

Conserving Surface Water: Trees and Drying Rates in Alameda Creek, California

Andrea Irons

ABSTRACT

In Alameda Creek, in northern California, some sections dry while others remain wet throughout each summer. To understand the causes of drying patterns, my study analyzed the correlation between vegetation (percent cover and sycamore presence) and drying rates in specific points throughout the creek. Other environmental variables, including elevation, range of temperatures, and average temperature, were also correlated with drying rates to account for groundwater flow paths. The relationship between *Platanus racemosa* (Western sycamore) and drying rates was of specific interest because *P. racemosa* is one of the largest in-channel trees in the system. Being a large tree, it may be capable of hydraulic lift, in which it redistributes water from deep soils into the surface layers. Results showed elevations and average temperatures to have significant correlations to drying rate, and in-channel sycamore trees have a significantly greater effect on drying rates than trees on the bank or more than 30 m away. Future research may analyze how *P. racemosa* biologically absorbs and releases water, and the groundwater flow paths that may be directing hydraulically-lifted water from distal trees.

KEYWORDS

hydraulic lift, stream ecology, surface water, groundwater, percolation, evapotranspiration

INTRODUCTION

Many streams and creeks dry in California during the arid Mediterranean summer, which constrains the life history strategies of aquatic species, including fish, macro-invertebrates, and vegetation (Poff, Allen, Bain, Carr, & Prestegard et al., 1997). Aquatic species conservation and management can be improved through understanding patterns and causes of summer drying, since water availability stresses populations in Mediterranean climates.

Understanding the causes of drying are difficult, because the pathways of water movement are multiple and complex. Surface waters are depleted by direct evaporation to the air, seepage into soils, and evapotranspiration through vegetation. However, creeks gain water through precipitation and groundwater inflow from the soil (Kondolf, 1989).

Groundwater and surface water interactions are not unidirectional, because streams can gain or lose water from inflow or seepage, respectively (Kondolf, 1989). Water that seeps into soils may then re-emerge later downstream or flow through bedrock cracks into a deep aquifer (Natesan, pers. comm.). Reaches with large temperature fluctuations are likely losing surface water to the soil, while pools with relatively constant temperatures are kept constant through groundwater inputs (Silliman & Booth, 1993). In order to account for groundwater inflow in my sites, I examined pool temperature fluxes and elevations (Figure 1). Elevation is also indicative of connectivity to groundwater, because pools closer to the water table would have the most efficient groundwater-surface water exchange.

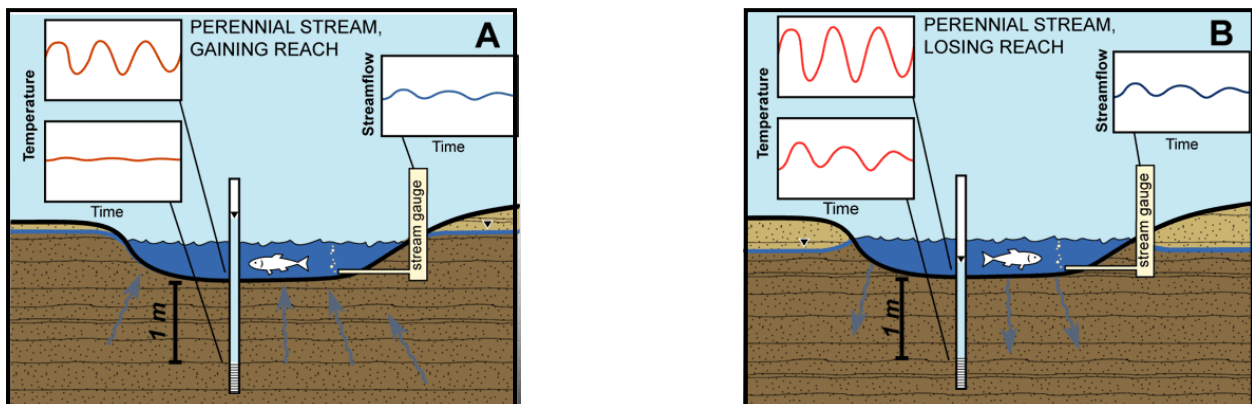


Figure 1: Fluctuations. Temperature variation of groundwater and stream under gaining (a) and losing stream (b) conditions (adopted from Stonestrom & Constanz, 2003)

In addition to this passive soil water flow, guided by substrate and groundwater table elevation, waters are actively transported between the soil and the surface by vegetation. Plants' complex redistribution of water can also significantly impact drying patterns (Le Maitre, Scott and Colvin, 1999).

The relationship between vegetation and water is complex because plant dispersal may be a consequence of water availability, but vegetation also affects water distribution between the surface and the soil (Le Maitre et al., 1999). Plants contribute and conserve water in several ways. Canopies funnel precipitation down along the trunk and roots, guiding percolation, the movement of surface water downward into the soil (Jofree & Rambal, 1993). Canopy shading also reduces surface water evaporation (Breshears, Nyhan, Hiel, & Wilcox, 1998). Large trees located in the channel can be hydraulic controls, meaning they direct stream flow. Water rushes around the trees at higher velocities, which erodes sediment on the stream bottom to create scour pools, deeper areas that can contain greater volumes of water (Pizzuto, 2010). In order to grow and develop, vegetation absorbs water from soil, which may in turn pull water from the stream channel. In addition to these perceptible and understood relationships, vegetation also affects water in less obvious ways.

