# Evaporation

An analysis of the California State Water Project's efficiency

ESM 121

Spring 2015

Kory Burt, Erin Good, Micah Shachar, Justin Pascual

**Abstract**

The ongoing drought in California has lead to decreasing water supplies even as water demand continues to increase. This paper seeks to evaluate the efficiency of water transport through the California State Water Project (SWP) canals. Performing a cost-benefit analysis of potential losses due to evaporation and the implementation of an evaporation reduction mechanism will allow us to reflect on the quality of our infrastructure and the possibility of new projects for improvement therein. Our research objectives were to calculate a rough estimate of volumetric evaporative losses using the surface area of one section of the SWP. An average price for water in California was determined, allowing us to calculate the economic costs of the water losses. The potential solutions that were evaluated were the implementation of either a solar grid to cover the SWP or using 25cm reflective balls to reduce evaporation. We found the solar grid to provide the most benefits, about $7.9 million annually, accounting for the 1 million acre-feet of water per year lost, as well as the energy production the solar panels would provide. The projected 25 year net benefit for the addition of solar panels yielded a total value of $484,389.


**Introduction** Water has been cycling on earth as long as water has existed on earth, precipitating down, flowing into depressions and evaporating back up to begin the cycle again. Here in modern-day California, humans have dramatically altered the local water cycle. This is a necessary modification of the natural flow patterns to support the massive population of the state. However, we have not managed to alter the sun's daily radiation, and so evaporative processes have remained free of human touch. California's central valley, where most of the landscape reformation in the state has taken place over the last 50 years, engenders a typical mediterranean climate: hot, dry air with a high evaporation potential. One of the greatest hydraulic engineering establishments the world has seen runs right through this valley, with close to 1000 miles of open-air canals transporting thousands of acre-feet of water across the state daily. Even with the impressive political and industrial muscle it took to build these canals, they are not without flaws, and they are aging too.  In this paper we aim to analyze an 80 mile SWP segment, starting at the Banks Pumping Plant and ending at the San Luis Reservoir, and establish an estimate of evaporative loss as well as how much that loss costs the state annually. As our clean water resources steadily decline and we fuel a skyrocketing atmospheric carbon dioxide concentration, it behooves us to scrutinize the quality of our infrastructure as well as our actions, and put critical thought into future actions as we move forward as a species. We also speculated on the economic feasibility of physical solutions to reduce the aforementioned losses.

**Objective**

The goal of our research was to provide a cost-benefit analysis of the implementation of an evaporation-reducing mechanism into the California State Water Project. To reach this goal, the objectives of our research were as follows:

1. Calculate the area of the SWP in question
2. Using area and evaporation rate, calculate the amount of water evaporated on a yearly basis
3. Find the average cost of price of water based on CA average water prices
4. Calculate the economic cost of the water evaporated annually
5. Consider the costs and feasibility of various methods of reducing evaporation from the canals
6. Conduct a cost benefit analysis evaluating the effectiveness of proposed strategies to reduce evaporation

**Hypothesis**

The inability of the California State Water Project canals to transport water efficiently due to evaporation, costs the state considerable amounts of valuable water loss each day. There are cost effective methods of conserving the water lost from evaporation each year that California could implement.

**Data Sources**

CIMIS and several government websites and publications under the Department of Water Resources were extremely helpful in defining evaporation rates, gathering information about the climate and details about the State Water Project, including the price of water. Estimates for our solar calculations came from numerous sources; multiple authors have speculated on this topic before, and the solar panel market is growing rapidly.

**Methods and Assumptions**

We followed a logical, step-by-step order proceeding towards our objectives. First, an estimate was found for evaporation using previously determined evaporation rate from the San Luis Reservoir. We made the assumption that climate and all other factors affecting evaporation are constant over the region in question. We then found the price of water per acre-foot the state is paid for the water bought from the canal. Using these numbers, we calculated numerical economic losses per day due to evaporation from canal. Possible solutions of how to reduce these losses were explored , assuming that implementation of evaporation-reduction mechanism will reduce evaporation by %100. Finally, we performed a cost benefit analysis of implementing solar panels, though we included no overhead on panel installation, because there was no reliable estimate of how much this might cost on such a scale.

