Campus Water Uses and Potential Water Efficiencies

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Abstract:

With recent increases in the price of water, saving water has become one of the main focuses for sustainability. The California Institute of Technology used 200,000,000 gallons of water in the year 2008; however the institute has never tracked this water to its destination within the campus. Using data collected from water meters on campus and from the utility company that supplies the campus with water, this research has produced a model that details how the water is distributed throughout campus. With this information, the institute can then identify the heaviest water users and implement measures that will reduce the water consumption on campus.

Introduction:

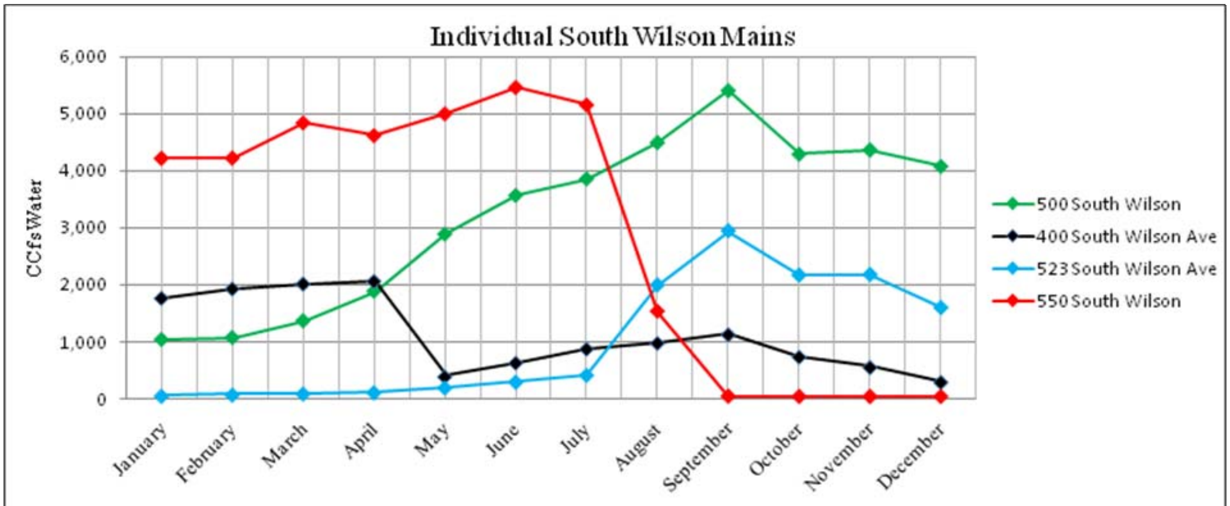
The green movement at the California Institute of Technology has made great strides in the past years. Most of the improvements that have been made concern improving electrical efficiency throughout the campus and reducing the carbon footprint. Previous efforts in this area include the installation of motion sensors to shut off lights, solar panels for cleaner energy, and energy efficient light bulbs. However, the institute may have overlooked the importance of water efficiencies and its environmental impact. In response to rising water costs and increasing water shortages in the Los Angeles area, the California Institute of Technology has proposed that water efficiency be one of its priorities in sustainability. As part of an ongoing movement to implement water efficiencies and study their environmental impacts, this report studied the distribution of water within the campus in order to determine areas in which water efficiencies may have the most impact on total water use. The results detailed the heaviest users as the central and satellite utility plants, which are responsible for providing campus with chilled water and electricity. Together, these two plants are responsible for 45% of the campus' water consumption. Thus, methods to improve efficiencies regarding the water consumption in the two utility plants would have the most effect on the total campus water consumption.

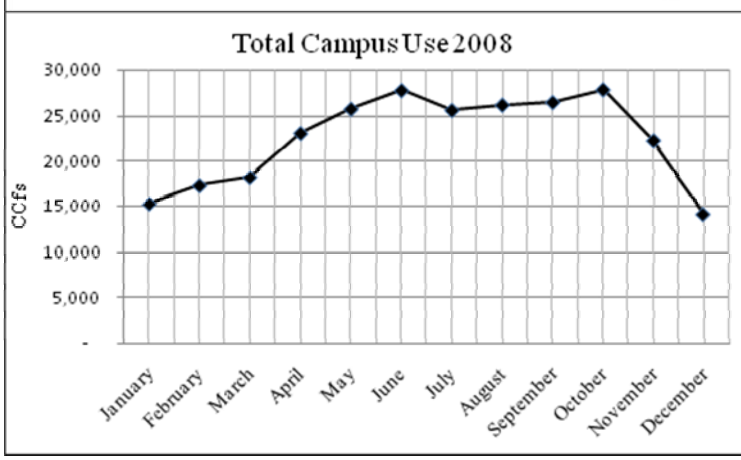
This report was broken into two sections. The first section summarized the water distributions through the California Institute of Technology campus and the second outlined proposed areas in which water efficiency could be improved.

