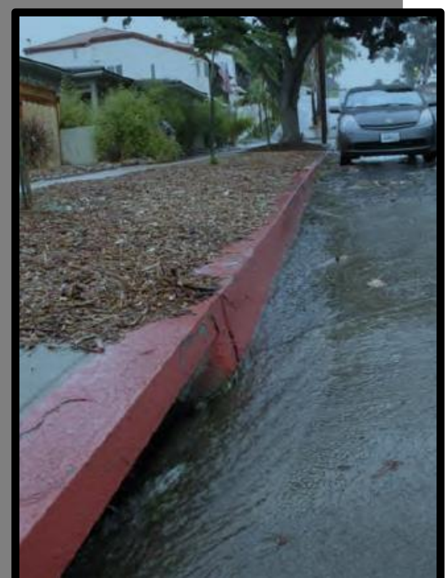
Fall 2015

Stormwater and Low-Impact Development

A San Diego Case study



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1. Introduction

Urban development has been historically damaging to natural hydrologic systems in the United States. Natural processes such as infiltration, percolation into aquifers, and evapotranspiration are disrupted when natural land cover is replaced by impervious surfaces such as buildings, roadways, sidewalks, and parking lots (Figure 1). Traditional civil engineering has placed emphasis on the rapid and direct routing of storm flows from the built environment into conveyance systems which discharge flows into downstream surface waters via networks of culverts, storm drains, and outfalls. As a result of both impervious development and conventional storm drain design, two problems can arise.

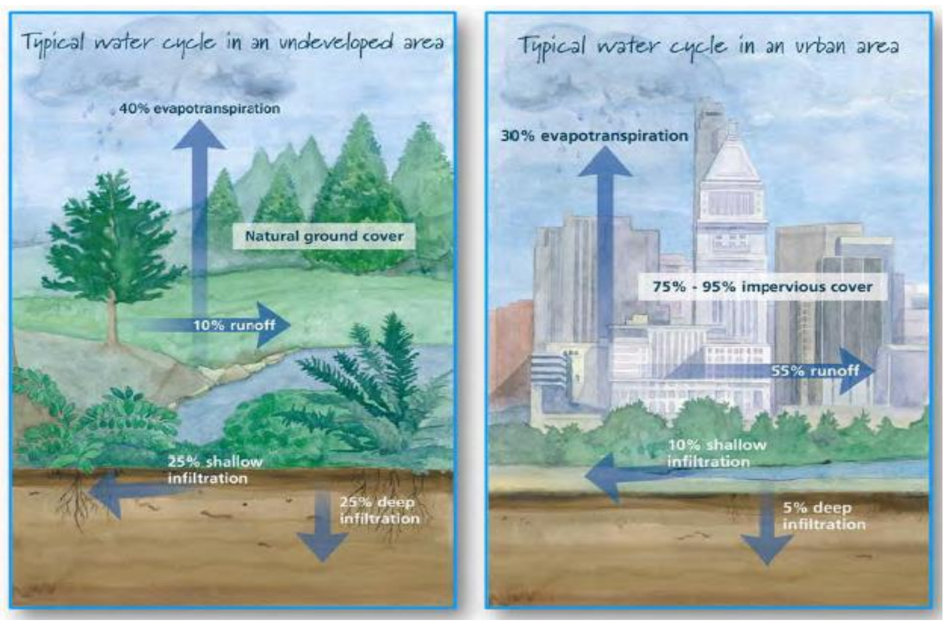


Figure 1: Impacts of the built environment on natural hydrologic processes (City of San Diego).

The first is that impervious development can create a serious flood risk by short circuiting storm flows and rapidly transporting precipitation to nearby surface waters. Whereas a natural receiving water might have a delayed, low intensity flow response (unit hydrograph) to a storm event, a receiving water in a built environment can undergo sharp, intense, and nearly instantaneous flow responses to the same storm. The second issue associated with urban development is water quality. Cities are major sources of aquatic contaminants including heavy metals (industry, automobiles), organics (solvents, cleaners), pesticides, nutrients (fertilizer), particles (roadways, construction) and bacteria (sewage, pet waste) (City of San Diego 2015). Much like the issue with flood concerns, the direct routing of runoff into nearby water bodies via conveyance systems allows for a rapid flushing of these contaminants into the environment with little to no treatment. In the watersheds of San Diego, coastal water quality is an area of concern and stormwater flows are often followed by public closures of beaches and bays due to bacterial loadings.

Low-impact development (LID) has gained popularity with stormwater entities over the past decade by working to replicate and restore natural hydrologic processes to better manage runoff. LID has manifested itself in a variety of forms including bioretention basins, vegetated swales, green roofs, and permeable pavement however these all aim to restore pervious land surfaces in some way addressing both flood and water pollution concerns. By diverting portions of storm flows into the subsurface (or taking it out of the system as is the case with rain barrels and green roofs), LID systems diminish flash flood risks and achieve improved water quality by decreasing contact with overland pollutants and/or providing a natural treatment system. Treatment processes include but are not limited to filtration (particles, bacteria), adsorption (organics, metals, nutrients), oxidation (bacteria, organics), and biodegradation (nutrients, organics) (City of San Diego 2015).

2. Research Goals and Study Area

The goal of this study is to examine the effectiveness of LID systems with respect to both storm flows and the improvement of impaired water bodies by taking advantage of the geospatial capabilities of ArcGIS. Six constructed LID sites located in the Clairemont neighborhood of San Diego, CA were selected for study due to their LID types and their proximity upstream of a popular recreational water body, Mission Bay. These sites include the Clairemont Boys and Girls Club (bioswale), San Diego Gas and Electric (SDG&E) Innovation Center (permeable pavement, infiltration trenches, and rain barrels), the Mt. Abernathy Green Street Pilot Project (bioretention basins), and the Genesee Plaza Shopping Center (vegetated swales) (Figure 2). The Mt. Abernathy Green Street Pilot is unique in that it is San Diego's first urban green street project. At over $1M, the project is a part of the Storm Water Department's Strategic plan which aims to meet Total Maximum Daily Load (TMDL) limits and storm water permit requirements for indicator bacteria in the Mission Bay Watershed (City of San Diego). All projects were built within a 6 month time span of one other from the winter of 2011 to late spring of 2012. For the water quality portion of this analysis, contaminant data obtained from the City of San Diego Storm Water Pollution Prevention Program (SWPP) was compared before and after the construction of the LID systems. An analysis on storm flow reduction was conducted using the rational method on a case study of the SDG&E Innovation Center using parameters that reflect pre- and post-LID conditions on the site.

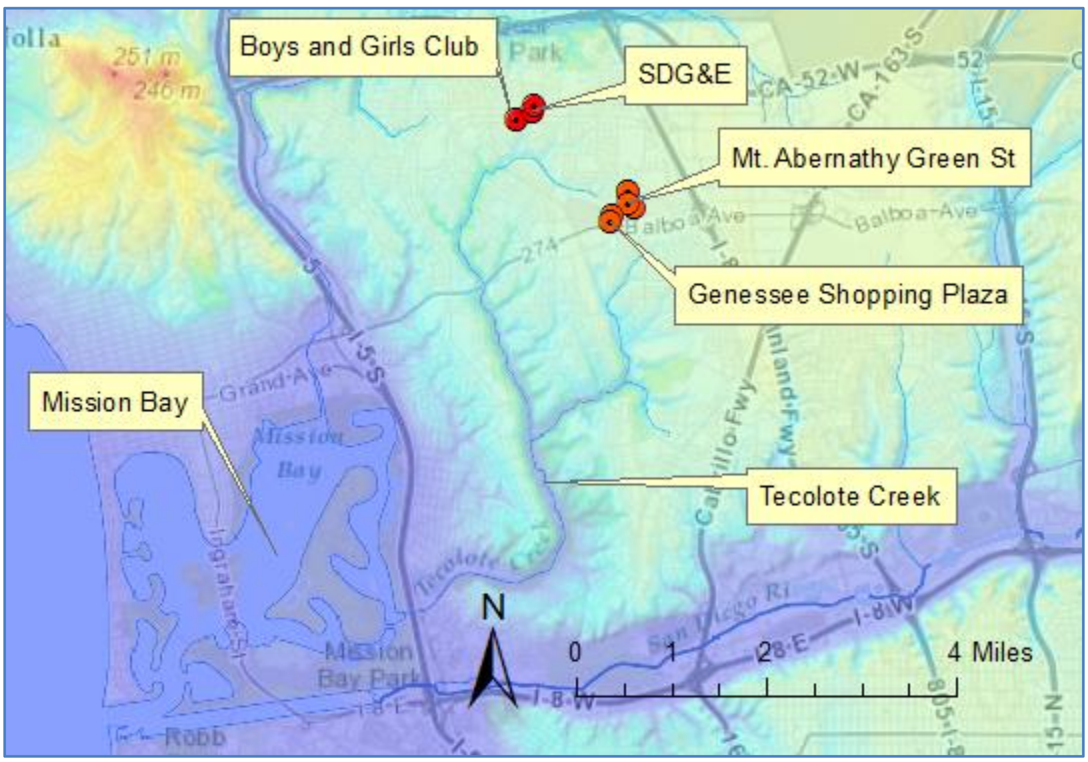


Figure 2: Study Area with NHDPlusV2 flowlines and NED30 elevation data

3. Methods and Results

3.A. Study Area Hydrology

GPS coordinates for recently constructed LID throughout the city were obtained from the San Diego Department of Storm Water website. The first step in selecting LID sites was to map them with NHDPlusV2 flowlines and NED30 elevation data to better understand possible flow patterns (Figure 3). The aforementioned sites we selected due to their proximity to Tecolote Creek which is a major tributary into the popular recreational water body, Mission Bay. To confirm the hydrology, watershed delineation was performed using both the ArcGIS server tool and the more rigorous python-coded DEM approach from the NED30 data using a 1000 unit stream threshold. The results in Figure 3 reaffirm the selected sites' importance to Tecolote Creek and Mission Bay. The DEM watershed analysis yields a basin with a drainage area of about 25 km^2 (10 mi^2) and drainage lines with a total length of 28.5 km (17.7 mi).

