Graphical Visualization of Potential Cost Savings from Energy Storage under Time-of-Use Electric Rates

Taewoo Kim, Paulo Cesar Tabares-Velasco
Colorado School of Mines, Golden, Colorado, USA

Abstract

Buildings play a prominent role in the electric grid: use about ¾ of the total electricity generated in the United States and drive electric peak demand in summer. Energy storage is one of the key technologies to reduce demand for energy and current transition towards Time-Of-Use (TOU) plans provides an opportunity to utilize storage technologies (electric and thermal) to further increase cost savings and reduce stresses on the grid during peak hour. Although there has been several efforts and studies reporting cost and energy savings, from different energy storage applications, their application is limited as previous studies have focused to particular climate(s), building design, and electric rate. This study proposes a framework that combines EnergyPlus with Google Fusion Tables to generate and visualize potential cost savings at state level when storage and TOU are present. It specifically uses California as a case study, showing annual potential cost savings up to \$350, and storage capacities up to 17 kWh for new residential buildings. This study allows homeowners to estimate their potential cost savings when using energy storage and current trend towards TOU.

Introduction

Buildings play a prominent role in determining the loads on the electric grid: buildings use about 75% of the total electricity generated in the United States and drive electric peak demand in the summer (EIA 2014, Denholm et al 2012). To address peak demand challenges, utility companies are implementing Time-Of-Use (TOU) plans, a demand-based plan, in favor over flat or tiered plans, to reduce energy use during peak times and provide customers the opportunity to cut costs. Peak hours care a time range when the energy demand is high, and thus appropriately, the price is at its highest within a day. Utility companies have several rates such as tiers and on/off peak rates to address these issues.

One of the solutions to reduce cooling energy use during peak hours is using energy storage. Energy storage technologies can vary from batteries to ice storage and using the building envelope mass, such as precooling. However, previous studies on precooling for demand response (DR) (Zong et al 2012, Lang et al 2014), have been limited primarily to emergencies and peak reduction calculations for specific locations (Arababadi and Parrish 2016, Booten and Tabares-Velasco 2012, German and Hoeschele 2014, German et al 2014, Turner et al 2015). Previous thermal storage research has focused largely on improving a building's capacity to reduce energy load (Booten and Tabares-Velasco 2012). Recent studies have looked into market price coordination (Yoon et al 2016), implementing community-scale control for air conditioning (Rhodes et al 2014), and highlighted the importance of storage on a large scale (Olsen et al 2013). In addition, reported cost savings are limited to particular climate, building design, precooling strategy, and/or electric rate. Thus they have limited potential to extrapolate to other cases. Past research also attempts to analyze savings with dynamic pricing and precooling, but such research is still not simple enough for the purpose of rapid estimations (Avci et al 2012, Cole et al 2014). Although there have been efforts to calculate energy cost savings over the entire United States (Maguire et al 2013, Christensen 2015), there is not an equivalent approach for residential building when TOU rates are available. Thus, this study develops a rapid framework to quickly generate potential electric cost savings when storage (electric or thermal) is used in conjunction with TOU rates. This study uses California as a preliminary test case and explores different mapping capabilities to better display geographical information.

Methodology

This study only considers potential cooling electricity cost savings. Electricity used for heating or appliances is assumed constant for all cases because this paper focuses on cooling strategy. Future work will address potential cost savings for heating and appliances. Furthermore, the utility calculations focus on California due to its diverse geography, climate, and ample availability of TOU rates. This study contrasts how TOU rates compare with flat rates when storage (either batteries or thermal storage) is available.

To produce whole house electric energy and electric cooling energy use, this study uses BEopt v2.5, NREL's simulation software for residential energy usage. BEopt v2.5 uses EnergyPlus v8.4 as the simulation engine. All simulations use a timestep of 5 minutes. The analyzed house represents a typically new house built in 2010: two story, three bedrooms, two bathrooms, slab-on-grade foundation, with an area of 2496 ft2. It follows NREL House Simulation Protocols (Hendron and Engebrecht 2010). All weather files are TMY3. In total, weather files for 50 cities are processed. This preliminary study simulates the same house (geometry, internal gains, and envelope characteristics), for all weather files, however, future research will address this limitation. The process to calculate potential savings requires the following inputs: utility rates of various utility companies, house characteristics, and local weather file.

