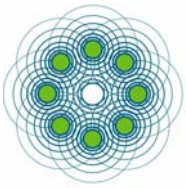
Los Angeles Basin

Water Augmentation Study
Phase II Final Report



The Los Angeles and San Gabriel Rivers Watershed Council

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EXECUTIVE SUMMARY

The *Los Angeles Basin Water Augmentation Study* is a long-term research project led by the Los Angeles & San Gabriel Rivers Watershed Council, to explore the potential for reducing surface water pollution and increasing local water supplies by increasing infiltration of urban storm water runoff. The Watershed Council has forged a unique partnership between local water supply, wastewater and public works agencies, the Los Angeles Regional Board, the California Department of Water Resources, and the US Bureau of Reclamation, which are jointly funding the study. Each partner contributes its own perspective to the shared concerns of bringing scientific evidence to bear on the feasibility of promoting infiltration without impacting groundwater quality. The study addresses a number of questions intended to better characterize the benefits of storm water capture for infiltration, including impacts on groundwater quality and assessing appropriate and most favorable geographic, geologic and hydrologic conditions for infiltration. The overall goals of the study will be to evaluate the costs and benefits of implementation, and determine the most effective strategy for developing this potentially significant source of water for southern California.

The focus of the early phases of the study was to monitor the fate and transport of runoff-borne pollutants by measuring storm water quality at the surface, as it infiltrates through the soil to groundwater. Phase I of the study focused on water quality assessment on single parcels utilizing infiltration structures, by monitoring two locations for one wet season. Phase II, just completed, expanded the monitoring in time and scope, adding new sites with different land uses and infiltration techniques, and monitoring all six sites for several years.

Monitoring Program

Monitoring sites are located throughout the Los Angeles area and include two industrial sites, an elementary school, a commercial office building, a private residence and a public park (see Figure 2 – Monitoring Site Locations). Groundwater depths range from 20 feet to over 350 feet below ground surface. All sites were retrofit with various infiltration structures, ranging from simple landscaped swales to large-scale underground infiltration fields. Monitoring equipment was installed as part of the study, including soil water samplers (lysimeters) installed beneath the ground surface and groundwater wells.

The monitoring program consisted of taking storm water runoff samples during storm events, and taking post-storm vadose zone samples from lysimeters and groundwater samples from monitoring wells. Samples were sent to a state-certified laboratory for analysis. Constituents analyzed included general minerals, metals, oil and grease, perchlorate, some pesticides, volatile and semi-volatile organic compounds, NDMA, surfactants, and bacteria.

The four years of monitoring saw a wide range of rainfall variability, from the driest year on record (2001-2002) to the second wettest year on record (2004-2005). Rainfall varied

geographically as well, with total rainfall amounts in 2005 ranging from about 22 inches at the park to over 37 inches at the Sun Valley industrial sites.

Summary of Water Quality Results

Soil appears to be very efficient at removing bacteria from stormwater. Fecal coliform and E. coli were detected in at least one stormwater sample from each site except Hall House, and total coliforms were detected at high levels in nearly all stormwater samples at all sites. With the exception of one sample at the Broadous School, bacteria were not detected, or detected at very low concentrations, in lysimeter and groundwater samples.

Concentrations of metals tended to be higher in stormwater than in subsurface water samples. Concentrations in subsurface samples were variable and generally stable or decreasing. Exceptions are increasing trends of copper in lysimeter samples collected at the Sun Valley site that could be associated with infiltration of storm water with relatively higher concentrations of copper. Most inorganic groundwater quality constituents do not show clear trends or show decreasing concentrations over the study period. In only one instance, involving low concentrations of nitrate, did concentrations of a constituent show a statistically significant, although slight, increase. Groundwater quality data from the shallow groundwater sites show groundwater quality improvement (decreasing salt concentrations) potentially associated with dilution by infiltrating stormwater.

At the non-industrial sites the concentrations of general monitoring parameters such as TDS and chloride tended to be less than or similar to concentrations in lysimeter and groundwater samples. This suggests that the infiltration of stormwater is not likely to have a significant negative impact to groundwater from these constituents. At the Veterans Park site, concentrations of TDS, nitrate, chloride, and other salts in groundwater samples (including pre-infiltration background samples) was much higher than concentrations in stormwater samples. This result is likely due to historical application of fertilizers. Data collected to date suggest that concentrations of many of these constituents in lysimeter and groundwater samples are decreasing with time, possibly due to dilution by infiltrated stormwater.

Other than acetone, VOCs and SVOCs detected in storm water are different than VOCs detected in subsurface samples. VOCs detected in groundwater samples during the monitoring period were also detected in initial background samples. With the possible exception of occasional low level detections of acetone, VOCs in stormwater do not appear to impact groundwater at all. At the industrial sites, groundwater constituents such as MtBE and chlorinated solvents were present in some lysimeter samples at greater concentrations than present in any stormwater samples. This finding suggests the presence of subsurface contamination prior to stormwater infiltration.

The industrial sites had detections of more organic compounds and higher concentrations of metals than the non-industrial sites. The filtration system in the detention basins at Sun Valley and the Metal Recycler site was somewhat effective at reducing concentrations of certain constituents, particularly the dissolved metals. For example, at the Metal Recycler

site, concentrations of dissolved arsenic, copper, chromium VI and lead were lower after filtration. The sedimentation basin at Veterans Park and the soil layers at the other sites would also be expected to reduce concentrations of metals and other solids, although effluent was not analyzed separately to verify this.

Although perchlorate was detected in some stormwater samples, there is no evidence of groundwater degradation by perchlorate from stormwater infiltration during this study. The occurrence of perchlorate in stormwater samples was unexpected, as the focus is typically on subsurface sources of perchlorate contamination. Perchlorate is a salt, which in addition to being a component of solid rocket fuel, is also an ingredient in fireworks and road flares. Other constituents of concern for groundwater (disinfection byproducts, 1,4-Dioxane, PAHs and DBCP) were not detected in stormwater.

Soil samples collected from four of the sites at the conclusion of the study indicated no significant increases in parameters monitored, and in many cases constituent concentrations were reduced.

The concentrations of many constituents vary throughout the sampling period, but there is no apparent pattern that can be tied to effects from infiltration. As stated above, VOCs detected in groundwater are routinely different than those in stormwater. VOCs detected in groundwater samples collected during the storm season were also detected in pre-season background samples, thus they do not appear to be the result of infiltration. Given the depth to groundwater at the two industrial sites and at Broadous, it seems unlikely that constituents introduced into the soil from stormwater infiltration would migrate all the way to the groundwater at a detectable concentration.

Data collected to date indicate that there is no statistically significant degradation of groundwater quality from the infiltration of stormwater-borne constituents. Groundwater quality has generally improved for most constituents at sites with shallow groundwater.

The data collected during this study show no immediate impacts, and no apparent trends to indicate that storm water infiltration will negatively impact groundwater at these sites. While variations in storm water and groundwater pollutants between types of land use were apparent, they may not be a barrier to infiltration. Filtration methods employed at the industrial sites seemed to be effective at removing certain pollutants prior to entering the infiltration system, which may make infiltration more feasible at these more polluted sites. Careful site characterization of surface and soil constituents at industrial sites should be conducted prior to implementing infiltration strategies.

While it is clear that site-specific conditions must be considered when urban runoff is being investigated for recharge as potable groundwater, it is also important to note that groundwater recharge offers a number of benefits to municipal water managers. Groundwater storage is less costly in terms of construction costs, environmental impacts, evaporation loss of water, and eutrophication as compared to surface-water reservoirs. Further, recharging groundwater puts the resource in closer proximity to the end-user than pumping water from reservoirs, an additional cost savings. With proper planning and

research, the use of urban runoff for recharge of groundwater offers a viable alternative to relying solely on purchased water for such activities, water that may not be available in present quantities for purchase in the future. On average, over 500,000 acre-feet of runoff flow to the ocean from the Los Angeles County basin each year. If some portion of this water can be captured for reuse, the pressure on supplies in northern and central California may be moderated.

Next Steps

Long-term Monitoring Program

While the data collected during this program do provide significant information, monitoring will continue in order to better assess the cumulative effects of infiltration. A reduced program of subsurface monitoring is under currently development. This program will likely include annual or bi-annual monitoring of lysimeters and groundwater wells at four or five sites. No storm water samples will be collected, as surface runoff quality has been well-characterized at these sites. Monitoring will be scheduled after significant storm events and late in the storm season, to ensure that infiltration to the deepest lysimeters has occurred. The analytical suite will be reduced but should include metals, general parameters, some organics, and perchlorate. We expect to continue monitoring for at least two additional years, and possibly longer if funding is available.

Phase III Work Plan

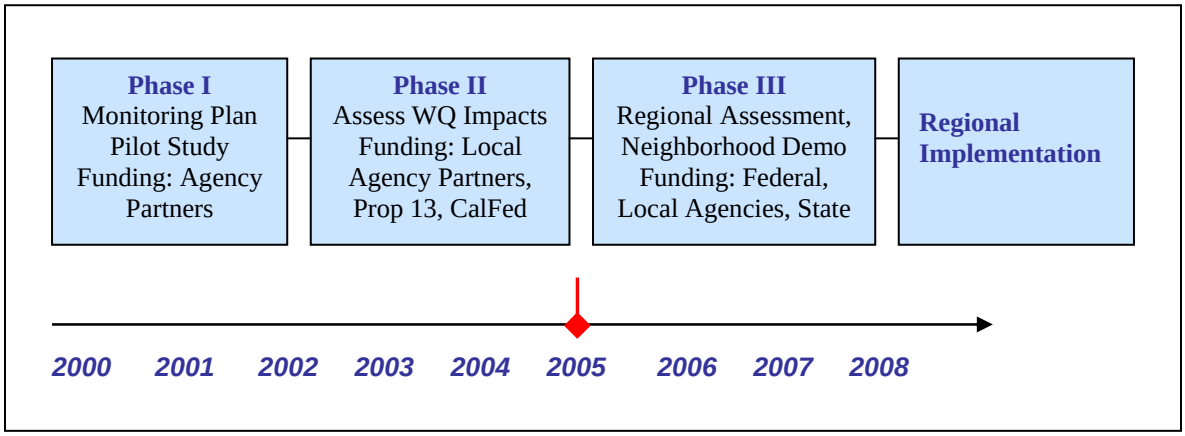
The third phase of the study will incorporate demonstration projects on a neighborhood scale. We propose to retrofit one or more small neighborhoods with state of the art Best Management Practices to address storm water infiltration as well as water conservation, pollution reduction and treatment, flooding, and habitat and stream restoration. Specific techniques will depend upon the sites selected, but may include conversion to native drought-tolerant landscapes, use of irrigation controllers, facilities to capture runoff for infiltration and/or reuse, restoring buried stream channels, and adding green space and habitat areas. The demonstration projects will be monitored for water quality as well as for reduction of runoff and water use, changes in property values, and other potential benefits. These neighborhood projects will provide real-world models of addressing existing infrastructure and will serve to integrate many on-going efforts in the region to address flood management, water quality, water supply and environmental restoration. Our goal is to demonstrate how these approaches can be applied on a regional scale in Southern California as well as in other geographic regions.

In addition to the demonstration project, we are assessing the overall feasibility of utilizing infiltration techniques to capture storm water for groundwater recharge. The Bureau of Reclamation is currently developing a groundwater augmentation model to predict the amount of additional water that could be available for deep percolation if infiltration is increased. They are also developing a regional cost and benefit assessment to determine the real cost of this new water supply. Researchers at UC Riverside are assessing costs on

a site-specific scale. The long-term goal of this project is a regional strategy for implementation.

The WAS is in its fifth year and is currently funded through 2006, through the second year of Phase III. The figure below illustrates each of the project phases, the goal of each, and source of funding.

Project Timeline



1. INTRODUCTION

1.1 Project Background

The Water Augmentation Study (WAS) is a ten year research program of the Los Angeles and San Gabriel Rivers Watershed Council (Watershed Council). The purpose of the program is to assess whether the capture and infiltration of stormwater at localized sites throughout the region is a viable means of augmenting water supply, without adversely affecting groundwater quality. The study began in 2000 in collaboration with representatives from academia and from federal, state and local public agencies. Several public agencies joined in a Memorandum of Understanding (MOU) to support the WAS, and formed a Technical Advisory Committee (TAC) to oversee the study. Each partner contributes its own perspective to the shared concerns of bringing scientific evidence to bear on the feasibility of promoting infiltration without adversely impacting groundwater quality. For Phase I, the TAC developed the monitoring program and provided oversight for the Pilot Study. For Phase II, a new MOU was signed and the TAC has continued to provide oversight and technical input on a number of program aspects. A third MOU was approved by seven of the agencies, to continue the partnership for Phase III of the study. The TAC currently consists of the Watershed Council and the following agency partners:

- City of Los Angeles Department of Water and Power
- City of Los Angeles Watershed Protection Division
- City of Santa Monica Environmental Programs Division
- Los Angeles County Department of Public Works
- Metropolitan Water District of Southern California
- United States Bureau of Reclamation
- Water Replenishment District of Southern California

1.2 Project Goals

This study addresses a number of questions intended to better characterize the benefits of stormwater capture for infiltration. The most important aspects initially are evaluating the potential impact on groundwater quality, and assessing appropriate and most favorable geographic, geologic and hydrologic conditions for infiltration.

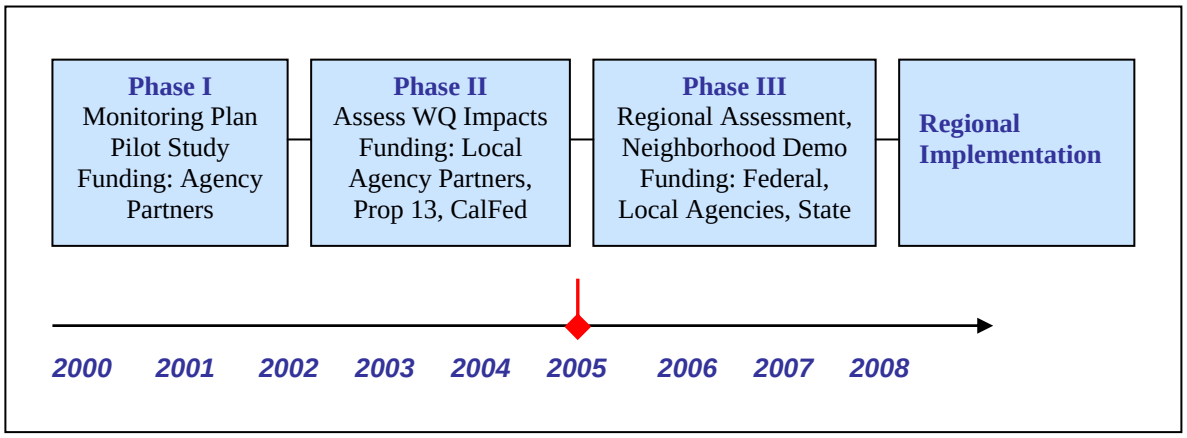
The focus of the early phases of the study was to monitor the fate and transport of runoff-borne pollutants by measuring stormwater quality at the surface, as it infiltrates through the soil and as it mixes with groundwater. Phase I of the study focused on water quality assessment on single parcels utilizing infiltration structures, by monitoring two locations for one wet season. Phase II, just completed, expanded the monitoring in time and scope, adding new sites with different land uses and infiltration techniques, and monitoring for several years. The specific goals of Phase II were to assess the cumulative impact of

infiltration on soil and groundwater, and evaluate the effects of different land uses on pollutant types and concentrations.

