output. This is because either the parameters occupy only a small portion of the model domain (e.g., *Sy_5*) or there are limited nearby observations (e.g., *MFR_2*).

8.3.2 Calibration

Manual calibration results of the PRMS submodel of SVHSM are shown in Figure 8-4. In general, agreement between simulated and observed flows is moderate but highly stream dependent. For example, there is strong agreement for Berry Creek, Lemon Creek, and Smithneck Creek but poor agreement for Cold Stream, Hamlin Creek, and Turner Creek. However, the lack of streamflow observations, particularly during the winter months, makes it difficult to fully ascertain the level of model performance.



Notes:

1. Smithneck Creek is a combination of Smitneck, Bear Valley, and Badenough creeks due to gage location.

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PRMS Streamflow Calibration Results

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Figure 8-4

When agreement is poor, the model appears to be capturing the general shape of the hydrograph, but either the timing or magnitude of flow is incorrect. This suggests that the PRMS submodel would benefit from detailed subwatershed-scale calibration efforts, as parameters that are currently assumed to be constant for the entire watershed (e.g., groundwater contributions) may vary across stream catchments. Furthermore, spatially distributed parameters were only adjusted during the manual calibration using scaling factors that applied to the entire model domain; adjustment of these parameters at the catchment scale is likely necessary to improve model performance.

During calibration of the SWBM and MODFLOW submodels of SVHSM, it was discovered that groundwater heads were equilibrating in the upper and lower layers of the model regardless of parameter values despite widespread distribution of low conductivity sediments (hydraulic property zones 3 and 4 and possibly 6). This was inconsistent with observations, especially those from nested wells located on the eastern side of the groundwater basin that showed a strong vertical gradient between the upper and lower portions of the aquifer system. Therefore, it was decided this was likely a structural error in the model and a quasi-3D confining bed was added to the bottom of layer 3 (*CB_3*) to restrict flow between the upper and lower model layers.

The addition of the quasi-3D confining bed generally improved model results and produced vertical gradients similar to those observed. However, this addition was made relatively late during the calibration process and the project timeline did not allow for an additional round of sensitivity analysis and calibration runs. The calibration results presented below use the version of the model with the quasi-3D confining bed and parameter values (see Appendix D) from a previous calibration run without the confining bed present.

Agreement between observed groundwater elevations and those simulated by the model is generally good (Figure 8-5). Linear regression of simulated and observed heads produces a slope of 1.09 with a correlation coefficient (R^2) of 0.87. Residuals, or the difference between observed and simulated values, are shown for each well in Figure 8-6. Some wells show very strong agreement (small magnitude residuals) between observations and simulated equivalents, while water levels in other wells are consistently overpredicted or underpredicted. Wells with the highest magnitude residuals tend to be irrigation (DMS) wells.

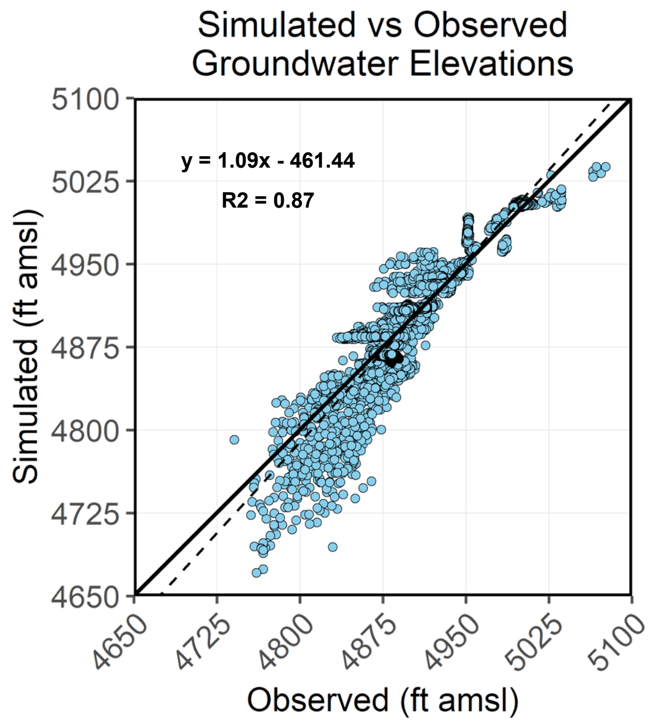


Figure 8-5. Simulated vs observed groundwater elevations. Solid line is one-to-one line. Dashed line shows linear regression of the data.

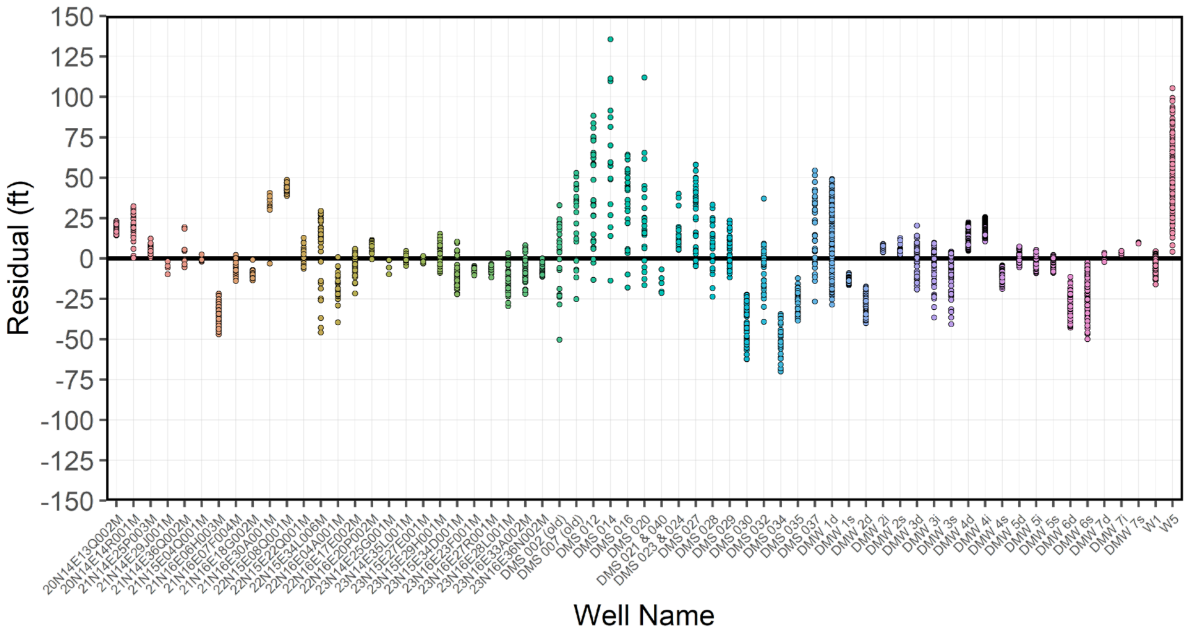
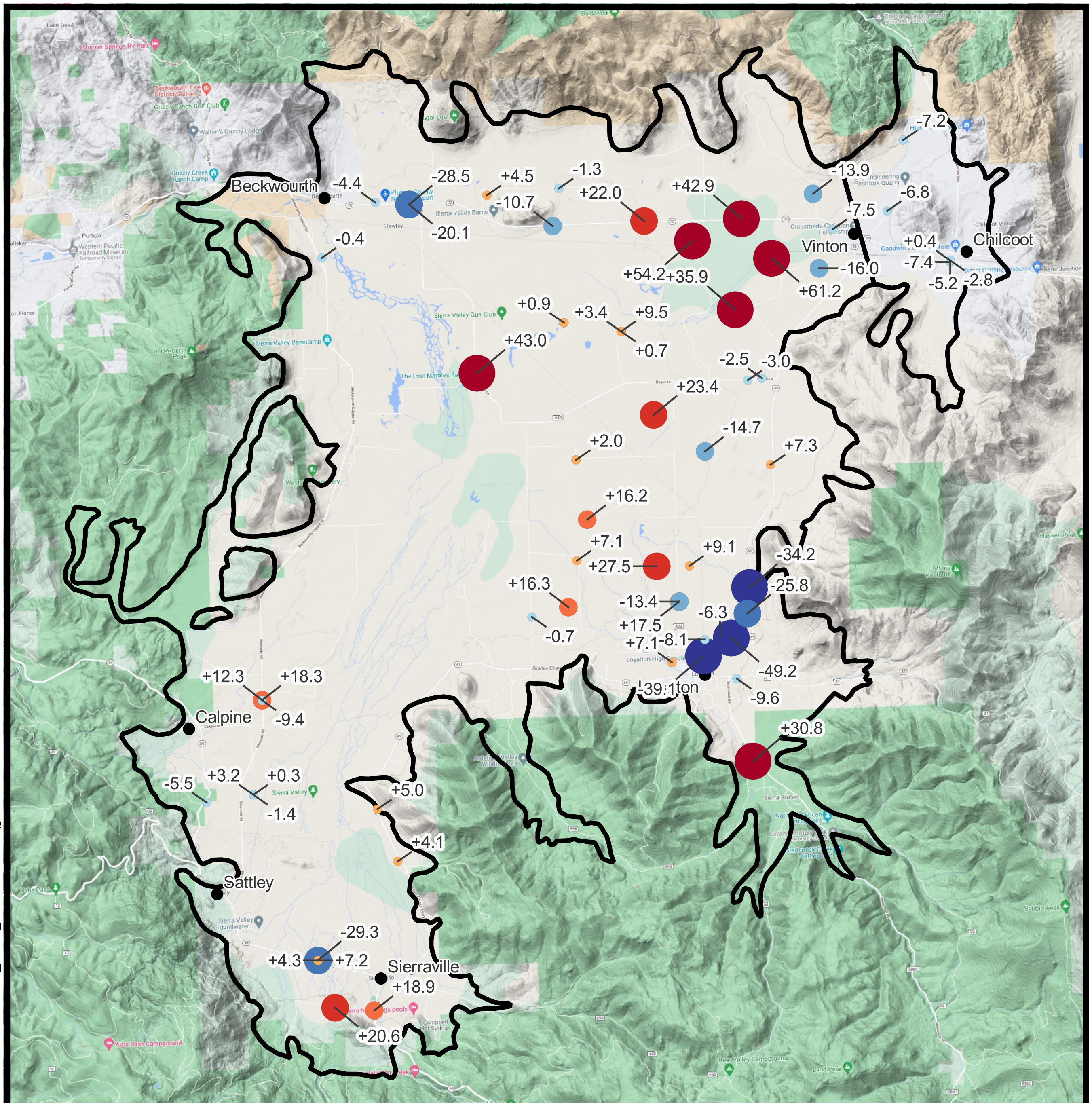


Figure 8-6. Agreement between simulated and observed groundwater levels varies by well. Small residual values indicate greater agreement between observations and simulated results. Residuals with the largest magnitudes tend to be from irrigation (DMS) wells.

Spatial distribution of average, minimum and maximum groundwater head residuals are shown in Figures 8-7 through 8-9. In general, the model appears to be doing a satisfactory job of representing groundwater elevations for most of the model domain. Approximately 26% of simulated heads are within 5 feet, 49% are within 10 feet, and 71% are within 20 feet of observed water levels. Two areas that show the greatest average model error in groundwater heads are the northeast portion of the valley where a large portion of groundwater pumping occurs, and to the northeast of Loyalton.

Selected hydrographs for wells located throughout the valley and at different depths are shown in Figure 8-10. While groundwater elevations and trends are generally captured at most wells, the hydrographs show the complex behavior of the aquifer system such as observed seasonal water level fluctuations up to 100 feet. Even though known extraction volumes were used to specify pumping rates for the majority of the simulation period, it appears that some pumping was either neglected or attributed to the wrong well as evidenced by the model not capturing significant drawdown events (e.g., 22N16E17E002M and DMW 3s). Wells that appeared to be poorly represented based on analysis of residuals (e.g., DMS 037 and W5) show that while the magnitude of simulated groundwater elevation is incorrect, the general trend of the hydrograph is captured by the model. This indicates that significant improvement in the representation of groundwater elevations would likely be achieved with a more thorough calibration effort than was possible to due project timeline constraints.



Explanation

Average Head Residual (ft)

- < -30
- -20 to -30
- -10 to -20
- 0 to -10
- 0 to 10
- 10 to 20
- 20 to 30
- >30

- City or Town
- Groundwater Basin

0 1 2 mi

N

Notes:
1. Negative residual indicates overestimation of groundwater elevation
2. Positive residual indicates underestimation of groundwater elevation
3. Labels indicate residual value
4. Multiple residuals at same location indicates nested monitoring well

Sierra Valley Groundwater Management District

SVHSM Documentation
Average Groundwater Head Residuals

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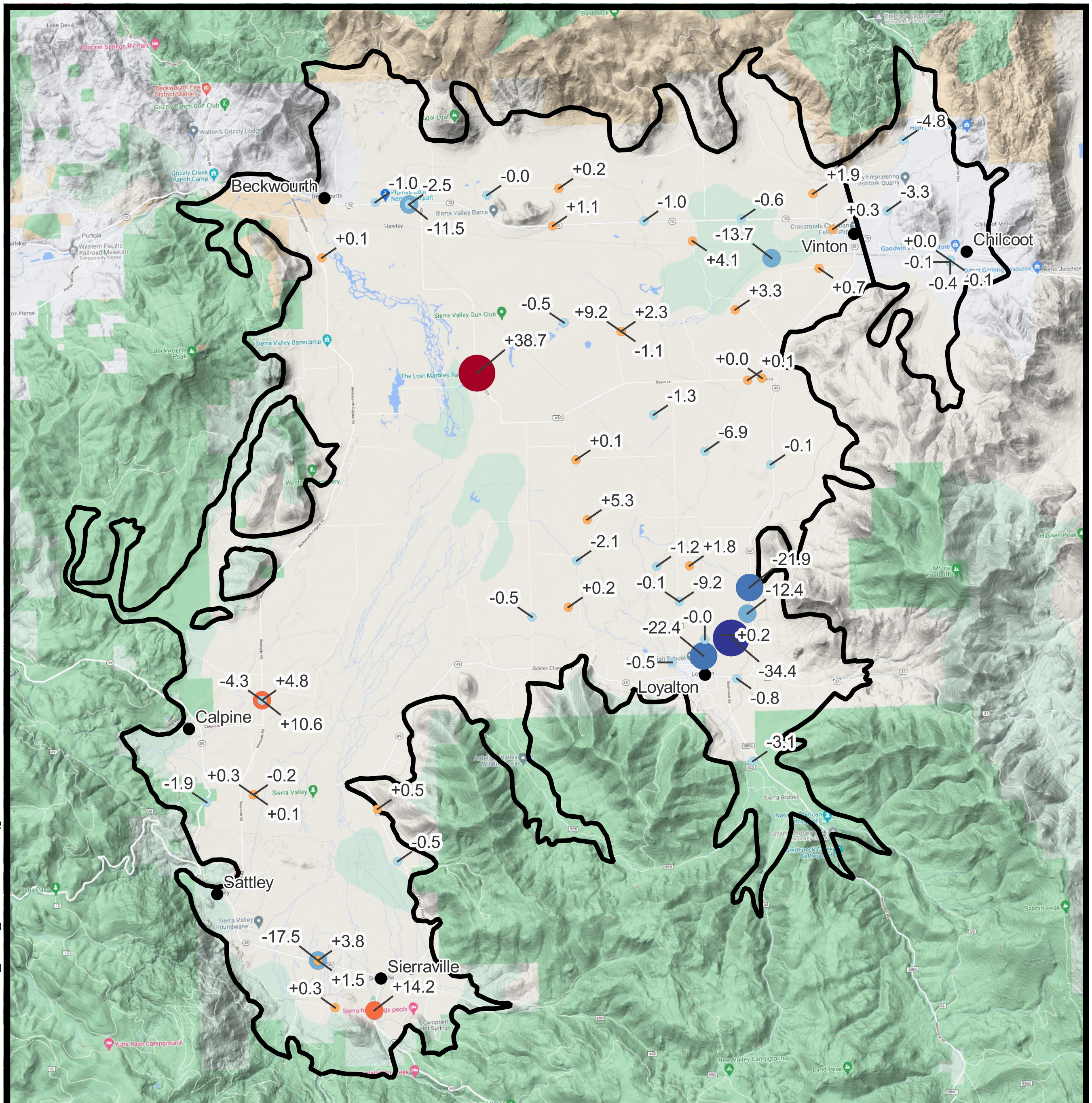
01/05/2022

Figure 8-7



Explanation

Minimum Head Residual (ft)

- < -30
- -20 to -30
- -10 to -20
- 0 to -10
- 0 to 10
- 10 to 20
- 20 to 30
- >30

City or Town

Groundwater Basin

0 1 2 mi

N

Notes:
1. Negative residual indicates overestimation of groundwater elevation
2. Positive residual indicates underestimation of groundwater elevation
3. Labels indicate residual value
4. Multiple residuals at same location indicates nested monitoring well

Sierra Valley Groundwater Management District

SVHSM Documentation

Minimum Groundwater Head Residuals

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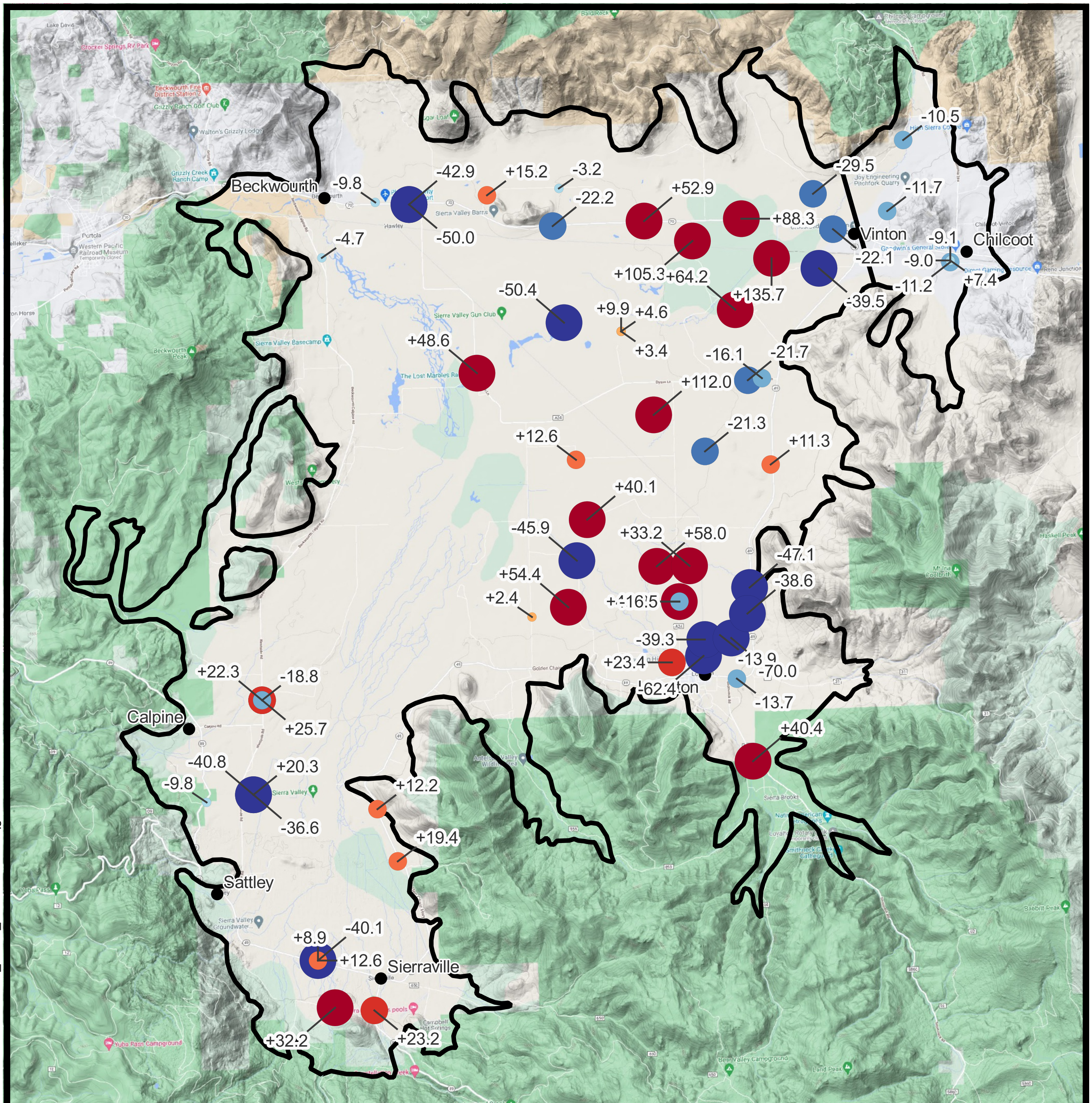
Figure 8-8



Explanation

Maximum Head Residuals (ft)

- < -30
- -20 to -30
- -10 to -20
- 0 to -10
- 0 to 10
- 10 to 20
- 20 to 30
- >30

- City or Town
- Groundwater Basin

0 1 2 mi

N

Notes:
1. Negative residual indicates overestimation of groundwater elevation
2. Positive residual indicates underestimation of groundwater elevation
3. Labels indicate residual value
4. Multiple residuals at same location indicates nested monitoring well

Sierra Valley Groundwater Management District

SVHSM Documentation

Maximum Groundwater Head Residuals

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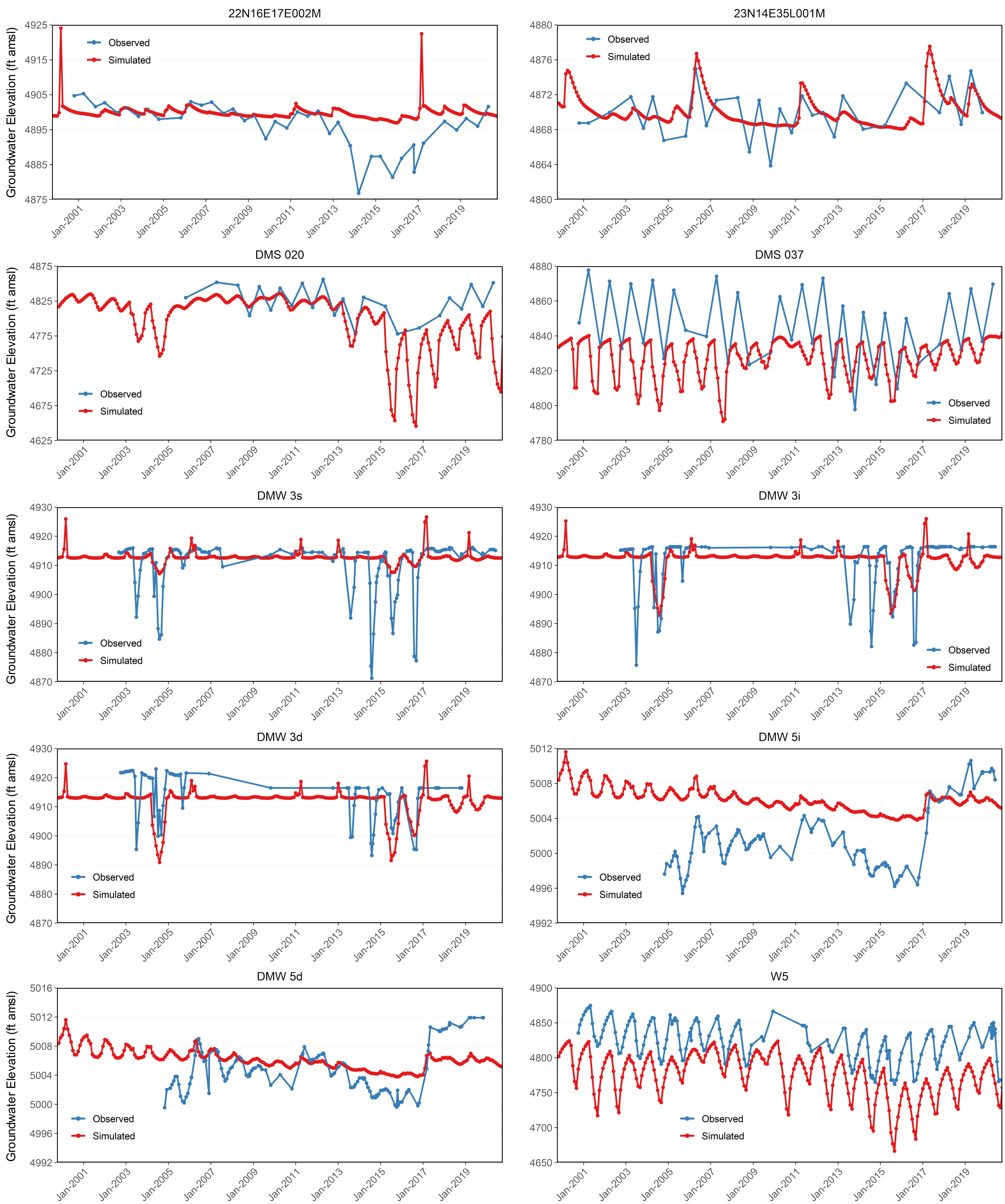

Notes:
1. See Figure 8-1 or DMS (https://sierra-valley.gladata.com) for wells locations.

Sierra Valley Groundwater Management District

SVHSM Documentation

Selected Groundwater Hydrographs

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Figure 8-10

Comparison of simulated streamflow to observed values at gages was done both graphically and using a modified version of the Nash-Sutcliffe model efficiency coefficient (NSE) (Nash and Sutcliffe, 1970). An NSE of 1.0 indicates the model perfectly matches observations, while a value of 0.0 means the model is no more accurate than predicting the mean value. Streamflow data were log-transformed because they span more than 3 orders of magnitude and large variance can produce high NSE values even if model fit is relatively poor (Jain and Sudheer, 2008). Therefore, NSE values presented here are conservative.

Surface water outflow from the Middle Fork Feather River is moderately well represented with the current parameterization of SVHSM (Figure 8-11) with an NSE of 0.65. Model mismatch during high runoff events is expected, as the duration of these is typically on the order of days, whereas SVHSM boundary conditions are specified on a monthly time scale. Simulated streamflow appears to be biased slightly high during the summer months.

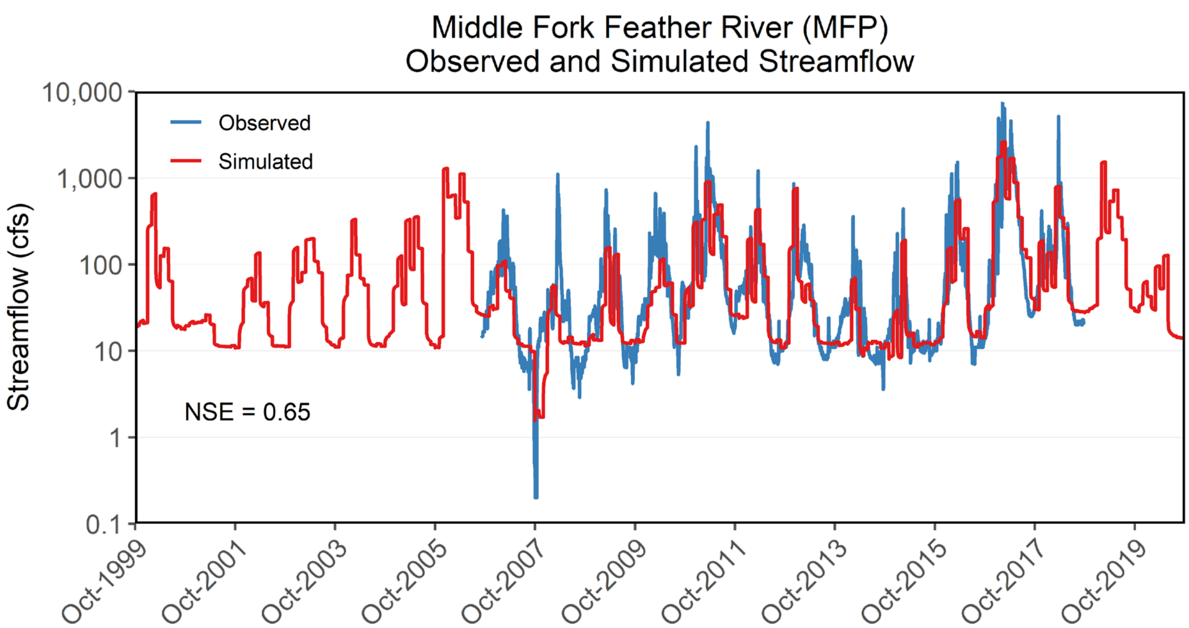


Figure 8-11. Surface water outflow from the basin via the Middle Fork Feather River is satisfactorially represented in SVHSM. NSE = Nash-Sutcliffe efficiency.

This may be due to overestimation of groundwater discharge to surface water near the gage, underestimation of stream leakage within the groundwater basin, misrepresentation of reservoir releases from Lake Davis via Big Grizzly Creek, which enters just above the gage, or a combination thereof.

9.0 Water Budgets

One of the key outputs of SVHSM are water budgets, which account for the movement of water into, within, and out of one of the three main hydrologic subsystems (i.e., land surface, surface water, and groundwater) that occurs during the simulation period. SVHSM simulates conditions from October 1, 1999 through September 30, 2020. We have defined the historical period to be WY 2000 through2015, and the current period to be the most recent five years (WY 2016 through 2020) for which data were available. Projected future water budgets that incorporate anticipated climate change effects were also evaluated for a 50-year planning horizon.

9.1 Historical Water Budgets

The historical annual surface water budget for the Basin is shown with water year types in Figure 9-1, summarized with average, minimum, and maximum flows in Table 9-1. The water budget reveals a wide range of surface water conditions that depend on the water year type. During dry, normal, and wet years, surface water fluxes within the Basin average about 58,000 AFY, 106,000 AFY, and 357,000 AFY, respectively.

The historical annual land surface water budget for the Basin is shown with water year types in Figure 9-2, summarized with average, minimum, and maximum flows in Table 9-2. The water budget reveals a wide range of conditions that depend on the water year type. During dry, normal, and wet years, land surface water fluxes within the Basin average about 166,000 AFY, 219,000 AFY, and 380,000 AFY, respectively.

The historical annual groundwater budget for the Basin is shown with water year types in Figure 9-3, summarized with average, minimum, and maximum flows in Table 9-3. The water budget reveals a wide range of conditions that depend on the water year type. During dry, normal, and wet years, groundwater fluxes within the Basin average about 25,000 AFY, 32,000 AFY, and 50,000 AFY, respectively.

The relative contributions of recharge attributed to the valley floor area versus the mountain-front area vary depending on the water year type. This is because valley floor recharge rates are calculated using the SWBM, while mountain-front recharge is largely unknown and currently simulated as a constant inflow (about 3,700 AFY) to the basin based on limited model calibration. During dry years, valley floor recharge varies between about 2,000 and 20,000 AFY. During normal years, valley floor recharge varies between about 8,000 and 38,000 AFY. During wet years, valley floor recharge is much greater, varying between about 32,000 and 68,000 AFY.

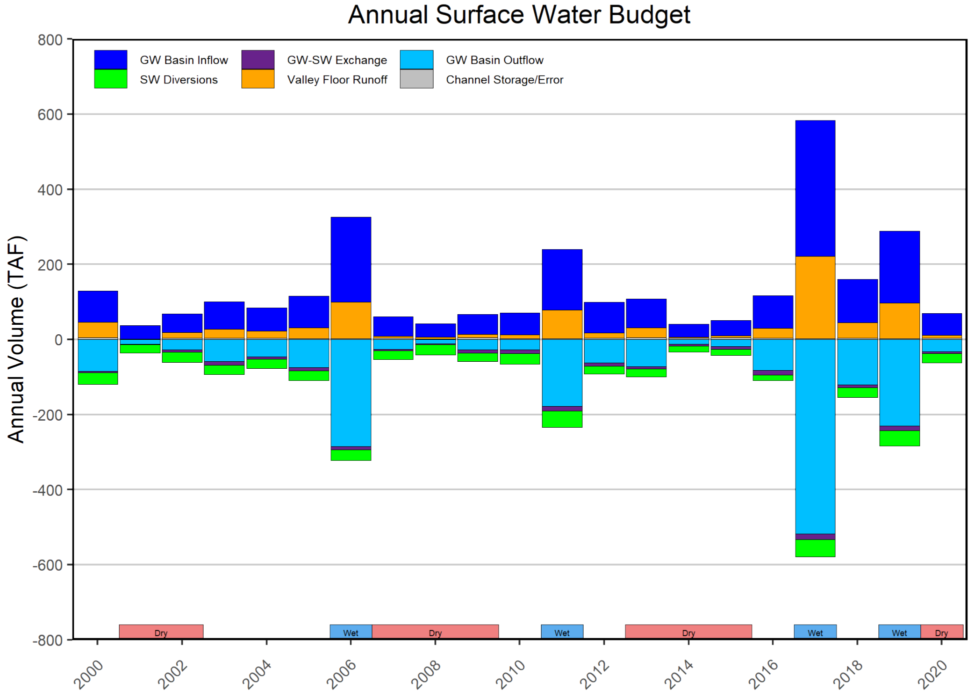


Figure 9-1. Historical and current annual surface water budget.

Table 9-1. Historical (WY 2001-2015) surface water budget summary.

Flow	Component	Annual Flow (AFY) Average	Minimum	Maximum
Inflow	Stream Flow	75,400	34,700	226,700
	Valley Floor Runoff	22,400	1,100	97,600
	Subtotal	**97,800**	**36,600***	**324,300***
Outflow	Stream Flow (MFFR)	-62,800	-11,900	-285,300
	SW Diversions	-25,000	-15,300	-43,300
	Subtotal	**-87,800**	**-29,400***	**-314,100***
Inflow/Outflow	GW Exchange	-7,000	-900	-13,600

Notes:
- Values represent water years 2001 through 2015. WY 2000 excluded to remove influence of assumed initial conditions.
- MFFR: Middle Fork Feather River
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY.

* Column arithmetic not applicable since values may come from different years and violate mass balance. Mass-conservative values shown.

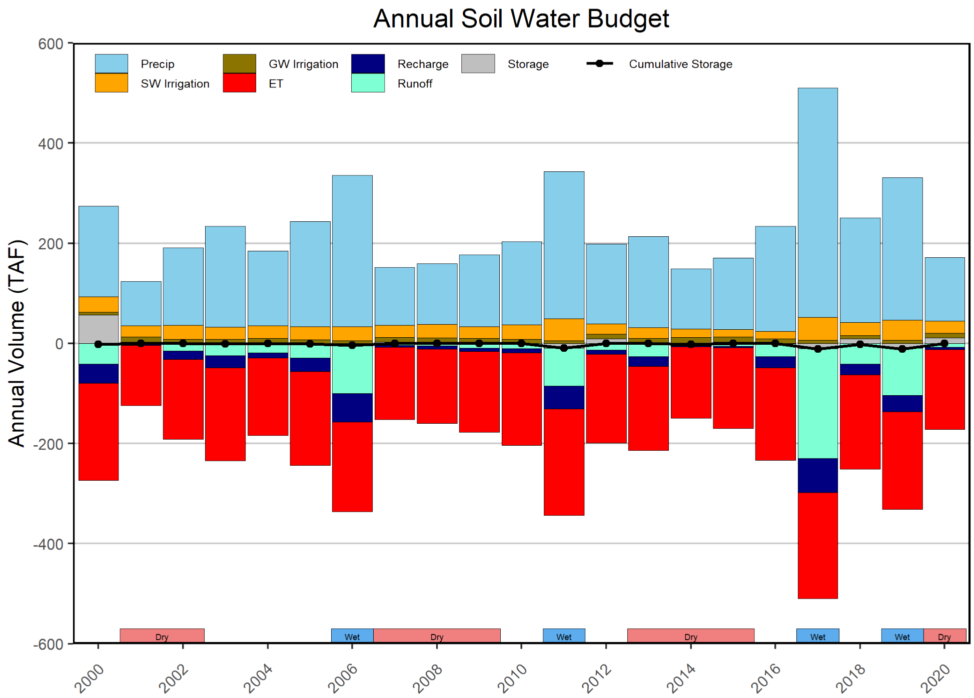


Figure 9-2. Historical and current annual land surface water budget.

Table 9-2. Historical (WY 2001-2015) land surface water budget summary.

Flow	Component	Annual Flow (AFY)		
		Average	**Minimum**	**Maximum**
Inflow	Precipitation	170,400	88,800	302,000
	Irrigation (from SW)	25,000	15,300	43,300
	Irrigation (from GW)	8,900	5,100	12,100
	Subtotal	**204,300**	**121,800***	**343,200***
Outflow	Evapotranspiration (Irrigated Fields)	-69,400	-57,700	-85,600
	Evapotranspiration (Non-Irrigated Fields)	-37,700	-26,200	-48,600
	Evapotranspiration (Native Vegetation)	-58,800	-36,800	-77,800
	Recharge (to GW)	-16,200	-2,400	-57,100
	Runoff	-22,400	-1,100	-97,600
	Subtotal	**-204,500**	**-124,200***	**-333,900***
	Change in Storage	**-100**	**-9,600***	**9,200***

Notes:
- Values represent water years 2001 through 2015. WY 2000 excluded to remove influence of assumed initial conditions.
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY.
* Column arithmetic not applicable since values come from different years which violates mass balance. Mass-conservative values shown.

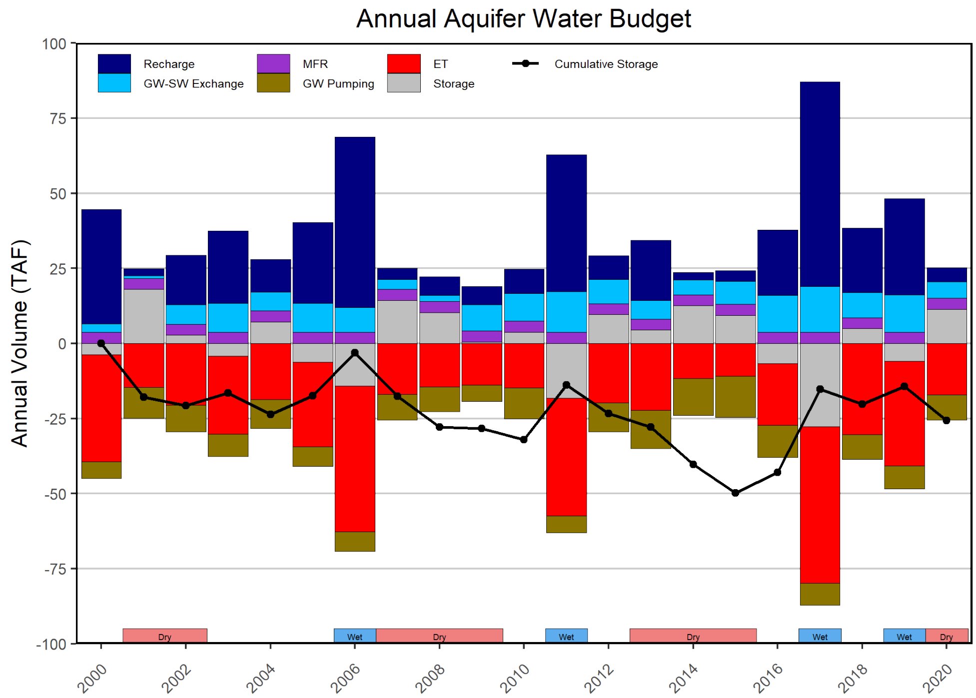


Figure 9-3. Historical and current annual groundwater budget.

Table 9-3. Historical (WY 2001-2015) groundwater budget summary.

Flow	Component	Annual Flow (AFY) Average	Minimum	Maximum
Inflow	Recharge (Valley Floor)	16,100	2,400	56,900
	Recharge (Mountain Front)	3,700	3,700	3,700
	Subtotal	**19,800**	**6,100**	**60,600**
Outflow	Evapotranspiration	-21,800	-11,000	-48,500
	Pumping (Agricultural)	-8,600	-5,200	-12,900
	Pumping (Municipal)	-500	-200	-700
	Subtotal	**-30,900**	**-19,300***	**-55,100***
Inflow/Outflow	Stream Exchange	7,400	2,100	13,600
	Change in Storage	**-3,300**	**-18,200***	**18,000***

Notes:
- Values represent water years 2001 through 2015. WY 2000 excluded to remove influence of assumed initial conditions.
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY.
- Increasing storage reported as a positive value, decreasing storage reported as a negative value.
* Column arithmetic not applicable since values come from different years which violates mass balance. Mass-conservative values shown.

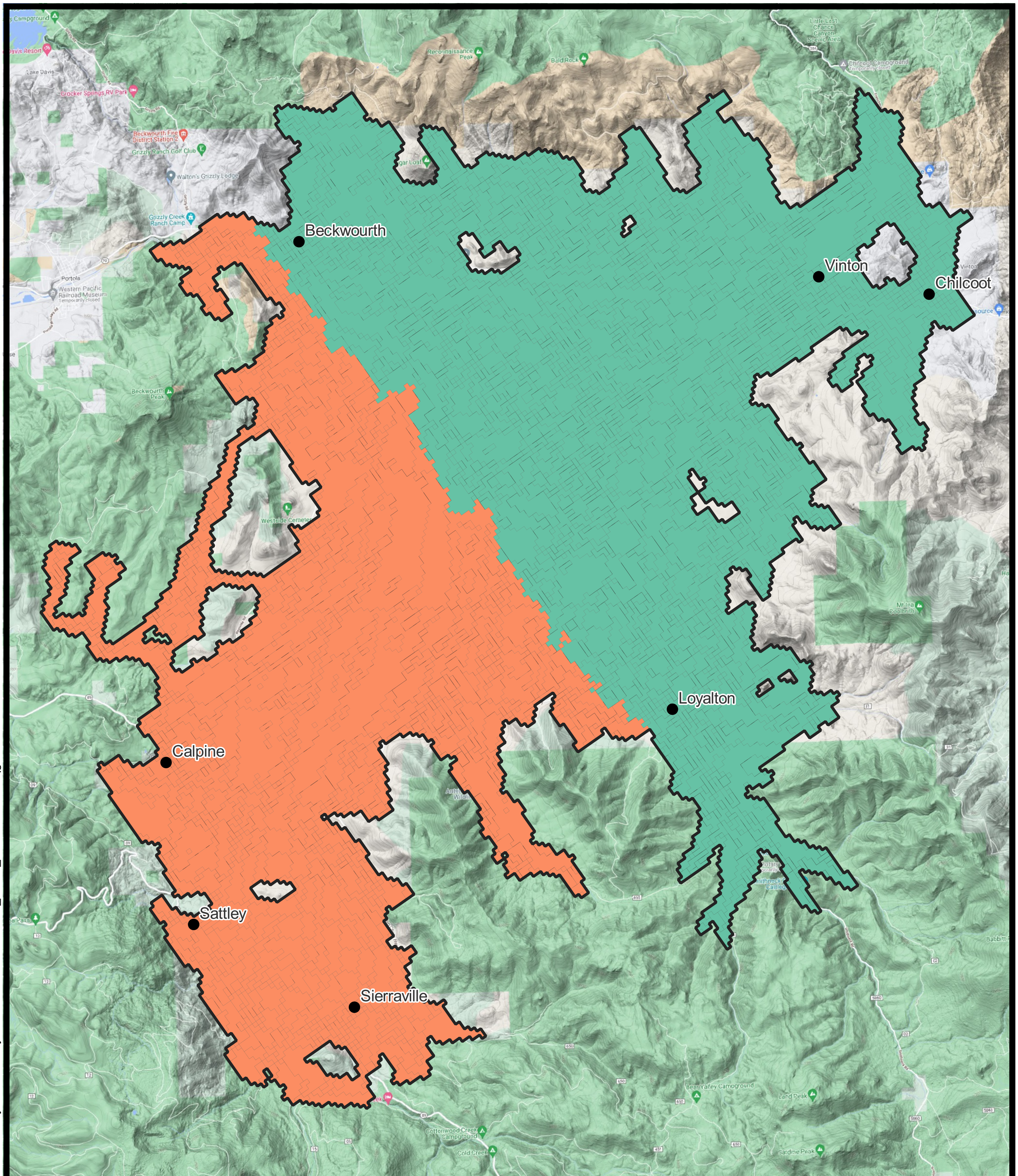
At the Basin scale, more surface water enters the groundwater basin than leaves via discharge from the MFFR. Fluxes of surface water into the groundwater system are largest for average and wet years following dry periods (e.g., 2016 and 2017), when groundwater levels are low and surface water can easily percolate into the subsurface. It should be noted that some groundwater does discharge to the Middle Fork Feather River, but these flows are small compared to the amount of stream percolation that occurs in the central and upper parts of the Basin. Underflow out of the groundwater basin is considered to be negligible, and therefore not simulated.

ET is typically the largest outflow component from the groundwater system. Rates are highly correlated with water year type. The volume of water lost to ET during dry, average, and wet years in the Basin is about 16,000 AFY, 24,000 AFY, and 44,000 AFY, respectively. Groundwater pumping is the second largest outflow from the aquifer and generally decreases as water year types become wetter. Groundwater pumping during dry, average, and wet water years was about 9,900 AFY, 8,500 AFY, and 6,800 AFY, respectively.

Results from SVHSM can be used to quantify fluxes between different portions of the groundwater basin. Zonal results are presented as the average daily flux for each water year due to how the data is exported from the model and file size limitations. Although these rates can only be used to estimate annual flux volumes for each zone, they are useful for comparing relative flux rates for each zone.

Two different zonal comparisons are presented below. One compares the eastside and westside portions of the basin (Figure 9-4), believed to be hydrogeologically separated by the Loyalton and Grizzly Valley Faults. The second subdivides the eastside portion of the basin into an upper and lower aquifer zone. The upper aquifer is defined as the first three layers of SVHSM and ranges from the upper 120 feet to 330 feet of the model. Zonal comparison plots have units of average daily rate, as opposed to units of volume used in the basin-wide plots. The flux rate (units of volume/time) for the last day of each month were averaged within a water year. This is due to how data is exported from SVHSM and computer storage limitations given the high number of model cells and time-steps. While the units may differ, they offer similar functionality as the volume unit plots.

Net recharge rates and corresponding changes in groundwater storage rates are shown for the westside and eastside Basin areas in Figure 9-5. Similar interannual patterns are observed for both the eastside and westside portions on the basin. The main difference between the two zones is that the eastside portion of the basin has much greater magnitudes when net recharge is negative (i.e., outputs are greater than inputs for that year). As a result, the eastside portion of the basin has experienced a simulated storage reduction of approximately 21,600 acre-ft (60 acre-ft/day * 360 days) over the 21-year simulation, or an overdraft on the order of 1,000 AFY. Storage in the westside portion appears to be in a dynamic equilibrium. This is due to the significantly greater groundwater pumping volume that occurs on the eastside of the basin compared to the westside (Figure 9-6).



Explanation

Budget Zone
- East Side
- West Side

- ● City or Town
- Groundwater Model Domain Boundary

0 1 2 mi

N

Sierra Valley Groundwater Management District

SVHSM Documentation

MODFLOW Groundwater Budget Zones

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01/07/2022

Figure 9-4

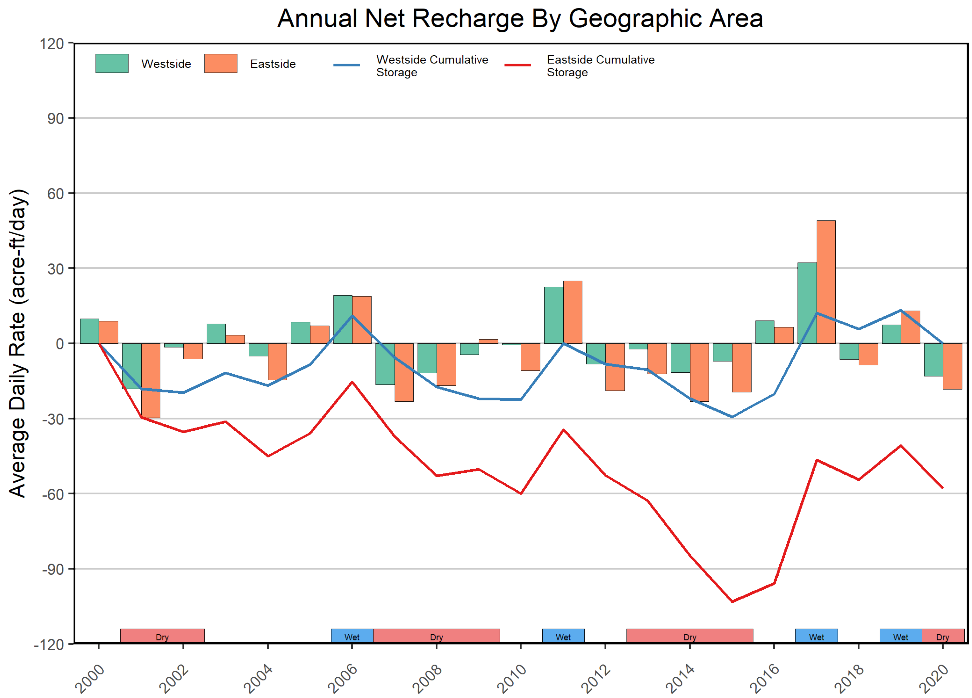


Figure 9-5. Historical and current annual net recharge rates by geographic area.

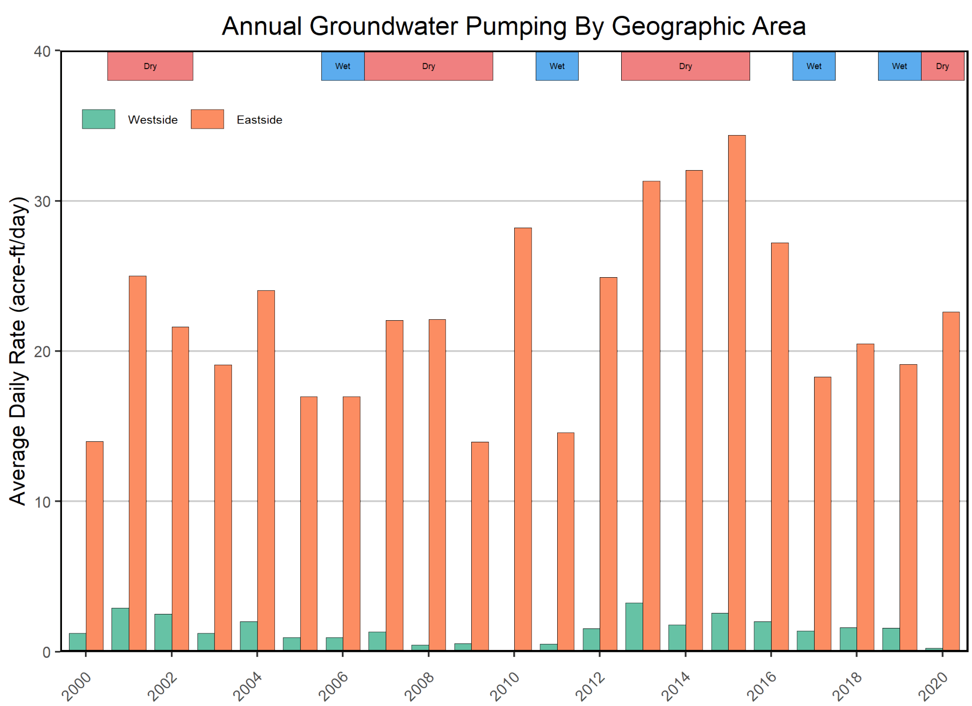


Figure 9-6. Historical and current annual pumping rates by geographic area.

Comparison of net recharge for the eastside upper and lower aquifer zones is shown in Figure 9-7. Rates differ substantially between the eastside upper and lower aquifers, with the upper aquifer showing a much greater range of net recharge values compared to the lower. Storage for both aquifer zones has decreased during the 21-year simulation, although simulated change in storage is lower for the upper aquifer compared to the lower. This is likely due to the upper aquifer having a smaller volume compared to the lower combined with similar simulated groundwater pumping in each zone (Figure 9-8). It should be noted that total well depth is missing from about 28% of simulated wells, and screen depth information is missing from about 51% of high capacity pumping wells. Assumptions made in the absence of these data are more likely to bias well and screen depths shallow. Therefore, a greater fraction of total groundwater pumping may be occurring in the lower aquifer.

In the context of observed long-term groundwater levels and the historical water budget, the Basin has historically operated with a small amount of overdraft, specifically on the eastside of the basin. Groundwater budget deficits occur during drought periods (i.e., dry and critical water years), and do not quite fully recover during subsequent wet periods. The amount of overdraft is relatively small compared to the overall water budget and suggests that recharge enhancement may be possible through management actions. The Basin sustainable yield has been estimated at about 6,000 to 7,000 AFY (Bachand and Carlton, 2020), consistent with SVHSM results. Historical groundwater pumping records indicate about 8,500 AFY water demand on average, resulting in an annual deficit of approximately 1,500 to 2,500 AFY.

9.2 Current Water Budgets

Current water budget conditions are represented by the five most recent water years (WY 2016-2020. This period represents a transition in observed climate conditions from the peak of the drought (i.e., 2016) and towards less dry conditions (i.e., 2017 through 2019), corresponding to a partial recovery of groundwater levels in the Basin.

Current (in addition to historical) water budgets for the surface water, land surface, and groundwater subsystems are shown in Figures 9-1 through 9-3, respectively, and are summarized in Tables 9-4 through 9-6. The number of above normal or wet year(s) recently has the Basin. Although the historical average deficit rate of 1,500 AFY is less than the current average 10,000 AFY surplus, these changes in groundwater in storage do not completely offset one another, because the historical average represents a significantly longer duration (and therefore volume) than the current average change in storage (i.e., 15 years versus five years). This is why tracking changes in groundwater in storage as the cumulative (total) of annual changes in storage is useful for comparing different time periods. The current estimated rate of recovery of groundwater in storage is similar to rates of recovery that occurred in the past, prior to full recovery of groundwater levels.

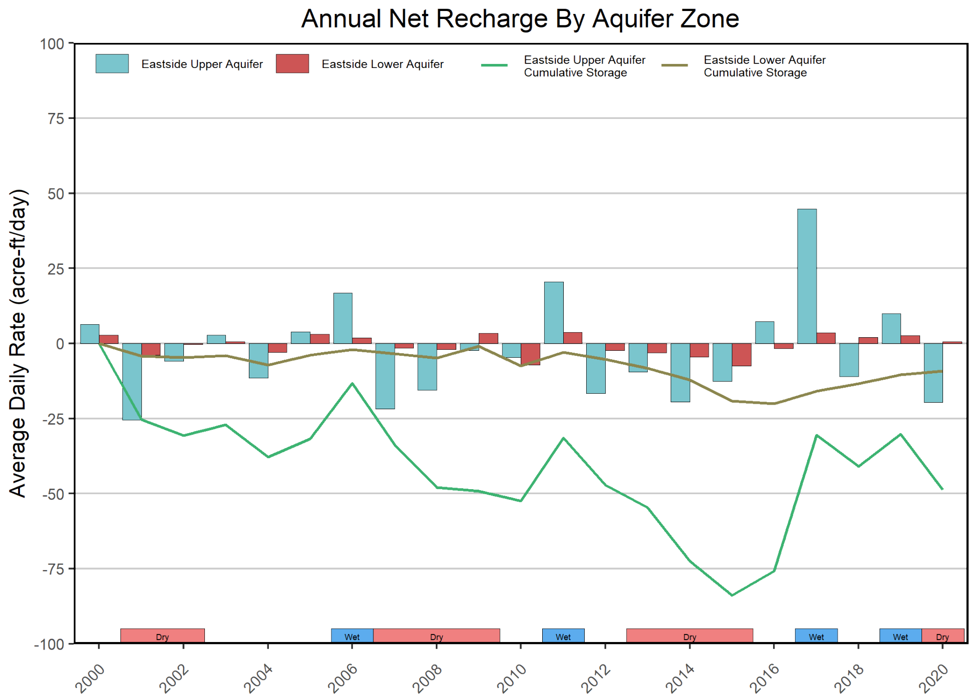


Figure 9-7. Historical and current annual net recharge by aquifer zone.

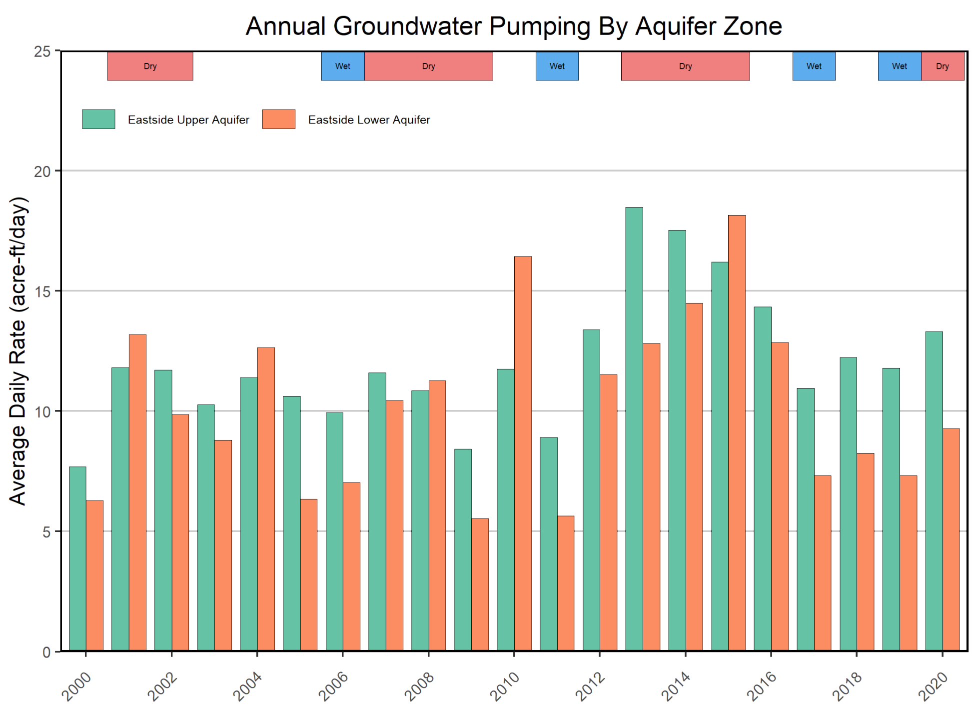


Figure 9-8. Historical and current annual groundwater pumping by aquifer zone.

Table 9-4. Current (WY 2016-2020) surface water budget summary.

Flow	Component	Annual Flow (AFY) Average	Minimum	Maximum
Inflow	Stream Flow	163,200	58,600	362,300
	Valley Floor Runoff	77,600	7,100	219,000
	Subtotal	**240,800**	**65,700***	**581,300***
Outflow	Stream Flow (MFFR)	-196,700	-32,500	-517,900
	SW Diversions	-30,300	-15,200	-46,100
	Subtotal	**-227,000**	**-56,600***	**-564,000***
Inflow/Outflow	GW Exchange	-10,800	-5,500	-15,300

Notes:
- Values represent water years 2016 through 2020.
- MFFR: Middle Fork Feather River
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY.

