Re-routing Groundwater for On-Campus Irrigation

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Abstract The University of California Berkeley currently draws millions of liters of domestic Bay Area water per year for irrigation purposes. Re-routing water from de-watering sumps on campus to irrigation systems could potentially save the campus tens to hundreds of thousands dollars a year and reduce domestic water consumption. Three indicators were selected to test the feasibility of constructing a water-reclaim-for-irrigation system: water quality, sump flow rate, and a cost/benefit analysis. Test sites across campus were sampled during the dry and wet seasons to give a representative view of a year long cycle. Water quality analysis was contrasted to known irrigation standards, sump flow rates assessed in relation to campus demand, and campus experts consulted for costs and benefits associated with constructing such a system. The water appears to be of good enough quality to prevent health or environmental damage, water flow sufficient to sustain several large plots on campus, and costs projected to outweighed by benefits within a ten year frame. This study has shown that connecting de-watering sumps and wells to irrigation lines on campus is a feasible alternative to current domestic water usage according to the factors assessed.

Introduction

There is not enough water throughout the United States to simultaneously fulfill all of the wants for water for agricultural, domestic, industrial, and environmental uses (Vaux 2005). As greater demands are made on [natural water resources] more rapid utilization cycles and more care about the way water is used becomes a necessity (Neis, 1984). Re-using water in urban settings can make a significant impact in water supply. For example, in its 2005 Draft Urban Water Management Plan the East Bay Municipal Utility District (EBMUD) claims that recycled water use, “...delays or eliminates the need for more potable water facilities, sustains the economy with increased water supply reliability, protects San Francisco Bay by reducing treated wastewater discharge, safeguards community and private investments in parks and landscaping with a drought-proof or drought-resistant water supply, and contributes to a green and healthy environment...”

The University of California, Berkeley has officially recognized minimizing water consumption and maximizing on site conservation and reuse as a priority in it's 2020 Long Range Development Plan (Berkeley 2005). UC Berkeley has already taken important steps in furthering this goal by implementing sustainable initiatives in new construction. However, the 2005 water audit of the campus notes that “most of UC Berkeley's future water use and corresponding wastewater production will not be from new development but already occurs in the existing campus infrastructure” (Daniels 2005). It would therefore be in the interest of the University to concentrate future efforts on making campus resources more efficient.

UC Berkeley currently draws millions of gallons of domestic Bay Area water per year for irrigation purposes alone[1]. Howard Trent, a senior engineer on campus, suggests that excess groundwater pumped from wells and buildings could be a viable alternative source of irrigation water (Trent 2005, pers. comm.). Because the University currently pumps this groundwater into storm drains that ultimately deposit it in the Bay, Trent's suggestion would require that additional piping be connected to existing groundwater pumps and de-watering sumps to reroute the water

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[1] . In the fiscal year of 04/05 irrigation water amounted to 137,896,813 liters (Black 2006).

for on campus purposes. My study evaluates the feasibility of implementing such a system on campus.

I hypothesize that pumping groundwater for on campus irrigation is a feasible alternative to expelling water into storm drains. For the purposes of this study, I define feasibility with three indicators: water quality, flow rate, and cost/benefit analysis. The combination of the three gives insight to the system's impact on campus environs, its ability to meet campus water demands and fiscal management requirements. Water quality is important to prevent public health complications; therefore groundwater was tested for nitrogen, phosphate, metals, and coliform bacteria. Additionally, the water was tested for salinity, pH, and mineral content (hardness), qualities that lead to soil degradation on irrigated plots and congestion in piping that would make this project unsustainable. The second indicator, availability of water supply, determines whether groundwater flows will be at levels adequate enough to meet campus irrigation domestic water use. The third factor, economic feasibility, focuses on costs of implementing pipes, storage units, and maintenance and on the benefits accrued. This paper seeks to determine if each indicator shows positive feasibility for the project on a whole.

Methods

Five study sites where de-watering sumps are located were selected on campus: HV Substation 3 behind Mulford Hall, Boalt Hall, Moffit Library, Stanley Hall, and Birge Hall (See Figure 1). In order to provide a representative data set, study sites were selected at different portions of campus. A preliminary assessment was then conducted to ensure sumps were not heavily contaminated or unreachable. To account for seasonal variability each site was sampled prior to and during the wet season, which lies between December to March in California. Dry season samples were collected December 5, 2005, and wet season samples were collected on late April 6, 2006.

