Title
Impacts of Urbanization on Peak Flow Using Remote Sensing

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Final Draft

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Landscape Architecture and Environmental Planning 222: Hydrology for Planners

Professor Matt Kondolf

Abstract:

The eastern edge of San Ramon, California, close to the Dublin border, is undergoing considerable residential development. Work in this area began at a development called Windemere in 2001 with the first homes being available for sale in 2002. The population, along with the number of housing units, in San Ramon has increased. I suspect housing developments are impacting the volume of water in the streams which may increase the risk of flooding. I compared the impacts of urbanization on stream peak flow in two neighboring drainage basins, the Alamo Creek and Tassajara Creek. Using 28 meter six band Landsat Imagery (landsat.usgs.gov), I measured Alamo Creek drainage basin and found it consists of 32 percent developed land area while the Tassajara Creek drainage basin is 6 percent developed land area. I made this determination using a maximum likelihood classification algorithm to delineate developed areas from non-developed land. I used the Rantz Method, to calculate the peak flow for 2, 10, 25, and 50 year return intervals for the two drainage basins. At the catchments of the two drainage basins, I conducted cross-sectional profiles, and recorded high water marks. I calculated peak flow from the high-water marks using the Manning's equation.

Problem Statement:

The development of land can impact the volume and water quality of creeks. Increased volume and the decline in water quality could lead to flooding and habitat changes (Rogers 1994). The population in the City of San Ramon has increased 11% and the number of housing units increased 13% in 2006 (California Department of Finance 2007). The population and the housing units for San Ramon have increased every year since 1984. The biggest increase in population occurred in 1988 – 1990 and again in 2006 (Table 1). With development, there is an increasing use of impervious materials, including paved roads, roofs, sidewalks, and parking lots, which elevates the concern for the risk of flooding. The influence of impervious materials also leads to removal of natural storage, retention, and recycling of precipitation, increases seasonal runoff, decreases groundwater recharge, increases widening of stream channels, increases floodwater velocities, and channel morphology changes because of the altered hydrology (Goudie 1990). The more urbanized the watershed becomes the more prone it is to flooding (Weng 2001).

Fish habitat is also compromised with artificially increased flow of the stream. These urbanized streams are impacted physically and chemically because of less fine grain material and greater levels of dissolved oxygen (Finkenbine 2000). With urbanization comes increased use of impervious materials that can reduce the runoff concentration time. This will result in peak discharges that are higher and occur sooner after rainfall starts in the watershed (Goudie 1990). The increased peak flow and shorter concentration times is leading to greater incising of urban streams and eroded banks. This can result in higher turbidity and a general degradation in water quality.

Methods:

I used Geographic Information Systems (GIS) technology for entering, analyzing, and displaying digital spatial data. I used remote sensing multispectral, multiresolution data to understand land processes and build urban land-cover data sets. Using remote sensing, I was able to quantify land use area and measure the density of the development within the drainage basins. I then compared it with measured high water marks in the catchments of the two drainage basins. I selected two neighboring drainage basins, Alamo Creek drainage basin (coordinates N 37.745682, W 121.916885), which was more developed and Tassajara Creek drainage basin (coordinates N37.749052, W121.875240), which was less developed to compare the effects urbanization had on peak flow. I compared these neighboring drainage basins because of their similar meteorological (CASIL-gis.ca.gov) and topographical (DEM-seamless.usgs.gov) conditions. The Tassajara Creek drainage basin (3,858 hectors) consisted of 5% development, mostly farmland, and a few clusters of homes. The Alamo Creek drainage basin (5,551 hectors) was 32% developed and contained the new Windemere development that is mostly residential, but also includes additional development such as paved walkways, schools, and a community center with a theater, library, restaurants, and a variety of other shops.

At each of the two catchments I measured a cross-sectional profile to estimate the stream depth and high water marks (Figure 2). Using the Manning's equation to analyze open channel flows, I calculated stream velocity and multiplied it by the cross-sectional area, based on the high water marks, to determine peak flow of the season (Table 2). The Manning's equation is an empirical equation that applies to uniform flow in streams and is a function of the stream velocity, flow area and stream slope.

$VA = (1.49 * R0.67\ \ S0.5)/ n$

VA = Flow rate (ft^3/s)

R = Hydraulic Radius (ft)

S = Channel Slope (ft/ft)

I selected the Manning's n-values, or the roughness coefficient to include a roughness with vegetation (Appendix 1). I found that the selection of the Manning's roughness coefficient can greatly affect the computational results. Therefore, I used a range of Manning's n values of 0.05 to 0.1 as an estimate of the streams roughness during peak flow.

In order to survey the cross-section, I used a one-hundred foot tape that I staked perpendicular to the stream flow which included the high water marks in the profile. I used a clinometer to assure the tape was suspended perfectly level across the stream. To measure the depth below the tape, I used a 10 foot poly-vinyl chloride pole with two-inch graduated lines. In addition, I recorded an elevation point every 3 feet along the transect (Figure 3). I used a clinometer to measure the percent slope of the steams by pacing off one hundred feet and recording the reading. I found the slope of both streams to be 2/3 of a percent.