* Column arithmetic not applicable since values may come from different years and violate mass balance. Mass-conservative values shown.

Table 9-5. Current (WY 2016-2020) land surface water budget summary.

Flow	Component	Annual Flow (AFY) Average	Minimum	Maximum
Inflow	Precipitation	257,500	127,000	457,600
	Irrigation (from SW)	30,300	15,200	46,100
	Irrigation (from GW)	7,900	6,500	10,100
	Subtotal	**295,700**	**161,100***	**510,200***
Outflow	Evapotranspiration (Irrigated Fields)	-78,100	-68,000	-89,600
	Evapotranspiration (Non-Irrigated Fields)	-43,000	-35,000	-49,100
	Evapotranspiration (Native Vegetation)	-67,100	-52,700	-73,400
	Recharge (to GW)	-29,700	-4,700	-68,400
	Runoff	-77,600	-7,100	-219,000
	Subtotal	**-295,500**	**-171,900***	**-499,400***
	Change in Storage	**300**	**-10,800***	**10,700***

Notes:
- Values represent water years 2016 through 2020.
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY.

* Column arithmetic not applicable since values come from different years which violates mass balance. Mass-conservative values shown.

Table 9-6. Current (WY 2016-2020) groundwater budget summary.

Flow	Component		Annual Flow (AFY) Average	Minimum	Maximum
Inflow	Recharge (Valley Floor)		29,600	4,700	68,100
	Recharge (Mountain Front)		3,700	3,700	3,700
		Subtotal	**33,300**	**8,400**	**71,800**
Outflow	Evapotranspiration		-31,000	-17,100	-52,200
	Pumping (Agricultural)		-8,000	-6,800	-10,200
	Pumping (Municipal)		-400	-400	-600
		Subtotal	**-39,400**	**-25,500***	**-59,500***
Inflow/Outflow	Stream Exchange		10,800	5,500	15,300
	Change in Storage		**-1,300**	**-27,700***	**11,300***

Notes:
- Values represent water years 2016 through 2020.
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY.
-Increasing storage reported as a positive value, decreasing storage reported as a negative value.
* Column arithmetic not applicable since values come from different years which violates mass balance. Mass-conservative values shown.

9.3 Projected Future Water Budgets

SVHSM was used to estimate water budgets for the 50-year (WY 2021-2070) planning and implementation horizon required by SGMA using the change factors from four future climate scenarios provided by DWR. These scenarios are described in greater detail in the climate change guidance provided by DWR (2018a), and are summarized in Table 9-7. Change factors are provided for precipitation, reference ET, and stream flow on a monthly basis for historical datasets. Future climate and stream flow inputs were generated using the following steps:

1. Identify historical water years with precipitation and reference ET data, as well as DWR climate change factors (WY 1990-2011 for Sierra Valley). Surface water inflows are only available from WY 2000-2011.
2. Future 50-year (WY 2021-2070) planning and implementation horizon was created by randomly sampling years from WY 2000-2011. For example, WY 2005 was used to represent WY 2050. Several iterations were performed, and the dataset with the most similar statistical distribution to the historical data was selected. For historical water years where surface water inflow data was unavailable, average inflows based on the projected water year type (i.e., dry, average, and wet) were used.
3. Values of precipitation, reference ET, and streamflow for a future month were multiplied by the change factor for the historical month used to represent it.

Table 9-7. Summary of future climate scenarios.

Abbreviation	Scenario	Description
2030	2030 (near future)	Central tendency of the ensemble general circulation models (GCMs).
2070	2070 (late future)	Central tendency of the GCMs.
2070DEW	2070 (late future)	Drier with extreme warming (2070 DEW) conditions (extreme scenario, single GCM: HadGEM2-ES with representative concentration pathway [RCP] 8.5)
2070WMW	2070 (late future)	Wetter with moderate warming (2070 WMW) conditions (extreme scenario, single GCM:CNRM-CM5 with RCP 4.5)

It is important to note that the projected water budget is based on assumptions of events that may occur in the future, and is not intended to represent a prediction of future conditions. Instead, the projected water budgets are constructed to simulate "what-if" scenarios that incorporate uncertainty and evaluate the Agency's ability to operate the Basin sustainably over the 50-year planning and implementation horizon required by SGMA.

Cumulative inputs of precipitation, reference ET, and stream inflow for the 50-year future simulation are shown for the four climate change scenarios as well as the unmodified historical inputs in Figure 9-9. In general, future climate is projected to produce greater precipitation, but with less runoff due to increased ET. Average changes from historical values for each month (Figure 9-10) show projected increases in precipitation occur during the winter months, with the majority of increased ET occurring during the growing season (April through October). Reduced streamflow inputs during the spring and early summer are from projected reductions in winter snowpack.

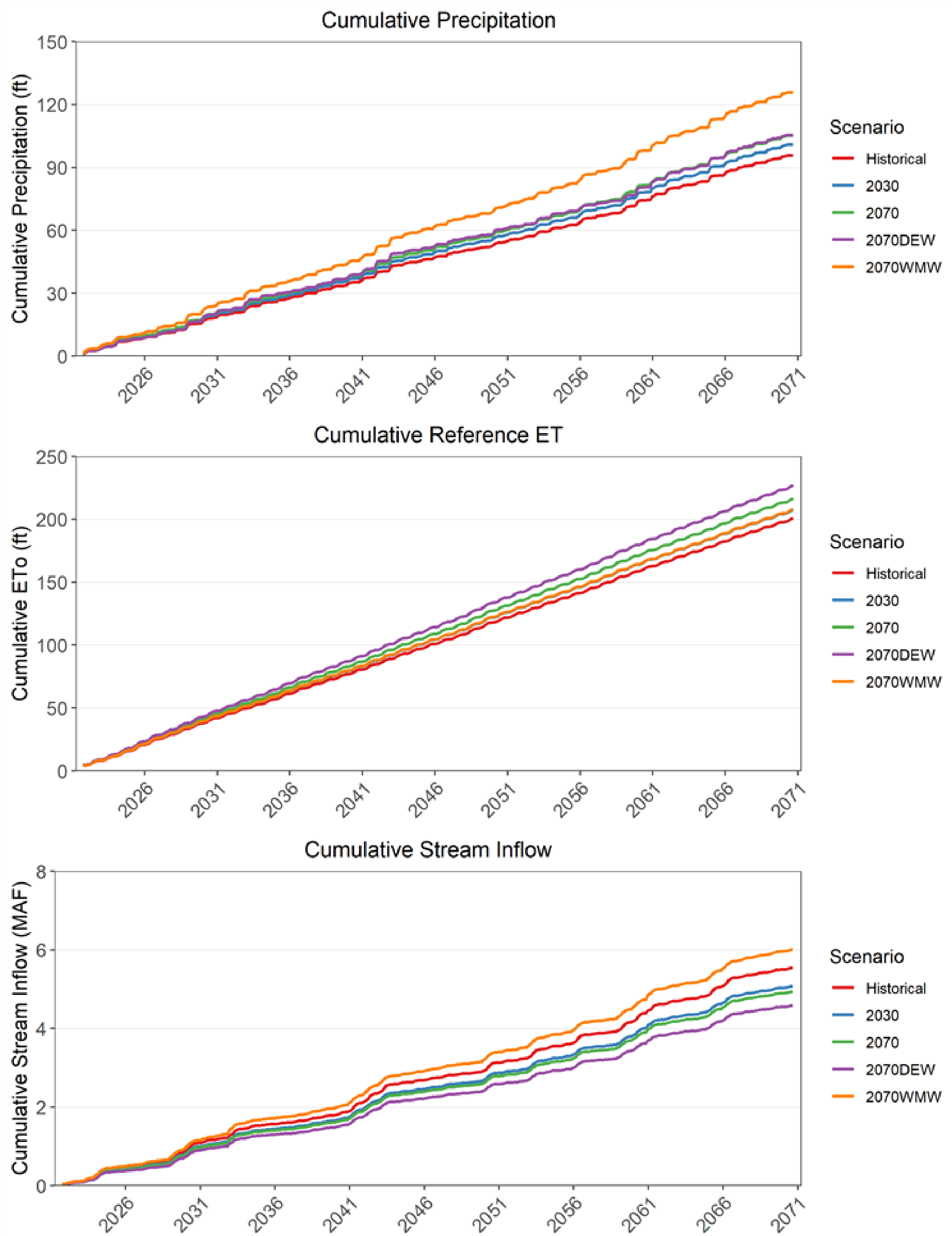


Figure 9-9. Cumulative inputs from simulated climate change scenarios.

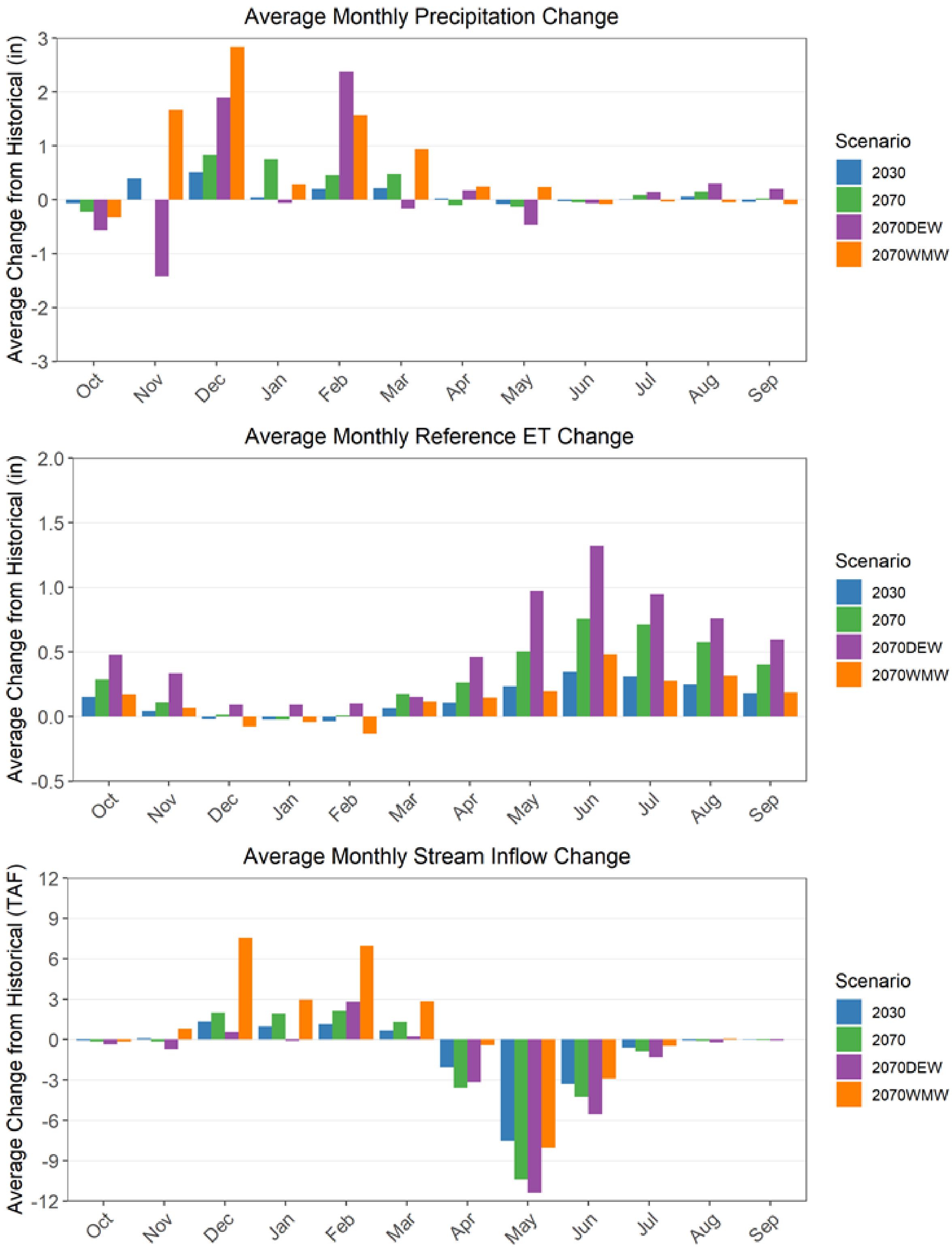


Figure 9-10. Average change from historical inputs by month using DWR climate change factors.

Sierra Valley has experienced a small population decline between 2010 and 2019, so changes in future water demand are only expected to occur due to greater crop water demand from increased reference ET. Future groundwater pumping is estimated using SVHSM, and assumes similar land use patterns as those observed historically. Figure 9-11 shows the estimated and observed annual groundwater pumping volumes from WY 2003-2020. In general, historical pumping is well represented by SVHSM and provides confidence in estimated future pumping. Future municipal groundwater pumping was assumed to be the same as historical.

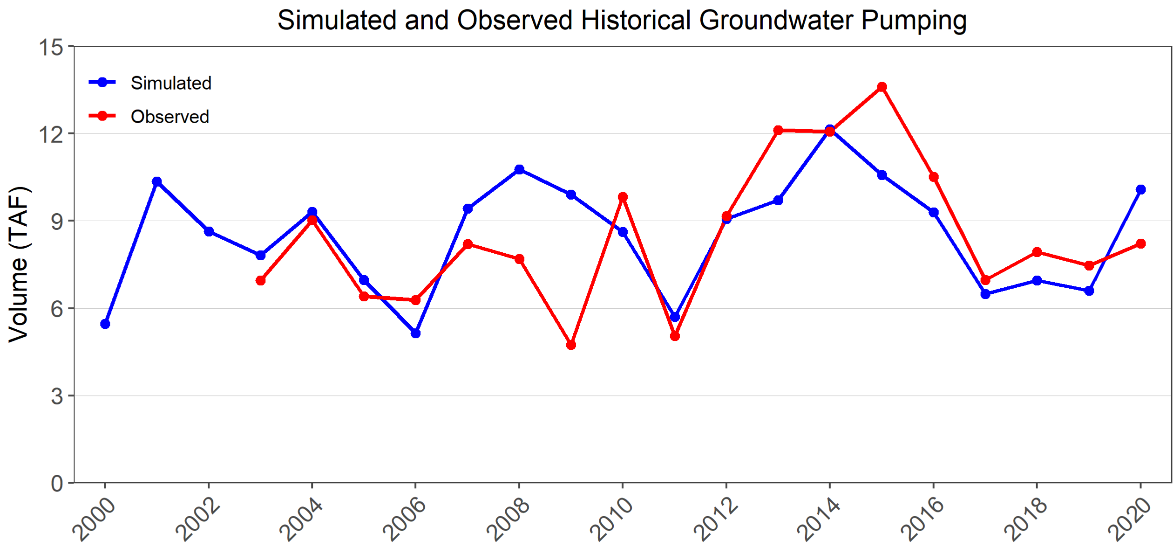


Figure 9-11. Historical groundwater pumping is well represented for most years by the SWBM submodel of SVHSM.

Projected agricultural groundwater demand ranges from 5,500 to 16,600 AFY, with average annual pumping ranging from 8,700 to 11,000 AFY in the four climate change scenarios (Figure 9-12). This corresponds to an increase in average annual groundwater pumping ranging from 200 to 2,500 AFY, compared to the observed historical average of 8,500 AFY.

Projected surface water inputs to Sierra Valley are shown in Figure 9-13. Annual inflows range from 27,800 to 270,600 AFY across all four scenarios. Annual average surface water inflows range from 91,500 to 120,100 AFY, which represents a change of –5,000 to +23,400 AFY from the historical annual average of 96,700 AFY.

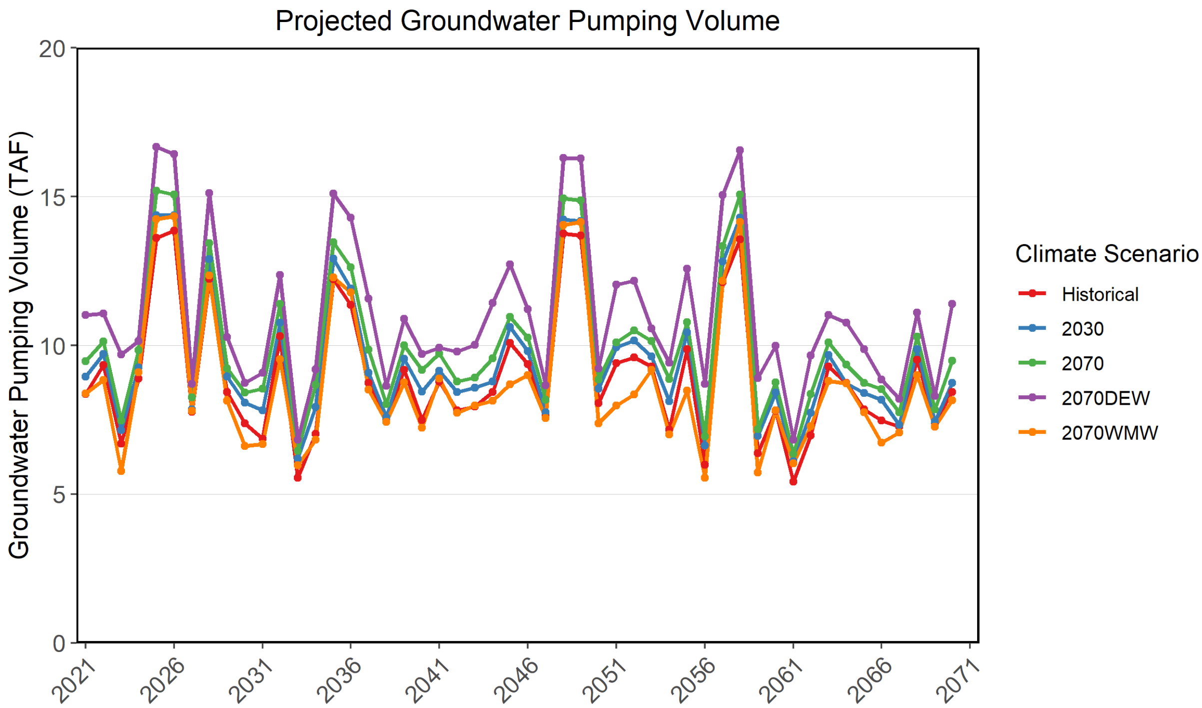


Figure 9-12. Estimated future groundwater pumping.

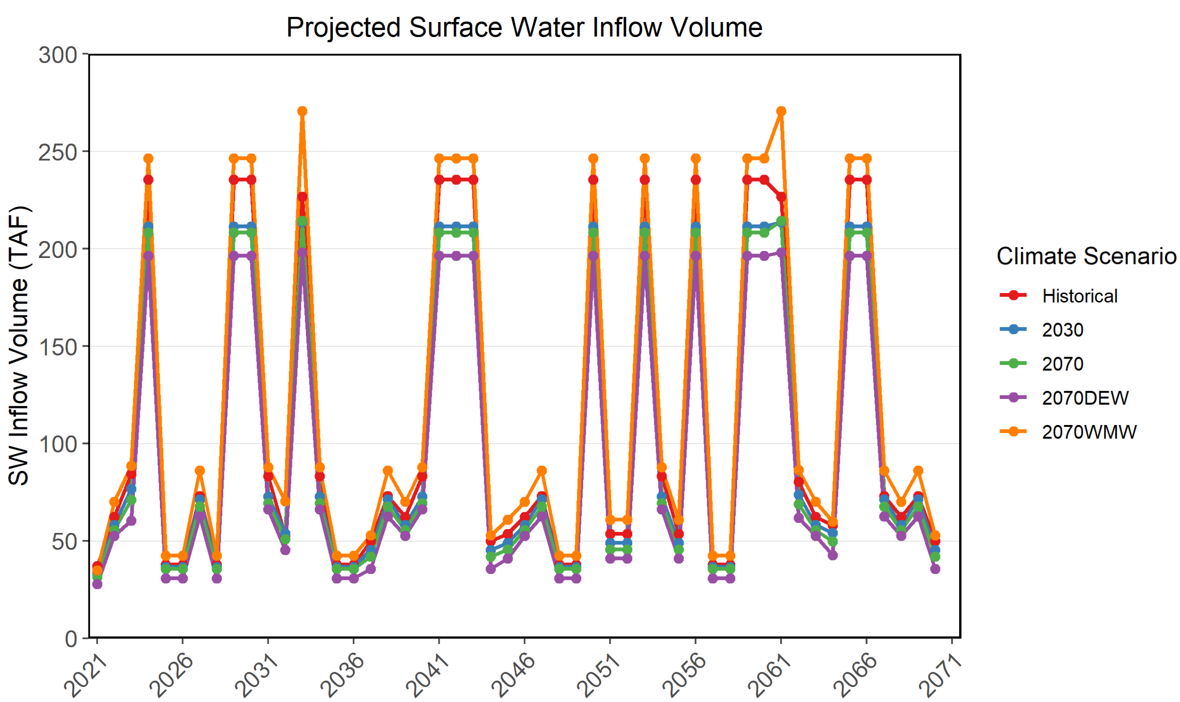


Figure 9-13. Estimated future surface water inflows to the Sierra Valley groundwater basin.

Surface water subsystem budgets over the 50-year (WY 2021-2070) planning and implementation horizon for each climate change scenario are shown in Figure 9-14 and summarized in Table 9-8. Tabulated water budgets are presented in Appendix 2-8. As mentioned in Section 2.2.3.5.3, average annual inflows range from 5,000 to 23,400 AFY when compared to the historical annual average of 96,700 AFY. Average annual surface water irrigation volumes range from 29,600 to 30,500 AFY across all scenarios, which represents a decrease of approximately 0 to 3% compared to annual estimated historical surface water irrigation volume. Surface water outflows from the MFFR are projected to increase on average between 0 and 57,000 AFY on average across all scenarios, largely due to increased valley floor runoff from increased storm intensity.

Projected future land surface (soil zone) water budgets for the groundwater basin are shown in Figure 9-15 and summarized in Table 9-9. In general, both the magnitude and variance of the annual average of the budget components increase. This means that more water moves through the system on average, but interannual variability also increases. In other words, wet years are projected to be wetter and dry years are projected to be drier, with fewer years that would be considered “average.” Results from the SWBM indicate that overall groundwater recharge for the basin is projected to increase by about 5,800 to 16,700 AFY, while groundwater irrigation is projected to increase approximately 100 to 2,500 AFY.

Projected future water budgets for the groundwater subsystem are shown in Figure 9-16 and summarized in Table 9-10. Groundwater pumping is projected to increase from about 0 to 2,300 AFY on average due to increased ET. However, projected increases in recharge due to increased precipitation offset increased pumping demand. Long-term changes in storage are projected to range from –500 to +100 AFY, which is a reduction from the –1,300 AFY simulated by SVHSM for WY 2001-2020. Figure 9-17 shows the time series of cumulative change in storage since the beginning of the model run for each future climate scenario. Changes in storage recover for the 2070WMW and 2030 scenarios during the latter 15 years of the future simulation following a simulated dry period that lasts for about 7 years. Partial recovery is observed for the 2070 and 2070DEW scenarios.

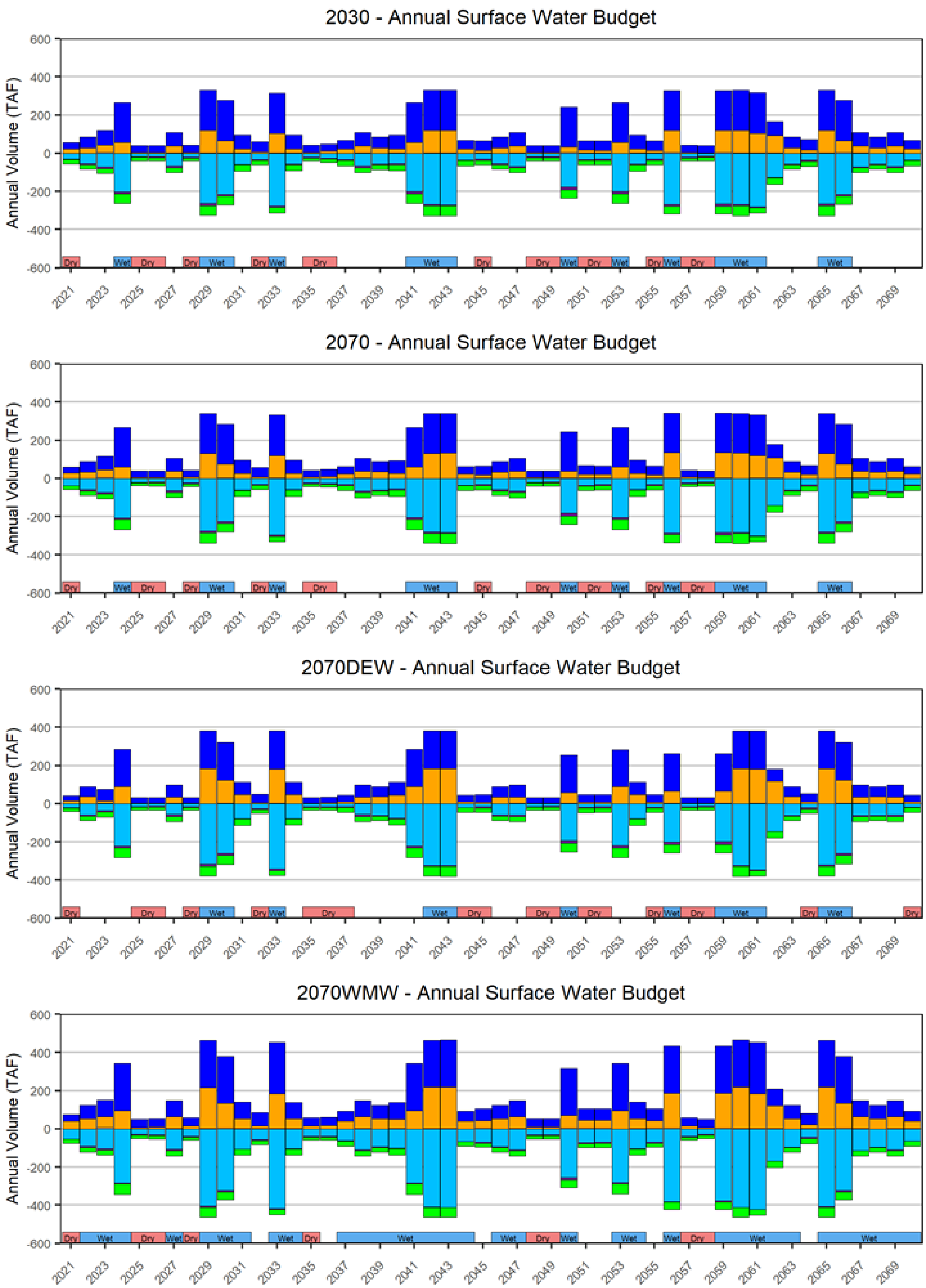


Figure 9-14. Projected future surface water budgets.

Table 9-8. Summary of projected surface water budgets.

Scenario	Flow	Component	Annual Flow (AFY)		
			Average	Minimum	Maximum
2030	Inflow	Stream Flow	102,700	36,600	213,600
		Runoff	41,400	3,300	132,500
		Subtotal	**144,100**	**39,900**	**346,100**
	Outflow	Stream Flow (MFFR)	-105,200	-16,500	-280,700
		SW Diversions	-30,600	-16,300	-52,200
		Subtotal	**-135,800**	**-32,800**	**-332,900**
	Inflow/Outflow	GW Exchange	**-7,200**	**-900**	**-15,900**
2070	Inflow	Stream Flow	100,000	35,700	214,300
		Runoff	47,400	3,700	132,500
		Subtotal	**147,400**	**39,400**	**346,800**
	Outflow	Stream Flow (MFFR)	-110,200	-18,200	-300,100
		SW Diversions	-30,300	-14,500	-52,700
		Subtotal	**-140,500**	**-32,700**	**-352,800**
	Inflow/Outflow	GW Exchange	**-5,900**	**1,000**	**-13,900**
2070DEW	Inflow	Stream Flow	92,800	30,900	198,100
		Runoff	55,700	1,900	184,400
		Subtotal	**148,500**	**32,800**	**382,500**
	Outflow	Stream Flow (MFFR)	-111,700	-13,300	-347,300
		SW Diversions	-29,800	-14,300	-51,600
		Subtotal	**-141,500**	**-27,600**	**-398900**
	Inflow/Outflow	GW Exchange	**-7,000**	**100**	**-15,800**
2070WMW	Inflow	Stream Flow	121,800	42,500	270,600
		Runoff	77,100	6,900	218,000
		Subtotal	**198,900**	**49,400**	**488,600**
	Outflow	Stream Flow (MFFR)	-162,900	-27,700	-422,900
		SW Diversions	-29,900	-15,300	-53,600
		Subtotal	**-192,800**	**-43,000**	**-476,500**
	Inflow/Outflow	GW Exchange	**-4,700**	**1,300**	**-11,800**

Notes:
- Values represent projections for WY 2022-2070. WY 2021 excluded to remove influence of assumed initial conditions.
- MFFR: Middle Fork Feather River
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Annual flow values (in acre-feet per year [AFY]) are rounded to the nearest 100 AFY; therefore, a discrepancy of 100 AFY may occur.

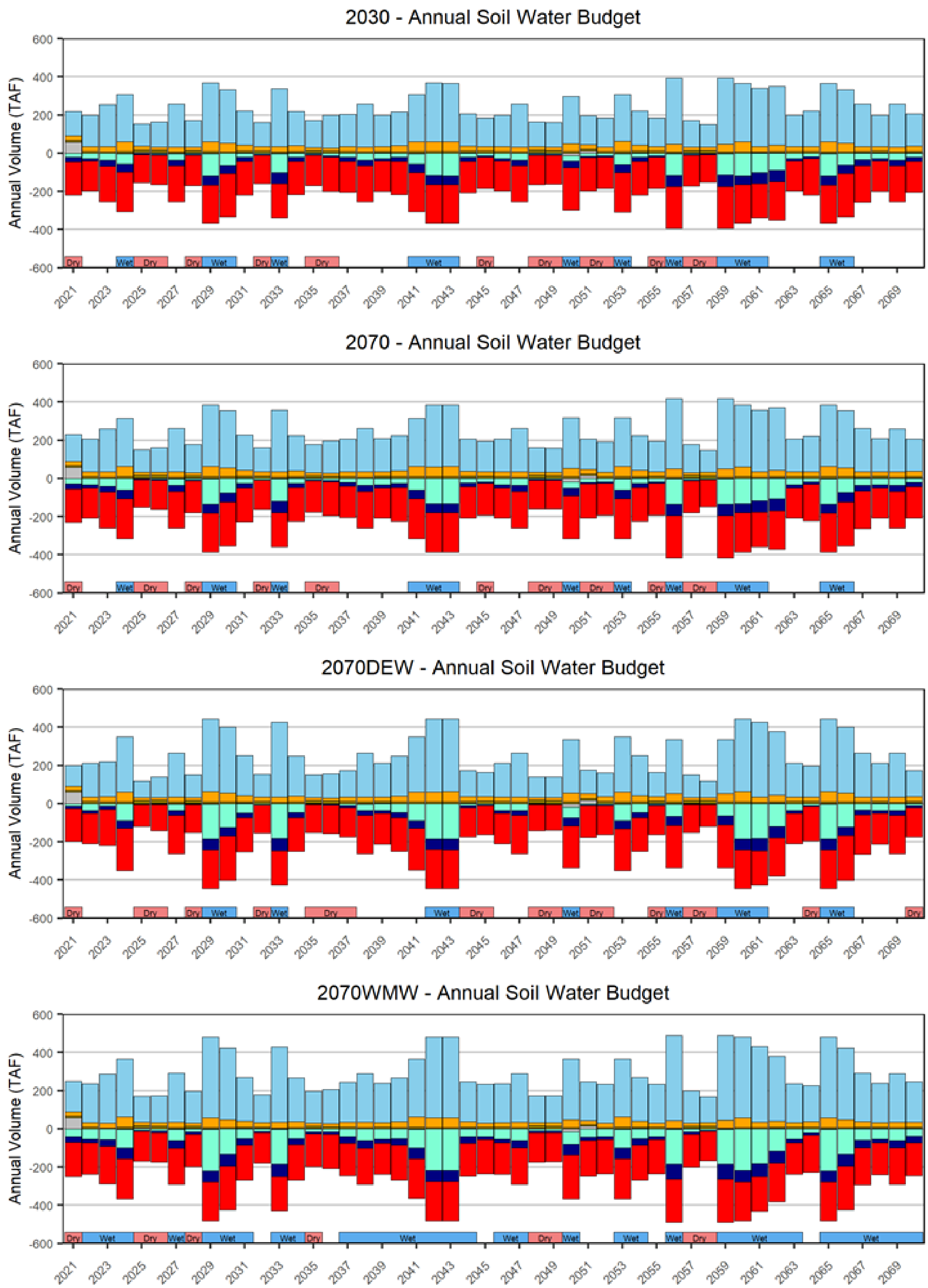


Figure 9-15. Projected future land surface (soil zone) water budgets.

Table 9-9. Summary of projected land surface water budgets.

Scenario	Flow	Component	Annual Flow (AFY) Average	Minimum	Maximum
2030	Inflow	Precipitation	207,900	118,000	345,500
		Irrigation (from SW)	30,600	16,300	52,200
		Irrigation (from GW)	9,500	5,900	14,800
		Subtotal	**248,000**	**140,200**	**412,500**
	Outflow	Evapotranspiration (Irrigated Fields)	-78,100	-63,300	-101,300
		Evapotranspiration (Non-Irrigated Fields)	-38,900	-32,200	-51,500
		Evapotranspiration (Native Vegetation)	-63,100	-47,900	-77,400
		Recharge to GW	-26,300	-3,800	-59,400
		Runoff	-41,400	-3,300	-118,000
		Subtotal	**-247,800**	**-150,500**	**-407,600**
		Change in Storage	**200**	**-13,500***	**12,300***
2070	Inflow	Precipitation	216,600	117,700	368,700
		Irrigation (from SW)	30,300	14,500	52,700
		Irrigation (from GW)	10,100	6,200	15,600
		Subtotal	**257,000**	**138,400**	**437,000**
	Outflow	Evapotranspiration (Irrigated Fields)	-78,800	-61,400	-103,600
		Evapotranspiration (Non-Irrigated Fields)	-39,200	-31,800	-52,000
		Evapotranspiration (Native Vegetation)	-63,900	-47,400	-79,600
		Recharge to GW	-27,600	-4,000	-61,000
		Runoff	-47,400	-3,700	-132,500
		Subtotal	**-256,900**	**-148,300**	**-428,700**
		Change in Storage	**100**	**-17,000***	**15,700***
2070DEW	Inflow	Precipitation	217,700	86,800	392,000
		Irrigation (from SW)	29,800	14,300	51,600
		Irrigation (from GW)	11,200	6,700	17,200
		Subtotal	**258,700**	**107,800**	**460,800**
	Outflow	Evapotranspiration (Irrigated Fields)	-78,400	-53,400	-106,300
		Evapotranspiration (Non-Irrigated Fields)	-38,400	-24,400	-52,700
		Evapotranspiration (Native Vegetation)	-60,900	-34,800	-75,700
		Recharge to GW	-25,300	-2,200	-65,500
		Runoff	-55,700	-1,900	-184,400
		Subtotal	**-258,700**	**-116,700**	**-484,600**
		Change in Storage	**0**	**-17,100***	**16,300***
2070WMW	Inflow	Precipitation	260,500	136,000	445,700
		Irrigation (from SW)	29,900	15,300	53,600
		Irrigation (from GW)	8,800	5,300	14,800
		Subtotal	**299,200**	**156,600**	**514,100**
	Outflow	Evapotranspiration (Irrigated Fields)	-79,000	-64,000	-101,600
		Evapotranspiration (Non-Irrigated Fields)	-40,800	-33,700	-56,300
		Evapotranspiration (Native Vegetation)	-65,900	-55,000	-81,700
		Recharge to GW	-36,200	-5,600	-79,200
		Runoff	-77,100	-6,900	-218,000
		Subtotal	**-299,000**	**-165,200**	**-536,800**
		Change in Storage	**200**	**-15,400***	**13,800***

Notes:
- WY 2021 excluded to remove influence of assumed initial conditions
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Values are rounded to the nearest 100 AFY
- Increasing storage reported as a positive value, decreasing storage reported as a negative value.

* Column arithmetic not applicable since values come from different years which violates mass balance. Mass-conservative values shown.

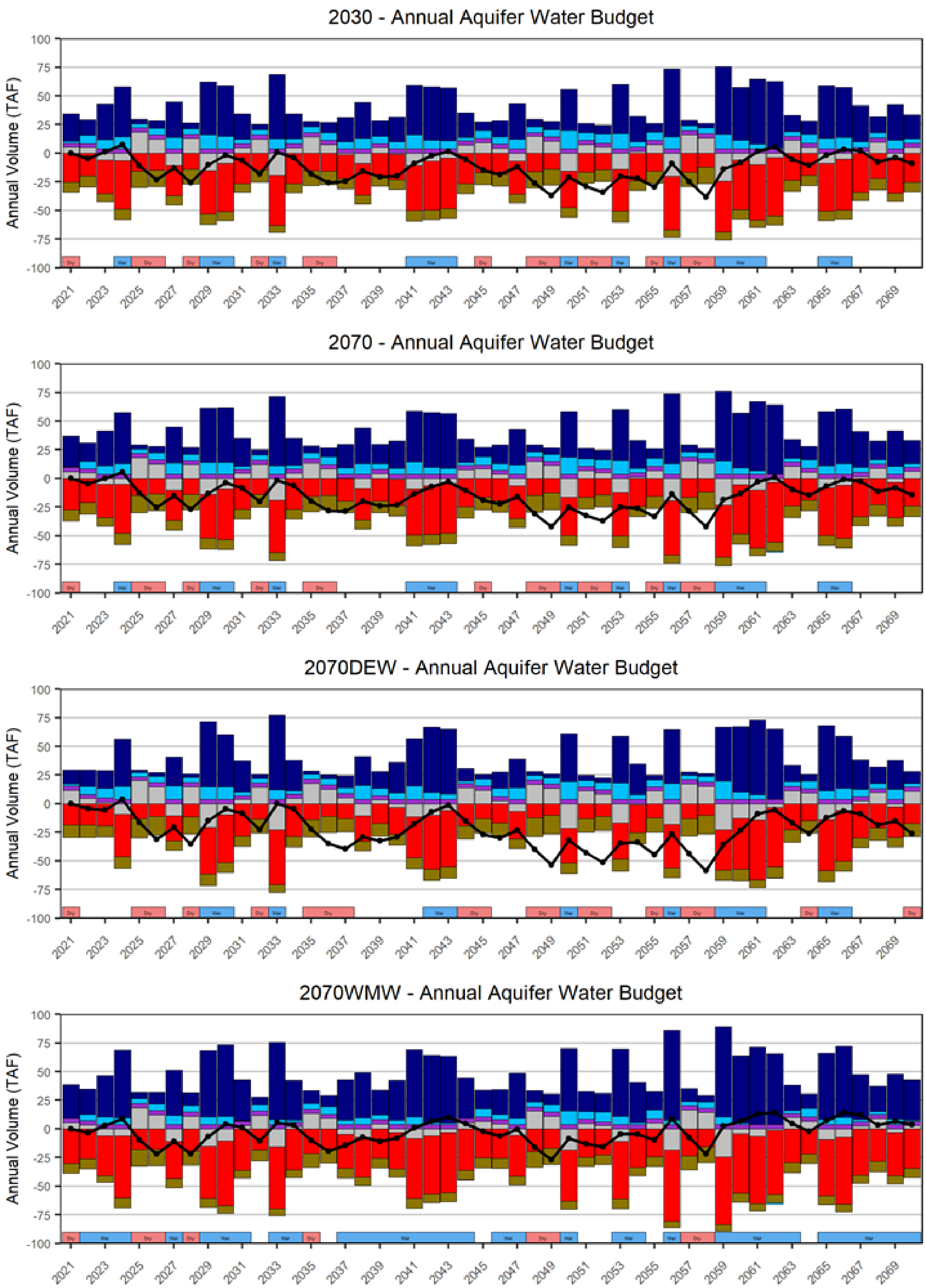


Figure 9-16. Projected future groundwater budgets.

Table 9-10. Summary of projected groundwater budgets.

Scenario	Flow	Component	Annual Flow (AFY)		
			Average	Minimum	Maximum
2030	Inflow	Recharge (Valley Floor)	26,200	3,800	59,200
		Recharge (Mountain Front)	3,700	3,700	3,700
		Subtotal	**29,900**	**7,500**	**29,900**
	Outflow	Evapotranspiration	-27,900	-12,300	-51,200
		Pumping (Wells)	-9,500	-6,100	-14,400
		Subtotal	**-37,400**	**-18,400**	**-65,600**
	Inflow/Outflow	Stream Exchange	**7,200**	**900**	**15,900**
		Change in Storage	**-200**	**-18,500***	**24,400***
2070	Inflow	Recharge (Valley Floor)	27,500	4,000	60,800
		Recharge (Mountain Front)	3,700	3,700	3,700
		Subtotal	**31,200**	**7,700**	**64,500**
	Outflow	Evapotranspiration	-28,300	-12,000	-52,400
		Pumping (Wells)	-10,000	-6,300	-15,200
		Subtotal	**-38,300**	**-18,300**	**-67,600**
	Inflow/Outflow	Stream Exchange	**5,900**	**-1,000**	**13,900**
		Change in Storage	**-500**	**-17,800***	**22,500***
2070DEW	Inflow	Recharge (Valley Floor)	25,200	2,200	65,300
		Recharge (Mountain Front)	3,700	3,700	3,700
		Subtotal	**28,900**	**5,900**	**69,000**
	Outflow	Evapotranspiration	-25,500	-10,200	-52,200
		Pumping (Wells)	-11,100	-6,800	-16,700
		Subtotal	**-36,600**	**-17,000**	**-68900**
	Inflow/Outflow	Stream Exchange	**7,000**	**-100**	**15,800**
		Change in Storage	**-500**	**-20,000***	**22,900***
2070WMW	Inflow	Recharge (Valley Floor)	36,100	5,600	79,000
		Recharge (Mountain Front)	3,700	3,700	3,700
		Subtotal	**39,800**	**29,900**	**82,700**
	Outflow	Evapotranspiration	-35,700	-15,500	-62,300
		Pumping (Wells)	-8,800	-5,500	-14,300
		Subtotal	**-44,500**	**-21,000**	**-76,600**
	Inflow/Outflow	Stream Exchange	**4,700**	**-1,300**	**11,800**
		Change in Storage	**100**	**-18,500***	**24,600***

Notes:
- Values represent projections for WY 2022-2070. WY 2021 excluded to remove influence of assumed initial conditions.
- Inflows are represented by positive values; outflows are represented by negative values.
- Minimum and maximum values represent the smallest and largest magnitudes of annual flows, respectively.
- Increasing storage reported as a positive value, decreasing storage reported as a negative value.

* Column arithmetic not applicable since values come from different years which violates mass balance. Mass-conservative values shown.

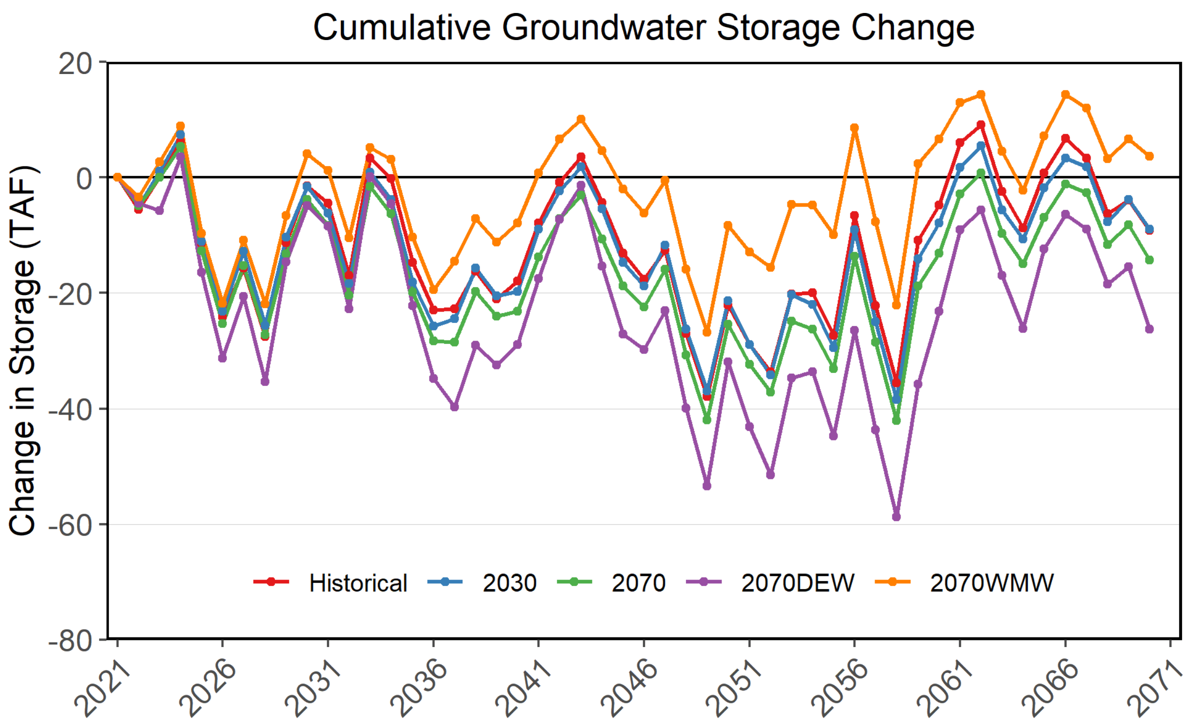


Figure 9-17. Projected change in groundwater storage from future climate scenarios.

Comparison of cumulative change in groundwater storage rates between the eastside and westside portions of the basin (Figure 9-18) shows similar interannual patterns between the two zones, but the magnitude of change is much greater for the eastside. Annual average change in storage rates range from about –0.1 to –1.6 acre-feet per day for the westside, compared to about –0.8 to –2.7 acre-feet per day for the eastside of the basin. Both sides of the basin exhibit the same pattern in storage rate changes as that observed in the basin wide change in storage volume (Figure 9-17).

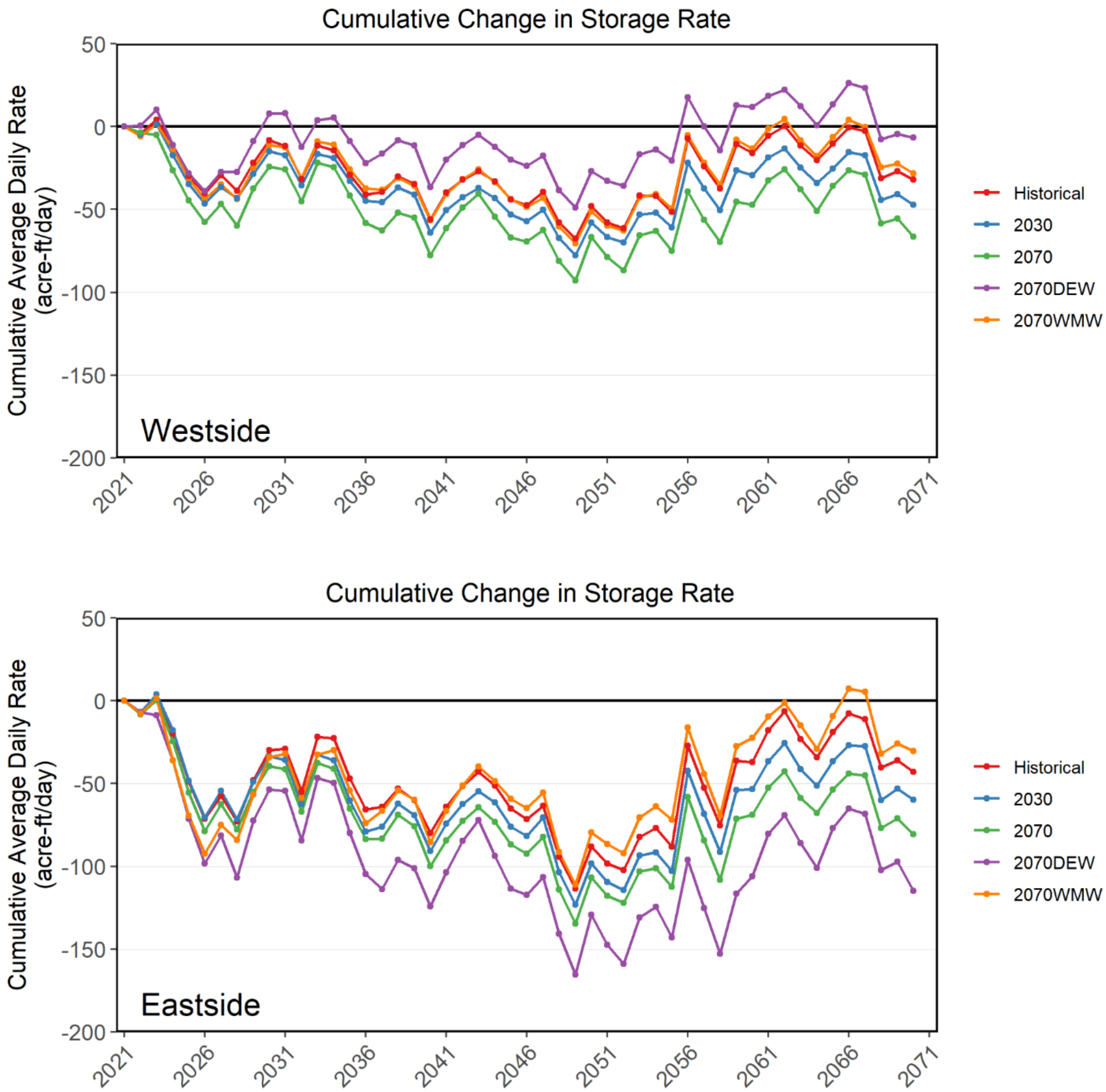
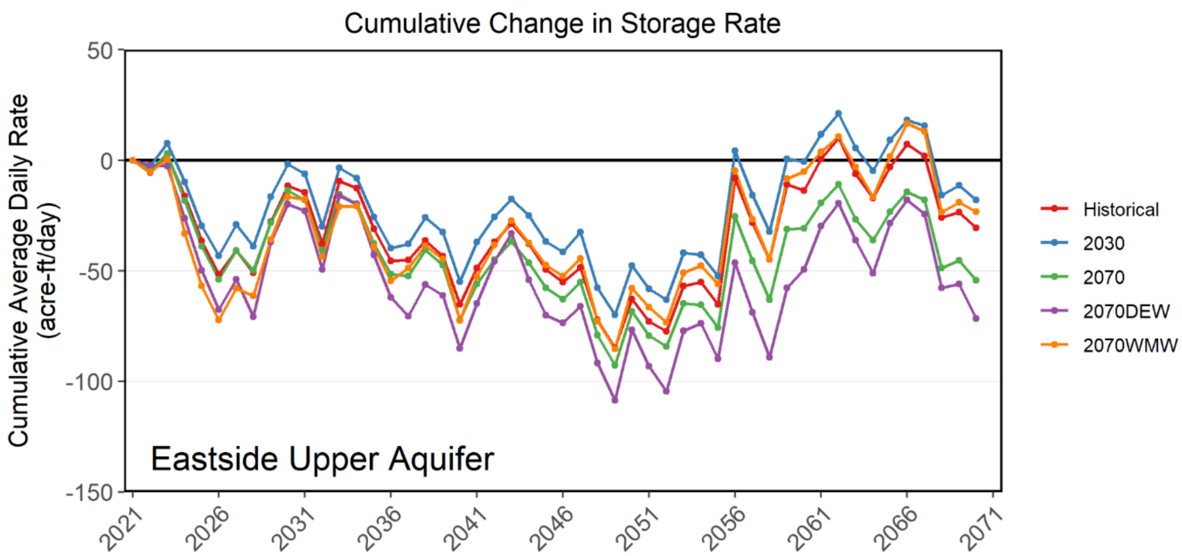


Figure 9-18. Eastside portion of the basin projected to experience greater declines in groundwater storage than the westside in the future.

Differences in cumulative changes in storage rates are much more apparent when comparing the eastside upper aquifer to the eastside lower aquifer (Figure 9-19). The eastside upper aquifer follows a similar interannual pattern to that observed when comparing the eastside of the basin to the westside, or looking at the change in volumetric storage for the groundwater basin as a whole. In contrast, changes in eastside lower aquifer storage are much more subdued on an interannual basis. Recovery of storage following the seven-year dry period is not observed in the eastside lower aquifer for any of the scenarios, although the 2070WMW scenario does come close. This indicates that groundwater levels in the eastside lower aquifer would continue to decline if current groundwater management practices were continued in the future.



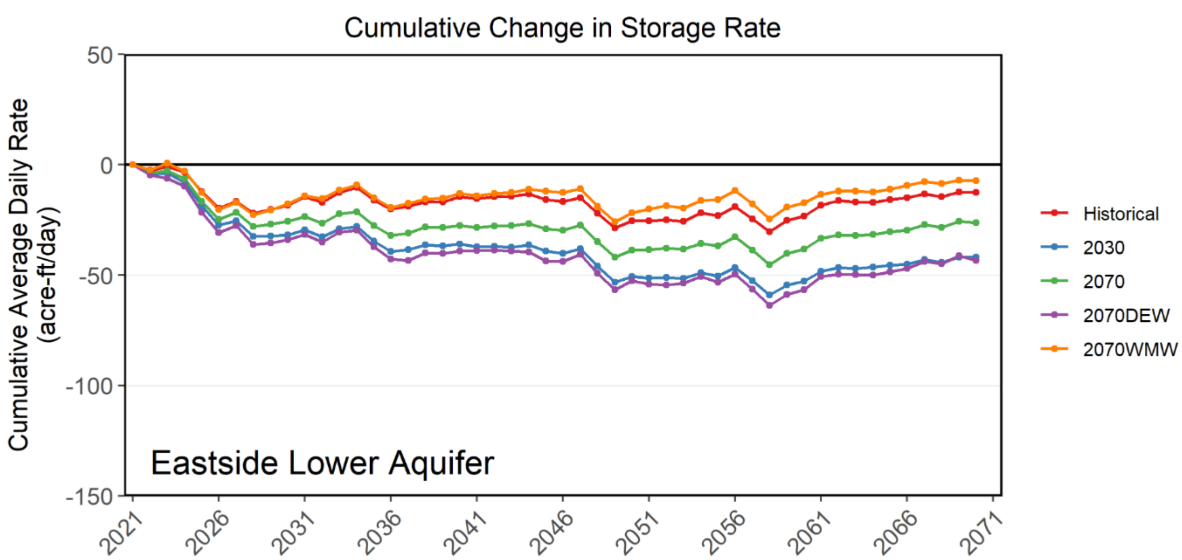


Figure 9-19. Continued declines in groundwater storage are expected for the eastside lower aquifer in the absence of management changes.

10.0 Future Work

Overall, representation of the Sierra Valley watershed hydrogeologic system by SVHSM is moderate to good despite limited time available for calibration efforts. The model captures the most salient intra- and inter-annual trends observed in available groundwater, surface water, and pumping data, making it a valuable tool for the basin moving forward. Additional calibration efforts are expected to greatly improve model results and are highly recommended. The following subsections suggest future data collection and model calibration efforts to focus on, in no particular order, based on understanding gained during initial model development and calibration.

10.1 Collection of Additional Streamflow Data

Flow data for streams that enter the groundwater basin along the margin of Sierra Valley are limited both spatially and temporally. Only 11 of the 17 (65%) streams where inflows to Sierra Valley are simulated by the PRMS submodel of SVHSM have flow data associated with them. Two of these streams are Little Last Chance Creek and Big Grizzly Creek for which daily or monthly totals are reported. However, flow in these streams is controlled by reservoir releases, and is therefore not suitable for calibration purposes. The remaining streams have a total number of flow observations that range from 7 to 124, which represents 0.09% to 1.6% of the SVHSM simulation period.

No flow data are available for streams that flow within Sierra Valley at a location sufficiently far enough away from the margins of the basin. While some flow observations are technically located within the valley, they are near enough to the margin that they have been associated with flow entering the valley, and are therefore used to specify stream inflow boundary conditions required for the SFR package the in MODFLOW submodel of SVHSM. The only surface water calibration data within the groundwater basin are streamflow data observed at the Middle Fork Feather River (MFP) gage, which represents total surface water outflow from the basin. Without additional streamflow data from locations within the valley, more detailed evaluation of model performance in the context of surface water flows and groundwater-surface water interactions cannot be performed.

Collection of flow data for streams that enter along the margin of Sierra Valley and flow within the groundwater basin is recommended in order to provide calibration points for SVHSM. Due to the high frequency of variation in surface water flows, data should be collected at a minimum of every two weeks, but preferably on a daily basis in order to identify periods of baseflow, snowmelt runoff, and storm runoff. Pressure transducers placed in streambeds are a relatively affordable method of estimating streamflow at sub-daily time intervals, and their deployment should be considered as part of future data collection efforts.

10.2 Collection of Additional Lithology Data

Information about aquifer geometry and sediment distribution is generally lacking on the western side of the valley. This is largely due to the preponderance of surface water use resulting in few groundwater wells with available well logs (see Figure 6-2). The USGS is currently conducting a seismic geophysical study of the basin, and an AEM survey conducted by DWR is expected in 2022. Both of these may provide additional geologic insight for this portion of the basin. Siting of future monitoring wells should prioritize this area if possible. In general, new wells drilled within the groundwater basin should have the lithology logs added to the DMS so their data can be incorporated into future model updates.

10.3 More Frequent Collection of Pumping Volume Data

Sierra Valley benefits from requiring flow meters to be installed on high-capacity (>100 gpm) wells. The availability of this dataset was extremely helpful during model development, and greatly reduced one of the largest sources of uncertainty in groundwater models developed in agricultural groundwater basins. Metered volumes are currently collected on an annual basis, with reads taken at the beginning and end of the growing season. Because SVHSM operates with monthly stress periods, the measured annual pumping volume must be distributed across the growing season months (see Section 5.1.6), which adds to model uncertainty.

Performing additional flow meter reads at the beginning/end of each month during the growing season would allow for a more accurate temporal distribution of groundwater pumping from each well. Because this additional data collection would likely result in a significant amount of effort for SVGMD staff, and therefore additional cost, we propose that these additional meter reads be performed voluntarily by growers. SVGMD staff would still perform meter reads at the beginning and end of the growing season to confirm total annual production volumes, and any intra-seasonal meter reads could be provided to SVGMD staff by growers at this time. This would facilitate the collection of higher resolution groundwater pumping volumes that would improve model performance without requiring an appreciable increase in SVGMD staff workload.

