Soil Characteristics and their Hydrologic Implications;

A study on the Memorial Glade microwatershed,

University of California, Berkeley campus.

Alexander Javier

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Abstract:

An analysis of soil characteristics and their hydrologic implications was conducted on the Memorial Glade microwatershed, University of California, Berkeley campus. Soil bulk density, water content, porosity and infiltration rate were measured to understand local site characteristics. These data were then matched to a runoff coefficient and storm frequency estimates to predict surface runoff during a 2, 5, 10 and 50 year storm event, with the goal of designing a vegetated swale on the site, thus increasing the aesthetic, functional and ecological value of the lawn.

Introduction:

Memorial Glade is a 1.85 acre lawn situated in the center of the University of California, Berkeley campus (figure 1). On sunny days, one would expect to find sunbathers, Frisbee players and more studious students reading under the shade of small redwood trees planted along the northern edge of ‘the glade’ as it is affectionately referred to. However, when it rains, finding a soul on the glade would be a daunting task. The glade slopes gently from east to west, with a hill on the north and northeast side, effectively concentrating all water to a single drain at the western corner. With the glade's bowl shape and single outflow, the site can be seen as a metaphorical microwatershed, complete with its own "wetland" of constantly saturated soil (figure 2). After years of passing through Memorial Glade and noticing the soggy west end, sometimes days after the last precipitation event, three questions about the glade's soil and hydrologic characteristics became apparent:

1) With all of the foot traffic on site, how compacted is the soil and could that be a factor in the constant saturation or heavy runoff during storm events?
2) Just how saturated is the soil? And
3) How much runoff does the glade produce during a storm?

Methods:

Three methods were used in assessing Memorial Glade's site characteristics. First, an initial survey was used to examine the glade's water transport. Secondly, soil cores were collected to analyze the soil qualities. Finally, a simple hydrologic model was used to predict the potential runoff hazard of the site.

1. Initial Survey

To explore Memorial Glade's water transport, an initial survey was conducted approximately two hours after a heavy rain. Prior to the survey, photographs were taken to portray the "peak flow" of the watershed (figure 3). With the drain as the centerpoint, depth of water was measured along 3 transects, at 30, 60 and 90 degree azimuths, every pace (step of both the left and right foot) for depth, resulting in 10 depth measurements per transect. Measurements were taken by placing a ruler at boot tip. These data were then used to construct a sketch map of the site, providing a rough estimate of the microwatershed's floodplain (figure 2).

2. Assessment of Soil Properties

A 10x10 meter grid oriented on cardinal directions was superimposed over a satellite image of the glade producing 117 potential quadrates for sampling (figure 8). After throwing out quadrates outside of the watershed boundary, 14 were randomly selected for sampling. Soil samples were taken within each of the 14 quadrates by inserting a 5.1 cm internal dia. metal tube 10 cm into the ground. Cores were then weighed and dried for 48 hours at 105 degrees Celsius to remove all water. One sample was later thrown out because of a large rock found inside the soil matrix, resulting in a sample size of 13 cores. All dried cores were then re-weighed and calculations for bulk density, porosity, graviometric water content and volumetric water content were performed with the equations as follows:

Bulk density = (Dry Weight)/(Sample Volume)= g/cm^3

Sample volume= $10cm*\pi*(2.54cm)^2 = 203\ cm^3$

Porosity- [1-(Bulk Density)/(Soil Solid Density)]*100 = % pore space

Soil solid density was approximated using the density of quartz ($2.65g/\ cm^3$), the most common soil constituent.

Graviometric Water Content- (wet weight-dry weight)/(dry weight)= gH2O/GSoil

Volumetric Water Content- (Graviometric Water Content)/(Bulk Density/Water Density)*100= % Water Volume.

Water Density= 1 g/ cm^3.

The saturation ratio of the soil was then calculated as the ratio of Volumetric Water Content to Porosity. This saturation ratio was subsequently used as an adjusted cover factor in the rational equation for calculating runoff.

