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Scott Valley Integrated Hydrologic Model: Data Collection, Analysis, and Water Budget

Final Report

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Executive Summary

The Scott Valley is an agricultural groundwater basin in Northern California, within the Scott River watershed and part of the much larger Klamath Basin watershed straddling the California-Oregon border. The Scott River provides important habitat for salmonid fish, including spawning and rearing habitat for coho and fall-run Chinook salmon and steelhead trout. Sufficient flows at adequately low temperatures during summer, for rearing, and fall, for spawning, are critical for healthy fish habitat in the mainstem and tributaries.

This report presents the data assembled and the methods used for data analysis and data modeling to prepare the Scott Valley Integrated Hydrologic Model Version 2, which is currently under development. The report includes precipitation data analysis, streamflow data analysis and modeling, geology and groundwater data review and analysis, evapotranspiration and soils data analysis, and preparation of relevant watershed, land use, topography, and irrigation data. The data collection and analysis efforts culminate in the development of a spatio-temporally distributed soil water budget model for the Scott Valley. The soil water budget model is used to determine spatially and temporally varying groundwater pumping rates, surface water diversion rates, and groundwater recharge across the groundwater basin. The spatial resolution of the soil water budget model is by individual fields (land use polygons). Temporal discretization is in daily time steps for the period from October 1, 1990 to September 30, 2011. This period includes several dry years, average years, and wet year periods. Methods and results of the soil water budget model are presented in this report. This report represents the next step toward a better understanding of the interactions between groundwater, surface water, landuse, and agricultural practices with a specific focus on the seasonal impacts of groundwater pumping on streamflow during critical low flow periods.

The work presented here relies on an extensive data collection facilitated by the voluntary and active collaboration of communities, landowners, the Scott River Watershed Council (SRWC), the Siskiyou Resource Conservation District (SRCD), and the Scott Valley Groundwater Advisory Committee (GWAC) which has been appointed by the Board of Supervisors in January 2011, meeting monthly since April 2011 and advising UC Davis on its data collection and modeling efforts.

In the data analysis and during the model development, numerous assumptions have been made as is common in building a conceptual and numerical integrated hydrologic model. Models cannot represent the complexity of the real system, but are an effort to capture salient hydrologic features with sufficient accuracy to develop modeling results that are useful for a better understanding of the watershed dynamics and water balance.

A key feature of the integrated hydrologic model includes that individual fields and other individual land use parcels are characterized by a set of properties (or attributes) that include:

- Land use: all land use has been simplified in that we divided the diversity of land use into four main categories: 1) Alfalfa/grain rotation, 2) Pasture, 3) land use with evapotranspiration but no irrigation (includes natural vegetation, natural high water meadow, misc. deciduous trees,

trees, riparian vegetation), and 4) land use with no evapotranspiration and no irrigation, but with potential recharge from precipitation via soil moisture storage (barren, commercial, dairy, extractive industry, municipal, industrial, paved, etc);

- Soil type: characterized by water holding capacity. For the Scott Valley, we are using a root-zone depth of 4 ft and also evaluate a hypothetical root-zone depth of 8 ft;
- Irrigation efficiency, which is usually determined by irrigation type. In the Scott Valley, flood, center pivot sprinkler, and wheel-line sprinkler irrigation are used almost exclusively; we also consider historic conversion of some fields from flood or sprinkler irrigation to center pivot irrigation, based on a review of 1990 - 2011 aerial photos;
- Water source: groundwater, surface water, subirrigated (shallow groundwater table), mixed groundwater-surface water, and non-irrigated (dry land farming).

Other key assumptions and simplifications include:

- the attributes of each polygon (landuse, irrigation type, irrigation source) do not change throughout the 21 year period except for conversion from sprinkler to center pivot on documented alfalfa/grain rotation fields;
- irrigated water is applied continuously and uniformly over the entire irrigation period, a simplification of the actual irrigation practice, where irrigation is applied during a number of specific irrigation events, the timing of which varies from field to field; also, the simulation does not account for irrigation non-uniformity within fields or between fields;
- applied irrigation amounts are computed based on crop evapotranspiration, which has been estimated from climate data; irrigation amounts are adjusted for precipitation, soil moisture availability, and account for commonly assumed irrigation efficiency of the irrigation system. This concept has been developed for the California Department of Water Resources (CDWR) Consumptive Use Program (Orang et al., 2008);
- reference ET, a key driver for simulating irrigation applications, is calculated from climate station data using the NWSETO program developed at UC Davis and is based on the Hargreaves and Samani (1982) equation;
- the start of the irrigation season is triggered by soil water depletion to 45% of soil water holding capacity (equivalent to a depletion factor of 0.55), recommended by FAO Publication 56, Table 22.
- direct uptake from shallow groundwater table is not accounted for in the soil water budget approach, but will be simulated in the integrated hydrologic model that is currently under development

The soil water budget approach presented here does not represent a complete water budget for either the surface watershed or the groundwater basin, since it does not include stream-groundwater interaction or evapotranspiration off shallow water-table from non-irrigated crops or natural landscapes. However, a streamflow regression analysis is performed to estimate all monthly tributary inflows into the Scott Valley based on incomplete sets of measured data. A complete surface watershed or groundwater basin budget requires an integrated groundwater-surface water model which is now under development (Scott Valley Integrated Hydrologic Model Version 2, to be completed by early 2014).

Output from the soil water budget simulation includes daily land use polygon (field) specific soil water fluxes in water years 1991 through 2011. These are aggregated to provide monthly, yearly and long-term average rates by polygon, by land use, and by subwatershed. The report presents and discusses the following output results obtained from the soil water budget simulation:

- irrigation from surface water and groundwater sources;
- recharge;
- crop evapotranspiration under optimal irrigation (no shortage);
- actual evapotranspiration after accounting for limited available water in the root zone (limited surface water supplies, no irrigation);
- water uptake deficiency.

Results of the soil water budget model are typical of Northern California, given the land use, irrigation water source, irrigation type, and precipitation and given the limitations listed above to build the soil water budget model. For example, average monthly recharge and pumping rates indicate strong seasonal changes. Most pumping occurs during summer months and most recharge occurs in late winter and early spring. On pasture, significant recharge may also occur during the irrigation season due to widespread surface water flooding at rates that are significantly higher than crop water use (relatively lower irrigation efficiency). In August-September, streamflow available for flood irrigation decreases significantly leading to increased pumping on some pasture fields, typically at higher efficiency than with flood irrigation and, hence, less recharge. Recharge in alfalfa is highest in July and August, when all fields are fully irrigated. Fields in grains (12.5% of the alfalfa/grain cropping area) are fallow after their harvest in July without significant recharge or pumping in August and September. During the winter months, differences in the amount of recharge between the three land use categories reflect varying levels of soil moisture depletion and slight differences in average soil characteristics across each land use type, mainly hydraulic conductivity and water holding capacity.

Simulated irrigation amounts have been compared with field-estimated applied water values provided by alfalfa and pasture irrigators engaged in the Scott Valley Groundwater Advisory Committee (GWAC). We find that the water budget model significantly overestimates the amount of applied water compared with grower-reported rates and compared with recent field measured amounts. Hence, the current approach will need further development to reconcile the differences between the ET-based soil water budget model and field irrigation rate data. The largest discrepancy is found in the amount of irrigation applied to alfalfa, which the model overestimates by 25% or more given the reported values. Probable explanations for the discrepancy include uncertainty in the available evapotranspiration and reference evapotranspiration rates for alfalfa and the lack of accounting for irrigation non-uniformity. The latter may effectively lead to higher than assumed irrigation efficiency. New data are collected in an ongoing field campaign. These will be critical to update irrigation rates in future versions of the soil water budget model.

The current soil water budget model has two important characteristics that make it rather useful for understanding the hydrology of Scott Valley: 1) it has been developed to allow for rapid adjustment of inputs and/or model assumptions. Results can be refined in the future, and further sensitivity analysis and tests can be performed as new data become available; and 2) it is a tool that has been developed in close collaboration with local stakeholders, agency personnel, and scientists, which is critical for constructive discussion of different water management scenarios and to mitigate conflicts.

1 Acknowledgments

Many people have supported our efforts of collecting, analyzing, and interpreting data. We acknowledge the feedback, support, and reviews that we have received from the Scott Valley Groundwater Advisory Committee, the Siskiyou Resources Conservation District, the Scott River Watershed Council, the Natural Resources Conservation Service Yreka Office, the County of Siskiyou, Ric Costales with the County of Siskiyou, Steve Orloff with University of California Cooperative Extension, Bryan McFadin with the North Coast Regional Water Board, Deborah Hathaway with Papadopulos and Associates, and from Sari Sommarstrom at Sommarstrom & Associates. These collaborations were critical for developing a better understanding of agricultural practices in Scott Valley. Review comments were helpful in clarifying this report. We are also grateful to Prof. Samuel Sandoval Solis, University of California, Davis, for his collaboration on analyzing precipitation data and providing a new classification of the water year types.

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2 Introduction

The Scott Valley is an agricultural groundwater basin in Northern California, within the Scott River watershed and part of the much larger Klamath Basin watershed straddling the California-Oregon border. The Scott River provides important habitat for salmonid fish, including spawning and rearing habitat for coho (*Onchorhynchus kisutch*) and fall-run Chinook salmon (*Onchorhynchus tschawytscha*) and steelhead trout (*Onchorhynchus mykiss*). Sufficient flows at adequately low temperatures during summer, for rearing, and fall, for spawning, are critical for healthy fish habitat in the mainstem and tributaries.

During the dry summer, streamflow in the Scott River system is low and relies almost entirely on groundwater return flow (baseflow) from the alluvial aquifer system underlying Scott Valley. Summer streamflows in dry years have been markedly lower since the late 1970s, when compared to the 1940s to 1960s. Both Van Kirk and Naman (2008) and Drake et al. (2000) concluded that a statistically significant contribution of this downward trend is due to climate effects represented by reduced snowpack at lower elevations, while Van Kirk and Naman (2008), using statistical analysis, also asserted that groundwater pumping for irrigation and increased consumptive water use was a significant cause. A physically-based groundwater model was used by S.S. Papadopulos & Associates (2012) to estimate potential late summer/early fall stream depletion impacts associated with groundwater pumping for irrigation.

As a result of low streamflow, but also due to the lack of widespread riparian vegetation, temperatures in the Scott River may exceed critically high temperatures during the summer months (North Coast Regional Water Quality Control Board, Staff Report for the Action Plan for the Scott River Watershed Sediments and Temperature TMDLs, 2011).

A groundwater (GW) study plan was requested of Siskiyou County and its Scott Valley stakeholders, as set forth in the Action Plan for the Scott River Watershed Sediment and Temperature Total Maximum Daily Load (TMDL, adopted Dec. 2005 by the Regional Water Board [RWB]). The Action Plan sets forth the elements to be contained in the GW Study Plan; it also identifies the needs of the RWB for certain information to be developed from the groundwater studies proposed in the GW Study Plan. It has been agreed by Siskiyou County and Regional Water Board staff that better knowledge of the hydrology and alluvial aquifer is needed to develop a possible array of solutions to water issues and associated problems. Siskiyou County with its management jurisdiction over groundwater (the RWB has water quality jurisdiction over GW under the Porter-Cologne Act) is committed to taking a community-based approach to implementing the GW Study Plan. The Scott Valley Community Groundwater Study Plan was developed by the University of California at Davis (Harter and Hines, 2008) with the voluntary assistance of communities, landowners, the Scott River Watershed Council (SRWC), and the Siskiyou Resource Conservation District (SRCD). The GW Study Plan was adopted by the Siskiyou County Board of Supervisors in February 2008. The primary goal of the GW study plan is: *"To provide a scientific approach that can be used by Siskiyou County, the Scott Valley community, the State of California, and other interested parties to objectively assess the Scott Valley's groundwater resources and their effect on surface water resources."* (Harter and Hines, 2008).

Subsequently, the Board of Supervisors appointed the Scott Valley Groundwater Advisory Committee (GWAC) in January 2011, a group which has been meeting monthly since April 2011. This committee supersedes the role of the Watershed Council (SRWC) for representing the community on groundwater matters.

The GW Study Plan provides an overall course of action to achieve the following overall study objectives:

1. consider groundwater occurrence throughout Scott Valley,
2. evaluate effects of groundwater on health of riparian vegetation,
3. evaluate effects of water use on Scott River flows,
4. identify opportunities and potential solutions for increasing water storage and/or addressing Scott River temperature issues, and
5. develop a tool capable of investigating groundwater hypotheses, such as those developed by the Scott River Watershed Council.

The GW Study Plan was intended to be a living blueprint of the hydrologic, ecologic, water resource management, and agricultural management research needs and of the investigative approaches that can be taken to develop management practices that meet the mandate for protection of water, agricultural, and ecological resources in the Scott Valley. The GW Study Plan summarizes the current status of knowledge about the hydro-agro-eco-geography of the Scott Valley and outlines potential approaches to addressing critical current research needs. Individual future study projects and tasks are described and scheduled to efficiently and timely make best use of funds to collect the information and data needed.

The GW Study Plan identifies further comprehensive analysis of existing data and development of new integrated groundwater-surface water assessment tools as a critical need. These tools are needed to understand the groundwater hydrology of the Scott River system and its relationship to surface hydrology, especially in areas where groundwater could affect Scott River water temperatures, potential riparian vegetation, and habitat connectivity for anadromous fish. Without integrated, interdisciplinary knowledge of the groundwater hydrology of Scott Valley and its dynamic linkages with streamflow, solutions to specific issues outlined in the Scott River TMDL and Action Plan will not be possible. Baseline data are needed to determine the best approach in the design and implementation of water projects, water management alternatives, and strategies to protect anadromous fish while also providing for current users of water, including agricultural operations.

With the voluntary assistance of communities, landowners, the SRWC, the GWA, and the Siskiyou RCD, this report provides key elements proposed by the GW Study Plan as set forth in the Scott River TMDL Action Plan. This report provides a review of data collected since the publication of the GW Study Plan and the various analyses performed to prepare the Scott Valley Integrated Hydrologic Model. It includes precipitation data analysis, streamflow analysis and modeling, evapotranspiration data analysis and modeling, soils and groundwater data assembly and analysis, landuse and topography data analysis, and development and analysis of a soil water budget model to estimate field-by-field daily pumping and groundwater recharge in the Scott Valley for Water Years 1991-2011. A separate report will be prepared on the integrated hydrologic modeling efforts with MODFLOW, once completed, by early 2014.

In this report we occasionally refer to Version 1 and Version 2 of the Scott Valley Integrated Hydrologic Model: Version 1 corresponds to the initial groundwater flow model developed with MODFLOW-2000 (Harbaugh et al., 2000) by a graduate student (Ryan Hines) and hand-calibrated against measured water level data. While unpublished, several presentations have been given on this tool at the community and agency level, which is the main reason for distinguishing the version currently in development from these earlier efforts. Version 2 is a revised integrated hydrologic model, also using MODFLOW-2000 and its Stream-Flow Routing Package, but with an improved water budget representation including a more detailed and realistic representation of irrigation practices and cropping patterns in the Scott Valley. For the development of Version 2, additional data collection and analysis was conducted to develop the new soil water budget model and to improve the conceptual basis of the integrated hydrologic model. This report combines relevant data first collected during the Version 1 development phase and all of the additional data and data analysis prepared for the Version 2 modeling effort in a single, comprehensive document.

The motivation for developing these integrated hydrologic modeling tools is based on acknowledging the importance of:

1. understanding how past and current pumping affects groundwater flows to the Scott River and how alternative future water management activities affect groundwater flow;
2. helping mediation of conflicts between:
    a. Landowners in Scott Valley, mostly farmers depending on agricultural pumping for crop production,
    b. Indian tribes downstream and commercial fisheries off-coast that depend on healthy fish populations,
    c. California Department of Fish and Wildlife, the U.S. Fish and Wildlife Service and the U.S. National Marine Fisheries Service responsible for the implementation of the state and federal Endangered Species Act (ESA; 16 U.S.C. 1531 et seq.)
    d. North Coast Regional Water Quality Control Board, State Water Resources Control Board, and U.S. Environmental Protection Agency responsible for the implementation of California's Porter-Cologne Water Quality Control Act and the Federal Clean Water Act.

A collaborative and open approach has been established involving many stakeholders, including local landowners, Valley residents, native tribes, and fisheries to develop acceptable concepts consistent with scientific as well as local knowledge of the system. Furthermore, there is a general need to improve communication between scientists, regulatory and planning agencies, environmental advocacy groups, and diverse local/regional stakeholder groups to develop sustainable water resources management. This study is designed as part of an effort to benefit these diverse stakeholder groups and communities by fully integrating currently available data, modern scientific methods, local-regional education, and public outreach.

In the following chapters, an overview of the study area, a detailed description of the data collection effort and of the methods used for data analysis, a description of the concepts of the soil water budget model, and extensive results are presented. This information provides the foundation for the forthcoming integrated hydrologic model (Version 2) of the Scott Valley.

3 Study Area

3.1 Physical Setting

The Scott Valley is located in the Klamath Mountains of Northern California, approximately 30 miles south of the Oregon border in Siskiyou County. Scott Valley is approximately 25 miles long and 10 miles wide at the largest point, although much of Scott Valley is less than 3 miles wide. The Scott River flows through the eastern and northern part of the valley, from south to north and across its northern flank to exit the Valley at its northwest corner toward the Klamath River. Approximately 8,000 people live in Scott Valley and its two towns of Fort Jones and Etna. Land use and the local economy are dominated by agriculture, primarily beef cattle-raising and forage production (alfalfa and grain hay and pasture).

3.2 Geologic Setting

The geologic formations in the Scott Valley can be divided into two units, the surficial alluvial deposits, and the underlying bedrock that also comprises the upland areas surrounding the Valley. The consolidated bedrock history of the Scott Valley area consists of a complex process and accretion and metamorphosis of several Klamath terranes. The Scott Valley is a tectonic Quaternary basin situated within the Palezoic/Mesozoic Klamath Mountains Province. The terranes identified in the Scott Valley area contain similar rock type and all are of marine origin, with the exception of plutons and intrusions. The formation of the modern alluvial Scott Valley occurred in recent geologic time, approximately 2 million years ago (MYA), by Basin and Range extensional tectonics.

Consolidated bedrock terranes in the Scott Valley area are, from east to west, progressively younger, with older terranes situated structurally beneath younger deposits. The Trinity and Rail Creek terrane plagiogranites, located in the southeastern uplands of the Scott Valley area and forming a portion of the uplands drained by the East Fork of the Scott River, are the oldest tectonic rocks identified in North America and mark the oldest convergent (non-cratonic) margin identified in North America (Elder, personal communication, 2009). A succession of terranes were accreted or deposited on the area between 450 and 130 MYA and are, in succession: Yreka terrane, Central Metamorphic belt, Stuart Fork terrane, and Western Paleozoic and Triassic belt (Sawyers Bar, Western Hayfork, Rattlesnake terranes). Several intrusive events occurred over this time period as well, creating the mafic intrusive complex (MIC) rocks that intruded into the Trinity terrane and consist of pyroxenite and gabbro, and the intrusion of major Klamath plutons (Russian Peak) consisting of diorite to granodiorite in the period between 174 to 138 MYA (Elder, personal communication, 2009).

Structurally, the Scott Valley consolidated bedrock deposits range from pre-Silurian to Jurassic and possibly Early Cretaceous age, and consist of the following strata in order of upward succession: Abrams and Salmon schists, the Chanchelulla formation of Hinds, greenstones which correlate to either the Copley greenstone or the Applegate group, and ultrabasic and granitic intrusive rocks (Mack, 1958; State of California, State Water Resources Control Board, 1975).

Over time, the current Klamath Mountains underwent an uplifting sequence with the last major episode occurring 4 MYA, which accompanied a tilting of the Western Cascade ranges. Faulting and subsequent uplift of the Klamath Mountains caused the formation of a tectonic graben, of which Scott Valley is the western-most portion (Elder, personal communication, 2009). The current hydrographic position of the Scott Valley is controlled by activity that occurred along two of the principal faults forming the tectonic graben, the northern Greenhorn fault and the western Scott Valley fault. Indications are that the early course of the Scott River ran south-north and intersected the Klamath River at a point further to the east than currently, with the area comprising the current lower Scott River canyon belonging to a separate watershed. The activity along the Greenhorn and Scott Valley faults, however, caused a dip in the alluvial Scott Valley during the Quaternary period which resulted in the Scott River altering its course in the northern section of the alluvial valley and turning almost due west, capturing several tributaries as well. The activity along the Scott Valley fault also contributed to this stream capturing, and resulted in the realignment of several existing tributaries, which has left remnant alluvial fans which are now stranded (referred to as Pleistocene alluvium in Mack, 1958). The dip associated with activity along the Scott Valley fault has also resulted in a tilting of the bedrock across the valley floor from east to west, with a dip also in the northerly direction associated with the Greenhorn fault (Elder, personal communication, 2009).

The maximum exposed thickness of these remnant alluvial fan deposits is projected to be less than 50 feet. The deposits are poorly sorted and consist of sand and silty clay with well-rounded granodiorite, serpentine, chert, and quartzite boulders that average 1 foot in diameter. In the northern portion of the Scott Valley, the remnant alluvial fan deposits are found in isolated patches along the edges of the Oro Fino Creek Valley and Quartz Valley, and possibly near Etna Creek near the town of Etna. Those deposits along Quartz Valley and Etna Creek represent old alluvial fans formed by Shackleford and Etna Creeks. The alluvial fans consist of poorly sorted boulders of western-mountain origin set in a matrix of brown sandy clay to a depth of approximately 100 feet (Mack, 1958).

The remainder of the alluvium located in the Scott Valley is from a more recent time. It is composed of alluvial fan deposits, and stream-channel and floodplain deposits related to the present course of the Scott River and its tributaries. The recent alluvium ranges in thickness from 0 feet to possibly greater than 400 feet in the western portion of the Scott Valley, at its widest point. However, there is no evidence of alluvial material sufficiently coarse to support groundwater pumping below depths of 250 feet. The thickness of the alluvium decreases to both the north and the south. The alluvial deposits vary greatly in composition based on spatial distribution. Along the west side of the valley, from Etna northward to Quartz Valley, the principal streams have built large bouldery and cobbly alluvial fans which are generally most permeable in their mountainward reaches (fan apex). The channel deposits of these streams differ with regard to the percentage of granitic bouldery material which they contain, ranging from mainly finer clay and sand to larger gravel and granitic boulder debris. The composition of the alluvium deposited by the tributary streams to the Scott River differs widely. While most of the tributaries run dry during the early part of the summer, due to irrigation diversions and infiltration of streamflow into the coarse gravel of the fanhead areas, other tributaries such as Crystal Creek maintain flow throughout the year owing to the relatively impervious nature of the underlying granitic rocks which prevent infiltration of streamflow to the groundwater aquifer (Mack, 1958).

At the downstream edge of the alluvial fans, the alluvium becomes progressively less coarse ranging to fine sand, silt, and clay. Groundwater well logs from these areas have shown that alluvium consists of lenses of water-bearing gravel confined between fairly impermeable beds of clay. The alluvium in this zone is much less permeable than the floodplain and stream channel deposits of the Scott River (Mack, 1958).

3.3 Data Availability and Assessment

Table 1 presents a summary of available data with information on data sources. In the following sections, data sources and methods of data analyses are described in more detail. Extensive analysis has been performed on all of these datasets to prepare input for the soil water budget model described in Sections 10 and 11, and for the Scott Valley Integrated Hydrologic Model Version 2 currently being developed. All data are archived either in Microsoft Excel spreadsheets or in an ESRI ArcGIS geospatial database using UTM 10 (NAD83) projection. The soil water budget model is written in FORTRAN code, which reads the necessary text files prepared using ArcGIS and Excel.

Table 1 Summary of available data

Data	Data source	Contact person or website	Notes
Climate Data			
• Average max daily temperature • Average min daily temperature • Max and min humidity • Wind speed • % cloud cover • Precipitation	National Climatic Data Center (NCDC)	http://www.ncdc.noaa.gov/oa/ncdc.html	These inputs are used in the NWSETO program to calculate the reference evapotranspiration (ET_0). Stations examined included Callahan (CAL), Fort Jones Ranger Station (FJN), and Greenview. However, the Greenview data was incomplete and was not used. For both CAL and FJN, data for precipitation, snow amounts (in water equivalents), and minimum and maximum temperatures was downloaded from the NCDC.
Streamflow Data			
Streamflow	USGS, DWR, SRCD	http://cdec.water.ca.gov/ SRCD data: see table 4	Gauging data available for: Scott River Ft. Jones (USGS 11519500), Shackleford Creek near Mugginsville (F25484); Mill Creek near Mugginsville (F25480); French Creek at Highway 3 near Callahan (F25650); Sugar Creek near Callahan (F25890); Scott River, East Fork, at Callahan (F26050); and Scott River, South Fork, near Callahan (F28100). Mofett Creek, Etna Creek, Patterson Creek, and Kidder Creek.
Data used to create the GIS layers			
Elevation data	Gesch, 2002, 2007 LiDAR data, 2010 (North Coast Regional Water Quality Control Board, NCRWQB)	http://ned.usgs.gov Watershed Sciences, Inc. , obtained from the NCRWQB	Used for the thalweg definition
Model extent	Mack Report	Mack, 1958	Modified for this project.
Land use, water source, irrigation methods	California Department of Water Resources, Division of Planning and Local Assistance (DPLA)	http://www.water.ca.gov/landwateruse/lusrvymain.cfm	Detailed inputs were provided by GWAC and have been used to update the DWR map.
Soil type, water holding capacity	Soil Survey Geographic (SSURGO) database	The Natural Resources Conservation Service (NRCS) National Geospatial Management Center. http://soildatamart.nrcs.usda.gov/	
Wells	California Department of Water Resources		Wells were geo-located using a multi-step procedure depending on the information contained within the well records obtained from DWR (see Section 8). Some well locations were visually verified in the field. No measurements were performed.
Scott Valley Tributaries	Mack report	Mack, 1958	

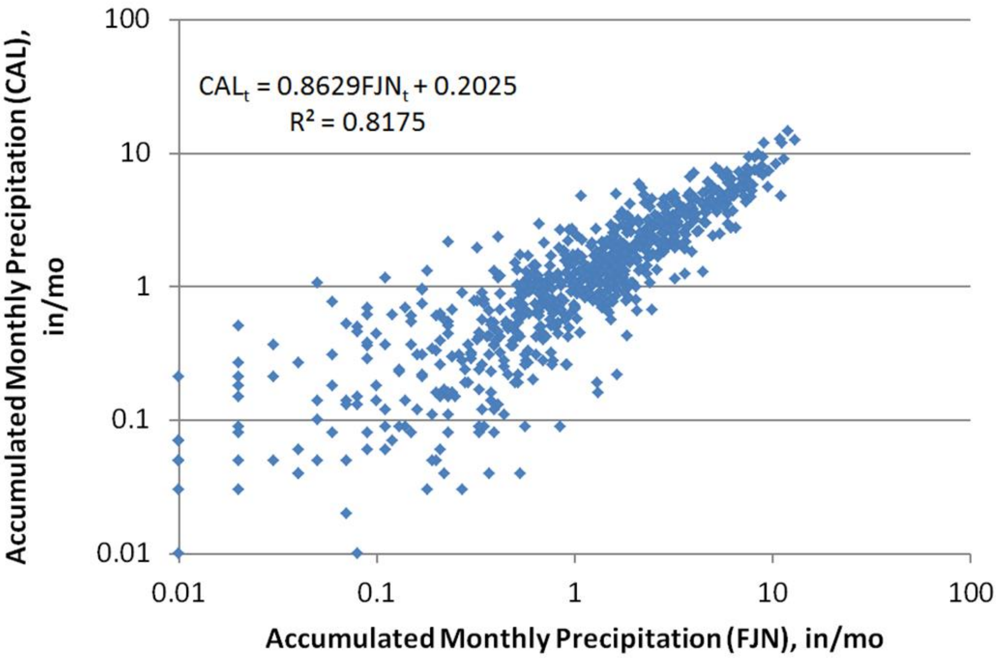
4 Precipitation

Precipitation in Scott Valley is dominated by storms approaching the Valley from the west and south. The Valley is therefore in the rain shadow of the mountain ranges surrounding it to the west and south. Precipitation stations in Scott Valley are sparse, mainly concentrated in the central and west part of the valley. Two stations have a nearly complete record of daily data since the 1940s. To determine the most representative precipitation time series for the soil water mass balance, several methods of precipitation estimation for the valley were evaluated.

4.1 Precipitation - CDEC Dataset, Monthly Values for Callahan and Ft. Jones Only

The California Data Exchange Center provides monthly precipitation records (accumulated precipitation in each month), in inches/month, for the Callahan (CAL) and Fort Jones (FJN) stations. Both sets of data were retrieved from the CDEC website on 6/28/2012 (http://cdec.water.ca.gov/). The National Weather Service operates the CAL station, the U.S. Forest Service is responsible for the FJN station. To obtain annual precipitation totals, monthly data were added for each site for each water year (WY). A water year, commonly used in hydrological statistics, begins on October 1 of the previous calendar year and ends on September 30 of the current calendar year.