I used a 10-meter digital elevation model (USGS) to calculate the area of the drainage basin within the two catchments. I accomplished this using ArcGIS -version 9.2 utilizing the watershed delineation algorithm to determine the contributing drainage area above the catchments. Once I determined the two drainage basins' boundaries, I calculated the classification of developed land and non-developed land using a maximum likelihood algorithm with the 28 meter six- band Landsat Imagery (Figure 4). Since developed areas contain vegetation, I used a spectral unmixing technique to further quantify the amount of vegetation within the developed area. I was able to create two homogeneous classes by using a spectral unmixing algorithm (Gong) in a PCI Geomatics programming package, which I identified as developed and non-developed. Developed areas consisted of buildings, roads, and non-living vegetation. Non-developed areas were comprised of living vegetation. The imagery I used for classification was taken in March, 2003. The classes were trained to be endmembers for the spectral unmixing algorithm. I used the algorithm to calculate the spectral irradiance of each pixel in each band to match with the spectral signatures of the homogeneous endmembers. This allowed a ratio to be determined for each pixel comprised of the two classes, developed, and non-developed (Figure 5). The month of March was chosen to capture areas that had live grasses in the developed area, which gave a different spectral signature in the near-infrared spectrum in mid to late summer as the grasses die off for the season. The irradiance digital number for each band gave a spectral signature for the developed and non-developed classes (Figure 6).

I used the Rantz Method to calculate the peak flows for each of the two drainage basins. The Rantz Method uses the following equation:

$$QT = KAaPb$$

QT = Peak Discharge (cfs)
A = Drainage area
P = Mean annual basin-wide precipitation
K,a,b are constants

The method describes the flood peak of different drainage basins in the San Francisco Bay Area. The only significant factors affecting peak flows were drainage area and average precipitation (Kondolf). I calculated the mean annual drainage basin-wide precipitation from a precipitation layer (CASIL- gis.ca.gov). I derived the areas of the drainage basins from the digital elevation model and watershed delineation algorithm using ArcGIS 9.2. I selected the central coast region regression equations to estimate recurrence intervals of peak discharge (Appendix 2).

Results:

Using a range of Manning's n values of 0.05- 0.1, I calculated the peak flow of the Tassajara Creek drainage basin (less developed) as 2,608 to 5,217 cfs while I found the Alamo Creek drainage basin (more developed) to be 8,418 to 16,836 cfs (Appendix 3). I calculated the cross-sectional area from the high water marks to be 296 ft^2 for the more developed catchment and 97 ft^2 for the less developed catchment (Figures 7 and 8).

I used the Rantz Method to estimate the peak flow for the two drainage basins, while neglecting the influence of urbanization (Table 2). When comparing the peak flow of the less developed catchment using the Manning's equation with that of the Rantz Method, I estimated the Return Interval (RI) to be about 10 years. I found the RI for the more developed location to be greater than 50 years.

I also found that the peak flow per drainage area varies in the Alamo Creek drainage basin (more developed) location from 2.18 - 4.36 cfs/ha compared to the Tassajara Creek drainage basin (less developed) location which ranged from 0.47 - 0.94 cfs/ha.

Discussion:

The more developed drainage basin shows a significant increase in the amount of peak flow compared to that of the less developed drainage basin. These results show there is an impact on peak flow as a result of urbanization. A 32% land cover consisting of impervious materials suggests that peak flows increased over that of the original peak flow. The results present wide estimates of peak flow due to the estimation of Manning's n and the difference in the catchments' size.

The City of San Ramon has planted additional trees and vegetation along the stream banks of Alamo Creek, the more developed drainage basin, to decrease the waterflow and to prevent erosion (Figure. 9). With continued development in the area the chance for flooding should be a concern.

Conclusions:

When a new housing development is being considered, planners need to assess the impact on neighboring streams. Uses of impervious material with innovative designs are imperative in keeping peak flow at an acceptable level. Artificially increased flow can destroy habitat of existing native flora and fauna that are not adapted to recover. Understanding the spatial pattern of the development in the drainage basins is important. For example, setting a buffer from a watercourse where no development can take place may decrease the peak flow rate. Perhaps a fragmented pattern of housing away from streams will allow the velocity of a stream to lessen.

Through the use of remote sensing and GIS, locations that are contributing to the greatest impacts can be targeted and spatial patterns can be recognized. Further classification of impervious materials and the spatial distribution may lead to a better understanding of their interactions with peak flow in urban streams. By defining spectral signatures of building materials through the process of spectral unmixing, materials can be quantified at the sub-pixel level.

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Figures and Tables:

