D. Assessment of Butte County Drought Impacts, 2012-2015

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Technical Memorandum

To: Butte County Department of Water and Resource Conservation

From: Davids Engineering

Date: March 28, 2016 (revised June 8, 2016)

Subject: **Assessment of Butte County Drought Impacts, 2012-2015**

Background and Overview

Previous analyses (Butte County Groundwater Inventory, DWR 2005; I&A Report 2001; and Butte Basin Groundwater Model Update, Water Management Scenario 2008) have estimated impacts to the basin of drought conditions. Two broad questions arise – (1) can we provide reasonable basin-wide estimates on the increased demand on the basin as a result of the drought, and (2) how do the previous analyses compare to the current 2012 – 2015 drought?

Butte County Department of Water and Resource Conservation (BCDWRC) has reported on groundwater elevations in relation to their period of record. Anecdotally, an increase in groundwater irrigation during winter months due to limited precipitation has been reported, though increased irrigation has not been quantified. This raises another important question: how does the increased groundwater demand affect overall groundwater demands in groundwater only areas and the basin as a whole?

Cutbacks to Settlement Contractors and curtailments to other surface water users in the County in 2015 resulted in increased pumping in those areas. Increased monitoring was conducted by the districts and in cooperation with BCDWRC to assess how the basin responds to the pumping. The amount of pumping in the districts has been estimated based on planted acres, surface water delivery and well metering. A hypothetical cutback scenario was analyzed in the Butte Basin Groundwater Model Update (2008). That scenario was limited to assessing the effect of increased pumping within the district boundaries without considering potential lowering of water levels in the surrounding areas of the basin due to drought conditions.

Davids Engineering (DE) has compiled available information describing land use within the Butte Basin for 2013, 2014, and 2015 and prepared estimates of groundwater pumping for agricultural irrigation through the 2015 irrigation season for comparison to prior years. This effort supports BCDWRC drought monitoring efforts while additionally providing updated datasets for the Butte Basin Groundwater Model (BBGM) and Butte County Water Inventory & Analysis (WI&A).

This technical memorandum (TM) summarizes the results of the analysis of agricultural supply and demand impacts of drought between 2012 and 2015 as estimated by the Integrated Water Flow Model (IWFM) Demand Calculator (IDC) component of the BBGM. The analysis is based on comparison of recent drought years to a baseline period of 2001 to 2007 that, on average, approximates long-term historical hydrology and recent land use patterns. First, hydrologic impacts of drought are examined including consideration of precipitation and streamflows. Next, land use changes are reviewed to support understanding of potential effects of land use on demands and changes in net recharge that have occurred during recent drought years. Then surface water supplies, groundwater pumping, reference evapotranspiration, crop evapotranspiration, and crop water demands are reviewed. Finally, potential impacts of drought on net recharge of the groundwater system are discussed. This analysis presents results of input data developed for the BBGM (precipitation, land use, diversions, crop evapotranspiration) and results from the IDC component of the BBGM that estimates complete land surface water budget (irrigation water demands, deep percolation).

Hydrologic Impacts of Drought

For purposes of this assessment, drought is generally defined by below normal precipitation and resulting reduction in available water supplies to support agricultural, urban, and environmental water demands. All else equal, reduced precipitation in Butte County and the watersheds it relies upon results in decreased surface water supplies, increased irrigation demands, and decreased groundwater recharge, although these impacts do not occur in direct proportion to decreased precipitation. Impacts on surface water supplies depend upon dynamics in the timing and amount of precipitation received as snowfall, melting and runoff of accumulated snowfall, reservoir storage and operations, and water rights considerations. Similarly, irrigation demands are influenced primarily by the timing and amount of precipitation occurring on the valley floor, along with reference evapotranspiration as influenced by solar radiation, temperature, wind speed, humidity, and other factors. Net recharge of the underlying groundwater system is influenced by a combination of these factors.

Precipitation

Precipitation for the WI&A has been estimated based on five weather stations utilized in the BBGM. For each station, a representative percentage of precipitation is utilized to calculate average precipitation for the region, based on the area represented by each station and long term average precipitation trends across the region. The stations and representative percentages include Chico University Farm (51 percent), Oroville (35 percent), Paradise (8 percent), Colusa (4 percent), and Marysville (2 percent).

For the 2001-2007 period, average water year[1] precipitation based on the weighted average of the stations described above was 28.5 inches, as compared to 27.7 inches on average for the 45-year period from 1971 to 2015 (103 percent of the long term average). In contrast, water year precipitation totals in recent drought years have been substantially less, totaling 24.8, 26.9, 19.2, and 22.1 inches for 2012, 2013, 2014, and 2015, respectively. On average during the recent drought, water year precipitation has been approximately 82 percent of the 2001-2007 average. Water year precipitation totals are shown graphically in Figure 1, along with averages for the 2001-2007 and 1971-2015 periods.

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[1] The water year refers to the period from October 1 to September 30 each year. For example, the 2001 water year began on October 1, 2000 and ended September 30, 2001. This definition of a water year is commonly used in California due to the rainy season typically beginning in October 1 each year. Precipitation and snowfall received between October 1 and the following spring contribute to available water supplies for the irrigation period that follows.

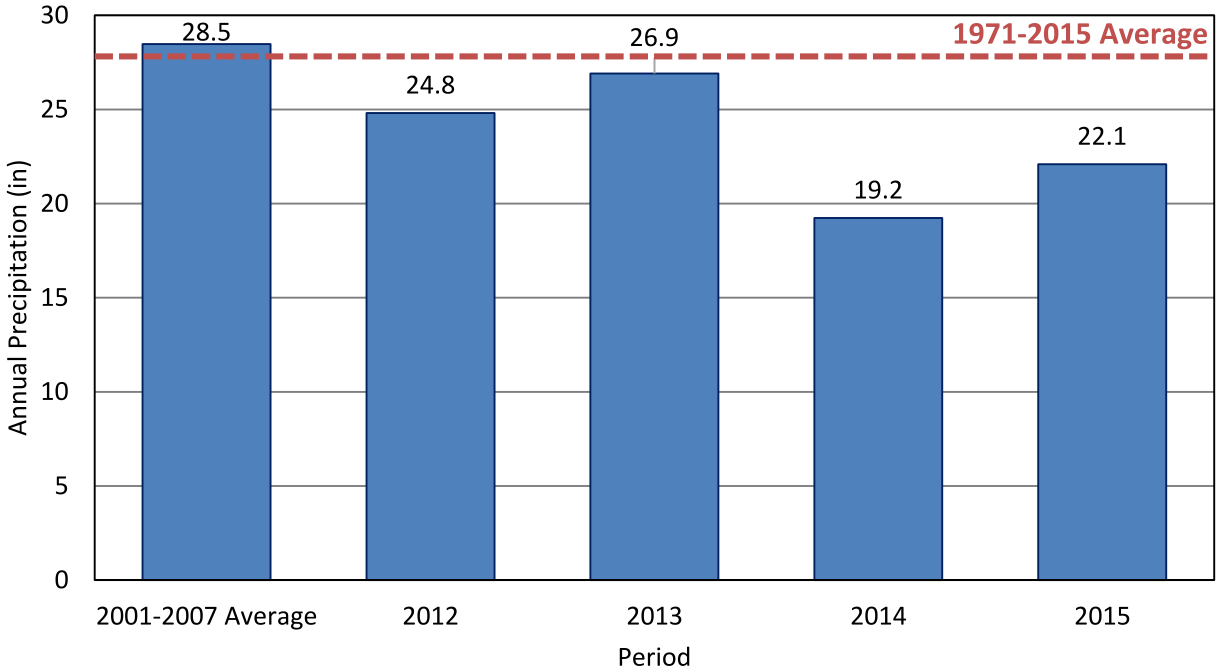

Figure 1. Average Precipitation for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Streamflows

Primary surface streams providing water supplies in Butte County include the Feather River and Butte Creek. Some water is also diverted from the Sacramento and other, minor sources. To evaluate drought impacts on surface streams, streamflows for the primary surface streams are reviewed. For the Feather River, estimates of full natural flow for the Feather River at Oroville gage are presented. Full natural flow represents the estimated streamflow that would occur without the impacts of reservoir storage and releases and provides a better representation of hydrologic impacts of drought than do actual flow data by removing the effects of storage. For Butte Creek, actual flows for the Butte Creek near Chico gage are presented, which are impacted to some extent by hydropower and reservoir operations in the upper watershed. In each case, total flow volumes are reviewed on a water year basis, along with April to July flows. By examining trends in April to July flows, one can evaluate impacts of drought on snowmelt and corresponding surface water supplies during the primary irrigation season, which occurs between April and September.

Feather River

For the period 2001-2007, average water year Feather River full natural flow was 4.09 maf[2], as compared to 4.32 maf on average for the 45-year period from 1971 to 2015 (95 percent of the long term average). In contrast, water year totals in recent drought years have been substantially less, totaling 2.86, 3.13, 1.72, and 2.02 maf for 2012, 2013, 2014, and 2015, respectively. On average during the recent drought, water year Feather River full natural flow has been approximately 59 percent of the 2001-2007 average. Water year full natural flow volumes are shown graphically in Figure 2, along with averages for the 2001-2007 and 1971-2015 periods. Volumes are expressed in thousands of acre-feet (taf).

[2] maf = million acre-feet

For the period 2001-2007, average April to July Feather River full natural flow was 1.67 maf, as compared to 1.67 maf on average for the 45-year period from 1971 to 2015 (100 percent of the long term average). In contrast, totals in recent drought years have been substantially less, totaling 1.36, 0.76, 0.57, and 0.38 maf for 2012, 2013, 2014, and 2015, respectively. On average during the recent drought, April to July Feather River full natural flow has been approximately 46 percent of the 2001-2007 average. April to July full natural flow volumes are shown graphically in Figure 3, along with averages for the 2001-2007 and 1971-2015 periods.

Butte Creek

For the period 2001-2007, average water year Butte Creek flow into the valley floor was 305 taf[3], as compared to 292 taf on average for the 45-year period from 1971 to 2015 (104 percent of the long term average). In contrast, water year totals in recent drought years have been substantially less, totaling 189, 218, 116, and 125 taf for 2012, 2013, 2014, and 2015, respectively. On average during the recent drought, water year Butte Creek flow has been approximately 53 percent of the 2001-2007 average. Water year flow volumes are shown graphically in Figure 4, along with averages for the 2001-2007 and 1971-2015 periods.

For the period 2001-2007, average April to July Butte Creek flow into the valley floor was 109 taf, as compared to 95 taf on average for the 45-year period from 1971 to 2015 (115 percent of the long term average). In contrast, totals in recent drought years have been substantially less, totaling 84, 46, 37, and 23 taf for 2012, 2013, 2014, and 2015, respectively. On average during the recent drought, April to July Butte Creek flow has been approximately 43 percent of the 2001-2007 average. April to July flow volumes are shown graphically in Figure 5, along with averages for the 2001-2007 and 1971-2015 periods.

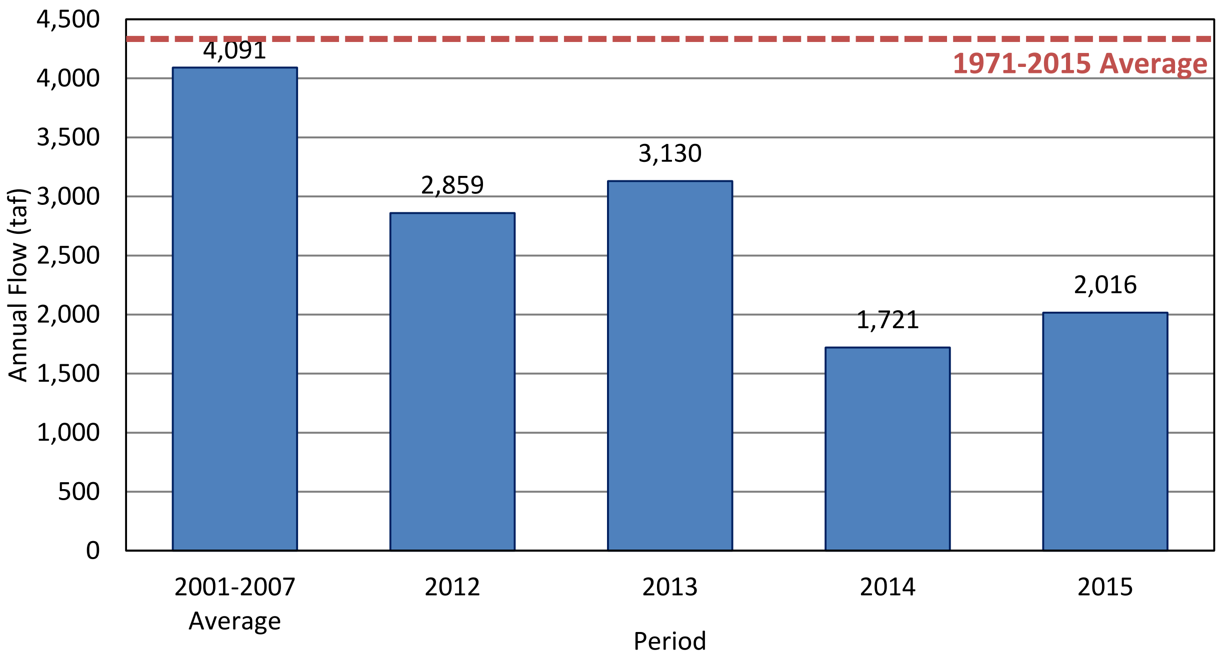

Figure 2. Average Feather River Full Natural Flow for 2001-2007 and by Water Year for 2012-2015 Drought Period.