During Phase III of our research we will assess through modeling how much additional groundwater recharge may be possible, and whether the additional recharge could provide sufficient water supply to offset the cost of implementation and extraction compared with the cost of developing new water supplies. We will implement one or more demonstration projects on a neighborhood scale, incorporating both infiltration and water conservation strategies. We will also assess other potential benefits and barriers (environmental, regulatory, social, and economic) to determine the best strategy for regional implementation.

The WAS is in its fifth year and is currently funded through early 2007, through the third year of Phase III. **Figure 1** illustrates each of the project phases, the goal of each, and source of funding for each phase.

Figure 1
Project Timeline



1.3 Project Activities during Phase II

1.3.1 Meetings

TAC meetings were held generally bi-monthly, for a total of eighteen meetings between July 2002 and April 2005. Members of the TAC include the agency funding partners, and representatives from the California Department of Water Resources, Los Angeles Regional Water Quality Control Board, Upper Los Angeles River Area Watermaster (ULARA), Main San Gabriel Basin Watermaster, West and Central Basin Municipal Water District, Santa Ana Watershed Project Authority, UC Riverside and TreePeople. Minutes were distributed to all TAC members.

Plenary meetings, open to all interested parties, were held periodically when there was a desire to communicate project progress to a larger audience. During Phase II, two plenary

meetings were held: in February 2003 and November 2004. Presentations at the first meeting included an update on Phase I and II monitoring, related activities in the Santa Ana Watershed Project Authority, and a presentation/discussion of preliminary plans for Phase III of the WAS. In preparation for that meeting, a 4-page color flyer was developed describing the long-range goals and timeline for the study. The second plenary meeting addressed results to date from Phase II monitoring, development of the runoff/infiltration model to quantify potential for new water supply from infiltration, and a presentation by the Sanitation Districts of LA County on the results of their Soil Aquifer Treatment study. The latter is a long-term collaborative research study to assess the impacts on groundwater quality of infiltrating treated wastewater in recharge basins.

1.3.2 Sample Collection

During the first year of Phase II (2002-2003), three sites were monitored: an elementary school, a commercial office site, and a single-family residence. Samples were collected over four storm events during that winter, between November and April. The field monitoring program was conducted by CDM, under contract to the Watershed Council. Three new monitoring locations were established for the 2003-2004 season, bringing the total to six sites. The new sites were a public park in Long Beach and two industrial sites, in Los Angeles and Sun Valley. Geomatrix Consultants, Inc. (Geomatrix) of Costa Mesa was retained by the Watershed Council to establish the three new monitoring sites and conduct the field sampling program for two seasons from 2003-2005. For the new sites, they assisted with site selection and evaluation, designed and constructed infiltration BMPs, designed a monitoring program and installed monitoring equipment. For all six sites, they assisted with preparation of the Sampling Plan and Quality Assurance Project Plan. During the rainy season, they monitored weather forecasts and, in consultation with the Watershed Council, identified storms suitable for sampling and mobilized their field crews accordingly. Two to three rounds of sampling were completed for each site each season. Geomatrix was also responsible for managing and analyzing the resulting data.

1.3.3 Laboratory Analysis

The Watershed Council contracted with Calscience Environmental Laboratories in Garden Grove, California to perform soil and water quality testing of field samples during the course of the study. Calscience provided sample checklists, labeled sample containers and coolers for each monitoring site and event. Samples were delivered to Calscience by sampling field staff after collection. Laboratory results and quality control data were transmitted to the Watershed Council and Geomatrix electronically and via hard copy reports. These data are included in the Appendix tables for each monitoring site.

1.3.4 Equipment Maintenance

Each monitoring location has a variety of equipment installed for infiltration and monitoring, including detention/sedimentation vaults, soil water samplers (lysimeters), groundwater monitoring wells, and subsurface soil moisture sensors. These are described in detail in the Project Study Plan (Section 3). Maintenance activities included inspecting

all facilities and equipment, testing the lysimeters, cleaning out the sedimentation vaults, collecting soil moisture data and replacing the datalogger batteries as needed.

During the course of the study, several lysimeters and well covers were damaged and replaced, and one lysimeter was relocated to provide a more representative sample from the vadose zone. We also installed a deep lysimeter (70-80 feet below ground surface) at one of our industrial sites to better characterize the pollutant removal capacity of the soil.

We also prepared Operations and Maintenance documentation for the BMPs installed at our newest sites, as they will be maintained by the property owners once this project is complete.

1.3.5 Presentations

Presentations on the WAS were made at a number of conferences and meetings during this phase of the project:

- Association of American Geographers 2002 Annual Meeting
- Floodplain Management Association 2004 annual conference
- Headwaters to Ocean 2003 and 2004 annual conferences in Long Beach, organized by the California Shore and Beach Preservation Association, CalCoast, the Wetlands Recovery Project and the Society of Wetlands Scientists
- Los Angeles County Department of Public Works BMP Task Force
- Main San Gabriel Basin Watermaster, Water Quality Management Committee
- Public Officials for Water and Environmental Reform 2002 annual Water Policy Conference
- State Water Resources Control Board Nonpoint Source 2003 bi-annual conference
- Southern California Water Dialogue
- Southern California Stormwater Monitoring Coalition

We also presented periodic updates on study progress at the Watershed Council's monthly stakeholders' meetings.

1.4 Purpose of this Report

This report provides information on activities undertaken during the monitoring phase of the WAS, from July 1, 2001 through April 30, 2005, and the water quality results from that monitoring. The Introduction describes the WAS background and timeframe, and highlights the project goals and accomplishments. Section 2 is a literature review of prior research that addresses runoff characteristics and infiltration studies. Section 3 describes the project activities and work plan, including the monitoring sites, the protocols for the sampling regime and monitored pollutants. Section 4 discusses the monitored events and the water quality results, and Section 5 assesses the data gathered over the past four years

and summarizes the conclusions from these results. Section 6 discusses project outcomes and what steps will be undertaken during the next phase. The Appendices (on the enclosed cd) include complete water quality and soil data results, trend analysis graphs, groundwater hydrographs and other technical data.

2. RELATED RESEARCH

This section reviews and summarizes the literature related to research on urban stormwater infiltration, including the long-term impacts of recharge on groundwater, and appropriate conditions for stormwater recharge.

2.1 Characteristics of Urban Stormwater Pollutants

2.1.1 The Nationwide Urban Runoff Program

Urban runoff is comprised of various flow phases and includes dry-weather base flows, stormwater, combined sewer overflows and, in applicable areas, snowmelt (Pitt et. al., 1996). Perhaps the most comprehensive study of the various constituents comprising urban stormwater pollution was undertaken by the U.S. Environmental Protection Agency's (EPA) Nationwide Urban Runoff Program (NURP). This research was conducted by the Water Planning Division of the EPA and entailed collecting and analyzing water sampling data between 1978 and 1982 in order to both determine the characteristics of urban stormwater runoff and to identify potential differences among contaminant concentrations attributed to varying land uses and geographic areas. EPA listed priority pollutants studied included heavy metals, organic pollutants, coliform bacteria, nutrients, oxygen-demanding substances, and suspended solids.

The NURP study entailed collection of runoff samples from 81 sites located in 22 different cities throughout the United States, and included more than 2,300 separate storm events. Concerning general levels of priority pollutants found in urban runoff, the NURP study identified heavy metals as the most prevalent substances, all 13 of which were detected in water samples. Lead, copper, and zinc occurred at the highest frequency, present in 91% of samples taken. The EPA noted that lead concentrations violated drinking water thresholds in 73% of the samples, though this does not necessarily mean that receiving waters (i.e. groundwater aquifers) would contain the same level of lead. Organic constituents -- 63 out of a total of 106 tested -- were detected at both lower concentrations and frequencies than heavy metals, occurring in no more than 20% of stormwater samples. Of these constituents, pentachlorophenol and chlordane exceeded the EPA's freshwater *acute* threshold, while freshwater *chronic* criteria were exceeded by pentachlorophenol, bias, phthalate, gamma-BHC, chlordane, and alpha-endosulfan. Detected carcinogens included alpha-BHC, gamma-BHC, chlordane, pyrene, chrysene, and phenanthrene. Rarely occurring organic constituents were speculated to be site-specific. Coliform bacteria were present in high levels in urban runoff samples. Nutrients, while found in runoff, appeared in lower concentrations while oxygen-demanding substances were detected in samples approximating levels found in secondary treatment plants (EPA 1983).

Finally, the EPA study concluded that total suspended solids concentrations present in stormwater runoff samples were higher in mineral and human-made products but lower in organic particulates than those discharged from sewage treatment plants. Suspended solids

found in runoff tended to have other types of contaminants absorbed onto them. On an annual load basis, suspended solids contained in urban runoff greatly exceed those released from secondary treatment plants. Thus, contaminated sediments, at least in some areas, are an issue requiring address, as is the need for consideration of urban runoff control where total suspended solids-related water quality problems exist (EPA 1983).

The data for ten measured contaminants were used to calculate the event mean concentration, or EMC. The EMC is defined as the total constituent mass discharge divided by the total runoff volume for each measured substance, and is based on the flow weighted average concentration of each identified priority pollutant. Results indicated that the EMCs at each test site and the median of the EMCs for all test sites were found to exhibit normal statistical distribution, and that their appeared to be no significant correlation between EMC values and runoff volumes. This finding is best explained by the high incidence of pollutant concentration variability from one rainfall event to another at most sites, effectively eclipsing site-to-site variability that could be present as well as influences owed to variations in land use, geographic location or other relative factors (slope, precipitation, urban density). Essentially, although there are differences in the concentrations of various constituents across land uses, the data do not provide a statistically significant basis for predicting differences in EMC values (EPA 1983).

2.1.2 Other Studies

The 1983 NURP study was a landmark research project, yielding comprehensive data sets that allowed for general characterization of the various pollutant substances found in urban runoff. Since this published report, numerous other studies have been conducted to both measure and describe these and other identified constituents in stormwater. A brief examination of more recent studies reveals that there are additional constituents that require attention. In 1994, EPA released a study addressing potential groundwater contamination from stormwater infiltration. The agency noted that volatile organic compounds, including the subset polycyclic aromatic hydrocarbons (PAHs), have been discovered in groundwater near industrial sites. Further, viruses have been detected in groundwater adjacent to stormwater recharge basins.

Viruses are a special case to contend with for a number of reasons: 1) enteric viruses are more resistant to environmental factors than are enteric bacteria, 2) viruses can survive for longer periods of time in water, 3) they can occur in both fresh and marine waters in the absence of fecal coliforms or other indicator bacteria, and 4) they are more resistant to common disinfectants than indicator bacteria (EPA 1994). Viruses are not commonly monitored in stormwater because of the cost and volume of sample needed. Available studies indicate that viruses are sometimes present in dry weather and wet weather flow. Santa Monica Bay Restoration Commission study measured enteric viruses in storm drains in concentrations from 0 to 10 infectious units per 100 liters during dry weather (SMBRP 1992). A study by Caltrans found the presence of at least one type of human virus in 12 of 97 samples taken at 20 sites in Southern California (Schroeder et al 2002). Further, this study found no correlation between the presence of human virus and standard indicator bacteria.

Concerning other potential environmental pollutants, a group of known but yet unregulated constituents that can make their way into urban runoff include pharmaceuticals and personal care products (PPCPs). This diverse group of compounds is found in human and veterinary drugs, X-ray media, bioactive food supplements, fragrances, and sun-screen agents (Lee 2004). Lee predicts that as urban population bases expand, PPCPs will play an increased role in water quality issues, noting that chemicals in domestic water supplies are transferred to urban runoff through leaking sanitary sewers and fugitive irrigation waters. Lastly, the EPA recently identified disinfection by-product agents (DBPs) as a group of water pollutants. Various DBPs form when a chemical used for disinfecting drinking water reacts with natural organic matter or bromide/iodine in the source water. Commonly used disinfectants include chlorine, ozone, chlorine dioxide, and chloramine (Lee 2004).

Perchlorate, which has become a significant pollutant of concern in groundwater, is rarely sampled in stormwater. Perchlorate is a salt, which is used as an oxidizer to help solid rocket fuel burn, and is an ingredient in fireworks and road flares. A recent study (Tipton 2003) suggests there is the potential for perchlorate to be reduced in surface soils through natural biodegradation before it can migrate to ground water.

2.2 Impacts from Urban Runoff on Groundwater Quality

2.2.1 The NURP Study

The EPA NURP study also evaluated the effect of urban stormwater runoff on groundwater aquifers and subsurface soils at sites in Long Island, New York and Fresno, California. This evaluation was based on extensive monitoring of infiltration recharge basins ranging from recent installations to others that had been in service in excess of twenty years. The most significant of these findings are summarized below.

- Heavy metals, an appreciable number of organic priority pollutants, most pesticides, and coliform bacteria are intercepted during the process of infiltration and effectively prevented from reaching groundwater underlying recharge basins.
- Most constituents accumulate in the upper soil layers. Concentrations were found to correlate with the length of time a basin has been in service. Effective retention of applicable constituents takes place with all soil types tested, ranging from clays to sands. The depth of constituent penetration is affected by soil type and water content, depth to groundwater, slope, and various bio-chemical parameters; however, in no case did contaminant enrichment of soil exceed several meters in depth, with the highest concentrations found near the surface.
- The limit of the ability of soils to retain/absorb urban runoff constituents is unknown and additional study is warranted. A related issue is the environmentally safe disposal of sediments in detention basins.

- At both NY and CA locations, groundwater surfaces were at least 20 feet below the base of the recharge basins. NURP findings may not be applicable at locations with shallow depths to groundwater.
- No significant differences in the interception or retention of runoff constituents were apparent for basins with vegetated versus non-vegetated recharge surfaces. However, vegetation does apparently help to maintain infiltration rates normal for the soil type.
- Surface soil accumulations of priority pollutants in installations used for both recharge and recreational use requires further investigation to determine whether such a practice creates unacceptable health risks or requires appropriately designed and conducted maintenance procedures.
- Urban runoff from central business districts and industrial sites, which were not included in the NURP study, may very well contain significantly higher levels of pollutants.
- Synergistic effects among urban runoff constituents were not examined. Various environmental parameters including temperature and pH may reduce or increase toxicity levels of particular constituents. More studies in this area are needed.

2.2.2 Recent Studies

Research conducted since the NURP study reinforces many of the general findings listed above. Most priority pollutants carried by stormwater sorb to soils, accumulating in the upper layers. Ferguson (1998) states that "the soil is a powerful filter and dynamic ecosystem that protects streams and aquifers from urban contamination." Metals, several pathogens, hydrocarbons, and numerous organic compounds will either: 1) sorb to soil particles, 2) volatilize at the surface, or 3) degrade by microbial processes in surface and sub-surface soil layers.

Two studies conducted in small residential communities in Wisconsin compared constituent levels in urban runoff samples with groundwater samples taken downgradient of drywells used for stormwater infiltration. Low levels of polynuclear aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs) detected in stormwater were not detected in groundwater with the exception of one well sample. However, sediment samples taken from the infiltration wells revealed that these contaminants were accumulating in the upper soil layers (Lindemann 1999, Dunning and Bannerman 1993). Similarly, studies of infiltration systems receiving highway runoff for several decades demonstrated the accumulation of heavy metals and hydrocarbons in the upper soil matrix much higher than those measured concentrations in nearby soils (Dierkes and Geiger 1999, Mikkelson et al 1997, Legret and Colandini 1999). In these studies, groundwater below infiltration systems was not impacted.