10.4 Subbasin Specific Calibration of PRMS

During manual calibration of the PRMS submodel of SVHSM, it was hypothesized that model performance may be improved if some parameters assigned to the entire model domain (e.g., *gwflow_coef*, *gwsink_coef)* were instead distributed spatially. Additionally, spatially distributed parameters may benefit from adjustment on a subbasin scale, as opposed to applying scaling factors to the entire model domain as was done in this instance due to time constraints. This would allow for different streamflow responses to similar climatic inputs that may result from physical differences in the basin due to geology, landcover, soil texture, etc. Additional streamflow data collection recommended in Section 10.1 would expand the number of subbasin streams to which this calibration effort could be applied.

10.5 Testing Alternative Representations of Confining Layer(s)

Due to the limited time available for model calibration, testing alternative representations of the confining layer(s) between the upper and lower aquifers was not possible. The current representation using a quasi-3D confining bed, while greatly improving model results, does have some significant limitations. It is applied across the entire model domain and the vertical conductivity can only be a single value. Given the large spatial extant and lithologic heterogeneity observed in the basin, the presence of a continuous confining layer present across the entire aquifer system is unlikely. However, it is clear that some type of confining layer (or layers) exists for a significant portion of the basin based on observed vertical head gradients. Therefore, future calibration efforts should explore alternative representations of this confining layer, especially since the quasi-3D confining bed in the current version of SVHSM was identified as the most sensitive parameter.

10.6 Testing Alternative Representations of Mountain Front Recharge

Due to the limited time available for model calibration, testing alternative representations of MFR was not possible. The current representation parameterizes MFR spatially, but not temporally. Future calibration efforts should explore the effects of varying MFR on an intra- and/or interannual basis. Additionally, further exploration of the spatial distribution of MFR and its control on simulated results should be considered.

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Appendix A
PRMS Water Budget

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
1989	10	3.381	0.463	3.09	0.295
1989	11	2.215	0.607	4.214	0.113
1989	12	0	0.356	3.502	0.08
1990	1	2.298	0.248	5.17	0.098
1990	2	3.458	0.201	8.054	0.082
1990	3	0.972	0.802	7.702	0.136
1990	4	1.256	1.938	6.238	0.261
1990	5	2.214	1.354	6.049	0.541
1990	6	0.146	1.678	3.866	0.195
1990	7	0	1.005	2.423	0.102
1990	8	0	0.497	1.627	0.048
1990	9	0.769	0.403	1.772	0.037
1990	10	0.278	0.461	1.414	0.03
1990	11	0.619	0.234	1.674	0.026
1990	12	0.516	0.161	1.926	0.023
1991	1	0	0.214	1.64	0.015
1991	2	0.909	0.65	1.814	0.024
1991	3	7.623	0.609	7.786	0.494
1991	4	0.232	1.397	5.797	0.213
1991	5	1.274	1.277	5.127	0.193
1991	6	0	1.158	3.484	0.111
1991	7	0.357	1.025	2.373	0.135
1991	8	1.047	1.045	2.038	0.088
1991	9	0.331	0.575	1.566	0.042
1991	10	2.178	0.436	3.086	0.064
1991	11	1.901	0.687	3.988	0.087
1991	12	1.465	0.268	4.861	0.075
1992	1	0.227	0.251	4.618	0.046
1992	2	2.854	0.586	6.441	0.136
1992	3	0.781	1.164	5.457	0.142
1992	4	0.284	1.365	3.894	0.106
1992	5	0	0.906	2.569	0.095
1992	6	0.322	0.634	1.943	0.066
1992	7	0	0.591	1.125	0.035
1992	8	0.595	0.439	1.116	0.026

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
1992	9	0	0.334	0.663	0.018
1992	10	2.447	0.46	2.533	0.041
1992	11	0	0.572	1.813	0.04
1992	12	8.532	0.11	9.866	0.132
1993	1	8.053	0.08	17.446	0.105
1993	2	6.662	0.185	23.476	0.157
1993	3	1.857	0.801	22.652	1.406
1993	4	1.097	1.485	18.324	2.846
1993	5	0.836	1.686	13.455	2.808
1993	6	1.456	1.874	9.559	2.455
1993	7	0	1.416	6.391	1.016
1993	8	0.282	1.046	4.554	0.54
1993	9	0	0.594	3.397	0.165
1993	10	1.192	0.884	3.244	0.125
1993	11	1.137	0.27	3.786	0.066
1993	12	1.613	0.258	4.768	0.092
1994	1	0.129	0.371	4.251	0.054
1994	2	3.538	0.353	7.024	0.137
1994	3	1.338	1.244	6.2	0.296
1994	4	0.113	1.234	4.512	0.124
1994	5	1.567	1.427	4.034	0.229
1994	6	0	0.857	2.776	0.101
1994	7	0	0.676	1.762	0.097
1994	8	0	0.365	1.157	0.051
1994	9	0.504	0.229	1.26	0.029
1994	10	0.406	0.467	1.053	0.028
1994	11	3.986	0.23	4.557	0.084
1994	12	1.835	0.177	5.708	0.136
1995	1	9.981	0.278	13.328	1.469
1995	2	0.742	0.614	12.533	0.29
1995	3	10.992	0.752	15.633	5.961
1995	4	2.234	1.421	14.065	1.33
1995	5	3.051	1.663	11.411	2.916
1995	6	1.143	1.788	8.665	1.27
1995	7	0.475	1.561	5.958	0.974
1995	8	0	0.969	4.148	0.349
1995	9	0	0.521	3.12	0.142
1995	10	0	0.377	2.387	0.059
1995	11	0.36	0.214	2.267	0.043
1995	12	4.197	0.395	5.346	0.303
1996	1	6.81	0.395	10.735	0.403

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
1996	2	7.7	0.525	13.094	3.694
1996	3	2.973	1.007	12.023	1.843
1996	4	3.231	1.881	10.129	2.212
1996	5	4.63	1.591	9.305	2.886
1996	6	0	1.716	6.305	0.497
1996	7	0	1.172	4.294	0.301
1996	8	0	0.634	3.101	0.158
1996	9	0.328	0.389	2.665	0.078
1996	10	0.876	0.43	2.81	0.062
1996	11	2.933	0.495	4.877	0.115
1996	12	12.461	0.346	13.395	2.759
1997	1	11.192	0.248	18.947	4.159
1997	2	0.191	0.33	17.721	0.302
1997	3	0.386	0.99	15.693	0.681
1997	4	0.256	1.501	13.328	0.469
1997	5	0.153	1.459	10.24	1.097
1997	6	1.127	1.55	7.808	1.358
1997	7	0	1.23	5.464	0.594
1997	8	0	0.794	3.973	0.29
1997	9	0.314	0.503	3.34	0.125
1997	10	1.209	0.854	3.315	0.101
1997	11	1.255	0.32	3.981	0.055
1997	12	1.427	0.237	4.864	0.073
1998	1	4.07	0.275	8.093	0.175
1998	2	6.711	0.351	12.854	0.882
1998	3	3.079	0.88	13.306	0.972
1998	4	1.02	1.535	11.537	0.475
1998	5	1.9	1.293	10.398	0.994
1998	6	0.159	1.574	7.674	0.702
1998	7	0	1.314	5.314	0.544
1998	8	0	0.833	3.863	0.219
1998	9	2.149	0.948	4.547	0.199
1998	10	0.543	0.968	3.766	0.073
1998	11	3.869	0.516	6.709	0.152
1998	12	1.792	0.177	7.603	0.186
1999	1	5.385	0.258	11.858	0.356
1999	2	6.718	0.352	15.976	1.512
1999	3	1.625	0.803	15.344	0.635
1999	4	1.302	1.412	14.077	0.548
1999	5	0	1.371	11.241	0.783
1999	6	0	1.336	8.363	0.912

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
1999	7	0	1.223	5.844	0.751
1999	8	0.276	0.892	4.486	0.312
1999	9	0	0.512	3.541	0.102
1999	10	1.217	0.513	3.889	0.082
1999	11	0.969	0.658	3.913	0.06
1999	12	0.212	0.253	3.638	0.044
2000	1	7.017	0.319	9.666	0.354
2000	2	5.674	0.542	12.508	1.472
2000	3	0.111	1.046	10.519	0.272
2000	4	1.295	1.656	9.106	0.45
2000	5	0.732	1.312	7.384	0.57
2000	6	0.205	1.224	5.429	0.469
2000	7	0	0.868	4.018	0.162
2000	8	0	0.585	3.039	0.092
2000	9	0	0.268	2.493	0.044
2000	10	1.146	0.32	3.087	0.042
2000	11	0.618	0.281	3.244	0.035
2000	12	0.42	0.301	3.215	0.029
2001	1	0.553	0.174	3.476	0.023
2001	2	1.859	0.244	4.993	0.024
2001	3	1.441	1.204	4.875	0.098
2001	4	1.608	1.343	4.741	0.095
2001	5	0	1.113	3.259	0.078
2001	6	0	0.655	2.352	0.044
2001	7	0	0.434	1.733	0.032
2001	8	0	0.263	1.334	0.03
2001	9	0.415	0.188	1.466	0.023
2001	10	0.519	0.26	1.654	0.015
2001	11	3.335	0.427	4.421	0.065
2001	12	4.884	0.225	8.437	0.227
2002	1	1.929	0.218	9.314	0.235
2002	2	0.905	0.499	9.131	0.155
2002	3	2.227	0.899	9.614	0.3
2002	4	0.734	1.531	8.095	0.218
2002	5	0.229	1.17	6.496	0.21
2002	6	0	1.127	4.688	0.267
2002	7	0	0.931	3.207	0.191
2002	8	0	0.506	2.346	0.067
2002	9	0	0.25	1.839	0.037
2002	10	0	0.165	1.476	0.025
2002	11	4.385	0.492	4.856	0.173

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
2002	12	6.656	0.307	10.241	0.415
2003	1	1.106	0.51	9.764	0.326
2003	2	0.959	0.468	9.403	0.266
2003	3	1.755	1.229	8.863	0.488
2003	4	3.315	1.296	9.552	0.691
2003	5	0.159	1.59	7.206	0.39
2003	6	0.173	1.245	5.254	0.43
2003	7	0.347	1.096	3.831	0.291
2003	8	1.369	1.285	3.438	0.155
2003	9	0	0.537	2.595	0.056
2003	10	0.114	0.386	2.086	0.038
2003	11	0.732	0.306	2.328	0.035
2003	12	5.666	0.266	7.322	0.137
2004	1	1.786	0.202	8.38	0.118
2004	2	4.426	0.392	11.391	0.527
2004	3	0.796	1.317	9.483	0.534
2004	4	0	1.412	7.1	0.312
2004	5	0.717	1.18	5.728	0.381
2004	6	0	1.04	4.094	0.187
2004	7	0	0.809	2.857	0.098
2004	8	0	0.451	2.089	0.054
2004	9	0	0.205	1.65	0.034
2004	10	2.563	0.403	3.563	0.064
2004	11	1.612	0.53	4.382	0.064
2004	12	4.135	0.249	7.909	0.093
2005	1	3.913	0.17	11.398	0.051
2005	2	0.592	0.343	11.433	0.052
2005	3	4.344	0.852	13.201	1.121
2005	4	0.796	1.584	10.973	0.616
2005	5	2.335	1.78	9.201	1.499
2005	6	0.569	1.547	6.855	0.686
2005	7	0	1.388	4.5	0.446
2005	8	0	0.747	3.211	0.146
2005	9	0.261	0.401	2.709	0.064
2005	10	0.207	0.376	2.258	0.045
2005	11	1.093	0.217	2.92	0.04
2005	12	13.083	0.431	10.099	4.83
2006	1	4.053	0.337	11.163	1.543
2006	2	3.55	0.513	11.497	1.82
2006	3	3.481	0.508	12.383	1.097
2006	4	4.674	1.853	11.057	3.025

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
2006	5	0.29	1.588	8.138	0.789
2006	6	0.172	1.321	5.926	0.482
2006	7	0	1.028	4.181	0.258
2006	8	0	0.558	3.152	0.119
2006	9	0	0.288	2.535	0.06
2006	10	0.216	0.277	2.216	0.042
2006	11	1.843	0.479	3.361	0.05
2006	12	1.367	0.248	4.272	0.051
2007	1	0.728	0.272	4.419	0.07
2007	2	5.068	0.554	8.361	0.194
2007	3	0.69	1.163	7.053	0.222
2007	4	0.556	1.613	5.373	0.144
2007	5	0.29	1.113	4.069	0.119
2007	6	0.342	0.915	3.137	0.082
2007	7	0	0.643	2.223	0.049
2007	8	0	0.33	1.691	0.031
2007	9	0.107	0.164	1.489	0.02
2007	10	1.204	0.633	1.927	0.031
2007	11	0.178	0.235	1.777	0.02
2007	12	2.063	0.122	3.631	0.025
2008	1	5.262	0.114	8.413	0.12
2008	2	2.439	0.329	10.076	0.136
2008	3	0.435	0.696	9.31	0.129
2008	4	0	1.216	7.703	0.105
2008	5	0.331	1.323	6.178	0.163
2008	6	0	1.253	4.303	0.2
2008	7	0	0.974	2.85	0.126
2008	8	0	0.539	2	0.048
2008	9	0	0.238	1.542	0.03
2008	10	0.554	0.322	1.603	0.027
2008	11	2.04	0.683	2.756	0.06
2008	12	1.726	0.198	4.163	0.026
2009	1	1.13	0.273	4.891	0.04
2009	2	2.942	0.371	7.156	0.113
2009	3	3.931	0.693	9.092	0.534
2009	4	0	1.433	6.888	0.182
2009	5	2.026	1.806	5.803	0.687
2009	6	0.514	1.271	4.321	0.252
2009	7	0	0.914	2.955	0.091
2009	8	0	0.466	2.162	0.053
2009	9	0	0.24	1.685	0.035

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
2009	10	1.951	0.794	2.59	0.066
2009	11	0.625	0.439	2.599	0.039
2009	12	2.713	0.12	5.06	0.028
2010	1	3.253	0.257	7.735	0.102
2010	2	2.384	0.432	9.185	0.162
2010	3	2.092	0.814	9.647	0.243
2010	4	3.37	1.377	10.447	0.561
2010	5	0.937	1.38	9.003	0.379
2010	6	0	1.603	6.436	0.433
2010	7	0	1.226	4.337	0.411
2010	8	0	0.695	3.15	0.124
2010	9	0	0.378	2.441	0.053
2010	10	4.527	1.194	5.187	0.29
2010	11	2.771	0.582	6.819	0.12
2010	12	6.887	0.272	12.035	0.703
2011	1	0.575	0.272	11.346	0.241
2011	2	3.809	0.24	14.161	0.242
2011	3	7.8	0.584	17.775	2.718
2011	4	0.72	1.267	15.59	0.712
2011	5	1.195	1.304	13.348	1.271
2011	6	1.739	1.833	10.336	2.056
2011	7	0	1.61	6.943	1.087
2011	8	0	1.034	4.948	0.444
2011	9	0.562	0.796	4.095	0.229
2011	10	1.371	1.08	3.919	0.126
2011	11	0.914	0.361	4.145	0.067
2011	12	0	0.169	3.715	0.047
2012	1	5.328	0.317	7.817	0.608
2012	2	0.946	0.435	7.599	0.157
2012	3	5.061	0.776	9.742	1.422
2012	4	1.807	1.942	8.032	0.747
2012	5	0.509	1.434	6.17	0.314
2012	6	0.318	1.197	4.686	0.17
2012	7	0.372	1.006	3.598	0.113
2012	8	0	0.605	2.656	0.067
2012	9	0.104	0.321	2.193	0.043
2012	10	1.05	0.398	2.642	0.039
2012	11	6.478	0.654	7.704	0.546
2012	12	7.128	0.29	11.045	2.558
2013	1	0.298	0.161	10.149	0.26
2013	2	0.13	0.318	9.326	0.154

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
2013	3	0.619	1.132	8.049	0.246
2013	4	0.306	1.555	6.124	0.199
2013	5	1.047	1.261	5.307	0.192
2013	6	0	0.982	3.867	0.129
2013	7	0	0.698	2.801	0.092
2013	8	0.18	0.407	2.304	0.045
2013	9	0.464	0.349	2.211	0.035
2013	10	0.577	0.3	2.316	0.029
2013	11	0.239	0.333	2.09	0.025
2013	12	0.638	0.213	2.406	0.022
2014	1	1.588	0.378	3.507	0.036
2014	2	4.658	0.795	6.686	0.312
2014	3	1.606	1.348	6.169	0.197
2014	4	0.317	1.555	4.423	0.108
2014	5	0.713	1.104	3.632	0.099
2014	6	0	0.768	2.574	0.057
2014	7	0.541	0.666	2.231	0.037
2014	8	1.685	1.439	2.242	0.073
2014	9	0.799	0.495	2.402	0.036
2014	10	0.517	0.835	1.969	0.032
2014	11	1.17	0.311	2.74	0.031
2014	12	4.01	0.43	5.682	0.22
2015	1	0	0.568	4.627	0.098
2015	2	4.161	0.911	6.792	0.561
2015	3	0.151	1.347	4.88	0.148
2015	4	1.117	1.211	4.304	0.117
2015	5	1.252	1.188	3.908	0.147
2015	6	0.809	1.419	2.938	0.1
2015	7	1.279	1.354	2.57	0.08
2015	8	0.675	0.916	2.116	0.05
2015	9	0	0.329	1.644	0.027
2015	10	1.64	1.074	2.068	0.048
2015	11	2.098	0.367	3.637	0.061
2015	12	4.258	0.248	7.093	0.196
2016	1	3.969	0.327	9.56	0.571
2016	2	0.794	0.732	8.444	0.386
2016	3	4.357	1.307	9.111	1.492
2016	4	1.725	2.003	7.5	0.652
2016	5	2.44	1.762	6.66	0.89
2016	6	0.159	1.51	4.658	0.188
2016	7	0	0.914	3.292	0.093

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
2016	8	0	0.501	2.451	0.058
2016	9	0	0.235	1.969	0.038
2016	10	5.75	0.884	6.213	0.295
2016	11	0.934	0.804	5.538	0.191
2016	12	6.21	0.331	8.684	1.918
2017	1	13.838	0.16	18.046	3.229
2017	2	13.295	0.335	22.269	7.414
2017	3	2.287	0.771	20.871	1.802
2017	4	4.529	1.535	17.207	5.265
2017	5	0.703	1.67	13.101	2.049
2017	6	0.147	1.542	9.588	1.351
2017	7	0	1.306	6.73	0.943
2017	8	0.535	1.094	5.053	0.651
2017	9	0.994	0.824	4.62	0.243
2017	10	0.414	0.635	4.026	0.071
2017	11	5.384	0.668	7.771	0.559
2017	12	0.303	0.382	6.882	0.187
2018	1	2.373	0.565	7.744	0.358
2018	2	0.698	0.469	7.404	0.125
2018	3	7.14	0.649	11.452	1.787
2018	4	1.853	1.873	9.244	1.263
2018	5	2.104	1.652	8.211	0.787
2018	6	0.42	1.708	6.115	0.277
2018	7	0	1.112	4.415	0.187
2018	8	0	0.532	3.456	0.114
2018	9	0	0.265	2.898	0.056
2018	10	0.273	0.288	2.65	0.042
2018	11	1.688	0.219	3.933	0.04
2018	12	1.364	0.232	4.862	0.049
2019	1	7.787	0.317	11.119	0.723
2019	2	13.331	0.217	21.885	1.585
2019	3	2.042	0.656	21.062	1.374
2019	4	1.18	1.874	17.26	2.166
2019	5	1.894	1.492	14.215	2.408
2019	6	0	1.773	10.092	1.51
2019	7	0	1.347	7.142	0.961
2019	8	0	0.936	5.314	0.414
2019	9	1.072	0.66	5.178	0.181
2019	10	0.403	0.73	4.458	0.08
2019	11	0.817	0.286	4.705	0.05
2019	12	4.705	0.28	8.481	0.204

Year	Month	Precip (inches)	ET (inches)	Storage (inches)	Runoff (inches)
2020	1	0.926	0.403	8.383	0.143
2020	2	0	0.611	7.375	0.079
2020	3	3.006	0.64	9.459	0.059
2020	4	1.277	1.735	8.373	0.23
2020	5	1.196	1.563	6.956	0.519
2020	6	0.152	1.211	5.241	0.234
2020	7	0	0.889	3.907	0.124
2020	8	0	0.509	3.081	0.069
2020	9	0	0.237	2.62	0.036

Appendix B
SWBM Water Budget

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
1999	10	13,573	1,480	28	-19,814	-135	-266	5,133	0
1999	11	14,336	0	0	-2,381	-331	-70	-11,554	0
1999	12	5,944	0	0	-427	-206	0	-5,311	0
2000	1	67,108	0	0	-8	-8,472	-15,006	-43,623	0
2000	2	52,494	0	0	-9	-24,188	-24,545	-3,751	0
2000	3	3,981	0	0	-9,308	-3,784	0	9,111	0
2000	4	13,150	131	27	-25,053	-903	-1,265	13,913	0
2000	5	7,293	3,495	277	-36,619	-139	0	25,693	0
2000	6	1,398	12,137	1,190	-41,954	-25	0	27,253	0
2000	7	0	7,306	2,002	-36,712	0	0	27,404	0
2000	8	0	4,897	1,809	-16,397	0	0	9,691	0
2000	9	1,464	1,461	139	-5,871	-14	0	2,821	0
2000	10	14,494	691	35	-8,455	-274	-115	-6,377	0
2000	11	9,487	0	0	-1,651	-134	-164	-7,539	0
2000	12	5,906	0	0	-383	-170	-17	-5,336	0
2001	1	7,557	0	0	-7	-242	-47	-7,260	0
2001	2	17,526	0	0	-10	-540	-169	-16,807	0
2001	3	15,323	0	0	-9,991	-485	-427	-4,421	0
2001	4	14,853	2,705	1,057	-23,600	-483	-158	5,625	0
2001	5	0	8,920	1,981	-37,161	0	0	26,260	0
2001	6	0	4,793	2,351	-22,162	0	0	15,018	0
2001	7	96	2,292	2,485	-6,535	0	0	1,663	0
2001	8	0	2,531	2,288	-5,428	0	0	609	0
2001	9	3,591	668	157	-5,282	-54	-37	958	0
2001	10	5,133	315	60	-1,592	-54	-105	-3,758	0
2001	11	37,309	0	0	-2,025	-427	-778	-34,078	0
2001	12	49,778	0	0	-353	-3,193	-2,528	-43,705	0
2002	1	18,307	0	0	-8	-3,402	-3,058	-11,839	0
2002	2	8,742	0	0	-13	-3,343	-1,104	-4,281	0
2002	3	24,104	0	0	-9,056	-5,794	-7,142	-2,112	0
2002	4	7,781	71	604	-22,660	-195	-17	14,416	0
2002	5	2,999	4,694	1,289	-37,083	-60	0	28,161	0
2002	6	0	11,458	2,014	-41,152	0	0	27,680	0
2002	7	1,037	7,071	2,422	-32,636	-6	0	22,112	0

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
2002	8	0	2,998	2,073	-10,520	0	0	5,449	0
2002	9	0	1,070	171	-3,006	0	0	1,766	0
2002	10	0	468	54	-927	0	0	404	0
2002	11	47,443	0	0	-1,306	-269	-1,358	-44,510	0
2002	12	65,315	0	0	-380	-6,032	-7,450	-51,453	0
2003	1	11,257	0	0	-8	-5,213	-1,450	-4,587	0
2003	2	10,171	0	0	-12	-4,326	-2,336	-3,496	0
2003	3	17,921	0	0	-8,187	-3,641	-6,896	803	0
2003	4	30,078	1	184	-18,723	-4,335	-3,942	-3,262	0
2003	5	3,574	767	765	-37,348	-82	0	32,324	0
2003	6	1,604	8,937	1,936	-46,991	-21	0	34,535	0
2003	7	3,280	9,277	2,658	-39,350	-21	0	24,156	0
2003	8	10,331	4,166	2,068	-25,041	-172	-77	8,726	0
2003	9	735	1,399	155	-7,488	-5	0	5,204	0
2003	10	1,112	600	63	-1,664	-35	0	-75	0
2003	11	11,005	0	0	-1,792	-229	-104	-8,880	0
2003	12	57,340	0	0	-360	-1,196	-1,785	-54,000	0
2004	1	19,491	0	0	-7	-1,548	-1,773	-16,162	0
2004	2	42,534	0	0	-10	-5,969	-13,310	-23,245	0
2004	3	8,598	0	0	-11,195	-1,855	-1,571	6,024	0
2004	4	465	709	476	-26,708	-3	0	25,061	0
2004	5	5,294	7,085	1,692	-37,349	-108	-2	23,387	0
2004	6	904	9,858	2,081	-36,430	-5	0	23,593	0
2004	7	0	3,888	2,670	-27,846	0	0	21,288	0
2004	8	0	2,126	2,173	-6,582	0	0	2,283	0
2004	9	1,899	1,194	165	-4,972	-15	0	1,729	0
2004	10	27,421	723	56	-5,267	-292	-548	-22,093	0
2004	11	20,130	0	0	-1,710	-281	-387	-17,752	0
2004	12	40,787	0	0	-285	-1,060	-2,954	-36,488	0
2005	1	36,238	0	0	-5	-6,464	-6,837	-22,932	0
2005	2	10,644	0	0	-9	-6,055	-605	-3,976	0
2005	3	41,799	0	0	-7,519	-10,736	-16,086	-7,458	0
2005	4	8,969	0	171	-21,887	-1,048	-190	13,985	0
2005	5	17,149	373	427	-32,889	-959	-743	16,642	0
2005	6	4,895	6,029	1,444	-41,738	-69	-1	29,441	0
2005	7	0	12,407	2,421	-43,050	0	0	28,222	0
2005	8	139	5,146	2,303	-24,669	-1	0	17,081	0
2005	9	2,753	1,407	142	-8,558	-37	0	4,293	0
2005	10	4,489	670	50	-4,984	-86	0	-140	0
2005	11	13,978	0	0	-1,874	-298	-131	-11,675	0

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
2005	12	127,443	0	0	-281	-3,744	-29,143	-94,276	0
2006	1	37,740	0	0	-9	-14,166	-17,600	-5,965	0
2006	2	31,975	0	0	-13	-10,499	-18,913	-2,550	0
2006	3	38,729	0	0	-6,078	-17,629	-13,327	-1,695	0
2006	4	43,630	0	0	-20,458	-10,598	-18,484	5,909	0
2006	5	2,582	220	340	-39,249	-33	0	36,141	0
2006	6	1,434	8,509	1,124	-42,885	-20	0	31,837	0
2006	7	0	10,101	1,959	-36,917	0	0	24,857	0
2006	8	0	6,649	1,516	-20,627	0	0	12,462	0
2006	9	0	2,643	159	-5,867	0	0	3,064	0
2006	10	2,383	877	41	-4,357	-42	0	1,098	0
2006	11	21,768	0	0	-1,925	-439	-236	-19,169	0
2006	12	15,964	0	0	-410	-358	-160	-15,036	0
2007	1	6,538	0	0	-8	-134	-270	-6,125	0
2007	2	46,381	0	0	-10	-2,275	-3,364	-40,732	0
2007	3	6,628	0	0	-10,086	-221	-165	3,844	0
2007	4	7,545	303	1,050	-24,962	-161	-71	16,296	0
2007	5	2,696	8,606	1,575	-41,050	-61	-4	28,237	0
2007	6	2,414	6,558	1,987	-34,611	-49	-6	23,706	0
2007	7	0	3,520	2,402	-14,130	0	0	8,208	0
2007	8	0	2,764	2,227	-6,396	0	0	1,406	0
2007	9	3,870	1,020	141	-6,284	-29	0	1,282	0
2007	10	14,743	537	22	-13,219	-243	-118	-1,722	0
2007	11	3,705	0	0	-1,861	-90	-8	-1,747	0
2007	12	21,532	0	0	-405	-419	-279	-20,429	0
2008	1	50,219	0	0	-7	-1,832	-1,728	-46,653	0
2008	2	22,377	0	0	-12	-2,352	-2,501	-17,512	0
2008	3	4,884	0	0	-8,609	-1,257	-63	5,045	0
2008	4	513	351	1,296	-27,774	-7	0	25,620	0
2008	5	3,804	8,063	1,654	-35,409	-57	0	21,946	0
2008	6	0	9,103	2,594	-35,755	0	0	24,059	0
2008	7	0	4,685	2,686	-17,116	0	0	9,745	0
2008	8	0	3,049	2,336	-6,296	0	0	912	0
2008	9	0	937	178	-2,483	0	0	1,368	0
2008	10	5,549	721	40	-5,437	-137	-16	-720	0
2008	11	22,343	0	0	-1,855	-263	-442	-19,782	0
2008	12	18,861	0	0	-458	-402	-227	-17,774	0
2009	1	10,195	0	0	-9	-358	-129	-9,699	0
2009	2	27,403	0	0	-12	-1,615	-1,355	-24,421	0
2009	3	38,096	0	0	-9,508	-2,916	-7,459	-18,212	0

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
2009	4	1,937	276	1,130	-26,399	-43	0	23,099	0
2009	5	13,916	6,972	1,662	-42,972	-299	-88	20,809	0
2009	6	4,755	8,357	1,906	-34,293	-75	-1	19,351	0
2009	7	0	3,835	2,710	-30,180	0	0	23,634	0
2009	8	599	2,392	2,267	-7,305	-4	0	2,052	0
2009	9	775	611	187	-3,297	-5	0	1,729	0
2009	10	19,835	669	39	-10,028	-121	-501	-9,893	0
2009	11	7,048	0	0	-2,505	-148	-71	-4,324	0
2009	12	27,948	0	0	-223	-492	-465	-26,768	0
2010	1	29,833	0	0	-6	-1,046	-1,387	-27,394	0
2010	2	21,626	0	0	-11	-2,084	-2,062	-17,468	0
2010	3	21,640	0	0	-9,604	-2,139	-2,413	-7,484	0
2010	4	30,476	20	494	-22,401	-2,011	-3,079	-3,499	0
2010	5	7,664	1,479	1,062	-36,198	-132	-27	26,151	0
2010	6	756	8,144	2,184	-46,008	-5	0	34,929	0
2010	7	0	12,057	2,592	-36,112	0	0	21,464	0
2010	8	0	4,585	2,071	-17,158	0	0	10,502	0
2010	9	0	1,274	173	-4,745	0	0	3,298	0
2010	10	44,631	2,222	12	-16,223	-348	-1,048	-29,246	0
2010	11	30,920	0	0	-2,297	-596	-964	-27,064	0
2010	12	68,161	0	0	-386	-6,610	-15,062	-46,103	0
2011	1	5,622	0	0	-8	-2,936	-1,367	-1,312	0
2011	2	34,009	0	0	-13	-9,469	-17,156	-7,370	0
2011	3	75,261	0	0	-6,470	-24,905	-40,051	-3,834	0
2011	4	9,114	1	50	-22,990	-547	-53	14,426	0
2011	5	9,072	1,067	319	-35,011	-183	-7	24,743	0
2011	6	11,915	6,984	1,106	-42,299	-158	-119	22,572	0
2011	7	0	12,791	2,250	-42,207	0	0	27,166	0
2011	8	0	13,242	1,846	-27,227	0	0	12,140	0
2011	9	5,489	7,008	119	-16,850	-76	-23	4,333	0
2011	10	14,229	1,601	19	-15,305	-164	-251	-129	0
2011	11	10,137	0	0	-1,998	-275	-31	-7,833	0
2011	12	202	0	0	-480	-7	0	285	0
2012	1	48,304	0	0	-4	-427	-1,859	-46,014	0
2012	2	9,973	0	0	-13	-778	-484	-8,697	0
2012	3	51,129	0	0	-8,147	-5,131	-10,383	-27,469	0
2012	4	15,684	76	225	-25,905	-1,017	-483	11,421	0
2012	5	3,325	3,680	1,376	-43,255	-68	-1	34,942	0
2012	6	2,692	7,692	2,237	-43,133	-53	-5	30,571	0
2012	7	3,164	3,981	2,691	-28,324	-42	-11	18,542	0

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
2012	8	0	2,733	2,341	-6,846	0	0	1,772	0
2012	9	869	1,283	180	-4,157	-6	0	1,831	0
2012	10	10,243	757	65	-5,733	-155	-158	-5,018	0
2012	11	70,575	0	0	-2,117	-742	-3,197	-64,519	0
2012	12	70,979	0	0	-473	-11,997	-20,448	-38,061	0
2013	1	4,453	0	0	-6	-3,397	-769	-281	0
2013	2	1,132	0	0	-14	-881	0	-237	0
2013	3	7,488	0	0	-9,782	-2,640	-1,329	6,263	0
2013	4	2,925	444	465	-29,135	-99	0	25,400	0
2013	5	7,521	7,300	1,387	-39,107	-135	-22	23,057	0
2013	6	1,091	7,115	2,188	-37,729	-13	0	27,348	0
2013	7	214	3,470	2,970	-28,025	-1	0	21,372	0
2013	8	1,255	1,890	2,482	-8,806	-17	0	3,196	0
2013	9	4,614	505	150	-6,657	-93	-23	1,505	0
2013	10	5,735	457	52	-1,812	-91	-91	-4,250	0
2013	11	3,694	0	0	-2,309	-85	-29	-1,271	0
2013	12	6,129	0	0	-354	-107	-91	-5,576	0
2014	1	14,073	0	0	-3	-136	-324	-13,610	0
2014	2	40,838	0	0	-15	-875	-1,526	-38,422	0
2014	3	16,238	0	0	-9,126	-833	-408	-5,870	0
2014	4	3,872	1,906	1,514	-28,261	-64	-30	21,063	0
2014	5	5,400	6,911	2,357	-38,723	-58	-87	24,201	0
2014	6	0	3,437	3,100	-27,893	0	0	21,356	0
2014	7	5,274	1,571	2,757	-10,523	-63	-23	1,007	0
2014	8	12,553	1,580	2,204	-16,994	-103	-167	928	0
2014	9	6,800	628	159	-6,306	-138	-31	-1,112	0
2014	10	5,879	366	59	-7,833	-135	-6	1,670	0
2014	11	14,771	0	0	-1,593	-270	-185	-12,722	0
2014	12	40,496	0	0	-277	-706	-978	-38,536	0
2015	1	0	0	0	-9	-4	-27	41	0
2015	2	36,950	0	0	-17	-1,513	-3,821	-31,599	0
2015	3	1,426	0	0	-11,074	-346	-6	10,000	0
2015	4	10,205	781	1,254	-28,152	-180	-104	16,196	0
2015	5	8,998	5,688	1,840	-34,050	-150	-57	17,733	0
2015	6	5,263	3,744	2,781	-40,605	-58	-12	28,888	0
2015	7	12,277	1,824	2,257	-24,491	-148	-28	8,309	0
2015	8	4,708	2,130	2,222	-9,885	-54	-63	943	0
2015	9	1,272	721	163	-3,589	-16	0	1,448	0
2015	10	16,207	614	40	-15,047	-181	-305	-1,327	0
2015	11	24,600	0	0	-1,908	-343	-436	-21,913	0

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
2015	12	42,812	0	0	-367	-918	-1,597	-39,929	0
2016	1	38,956	0	0	-6	-3,373	-5,709	-29,869	0
2016	2	10,051	0	0	-14	-4,420	-467	-5,151	0
2016	3	41,539	0	0	-8,648	-9,548	-15,419	-7,924	0
2016	4	16,572	2	404	-27,401	-1,246	-1,048	12,717	0
2016	5	17,123	387	953	-36,164	-1,727	-931	20,360	0
2016	6	1,033	7,714	2,427	-44,996	-16	0	33,838	0
2016	7	0	4,018	2,648	-36,050	0	0	29,383	0
2016	8	577	1,797	2,650	-11,985	-4	0	6,965	0
2016	9	0	654	180	-2,902	0	0	2,068	0
2016	10	57,561	2,664	33	-11,252	-503	-1,449	-47,054	0
2016	11	12,596	0	0	-2,457	-421	-320	-9,398	0
2016	12	61,813	0	0	-419	-3,670	-14,189	-43,535	0
2017	1	124,865	0	0	-7	-20,280	-87,862	-16,716	0
2017	2	117,208	0	0	-12	-25,190	-89,798	-2,207	0
2017	3	23,974	0	0	-7,461	-8,693	-8,697	876	0
2017	4	38,509	0	0	-23,652	-9,326	-16,676	11,145	0
2017	5	4,891	1,241	525	-44,653	-103	-17	38,116	0
2017	6	1,368	9,110	1,648	-43,836	-26	0	31,736	0
2017	7	0	14,398	2,627	-39,240	0	0	22,214	0
2017	8	4,549	12,302	1,570	-21,434	-37	0	3,050	0
2017	9	10,268	6,359	92	-17,609	-134	-13	1,039	0
2017	10	4,856	1,646	45	-9,513	-75	-64	3,105	0
2017	11	60,526	0	0	-1,708	-591	-2,058	-56,169	0
2017	12	3,694	0	0	-440	-357	-33	-2,863	0
2018	1	24,556	0	0	-9	-2,651	-3,236	-18,660	0
2018	2	8,810	0	0	-14	-2,761	-745	-5,290	0
2018	3	70,669	0	0	-8,167	-12,839	-32,560	-17,103	0
2018	4	16,655	0	25	-23,717	-2,012	-1,986	11,035	0
2018	5	16,521	252	553	-38,761	-172	-241	21,848	0
2018	6	2,736	8,455	2,084	-46,527	-51	-14	33,317	0
2018	7	0	6,531	2,329	-38,416	0	0	29,555	0
2018	8	0	5,853	1,750	-15,660	0	0	8,057	0
2018	9	0	3,014	171	-5,410	0	0	2,225	0
2018	10	3,579	1,184	35	-5,304	-61	-23	589	0
2018	11	18,627	0	0	-384	-346	-248	-17,649	0
2018	12	15,424	0	0	-376	-265	-236	-14,547	0
2019	1	70,657	0	0	-9	-2,067	-8,518	-60,063	0
2019	2	118,127	0	0	-9	-16,611	-77,955	-23,553	0
2019	3	22,196	0	0	-8,022	-10,227	-6,545	2,598	0

Year	Month	Volume (AF)							
		Precip	SW Irrigation	GW Irrigation	ET	Recharge	Runoff	Storage	Error
2019	4	10,568	2	10	-24,269	-2,147	-1,232	17,067	0
2019	5	15,372	411	244	-36,436	-240	-32	20,682	0
2019	6	0	8,896	1,840	-45,797	0	0	35,061	0
2019	7	0	12,390	2,472	-37,158	0	0	22,297	0
2019	8	0	12,315	1,898	-22,661	0	0	8,448	0
2019	9	9,815	5,138	96	-14,819	-194	-61	25	0
2019	10	3,933	1,309	31	-11,038	-54	-59	5,877	0
2019	11	10,328	0	0	-612	-233	-93	-9,390	0
2019	12	47,299	0	0	-314	-717	-1,244	-45,024	0
2020	1	10,103	0	0	-8	-719	-470	-8,906	0
2020	2	1,265	0	0	-17	-170	0	-1,078	0
2020	3	30,901	0	0	-6,908	-2,206	-4,656	-17,130	0
2020	4	10,910	514	822	-29,235	-477	-503	17,970	0
2020	5	9,475	3,633	1,697	-36,537	-122	-118	21,972	0
2020	6	1,949	9,318	2,354	-38,855	-14	0	25,249	0
2020	7	292	4,650	2,832	-26,147	-2	0	18,374	0
2020	8	547	3,362	2,169	-7,077	-4	0	1,002	0
2020	9	0	1,270	182	-3,320	0	0	1,869	0

Appendix C
MODFLOW Water Budget

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
1999	10	134	-1185	311	324	-49	116	-349
1999	11	329	-881	301	455	-16	-189	0
1999	12	204	-749	311	267	-15	-18	0
2000	1	8452	-2429	311	1331	-20	-7645	0
2000	2	24143	-6236	291	-1391	-17	-16790	0
2000	3	3778	-9627	311	-402	-8	5953	5
2000	4	899	-3634	301	950	-43	1530	3
2000	5	138	-3161	311	1277	-296	1731	0
2000	6	25	-2663	301	761	-1192	2769	1
2000	7	0	-2074	311	-264	-1985	4012	1
2000	8	0	-1713	311	-165	-1798	3372	7
2000	9	14	-1356	301	-156	-177	1375	1
2000	10	272	-1191	311	-94	-52	755	1
2000	11	133	-756	301	288	-12	47	0
2000	12	169	-785	311	92	-15	228	0
2001	1	241	-951	311	33	-16	384	2
2001	2	536	-1177	281	90	-16	286	1
2001	3	483	-1872	311	625	-19	474	2
2001	4	480	-1638	301	199	-1040	1698	0
2001	5	0	-1637	311	-87	-1956	3370	1
2001	6	0	-1338	301	-68	-2302	3405	-2
2001	7	0	-1228	311	-66	-2421	3382	-21
2001	8	0	-1126	311	-65	-2236	3091	-24
2001	9	54	-941	301	16	-198	768	0
2001	10	54	-869	311	135	-84	453	0
2001	11	424	-647	301	942	-20	-1001	-2
2001	12	3185	-931	311	870	-20	-3415	0
2002	1	3396	-1947	311	745	-30	-2479	-4
2002	2	3334	-3009	281	397	-30	-973	0
2002	3	5772	-4250	311	1461	-29	-3274	-9
2002	4	193	-2163	301	899	-612	1382	1
2002	5	60	-1892	311	1194	-1296	1624	0
2002	6	0	-1513	301	384	-2024	2852	0

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
2002	7	6	-1315	311	-63	-2412	3441	-32
2002	8	0	-1121	311	-65	-2067	2886	-56
2002	9	0	-957	301	-51	-255	962	0
2002	10	0	-805	311	-7	-103	604	0
2002	11	267	-669	301	1447	-23	-1326	-3
2002	12	6021	-1759	311	1512	-31	-6054	0
2003	1	5198	-3342	311	431	-24	-2578	-3
2003	2	4313	-3871	281	687	-22	-1389	0
2003	3	3623	-3937	311	1806	-640	-1169	-5
2003	4	4302	-3013	301	1619	-657	-2567	-15
2003	5	82	-2553	311	1169	-1130	2115	-6
2003	6	21	-2048	301	919	-1441	2204	-43
2003	7	21	-1639	311	177	-1642	2704	-67
2003	8	170	-1333	311	81	-1327	2028	-69
2003	9	5	-1144	301	-61	-442	1321	-20
2003	10	35	-1002	311	-3	-289	937	-11
2003	11	227	-604	301	364	-30	-258	0
2003	12	1189	-567	311	847	-28	-1754	-2
2004	1	1545	-1154	311	452	-28	-1129	-3
2004	2	5955	-3129	291	1683	-24	-4777	-1
2004	3	1846	-3629	311	1379	-874	956	-10
2004	4	3	-2022	301	1080	-1077	1704	-10
2004	5	107	-1842	311	860	-1462	1994	-32
2004	6	5	-1419	301	-123	-1697	2890	-43
2004	7	0	-1318	311	-64	-1959	2959	-70
2004	8	0	-1131	311	-61	-1619	2440	-60
2004	9	15	-982	301	-56	-503	1213	-13
2004	10	289	-834	311	392	-265	104	-3
2004	11	279	-572	301	637	-23	-623	-1
2004	12	1056	-659	311	888	-23	-1577	-4
2005	1	6446	-1593	311	503	0	-5667	0
2005	2	6036	-3759	281	-453	0	-2108	-3
2005	3	10693	-7830	311	2169	-553	-4805	-15
2005	4	1039	-3150	301	1238	-667	1213	-25
2005	5	950	-2873	311	2629	-879	-204	-66
2005	6	69	-2330	301	1326	-1116	1609	-141
2005	7	0	-1928	311	679	-1459	2160	-236
2005	8	1	-1504	311	-118	-1355	2443	-223
2005	9	37	-1175	301	-24	-258	1100	-19
2005	10	85	-1021	311	8	-176	785	-8

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
2005	11	296	-816	301	437	-16	-202	0
2005	12	3732	-1193	311	3463	-15	-6298	0
2006	1	14111	-4879	311	-78	-20	-9445	0
2006	2	10461	-7550	281	660	-17	-3836	-2
2006	3	17567	-9885	311	-242	-398	-7355	-1
2006	4	10549	-9491	301	1926	-638	-2662	-15
2006	5	33	-4997	311	1669	-1089	3996	-76
2006	6	20	-2996	301	790	-1246	3005	-126
2006	7	0	-2317	311	-94	-1440	3379	-161
2006	8	0	-1893	311	-211	-1266	2914	-145
2006	9	0	-1562	301	-165	-282	1700	-8
2006	10	42	-1255	311	-150	-164	1217	2
2006	11	435	-978	301	412	-12	-158	0
2006	12	355	-886	311	178	-15	57	0
2007	1	133	-1135	311	348	-16	360	1
2007	2	2270	-1813	281	1168	-16	-1892	-1
2007	3	220	-2214	311	847	-739	1560	-15
2007	4	160	-1761	301	666	-900	1496	-38
2007	5	61	-1810	311	100	-1455	2718	-76
2007	6	48	-1482	301	-65	-1575	2643	-130
2007	7	0	-1404	311	-62	-1758	2773	-140
2007	8	0	-1263	311	-60	-1601	2482	-131
2007	9	29	-1018	301	-59	-355	1076	-25
2007	10	241	-881	311	132	-209	396	-11
2007	11	89	-704	301	271	-20	63	0
2007	12	415	-670	311	319	-20	-356	-1
2008	1	1825	-892	311	665	-30	-1882	-1
2008	2	2348	-1946	291	565	-30	-1232	-3
2008	3	1254	-2144	311	213	-639	986	-19
2008	4	7	-1518	301	216	-945	1924	-16
2008	5	57	-1339	311	-30	-1212	2169	-43
2008	6	0	-1260	301	-14	-1564	2450	-87
2008	7	0	-1170	311	-39	-1636	2421	-113
2008	8	0	-1081	311	-47	-1551	2259	-109
2008	9	0	-905	301	54	-451	979	-20
2008	10	136	-768	311	69	-265	509	-8
2008	11	261	-599	301	918	-23	-858	0
2008	12	398	-614	311	443	-31	-509	-2
2009	1	356	-732	311	326	-24	-239	-1
2009	2	1610	-1183	281	801	-22	-1493	-6

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
2009	3	2906	-2374	311	2456	-387	-2927	-14
2009	4	42	-1559	301	820	-570	955	-11
2009	5	297	-1824	311	2246	-877	-204	-51
2009	6	74	-1216	301	625	-796	947	-65
2009	7	0	-1185	311	30	-1079	1866	-56
2009	8	4	-1027	311	58	-934	1519	-68
2009	9	5	-926	301	61	-343	878	-24
2009	10	120	-820	311	456	-165	94	-5
2009	11	146	-684	301	508	-30	-241	0
2009	12	488	-337	311	499	-28	-934	0
2010	1	1042	-683	311	648	-28	-1291	0
2010	2	2081	-1586	281	705	-24	-1457	0
2010	3	2130	-2219	311	1184	-884	-531	-8
2010	4	1992	-1992	301	2300	-1046	-1569	-15
2010	5	131	-1655	311	1388	-1483	1285	-24
2010	6	5	-1534	301	1177	-1949	1910	-91
2010	7	0	-1365	311	608	-2334	2649	-131
2010	8	0	-1091	311	62	-1980	2601	-98
2010	9	0	-937	301	69	-442	982	-27
2010	10	345	-933	311	1814	-219	-1319	0
2010	11	592	-799	301	948	-23	-1022	-2
2010	12	6589	-1856	311	1610	-23	-6631	0
2011	1	2925	-2574	311	305	-24	-944	-1
2011	2	9426	-4809	281	1137	-20	-6032	-18
2011	3	24796	-11689	311	414	-384	-13453	-6
2011	4	543	-5057	301	402	-575	4376	-9
2011	5	182	-2868	311	1909	-797	1256	-8
2011	6	157	-2960	301	2457	-950	963	-32
2011	7	0	-2635	311	1585	-1220	1915	-44
2011	8	0	-1878	311	651	-1131	2005	-42
2011	9	75	-1444	301	250	-197	1018	3
2011	10	163	-1227	311	463	-111	402	1
2011	11	272	-861	301	413	-23	-104	0
2011	12	6	-844	311	357	-24	194	1
2012	1	425	-1274	311	1724	-26	-1163	-4
2012	2	776	-1466	291	488	-22	-68	0
2012	3	5117	-4029	311	2254	-729	-2937	-12
2012	4	1007	-2781	301	1480	-1057	1045	-4
2012	5	67	-2221	311	1015	-1629	2411	-45
2012	6	53	-1544	301	-95	-1858	3085	-58

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
2012	7	42	-1384	311	-14	-2116	3114	-47
2012	8	0	-1190	311	-35	-1828	2684	-58
2012	9	6	-1021	301	33	-317	998	0
2012	10	154	-938	311	183	-209	500	0
2012	11	737	-917	301	2385	-23	-2484	0
2012	12	11953	-3169	311	1503	-39	-10559	0
2013	1	3380	-2842	311	-284	-31	-535	0
2013	2	877	-3135	281	237	-22	1763	2
2013	3	2624	-2912	311	855	-1082	201	-3
2013	4	99	-2000	301	723	-1540	2376	-41
2013	5	134	-1652	311	521	-2014	2609	-92
2013	6	13	-1376	301	-34	-2280	3259	-116
2013	7	1	-1305	311	13	-2708	3467	-221
2013	8	17	-1140	311	51	-2325	2934	-152
2013	9	93	-956	301	73	-449	938	0
2013	10	90	-835	311	120	-278	592	0
2013	11	84	-640	301	331	-22	-54	0
2013	12	106	-446	311	267	-27	-213	-1
2014	1	135	-829	311	553	-24	-147	-1
2014	2	872	-1183	281	1728	-21	-1680	-3
2014	3	830	-1479	311	1198	-964	99	-4
2014	4	63	-1289	301	484	-1443	1841	-43
2014	5	57	-1165	311	24	-2099	2814	-57
2014	6	0	-1031	301	4	-2526	3144	-109
2014	7	62	-979	311	101	-2513	2926	-91
2014	8	103	-946	311	222	-2142	2381	-71
2014	9	137	-819	301	95	-382	666	-2
2014	10	134	-690	311	69	-240	416	0
2014	11	268	-545	301	503	-27	-499	0
2014	12	701	-448	311	1486	-23	-2031	-3
2015	1	4	-721	311	692	-24	-263	-1
2015	2	1510	-1460	281	2469	-26	-2778	-4
2015	3	345	-1379	311	862	-1286	1144	-2
2015	4	178	-1153	301	877	-1641	1402	-35
2015	5	149	-1044	311	253	-1921	2194	-58
2015	6	58	-1017	301	94	-2746	3253	-57
2015	7	147	-932	311	143	-2561	2820	-72
2015	8	53	-872	311	138	-2434	2732	-71
2015	9	16	-715	301	72	-669	986	-9
2015	10	180	-666	311	317	-427	280	-4

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
2015	11	340	-483	301	824	-27	-954	0
2015	12	914	-463	311	1351	-28	-2089	-4
2016	1	3365	-985	311	2016	-29	-4679	0
2016	2	4406	-2774	291	1065	-25	-2964	-1
2016	3	9498	-5223	311	2845	-775	-6662	-6
2016	4	1230	-2906	301	1694	-1256	918	-20
2016	5	1707	-2348	311	2178	-1453	-438	-44
2016	6	16	-1473	301	-83	-1940	3114	-64
2016	7	0	-1254	311	50	-2220	3052	-61
2016	8	4	-1109	311	65	-2150	2817	-63
2016	9	0	-893	301	62	-428	957	-2
2016	10	499	-845	311	1491	-209	-1247	-1
2016	11	419	-777	301	1187	-22	-1111	-3
2016	12	3659	-1512	311	2777	-24	-5213	-2
2017	1	20190	-3785	311	132	-25	-16823	0
2017	2	25088	-8978	281	-1014	-23	-15354	0
2017	3	8650	-12177	311	543	-518	3189	-3
2017	4	9286	-8933	301	2604	-717	-2553	-11
2017	5	102	-5146	311	2672	-1206	3265	-2
2017	6	25	-3429	301	1942	-1345	2489	-16
2017	7	0	-2858	311	1384	-1678	2808	-32
2017	8	37	-2270	311	1224	-1278	1950	-25
2017	9	133	-1608	301	367	-196	1005	3
2017	10	74	-1406	311	80	-143	1087	4
2017	11	587	-1099	301	1618	-20	-1389	-2
2017	12	356	-998	311	373	-21	-22	0
2018	1	2647	-1965	311	759	-20	-1735	-3
2018	2	2758	-2937	281	215	-19	-301	-1
2018	3	12795	-8074	311	1712	-621	-6126	-2
2018	4	1994	-4306	301	1616	-864	1254	-5
2018	5	171	-3090	311	1815	-1259	2041	-11
2018	6	50	-2096	301	146	-1577	3123	-53
2018	7	0	-1777	311	-21	-1763	3177	-72
2018	8	0	-1499	311	29	-1508	2607	-60
2018	9	0	-1274	301	38	-309	1245	0
2018	10	60	-1058	311	124	-178	741	1
2018	11	343	-859	301	429	-22	-193	0
2018	12	262	-662	311	294	-23	-183	0
2019	1	2061	-1354	311	1779	-25	-2778	-6
2019	2	16542	-4759	281	614	-24	-12655	0

Year	Month	Volume (AF)						
		Recharge	ET	MFR	GW-SW Exchange	GW Pumping	Storage	Error
2019	3	10179	-8765	311	230	-543	-1415	-2
2019	4	2130	-4624	301	1988	-837	1032	-10
2019	5	238	-3707	311	2759	-1112	1502	-8
2019	6	0	-3252	301	2183	-1527	2249	-45
2019	7	0	-2631	311	1559	-1618	2319	-60
2019	8	0	-1871	311	404	-1454	2554	-57
2019	9	193	-1397	301	187	-259	976	1
2019	10	53	-1215	311	123	-180	910	3
2019	11	231	-934	301	462	-25	-35	0
2019	12	713	-784	311	774	-27	-988	-1
2020	1	717	-1037	311	329	-24	-298	-1
2020	2	170	-1570	291	288	-23	846	3
2020	3	2203	-2311	311	887	-675	-420	-5
2020	4	473	-2057	301	967	-1098	1385	-30
2020	5	121	-1975	311	1539	-1273	1222	-54
2020	6	14	-1547	301	91	-1577	2664	-53
2020	7	2	-1431	311	61	-1896	2851	-103
2020	8	4	-1210	311	68	-1568	2317	-79
2020	9	0	-1086	301	64	-50	771	0

Appendix D
SWBM and MODFLOW Parameter Values

SHVSM Submodel	Parameter					
	Group	**Type**	**Description**	**Name**	**Value**	**Units**
SWBM	SWBM	Effective Rooting Depth	Total depth that plants can access soil moisture from. Accounts for root depth and capillary movement of water into root zone.	RD_Alf_Irr	1.97E+01	ft
				RD_Grn_Irr	6.56E+00	ft
				RD_Pstr_Irr	6.56E+00	ft
				RD_NatVeg	9.84E+00	ft
				RD_Barren	0.00E+00	ft
				RD_Water	6.56E+00	ft
				RD_Alf_NI	1.97E+01	ft
				RD_Grn_NI	6.56E+00	ft
				RD_Pstr_NI	6.56E+00	ft
		Effective Irrigation Efficiency	Ratio of crop water uptake to applied water.	Fld_IE_Alf	7.00E-01	-
				Fld_IE_Grn	7.00E-01	-
				Fld_IE_Pstr	7.00E-01	-
				WL_IE_Alf	1.25E+00	-
				WL_IE_Grn	1.25E+00	-
				WL_IE_Pstr	1.00E+00	-
				CP_IE_Alf	1.35E+00	-
				CP_IE_Grn	1.35E+00	-
				CP_IE_Pstr	1.15E+00	-
		Crop Coefficient (Kc) Scaling Factor	Scaling factor that allows crop coefficients to be adjusted uniformly. Allows for single parameter to adjust crop coefficients that vary over time.	KcMltAlfIrr	9.60E-01	-
				KcMltGrnIrr	9.60E-01	-
				KcMltPstrIrr	9.60E-01	-
				KcMltNatVeg	9.60E-01	-
				KcMltWater	9.60E-01	-
				KcMltAlfNI	9.60E-01	-
				KcMltGrnNI	9.60E-01	-
				KcMltPstrNI	9.60E-01	-
MODFLOW	Kx	Hydraulic Conductivity	Sediment hydraulic conductivity along rows.	Kx_1	3.20E+01	ft/day
				Kx_2	1.64E+01	ft/day
				Kx_3	6.56E-01	ft/day
				Kx_4	3.22E-02	ft/day
				Kx_5	3.28E-03	ft/day
				Kx_6	3.76E+00	ft/day
				Kx_7	3.28E+00	ft/day
				Kx_8	3.28E+00	ft/day
	Hani	Horizontal Anisotropy	Scaling factor that adjusts aquifer hydraulic conductivty along columns based on Kx value.	HANI_1	1.00E+00	-
				HANI_2	1.00E+00	-
				HANI_3	1.00E+00	-
				HANI_4	1.00E+00	-
				HANI_5	1.00E+00	-
				HANI_6	1.00E+00	-
				HANI_7	1.00E+02	-
				HANI_8	1.00E+02	-

SHVSM Submodel	Parameter					
	Group	Type	Description	Name	Value	Units
MODFLOW	Kvar	Vertial Anisotropy	Scaling factor that adjusts vertical hydraulic conductivty of aquifer based on Kx value.	KVAR_1	1.00E+00	-
				KVAR_2	5.00E+00	-
				KVAR_3	2.00E+01	-
				KVAR_4	5.00E+01	-
				KVAR_5	1.00E+00	-
				KVAR_6	2.00E+00	-
				KVAR_7	1.00E+00	-
				KVAR_8	1.00E+00	-
	Sy	Specific Yield	Unconfined aquifer storage coefficient.	Sy_1	1.50E-01	-
				Sy_2	1.00E-01	-
				Sy_3	6.00E-02	-
				Sy_4	3.00E-02	-
				Sy_5	1.00E-03	-
				Sy_6	4.00E-02	-
				Sy_7	2.00E-01	-
				Sy_8	2.00E-01	-
	Ss	Specific Storage	Confined aquifer storage coefficient.	Ss_1	3.28E-06	1/ft
				Ss_2	3.28E-05	1/ft
				Ss_3	6.56E-05	1/ft
				Ss_4	6.56E-04	1/ft
				Ss_5	3.28E-05	1/ft
				Ss_6	3.28E-05	1/ft
				Ss_7	3.28E-04	1/ft
				Ss_8	3.28E-04	1/ft
	MFR	Mountain Front Recharge	Flux of water into model from surrounding bedrock.	MFR_1	4.09E+00	AF/day
				MFR_2	0.00E+00	AF/day
				MFR_3	9.80E-01	AF/day
				MFR_4	1.10E+00	AF/day
				MFR_5	2.56E+00	AF/day
				MFR_6	1.31E+00	AF/day
	Q3DCB	Quasi-3D Confining Bed	Vertical hydraulic conductivity of Quasi-3D confining layer.	CB_3	4.76E-05	ft/day
	SFR	Streambed Hydraulic Conductivity	Hydraulic conductivity of sediments in stream channels.	BedK_1	3.28E+00	ft/day
				BedK_2	3.28E-01	ft/day
				BedK_3	3.28E-02	ft/day
		Manning Roughness Coefficient	Coefficient that defines how easily water can flow through a channel.	Manning_n_1	3.50E-02	-
				Manning_n_2	3.50E-02	-
				Manning_n_3	3.50E-02	-

Appendix 3-1: Well Impact Analysis

Vulnerable well impact analysis in the Sierra Valley Subbasin: well inventory, historical groundwater trends, and analysis to inform Sustainable Management Criteria

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2021-09-12

Table of Contents

1. Executive Summary

Groundwater planning under the Sustainable Groundwater Management Act (SGMA) aims to curb the chronic lowering of groundwater levels, which may impact shallow, vulnerable wells and cause dewatering or failure. Relatively shallow residential, agricultural, and public wells (henceforth “vulnerable wells”) in the Sierra Valley Subbasin (SV) are beneficial uses of groundwater identified by stakeholders in the SV groundwater sustainability plan (GSP) working group. Residents and water users in the SV that rely on drinking water obtained from private domestic wells are considered beneficial users of groundwater. The GSP aims to halt the chronic groundwater level decline that can lead to significant and unreasonable impacts to vulnerable wells that hamper access to water for drinking, irrigation, and municipal/industrial use.