[3] taf = thousand acre-feet

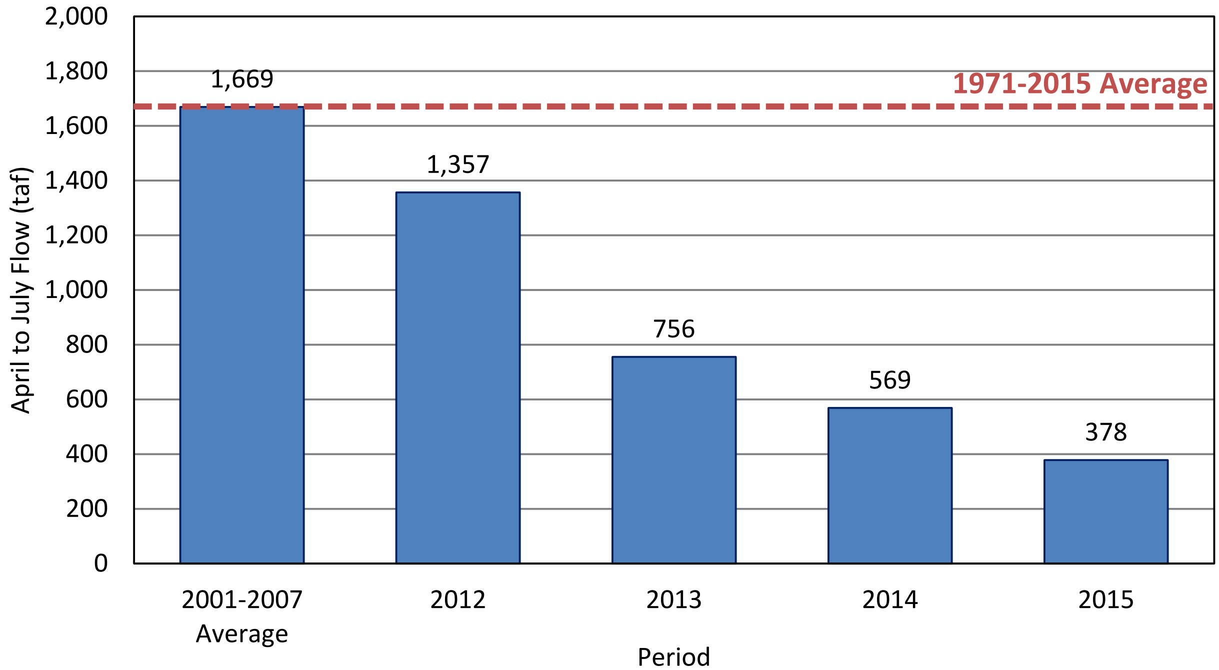

Figure 3. Average Feather River April-July Full Natural Flow for 2001-2007 and each April-July for 2012-2015 Drought Period.

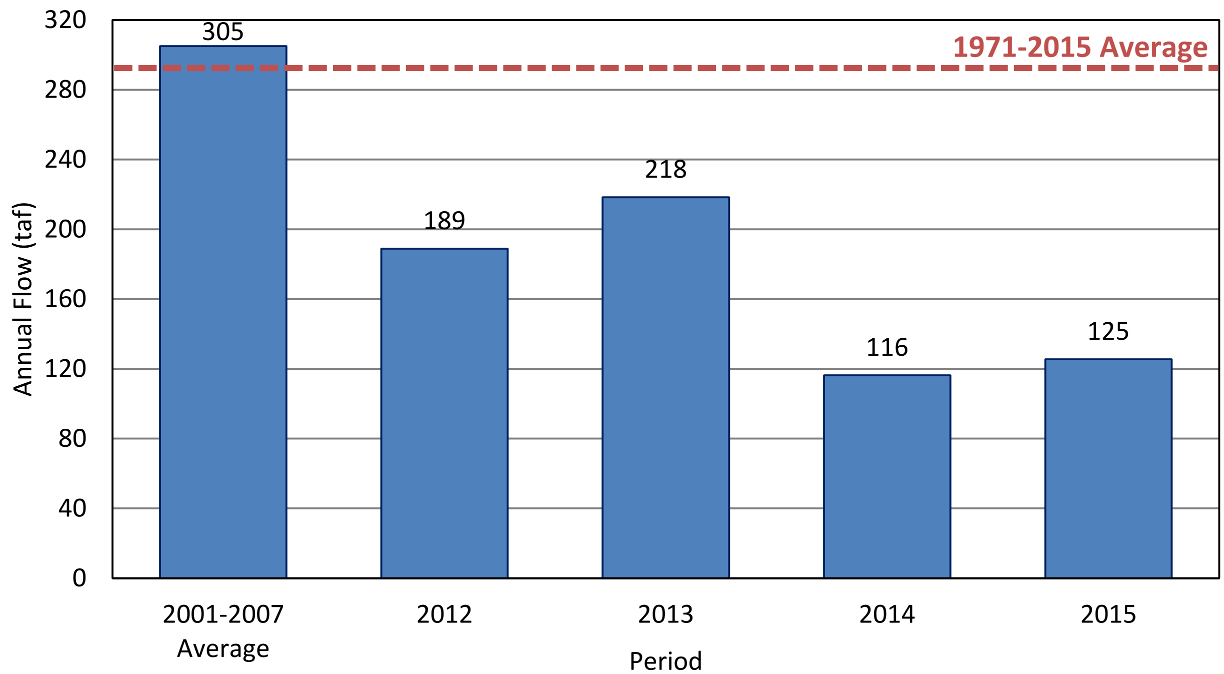

Figure 4. Average Butte Creek Flow for 2001-2007 and by Water Year for 2012-2015 Drought Period.

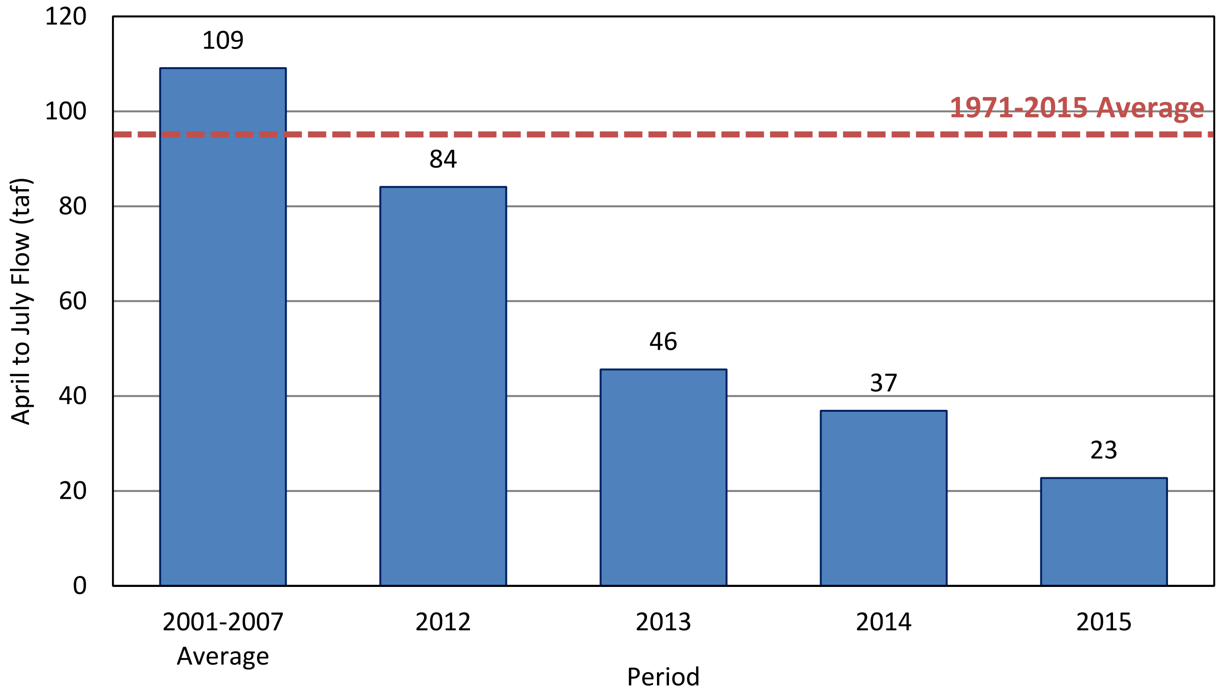

Figure 5. Average Butte Creek April-July Flow for 2001-2007 and each April-July for 2012-2015 Drought Period.

Comparison of Irrigated Land Use between Baseline Period and Recent Drought Years

Irrigated land uses between the 2001-2007 baseline period and 2012-2015 drought years are summarized based on land use surveys conducted by the Department of Water Resources and agricultural commissioner crop report data. Changes in land use influence irrigation demands and have the potential to mediate or exacerbate the effects of drought. As demonstrated below, changes in irrigated land use are not likely to have substantially affected water demands between the baseline and drought period. Irrigated land uses are summarized for the County as a whole and for two general areas within the County. These are the Feather River Settlement Contracts (FRSC) area, which is primarily supplied with surface water from Lake Oroville via Thermalito Afterbay and consists of rice, and other "mixed supply" areas, which are primarily supplied with groundwater and consist of orchards but have access to surface water in some cases (Figure 6[4]). The FRSC area includes the following subinventory units from the WI&A: Biggs-West Gridley, Butte, Butte Sink, Richvale, and Western Canal. The "Mixed Supply" area includes the following subinventory units from the WI&A: Angel Slough, Cherokee, Durham/Dayton, Esquon, Llano Seco, M&T, North Yuba, Pentz, Thermalito, and Vina.

As indicated in Figure 7, irrigated acreage in Butte County averaged approximately 248 thousand acres between 2001 and 2007, and varied between approximately 233 and 257 thousand acres during the 2012 to 2015 drought period, averaging 241 thousand acres (97 percent of the 2001-2007 average)[5]. Reduced acreages in 2012, 2014, and 2015 (as compared to 2013 and the 2001-2007 baseline period)

[4] Figure 6 additionally identifies the Foothill area, which does not contain significant irrigated cropland but is an area of potential recharge from percolation of precipitation.

[5] In contrast to the "irrigated agriculture" land use category described in the 2016 Water Inventory and Analysis report, irrigated acreage quantified as part of this drought impacts assessment includes managed wetlands and excludes acres associated with temporary idling of cropland.

are primarily the result of idling of rice for water transfers (2012 and 2014) and fallowing due to reduced surface water supplies (2015). These reductions are more clearly demonstrated in Figure 8, which includes only the FRSC area.

