California Energy Commission

Estimated Energy Requirements under Drought Conditions

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EXECUTIVE SUMMARY

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo conducted this study on behalf of the California Energy Commission (CEC). For this study, ITRC utilized an agricultural water energy use model developed in a previous study titled *California Agricultural Water Energy Requirements* in order to estimate energy requirements during drought periods.

Results of the estimated current energy requirements for an average year from the *California Agricultural Water Energy Requirements* report were used as the baseline. That report, which describes the basic data used for this model, can be obtained online at http://www.itrc.org/reports/cec/energyreq.html. Assumptions and analyses used to estimate the results shown in **Table ES-1** are described in the body of this report.

Table ES-1 shows the results of different drought severities on energy requirements. A drought severity of 20% signifies a reduction in surface water availability of 20% in the Sacramento and San Joaquin Valleys. For this study, crop acreage and irrigation types are assumed to remain the same as the baseline study; therefore, applied water requirements are assumed to remain the same. It is assumed that reductions in surface water deliveries are replaced by groundwater pumping. The results in the table are shown for year 1 and year 5 of a consecutive drought.

Table ES-1. Estimated total energy requirements under different drought severities for the first and fifth years of a consecutive drought.

Surface Water Reduction	Consecutive Year of Drought	Total Energy Use for CA Ag Water
		MWH/Year
Baseline	**0**	**10,159,900**
20%	**1**	**10,991,867**
20%	**5**	**12,292,867**
40%	**1**	**12,136,520**
40%	**5**	**16,825,220**
60%	**1**	**13,422,847**
60%	**5**	**22,857,647**

Confidence Interval	**+/- 14%**

The reduction in surface water supplies results in decreased district surface water pumping as well as energy used for conveying water to these districts, which are located primarily along the California Aqueduct and the Delta-Mendota Canal. However, this reduction is offset by the increase in energy used to pump groundwater by the districts and on-farm. In addition, energy requirements for transfers and returns from groundwater banking to Metropolitan Water District (MWD) increase substantially depending on the amount of surface water reduced.

Interestingly, the energy requirements for year 1 of droughts at different severities are not as significant as for year 5. This indicates that the increased total dynamic head (TDH) and decreased pump efficiency due to groundwater overdraft are more pressing concerns during later years of a significant consecutive drought.

The results from this study indicate that the average energy requirement for agricultural water increases from 0.28 MWH/AF during a typical year to 0.63 MWH/AF during the fifth year of a consecutive drought with a 60% reduction in surface water supplies (**Table ES-2**). This is a more than two-fold increase in energy required to receive the same volume of water.

Table ES-2. Estimated energy requirement per acre-foot of water used for agricultural purposes.

Surface Water Reduction	Consecutive Year of Drought	Energy Requirement for Ag Water
		MWH/AF
Baseline	**0**	**0.28**
20%	**1**	**0.30**
20%	**5**	**0.34**
40%	**1**	**0.33**
40%	**5**	**0.46**
60%	**1**	**0.37**
60%	**5**	**0.63**

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BACKGROUND

The Irrigation Training and Research Center (ITRC) of California Polytechnic State University, San Luis Obispo has prepared this report under a contract with the California Energy Commission (CEC). This study is a continuation of a previous study conducted by ITRC for the CEC summarized in a report titled *California Agricultural Water Energy Requirements*, completed in December 2003. That study focused on determining a baseline energy requirement for agricultural sectors as well as analyzing potential future trends in the agricultural water community to predict future energy requirements.

This study utilized the data and model developed in the *California Agricultural Water Energy Requirements* analysis in order to quantify the impact of drought conditions on energy requirements of the agricultural water sector. Details on model development and data used to estimate the baseline energy requirements can be found in the *California Agricultural Water Energy Requirements* report (http://www.itrc.org/reports/cec/energyreq.html).

A drought occurs when the surface water supply is below a normal or baseline level for consecutive years. Droughts in California can be caused by below normal precipitation and snow pack during the fall, winter, and early spring seasons. They can also occur when snow and rainfall are very low in the later winter and spring and temperatures are unusually warm during this period regardless of what happened in fall and early winter. The reason for this is that many storage reservoirs along the Sierra Nevada Mountains are used for flood control during the winter and spring. Water cannot be stored for agricultural use during this time; therefore, all water not utilized is lost to rivers and eventually the ocean or the Tulare Lake Basin. In some areas (e.g., eastern Kern county), groundwater storage projects have been completed to take the water that would typically be lost and use it to recharge groundwater aquifers. Because of the significant groundwater overdraft throughout much of California's Central Valley, groundwater recharge has become popular, and has slowed the rate of groundwater level decline.