In some cases, vegetation may actively contribute water to surface soils through the hydraulic lift process (Caldwell, 1998). Hydraulic lift (HL) has only recently been discovered, and its implications have yet to be understood (Burgess, Adams, Turner & Ong, 1998). During HL, a plant's deep taproot pulls groundwater up into the shallower root mass, from which water flows outward into surface soils. Some plants exercise this overnight to increase soil water availability (Richards & Caldwell, 1987). Water in higher layers of the substrate will more readily flow into the stream channel than deeper groundwater will (Kondolf, 1989). Therefore, HL may be contributing surface water, but this process has not been quantified in existing literature (Ishikawa and Bledsoe, 2001). More broadly, researchers are uncertain whether vegetation causes a net gain or loss of surface water (Chen, 2006; Le Maitre et al., 1999).

Therefore, I explored the complex relationship between surface water levels and vegetation in scour pools in an intermittent creek, to establish whether vegetation induces a net gain or net loss in surface water quantity during the dry season. My main objective was to establish a correlation between vegetation and the dewatering rates of surface water, which required accounting for extraneous groundwater processes. I also searched for evidence that

vegetation on Alameda Creek (particularly *P. racemosa*) redistributes groundwater to the surface through HL, thus affecting the rate of dewatering.

I addressed the following questions: 1) Does vegetation conserve or deplete surface water? And 2) are *P. racemosa* trees on Alameda Creek performing hydraulic lift? I hypothesized 1) Areas with more vegetation will retain surface water longer than areas without as much cover, and 2) *P. racemosa* conserve water through hydraulic lift. My second hypothesis would be supported if diurnal water level patterns are more pronounced in a pool with a higher proximity to *P. racemosa* (i.e. a higher “sycamore index”) than in a pool that has a lower sycamore index. If my hypotheses could not be confirmed, then vegetation may have no net effect on drying rates, i.e., vegetation conserves water through funneling percolation, shading, and possibly hydraulic lift, but absorbs an equal amount of water for growth.

METHODS

Study site

My study was conducted on Alameda Creek, which runs from the city of Fremont to the San Francisco Bay, California. I studied a section of this creek in Alameda County, upstream of the Sunol Regional Wilderness. Because the San Francisco Public Utilities Commission owns and restricts public access to this section of the creek, my 25 sampling sites were not tampered with for the duration of the study.

Portions of the stream below the Alameda Creek Diversion Dam dry over the summer, due to California’s hot Mediterranean climate and limited releases allowed to bypass the dam. Drying limits habitat availability for fish, specifically Alameda’s rainbow trout (*Oncorhynchus mykiss*) population. *O. mykiss* are vulnerable because they require cool water temperatures and cover in order to survive, and the creek satisfies these requirements for most of the year. I recorded several variables that may affect surface water levels, which may in turn affect trout populations: the presence of *P. racemosa* and other general tree cover, and elevation and temperature data at all of my sites (Table 1).

Table 1: Sites. GPS coordinates for all monitored sites. *Incorrect coordinate recorded: Could not calculate percent cover.

Site	Northing	Westing	Site	Northing	Westing	Site	Northing	Westing
A	37.50659	-121.807	J	37.50533	-121.801	R	37.50263	-121.791
B	37.50703	-121.806	K	37.50459	-121.798	S	37.50254	-121.79
C	37.50733	-121.805	L	37.50463	-121.798	T	37.50273	-121.79
D	37.50727	-121.805	M	37.50446	-121.798	U	37.50288	-121.789
E	37.50677	-121.804	N	37.50379	-121.796	V	37.50282	-121.789
F	37.50662	-121.803	O	NA*	-121.862	W	37.50237	-121.788
G	37.50628	-121.803	P	37.50254	-121.794	X	37.5021	-121.788
H	37.50578	-121.801	Q	37.50261	-121.791	Y	37.50149	-121.787
I	37.50545	-121.801						

Data collection

I collected data during the dry season (June through September, 2010) to prevent rain from affecting water depths.

Biweekly pool depths and temperatures

To find pool drying rates, I measured maximum pool depths at each site once every two weeks. I measured depths with a measuring rod at the same location in each pool, using detailed site descriptions (rock shape, color, etc.).

To determine the relationship between the decreasing water levels and increasing temperatures, I collected water temperatures at each site during depth sampling. I measured temperatures to the nearest 0.5 degrees Celsius, and calculated an average and range for each site.

Sycamore indices and percent cover

To determine whether *P. racemosa* affected drying rates, I noted whether trees were on the bank or in the channel near my depth sampling points. For my analysis of a general

relationship between the presence of riparian vegetation and drying, I manually calculated percent cover within a 30 m radius of each point, using ArcGIS and Microsoft Paint.

In order to establish whether elevation was strongly related to pool drying, and to ensure it was not a confounding variable in my study, I used a U.S. Geological Survey topographic map in ArcGIS to find elevations corresponding to my site GPS points.

Levellogger data

I compared diurnal depth and temperature trends in two pools, sites A and M. Site A had *P. racemosa* roots in it, and M did not. Therefore, I used site M as a “control pool” to identify significant diurnal fluctuations in Site A, which would be indicative of HL. Automatic Solinst Levelloggers collected hourly temperature and depth.

Data Analysis

Data normalization and regression

I first checked whether my data set was normal by using Shapiro-Wilks tests, and made necessary transformations (natural log, inverse, log, square, or square root) to achieve normality in most variables (R Development Core Team, 2009). I also viewed the histogram for each variable to make a qualitative assessment of normality.

I then used Spearman’s rank correlation regression analysis to assess the strength of correlations between normalized average and range of pool temperature, percent cover, and elevation upon normalized pool drying rates. This exploratory analysis allowed me to assess which variables were having the strongest effect on water level.