Location of the Two Drainage

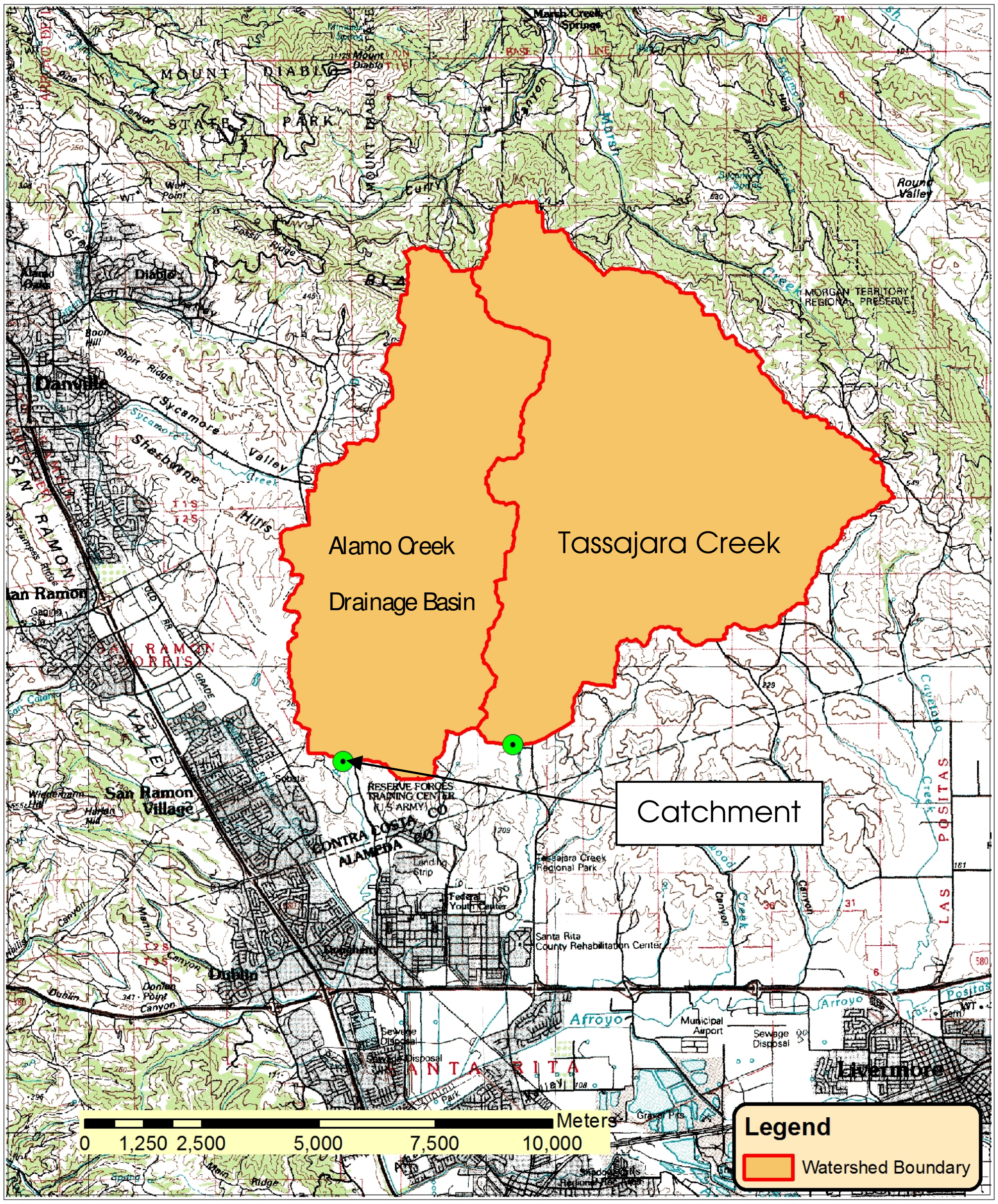


Figure 1: Map of Alamo Creek (more developed)and Tassajara Creek (less developed) drainage basins located on the eastern edge of San Ramon, California

CITY OF SAN RAMON
POPULATION ESTIMATES BY YEAR*

Year	Population	Percent Change	HOUSING UNITS* Single	HOUSING UNITS* Multiple	HOUSING UNITS* Total	HOUSING UNITS Percent Change Single	HOUSING UNITS Percent Change Multiple	HOUSING UNITS Percent Change Total	Persons Per Household
1/1/1984	23,444	N/A	7,063	613	7,676	N/A	N/A	N/A	N/A
1/1/1985	25,352	8.14%	7,245	1,141	8,386	2.58%	86.13%	9.25%	N/A
1/1/1986	26,417	4.20%	7,402	1,181	8,583	2.17%	3.51%	2.35%	N/A
1/1/1987	27,439	3.87%	7,792	1,283	9,075	5.27%	8.64%	5.73%	N/A
1/1/1988	30,404	10.81%	8,455	1,992	10,447	8.51%	55.26%	15.12%	N/A
1/1/1989	33,879	11.43%	8,968	2,567	11,535	6.07%	28.87%	10.41%	N/A
1/1/1990	35,303	4.20%	9,379	2,810	13,319	4.58%	9.47%	15.47%	2.747
1/1/1991	35,950	1.83%	10,304	3,475	13,779	9.86%	23.67%	3.45%	2.720
1/1/1992	36,196	0.68%	10,433	3,498	13,931	1.25%	0.66%	1.10%	2.705
1/1/1993	38,880	7.42%	10,651	4,078	14,721	2.09%	16.58%	5.67%	2.737
1/1/1994	39,595	1.84%	10,843	4,086	14,921	1.80%	0.20%	1.36%	2.748
1/1/1995	40,880	3.25%	11,145	4,166	15,303	2.79%	1.96%	2.56%	2.742
1/1/1996	40,659	-0.54%	11,438	4,166	15,604	2.63%	0.00%	1.97%	2.746
1/1/1997	42,309	4.06%	11,836	4,251	16,087	3.48%	2.04%	3.10%	2.765
1/1/1998	43,422	2.63%	12,216	4,251	16,467	3.21%	0.00%	2.36%	2.796
1/1/1999	44,688	2.92%	12,529	4,251	16,780	2.56%	0.00%	1.90%	2.825
4/1/2000	44,722	0.08%	12,708	4,844	17,552	1.43%	13.95%	4.60%	2.634
1/1/2001	45,916	2.67%	12,890	4,939	17,829	1.43%	1.96%	1.58%	2.663
1/1/2002	46,834	2.00%	13,214	4,939	18,142	2.51%	0.00%	1.76%	2.669
1/1/2003	47,035	0.43%	13,297	4,939	18,236	0.63%	0.00%	0.52%	2.667
1/1/2004	48,755	3.66%	13,964	4,986	18,950	5.02%	0.95%	3.92%	2.661
1/1/2005	50,855	4.31%	14,834	5,074	19,908	6.23%	1.76%	5.06%	2.642
1/1/2006	56,505	11.11%	16,064	6,340	22,404	8.29%	24.95%	12.54%	2.608
1/1/2007	58,035	2.71%	16,776	6,340	23,116	4.43%	0.00%	3.18%	2.597

*Demographics Research Unit, Dept. of Finance, State of California, Table E-5: County/State Population and Housing Estimates 1/1/2007, Released 5/1/2007

G://excel-spreadsheet/DOF Population Estimates/popest.rev.06-13-07

Table 1: Percent increase per year for the population and housing units in San Ramon, CA.