From an energy standpoint, using the groundwater aquifer to store water is not ideal. Pumping water from the groundwater aquifers is the largest component of energy use in the agricultural water sector. During drought periods when surface water supplies are reduced, farmers are forced to pump even greater amounts from the groundwater to meet their crop water requirements. As the groundwater levels drop, energy requirements become even greater because: (i) additional energy is needed to pump from this lower level (higher TDH) and (ii) the pump efficiency drops as the TDH increases. However, in places where building additional large storage reservoirs is not an option, increased groundwater pumping remains the best solution at this time.

This study examines how energy use by agricultural water sectors in California will be impacted by different drought severities for years 1 and 5 of a consecutive drought. Due to the complexity of the system certain assumptions were made to predict energy use for each drought scenario. These assumptions will be discussed in the next section.

AGRICULTURAL ENERGY USE MODEL INPUTS

The details on the basic data used for the model can be found in the *California Agricultural Water Energy Requirements* report. Data and assumptions used specific to the drought analysis are detailed below. This information includes assumed levels of drought, amount of water transfers and water banking, as well as the impact from groundwater overdraft on groundwater levels and pump efficiency.

Drought Severity

Drought severity is the percent reduction in annual surface water supplies in the Sacramento and San Joaquin hydraulic basins. **The percentage of drought severity is equal to the percent reduction in surface water supplies.** For this analysis, multiple levels of drought severity were run through the model based on a single drought year and year 5 of a five-year consecutive drought. The Lower Colorado River Basin was not analyzed in this study. Six model runs were made with the drought scenarios listed in **Table 1**.

Table 1. Drought severity and year of consecutive drought used for the model.

Model Run ID	Drought Severity	Drought Year
A	20%	1
B	20%	5
C	40%	1
D	40%	5
E	60%	1
F	60%	5

The drought severity values were chosen to show how a range of drought conditions could impact energy use. It is not likely that a five-year consecutive drought will have exactly 40% reduction in water supplies each year. However, over a five-year drought period the reduction in annual surface water supplies could show an average of 40%. Therefore, during year 5 the energy requirement results from this study would be representative.

Figure 1 shows historic Sacramento and San Joaquin Four Rivers Unimpaired Runoff data (California Department of Water Resources (DWR) *The California Water Plan Update* Bulletin 160-98, Figures 3-4 and 3-5). **Table 2** shows the average annual volume of runoff and average percent of normal for severe droughts since 1901 (DWR Background – Droughts in California, http://watersupplyconditions.water.ca.gov/background.cfm).