While the general consensus is that stormwater infiltration poses few significant risks to underlying aquifers, adverse impacts to groundwater from runoff infiltration can take place. Fisher et al (2003) compared ambient groundwater quality to that receiving

infiltrated runoff in 16 detention basins located in southern New Jersey. The basins differed in surface area, depth, and number and size of inlets and outlets but all were located in newly developed urban areas. Analyses of water samples taken from installed wells indicated elevated levels of four pesticides in runoff, lower levels of dissolved oxygen (DO) in groundwater under infiltration basins (a probable result of increased microbial activity due to greater concentrations of organic compounds in runoff), and greater occurrence of petroleum hydrocarbons. Infiltration rates among the 16 basins varied due to accumulated sediment near inlet channels and at low points in the basins. The researchers note that because low concentrations of DO can affect both the persistence and transformation of other polluting substances, the groundwater quality beneath detention basins can be adversely impacted by the influx of large volumes of poorly oxygenated stormwater. Hence, infiltrating stormwater can, on the one hand, serve to dilute pollutants of concern but can also increase the occurrence of other substances above the amounts found in ambient groundwater.

In four other studies described here, reported results support most of the NURP findings, but each also points out select issues concerning the use of urban runoff to recharge groundwater aquifers. In a study taking place in Lyon, France, researchers took water and soil samples from an infiltration basin in operation for over 30 years, located on a university campus in an urban area. The basin has a partially clogged cobble layer contaminated by hydrocarbons and heavy metals (owed to its extended use). The groundwater table fluctuates between 2.5–3.5 meters below the surface of the infiltration bed. Results for priority pollutants concentrations in infiltration bed sediments were similar to those reflected in other studies, with reduced concentrations found at depth. However, mineralization of organic compounds originally retained in detention basin sediments acted as a source of dissolved contaminants, being attributed to elevated concentrations of phosphate and dissolved organic carbon in receiving groundwater (Datry et al 2004). The problem of reduced DO in urban runoff transferring to groundwater was reiterated in this research project. A similar study of the same basin concluded that discrepancies can occur when evaluating the contamination potential from analysis of nutrient concentrations in inflow stormwater and the environmental risk resulting from percolation of inflow water through permeable sediment (Datry et al 2003).

In another study, Barraud et al (1999) measured various urban runoff constituents in both newly built and 30 year-old detention basins in Valence, France. These basins drain runoff from heavily traveled roads and open space, and the bottoms of each are very close to the water table. Results indicated that some organic constituents were not being retained in bed sediments but rather were part of the washdown at the beginning of infiltration, due to a permanent saturated soil layer in both shallow basins. Bottom soil was contaminated by hydrocarbons but this is not surprising given the shallow depth of the basins. The authors point out that the sediment bed of the older detention basin (~30 years) was contaminated with heavy metals and mineral oils impacting at least a one meter radius of soil. In another study, also examining the spatial distribution of constituents in a 14 year-old constructed infiltration basin located in France, researchers noted that zinc, a highly mobile heavy metal, was found below 30 centimeters of top soil—the depth limit of other metals reported in other studies (Dechesne et al 2004).

In a comprehensive review of groundwater contamination literature concerning urban runoff constituents, Pitt et al (1996) reaffirmed most of the findings of studies previously discussed. Additionally, the authors state the following:

- Viruses, in low levels, may be found in stormwater and small amounts can cause health problems. Most viruses do die off or adsorb to soil, and most are removed within the first few meters. However they are so small that they could be transported through cracks or through very permeable soils to underlying groundwater. The highest probability of transferring viruses from the surface is where the aquifer is near the surface.
- Nitrogen contact with soil can lead to nitrate leaching. Nitrates are quite soluble and will stay in solution in percolating water migrating to groundwater.
- Heavy and repetitive use of mobile pesticides on irrigated or sandy soils can contaminate aquifers. Pesticides decompose at different rates on soil surfaces but can take much longer to degrade in subsurface soils due to reduced microbial activity. Pesticide leaching into the vadose zone and groundwater is a possibility.
- Sorption of organic constituents can be countered by resolubilization during wet periods. Factors affecting microbial degradation include temperature, pH, soil moisture content, ion exchange capacity of soil, and air availability.

It should be noted that Pitt's evaluation of constituent transport potential was based on the worst case scenario: sandy soils with low organic content overlying shallow water tables. Most organic compounds would be less mobile through soils having a higher proportion of clay and organic matter. Natural organic matter also impacts sorption of metals in soil. In laboratory simulations, high concentrations of organic matter, particularly humic acid, were found to react with heavy metals and increase metal attenuation in soil (Hathhorn and Yonge 1995). Essentially, extremely coarse or extremely clay-rich soils may not filter constituents as well as more medium-grained soils with organic content.

2.2.3 Federal Agency Studies of Groundwater Recharge in California

The United States Geological Survey (USGS) has been involved in artificial recharge of aquifers in the state of California since the 1960s, when the California Water Plan was approved to import water from the northern part of the state and deliver it to the southern area for subsurface storage via recharge. Prior to USGS involvement, the state had been engaged in utilizing stormwater for recharge of groundwater through the use of spreading basins since the early 1900s (USGS 2001). Currently, the central and west coast groundwater basins in Los Angeles County are artificially recharged using three sources of water: 1) purchased water originating from northern California and the Colorado River, 2) treated recycled water purchased from the Los Angeles County Sanitation District, and 3) diverted stormwater runoff. The urban runoff that is used is directed to holding ponds located at the Rio Hondo and the San Gabriel River Spreading Grounds, in Montebello and Pico Rivera. The Water Replenishment District (WRD) of Southern California reports that average annual use of potable water in the area is 250,000 acre-feet, while average annual

recycled and stormwater use are 50,000 and 40,000 acre-feet, respectively (WRD Fact Sheet). The USGS has conducted a multitude of studies to further the understanding of the processes involved in recharge, the most relative of which are summarized below.

Concerning the fate and transport of pathogens in recharge projects, Metge (2002) notes that temperature, salinity, DO, pH, microbial size, nutrient availability, and microbial growth are factors that influence the survival of most pathogens in groundwater matrices. Many viruses become inactivated at temperatures above 200ºC but can survive below 100ºC. A USGS-developed model indicated that the degree of aquifer heterogeneity assisted in determining the degree of viral transport within the soil matrix. In another USGS study examining the same issues at a research site in Montebello, researchers found that coliform bacteria increased rapidly and immediately after recharge using treated wastewater, noting that bacteria can move quickly through underlying soil, within a matter of days. Further, using a proxy medium (in replacement of a live virus) and bromide as a tracer for assessing the subsurface transport of the virus in three separate periods of time Anders et al (2003) found that adsorption was the predominant removal mechanism during recharge processes. Here, higher temperatures and changes in entrapped air, sealing of the soil surface, and the effect of biofilms sealing soil matrix pore space were the determining factors. In one other study, USGS researchers determined that untreated groundwater located in Los Angeles area basins containing low-levels of volatile organic compounds (VOCs) was most likely contaminated by industrial wastewater that was recharged into forebay areas. Most of the wells with high concentrations of multiple VOCs were located in close proximity to recharge facilities, with VOC concentrations dropping off beyond 10-15 kilometers in distance. Hydrology and the acceleration of groundwater flow produced by recharge actions in conjunction with pumping are likely factors in controlling the distribution of VOCs (Shelton et al 2001).

Finally, in what might be considered the most comprehensive assessment of artificial recharge using tertiary-treated wastewater, a 10-year study was recently completed by USGS, Los Angeles County Sanitation Districts and others to assess water quality at recharge facilities in Montebello Forebay. A research basin was constructed adjacent to spreading grounds in Pico Rivera for a limited number of tests and analyses of samples taken at deep-seated monitoring wells located up to ten miles from the basins was also carried out. Results of this study are summarized below:

- At the research basin, DOC and dissolved nitrogen in percolating water significantly decreased. The decrease in DOC was independent of operating conditions. Reduced nitrogen in subsurface recycled water was attributed to the oxidation of nitrogen to nitrate, with denitrification taking place as the environment becomes more reducing.
- Experiments using tracers and employing extrapolation from results indicate that viruses die off or become inactive over a distance of about 100 feet from Montebello Forebay, meeting current DOHS requirements. No infective viruses were detected in groundwater samples.
- Removal of organics occurs mostly within the top 10 feet of soil.

It should be noted that recharge has also been implemented in the central portion of California since 1956, when the Fresno Metropolitan Flood Control District constructed a multi-use flood control system comprised of 143 stormwater ponding basins and five large flood-control dams and reservoirs. Each watershed located in the Fresno-Clovis metro area is approximately one square mile in area and is served by a basin ranging in size from 10 to 40 acres, with a holding capacity of between 100 and 600 acre-feet of water. Studies conducted by the District indicate that ponding basins remove between 50% - 83% of commonly occurring runoff constituents. On an annual basis, about 17,000 acre-feet of stormwater are recharged back into local aquifers providing potable water. Thirty basins serve community recreational activities (sport fields, dog runs, open space). According to Mr. Daniel Rourke of the Fresno Flood Control District, most basins are cleaned every 4-5 years, with some being cleaned at a higher frequency due to lower infiltration rates (pers. comm. 2004). In addition to the studies conducted of these basins under NURP, another USGS study of an industrial catchment in Fresno found that contaminants do not reach groundwater but tend to accumulate in the surface sediments (upper 1.5 inches). Concentrations of stormwater constituents in soil decreased with depth and reached background concentrations at depths of only 6.3 inches (Schroeder 1995).

2.3 Constituent Concentrations and "First Flush"

The "first flush" effect describes an initial storm event whereby build-up of constituents during dry periods are flushed from urban surface areas by runoff. During these first flush periods, very large quantities of constituents are discharged into receiving waters, or alternatively, into retention basins. Within a given storm event, there may also be a "first flush" effect as constituents are initially washed off. Urbonas and Stahre (1993) note that as rainfall continues, surface constituent build-up is depleted and concentrations are diluted by larger flow volumes. The amount of surface constituents washed off also depends on the intensity and the duration of the storm event, the size of the watershed area being drained, the amount of impervious area, and the frequency of dry weather periods. Ferguson (1994) found that with storms of long duration, initial runoff had higher concentrations of constituents than runoff generated later in the storm. In a study conducted by the Southern California Coastal Water Research Project (SCCWRP), the effect of rainfall intensity and duration on contaminant concentrations in runoff was assessed by sampling simulated events of varying rainfall intensities. Within a given storm, concentrations of suspended solids, total and dissolved metals and polycyclic aromatic hydrocarbons (PAHs) in runoff were consistently greater at the beginning of the storm events (<10 minutes) than later in the event (10-40 minutes). Variability between storms indicated that constituent concentrations were inversely correlated with rainfall duration or intensities: shorter rainfall durations or lower rainfall intensities produced greater runoff concentrations (Tiefenthaler and Schiff 2002).

The variation in constituent concentration within a storm has implications for treatment and monitoring. If the beginning of the storm contains the highest concentration of constituents, the total volume requiring pretreatment may be considerably less than the total storm runoff. For monitoring purposes, composite samples with results reported as

EMCs become a more consistent measure than single grab samples taken at a random point during the storm event (Strecker 1994).

In addition to constituent concentrations during a storm event, Urbonas and Stahre (1993) discuss whether early season storms constitute the only "first flush", containing higher concentrations of constituents than later storm events. In arid regions, such as southern California, there may be several dry weeks between storm events. These dry periods allow constituents to accumulate repeatedly, impacting constituent concentrations in subsequent storms. Thus, there may be multiple "first flush" events throughout the season. In a study conducted by SCCWRP to assess the relationship between antecedent rainfall and pollutant build-up, researchers found that virtually all of the accumulation occurred within one month after wet weather for total suspended solids, total trace metals, and dissolved trace metals (Tiefenthaler et al 2002).

2.4 Constituent Removal Effectiveness of BMPs

The utilization of urban runoff for artificial recharge of groundwater may necessitate pre-treatment to maximize the removal of as many constituents as possible prior to release for infiltration. Structural best management practices or BMPs can be very effective at removing constituents from stormwater runoff prior to infiltration. Pre-treatment associated with many types of BMPs can significantly reduce the potential for adverse groundwater impacts (Schueler 1987). Some of the more common BMPs employed include the following:

- Sedimentation or settling of suspended solids, which removes particulates and sorbed constituents such as metals, hydrocarbons and nutrients
- Filtration to remove particulates and associated constituents. Organic filtration media can also remove soluble nutrients
- Biological uptake or degradation by plants and microorganisms is effective for removing nutrients and toxic organic compounds. Sedimentation basins, ponds, and wetlands promote degradation and/or volatilization of certain organic compounds (EPA 1999).

Most often, simple filtration through soil is the BMP most often used to naturally treat urban runoff for recharge. As previously discussed, infiltration is appropriate for areas that have relatively permeable soils. However, Lee (2000) cautions that the very soils that are conducive to filtration of heavy metals, hydrocarbons and most bacterial pathogens perform poorly in filtering and adsorbing contaminates that might otherwise enter an aquifer. Additionally, clogging of infiltration beds restricts maximum performance. Lee reports that current guidelines for effective infiltration call for minimum soil permeability rates of about .52 inches/hour. For this and other stated reasons, a groundwater monitoring element is suggested to ensure that water quality is not impaired in receiving groundwater.

On a local level, the County of Orange, California, commissioned a study to determine the most appropriate BMPs to comply with federal regulations included in the County's

stormwater permit. Based on runoff pollutant reduction rates and maintenance requirements, infiltration basins and trenches were among seven BMPs deemed feasible for implementation (RBF 2003). In another study, researchers examined the long-term effectiveness of four types of permeable pavement systems comprised of a matrix of concrete or plastic structures with spaces filled with sand, gravel, or soil constructed within a parking lot in Renton, Washington. Results demonstrated that stormwater effectively infiltrates through the voids into underlying soil in the four permeable pavement systems used, and that all showed only minor signs of wear and tear after six years of use (Brattebo and Booth 2003). A study conducted in Mexico found that untreated wastewater used for irrigation did not significantly impact groundwater, with the exception of nitrates (Downs et al 2000). The reservoir and canal system served as vehicles for volatilization, degradation, and filtration of dozens of measured contaminants including metals, semi-volatile organics and pesticides.

The effectiveness of BMPs varies with local weather conditions, the nature and concentration of targeted constituents, and geologic parameters of the individual site. Local, physical conditions that can make stormwater infiltration inappropriate include steep slopes, slow percolating soils, shallow water tables, and nearby groundwater use. In addition, it should be noted that assessing the effectiveness of BMPs at removing constituent concentrations is itself subject to uncertainties because of inconsistencies in study methods (such as sample collection and constituent analysis) and reporting protocols (Strecker et al 2001). **Table 3** summarizes the comparative removal effectiveness of various BMPs.

2.5 Conditions for Groundwater Recharge

Groundwater originates, in part, from the infiltration and percolation of surface water through the soil matrix. There are a number of variables that determine whether conditions are suitable for groundwater recharge using urban runoff in a given location. First, the ability of surface water to reach groundwater depends on a number of factors, including: 1) permeability of surface soil and the subsurface soil matrix, 2) antecedent soil moisture, 3) soil properties such as texture, organic content, porosity and hydraulic conductivity (which in turn determine rates of infiltration and percolation), 4) depth to groundwater, and 5) the volume of water available for infiltrating to an aquifer (Dunne and Leopold 1979, Novotny and Olem 1994, Urbonas and Stahre 1993). Secondly, water moves through the soil under gravitational forces, displacing water stored previously until it eventually reaches the saturated zone. Successive storms that keep this soil layer moist provide a greater opportunity for this stored water to reach groundwater. If, however, the soil layer is dry, percolation rates will decrease because the capillary forces holding water in the soil are stronger than the gravitational forces that tend to drive moisture further down (Dunne and Leopold 1979). Small storms may not produce a sufficient volume of runoff to infiltrate beyond the root zone before the soil begins to dry out again. Finely textured soils, such as clays (which have expanding properties when exposed to water), have lower infiltration rates and may require less intense but longer duration storms to achieve sufficiently deep percolation to reach groundwater. The various factors that affect infiltration make it difficult to calculate whether runoff from a given storm event will actually reach

groundwater sources. Under some circumstances, it may be that only the infrequent, large storm events will generate sufficient volumes of surface water to reach groundwater, and only with sufficient antecedent moisture.