Years 1981-1983 at the CAL station were recorded as “missing data”, so these years were removed from the initial analysis. Both, monthly and annual total precipitation at the CAL and FJN stations for WY 1944-2011 show a relatively strong linear trend (Figure 1). The correlation coefficient (r^2) is 0.82 for the monthly data and 0.77 for the annual totals indicating moderate correlation between the upper and lower valley precipitation. This data set was originally employed to develop a representative monthly precipitation time series (uniform across the Scott Valley groundwater basin) as part of a Version 1 (a draft version) of the Scott Valley Integrated Hydrologic Model. The average (mean) of the two annual data values was used to estimate the Scott Valley rainfall per WY. The linear regression equation obtained from the monthly totals was used to fill in the years 1981-1983 at the CAL station (Figure 1). With the CAL data series filled in, the average annual precipitation at CAL and FJN is 21.3 in/yr for 1944-2011, and 21.4 in/yr for 1991-2011. For WYs 1991-2011 (21 years), the average annual precipitation is 21.2 in/yr at FJN and only slightly higher, 21.5 in/yr, at CAL.



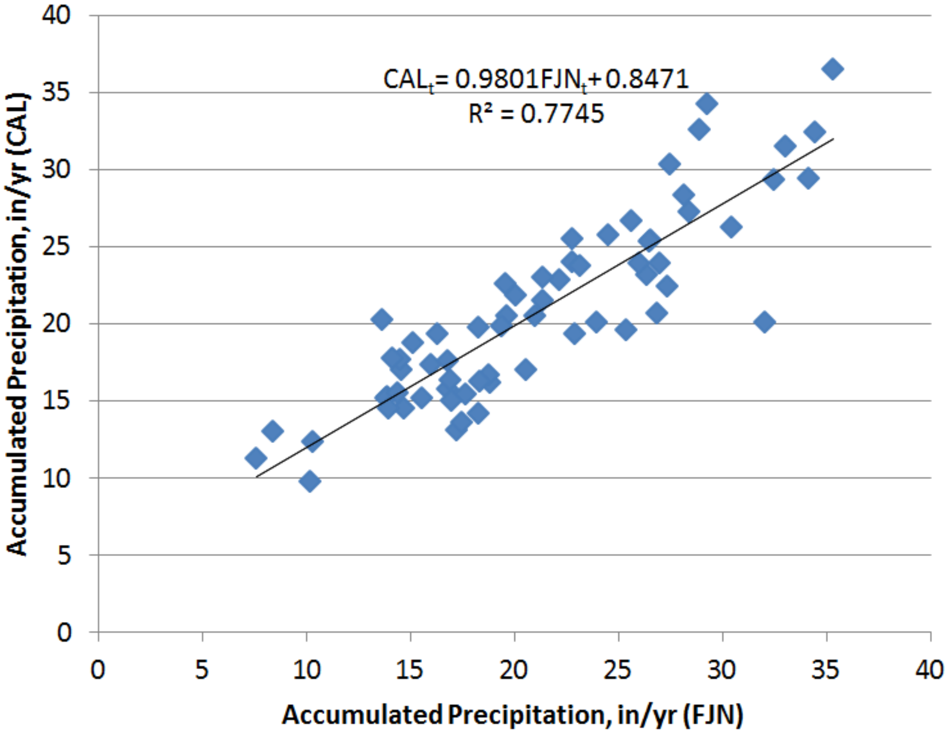


Figure 1. Linear regressions of the monthly (top) and annual (bottom) precipitation totals at Callahan (CAL) and Fort Jones (FJN) precipitation stations from 1944 to 2011, not including 1981-1983, for which CAL data are missing in the CDEC dataset. Note that the plot of the monthly precipitation data is on a log-log scale and does not show months in which either of the two stations recorded zero precipitation. The linear regression function is only shown for the annual precipitation data.

4.2 Precipitation - NOAA Dataset, Daily Values for Callahan and Ft. Jones Only

Daily precipitation data reported in units of tenth of millimeter [1/10 mm] was retrieved from the NOAA website (http://www.ncdc.noaa.gov/cdo-web/) for the Callahan and Fort Jones sites, GHCND:USC00041316 and GHCND:USC00043182, respectively, on June 29, 2012 (Figure 2). Ft. Jones station data begin in 1936, Callahan station data begin in 1943.

Summing daily precipitation data, not including missing days, for WYs 1944-2011, the average annual total precipitation is 17.8 in/yr for the Fort Jones station and 21.0 in/yr for the Callahan station. The average of monthly totals (unadjusted for missing values, occurring predominantly at the Fort Jones station), is 19.4 in/yr for WYs 1944-2011. Figure 3 shows the monthly distribution of the unadjusted monthly totals for the complete period of record. The average annual totals are significantly lower than those obtained from the CDEC monthly dataset (which are based on the same station values, but the CDEC data are aggregated differently). This is due to missing values being interpreted here as zero precipitation. This introduces a bias toward lower precipitation, which is addressed in two ways: by replacing missing values at one station with the values measured at the second station (this section), and by using statistical analysis (described in Section 4.4).

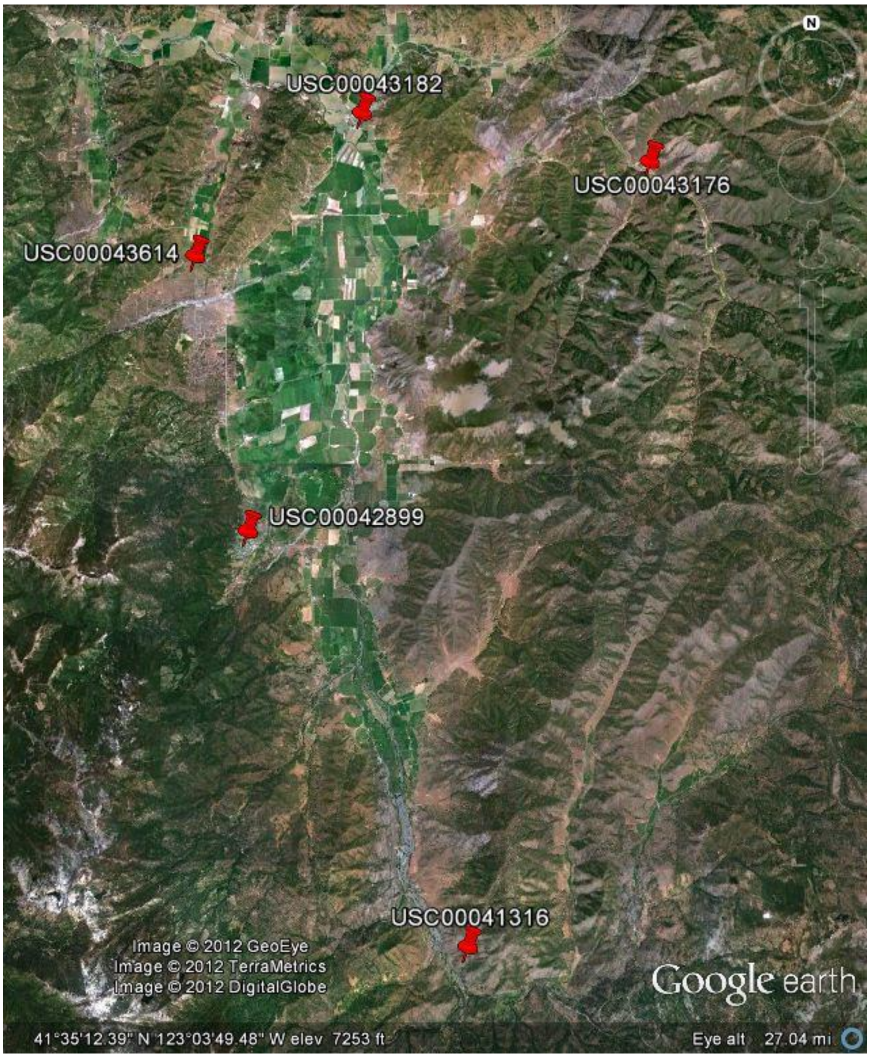


Figure 2. Precipitation gauges in Scott Valley with data available through NOAA. USC00043176 was not used, since it is outside of the Valley floor. USC00043182 corresponds to the CDEC "FJN" station and USC00041316 corresponds to the CDEC "CAL" station.

A plot of the precipitation time series at Fort Jones and Callahan shows that the sites follow similar precipitation patterns. Additionally, the peaks and troughs in the yearly precipitation are of similar magnitudes for the comparison time period, 1943-present.

The Wilcoxon rank-sum test was used to determine if the average precipitation (from the average of the precipitation at Callahan and Fort Jones) provided a good approximation for each site. Both time series compare to the average valley precipitation with 95% confidence, therefore the average valley precipitation can be considered a reliable model for the Scott Valley.

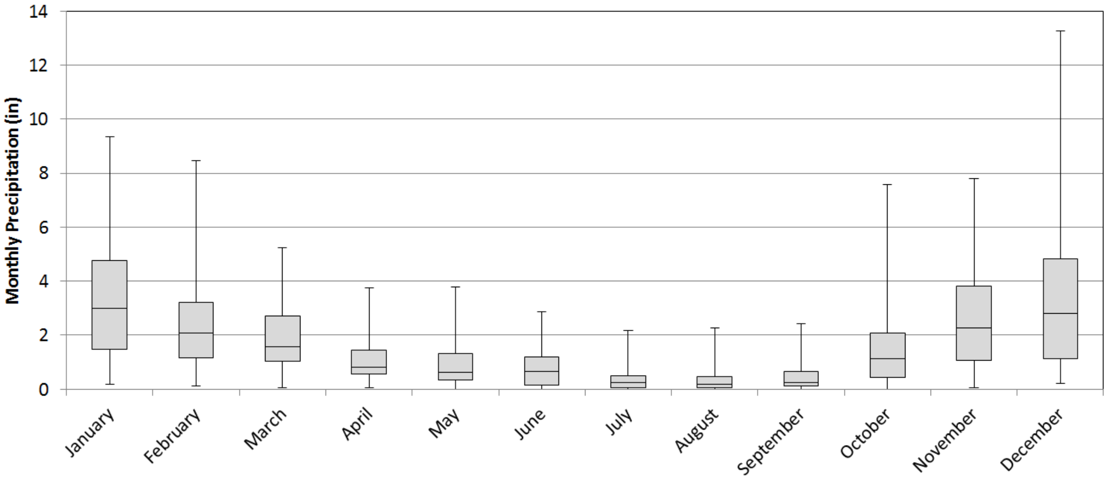


Figure 3. Minimum, 25% quartile, median, 75% quartile and maximum unadjusted monthly precipitation (average of Fort Jones and Callahan), 1944-2011. Missing daily data (mostly at the Fort Jones station) here counted as zero precipitation. See below for adjusted dataset results.

For purposes of classifying the water year type and for the soil water budget model presented below, missing data at one station (usually Ft. Jones) were replaced with measured data from the other station, rather than assuming zero precipitation on days with missing values and averaging the two stations' values. This procedure yielded a second, spatially uniform time-series of Scott Valley groundwater basin precipitation, with daily varying values for WY 1991-2011. This data series is in addition to the monthly average time series (Section 4.1). A more refined method for estimating missing data in this data series is described in Section 4.4.

Table 2 and Table 3 summarize the information collected from the NOAA internet site. Note that the elevation difference between the CAL and FJ stations is approximately 460 ft. Yearly total precipitation used in the soil water budget model is presented in Figure 4.

Table 2. Information about the two precipitation stations used: Fort Jones and Callahan (from NOAA, http://www.noaa.gov)

Fort Jones Ranger Station STN	**Callahan**
NOAA Station Id: CA043182	NOAA Station Id: CA041316
Latitude: 41°36'00N	Latitude: 41°18'40N
Longitude: 122°50'52W	Longitude: 122°48'16W
Elevation: 2725'	Elevation: 3185'

Table 3. Long-term historical averaged monthly precipitation and annual total for Fort Jones and Callahan in inches (from NOAA, http://www.noaa.gov). For this analysis, missing data at one station are replaced by the value measured at the other station prior to computing averages and totals.

Monthly Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg. Annual Total
Fort Jones	3.72	2.95	2.43	1.34	0.95	0.67	0.42	0.58	0.74	1.22	3.26	3.52	21.8
Callahan	3.72	2.94	2.44	1.34	1.15	0.82	0.46	0.35	0.64	1.39	2.95	3.1	21.3

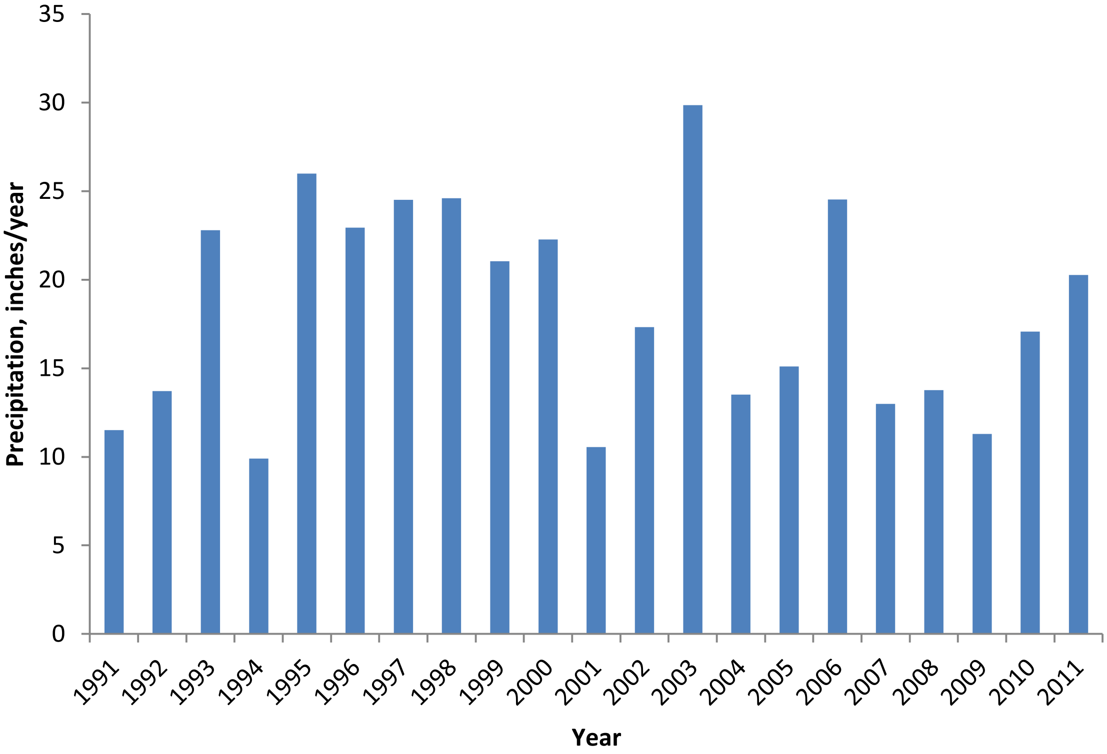


Figure 4. Precipitation in inches/year. One single value is used daily across the whole valley. For this analysis, missing data at one station are replaced by the value measured at the other station prior to computing averages and totals.

The adjusted precipitation data are used to recalculate year types. Our analysis principally relies on the analysis presented in Deas and Tanaka (2006). We updated their analysis to also include years 2005 through 2011. We recalculated the exceedance probability curve for the period 1936-2011, then used the percentile thresholds suggested in Table 4 (here: Figure 5) of Deas and Tanaka (2006), which identifies dry years, and then select these years in our 21 year modeling period, from 1990 - 2011. Results are presented in Figure 6.

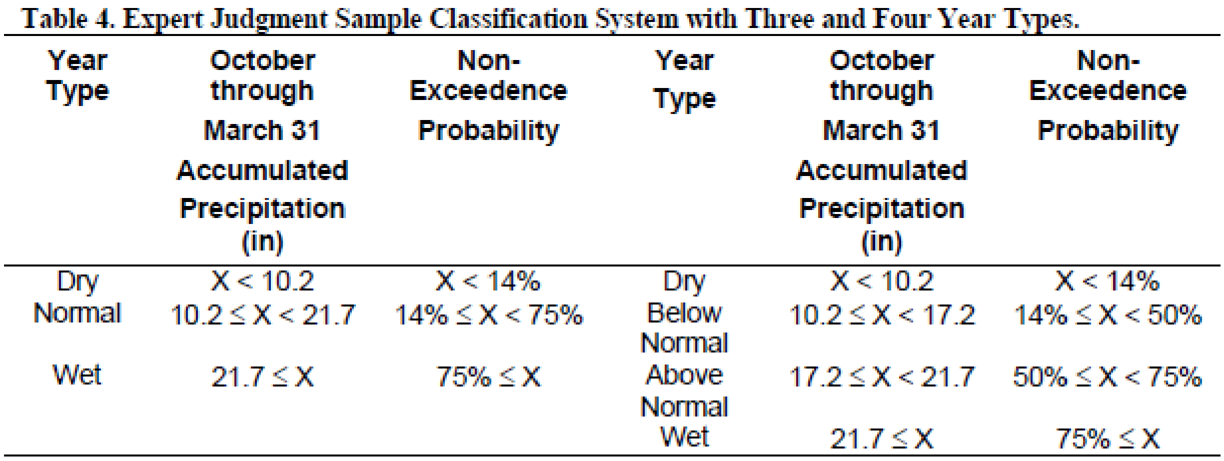


Table 4. Expert Judgment Sample Classification System with Three and Four Year Types.

Year Type	October through March 31 Accumulated Precipitation (in)	Non-Exceedence Probability	Year Type	October through March 31 Accumulated Precipitation (in)	Non-Exceedence Probability
Dry	X < 10.2	X < 14%	Dry	X < 10.2	X < 14%
Normal	10.2 ≤ X < 21.7	14% ≤ X < 75%	Below Normal	10.2 ≤ X < 17.2	14% ≤ X < 50%
Wet	21.7 ≤ X	75% ≤ X	Above Normal	17.2 ≤ X < 21.7	50% ≤ X < 75%
			Wet	21.7 ≤ X	75% ≤ X

Figure 5. Expert judgment classification from Deas and Tanaka (2006), Table 4.

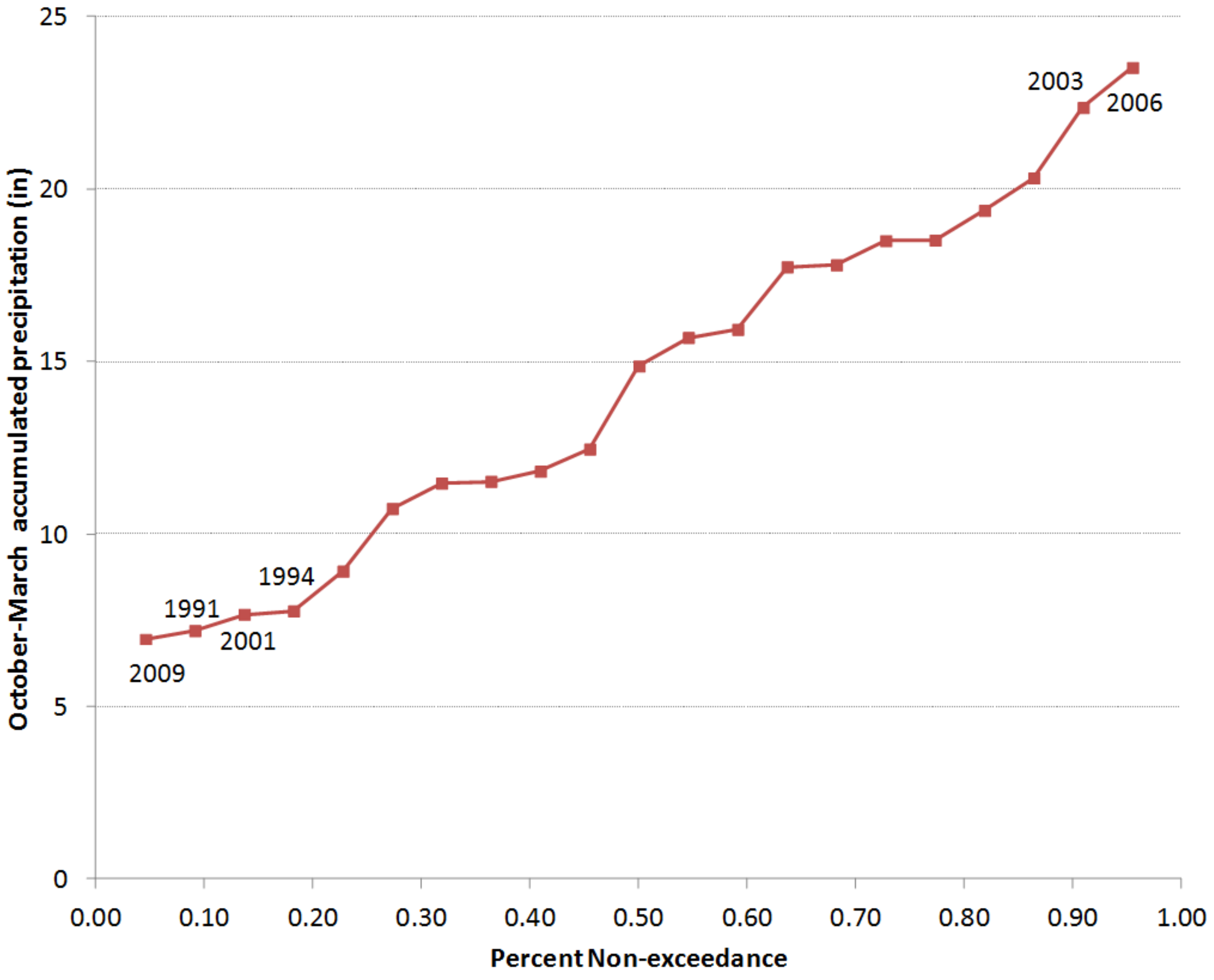


Figure 6. Analysis of precipitation to evaluate the year type.

Our results are in agreement with previous reports (Deas and Tanaka, 2005, 2006, 2009). The dry and below normal years identified in our study period are (listed in order from most dry to less dry): 2009, 1991, 2001, 1994, 1992, 2005, 2004, 2007, 2010, 2008, 2002, and 1993. The wettest years in the WY 1991 – 2011 period are 2006 and 2003. This order is slightly different from that shown in Figure 4, since the year classification is based on October-March data and does not include precipitation in April through September.

4.3 Precipitation - Watershed Method, Annual Average Total Precipitation

California Rivers Assessment (CARA) is a computer-based data management system designed to provide access to information and tools with which to make sound decisions about the conservation and use of California's rivers (http://endeavor.des.ucdavis.edu/newcara/). For the Scott River Basin, CARA reports an average precipitation of 35.87 inches per year. The precipitation coverage is represented in a precipitation map showing lines of equal rainfall ("isohyets") based on long-term mean annual precipitation data compiled from maps and information sources at the USGS, the California Department of Water Resources, and the California Division of Mines. Source maps are based primarily on National Weather Service data for approximately 800 precipitation stations throughout California collected over a sixty-year period (1900-1960). The minimum mapping unit is 1000+ acres and the isohyet contour intervals are variable due to the degree of variation of annual precipitation with horizontal distance. The CARA database utilizes a weighted average to determine a single value of mean annual precipitation; the isohyet areas, after intersection, are multiplied by the average rainfall for each isohyet-derived polygon and divided by the total area of the CARA watershed[1].

The CARA Model suggests an average precipitation of 35.87 in/yr across the watershed, much higher than the 21.6 in/yr measured on the valley floor overlying the groundwater basin (see Section 4.2). The CARA watershed area of the Scott Valley includes the high precipitation and snowfall areas of the uplands and mountains. Spatial analysis of the CARA isohyet contour map against a satellite image of the Scott Valley (Figure 7) shows that the valley floor overlying the groundwater basin has average annual precipitation values of 18-22.5 inch isohyets. A spatial analysis of the contributing isohyet areas (Table 4) yields an estimated yearly precipitation of 20 in for the area overlying the Scott Valley groundwater basin comparable to the NOAA-derived estimation (Table 3).

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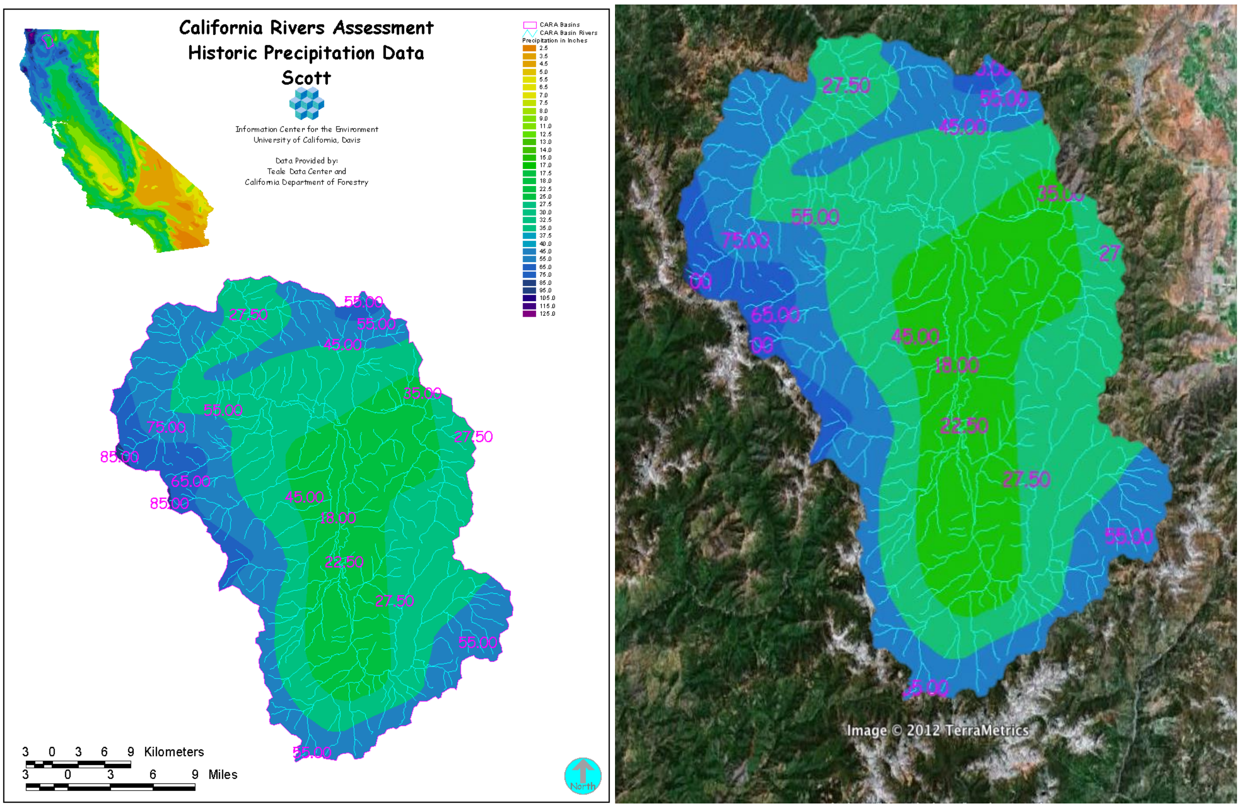
[1] On 6/29/2012 the UC Davis Information Center for the Environment (ICE) was contacted to see how they created the CARA model. The response from ICE suggested that the model was outdated and use of PRISM (http://www.prism.oregonstate.edu/) or other more recent models would be more appropriate.

Table 4. Scott Valley precipitation, CARA model approach.

Average Precip per Isohyetal unit (in)	Area (acres)	Basin Relative Contribution	Valley Floor Relative Contribution
18	72130.97	0.14	0.56
22.5	57635.41	0.11	0.44
27.5	88116.19	0.17	N/A
35	127505.25	0.24	N/A
45	88614.9	0.17	N/A
55	55521.7	0.11	N/A
65	20445.65	0.04	N/A
75	10077.12	0.02	N/A
85	933.1	0.00	N/A
Average Precip (in/yr)=		35.87	20.00



(A) (B)

Figure 7. CARA isohyet overlay for the Scott Valley (A) with aerial photo (B).

4.4 Considering Spatial Trends in the Precipitation Modeling Method

NOAA has precipitation stations not only at Fort Jones (station ID USC00043182) and Callahan (station ID USC00041316), but at two additional locations on the Scott Valley floor, at Greenview and at Etna (Figure 2). As mentioned above, the Fort Jones data series is the longest, beginning in 1936, while Callahan data are available from 1943 to present. Other stations have significantly shorter observation periods. The long historical datasets at Fort Jones and Callahan provide the most representative view of the highly variable precipitation record compared to other stations. But additional stations are valuable to determine possible spatial trends in precipitation patterns across Scott Valley. Furthermore, missing values at the Ft. Jones station (and the few missing values at the Callahan station are here replaced with statistically based estimates of the precipitation on missing data days to obtain a more accurate record of daily, monthly, and annual precipitation totals.

We use the NOAA precipitation data at all four Valley floor stations for further analysis and for developing regression equations. First, data were inspected visually and extreme outliers were removed. Then, with use of StatPlus®, the upper outlier boundary was calculated (Outlier≥Q3+1.5*IQR, where IQR is the inner quartile range). The subsequent data analysis was completed without those outling values.

The NOAA stations overlying the groundwater basin are located at Fort Jones, Callahan, Greenview, and Etna. The Fort Jones and Callahan stations are discussed in sections 2.1 and 2.2. The additional two stations are located in Etna and Greenview. Local residents report that precipitation is generally lower near the eastside of the valley floor than the westside of the valley floor. We used the additional precipitation records from Etna and Greenview to determine whether the climate station data available within the area overlying the Scott Valley groundwater basin are sufficient to verify such significant spatial trends..

Besides being of significantly less extent in time, the temporal resolution of the reported data differs across the precipitation stations: the Fort Jones and Callahan stations report precipitation values daily in 1/10th mm. The Greenview station reports precipitation values only as monthly totals in 1/10th mm. The Etna station reports precipitation values hourly in 1/100th in.