Infiltration rate was measured on 4 random quadrates, 3 on the flat section of the glade and 1 on the hill. After observations, one additional datum was added to increase sampling of the hillslope. To measure infiltration rate, a 2 inch dia. plastic tube was placed in a 2 inch deep hole made by the soil corer. The plastic tube was then filled with 4 inches of water and the half inch and one inch infiltration times were noted. In this case, inches were used instead of centimeters to conform to American hydrologic convention and because rainfall data is most often described in inches.

3. Hydrologic Modeling

The rational equation for calculating the runoff potential of a drainage basin is an oversimplified but common way of computing the discharge (Q) of a watershed based on three variables: Q=CIA where,

C is the cover factor and the most arbitrary of the variables, based on what proportion of rainfall a given surface will convert to surface runoff. For a relatively flat lawn, the Texas Department of Transportation’s Hydrology Handbook suggests a value of C=0.17.

I is the rainfall intensity in inches. For storm frequencies (j) of 5, 10, 25 and 100-years, rainfall intensity was calculated based on the City of Oakland Department of Public Works’ Storm

Drainage Design Guidelines equation where intensity of a given storm frequency (I_j)= $(0.33+0.091144*MAP)*(0.249+0.1006*K_j)*T_j^{-0.56253}$.

K_j= Storm frequency factor (figure x) and T_j= (Time of Concentration/60).

MAP= mean annual precipitation in inches. According to 1981 USGS soil surveys of Alameda County, mean annual precipitation is 17 inches (24).

Concentration time is defined in the Drainage Design Guidelines as the maximum overland flow length/(60*velocity) (pp.8-10). Measured through GIS, the maximum length of overland flow for Memorial Glade is 390 ft while the velocity was determined to be 0.3 ft^3/s using figure 7.

A is the acreage of the watershed, 1.85 for Memorial Glade.

Corresponding 5, 10, 25 and 100-year precipitation estimates were projected for 6 and 24 hours to display the potential cumulative discharge of the glade.

Results:

1. Initial Survey

The initial survey resulted in a mean water depth of 0.7cm with a standard deviation of 0.9 (table 1).

2. Assessment of Soil Properties

Mean Bulk density was 0.99 g/cm^3 with a standard deviation of 0.19. Mean porosity was 62.79% and a standard deviation of 7.09. Graviometric and volumetric water content means were 0.54 g/g and 50%, respectively, with respective standard deviations of 0.18 and 9% (table 2).

The sites saturation ratio was determined to be 0.80. Calculating one standard deviation down and up resulted in 0.74 and 0.94 saturation ratios (table 3).

The mean half inch and one inch infiltration rates were 7.01 minutes and 16.49 minutes with standard deviations of 2.00 and 6.88, respectively (table 4, figure 5).

3. Hydrologic Modeling

Using the conventional cover factor (C=0.17) in the rational equation, discharge for 5, 10, 25 and 100 year storm events were 0.34 ft^3/s, 0.40 ft^3/s, 0.48 ft^3/s and 0.60 ft^3/s, respectively (table 5). However, when adjusting the rational method by using the saturation ratio (C=0.80), 5, 10, 25 and 100-year discharges became 1.59 ft^3/s, 1.89 ft^3/s, 2.27 ft^3/s and 2.82 ft^3/s, respectively (table 6). To compare the discrepancy between the conventional and adjusted discharges, cumulative discharges for storms of 6 and 24 durations were plotted (table 7, figure 6).

Discussion:

Considering its extent of use and frequency of flooding, the bulk density of Memorial Glade's soil (0.99 g/ $cm^{3)}$.was lower than expected, resulting in a corresponding porosity that was higher than expected. Typically, soil bulk density ranges from 1.1-1.6 while porosity ranges from 25 to 70% (Argonne: Soil Density, Total Porosity). A bulk density of 0.99 and porosity of 62.79% are low but within the expected range of a soil, refuting the hypothesis that heavy use of the glade would have, over time, compacted the soil, thus reducing pore space and increasing bulk density. However, high grass root densities in the first few centimeters of soil may have decreased bulk density reading and skewed the data. Future measurements documenting the change in soil density with depth could illustrate the impact of the rhizosphere on the data.

