NORTH SAN BENITO BASIN GROUNDWATER MODEL UPDATE AND ENHANCEMENT 2020

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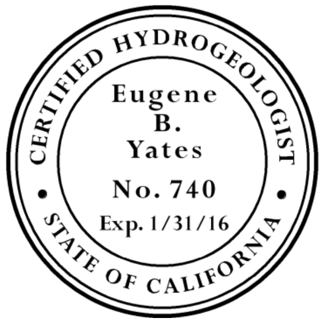

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1. INTRODUCTION

In 2001, San Benito County Water District (District) developed a groundwater flow model of the San Benito County part of the Gilroy-Hollister Groundwater Basin (Yates and Zhang, 2001). The model has undergone revisions and enhancements to meet the needs of specific projects, most recently in 2014 (Todd Groundwater 2015). Extensive revisions, an update of the calibration period and recalibration have been done in 2019 to meet the needs of two projects: preparation of a groundwater sustainability plan for the North San Benito Subbasin and evaluation of potential impacts of enlarging Pacheco Reservoir. Major elements of this work include:

- Expanding the modeled area to include all of the North San Benito Subbasin of the Gilroy-Hollister Groundwater Basin in San Benito County plus the basin area along Pacheco Creek that extends north into Santa Clara County. This included a major expansion to the southeast, nearly doubling the total model area.
- Implementing a fine, uniform model grid.
- Updating all model input time series data as well as water-level hydrographs used for model calibration through water year 2019.
- Recalibration of the hydraulic characteristics of aquifer materials, stream beds and faults.
- Preparation of hydrologic time series data for model input back to water year 1922 to enable simulation of the 1922-2003 period used for the Pacheco Reservoir Expansion Project design work.
- Change from MODFLOW2000 to MODFLOW2005 and from STR to SFR stream flow module.

This report documents the expanded, updated and recalibrated model, including ancillary modeling steps used to prepare inflows to the groundwater model.

2. BOUNDARIES OF THE BASIN, MODEL AND WATERSHED

The Gilroy-Hollister Groundwater Basin as defined by the California Department of Water Resources (DWR) includes two subbasins: the North San Benito Subbasin (herein Basin) and Llagas Subbasin, and encompasses valley floor and adjacent hilly areas in northern San Benito County and southern Santa Clara County, as shown in **Figure G-1**. The basin consists of unconsolidated to slightly consolidated sediments with primary porosity that store and transmit significant quantities of groundwater. These formations occur not just beneath the valley floor areas but also in some of the adjacent upland areas. Consequently, the basin boundaries are defined by geology and faults, not by topography. For example, the San Andreas Fault forms much of the southeastern boundary of the basin and cuts across hilly terrain southeast of Hollister. However, almost all extraction and use of groundwater occur in the valley floor areas.

The Hollister Valley extends 10 miles northwest from Hollister to the Pajaro River, which is the county line. A broad, flat region on the San Benito County side of the river is known as the Bolsa subarea. Beyond the river, the Llagas Valley and subbasin continue another 15 miles northwest in Santa Clara County and include the cities of Gilroy and Morgan Hill. The San Juan Valley trends west from Hollister along the San Benito River and includes the City of San Juan Bautista. It is separated from the Bolsa subarea by the Lomerias Muertas and Flint Hills, which are an upward fold of Purisima Formation that rises as much as 1,100 feet above the valley floor areas. The Purisima Formation also makes up the hills along the southern edges of the San Juan and Hollister Valleys, but it is truncated by the San Andreas Fault. The basin extends southeast of Hollister 25 miles up the valleys associated with Tres Pinos Creek and the San Benito River. Except for the relatively small Paicines and Tres Pinos Creek Valleys, that region is mostly hilly upland areas with hydrogeologic characteristics similar to those of the hills farther north.

The area simulated by the groundwater model includes the entire Gilroy-Hollister Basin in San Benito County plus alluvium beneath Pacheco Creek in Santa Clara County. The Llagas Subbasin is represented as a gradient-dependent groundwater inflow boundary.

Water enters the basin as surface runoff and subsurface inflow from watersheds draining the Diablo Range bordering the eastern edge of the basin and the Gabilan Range bordering the southwestern edge. To develop estimates of surface and subsurface inflows from these tributary areas to the groundwater basin, a rainfall-runoff-recharge model is used to simulate the entire watershed tributary to the Basin. This model simulates all near-surface hydrologic processes, including rainfall, runoff, infiltration, evapotranspiration, effects of impervious areas and irrigation, soil moisture storage and percolation to stream base flow and deep groundwater recharge.

3. BASIN GEOLOGY AND STRUCTURE

3.1. BASIN FILL GEOLOGY

The geologic materials that comprise the basin fill are non-marine sediments of Pliocene age or younger (less than 5 million years old). Some deposits are named, others are referenced simply by age. Data from exploratory oil wells indicate that basin fill sediments extend as much as 4,000 feet below the ground surface near the center of the basin, far beyond the depths of water supply wells (Kilburn, 1972). **Figure G-2** shows a map of the geologic materials exposed at the land surface (CGS, 2002). In the valley floor areas, surficial deposits consist of relatively young alluvium, generally less than 200 feet thick. Most of the basin fill consists of Pliocene and Pleistocene age clays, silts, sands and gravels, including the Purisima Formation. These formations are exposed at the land surface in the hills surrounding the valleys. In the eastern and southeastern parts of Hollister Valley, semi-consolidated deposits are encountered in the subsurface that yield little groundwater and are commonly referred to as the San Benito Gravels of Lawson 1895.

The basin is structurally complex. The substantial depth of the basin and the current topography of the land surface resulted in part from folding of the geologic deposits. For example, the high hills that separate the Bolsa area from the San Juan Valley are associated with the Sargent anticline (upward fold).

3.2. FAULTS

Basin fill materials are cut by several faults that can be mapped on the basis of surface geology and/or their effects on groundwater levels. The most prominent of these is the Calaveras Fault, which bisects the Hollister Valley from northwest to southeast. It offsets hills west of the Hollister Airport and created San Felipe Lake at the north end of the valley (a sag pond). It acts as a barrier to the generally westward movement of groundwater, resulting in flowing wells and perennial stream base flow on the east side of the fault in the northern part of the valley. Geologic mapping as well as groundwater level data indicate that the fault consists of several parallel splinters.

The Ausaymas Fault (Quien Sabe Fault on some maps) crosses the northeastern part of Hollister Valley (see Figure G-2). It created a series of low hills in the valley floor area near Orchard Road and Comstock Road, and it also acts as a barrier to groundwater flow. It trends from the mouth of Pacheco Creek valley toward Santa Ana valley, but geologic maps generally show it disappearing before it gets there. Based on model calibration efforts for this study, there is hydrologic evidence (abrupt changes in groundwater levels) that a branch of the fault might trend southeast toward the southern part of Hollister. This branch is included in the groundwater model.

The Tres Pinos Fault is shown on some geologic maps (see Figure G-2) curving northwest from the town of Tres Pinos along Highway 25 toward Hollister (for example, Kilburn, 1972). There is some water-level evidence that the fault is present, and it is also included in the groundwater model.

Faulting is also associated with the Sargent Anticline in the Lomerias Muertas and Flint Hills. There is a barrier to groundwater flow that crosses the narrow gap of alluvium between the eastern end of the Flint Hills and the low hills of exposed Plio-Pleistocene materials in Hollister. That barrier is included as a fault in the groundwater model.

4. MODELING SOFTWARE AND DIGITAL FILE AVAILABILITY

The computer program used to simulate groundwater flow continues to be MODFLOW 2005, which is public-domain software developed by the U.S. Geological Survey (Harbaugh, 2005). The various versions of MODFLOW are the most widely used groundwater modeling software in the United States. Several commercially available (proprietary) software programs were used to prepare model input and evaluate model output. These include Microsoft Excel, Groundwater Vistas, and ArcGIS. Finally, the rainfall-runoff-recharge model and several pre-processing utility programs were developed in the Fortran 90 programming language by Todd Groundwater.

Readers interested in obtaining input files for the rainfall-runoff-recharge model and groundwater model, or the files used to produce figures in this documentation may obtain them from the District:

San Benito County Water District
30 Mansfield Road
Hollister, CA 95024
Tel. 831-637-8218
Attn. Jeff Cattaneo, Sara Singleton or Garrett Haertle

5. MODEL GRID AND LAYERS

MODFLOW uses a finite-difference numerical method that requires a rectilinear grid of model cells. In plan view, the model grid contains 200 rows by 271 columns of cells. The spacing between rows is uniformly 500 feet. The spacing between columns is 500 feet in the main Basin area and 1,000 feet in the southeastern part of the Basin, as shown in **Figure G-3**. The larger grid spacing in that region reflects the lack of pumping stresses and water-level data in that area.

The model has five layers numbered 1 through 5 from top to bottom. In most areas, the layers simply represent depth intervals within the basin and do not correspond to identifiable geologic features. Where upward water-level gradients are present, layer 2 is used to represent the low-permeability clay and silt layers that restrict vertical flow. Individual gravel, sand, silt and clay layers within the basin tend to be thin and of limited areal extent. Previous studies have had limited success correlating layers between wells on the basis of well completion reports prepared by drillers. This could be due to inconsistent use of lithologic descriptors by drillers, the difficulty in identifying clay layers when drilling with the mud-rotary method (the most common method), and/or actual discontinuity of layers over short distances. Recent re-analysis of geologic information for the Groundwater Sustainability Plan (see Section 3.6) reached the same conclusion.

The top of the basin and the groundwater model is the land surface. Elevation points every 10 meters were extracted from the National Elevation Dataset to define the top of layer 1 (http://ned.usgs.gov). The bottom of the model grid was set at a depth slightly below the depth of most water supply wells. Because of layering within the basin fill sediments, groundwater at depths much greater than water supply wells tends to remain inactive and has little effect on water levels and flow in the overlying, actively-pumped aquifers. The bottom elevation of layer 1 was carefully selected as a surface slightly below the minimum historical water level recorded during water years 1975-2017. This had the advantage of preventing layer 1 cells from going dry during the calibration simulation but the disadvantage of creating a thick top layer in some places, which decreased the ability to simulate vertical gradients precisely. Dry cells cannot be included in the mathematical operations used to simulate groundwater flow, so cells are permanently removed from the active flow domain if they go dry. Other versions of MODFLOW are available that can simulate unsaturated and saturated conditions concurrently. This keeps all cells active, but at the cost of substantially increased model run time.

The thicknesses of layers 2 through 5 are constant throughout the modeled area, so their bottom elevations have the same shape as the bottom of layer 1 but at a lower elevation. Layer 2 is only 20 feet thick, which serves two purposes. It allows more realistic simulation of salt concentrations near the water table, because salt loads from the ground surface are not averaged over a large depth interval. Also, layer 2 is used in some locations to represent fine-grained layers that create confined conditions and upward water-level gradients. Layers 3, 4 and 5 are 120 feet, 180 feet and 260 feet thick, respectively. Thus, the total saturated thickness represented by the model is about 600-780 feet, depending on the saturated thickness of layer 1 at any given place and time. **Figures G-4 and G-5** show cross sections of the model grid along row 98 and column 76, respectively, to illustrate the shapes and relative thicknesses of the layers.

6. SIMULATION PERIOD AND TIME STEPS

The model calibration period was updated to simulate the historical period of water years 1975-2017. This 43-year period is desirable for model calibration purposes because it includes a wide range of hydrologic and water use conditions. It begins when groundwater levels were low in some parts of the basin due to preceding decades of groundwater overdraft. The low initial water levels were immediately accentuated by the 1976-1977 drought. Water levels generally rose during the wet period of water years 1978-1986 and then declined during the drought of 1987-1992. Recovery from the drought was very rapid due to wet climatic conditions and the beginning of water imports in the early and mid-

1990s. In the early years of operation, imported water was actively percolated through creek beds during the dry season as well as used directly for agricultural and urban uses, offsetting groundwater pumping. Water-level recovery was so dramatic that by the late 1990s, wells in some locations began flowing under artesian pressure (that is, without pumping). The calibration period also includes the 2013-2015 drought and most of the subsequent recovery.

The model is transient and advances in monthly time increments. Monthly-average values of inflows and outflows are applied during each of these "stress periods". Internally, the model subdivides each stress period into three computational time steps that increase in duration from approximately 6 to 14 days. Model inputs related to rainfall recharge and stream recharge were calculated daily using the rainfall-runoff-recharge model, then averaged to monthly values for input to the groundwater model. This is generally more accurate than working directly with monthly values of rainfall and stream flow because runoff and recharge processes are nonlinear.

7. RAINFALL-RUNOFF-RECHARGE MODEL

A rainfall-runoff-recharge model developed by Todd Groundwater was used to prepare estimates of groundwater recharge from rainfall, irrigation, bedrock inflow, and pipe leaks. It also generated the estimates of groundwater use for agricultural irrigation and flows in ungauged streams tributary to or within the basin. The rainfall-runoff-recharge model is built around a soil moisture balance of the root zone, which is simulated continuously using daily time steps for the 43-year calibration period. Numerous variables are involved in the physical processes of rainfall, interception, runoff, infiltration, root zone soil moisture storage, evapotranspiration, irrigation, shallow groundwater storage, recharge of deeper regional aquifers from shallow groundwater, and lateral flow of shallow groundwater into streams. Accordingly, the groundwater basin and tributary watersheds were divided into small recharge zones over which the most influential variables were relatively homogeneous. The daily water balance was then simulated for each zone, and the results aggregated geographically to cells in the groundwater model grid and temporally to the model stress periods.

The rainfall-runoff-recharge model provides several benefits to the groundwater modeling effort:

- It represents the hydrological processes with governing equations that reflect the actual physical processes, at least in a simplified way. This allows sensitivity or suspected errors to be traced to specific assumptions and processes.
- It enforces the principle of conservation of mass on the recharge and stream flow values. Beginning with rainfall, all water mass is accounted for as it moves through the hydrological system.
- It allows additional data sets to be included in model calibration. In tributary watersheds with gauged stream flow data, measured flows can be compared with simulated flows, which consist of the sum of direct runoff and shallow-groundwater

seepage to streams. Simulated irrigation frequency can be compared with actual grower practices, and applied irrigation amounts can be compared with water delivery data recorded by the District. Simulated urban irrigation amounts can be compared with seasonal variations in measured urban water use, which are primarily the result of urban irrigation.

- It provides estimates of stream flow in ungauged tributary streams, as well as runoff from valley floor areas within the active model domain.
- It provides estimates of inflow from bedrock and/or upland areas adjacent to the active model domain and constrains the amounts of inflow according to the water balance for each tributary watershed.
- It simulates the effects of runoff from impervious surfaces in urban areas, either to storm drainage systems or to adjacent pervious soils.
- It simulates changes in land use over the 43-year calibration period and the resulting changes in recharge and irrigation demand.
- It combines and parses all of these flows—plus estimated recharge from leaky water and sewer pipes—into recharge values by model cell and stress period in the format required by MODFLOW.

The following sections describe the input data sets and the assumptions and governing equations used to simulate each hydrologic process included in the rainfall-runoff-recharge model.

7.1. LAND USE AND RECHARGE ZONES

Recharge zones were developed by intersecting and editing numerous maps in GIS. The starting point was a map of land parcels in San Benito County current as of 2014. Parcel-based recharge zones are necessary for the San Benito model because the use of imported water use is recorded by parcel. Parcel numbers that changed subsequent to 2014 were linked to the prior parcel locations so that the complete history of imported water use could be simulated seamlessly. The rainfall-runoff-recharge model estimates irrigation pumping by subtracting the use of imported water and recycled water from simulated irrigation demand. Urban parcels were consolidated into zones with relatively homogeneous proportions of irrigated, non-irrigated and impervious land cover, which vary depending on the density and type of urban development. Agricultural parcels were assigned a crop type based on land use surveys by DWR in 1975, 1997 and 2010. Land use in 2014 developed using remote sensing techniques was obtained from DWR. To interpolate smoothly between the years with land use information, parcels with changed land use were each assigned different transition years during the interval between mapping dates.

Parcels were subdivided as needed to reflect the boundaries of agricultural fields. In upland areas of the tributary watersheds, recharge zones were manually delineated into grass, shrub and tree categories based on recent air photos (Google Earth). Those land use polygons were further split if they overlapped a watershed boundary. A few large expanses of grassland in the tributary watersheds were also divided if they spanned a rainfall gradient exceeding 1 in/yr of average annual rainfall. Divisions were also made if recharge zones overlapped two distinctly different soil types. Finally, a few extra polygon divisions were made where necessary to simulate land use changes from earlier years. This process of overlapping, consolidating and splitting polygons resulted in 2,768 recharge zones, of which 23 were in external watersheds with gauged streams that were included for the purpose of calibrating model parameters. A map of the zones and their land uses in 2014 is shown in **Figure G-6.**

Land use in each zone was assigned to one of twenty-one categories. The many types of agricultural crops grown in San Benito County were consolidated into eight groups that reflect distinct root depths, growing seasons or crop coefficients for evapotranspiration. A separate category for small vegetables was used in the Bolsa area, where poor drainage results in a shorter growing season. Natural vegetation was divided into five categories, and urban and developed land uses into seven categories. The categories are listed in **Table G-1** along with their total acreages in 2014 in the groundwater basin management areas and tributary watersheds.

Each land use category is further divided into irrigated, non-irrigated and impervious subareas. These are not explicitly mapped but are expressed as percentages of total zone area. Zones representing irrigated cropland, for example, were mostly assumed to be 92 percent irrigated, with the remainder consisting of farm roads and occasional buffer areas of natural vegetation. Based on examination of aerial photographs, the percent impervious cover in urban land use areas was estimated to be 10 percent for rural residential, 20 percent for urban residential, 70 percent for commercial and 80 percent for industrial. The corresponding percent irrigated area for those categories was estimated to be 10, 13, 10 and 0 percent, respectively.

7.2. RAINFALL

The distribution of average annual rainfall over the basin and tributary watersheds was obtained from PRISM climate modeling (http://www.prism.oregonstate.edu/), shifted uniformly downward slightly so that the modeled value for Hollister matched the long-term average at the Hollister climate station. Also, high simulated values of rainfall in the upper parts of some tributary watersheds were identified as a possible cause of excessively high simulated stream flow. Annual precipitation was adjusted slightly downward in those areas to be more consistent with isohyetal patterns mapped by Rantz (1969) and to match measured stream flow in watersheds with gauges. Each recharge zone was assigned an average annual rainfall value based on its location, as shown in **Figure G-7**.

The surface hydrology model requires daily rainfall as one of two transient inputs. Daily rainfall for the Hollister station during 1975-2014 was used for this purpose, with missing values supplied by correlation with rainfall in Gilroy. Daily rainfall for each recharge zone was calculated as Hollister daily rainfall multiplied by the ratio of zonal average-annual rainfall to Hollister average-annual rainfall.

7.3. INTERCEPTION

Plant leaves intercept some of the rain that falls from the sky, and the amount is roughly proportional to the total leaf area of the vegetation canopy. The estimated interception on each day of rain ranged from zero for industrial, idle and vacant land uses, to 0.03 inch for most crops including turf and 0.06 inch for trees in full leaf. These estimates were inferred from published results of interception studies (Viessman and others, 1977). For each day of the simulation, rainfall reaching the land surface (throughfall) is calculated as rainfall minus interception. Interception storage is assumed to completely evaporate each day and is not carried over from one day to the next.

7.4. RUNOFF AND INFILTRATION

Most throughfall infiltrates into the soil, but direct runoff occurs when net rainfall exceeds a certain threshold. The threshold at which runoff commences and the percent of additional rainfall that runs off are significantly influenced by a number of variables, including soil texture, soil compaction, leaf litter, ground slope, and antecedent moisture. These factors can be highly variable within a recharge zone, and data are not normally available for them. Also, the intercept and slope of the rainfall-runoff relationship depend on the time increment of analysis. Most analytical equations for infiltration and runoff apply to spatial scales of a few square meters over periods of minutes to hours (Viessman and others, 1977). They are suitable for detailed analysis of individual storm events. The curve number approach to estimating runoff also applies to single, large storm events. It is not suitable for continuous simulation of runoff over the complete range of rainfall intensities (Van Mullen and others, 2002). The approach used in the rainfall-runoff-recharge model is similar but less complex than the approach used in popular watershed models such as HSPF (Bicknell and others, 1997).

In the rainfall-runoff-recharge model, daily infiltration is simulated as a three-segment linear function of throughfall, and throughfall in excess of infiltration is assumed to become runoff. The general shape of the relationship of daily infiltration to daily net rainfall is shown in **Figure G-8** (upper graph). Below a specified runoff threshold, all daily throughfall is assumed to infiltrate. Above that amount, a fixed percentage of throughfall is assumed to infiltrate, which is the slope of the second segment of the infiltration function. Finally, an upper limit is imposed that represents the maximum infiltration capacity of the soil. The runoff threshold, the percentage of excess net rainfall that infiltrates, and the maximum daily infiltration capacity were assumed to vary by land use and were among the variables adjusted for model calibration. The runoff threshold ranged from 0.2 inches per day (in/d) for unpaved areas in industrial and commercial zones to 1.1 in/d for turf and natural vegetation areas. The infiltration percentage for excess rainfall ranged from 55 percent in commercial and industrial areas to 87 percent in large turf areas and upland natural vegetation. The maximum daily infiltration was set to 8 in/d for all land uses and soil types, which for practical purposes puts no upper limit on daily infiltration.

The above parameter values are for soils that are relatively dry. Infiltration rates decrease as soils become more saturated. This phenomenon led to the development of the Antecedent Runoff Condition adjustment factor for rainfall-runoff equations (Rawls and others, 1993). However, application of the concept has been focused on individual storm events. For the purpose of the rainfall-runoff-recharge model, the adjustment provides a means of simulating empirical observations that a given amount of rainfall produces less runoff at the beginning of the rainy season when soils are relatively dry than at the end of the rainy season when soils are relatively wet. This effect is included in the recharge model as a multiplier that decreases the estimated infiltration as soil saturation increases. This multiplier is applied to the runoff threshold, the infiltration slope and the maximum infiltration rate. The multiplier decreases from 1.0 when the soil is dry to a user-selected value between 1.0 and 0.60 when the soil is fully saturated (lower graph in **Figure G-8**). A low value has the effect of decreasing infiltration (and potential groundwater recharge) toward the end of the rainy season or in very wet years, and also to increase simulated peak runoff during large storm events. The multiplier under saturated conditions was assumed to be 0.75 for the San Benito rainfall-runoff-recharge model.

Runoff from impervious surfaces was assumed to equal 100 percent of rainfall. Runoff that flows into a storm drain system (known as “connected impervious runoff”) contributes to stream flow but not groundwater recharge. However, runoff from some impervious surfaces flows onto adjacent areas of pervious soils (“disconnected impervious runoff”). The surface hydrology model treats this type of runoff as if it were a large increment of additional rainfall where it flows over or ponds on the pervious soils. The excess water can quickly saturate the soil and initiate deep percolation. The model incorporates this process by means of a variable representing the fraction of impervious runoff that becomes deep percolation. Data and literature values are not available for this variable. It was estimated to be 10 percent in commercial and industrial areas and 30 percent in residential areas. The study area is not heavily urbanized, so this variable does not strongly influence the water balance or simulation results.

