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Technical Memorandum

To: Butte County Department of Water and Resource Conservation

From: Davids Engineering

Date: October 11, 2013

Subject: **Recommended Methodologies for Update of Butte County Water Inventory and Analysis and Butte Basin Groundwater Model**

Overview

This technical memorandum describes proposed methodologies for the update of the Butte County Water Inventory and Analysis Report (WI&A) and the Butte Basin Groundwater Model (BBGM) to reflect conditions through 2012. Additionally, time series datasets will be developed for the BBGM to support evaluation of projected water demands and potential effects of climate change on local water supplies.

Discussion and proposed methodologies are provided for the following:

- Precipitation
- Reference Evapotranspiration (ET)
- Land Use
- Future Cropping
- Crop Coefficients
- Irrigation Efficiency
- Rimflows
- Diversions
- Urban Pumping
- Climate Change Hydrology (precipitation and stream flows)

As an added note, this work will be supported by detailed water balance analyses being conducted concurrently for the Feather River Regional Agricultural Water Management Plan (FRRAWMP). The FRRAWMP study area extends from the Sacramento River and Sutter Bypass in the west to the Feather River in the east and from Western Canal Water District in the north to Freemont Weir in the south. An objective of the coordination of these efforts is to ensure consistency between these efforts and that the most current understanding of the surface and groundwater hydrology of the Butte Basin is incorporated into the Department's water management planning.

Methodologies for Individual Datasets

Precipitation

Existing IWFM input data files of precipitation for the five weather stations represented in the model (Chico University Farm, Colusa 2 SSW, Marysville, Oroville, and Paradise) as described by CDM (2008)

have been compared to raw precipitation data provided by Dr. Christina Buck at the Butte County Department of Water and Resource Conservation (BCDWRC). Data was downloaded from the Western Regional Climate Center (WRCC, http://www.wrcc.dri.edu/climatedata/climsum/) in April 2013. The station locations are shown in Figure 1.

Differences between aggregated precipitation amounts between the model files and raw data for a given station are largely explained by the lack of time tracking in the existing model (each month has exactly 30 days); any precipitation recorded on the 31st day of a month is not included in the existing model. For the month of February, February 29 and February 30 are added for each year. In years with a leap day, precipitation for February 29, if any, is included, and precipitation for February 30 is set to zero. In other years, precipitation for both added days is set to zero.

There is a gap in data availability for the Oroville station for the period Sept. 1975 to Jan. 1983. Based on review of the model input files, it appears the model was run with zero precipitation in approximately 30% of the model domain for that period. Moving forward, it is recommended that the data gap for Oroville be filled using data from another station based on linear regression (e.g., Paradise or Marysville), as described below.

A summary of water year precipitation by station represented in the existing model files is provided in Figures 2 through 6. In each figure, the raw totals from WRCC are presented, along with the annual totals from the existing BBGM. For the Chico University Farm weather station, updated totals representing initial estimates for the BBGM update resulting from the application of the quality control procedures described above are included.

Additionally, it is recommended that general quality control procedures be applied to all of the precipitation data to identify data gaps and extreme values, possibly resulting from data entry errors. Gaps for a given station would be filled based on correlation to neighboring stations. Correlations between the Oroville station and the Marysville and Paradise stations are provided in Figures 7 and 8, respectively. These correlations can be used to develop an initial estimate of the missing precipitation records for the Oroville station.

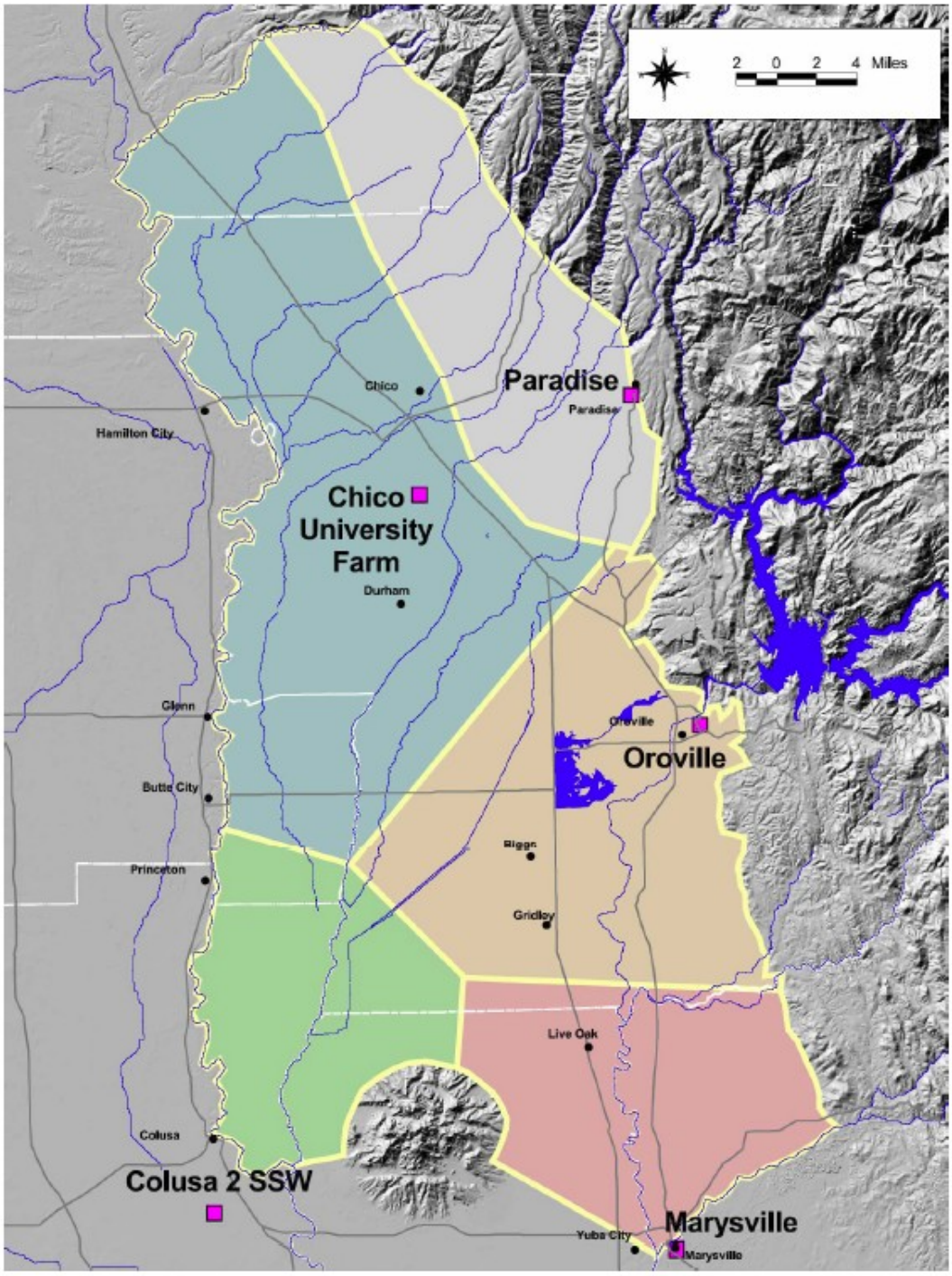

Figure 2-5
Precipitation Gages Assigned in the Model

CDM

Butte Basin Groundwater Model Update
Phase II Report

Figure 1. BBGM Precipitation Station Locations (CDM, 2008).

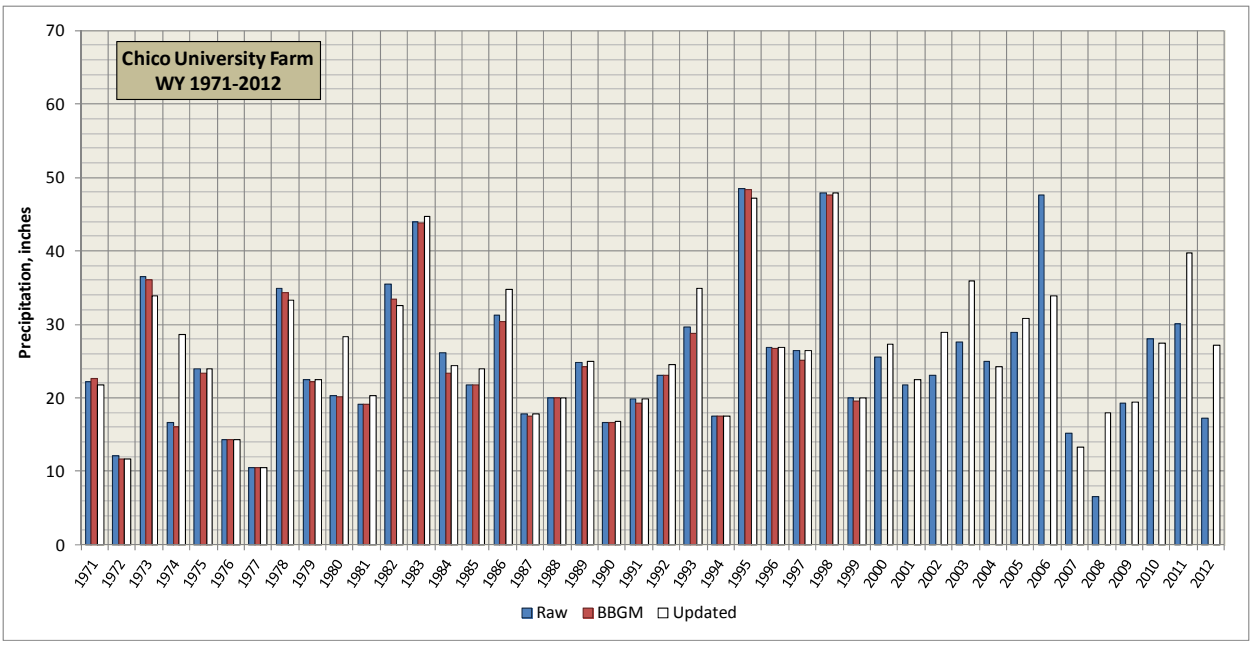

Figure 2. Summary of Annual Precipitation at Chico University Farm.

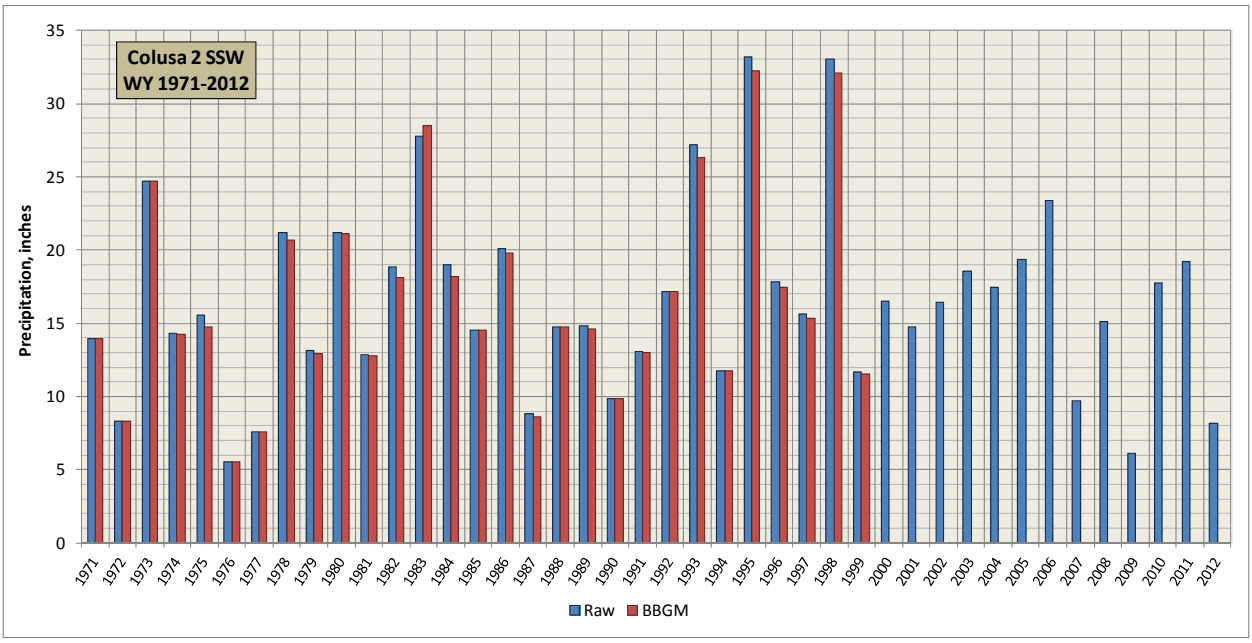

Figure 3. Summary of Annual Precipitation at Colusa 2 SSW.

