LAND USE AND CONSUMPTIVE WATER USE OF CUYAMA GROUNDWATER BASIN FOR WATER YEARS 1996 THROUGH 2016

To: Woodard & Curran

From: Land IQ

Date: June 19, 2018

INTRODUCTION

Accurate and current information on constantly changing consumptive water use for crops is critical not only to water rights administration, but also to sustainable groundwater management, agricultural irrigation management, and to environmental and water quality protection. Land IQ has been contracted by Woodard & Curran to analyze consumptive water use in the Cuyama Groundwater Basin for these purposes and overall Groundwater Sustainability Plan (GSP) development data resources.

This memorandum provides methods and results of crop type identification for selected water years (1996, 2000, 2003, 2006, 2009, 2012, 2014 & 2016) during the 20 year time period. Multiple sources of data are used in the identification of each field. These sources include aerial imagery, satellite photography, DWR land use surveys and ground survey information.

This documentation also provides estimates of crop evapotranspiration (ET) for the 1996 and 2016 water years (10/1/1995 – 9/30/1996, 10/1/2015 – 9/30/2016). The surface energy balance model, METRIC (Mapping Evapotranspiration with high Resolution and Internalized Calibration), is applied to estimate monthly and annual evapotranspiration. The input data include CIMIS weather station data and USGS Landsat 5 & 8 satellite images.

DETERMINING LAND USE

Land use is one of the most influential inputs to a consumptive use or groundwater model. This analysis was used to develop estimates of land uses associated with agricultural production in the Cuyama Groundwater Basin. Crop type information optimizes estimations of evapotranspiration, applied water, deep percolation return flows and other water balance input data requirements.

LAND USE DATA SOURCES

Available resources for crop mapping in recent years are more refined and accurate and in past years. Table 1 shows the types of aerial/satellite imagery as well as data availability for each year. Taking this into account, the accuracy and specifity of crop identification is greatest in the most recent mapping years (2014 & 2016). In more recent years, data allows individual crop types to be identified, instead of a more general category (e.g. Miscellaneous Truck Crops).

TABLE 1. SUMMARY OF DATA SOURCES AVAILABLE FOR EACH ANALYSIS YEAR

Year	Land Use Survey Data	Google Earth	NAIP Imagery	Landsat
2016	✔	✔	✔	✔
2014	✔	✔	✔	✔
2012	-	✔	✔	✔
2009	-	✔	✔	✔
2006	-	✔	✔	✔
2003	-	-	✔	✔
2000	-	-	-	✔
1996	✔	-	-	✔

LAND USE SURVEY DATA

The California Department of Water Resources (DWR) publishes land use data for regions on a rotating schedule for all or portions of each California County (DWR, 2018). The Cuyama Valley was last surveyed by DWR in 1996, including >90% of the fields in the Valley. Since then, Land IQ has completed statewide crop mapping for DWR in 2014 and 2016, encompassing the entire Cuyama Valley. In these three years, this data was used as a base layer and updated as needed.

GOOGLE EARTH

Google Earth provides high resolution satellite imagery with some temporal variation. Currently, most Google Earth data is provided by DigitalGlobe's WorldView-3 satellite, providing sub-meter resolution (Digital Globe, 2010). The street view function is also very helpful when identifying past years' crops. The street view in this area is very limited, however, and only available in 2008.

NAIP AERIAL IMAGERY

The National Agriculture Imagery Program (NAIP) captures aerial imagery during the growing season for public use (USDA, 2017). The imagery for the Cuyama Valley was available starting in 2003. NAIP imagery has a fairly high resolution of one meter. This imagery is used to update the field boundary layer for each year because the high resolution allows for the identification of fields that have split or have a different footprint. The drawback to NAIP imagery is that it is only a snapshot in time, with no temporal variation. Figure 1 shows 2009 NAIP imagery of the Cuyama Valley at two different scales to show detail.

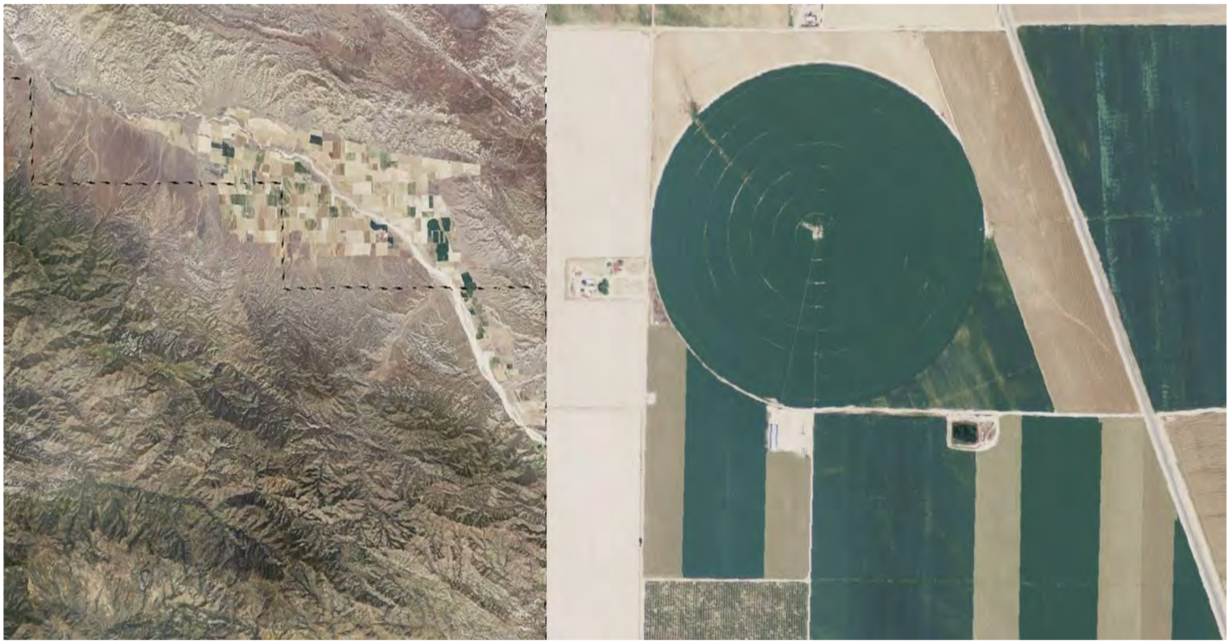

FIGURE 1. NATURAL COLOR COMPOSITE OF NAIP IMAGE, FOR 05/05/2012; 1:300,000 SCALE ON LEFT; 1:9,000 SCALE ON RIGHT.

LANDSAT SATELLITE IMAGERY

Landsat satellite imagery is a joint project between the USGS and NASA that collects imagery for public use. Landsat provides lower resolution imagery (30 x 30 meter pixels) but at a much higher frequency than NAIP (USGS, 2007). Depending on year and cloud cover, imagery for an area could be as frequent as every 8 days. This frequency allows for the observation of the crop in all stages of development. All imagery dates during the growing season are used to identify the color and texture changes, to support the crop type identification.

The Cuyama Valley is within Landsat reference system path 42 and row 36. Landsat 5, 7, and 8 were used for appropriate years. All available growing season images were utilized, except those that had cloud contamination. Figure 2 is an example of the agriculture area in Landsat 5 on June 26, 2009.

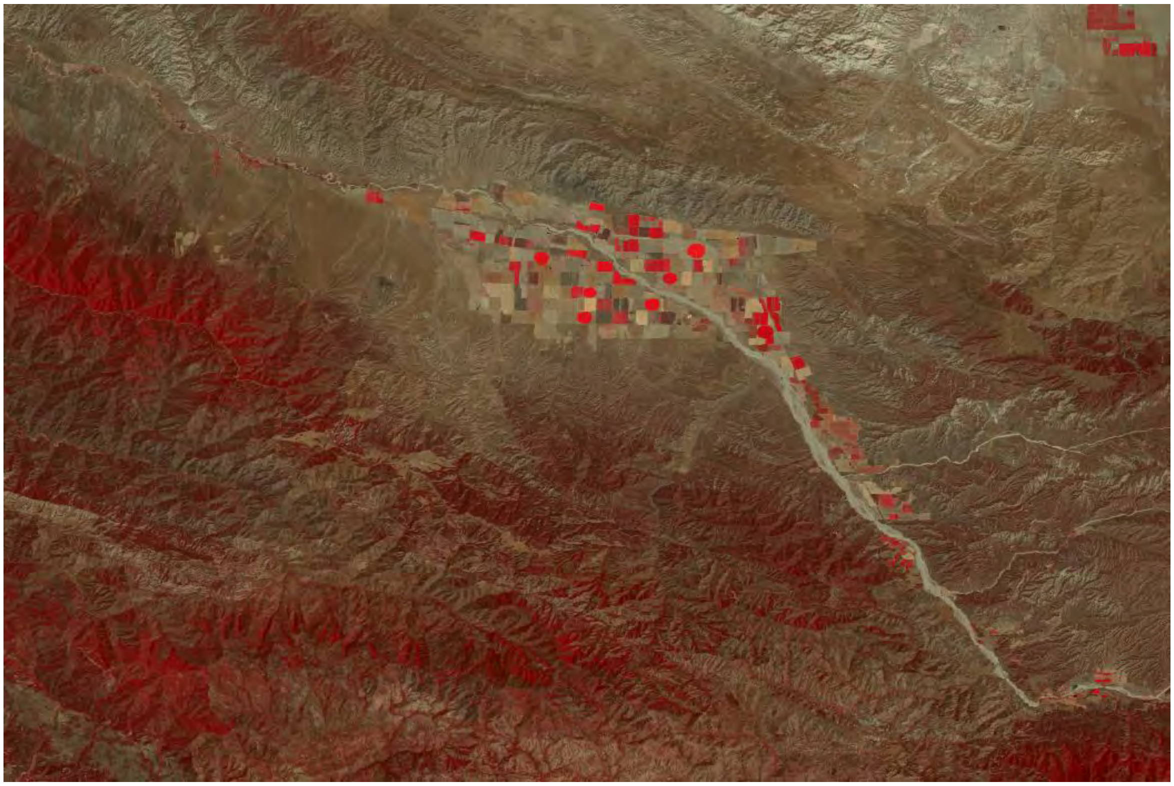

FIGURE 2. FALSE COLOR COMPOSITE OF LANDSAT 5 IMAGE, PATH 42 ROW 36, FOR 06/26/2009. AGRICULTURE IS IN THE MIDDLE OF THE IMAGE.

LAND USE RESULTS

Classification and field boundary updates were completed for each year, using the data sources available. Table 2 summarizes the results of the classification and boundaries. The top 5 crop classes during the 20 year period (excluding idle) were miscellaneous truck, miscellaneous grain and hay, carrots, alfalfa and alfalfa mixtures, and apples.

TABLE 2. SUMMARY OF CROP MAPPING RESULTS

DWR Crop	1996	2000	2003	2006	2009	2012	2014	2016
Alfalfa & alfalfa mixtures	3,574	2,586	1,950	2,201	935	1,356	168	235
Apples	2,475	2,478	1,417	773	518	282	307	331
Beans (dry)	-	259	-	-	-	-	1,064	-
Bush berries	-	-	-	-	-	-	-	21
Carrots	4,698	843	307	566	5,582	6,654	2,302	5,572
Citrus	-	2	2	2	4	4	2	2
Cole crops	-	-	107	137	292	236	182	383
Corn, sorghum and sudan	-	185	209	-	74	-	32	173
Grapes	357	794	768	768	765	853	1,303	1,241
Greenhouses	-	-	-	-	-	-	-	5
Idle	-	8,286	9,971	12,247	9,139	8,449	15,352	13,572
Lettuce/leafy greens	-	-	-	271	212	171	-	612
Melons, squash, and cucumbers	12	-	-	-	-	-	562	50
Miscellaneous deciduous	12	10	10	16	41	35	10	6
Miscellaneous field crops	114	-	-	-	-	-	-	-
Miscellaneous grain and hay	7,462	5,756	5,580	4,712	8,767	6,367	851	3,198
Miscellaneous grasses	-	192	485	192	111	14	22	-
Miscellaneous subtropical fruit and nut	-	-	-	-	-	-	-	7
Miscellaneous truck	3,723	6,842	8,083	9,380	3,451	4,078	6,100	3,322
Mixed pasture	737	104	91	398	273	392	97	142
Native	-	-	-	-	-	166	-	-
Olives	-	4	4	4	4	4	4	517
Onions and garlic	313	10	315	527	983	1,231	615	2,190
Peaches/nectarines	413	348	284	213	75	-	-	-
Pistachios	676	604	604	757	757	722	802	722

DETERMINING CONSUMPTIVE USE

Traditional methods of calculating evapotranspiration can be done quite accurately using weighing lysimeters and eddy correlation monitoring techniques. These methods are limited, however, because they provide point values of ET for a specific location and fail to provide the ET on a regional scale. This limitation has motivated the development of using remotely sensed (RS) data from satellites to evaluate ET over vast areas. Satellite data are ideally suited for deriving spatially continuous ET surfaces that can be pared down to the field scale because of their temporal and spatial characteristics. However, the most accurate use of RS models require calibration to surface measurements.

SURFACE ENERGY BALANCE CONSUMPTIVE USE ANALYSIS – METRIC MODEL

METRIC estimates surface evapotranspiration (ET) based on the evaluation of the energy balance at the earth's surface. METRIC model processes instantaneous remotely-sensed images and weather data, and estimates the partitioning of energy into net incoming radiation (R_n), heat flux into the ground (G), sensible heat flux to the air (H), and latent heat flux (LE). The latent heat flux is computed as a residual in the energy balance, representing the energy consumed by ET. The main advantage of using the energy balance is that the actual ET is computed, rather than a potential ET. A disadvantage of the energy balance approach is in the complexity of calculations and the need for human oversight during calibration. Figure 3 shows a general workflow of the METRIC process.

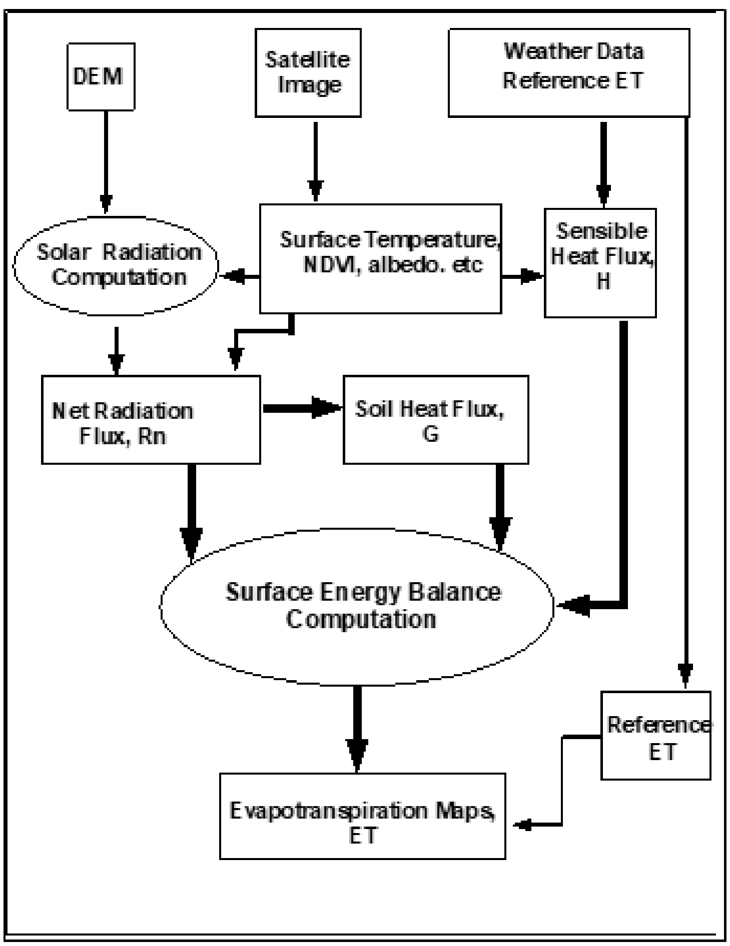

FIGURE 3. GENERAL WORKFLOW OF THE METRIC PROCESS

For the Cuyama Groundwater Basin METRIC application, the Cuyama station (CIMIS station #88) was selected to produce the reference ET (ETo) during calibration. During the internal calibration of sensible heat flux in METRIC, multiple pairs of hot and cold pixels are selected for the model, the one with relative stable result is selected for final calibration. A detailed description of METRIC can be found in Allen et al. (2007a, b; 2008).

METRIC Input Data – Satellite Images

The Cuyama Groundwater Basin is within Landsat reference system path 42 and row 36. For the 1996 water year, Landsat 5 images were used, and for the 2016 water year, Landsat 8 images were used. All available images were utilized, except those that had cloud contamination.

Tables 3 and 4 provide a list of the images used for each water year. A total of 14 Landsat 5 images were modeled by METRIC for the 1996 water year, and a total of 17 Landsat 8 images were modeled for the 2016 water year. For each image, the METRIC model was used to estimate actual daily ET. Linear interpolation was then used to calculate monthly and annual ET.

TABLE 3. DATES OF THE LANDSAT 5 SATELLITE IMAGES USED FOR METRIC PROCESSING IN 1996 WATER YEAR

#	Date of Landsat	Image Type
1	9/24/1995	Landsat 5
2	10/10/1995	Landsat 5
3	11/11/1995	Landsat 5
4	11/27/1995	Landsat 5
5	1/14/1996	Landsat 5
6	5/21/1996	Landsat 5
7	6/6/1996	Landsat 5
8	6/22/1996	Landsat 5
9	7/8/1996	Landsat 5
10	7/24/1996	Landsat 5
11	8/9/1996	Landsat 5
12	8/25/1996	Landsat 5
13	9/10/1996	Landsat 5
14	9/26/1996	Landsat 5

TABLE 4. DATES OF THE LANDSAT 8 SATELLITE IMAGES USED FOR METRIC PROCESSING IN 2016 WATER YEAR

#	Date of Landsat	Image Type
1	10/1/2015	Landsat 8
2	11/18/2015	Landsat 8
3	1/21/2016	Landsat 8
4	2/6/2016	Landsat 8
5	3/9/2016	Landsat 8
6	3/25/2016	Landsat 8
7	4/26/2016	Landsat 8
8	5/12/2016	Landsat 8
9	5/28/2016	Landsat 8
10	6/13/2016	Landsat 8
11	6/29/2016	Landsat 8
12	7/15/2016	Landsat 8
13	7/31/2016	Landsat 8
14	8/16/2016	Landsat 8
15	9/1/2016	Landsat 8
16	9/17/2016	Landsat 8
17	10/3/2016	Landsat 8

METRIC INPUT DATA – WEATHER DATA

METRIC utilizes reference ET as calculated by the ASCE standardized Penman-Monteith equation (ASCE-EWRI 2005) for calibration of the energy balance process. For our study, grass reference ET (ETo) is used in the modeling process. Hourly weather data time steps are needed to represent ETo at the time of the Landsat overpass for calibration of the METRIC energy balance estimation process. ETo was calculated using the RefET software from the University of Idaho (Allen, 2013). California Irrigation Management Information System (CIMIS) weather station #88 at Cuyama was used to provide hourly weather data for ETo calculation. Figure 4 is an example of weather data for May 21st, 1996. Figure 5 shows the annual reference ETo for 1996 and 2016 water years calculated from the CIMIS Cuyama weather station using RefET software.

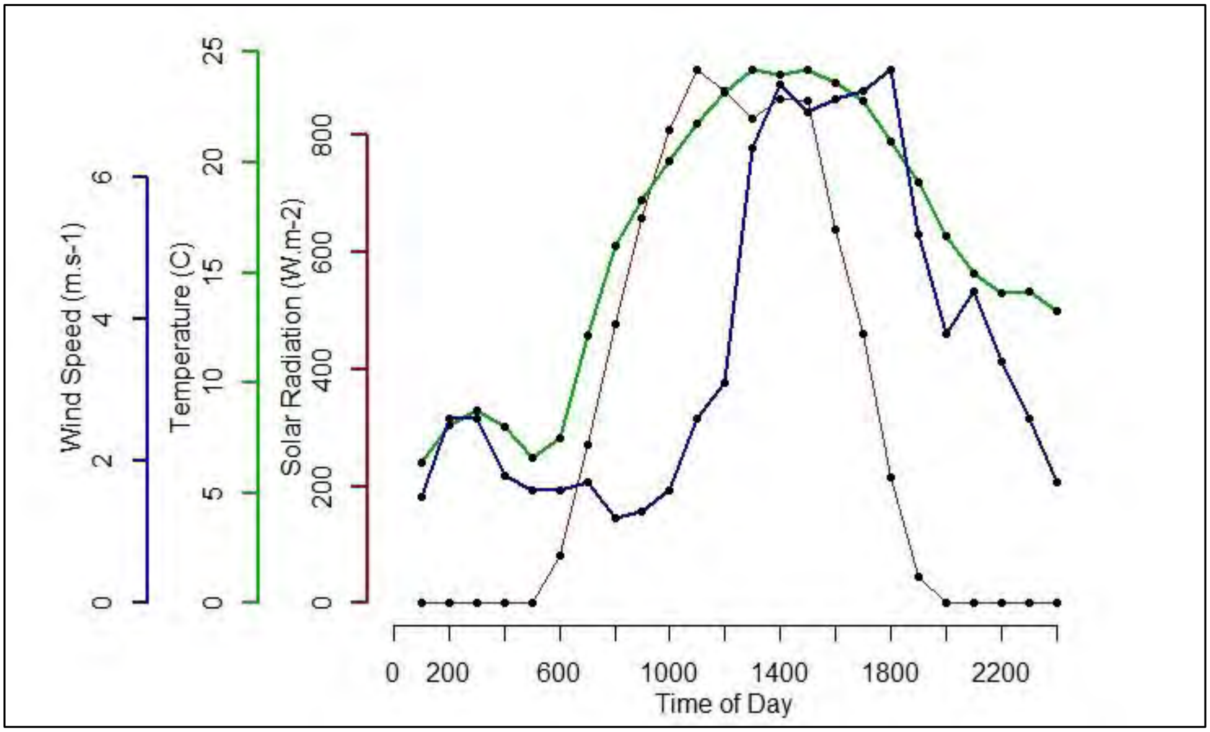

FIGURE 4. CIMIS CUYAMA #88 STATION WEATHER DATA ON MAY 21ST, 1996.

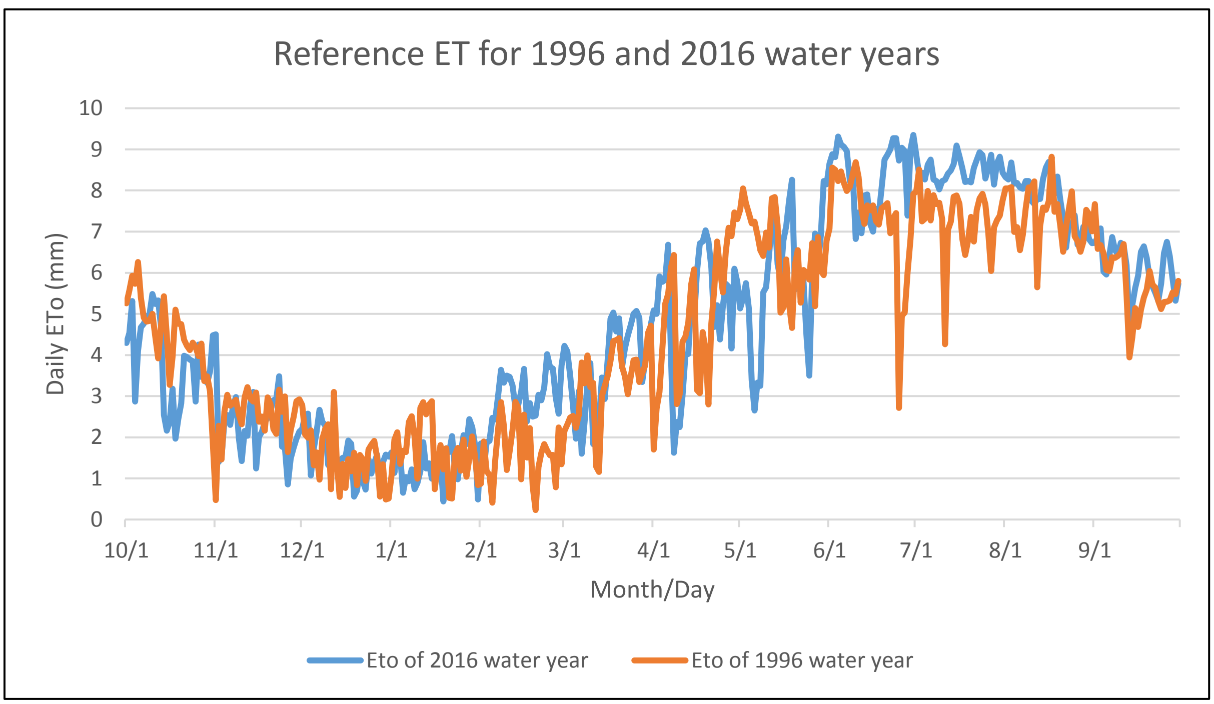

FIGURE 5. REFERENCE EVAPOTRANSPIRATION FOR 1996 AND 2016 WATER YEARS.

CONSUMPTIVE USE RESULTS

The annual ET data for the 1996 and 2016 water years are summarized by major crop types within each year. Tables 5 and 6 show the results of average crop actual ET. Major crops, such as alfalfa, apples, and carrots, have relative higher annual ET in 2016 than 1996, and these could be attributed to a number of factors:

➔ 2016 total annual ETo is higher than 1996 total annual ETo. As shown in Figure 5, during the month of June and July, ETo is consistently higher in 2016.

➔ The underlying crop layers used for generating the statistics are created differently. 2016 crop layer is created by Land IQ while 1996 crop layer is created by DWR.

➔ The field boundary of 2016 is more accurate, compared with 1996 field boundary. And this could cause differences in ET stats.

➔ Crop variety and irrigation methods are different in those 2 years, making crops evaporate more water in 2016.

Figure 6 shows the overview of 2016 water year ET over the whole Cuyama Basin. The focus and calibration area for METRIC ET evaluations was the agricultural growing region (valley floor) itself. The surrounding mountains with different elevations and aspects may have differing results.

TABLE 5. SUMMARY OF CROP EVAPOTRANSPIRATION OF 1996 WATER YEAR

Crop Types	1996 Water Year ET (mm)	1996 Crop Acres
Alfalfa and Alfalfa Mixtures	1163	3579
Apples	905	2478
Carrots	800	4705
Grapes	846	357
Miscellaneous Grain and Hay	590	7474
Miscellaneous Truck Crops	618	3729
Mixed Pasture	807	738
Onions and Garlic	591	313
Peaches/nectarines	819	414
Pistachios	683	677

TABLE 6. SUMMARY OF CROP EVAPOTRANSPIRATION OF 2016 WATER YEAR

Crop Types	2016 Water Year ET (mm)	2016 Crop Acres
Alfalfa and Alfalfa Mixtures	1365	235
Apples	1204	331
Carrots	1077	5576
Grapes	822	1242
Miscellaneous Grain and Hay	824	3201
Miscellaneous Truck Crops	818	3324
Mixed Pasture	633	142
Onions and Garlic	986	2192
Pistachios	1266	722
Lettuce/Leafy Greens	789	613
Olives	737	517
Safflower	714	810

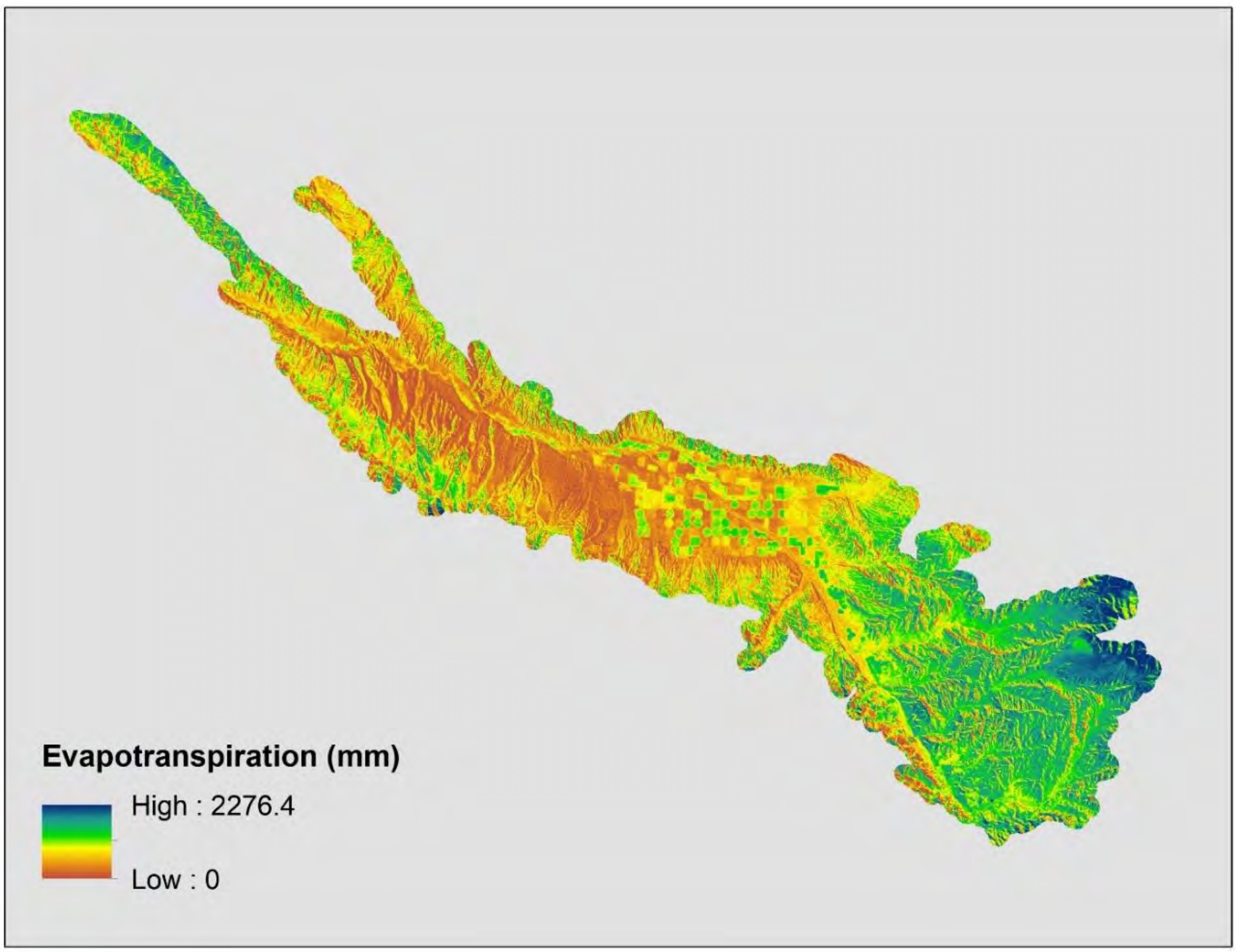

FIGURE 6. 2016 WATER YEAR EVAPOTRANSPIRATION OF THE CUYMA BASIN.

DATA DELIVERABLES

Data delivered as part of the consumptive water analysis efforts are summarized in Table 7.

TABLE 7. SUMMARY OF CROP MAPPING DATA DELIVERABLES

#	File Name	Description
1	CuyamaValley_2016_LandUse_Classification.shp	Crop classification for 2016 water year (attribute: Crop2016)
2	CuyamaValley_2014_LandUse_Classification.shp	Crop classification for 2014 water year (attribute: Crop2014)
3	CuyamaValley_2012_LandUse_Classification.shp	Crop classification for 2012 water year (attribute: Crop2012)
4	CuyamaValley_2009_LandUse.shp	Crop classification for 2009 water year (attribute: Crop2009)
5	CuyamaValley_2006_LandUse.shp	Crop classification for 2006 water year (attribute: Crop2006)
6	CuyamaValley_2003_LandUse.shp	Crop classification for 2003 water year (attribute: Crop2003)
7	CuyamaValley_2000_LandUse.shp	Crop classification for 2000 water year (attribute: Crop2000)
8	CuyamaValley_1996_LandUse.shp	Crop classification for 1996 water year (attribute: Crop1996)
9	1995-10_ETa.tif	Raster image of total evapotranspiration (unit: mm) for October 1995
10	1995-11_ETa.tif	Raster image of total evapotranspiration (unit: mm) for November 1995
11	1995-12_ETa.tif	Raster image of total evapotranspiration (unit: mm) for December 1995
12	1996-01_ETa.tif	Raster image of total evapotranspiration (unit: mm) for January 1996
13	1996-02_ETa.tif	Raster image of total evapotranspiration (unit: mm) for February 1996
14	1996-03_ETa.tif	Raster image of total evapotranspiration (unit: mm) for March 1996
15	1996-04_ETa.tif	Raster image of total evapotranspiration (unit: mm) for April 1996
16	1996-05_ETa.tif	Raster image of total evapotranspiration (unit: mm) for May 1996
17	1996-06_ETa.tif	Raster image of total evapotranspiration (unit: mm) for June 1996
18	1996-07_ETa.tif	Raster image of total evapotranspiration (unit: mm) for July 1996
19	1996-08_ETa.tif	Raster image of total evapotranspiration (unit: mm) for August 1996
20	1996-09_ETa.tif	Raster image of total evapotranspiration (unit: mm) for September 1996
21	1996_total_ETa_mm.tif	Raster image of total evapotranspiration (unit: mm) for 1996 water year

22	2015-10_ETa.tif	Raster image of total evapotranspiration (unit: mm) for October 2015
23	2015-11_ETa.tif	Raster image of total evapotranspiration (unit: mm) for November 2015
24	2015-12_ETa.tif	Raster image of total evapotranspiration (unit: mm) for December 2015
25	2016-01_ETa.tif	Raster image of total evapotranspiration (unit: mm) for January 2016
26	2016-02_ETa.tif	Raster image of total evapotranspiration (unit: mm) for February 2016
27	2016-03_ETa.tif	Raster image of total evapotranspiration (unit: mm) for March 2016
28	2016-04_ETa.tif	Raster image of total evapotranspiration (unit: mm) for April 2016
29	2016-05_ETa.tif	Raster image of total evapotranspiration (unit: mm) for May 2016
30	2016-06_ETa.tif	Raster image of total evapotranspiration (unit: mm) for June 2016
31	2016-07_ETa.tif	Raster image of total evapotranspiration (unit: mm) for July 2016
32	2016-08_ETa.tif	Raster image of total evapotranspiration (unit: mm) for August 2016
33	2016-09_ETa.tif	Raster image of total evapotranspiration (unit: mm) for September 2016
34	2016_total_ETa_mm.tif	Raster image of total evapotranspiration (unit: mm) for 2016 water year
35	Reference_ETo	Reference ET for 1996 and 2016 water years
36	Cuyama Consumptive Use Report	Memorandum summarizing consumptive use efforts (this document)

References

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Attachment C-2

Climate Change Scenario Development

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1. CLIMATE CHANGE SCENARIO DEVELOPMENT

1.1 Regulatory Background

As prescribed in Section 354.18(d)(3) and Section 354.18(e) of the SGMA regulations, climate change conditions were incorporated into the projected water budgets for the Cuyama Valley Groundwater Basin *Groundwater Sustainability Plan*.

Section 354.18(d)(3) of the SGMA regulations state:

> *"(d) The Agency shall utilize the following information provided, as available, by the Department pursuant to Section 353.2, or other data of comparable quality, to develop the water budget:*
>
> *(1) Historical water budget information for mean annual temperature, mean annual precipitation, water year type, and land use.*
>
> *(2) Current water budget information for temperature, water year type, evapotranspiration, and land use.*
>
> *(3) Projected water budget information for population, population growth,* ***climate change****, and sea level rise."*

Section 354.18(e) of the SGMA regulations state:

> *"(e) Each Plan shall rely on the best available information and best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology, water demand, water supply, land use, population,* ***climate change****, sea level rise, groundwater and surface water interaction, and subsurface groundwater flow. If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater, the Plan shall identify and describe an equally effective method, tool, or analytical model to evaluate projected water budget conditions."*

Climate change analysis is an area with continued evolution in terms of methods, tools, forecasted datasets, and the predictions of actual greenhouse gas concentrations in the atmosphere. There is a large number of available combinations of these elements that result in many potential ways to evaluate climate change impacts. For the purposes of this GSP, the method proposed by the California Department of Water Resources (DWR) as a valid method of evaluation in its guidance document was considered adequate (DWR, 2018). Similarly, the "best available information" was deemed the information provided by DWR, customized for the method proposed.

The following resources from DWR were used to carry out the climate change analysis:

- SGMA Data Viewer
- Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development
- Sustainability Plan Development and Appendices (Guidance Document)
- Water Budget BMP
- Desktop IWFM Tools

SGMA Data Viewer provides the location for which the climate change forecasts datasets[1] were downloaded for the Cuyama subbasin (DWR, 2019). The guidance document details the approach, development, applications, and limitations of the datasets available from the SGMA Data Viewer (DWR, 2018). The Water Budget BMP describes in more granular detail how projected water budgets should be computed (DWR, 2016). The Desktop IWFM Tools are available to calculate the projected precipitation and evapotranspiration inputs under climate change conditions (DWR, 2018).

Generally, the methods suggested by DWR in the above resources were used, with a few exceptions to ensure the resolution and scale matched that of the historical and current water budgets. Figure C-2-1 shows the overall process consistent with the Climate Change Resource Guide (DWR, 2018) that describes workflow beginning with baseline historical conditions to perturbed 2070 conditions for the projected model run.

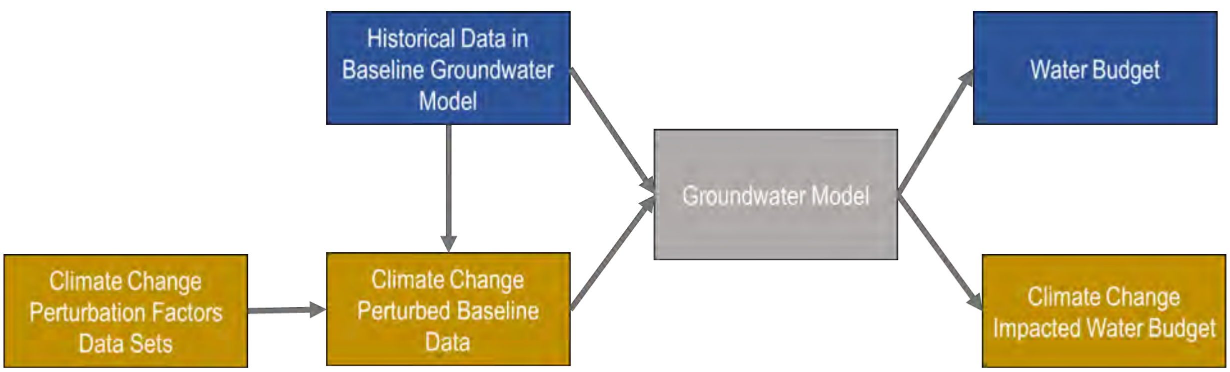

Figure C-2-1: Model Process

[1] In the industry, climate change impacted variable forecasts are sometimes referred to as "data" and their collections are called "datasets." Calling forecasted variable values "data" can be misleading, so this document tries to be explicit about data (i.e., historical data) versus forecasts or model outputs.

Table C-2-1 below summarizes the forecasted variable datasets provided by DWR that were used to carry out the climate change analysis (DWR, 2019).

Table C-2-1. DWR Forecasted Datasets

Input Variable	DWR-provided dataset
Precipitation	Change factors: VIC model-generated GIS grid with associated change factor time series for each cell
Reference ET	Change factors: VIC model-generated GIS grid with associated change factor time series for each cell

1.2 Climate Change Analysis Methodology

For climate change impacts on groundwater, accepted methods include the assessment of the impacts on the individual water resource system elements that are impacted and directly link to groundwater. These elements include precipitation, streamflow, evapotranspiration and, for coastal aquifers, sea level rise as a boundary condition. For Cuyama, sea level is not relevant. Additionally, in the Cuyama model does not have any stream inflows. For this reason, streamflow under climate change was not perturbed in this analysis.

The methods for perturbing the precipitation and evapotranspiration input files is described in the following sections. Two future scenarios were evaluated in this analysis, according to DWR guidance (DWR, 2018):

- Water Budget under 2030 central tendency conditions to assess near-future impacts of climate change.
- Water Budget under 2070 central tendency conditions to assess impacts of climate change over the long-term planning and implementation period.

1.2.1 Perturbed Precipitation under Climate Change

Projected precipitation change (perturbation) factors are provided by DWR, calculated using a climate period analysis based on historical precipitation from January 1915 to December 2011 (DWR, 2018). Change factors provided by DWR were calculated as a ratio of the value of a variable under a "future scenario" divided by a baseline. DWR used a macroscale hydrologic model that solves the full water and balance in a watershed, called the Variable Infiltration Capacity (VIC) Model. The baseline data corresponds to the 1995 historical template detrended scenario by the VIC model through global circulation model (GCM) downscaling. The "future scenario" corresponds to VIC outputs of the simulation of future conditions using GCM forecasted hydroclimatic variables as inputs. These change factors are thus a simple perturbation factor that corresponds to the ratio of a future with climate change divided by the past without it. Change factors are available on a monthly time step and spatially defined by the VIC model grid. Supplemental tables with the time series of perturbation factors are available by DWR for each grid cell.

Because the Cuyama model has a daily time step, the historical baseline time series (water year 1960 to water year 2017) was aggregated monthly. DWR change factors, or perturbation factors, were then multiplied by historical baseline precipitation to generate projected precipitation under 2030 and 2070 central tendency future scenarios using the Desktop IWFM GIS tool (DWR, 2018). The tool calculates an area weighted precipitation change factor for each model grid geometry. This model grid geometry was generated based on polygons generated around the PRISM nodes that are within the model region.

However, the DWR tool only includes change factors through 2011. The remaining five years of the time series were synthesized according to historically comparable water years. The perturbation factor from the corresponding month of the comparable year was applied to the baseline of the missing years (i.e., 2012 to 2017) to generate projected values. Months with no precipitation in the baseline were assumed a monthly precipitation of 1 millimeter under climate change to account for increased precipitation that cannot be calculated from a baseline of 0 millimeter for these synthesized years. Table C-2-2 below shows the comparable water years assigned for each missing year.

Table C-2-2. Water Years Assigned for Missing Years

Water Year with Missing Change Factors	Comparable Water Year on Record	
	April to September	October to March
2012	1987	2009
2013	1990	1990
2014	1990	1989
2015	2001	1990
2016	1990	1989
2017	1990	1990

Applying Change Factors to Precipitation and ET

DWR datasets include scenarios for 2030 and 2070 timeframes and for conditions similar to historical in terms of precipitation forecasted (central tendency) and conditions wetter and drier. All scenarios available present higher future temperatures. The team selected the 2070 central tendency forecasted conditions for the analysis.

After applying the change factor to the model simulation period (baseline) analysts obtained the precipitation and evapotranspiration under climate change. The resulting perturbed precipitation values and the baseline precipitation values can be found in Figure C-2-2 below. The exceedance plot for these two times series can be found in Figure C-2-3.

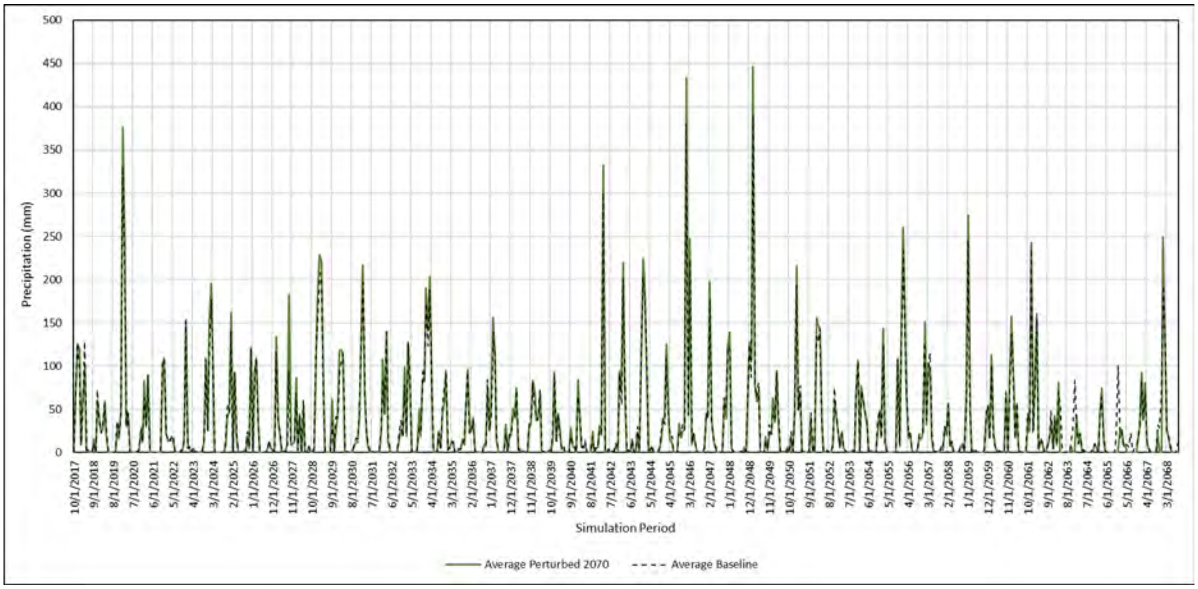

Figure C-2-2. Precipitation Perturbation Factors as Compared to Baseline Values

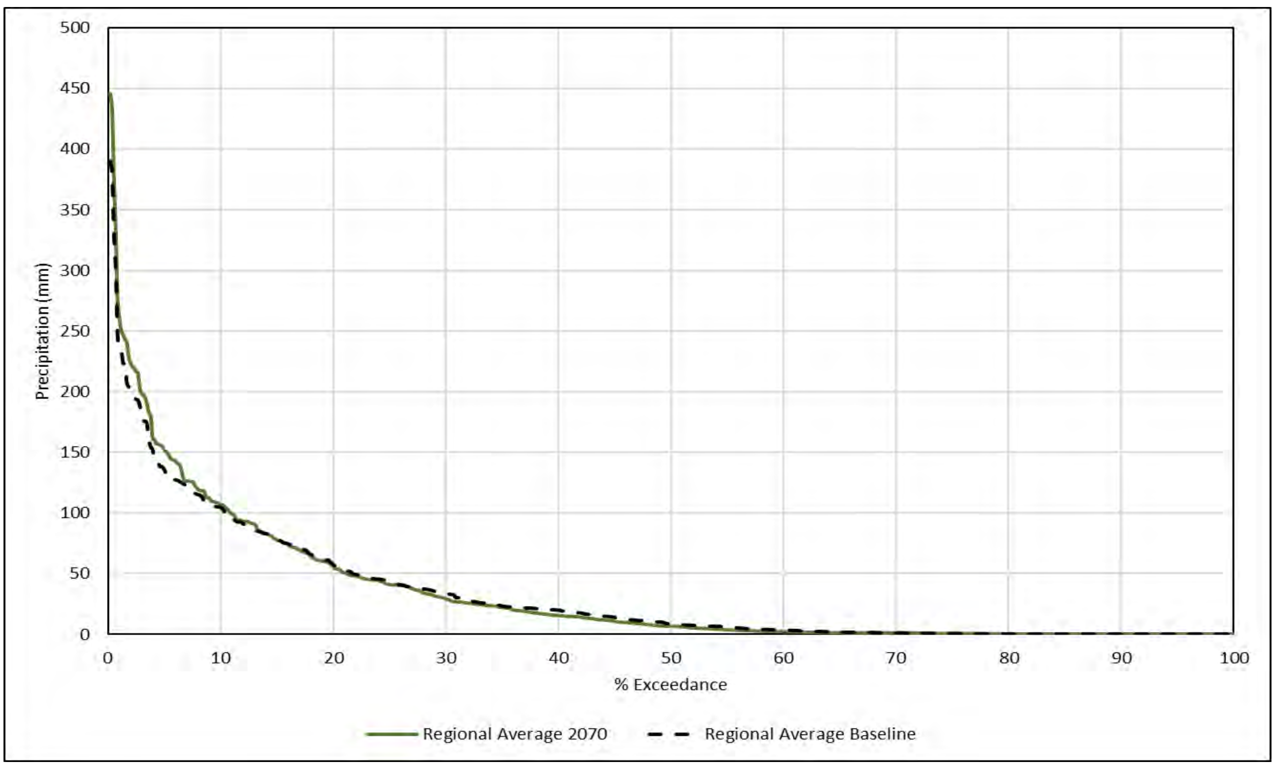

Figure C-2-3. Exceedance of Precipitation Perturbation Factors as Compared to Baseline Values

Figure C-2-4 shows the difference between the regional average under 2070 climate change conditions and the regional average under historical baseline conditions plotted against different amounts of projected monthly precipitation.

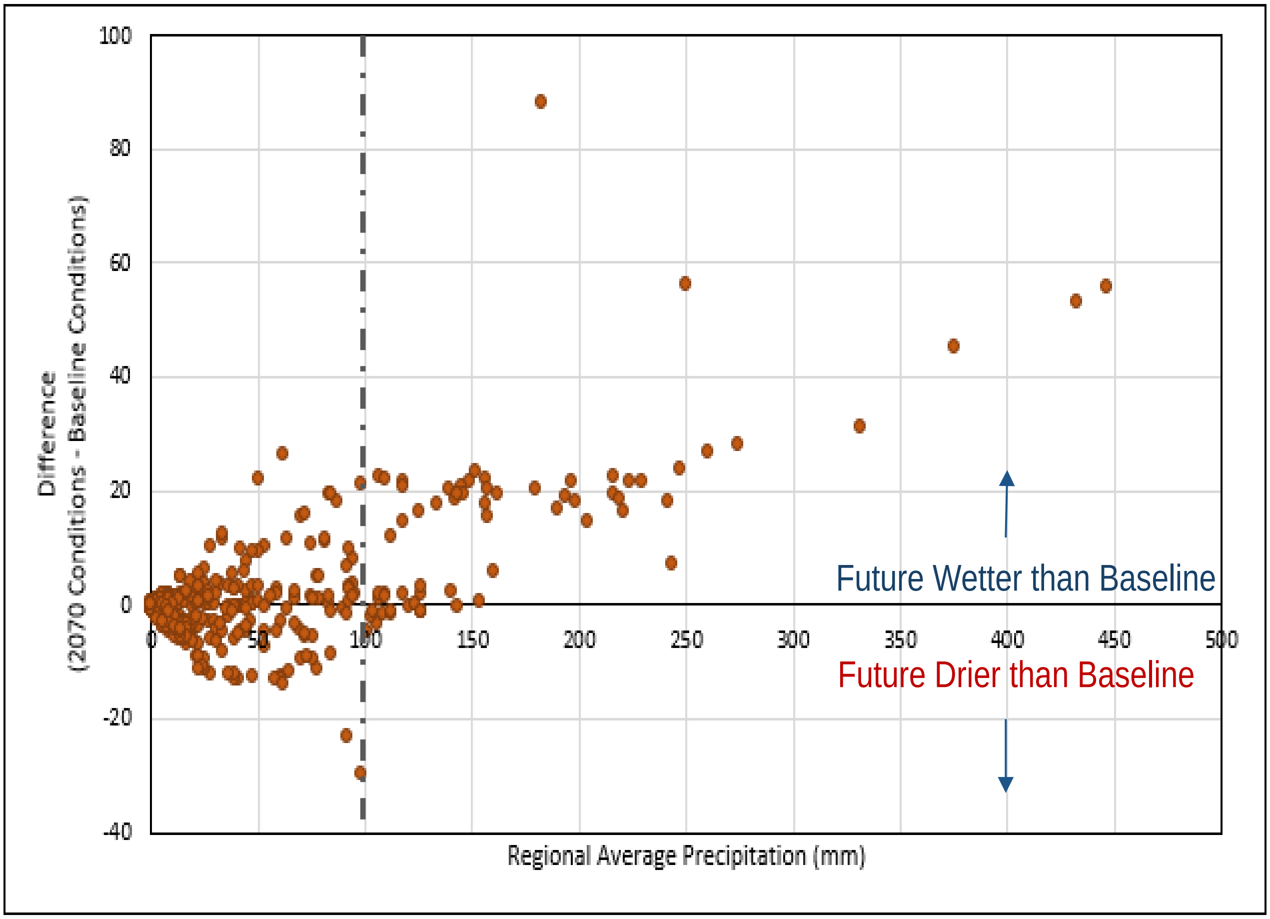

Figure C-2-4. Difference in Monthly Precipitation Estimates as Compared to Baseline Values

This plot demonstrates that in 2070 with climate change added, in low precipitation months, there is approximately equal probability that the month will be wetter or drier than historical conditions. However, under climate change, the 2070 conditions will be always wetter on average in months with precipitation above approximately 100mm. Therefore, under climate change conditions, the occurrence of low precipitation months will likely not change, but the higher precipitation months will be wetter overall than the baseline.

It is important to note that, while the central tendency scenario shows limited changes in future precipitation compared to historical record, the drier and wetter scenarios do show more variability. Figure C-2-5 shows the exceedance curve for the wet scenario and it shows a larger difference to baseline compared to the central tendency. The use of other scenarios can be explored in future GSP updates.

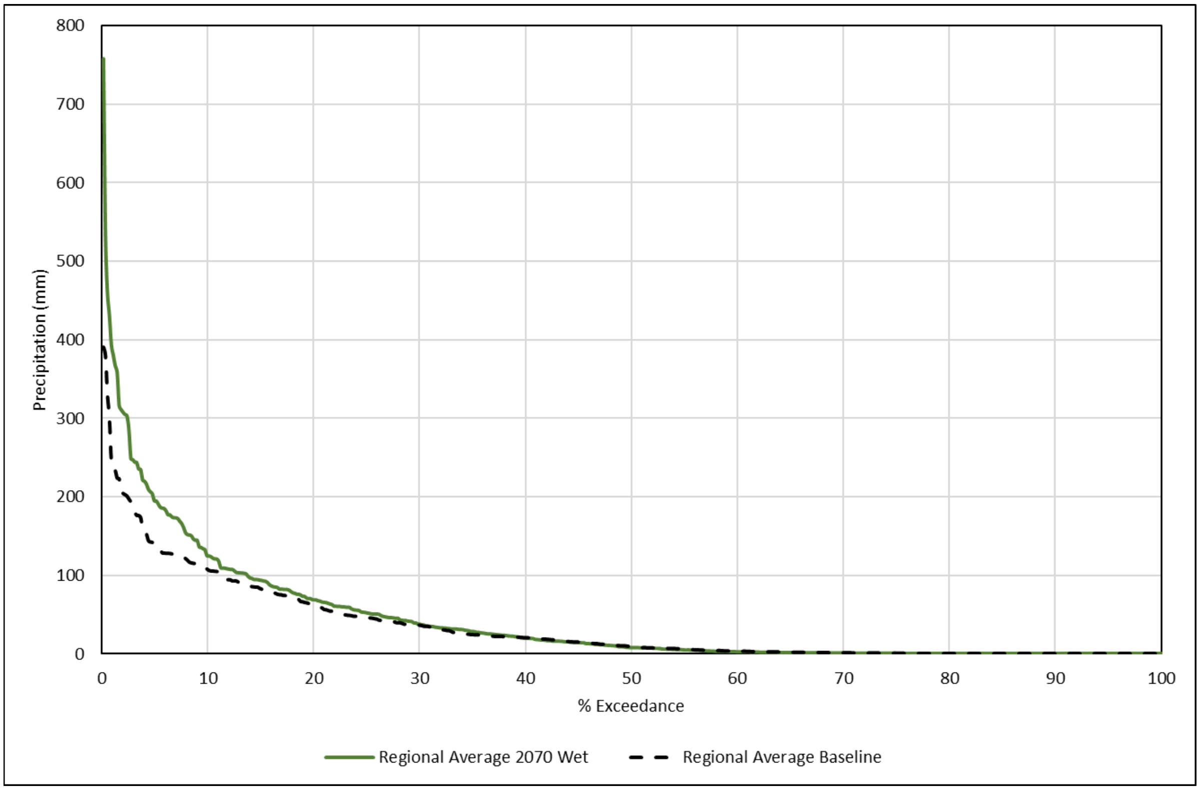

Figure C-2- 5. Exceedance of Wet Scemario Precipitation Estimates as Compared to Baseline Values

Perturbed Evapotranspiration under Climate Change

Reference evapotranspiration (ET) is differentiated only by crop in the Cuyama model. However, because there is no spatial component to ET, the same crop in a different part of the basin is modeled with the same ET. Change factors for ET are available in the same spatially distributed manner as precipitation, as described above. However, to match the level of discretization with the Cuyama model, an average ET change factor was calculated across all VIC grid cells within the Cuyama Subbasin boundary. Therefore, the tool to process ET provided by DWR was not needed or used. Change factors provided by DWR for water year 1964 through December 1, 2011 were averaged. This average ET change factor was then applied to the baseline ET time series for each crop type. Because the same ET change factor was applied over the entire baseline time series, no synthesis was required in this analysis.

- For 2030, average change factor is: **1.03**
- For 2070, average change factor is: **1.07**

To better show the impact of climate change, a sample of years (1994 and 1995) for one crop (melons) is included in Figure C-2-6. Figure C-2-7 shows the exceedance curve for these estimates.

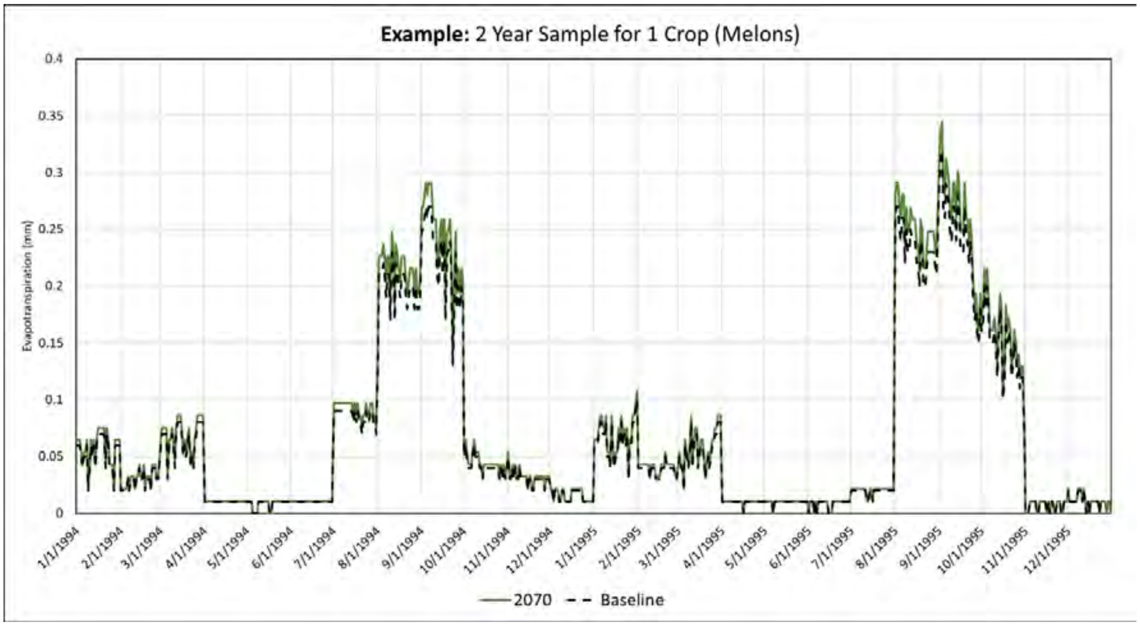

Figure C-2-6. Changes in Melon Evapotranspiration in 1994 and 1995 as Compared to Baseline Values

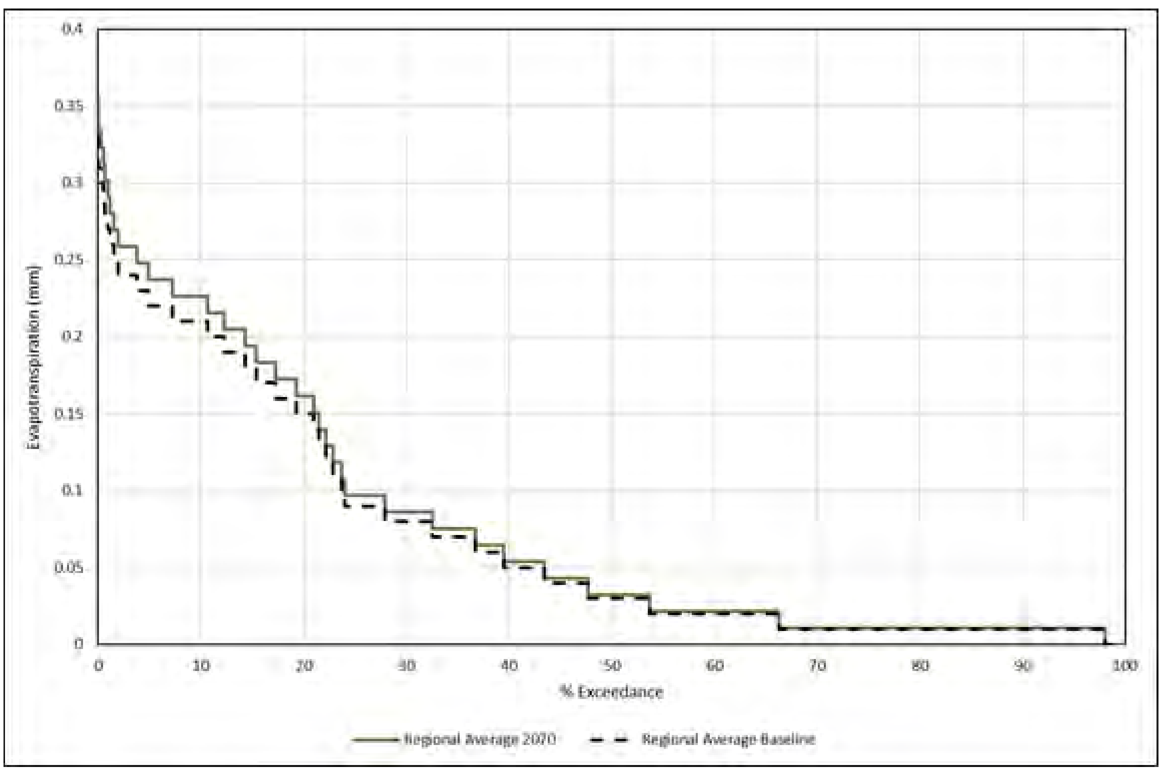

Figure C-2-7. Exceedance of Melon Evapotranspiration in 1994 and 1995 as Compared to Baseline Values

Considerations for this Analysis

By using DWR's climate change datasets, this GSP has chosen to use a climate period analysis. A "period of analysis" method is what DWR proposes since it provides an intuitive way to compare the past and future conditions, preserving historical temporal trends. Under a period of analysis (sometimes referred to as the "delta method") precipitation and Crop ET patterns from the past are mirrored into the future and shifted either higher or lower in magnitude (DWR, 2018). When using a period of analysis method, any difference between the baseline historical conditions and the projected conditions can be attributed only to climate change.