7.5. ROOT ZONE DEPTH AND MOISTURE CONTENT

The storage capacity of the root zone equals the product of the vegetation root depth and the available water capacity of the soil. The available water capacity for each recharge zone was a depth-weighted average for the dominant soil type, as reported in the soil survey (Natural Resources Conservation Service, 2015). Root depth is a complex variable. Except for cropland, vegetation cover typically consists of a mix of species with different root depths. At a very local scale, roots are deepest directly beneath a plant and shallower between plants. Root density and water extraction also typically decrease with depth within the root zone. To complicate matters, root depth is somewhat facultative for some plants, which means that roots will tend to grow deeper in soils with low available water capacity, such as sands. Finally, root depth in upland watershed areas can be restricted by shallow bedrock.

The root depth selected for each recharge zone essentially represents an average of all these factors. Simulated recharge and stream base flow are both quite sensitive to vegetation root depth, and values were adjusted during the joint calibration of the rainfall-runoff-recharge model and the groundwater flow model. Separate root depths were specified for irrigated and non-irrigated vegetation in each recharge zone. Root depths for turf and crops were required to be the same in all zones. Some variation in rooting depths of natural vegetation among watersheds was introduced while calibrating simulated stream flow to measured stream flow. In general, however, root depths did not appear to be greatly restricted by shallow bedrock in the tributary watershed areas.

7.6. EVAPOTRANSPIRATION

Evapotranspiration is affected by meteorologic conditions, plant type, plant maturity, and soil moisture availability. All of these factors are included in the rainfall-runoff-recharge model. The evaporative demand created by meteorological conditions is represented by reference evapotranspiration (ETo). Numerous equations have been developed over the years relating ETo to solar radiation, air temperature, relative humidity and wind speed. For the purposes of this study, daily values of ETo were obtained from a microclimate station in Hollister that is part of the California Irrigation Management Information System (CIMIS) network. However, those data had to be extrapolated in space and time to obtain values for every recharge zone for the entire 1975-2017 calibration period. Spatially, the study area overlaps two regions in a statewide map of ETo zones prepared by the CIMIS program (Jones, 1999). Most of the study area is in zone 10, but the San Juan Valley is in zone 3 due to the influence of cool marine air that blows inland through Chittenden Gap along the Pajaro River. Annual ETo in zone 3 is 94 percent as large as in zone 10 (46.2 versus 49.1 inches). Accordingly, daily ETo values from the Hollister CIMIS station were multiplied by 0.94 to obtain ETo for zones in the San Juan Valley.

The Hollister CIMIS station began operation in 1994. ETo for each day during water years 1974-1993 was estimated to equal average ETo for the corresponding calendar month multiplied by an adjustment factor derived from the relationship between ETo and air temperature. The factor equaled the slope of a linear regression of ETo versus maximum air temperature for that month of the year, using data from the period of record for the Hollister CIMIS station. Historical daily air temperatures were obtained from the National Oceanic and Atmospheric Administration climate station in Hollister and used to generate the multipliers to convert average monthly ETo to estimated daily ETo.

Vegetation factors are lumped into multipliers called crop coefficients. Reference ET is the amount of water evapotranspired from a broad expanse of turf mowed to a height of 4-6 inches with ample irrigation. ETo is multiplied by a crop coefficient to obtain the actual ET of a different crop or vegetation type at a particular stage in its growth and development. Although primarily used for agricultural crops, crop coefficients can also be applied to urban landscape plants and natural vegetation. Compilations of crop coefficients for many plant types based on field studies are available from numerous sources, in some cases specified by calendar month and in others by growth stage of the plant. Monthly crop coefficients for the 21 land use categories in the surface hydrology model are shown in **Table G-2.** These were developed from a comparison of published values from six sources (Blaney and others, 1963; DWR, 1975; U.N. Food and Agriculture Organization, 2006; Snyder and others, 2007; Williams, 2001; and ITRC, 2003), adjusted to reflect combinations of crops and growing seasons represented by the land use categories. Small vegetables are a dominant crop. Because of their short growing seasons, multiple crops are often grown each year. The monthly crop coefficients reflect a mix of growth stages due to staggered planting of different fields. Based on input from several local growers, the growing season for small vegetables is March-November in most parts of the basin and April-November in the Bolsa area, where poorly-drained soils delay the planting season. Most fields are bare soil during December-February, and the crop coefficient represents an estimate of evaporation from soils periodically wetted by rain events.

7.7. IRRIGATION

Evapotranspiration gradually depletes soil moisture, and for irrigated areas the rainfall-runoff-recharge model triggers an irrigation event whenever soil moisture falls below a specified threshold. The amount of applied irrigation water is equal to the volume required to refill soil moisture storage to field capacity, divided by the assumed irrigation efficiency. An irrigation threshold equal to 80 percent of maximum soil moisture storage was used for urban landscaping and all crops. This variable primarily affects the frequency of irrigation; a higher threshold results in more frequent irrigation but approximately the same total amount of water applied annually. Irrigation efficiency was assumed to be 75 percent for urban landscaping, reflecting the low application uniformity, overspray and inattention to soil moisture conditions common in residential landscape practice. An efficiency of 85 percent was assumed for all agricultural crops except vineyards, which are drip-irrigated and assigned an efficiency of 95 percent. Regulated deficit irrigation was also applied to vineyards. This is the practice of intentionally water-stressing the vines between veraison and harvest to improve berry quality. The model simulates this by applying only 60 percent of the vineyard ET demand during July-September (Pritchard, 2009).

Because irrigation is assumed to completely refill soil moisture storage and is less than 100 percent efficient, simulated soil moisture exceeds capacity immediately following an irrigation event. The excess is assumed to become deep percolation beneath the root zone.

7.8. DEEP PERCOLATION FROM ROOT ZONE TO SHALLOW GROUNDWATER

The surface hydrology model updates soil moisture storage each day to reflect inflows and outflows. Rainfall infiltration and applied irrigation water are added to the ending storage of the previous day, and ET is subtracted. If the resulting soil moisture storage exceeds the root zone storage capacity, all of the excess is assumed to percolate down from the root zone to shallow groundwater on that day.

7.9. MOVEMENT OF SHALLOW GROUNDWATER TO DEEP RECHARGE AND STREAM BASE FLOW

A shallow groundwater storage component may not be part of all groundwater systems, but its presence is sometimes indicated by groundwater hydrographs and stream base flow. In upland watersheds, for example, the shallow groundwater reservoir is what supplies base flow to streams. Without it, simulated stream flow consists of large flows occurring only on rainy days. Physically, it represents the overall permeability and storage capacity of deep soil horizons and bedrock fractures beneath hillsides bordering a gaining stream. It is the integration of shallow and deep, fast and slow flow paths between the point of rainfall infiltration and the stream. In valley floor areas with flat terrain and deep deposits of unconsolidated basin fill, the presence of a shallow groundwater system is sometimes evident in a lack of response of deep well hydrographs to rainfall recharge events or even wet versus dry years. The shallow zone in that case attenuates the pulses of recharge percolating beneath the root zone into a relatively steady recharge flux, and there may be little outflow to streams.

In the surface hydrology model, the only inflow to shallow groundwater storage is deep percolation from the root zone. There are two outflows: laterally to a nearby creek and downward to the regional groundwater flow system. Outflow to streams is specified as a certain percentage of current groundwater storage, which results in a first-order logarithmic recession of stream base flow, consistent with gaged stream flows. Outflow to the regional groundwater system is simulated as a constant downward flux. This is consistent with flow across confining layers in which the vertical head gradient is near unity. Both outflows are calculated and subtracted from shallow groundwater storage each day. They continue until the storage has been exhausted, resuming whenever a new influx of deep percolation from the root zone arrives. There is no assumed maximum capacity of shallow groundwater storage.

The two parameters defining shallow groundwater flow are the recession constant for flow to streams and the constant downward flow rate for deep recharge. Both of these are obtained by calibration. The recession constant can generally be calibrated by matching simulated to measured stream base flow in gaged watersheds. The deep recharge rate can be used to adjust the long-term partitioning of shallow groundwater mass into base flow versus recharge.

The shallow groundwater component of the surface hydrology model is simple but adequate to capture the fundamental behaviors of logarithmic stream base flow and attenuated deep recharge. Other watershed models invoke more complex systems of storage and flow to simulate these processes. For example, the Precipitation and Runoff Modeling System (PRMS) developed by the U.S. Geological Survey includes a total of seven storage components between the point where a rain drop reaches the ground and the stream into which it ultimately flows (Markstrom and others, 2015). This larger number of components and parameters enables relatively detailed matching of observed stream flow hydrographs but is unnecessarily complex for the purposes of groundwater modeling.

7.10. CALIBRATION OF RAINFALL-RUNOFF-RECHARGE MODEL

The primary basis for calibrating the rainfall-runoff-recharge model was a comparison of measured and simulated daily stream flow at four gauge locations: Tres Pinos Creek, Cedar Creek, Pacheco Creek near Dunneville, and Pescadero Creek near Chittenden. The locations of the gauges are shown in **Figure G-7**, and the period of record for each gauge at least partially overlaps the calibration period. Hydrographs of measured daily flows and simulated daily and monthly flows are shown in **Figure G-9**. A comparison of daily flows shows that the number and timing of simulated flow events generally correspond with measured events. The peak flows for individual events do not match well for many individual events, but simulated peaks do not consistently over- or underestimate measured peaks. Some of the differences are probably due to differences in rainfall intensity between the watershed and the rain gauge location during individual storms. The model under-simulates the duration of base flow recession in most cases. This is partly necessary to decrease annual simulated discharge—a key parameter for groundwater recharge opportunity—to match measured annual discharge. The Pacheco Creek near Dunneville gauge and the Tres Pinos Creek near Tres Pinos gauge are in the interior of the Basin, where flows are affected by gains and losses along the valley floor reach upstream of the gauge. The gains and losses are simulated by the groundwater model but not the rainfall-runoff-recharge model. Simulated monthly flows from the groundwater model are also shown on the hydrographs for those two locations. For the Pacheco Creek gauge, simulated monthly flows correspond reasonably well to the measured and simulated daily flows, after allowing for monthly averaging. The model under-simulates low flows at the Tres Pinos Creek gauge, probably by shunting slightly too much water into the groundwater system, which also flows toward the main Basin area.

8. STREAM-AQUIFER INTERACTION

The groundwater model dynamically simulates groundwater recharge from stream percolation and groundwater discharge into streams. Percolation from streams is a function of stream flow and—where the water table is equal to or higher than the stream bed elevation—the difference in water level between the creek and water table. The MODFLOW stream flow routing (SFR) module is used to simulate these processes. Each stream in the basin is simulated as a sequence of reaches, each of which is a model grid cell along the alignment of the channel. Flow is specified at the upstream end of each stream segment and routed down the reaches, with flow to or from the aquifer calculated on the basis of wetted channel area, channel bed hydraulic conductivity and the difference in elevation between the stream surface and the simulated groundwater level in model layer 1 at that reach. By this means conservation of mass is applied concurrently to the stream and the aquifer. Streams can dry up completely as they cross the basin; and conversely, groundwater discharge can create stream flow in a segment that is dry farther upstream. The stream flow routing module allows for a network of channel segments, with multiple inflows or diversions at the start of each segment.

The San Benito model includes a network of 52 stream segments containing a total of 1,133 stream reaches (**Figure G-3**). The simulated waterways are Pacheco Creek, Arroyo de las Viboras, Arroyo Dos Picachos, Santa Ana Creek, an unnamed channel along Highway 25 southeast of Hollister, Tres Pinos Creek, the San Benito River, San Juan Creek, Miller Canal and the Pajaro River. There are three sources of surface inflow to the stream network: surface flow where the creek first enters the groundwater model domain, releases of imported CVP water for percolation (groundwater recharge), and simulated runoff from within the model domain simulated by the surface hydrology model. In addition, a number of stream segments gain flow from groundwater. For each creek that enters the groundwater basin, monthly surface inflow for the groundwater model was set equal to the sum of surface runoff and base flow simulated by the rainfall-runoff-recharge model, subtotaled for each monthly stress period. Historical monthly releases of CVP water into creeks for percolation during the dry season were obtained from District records and added to the stream segments at the corresponding locations and dates. Finally, simulated runoff from valley floor areas was also subtotaled to monthly values and added as inflow to the nearest stream segment.

Two of the variables used to calculate flow between the stream and aquifer—stream width and stage—are functions of stream flow. Based on field measurements of flow by the USGS at gauge locations and by the District at a number of small stream sites, functions relating depth and width to flow for small, medium and large channels were entered into the MODFLOW stream flow routing package as lookup tables.

9. GROUNDWATER INFLOW

Groundwater inflow into the basin from adjacent uplands—also called mountain front recharge—is very difficult to estimate. If the basin is bounded by igneous or metamorphic rocks with very limited groundwater flow through fractures, it can be reasonable to assume that inflow from bedrock is negligibly small. In the case of the North San Benito Basin, however, sedimentary rocks adjacent to the basin might have some primary porosity. Tributary watersheds in these upland areas were included in the rainfall-runoff-recharge model in order to enforce conservation of mass in the watersheds and and produce reasonable groundwater flow rates from the watersheds into the basin. The resulting estimates are still highly uncertain, however, because groundwater outflow from the watersheds—and surface outflow, too, for that matter—are both small compared to the two largest flows in the watershed water balances: rainfall and evapotranspiration. Thus, a small error in the estimate of either of those flows can result in a large error in groundwater outflow.

Ultimately, groundwater flows produced by the rainfall-runoff-recharge model were calibrated based on their effect on simulated groundwater levels at nearby wells within the basin. In almost all cases, the initial groundwater inflow estimates were too high. The estimates were lowered primarily by increasing the estimated root depth of natural vegetation in the watersheds, which is highly uncertain due to the effects of shallow bedrock on rooting depth.

Groundwater inflow from tributary watersheds was smoothed over time to reflect attenuation of recharge pulses that occur during wet months and wet years as they gradually flow through long, relatively slow flow pathways. Smoothing was accomplished by a moving average of simulated groundwater recharge in the tributary areas over the preceding 2-10 years. This range represents local variability that was indicated by rates of recession in stream base flow and groundwater levels near the basin boundary during prolonged droughts.

The final estimate of average annual groundwater inflow during the calibration period was 5,400-7,200 AFY under normal climatic conditions. Bedrock inflow was represented in the groundwater model as a number of "injection wells" along the margin of the basin. The inflow from each tributary watershed was divided among several model cells along the boundary between the model and watershed. These are indicated by red cells along the margin of the active model flow region in **Figure G-3**.

10. ARTIFICIAL RECHARGE

Four programs have been implemented over the years to augment natural recharge of the groundwater basin. One is percolation of water released from Hernandez Reservoir (45 miles southeast of Hollister) along the channels of Tres Pinos Creek and the San Benito River. In the early years of operation, the target reaches for percolation were the reach of Tres Pinos Creek between the town of Tres Pinos and the San Benito River and the reach of the San Benito River from approximately the model boundary downstream to near Bixby Road in the San Juan Valley. Following the widespread recovery of groundwater levels in the 1990s, both of those target reaches were shortened. The second program consisted of releasing imported CVP water into local stream channels during the dry season. This was done at 13 locations in the early 1990s, but the number of locations and the amounts released were also substantially curtailed by the late 1990s. Percolation releases commenced in 1987, peaked at 10,000-11,000 AFY in 1996-1997 and were ramped down to zero by 2009. Discharge of CVP water to local creek channels is no longer permitted because of the risk of introducing non-native zebra mussels. Both of these recharge programs were included in the groundwater model by adding the historical percolation releases to the natural flows in the affected streams and allowing the MODFLOW stream package to calculate the amount and location of percolation downstream of the discharge points.

The third recharge program also involves percolation of CVP water, but in off-channel ponds instead in creek channels. That program commenced in 2017 and and achieved 2,500-5,000 AFY of recharge since then. The fourth recharge program is percolation of municipal wastewater at six locations. The Hollister Industrial Wastewater Treatment Plant ponds and the eastern and western sets of ponds for the Hollister Domestic Wastewater Treatment Plant are located next to the San Benito River near San Juan Road. Sunnyslope County Water District operates two smaller sets of wastewater percolation ponds in the Ridgemark development at the southeast edge of Hollister. Finally, wastewater from the town of Tres Pinos is percolated at a pond adjacent to the San Benito River. All of these locations are shown as red model cells in **Figure G-3**. Annual percolation at the facilities has evolved in response to increasing population and decreasing per-capita indoor water use. Annual percolation increased from about 1,400 AFY to over 4,400 AFY during 1975-2001, then fluctuated in the 2,0000-4,000 AFY range through 2017. Wastewater from San Juan Bautista is discharged to a small creek channel that has little interaction with the groundwater basin because it is on the southwest side of the San Andreas Fault along most of its length. It is not included in the model.

11. GROUNDWATER PUMPING

Groundwater pumping from agricultural, municipal and rural domestic wells is included in the model at locations defined by geographic coordinates rather than by model grid row and column. This simplifies modification of the grid, if needed. Agriculture has historically accounted for 60-90 percent of water use as tabulated by the District. The District estimates agricultural pumping by means of hour meters installed on large irrigation wells. The discharge rate of the well is periodically measured, and the duration of pumping is multiplied by the discharge rate to obtain the volume of water pumped. An alternative estimate of total irrigation water use can be obtained by simulating crop water demand based on ETo, crop coefficient and irrigation efficiency, as is done in the surface hydrology model. Groundwater use is then estimated as total irrigation demand minus the amount of imported water or recycled water used for irrigation, which are metered. Past comparisons of the two estimates have consistently found that the hour meter estimate is much smaller than the crop water demand estimate. For consistency with the estimate of groundwater recharge, the crop water demand estimate from the surface hydrology model is used in the groundwater model.

Agricultural pumping averaged about 26,000 AFY during 1988-1992 (the first 5 years of the District's hour-meter program) and gradually declined to about 16,000 AFY in recent normal and wet years. Pumping increases when imported water supplies are curtailed. In 2009, 2013 and 2014, for example, agricultural groundwater pumping was 21,000-25,000 AFY, according to District hour-meter estimates.

The location of agricultural pumping is assigned to the center of each recharge zone. This was found to produce better calibration results than attempts to link zonal irrigation demand to physical well locations. One exception to this method was in the southeastern part of the San Juan Valley, where irrigation is supplied by off-site wells near the San Benito River. In the model, all recharge zones south of Highway 156 and east of Bixby Road were assumed to be supplied by wells along the San Benito River between Mitchell and Flint Roads.

The distribution of pumping among model layers was assumed to be the same for all irrigation wells. In order to obtain high rates of output, irrigation wells are typically relatively deep and have long screened intervals. Irrigation pumping was divided between model layers 3 and 4 (60 and 40 percent, respectively). This reduced problems with model cells going dry when pumping was assigned to layers 1 and 2, which are much thinner. Vertical gradients within the interval of maximum pumping (about 150-600 feet below ground surface) are unknown but probably small, given that the boreholes themselves allow equalization of water levels when the pumps are off. Also, the zonal pattern of aquifer characteristics is the same for model layers 3, 4 and 5 (with a few local exceptions), which means that differences in estimated hydraulic conductivity between layers would not be a likely cause of vertical variations in groundwater extraction. The calibrated model produced water levels for layers 3, 4 and 5 that were typically within a few tenths of a foot of each other. Larger gradients—mostly downward, but upward in recent years at two locations—were present between layers 1 and 3.

Groundwater pumping at municipal supply wells is metered and recorded by the water purveyors. The City of Hollister, Sunnyslope County Water District and the City of San Juan Bautista were supplied by six, eight and three wells during the calibration period, respectively. Municipal pumping totaled 5,000-7,500 AFY during 1988-2002. When the Lessalt Water Treatment plant was completed in 2003, some use shifted to imported water and municipal pumping dropped to around 5,000 AFY. Further decreases occurred due to conservation during the 2013-2015 drought and completion of the West Hills Water Treatment Plant in 2017. Municipal groundwater pumping has been less than about 3,000 AFY since then. Municipal pumping during 1975-1987 was projected backward from more recent data based on population trends. Metered pumping was assigned to the actual well locations with the same depth distribution as irrigation pumping. There are 50 commercial and industrial supply wells that pumped more than 20 AFY (according to the District's estimate), and their production was included individually in the model according to their respective locations and volumes reported to the District.

Domestic pumping at rural residences amounts to 2-3 percent of total basin-wide groundwater production. Rather than include hundreds of domestic wells in the model individually, total rural domestic pumping was divided among 130 hypothetical well locations that were scattered throughout areas where there are large numbers of rural residences. The District's estimates of rural domestic pumping during 2006-2008 (which averaged 490 AFY) was extrapolated backward and forward in time based on countywide population trends. Rural domestic pumping was assigned to model layers 2 and 3, reflecting the relatively shallow depth of typical domestic wells.

11.1. EVAPOTRANSPIRATION BY RIPARIAN VEGETATION

In locations where the water table is shallow, some plants (phreatophytes) can extract water directly from the water table to meet evaporative demand. In northern San Benito County, this occurs along some stream reaches where riparian vegetation includes phreatophytes such as willow, cottonwood and sycamore trees. Phreatophytic vegetation uses rainfall in preference to groundwater, and the consumptive use of groundwater was roughly estimated as annual ETo (48 inches) minus annual rainfall (14 inches), or 34 inches per year. This same differencing approach was applied monthly throughout 1975-2017 to create a complete time series of one-dimensional riparian ET demand.

Evapotranspiration of groundwater by phreatophytes was not included in the 2014 version of the groundwater model. However, effects of pumping on groundwater dependent ecosystems—including riparian vegetation—must be addressed in groundwater sustainability plans. Accordingly, the MODFLOW evapotranspiration (EVT) module was added to the 2019 version of the model. For each stream cell in the model, the total canopy width of the riparian vegetation corridor was estimated from inspection of recent aerial photographs (Google Earth). Utilization of groundwater by phreatophytes was assumed to decrease linearly with water table depth, reaching zero when the water table is more than 15 feet below the stream bed elevation.

11.2. Drains

The model successfully simulated upward head gradients in areas where flowing wells have historically been observed: along the lower end of Pacheco Creek and in the San Juan Valley west of San Juan Bautista. By definition, the groundwater elevation at a flowing well is higher than the ground surface. In reality, the water that flows out of wells or discharges from seeps does not pond to any significant depth, but rather flows via ditches to a nearby creek channel. In the San Juan Valley, agricultural tile drains are common in the shallow groundwater area, and most of the drain sumps discharge to San Juan Creek. Drains are less common along lower Pacheco Creek. In that area, the MODFLOW drain package was used to represent surface runoff of discharging groundwater and thereby prevent simulated water levels from rising above the ground surface, which could alter the amount of groundwater discharge simulated by the model. The area with drain cells is shown in **Figure G-3**.

