CALMAC Study ID CPU0035.01
Volume 8 of 15
Appendix G

Embedded Energy in Water Studies
Study 1: Statewide and Regional Water-Energy Relationship

Prepared by
GEI Consultants/Navigant Consulting, Inc.

Prepared for the
California Public Utilities Commission
Energy Division

Managed by
California Institute for Energy and Environment

August 31, 2010

Appendix G Groundwater Energy Use

Approximately 14.5 million acre-feet of groundwater is pumped annually, for agricultural, municipal, and industrial uses throughout the state (DWR Bulletin 118, 2003 Update). Groundwater is the most utilized marginal water supply for water agencies in California. As a part of Study 1, a model was developed to forecast energy consumption of California's water system. The model forecasts annual energy consumption, then displays monthly energy consumption as a function of supply. As a part of the model groundwater was used as the marginal or balancing supply to meet projected water demand in each of the State's ten hydrologic regions. In order to forecast energy consumption of the State's water system energy intensity values for each system component were developed. Energy intensity is a per unit value of energy use, therefore a forecasted amount of water use can be used to determine energy consumption.

There were two components of developing the groundwater portion of the model, first energy intensity of groundwater needed to be determined for each hydrologic region. Second, monthly groundwater pumping trends needed to be determined.

In order to develop energy intensities for each hydrologic region the Study Team needed to determine the volume of water pumped, and depth to water for each hydrologic region. The California Department of Water Resources (DWR) tracks water supply and demand through annual water balances, which track total groundwater withdrawal. DWR Supplied water balances for each Planning Area for water years 1998-2005[1]. The most detailed level of data available was at the Planning Area Level, Attachment A shows the DWR Planning Area Map. There are 57 Planning Areas that breakdown the hydrologic regions into more manageable and unique regions. It was decided to develop groundwater energy intensities by Planning Area then role the Planning Area energy intensities up the hydrologic region level. Table G-1 shows the energy intensities develop for each of the hydrologic regions.

[1] Department of Water Resources Bulletin 160 Updates 2005 and 2009.

Table G-1. Energy Intensity for Each Hydrologic Region by Water Year

Energy Intensity, I (kWh/AF)								
					Water Year			
	1998	1999	2000	2001	2002	2003	2004	2005
North Coast	173	169	169	162	162	167	166	176
San Francisco Bay	310	341	342	346	340	347	339	357
Central Coast	404	368	388	431	454	524	533	585
South Coast	505	536	541	581	569	596	610	593
Sacramento River	178	176	184	188	187	183	177	177
San Joaquin River	226	230	223	226	212	255	229	243
Tulare Lake	369	351	369	378	396	409	409	431
North Lahontan	159	150	163	175	167	175	176	170
South Lahontan	379	351	356	332	336	350	349	362
Colorado River	405	417	435	442	422	450	480	520

Development of monthly pumping trends was looked at from two perspectives, agricultural pumping and Municipal and Industrial (Urban) Pumping. In the case of agriculture, the pumping season typically last 6 to 8 months depending on the water year type and water availability. Alternatively, urban pumping is more constant throughout the year though it was found there is a relative increase in production during the summer months due to outdoor residential water use. Data collected for both Study 1 and Study 2 were used to develop monthly profiles for both agricultural and urban groundwater pumping. Table G-2 shows the percent of total groundwater production for each hydrologic region by agricultural and urban uses.

DWR created future demand projections for 2010, 2020 and 2030 based on the water year 2000. Since the model also uses the demand projections, the monthly profiles were developed based on water year 2000. Data collected from Modesto Irrigation District was used to create the agricultural production profile. Data collected for Study 2 was used to develop urban production profiles. These profiles were then used in conjunction with the agricultural and urban water volumes for each Hydrologic Region to distribute the annual volumes from the water balance to monthly volumes.

Table G-2. Percent of Hydrologic Region Groundwater Production by Use.