California Institute of Technology Water Map

Campus Water Mains

The California Institute of Technology received its water from the City of Pasadena through eight water mains. The original assumption was that these eight mains were independent of each other and that specific buildings on campus could be mapped to a respective campus water main. Thus, examining the water supply from each main may provide insight into the heaviest water users on campus. The City of Pasadena kept monthly records of the water supplied by each of the eight campus mains for the year 2008. Upon reviewing the monthly records for each of the campus mains, it was concluded that several of the campus mains were interconnected and servicing the same area of campus. Analysis from this data showed that at least four of the mains (400 Wilson Ave, 500 Wilson Ave, 523 Wilson Ave, and 550 Wilson Ave) were interconnected. These four mains had significant variations in their water supply, which was inconsistent with total campus water reports that showed a sinusoidal water consumption trend where more water was used in the summer and less in the winter (figures 1 and 2). However, when the four mains' water contributions were combined, the familiar trend became apparent (fig. 3), which was evidence that these mains were interconnected.





The graph above (Figure 1) depicts the monthly water usage for four of the campus mains suspected of being interconnected. The water supply for these four mains varied drastically from the expected sinusoidal curve of the total campus water use like that in the graph to the left (Figure 2).

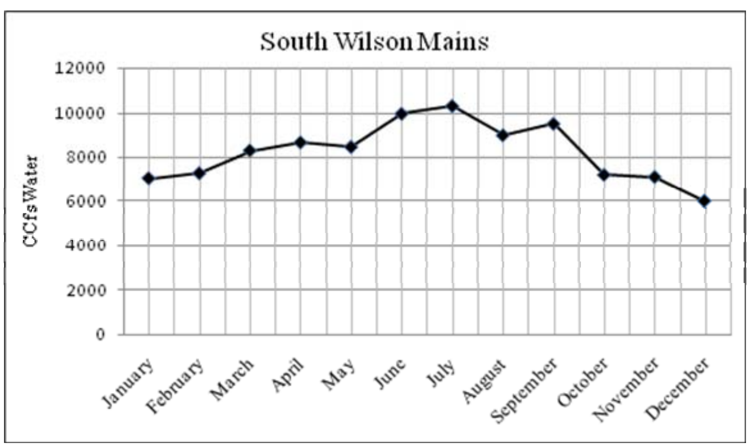


Figure 3: The summed water contributions from the four water mains in question. Their summed contribution now depicts the expected sinusoidal curve.

This conclusion was later confirmed by the California Institute of Technology's facilities department. Along with the four mains previously mentioned, they also reported that one other main (1250 East Del Mar) were also interconnected and supplying the same area of campus with water. It is interesting to point out that the 1250 East Del Mar main did not exhibit an abnormal variation in its water supply that would make it suspect. It was reported that these five mains were all interconnected by pipes whose valves had been left open. The reason for this was that all five mains needed to be connected in order to obtain enough pressure to get water to the top floor of the campus' largest building. This finding made it difficult to measure the water usage of specific buildings the data from respective mains for these five mains.

Approximate Campus Water Map

Despite this setback, the remaining three independent mains could still be mapped to certain buildings on campus. In order to determine which buildings corresponded with each of these three remaining mains, the California Institute of Technology provided the monthly water readings for several buildings and a Goss report that detailed the piping system throughout campus. Unfortunately, many of the monthly water reports for individual buildings were either inaccurate or missing. The California Institute of Technology at the time of this report had approximately 60% of its buildings metered, and was in the process of installing meters in all of its buildings. Thus, to estimate the water use for the missing buildings, all of the buildings were grouped into a subcategory and labeled as research, student life, irrigation, or other. The buildings in one subcategory with known monthly water values were averaged to obtain an average water use per floor area value and then applied to the other unknown buildings to obtain an estimated water use. With this estimated water consumption for all the buildings, the pipelines from the Goss report were analyzed to determine which mains were likely to supply each building with water.

Upon further inspection of the Goss report, it was discovered that each campus main was directly connected to a large pipeline that ran through the California Institute of Technology campus. Figure 4 depicts the completed map with the main pipelines running through campus and the respective areas each one serves. This was particularly important for the five interconnected mains, because these large pipelines could be traced to specific buildings. The Goss report also showed several pipelines that connected the large pipelines of four mains that were interconnected. The Goss report didn't show any pipes that connected the final main (the Del Mar main) to the other four. Thus, five interconnected mains could now be traced to specific buildings assuming that these mains were independent of each other.

Fluctuations in Water Supply

The next step in the analysis for the campus map was to determine the reason for the fluctuations in the water provided by each of the five interconnected mains. Why, for instance, did the 550 Wilson Ave main provide the campus with 4800 CCFs of water in March and only 39 CCFs of water in September? One possible explanation this was that more water would flow through a main if that particular main was experiencing a higher pressure drop between the city line and the campus pipeline. Unfortunately, this would mean that there may be no intake valve at the point of entry into campus that can control the amount of water each main supply. However, at least one piece of data suggests otherwise. According to the monthly reports, a building labeled "geophysics" exhibited similar heavy water use followed by a sudden drop between the months of July and September as the 550 Wilson Ave main (Figures 5 and 6). The explanation follows that as a building experiences increased demand, water pressure in its pipelines drop, resulting in a larger pressure gradient and increased water flow through its supplying main.