The analyzed utility companies with TOU options in California are: PG&E, SCE, SMUD, LADWP, City of Riverside, Liberty Utilities, and SDG&E. Pacificorp, the company primarily responsible for Northern California, and Imperial Irrigation District, the company responsible for southeastern California, both do not currently provide TOU plans, and thus the contents of this paper excludes the territory that those two companies cover. In addition, many companies offer Electric Vehicle (EV) plans for households owning electric vehicles; however, this study excludes these plans including EV because the population of EV owning households is small in comparison to the normal household. In California, there are about three EVs for every 1000 vehicles (Chase 2014). Since EV plans account for heavy electricity usage, including those EV plans in the calculation misrepresents the average savings. Figure 1 illustrates the included utility companies' boundaries. It covers about 92% of total utility companies' subscriptions.

Table 1 shows the actual utility rate plan names referenced from each company. For example, Plan ETOU-A is the Time-of-Use Rate Plan "A" valid in PG&E territory that has higher rates from 3pm to 8pm. Figure 2 shows example of two rates for SCE and PG&E, two of the largest utility companies in California.

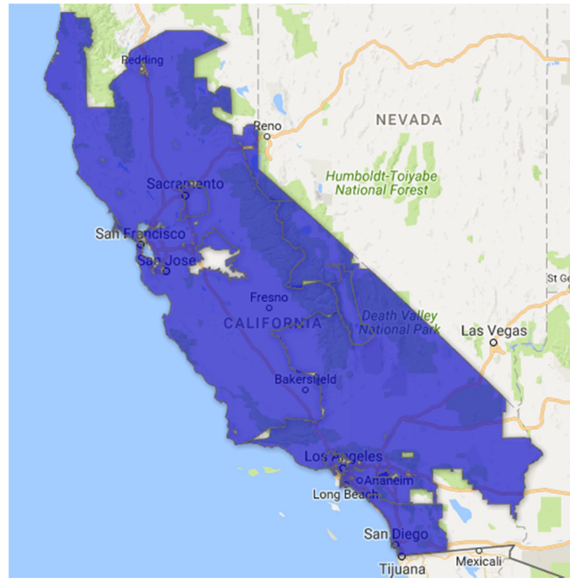

Figure 1: Coverage area of utilities rates considered in this study. Map data: Google, INEGI.

Table 1: California Utility Companies and their TOU plans

Companies	**Plans**
PG&E	ETOU-A, ETOU-B
SCE	ETOU-D-A, ETOU-D-B, ETOU-D-T
SMUD	RTO1
LADWP	R-1B
Riverside	D-TOU
SDG&E	TOU, TOU+
Liberty Utilities	TOU-D-1

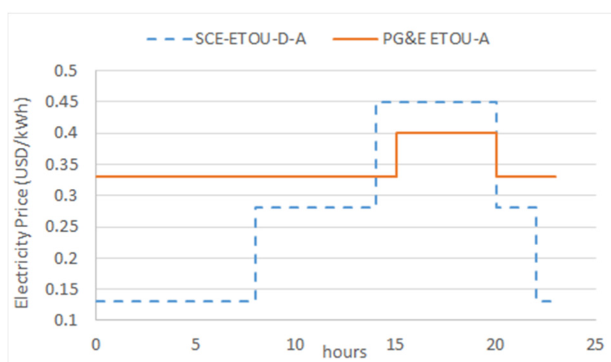

Figure 2: Example of hourly variable electricity rates for SCE and PG&E during summer months of June to September

The selection of analyzed cities is based on the electric rates: if a city has TOU, then it is analyzed. From the total of 58 counties in California, eight counties are excluded because there are no TOU plans in those regions: Del Norte, Siskiyou, Modoc, Lassen, Imperial, Sierra, Plumas, and Nevada counties.