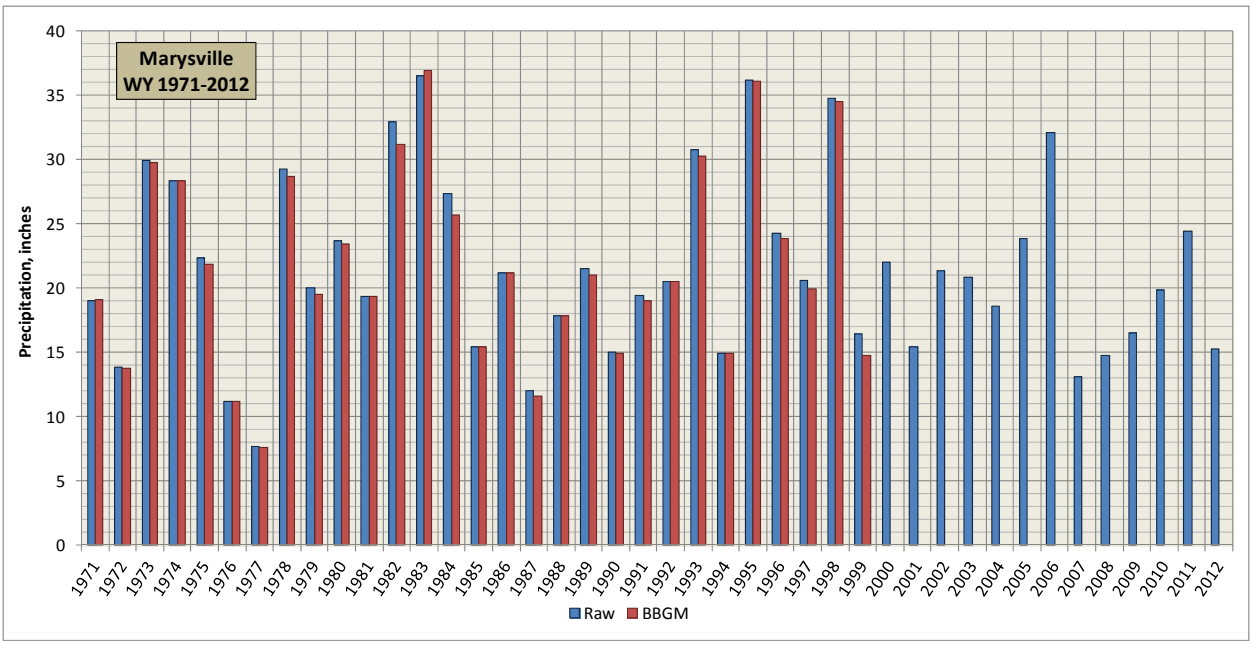

Figure 4. Summary of Annual Precipitation at Marysville.

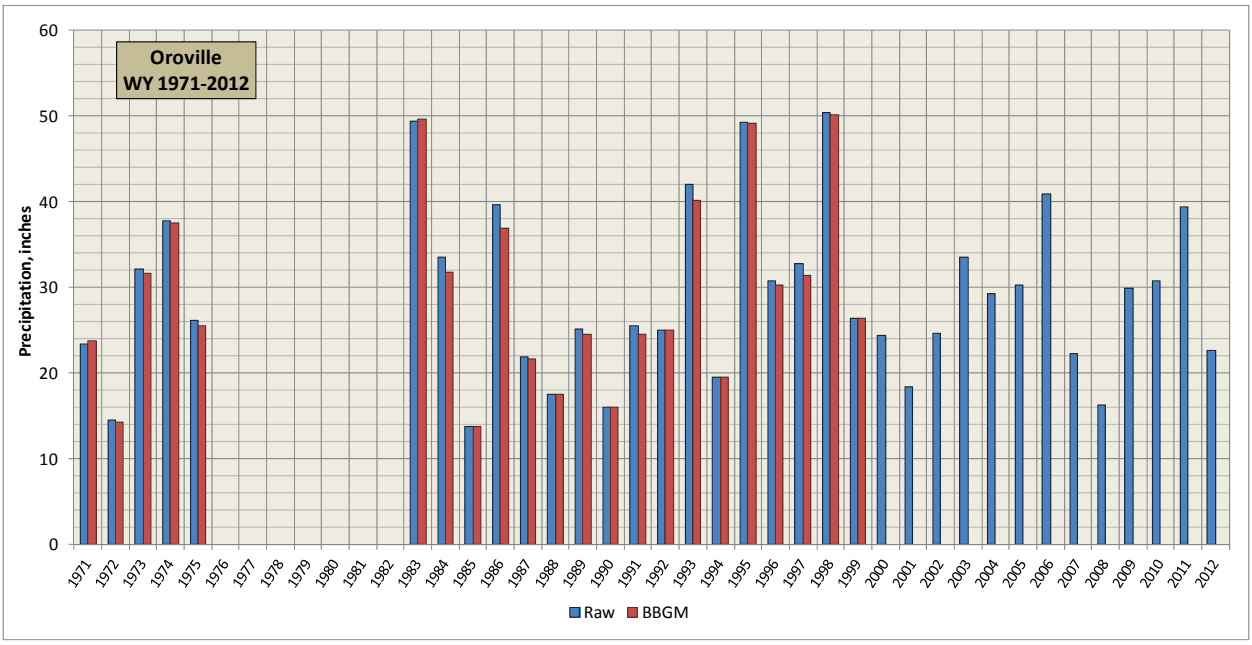

Figure 5. Summary of Annual Precipitation at Oroville.

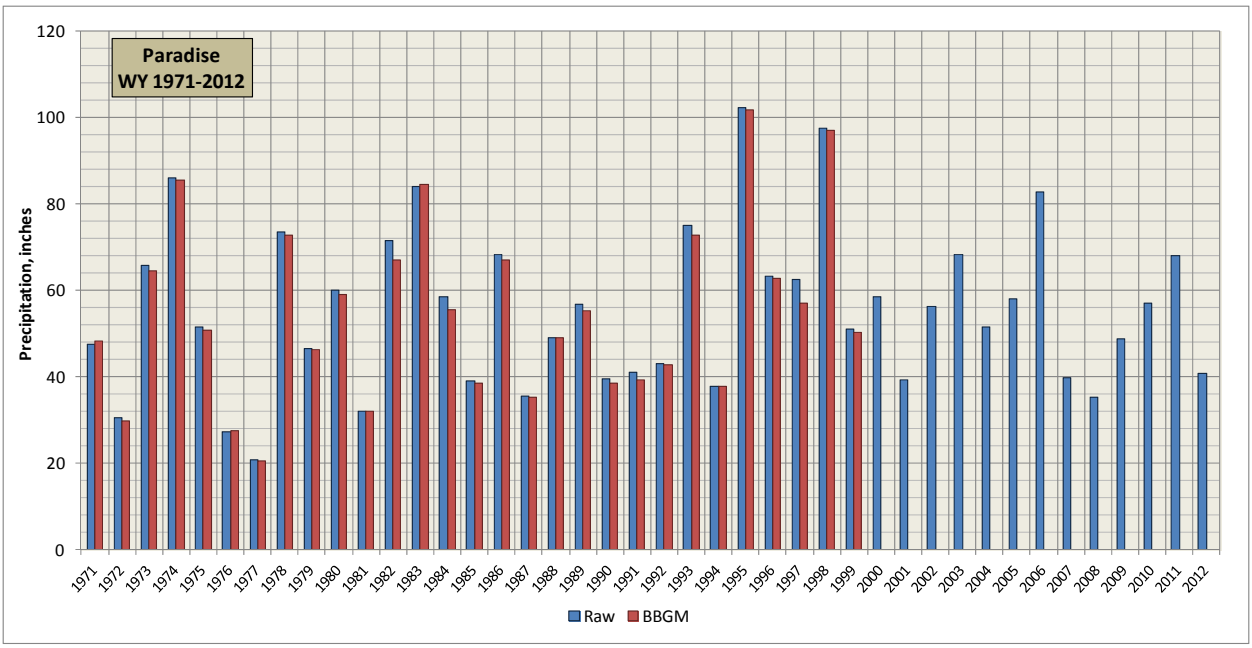

Figure 6. Summary of Annual Precipitation at Paradise.

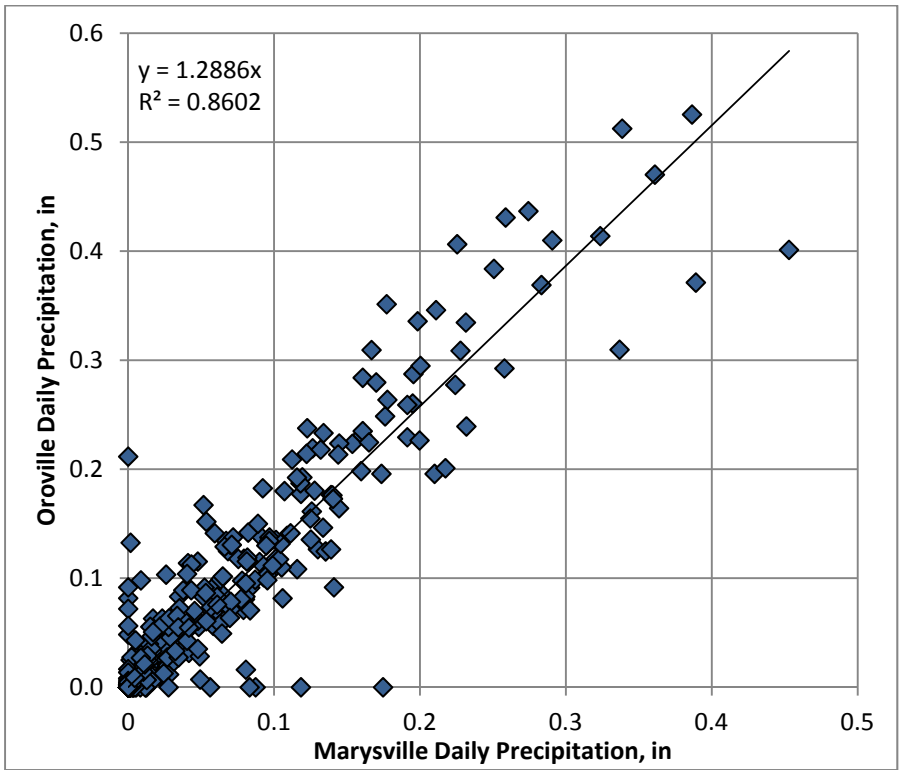

Figure 7. Correlation to Predict Precipitation at Oroville from Marysville.

