Dry Season Urban Runoff in the Chollas Creek Watershed and San Diego Bay

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ABSTRACT

Urban runoff impacts both the quantity and quality of southern California watersheds. Within highly developed watersheds, the volume of urban runoff is magnified from increased surface area of impervious substrate. Anthropogenic sources can elevate the natural concentrations of contaminant in receiving waterbodies, potentially resulting in adverse impacts to ecological receptors. For example, zinc has been found to cause damage to cell membranes, inhibit enzyme activity, and influence the toxicity of other heavy metals (Fairey et al. 1998; Brown and Newell 1972).

Chollas Creek, a small watershed located south of downtown San Diego, has been impacted by dense population and a history of development. Its current status as an impaired water body by the California Regional Water Quality Control Board reflects, in part, the impacts of urban runoff on water quality. Though the predominant condition of southern California watershed is dry, management to improve water quality generally focuses on the loading that results from high volume flow from storm events. This report is intended to provide a summary of dry weather data within Chollas Creek, focusing on the amount of water discharged into San Diego Bay and the contaminants that are present in the dry weather discharge. This reports also highlights the value and limitations in using micro-drainage basin maps to evaluate relationship between land use, human activities, and drainage area to the quantity and quality of urban runoff from the dry season.

INTRODUCTION

The Chollas Creek encompasses approximately 16,270 acres of mostly urbanized land in the cities of La Mesa, Lemon Grove, National City, San Diego and unincorporated regions of San Diego County (Weston 2006) (Figure 1). At the mouth of the Creek in San Diego Bay is a "toxic hotspot," designated as such by the California Bay Protection and Toxics Cleanup (Toxic Hot Spot) Program for the presence of contaminated sediments that could have adverse effects on the local fauna (Think Blue San Diego 2004). Also, according to a comparison based in part on the data collected under the Toxic Hot Spot Program, San Diego Bay is considered the second most polluted bay in the United States (Long 2000).

Figure 1. Extent of the Chollas Creek Watershed shown in green

The pollutants found at the mouth of Chollas Creek and San Diego Bay today can be attributed to historical anthropogenic sources such as raw sewage and untreated industrial discharge from fish canneries (Fairey et al. 1998); however, significant inputs of contaminants remain to this day. For example, studies have shown that nonpoint source pollution from the Chollas Creek Watershed is one of the main contributors to degraded water quality and habitats in San Diego Bay (Schiff et al. 2003).

In addition, hydromodification of the Chollas Creek watershed has been substantial. It is estimated that over 30% of the creek was channelized prior to 1975 and there are approximately 800 storm drains and other discharge points (Weston 2006). This has had significant impacts on the flow regime and riparian habitats of the creek. Runoff discharged through the municipal storm water sewer systems (MS4) (Weston 2006) from highly impervious urban landscapes occurs at amplified magnitude and frequency increasing erosion rates in the riparian zone and providing a means of transport for pollutants deposited onto streets (Stein and Ackerman 2007).

In 1998, Chollas Creek was placed on the Clean Water Act Section 303(d) impaired water body list by the State Water Resources Control Board (SWRCB) for beneficial use impairments due to elevated levels of diazinon, lead, copper, zinc, and bacterial indicators (1998). In 2002 a Total Maximum Daily Load (TMDL) was established for diazinon; a ban of the pesticide may have contributed to the removal of diazinon from the causes of impairment (SWRCB 2007). In 2007 a TMDL was established for dissolved copper, lead and zinc.

One criterion of the TMDL required by the Environmental Protection Agency is that it "must show how the TMDL accounts for seasonal variations and critical conditions," in order to "ensure that the TMDL will protect the receiving water during the periods in which it is most sensitive to the impacts associated with the pollution(s) of concern" (EPA 2000). The timing of the life cycles of both the riparian and marine invertebrates, for example, might be an important consideration for this seasonality criterion. However, programs for runoff typically target wet season or stormwater because of the high volume of water discharged during and after a storm. A lack of data on dry season runoff can be partially attributed to this wet weather focus: the 2002 diazinon TMDL states: "In any twelve-month period, by far the majority of runoff entering the creek is storm water runoff. Therefore, in the absence of information indicating otherwise, storm water runoff is believed to contain most of the mass of diazinon that enters the creek"(CA RWQCB 2002). The Total Maximum Daily Load for dissolved metals in the Chollas Creek uses a concentration-based approach to setting limits on metals; this enables the policy to be applicable to both dry and wet season conditions within Chollas Creek (CA RWQCB 2007). Still, to date most efforts have focused on wet weather monitoring. More research is needed on dry season data in the Chollas Creek Watershed in order to ensure that the "seasonality" requirement of the EPA is being sufficiently met.

This report synthesizes data from the City of San Diego's Dry Weather Monitoring program and from the Regional Ecology Network and Environmental Workbench for Sustainable Development (RENEW-SD) program at UC San Diego. The purposes of this report are to:

1. Compile estimates for possible levels of dry season flow within the Chollas Creek Watershed;
2. Provide a range of estimates of loads for cadmium, copper, lead, zinc, total suspended solids, total petroleum hydrocarbons (TPH), and polycyclic aromatic hydrocarbons (PAH); and
3. Map drainage basin area and evaluate land uses for selected sites and explore the value and limitations for describing possible sources of flow and contaminants.

METHODS

Drainage Area Mapping

The perimeter of a drainage basin for a single station was determined in the field by examining the stormdrain network, street features, and topology of the surrounding land. Starting at the targeted outfall, two people walked or drove along the perimeter, marking on a large printed aerial map the boundary between runoff flowing into the targeted outfall and runoff flowing into an adjacent outfall. Perimeters were then traced onto digital Google Earth Pro (2009) maps and the area and land use for each drainage basin were compiled in ArcGIS Desktop Version 9.3 (ESRI 2008) using San Diego Association of Governments GIS files (SANDAG 2008).

Sampling

Under RWQCB Order 2001-01, the City of San Diego began operating dry weather monitoring in the Chollas Creek Watershed in 2001. Samples are taken once a year between June and September from established dry weather monitoring stations. Between 9 July 2007 and 15 August 2007, a subset of the City of San Diego's Dry Weather Monitoring Program was monitored for the RENEW-SD study. Thirty-two sites were visited between one and six times; for the stations that had flow, a minimum of three sampling events were recorded. Flow rate was measured in triplicate by measuring the amount of time to fill a container of known volume.