We applied a linear regression analysis to reconstruct complete precipitation records for the Etna and Greenview stations for 1943-2011, using StatPlus® software. The same regression procedure was used to also fill in the few missing values in the Fort Jones and those in the Callahan records during that time period. Separate regression equations were generated for each of twelve calendar months. For each month of the year, separate regressions were generated for each of the four stations against all other three station records (12 x 4 x [4-1] regression equations). At each of the four precipitation stations, the three regression equations were ranked separately for each of the twelve calendar months by their correlation coefficient. Missing daily precipitation data were then computed using the highest ranked station-to-station specific regression equation for which data at any of the other three stations were available. For the Greenview station, regression equations were used to generate daily data from monthly total reported precipitation.

Daily data from October 1990 to September 2011 were compared for spatial precipitation trends across the Scott Valley groundwater basin. Over the 20 year study period, the average yearly precipitation, computed from the annual totals during 1990-2011 for Callahan, Fort Jones, and Greenview differed by less than 0.8 in (less than 4%), with values of 21.34, 22.05, and 21.27 inches respectively. At the Callahan station, 88% of the yearly precipitation occurs from October to April, while it is 90% at Fort Jones. Only about 2-inches of precipitation occur during the irrigation season, most of which would likely not reach the groundwater basin.

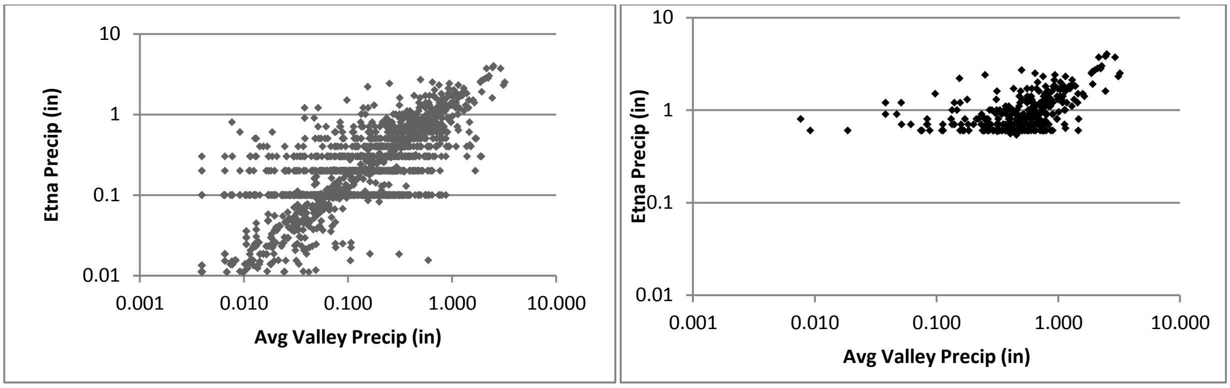
The Etna station recorded an average annual precipitation of 27.98 inches, approximately 30% higher than the other three stations. From Figure 7, we can see that the location of the Etna station places it on the edge of the model extent along the western mountains, not unlike the Greenview station.

To determine the quality of the estimated Greenview values, monthly precipitation from NOAA was compared with estimated monthly totals of daily data obtained from the regression analysis using a two sample homoscedastic t-test at alpha level 0.05. The test failed to reject the null hypothesis H_0: μ_1=μ_2 (p=.05593), so we can conclude that the regression precipitation values do not significantly differ from the NOAA values.

With all missing values at Greenview, Ft. Jones, and Callahan replaced by regression estimated values (but not considering the Etna data series), the average annual precipitation across all three stations, for WYs 1944-2011 is 21.3 in/yr, for WYs 1991-2011, it is 21.8 in/yr (Figure 11). In comparison, the average annual precipitation at Ft. Jones and Callahan only, with missing values replaced by estimated values, is 21.5 in/yr for WY 1944-2011 and 22.0 in/yr for WY 1991-2011, consistent with the average annual precipitation obtained from the CDEC dataset of monthly precipitation totals (see above). The precipitation data from the NOAA and CDEC online repositories are very similar, but not quite identical due to different handling of missing values in the aggregation of daily data to monthly data. They also differ in the time steps and measurement units of the reported values. But for practical purposes, these differences are negligible.

The precipitation measured at the Etna station often differs markedly from the values measured at the other stations, which prompted additional data analysis. In the 20 year period from October 1990 to September 2011, there are 167 days for which the difference between Etna and the average valley precipitation, computed from the Fort Jones, Callahan, and Greenview data, is greater than 0.5 inches. As shown in Figure 8A, Etna precipitation is frequently greater than the average valley precipitation. Figure 8B shows the same comparison but only for cases when Etna has precipitation exceeding 0.5 in. In some instances, Etna's precipitation is two orders of magnitude higher than the average valley precipitation. Of 167 days with differences exceeding 0.5 inches, only 40 days show Etna precipitation to be less than the average valley precipitation. Thirty-nine days return a difference between Etna and the average valley value that is larger than 1 inch. Of these, Etna has the lower precipitation on only 10 days. Notably, on each day where

Etna records a value that is more than 0.5 inches lower than the average, the Etna recording is 0 inches. It is therefore unclear, whether there are operating or local positioning biases to the Etna data series.



(A) (B)

Figure 8. Etna precipitation compared to average Scott Valley precipitation. A: all Etna precipitation; B: only Etna precipitation exceeding 0.5 in.

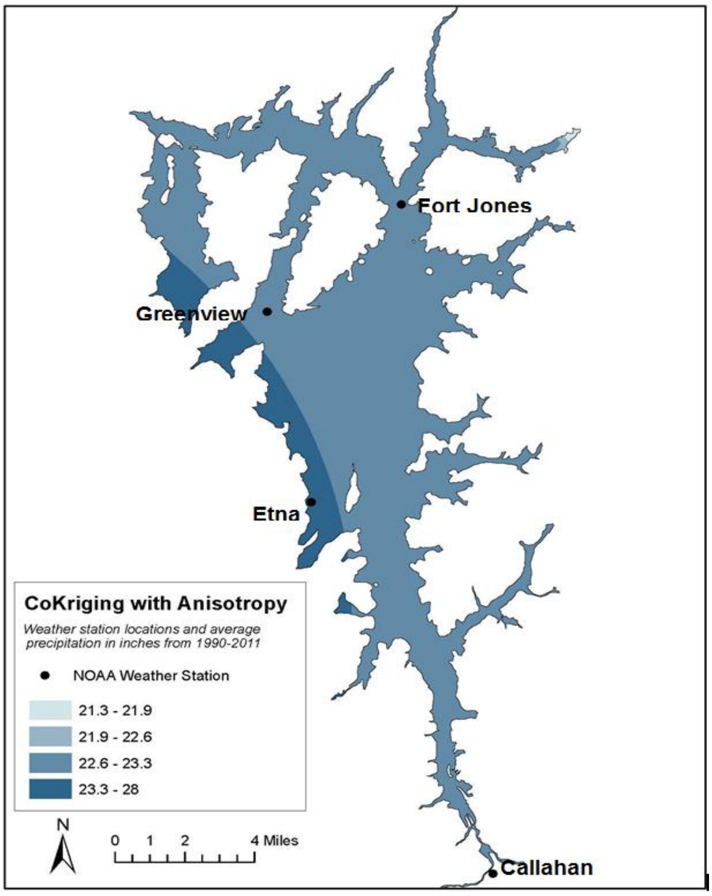


Figure 9. Valley floor precipitation cokriging interpolation with anisotropy.

Average annual total precipitation measured at Etna, Greenview, Fort Jones, and Callahan were interpolated (using ArcGIS®) and mapped across the groundwater basin (Figure 9). We used cokriging with large NNW-SSE anisotropy to map spatially variable precipitation across the valley. The anisotropy reflects the hypothesized strong precipitation gradient across the West-East extent of the valley. However, even if the Etna precipitation were considered relatively accurate, the high precipitation at the western-most margin of the Scott Valley groundwater basin only affects a relatively small area of the basin and would exclude the Greenview area. The Greenview station, also on the westside of the Valley, agrees well with those at Callahan and Fort Jones.

While of nearly identical yearly averages, daily values at Greenview, Callahan, and Fort Jones exhibit significant variance among each other, as would be expected across the significant extent of the groundwater basin (25 miles long and up to 10 miles wide at its widest point). But given that the integrated hydrologic model for which this data series is developed operates effectively at monthly stress periods, a spatially averaged daily precipitation value, obtained from the relatively complete Callahan and Fort Jones stations, is considered adequately representative of precipitation dynamics across the Scott Valley groundwater basin.

In conclusion, using the four available precipitation stations, it was not possible to either support or disprove the observation of a strong west-east gradient in precipitation totals reported by local residents. Additional stations on the eastern margin of the Valley and on the Valley's southwest side would be needed to support these qualitative observations. Furthermore, the number and location of the precipitation stations for which data were available, and the temporal extent of the data currently do not justify a spatially distributed precipitation map for the groundwater basin. Future precipitation gauges would be needed to enhance our understanding of orographic precipitation mechanisms in the valley, which may lead to alternative rainfall estimates. Until such additional data are available, daily precipitation across the entire Scott Valley groundwater basin is assumed to be uniform, represented by the arithmetic average of the measured daily Fort Jones and Callahan or at Fort Jones, Callahan, and Greenview, with missing data replaced by the regression estimated data. This time series, developed from daily data, was used for the streamflow regression analysis described in the next section.

The choice of uniform precipitation does not preclude future alternative approaches in the integrated hydrologic modeling effort. Spatially variable precipitation, if additional data become available, could be accommodated by the water budget model described in this report and hence become part of a groundwater-surface water model.

5 Streamflow

The Scott Valley groundwater basin and its overlying streams are fed by runoff from the surrounding mountains. Tributaries to the Scott River, including the two forks of the Scott River itself, emanate from the mountains carrying significant runoff.

Understanding groundwater-surface water interactions in the Scott Valley requires some knowledge of the streamflow amounts that enter the valley floor overlying the groundwater basin. In this section, we describe and investigate available data. We also construct time series of streamflow in all major tributaries of the Scott River and for the South Fork and East Fork of the Scott River, which join at the upper end of the Scott Valley floor. The main purpose for developing these time series is to provide an approximation of surface flows into the Scott Valley as part of the Scott Valley Integrated Hydrologic Model.

The eight tributaries of interest here are Sugar, French, Etna, Patterson, Kidder, Mill (a tributary to Shackleford Creek), Shackleford, and Moffett Creeks. There are other tributaries to the Scott River, but their flows tend to be ephemeral, relatively smaller, and their exact magnitude is not as critical to understanding groundwater-surface water interactions in Scott Valley. In an integrated hydrologic model, these may be represented as a diffuse source of recharge along the mountain front around Scott Valley. The Scott River itself is gauged near Callahan at both the East and South Forks (upstream of the confluence). An additional long-standing gauge ("Ft. Jones") is located downstream of Scott Valley, west of Fort Jones on the Scott River.

Location of the flow gauges has been provided by SRCD and is shown in Figure 10. The gauges at Sugar Creek, Moffet Creek, and Kidder Creek are located above irrigation diversions and do not reflect tributary inflows to the Scott River. Gauges at French Creek, South Fork, and East Fork are located at the margin, but within the Scott Valley.

Most of the tributaries have very limited records of streamflow gauging, while the Ft. Jones gauge has a complete record for the past seventy years (Figure 11). To develop an appropriate groundwater-surface water model for the Scott Valley groundwater basin, it is therefore necessary to also develop a model of the main stem and tributary streamflows, at the upgradient boundary of the Scott Valley floor, for those time periods for which no streamflow data are available.

Here, we chose to determine missing tributary and main stem streamflow data at the upstream margins of the groundwater basin through statistical regression analysis. A number of independent predictor variables are considered for the regression analysis: streamflow of the Scott River at the downstream Fort Jones gauging station, streamflow at the East Fork and South Fork gauging stations in Callahan, streamflows on the tributaries when measured (Table 5), precipitation data, temperature data, and snowpack data. The program R® was used to create linear regression models with accompanying diagnostic plots (see Appendix A).

5.1 Snow Water Content for Regression Modeling

Snow water content stations are located throughout the Scott Valley. The measurements considered here are those taken in the month of April. The stations at Box Camp (BXC) and Marble Valley (MBV) were not used since the snowmelt from these stations enters the Scott River downstream (north) of the Scott Valley. For the model, the yearly average of the measured snow water content at Middle Boulder 1 (MBL), Etna Mountain (ETN), Dynamite Meadow (DYM), Swampy John (SWJ), and Log Lake (LOG) were used to aggregate across intra-watershed variabilities and to obtain a representative dataset of the snow water content for the regression analysis.

An additional snowmelt-related variable investigated here is the number of days in a given calendar year (not water year), on which the temperature at Callahan exceeded 21°C. At this temperature the entire watershed is under snowmelt conditions.

5.2 Precipitation for Regression Modeling

Daily mean precipitation computed from measured data at the Fort Jones, Greenview, and Callahan stations for 1943 – 2011 (see Section 4.4) were used to compute the following additional independent variables in the regression:

“MoPrecip”: sum of the average daily precipitation during the current month t

“PrevMoPrecip”: sum of the average daily precipitation during the prior month, t -1

“WYPrecip2Date”: sum of the average daily precipitation between the beginning of the current water year (starting on October 1) and the beginning of the current month, t

“WYPrecip”: sum of the average daily precipitation for the entire water year, of which the current month, t, is part (a model with “perfect foresight” because it includes information that represents events in the future relative to the date of the estimated streamflow).

5.3 Flow Gauges

Daily mean discharge has been recorded at Scott River near Fort Jones CA (USGS 11519500) since October 1, 1941 (Figure 11). This data is available at http://waterdata.usgs.gov/nwis, with average daily values reported in cubic feet per second (cfs). For the regression, daily data were converted to units of acre-feet per day (1.9835 AF/day equals 1 cfs). This dataset is the most robust of all the streamflows in the Scott Valley. The published record has no missing daily flows. On some days, data are estimated by the USGS, and then approved for publication. Because of the abundant data available, the Scott River near Fort Jones flow was a major component of the regression model. Table 5 lists the dates of available tributary streamflow data used for the regression analysis, including the east and south fork of the main stem Scott River.

Tributary flow was downloaded from the Water Data Library (http://www.water.ca.gov/waterdatalibrary/). The following list includes the code for each tributary: Shackleford Creek near Mugginsville (F25484); Mill Creek near Mugginsville (F25480);

French Creek at Highway 3 near Callahan (F25650); Sugar Creek near Callahan (F25890); Scott River, East Fork, at Callahan (F26050); and Scott River, South Fork, near Callahan (F28100). Dates for which data are available are listed in Table 5. Data are provided as average daily flows (cfs) and were converted to units of (AF/day).

Daily data were used for the regression analysis. Complete sets of daily data with measured values, when available, and with regression estimated values otherwise, were aggregated to monthly totals (AF/mo) for each individual month in the time series.

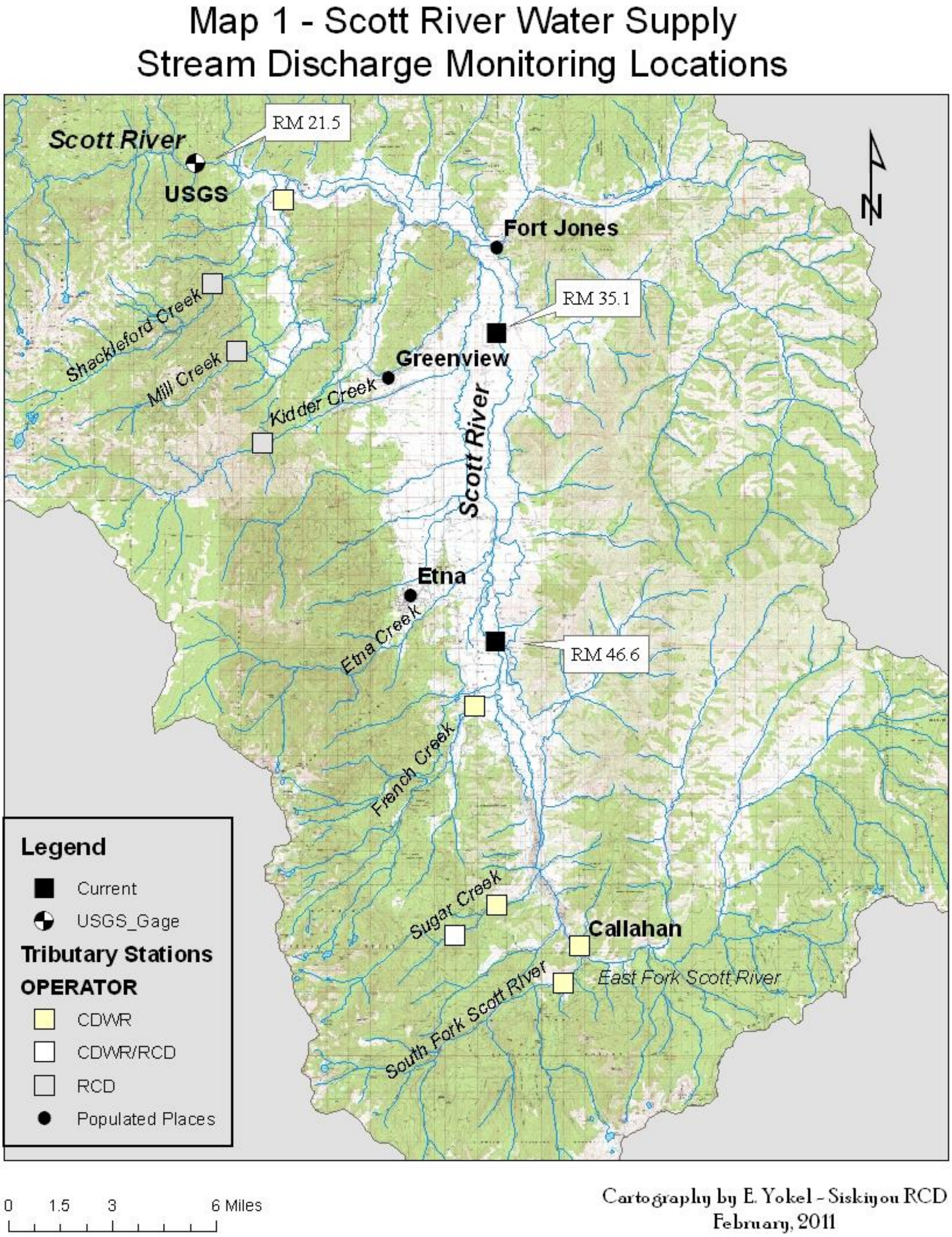


Figure 10. Streamflow measurements in Scott Valley (E. Yokel, Siskiyou RCD, 2011).

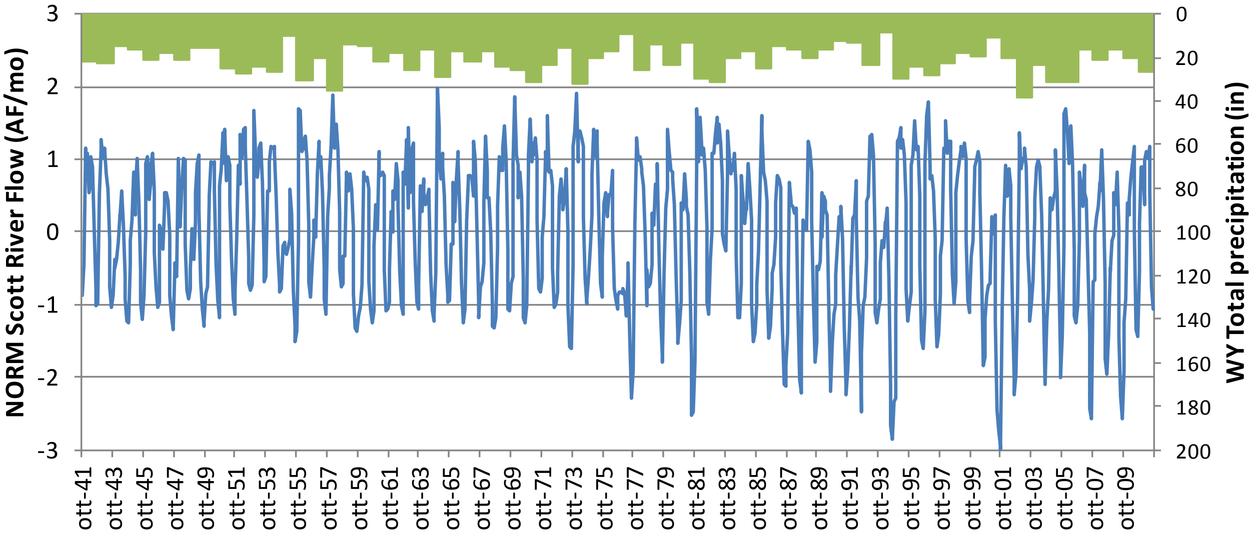


Figure 11. Log-transformed, normalized monthly average Scott River streamflow at Fort Jones, October 1941 through September 2011, computed from reported daily discharge (blue line). Water year total precipitation(green hanging bars) are computed as the average of measured and estimated daily precipitation data at the Fort Jones, Callahan, and Greenview stations (Section 4.4).

Missing data from the CDEC database are noted with a quality code of 160 or 255. Code 160 indicates that the flow was higher than the gage capacity, a situation for which it is difficult to estimate an exact value. Similarly, the tributaries that are measured manually are measured only under wadeable, non-flooding, conditions. Because many of the high value flows are missing from the raw data, the regression models have difficulty replicating the peak flows. However, the goal of the model is to understand the late summer/fall flows, which may affect fish, particularly juvenile coho and fall-run Chinook salmon. Inaccurate prediction of high flow events is not significantly affecting our analysis of late summer low flows. High flood flow may impact late summer low flows indirectly – if at all - through groundwater recharge. Recharge from flood events is difficult to predict, even if high flood flows were known precisely. While it is important for the model to represent the streamflows accurately each month, more focus was therefore placed on the accuracy of low flow events.

Table 5. Dates of available tributary streamflow data used for the regression analysis, including the east and south fork of the main stem Scott River.

	Pre-WY1972 Data Range	Post-WY1972 Data Range
Kidder	4/72-9/72	10/02-9/11
Mill	-	12/04-9/05
Shackleford	10/56-9/60	10/04-9/11
Sugar	9/57-9/60, 5/72-9/72	10/09-9/11
Moffett	10/58-9/67, 4/72-9/72	-
East Fork	10/59-9/72	10/72-9/74, 7/02-9/11
South Fork	10/58-9/60, 4/72-9/72	7/02-9/11
French	-	10/04-9/11
Etna	4/72-9/72	-
Patterson	4/72-9/72	-

The degree to which unmeasured and poorly (under)predicted high flows may affect groundwater recharge will need to be determined through sensitivity analysis with the integrated hydrologic model.

5.4 Statistical Analysis: Streamflow Regression Methods

Monthly averages of reported daily streamflow data for the Scott River gauge at Fort Jones and at the two gauges in Callahan are log-normally distributed. For the regression analysis, all existing monthly average streamflow data, $x_{i,t}$, at gauging station i and month (time) t were therefore log-transformed and normalized to obtain a normally distributed data series of monthly flows, Norm($x_{i,t}$), for each gauging station i:

$$Norm(x_{i,t}) = \frac{\log(x_{i,t}) - \mathrm{M}[\log(\boldsymbol{x}_i)]}{\mathrm{STD}[\log(\boldsymbol{x}_i)]}$$

where M is the arithmetic mean (of the log-transformed data series xi) and STD is the standard deviation.

Four transformed data series computed from known data sets were alternately used as independent variables to build regression models of normalized log-transformed tributary flows using linear regression:

- "Norm(Scott)": Norm(Scott River Flow at Fort Jones)
- "ProductWeightedNorm(Scott)": $\sqrt[3]{\text{Norm(Scott River Flow at Fort Jones)} \times \text{WYPrecip} \times \text{AvgSnowWC}}$
- "RatioWeightedNorm(Scott)": $\frac{\text{Norm(Scott River Flow at Fort Jones)}}{\sqrt{\text{Total WYPrecipt} \times \text{AvgSnowWC}}}$
- "SumWeightedNorm(Scott)": [Norm(Scott River Flow at Fort Jones) + WYPrecip + WYPrecip2Date + MoPrecip + PrevMoPrecip + AvgSnowWC]

The following dependent variable time series were separately used against each of the above four independent variables to build a number of regression models for comparison:

- "Norm(*Streamname*)": each individual normalized tributary flow gauge time series, all times
- "Norm(EastTribs)": the combined record of all normalized tributary flow time series of tributaries along the east side of Scott Valley, all times
- "Norm(WestTribs)": the combined record of all normalized tributary flow time series of tributaries along the west side of Scott Valley, all times
- "Norm(Tribs)": the combined record of all normalized tributary flow time series, all times

To investigate seasonal biases in the regression models, the combined dataset of all normalized, log-transformed tributary data, "CombinedTribs", was dissected into

- "Norm(Tribs-Season)": season-of-the-year data (4 datasets) and

- “Norm(Tribs-Month)”: month-of-the-year data (12 datasets)

These 4 and 12 datasets were used to compute separate regressions for each season (fall: Oct-Nov, winter: Dec-Feb, spring: Mar-Jun, summer: Jul-Sep) and separate regressions for each calendar month (Oct through Sep), respectively.

Over the period of record, the normalized flow data for the Scott River show a significant shift that occurs sometime during the long drought-free period between the 1955 drought and the 1977 drought. Beginning with the 1977 drought, summer month low flows (but not winter month high flows) are significantly lower than in the 1955 drought and earlier. We therefore created another set of regressions using a split “Norm(Tribs)” dataset:

- Norm(Tribs)-Pre-WY1972, which includes WY 1943 to WY 1972, and
- Norm(Tribs)-Post-WY1972, which includes WY 1973 to WY 2011 data.

Note that in the above lists, “tributary flow” and “tribs” include the South and East Fork of the Scott River. For all of the above regressions, subsets of each log-transformed, normalized data series were used for the time period of interest. However, across all analyses, the normalization of each stream gauge’s dataset by its mean and standard deviation remains the same and is always based on the total period of record for each stream gauge. In other words, we did not renormalize the individual data series from original data for the particular time series used in the analysis, neither for the independent nor for the dependent data series.

Additional regressions were implemented using the number of days in the calendar year to date at which the temperature exceeded 21°C. This temperature was selected by computing the temperature difference between Fort Jones and the highest point in the watershed, using the dry adiabatic lapse rate (DALR). At 21°C, all of the surrounding snow-capped mountains have temperatures above freezing, and they are contributing flow to the tributaries.

Goodness of fit was determined in a number of ways. First, the diagnostic plots from R were visually examined. “Residuals vs Fitted” shows residual values as a function of the fitted value. If the assumption of linear dependency between dependent and independent variable is justified, these bounce randomly around the 0 line. If the results in the plot are closer together on one part of the x-axis (e.g., the left side) than on the other part of the axis (where they would be more spread apart or fanned out), then this would indicate a violation of the homogeneity assumption that the residuals are independent of the magnitude of the predicted value. The “Q-Q plot” should show linearity if the data are normally distributed. “Residuals vs. Leverage” should show no pattern. “Scale-Location” plots should also show no patterns and issues of heteroscedasticity would be noticeable through fan-like patterns in the plots.

5.5 Streamflow Regression: Results and Discussion

The regression slopes of the normalized tributary flows against the Scott River flows are all less than 1 with a positive regression intersect (Table 6). This indicates that the geometric mean flows of the tributaries have a tendency to occur when the Scott River below Ft. Jones is at less than geometric mean flow; and the low flow on the tributaries tend to be less extreme than on the Scott River, or the high flows are not as extreme as on the Scott River, or both (relative to the standard deviation). The only exception is Moffett Creek, which has regression slope slightly larger than 1 with a slightly negative regression intersect.

The behavior observed on most tributaries is even more exaggerated when the normalized data are separated into a pre-WY1972 and post-WY1972 series: prior to (and including) WY 1972, tributary geometric mean flow occurs at approximately the Scott River geometric mean flow, with the slope being slightly larger than 1 (high flows and/or low flows on the tributaries tend to be slightly stronger than on the Scott River). After WY1972, tributary geometric mean flows occur when the Scott River is at less than geometric mean flow and the extreme events (highs or lows or both) are less exaggerated on the tributaries than on the main stem of the Scott River below Ft. Jones: the log-transformed flows on the tributaries vary only at 84% of the relative variation on the main stem below Scott Valley. Separating the time-series into two series, however, yields an only slightly better correlation coefficient, r^2.

Fitting each tributary separately against the Scott River data, or fitting the combined west side tributaries separately from the combined east side tributary data also does not produce a much higher correlation coefficients (Table 6). It therefore appears that a single regression for the combined dataset of normalized, log-transformed tributary flows is adequate and also takes advantage of the information that may be collected on some tributaries but not at others, given that tributary flows are highly correlated among each other.

When weighting the regressions by additional information, two models emerge with correlation coefficients similar to (and not much higher than) the unweighted regressions: the product-weighted regression and the sum-weighted regression. The ratio-weighted regression, on the other hand, performed very poorly.

The product-weighted regression provides large weights when high flow events coincide with wet years and large snow pack, and low weights when low flow events coincide with dry years and small snow packs. The product-weighted regression implies that tributary flows are relatively smaller (compared to Scott River flows) in dry years with low snow pack than in average or wet years or in years with higher snowpacks.

The sum-weighted regression provides the best correlation coefficient, if only slightly better than the unweighted correlations. The sum-weighted correlation assigns additional weights to several precipitation and snow-pack related data. But that does not significantly improve the predictive capability, if the Scott River dataset alone was used.