The calculation of the potential cooling electric cost savings follows the next steps:

1) Choose city, weather file, and the appropriate TOU rates.
2) Simulate baseline house without storage using BEopt (Figure 3).
3) Calculate the electric cost assuming occupants do not change their energy use during peak times using sub-hourly data for cooling electric energy use and the appropriate electric rate.
4) Calculate the potential cost savings assuming all cooling energy during peak time is shifted evenly to off peak hours as seen in Figure 4. This step assumes: (1) there are no losses or penalties, (2) no size or dispatch limitations, and (3) occupants' comfort is always met. Although these three assumptions might not be realistic, they represent an ideal storage system that perfect matches all needs for a building. Thus, giving the maximum or potential cost savings any system could ever achieve as the focus of this study is to calculate potential (maximum) cost savings and minimum storage size. If a city has more than one TOU rates, repeat step 3-4 to calculate energy cost for the other TOU rates and average the savings from the different rates.
5) Calculate the minimum and maximum cost savings for cities with more than 1 TOU rate, to obtain range of potential cost savings for each county. Minimum and maximums are calculated by obtaining the highest and lowest cost savings from calculated values in a particular location.
6) Upload the csv file from step 5 into Google Fusion Tables and map the results for average, maximum, and minimum values. Maximums and minimums values for each county are highest and the lowest savings within each county. The boundary of the counties are from kmz file provided by California State University Northridge (CSUN, 2016).

The intention of this approach is to calculate the potential cost savings, break-even cost for energy storage, and minimum storage capacity needed when an energy storage technology is used. The energy used in the red shaded region (peak hours) in Figure 3 is shifted evenly to the non-shaded region (the off-peak hours) as shown in Figure 4. Although shifting a portion of the peak load is a viable option instead of shifting the entirety, this study assumes a no sizing/dispatch limitations with the intent that the entire peak load will be fully shifted. For cities with more than one TOU rates, this study uses simple arithmetic average potential savings from all available plans. For example, for a city with SCE subscription, the average cost savings equates to the arithmetic averages of the cost savings among ETOU-D-A, ETOU-D-B, and ETOU-D-T.

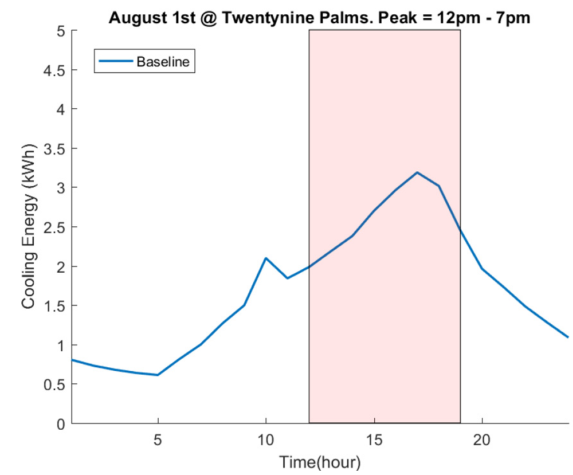

Figure 3: Sub-hourly energy use profile for a summer day. Peak hours are denoted with red background

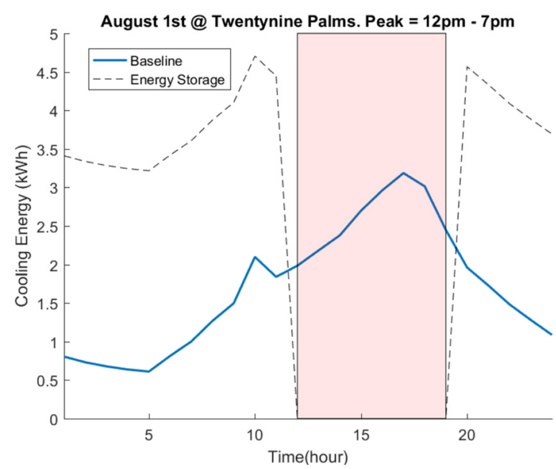

Figure 4: Sub-hourly energy use profile for a summer day. Peak hours are denoted with red background. Potential cost savings are calculated by shifting on-peak energy use evenly to off-peak time of the day

One TMY3 file is used for each city, and the counties values are averages of the results from the cities within its boundaries as a county might have multiple cities. Therefore, each county calculation is based on multiple TMY3 locations if it has more than one city in its boundary. Among the 50 counties considered in this study, 18 counties lacked TMY3 locations directly within their boundaries. Therefore, this study uses the TMY3 weather file with the closest proximity and similar climate zone to that county to serve as substitutes in the calculation.

Results

Figures 5-7 display the average, maximum, and minimum savings between TOU plans with and without energy storage. Table 2 in Appendix shows the values for all analyzed counties. The red dots represent the cities where the weather file is extracted from. Counties are shaded based on the cost savings in dollars. Higher savings equate to a darker hue. In all cases, Figures 5-7 show that there are significant cost savings of approximately $170-360 in the southeastern region, moderate cost savings of $60-120 in the central region, and little to zero savings in the coastal region.