While the 1981 USGS soil survey of Alameda County classifies Memorial Glade within the miscellaneous “urban land complex,” land adjacent to the UC Berkeley campus is described under the category of “Urban Land-Tierra Complex,” expanding on the historic nature of the local soils. The local Tierra loam soil is characterized as deep alluvial deposition with slow permeability, thus restricting water movement in the soil. In fact, “if irrigation is applied in excess of plant needs, water can accumulate above the subsoil,” (USGS, 26). This description is compatible with findings on the glade’s floodplain, where water remained above the soil for over two hours on a sunny day, more than a week after all precipitation had ceased (figure 4). In light of this, a future study of the glade’s evapotranspiration rate and watering schedule should be conducted to decrease saturation, increase water absorptivity and increase water efficiency of the site.

As demonstrated by the differences between infiltration rates of the hill slope (samples 33 and 35) and the flat land (samples 70, 94 and 97) in figure 5, not all of the space experiences such over-watering. This suggests that water moves downslope with gravity where it concentrates in the flat portion of the glade, a movement pattern indicative of saturated soil. In the case of an unsaturated soil, water would more in all directions through capillary action rather than downhill with gravity. A mean saturation ratio of 0.80 dictates that 80% of the soil’s available pore space is already filled with water and that the site only has 20% of its potential available for infiltration during a rainstorm (or watering). Using the saturation ratio as an estimate for the proportion of precipitation bound to runoff from the site (as opposed to the 0.17 originally used) results in highly elevated 5,10,25 and 100-year peak discharges (table 3) as well as huge 6 and 24-hour cumulative discharges (table 7, figure 6). As shown in the figure, the discharge of a 6-hour event using the adjusted C-value in the rational equation is actually higher than a 24-hour event under the conventional C-value. While it is extremely unlikely that such heavy precipitation could last 6 or 24 hours, the ratio between the C-values is preserved regardless of storm length. Though the conventional C-value of 0.17 has now been shown to be a gross underestimate of Memorial Glade's runoff, it has been included to demonstrate the way specific site characteristics can influence the outcome of the rational method and therefore the risk in using simple formulas to model complex systems.

Conclusion:

Before any redesign of Memorial Glade can be undertaken, further research is necessary. As noted earlier, studying the site's evapotranspiration rate in conjunction with its watering schedule could lead to decreased water needs and increased water storage capacity in the existing soil. Examining the change in porosity and density with depth will provide a more accurate understanding of the soil-water dynamics of this site. Currently, grain size distribution tests are being conducted to look at the proportion of sand, silt and clay in the soil, indicating its location on the soil textural triangle. Hopefully with this information, changes in porosity and water pressure within the soil could be calculated, if there is any addition of material to increase infiltration (e.g. sand). If, after the above studies are conducted, a swale is still necessary to capture excess runoff, student surveys and economic analysis will be conducted before drafting and submitting designs to the campus landscape architect.