In the Q-Q plot, most models showed some tailing off the line y=cx for low x values. Also, some trends appear in residuals. For many regressions against Norm(Scott) and SumWeightedNorm(Scott), the correlation coefficient, r^2, is larger than 80% (Table 6) indicating an overall strong, but not perfect, goodness of fit. R-squared can give an approximate indication of how well the estimated data fit the measured data overall, but it is important not to base all judgment on this value alone. Some models had r^2 larger than 70%, yet failed to model the high and low streamflow values well.

A visual comparison of the plotted estimated and actual values was made (see Appendix A). This method of determining goodness of fit was the best way to see how well the regression modeled the flow, especially the important summer/early fall flow.

Mill, Etna, and Patterson were difficult to analyze since these tributaries were only gauged for one year. With so few points to compare, it is difficult to tell which regression provides the best fit. To be conservative, the regression that shows the best for the other tributaries should also be used for these three flows.

Table 6. Key regression slopes, intersects, and regression coefficients. Availability of data from individual streams is listed in Appendix (also see Table 5).

Dependent Variable	Independent Variable	Regression Slope [-]	Regression Intersect [-]	r^2 [%]
Norm(Tribs)	Norm(Scott)	0.903	0.122	81.2
Norm(Tribs)-Pre-WY1972	Norm(Scott)	1.053	-0.000405	84.7
Norm(Tribs)-Post-WY1972	Norm(Scott)	0.840	0.218	82.4
Norm(WestTribs)	Norm(Scott)	0.881	0.205	81.4
Norm(EastTribs)	Norm(Scott)	0.964	0.00975	83.7
Norm(Kidder)	Norm(Scott)	0.804	0.129	76.7
Norm(Shackleford)	Norm(Scott)	0.952	0.243	89.9
Norm(Sugar)	Norm(Scott)	0.979	0.0406	83.0
Norm(Moffett)	Norm(Scott)	1.044	-0.0567	78.0
Norm(EastFork)	Norm(Scott)	0.941	0.0364	87.4
Norm(SouthFork)	Norm(Scott)	0.900	0.317	82.1
Norm(French)	Norm(Scott)	0.879	0.350	82.2
Norm(Tribs-Summer)	Norm(Scott)	0.758	-0.123	50.1
Norm(Tribs)	RatioWeighted-Norm(Scott)	18.66	0.14	37.0
Norm(Tribs)	ProductWeighted-Norm(Scott)	0.1118	0.006066	76.3
Norm(Tribs)	SumWeighted-Norm(Scott)	0.930	0.370	82.3
Norm(Tribs)	SumWeighted-Norm(Scott) – Pre-WY1972	1.111	0.240	85.6
Norm(Tribs)	SumWeighted-Norm(Scott) – Post-WY1972	0.876	0.682	83.7

For the best fit, we were particularly interested in matching flows during the low flow season, if not perfectly, then at least such that flows are over-predicted in some years and under-predicted in other years. Ideally, the regression would have zero bias, where bias is here defined as

$$\text{Bias} = \text{Norm(Trib)}_{\text{actual}} - \text{Norm(Trib)}_{\text{predicted}}$$

Bias was calculated separately for each calendar month and each tributary for the time period of record, using two example regressions. Data are not available in all months to compute bias (Table 7 - Table 10).

Comparing prediction results between various regression methods, qualitative differences in the overall pattern of fit are small compared to the large annual variations in streamflow. Weaknesses in one prediction are repeated, at slightly better or worse levels, in other predictions.

A large number of negative bias occurs during the summer months at the East Fork, in particular. Visual inspection of predicted vs. measured time series indicates that predicted values for the earlier time period at the East Fork seemed to have a particularly significant bias, not being able to predict the low flows in most summer months. While the East Fork has significant bias, especially for September's low flows, no adjustments were made to correct this bias or any other stream's bias. Not enough month-specific data are available to correct for potential bias.

For the pre- and post-1972 regressions (Norm(Tribs)Pre-WY1972, Norm(Tribs)Post-WY1972), streams had at most 13 datapoints, and commonly much less (Table 7-Table 10).

From the many individual regressions, we found that those regressions that included all tributaries in the equation provided a better fit overall than the regressions for individual tributaries, or the regressions for individual months or individual seasons.

The regressions of normalized tributary streamflows vs. RatioWeightedNorm(Scott) provided the relatively poorest fit ($r^2 < 0.4$), although some summer flows are better predicted than by other models. A much better correlation was obtained when computing a regression of tributary flows vs. ProductWeightedNorm(Scott) (r^2 =76.3%). Commonly, this regression, however, tends to significantly underestimate peak flows and overestimate low flows.

In summary, of the many regression models developed, two regression models stood out as having a significant better fit, particularly in the critical low-flow season: Norm(Tribs) vs Norm(Scott) and Norm(Tribs) vs SumWeightedNorm(Scott).

The best fit was obtained by the split time period regressions, Norm(Tribs)Pre-WY1972 and Norm(Tribs)Post-WY1972 vs. SumWeightedNorm(Scott), particularly in the critical summer months. Splitting the regression gave slightly better results (r^2 values of 84.7% and 82.4%) than the fully combined regression Norm(Tribs) vs. SumWeightedNorm(Scott) (r^2=81.2%). The split regression model would also provide the best possible fit for the flows at Mill, Etna, and Patterson given the lack of raw streamflow data for these tributaries. The regression is considered particularly good, given the large variability in flow volume and geographical range within the valley. The split Norm(Tribs)Post-WY1972 vs. SumWeightedNorm(Scott) and the split Norm(Tribs)Post-WY1972 vs. Norm(Scott) will be the best candidates for use in the groundwater-surface water model.

Table 7. Regression bias for Norm(Tribs)- Pre-WY1972 vs. SumWeightedNorm(Scott). White areas indicate that data are available to compute a bias for those months.

	Kidder	Mill	Shackleford	Sugar	Moffett	East Fork	South Fork	French	Etna	Patterson
	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum
January	▨	▨						▨	▨	▨
February	▨	▨	-0.28 / 4	-0.13 / 3		-0.16 / 13	-0.13 / 2	▨	▨	▨
March	▨	▨	-0.17 / 4	-0.14 / 3				▨	▨	▨
April	▨	▨		-0.17 / 3				▨	▨	▨
May	▨	▨			-0.45 / 10			▨	▨	▨
June	▨	▨			-0.65 / 10			▨	▨	▨
July	▨	▨		-0.13 / 4	-0.11 / 10			▨	▨	▨
August	▨	▨		-0.46 / 4		-0.15 / 13		▨	▨	▨
September	▨	▨		-0.26 / 5		-0.42 / 13		▨	▨	▨
October	▨	▨				-0.24 / 13		▨	▨	▨
November	▨	▨			-0.24 / 9			▨	▨	▨
December	▨	▨						▨	▨	▨

▨ Indicates one or fewer years of data, so no average bias calculated

□ Indicates bias was > -0.1

Table 8. Regression bias for Norm(Tribs)- Post-WY1972 vs. SumWeightedNorm(Scott). White areas indicate that data are available to compute a bias for those months.

	Kidder	Mill	Shackleford	Sugar	Moffett	East Fork	South Fork	French	Etna	Patterson
	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum
January		▨		▨	▨	-0.34 / 6	-0.12 / 5		▨	▨
February	-0.11 / 6	▨		-0.29 / 2	▨				▨	▨
March	-0.27 / 8	▨		▨	▨				▨	▨
April		▨		▨	▨				▨	▨
May		▨			▨				▨	▨
June		▨		▨	▨				▨	▨
July		▨			▨				▨	▨
August		▨	-0.15 / 7		▨	-0.23 / 10		-0.28 / 7	▨	▨
September		▨	-0.40 / 7	-0.19 / 2	▨	-0.50 / 10		-0.16 / 7	▨	▨
October	-0.58 / 8	▨	-0.68 / 5	▨	▨	-0.13 / 8			▨	▨
November		▨			▨				▨	▨
December		▨		▨	▨	-0.32 / 5	-0.12 / 4		▨	▨

▨ Indicates one or fewer years of data, so no average bias calculated

□ Indicates bias was > -0.1

Table 9. Regression bias for Norm(Tribs)- Pre-WY1972 vs. Norm(Scott). White areas indicate that data are available to compute a bias for those months.

	Kidder	Mill	Shackleford	Sugar	Moffett	East Fork	South Fork	French	Etna	Patterson
	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum
January	▨	▨	-0.14 / 4			-0.11 / 13		▨	▨	▨
February	▨	▨	-0.38 / 4	-0.26 / 3		-0.15 / 13	-0.19 / 2	▨	▨	▨
March	▨	▨	-0.20 / 4	-0.18 / 3				▨	▨	▨
April	▨	▨		-0.15 / 3				▨	▨	▨
May	▨	▨			-0.40 / 10			▨	▨	▨
June	▨	▨			-0.62 / 10			▨	▨	▨
July	▨	▨		-0.15 / 4	-0.12 / 10			▨	▨	▨
August	▨	▨		-0.50 / 4	-0.13 / 10	-0.24 / 13		▨	▨	▨
September	▨	▨		-0.30 / 5		-0.53 / 13		▨	▨	▨
October	▨	▨				-0.18 / 13		▨	▨	▨
November	▨	▨			-0.22 / 9			▨	▨	▨
December	▨	▨						▨	▨	▨

▨ Indicates one or fewer years of data, so no average bias calculated

□ Indicates bias was > -0.1

Table 10. Regression bias for Norm(Tribs)- Post-WY1972 vs. Norm(Scott). White areas indicate that data are available to compute a bias for those months.

	Kidder	Mill	Shackleford	Sugar	Moffett	East Fork	South Fork	French	Etna	Patterson
	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum	Avg / #Datum
January		▨		▨	▨	-0.30 / 6			▨	▨
February	-0.15 / 6	▨		-0.27 / 2	▨	-0.16 / 4			▨	▨
March	-0.30 / 8	▨		▨	▨				▨	▨
April		▨		▨	▨				▨	▨
May		▨			▨				▨	▨
June		▨		▨	▨				▨	▨
July		▨			▨				▨	▨
August		▨	-0.19 / 7		▨	-0.23 / 10		-0.33 / 7	▨	▨
September		▨	-0.46 / 7	-0.27 / 2	▨	-0.52 / 10	-0.16 / 8	-0.23 / 7	▨	▨
October	-0.53 / 8	▨	-0.60 / 5	▨	▨	-0.22 / 8			▨	▨
November		▨			▨				▨	▨
December		▨		▨	▨	-0.26 / 5			▨	▨

▨	Indicates one or fewer years of data, so no average bias calculated
☐	Indicates bias was > -0.1

6 Evapotranspiration and Crop Coefficients

Evapotranspiration was calculated using a program designed at UC Davis, the NWSETO program (Snyder, 2002). The NWSETO program is used to calculate reference evapotranspiration (ET_0) for short grass. The atmospheric inputs for this program include, for each month, average maximum daily temperature, average minimum temperature, maximum and minimum humidity, wind speed, and percent cloud cover. The NWSETO program provides two alternative reference ET_0 values based on either the Penman-Monteith (1965) or based on the Hargreaves and Samani equations (1982). The calculated ET_0 obtained from the climate records and NWSETO were compared and evaluated on the basis of observed values available for Scott Valley as discussed below, prior to using it within the water budget model. The two sets of data were generally in agreement. For this study, the ET_0 values calculated by NWSETO using the Hargreaves and Samani equation have been used.

Crop coefficients (k_c) and ET_0 are used to estimate specific crop evapotranspiration rates. The k_c is a dimensionless number (usually between 0.1 and 1.2) that is multiplied by the ET_0 value to obtain an estimate of the actual crop ET (ET). The estimate of actual crop ET is primarily designed to help an irrigation manager schedule irrigation frequency and amount, but is here used to estimate actual crop ET for simulating a daily soil water budget. Crop coefficients vary by crop, stage of growth of the crop, and by some cultural practices. Coefficients for annual crops vary widely throughout the season, with a small coefficient in the early stages of the crop (when the crop is just a seedling or, in the case of alfalfa, has been recently cut) to a large coefficient when the crop is at full cover (the soil completely shaded).

Crop coefficients have been assigned as follows:

- alfalfa: $k_c = 0.95$ (Steve Orloff and Blaine Hanson, University of California, personal communication) from February 15 to November 15, and $k_c=0$ for the remainder of the winter months. In alfalfa, a constant k_c value is used for two reasons: first, the growing period of alfalfa broadly coincides with that of the reference crop; secondly, alfalfa cuttings do not occur at the same time across the entire study area. A time-varying k_c value that reflects individual cutting events on individual fields would require knowledge (or simulation) of individual field cutting events over the period of interest. That level of detail in the spatio-temporal variability of field-by-field water budgets was deemed not critical for the current modeling effort. Also, using a slightly different growing period, such as March 1st- October 31st would not significantly change the final ET value because the ET in February and March is almost negligible. Simulations yield a 1990-2011 average annual ET in alfalfa of 1,200 mm (39.4 inches), very close to the field values measured by Blaine Hanson (Hanson et al., 2011a);
- grain (wheat, barley, oats and triticale): we use a daily varying k_c according to UCCE Leaflet 21427. Leaflet 21427 lists crop coefficients for two crops similar to the “grain” category here: summer barley in Northern California Mountain Valleys and small winter grain in the Sacramento Valley. The following is a combination of “barley” for “Mountain Valleys”

(planting date: 4/30, harvest date: 8/31) with the “small grain” for “Sacramento Valley” (planting date: 12/16, harvest date: 8/04) supported by the recommendation provided by Steve Orloff and general information provided by the GWAC:

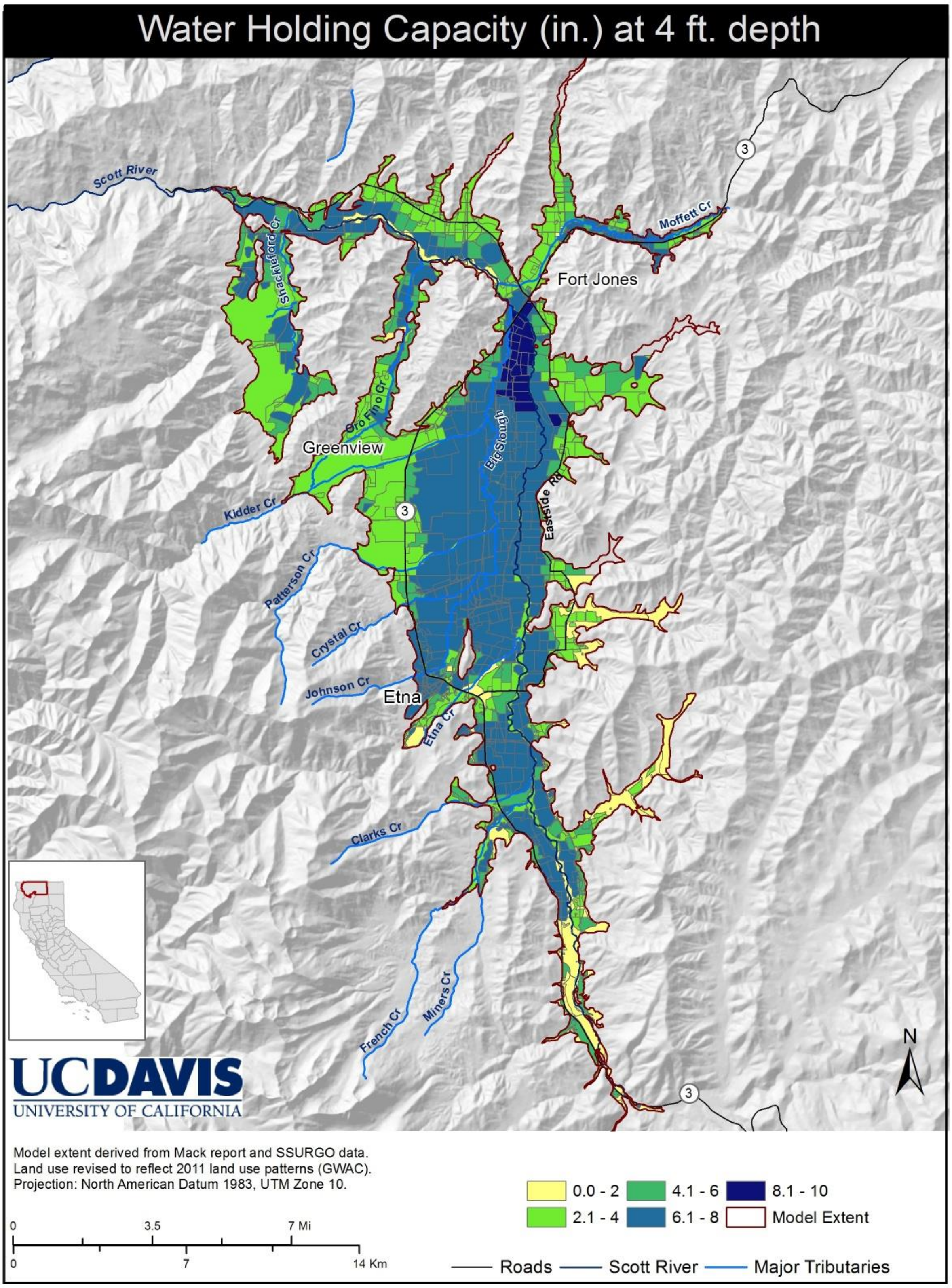
  - planting date A: March 15, k_c=0
  - early season date B: April 20, k_c=0.27
  - mid season start date C: May 15, k_c=1.15
  - mid season end date D (after 70% of the 127 day period or 90 days): June 15, k_c=1.15
  - harvest date E, July 20, k_c=0

  The daily k_c values vary linearly between the above dates and values.

- pasture: k_c = 0.9 as suggested by the UCCE Leaflet 21427 for grazed pasture statewide, and confirmed by Steve Orloff. To account for winter frost, we set k_c=0.9 from February 15 to November 15, but zero over the winter (same as for alfalfa).
- natural vegetation: k_c = 0.6

7 Soils

The Soil Survey Geographic (SSURGO) Database, maintained by the Natural Resources Conservation Service (NRCS), was used to obtain spatial and tabular soils data for our project area. This database contains soil attributes, which describe variables such as texture, particle size or water holding capacity. We used information from this database to evaluate water holding capacity (WHC) for each of the land use polygons delineated by the California Department of Water Resources (DWR). The recommendation by UC Cooperative Extension personnel was to use a root-zone depth of 4 ft (122 cm) to compute WHC. Available information in the SSURGO database was WHC to 100 cm and to 150 cm. To simulate WHC at the recommended depth of 4 ft (122 cm), we mapped WHC for both 100 cm and 150 cm in each soil map unit, then obtained the WHC used for the soil water budget simulation using an area-weighted average of all intersecting soil type polygons and their WHCs at 100 cm and at 150 cm within each DWR land use polygon (Figure 12). For modeling purposes, the same root zone depth was assumed for all crops. In practice, grain and alfalfa are do not have the same rooting depth; however, a sensitivity analysis of the root zone depth, presented later in the report, shows that doubling the root zone depth does not significantly affect results. Selecting a uniform root zone depth for both crops in the soil water budget model is therefore a reasonable assumption.



Model extent derived from Mack report and SSURGO data.
Land use revised to reflect 2011 land use patterns (GWAC).
Projection: North American Datum 1983, UTM Zone 10.

Figure 12. Map of water holding capacity in the top 4 ft (122 cm), in [inches of water].

8 Groundwater

8.1 DWR Well Log Review

The main focus of our well log analysis was on identifying geologic structure within the Scott Valley alluvium and on identifying the location of irrigation (agricultural) wells, regardless of whether these were active or inactive. Well locations are used in the water budget model to represent groundwater pumping required to meet agricultural water demands in wells nearest to each field, when not met by surface water supplies.

A scanned copy of all well logs available for the Scott Valley and immediately surrounding areas was obtained from the California Department of Water Resources (CDWR). An extensive review of these 1,701 well logs was conducted in order to gain a better understanding of the hydrogeology of the valley. Well logs typically provided information on the well's location, on geologic facies encountered during drilling, albeit at varying degrees of description detail and accuracy, and for some wells the logs provided information on the hydrologic characteristics of the well, including specific capacity or pumping data. Well logs also indicated the major use of the well. Our review included the following:

- Domestic Wells: 1,302
- Irrigation Wells: 240
- Industrial Wells: 3
- Public/Municipal Wells: 4
- Other (Monitoring, Test, etc.): 152

The number of wells identified to be in or near the Scott Valley was 598 wells. The number of wells located within the Version 2 model boundaries and included in our GIS database is 406 wells:

- Domestic Wells: 192
- Irrigation Wells: 182
- Other: 32

Well logs were first geo-located throughout the integrated hydrologic modeling area (see below) using a variety of information. The primary information used was the parcel number of the property where the well was situated. This information was typically provided on the well log itself. Parcel numbers and associated locations for the Scott Valley area were obtained from the Siskiyou County Assessor's Office files. The second datum used for geo-locating a well was the well owner and address listed on the well log. If neither of these two methods obtained a location match, the well logs were categorized by their township/range/section information, which was obtained by reviewing the well location sketch provided by the driller, and from a review of aerial photography to identify the parcels where the wells are situated. Additionally, a field survey was conducted throughout the valley to verify well locations where accessible or viewable from public access places.

In some instances, wells were only placed within the centroid of the property polygon based on a computerized geographic information system (GIS) geo-location process used to match well owners and parcel numbers with their location. In many instances, these locations were improved by canvassing the valley and through the reviews of aerial photographs as discussed above. Despite these extensive efforts and the multitude of approaches, the location of wells related to some well drilling logs could only be approximated in a very rough manner. A lack of confidence identifier was included in the GIS layer of the well location to convey the approximate nature of the geo-location. Ultimately, 598 wells were identified to be within the Scott Valley. Of these, 54 wells could not to be matched to a particular property. The remaining 544 wells were used to characterize the geologic deposits and heterogeneous character of the alluvial deposits comprising the Scott Valley aquifer (Section 8.2).

In the well database updated for Version 2 of the integrated hydrologic model, we consider a total of 406 wells located within the revised integrated hydrologic model domain (Figure 13). Out of these, 182 are irrigation wells and will be used in the model. Pumping for each field is assigned in the new conceptual model to the nearest well. This implies that each field has exactly one associated well, while one well can serve multiple fields.

After discussion with the GWAC, there was also the suggestion to try a simpler approach that equally distributes the amount of pumped water among all the wells within a subwatershed. A third option is to associate a “virtual” well with each field. These alternatives maybe considered as part of a sensitivity analysis on pumping representation in version 2 of the Scott Valley Integrated Hydrologic Model.

The model likely over-represents the actual number of active irrigation wells, as the well locations identified in Figure 13 were not adjusted for wells that are no longer in service. However, groundwater pumping values are obtained from the new soil water budget model explained in detail in chapter 10. They are not related to the number of wells. For modeling purposes, spreading groundwater pumping to more wells than are actually active does not cause significant error, because new wells are typically drilled nearby wells to be deactivated. The integrated hydrologic model lumps groundwater pumping within any 50 m (165 ft) model grid cell. The overall extraction of groundwater is unaffected by the number of wells. Instead, groundwater pumping is driven by the actual monthly irrigation demand.

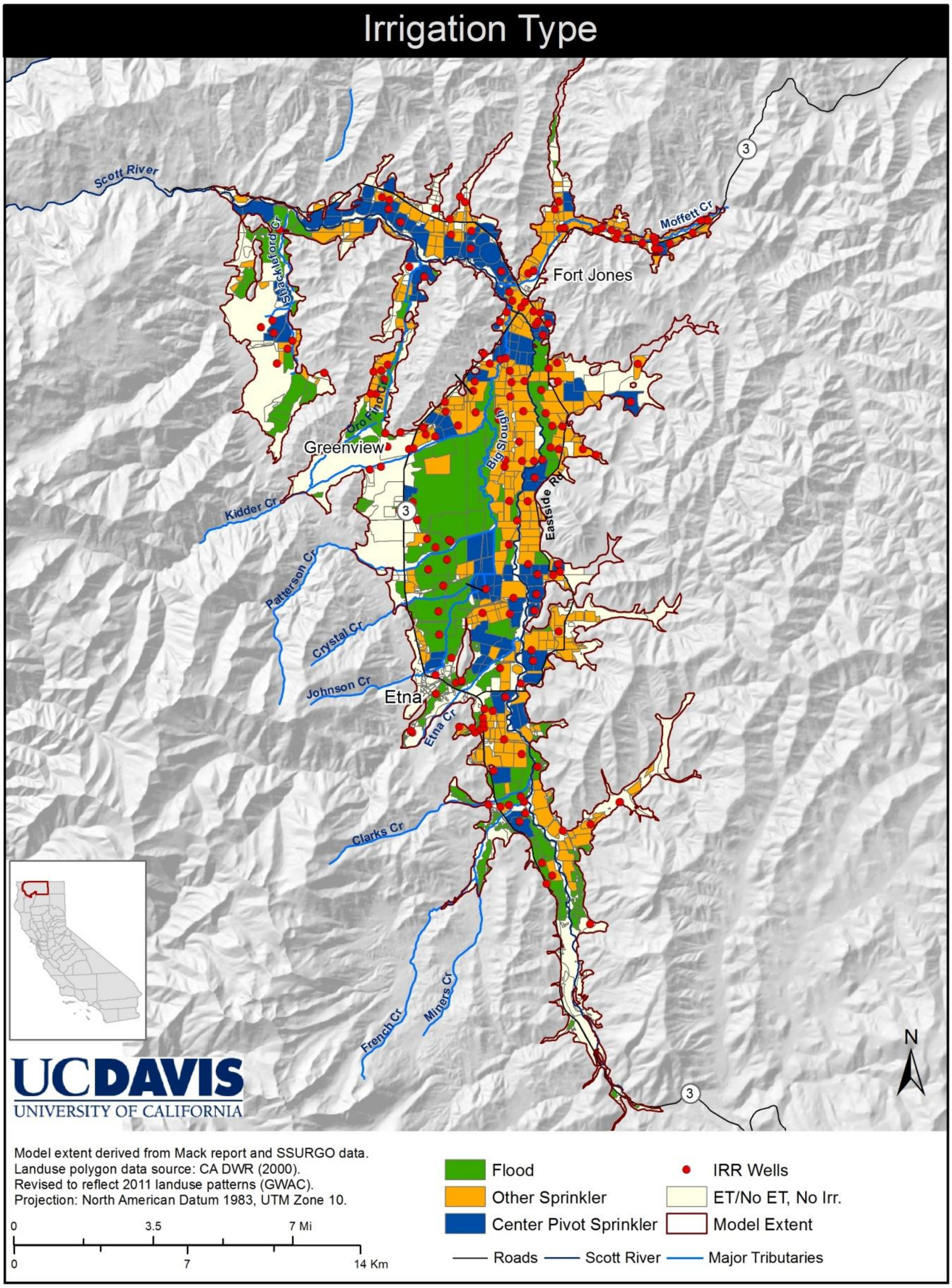


Figure 13. Map of the irrigation type and of the available irrigation wells for Version 2 of the integrated hydrologic model. Locations have been refined by inspection (see text) and may not coincide with those reported by the California Department of Water Resources. The irrigation type reflects recent (2011) conditions. The year of conversion from "Other Sprinkler" (typically wheelline) to "Center Pivot" is an attribute of the "Center Pivot Sprinkler" polygons, if the conversion occurred after 1990, and is taken into account in the soil water budget model.

8.2 Geologic Heterogeneity

The well logs obtained from DWR revealed a tremendous amount of heterogeneity within the alluvial deposits of the Scott Valley. A preliminary geostatistical analysis of the geologic heterogeneity was performed using the so-called transition probability approach (Carle and Fogg, 1996). The transition probability approach is a modified indicator variogram analysis that describes the joint probability distribution of a discrete set of hydrogeologic or geologic facies groups throughout the aquifer system. The transition probability is defined by:

a) a finite number of facies, typically the three to five most common facies observed in a set of geologic records (well logs), e.g., coarse-grained stream deposits, coarse-to-fine grained overbank deposits, and fine-grained flood-plain deposits. One of these facies (usually the facies with the largest volumetric proportion) is designated as "background facies".

b) The volumetric percentage of each facies within the aquifer system of interest.

c) The mean lengths (average straight-distance extent) of all but the background facies in the dip, strike, and vertical direction.

d) The juxtapositional preference among the facies sequence, in other words, the likelihood that one particular facies is located adjacent to another particular facies with a probability that is significantly higher or lower than that obtained if the facies are randomly assembled.

Within the context of groundwater modeling, the transition probability analysis provides a quantitative analysis of the geologic heterogeneity encountered in a groundwater basin. It also provides the simulation framework for generating equally-probable, random realizations of the highly heterogeneous aquifer architecture, conditioned to the specific well logs at the locations where these are available. These random realizations can also be conditioned to surficial geologic information available in soils maps (Weissman, 1999). The more concrete information available, the more specific the random realizations of the aquifer architecture (less variability between individual realizations).

To illustrate the geologic heterogeneity of the Scott Valley, a single realization of the Scott Valley aquifer was generated with the geostatistics software T-PROGS. T-PROGS utilizes the transition probability method, a modified form of indicator kriging, through calculation of transition probability measurements, modeling spatial variability with Markov Chain models, and conditional simulation of the well log information. In this context, the term "indicator" is used to denote categorical classification of aquifer sediments (e.g., coarse, intermediate, fine), as opposed to continuum values (numeric values, for example, hydraulic conductivity varying log-normally with a mean of 20 feet per day and a standard deviation of 10 feet per day).