Using a climate period analysis in contrast to a transient analysis, however, brings also some disadvantages. While a significant advantage of this method is that the climate change signal can be isolated from signals of other impacts, temporal changes in the water resources system are ignored in favor of adopting the temporal trends of the past. In a continuously changing and variable climate in California, this approach incurs significant disadvantages. Inter-annual variability in the climate period analysis follows the exact patterns of the historical period it references. Shifting seasonality of precipitation, peak snowmelt, and temperature, are important climate impacts expected through the GSP planning horizon that are not captured in the projected water budget (Langridge, Sepaniak, Fencl, & Mendez, 2018) (PPIC, 2019). Longer drought period than have been recorded historically are also expected according to many climate experts (PPIC, 2019). These changes are also not captured.

Opportunities for Future Refinement

The regulations dictate that GSPs reflect the best available science to make climate change projections. For future GSP updates, climate change analysis incorporation should build off of this baseline work to continually improve projections into the future. Some refinements or modifications may include:

- Use other scenarios (dry and wet) in addition to the central tendency scenario
- Use a transient method as opposed to a period of record method
- Incorporate paleohydrology observations and make inferences about the impacts of longer droughts captured in the paleorecord

1.3 References

DWR. (2016). *Best Management Practices for the Sustainable Management of Groundwater Water Budget.*

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DWR. (2018). *Guidance for Climate Change Data Use During Groundwater Sustainability Plan Development.*

DWR. (2018, December 13). *SGMA Climate Change Resources*. Retrieved from https://data.cnra.ca.gov/dataset/sgma-climate-change-resources

DWR. (2019). *SGMA Data Viewer*. Retrieved from https://sgma.water.ca.gov/webgis/?appid=SGMADataViewer

Langridge, R., Sepaniak, S., Fencl, A., and Mendez, L.-E. (2018). Adapting to Climate Change and Drought in Selected California Groundwater Basins: Local Achievements and Challenges. *California's Fourth Climate Change Assessment*.

PPIC. (2019). *Climate Change*. Public Policy Institute of California. Retrieved from https://www.ppic.org/wp-content/uploads/californias-future-climate-change-january-2019.pdf

Attachment C-3

Groundwater Level Hydrographs for Calibration Wells

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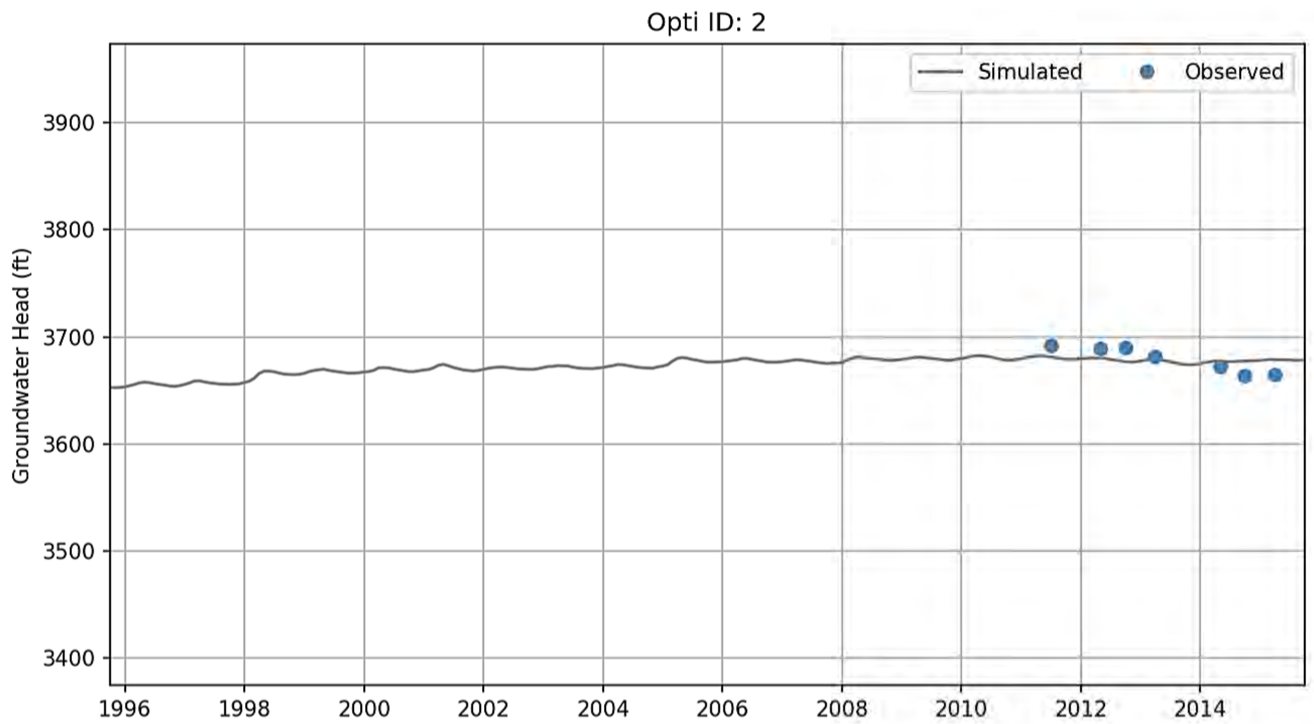
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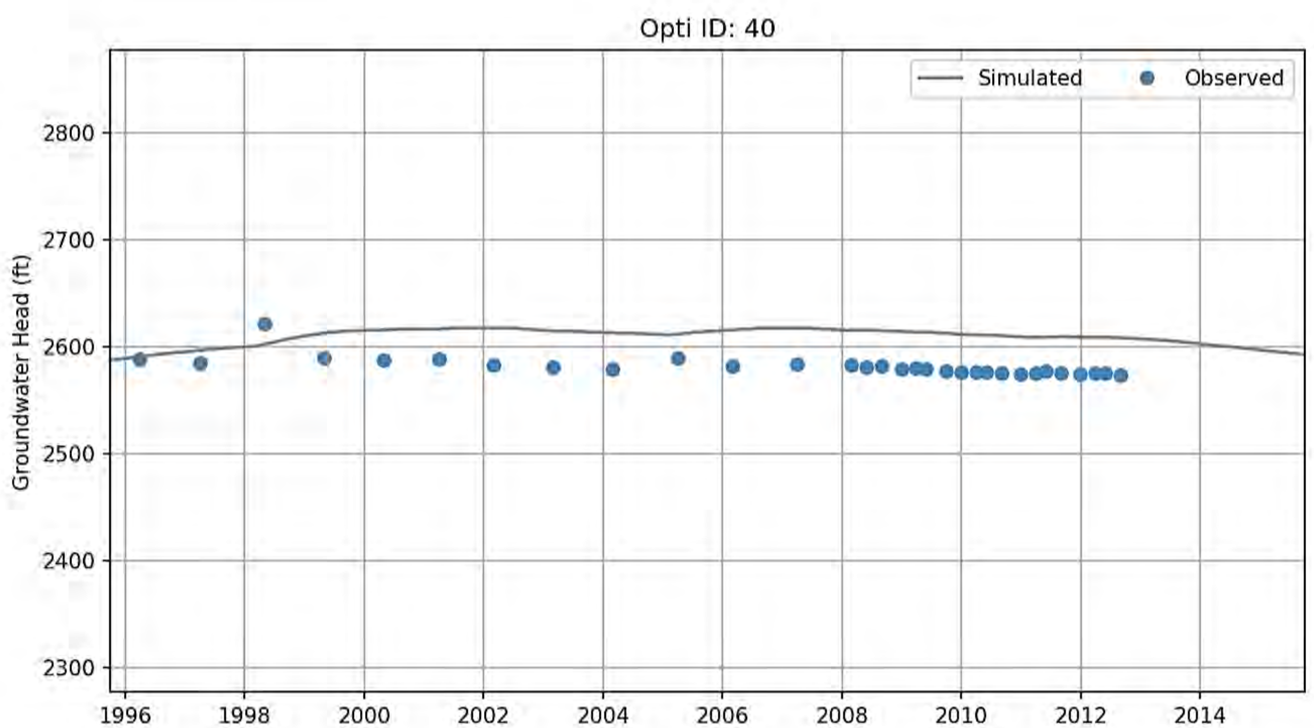
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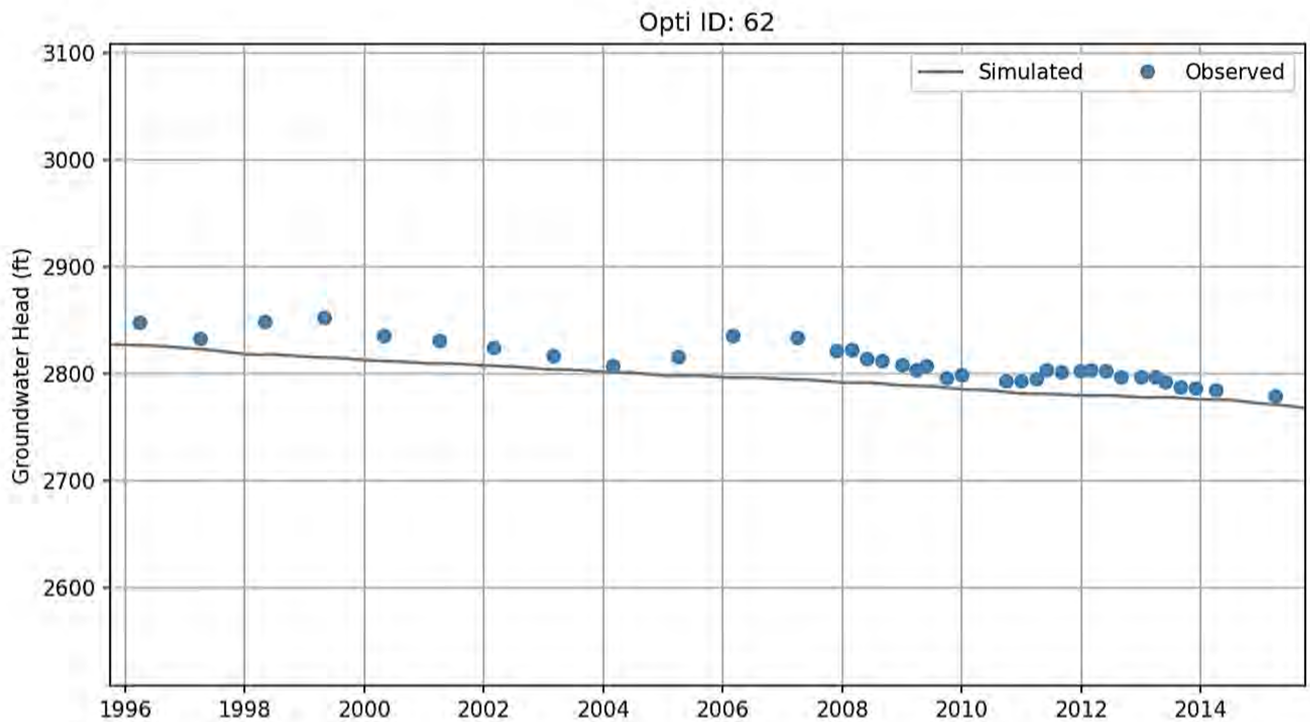
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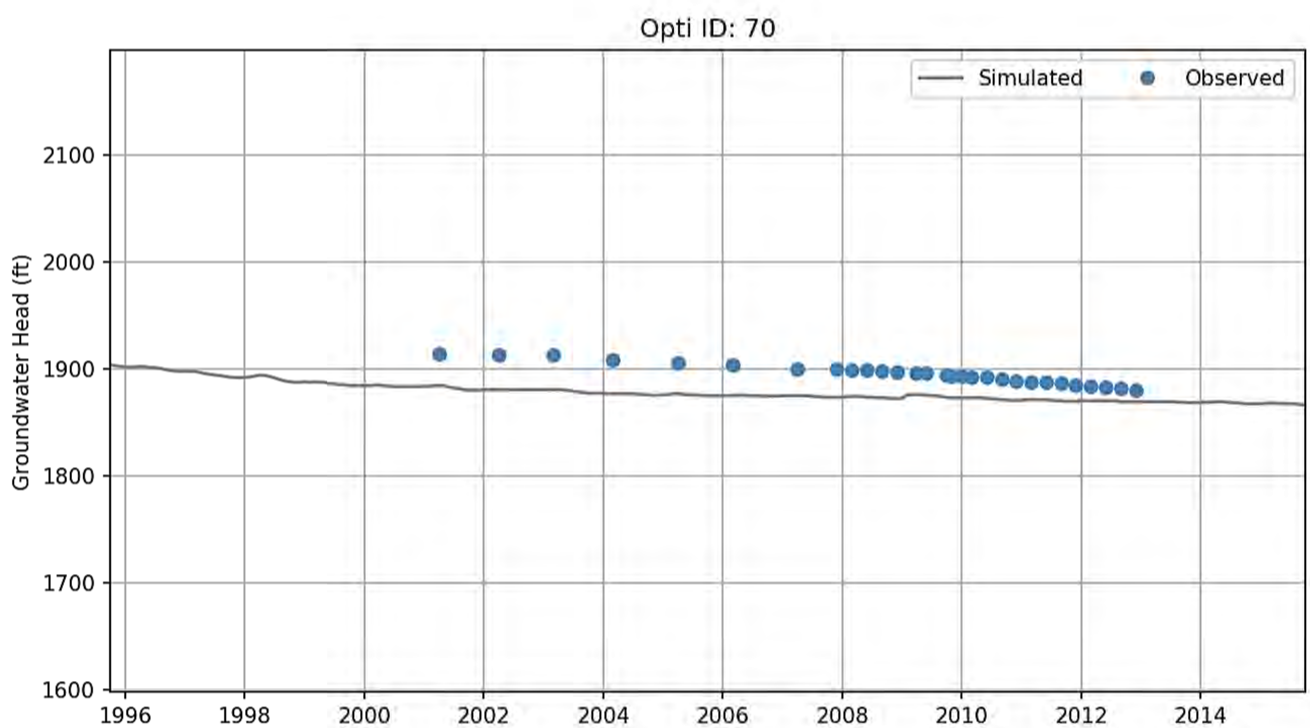
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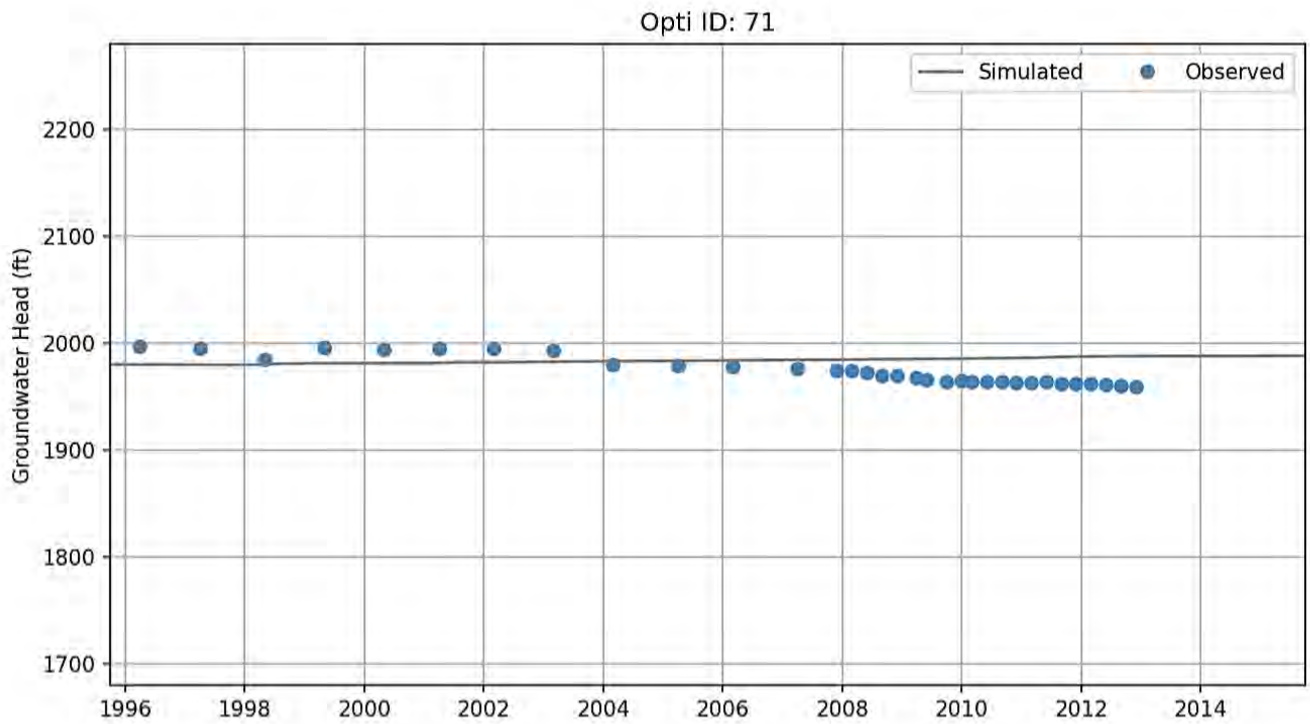
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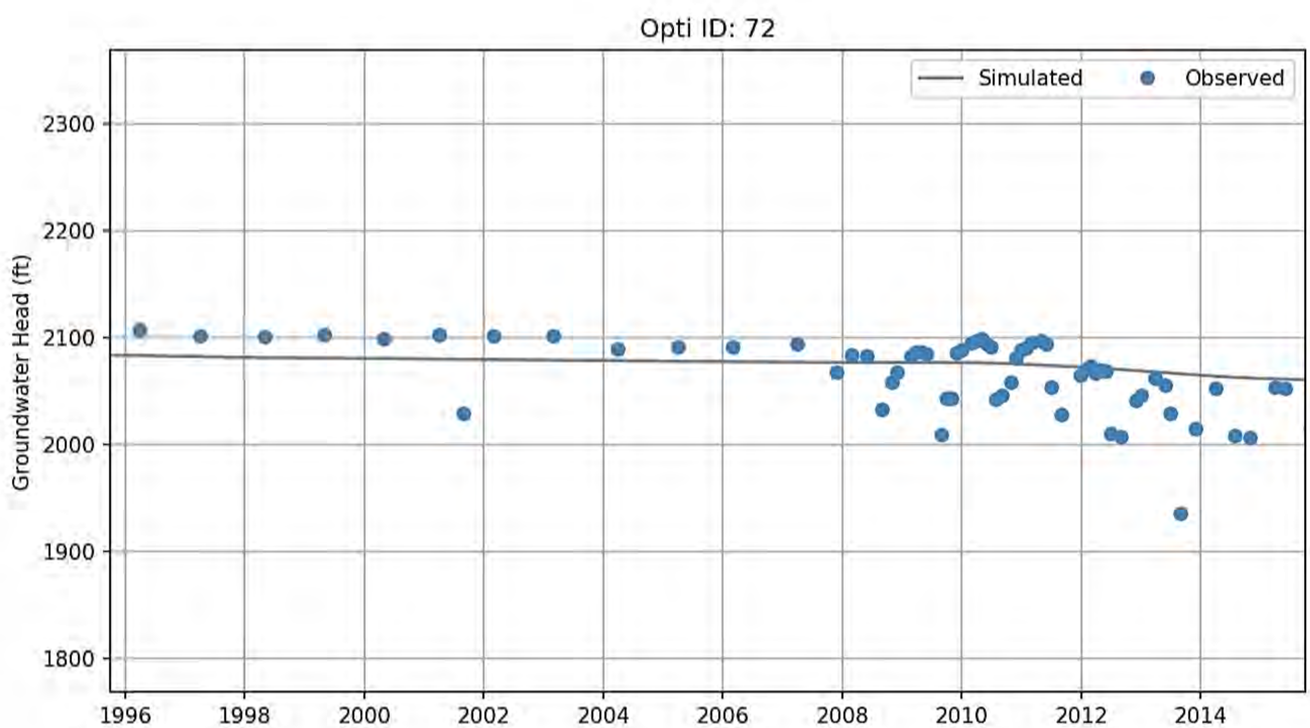
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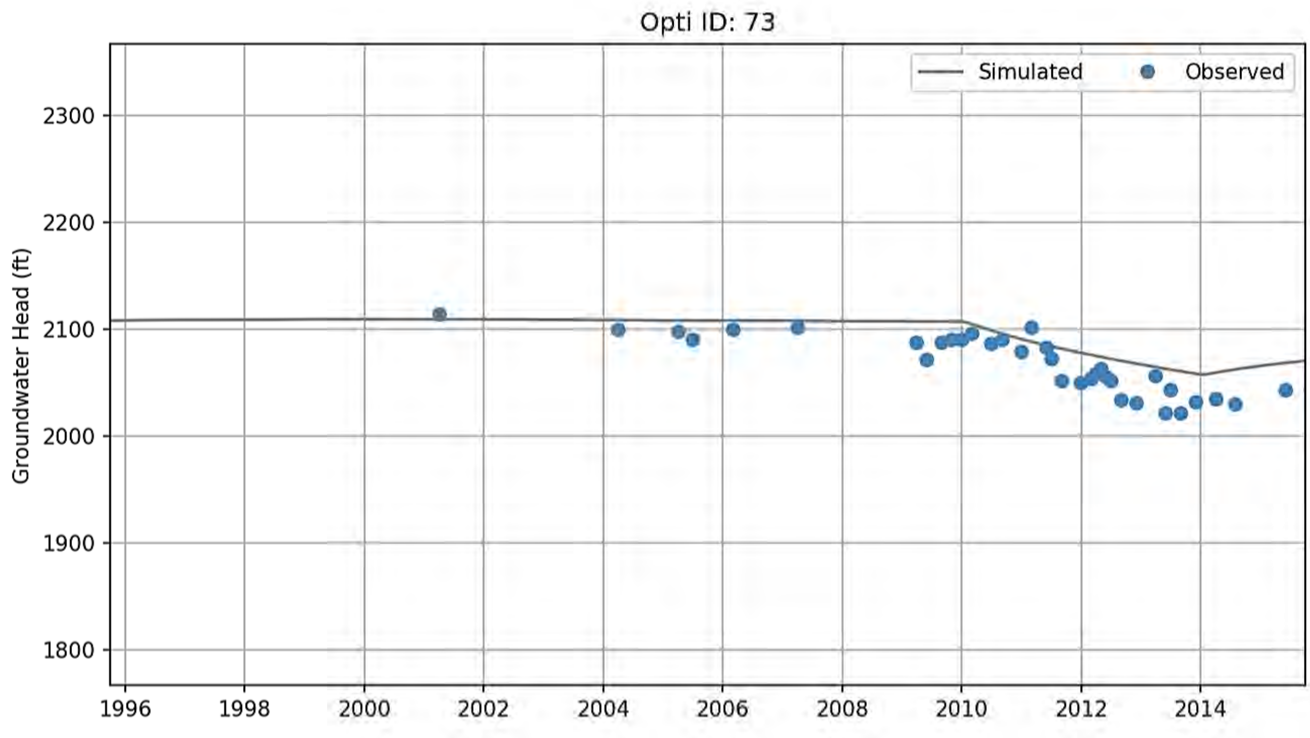
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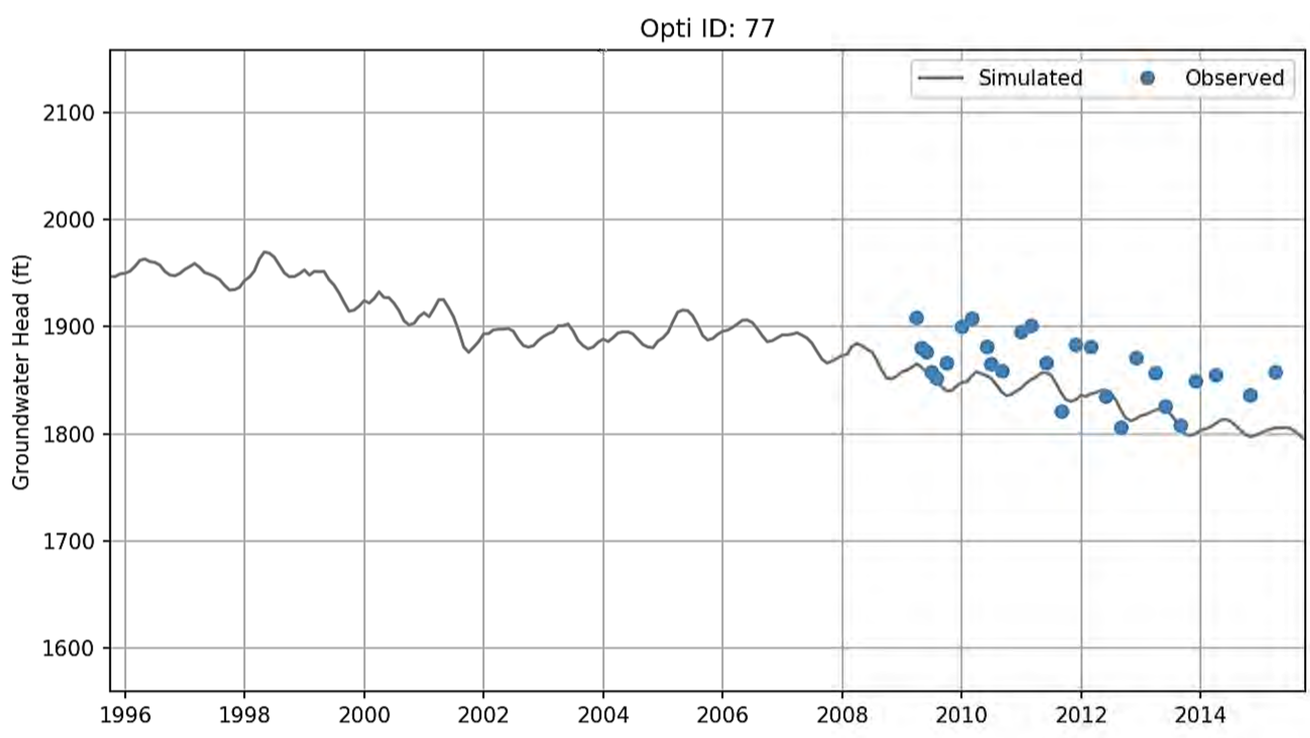
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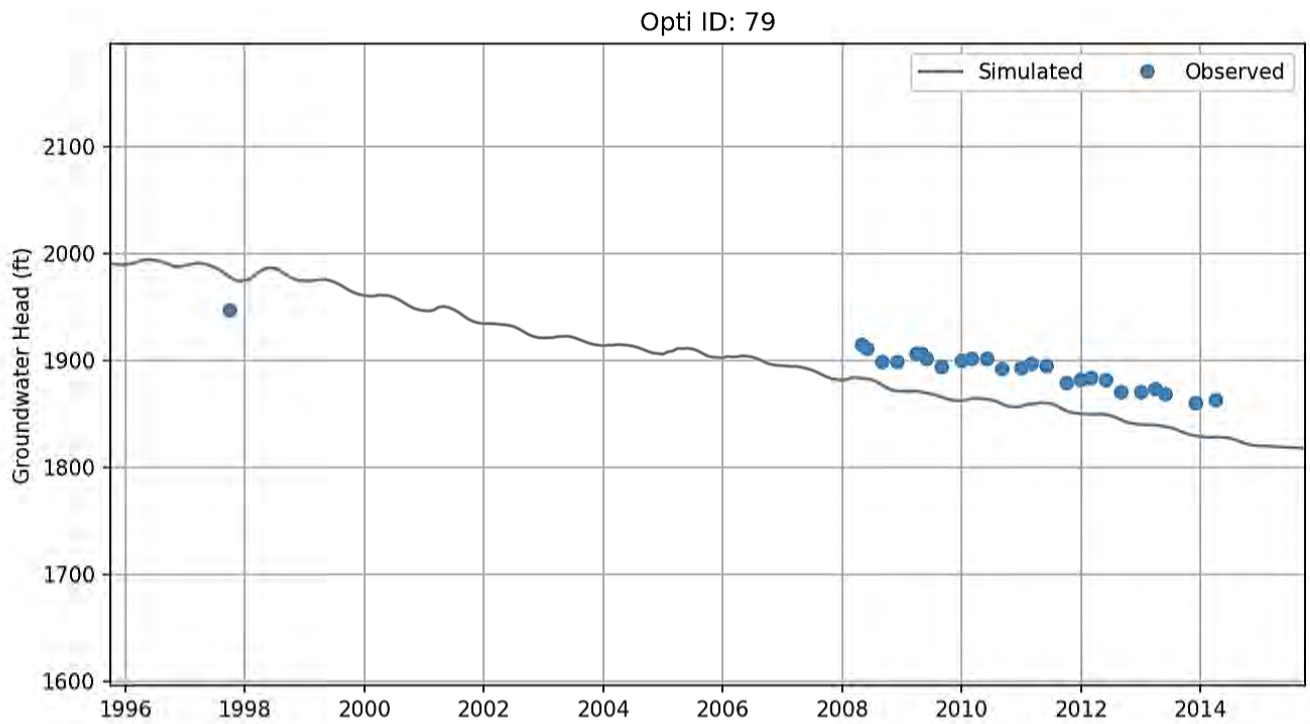
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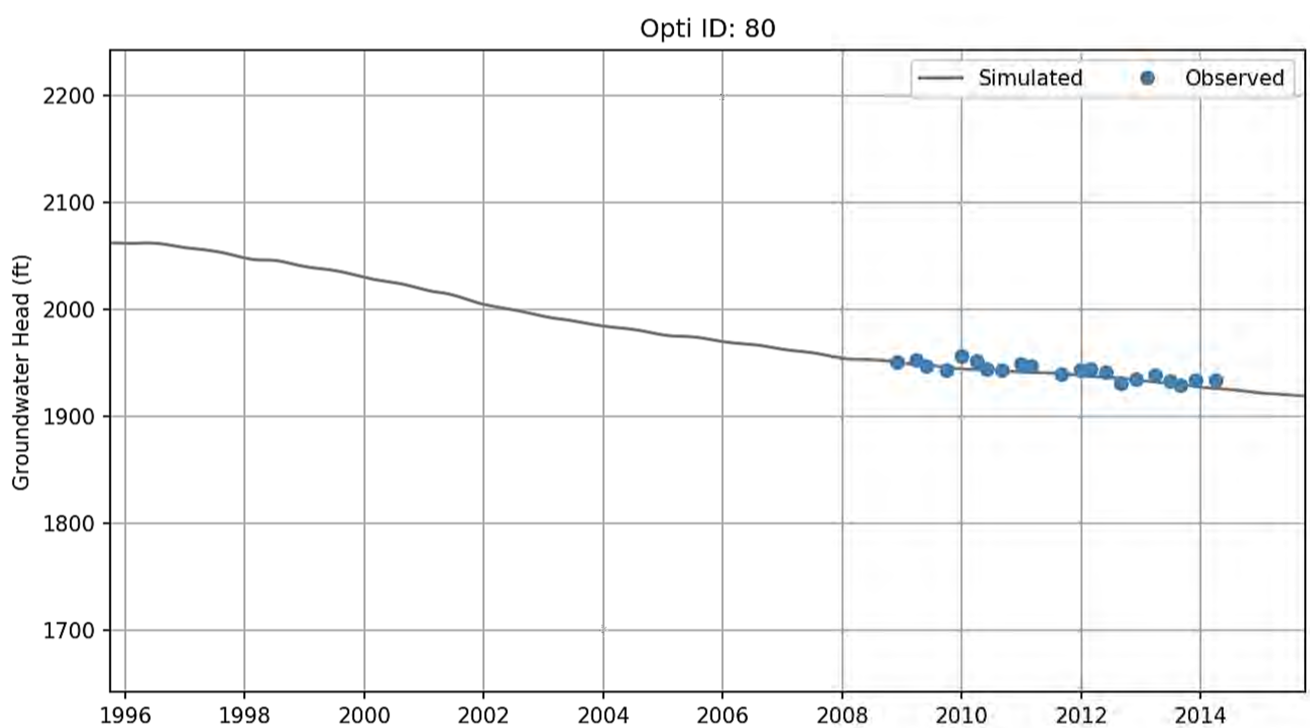
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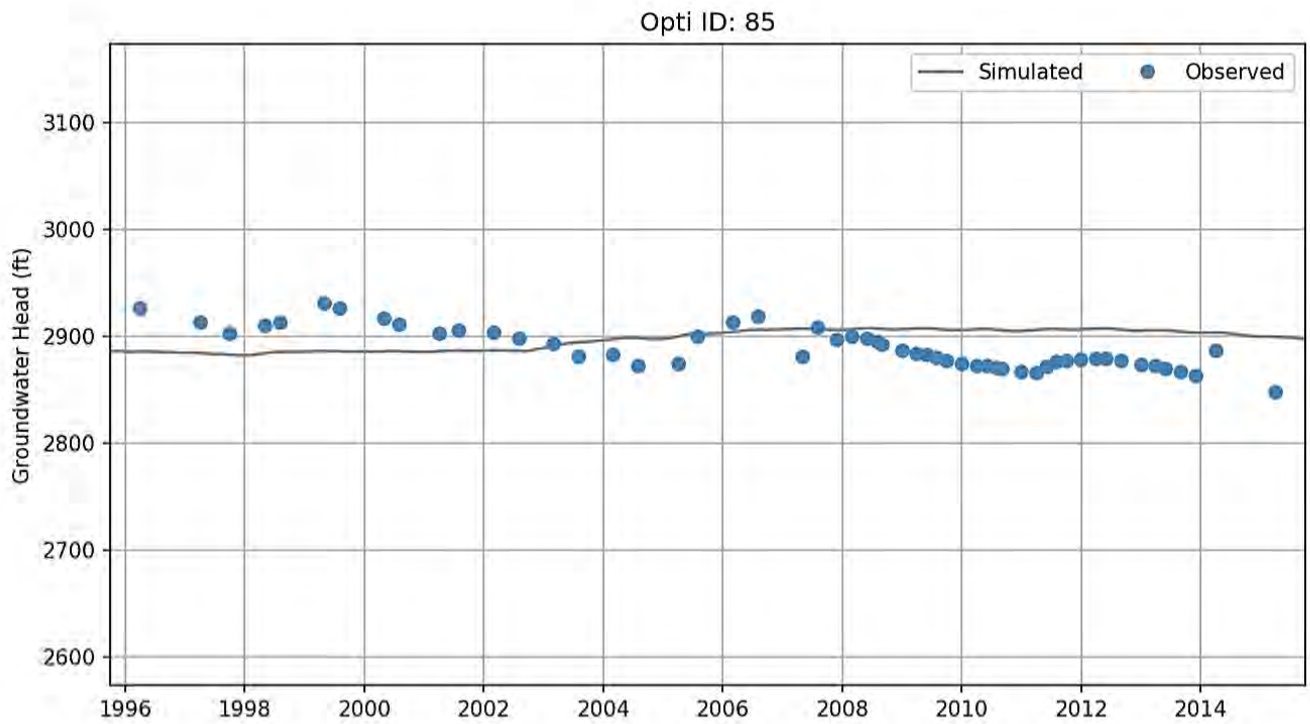
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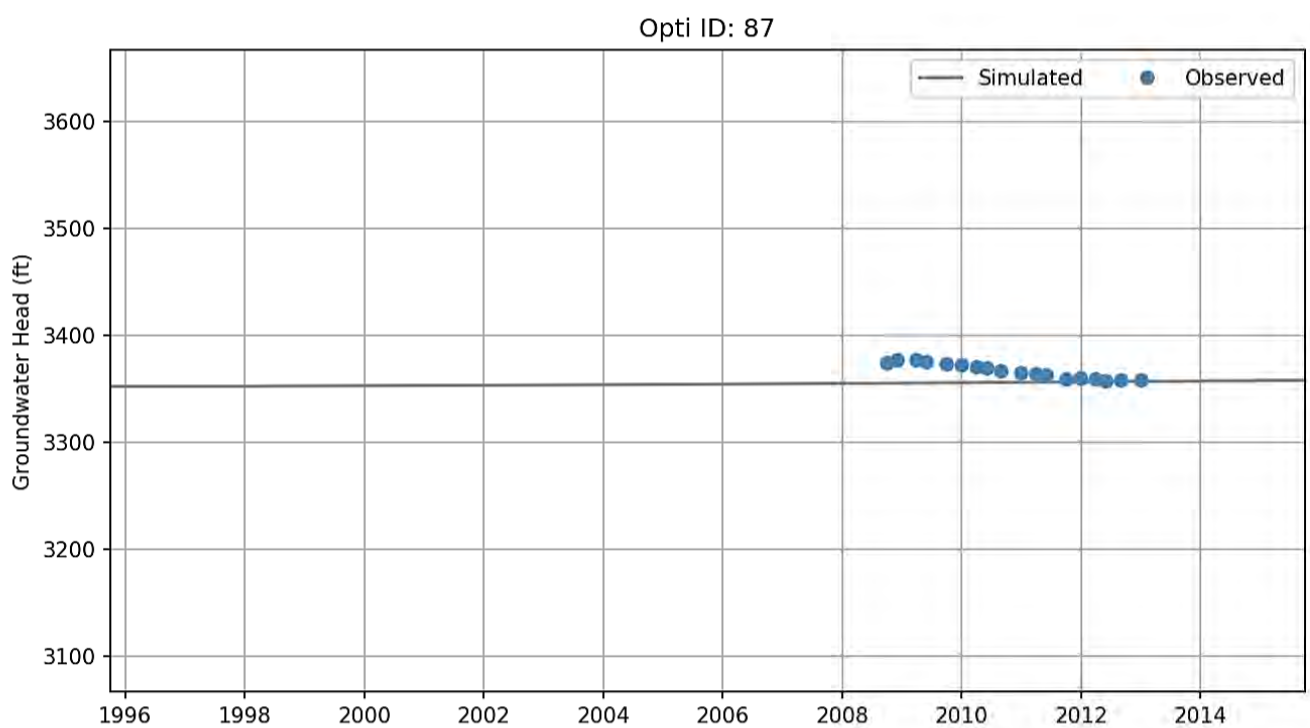
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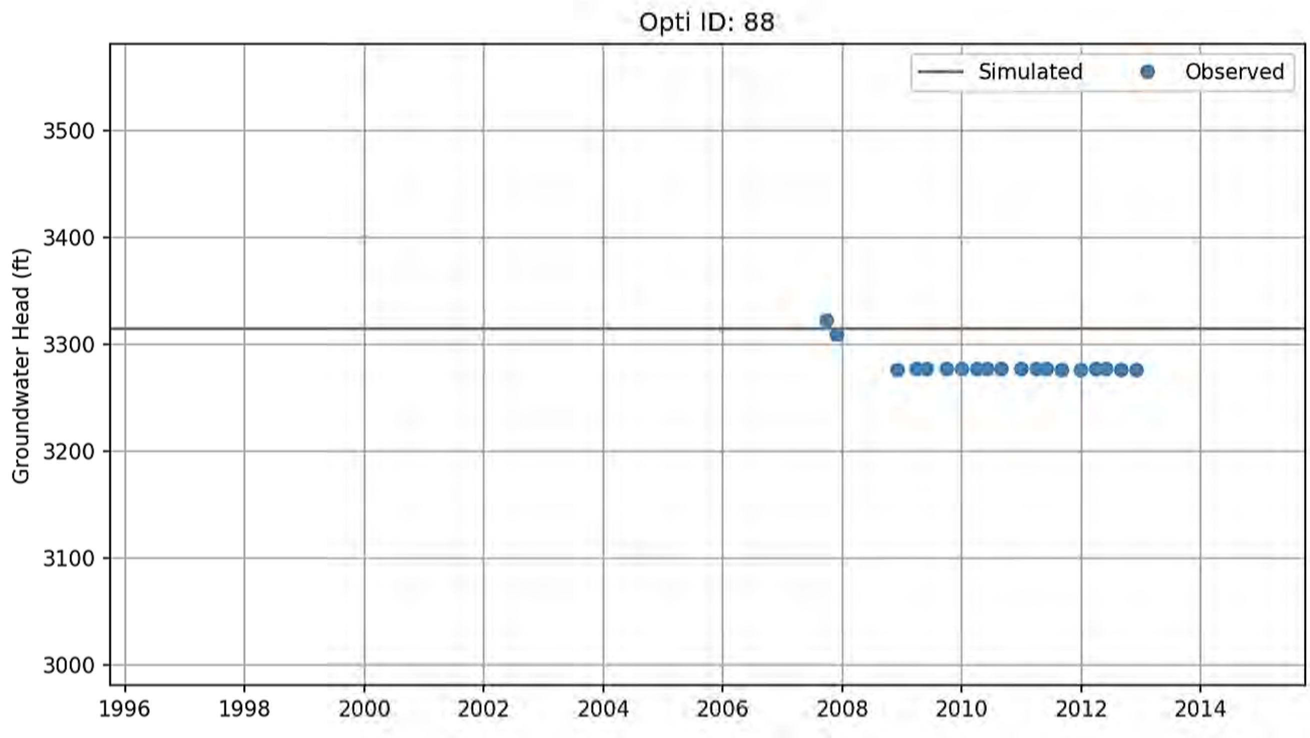
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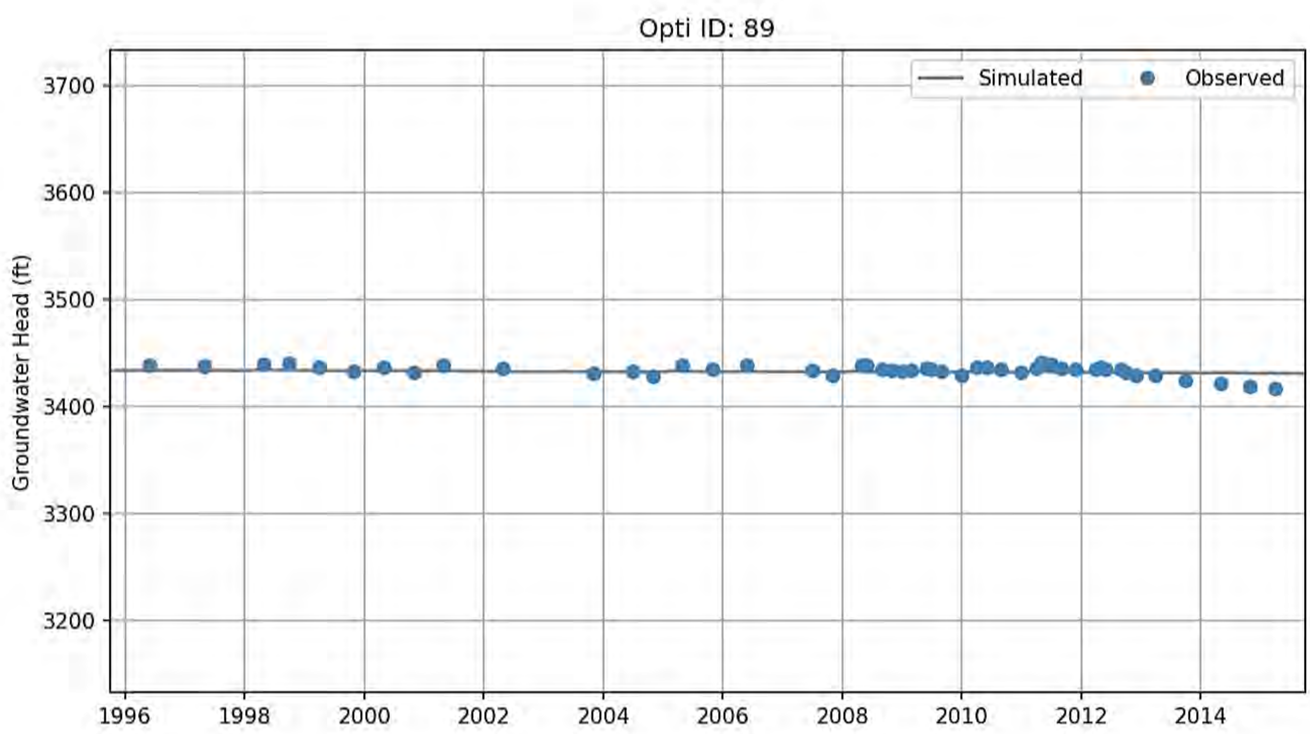
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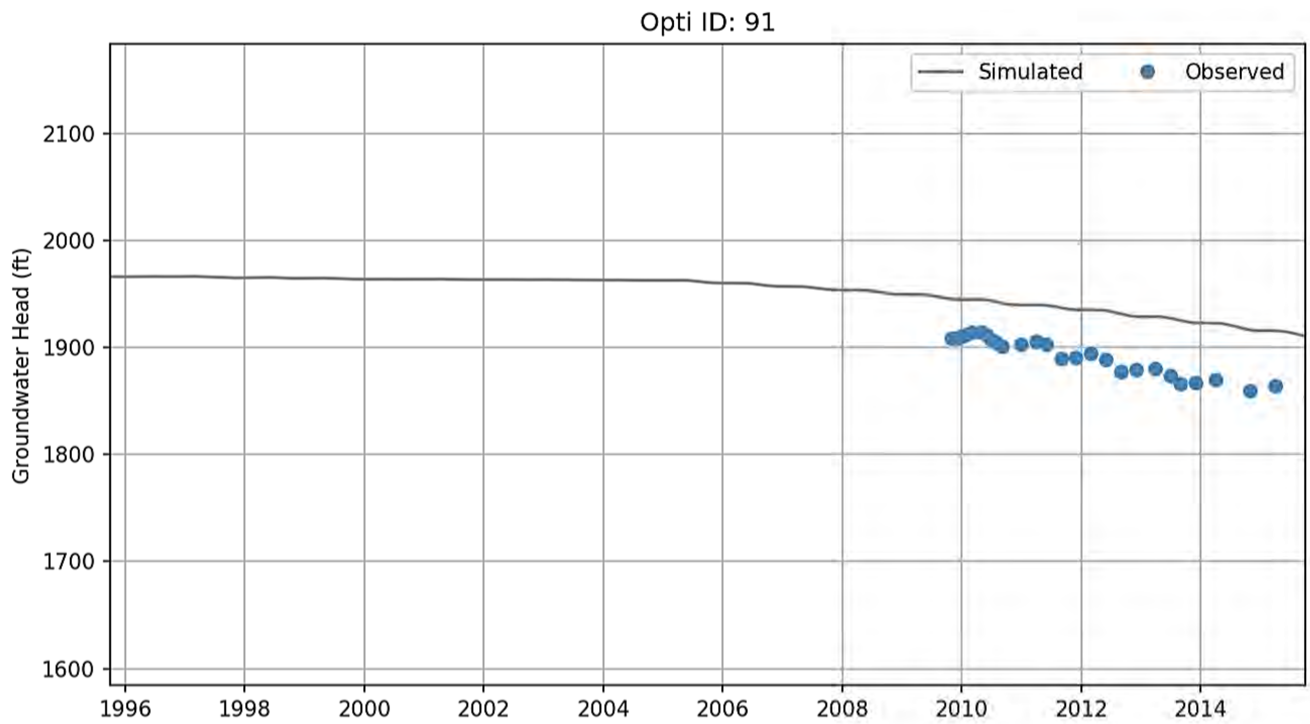
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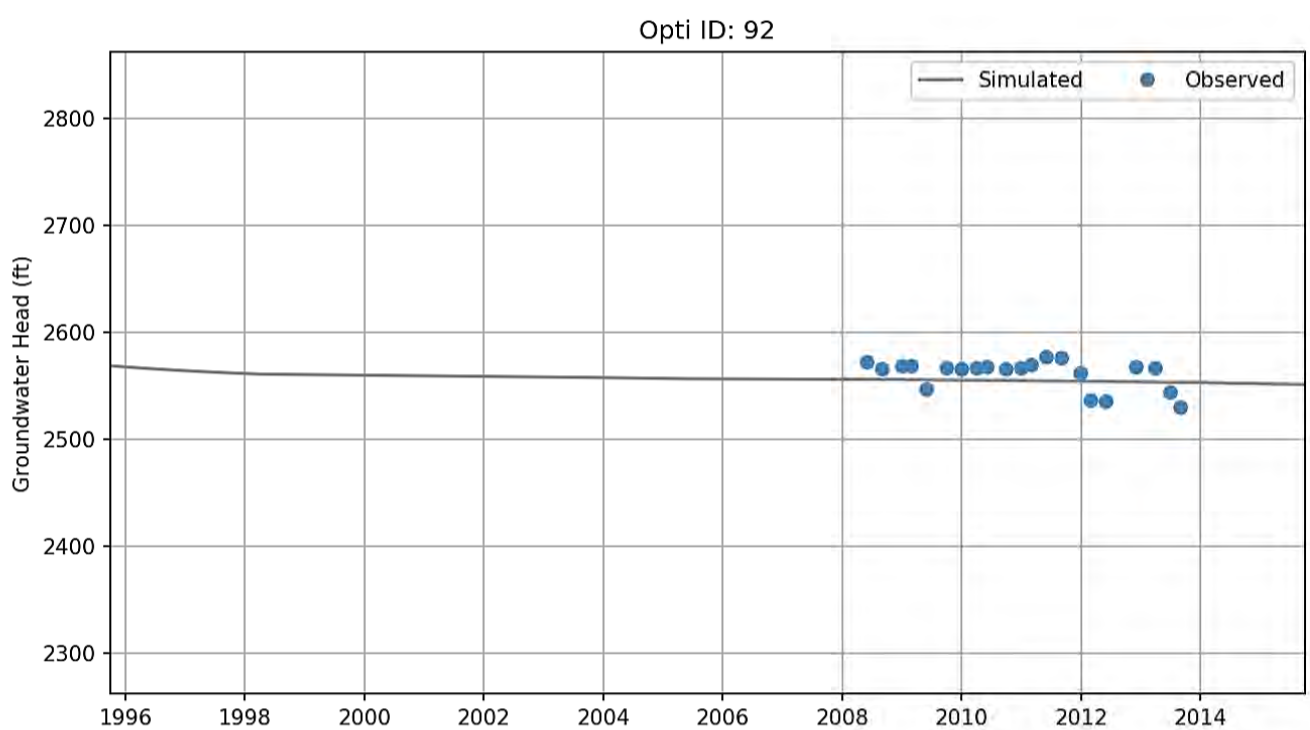
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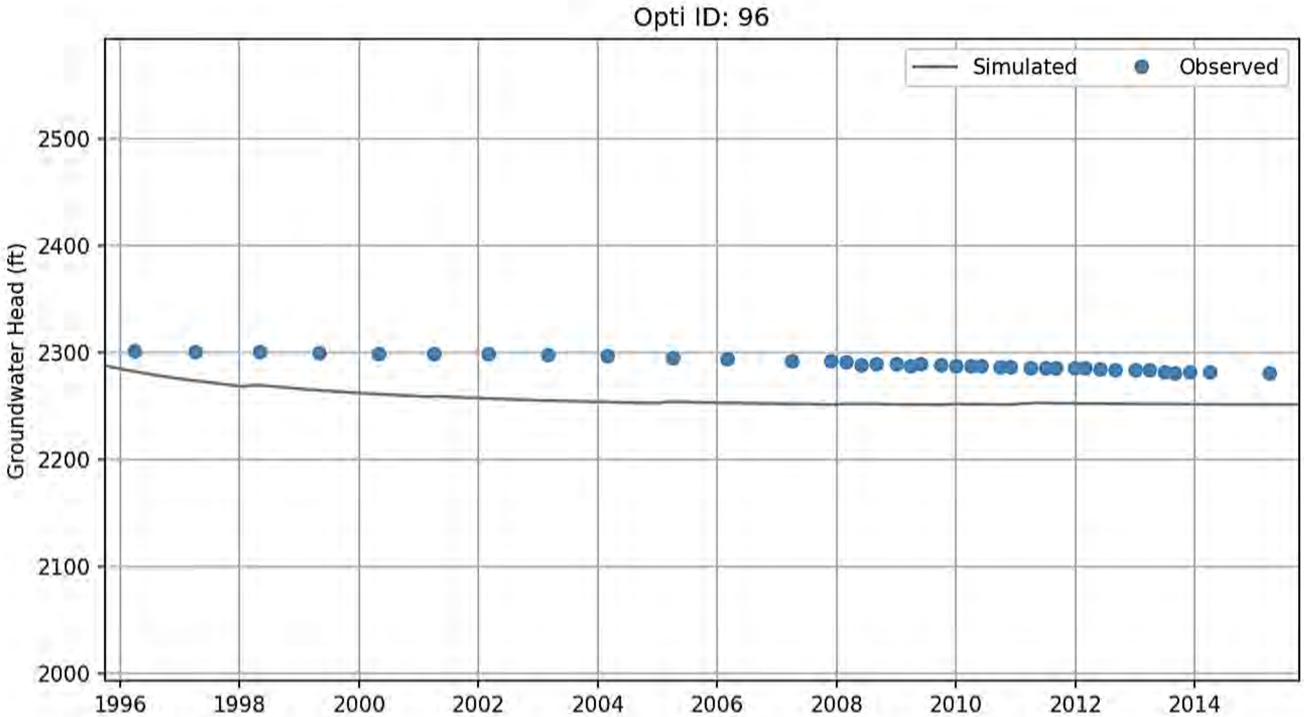

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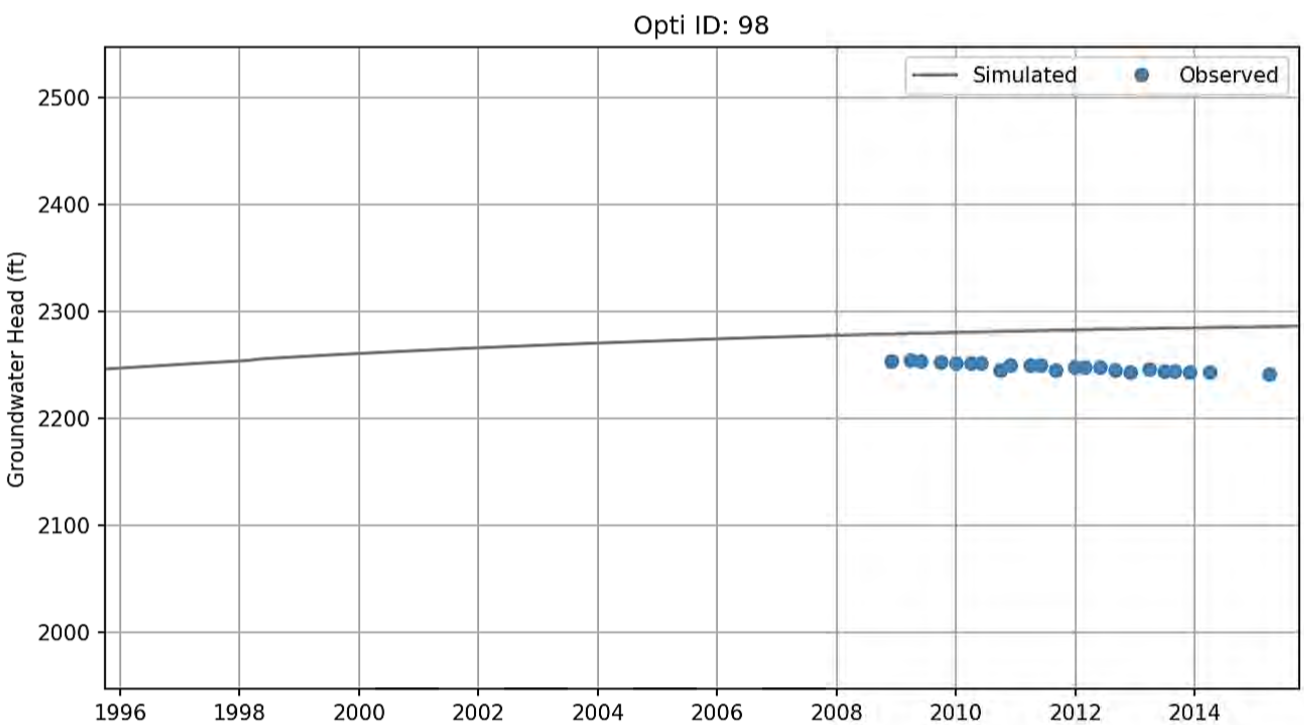

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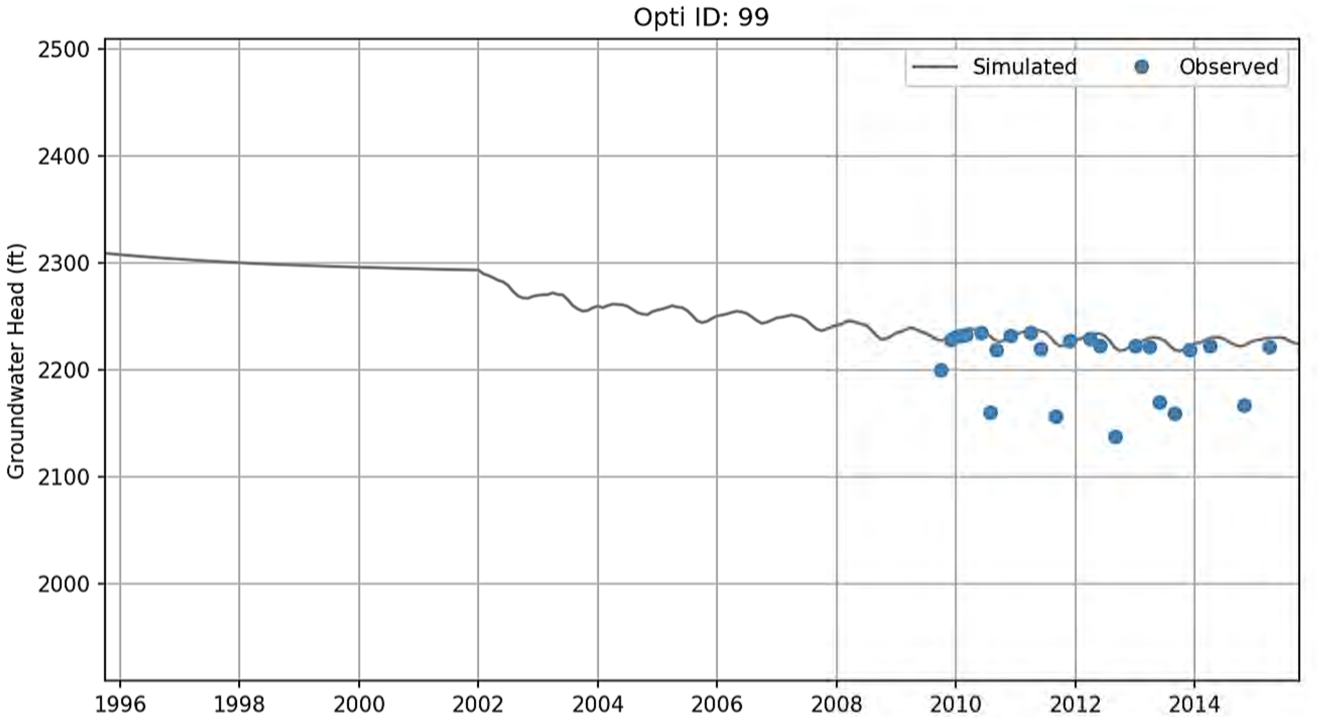