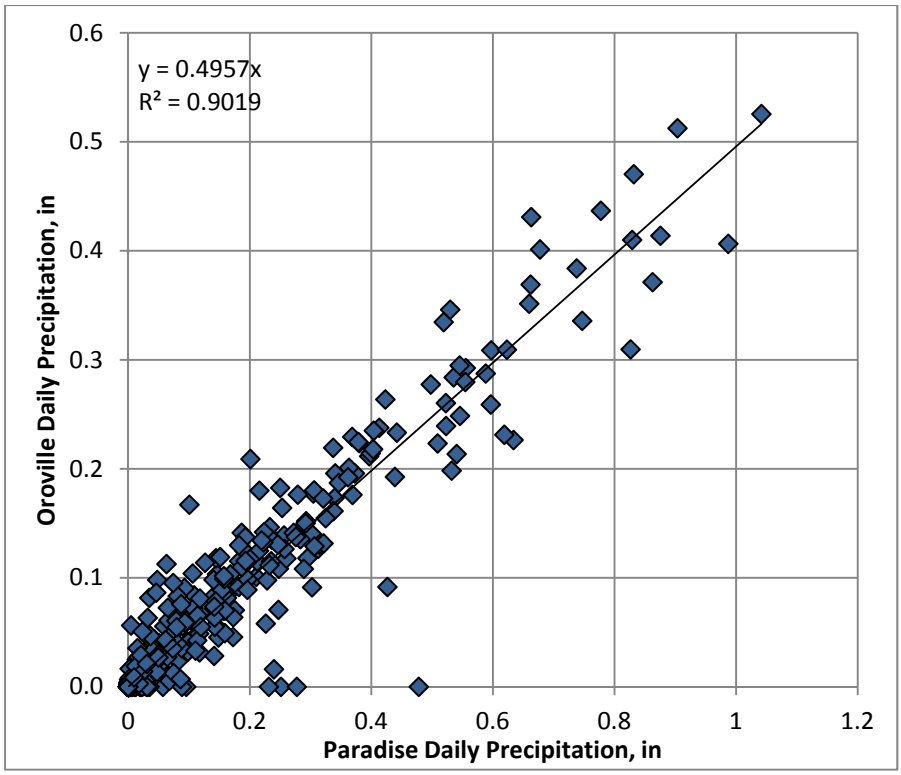

Figure 8. Correlation to Predict Precipitation at Oroville from Paradise.

Reference Evapotranspiration

An inventory and review of the period of record for nearby CIMIS stations has been performed. A map of active and inactive stations in the area is provided in Figure 9. The Durham CIMIS station is located in the center of the model domain and has a long period of record (established in October 1982). Initially, there was some concern about the site characteristics (under-irrigated pasture that could bias ETo estimates). Based on comparison to the Orland station, it is believed that the Durham station is well suited for the ET analysis moving forward. Reference ET is slightly less at the Durham station, potentially due to less wind and greater rainfall occurring on the east side of the Valley (Figure 10). A double mass analysis of cumulative ETo at the two stations does not suggest that any corrections to the historical data are needed due to changes in data collection practices or local conditions at the site (Figure 11).

Some additional QC is needed of the parameters used to calculate ETo. Quality control procedures will be applied based on the methodology of Allen et al. (2005). It is recommended that ETo prior to the period of record (1970-1982) be estimated based on temperature using the approach of Hargreaves and Samani (1985). It is recommended that a site specific analysis be performed to parameterize the Hargreaves-Samani equation based upon available ETo data from the site.

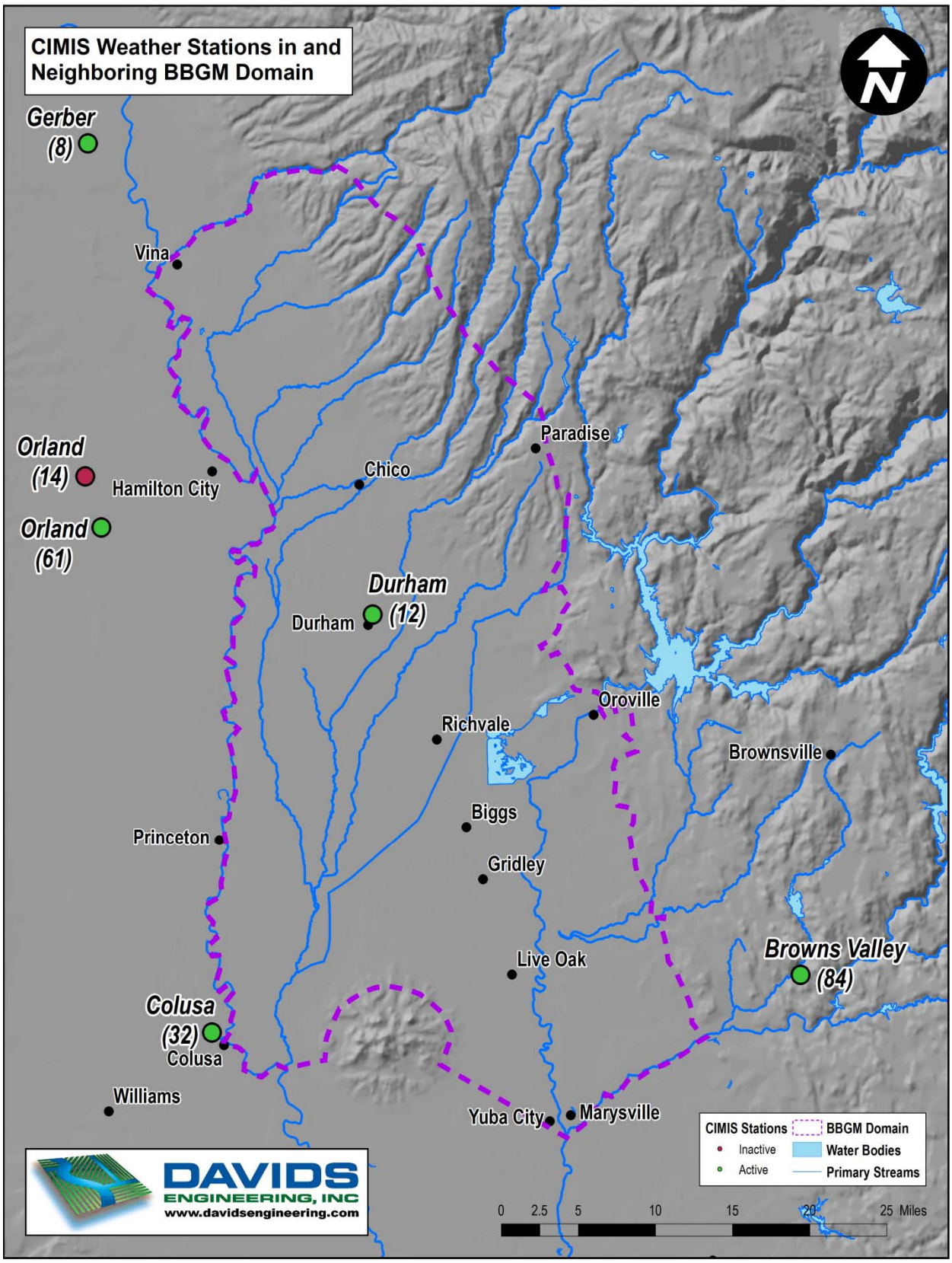

Figure 9. Active and Inactive CIMIS Weather Stations in and Neighboring BBGM Domain.

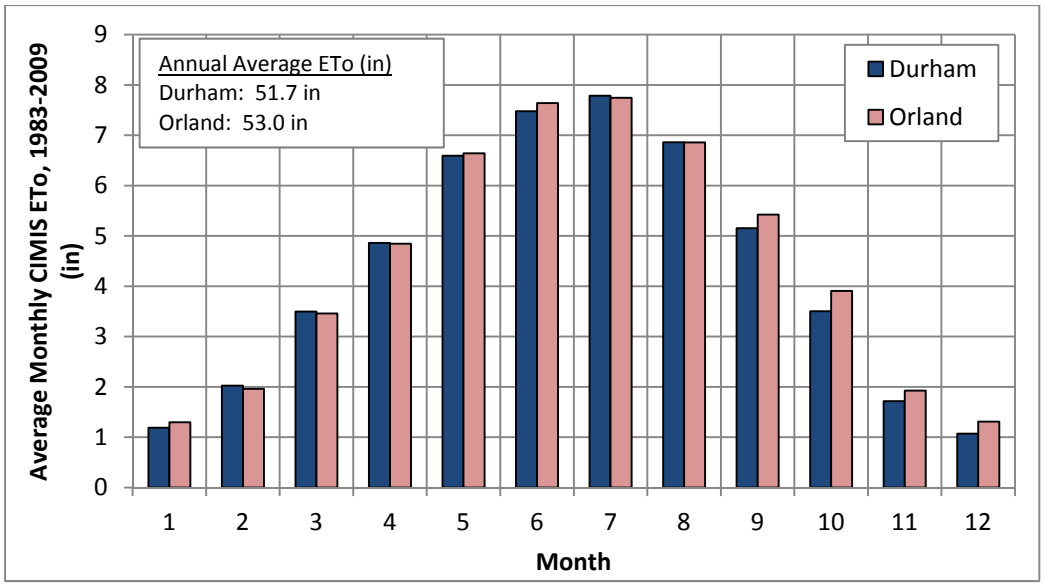

Figure 10. Comparison of Durham and Orland CIMIS Average Monthly ETo.

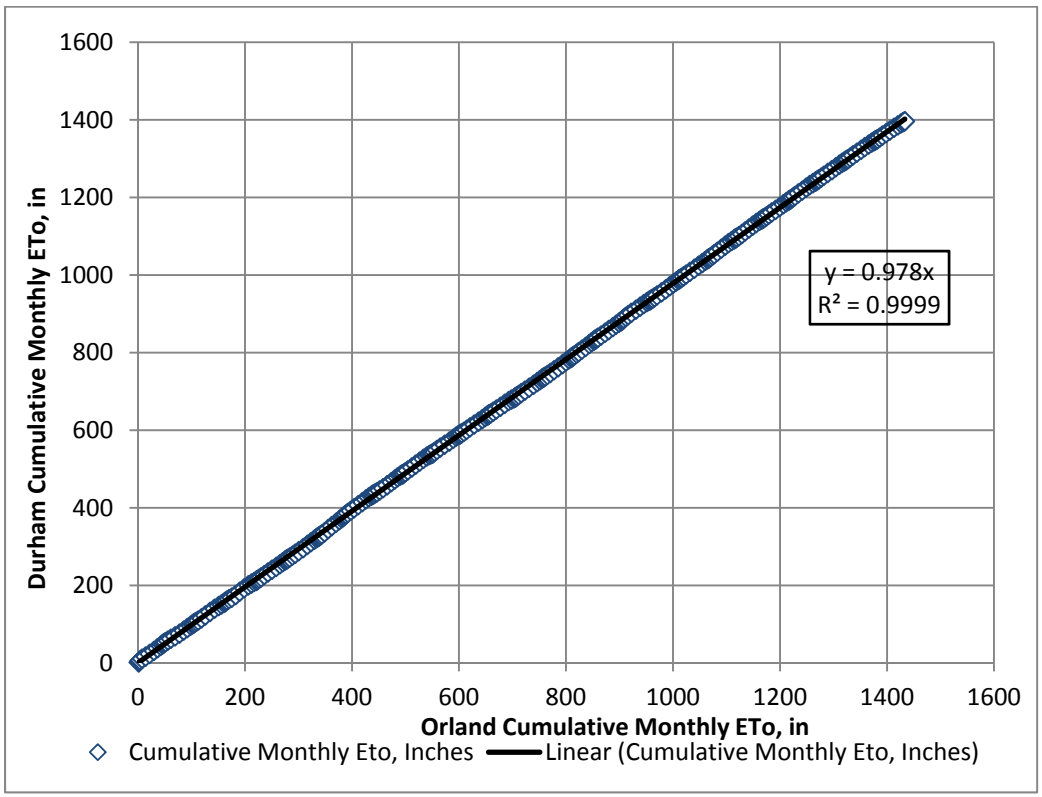

Figure 11. Double Mass Analysis of Durham and Orland CIMIS Monthly ETo.