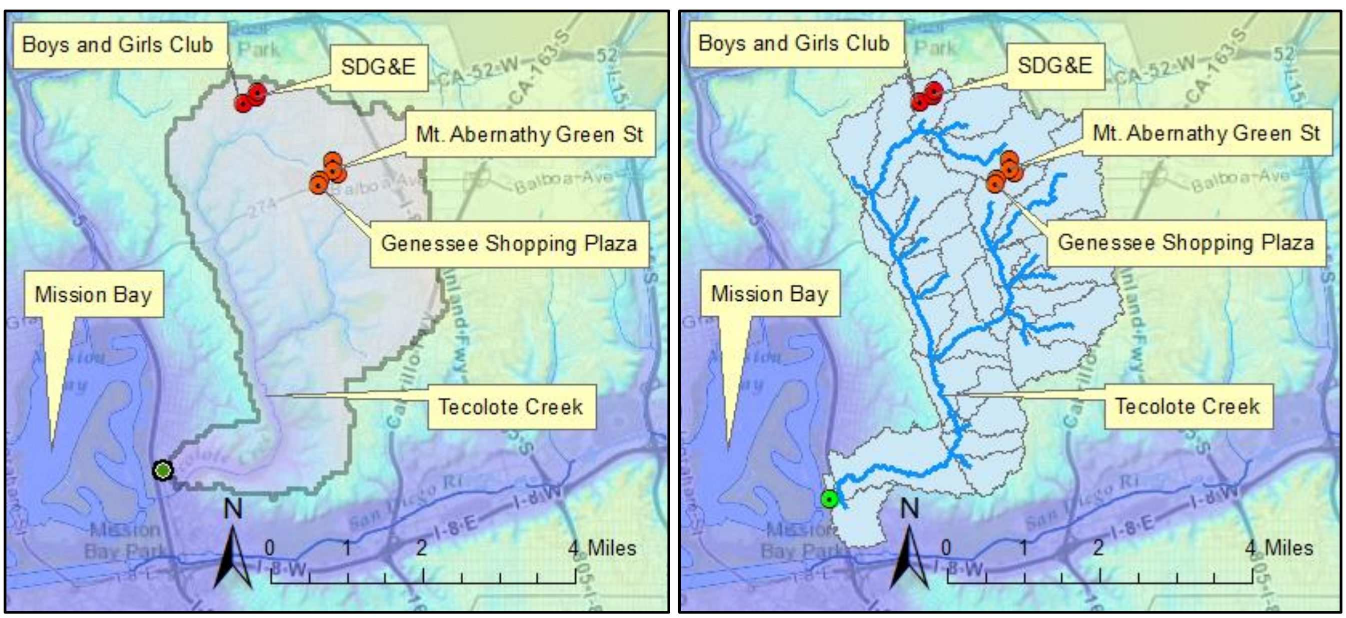


Figure 3: ArcGIS services watershed delineation (left). DEM watershed delineation with catchments and drainage lines (right).

Because impervious land cover is the key contributor to the water-related problems with urban development, its analysis within the watershed was conducted. The Get Data tool from the AutoHMS toolbox was used to obtain the NLCD Percent Impervious data from 2011. Zonal statistics on the watershed basin returned a mean value of 60.08% impervious (Figure 4).

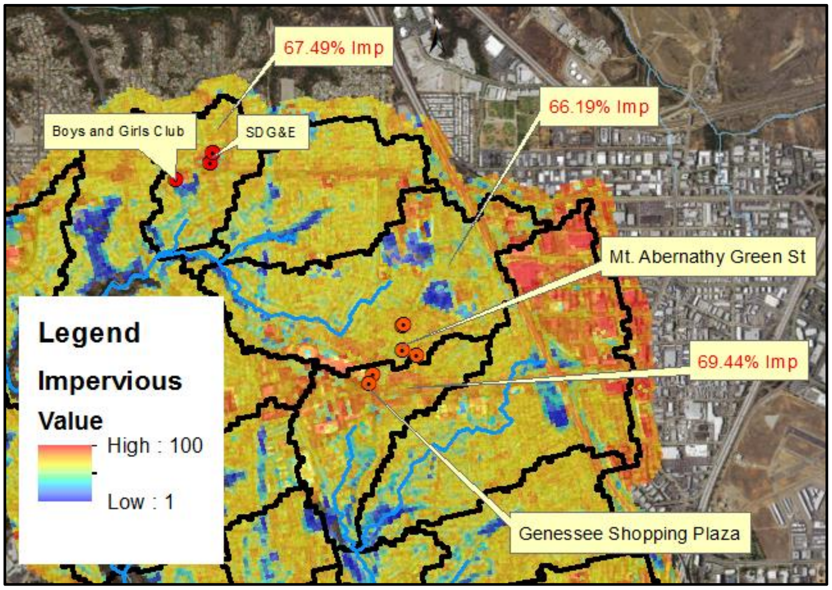


Figure 4: % impervious cover of the watershed basin

The catchments encompassing the clusters of LID sites (LID not yet built as of 2011, however) were 67.49%, 66.19%, and 69.44% (Figure 5). These values are indicative of a residential or moderately developed commercial area (San Diego County 2003). The three catchments of concern have mean impervious values that are higher than the watershed basin mean suggesting that these are appropriate locations to consider LID.

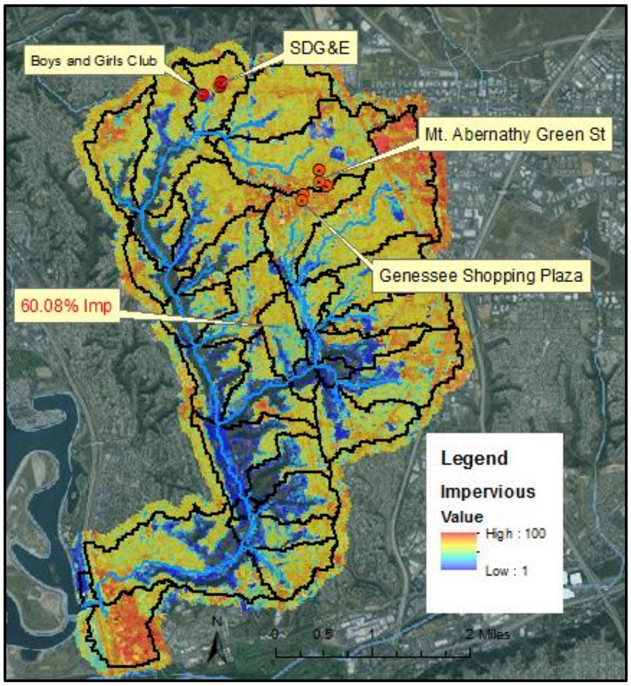


Figure 4: % impervious cover of the catchments of concern

3.B. Storm Flows

One risk that impervious urban development poses with respect to stormwater is that of flash flooding during intense precipitation events. At the onset of this study, one approach to analyzing changes in runoff flows was to choose two precipitation events of similar intensity before and after LID construction and compare USGS stream gage flows for these storms. However, no USGS gages were present in the selected watershed. An HEC-HMS model was considered to model two responses (before and after LID) to a given storm however the scale of such model would be inappropriate for the LID projects of concern. Therefore, a localized analysis of runoff flows using the rational method was conducted (Equation 1). Storm flow calculations were carried out on the SDG&E development adjacent to DW0563.

$$\boldsymbol{Q = c * i * A} \qquad \textbf{(1)}$$

$$Q = peak\ discharge\ (cfs)$$
$$c = runoff\ coefficient\ (-)$$
$$i = rainfall\ intensity\ \left(\frac{in}{hr}\right)\ for\ period\ of\ time,\ T$$
$$A = drainage\ area\ (acres)$$

Equation 1: The rational method

3.C.i. Rational Method on SDG&E Site

To better organize the ensuing method, Figure 6 outlines the process graphically in a flowchart.

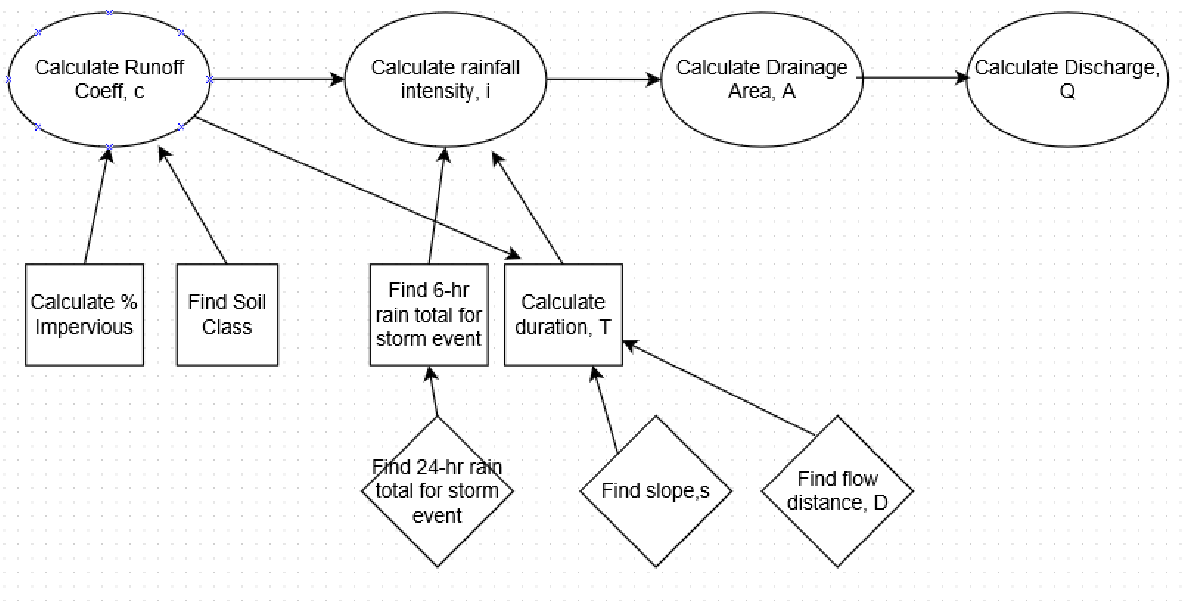


Figure 5: Rational Method Flowchart

The first step in my rational method analysis was to calculate values of the runoff coefficient, c, for instances before and after the LID was constructed. Table 1, taken from the San Diego County Hydrology Manual, offers a guideline for c values based on percent impervious cover and soil type.