Sycamore Index

To determine the significance of sycamore influence upon water levels, I coded each pool as **0**, **1**, or **2**, based on *P. racemosa* proximity. Pool classifications are defined as follows: **0** had no *P. racemosa* within a 30 m radius, **1** had at least one on the bank within that radius, and **2** had

at least one in the channel. I used an ANOVA test, through the R Commander package in the R program, to determine which category of sycamore influence had the greatest effect on drying rate over the entire dataset (R Development Core Team, 2009).

Hydraulic Lift

To analyze diurnal water level patterns, I plotted the sycamore and control pools' depths and temperatures over time in Microsoft Excel. I gave a qualitative assessment of the graphs, in order to deduce whether *P. racemosa* caused pronounced fluctuations in water levels.

RESULTS

General pool characteristics

I calculated percent cover and sycamore index for each pool in order to analyze the relationship between vegetation and drying rate, but I also found elevation, and average and range of water temperature to assess the strength of additional groundwater processes. Of all sites, G had the fastest drying rate, and R had the slowest rate (Table 2). The sites with the greatest percentage of vegetation cover were E and J. Site V had the highest elevation. The sites with the highest average water temperatures over their respective drying periods were L, K, N, and X. No perfect linear relationship was evident, i.e. site G did not have the greatest percent cover or highest elevation.

Table 2: Site Characteristics. I recorded drying rate and temperature biweekly, and collected percent cover and sycamore indices for each site. Percent cover and sycamore indices are considered constants throughout the drying period. Sites are ordered from downstream to upstream.

Site	Elevation (m)	Drying Rate (cm/day)	Temp Avg (°C)	Temp Range (°C)	Percent Cover (%)	Sycamore Index
A	60.9	1.74	17	17	79.5	2
B	61.9	2.07	0	0	78.6	2
C	62.4	0.82	20	20	62.5	0
D	62.5	0.76	18	18	65	1
E	62.6	2.62	17.3	17.5	90.8	2
F	62.8	0.85	17.5	17.5	78.3	1
G	63.0	4.60	9.5	19	88.4	2
H	66.3	1.28	18.5	18.5	73.9	2
I	63.2	1.43	20	21.5	88.2	1
J	63.6	0.73	19.8	22	90.8	2
K	64.4	0.49	22	25	84	1
L	65.7	0.27	22.3	25	80.7	2
M	64.8	1.31	17.2	24.5	77.3	2
N	66.1	0.09	22	5	77.3	1
O	66.1	0.98	18.8	25.5	NA	2
P	66.8	0.94	16.6	22	71.2	0
Q	68.8	0.15	19.8	6	66.4	1
R	68.3	0.03	20.3	5.5	85.6	1
S	68.2	0.09	20.9	4	81.7	0
T	68.4	0.34	21	6.5	75.8	0
U	69.9	0.34	19	26	55	0
V	70.4	0.46	18.6	25.5	43.7	0
W	70.0	0.27	18.1	25	52.9	0
X	69.1	0.61	21.6	24	66.4	2
Y	69.6	0.82	20.3	4.5	78.2	1

Table 3. Shapiro-Wilks Tests. Tests were conducted for each site within the data subset to determine normality.

Variable	W	p-value
Average Drying Rate	0.7711	7.765e-05
Average Temperature	0.6578	2.074e-06
Range Temperature	0.8414	0.001215
Elevation	0.9301	0.08741
Percent Cover	0.9291	0.09315

Normality was confirmed for nearly all variables through the Shapiro-Wilks tests (Table 3). Since the p-values for both elevations and percent cover were greater than 0.05, the null hypothesis that the dataset is normal cannot be rejected. Therefore, elevations and percent cover were normally distributed and could be used without transformation in the regression analysis. To normalize drying rate, I took the natural log. I nearly normalized average temperatures by squaring all values. Transformations could not normalize the range of temperatures, so raw values were used, though one assumption of my statistical analysis was normality. Sycamore index was categorical, so it did not need to be normal. Shapiro-Wilkes confirmed normality for transformed drying rate and nearly confirmed it average temperature (Table 4).

Table 4: Shapiro-Wilks Tests for Transformed Variables. These were conducted for each site within the data subset to determine normality.

Variable	W	p-value
$\ln(\text{Average Drying Rate})$	0.9608	0.431
$(\text{Average Temperature})^2$	0.9159	0.04751

Spearman's Rank Correlation and ANOVA

Elevation and average temperatures each had a significant correlation with drying rate, at the 1% level. Elevation also had a significant correlation with percent cover, at the 5% level (Table 5).

Table 5. Spearman’s Rank Correlation. Demonstrates strength of correlations between variables.
 *significant at the 5% level, **significant at the 1% level.

	(Average_Temp) ²	Elevation	Ln(Drying)	Percent_Cover	Range_Temp
(Average_Temp) ²		0.1451	0.0004	0.8077	0.6295
Elevation	0.1451		0.0028	0.0195*	0.4691
Ln(Drying)	0.0004**	0.0028**		0.2068	0.6287
Percent_Cover	0.8077	0.0195	0.2068		0.1453
Range_Temp	0.6295	0.4691	0.6287	0.1453	

ANOVA analysis of sycamore influence showed a very weak relationship between sycamore presence and drying rate. However, sycamore_2 sites had a significantly stronger effect on drying rate than sycamore_1 or _0 sites (Figure 2).

