INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES (“LID”) FOR THE SAN DIEGO REGION

By Richard R. Horner [†]

[†] Richard R. Horner, Ph.D., Research Associate Professor, University of Washington Departments of Civil Engineering and Landscape Architecture; Adjunct Associate Professor, University of Washington Center for Urban Horticulture

INTRODUCTION

This purpose of this study is to investigate the relative impact of three levels of storm water treatment best management practices (BMPs) on certain water quality and water reuse factors: basic “treat-and-release” BMPs (e.g., drain inlet filters, CDS units), commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and low-impact design (LID) practices. Low-impact methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development in the San Diego region that would require Standard Urban Stormwater Management Plans (SUSMPs).

With respect to each of the six development models, three assessments were undertaken. To establish a baseline, for each case study annual storm water runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no storm water management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies. The first group of calculations estimated the extent to which the basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site. The second group of calculations estimated the extent to which commonly used soil-based BMPs and low-impact site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates.

The assessment of basins, biofiltration, and low-impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedences of California Toxics Rule (CTR) acute saltwater criteria for copper and zinc.

The results of this analysis show that in developments implementing no post-construction BMPs, storm water runoff volume and pollutant loading are substantially increased and recharge rates are substantially decreased compared to pre-development conditions. Second, developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but storm water runoff volume and recharge rates are similar to developments with no BMPs. Third, developments implementing traditional basins and biofilters, and even more so low-impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, and draws conclusions, and makes recommendations relative to utilizing low-impact site design practices in SUSMPs.

CASE STUDIES

Four case studies were derived directly from building permit records for development projects in the City of San Marcos: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), and an office building (OFF). The records provided data on total site areas, numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies through some reasonable assumptions, as detailed below. Larger developments were not represented in the sampling of building permits from the San Marcos database. To take larger development projects into account in the subsequent analysis, two larger scale case studies were hypothesized: a relatively large single-family residential development (Lg-SFR) and a sizeable commercial retail installation (COMM). The Lg-SFR scenario assumed 1000 homes, and scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The hypothetical COMM scenario consisted of a building with a 2-acre footprint and 500 parking spaces. As with the smaller-scale cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, which were also handled as follows.

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average (http://nemo.uconn.edu/publications/tech_papers/tech_paper_5.pdf). The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns, of course. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide.

Exclusive of the COMM case, the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees). For the hypothetical COMM scenario, the hypothetical total impervious cover was enlarged by 10 percent to represent the landscaping, on the belief that a typical retail commercial establishment would typically be mostly impervious.

Table 1 summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
San Marcos permit nos.	24718	30315-30337	31515	35339	Hypoth.	Hypoth.
San Marcos permit date	3/5/04	3/5/04	3/11/04	5/16/06	-	-
No. of buildings	11	23	1	1	1000	1
Total area (ft^2)	476982	132227	33669	92612	5749000	226529
Roof area (ft^2)	184338	34949	3220	7500	1519522	87120
Parking spaces	438	-	33	37	-	500
Parking area (ft^2)	77088	-	5808	6512	-	88000
Access road area (ft^2)	22212	-	6097	6456	-	23732
Walkway area (ft^2)	33960	10656	1362	2078	463289	7084
Driveway area (ft^2)	-	13800	-	-	600000	-
Landscape area (ft^2)	159384	72822	17182	70066	3166190	20594

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

METHODS OF ANALYSIS

Annual Storm Water Runoff Volumes

For each case study site the annual surface runoff volumes produced were estimated for both pre- and post-development conditions. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used: $C = 0.009\ I + 0.05$, where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With $I = 100$ percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. Jurisdictions under the San Diego municipal storm water permit generally perform water quality analyses with respect to the 85th percentile rainfall quantity (the 85th percentile rainfall is the amount exceeding the precipitation in 85 percent of all events over time). That event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff. This meteorological statistic for San Marcos is 0.75 inch of rainfall (http://www.co.san-diego.ca.us/dpw/watersheds/pubs/susmp_85precip.pdf).

To select CN for the pre-development case, an analysis performed in the area of the Cedar Fire in San Diego was used in which CN was determined before and after the 2003 fire (http://www.ufei.org/files/pubs/SanDiegoUrbanEcosystemAnalysis-PostCedarFire.pdf). Here, CN = 83 was estimated for the pre-existing land cover, which was generally chaparral. For post-development landscaping, CN = 86 was selected based on tabulated data in NRCS (1986) and professional judgment.