RUNOFF COEFFICIENTS FOR URBAN AREAS

Land Use		Runoff Coefficient "C"				
			Soil Type			
NRCS Elements	County Elements	% IMPER.	A	B	C	D
Undisturbed Natural Terrain (Natural)	Permanent Open Space	0*	0.20	0.25	0.30	0.35
Low Density Residential (LDR)	Residential, 1.0 DU/A or less	10	0.27	0.32	0.36	0.41
Low Density Residential (LDR)	Residential, 2.0 DU/A or less	20	0.34	0.38	0.42	0.46
Low Density Residential (LDR)	Residential, 2.9 DU/A or less	25	0.38	0.41	0.45	0.49
Medium Density Residential (MDR)	Residential, 4.3 DU/A or less	30	0.41	0.45	0.48	0.52
Medium Density Residential (MDR)	Residential, 7.3 DU/A or less	40	0.48	0.51	0.54	0.57
Medium Density Residential (MDR)	Residential, 10.9 DU/A or less	45	0.52	0.54	0.57	0.60
Medium Density Residential (MDR)	Residential, 14.5 DU/A or less	50	0.55	0.58	0.60	0.63
High Density Residential (HDR)	Residential, 24.0 DU/A or less	65	0.66	0.67	0.69	0.71
High Density Residential (HDR)	Residential, 43.0 DU/A or less	80	0.76	0.77	0.78	0.79
Commercial/Industrial (N. Com)	Neighborhood Commercial	80	0.76	0.77	0.78	0.79
Commercial/Industrial (G. Com)	General Commercial	85	0.80	0.80	0.81	0.82
Commercial/Industrial (O.P. Com)	Office Professional/Commercial	90	0.83	0.84	0.84	0.85
Commercial/Industrial (Limited I.)	Limited Industrial	90	0.83	0.84	0.84	0.85
Commercial/Industrial (General I.)	General Industrial	95	0.87	0.87	0.87	0.87

Table 1: Runoff coefficient calculation

NLCD impervious land cover data is provided on a 30 meter by 30 meter grid size resolution which is too coarse to analyze changes within the scale of city lots. Instead, high resolution JPEG 2000 aerial images of the SDG&E lot were obtained from the

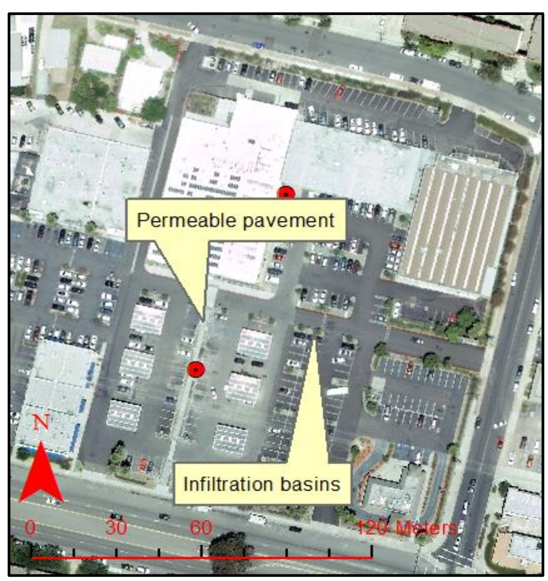


Figure 6: Aerial images of the SDG&E sites. LID includes permeable pavement and planted infiltration basins within the parking lot

National Map database (Figure 7). Custom polygons were drawn outlining the entire SGD&E property, the impervious parking lot before LID, the impervious roof, and the parking lot LID (permeable pavement walkways and infiltration basin) (Figure 8). The SDG&E site was fitted with a rainwater harvesting LID system, however this was not taken into account in the analysis and roof area was considered impervious in both cases for a conservative estimate. To determine the percent impervious land cover of the lot, the LID installments were assigned a value of 0 and the conventional pavement and roofing was assigned a value of 1.

Figure 7: Polygon of the entire SDG&E property (brown). Polygon of the impervious roof (yellow). Polygon of the impervious asphalt (pink). Polygons of the pervious LID (blue). The middle image represents pre-LID conditions and the right reflects post-LID conditions.

Pre-LID percent impervious land cover was calculated by taking the sum of the area of the impervious parking lot and the area of the roof and dividing it by the total property area (yellow plus pink divided by brown). The post-LID percent impervious value was calculated by taking the sum of the area of the impervious parking lot and the area of the roof minus the impervious LID and dividing that total by the total property area. (yellow plus pink minus blue divided by brown). The results are offered in Table 2.

Total Area-Brown (m^2)	Roof Area-Yellow (m^2)	Pre-LID Impervious Area- Pink (m^2)	Post-LID Pervious Area-Blue (m^2)
15025.23	3639.05	10813.55	1436.18

Pre-LID % Impervious	Post-LID % Impervious
96.2%	86.6%

Table 2: Polygon areas (top) and calculated % impervious values (bottom).

The second required parameter for the runoff coefficient, c, is the soil type. Soil classification data (Hydrologic Soil Groups) for the basin was obtained via the AutoHMS get Data tool (Figure 9).

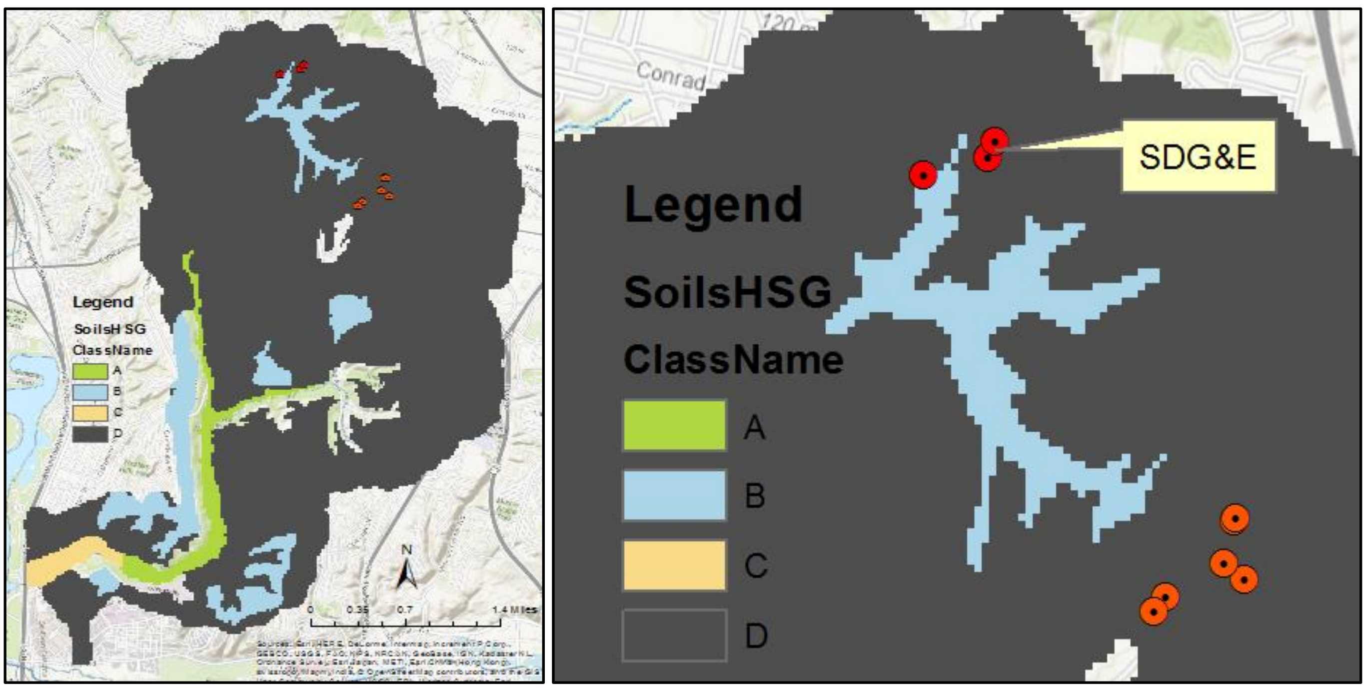


Figure 8: HSGs for the basin (left) and localized LID sites (right).

The SDG&E site has a Hydrologic Soil Group (HSG) of D indicative of low conductivity clays (San Diego County 2003). Table 3 shows the runoff coefficients for the given % impervious and soil classes using Table 1.

	Pre-LID	Post-LID
% Impervious	95%	85%
Soil Class	D	D
Runoff Coefficient, c	0.87	0.82

Table 3: Runoff Coefficients for pre-and post-LID conditions.

To find a storm of interest, a shapefile containing 85th percentile 24-hr rainfall totals as isopluvial contours in inches was obtained from a San Diego Regional GIS database, SanGIS (Figure 10).