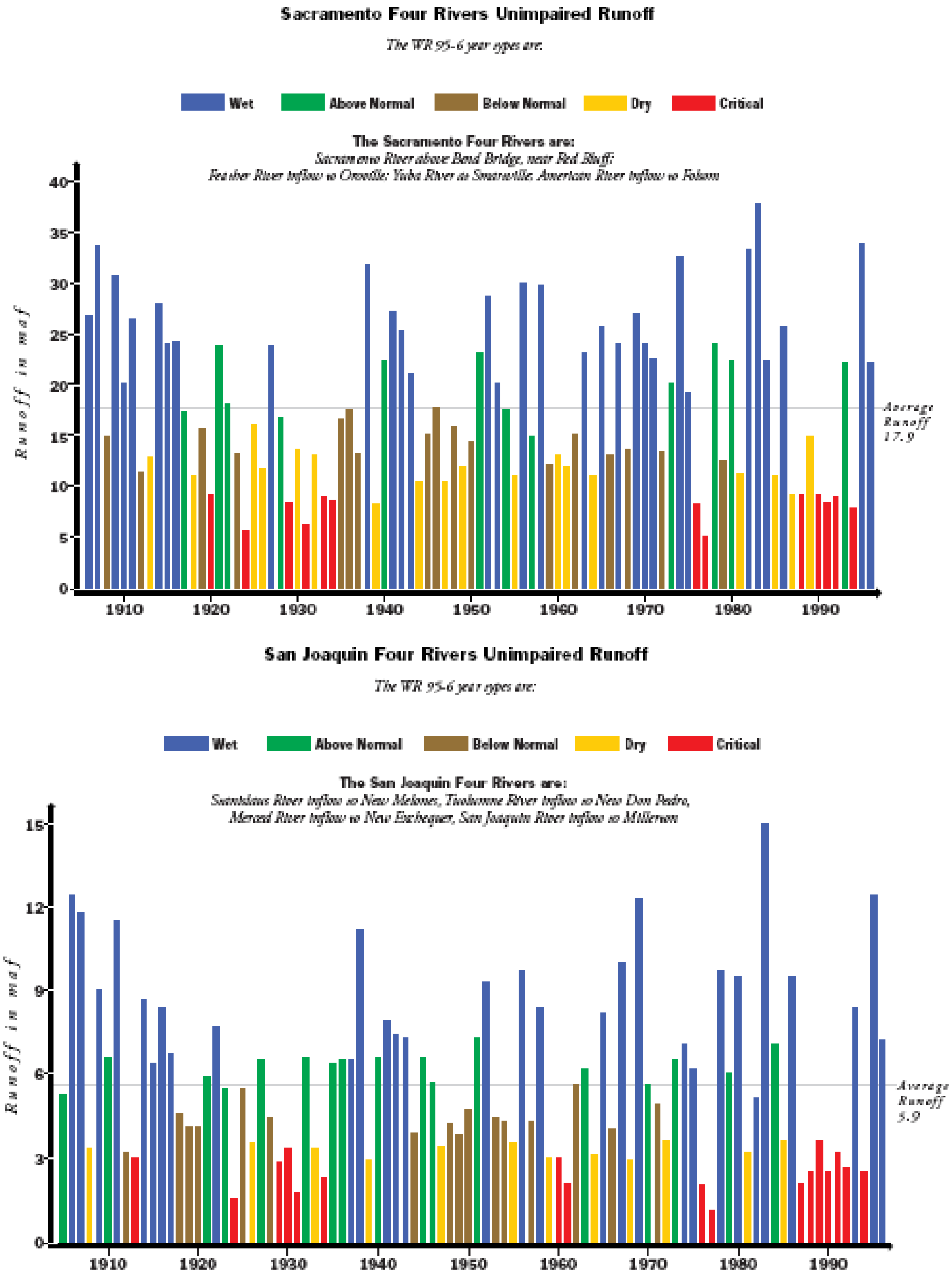

Figure 1. Annual unimpaired runoff from the Sacramento and San Joaquin Four Rivers (DWR Bulletin 160-98).

Table 2. Severity of extreme droughts in the Sacramento and San Joaquin Valleys (DWR Background - Droughts in California)

Drought	Sacramento Valley Runoff			San Joaquin Valley Runoff		
Period	(maf/yr)	(% Average)	(% Reduction)	(maf/yr)	(% Average)	(% Reduction)
1929-34	9.8	55	45	3.3	57	43
1976-77	6.6	37	63	1.5	26	74
1987-92	10	56	44	2.8	47	53
Average Runoff	**17.9**			**5.9**		

Crop Acreage and Irrigation Systems

For this study the crop acreage and irrigation system usage was assumed to be the same as the baseline year. Therefore, the applied water requirements remain the same for every drought severity and consecutive drought year analyzed. Since the surface water supply is reduced, it is assumed that additional water is supplied through groundwater pumping by irrigation districts and farmers.

Water Banking and Water Transfers

Water banking and water transfers have become an important component of the California water market. Water banking specifically has allowed agencies like Metropolitan Water District of Southern California (MWD) to store water during normal and wet years in groundwater aquifers in Kern County. During water-short years MWD can access this water either through in lieu or direct pumping agreements with water agencies in Kern County (more details on water banking and water transfers can be found in the *California Agricultural Water Energy Requirements* report).

For this study ITRC assumed that the pumping at Edmonston Pumping Plant on the California Aqueduct would remain unchanged from a baseline value of 961,000 acre-feet (AF) per year. The access to surface water supplies would be reduced based on the severity of the drought and would be made up primarily through water bank stores. For example, if the drought severity caused a 20% reduction in surface water supplies, the surface water through Edmonston Pumping Plant would be reduced to 768,000 AF (961,000*80%) and the remaining 192,200 AF would be supplied by the water banks in Kern county.

The water agencies with water banking agreements have a limited capacity and therefore can only return a limited volume of water per year to MWD. If the water banking supply were unable to meet the deficit at Edmonston, this study assumed that the remainder of the deficit would be met through groundwater substitution water transfers from the Sacramento Valley.

Table 3 shows the maximum water supplies that can be returned to MWD from its water banking partners in Kern county. In lieu delivery is water that would normally be taken by Semitropic Water Storage District from the California Aqueduct; Semitropic would forgo this delivery during drought years and send it on to MWD. That water would be pumped instead by MWD (or its farmers) and be used to meet applied water requirements.

Table 3. Assumed annual water banking supplies from MWD's major water banking partners in Kern County.