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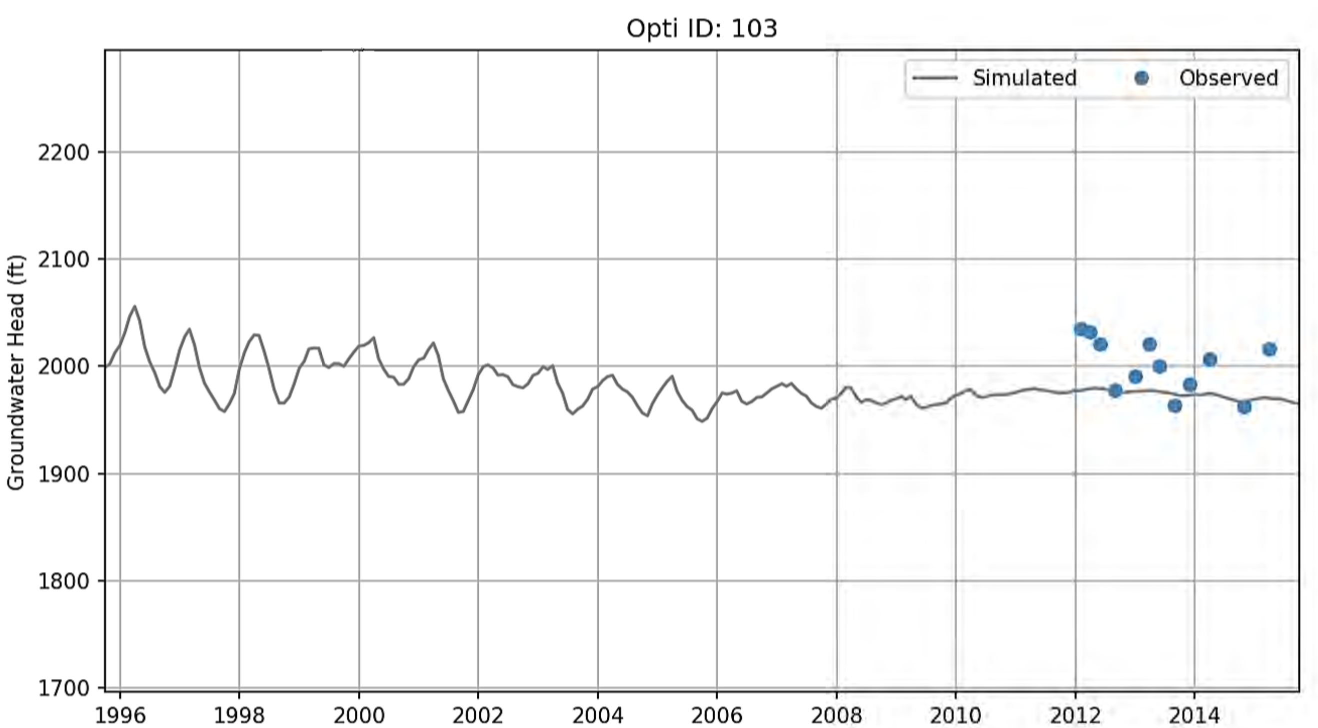

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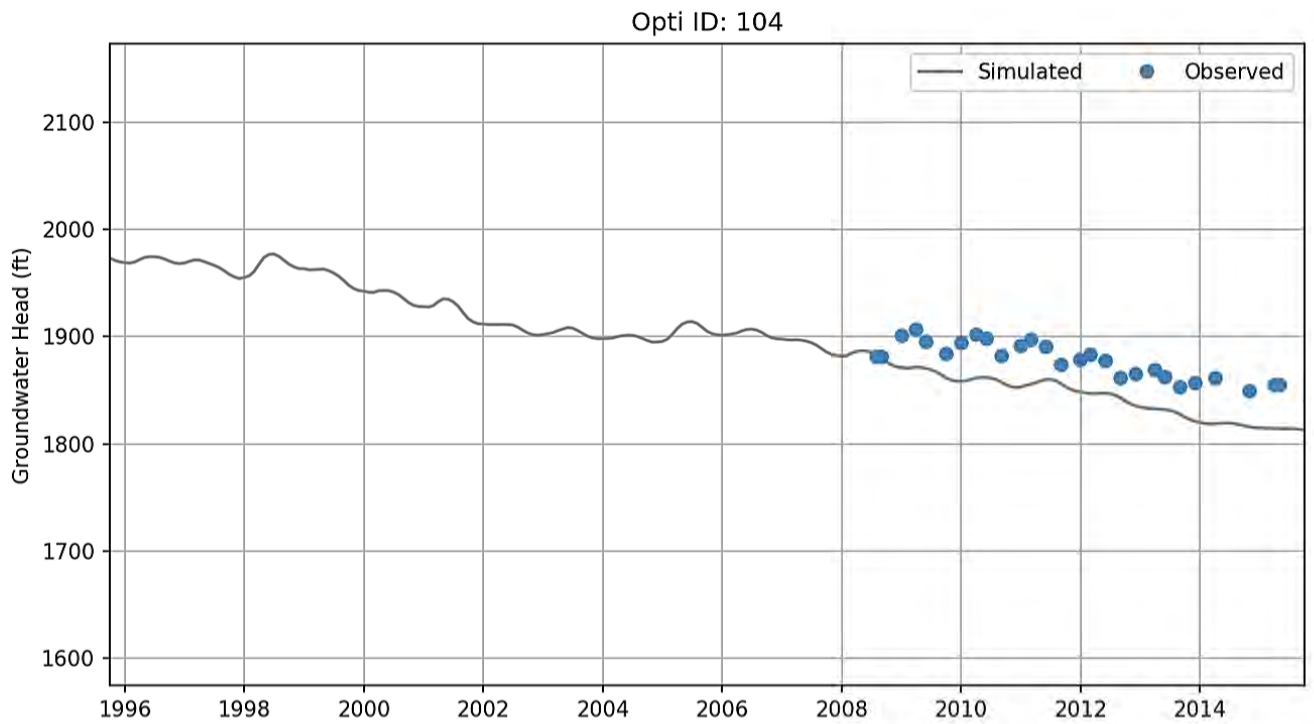
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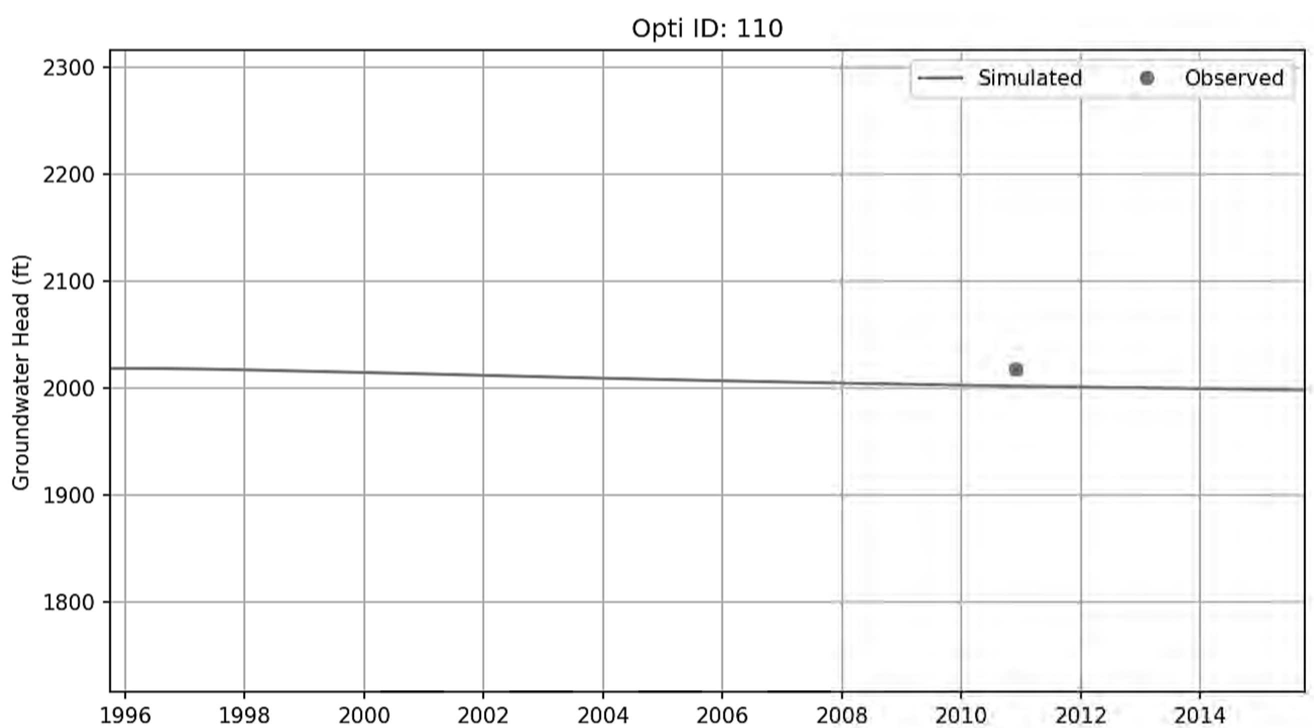
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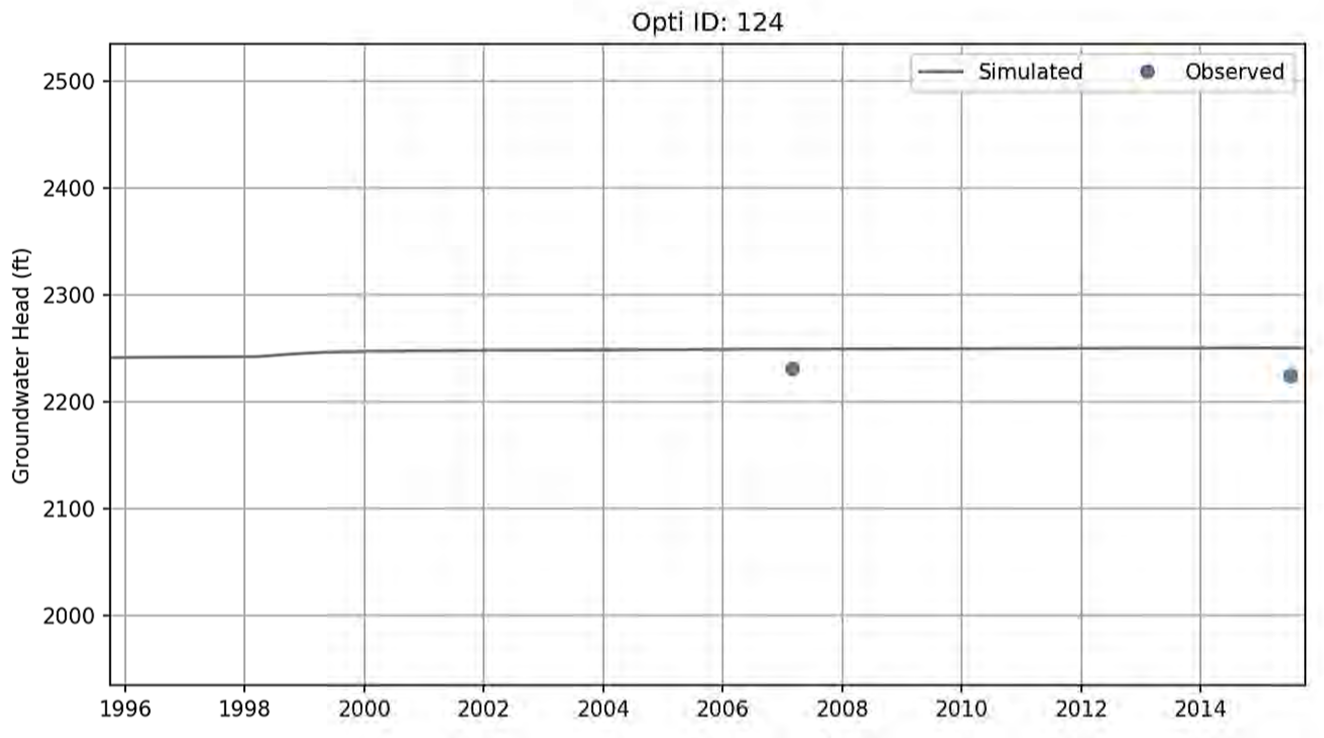
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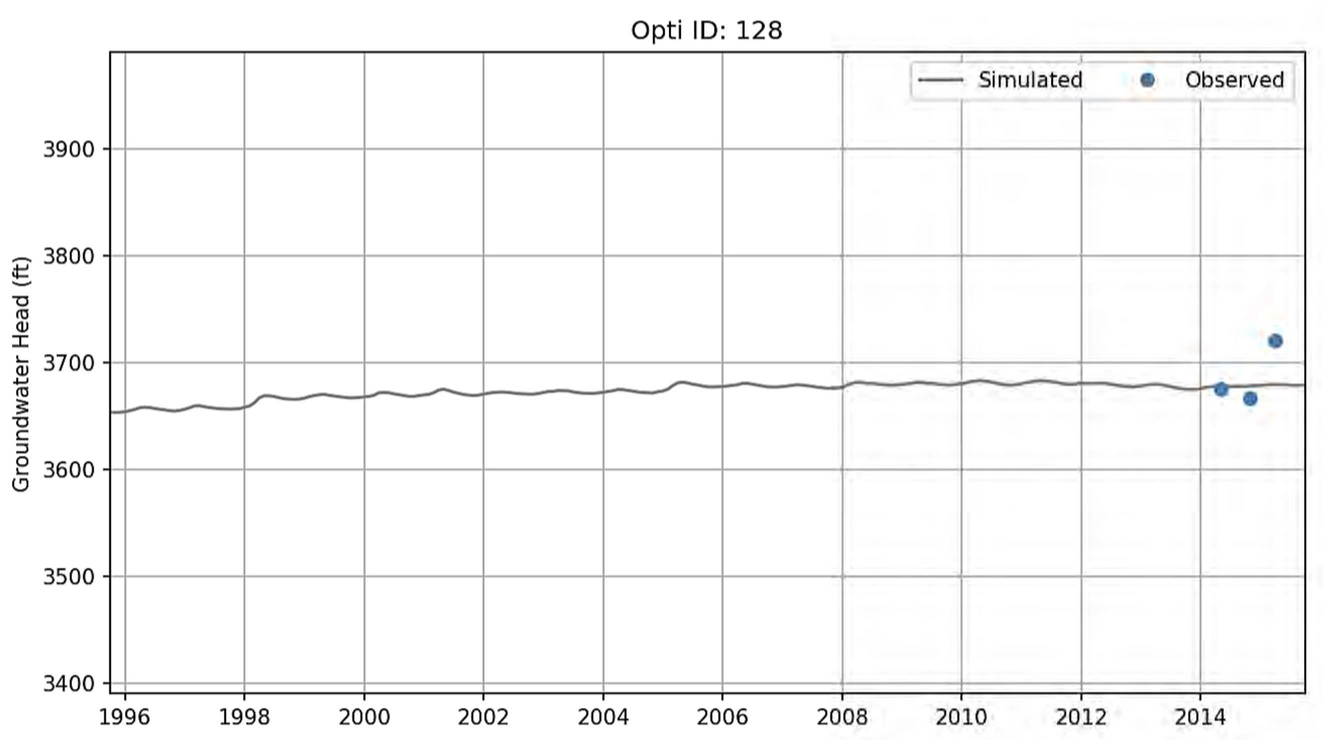
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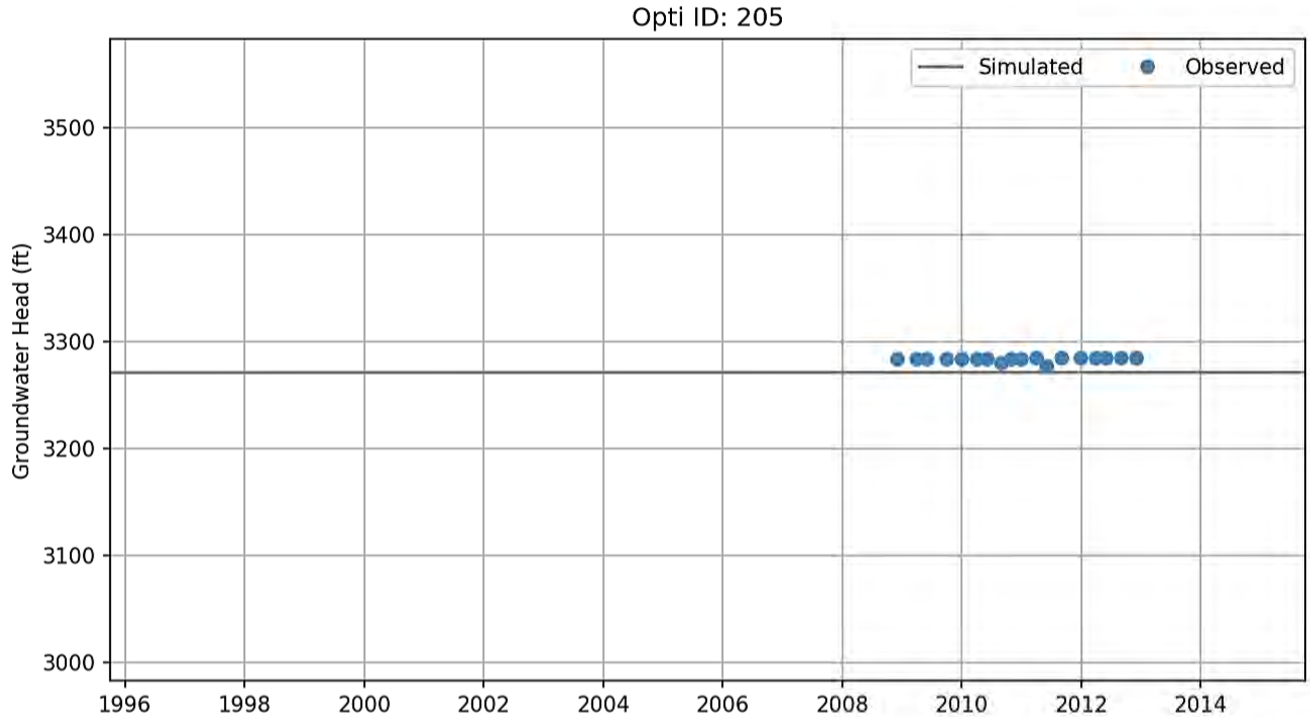
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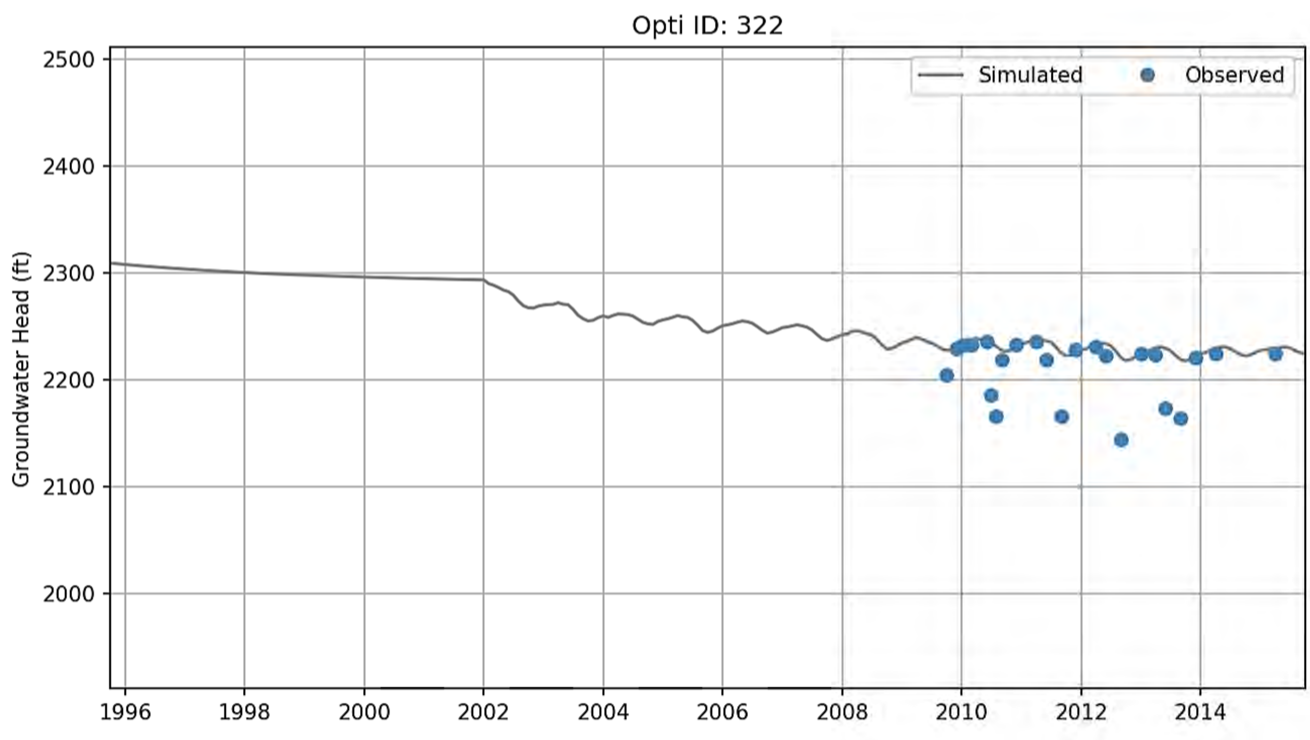
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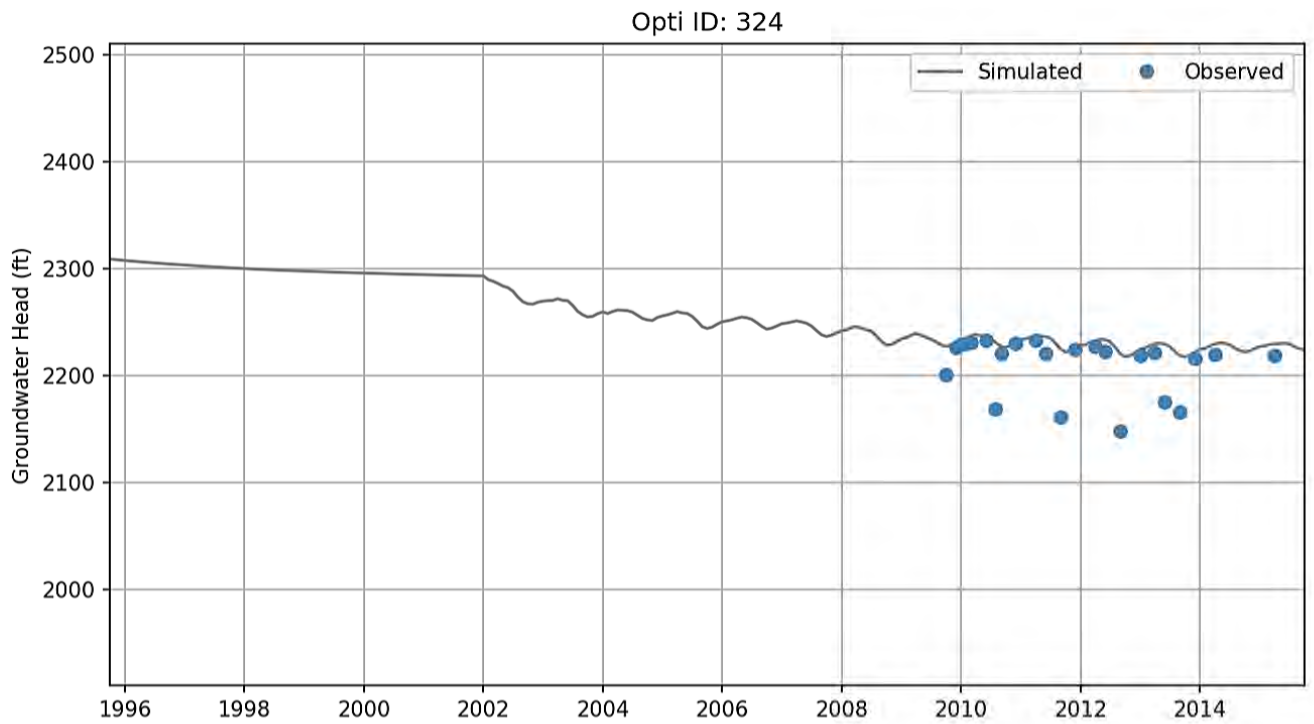
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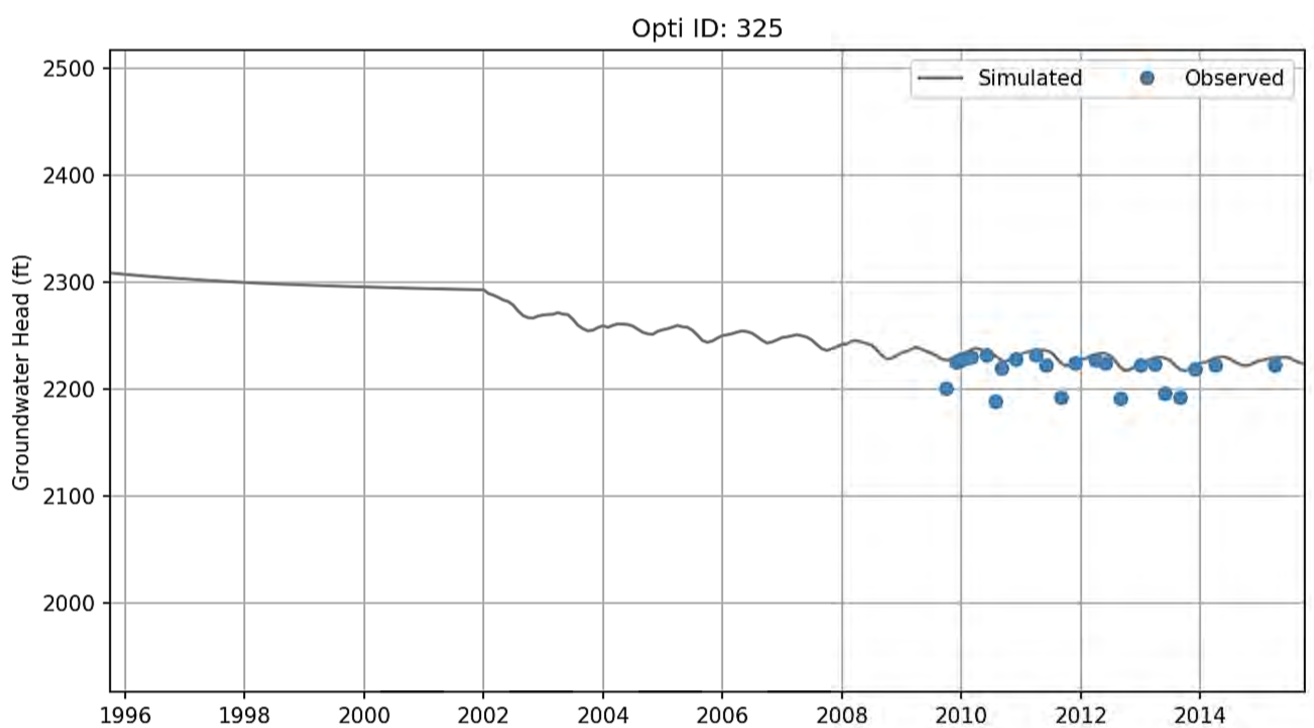
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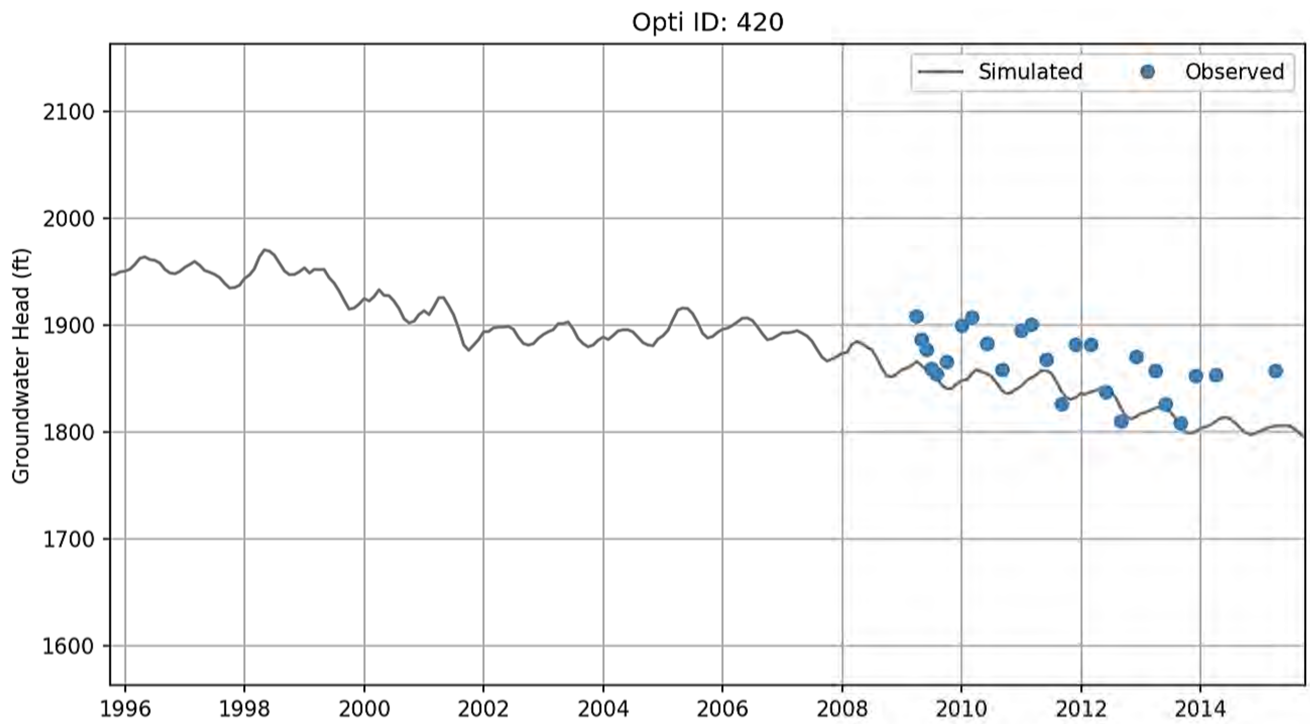
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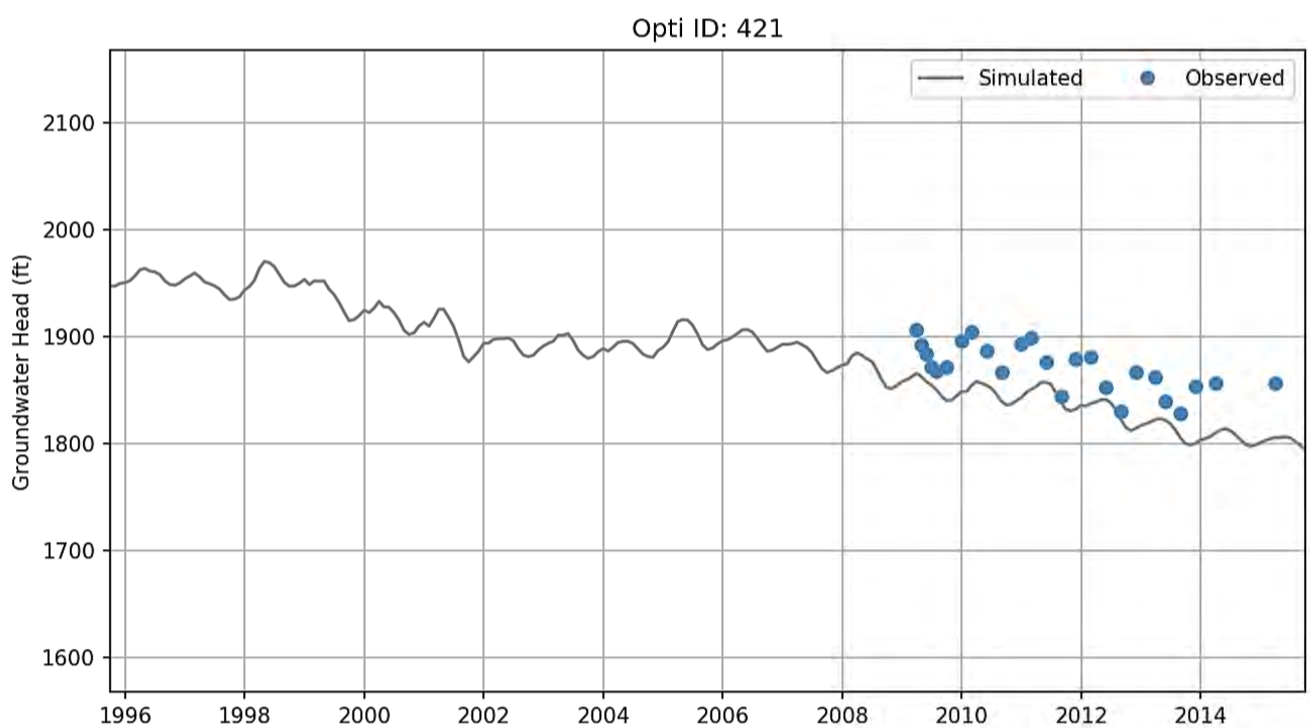
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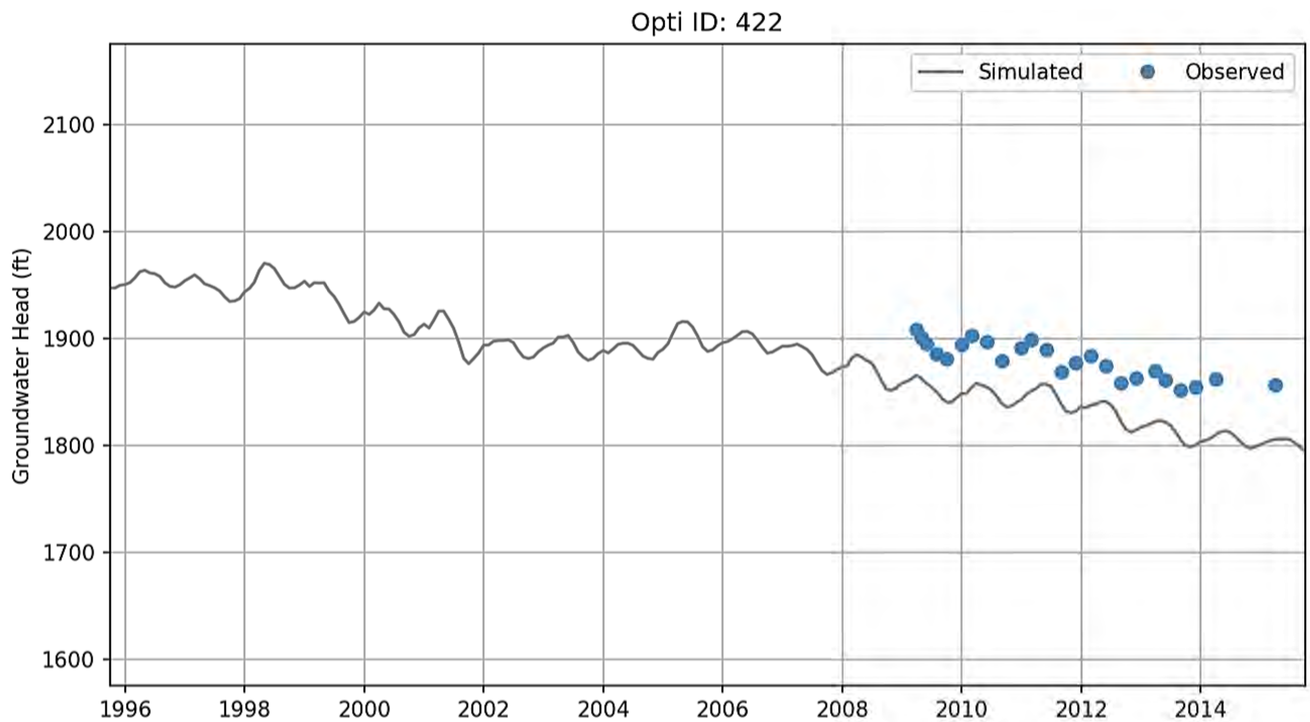
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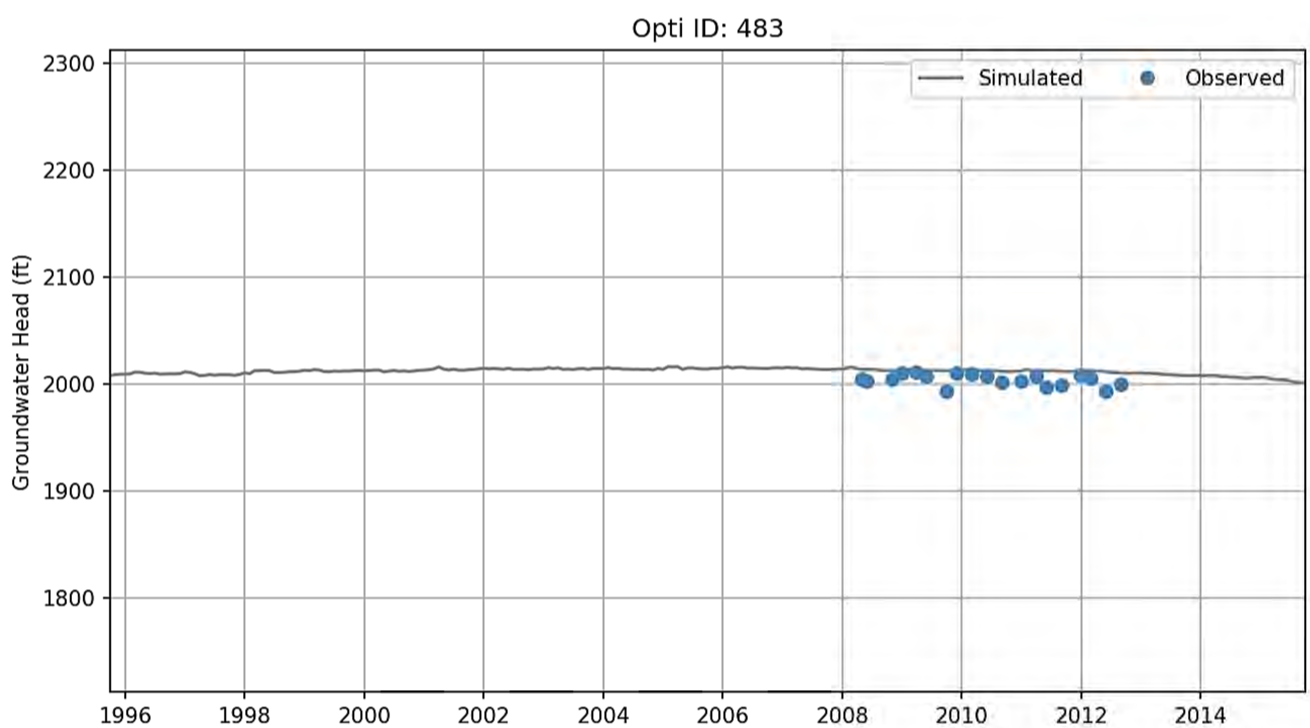
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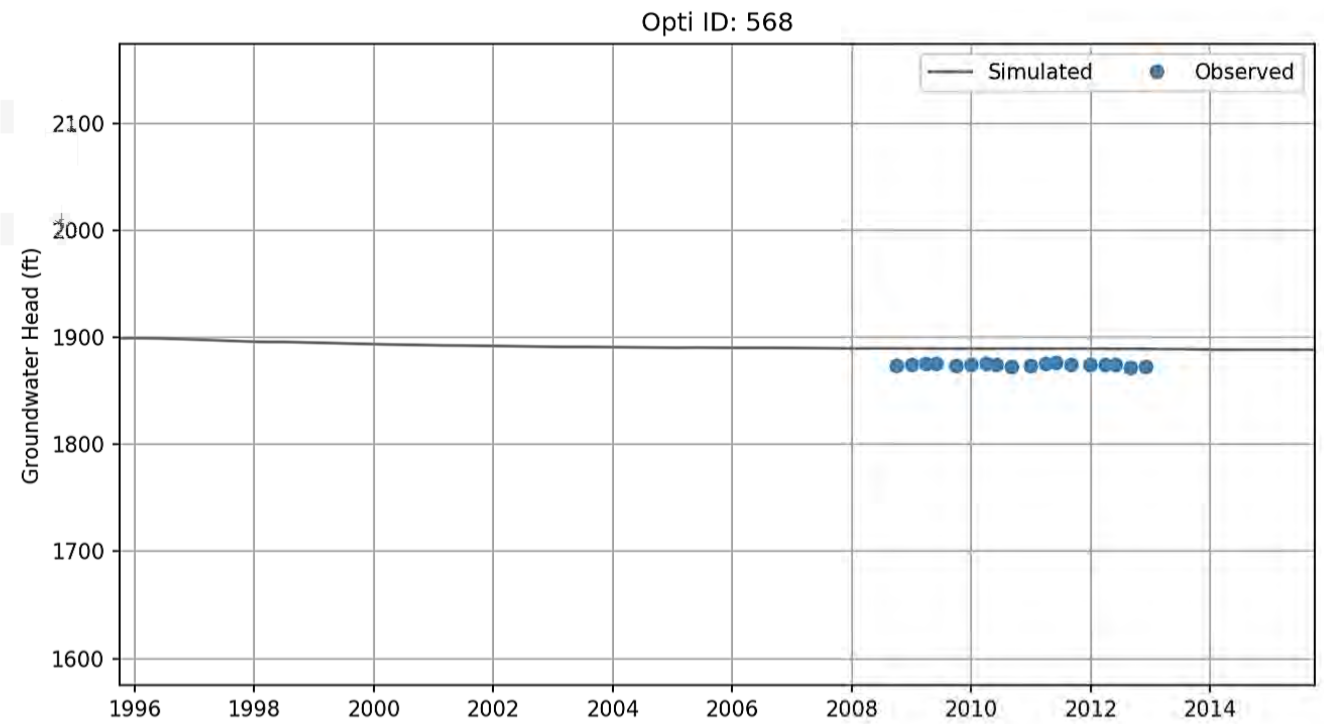
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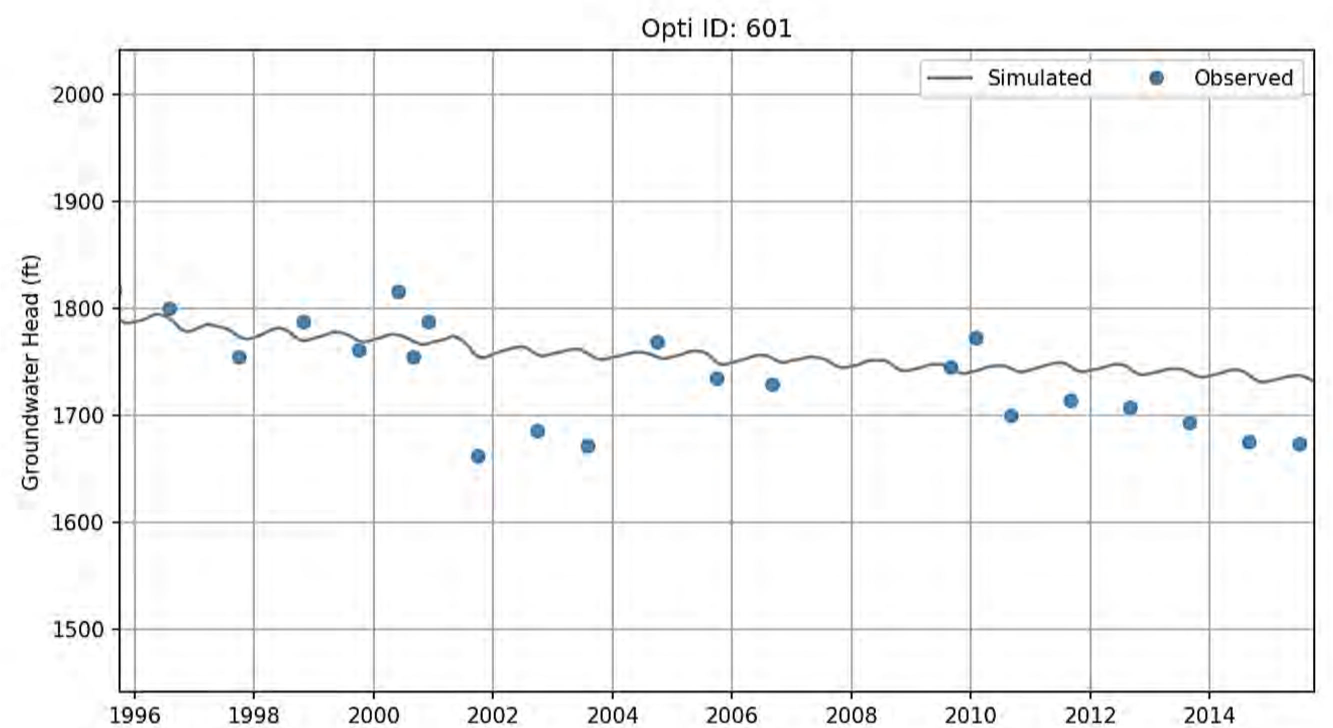
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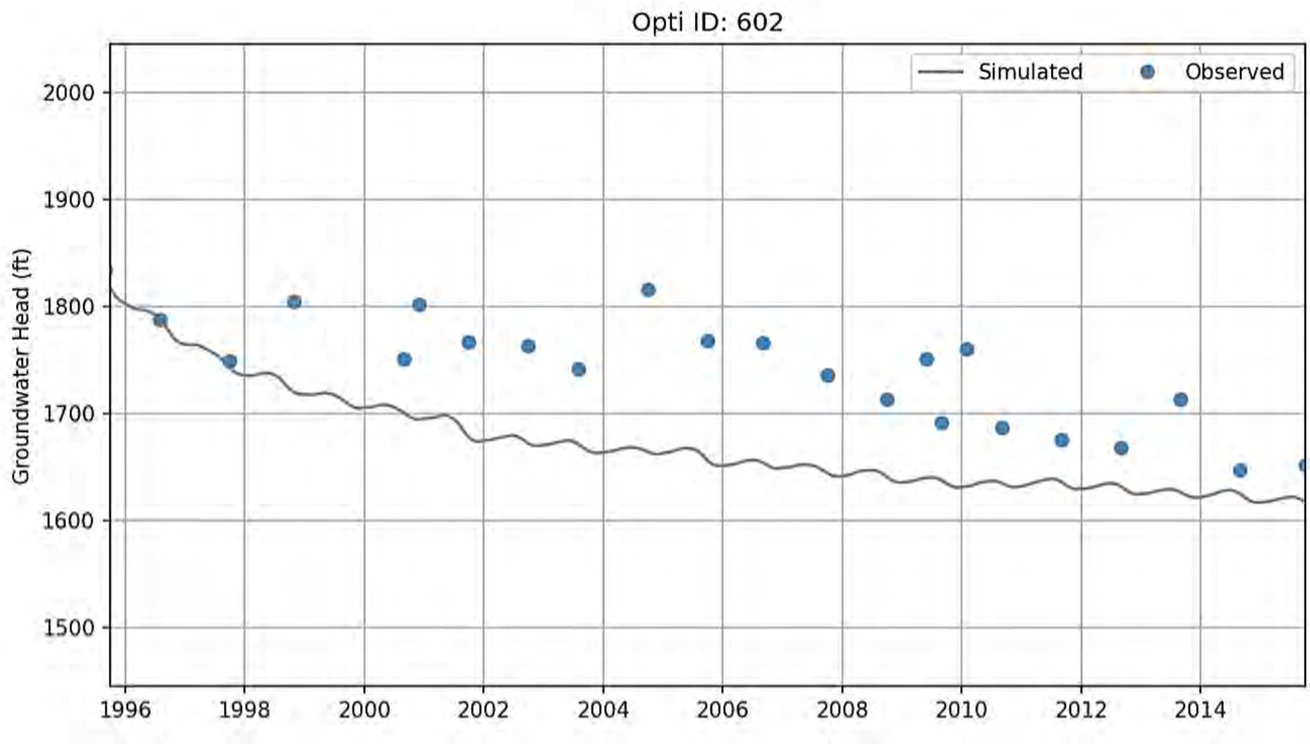
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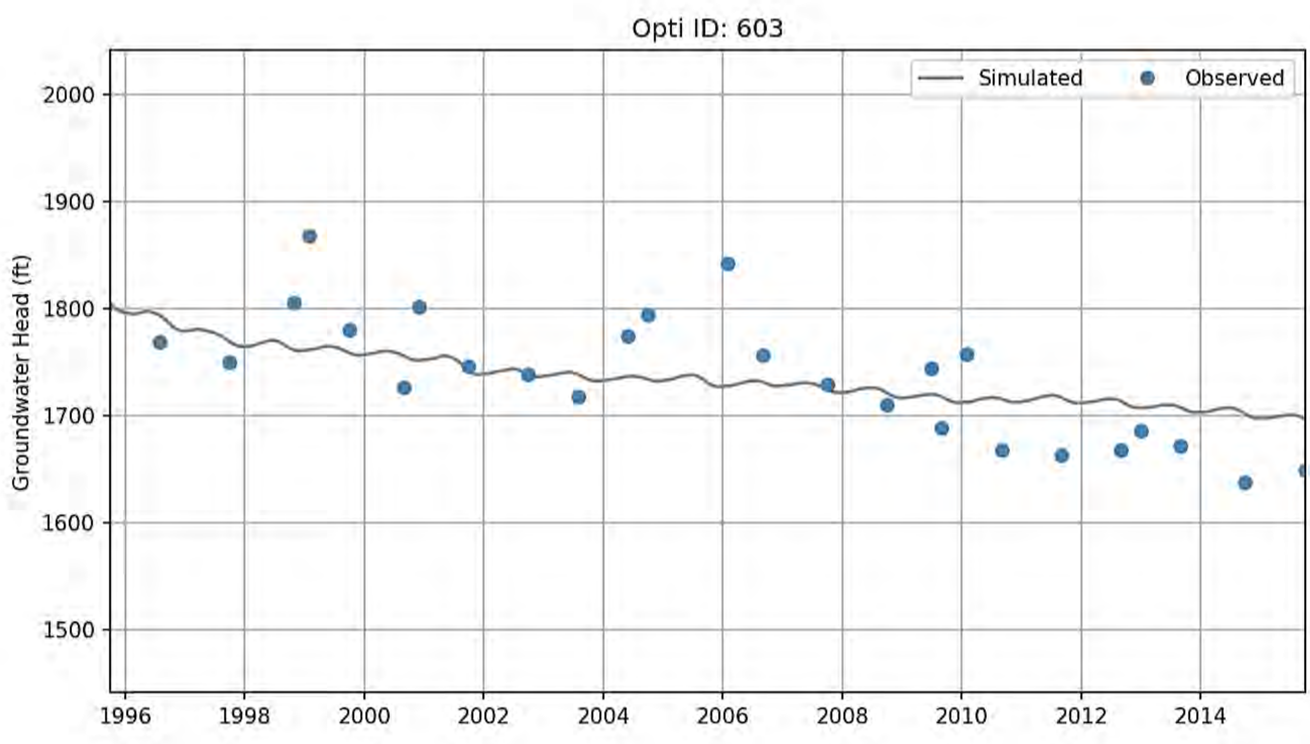
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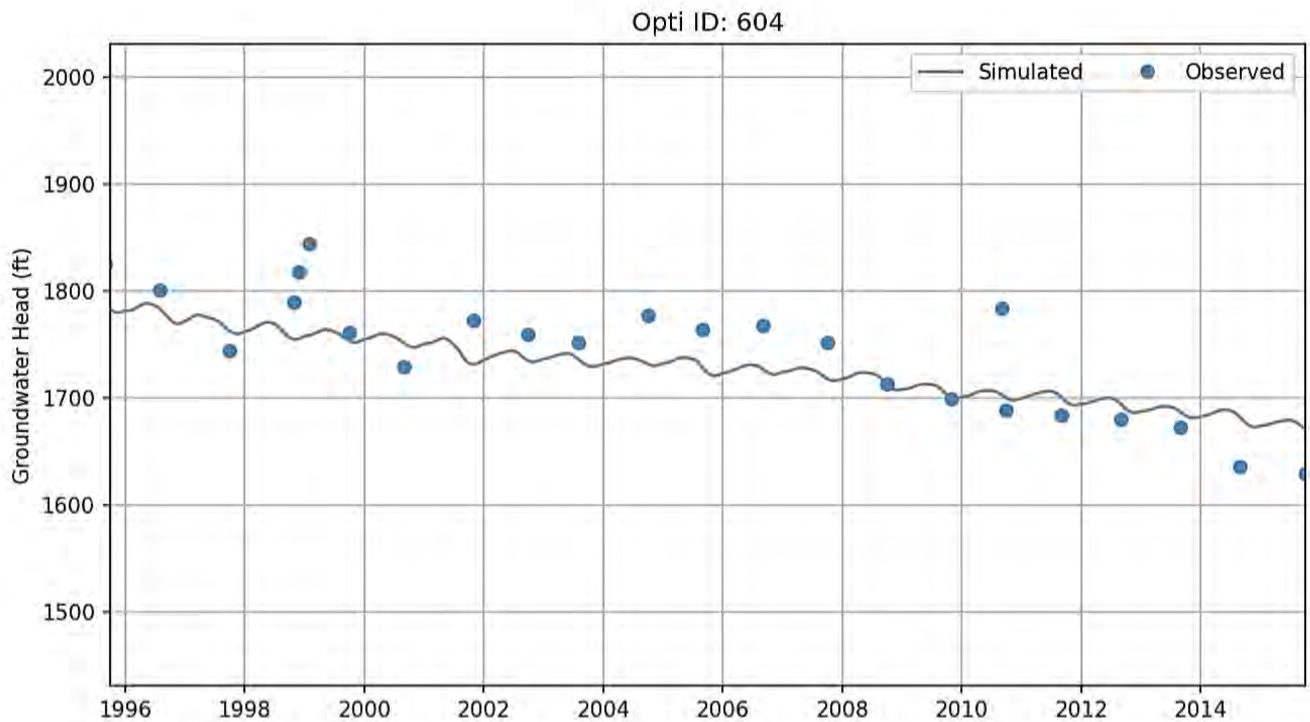
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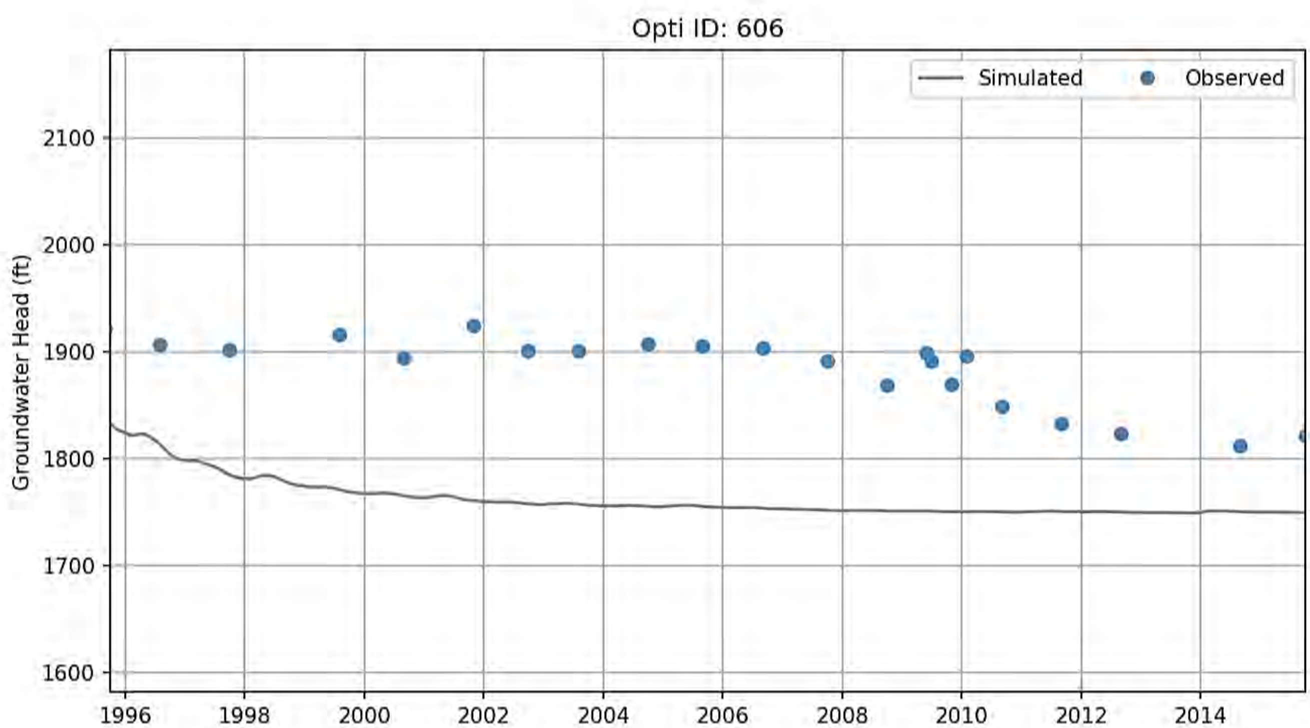
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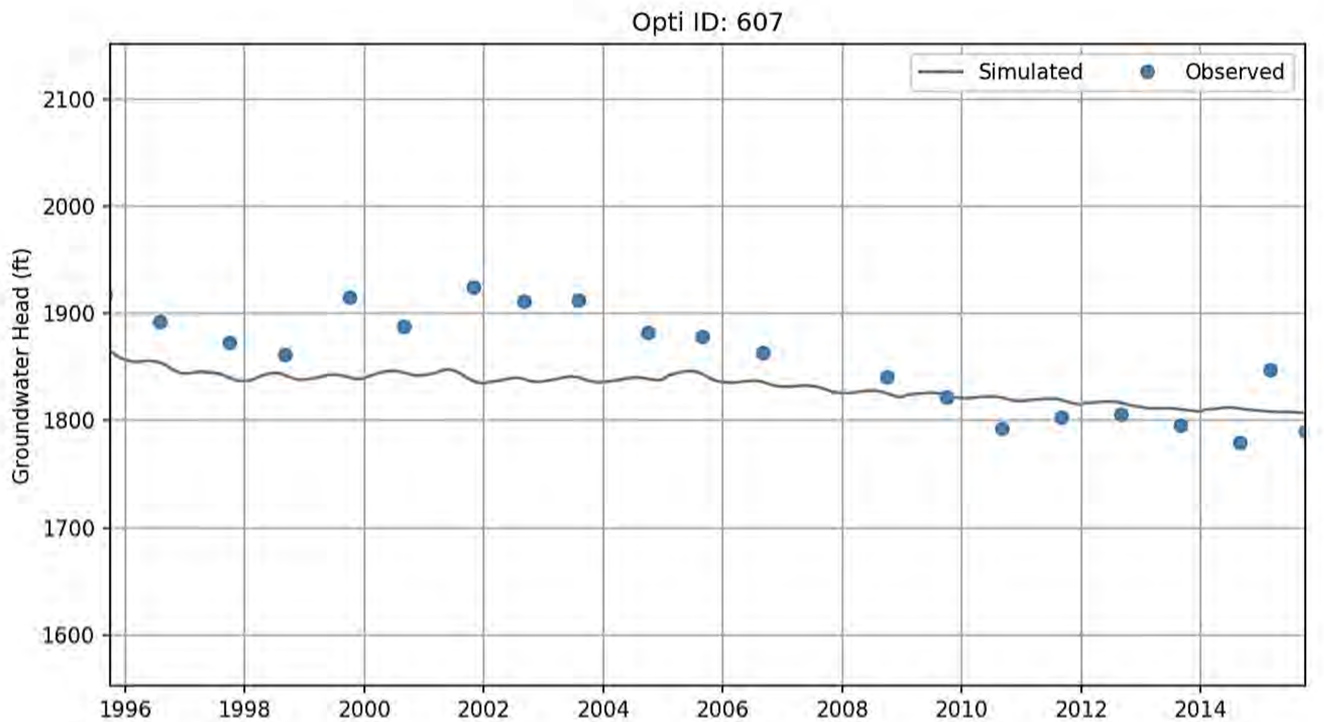
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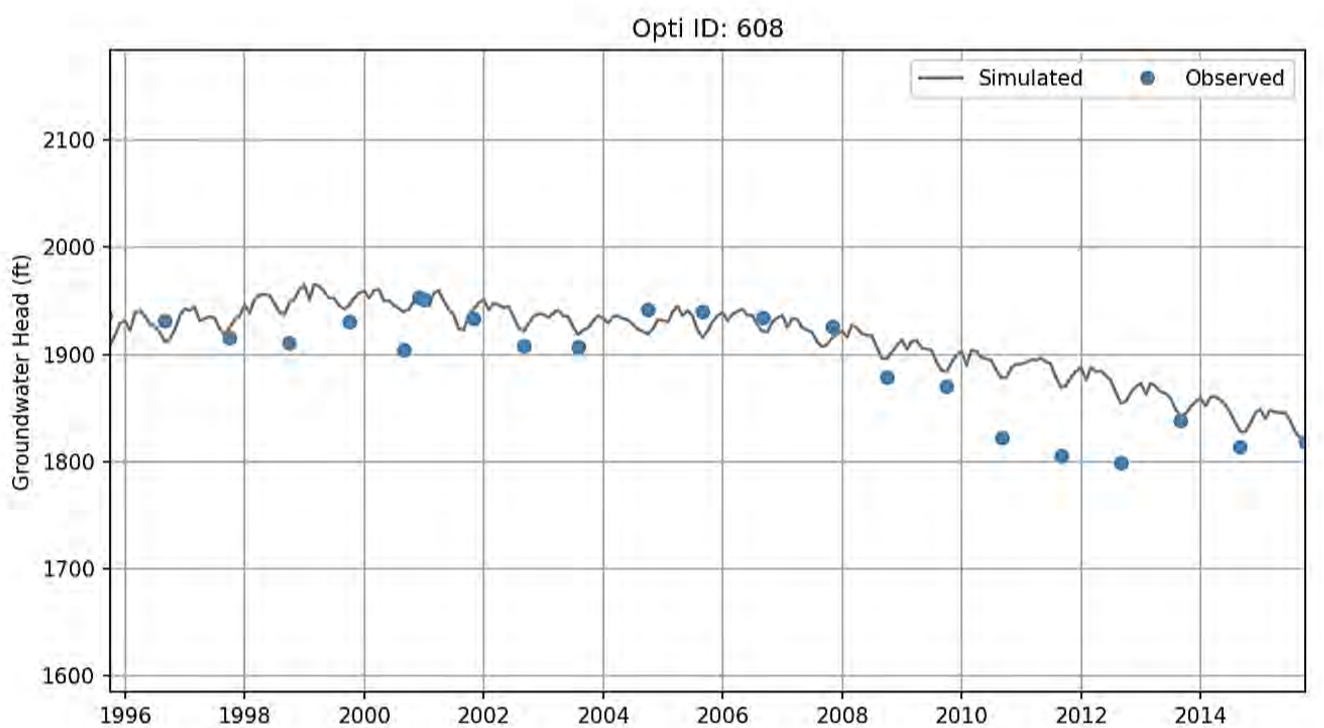
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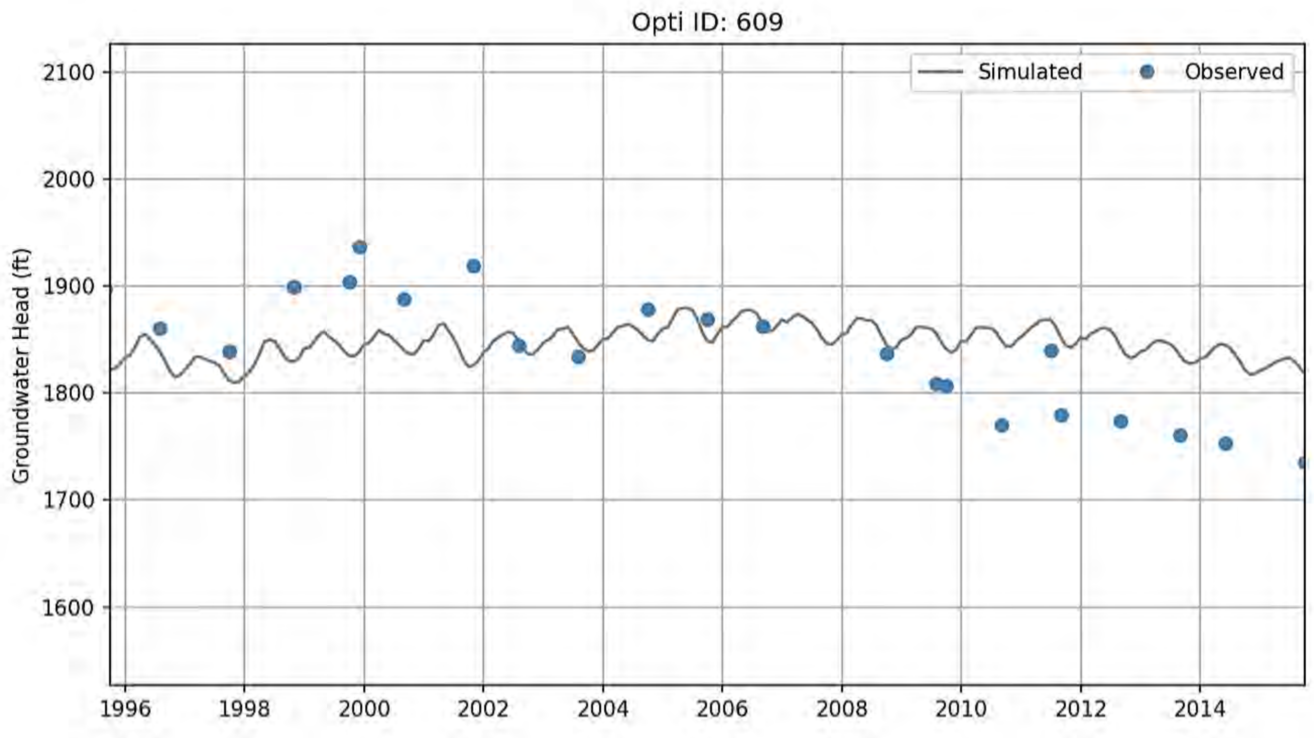
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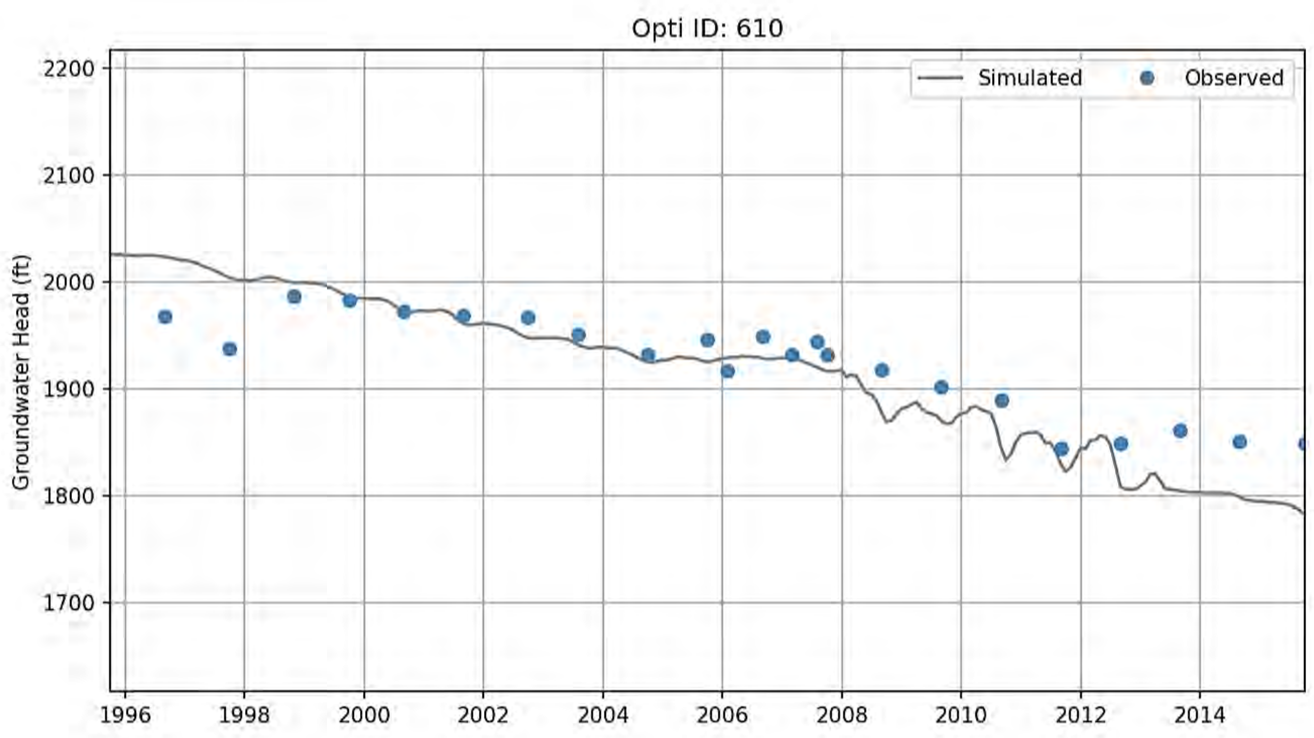
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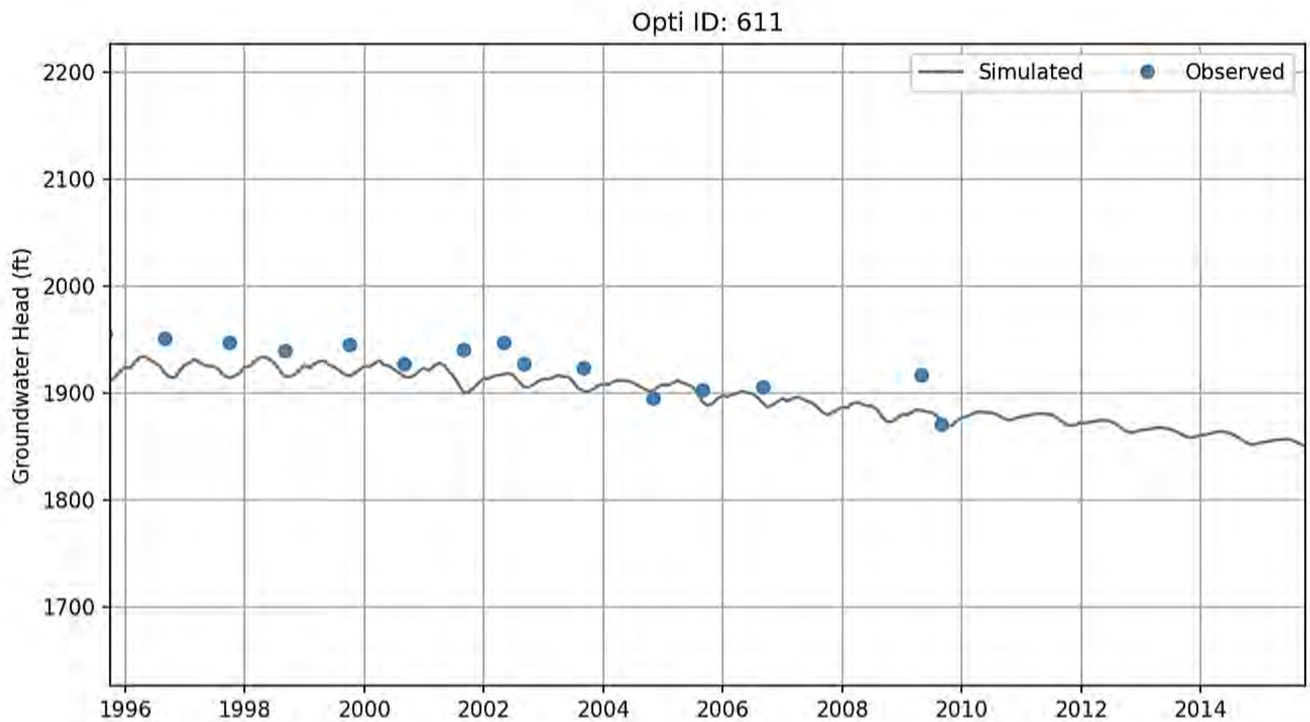
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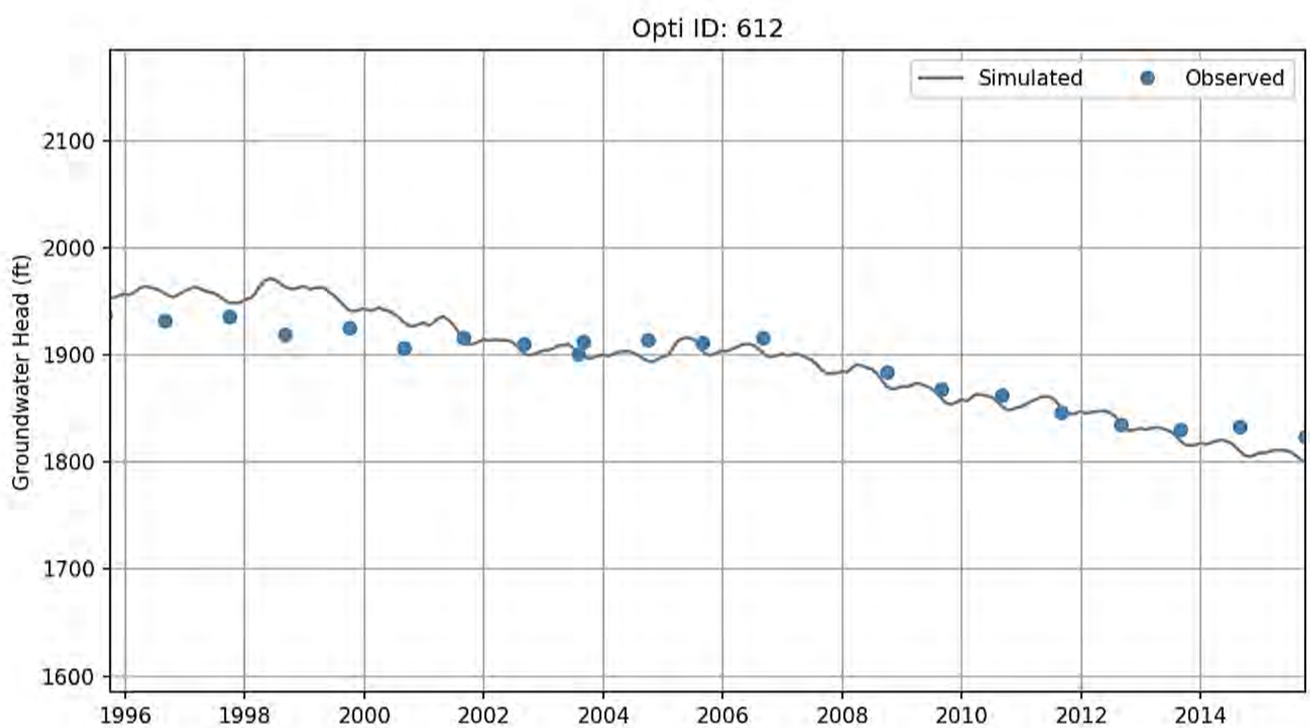
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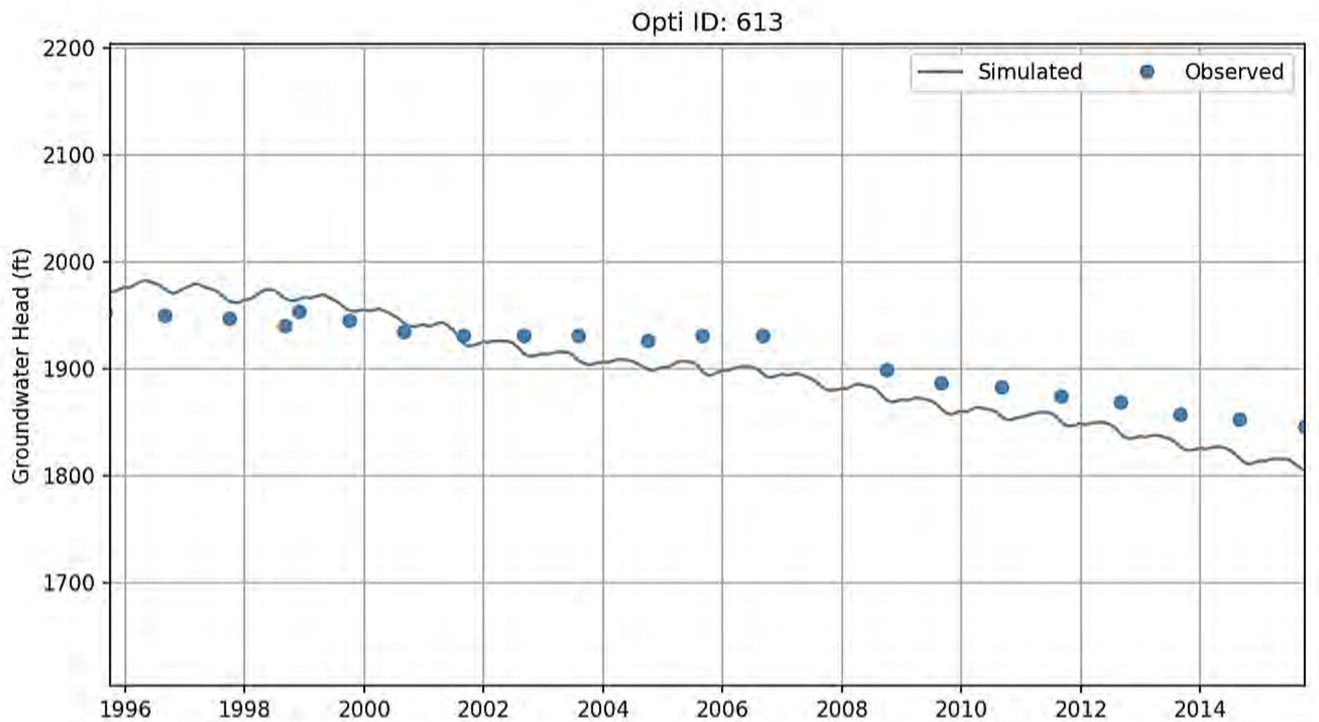
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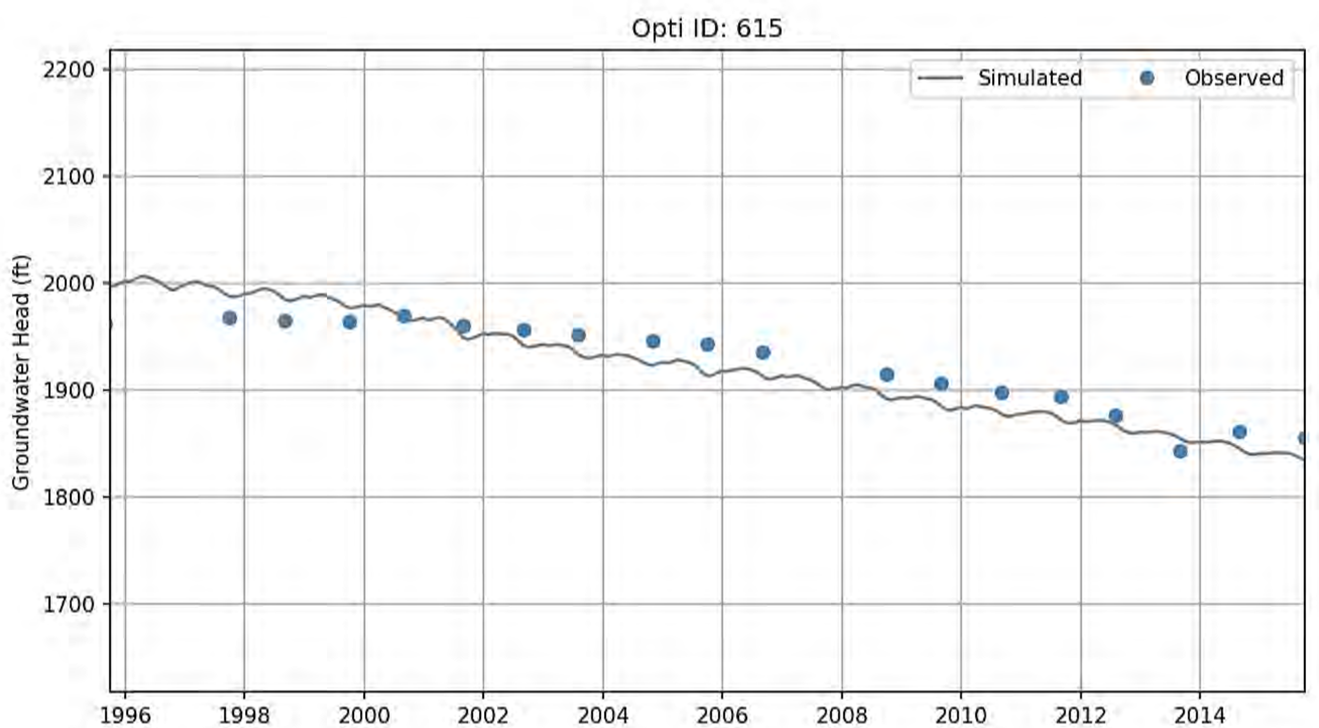
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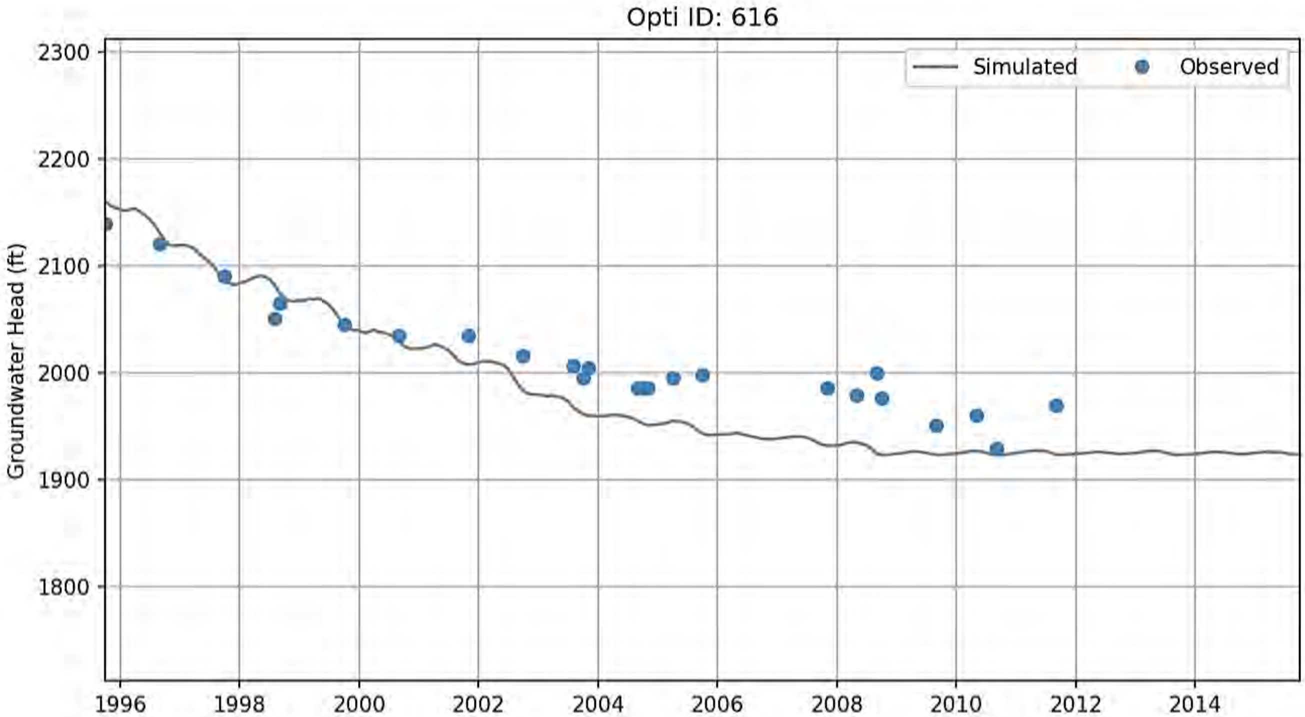
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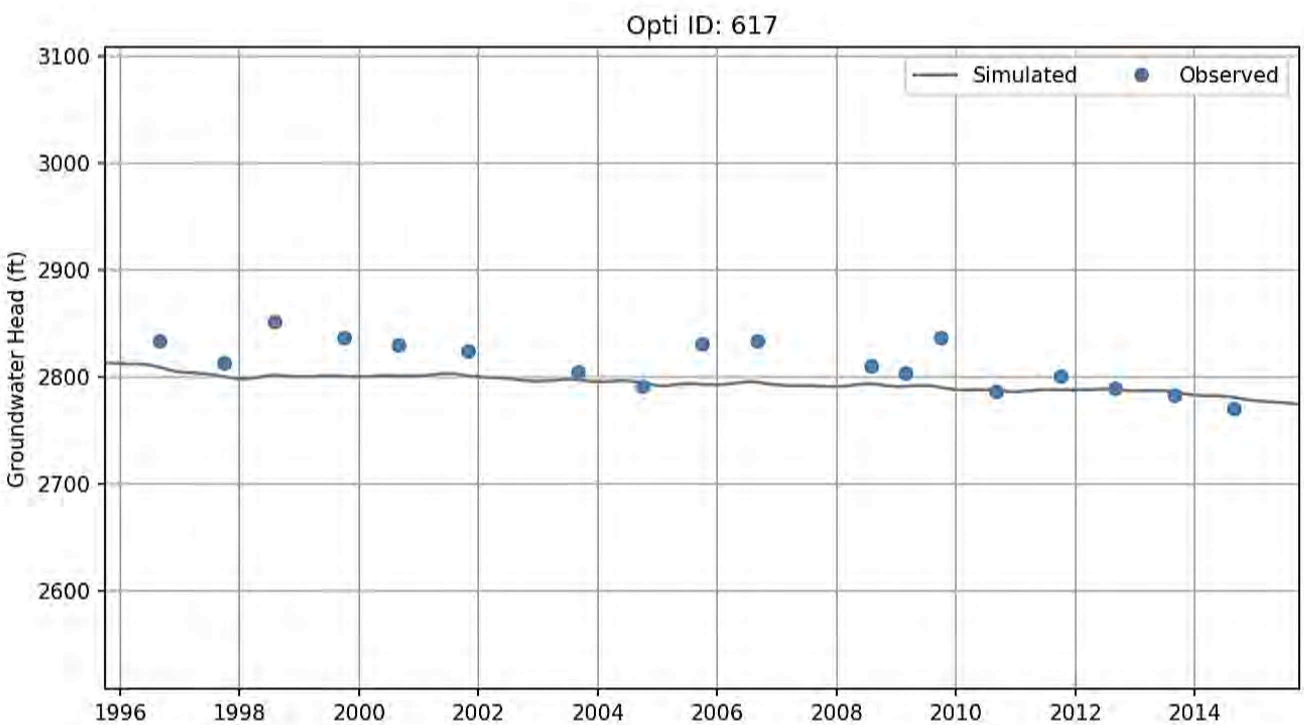
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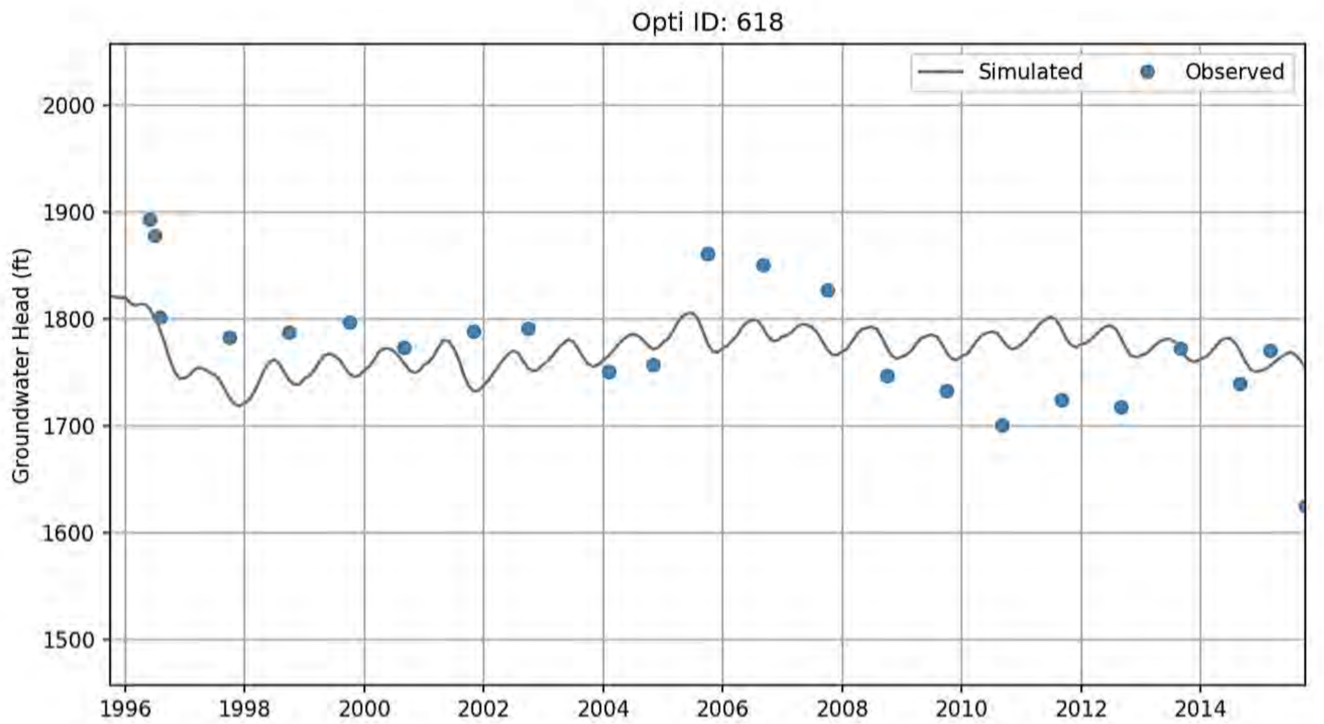
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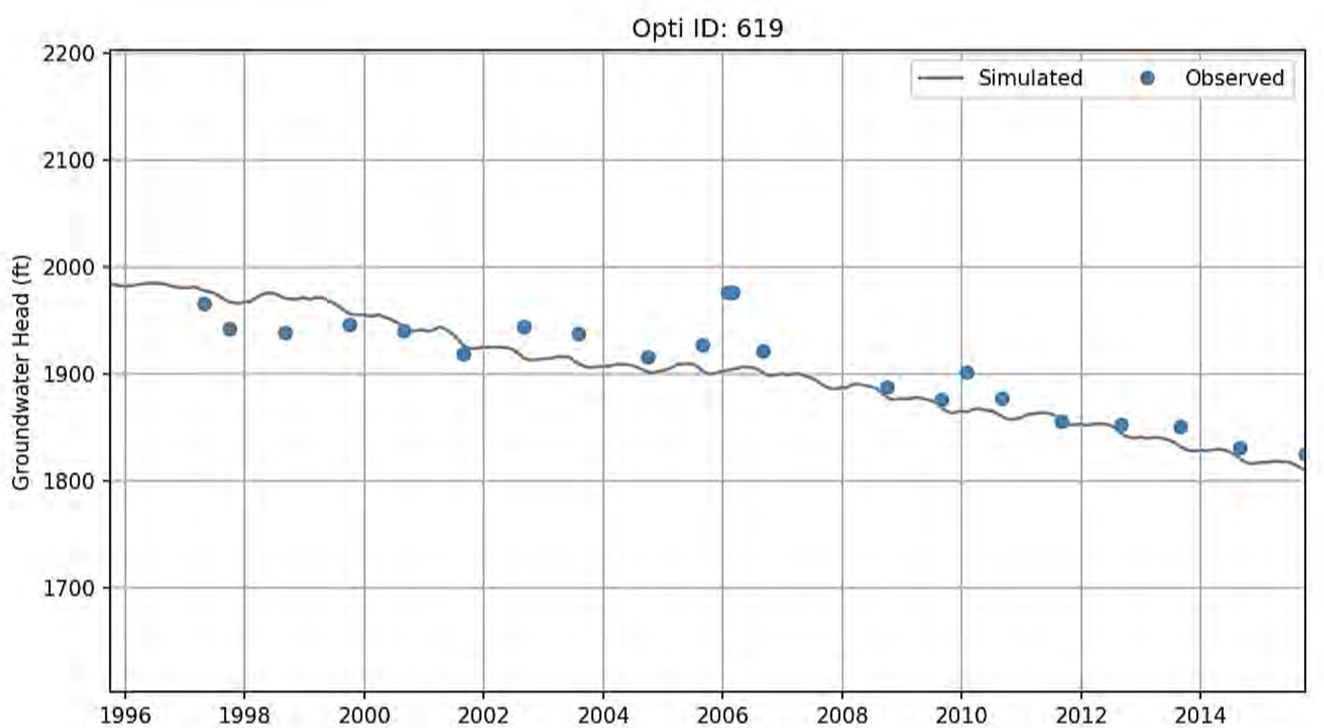
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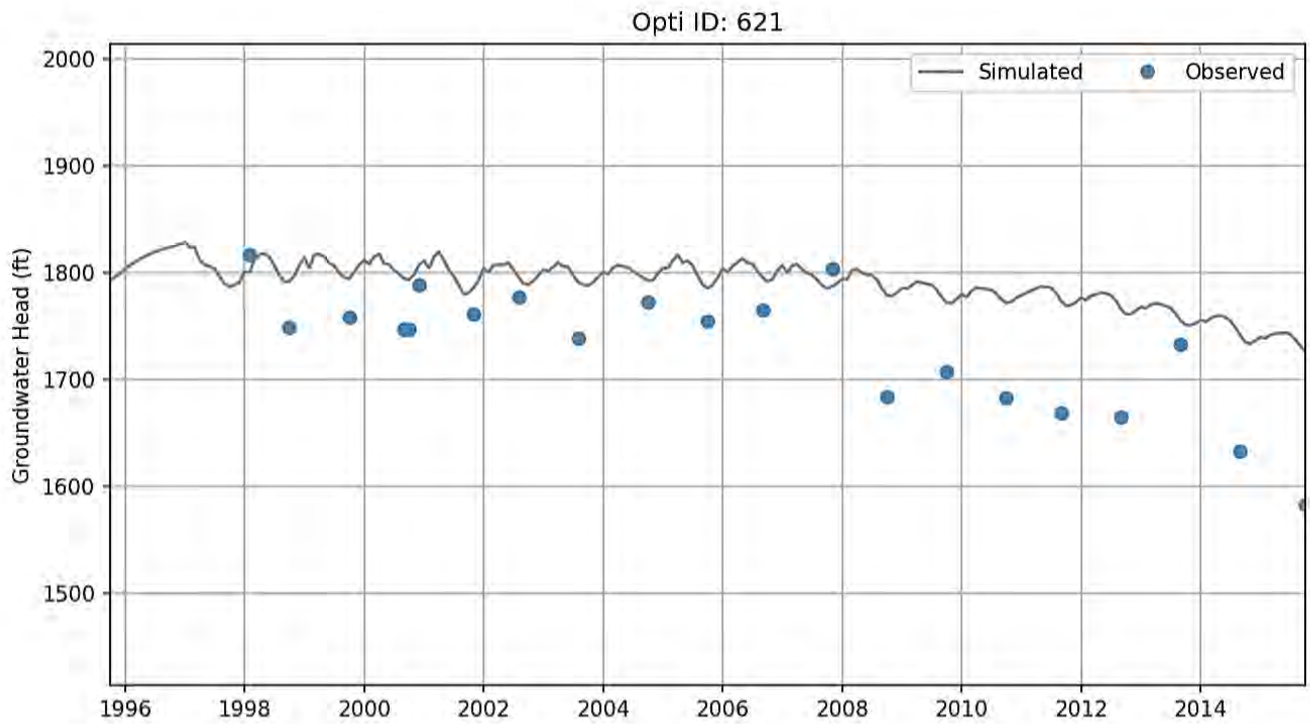