Although shallow wells in the SV provide beneficial uses of groundwater, the SV lacks a comprehensive well census (i.e., inventory) for domestic wells and understanding of how sustainable management criteria (SMC) may impact vulnerable wells in the SV. These knowledge gaps motivate this memorandum, which aims to provide a well inventory based on best available data, and well protection analysis to inform critical decision-making in support of unstainable groundwater management in the SV.

No wells in the SV were reported dry during the past 2012-2016 drought. Herein, we assess potential impacts to vulnerable wells that may result during the SGMA planning and implementation period (2022-2042). First, we take inventory of wells in the SV using publicly available, digitized well completion reports to describe the location and depths of different types of wells (e.g., domestic, public, agricultural). Next, we analyze historical groundwater elevation trends in the SV from 2000-2020. Then, we combine well construction data and modeled groundwater levels to assess the count and location of impacted wells assuming different groundwater level scenarios (i.e., a return to the fall 2015 low, and established groundwater level minimum thresholds, or MTs). Finally, we advance recommended sustainable management criteria that mitigate impacts to vulnerable wells.

Results suggest that the most common well types with direct beneficial uses are domestic (n = 540), agricultural (n =105), public (n = 22) and industrial (n = 6) wells[1], although the actual number of “active” wells today is likely less due to ageing and well retirement. Assuming 31 to 40 year retirement ages (based on Pauloo et al, 2020), and that wells with pumps above initial groundwater level conditions are inactive, the number of assumed active wells in the SV is much lower: domestic (n = 325 - 450), agricultural (n = 57 - 61), public (n = 14 - 21), and industrial (n = 1). An ongoing well “census” would supersede these data, but in its absence, this approach provides a reasonable approximation of the count and location of active wells.

During fall of 2015, groundwater levels reach a [modern] historical low in the SV after four consecutive years of drought and excess pumping to augment lost surface water

[1] At the time of writing (2021-09-12), these are the well counts provided by the online well completion report database. Note that “public” wells are municipal wells, and “domestic” wells are private residential wells.

supply. Data from the DWR and Cal OPR suggests that during this time, no wells in the SV were reported dry, in contrast to more than two thousand wells reported dry across California (Pauloo et al, 2020)[2]. Thus, a return to Fall 2015 groundwater level lows is unlikely to result in catastrophic and widespread well impacts, which we confirm via modeling described in this memorandum.

For the purposes of this study, we assume significant and undesirable results to occur when 5% or more of wells of any type (domestic, agricultural, public, industrial) are impacted. Thus, well impact analysis under projected groundwater level conditions was evaluated to assess impacts assuming a return to historic Fall 2015 lows, and projected groundwater level MTs. Results suggest that even assuming a worst-case scenario where all representative monitoring points (RMPs) reach MTs at the same time, only domestic wells are impacted on the order of 2% (n = 6 - 10). Thus, all well types are highly unlikely to impacted at the 5% undesirable result threshold.

Well protection analysis thus informed and validated minimum thresholds (MTs) which avoid significant and unreasonable impacts to wells in the basin. Possible well protection measures may include a combination of regional groundwater supply and demand management (e.g., managed aquifer recharge and pumping curtailments that increase or maintain groundwater levels); well protection funds to internalize well refurbishment and replacement costs; domestic supply management, (e.g., connecting rural households to more reliable municipal water systems); and proactive community-based monitoring that acts as an early warning systems to anticipate impacts at the level of individual wells.

[2] Outage data analyzed by Pauloo et al (2020) was provided via an agreement between Cal OPR and the authors, but has since been released by the DWR at MyDryWaterSupply: https://mydrywatersupply.water.ca.gov/report/publicpage.

2. Introduction

Around 1.5 million Californians depend on private domestic wells for drinking water, about one third of which live in the Central Valley (Johnson and Belitz 2016). Many fewer wells are found in the Sierra Valley Subbasin (SV), and these wells tend to be in mixed agricultural-residential land. Private domestic wells are more numerous than other types of wells (e.g., public or agricultural), and tend to be shallower and have smaller pumping capacities, which makes them more vulnerable to groundwater level decline (Theis 1935; Theis 1940; Sophocleous 2020; Greene 2020; Perrone and Jasechko 2019). During previous droughts in California, increased demand for water has led to well drilling and groundwater pumping to replace lost surface water supplies (Hanak et al 2011; Medellín-Azuara et al 2016). Increased pumping lowers groundwater levels and may partially dewater wells or cause them to go dry (fail) altogether. During the 2012–2016 drought, 2,027 private domestic drinking water wells in California's Central Valley were reported dry (Cal OPR 2018). Notably, zero dry wells were reported in the SV, which suggests a combination of relatively stable groundwater levels and more favorable well construction properties (e.g., deeper wells and pump locations). Moreover, this observation implies that a return to 2015 low groundwater levels would not cause widespread and catastrophic well failure in the SV.

Until recently, few solutions and data products existed that addressed the vulnerability of shallow wells to drought and unsustainable groundwater management (Mitchell et al. 2017; Feinstein et al. 2017). A lack of well failure research and modeling approaches can largely be attributed to the fact that well location and construction data (well completion reports, or WCRs) were only made public only in 2017. Released digitized WCRs span over one hundred years in California drilling history and informed the first estimates of domestic well spatial distribution and count in the state (Johnson and Belitz 2015; Johnson and Belitz 2017). Since then, these WCRs, provided in the California Online State Well Completion Report Database (CA-DWR 2018), have been used to estimate failing well locations and counts (Perrone and Jasechko 2017), and domestic well water supply interruptions during the 2012–2016 drought due to overpumping and the costs to replenish lost domestic water well supplies (Gailey et al 2019). A regional aquifer scale domestic well failure model for the Central Valley was developed by Pauloo et al (2020) that simulated the impact of drought and various groundwater management regimes on domestic well failure. More recently, Bostic and Pauloo et al (2020), EKI (2020), and Pauloo et al (2021), estimated the impact of reported groundwater level minimum thresholds in critical priority basins on domestic wells across California's Central Valley and found that thousands of domestic wells were potentially vulnerable.

California's snowpack is forecasted to decline by as much as 79.3% by the year 2100 (Rhoades et al 2018). Drought frequency in parts of California may increase by more than 100% (Swain et al 2018). A drier and warmer climate (Diffenbaugh 2015; Cook 2015) with more frequent heat waves and extended droughts (Tebaldi et al 2006; Lobell et al 2011) will coincide with urban development and population growth, land use change, conjunctive use projects, and implementation of the Sustainable Groundwater Management Act (SGMA 2014), in which groundwater sustainability plans (GSPs) will specify groundwater level minimum thresholds (MTs) that among other outcomes, protect vulnerable wells.

In this technical memorandum, we analyze how projected hydrologic conditions may impact vulnerable wells in the SV, and acknowledge that results are limited by the uncertainty on the actual number and/or construction information available for domestic wells in the SV. In Section 3, the methodology is explained, followed by the results in Section 4, and a discussion of the results in terms of how they impact sustainable groundwater management in Section 5. This memorandum closes with a discussion of future actions and SGMA management recommendations.

3. Methods

Key data that inform this analysis include seasonal groundwater level measurements taken by various state-level and local sources, and well completion reports (WCRs) from the California Department of Water Resources (CA-DWR 2018).

3.1 Groundwater level

Historic and present-day groundwater conditions were analyzed using all available data from the California Department of Water Resources (DWR) Periodic Groundwater Level Database. Most groundwater level data is collected biannually in spring and fall and intended to capture seasonal variation – notably due to winter recharge and pumping and recharge during the dry growing season.

Duplicate measurements between data sources were reconciled by comparing monitoring site identification codes and position (latitude and longitude).

Groundwater levels were assessed at biannual seasonal intervals during the period from spring 2000 to fall 2020 and encompass what can be considered "historic"[3] to approximately "present-day" seasonal conditions. This temporal range was selected because poor data density prior to spring 2000 and after fall 2020 prohibits meaningful analysis. "Spring" was defined as the months of March, April, and May and "fall" was defined as the months of August, September, and October.

At each monitoring location, the average groundwater level measured during spring and fall was computed by taking the grouped mean of observations in each spring and fall respectively. Next, to improve spatial data density and ascertain long-term regional trends, data were arranged in 4-year running seasonal means. For example, the 2000-2003 spring level is defined as the average spring groundwater elevation in 2000, 2001, 2002, and 2003. A four-year sliding window was applied to data from 2000 to 2020, resulting in 36 seasonally averaged groundwater elevation conditions (e.g., spring 2000-2003, fall 2000-2003, …, spring 2017-2020, fall 2017-2020). Windows of differing length (e.g., 1, 2, and 3-year long running means) were explored but resulted in larger groundwater level variance due to a lack of adequate spatial density, and hence, not used. By contrast, 4 year running means gave adequate regional spatial data density and were not so long in duration as to dampen the impact of significant dry periods such as the 2012-2016 drought.

After data were grouped into seasonal 4-year windows, ordinary kriging[4] (Journel A.G. and Huijbregts, 1978) was applied to groundwater elevation measurements to generate

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[3] Importantly, this period contains the recent 2012-2016 drought.

[4] An exponential variogram model was used, and results did not appreciably differ from linear or spherical models. Stationarity across the unconfined to semiconfined aquifer is a reasonable assumption in the unconsolidated, alluvial aquifer-aquitard system that spans Sierra Valley. Data outliers were controlled by removing tails of the distribution above and below the 97.5^{th} and 2.5^{th} percentiles respectively. Groundwater elevations were approximately normal in distribution, thus log-transformation and exponentiation after kriging was not required.

groundwater level surfaces across the SV at a 500 meter (0.31 mile) resolution. Groundwater level measurements were screened to include data from wells shallower than 300 feet in total completed depth to reflect conditions in the unconfined to semiconfined production aquifer.

3.2 Well Completion Reports (WCRs)

The well completion report database (CA-DWR, 2020) was used to filter and clean WCRs within the SV. Similar well types were grouped into categories (e.g., “domestic”, “private residential”, and “residential” were all grouped together) to enable analysis of wells by type. The majority of wells are accurate to the centroid of the nearest section in the PLSS Survey system (1 square mile grid cells). All wells reviewed in the SV had a total completed depth.

3.4 Projected groundwater management

Well impacts are characterized in terms of historical data and future, anticipated hydrology. Forward-simulated hydrologic conditions based on groundwater level MTs were assessed to ensure that MTs would not significantly and unreasonably impact wells.

Differences in groundwater level between each of the scenarios tested (i.e., fall 2015, and the MT scenario) and the “baseline” inform how wells in the basin may respond to historical drought projected groundwater management.

3.3 Classification of failing wells and cost estimate

The initial set of wells to consider are a subset of all domestic wells in the WCR database. Wells are removed based on the year in which they were constructed[5], and their estimated pump location relative to the initial groundwater level condition prior to impact analysis. In other words, wells that are likely to be inactive, or already dry at the initial condition are not considered, and do not count towards the well impact count.

Next, we assign a “critical datum”[6] to each well, equal to 30 feet above the total completed depth, roughly 3 times the height of water column required to prevent

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[5] Two previous studies estimate well retirement ages at 28 years in the Central Valley (Pauloo et al 2020), and 33 years in Tulare county (Gailey et al 2019), thus, we use the average of these two studies and remove wells older than a retirement age of 31 years. To account for uncertainty in the well retirement age, we also consider another well retirement age of 40 years. Importantly, these numbers reflect mean retirement ages in the retirement age distribution. Although some wells in the population may be active for longer than 31 or 40 years, some will also retire before 31 or 40 years. Thus, results should be interpreted as an average estimate of well impacts.

[6] A standard approach for the choice of a critical datum is not well established. Other studies (e.g., Gailey et al, 2019; Pauloo et al, 2020; Bostic and Pauloo et al, 2020; Pauloo et al, 2021) estimate pump locations in different ways. Since considerable uncertainty exists in estimating pumps at a local scale, but WCR data for total completed depth is present and reliable for nearly all wells in the dataset, it is favored. An operating margin of 30 feet added to the bottom of each well’s total completed depth is a reasonable

decreased well function and cavitation as calculated by Pauloo et al 2020 using standard assumptions of pumping rate, net positive suction head, barometric pressure head, vapor pressure, and frictional losses (see Pauloo et al 2020, SI Appendix Section S2.3). If groundwater level scenarios imply a groundwater elevation below this critical datum, the well is considered "impacted" and may require pump lowering or well deepening to rehabilitate it (**Error! Reference source not found.**).

In reality, wells dewater and experience reduced yield when the groundwater level approaches the level of the pump. However, for the purposes of this study, we assumed wells maintain the net positive suction head (Tullis 1989) required to provide uninterrupted flow until groundwater falls below the critical datum. At this point, we assume the well needs replacement (i.e., a well deepening event). Therefore, the well impact estimates provided in this study should be interpreted as a worse-case scenario wherein wells can no longer access reliable groundwater and are deepened. In most cases, pumps will be able to be lowered into the 30 foot operating margin prior to a deepening event – this is more affordable than a well deepening, so the impact estimate is conservative in this sense.

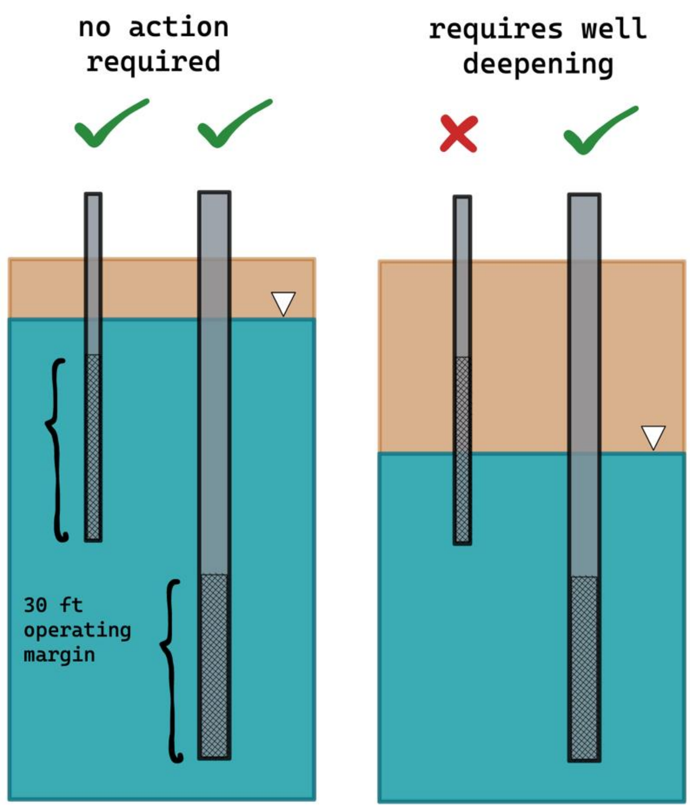

Figure 1: Wells are assigned a 30 foot operating margin above the total competed depth. When groundwater levels are above this "critical datum" at a well, the well is active (left), and the well is impacted when the groundwater falls

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column of water necessary for the well to properly function, although wells with greater pumping capacities may require a longer water column.

below the critical datum, which triggers a well deepening event. Note that in reality, cones of depression form around active pumping wells, but are not shown in the figure above for simplicity.

4. Results

4.1 Groundwater levels

Groundwater level analysis in this memorandum is consistent with that conducted in Chapter 2 of the GSP. The lower and upper bookends of the groundwater level estimates (Figure 2 and Figure 3) demonstrate characteristic seasonal oscillation and increasing depth to groundwater in the central portion of the basin used for agricultural purposes.

Key groundwater levels include the initial condition (average 2020 levels), and 2 boundary conditions at which well impacts are evaluated. The first boundary condition is the Fall 2015 low, and the other is the projected MT.

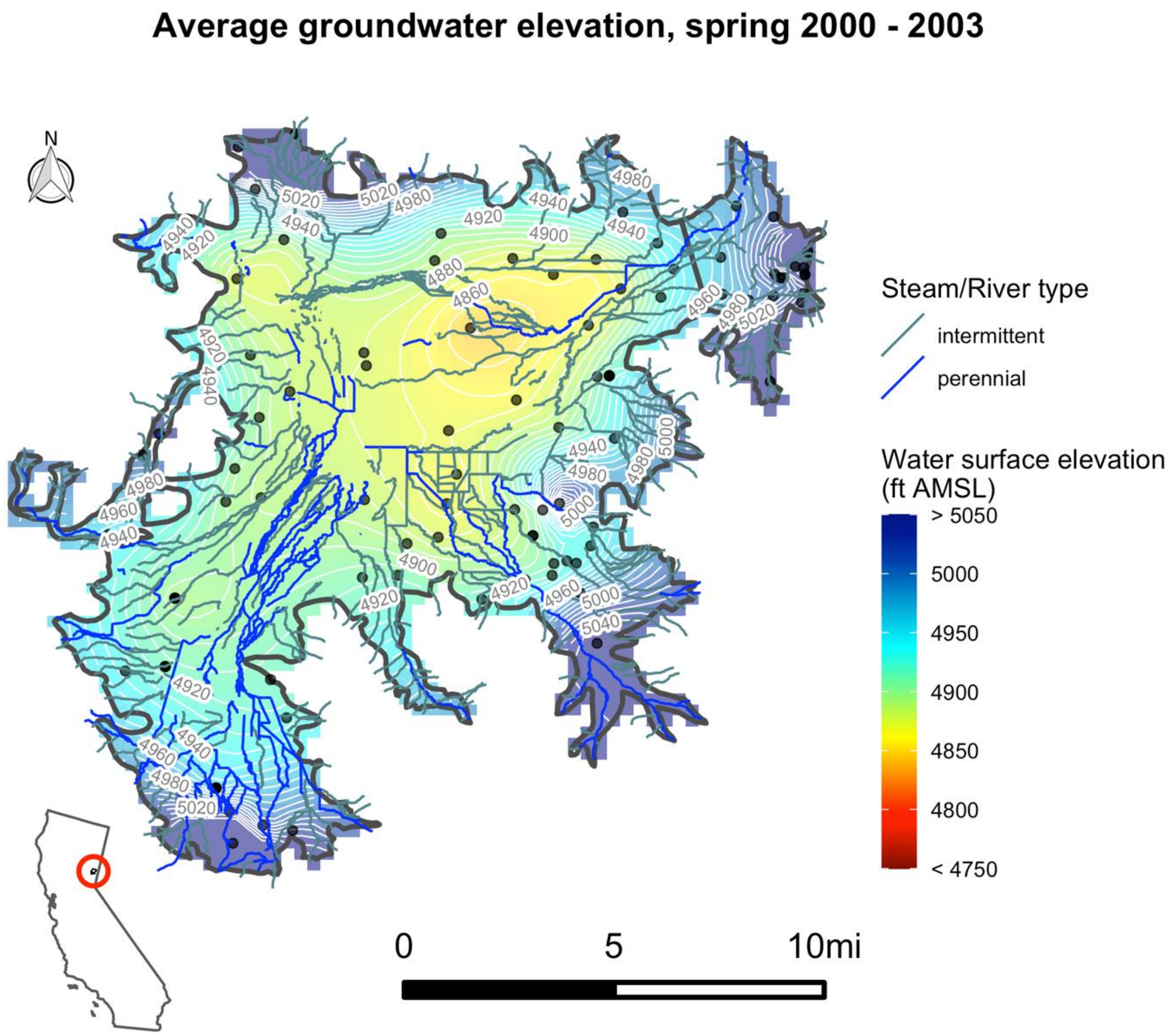

Figure 2: Estimated groundwater elevation for spring 2000 – 2003.

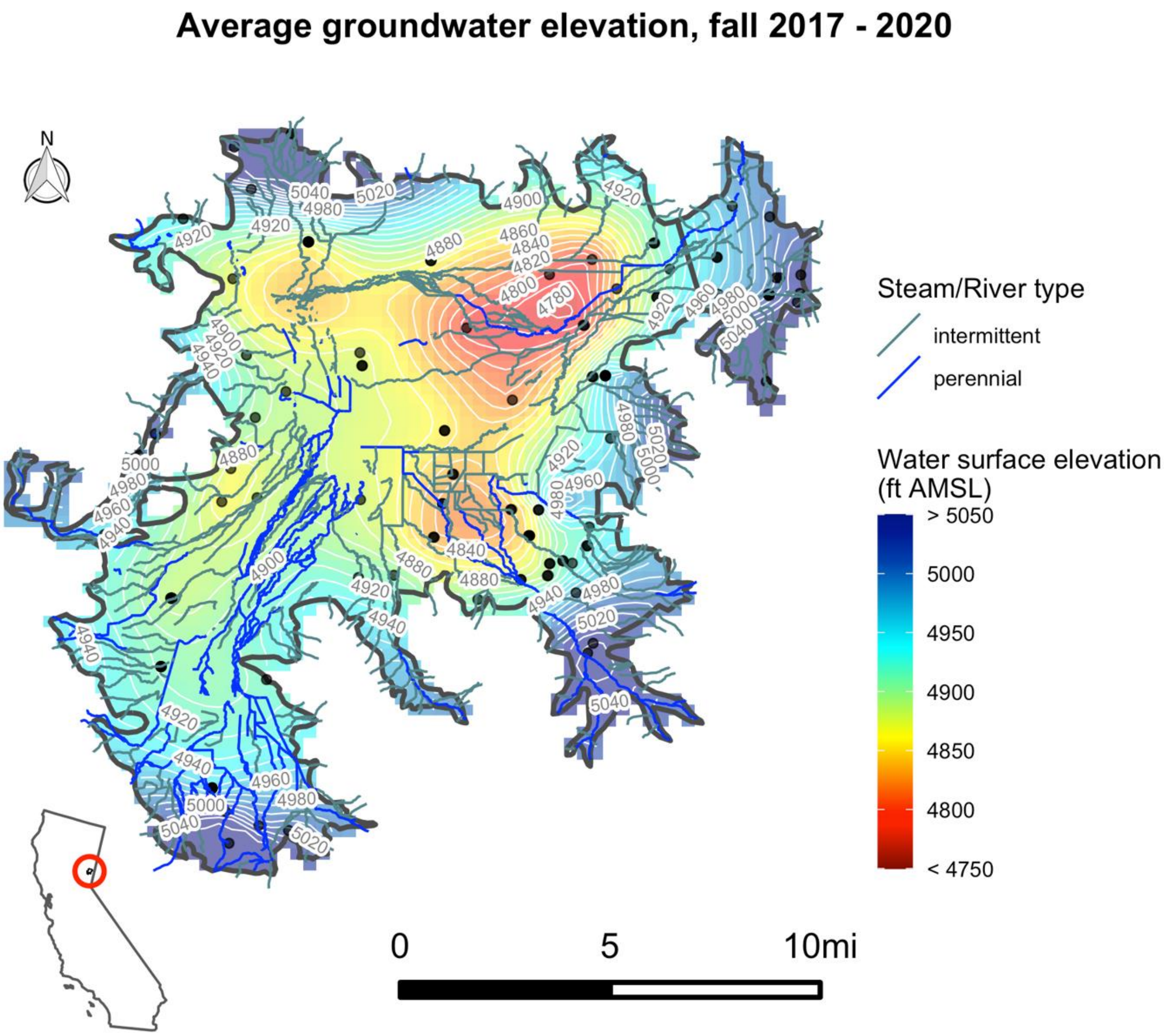

Figure 3: Estimated groundwater elevation for fall 2017 – 2020.

4.2 Well inventory and characteristics

Results suggest that the most common well types (Figure 3) with direct beneficial uses are domestic (n = 540), agricultural (n =105), public (n = 22) and industrial (n = 6) wells , although the actual number of “active” wells today is likely less due to ageing and well retirement. Assuming 31 to 40 year retirement ages (based on Pauloo et al, 2020), and that wells with pumps above initial groundwater level conditions are inactive, the number of assumed active wells in the SV is lower (Figure 5): domestic (n = 325 - 450), agricultural (n = 57 - 61), public (n = 14 - 21), and industrial (n = 1).

Most wells are deeper than long-term average depths to groundwater in the SV (Figure 6) and newer wells tend to be deeper

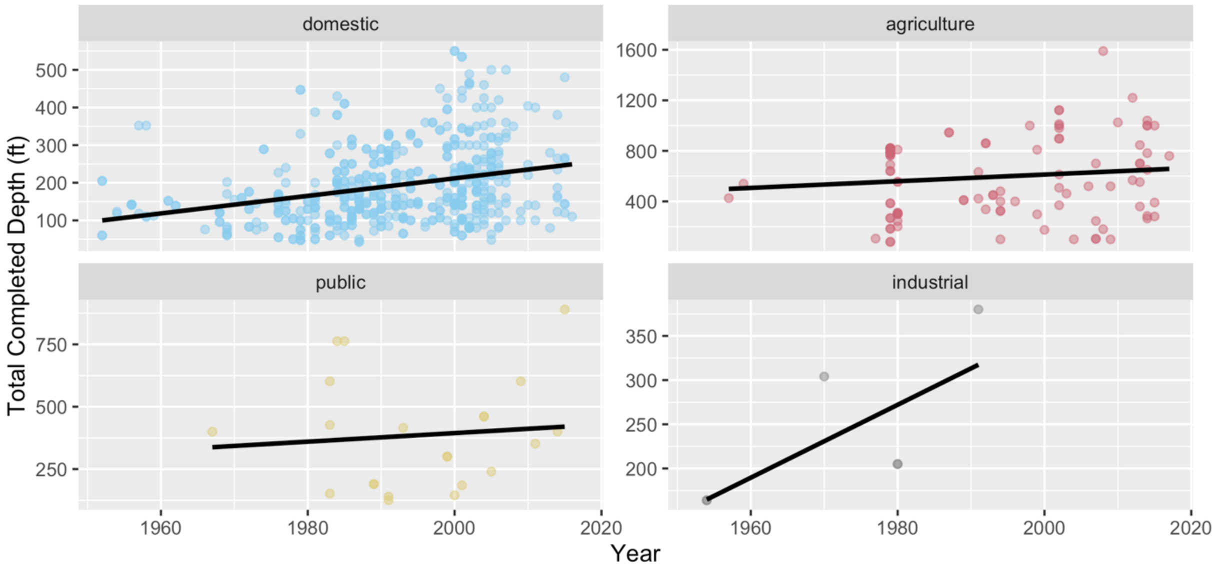

Figure 7), which suggests a buffer against potential well impacts from declining groundwater levels, especially for newer wells. Wells are drilled deeper over time largely due to improvements in drilling technology and the need for deeper groundwater unimpacted by surface contaminants and with sufficient transmissivity to support well yield targets.

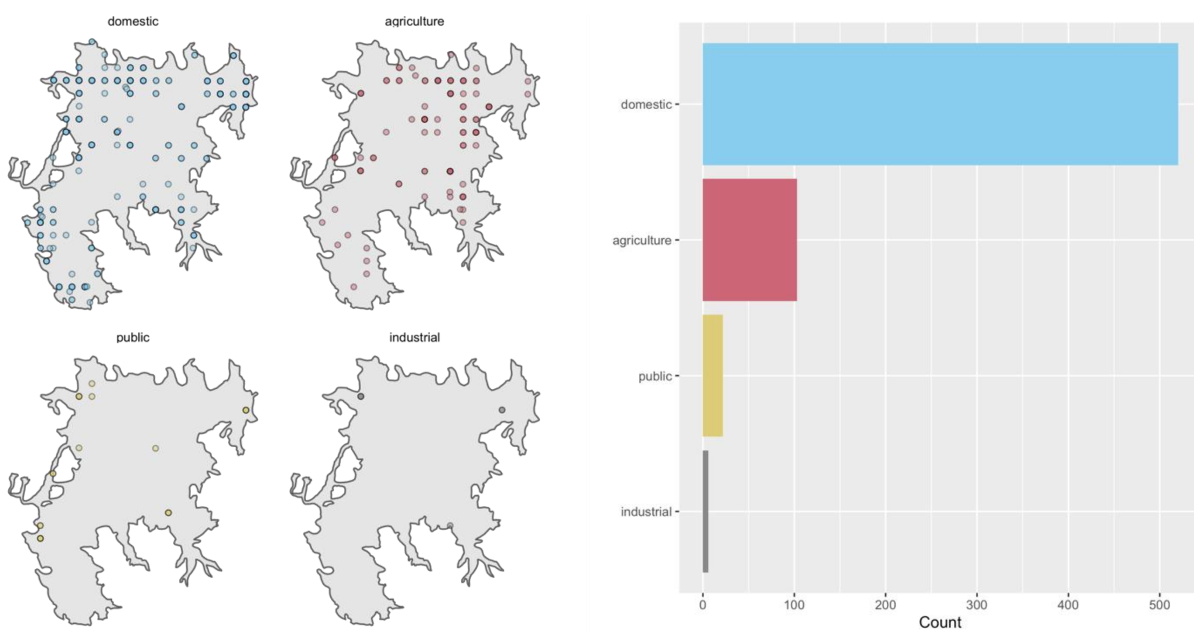

Figure 4: Estimated active well location (left) and count (right) in the Sierra Valley for major well types. Points are semi-transparent to improve visibility. Where points appear more opaque, this indicates multiple wells at the same section centroid.

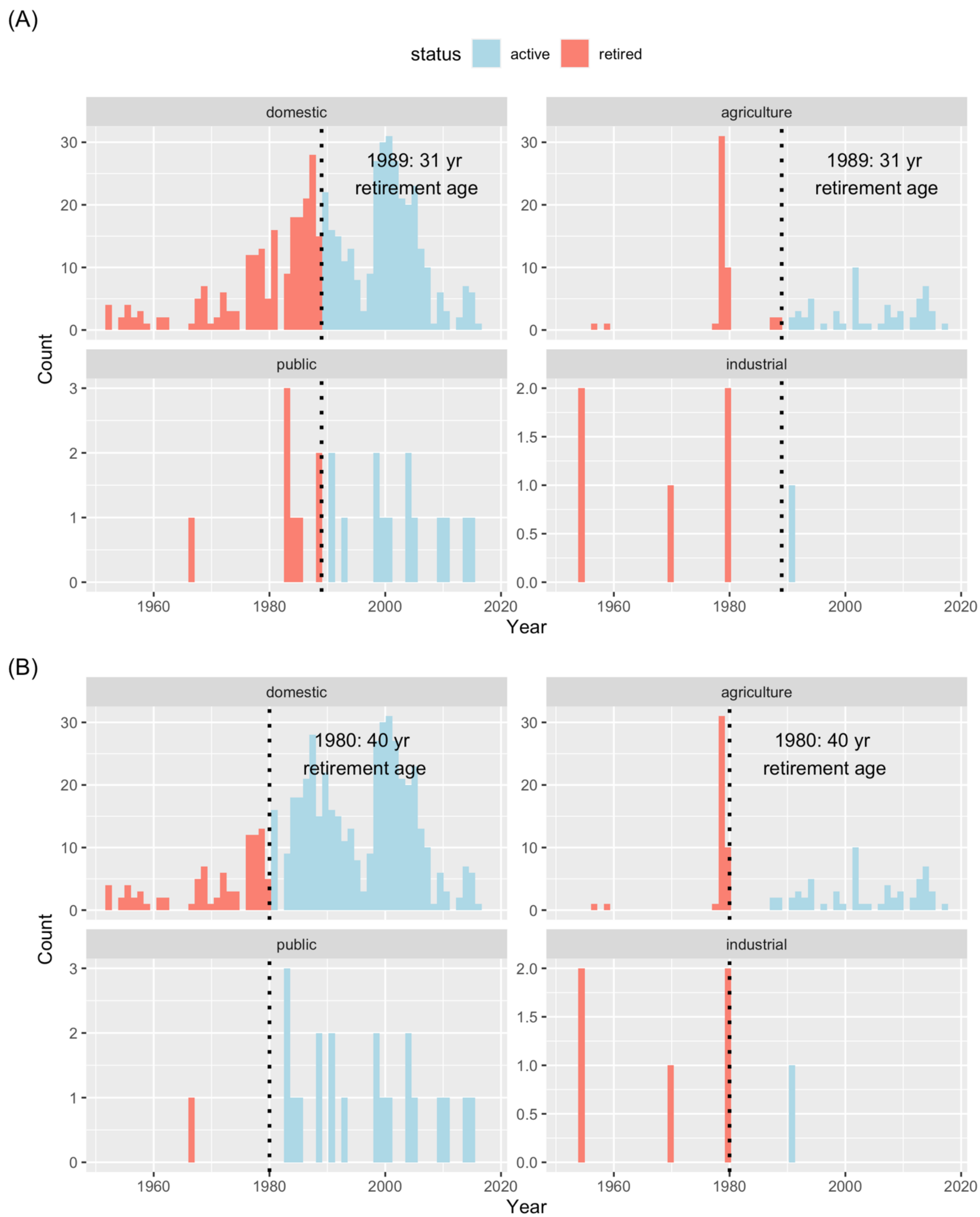

Figure 5: Well retirement ages of (A) 31 years and (B) 40 years were used to determine a likely range of active wells in the basin. The effect of retirement age on the determination of active wells depends on the count of wells drilled per year.

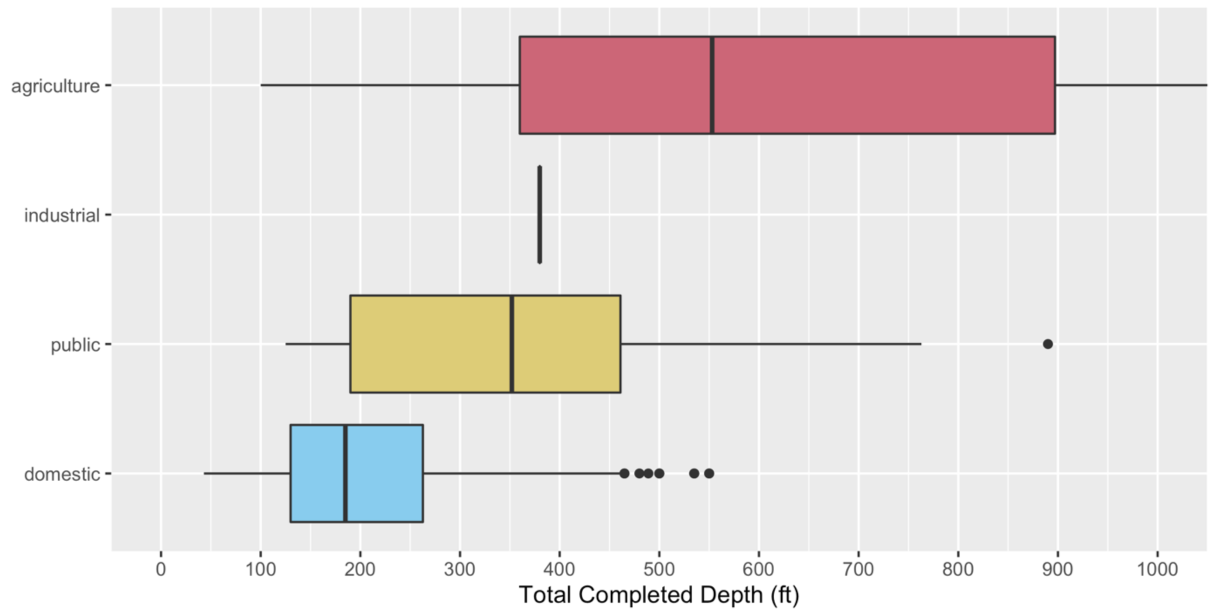

Figure 6: Total completed depth of active wells per well type. Agricultural wells tend to be the deepest, followed by public and domestic wells. Very few industrial wells exist in the basin (n = 7) and of these, only 1 is estimated to be active.

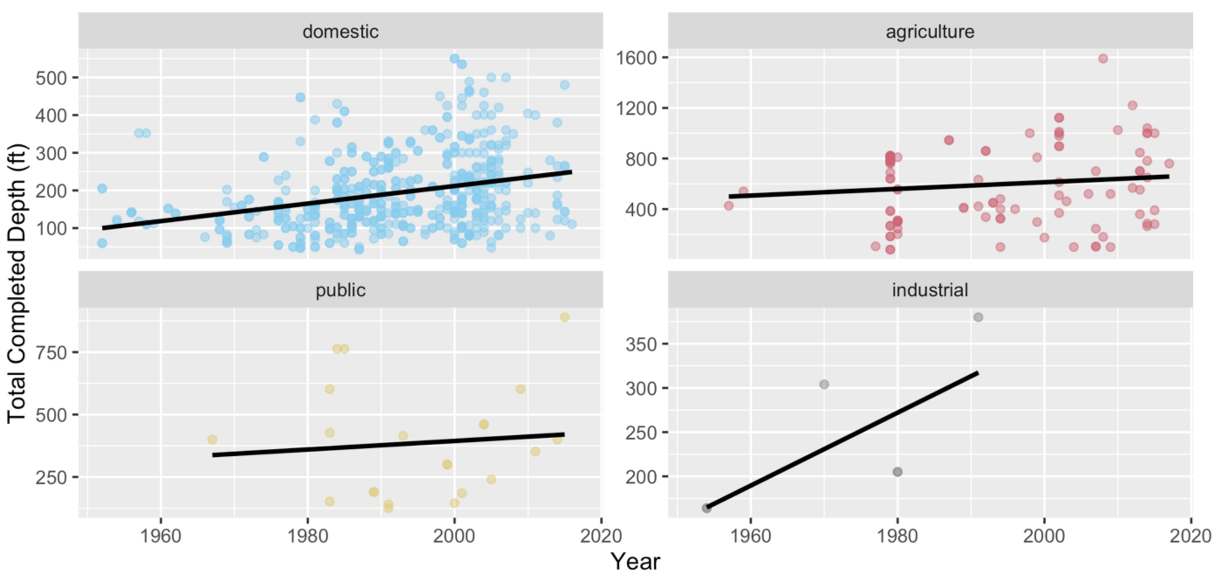

Figure 7: Total completed depth of wells has generally increased over time for all well types.

4.3 Well impacts: location, count, and cost

The difference between roughly present-day groundwater levels (average 2020 levels) and Fall 2015 lows is very similar the difference between present-day conditions and proposed MTs (Figure 8). Thus, a return to Fall 2015 levels, as well as those implied by MTs will likely show little appreciable difference on well impacts. This observation is supported by the well impact analysis, which finds that only 2% of domestic wells (n = 6 -10) are impacted at groundwater level MTs, and that no other well types are impacted (Figure 9 and Table 1). Moreover, the point patterns of estimated active and dry wells do not appreciably differ when considering 31 and 40 year retirement ages, which suggests little dependence of impact on retirement age (Figure 9). Impacted wells are minimal and tend to occur near basin boundaries where groundwater level data is most uncertain, suggesting possible model artifacts.

These results are unsurprising, as well depths are relatively deep compared to groundwater elevations, and MTs do not begin to approach depths that intersect the critical datum of most wells.

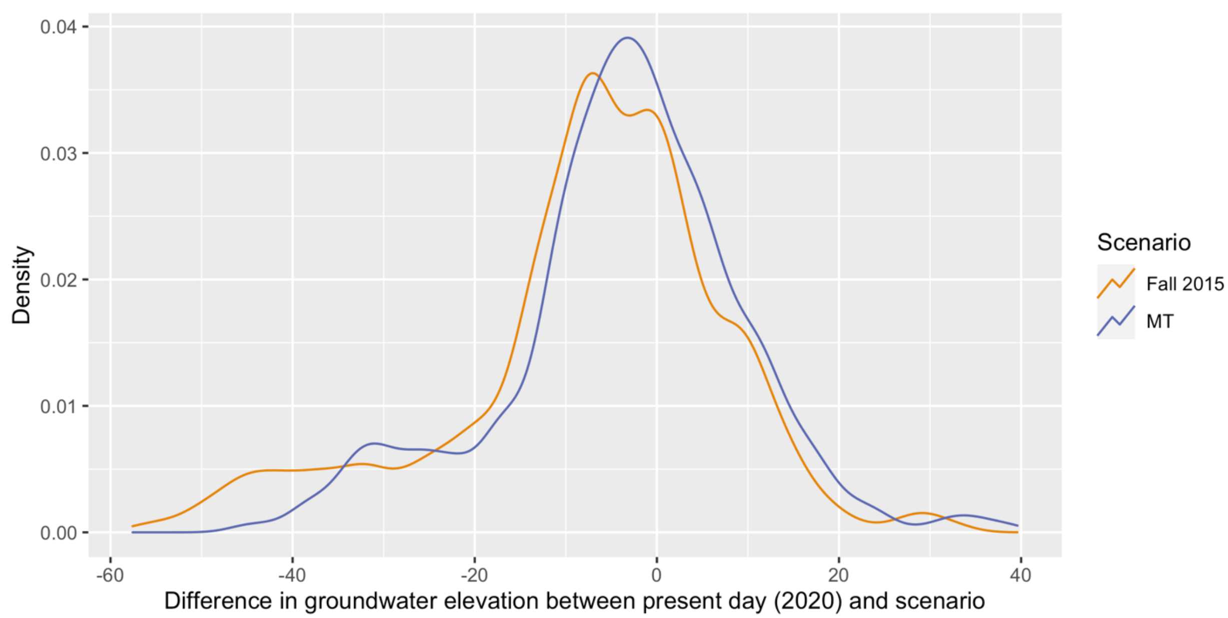

Figure 8: Groundwater level difference between a present day (2020) scenario and both the Fall 2015 groundwater level (orange line) and the MT scenario (blue line) is roughly equivalent, which suggests that groundwater levels do not vary considerably between these where MTs are set and historically observed values.

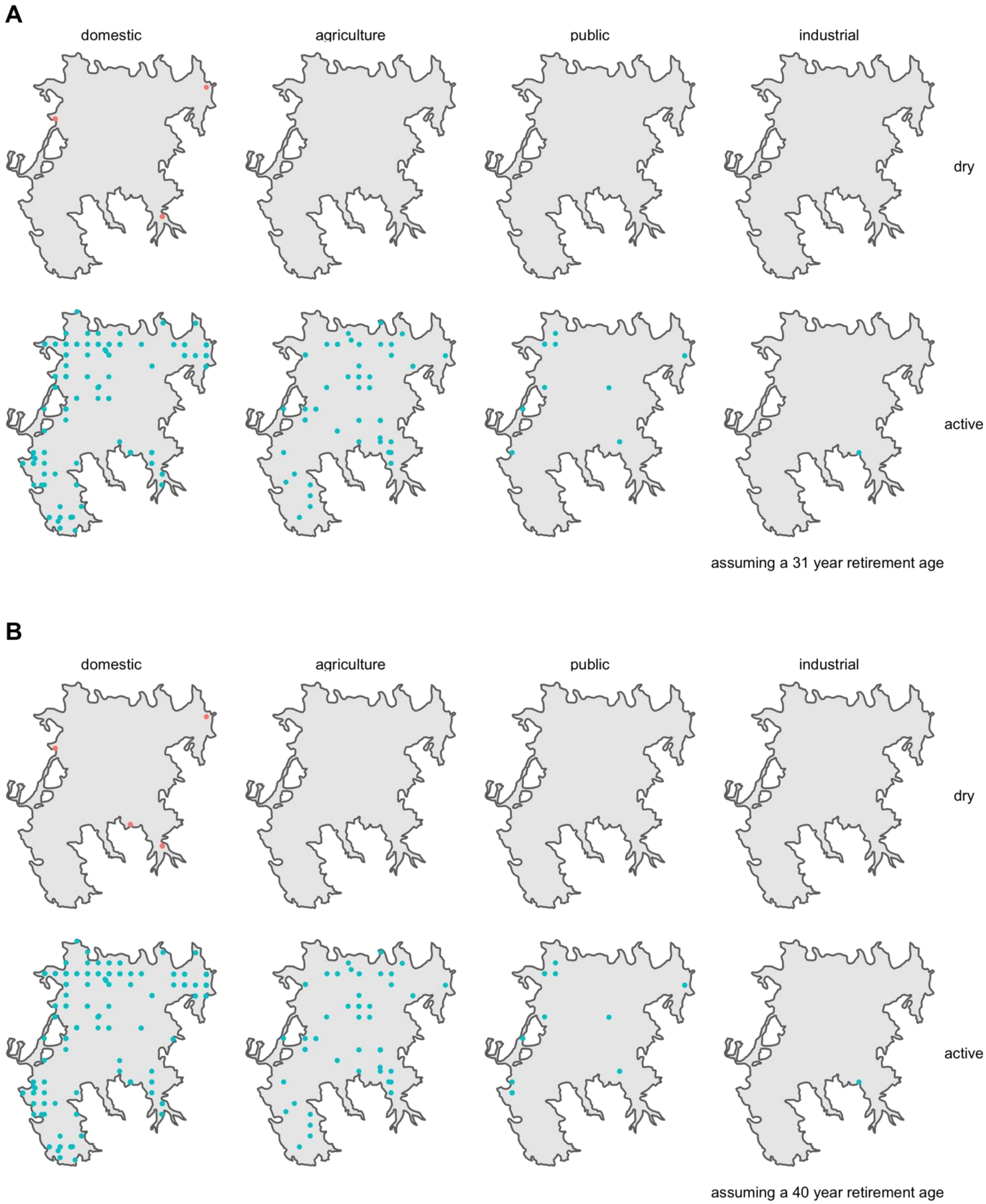

Figure 9: Locations of estimated impacted wells assuming (A) 31 year retirement age and (B) 40 year retirement age.

Table 1: Well impact summary for all well types under 31 and 40 year retirement age assumptions do not exceed 2% relative to the number of initially active wells (n = 325 and n = 450 respectively).

Well type	Impacted well count and percentage (31 yr retirement age)	Impacted well count and percentage (40 yr retirement age)
domestic	6 (2%)	10 (2%)
agriculture	0 (0%)	0 (0%)
public	0 (0%)	0 (0%)
industrial	0 (0%)	0 (0%)

5. Discussion

Vulnerable wells in the SV tend to be privately owned and adjacent to or within areas of concentrated groundwater extraction for agricultural and municipal use. Due to their relatively shallow depth, these wells may be vulnerable when water levels substantially decline due to drought or unsustainable management. With the passage of the Sustainable Groundwater Management Act, local groundwater sustainability agencies will develop sustainable management criteria including minimum thresholds and objectives, measured at monitoring networks that will chart progress towards, or deviance from, sustainability goals. Sustainable management criteria should identify vulnerable wells as beneficial users of groundwater, and hence, identify the quantitative thresholds at which they will be impacted by declining groundwater levels, and the percentages (or count) of impacts above which, local agencies deem significant and unreasonable. The GSP should then set groundwater level MTs according to these thresholds and manage groundwater levels above them to ensure that at MTs, significant and unreasonable impacts occur, and that at MOs, significant and unreasonable impacts are avoided.

Data from the DWR and Cal OPR suggests that during Fall 2015, no wells in the SV were reported dry, even though this period represents a [modern] historic groundwater level low. Results are consistent with this observation and suggest that a return to Fall 2015 groundwater level lows is unlikely to result in catastrophic and widespread impacts to wells. Moreover, additional declines anticipated under projected MTs result in negligible impacts to wells, largely owing to the relatively deep total completed depth of wells compared to present day groundwater levels, and minimal to no groundwater level decline in most parts of the basin. The percentage of domestic wells impacted in the worst-case scenario assuming all RMPs reach MTs simultaneously is 2% (n = 6 - 10), even when considering 31 and 40 year retirement ages. No other well types are impacted.

Well protection analysis thus validates minimum thresholds (MTs) which avoid significant and unreasonable impacts to wells in the basin and allow the basin to achieve projected growth targets within a framework of regional conjunctive use and PMA.

6. Conclusion

Well completion reports and groundwater level data were analyzed to estimate groundwater thresholds at which different well types in the SV reach levels of impact deemed significant and unreasonable. Results suggest that projected groundwater MTs will not lead to widespread catastrophic well failure in the SV.

Well impact analyses depend on reliable data to determine the set of active wells to consider, and their critical datum (the vertical elevation at which a well is estimated to be impacted by declining groundwater levels). Reasonable assumptions are made for modeling purposes, but are not accurate to every well across the basin. Results are sensitive to well retirement age. A “well census” may improve understanding of well retirement and well vulnerability more generally. Such a census, if performed, should take place at the county level; results of the census may be attached to the parcel database used to better inform well protection and rates and fee schedules.

Top-down approaches like the analysis provided herein should be combined with bottom-up approaches. Localized, volunteer-based vulnerable well monitoring may empower point-of-use crowdsourced data and facilitate an early warning system to prioritize well rehabilitation measures before wells go dry. Truly, the best indication of well vulnerability will come from measurements at point-of-use wells. SGMA does not require this level of monitoring or provide guidance on how to achieve it, but GSAs may consider local monitoring programs outside of GSP RMP network to improve communication with well owners and take corrective actions as needed.