Figure 1: Aerial Photo of Memorial Glade

Figure 2: Sketch Map

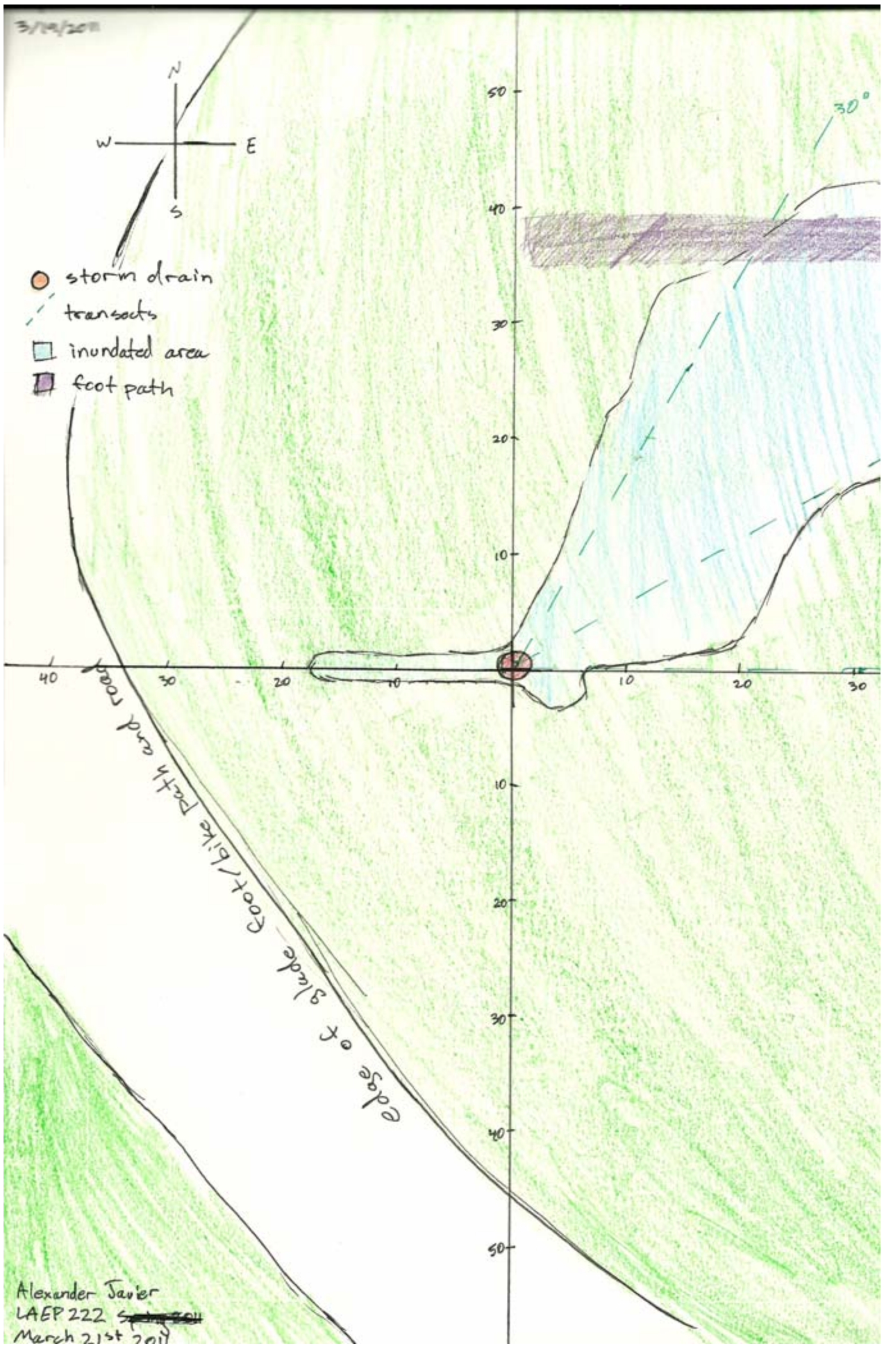


Figure 3: Runoff during a storm