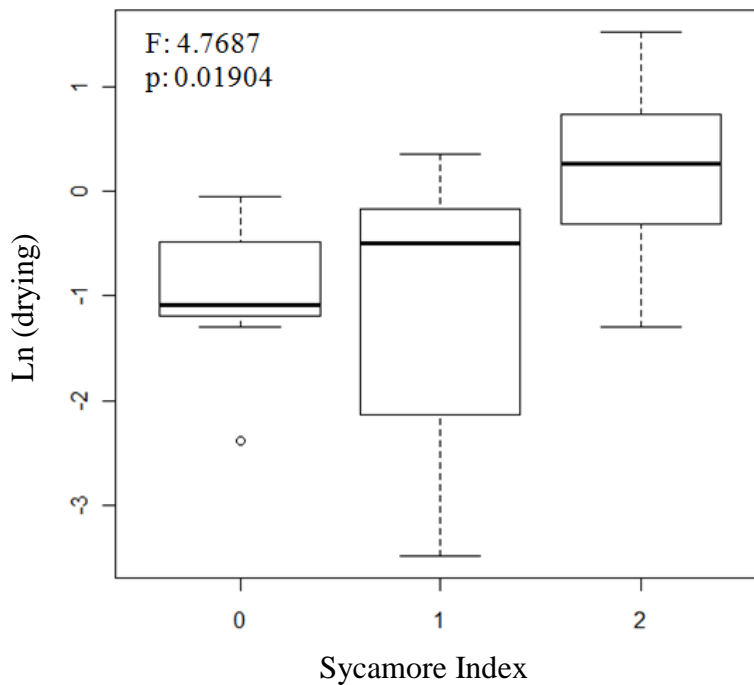


Figure 2: Boxplot of Sycamore Index versus drying rate, visualizing ANOVA results.

Levelogger data

The sycamore pool had greater depth and temperature fluctuations than the control pool, which intensified over time (Figures 1-3).

Figure 1. Water levels from June 11 through August 23, 2010.