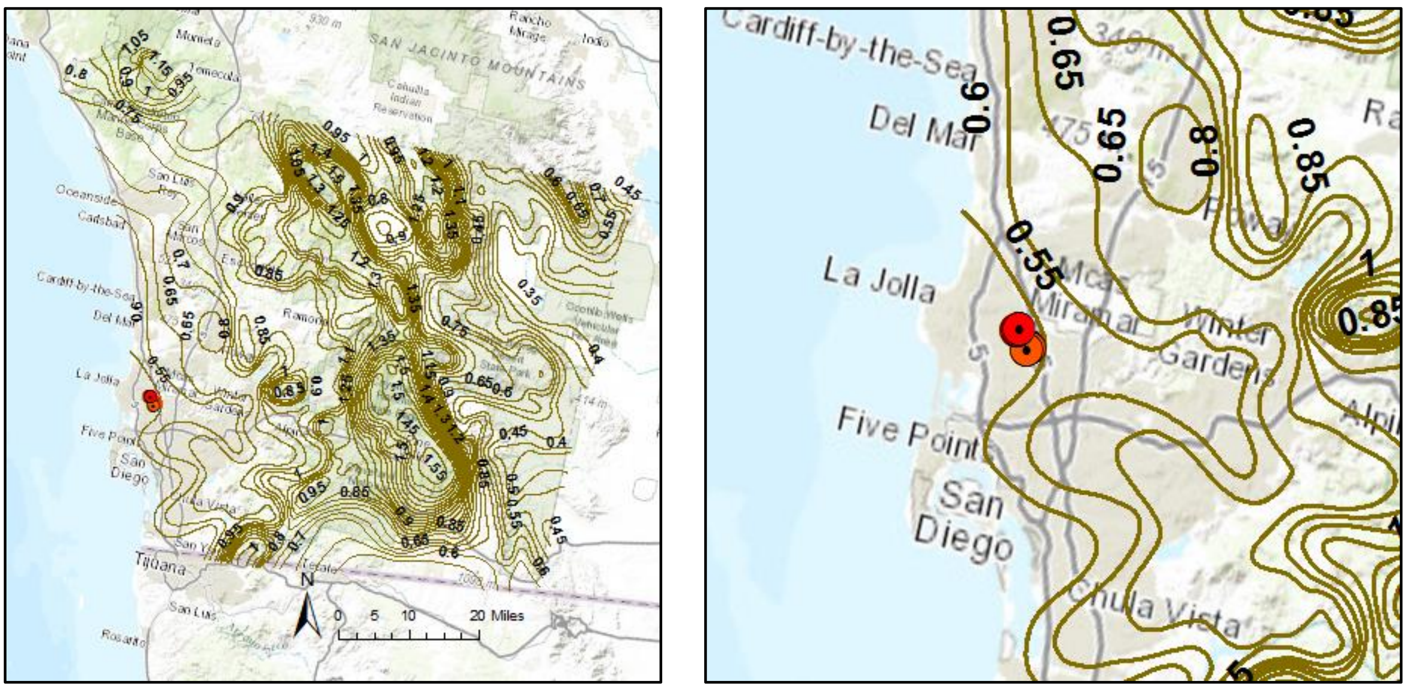


Figure 9: 85th percentile 24-hr rainfall totals in inches for San Diego County (left) and near the SDG&E site (right)

The 85th percentile 24 hour rainfall amount for the SDG&E site is 0.55 inches and was denoted as P^{24}. P^{6}, the 6 hour rainfall total, is typically 45% to 65% of the P^{24} value (San Diego County 2003). For the purposes of this study, the median value of 55% was chosen.

Rainfall intensity, i, is the precipitation in inches per hour for a period of time it takes for water to travel from the drainage area to the point of concern, T shown in Equation 2 (San Diego County 2003).

$$\boldsymbol{T = \frac{1.8*(1.1-c)*\sqrt{D}}{s^{\frac{1}{3}}}} \qquad \textbf{(2)}$$

$T = overland\ flow\ time$ (minutes)

$c = runoff\ coefficient$

D=watercourse distance (ft)

s=slope

Equation 2: Overland flow time

Because the 30 meter DEM is too coarse for slope calculation on this scale, slope values contained in the attribute table for the storm water conveyance system layer were used. The average slope for the two pipe segments running across the lot was used and the watercourse distance was estimated by drawing a watercourse path line to the stormwater inlet (Figure 11).

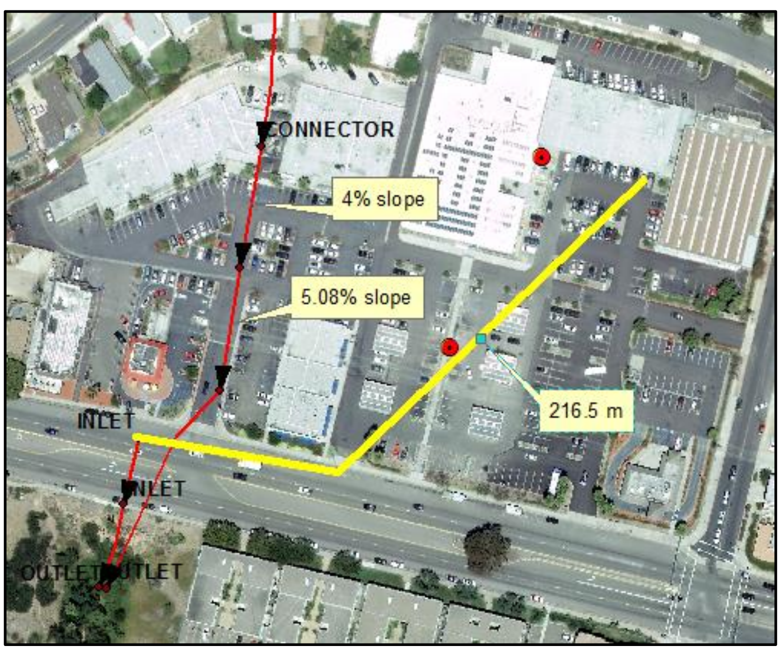


Figure 10: Slope and watercourse distance

Table 4 summarizes the factors that go into the calculation for T in both cases.

	Pre-LID	Post-LID
Slope (%)	4.54	4.54
Watercourse Dist. (ft)	710.12	710.12
Runoff Coefficient, c	0.87	0.82
Overland Flow Time (min)	6.66	8.11

Table 4: Calculation of the overland flow time, T

From Equations 3 and 4 obtained from the San Diego County Hydrology Manual, we can calculate the rainfall intensity, i, for a 1-hour storm duration.

$$\boldsymbol{P^6 = P^{24} * 0.55 \quad (3)}$$

$$\boldsymbol{i = P^6 * 7.44 * T^{-0.645} \quad (4)}$$

$$i = rainfall\ intensity\ \left(\frac{in}{hr}\right)$$
$$T = duration\ or\ overland\ flow\ time\ (min)$$
$$P^6 = 6\ hr\ rainfall\ total\ (in)$$
$$P^{24} = 24\ hr\ rainfall\ total\ (in)$$

Equations 3 and 4: 6 hr rainfall and rainfall intensity

Drainage area, A, was taken as the area of the entire property (the brown area in Figure 7). With all of the necessary parameters the calculation or runoff, Q, was calculated as summarized in Table 5

.

	Pre-LID	Post-LID
Runoff Coefficient, c	0.87	0.82
Intensity, I (in/hr)	0.66229	0.58337
Area (acres)	3.71	3.71
Discharge (cfs)	2.139	1.7761

Flow Difference (cfs):	0.3632
Percent Difference:	16.98%

Table 5: Rational method results

From the analysis, we observe a 17% reduction in peak flow at the storm drain inlet. This magnitude of reduction is not monumental, however it can still have a significant effect on flooding potential. Additionally, this analysis fails to account for the on-site rainwater harvesting system and thus is a conservative estimate. Appendix B includes a pipe capacity chart for gravity flows as a function of pipe diameter and slope. Using the slope s calculated above and taking the pipe size of 18 inches from the conveyance system attribute table, we see that the pipe capacity that the chosen inlet drains to is about 5 cfs. For our chosen storm, our pre-LID conditions accounted for nearly half of that flow capacity making the LID flow reduction crucial. It is important to recognize that the SDG&E property only accounts for a portion of what drains to that chosen inlet. If LID undergoes more widespread implementation to adjacent lots and across the entire watershed, the reduction of flood potential in the basin can be immense.

3.C. Water Quality

The second water-related risk of impervious urban development is that of water quality. The City of San Diego SWPP program involves an extensive sampling regimen of nearly 500 inlets, storm drains and outfalls throughout the city characterized by unique IDs (i.e., DW2727). As an intern of the program in the summer of 2011, I gained first-hand experience with this pollution management team. The group is responsible for identifying impaired water bodies and their pollution sources by taking daily grab samples and testing with EPA methods for ammonia, nitrate, phosphorus, turbidity, indicator bacteria and more. The SWPP program is still in operation as of this report. To gain spatial context of the LID sites with respect to monitoring locations, conveyance system ArcGIS layer packages were obtained from contacts at the San Diego Storm Water Department. Included in these layer packages are conveyance system structures with labels (inlet, pipe, outfall), flow directions, and monitoring site locations with IDs.

All water quality samples were taken in the summer of the given year, with years spanning from 2008 to 2013. Each monitoring site includes data for turbidity, ammonia, nitrate, phosphate, pH and detergents reported as concentrations in mg/L. DW0275 and DW0106 are special sites of concern that include additional analyses such as indicator bacteria, metals, and organics reported in various concentration values.

3.C.i. Water Quality of DW0563

Monitoring site DW0563 is located 170 feet downstream of the inlet draining the Clairemont Boys and Girls Club and 711 feet from the northernmost inlet above the SDG&E site (250 feet from the southern SDG&E inlet to DW0563) (Figure 12).