Figure 4: Soil Saturation Evidence

Figure 5: Infiltration Rate

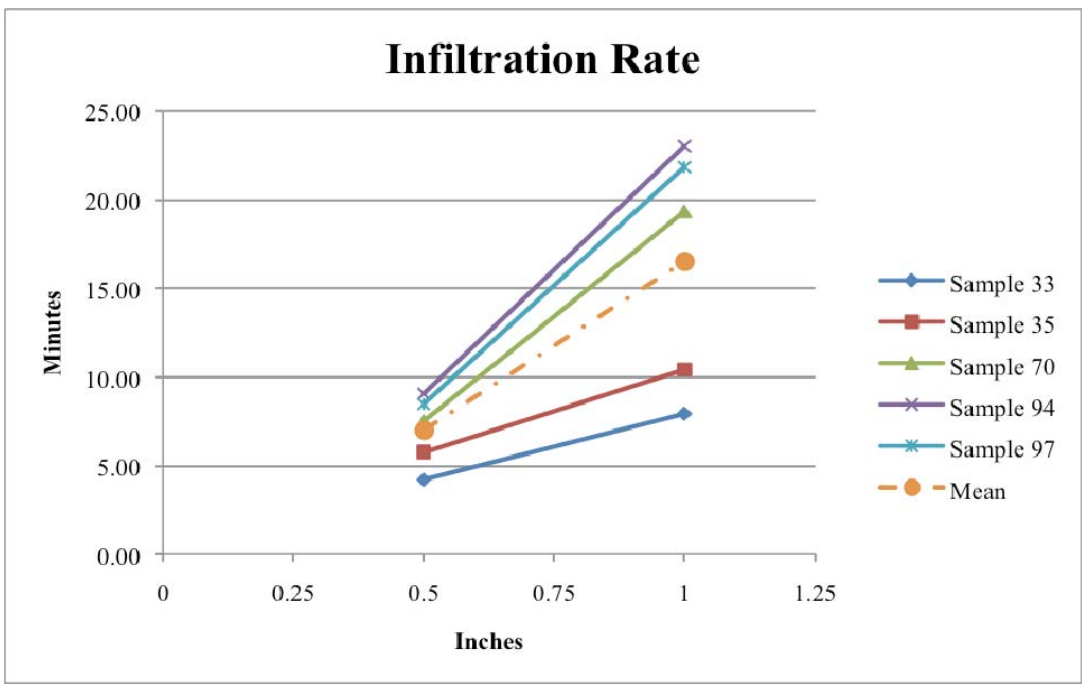