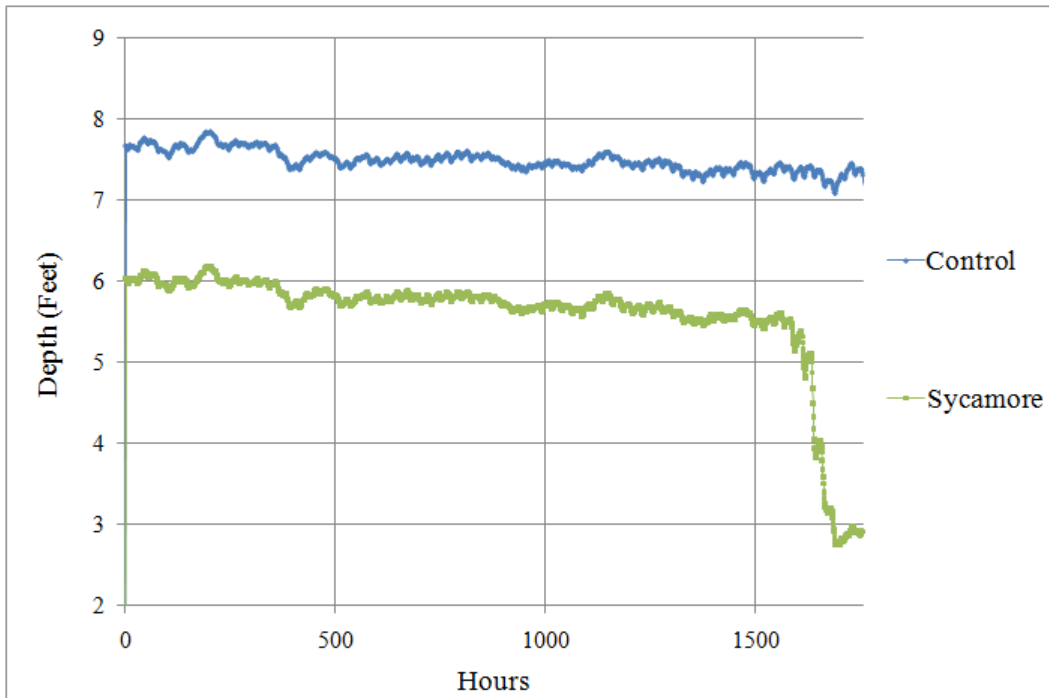


Figure 2. June 14, 2010 Water Levels

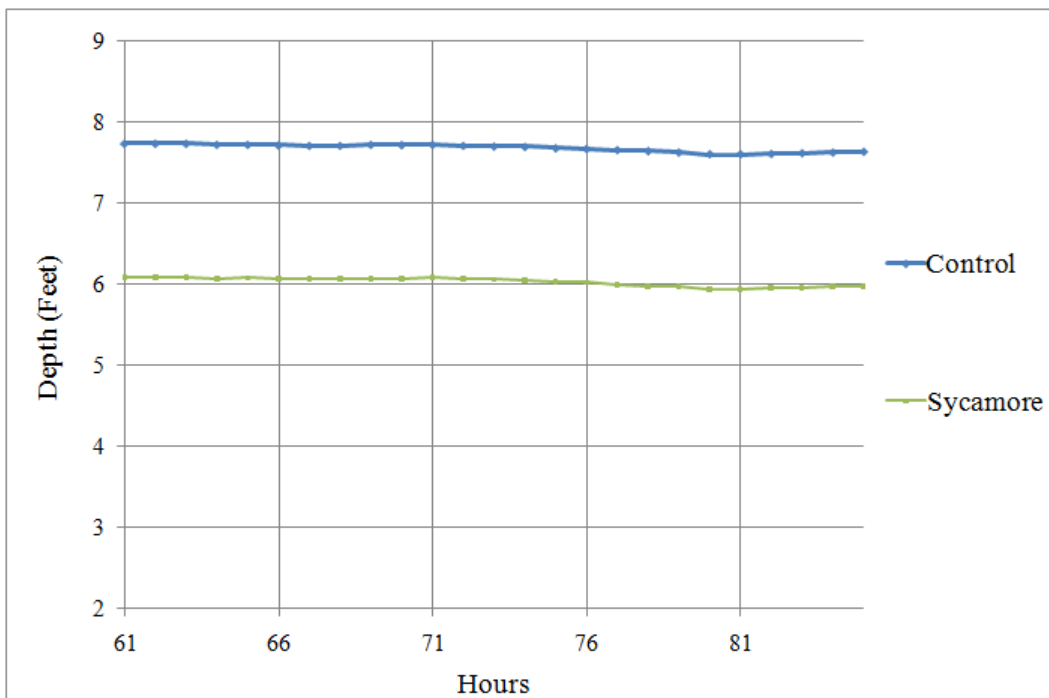
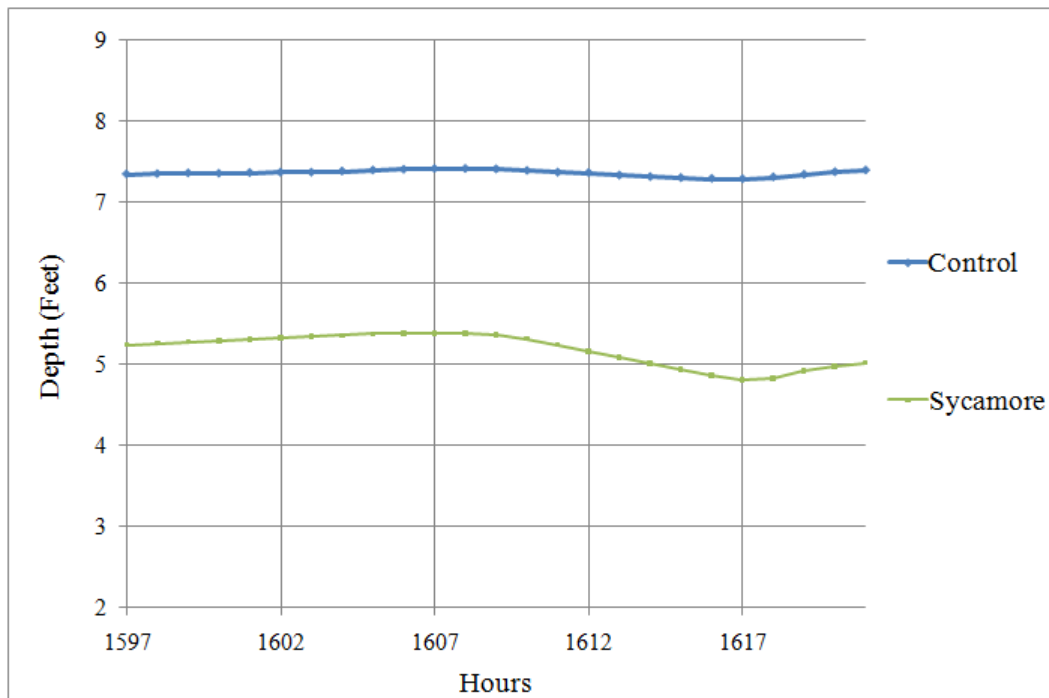


Figure 3. August 17, 2010 Water Levels

Because diurnal sycamore pool fluctuations intensified as summer progressed, I suspected that patterns may have been exaggerated by water volume available in each pool. Diurnal sycamore pool fluctuations in depth were not consistently greater than control pool fluctuations when I graphed both pools, beginning at midnight and with similar depths, but on different days (Figures 4-5).