12. MODEL CALIBRATION

Model calibration is a process in which inputs to the model and parameters within the model are adjusted until the model is able to simulate historically observed groundwater levels and flows with a reasonable level of accuracy. The calibration period for the San Benito model was water years 1975-2017 (water years in this case begin October 1 of the preceding calendar year and end September 30). The District has systematically monitored groundwater elevations since 1976. A total of 8,480 measured water levels at 84 well locations were used for calibrating the model and statistically evaluating its accuracy. Stream flow at three gauge locations within the basin—the San Benito River at San Juan Road, Tres Pinos Creek near Tres Pinos and Pacheco Creek at Walnut Avenue—was also compared with stream flows simulated by the model.

12.1. Method

Joint calibration of the surface hydrology model and groundwater flow model was achieved by trial-and-error adjustments of selected variables, as informed by the timing and location of model residuals. The residual for each water-level measurement equals the observed water level minus the simulated water level at that location and date. All inputs to a model are estimates that are subject to errors or uncertainty, but some are better known than others. Also, some have relatively pronounced effects on simulation results. For example, the amount of water pumped by municipal wells is metered and is considered highly accurate compared to most model inputs. Accordingly, the amount of municipal pumping was not adjusted during calibration. Conversely, the rate of leakage from the shallow groundwater zone to the principal water supply aquifer is highly speculative, and plausible values cover a wide range. Variables were selected for adjustment during calibration based on their relative uncertainty, the sensitivity of results to that variable, and whether the variable might logically be connected to an observed pattern of residuals based on hydrologic processes. In practice, most of the calibration effort focused on adjustments to horizontal and vertical hydraulic conductivity, the locations and conductances of faults, stream bed vertical hydraulic conductivity, and several tributary watershed parameters: root depths of natural vegetation, rainfall-runoff thresholds and slopes, and the leakage and recession rates for shallow groundwater. Variables that were not adjusted during calibration include land use, crop root depths, pumping locations, and groundwater pumping (agricultural, municipal, commercial-industrial or rural domestic).

The measured water levels that served as the basis for calibration are themselves subject to substantial uncertainty stemming from wellhead elevation errors, effects of recent pumping at the measured well, and wells that for unknown reasons have water levels inconsistent with water levels at nearby wells. Wellhead elevations were estimated by District staff from U.S. Geological Survey topographic maps with a contour interval of 10 feet. Almost all of the wells used to monitor water levels are active water supply wells. If a well was pumping shortly before the water level is measured, the water level will be much lower (by feet to tens of feet) than if the well had been idle for a day or more. In some hydrographs, pumping-affected water levels stand out as obvious anomalies. A number of those points were removed from the calibration data set. In other cases, water levels fluctuate over a wide range seasonally and between measurements, and pumping effects could not be systematically identified and eliminated. This was particularly true for wells in the Bolsa area, where the degree of aquifer confinement is high and the magnitude of short-term water-level fluctuations is consequently greater. In two wells (12S/5E-22N1 and 13S/5E-3H1) the measured hydrographs exhibited large intermediate-term fluctuations completely unlike the water-level patterns at nearby wells. These appeared to be situations where pumping at the well was discontinued for several years, then later resumed. These wells were omitted from the statistical evaluation of calibration accuracy.

Model performance during the calibration process was evaluated primarily by visual inspection of superimposed measured and simulated water-level hydrographs. Adjustments to model inputs and parameters were made only if two or more wells in a given area exhibited similar patterns of discrepancies between measured and simulated water levels. In accordance with the principle of parsimony in modeling, calibration began with a small number of broad zones for hydraulic conductivity and storativity. Zones were subdivided during calibration if a pattern of residuals at multiple wells warranted it. Although storativity and hydraulic conductivity are not necessarily correlated, in practice they often are to some degree. Thus, for simplicity, the same zonation pattern was used for both variables.

The process of manually calibrating a groundwater model produces considerable insight into the groundwater flow system and the factors that influence it. Water levels for some wells were easy to reproduce with the model, while others were more difficult.

12.2. Results

12.2.1. Aquifer Characteristics

The groundwater model represents the basin fill materials in terms of their ability to store and transmit groundwater. Horizontal and vertical hydraulic conductivity define the permeability of the aquifer, which is its ability to transmit groundwater flow. The ability to store water consists of two components. At the water table, storage of water associated with filling or draining the empty (air-filled) interstices between mineral grains is represented by the specific yield of the aquifer. In deep aquifers, there is a much smaller ability to store and release groundwater that derives from the compressibility of the water and aquifer materials (specific storativity). Thus, the initial response to pumping from a deep aquifer is a large drop in water level (head) within that aquifer. With sufficient time, however, the decrease in head creates downward movement of groundwater that eventually accesses the storage capacity at the water table. In other words, the storage response of the aquifer depends partly on the duration of pumping and observation. For groundwater management purposes, storage responses over periods of months to decades are usually the most relevant.

Aquifer characteristics can be estimated in two ways. The first is by means of an aquifer test in which one well is pumped while water levels are measured at a nearby well. This approach typically measures horizontal hydraulic conductivity over distances of tens to hundreds of feet and storage responses over periods of 1-3 days. The second approach is to calibrate a groundwater flow model such that the aquifer characteristics reproduce measured historical water levels throughout the basin given estimates of historical recharge and pumping. The latter approach produces estimates of aquifer characteristics averaged over spatial scales of thousands to tens of thousands of feet and time scales of months to decades. The estimates account for preferential flow through localized sand and gravel lenses in the basin fill materials and for delayed water-table responses to deep pumping. Also, model calibration provides estimates of vertical hydraulic conductivity across the layers of alluvial deposits, which is rarely measured by aquifer tests. The temporal and spatial scales represented by the model calibration approach are better for addressing most long-term groundwater management questions. Calibration of hydraulic conductivity and specific yield values for the San Benito model were guided by the range of reasonable values for various sediment textures indicated by aquifer tests and calibrated groundwater models in other areas.

Figure G-10 shows the distribution of aquifer characteristics derived from model calibration in model layer 1 (upper left), model layer 2 (upper right) and model layers 3, 4, and 5, which have the same characteristics. The distribution consists of a mosaic of zones of uniform characteristics. A total of 24 zones were delineated, with horizontal and hydraulic conductivities ranging from 0.2 to 120 feet per day (ft/d), vertical hydraulic conductivities from 0.005 to 5 ft/d, specific storativity ranging from 0.000005 to 0.0002 per foot, and specific yield ranging from 0.02 to 0.18.

Horizontal hydraulic conductivity naturally ranges over several orders of magnitude: from 0.01 to 1,000 ft/d for the range of silt, sand and gravel textures found in the basin aquifers (Fetter, 1994). Therefore, the range in the model is reasonable. It should be noted that in flow systems where hydraulic conductivity varies by more than an order of magnitude, almost all of the groundwater movement will be through the relatively permeable zones.

The distribution of horizontal hydraulic conductivity is also reasonably consistent with expected depositional patterns. Coarse, permeable deposits are expected to be relatively abundant where large creeks and the San Benito River enter the basin, and along their present channel alignments in model layer 1. Sediment grain size and permeability are expected to decrease toward the center of the basin due to lower stream gradients and velocities. Also, relatively continuous silt-clay layers must be present at lower elevations in the basin to produce the flowing artesian wells that were widespread prior to 1920 (Clark, 1924) and reappeared in similar locations following groundwater recovery in the 1990s. Hydraulic conductivity in hilly upland areas is also relatively low, partly due to the finer average grain size and greater degree of consolidation of those geologic formations and partly due to folding and local faulting that act to impede horizontal groundwater flow.

The hydraulic conductivity values across faults included in the model are shown in **Figure G-11**. The values assume a fault plane thickness of 1 foot and were obtained entirely by calibration to match the observed difference in water levels across the fault. Faults can obstruct groundwater flow by offsetting permeable layers within the basin fill and by creating a shear zone of crushed material (fault gouge) that has relatively low permeability.

12.2.2. Water Levels

Hydrographs comparing simulated with measured water levels during water years 1975-2017 were prepared for the 84 well locations shown in **Figure G-12**. The hydrographs are shown in **Figure G-13 a through f** according to township/range location or generally west to east. At most wells, the model reproduces the water level history reasonably well, including the long-term recovery from overdraft, water-level declines during the 1987-1992 drought, subsequent rapid recovery during the 1990s, the leveling off of water levels at wells that recovered to the elevation of a nearby stream, and another cycle of decline during the 2013-2015 drought.

The difference between each measured water level and the corresponding simulated water level is the residual. Residuals can be summarized statistically to obtain an objective measure of model performance. The model calibration guidelines presented in ASTM D-5490-93 recommends that these statistical summaries be calculated. The residuals statistics are not a completely objective measure of model performance because some water-level measurements were omitted or assigned a low weight based on a subjective conclusion that they were not representative of ambient groundwater conditions (such as a measurement made while the well pump was operating). Measurements that clearly appeared to be affected by pumping (much lower than prior and subsequent measurements at that well) were omitted from the calibration set in this case, but most were retained even if they seemed “noisy”.

Deciding whether model performance is “good enough” based on residuals statistics is also subjective. A common rule of thumb is to consider model performance acceptable if the root-mean-squared residual is less than 10 percent of the total range of measured water levels (Environmental Simulations, Inc., 2011). In the present case, the total elevation range of the 8,480 water-level observations was 780 feet. The mean residual was -8.68 feet, which indicates a slight bias toward simulated water levels that are higher than measured water levels. Most of this bias is in the Bolsa area, where simulated water levels are generally near the upper part of the broad spread of measured water levels (many of which are probably low due to recent or nearby pumping). In other cases, large discrepancies were associated with localized patterns that calibration adjustments were simply unable to reproduce. For example, measured water levels in several wells in the area around McCloskey, Fallon and Fairview Roads (wells 12S/5E-36B20, -24N1, and to a lesser degree -14N1 and -23A20) stayed flat or declined during 1976-1984 then rose during 1985-1992, which was opposite of the simulated trends and the observed trends at most wells. No combination of model parameters and inputs was able to reproduce this local pattern.

The root-mean-squared error (RMSE) was 3.5 percent of the range of water levels. **Figure G-14** shows a scatterplot of simulated versus observed water levels. Although there is some spread to the data cluster, it is fairly centered on the 1:1 line throughout the range of water levels. The RMSE is most sensitive to the largest discrepancies between measured and simulated water levels. Simulated water levels are mostly higher than measured water levels in the Bolsa area at the low end of the elevation range. This is because most of the measured water levels are probably affected by pumping. At the high end of the elevation range, the model had difficulty simulating a water level profile along Paicines Valley as flat as the measured profile, so many simulated water levels at the upstream end of the valley are consistently higher than the measured water levels.

Contours of simulated groundwater levels are shown in **Figure G-15** for October 1992 and in **Figure G-16** for March 2012. Measured water levels on those dates are posted as points. The fall 1992 contours represent a condition of drought-related low water levels prior to the importation of significant quantities of water. The spring 2012 water levels represent the basin in a near fully-recovered state under normal climatic conditions. Faults cause conspicuous stair-steps in the water-level surface in both maps. On the earlier date, water levels in the Hollister Subbasin east of the Calaveras Fault had yet to recover from overdraft during prior decades. A broad pumping trough in that area was centered around the airport. By 2012, water levels in that area had mostly recovered, and a northwesterly gradient prevailed throughout that area.

12.2.3. Stream Flow

Simulated stream flow was compared with measured stream flow at three locations within the basin where stream gauges were operating during all or part of the calibration period.

To be consistent with model output, measured daily flows were averaged to monthly values. **Figure G-17** shows flows in Pacheco Creek at Walnut Avenue, Tres Pinos Creek near Tres Pinos and the San Benito River at San Juan Road. At the Pacheco Creek gauge, the simulated pattern of high and low flows generally matched the measured pattern, although the model tended to slightly more small flow events. At the Tres Pinos Creek gauge, simulated stream flows were generally smaller and less frequent than measured flows. The model probably slightly overestimates subsurface flow at that location. At the San Benito River gauge near San Juan Road, the model consistently produces too much base flow, on the order of 10-20 cfs. This is the opposite of the Tres Pinos Creek bias and likely is associated with an underestimate of subsurface flow along the river corridor at that location. Relatively small changes in aquifer hydraulic conductivity can noticeably change the amount of flow shunted from groundwater to surface water or vice versa.

12.2.4. Water Balance

The ZoneBudget post-processing program was used to extract annual water balances from the model for the four management areas in the basin. **Figures G-18 through G-21** show annual inflows and outflows during 1975-2017 as stacked bars for each of the four management areas. Annual storage change is not included in the stacked bars; rather, cumulative storage change is shown as a line.

In the Southern MA, inflows were dominated by large amounts of stream percolation and rainfall recharge in exceptionally wet years. That recharge raised groundwater levels, which concurrently increased groundwater discharge back to the streams along gaining reaches. The apparent long-term increase in storage is mostly an artifact of selecting initial water levels in upland areas (where no data are available) that were too low, and partly the result of average annual rainfall during 1975-2017 that was slightly higher than the longer-term average.

In the Hollister MA, rainfall and stream recharge are also large during wet years, but other inflows—including irrigation deep percolation, bedrock inflows and inflows from other management areas—is relatively steady. Outflows are dominated by agricultural groundwater pumping, followed by relatively steady outflows to other management areas. The cumulative increase in storage during 1975-2017 was real. Importation of CVP water beginning in the early 1990s resulted in rapid recovery from prior decades of groundwater overdraft. The pattern of inflows and outflows was generally similar in the San Juan MA, which also received CVP water.

In the Bolsa MA, relatively steady subsurface inflows of groundwater from other MAs and the Llagas Subbasin comprise a substantial part of total inflows. Recharge from rainfall and streams are significant but vary greatly from year to year. Agricultural pumping is by far the largest outflow, followed by groundwater discharge to the Pajaro River when groundwater levels are relatively high. There was little long-term change in storage in the Bolsa MA.

13. SIMULATION OF FUTURE CONDITIONS

The historical period used for model calibration consisted of only 43 years (water years 1975-2017). Longer periods were needed to simulate future conditions. To comply with the Sustainable Groundwater Management Act, future simulations needed to include at least 50 years, and design work for possible expansion of Pacheco Reservoir was based on the 1922-2003 period simulated by DWR's CalSim2 model. These needs were met by simulating water years 1922-2007 as two back-to-back 43-year simulations (1922-1964 followed by 1965-2007). This period takes advantage of DWR's CalSim2 simulations of CVP availability, which cover the period 1922-2003. It also includes the two largest droughts in the historical record: 1923-1935 and 1987-1992.

The future baseline simulation serves as a reference condition against which to compare alternative management scenarios. Data and assumptions used in the future baseline simulation are described in Section 5 of the GSP ("Water Budget"). Inputs and results of the "climate change" and "future growth" scenarios are described in Section 8 ("Management Actions"). Other scenarios related to specific management actions recommended in the GSP are also described in Section 8.

14. MODEL LIMITATIONS

The groundwater flow model is an appropriate tool for evaluating groundwater conditions at the basin and subarea scale over periods of months to decades. Given its reasonable calibration under a wide range of historical hydrologic and water management conditions, it should produce reliable results under a similar range of future conditions. However, some aspects of the model and some types of applications may be less reliable. Limitations in model accuracy and in types of applications include the following:

- As with any regional model, the model cannot simulate details of water levels and flow at spatial scales smaller than one model cell. It cannot, for example, simulate drawdown within a pumping well. It can only simulate the average effect of that pumping on the average water level of the cell in which the well is located.
- The monthly stress periods of the model preclude simulation of brief hydrologic stresses. For example, the model cannot simulate the effects of daily pumping cycles on water levels, or the amount of recharge associated with peak stream flow events.
- The vertical dimension of the model is relatively crudely implemented, and its accuracy is unknown due to lack of depth-specific water-level data. With a few local exceptions, model layers do not correspond to known geologic horizons. The distribution of pumping among layers is by fixed percentages that bear some relation to layer thickness but not transmissivity. Given the lack of depth-specific water-level data within the main production interval (roughly 150-600 feet below ground surface) it was not possible to calibrate vertical hydraulic conductivity in

most areas. An exception was the constraint on vertical hydraulic conductivity imposed by the occurrence of flowing wells in two areas.

- Surface and subsurface inflows from tributary watersheds around the perimeter of the basin remain uncertain. The new rainfall-runoff-recharge model simulates watershed hydrology explicitly but flows from the watersheds to the groundwater basin are small compared to rainfall and ET. Accurate data for those variables within the watershed areas are not available, and a small error in rainfall or ET can result in a large error in simulated watershed outflow.
- Model calibration is better in some parts of the basin than others. For any future model application that focuses on a particular subarea, it would be prudent to evaluate the quality of model calibration for that area before conducting simulations of alternative conditions.

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TableG-1. 2014 Land Use by Management Area (acres)

	1	2	3	4	5	
Land Use	**Bolsa**	**Hollister**	**San Juan**	**Southern**	**Watersheds**	**Total**
Subtropical	0	42	17	0	0	59
Deciduous orchard	452	4,976	797	240	125	6,590
Field crops, irrigated	953	2,316	581	330	60	4,240
Grain, nonirrigated	2,510	4,612	342	847	3,552	11,863
Idle	218	437	628	831	403	2,517
NV-riparian	161	318	460	478	112	1,530
Not surveyed	0	0	0	0	0	0
NV-grass	7,977	22,950	14,732	48,877	218,682	313,218
NV-brush	0	411	0	226	64,445	65,083
NV-brush/trees	6	63	0	0	56,665	56,734
Water	195	22	264	175	155	811
Pasture, nonirrigated	5,708	564	60	123	420	6,874
Rural residential	56	1,740	82	53	110	2,041
Semiagricultural	379	536	56	92	312	1,375
Small vegetables	951	7,378	5,756	820	4,665	19,570
Small vegetables, Bolsa	3,370	764	0	0	0	4,134
Urban commercial	0	712	62	13	73	861
Urban industrial	14	297	424	36	105	876
Urban turf	0	522	343	91	1	958
Urban residential	5	3,370	251	6	90	3,722
Urban vacant	0	367	0	0	40	408
Vineyard	0	163	0	1,743	1,252	3,158
Total	22,955	52,560	24,857	54,979	351,268	506,620

Table G-2. Monthly Crop Coefficients for Vegetation Types Simulated by the Recharge Program

Agricultural	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subtropical[1]	0.50	0.50	0.50	0.50	0.50	0.63	0.91	0.82	0.49	0.46	0.50	0.50
Deciduous orchard[2]	0.20	0.20	0.25	0.35	0.50	1.10	1.10	1.10	1.10	0.65	0.20	0.20
Field crops, irrigated[3]	0.50	0.50	0.50	0.50	0.50	0.63	0.91	0.82	0.49	0.46	0.50	0.50
Grain, nonirrigated[4]	0.90	1.05	1.05	0.90	0.50	0.20	0.20	0.20	0.20	0.24	0.33	0.65
Idle (bare soil)[5]	0.90	0.80	0.50	0.30	0.20	0.20	0.20	0.20	0.20	0.30	0.50	0.90
Pasture, nonirrigated[6]	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Small vegetables[7]	0.50	0.50	0.50	0.60	0.80	0.95	0.95	0.95	0.85	0.60	0.50	0.50
Small vegetables - Bolsa	0.50	0.50	0.50	0.50	0.40	0.65	0.90	0.95	0.85	0.60	0.50	0.50
Vineyard[8]	0.81	1.05	1.05	0.90	0.50	0.35	0.45	0.50	0.50	0.20	0.33	0.57
Natural												
Riparian phreatophytes[9]	0.75	0.75	0.75	0.75	0.85	1.00	1.10	1.10	1.10	0.95	0.85	0.75
Grass[10]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Brush[11]	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Trees[11]	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Water[12]	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
Urban[13]												
Rural residential	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Semiagricultural	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Commercial	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Industrial	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Lawn, golf course, sod farm	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Residential	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Vacant or paved	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80

Sources and Assumptions

Note: FAO 56 = U.N. Food and Agriculture Organization Publication 56 (2006). BIS = Basic Irrigation Scheduling computer program by Snyder and others (2007). Bulletin 113-3 = DWR (1975). ITRC = Irrigation Training and Research Center (2003).

Kc = crop coefficient.

1 FAO 56, Table 12 (single Kc by growth stage). The low-Kc season is assumed to be winter in CA.

2 Kc for walnuts from FAO 56 Table 12 for May-Oct; bare soil (0.2) for other months plus some cover crop ET Mar-Apr.

3 ITRC values shifted to summer season. Assume bare soil = K_{ini} from FAO 56 (typically 0.20).

4 BIS Kc for winter grains. Assume other months are bare soil at Kc=0.20

5 Assume similar to reference ET conditions in winter. Automatically depletes soil moisture in summer until soil is dry (nonirrigated), so summer Kc not important.

6 Most areas mapped as pasture are not irrigated. ET in winter is close to ETo. Soil moisture depletion in summer reduces Kc.

7 Assume these are cool season crops (e.g. lettuce, broccoli, celery) grown March-November (April-November in Bolsa) with staggered plantings. Full-canopy Kc is 0.90-1.0. Time-weighted average Kc over the entire crop growing period was calculated for 10 cool-season truck crops from FAO 56 growth-stage Kc values (Kc as % of growing season). Average was 0.78. Decreased slightly here to reflect brief idle periods between crops (bare soil at Kc=0.20).

8 Assume 3-ft-wide canopy and 10-foot row spacings, using equations from Williams (2001). With winter cover crop of grasses simulated as nonirrigated grain.

9 Assume mostly trees (cottonwood, sycamore, willow), deciduous with shrub willow understory (willow Kc in winter). Monthly Kc values reflect total canopy leaf area and unrestricted root access to water.

10 Similar to reference ET conditions in winter. Annual grasses deplete soil moisture in summer until soil is dry, so summer Kc not important.

11 Kc less that 1.0 because of drought-tolerant adaptation to carry some soil moisture over to following year (Blaney and others, 1964). Soil moisture depletion in summer is not as extreme as for annual grasses.

12 Farm ponds (e.g. for vineyard frost protection). Evaporation estimated as average ratio of pan evaporation to ETo (1.26) multiplied by a pan-to-lake coefficient of 0.9 (for a pond or small lake).