Figure 6: 6 and 24-hour cumulative discharge

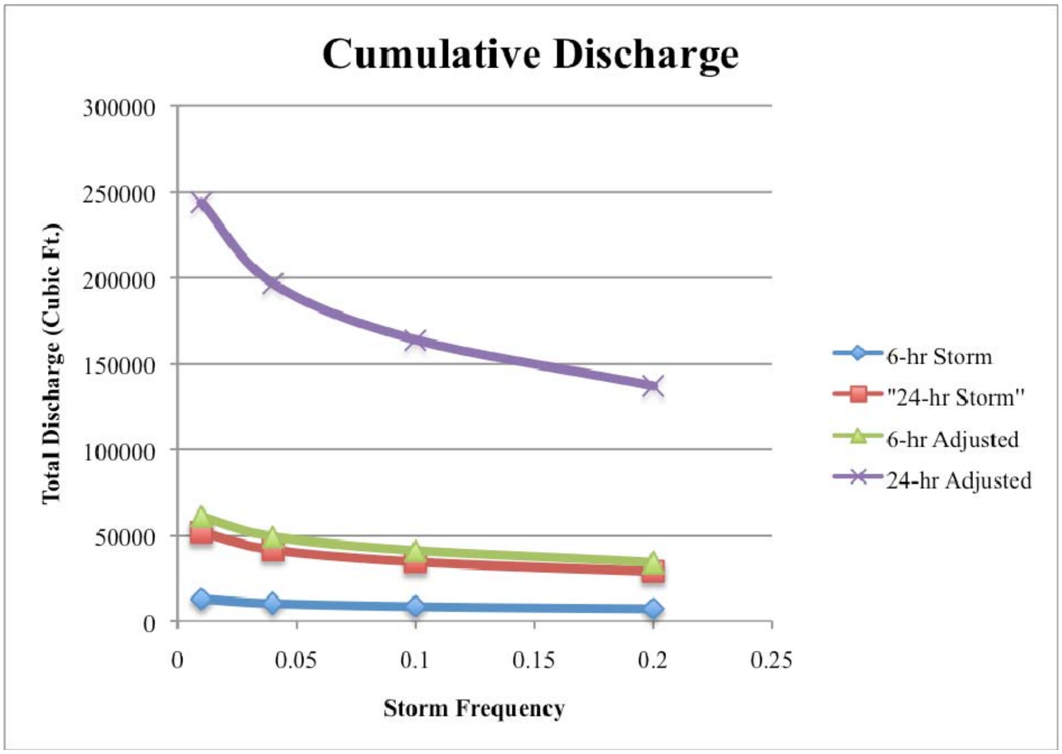
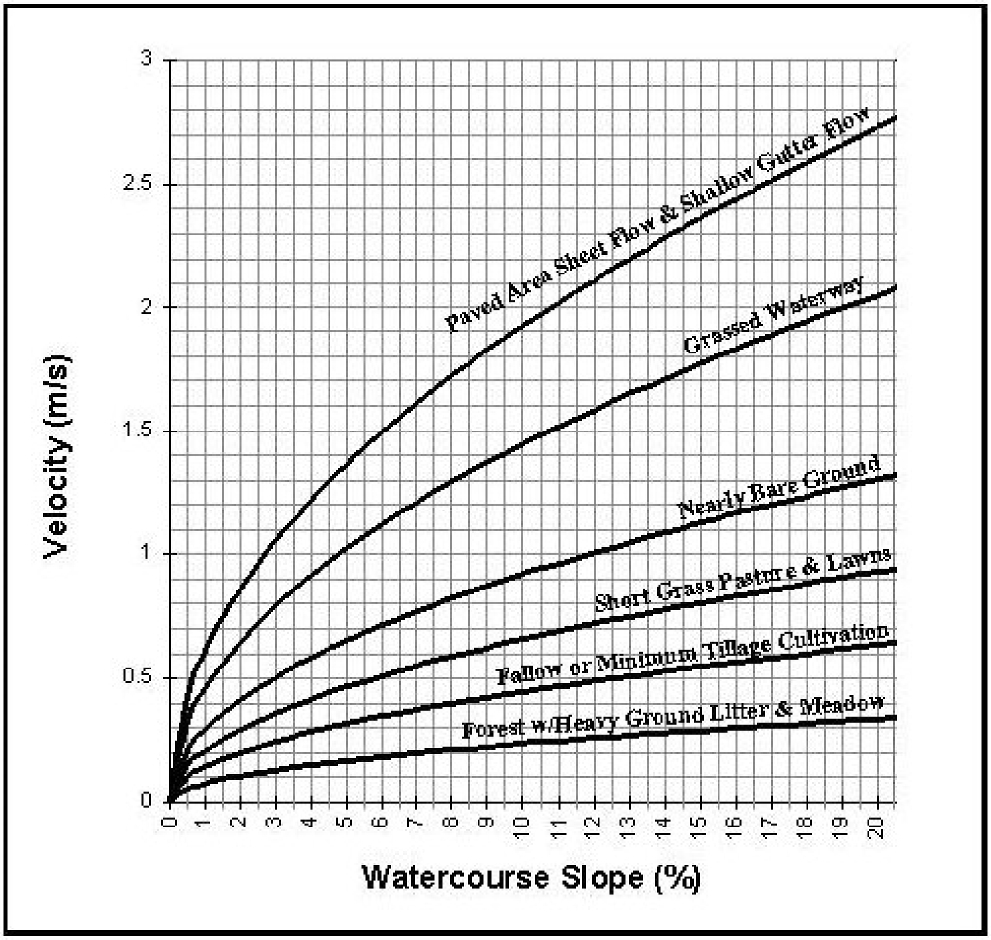