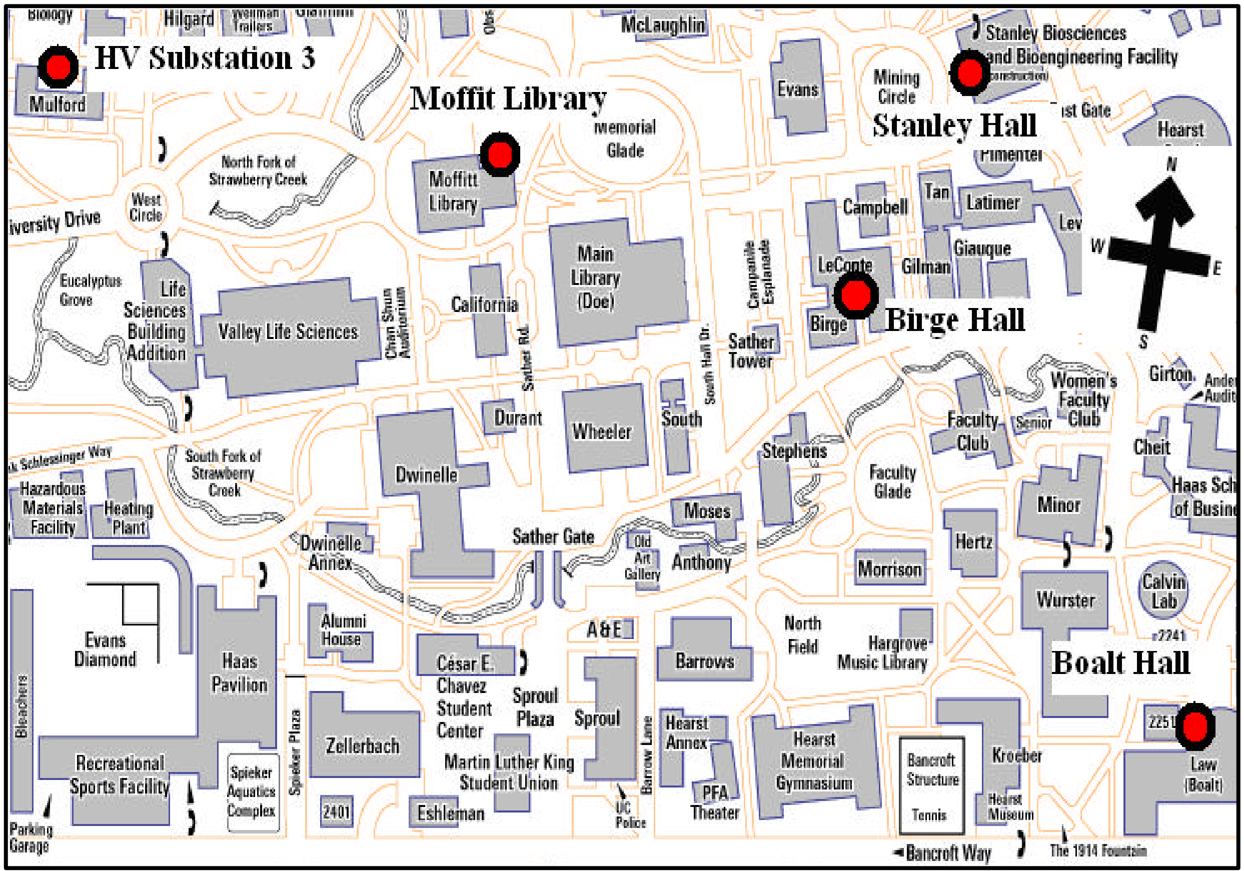

Figure 1: Section of campus containing study sites. Sites represented by red circles.

Water Quality Water samples were collected in plastic bottles provided by EBMUD, who agreed to analyze the chemical and bacterial content of the water, including a sterile 105mL bottle with chlorine neutralizing powder for bacteria. All sites were sampled on the same day Samples were stored in a cooler with ice packs to prevent degradation. Within twelve hours all samples were delivered to the EBMUD water quality lab in Oakland for analysis. Results were then tabulated and compared to known California irrigation standards, and the California Drinking Water Quality Database (CDWQD) to determine suitability for irrigation use.

Flow Rates Building sumps pump water out of concrete or metal wells and are triggered by a float switch that rises with the water level. The flow rate was calculated by measuring the rate of volumentric change in the well. To calculate the volume, I multiplied the change in the height of the float by the cross sectional area (length x width for a rectangular shape or radius^2 x pi for a circular shape) and divided by time.

The flow rate data was then contrasted to the water demand of irrigated plots surrounding the sumps. Water demand on Memorial Glade was calculated as a proxy for areas on campus of the same size. Irrigation plans were consulted for information on the number of sprinkler valves on the glade, their maximum flow, the number of watering cycles per day, and the duration of the cycles. Two water demand scenarios were explored due to seasonal variation in sprinkler flow rate, and the number and duration of cycles.