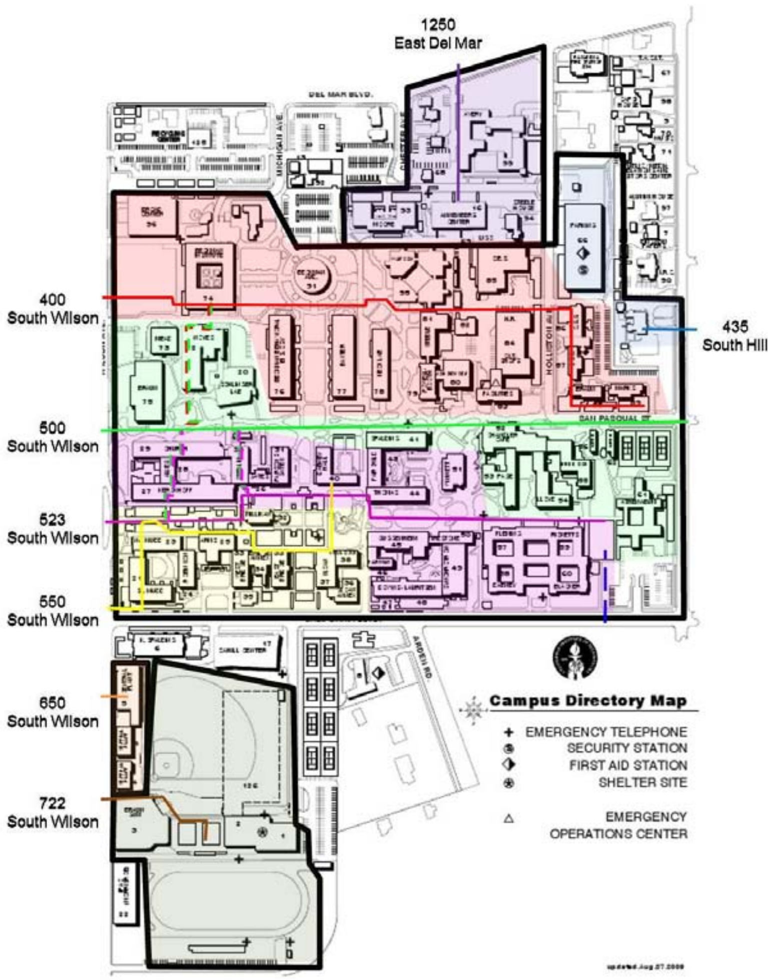
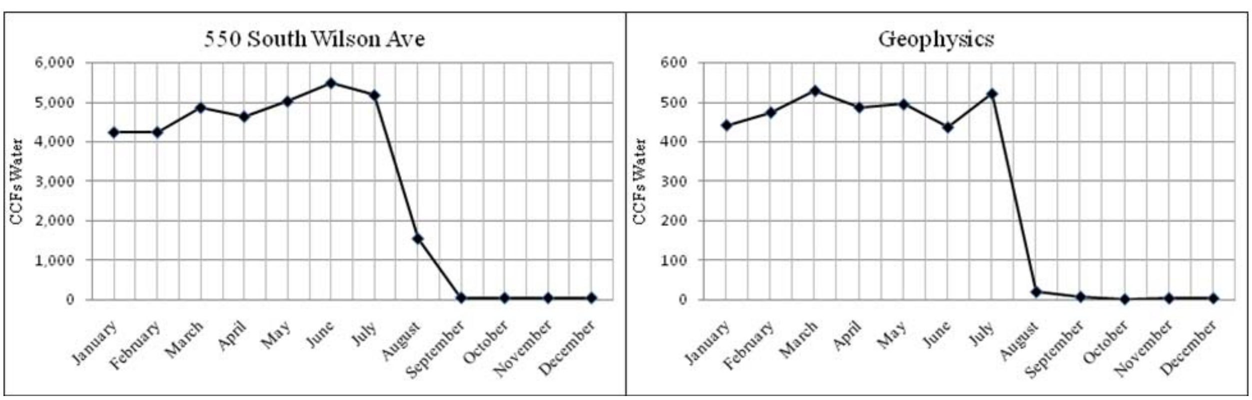


Figure 4: A depiction of the campus water map. The eight campus mains are labeled with their major pipelines color coded with areas of the campus. Dashed lines between the major lines represent the interconnecting pipelines.