Figure 7: Concentration time



source: http://onlinemanuals.txdot.gov/txdotmanuals/hyd/time_of_concentration.htm

Figure 8: Sampling Scheme

QuickTime™ and a
decompressor
are needed to see this picture.

Table 1: Initial Survey Data

Initial Survey			
Azimuth	30	60	90
Paces from drain	**Water Depth (cm)**	**Water Depth (cm)**	**Water Depth (cm)**
1	1.2	1.4	0.1
2	1.5	0.7	0.3
3	0.8	0.7	2.8
4	0.8	1	0.2
5	0.3	1.5	0
6	0	4	0
7	0	1.3	0
8	0	0.3	0.1
9	0.5	1.2	0
10	0.5	1.1	0
Transect Mean	0.6	1.3	0.4
Std. Dev.	0.5	1.0	0.9
Total Mean	0.7		
Std. Dev.	0.9		

Table 2: Memorial Glade Soil Core Characteristics.

Soil Characteristics						
Sample #	**Wet Weight (g)**	**Dry Weight (g)**	**Bulk Density (g/cm^3)**	**Graviometric Water Content (g/g)**	**Porosity (%)**	**Volumetric Water Content (cm^3/cm^3)**
43	299.34	184.25	0.91	0.62	65.70	0.57
46	356.04	239.31	1.18	0.49	55.44	0.58
47	305.06	204.24	1.01	0.49	61.97	0.50
55	289.00	174.62	0.86	0.66	67.49	0.56
56	319.54	209.43	1.03	0.53	61.01	0.54
58	334.09	248.84	1.23	0.34	53.67	0.42
67	268.90	152.27	0.75	0.77	71.65	0.58
79	247.40	129.57	0.64	0.91	75.88	0.58
94	343.90	232.88	1.15	0.48	56.64	0.55
96	305.96	226.10	1.12	0.35	57.90	0.39
99	282.56	180.00	0.89	0.57	66.49	0.51
101	257.54	170.20	0.84	0.51	68.31	0.43
112	309.86	246.63	1.22	0.26	54.08	0.31
Mean	301.48	199.87	0.99	0.54	62.79	0.50
Std. Dev	32.54	38.07	0.19	0.18	7.09	0.09
Core Volume (cm^3)	203					
Quartz BD (g)	2.65					

Table 3: Average saturation ratio of Memorial Glade soil samples.

Runoff Adjustment		1 Std. Dev. Down	1 Std. Dev. up
Mean porosity (%/vol.)	62.79	55.70	62.79
Mean Volumetric Water Content (%/vol)	50	41.00	59.00
Saturation Ratio (Adjusted C)	0.80	0.74	0.94
Standard Deviations			
Porosity	7.09		
Volumetric Water Content	9		

Table 4: Infiltration

Infiltration Rate		
Sample #	**1/2 inch (min)**	**1 inch (min)**
33	4.22	7.92
35	5.75	10.40
70	7.52	19.32
94	9.07	23.00
97	8.48	21.82
Mean	7.01	16.49
Std. Dev.	2.00	6.88

Table 5: Discharge for a given event using:

Rational Method Runoff Calculations			
Storm Freq.	**Q (cfs)**	**I (in)**	**Freq. Factor (kj)**
5 yr	0.34	1.07	0.719
10 yr	0.40	1.28	1.339
25 yr	0.48	1.54	2.108
100 yr	0.60	1.91	3.211
Cover Factor (C)	0.17		
Acreage (A)	1.85		
Mean Annual Precip. (in)	17		
Velocity (cfs)	0.3		
Length (ft)	390		
Concentration time	21.67		
Storm Duration (Ti)	0.36		

Table 6: Adjusted Discharge

Rational Method Runoff Calculations			
Storm Freq.	**Q (cfs)**	**I (in)**	**Freq. Factor (kj)**
5 yr	1.59	1.07	0.719
10 yr	1.89	1.28	1.339
25 yr	2.27	1.54	2.108
100 yr	2.82	1.91	3.211
Cover Factor (C)	0.80		
Acreage (A)	1.85		
Mean Annual Precip. (in)	17		
Velocity (cfs)	0.3		
Length (ft)	390		
Concentration time	21.67		
Storm Duration (Ti)	0.36		

Table 7: 6 and 24-hour storm cumulative discharge

C=0.17

Total Discharge	
6-hr Storm (ft^3)	**24-hr Storm (ft^3)**
7276	29104
8688	34754
10440	41761
12953	51811

C=0.80

Total Discharge	
6-hr Storm (ft^3)	**24-Hr Storm (ft^3)**
34240	136962
40887	163547
49130	196521
60954	243816

References:

Alameda County, Western Part Soil Survey Manuscript. 1981. USDA Natural Resources Conservation Service. http://soils.usda.gov/survey/online_surveys/california/. April 25, 2011.

City of Oakland Department of Public Works Agency Storm Drainage Design Guidelines http://www.oaklandnet.com/government/ceda/docs/032108_guidelines_storm_drainage_design.pdf. April 20, 2011

Classifications of Soil Water. The Pedosphere. http://www.pedosphere.com/volume01/pdf/Section_08_03.pdf. May 5, 2011.

Volumetric Water Content. Soil Density. Total Porosity. Argonne National Laboratory.

http://web.ead.anl.gov/resrad/datacoll/volcont.htm.

http://web.ead.anl.gov/resrad/datacoll/soildens.htm

http://web.ead.anl.gov/resrad/datacoll/porosity.htm May 6, 2011.

Pallud, Celine. March 2011. Bulk Density and Porosity Protocols.

Texas Department of Transportation Hydraulic Design Manual. 2009. http://onlinemanuals.txdot.gov/txdotmanuals/hyd/index.htm. April 25, 2011.