Water Banking Partner	Maximum Banking Supply to MWD (AF)	Estimated Minimum Supply from In Lieu Deliveries (AF)	
AEWSD	75,000		
Semitropic	90,000	55,000	
Kern WB	240,000		
Total	**405,000**	**55,000**	**460,000 AF**

The 55,000 AF value shown in Table 3 is considered the minimum in lieu amount that could be supplied by Semitropic. A maximum in lieu return of 133,000 AF is possible however, during a drought period Semitropic's water allocation would reduced, and it is unlikely much more than that minimum amount would actually be available for in lieu deliveries. Case studies on each of these water banking partners can be found in Attachment G of the *California Agricultural Water Energy Requirements* report.

Groundwater Levels and Pump Efficiency

Drought conditions increase the need for groundwater pumping in order to offset a deficit in surface water supplies. An increase in groundwater pumping results in greater groundwater overdraft and therefore a decrease in the groundwater levels. In terms of energy use, two factors are impacted with a drop in groundwater levels:

1. The pump must lift the water further (increase in total dynamic head (TDH)), requiring more energy.
2. As the TDH increases, the pump efficiency decreases.

The amount of increased energy required to lift groundwater higher and the decrease in pump efficiency will depend on the pump curve. Pump curves vary by impeller model and manufacturer. However, for this study ITRC made estimates regarding the drop in groundwater level and decrease in pumping plant efficiency associated with each drought scenario. The results are shown in **Table 4** (details on how these values were estimated can be found in **Attachment A**).

Table 4. Estimated change in groundwater level (%) and decrease in pumping plant efficiency throughout the state under each drought scenario.

Drought Severity	Consecutive Drought Year	**Decrease in GW Level**	**Decrease in Pump Efficiency**

20%	1	**2%**	**0%**
20%	5	**10%**	**10%**
40%	1	**4%**	**2%**
40%	5	**19%**	**21%**
60%	1	**6%**	**3%**
60%	5	**27%**	**27%**

Conveyance to Irrigation Districts

Water conveyed to water districts, particularly in the western and southern areas of the San Joaquin Valley, requires a certain amount of pumping. Major pumping facilities are located on the California Aqueduct and the Delta-Mendota Canal. Data from the California DWR and the US Bureau of Reclamation were used to analyze the energy requirements for delivering water to districts.

The majority of pumping occurs on the California Aqueduct from the Delta to Southern California. Pumping into the Delta-Mendota Canal is also an important component. Data from the *State Water Project Annual Report of Operations 1997* was used to estimate agricultural pumping requirements in the California Aqueduct and the Delta-Mendota Canal. Municipal and industrial (M&I) water was not included in the energy use component for the baseline data. However, the increase in energy use due to water banking returns and water transfers from agriculture to Metropolitan Water District of Southern California (MWD) was included in the energy requirement for each drought scenario.

Table 5. Estimated agricultural pumping on the DMC and the California Aqueduct and the energy required at each pump station for the baseline estimate

California Aqueduct	**MWh/AF**	**Total Pumped (AF)**	**Ag Water Pumped (AF)**	**MWh for Ag Water Pumping**
Banks Pumping Plant	0.28	2,544,686	1,603,294	450,526
Gianelli Pumping\Generation	0.05	1,774,467	1,774,467	79,851
Dos Amigos Pumping Plant	0.13	3,580,709	2,639,317	353,668
Buena Vista Pumping Plant	0.24	1,154,799	248,407	60,675
Teerink Pumping Plant	0.26	1,042,703	136,311	36,054
Chrisman Pumping Plant	0.62	993,686	87,294	53,901
Edmonston Pumping Plant	2.26	961,114	54,722	123,666
Delta-Mendota Canal				
Tracy Pumping Plant	0.60		869,917	526,125
O'Neill Pumping Plant	0.07		481,117	35,122
			Total	**1,719,588**

As explained previously, it was assumed that during a drought the volume of agricultural water pumped would be reduced at all pumping stations except for Edmonston, which is assumed to remain at 961,000 AF because of water banking returns and water transfers. Water transfers were handled separately and are not included in **Table 6**. Table 6 indicates the new agricultural water pumping at each pumping station along the California Aqueduct and the Delta-Mendota Canal.

Table 6. Adjusted annual volume of agricultural water pumped based on drought severity.