Land Use

It is recommended that the land use analysis be performed by groundwater model element. Dr. Buck has provided unpublished GIS-based DWR land use surveys, which were obtained from staff at the DWR Northern District. These surveys have been compiled along with historical published GIS-based land use

surveys available from DWR. Available DWR land use surveys are listed in Table 1. Land use based on the most recent land use survey for each county is shown in Figure 12 and summarized in Table 2.

Table 1. Available DWR Land Use Surveys for BBGM Domain.

County	DWR Survey Years	Approximate Acres within BBGM Domain	Percent of BBGM Domain
Butte	1994, 1999, 2004, 2011*	517,503	64%
Tehama	1994, 1999, 2005*, 2012*	76,879	9%
Glenn	1993, 1998, 2003, 2009*	45,037	6%
Colusa	1993, 1998, 2003, 2009*	42,046	5%
Sutter	1998, 2004	69,009	9%
Yuba	1995, 2005*	58,831	7%

* Survey not yet finalized.

The IWFM Demand Calculator (IDC) v. 4.0 allows for land use to be specified at the element scale. A sample overlay of the element delineations with available land use information is provided in Figure 13. The element-scale land use analysis would be accomplished through the following process:

- Reclassify the detailed DWR land use attributes to the crops represented in the model as described by CDM (2008) for each available land use survey.
- Intersect the GW model elements with the DWR land use surveys in GIS to establish land use within each element at the time of each land use survey.
- Compile crop acreages from county agricultural commissioner annual crop surveys for 2000 through 2012.
- For each land use and DWR survey, determine an adjustment factor to be applied to the commissioner crop survey to correct for differences in acreage. For counties with multiple DWR land use surveys, determine the adjustment factor to be applied to each land use over time by interpolating between land use survey years.
- For each element and land use survey, determine the fraction of total acreage by land use existing within the element. For counties with multiple DWR land use surveys, determine the fraction to be applied to each element and land use over time by interpolating between land use survey years.
- For the period prior to 2000, assign land use to each element by year based on the total acreage of each land use in the existing model files in a given year and the fraction of total acreage by land use existing within the element in 2000.
- A special adjustment would be made in years of fallowing based water transfers. In such years, the rice acreage for elements within each participating water district would be adjusted based on the amount of land fallowed. This would allow for accurate representation of the spatial distribution of fallowing in the BBGM, as compared to assuming that reductions in rice acreage from water transfers are distributed uniformly across a county.

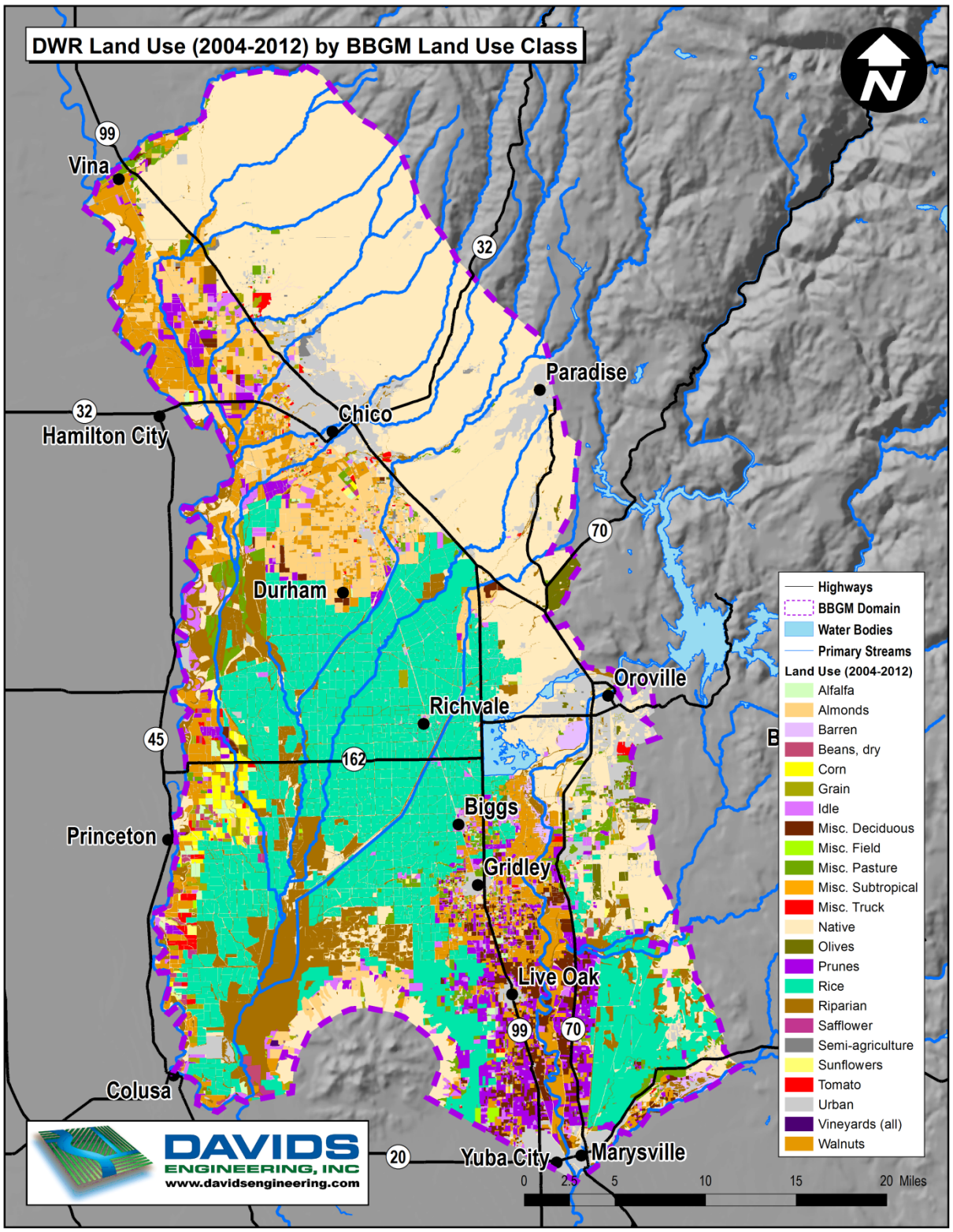

Figure 12. Most Recent DWR Land Use Survey (2004-2012) by BBGM Land Use Class[1].

[1] "BBGM Land Use Class" refers to the land use classes represented in the BBGM, as described by CDM (2008). DWR land use data have been reclassified according to these classes.

Table 2. Acreage by BBGM Land Use Class based on Most Recent DWR Land Use Surveys.

Land Use Class	Acres
Tree and Vine Crops	
Walnuts	59,689
Almonds	41,412
Prunes	27,631
Olives	4,303
Vineyards	115
Misc. Deciduous (all except almonds, prunes, walnuts)	14,637
Misc. Subtropical (all except olives)	1,657
Subtotal	149,443
Forage and Other Crops	
Rice	179,486
Grain	7,031
Corn	4,641
Alfalfa	3,264
Beans, dry	2,114
Tomato, melon, squash, cucumber	1,792
Sunflowers	1,647
Misc. Pasture (all except alfalfa)	15,501
Misc. Truck (all except tomato, melon, squash, cucumber)	2,013
Safflower	1,000
Misc. Field (all except dry beans, corn, safflower, sunflower)	663
Idle	13,282
Subtotal	232,435
Other	
Native	272,060
Riparian	79,257
Urban	66,792
Barren	4,737
Semi-agricultural	4,615
Subtotal	427,461
TOTAL	**809,340**

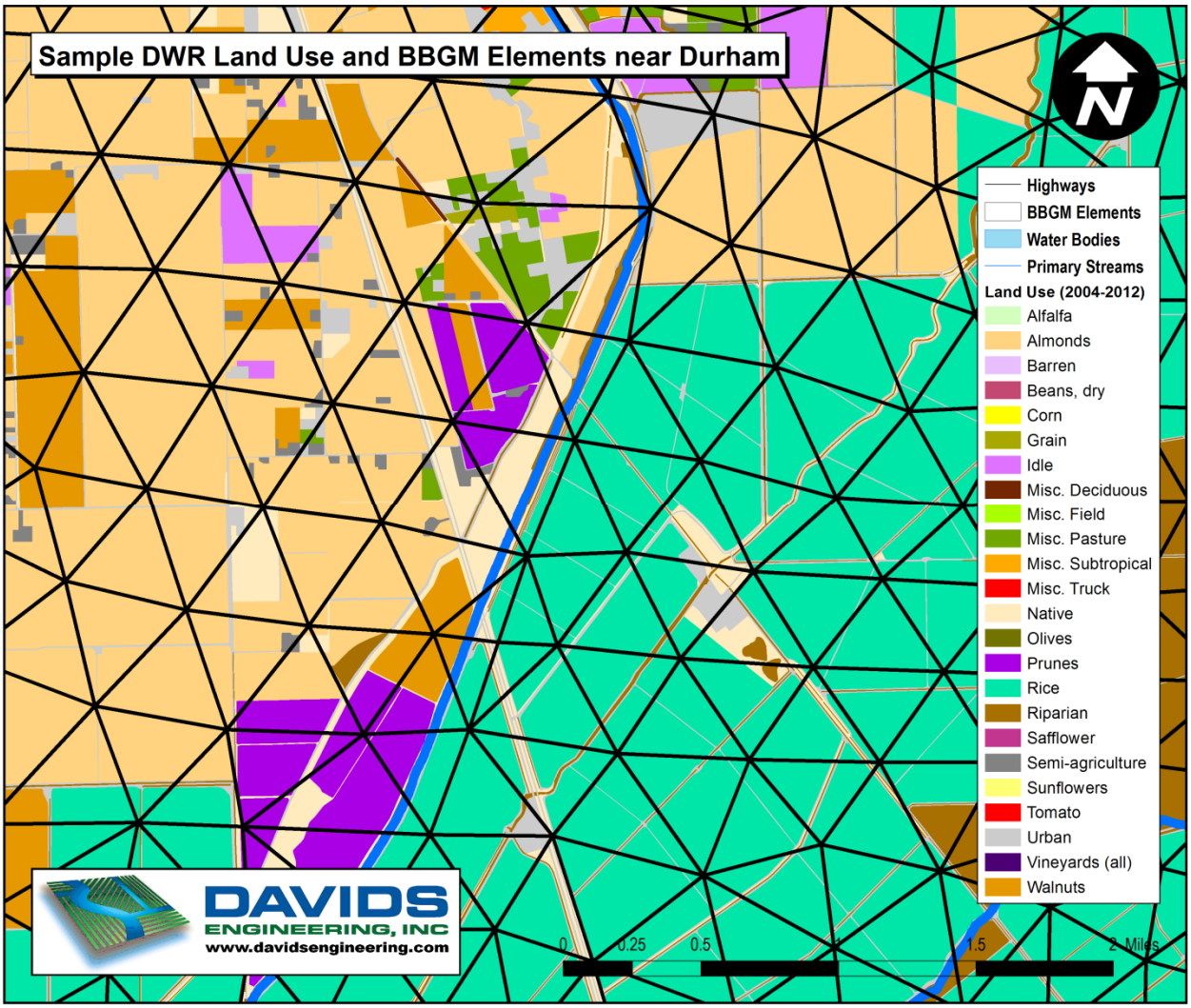

Figure 13. Sample Overlay of BBGM Elements with DWR Land Use Survey.