Lab Analyses

A variety of lab analyses were conducted each year from 2002 to 2008 for selected sites within the City of San Diego's Dry Weather Monitoring Program. All certified lab analyses employed EPA-approved methods (Calscience, Maxxam Analytical). In 2007, lab analyses were conducted for the RENEW-SD study for total metals (including copper, zinc, lead, and cadmium), total petroleum hydrocarbons (TPH) (including gasoline, motor oil, and diesel), polycyclic aromatic hydrocarbons (PAH), and total suspended solids (TSS). Samples for total cadmium, copper, lead, and zinc (including dissolved and total fraction) were stored at 4 degrees Fahrenheit and composited prior to analysis. PAHs measured for carcinogenic potential were compared to toxicity equivalent factors described by Nisbet and LaGoy (1992) for benzo[a]pyrene (B[a]P) ($C_{20}H_{12}$), a highly carcinogenic tetracylclic hydrocarbon (Fang et al. 2004) .

Data Analysis

Analysis of data included both the City of San Diego's dry weather data from 2002 - 2008 and RENEW-SD's dry weather data from 2007. Flow events were extrapolated to provide a range of possible flow values at each site for the dry season. Total area of each drainage was used to normalize the daily flow values by area. The average percent of stations flowing (obtained from the City of San Diego's dry weather data) was used to estimate a range of flow values for the entire Chollas Creek Watershed.

For calculation purposes, non-detects of pollutants were converted to half the reporting limit based on EPA's Non Detect Policy (EPA 1997). This has been the accepted procedure in recent studies of water quality (Stein et al. 2008). Maximum seasonal loads were determined by multiplying the maximum seasonal flow by the highest concentration of a contaminant within a single station, using:

$$Load = \sum F_{\max} C_{\max} \qquad \text{(Stein and Yoon 2008)}$$

where $F_{\max}$ was the maximum average flow for all stations, and $C_{\max}$ was the maximum average concentration at a single station.

Minimum and average seasonal loads were calculated in the same way. Since the metals analysis used composite samples (more than one sampling event contained in sample for each station), the range of loads was calculated based on the minimum, maximum, and average values for seasonal flow only.

Polycyclic aromatic hydrocarbons were extracted from suspended solids and water. Values were recorded as dry weight, and combined with average estimates for total suspended solids at each site to determine the dry weather loading of PAHs.

Uncertainty and Bias

The site selection process employed by the City of San Diego for their Dry Weather Monitoring Program could be a source of bias. As a program tasked with pollution prevention, the sites were selected based on criteria that might make them more likely to have dry season flow and contaminants present in the flow. Other selection criteria included accessibility issues (outfalls that occurred on private property were avoided).

As such, flow rates and loading may represent overestimates when extrapolated to the entire watershed; however, there are insufficient data to determine if that is the case. Furthermore, both sets of data from the City of San Diego and RENEW-SD are limited and show a high degree of variability. Extrapolation using these data to a watershed level is likely to generate estimates of flow rates and loads with an inherent amount of uncertainty.

RESULTS

Land Use

Residential and transportation land uses constituted the highest percent area of each of the six drainages that were mapped, on average accounting for approximately 62% and 24% of the total land uses, respectively (Table 1). Size of drainage sites ranged from 1.14km^2 at DW120 to .07 km^2 at DW189. DW203 had the greatest diversity in land uses with 19 SANDAG-defined land uses occurring within the basin; DW189 was not only the smallest drainage basin, but it also had the lowest land use diversity, with only 2 land uses occurring with the basin. Transportation, residential, and open space categories were grouped from the original SANDAG designations: transportation group included road right-of-ways, parking lots, and freeways; residential included single family, multi-family and spaced rural residential; open space included parks, open space, and undeveloped land.

Flow

The percentage of sites flowing between 2002 and 2008 ranged from 17% to 38%; on average, 24% of the sites were flowing during the dry season. The site with the most consistent flow was DW120, with flow measured 4 out of 5 years (Table 2). 2005 showed the highest percentage of sites flowing, but 2002 and 2004 were higher in average flow (Table 2). Sites DW120 and DW325 had the highest daily flow, though sites DW325 and DW189 had the highest normalized flow values (Figure 2-3). Even though the percent of sites flowing varied, the greatest variation is seen in the mean flow (4/6-104.5 m3/day). Over the entire dry season at Chollas Creek, between 13,000 and 96,000 m3 is discharged to the San Diego Bay.

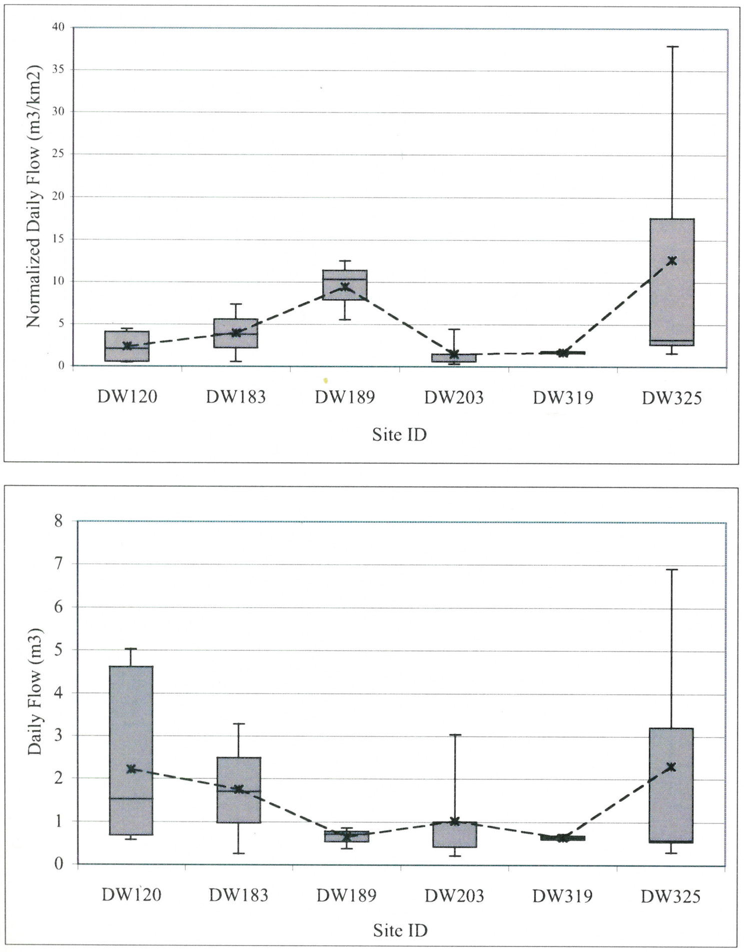
Table 1. Chollas Creek Land Use by Site

Site ID	DW120		DW183		DW189		DW203		DW319		DV
Land Use	Area (m2)	Percent	Area (m2)	Percent	Area (m2)	Percent	Area (m2)	Percent	Area (m2)	Percent	Area (m2)
Arterial Commercial							5.2	0.8	5.6	1.5	798.2
Communications and Utilities			5963.8	6.0							0.4
Schools	33.2	2.9	8.2	1.8			30.8	4.5			
Fire/Police Station			3707.1	3.7							
Light Industry - General							576.0	0.6			
Residential	799.3	70.5	677.1	59.5	57.1	80.8	294.9	43.3	258.0	68.1	90.1
Office and Retail			3.9	0.9			6.8	1.0	12.4	3.3	12.0
Open Space	54.1	4.8	23.3	5.2			109.2	16.0	13.7	3.6	25.3
Other Health Care							7.4	1.1			
Transportation	249.9	22.1	101.3	22.8	13.6	19.2	201.1	29.5	89.1	23.6	50.0
Religious Facility							20.9	3.1			2.7
Warehousing & Junkyard							0.5	0.1			