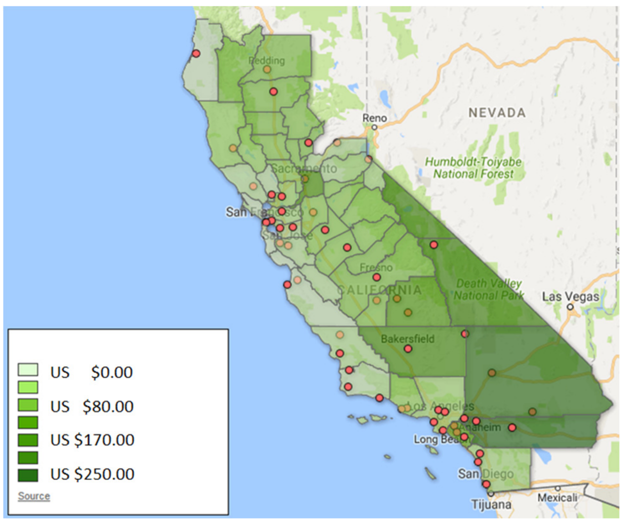

Figure 5: Annual average cooling electric cost savings for new home with energy storage subject to TOU rates. Map data: Google, INEGI.

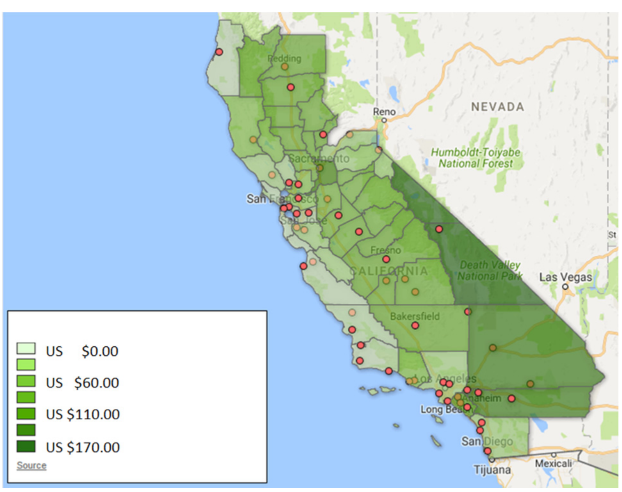

Figure 6: Annual minimum cooling electric cost savings for new home with energy storage subject to TOU rates. Map data: Google, INEGI.

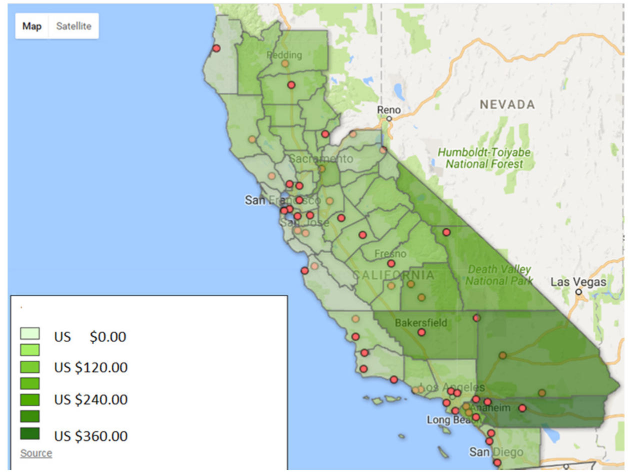

Figure 7: Annual maximum cooling electric cost savings for new home with energy storage subject to TOU rates. Map data: Google, INEGI.

Figures 5-7 also shows that potential cost savings greatly depend on the utility rate. Assuming a desire payback of 10 years and using average results (Figure 5), an energy storage system should have a break even cost of US$1,100-2,500 for this specific case.

Savings can also be calculated by comparing the same home having flat electric rates (tier or not tier) and no energy storage to the same home having energy storage and TOU rates. Figure 8 shows average cooling electric cost savings when compared to same house using flat electric rates. The region with below zero savings represents PG&E territory which no longer offers flat rates.