The recommended approach is generally consistent with the process applied by DWR for the California Water Plan updates (though DWR applies it at a coarser resolution) and would provide improved spatial representation of land use within the BBGM while inherently accounting for year-to-year changes in cropping within the model domain. By utilizing the commissioners' crop reports to estimate annual changes in cropping, the approach inherently accounts for economic and other factors that affect annual cropping decisions. Water district-specific accounting for fallowing-based transfers, which can result in thousands of acres of reduced cropping in some years, would ensure that the impacts of transfers are explicitly accounted for in the model. A more detailed approach to map individual fallowed fields within irrigation districts within a given year could be applied, but would require substantially greater effort while providing little additional benefit, as fallowing tends to be distributed relatively uniformly within the rice growing areas of participating districts.

Initially, the following additional sources were considered to provide annual updates to cropping information:

- Pesticide use reporting (PUR) data from the Dept. of Pesticide Regulation
- National Agricultural Statistics Service Cropland Data Layer (CDL) data
- Normalized Difference Vegetation Index (NDVI) data

Ultimately, it is concluded that the agricultural commissioners' annual crop reports provide the most reliable and consistent source of detailed annual cropping information. The availability of DWR crop surveys for 1999, 2004, and 2011 for Butte County will allow the spatial distribution of irrigated areas and crops to be updated every five to seven years for the update period within the core BBGM domain.

It is not recommended that the PUR data be used at this time due to the adequacy of other available data and due to limitations in the PUR data. In particular, although the PUR data is reported annually, and cropping can be estimated at the section scale, some cropping may not be reported if agrochemicals were not applied, and some fields may be double-counted if ownership or other changes occur.

It is not recommended that the CDL data be used at this time because it is not available for the full time period corresponding to the BBGM update and contains limitations in the level of detail with which crops can be accurately distinguished. For example, distinguishing between tree and vine crops is challenging using the satellite-based classification approach used to develop the CDL data.

Analysis of peak-season NDVI imagery over the period from 1985 to 2011 has been performed by Davids Engineering as part of a separate effort. This analysis demonstrates changes in both the extent and intensity of cropping from the mid 1980's to present. It is recommended that this information be used to validate the crop acreages developed from the DWR surveys and commissioners' reports and to assist in projecting future cropping based on recent trends coupled with analysis of additional irrigable areas, as described in the following section.

Another source of available cropping data is the annual reports of the Joint Districts (BWGWD, RID, BWD, and SEWD). These reports provide annual acreages by general crop type for each of the districts; however, the cropping information is provided at a coarser level of detail than the crop types represented in the BBGM. Additionally, cropping data provided by Western Canal Water District (WCWD) is available. These sources of cropping data will be used to validate the cropping information from the DWR crop surveys and commissioners' crop reports.

Future Cropping

The current level of effort does not allow for detailed economic modeling to predict future changes in cropping in the BBGM domain; however, an existing study using the Statewide Agricultural Production Model (SWAP) projects changes to cropping patterns for the Sacramento Valley in 2050 (Howitt, Medellin-Azuara, and MacEwan, 2009). It is recommended that the results of this study (or more recent work, if available) be used to project general changes in future cropping within the existing agricultural area. In the future, the county could consider developing an economic model specific to the BBGM domain to specifically evaluate factors affecting cropping decisions in the area and to more precisely predict future cropping patterns; however, development of a local economic model is beyond the scope of the current effort.

In addition to considering general cropping projections for the existing agricultural area, based on observed changes in the extent and intensity of cropping in the region since the mid 1980's, it is recommended that an analysis of potential new irrigated areas in the model domain be conducted. The methodology will include the following:

- Profile topography, soils, and water sources for new agricultural areas along valley edge identified via NDVI, CDL, and other available data
- Identify similar areas in BBGM domain and Butte. Co. as a whole
- Develop crop projections for potentially new irrigated areas

Resulting from this will be a new cropping pattern scenario (specified elemental land use) and potentially adjusted irrigation efficiencies that can be used as input to run a future cropping model scenario and update projected future agricultural surface water and groundwater demands as described in the later section entitled "Diversions".

Crop Coefficients

In the interest of developing the best available estimates of actual ET rates in the BBGM domain, it is recommended that crop coefficients be developed based on available results of a recent Surface Energy Balance Algorithm for Land (SEBAL) analysis of the Sacramento Valley for 2009. These crop coefficients will be calculated on a monthly basis for each of the land use classes represented in the BBGM based on actual ET from the SEBAL analysis and reference ET from the Durham CIMIS station. For 2009, detailed land use datasets are available from DWR for Glenn and Colusa counties to support the analysis. The crop coefficients and resulting ET estimates will be validated using other available SEBAL datasets for 2001 and 2010.

The SEBAL datasets correspond to the irrigation season from approximately March through September. It is recommended that crop coefficients during the winter period be estimated using the Basic Irrigation Scheduling (BIS) tool developed by Dr. Richard Snyder at U.C. Davis in cooperation with DWR[2] based on reference ET and precipitation patterns.

A sample SEBAL image depicting actual ET for July 26, 2009 is shown in Figure 14. As indicated, data is available for the majority of the model domain, with the northern edge of the satellite image at approximately Chico. Preliminary estimates of monthly crop coefficients based on the SEBAL analysis and BIS tool are provided in Table 3. These estimates may appear low for some crops, as they reflect average values across many fields which may be immature, only partially cropped, or not achieving full ET for other reasons. Finalization of the crop coefficients would consider the representativeness of the monthly values for each land use class for the BBGM domain as a whole.

[2] Available at http://biomet.ucdavis.edu/irrigation_scheduling/bis/BIS.htm.

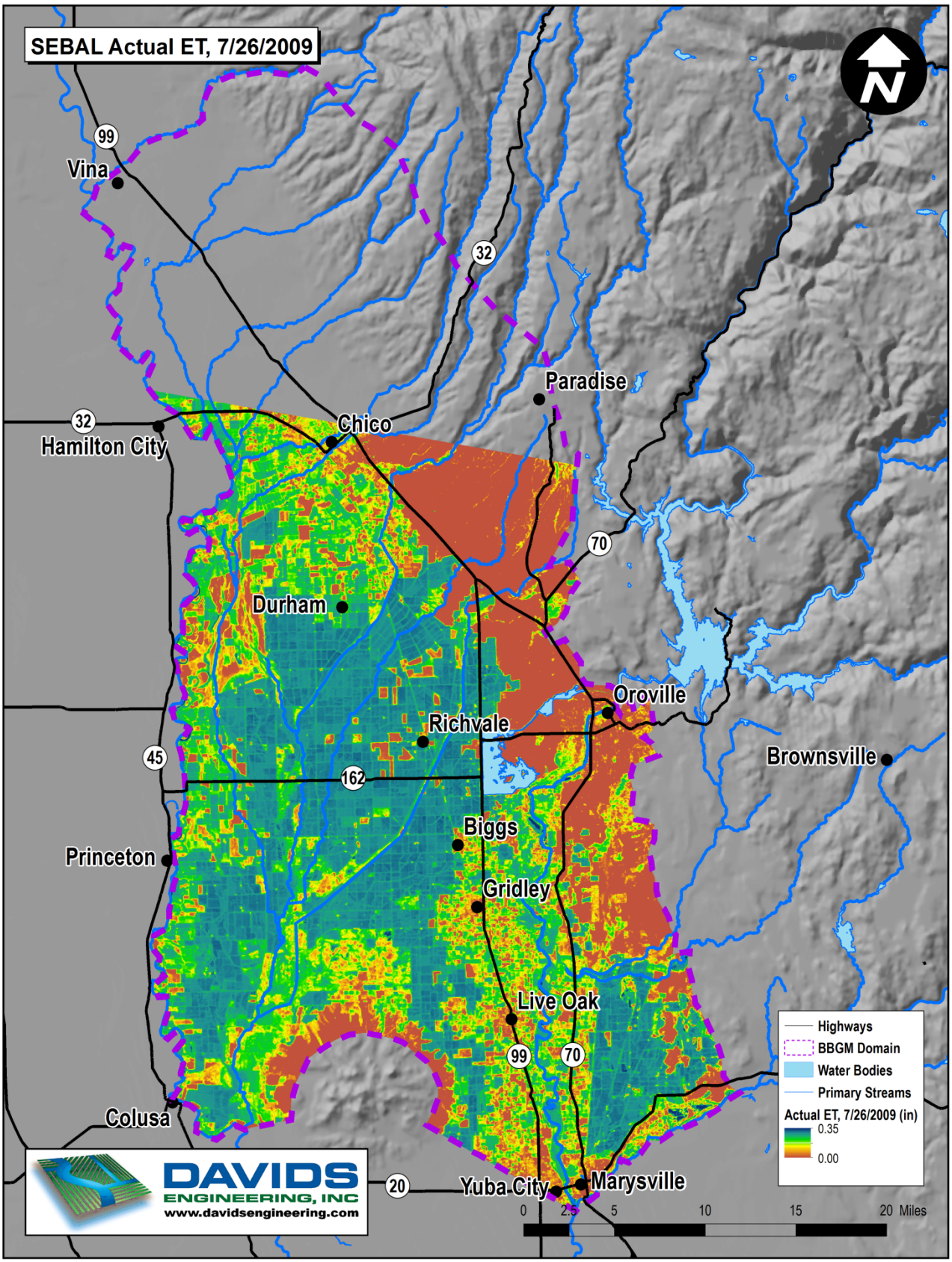

Figure 14. Sample SEBAL Results for July 26, 2009.

Table 3. Preliminary Estimates of Monthly Crop Coefficients by BBGM Land Use Class.

Land Use Class	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Alfalfa	1.02	0.97	0.86	0.86	0.99	0.83	0.66	0.65	0.71	0.67	0.94	1.02
Almonds	1.02	0.97	0.76	0.81	0.97	0.82	0.62	0.53	0.53	0.56	0.94	1.02
Barren/wasteland	1.02	0.97	0.69	0.43	0.55	0.37	0.20	0.24	0.24	0.49	0.94	1.02
Beans, dry	1.02	0.97	0.69	0.20	0.35	0.38	0.60	0.74	0.42	0.49	0.94	1.02
Corn	1.02	0.97	0.69	0.38	0.59	0.89	0.90	0.78	0.41	0.49	0.94	1.02
Grain (all)	1.02	0.97	0.84	0.74	0.68	0.42	0.24	0.22	0.26	0.49	0.94	1.02
Idle	1.02	0.97	0.70	0.51	0.48	0.28	0.15	0.16	0.21	0.49	0.94	1.02
Misc. Deciduous (all except almonds, prunes, walnuts)	1.02	0.97	0.69	0.45	0.71	0.61	0.50	0.54	0.58	0.54	0.94	1.02
Misc. Field (all except dry beans, corn, safflower, sunflower)	1.02	0.97	0.69	0.45	0.41	0.60	0.72	0.74	0.65	0.49	0.94	1.02
Misc. Pasture (all except alfalfa)	1.02	0.97	0.71	0.68	0.81	0.66	0.53	0.55	0.66	0.58	0.94	1.02
Misc. Subtropical (all except olives)	1.02	0.97	0.87	0.79	0.75	0.64	0.50	0.53	0.64	0.56	0.94	1.02
Misc. Truck (all except tomato, melon, squash, cucumber)	1.02	0.97	0.69	0.52	0.63	0.55	0.42	0.41	0.30	0.49	0.94	1.02
Olives	1.02	0.97	0.72	0.55	0.62	0.47	0.34	0.37	0.51	0.49	0.94	1.02
Prunes	1.02	0.97	0.69	0.67	0.89	0.77	0.60	0.55	0.58	0.58	0.94	1.02
Rice	1.02	0.97	0.69	0.45	1.01	1.16	1.14	1.08	0.89	0.49	0.94	1.02
Safflower	1.02	0.97	0.69	0.45	0.70	0.82	0.60	0.48	0.34	0.49	0.94	1.02
Semi-agriculture	1.02	0.97	0.69	0.45	0.40	0.24	0.17	0.20	0.27	0.49	0.94	1.02
Sunflowers	1.02	0.97	0.69	0.45	0.64	0.98	0.65	0.38	0.27	0.49	0.94	1.02
Tomato, melon, squash, cucumber	1.02	0.97	0.69	0.45	0.50	0.47	0.59	0.53	0.29	0.49	0.94	1.02
Vineyards (all)	1.02	0.97	0.69	0.45	0.35	0.32	0.20	0.21	0.27	0.49	0.94	1.02
Walnuts	1.02	0.97	0.69	0.54	0.94	0.88	0.75	0.79	0.82	0.79	0.94	1.02
Urban	1.02	0.97	0.69	0.47	0.50	0.37	0.21	0.23	0.30	0.49	0.94	1.02
Native	1.02	0.97	0.73	0.59	0.60	0.43	0.27	0.28	0.29	0.49	0.94	1.02
Riparian	1.02	0.97	1.01	0.90	0.93	0.89	0.69	0.68	0.77	0.71	0.94	1.02