13 Irrigation in all urban land use categories assumed to be for turf. Turf Kc from BIS.

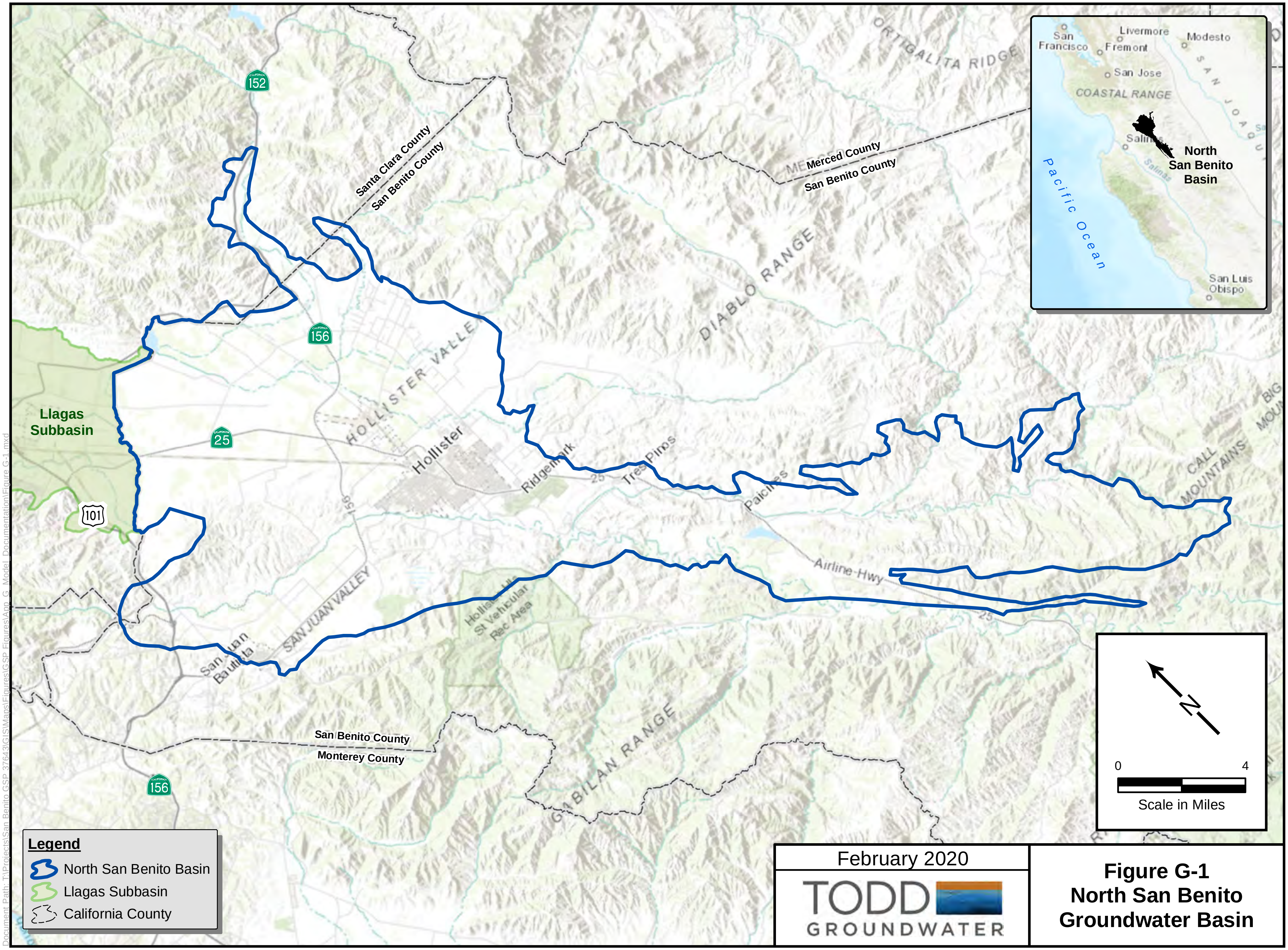

Figure G-1
North San Benito Groundwater Basin

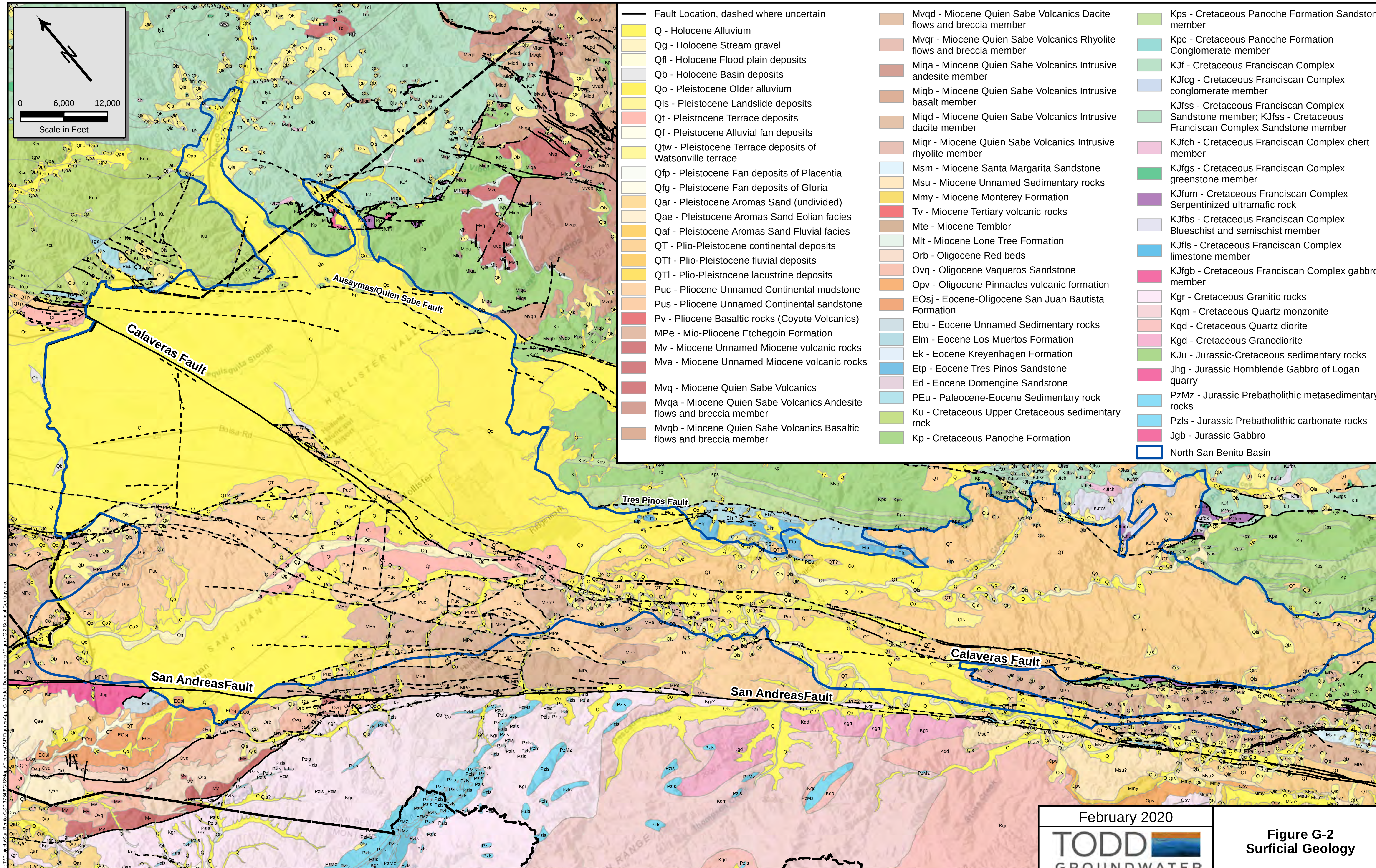

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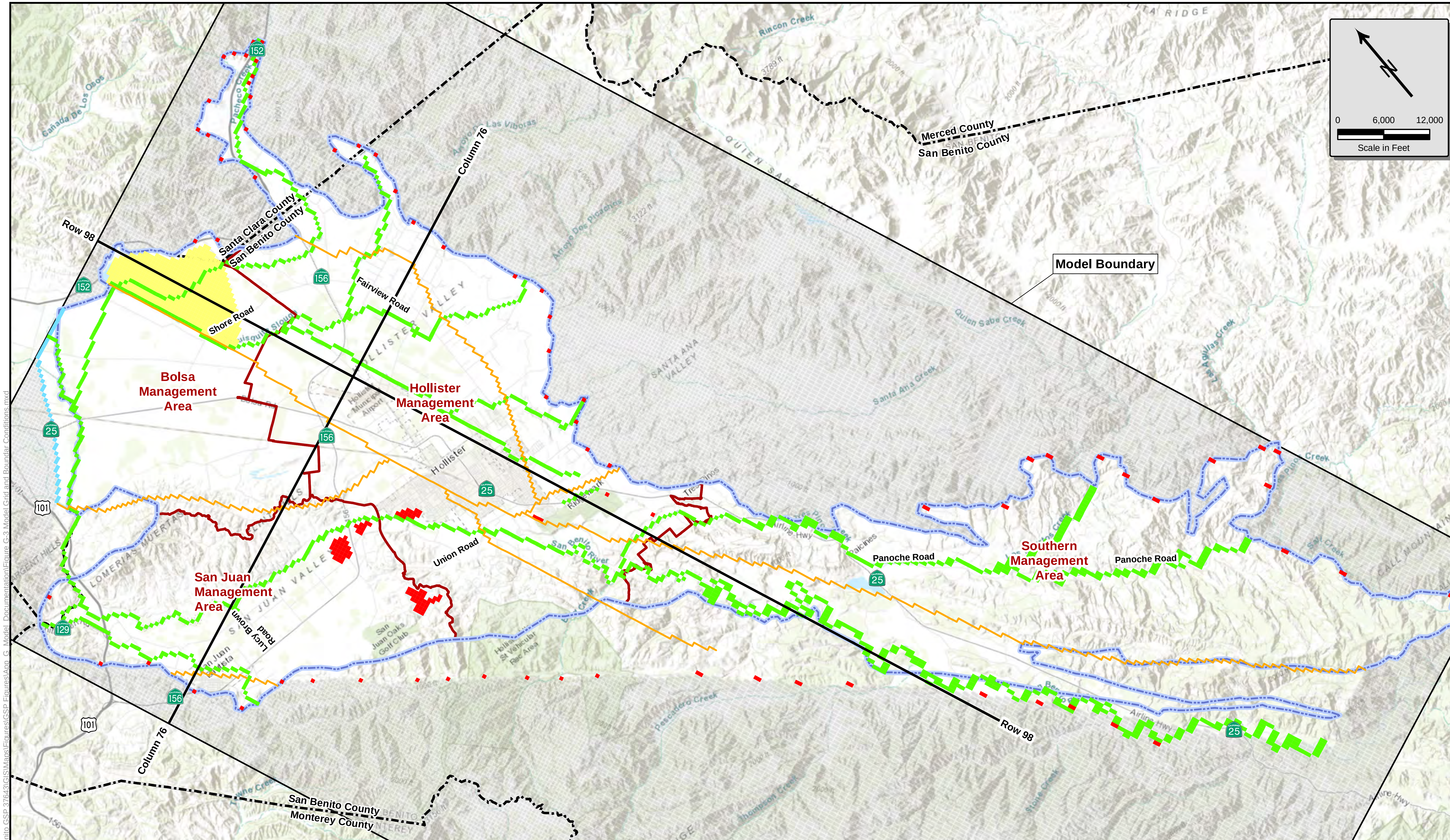
Figure G-2
Surficial Geology



Management Areas	Flowing Wells Area	Stream Cells	Faults in Model
North San Benito Basin	Subsurface Inflow from Llagas	Inactive Cells	Cross Section Line
San Benito County	Wastewater Ponds, San Justo and Bedrock Inflow		

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Figure G-3
Model Grid and Boundary Conditions

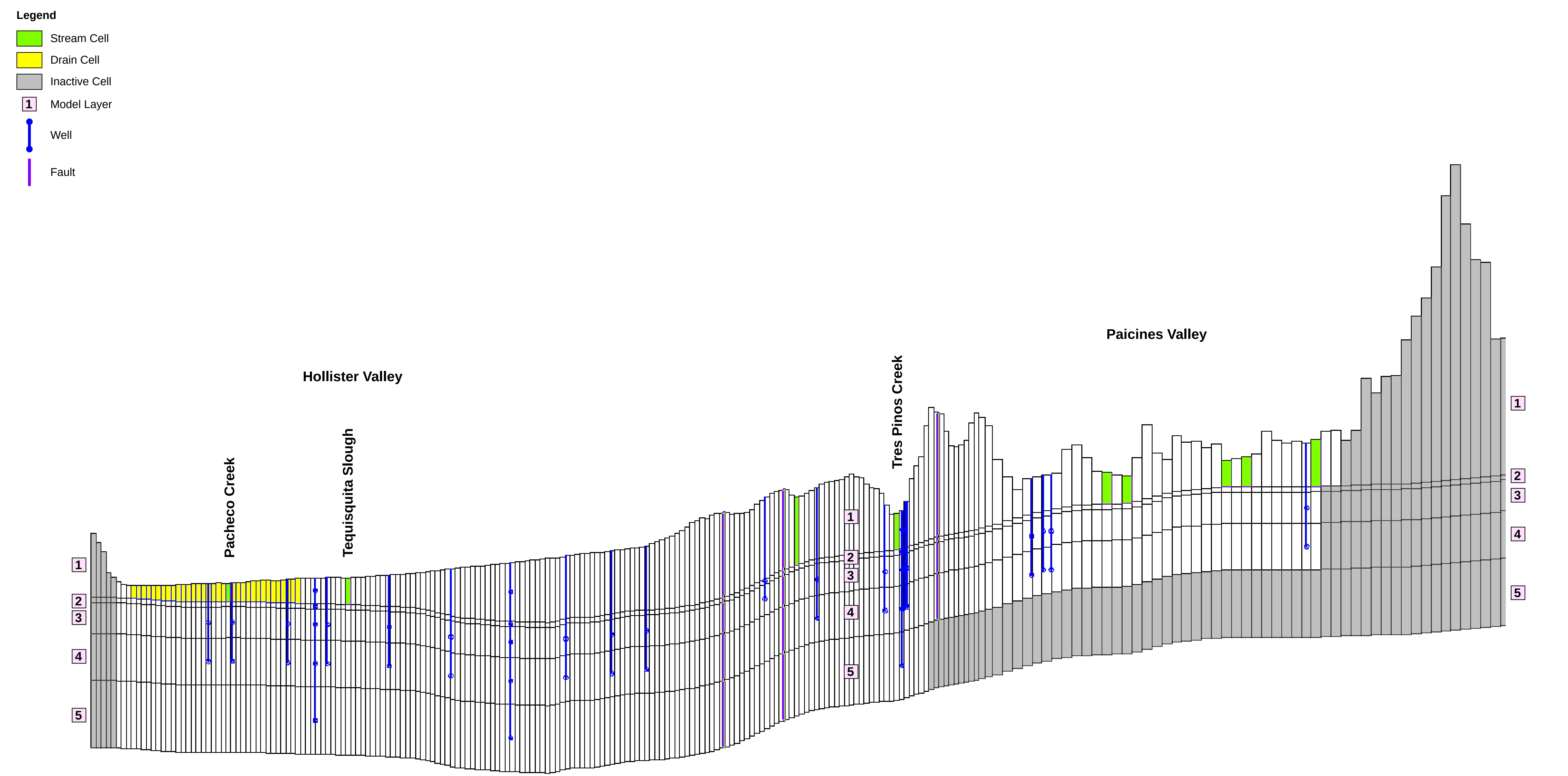

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Figure G-4
Cross Section of Model Grid Along Row 98

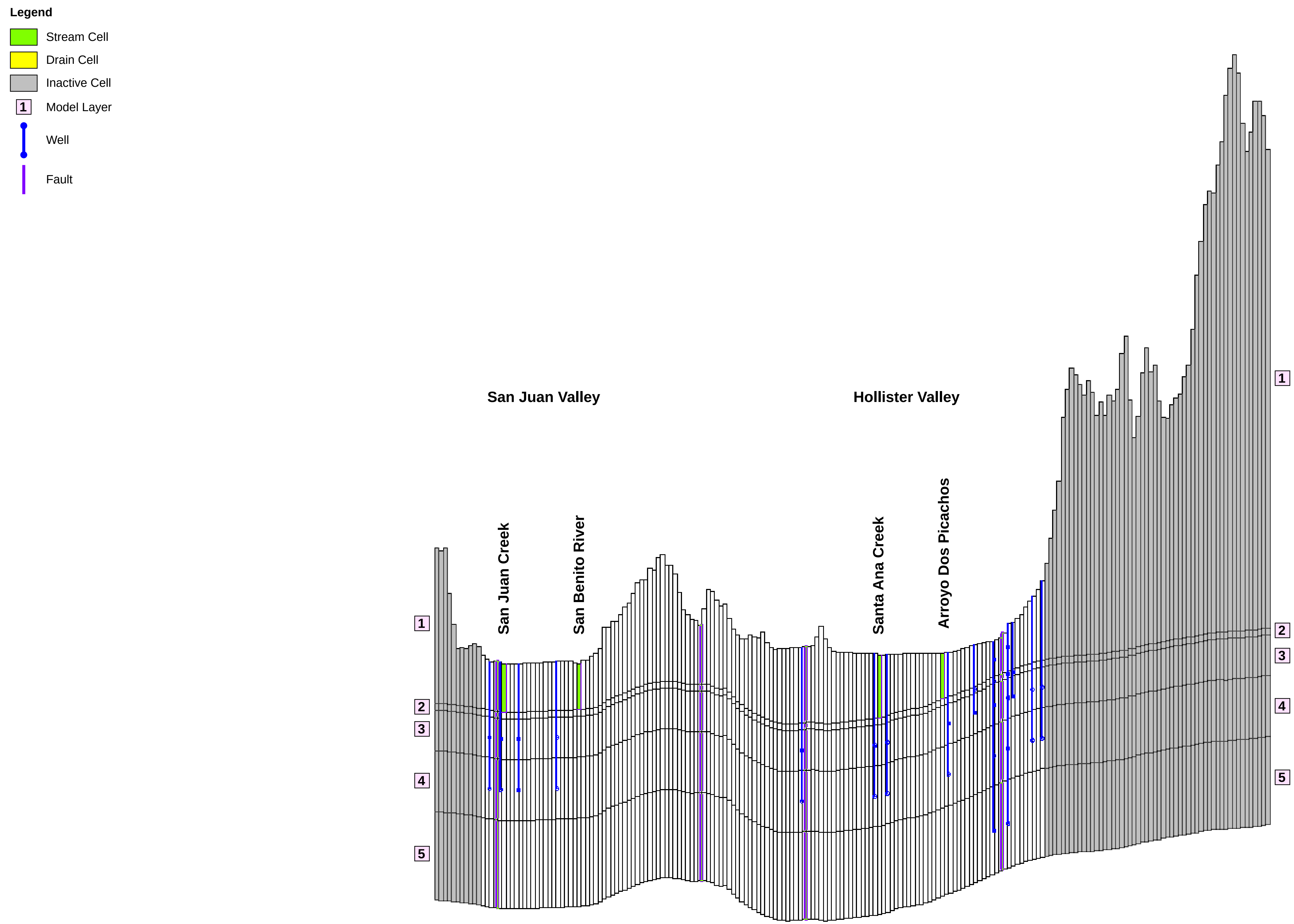

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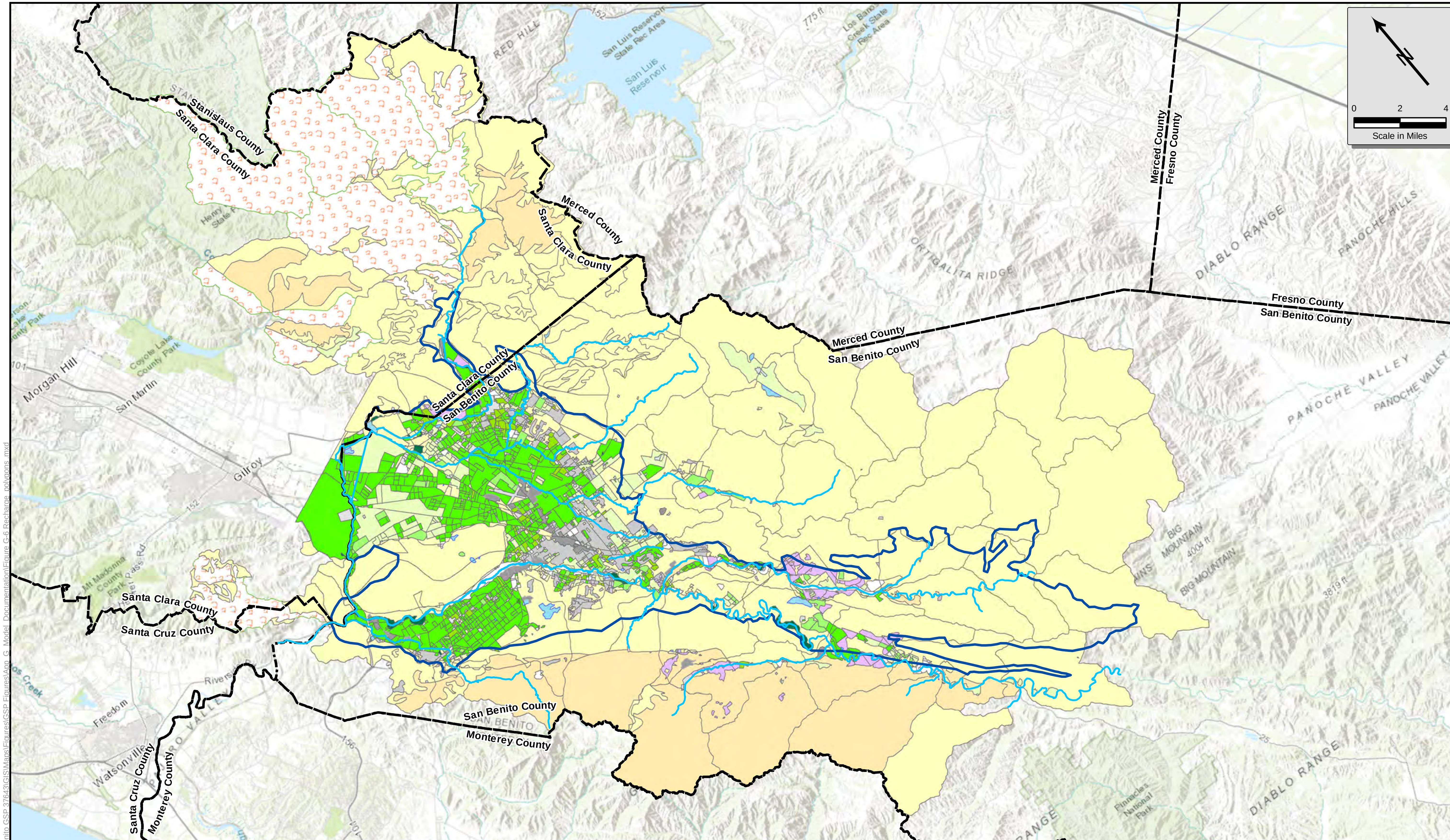
Figure G-5
Cross Section of Model Grid Along Column 76



North San Benito Basin	**2014 Land Use**	Grain, nonirrigated	NV-grass	Semiagricultural	Urban industrial	Vineyard
	Citrus	Idle	NV-riparian	Small vegetables	Urban residential	Water
	Deciduous orchard	NV-brush	Pasture, nonirrigated	Small vegetables, Bolsa	Urban turf	
	Field crops, irrigated	NV-brush/trees	Rural residential	Urban commercial	Urban vacant	