Table 1
Removal Efficiency of Stormwater BMPs

BMP Types	Suspended Sediment	Phosphorous	Nitrogen	Oxygen Demand	Metals	Bacteria
Bio-retention	High	Moderate	Moderate	Mod Low	Moderate to Mod High	Mod Low
Catch basin inserts	Mod High	Low	Low	Low	Mod High (those designed for metals)	Low
Extended detention basin	High	Moderate	Mod Low	Moderate	Mod High	Low
Grass swale	Moderate to Mod High	Mod Low	Mod Low	Mod Low	Mod Low	Unknown
Infiltration basin	High	Moderate	Moderate	Mod High	High	Mod High
Media filtration	Mod High to High	Mod Low[1]	Mod Low[1]	Unknown	Mod High	Low
Porous pavement	High	Moderate	Mod High	Mod High	High	High
Retention basin	Mod High	Moderate	Moderate	Unknown	Mod High	Moderate
Wetland or wet pond	High	Mod High	Moderate	Mod Low	Mod High	Mod High

KEY:
High 80-100% Removal
Mod High 60-80% Removal
Moderate 40-60% Removal
Mod Low 20-40% Removal
Low 0-20% Removal

Source: Glick, 1998, Schueler, 1987, USEPA, 1999
[1] Removal efficiency is high if organic media used

While infiltration can be an important component of stormwater management, there are a number of caveats that must be factored in when planning a recharge facility. According to the USGS, ideal conditions for groundwater recharge are rare, thus a well developed set of guidelines offers the best strategy for determining the suitability of a recharge operation. Pretreatment of stormwater to remove suspended solids significantly reduces clogging of the surface soil, and periodic cleaning is required to maintain infiltration rates. The presence of faults or folds and clay lenses below the surface can inhibit recharge by directing infiltrating water away from the targeted area (USGS 2004).

Sites where the groundwater table is less than ten feet below the infiltration bed or where very sandy soils and low organic content exist are least suitable for groundwater recharge unless runoff is first treated to remove pollutants (Urbonas and Stahre 1993). Too much

infiltration in areas of shallow groundwater could also create conditions for liquefaction. Liquefaction is caused by creating a shallow water table in poorly consolidated geologic materials, which can results in unstable soils particularly when shaken by an earthquake (USGS 2004). As previously discussed, some constituents are more mobile under certain conditions. Pitt et al (1996) recommend that in the following cases runoff should be diverted or treated:

- Dry-weather storm drainage effluent should be diverted or pretreated due to potentially high concentrations of pathogens, soluble heavy metals and pesticides;
- Combined sewage overflows should be diverted because of poor water quality;
- Runoff from manufacturing industrial areas should be diverted or pretreated because of potentially high concentrations of soluble toxicants;
- Construction site runoff should either be diverted or treated prior to release for infiltration due to high concentrations of suspended solids which can quickly clog infiltration beds; and
- Runoff from vehicle service stations and other critical source areas should be pretreated to minimize or eliminate groundwater contamination from petroleum hydrocarbons.

2.6 Summary

The most significant impacts on groundwater quality in urban environments come from leaking or leaching of contaminants from underground storage tanks, septic systems, landfills, or previously contaminated soil in industrial areas (WEF 1998). In general, concentrations of constituents in urban runoff are many orders of magnitude more dilute than pure product or other historical pollution sources (WEF 1998). This review indicates that infiltration of stormwater has not been found to pose considerable risk to groundwater contamination, given appropriate soil characteristics, depth to aquifers, pretreatment of problematic substances, diversion of runoff from select sources, knowledge of geological formations that may inhibit effective infiltration, and proper design and maintenance of infiltration facilities. Some urban runoff pollutants, such as nitrates and viruses, may have the potential to reach groundwater under certain conditions. The use of BMPs for pretreatment of stormwater greatly reduces the potential risk of groundwater contamination.

There is also the potential to increase soil contamination as a result of pollutant accumulation in the top layers of soil, which may present long-term disposal planning issues in some situations. Individual site conditions should be assessed to determine this. While the ability of soils to continue to filter and adsorb constituents is not precisely known, some researchers estimate that it could take upwards of 200 years to exhaust soil capacity in particular locations (Cox and Livingston 1997, Mikkelson et al 1996, Pitt et al 1996, WEF 1998).

While it is clear that numerous caveats must be considered when urban runoff is being investigated for recharge of potable groundwater, it is also important to note that groundwater recharge offers a number of benefits to municipal water managers. Groundwater storage is less costly in terms of construction costs, environmental impacts, evaporation loss of water, and eutrophication as compared to surface-water reservoirs (USGS 2004). Further, recharging groundwater puts the resource in closer proximity to the end-user than pumping water from reservoirs, an additional cost savings. With proper planning and research, the use of urban runoff for recharge of groundwater offers a viable alternative to relying solely on purchased water for such activities, water that may not be available in present quantities for purchase in the future.

3. PROJECT STUDY PLAN

The objective of the monitoring program was to evaluate the potential effects of infiltrating urban stormwater runoff on groundwater quality, via engineered infiltration systems referred to as Best Management Practices (BMPs). During the Phase I Pilot Study, two sites were monitored in the Los Angeles area. The monitoring plan included installation of monitoring wells and lysimeters, baseline soil and groundwater sampling, and subsequent monitoring of stormwater runoff and infiltration associated with storm events during the 2001-2002 season. Because the winter season was dry, most of the data collected was baseline groundwater data; only one storm event was sampled.

The Phase II work plan called for adding at least three new monitoring locations – residential, commercial and industrial – and retrofitting the properties with infiltration BMPs and subsurface monitoring equipment. Soil samples were collected during installation of the monitoring equipment, to characterize constituent concentrations prior to infiltration. For each winter between 2002 and 2005, several storm events were monitored, including the first storm of each season. Subsurface monitoring followed each sampled storm event.

3.1 Monitoring Sites

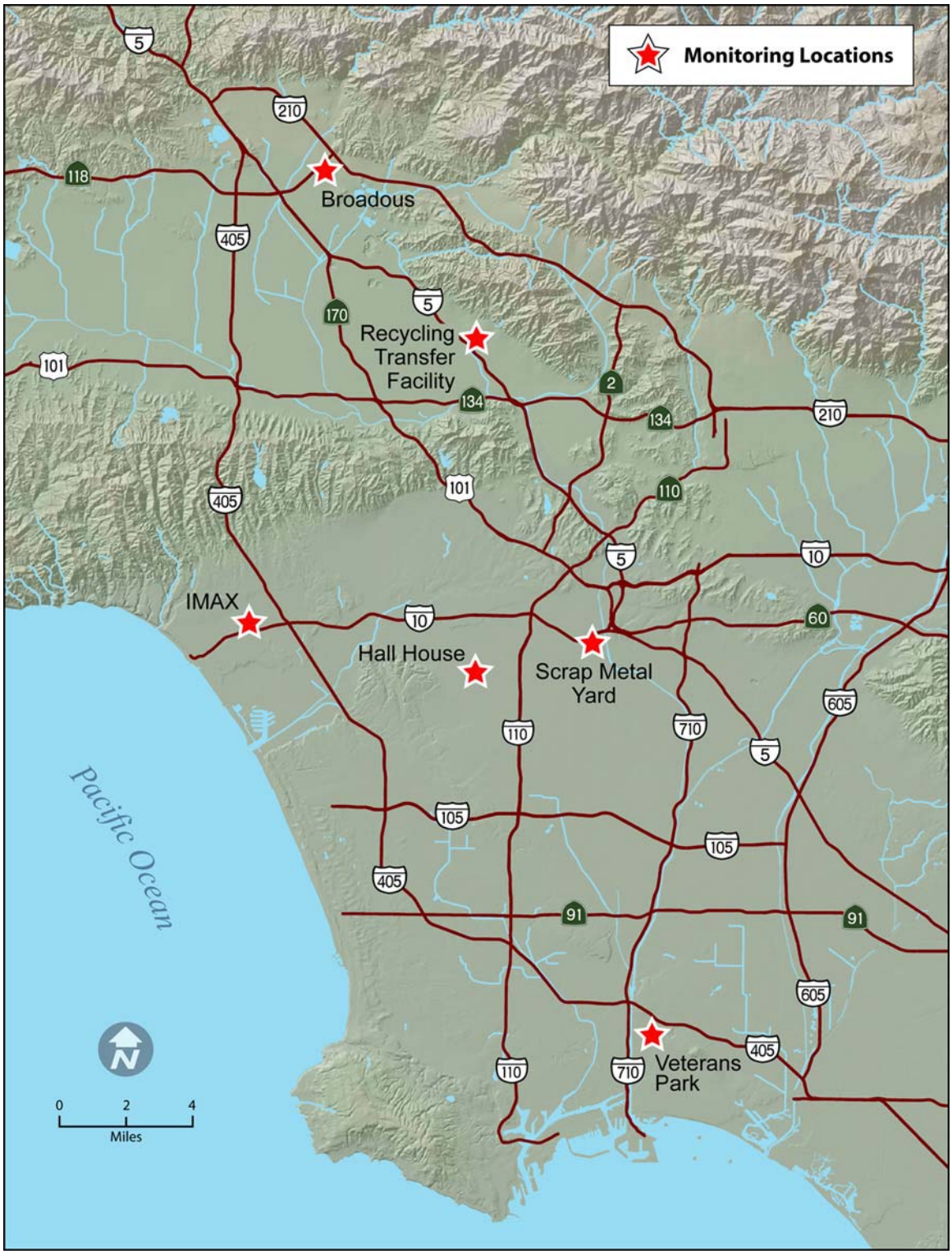
Three locations were monitored during 2002-2003 winter. Six locations were monitored during the 2003-2004 and 2004-2005 seasons (**Figure 2)**. Two of these sites, the Broadous Elementary School and IMAX Corporation, were established during the Phase I Pilot Study. A residential location was added to the program in 2002. Three additional monitoring locations were added prior to the 2003-2004 rainy season: two industrial and one commercial/recreational site. Geomatrix Consultants designed and constructed BMPs and installed monitoring equipment at the three new sites. Each of the monitoring sites is described briefly in the following sections. For the industrial sites, which are privately owned, only a generic name and location are provided.

3.1.1 Broadous Elementary School

The Broadous Elementary School (Broadous) is located in Pacoima, a neighborhood within the city of Los Angeles. The BMP for the seven acre site consists of a runoff collection system, sedimentation tank, and subsurface infiltration system installed in 2001 in the playground area of the school (Figure 3)

Runoff samples are collected from one sample point in the playground area near the inlet to the BMP. The original lysimeter was installed adjacent to the infiltration BMP, 25 feet downgradient and at a depth of 60 feet. Prior to the 2003-2004 rainy season, a new lysimeter was installed at the edge of the infiltration system, at a depth of 24 feet, to better characterize water quality exiting the BMP.

Figure 2
Monitoring Site Locations



There are also two groundwater monitoring wells at the site, one upgradient and one downgradient of the infiltration BMP. In January of 2003, soil moisture sensors were installed downgradient of the infiltration system, at depths of 25, 35, 45 and 55 feet below the ground surface. These sensors track infiltration rates in the vadose zone throughout the year and were used to estimate timing of subsurface sampling.

Figure 3
Broadous School Monitoring Site

3.1.2 IMAX Corporation

The IMAX office building is a commercial office facility located in Santa Monica. The 3.5 acre site is equipped with two types of BMPs that are monitored: a drywell receiving roof runoff and a landscaped area that receives parking lot runoff (**Figure 4**). Runoff samples were collected from the front parking lot as it drains into the landscaping, and from the roof downspout at the rear of the building. There are lysimeters adjacent to each of the BMPs, and upgradient and downgradient groundwater wells at the site. There are also four soil moisture sensors in the landscaped area, at depths of 2, 5, 10 and 20 feet below the surface, which track infiltration rates after storm events and throughout the year.

Figure 4
IMAX Monitoring Site

3.1.3 Residential Monitoring Site

The Hall residence (Hall House) is located in south Los Angeles. The Hall House is an ongoing demonstration project of TreePeople, and was retrofitted seven years ago with a number of BMPs to contain runoff on site. The front lawn of the Hall House serves as a swale to collect runoff from the roof (**Figure 5**) and also has a drywell that collects runoff conveyed from a trench drain in the driveway. A lysimeter is installed at the edge of the lawn nearest the roof drain. Runoff samples are collected from the roof drain and the driveway. Local groundwater is at a depth of approximately 200 feet below the ground surface. Because of the site configuration in relation to the direction of groundwater flow, there is no groundwater monitoring well installed at this site.

Figure 5
Hall House Front Lawn

3.1.4 Metal Recycler

The Metal Recycler is an industrial site located at the southern edge of downtown Los Angeles (**Figure 6**). Facility operations include recycling of bulk ferrous and non-ferrous metals and appliances. The infiltration BMP at this site was designed to intercept runoff from a 0.85 acre portion of the site, pretreat the collected stormwater to reduce the concentrations of sediment, oil and grease, and infiltrate the treated stormwater. The stormwater treatment system consists of a concrete detention/sedimentation basin that receives site runoff and discharges into a subsurface infiltration gallery through a modified standpipe designed to perform limited runoff pretreatment.

Stormwater samples were collected from two locations at this site, representing influent to and effluent from the stormwater treatment device. The four lysimeters are installed adjacent to the infiltration gallery, at depths ranging from 20 to 52 feet. The monitoring well is downgradient of the infiltration gallery. This well was also used for geophysical logging to collect conductivity data that may indicate the path of the wetting front after a storm.

Figure 6
Metal Recycler Detention Basin

3.1.5 Recycling Facility

The recycling facility is an industrial facility located in Sun Valley, a neighborhood of the city of Los Angeles (**Figure 7**). Operations at the site consist of receiving and sorting materials for recycling: paper, glass, plastics and metal containers. The infiltration BMP at the Sun Valley site was designed to intercept runoff from a 2.3 acre portion of the paved yard. The stormwater treatment system is similar to that at the Metal Recycler, consisting of a concrete detention/settling basin which discharges into a subsurface infiltration gallery through a modified standpipe designed to perform some pretreatment. Runoff from a portion of the roof is directed to the same underground infiltration gallery via separate buried piping, however it does not undergo pretreatment.

Sample collection points at the site consist of three stormwater sample collection locations, five vadose zone lysimeters and one monitoring well installed in the vadose zone for geophysical logging. No groundwater monitoring wells have been installed at this site however there is an existing downgradient well off-site that was sampled periodically. Stormwater samples were collected from roof runoff, from the yard area entering the sedimentation basin prior to treatment, and from the pipe that directs stormwater from the basin to the infiltration trench. The lysimeters are installed in pairs near the infiltration area at depths ranging from 22 to 71 feet. The monitoring well is competed to a depth of approximately 143 feet. Groundwater is estimated to occur at about 350 feet below the surface.

Figure 7
Sun Valley Recycling Facility Detention Basin

3.1.6 Veterans Park

Veterans Park is located in west Long Beach. The site is a public park operated by the City of Long Beach (**Figure 8)**. The infiltration BMP at Veterans Park was designed to intercept runoff from a 0.5 acre portion of the site (a parking lot and adjoining sidewalks), treat the collected stormwater to reduce the concentrations of sediment and oil and grease, and infiltrate the treated stormwater. Stormwater collection for the BMP system consists of catch basins positioned to intercept surface flow along existing flow lines at the eastern and western edges of the parking lot. The discharge pipelines from the catch basins direct stormwater to a buried, concrete sand/oil interceptor, then to an underground infiltration gallery.