Irrigation Efficiency

It is recommended that irrigation efficiency estimates be used in conjunction with estimates of crop ET of applied water to estimate applied water amounts where delivery data are unavailable. Efficiency assumptions used in the current model would be reviewed and updated. Irrigation efficiency would be assigned primarily based on irrigation method, and could be varied over time to reflect advances in irrigation management, as determined based on the detailed water balances being prepared as part of the FRRAWMP. Current BBGM estimates are based on consultation with UCCE Farm Advisor Joe Connell

by Linda Bond of HCI during a prior model update. Additional estimates of irrigation efficiency by region and by irrigation method have been compiled from the following sources:

- Estimates developed by Davids Engineering in 2011 to support the update of the SacFEM Sacramento Valley groundwater model for GCID
- Results of multi-year water balance analysis conducted by Davids Engineering for GCID
- Table 8 on Page 26 of "Agricultural Water Use in California: A 2011 Update" by Canessa et al. (2011)
- Tables 2.12 and 2.13 of the CalFed "Water Use Efficiency Comprehensive Evaluation" (2006)
- Appendix J: Groundwater Hydrology for the CALVIN Model (Davis and Jenkins, 2001), which reports an estimated aggregate efficiency for the Sacramento Valley of 65% from the Central Valley Ground-Surface Water Model.
- Distribution uniformity evaluations conducted by the Tehama County Resource Conservation District.

Ultimately, irrigation efficiency developed through water balance analysis as part of the FRRAWMP would be used to validate irrigation efficiency estimates and refine them as appropriate. Updates to both historical (pre 2000) and new (2000 – 2012) datasets would be considered.

Crop acreages by irrigation method based on the most recent DWR land use surveys are summarized in Table 4. Initial estimates of irrigation efficiency by irrigation method are summarized in Table 5. As indicated, rice is assigned a lower efficiency than other crops with level basin irrigation based on differences in irrigation practices. Rice is flooded for much of the growing season with continuous inflow and tailwater outflow, whereas other crops irrigated via level basins are irrigated periodically, similar to graded borders and furrow. Additionally, irrigation efficiency values are assumed to be marginally greater for groundwater-only areas.

Table 4. BBGM Study Area Acreage by Crop and Irrigation Method based on Most Recent DWR Land Use Surveys.

Land Use Class	Level Basin	Graded Border	Furrow	Wild Flooding	Solid Set Sprinkler	Portable Sprinkler	Drip	Micro-spray	Not Specified/ Not Applicable	Unknown
Tree and Vine Crops										
Walnuts	3,312	6,908	486	212	19,051	7,289	1,734	18,901	455	1,342
Almonds	637	482	86	0	25,197	2,623	2,958	8,485	527	418
Prunes	7,532	6,469	508	1,218	417	192	2,698	7,906	109	582
Olives	0	220	99	96	170	1,943	978	57	644	95
Vineyards	0	0	9	0	0	0	13	0	92	0
Misc. Deciduous (all except almonds, prunes, walnuts)	4,592	2,028	270	41	317	121	1,305	5,218	141	605
Misc. Subtropical (all except olives)	24	17	96	0	36	16	1,209	149	60	50
Subtotals	16,097	16,123	1,554	1,567	45,188	12,183	10,894	40,716	2,029	3,092
Forage and Other Crops										
Rice	179,374	0	0	0	0	0	0	0	56	57
Grain	221	179	0	167	0	321	0	0	5,667	477
Corn	0	0	4,500	107	0	0	18	0	0	16
Alfalfa	258	2,384	0	358	121	101	0	0	9	34
Beans, dry	0	64	1,269	0	0	780	0	0	0	0
Tomato, melon, squash, cucumber	0	24	1,704	0	0	0	65	0	0	0
Sunflowers	0	0	1,466	85	2	9	0	0	0	85
Misc. Pasture (all except alfalfa)	1,591	5,086	0	1,778	285	534	0	25	5,213	987
Misc. Truck (all except tomato, melon, squash, cucumber)	7	11	436	53	178	31	1,090	37	0	170
Safflower	142	45	137	0	0	0	0	0	676	0
Misc. Field (all except dry beans, corn, safflower, sunflower)	49	8	571	0	0	1	21	0	0	13
Idle	256	12	99	0	57	8	0	0	7,477	5,373
Subtotals	181,899	7,813	10,182	2,549	643	1,786	1,193	62	19,097	7,212
Other										
Native	0	0	0	0	0	0	112	38	271,394	516
Riparian	9,348	2,518	0	19,497	0	0	32	0	39,906	7,957
Urban	0	0	0	0	1,147	1	0	20	65,485	139
Barren	0	0	0	0	0	0	0	0	4,737	0
Semi-agricultural	0	0	0	0	0	0	0	0	4,615	0
Subtotals	9,348	2,518	0	19,497	1,147	1	144	58	386,136	8,612
TOTAL	207,344	26,454	11,736	23,612	46,979	13,971	12,231	40,836	407,262	18,915

Table 5. Initial Estimates of Irrigation Efficiency by Irrigation Method.

Irrigation Method	Acres	Irrigation Efficiency by Water Source	
		Surface Water	Groundwater
Level Basin (Rice)	179,374	50%	55%
Level Basin (Other Crops)	18,622	70%	75%
Graded Border	23,936	65%	75%
Furrow	11,736	65%	75%
Wild Flooding	4,116	50%	60%
Solid Set Sprinkler	45,831	75%	80%
Portable Sprinkler	13,969	70%	75%
Drip	12,087	85%	90%
Microspray	40,778	85%	90%
Totals	350,449	62%	68%

Rimflows

The sources of existing rimflows have been identified for the 17 rimflows represented in the BBGM. The modeled streams, rimflow locations, and associated stream gages are shown in Figure 14. The map additionally shows the BBGM stream nodes, subregions, and stream gage sites used for calibration.

Major rimflows are based on USGS and CDEC stream gages. These include Deer Creek, Big Chico Creek, the Upper Feather River, the Yuba River, and the Sacramento River. Some of these sites are located at the valley edge, downstream of the rimflow node in the model (the model domain includes portions of the foothills of the Sierra Nevada Mountains). Based on recent study of the Lower Tuscan Aquifer, little surface- groundwater interaction occurs in stream reaches in the foothill area where the Tuscan outcrop intersects stream reaches. Thus, this difference in location between the rimflow location and the downstream gage is not of great concern.

The majority of remaining rimflows are estimated based on a multiplier applied to the gaged Big Chico Creek near Chico inflows to the BBGM domain. These multipliers were determined based on a USGS study by Nady et al. (1983) referenced by CDM and HCI (CDM 2008, HCI 1996) and are listed in Table 6. Earlier documentation of the original BBWUA groundwater model states that the rimflows were developed based on gaged Butte Creek flows; however, the current IWFM model input files state that the gage used is the Big Chico Creek near Chico gage. This has been confirmed through review of the historical rimflow data in the model input files.

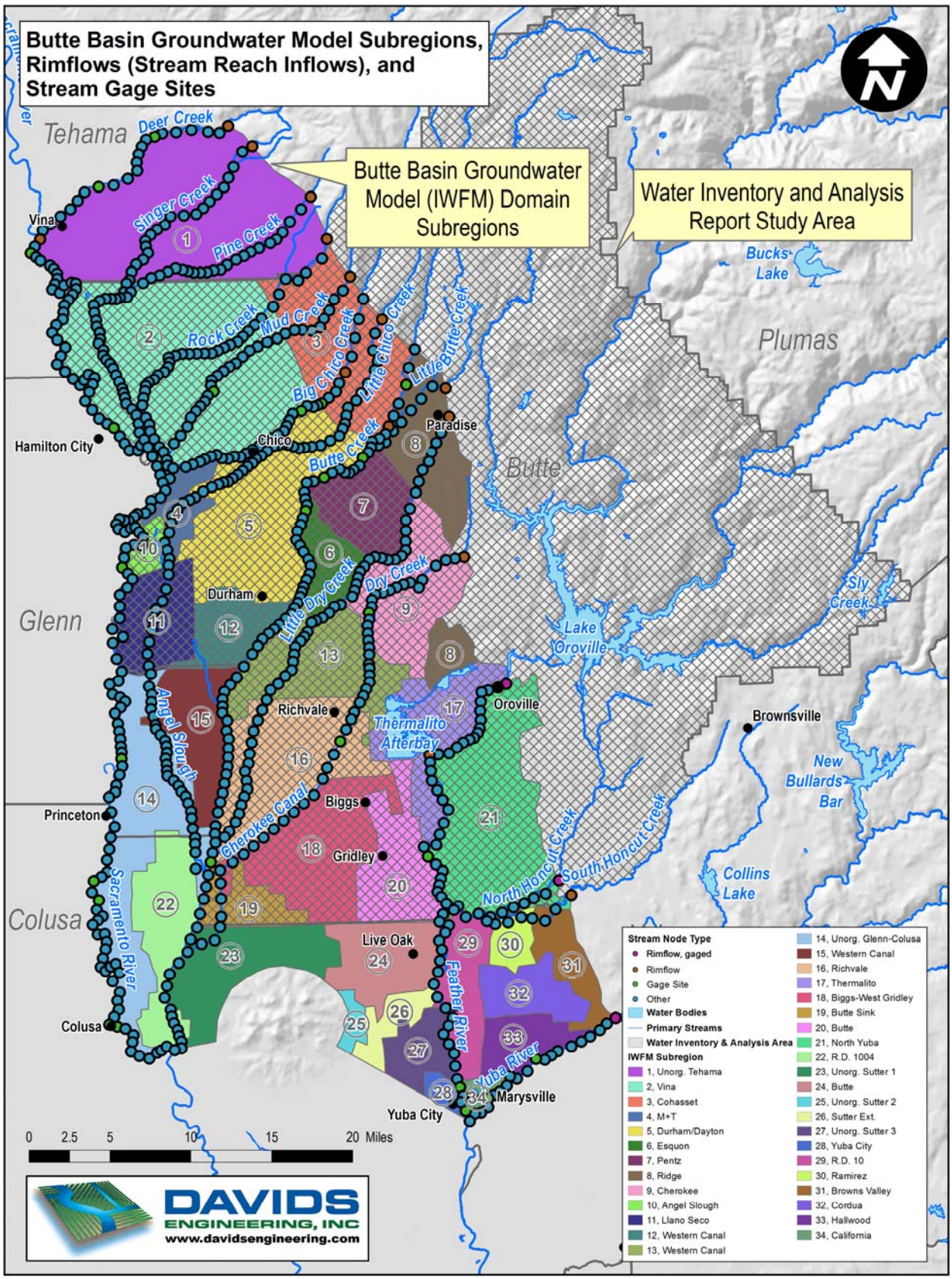

Figure 14. BBGM Rimflows, Stream Nodes, and Subregions.