The graph to the left (figure 5) depicts the water supply from the 550 South Wislon Ave main. Notice the drop in supply occurs at the same time that the drop in demand from geophysics occurs (right graph: figure 6)

No similar correlation was found in the other mains, which suggests there may be another explanation for the phenomena observed between the 550 Wilson Ave main and the Geophysics meter. It's possible that the geophysics meter tied into a line that branched off the 550 Wilson Ave main, and that when the main stopped supplying water, the geophysics building started to receive water from other lines branching off the other mains in the area. Further investigation in this area will be required to determine if building demands can affect supply from the mains. If that is the case, then the California Institute of Technology can implement strategies to reduce demand from buildings near the entrance of mains that have been experiencing large flow volumes, reducing water flow through those main.

Water Uses

The final piece in the campus map was to identify what all the water was being used for. Was the water being used in the laboratories on campus, or were the student dormitories the largest offenders of water use? To answer this question, the same building meters were analyzed again and water usage from buildings in each subcategory (research, student life, gyms, irrigation, and utility plants) was summed to give an approximation for the water distribution on campus (Fig. 7). The analysis showed that the largest water users at the California Institute of Technology were the two utility plants on campus: the central and satellite plants. Thus, proposing water efficiency measures for the two plants would most likely produce the largest water savings. But, it was first imperative that the water usage for the plants themselves be investigated. Research facilities used the next largest amount of water; however, improvements in this area would have to be specific to each facility and was not within the scope of this report.

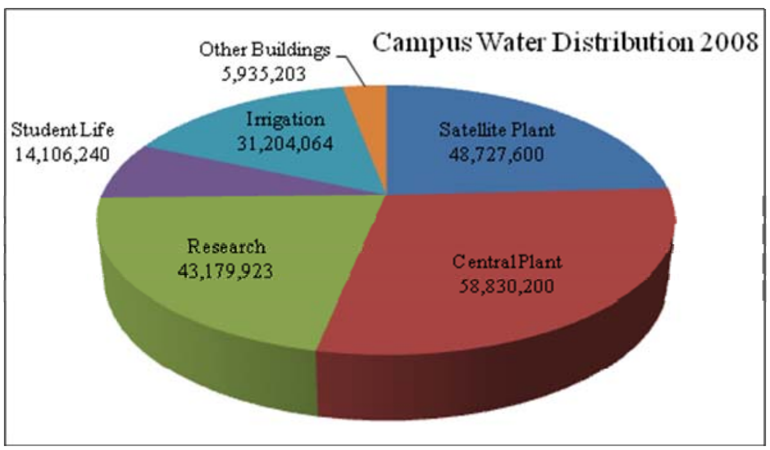


Figure 7 depicts the water distribution for the campus during the year of 2008. The total water use for this year was 201,983,230 gallons.

Plant Maps

There are two utility plants at the California Institute of Technology: the central plant and the satellite plant. Both plants are responsible for providing chilled water to the campus, but the central plant also produces electricity, deionized (DI) water, and steam. Each month, both of the plants report on their water uses. This data was compiled to give a complete water map for the central plant for the year of 2008 (Fig. 8). A similar chart was not created for the satellite plant because all of the satellite plant water was used in the cooling towers. This analysis shows that the cooling towers at the two plants use the most water, indicating that improvements in water efficiencies for the cooling towers would produce the greatest water savings.

The reports from the utility plants also included data on where the water went after going through the plant. Much of the plant operations are closed cycles; however, there are many sources for water loss within the system. Figure 9 depicts the distribution of water losses from the central and satellite plants.

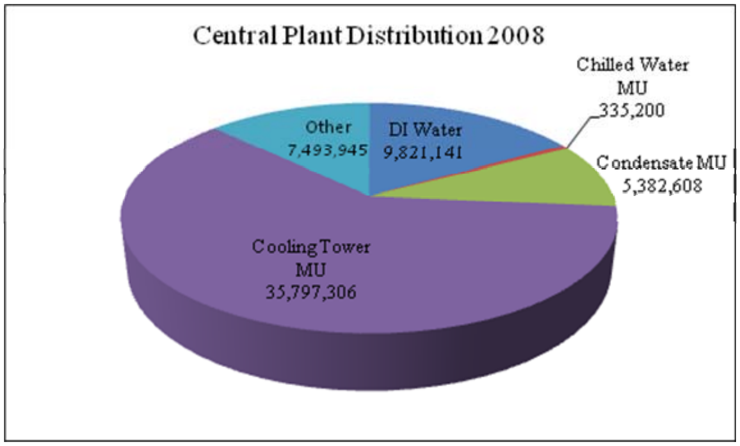


Figure 8 depicts the water distribution for the central plant for 2008. The central plant used 58,830,200 gallons for the entire year.