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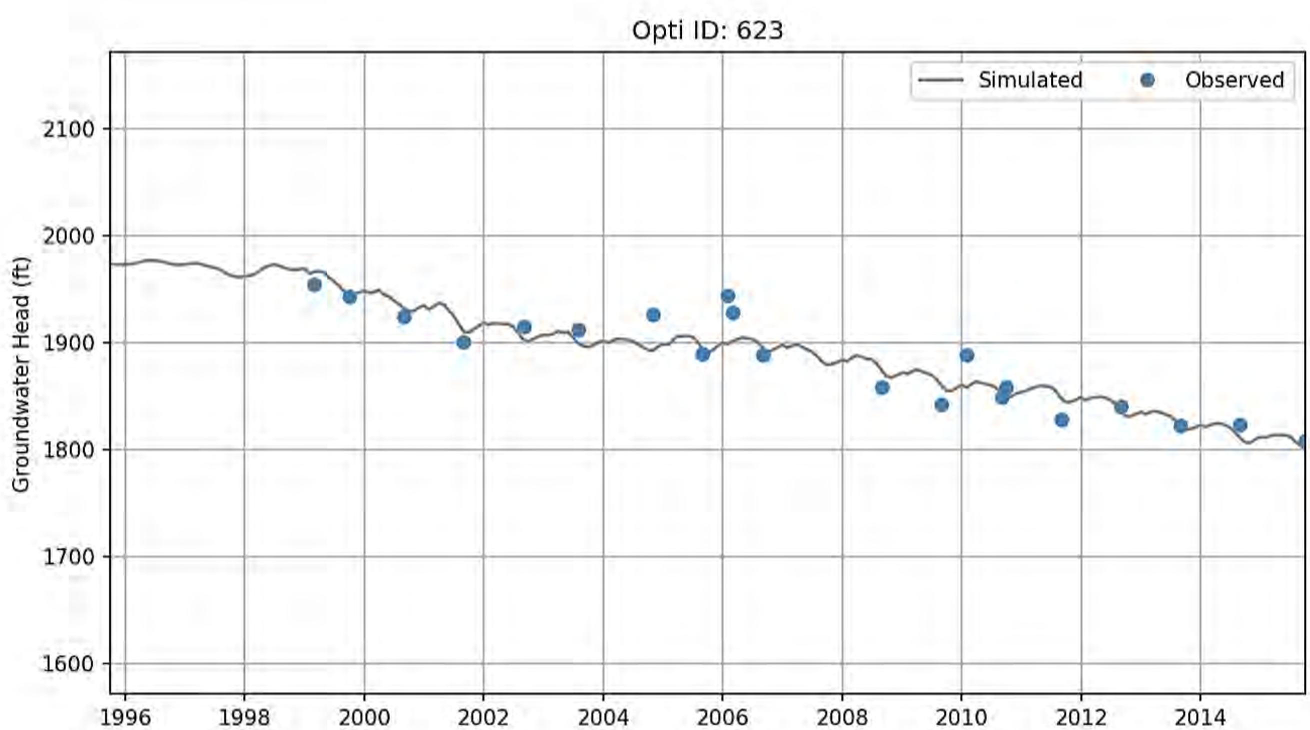

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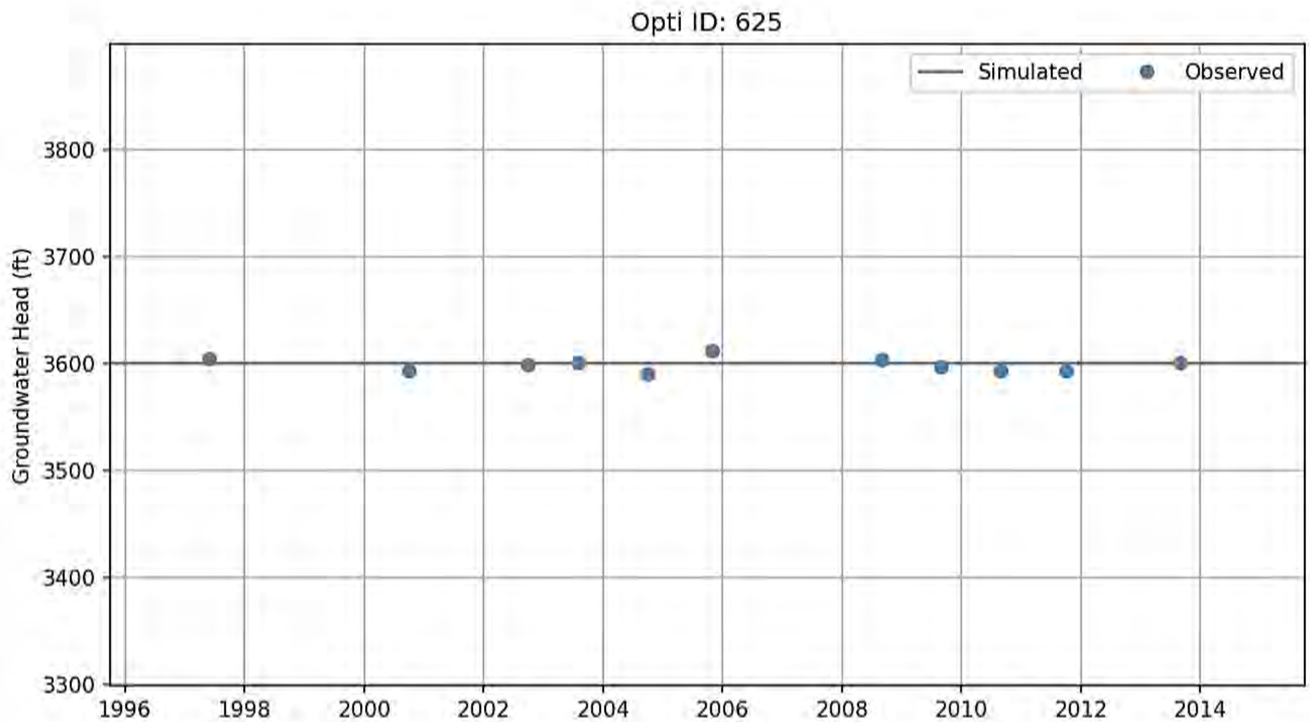

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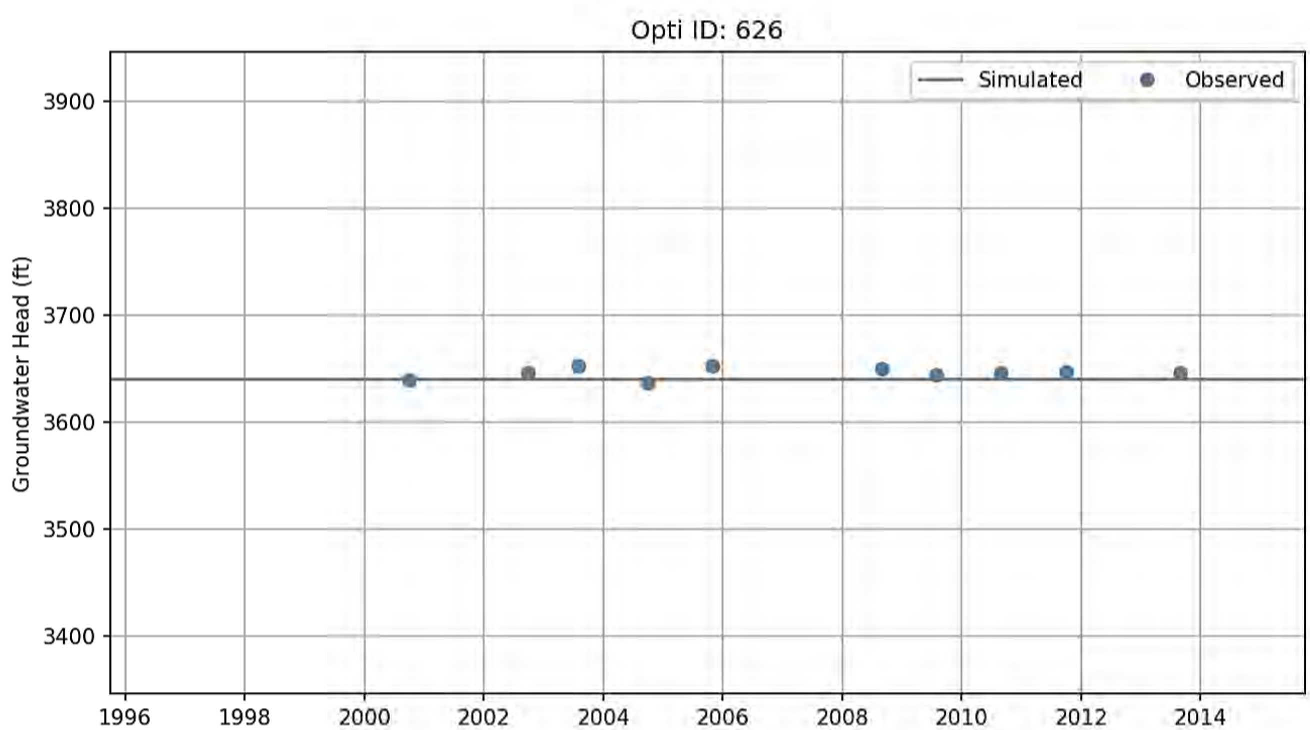

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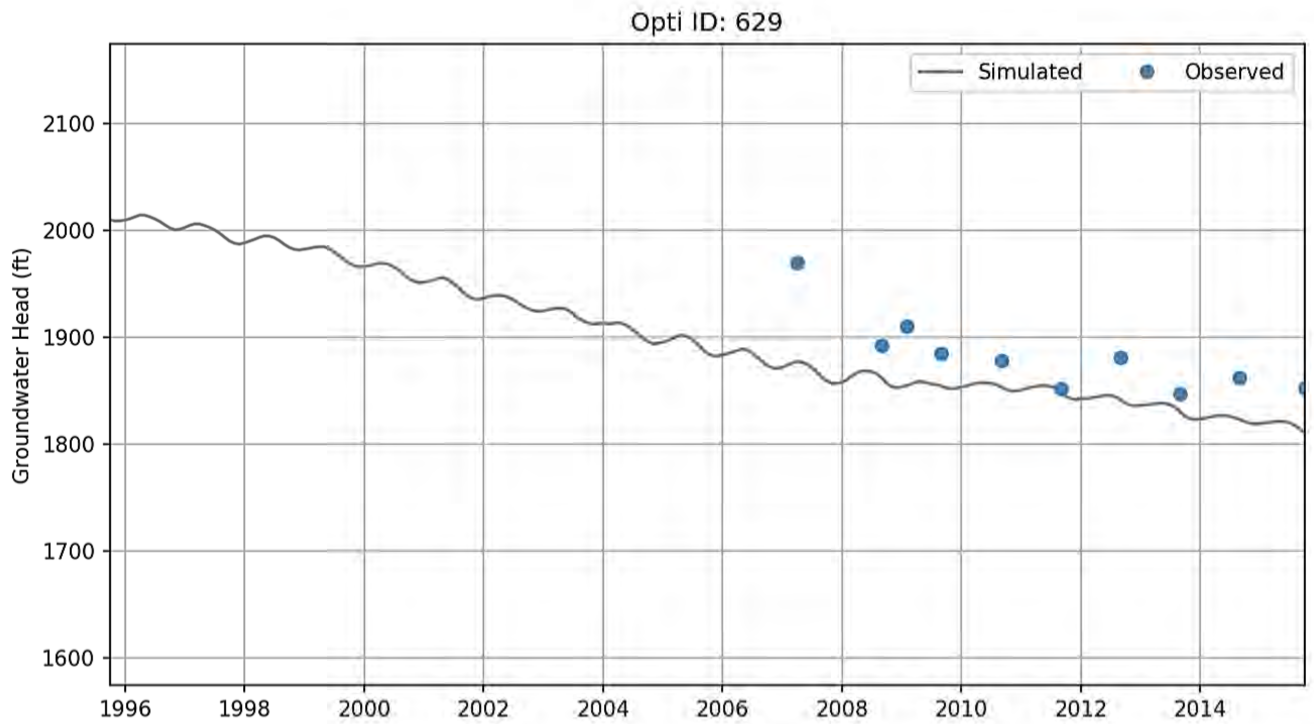
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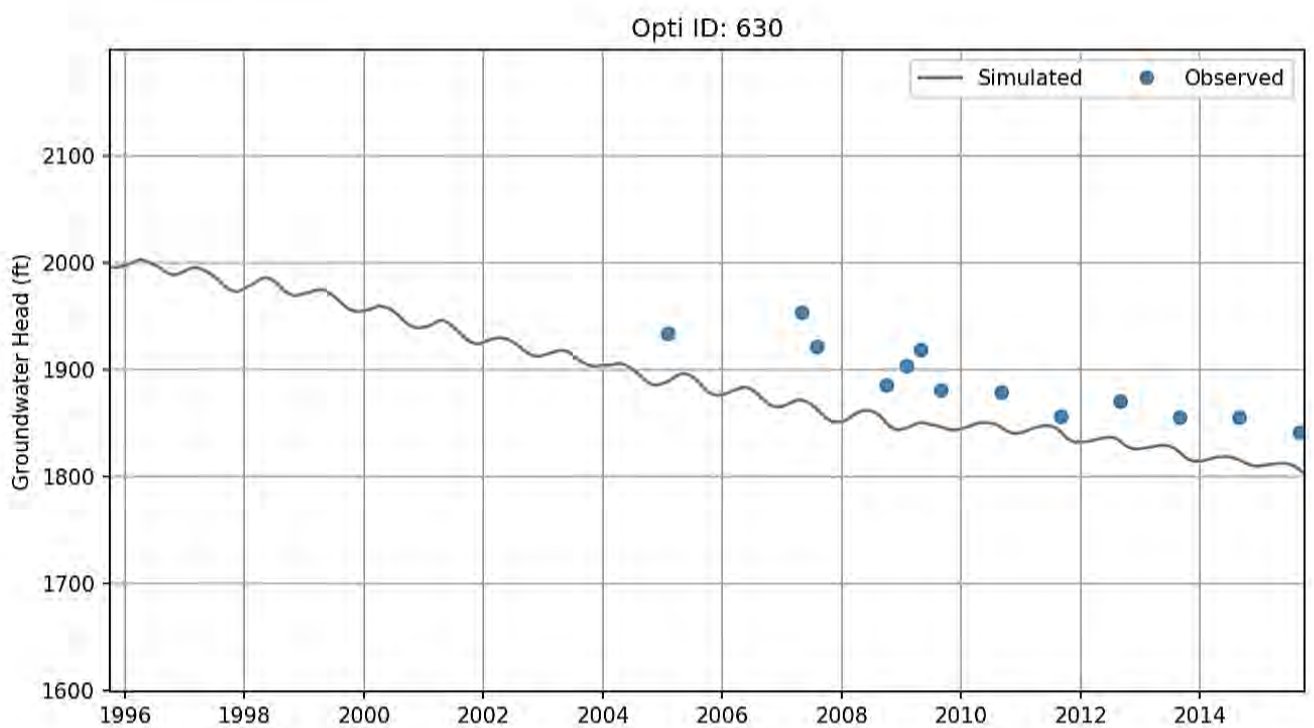
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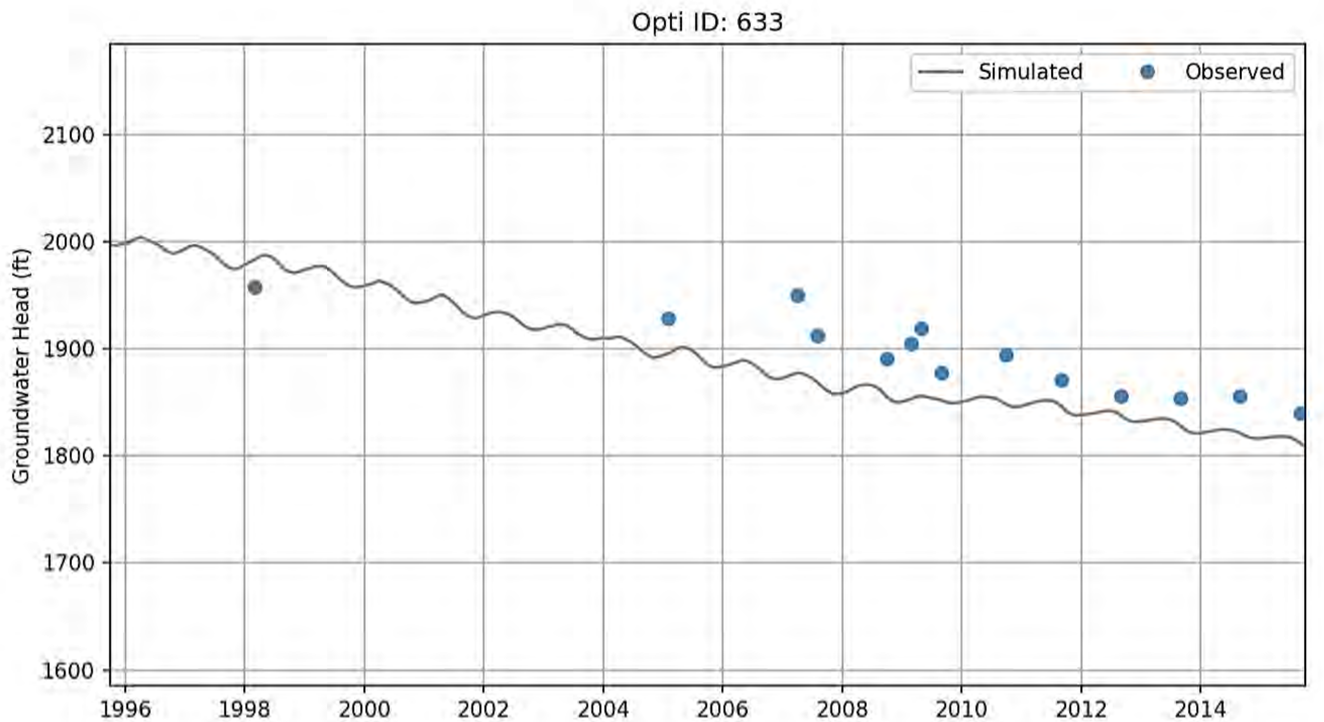

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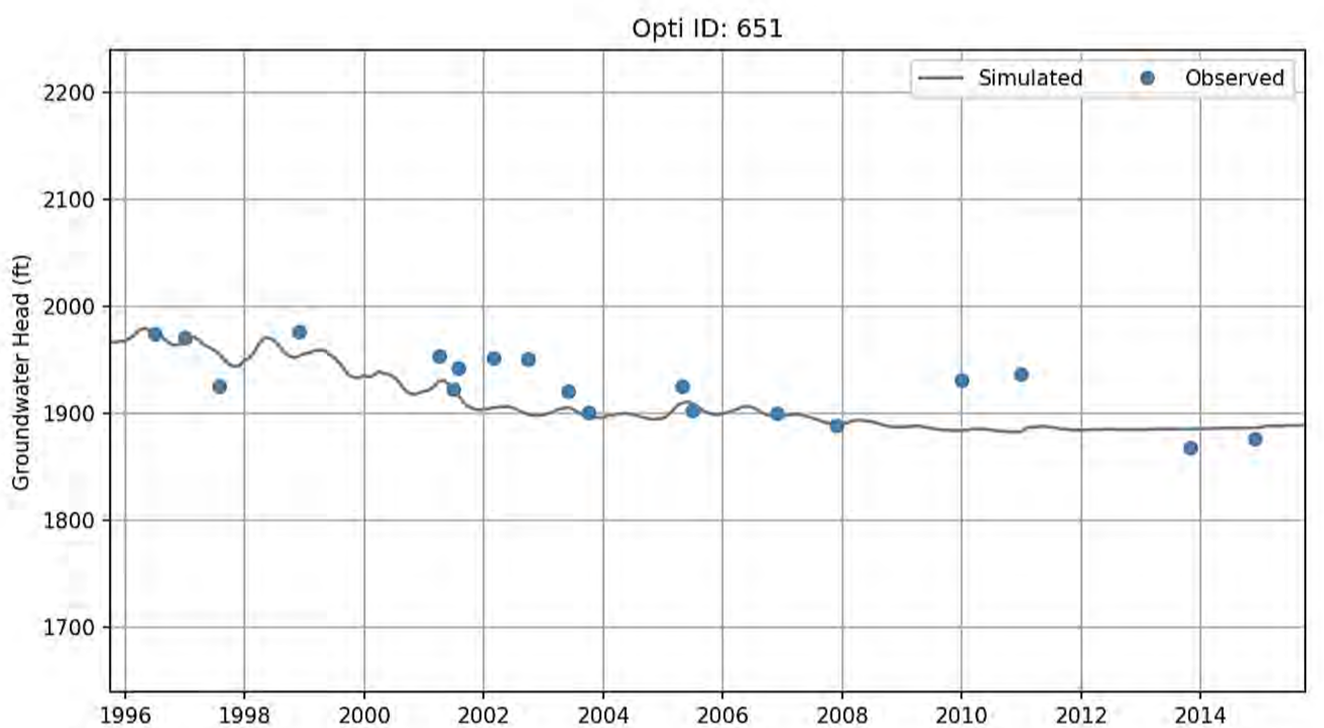