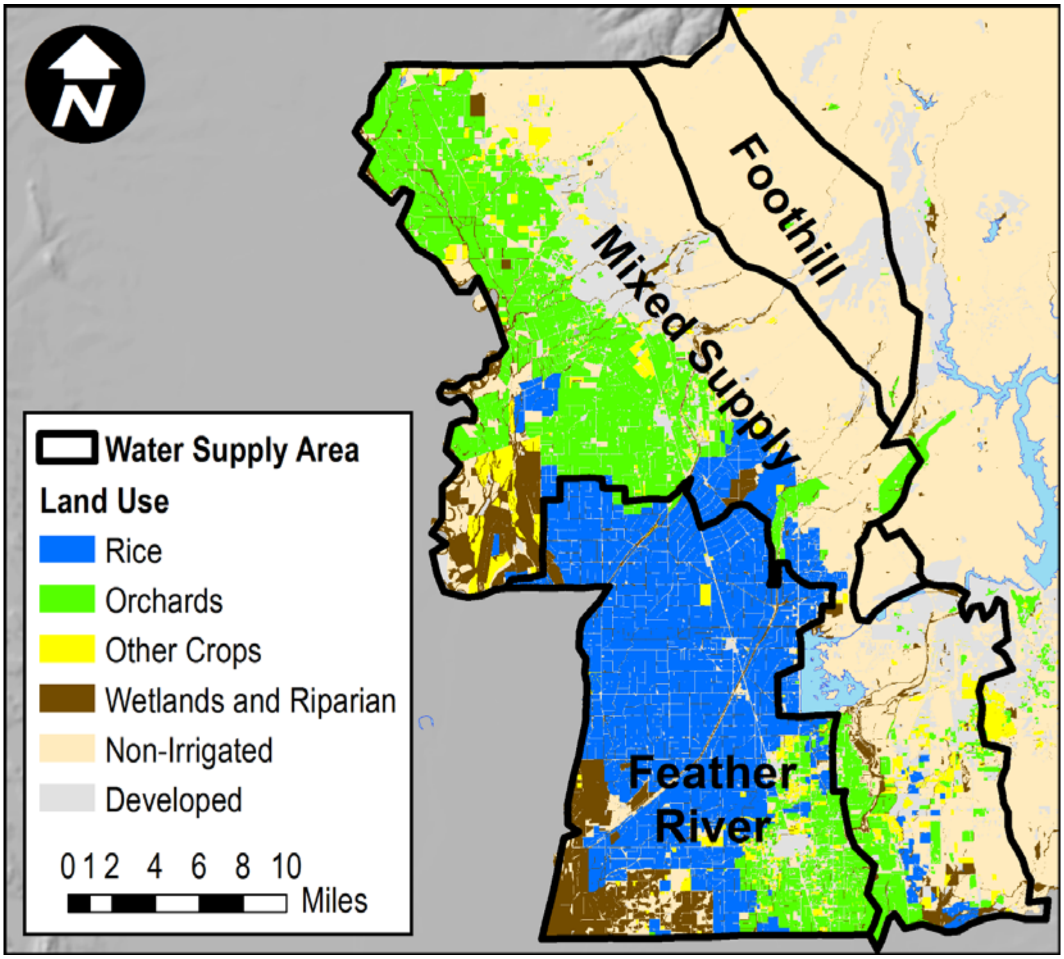

Figure 6. Butte County Feather River, Mixed Supply, and Foothill Areas.

As indicated in Figure 9, irrigated acreage in Butte County outside of the FRSC area (the "Mixed Supply" area) was relatively similar between the baseline and drought periods. Comparing 2014 and 2015 to the baseline period, there has been some reduction in rice acreage and acreage of other, non-permanent crops.

All else equal, changes in irrigated land use between the baseline period and recent drought years are not likely to have greatly influenced irrigation demands. Rather, drought effects such as decreased precipitation and streamflows are likely to have a greater effect. One possible exception is 2013, a year in which the rice acreage was almost fully planted due to no crop idling based water transfers or curtailed Feather River water supplies in the FRSC area.

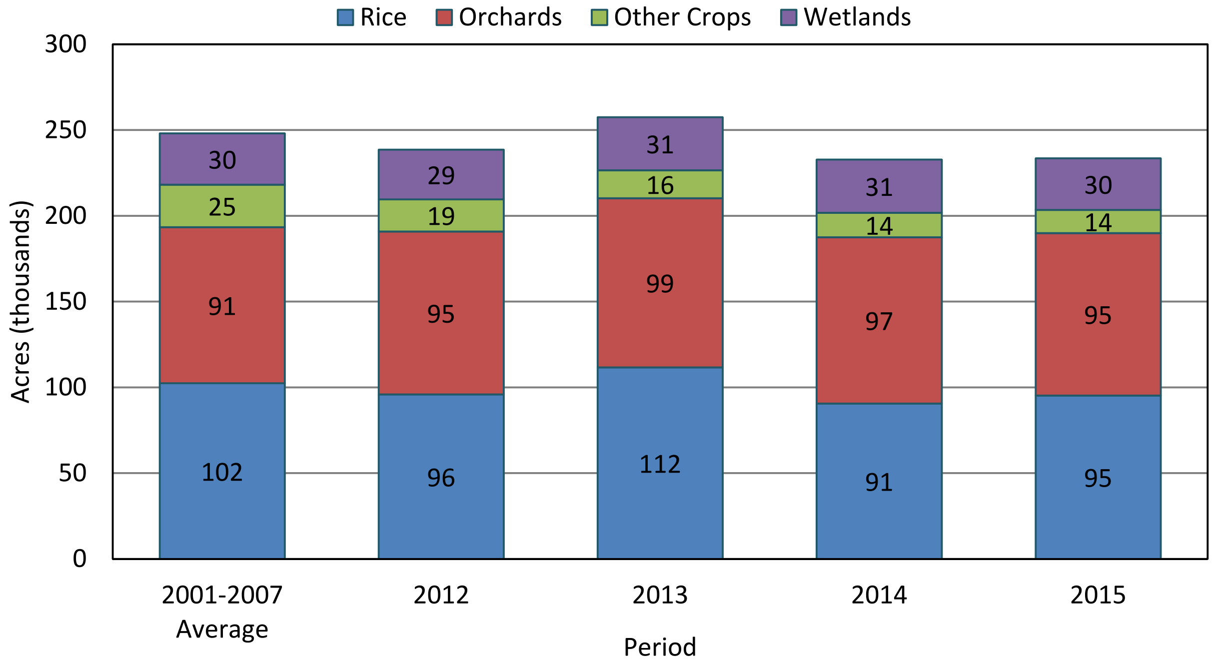

Figure 7. Butte County Irrigated Land Uses for 2001-2007 and by Water Year for 2012-2015 Drought Period.

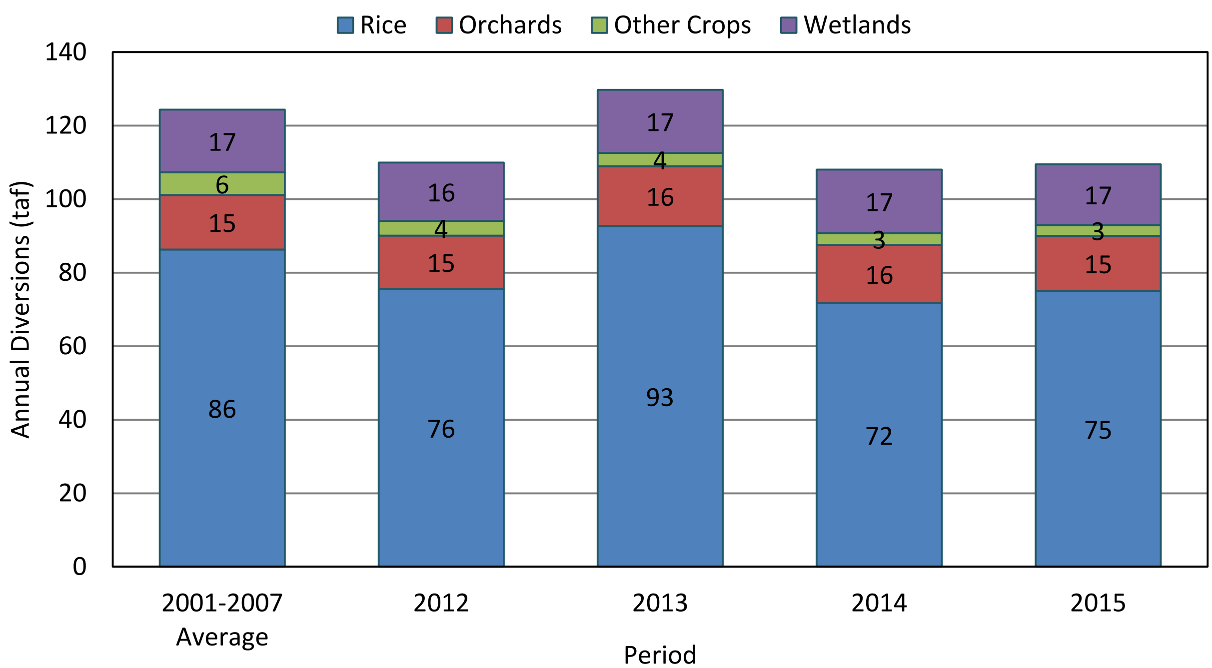

Figure 8. Butte County FRSC Area Irrigated Land Uses for 2001-2007 and by Water Year for 2012-2015 Drought Period.

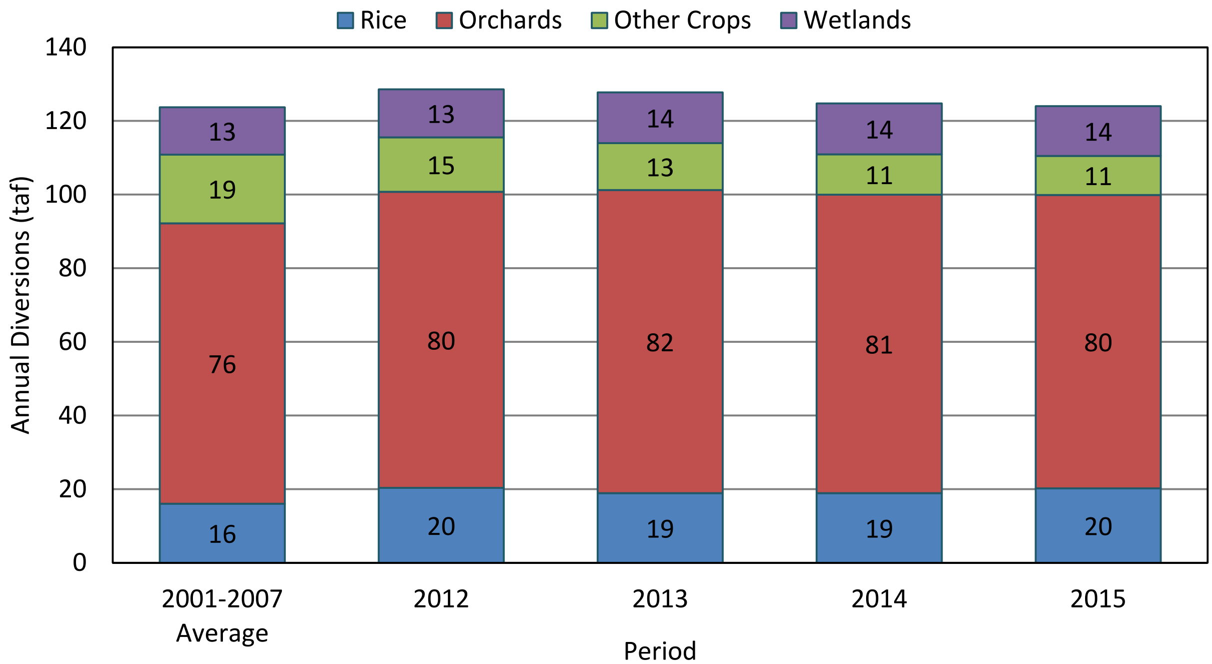

Figure 9. Butte County Mixed Supply Area Irrigated Land Uses for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Irrigation Water Supplies

Reliance on surface water and groundwater supplies for irrigation between the baseline and drought period are summarized below. For surface water supplies, County-wide estimates of diversions for irrigation are summarized, and then divided based on supply source, including the Feather River, Butte Creek, the Sacramento River, and other sources[6]. For groundwater pumping, County-wide estimates are presented, and then shown for the FRSC area relying primarily on surface water for irrigation and the remaining areas of the County relying primarily on groundwater for irrigation.

Surface Water Supplies

As indicated in Figure 10, surface water supplies in 2012 and 2013 were similar to the baseline period, with estimated diversions of 766 and 785 taf in 2012 and 2013, respectively, and 792 taf for the baseline period (2001-2007). Estimated diversions were less in 2014 and 2015, at 692 and 431 taf, respectively. Overall, surface water supplies averaged 669 taf annually between 2012 and 2015, or 84 percent of diversions during the baseline period. Surface water supplies were 87 and 54 percent of the average for the baseline period in 2014 and 2015, respectively. Reduced surface water supplies in 2014 and 2015 result from a combination of factors, including the following:

- Reduced FRSC diversions resulting from idling and reduced fall/winter water use for rice straw decomposition and habitat (2014),
- Curtailment of FRSC surface water supplies (2015), and
- Reduced availability of surface water from Butte Creek during both years.

As demonstrated in Figure 10, the primary source of surface water for irrigation in Butte County is water from the Feather River diverted from the Afterbay to the FRSC area, which has been a relatively reliable

[6] Other sources include miscellaneous riparian diversions and surface water supplies from the Feather River watershed other than the Feather River Settlement Contractors (e.g., South Feather Water and Power).

source of water during the recent drought. Substantial reductions in this supply occurred in 2014 and 2015 for the reasons stated above. Similar reductions occurred in Butte Creek due to reduced water availability and curtailment of diversions. Supplies from Butte Creek are relatively sensitive to drought, with supplies from the Sacramento River and other sources being more reliable.

Estimates of historical diversions are subject to uncertainty. In particular, estimates for 2015 for Butte Creek, the Sacramento River, and other sources should be considered provisional. Diversions from the Feather River for the FRSC area are based on reported values.