% of Hydrologic Region Groundwater Production													
Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Coast	Ag	0.0%	0.0%	1.0%	11.8%	10.6%	12.7%	13.9%	13.6%	9.1%	7.9%	0.0%	0.0%
	Urb	1.3%	1.2%	1.4%	1.7%	2.1%	2.1%	1.9%	1.9%	1.7%	1.5%	1.1%	1.2%
San Francisco Bay	Ag	0.0%	0.0%	0.2%	2.1%	1.9%	2.3%	2.5%	2.4%	1.6%	1.4%	0.0%	0.0%
	Urb	5.5%	4.1%	4.9%	6.9%	8.8%	9.3%	9.7%	9.2%	9.1%	8.2%	5.0%	5.0%
Central Coast	Ag	0.0%	0.0%	1.0%	11.4%	10.2%	12.3%	13.4%	13.1%	8.8%	7.6%	0.0%	0.0%
	Urb	1.3%	1.1%	1.6%	2.2%	2.3%	2.6%	2.8%	2.3%	1.9%	1.6%	1.1%	1.2%
South Coast	Ag	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Urb	4.8%	4.3%	6.2%	8.4%	8.8%	10.0%	10.8%	8.9%	7.1%	6.0%	4.2%	4.5%
Sacramento River	Ag	0.0%	0.0%	1.1%	12.7%	11.4%	13.7%	15.0%	14.6%	9.8%	8.5%	0.0%	0.0%
	Urb	0.9%	0.8%	1.0%	1.0%	1.2%	1.4%	1.5%	1.4%	1.4%	1.4%	0.7%	0.5%
San Joaquin River	Ag	0.0%	0.0%	1.2%	13.6%	12.2%	14.6%	16.0%	15.6%	10.5%	9.0%	0.0%	0.0%
	Urb	0.4%	0.4%	0.6%	0.8%	0.8%	0.9%	1.0%	0.8%	0.6%	0.5%	0.4%	0.4%
Tulare Lake	Ag	0.0%	0.0%	1.2%	13.9%	12.4%	14.9%	16.3%	15.9%	10.7%	9.2%	0.0%	0.0%
	Urb	0.3%	0.3%	0.4%	0.6%	0.6%	0.7%	0.8%	0.6%	0.4%	0.3%	0.2%	0.3%
North Lahontan	Ag	0.0%	0.0%	1.2%	13.7%	12.3%	14.7%	16.1%	15.7%	10.5%	9.1%	0.0%	0.0%
	Urb	0.4%	0.3%	0.5%	0.7%	0.7%	0.8%	0.9%	0.7%	0.6%	0.5%	0.3%	0.4%
South Lahontan	Ag	0.0%	0.0%	0.7%	8.7%	7.8%	9.3%	10.2%	9.9%	6.7%	5.8%	0.0%	0.0%
	Urb	2.4%	2.1%	3.0%	4.1%	4.3%	4.9%	5.3%	4.3%	3.4%	2.9%	2.0%	2.2%
Colorado River	Ag	0.0%	0.0%	0.5%	5.6%	5.0%	6.0%	6.5%	6.4%	4.3%	3.7%	0.0%	0.0%
	Urb	3.6%	3.2%	4.6%	6.2%	6.5%	7.4%	8.0%	6.5%	5.2%	4.4%	3.1%	3.3%

G.1 Groundwater Energy

Energy consumption of groundwater pumping can be calculated using well known engineering equations and conversions. The steps taken to determine variables for each equation are discussed in the following sections.

In order to calculate groundwater energy consumption several variables need to be determined including; flow rate, pumping head, and plant efficiency that are used in the following equation:

$$BHP = \frac{Q * G * H}{3960 * np}$$

In this equation BHP is the Brake Horse Power, Q is the pump flow in gallons per minute (gpm), G is the specific gravity of the fluid pumped, H is the total dynamic head pump, and n_p is the pumps efficiency.