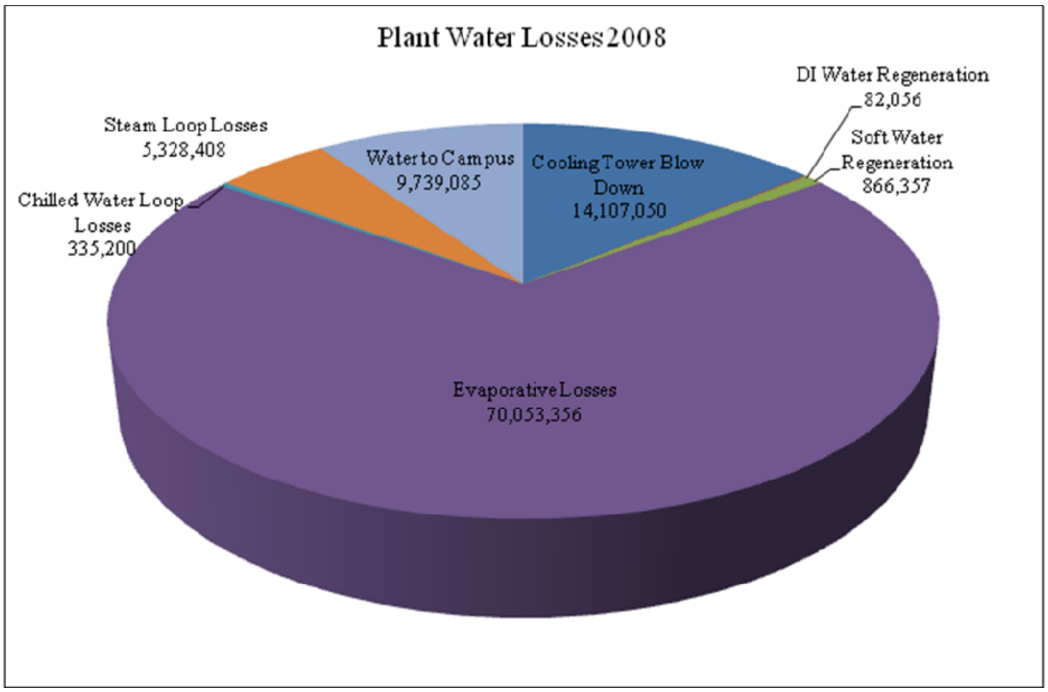


Figure 9 depicts the water losses from both the central and satellite plants. The most significant loss of water comes from evaporative losses. Decreasing the amount of evaporative losses would in turn reduce the amount of make-up water required to replace that water and thus save water.

Improved Water Efficiencies:

Water Reuse

As noted before, the monthly reports for the two plants on campus reported their waste water output. The largest of these was the tower blow down, contributing more than 14,000,000 gallons of waste water in the year 2008 between both plants, but the regeneration process from the soft water producers also contributed a significant amount at 866,000 gallons. This report investigated whether the waste water from these sources could be reused with little or no treatment.

The main concern for reclamation of waste water from these sources was their salt content. In the tower blow down water, evaporative processes caused salt build-up in the remaining circulating water. For the soft water regeneration process, salt water content was a result of mixing soft water and high concentrations of brine. Chemicals were also added to the tower water in order to prevent bacterial build-up, so this waste water was considered ideal for non-potable campus uses so long as the salt concentrations were acceptable.

The tower only blew down water when salinity levels reached a dangerous level that could compromise tower equipment. The salinity level was determined by the water's electric conductivity (EC). Tap water has an EC of approximately 0.5 mS/cm, which is equivalent to a total dissolved salt (TDS) concentration of 0.25 parts per thousand (ppt). Comparatively, the tower blow down was designed to release water when the EC reached 3.5 mS/cm, or approximately 1.8ppm.

The soft water regeneration process involved mixtures of soft water and high concentrations of brine. However, there were three parts to the regeneration process, each requiring a different ratio of soft water and brine. The first was a brief rinse of soft water through the resin, followed by a longer blast of soft water and highly concentrated brine, and then finally a rinse of the system with soft water. This presented a problem, because the concentration of the waste water from the soft water regeneration process was different depending on the stage in the regeneration process. To get a better idea of the concentrations of the waste water during each period, a sample of waste water was analyzed every five minutes during the 90 minute regeneration cycle. The analysis involved a specific gravity measurement and is presented in table 1. The soft water specific gravity was measured to be 1.006 whereas the brine specific gravity was 1.19. Using this information, the ratios of soft water to brine could be determined at each step in the process. The concentrations of the waste water were determined based on the salt concentrations of the brine and the soft water. The plant uses 100% saturated brine for soft water regeneration, so the concentration for a 100% saturated solution is approximately 360ppt. Soft water salt concentrations are very similar to tap water concentrations with a maximum accepted value of 0.5ppt. Based on this analysis, table 1 shows the salinity concentrations for each sample collected during the regeneration process. Unfortunately, this process produces a lot of saline waste water that is might not be usable for most processes. For this analysis, only water with less than 20ppt salt was considered as usable.