	Percent of Surface Water Reductions due to Drought		
	20%	**40%**	**60%***
California Aqueduct	**Adjusted Annual Volume of Water Pumped (AF)**		
Banks Pumping Plant	1,282,635	961,976	641,318
Gianelli Pumping\Generation	1,419,574	1,064,680	709,787
Dos Amigos Pumping Plant	2,111,454	1,583,590	1,055,727
Buena Vista Pumping Plant	198,726	149,044	99,363
Teerink Pumping Plant	109,049	81,787	54,524
Chrisman Pumping Plant	69,835	52,376	34,918
Edmonston Pumping Plant	Assumed to Remain Unchanged		
Delta-Mendota Canal			
Tracy Pumping Plant	695,934	521,950	347,967
O'Neill Pumping Plant	384,894	288,670	192,447

*Water transfers are not included in this table. During the 60% drought condition 116,600 AF of transfers from Northern California to MWD would increase the pumping along the CA Aqueduct from Banks to Chrisman pumping plants.

RESULTS AND CONCLUSION

Table 7 contains the estimated energy requirements for all major factors taken into account for this model. The baseline (energy use for a normal water year) can be compared to droughts of various severities for years 1 and 5 of a consecutive drought.

Drought conditions will increase the energy requirements throughout the state because of the increase in groundwater use, which requires significantly more energy compared to surface water. If a 60% reduction in surface water occurs for a number of consecutive years, the energy requirement could increase more than two-fold. The majority of this energy would be required during the summer peak season (May through October). However, the water banking returns to MWD would likely take place during fall through early spring.

There are a number of factors that will affect the actual energy requirements that could not be predicted with a high level of confidence. For example, severe consecutive drought years will likely lead to a reduction in irrigated agriculture acreage throughout the state. Or there could be a shift from longer season annual crops to shorter season crops, which require less water. The extent of these possible changes is unknown; regardless, energy requirements are sure to increase dramatically.

Table 7. Estimated energy requirements based on drought year and drought severity

Surface Water Reduction	Consecutive Year of Drought	District Surface Water Pumping	District Groundwater Pumping	On-Farm Groundwater Pumping	On-Farm Booster Pumping	Conveyance to Districts	Energy for Water Banking and Transfers to MWD	Total Energy Use for CA Ag Water	Energy Requirement for Ag Water
		MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/Year	MWH/AF
Baseline	**0**	821,800	246,000	4,499,000	2,873,500	1,719,600	Variable	**10,159,900**	**0.28**
20%	**1**	657,400	300,300	5,693,700	2,873,500	1,400,400	+66,567	**10,991,867**	**0.30**
20%	**5**	657,400	382,900	6,912,100	2,873,500	1,400,400	+66,567	**12,292,867**	**0.34**
40%	**1**	493,100	369,000	7,159,900	2,873,500	1,081,200	+159,820	**12,136,520**	**0.33**
40%	**5**	493,100	625,300	11,592,300	2,873,500	1,081,200	+159,820	**16,825,220**	**0.46**
60%	**1**	328,700	436,400	8,646,300	2,873,500	762,000	+375,947	**13,422,847**	**0.37**
60%	**5**	328,700	901,400	17,616,100	2,873,500	762,000	+375,947	**22,857,647**	**0.63**

Confidence Interval +/-	**14%**

Attachment A

Estimation of Groundwater Level and Pump Efficiency Change under Drought Conditions

ESTIMATION OF GROUNDWATER LEVEL CHANGE UNDER DROUGHT CONDITIONS

This analysis was conducted on a valley-wide basis and incorporated specific yield, aquifer surface area, and predicted groundwater overdraft from the Sacramento and San Joaquin Valleys. Specific yield (%) values for aquifers throughout the region were obtained from the California Department of Water Resources (DWR) individual groundwater basin website (http://www.groundwater.water.ca.gov/bulletin118/basin_desc/). The surface area of the groundwater aquifers throughout the valleys was obtained from a DWR geographic information system (GIS) shapefile of groundwater basins (**Figure A-1**).

The groundwater overdraft was estimated under each drought scenario for years 1 and 5 of a consecutive drought. The Energy Analysis Model was utilized to make this estimation. The total estimated overdraft due to drought conditions alone is shown in **Table A-1**.

Table A-1. Estimated groundwater deficit in the Sacramento and San Joaquin Valleys under each drought scenario.

	Estimated Groundwater Deficit (AF)		
Consecutive Drought Year	**20%**	**40%**	**60%**
After Year 1	3,833,156	7,666,312	11,616,068
After Year 5	19,165,779	38,331,559	58,080,338

Figure A-1. Groundwater basins used to determine the groundwater aquifer surface area in the San Joaquin and Sacramento Valleys.

The surface area of the groundwater aquifers and the specific yield examined in this analysis is shown in **Table A-2**. Specific yield is shown as the ratio of the volume of water in a specific volume of soil (ft^3 of Water/ft^3 of Soil). The Average Groundwater Yield describes the volume of water per foot of soil depth over the entire groundwater aquifer.