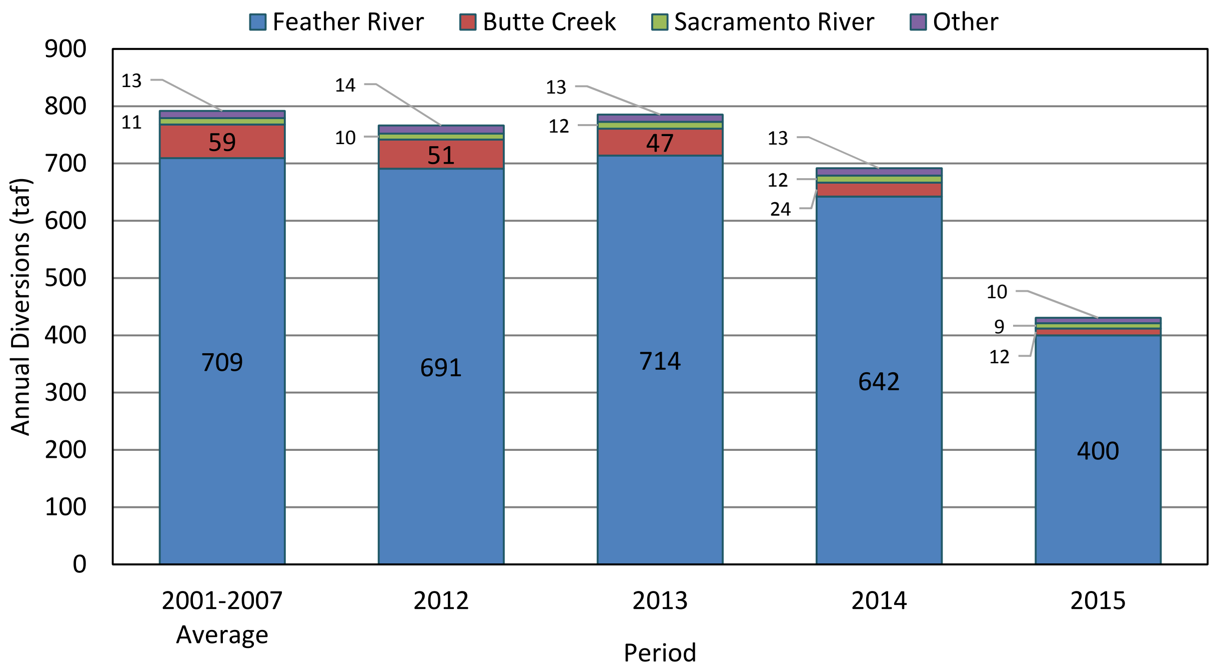

Figure 10. Butte County Surface Water Diversions for 2001-2007 and by Water Year for 2012-2015 Drought Period by Water Source.

Groundwater Pumping

Groundwater pumping in this analysis is estimated based on the difference between estimated agricultural irrigation demands and available surface water to meet those demands. Irrigation demands not met by surface water diversions are assumed to be met by groundwater. Irrigation demands have been estimated using the IDC component of the BBGM. As indicated in Figure 11, estimates of groundwater pumping for irrigation averaged approximately 365 taf during the baseline period and increased during the recent drought period to 385, 398, 438, and 592 taf in 2012, 2013, 2014, and 2015, respectively. Average pumping between 2012 and 2015 was approximately 453 taf, or 124 percent of the average for the baseline period. As illustrated in Figure 12, the increase in groundwater as a source of irrigation supply in 2015 relative to 2014 of approximately 154 taf resulted primarily from increased pumping in the FRSC area (126 taf greater than in 2014), which is primarily due to curtailment of available surface water supplies. By comparison in Figure 13, reliance on groundwater as a source of supply increased in the Mixed Supply area of the County from approximately 344 taf in the 2001 to 2007 baseline period to 395 taf on average between 2012 and 2015 (115 percent of the average for the baseline period). Groundwater pumping in the Mixed Supply area is estimated to have been 436 taf in 2015 (127 percent of the baseline period average). This increase is due to a combination of reduced surface water supply and reduced precipitation to meet crop water demands.

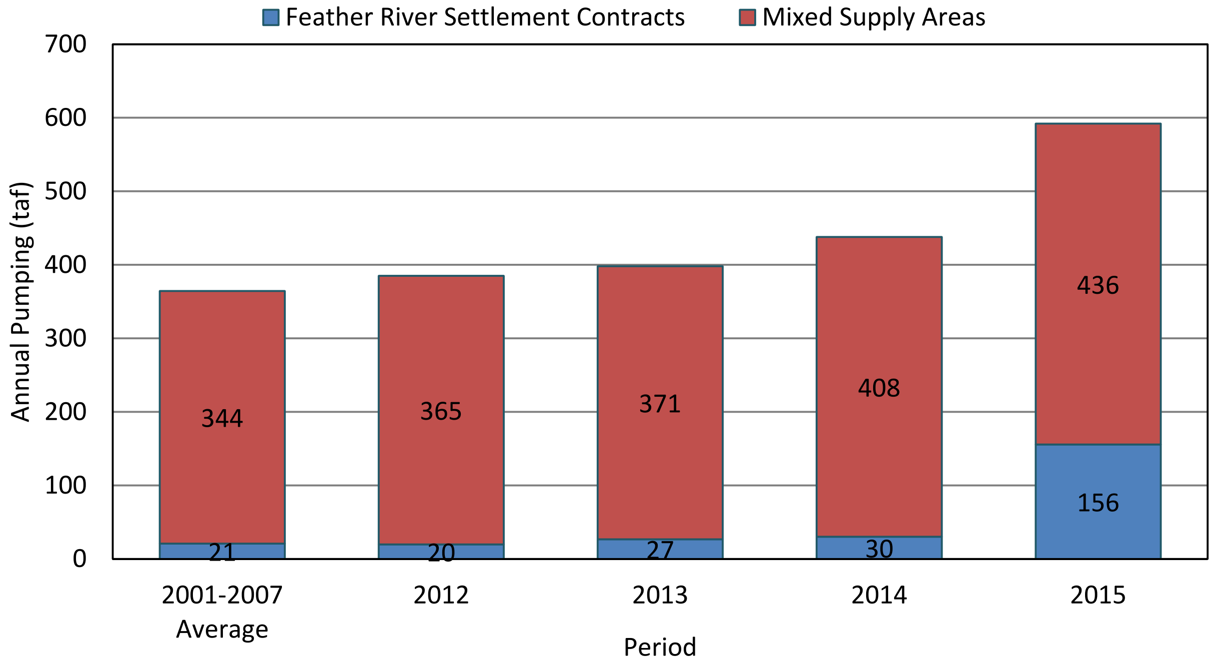

Figure 11. Butte County Estimated Groundwater Pumping for Irrigation for 2001-2007 and by Water Year for 2012-2015 Drought Period.

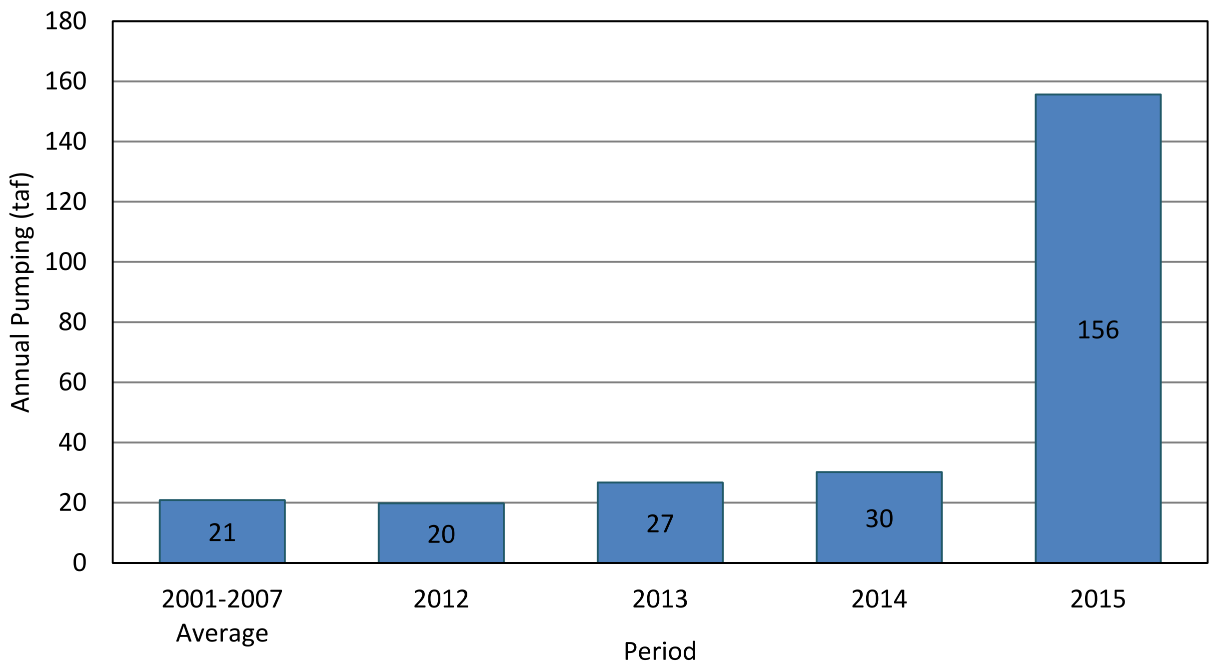

Figure 12. Butte County FRSC Area Estimated Groundwater Pumping for Irrigation for 2001-2007 and by Water Year for 2012-2015 Drought Period.

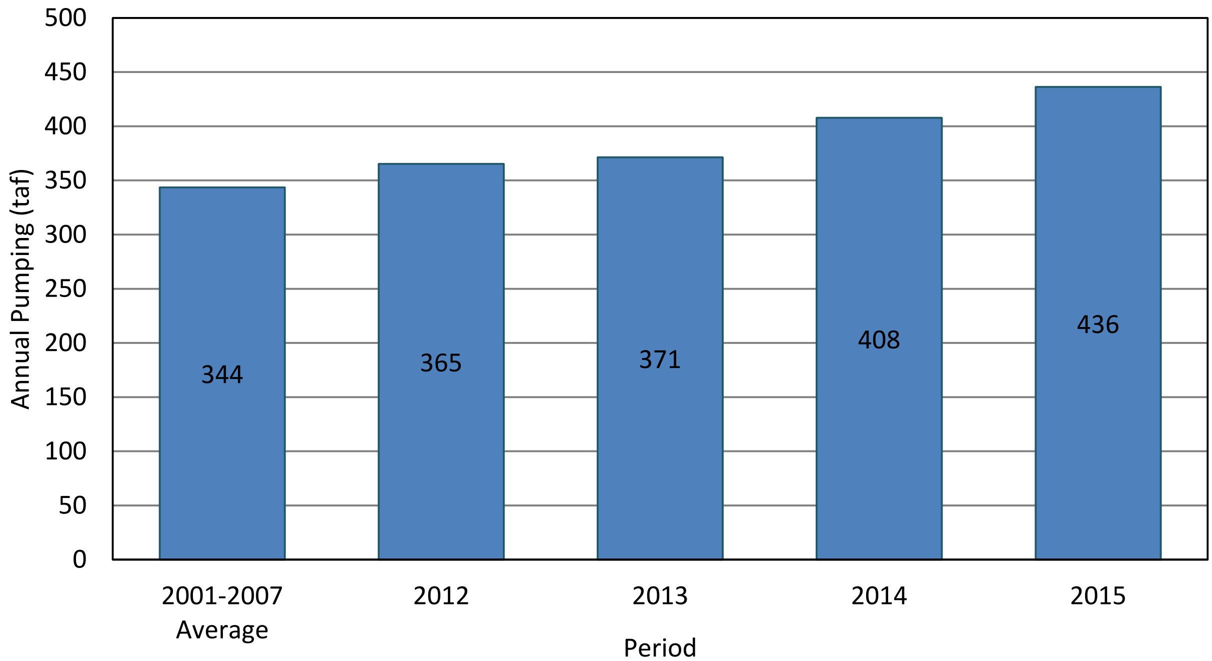

Figure 13. Butte County Mixed Supply Area Estimated Groundwater Pumping for Irrigation for 2001-2007 and by Year for 2012-2015 Drought Period.

Irrigation Demands

Irrigation demands between the baseline and drought period are described below. These demands are estimated using the IDC component of the BBGM. As discussed previously, changes in land use are not believed to have greatly influenced irrigation demands between the baseline and drought periods. As a result, differences in irrigation demands are believed to have resulted primarily from drought impacts on precipitation and available irrigation water supplies. Irrigation demands are evaluated by considering reference evapotranspiration (ET), a measure of atmospheric demand for water as influenced by radiation, temperature, wind speed, and humidity; crop evapotranspiration, which incorporates the influence of reference ET and the actual crops grown; and applied water demands, which incorporate crop ET and considerations of irrigation efficiency to estimate total irrigation requirements. Specifically, annual estimates of reference ET and crop ET between the baseline period and drought period are compared, and monthly estimates of applied water demands for orchard crops between the two periods are compared. The monthly applied water estimates help to illustrate how applied water demands are influenced by drought, particularly with respect to irrigation during the winter and spring.