Pre- and post-development runoff quantities were computed with these CN values and the 85th percentile rainfall, and then divided by the rainfall to obtain runoff coefficients. The results were 0.07 and 0.12, respectively. Finally, total annual runoff volumes were estimated based on an average annual precipitation of 10.26 inches (http://www.wrcc.dri.edu/cgi-bin/cliMONtpre.pl?casand).

Storm Water Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 85th percentile precipitation event was used as a basis for volumes. Storm water pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low-impact site design of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment A (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in San Diego SUSMPs? The currently applicable SUSMP program associated with the San Diego County MS4 permit provides regulated entities with a large number of choices. These options include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study.

The principal basis for the analysis of BMP performance was the California Department of Transportation's BMP Retrofit Pilot Program (Caltrans, 2004), performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips respectively lost 40, 50 and 30 percent of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The Caltrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations and developed equations for the functional relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In a relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study sites' runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the Caltrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly lengthy ponding, while not allowing percolating water to reach groundwater before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by Caltrans after the pilot study. However, the intent of the investigation was to determine the ability of pervious areas to manage the site runoff. It determined what contribution these areas could make in their original condition, and then assessed how they could serve further if soils were modified using a low-impact site design technique.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. Soils are similar in the San Marcos area (http://websoilsurvey.nrcs.usda.gov/app), thus making the conclusions of this study applicable for these purposes. This information was used to estimate how much of each case study site's annual runoff would be infiltratable and if the pervious portion would provide sufficient area.

Volume and Pollutant Source Reduction Strategies

As pointed out earlier, the essence of low-impact site design is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If these abilities are not adequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then the choice is to practice source reduction, upgrade infiltration and treatment capabilities, or both.

Soils can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition, a standard low-impact site design technique. Bioretention cells with these upgraded soils can be built to hold runoff and effect its transfer to the subsurface zone, another standard low-impact tool. Of course, the space needed must be available to do so. This phase of the analysis determined for the case study sites if that space would indeed be available, assuming the soils and vegetation could be built up to use it effectively.

Source reduction can be accomplished through low-impact site design in various ways. Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. Of course, the soils must be capable of infiltrating the runoff passing through and may require renovation of the same type as discussed for bioretention. Water can also be "harvested," that is, captured and stored for reuse in irrigation or gray water systems. Many successful systems of this type are in operation, for example Natural Resources Defense Council offices, Santa Monica, CA; King County Administration Building, Seattle, WA; two buildings on the Portland State University campus, Portland, OR. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings (http://www.poweryourdesign.com/LEEDGuide.pdf). Runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. The investigation concluded by determining how harvesting could contribute to storm water management for case study sites where infiltration capacity, available space, or both appeared to be limited.

RESULTS OF THE ANALYSIS

1. *"Base Case" Analysis: Development Without Traditional BMP or LID Approaches*

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no BMPs on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would not lose half or more of the pre-development recharge.

Table 2. Pre- and Post-Development Without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Precipitation[b]	9.35	2.59	0.66	1.82	113	4.44
Pre-development runoff[c]	0.65	0.18	0.05	0.13	8	0.31
Pre-development recharge[d]	8.69	2.41	0.61	1.69	105	4.13
Post-development impervious runoff[c]	5.91	1.11	0.31	0.42	48	3.83
Post-development pervious runoff[c]	0.37	0.17	0.04	0.16	7	0.05
Post-development total runoff[c]	6.29	1.28	0.35	0.58	56	3.88
Post-development recharge[d]	3.06	1.31	0.31	1.23	57	0.56
Post-development recharge loss (% of pre-development recharge)	5.63 (65%)	1.10 (46%)	0.30 (49%)	0.46 (27%)	48 (46%)	3.57 (86%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

[b] Volume of precipitation on total project area

[c] Quantity of water discharged from the site on the surface

[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings.

Table 3. Pollutant Concentration and Loading for Case Study Land Use and Cover Types

	Concentrations					**Loadings**		
Land Use	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
Residential roof	25	0.013	0.159	0.11	55	0.029	0.350	0.242
Commercial roof	18	0.014	0.281	0.14	40	0.031	0.619	0.309
Access road/driveway	120	0.022	0.118	0.66	264	0.048	0.260	1.455
Parking	75	0.036	0.097	0.14	165	0.079	0.214	0.309
Walkway	25	0.013	0.059	0.11	55	0.029	0.130	0.242
Landscaping	213	0.013	0.059	2.04	59	0.004	0.016	0.568