The T-PROGS geostatistical analysis was based on the information obtained from the 544 wells that were geo-located in the valley. Following a review of these well log records, it was determined that three geologic facies would be modeled: clay or fine-grained sediments, sand, and gravel. As such, in one-foot vertical increments, the data from the well logs was interpreted as one of the three listed facies, and transition probability statistics were calculated including mean length, proportion, and transition probabilities. Within the combined digitized well logs, a total of 3,982 geologic facies transitions were recorded in the vertical direction (z-direction).

In order to complete the analysis, a review of the SSURGO soil mapping of the ‘C Horizon’ soil (approximately 0.1 to 0.15m below ground surface) was undertaken to provide information on the nature of the lateral variability observed in geologic deposits. Each deposit identified by the SSURGO mapping (in the subreport entitled Wind Erosion Prediction System Related Attributes) was interpreted as one of the three facies chosen for analysis using at least one of the following indicators: percentage of silt/clay versus sand, and grain size analysis provided to determine between sand and gravel. If the percentage of silt and clay was greater than 50%, the texture was considered to be clay. This particular limit was chosen as it fit the qualitative description of deposits described as loam, clayey-loam, or clay. If the percentage of sand was greater than 50%, the texture was considered to be either sand or gravel with the fragment descriptor being the parameter deciding between the two. If the fragment percentage was greater than 40, the gravel indicator was selected. Also, in a few instances the description was “stratified sandy loam and clay loam”. In these cases, sandy loam was chosen as the key layer depending on overall percentages. This seemed to match descriptions of gravel material versus sandy loam. If sandy loam was the description of the material, it was generally labeled as belonging to the sand fraction.

For the geostatistical analysis of the soils information, the deepest soil horizon profile was used. For example, most of the soils were given a description to a depth of approximately 150 cm (5 ft), split between at least two soil horizons: the upper soil horizon less than 50 cm (1.7 ft), and at least one deeper horizon which was typically close to 100 cm (3 ft) in depth. Often, the data for this deeper soil horizon were incomplete and only included the percentage of clay. In these cases, the information provided was often descriptive but sufficient to make a determination of the category to which the soil belonged (clay/sand/gravel).

To complete the analysis, the soil maps had to be discretized so that mean lengths, proportions, and transitions could be calculated. In previous applications, cross-sections of arbitrary discretization were used to accomplish the analysis. For this study, a 50 m by 50 m grid was used to discretize the soil map (not including the tailings area in the southern Scott Valley). In GIS, the grid was overlain on the soil map, and a Spatial Join operation was completed so that each model grid node was provided with a single soil type. This Spatial Join was completed based on the soil type with the highest percentage of area within the grid cell (as calculated by the GIS function). Essentially, the process allowed for 621 horizontal (rows) and 420 vertical (columns) cross-sections to be evaluated as input data. Once discretized, the transition probability data was calculated, including mean length, proportion, and transition for each of three facies.

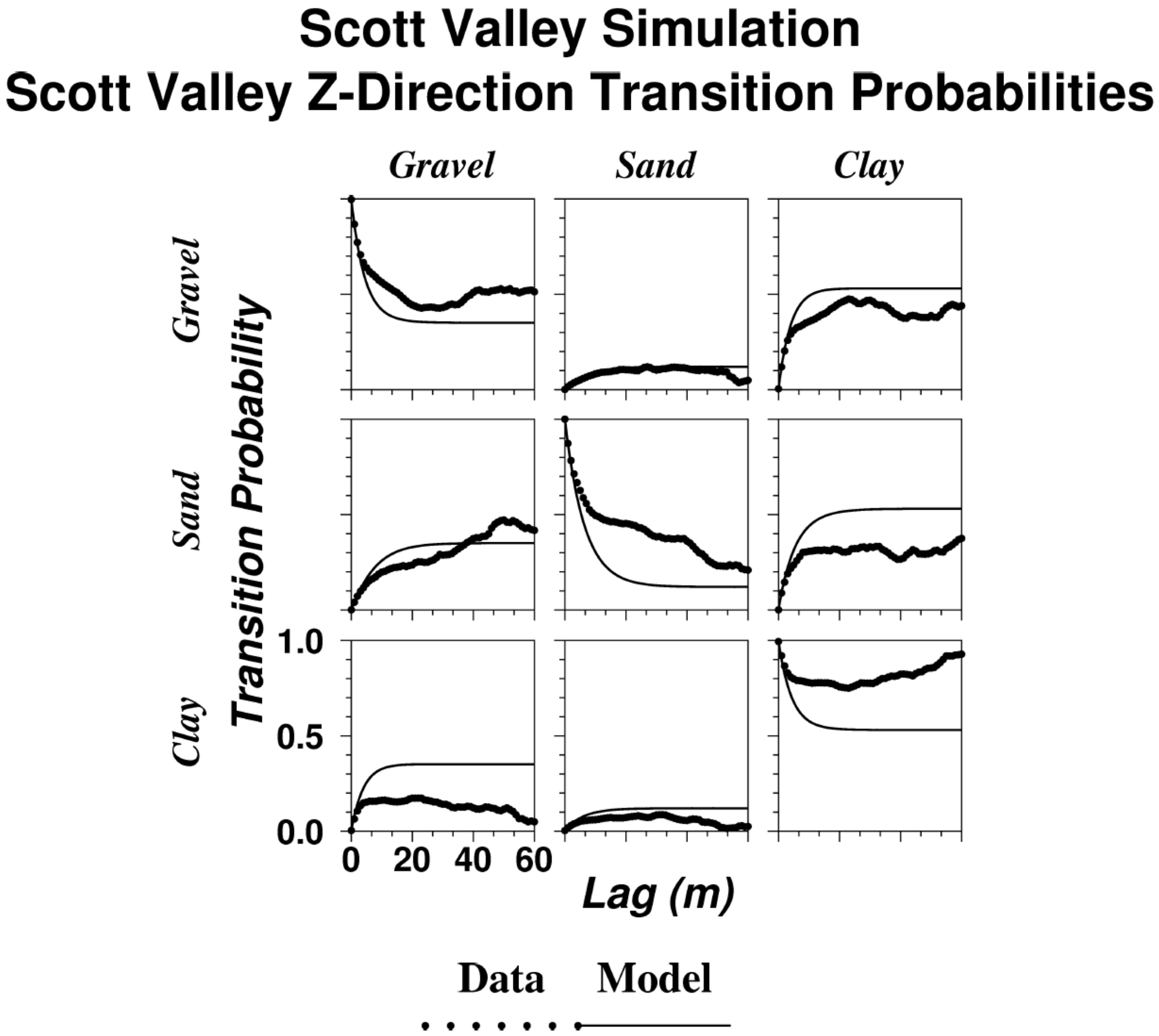


Figure 14. Vertical transition probability curves obtained from an analysis of 544 wellbore logs located within the study area in Scott Valley.

The results of the data analysis show the relative proportions of deposits and display the differing mean lengths of deposits in each of the ordinal directions. The above transition probability curves represent important aspects of the geologic facies deposits (Figure 14). The curves for each type asymptotically approach the value that represents the proportion of each facies deposit. From the z-direction analysis, the proportions of each facies obtained are 51% for clay, 37% for gravel, and 12% for sand. Similar proportions arose from the analysis of the soils map in the XY lateral plane, with proportions of 61% for clay, 28% for gravel, and 11% for sand. Furthermore, in the above transition probability diagram, one can draw a tangent along each auto-transition curve and extend the tangent to the x-axis. The value at which the tangent intersects the x-axis represents the mean length of the particular facies. The mean lengths of each deposit in the z-direction obtained from this analysis were 15.0 m (49 ft) for clay, 12.7 m (42 ft) for gravel, and 10.1 m (33 ft) for sand. The mean lengths of each deposit in the X direction (east-west cardinal directions) were 1,379 m (4,524 ft) for clay, 755 m (2,477 ft) for gravel, and 640 m (2,099 ft) for sand.

The results of the transition probability analysis above were used as input for a Markov-chain random field generator (included in the TPROGs software package) to generate random, equi-probable aquifer structure conditioned on the geologic facies information available for Scott Valley, obtained from the well logs (representative of the vertical dimension) and the soils maps available for Siskiyou County (representative of the lateral dimensions). Figure 15 represents one such realization created with the T-PROGs software with a discretization of 10 ft vertically, 500 ft in the x (W->E) direction and 1,000 ft in the y (S->N) direction. It should be noted that any number of realizations can be created, and although each one will be different, they all will have similar "patterns" with all realizations having the same overall proportion of each geologic facies, determined from the z-direction analysis, and the same mean lengths and juxtapositional preference in each of the three directions. At the surface and along well locations, each realization will preserve the actually known data.

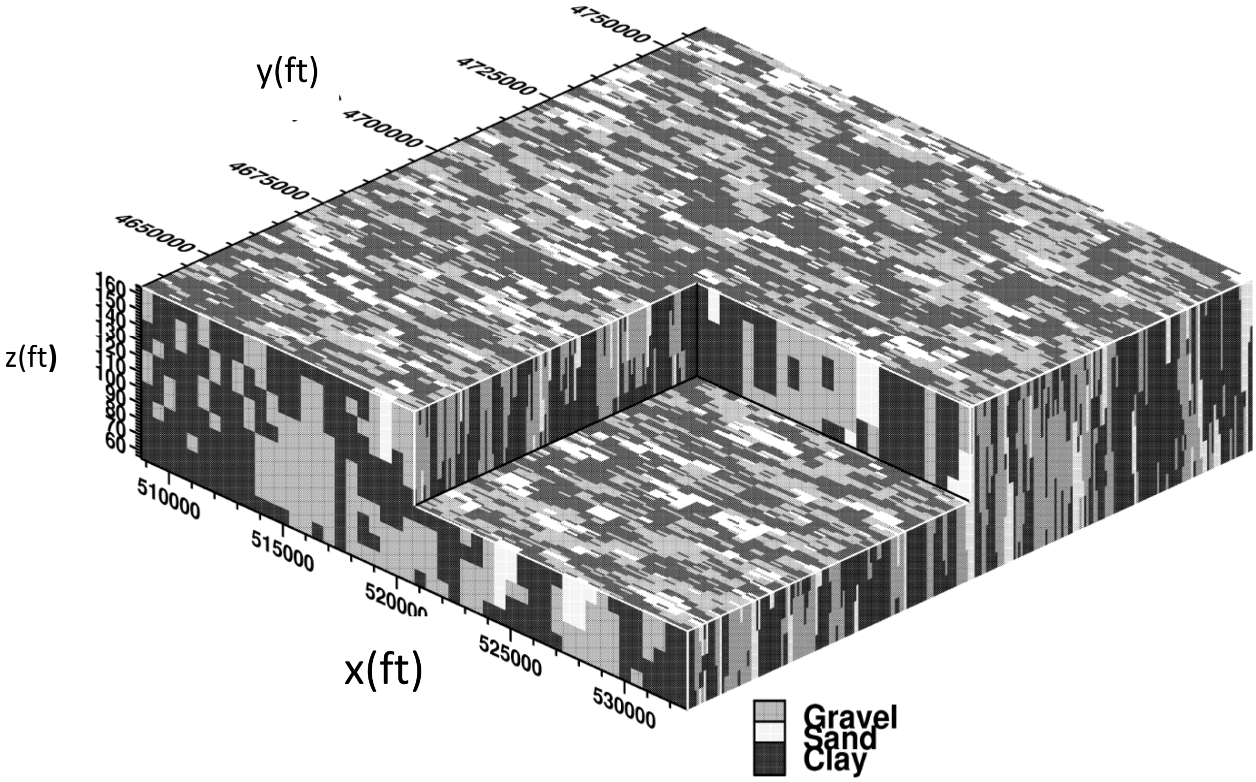


Figure 15. TPROGS Realization of the Scott Valley geologic deposits. Length units are in feet. The image shows a hypothetical aquifer volume that is approximately 100 ft thick, 6 miles in the x direction and 25 miles in the y direction. Note that this image is stretched in the X-direction relative to the y-direction and it does not consider the actual boundaries of the Scott Valley aquifer. It is shown only to conceptually illustrate the heterogeneity encountered in the alluvial deposits of Scott Valley.

While the realization shown in Figure 15 is random, it has important features to note that are shared by all realizations and that are indicative of the overall patterns in the Scott Valley aquifer architecture: the facies exhibit somewhat preferential, elongated connectivity in the y (north-south), but less connectivity in the x direction (east-west), a pattern that represents observations in the well logs and in the soil map. It is also obvious from the above illustration that the gravel deposits, which are the hydraulically most conductive facies within the aquifer, are highly connected throughout the aquifer system and not isolated from one-another by clay-layers or clay walls. In particular considering that gravel and sand make up approximately half of the aquifer sediments, the connectivity of these coarser-grained sediments is very high and it appears unlikely that significant proportions of sand and gravel would be completely isolated from the regional aquifer system (i.e., encased and surrounded completely by clay). They are likely well-connected to the main-stem of the Scott River.

On the other hand, a review of the boring logs in certain areas shows that a clay layer exists over portions of the valley. This realization as well as hand-drawn cross-sections of the valley created from boring logs, show that these clay layers or lenses may not be broad enough to act as a true confining features. As such, portions of the aquifer may be semi-confined, where they are located below a local clay layer or a clay lens that is relatively broad in extent. However, a spatially extensive confined aquifer does not appear to be present in the Scott Valley. We also note that no sand and gravel has been recorded below about 76 m (250 ft) depth in the few existing logs that exceed such depth.

The geostatistical realization of the Scott Valley aquifer indicates that the Scott River, which intersects with the surficial layer of this aquifer model, is alternately passing along finer and coarse-grained sediments. It is important to keep in mind, however, that this model was created with a lateral resolution of 150 m (500 ft) and also largely depends on the resolution and surveying detail of soil mapping units, which is typically on the order of several hundred meters. The above illustration therefore ignores variability that inevitably occurs at scales smaller than about 150 m – 300 m (500 ft – 1,000 ft).

The analysis here provides an initial survey of spatial variability in the Scott Valley groundwater system. Spatial variability, such as that shown in Figure 15 may be incorporated into future groundwater models, after further analysis of well logs, additional review of streambed sediment studies not reviewed here, and perhaps an improved geostatistical assessment of facies variability in the alluvial system. However, Version 2 of the Integrated Hydrologic Model will not yet include such detailed hydrogeologic facies representation.

9 Watersheds, Land Use, Irrigation, and Land Elevation

A variety of data were used to create input for the model. The model extent was determined based on the extent of groundwater storage units outlined by Seymour Mack in 1958 (Mack, 1958), while the land use data were derived from the California Department of Water Resources (DWR) Land Use survey data. The most recent land use data for Siskiyou County available from the DWR is from the 2000 DWR land use survey. Although a more recent land use survey has been completed by CDWR in 2010, the processed data were not available for use in our project. Since the modeling period is 1990 -2011, the 2000 land use survey was used as the basis upon which we developed the spatial component of our model.

9.1 Model Boundaries and Subwatersheds

Our study area boundaries were selected to represent the Scott Valley area containing surficial alluvial deposits. To delineate these areas in a digital map, a spatial analysis was performed and we assumed that the extent of the alluvium was defined largely by the absence of steep topographic gradients (more than 3%). A digital elevation model (DEM), derived from National Elevation Data (NED), was created and topographic gradients (slope) were computed. The DEM with slopes was then draped over 2005 National Agriculture Imagery Program (NAIP) color aerial imagery, and used as a visual guide to manually digitize the contiguous areas of the Scott Valley that have a three percent slope or less.

The Scott Valley model area covers approximately 50,000 acres. It is subdivided into nine subwatersheds for purposes of modeling surface water supplies and the distribution of these supplies within subwatersheds (Table 11, Figure 16). The subwatersheds are Scott, French, Etna, Patterson, Kidder, Moffet, Mill, Shackleford, and the Scott River Tailings. These subwatersheds were created partly based on the water storage units delineated by Seymour Mack in his 1958 report. Crystal and Patterson Creek are combined into a single subwatershed. Similarly, Johnson and Etna Creek are combined into a single subwatershed. Other smaller subwatersheds are included with larger ones (Figure 16).

Mack (1958) and our Scott Valley model Version 1 data work did not include the Scott River Tailings subwatershed located in the upstream part of the valley. For Version 2 of the Scott Valley Integrated Hydrologic Model, the southern tailings area of the Scott Valley is included in the analysis and in the groundwater flow domain. From visual field inspection, it appears that the tailings aquifer consist primarily of large boulders, with very high hydraulic conductivity and rapid connectivity to the stream. During the late summer and fall low flow season, the Scott River, at the surface, is often disconnected across this highly permeable subwatershed.

Table 11: Total areas of subwatersheds (Figure 16), total area for various irrigation types (Figure 13), total area for various irrigation water sources (Figure 19), and total area of land use (Figure 18), in acres. All values represent 2011 conditions. Note that not all acreage in the alfalfa/grain and pasture category is irrigated.

Subwatershed Name	Area (acres)	Irrigation Type	Area (acres)	Water Source	Area (acres)	Land Use	Area (acres)
Etna Creek	4,223	Non-irrigated	18,549	DRY	3,356	Water	166
French Creek	501	Flood	10,864	GW	16,526	Alfalfa/Grain	17,421
Kidder Creek	9,298	Sprinkler	12,564	MIX	3,949	Pasture	16,578
Mill Creek	2,237	Center Pivot	6,928	SUB	2,106	ET/No Irrig.	14,151
Moffett Creek	2,437	Unknown	1,107	SW	7,596	No ET	1,695
Patterson Creek	4,032			None/unknown	16,478		
Scott River	20, 736						
Scott River tailings	3,562						
Shackleford Creek	2,984						
Study Area Total	**50,011**	**Total**	**50,011**	**Total**	**50,011**	**Total**	**50,011**

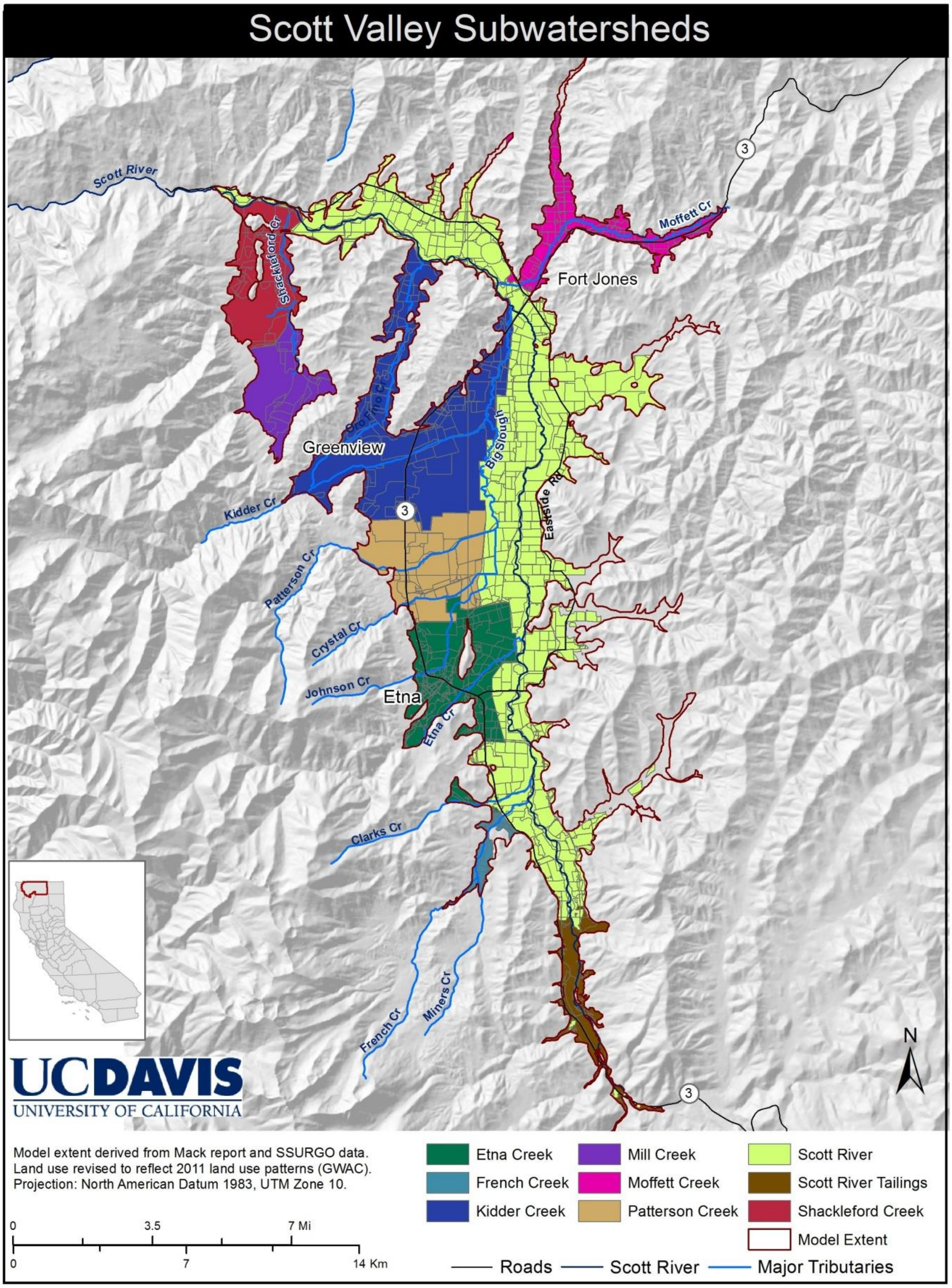


Figure 16. Map of the Scott Valley with the boundaries of the integrated hydrologic model study and the nine subwatersheds.

9.2 Land Use Categories

The CDWR land use surveys delineate polygon shapes identifying areas with various types of land use (i.e. residential, commercial, agriculture). We used the existing year 2000 land use database, which also includes attributes such as irrigation type, water source, and expanded the database to include values that describe water holding capacity, and soil hydraulic conductivity for each land use polygon. Using extensive feedback from the Scott Valley Groundwater Advisory Committee (GWAC), we confirmed or updated the water source, irrigation type and land use associated with each polygon. Feedback was provided by the GWAC and local landowners through marked up large maps that reflect the knowledge of local landowners about dominant 2000 – 2011 conditions and changes in irrigation type, water source, and land use that have occurred since the DWR survey in 2000. It is assumed that the feedback effectively reflects conditions in 2011 and the years immediately preceding 2011.

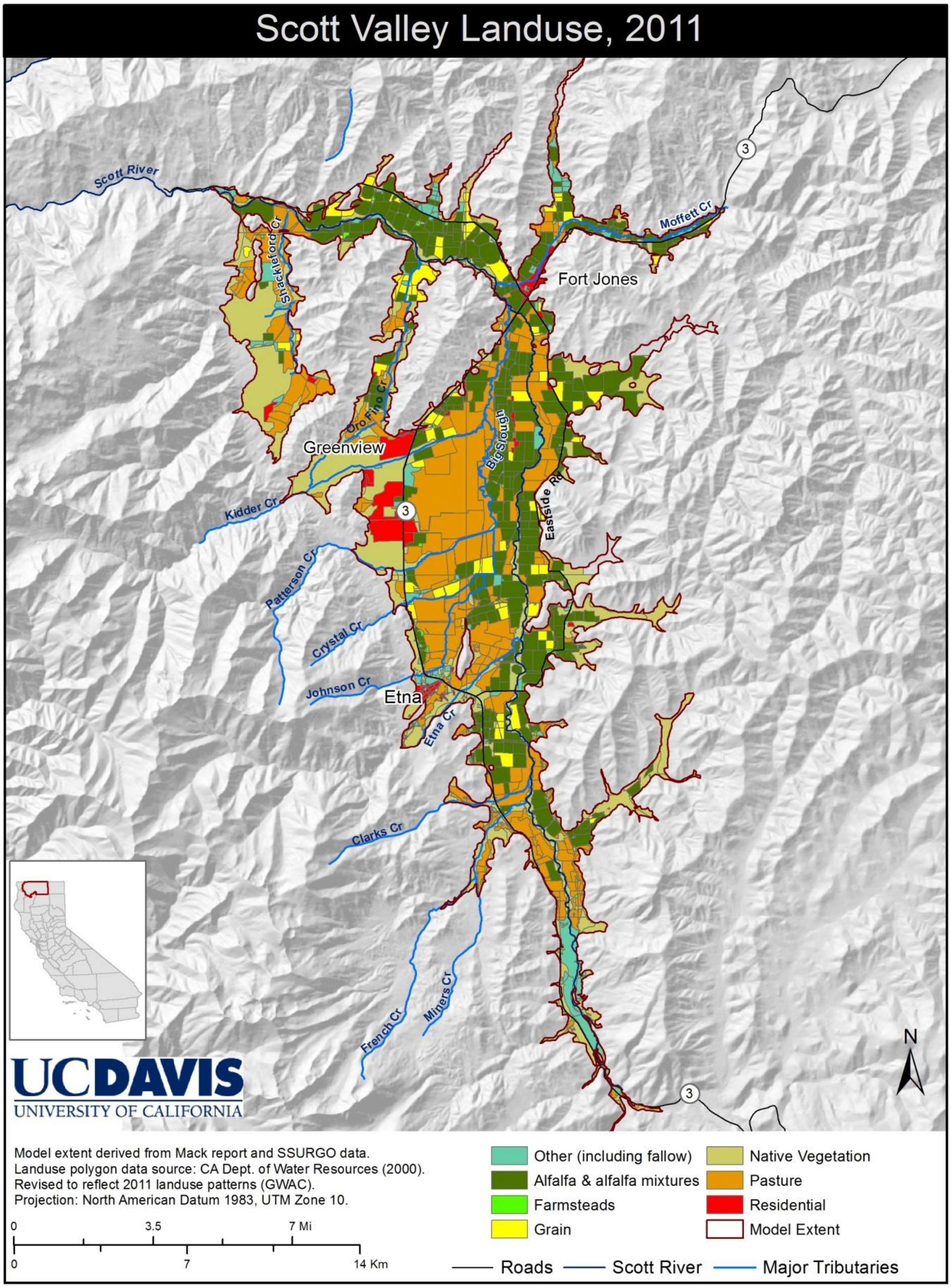
It is important to note that some of the feedback provided on land use, water source, and irrigation type reflects an outright correction of the CDWR 2000 landuse map (i.e., reflects year 2000 conditions as well as year 2011 conditions), some reflects land use changes since the year 2000 survey. For modeling purposes, we did not make a distinction between these two types of suggestions. However, the most important irrigation type change is that from sprinkler irrigation to center pivot irrigation due to the efficiency increase. That specific change was explicitly tracked in the land use database by adding a conversion date to those polygons that are in center pivots in 2011. The dynamics of that change are reflected in the soil water budget model (see below). With these dynamics simulated explicitly, and with the overall feedback from the GWAC and local landowners, the resulting landuse, irrigation type, and water source map is considered more representative of 1991 – 2011 conditions than the CDWR 2000 map. No changes were made to the shape of individual land use polygons defined in the CDWR 2000 survey.