Reference Evapotranspiration

Reference ET, as estimated based on the California Irrigation Management Information System (CIMIS) weather station at Durham, averaged approximately 50.4 inches between 2001 and 2007 on an annual basis (Figure 14). Between 2012 and 2015, annual reference ET has ranged from 50.1 to 52.9 inches and averaged 51.4 inches (102 percent of the baseline period average). The relatively similar reference ET between the baseline and drought periods indicates that, all else equal, irrigation demands are likely influenced more by reduced precipitation during drought than by other factors related to weather on the valley floor.

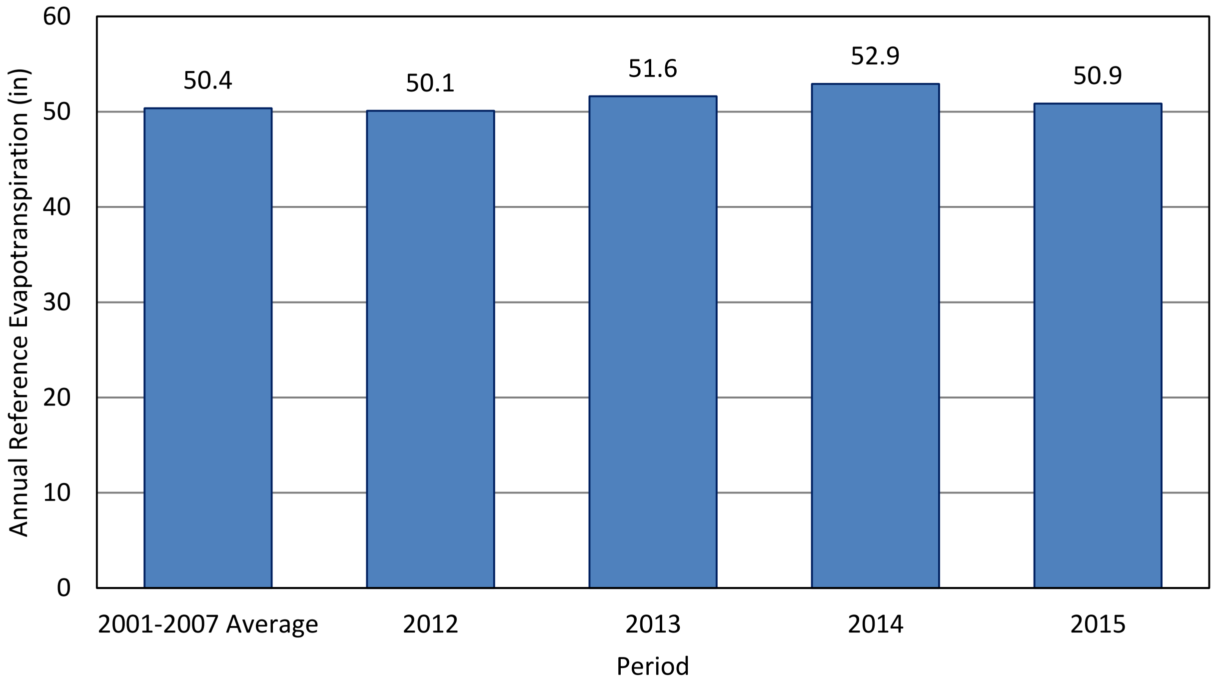

Figure 14. Butte County Estimated Reference Evapotranspiration for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Crop Evapotranspiration

Crop evapotranspiration estimates for Butte County are presented in Figure 15 for the baseline and drought periods. Crop ET is divided into ET of applied water (the amount of ET resulting from irrigation) and ET of precipitation (the amount of ET resulting from precipitation). The ET of applied water provides an estimate of the amount of irrigation water required to produce a crop assuming an irrigation efficiency of 100 percent. In other words, it represents the minimum irrigation requirement (not including frost protection, leaching, or other non-consumptive crop water needs).

As indicated, total crop ET has been somewhat greater during the drought period than the baseline period, with the greatest crop ET occurring in 2013. ET in 2013 was greater than other years primarily due to increased planted acreage during that year. Total crop ET averaged 846 taf annually for the baseline period and ranged from 826 to 914 taf between 2012 and 2015, with an average of 863 taf (102 percent of the baseline period average). ET of applied water averaged 636 taf annually for the baseline period and ranged from 611 to 687 taf between 2012 and 2015, with an average of 653 taf (103 percent of the baseline period average). ET of applied water during the drought period was greater than the baseline period in all years but 2012, reflecting the influence of reduced precipitation on applied water demands.

Figure 16 shows that ET of applied water for the FRSC area was generally less during the drought period than the baseline period (353 taf as compared to 366 taf, or 96 percent of the baseline period average). This is due to the ET of applied water for rice (the primary crop in this area) being relatively insensitive to precipitation and due to reduced acreage during the drought period due to crop idling for transfer and due to curtailment of surface water supplies in 2015. Conversely, ET of applied water increased during the drought period for Mixed Supply areas of the County (300 taf as compared to 269 taf, or 111 percent of the baseline period average) (Figure 17). These areas are dominated by orchards, for which the amount of irrigation required is strongly influenced by precipitation timing and amounts.

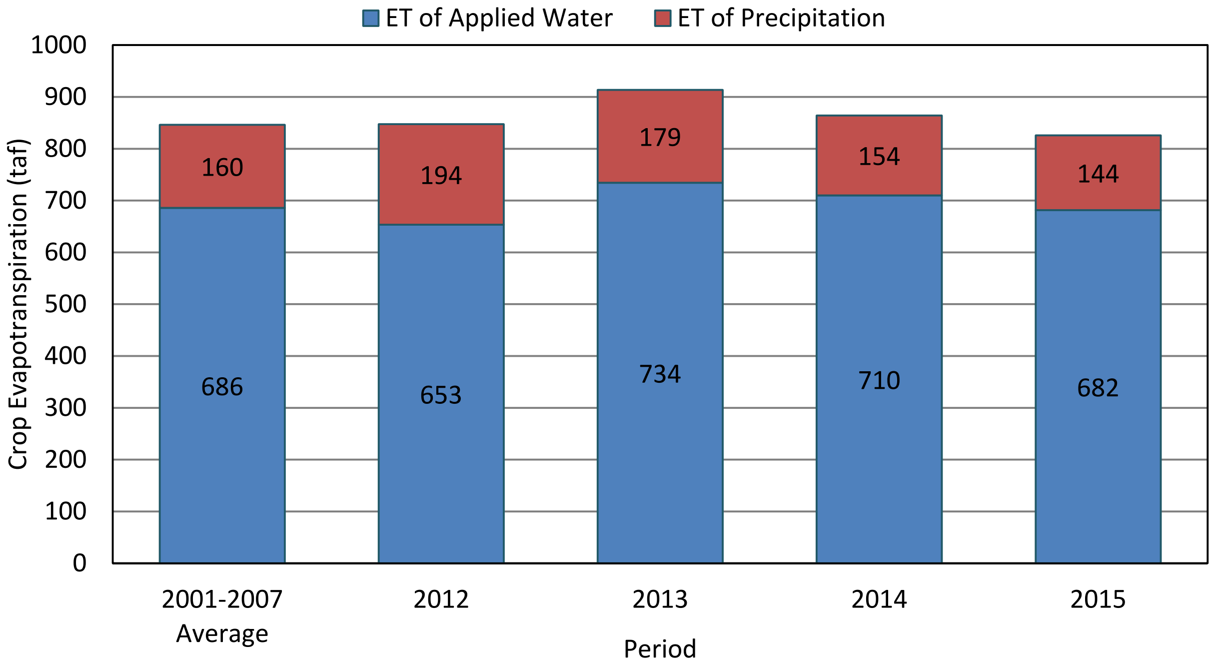

Figure 15. Butte County Estimated Crop Evapotranspiration for 2001-2007 and by Water Year for 2012-2015 Drought Period.

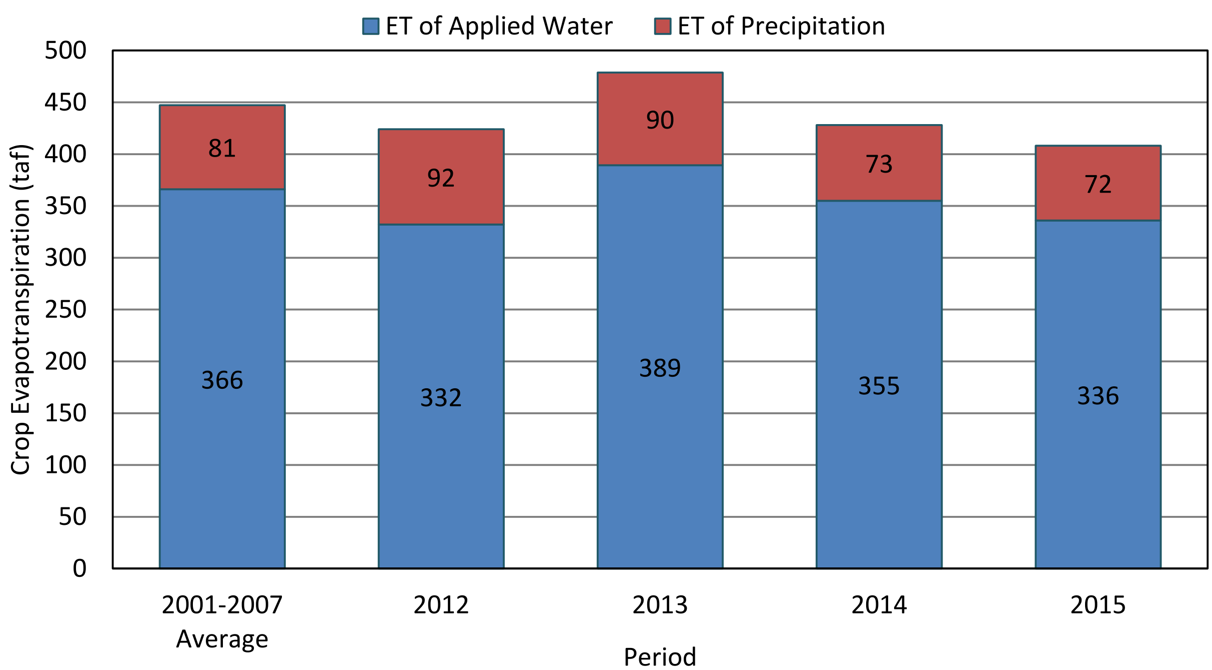

Figure 16. Butte County FRSC Area Estimated Crop Evapotranspiration for 2001-2007 and by Water Year for 2012-2015 Drought Period.

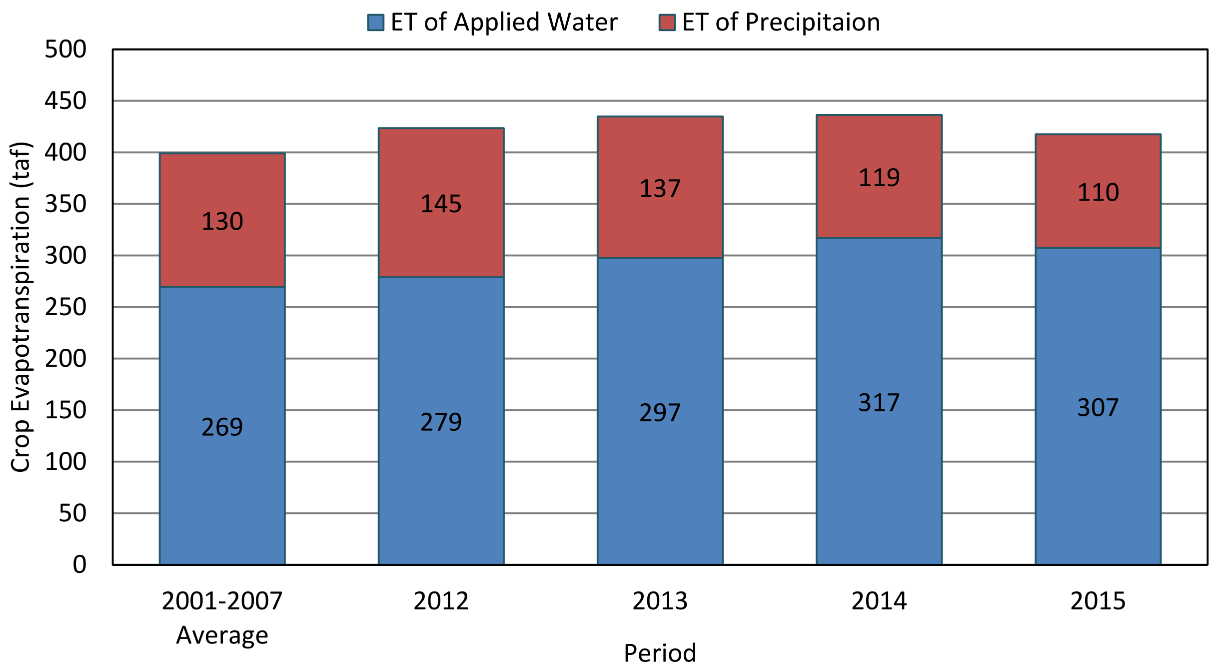

Figure 17. Butte County Mixed Supply Area Estimated Crop Evapotranspiration for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Monthly Applied Water Demands for Orchards

It has been observed that during periods of drought, irrigation of orchards between January and March may occur to supplement precipitation stored in the root zone and support development of the crop canopy. In order to evaluate impacts of drought on orchard water demands, applied water requirements estimated using the BBGM for the 2012 to 2015 drought period have been developed and compared to the 2001 to 2007 baseline period. These estimates are shown in Figure 18, which presents estimated average monthly applied water for orchards for the baseline and drought periods. For each month the estimated applied water, expressed in inches of depth, is shown. As indicated, applied water amounts for orchards during the drought period are greater than the baseline period between January and March, supporting the observation that irrigation is likely to occur during these months in drought years and providing an estimate of the amount of water applied.