Figure 2 Alamo Creek cross-sectional profile was measured to estimate the stream depth and high water marks. 4/19/2008

RI (years)	Alamo Creek (cfs)	Tassajara Creek (cfs)
2	373	523
5	1051	1482
10	1619	2280
25	2343	3287
50	3401	4657

Table 2: Peak flow for return intervals of 2, 5 ,10 , 25, and 50 years

Figure 3: Measuring cross-sectional area of the stream at Alamo Creek. 4/19/2008

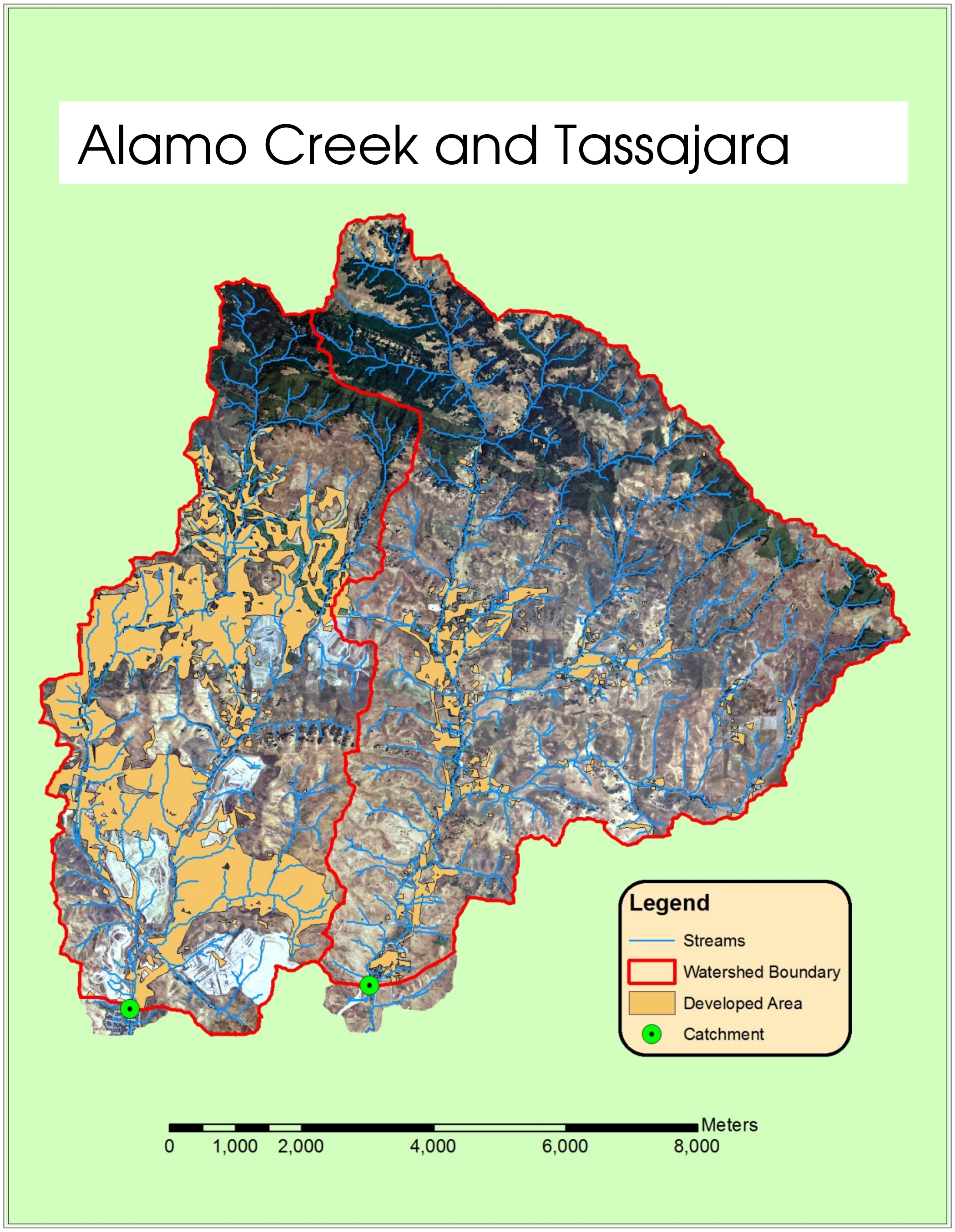


Figure 4: The developed area (orange) shown above is being compared with 1m Imagery from the National Agriculture Imagery Program. The 1m Imagery was taken two years after the 28 meter Landsat Imagery that was used for classification. Note the development at the southern end of the urban drainage basin that was not classified.