Cost/Benefit Analysis A cost-benefit analysis is the process of weighing the total expected costs vs. the total expected benefits in order to choose the best or most profitable option. In this analysis campus officials and experts were consulted for costs of implementation and maintenance costs, to be contrasted with the benefits accrued. Costs considered include: Valves, storage containers, electricity costs of pressurizing the system, and maintenance. Estimated benefits are a self sustained system and reduction of domestic bay water costs.

Results

Water Quality Water quality results are displayed in the tables below, highlighted figures exceed known standards. Standards could not be found for every tested item provided by the EBMUD standard water quality package; these columns are left blank. Water hardness was omitted from wet season data due to an error during EBMUD lab testing. Coliform counts are difficult to compare to CDWQD standards due to usage differences. CDWQD standards are for drinking water and require that there be less than 5.0% samples total coliform-positive in a month. However, as only two samples were taken and they consisted of groundwater that has percolated through soil containing fecal matter, samples were expected to be coliform-positive and were estimated by most probably number (MPN).

Table 1: Water quality samples collected 12/15/2005. Highlighted figures exceed standards.

*More than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E.coli fecal coliforms, system has an acute MCL violation.

MPN - Most Probable Number. This is a statistical number generated by Microbiologists years ago. What it really means is that the estimated number [most likely number] of organisms per sample volume is reported. Bacteria are quite ubiquitous organisms and are not consistent like ammonia or alkalinity.

Date Collected: 12/15/2005	HV Substation 3	Moffit Library	Birge Hall	Boalt Hall	Stanley Hall	California Drinking Water Quality Database	Irrigation Standards
Salinity (%)	0.1	0.2	0.3	0.3	0.5		
Nitrite as N (mg/L)	0	0	0	0	0	1	
Nitrate as N (mg/L)	0.5	0.91	0.68	3	1.2	10	10
Orthophosphate as P (mg/L)	0.13	0.02	0.02	0.02	0.02	n/a	
Organic Nitrogen as N (mg/L)	0.7	0.42	0.7	Lost	0.7		
Hardness (mg/L)	130	230	210	210	400		
Ammonia as N (mg/L)	0.5	0.5	0.5	0.5	0.5	n/a	1
Total Kjeldahl Nitrogen as N (mg/L)	1.2	1.2	1.2	Lost	1.2		
Total Phosphate as P (mg/L)	0.27	0.13	0.11	0.09	0.05	n/a	1
Arsenic (ug/L)	**20**	**20.8**	**20.8**	**20.8**	**20.8**	10	
Silver (ug/L)	7.28	7.28	7.28	7.28	7.28	100	
Boron (ug/L)	36.6	110	103	74.8	293	n/a	<500
Cadmium (ug/L)	0.83	0.83	0.83	0.83	0.83	5	
Chromium (ug/L)	7.28	7.28	7.28	7.28	15	50	
Copper (ug/L)	32.2	8.32	8.32	8.32	8.32	1000	<100
Iron (ug/L)	87	60	32	**820**	44	300	<200
Magnesium (ug/L)	9400	**19000**	**25000**	**22000**	**51000**	n/a	<12,152.5
Sodium (ug/L)	39000	49000	**78000**	**69000**	**87000**	n/a	<68,969
Nickel (ug/L)	5.2	5.2	5.2	5.41	5.2	100	
Lead (ug/L)	17.4	7.62	9.98	15.3	11.7	n/a	
Zinc (ug/L)	500	30	**140**	100	28	5000	<100
E. Coli (MPN/100mL)	2	2	2	2	2		
Total Coliforms (MPN/100mL)	30	100	2	30	4	5%*	

Table 12: Water quality samples collected 2/13/2006. Highlighted figures exceed standards.

*More than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E.coli fecal coliforms, system has an acute MCL violation.

MPN - Most Probable Number. This is a statistical number generated by Microbiologists years ago. What it really means is that the estimated number [most likely number] of organisms per sample volume is reported. Bacteria are quite ubiquitous organisms and are not consistent like ammonia or alkalinity.