On an annual basis, average applied water requirements for orchards were 30.5 inches for the 2001 to 2007 baseline period, as compared to 31.9 inches between 2012 and 2015 (1.4 inches greater). Estimated applied water between October and March was 2.9 inches for the baseline period and 4.4 inches for 2012 to 2015 (1.5 inches greater). This suggests that the primary impact of drought on orchard water demands is to increase irrigation water requirements during the winter period.

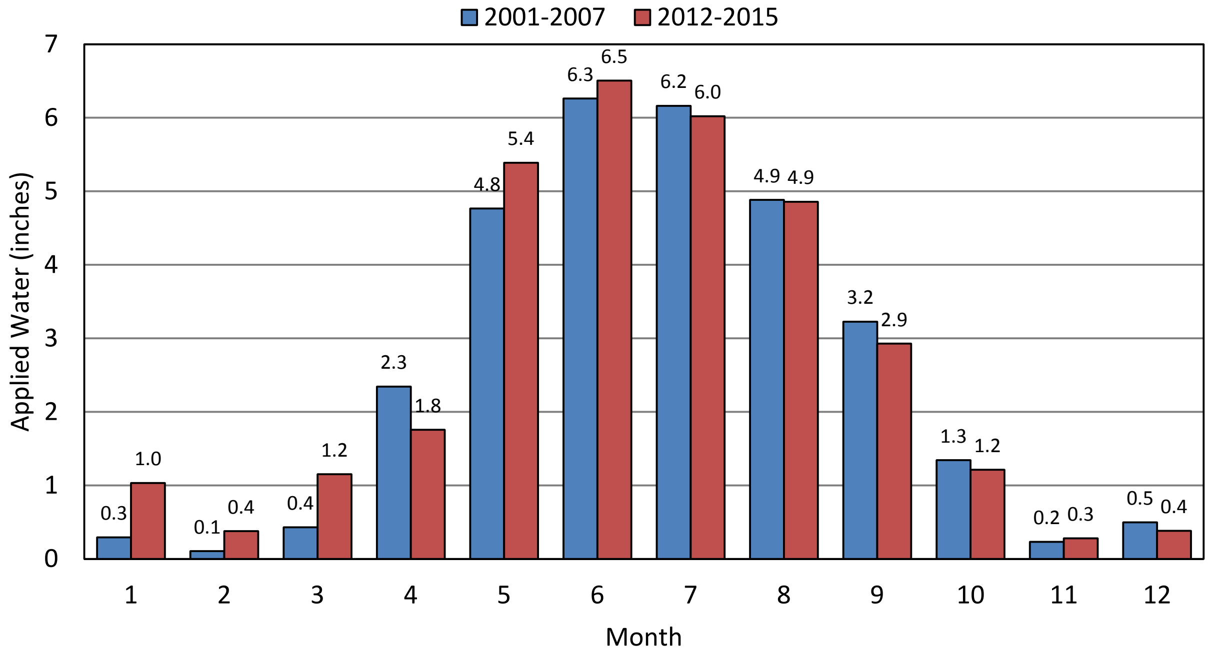

Figure 18. Butte County Orchard Estimated Applied Water for 2001-2007 and for 2012-2015 Drought Period.

To better understand winter orchard demands during drought as compared to baseline conditions, average monthly orchard demands estimated using the BBGM for the months of January, February, and March are summarized in Figure 19 for the 2001-2007 baseline periods and for each year from 2012 to 2015. As indicated, the BBGM suggests that winter orchard applied water demands have been consistently greater between 2012 and 2015 than average demands for the 2001-2007 period and similar for each year, averaging 2.6 inches during the drought, as compared to 0.8 inches for the baseline period. The timing of winter demands estimated by the BBGM differs across drought years, however:

- During 2012, the BBGM predicts substantial irrigation during the months of January and March,
- During 2013, the BBGM predicts substantial irrigation during the months of January and February,
- During 2014, the BBGM predicts substantial irrigation during January, and
- During 2015, the BBGM predicts substantial irrigation during March.

Differences in the timing of winter demands result from differences in timing and amounts of precipitation from prior months and during the January to March period. For example, January and February applied water demands were estimated to be small during 2015, presumably due to substantial precipitation that occurred in December 2014 and February 2015.

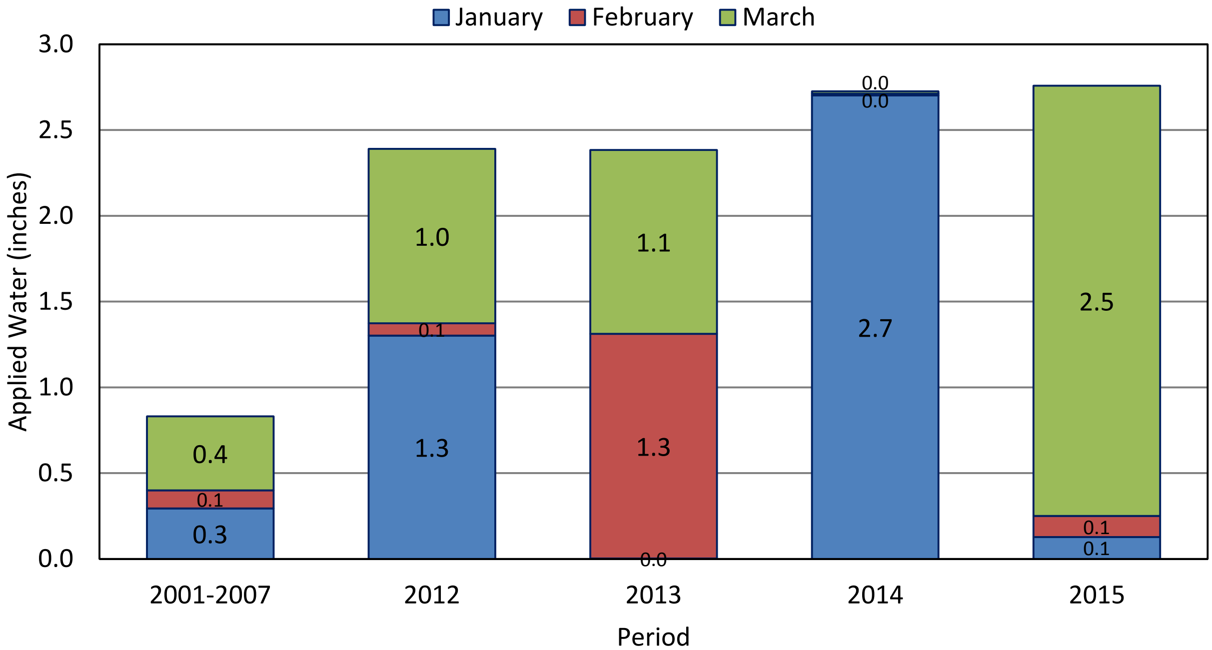

Figure 19. Butte County Orchard Estimated January to March Applied Water by Month for 2001-2007 and for 2012-2015 Drought Period.

Deep Percolation

Deep percolation, or the vertical downward movement of water from the root zone to the underlying groundwater system, is an important source of recharge. Deep percolation results from both precipitation and irrigation processes. In order to understand potential impacts of drought on groundwater recharge, estimates of deep percolation of applied water and deep percolation of precipitation are summarized for the 2001-2007 baseline period and for the 2012-2015 drought period. These estimates were developed using the IDC component of the BBGM.

Deep Percolation of Applied Water

Deep percolation of applied water estimates for Butte County are presented in Figure 20 for the baseline and drought periods. Deep percolation of applied water is divided based on the FRSC and Mixed Supply areas. As indicated, total deep percolation of applied water has been less during the drought period than the baseline period, averaging 195 taf between 2012 and 2015 as compared to 213 taf between 2001 and 2007 (91 percent of the baseline period). For the FRSC area, deep percolation of applied water has also been less during the drought period than the baseline period, averaging 88 taf between 2012 and 2015 as compared to 100 taf between 2001 and 2007 (88 percent of the baseline period). For the Mixed Supply area, deep percolation of applied water has also been less during the drought period than the baseline period, averaging 106 taf between 2012 and 2015 as compared to 113 taf between 2001 and 2007 (95 percent of the baseline period).

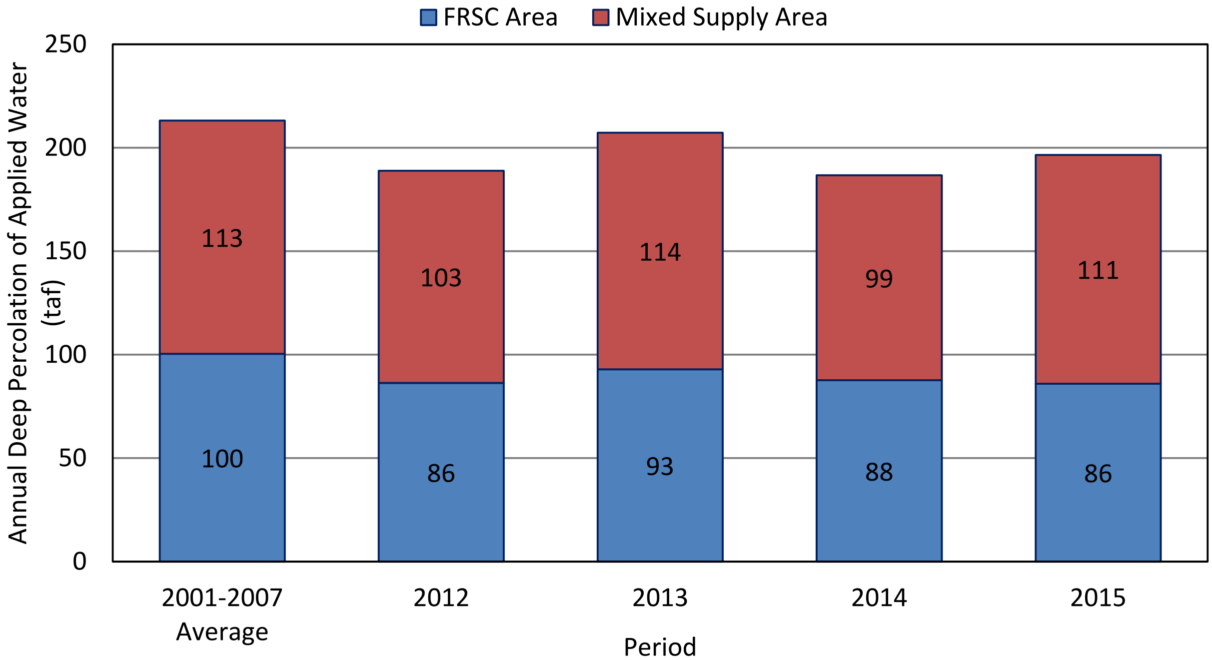

Figure 20. Butte County Estimated Deep Percolation of Applied Water for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Deep Percolation of Precipitation

Deep percolation of precipitation estimates for Butte County are presented in Figure 21 for the baseline and drought periods. Deep percolation of precipitation is divided based on the FRSC and Mixed Supply areas, as well as the Cohasset and Ridge foothill areas, which may be an important source of recharge. For the FRSC and Mixed Supply areas, non-irrigated lands of native vegetation are also included. A substantial portion of the Mixed Supply area includes non-irrigated lands where recharge from deep percolation of precipitation occurs (for example in the Vina subregion).