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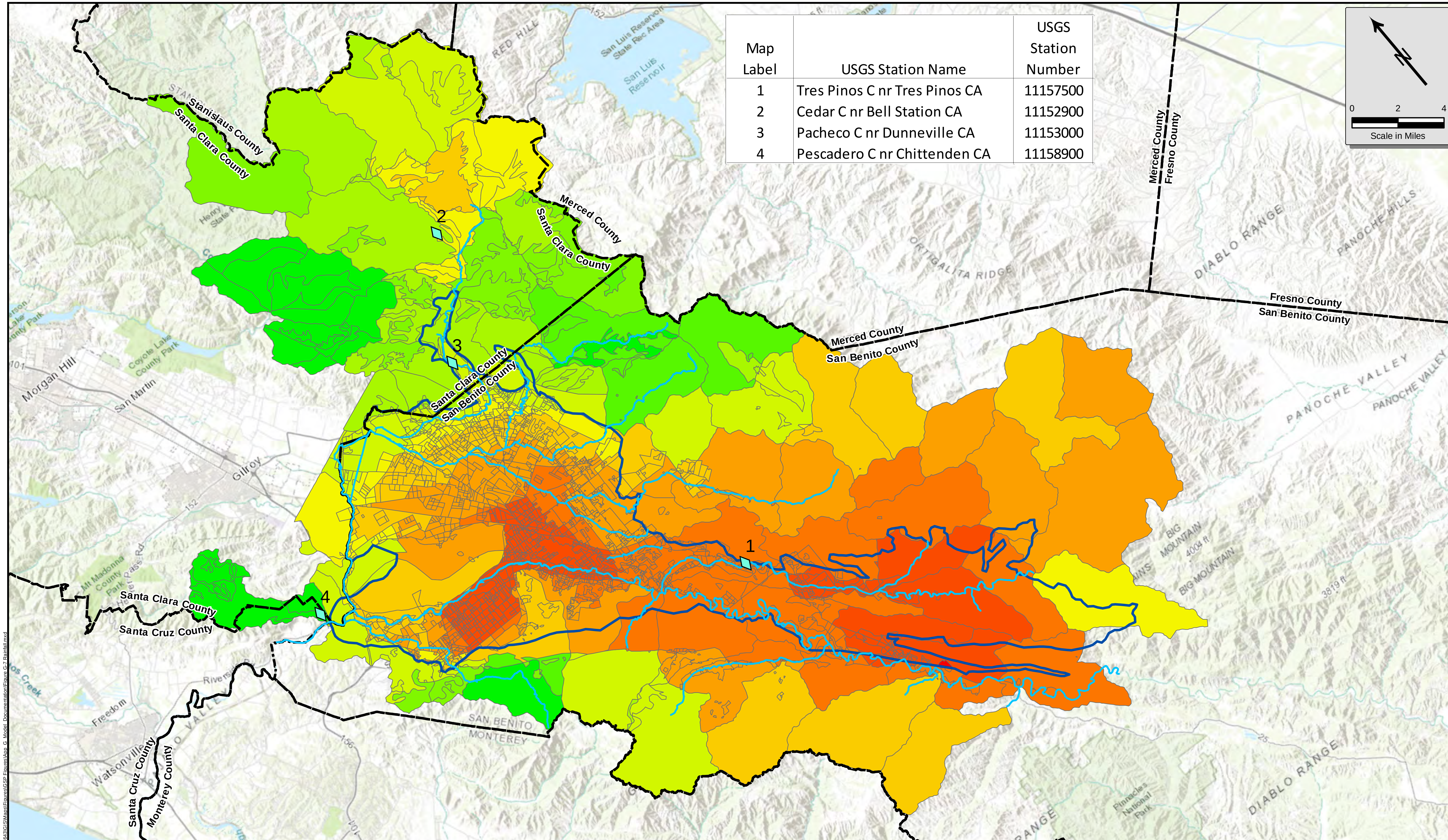
Figure G-6
Rainfall-Runoff-Recharge Polygons



Map Label	USGS Station Name	USGS Station Number
1	Tres Pinos C nr Tres Pinos CA	11157500
2	Cedar C nr Bell Station CA	11152900
3	Pacheco C nr Dunneville CA	11153000
4	Pescadero C nr Chittenden CA	11158900

Stream Gauge

North San Benito Basin

Average Annual Precipitation (inches)

14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
20 - 21
21 - 22
22 - 23
23 - 26

Source: PRISM_ppt_30yr_normal_4kmM2_annual_bil

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Figure G-7
Average Annual Precipitation

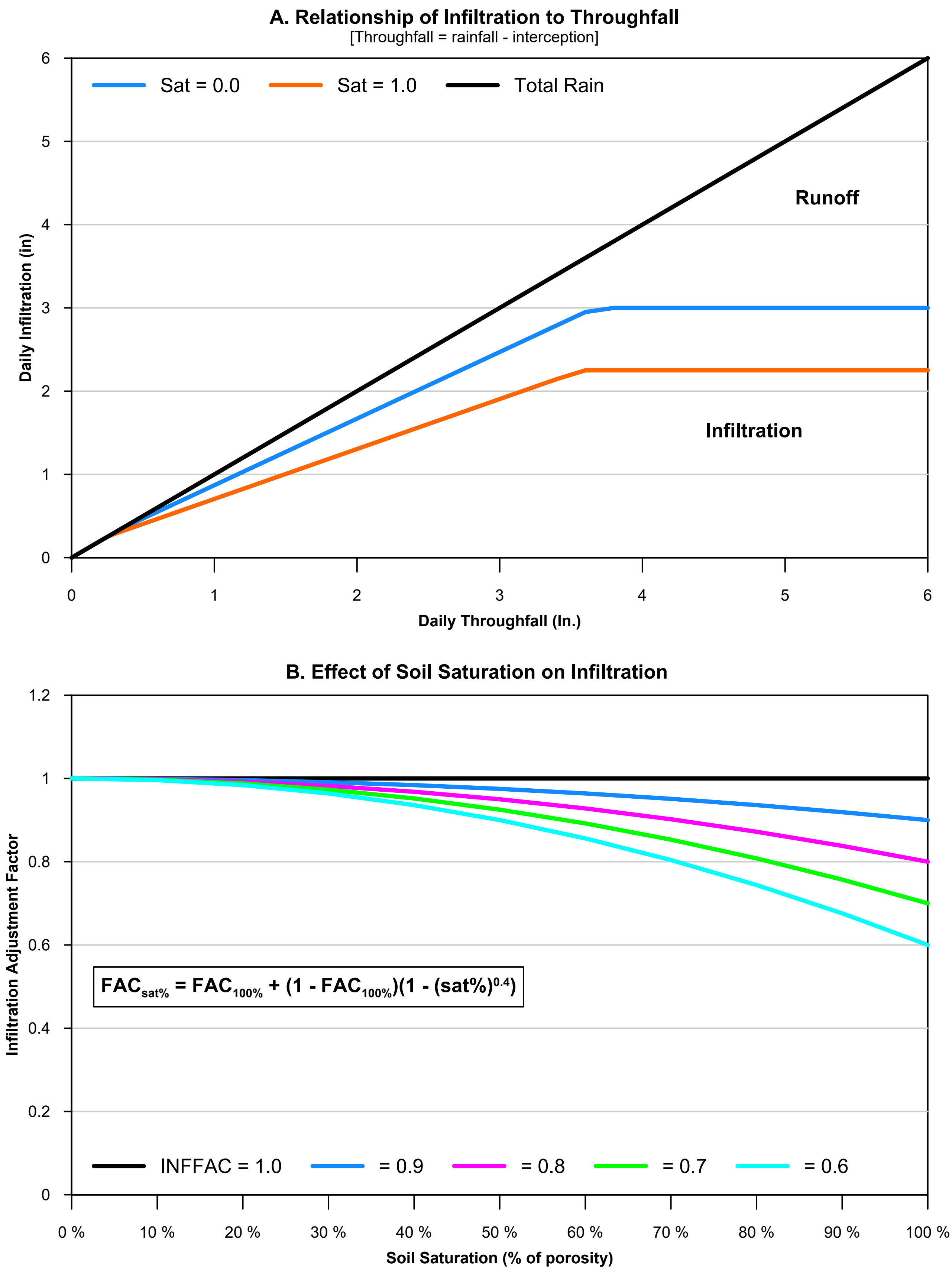

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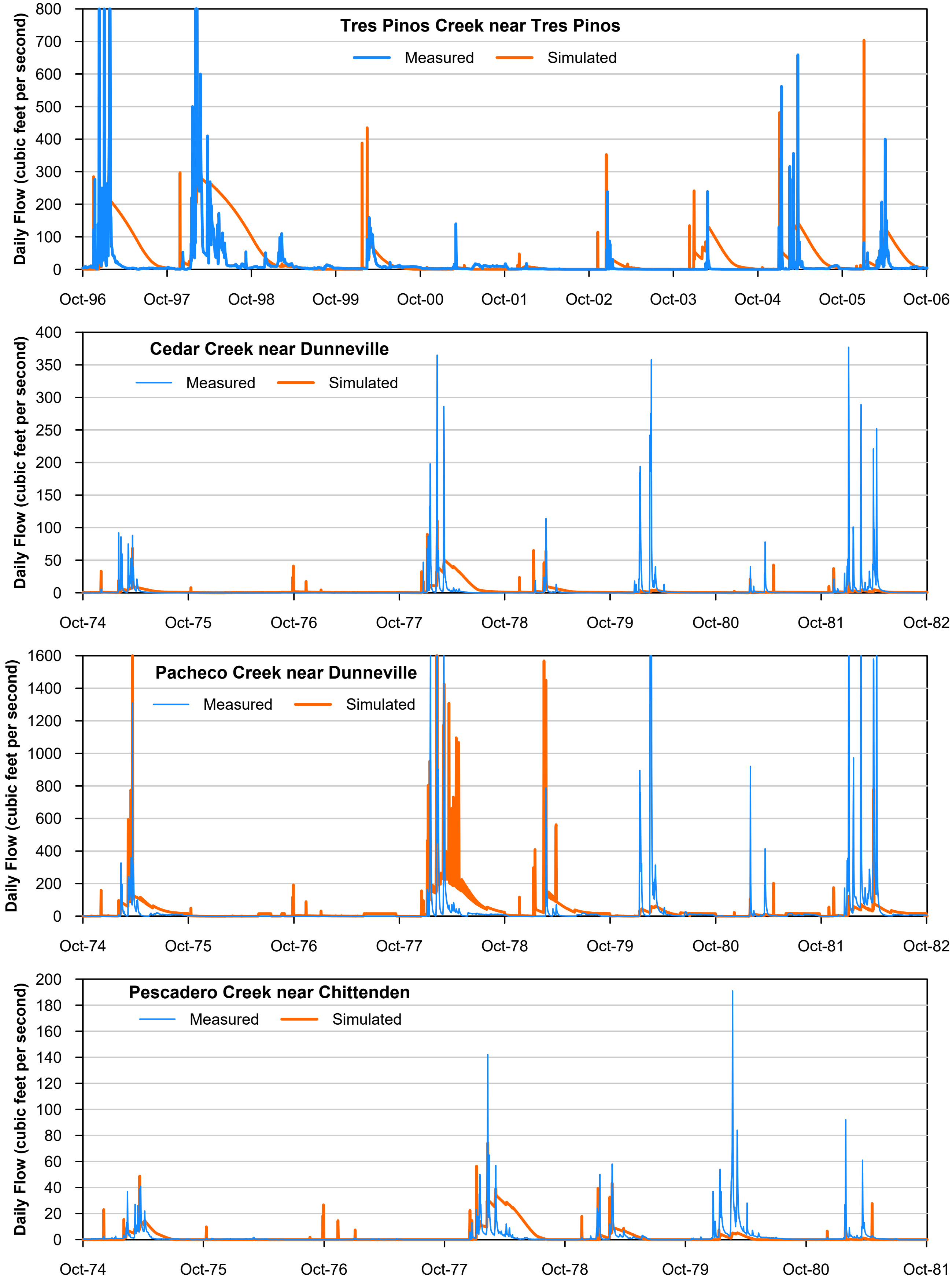
Figure G-8
Relationship of Infiltration to Throughfall and Soil Saturation

Data:
T:\Projects\San Benito GSP 37643\Model\RCH\Antecedent_moisture_adjustment.xls Sheet1

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-8 Relationship of Infiltration to Throughfall and Soil Saturation.gpj



Data:
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Sheet: RechargeSimstreamQ
Columns: BL-BV

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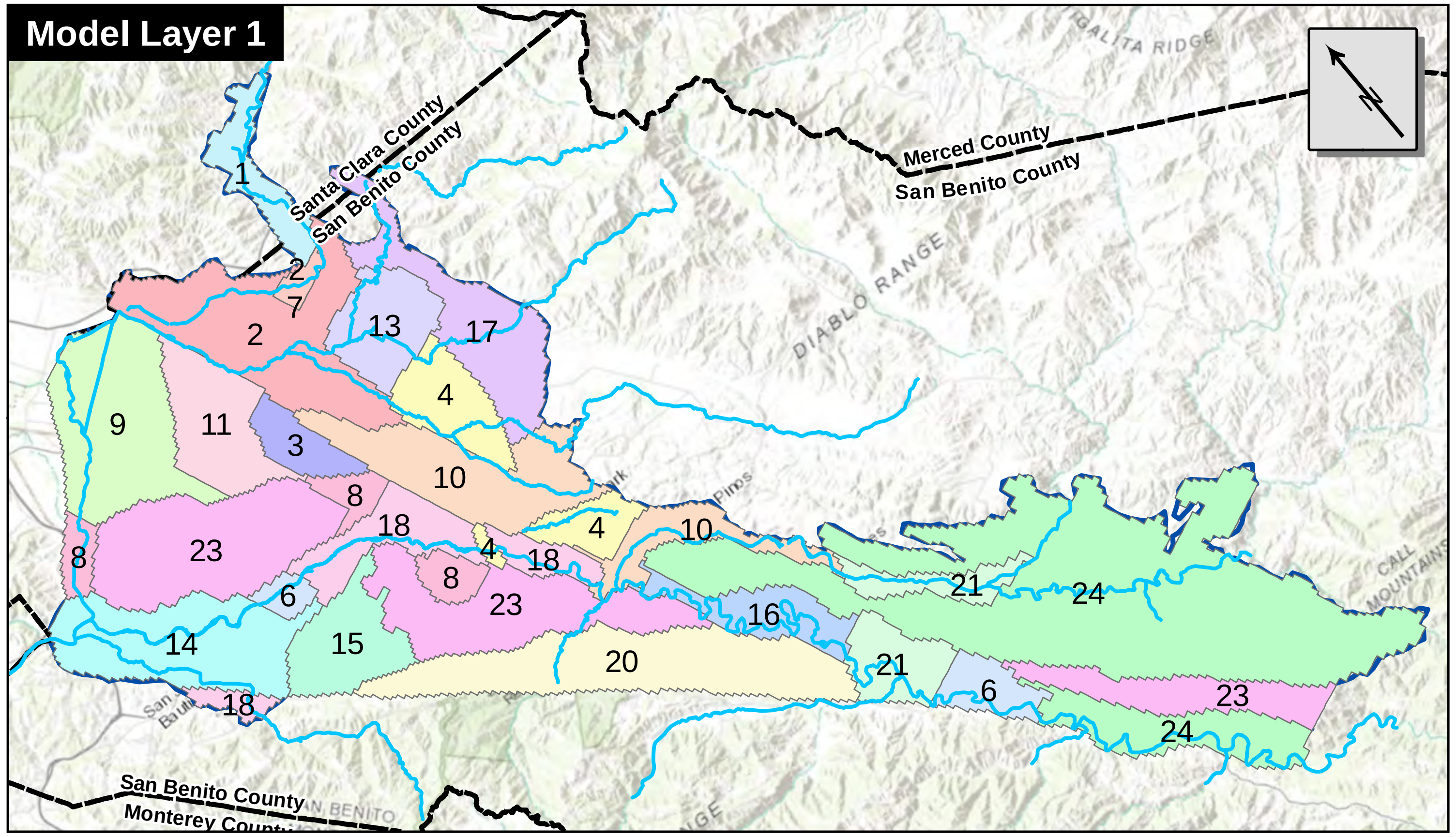
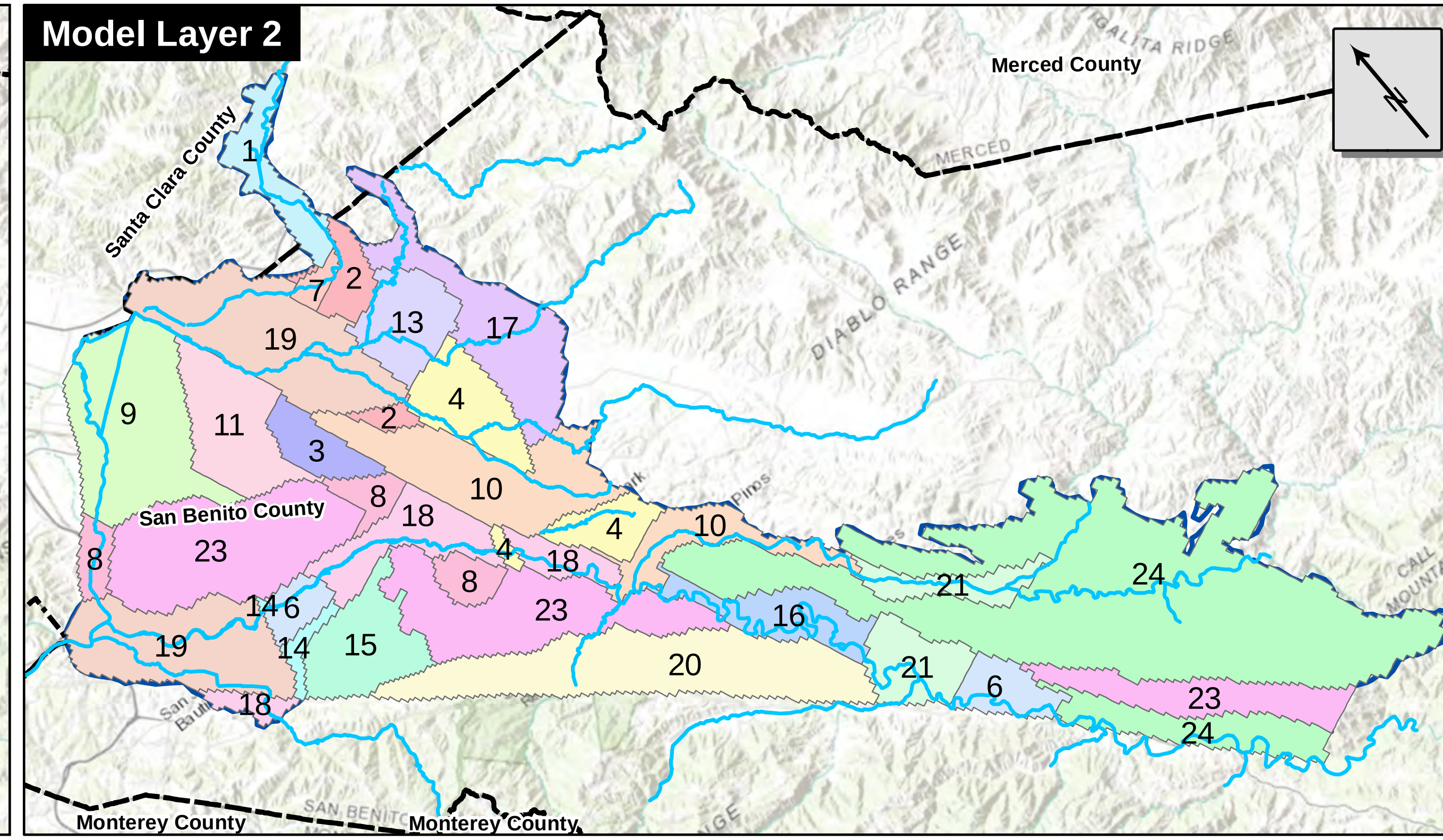
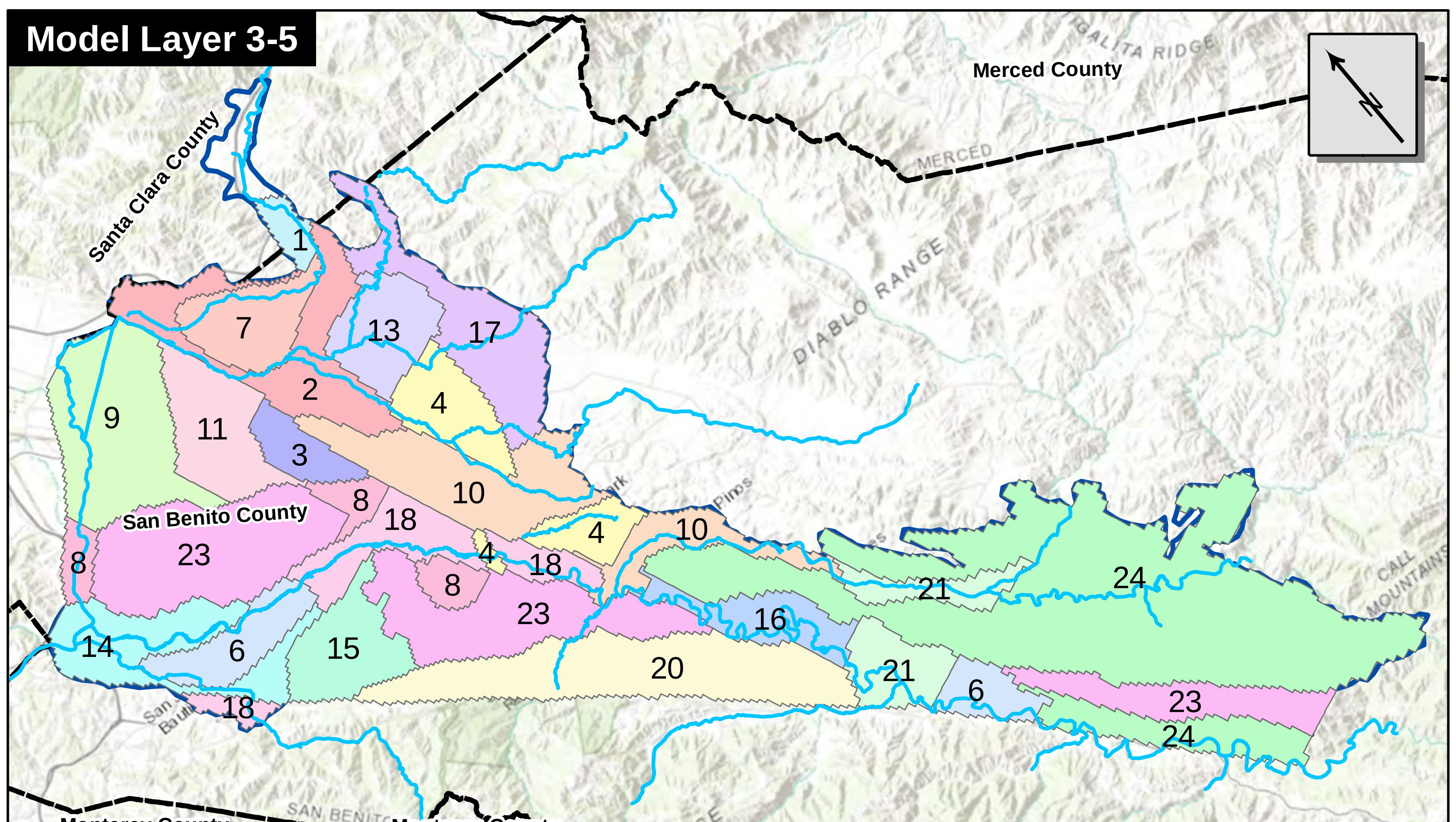
Figure G-9
Measured and Simulated Daily Stream Flows