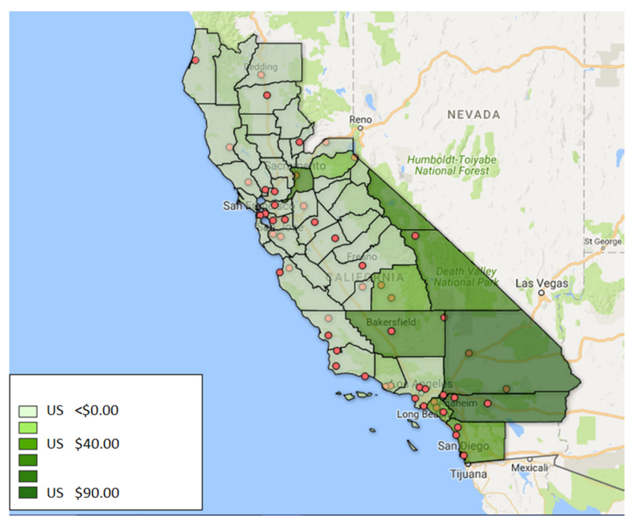

Figure 8 Annual potential average cooling electric cost savings for new home with energy storage subject to TOU rates vs new home with no energy storage and subject to flat rates. Map data: Google, INEGI.

Finally, Figure 9 shows the minimum energy storage size for a new home located in each county. For most cases, the required minimum electric storage to meet all on-peak demand is between 5 to 20 kWh.

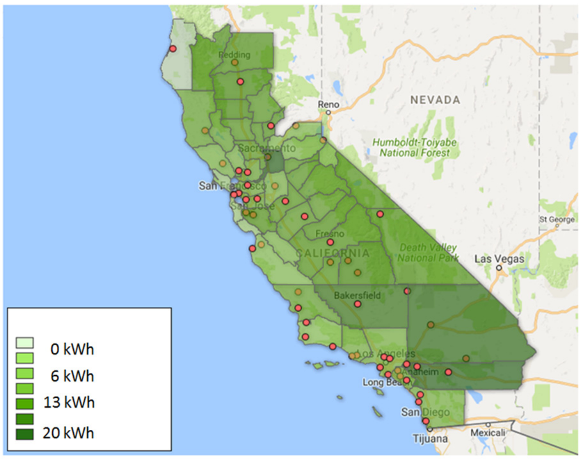

Figure 9: Estimated minimum energy storage to fully shifted cooling electric energy use off peak. Map data: Google, INEGI.

Discussion

For the analyzed home, annual cooling electric cost savings range from \$0 to \$360. Southeastern California had the highest costs savings in all cases. This is expected, as the local climate characteristics naturally produce such results. Extreme temperature swings range from -16˚C to 46.7˚C (3˚F to 116˚F). In addition, medium-to-high desert dominates the region. Therefore, energy storage, used primarily during the summer, provides one of the highest savings for climate zone 14.

In contrast, the coastal region, dominated by marine climates, displayed savings ranging up to \$100, as seen in Figure 7. Specifically, in all PG&E territory, the comparison between flat and TOU rates produced negative cost savings, unlike other electrical companies' savings. However, PG&E has discontinued this rate, thus the comparison is no longer valid (MaInight 2016). In contrast, other companies still provide both flat/tiered options as well as TOU options. Overall, TOU rates combined with energy storage provide savings to consumers compared to their previous flat electricity rates.

As shown in Figure 9, shifted electric cooling energy ranges from 0 to 20 kWh. For comparison, a residential battery capability is 14kWh (Tesla 2016). Assuming a coefficient of performance (COP) equal to 3, the thermal storage size would range from 0 to 17 Ton-hrs. This is similar to residential ice storage units on the market: 20 Ton-hrs (Ice 2016). For the highest shift in energy, which occurred in Palm Springs, the savings per kWh is \$0.22 in the summer and \$0.10 in the winter. For the lowest shift in energy, which occurred in Arcata, the savings per kWh is \$0.089 in the summer and \$ 0.016 in the winter.

In addition, Figure 10 shows scatter plot for the average potential annual cost savings versus cooling degree hours (CDH, base 23.3˚C). Cost savings are strongly related to CDH, however the spread on the data is probably related to changes in TOU that not necessary match with the weather data.