As indicated in Figure 21, total deep percolation of precipitation has been substantially less during the drought period than the baseline period, averaging 187 taf between 2012 and 2015 as compared to 305 taf between 2001 and 2007 (61 percent of the baseline period). For the FRSC, Mixed Supply, and Foothill areas deep percolation of precipitation was similarly less during the drought period than the baseline period as follows:

- FRSC Area: 18 taf annually between 2012 and 2015, compared to 25 taf between 2001 and 2007 (72 percent of baseline period average)
- Mixed Supply Area: 121 taf annually between 2012 and 2015, compared to 188 taf between 2001 and 2007 (64 percent of baseline period average)
- Foothill Area: 48 taf annually between 2012 and 2015, compared to 92 taf between 2001 and 2007 (52 percent of baseline period average)

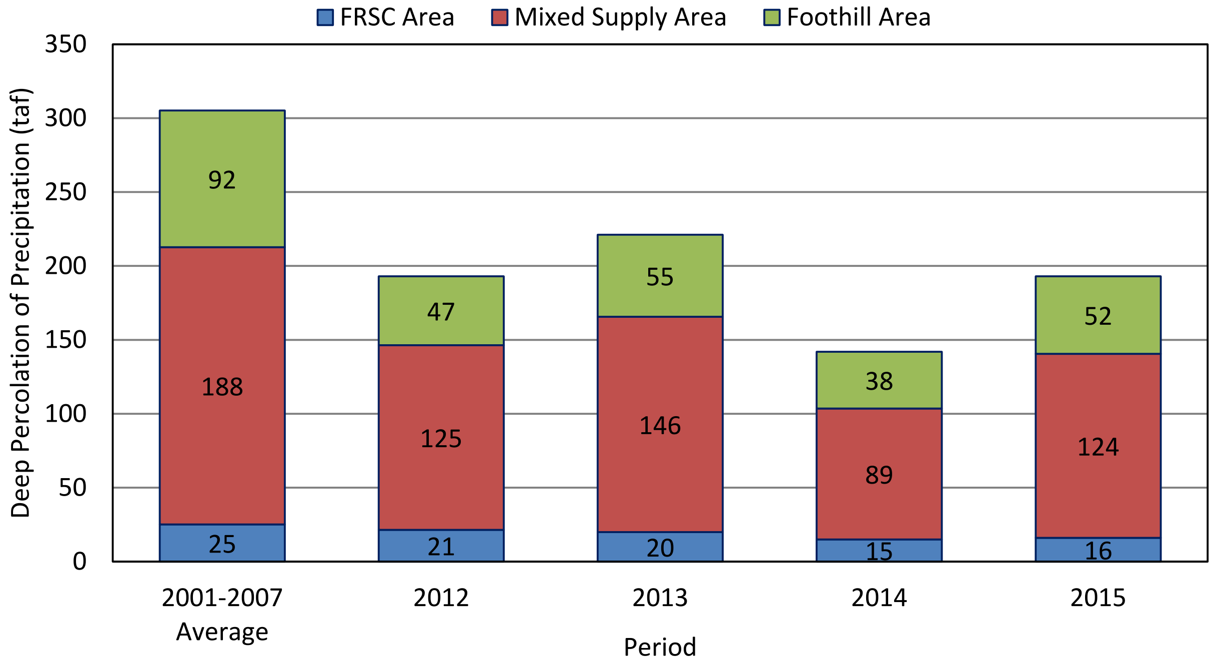

Figure 21. Butte County Estimated Deep Percolation of Precipitation for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Summary

The recent 2012 to 2015 drought period is marked by a reduction in precipitation and surface water supplies, including important spring runoff from snowmelt. Reduced precipitation on the valley floor has led to increased irrigation demands, particularly for non-rice crops, which are more dependent on precipitation to meet irrigation water demands, particularly during the late winter/early spring. The reduction in surface water supplies has led to increased demand for groundwater to meet crop irrigation requirements. This is particularly true for 2015, when Butte Creek water supplies were curtailed and FRSC supplies were curtailed for the first time since 1992. Impacts of the drought are summarized in Table 1 on the following page by providing a comparison of average values for the drought period to the baseline period. For each component of the system considered, the difference and percent difference of the drought period from the baseline period is provided.

Over this same period, groundwater recharge from precipitation in the form of deep percolation of precipitation on irrigated and non-irrigated lands has decreased. The combination of the drought impacts of reduced supplies and reduced recharge from precipitation is that net recharge of the groundwater system has declined during the 2012 to 2015 period, as compared to the 2001 to 2007 baseline period. Additional information describing seepage from and accretions to streams, canals, and drains is needed to fully quantify impacts of drought on groundwater recharge; however observations can be made regarding the impact of drought on net recharge from the irrigated and non-irrigated land surfaces in the County.

Table 1. Comparison of 2012-2015 Drought Period to 2001-2007 Baseline Period for Components of the System Evaluated.

System Component	Period		Difference	
	2001-2007 (Baseline)	2012-2015 (Drought)	Absolute	Percent
Precipitation				
Valley Floor Precipitation (inches)	28.5	23.3	-5.2	-18%
Water Year Streamflows				
Feather River Full Natural Flow (maf)	4.09	2.43	-1.66	-41%
Butte Creek Flow (taf)	305	162	-143	-47%
April-July Streamflows				
Feather River Full Natural Flow (maf)	1.67	0.76	-0.90	-54%
Butte Creek Flow (taf)	109	47	-62	-57%
Irrigated Acres (Thousands)				
FRSC Area	124	114	-10	-8%
Mixed Supply Area	124	126	3	2%
Butte County (Total)	248	241	-7	-3%
Surface Water Supplies (Diversions)				
Lake Oroville (taf)	709	612	-98	-14%
Butte Creek (taf)	59	34	-25	-43%
Sacramento River (taf)	11	11	0	-2%
Other (taf)	13	12	0	-3%
Butte County (Total)	792	669	-123	-16%
Groundwater Pumping				
FRSC Area (taf)	21	58	37	178%
Mixed Supply Area (taf)	344	395	52	15%
Butte County (Total)	364	453	89	24%
Reference Evapotranspiration				
Reference Evapotranspiration (inches)	50.4	51.4	1.0	2%
Crop Evapotranspiration				
FRSC Area (taf)	447	435	-12	-3%
Mixed Supply Area (taf)	399	428	29	7%
Butte County (Total)	846	863	17	2%
Crop Evapotranspiration of Applied Water				
FRSC Area (taf)	366	353	-13	-4%
Mixed Supply Area (taf)	269	300	31	11%
Butte County (Total)	636	653	18	3%
Deep Percolation of Applied Water				
FRSC Area (taf)	100	88	-12	-12%
Mixed Supply Area (taf)	113	107	-6	-5%
Butte County (Total)	213	195	-18	-9%
Deep Percolation of Precipitation				
FRSC Area (taf)	25	18	-7	-28%
Mixed Supply Area (taf)	188	121	-67	-36%
Foothill Area (taf)	92	48	-44	-48%
Butte County (Total)	305	187	-118	-39%

Potential Impacts on Groundwater Recharge

Key components of groundwater recharge are the vertical flows to and from the groundwater system. Flows to the groundwater system include deep percolation of applied water and precipitation. Flows from the groundwater system include groundwater pumping. Other flows include seepage from and accretions to streams, canals, and drains. Despite not accounting for these flows in the current drought assessment, observations can be made about drought impacts on groundwater recharge on irrigated and non-irrigated land surfaces in the County by comparing estimates of deep percolation and groundwater pumping for the 2012 to 2015 drought and 2001 to 2007 baseline periods.

Figure 22 shows county-wide estimates of deep percolation of applied water, deep percolation of precipitation, and groundwater pumping for the baseline period and the years 2012 through 2015. Deep percolation, which represents an inflow to the groundwater system, is shown as a positive number. Groundwater pumping, which represents an outflow from the groundwater system, is shown as a negative number. Additionally, the land surface net recharge (deep percolation minus groundwater pumping) is shown, representing the net recharge occurring from vertical flows into and out of the root zone on irrigated and non-irrigated lands.

As indicated in Figure 22, it is estimated that net recharge from these processes averaged approximately 154 taf during the baseline period, and that net extraction has occurred during the drought, ranging from net recharge of 30 taf to net extraction of 202 taf annually with average net extraction of 71 taf. Thus, it is estimated that the average annual net recharge resulting from deep percolation and groundwater pumping (and not considering stream seepage and accretions) has decreased by approximately 225 taf for the drought period compared to the baseline period.

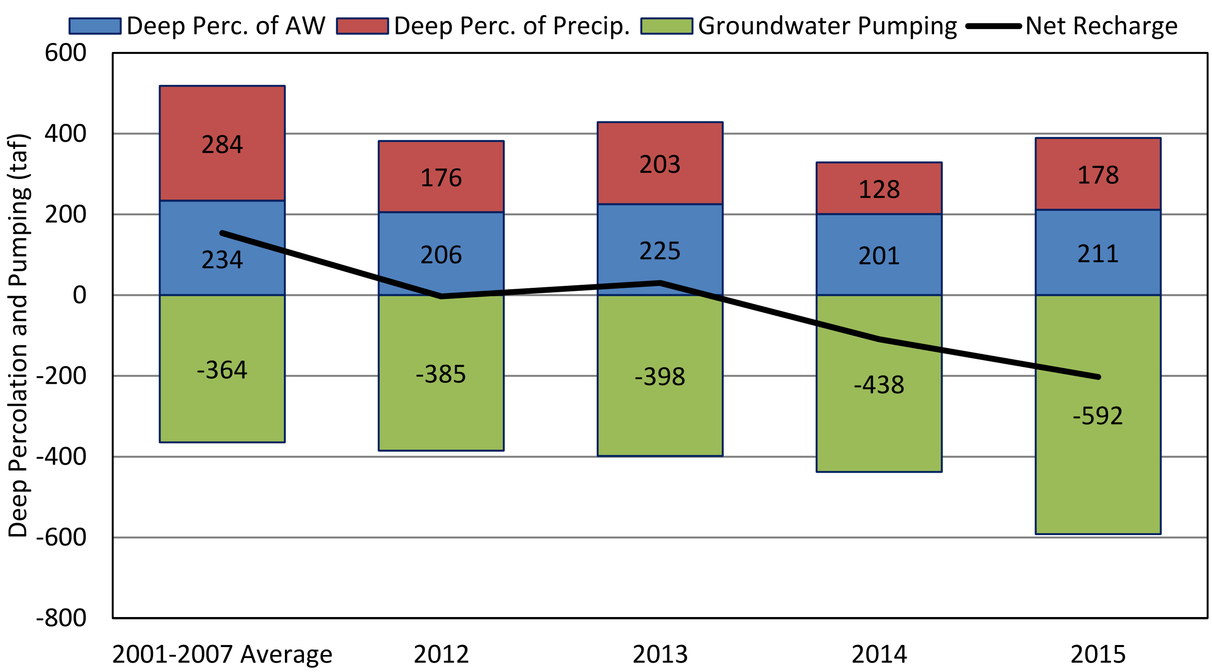

Figure 22. Butte County Estimated Deep Percolation, Groundwater Pumping, and Land Surface Net Recharge (Deep Percolation – Pumping) for 2001-2007 and by Water Year for 2012-2015 Drought Period.

For the FRSC area (Figure 23) it is estimated that net recharge from these processes averaged approximately 105 taf during the baseline period, and that net recharge has decreased during the drought, with net recharge of approximately 88 taf, 86 taf, and 72 taf in 2012, 2013, and 2014, respectively, and net extraction of 54 taf in 2015. During the drought period, net recharge has averaged approximately 48 taf annually. Thus, it is estimated that the average annual net recharge resulting from deep percolation and groundwater pumping (and not considering stream seepage and accretions) has decreased by approximately 56 taf for the drought period compared to the baseline period.