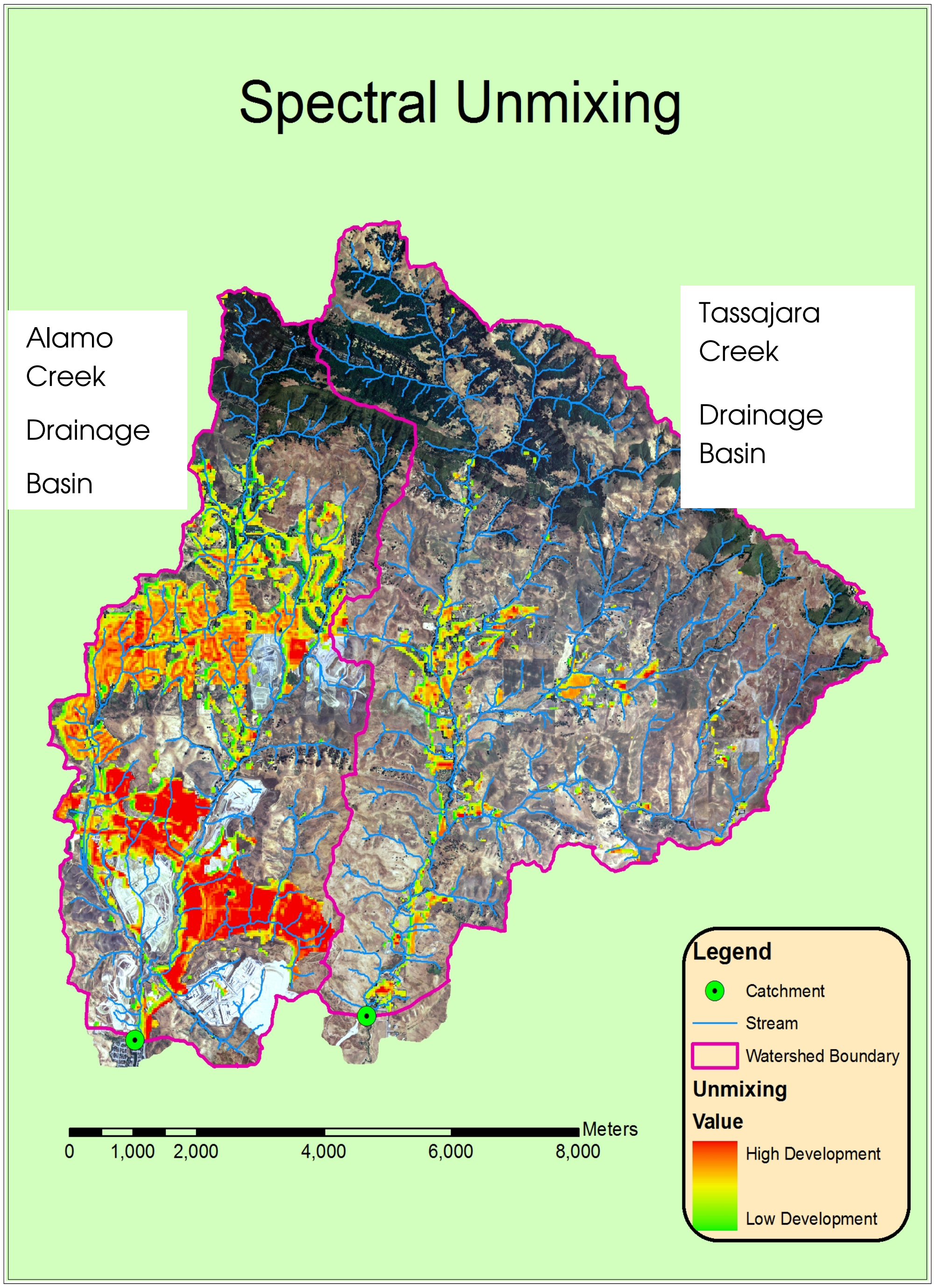


Figure 5: Two homogenous classes, developed (pure buildings, roads) and non-developed (pure vegetation), were trained to be endmembers for the spectral unmixing algorthm . The algorthm calculated the spectral irradiance of each pixel in each band to match with spectral signatures of the homogenous endmembers. This allows a ratio to be determined for each pixel comprised of the two classes, developed and non-developed.