Stormwater samples are collected from surface flow entering the two catch basins located in the parking lot. The two lysimeters are located adjacent to the infiltration area. Four groundwater monitoring wells are located both upgradient and downgradient of the infiltration gallery.

Details for the infiltration BMPs and monitoring points at each location are provided in **Table 2** and **Table 3**.

Figure 8
Veterans Park Parking Lot

Table 2
Monitoring Sites BMP Hydrology

Parameter	Units	Broadous	IMAX	Hall House	Metal Recycler	Veterans Park	Sun Valley
Sample Point		Paved school yard	1) Roof 2) Parking lot	1) Roof 2) Driveway	Paved Yard	Parking lot	1) Roof 2) Paved Yard
Design Rainfall	inches	0.75	0.75	10	0.75	0.75	0.75
Design Storm Intensity (max)	in/hr	0.75	0.75	100-year event	0.75	0.75	0.75
Catchment Area (est)	sq. ft.	305,000	1) 47,916 2) 68,390	3,000	37,200	21,200	1) 51,000 2) 75,000
Runoff Volume	gallons	95,200	N/A	N/A	17,400	9,900	1) 23,850 2) 35,065
Design Runoff Rate	gal/min	N/A	N/A	N/A	286	165	1) 394 2) 580
BMP Inlet		Sheet flow direct to pretreatment separator	1) roof drain to dry well 2) Sheet flow into landscape strip	1) Roof drain to landscaping 2) Sheet flow to driveway drain	Sheet flow direct to sedimentation basin	Sheet flow to catch basin; pipes to buried sedimentation vault	1) Roof drain direct to buried perforated pipes 2) Sheet flow direct to sedimentation basin

Parameter	Units	Broadous	IMAX	Hall House	Metal Recycler	Veterans Park	Sun Valley
Sediment Removal		Yes	No	Yes	Yes	Yes	1) No 2) Yes
Oil/Grease Removal		Yes	No	Yes	Yes	No	1) No 2) Yes
Recharge Method		Buried infiltration units in gravel bed	Direct through soil	Buried dry well	Buried perforated pipeline in gravel bed	Buried perforated pipeline in gravel bed	Buried perforated pipeline in gravel bed

N/A: data not available

Table 3
Monitoring Points

Site Date Completed	Surface Water Monitoring Point ID	Collection Point	Lysimeter ID	Installed Depth (ft)	Monitoring Well ID	Initial Groundwater Depth
Broadous	B-SW-01	School Yard	B-LS-02	24	B-MW-01	155 feet
					B-MW-02	139 feet
IMAX	I-SW-01	Roof Drain	I-LS-01	8	I-MW-01	32 feet
	I-SW-02	Parking Lot	I-LS-03	10	I-MW-02	31 feet
Hall House	H-SW-01	Roof Drain	H-LS-01	8	none	
	H-SW-02	Driveway				
Veterans Park	V-SW-01	Parking Lot	V-LS-01	15	V-MW-01	23 feet
	V-SW-02	Roof Drain	V-LS-02	15	V-MW-02	23 feet
					V-WM-03	23 feet
					V-MW-04	22 feet
Metal Recycler	M-SW-01	Detention Basin Inlet	M-LS-01	37	M-MW-01	225 feet
	M-SW-02	Detention Basin Outlet	M-LS-02	51		
			M-LS-03	37		
			M-LS-04	51		
Sun Valley	S-SW-01	Roof Drain	S-LS-01	25	S-MW-01	143 feet Installed casing to run geophysical logs. (groundwater depth is ~350 feet below surface)
	S-SW-02	Detention Basin Inlet	S-LS-02	47		
	S-SW-03	Detention Basin Outlet	S-LS-03	25		
			S-LS-04	47		
			S-LS-05	71		

3.2 Sampling Program Scope

Surface water sampling occurred during rain events, with subsurface sampling following. The goal was to sample at least two storm events at each monitoring site each year.

3.2.1 Mobilization Criteria

Sampling crews were mobilized only if a predicted storm was likely to produce sufficient runoff for sample collection and no significant rainfall occurred within 48 hours prior. To assess the mobilization criteria professional weather consultants, Weather Watch in San Diego and Meteorological Solutions (through Los Angeles County Pubic Works), were consulted to provide more comprehensive weather data than is commonly available through the Internet. Services included long- and short-range forecasts via their websites, email updates, and telephone consultation available near the onset of a storm. For pending storm events, estimates of total rainfall and probability of predicted rainfall were provided in 3-hour increments.

3.2.2 Subsurface Sampling Schedule

After each storm, lysimeter samples were collected from all sites. The volume of each lysimeter is typically less than required for the full suite of analytes, therefore when necessary sampling was conducted over a two or three day period. All sites except Hall House and Sun Valley have on-site monitoring wells. Wells at sites with relatively shallow groundwater were sampled in response to monitored storms (just after the collection of lysimeter samples), and wells at sites with relatively deep groundwater were sampled periodically throughout the storm season.

Induction logs are collected at the two sites with the deepest underlying groundwater, the Metal Recycler and Sun Valley. The intent was that these logs would distinguish zones of percolating stormwater (high conductivity wet soil) from other regions of the subsurface (low conductivity dry soil). Soil moisture data is also continuously recorded from sensors installed in 2003 at IMAX and Broadous. These data are periodically downloaded from the dataloggers at each site.

3.2.3 Sampling Procedures

During the 2001-2002 and 2002-2003 monitoring seasons, runoff samples were discrete grab samples collected during the early portion of the runoff event. During the 2003-2004 and 2004-2005 monitoring seasons, runoff samples were collected manually as time-weighted composite samples at twenty minute increments, with volatile organics and bacteria collected as grab samples. At the Metal Recycler and Sun Valley sites, automated samplers were used during the 2003-2004 season to collect whole storm flow-weighted composite samples, but due to equipment difficulties these were not reinstalled the next season. The flow-weighted composite samples are useful for estimating EMCs. The grab samples and two-hour time-weighted composites are likely more representative of the "first flush" concentration which may be higher than EMC for many constituents. All

water samples were submitted for analysis to Calscience Environmental Laboratories, Inc. in Garden Grove, California, within a few hours of collection.

3.2.4 Analytical Suite

The analytical suite is presented in **Table 4.** Additionally, temperature, pH and conductivity were measured in the field. Not all constituents were analyzed from lysimeter samples, for several reasons. Sampling from the lysimeters is restricted by the amount of water that can be evacuated from a lysimeter, which varies according to soil moisture conditions. Additionally, some analytes, such as total suspended solids and turbidity, are not measurable in a lysimeter, as they would be filtered by the lysimeter itself. Therefore, the sampling suite for lysimeters was reduced to selected priority analytes. A detailed list of constituents, including detection limits and laboratory methods, is provided in **Appendix B**.

Some constituents have consistently resulted in non-detects at all sample points. Bacteriological constituents (total coliforms, E. coli, and fecal coliforms) occur in stormwater, sometimes in very high concentrations, but detections in the lysimeter and groundwater samples have been extremely low or not detected at all. At the end of each season, the TAC revisited the constituent list to eliminate some of these constituents for the next season. For example, NDMA, pesticides, 1,4-Dioxane and bacteriological constituents were dropped from the list for the oldest sites after two years, and for the newest sites after one round of samples. Fuel oxygenates, in addition to MtBE, were added to the organics analysis (DIPE, ETBE, TAME, TBA and ethanol). The detection limit for 1,2,3-trichloropropane, an emerging contaminant in groundwater, was reduced to 0.005 µg/L for one round of samples at all sites.

Table 4
Summary of Analytical Suite

Category	Stormwater and wells	Lysimeters
General Minerals	X	X
Trace Metals (total & dissolved)	X	X
Oil and Grease	X	Hall House
Perchlorate	X	X
Glyphosate	X	Vets Park
Volatile organic compounds (VOCs)	X	X
Semi-volatile organic compounds (SVOCs)	X	
NDMA	X	
Surfactants	X	
Bacteria (total coliform, fecal coliform, e. coli)	X	X

3.2.5 Quality Control

In order to ensure the validity of sample results, a number of laboratory quality control procedures were followed, in accordance with our state-approved Quality Assurance Project Plan. The Quality Assurance Program Plan (QAPP) addresses field sample collection procedures, sample tracking and handling, and laboratory quality assurance and quality control (QA/QC) requirements. The laboratory selected for this project, Calscience Environmental Laboratories, is a certified laboratory with extensive experience with stormwater sampling requirements and a full range of analytical capabilities.

3.2.5.1 Field Quality Assurance/Quality Control

Field QA/QC samples were collected periodically and used to evaluate potential contamination and sampling error occurring prior to sample delivery to the analytical laboratory, and to verify laboratory results. Field QA/QC samples include trip blanks, equipment blanks, field blanks, and field duplicates.

Blank samples help verify that the equipment and the sample containers are not a source of contamination, and that the sampling techniques used are non-contaminating. Duplicates are used to assess variability attributable to shipment, storage, and/or laboratory handling and analysis. Procedures for collecting field blanks and duplicates are the same as that used for collecting the field samples.

3.2.5.2 Laboratory Quality Assurance/Quality Control

Analytical quality assurance/quality control for this study included the following:

- Employing analytical chemists trained in the procedures to be followed.
- Adherence to documented procedures, EPA methods, written Standard Operating Procedures, and other approved Standard Methods.
- Calibration of analytical instruments.
- Complete documentation of sample tracking and analysis.
- Internal laboratory quality control checks through the analysis of method blanks, MS/MSDs, lab duplicates, and lab control samples.

The last point references additional sample analysis that is performed routinely by the lab. Method blanks are run by the laboratory for each sample batch to determine the level of contamination, if any, associated with laboratory reagents and equipment. MS/MSDs, lab duplicates and lab control samples/duplicates are also run routinely for each batch, as sample volume is available and when samples are collected specifically for this purpose. Duplicate analyses results are evaluated by calculating the relative percent difference between the two sets of results. This serves as a measure of the reproducibility (precision) of the sample results.

3.2.5.3 Data Quality Objectives

Data quality objectives (DQOs) are quantitative and qualitative statements that clarify study objectives, and specify the tolerable levels of potential errors in the data. As defined in the Quality Assurance Project Plan, DQOs specify the quantity and quality of data required to support the study objectives. DQOs are generally used to determine the level of error considered to be acceptable in the data produced by the monitoring program. They are also used to specify acceptable ranges of field sampling and laboratory performance. DQOs for accuracy and precision have been achieved overall in the collected QA/QC samples.

Volatile organic compounds (VOCs) are of particular concern for groundwater quality. Because of their volatile nature, VOCs are rarely included in stormwater monitoring programs, so there is little comparative data. Over the course of the study methylene chloride was detected in a number of QC samples corresponding to field detections. These detections are likely the result of laboratory contamination and are flagged as such by the laboratory. In addition, acetone, toluene and 2-butanone (MEK) were detected in at least one field blank collected on the same day at the Broadous School, Hall House, and IMAX sites, as well as in an equipment blank, which may indicate contamination by sampling equipment. Although acetone is used on occasion in the laboratory, it was not present in any trip blanks in cases where it was detected in corresponding field samples, nor was it ever reported in laboratory method blanks. MEK is also often attributed to laboratory contamination however Calscience does not use it in their laboratory.

In one source identification study undertaken by USGS, toluene, acetone and MEK were found in all stormwater samples from a parking lot (Lopes et al 2000). This study also detected acetone and MEK in direct precipitation samples, indicating atmospheric sources. Acetone is an unregulated compound and is common in the environment from solvents, air emissions, and is a by-product of photosynthesis. Acetone was present in most stormwater samples at all sites, but only present in a few lysimeter and groundwater samples.

Dissolved organic carbon (DOC) was also detected in method blanks, indicating interference from the filter material used in sample filtration. When this occurs, reported DOC results are slightly inflated and are flagged as such by the laboratory. Overall, data quality and reliability seemed more than adequate to achieve the goals of the study.

4. MONITORING RESULTS

This section presents the results of the monitoring performed during the course of the Phase I and II monitoring program, from 2001 to 2005. Monitoring results include all analytical results from:

- Soil samples from all sites during lysimeter installation (pre-infiltration) and at the end of the monitoring phase.
- Pre- and post-season groundwater samples from upgradient and downgradient wells.
- Stormwater samples at all sites.
- Lysimeter samples from all sites.
- Post-storm groundwater samples from downgradient wells

A schedule of storm events sampled for each monitoring site is provided in **Table 5**. Additional sampling dates for limited lysimeter sampling, and baseline and end of season groundwater sampling are reflected in the **Appendix C** tables.

Table 5
Storm Event Sample Collection Dates

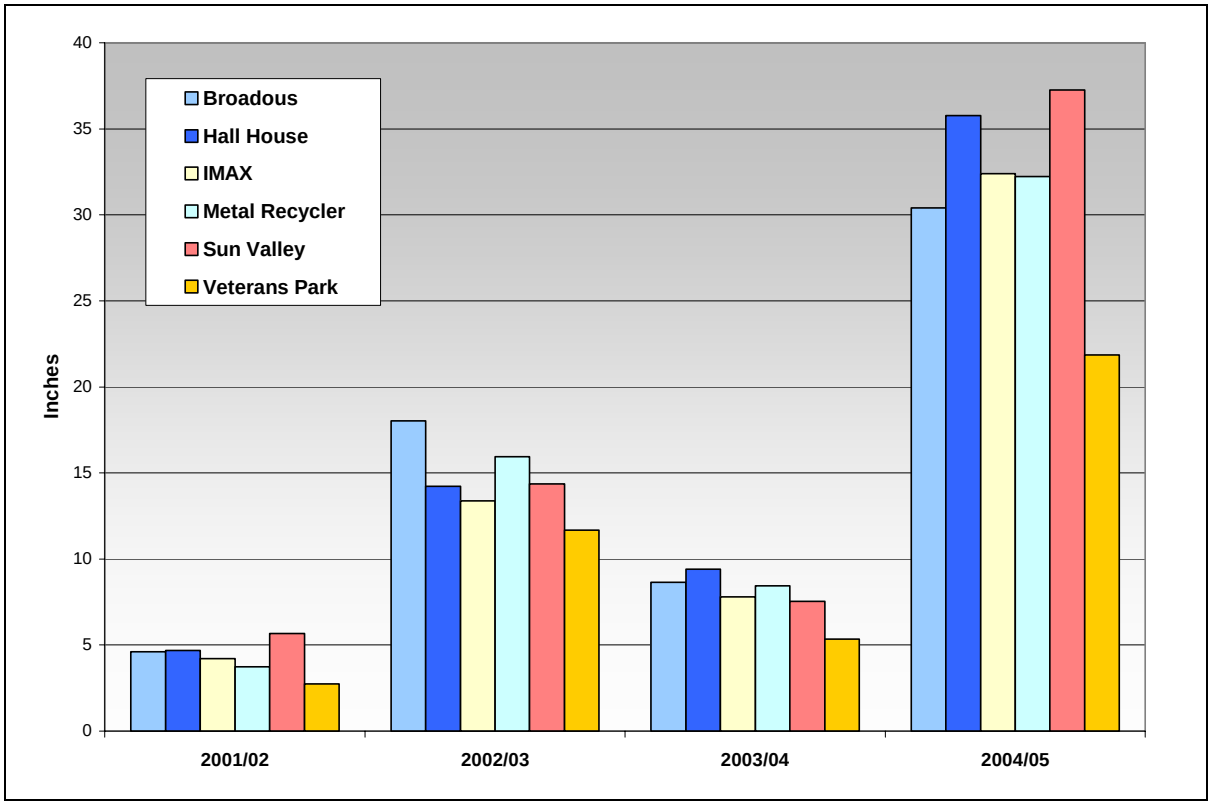
Event Date	IMAX	Broadous	Hall House	Metal Recycler	Sun Valley	Veterans
12/03/01		X				
11/08/02	X	X				
12/16/02	X	X	X			
2/12/03	X	X	X			
3/15/03	X	X				
2/02/04	X	X	X	X	X	X
2/18/04				X	X	X
2/25/04	X	X	X			
10/19/04					X	X
10/26/04				X		
12/27/04	X	X		X	X	X
1/07/05			X			
2/11/05				X	X	X
2/18/05	X	X	X			
Total Events	8	9	6	5	5	5

4.1 Description of the Storm Seasons

Annual rainfall for the six monitoring locations is shown in **Figure 9**, measured from the nearest Los Angeles County rain gauge. The four years of monitoring saw a wide range of rainfall variability, from the driest year on record (2001-2002) to the second wettest year on record (2004-2005). Rainfall varied geographically as well during the study. Total

rainfall amounts during 2004-05 ranged from about 22 inches at Veterans Park, to over 37 inches at the Sun Valley site (LACDPW 2005). This spatial and temporal variability presents some challenges not just for monitoring, but also for trying to appropriately size infiltration facilities to capture runoff cost-effectively.