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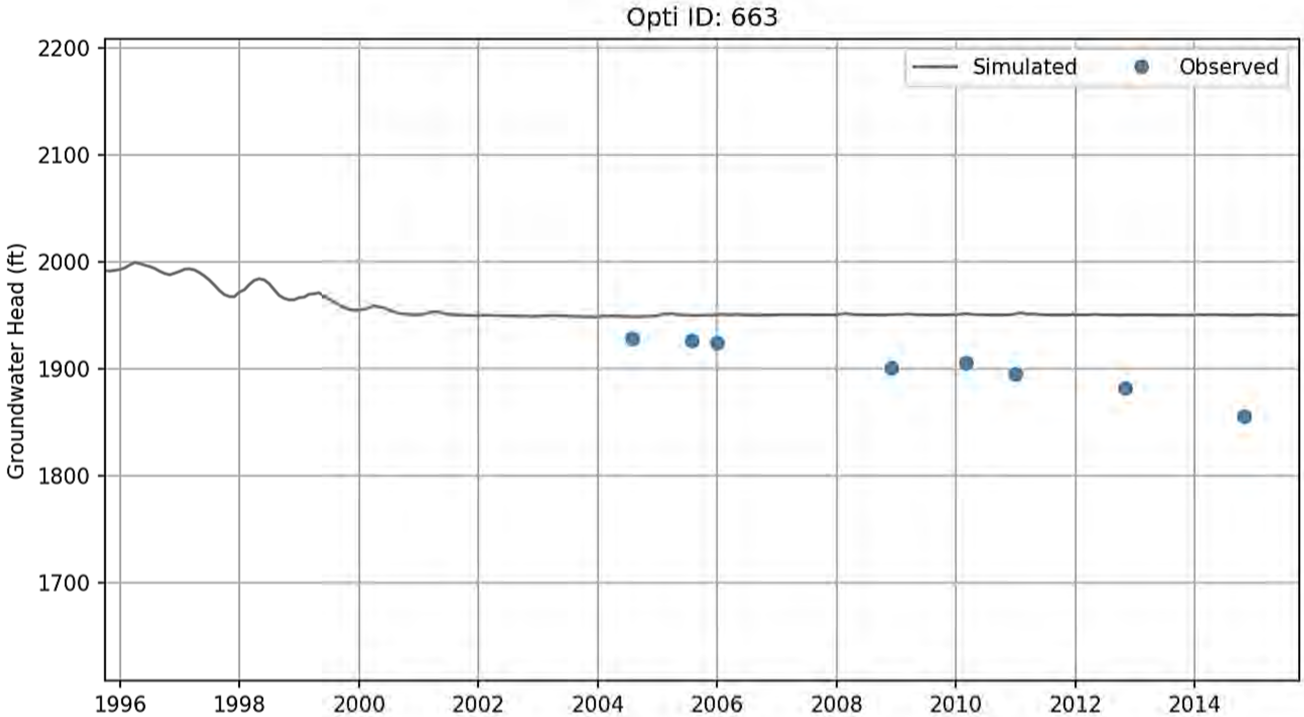
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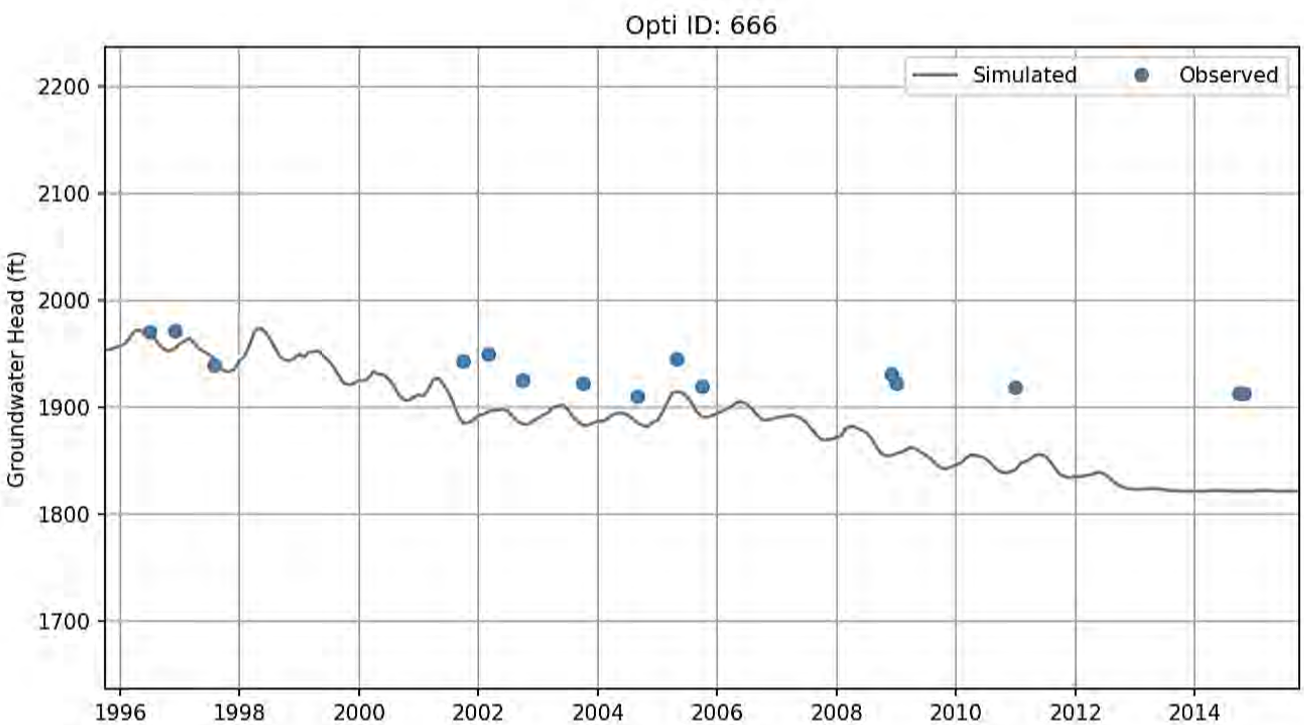
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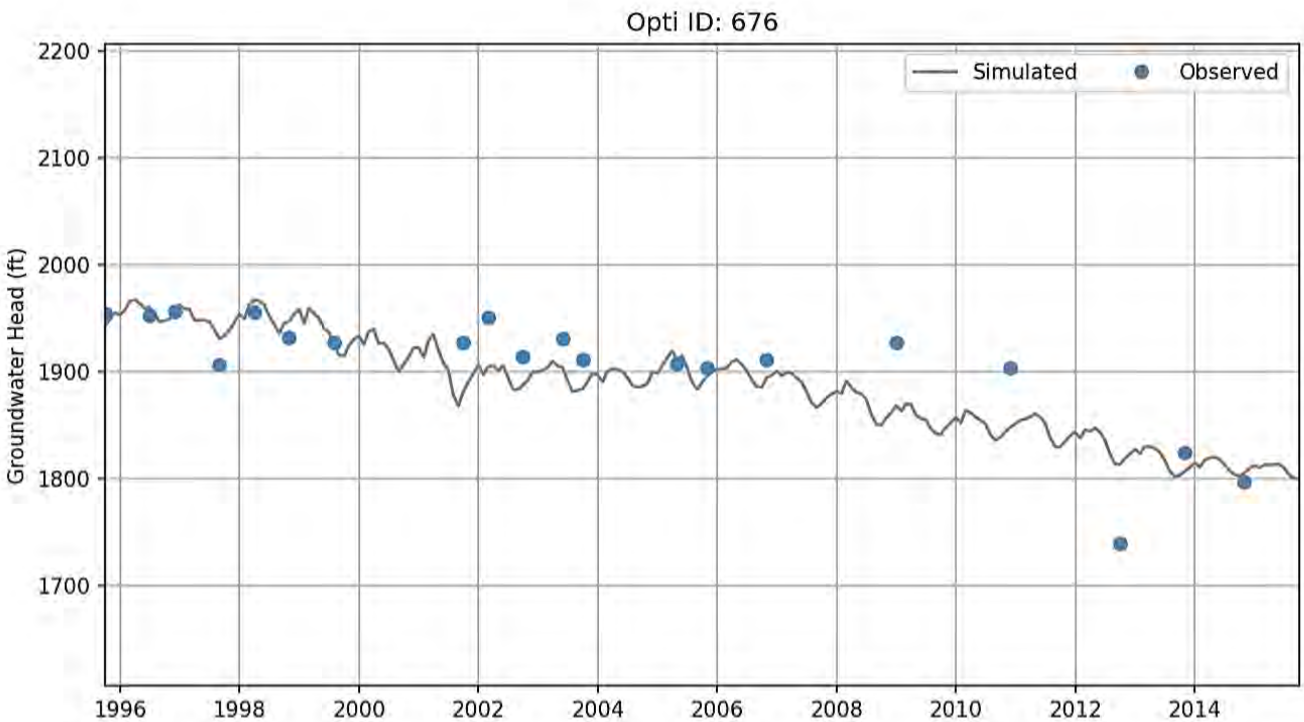
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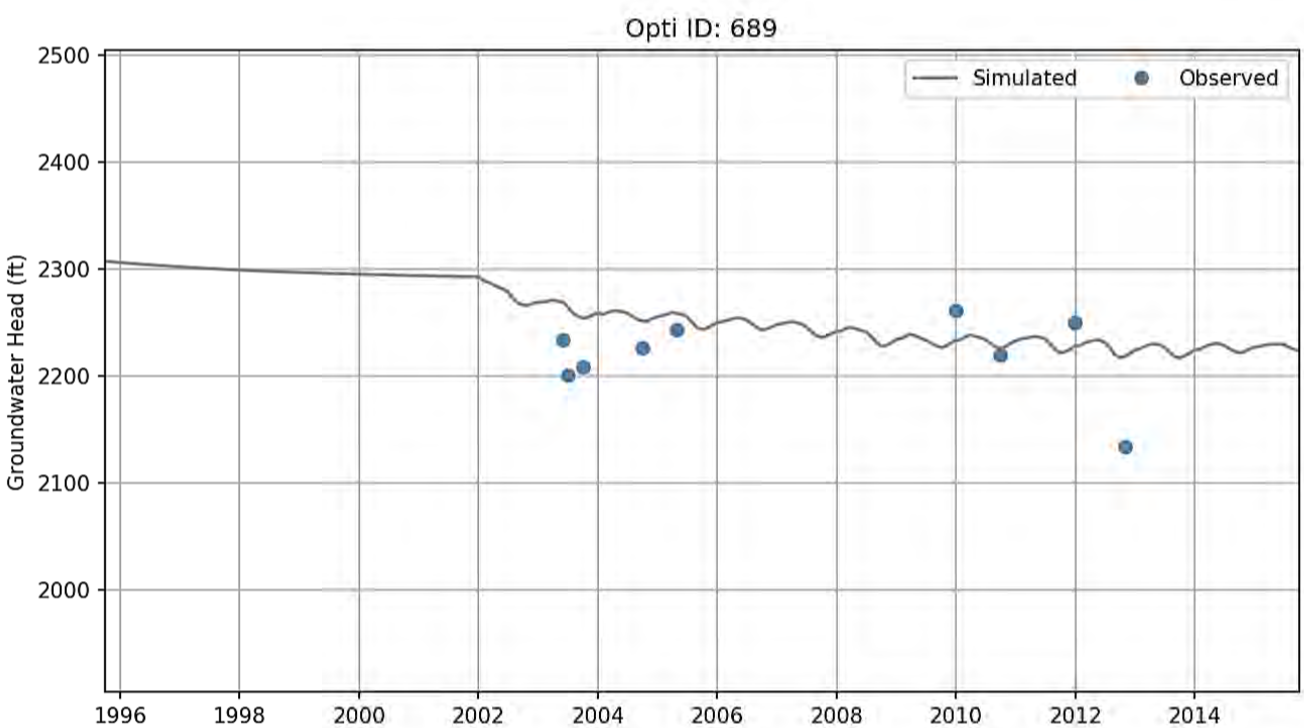
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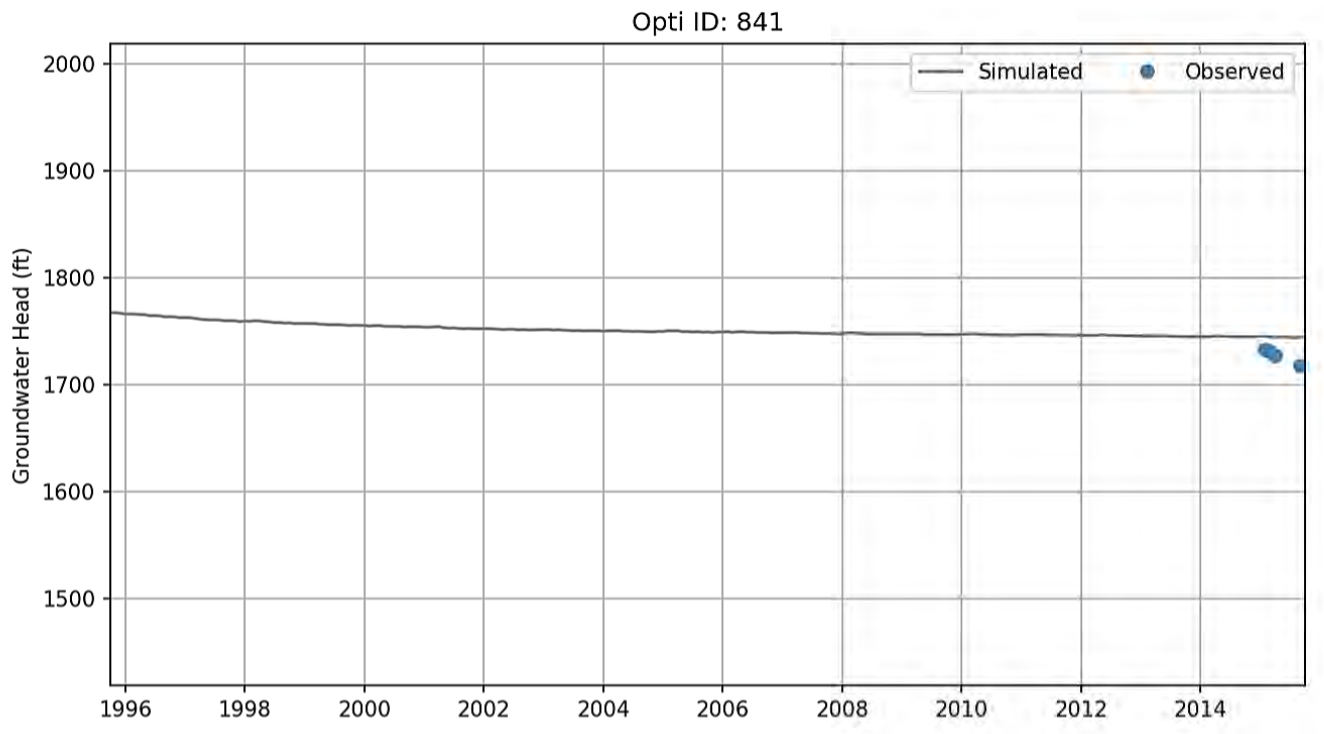
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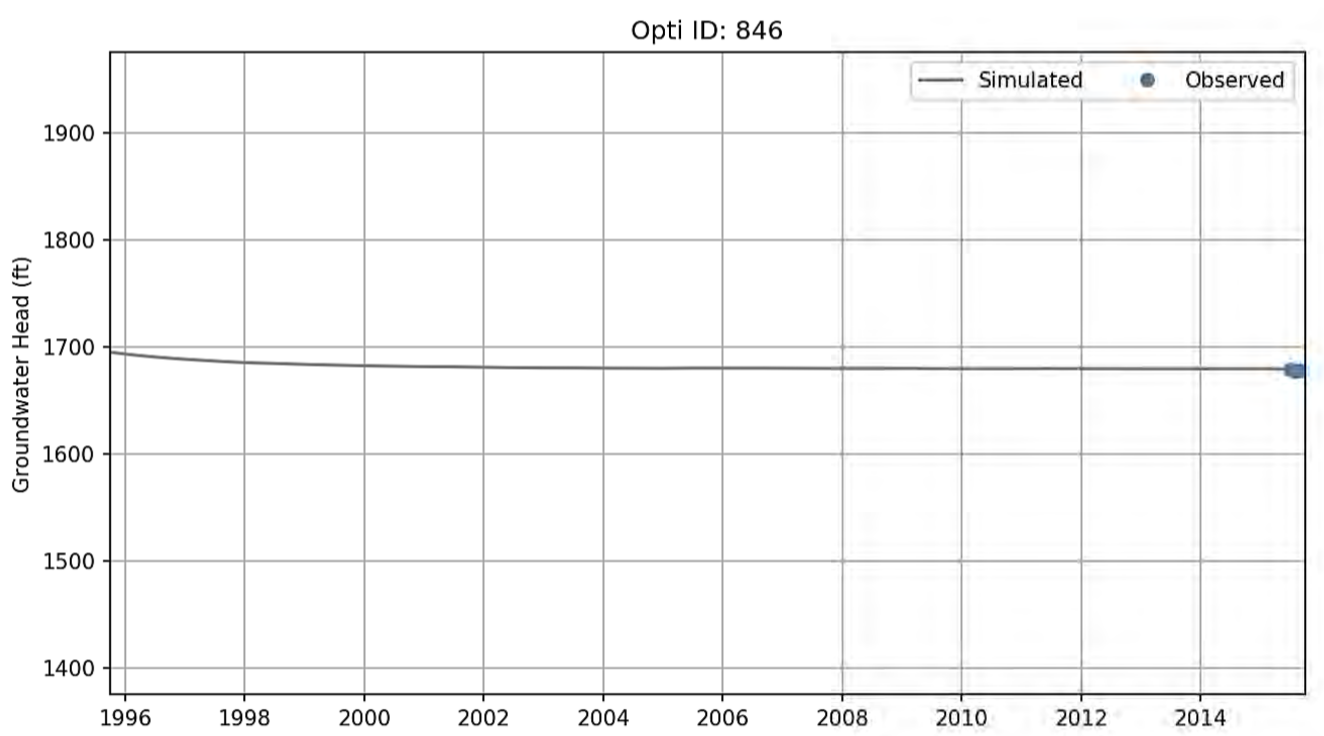
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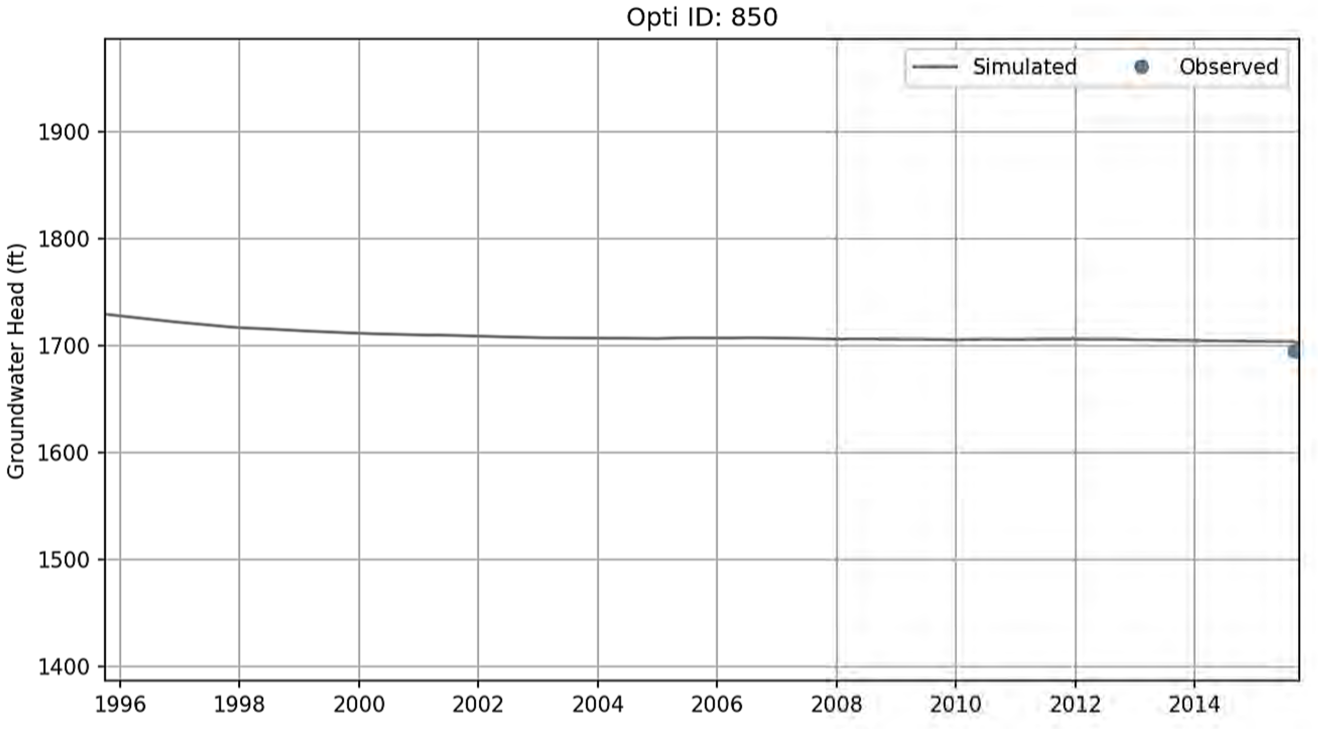

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1996
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Attachment C-4

Evapotranspiration and Applied Water Estimates

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Technical Memorandum

To: Woodard & Curran

From: Davids Engineering

Date: January 7, 2018

Subject: **Cuyama Basin Development of Evapotranspiration and Applied Water Estimates Using Remote Sensing**

1 Summary

The purpose of this effort is to develop time series estimates of agricultural water use for the Cuyama Basin from October 1994 through December 2017. The approach builds upon estimates of actual evapotranspiration (ETa) developed using remotely sensed information from the Landsat satellite.

The consumptive use of water (i.e., evapotranspiration) is the primary destination of infiltrated precipitation and applied irrigation water within the Cuyama Basin. Quantification of consumptive use was achieved by performing daily calculations of evapotranspiration (ET) for individual fields from October 1996 through December 2017. ET was separated into its evaporation (E) and transpiration (T) components. Transpiration was quantified using a remote sensing approach where Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), which was subsequently translated to a basal crop coefficient and combined with reference ET to calculate transpiration over time.

A spatial coverage of field boundaries was developed for the Cuyama Basin, and individual field polygons were assigned cropping and irrigation method information over time based on available data. Field boundaries were delineated by combining polygon coverages in GIS format from Bolthouse Farms, Grimmway Farms, LandIQ, and the California Department of Water Resources (DWR). The area encompassed by the field boundary GIS coverage includes only the Cuyama Basin.

Crop ET was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. Due to the remote sensing approach crop ET estimates are relatively insensitive to crop type and irrigation method so detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing relatively reliable estimates of crop ET. The amount of green vegetation present over time was estimated for each field polygon based on NDVI, which is calculated using a combination of red and near infrared reflectances as measured using multispectral satellite sensors onboard Landsat satellites. Following the preparation of NDVI imagery spanning the analysis period all images were quality controlled to remove pixels affected by clouds.

Mean daily NDVI values for each field were converted to basal crop coefficients. Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State

University[1]. Daily reference evapotranspiration (ET_o) was estimated based on information from California Irrigation Management Information System (CIMIS) weather stations. Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the Cuyama Basin.

A summary for the 1994 to 2017 analysis period of the annual ET of applied water (ET_{AW}), ET_c (synonymous with ET_a), applied water (AW), deep percolation of applied water (DP_{AW}) and deep percolation of precipitation (DP_{pr}) estimates based on the root zone water balance model is given in the Results section.

Application of remote sensing combined with daily root zone water balance modeling (RS-RZ model) provides an improved methodology for estimation of surface interactions with the groundwater system including net groundwater depletion through estimation of ET of applied water and other fluxes.

2 Introduction

The purpose of this effort is to develop time series estimates of agricultural, urban, and native vegetation water use for the Cuyama Basin from 1996 through 2017. Demand has been quantified at the field scale using a remote-sensing based daily root zone water balance model. Results from this model were used to parameterize an IWFM Demand Calculator (IDC) application that will be incorporated into an IWFM application for the Basin to support GSP development.

3 Methodology

3.1 Daily Root Zone Simulation Model

A conceptual diagram of the various surface layer fluxes of water into and out of the crop root zone is provided in Figure 3.1. The consumptive use of water (i.e., evapotranspiration or ET) is the primary destination of infiltrated precipitation and applied irrigation water within the Cuyama Basin. Quantification of consumptive use was achieved by performing daily calculations of ET for individual fields from October 1994 through December 2017. Evapotranspiration was separated into its evaporation (E) and transpiration (T) components. Additionally, each component was separated into the amount of E or T derived from precipitation or applied water.

[1] PRISM website: http://prism.oregonstate.edu/

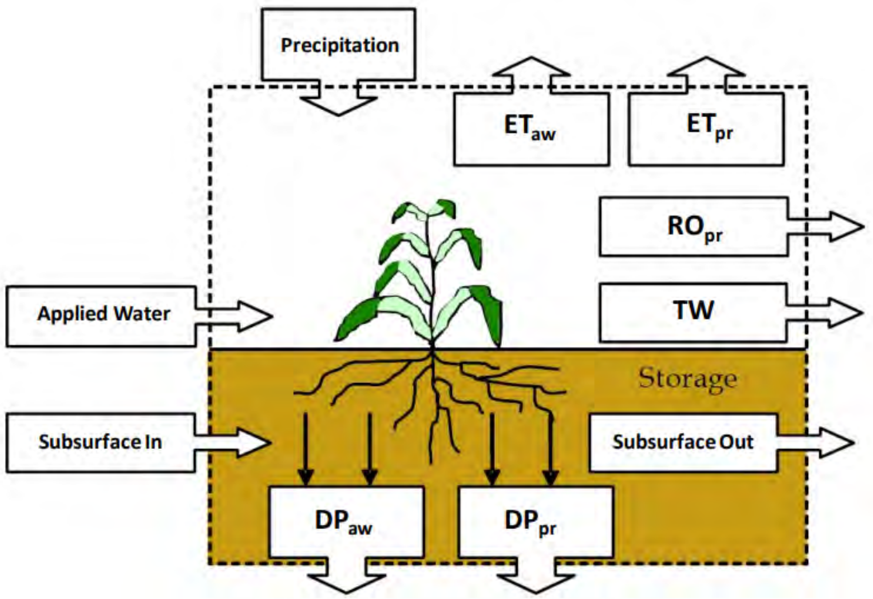

Figure 3.1. Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone

Transpiration was quantified using a remote sensing approach whereby Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of the amount of green vegetation present. NDVI values were calculated and interpolated for each field over time. NDVI values were then converted to transpiration coefficients that were used to calculate transpiration over time by multiplying daily NDVI by daily reference evapotranspiration (ET_o). Evaporation was quantified by performing a surface layer water balance for the soil based on the dual crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998). On a daily basis, evaporation was calculated based on the most recent wetting event (precipitation or irrigation) and the evaporative demand for the day (ET_o). This methodology is described in greater detail in the Davids Engineering report for the Kaweah Delta Water Conservation District (Davids Engineering 2013).

3.2 Development of Field Boundaries

A spatial coverage of field boundaries was developed for the Cuyama Basin, and individual field polygons were assigned cropping and irrigation method information. For each field polygon, daily water balance calculations were performed for the 1994 to 2017 analysis period, and irrigation events were simulated to estimate the amount of water applied to meet crop irrigation demands. This section describes the development of the field polygon coverage and assignment of cropping and irrigation method attributes.

3.2.1 Development of Field Boundaries

Field boundaries were delineated by combining polygon coverages in GIS format from Bolthouse Farms, Grimmway Farms, LandIQ, and the California Department of Water Resources (DWR). The area encompassed by the field boundary GIS coverage includes only the Cuyama Basin.

3.3 Assignment of Cropping and Irrigation Method

As described previously, crop evapotranspiration (ET) was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. A result of the remote sensing approach is that crop transpiration was estimated with little influence from the assigned crop type for each field. Additionally, crop transpiration is the dominant component of ET, meaning that ET estimates are likewise largely independent of the assigned crop type.

Crop evapotranspiration is driven to some extent by the characteristics of the irrigation method and its management, including the area wetted during each irrigation event and the frequency of irrigation. Surface irrigation methods typically wet more of the soil surface than micro-irrigation methods; however, surface irrigated fields are typically irrigated less frequently than their micro-irrigated counterparts. As a result, evaporation rates can be similar among surface and micro-irrigated fields and estimates of evaporation are likewise somewhat independent of the assigned irrigation method. Parameters related to irrigation method were assigned based the predominant irrigation method for each crop, as described by recent historical DWR land and water use surveys.

A key result of the relative insensitivity of the crop ET estimates to crop type or irrigation method (due to the remote sensing approach), is that detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing reliable estimates of crop ET at the field scale and, more importantly, at coarser scales due to the cancellation of errors in individual field estimates as they are aggregated.

Crop types were assigned to each field based on a combination of data from Bolthouse Farms, Grimmway Farms, LandIQ, and DWR. For fields farmed by Bolthouse or Grimmway, the local data were used. For other fields, available data from LandIQ and DWR were used.

3.4 NDVI Analysis

The amount of green vegetation present over time was estimated for each field polygon based on the Normalized Difference Vegetation Index (NDVI), which is calculated using a combination of red and near infrared reflectances, as measured using multispectral satellite sensors onboard Landsat satellites. NDVI can vary from -1 to 1 and typically varies from approximately 0.15 to 0.2 for bare soil to 0.8 for green vegetation with full cover. Negative NDVI values typically represent water surfaces.

3.4.1 Image Selection

Landsat images are preferred due to their relatively high spatial resolution (30-meter pixels, approx. 0.2 acres in size). A total of 671 raw satellite images were selected and converted to NDVI spanning the period from July 1994 to April 2018. Of the images selected, 207 were from the Landsat 5 satellite, 364 were from the Landsat 7 satellite (first available in 2001), and 100 were from the Landsat 8 satellite (first available in 2013). These images were used to process and download surface reflectance (SR) NDVI from the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA)[2].

There was sufficient cloud-free Landsat imagery available that no cloud gap filling was necessary. The number of days between image dates ranged from 8 to 96, with an average of 13 days. Generally, there was at least one image selected for each month.

3.4.2 Extraction of NDVI Values by Field and Development of Time Series NDVI Results

Following the preparation of NDVI imagery spanning the analysis period, all images were masked using the Quality Assessment Band (BQA) provided by ESPA to remove pixels affected by clouds and cloud shadows. Then, mean NDVI was extracted from the imagery for each field for each image date. These NDVI values were interpolated across the full analysis period from October 1, 1994 to December 31, 2017 to provide a daily time series of mean NDVI values for each field.

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[2] USGS ESPA website: https://espa.cr.usgs.gov/

Landsat satellite 5 and 7 bandwidths were adjusted to be consistent with bandwidths from Landsat 8 using the following empirical relationship:

$$\text{(Equivalent L8 mean NDVI)} = 0.984*\text{(L5/7 mean NDVI)} - 0.0421 \quad [3.1]$$

3.4.3 Development of Relationships to Estimate Basal Crop Coefficient from NDVI

Basal crop coefficients (K_{cb}) describe the ratio of crop transpiration to reference evapotranspiration (ET_o) as estimated from a ground-based agronomic weather station. By combining K_{cb}, estimated from NDVI, with an evaporation coefficient (K_e), it is possible to calculate a combined crop coefficient ($K_c = K_{cb} + K_e$) over time[3]. By multiplying K_c by ET_o, crop evapotranspiration (ET_c) can be calculated. For this analysis, ET_o, K_{cb}, K_e, and ET_c (synonymous to actual ET, ET_a) were estimated for each field on a daily time step from October 1, 1994 to December 31, 2017.

Mean daily NDVI values for each field were converted to basal crop coefficients using the relationship based on cropping information from the 2007 Tulare County crop survey conducted by DWR, combined with an analysis of actual evapotranspiration (ET_a) by crop conducted using the Surface Energy Balance Algorithm for Land (SEBAL®) for 2007 (Bastiaanssen et al., 2005; SNA, 2009). Specifically, a relationship between actual basal crop coefficients estimated using SEBAL and field-scale mean NDVI values developed by Davids Engineering (2013) was applied using NDVI data from Landsat to calculate daily basal crop coefficients for each field over time[4].

3.5 Precipitation

Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University. Specifically, each field was assigned estimated precipitation from the 4km PRISM grid cell within which its centroid fell.

Annual precipitation totals, averaged over the study area for water years 1995 to 2017, are shown in Figure 3.1. Water year precipitation over the study period varied from 2.7 inches in 2014 to 25.0 inches in 1998, with an annual average of 9.3 inches.

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[3] The estimation of Ke is based on a daily 2-stage evaporation model presented in FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998).

[4] This relationship is developed based on comparison of the combined crop coefficient to NDVI for individual fields but represents only the transpiration component of ET. Thus, the relationship developed predicts the basal crop coefficient, Kcb.

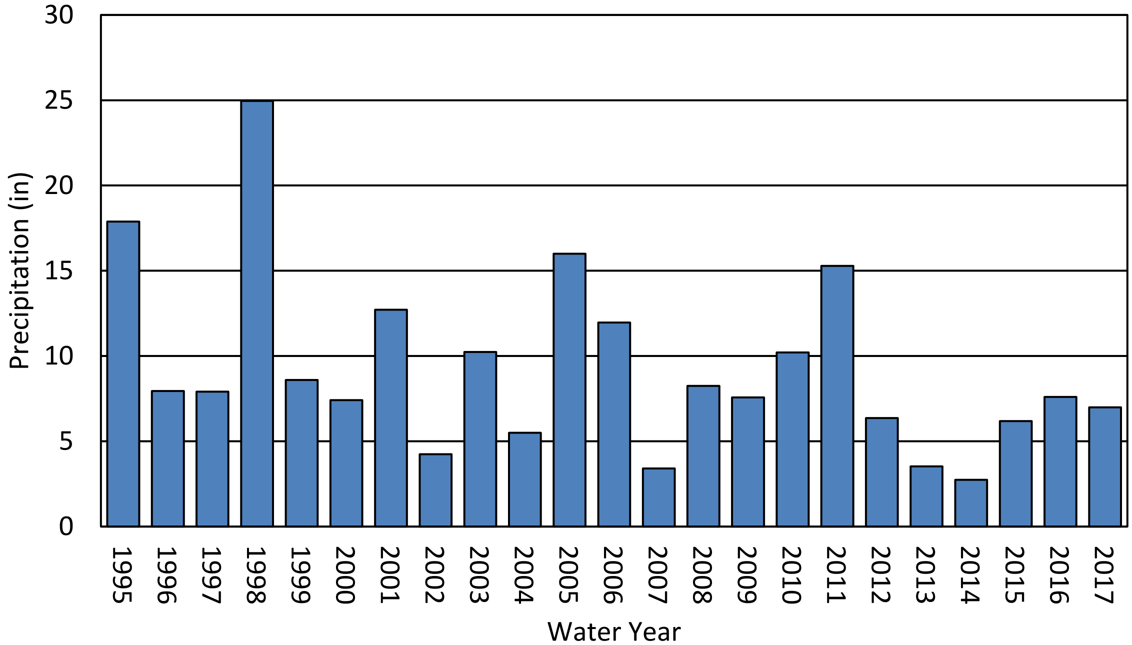

Figure 3.2. Annual Precipitation Totals

3.6 Estimation of Daily Reference Evapotranspiration

Daily reference evapotranspiration (ET_o) was estimated based on information from the California Irrigation Management Information System (CIMIS) weather station at Cuyama. ET_o provides a means of estimating actual crop evapotranspiration over time for each field. Based on review of nearby weather stations with data available during the period of analysis, the Cuyama station (88) was selected based on it being located within the Cuyama Basin, having relatively good fetch, and having available data during the analysis period.

Individual parameters from the available data including incoming solar radiation, air temperature, relative humidity, and wind speed were quality-controlled according to the procedures of Allen et al. (2005). The quality-controlled data were then used to calculate daily ET_o for the available period of record.

3.7 Estimation of Root Zone Water Balance Parameters

Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the Cuyama Basin. Crop parameters of interest include root depth, NRCS curve number[5], and management allowable depletion (MAD). Root depth was estimated by crop group based on published values and a representative mix of individual crops within each crop group for the Cuyama Basin. Curve numbers were estimated based on values published in the NRCS National Engineering Handbook, which provides estimates based on crop type and condition. MAD values by crop were estimated based on values published in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

[5] The curve number runoff estimation method developed the Natural Resources Conservation Service (NRCS) was used to estimate runoff from precipitation in the model. For additional information, see NRCS NEH Chapter 2 (NRCS, 1993).

Soil hydraulic parameters of interest include field capacity (% by vol.), wilting point (% by vol.), saturated hydraulic conductivity (ft/day), total porosity (% by vol.), and the pore size distribution index (λ, dimensionless). These parameters were estimated by first determining the depth-weighted average soil texture (sand, silt, clay, etc.) based on available NRCS soil surveys. Then, the hydraulic parameters were estimated using hydraulic pedotransfer functions developed by Saxton and Rawls (2006). Next, hydraulic parameters were adjusted within reasonable physical ranges for each soil texture so that the modeled time required for water to drain by gravity from saturation to field capacity agreed with typically accepted agronomic values. Unsaturated hydraulic conductivity (e.g. deep percolation) within the root zone was modeled based on the equation developed by Campbell (1974) for unsaturated flow.

4 Results

4.1 Crop Evapotranspiration

Estimated annual crop evapotranspiration volumes for fields with their centroid within the Cuyama Basin are shown in Figure 4.1. Estimated volumes of ET derived from applied water (ETaw) and precipitation (ETpr) are shown in thousands of acre-feet (taf). Annual ETaw ranged from 38 taf to 53 taf, with an average of 44 taf. Annual ETpr ranged from 4 taf to 33 taf, with an average of 15 taf. Total crop ET ranged from 43 taf to 76 taf, with an average of 58 taf.

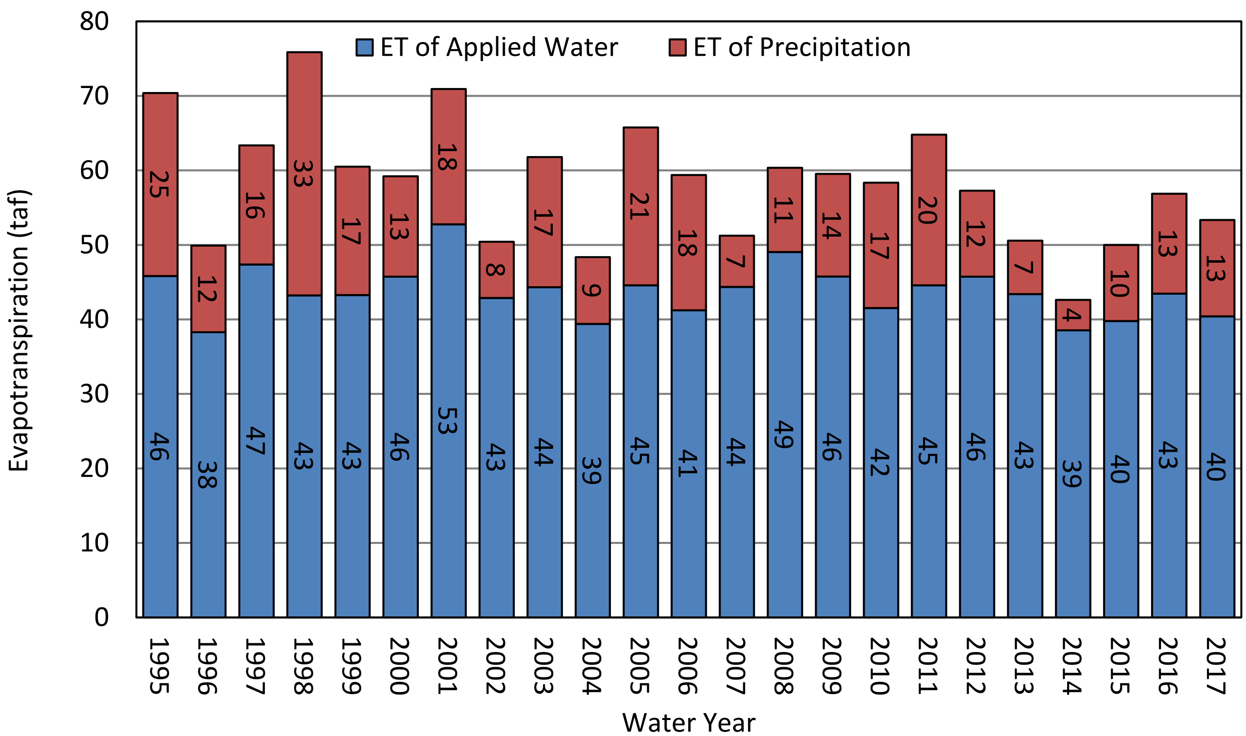

Figure 4.1. Cuyama Basin Crop ET by Water Year

4.2 Irrigation Demands

Annual estimated irrigation demands for fields with their centroid within the Cuyama Basin are shown in Figure 4.2 in thousands of acre feet. Annual demands ranged from 52 taf to 73 taf, with an average of 60 taf.

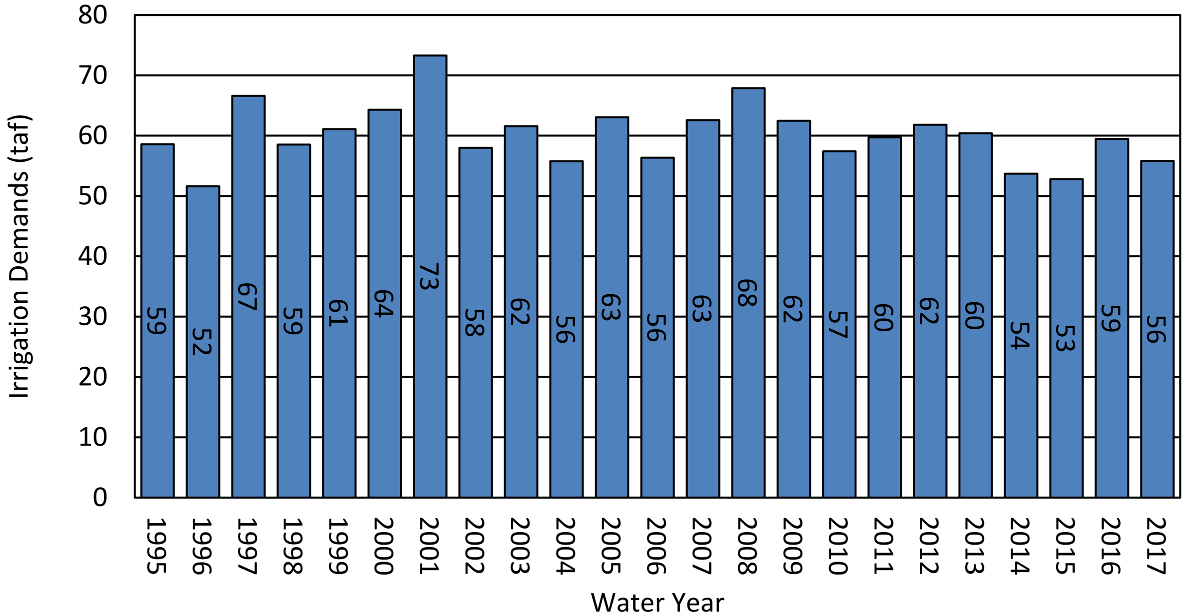

Figure 4.2. Cuyama Basin Irrigation Demands by Water Year

4.3 Deep Percolation

Estimated annual deep percolation volumes for fields with their centroid within the Cuyama Basin are shown in Figure 4.3. Estimated volumes of deep percolation derived from applied water (DPaw) and precipitation (DPpr) are shown in thousands of acre-feet. Annual DPaw ranged from 15 taf to 19 taf, with an average of 17 taf. Annual DPpr ranged from 4 taf to 28 taf, with an average of 10 taf. Total deep percolation ranged from 20 taf to 47 taf, with an average of 27 taf.

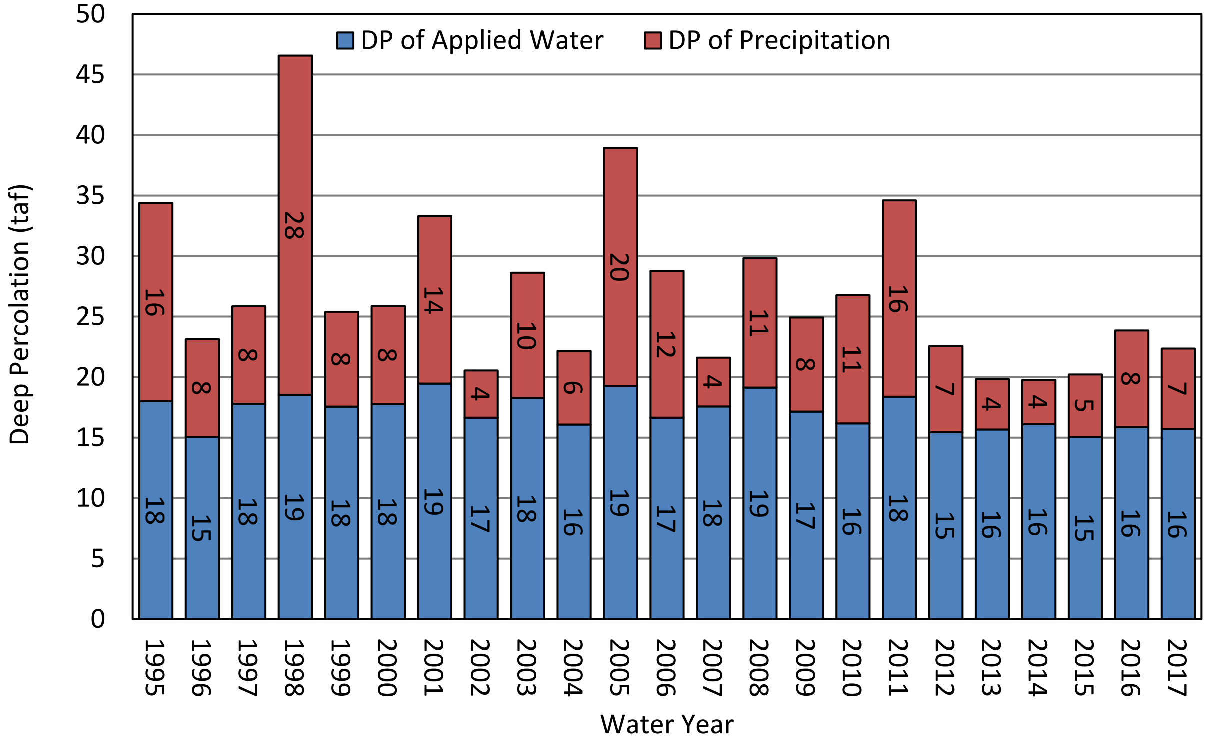

Figure 4.3. Cuyama Basin Deep Percolation by Water Year

4.4 Annual Evapotranspiration by Crop for 2014

Estimated annual evapotranspiration by crop is shown in Figure 4.4, along with the estimated acreage for each crop. Figure 4.4 shows the estimated total ET by crop in inches in 2014. Annual ET ranges from 5 inches for young perennials to 59 inches for alfalfa. The primary crops are carrots, representing 5,500 acres. Grapes, miscellaneous truck crops, pistachios, potatoes and onions and garlic are also significant, representing 948, 838, 761, 668 and 646 acres, respectively.

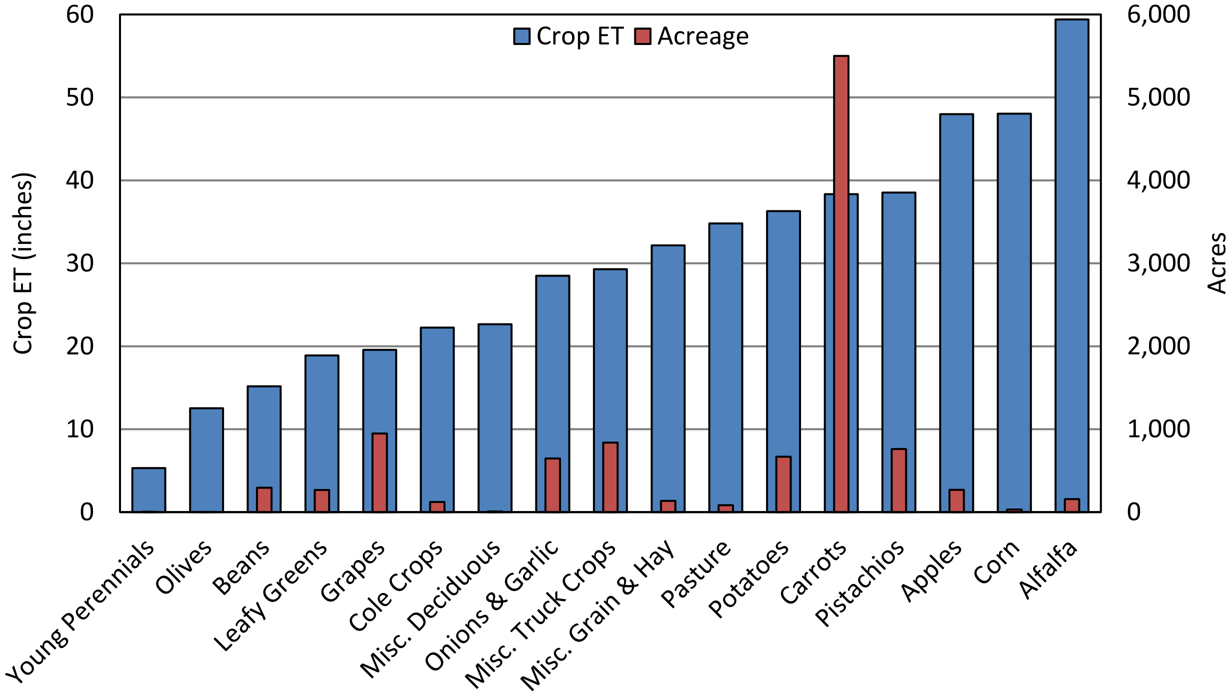

Figure 4.4. Cuyama Basin 2014 ET by Crop and Crop Acreage

Additional monthly plots of the "fraction of reference ET" (ET_{oF}), ET_a and AW by crop for 2014 can be found in the appendix.

5 References

Allen, R.G, L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO. Rome, Italy.

Allen, R.G., Walter, I.A., Elliott, R.L., Howell, T.A., Itenfisu, D., Jensen, M.E., and R.L. Snyder. 2005. The ASCE Standardized Reference Evapotranspiration Equation. Technical Committee on Standardization of Reference Evapotranspiration. American Society of Civil Engineers. Reston, VA.

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Davids Engineering. 2013. Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing. Kaweah Delta Water Conservation District. http://www.kdwcd.com/wp-content/uploads/2018/07/KDWCD-NDVI-ET-Analysis-FINAL-REPORT-March-2013.pdf

NRCS. 1993. Chapter 2 - Watershed Project Evaluation Procedures. National Engineering Handbook Part 630, Hydrology.

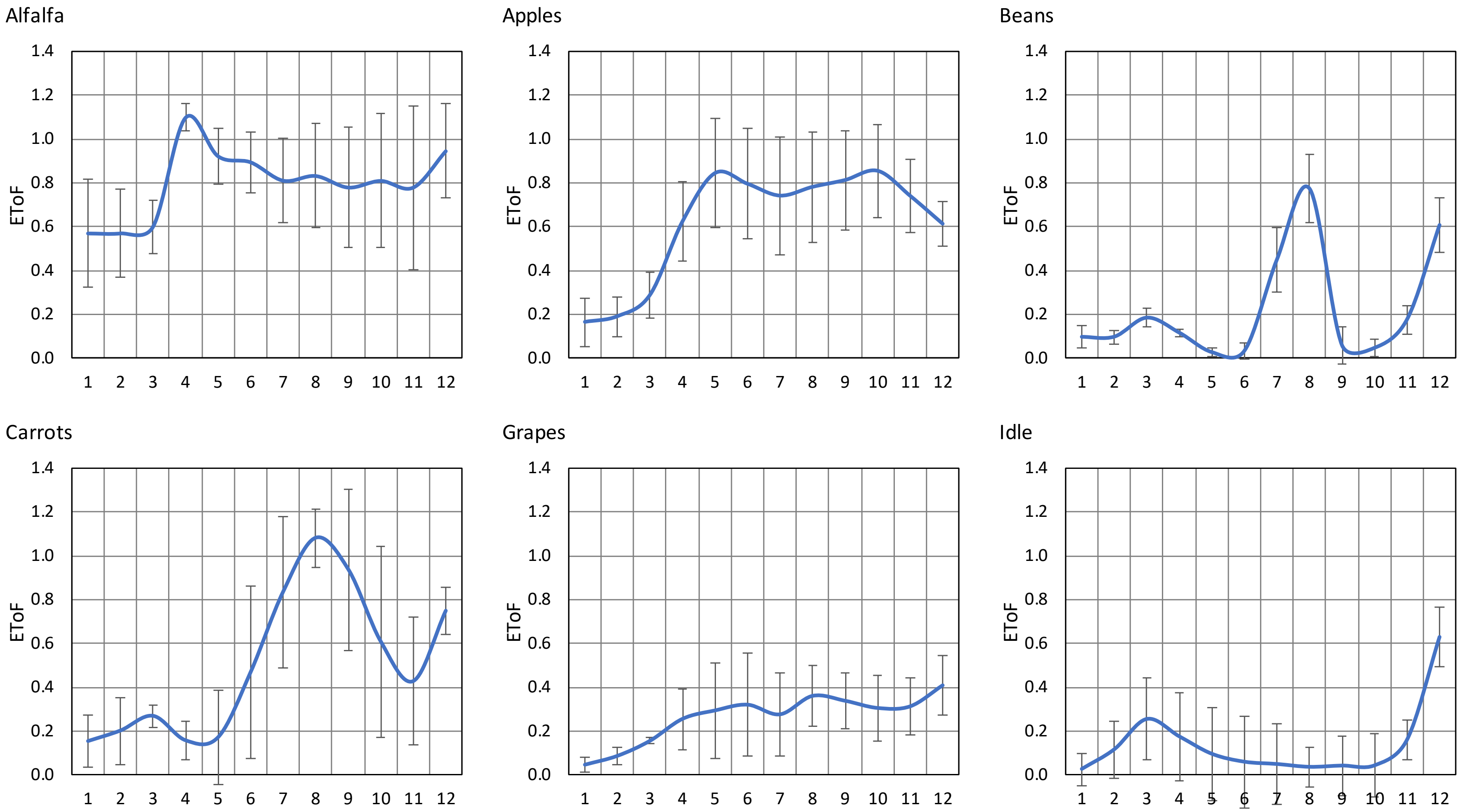
Saxton, K.E. and W.J. Rawls. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Sci. Soc. Am. J. 70:1569–1578.

6 Appendix

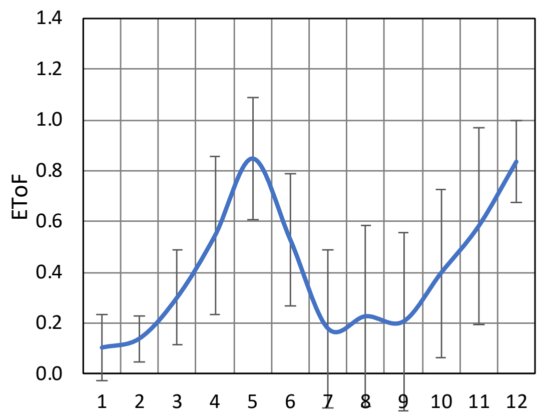
This appendix includes the following figures:

- Average monthly crop water use coefficients or "fraction of reference ET" (EToF) by crop, along with error bars depicting the standard deviation among fields.
- Average monthly crop ET by crop, along with error bars depicting the standard deviation among fields.
- Average monthly applied water by crop, along with error bars depicting the standard deviation among fields.

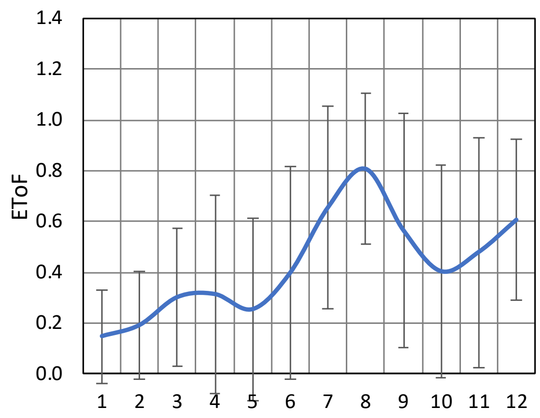
EToF 2014


Alfalfa
Apples
Beans
Carrots
Grapes
Idle
EToF
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12

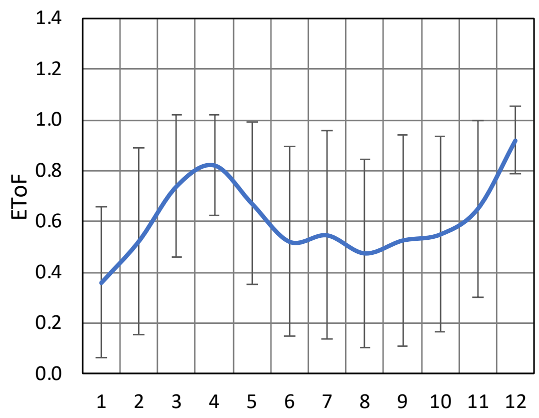
Misc. Grain and Hay



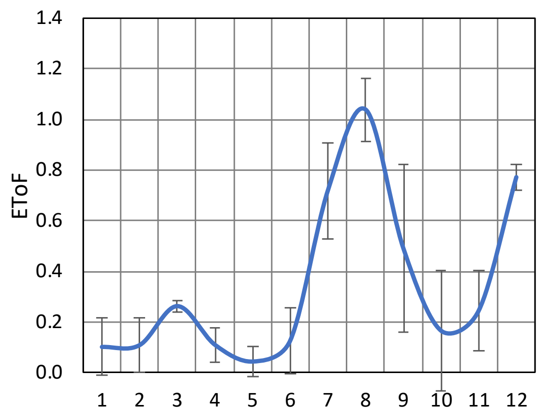
Misc. Truck



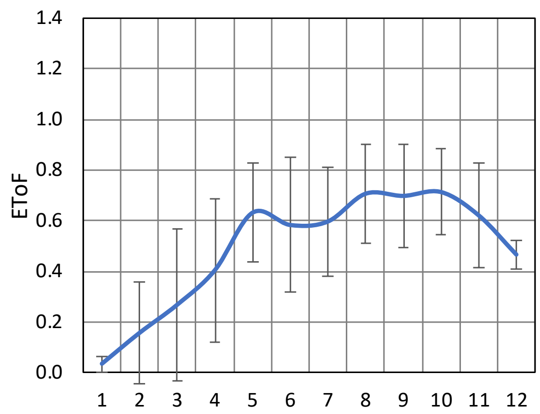
Mixed Pasture



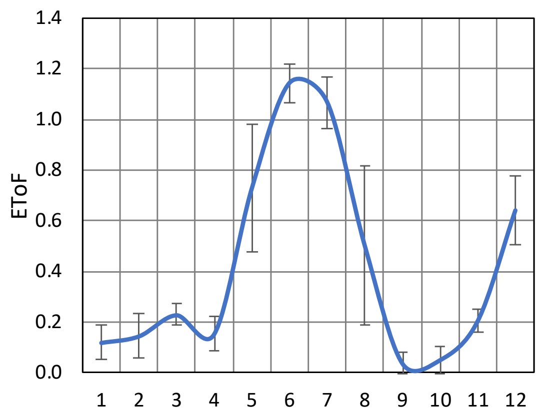
Onions and Garlic



Pistachios

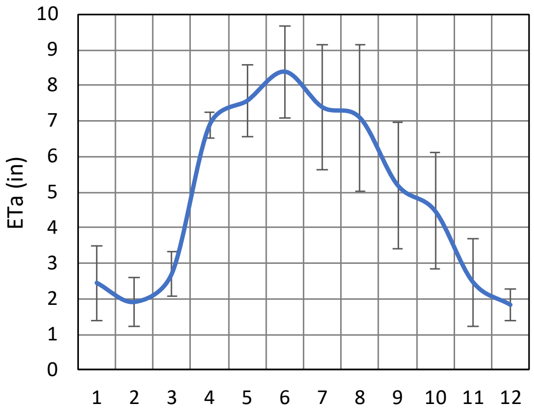


Potatoes

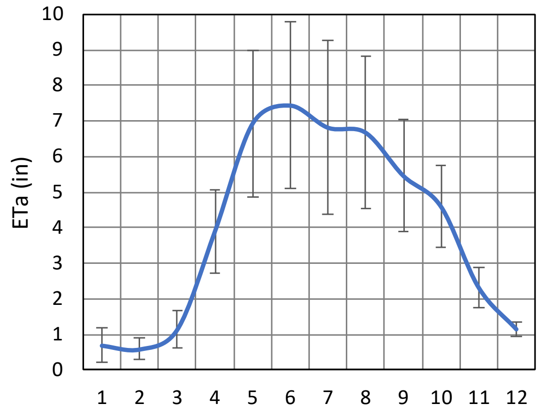


ETc 2014

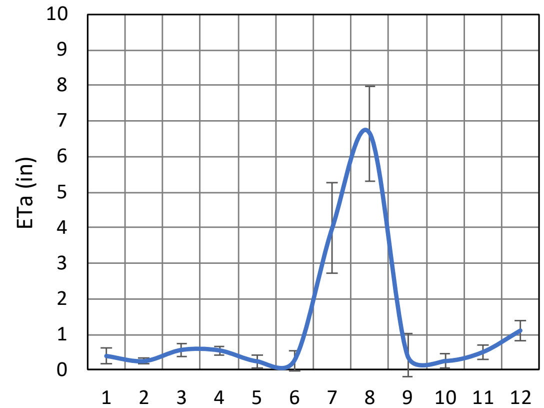
Alfalfa



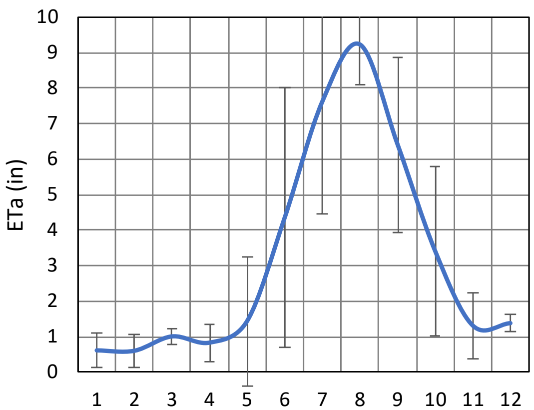
Apples



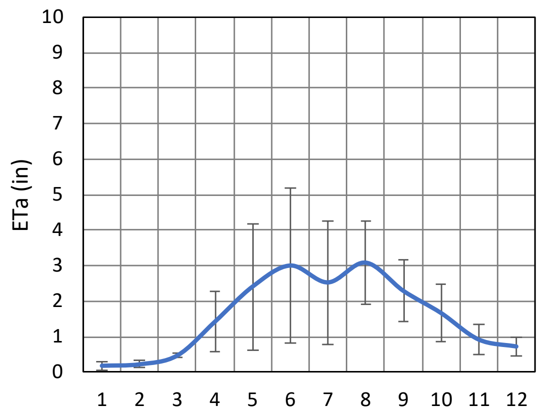
Beans



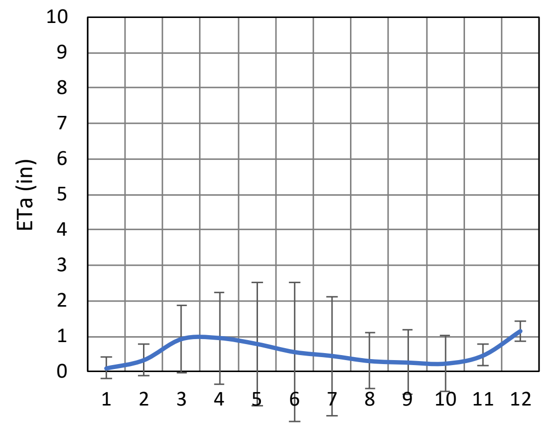
Carrots



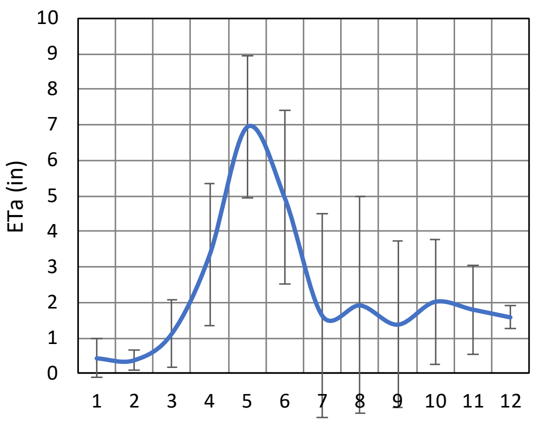
Grapes



Idle



Misc. Grain and Hay



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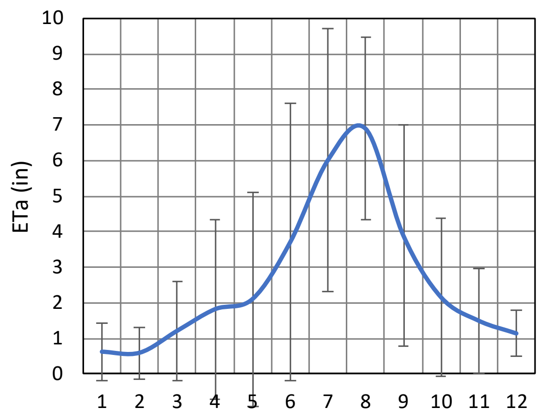
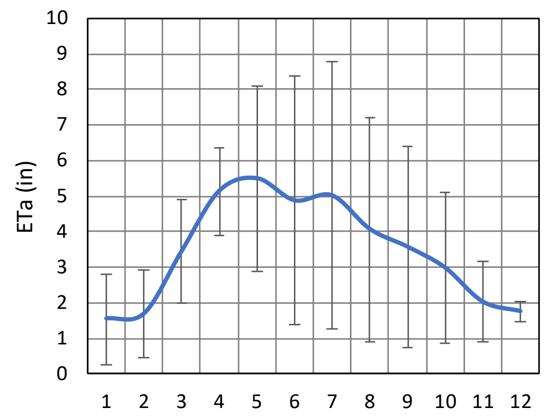


Mixed Pasture



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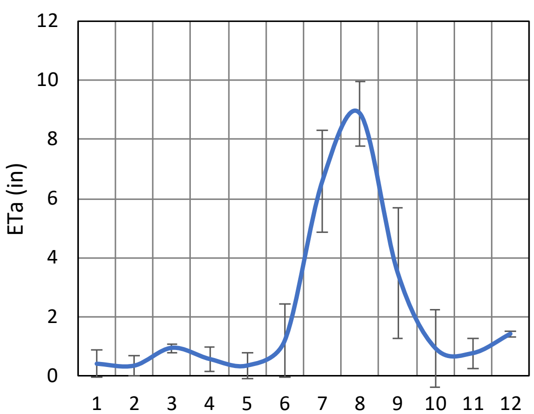