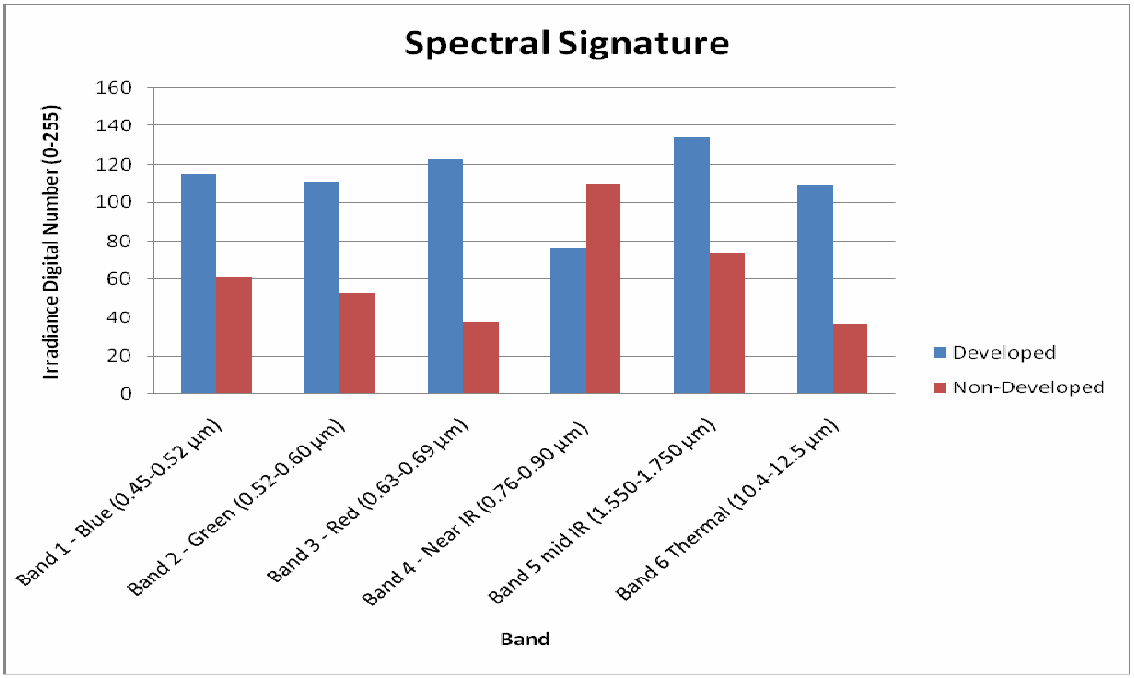


Figure 6: Spectral signatures of developed and non-developed classes

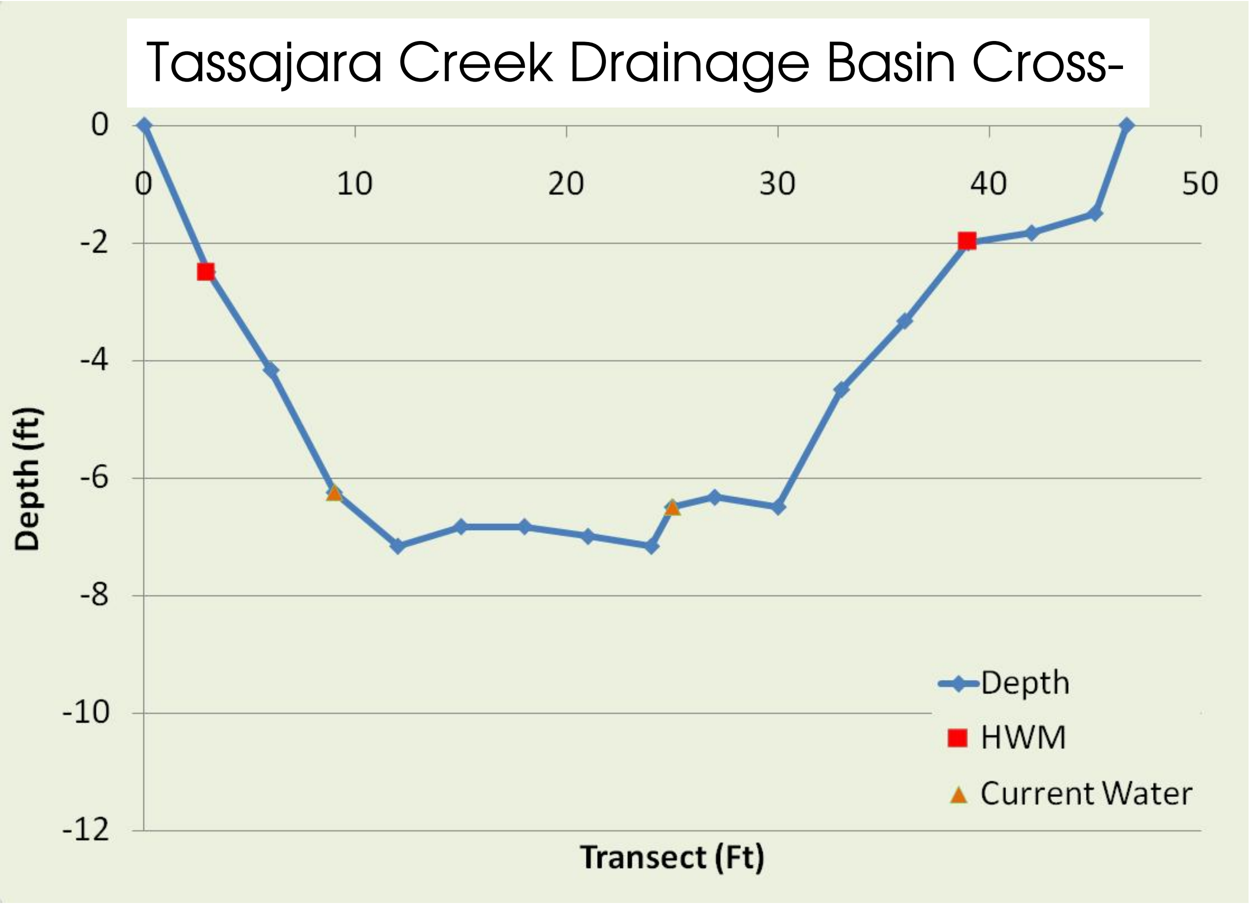


Figure 7 : Cross-sectional profile of Tassajara Creek Drainage Basin (less developed)