Table 2. Flowing Dry Weather Monitoring Stations from 2002 - 2008

2002	2003	2004	2005	2006	2007	2008
DW118	DW117	DW118	DW117	DW123	DW120	DW117
DW120	DW118	DW120	DW129	DW124	DW123	DW120
DW123	DW120	DW144	DW123	DW192	DW183	DW123
DW183	DW183	DW145	DW184	DW201	DW184	DW184
DW184	DW196	DW169	DW189	DW207	DW189	DW195
DW189	DW203	DW178	DW192	DW211	DW211	DW201
DW196		DW184	Dw196	DW312	DW325	DW207
DW205		DW187	DW201	DW313		DW313
DW206		DW200	DW203	DW320		DW325
DW298		DW207	DW207			DW378
		DW215	DW208			DW379
		DW218	DW313			DW380
		DW225	DW319			DW460
		DW226				DW462
		DW236				DW472
		DW239				
		DW245				
30% (294.5)	18% (4.6)	23% (104.5)	38% (6.4)	23% (1.8)	17% (14.5)	22% (19.6)

Percent of total sampled stations flowing (mean flow in m3/day)



Figures 2-3. Daily flow (m3) and normalized daily flow (m3/km2) for six RENEW-SD sites in Chollas Creek Watershed. Gray boxes represent range of values between 25th and 75th %; error bars indicate minimum and maximum values; dashed line connecting stars indicate means.

Pollutants

Non-detects were observed for all parameters measured (Table 3). Sites DW325 and DW183 were identified as the highest per km2 total loading of contaminants, with copper and total suspended solids highest at DW183, and lead, zinc, cadmium, gasoline, motor oil and diesel highest at DW325 (Table 4). Of the four metals, total zinc (including dissolved and particulate) had the highest loading at all six sites. Cadmium was not detected at any of the six sites (Table 3), and calculations of loading are based on half the reporting limit. Of the total petroleum hydrocarbons, motor oil had the highest loading, while gasoline was not detected above the reporting limit (Table 3).

Table 3. Minimum, mean, and maximum total concentratins for all samples

	Minimum	Mean	Maximum	% Non Detect	Detection Limit
Total Metals					
Cadmium	ND	ND	ND	100	0.001
Copper	ND	0.0143	0.039	33	0.01
Lead	ND	0.0041	0.012	83	0.005
Zinc	ND	0.102	0.189	16	0.02
Total Petroleum Hydrocarbons					
Diesel	ND	0.4	1	9	0.05
Gasoline	ND	ND	ND	100	.05-.1
Motor Oil	ND	0.6	1.4	36	0.25
Total Suspended Solids	ND	23.75	261	0	1

Values in mg/l, n ranges from 4 to 22

Table 4. Total Dry Season Loads at Chollas Creek, Normalized by Area

		Site						
		DW120	DW183	DW189	DW203	DW319	DW325	Average
Total Lead (g/km2)	Low	0.18	1.12	1.45	0.15	0.58	0.55	0.67
	Average	0.88	7.19	2.90	0.59	0.63	4.94	2.86
	High	1.68	13.48	4.35	1.76	0.71	14.28	6.04
Total Zinc (g/km2)	Low	6.1	16.8	8.4	4.7	9.3	26.1	11.9
	Average	28.1	113.6	14.4	22.5	28.1	207.0	68.9
	High	53.2	213.1	19.1	66.9	31.4	621.3	167.5
Total Copper (g/km2)	Low	1.2	3.5	4.2	0.5	3.5	1.2	2.4
	Average	5.8	23.4	7.2	2.5	3.9	9.7	8.7
	High	10.9	44.0	9.6	7.5	4.4	29.0	17.5
Total Cadmium(g/km2)	Low	0.04	0.04	0.43	0.03	0.11	0.11	0.13
	Average	0.18	0.29	0.72	0.12	0.13	0.99	0.41
	High	0.39	0.56	1.01	0.34	0.16	2.91	0.90
Total Suspended Solids (Kg/km2)	Low	0.08	0.78	1.52	0.05	0.68	0.29	0.57
	Average	12.0	56.6	7.1	2.5	2.6	13.9	15.8
	High	84.5	294.2	7.7	19.8	5.2	35.4	74.5
Gasoline (g/km2)	Low	1.9	4.5	21.1	1.2	5.8	6.1	6.8
	Average	9.0	30.0	36.1	8.6	10.8	48.4	23.8
	High	17.1	56.4	47.9	34.1	14.5	145.2	52.5
Motor Oil (g/km2)	Low	78.0	124.7	105.7	6.1	29.1	63.4	67.8
	Average	431.9	841.3	180.7	152.3	113.7	697.0	402.8
	High	955.3	1578.3	239.5	818.8	217.9	2671.0	1080.1
Diesel (g/km2)	Low	51.5	89.1	21.1	3.6	25.6	31.7	37.1
	Average	273.5	600.9	119.3	94.7	66.3	377.5	255.4
	High	586.8	1127.4	268.2	511.8	116.2	1509.7	686.7

☐ Highest Value ⬚ Value close to or within same order of magniture as highest value

Of the 12 PAHs tested, ten were detected from stations DW183 and DW203, including 2-methylnaphthalene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,l)perylene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene. Total PAHs for DW183 were .258 μg/g and for DW203 were .325μg/g for a single sampling event (Table 5), and 6.5 g and .5 g for the entire dry season, respectively.

Table 5. Polycyclic aromatic hydrocarbons (PAHs) at DW183 and DW203

PAH	DW183 B[a]P Eq (ug/g)	DW183 Average Dry Season Loading (g)	DW203 B[a]P Eq (ug/g)	DW203 Average Dry Season Loading (g)
2-Methylnaphthalene	0.0004	0.010		
Benzo(a)Pyrene	0.2	5.044		
Benzo(b)fluoranthene	0.03	0.757	0.300	0.502
Benzo(g,h,I)perylene	0.006	0.151		
Chrysene	0		0.020	0.033
Fluoranthene	0.0005	0.013	0.003	0.005
Indeno(1,2,3-cd)pyrene	0.02	0.504		
Naphthalene	0.0001	0.003		
Phenanthrene	0.0004	0.010		
Pyrene	0.0006	0.015	0.002	0.003
TOTAL	**0.258**	**6.507**	**0.325**	**0.544**

Toxicity equivalence units (BaPEq) from Nisbet and LaGoy (1992)
Total weight of extracted sediment estimated as 1 g

DISCUSSION

A number of studies have looked at southern California's dry weather water quality, providing evidence to show that that dry weather flow can be a substantial source of pollutants in urbanized areas. These studies focus on comparison of flow and water quality loadings in the arid western United States for dry versus wet weather (Stein and Ackerman 2007, McPherson et al. 2002, Piechota and Bowland 2001) for natural versus developed catchments (Stein and Yoon 2008), and for different land use types (Stein et al. 2008). This report is limited in scope to looking only at dry weather flow, loadings, and land use types at a singe watershed, yet its findings are significant in building an understanding of a previously unknown and underrepresented component of water quality for Chollas Creek and San Diego region.