Table A-2. Specific yield and aquifer surface area for the aquifers in the San Joaquin and Sacramento Valleys.

Region	**Specific Yield (ft^3 Water/ft^3 Soil)**	**Aquifer Area (acres)**	**Aquifer Area (ft^2)**	**Average Groundwater Yield (AF/ft soil)**
Sacramento	0.07	4,400,000	1.92E+11	308,000
San Joaquin	0.11	8,710,000	3.79E+11	958,100
Overall	**0.09**	**13,110,000**	**5.71E+11**	**1,179,900**

The average and percent drops in groundwater depth were estimated utilizing the groundwater overdraft and the Average Groundwater Yield over the same area. These values are shown in **Tables A-3** and **A-4**.

Table A-3. Estimated drop in groundwater depth in the Sacramento and San Joaquin Valleys for each of the three drought scenarios.

	Average Drop in Groundwater Depth (ft)		
Consecutive Drought Year	**20%**	**40%**	**60%**
After Year 1	3	6	10
After Year 5	16	32	49

Table A-4. Estimated percent drop in groundwater depth in the Sacramento and San Joaquin Valleys.

Drought Severity	Consecutive Drought Year	**Decrease in GW Level**
20%	1	**2%**
20%	5	**10%**
40%	1	**4%**
40%	5	**19%**
60%	1	**6%**
60%	5	**27%**

Reality Check

In order to authenticate values shown in **Table A-4**, actual groundwater elevation data was taken from wells in four California counties for the spring and fall of 1987 and the fall of 1992, which are years 1 and 5 of the most recent consecutive drought in California. The data was obtained from the California Department of Water Resources (DWR) online groundwater data website (http://well.water.ca.gov/). The averaged data is shown in **Table A-5**.

Table A-5. Reality check of average groundwater depths for four counties from Spring of 1987 and fall of 1992.

	Average Depth to Groundwater (ft)			**Spring-Fall 1987**		**1987-1992**	
County	Spring 1987	Fall 1987	Fall 1992	Actual GW Drop (ft)	% Drop	Actual GW Drop (ft)	% Drop
Kern	205	218	251	13	6%	46	19%
Kings	57	69	88	12	17%	31	35%
Glenn	18	20	28	2	8%	10	36%
Sacramento	78	85	89	7	9%	12	13%
			Average	**9**	**10%**	**25**	**26%**

The average reduction in available surface runoff during the 1987-92 drought was approximately 47% of the average supplies. This check indicates that the values in **Table A-4** are in the correct ballpark.

Decrease in Pumping Plant Efficiency

The drop in groundwater depth increases both total dynamic head (TDH) and pumping plant efficiency. The example pump curve in **Figure A-2** illustrates how the pumping plant efficiency changes at different flow rates and heads for this example impeller.

The analysis on the following pages examines three separate scenarios to estimate the drop in pump efficiency due to overdraft from drought conditions:

1. A decrease in efficiency due to an increase in TDH
2. A decrease in efficiency due to pump wear
3. The most realistic scenario, taking into account both increased TDH and pump wear

Scenario 1. In this scenario, pumping plant efficiency starts at 52% prior to the overdraft. Only the design pump curve will be used to determine the new pumping plant efficiency with a groundwater level drop of 10%. This assumes that the sole reason for the pumping plant's decreased efficiency was an increase in TDH (above the optimal design TDH).

Analyzing the pump curve in **Figure A-2,** the 52% efficiency is circled in green. The corresponding TDH and flow rate (GPM) are indicated. If the TDH increases 10% (3.5 feet), the new estimated pumping plant efficiency is 36% (indicated in red).