Date Collected: 02/13/2006	HV Substation 3	Moffit Library	Birge Hall	Boalt Hall	Stanley Hall	California Drinking Water Quality Database	Irrigation Standards
Salinity (%)	0	0.3	0.3	0.3	0.5		
Nitrite as N (mg/L)	0	0	0	0	0	1	
Nitrate as N (mg/L)	0.5	0.92	0.86	6.8	1.2	10	10
Orthophosphate as P (mg/L)	0.09	0.04	0.05	0.04	0.02	n/a	
Organic Nitrogen as N (mg/L)	0.7	0.7	0.7	0.7	0.7		
Hardness (mg/L)							
Ammonia as N (mg/L)	0.5	0.5	0.5	0.5	0.5	n/a	1
Total Kjeldahl Nitrogen as N (mg/L)	1.2	1.2	1.2	1.2	1.2		
Total Phosphate as P (mg/L)	0.13	0.06	0.09	0.06	0.03	n/a	1
Arsenic (ug/L)	**20.8**	**20.8**	**20.8**	**20.8**	**20.8**	10	
Silver (ug/L)	7.28	7.28	7.28	7.28	7.28	100	
Boron (ug/L)	19.5	123	96	99.5	263	n/a	<500
Cadmium (ug/L)	0.83	0.83	0.83	0.83	0.83	5	
Chromium (ug/L)	7.28	7.28	7.28	7.28	7.28	50	
Copper (ug/L)	30.6	8.32	8.32	8.32	8.32	1000	<100
Iron (ug/L)	36	**210**	25	56	28	300	<200
Magnesium (ug/L)	38000	**23000**	**26000**	**25000**	**53000**	n/a	<12,152.5
Sodium (ug/L)	8300	58000	**79000**	**69000**	**83000**	n/a	<68,969
Nickel (ug/L)	5.2	5.2	5.2	5.2	5.2	100	
Lead (ug/L)	8.73	8.75	7.32	7.57	18.4	n/a	
Zinc (ug/L)	**160**	16	**130**	27	18	5000	<100
E. Coli (MPN/100mL)	2	2	2	2	2		
Total Coliforms (MPN/100mL)	500	2	17	2	4	5%*	

Flow Rate The quantity of water pumped out of each de-watering sump per minute is shown below in Table 1. HV Substation 3 and Boalt Hall remained essentially stagnant and are thus unsuitable for irrigation. Stanley Hall and Moffit Library proved to be the most active, pumping 10.33 and 12.60 liters/minute respectively. At 12.60 liters/minute the Moffit Library sump produces approximately 18,000 liters/day.

Table 3: Flow rates from all sample sites, Moffit Library wet season data omitted due to sump maintenance for the Spring semester.

In liters/minute	Dry Season (12/13/05)	Wet Season (3/7/06)
Boalt Hall	0	1.32
Birge Hall	0.95	7.38
Stanley Hall	10.33	31
Moffit Library	12.60	N/a
HV Substation 3	0	0

Directly adjacent to Moffit Library lies Memorial Glade, a grassy turf with the highest water consumption on campus (Lico 2006, pers. comm.). It contains 14 sprinkler valves with maximum flow rates ranging from 17 to 56 gallons/minute. These sprinklers are typically active up to 3 times a day for a variable duration of time determined by climatic conditions. The hottest summer days usually see the sprinklers active 3 times a day for 20 minute intervals, using an estimated 160,000 liters/day. During the cooler spring days sprinklers are active 2 times a day for 10 minute intervals, an estimated 50,000 liters/day. Moffit sump's water supply, at 18,000 liters/day, covers 11-36% of Memorial Glade's demand.

Cost/Benefit Analysis While a comprehensive cost/benefit analysis of implementing a groundwater to irrigation system on campus would require an in depth look at every sump and irrigation line on campus, a rough sketch of some of the costs and benefits are outlined below. Most of the cost would come from ground tanks used to store water; valves and valve heads would not need replacement but give an indication of infrastructure costs such as piping. As one can see from the benefits side EBMUD would subsidize 25% of costs per project, where each project is defined by a main irrigation line that will be converted to partial groundwater use. Additionally, it appears that the water savings per year would make a large contribution towards costs of implementation.

Table 4: A brief description of costs and benefits.

Cost Description	**Cost in Dollars**	**Benefit Description**	**Benefit in Dollars**
Ground tank 5,000 gallons	~ 8,000	Domestic Water Savings	132,000/year*
Ground tank 10,000 gallons	~ 12,000	EBMUD contribution	25% of cost/project
Electricity to pressurize system	~ 2/pump/day	*If all irrigation on campus were supplied by groundwater wells, according to irrigation needs and water costs from fiscal year 04/05.	
Valves, valve	~ 140 each.		
Maintenance	Negligible		

Discussion

Water Quality The California Department of Health Services writes the standards for wastewater use in irrigation. However aside from bacteria levels these are only technical objectives. According to Wil Bruhns, Chief at the Bay Area Water Board, Oakland office, there is no legal permission required to use pumped groundwater for irrigation. Nonetheless, in considering human health risks, contamination of water or soil, and environmental damage to soil and plants one should ensure water quality is within acceptable parameters.