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-9 Measured and Simulated Stream Flows.gpj







Map No.	Kh	Kv	S_0	Sy	Map No.	Kh	Kv	S_0	Sy
1	140	2	7.00E-05	0.07	13	11	0.5	5.00E-05	0.1
2	4	0.05	2.00E-05	0.1	14	4	0.02	7.00E-05	0.15
3	60	0.5	5.00E-06	0.02	15	1.5	0.3	7.00E-05	0.15
4	4	0.5	7.00E-05	0.07	16	4	0.5	7.00E-05	0.1
5	60	0.05	7.00E-05	0.15	17	4	0.5	5.00E-05	0.1
6	120	5	7.00E-05	0.15	18	70	0.1	1.00E-04	0.18
7	100	0.5	1.00E-05	0.01	19	1	0.005	5.00E-05	0.1
8	3	0.1	2.00E-04	0.1	20	1	0.01	5.00E-05	0.1
9	20	1	5.00E-06	0.02	21	80	0.05	5.00E-05	0.12
10	6	0.5	7.00E-05	0.1	22	4	0.2	5.00E-05	0.15
11	6	0.1	5.00E-06	0.02	23	0.2	0.02	1.50E-05	0.05
12	100	1	2.00E-05	0.1	24	0.8	0.08	5.00E-05	0.1

Kh = horizontal hydraulic conductivity (feet per day)
Kv = vertical hydraulic conductivity (feet per day)
So = Specific storativity (per foot)
Sy = Specific yield (dimensionless)

0 2 4
Scale in Miles

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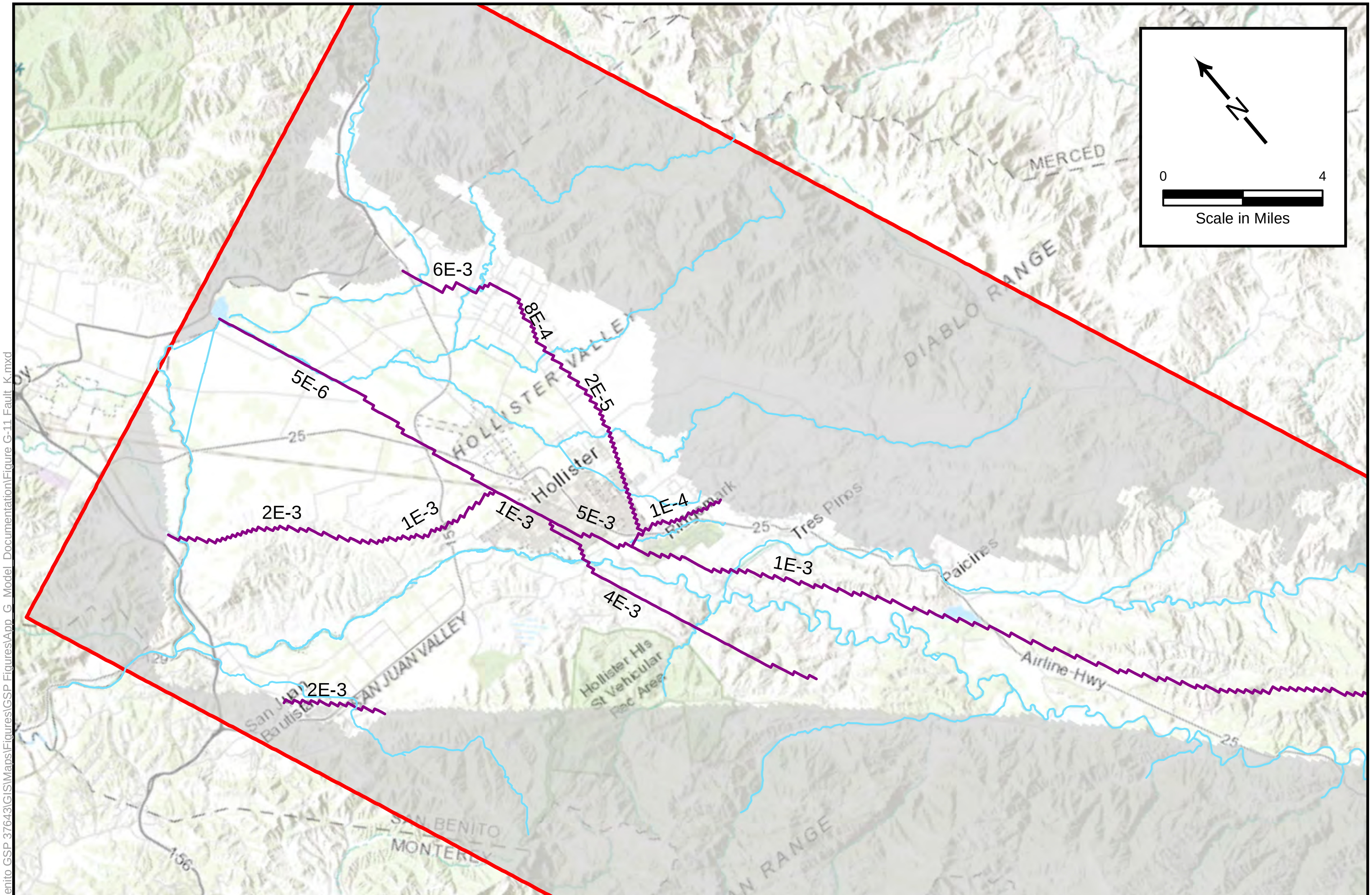
Figure G-10
Calibrated Aquifer Characteristics

Path: T:\Projects\San Benito GSP 37643\GIS\Maps\Figures\GSP Figures\App_G_Model_Documentation\Figure G-10 Aquifer characteristics.mxd



2E-3 Fault cells with hydraulic conductivity in feet per day assuming fault plane is 1 foot thick

Model grid outline

Inactive cells

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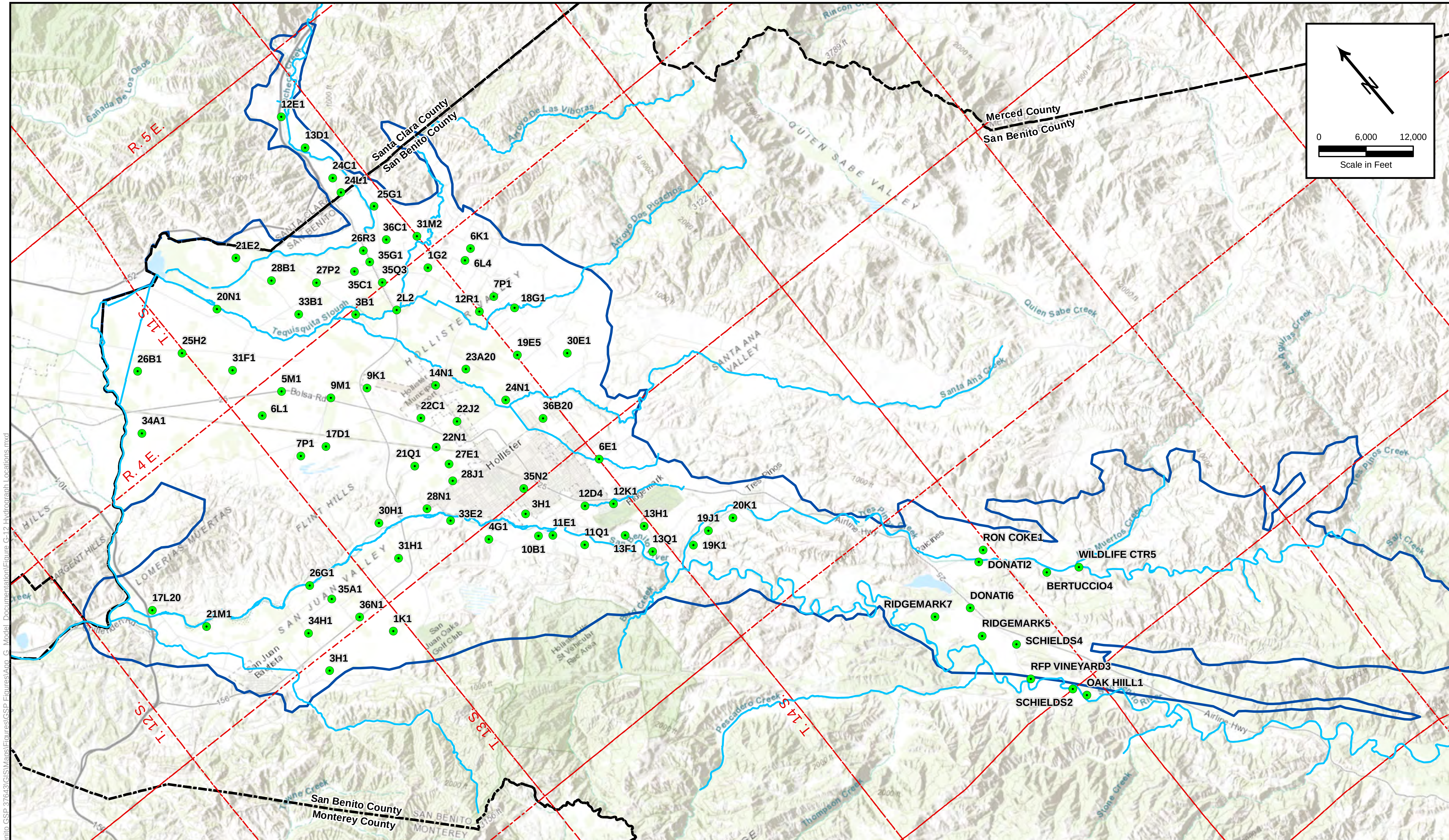
Figure G-11
Fault Plane Permeabilities

Path: T:\Projects\San Benito GSP 37643\GIS\Maps\Figures\GSP Figures\App_G_Model_Documentation\Figure G-11 Fault_K.mxd



- Hydrograph Well
- Township
- North San Benito Basin

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Figure G-12
Locations of Hydrograph Wells

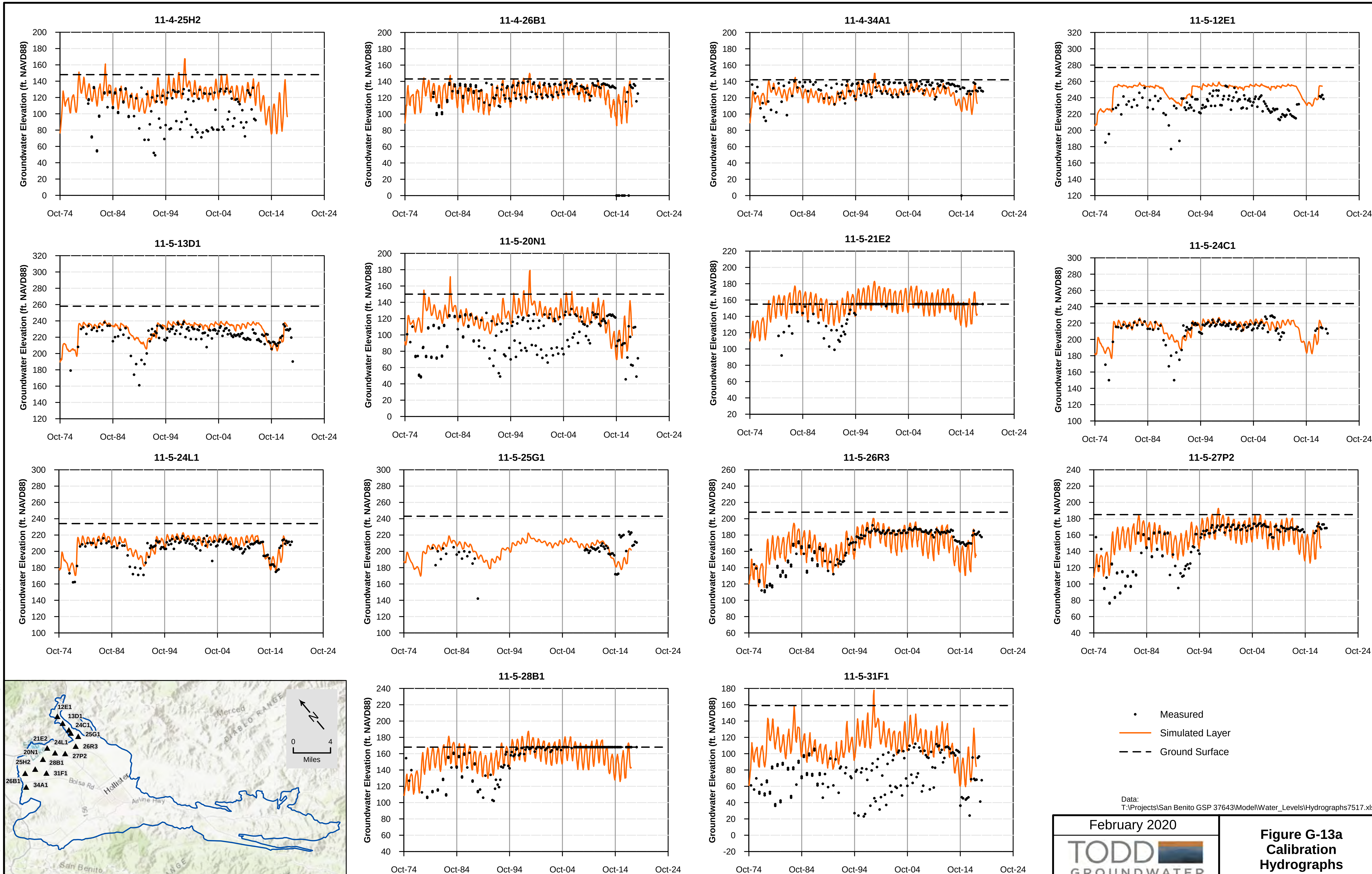

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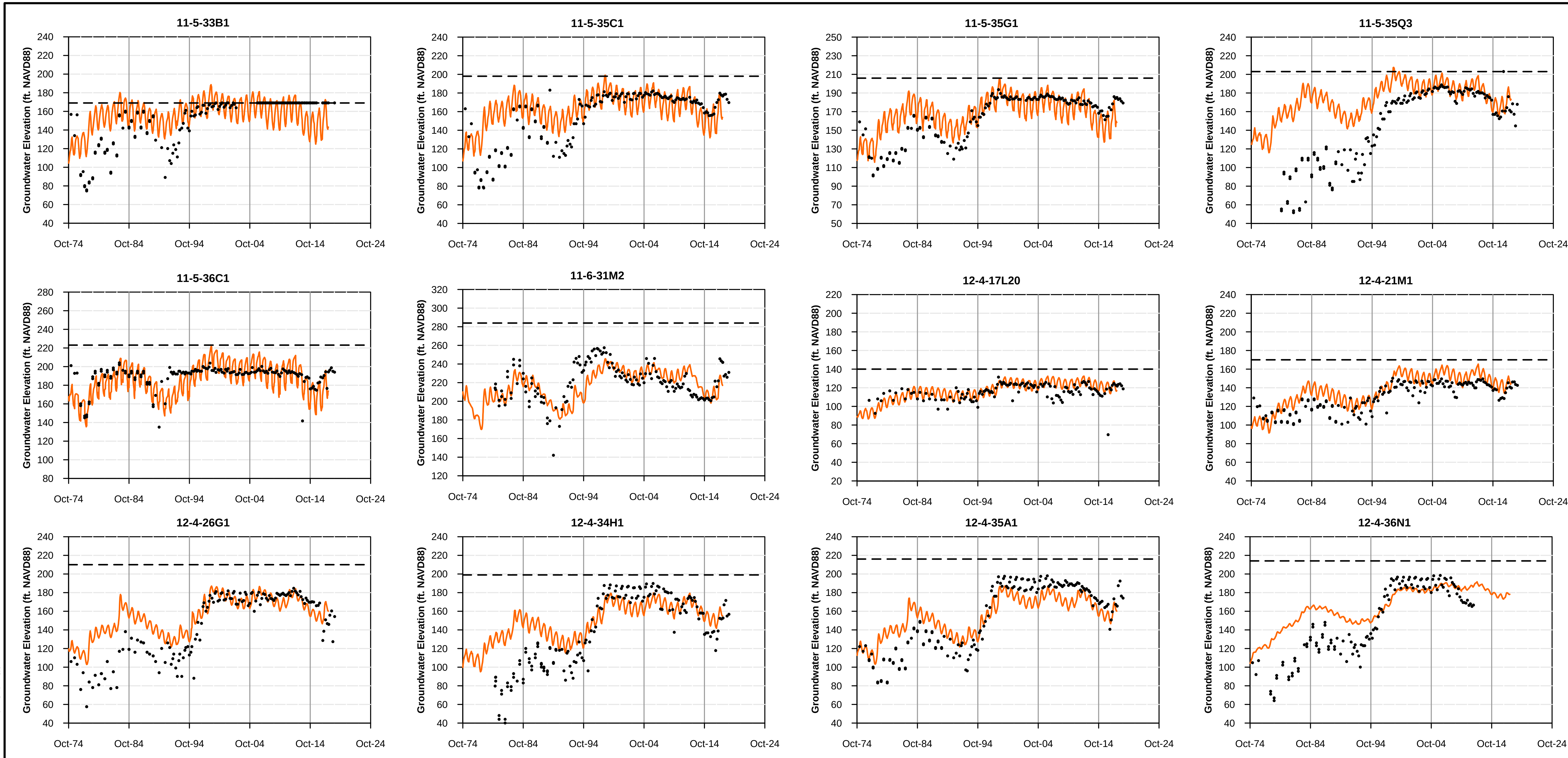
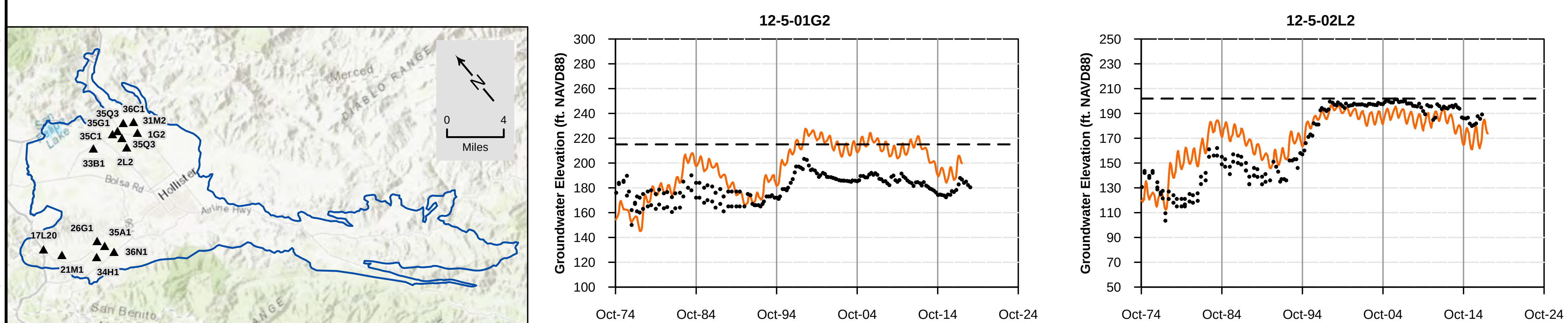
Figure G-13a
Calibration Hydrographs





Measured

Simulated Layer

Ground Surface

Data:
T:\Projects\San Benito GSP 37643\Model\Water_Levels\Hydrographs7517.xlsm

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Figure G-13b
Calibration Hydrographs

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-13b Calibration Hydrographs.gpj