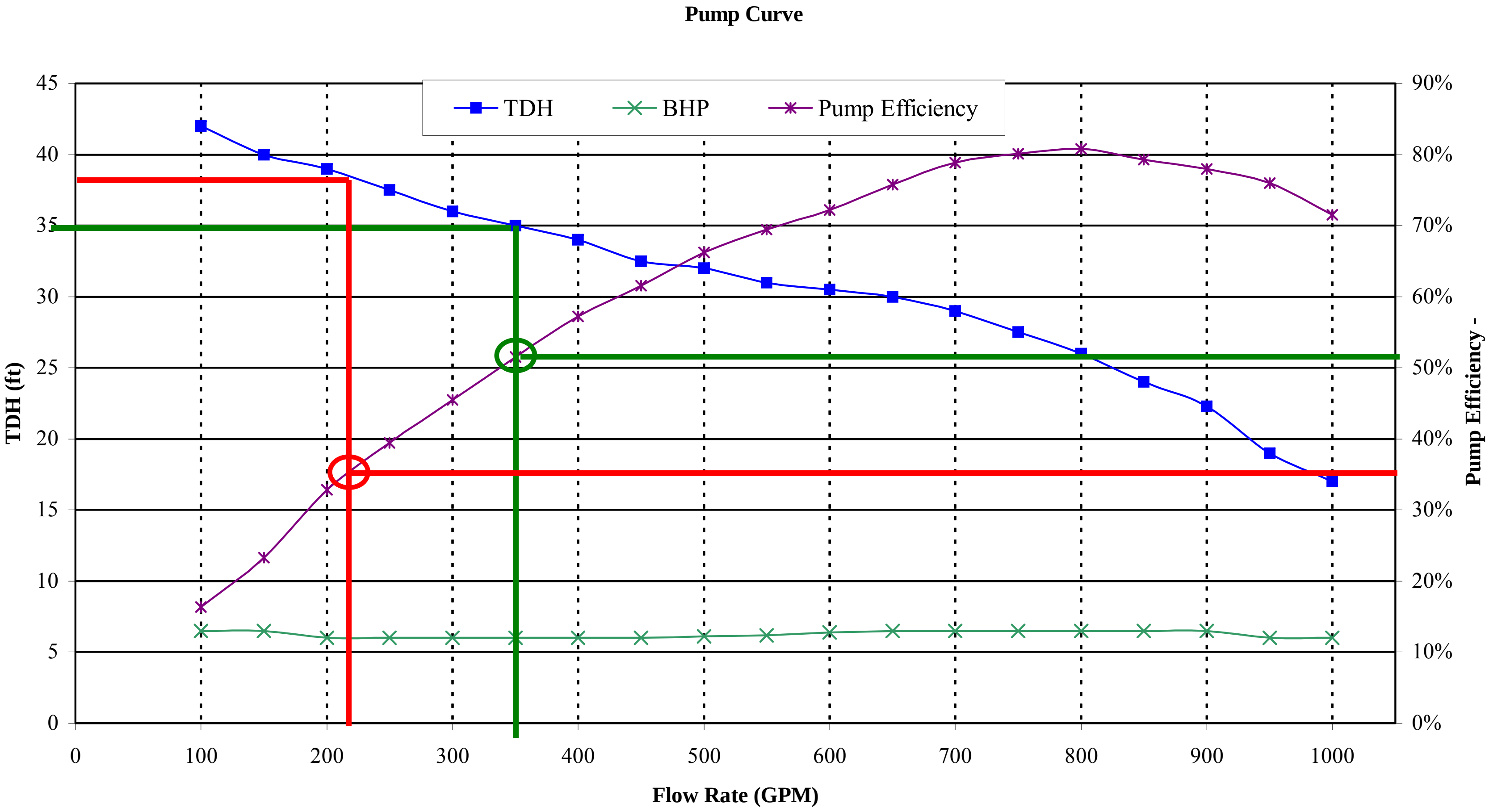

Figure A-2. Typical vertical pump curve showing the predicted efficiency drop off under Scenario 1.

Scenario 2. In this scenario, pumping plant efficiency is 52% and it is assumed that pump wear is the sole cause of this reduction. The new pumping plant efficiency is determined with a groundwater level drop of 3.5 feet (same as Scenario 1).

Since we are assuming pump wear is the sole cause of the pumping plant efficiency reduction (from the ideal efficiency of 80% to 52%) the total dynamic head is assumed to be at the same level as it was when the pump was installed. This is not a realistic assumption, but it will stress the point that the reduction in efficiency caused by pump wear is less than that caused by increased TDH for the same drop in groundwater level.

Figure A-3 illustrates the new pump curve adjusted by modifying the pump efficiency down and keeping the same TDH and brake horsepower (BHP) as the original curve shown in **Figure A-2**. The flow rate was calculated using these assumptions. The original pump curve is shown for comparison purposes.

The green circle and lines show the assumed starting TDH, pump efficiency, and flow rate (26 feet, 52%, and 514 GPM, respectively). The red lines and circle indicate the TDH increase of approximately 3.5 feet. The new pumping plant efficiency is approximately 49% under this scenario, compared with 36% in Scenario 1.