Possible natural and anthropogenic sources are discussed in this section for the flow and loading measurements at Chollas Creek, referencing the land use analysis that was conducted for this project as well as similar studies that have taken place in southern California. Policy and management recommendations are also discussed, with knowledge gaps and potential for future research identified.

Flow

In 2007, Chollas Creek dry weather flow was highly variable, which is consistent with trends from both natural and developed drainage basins (Stein and Yoon 2007). Total flow for the Chollas Creek between May 1 and September 30, 2007 represents between 0.2% and 1.8% of the average total annual flow of Chollas Creek (TetraTech 2008). This is low relative to other studies of southern California watersheds; McPherson et al. (2002) found that dry weather flow accounted for 10-30% of the annual volume of water in the Ballona Creek Watershed in Los Angeles.

The largest drainage area at site DW120 corresponded to the largest daily flow, following Stein and Ackerman's (2007) findings that a few large storm drain systems dominate the overall storm drain volume for the dry season. When considering small area sites with high per km^2 flow, such as DW189, flow could be considered to be sourced at perhaps a localized high flow event, such as a broken sprinkler. (Figure 3) On the other hand, high flow from a large drainage area shows relatively low normalized flow, which could be interpreted as a culmination of low flow from a large area.

Best management practices that focus on reducing the runoff of water or enhancing filtrations of water before entering the stormdrain networks should continue to be implemented and developed. Recommendations for the City of San Diego from Weston Solutions (2006) include "infrastructure intensive" BMPs which require storage of large volumes of water that occur during wet months. Emphasis on the wet weather is warranted given the high loadings, but may not be sufficient in minimizing discharge of water to San Diego Bay in the dry season. Porous pavements, sunken vegetated islands, and sidewalk strips could help reduce runoff and filter water before entering the stormdrain network.

Education and outreach promoting sustainable uses of water during the cutbacks of imported water allocation from the State Water Project and the general drying trend for southern California (California DWR 2008) is an important component of addressing water quality issues in Chollas Creek. As mentioned before, between 13,000 and 96,000 m3 of water is estimated to be discharged to San Diego Bay during the dry season from Chollas Creek; this discharge should be considered wasted water reflecting unsustainable uses within the Chollas Creek Watershed. Approaching the problem from both a water quality and water conservation perspective is needed in order to prevent simply delaying the contamination of the watershed; reduced flow could accumulate contaminants that are carried to the watershed after the first rain, a phenomenon known as "first flush." Only coupled with enhanced filtration of water will those dry weather inputs be minimized.

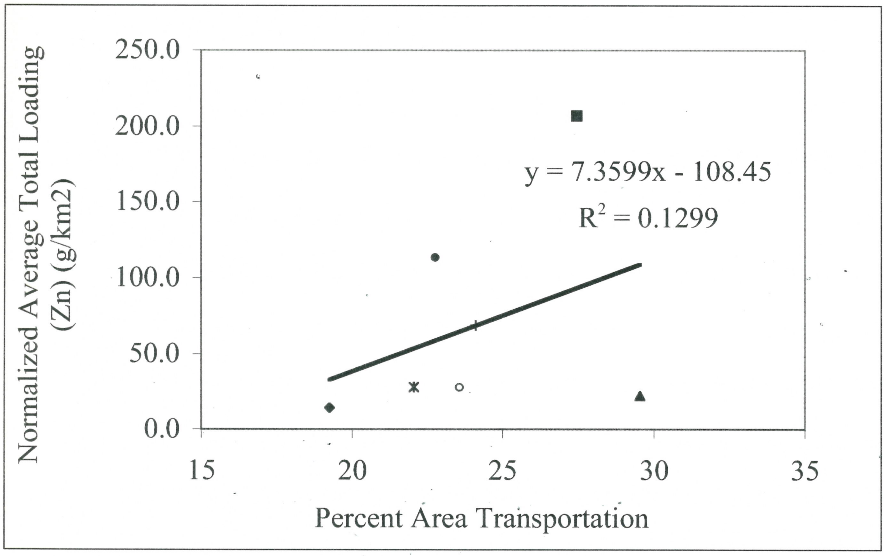
Total Metals

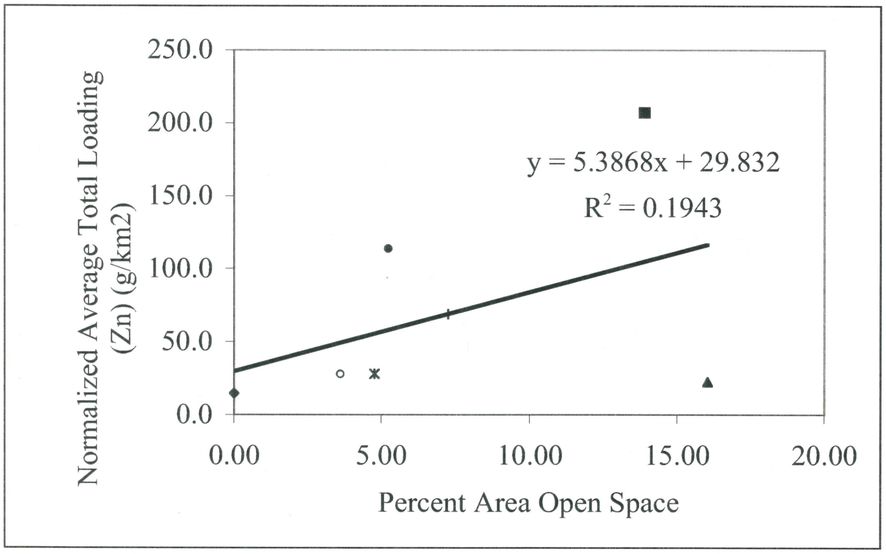
Total loading of the total metals detected in 2007 represented 1% or less of the total annual loading (TetraTech 2008). This is low relative to other southern California watersheds; a 2002 study of Ballona Creek watershed in Los Angeles County found that between 8-42% of the annual total trace metal pollution was from the dry weather flow (McPherson 2002). A study of wet and dry loadings of metals in Korea found a similar percentage of dry weather contribution to the Ballona Creek Study: between 7 and 56% (Kang et al. 2009). Nevertheless, dry season flow adds to the deposition of bioavailabe metals in the sediments of San Diego Bay, where, eventually responses above 60μg/g were found to produce chronic toxicity to either infaunal organisms or possibly fish living in contact with or feeding in the sediment of San Diego Bay (Anderson et al. 1999).