Figure 11: DW0563 Relative to the Boys and Girls Club and SDG&E

Completed in late winter of early 2012, the LID on the SDG&E property includes a roof-integrated rainwater harvesting system, permeable pavement walkways, and infiltration basins throughout the parking lot. Also completed in early 2012, the boys and Girls Club LID includes parking lot bioswales. All of these developments work by decreasing overland flow over the parking lot surface, thus we would expect decreased loadings of organics and metals associated with parking lot runoff. DW0563 is not a priority site, however, and does not include these water quality analyses. The reduction in overland flow is also expected to reduce turbidity loading and the infiltration basins should attain some level of nutrient reduction. The bioswales also have high bacteria, metals, oil and grease and organics removal potential as well as medium and nutrient treatment potential (City of San Diego Storm Water 2011). Figure 13 shows the concentration data for the site.

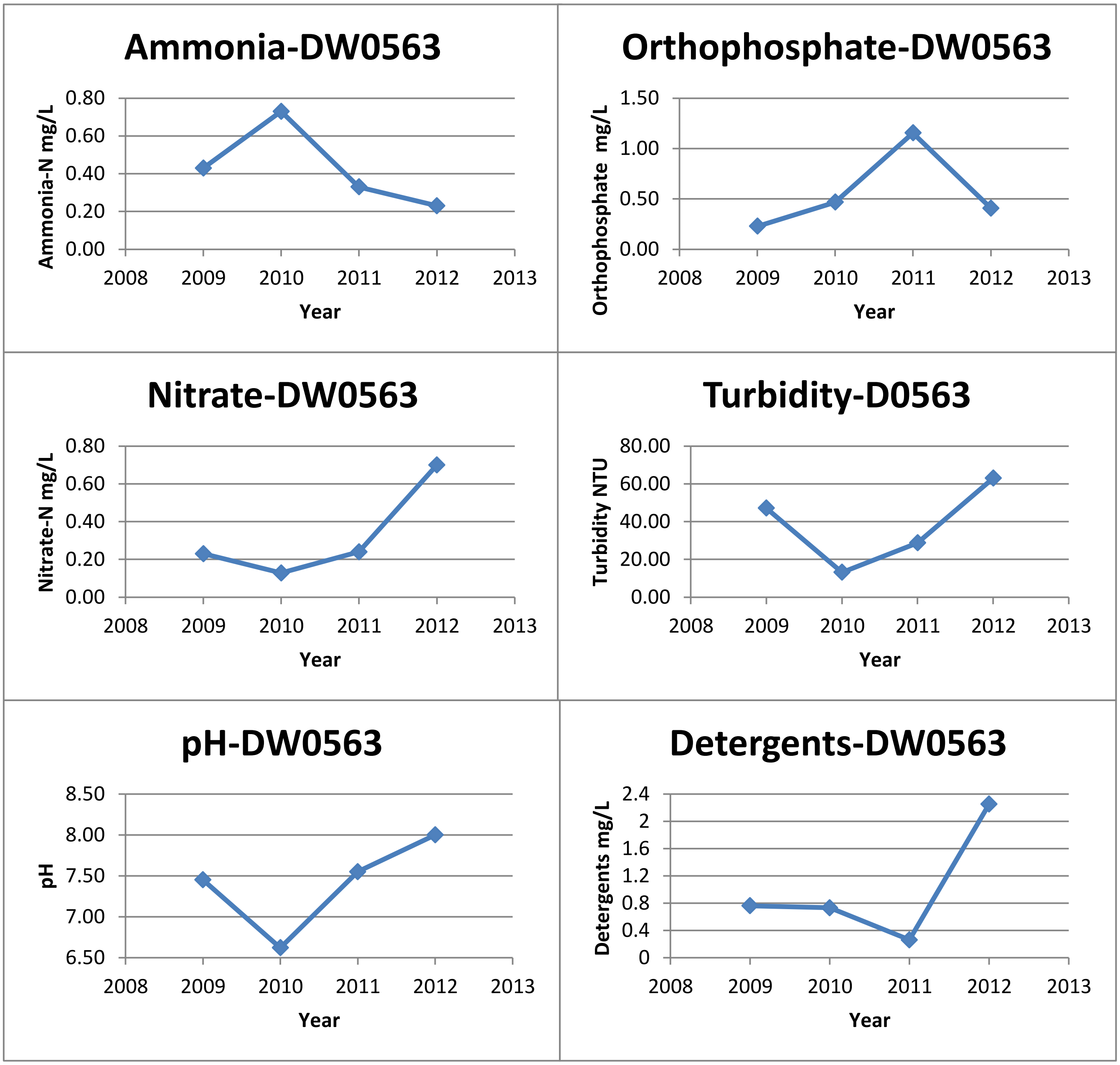


Figure 13: DW0563 water quality concentrations

Because 2013 data does not exist for this site (the monitoring site was dry in 2013), the only time point we have for post-LID conditions is 2012. It is worth noting that a dry sampling event can be a positive mark for LID. Although it may just reflect overall drier conditions, an absence of flow could be indicative of the pervious surfaces retaining flow in the subsurface. The only clear pollutant reduction into year 2012 is for ammonia, which means nitrification may be occurring. Nitrification is a process where microbes convert ammonia into nitrate. This is further supported by the increase in nitrate concentrations. Turbidity and detergents show increases for 2012 which may correlate to residuals of the construction project (earth moving, landscaping, washing etc.) as equilibrium still may not have been achieved in the system yet.

3.C.ii. Water Quality of DW0275

Monitoring site DW0275 is located 1580 feet downstream of the inlet closest to the northern LID sites and 1476 feet downstream of the inlet closest to the southern LID sites (Figure 14).

Figure 13: DW0275 relative to the Mt. Abernathy LID

Completed in the spring of 2012, the LID in the Mt. Abernathy Green Street project includes several bioretention basins. As previously mentioned, the Green Street Project is a pilot designed to lower the loading of fecal indicator bacteria (enterococci and coliforms) into the Mission Bay Watershed. Bioretention basins allow for settling of solids, biodegradation by plants and microbes, filtration, and hydrologic controls such as storage and infiltration of water (City of San Diego Storm Water 2011). Due to these bioretention basins, we would expect decreased sediment, bacteria, organics, metals and nutrient loadings. Figures 15 and 16 show the water quality data for DW0275