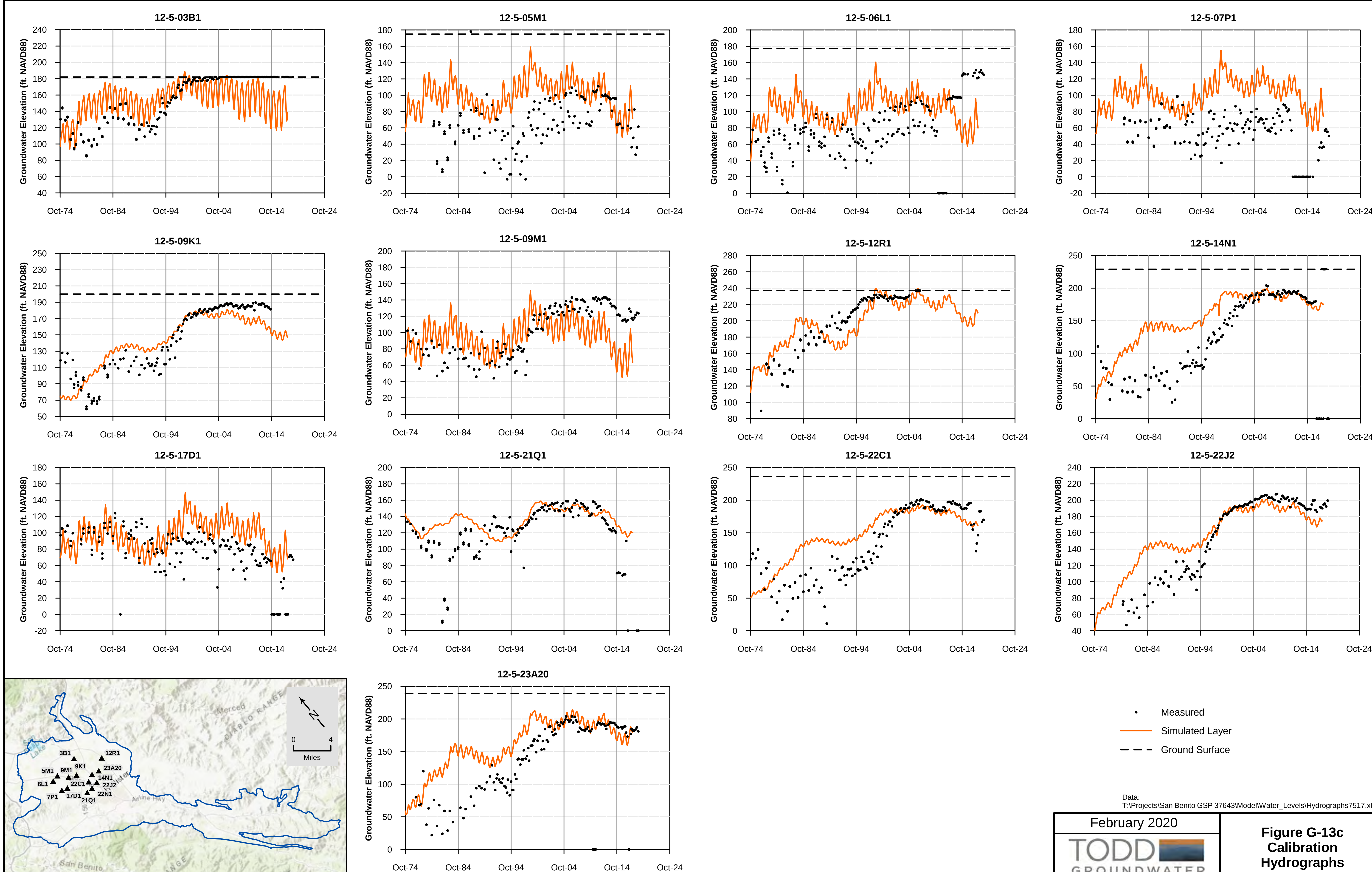

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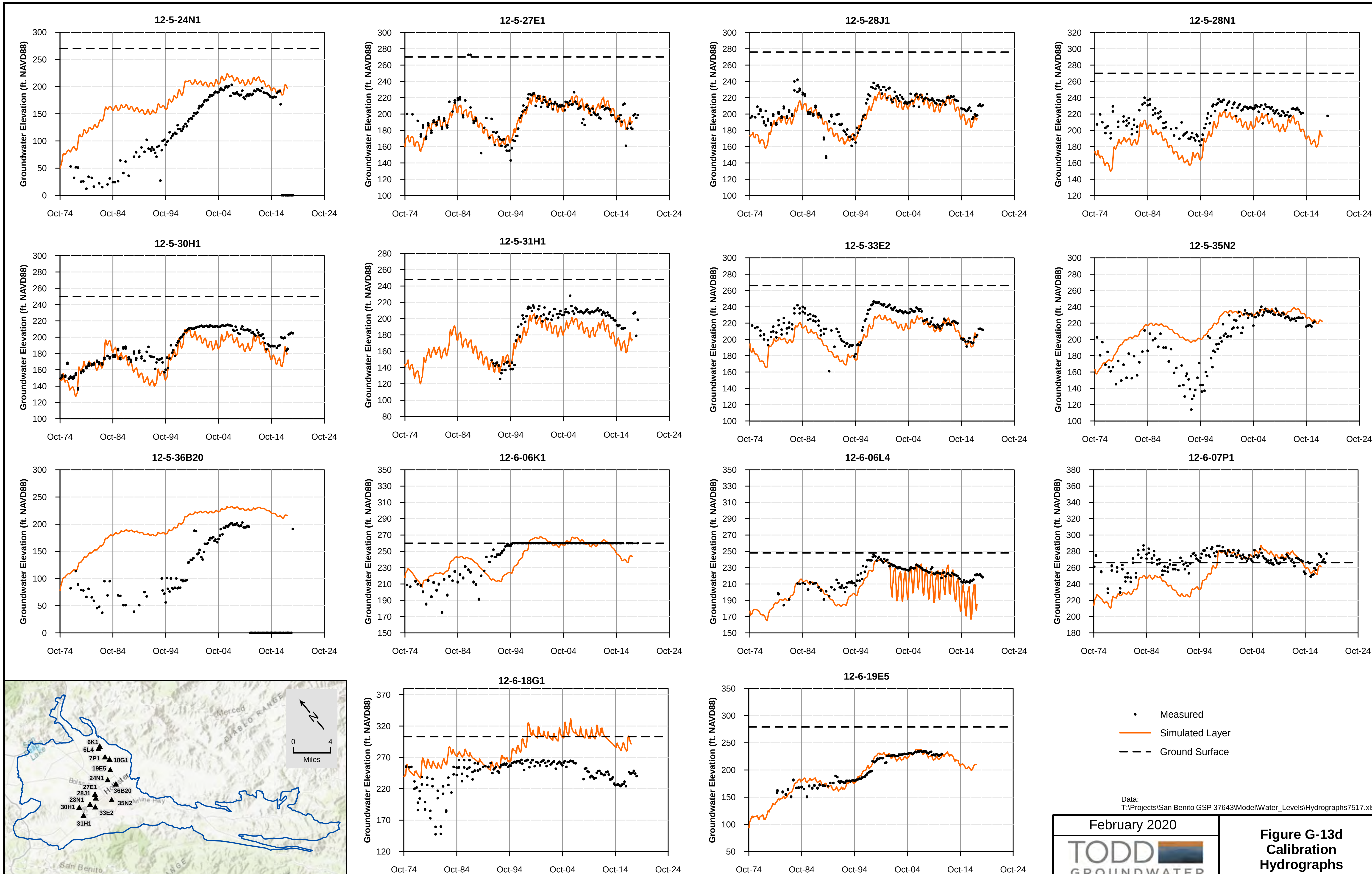
**Figure G-13c
Calibration
Hydrographs**



Data:
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Figure G-13d
Calibration Hydrographs

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-13d Calibration Hydrographs.jpg

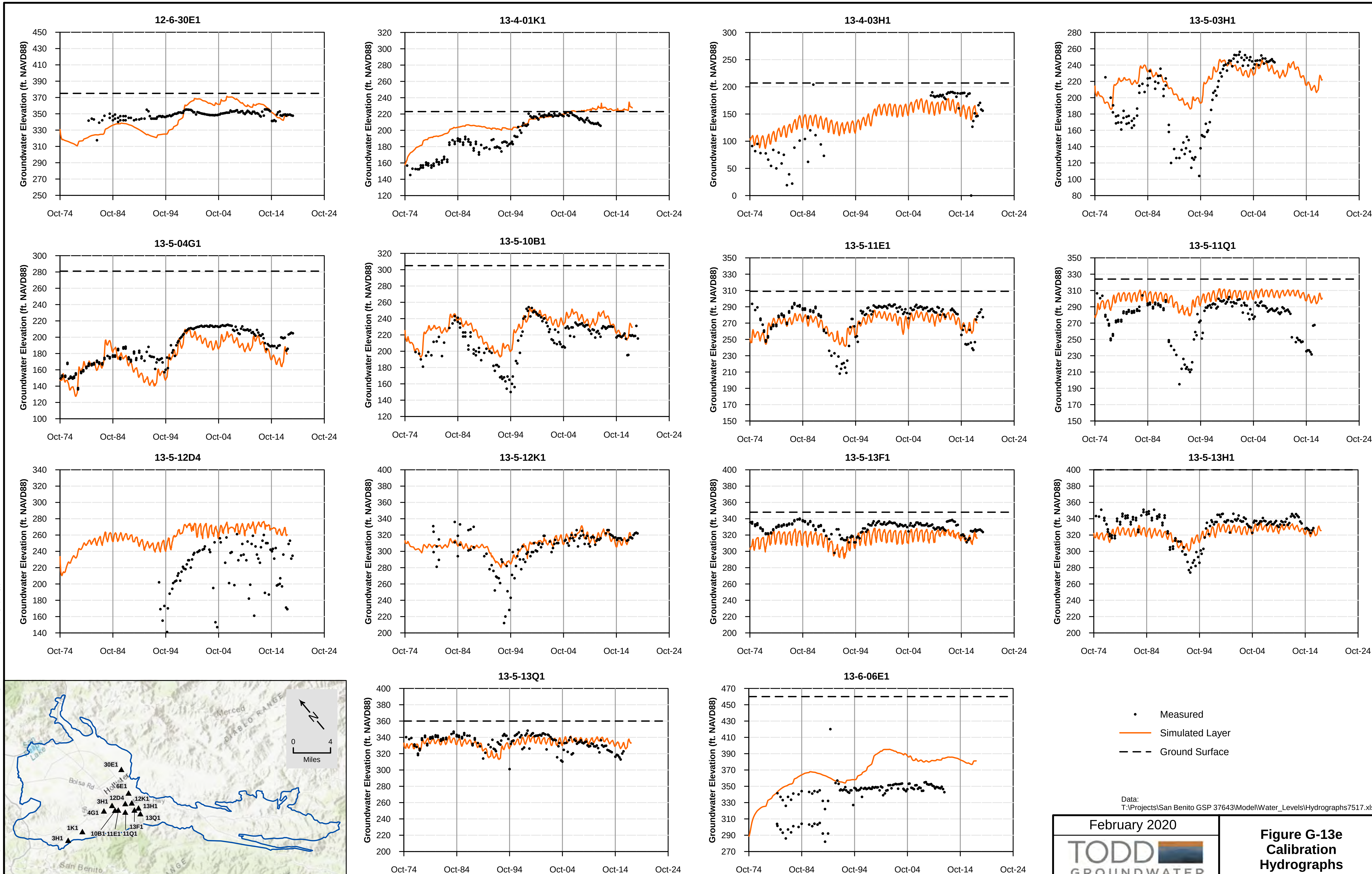

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Figure G-13e
Calibration Hydrographs

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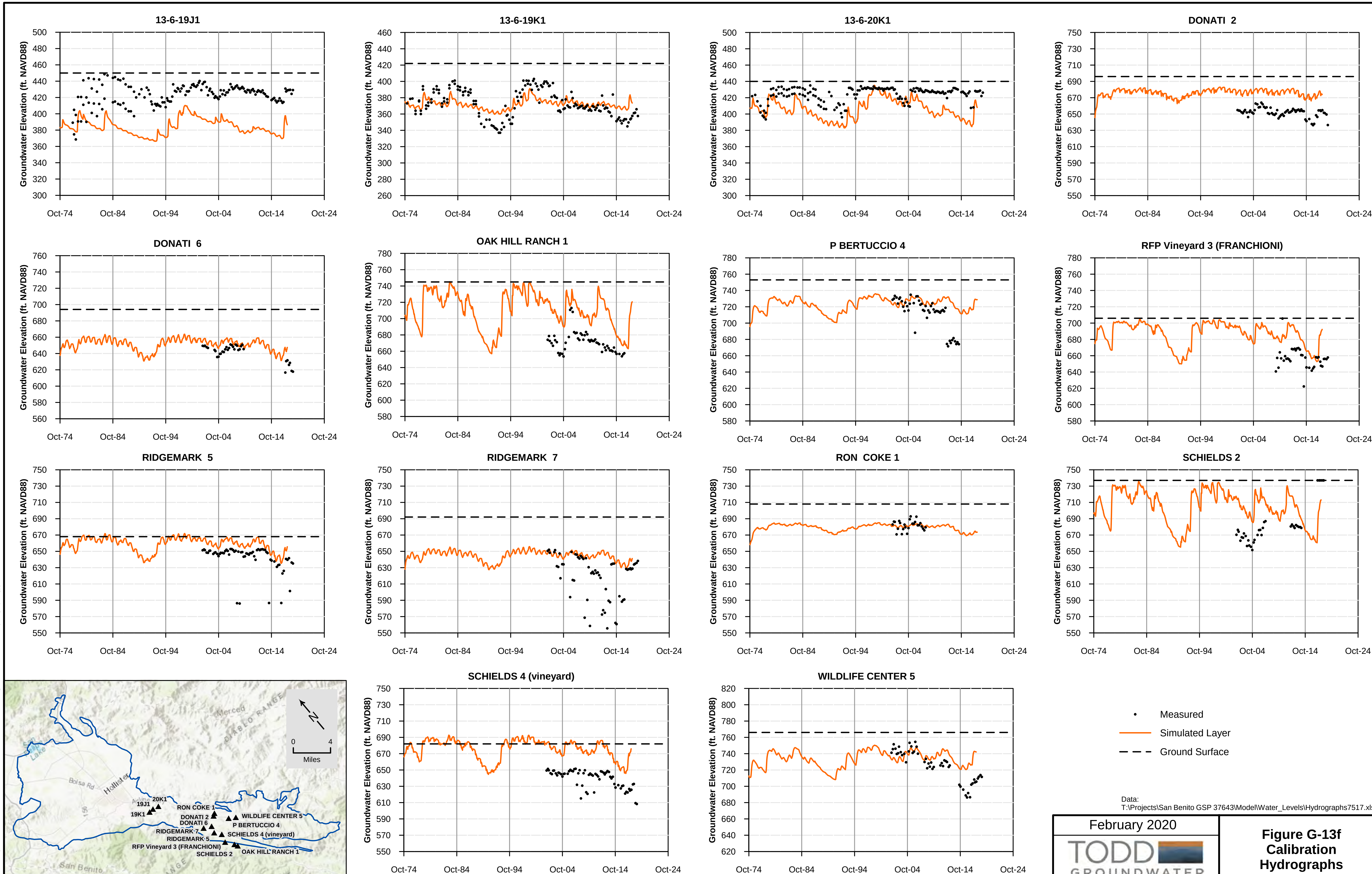

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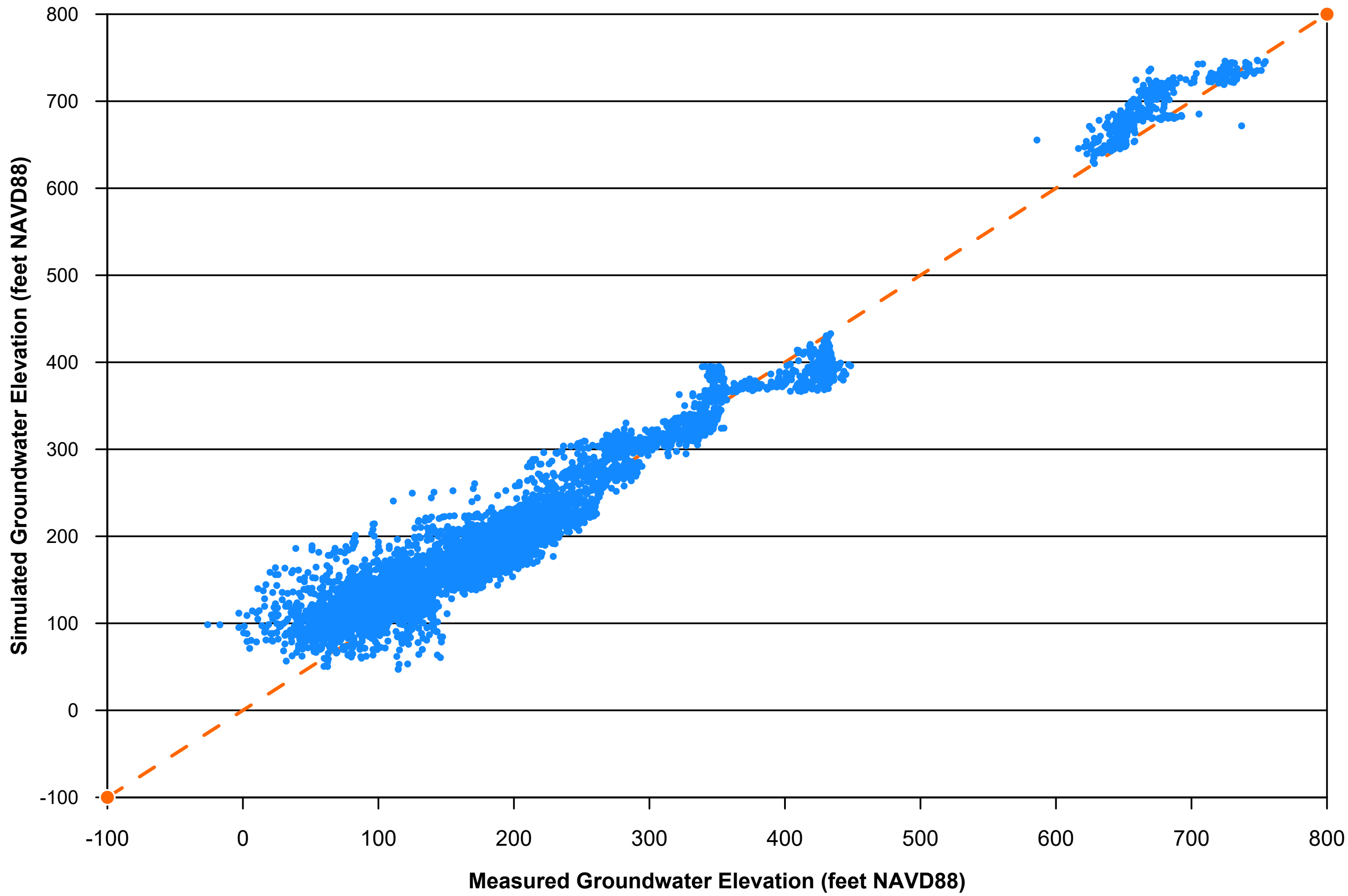
Figure G-13f Calibration Hydrographs

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-13f Calibration Hydrographs.gpj



Data:
T:\Projects\San Benito GSP 37643\Model\Water_Levels\Run054c_Calibration.xlsx Run054c_Calibration

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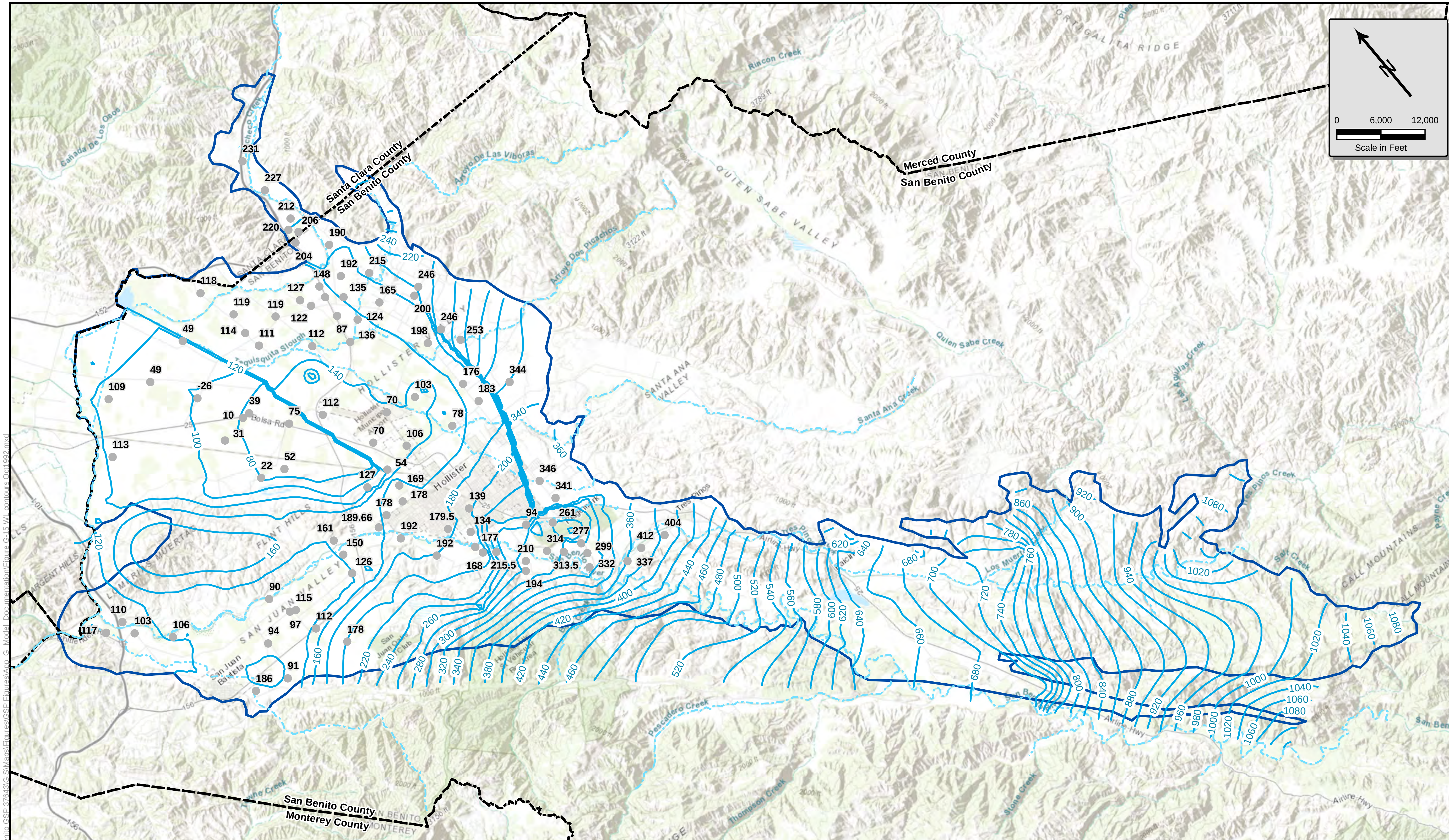
TODD GROUNDWATER

Figure G-14
Scatterplot of Simulated versus Measured Water Levels



Path: T:\Projects\San Benito GSP 37643\GIS\Maps\Figures\GSP Figures\App_G_Model_Documentation\Figure G-15 WL contours Oct1992.mxd

- Measured Groundwater Elevation (feet NAVD88)
- Simulated Groundwater Elevation (feet NAVD88)
- North San Benito Basin

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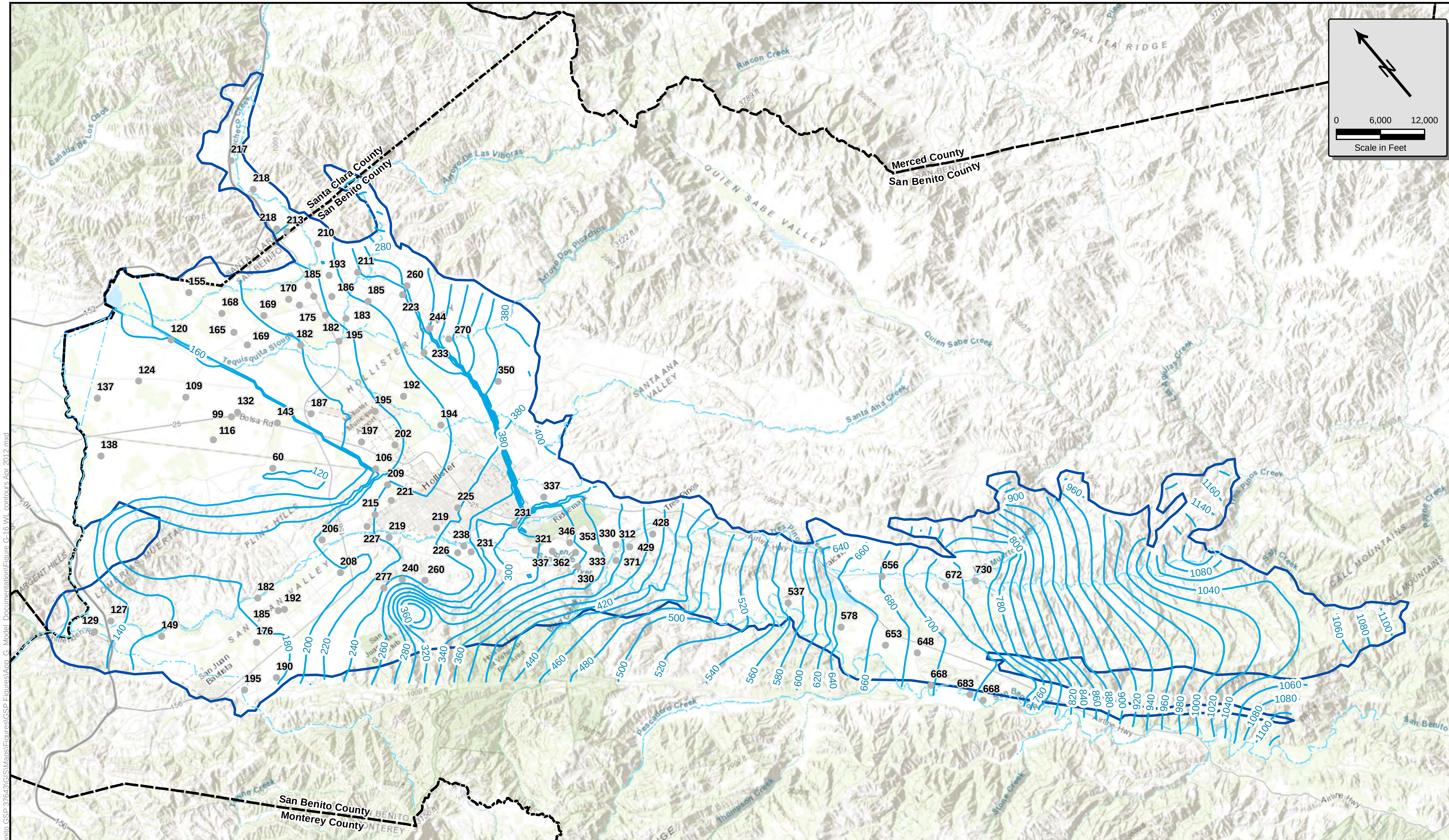
TODD GROUNDWATER