**Results**

Users

Throughout the span of the entire length of the State water project there are five contractors that use project water primarily for agricultural purposes (mainly southern San Joaquin) and the remaining 24 primarily for municipal purposes. Within these contractors, the water is allocated to the approximated 25 million Californians who depend on it for at least a portion of their water needs. When taking account all of the incoming water that California receives from precipitation and imports from Colorado, Oregon and Mexico, the distribution of water of approximately 200 million acre-ft/ year, on an average wet year, is divided at about 8.8 million acre-ft (11%) for urban uses, 34.3 million acre-ft (42%) for agriculture uses, and 39.4 million acre-ft/ year (47%) to environmental water. The water distributed by the state water project makes up about 2.08% (4.17 million acre-ft/year) of that total annual distributed water. (Bulletin 132-12)

**Table 1-6 Long-term Water Supply Contracting Agencies, by Area, as of December 31, 2011**

| Contracting Agency | Cumulative Deliveries (af)[a] | Annual Table A (af) | Payments (in dollars)[a] | Gross Area (acres) | Assessed Valuation (in dollars)[a] | Estimated Population |
|---|---|---|---|---|---|---|
| **South Bay Area** | | | | | | |
| Alameda County Flood Control and WCD–Zone 7 | 1,442,835 | 80,619 | 222,285,925 | 275,900 | 39,514,000,000 | 224,000 |
| Alameda County WD | 1,228,377 | 42,000 | 118,050,268 | 67,200 | 46,622,164,000 | 326,000 |
| Santa Clara Valley WD | 3,933,997 | 100,000 | 356,031,813 | 849,000 | 299,096,733,565 | 1,781,642 |
| *Subtotal* | *6,605,209* | *222,619* | *696,368,006* | *1,192,100* | *385,232,897,565* | *2,331,642* |

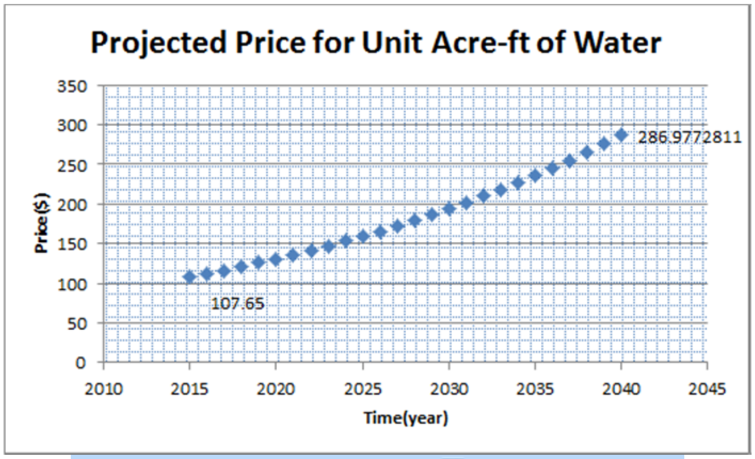
In this analysis, we are looking at just the 80 mile stretch that covers the southern bay area users. These contracted users include residence under the Alameda county Flood Control and WCD, Alameda County WD, and Santa Clara Valley WD, which encompasses an estimated population of 224,000, 326,000, 1,781,642 respectively. Within these contracted users, water is allocated at 80,619 acre-ft/year to Alameda county Flood Control and WCD, 42,000 acre-ft/year to Alameda County WD, and 100, 000 acre-ft/year to Santa Clara Valley water District. This totals to about 222,619 acre-ft/year for the south Bay Area that is allocated from the SWP.

Price

An important factor to consider in this analysis for the amount that is evaporated from the State Water Project, is the translated price that is lost from evaporation. An average price of $107.62 per acre-foot, taken from the latest competed bulletin 132 for the state water project. A cost benefit analysis of the viability of the solutions applied use this price and an estimated inflation rate of the cost of a unit of water. The future price of water will be estimated using an estimated inflation rate of 4 percent, which was take from the notice to state water project contractor, Bulletin 132-15. (Bulletin 132-2015)The price for a unit of water will project to 2040.

(in dollars per acre-foot)

| Project Service Area and Water Supply Contractor | Transportation Charge: Capital Cost Component | Transportation Charge: Minimum OMP&R Component | Transportation Charge: Off-Aqueduct Component | Transportation Charge: Variable OMP&R Component | Transportation Charge: Total | Delta Water Charge | Water System Revenue Bond Surcharge | Total Equivalent Unit Charge |
|---|---|---|---|---|---|---|---|---|
| SOUTH BAY AREA | | | | | | | | |
| Alameda County Flood Control and Water Conservation District, Zone 7 | 48.69 | 50.73 | 8.96 | 22.09 | 130.47 | 38.80 | 8.76 | 178.03 |
| Alameda County Water District | 29.92 | 31.72 | 7.52 | 14.28 | 83.44 | 28.57 | 4.79 | 116.79 |
| Santa Clara Valley Water District | 24.79 | 22.10 | 6.71 | 11.46 | 65.06 | 19.03 | 3.30 | 87.39 |
| South Bay Area | 29.70 | 28.54 | 7.23 | 13.73 | 79.19 | 23.95 | 4.47 | 107.62 |