We aggregated the land use polygons into four main categories each of which reflects a common water demand:

1. new “alfalfa/grain rotation” land use category: all land use parcels in this category are assumed to be on an alfalfa-grain rotation. Since we do not have exact data on the rotation, we simulate the rotation by creating an eight-year cycle. Each field in this category is randomly assigned one of the eight years in the cycle during which it goes into “grain” rotation. All other years, a field is assumed to be in “alfalfa” land use. Each year, one out of eight fields is in “grain” and the rest are “alfalfa”. The same eight-year rotation is followed throughout the simulation period (1990-2011). This new land use category includes the following CDWR land use classes:
    a. grain (wheat, barley, oat, triticale)
    b. corn
    c. alfalfa, mixed alfalfa/orchardgrass
    d. rice
    e. sudan
    f. miscellaneous truck crops

2. new “pasture” land use category. This includes the following CDWR land use classes:
    a. pasture
    b. highwater pasture
    c. improved pasture
    d. mixed pasture
    e. grass
    f. cemeteries
    g. lawns
    h. institutions
    i. schools
    j. residential
    k. recreation
    l. nursery
3. new land use category “ET without irrigation” representing pasture-like ET (crop coefficient, $k_c = 0.6$) but without irrigation. This includes:
    a. natural vegetation
    b. natural highwater meadow
    c. misc. deciduous trees
    d. trees
4. new land use category “no ET and no irrigation” for all land uses without ET ($k_c = 0$) and without irrigation (but with recharge from precipitation via soil moisture storage). This includes:
    a. barren
    b. commercial
    c. dairy
    d. extractive industry
    e. farmsteads
    f. industrial
    g. livestock feedlots
    h. municipal
    i. paved
    j. storage
    k. trailers
    l. unpaved
    m. vacant

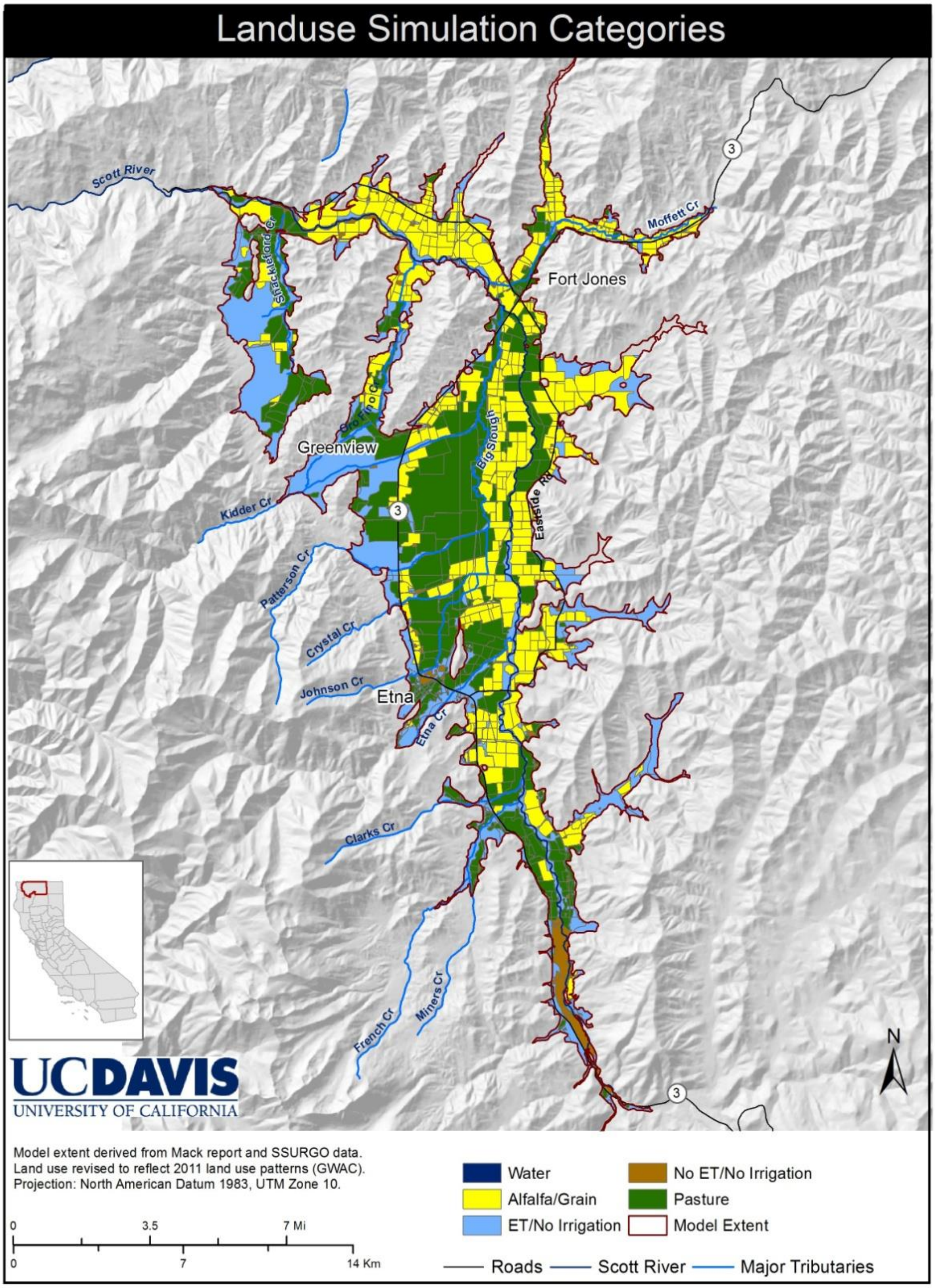
Figure 17 presents the updated land use map using a lumped land use categorization scheme based on the definition of land use categories also used in the CDWR 2000 map. Figure 18 shows the same land use map after re-categorization into the newly assigned four land use categories as listed above. Both maps reflect the changes suggested by the GWAC. The new land use categories of Figure 18 are used in the water budget model development. A separate, fifth landuse category is comprised of 166 acres of open water areas (streams, lakes, wetlands) within the study area (Table 11).



Model extent derived from Mack report and SSURGO data.
Landuse polygon data source: CA Dept. of Water Resources (2000).
Revised to reflect 2011 landuse patterns (GWAC).
Projection: North American Datum 1983, UTM Zone 10.

Figure 17. Land use categories based on DWR 2000 map and updated for 2011 using suggestions from GWAC and local landowners.

Landuse Simulation Categories



Model extent derived from Mack report and SSURGO data.
Land use revised to reflect 2011 land use patterns (GWAC).
Projection: North American Datum 1983, UTM Zone 10.

Figure 18. Aggregated five land use categories developed for the new conceptual soil water budget model from the landuse map shown in Figure 17.

9.3 Irrigation Type and Irrigation Water Source

Irrigation types were derived based on the DWR categories and summarized in three groups for modeling purposes as follows:

- “surface flood irrigation” consists of the following CDWR categories:
    - iB - border flood irrigation: the correspondent water source is surface water, mix or sub-irrigation (per June 2011 GWAC meeting, this is the same as wild flooding)
    - iF - furrow irrigation: it applies only to a few small fields, often now in center pivots with groundwater as water source for irrigation
    - iW - wild flooding: the correspondent water source for irrigation is surface water or sub-irrigation
- “center pivot sprinkler irrigation” consists of the following CDWR categories:
    - iC - center pivot: typically with groundwater as water source for irrigation
    - others that were converted to center pivot sometime in the last 20 years, with dates and prior crop specified in the new land use polygon table
- “other sprinkler irrigation” consists of the following CDWR categories:
    - iH - handmoved sprinkler irrigated
    - iR - wheel-line sprinkler irrigated

Unknown irrigation type affects 1107 acres (Table 11), of which 27 acres are classified as pasture and the remainder (1080 acres) as alfalfa/grain. In addition, 700 acres of alfalfa/grain and 1,861 acres of the pasture category, mostly residential land use in the original DWR classification (e.g., in the Ft. Jones and Etna area) are classified as non-irrigated in the year 2000 CDWR land use survey. In total, 18,549 acres are not irrigated within the study area, with or without ET.

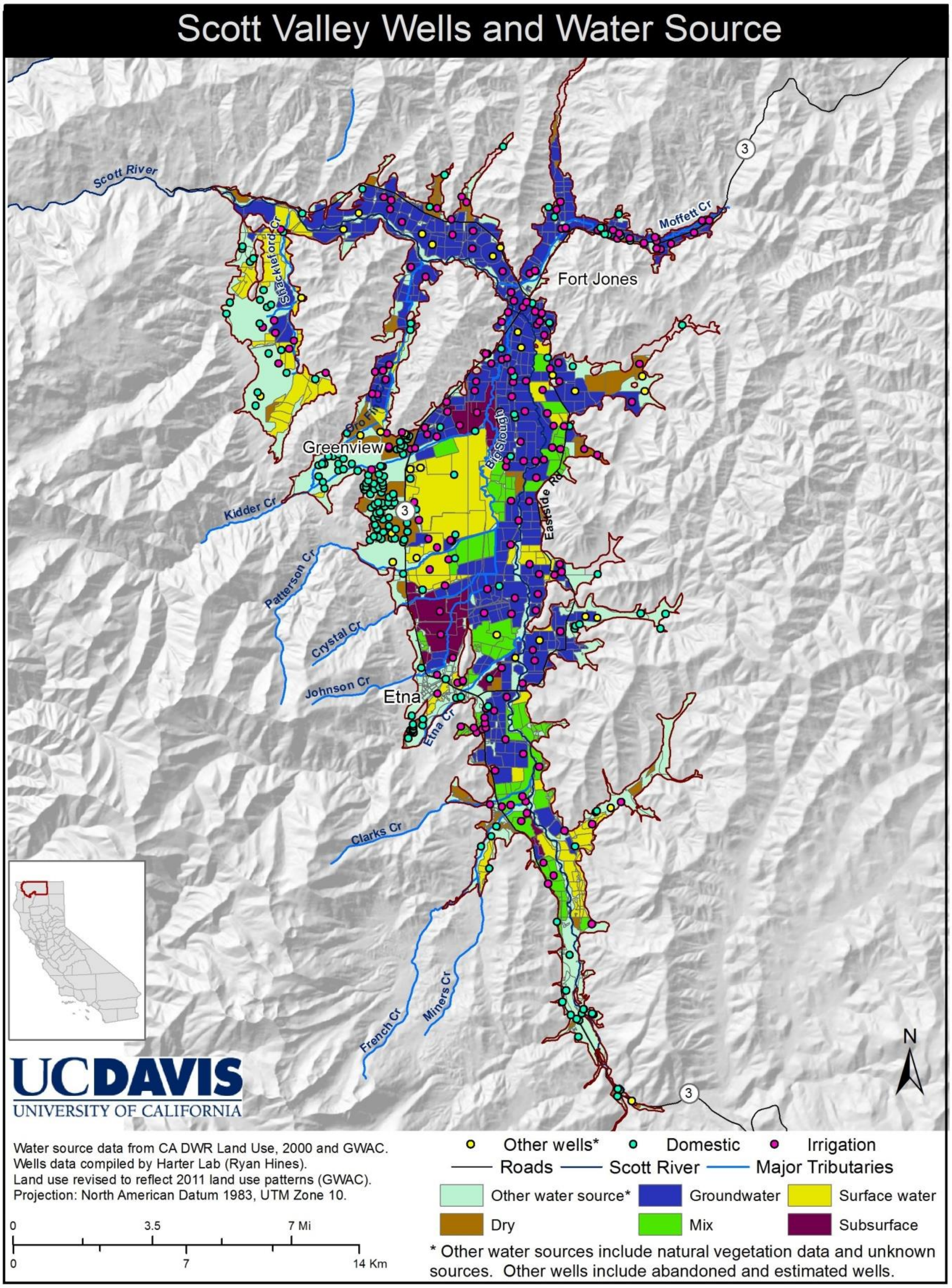
The irrigation efficiency values used in the water budget model have been fixed based on suggestions from Steve Orloff and the GWAC. As a future modeling task, we will use irrigation efficiency as a calibration tool to check against the irrigation scheduling suggested by the GWAC. The values used in the model are:

- surface flood irrigation: 0.70 (Steve Orloff, 2011, oral communication)
- center pivot sprinkler: 0.9 (Steve Orloff, 2011, oral communication)
- other sprinkler irrigation: 0.75 (Steve Orloff, 2011, oral communication)

Irrigation water sources are represented in Figure 19 and are summarized in Table 11 as:

- Groundwater (GW)
- Surface water (SW)
- Subirrigation (SUB)
- Mixed surface water-groundwater (MIX)
- Dry (DRY)
- None/unknown/other

There are no known water sources on 177 acres of alfalfa/grain and on 475 acres of pasture, and on practically all open water and other unirrigated land uses (with or without ET).



Water source data from CA DWR Land Use, 2000 and GWAC.
Wells data compiled by Harter Lab (Ryan Hines).
Land use revised to reflect 2011 land use patterns (GWAC).
Projection: North American Datum 1983, UTM Zone 10.

* Other water sources include natural vegetation data and unknown sources. Other wells include abandoned and estimated wells.

Figure 19. Water source assigned to each polygon, based on data from the CDWR Land Use, 2000, and based on revisions suggested by the Scott Valley GWAC (2011).

9.4 LiDAR Land Surface Elevation Data Analysis

LiDAR data, published by Watershed Sciences, Inc. (2010) and obtained from the NCRWQB in 2012, were used to create a bare earth digital elevation model of the Scott River area.

Because Light Detection and Ranging (LiDAR) data are typically of higher resolution than National Elevation Data (LiDAR is sub-meter accuracy while NED is available in three to 30 meter resolution), they provide a more accurate digital elevation model.

This high resolution bare earth DEM was then used to create a digitized model of the Scott River thalweg. Draped over the 2005 NAIP color aerial imagery, the bare earth DEM was categorized into 10 centimeter classifications, which showed the river channel morphology in great detail. Using the aerial imagery as a guide, the Scott River thalweg was digitized in ArcGIS, with a vertex placed every 1/3 of a meter. Elevation values from the bare earth DEM were then assigned to each of these vertices in ArcGIS. Average slope between vertices were also calculated in ArcGIS.

10 Soil Water Budget Model - Methods

10.1 Introduction and Overview

We have developed a soil water budget model that serves to define the spatio-temporal distribution of groundwater pumping, surface water diversions, groundwater recharge, and evapotranspiration throughout the Scott Valley. The soil water budget model computes spatially and temporally varying water fluxes across the approximately 50,000 acre study area. The spatial resolution is variable and equal to the individual fields and land use units (polygons) identified by the 2000 CDWR land use map, which has been updated (Figure 17), and converted into five major land use categories (Figure 18). In time, the model operates on daily information values, primarily driven by available climate and streamflow data resolution and the need to properly represent soil water storage dynamics. For surface water accounting purposes, the model domain is subdivided into nine major subwatersheds (Figure 16).

The field soil water budget method is a simple root zone bucket model at each land use polygon as described below. This model, however, does not represent a complete surface water budget of the Scott Valley, since it does not account for river-groundwater interaction or evapotranspiration off shallow water-table from non-irrigated crops or natural landscapes, or from open water surfaces (the latter being the “Water” land use category in Figure 18). The complete surface water budget will be considered when this model is coupled to the MODFLOW groundwater-surface water model which is under development.

The output from the soil water budget model is a 21 year time-series (1990-2011) of daily surface water diversions, pumping, irrigation, evapotranspiration, and recharge values at each land use polygon except those designated as “Water”. The model also computes the theoretical irrigation deficiency, defined as the difference between optimal crop evapotranspiration and actual evapotranspiration. Using a daily time-step for the soil water budget model allows us to account for the often rapid dynamics in soil moisture and for carry-over storage of soil moisture for later plant evapotranspiration.

In contrast, the integrated hydrologic model will be driven by monthly stress periods, which means that pumping and recharge are constant within a month. For the integrated hydrologic model, daily water fluxes from the soil water budget model will be aggregated for each month to provide monthly, land use polygon specific recharge, pumping, evapotranspiration, and surface water delivery values. The monthly stress periods in the integrated hydrologic model reflect the generally slower dynamics of groundwater flow. However, if warranted, the budget model described here can also be applied to an integrated hydrologic modeling scenario with weekly or bi-weekly varying stress periods or to stress periods of varying period length.

The conceptual approach is largely derived from the approach taken for Version 1, but has been revised in close collaboration with UC Cooperative Extension personnel, the Scott Valley GWAC, and technical experts familiar with the Scott Valley. Some of the key differences between the revised Version 2 soil water budget model and the earlier (unpublished) Version 1 soil water budget model include:

- daily rather than monthly time-step
- soil moisture storage changes in the soil root zone are tracked
- the southern part of Scott Valley with the tailings is included in the model domain
- revised and updated land use map and land use categories are used
- irrigation schedules and irrigation demands have been revised

Whereas the previous soil water budget model (Scott Valley Integrated Hydrologic Model Version 1) was compiled in a spreadsheet, the new soil water budget model has been developed and compiled as a Fortran program, which allows for more efficient control on various conceptual model scenarios and inclusion of soil water budget model variables in model sensitivity and calibration procedures. The development of this code and its linkage to a GIS database provides us with the capability to include detailed spatial information, readily adjust for newly available information from local parties, and provides flexibility to generate a multitude of future simulation scenarios.

10.2 Description of the Soil Water Budget Model

10.2.1 Model Input Preparation

The following data have been compiled in the previous sections to provide input for the soil water budget model:

- climate (digital climate station records)
    - precipitation
    - potential evapotranspiration
- streamflow
    - daily streamflow data on all tributaries including main stem forks
    - subwatershed delineation
- land use:
    - crops with crop coefficient
    - irrigation method
    - irrigation water sources
- soil properties (digital USDA soil maps with properties)
    - water holding capacity
- hydrogeology
    - location of pumping wells

Each land use polygon in the Scott Valley is characterized by a set of properties (or attributes) mainly derived from the GIS analysis:

- Land use, divided into the five main categories as described above (Figure 18): 1) alfalfa/grain rotation with seven years of alfalfa followed by one year of grain, 2) pasture (including some urban landscapes, see above), 3) evapotranspiration without irrigation (includes natural vegetation, natural highwater meadow, misc. deciduous trees, trees), and 4) no evapotranspiration and no irrigation with recharge from precipitation via soil moisture storage (barren, commercial, dairy, extractive industry, municipal, industrial, paved, etc); 5) water surfaces (mostly streams), which are not included in the soil water budget model, but will be part of the integrated hydrologic model.

- Soil type derived water holding capacity (Figure 12). The model is assuming a root-zone depth of 4 ft (8 ft in the sensitivity analysis described below).
- Irrigation type (Figure 13): flood, center pivot, or sprinkler; some fields switch from flood or sprinkler to center pivot at some field-specific date between 1991 and 2011, based on review of historic aerial photos.
- Water source (Figure 19): groundwater "GW", surface water "SW", subirrigated "SUB", mixed groundwater-surface water "MIX", and farming without irrigation "DRY".

However, the alfalfa/grain land use and the pasture land use include areas for which either the irrigation type is not known or the water source is not known or both (Table 11). For the soil water budget model, the following assumptions are made to account for all potential combinations of land use, irrigation type, and water source:

If the land use is either alfalfa/grain or pasture, and:

a) water source is GW, MIX, or SW, but the irrigation type is unknown (480, 2, and 335 acres, respectively): assume that the irrigation type is "other sprinkler irrigation";
b) water source "DRY" or "SUB", but the irrigation type is unknown (200 and 34 acres, respectively): treat the land use as "ET without irrigation";
c) irrigation type is unknown and the water source is unknown (56 acres): assume that the irrigation type is "other sprinkler irrigation" and the water source is GW;
d) irrigation type is "center pivot" or "other sprinkler" or "flood", but the water source is unknown (177 acres of alfalfa/grain and 475 acres of pasture): assume that the water source is GW;
e) irrigation type is "non-irrigated", regardless of water source (700 acres of alfalfa, 1861 acres of pasture land use, mostly in residential areas): treat the land use as "ET without irrigation". This includes 484 acres of alfalfa/grain and 1275 acres of pasture classified as having a "DRY" water source; and 10 acres of pasture classified as having a "SUB" water source. No or unknown water source is specified for 120 acres of non-irrigated alfalfa/grain and for 469 acres of pasture land use.

These assumptions may not accurately reflect the irrigation type or water source in all cases, but due to the relatively minor acreage of these special cases, the above simulation process is a representative simplification that does not significantly affect the outcome of the soil water budget model.

10.2.2 Tipping Bucket Approach for Soil Water Budget Modeling

The soil water budget calculations are performed using a tipping bucket approach. The main concepts associated with the tipping bucket approach here are the following:

- The simulation starts with the beginning of water year 1991, on October 1, 1990 and is performed daily.
- We assume that the initial soil water content on October 1, 1990 is zero, since the starting point is after the completion of the irrigation season (the soil water profile fills during the first winter months).
- We assume that adjusted daily precipitation (Padj) is the portion of daily precipitation (P) that infiltrates into the soil and is available for daily evapotranspiration (ET) or recharge:
    - if $P > 0.2*ET_0$, Padj(*i*) = P
    - if $P <= 0.2*ET_0$, Padj(*i*) = 0 (FAO Bulletin 56)
    - ET_0 is the daily reference evapotranspiration (FAO Bulletin 56)

  This effectively assumes that precipitation events of less than 20% ET_0 on any given day will sit on leaves or bare ground and evaporate before the end of the day, without affecting soil water storage, plant evapotranspiration, etc. For all soil water budget computations, we use adjusted precipitation and not precipitation. Adjusted precipitation is the same across the valley, since we only use one ET_0 value.

With daily time-steps, the tipping bucket approach used to calculate daily soil moisture storage changes and deep percolation in each polygon can be expressed as follows:

Theta (i) = max(0, theta(i-1) + Padj(i) + Irrig(i) –actualET(i) –Recharge(i)) Eq. 1

Recharge (i) = max(0, theta(i-1) + Padj(i) + Irrig(i) –actualET(i) – WC4(i)) Eq. 2

Where:

- Theta(i) = water content at the end of day i
- Padj(i) = precipitation on day i
- Irrig(i) = irrigation on day i
- ET(i) = evapotranspiration on day i= ET_0*crop_coefficient
- Recharge (i) = deep percolation to groundwater
- Actual ET(i) = min (ET(i), theta(i-1) + Padj(i) + Irrig(i)) Eq. 3

Groundwater recharge is defined here as the amount of soil water that cannot be held against gravity, i.e., the amount of soil water that is above the water holding capacity, WC4, of the root zone in the land use polygon at the end of each day. The model does not account for the time delay between water leaving the root zone and water reaching the water table at the top of the groundwater system. Given that water table depth is generally less than 20 ft and that recharge values are aggregated monthly for the integrated hydrologic model, the assumption of “instantaneous recharge” is justified, but can be evaluated as part of a sensitivity analysis with the integrated hydrologic model.

The above algorithm intrinsically exerts complete mass balance control on each land use polygon:
Padj(i) + Irrig(i) – actualET(i) – Recharge(i) = theta(i)-theta(i-1) Eq. 4

Furthermore, we can compute deficit irrigation for each polygon as follows:

Deficiency(i)= ET(i) – actualET(i) Eq. 5

10.2.3 Irrigation Water Source Simulation

Where does the irrigation water, Irrig(i), come from? The source of the irrigation water depends on the water source and land use specified for an individual land use polygon.

- For pasture, irrigation water typically is supplied by surface water. Groundwater pumping in pasture occurs only for polygons where the GIS land use coverage indicates that irrigation water is being sourced fully or partially from groundwater (“GW” or “MIXED”, see below).
- Alfalfa/grain land use polygons can be irrigated with surface water, groundwater, or a mix of surface water/groundwater. Based on information from the GWAC, the distinction between “SURFACE WATER” and “MIXED” water source was ignored, and all alfalfa/grain fields with “SURFACE WATER” source were treated as if equipped for a “MIXED” source: in either case, alfalfa/grain is always fully irrigated. First with surface water and when surface water allocations dry up, groundwater is used for irrigation.

The simulated decision process that leads to a land use polygon switching from surface water irrigation to groundwater irrigation can be summarized as follows:

- Total monthly discharge rates in the Scott River and in its tributaries at the entry into the Scott Valley are obtained for each of the nine subwatersheds as calculated by the regression analysis (chapter 5).
- Within each subwatershed and for each month, the surface water used for irrigation by each polygon is subtracted from the total monthly discharge of the respective subwatershed stream in a given month.
- Once the total irrigation demand within a subwatershed, in a given month, exceeds (estimated) stream discharge, and if the field is alfalfa/grain, then groundwater is used to make up the difference between surface water available and the irrigation demand. The available amount of surface water is distributed to all polygons designated for use of surface water at equal water depth (water volume proportional to polygon size). For each polygon, the difference between surface water supply and irrigation demand for a given month with surface water shortage is obtained by groundwater pumping.

- Canal losses to groundwater are currently not considered separately. Effectively, these are included in the irrigation efficiency concept and therefore contribute to diffuse landscape recharge.

The surface water delivery and groundwater pumping rates are driven by irrigation schedules and by precipitation and evapotranspiration. Urban and domestic pumping for irrigation of lawns, golf courses, cemeteries, etc. is included in the soil water budget model, but allocated to nearby agricultural wells. Domestic and urban water use other than for domestic/urban/residential irrigation is currently neglected in the soil water budget model, but can be accounted for in the MODFLOW groundwater-surface water model. Domestic/urban water use other than that used for lawn/garden irrigation in Scott Valley is only a very small fraction of total water use in the Scott Valley.

In the current water budget calculations, we apply an irrigation management scheme in which irrigation is driven by crop ET and available precipitation (see below for details).

Recharge occurs across the entire integrated hydrologic modeling domain, either from irrigation and rainfall, or from rainfall only (non-irrigated land uses).

10.2.4 Irrigation Management and Scheduling Simulation

The irrigation simulation is based on irrigation efficiency and evapotranspiration as the drivers for computing applied water demand. It is based on the concepts developed for the CDWR Consumptive Use Program (Orang et al., 2008). Irrigation amount is calculated using the same approach for alfalfa, grain, and pasture, but the irrigation scheduling and irrigation demands differ depending on three variables: crop type, irrigation type, and water source. Details of the irrigation management model are described here. Note that land use designated as “Water” is not associated with recharge, irrigation, evaporation, groundwater pumping, or surface water deliveries.

1) Alfalfa/grain and pasture

Following the literature (FAO publication 56) for alfalfa, irrigation in each polygon *k* starts on the first day *i* on or after March 25th when the soil water content has dried to less than 45% of field capacity:

$$\mathrm{Theta}(i) < (1-0.55)*\mathrm{WC4}(k) \qquad \text{Eq. 6}$$

The depletion factor 0.55 is from FAO Publication 56, Table 22.

The last alfalfa irrigation application occurs on September 5th (typically it ends prior to the 3rd cutting which is anytime between the last week of August and the 3rd week of September. According to GWAC, few fields are irrigated after Labor Day). It is important to note that these “irrigations” are not simulated as individual events but are spread evenly across the irrigation season, i.e., the irrigation demand is computed daily based on the crop water demand (see below).

For grain, the first irrigation on a field *k* is determined exactly as for alfalfa but the earliest potential starting date is March 15th. However, the last day of continuous irrigation on grain is simulated to be much earlier than in alfalfa, on July 10th, after which the grain is harvested.

For pasture, the irrigation season is always from April 15th through October 15th (184 days). However, on pasture that is surface water irrigated (which represents most pasture), no irrigation occurs once surface water supplies become unavailable (the explanation of when surface water is considered unavailable is presented above). When applied, irrigation is applied continuously based on daily ET demand (again, we do not distinguish individual irrigation events).

The approach chosen here for simulating irrigation assumes that fields are all irrigated with the same, irrigation type-specific irrigation efficiency. This represents a simplification of reality, where some fields are relatively over-irrigated (mainly pasture fields) and others are relatively under-irrigated. However, the irrigation efficiencies are chosen to represent average irrigation management practices, given the irrigation type. The approach here also neglects irrigation non-uniformity within individual fields. Large non-uniformity with significant under-irrigation in some parts of the field may effectively increase field-scale irrigation efficiency.

For each polygon j and for each day i, the daily irrigation amount is calculated as shown in eq. 7 based on the evapotranspiration of the crop, adjusted for precipitation and considering the irrigation efficiency of the crop:

Irrig_j(i)=(1/irrigation_efficiency_j)*(Max(0, (ET_j(i)-Padj(i)) Eq. 7

Where:

- ET_j(i) = Kc_j* ET_0(i) where K_c is the crop coefficient,different for each crop
- Padj(i) is the adjusted precipitation on day i (Eq. 4)

For the soil water budget model, we assume that there is no contribution to evapotranspiration from groundwater. Groundwater contribution will be thoroughly evaluated once the integrated hydrologic model is developed, calibrated and coupled to the soil water budget model. This may require an iterative coupling process between the integrated hydrologic model development and the soil water budget model development.

2) ET/no irrigation category

The main assumption in this land use category is that, at all times:

Irrig(*i*) = 0

ET in this land use category is computed separately by two models: the soil water budget model and the groundwater flow model (MODFLOW).

In the first step, we use the soil water budget model to compute daily ET (on day *i*):

$ET(i) = k_c * ET_0(i) = 0.6 * ET_0(i)$

With the additional constraint that ET(*i*) <= Theta(*i*-1) + Padj(*i*)

This latter constraint is the key difference to an irrigated crop: here, ET is constrained to the naturally available water.

In a second step, ET that is due to direct uptake from the water table will be computed with the groundwater flow model (MODFLOW with the evapotranspiration, ET, package). The MODFLOW ET package uses root zone depth and maximum possible crop ET as input parameters.

The recharge is computed as indicated in the soil water budget model (Eq. 2, section 5.1). Note that recharge is computed without consideration of ET directly from the water table. This means that recharge may occur even if the water table is in the root zone. This conceptual dilemma results from the fact that:

- recharge computation is done *prior* to MODFLOW and is an input to MODFLOW
- direct ET from the water table is computed *as part* of the MODFLOW simulation

Effectively, the explicit coupling of these two components will not have much influence on the result, as water mass is still conserved by not allowing the sum of the two ET values (soil water budget model and MODFLOW) to be larger than the optimal ET from this land use category (0.6 * ET_0). Note that this simulation process only applies to non-irrigated ET land uses.

3) No ET / no irrigation category

Land use categories of this type have neither irrigation nor evaporation, or evapotranspiration from plants:

Irrig(*i*) = 0 at all times

ET(*i*) = 0 at all times

In the polygons within this category, we assume that runoff is negligible and that therefore recharge is equal to the adjusted precipitation:

Recharge (*i*) = Padj(*i*)

10.3 Calibration of Reference Evapotranspiration (ET_0)

Due to the sparse amount of observed data, calibration of the soil water budget model alone (i.e., not yet coupled to the groundwater MODFLOW model) is very difficult. Some values of reference ET and ET were provided by Hanson et al. (2011a) and have been used for a hand-calibration of the ET component used in the model.

Reference ET (ET_0) for the soil water budget model has been calculated with the NWSETO program developed at UC Davis, which is based on the Hargreaves and Samani (1982) equation. The reference ET values are summarized in Table 12 for the years 2007-2010 and are compared against reference ET values calculated with the Hargreaves equation (Hargreaves et al., 1985).

Table 12 Reference ET (Seasonal Reference ET) calculated with the Hargreaves equation (Hargreaves et al., 1985) (modified from Hanson et al., 2011a) and obtained with the NWSETO program used here (Hargreaves and Samani, 1982).

	ET_0 (March 15-October 1)	
Year	NWSETO calculated values (in)	ET_0 values (March 15-October 1) with Hargreaves eq. (in)
2007	40.12	44
2008	39.48	42.6
2009	40.4	40.4
2010	38.12	37.4

The reference ET(ET_0) values calculated with the NWSETO program overall were in agreement with the reference ET values based on the Hargreaves equation (Table 12).

With the above reference ET values, crop evapotranspiration (which we call ET, as mentioned above) is calculated as:

$ET=k_c*ET_0$

where ET_0 is the reference ET described above and k_c is the crop coefficient.

Observed values of alfalfa ET in Scott Valley were also available (Hanson et al., 2011a) and have been compared with the calculated values.