Figure G-15
Simulated Groundwater Elevation October 1992



Measured Groundwater Elevation (feet NAVD88)

Simulated Groundwater Elevation (feet NAVD88)

North San Benito Basin

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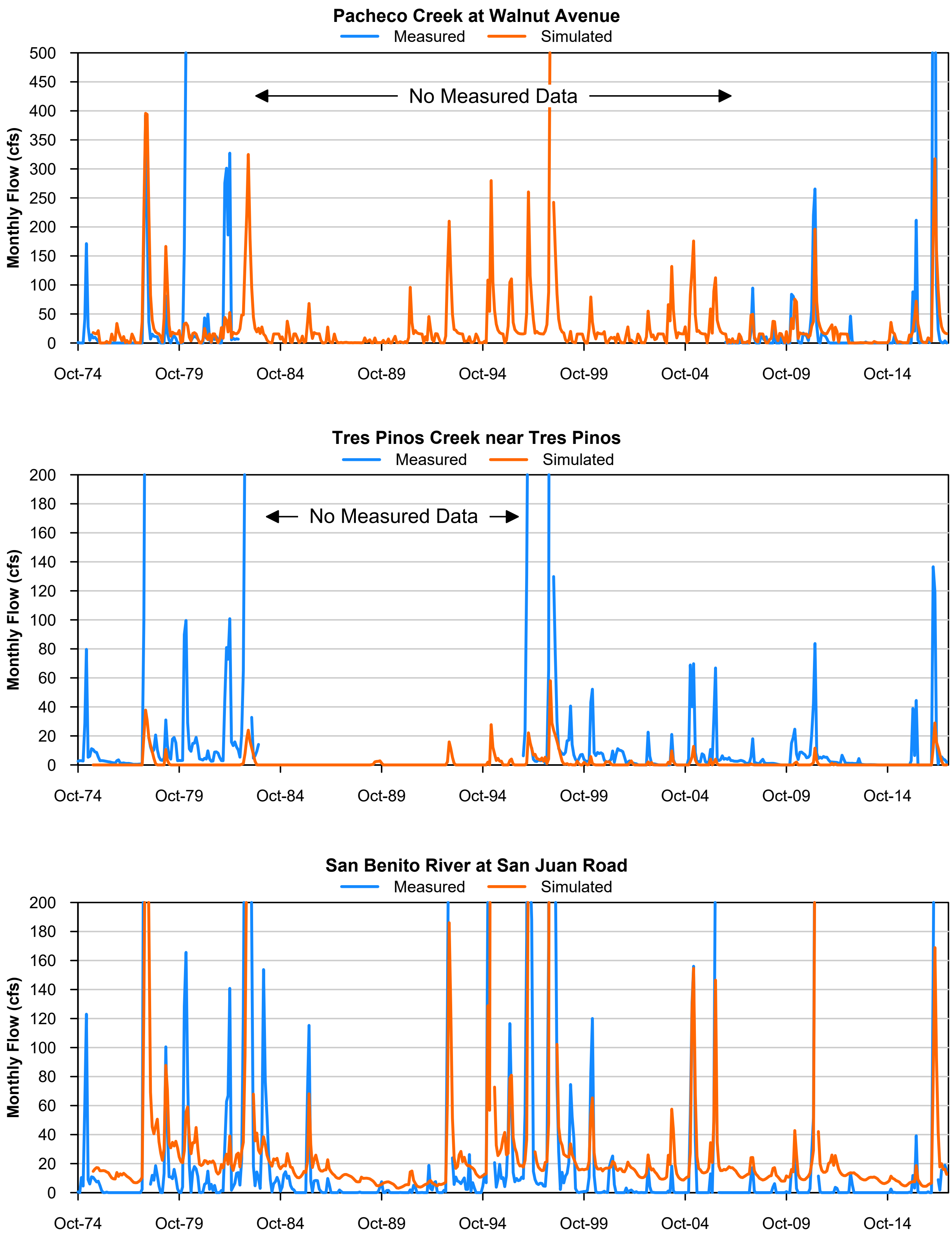
TODD GROUNDWATER

Figure G-16
Simulated
Groundwater Elevation
April 2012

Path: T:\Projects\San Benito GSP 37643\GIS\Maps\Figures\GSP Figures\App_G_Model_Documentation\Figure G-16 WL contours Apr 2012.mxd



Data:
T:\Projects\San Benito GSP 37643\Model\GWV\SB7517_gage_str_35locations.xlsx Measured

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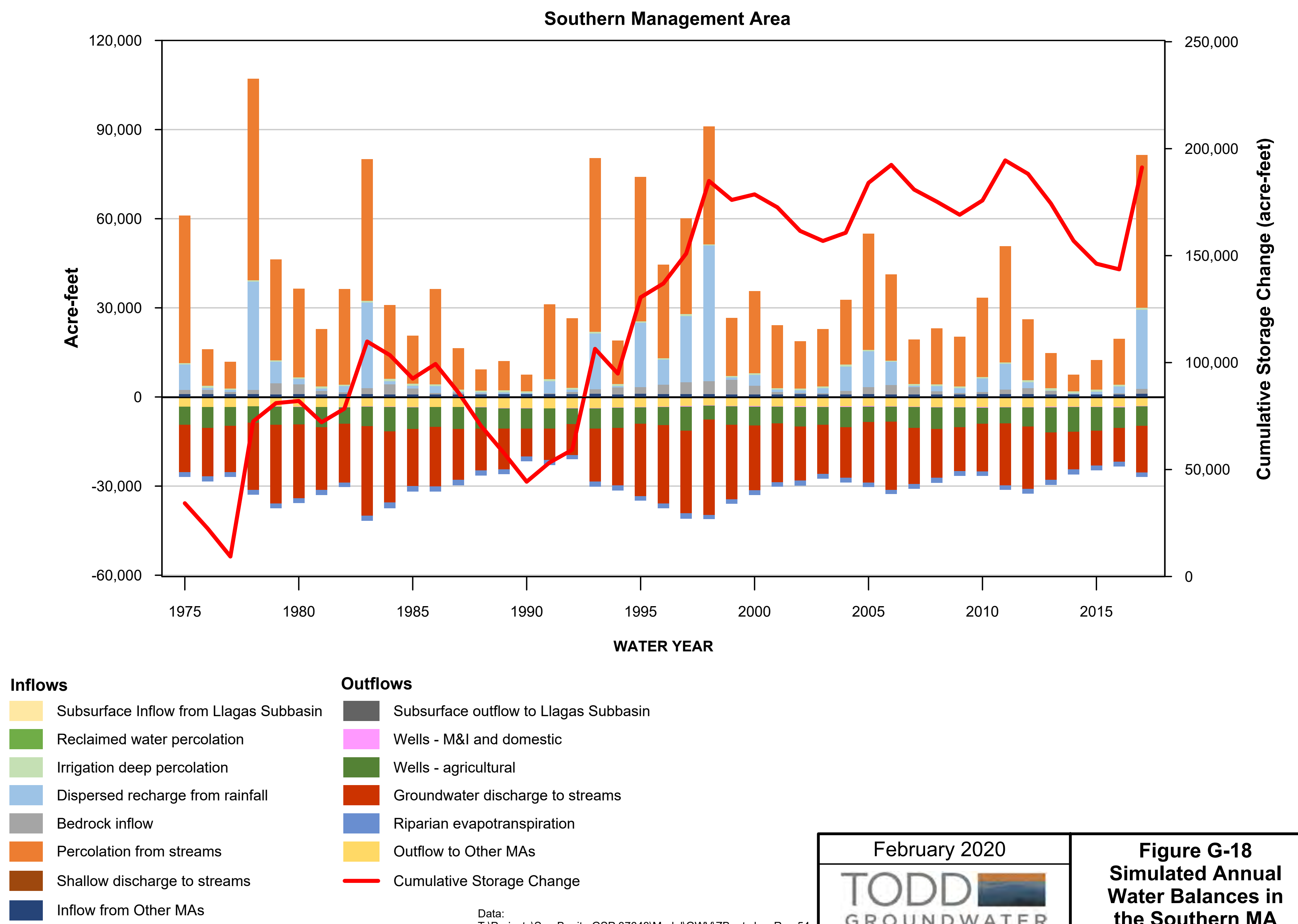
TODD GROUNDWATER

Figure G-17
Simulated and Measured Monthly Stream Flows

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-17 Simulated and Measured Monthly Stream Flows.gpj



Data:
T:\Projects\San Benito GSP 37643\Model\GWV\ZBout.xlsx Run 54c

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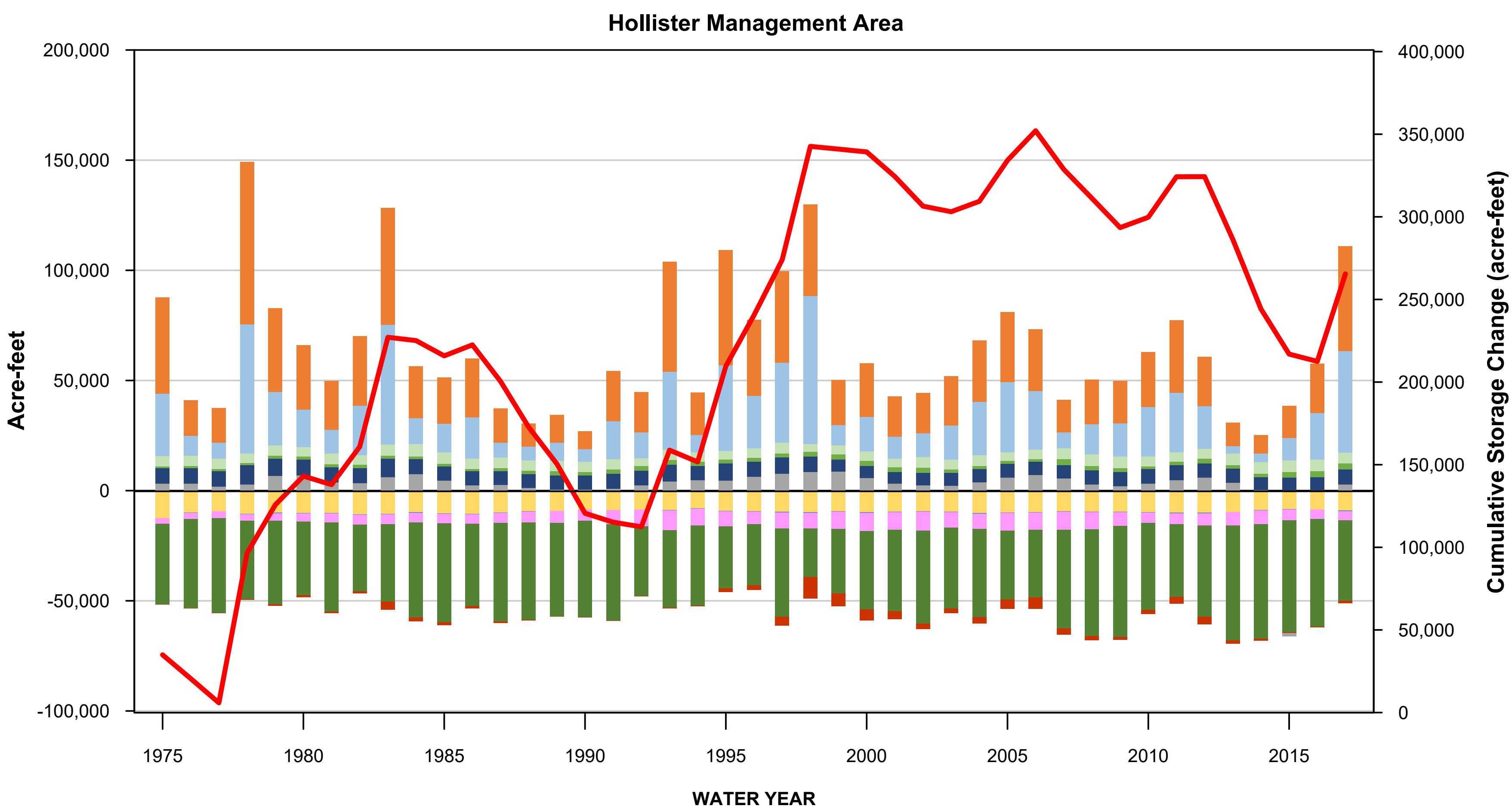
TODD GROUNDWATER

Figure G-18
Simulated Annual Water Balances in the Southern MA



Inflows

- Subsurface Inflow from Llagas Subbasin
- Reclaimed water percolation
- Irrigation deep percolation
- Dispersed recharge from rainfall
- Bedrock inflow
- Percolation from streams
- Shallow discharge to streams
- Inflow from Other MAs

Outflows

- Outflow to Other MAs
- Subsurface outflow to Llagas Subbasin
- Wells - M&I and domestic
- Wells - agricultural
- Groundwater discharge to streams
- Riparian evapotranspiration
- Cumulative Storage Change

Data:
T:\Projects\San Benito GSP 37643\Model\GWV\ZBout.xlsx Run 54c

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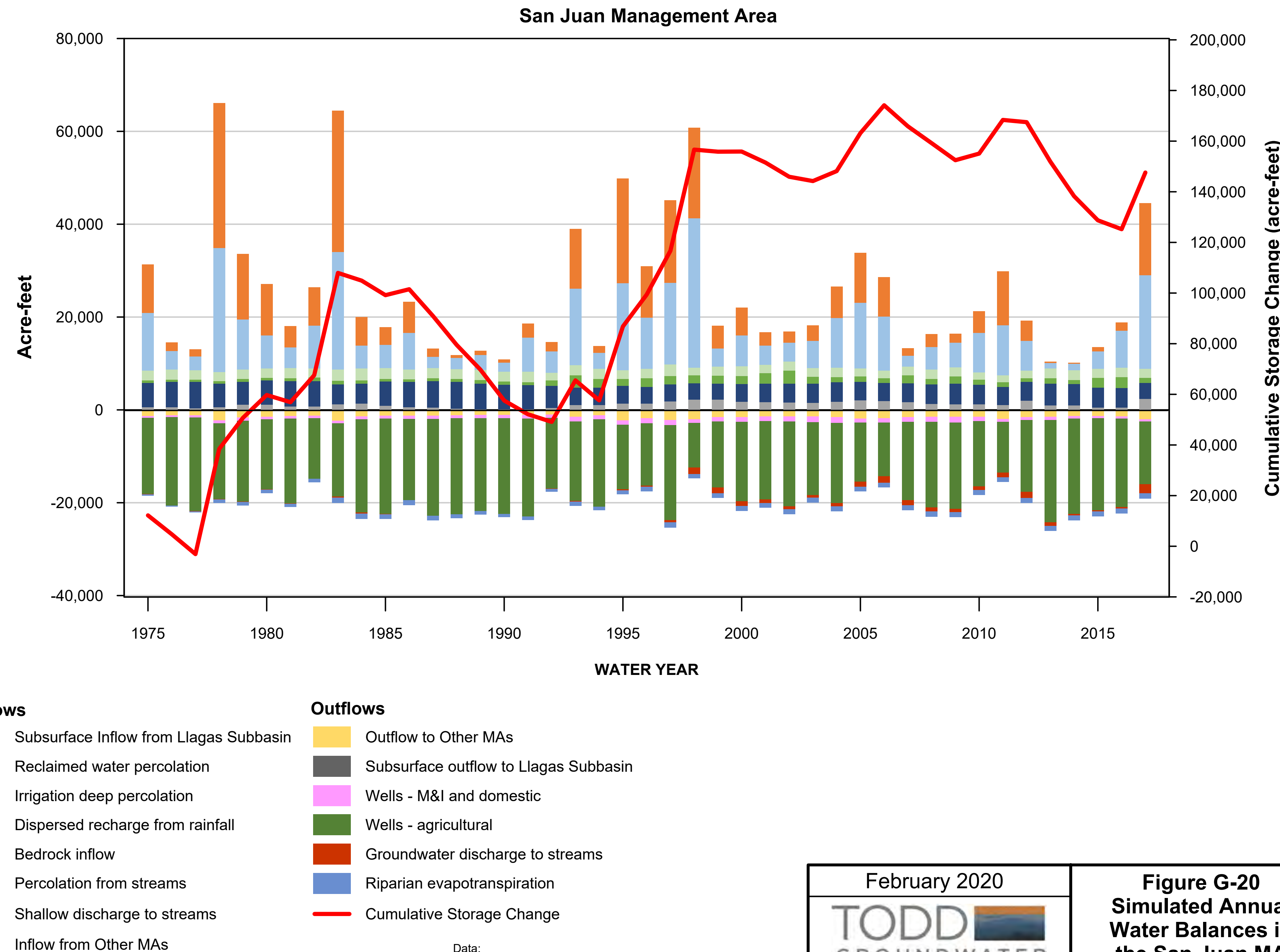
TODD GROUNDWATER

Figure G-19
Simulated Annual Water Balances in the Hollister MA

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-19 Simulated Annual Water Balances in the Hollister MA.gpj



Data:
T:\Projects\San Benito GSP 37643\Model\GWV\ZBout.xlsx Run 54c

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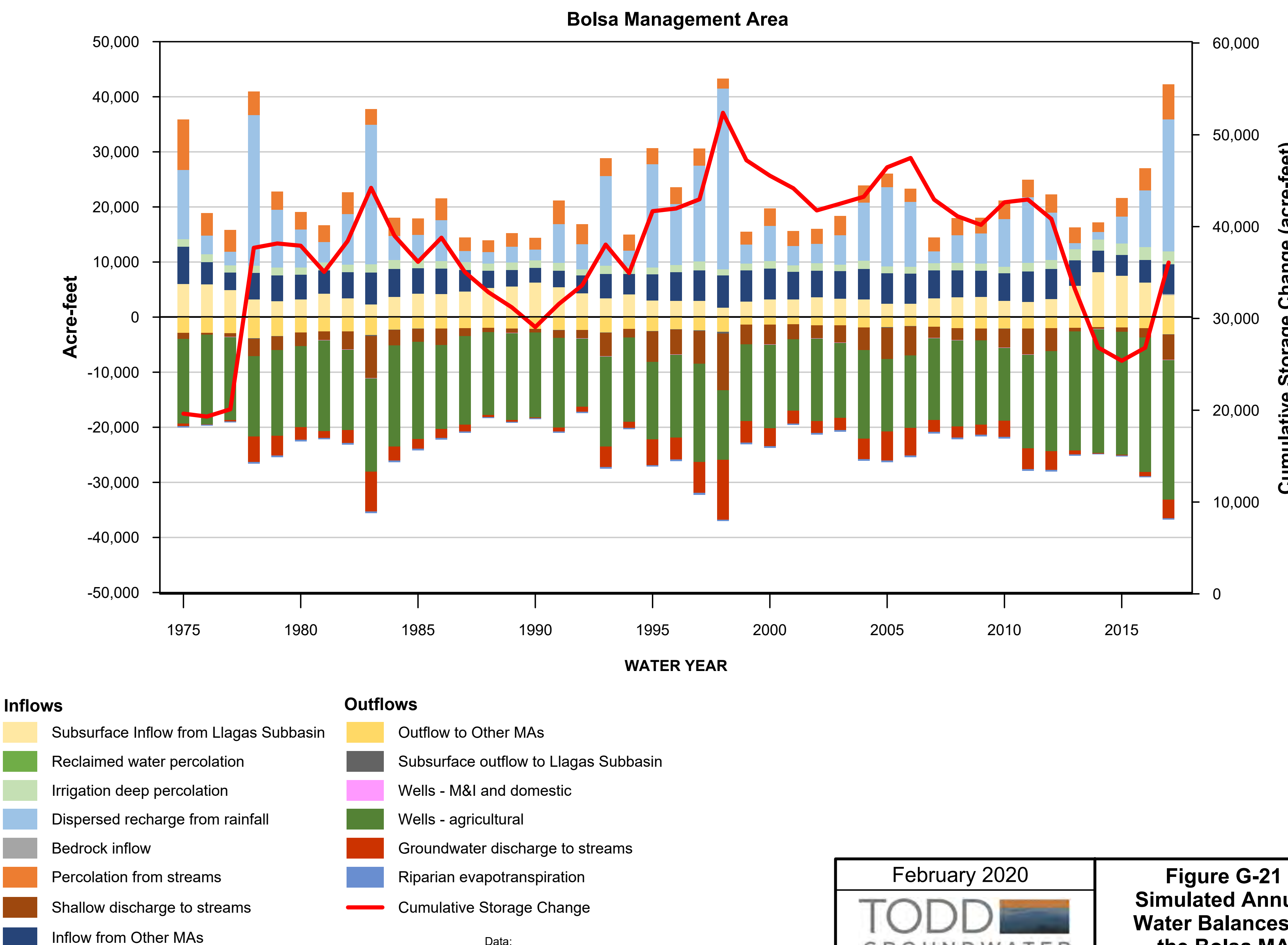
Figure G-20 Simulated Annual Water Balances in the San Juan MA

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-20 Simulated Annual Water Balances in the San Juan MA.gpj



Data:
T:\Projects\San Benito GSP 37643\Model\GWV\ZBout.xlsx Run 54c

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TODD GROUNDWATER

Figure G-21
Simulated Annual Water Balances in the Bolsa MA

Path: T:\Projects\San Benito GSP 37643\GRAPHICS\SanBenitoGSP\Figure G-21 Simulated Annual Water Balances in the Bolsa MA.gpj