Figure 4. August 18 (Sycamore) and September 20 (Control), 2010 Water Levels

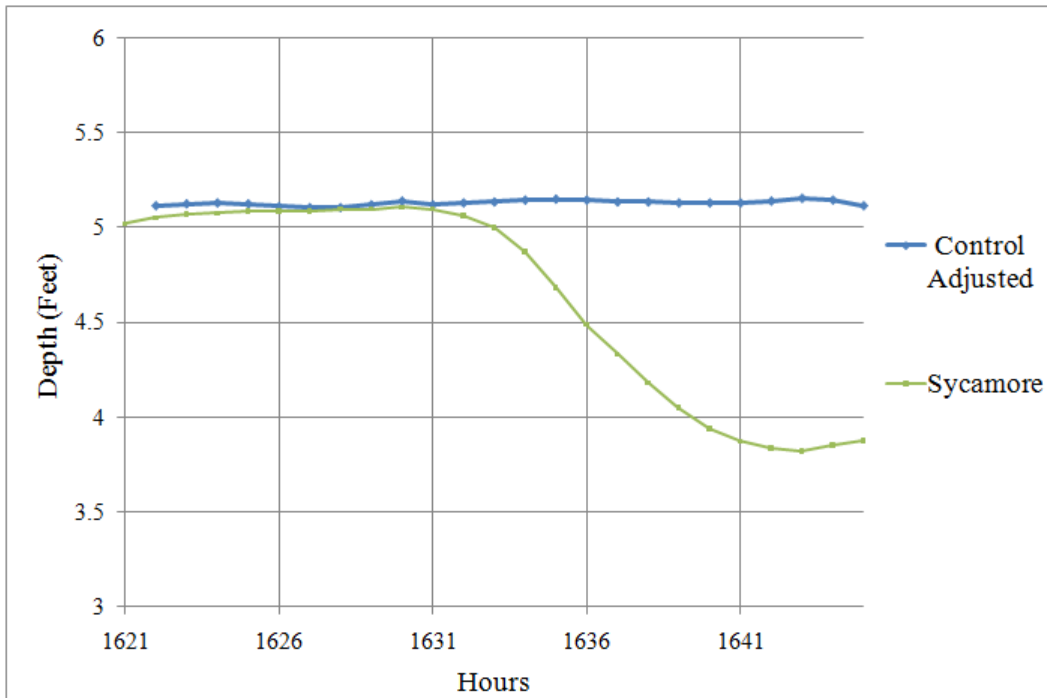
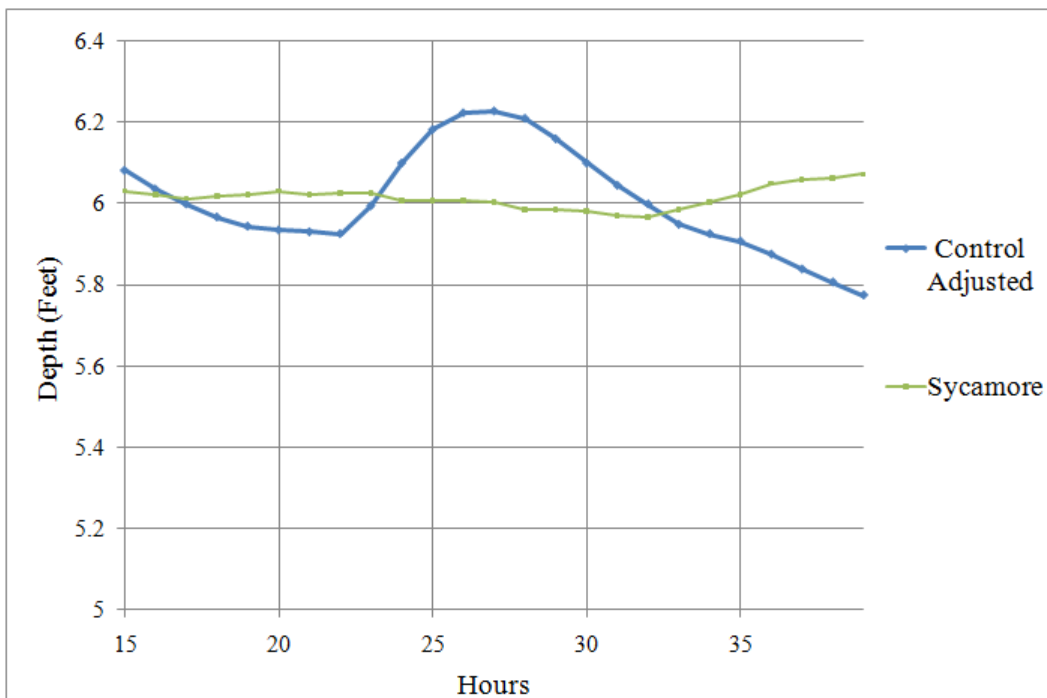


Figure 5. June 12 (Sycamore) and August 26 (Control), 2010 Water Levels



The magnitude of temperature fluctuations for the sycamore and control pool were generally the same throughout the summer, with the sycamore pool becoming warmer as it neared drying (Figures 6-8).

Figure 6. Temperatures from June 11 through August 23, 2010.