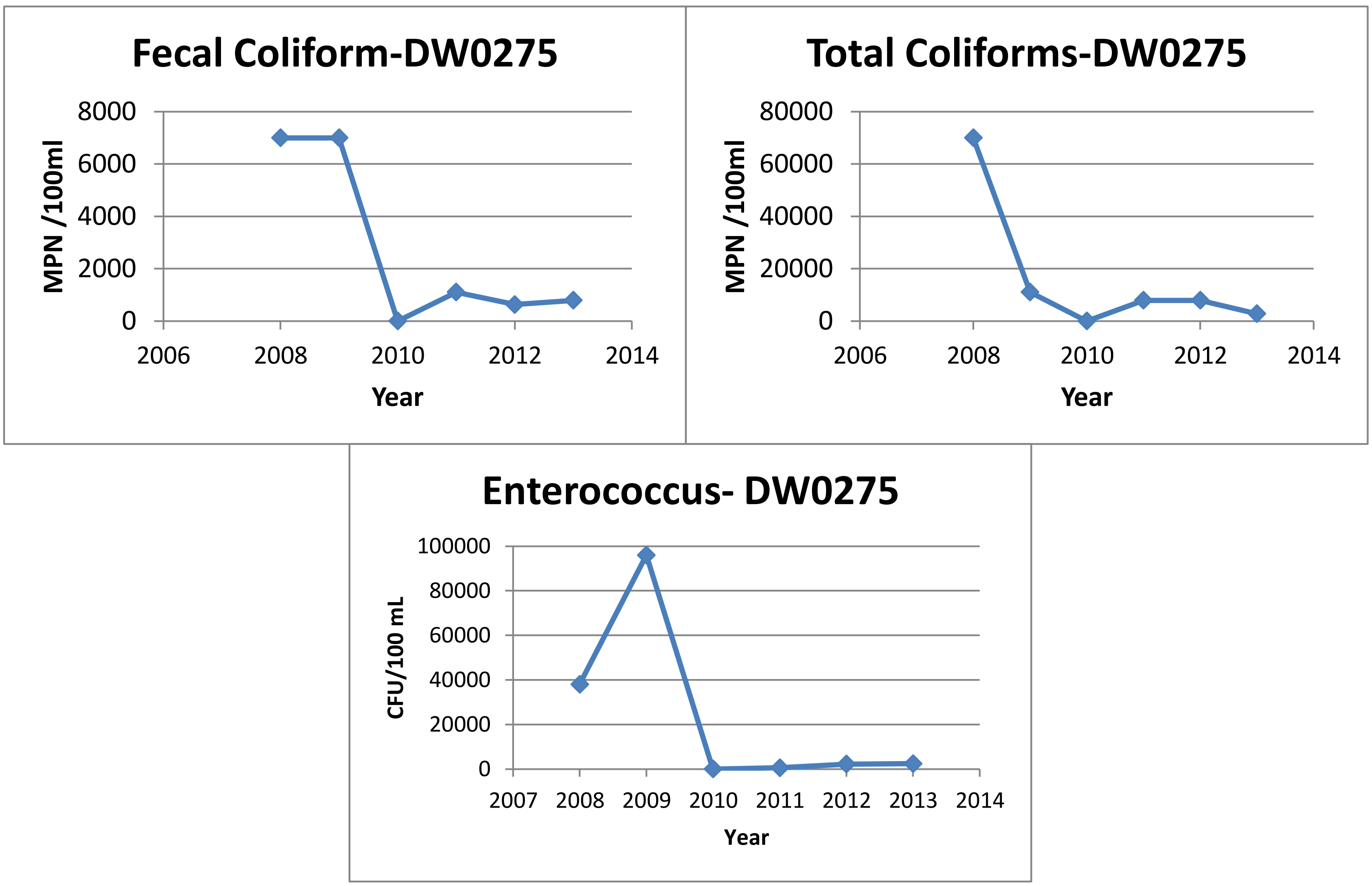


Figure 15: DW0275 indicator bacteria concentrations

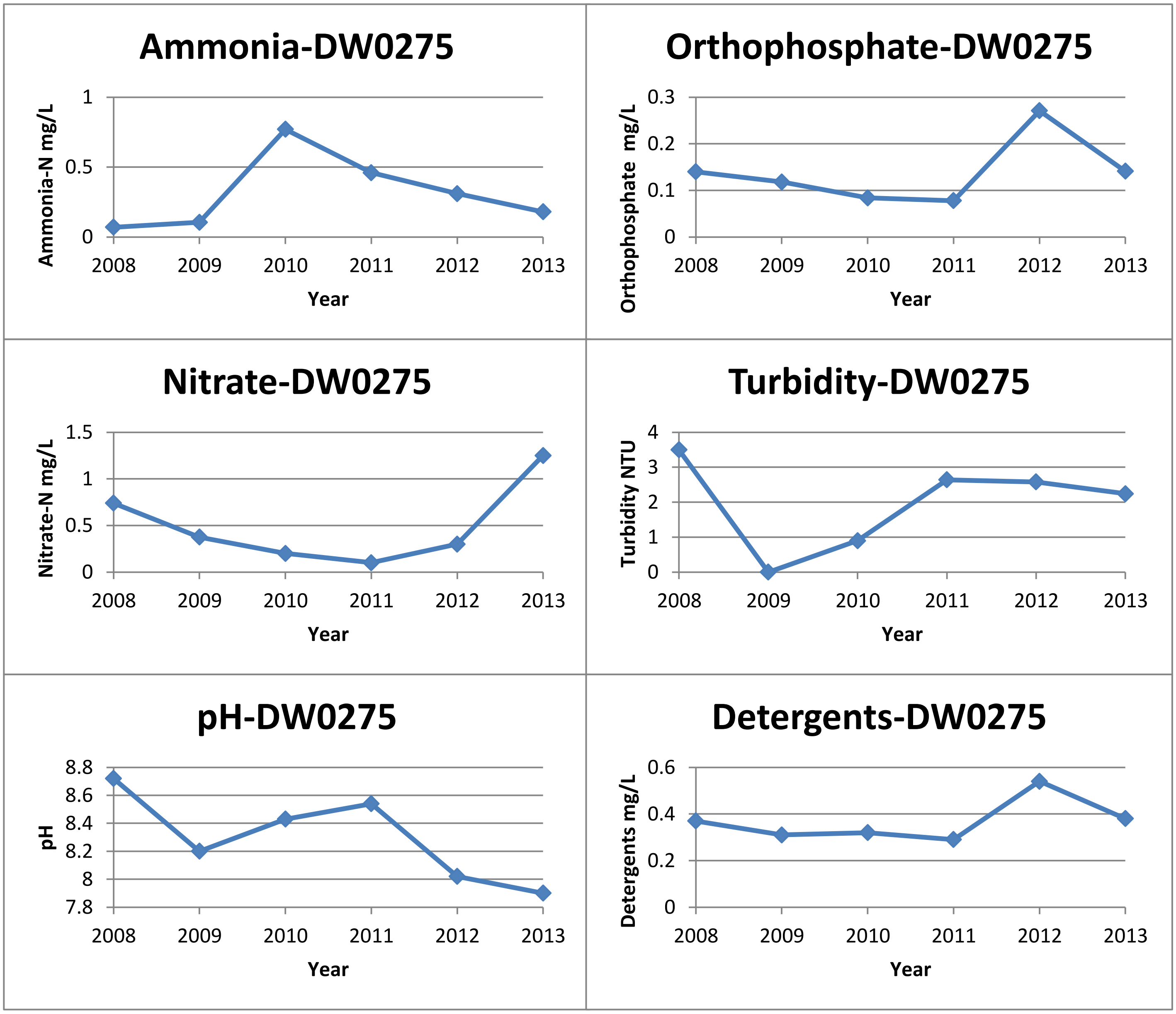


Figure 16: DW0275 water quality concentrations

From Figure 15, it is evident that indicator bacteria concentrations have remained low since the implementation of LID in 2012. Although fecal coliforms were at a minimum in 2010, concentrations did not reach the high levels that were observed in 2009 and 2010 with the LID in place. Total coliforms decrease from 2012 to 2013 as the new system likely approaches equilibrium after the first complete year since implementation. Enterococcus levels are observed to be near-zero and are far from the magnitudes of 2008 and 2009. Although it would strengthen our analysis with the presence of 2014 and 2015 data, it is evident that acceptable bacteria levels have been maintained in the presence of LID. In Figure 16, the same relationship for ammonia and nitrate are observed, again supporting the likelihood of nitrification occurring in the LID systems. Turbidity undergoes a slight decreasing trend, which could be the result of the system approaching equilibrium after construction. pH levels are strongly decrease since LID implementation and are approaching healthy neutral levels away from basicity (usually 6-8) which may be indicative of lowered ammonia levels It is interesting to note that phosphorus and detergents follow the same rising trend, although phosphate-based detergents have been banned in California. It is possible that other industrial phosphate- containing detergents were present in the area; possibly even linked to the construction itself.

3.C.iii. Water Quality of DW0106

Monitoring site DW0106 is located 5900 feet (1.1 miles) downstream of the Genessee Shopping Plaza development (Figure 17).

Figure 17: DW0106 relative to the Genessee Shopping Plaza LID

The Genessee Shopping Plaza LID, which was completed just before the sampling event in 2013, includes vegetated swales which can remove bacteria and particles by physical filtration as well as metals, organics and some nutrients via biological processes (City of San Diego Storm Water 2011). Figures 18 and 19 depict the water quality data for this site.