The CTR acute criteria for copper and zinc are 0.0048 mg/L and 0.090 mg/L, respectively. It may be seen in Table 3 that all developed land uses are expected to discharge copper above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from some land covers would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 follows with the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.090 mg/L acute zinc criterion, and the retail commercial development does so by a wide margin. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates Without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.175
Lbs. TSS/year	920	241	87	169	10461	594
Lbs. TCu/year	0.32	0.051	0.022	0.032	2.24	0.25
Lbs. TZn/year	2.16	0.423	0.121	0.210	18.38	1.84
Lbs. TP/year	4.58	1.66	0.50	1.24	72.35	2.34

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

2. "Traditional SUSMP" Analysis: Effects of Basic Treatment BMPs

Post-Development Runoff Volumes

The current SUSMP program permits regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. According to Regional Board staff and third party reviews of the program (Tetra Tech, Inc. 2005), a wide variety of BMPs are selected. Many projects rely on drain inlet inserts, CDS units, and similar manufactured BMPs. Regulated entities currently can select these or other "treat-and-release" techniques in order to satisfy the current San Diego County MS4 Permit. As a category, such treatment BMPs do not permit any collected runoff contact with soils. Therefore, they discharge as much storm water runoff as equivalent sites with no BMPs, and afford zero savings in recharge.

Effects of BMPs on Pollutant Discharges

Table 5 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The "basic" BMPs in this table, the CDS units, are not expected to drop any of the concentrations sufficiently to meet the acute zinc criterion at the discharge point. The loading reduction results show the CDS unit always performing below 50 percent and most often in the vicinity of 20 percent, with zero copper reduction.

The Caltrans study (2004) produced less data on drain inlet insert performance. These devices were found to reduce pollutant mass loadings by the following amounts (average of the performance of two models): TSS—8.5 percent, TCu—1.0 percent, and TZn—1.5 percent.

3. LID Analysis: Relative Effect of Conventional Soil-Based BMPs and Low-Impact Development Approaches

Annual surface runoff and recharge predicted to occur with the three soil-based BMP types commonly employed in California were estimated. An assumption was full service of all portions of the case study sites with one of these practices. Although the analysis assumed use of one or another of the BMP types throughout each site, a project designer could elect to use more than one BMP to serve different portions. Table 6 gives the estimates, along with the savings in recharge afforded by the LID site design techniques relative to a condition with no BMPs. The percentages of savings exactly reflect the degree of infiltration observed in the Caltrans pilot study: 40, 50, and 30 percent, respectively, for EDBs, swales, and filter strips.

Table 5. Case Study Pollutant Concentration and Loading Estimates With BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.131
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.098
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.068
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.048
Loading Reductions:						
CDS TSS loading reduction	15.7%	19.9%	22.0%	24.0%	19.9%	16.9%
CDS TCu loading reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn loading reduction	22.7%	22.4%	22.9%	23.1%	22.4%	25.1%
CDS TP loading reduction	30.6%	41.5%	40.7%	45.9%	41.5%	20.3%
EDB TSS loading reduction	68.1%	73.7%	79.0%	81.1%	73.7%	71.7%
EDB TCu loading reduction	61.9%	55.7%	66.2%	63.0%	55.7%	66.8%
EDB TZn loading reduction	59.7%	59.6%	60.4%	61.9%	59.6%	66.6%
EDB TP loading reduction	61.9%	69.7%	69.1%	72.9%	69.7%	54.5%
Swale TSS loading reduction	68.8%	71.1%	73.1%	73.9%	71.1%	69.4%
Swale TCu loading reduction	72.5%	68.5%	78.2%	73.3%	68.5%	75.8%
Swale TZn loading reduction	78.4%	78.1%	84.3%	78.8%	78.1%	80.7%
Swale TP loading reduction	66.3%	70.7%	67.2%	76.2%	70.7%	55.0%
Filter strip TSS loading reduction	69.9%	75.4%	80.6%	82.6%	75.4%	72.3%
Filter strip TCu loading reduction	74.4%	69.1%	78.2%	75.4%	69.1%	78.7%
Filter strip TZn loading reduction	78.3%	77.9%	78.4%	78.7%	77.9%	80.9%
Filter strip TP loading reduction	48.4%	53.1%	63.7%	59.8%	53.1%	34.6%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant;
OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
CDS— continuous deflective separation unit; EDB—extended-detention basin

Effects of BMPs on Pollutant Discharges

Table 5 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from the EDBs, swales, and filter strips. Effluents from each case study site are expected to fall below the CTR acute zinc criterion if treated with swales or filter strips. All but the large commercial site would meet the criterion with EDB treatment. These infiltration-oriented BMPs, swales, filters, and EDBs, if fully implemented and well maintained, are predicted to prevent the majority of the pollutant masses generated on most of the development sites from reaching a receiving water. Only total phosphorus reduction falls below 50 percent for two case studies. Mass loading reductions range above 80 percent for the EDB, swale, and filter strip.