$$F_T = P(1+i)^T \quad \text{...Eq. 2.1}$$

<u>Calculations</u>

The rate of evaporation in inches per day from the San Luis Reservoir was obtained (DWR) after a number of unsuccessful attempts to estimate evaporation based on empirical formulas. This depth per day multiplied by the total area of the section of the canal we analyzed gave us a rate of volume evaporated per day. The total comes out to 27 acre-foot/day, or 9855 acre-foot/year. At a price of $107 per acre-foot, the total cost of evaporation comes to about 1 million dollars per year that is lost due to evaporation from this section of the canal. If we extrapolate this number to generalize the entire SWP, with 700 miles of canals, the volumetric evaporative comes to about 9300 acre-feet per day that is evaporated away. Besides just the lump sum that the state is losing from this water, California is also losing water that could have been used for irrigation, or even released as environmental flows.

| **Volumetric Evaporation Calculation** | **Economic Loss Calculations** | |
| --- | --- | --- |
| | Evaporative Loss / Day | 27 AF |

| | | | |
|---|---|---|---|
| E (San Luis Reservoir) | 0.3 in/day | Price / Acre-Foot | $107 |
| SWP Aqueduct Area | 1067 Acres | Dollar Amount Lost / Day | $2889 |
| Volume Evaporated | 27 AF/day | Dollar Amount Lost / Year | $1,054,485 |

Cost-Benefit Analysis

With a statistically significant amount of water lost to evaporation, finding potential solutions is the next logical step, to help reach our statewide consumption reduction goals. In order to decide the most (cost) effective method of preventing evaporation, a cost-benefit analysis of different possible solutions was performed. The three main solutions we came up with were installing solar panels to cover the aqueduct, filling the aqueduct with floating plastic balls to reflect the sun, and covering the surface area with a reflective film.

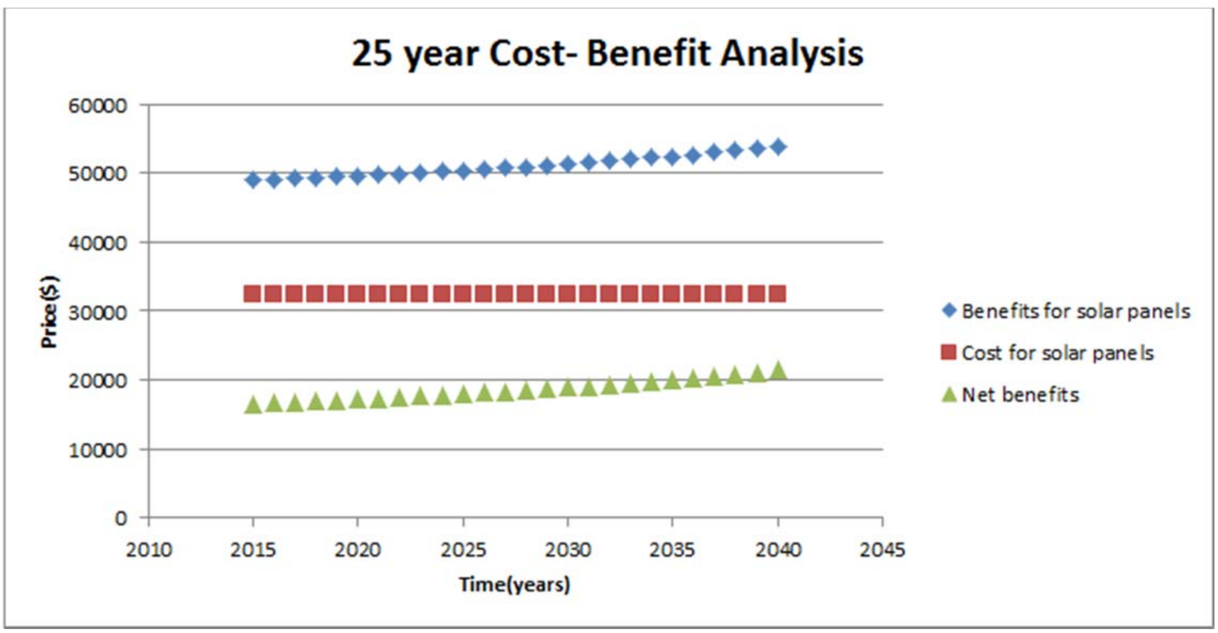
Looking into the plastic balls solution, it became clear that far too many units would be needed to cover the whole 80 miles of aqueduct and the amount of plastic that it would take to do so would be harmful to the environment. Similar problems arise from methods involving reflective film compounds.