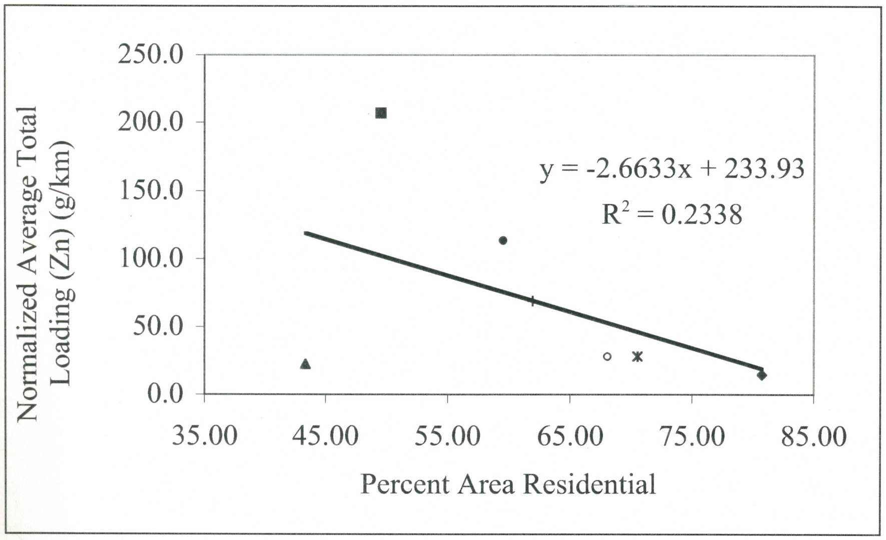
Sources of metals include natural or "background" levels, anthropogenic input from roads and industrial land uses, or atmospheric deposition. In southern California, natural watersheds (those with >95% undeveloped) have shown natural concentrations of zinc, copper, and lead at less than 1 μg/l (Stein and Yoon 2008). Development is considered the main source of elevated levels of metals, particularly residue from tires and brake pads on roads and streets. Zinc is added as zinc oxide to the tires during the curing process to make the rubber more durable (Smolders and Degryse 2002), and zinc, lead, and copper are used in brake pads (Woodward-Clyde Consultants 1994).

Another potential source of metals is atmospheric deposition, though the mechanism has only recently been studied at a watershed scale. Metal-bearing particulates can be deposited onto surfaces such as plants and roads, or directly onto a microlayer film covering coastal and inland waters and wetlands (Lu et al. 2003). In southern California, atmospheric deposition has been shown to be a significant contributor to metal pollution in coastal waters and river systems (Lu et al. 2003, Sabin and Schiff 2008). Again, dry weather data are limited; during the mid 1970s, atmospheric deposition studies were conducted at a number of sites along the coast between Santa Barbara and San Diego (Young et al. 1976, Young and Jan 1977). Measurements taken in 2006 by Sabin and Schiff were compared with the historical conditions in 1975; fluxes of both copper and lead were generally lower in 2006 than in 1975, whereas the flux of zinc was higher in 2006 than in 1975 (Sabin and Schiff 2008). Two hotspots were identified at Los Angeles Harbor and San Diego Bay, and high deposition of metals was directly linked to proximity to urban areas (Sabin and Schiff 2008).

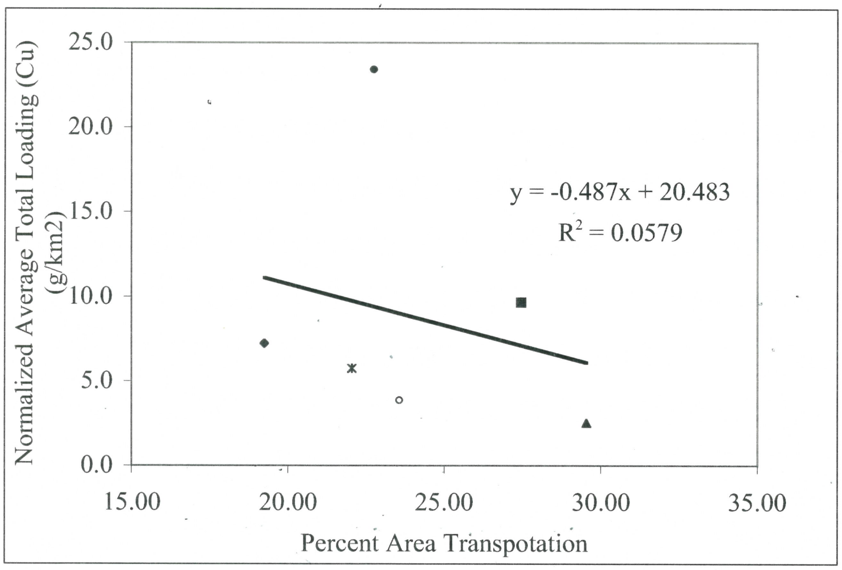
Higher normalized loading of zinc appears to be related to the percent of land use as transportation within the drainage (Figure 4); copper appears to follow an inverse relationship (Figure 7). Further sampling is needed to determine if the trends shown in these preliminary scatter plots based on few sampling events reflect conditions for the entire dry season within the Chollas Creek Watershed. With such wide scatter it is difficult to draw relationship between land uses and loading, and it is possible there are other factors influencing the loading of metals such as the presence of major transportation arteries and the slope of the roads (e.g. a downward sloping road would cause more drivers to use their breaks). Other studies, which have focused on wet weather, have shown copper and zinc linked to transportation and industrial land uses in the Chollas Creek (CA RWQCB 2007), and it is likely that the dry weather loading follows the same trends. A positive relationship between zinc and open space could be related to the natural sources of zinc (Figure 5).