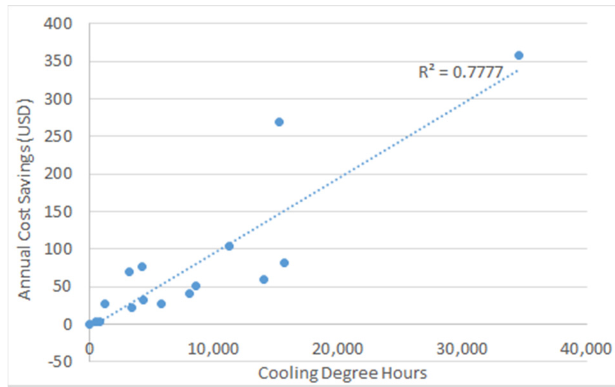

Figure 10: Scatter plot for average climate zone annual cost savings vs cooling degree hours (base 23.3˚C).

Finally, Figure 11 plots total energy shifted versus cost savings. Storage and cost savings are also strongly related.

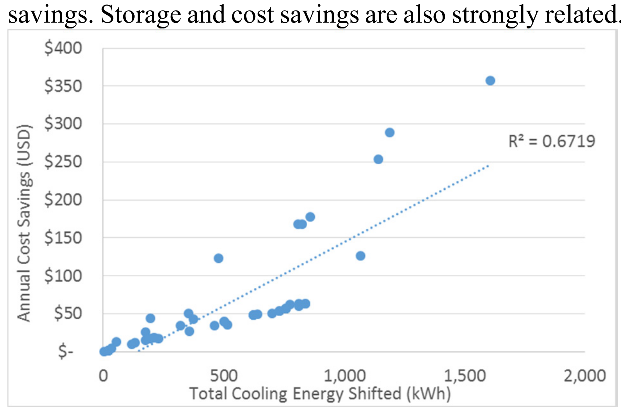

Figure 11: Scatter plot for average county annual cost savings vs average total kWh moved in a year for each county.

Conclusion

This study shows preliminary results of a new methodology that combines EnergyPlus and Google Fusion Tables to rapidly estimate the potential electric cost savings cost savings from using storage technologies and TOU. This methodology can show the estimated savings an owner of a new home can achieve if interested in completely shifting the cooling energy use during peak time. This also allows to: pinpoint areas or cities that could obtain the most benefit, size storage systems per location, and calculate break even cost of energy storage technologies. Preliminary results show potential savings up to $300 with the highest cost savings in San Bernardino and Riverside locations. Future research will look into: partial vs full storage, analyzing new and existing homes' envelope specifications based on local codes and climate zone in California and other States for cooling and heating applications.

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Appendix

Table 2: Electric cooling cost savings from each California counties

California COUNTY	Cooling Electric Energy Shifted (kWh)	Electric Cost Savings (USD)	Analyzed Cities per County
Butte	760	*57*	1
Glenn	811	*63*	1
Mendocino	500	*39*	1
Shasta	774	*62*	1
Tehama	811	*63*	1
Trinity	774	*62*	1
Humboldt	4	*0*	1
Kern	1143	*159*	2
Kings	813.5	*60*	1
Los Angeles	374	*31*	4
Monterey	35.05	*3*	2
San Luis Obispo	462	*20*	2
Santa Barbara	52.5	*6*	3
Tulare	858.4	*118*	2
Ventura	197	*43*	2
Alameda	176	*15*	3
Contra Costa	359	*27*	1
Sacramento	1067	*127*	1
San Francisco	19	*2*	1
San Mateo	19	*2*	1
Santa Cruz	20	*2*	1
Sutter	760	*57*	1
Yuba	760	*57*	1
Colusa	760	*57*	1
Lake	500	*40*	1
Marin	19	*2*	1
Napa	131	*22*	1
Solano	516	*36*	1
Sonoma	176	*16*	1
Yolo	640	*50*	1
San Benito	196	*17*	1
San Joaquin	624	*48*	1
Santa Clara	210	*18*	2
Fresno	837	*63*	1
Madera	837	*63*	1
Mariposa	732	*54*	1
Merced	732	*54*	1
Mono	826	*168*	1
Stanislaus	700	*51*	1
Alpine	118	*10*	1
Amador	624	*48*	1
Calaveras	624	*48*	1
El Dorado	228	*17*	1
Placer	211	*19*	1
Tuolumne	356	*51*	1
Inyo	810	*167*	1
Riverside	1608	*244*	2
San Bernardino	1189	*232*	3
Orange	479	*98*	3
San Diego	319	*27*	3