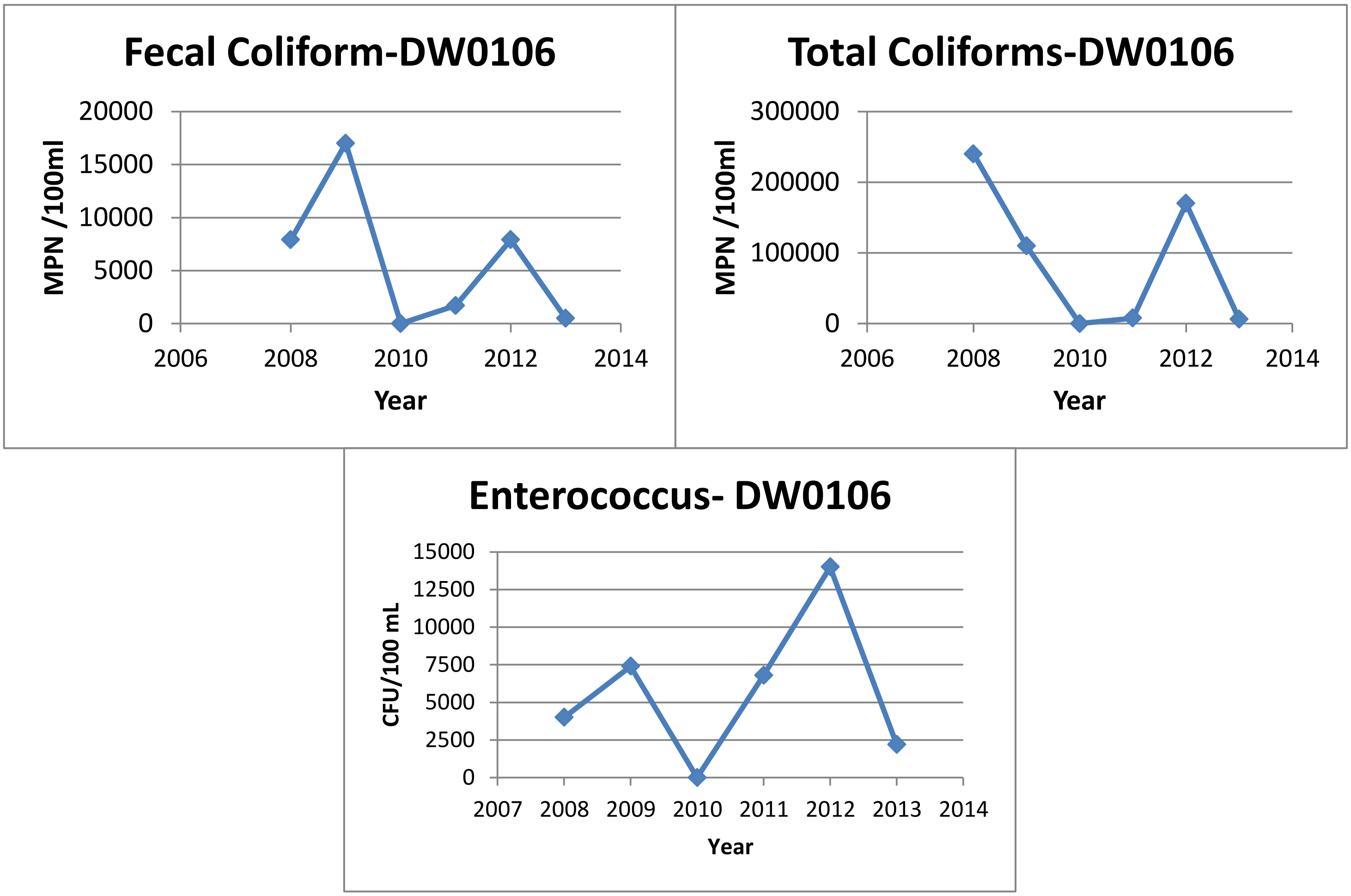


Figure 18: DW0106 indicator bacteria concentrations

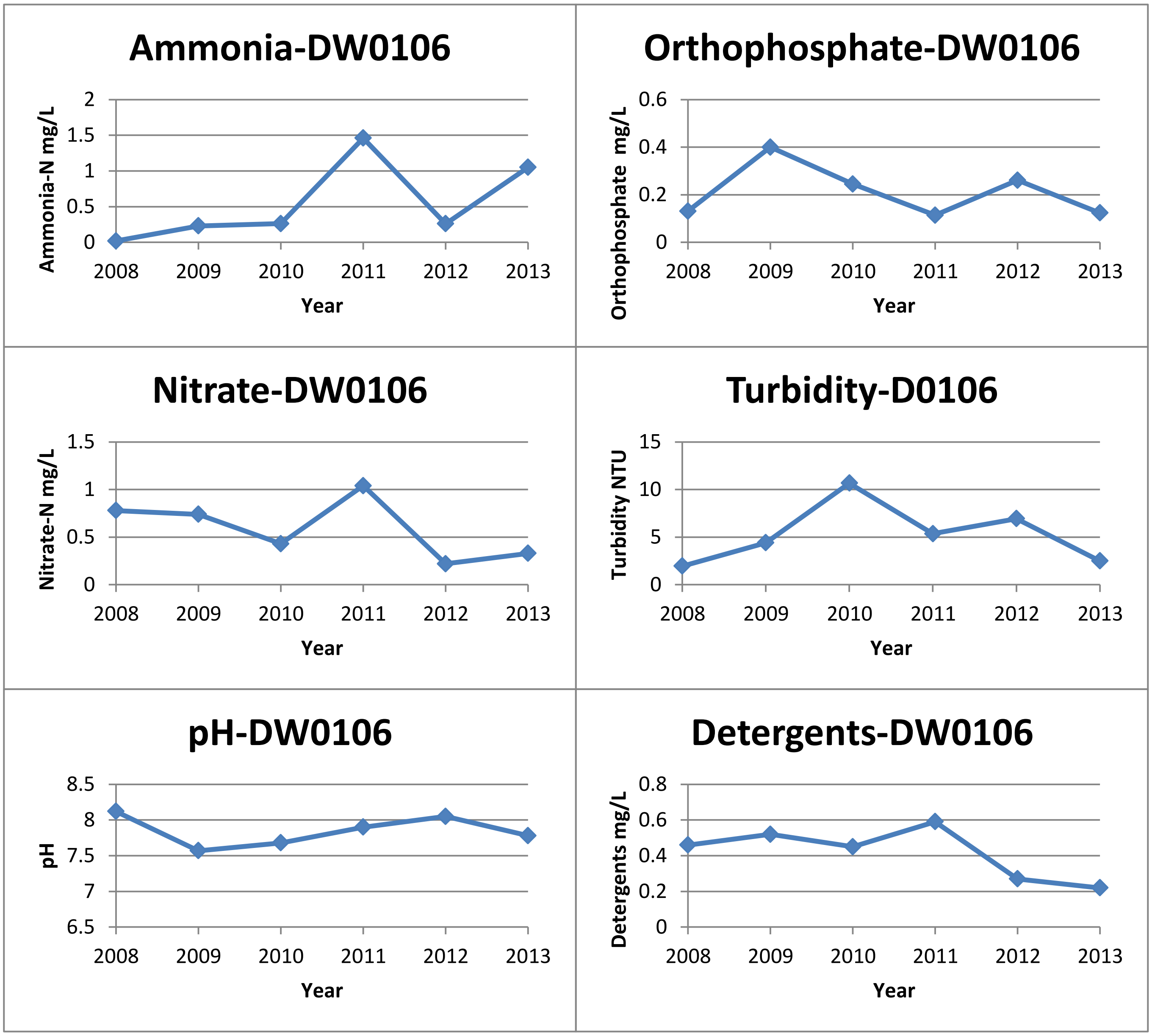


Figure 19: DW0106 water quality concentrations

Because this site is a considerable distance downstream of the Genessee Shopping Center, we must use caution in making claims about the effectiveness of these LID structures since many other inputs come into the conveyance system between the LID sites and the monitoring site. However, for the purposes of this project, we can make the assumption that these LID implementations were the only changes to the system and that changes in observed water quality are likely due to the new development. In each of the indicator bacteria plots, we observe high levels in 2012 followed by a significant drop in 2013. Although we are relying on one data point in making any claim of effectiveness, the vegetated swales could be a contributor to this high reduction in bacteria load. Phosphate, turbidity and detergent concentrations have also dropped from 2012 to 2013 to average or below average concentrations for the site after a period of high levels from 2009 to 2011. We do not observe the same trends for the nitrogenous compounds that we did for the other two monitoring sites, indicating that nitrification is probably not occurring with these vegetated swales. In fact, nitrogen concentrations have increased in 2013. One hypothesis is that the vegetated swale may have been fertilized at implementation to stimulate initial plant growth.

4. Conclusion and Future Work

This study shows that LID is a promising technology to combat flooding risks and water quality concerns associated with the widespread development of impervious urban land. In the hydrologic realm, the use of the rational method allowed us to quantify the pre-and post-LID peak flow characteristics of the SDG&E LID site by using parameters obtained from various sources within the ArcGIS platform. The results showed a nearly 20% reduction in peak flow for the same precipitation event. Actual reduction in flow may be even greater due to the fact that the roof rainwater collection system was ignored and assumed completely impervious. Water quality analyses showed reduction of indicator bacteria numbers with the presence of LID technology. This is important since this watershed has been historically impaired by indicator bacteria loads and is an important upstream contributor to the Mission Bay recreational water body. In addition, the decline in ammonia concentrations and rise in nitrate concentrations for DW0563 and DW0275 are indicative of nitrification. The reduction of ammonia is important in natural receiving water due to toxicity toward aquatic wildlife such as fish. The acquisition of data for years 2014 and 2015 (still being processed by the city) would help strengthen any claims made about the effectiveness of LID since this study only included a max of two years of data post-development. This is especially important since many of the rises in pollutant concentrations may be connected to the initial construction of the LID itself (fertilizer, particles, and detergents). More complex hydrological analyses such as a modified rational method for junction analysis can be used for more detailed hydrologic behavior of the study areas. These sites were few and sparse in the selected watershed, but more widespread implementation of bioswales, infiltration basins, vegetated swales, permeable pavement and rain collections systems would likely have a tremendous impact on the hydrologic and environmental health of the basin. ArcGIS was an immensely helpful tool for gaining spatial awareness of these LID sites in terms of proximity to monitoring locations and attaining a more complete understanding of their hydrologic conditions.

5. Appendix

A. Example of Conveyance System Attribute Table

Table

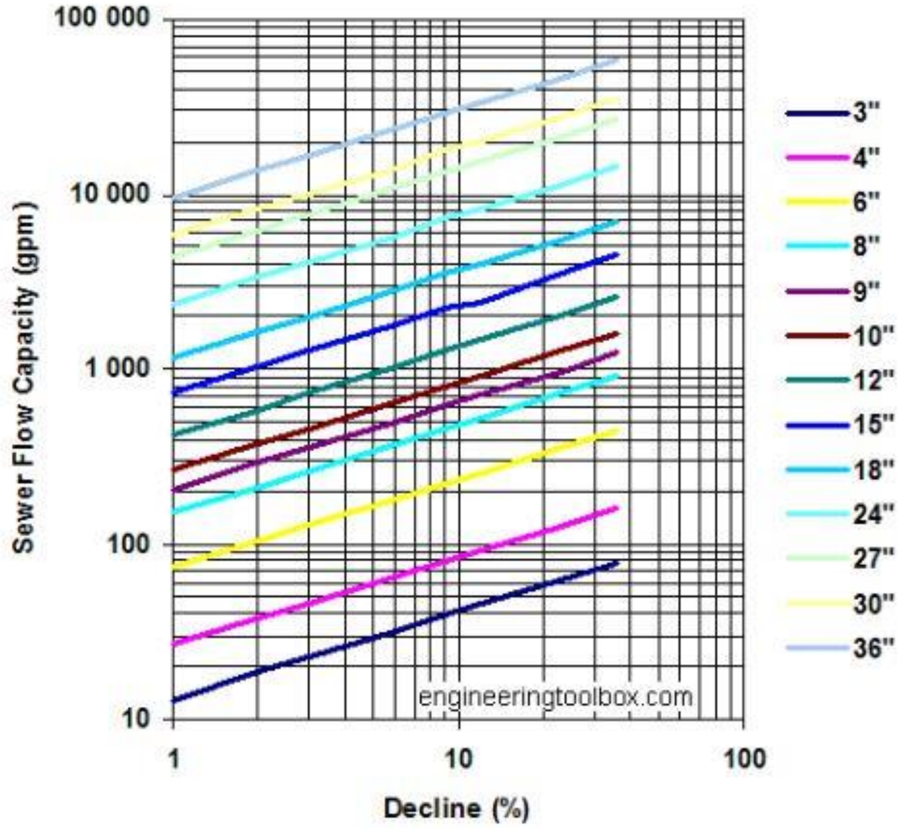
SD Conveyance selection

GIS ID	Drain Conveyance Type	Diameter	Width	Height	Actual Length	Lined	Slope	Installation Date	Status	Owne
DC014714	CULVERT	0	24	48	0	NO	<Null>	12/31/1937	ACTIVE	CITY OF SAN
DC043363	CULVERT	0	96	72	0	NO	<Null>	1/9/1958	ACTIVE	CITY OF SAN
DC014558	CULVERT	0	120	120	167	NO	1	10/18/1957	ACTIVE	CITY OF SAN
DC012786	CULVERT	0	216	36	50	NO	0	8/9/1982	ACTIVE	CITY OF SAN
DC041916	CULVERT	0	288	192	40	NO	1.65	12/23/1966	ACTIVE	CITY OF SAN
DC012262	STORM DRAIN PIPE	21	18	22	44	NO	0.48	<Null>	ACTIVE	CITY OF SAN
DC050081	STORM DRAIN PIPE	18	0	0	43	NO	1	12/1/1991	ACTIVE	CITY OF SAN
DC050082	STORM DRAIN PIPE	18	0	0	75	NO	4.94	12/1/1991	ACTIVE	CITY OF SAN
DC050083	STORM DRAIN PIPE	18	0	0	200	NO	2.65	12/1/1991	ACTIVE	CITY OF SAN
DC050084	STORM DRAIN PIPE	18	0	0	150	NO	0.62	12/1/1991	ACTIVE	CITY OF SAN
DC051032	STORM DRAIN PIPE	18	0	0	17.25	NO	5	1/11/1999	ACTIVE	PRIVATE
DC051033	STORM DRAIN PIPE	18	0	0	54.5	NO	2	1/11/1999	ACTIVE	CITY OF SAN
DC051034	STORM DRAIN PIPE	18	0	0	15.23	NO	16.52	1/11/1999	ACTIVE	CITY OF SAN
DC051035	STORM DRAIN PIPE	30	0	0	77.24	NO	0.5	1/11/1999	ACTIVE	CITY OF SAN