The solar panels option however, provides multiple benefits. Not only would it reduce evaporation, but covering the aqueduct with solar panels would reduce our carbon footprint by creating green energy and mobilize americans by providing thousands of jobs. Although solar panels are expensive and need to be replaced every 20-30 years, the benefit they bring outweighs the cost. We came to this conclusion by finding the average cost of solar panels for the 80 mile stretch and comparing it to the average benefits. To find the cost we found how many square feet the panels would have to cover, how many watts per square foot could be produced, and how much watts are being sold for. Polycrystalline solar PV cells have a real-world output of about 10 watts per square foot and there are approximately 528,000 square feet per mile of the aqueduct (Clarke, 2012). We then found that solar panels are currently selling for around $0.70 per watt. In order to get the total cost of the solar panels along we multiplied the square feet per mile (528,000) by 80 miles, then multiplied that by the watts per square foot (10), and lastly multiplied the cost per watt ($0.70) to get a total of $295,680,000. Assuming that the panels need to be replaced every 25 years, the total cost per day for those 25 years will be about $32,403 (Clarke, 2012). The calculation of the daily cost does not include the cost of labor or installation. We also assumed that the price of electricity and the cost of solar remained constant throughout the 25 years because we could not find an appropriate interest rate to represent the changing prices. In reality, the prices of solar are decreasing while the efficiency is increasing which would result in a larger benefit at the end of the 25 year period.

To find the benefits we found the cost of energy that will be produced by the solar panels and added that to the cost of water saved by stopping evaporation. Solar PV will produce about 24 megawatt hours of power each day by each mile, resulting in 1,920 megawatt-hours each day (24x80) (Clarke, 2012). We found that a megawatt is about $24 of energy so the total benefit from the solar alone would be $46,080 per day (1,920x$24) ("Electricity Price Ticker"). By adding this to the cost of water, $2889 per day, you get a total benefit of $48,969 per day. When comparing the total cost of the solar panels, *$32,403* per day, with the total benefit, *$48,969* per day, it is clear that the benefit outweighs the cost and the solar panels should be installed as a way to prevent evaporation from the canal.

The 25 year cost-benefit analysis was done using the projected annual cost of water. The benefits of covering the canals increases over time due to the increasing cost of water. If the drought continues and the climate keeps warming we can also assume that the rate of evaporation may also increase and thus adding further benefit to the installment of solar panels. In the span of 25 years, when considering the cost of the solar panels, and the benefits of electricity production and the monetary interpretation of evaporation loss, we will yield a total net benefit of *$484,388* per year.

| Solar Panel Coverage | | |
|---|---|---|
| | **Cost** | **Net Benefit** |
| **Per day** | $32,403 | $48,969 |
| **Per year** | $11,827,095 | $17,873,685 |
| **25 years** | $295,680,000 | $484,389 |




**Limitations**

Our estimations are very limited by many factors. Firstly, our evaporation calculations do not take into account the flow rate of the SWP but rather assumes the evaporation rates are similar to that of a standing body of water. It is also worth noting that our results were inconsistent with both CIMIS's ETo estimate for the area in question, and empirical models taking climate into account. The number we used for evaporation was an estimate that is not very recent, which may account for some of the difference. When calculating costs associated with implementing solar, we did not take into account the cost of installation or the costs associated with linking up the new energy source to the energy grid and what losses the private energy sector would experience as a result of the increased energy supply. Limitations aside, we still believe that implementing a reasonable solution is a cost effective method of increasing water supply based off of projected increase in population and potential continuity or increased severity of the drought in California.

**Conclusions**

Our hypothesis proved to be true: the SWP is losing water and thus costing the state money, and it is economically favorable to implement solar panels over the canals to prevent losses and produce power. It is economically beneficial to install solar panels not only because of the benefits inherent in preventing water loss but also to meet water and energy demand as the population of California is projected to increase. Considering climate change, it is expected that average temperatures in california will increase significantly and precipitation will become more variable (Melillo et al. 2014). It is feasible, then, that some measures must be taken to increase water supply to meet increasing demand and water efficiency should be considered as a significant source of preserving our limited water supply. Solar is one of the more expensive options, but in our analysis still presents economic benefits, as well as inciting a state-lead initiative to move off of fossil fuel energy production. Cheaper solutions are also available, and our research suggests that any of these lesser-cost methods are likely to be economically effective under any climate scenario. As we move forward, however, in the face of a ecological devastation, economics can no longer be the only factor that is considered when implementing infrastructure reforms.

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