Under normal design conditions all of these factors would be determined for single pump, however for this study the most detailed water data available for statewide groundwater production was Department of Water Resources (DWR) Planning Area water balances. Therefore, each planning area is being treated as two pumps, an agricultural (AG) pump and a municipal/industrial (MI) pump. The two pump method is being used in modeling groundwater energy consumption because AG and MI pumping have considerably different operational standards and conditions that apply. The following sections describe how AG and MI flows, pump head, and pumping plant efficiency were determined for each DWR Planning Area (PA), how those values were rolled up to provide groundwater energy intensity values for each hydrologic region.

G.1.1 Flow

Annual Production volumes in acre-feet were taken from DWR's planning area water balances for water years 1998 through 2005[2] [3]. Total groundwater production is the sum of the net groundwater withdrawal and deep percolation of surface and groundwater categories from the water balance. These data are based on the data collected from urban agencies that use groundwater as a supply, and estimated agricultural groundwater production. Agricultural groundwater production for each region is based on the crop specific acreage that is surveyed by DWR and the evapo-transpiration rates of each crop.

G.1.2 DWR Water Balances

DWR water balances provide supply and demand information for water years. Water years start in October and continue through September of the following year. For example, water year 1998 starts in October of 1997 and ends in September of 1998. The Applied Water Use numbers were used for the groundwater energy model. The Applied Water Use balances were used as opposed to Net Water Use because they provide total groundwater withdrawal where the Net Water Use balances only provide net groundwater withdrawal which in some cases was significantly lower than the total groundwater withdrawal. To acquire total groundwater withdrawal the Groundwater Net Withdrawal and Deep Percolation of Surface and Groundwater categories were added together. Attachment A shows an example of DWR's water balance.

Agricultural groundwater production and Municipal and Industrial groundwater production serve vastly different purposes and thus need to be analyzed differently. To analyze each component of groundwater production differently a flow was needed for each. In order to distribute the volumes from each Planning Area water balance into AG and MI volumes, the percent of total AG and MI volume for each year was determined. For example in Planning Area 403 (Santa Ana Planning Area), which is part of the South Coast Hydrologic Region, has high MI demand therefore it is assumed that a large percentage of the groundwater pumped is used for MI purposes.

[2] 1998, 2000, and 2001 water balances are available to the public at http://www.waterplan.water.ca.gov/
[3] 1999, 2002, 2003, and 2005 water balances were provided by the California Department of Water Resources.

Table G-3. Example of Agricultural and Urban distribution for Planning Area 403.

	Water Year							
	1998	1999	2000	2001	2002	2003	2004	2005
AG Demand (AF)	182,400	242,200	255,300	213,900	252,900	159,800	183,300	124,600
M&I Demand (AF)	1,135,300	1,137,500	1,252,200	1,178,300	1,333,300	1,267,000	1,373,600	1,175,600
Total AG/M&I Demand (AF)	1,317,700	1,379,700	1,507,500	1,392,200	1,586,200	1,426,800	1,556,900	1,300,200
% AG	14%	18%	17%	15%	16%	11%	12%	10%
% MI	86%	82%	83%	85%	84%	89%	88%	90%
Total GW Withdrawal (AF)	765,000	861,600	883,500	859,400	972,000	580,600	610,100	487,500
AG Volume (AF)	105,894	151,250	149,624	132,040	154,973	65,027	71,829	46,718
M&I Volume (AF)	659,106	710,350	733,876	727,360	817,027	515,573	538,271	440,782

For purposes of the pumping power calculation, the flow rate needed to be in units of gallons per minute (gpm). To determine a flow rate in gpm the AG and MI volumes were used in conjunction with a pumping time. The pumping time for agricultural pumping was based on 6 months, normal agricultural season of April to September, while 12 months of pumping time was used for MI. The volumes produced for each year were converted to flow using the following conversion:

$$Q = \frac{\left(V * \frac{325851 gal}{1\ AF}\right)}{t * \frac{1 year}{12\ months} * \frac{366\ days}{1 year} * \frac{24\ hours}{1\ day} * \frac{60\ min}{1 hour}}$$

Where Q is the *average* flow rate in gallons per minute, V is the annual volume of groundwater produced in acre-feet (AF), and t is the pumping season length in months. A flow value was calculated for agricultural and municipal uses in each Planning Area for each water year. (Note:

a well's specific peak flow rate may be underestimated, especially MI wells, since most are not pumped fully 24 hours a day.)