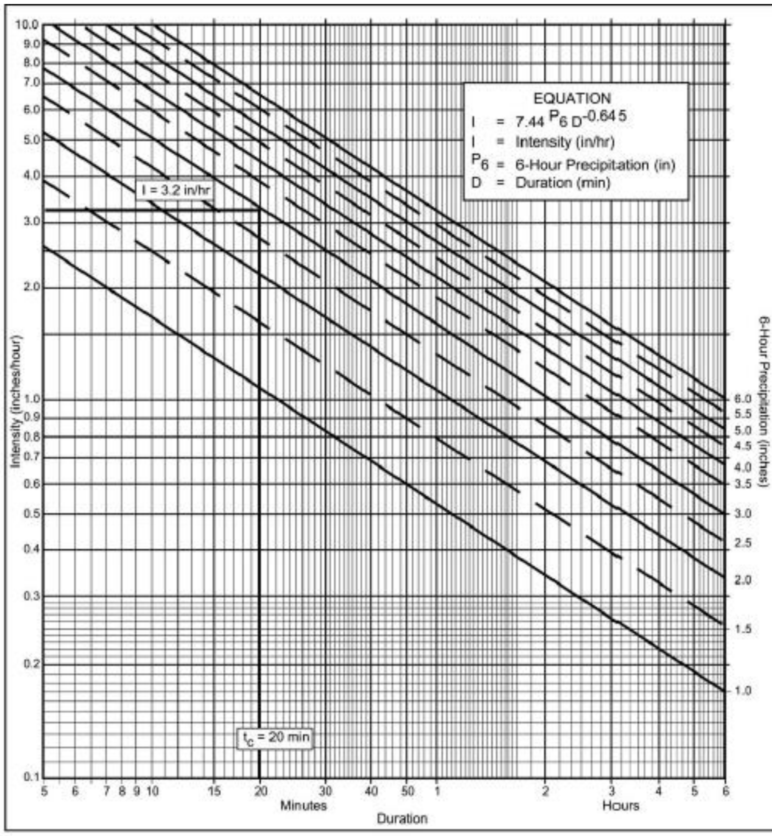
0 (0 out of 2313 Selected)

SD Conveyance selection

B. Pipe Capacity Chart



C. Intensity-Duration Design Chart



Directions for Application:

(1) From precipitation maps determine 6 hr and 24 hr amounts for the selected frequency. These maps are included in the County Hydrology Manual (10, 50, and 100 yr maps included in the Design and Procedure Manual).

(2) Adjust 6 hr precipitation (if necessary) so that it is within the range of 45% to 65% of the 24 hr precipitation (not applicaple to Desert).

(3) Plot 6 hr precipitation on the right side of the chart.

(4) Draw a line through the point parallel to the plotted lines.

(5) This line is the intensity-duration curve for the location being analyzed.

Application Form:

(a) Selected frequency __50__ year

(b) P_6 = __3__ in., P_{24} = __5.5__, $\frac{P_6}{P_{24}}$ = __54.5__ %[(2)]

(c) Adjusted $P_6^{(2)}$ = __3__ in.

(d) t_x = __20__ min.

(e) I = __3.2__ in./hr.

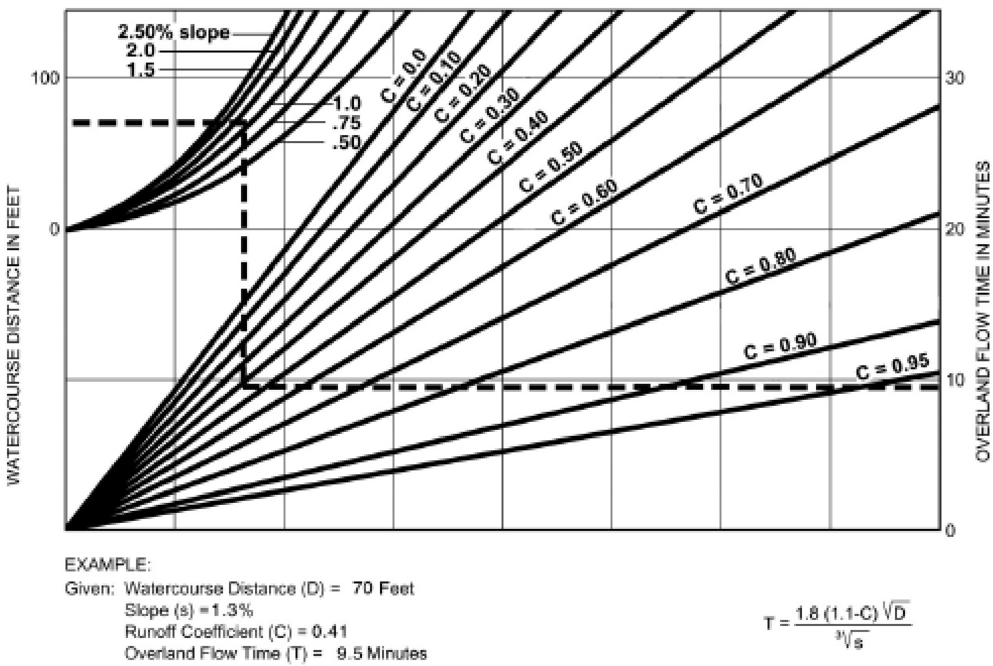
Note: This chart replaces the Intensity-Duration-Frequency curves used since 1965.

P6	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
Duration	I	I	I	I	I	I	I	I	I	I	I
5	2.63	3.95	5.27	6.59	7.90	9.22	10.54	11.86	13.17	14.49	15.81
7	2.12	3.18	4.24	5.30	6.36	7.42	8.48	9.54	10.60	11.66	12.72
10	1.68	2.53	3.37	4.21	5.05	5.90	6.74	7.58	8.42	9.27	10.11
15	1.30	1.95	2.59	3.24	3.89	4.54	5.19	5.84	6.49	7.13	7.78
20	1.08	1.62	2.15	2.69	3.23	3.77	4.31	4.85	5.39	5.93	6.46
25	0.93	1.40	1.87	2.33	2.80	3.27	3.73	4.20	4.67	5.13	5.60
30	0.83	1.24	1.66	2.07	2.49	2.90	3.32	3.73	4.15	4.56	4.98
40	0.69	1.03	1.38	1.72	2.07	2.41	2.76	3.10	3.45	3.79	4.13
50	0.60	0.90	1.19	1.49	1.79	2.09	2.39	2.69	2.98	3.28	3.58
60	0.53	0.80	1.06	1.33	1.59	1.86	2.12	2.39	2.65	2.92	3.18
90	0.41	0.61	0.82	1.02	1.23	1.43	1.63	1.84	2.04	2.25	2.45
120	0.34	0.51	0.68	0.85	1.02	1.19	1.36	1.53	1.70	1.87	2.04
150	0.29	0.44	0.59	0.73	0.88	1.03	1.18	1.32	1.47	1.62	1.76
180	0.26	0.39	0.52	0.65	0.78	0.91	1.04	1.18	1.31	1.44	1.57
240	0.22	0.33	0.43	0.54	0.65	0.76	0.87	0.98	1.08	1.19	1.30
300	0.19	0.28	0.38	0.47	0.56	0.66	0.75	0.85	0.94	1.03	1.13
360	0.17	0.25	0.33	0.42	0.50	0.58	0.67	0.75	0.84	0.92	1.00

Intensity-Duration Design Chart - Example

FIGURE **3-2**

D. Overland Flow Time



SOURCE: Airport Drainage, Federal Aviation Administration, 1965

7. Sources

"Capacities of Sewer Pipes." *Engineering Toolbox*. Web. 04 Dec. 2015. <http://www.engineeringtoolbox.com/sewer-pipes-capacity-d_478.html>.

City of San Diego. *Urban Greening Project Descriptions*.

"City of San Diego Low Impact Development Design." *City of San Diego Low Impact Development Design*. City of San Diego, n.d. Web. 04 Dec. 2015. <https://www.google.com/maps/d/u/1/viewer?mid=zSEDwxBtGFl0.kxu4DceRvDCQ&authuser=1>.

City of San Diego Storm Water. *San Diego Low Impact Development Design Manual*. July 2011.

"Ecology-Isopluvials_85th Percent." *SanGIS GIS Data Warehouse*. SanGiS, n.d. Web. 04 Dec. 2015. <http://rdw.sandag.org/Account/gisdtview?dir=Ecology>.

San Diego County. Department of Public Works Flood Control Section. *San Diego County Hydrology Manual*., June 2003.

"TNM Download." *The National Map*. USGS, n.d. Web. 04 Dec. 2015. <http://viewer.nationalmap.gov/basic/#productSearch>.