Table 6. Summary of Rimflow Locations and Data Sources.

Site Name	Stream Node	Source	USGS Site	USGS Site ID	CDEC Site ID	Avg. Flow (cfs)	Begin Date	End Date	Notes
DEER CREEK (REACH 1)	1	Measured	DEER C NR VINA CA	11383500	DCV	345	1-Oct-70	present	
SINGER CREEK (REACH 2)	23	BIG CHICO C NR CHICO X 0.1225				19			
UPPER PINE CREEK (REACH 3)	47	BIG CHICO C NR CHICO X 0.755				115			
ROCK CREEK (REACH 5)	101	BIG CHICO C NR CHICO X 0.215				33			
MUD CREEK (REACH 6)	140	BIG CHICO C NR CHICO X 0.6275				96			
BIG CHICO CREEK (REACH 7)	177	Measured	BIG CHICO C NR CHICO CA	11384000		153	10/1/1970	9/30/1986	Use new DWR gage for 1999 through 2012
LITTLE CHICO CREEK (REACH 8)	209	BIG CHICO C NR CHICO X 0.29				44			
UPPER BUTTE CREEK (REACH 11)	300	Calculated	BUTTE C NR CHICO CA - Little Butte Creek			375	10/1/1970	present	
LITTLE BUTTE CREEK (REACH 10)	342	BIG CHICO C NR CHICO X 0.36				55			
LITTLE DRY CREEK (REACH 12)	351	BIG CHICO C NR CHICO X 0.055				8			
DRY CREEK (REACH 13)	409	BIG CHICO C NR CHICO X 0.455				70			
UPPER FEATHER RIVER (REACH 16)	506	Measured	FEATHER R A OROVILLE CA	11407000		1110	10/1/1970	9/30/2011	
MIDDLE FEATHER RIVER (REACH 17)	522	Calculated	Thermalito Releases + Upper Feather River			4998	10/1/1970	9/30/2011	
NORTH HONCUT CREEK (REACH 18)	544	BIG CHICO C NR CHICO X 0.6025				79			
SOUTH HONCUT CREEK (REACH 19)	552	BIG CHICO C NR CHICO X 0.3625				55			
YUBA RIVER (REACH 20)	587	Measured	YUBA R NR MARYSVILLE CA	11421000		2502	1-Oct-70	present	
SACRAMENTO RIVER (REACH 22 - SAC_A)	608	Measured	SACRAMENTO R A VINA BRIDGE NR VINA CA	11383730	VIN	14311	1/1/1984	present	

The original Big Chico Creek near Chico gage was discontinued in 1986. A new gage was established by DWR in October 1996. For the 1999 to 2012 update, it is recommended that the new gage be used. A regression of the rimflow data from the existing IWFM model files for Big Chico Creek to the new site is shown in Figure 15 for the period July 21, 1997 to September 30, 1999. The model flows are approximately 10% less than the flows recorded at the new site. It is recommended that the relationship for the period of overlap be used to synthesize a historical record for the prior upstream gage site to ensure consistency with the existing time series data.

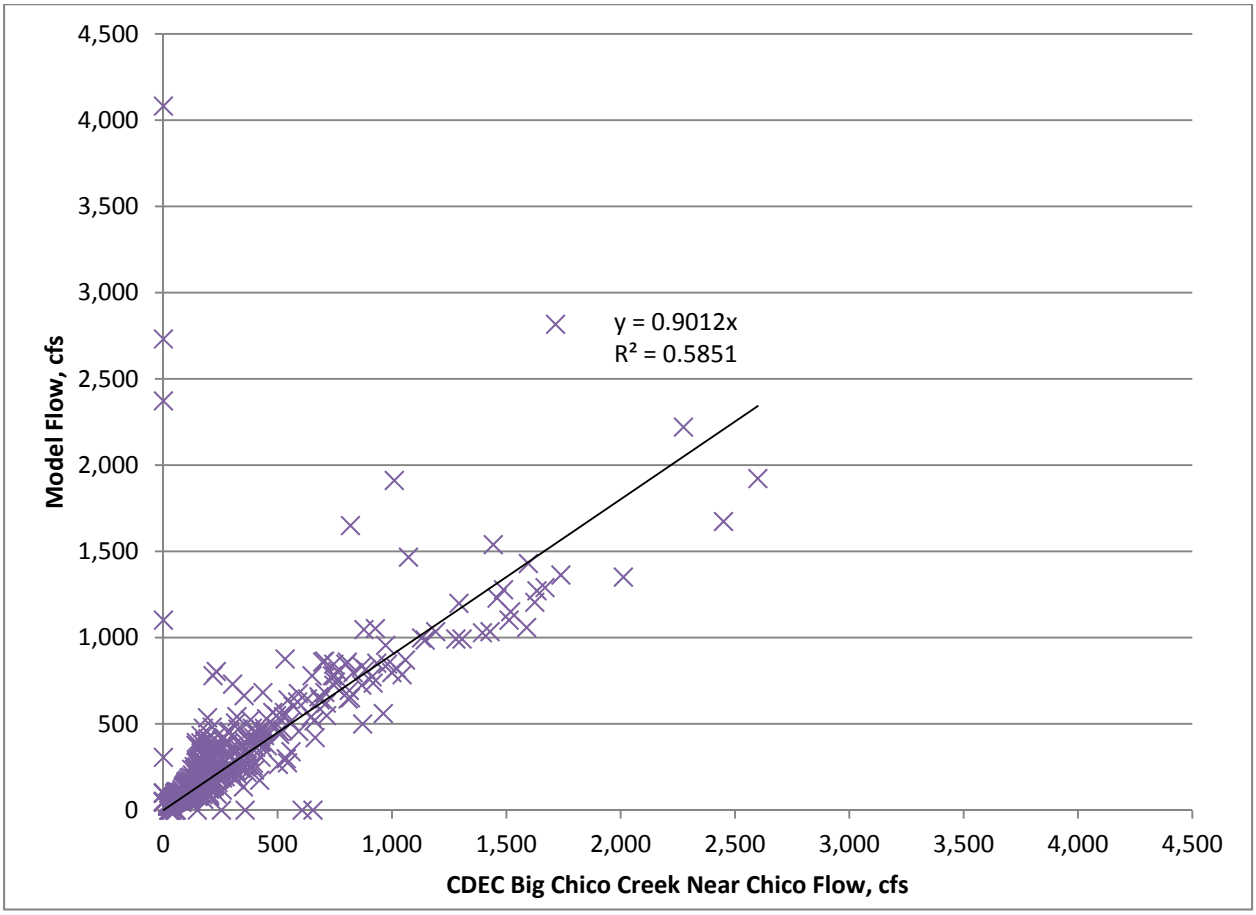

Figure 15. Relationship of BBGM Big Chico Creek Flows to New Big Chico Creek near Chico DWR Gage Data.

The remaining two rimflows (Middle Feather River and Upper Butte Creek) are calculated based on a combination of flows. The Upper Butte Creek rimflow is calculated as the gage flow for Butte Creek near Chico, minus the estimated rimflow for Little Butte Creek (as calculated based on the Big Chico Creek inflow). The Middle Feather River rimflow is calculated as the gaged releases from Thermalito Afterbay to the Feather River, plus the gaged Upper Feather River rimflow. Thus, it is assumed that no losses or accretions occur between the gaged Upper Feather River Inflow (0.4 miles downstream of Thermalito Diversion Dam) and the inflow of Thermalito releases to the Feather River. IWFM documentation will be reviewed to determine whether the addition of the Upper Feather River rimflow to the Thermalito releases results in overestimation of flows in the Feather River downstream of the Middle Feather River

inflow. Other than this consideration, it is recommended that this methodology be applied to the model update as well.

Diversions

Diversions have been estimated historically based on a combination of available diversion records from water districts and other water users and based on independent estimates of agricultural water demand. The primary surface water users in Butte County divert from Thermalito Afterbay, and diversion records have been compiled through 2012.

As described in detail by HCI (1996), water user areas were developed based on a combination of water source and general land use type (rice, non-rice crops, native vegetation, native riparian) as determined from DWR land use surveys and based on water supplier service areas. Those areas outside of water supplier service areas are divided based on the USGS 24k quad map grid. Additionally, as part of the conversion of the model to IWFM, a lesser number of diversions were added based on the Stony Creek Fan Integrated Groundwater and Surface Water Model (SCFIGSM) study completed in 2003 (WRIME 2003). These represent diversions from the Sacramento River on the western border of the BBGM domain.

For each water user area with a surface water supply, it is recommended that diversions be estimated based on cropping, weather conditions, estimated irrigation efficiencies, and estimated conveyance losses using IDC. Then, the initial estimate of diversions would be compared to available delivery data, which appears to be consistent with model development and prior updates based on review of available documentation and model data files. Based on development of detailed water balances by supplier as part of the FRRAWMP, final estimates of total surface water supply would be developed, considering the availability of drainage inflows from upgradient areas to meet irrigation demands, internal reuse within irrigation districts, and other factors.

It is recommended that user areas with a combination of surface water and groundwater supplies be considered on a case-by-case basis and that the quantity of surface water available over time be estimated and added to the diversion time series data for the model. Remaining demands not met by available surface water supplies would be estimated using a subsequent IDC run to quantify groundwater pumping for irrigation.

Surface water supplies for municipalities, such as Yuba City will be obtained from the municipalities. In general, effort will be focused on estimating the major diversions. Minor diversions will not be represented explicitly; but rather use will be estimated based on estimated demands using IDC.

It is recommended that time series of monthly diversions for the period 1999 through 2012 be developed for each of the urban entities listed in Table 6 in the following section using existing water master plans, water supply assessments (WSAs), groundwater management plans (GWMPs), urban water management plans (UWMPs), and service provider diversion records. For cases in which only annual diversion records are available, representative monthly urban demand patterns (monthly demand as a percentage of annual demand for each month of the year) for other Butte County entities would be used to estimate monthly diversions.

Urban Pumping[3]

The BBGM currently simulates pumping for urban supply from 101 wells. These wells are explicitly included in the model and are referenced by their horizontal coordinates and pumping intervals. The recommended initial step in updating the pumping time series is to review the data sources used for historical pumping information and then update the list of wells to be included in future BBGM analyses. New or planned urban wells not included in the 101 BBGM wells would be identified and located. Time series would be developed for the pumping of these wells. Idle, abandoned or destroyed urban wells currently in the list of 101 urban wells in the BBGM would also be identified. The time series for these wells would be updated as necessary to reflect cessation of pumping. The well updates would be accomplished by performing a GIS-based comparison of the 101 urban wells currently in the model to the locations of wells operated or planned by the urban entities, as documented in their UWMPs, capital improvement programs or other readily available documents.

Table 7 lists the urban water users that would be evaluated and the corresponding BBGM subregions.

Table 7. BBGM Urban Water Users.

Urban Entity	BBGM Subregion		Number of Wells	Surface Water Diversions	Comments
	Name	Number			
Biggs	Butte (North)	20	2	No	Including 1 well in Biggs-West Gridley
Chico	Vina	2	39	No	
	Durham/Dayton	5	23		
Gridley	Butte	20	5	No	
Durham	Durham/Dayton	5	4	No	
Live Oak	Butte (South)	24	5	No	
Marysville	California	34	13	No	Including 1 well in Hallwood
Oroville[1]	North Yuba	21	3	Yes	Including 1 well near North Yuba Thermalito Boundary
	Thermalito	17	7		
Paradise I.D.	NA	NA	1	Yes	Outside of Model Domain
Yuba City	Yuba City	28	1[2]	Yes	
Total BBGM Urban Wells			101		

1. Includes South Feather Water and Power Agency (formerly Oroville-Wyandotte I.D.), Thermalito Irrigation District, and California Water Service Company).
2. Based on review of information provided by Yuba City as part of 1995-96 model update. Well represented a minor component of supply and is not currently represented in the model.