Figure 9
Annual Rainfall by Monitoring Site



4.2 Groundwater Conditions

Depth to groundwater was measured whenever groundwater monitoring wells were sampled. Hydrographs depicting the groundwater elevations calculated for the sites are shown in **Appendix I**. Although groundwater elevations in the monitoring wells varied over the term of the study, all wells designated as downgradient were considered to have been subject to potential influence by stormwater infiltrated during the period of the study.

4.3 ANALYTICAL RESULTS

This section provides analytical results for all sampling points for selected constituents of concern in groundwater, including: general monitoring parameters (total dissolved solids [TDS], total suspended solids [TSS], nitrate, and chloride), total and dissolved metals (aluminum, arsenic, cadmium, copper, hexavalent chromium, lead, mercury, and zinc), volatile organic compounds (VOCs), semi-volatile compounds (SVOCs), biological

constituents (total coliforms, fecal coliform, and E. coli), and other constituents of interest such as perchlorate, NDMA, 1,4-dioxane and glyphosate. Polycyclic aromatic hydrocarbons, or PAHs, were not detected in any sample during the course of this study.

Comprehensive water quality analytical results are presented in **Appendix C**. Concentration ranges (minimum, maximum) of selected constituents discussed in this section are presented in site-specific summary tables (**Tables 6 to 11**) at the end of this section. The summary tables contain ranges of analytical results for selected general monitoring parameters, dissolved metals, biological and other constituents, and any VOCs and SVOCs detected in at least one sample.

For comparison purposes, results from other water quality sampling programs are presented in **Appendix D**. Data from this study were compared to those from the Los Angeles County Public Works' land use monitoring program (LACDPW 2002) and the Southern California Coastal Water Research Project's (SCCWRP) region-wide comparison of constituent loads from different land uses (Ackerman 2003), to assess whether the sites sampled for this study were typical for their land use. The LACDPW data were collected between 1994 and 2000 for compliance with LACDPW's 1996 NPDES stormwater permit, and results are summarized by land use category. Values represent the mean and median of all EMCs, analyzed from flow-weighted composite samples. The constituents included in these two previous studies are similar to those included in the WAS program but not as extensive, for example VOCs and perchlorate were not included. VOCs are not typically sampled in stormwater because of their volatility, and perchlorate has not been identified as a pollutant of concern for stormwater. Although results based on EMCs and composite samples are not directly comparable, the concentrations of general monitoring parameters and metals in stormwater samples collected and analyzed for this study were generally within the range of results reported for similar land use types in the previous studies. Appendix D also includes composite results from recent groundwater samples taken from monitoring wells throughout the West and Central Basins.

4.3.1 Broadous School

Monitoring began at this site in October 2001. A summary of sampled storm events is contained in Table 5. Figure A-1 is a site location map showing the installed monitoring and infiltration BMP systems.

Surface stormwater samples were collected at one location in the playground (B-SW-01). At the beginning of the 2003-2004 monitoring season, the location of B-SW-01 was changed in an attempt to collect samples more representative of stormwater runoff that is infiltrated. During the 2001-2002 and 2002-2003 monitoring seasons, samples collected at B-SW-01 were single grab samples collected near the beginning of storm runoff. Samples collected from B-SW-01 during the last two monitoring seasons were time-weighted composites of aliquots collected at approximately 30-minute increments during the first two hours storm runoff.

Soil pore fluid samples were collected from a single lysimeter, B-LS-01. At the beginning of the 2003-2004 monitoring season, the original lysimeter was abandoned because of difficulty collecting samples at that depth, and a new lysimeter, B-LS-02, was installed in a position closer to the infiltration BMP. Pore fluid samples were typically collected daily over a two or three day period beginning one day after collection of a stormwater sample.

Groundwater samples were collected from two monitoring wells, B-MW-01 (upgradient) and B-MW-02 (downgradient). Because groundwater at the site is relatively deep (greater than 130 feet below ground surface [bgs]), groundwater samples were collected periodically during the season rather than in direct response to a storm event.

Appendix H presents soil boring logs for Broadous School. Soil analytical data for one sample, B-L-D, collected from the lysimeter borehole on August 26, 2001, are contained in Tables E-1 through E-3. The depth of sample B-L-D was 32 feet below ground surface. The boring logs indicate that the upper 35 feet of sediment at this site is composed of relatively uniform silty sands with some gravel. The soil chemical analytical results indicate VOCs were not detected. Perchlorate was reported at 330 ug/kg, but concentrations of other salts and metals were within the expected ranges for these constituents.

4.3.2 Hall House

Monitoring began at this site in December 2002. A summary of sampled storm events is contained in Table 5. Figure A-2 is a site location map showing the installed monitoring and infiltration BMP systems.

Surface stormwater samples were collected at two locations, the roof drain (H-SW-01) and the driveway (H-SW-02). During the 2002-2003 monitoring season, samples collected at the two monitoring stations were single grab samples collected near the beginning of storm runoff. Samples collected during the 2003-2004 and 2004-2005 monitoring seasons were time-weighted composites of aliquots collected at approximately 30-minute increments during the first two hours of storm runoff.

Soil pore fluid samples were collected from a single lysimeter, H-LS-01. Pore fluid samples were typically collected daily over a two or three day period beginning one day after collection of a stormwater sample.

No monitoring wells are installed at the Hall House site.

Appendix H presents soil boring logs collected at the Hall House site. Soil analytical data for samples HA-1 and HA-2, collected at depths of 1 and 8 feet bgs on October 28, 2002, and sample H-B-1, collected at a depth of 8 feet bgs on March 10, 2005, are contained in Tables E-1 through E-3. The boring logs indicate that the upper 6 feet of sediment is composed of silt with minor amounts (<10%) of sands and clay. Between 6 and 8 feet bgs some gravel and nonplastic clay were encountered. The soil chemical analytical results did not indicate detected VOCs. Concentrations of salts (nitrate, chloride, sulfate) and some

metals (arsenic, lead) were near the lower end of the ranges expected for these constituents, especially considering the fine-grained fraction of sediment present in the sampled depth interval.

4.3.3 IMAX

Monitoring began at this site in October 2001. A summary of sampled storm events is contained in Table 5. Figure A-3 is a site location map showing the installed monitoring and infiltration BMP systems.

Surface stormwater samples were collected at two locations; a roof drain (I-SW-01) and a station for collecting parking lot runoff as it discharges into a planter area (I-SW-02). During the 2001-2002 and 2002-2003 monitoring seasons, samples collected at the two monitoring stations were single grab samples collected near the beginning of storm runoff. Samples collected from these monitoring stations during the 2003-2004 and 2004-2005 monitoring seasons were time-weighted composites of aliquots collected at approximately 30-minute increments during the first two hours of storm runoff.

For the first two years of the project, soil pore fluid samples were collected from lysimeters I-LS-01 and I-LS-02. During the summer of 2004, lysimeter I-LS-02 was damaged during road construction. At the beginning of the 2004-2005 monitoring season, this lysimeter was replaced with new lysimeter, I-LS-03, installed in the planter area about 20 feet from the original location. Pore fluid samples were typically collected daily over a two or three day period beginning one day after collection of a stormwater sample.

Groundwater samples were collected from two monitoring wells, I-MW-01 (upgradient) and I-MW-02 (downgradient). Both wells were sampled before and after each monitoring season. I-MW-02 was also sampled after each sampled storm event. Upgradient well I-MW-01 was sampled occasionally during each monitoring season, but not after each sampled storm.

Appendix H presents soil boring logs for IMAX and soil analytical data for two samples, I-LS-02 collected from the lysimeter borehole 5 feet bgs on October 16, 2001 and soil sample I-B1 collected approximately 8 feet west of I-LS-02 on March 10, 2005, also at 5 feet bgs. The boring logs for I-LS-2 and I–B1 indicate that the upper 5 feet of sediment at this site is composed primarily of plastic clays and silt with minor amounts (<5%) of sand. The soil chemical analytical results did not indicate detected VOCs. Concentrations of salts (nitrogen, nitrate, chloride, sulfate) and some metals (arsenic, chromium) were reported at relatively high concentration relative to other soil samples tested. Perchlorate was also reported in the sample collected in 2001 but was not detected in the sample from March 2005.

4.3.4 Metal Recycler

Monitoring began on this site in November 2003. A summary of sampled storm events is contained in Table 5. Figure A-4 is a site location map showing the installed monitoring and infiltration BMP systems.

Surface stormwater samples were collected at two locations, one collecting runoff from a paved work yard as it enters a catch basin (M-SW-01) and the other sampling the same runoff after pre-treatment (M-SW-02). During the 2003-2004 monitoring season, flow-weighted composite samples were collected using automated equipment. Automated sampling was discontinued because of difficulties using this equipment, and during the 2004-2005 monitoring season samples collected from these monitoring stations were time-weighted composites of aliquots collected at approximately 30-minute increments during the first two hours of storm runoff.

Soil pore fluid samples were collected from four lysimeters, M-LS-01, M-LS-02, M-LS-03, and M-LS-04. Pore fluid samples were typically collected daily over a two or three day period beginning one day after collection of a stormwater sample.

Groundwater samples were collected from one monitoring well, M-MW-01. Groundwater samples were collected at the beginning and end of each monitoring season. Because groundwater at the site is relatively deep (greater than 200 feet bgs), groundwater samples during each monitoring season were collected periodically during the season rather than in direct response to a storm event.

Appendix H presents soil boring logs for the Metal Recycler and soil analytical data for two soil samples, M-LS-01 and M-LS-02 collected at 20 and 36.5 feet bgs, respectively, on November 11, 2003. The boring logs indicate that the upper 50 feet of sediment is composed of relatively uniform (poorly graded) silty fine sands. The soil chemical analytical results did not report detected VOCs or perchlorate. However, some of the soil-gas samples collected during the site assessment contained tetrachloroethylene (PCE) and trichloro-fluoromethane. Concentrations of salts and metals (arsenic, chromium) were relatively low compared to those in soil samples from the other sites.

4.3.5 Sun Valley

Monitoring began at this site in October 2003. A summary of sampled storm events is contained in Table 5. Figure A-5 is a site location map showing the installed monitoring and infiltration BMP systems.

Surface stormwater samples were collected at three locations, representing roof runoff (S-SW-01), runoff from the paved yard into a collection basin (S-SW-02), and flow discharging from the collection basin after treatment (S-SW-03). During the 2003-2004 monitoring season, flow-weighted composite samples were collected using automated equipment. Automated sampling was discontinued because of difficulties using this equipment, and during the 2004-2005 monitoring season samples collected from these

monitoring stations were time-weighted composites of aliquots collected at approximately 30-minute increments during the first two hours storm runoff.

Soil pore fluid samples were collected from five lysimeters, S-LS-01, S-LS-02, S-LS-03, S-LS-04, and S-LS-05. Pore fluid samples were typically daily collected over a two or three day period beginning one day after collection of a stormwater sample.

Groundwater beneath the site occurs at more than 300 feet bgs and no on-site monitoring wells were installed. As an indication of regional groundwater quality, samples were collected from EV-10, an inactive groundwater supply well owned by the Los Angeles Department of Water and Power and located about a mile downgradient from the site. Groundwater samples were collected from EV-10 at the beginning and ending of each monitoring season.

Appendix H presents soil boring logs collected at the Sun Valley site. Soil analytical data is presented in Tables E1 through E3. Five soil samples collected at this site were analyzed: S-1 (collected at 5 feet bgs on October 29, 2003), S-LS-01 and S-LS-02, (collected at 23 and 46 feet bgs, respectively, on November 11, 2003), and S-B-01-1 and S-B-01-2 (collected at 23 and 46 feet bgs, respectively, on March 17, 2005). The boring logs indicate that the upper 50 feet of sediment is composed of relatively uniform (poorly graded) sand with gravel. The soil chemical analytical results did not indicate detected VOCs or perchlorate. Concentrations of salts and metals (arsenic, chromium, nickel, zinc) were low compared to those in soil samples from the other sites.

4.3.6 Veterans Park

Monitoring began on this site in November 2003. A summary of sampled storm events is contained in Table 5. Figure A-6 is a site location map showing the installed monitoring and infiltration BMP systems.

Surface stormwater samples are collected at two locations where runoff enters parking lot catch basins (V-SW-01 and V-SW-02). Samples collected from these monitoring stations were time-weighted composites of aliquots collected at approximately 30-minute increments during the first two hours storm runoff.

Soil pore fluid samples were collected from two lysimeters, V-LS-01 and V-LS-02. Pore fluid samples were typically daily collected over a two or three day period beginning one day after collection of a stormwater sample.

Groundwater samples were collected from four monitoring wells. V-MW-01 is downgradient to crossgradient and is more than 100 feet from the infiltration gallery. The other three wells are within about 30 feet of the infiltration gallery: V-MW-02 (relatively upgradient), V-MW-03 (relatively upgradient), and V-MW-04 (relatively downgradient). All wells were sampled before and after each monitoring season. V-MW-04 was also sampled after each sampled storm event. The other three wells were sampled occasionally during each monitoring season, but not after each sampled storm.

Appendix H presents soil boring logs for Veterans Park and soil analytical data for two samples, V-LS-1 and V-B1, collected at 10 to 15 feet bgs on October 29, 2003 and March 11, 2005, respectively. The boring logs indicate that the upper 10 feet of sediment is composed of interbedded silts and fine sands. The soil chemical analytical results did not indicate detected VOCs or perchlorate. Concentrations of salts (alkalinity, calcium, potassium, chloride and sulfate) were variable, as were metals concentrations (barium, chromium, copper and zinc).