Several non potable uses for this water were investigated for the purposes of this research. The first involved irrigation of fields and grassy areas on campus. Plants and grass can be harmed by high salt concentrations; however there are several grass species that can withstand the tower blow down salt concentrations (2ppt) such as Kentucky bluegrass or Buffalograss. Despite the fact that these grasses can withstand the salinity level of the tower blow down, the soil may not. Thus, to determine if the tower blow down water can be used for irrigation purposes, the institute will need to experiment with a small area in order to determine if the salt concentrations will not adversely affect soil integrity or grass growth.

Time	Sample	Specific Gravity	% Soft Water	% Brine	ppt Salt
10:05	1	1.006	97.87	2.13	8.15
10:10	2	1.005	98.40	1.60	6.24
10:15	3	1.006	97.87	2.13	8.15
10:20	4	1.007	97.34	2.66	10.06
10:25	5	1.022	89.36	10.64	38.74
10:30	6	1.024	88.30	11.70	42.57
10:35	7	1.060	69.15	30.85	111.41
10:40	8	1.062	68.09	31.91	115.23
10:45	9	1.056	71.28	28.72	103.76
10:50	10	1.055	71.81	28.19	101.85
10:55	11	1.054	72.34	27.66	99.94
11:00	12	1.052	73.40	26.60	96.11
11:05	13	1.028	86.17	13.83	50.22
11:10	14	1.015	93.09	6.91	25.36
11:15	15	1.010	95.74	4.26	15.80
11:20	16	1.004	98.94	1.06	4.32

Table 1 shows the specific gravity of each sample, the resulting percentages of the soft water and brine, and the resulting sample salinity in ppt.

The institute has also proposed that the waste water could be used to refill certain water features (such as fountains) around campus. Students at the California Institute of Technology often use the various fountains for certain traditions, but the salt concentrations are safe for human contact. However, the various chemicals used in the tower to control bacterial growth are also a concern in this case. Such chemicals should be checked to see if they're safe for human contact. Otherwise, the waste water could be reliably used to refill such water features.

A final possible use for this waste water would be to reuse it within the plant system. The water could be sent back to the soft water producers mixed with normal tap water and used within the plant for the towers, DI production, and make-up water for the other water systems. Reusing this water in this manner would raise the total salinity level of the soft water produced by approximately 0.02ppm. This is because most of the water being fed to the soft water producers will be tap water and the small amounts of higher saline water will raise the salinity of the solution by approximately 0.02ppm. As a result, tower blow downs will likely occur more frequently because the salt concentrations of the feed water are slightly increased and some other systems might be affected as well. The best way to approach the system would be to slowly increase the amount of tower blow down and soft water regeneration waste water given to the soft water purifiers, watching for any effects on the machinery or efficiency of the various processes within the plants.

Cooling Tower Efficiency

The largest users of water in the two plants are the cooling towers. The cooling towers cool water through evaporation and heat exchange with the air and then sends the cool water to the water chillers, the steam generators, and other heat producing processes. Making the cooling towers more water efficient would significantly reduce water use at the California Institute of Technology. This research investigated possibility of making the towers more efficient by changing the time of day the towers are used. The idea was inspired by a project that was seeking government funding and involved running the cooling towers and water chillers mainly in the evenings when electricity was cheapest and storing the chilled water in underground tanks for use during the day. However, the idea of running the cooling towers in the evenings would not only save money in electrical costs, but also theoretically save water. Cooling towers rely on evaporation of water and heat exchanges with the ambient air. Pasadena weather is rather consistent, being warmer and drier during the day and cooler and more humid during the evening. Thus, during the day, more cooling would result from evaporation because the air would be warm (less heat exchange) and dry (more evaporation). But during the evenings, more cooling will result from heat exchange with the air because it's cooler and more humid.

In order to show that this idea could be feasible, a model was created for the cooling towers. This model represented an ideal cooling tower based on thermodynamic properties of the water and the air, assuming that the mass and enthalpy of each is conserved between intake and output. The main purpose of the model was to predict the amount of evaporation as a function of the ambient air temperature and humidity (the two main factors that will affect the cooling of the water). The amount of water used by the tower directly correlated to the amount of water was evaporated, because the cooling tower make-up water replaces evaporated water and blow down water, and blow down occurs as a result of high salinity concentrations due to evaporation. Thus, reducing evaporative losses would reduce the amount of water the cooling towers used. This model also depended on certain specifications from the cooling tower. The first specification was the temperature of the air being ejected, which was a result of heat exchange between the cycling water and the air. The second specification was the amount of water that circulated through the tower and the temperature of that water during intake and output. Finally, the last specification regarded the air flow, which was dependent on the strength of the fan on the top of the tower and its size.

Several temperature measurements over the top of the tower were collected during the course of this study. The temperature of the air being ejected was determined by measuring the air temperature at the top of the cooling tower where the output air was ejected. The outlet air temperature was read at 82 degrees F, which was significantly cooler than the ambient air temperature at the time of 102 degrees. It was discovered that this output air temperature was likely a simple heat exchange between the water and air inside the cooling tower and could thus be calculated using the intake water temperature, intake air temperature, and the volumetric flows of each.