G.1.2.1 Total Dynamic Head

The Total Dynamic head of a pump is a combination of static water level, well drawdown, column losses, and discharge pressure. This section discusses the calculations, sources, and assumptions used to determine values for each of these factors.

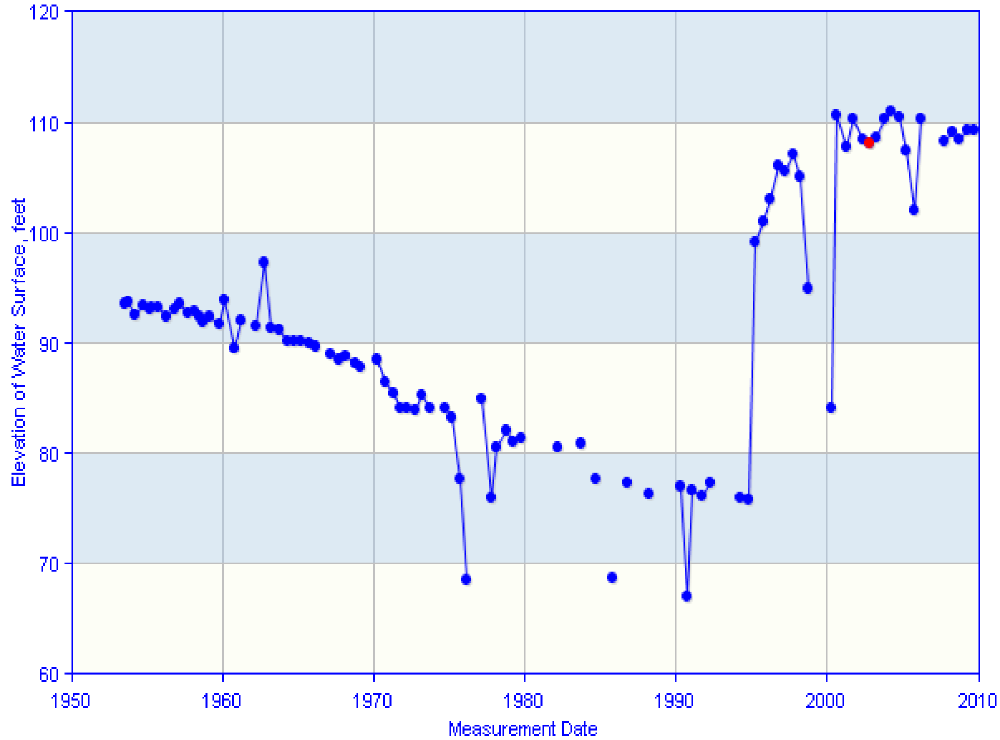
G.1.2.2 Static Head

Static head is the depth to the water surface prior to pumping. The California Water Data Library (CWDL)[4] was utilized to determine static water levels in each of the Planning Areas. The CWDL is maintained and operated by DWR and is the most reliable source of groundwater basin information available. Groundwater level data were downloaded from the CWDL for each groundwater basin in the state for each year included in the study. Typically each well monitored by DWR is measured twice a year, once in spring prior to the AG pumping season and once in fall after the typical AG pumping season is complete. These numbers represent the high and low static water level range for each well. Each well was assigned to a Basin using the Integrate Water Resources Information System (IWRIS)[5]

Each groundwater basin was assigned to a Planning Area using DWR – Bulletin 118[6] update 2003. Bulletin 118 includes maps of each hydrologic region and the basins that correspond to each region. All region maps are included as attachments. Once the basins were assigned to planning areas, an average static head requirement for each Planning Area was determined from the water levels downloaded. The average water level across the Planning Area was calculated from the wells associated with each PA. This number takes into account the two key components of the static head pumping requirement, the range of water levels throughout the pumping season and the changes in topography throughout the Planning Area, resulting in a single static head for the Planning Area.