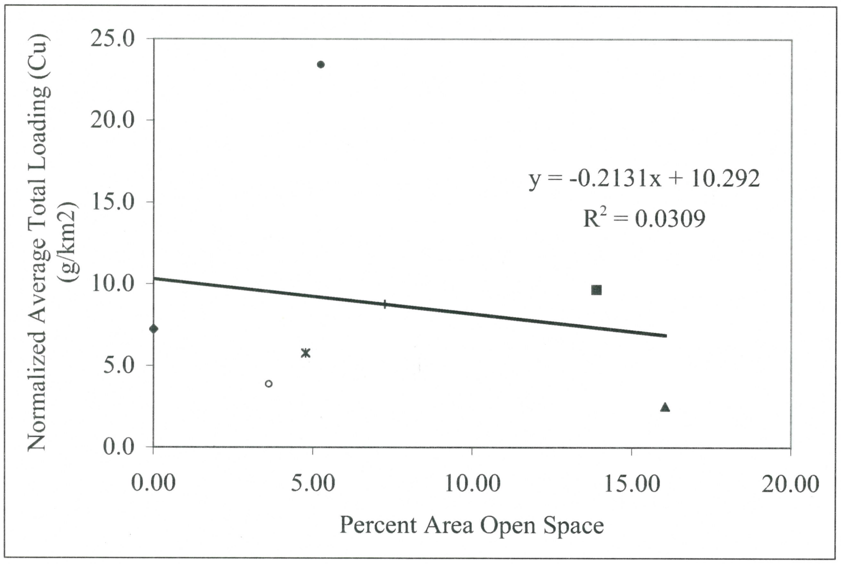




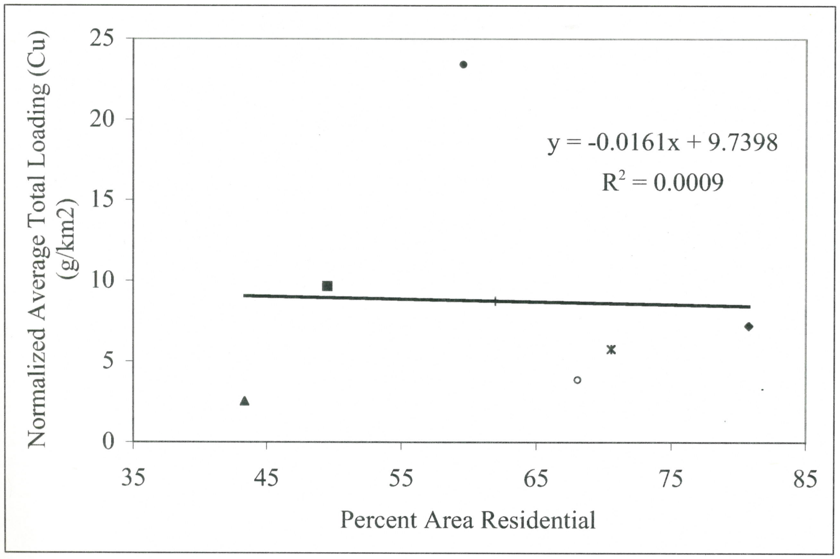
Figures 4-6. Scatter plots for zinc: transportation, open space and residential land uses.



Figures 7-9. Scatter plots for copper: transportation, open space, and residential land uses.



* DW120
● DW183
◆ DW189
▲ DW203
○ DW319
■ DW325
\+ Average



Concentrations of total lead, copper, and zinc during the low volume dry season flow can be harmful to the biota of Chollas Creek, depending on the bioavailability of the metal for uptake by organisms. Dissolved metals are used to set and measure levels for TMDLs because "dissolved metal more closely approximated the bioavailable fraction of the metal in the water column than does total recoverable metal" (EPA 2000). Studies have shown that the percent of metals in dissolved fraction from southern California stormdrains is between 80-85% (Stein and Tiefenthaler 2005). Preliminary analysis of the fraction of dissolved metals in Chollas Creek total metals indicates a much lower percentage, and further data collection and research is needed. Furthermore, the TMDL for metals in Chollas Creek is hardness-dependent. Therefore, in order to determine compliance with the TMDL, measurements are needed for dissolved metals and hardness.

As part of the City of San Diego's Pollution Prevention Program, street sweeping is conducted monthly to remove both macro- and microscopic pollutants; this has been proven to be an effective measure to control diffuse pollution (Muhammad and Hooke 2006). In addition, Chollas Creek was one of the neighborhoods chosen for a street sweeping pilot study to determine the optimal street sweeping frequencies and machinery to better comply with clean water regulations (Think Blue 2009). At a regional level, continuing to work to provide residents with more transportation options (e.g. public transportation, commuting, cycling, and walking would also help to reduce the number of single passenger trips and contribute to the overall reduction of metals loading.

Total Petroleum Hydrocarbons

Assuming no natural seepage of crude oil in the Chollas Creek Watershed, the majority of the total petroleum hydrocarbons can be attributed to anthropogenic sources. PAHs peaked in the 1950s and 1960s and showed regional decline in the United States in the 1970s and 1980s because of reduced use of coal for home heating, industrial emissions controls, and increased efficiency of power plants (Heit et al. 1988). Recent increases in PAHs have been attributed to a different source: vehicle use (Van Metre et al. 2000). A study of urban runoff in Rhode Island showed the highest concentrations of

TPHs at industrial and highway sites, with lower levels at commercial and residential sites (Latimer et al. 1990). In this study, only one site had industrial land use, which did not correlate to the highest concentration or highest loading of total petroleum hydrocarbons. Wide scatter, as with total zinc and copper, make it difficult to correlate high motor oil to a particular land use.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons are created by incomplete combustion of hydrocarbons.. As such, industrial and transportation land uses where fossil fuels are consistently being burned are the primary source of PAHs, but burning of wood, tobacco, incense, and even food products can produce PAHs. The major wildfires of 2007 occurred after the sampling events, and are not likely to have been a significant contributor to PAHs. Fairey et al. (1998) commented on the possible sources of PAHs in the San Diego Bay: " although it is difficult to isolate the sources, some probable contributors include urban storm drains, groundwater flow toward the [San Diego] Bay from naval waste oil and drum disposal sites, various commercial recreational shipping activities, and minor spills during fueling operations." PAHs are also known to be found in sewage effluent (Eganhouse and Gossett 1991). A sewage spill was believed to have been observed during one of the field sampling events at DW183, one of the two sites where PAHs were detected. Also, PAHs are typically found in soils, sediment, or oily substances because of their lipophilic properties; therefore, in water samples, PAHs are bounded to total suspended sediments. The highest value for total suspended solids was at DW183.

The other site where PAH's were detected was DW203, which is characterized by having the highest diversity of land uses within the drainage, including warehousing, landfill, and industrial land use, which likely contributes to the presence of PAHs. Levels of PAHs detected at DW203 were an order of magnitude lower than those measured in DW183, suggesting that during the dry season sources of PAHs in drainages dominated by residential land use might be limited (e.g. to cases involving spills). However, drainages that have a greater potential for having sources of PAHs by virtue of their land uses should be monitored carefully.

CONCLUSIONS

Urban runoff is both a water quality and a water conservation issue, which makes management both challenging and critical. This report provides suggestions for possible total loadings of water and contaminants during the dry season at Chollas Creek, while also identifying some possible links with land use.