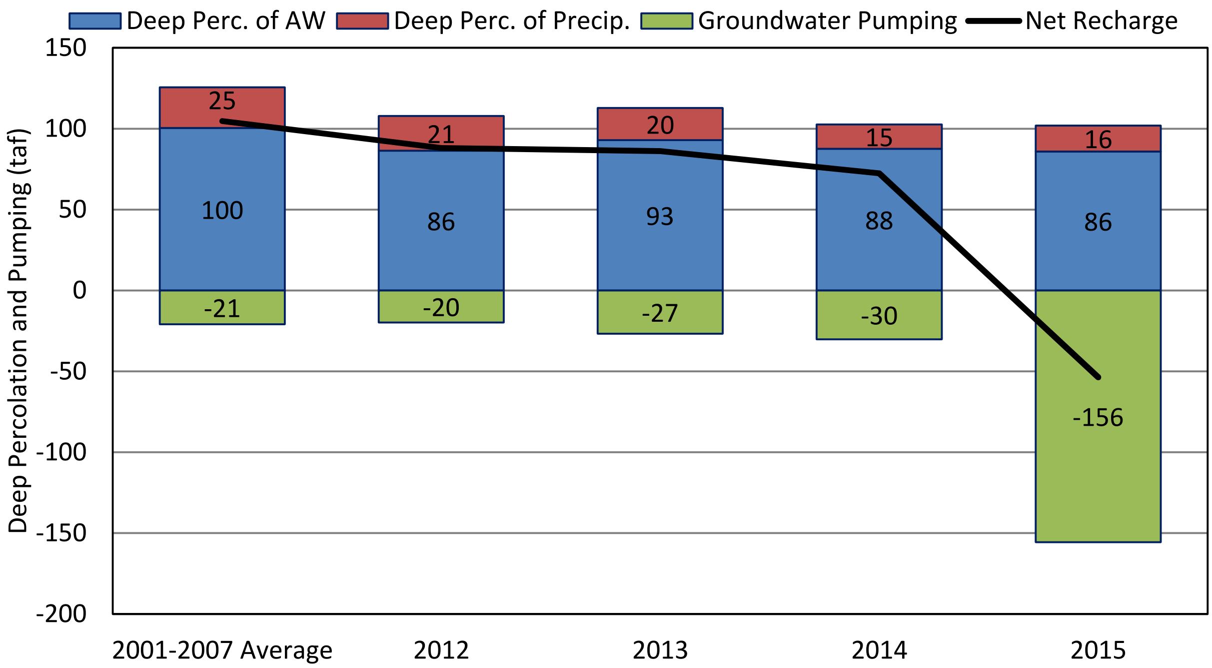

Figure 23. Butte County FRSC Area Estimated Deep Percolation, Groundwater Pumping, and Land Surface Net Recharge (Deep Percolation – Pumping) for 2001-2007 and by Water Year for 2012-2015 Drought Period.

For the Mixed Supply area (Figure 24) it is estimated that net extraction from deep percolation and pumping averaged approximately 43 taf during the baseline period, and that net extraction has increased during the drought, ranging from 111 taf to 220 taf annually and averaging 167 taf. Thus, it is estimated that the average annual net extraction resulting from deep percolation and groundwater pumping (and not considering stream seepage and accretions) has increased by approximately 124 taf for the drought period compared to the baseline period.

For the Foothill area, where deep percolation of applied water and groundwater pumping are essentially zero, it is estimated that net recharge from deep percolation averaged approximately 92 taf during the baseline period, and that net recharge has decreased during the drought, ranging from 38 taf to 55 taf annually and averaging 48 taf (Figure 25). Thus, it is estimated that the average annual net recharge (not considering stream seepage and accretions) has decreased by approximately 44 taf for the drought period compared to the baseline period.

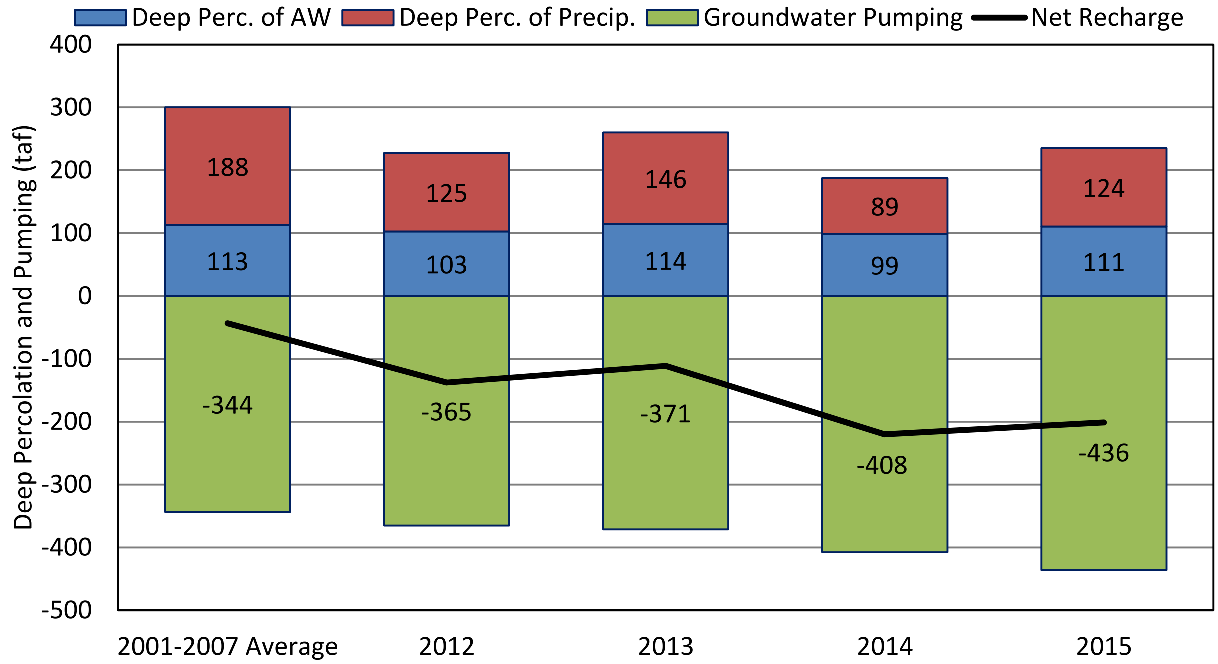

Figure 24. Butte County Mixed Supply Area Estimated Deep Percolation, Groundwater Pumping, and Land Surface Net Recharge (Deep Percolation – Pumping) for 2001-2007 and by Water Year for 2012-2015 Drought Period.

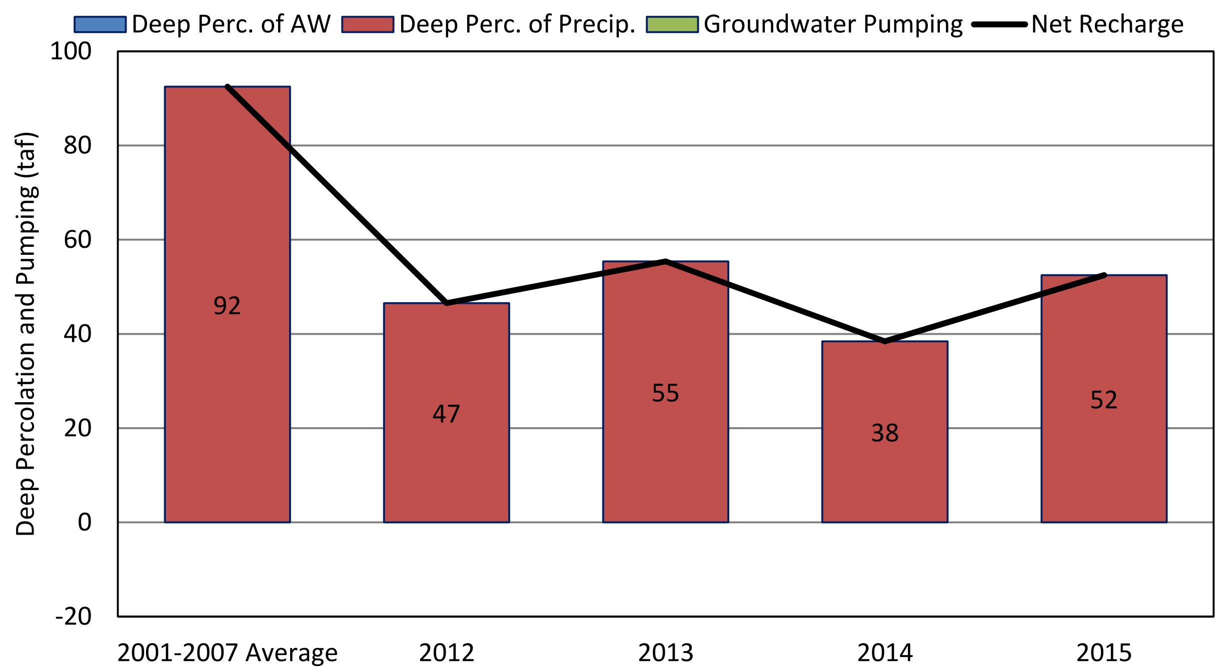

Figure 25. Butte County Foothill Area Estimated Deep Percolation, Groundwater Pumping, and Land Surface Net Recharge (Deep Percolation – Pumping) for 2001-2007 and by Water Year for 2012-2015 Drought Period.

Based on the analysis presented herein, the primary impacts of drought on groundwater recharge are reductions in available surface water supplies, which lead to increased groundwater pumping, and decreased deep percolation of precipitation. Increases in crop irrigation requirements and evapotranspiration of applied water experienced during drought also impact recharge to a lesser extent.

Comparison to Prior Estimates of Drought Impacts

Normal and drought year water supplies and demands were estimated as part of the Butte County Water Inventory and Analysis (WI&A) prepared in 2001. As part of the analysis of agricultural supplies and demands, normal and drought years were defined as follows:

- Normal Year – Cropping pattern, ET rates, and precipitation from 1997
- Drought Year – Cropping pattern and ET rates from 1997; precipitation from 1977

In addition to reducing precipitation to 1977, reductions in surface water supplies and resulting increases in groundwater pumping were estimated.

In order to compare the analysis presented herein to the 2001 WI&A, the following are compared:

- Surface water diversions (compared to surface water "supplies" from the 2001 WI&A),
- Groundwater pumping (compared to groundwater "supplies" from the 2001 WI&A),
- Net recharge of applied water[7]

Surface water diversions were estimated to decrease from 774 taf to 591 taf for the 2001 WI&A between normal and drought years. This represents a decrease of 183 taf, or 24%. For the current analysis, surface water diversions were estimated to decrease from 792 taf to 669 taf between the 2001-2007 average and the 2012-2015 average, a decrease of 123 taf, or 16%. The decrease is less than for the 2001 WI&A analysis in part because in that analysis the drought year is meant to represent a year in which Feather River and other surface water supplies are curtailed. Comparison of the 2001-2007 average (normal year) to 2015 (a curtailment year) suggests a decrease in surface water diversions from 792 taf to 431 taf (361 taf, or 46%).

Groundwater pumping was estimated to increase from 439 taf to 641 taf for the 2001 WI&A between normal and drought years. This represents an increase of 202 taf, or 46%. For the current analysis, groundwater pumping was estimated to increase from 364 taf to 453 taf between the 2001-2007 average and the 2012-2015 average, an increase of 89 taf, or 24%. The increase is less than for the 2001 WI&A analysis in part because in that analysis the drought year is meant to represent a year in which Feather River and other surface water supplies are curtailed. Comparison of the 2001-2007 average (normal year) to 2015 (a curtailment year) suggests an increase in groundwater pumping from 364 taf to 592 taf (228 taf, or 63%).

Net recharge of applied water was estimated to decrease from -281 taf to -419 taf for the 2001 WI&A between normal and drought years. This represents a decrease of 138 taf, or 49%. For the current analysis, net recharge of applied water was estimated to decrease from -151 taf to -258 taf between the 2001-2007 average and the 2012-2015 average, a decrease of 107 taf, or 71%. The decrease is less than for the 2001 WI&A analysis in part because in that analysis the drought year is meant to represent a year in which Feather River and other surface water supplies are curtailed. Comparison of the 2001-2007 average (normal year) to 2015 (a curtailment year) suggests a decrease in net recharge of applied water from -151 taf to -395 taf (244 taf, or 162%).

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[7] Calculated as Deep Percolation of Applied Water – Groundwater Pumping.

Comparison of the current analysis to the 2001 WI&A normal and drought year water supplies and net recharge of applied water shows general agreement: during drought years, surface water diversions decrease, groundwater pumping increases, and net recharge of applied water decrease. Changes in these components of the water balance are reasonably similar, with average changes in hydrology being somewhat less for the comparison of 2012-2015 average conditions to 2001-2007 baseline conditions than for the comparison of 2015 conditions to 2001-2007 baseline conditions. These two comparisons for the current analysis tend to bound (changes are less than and greater than, respectively) the 2001 WI&A.

A limitation of the 2001 WI&A is that cumulative effects of drought are not examined, with a drought year representing a historically rare condition in which Feather River supplies are curtailed. Additionally, the evaluation of net recharge for the 2001 WI&A analysis does not consider deep percolation of precipitation, an important source of recharge. When the focus is narrowed to net recharge of applied water alone, without considering recharge from precipitation, the results have the potential to be misleading, suggesting unsustainable conditions. The current analysis provides a more robust depiction of potential impacts of drought on the groundwater system by accounting for the contribution of precipitation to groundwater recharge and considering cumulative effects of drought across years, including both Feather River full supply and curtailment years. Additional consideration of seepage from and accretions to streams, canals, and drains is needed along with consideration of subsurface boundary inflows and outflows to fully characterize impacts of drought on the groundwater system. These components of the system can be incorporated through future application of the BBGM.