[4] http://www.water.ca.gov/waterdatalibrary/
[5] http://www.water.ca.gov/iwris/
[6] http://www.water.ca.gov/groundwater/bulletin118/gwbasin_maps_descriptions.cfm

Figure G-1. Example Groundwater Measurements for CWDL.



.

Table G-4. Example of data collected from CWDL.

Meas. Date	R.P. Elev.	G.S. Elev.	RPWS	WSE	GSWS	QM Code	NM Code	Agency	Comment
4/6/1998	215	214	110.0	105.0	109.0			5108	
10/6/1998	215	214	120.1	94.9	119.1			5108	
4/12/1999	215	214					9	5108	
10/13/1999	215	214					9	5108	
4/29/2000	215	214	130.9	84.1	129.9			5108	
9/25/2000	215	214	104.3	110.7	103.3			5108	
4/18/2001	215	214	107.2	107.8	106.2			5108	
9/26/2001	215	214	104.7	110.3	103.7			5108	
5/23/2002	215	214	106.5	108.5	105.5			5108	
11/1/2002	215	214	106.9	108.1	105.9	4		5108	
4/23/2003	215	214	106.4	108.6	105.4			5108	

10/21/2003	215	214	104.8	110.2	103.8	5108
4/14/2004	215	214	104.1	110.9	103.1	5108
10/28/2004	215	214	104.5	110.5	103.5	5108
4/28/2005	215	214	107.6	107.4	106.6	5108
10/20/2005	215	214	113.0	102.0	112.0	5108

G.1.2.3 Data Gaps

There were a couple different types of data gaps in the groundwater level data that needed to be handled.

- Data for the Planning Area was available for years surrounding the data gap.
- There was no data available for the Planning Area, but data was available for other Planning Area's in the same hydrologic zone with similar topography.
- There was no data for a Planning Area or Planning Areas with similar characteristics in the same hydrologic region.

In the first scenario, a linear interpolation method was used to fill in data gaps. Having available data from years prior to and after the study period allowed a simple linear interpolation of the data to determine the water levels in a Planning Area for the years in question. The difference in the water level prior to the data gap and after the data gap were split by the number of years missing from the data and then added sequentially to the baseline or prior data point for each year of the missing sequence. The data was interpolated for the individual well data downloaded from CWDL. For example planning area 707 – Uplands Planning Area in the Tulare Lake hydrologic region had well measurement data for 1997, 1999, 2002 and 2004. Therefore, three interpolations were required to fill in the annual gaps in the data that pertained to the study period, 1998-2005. Table G-5 shows results of the interpolation for Planning Area 707.

Table G-5. Data Interpolation Example

Water Levels (ft-bgs)							
Planning Area	Year	Previous	Target	Post	Data Gap (Years)	Sequence Year	Annual Change (ft)
707	1998	50.43	45.00	42.29	2	2	-2.71
707	2000	42.29	46.30	54.33	2	1	4.01
707	2001	42.29	50.31	54.33	2	2	4.01
707	2003	54.33	55.51	56.69	1	1	1.18

In the event that no water level data was available for a Planning area within the years requested from CWDL, and there was a Planning Area in the same hydrologic region that had the same characteristics the water level data from the similar Planning Area were substituted for the missing data. For example, Planning Area 502 – Upper Northwest Planning Area, which is part of the Sacramento River Hydrologic Region, did not have any pertinent groundwater level data available. Planning Area 505 – Southwest Planning Area has similar characteristics to that of Planning Area 502 and is also part of the Sacramento River Hydrologic Region. Therefore, the groundwater level information from this adjacent planning are were applied to Planning Area 502. This method was applied to Planning Area's: 502, 601, 604, 610, and 705. The total production from these planning areas was less than 4% of the statewide groundwater production for any of the years included in this study. Of that total, as much as 95% came from Planning Area 705.