- Mapping micro-drainages can provide important insight into the sources of flow and/or contaminant loading. Future drainage mapping should focus on the discharge points that have been identified as "problematic" in terms of the magnitude and consistency of flow, and the total loading of pollutants.
- Information on land uses within each micro-drainage has shown to be insufficient in explaining the sources of contaminants. Further studies should also look at other elements, such as the volume of traffic on each of the transportation land uses, and the slope of roads.
- Continued development of best management practices, such as the Chollas Creek Street Sweeping pilot study, are important in determining the most effective and efficient way of improving water quality in the Chollas Creek. Infrastructure-intensive BMPs, such as large holding basins for large volume wet season flow, should be implemented along with BMPs targeting smaller volume discharge, such as porous pavement and vegetated strips or patches along roads.
- Education and outreach should emphasize both water conservation and water quality during the dry season to promote more sustainable uses of water and better natural filtration of water.

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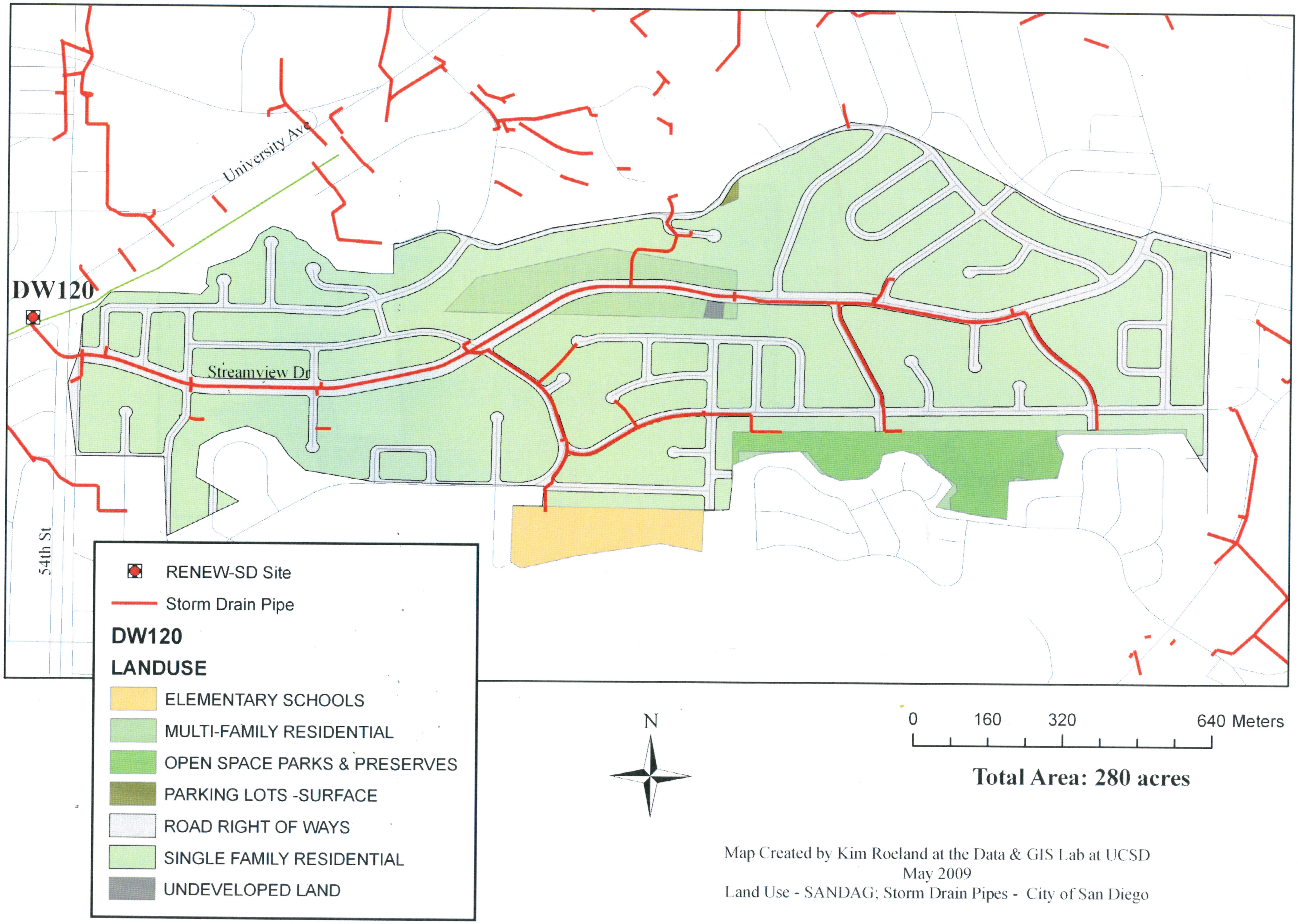
APPENDIX

Land Use Analysis Maps for DW120, DW183, DW189, DW203 DW319, DW325

DW120 Drainage Land Use Map



Total Area: 280 acres

Map Created by Kim Roeland at the Data & GIS Lab at UCSD
May 2009
Land Use - SANDAG; Storm Drain Pipes - City of San Diego