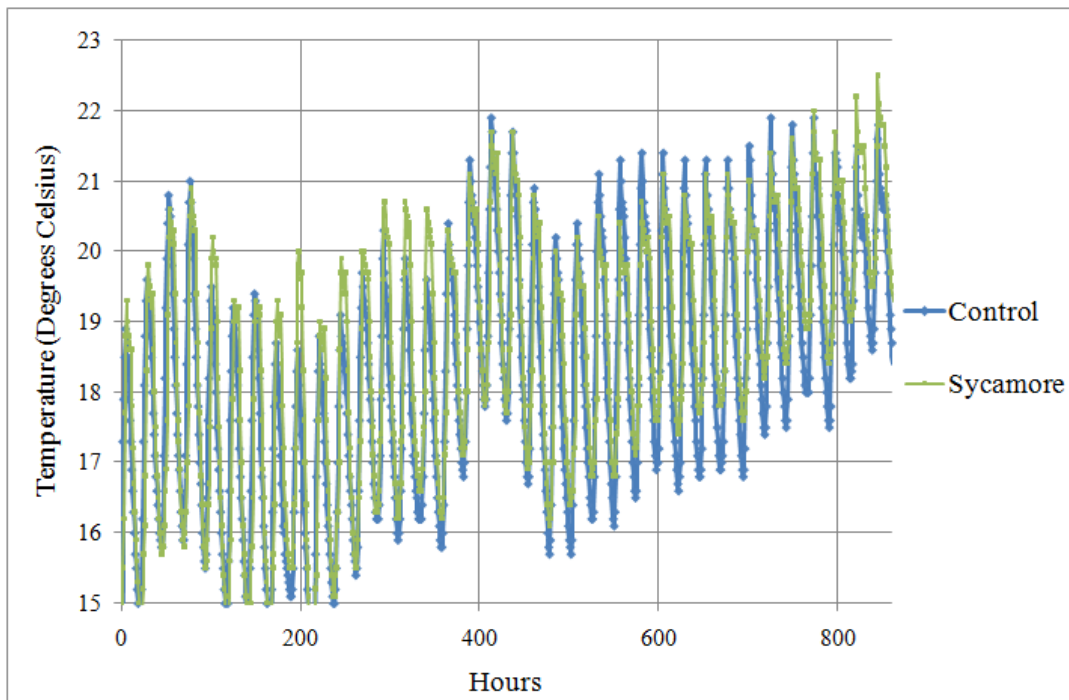


Figure 7. June 14, 2010 Temperatures

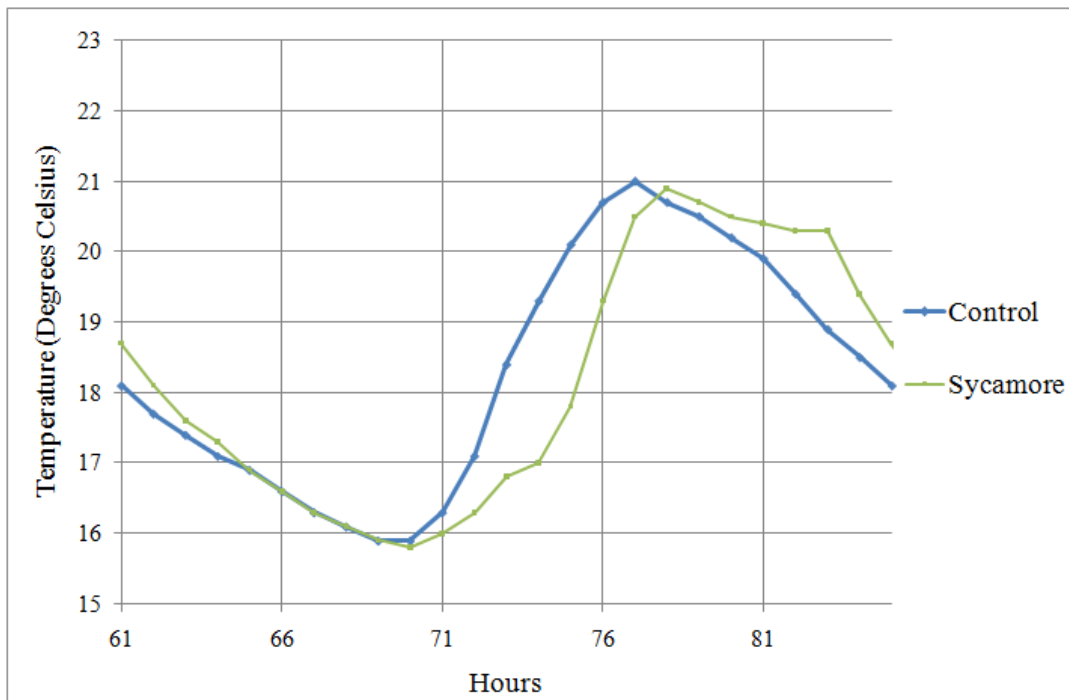
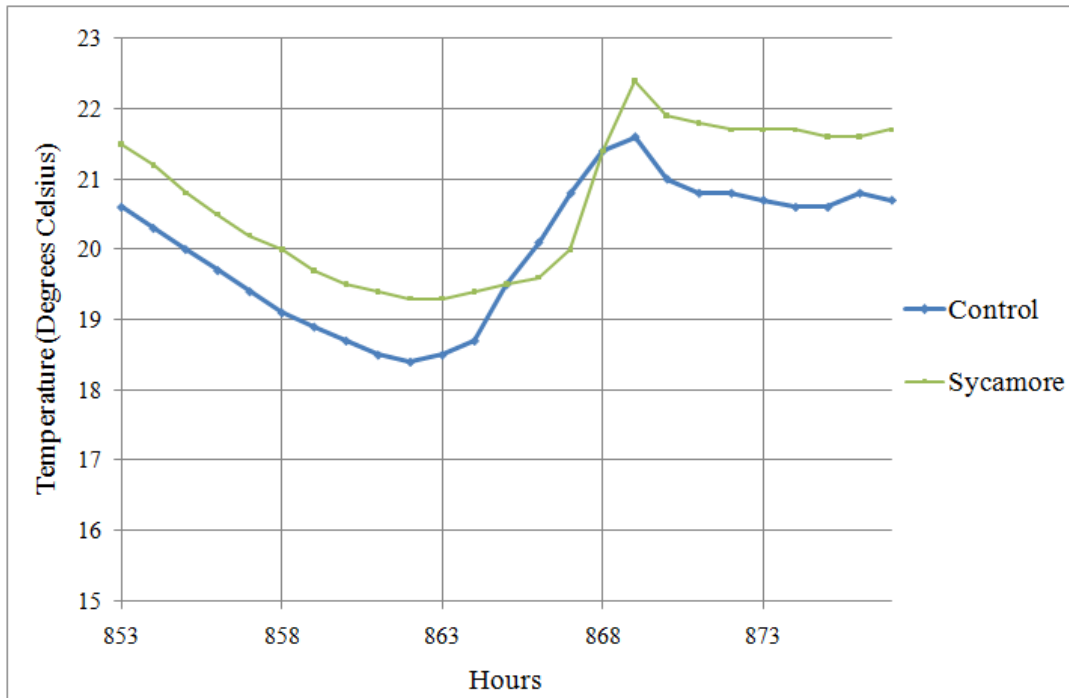


Figure 8. August 17, 2010 temperatures

DISCUSSION

Effects of groundwater flow

Although I had hoped to vegetation to be significantly responsible for drying rates, I found instead that the combination and interaction of many factors may determine which areas of Alameda Creek go dry. The significant correlation between elevation and drying rate suggest that subsurface groundwater flows may have a stronger influence on drying rates than above-ground vegetation, but the correlation with range of temperature could not confirm this trend. Temperature range had the weakest correlation to drying rate, but this correlation may be an error due to the abnormality of the temperature range variable. A strong correlation to temperature fluctuations was expected, because reaches with large temperature fluctuations may have lost surface water to the soil at a greater rate (Silliman & Booth, 1993). Because elevation is also indicative of connectivity to groundwater, it logically follows that average temperature and elevation had the strongest correlations to drying rate.