Table 6 Summary Results – Broadous

			Monitoring Station[2]				
Constituent	**Units[1]**	**Fraction**	**B-SW-01**	**B-LS-01**	**B-LS-02**	**B-MW-01**	**B-MW-02**
General Monitoring Parameters							
Nitrate (as N)	mg/L	N/A	ND - 1	0.583 - 110	2.4 - 4	0.3 - 8.4	5.6 - 10.509
Total Kjeldahl Nitrogen	mg/L	N/A	1.1 - 6.2	--	ND	ND - 0.34	ND - 0.35
Ammonia-Nitrogen	mg/L	N/A	ND - 1.02	ND - 0.14	ND - 0.35	ND	ND - 0.33
Total Dissolved Solids	mg/L	N/A	43 - 330	78 – 1700	490 - 990	540 - 680	570 - 846
Total Suspended Solids	mg/L	N/A	12 - 200	130	--	ND - 2548	ND - 2100
Chemical Oxygen Demand	mg/L	N/A	23 - 220	247	ND - 36	ND - 32.37	ND - 120
Chloride	mg/L	N/A	2 - 72	70-160	37 - 130	22-87	19-28.28
Metals							
Aluminum	µg/L	Dissolved	ND - 259	ND	ND	ND	ND
Aluminum	µg/L	Total	337 - 6500	ND - 68.7	ND	ND - 176	ND - 17900
Arsenic	µg/L	Dissolved	ND - 2.5	2.18 - 5.63	1.91 - 11.3	ND	ND - 1.29
Arsenic	µg/L	Total	ND - 2.99	ND - 7.92	2.2 - 12.3	ND - 3.5	ND - 2.86
Cadmium	µg/L	Dissolved	ND	ND	ND - 0.215	ND	ND
Chromium, Hexavalent	µg/L	Dissolved	ND - 0.49	0.39 – 0.59	0.62 - 1.2	0.1 - 1.7	ND - 1.1
Copper	µg/L	Dissolved	ND - 22.1	5.83 - 66.9	2.68 - 19	ND - 5.27	ND - 87
Copper	µg/L	Total	4.33 - 39.9	10.3 - 220	2.85 - 19	ND - 73.1	ND - 87
Lead	µg/L	Dissolved	ND - 1.22	ND - 0.54	ND - 0.695	ND	ND - 9.56
Lead	µg/L	Total	ND - 36.3	ND - 6.44	ND - 0.84	ND - 34.7	ND - 30.4
Mercury	µg/L	Dissolved	ND	--	ND	ND	ND - 0.109
Zinc	µg/L	Dissolved	7.54 - 369	42.2 - 828	6.91 - 71.8	ND - 412	ND - 77.5
Zinc	µg/L	Total	14.1 - 369	ND - 2060	11.1 - 25.9	5.69 - 950	ND - 157
Other Constituents							
MBAS (Surfactants)	mg/L	N/A	ND - 0.38	--	--	ND	ND
Oil and Grease	µg/L	N/A	ND - 3.6	--	--	ND - 1.3	1.6 - 2.9
Perchlorate	µg/L	N/A	ND - 5.2	ND	ND	ND	ND

			Monitoring Station[2]				
Constituent	**Units[1]**	**Fraction**	**B-SW-01**	**B-LS-01**	**B-LS-02**	**B-MW-01**	**B-MW-02**
Volatile Organic Compounds							
Benzene	µg/L	N/A	ND	ND	ND	ND - 2.3	ND - 0.87
Toluene	µg/L	N/A	ND	ND	ND	ND - 6.4	ND
Ethylbenzene	µg/L	N/A	ND	ND	ND	ND - 1.2	ND - 1.1
o-Xylene	µg/L	N/A	ND	ND	ND	ND - 8.4	ND - 3.2
p/m-Xylene	µg/L	N/A	ND	ND	ND	ND - 5.7	ND - 3.8
Tetrachloroethylene (PCE)	µg/L	N/A	ND	ND	ND	ND - 44	ND - 1.5
1,2,4-Trimethylbenzene	µg/L	N/A	ND	ND	ND	ND - 1.1	ND - 1
1,3,5-Trimethylbenzene	µg/L	N/A	ND	ND	ND	ND - 1.1	ND - 0.55
2-Butanone (Methylethyl ketone)	µg/L	N/A	ND - 8.8	ND	ND	ND - 1	ND - 1
Acetone	µg/L	N/A	ND - 37	ND	ND - 600	ND - 26	ND - 2.7
Carbon disulfide	µg/L	N/A	ND	ND - 5.6	ND – 2.5	ND	ND
Diethyl Ether	µg/L	N/A	ND - 0.8	ND	ND	ND	ND
Naphthalene	µg/L	N/A	ND	ND	ND	ND - 1.1	ND - 1.1
Tert-Butyl Alcohol (TBA)	µg/L	N/A	ND	ND - 12	ND	ND	ND
Semi-Volatile Organic Compounds							
Bis(2-Ethylhexyl) Phthalate	µg/L	N/A	ND - 20	--	--	ND - 4.8	ND - 74.3
Biological Parameters							
Total Coliforms	MPN/100 mL	N/A	1300 - 35000	ND - 90000	--	12 - 30000	ND - 11000
Fecal Coliform	MPN/100 mL	N/A	80 - 5000	ND	--	23	ND - 1.1
E. coli	MPN/100 mL	N/A	20 - 1300	ND	--	6.9	ND
1. Units of measure: mg/L = milligrams per liter, µg/L = micrograms per liter, MPN/100 mL = most probable number per 100 milliliters.							
2. "--" indicates the constituent was not analyzed for. Analytes not detected are indicated by ND.							

Table 7 Summary Results – Hall House

			Monitoring Station[2]		
Constituent	**Units[1]**	**Fraction**	**H-SW-01**	**H-SW-02**	**H-LS-01**
General Monitoring Parameters					
Nitrate (as N)	mg/L	N/A	ND - 0.39	0.24 - 1.5	ND - 0.28
Total Kjeldahl Nitrogen	mg/L	N/A	ND - 2	1.4 - 24	ND - 0.28
Ammonia-Nitrogen	mg/L	N/A	ND - 0.49	0.28 - 2	ND
Total Dissolved Solids	mg/L	N/A	10 - 82	28 - 48	290 - 610
Total Suspended Solids	mg/L	N/A	ND - 51	9.6 - 110	--
Chemical Oxygen Demand	mg/L	N/A	5 - 74	69 - 280	ND - 5.1
Chloride	mg/L	N/A	ND-3.2	ND-3.4	ND-65
Metals					
Aluminum	µg/L	Dissolved	ND	ND - 122	ND
Aluminum	µg/L	Total	ND - 2540	1340 - 8210	ND
Arsenic	µg/L	Dissolved	ND	ND - 1.19	ND - 4.26
Arsenic	µg/L	Total	ND - 1.31	ND - 3.56	ND
Cadmium	µg/L	Dissolved	ND - 0.396	ND	ND - 0.245
Chromium, Hexavalent	µg/L	Dissolved	ND - 0.41	ND - 0.95	0.37 - 0.66
Copper	µg/L	Dissolved	1.3 - 6.93	3.81 - 17	1.58 - 7.71
Copper	µg/L	Total	1.55 - 41.3	28.8 - 123	2.43 - 6.4
Lead	µg/L	Dissolved	1.86 - 6.16	0.522 - 3.12	ND - 0.591
Lead	µg/L	Total	8.81 - 99.3	46 - 138	ND - 0.598
Mercury	µg/L	Dissolved	ND	ND	ND
Zinc	µg/L	Dissolved	86.3 - 496	27.4 - 88.1	ND - 56.9
Zinc	µg/L	Total	93.4 - 933	189 - 849	6.36 - 38.3
Other Constituents					
MBAS (Surfactants)	mg/L	N/A	ND - 0.37	ND - 0.36	--
Oil and Grease	µg/L	N/A	ND - 2.2	1.6 - 52	ND - 1.1
Volatile Organic Compounds					
2-Butanone (Methylethyl ketone)	µg/L	N/A	ND	ND - 1.8	ND
Acetone	µg/L	N/A	7.9 - 26	6.6 - 15	ND
Carbon disulfide	µg/L	N/A	ND	ND	ND - 3.6
Tert-Butyl Alcohol (TBA)	µg/L	N/A	ND	ND	ND - 12
Semi-Volatile Organic Compounds					
Bis(2-Ethylhexyl) Phthalate	µg/L	N/A	ND	400	--
Biological Parameters					
Total Coliforms	MPN/100 mL	N/A	ND - 600	--	--
Fecal Coliform	MPN/100 mL	N/A	ND	--	--
E. coli	MPN/100 mL	N/A	ND	--	--

1. Units of measure: mg/L = milligrams per liter, µg/L = micrograms per liter, MPN/100 mL = most probable number per 100 milliliters.

2. "--" indicates the constituent was not analyzed for. Analytes not detected are indicated by ND.

Table 8 Summary Results – IMAX

			Monitoring Station[2]						
Constituent	**Units[1]**	**Fraction**	**I-SW-01**	**I-SW-02**	**I-LS-01**	**I-LS-02**	**I-LS-03**	**I-MW-01**	**I-MW-02**
General Monitoring Parameters									
Nitrate (as N)	mg/L	N/A	0.15 - 0.44	ND - 1.2	7.7 - 320	0.41 - 8.2	0.41 - 1	3.2 - 16	7.2 - 24.365
Total Kjeldahl Nitrogen	mg/L	N/A	ND - 1.5	0.84 - 2.1	ND - 0.46	ND	ND	ND - 1	ND - 0.42
Ammonia-Nitrogen	mg/L	N/A	ND - 0.35	ND - 0.56	ND - 0.056	ND - 0.063	ND	ND - 0.337	ND
Total Dissolved Solids	mg/L	N/A	6.7 - 34	6.7 - 37	710 - 3000	130 - 750	180 - 750	630 - 840	500 - 882
Total Suspended Solids	mg/L	N/A	ND - 110	ND - 140	--	--	--	7.1 - 130	ND - 1667
Chemical Oxygen Demand	mg/L	N/A	7.7 - 64	13 - 61	ND - 58	6 - 36	5.1 - 20	ND - 7.6	ND - 131.6
Chloride	mg/L	N/A	ND-1.8	ND-3.6	53-120	ND-94	ND - 94	22-60	29-50
Metals									
Aluminum	µg/L	Dissolved	ND	ND - 105	ND	ND	ND	ND	ND
Aluminum	µg/L	Total	ND - 1180	105 - 952	ND - 455	124 - 455	ND	8.8 - 3680	ND - 495
Arsenic	µg/L	Dissolved	ND	1.3 - 138	1.62 - 6.78	2.2 - 22.1	3.17 - 4.77	ND - 1.4	ND - 2
Arsenic	µg/L	Total	ND - 6.51	1.44 - 153	1.51 - 8.47	9.74 - 28.6	3.15 - 5.39	ND - 4.3	ND - 5.15
Cadmium	µg/L	Dissolved	ND	ND	ND - 0.524	ND	ND	ND	ND
Chromium, Hexavalent	µg/L	Dissolved	ND - 0.3	ND - 0.61	2 - 35.2	0.55 - 74	0.55 - 1	5.6 - 24	ND - 4.6
Copper	µg/L	Dissolved	1.17 - 8.2	1.99 - 137	ND - 10.1	ND - 4.48	ND - 1.32	ND - 5.22	ND - 38.5
Copper	µg/L	Total	2.51 - 37.7	4.99 - 157	3.65 - 25.5	3.01 - 34	ND - 1.26	ND - 20.8	ND - 47.3
Lead	µg/L	Dissolved	ND	ND - 0.769	ND - 0.866	ND	ND	ND	ND - 0.816
Lead	µg/L	Total	ND - 76.4	0.947 - 13.7	ND - 6.3	0.723 - 9.4	ND	ND - 3	ND - 11.2
Mercury	µg/L	Dissolved	ND	ND	--	ND	ND	ND	ND - 0.154
Zinc	µg/L	Dissolved	37.7 - 169	32.5 - 757	25 - 130	21 - 4650	6.89 - 9.07	ND - 75.3	ND - 400
Zinc	µg/L	Total	60.6 - 566	50.3 - 1240	62.8 - 209	120 - 7050	8.5 - 14.2	ND - 80.1	ND - 400
Other Constituents									
MBAS (Surfactants)	mg/L	N/A	ND - 0.19	ND - 0.19	--	--	--	ND - 0.19	ND - 0.15
Oil and Grease	µg/L	N/A	ND - 58	ND - 1.7	--	--	--	ND - 1	1.7
Perchlorate	µg/L	N/A	ND - 14	ND	ND	ND	--	ND - 8.2	ND - 15

			Monitoring Station[2]						
Constituent	**Units[1]**	**Fraction**	**I-SW-01**	**I-SW-02**	**I-LS-01**	**I-LS-02**	**I-LS-03**	**I-MW-01**	**I-MW-02**
Volatile Organic Compounds									
Methyl-t-Butyl Ether (MtBE)	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND - 1.3
Benzene	µg/L	N/A	ND	ND	ND	ND	ND	ND - 3.1	ND - 2.6
Toluene	µg/L	N/A	ND	ND	ND	ND	ND	ND - 2.4	ND - 16
Ethylbenzene	µg/L	N/A	ND	ND	ND	ND - 27	16 - 27	ND - 2.1	ND - 9.3
o-Xylene	µg/L	N/A	ND	ND	ND	ND - 37	33 - 37	ND - 5.6	ND - 19
p/m-Xylene	µg/L	N/A	ND	ND	ND	ND - 170	89 - 170	ND - 6.7	ND - 33
Tetrachloroethylene (PCE)	µg/L	N/A	ND	ND	ND	ND	ND	ND - 0.73	ND - 38
1,2,4-Trimethylbenzene	µg/L	N/A	ND	ND	ND	ND - 2.1	1.2 - 2.1	ND - 1.9	ND - 6.9
1,3,5-Trimethylbenzene	µg/L	N/A	ND	ND	ND	ND - 0.6	ND - 0.6	ND - 0.81	ND - 3
2-Butanone (Methylethyl ketone)	µg/L	N/A	ND - 1.5	ND - 1.7	ND	ND	ND	ND	ND
Acetone	µg/L	N/A	2.5 - 17	2.6 - 15	ND - 3.7	ND - 2.1	ND - 2.1	ND - 2.7	ND - 3.1
Carbon disulfide	µg/L	N/A	ND	ND	ND - 1.2	ND - 24	1.4 - 24	ND	ND
Diethyl Ether	µg/L	N/A	ND - 0.88	ND - 1.2	ND	ND	ND	ND	ND
Naphthalene	µg/L	N/A	ND	ND	ND	ND	ND	ND - 2.1	ND - 1.6
n-Propylbenzene	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND - 0.75
Tert-Butyl Alcohol (TBA)	µg/L	N/A	ND	ND	ND - 13	ND	ND	ND	ND
Semi-Volatile Organic Compounds									
Bis(2-Ethylhexyl) Phthalate	µg/L	N/A	ND	ND	--	--	--	ND	ND - 202.3
Phenol	µg/L	N/A	ND	ND	--	--	--	ND	ND - 18
Biological Parameters									
Total Coliforms	MPN/100 mL	N/A	500	ND - 13000	ND - 8	ND - 13	--	ND - 800	11 - 110
Fecal Coliform	MPN/100 mL	N/A	20	ND - 260	ND	ND	--	ND	ND
E. coli	MPN/100 mL	N/A	20	ND - 120	ND	ND	--	ND	ND

1. Units of measure: mg/L = milligrams per liter, µg/L = micrograms per liter, MPN/100 mL = most probable number per 100 milliliters.

2. "--" indicates the constituent was not analyzed for. Analytes not detected are indicated by ND.