DW183 Drainage Land Use Map

Total Area: 110 acres

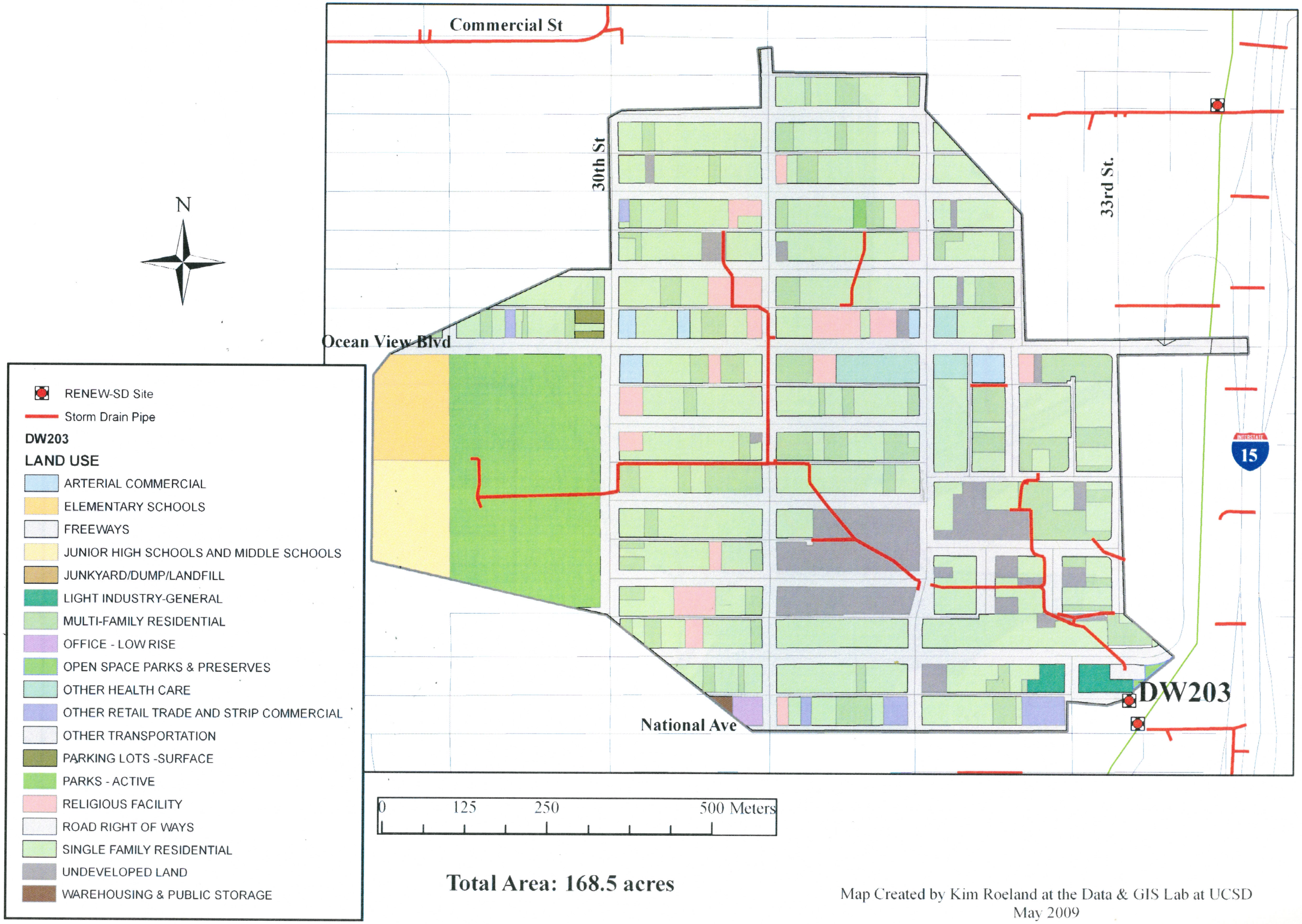
Map Created by Kim Roeland at the Data & GIS Lab at UCSD
May 2009
Land Use - SANDAG; Storm Drain Pipes - City of San Diego

DW189 Drainage Land Use Map

Total Area: 17.27 acres

Map Created by Kim Roeland at the Data & GIS Lab at UCSD
May 2009
Land Use - SANDAG; Storm Drain Pipes - City of San Diego

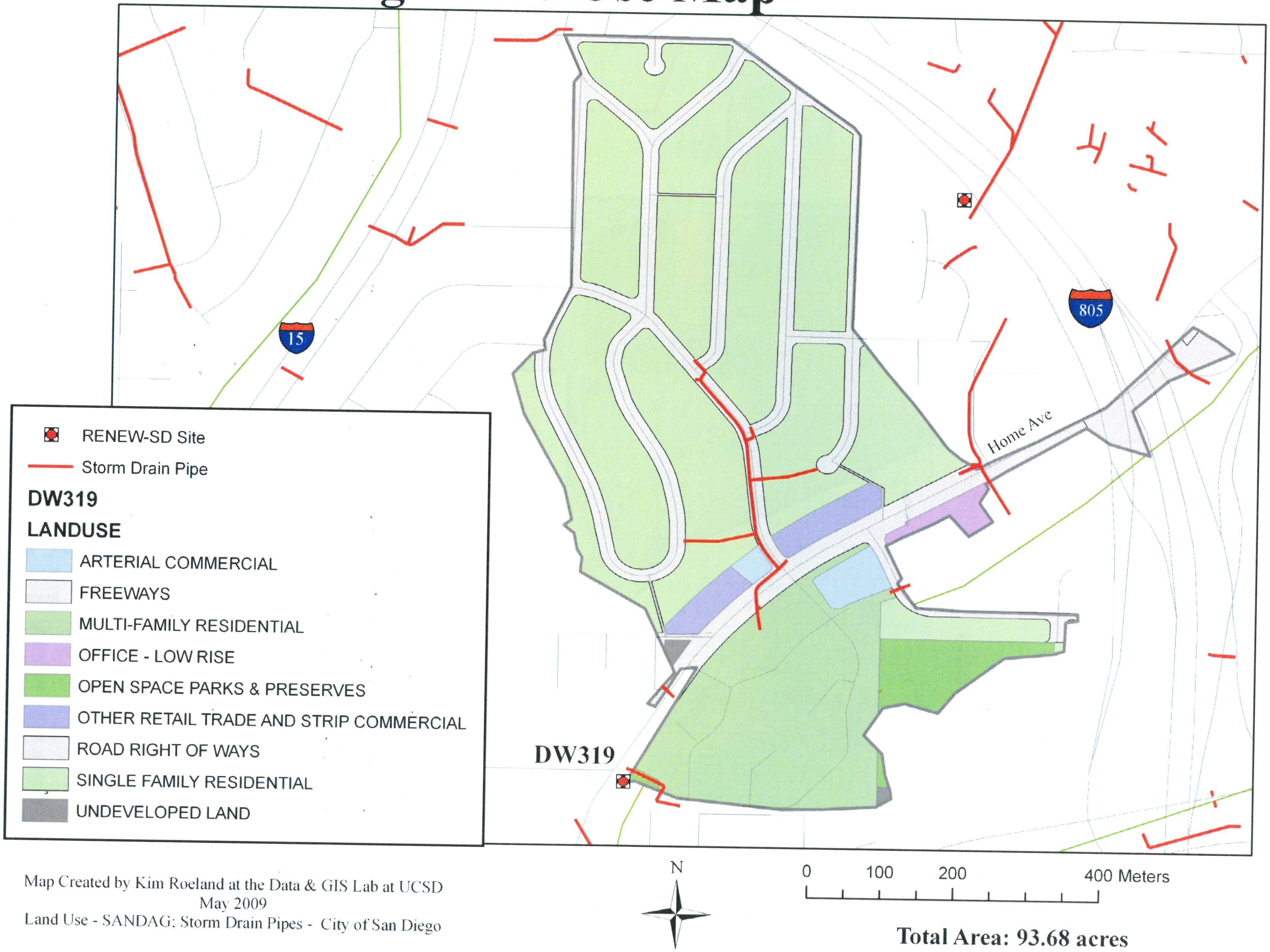
DW203 Drainage Land Use Map



Total Area: 168.5 acres

Map Created by Kim Roeland at the Data & GIS Lab at UCSD
May 2009

DW319 Drainage Land Use Map



Map Created by Kim Roeland at the Data & GIS Lab at UCSD
May 2009
Land Use - SANDAG; Storm Drain Pipes - City of San Diego

Total Area: 93.68 acres

DW325 Drainage Land Use Map

Total Area: 45 acres

Map Created by Kim Roeland at the Data & GIS Lab at UCSD
May 2009
Land Use - SANDAG; Storm Drain Pipes - City of San Diego