Inorganic and organic nitrogen levels were well below drinking water standards; however there is no standard for phosphorous. This water is going to be sprayed onto lawns and levels of these two chemicals could require reduction of applied fertilizer. Information about the amount of fertilizer applied to campus lawns, and their nitrogen and phosphorous levels, should be studied at a later time to determine if the nitrogen and phosphate will make a significant impact.

Of the metals, arsenic levels pose the highest toxic health threat. Recently the EPA reduced the arsenic standard to 10ug/L, a level that water systems had to adopt by *January 23, 2006.* Higher levels of arsenic tend to be found more in ground water sources than in surface water sources (i.e., lakes and rivers) of drinking water (WWW1. 2006). Such a trend fits with the water quality results, which show a consistent level of 20.8ug/L for all sumps, during dry and wet seasons.

Water samples came out Coliform-positive, posing a potential health risk. As mentioned above, Coliform contamination in groundwater is common due to percolation through fecal matter in the soil. However, as this water will be directly applied to lawns there is minimal chance of significant human and animal consumption.

Water hardness is a concern for build up of solids in the piping system, and possibly a buildup of deposits in the soil which would stress vegetation growth. EBMUD drinking water has a hardness that generally ranges from 50-150 mg/l, Strawberry Creek water is closer to 500 mg/l. Except for Stanley Hall, the levels detected are within standard range. Stanley results are most likely not an issue considering it is well below Strawberry Creek water. Additionally levels may decrease over time as the concrete cures longer and things settle around the construction site (Maranzana 2006, pers. comm.).

Flow Rates During the dry season the flow rate is relatively constant because the sumps only pump out the excess water in the water table. However during the rainy season flows can fluctuate dramatically (Trent 2005, pers. comm.). Measurements taken during the dry season are more useful as there is not much irrigation demand during wet seasons. Wet season measurements are useful for showing a full range of the quantity of water produced by sumps. The information is also useful if the campus is interested in using this water for other facilities (such as toilets).

Results show that the Moffit library sump could cover approximately 11-36% of Memorial glade's needs. In analyzing this figure it is important to keep several extraneous facts in mind. Firstly, domestic water would be used to supplement water from the sumps. Any gap in supply would immediately be filled by a domestic water line, thus reducing concern of insufficient watering. Secondly, Memorial glade is the highest irrigation consumer on campus, areas adjacent to sumps that contain more shade – including areas with shrubs, trees, and ornamental plants would require less water. Finally, this report only tested five de-watering sumps, there are other sumps and wells on campus that can also be tied into the irrigation system. In addition there are old wells that have been used by the engineering colleges that have yet to be explored by PP-CS (Trent 2006, pers. comm.). With this additional information it is possible that the sumps could cover a larger portion of campus irrigation demand.

Cost/Benefit Analysis EBMUD's subsidization of a portion of the costs combined with returns on domestic water costs appear to offset the initial investment over the course of a few years. A few costs, such as labor and piping, were not discussed because the information was unavailable at the time. However, from this preliminary study the projected costs would not create an insurmountable hurdle.

Some issues that are important for the economic aspect of this study yet are difficult to quantify include environmental benefits/costs and future water prices. Reusing groundwater for irrigation on campus would be reducing its dependence on outside water sources, therefore increasing its self-sustainability. Water diverted from the bay would also decrease fertilizer/pesticide run-off from the campus and delay the need to build new wastewater treatment facilities in Berkeley or Oakland. In case of a drought or other water crises where water prices increase, a self-sustaining irrigation system has the potential to save the university far more money than it would currently. On a less positive note, the reuse of water in public spaces could create landscaping and/or health damages, such as soil salinity or human illness, with resulting costs that are difficult to estimate.

Conclusion

This study has shown that connecting de-watering sumps and wells to irrigation lines on campus is a feasible alternative to current domestic water usage according to the factors assessed. The quality of the groundwater overall lies within standards and has been deemed good by the UC Berkeley EH&S department (Maranzana 2006, pers. comm.). Flow rates from de-watering sumps indicate that they have potential to cover an adequate fraction of water demand. The cost/benefit analysis needs further detailing, but appears to be pointing at an pay-off of initial investment after a few years. Should UC Berkeley choose to proceed with this project it is recommended that a landscape designer look into effects of salinity and other metals that exceeded standards (such as magnesium and zinc). A more thorough analysis of the flow rates of sumps and wells on campus in addition to the costs and benefits accrued would be relevant for a follow up study.

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