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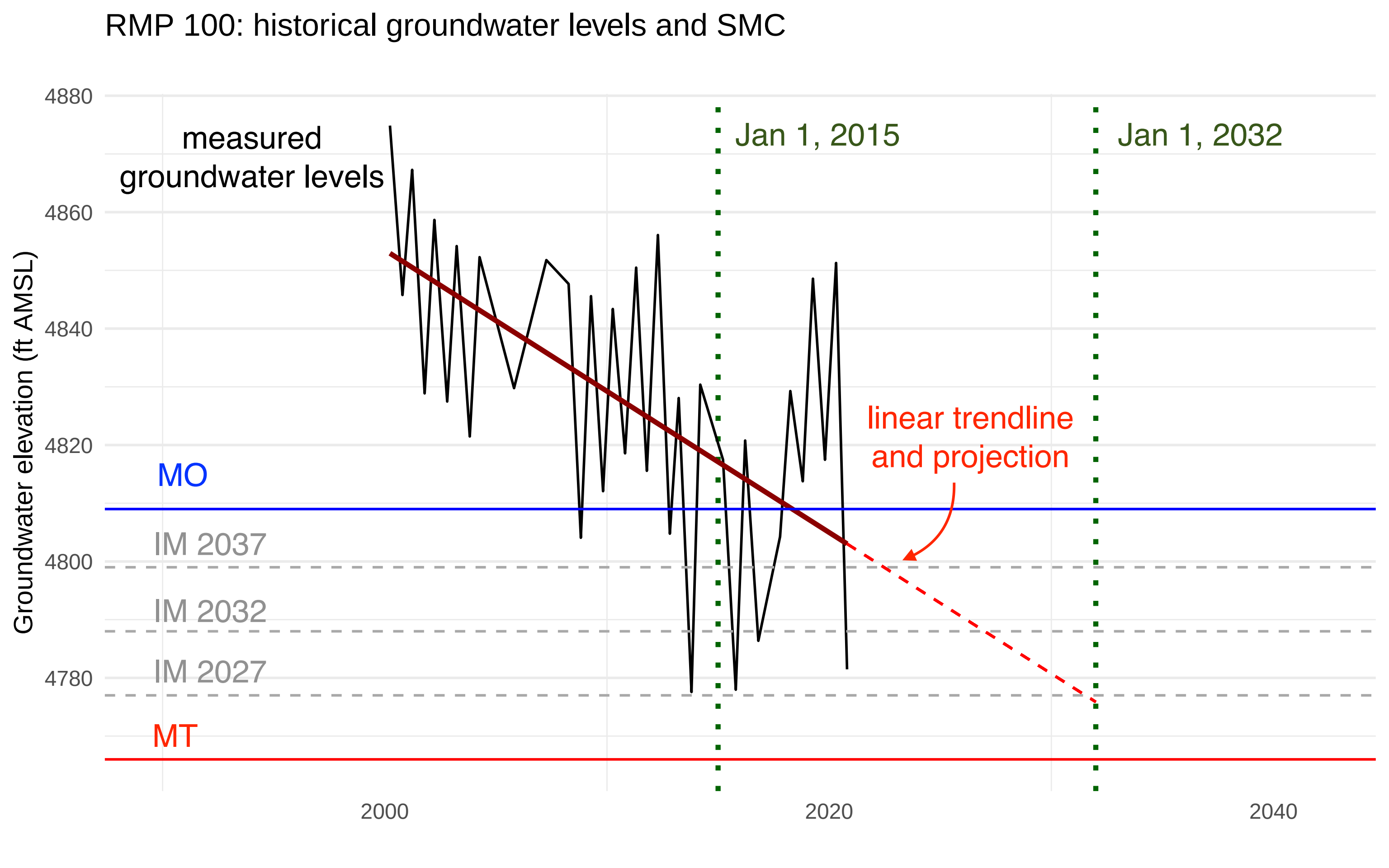
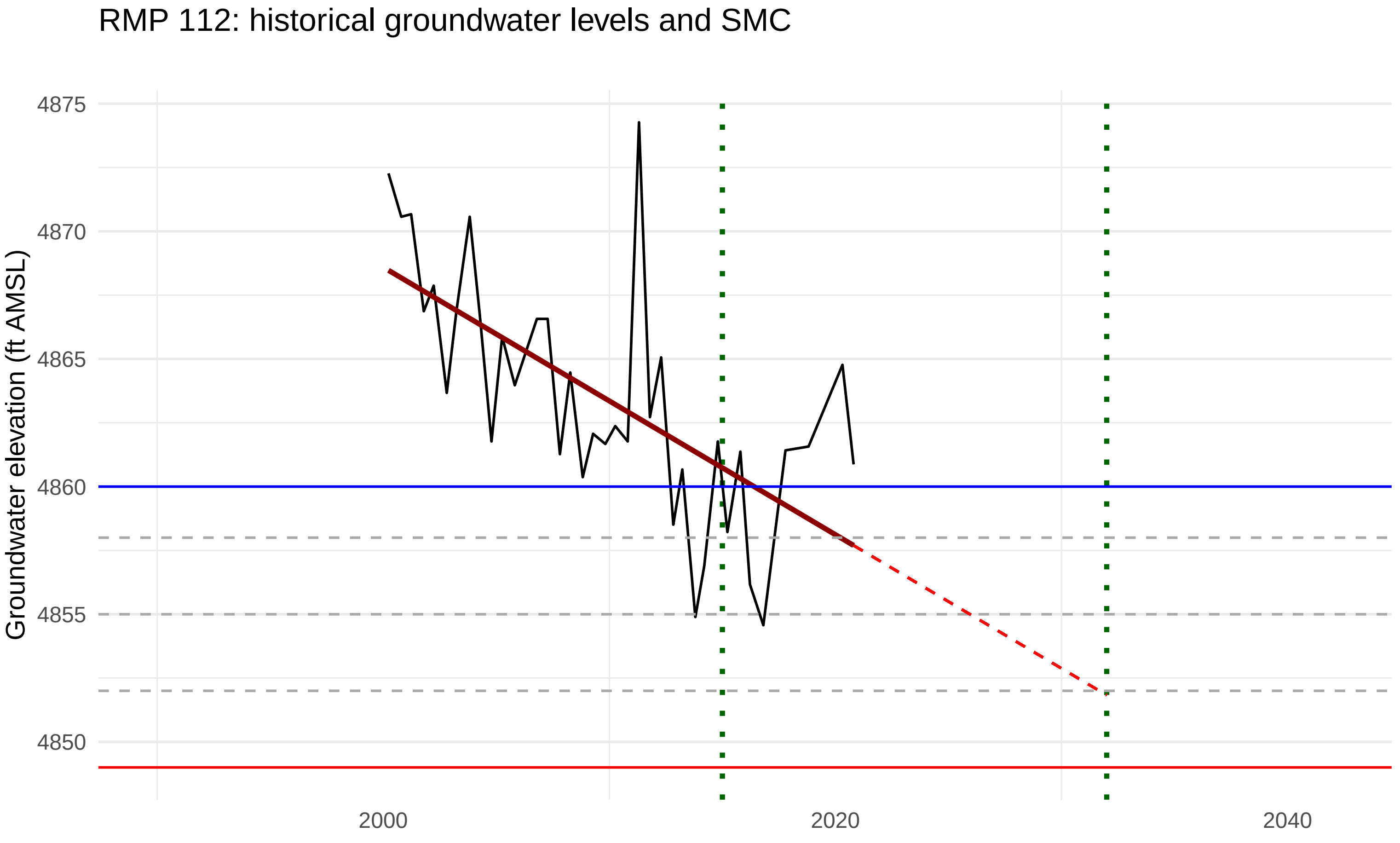
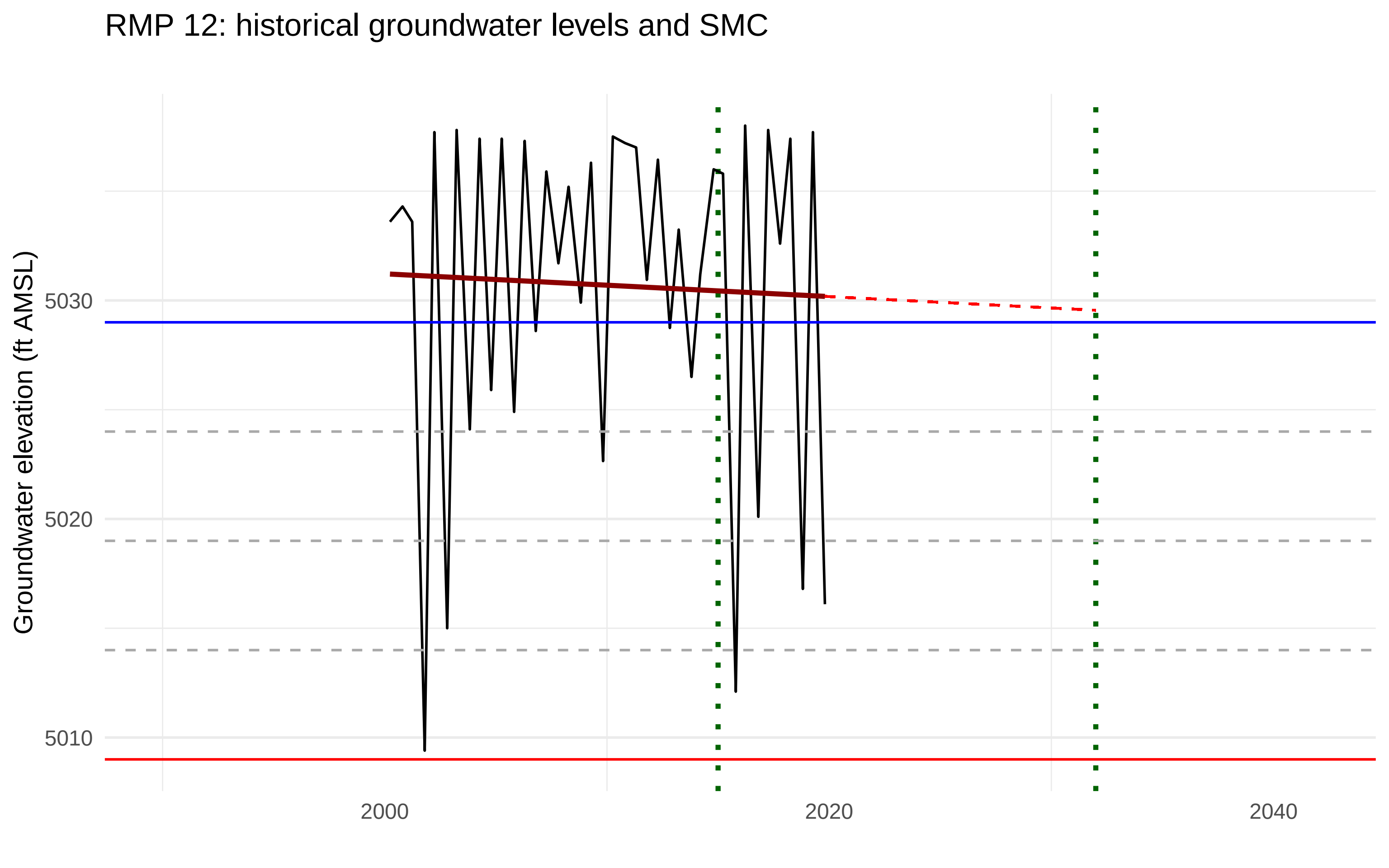
Appendix 3-2: Historical Groundwater Levels



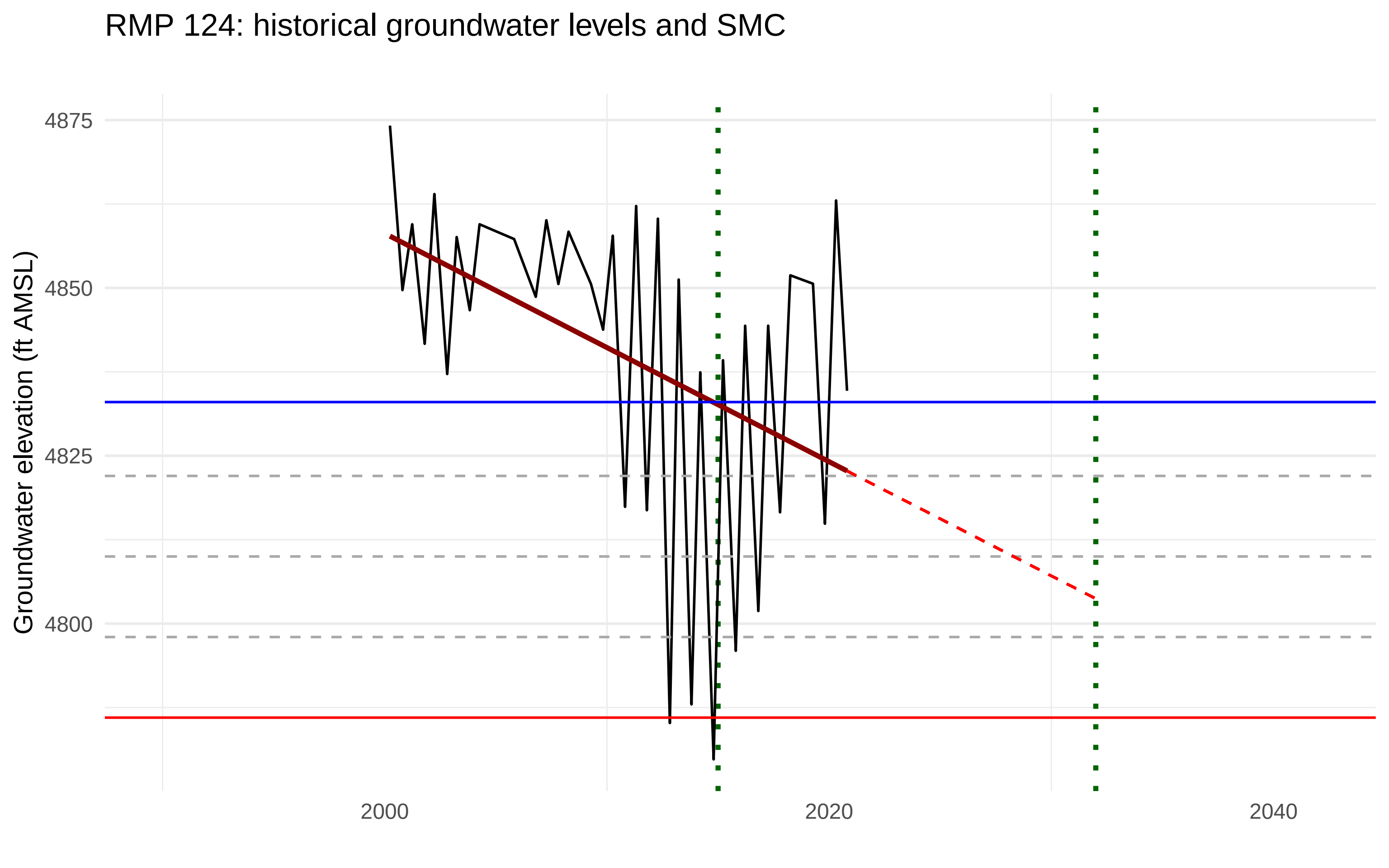
RMP 100: historical groundwater levels and SMC
measured groundwater levels
Jan 1, 2015
Jan 1, 2032
linear trendline and projection
MO
IM 2037
IM 2032
IM 2027
MT
Groundwater elevation (ft AMSL)
4880
4860
4840
4820
4800
4780
2000
2020
2040



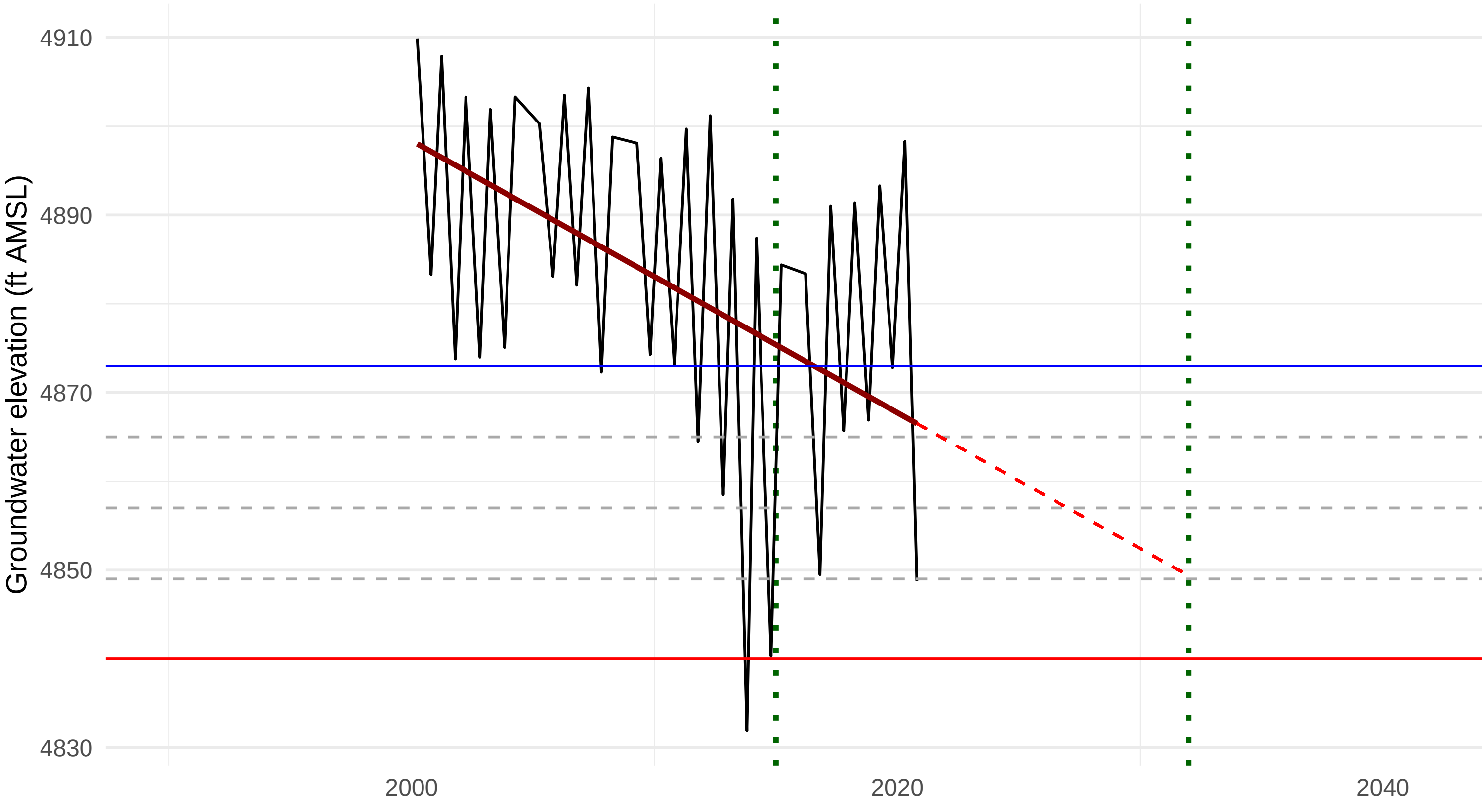
RMP 112: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4875
4870
4865
4860
4855
4850
2000
2020
2040

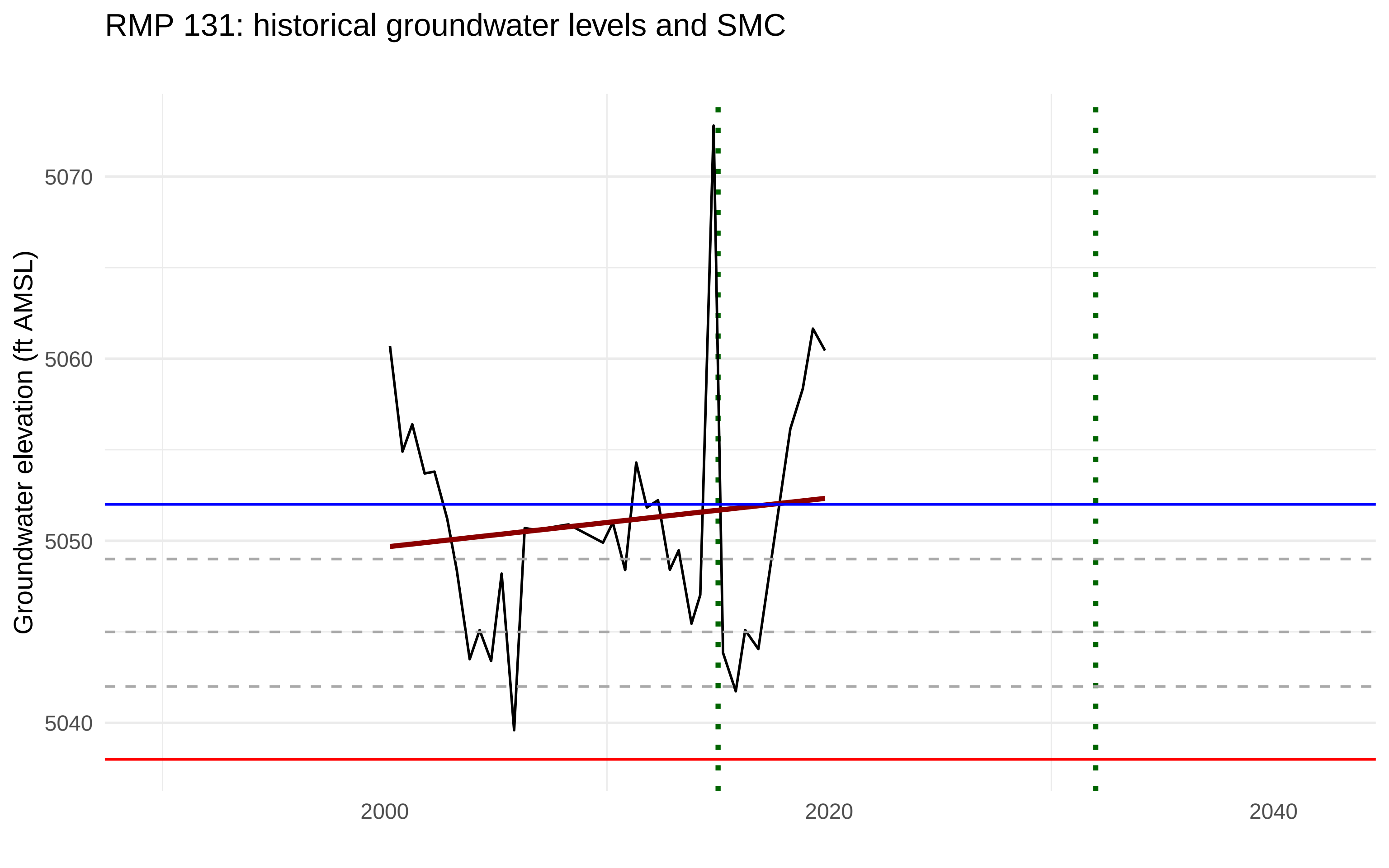


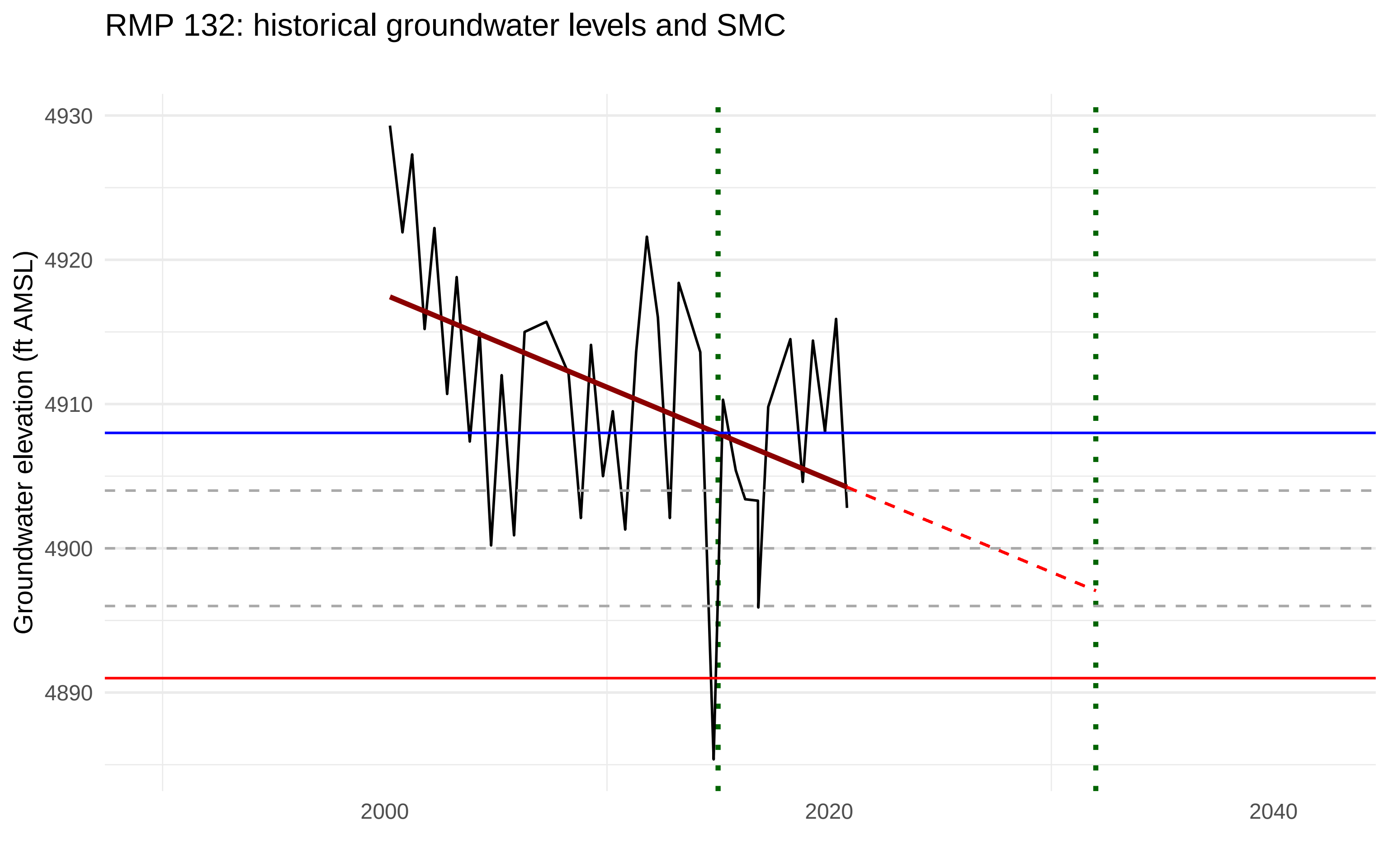
RMP 12: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
5030
5020
5010
2000
2020
2040


RMP 124: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4875
4850
4825
4800
2000
2020
2040

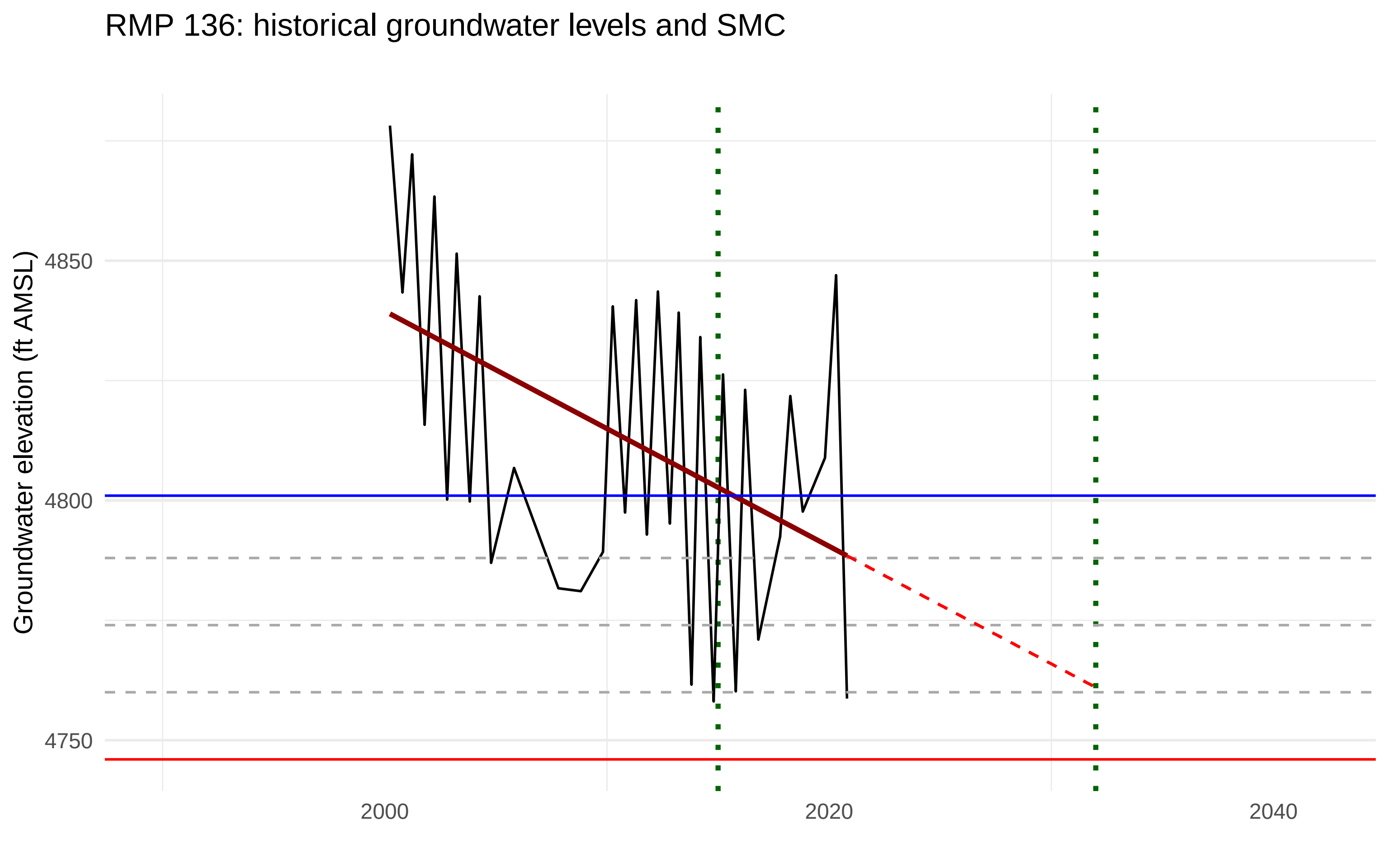
RMP 130: historical groundwater levels and SMC

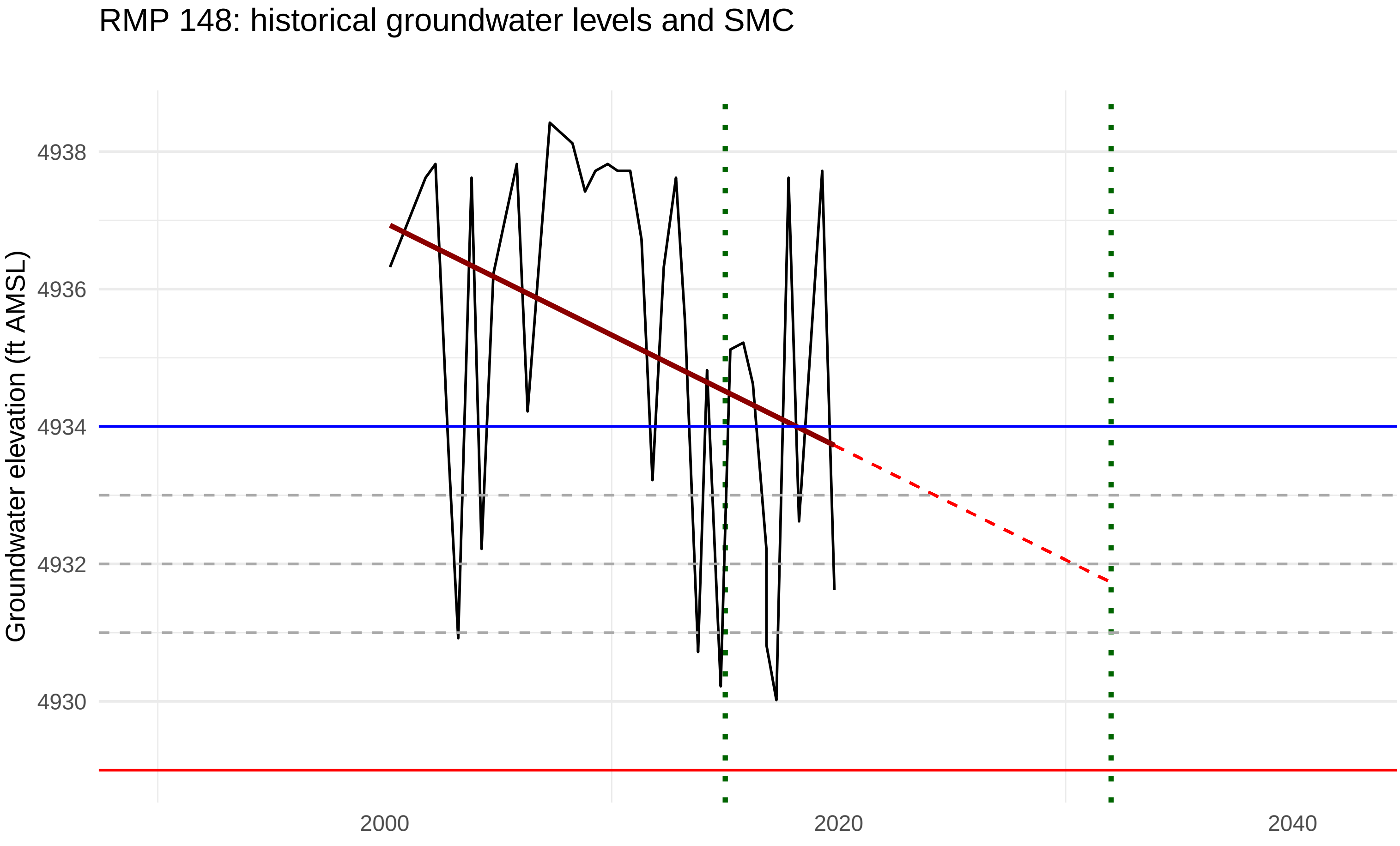



RMP 131: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
5070
5060
5050
5040
2000
2020
2040

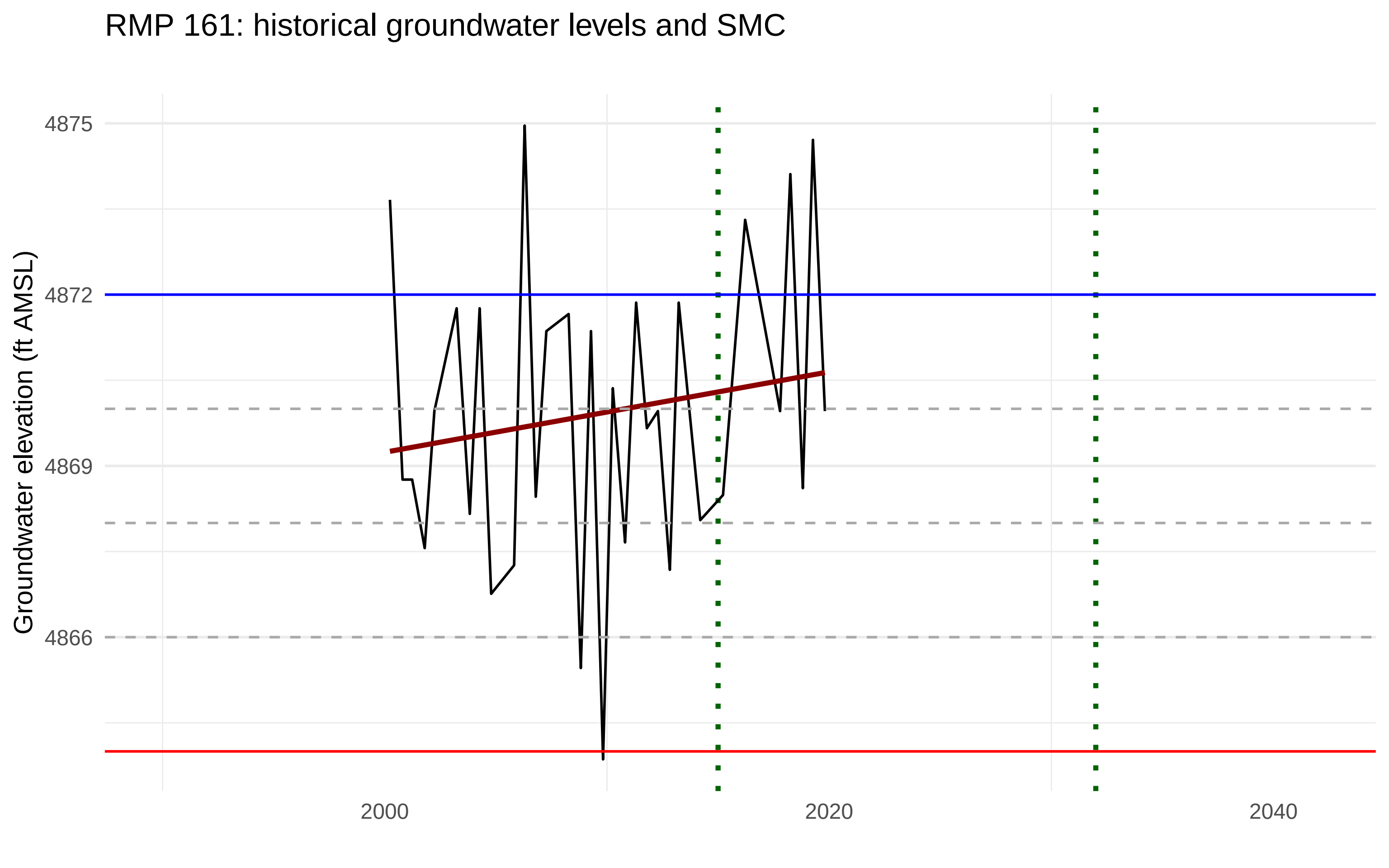


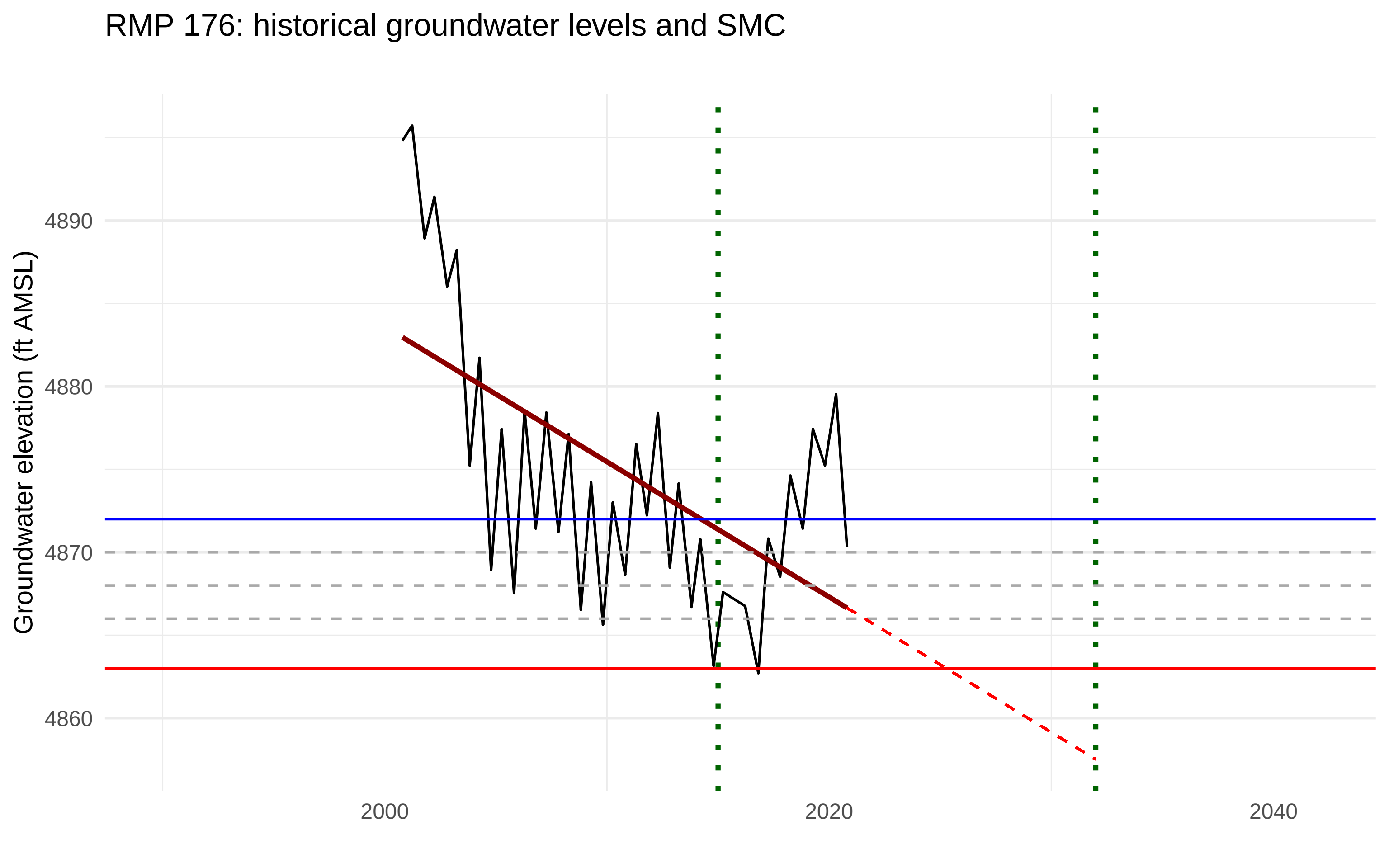
RMP 132: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4930
4920
4910
4900
4890
2000
2020
2040


RMP 136: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4850
4800
4750
2000
2020
2040

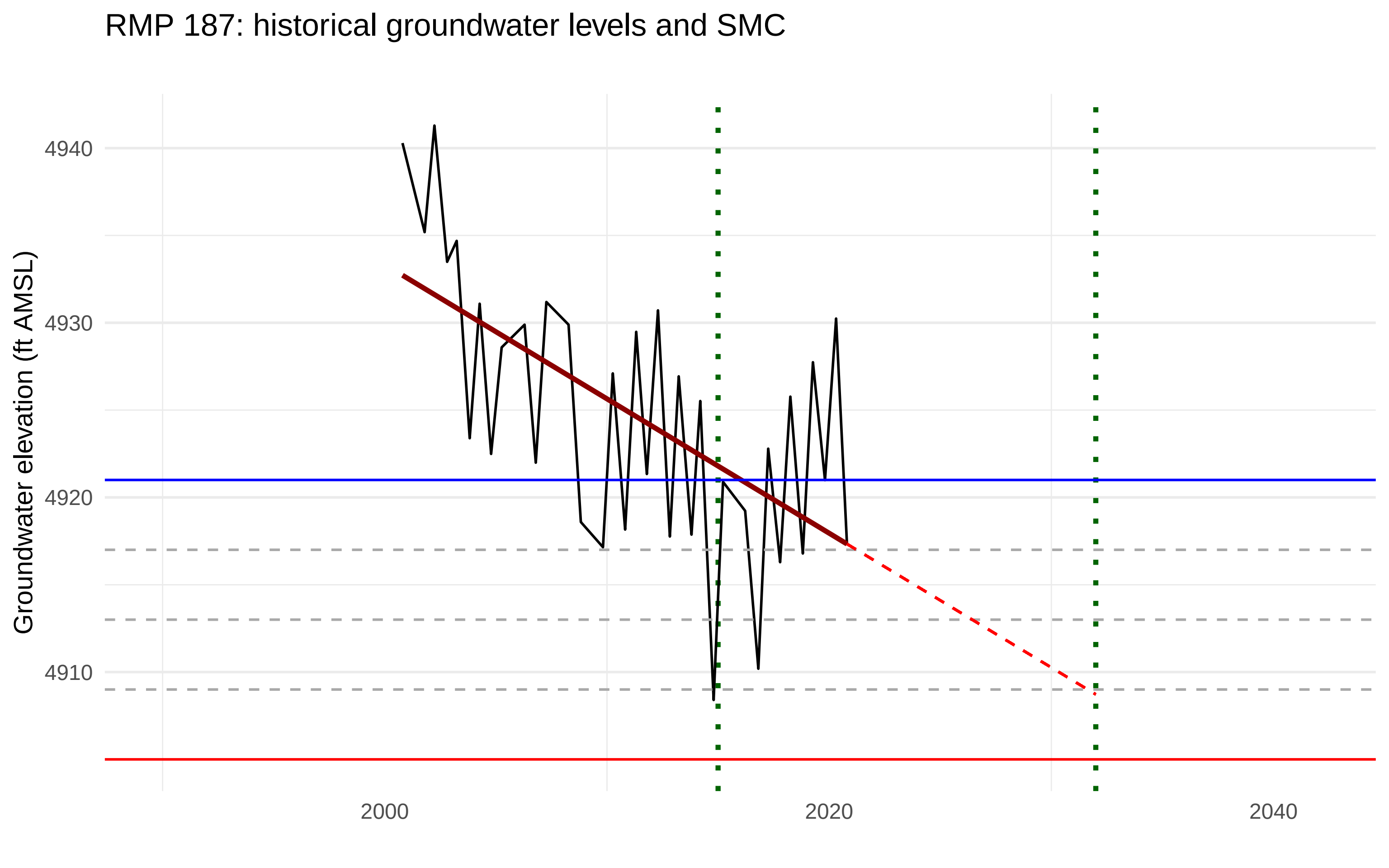


RMP 148: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4938
4936
4934
4932
4930
2000
2020
2040

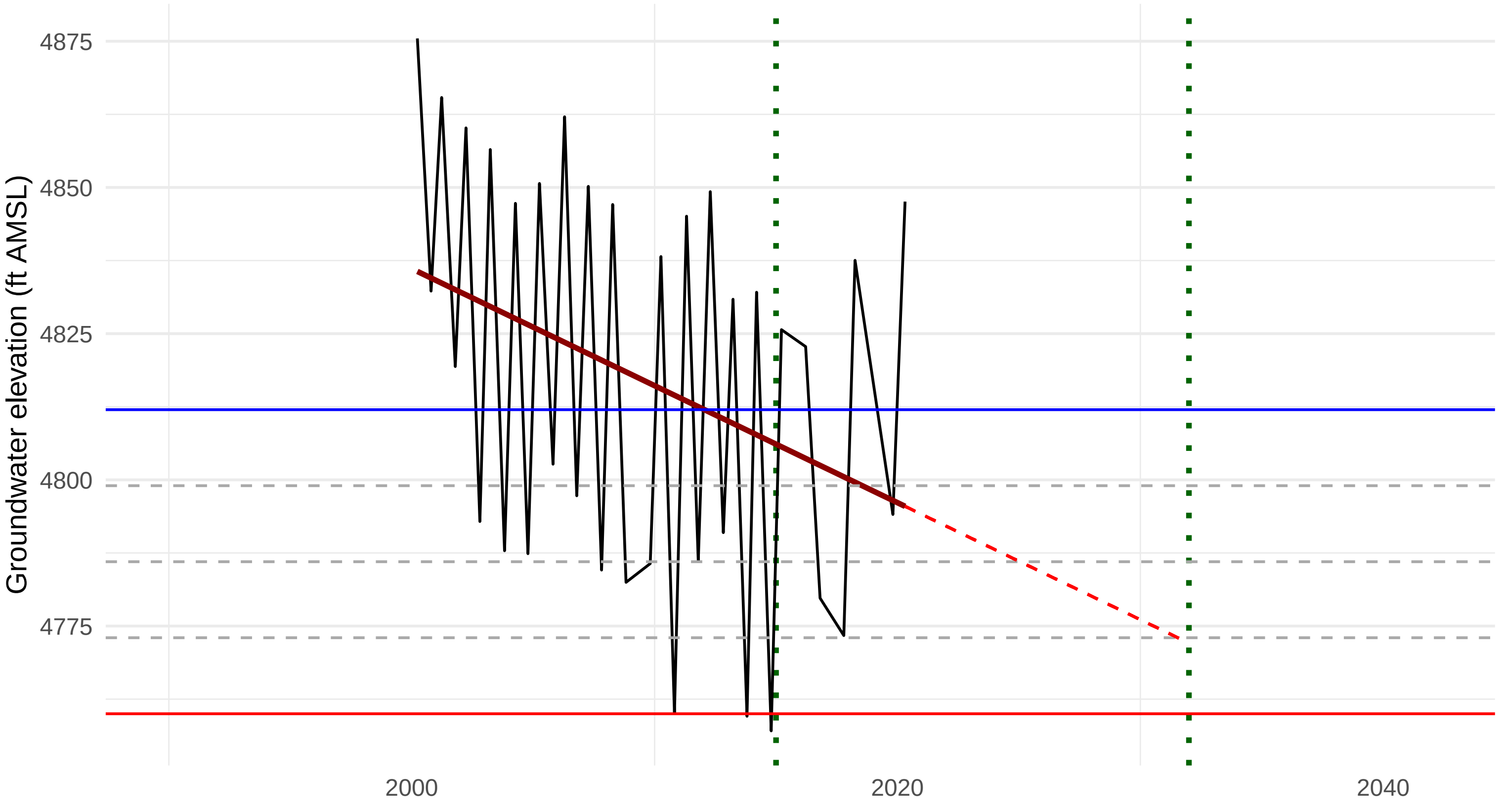

RMP 161: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4875
4872
4869
4866
2000
2020
2040

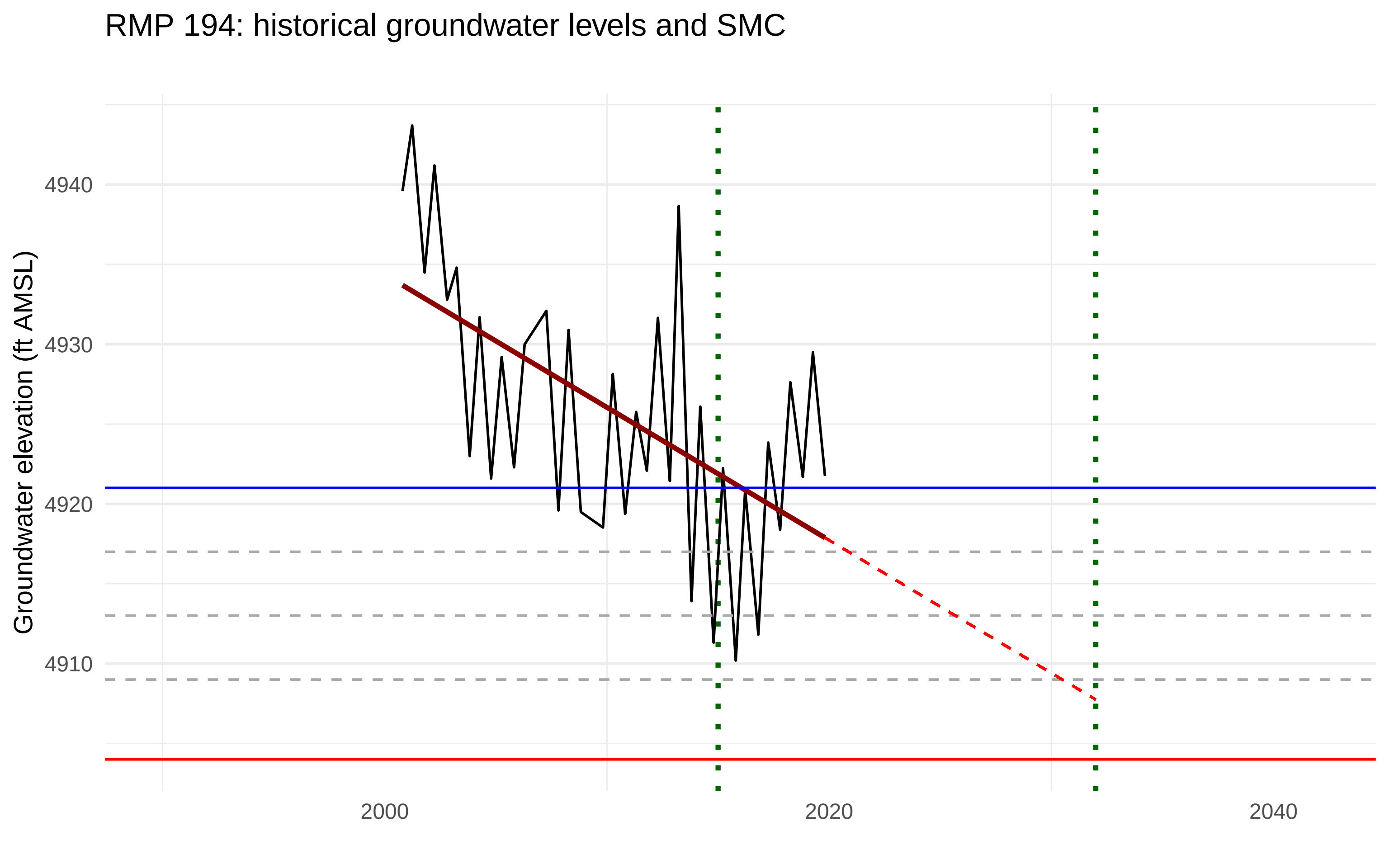

RMP 176: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4890
4880
4870
4860
2000
2020
2040

RMP 185: historical groundwater levels and SMC

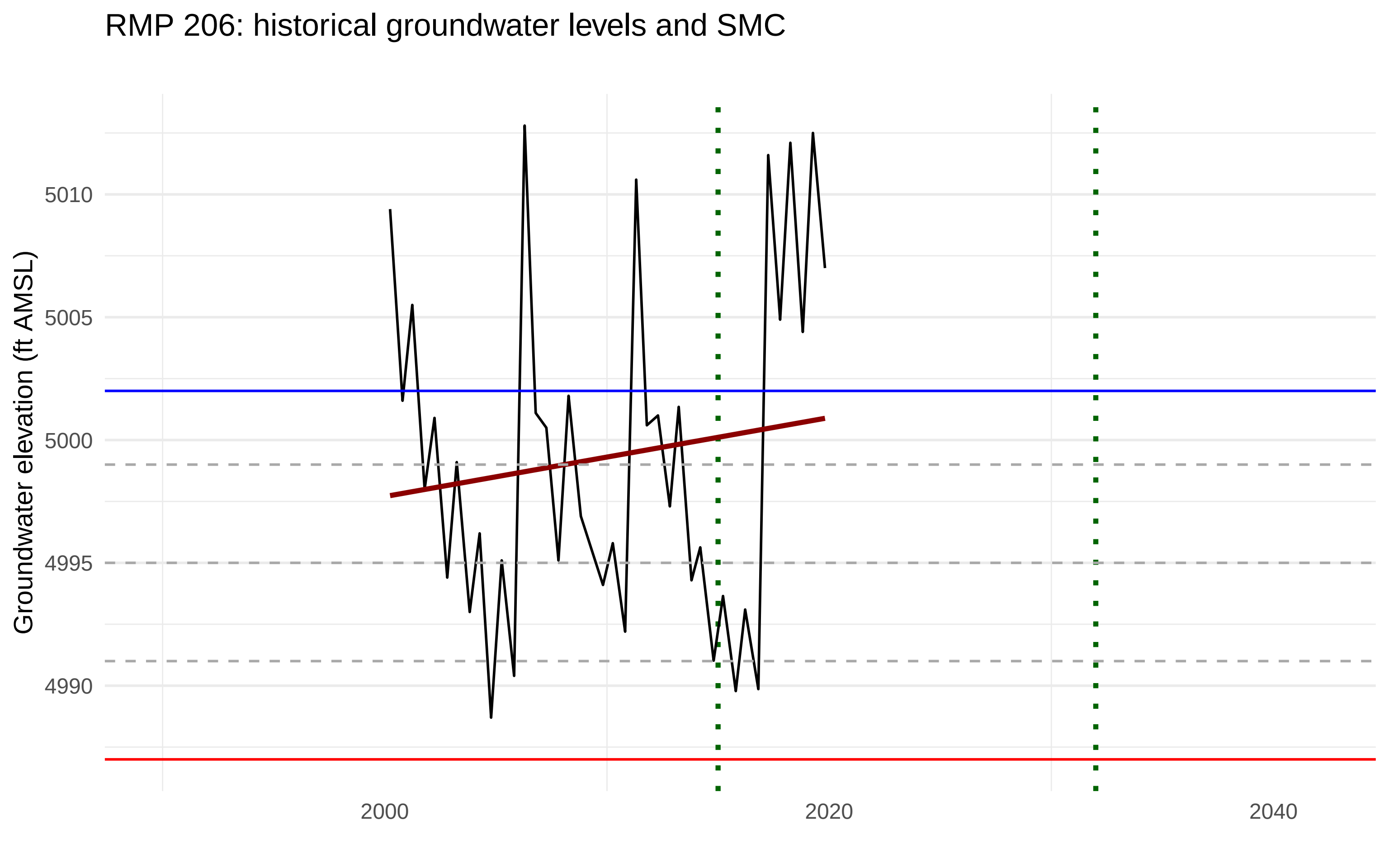

RMP 187: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4940
4930
4920
4910
2000
2020
2040

RMP 190: historical groundwater levels and SMC

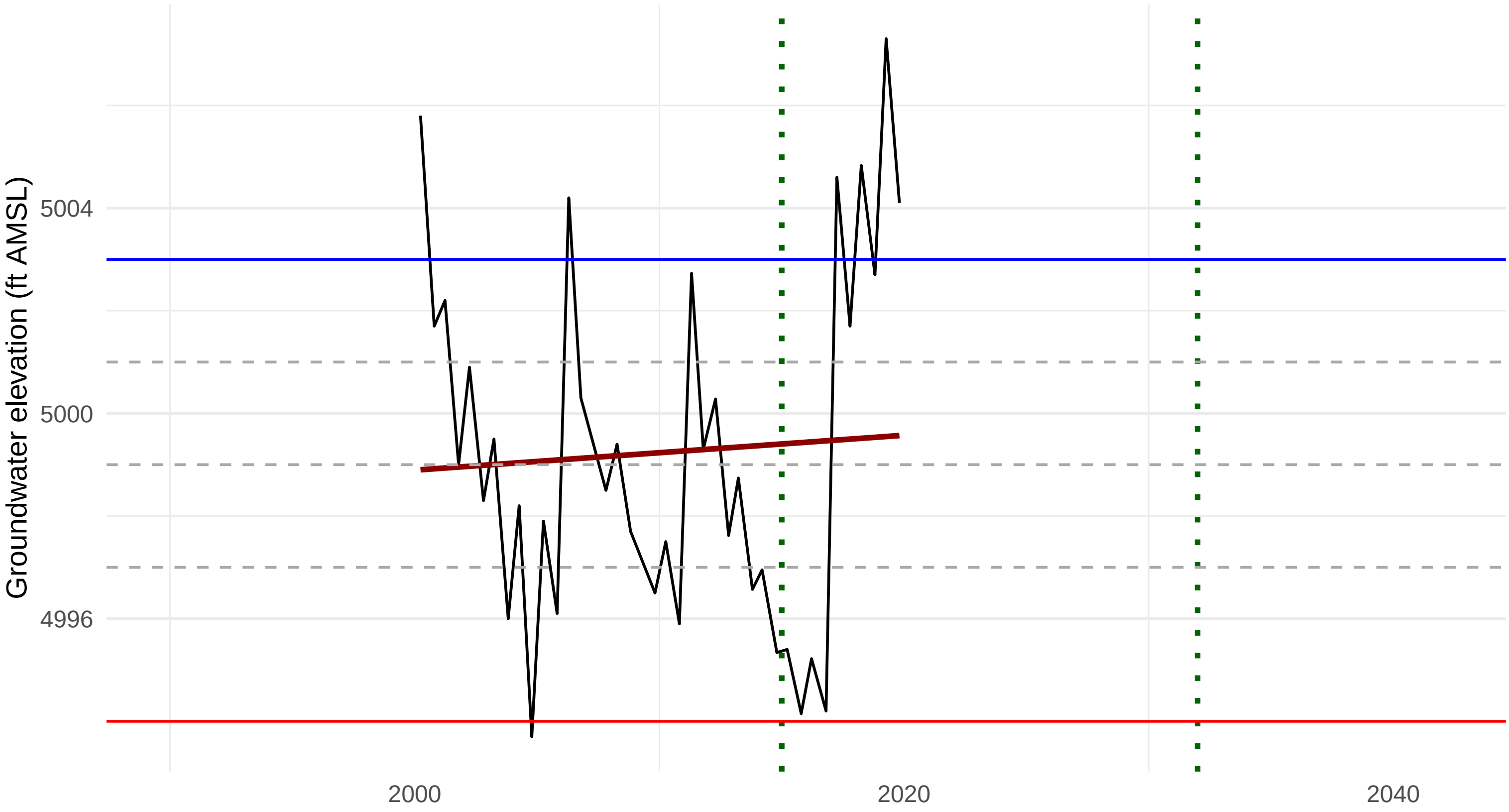


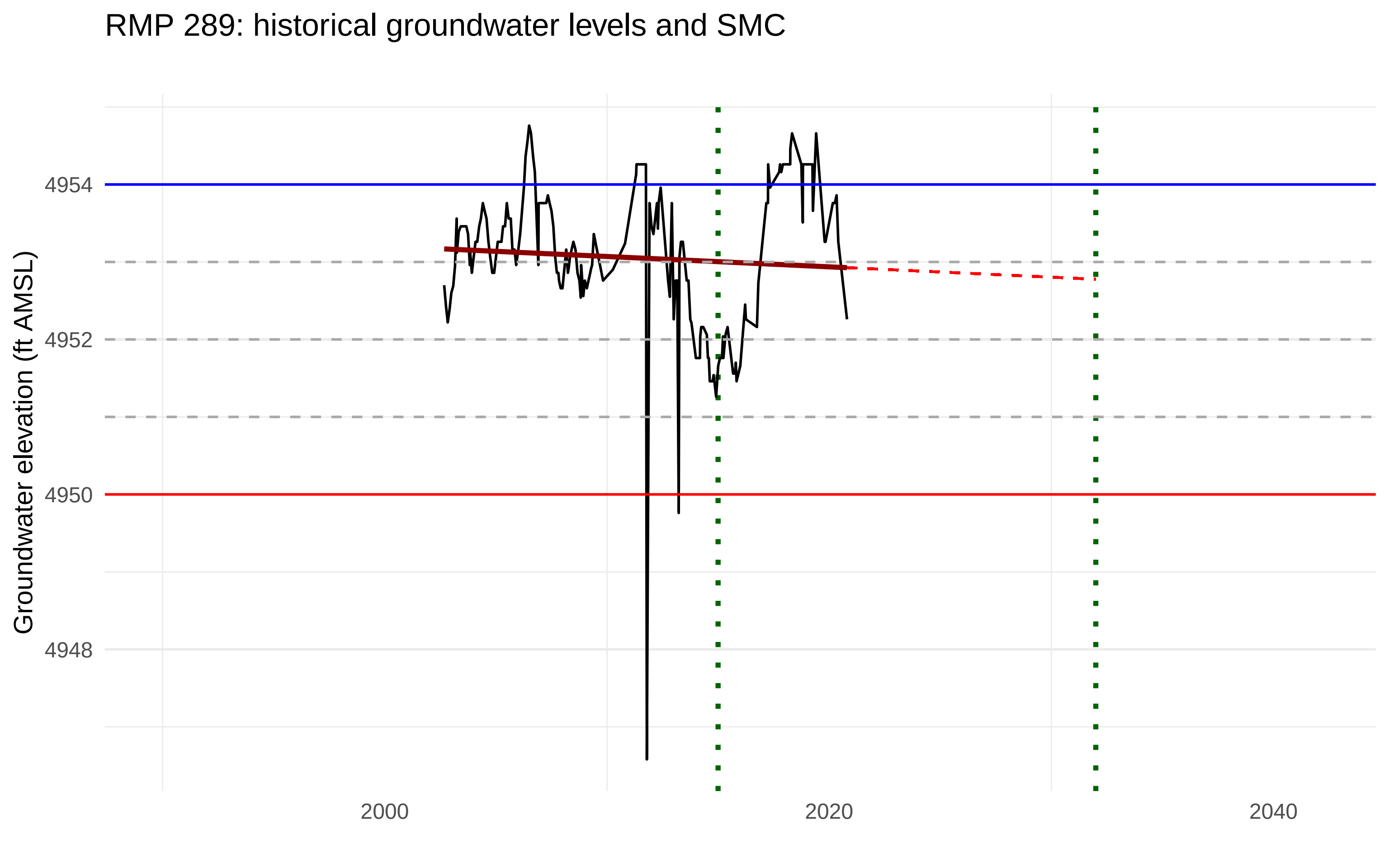


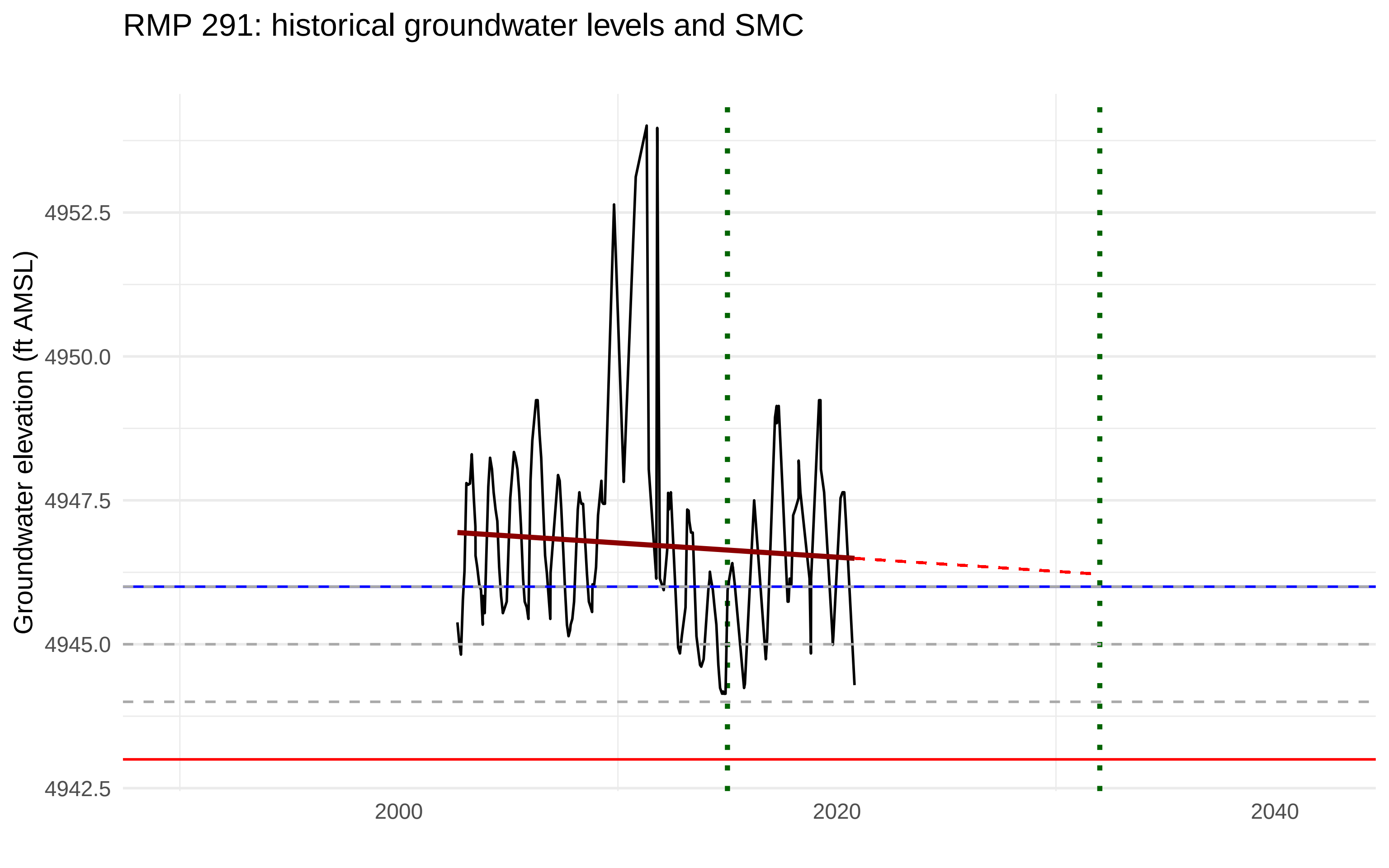
RMP 194: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4940
4930
4920
4910
2000
2020
2040