G.1.2.4 Drawdown

One of side effects of pumping is well drawdown. Drawdown is the change in water levels at a well due to pumping. The drawdown in a well is dependent on the flow rate in the well and length of pumping. For large groundwater pumps significant geologic investigations and aquifer testing are performed to determine aquifer capacity, or pumping rate. For this study, an average drawdown of 35 feet[7] was used in determining the pumping TDH for each well in the hydrologic regions.

G.1.2.5 Column Losses

The friction losses in the pump column are based on the size of the column, column material, shaft size, flow, and length of column. For purposes of this model, pipe friction losses were taken for pipe diameters of 2" – 12" for flows with an equivalent velocity of approximately 5 feet per second (fps)[8]. The resulting aggregate value of friction loss was 2.98 feet per 100 feet of column.

The column length or pump setting was determined by using the groundwater levels for each planning area, and anticipated drawdown for wells in the planning area. The total pump setting was calculated for each planning area by totaling the static water level, drawdown, and the Net Positive Suction Head Required. For this model the Net positive suction head was determined to be twenty feet, or two ten foot column lengths.

G.1.2.6 Discharge Pressure

The discharge pressure for agricultural purposes and municipal purposes can be significantly different. In general; agricultural pumping requires little discharge pressure as water is discharged after short piping system into system drainage canals, from which point water is delivered by gravity to turnouts and siphons along the canal.

[7] California Agricultural Water Electrical Energy Requirements, Irrigation Research and Training Center (ITRC), 2003
[8] Johnston Pump Company Pump Manual, Version 1996.

For municipal purposes, groundwater requires high head to compensate for elevation changes, distribution pipe friction loss, and distribution system pressures. For the purposes of this model, municipal system pressures were determined to be 60 psi or 138.6 feet, which takes into account varying topography and size of the various distribution systems in each Planning Area and Hydrologic Region.

G.1.2.7 Energy

Energy consumption of groundwater pumping can be determined through a series of established calculations and conversions. The following steps were taken to determine the energy consumption of groundwater production in each Planning Area for each water use.

1. Calculate the pump horse power or Brake Horse Power using:
    - $BHP = \frac{Q*G*TDH}{3960*np}$
        - BHP – Brake horse power
        - Q – Flow in gallons per minute (gpm).
        - G – Specific Gravity of the fluid (Water).
        - TDH – Total Dynamic Head (ft)
        - np – pump efficiency
2. Calculate the Input Horse Power (IHP) using :
    - $IHP = \frac{BHP}{nm}$
        - IHP - Input Horse Power
        - BHP - Brake Horse power
        - nm – Motor efficiency
3. Convert Horse Power to kilo-watts (kW) using:
    - $kW = IHP * 0.746$
        - kW – kilo-watt
        - IHP – Input Horse power