Effects of vegetation

In contrast, percent cover had the least obvious correlation to drying rate, even though vegetation's shading affects surface water temperatures. This was unexpected, considering that other modeling studies have shown that vegetation controls soil drying rates (Atchley & Maxwell, 2001).

I examined the influence of *P. racemosa* because they are the largest trees in the system, so they may effectively pump water up toward the surface through HL. The ANOVA test for sycamore index showed that many sites with the highest sycamore index had the greatest drying rates. I propose two possible explanations for this trend: 1) *P. racemosa*'s in-channel roots absorb water directly from the stream, not from HL water in the soil or 2) *P. racemosa* does perform HL, but does not release enough water at night to compensate for the amount of soil water they absorb during the day, which is being indirectly drawn from the stream. Though the exact pathway through which they absorb water cannot be confirmed, *P. racemosa* presence in the stream channel causes drying rates to locally increase throughout Alameda Creek. However, *P. racemosa* may still not have a net negative effect on general water availability; the scour pools which they create dry at a faster rate, but they may persist longer due to their greater initial volumes than the surrounding stream channel.

Sycamore pool vs. control pool: Levelloggers

My initial observation of hourly depths in both pools showed that the sycamore pool fluctuations were much more pronounced when it was nearly dry. These fluctuations could indicate increased absorption by *P. racemosa*, or they could be exaggerated trends due to the minimal volume of water in the sycamore pool. In order to rule out the effects of inflows into drastically different water volumes, I compared 24-hour trends between pools when they had nearly the same initial water depth. The results showed inconsistent variations in depth between the sycamore and control pools. Depth fluctuations did not always follow the diurnal pattern of HL – perhaps there is a time lag for HL water to reach the stream, which makes levels swell at unexpected times. The HL process could not be confirmed, nor could the net effect of *P.*

racemosa in particular be determined due to the inconsistent and random variations between pools.

Since temperature fluctuations were relatively consistent between the sycamore and control pools, they both had the same connectivity to groundwater. Inflows are stabilizing temperatures, or seepage is magnifying variations in temperature for both pools, consistently. Therefore, *P. racemosa* specifically is not increasing water inflows into the stream, because sycamore pool temperatures are not more stable than control pool temperatures.

Limitations

Ultimately, the regressions of this study suggest relationships between drying rate and groundwater connectivity, but cannot confirm whether *P. racemosa* is moving significant amounts from deep soil layers to the stream. Vegetation may affect groundwater elevations, but plant distributions may also be a consequence rather than a cause of water availability (Baird & Maddock, 2005). Though substrate also affects groundwater flow paths, soil composition was ignored because all soils were considered to be homogenous in this study. However, substrate composition and uneven groundwater table elevations would affect groundwater flow paths, which may have the greatest effect on drying patterns throughout Alameda Creek.

Broader implications

Because the groundwater table is raised or lowered by water inputs over time, increased rainfall or releases from the upstream dam would result in a higher water table. The results of this study indicate that increased surface water – groundwater exchange allows surface water evaporate more slowly. Managers may consider raising the groundwater table through water releases from the dam, in order to slow drying rates throughout the creek.

Because the Levellogger data does not show a consistent relationship between in-stream *P. racemosa* and HL, trees further away from the stream channel may have more of an effect on water levels than anticipated. This implication has not yet been supported by research, but if more large trees grow along a subsurface flow path to the stream, perhaps they may indirectly contribute HL water to it. Off-bank vegetation recruitment and conservation may be intensified if

further research confirms that trees significantly and actively increase surface water availability, rather than simply dewater streams. The effects of large tap-rooted trees, vegetation cover, and elevation should be similar in other alluvial, ephemeral streams, if there are no additional mechanisms affecting groundwater-surface water exchange.

Future Directions

Further research is necessary to confirm whether large trees directly lower surface water levels. For instance, Dawson (1993) demonstrated exactly how maple trees transported water by measuring evapotranspiration rates, water flow through the tree trunk, and soil saturation. If less water is depleted from the surface than is released through evapotranspiration, then trees' net effect would be pumping groundwater up rather than depleting it from surface soils. If future studies also measure water content throughout the tree, they may provide stronger evidence that vegetation actively decreases surface water evaporation rates, which can have implications for water conservation strategies.

ACKNOWLEDGEMENTS

This work would not have been possible without the guidance of UC Berkeley Environmental Sciences 196 instructors, Patina Mendez and Lara Roman. Data was collected with the assistance of Aaron Brinkerhoff, San Francisco Public Utilities Commission (SFPUC) biologist. Ellen Natesan (SFPUC) acted as a mentor throughout this project. Levelloggers were borrowed from and deployed by Niall McCarten, PhD student in UC Davis' Ecohydrology Program. Obiajulu Nzewi and Amod Dhakal provided insights into groundwater functions and downloaded Levellogger data. GIS layers were acquired from USGS with the help of Kevin Koy, UC Berkeley Geographic Informatics Facility, and from McBain and Trush's Brian Powell. Nicholas Garcia-Guerrero, Environmental Sciences student peer, provided invaluable GIS and statistical support.

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