[3] Developed in consultation with West-Yost Associates.

Time series of monthly pumping for the period 1999 through 2012 would be developed for each of the wells identified for inclusion in the updated BBGM using previous time series used in BBGM, existing water master plans, WSAs, GWMPs, UWMPs, and service provider pumping records. For cases in which only annual pumping records are available, representative monthly urban demand patterns (monthly demand as a percentage of annual demand for each month of the year) for other Butte County entities would be used to estimate monthly pumping. If well-specific pumping rates are not available for a listed urban entity, then pumping will be equally distributed among that entity's wells.

Rural residential use of groundwater is not currently represented in the BBGM. In order to support update of the WI&A, it is recommended that time series of monthly pumping for the period 1999 through 2012 be developed for rural residential ground water usage based on previous BBGM estimates, U.S. Census Bureau population estimates and published per capita water usage rates for the Sacramento Valley. Outdoor water use for rural residential populations would be estimated based on an estimate of the irrigated area associated with a rural residence, estimated ET rates, and estimated irrigation efficiencies.

In addition to updating model time series through 2012, projections of future demand will be developed. For example, the level of demand in 2040 could be estimated. It is recommended that the methodologies described above be used to estimate future demands.

Climate Change

Overview

Evaluation of the potential impacts and effects of climate change on water management in Butte County could address one or more specific objectives, including:

- Warmer air temperatures may lead to more winter precipitation, more rain, and less snow. What effect does this have on basin hydrology in general and on groundwater conditions in particular?
- What is the vulnerability of the system to potential climate change impacts?
- What would be the effects of a prolonged drought? For example, what if we had not experienced several wet years after the 1990s drought?

The approach to evaluating potential climate impacts will depend upon the potential outcomes of greatest concern. Based on those questions, a range of analytical methodologies are available. Two key questions are:

- What future scenario should be evaluated? (warm, warm and dry, etc.)
- What potential outcomes of climate change are of greatest concern?

Potential Future Conditions

Potential impacts of climate change are estimated based on projected changes in greenhouse gasses under different emission scenarios. These scenarios are driven by assumptions related to population growth, economic activity, societal attitudes and behavior, and technological advancement. Based on the emission scenarios, global climate models (GCMs) are developed by climate scientists to project changes in climate such as temperature and precipitation. There are a large number of GCMs and emission scenarios available.

In California, the Governor's Climate Action Team selected six GCMs and two emission scenarios, resulting in 12 climate change scenarios and recommended them for the 2009 California Water Plan update. To demonstrate the range in variability in future conditions among scenarios, projections of temperature and precipitation from the studies are shown in Figures 16 and 17, respectively. As indicated, the scenarios project increases in temperature. Results vary substantially among GCMs in the timing and degree of temperature increase; however, temperature increases under the high emission scenario (A2) tend to be greater than the lower emission scenario (B1). With respect to precipitation, the results are somewhat more mixed, with a general projection of decreasing annual precipitation as the century progresses.

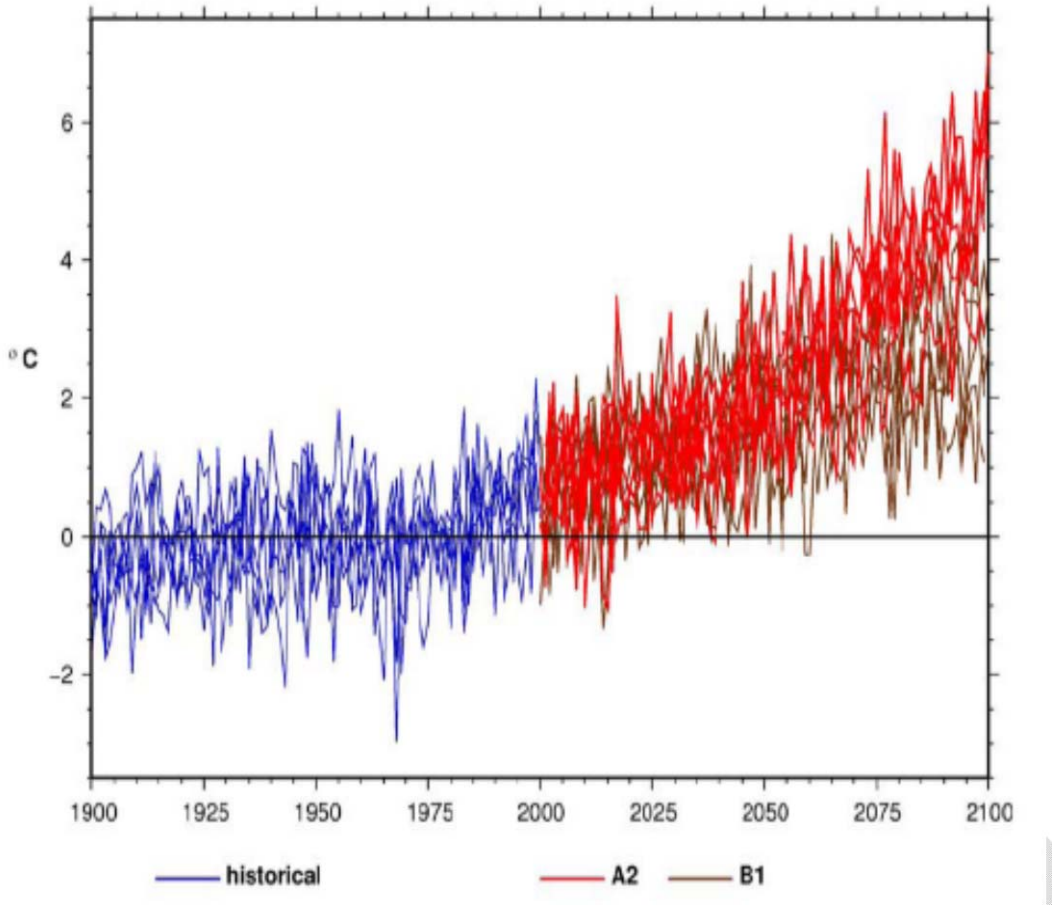

Figure 16. Projections of Mean Temperature Increase for Sacramento Area from 12 CAT Scenarios (Cayan et al., 2008).

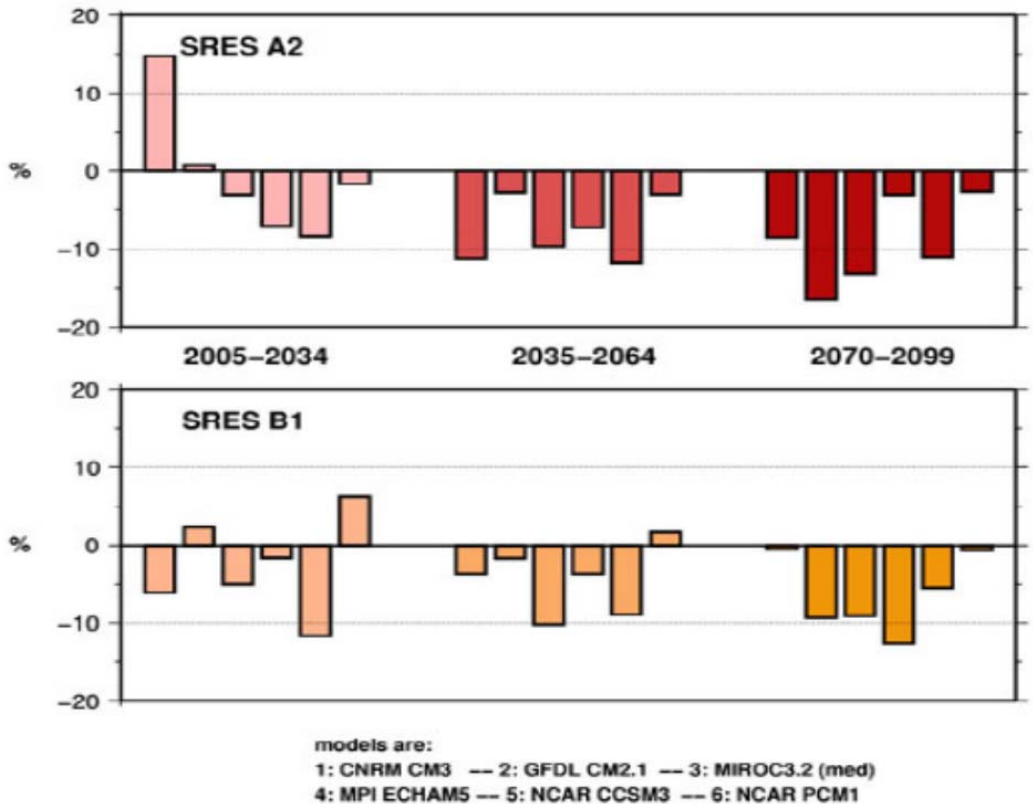

Figure 17. Projected Changes in Precipitation Relative to 1961-1990 Average for Northern California from 12 CAT Scenarios (Cayan et al., 2008).

Increased temperature and reduced precipitation are expected to result in reduced winter snowpack and increased runoff earlier in the year, which will reduce available surface water supplies and increase reliance on groundwater. Additionally, applied water demands will increase as less precipitation is available to support crop growth. A more in-depth discussion of climate change and groundwater in California has been developed by Fisher et al. (2013) and is available at the California Water Blog (http://californiawaterblog.com/2013/10/09/groundwater-and-climate-change-in-california/)

It is recommended that the advisory committee be consulted to discuss the type of climate change scenario to consider, in addition to discussing the questions to be addressed through the climate change analysis.

Example Studies

The following table (Table 8) summarizes studies that have been conducted in California to assess potential impacts of climate change on water management. These examples are intended to support discussion of the questions to be addressed through the current effort related to potential implications of climate change on water management in Butte County.

Table 8. Example Climate Change Studies from California.

Study	Objectives of Climate Change Analysis	Technical Approach
DWR Upper Feather River Basin Snowmelt Study	Evaluate the hydrological response and sensitivity to climate warming of the Upper Feather River Basin. Quantify significant changes in stream flow timing and increased frequency and magnitude of extreme flows. Evaluate overall impact on water supply.	Sensitivity Analysis: Incrementally increase mean temperatures to evaluate hydrologic impacts using the PRMS hydrologic model (a rainfall-runoff model).
2013 Water Plan Update	Quantify uncertainty surrounding future climate change to evaluate resource management strategies.	Scenario Analysis: Apply 12 CAT scenarios, 5 scenarios repeating historical climate, 5 scenarios repeating historical climate with severe 3-year drought, and 5 scenarios repeating historical climate with warming temperatures.
2009 State Water Project Delivery Reliability Report	Estimate the amount of SWP water deliveries for conditions twenty years in the future. Evaluate impacts to source water supply, conveyance, and demands.	Scenario Analysis: Apply one selected CAT scenario representing a "median" condition and evaluate reliability using CALSIM II.
Bay Delta Conservation Plan	Evaluate climate change implications of BDCP alternatives on natural communities, terrestrial species, and aquatic species.	Ensemble Approach: Combine scenarios to develop ensembles. Five ensembles developed to represent range of potential future conditions.

Available Data

Datasets available related to surface hydrology include downscaled GCM results that include projections of precipitation at 12 kilometer resolution and daily or monthly timescales for 112 GCM-emission scenario combinations (i.e., climate change scenarios). These data have additionally been used to develop stream flow projections for major streams in California. As a result, time series data can be developed for precipitation in the BBGM domain and are available for the following modeled streams:

- Deer Creek near Vina
- Feather River at Oroville
- Sacramento River at Bend Bridge
- Mill Creek near Los Molinos

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