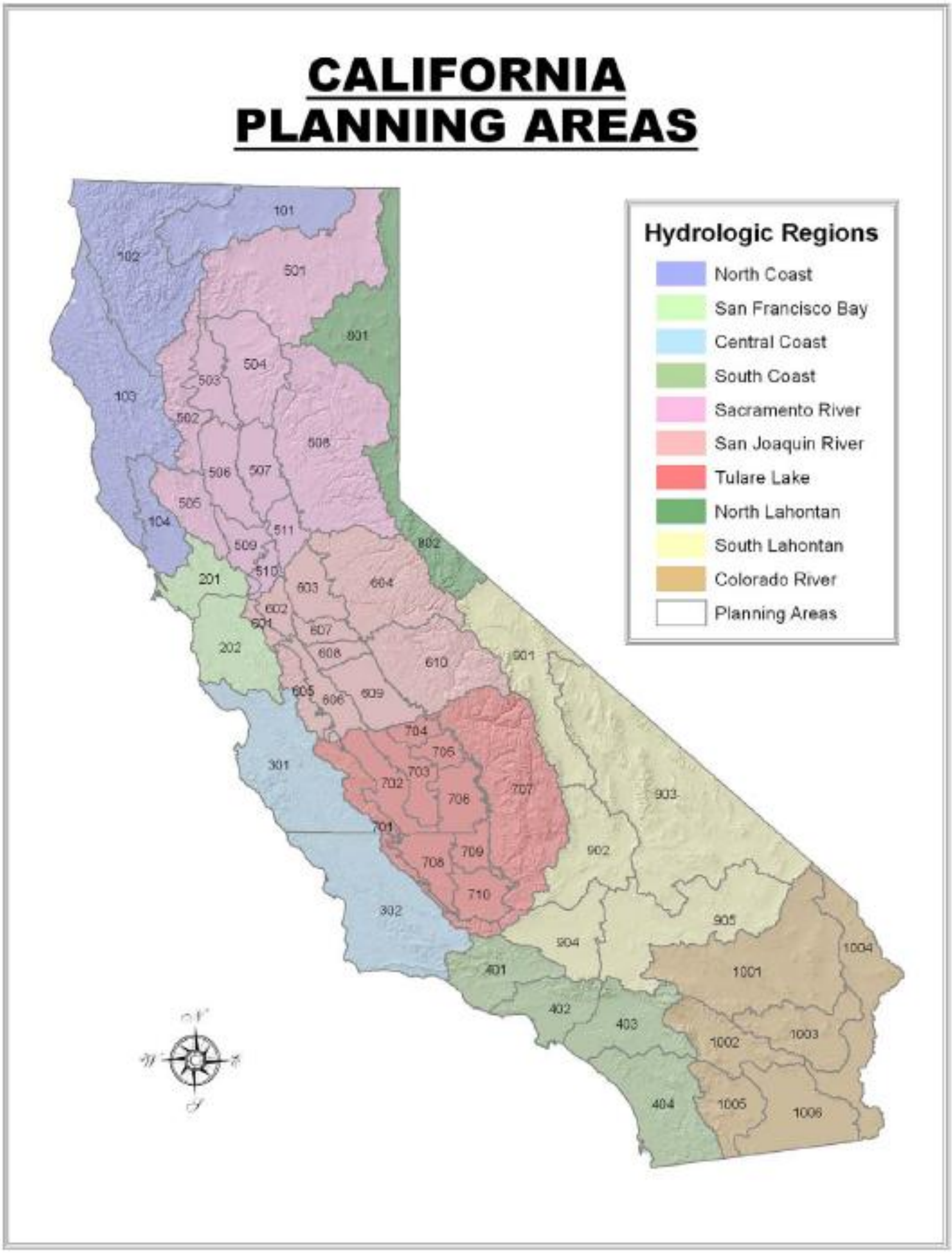
G.2 Energy Intensity

The energy intensity for each water use in each planning area was then calculated using the following steps.

1. Determine the time required to produce 1 acre-foot of water using:
    - $T = \frac{Total\ Hours}{Total\ Volume}$
        - Hours per acre-foot, T (hrs/AF)
        - “Total hours” is the total number of hours in the pumping season.
        - Total Volume of the water use (Ag or Urban) for the Planning Area.