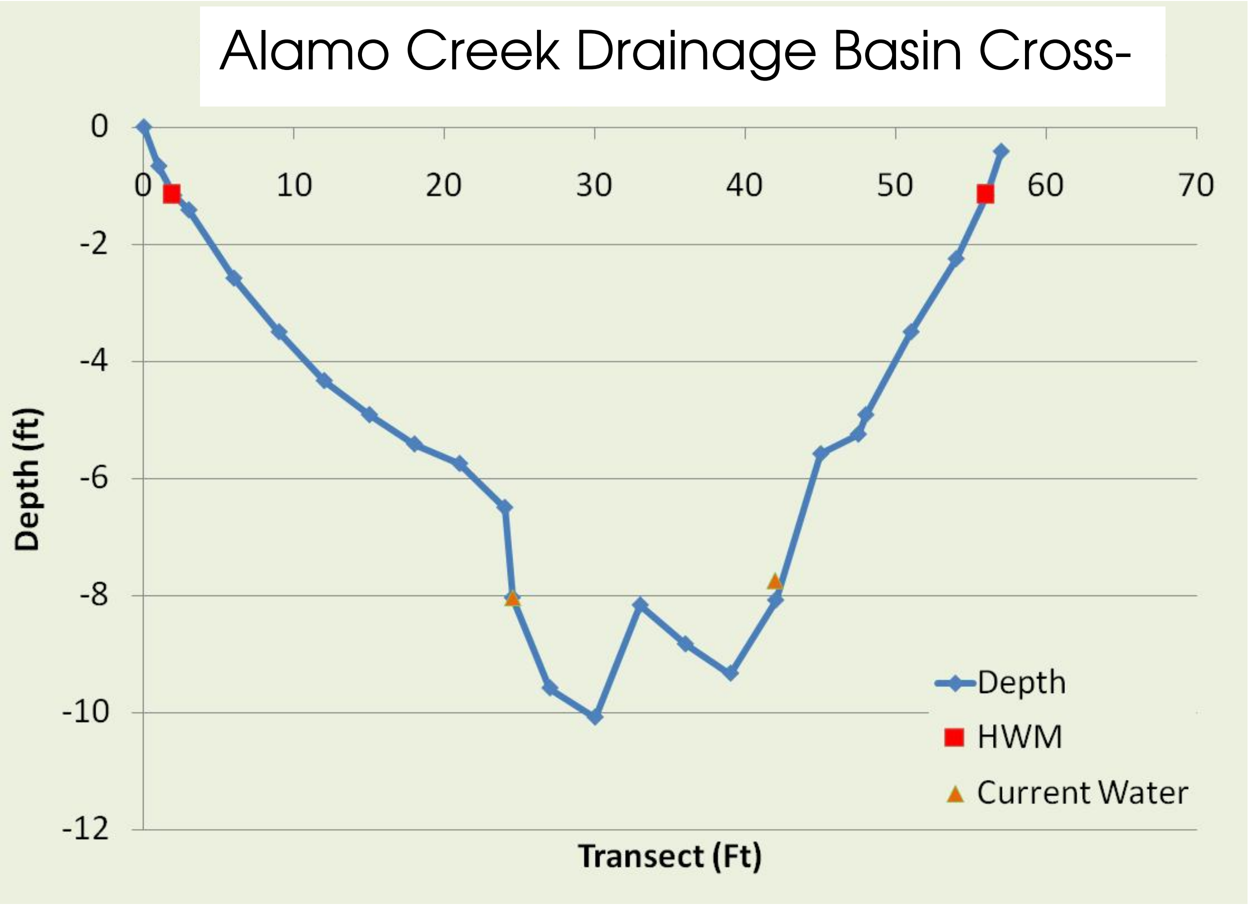


Figure 8: Cross-sectional profile of Alamo Creek Drainage Basin (more developed)

Figure 9: Trees are planted on the bank of Alamo Creek catchments. 4/19/2008

Appendices:

Manning's n for Channels (Chow, 1959).

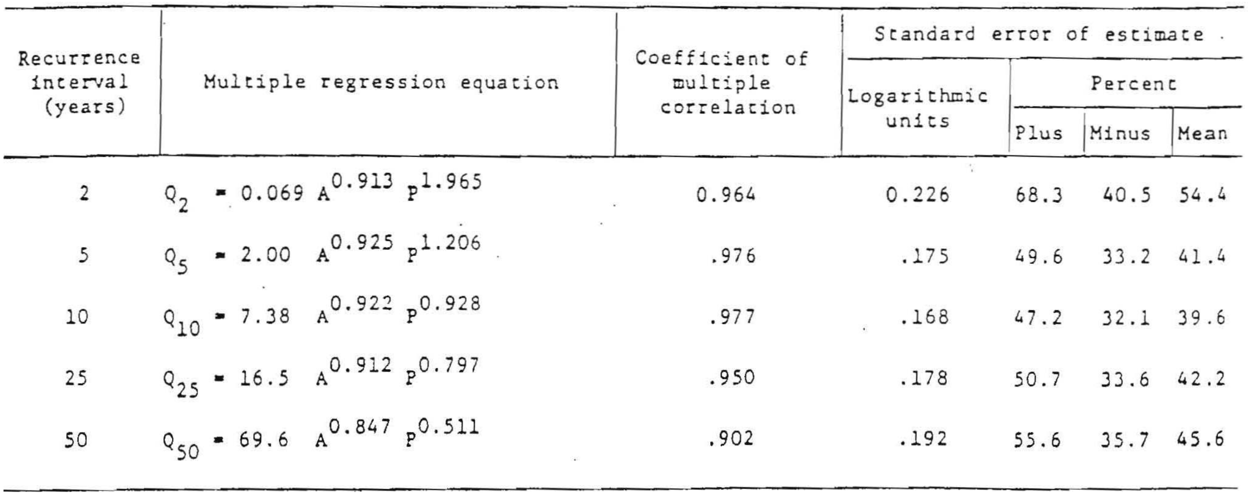
Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160

Type of Channel and Description	**Minimum**	**Normal**	**Maximum**
d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. same as 4. with flood stage reaching branches	0.100	0.120	0.160

Appendix 1: Manning's n values

http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

Central Coast Region – Regression equations



Recurrence interval (years)	Multiple regression equation	Coefficient of multiple correlation	Standard error of estimate		
			Logarithmic units	Percent		
				Plus	Minus	Mean
2	$Q_2 = 0.069\ A^{0.913}\ P^{1.965}$	0.964	0.226	68.3	40.5	54.4
5	$Q_5 = 2.00\ A^{0.925}\ P^{1.206}$	.976	.175	49.6	33.2	41.4
10	$Q_{10} = 7.38\ A^{0.922}\ P^{0.928}$	.977	.168	47.2	32.1	39.6
25	$Q_{25} = 16.5\ A^{0.912}\ P^{0.797}$	.950	.178	50.7	33.6	42.2
50	$Q_{50} = 69.6\ A^{0.847}\ P^{0.511}$	.902	.192	55.6	35.7	45.6

Appendix 2 - Rantz Method for estimating peak flow.