The amount of water that circulates through the cooling tower was not available when this research was done, but the flow was estimated based on chilled water demand. This was because the cooling tower is mostly used by the water chillers. The required volumetric flow of water from the cooling towers for use by the chillers was recorded as 4000 gallons per minute per water chiller. The plant also supplied daily logs for the month of August, 2009 that reported that only two of the chillers were working full time. Thus, during the month of August, it could be assumed that an average of 8000 gallons per minute was circulating through the cooling towers due to the chillers' demand.

The air flow could be calculated based on the fan strength and speed. Each fan has a fan curve that determines the volumetric flow of air based on the pressure gradient through the fan. Unfortunately, this information could not be obtained and the air flow had to be determined using another method. When the temperature of the output air was taken, the tower fans were operating at full power. Using this information, the maximum volumetric flow could be estimated based on the known intake air and water temperatures, the water volumetric flow, and the output air temperature. As a result, it was estimated that the fans could move at most 500kg/s of air.

This information was then used to create a function that estimated the evaporation based on ambient air temperature and humidity (fig. 10). As can be observed, the amount of evaporation was mainly affected by the ambient air temperature and was significantly lower with lower air temperatures. This model was designed based on the specification outlined earlier, but the variables can be changed to give similar estimates for other cooling towers.

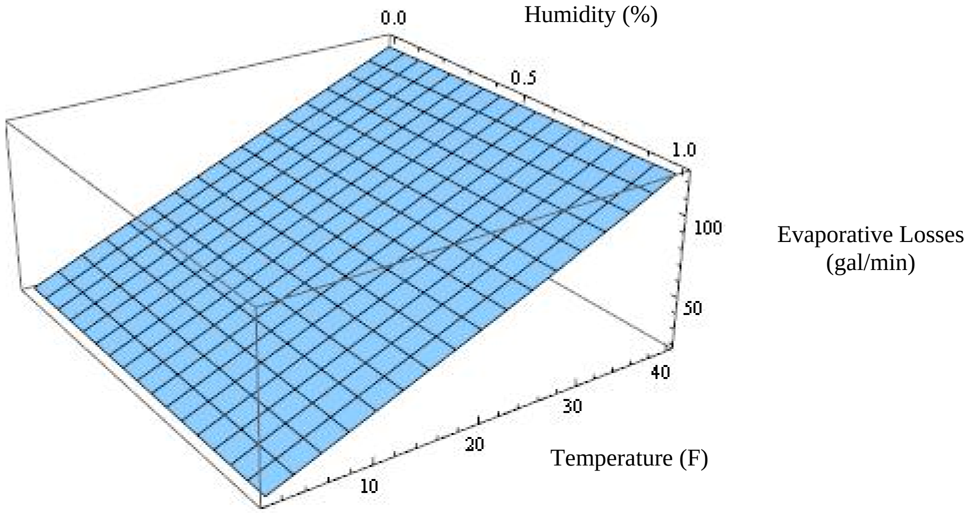


Figure 10 depicts the relation theoretical relationship between the evaporative losses and the ambient humidity and temperature. This model assumed an air mass flow of 500 kg/s and a water volumetric flow of 8000 gal/min. The model also assumes the water is cooled by 10 degrees F.

With this model, the next step in the investigation looked into the amount of water that could be saved by operating the cooling towers solely in the evenings. To perform this estimate, an accurate trend detailing all of the variables had to be kept. The central plant kept such trends for the tower fan speeds and the intake and output water temperature at one minute intervals from July 2008 to August 2009. The ambient temperature and humidity were taken from the records of a weather station within a mile of the central plant and was accepted as an accurate assessment of the ambient conditions around the plant. These temperature and humidity readings were taken at approximately five minute intervals from July 2008 to August 2009. Unfortunately, the water flow through the towers and the output air temperature were not trended. The water flow was estimated based on the water chillers. It was known that during the month of August, the chillers required approximately 8000 gallons per minute of water for operation. Because the month of August had one of the highest chilled water demands in 2008, it was assumed that 8000 gallons per minute of water represented the conditions during peak demand. Afterwards, it was assumed that for a cooler month such as February, the demand for chilled water would be significantly less, and thus would require at most one chiller to be operational at all times. Thus, it was estimated that 4000 gallons per minute were flowing through the towers from the chillers during February. The estimated water flow for the months in between was estimated assuming a sinusoidal pattern in the demand of chilled water. For example, for the month of November, the water flow was estimated to be 6000 gallons per minute. The output temperature of the air was estimated based on a simple heat exchange between the water and air in the tower and could be computed using the intake temperature of air and water and their respective mass flow rates.