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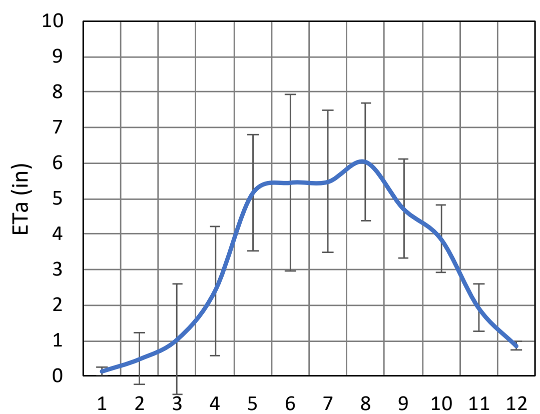
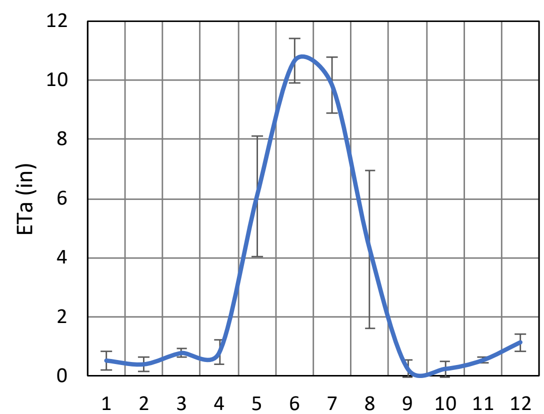
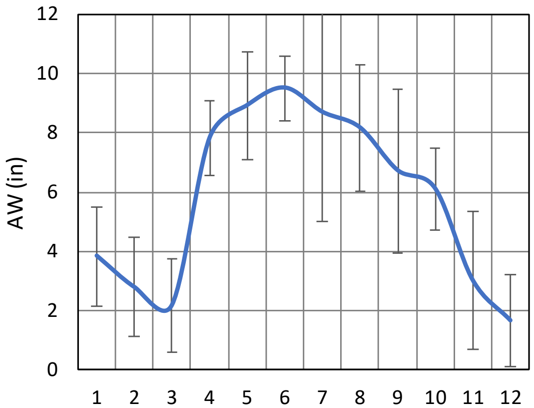


Potatoes



AW 2014

Alfalfa



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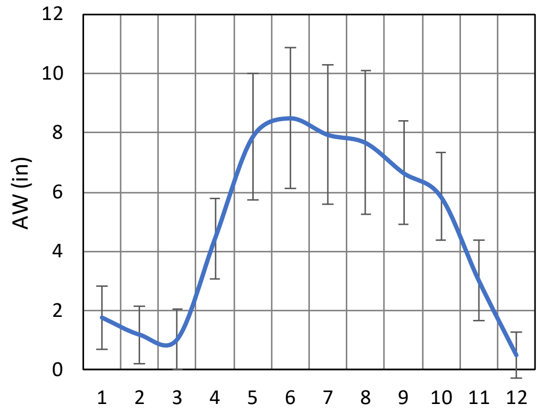

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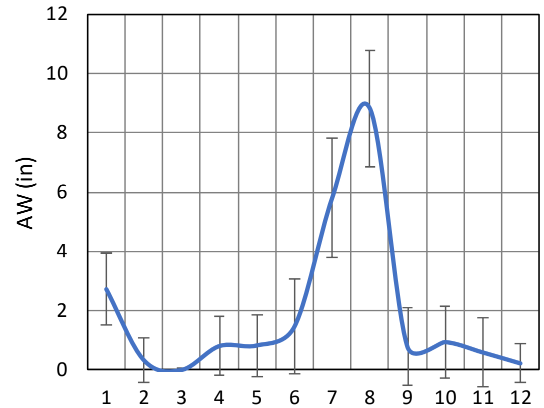

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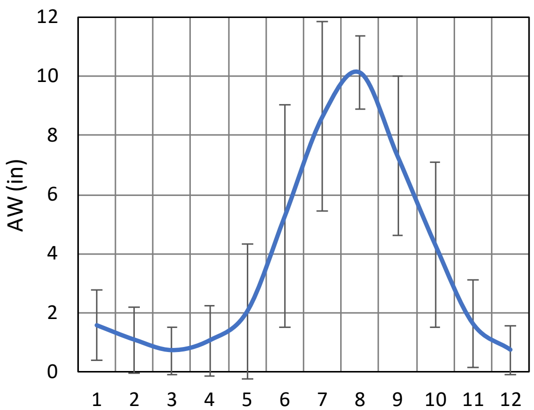

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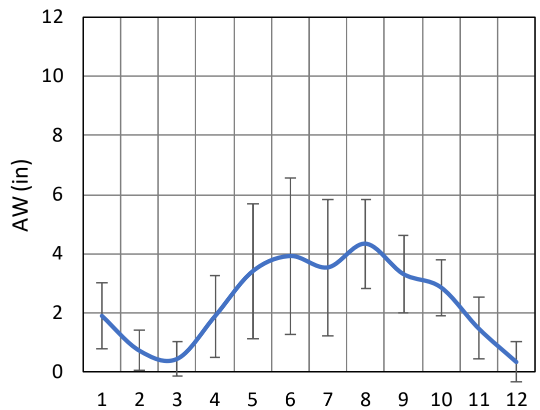

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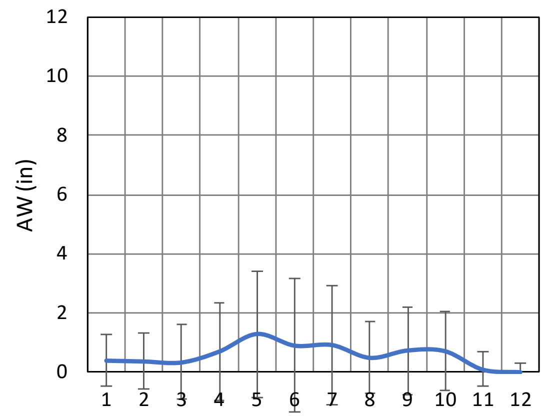

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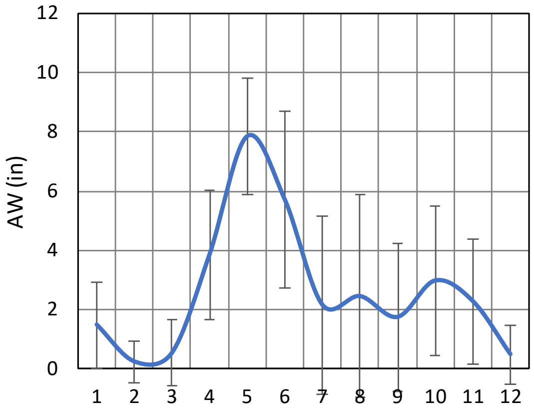

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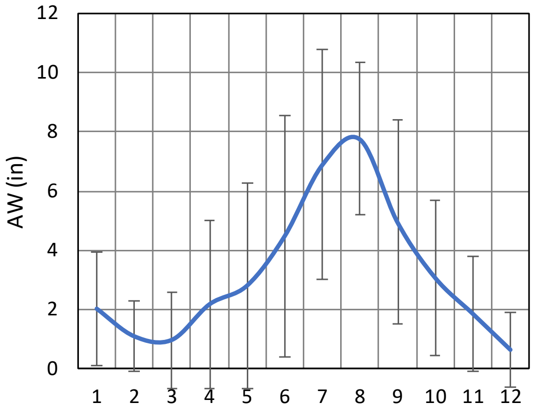

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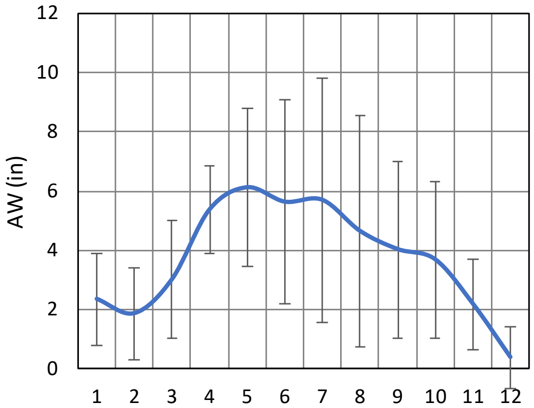

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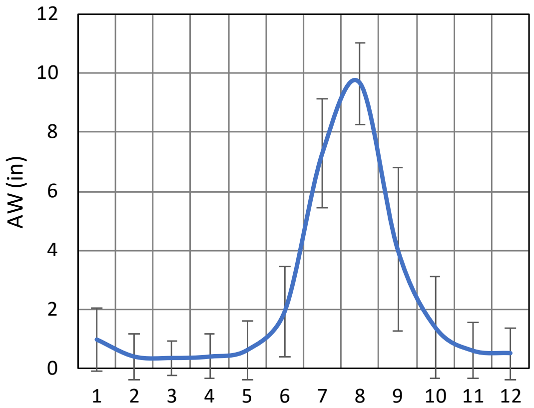

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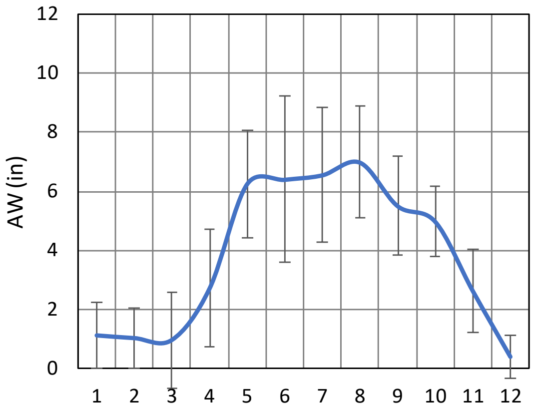

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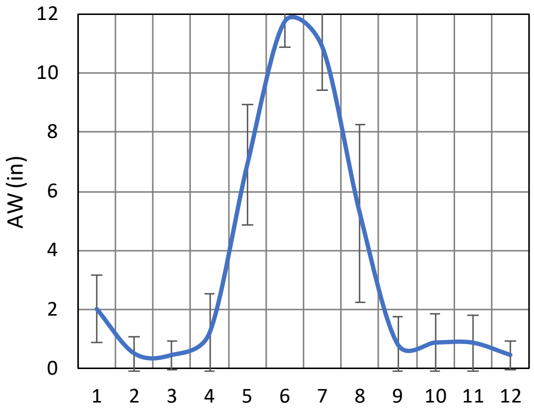

Chapter 2
Appendix D

Technical Memorandum:
Verification of NCCAG-Identified Locations

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TECHNICAL MEMORANDUM

TO: Cuyama Groundwater Sustainability Agency

CC: Brian Van Lienden, Woodard & Curran PM

PREPARED BY: William L. Medlin, PWS, ENV SP

REVIEWED BY: John Ayres and Micah Eggleton

DATE: February 15, 2019

RE: Cuyama GSP Groundwater Dependent Ecosystems Study

As part of the California Sustainable Groundwater Management Act (SGMA), Groundwater Sustainability Agencies (GSAs) are required to develop a Groundwater Sustainability Plan (GSP) to help ensure that groundwater is available for long-term, reliable water supply uses. SGMA was put into place and is enforced by the California Department of Water Resources (DWR). Once implemented, each GSP must address certain key elements such as a baseline groundwater assessment, monitoring, establishing best management practices (BMPs), and setting new regulations with the goal of defining a pathway to achieve sustainable groundwater management within 20 years (DWR 2018).

Within the GSP, a baseline assessment of groundwater conditions must be completed, and part of that assessment includes identification of groundwater dependent ecosystems (GDEs) and an assessment of potential impacts on GDEs. SGMA defines GDEs as “ecological communities or species that depend on groundwater emerging from aquifers or on groundwater occurring near the ground surface.” The identification and determination of GDEs within a groundwater basin is the responsibility of the GSA that governs the basin. This study specifically focuses on GDEs identified within the Cuyama Valley groundwater basin.

1. CUYAMA VALLEY GROUNDWATER BASIN ECOLOGICAL SETTING

The Cuyama Valley groundwater basin encompasses multiple California ecoregions (Griffith et al. 2016). In terms of land area, the dominant ecoregion is the Central California Foothills and Coastal Mountains (6), sub-ecoregion Cuyama Valley (6am). This ecoregion is characterized by its Mediterranean climate with hot, dry summers and cool, moist winters. Typical vegetative communities consist of chaparral and oak woodlands; grasslands are present at some lower elevations and pine forests are observed at high elevations. Most of the region is comprised of open, low mountains and foothills with some irregular plains and narrow valleys in certain locations. More specifically, the Cuyama Valley is a narrow valley with significant agricultural production. The mainstem Cuyama River flows through the center of the valley from southeast to northwest.

A minor part of the Cuyama Valley ground water basin is in the Southern California Mountains (8) ecoregion, in the Northern Transverse Range (8g) sub-ecoregion. This ecoregion, like other California ecoregions, is characterized by a Mediterranean climate of hot, dry summers and cool, moist winters. Chaparral and oak woodland vegetative communities are still ever-present, however the elevations in this ecoregion are higher generally leading to cooler summers and greater rainfall which result in denser vegetation and large areas of coniferous forests. There is a slope effect that causes some significant ecological differences in the Transverse Range. South-facing slopes receive more annual precipitation (30-40 inches) than the northern-facing slopes (15-20 inches), yet evaporation rates contribute to the development of chaparral communities. While on the northern-facing side of parts of the ecoregion, lower temperatures and evaporation coupled with slow snow melt allow for a coniferous forest that transitions to desert montane habitat. Some areas of severe erosion are common where vegetation has been removed via fire, overgrazing, or other land clearing practices. Many areas in this ecoregion are National Forest public land (Griffith et al. 2016). The Cuyama River headwaters (Quatal Canyon Creek, Apache Canyon Creek, and Cuyama Creek) flow through this ecoregion. Figure 1 (Attachment A) illustrates the general location of the Cuyama Valley groundwater basin in the context of the Ecoregions of California.

2. GDE ASSESSMENT AND FIELD VALIDATION

Using Geographic Information Systems (GIS), Woodard & Curran completed a preliminary desktop analysis of the California DWR *Natural Communities Commonly Associated with Groundwater* (NCCAG) geospatial data set. Woodard & Curran attempted to identify NCCAG polygons that appeared to be "probable GDEs" based on the following observations:

- Presence of a mapped USGS spring or seep
- Inundation visible on aerial imagery
- Saturation visible on aerial imagery
- Dense riparian and/or wetland vegetation visible on aerial imagery

Areas that did not exhibit the above characteristics (or similar) were considered "probable non-GDEs" for purposes of this study. Reference Figure 2 (Attachment A) for geospatial representation of our basin-wide GDE desktop assessment.

In addition to the preliminary desktop analysis of the NCCAG data set, Woodard & Curran also completed a preliminary GDE field validation study throughout portions of the Cuyama Valley groundwater basin. The field study was conducted only on publicly accessible lands (including the Los Padres National Forest) where the NCCAG data set indicated potential presence of GDEs. Field observations were made at NCCAG-mapped seeps, springs, and at other riparian habitats to document plant communities, aquatic or semi-aquatic wildlife, indicators of surface and subsurface hydrology, presence of hydric soils, and other relevant ecological and hydrological data. Photographs were taken in the four cardinal directions (north, east, south, west) at each field validation assessment location, and additional photographs were taken of plant species and other relevant ecological data. Global Positioning System (GPS) points were also collected using a sub-meter Trimble Geo 7x GPS unit at the field validation assessment locations. Preliminary determinations were made at these field assessment locations as to whether an area would be classified as a GDE. Figure 3 (Attachment A) shows the locations of GDE field validation assessment data collection points.

3. RESULTS

Out of 486 NCCAG-mapped polygons (128 GDE_wetland and 358 GDE_vegetation), the preliminary desktop analysis yielded 123 "probable GDEs" and 275 "probable non-GDEs" based on the above-described methodology. Individual polygons were not assessed due to time constraints, but rather groupings of similarly-situated riparian areas or clusters of polygons were assessed via GIS for probability of GDE classification.

The preliminary GDE field validation study assessed six (6) locations in the field on publicly accessible lands. All field assessment sites were in the Los Padres National Forest public lands. One (1) location was along the upper mainstem of the Cuyama River, and the other five (5) locations were in the Apache Canyon Creek watershed. Table 1 below describes each of the field assessment sites in more detail.

Table 1: GDE Field Validation Data Collection Sites

GPS Data Point Name	Latitude / Longitude	NCCAG-Mapped Polygon?	NCCAG Vegetation / Wetland Type	Dominant Plant Species Observed	Other Notes
probable Non-GDE 1	34.760116 N, 119.419661 W	Yes	Vegetation - Riversidean Alluvial Scrub	*Hesperoyucca whipplei, Arctostaphylos glauca, Lepidospartum squamatum, Ericameria nauseosa, Eriogonum fasiculatum, Bromus carinatus*	Soils at data point are sandy, dry and friable; would not stay in soil auger. This location does not appear to be a GDE.
probable Non-GDE 2	34.761994 N 119.375711 W	Yes	Vegetation - Scalebroom	*Lepidospartum squamatum, Ericameria nauseosa, Eriogonum fasiculatum*	Soils at data point are dry and friable; Some pines and junipers are growing in the riparian zone adjacent to river bed; no evidence of hydrology that persists beyond flashy storm events. This location does not appear to be a GDE.
GDE 1	34.778902 N 119.341961 W	No	N/A	*Juncus xiphoides, Juncus patens, Typha domingensis, Scirpus microcarpus, Salix exigua, Salix laevigata, Castilleja sp., Isoetes howellii*	A small stream is flowing at this location and hydrophytic vegetation is present throughout the channel; brown algae observed in flowing stream; crystallized salt or other calcic material observed on stream channel sediments; soils are saturated to the surface in this area. This location appears to be a GDE.
GDE 2	34.801748 N 119.293979 W	Yes	Wetland - Palustrine, Scrub-Shrub, Seasonally Saturated	*Clematis ligusticifolia, Juncus effusus, Salix laevigata, Urtica dioica*	Data point is located at US Forest Service Nettle Springs Campground; USGS mapped spring indicated at data point; groundwater is seeping out of the hillside at this data point; soils sampled on hillslope are hydric and saturated at the surface; water flows in a small channel for approximately 300-500 feet downstream of the spring before drying up. This location appears to be a GDE.
GDE 3	34.772312 N 119.346965 W	No	N/A	*Salix lasiolepis, Baccharis salicifolia, Baccharis pilularis Distichlis spicata, Artemisia californica,*	Data point is located within a small floodplain depression willow thicket. Hydrophytes are present and soils are saturated at

				Juncus patens, Anemopsis californica, Leymus triticoides	the surface by what appears to be groundwater. Soils are hydric. This location appears to be a GDE.
GDE 4	34.773548 N 119.346732 W	Yes	Vegetation - Riparian Mixed Shrub	*Salix laevigata, Juncus patens, Leymus triticoides, Anemopsis californica, Melilotus sp., Isoetes howellii*	A small stream is flowing at this location and hydrophytic vegetation is present throughout the channel; crystallized salt or other calcic material observed on stream channel sediments; soils are saturated to the surface in this area. This location appears to be a GDE.

4. CONCLUSIONS

The Cuyama Valley groundwater basin is a significantly stressed aquifer due to several factors including climate, industrial-scale agriculture, oil and gas exploration and production, ranching, and other land uses. The combination of these factors has drawn the groundwater down to greater than 600 feet below the ground surface in some locations, and this affects GDEs by limiting the amount of groundwater available to ecological communities living at the surface. Especially affected is the Cuyama River mainstem which was observed to be dry throughout much of its reach that was visible during our preliminary GDE field validation study.

However, there do appear to be some GDEs present within the Cuyama Valley groundwater basin as indicated in Table 1. All these areas (GDE 1 – 4) were located within the headwaters of the Cuyama River along Apache Canyon Creek and its floodplain. Areas mapped by the NCCAG data set as seeps and/or springs and the immediately downstream riparian corridors were among the GDEs that were assessed in the field. These locations had hydrophytic vegetation and other near-surface hydrologic indicators that would suggest that the ecological community is dependent on groundwater being present for significant durations during the growing season each year.

Due to access limitations because of private property restrictions, further study should be done along the mainstem of the Cuyama River (and other select tributaries) to determine if GDEs are present within the channel or riparian area.

5. REFERENCES

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ATTACHMENT A: FIGURES

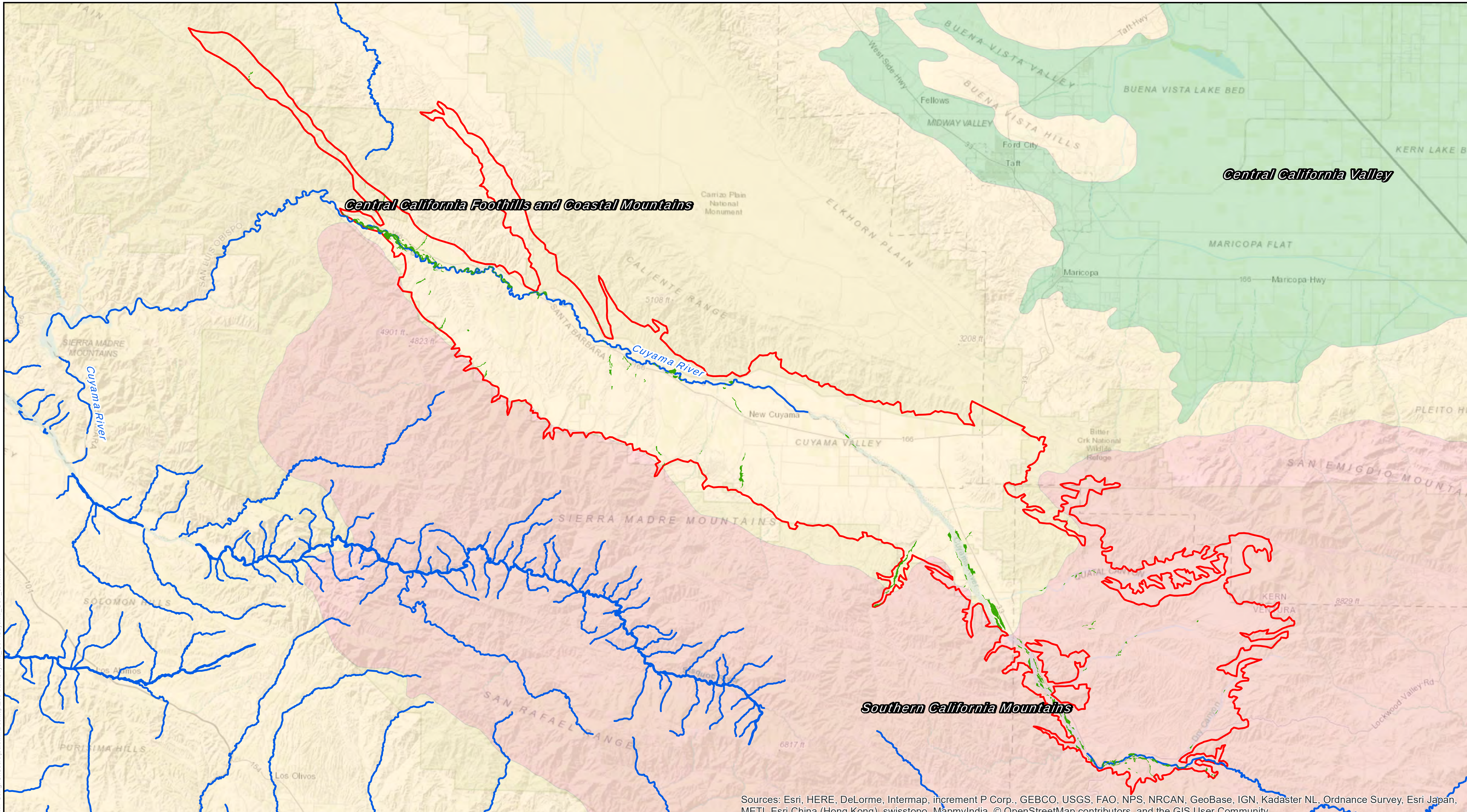

Figure 1:
California Ecoregions

Cuyama Valley Groundwater Basin

Kern, San Luis Obispo, Santa Monica, and Ventura Counties, CA

Legend

- NCCAG Groundwater Dependent Ecosystem
- USGS NHD Streams
- Cuyama Valley Groundwater Basin
- Central California Foothills and Coastal Mountains
- Central California Valley
- Southern California Mountains

0 1.25 2.5 5 Miles

N

WOODARD & CURRAN

Project #: 0011078.01
Map Created: February 2019

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions.
Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources: USEPA Level III Ecoregions of California(2016), USGS NHD**

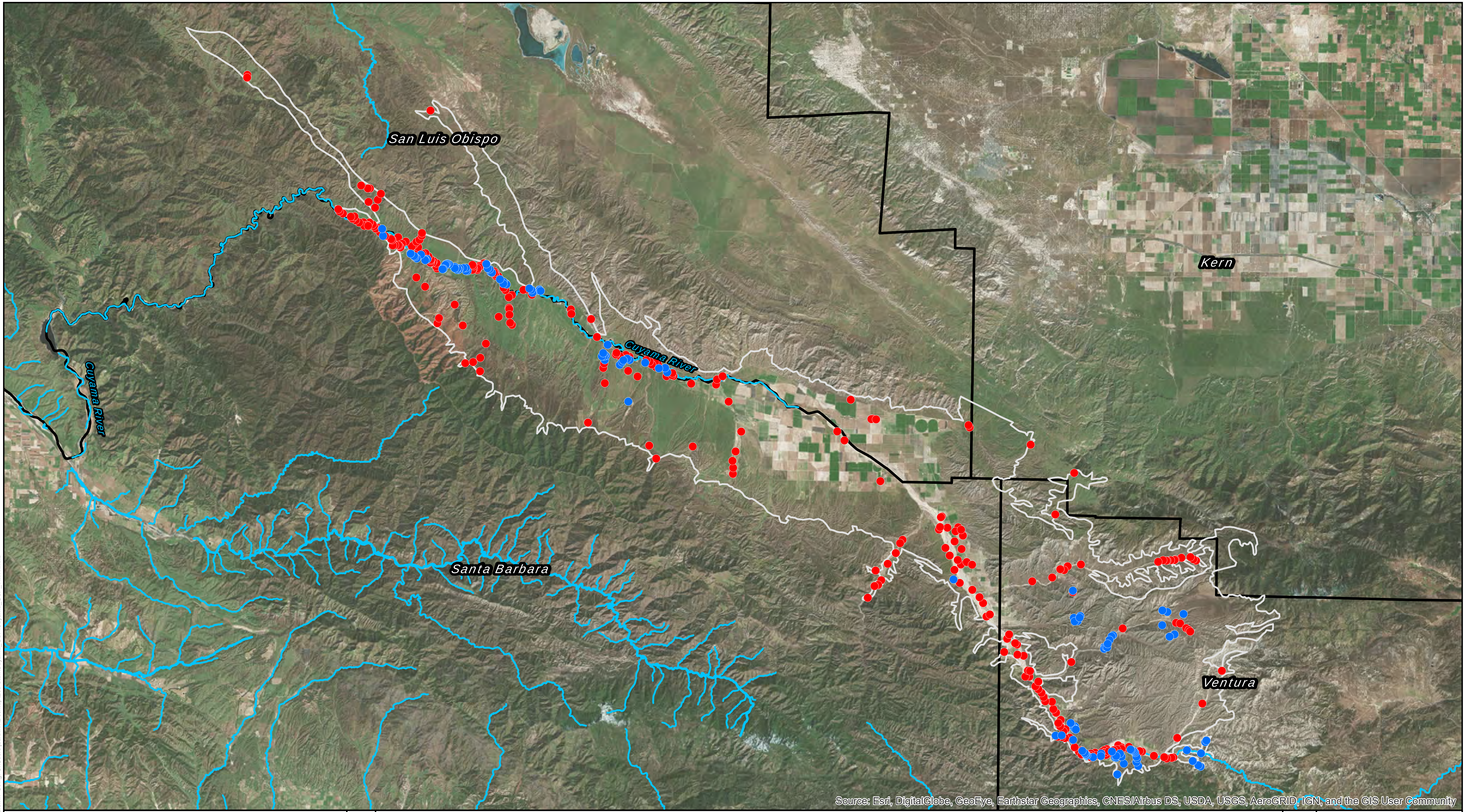

Figure 2: Basin-Wide Groundwater Dependent Ecosystem (GDE) Desktop Assessment

Cuyama Valley Groundwater Basin

Kern, San Luis Obispo, Santa Monica, and Ventura Counties, CA

Legend

- Probable GDE
- Probable Non-GDE
- Streams
- Cuyama Valley Groundwater Basin
- County Boundary

N

0 1.25 2.5 5 Miles

WOODARD & CURRAN

Project #: 0011078.01
Map Created: February 2019

Third Party GIS Disclaimer: This map is for reference and graphical purposes only and should not be relied upon by third parties for any legal decisions. Any reliance upon the map or data contained herein shall be at the users' sole risk. **Data Sources: USGS NHD**

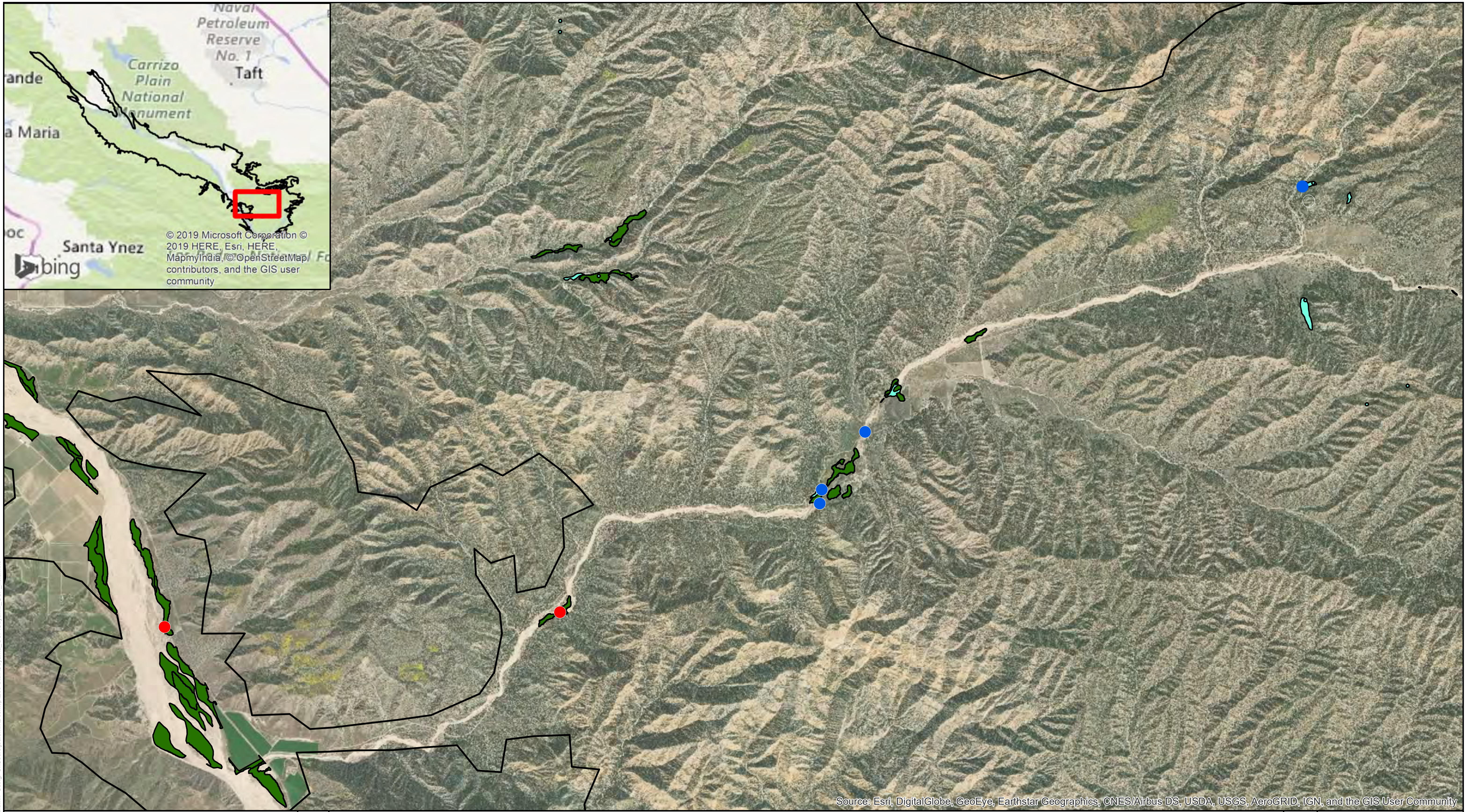

Figure 3: Groundwater Dependent Ecosystem (GDE) Field Validation Sites

Cuyama Valley Groundwater Basin

Kern, San Luis Obispo, Santa Monica, and Ventura Counties, CA

Legend

- Confirmed GDE Data Point
- Probable Non-GDE Data Point
- NCCAG GDE Wetland
- NCCAG GDE Vegetation
- Cuyama Valley Groundwater Basin

1 inch = 3,000 feet

0 1,500 3,000 6,000 Feet

N

WOODARD & CURRAN

Project #: 0011078.01

Map Created: February 2019

 Data Sources: CADWR - Natural Communities Commonly Associated with Groundwater(2018)

ATTACHMENT B: PHOTOGRAPHS

Photo Number: 1 | View Direction: North | Date: October 23, 2018
Description: Representative photograph taken of potential incorrectly mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "probable non-GDE 1".

Photo Number: 2 | View Direction: South | Date: October 23, 2018
Description: Representative photograph taken of potential incorrectly mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "probable non-GDE 1".

Photo Number: 3 | View Direction: North | Date: October 23, 2018
Description: Representative photograph taken of potential incorrectly mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "probable non-GDE 2".

Photo Number: 4 | View Direction: South | Date: October 23, 2018
Description: Representative photograph taken of potential incorrectly mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "probable non-GDE 2".

Photo Number: 5 | **View Direction: North** | **Date: October 23, 2018**

Description: Representative photograph taken of unmapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 1".

Photo Number: 6 | **View Direction: South** | **Date: July 26, 2018**

Description: Representative photograph taken of unmapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 1".

Photo Number: 7 | **View Direction: North** | **Date: October 23, 2018**

Description: Representative photograph taken of field-verified mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 2".

Photo Number: 8 | **View Direction: South** | **Date: July 26, 2018**

Description: Representative photograph taken of field-verified mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 2".

Photo Number: 9 | **View Direction: North** | **Date: October 23, 2018**

Description: Representative photograph taken of unmapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 3".

Photo Number: 10 | **View Direction: South** | **Date: October 23, 2018**

Description: Representative photograph taken of unmapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 3".

Photo Number: 11 | **View Direction: East** | **Date: October 23, 2018**

Description: Representative photograph taken of field-verified mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 4".

Photo Number: 12 | **View Direction: South** | **Date: October 23, 2018**

Description: Representative photograph taken of field-verified mapped groundwater dependent ecosystem (CA DWR NCAG dataset 2018). Photo taken a GPS point "GDE 4".

Chapter 4 Appendices

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Chapter 4
Appendix A

Monitoring Protocols
for Groundwater Level Monitoring Network

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California Statewide Groundwater Elevation Monitoring (CASGEM) Program

Procedures for Monitoring Entity Reporting

December 2010

Department of Water Resources (DWR) will use the internet as the primary communication tool to notify interested parties and groundwater Monitoring Entities of the status of the CASGEM program on an ongoing basis. Information will be posted at the following website: http://www.water.ca.gov/groundwater/casgem

In addition to the above-referenced website, DWR will distribute information via email. In order to be placed on the CASGEM contact list, please register your contact information at the following website: http://www.water.ca.gov/groundwater/casgem/register/

For questions about the Reporting Procedures, or other technical issues, please contact:

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INTRODUCTION TO CASGEM PROGRAM

In November 2009 Part 2.11 (Groundwater Monitoring) was added to Division 6 of the Water Code by Senate Bill 6 (7th Extraordinary Session) (SB 6), a copy of which is included in the Appendix. (All statutory references in this document are to the Water Code.) The new law directs that groundwater elevations in all basins and subbasins in California be regularly and systematically monitored, preferably by local entities, with the goal of demonstrating seasonal and long-term trends in groundwater elevations. The Department of Water Resources (DWR) is directed to make the resulting information readily and widely available.

DWR developed the California Statewide Groundwater Elevation Monitoring (CASGEM) program in accordance with SB 6 to establish a permanent, locally-managed system to monitor groundwater elevation in California's alluvial groundwater basins and subbasins identified in DWR Bulletin 118. The CASGEM program will rely and build on the many, established local long-term groundwater monitoring and management programs. DWR's role is to coordinate information collected locally through the CASGEM program and to maintain the collected groundwater elevation data in a readily and widely available public database. DWR will also continue measuring its current network of groundwater monitoring wells as funding allows.

The goals of the CASGEM program are to:

- Establish procedures for notification and data reporting by prospective Monitoring Entities (this document)
- Verify local Monitoring Entities in accordance with the Water Code
- Develop an interface for local entities to enter data into a database compatible with DWR's Water Data Library
- Maintain the database and make it easily accessible to the public and local entities for use in water supply planning and management

If no local entities volunteer to monitor groundwater elevations in a basin or part of a basin, DWR may be required to develop a monitoring program for that part. If DWR takes over monitoring of a basin, certain entities in the basin may not be eligible for water grants or loans administered by the state.

During August and September 2010, DWR held 10 workshops throughout the state in cooperation with Association of California Water Agencies (ACWA) to introduce the CASGEM program and explain the purpose and process of the program to local agencies and stakeholders. A copy of the DWR presentation is available on the CASGEM website (http://www.water.ca.gov/groundwater/casgem). A summary of

Frequently Asked Questions (FAQs), primarily from the workshops, is provided in on the CASGEM website.

DWR's main role is to administer the CASGEM program through providing public outreach; creating and maintaining the CASGEM website and online data submittal system; and, supporting local entities through the process of becoming a Monitoring Entity and preparing Monitoring Plans. DWR will use the CASGEM website to provide up-to-date information on the program. The website will also be the access point for the online notification and data submittal systems.

Staff from the DWR regional offices will be available to assist potential Monitoring Entities with the online notification submittal process. After receiving notification from prospective Monitoring Entities, DWR will review them for completeness, verify the authority of the applying entity under Section 10927, and check for overlapping monitoring areas. DWR will advise each party on the status of their notification within three months of submittal and will work with entities to address any deficiencies in their submittals.

DWR encourages local agencies and groups to collaborate to determine who will serve as the Monitoring Entity for the area. However, if more than one party seeks to become the Monitoring Entity for the same area and overlapping monitoring area issues cannot be resolved locally, DWR will make a final determination of the Monitoring Entity for the area. DWR's determinations will consider the order in which entities are identified in Section 10927 and other factors as described in the Water Code.

DWR will post the selection of each Monitoring Entity and its monitoring area on the CASGEM website and will notify each Monitoring Entity in writing. A map-based interface will be available for users to identify the Monitoring Entity for each basin in the state.

DWR will prepare the first status report on the CASGEM program for the Governor and Legislature by January 1, 2012. In this initial report, DWR will report on the extent of groundwater elevation monitoring within each basin. This report will include a statewide prioritization of basins based on water supply, water demand, and other factors identified in Section 10933. DWR will explore options for basins without identified monitoring, with a focus on identifying options for local monitoring. Future status reports on the CASGEM program will be prepared by DWR in years ending in 5 or 0.

PURPOSE OF MONITORING ENTITY REPORTING PROCEDURES

The purpose of these procedures is to introduce the CASGEM program and its components as the framework for implementing SB 6, with particular emphasis on the initial step of establishing Monitoring Entities for each Bulletin 118 basin in the state.

A summary of the requirements of local entities to comply with the CASGEM program is presented in Table 1.

Table 1. Quick Guide for Local Entities

- Determine whether you qualify as a potential Monitoring Entity (see "Requirements to become Monitoring Entity" on pages 9-13)
- Identify the basins within your area (see Bulletin 118)
- Collaborate with other local entities to identify and choose the prospective Monitoring Entity (or Entities) for your area
- Submit Monitoring Entity notification to DWR through CASGEM website (http://www.water.ca.gov/groundwater/casgem) on or before January 1, 2011
- DWR will review the notification and advise the prospective Monitoring Entity of the status of the notification within 3 months of submittal
- Work with staff of the DWR regional office to address any deficiencies in the submittal
- If more than one party seeks to become the Monitoring Entity for the same area, work with staff of the DWR regional office to resolve
- Check the CASGEM website for a listing of the selected Monitoring Entities
- Develop and submit a Monitoring Plan to DWR through the CASGEM website
- Staff from the DWR regional office are available to assist with the Monitoring Plan and to recommend changes
- Submit monitoring data to DWR through the CASGEM website on or before January 1, 2012

CASGEM SCHEDULE

CASGEM Schedule		DWR Activities		Local Entity Activities
2010	July-September	ACWA/DWR Workshops		Collaborate to identify prospective Monitoring Entities
	October-December	•Draft Procedures and Guidelines •Solicit Comments •Finalize Procedures and Guidelines		
		Notification System ready online		Prospective Monitoring Entities submit notifications to DWR
2011	January 1, 2011	Review and designation of Monitoring Entities	Review Monitoring Plans and provide recommendations	Monitoring Entity notifications due to DWR on or before 1/1/2011
	January-March			Monitoring Entities develop and submit Monitoring Plans to DWR
	April-June			
	July-September			Groundwater elevation monitoring begins and continues
	October-December	Preparation of first CASGEM status report		
2012	January 1, 2012	DWR submits first CASGEM status report to Governor and Legislature		First CASGEM data submittals due to DWR on or before 1/1/2012

A timetable for implementing the CASGEM schedule is shown above.

Monitoring Entities

The CASGEM program establishes the framework for collaboration between local monitoring parties and DWR to collect groundwater elevation data throughout the state's 515 basins as defined in Bulletin 118. A Monitoring Entity is a local agency or group that voluntarily takes responsibility for conducting or coordinating groundwater elevation monitoring and reporting for all or part of a groundwater basin.

To determine if you are within a Bulletin 118 basin, please refer to maps and descriptions in Bulletin 118, available online at: http://www.water.ca.gov/groundwater/bulletin118/gwbasin_maps_descriptions.cfm. Geographic Information System (GIS) shapefiles of the basins are also available at this website. DWR can assist in identifying other potential local monitoring parties in each basin.

Roles and Responsibilities of Monitoring Entities

Through the CASGEM program, local entities with appropriate authority may notify DWR of their intent to be a Monitoring Entity. Monitoring Entities will have specific responsibilities, including:

- Coordinate with DWR to establish a Monitoring Plan
- Conduct or coordinate the regular and systematic monitoring of groundwater elevations as specified in the Monitoring Plan
- Submit monitoring data to DWR in a timely manner

A Monitoring Entity can perform monitoring for any number of basins or portions thereof, but no area can have more than one Monitoring Entity. While the Monitoring Entity is responsible for compiling the data and submitting it to DWR for a particular area, the actual measurements can be taken by any number of agencies that would work under the direction of the Monitoring Entity. (Cooperating agencies would submit data to the Monitoring Entity, not to DWR.) Thus, assuming there are no overlapping areas or gaps in basin coverage for a given area, there are three possible basic scenarios, illustrated in Figure 1:

- A single Monitoring Entity that collects and reports groundwater elevation data for the entire basin (Scenario A);
- Multiple Monitoring Entities that collect and report groundwater elevation data for their portion of the basin (Scenario B); or

- An umbrella Monitoring Entity that coordinates and reports groundwater elevation data collected by multiple agencies within the basin (Scenario C).

Scenario A. One Monitoring Entity collects and reports data for entire basin

Scenario B. One basin, several Monitoring Entities collecting and submitting data

Scenario C. One basin, one Monitoring Entity coordinating and submitting data collected by several agencies

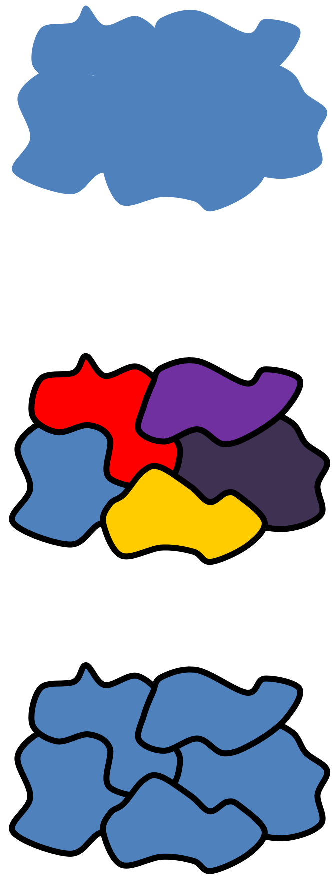

Figure 1. Illustration of possible Monitoring Entity scenarios for a monitored basin.

DWR currently monitors water elevations in about 4,000 wells statewide and cooperates with local and federal agencies to monitor roughly an additional 6,000 wells. DWR plans to continue monitoring groundwater elevations, contingent upon available funding. In some basins DWR currently does most, if not all, of the water-elevation monitoring. In these basins, a local entity still needs to notify DWR of their intent to become the Monitoring Entity. The Monitoring Entity must determine which DWR wells will be included in their CASGEM monitoring network. As long as DWR continues its monitoring program, the department will transmit its groundwater elevation data to the CASGEM system. However, if DWR is unable to continue monitoring for any reason, the Monitoring Entity will be required to re-evaluate its monitoring network to determine which wells to retain in its monitoring network.

Requirements to Become Monitoring Entity

Section 10927 of the Water Code defines the types of entities that may assume responsibility for monitoring and reporting groundwater elevations as part of the CASGEM program.

A summary list of eligible entities, in order of priority, and notification requirements for each entity is provided below:

1. A **watermaster or water management engineer** appointed by a court or pursuant to statute to administer a final judgment determining rights to groundwater [Section 10927(a)].
   Notification Requirements:
   - Name of Agency
   - Agency Contact Name
   - Address
   - Telephone Number
   - Email Address
   - Any other relevant contact information
   - Authority (as listed in Section 10927)
   - Name and number of basin to be monitored (from Bulletin 118)
   - Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
   - Statement that the entity will comply with the requirements of Water Code Part 2.11
   - Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

2. A **groundwater management agency** with statutory authority to manage groundwater pursuant to its principal act that is monitoring groundwater elevations in all or a part of a groundwater basin on or before January 1, 2010 [Section 10927(b)(1)].
   Notification Requirements:
   - Name of Agency
   - Agency Contact Name
   - Address
   - Telephone Number
   - Email Address
   - Any other relevant contact information
   - Authority (as listed in Section 10927)

- Name and number of basin to be monitored (from Bulletin 118)
- Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
- Statement that the entity will comply with the requirements of Water Code Part 2.11
- Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

3. A **water replenishment district** established pursuant to Water Code Division 18 (commencing with Section 60000). This part does not expand or otherwise affect the authority of a water replenishment district relating to monitoring elevations [Section 10927(b)(2)].

   Notification Requirements:

   - Name of Agency
   - Agency Contact Name
   - Address
   - Telephone Number
   - Email Address
   - Any other relevant contact information
   - Authority (as listed in Section 10927)
   - Name and number of basin to be monitored (from Bulletin 118)
   - Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
   - Statement that the entity will comply with the requirements of Water Code Part 2.11
   - Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

4. A **local agency that is managing all or part of a groundwater basin pursuant to Water Code Part 2.75** (commencing with Section 10750) and that was monitoring groundwater elevations in all or part of a groundwater basin on or before January 1, 2010, or a local agency or county that is managing all or part of a groundwater basin pursuant to any other legally enforceable groundwater management plan with provisions that are substantively similar to those described in that part and that was monitoring groundwater elevations in all or a part of a groundwater basin on or before January 1, 2010 [Section 10927(c)].

Notification Requirements:

- Name of Agency
- Agency Contact Name
- Address
- Telephone Number
- Email Address
- Any other relevant contact information
- Authority (as listed in Section 10927)
- Name and number of basin to be monitored (from Bulletin 118)
- Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
- Statement that the entity will comply with the requirements of Water Code Part 2.11
- Copy of current groundwater management plan
- Statement describing the ability or qualifications of the entity to conduct the groundwater monitoring functions required
- Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

5. A **local agency that is managing all or part of a groundwater basin pursuant to an integrated regional water management plan** prepared pursuant to Water Code Part 2.2 (commencing with Section 10530) that includes a groundwater management component that complies with the requirements of Section 10753.7 [Section 10927(d)].

Notification Requirements:

- Name of Agency
- Agency Contact Name
- Address
- Telephone Number
- Email Address
- Any other relevant contact information
- Authority (as listed in Section 10927)
- Name and number of basin to be monitored (from Bulletin 118)
- Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
- Statement that the entity will comply with the requirements of Water Code Part 2.11
- Copy of current groundwater component of integrated regional water management plan
- Statement describing the ability or qualifications of the entity to conduct the groundwater monitoring functions required

- Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

6. A **county** that is not managing all or a part of a groundwater basin pursuant to a legally enforceable groundwater management plan with provisions that are substantively similar to those described in Water Code Part 2.75 (commencing with Section 10750) [Section 10927(e)].
   Notification Requirements:
   - Name of County
   - County Contact Name
   - Address
   - Telephone Number
   - Email Address
   - Any other relevant contact information
   - Authority (as listed in Section 10927)
   - Name and number of basin to be monitored (from Bulletin 118)
   - Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
   - Statement that the entity will comply with the requirements of Water Code Part 2.11
   - Statement describing the ability or qualifications of the entity to conduct the groundwater monitoring functions required
   - Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

7. A **voluntary cooperative groundwater monitoring association** formed pursuant to Section 10935 [Section 10927(f)]. As described in the Water Code Section 10935, the voluntary associations may be established by contract, a joint powers agreement, a memorandum of agreement, or other form of agreement deemed acceptable by DWR, so long as it contains: the names of the participants; the boundaries of the area covered by the agreement; the name or names of the parties responsible for meeting the requirements; the method of recovering the costs associated with meeting the requirements; and other provisions that may be required by DWR. Entities seeking to form a voluntary association should notify DWR, which will work cooperatively with the interested parties to facilitate the formation of the association.

Notification Requirements:

- Name of Association
- Association Contact Name
- Address
- Telephone Number
- Email Address
- Any other relevant contact information
- Authority (as listed in Section 10927)
- Name and number of basin to be monitored (from Bulletin 118)
- Map and shapefile showing area to be monitored (Shapefiles do not need to be submitted by the initial January 1, 2011 notification date; Regional Offices can provide assistance to potential Monitoring Entities with shapefiles.)
- Statement that the entity will comply with the requirements of Water Code Part 2.11
- Statement describing the ability or qualifications of the entity to conduct the groundwater monitoring functions required
- Statement of intent to meet the association formation requirements described in Section 10935
- Additional information deemed necessary by DWR to identify monitoring area or qualifications of the Monitoring Entity

Local agencies are encouraged to coordinate among themselves to determine the proposed Monitoring Entity or Entities that best suits their area. The resulting interested entity (or entities) should notify DWR of its intent to become a groundwater Monitoring Entity for one or more basins, or portions thereof by the January 1, 2011 deadline. Certain basic information is required for notification, including contact information and additional details depending on the authority of the entity desiring to monitor groundwater (Section 10928), as listed above. This notification information will be submitted to DWR using an online system that will be available by mid-December 2010.

MONITORING PLANS

Monitoring Entities will each develop a Monitoring Plan that includes the following sections: Monitoring Sites and Timing, Field Methods, and Data Reporting. Monitoring Plans should be completed and submitted to DWR by summer 2011. Staff from the DWR regional offices will be available to assist Monitoring Entities with the development of Monitoring Plans, if needed. In determining what information should be reported to DWR, the department will defer to existing monitoring programs if those programs result in information that demonstrates seasonal (annual high and low groundwater elevations) and long-term trends in groundwater elevations. Staff from the DWR regional offices will assist Monitoring Entities to address any gaps in basin coverage (see below) and other monitoring issues and may make recommendations for the location of additional wells. However, the department has no authority to require a Monitoring Entity to install additional wells unless funds are provided for that purpose. Once a Monitoring Plan is established with DWR, Monitoring Entities should notify DWR of any changes to the plan.

Key Components of Monitoring Plans

Submit to DWR by summer 2011

- Monitoring Sites and Timing
  - Well Network Design
  - Selected wells (current)
  - Planned (future) wells
  - Frequency to capture seasonal highs and lows
  - Map and shapefile of monitoring area and well locations

Field Methods for groundwater monitoring

- Methods for measuring
  - Reference Point
  - Static water level
  - Depth to water
  - Standardized form for data collection

Data Reporting

- Online data submittal, minimum July & January each year

DATA GAPS

A data gap refers to a basin or portion of a basin that is not included in any of the Monitoring Plans submitted to DWR. This is essentially an area that lacks the density of monitoring wells that would allow seasonal and long-term trends in groundwater elevations to be determined for the basin, subbasin, or a portion thereof. Among the 515 basins defined by Bulletin 118, data gaps may exist for a variety of reasons, including a lack of suitable monitoring wells, lack of groundwater use, access issues, and jurisdictional issues, among others.

If no local entity is able and/or willing to fill a data gap, the department may be required to perform groundwater monitoring functions. If DWR performs this monitoring, local agencies and the county that have the authority under Section 10927 to monitor the area of the data gap would be potentially ineligible for a water grant or loan awarded or administered by the state. The Monitoring Entity or entities with the authority to monitor the area of the data gap should provide detailed information regarding the nature of and reason for the data gap so that DWR may include such information in the prioritization of groundwater basins and subbasins as appropriate.

Agencies and counties that are eligible to be designated Monitoring Entities but choose not participate in the CASGEM program will not lose their state water grant and loan eligibility if their entire service area qualifies as a disadvantaged community (Water Code Section 10933.7(b)). It will be the responsibility of the local agency or county applying for a state water grant or loan to demonstrate their disadvantaged community status at the time they are applying for the grant or loan.

MONITORING SITES AND TIMING

The Monitoring Plan will identify the wells to be monitored and the frequency with which they will be monitored. The Monitoring Plan should explain how proposed monitoring will be sufficient to demonstrate the seasonal and long-term groundwater elevation trends in the monitored area. The density of monitoring locations will depend on the complexity of the basin.

Because of security concerns, the California Department of Public Health (DPH) routinely limits the disclosure of detailed public water supply well location information. Pursuant to Water Code Section 10931, the DWR is required to collaborate with DPH to ensure that the information reported to the CASGEM program will not result in the inappropriate disclosure of information of concern to DPH. At this time, DWR has reached no agreement with DPH regarding the appropriate treatment of public water supply well data. As a result, CASGEM does not currently plan to use such well information in its database.

The Monitoring Plan should contain a table identifying the wells to be monitored and the timing of that monitoring. Because the law specifies that information should demonstrate seasonal and long-term trends in groundwater elevations, at a minimum monitoring should be conducted at each location for the yearly high and low for the basin. The yearly high and low groundwater elevations typically occur in spring and fall, but this may vary from basin to basin. It is very important that the timing of all the measurements in the basin is coordinated. Rationale for selection of the timing (seasonal highs and lows) should be included in the Monitoring Plan.

The information on the monitoring sites and timing to be submitted in the online system should include:

- Well identification number
- State well number
- Location (decimal latitude and longitude, North American Datum (NAD) 83)
- Reference point elevation (feet, North American Vertical Datum (NAVD) 88)
- Land surface datum (feet, NAVD88)
- Map and shapefile with monitoring locations, Bulletin 118 groundwater basin boundary, and boundary of monitoring area
- Frequency and timing of measurements

FIELD METHODS

The consistent and documented collection of groundwater elevation data is important for ensuring that the data can be used across the state, regardless of the Monitoring Entity. The field methods should meet a common set of basic requirements; however, the methods do not have to be exactly the same. Many entities already have in place monitoring efforts that are successful in meeting local needs and that can meet the needs for this program, either as-is or with the incorporation of individual components. The CASGEM program wishes to maintain, to the greatest extent possible, the procedures of high-quality local groundwater elevation monitoring programs, so long as they meet the overall program goals and policies. Of particular concern are the following basic requirements:

- Method(s) to establish the Reference Point, including step-by-step instructions
- Method(s) to ensure static groundwater elevation
- Method(s) to measure depth to water, including step-by-step instructions
- Method(s) and form(s) for recording measurements

It is the responsibility of each Monitoring Entity to develop and implement monitoring protocols that are appropriate to local groundwater basin conditions, protect the water quality of its monitoring wells, and maintain the quality of the data that it submits to the CASGEM Program. DWR has developed field guidelines (Department of Water Resources Groundwater Elevation Monitoring Guidelines) based on a review of existing field methods from DWR and other organizations, which is available on the CASGEM website. Monitoring Entities are welcome to refer to these guidelines when developing field methods for their own Monitoring Plans. However, the DWR guidelines are for internal use in the event that the Department is required to perform groundwater monitoring functions pursuant to Section 10933.5 and are not binding on any other agency. The core of the CASGEM program will rely and build on the many, established local long-term groundwater monitoring and management programs. The department will defer to existing monitoring programs that result in information that demonstrates seasonal and long-term trends in groundwater elevations.

DATA REPORTING

DWR will develop an online data submittal system for Monitoring Entities to submit their groundwater elevation data. Several methods of submitting data will be available, such as direct online data entry, or upload of data files for batch entry. Initial groundwater elevation data should be submitted to DWR by January 1, 2012. Thereafter, data should be submitted as soon as possible after collection, but no later than January 1st and July 1st of each year, at the minimum. Historical data can also be submitted via the DWR data system to aid in data interpretation. All submitted data will be available to the public, except for confidential data.

Each groundwater elevation data measurement submitted to the online system should include:

- Well identification number
- Measurement date
- Reference point and land surface elevation
- Depth to water
- Method of measuring water depth
- Measurement quality codes

The Monitoring Entity information, well information, and groundwater elevation information is to be provided by the Monitoring Entity. Items labeled as required must be submitted to DWR to report groundwater elevations. Items labeled as recommended should be submitted to DWR if they are available, as they assist in fully evaluating the quality of measurements. DWR will provide standard form(s) for Monitoring Entities to submit groundwater elevation data online. However, if Monitoring Entities cannot use the standard form(s) or provide the data elements listed below, DWR will work cooperatively with Monitoring Entities to develop alternate methods of submitting data.

Entity Information

All entities assuming groundwater monitoring functions as delineated in Section 10927 (a)-(f) are required to submit the following information:

- Monitoring Entity's name, address, telephone number, contact person name and email address, and any other relevant contact information (Section 10928 (a) (1), 10928 (b) (1))
- Name, address, telephone number, email address and any other relevant contact information for entities collecting data that is submitted by a designated submitting entity (Monitoring Entity)
- Groundwater basins being monitored
    - Identify entire basins monitored
    - Identify partial basins monitored

Well Information

The following information about each well is required for the CASGEM online system:

- Unique well identification number. Agencies may use an existing State Well Number, an existing local well designation, or develop their own identification name, using the following protocol:
    - Agency name, abbreviation, or acronym followed by a sequential number (e.g., SGA 01)
    - Groundwater basin – followed by a sequential number (e.g., Llagas 03)
    - Geographic name – followed by a sequential number (e.g., Yolo 12)
    - Well names should be 15 characters long or less
    - Avoid using owner/business names or specific locational information for privacy and security
- Decimal latitude/longitude coordinates of well, using horizontal datum NAD83, and the method of determining coordinates (Actual coordinates are preferred; however, Monitoring Entities may submit approximate locations, as needed, to protect the privacy of well owners. For example, to protect the privacy of a well owner, a Monitoring Entity may submit well coordinate locations that are only within 1000-feet of the actual well location.)
- Groundwater basin or sub-basin
- Reference point elevation of the well (feet) using NAVD88 vertical datum
- Elevation of land surface datum at the well (feet) using NAVD88 vertical datum
- Use of well (e.g., dedicated monitoring, irrigation, domestic, etc)
- Well completion type (e.g. single well, nested, or multi-completion wells)
- Depth of screened interval(s) and total well depth of well, if available (feet)
- Well Completion Report number (DWR Form 188), if available

The following information about each well is recommended for the CASGEM online system:

- State Well Number – assigned by DWR in most cases
- Method by which land surface elevation was determined (for example, topographic map, GPS, etc.)
- Written description of location of well, including distance from nearby landmarks and location of reference point in relation to well appurtenances (DWR Form 429)
- Well information comments

Groundwater Elevation Information

The following information for each groundwater elevation measurement is required for the CASGEM online system:

- Well identification number (see Well Information, above)
- Measurement date
- Reference point elevation of the well (feet) using NAVD88 vertical datum
- Elevation of land surface datum at the well (feet) using NAVD88 vertical datum
- Depth to water below reference point (feet) (unless no measurement was taken)
- Method of measuring water depth
- Measurement Quality Codes

    - If no measurement is taken, a specified “no measurement” code, must be recorded. Standard codes will be provided by the online system. If a measurement is taken, a “no measurement” code is not recorded.)
    - If the quality of a measurement is uncertain, a “questionable measurement” code can be recorded. Standard codes will be provided by the online system. If no measurement is taken, a “questionable measurement” code is not recorded.)
- Measuring agency identification

The following information for each groundwater elevation measurement is recommended for the CASGEM online system:

- Measurement time (PST/PDT with military time/24 hour format)
- Comments about measurement, if applicable

Groundwater elevation data shall be submitted electronically to DWR’s online system. DWR will develop electronic data transmittal (EDT) alternatives and data standards to permit bulk data transfer and assist Monitoring Entities in EDT reporting to DWR. As stated above, if Monitoring Entities cannot use the standard form(s) or provide the necessary groundwater elevation data elements, DWR will work cooperatively with Monitoring Entities to develop alternate methods of submitting data.

The CASGEM online data submittal system will be compatible with the Water Data Library (WDL) (http://www.water.ca.gov/waterdatalibrary/), DWR’s existing groundwater elevation database. The CASGEM system will include data reporting options similar to those in WDL, such as hydrographs, seasonal contour data, and data downloads. The combined accessibility of the WDL and the CASGEM system will be a significant resource for local agencies in making sound groundwater management decisions.