Table 6. Distribution of Surface Runoff Versus Recharge to Groundwater With BMPs

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Total runoff with EDBs[a, b]	3.77	0.77	0.21	0.35	33	2.33
Recharge with EDBs [c]	5.58	1.83	0.45	1.46	79	2.11
Recharge savings with EDBs[d]	2.52	0.51	0.14	0.23	22	1.55
Total runoff with swales[b]	3.14	0.64	0.17	0.29	28	1.94
Recharge with swales[c]	6.20	1.95	0.49	1.52	85	2.50
Recharge savings with swales[d]	3.14	0.64	0.17	0.29	28	1.94
Total runoff with filter strips[b]	4.40	0.89	0.24	0.41	39	2.72
Recharge with filter strips[c]	4.95	1.70	0.42	1.41	74	1.72
Recharge savings with filter strips[d]	1.89	0.38	0.10	0.18	17	1.16

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial; EDBs—extended-detention basins

[b] Quantity of water discharged from the site on the surface

[c] Quantity of water infiltrating the soil; the difference between precipitation and runoff

[d] Difference between recharge with and without BMP (the latter from Table 2)

Expected Infiltration Capacities of the Case Study Sites

Table 7 summarizes the results of the infiltration analysis. The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate. Based on the findings of Chralowicz et al. (2001), it was assumed that a site in the size range 0-5 acres could infiltrate 0.9-1.9 acre-ft/year with an infiltration device of feasible size, one in the range 5-10 acres could recharge 1.8-3.8 acre-ft/year, etc. As shown in the table, three of the six sites should be able to infiltrate the full annual runoff volume. The remainder could recharge to the ground about half or somewhat more of the annual production. These figures pertain to infiltrating in the native soils, with no soil improvements through composting such as often performed in low-impact site design.

Next, it was sought to determine whether the sites, as planned, have sufficient pervious area for surface infiltration facilities. Again, the results of Chralowicz et al. (2001) were used, and it was assumed that infiltration would take 0.1-0.5 acres on a site of 0-5 acres total area, 0.2-1.0 acres on a 5-10 acre property, etc. A site low in the range would likely need a smaller infiltration area than one higher in the size range. Five of the six case study sites clearly have more pervious area than required for infiltration facilities. The commercial retail development was the only development project that came close to lacking sufficient pervious area.

Table 7. Summary of Infiltration Analysis

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Total annual runoff (acre-ft)	6.29	1.28	0.35	0.58	56	3.88
Project area (acres)	11.0	3.0	0.8	2.1	132	5.2
Infiltration capacity (acre-ft)	2.7-5.7	0.9-1.9	0.9-1.9	0.9-1.9	24-51	1.8-3.8
Infiltration assessment	~Half+	All	All	All	~Half+	~Half+
Infiltration area needed (acres)	0.3-1.5	0.1-0.5	0.1-0.5	0.1-0.5	2.7-14	0.2-1.0
Pervious area available (acres)	3.7	1.7	0.4	1.6	72.7	0.5
Adequate area?	Yes	Yes	Yes	Yes	Yes	Maybe

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

As Table 7 shows, the case study sites offer considerable promise to manage storm water by infiltration. For any development project at which infiltration-oriented BMPs are considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration.

Volume and Pollutant Source Reduction Through Low-Impact Site Design

The preceding analysis showed that half the sites potentially could infiltrate all runoff produced in an average year, and also have the land to do so. The other three could recharge half or more of the runoff, and at least two have adequate land. One goal of this exercise was to identify alternatives that would reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate all of the remaining runoff. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

This analysis considered scenarios in which all roof runoff is either harvested and stored for some beneficial use or is spread over lawns or into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like the retail and office buildings, while distribution on or in the soil would fit best with residences and relatively small commercial developments like the restaurant. Table 8 shows the consequences of preventing roofs from generating runoff.

With the subtraction of roof runoff, all sites have the capacity to infiltrate all of the annual runoff volume. Comparison of the third and last rows of the table indicates the significant role of roof runoff, especially in the residential cases. With roof runoff included, the only case that was doubtful in having enough pervious area for full infiltration was the commercial case study site. Harvesting runoff from its 2-acre roof brings it into the situation of having sufficient land. These results show that a combination of roof runoff source reduction and land treatment of the remaining runoff for maximum infiltration appears to be an entirely feasible plan to manage storm water from a range of typical San Diego area developments.