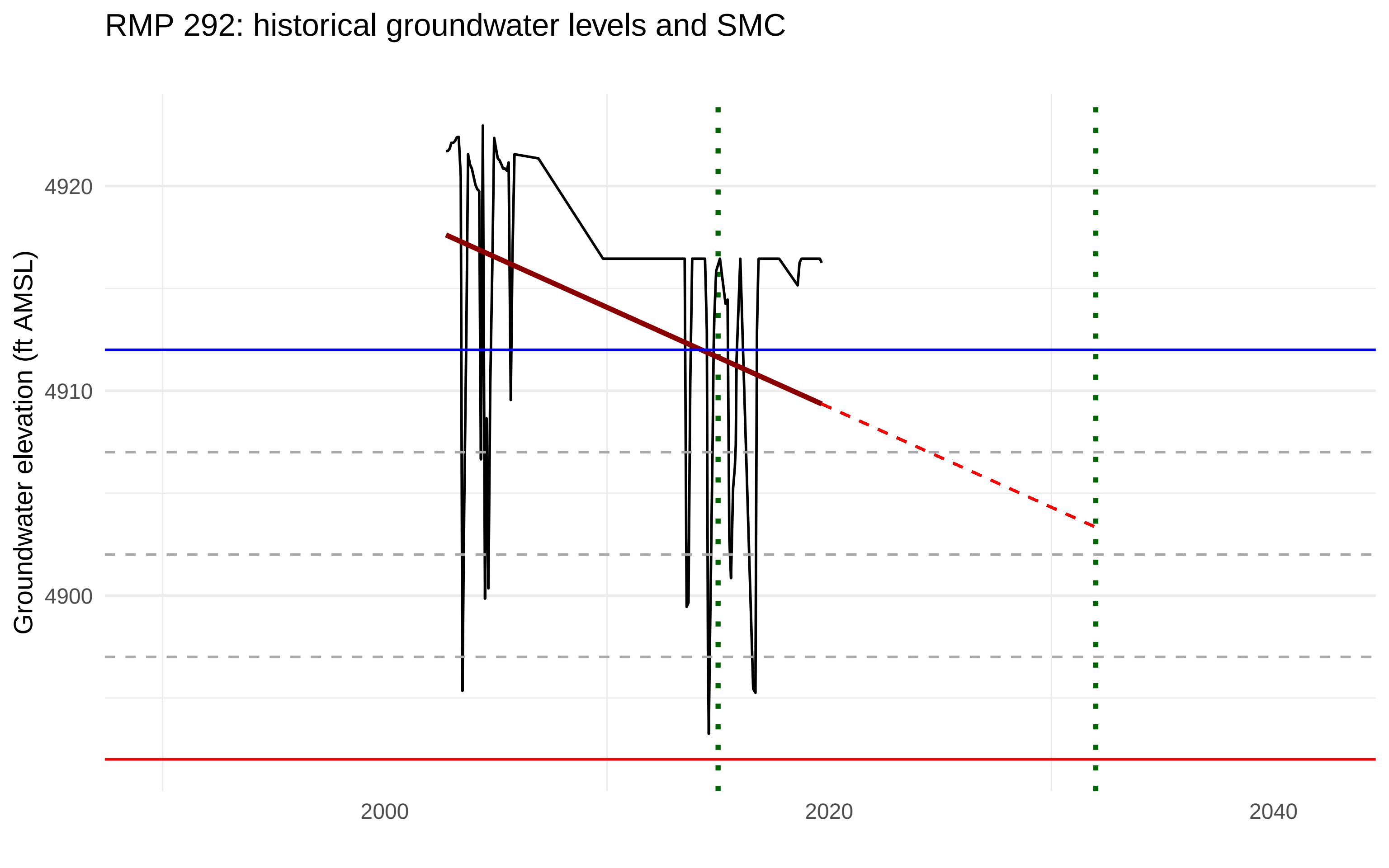

RMP 206: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
5010
5005
5000
4995
4990
2000
2020
2040

RMP 209: historical groundwater levels and SMC



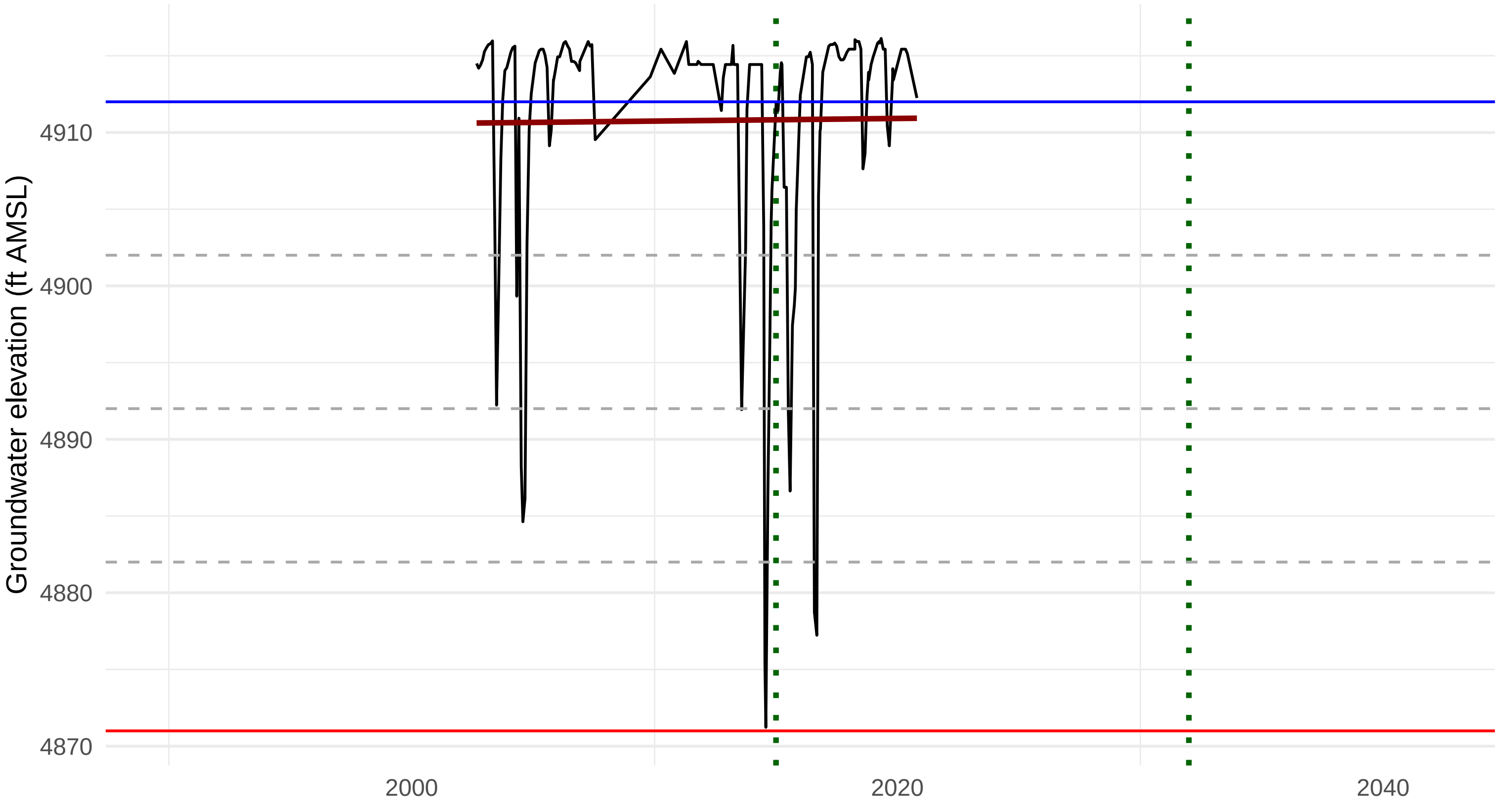

RMP 289: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4954
4952
4950
4948
2000
2020
2040


RMP 291: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4952.5
4950.0
4947.5
4945.0
4942.5
2000
2020
2040

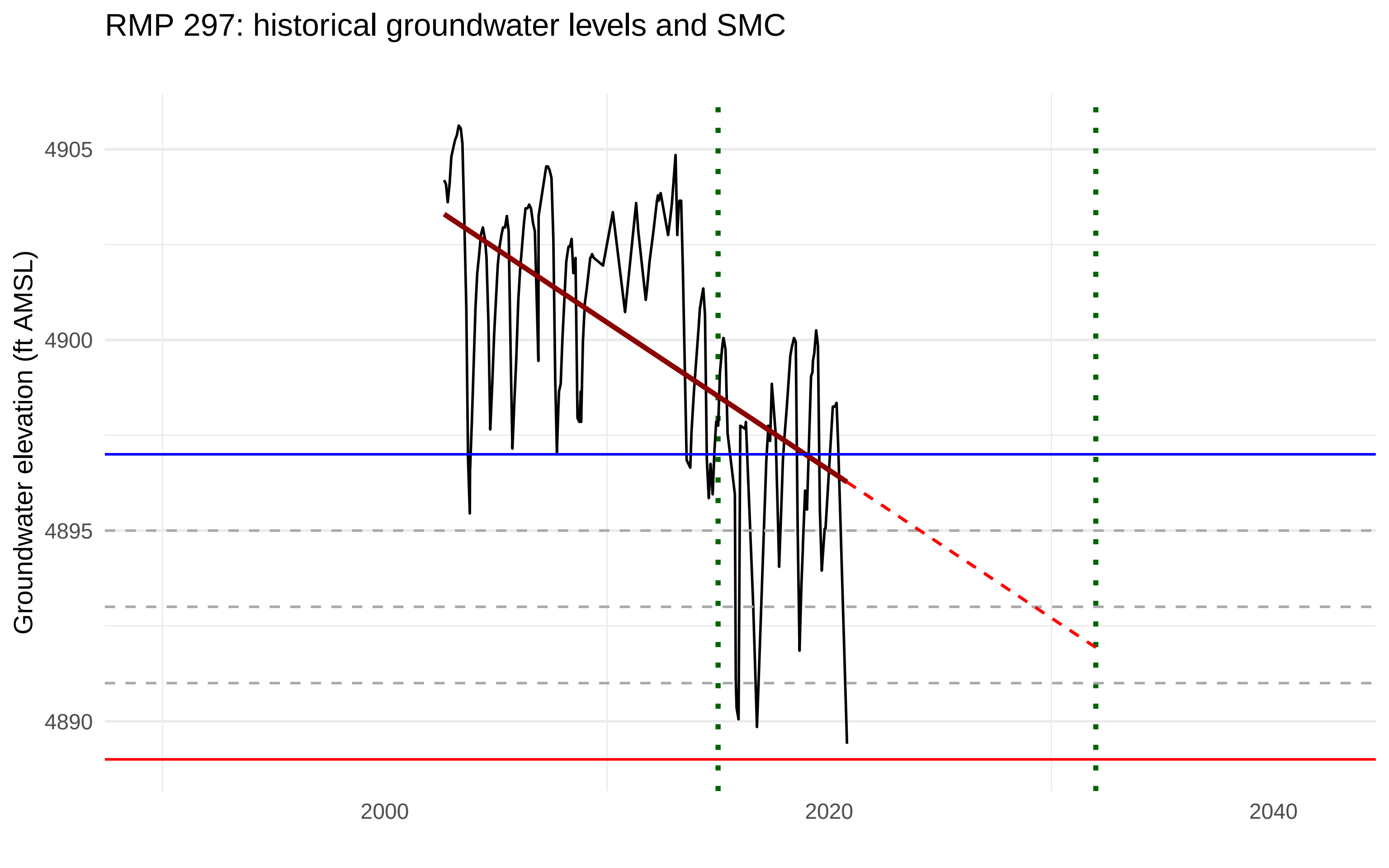


RMP 292: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4920
4910
4900
2000
2020
2040

RMP 294: historical groundwater levels and SMC

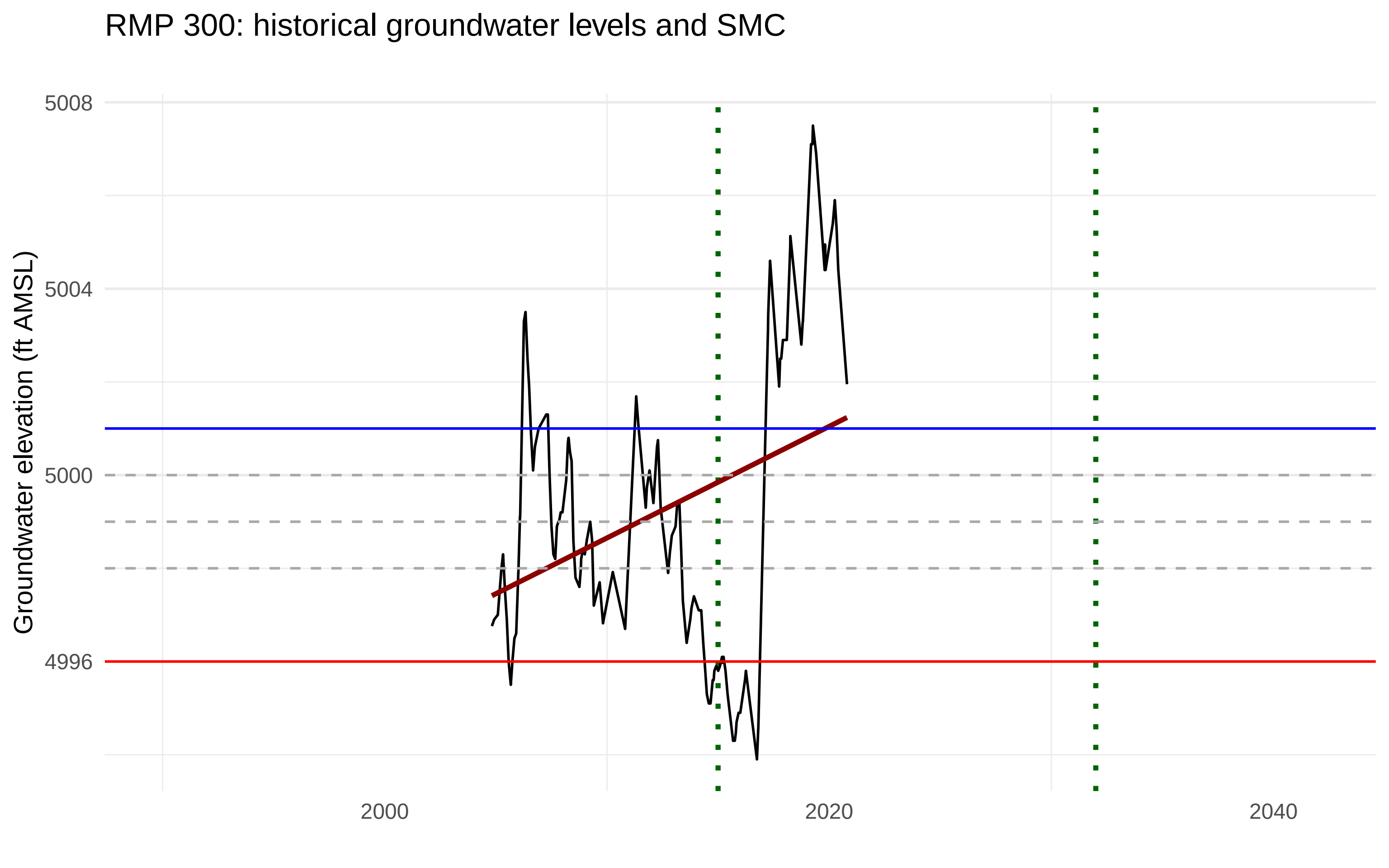



RMP 296: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4890
4885
4880
4875
2000
2020
2040

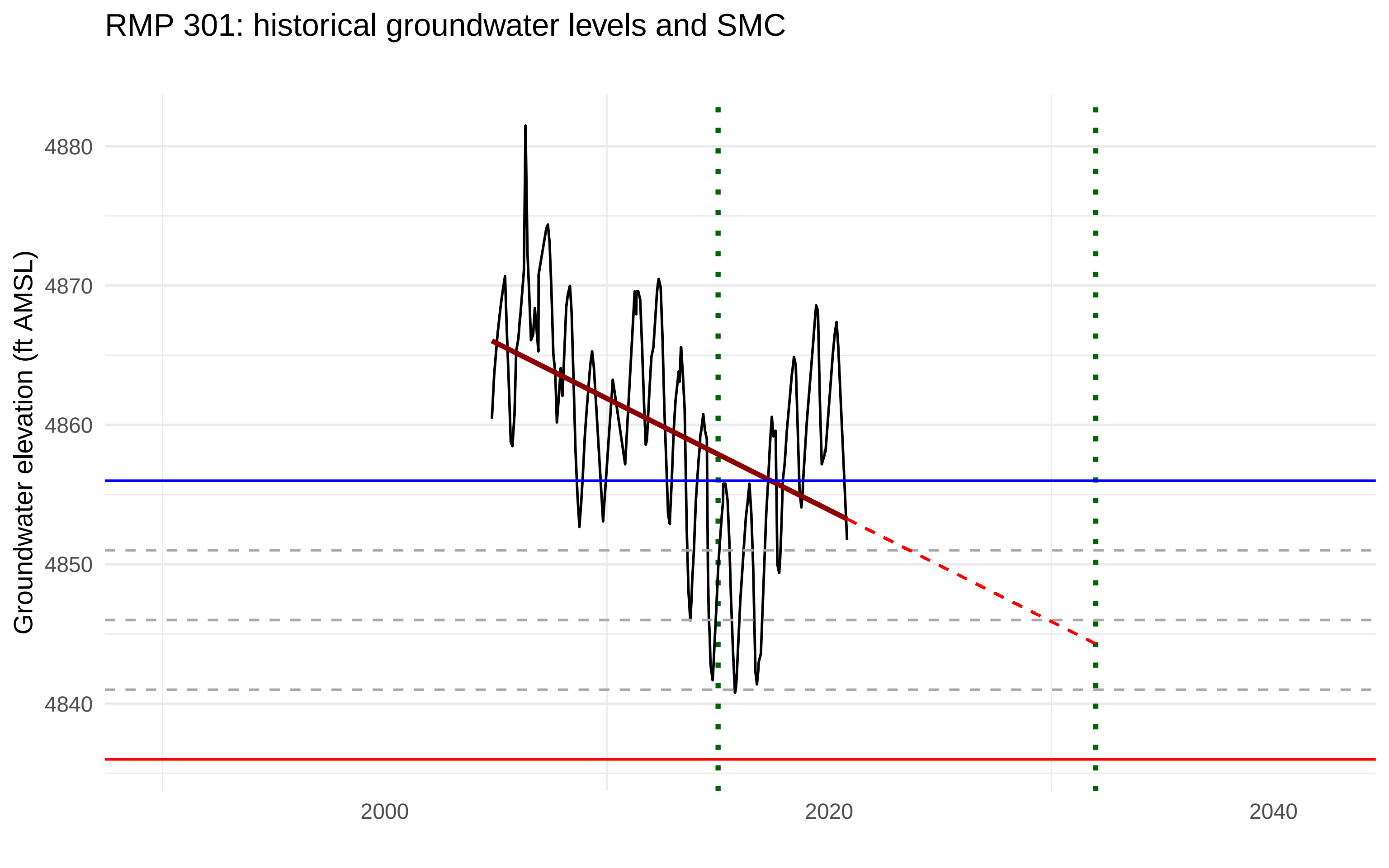


RMP 297: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4905
4900
4895
4890
2000
2020
2040

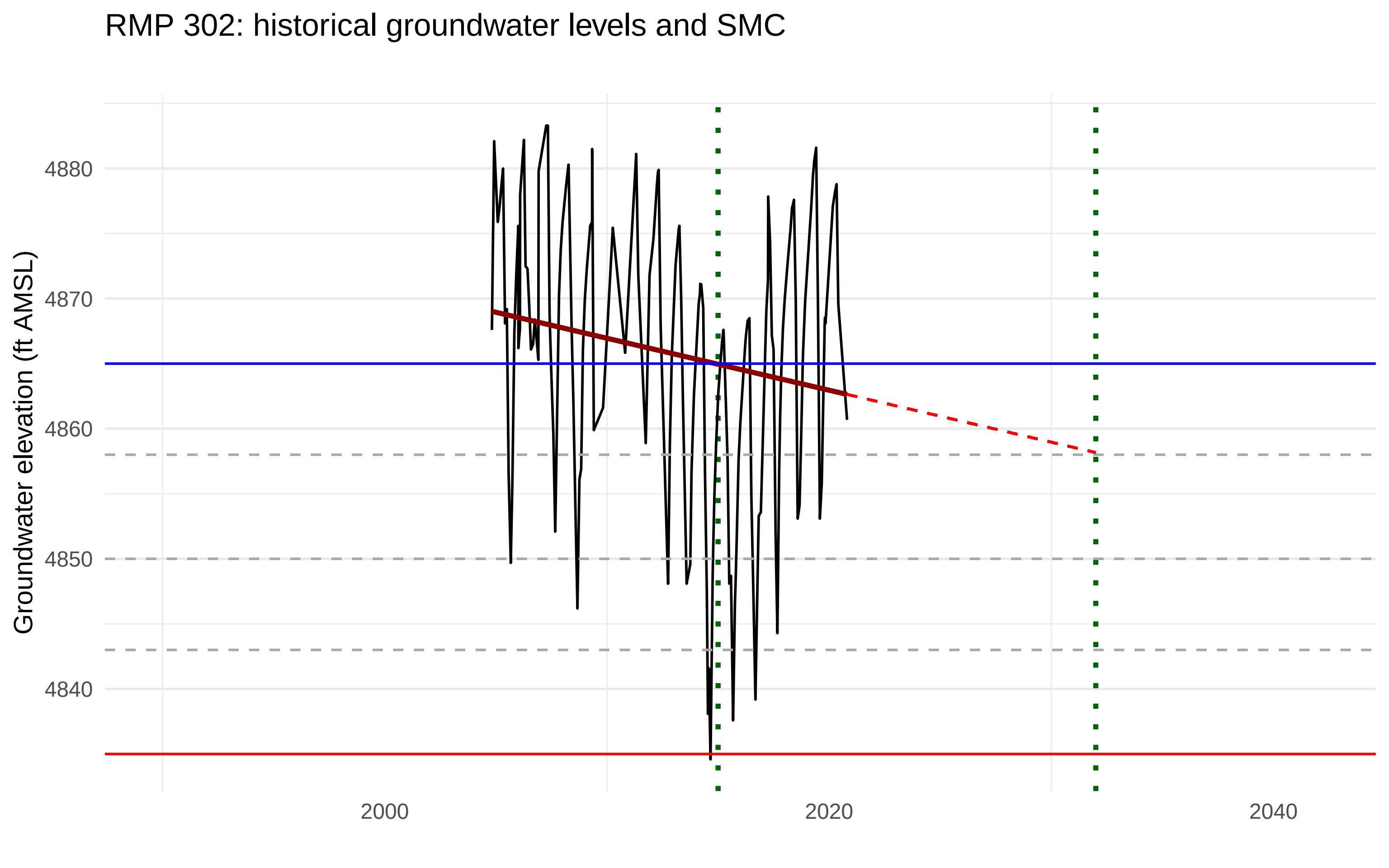
RMP 298: historical groundwater levels and SMC



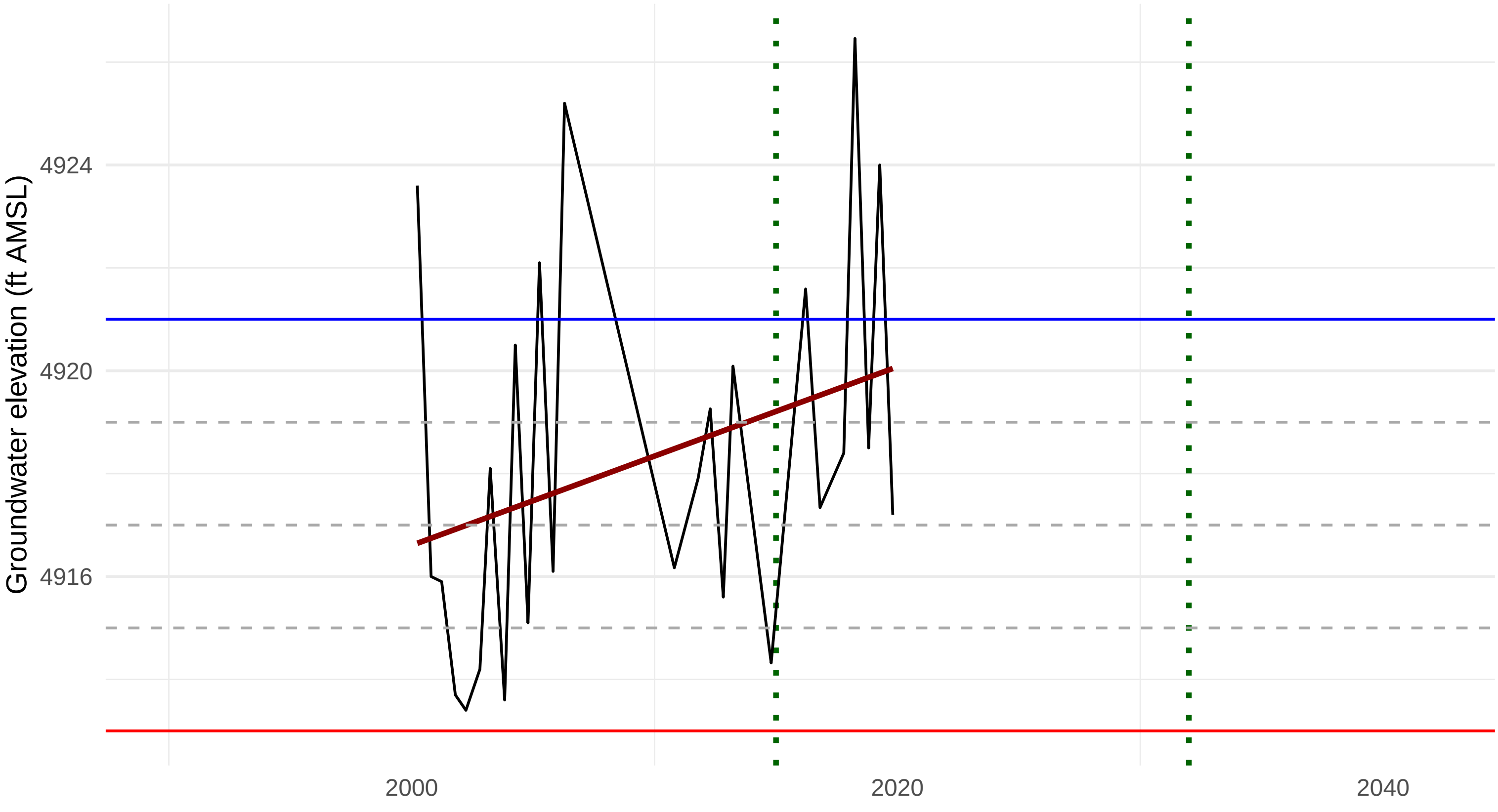
RMP 300: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
5008
5004
5000
4996
2000
2020
2040



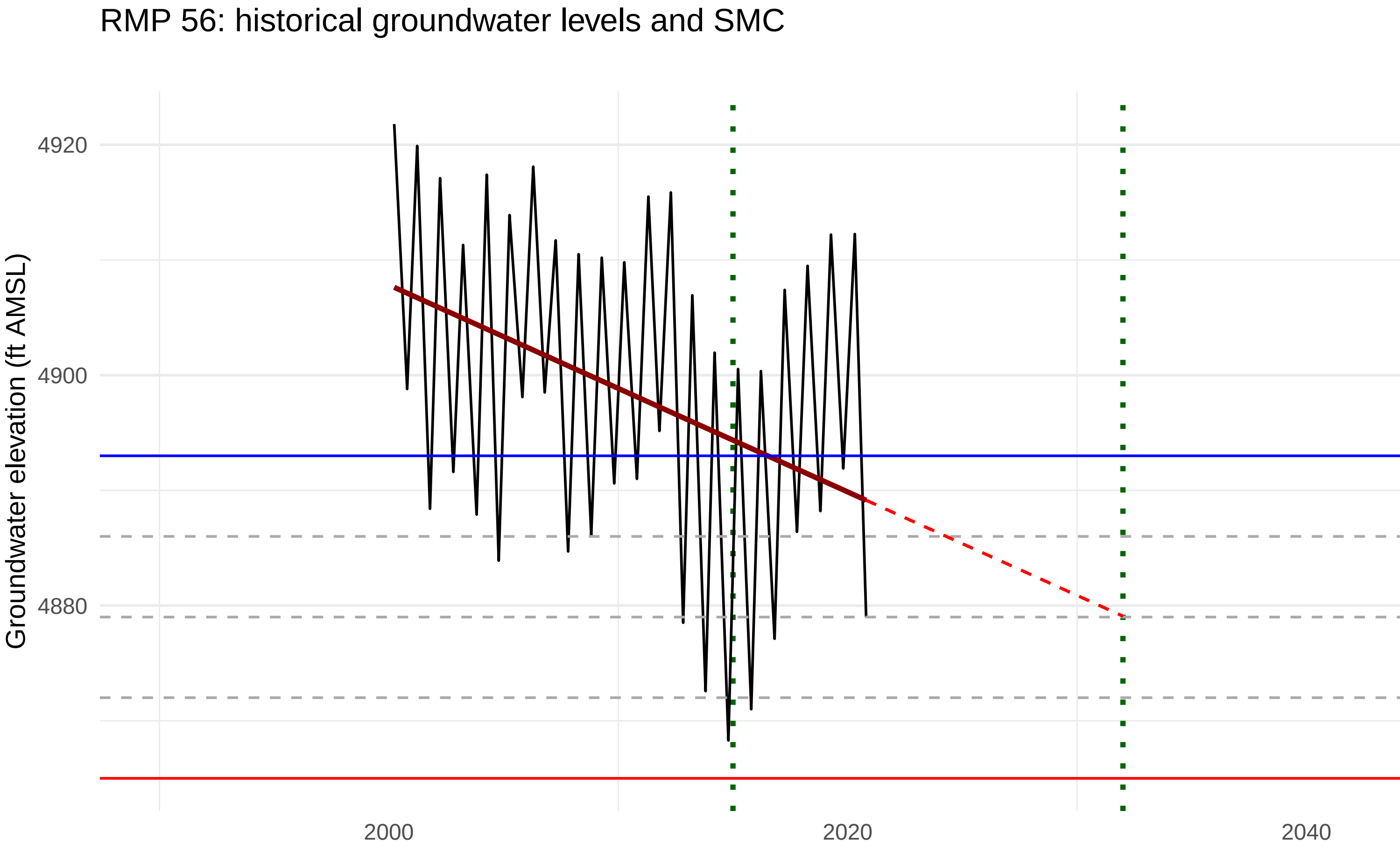
RMP 301: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4880
4870
4860
4850
4840
2000
2020
2040


RMP 302: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4880
4870
4860
4850
4840
2000
2020
2040

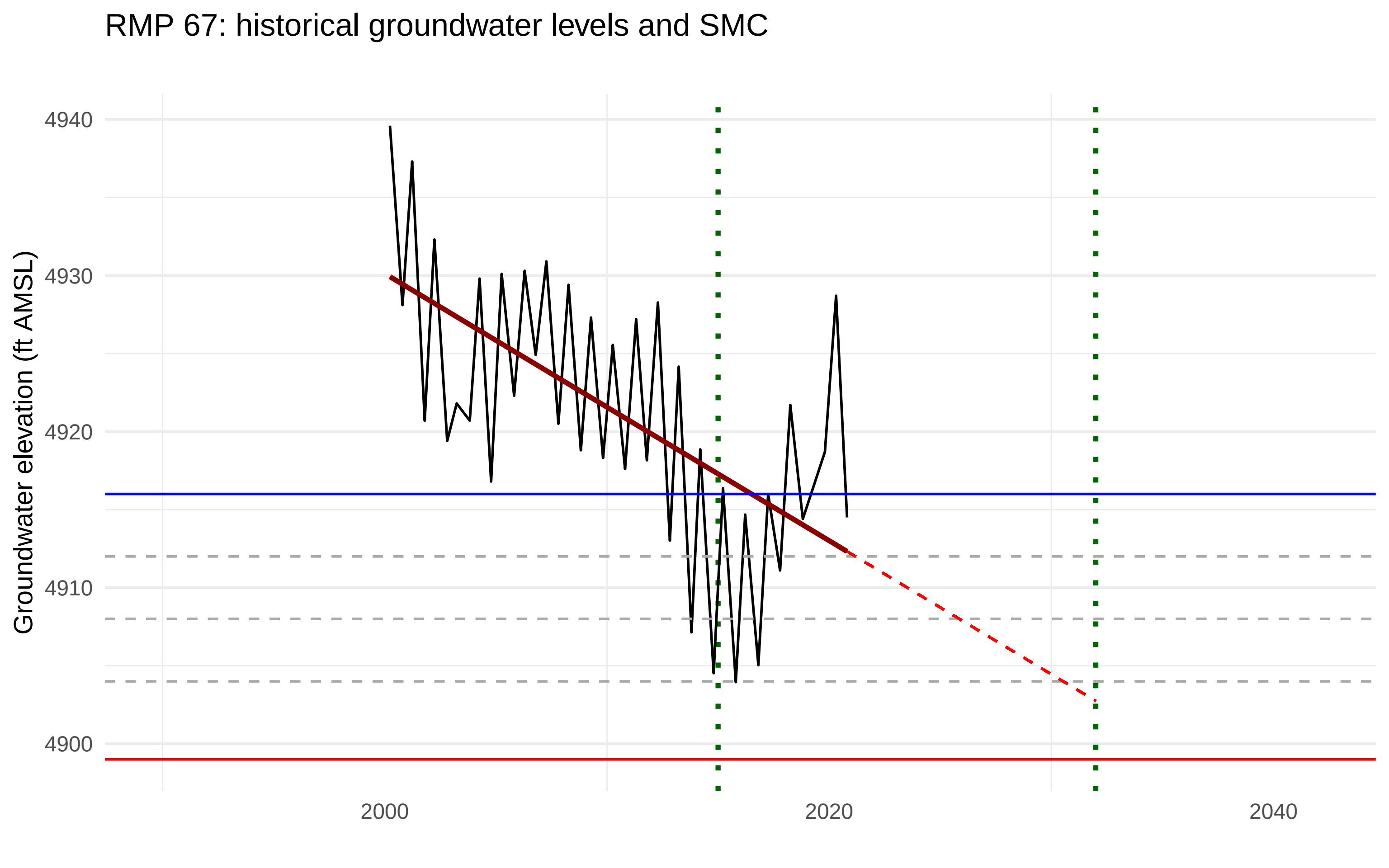
RMP 31: historical groundwater levels and SMC

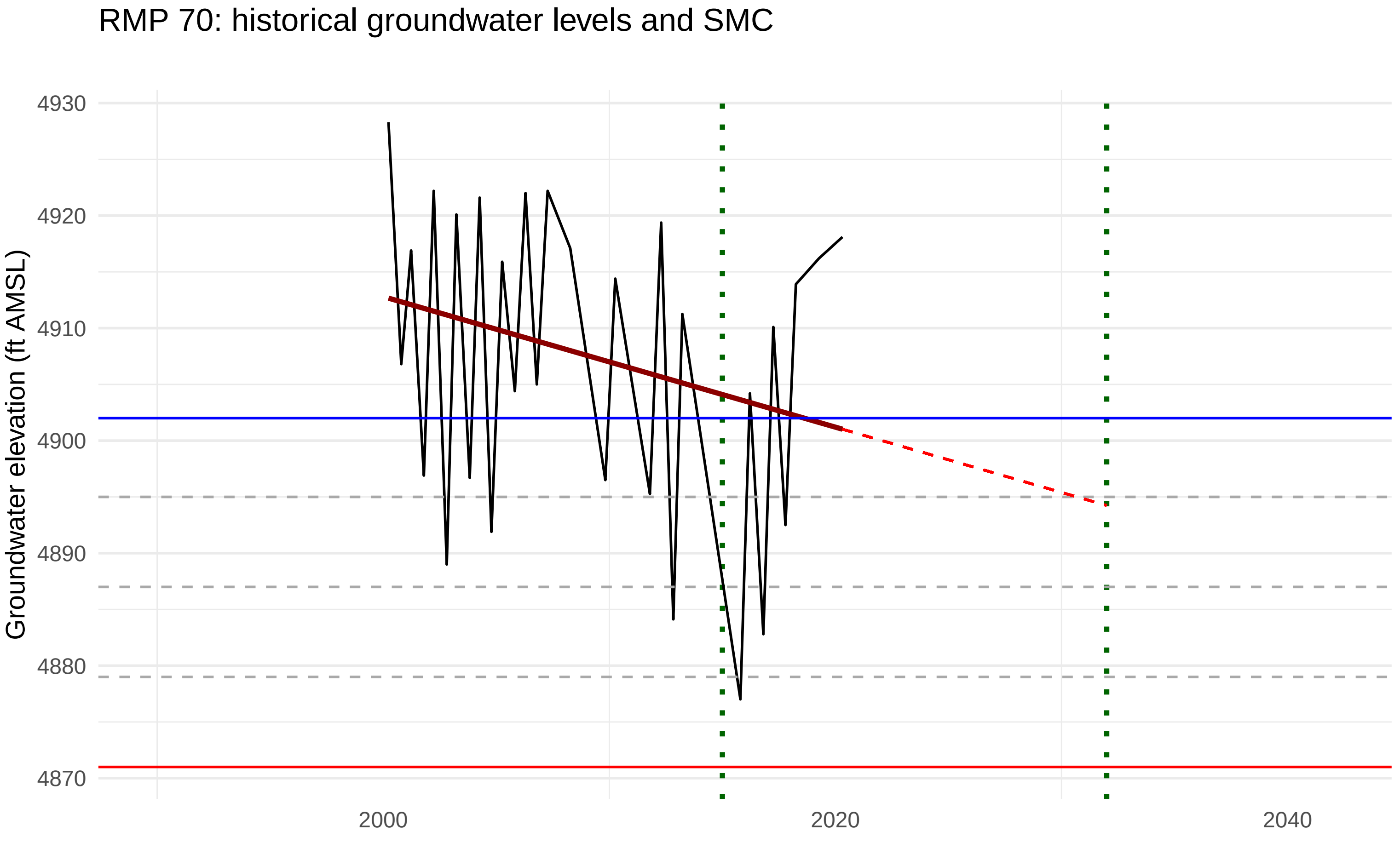


RMP 43: historical groundwater levels and SMC



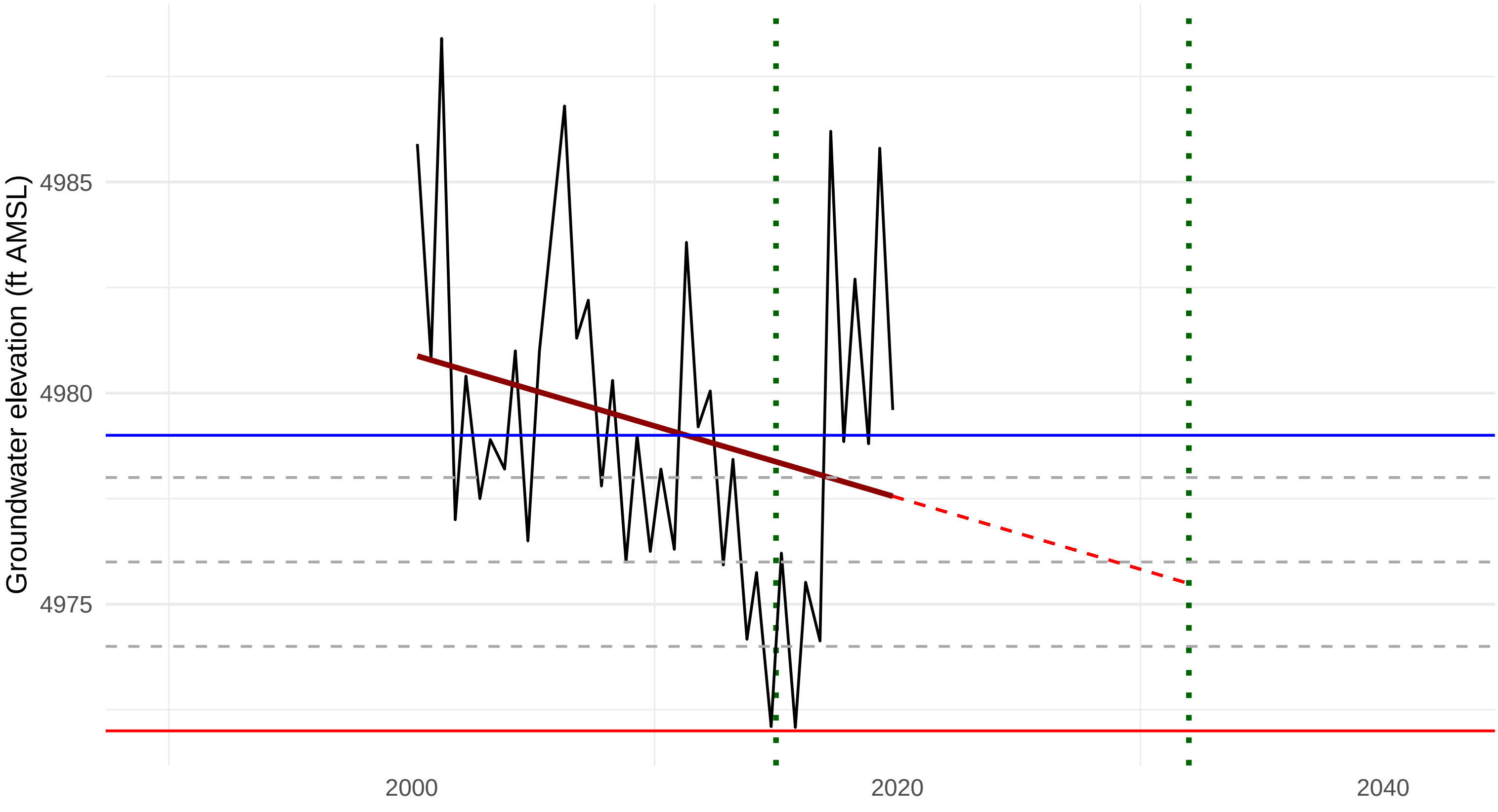
RMP 56: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4920
4900
4880
2000
2020
2040

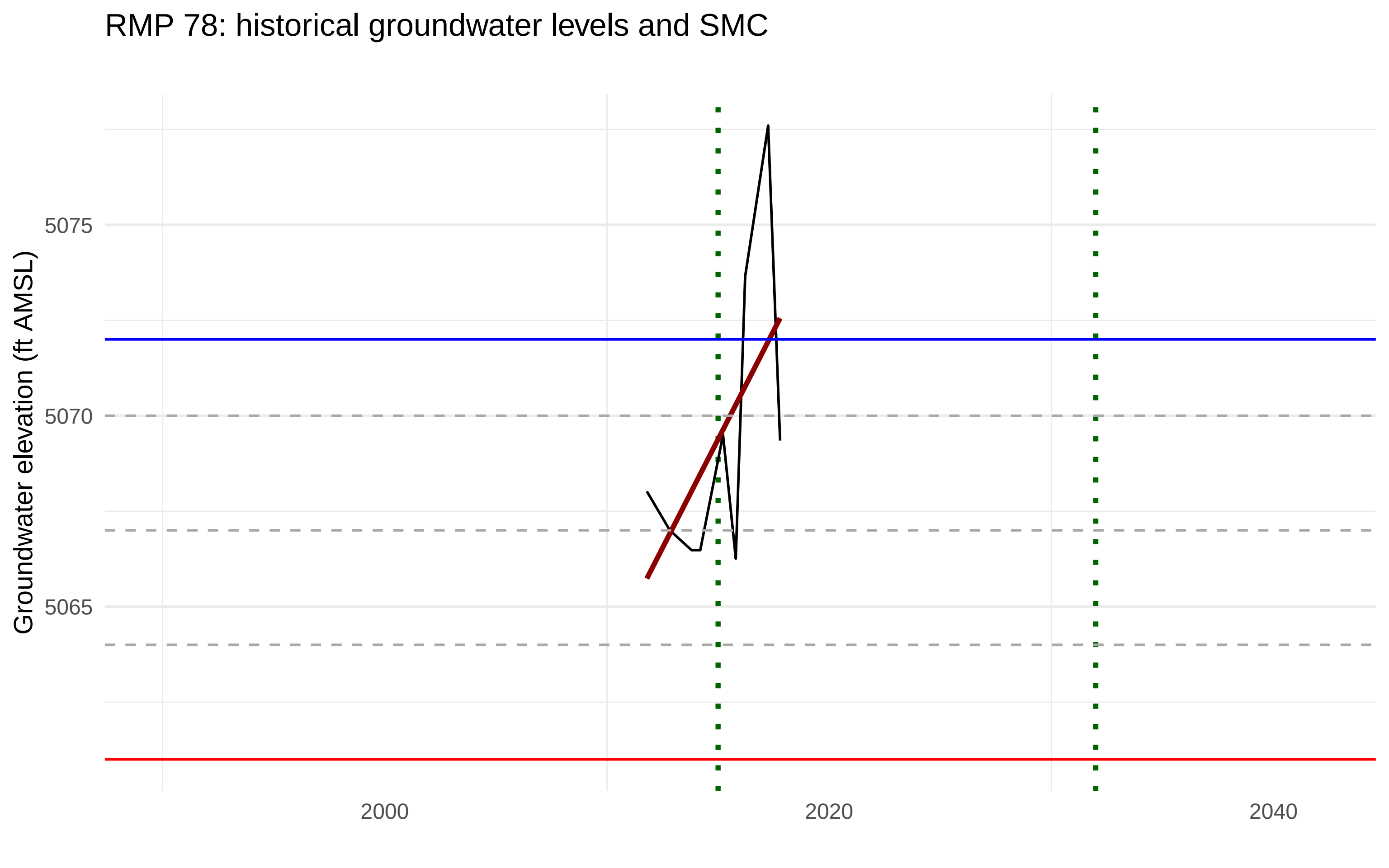

RMP 67: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4940
4930
4920
4910
4900
2000
2020
2040

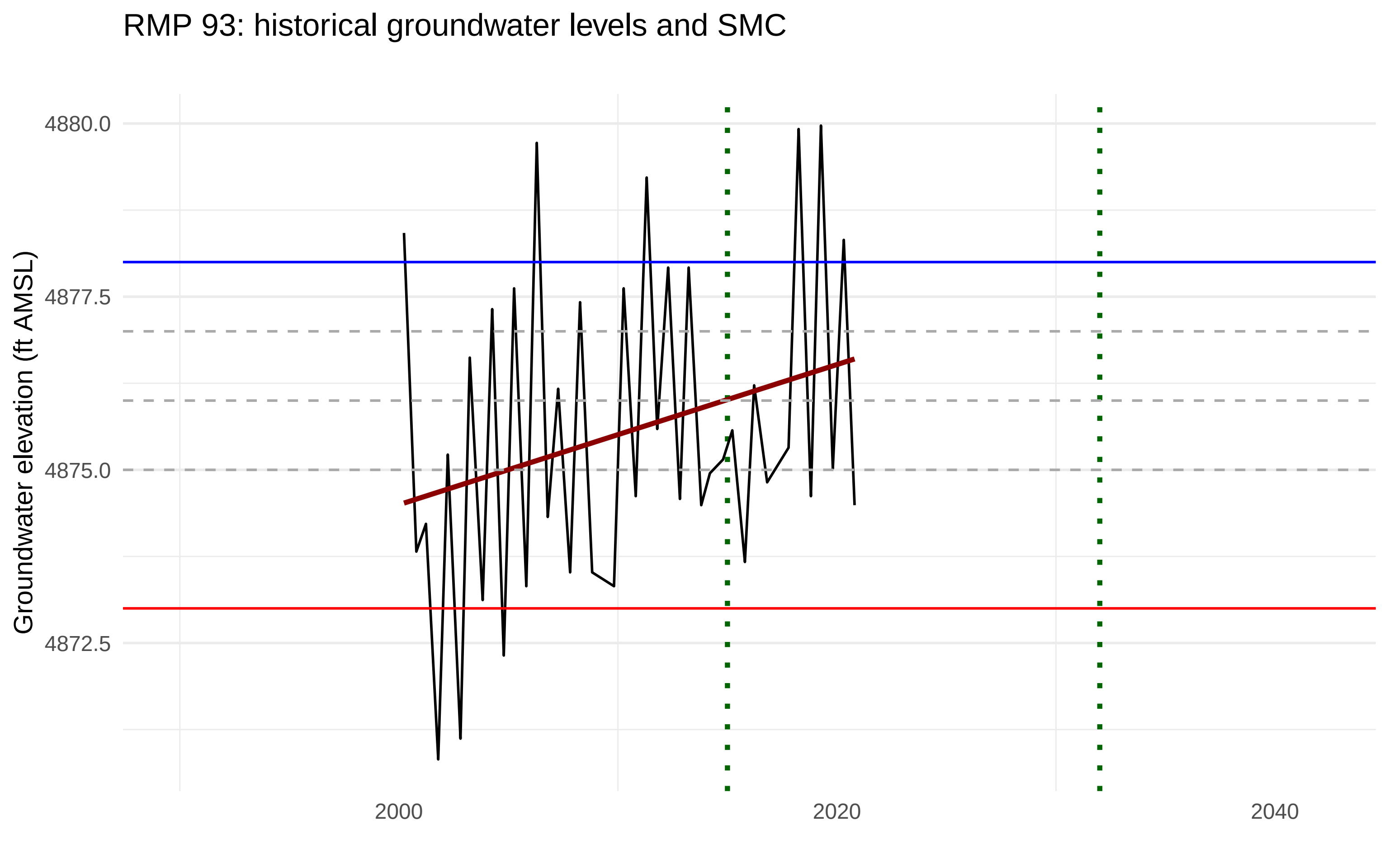


RMP 70: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4930
4920
4910
4900
4890
4880
4870
2000
2020
2040

RMP 73: historical groundwater levels and SMC

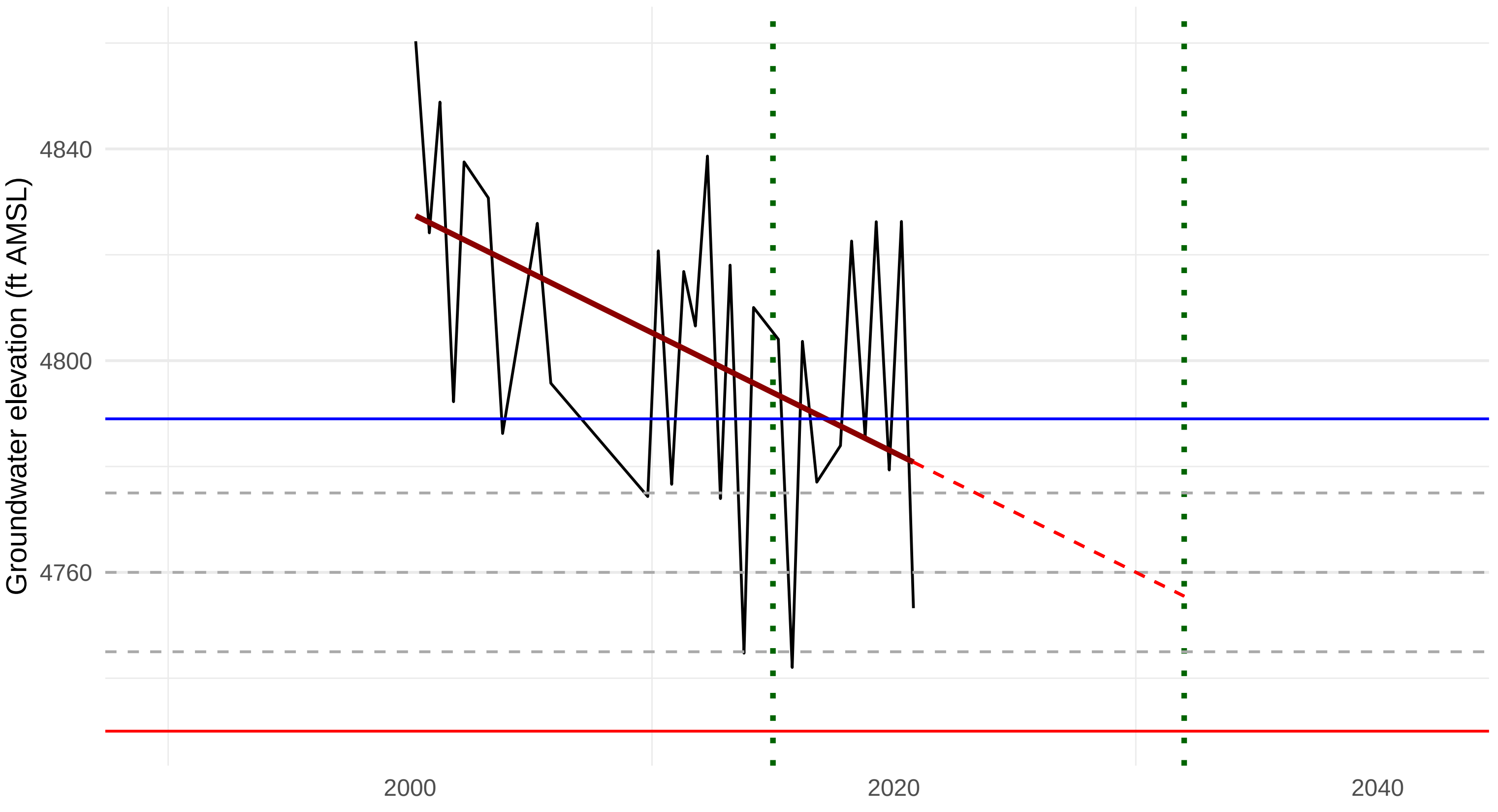



RMP 78: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
5075
5070
5065
2000
2020
2040



RMP 93: historical groundwater levels and SMC
Groundwater elevation (ft AMSL)
4880.0
4877.5
4875.0
4872.5
2000
2020
2040

RMP 94: historical groundwater levels and SMC



Appendix 3-3: GDE/NDVI Assessment

1 Sierra Valley Groundwater Dependent Ecosystems SMC Assessment

To assess whether Sustainable Management Criteria (SMC) are likely to impact groundwater dependent ecosystems (GDEs), we assessed the linkage between groundwater elevation and vegetation health and considered the species composition of GDEs near Representative Monitoring Points (RMPs). SMC may negatively affect GDEs if they lower groundwater elevation below the rooting depth of GDE vegetation. At each RMP, we assessed changes in NDVI and groundwater depth through time and relationships between NDVI and groundwater depth. The results are presented in this appendix.

1.1 Methods

For each RMP with defined SMC, we compiled the areal extent and dominant vegetation community of mapped GDE polygons that fall within a 1-mile radius. GDE polygons that lie partially within this area are also included, and a single GDE polygon may be counted in analyses for multiple wells. We also tracked Normalized Difference Vegetation Index (NDVI) trends through time and the relationship between NDVI and groundwater depth at these wells, noting any changes that occurred at groundwater elevations near the MO or MT. NDVI, which estimates vegetation greenness, was generated from surface reflectance corrected multispectral Landsat imagery from July 1 to September 30 of each year, which represents the summer period when GDE species are most likely to use groundwater (Klausmeyer et al. 2019). Vegetation polygons with higher NDVI values indicate increased density of chlorophyll and photosynthetic capacity in the canopy, an indicator of vigorous, growing vegetation. NDVI is a commonly used proxy for vegetation health in analyses of temporal trends in health of groundwater-dependent vegetation and is essentially a measure of the greenness of remotely sensed images (Rouse et al. 1974 and Jiang et al. 2006 as cited in Klausmeyer et al. 2019).

This analysis was conducted for the 30 RMP where any GDEs occur within a one-mile radius, including four shallow wells (total completion depth < 100 ft). Changes to the areal extent of dominant vegetation communities through time would require repeated mapping efforts, which are not available. In addition, the available vegetation maps lack species information so we were therefore unable to assess potential effects of MTs and MOs using rooting depth. Instead, we relied on linkages between summer NDVI values and summer groundwater depth.

The depth to groundwater was the water depth measured closest in time to August 1 (the median summer NDVI date). Only measurements within 13 weeks of August 1 were used. Linear regression was used to test whether NDVI changed in response to changes in groundwater elevation (or depth). Where the regression was statistically significant (p-value<0.05), it was assumed that changes to water depth were at least partially responsible for changes in NDVI. Changes to NDVI are not solely dependent on groundwater levels and could also result from more abundant surface water, higher soil moisture content, and other climatic factors (e.g., summer rainfall or temperatures).

1.2 Results

Table Appendix 3-3-1 and Figure Appendix 3-3-1 to Appendix 3-3-30 show the results of this analysis for each RMP well where GDEs occur within a 1-mile radius. The first panel of each figure shows time series of NDVI and groundwater elevation. The second panel shows summer NDVI versus depth to groundwater, where available within 13 weeks of August 1.

13 of the RMPs with GDEs within a 1-mile radius have a statistically significant (p-value < 0.05) relationship between summer NDVI and groundwater elevation. Based on historical NDVI and groundwater levels, MOs and MTs were adjusted to conservatively limit impacts at RMP IDs 93, 209, 291, and 300.

Table Appendix 3-3-1: Summary statistics for RMPs and linear regression.