As shown in Table 13 , observed and calculated alfalfa ET values for the period March 15-October 1 are in agreement for three of the years considered: 2007, 2009 and 2010. The values for 2008 are in disagreement because of a significant number of smoke days that occurred in June-July 2008 and are not accounted for in the NWSETO-based ET estimate.

Table 13 Measured and calculated ET values for alfalfa using a crop coefficient k_c =0.95 . Measured values were obtained from Hanson et al., 2011a, Table 2).

Crop coefficient for Alfalfa= 0.95	ET (March 15-October 1)	
Year	Calculated values with k_c=0.95	Measured values (March 15-October 1)
2007	38.11	38.3
2008	37.34	29.4
2009	38.48	38.8
2010	36.13	36.03

* values for 2008 are expected to be lower than other years because of the numerous smoke days

11 Soil Water Budget Model: Results

This section presents the results of the soil water budget analysis. Results are compared against irrigation, evapotranspiration and recharge data available from relevant literature and against data provided by the local GWAC.

The water budget simulation provides daily, field-by-field land use polygon specific outputs for all of the following variables, which are aggregated to provide yearly and long-term average rates by polygon, by land use, and by subwatershed:

1. Pumping: each polygon is assigned to the nearest well in the irrigation well database. If there are multiple wells in one polygon, the total pumping need is evenly split between the wells, while the pumping rate in a well that is serving multiple polygons is the sum of all daily water needs in the associated fields;
2. Recharge, deep percolation, as calculated with Eq. 2;
3. Crop Evapotranspiration (ET) under optimal irrigation (=crop coefficient multiplied by ET_0);
4. Actual ET- the ET actually occurring, limited by the available water in the root zone including the amount of irrigation and precipitation on a given day *i* (Eq. 3);
5. Deficiency - the difference between optimal crop ET and actual ET, which may be limited by the amount of water available (e.g., where surface water is the only source of irrigation water or where no irrigation water is supplied) (Eq. 5).

Daily pumping and recharge rates are aggregated to monthly totals for the MODFLOW groundwater-surface water simulation.

As part of the extensive GIS analysis described above, the watershed has been subdivided into a total of 2,119 polygons, 710 of which are alfalfa/grain (with an 8 year rotation, i.e., 1 year grain followed by 7 years alfalfa), 541 are pasture, 451 polygons are in the category with evapotranspiration but no irrigation, 417 do not have evapotranspiration nor irrigation (Figure 18). Each polygon is also associated with a subwatershed, an irrigation type, and a water source. Table 14 presents a summary of polygon area, and the fraction of the area irrigated by different water sources used in the soil water budget model.

Table 14. Summary of number of polygons, area, and % of the area irrigated with each of the water sources used in the soil water budget model. The area of alfalfa/grain changes slightly every year because of the rotation, but the overall ratio is of alfalfa area to grain area is 7:1. 177 acre (1%) of alfalfa/grain and 475 acres (3%) of pasture have no or unknown water sources.

	Total /Irrigated Area (ac)	*% area with SW irrigation*	*% area with GW irrigation*	*% area with mixed (GW/SW) irrigation*	*% area dry*	*% area subirrigated*
Alfalfa	15,200 / 13,900	7	77	7	6	1
Grain	2,200 / 2,000	7	77	7	6	1
Pasture	16,600 / 11,900	39	18	16	13	11

Results are presented for the entire 21 year period starting on October 1, 1990. As noted earlier, results reported here are based on the precipitation time series described in section 4.2 and based on a complete, mostly synthetic streamflow dataset obtained by regression as presented in Chapter 5.

11.1 Water Budget Analysis

Average annual values totaled over the project area are computed for irrigation, crop evapotransporation (ET), actual evapotranspiration, deficiency, recharge, and pumping. These are values estimated using the daily values calculated in the soil water budget model (Table 15). Simulation results must not be confused with measured values and they have not been calibrated against field data. For recharge and pumping, no field records exist. Irrigation and evapotranspiration totals are compared against reported field data later in this section.

Maps showing the polygon specific yearly average values over the 21 year period in inches/year for irrigation, recharge, pumping, recharge minus pumping and deficiency are also presented to provide information on the spatial distribution of the results (Figure 20 to Figure 25).

Table 15. Average simulated annual water budget terms averaged over the 21 year period. The numbers represent rates in inches/year for each land use (top) and in acre-feet/year over the entire study area (bottom). Note that these are soil water budget model simulation results and do not reflect actually measured values. Irrigation includes irrigation with surface water and irrigation with groundwater. Recharge also includes all landuse polygons irrespective of whether irrigation water is from surface water or from groundwater. All calculations assume that the water table is below the root zone.

Inches/Year	Crop ET[1]	Actual ET[2]	Irrigation	SW Irrigation	GW Pumping	Recharge	Deficiency	Area
Alfalfa	42.0	40.1	33.1	4.1	29.0	14.6	1.9	13,893 ac
Grain	16.2	16.1	14.1	2.1	11.9	18.4	0.1	1,985 ac
Pasture	40.0	33.9	29.7	20.8	9.0	17.2	6.1	11,909 ac
ET noIRR	11.2	10.8	0.0	0.0	0.0	10.8	0.4	20,363 ac
noET noIRR	0.0	0.0	0.0	0.0	0.0	21.5	0.0	1,695 ac

Acre-Feet/ Year	Crop ET[1]	Actual ET[2]	Irrigation	SW Irrigation	GW Pumping	Recharge	Deficiency	Area
Alfalfa	48,700	46,400	38,300	4,730	33,600	16,900	2,230	13,893 ac
Grain	2,670	2,660	2,330	355	1,970	3,040	11	1,985 ac
Pasture	39,700	33,700	29,500	20,600	8,890	17,100	6,060	11,909 ac
ET noIRR	18,900	18,300	-	-	-	18,300	636	20,363 ac
noET noIRR	-	-	-	-	-	3,040	-	1,695 ac

[1] Crop ET = ET_0 * crop_coefficient

[2] Actual ET = estimated actual ET occurring, limited by available water in the root zone (with or without irrigation)

A total of 15,900 acres of the “alfalfa/grain” category, which includes miscellaneous crops, is irrigated. Total crop ET from alfalfa is nearly 49,000 acre-feet per year (af/y) and 2,700 af/y from grains. Crop ET is met by precipitation, soil moisture, and an estimated 38,000 af/y of irrigation onto alfalfa and 2,300 af/y of irrigation onto grains. Total pumping for those two crops is estimated to be about 35,600 af/y, while only about 5,000 af/y of irrigation water are estimated to be from surface water.

Irrigated “pasture” including some residential/urban lawn areas covers 12,000 acres with an estimated total crop ET of nearly 40,000 af/y. Two-thirds of the nearly 30,000 af/y of irrigation water is from surface water (20,600 af/y) with the remainder from groundwater (8,900 af/y).

Total surface water deliveries to irrigated areas are estimated to be about 26,000 af/y, groundwater pumping is estimated to be on the order of 44,500 af/y not including groundwater uptake in about 2,100 acres of subirrigated areas.

An additional 19,000 af/y of consumptive use occurs on lands in the “ET - no Irrigation” land use areas (including dry farmed or sub-irrigated crops). This estimated ET is supplied by precipitation and soil moisture storage and does not account for any groundwater uptake.

Analysis of the spatial and temporal distribution of irrigation and recharge fluxes suggests the following main findings:

- Highest irrigation and pumping rates occur in polygons with pasture as land use and groundwater as water source (Figure 20 and Figure 23): this can be explained by the fact that pasture has the longest irrigation season. In polygons with groundwater as water source, irrigation rate and pumping rate are the same.
- Highest recharge rates (Figure 21) occur in polygons with pasture as land use and with groundwater as water source, in vacant land use polygons located in the tailings subwatershed, and in polygons with very small water holding capacity. Recharge is expected to be higher where there is higher irrigation or less plant transpiration;
- The lowest recharge rates (almost zero recharge) occur, for example, in some polygons south of Greenview around Highway 3: as shown in Figure 19, they correspond to dryland. They rely on precipitation as water source for plants, which efficiently scour available moisture and therefore show little natural recharge, typical of a semi-arid climate;
- Low recharge rates (between 4 and 8 in/year) occur in some fields north of Etna: these have pasture as land use, but they are subirrigated (high water table);
- Deficiency (Figure 25) occurs in the months immediately following the end of the irrigation season (September, October, November).

A year-specific analysis of the water budget for the 21 year period has also been performed (Figure 26 to Figure 28).This analysis allows us to highlight differences in the water budget between dry and wet years (highlighted with red and blue arrows, respectively). Dry and wet year classification is identical to that shown in Figure 6.

As expected, dry years are marked by smaller amounts of recharge to groundwater and a smaller amount of applied surface water. Lower surface water use reflects the modeled constraints in irrigation of pasture, which is limited by the estimated or measured (when available) monthly flow in the stream associated with the subwatersheds to which a field belongs.

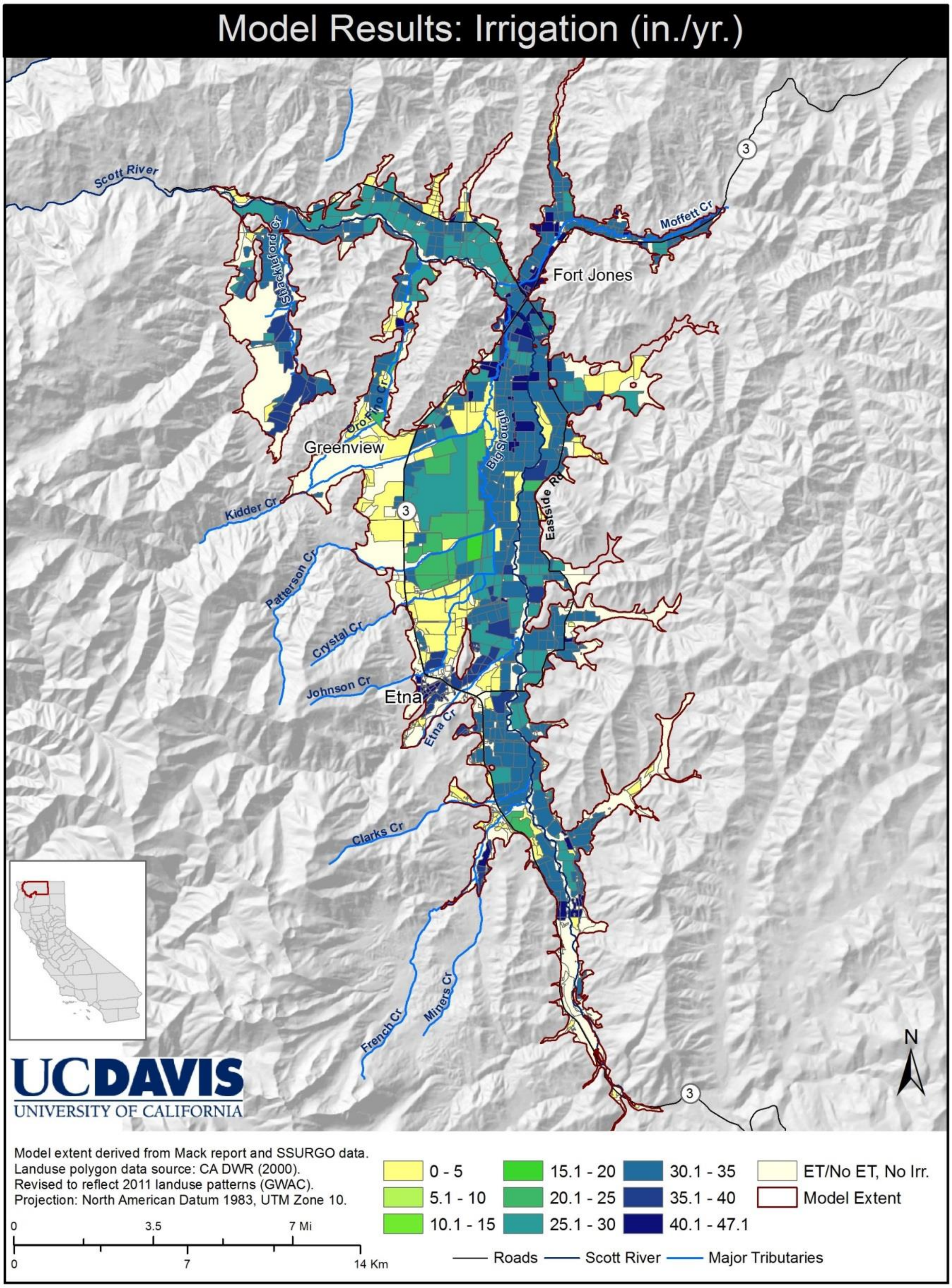
Typical characteristics contrasting alfalfa/grain soil water budgets with pasture water budget dynamics include:

1) Alfalfa/grain land use (Figure 27) is higher in actual evapotranspiration, higher in applied groundwater and has an overall low fraction of applied surface water. This is expected considering that alfalfa/grain is mostly groundwater irrigated (Table 14);
2) Pasture land use has higher applied surface water and almost no applied groundwater. The amount of applied groundwater does not change dramatically from year to year because there are no large differences in the length of the pasture irrigation season between different years. Large differences occur in the use of surface water between wet and dry years. Where the water source is groundwater, year-to-year differences in groundwater use are small and due to annual differences in the irrigation start date, but then irrigation continues for the entire season each year, regardless of year type (wet, normal, dry);
3) Recharge in alfalfa/grain is similar to pasture. A few pastures have high recharge rates due to being irrigated with groundwater at high irrigation rates (low irrigation efficiency assigned by the model).

Effects of dry and wet years on the amount of applied surface water and applied groundwater are shown in more detail for alfalfa and for pasture (Figure 29). In dry years, the amount of applied surface water generally decreases while the amount of groundwater use increases.

The results of the soil water budget model are generally in agreement with what would be expected considering the background information on land use, irrigation water source, irrigation type, and precipitation.

The soil water budget model can be adjusted to accommodate changes in inputs and/or operational assumptions. Further sensitivity analysis and tests can be performed to evaluate assumptions.



Model extent derived from Mack report and SSURGO data.
Landuse polygon data source: CA DWR (2000).
Revised to reflect 2011 landuse patterns (GWAC).
Projection: North American Datum 1983, UTM Zone 10.

Figure 20. Map of land use polygon specific average annual irrigation rates (inches/year) between October 1990 and September 2011.

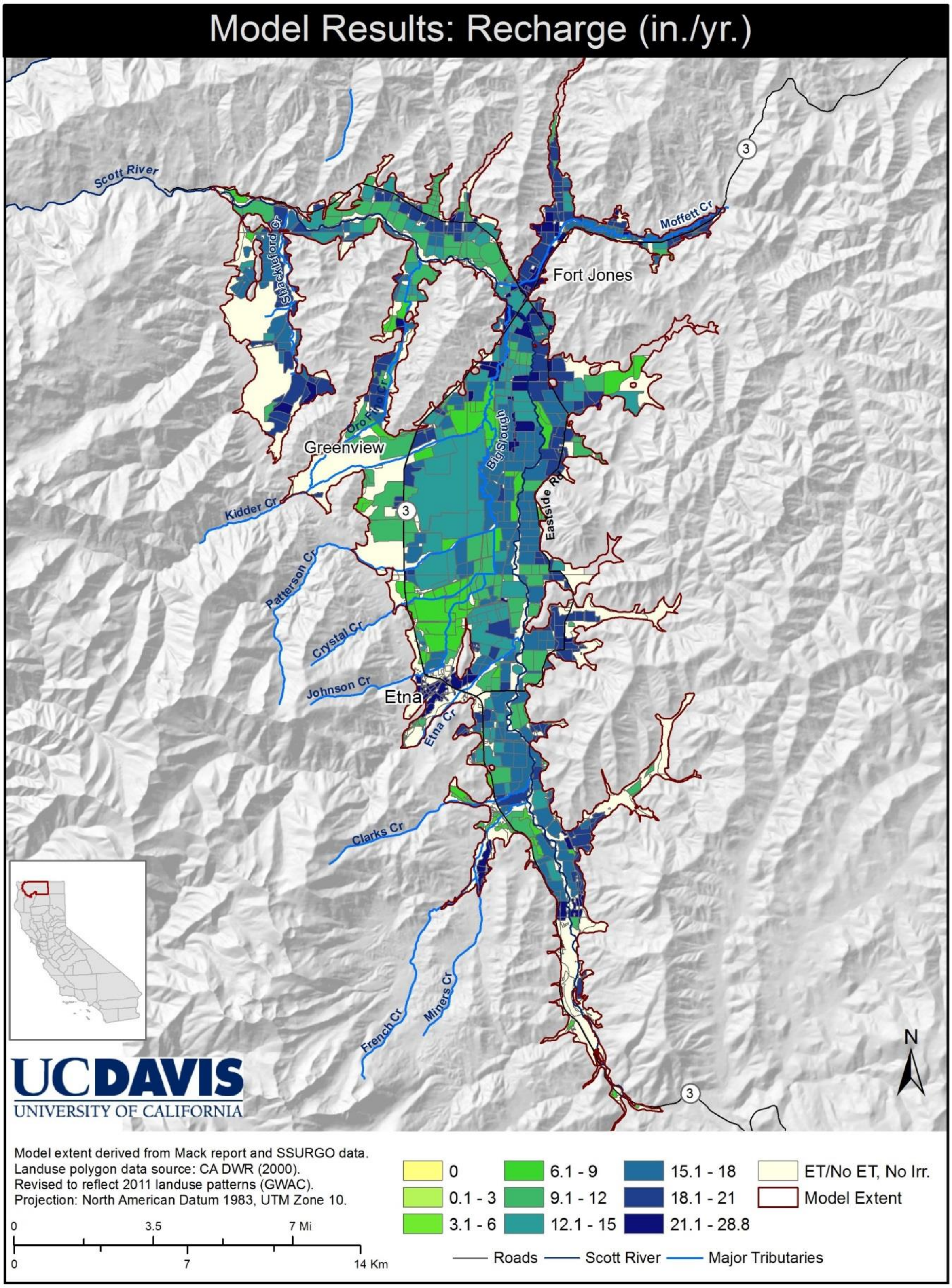


Figure 21. Map of land use polygon specific average annual recharge rates (inches/year) between October 1990 and September 2011.

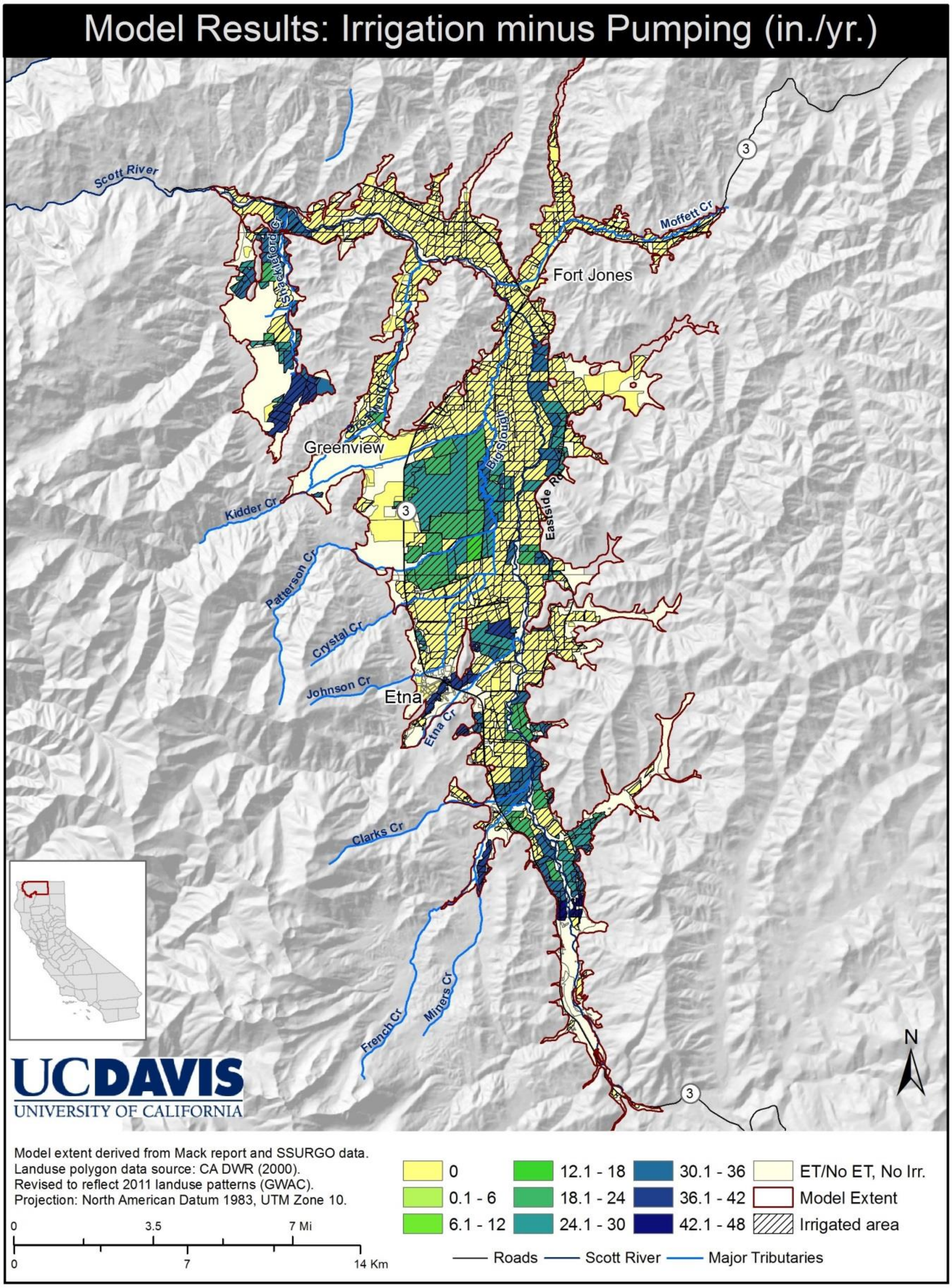


Figure 22. Map of land use polygon specific average annual applied surface water rates (inches/year) between October 1990 and September 2011. The amount of applied surface water is calculated as the difference between the total irrigation and the pumping.

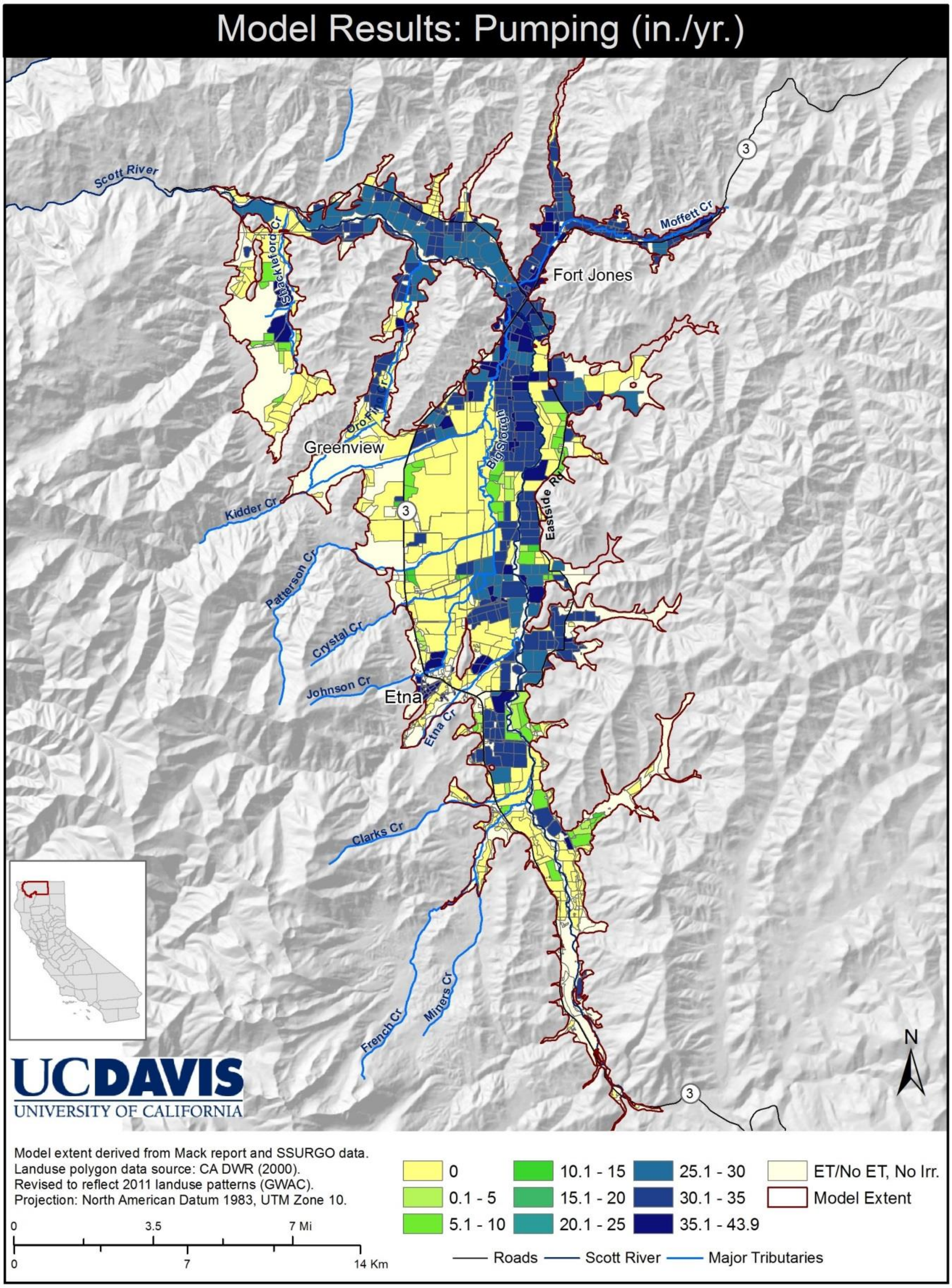


Figure 23. Map of land use polygon specific average annual pumping rates (inches/year) between October 1990 and September 2011.

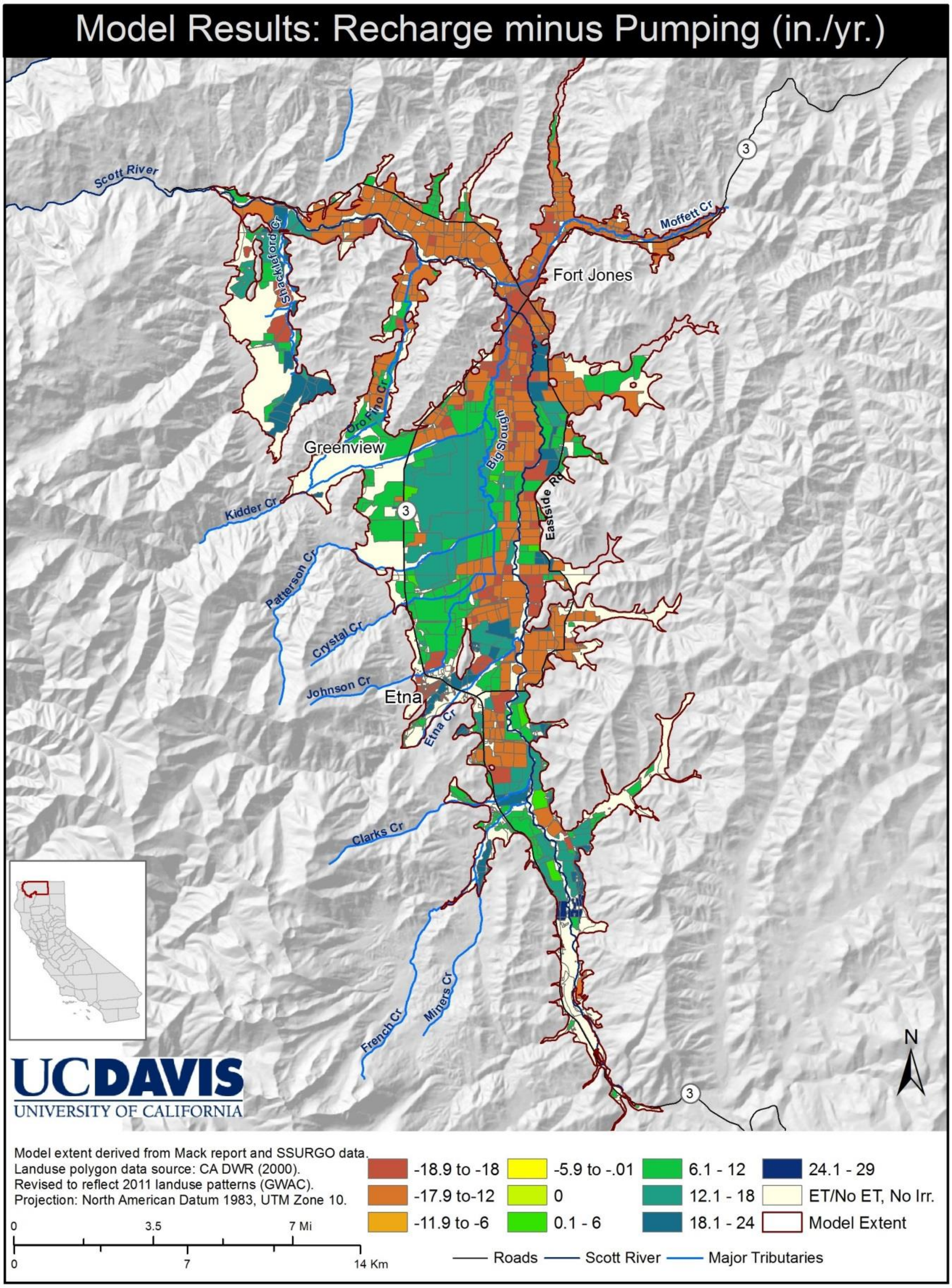


Figure 24. Map of land use polygon specific average annual recharge minus pumping rates (inches/year) between October 1990 and September 2011.