References

California Departement of Water Resources. (2003). *California's Groundwater, Bulletin 118-03.*

California Department of Water Resources. (2009). *California Water Plan Update 2009, Bulletin 160-09.*

APPENDIX – SENATE BILL 6 (7TH EXTRAORDINARY SESSION) - GROUNDWATER MONITORING

Senate Bill No. 6

CHAPTER 1

An act to add Part 2.11 (commencing with Section 10920) to Division 6 of, and to repeal and add Section 12924 of, the Water Code, relating to groundwater.

[Approved by Governor November 6, 2009. Filed with Secretary of State November 6, 2009.]

Legislative Counsel's Digest

SB 6, Steinberg. Groundwater.

(1) Existing law authorizes a local agency whose service area includes a groundwater basin that is not subject to groundwater management to adopt and implement a groundwater management plan pursuant to certain provisions of law. Existing law requires a groundwater management plan to include certain components to qualify as a plan for the purposes of those provisions, including a provision that establishes funding requirements for the construction of certain groundwater projects.

This bill would establish a groundwater monitoring program pursuant to which specified entities, in accordance with prescribed procedures, may propose to be designated by the Department of Water Resources as groundwater monitoring entities, as defined, for the purposes of monitoring and reporting with regard to groundwater elevations in all or part of a basin or subbasin, as defined. The bill would require the department to work cooperatively with each monitoring entity to determine the manner in which groundwater elevation information should be reported to the department. The bill would authorize the department to make recommendations for improving an existing monitoring program, and to require additional monitoring wells under certain circumstances. Under certain circumstances, the department would be required to perform groundwater monitoring functions. In that event, prescribed entities with authority to assume groundwater monitoring functions with regard to a basin or subbasin for which the department has assumed those functions would not be eligible for a water grant or loan awarded or administered by the state.

(2) Existing law requires the department to conduct an investigation of the state's groundwater basins and to report its findings to the Governor and the Legislature not later than January 1, 1980.

This bill would repeal that provision. The department would be required to conduct an investigation of the state's groundwater basins and to report its findings to the Governor and the Legislature not later than January 1, 2012, and thereafter in years ending in 5 or 0.

(3) The bill would take effect only if SB 1 and SB 7 of the 2009–10 7th Extraordinary Session of the Legislature are enacted and become effective.

The people of the State of California do enact as follows:

SECTION 1. Part 2.11 (commencing with Section 10920) is added to Division 6 of the Water Code, to read:

PART 2.11. GROUNDWATER MONITORING

Chapter 1. General Provisions

10920. (a) It is the intent of the Legislature that on or before January 1, 2012, groundwater elevations in all groundwater basins and subbasins be regularly and systematically monitored locally and that the resulting groundwater information be made readily and widely available.

(b) It is further the intent of the Legislature that the department continue to maintain its current network of monitoring wells, including groundwater elevation and groundwater quality monitoring wells, and that the department continue to coordinate monitoring with local entities.

10921. This part does not require the monitoring of groundwater elevations in an area that is not within a basin or subbasin.

10922. This part does not expand or otherwise affect the powers or duties of the department relating to groundwater beyond those expressly granted by this part.

Chapter 2. Definitions

10925. Unless the context otherwise requires, the definitions set forth in this section govern the construction of this part.

(a) “Basin” or “subbasin” means a groundwater basin or subbasin identified and defined in the department’s Bulletin No. 118.

(b) “Bulletin No. 118” means the department’s report entitled “California’s Groundwater: Bulletin 118” updated in 2003, or as it may be subsequently updated or revised in accordance with Section 12924.

(c) “Monitoring entity” means a party conducting or coordinating the monitoring of groundwater elevations pursuant to this part.

(d) “Monitoring functions” and “groundwater monitoring functions” means the monitoring of groundwater elevations, the reporting of those elevations to the department, and other related actions required by this part.

(e) “Monitoring groundwater elevations” means monitoring groundwater elevations, coordinating the monitoring of groundwater elevations, or both.

(f) “Voluntary cooperative groundwater monitoring association” means an association formed for the purposes of monitoring groundwater elevations pursuant to Section 10935.

Chapter 3. Groundwater Monitoring Program

10927. Any of the following entities may assume responsibility for monitoring and reporting groundwater elevations in all or a part of a basin or subbasin in accordance with this part:

(a) A watermaster or water management engineer appointed by a court or pursuant to statute to administer a final judgment determining rights to groundwater.

(b) (1) A groundwater management agency with statutory authority to manage groundwater pursuant to its principal act that is monitoring groundwater elevations in all or a part of a groundwater basin or subbasin on or before January 1, 2010.

(2) A water replenishment district established pursuant to Division 18 (commencing with Section 60000). This part does not expand or otherwise affect the authority of a water replenishment district relating to monitoring groundwater elevations.

(c) A local agency that is managing all or part of a groundwater basin or subbasin pursuant to Part 2.75 (commencing with Section 10750) and that was monitoring groundwater elevations in all or a part of a groundwater basin or subbasin on or before January 1, 2010, or a local agency or county that is managing all or part of a groundwater basin or subbasin pursuant to any other legally enforceable groundwater management plan with provisions that are substantively similar to those described in that part and that was monitoring groundwater elevations in all or a part of a groundwater basin or subbasin on or before January 1, 2010.

(d) A local agency that is managing all or part of a groundwater basin or subbasin pursuant to an integrated regional water management plan prepared pursuant to Part 2.2 (commencing with Section 10530) that includes a groundwater management component that complies with the requirements of Section 10753.7.

(e) A county that is not managing all or a part of a groundwater basin or subbasin pursuant to a legally enforceable groundwater management plan with provisions that are substantively similar to those described in Part 2.75 (commencing with Section 10750).

(f) A voluntary cooperative groundwater monitoring association formed pursuant to Section 10935.

10928. (a) Any entity described in subdivision (a) or (b) of Section 10927 that seeks to assume groundwater monitoring functions in accordance with this part shall notify the department, in writing, on or before January 1, 2011. The notification shall include all of the following information:

(1) The entity's name, address, telephone number, and any other relevant contact information.

(2) The specific authority described in Section 10927 pursuant to which the entity qualifies to assume the groundwater monitoring functions.

(3) A map showing the area for which the entity is requesting to perform the groundwater monitoring functions.

(4) A statement that the entity will comply with all of the requirements of this part.

(b) Any entity described in subdivision (c), (d), (e), or (f) of Section 10927 that seeks to assume groundwater monitoring functions in accordance with this part shall notify the department, in writing, by January 1, 2011. The information provided in the notification shall include all of the following:

(1) The entity’s name, address, telephone number, and any other relevant contact information.

(2) The specific authority described in Section 10927 pursuant to which the entity qualifies to assume the groundwater monitoring functions.

(3) For entities that seek to qualify pursuant to subdivision (c) or (d) of Section 10927, the notification shall also include a copy of the current groundwater management plan or the groundwater component of the integrated regional water management plan, as appropriate.

(4) For entities that seek to qualify pursuant to subdivision (f) of Section 10927, the notification shall include a statement of intention to meet the requirements of Section 10935.

(5) A map showing the area for which the entity is proposing to perform the groundwater monitoring functions.

(6) A statement that the entity will comply with all of the requirements of this part.

(7) A statement describing the ability and qualifications of the entity to conduct the groundwater monitoring functions required by this part.
(c) The department may request additional information that it deems necessary for the purposes of determining the area that is proposed to be monitored or the qualifications of the entity to perform the groundwater monitoring functions.

10929. (a) (1) The department shall review all notifications received pursuant to Section 10928.

(2) Upon the receipt of a notification pursuant to subdivision (a) of Section 10928, the department shall verify that the notifying entity has the appropriate authority under subdivision (a) or (b) of Section 10927.

(3) Upon the receipt of a notification pursuant to subdivision (b) of Section 10928, the department shall do both of the following:

(A) Verify that each notification is complete.

(B) Assess the qualifications of the notifying party.

(b) If the department has questions about the completeness or accuracy of a notification, or the qualifications of a party, the department shall contact the party to resolve any deficiencies. If the department is unable to resolve the deficiencies, the department shall notify the party in writing that the notification will not be considered further until the deficiencies are corrected.

(c) If the department determines that more than one party seeks to become the monitoring entity for the same portion of a basin or subbasin, the department shall consult with the interested parties to determine which party will perform the monitoring functions. In determining which party will perform the monitoring functions under this part, the department shall follow the order in which entities are identified in Section 10927.

(d) The department shall advise each party on the status of its notification within three months of receiving the notification.

10930. Upon completion of each review pursuant to Section 10929, the department shall do both of the following if it determines that a party will perform monitoring functions under this part:

(a) Notify the party in writing that it is a monitoring entity and the specific portion of the basin or subbasin for which it shall assume groundwater monitoring functions.

(b) Post on the department's Internet Web site information that identifies the monitoring entity and the portion of the basin or subbasin for which the monitoring entity will be responsible.

10931. (a) The department shall work cooperatively with each monitoring entity to determine the manner in which groundwater elevation information should be reported to the department pursuant to this part. In determining what information should be reported to the department, the department shall defer to existing monitoring programs if those programs result in information that demonstrates seasonal and long-term trends in groundwater elevations. The department shall collaborate with the State Department of Public Health to ensure that the information reported to the department will not result in the inappropriate disclosure of the physical address or geographical location of drinking water sources, storage facilities, pumping operational data, or treatment facilities.

(b) (1) For the purposes of this part, the department may recommend improvements to an existing monitoring program, including recommendations for additional monitoring wells.

(2) The department may not require additional monitoring wells unless funds are provided for that purpose.

10932. Monitoring entities shall commence monitoring and reporting groundwater elevations pursuant to this part on or before January 1, 2012.

10933. (a) On or before January 1, 2012, the department shall commence to identify the extent of monitoring of groundwater elevations that is being undertaken within each basin and subbasin.

(b) The department shall prioritize groundwater basins and subbasins for the purpose of implementing this section. In prioritizing the basins and subbasins, the department shall, to the extent data are available, consider all of the following:

(1) The population overlying the basin or subbasin.

(2) The rate of current and projected growth of the population overlying the basin or subbasin.

(3) The number of public supply wells that draw from the basin or subbasin.

(4) The total number of wells that draw from the basin or subbasin.

(5) The irrigated acreage overlying the basin or subbasin.

(6) The degree to which persons overlying the basin or subbasin rely on groundwater as their primary source of water.

(7) Any documented impacts on the groundwater within the basin or subbasin, including overdraft, subsidence, saline intrusion, and other water quality degradation.

(8) Any other information determined to be relevant by the department.

(c) If the department determines that all or part of a basin or subbasin is not being monitored pursuant to this part, the department shall do all of the following:

(1) Attempt to contact all well owners within the area not being monitored.

(2) Determine if there is an interest in establishing any of the following:

(A) A groundwater management plan pursuant to Part 2.75 (commencing with Section 10750).

(B) An integrated regional water management plan pursuant to Part 2.2 (commencing with Section 10530) that includes a groundwater management component that complies with the requirements of Section 10753.7.

(C) A voluntary groundwater monitoring association pursuant to Section 10935.

(d) If the department determines that there is sufficient interest in establishing a plan or association described in paragraph (2) of subdivision (c), or if the county agrees to perform the groundwater monitoring functions in accordance with this part, the department shall work cooperatively with the interested parties to comply with the requirements of this part within two years.

(e) If the department determines, with regard to a basin or subbasin, that there is insufficient interest in establishing a plan or association described in paragraph (2) of subdivision (c), and if the county decides not to perform the groundwater monitoring and reporting functions of this part, the department shall do all of the following:

(1) Identify any existing monitoring wells that overlie the basin or subbasin that are owned or operated by the department or any other state or federal agency.

(2) Determine whether the monitoring wells identified pursuant to paragraph (1) provide sufficient information to demonstrate seasonal and long-term trends in groundwater elevations.

(3) If the department determines that the monitoring wells identified pursuant to paragraph (1) provide sufficient information to demonstrate seasonal and long-term trends in groundwater elevations, the department shall not perform groundwater monitoring functions pursuant to Section 10934.

(4) If the department determines that the monitoring wells identified pursuant to paragraph (1) provide insufficient information to demonstrate seasonal and long-term trends in groundwater elevations, and the State Mining and Geology Board concurs with

that determination, the department shall perform groundwater monitoring functions pursuant to Section 10934.[1]

10933.5. (a) Consistent with Section 10933, the department shall perform the groundwater monitoring functions for those portions of a basin or subbasin for which no monitoring entity has agreed to perform the groundwater monitoring functions.

(b) Upon determining that it is required to perform groundwater monitoring functions, the department shall notify both of the following entities that it is forming the groundwater monitoring district:

(1) Each well owner within the affected area.

(2) Each county that contains all or a part of the affected area.

(c) The department shall not assess a fee or charge to recover the costs for carrying out its power and duties under this part.

(d) The department may establish regulations to implement this section.

10933.7. (a) If the department is required to perform groundwater monitoring functions pursuant to Section 10933.5, the county and the entities described in subdivisions (a) to (d), inclusive, of Section 10927 shall not be eligible for a water grant or loan awarded or administered by the state.

(b) Notwithstanding subdivision (a), the department shall determine that an entity described in subdivision (a) is eligible for a water grant or loan under the circumstances described in subdivision (a) if the entity has submitted to the department for approval documentation demonstrating that its entire service area qualifies as a disadvantaged community.

10934. (a) For purposes of this part, neither any entity described in Section 10927, nor the department, shall have the authority to do either of the following:

(1) To enter private property without the consent of the property owner.

[1] The reference in Section 10933(e)(4) to Section 10934 has been amended by Stats. 2010, Ch. 328, sec. 237 (S.B. 1330). The new reference will be to Section 10933.5.

(2) To require a private property owner to submit groundwater monitoring information to the entity.

(b) This section does not apply to a county or an entity described in subdivisions (a) to (d), inclusive, of Section 10927 that assumed responsibility for monitoring and reporting groundwater elevations prior to the effective date of this part.

10935. (a) A voluntary cooperative groundwater monitoring association may be formed for the purposes of monitoring groundwater elevations in accordance with this part. The association may be established by contract, a joint powers agreement, a memorandum of agreement, or other form of agreement deemed acceptable by the department.

(b) Upon notification to the department by one or more entities that seek to form a voluntary cooperative groundwater monitoring association, the department shall work cooperatively with the interested parties to facilitate the formation of the association.

(c) The contract or agreement shall include all of the following:

(1) The names of the participants.

(2) The boundaries of the area covered by the agreement.

(3) The name or names of the parties responsible for meeting the requirements of this part.

(4) The method of recovering the costs associated with meeting the requirements of this part.

(5) Other provisions that may be required by the department.

10936. Costs incurred by the department pursuant to this chapter may be funded from unallocated bond revenues pursuant to paragraph (12) of subdivision (a) of Section 75027 of the Public Resources Code, to the extent those funds are available for those purposes.

SEC. 2. Section 12924 of the Water Code is repealed.

SEC. 3. Section 12924 is added to the Water Code, to read:

12924. (a) The department, in conjunction with other public agencies, shall conduct an investigation of the state's groundwater basins. The department shall identify the state's groundwater basins on the basis of geological and hydrological conditions and consideration of political boundary lines whenever practical. The department shall also investigate existing general patterns of groundwater pumping and groundwater recharge within those basins to the extent necessary to identify basins that are subject to critical conditions of overdraft.

(b) The department shall report its findings to the Governor and the Legislature not later than January 1, 2012, and thereafter in years ending in 5 or 0.

SEC. 4. This act shall take effect only if Senate Bill 1 and Senate Bill 7 of the 2009–10 Seventh Extraordinary Session of the Legislature are enacted and become effective.

Chapter 4
Appendix B

USGS Groundwater Data Collection Protocols and Procedures for the National Water-Quality Assessment Program: Collection and Documentation of Water-Quality Samples and Related Data

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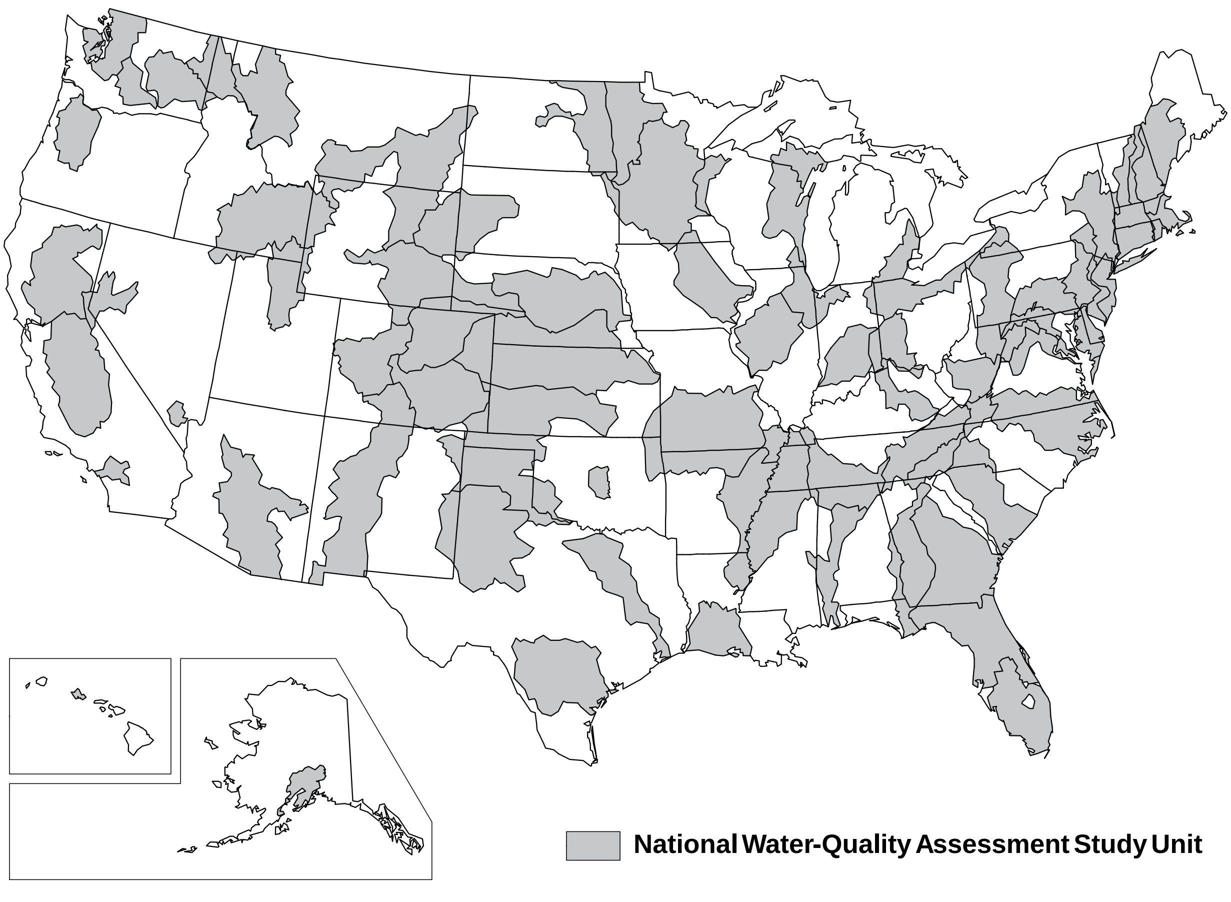
GROUND-WATER DATA-COLLECTION PROTOCOLS AND PROCEDURES FOR THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM: COLLECTION AND DOCUMENTATION OF WATER-QUALITY SAMPLES AND RELATED DATA

U.S. GEOLOGICAL SURVEY

Open-File Report 95-399



NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

GROUND-WATER DATA-COLLECTION PROTOCOLS AND PROCEDURES FOR THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM: COLLECTION AND DOCUMENTATION OF WATER-QUALITY SAMPLES AND RELATED DATA

By Michael T. Koterba, Franceska D. Wilde, and Wayne W. Lapham

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U.S. Geological Survey

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1995

U.S. DEPARTMENT OF THE INTERIOR

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the NationÕs freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

(signed)

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter
	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	3785	milliliter
	Flow	
gallon per minute (gal/min)	0.06308	liter per second

Physical and Chemical Water-Quality Units

Temperature: Water and air temperature are given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$°F = 1.8(°C) + 32$$

Specific electrical conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius.

method detection limit (MDL): The minimum concentration of a substance that can be identified, measured, and reported with 99-percent confidence that the analyte concentration is greater than zero; determined from analysis of a sample in a given matrix containing analtye.

minimum reporting level (MRL): The smallest measured concentration of a constituent that may be reliably reported using a given analytical method. In many cases, the MRL is used when documentation for the method detection limit is not available.

micrometer (µm), or "micron": The millionth part of the meter--the pore diameter of filter membranes is given in micrometer units.

milligrams per liter (mg/L) or micrograms per liter (µg/L): Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) or water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million.

millivolt (mV): A unit of electromotive force equal to one thousandth of a volt.

nephelometric turbidity unit (NTU): A measure of turbidity in a water sample, roughly equivalent to Formazin turbidity unit (FTU) and Jackson turbidity unit (JTU).

normality, *N* (equivalents/L): The number of equivalents of acid, base, or redox-active species per liter of solution. Examples: a solution that is 0.01 formal in HCl is 0.01 *N* in H^+. A solution that is 0.01 formal in H_2SO_4 is 0.02 *N* in H^+.

GROUND-WATER DATA-COLLECTION PROTOCOLS AND PROCEDURES FOR THE NATIONAL WATER-QUALITY ASSESSMENT PROGRAM: COLLECTION AND DOCUMENTATION OF WATER-QUALITY SAMPLES AND RELATED DATA

By Michael T. Koterba, Franceska D. Wilde, and Wayne W. Lapham

ABSTRACT

Protocols for ground-water sampling are described in a report written in 1989 as part of the pilot program for the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS). These protocols have been reviewed and revised to address the needs of the full-scale implementation of the NAWQA Program that began in 1991. This report, which is a collaborative effort between the NAWQA Program and the USGS Office of Water Quality, is the result of that review and revision.

This report describes protocols and recommended procedures for the collection of water-quality samples and related data from wells for the NAWQA Program. Protocols and recommended procedures discussed include (1) equipment setup and other preparations for data collection; (2) well purging and field measurements; (3) collecting and processing ground-water-quality samples; (4) equipment decontamination; (5) quality-control sampling; and (6) sample handling and shipping.

INTRODUCTION

The full-scale implementation of the National Water-Quality Assessment (NAWQA) Program in 1991 required updating the ground-water protocols prepared for the NAWQA pilot program (Hardy and others, 1989) and more detailed information for collecting ground-water-quality data in the NAWQA Program. That effort has resulted in this report and a companion report by Lapham and others (in press). Broader based reports that establish and document ground-water data-collection protocols and procedures for all U.S. Geological Survey (USGS) programs include Radtke and Wilde (in press) and two planned companion reports.[1]

This report describes protocols and recommended procedures for collecting ground-water-quality samples and related data (hereafter referred to as ground-water-quality data) specifically for the Occurrence and Distribution Assessment component of the full-scale NAWQA Program. In addition to updating and expanding the report by Hardy and others (1989), this report complements other reports prepared for the NAWQA Program, including those that describe NAWQA well installation, selection, and documentation (Lapham and others, in press), design of the NAWQA Program (Gilliom and others, 1995; Alley and Cohen, 1991), the conceptual

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[1]For further information about the status of these planned reports contact the Office of Water Quality, U.S. Geological Survey, 412 National Center, Reston, VA 22092.

framework of the NAWQA Program (Leahy and Wilber, 1991; Hirsch and others, 1988; Cohen and others, 1988), an implementation plan for the NAWQA Program (Leahy and others, 1990), and a description of a quality-assurance (administrative) plan for the NAWQA pilot program (Mattraw and others, 1989).

For the purposes of this report, a protocol identifies a course of action that is mandatory under most circumstances as a consequence of USGS and NAWQA policies. For example, the routine collection of quality-control samples throughout the period during which ground-water-quality data are being collected is a protocol, and the requirement that equipment be decontaminated between uses according to prescribed methods to avoid cross-contamination of water-quality samples and the wells being sampled is a protocol. A recommended procedure is one that generally is preferred over other procedures that are available or commonly used. A procedure generally is recommended for the purpose of conforming to rules for good field practices and is expected to result in reproducible data of a desired and defined quality. Recommended procedures are not protocols because they are either too restrictive or possibly inappropriate in some situations. For example, one recommended procedure is to measure the water level in the well before ground-water-quality data are collected; this is not possible for some water-supply wells. Another recommended procedure is that equipment decontamination, which is required, be conducted in the field immediately after use; this, however, is not possible for some field-site conditions.

Although modifications are likely as new technologies evolve, the protocols and recommended procedures for data collection and documentation described in this report are considered capable of producing representative data of known quality that are suitable for assessment, while also being feasible to employ, given limitations of time and funds. Their use promotes consistency and comparability of ground-water data among Study Units in the NAWQA Program.

Background

The USGS began full-scale implementation of the NAWQA Program in 1991. The goals of the NAWQA Program are to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources; (2) define long-term trends in water quality; and (3) identify, describe, and explain major factors that could affect observed water-quality conditions and trends (Hirsch and others, 1988).

The design concepts of the NAWQA Program are based in part on a pilot program that began in 1986. The NAWQA pilot program consisted of seven Study Units conducting water-quality assessment in separate study areas. These study areas were distributed geographically throughout the continental United States and represented diverse hydrologic environments and water-quality conditions. Four of the pilot assessments focused on surface water and three focused on ground water. The ground-water pilot study areas were the Carson River Basin in Nevada and California (Welch and Plume, 1987); the Central Oklahoma Aquifer in Oklahoma (Christenson and Parkhurst, 1987); and the Delmarva Peninsula in Delaware, Maryland, and Virginia (Bachman and others, 1987).

The NAWQA Program design that has evolved from the pilot program consists of two major components: (1) Study-Unit Investigations of both surface and ground water, and (2) National Assessment activities, which combine results of individual Study Units for selected topics. This design provides information on water quality for policymakers and managers at local, State, regional, and national scales.

Components and attributes of the current ground-water-sampling design for a Study Unit are described in Lapham and others (in press) and Gilliom and others (1995). In brief, for the full-scale NAWQA Program, investigations of 60 Study Units, ranging in area from 1,200 to more than 60,000 square miles, are ongoing or planned. The 60 Study Units include parts of most of the major river basins and aquifer systems in the Nation, and incorporate about 60 to 70 percent of the Nation's water use and population served by public water supply. Investigations in each Study Unit are being conducted on a rotational rather than a continuous basis. One-third of the Study Units are being studied intensively at any given time. For each Study Unit, a 3- to 4-year intensive period of data collection and analysis will be alternated with a 6- to 7-year period of low-intensity assessment activities. The first intensive period of study for 20 of the 60 Study Units, which is referred to as the Occurrence and Distribution Assessment, began in 1993.

Data from each Occurrence and Distribution Assessment will be aggregated and compared for selected topics from all Study Units, as well as from other programs, to obtain regional and national perspectives on water quality. Consistent methods of data collection by the Study Units are needed for comparability of data. The protocols and recommended procedures described in this report are intended to ensure that consistency.

Purpose and Scope

This report describes protocols and recommended procedures to be used by the NAWQA Program for the collection of ground-water-quality data from wells. Protocols and recommended procedures discussed relate to the plans and preparations for ground-water sampling, and the collecting, processing, and handling of ground-water samples, including well purging, field measurements taken during purging, equipment decontamination, quality-control sampling, and sample documentation, handling, and shipping. Quality-assurance protocols and procedures are incorporated for each data-collection activity.

Quality Assurance and Quality Control

In this report, quality assurance refers to activities that control or guide data-collection methods, such as protocols, recommended procedures, and work plans and schedules. Quality control refers to the data or measurements generated to quantify measurement bias and variability associated with the data-collection process. The quality assurance (QA) activities and quality control (QC) data associated with NAWQA protocols and recommended procedures described in this report are best carried out as an integral part of the plans, preparations, implementation, and documentation used to obtain ground-water-quality data (Shampine and others, 1992). To emphasize the importance of an integrated approach, and the need for all NAWQA ground-water staff to participate, the protocols and recommended procedures that relate to QA and QC appear throughout this report in relation to a variety of responsibilities and activities, rather than being segregated in a separate section.

An integrated approach to QA and QC helps to clarify what needs to be done, when, and by whom through QA activities that are logically and efficiently coordinated with other activities and through the collection of data to assess that the ground-water data collected are of a quality suitable for Study-Unit and National Assessments. In order of discussion, the data-quality requirements for NAWQA ground-water sampling and the role of QC sampling are described in "Data-Quality Requirements." Equipment and supplies specific to QC sampling are described, along with those generally required to obtain water-quality data, in "Selection and Purchase of Equipment and Supplies." The QA requirements for field instruments and water-quality vehicles are incorporated under the respective topics (see "Field Instruments" and "Water-Quality Vehicles"). The design for selecting QC sample types and scheduling their collection are described immediately following the discussion of the design of water-quality sampling schedules.

Protocols and recommended procedures to be followed in collecting QC samples are incorporated as part of a number of activities that occur in chronological order and that define the overall data-collection process at a well. For example, the collection of replicate ground-water samples is described after well purging, and as part of the discussion on the collection of water-quality samples (see "Sample Collection and Processing"), whereas the collection of field blanks is described after equipment decontamination (see "Preparation of Blank Samples"). Preparing special types of samples, including QC samples such as field spikes, is described after the section on field blanks because that is when field-spiked samples for pesticides and volatile organic compounds will be prepared (see "Preparation of Other Routine Quality-Control Samples and Field Extracts of Pesticide Samples"). Finally, documentation activities relating directly to QA and QC are described throughout this report.

Although this report includes many QA-QC protocols and recommended procedures, it does not replace the need for individual Study Units to assess, review, and possibly expand on those described. Study Units are encouraged to publish their QA-QC plans and results independent of any work performed at the national level of the NAWQA Program, and as appropriate for their particular needs.

Acknowledgments

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COLLECTION AND DOCUMENTATION OF WATER-QUALITY SAMPLES AND RELATED DATA

Ground-water-quality data for the Occurrence and Distribution Assessment of the NAWQA Program are to be collected and documented in accordance with the specific protocols and recommended procedures described in this report and in Lapham and others (in press). Protocols and recommended procedures are provided that cover plans and preparations, collection methods, and the documentation of activities before, during, and after water-quality data are collected. The principles underlying these protocols and recommended procedures have been shown to produce data suitable for the Occurrence and Distribution Assessments of NAWQA in selected pilot areas (Christenson and Rea, 1993; Hamilton and others, 1993; Koterba and others, 1993; and Rea, in press).

The NAWQA ground-water protocols and recommended procedures are applicable for data commonly collected for all three ground-water components (Study-Unit Surveys, Land-Use Studies, and Flowpath Studies) of the NAWQA Program (table 1). Although they are consistent with general guidelines for USGS ground-water data collection (F.D. Wilde, U.S. Geological Survey, written commun., 1995--see footnote 1), these protocols and recommended procedures reflect NAWQA Program objectives, and could differ in some aspects from those of other USGS programs. In particular, because of the perennial nature of the NAWQA Program, methods used by individual Study Units are constrained by the need for national consistency in the quality of data collected and by the degree and type of documentation required.

Data-Quality Requirements

The importance of national consistency in data collection cannot be overstated. Inconsistent methods can lead to variable and biased data measurements.[2] Modifications to collection and analytical methods potentially result in data whose measurements vary or are biased in relation to previously collected data. If not quantified and documented, such modifications complicate trend analysis (Smith and Alexander, 1989).

The protocols and recommended procedures for NAWQA are designed to reduce inconsistencies and enhance the quality of data used in spatial and trend analysis. The purpose of data-quality requirements is to ensure that data-collection methods are consistent, and that the data obtained meet study needs. The NAWQA Program has three requirements related to sample collection: (1) document the methods used to collect ground-water-quality data and all quality-assurance and quality-control measures, (2) ensure that the quality of data collected is known, and (3) demonstrate that the quality of data obtained is suitable for assessment objectives. In meeting these requirements, it is necessary that data-collection and analytical methods be designed, planned, and executed as consistently as possible. This will help reduce bias and variability among the data collected within a single Study Unit and among Study Units.

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[2]The term “bias” is defined in this report as a systematic error that is manifested as a consistent positive or negative deviation from the known or true value. “Variability” is defined as measurement reproducibility or the degree of similarity among independent measurements of the same quantity, often measured as a variance or relative standard deviation and without reference to the known probable or true value.

Table 1. Summary of current (1995) required, recommended, and optional water-quality constituents to be measured in the three ground-water components of the Occurrence and Distribution Assessment, National Water-Quality Assessment Program (from Lapham and others, in press)

[Required water-quality constituents to be measured for the Occurrence and Distribution Assessment are determined partly by the water-quality topics of national interest selected for National Assessment. Topics selected for National Assessment (1994) are nutrients, pesticides, and volatile organic compounds. The topics selected can change over time. Quality-control samples also are required - types of quality-control samples depend on study component. Req, Required; Rec, Recommended; Opt, Optional; NWQL, National Water Quality Laboratory; SC, Schedule; LC, Laboratory Code]

Water-quality constituent or constituent class	Study-Unit Survey	Land-Use Studies	Flowpath Studies[1]	Method[2]
Field measurements				
- Temperature	Req	Req	Req	Field
- Specific electrical conductance	Req	Req	Req	Field
- pH	Req	Req	Req	Field
- Dissolved oxygen	Req	Req	Req	Field
- Acid neutralizing capacity (ANC) (unfiltered sample)[3]	Rec	Rec	Rec	Field incremental
- Alkalinity (filtered sample)[3]	Req	Req	Req	Field incremental
- Turbidity[4]	Rec	Rec	Rec	Field
Major inorganics	Req	Req	Req	NWQL SC2750
Nutrients	Req	Req	Req	NWQL SC2752
Filtered organic carbon	Req	Req	Opt	NWQL SC2085
Pesticides	Req	Req	Opt	NWQL SC2001/2010 NWQL SC2050/2051
Volatile organic compounds (VOCs)	Req	Req or Opt[5]	Req or Opt[6]	NWQL SC 2090
Radon	Req	Req or Rec[7]	Req or Rec[6]	NWQL LC 1369
Trace elements[4]	Opt	Opt	Opt	NWQL SC 2703
Radium	Opt	Opt	Opt	NWQL-Opt
Uranium	Opt	Opt	Opt	NWQL-Opt
Tritium, tritium-helium, chlorofluorocarbons (CFCs)[8]	Rec	Rec	Rec	NWQL LC1565 (tritium)
Environmental isotopes[9]	Rec	Rec	Rec	NWQL-Opt

[1]Selection of constituents for measurement in Flowpath Studies is determined by Flowpath-Study objectives. During at least the first round of sampling, however, the broad range of constituents measured in Study-Unit Surveys and Land-Use Studies will be measured.

[2]Schedules and laboratory codes listed are required for Study Units that began their intensive phase in 1991 or 1994, and apply until changed by National Program directive. Schedules for radium and uranium can be selected by the Study Unit, but require NAWQA Quality-Assurance Specialist approval. A detailed discussion is found in the “Sample Collection and Processing” section of this report.

[3]ANC (formerly referred to as unfiltered alkalinity) is measured on an unfiltered sample. Alkalinity is measured on a filtered sample. A Study Unit could have collected ANC, alkalinity, or both to date.

[4]Turbidity measurements are required whenever trace-element samples are collected to evaluate potential colloidal contributions to measured concentrations of iron, manganese, and other elements.

[5]VOCs are required at all urban Land-Use Study wells, but are optional in agricultural Land-Use Studies. If VOCs are chosen as part of an agricultural Land-Use Study, then they should be measured in at least 20 of the Land-Use Study wells.

[6]VOCs are required at all urban flowpath wells for at least the first round of sampling. If VOCs are measured in an agricultural Land-Use Study, then they should be measured at all Flowpath-Study wells within that Land-Use Study for at least the first round of sampling.

[7]Radon is required at any Land-Use or Flowpath Study well if that well also is part of a Study-Unit Survey; otherwise radon collection is recommended for Land-Use or Flowpath-Study wells located in likely source areas.

[8]Collection of tritium, tritium-helium, chlorofluorocarbons (CFCs), and (or) other samples for dating ground water is recommended, depending on the hydrogeologic setting. For tritium methods, see NWQL catalog; for CFCs, see Office of Water Quality Technical Memorandum No. 95.02 (unpublished document located in the USGS Office of Water Quality, MS 412, Reston, VA 22092).

[9]For a general discussion of the use of environmental isotopes in ground-water studies, see Alley (1993).

This report comprises a substantial part of the documentation requirement. Because of diverse site conditions, well types, equipment requirements, and staff experience, situations could arise where NAWQA protocols and recommended procedures described in this report need to be modified. Modifications at the program level will be made in a systematic manner and initially documented through internal, regional, or national memorandums. For modifications internal to Study Units, the chief of the Study Unit is responsible for ensuring that the proposed modification is discussed with the NAWQA Program Quality-Assurance (QA) Specialist before implementation, and that any modifications used are clearly documented in Study-Unit publications. It also is necessary for the NAWQA Program or individual Study Units to provide evidence of the effect, or lack thereof, of modifications on data quality.

To ensure data quality and suitability (the second and third data-quality requirements) each Study Unit will routinely follow protocols and recommended procedures that are described in detail in the following sections. The QA-QC measures include (1) the collection of selected QC samples in the field to test equipment and methods before data collection begins, and (2) the routine collection of selected QC samples (such as blanks, replicates, and spiked replicate samples) during ground-water-quality sampling. Additional QC samples and QA measures will be taken if modifications in methods of sample and data collection occur that require quantification.

Individual NAWQA Study Units or National Synthesis teams may find it necessary to expand QC data collection to identify specific sources of measurement bias or variability. In addition, it has been necessary in some cases to enhance collection of QC data in order to interpret the corresponding ground-water-quality data (Koterba and others, 1991; Ferree and others, 1992; and Koterba and others, 1994). Study-Unit and National-Synthesis-Team budgets, plans, and preparations need to remain flexible to allow for the possibility that additional QC data could be needed.

Plans and Preparations

Plans and preparations for ground-water sampling are completed well in advance of data-collection activities, yet must remain flexible enough to be modified if circumstances dictate. Preparations include becoming familiar with the protocols and recommended procedures described in this document. Sampling equipment and supplies need to be obtained in time for sampling and for the staff to be trained in their use. The ground-water staff also needs to become familiar with and develop the documentation and management of samples and data, including that for QC samples. Finally, the ground-water staff should make detailed plans and preparations for the first field season, which for most Study Units commonly will begin early in the first year of the Occurrence and Distribution Assessment.

As the Study-Unit Investigation progresses, subsequent plans and preparations for each field season are required annually, and are developed as part of the general workplan. Study Units commonly will complete preparations for sampling several weeks in advance of each field season. Documenting site conditions, water-quality data collection, and reviewing collected data are processes that begin before each field season, continue during data collection, and often extend months beyond each field season.

Five key elements to consider in the initial and (in some cases) annual plans and preparations include (1) site visits to assess conditions that could affect sample and data collection; (2) selecting and obtaining sampling equipment and supplies early, to ensure that those eventually used best meet field conditions and fall within NAWQA Program requirements or recommendations; (3) training, to prepare field teams; (4) conducting a field evaluation, to determine that the equipment and procedures will provide high-quality data and that planned documentation and management activities are adequate; and (5) developing detailed schedules that clearly describe staff responsibilities before, during, and after each field season. Each of these planning and preparation elements is described below in detail.

Site Visits

Wells selected or installed for each ground-water component are visited at least once before sampling. During this or any other visit, site data are reviewed to determine if information is needed to (1) complete documentation requirements (Lapham and others, in press), and (2) plan water-quality sampling activities (table 2). In addition, plans currently (1995) are being developed for screening wells for high concentrations (10 μg/L or greater) of volatile-organic-compound (VOC) contamination (John Zogorski, VOC National Synthesis Team, U.S. Geological Survey, written commun., 1995). This could add to the information that needs to be collected during these site visits for selected wells sampled after 1995.

Selection and Purchase of Equipment and Supplies

Because of the need to obtain nationally consistent data over many years on a wide variety of chemical constituents (table 1), most equipment and supplies not provided by the Study Unit generally should be obtained from one of three USGS suppliers: the Hydrologic Instrumentation Facility, Quality Water Service Unit, and National Water Quality Laboratory (table 3). Each of these suppliers offers the advantage of stocking equipment that otherwise would have to be obtained from multiple sources. These suppliers also conduct QC checks and provide QC data for selected supplies and equipment distributed to USGS personnel. For these reasons, these suppliers are designated as the required or sole-source supplier for such items (table 3, USGS supplier with “S” designation). The USGS suppliers also are recommended as sources for other equipment (table 3, USGS supplier with “R” designation) in order to reduce the time, effort, paperwork, and cost to the Study Unit to locate and obtain equipment. Should the need arise, each supplier also can provide equipment not previously available.

Table 2. Information to obtain when planning water-quality data-collection activities

1. **Type of Well Hookup for Sampling:** Determine if a hookup to a garden-hose-threaded flow valve (common for water-supply wells) or to a portable, submersible pump (common for monitoring wells) is needed for sample collection.

2. **Depth Measurements**: Measure the depth of the well and depth to the water level in the well to check well-construction integrity and to determine pump lift, height of water column, volume of standing water held in the well, and purge volume.[1]

3. **Site Conditions and Restrictions:** Note road or access conditions to the well, areas of low clearance, limits on arrival and departure times, or presence of roaming animals (for example, livestock or pets) that could create problems for a field team.

4. **Contact Person**: Obtain land- or well-owner name and telephone numbers (business and home) and contact owner before or upon arrival, and perhaps upon departure.

5. **Local Maps and Photographs**: Locate well on maps, site sketches, or photographs, and indicate the measuring point for well-depth measurements, as well as areas for equipment setup and waste discharge.

6. **Travel Maps and Travel Times**: Identify route and travel times from District office or previous site, and possible tunnel or bridge restrictions on the transport of gasoline, bottled gas, or methanol (or other organic cleaning agent).

[1]Measurements are made in accordance with National Water-Quality Assessment Program and U.S. Geological Survey protocols (Lapham and others, in press). Purge volume is defined as three times the volume of standing water in the well casing or, in absence of a casing, the borehole.

Table 3. Equipment, supplies, and suppliers for ground-water-quality sampling for the National Water-Quality Assessment Program

[OM, open market; HIF, U.S. Geological Survey Hydrologic Instrument Facility, Stennis Space Center, Miss.; R, recommended supplier; QWSU, Quality Water Service Unit, Ocala, Fla,; SU, Study Unit; µm, micrometer; mm, millimeter; S, sole (required) source of supplies indicated; NWQL, National Water Quality Laboratory, Arvada, Colo.; mL, milliliter; L, liter; ASTM, American Society for Testing and Materials; SC, NWQL analytical schedule; FA, filtered and acidified sample; FU, filtered (unacidified) sample; RU, raw (unfiltered) sample; FCC, filtered, chilled (no preservative added) sample; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; DIW, deionized water; BTD&QS, Branch of Technical Development and Quality Systems, Arvada, Colo.]

Equipment and supplies	Suppliers
1. Well-head setup or connection	
• Monitoring well: submersible pump and reel system	OM[1]
• Water-supply well: hook-up segment with garden-hose thread	HIF[2], R
2. Sample-flow transfer system from pump reel to collection point	
• Antibacksiphon device, Teflon, connected in line	HIF, R[3]
• Extension lines for sample flow, Teflon, with connectors	HIF, R
• Manifold, with connectors and Teflon valves, for routing sample flow	HIF, R
• Sample-collection equipment that has connectors to manifold:	
Radon collector with septa, and connectors to manifold	HIF, R
Glass syringe with leur-locked stainless-steel needles	QWSU, R
Teflon, line with connector to manifold, either open ended for turbidity sample collection, or with connector to flowthrough turbidimeter	HIF, R
• Sample-collection and processing chamber frame, PVC or inert material with sample-flow-transfer port	HIF, R
• Preservation-chamber frame, PVC or inert material	HIF, R
• Transparent disposable covers and plastic clips to hold covers inside frames for sample and preservation chamber frames	SU, HIF, R[4]
• Flowthrough chamber with field-instrument ports, manifold connections, and waste line	OM[5]
3. Sample-filtration equipment	
Organic carbon, filtered fractions	
• Stainless-steel cylinder unit with nitrogen-gas deso-quick connect, gas scrubber, and gas line with connector to secondary regulator	HIF, R
• Nitrogen gas tank, with primary and secondary regulators	OM
• Filter membranes, 0.45-µm, 47-mm diameter, silver	QWSU, S
• Safety belts, to secure gas tank	OM
• Container, to collect spent silver nitrate membranes	SU
Pesticides	
• Aluminum or stainless-steel unit	OM, NWQL[6]
• Filter membranes, 0.7-µm, 142-mm diameter, baked, GF/F grade glass microfiber	QWSU, S
• Connector from filter unit to sample-chamber outflow tube	SU[6]

Table 3. Equipment, supplies, and suppliers for ground-water-quality sampling for the National Water-Quality Assessment Program--Continued

Equipment and supplies	Suppliers
Inorganic (major ions, nutrients, and trace elements)	
• Filter units, capsule with self-contained 0.45-μm[7], pleated, Supor capsule	QWSU, S
• Convoluted (spiral configuration) Teflon sample-flow lines from filter unit to sample-chamber outflow tube[8]	OM
4. Sample Bottles (sample containers, caps, and protective foam sleeves)	
Organic samples	
• Volatile organic sample (SC2090), 40-mL amber vial, baked (Teflon-lined cap)--three vials per sample (Also includes trip blanks.)	NWQL, S
• Pesticides (SC2001 or 2010) sample: 1-L amber bottle, baked (Teflon-lined cap)	QWSU, S
• Pesticides (SC2050 or 2051) sample: 1-L amber bottle, baked (Teflon-lined cap)	QWSU, S
• Organic carbon (SC2085) samples (filtered): 125-mL, amber bottle, baked (Teflon-lined cap)	QWSU, S
• Sleeves, foam, for 40-mL, 1-L, and 125-mL containers	QWSU, S
Inorganic samples	
• Radon (LC1369) sample: scintillation vial (one per transport tube)	NWQL, S
• Major cations (SC2750): filtered, acid-rinsed, 250-mL clear polyethylene bottle (with clear cap), FA--two per sample (one archived by SU)	QWSU, S
• Trace elements (SC2703, SC172, LC112 for arsenic and LC87 for selenium for field blanks): acid-rinsed, 250-mL clear polyethylene bottle (with clear cap), FA--one per sample	QWSU, S
• Major anions (SC2750): 500-mL, clear polyethylene bottle labeled FU, clear 28-mm neck (with black cap)--one per sample	QWSU, S[9]
• Nutrients (SC2752): 125-mL amber polyethylene bottle (with black cap), FCC--one per sample	QWSU, S
• Unfiltered sample (SC2750) RU for laboratory measurements: 250-mL clear polyethylene bottle (with black cap)--one per sample	QWSU, S
(Order black caps for 28-mm bottle neck separately)	QWSU, S
5. Sample and Shipping Forms and Shipping Supplies	
• Field form (standard National Water Quality Field Form or District analog)[10]	SU
• Analytical Services Request (ASR) forms for NWQL	NWQL, S
• Sample Reply Form (Study Unit to NWQL) and return envelope, self-addressed, stamped (see appendix, fig. A20, for example)	SU
• Overnight shipping labels	Contract Carrier
• Surface-mail shipping labels (supplied and prepared at District Office)	SU

Table 3. Equipment, supplies, and suppliers for ground-water-quality sampling for the National Water-Quality Assessment Program--Continued

Equipment and supplies	Suppliers
• Coolers, with latch lid and drain port, maximum loaded weight of 50-60 lbs. (for overnight sample delivery)	OM
• Heavy cardboard boxes, maximum loaded weight, 20 lbs. (surface delivery)	OM
• Plastic bags, heavy, 4-mil (for holding ice and overnight samples in cooler)	OM
• Plastic bags, resealable (for holding ASR and other forms mailed with samples)	OM
• Filament tape (to secure lid and drain cap of cooler, and surface-delivery boxes)	OM
6. Field-titration equipment[11]	
• Digital or other titrator meeting USGS specifications	QWSU, R
• Acid cartridges (for digital titrator)--0.16 and 1.6 Normal sulfuric acid	QWSU, S
• Extra acid-delivery tubes for digital titrator, clear plastic	QWSU, R
• Glass beakers (250 mL)	OM
• Volumetric pipets, glass, Class A (for preparing filtered samples)	OM
• Magnetic stirrer and small Teflon-coated stir bars	OM
7. Field instruments[11]	
• pH (electrometric) meter	OM
• pH electrodes and refill solutions (specify type of electrode)	QWSU, R
• Specific electrical conductance meter	OM
• Dissolved-oxygen (amperometric) meter and associated equipment (sensor cable, membrane and solution kit)	OM or QWSU
• Pocket barometer (used for pressure correction to dissolved-oxygen meter)	HIF, R
• Calibration wand and cup (for dissolved oxygen)	HIF, R[12]
• Turbidity (nephelometric) meter (turbidity measurement generally is recommended, but required for trace-element sampling)	OM
• Temperature measurement: thermistor thermometer (recommended), possibly part of other field meters.	QWSU, R
Also need a liquid-in-glass thermometer, ASTM certified, 0.1°C-graduated range of -5 to 45°C (for calibrating thermistor thermometer)	OM, R
8. Miscellaneous equipment and supplies	
• Parafilm	HIF, R
• Forceps (tweezers), Teflon-tipped stainless steel (to handle filter membranes for organic and inorganic samples); or steel forceps (for flat glass-fiber and silver membranes) and plastic forceps (for cellulose nitrate or other inorganic-sample membranes)	OM
• Plastic beakers and small cups, used to hold solutions for calibrating or checking field-instrument sensors	OM, R

Table 3. Equipment, supplies, and suppliers for ground-water-quality sampling for the National Water-Quality Assessment Program---Continued

Equipment and supplies	Suppliers
9. Decontamination equipment and supplies	
• District deionized water (DIW) (conductivity ≤1 µS/cm), quality controlled	SU
• Inorganic-free blank water (IBW) (quality controlled for major ions and trace elements)	QWSU, S[13]
• Pesticide-free blank water (PBW) or volatile and pesticide-free blank water (VPBW) (for pesticides or volatile organics)	NWQL, S[13]
• Methanol, pesticide-grade high purity (organic-sampling equipment)	OM
• Laboratory detergent, phosphate free, concentrated: diluted to a 0.1 percent decontamination solution, by volume, with DIW	QWSU, R
• Wash bottles, polyethylene, 250 mL or 500 mL (for DIW and IBW)	QWSU, R
• Wash bottles, Teflon, 500 mL (for PBW and VPBW)	QWSU, R
• Wash bottle, for methanol or other organic solvent, 250 mL	OM
• Laboratory gloves, powderless (latex or vinyl) (for decontamination and sample collection)	QWSU, R
• Plastic trays (3)	HIF, R
• Pump standpipes (glass graduated cylinders or pipette jars are preferred)	HIF, R[14]
• Forced-hot-air dryer, portable, vehicle-powered (for evaporating methanol residues)	OM
• Teflon bags, small (for small organic-sampling equipment and pump intake)	HIF, R
• Heavy aluminum foil (for wrapping organic-carbon and pesticide-filter-unit inlets and outlets	OM
• Plastic bags, resealable (for small inorganic sampling equipment)	OM
• Plastic bags, large, for enclosing cleaned pump reel, extension lines, and other large equipment	HIF, R
• Paper tissues, lint free, soft, disposable, large and small sizes (for example, Kimwipes)	OM
10. Safety equipment	OM[15]
• Fire extinguishers (A-B-C type) with mounts	
• Safety goggles or glasses	
• Eye-wash bottle	
• Emergency spill kits for any chemicals being used	
• Approved containers for transporting pure and used methanol	
• Safety cones, large	
• Material Safety Data Sheets	
11. Chemical reagents (kits include equipment for dispensing reagent)	
Preservatives	
• VOC samples (SC2090) -- 1:1 hydrochloric acid (kit)	NWQL, S
• Acrolein and acrylonitrile samples (SC1401) -- 1:1 hydrochloric acid	NWQL, S[16]
• VOC samples in chlorinated water matrix--ascorbic acid (with scoop)	NWQL, S[17]
• Inorganic (FA) samples for major cations (SC2750) and trace elements (SC2703)--nitric acid, 1-mL glass ampoule, one per sample	QWSU, S[18]

Table 3. Equipment, supplies, and suppliers for ground-water-quality sampling for the National Water-Quality Assessment Program--Continued

Equipment and supplies	Suppliers
Standards	
• pH standard buffers (pH 4, 7, and 10)	QWSU, S
• Specific electrical conductance standards (50 to 50,000 µS/cm; for low-conductivity waters of ≤20 µS/cm, use pH 4.31 buffer)	QWSU, S[19]
• Turbidity standards--Formazin	OM
• Dissolved-oxygen “zero” standard dilutions, freshly prepared with reagent grade sodium sulfite and cobalt chloride	OM[20]
Spike and other solutions	
• VOCs (SC2090, SC2091, SC2092): standard NAWQA spike solution and spike-solution kit	NWQL, S
• Pesticides (SC2050 or 2051 and SC2001 or 2010): standard NAWQA spike solution and spike-solution kits	NWQL, S
• Mixtures, required for trace elements (SC2703)	BTD&QS, S
• IBW, PBW, VPBW (see no. 9, “Decontamination equipment and supplies”)	NWQL and QWSU, S
12. Optional Equipment[21]	
• Equipment for isotope, radiochemical, and other special samples--for example, deuterium-oxygen, tritium, uranium, radium, mercury, chlorofluorocarbons	OM
• Field solid-phase-extraction equipment for pesticide samples	NWQL, S

[1] That meets NAWQA Program requirements; see text.

[2] To remove oils and other manufacturing or shipping residues, and before assembling HIF or other equipment that includes Teflon tubing (without metal fittings), soak tubing for 30 minutes in a 5 percent hydrochloric acid solution rinsed with tap water until rinsate has pH similar to tap water, then final rinse three times with DIW. For a 5-percent acid solution, add 5 milliliters of 12 normal (concentrated) acid (specific gravity 1.19 and trace-element free) to each 100 milliliters of DIW (specific conductance not to exceed 1.0 microsiemens at 25 degrees Celsius).

[3] Required for each portable pump system (monitoring wells) or hook-up setup (water-supply wells). Purchase separately from pump system; a single unit can be interchanged between portable-pump and hook-up systems.

[4] Recommended design that allows cover to be attached inside frame with small, plastic clips.

[5] Flowthrough chamber from HIF meets design criteria for use with individual field instruments--pH, dissolved oxygen, specific electrical conductance, and temperature--required for ground-water-quality sample collection.

[6] For aluminum filter unit purchased through NWQL that is set up for solid-phase extraction, SU supplies a short Teflon tube (1/2-inch outer diameter, 3/8-inch inner diameter) that slips over standard nipple connection on filter unit and is connected by a 5/8-inch outer diameter by 1/2-inch inner diameter Teflon sleeve to the tube extending from the sample chamber frame to the filter unit.

[7] For ground water that contains colloidal material, filter membranes with a pore size less than 0.45 µm are required if the filtrate data must represent ion concentrations in solution. The filter pore size in general should not exceed 0.2 µm.

[8] Commonly sold in 5-foot lengths and can be cut into small lengths. Convoluted is preferred over corrugated type because latter is prone to trapping sediment, and must be replaced frequently (Johnson and Swanson, 1994).

[9] RU sample is not needed with trace-element schedule SC2703 if field conductivity is recorded on trace-element ASR form, along with a notation (in comment line to laboratory) that there is “no RU sample.”

Table 3. Equipment, supplies, and suppliers for ground-water-quality sampling for the National Water-Quality Assessment Program--Continued

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[10]To be filed with ASR Forms (SU copy) every time samples are collected at well (see appendix, fig. A8, for example).

[11]Refer to table 5 and Radtke and Wilde (in press) for descriptions of equipment and equipment specifications.

[12]Use air-calibration-chamber-in-water method (Radtke and Wilde, in press, Sec. 6.2).

[13]IBW, PBW and VPBW are laboratory-produced waters quality-controlled for specified analyses. The primary use of these waters is for blank samples, but they also can be used in small quantities for ultraclean decontamination procedures. PBW and VPBW contain about 0.1 mg/L of organic carbon (NWQL Technical Memorandum 92.01--unpublished document available from NWQL, 5293 Ward Road, Arvada, CO 80002), but analyses could differ among lots.

[14]Glass is the preferred standpipe material for decontaminating pump equipment because it does not readily absorb contaminants (Reynolds and others, 1990), especially if used repeatedly after equipment exposure to volatile organic compounds.

[15]Contact District Safety Officer for suppliers and specifications.

[16]Acrolein requires careful acidification to pH between 4 and 5 (acrylonitrile can withstand acidification to pH less than 2).

[17]Only required if sample water for VOC analyses is chlorinated; ascorbic acid will be supplied with the VOC preservative kit (NWQL) upon request. Otherwise, obtain ascorbic acid from the OM. DO NOT SUBSTITUTE SODIUM THIOSULFATE for ascorbic acid.

[18]Ultrapure nitric acid also available in 1-mL glass or Teflon ampoules.

[19]Purchase standards that bracket water-quality sample values.

[20]Prepare dissolved-oxygen standard solution fresh on day of use instead of repeatedly purchasing and discarding commercially available solutions.

[21]For assistance with (1) isotope, radiochemical, and other specialized equipment, contact the NAWQA Quality Assurance Specialist; (2) solid-phase extraction equipment, contact the NWQL, Methods Research and Development Program; and (3) chlorofluorocarbons (CFCs), contact Niel Plummer or Ed Busenberg, USGS National Research Program, MS 432, Reston, VA 22092.

Equipment not commonly provided by the Study Unit or USGS suppliers usually can be obtained on the open market (table 3, OM under supplier) and includes portable pumps for collecting samples at monitoring wells, and field instruments, vehicles, and storage facilities associated with ground-water-quality data collection. Each of these items is discussed separately below.

Pump systems

Several low-discharge, submersible pumps are available for collecting water-quality samples from wells. These pumps contain sample-wetted parts that consist mainly of Teflon and corrosion-resistant 316-stainless steel. On the basis of pump characteristics and results from decontamination tests (F.D. Wilde, U.S. Geological Survey, written commun., 1995--see footnote 1) these pumps are suitable for collecting a wide array of samples, including those required for NAWQA (table 1).

Use of low-discharge, submersible, portable pumps (such as the Fultz Model No. SP-300, Keck Model No. SP-84, Grundfos Model No. Redi-Flo2, and Bennett Model No. 180 or 1800) is required for NAWQA when sample collection from monitoring wells involves microgram-per-liter concentrations of VOCs, pesticides, or possibly trace elements. These pumps also are suitable for the collection of major ion, nutrient, and selected radionuclide samples.

From among suitable pump types, the choice for each Study Unit comes down to weighing the differences in pump performance characteristics (for example, pump diameter, lift capability, flow rate, portability, repairability, and power requirements) against characteristics of wells in the network (for example, well internal diameter, accessibility, purge volumes and times, and lift requirements) to determine the pump(s) that best meet Study-Unit needs. This decision process is illustrated for three pumps and shallow wells (table 4). (A similar process can be used to evaluate other pumps and deeper wells than those illustrated in table 4.) To select which of these pumps best meets sampling needs, the Study Unit can compare selected pump characteristics--primarily lift potential and pumping rate--with anticipated well or site characteristics--primarily depth to water level (lift), purge volume, and purge time (which, for practical reasons, is best kept to less than about 2 hours). If more than one pump type is adequate, other factors, such as repairability, power requirements, or cost can be used to refine the selection process. If most wells can be sampled with one pump type, and only a few wells require a second pump type (for example, deep wells), the Study Unit should consider collaborating with other Study Units or projects within the District to obtain the second pump to collect samples. (Well development is not at issue in this discussion. Pumps to be used for the collection of water-quality samples are not designed, and should not be used, to develop wells.)

Table 4. Example of a method to determine pump-system suitability as a function of selected well and pump characteristics

[in, inches; ft, feet; gal, gallons; ---, not applicable]

Well characteristics					Pump characteristics and suitability	
Well	Diameter (in)	Water-column height (ft)	Required purge volume[1] (gal)	Required lift or total dynamic head[2] (ft)	Maximum pumped volume at given lift in 2 hours for indicated pump system[3,4]	Pump-system suitability[5,6]
1	2	20	10	25	120 (Fultz SP-300)	Suitable
1	2	20	10	25	144 (Keck SP-84)	Suitable
1	2	20	10	25	840 (Grunfos Redi-Flo2)	Suitable
2	4	60	118	75	96 (Fultz SP-300)	Unsuitable
2	4	60	118	75	132 (Keck SP-84)	Suitable
2	4	60	118	75	768 (Grunfos Redi-Flo2)	Suitable
3	2	40	20	160	---[7] (Fultz SP-300)	Unsuitable[7]
3	2	40	20	160	---[7] (Keck SP-84)	Unsuitable[7]
3	2	40	20	160	538 (Grunfos Redi-Flo2)	Suitable

[1]**Required purge volumes** (in gallons) as a function of well diameter and water-column height.

Well diameter (in inches)	Water-column height (in feet) 20	40	60	80	100	120	140	160	180	200	240	260
	Required purge volume (in gallons)											
2	10	20	29	39	49	59	69	78	88	98	108	118
4	39	78	118	157	196	235	274	313	353	392	431	470
6	88	176	264	353	441	529	617	705	793	881	969	1,058

Where **purge volume** equals three times the borehole or casing volume. The borehole or casing volume, V (in gallons), is calculated as $V = 0.0408 \times H \times D^2$, where H is the **water-column height** (in feet), and D is the well **diameter** (in inches).