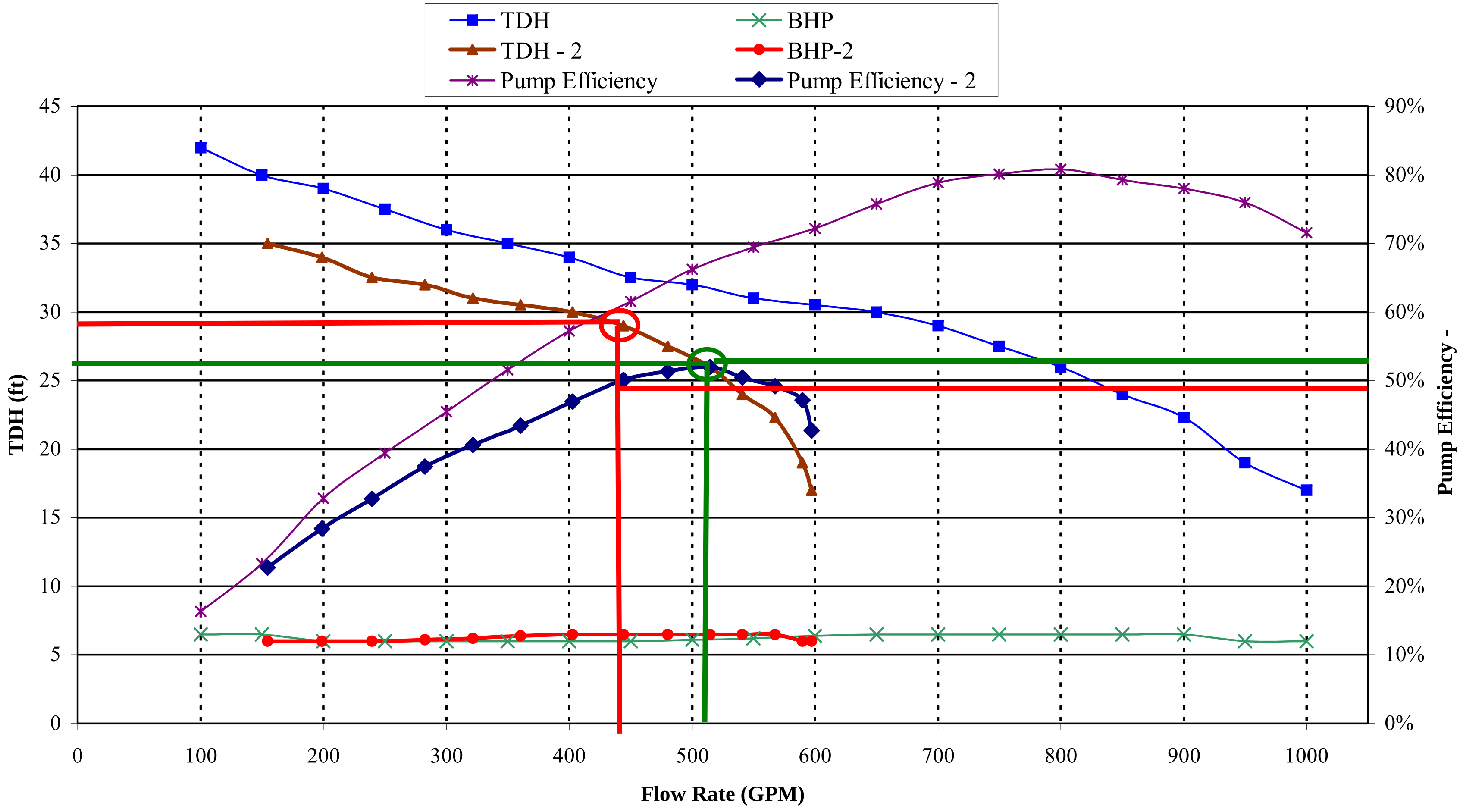

Figure A-3. Modified pump curves for Scenario 2 overlaid on the original pump curves.

Scenario 3: Realistic Conditions. Both a drop in groundwater level and pump wear incurred from the time the pump was installed to just prior to the drought conditions will impact the efficiency of pumps in California. Therefore, neither of the first two scenarios discussed provides an accurate estimate of how the pump efficiency will change as a result of overdraft during a drought.

A more realistic estimate would include some drop in water level as well as pump wear. This can be determined by averaging the results of Scenarios 1 and 2. Using the example outlined in the previous scenarios, the average efficiency would be **42.5%** (average of 36% and 49%).

The following table shows the estimated change in groundwater level (%) and change (decrease) in pump efficiency (%) using the average of the methods described in Scenarios 1 and 2.

Table A-6. Estimated decrease in pump efficiency for the corresponding drought severity for years 1 and 5.

Drought Severity	Consecutive Drought Year	**Decrease in Groundwater Level**	**Decrease in Pump Efficiency**
20%	1	**2%**	**0%**
20%	5	**10%**	**10%**
40%	1	**4%**	**2%**
40%	5	**19%**	**21%**
60%	1	**6%**	**3%**
60%	5	**27%**	**27%**