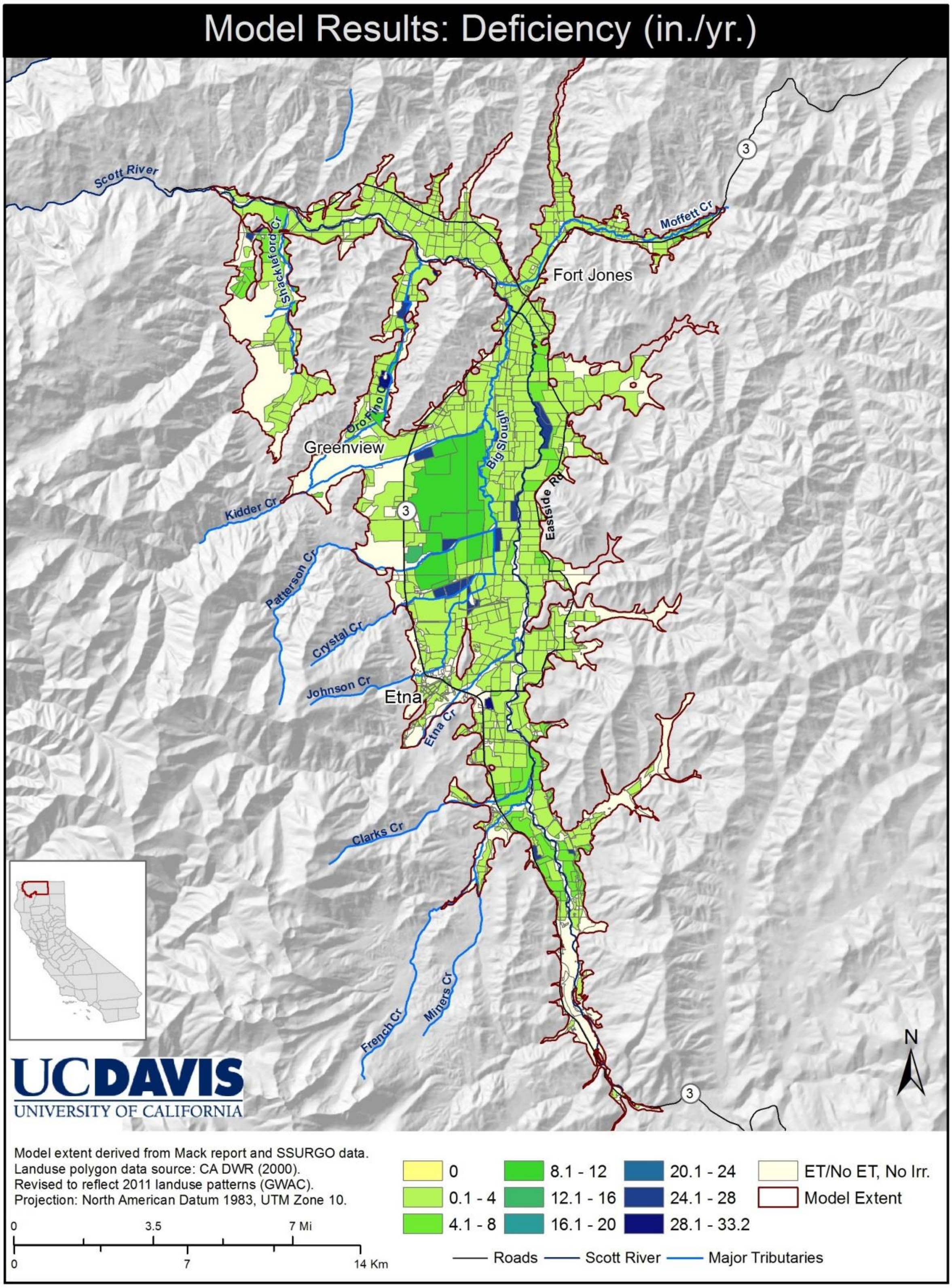


Figure 25. Map of land use polygon specific average annual deficiency rates (inches/year) between October 1990 and September 2011. Deficiency is defined as the difference between actualET and ET under optimal water supply conditions. Deficiency occurs in pasture or after the irrigation season ends in alfalfa

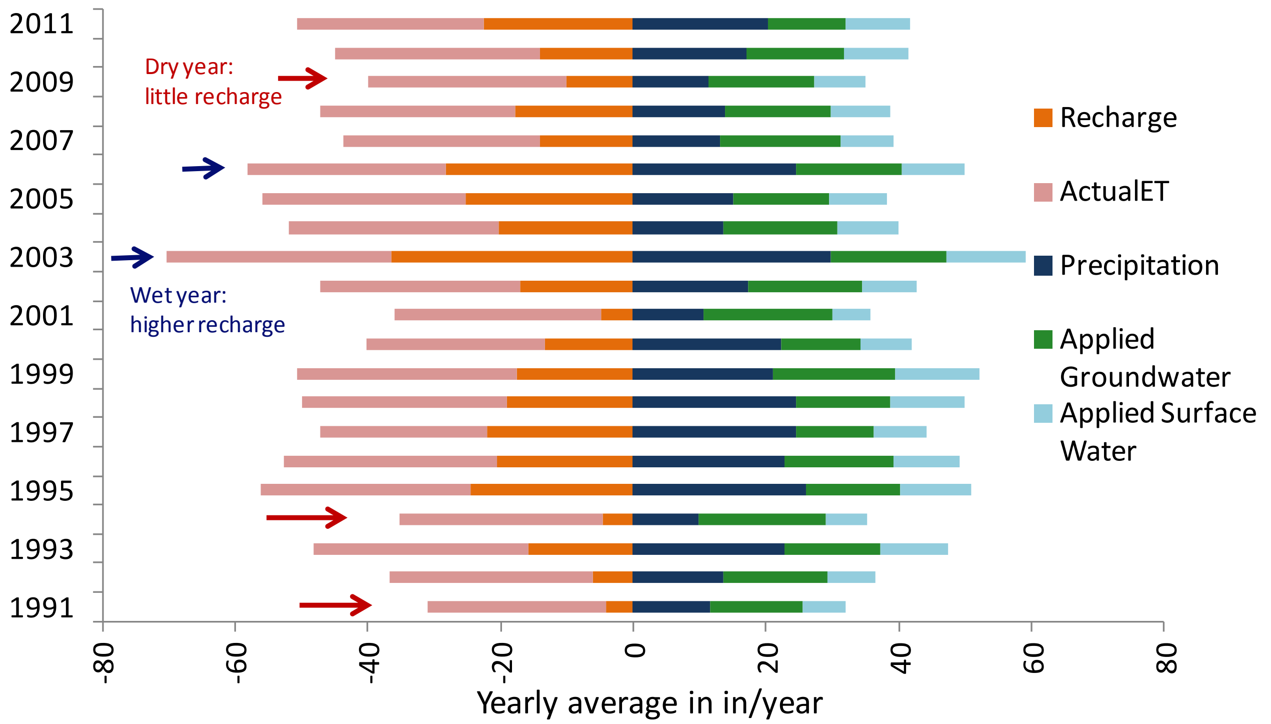


Figure 26. Yearly soil root zone water budget in in/year, area-weighted average for the entire Scott Valley project area. Input to the root zone shown as positive values (precipitation, applied groundwater and surface water). Output from the root zone shown as negative values (actual ET and recharge).

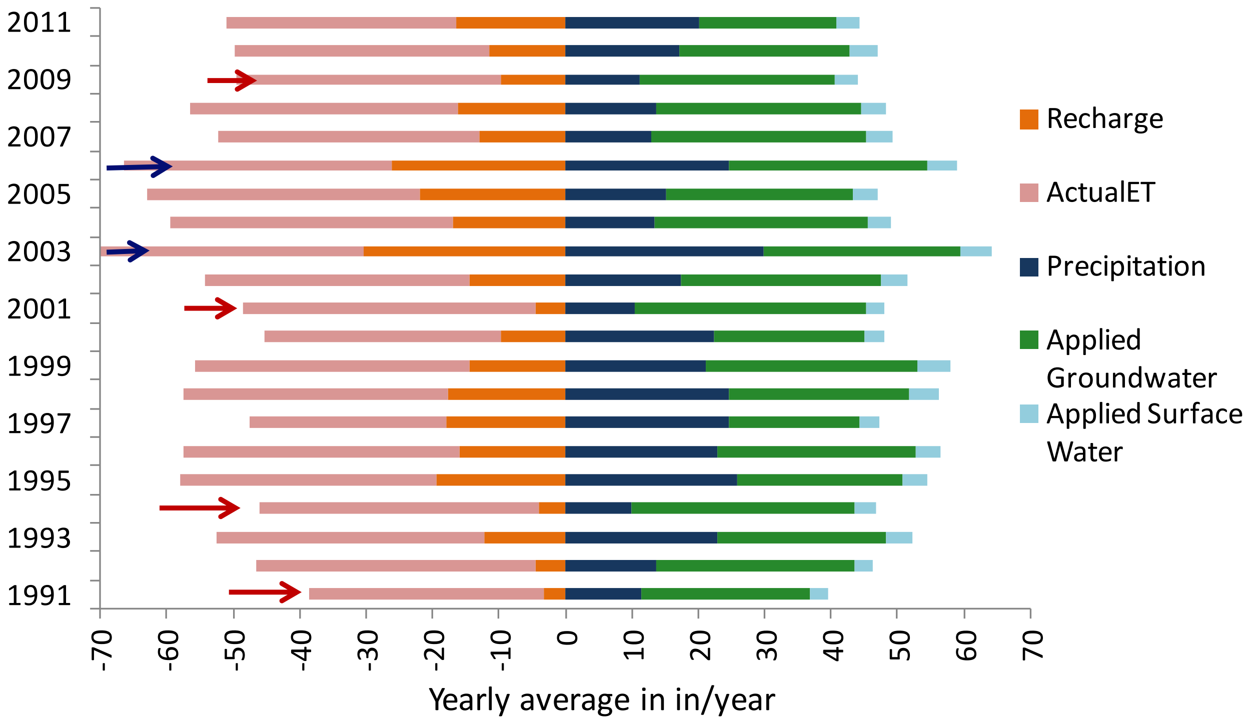


Figure 27. Yearly soil root zone water budget in in/year, area-weighted average for the alfalfa polygons over the entire Scott Valley project area. Input to the root zone shown as positive values (precipitation, applied groundwater and surface water). Output from the root zone shown as negative values (actual ET and recharge).

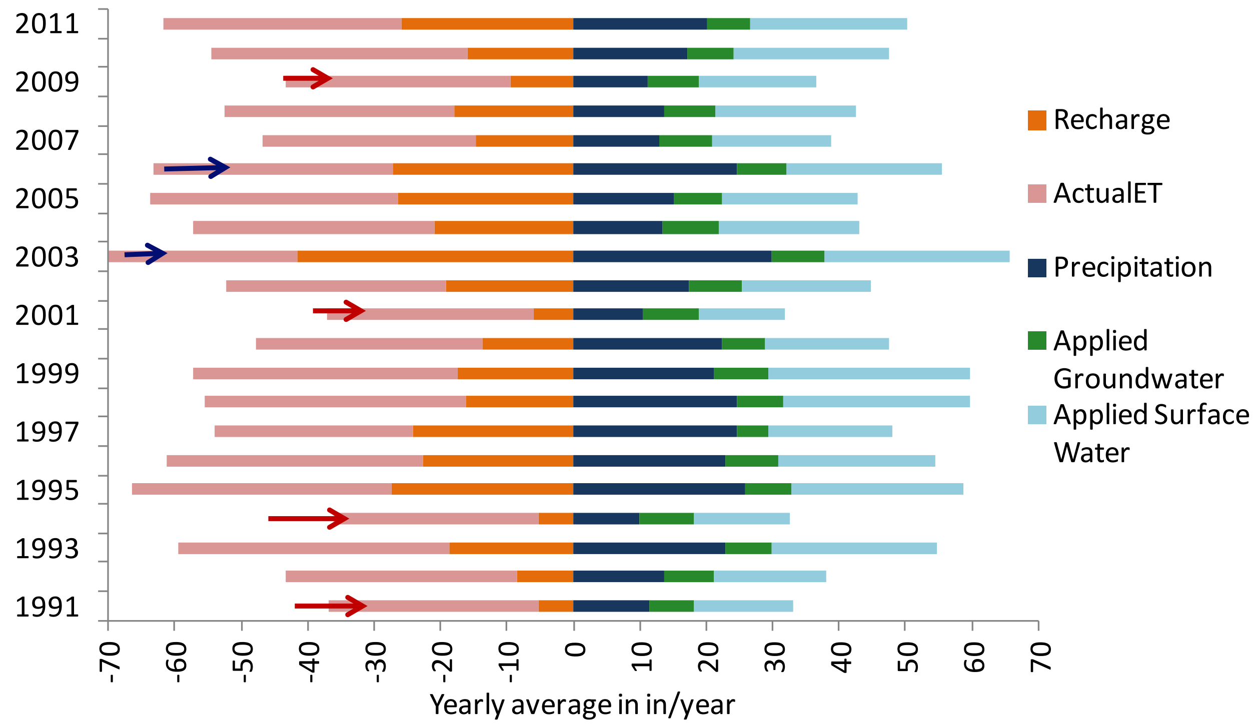


Figure 28 Yearly soil root zone water budget in in/year, area-weighted average for the pasture polygons over the entire Scott Valley project area. Input to the root zone shown as positive values (precipitation, applied groundwater and surface water). Output from the root zone shown as negative values (actual ET and recharge).

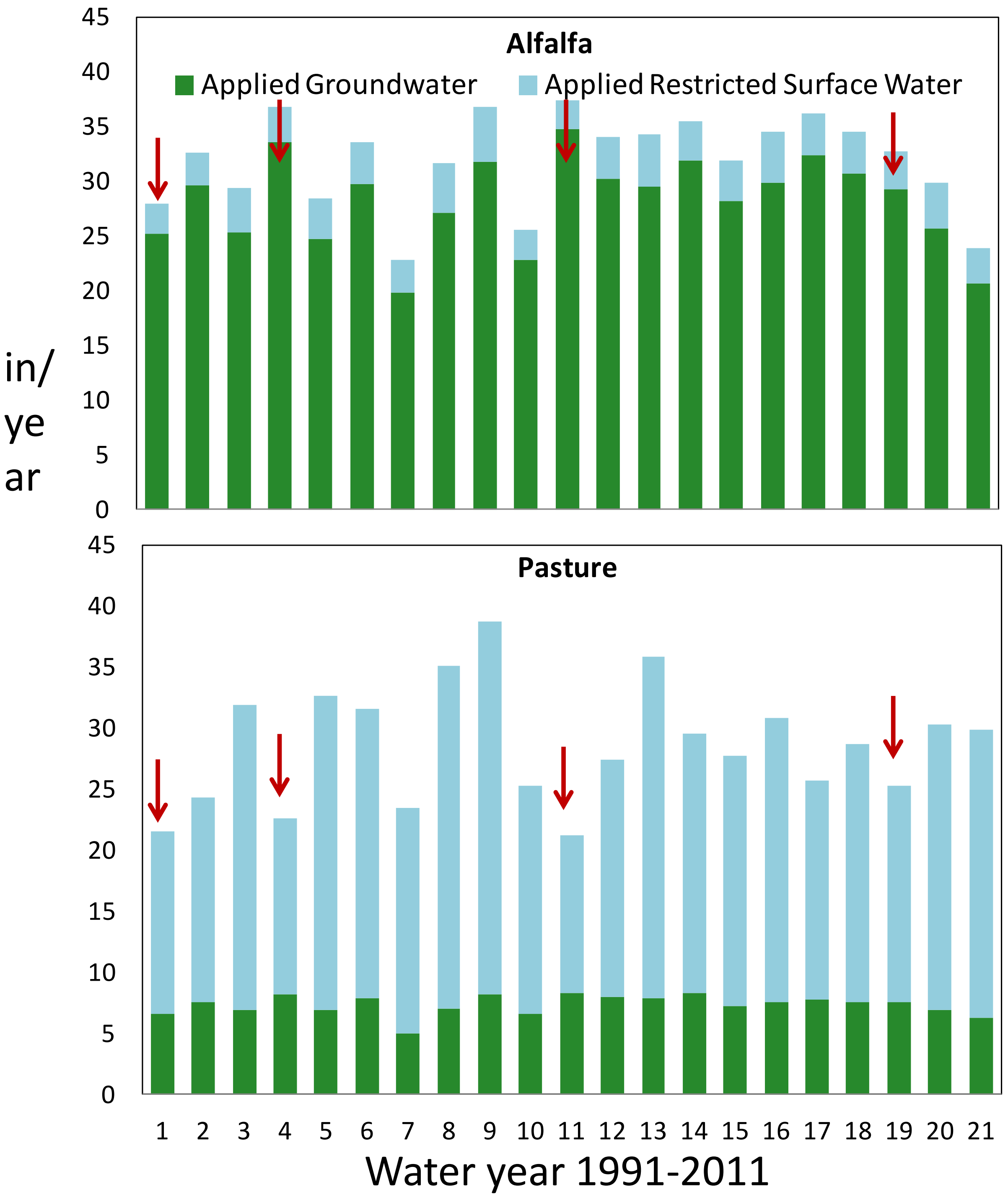


Figure 29. Yearly values of applied surface water and applied groundwater in in/year for alfalfa/grain (above) and pasture (below), area-weighted average over all alfalfa/grain land use polygons in the project area. Dry years are highlighted.

11.2 Sensitivity Analysis: Water Holding Capacity

Water holding capacity is a critical parameter in the soil water budget model. But the actual value of the parameter is quite variable and locally uncertain. Based on expert suggestions, to compute the above results we used a water holding capacity that corresponds to a rooting depth of 4 feet. Roots may eventually grow deeper than 4 feet and access deeper water if shallow moisture is depleted.

To test the sensitivity of the soil water budget simulation results to the value chosen for water holding capacity, a simple sensitivity test was implemented. A second simulation was run assuming that root zone depth is 8 ft depth with a water holding capacity that is exactly twice as large as that at 4 ft depth.

The results provided by the soil water budget model with the alternative water holding capacity are summarized and compared to the original values in Table 16. At double the water holding capacity, the irrigation amount for alfalfa decreases by about 1 in and, as expected, the only noticeable change is a substantial decrease in groundwater recharge. Because of the significant effect on recharge, additional sensitivity analyses should be carried out once the soil water budget model is coupled to the integrated hydrologic model.

Table 16. Sensitivity of average fluxes due to doubling of the soil water holding capacity. Changes (in percent) are relative to the original results (Table 15). Positive values indicate a relative increase compared to original results.

	CropET	Actual ET	Irrigation	SW irrigation	GW irrigation	Recharge
Alfalfa	0	3.7	-3.3	-4.6	-3.1	-24
Grain	0	1.2	-1.2	-1.0	-1.3	-13
Pasture	0	11.3	0.0	0.0	0.0	-23

11.3 Comparison with Available Data

The GWAC provided us with grower information on the amount of irrigation that is typically applied to different crops as a function of the irrigation type used (Table 17). The information was developed from the GWAC’s knowledge of typical Scott Valley irrigation schedules, sprinkler spacing, sprinkler nozzle sizes, and sprinkler flow rates.

The irrigation rates computed from the information provided by the GWAC (Table 17) are significantly lower than the irrigation rates estimated from the soil water budget model. In the soil water budget model, the simulated irrigation rate is primarily driven by the assumption that evapotranspiration demands not met by precipitation and soil moisture are fully met by irrigation (Table 15). The largest discrepancy between reported data and simulated data is for the amount of irrigation applied to alfalfa (reported: 19.5-22 inches, simulated: 33 inches). Several factors may contribute to this difference:

- Reported irrigation rates underestimate actual irrigation rates used by growers;
- Reference evapotranspiration computed by the NWSETO method from Scott Valley and nearby climate data overestimates actual reference evapotranspiration;
- Irrigation practices result in deficit irrigation of alfalfa, which means that the crop coefficient for alfalfa used here assuming optimal irrigation is too large, and the field scale irrigation efficiency chosen is too low;
- The soil moisture profile remains relatively dry during the irrigation season. This would mean that irrigation efficiencies are higher than assumed during the irrigation season;

- The root zone depth is much larger than 4 feet and roots may possibly tap into the water table;
- A combination of the above.

To address this discrepancy, field experiments were developed in spring of 2012 to collect more information on alfalfa evapotranspiration, reference evapotranspiration, irrigation rates, soil moisture dynamics, groundwater levels, and forage yield. Eight alfalfa fields (four center pivot irrigated and four wheel-line sprinkler irrigated fields) were selected for monitoring over the 2012-2013 production season. Data collected include:

1. Three surface renewal system installed in three alfalfa fields (all of the irrigated with center pivots that have permanently installed flow meters) to calculate alfalfa ET.
2. A CIMIS type weather station installed in one irrigated pasture field to estimate ETo in order to determine the appropriate alfalfa crop coefficient.
3. Soil samples collected to 8 ft. depth in April, August, and early October to determine gravimetric soil moisture content.
4. Watermark soil moisture sensors installed at 1 ft. increments to 8 ft. depth at two locations in all fields to determine soil moisture tension and wetting and drying patterns over the season.
5. A tipping rain gauge installed in each field to monitor irrigation application rate and in-season rainfall.
6. Portable Ultrasonic Doppler flow meter used to determine flow rate in center pivot fields.
7. Nozzle discharge rate monitored in wheel-line fields.
8. Alfalfa yield determined in all eight fields by hand cutting a representative area and comparing with grower yield values.

The project is intended to be continued for at least one, possibly two years, depending on interannual variability in the dataset. The dataset will be critical to help refine the soil water budget model to minimize the difference between simulated and measured irrigation rates.

Table 17. Total seasonal irrigation amount computed from information on typical irrigation frequency, nozzle sizes, nozzle spacing, and nozzle flow rates, provided by the GWAC for each crop and each irrigation type.

Alfalfa		**Grain**		**Pasture**	
Irrigation Type	*Irrigation in inches*	*Irrigation Type*	*Irrigation in inches*	*Irrigation Type*	*Irrigation in inches*
Sprinkler	22”	Sprinkler	8.25”	Sprinkler	n/a
Center Pivot	19.5”	Center Pivot	6”	Center Pivot	n/a

12 Future Work

Work that is currently planned or ongoing will concentrate on four main tasks: 1) evaluation of the field experiments to determine alfalfa irrigation and evapotranspiration rates, 2) refinement of the soil water budget model, 3) development of Version 2 of the Scott Valley Integrated Hydrologic Model, and 4) initiation of scenario alternatives to simulate future streamflow and groundwater conditions under various management/project options.

The dataset produced with the effort presented in this report is used to build Version 2 of the Scott Valley Integrated Hydrologic Model. The model is implemented using MODFLOW-2000 and it will be coupled to the soil water budget model and streamflow data presented here. The soil water budget model provides groundwater pumping, surface water diversion, and groundwater recharge rates that are also used as inputs in the groundwater flow model. It also provides the evapotranspiration data for the water budget.

In summary, Version 2 of the Scott Valley Integrated Hydrologic Model will perform the following refinements that are improvements over the (draft) Version 1 of the model:

1. Extended modeling area to include the dredge-tailing area in the southern Scott Valley and make some minor adjustments to the edge of the modeling area, based primarily on land surface topography data.
2. Refined land surface elevation representation, especially of stream channels, using neìwly available LIDAR data obtained from the U.S. Forest Service.
3. Updated groundwater pumping, surface water diversion, and groundwater recharge using the values calculated with the new soil water budget model.
4. Revised regression model of streamflow data based on the evaluation of additional data that have become available since 2008.
5. Extension of the time period simulated by the integrated hydrologic model to include 2009, 2010, and most of 2011 (through September 30, 2011).
6. Extensive sensitivity analysis, calibration and uncertainty analysis.

Regarding this last task, parameters from both models (the soil water budget model and the MODFLOW integrated hydrologic model) will be included simultaneously in the sensitivity analysis allowing us to evaluate the sensitivity of model results to parameters and observations. The integrated hydrologic model will be calibrated and validated using measured groundwater level data available for the Scott Valley and using measured streamflow data downstream of Scott Valley.

The information that we obtain with this type of analysis will quantify and illustrate the sensitivity of model results to parameters and algorithm choice. It will also describe the relationship between different types of data and the processes represented. Furthermore, our approach will allow the evaluation of uncertainty in the model output for 1991-2011 and for any of the scenario analyses. The sensitivity analysis will be used to identify the most critical information needed to reduce model prediction uncertainty. The evaluation of data needs will include a determination of optimal areas or locations at which to collect data and whether there are seasonal preferences to collecting certain data. All these tasks will be performed using an automatic inversion code such as UCODE_2005 (Poeter et al., 2005) or PEST (Doherty, 2010) which allow the coupling of the two models and the automatic calibration of parameters involved in all the processes.

The approach described in this report and the integrated hydrologic model currently under development provide a framework to efficiently and effectively develop and evaluate future data collection campaigns and alternative water management scenarios. In the soil water budget model much of the information related to a field is parameterized with parameters available from geospatial databases. Future water management scenarios can be efficiently coded into the soil water budget model and the integrated hydrologic model as needed to simulate future conditions.

13 Conclusions

Precipitation and streamflow data have been analyzed, a revised streamflow regression model to generated synthetic data for stations that have only a very limited period of record has been prepared specifically for use with the integrated hydrologic model, and a new conceptual model for the simulation of the soil water budget has been developed and used to estimate streamflow diversions, groundwater pumping, groundwater recharge, and crop evapotranspiration. The model is based on a spatially distributed soil water dynamics approach and puts together a wide array of information in a tractable, physically and hydrologically rigorous approach.

Comprehensive datasets were compiled, and we worked closely with local stakeholders and committees to refine these dataset as well as the conceptual framework used to represent various landuses, especially agricultural landuses, and irrigation management practices. The contributions of various stakeholders have been essential to update our GIS database and soil water budget model with the most complete, accurate reflection of land use and agricultural practices in Scott Valley.

The study shows that precipitation across the valley floor, while variable during any given rainfall event, is overall of similar magnitude between Callahan, Fort Jones, and Greenview. Significantly higher precipitation may occur at the far western margin of the valley (Etna), but available data do not allow for sufficient quantification of such effects. Precipitation patterns define streamflow. Years with low precipitation result in the lowest summer flows on the Scott River and its tributaries. We are able to estimate tributary flows with a newly developed statistical model that takes advantage of the long time series at the Ft. Jones streamflow gauging station immediately downstream from Scott Valley. The statistical model also shows that snow pack and precipitation data further aid in tributary streamflow estimation, even if only slightly. Also, developing separate regression models for the time period before fall of 1972 and the period since then, further improves statistical estimates of tributary streamflow into the Scott Valley. However, the data series for the tributaries are extremely limited. The synthetic dataset generated will be sufficient for purposes of the integrated hydrologic model. It will be important to continue streamflow monitoring on all tributaries.

Landuse in the Scott Valley, for hydrologic purposes, can be divided into four categories: irrigated fields in alfalfa-grain rotation (nearly 16,000 acres), irrigated fields with pasture (12,000 acres), non-irrigated parcels with natural or other vegetation that consumes water through evapotranspiration, and land parcels that are effectively barren of vegetation or open water bodies (no irrigation and no evapotranspiration).

Soil water budget simulations show that significant amount of groundwater recharge occurs across the Scott Valley from both precipitation and irrigation. We estimate that the average annual recharge is 15 inches in alfalfa, and about 17-18 inches in grain and pasture. Irrigation on alfalfa is highest (33 inches), followed by pasture (30 inches) and grain (14 inches), which has a relatively short growing season. Based on soil water budget simulations, groundwater pumping is estimated to be highest in alfalfa fields, averaging 29 inches per year, supplying most of the irrigation water there. It is much lower in grain fields (less than 12 inches per year), and lowest in pasture (averaging 9 inches per year), since most pasture is irrigated with surface water. Rainfall also provides a significant amount of crop water supplies via soil moisture storage.

Large field-to-field and year-to-year variations occur both with groundwater pumping and recharge. The variability shown in this report is due to varying irrigation practices within the same crop type, varying water sources, and due to inter-annual climate variations. Variability within fields or between individual growers is not simulated, but further adds to actual variability in groundwater use and recharge.

The alfalfa irrigation results obtained with the simulation model are much higher than recently measured and grower-reported irrigation rates, thus clearly identifying the need for further research work to clarify actual irrigation practices and to measure evapotranspiration occurring in alfalfa fields. Work is needed to test to what degree the discrepancy between measured and simulated irrigation rates is due to soil moisture storage currently not accounted for, potential water table encroachment and root water uptake directly from groundwater, variability in actual irrigation rates, or possibly misleading ET rates published by the California Department of Water Resources and available in the scientific literature. It will be important to thoroughly validate and possibly improve the soil water budget model against new field data as part of performing water management scenario simulations and prior to making policy decisions.

Finally, we recognize that a tool such as the one presented here is critical for discussion of alternative water management scenarios with the Groundwater Advisory Committee and other stakeholders as an effective mechanism to mitigate conflicts.

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15 Appendix A

The appendix illustrates detailed results of the streamflow regression analysis (Section 5). Due to its size, this appendix is provided as a separate PDF file.