Using these estimates and the model, three cooling tower scenarios were tested. The first involved a cooling tower running all day at the specified conditions. The second scenario involved a cooling tower running from 9:00am to 9:00pm (during the day) having twice as much water volumetric flow and twice as much mass air flow (but never more than 500kg/s, which was assumed to be the maximum). The final scenario involved a cooling tower running from 9:00pm to 9:00am (during the evening) with again, twice as much water volumetric flow and twice as much air mass flow never exceeding 500 kg/s. The data was analyzed monthly and summarized in figure 11. One can observe that the significant reductions in evaporation can be obtained by operating the cooling towers in the evening based on this analysis. It was assumed that currently, the amount of evaporation due to water required by the chillers fell between the first and second scenarios because chilled water demand rises and falls depending on the time of day. It was also assumed that running the cooling towers during the evening would not completely satisfy chilled water demands and the cooling towers would need to operate during the day at some capacity. Thus, the improved evaporation would fall somewhere between scenario one and scenario three. Regardless, based on this estimate, there would be approximately 10% reductions in cooling tower evaporation.

Much of the data to perform this cooling tower analysis was missing, and as a result, these figures should be regarded more as a first estimate than serious figures. Despite this, the research suggests that the idea of operating the towers more during the evenings should be further investigated for its potential water savings. Specifically, a trend of the output air temperature and water flow into the towers should be recorded. The fan curves should also be consulted to confirm the mass air flow of the fans. With this data, a more detailed analysis can be performed to determine more accurate savings estimates.

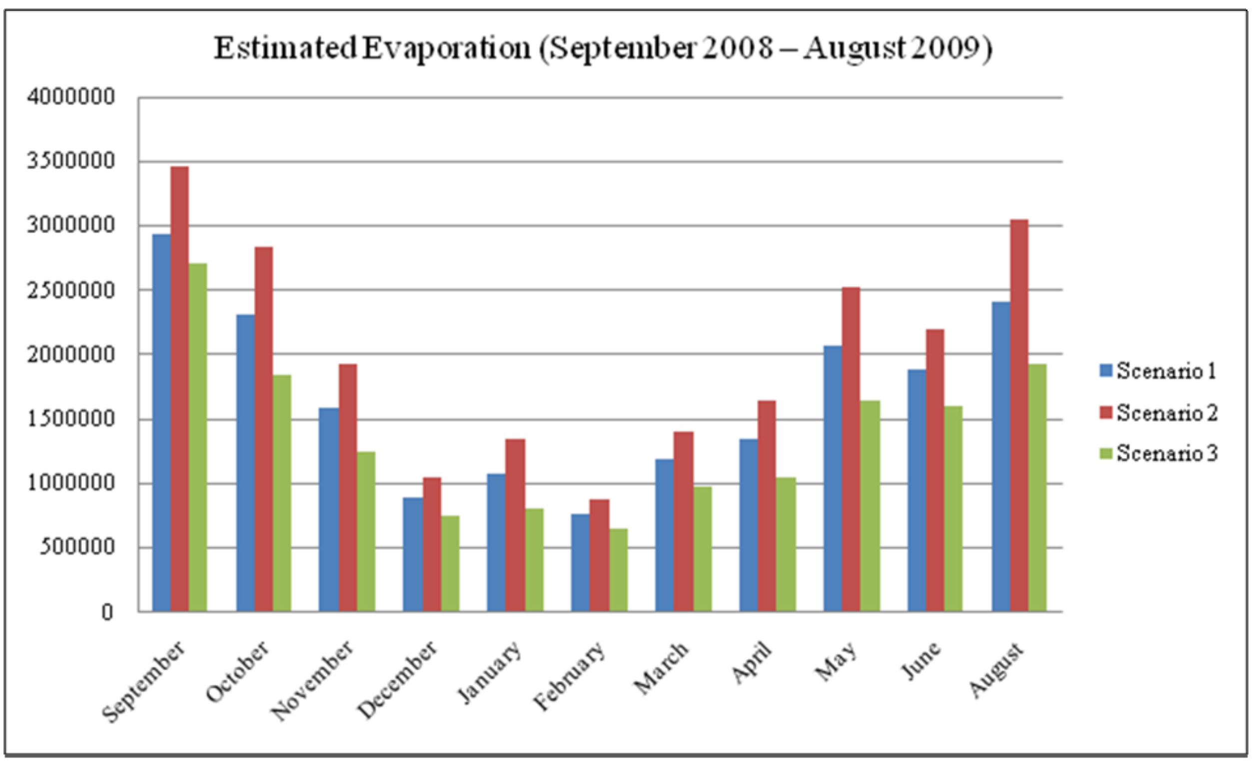


Figure 10 shows the estimated evaporation based on three different scenarios. In the first, the cooling towers are run for the entire day. In the second, the cooling towers are run from 9:00am to 9:00pm with twice the water and air flow through the tower. In the third, the cooling towers are run from 9:00pm to 9:00am with twice the water and air flow through the tower. There was not enough data available to include July 2009.

Acknowledgements:

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