Appendix 3 -Raw data

Alamo Creek Catchment

Cross-section			Depth		HWM	Current Water
ft	ft	in	ft	ft below datum	ft below datum	ft below datum
0	0	0	0.0	0.0		
1				-0.7		
2				-1.2	-1.2	
3	1	5	1.4	-1.4		
6	2	7	2.6	-2.6		
9	3	6	3.5	-3.5		
12	4	4	4.3	-4.3		
15	4	11	4.9	-4.9		
18	5	5	5.4	-5.4		
21	5	9	5.8	-5.8		
24	6	6	6.5	-6.5		
24.5				-8.0		-8.0
27	9	7	9.6	-9.6		
30	10	1	10.1	-10.1		
33	8	2	8.2	-8.2		
36	8	10	8.8	-8.8		
39	9	4	9.3	-9.3		
42	8	1	8.1	-8.1		-7.8
45	5	7	5.6	-5.6		
47.5				-5.3		
48	4	11	4.9	-4.9		
51	3	6	3.5	-3.5		
54	2	3	2.3	-2.3		
56				-1.2	-1.2	
57	0	5	0.4	-0.4		
57.7	0					

Alamo Creek Catchment

Cross-section			Depth (ft)	area (ft^2)	wet per
	ft	in	ft		ft
0.0	0.0	0.0	0.0		
1.0	0.5	0.0		0.0	1.0
3.0	1.0	5.0	1.4	1.4	2.5
6.0	2.0	7.0	2.6	6.0	3.2
9.0	3.0	6.0	3.5	9.1	3.1
12.0	4.0	4.0	4.3	11.8	3.1
15.0	4.0	11.0	4.9	13.9	3.1
18.0	5.0	5.0	5.4	15.5	3.0
21.0	5.0	9.0	5.8	16.8	3.0
24.0	6.0	6.0	6.5	18.4	3.1
24.5				1.6	6.5
27.0	9.0	7.0	9.6	12.0	9.9
30.0	10.0	1.0	10.1	29.5	3.0
33.0	8.0	2.0	8.2	27.4	3.6
36.0	8.0	10.0	8.8	25.5	3.1
39.0	9.0	4.0	9.3	27.3	3.0
42.0	8.0	1.0	8.1	26.1	3.3
45.0	5.0	7.0	5.6	20.5	3.9
47.5				7.0	6.1
48.0	4.0	11.0	4.9	1.2	4.9
51.0	3.0	6.0	3.5	12.6	3.3
54.0	2.0	3.0	2.3	8.6	3.3
57.0	0.0	5.0	0.4	4.0	3.5
57.7	0.0			0.1	0.8

SUM (HWM) **296.1** **83.4**

Urban Catchment

Manning Equation

S = Slope (2/3%) **R = Hydro radius**

	n =0.05	n = 0.1	
v	**56.86001**	**28.43**	**ft/s**
Q	**16836.49**	**8418.243**	**cfs**

vol/ area	**Alamo Creek**	**4.363501**	**2.18175**	**cfs/ha**

Tassajara Creek Drainage Basin

Tassajara Creek Catchment

Cross-section			Depth	ft below datum	HWM	Current Water
	ft	in	ft			
0.0	0.0	0.0	0.0	0.0		
1.0	0.0	10.0	0.8	-0.8		
3.0	2.0	2.0	2.2	-2.2	-2.2	
6.0	3.0	0.0	3.0	-3.0		
9.0	4.0	1.0	4.1	-4.1		
12.0	4.0	5.0	4.4	-4.4		
13.0	4.0	7.0	4.6	-4.6		-4.6
15.0	4.0	11.0	4.9	-4.9		
18.0	5.0	4.0	5.3	-5.3		
21.0	4.0	7.0	4.6	-4.6		-4.6
24.0	2.0	8.0	2.7	-2.7		
27.0	1.0	7.0	1.6	-1.6		
27.5	1.0	4.0	1.3	-1.3	-1.3	
29.0				0.0		

Tassajara Creek Catchment

Cross-section			Depth (ft)	area (ft^2)	Wet per
0.0	0.0	0.0	0.0		
1.0	0.0	10.0	0.8	0.4	1.3
3.0	2.0	2.0	2.2	3.0	2.4
6.0	3.0	0.0	3.0	7.8	3.1
9.0	4.0	1.0	4.1	10.6	3.2
12.0	4.0	5.0	4.4	12.8	3.0
13.0	4.0	7.0	4.6	4.5	1.0
15.0	4.0	11.0	4.9	9.5	2.0
18.0	5.0	4.0	5.3	15.4	3.0
21.0	4.0	7.0	4.6	14.9	3.1
24.0	2.0	8.0	2.7	10.9	3.6
27.0	1.0	7.0	1.6	6.4	3.2
27.5	1.0	4.0	1.3	0.7	0.6
29.0			0.0	1.0	2.0
			total	96.8	29.5

Tassajara Catchment

Manning Equation

S = Slope (2/3%) **R = Hydro radius**

		n =0.05	n = 0.1	
	v	**53.9**	**27.0**	**ft/s**
	Q	**5216.6**	**2608.3**	**cfs**
vol/ area	**Tassajara Creek**	**0.9**	**0.5**	**cfs/ha**