2. The Energy Intensity, EI (kWh/AF) can be determined by multiplying the power required by the time is takes to produce 1 acre-foot of water.
    1. $EI = kW * T$

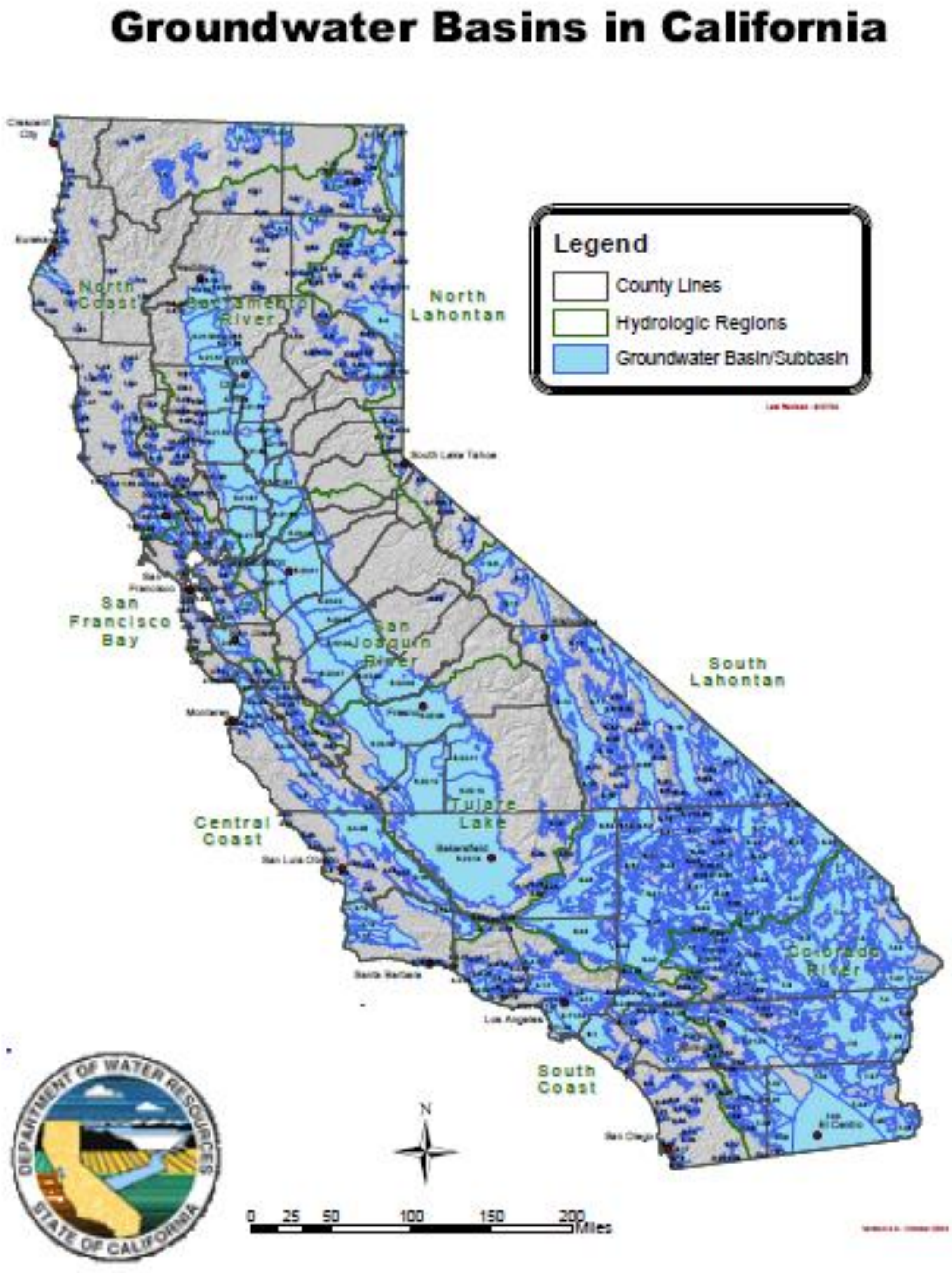
G.3 Attachment A: DWR Planning Area Map.



[9]

[9] http://www.waterplan.water.ca.gov/docs/maps/pa-web.pdf

G.4 Attachment B: Groundwater Basin Map and Hydrologic Regions



[10]

[10] http://www.water.ca.gov/groundwater/bulletin118/maps/statewide_basin_map_V3_subbas.pdf