[2]In these examples, the **required lift** is equivalent to total dynamic head and is estimated as the depth to water in the well. This assumes that the purge takes place with the pump intake at the top of the water column, and that the water level in the well does not decline appreciably with pumping. Note that for submersible pumps (for example, helical rotor gear, progressing cavity, bladder, and piston pumps) Lift = pump depth + frictional tubing loss; for centrifugal-pump designs, this is more accurately described as total dynamic head (TDH), where TDH = depth to water + frictional tubing loss.

Table 4. Example of a method to determine pump-system suitability as a function of selected well and pump characteristics--Continued

[3]**Maximum pumped volume** is calculated using the pumping rate for a given pump system from manufacturer's specifications at the required lift (or TDH) multiplied by an assumed purging time of 2 hours.

Example pumping rates in gallons per minute (gpm) as a function of lift (TDH) for selected pump systems from manufacturer's specifications. With antibacksiphon device, extension lines, and directional-control flow valves that follow pump-reel system, effective pumping rate is assumed to be 80 percent of that given by the manufacturer. Actual rates, particularly as lifts approach the limit of each system, could be less than those specified.

Pump system	Lift (in feet)											
	0	25	50	75	100	125	150	175	200	225	250	275
	Pumping rate (gpm)											
Fultz Model No. SP-300	1.1	1.0	0.9	0.8	0.7	0.5	0.4	---	---	---	---	---
Keck Model No. SP-84	1.3	1.2	1.2	1.1	1.0	0.9	0.8	---	---	---	---	---
Grunfos Model No. Redi-Flo2	7.2	7.0	6.7	6.4	6.0	5.7	5.0	4.4	3.8	3.0	2.1	---

Example **maximum pumped volume** (gal) as a function of lift for the three pump systems given above, assuming pumping time is 2 hours.

Pump system	Lift (in feet)											
	0	25	50	75	100	125	150	175	200	225	250	275
	Maximum pumped volume in 2 hours (in gallons)											
Fultz Model No. SP-300	132	120	108	96	84	60	48	---	---	---	---	---
Keck Model No. SP-84	156	144	144	132	120	108	96	---	---	---	---	---
Grunfos Model No. Redi-Flo2	864	840	804	768	720	684	600	538	456	360	252	---

[4]For practical reasons, and except when quality-control samples are taken, field teams aim to complete all activities at each well within 4 to 6 hours. Thus, purge times generally need to be kept under 2 1/2 hours, with the pumping rate during the last half hour equal to the sampling rate (no more than about one tenth of a gallon per minute).

[5]Pump-system suitability is determined as follows:

Suitable if the **maximum pumped volume** at a given lift (or TDH) in 2 hours for the indicated pump type is equal to or greater than the **required purge volume**.

Unsuitable if the **maximum pumped volume** at a given lift in 2 hours for the indicated pump system is less than the **required purge volume** or if the **required lift** (or TDH) exceeds the maximum for the pump.

[6]When two or more pump types meet requirements outlined above, other factors considered in pump selection include ability of pump system to be decontaminated adequately, portability, susceptibility of pump to seizure, ease of repair and use in the field, and cost. It is assumed comparison is among pumps that are constructed and can be operated in a manner suitable for NAWQA sampling.

[7]**Required lift** exceeds maximum lift of the pump; therefore, pump is unsuitable under conditions given in this example.

Regardless of the pump type chosen, the pump system (pump intake, tubing, and reel) must meet certain requirements. The pump can be purchased without an antibacksiphon because a suitable antibacksiphon is to be added by the Study Unit (table 3). The pump line should be solid, high-density Teflon tubing. Teflon-lined polypropylene or other tubing is not recommended because the exterior tubing often is not as inert as Teflon. In addition, the outer tubing can separate from the Teflon lining, causing the thin-walled Teflon tubing to pinch or collapse. Suitable pump tubing can be ordered in 50-ft segments connected with 316-stainless steel (SS-316) quick connections, which makes it possible to use the shortest length of tubing needed for each well. In addition, it is recommended that the reel that holds the tubing be designed to turn (while raising or lowering the pump intake and tubing), while the pump is in operation, and while the pump-reel outlet is connected to an extension line that runs to the remainder of the sample-collection setup.

Other types of equipment (bailers, bladder pumps, peristaltic pumps) can be considered for some site conditions, or special data-collection needs. The use of such equipment generally is not recommended. Most alternative sample-collection devices are either limited in their lift potential, constructed of materials that are unsuitable or difficult to decontaminate, or deliver the sample in a manner (for example, under suction) that they cannot be used for most sites, or do not provide data of suitable quality for all NAWQA constituents (F.D. Wilde, U.S. Geological Survey, written commun., 1995--see footnote 1).

Study Unit staff that need to collect ground-water-quality samples using equipment other than that specified (table 3) must discuss their plans with the NAWQA QA Specialist. At a minimum, it is expected that sufficient QC data are available, or will be collected, to verify that the ground-water data obtained with the alternative equipment is similar in quality to data being obtained by the NAWQA Program in general.

Field instruments

Each Study Unit is to obtain suitable field instruments to collect data for pH, specific electrical conductance (SC), dissolved oxygen (DO), and temperature (T). If samples for trace elements (such as iron, manganese, aluminum, or uranium) are collected, sample turbidity (TU) also is measured. These data (pH, SC, DO, T, and possibly TU) are part of the required water-quality record for each ground-water sampling site (table 1), and also serve as QC measures that are used to assess the chemical variability of water before and at the time samples for other chemical constituents are collected. In collecting these data, however, the field instruments used must meet certain requirements (table 5).

Table 5. Requirements for meters and sensors used for field measurements taken at ground-water-quality sites of the National Water-Quality Assessment Program (modified from Radtke and Wilde, in press)

[°C, degrees Celsius; mV, millivolt; Δmv/ΔpH, change in millivolts divided by change in pH at measurement temperature (in °C); ≥, greater than or equal to; µS/cm, microsiemens per centimeter at 25°C; ≤, less than or equal to; >, greater than; mg/L, milligrams per liter; NTU, nephelometric turbidity units; NWIS-I, National Water Information System-I]

Field measurement	Performance requirements
Temperature (°C) (recommend thermistor-type thermometer)	Reading to 0.1°C for temperatures from -5 to 45°C; bias within 0.2°C. (Requirement applies to any thermistors used in association with other field measurements, including those contained in other field-measurement systems. Sampling thermal systems can require readings and calibration to 52°C.)
pH (standard units; require electrometric method) and field titrations	Reading to 0.1 standard unit (or 0.05 unit for instruments that display more than two digits to the right of the decimal). Temperature compensating; mV readout; rapid electrode response--maximum 15- to 20-second elapsed time for reading to "lock-on" the low pH calibration buffer after meter is calibrated with high pH 7 buffer; pH electrode must pass slope-test [(Δmv/ΔpH) ≥ 0.94 x (Theoretical Nernst slope)], corrected for temperature.[1]
Specific electrical conductance (µS/cm at 25°C)	Reading within 5 percent of full scale at ≤100 µS/cm or within 3 percent of full scale at >100 µS/cm; temperature compensation range from -2 to 45°C or greater, if needed. Instrument must compensate for temperature to provide readings at 25°C, or temperature readings are required to apply correction factor and report measurement at 25°C.
Dissolved oxygen[2] (require amperometric method)	Reading to 0.3 mg/L or less for concentrations ≥1 mg/L. Temperature compensation and temperature measurement required. Field barometer needed to determine barometric pressure correction factor.
Turbidity (recommend nephelometric method)	Select instrument designed to provide precise and unbiased measurements at 0 to 40 NTU. Reading within 5 percent full scale for 1 to 500 NTU, and within 0.02 NTU for turbidity less than 1 NTU. Turbidity entered into the NWIS-I data base must be made using nephelometric measurements.

[1]Slope test and temperature correction are described in Radtke and Wilde (in press).

[2]Use spectrophotometric or iodometric method for accurate measurements of dissolved-oxygen concentrations less than 1 mg/L (Radtke and Wilde, in press).

Water levels are to be determined whenever possible before other water-quality data are collected from wells (Lapham and others, in press). The static water level within a few hundred feet below land surface is measured using a chalked steel tape, and the measurement is repeated until two consecutive measurements differ by no more than 0.02 ft, or until the reason for less precise measurements is determined and documented. In addition, the depth from land surface to the bottom of the well is measured during each site visit whenever possible to verify the integrity of the well construction.

Each field instrument must be calibrated, operated, maintained, and stored, and the necessary calibration and test results documented according to USGS protocols. The protocols for ground-water-quality field measurements are described in Radtke and Wilde (in press).

Water-quality vehicles

Different vehicle designs will be used among Study Units because of differences in terrain, accessibility of sites, travel distances, trip duration, and other factors. In selecting and modifying a vehicle for water-quality data collection, however, it is recommended that safety and quality control be given high priorities. Study Unit staff also are encouraged to research designs already in use and to dedicate vehicle(s) solely to the collection of water-quality data.

Safety is a vital concern. The most important thing a water-quality vehicle will carry is the field team. To protect the team, all equipment is secured and properly stored behind passenger barriers when in transit, and without affecting the driver's visibility. In addition, vehicle supplies should include safety cones; safety glasses; fire extinguishers; first-aid, eye-wash, and chemical-spill kits; and Material Safety Data Sheets--all placed where they are readily accessible. If sample collection or processing occurs inside the vehicle, ventilation must be adequate and there must be sufficient room to operate. Flex hose is used to vent combustion exhaust away from a vehicle that is stationary with the engine running, and is stored and transported outside of the sampling vehicle. Flammable solvents (such as methanol) and pressurized gases (such as nitrogen) are transported according to local and State regulations. Regular service and maintenance and before-departure safety inspections of the vehicle are scheduled by the field team. If questions arise in regard to safety or inspection procedures, methods, or equipment, contact the District safety officer.

Quality assurance of the sampling vehicle is critical to a successful investigation. This vehicle should enable the field team to collect high-quality samples and data. Despite diverse external conditions, the vehicle should provide a clean environment for sampling and equipment, and a suitable environment for protecting equipment from damage during transport. The vehicle design also should provide temporary protection of field instruments, chemical reagents, buffers, preservatives, standards, and most water-quality samples from extreme heat and cold. It also must provide for the temporary (and contaminant-free) storage of some samples (VOCs, pesticides, nutrients), and some reagents (for example, spike solutions for pesticides and VOCs and VOC acid preservative) at near-freezing temperatures. If the vehicle interior is used for the collection or processing of water-quality samples, then adequate lighting, plumbing, and counter space are needed. Sample collection and preservation chambers are used whether working inside or outside the vehicle. These reduce contamination of and from the vehicle interior.

Obtain and design vehicles that can be dedicated solely to water-quality sampling. A vehicle used for water-quality data collection is not used for the storage (even temporary) of a generator using gasoline or other types of fume-producing fuels, or of heavily soiled equipment, clothing, or tools. Nor should a vehicle previously used for such storage be converted to a water-quality vehicle. One might even question the adoption of a used water-quality vehicle if samples were collected and, in particular, preserved within the vehicle without regard to possible vehicle contamination. In each case above, there is a risk that the vehicle will be, or has been, permanently contaminated.

Storage facilities

Field vehicles are not suitable for storage of most supplies and some equipment used for water-quality data collection. When not in operation, the vehicles cannot provide adequate protection from extreme heat or cold, which can destroy or degrade chemical standards, buffers, and other reagents, as well as damage some field instruments. Especially during extremes in temperature, remove sensitive supplies and equipment from an idle vehicle to a safe indoor location on a daily basis. Clean and secure facilities, which are separate from those used for other types of NAWQA equipment (such as generators, fuel, drilling supplies and materials, and permanently soiled gear), are needed for longer periods of storage.

Timing of purchases

Durable equipment and supplies (such as vehicles, pump systems, plastic bottles) are ordered well in advance of the first field season, and thereafter on an as-needed basis. Begin vehicle purchase and modification(s) 12 to 14 months before the vehicle is needed for water-quality data collection. Nonperishable, and limited quantities of perishable supplies (see below) are purchased and on hand at least 3 to 6 months before water-quality data collection begins. Pump systems and other sample-collection equipment also can take up to several months to obtain, assemble, and modify to complement vehicle design.

Some supplies, such as most chemical solutions, have a limited shelf life. As part of their planning, Study Units should (1) follow manufacturer's recommendations on storage, and (2) query their suppliers about shelf life for any preservatives, buffers, standards, and reference samples, as well as for blank, spike, surrogate, and instrument-sensor solutions, or any other chemical reagents. This will prevent overstocking and reduce waste. Upon receiving these supplies, the date of receipt and the expiration date should be marked clearly on time-sensitive supplies. Study Units also are required to record supply lot numbers. Without these records, the QA and QC information that exists for these supplies, and provided by lot number, cannot be utilized by the Study-Unit or NAWQA National Program. This is one of the quality-assurance measures that could be needed to correctly interpret water-quality QC data.

Study-Unit staff are likely to select the most appropriate vehicle design, pump system, and related equipment after information from site visits is obtained, and after sampling teams have had some training (see "Training" below). Following training, the field teams need their equipment and supplies for practice, and to verify that they are suitable for water-quality data collection (see "Field Evaluation" below). Therefore, most nonperishable equipment and supplies need to be on hand at least 3 to 6 months in advance of the first field season of data collection.

Training

Modifications in USGS protocols and recommended procedures (F.D. Wilde, U.S. Geological Survey, written commun., 1995--see footnote 1), and the need for consistency dictate that training in the collection and management of water-quality data is required for most Study-Unit staff. This training is to be obtained through USGS Level I courses and field experience, ideally before water-quality data collection begins (table 6).

Field Evaluation

Each Study Unit is required to test and evaluate the sample-collection equipment and procedures that commonly will be used (table 6, no. 4). This is separate from, and occurs after, the field training with Study-Unit equipment. To avoid unnecessary delay in planned data collection while awaiting laboratory results, this test should be conducted at least 2 months before sample and data collection begin. Ideally, the evaluation can occur toward the end or after the field exercise devoted to equipment shakedown and cross-training (table 6, no. 3).

To conduct the test, the Study Unit selects a well with measurable concentrations of as many of the following contaminants as possible: VOCs, pesticides, nutrients, and (if targeted for investigation by the Study Unit) trace elements. The field team collects samples for all constituents (in the order and manner in which samples commonly are going to be collected--see "Sample Collection and Processing"). After sample collection, equipment is decontaminated. Field blanks for all constituents are collected with the decontaminated equipment. Two field-spiked, blank samples are prepared for the VOC schedule and for each pesticide schedule. One blank sample for the VOC schedule is spiked by one field-team member, and its replicate is spiked by the other field-team member. One field-team member also spikes the blank sample for one pesticide schedule; the other field-team member spikes the other blank sample for the second pesticide schedule. (Definition of QC samples is provided in "Design of Quality-Control Sampling and Schedules.") All ground-water-quality samples and QC samples are sent to the NWQL for analysis.

Data from the ground-water-quality and QC samples are evaluated by the Study Unit, and the evaluation and data are forwarded as soon as possible to the National Program (NAWQA QA Specialist). These data are to confirm that (1) the ground water contained measurable levels of some contaminants, (2) decontamination procedures removed contaminants from equipment, and (3) the procedures used to prepare spiked blanks led to acceptable recoveries of selected VOCs and pesticides.

The evaluation assures the field team, Study Unit, and National Program that the protocols and procedures are satisfactory. Potential problems identified by the Study Unit(s) are corrected before sample and data collection begins.

Table 6. Recommended sequence of training-related activities to prepare for National Water-Quality Assessment (NAWQA) Program ground-water-quality data collection

[USGS, U.S. Geological Survey; QC, quality control; NWQL, National Water Quality Laboratory]

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1. Determine data-collection and management training needs.

- Review protocols and recommended procedures (this report).
- Review National Field Manual (Radtke and Wilde, in press).
- Incorporate possible modifications to above (commonly described in NAWQA or USGS internal memorandums).

2. Train field team(s) and data-management personnel accordingly and formally.

- Through USGS Level I and higher level training courses.[1] Field Water-Quality Methods for Ground Water and Surface Water (G0282) currently is required for at least one member of each team placed in field for data collection. It is recommended that at least one member of the Study-Unit staff attend the course Quality-Control and Sample Design and Interpretation (GO342). (A field team is assumed to consist of two people.)
- Take data-collection and QC training courses early, ideally in the fiscal year before intensive data collection begins.

3. Enhance and reinforce formal training.[2]

- New field team(s) can accompany or temporarily employ experienced (mentor) teams from another Study Unit that is completing data collection in the fiscal year before the new team will begin data collection. Select mentors on the basis of similarities in types of wells, terrain, equipment, and other factors that the two Study Units have in common.
- New field team(s) should practice data collection with equipment that will be used, and alternate activities to ensure each team member is cross-trained in all aspects of data collection.

4. Evaluate data-collection protocols, recommended procedures, and equipment.[3]

- Conduct data collection at a contaminated well at least 2 months before any water-quality data collection begins. Include field blanks and field-spiked source-solution blanks. Submit ground-water-quality and all QC samples to NWQL for analysis.
- Evaluate and share results with the National Program. (See text for further discussion).

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[1]The Level I course provides individual training in ground-water-quality and surface-water-quality data-collection protocols and procedures that include those for the National Water-Quality Assessment Program. Other courses can be taken that cover data management and analysis, such as that recommended for QC.

[2]Because modifications to protocols and recommended procedures are likely to occur, training without taking the formal course currently is not considered an acceptable substitute for all members of a field team.

[3]See discussion in section entitled “Field Evaluation.”

Design of Ground-Water-Quality Sampling Schedules

As part of planning for field sampling, schedules are prepared annually or more frequently, if needed, for the collection of ground-water-quality and QC data for each ground-water component (Study-Unit Survey, Land-Use Study or Flowpath Study) targeted for investigation each year. These schedules list the daily activities for the field team, data managers, and support staff.

For ground-water-quality samples, the schedule describes the timing and order in which wells for each ground-water component are targeted for data collection (table 7). General scheduling considerations include component factors, travel times, personnel requirements, and site conditions (table 8). Each schedule is designed over a period of several months, and before any ground-water-quality samples are collected.

Study Units will pay particular attention to factors that enhance the consistency and quality of samples and data obtained and provide the Study Unit and National Program with the necessary data to determine the quality and suitability of data collected for NAWQA assessments (table 9). The design and scheduling of QC data collection, which are critical and integral parts of water-quality data and data collection (Shampine and others, 1992), are discussed in detail in the next section. For most of the other factors (tables 8 and 9), it is assumed that the information needed is obtained through staff planning meetings and site visits conducted before data collection begins.

As a general rule, except for Flowpath Studies, most Study Units will find that a single, two-person field team often needs a day to conduct data-collection activities at one well. With experience, and under the optimum field conditions, some teams will be able to collect data from more than one well per day. In the case of Flowpath Studies, the close proximity and shallow depths of wells also could permit sampling at more than one well per day. In addition, wells targeted for QC data collection could require an additional team member to complete activities in a single day.

Table 7. Example of a sampling schedule for a 28-well Land-Use Study

[Assumes (a) one (two-person) field team generally collects samples on a weekly run (Monday-Thursday); (b) incorporation of general scheduling considers component factors, travel times, personnel, and site conditions (table 8), as well as requirements to enhance data quality (table 9); and (c) routine quality-control sampling occurs at selected wells distributed throughout the collection period (third person possibly joins team). SRS, standard reference samples for trace elements; VOC, volatile organic compound]

Period of activity	Activity to be conducted by team
Week 1 Day 1 (M)	Depart for Well 1: collect ground-water (GW) samples.
2 (T)	Well 2: Collect GW and quality-control (QC) samples.
3 (W)	Well 3: Collect GW samples.
4 (Th)	Well 4: Collect GW samples, return to office, unload vehicle.
5 (F)	Evaluation and preparation: Study Unit reviews progress, plans, sampling schedule, and completes final preparations for following week's activities.
Week 2 Days 8-12	Wells 5-8: Similar schedule as week 1, but without QC data collection.
Week 3 Day 15 (M)	Well 2: Review QC data and continue sampling if no problems appear; decision to sample two wells per day when possible is made.
16 (T)	Team and staff complete preparations, team departs office.
17 (W)	Well 9: Collect GW and QC samples (including one SRS).
18 (Th)	Wells 10 and 11: Collect GW samples.
19 (F)	Team returns to office and, aided by staff, unloads and cleans vehicle.
Week 4 Days 22-26	Wells 12-15: Similar to schedule for week 2.
Week 5 Day 29 (M)	Well 9: Review QC data and continue sampling if no problems appear. Team, aided by staff, completes preparations, and departs office.
30 (T)	Wells 16 and 17: Collect GW samples.
31 (W)	Well 18: Collect GW samples.
32 (Th)	Well 19: Collect GW and QC samples (with VOC trip blank, as planned); team returns to office late in day.
33 (F)	Team and staff unload, clean, and restock vehicle.
Week 6 Days 36-40	Wells 20-23: Similar to schedule for week 2.
Week 7 Day 43 (M)	Well 24: Team departs office, collects GW samples.
44 (T)	Well 25: Collect GW samples.
45 (W)	Wells 26 and 27: Collect GW samples.
46 (Th)	Well 28: Collect GW and QC samples, team returns to office and with staff unloads and cleans vehicle.
47 (F)	Vehicle goes in for regular service and maintenance.
Week 8 Day 50 (M)	Team and staff receive QC data (wells 19 and 28). If QC data are satisfactory, sample collection continues unabated. Team and staff prepare for next component to be sampled. Remaining two SRS samples needed for the year will be included in data collection for the next component.

Table 8. Basic considerations in designing annual ground-water-quality sampling schedules for Study-Unit components (Land-Use Studies, Study-Unit or Subunit Surveys, and Flowpath Studies) of the National Water-Quality Assessment Program

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1. **Component factors**
   - Number of each type of component.
   - Number of wells per component.

2. **Travel times**
   - Between office and wells.
   - Between wells.
   - Between well and overnight shipping sites.

3. **Personnel**
   - Number of field teams.
   - Number of individuals per team (generally consider two members; possibly third person at wells that include QC sample collection).
   - Experience of personnel in team.
   - Office staff support.

4. **Site and seasonal conditions**
   - Equipment setup time (water-supply or monitoring well).
   - Purge time.
   - Data-collection requirements (ground-water quality only or ground-water quality and quality control).
   - Duration of field season.

Table 9. Requirements for the design of National Water-Quality Assessment Program ground-water-quality sampling schedules to enhance data quality

[QA, quality assurance; QC, quality control; VOC, volatile organic compound; NWQL, National Water Quality Laboratory; μg/L, micrograms per liter]

1. **Schedule to avoid seasonal or other problems in data used for spatial analysis**
   - Except for Flowpath Studies, collect all samples for all components in shallow-depth wells between late spring and early fall if those samples include seasonally-applied chemicals.[1]
   - Except as noted below, complete sampling for a given component in the shortest time possible, and before the same field team begins data-collection at another component.

2. **Integrate quality-assurance and quality-control (QA and QC) data collection** into each component schedule
   - Conduct QA procedures and collect QC data at selected sites in each component throughout the period of water-quality data collection.

3. **Set reasonable performance levels;** initially, collect samples at one well per day for Land-Use Studies (or Study-Unit Survey) so that:
   - With time and experience, the long-term average could approach two wells per day.
   - Wells selected for QC data collection typically will require a full day and possibly an additional person.
   - Sampling at more than two wells per day could be possible, particularly for Flowpath Studies (shallow-depth wells in close proximity).

4. **Avoid over-specialization**; schedule frequent rotation of duties among the field-team members
   - Prepare for unexpected absences to prevent a halt in sampling, or the collection of potentially poor-quality data.

5. **Schedule data collection at wells known or suspected of having high (greater than 10 μg/L) VOC or pesticide concentrations** near the end of the data-collection period to avoid cross-contamination of other wells or samples
   - Take additional field blanks to check that equipment is decontaminated before the same equipment is used at another well.
   - Notify NWQL (on Analytical Service Request form--comment to laboratory line) if it is known or suspected that VOC or pesticide concentrations are expected to exceed 10 μg/L.

6. **Plan for resampling**, regardless of whether or not it can be anticipated
   - Despite the best planning, teams sometimes find they are inadequately equipped for data collection..
   - Data-quality reviews could indicate resampling is necessary.
   - Resampling is recommended near the end of the fiscal year (first week in September).

7. **Provide time for data review, schedule revision, and equipment maintenance**, if the component consists of 20 or more wells, which generally will require 2 or more months to sample
   - With intermittent periods (day or two in length) of no data collection.
   - To review progress, make scheduled revisions, and discuss QC data.
   - To restock, maintain, repair, or replace equipment and supplies.

8. **Schedule data collection to avoid exceeding sample-holding time**, which begins when the sample is collected, and ends with sample analysis
   - Holding times for water samples of radon, nutrients, pesticides, and VOCs are the shortest--3, 5, 7, and 14 days, respectively.
   - From late spring to early fall (the peak analysis period) at least half the holding time can expire **after** samples are logged in at the NWQL.
   - Because radon has a short half-life (3.6 days), samples for this element should not be collected on a Friday, unless they can reach the NWQL by noon on that Friday.

[1]Pesticide concentrations measured in ground water nationwide appear higher and more uniform throughout this period than the concentrations measured from late fall to early spring (J.E. Barbash and E.A. Resek, in prep., Pesticides in Ground Water; Distribution, Trends, and Governing Factors: Ann Arbor Press, Chelsea, Mich.).

Design of Quality-Control Sampling and Schedules

Each Study Unit is required to collect similar types of QC samples (table 10). Those that are collected regularly throughout each field season are referred to as “routine QC samples.” Additional QC samples, referred to as “topical QC samples,” occasionally could be collected by some or all Study Units to isolate and resolve problems or evaluate modifications to NAWQA field methods.

The data obtained from routine or topical QC sampling are used to estimate the potential bias (either from contamination or in recovery) and measurement variability for selected analytes. Routine QC samples provide the data required by the NAWQA Program to make general inferences about bias and variability for all water-quality data collected. Bias and variability measurements from routine QC samples reflect combined field and laboratory errors that occur during data collection. Measurements obtained from topical QC sampling will reflect errors associated with a specific field or laboratory procedure employed by NAWQA and targeted for study.

Study Units can use QC data in several ways. Those that can derive bias and variability estimates from routine QC sampling in a timely manner can use the results not only to assess the quality of data being collected, but also, in some cases, to identify wells that need to be resampled (Koterba and others, 1991). In the case of topical QC data, sources of sample contamination or bias that occur as a result of sample collection and processing, initially identified through routine QC sampling, can be isolated and eliminated (Rea, in press; Koterba and others, 1991).

Bias and variability estimates also can be used during data analysis and interpretation of ground-water-quality data. For each ground-water component, the magnitude of these error estimates provide an indication of the quality of ground-water data collected (Koterba and others, 1991 and 1993). In addition, as water-quality data from different Land-Use Studies or Subunit Surveys are compared, contrasted, or combined, the corresponding routine estimates of bias and variability from QC data also can be compared, contrasted, and combined to make inferences about the quality and suitability of the aggregated water-quality data that are being used for Study-Unit or National Assessments.

In some cases, data analysis and interpretation can depend on the timely analysis of routine and topical QC data obtained in the field combined with timely discussion of these data with the National Program and the NWQL. Examples of the above, which led to modifications in Study-Unit field methods and in the QC sampling design, and ultimately improved data quality, analysis, and interpretation include studies by Ferree and others (1992) and Koterba and others (1994). Their experience indicates how critical it is for Study-Unit plans to remain flexible. These plans must allow for the possible modification of the initial designs for routine QC sampling (as described below), or the methods used to collect these and ground-water-quality samples (described later in this report). Such modification could prove critical to correctly identifying the occurrence and distribution of contaminants in ground water and their relation to Study-Unit landscape and subsurface features.

Table 10. Quality-control samples for ground-water components of the National Water-Quality Assessment (NAWQA) Program

[Definitions are consistent with those of the U.S. Geological Survey Branch of Technical Development and Quality Systems (BTD&QS) and the Office of Water Quality. NWQL, National Water Quality Laboratory; VOCs, volatile organic compounds]

Sample type	Description	Purpose
1. Blanks[1]	Types include field, source-solution, and trip.	Assess bias from contamination of blank water.
•Field	Blank water passed through equipment in the field, and collected in a manner similar to that used to collect water-quality data, but after equipment is used and decontaminated.	Verify that decontamination procedures are adequate, and that field and laboratory protocols and recommended procedures do not contaminate samples.
•Source solution[2]	Blank water placed directly in the sample container, but in a clean environment.	Verify that blank water is contaminant-free just before it is used for a field blank.
•Trip	Blank water placed in sample container by NWQL, shipped to study with empty containers, and returned unopened by Study Unit from field for analysis.	Verify that shipping, handling, and intermittent storage of containers does not result in contamination or cross-contamination of samples.
2. Replicates[3]	Two or more ground-water-quality samples collected sequentially for the same analytes.	Assess combined effects of field and laboratory procedures on measurement variability.
3. Field spikes[4]	Types include samples prepared from blank water or from ground water.	Assess recovery bias of analytes in spike solution.
•Source-solution water[5]	Two source-solution blanks to which identical volumes of spike solution are added, but by different members of field team. For VOCs, preserve with NWQL acid before spiking.	Verify equipment and procedures for field spiking, handling, shipping, and analysis lead to similar results among Study Units.
•Ground water	Two or more replicate ground-water-quality samples to which identical volumes of spike solution are added in a manner that does not substantially alter sample matrix. For VOCs, preserve with NWQL acid before spiking.	Assess recovery bias and variability in relation to different ground-water matrices.

Table 10. Quality-control samples for ground-water components of the National Water-Quality Assessment (NAWQA) Program--Continued

Sample type	Description	Purpose
4. Standard reference (mixtures)	Prepared by BTD&QS as mixtures, sent to Study Units collecting trace-element samples, shipped unopened from field to NWQL for analysis.	Assess recovery bias and variability of selected trace elements.

[1]Blank water is certified by supplier as free of analytes of interest at concentrations that exceed NAWQA detection or reporting level. A trip blank is only required for VOCs.

[2]Because blank solutions are not regularly analyzed for dissolved organic carbon (DOC), source-solution blanks are required along with field blanks for this analyte. A source-solution blank for DOC is required each time a field blank for DOC is taken.

[3]Chemical composition of water entering the well and being collected is assumed constant during time needed to collect sequential samples (including replicates).

[4]Spike solutions for NAWQA contain either selected VOC or pesticide analytes; solutions are obtained and used in accordance with instructions from the NWQL. At least one unspiked (background) ground-water sample from the same well used to obtain the samples for field spikes is analyzed in conjunction with field-spiked samples (see text).

[5]Preserved and spiked source-solution blanks for pesticides and VOCs are prepared only as part of the initial evaluation of equipment and procedures before data collection begins.

Routine quality-control samples: type, number, site selection, and timing

The current NAWQA QC sampling design for ground water is based on the integrated approach described by Shampine and others (1992). Under this design, it is recommended that each Study Unit follow similar procedures (tables 11 and 12) to identify (1) the types of routine QC samples collected, (2) the wells at which these samples will be obtained, and (3) the timing of QC sample collection for each of the ground-water components scheduled for data collection in each field season. These procedures ensure that the data obtained for each routine QC sample type (1) represent major differences in the major ion chemistry (sample matrix) of ground water targeted for study, (2) are suitable for estimating measurement bias and variability for the analytes of interest, and (3) reflect possible temporal variations in field and laboratory methods during the time period that ground-water-quality data are collected (table 13).

It would be ideal in terms of planning, efficiency in the field, and costs **if similar routine QC designs** could be used for **all** ground-water components. Because Land-Use Studies, Study-Unit (or Subunit) Surveys, and Flowpath Studies differ in their design and scope, the types and numbers of routine QC samples, the wells selected for collecting these samples, and the timing of visits to the wells selected will differ somewhat among these components.

It would be ideal in terms of planning, efficiency, and costs if **all** routine QC samples could be collected at the **same** well sites for each ground-water component. Representative and suitable QC data, however, often can only be obtained by scheduling the collection of different types of routine QC samples at different wells within a given component (see below), or, in the case of the VOC trip blank and (possibly) trace-element standard reference samples, at wells selected from among several components sampled in the same field season (table 13, footnote 1).

Land-Use Studies. A typical Land-Use Study is focused primarily on one major land-use classification, and for ground water, involves the collection of samples for a variety of analytes (table 1) from each of a relatively small number of wells (about 30, including reference wells) completed at shallow depths and often in a single aquifer. Therefore, a typical design for routine QC data collection requires the collection of many different QC sample types to cover the variety of analytes being investigated (table 12). It also requires a minimal number of samples for each QC-sample type because differences in the quality of ground water among wells are assumed to reflect chiefly the intensity of a single land use on the shallow part a single aquifer.

Some wells in the Land-Use Study will need to be chosen (if possible, and according to methods described later in this section) specifically to collect the required number of routine, replicate ground-water samples and routine field blanks (table 13). These wells are chosen, in part, because they are likely to provide samples with measurable (greater-than-method-reporting-level) concentrations. (Estimating the variability of measurements for a given analyte using replicate samples requires that these samples contain measurable, greater-than- or equal-to-method reporting-level concentrations for that analyte.) They also are selected, if possible, to provide a range in measurable concentrations that reflect the effects of that land use on shallow ground-water quality.

Table 11. Procedures to identify the type and schedule the annual collection of routine quality-control data for ground-water components of the National Water-Quality Assessment Program

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1. **Identify analyte groups for which water-quality data will be collected that field season**
   - On the basis of national requirements (table 1).
   - To which are added local Study-Unit interests, such as trace elements.

2. **Identify routine quality-control (QC) data to be collected**
   - On the basis of the Study-Unit component (for example, see table 12).
   - Determine QC sample types by analyte group to be collected.
   - Determine number (or frequency) of each type to be collected.

3. **Identify wells and develop schedules for routine QC data collection for each component**[1]
   - Select wells to provide suitable and representative QC data (see text and table 13).
   - Schedule visits to these wells to provide QC data collection for each analyte group throughout the months that water-quality data for that analyte group and component are being collected (see text and table 13).

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[1]If volatile-organic-compound (VOC) and trace-element samples are collected during a given field season, then at least one VOC trip blank, in addition to field blanks and spiked replicate samples, and at least three trace-element standard-reference samples are sent from the field to the National Water Quality Laboratory for analysis.

Table 12. Required type and minimum number (or frequency) of routine quality-control samples for a Land-Use Study of the National Water-Quality Assessment Program

[Field blanks and field-spiked, source-solution blanks taken during the evaluation of methods are not included below. Assume study consists of 25 to 30 wells. Trace-element field blanks use National Water Quality Laboratory (NWQL) Schedule SC172 with selenium (LC0087) and arsenic (LC0112). All other routine quality-control samples use the same NWQL schedule or laboratory code used for the corresponding water-quality samples. DOC, dissolved (filtered) organic carbon; ALK, alkalinity (field-titration, filtered ground-water sample); and ANC, acid-neutralizing capacity (field titration, unfiltered ground-water sample; VOCs, volatile organic compounds]

Analyte group[a]	Routine quality-control sample type	Required number (frequency)
1. Commonly present in measurable concentrations: major ions, nutrients, and DOC. (ALK and ANC--replicates only)	**Field blanks**	Minimally at 2, but preferably at 3, well sites.
	Source-solution blanks	(Every time a DOC field blank is taken, only for DOC.)
	Replicate (2) ground-water samples per well	Minimally from 2, but preferably from 3 wells at different sites.
2. Commonly present in measurable concentrations in some, but usually not all, areas:		
• Pesticides or VOCs	**Field blanks**	Minimally at 2, but preferably at 3, well sites.
	Trip blank	(One per field season, only for VOCs.)
	Field-spiked, replicate (2) samples per well	Minimally at 2 well sites.
• Trace elements (such as NWQL SC2703)[b]	**Field blanks**	Minimally at 3 to 5 well sites.[c]
	Standard-reference-sample mixtures	(Three per field season.)
	Replicate (2) ground-samples per well	Minimally from 3 to 5 wells at different sites.
• Radionuclides (such as radon)	**Replicate (2) ground-samples per well**	Minimally from 3 wells at different sites.

[a]For tritium, deuterium-oxygen isotopes, or chlorofluorocarbons, contact a National Water-Quality Assessment Program Quality-Assurance Specialist.

[b]Through 1995, some Study Units collected and temporarily archived water-quality and quality-control samples.

[c]If trace-element concentrations of interest are low (less than 10 µg/L), collect the maximum number of field blanks, and the minimum number of replicate sample sets specified. For high concentrations, collect the minimum number of field blanks, and maximum number of replicate sample sets.

Table 13. Well- and site-selection criteria for routine quality-control samples collected for ground-water components of the National Water-Quality Assessment Program

[Field blanks and field-spiked, source-solution blanks taken during the evaluation of data-collection methods are not considered below. DOC, dissolved (filtered) organic carbon; VOC, volatile organic compounds; NWQL, National Water Quality Laboratory]

Routine QC sample type	Well (site) selection criteria for Study-Unit (or Subunit) Survey, or Land-Use or Flowpath Study ground-water components
Field blanks (all analytes, except radon)	Select wells where it is known or suspected that ground water (1) at each well contains measurable (greater-than-method-reporting-level) concentrations of most to all analytes and (2) collectively, for the wells chosen, reflects some of the diversity in ground-water-quality conditions (range in concentrations for these analytes) for which the ground-water component is designed.[a]
Source-solution blanks (DOC)	Use the same well sites selected for DOC field blanks (above) for each component.
Trip blank (VOC)	Sent from one randomly selected well site from among all well sites for all components at which VOC samples are collected during the same field season.
Replicate ground-water samples (inorganic analytes, radionuclides (radon), and DOC)	Use the same wells selected for field blanks (above) for each component.[a]
Field-spiked, replicate, ground-water samples (VOC and pesticides)	Select wells where it is known or suspected that ground water at each well (1) contains measurable concentrations of inorganic analytes and DOC (similar to those found at routine QC sites selected for field blanks and replicate ground-water samples), but (2) do not contain measurable concentrations of those VOCs or pesticides found in NAWQA-NWQL spike solutions and of interest to the Study Unit for each component.[a]
Standard-reference samples (trace elements)	Sent from 3 well sites selected from among all well sites for all components at which trace-element samples are collected during the same field season.[a]

[a]Schedule data collection for selected wells so that water-quality and routine QC samples are obtained from at least one of these wells early, at least another of these wells mid-way through, and at least at still another of these wells near the end of the entire time period during which water-quality data that relate to the type of QC sample type specified are being collected for the component or, in the case of trace-element standard reference samples, for the field season.

Field blanks are collected at the same wells used to obtain replicate ground-water samples; namely, at wells likely to have measurable concentrations of analytes in ground water. This makes it possible to verify that (1) the sampling equipment was exposed to measurable concentrations of contaminants, and (2) equipment decontamination procedures were effective. (The latter cannot be verified if the wells selected for field blanks contain no measurable contaminants.)

Additional Land-Use Study wells that differ from those selected for replicate ground-water samples and field blanks need to be selected for VOC and pesticide field-spiked samples. Criteria for selection of wells for spiked samples (table 13) ensure that the QC data are representative--reflect the type(s) of ground water in the Land-Use Study area where VOC or pesticide contaminants are found but that unspiked samples do not contain the VOCs or pesticides of interest. This means that recovery estimates from spiked samples (in which the analytes of interest have been added in the spike solution) are likely to reflect recoveries from ground-water samples that contain these same analytes in similar concentrations.

The criteria also ensure that the field-spiked QC data are suitable--reflect recoveries that are unbiased. Samples that contain measurable concentrations of pesticides or VOCs--in excess of a few tenths of a microgram per liter--and that are spiked with similar VOCs or pesticides in accordance with current NWQL protocols generally will provide recovery estimates that have a positive bias. The bias results because the recovery generally is calculated on the basis of the measured concentration divided by the theoretical concentration of the spiked sample, where the latter is estimated from the amount of analyte added in the spike solution. Recovery estimates cannot be determined precisely by correcting for the background (unspiked) sample concentration, unless at least triplicate unspiked, and triplicate spiked, samples are collected.

The scheduling (timing) of routine QC data collection for the Land-Use Study is determined after the wells for routine QC data collection have been selected. This involves scheduling site visits at these wells such that routine QC data are obtained early, about mid-way through, and near the end of the 1- to 3-month period it commonly takes to complete data collection for a Land-Use Study. This implies that the ground-water sampling schedule for a Land-Use Study, or any other ground-water component, cannot be finalized until the routine QC sampling design is developed (table 7).

Study-Unit (or Subunit) Surveys. A typical Study-Unit Survey is designed to obtain occurrence and distribution data on a variety of analytes (table 1). In this respect, a Study-Unit Survey is somewhat similar to a Land-Use Study. A Study-Unit Survey differs from a Land-Use Study in some respects, which affects the routine QC design.

A Study-Unit Survey can involve data collection from as many as 100 to 120 wells associated with multiple, rather than one, land use. These wells also often will be distributed among several Subunit Surveys, each consisting of about 30 wells. The 30 wells in each Subunit Survey often will be completed in shallow and deep parts of one or more aquifers. Thus, wells in a subunit generally will reflect a greater diversity in land-use and water-quality conditions than that associated with a single Land-Use Study. Overall, data collection from these Subunit Surveys collectively will take more time to complete than it will take to complete a single Land-Use Study.

Because Study-Unit or Subunit Surveys and Land-Use Studies often will involve the collection of similar types of ground-water-quality data, the types of routine QC samples required for a survey for each analyte are similar to those required for a Land-Use Study (table 12). The minimum number of each type of QC sample required for each Subunit Survey is at least the same number as that required for a Land-Use Study. Because of the potential for a greater diversity in landscape and subsurface conditions in Subunit Surveys compared to Land-Use Studies, however, it is recommended that at least one or two additional sites be selected for replicate ground-water samples for the inorganic analytes (major ions, nutrients, alkalinity, acid neutralizing capacity, dissolved organic carbon, and possibly trace elements) and the field blanks in each Subunit Survey.

If the Study-Unit Survey is designed as a single entity (not conducted using Subunit Surveys), then the minimum number of QC samples required for each sample type for the survey is increased in direct proportion to the number required for a Land-Use Study (table 12) on the basis of the total number of wells being sampled for the survey divided by the total number of wells being sampled for a Land-Use Study (which for the purposes of this calculation is taken as 25). Thus, a survey that involves 50 wells requires twice the minimum number of each type of QC sample than generally is required for a Land-Use Study.

Survey wells are selected for routine QC samples and scheduled for data collection using the same approach outlined above for a Land-Use Study. Different wells are selected for the different types of QC samples to provide QC data that are representative of differences in water quality, suitable for providing estimates of measurement bias, variability, and recovery, and cover the time period during which the Survey ground-water-quality data are collected (table 13).

Flowpath Studies. A typical Flowpath Study will assess spatial differences and possibly temporal variability in each of a selected number of analytes among wells located in different parts of a local ground-water flow system. The number of wells used for water-quality data collection commonly will be less than 20, with most wells completed in a single aquifer that underlies a single land use.

The routine QC design for a Flowpath Study involves the selection of routine QC sample types (as described in table 12) that relate to only those analytes that are targeted for investigation by the Study Unit. These routine QC sample types are to be collected at selected sites the first time the flowpath wells are sampled and, thereafter, at sites and times that reflect Flowpath Study objectives--such as evaluating spatial or temporal differences in analyte concentrations. As a general rule, the sites selected and frequency of routine QC sample collection are to be sufficient to establish that possible spatial differences or temporal trends in analyte concentrations at, or among, flowpath wells are not primarily a function of measurement bias or variability that result from field and laboratory methods.

Nested Studies. Ideally, the ground-water design for a Study Unit calls for Flowpath Studies to be located in selected Land-Use Study areas, and that each Land-Use Study be located in a (Subunit) Survey area. Theoretically, this implies that routine QC data collected for one component could serve as routine QC data for another component. Ideally, this also is efficient in terms of planning, field work, and costs. Use of this approach, however, requires the routine QC design requirements be met for each individual component.

To ensure that routine QC data from one component are valid routine QC data for another component, one component must be geographically nested within the other. That is, at least one well must be part of both components--the well that will be used to obtain the QC data common to both components. Data collection for both components must overlap in time, and occur at the well targeted to provide the required ground-water and routine QC data needed for both components during that period of data-collection overlap.

Example of routine quality-control design: a case study

Regardless of the ground-water component, the design, and in particular, selection of sites for routine QC data collection commonly will be determined using limited information. In particular, to obtain representative QC data, the wells selected are to reflect the diversity of water-quality conditions likely to be found among the wells used to collect ground-water data in each component. In a number of cases, however, the quality of ground water in terms of analyte concentrations at each well will not be known until after NAWQA data are collected.

When water-quality data are lacking, other types of data are used to make inferences about the likely quality of water at each well. Useful ancillary data include (1) water-quality data from nearby wells (retrospective data), (2) data on surface features (such as land use, crop types, and associated chemical use) from site visits and published data, and (3) data on subsurface features (such as lithology and well depth) which are obtained during well selection (or installation) and from published data on aquifer characteristics.

An inferential approach to identify and evaluate routine QC-sample data-collection sites and data was employed in the Delmarva Peninsula pilot NAWQA study. In this study, Hamilton and others (1992) used retrospective water-quality data (primarily major cations and anions) to describe spatial and depth-related differences in ground water throughout the Study Unit, and to identify agriculturally-affected ground water as well as unaffected (or natural) types of ground water in the study area (fig. 1-A, encircled regions). To design QC sampling for this Study-Unit Survey, Koterba and others (1991) used the above information along with data on surface features (general land use, and different agricultural activities such as crop type and related liming, and fertilizer and pesticide use) and subsurface features (well depth and aquifer lithology) at each well to select those for replicate routine QC samples (except those for field spikes) and some field blanks. The combined ancillary data described above indicated that different types of ground water were likely to be encountered (fig. 1-A), and that most analytes (major ions, nutrients, organic carbon, trace elements, and perhaps pesticides) were likely to be found at detectable (above detection level, but less than reporting level) or higher concentrations at the selected wells.

Additional wells for QC data collection were selected that reflected a diversity in ground-water types, but where it was initially inferred that pesticides found in NAWQA spike solutions and of interest to the Delmarva Peninsula Study-Unit staff (primarily triazines and acetanilides) were not likely to be found in samples from this second set of wells. These wells were used to obtain samples for pesticide field spikes.

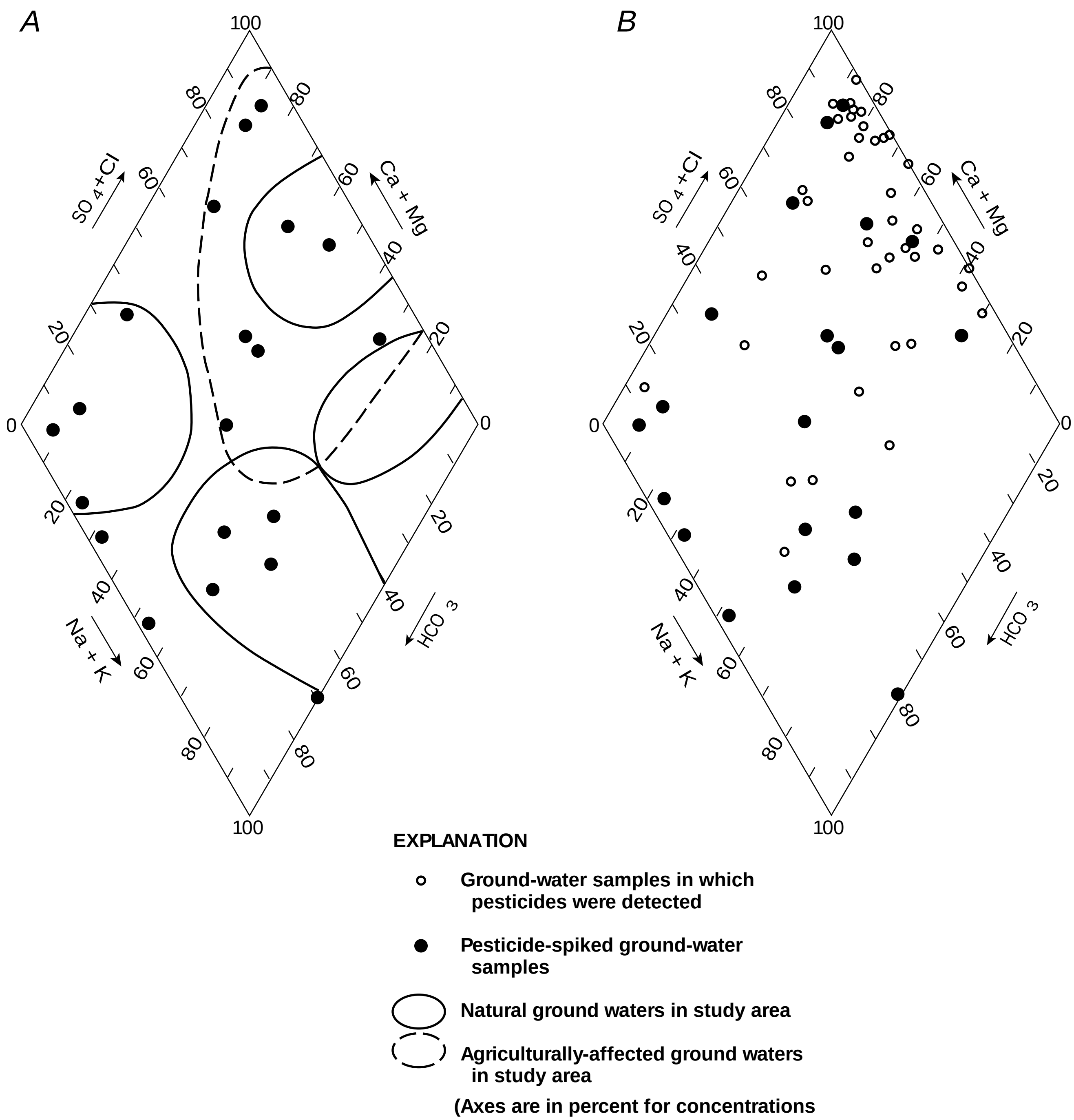

Figure 1. Distribution of wells selected for pesticide spikes in relation to the major-ion composition of (A) natural and agriculturally-affected ground waters, and (B) ground-water samples in which pesticides were detected in the Delmarva Peninsula (Koterba and others, 1993).

As water-quality samples and data were obtained by the Delmarva Study Unit, the major-ion data were plotted, including data from those wells selected for routine QC sampling. In general, plots illustrated that the different types of ground water described by Hamilton and others (1992) were being collected, and in particular, that the sites chosen for QC data collection also reflected most of the different types of ground water found in the Study-Unit Survey area (fig. A1, plotted points). Thus, the QC data were considered representative of the types of ground-water quality found in the study area.

Another key element addressed by the staff of the Delmarva Peninsula Study was to assess the suitability of replicate ground-water sample or field-spiked ground-water sample QC data to provide estimates of the method (field and laboratory) variability in concentration measurements or method bias in recovery, respectively, for selected analytes. This was done in part by using field-blank and unspiked (background) concentration data. In the Delmarva Peninsula Study, field blanks (12) were collected at different sites and times, and in each case, after equipment was contaminated (as later verified by the ground-water samples collected), and then field decontamination procedures were conducted. Blank data provided no evidence that samples (ground-water or other QC, including replicate or field-spiked samples) were subject to contamination in the field (by ambient conditions or equipment cross-contamination) or thereafter (during handling, shipping, and laboratory analysis). Further evidence that the QC data from field-spiked samples was suitable also came from the corresponding unspiked ground-water samples. Of 21 wells selected for field-spiked samples, only one yielded an unspiked sample that had a measurable concentration for any of the pesticides of interest. Thus, on the basis of field-blank and background-sample concentration data, it was demonstrated that there was: (1) no evidence samples of any type were contaminated during or after their collection, (2) that field decontamination procedures were adequate, and (3) that replicate and field-spiked data were not compromised by ambient or cross-contamination, and were suitable for estimating, in an unbiased manner, the method variability in concentration measurements and the method bias in recovery for selected analytes.

Additional data plots (for example, fig. 1-B) were constructed to illustrate that the wells chosen for pesticide field spikes generally reflected the types of ground water in which these same pesticides appeared as a result of what was considered normal pesticide use in the Study-Unit Survey area. Thus, it was argued that field-spiked sample data were representative of the types of ground water in which pesticides sometimes were found.

In terms of estimating pesticide recovery and measurement variability, only one of the 21 wells chosen by the Delmarva Peninsula Study-Unit staff for field spikes yielded a background sample with measurable concentrations of some of the pesticides found in NAWQA spike solutions and of interest to the Study Unit. This implied that, except for the data from that one well, the field-spiked sample data were suitable for obtaining unbiased recovery and variability estimates for those pesticides of primary interest to the Study Unit. Thus, for most of the pesticide analytes in question, recovery and measurement variability estimates were obtained using spiked samples from all 21 wells (Koterba and others, 1993). In the case of the one analyte found in the background sample from one well, the data from only 20 wells was used to estimate recovery and measurement variability.

The preceding discussion offers one approach that made it possible to select wells and design ground-water and routine QC sampling schedules each year to provide representative and suitable QC data for a 100-well Study-Unit Survey, which took 2 years to complete sample collection. Although the example above is for a Study-Unit Survey, the approach also is applicable to Land-Use and Flowpath Studies.

The above approach also illustrates how a Study Unit can graphically demonstrate that the wells selected for routine QC data collection represent different types of ground-water quality found in a component study area. If this visual analysis of QC data is made in a timely manner (before ground-water sampling for a component is complete), it is possible to incorporate wells not yet sampled, or initially selected, into the routine QC design to improve the representative nature of the QC data.

Topical quality-control samples

Field and laboratory equipment and methods for the collection of ground-water-quality data, including those for QC, could be modified as a result of routine QC data analysis, shifts in National Program priorities, or results from other studies. Modifications will be designed and implemented in a systematic manner, preceded by a NAWQA memorandum that explains the nature of the modification, the reason for the modification, and the manner in which the modification will be documented and evaluated. As part of this modification process, which is considered topical in nature, Study-Unit participation could be requested by the National Program. On some occasions, this could require additional QC samples be collected by some or all Study Units.

Individual Study Units could find additional QC samples are necessary to address a topic of local concern. For example, additional field and trip blanks could be required to verify that VOC contaminants are in the ground water, and are not being introduced during and after sample collection (Rea, in press). In other cases, additional blanks and spiked samples could be required to correctly assess method-related problems (Koterba and others, 1994).

Sample Coding and Data Management

The current electronic systems for sample and data management (LIMS-NWQL, NWIS-I-QWDATA, and NWIS-I-QADATA) do not provide a simple means of relating or differentiating among ground-water-quality and QC samples obtained from a single well. Although there are several ways to overcome this problem, the need to aggregate ground-water-quality and QC data on a regular basis at the Study Unit and National Program level requires consistent coding and management of samples and data among Study Units. For this reason, protocols for coding and electronically storing routine QC samples and data were developed (tables 14 and 15). In the case of topical QC data, coding is provided as part of each national topical QC-data request.

Table 14. Sample container coding requirements for ground-water-quality and routine quality-control samples of the National Water-Quality Assessment (NAWQA) Program

[NWQL, National Water Quality Laboratory, Denver, Colo.; SC, laboratory schedule; LC, laboratory code (in lieu of schedule); FA, filtered and acidified (nitric acid); RU, raw (unfiltered) and untreated; FU, filtered and untreated]

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1. Routine ground-water sample-bottle labels:

- NAWQA and Study-Unit four-letter code: for example, “NAWQA-POTO” (for Potomac NAWQA Study Unit)
- Local well identifier code
- Bottle type--NWQL sample designation schedule or laboratory code: for example, FA-SC2750
- Date of sample collection (MM-DD-YY, month-day-year), for example, 06-31-94
- Time of sample collection (HH:**00**, hours-minutes, military time)[a] for example, 12:00

2. Routine quality-control sample-bottle labels:

- NAWQA and Study-Unit four-letter code, same as above
- Local well identifier code, same as above
- Bottle type--NWQL schedule or laboratory code, where schedule or laboratory code used is given below
- Date of sample collection (MM-DD-YY, month-day-year), same as above
- Time of sample collection (HH:MM, hours-minutes, military time) where minutes are assigned values other than 00, according to the following format:

Time	Routine QC-sample type time-of-collection codes.[b]
HH:**01**	**Replicate--organic-carbon, nutrient, pesticide, volatile-organic, radon or major ion samples,** use SC2085, SC2752, SC2001 and SC2050, SC2090, SC2091, or SC2092, LC1369, and SC2750 (FA, RU, and FU), respectively. (For replicate cartridges, use SC2010 and SC2050, in lieu SC2001 and SC2051, respectively. Replicates for pesticide and volatile-organic compounds are optional.)
HH:**02**	**Field spike-1st--for pesticide or volatile-organic samples,** use same schedules cited under replicates above.
HH:**03**	**Field spike-2nd--for pesticide or volatile-organic samples,** use same schedules cited under replicates above.
HH:**04**	**Field spike-3rd (optional)--for pesticides or volatile-organic samples,** use schedules cited under replicates above.
HH:**05**	**Field blank--pesticide, volatile-organic, organic-carbon samples--(which require NWQL pesticide and VOC-free blank water, or if no field blank for VOCs taken, require NWQL pesticide-free blank water),** use same schedules cited for replicates above. **Field blank--nutrient samples (which require QWSU inorganic-free blank water),** for SC2752**.**
HH:**06**	**Field blank--major-ion (which require QWSU inorganic-free blank water)** for SC2750.
HH:**07**	**Solution blank--organic carbon only, (required because NWQL blank water is not analyzed for organic carbon),** use SC2085.

Table 14. Sample container coding requirements for ground-water-quality and routine quality-control samples of the National Water-Quality Assessment (NAWQA) Program--Continued

Time	Routine QC-sample type time-of-collection codes.[b]
HH:**08**[b]	**Trip blank--volatile organic samples only (which requires NWQL trip blanks found in box that sample vials are obtained in),** use SC2090.
HH:**09**[b]	**Primary trace-element ground-water-quality sample**, such as for SC2703.
HH:**10**[b]	**Replicate trace-element ground-water-quality sample,** such as for SC2703.
HH:**11**[b]	**Field blank--trace-element samples only (which require QWSU inorganic-free water),** and in lieu of SC2703 use SC172 and add LC0112 (arsenic) and LC0087 (selenium).
HH:12[b]	**Standard Reference Sample--for trace-element samples only,** such as for SC2703.

[a]This is a generic time value--the nearest hour to the true time--that is the basis for linking samples taken from a well during a particular visit. Some situations, or samples, require the true time of collection also be recorded--for example, to identify the time at which radon is taken. True time can be recorded, along with the reason it is being recorded, on the field form, as in the case of radon, in the message to the laboratory section on the NWQL-ASR form.

[b]Except for trace elements (for example, SC2703), additional sample bottles under other schedules can be added under the above time codes if and only if (1) they do not contain analytes in common with the samples and schedules already listed, and (2) if they are composed of blank water, it is the same type of blank water being used for the samples already listed above. If these conditions cannot be met, use other time codes (and NWQL analytical service request forms) for the additional samples. Note that for trace elements, unique time codes are required.

Table 15. Storage and coding requirements for ground-water-quality and quality-control samples and data of the National Water-Quality Assessment Program

[NWIS-I, National Water Inventory System; QWDATA, Quality of Water Data Base; QADATA, Quality-Assurance Data Base; NWQL, National Water Quality Laboratory; BTD&QS, Branch of Technical Development and Quality Systems; QWSU, Quality Water Service Unit; mL, milliliters]

1. Data Storage (check District policy):

- Routine ground-water-quality data in NWIS-I (QWDATA) database.
- Routine quality-control data in NWIS-I (QADATA) database.
- Topical quality-control data in NWIS-I (QADATA) database.

2. Sample and Data Coding on Analytical Service Request (ASR) Forms:

- Use same local well identifier as on sample container, add corresponding station identification code (15-digit latitude-longitude-sequence number) and use same date for all ground-water and quality-control samples collected at a well during a site visit.
- Use different time-of-sample collection codes for quality-control samples.[1]
- Use additional codes below for quality-control samples (in accordance with BTD&QS):[2]

For BLANKS: Coding required

Blank type	Sample medium	Sample type	Blank solution type (99100)	Blank solution source (99101)	Blank sample type (99102)
Trip	Q	2	10, 40, or 50	10, 60, or 80	30
Equipment	Q	2	10, 40, or 50	10, 60, or 80	80
Field	Q	2	10, 40, or 50	10 or 80 only	100
Solution	Q	2	10, 40, or 50	10 or 80 only	1

where Q denotes an artificial sample; 2 implies a blank sample; blank solution type 10, 40, or 50 implies inorganic-free, pesticide-free, or volatile-organic-free blank water, respectively; blank solution source 10, 60, or 80, implies blank water from the NWQL, District, or QWSU (Ocala), respectively; blank sample type 30, 80, 100, and 1 correspond to the blank types specified in the first column, respectively. Only NWQL or QWSU water should be used for field blanks. Record lot number of blank solution on ASR form.[3]

For REPLICATES: Coding required

	Sample medium	Sample type	Replicate type (99105)
Regular sample	6	7	20
Second sample	S	7	20

where 6 implies a ground-water sample; S implies a replicate ground-water sample; 7 implies replicate samples; and 20 implies samples were collected sequentially.