Table 8. Summary of Roof Runoff Source Reduction Analysis

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Annual impervious (minus roof) runoff (acre-ft)	2.48	0.46	0.25	0.28	19.8	2.21
Annual pervious runoff (acre-ft)	0.37	0.17	0.04	0.16	7.5	0.05
Total annual runoff (minus roof) (acre-ft)	2.85	0.63	0.29	0.44	27.3	2.26
Project area (acres)	11.0	3.04	0.77	2.13	132	5.20
Infiltration capacity (acre-ft)	2.7-5.7	0.9-1.9	0.9-1.9	0.9-1.9	24-51	1.8-3.8
Infiltration assessment	All	All	All	All	All	All
Total annual runoff (with roof) (acre-ft)	6.29	1.28	0.35	0.58	56	3.88

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

Table 9 summarizes the water retention and reuse benefits of the full LID approach involving infiltration by design, supplemented by harvesting from roofs in the MFR, Lg-SFR, and COMM cases. Infiltration contributes to the groundwater resource, while harvesting captures water for use in such applications as irrigation and gray water distribution systems. LID methods offer significant benefits relative to no BMPs in all cases. These benefits are particularly impressive with relatively high site imperviousness, such as in the MFR and COMM cases.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use With a Full LID Approach Compared to Development Without Any BMPs

Water Capture	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Without BMPs[b]	3.06	1.31	0.31	1.23	57	0.56
With full LID approach[c]	9.35	2.59	0.66	1.82	113	4.44
LID benefit[d]	6.29	1.28	0.35	0.58	56	3.88

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

[b] Water incidentally infiltrated on pervious areas remaining on the development site and recharged to groundwater

[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs

[d] Water capture for which LID approaches are directly responsible; the difference between capture with the full LID approach and without BMPs

SUMMARY AND CONCLUSIONS

This paper demonstrated that common San Diego area residential and commercial development types subject to SUSMPs are likely, without storm water management, to reduce groundwater recharge from the predevelopment state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed CTR acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Many San Diego SUSMP projects have been getting mostly traditional commercially manufactured filtration and hydrodynamic BMPs for storm water management. Such BMPs are included in the SUSMP menu of options currently, and they do have some beneficial impact on runoff quality compared to development without BMPs. However, they are not optimal solutions. These devices do not stem the loss of groundwater recharge, still allow zinc as well as copper water quality criteria violations from all development types analyzed, and capture relatively small fractions of the pollutant mass loadings produced in urban areas.

Conventional soil-based BMP solutions that promote and are component parts of low-impact development approaches, by contrast, regain 30-50 percent of the recharge lost in development without storm water management. It is expected they generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that the loam soils typical of the San Marcos area, where the case studies were set, should infiltrate at least half of all the runoff produced in an average year, and all of it for some development types and site designs. Soil enhancement (typically, with compost) can advance infiltration and lower its risk of failure. Using additive LID approaches, including specifically subtracting the roof runoff by harvesting it for reuse or distributing it in the soil with infiltration trenches, reduces overall runoff sufficiently to conclude that all development examples assessed could infiltrate their surface runoff production.

RECOMMENDATIONS

Low-impact site design techniques emphasize runoff volume and pollutant reduction at their sources and management of runoff and pollutants through vegetation and soil treatment. This type of treatment can infiltrate and evaporate much or even all of the runoff produced in design events. This report shows low-impact site design techniques to be capable of regaining the groundwater recharge lost in development to a greater extent than conventional BMPs. At the same time LID techniques substantially preserve pre-development hydrologic conditions and prevent most or all pollutant transport to receiving waters.

REFERENCES

California Department of Transportation. 2004. BMP Retrofit Pilot Program Final Report. California Department of Transportation, Sacramento, CA.

Chralowicz, D., T. Goff, M. Mascali, and E. Taylor. 2001. Infiltration of Urban Runoff to Recharge Groundwater Used for Drinking Water: A Study of the San Fernando Valley, California. Master of Environmental Science and Management Report, University of California at Santa Barbara, Santa Barbara, California.

Herrera Environmental Consultants, Inc. Undated. Pollutant Concentrations for Urban Source Areas, unpublished data table.

Natural Resource Conservation Service. 1986. Urban Hydrology for Small Watersheds, Technical Release-55. U.S. Department of Agriculture, Washington, D.C.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Washington, D.C.

Tetra Tech, Inc. 2005. San Diego Standard Urban Storm Water Mitigation Plan (SUSMP) Evaluation. Report to San Diego Regional Water Quality Control Board, San Diego, CA.

U.S. Environmental Protection Agency. 1983. Results of the Nationwide Urban Runoff Program: Volume 1 - Final Report, Report No. 832R83112. Office of Water, Washington, D.C.

ATTACHMENT A

Pollutant Concentrations for Urban Source Areas (Herrera Environmental Consultants, Inc. undated)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7

Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	
Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.