RMP ID	Site Code	Screened Interval (ft BGS)	Total Completion Depth (ft BGS)	MO (ft AMSL)	MT (ft AMSL)	GDE Area Within One Mile (Acres)	Number of Groundwater Elevation Measurements	NDVI vs. Depth to Groundwater Linear Regression p-Value
12	395808N1203851W001	Unknown	40	5,029	5,009	215	35	0.09
31	396391N1203667W001	Unknown	60	4,921	4,913	178	29	0.003
56	396814N1202407W001	35 – 325	360	4,893	4,865	36	30	0.02
67	396934N1202234W001	Unknown	200	4,916	4,899	45	31	0.327
70	396864N1202299W001	161 – 245	400	4,902	4,871	54	23	0.204
78	396599N1202229W001	Unknown	400	5,072	5,061	64	6	0.103
93	397667N1203238W001	Unknown	943	4,878	4,873	840	36	0.028
130	397081N1202449W001	150 – 420	426	4,873	4,840	46	30	0.149
131	397927N1201294W001	Unknown	130	5,052	5,038	104	32	0.005
132	397945N1201920W001	Unknown	251	4,908	4,891	270	30	0.247
136	397831N1202245W001	589 – 816	820	4,801	4,746	<1	35	0.247
148	397372N1202128W001	70 - 190	205	4,934	4,929	64	31	0.618
161	398020N1203815W001	Unknown	18	4,872	4,864	537	28	0.008
176	398094N1202932W001	Unknown	137	4,872	4,863	<1	31	0.378
185	398107N1201653W001	Unknown	300	4,958	4,955	179	35	0
187	398165N1201934W001	Unknown	257	4,921	4,905	275	30	0.895
190	398098N1202211W001	477 – 180	820	4,812	4,760	1	31	0.263
194	398059N1201862W001	230 – 290	297	4,921	4,904	311	28	0.771
206	398024N1201371W001	Unknown	230	5,002	4,987	118	33	0.012
209	397951N1201418W001	Unknown	50	5,003	4,994	159	35	0
289	395951N1203910W003	420 – 450	675	4,954	4,950	399	19	0.115
291	395951N1203910W001	85 – 100	675	4,946	4,943	399	19	0.042

RMP ID	Site Code	Screened Interval (ft BGS)	Total Completion Depth (ft BGS)	MO (ft AMSL)	MT (ft AMSL)	GDE Area Within One Mile (Acres)	Number of Groundwater Elevation Measurements	NDVI vs. Depth to Groundwater Linear Regression p-Value
292	396444N1204137W003	340 – 455	440	4,912	4,892	543	13	0.313
294	396444N1204137W001	90 – 100	440	4,912	4,871	543	18	0.115
296	396722N1204095W002	530 – 550	720	4,883	4,875	97	19	0.004
297	396722N1204095W001	210 – 240	720	4,897	4,889	97	19	0.022
298	397956N1201417W001	290 – 320	360	5,007	4,998	159	17	0
300	397956N1201417W003	75 – 90	360	5,001	4,996	159	17	0.001
301	398170N1203478W001	310 – 340	490	4,856	4,836	50	17	0.529
302	398170N1203478W002	115 - 130	490	4,865	4,835	50	17	0.718

Figure Appendix 3-3-1. RMP 12

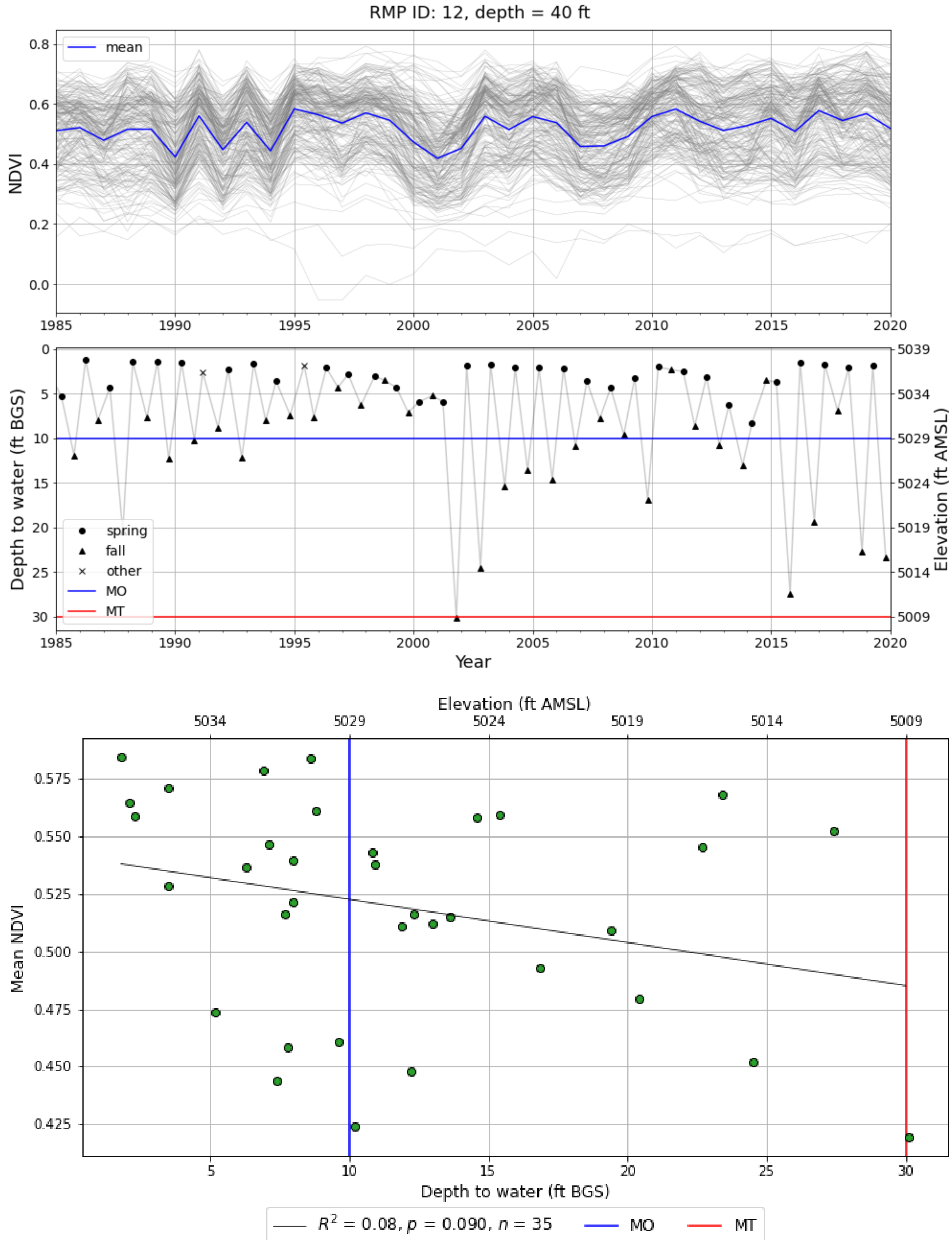


Figure Appendix 3-3-2. RMP 31

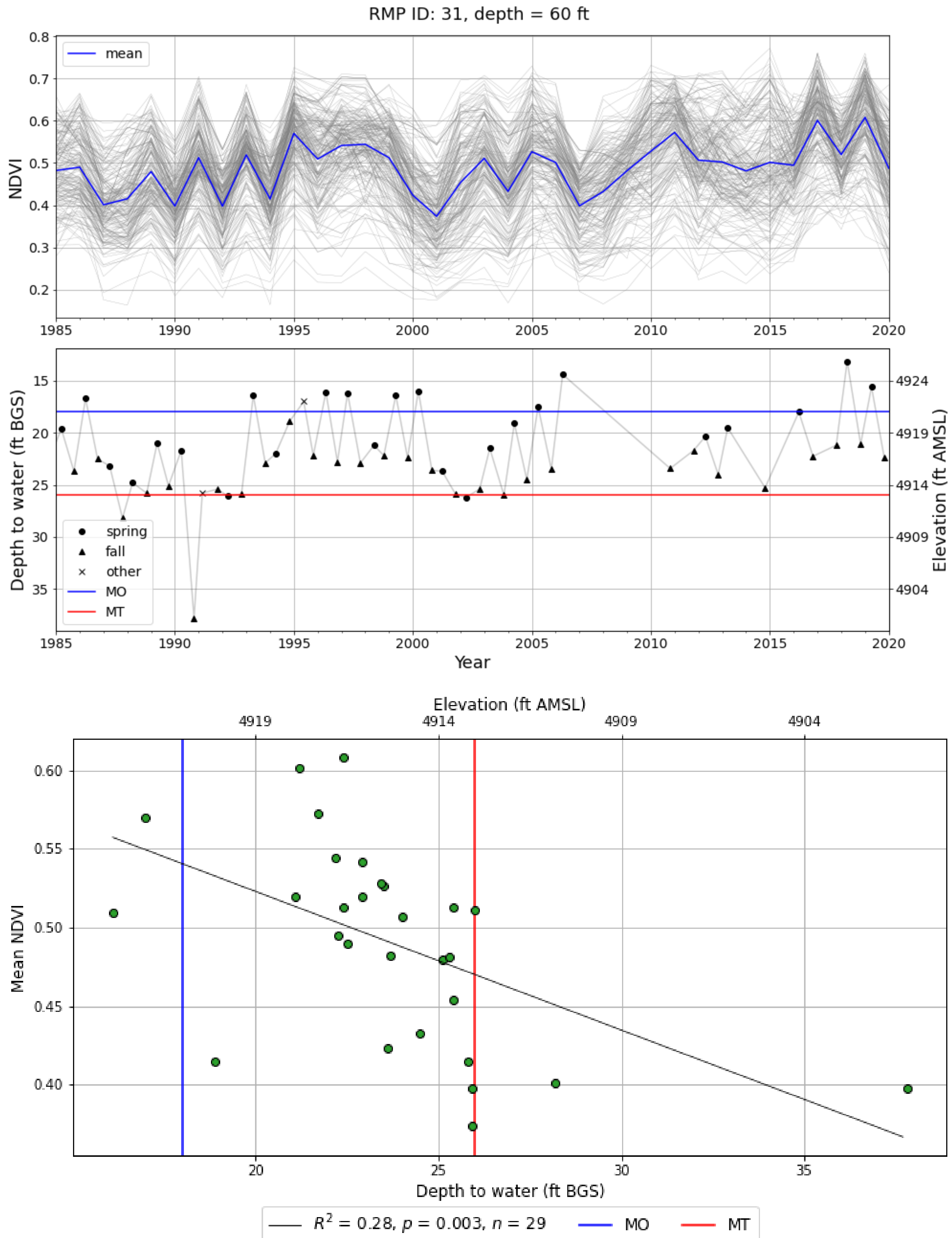
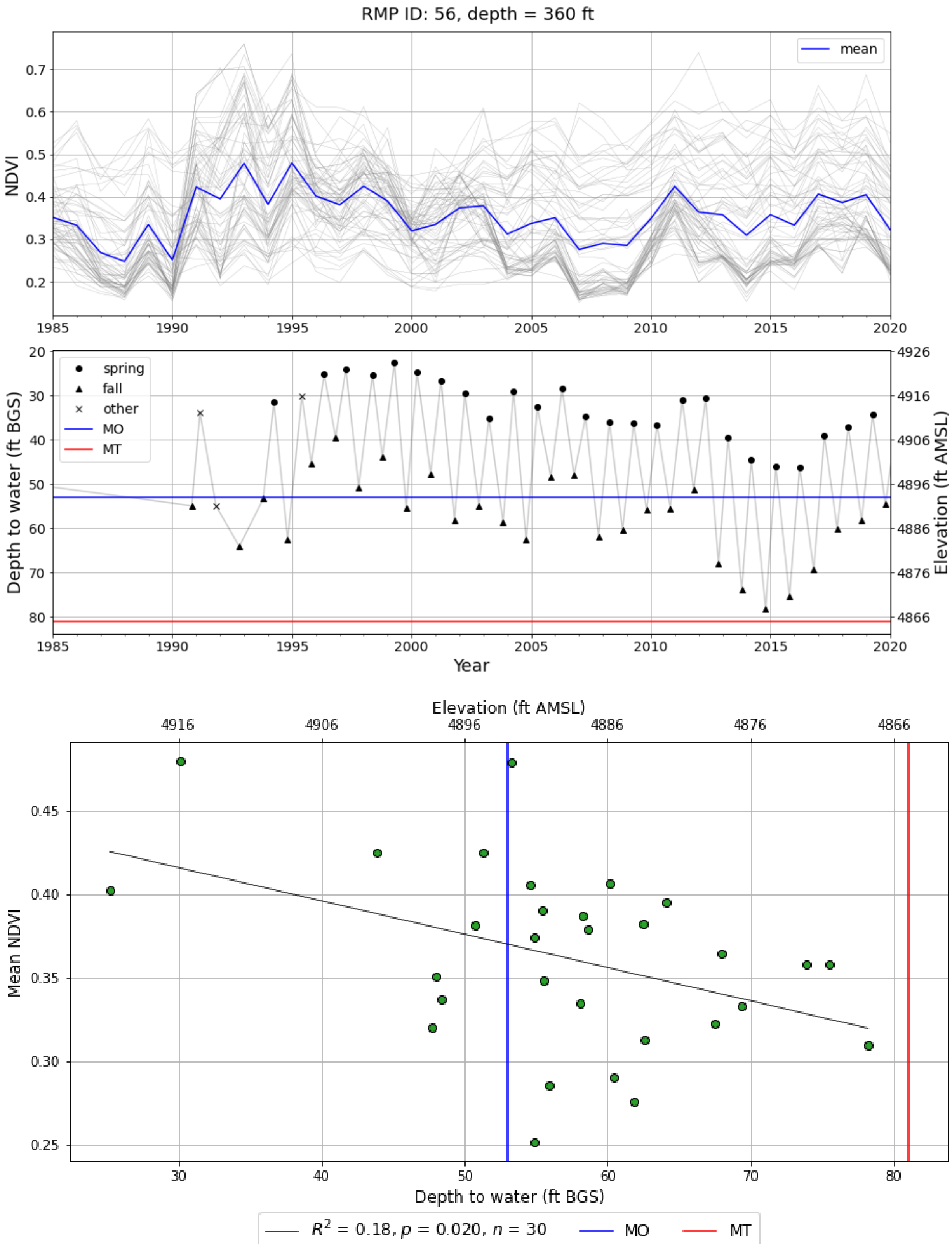


Figure Appendix 3-3-3. RMP 56



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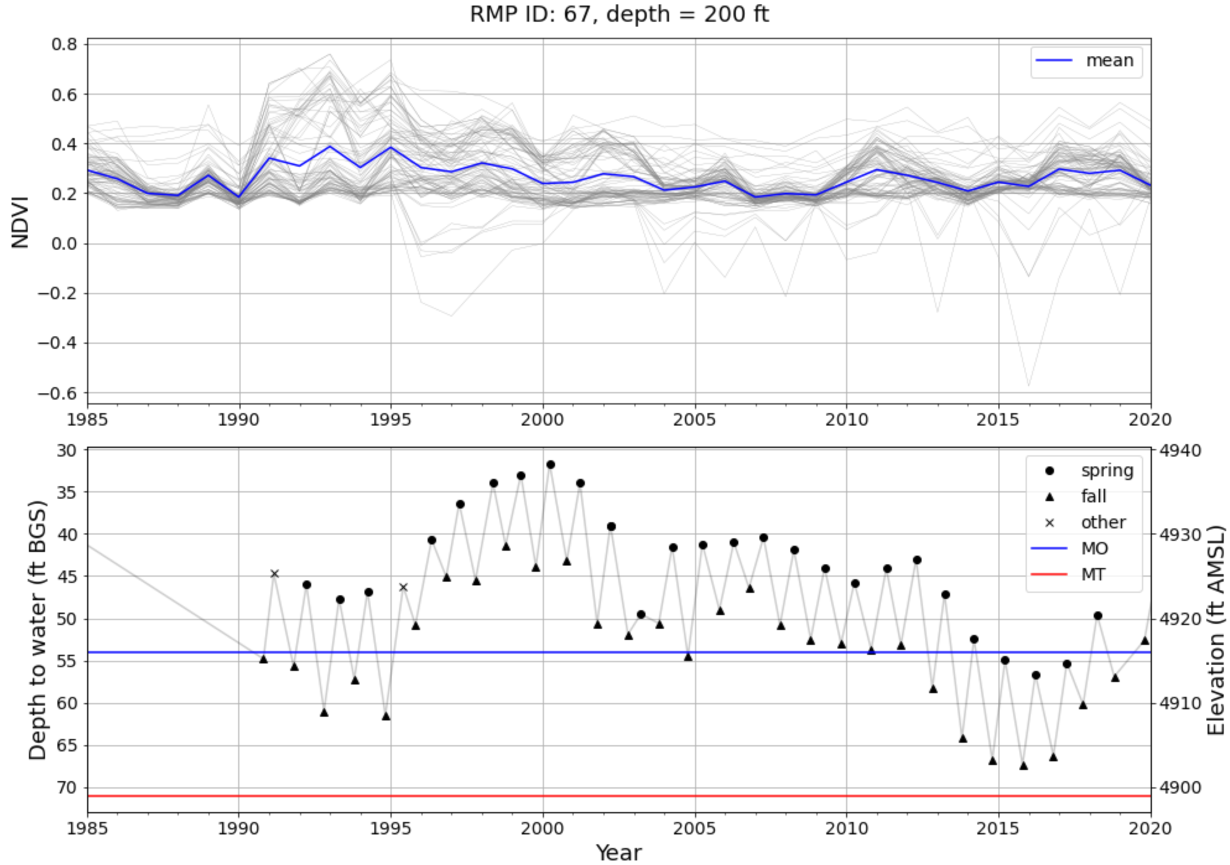


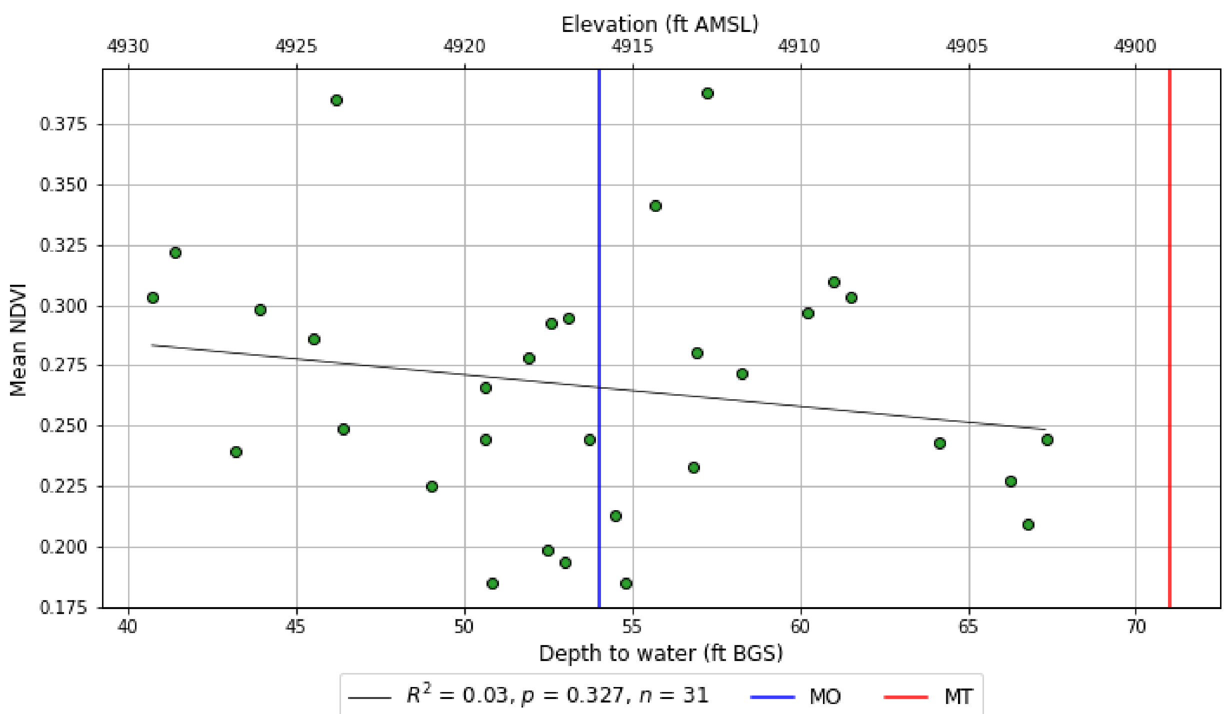
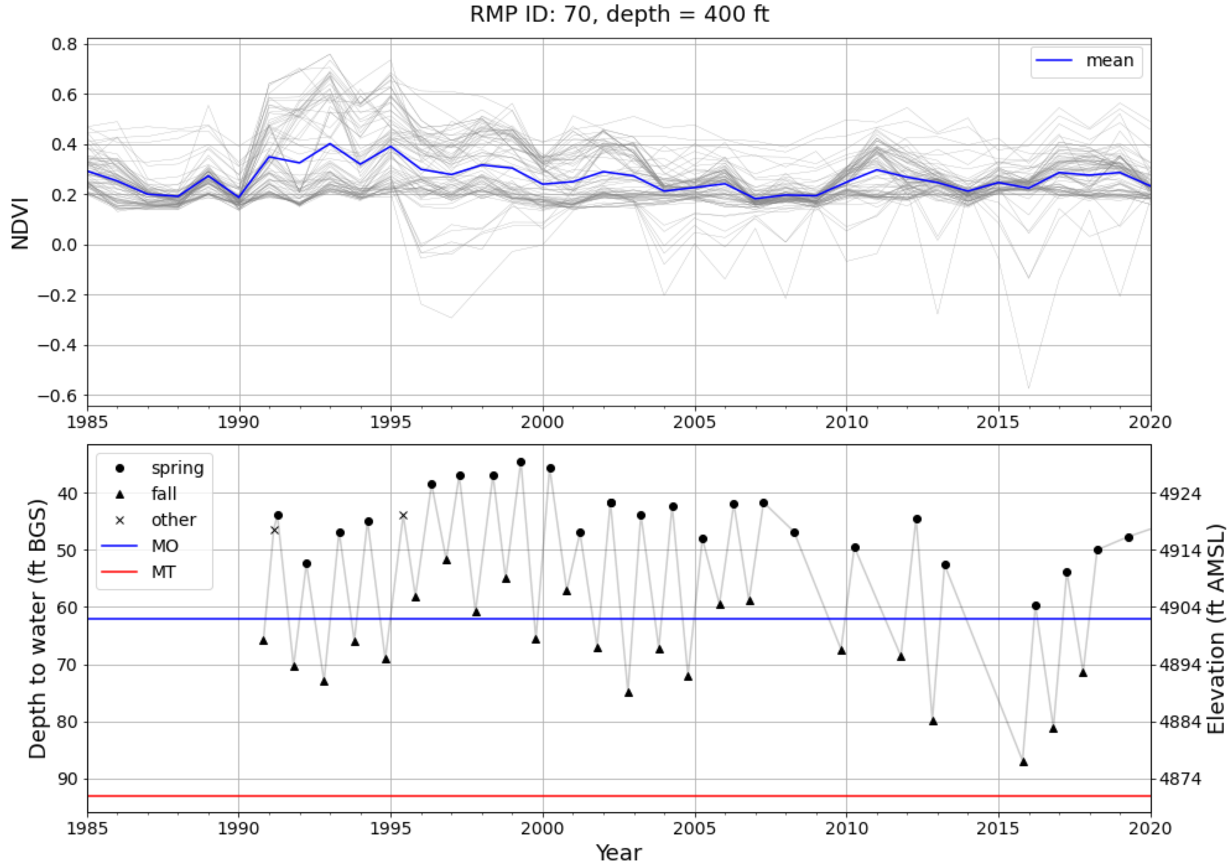
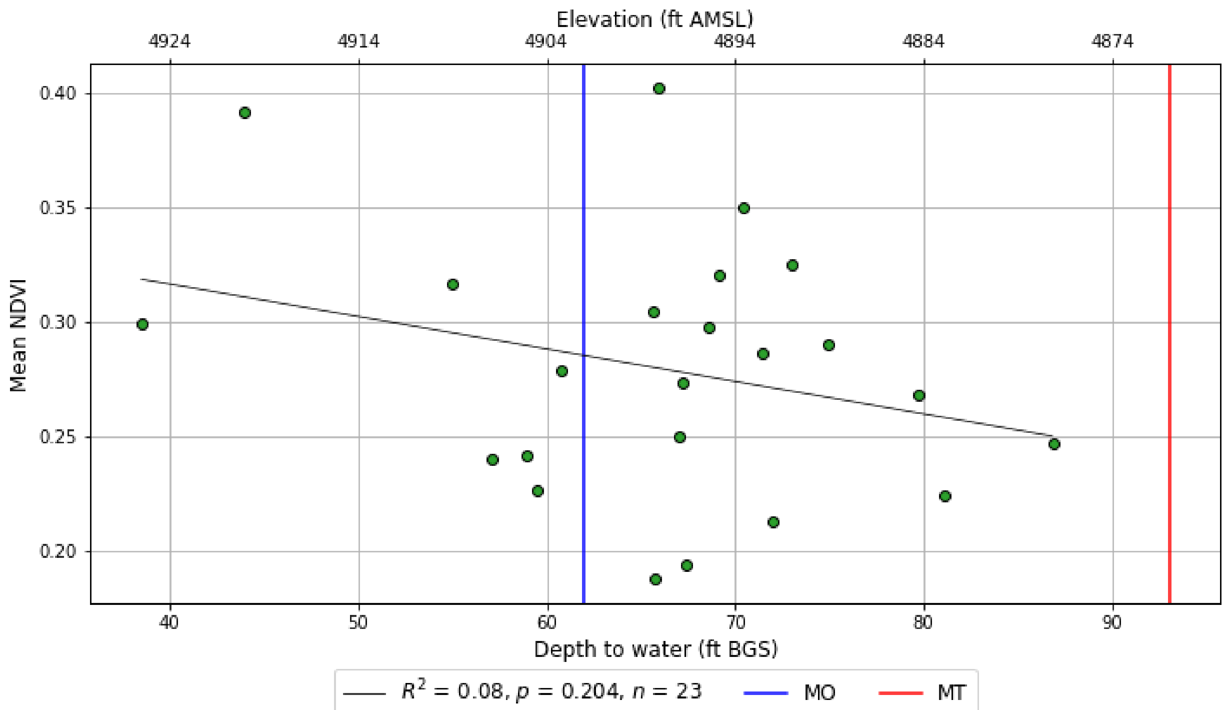


Figure Appendix 3-3--5. RMP 70





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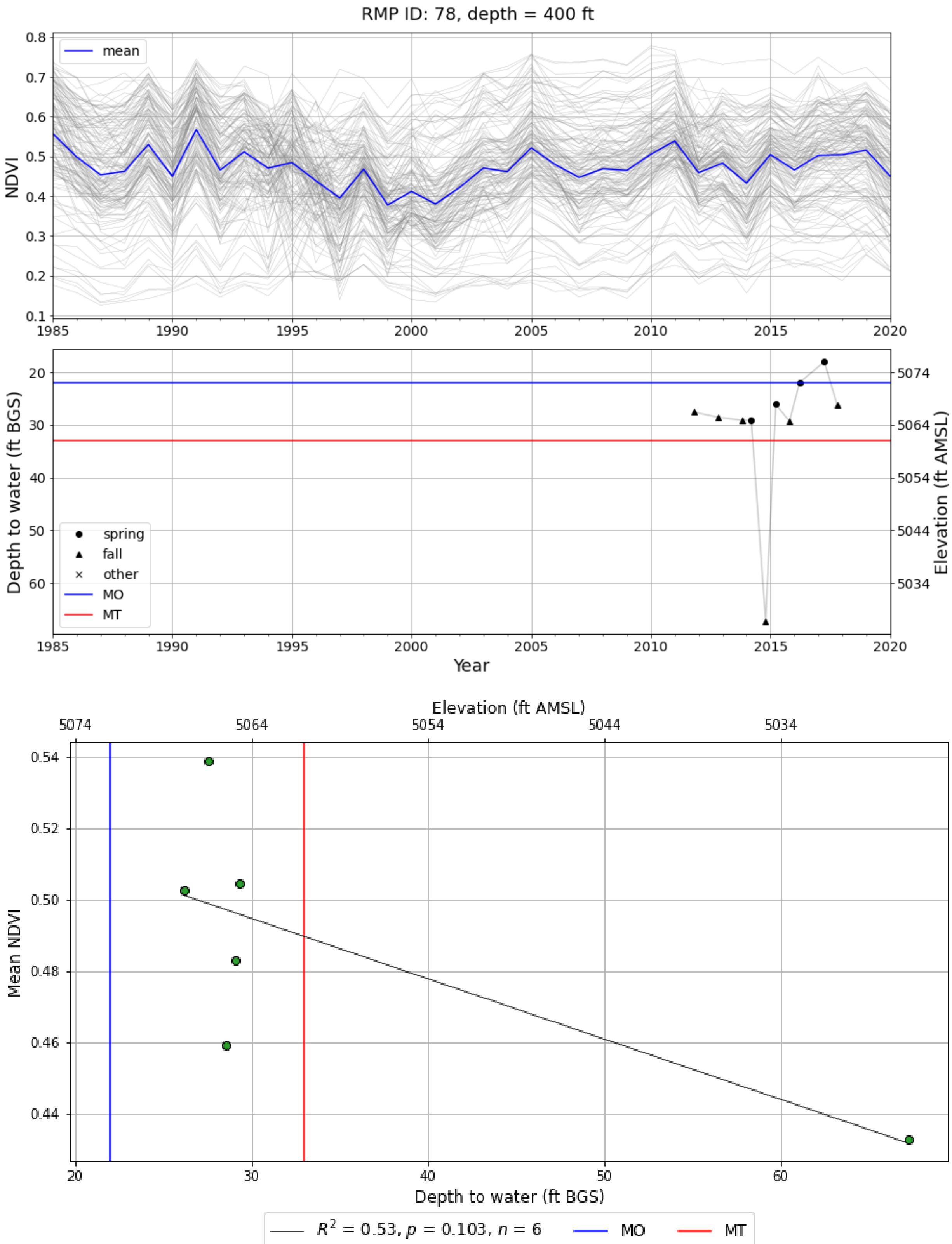

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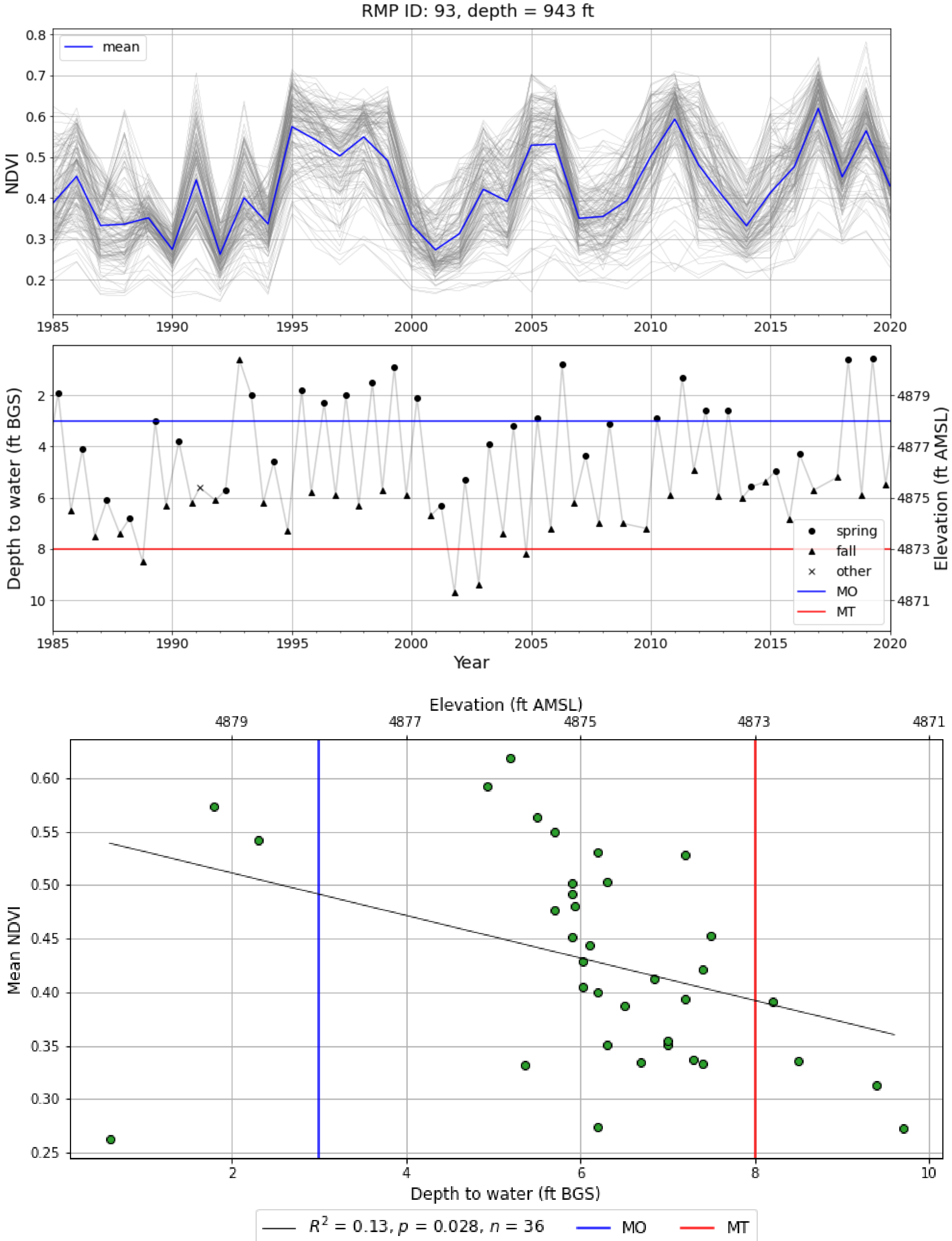

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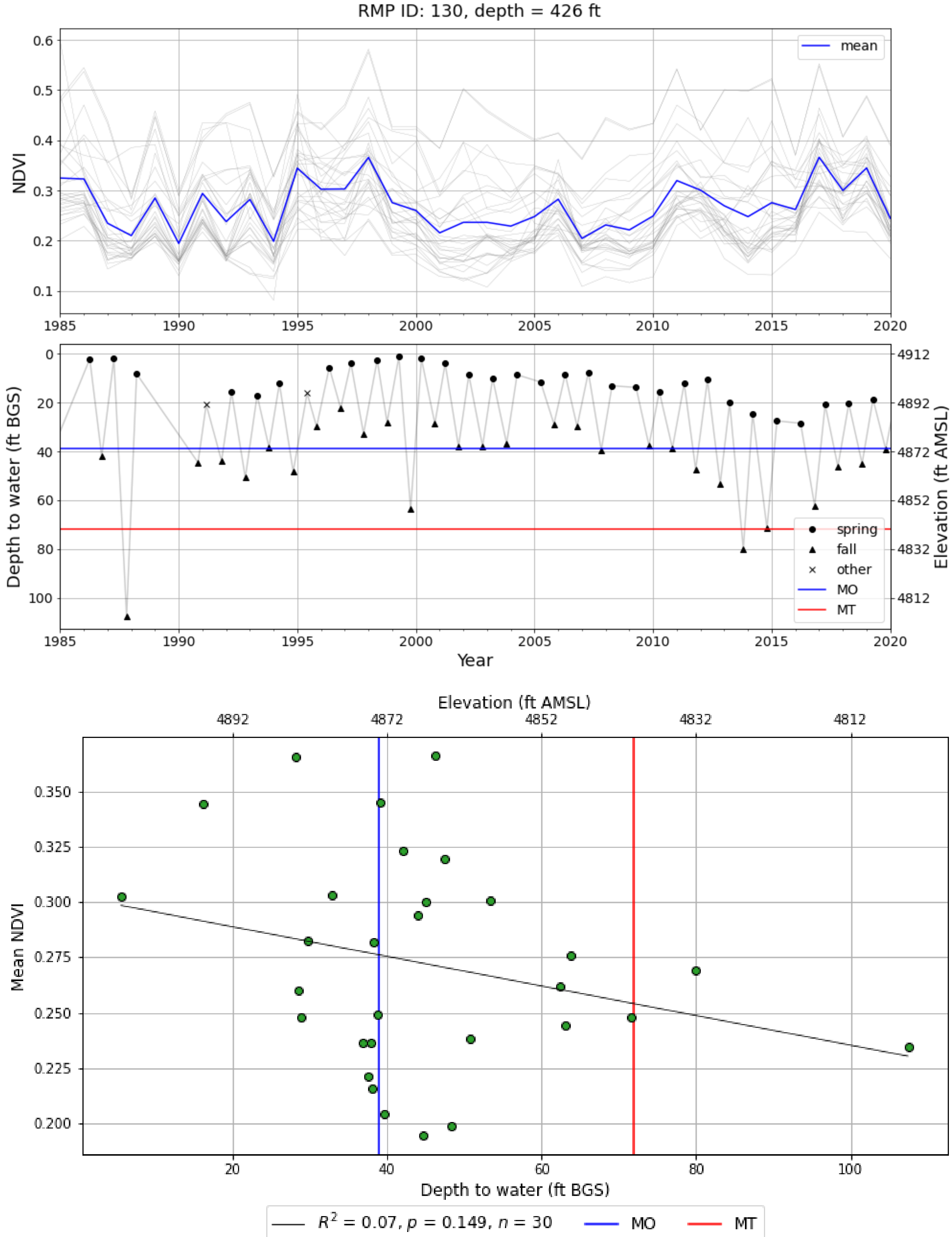

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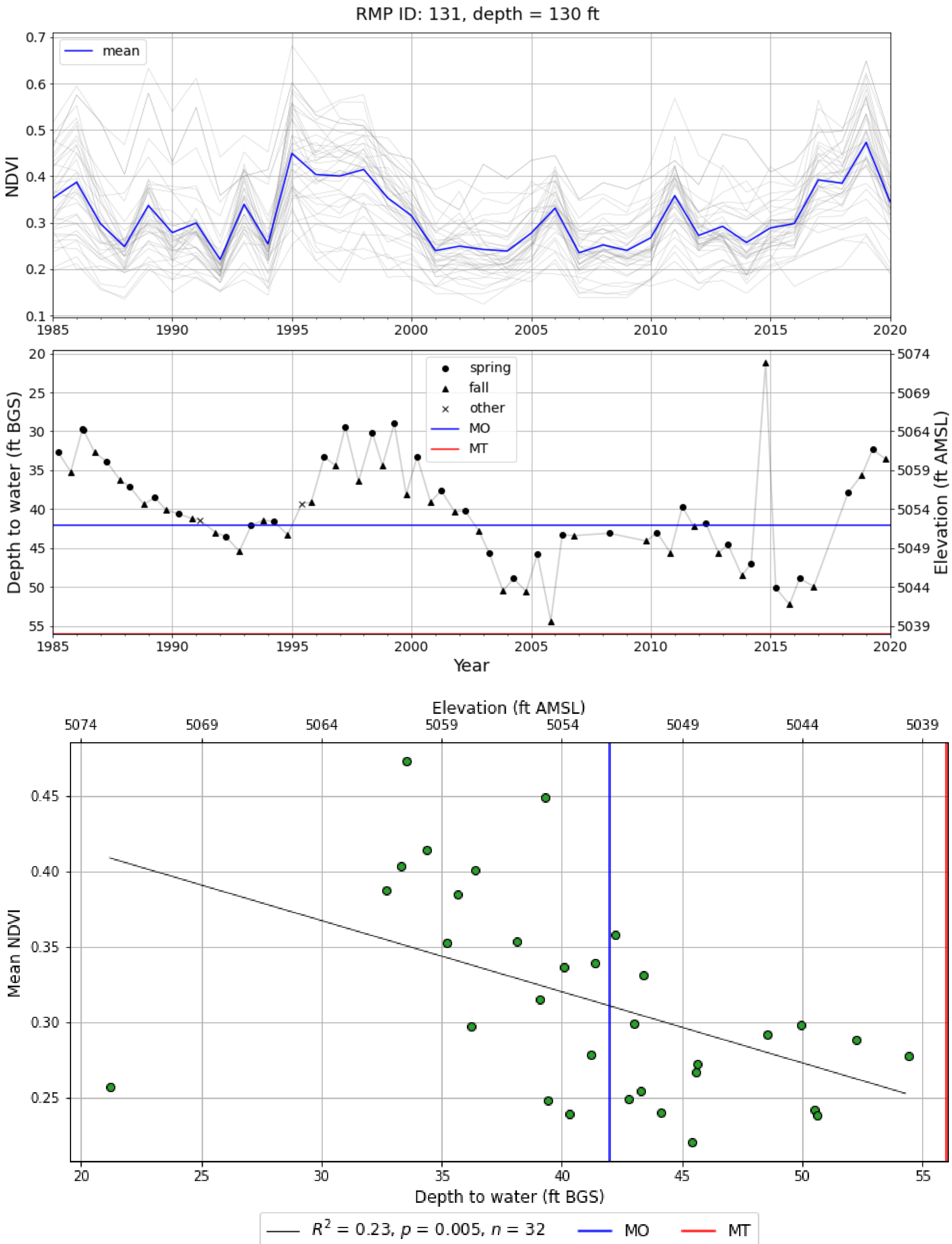

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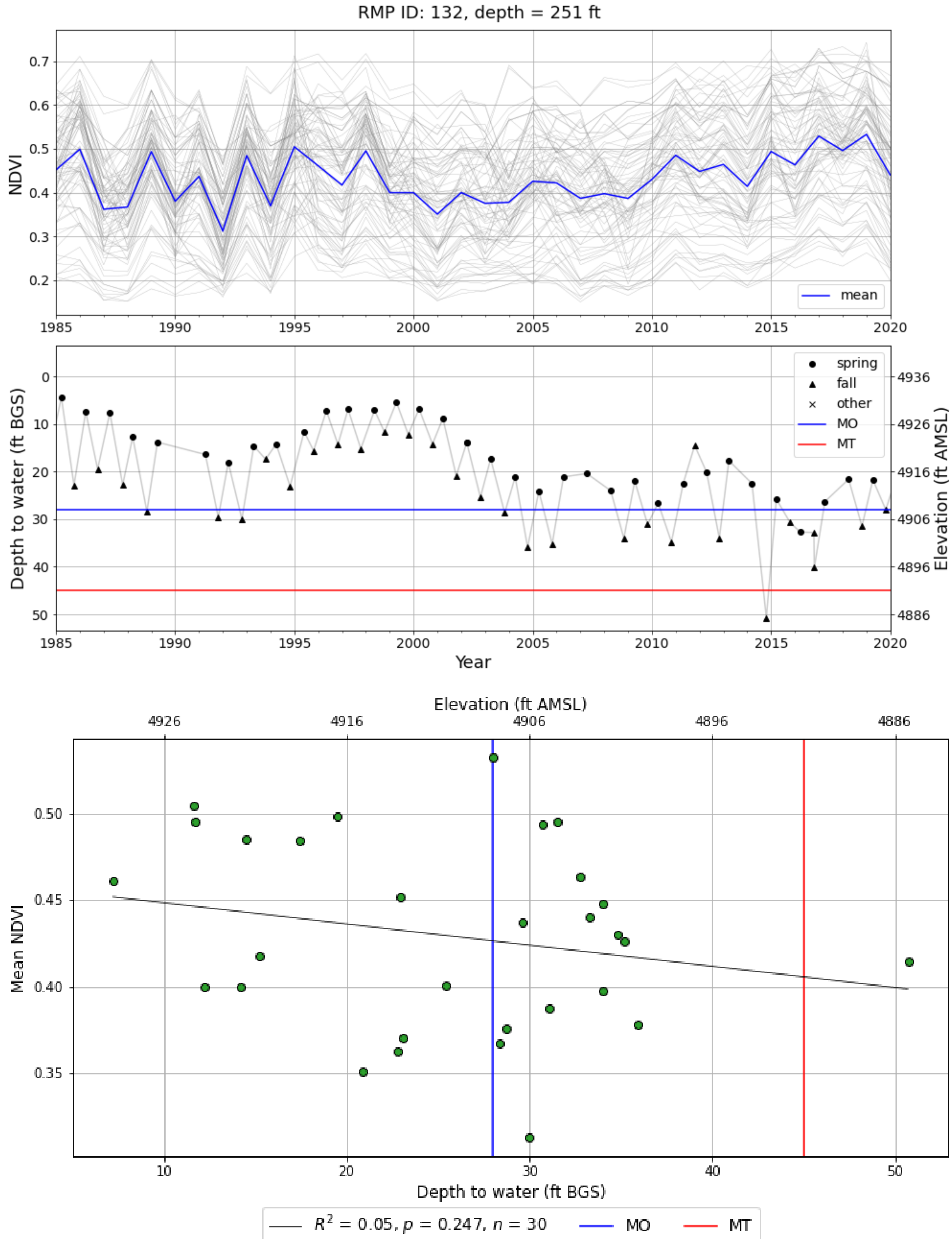

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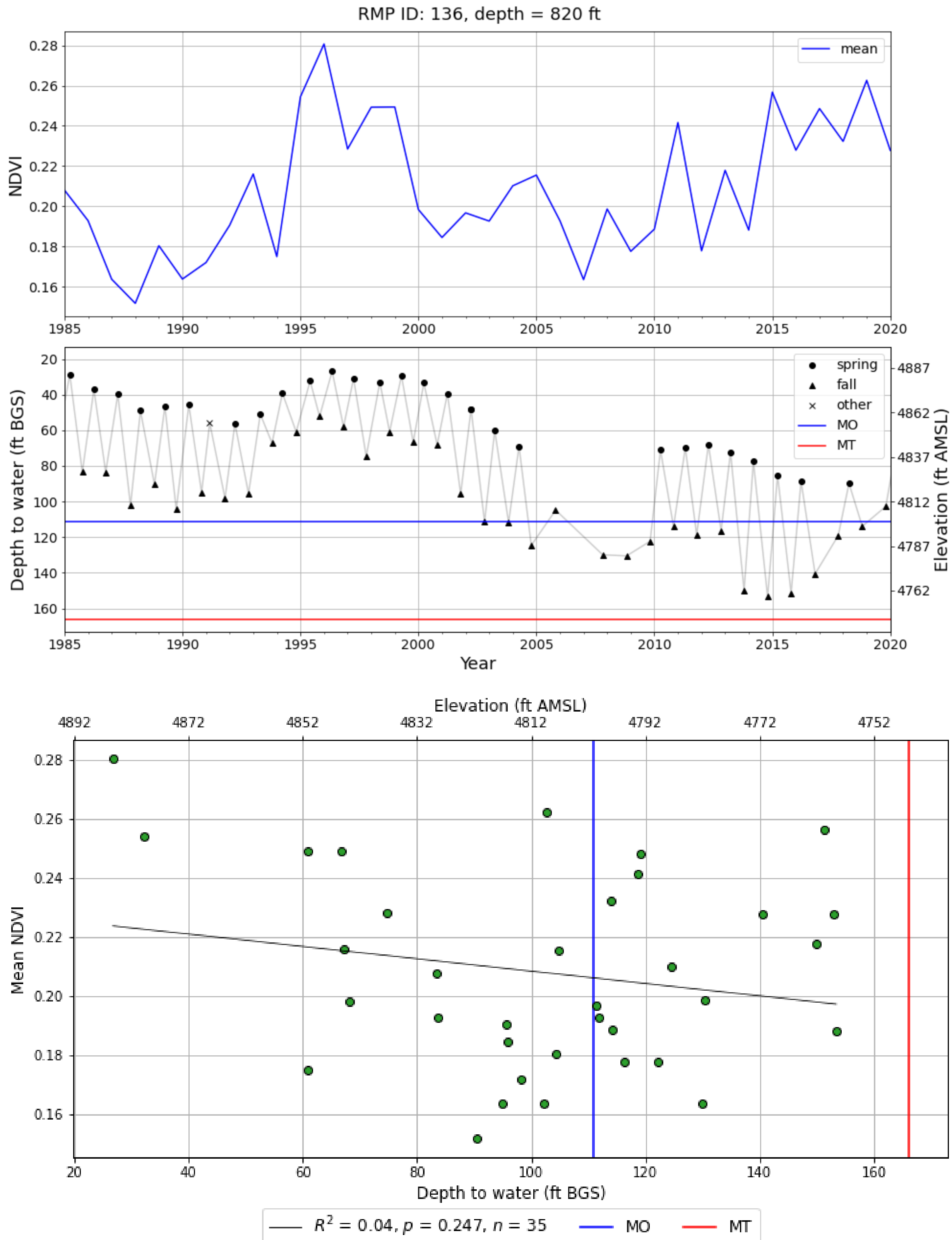

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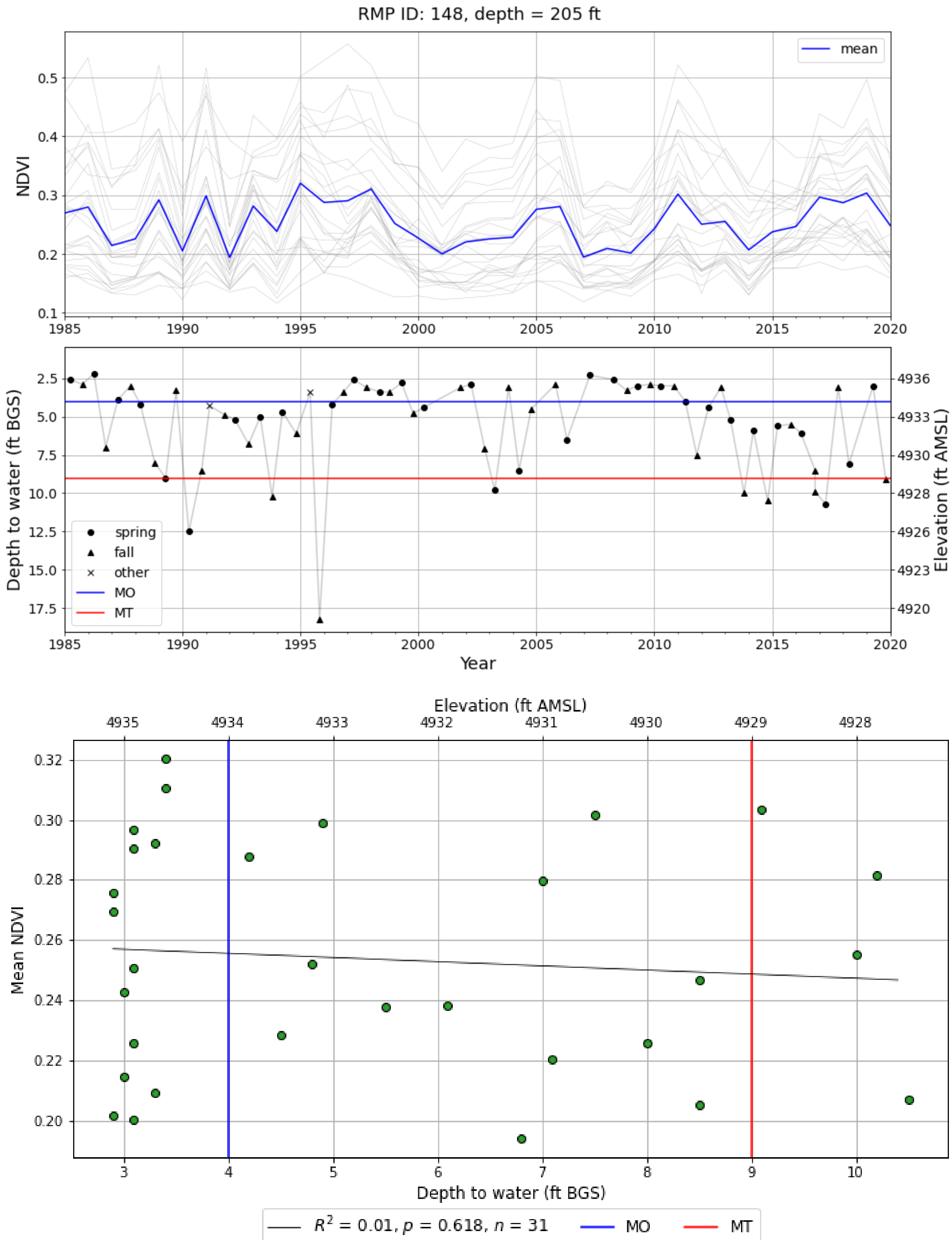

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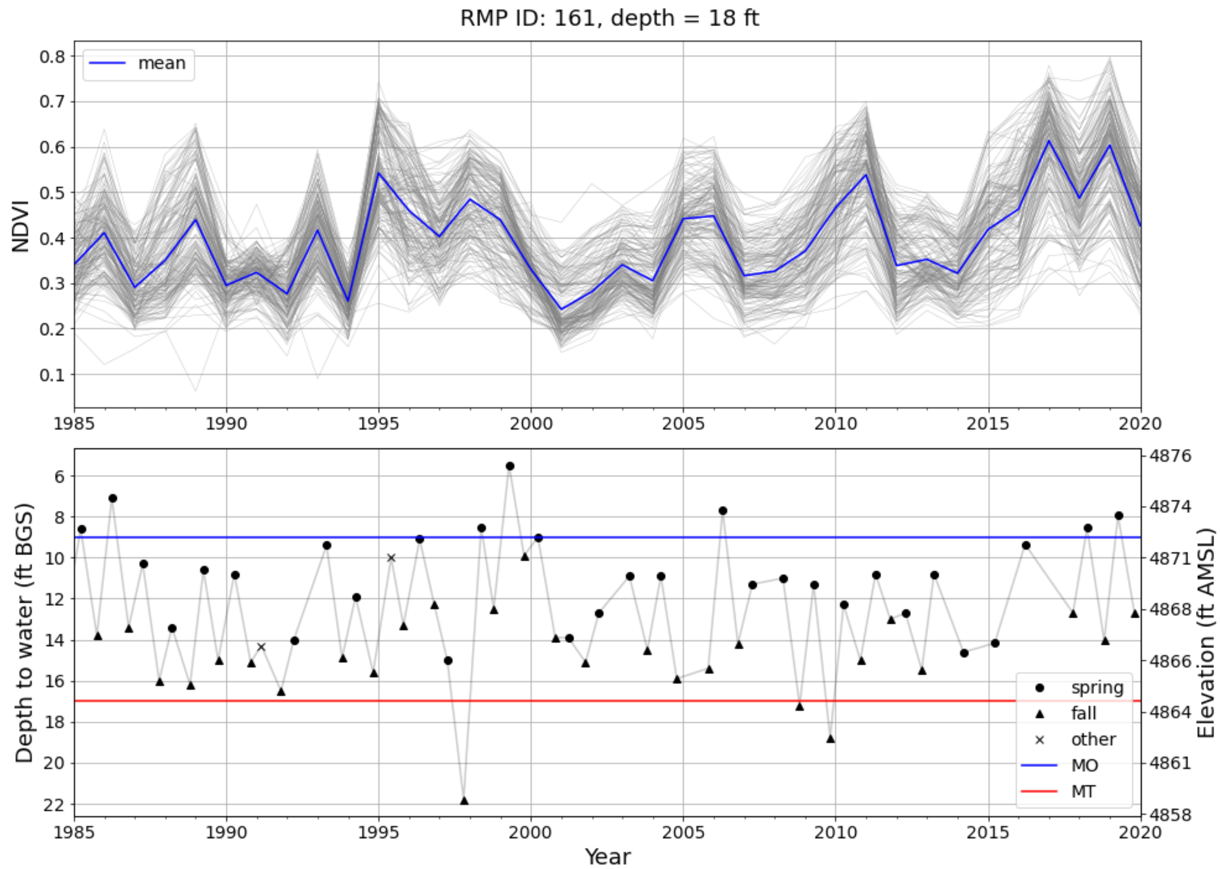

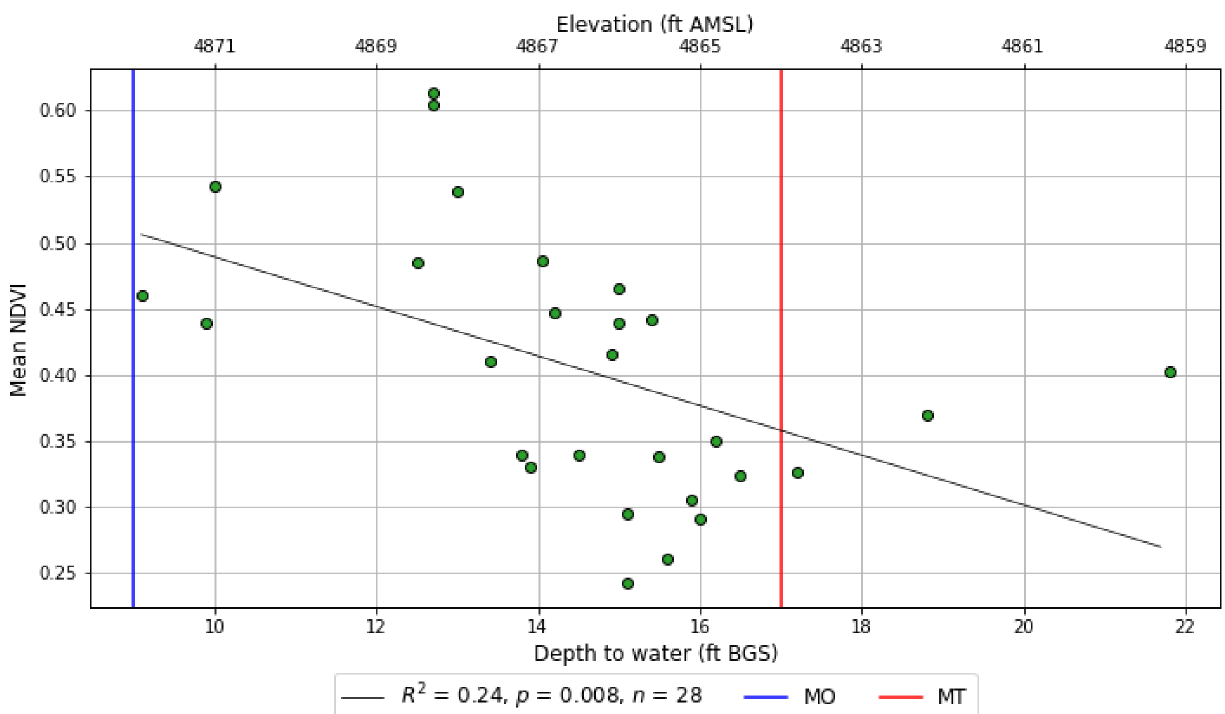

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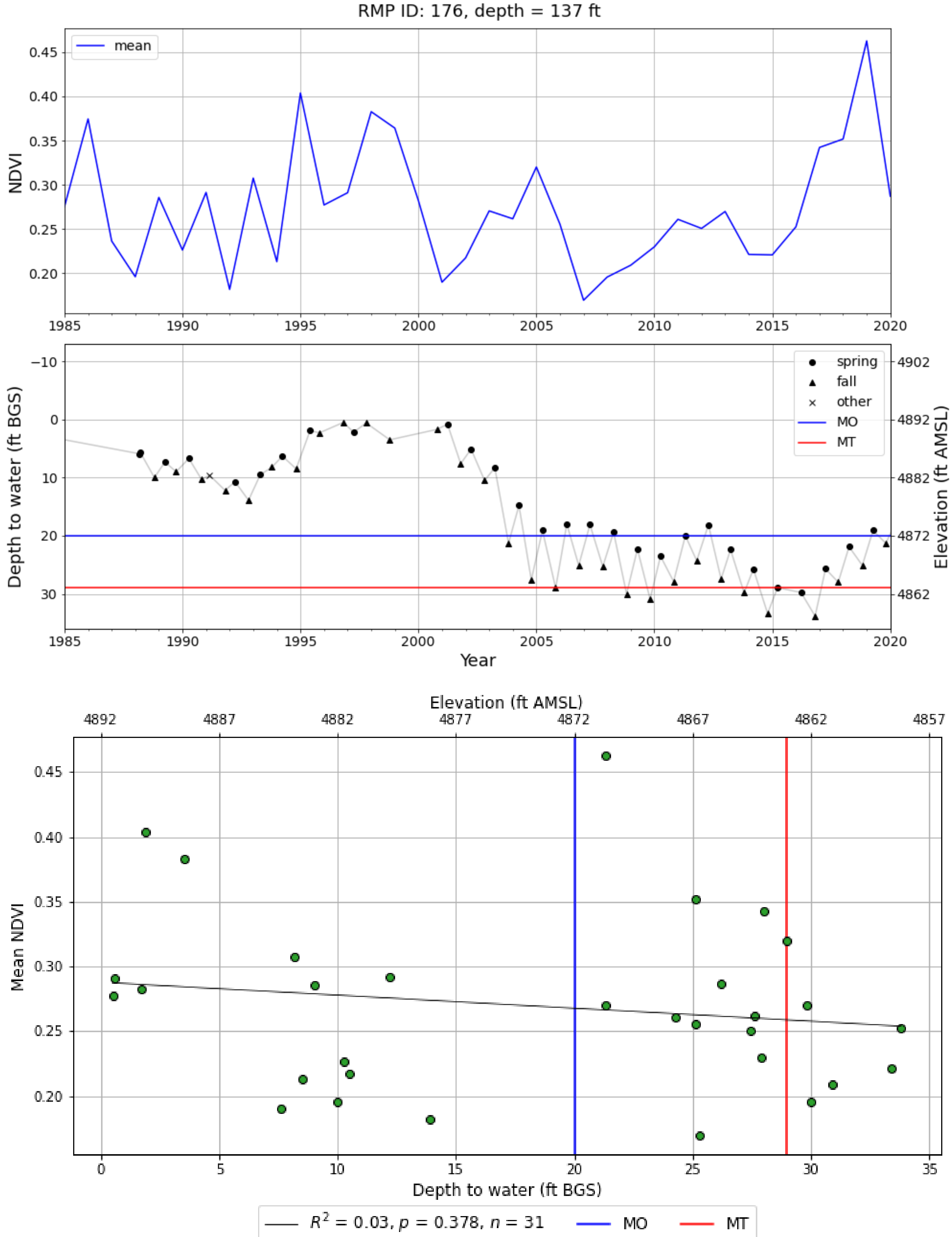

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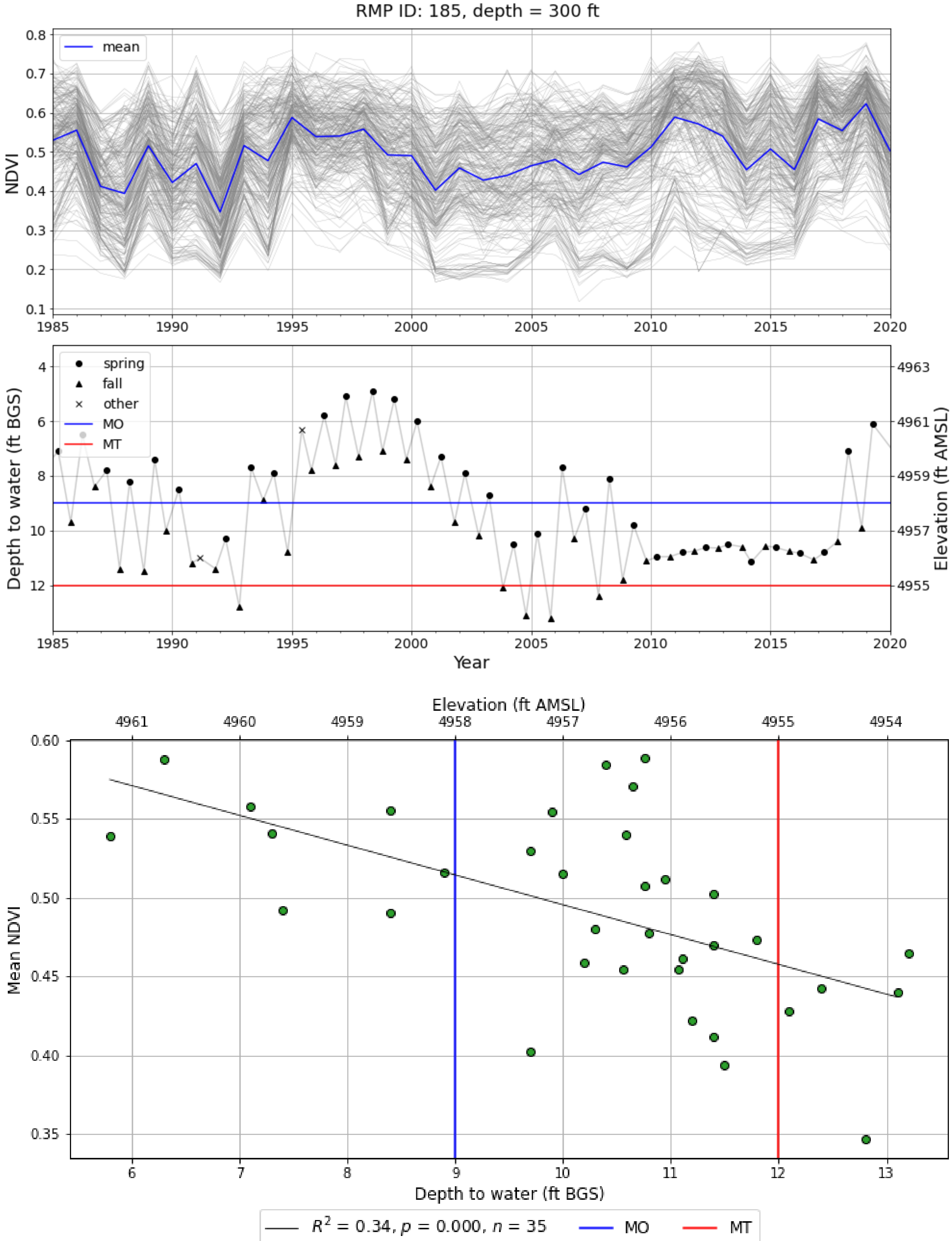

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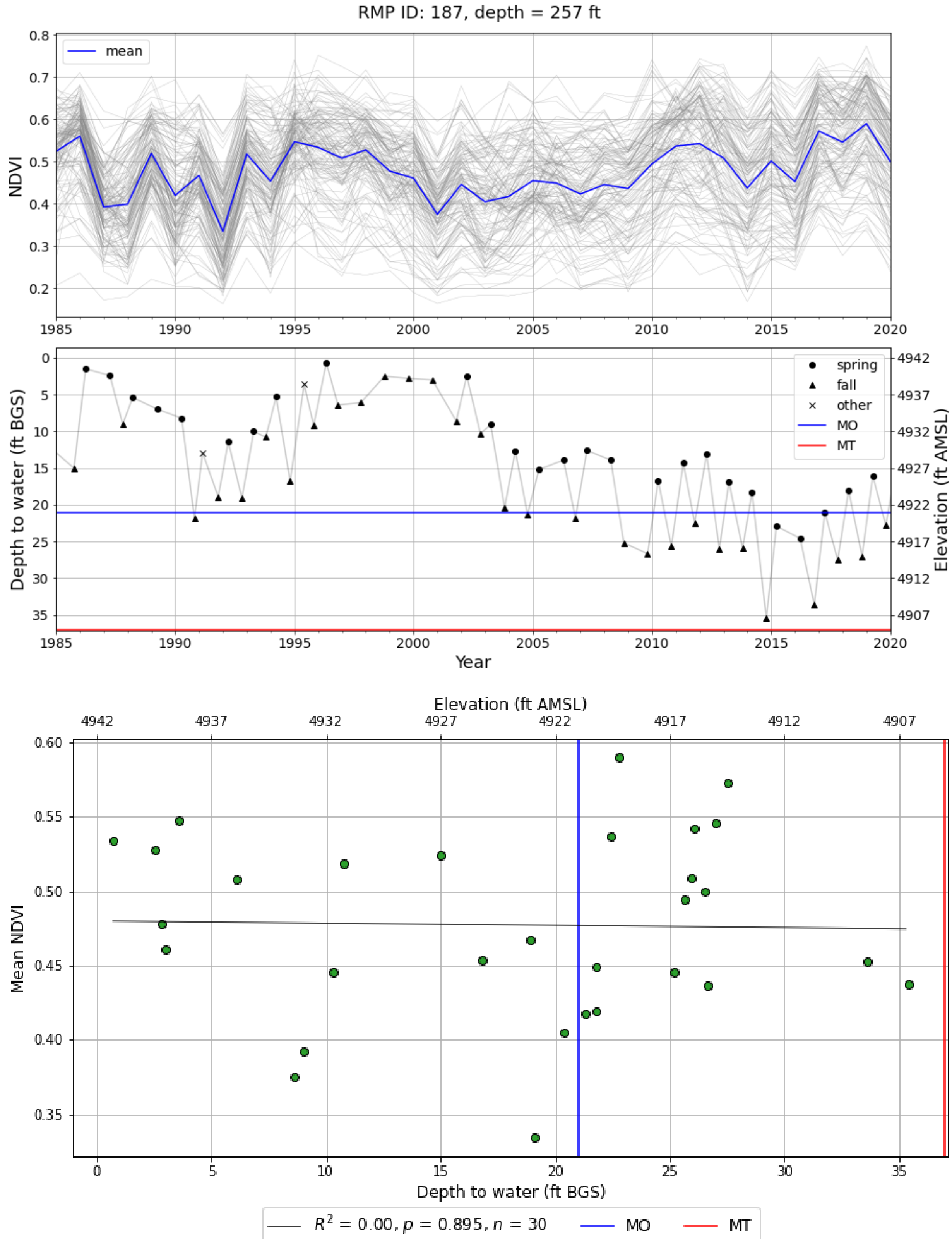

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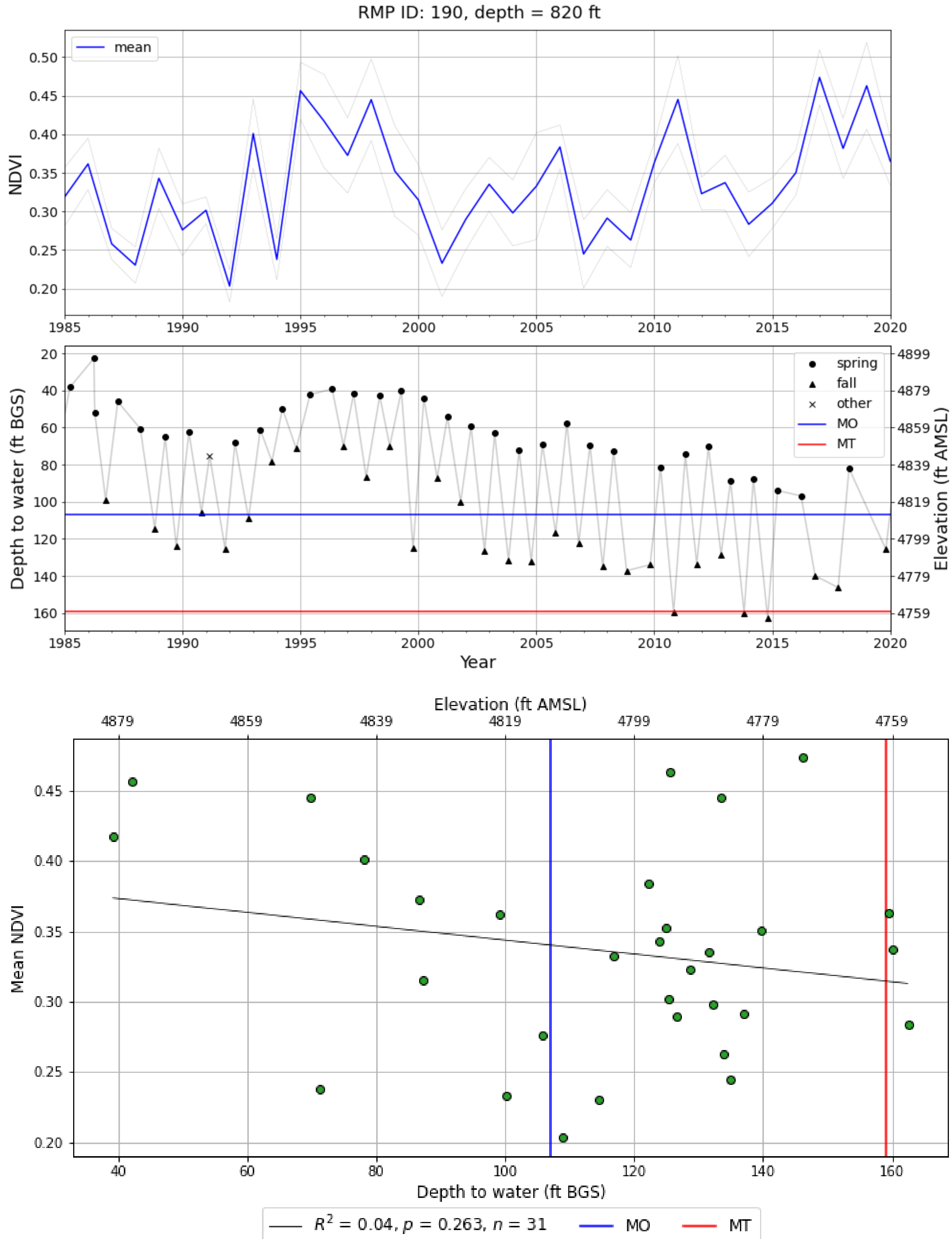

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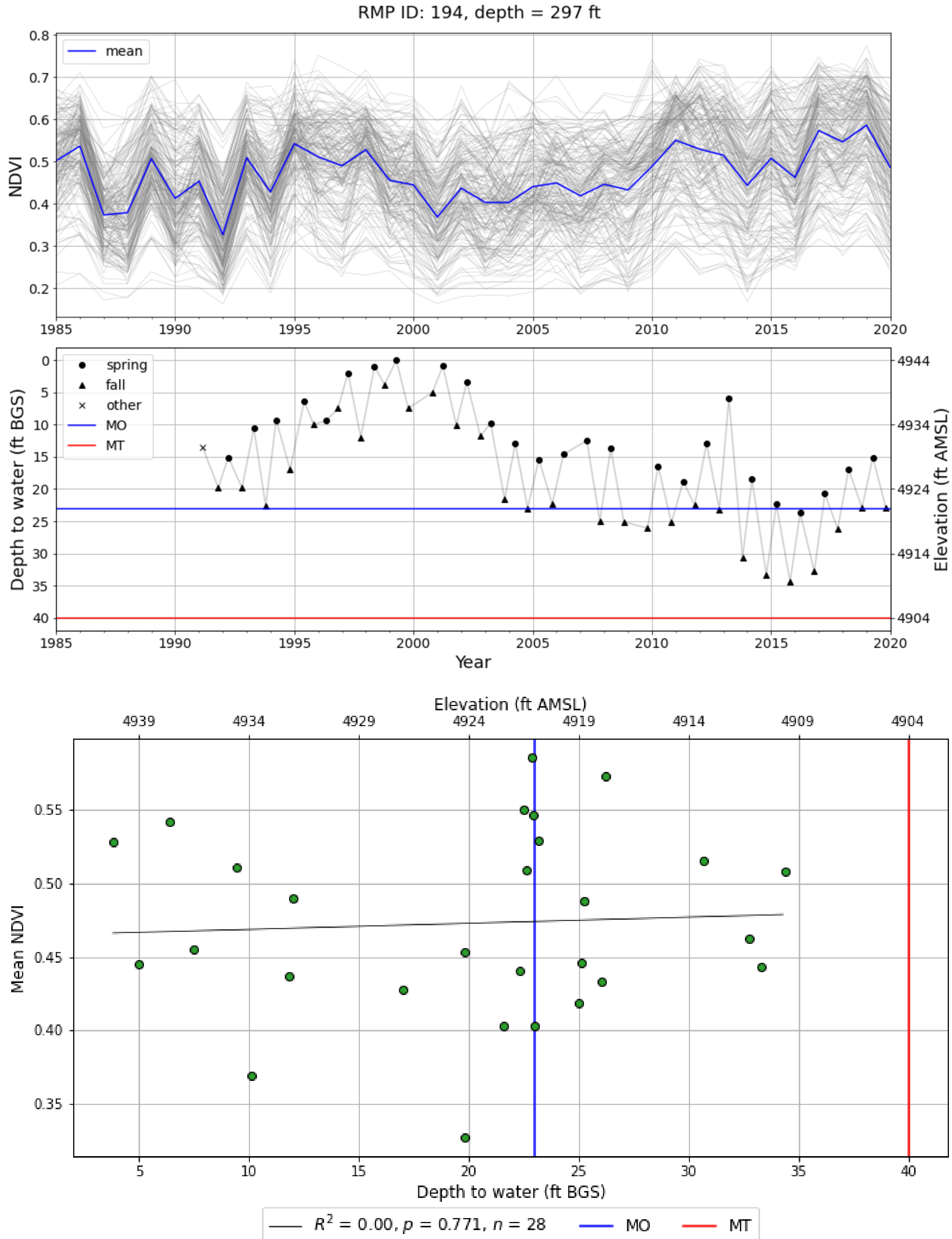

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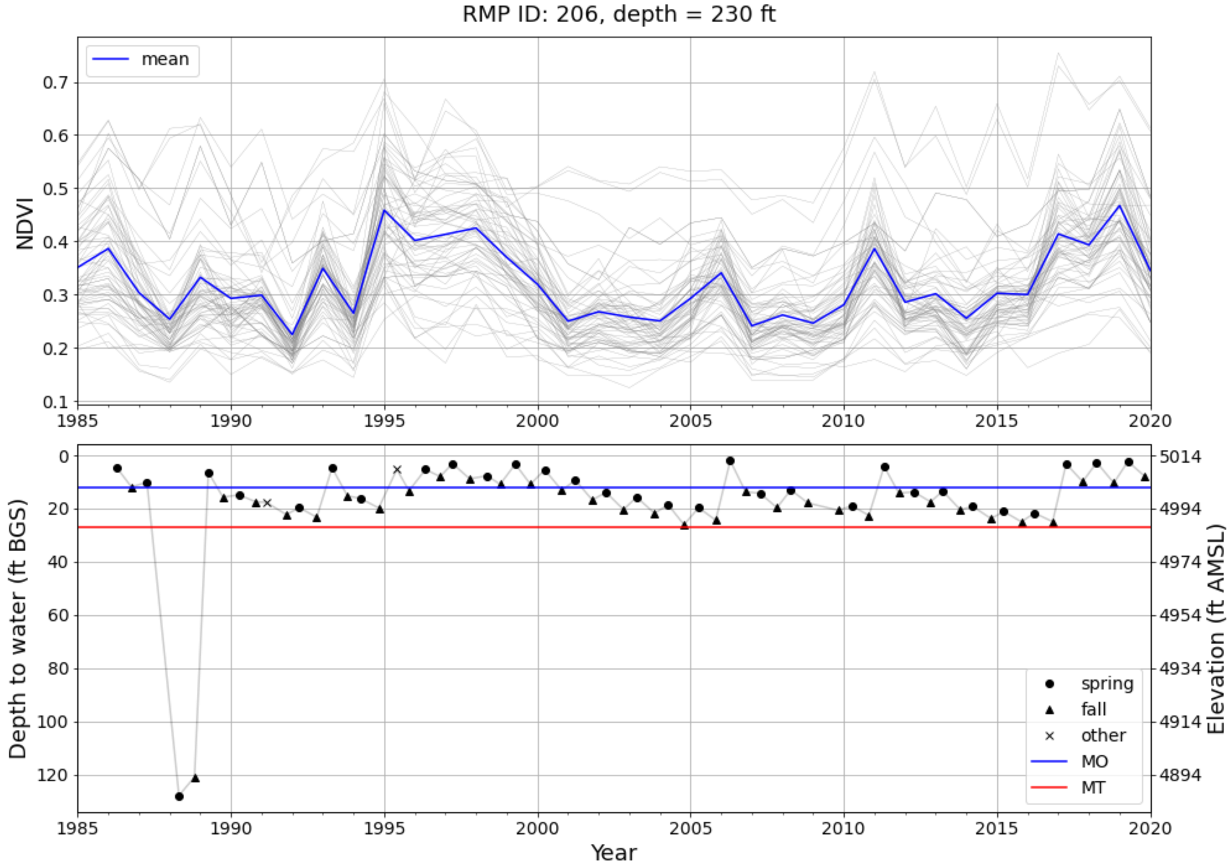

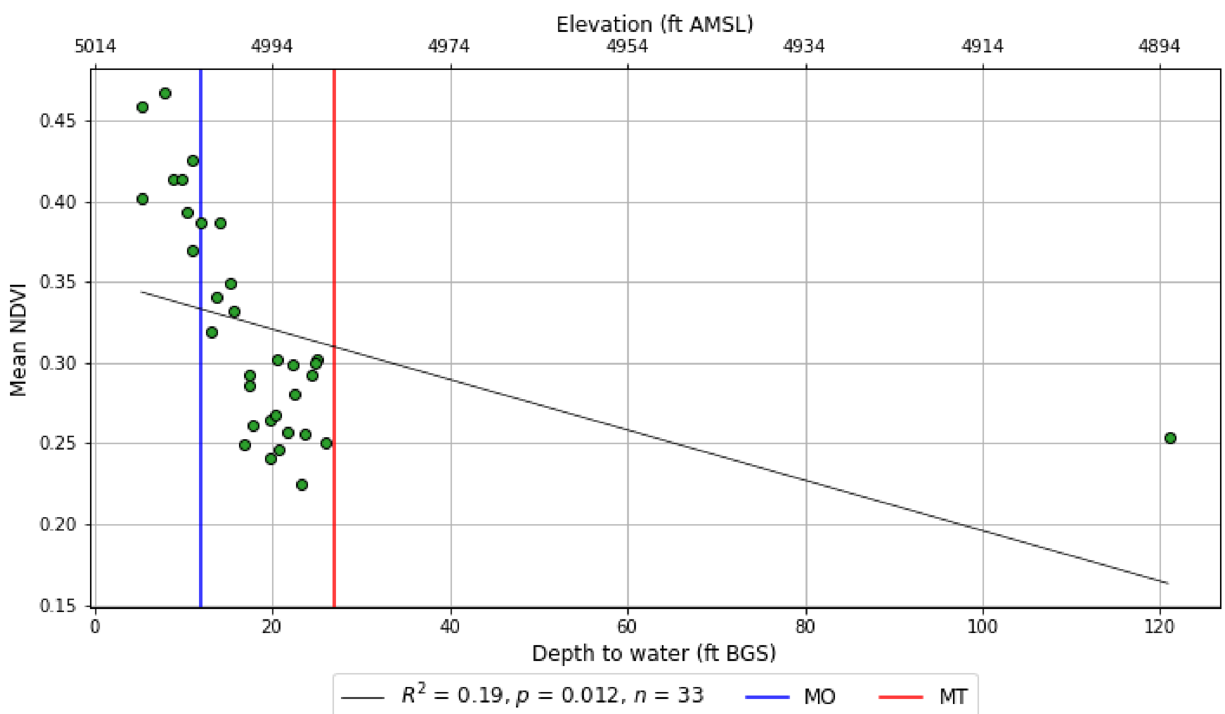

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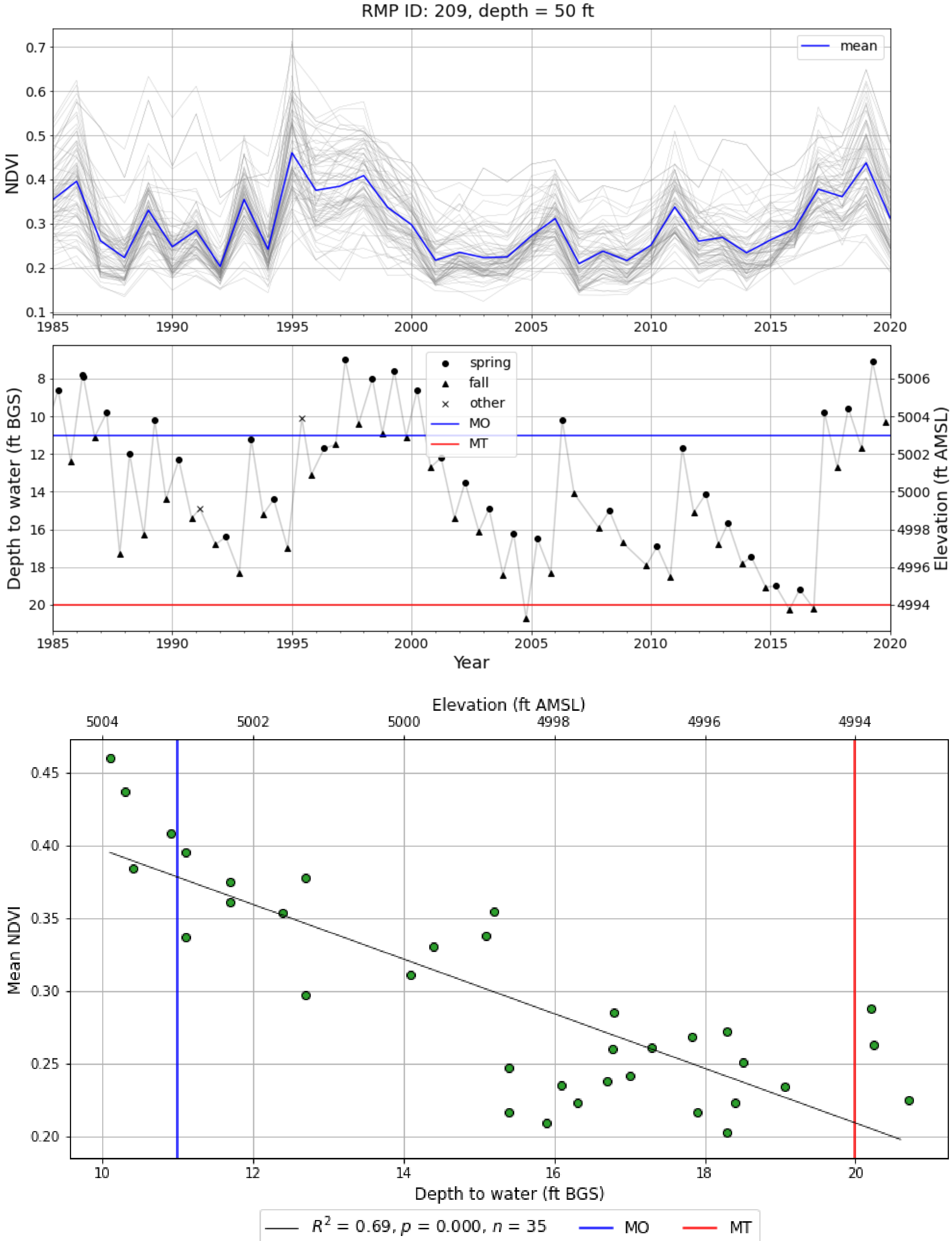

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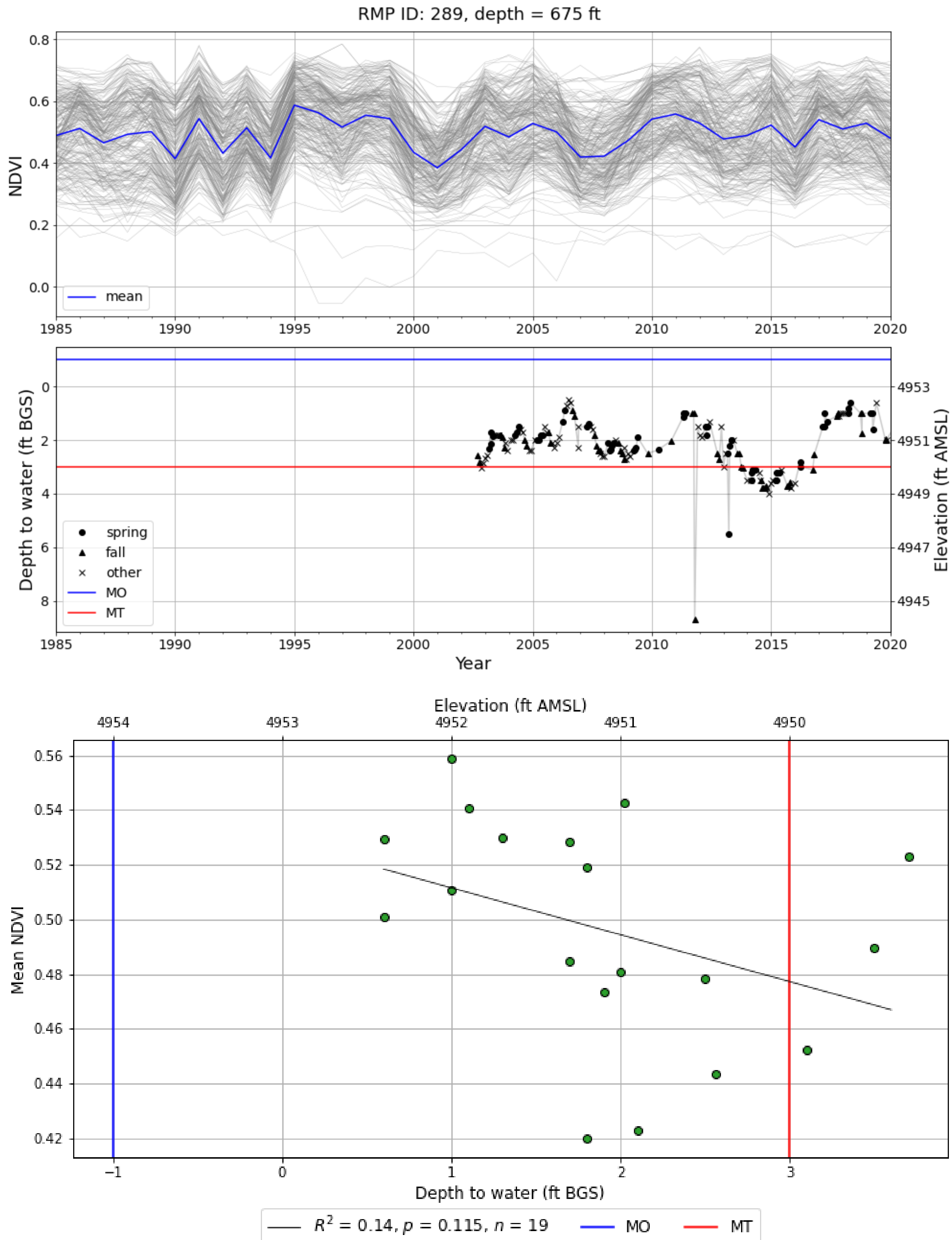

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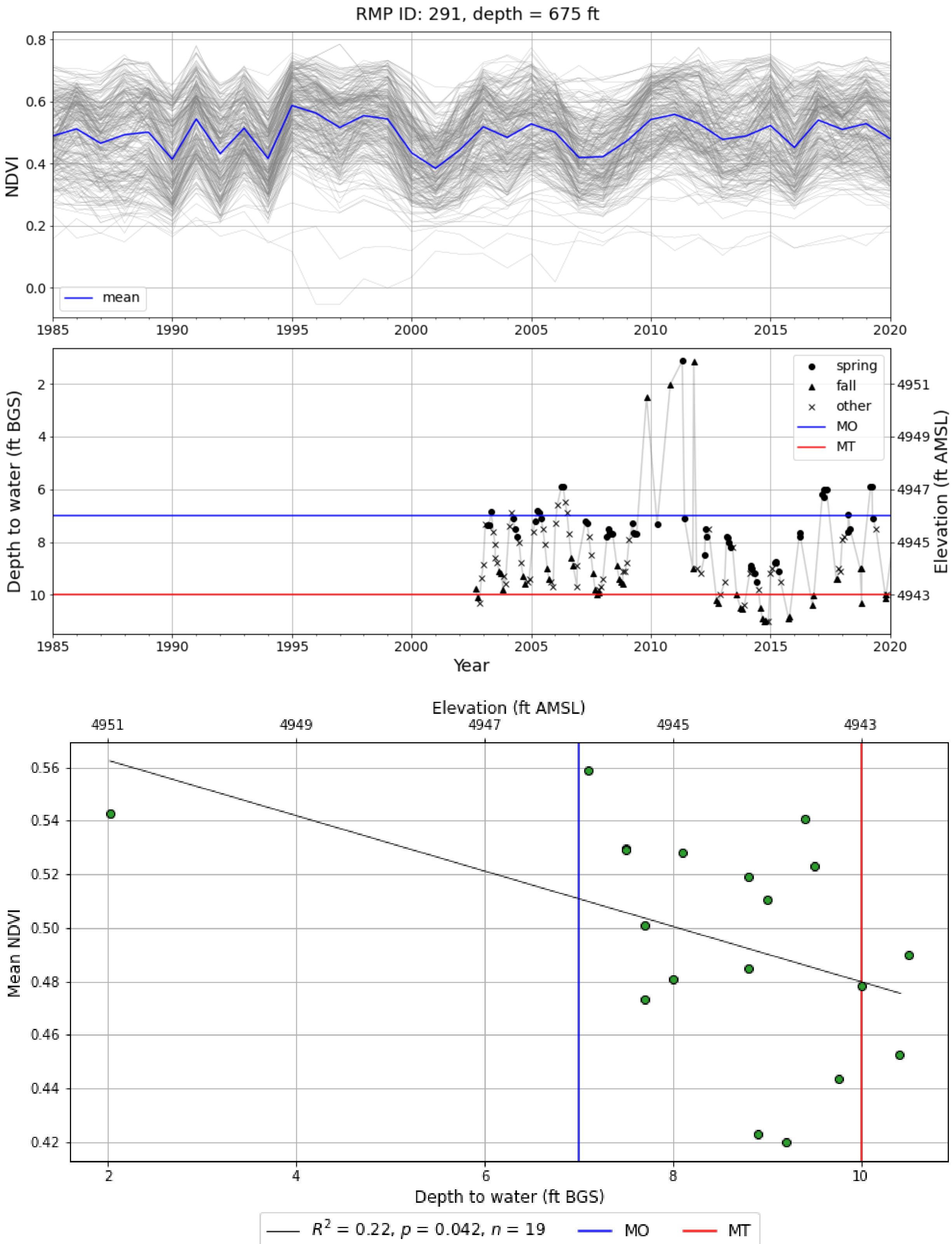

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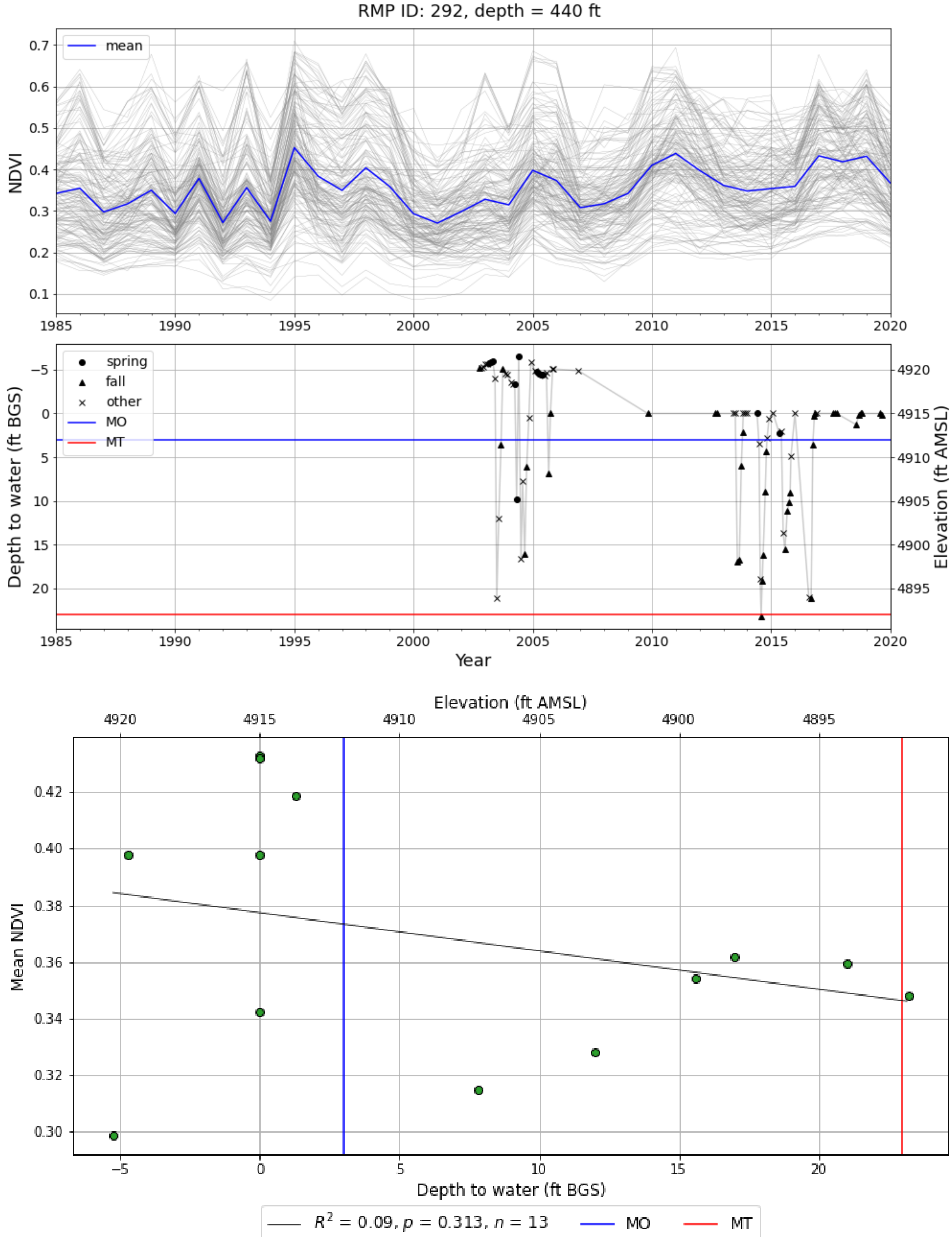

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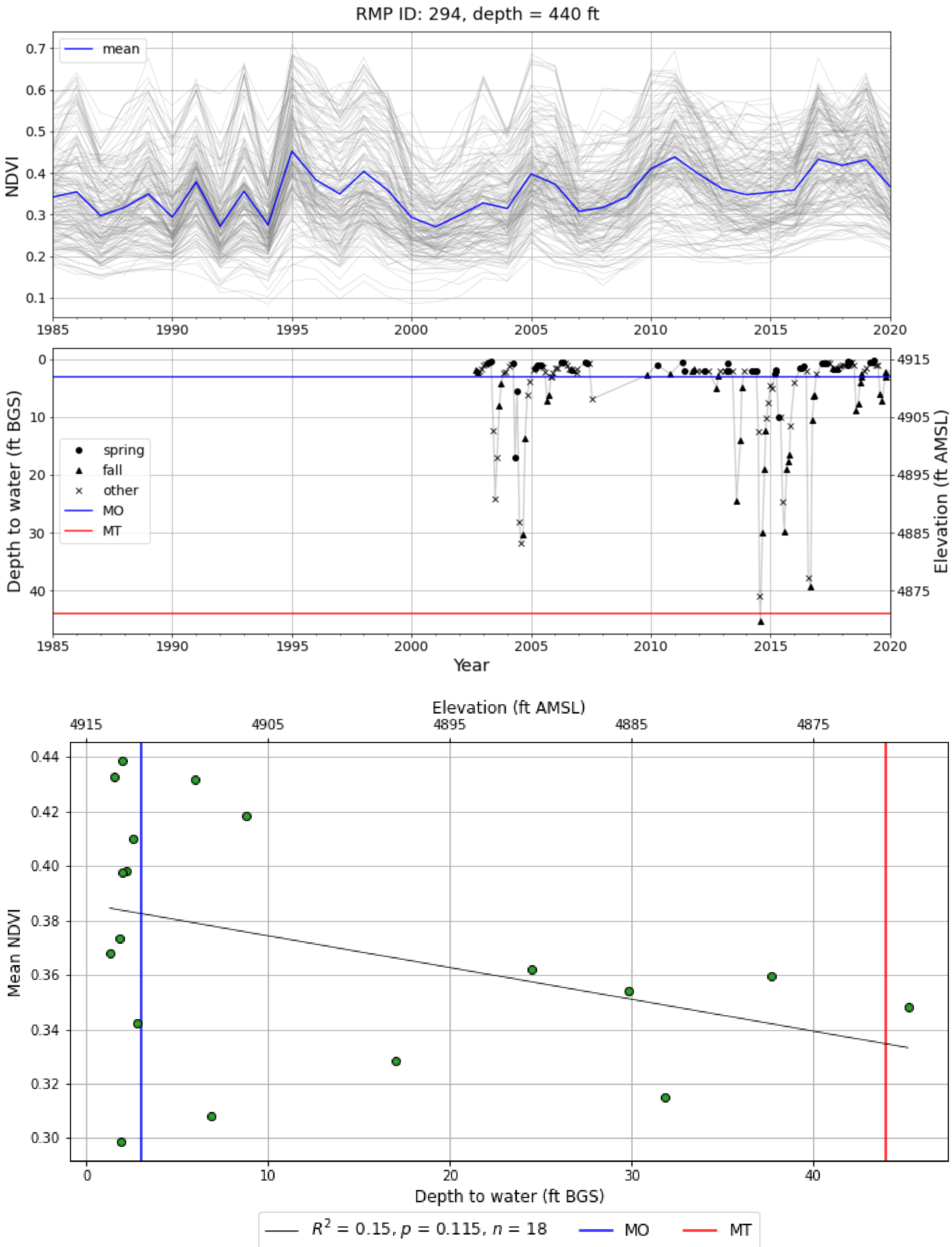

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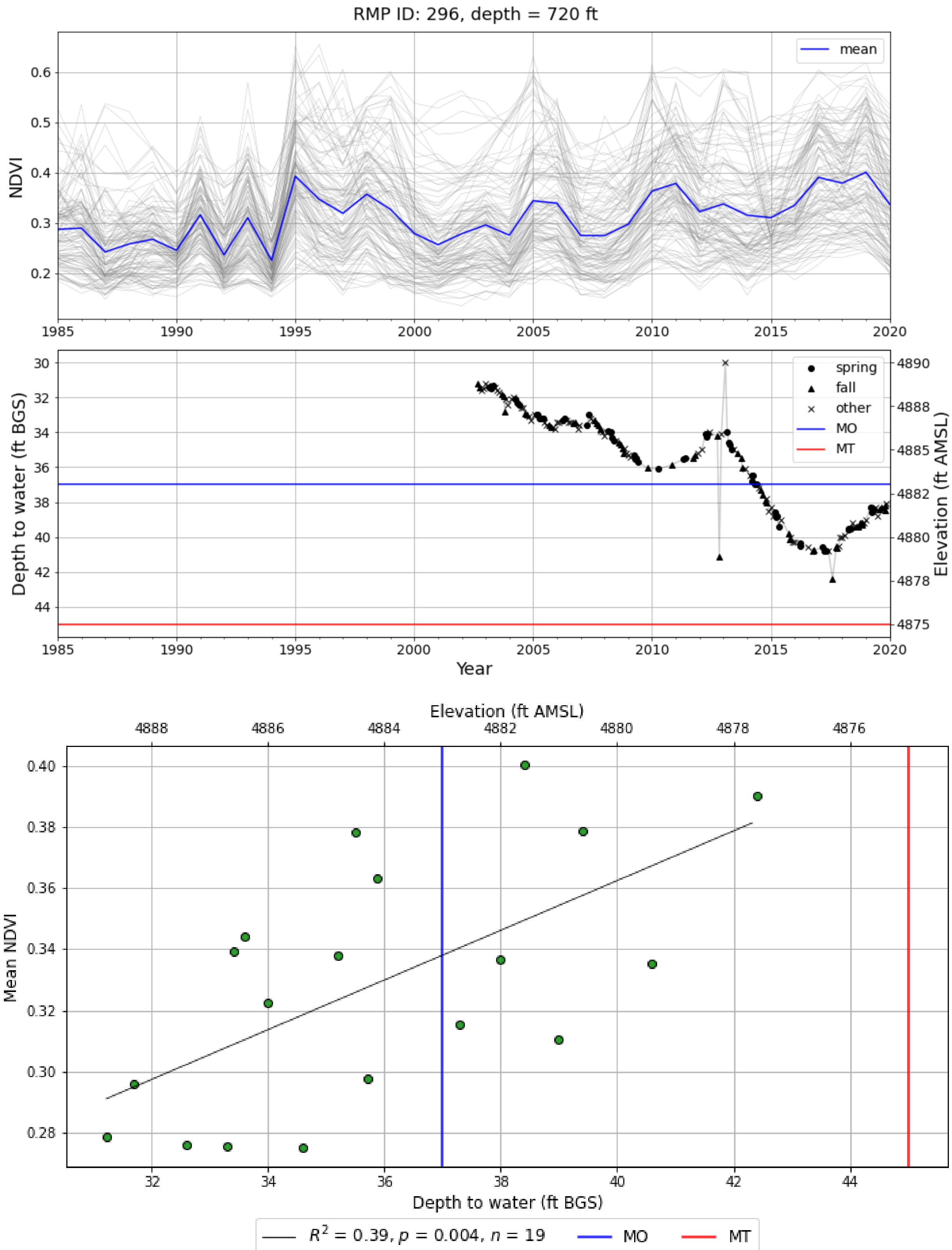

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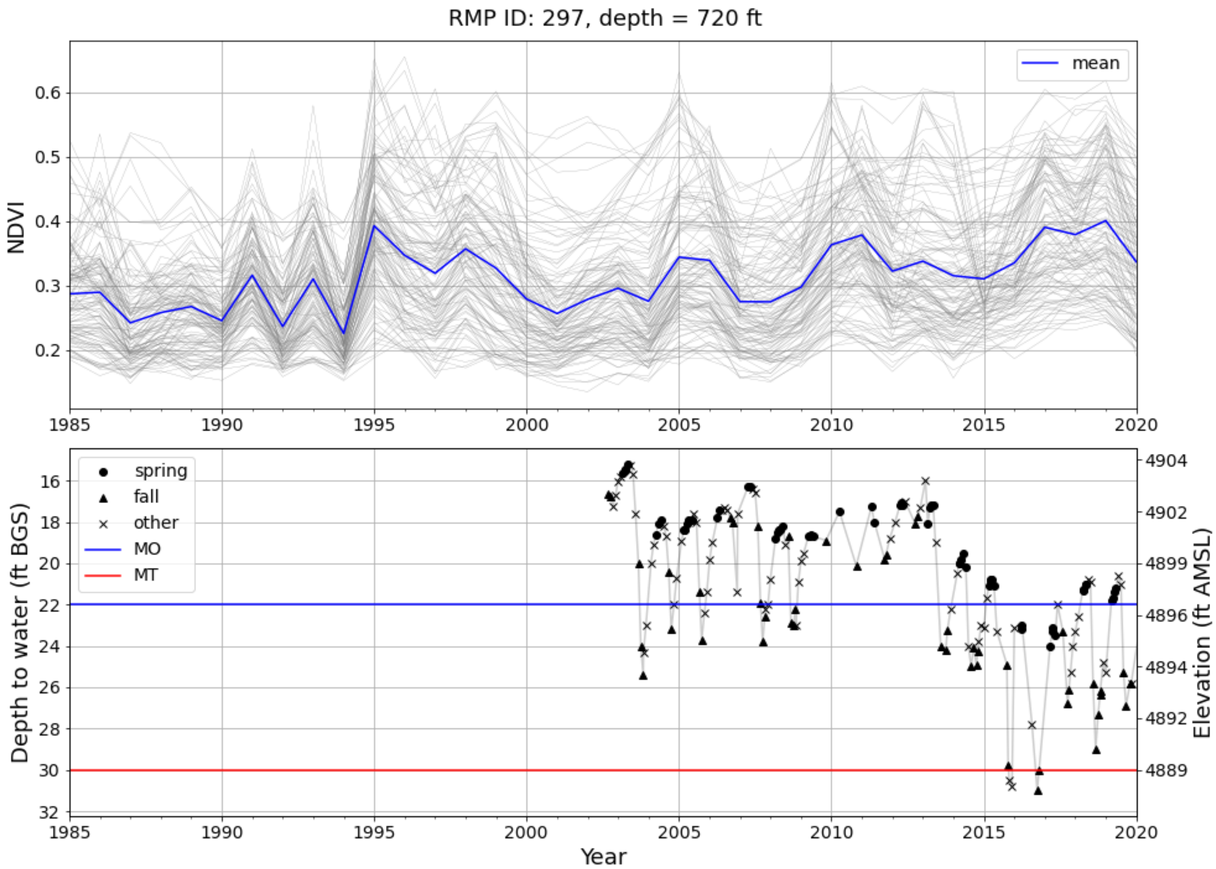

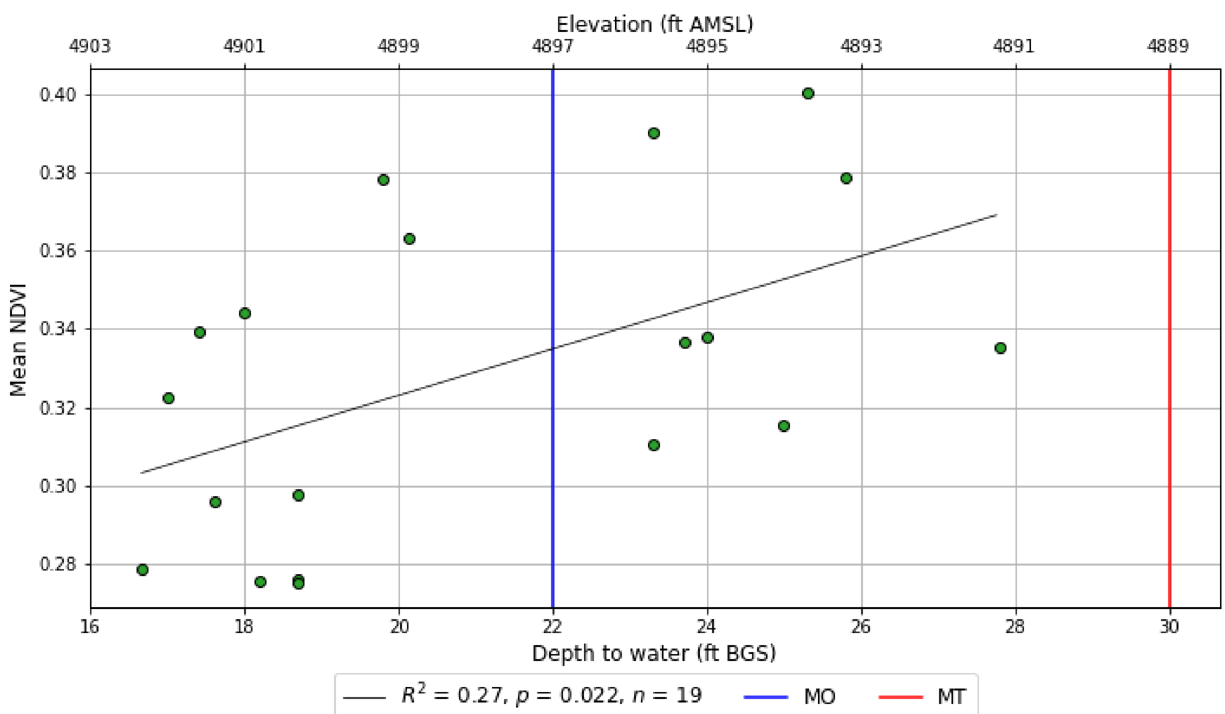

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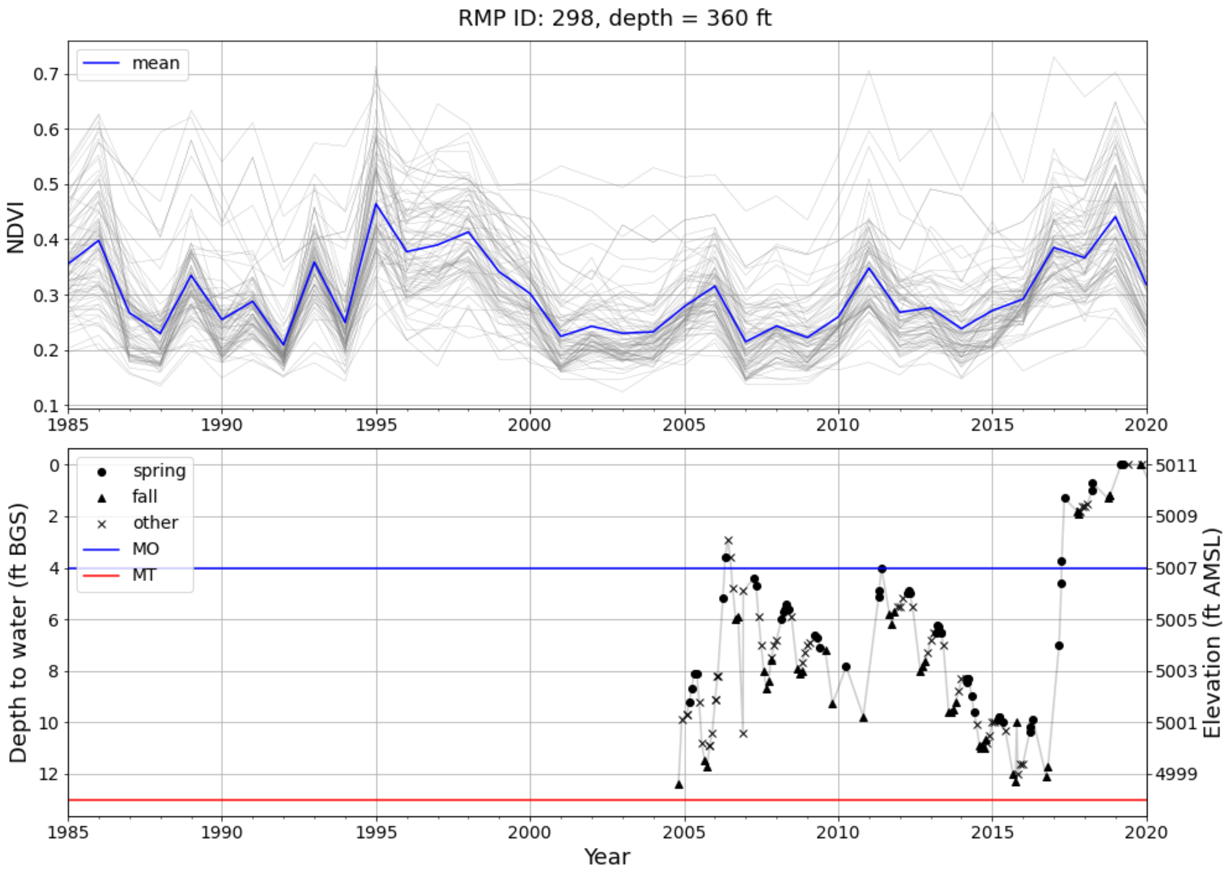

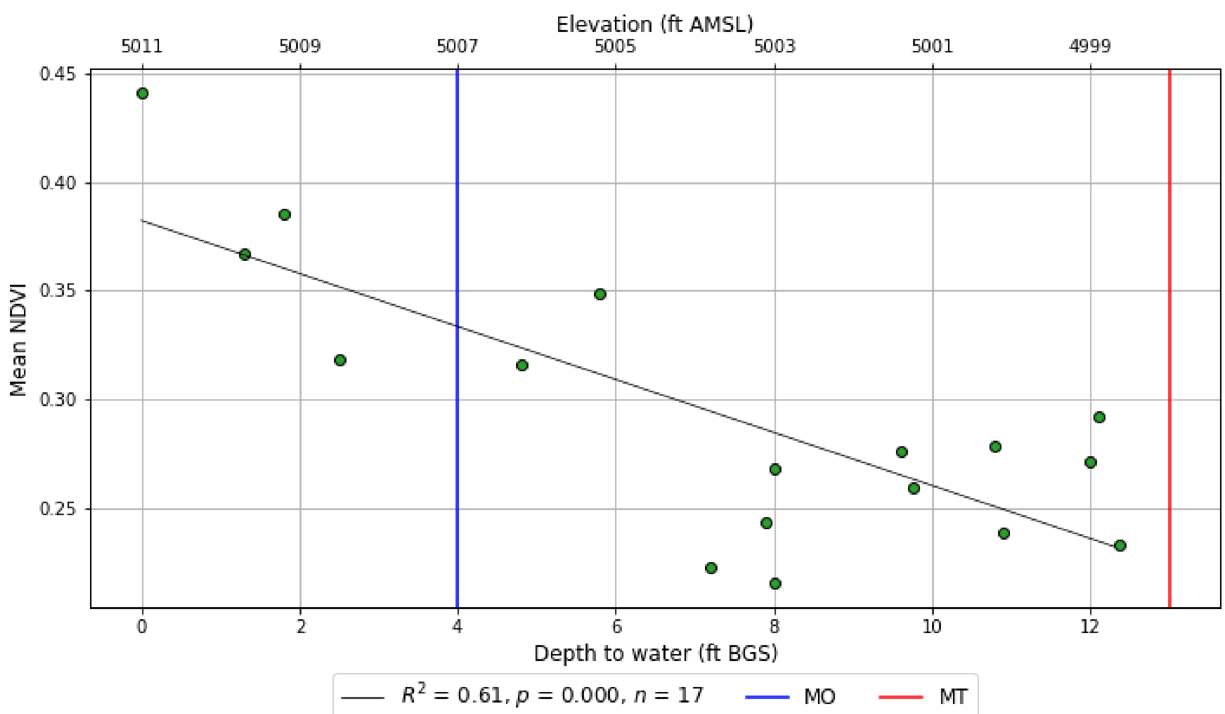

Figure Appendix 3-3-28. RMP 300