Table 9 Summary Results - Metal Recycler

			Monitoring Station[2]						
Constituent	**Units[1]**	**Fraction**	**M-SW-01**	**M-SW-02**	**M-LS-01**	**M-LS-02**	**M-LS-03**	**M-LS-04**	**M-MW-01**
General Monitoring Parameters									
Nitrate (as N)	mg/L	N/A	1.6 - 4.2	3.2 - 4.2	1 - 16	1 - 5.6	ND - 3.8	5.7 - 12	ND - 0.12
Total Kjeldahl Nitrogen	mg/L	N/A	6.4 - 11	8.3 - 9.5	ND - 2.7	ND - 1.4	0.98 - 1.3	2.1 - 2.5	ND - 1.1
Ammonia-Nitrogen	mg/L	N/A	0.84 - 1.9	0.91 - 2.5	ND - 2.1	ND - 0.28	ND	ND - 0.7	ND
Total Dissolved Solids	mg/L	N/A	520 - 1400	670 - 1400	570 - 1700	630 - 1300	1100 - 1200	820 - 1100	840 - 1100
Total Suspended Solids	mg/L	N/A	61 - 1200	100 - 1200	--	--	--	--	ND - 20
Chemical Oxygen Demand	mg/L	N/A	570 - 3400	420 - 2100	13 - 54	18 - 46	33 - 79	84 - 240	ND - 57
Chloride	mg/L	N/A	35-100	50-72	28-110	35-99	60-110	36-79	70-86
Metals									
Aluminum	µg/L	Dissolved	ND - 248	ND - 379	ND	ND	ND	ND	ND
Aluminum	µg/L	Total	434 - 8360	868 - 5620	ND	ND	ND	ND	ND - 330
Arsenic	µg/L	Dissolved	ND - 2.96	ND - 2.94	ND - 5.14	ND - 3.1	3.32 - 13.9	2.88 - 5.67	0.765 - 5.65
Arsenic	µg/L	Total	1.72 - 11.9	4.16 - 10.3	ND - 4.02	0.992 - 2.98	8.52 - 13.5	2.77 - 5.44	1.83 - 8.39
Cadmium	µg/L	Dissolved	0.627 - 3.26	0.285 - 14.1	0.294 - 0.761	ND - 0.637	ND	ND - 0.27	ND
Chromium, Hexavalent	µg/L	Dissolved	6.3 - 74	ND - 52	ND - 1.9	ND - 4.2	ND - 0.6	6 - 14	ND - 0.23
Copper	µg/L	Dissolved	59.7 - 158	47 - 153	3.01 - 17.4	3.33 - 6.99	2.93 - 6.54	7.36 - 16.5	ND - 1.41
Copper	µg/L	Total	148 - 792	124 - 330	3.58 - 27.2	4.17 - 14.6	3.08 - 6.69	8.74 - 17.3	ND - 3.46
Lead	µg/L	Dissolved	11.8 - 120	3.69 - 185	ND - 6.82	ND - 0.632	ND - 1.62	ND - 0.95	ND
Lead	µg/L	Total	292 - 3020	460 - 1560	1.33 - 6.9	0.872 - 4.23	ND - 0.785	ND - 0.61	ND - 1.16

			Monitoring Station[2]						
Constituent	**Units[1]**	**Fraction**	**M-SW-01**	**M-SW-02**	**M-LS-01**	**M-LS-02**	**M-LS-03**	**M-LS-04**	**M-MW-01**
Mercury	µg/L	Dissolved	ND - 0.235	ND - 0.279	ND	ND	ND	ND	ND - 0.103
Zinc	µg/L	Dissolved	16.9 - 244	26.6 - 1550	35.7 - 101	20.6 - 165	19.5 - 26.3	21.2 - 27.2	ND - 14
Zinc	µg/L	Total	957 - 3220	1170 - 2790	64 - 141	18.5 - 195	12.2 - 27.2	11.4 - 45	ND - 17.3
Other Constituents									
MBAS (Surfactants)	mg/L	N/A	0.48 - 1.7	0.86 - 1.7	--	--	--	--	ND
Oil and Grease	µg/L	N/A	49 - 390	17 - 170	--	--	--	--	ND - 2.4
Perchlorate	µg/L	N/A	ND - 120	ND - 170	13 - 140	15 - 54	ND - 33	10 - 18	ND
Volatile Organic Compounds									
Methyl-t-Butyl Ether (MtBE)	µg/L	N/A	ND - 1.3	ND - 1.7	ND - 33	ND - 26	ND - 10	ND - 2.9	ND
Benzene	µg/L	N/A	ND - 0.83	ND - 2.3	ND - 0.65	ND - 2.3	ND - 0.7	ND	ND
Toluene	µg/L	N/A	ND - 5.8	ND - 25	ND - 13	ND - 5.8	ND - 3	ND	ND
Ethylbenzene	µg/L	N/A	ND - 2	ND - 7.1	ND - 4.3	ND - 0.7	ND - 0.93	ND	ND
o-Xylene	µg/L	N/A	ND - 3.8	ND - 11	ND - 8.1	ND - 1.5	ND - 2.9	ND	ND
p/m-Xylene	µg/L	N/A	ND - 8.6	ND - 28	ND - 19	ND - 2.7	ND - 3.7	ND	ND
Tetrachloroethylene (PCE)	µg/L	N/A	ND	ND	ND - 0.92	ND	0.51 - 1.1	ND	ND
1,2,4-Trimethylbenzene	µg/L	N/A	ND - 4.3	ND - 10	ND - 4	ND	ND - 0.83	ND	ND
1,3,5-Trimethylbenzene	µg/L	N/A	ND - 1.1	ND - 2.8	ND - 1.3	ND	ND	ND	ND
2-Butanone (Methylethyl ketone)	µg/L	N/A	5.2 - 14	5.4 - 32	ND	ND - 11	ND - 1.3	ND	ND
4-Methyl-2-pentanone (MIBK)	µg/L	N/A	ND	ND - 21	ND	ND	ND - 10	ND	ND
Acetone	µg/L	N/A	20 - 79	19 - 190	ND - 4.4	ND - 34	ND - 37	ND - 16	ND
Carbon disulfide	µg/L	N/A	ND	ND	ND - 6.9	ND - 3.5	ND - 2	ND - 0.57	ND - 1.7
Dichlorodifluoromethane	µg/L	N/A	ND - 4.1	ND - 3.8	ND	ND	ND	ND	ND
Diethyl Ether	µg/L	N/A	ND	ND - 1.1	ND	ND - 1.7	ND	ND	ND
Ethanol	µg/L	N/A	160 - 1200	120 - 22000	ND	ND - 3200	ND	ND	ND
Methyl Methacrylate	µg/L	N/A	ND - 3.9	ND - 3.1	ND - 2.3	ND	ND	ND	ND

			Monitoring Station[2]						
Constituent	**Units[1]**	**Fraction**	**M-SW-01**	**M-SW-02**	**M-LS-01**	**M-LS-02**	**M-LS-03**	**M-LS-04**	**M-MW-01**
Naphthalene	µg/L	N/A	ND - 1.7	0.51 - 8.6	ND	ND	ND	ND	ND
n-Propylbenzene	µg/L	N/A	ND	ND - 1.1	ND - 0.69	ND	ND	ND	ND
Styrene	µg/L	N/A	ND - 1.3	ND - 7.2	ND - 1.5	ND	ND	ND	ND
Tert-Butyl Alcohol (TBA)	µg/L	N/A	ND - 15	ND - 22	ND - 11	ND - 17	ND - 24	ND	ND
Tetrahydrofuran	µg/L	N/A	ND	ND - 11	ND	ND	ND - 3.6	ND	ND
Trichlorofluoromethane	µg/L	N/A	ND -4.2	ND - 28	ND - 1	ND - 1.8	ND - 1.4	ND - 0.7	ND
Semi-Volatile Organic Compounds									
4-Methylphenol (p-Cresol)	µg/L	N/A	ND	ND - 24	--	--	--	--	ND
4-Nitrophenol	µg/L	N/A	ND	ND - 19	--	--	--	--	ND
Benzoic acid	µg/L	N/A	ND -770	ND - 560	--	--	--	--	ND
Benzyl alcohol	µg/L	N/A	ND	ND - 40	--	--	--	--	ND
Bis(2-Ethylhexyl) Phthalate	µg/L	N/A	ND	23 - 26	--	--	--	--	ND
Butyl Benzyl Phthalate	µg/L	N/A	ND	ND - 11	--	--	--	--	ND
Phenol	µg/L	N/A	ND	ND - 62	--	--	--	--	ND
Biological Parameters									
Total Coliforms	MPN/100 mL	N/A	2400	270	20	ND	ND	ND	ND
Fecal Coliform	MPN/100 mL	N/A	230	40	ND	ND	ND	ND	ND
E. coli	MPN/100 mL	N/A	310	10	ND	ND	ND	ND	ND

1. Units of measure: mg/L = milligrams per liter, µg/L = micrograms per liter, MPN/100 mL = most probable number per 100 milliliters.

2. "--" indicates the constituent was not analyzed for. Analytes not detected are indicated by ND.

Table 10 Summary Results - Sun Valley

			Monitoring Station[2]								
Constituent	**Units[1]**	**Fraction**	**S-SW-01**	**S-SW-02**	**S-SW-03**	**S-LS-01**	**S-LS-02**	**S-LS-03**	**S-LS-04**	**S-LS-05**	**EV-10**
General Monitoring Parameters											
Nitrate (as N)	mg/L	N/A	ND - 0.62	ND - 0.63	ND - 1.8	2.2 - 15	1 - 17	1.9 - 17	0.43 - 36	ND - 0.77	1.7 - 2.1
Total Kjeldahl Nitrogen	mg/L	N/A	0.7 - 3.6	1.4 - 11	1.5 - 13	ND - 1.4	ND - 0.84	ND - 1.1	ND - 0.56	0.98 - 6.7	ND - 0.14
Ammonia-Nitrogen	mg/L	N/A	ND - 0.35	0.21 - 1.8	0.28 - 1.2	ND - 0.56	ND	ND	ND - 0.28	ND - 0.28	ND
Total Dissolved Solids	mg/L	N/A	44 - 94	48 - 420	76 - 460	340 - 920	720 - 2200	350 - 1000	310 - 1300	810 - 4500	420 - 430
Total Suspended Solids	mg/L	N/A	9.5 - 290	41 - 930	31 - 780	--	--	--	--	--	1.5 - 14
Chemical Oxygen Demand	mg/L	N/A	13 - 170	48 - 730	71 - 900	ND - 53	ND - 20	ND - 35	ND - 15	13 - 51	5 - 5.1
Chloride	mg/L	N/A	ND-2.7	ND-21	3.5-18	10-28	13-38	12-30	8.1-35	34-81	25-26
Metals											
Aluminum	µg/L	Dissolved	ND	ND - 97.3	ND - 198	ND	ND	ND	ND	ND	ND
Aluminum	µg/L	Total	84.5 - 2530	514 - 3660	406 - 6570	ND	ND - 50.3	ND	ND	ND	ND
Arsenic	µg/L	Dissolved	ND - 1.05	ND - 11.6	1.1 - 9.93	4.63 - 15.7	4.82 - 11.4	ND - 5.16	2.16 - 6.97	3.17 - 31.2	ND - 0.879
Arsenic	µg/L	Total	ND - 1.65	0.809 - 13.9	1.44 - 13	4.38 - 13.3	4.58 - 13.4	ND - 6.65	1.84 - 7.79	3.12 - 30.6	ND - 0.849
Cadmium	µg/L	Dissolved	ND - 0.244	ND - 0.764	ND - 0.614	ND - 0.272	ND - 0.501	ND	ND - 0.23	0.2 - 0.586	ND
Chromium, Hexavalent	µg/L	Dissolved	ND - 0.48	ND - 0.98	0.37 - 1.3	0.43 - 6.2	ND - 31	12 - 26	1.3 - 5.5	ND - 1	0.23 - 0.26
Copper	µg/L	Dissolved	6.54 - 13.5	7.35 - 43.7	11.3 - 23.3	1.78 - 8.76	ND - 7.77	1.14 - 7.07	2.74 - 41.5	2.3 - 5.19	1.03 - 1.13
Copper	µg/L	Total	8.63 - 42.2	19.3 - 83.5	19.2 - 86.2	2.52 - 9.04	1.03 - 8.23	2.35 - 6.73	3.22 - 33.7	2.4 - 5.99	4 - 5.25
Lead	µg/L	Dissolved	ND - 0.603	ND - 6.09	ND - 58.2	ND - 0.592	ND	ND - 0.608	ND - 1.68	ND - 0.838	ND
Lead	µg/L	Total	3.66 - 63.6	19.4 - 108	10.6 - 956	ND - 5.46	ND - 0.847	ND - 1.51	ND - 1.48	0.582 - 3.57	0.652 - 1.07
Mercury	µg/L	Dissolved	ND	ND -	ND -	ND	ND	ND	ND	ND	ND

			Monitoring Station[2]								
Constituent	**Units[1]**	**Fraction**	**S-SW-01**	**S-SW-02**	**S-SW-03**	**S-LS-01**	**S-LS-02**	**S-LS-03**	**S-LS-04**	**S-LS-05**	**EV-10**
				0.168	0.192						
Zinc	µg/L	Dissolved	23.4 - 74	38.5 - 174	43.6 - 350	ND - 17.7	9.4 - 31.3	ND - 18.6	18.7 - 49.7	7.37 - 28.6	14.2 - 61.6
Zinc	µg/L	Total	98.4 - 284	99 - 387	83.2 - 669	ND - 19.8	12 - 61.3	8.37 - 59.8	17.7 - 52.5	10.2 - 38.2	40.8 - 42.7
Other Constituents											
MBAS (Surfactants)	mg/L	N/A	0.24 - 0.42	0.32 - 4.1	0.32 - 3.9	--	--	--	--	--	ND
Oil and Grease	µg/L	N/A	ND - 5.7	2.2 - 48	2 - 54	--	--	--	--	--	ND
Perchlorate	µg/L	N/A	ND	ND - 6.1	ND - 6.5	ND	ND	ND - 7.2	ND - 2.4	ND	ND
Volatile Organic Compounds											
Methyl-t-Butyl Ether (MtBE)	µg/L	N/A	ND	ND	ND	ND	ND - 7.3	ND	ND - 1.3	ND	ND
Toluene	µg/L	N/A	ND	ND - 0.59	ND - 11	ND	ND	ND	ND	ND	ND
Trichloroethylene (TCE)	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND	1.2
Tetrachloroethylene (PCE)	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND	4.1 - 4.9
1,1,1-Trichloroethane	µg/L	N/A	ND	ND	ND	5.4 - 18	3.3 - 17	5.2 - 18	3.7 - 17	ND - 1.4	ND
1,1-Dichloroethane	µg/L	N/A	ND	ND	ND	0.56 - 1.6	0.56 - 2.1	ND - 1.4	ND - 1.3	ND	3.5 - 3.6
1,1-Dichloroethylene	µg/L	N/A	ND	ND	ND	0.97 - 3.7	0.76 - 4.4	1.3 - 4.1	1.3 - 4.4	ND	ND
1,2-Dichloroethane	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND	ND - 6.4
1,4-Dichlorobenzene	µg/L	N/A	ND	ND - 4.7	ND - 1.3	ND	ND	ND	ND	ND	ND
2,2-Dichloropropane	µg/L	N/A	ND	ND	ND	ND	ND	ND - 0.97	ND	ND	ND
2-Butanone (Methylethyl ketone)	µg/L	N/A	ND - 3.7	1.7 - 6.1	1 - 12	ND	ND - 1.2	ND	ND	ND - 670	ND
2-Hexanone	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND - 6.5	ND
4-Methyl-2-pentanone (MIBK)	µg/L	N/A	ND	ND - 7.2	ND - 64	ND	ND	ND	ND	ND	ND
Acetone	µg/L	N/A	4 - 40	16 - 70	12 - 130	ND - 7.3	6.4 - 30	ND - 4.4	ND - 5.5	56 - 2200	ND - 2.5
Carbon disulfide	µg/L	N/A	ND	ND	ND	ND - 54	1.6 - 10	ND - 76	0.57 - 2.2	ND - 1.8	ND
Chloroform	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND - 2.1	ND
Dichlorodifluoromethane	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND	5.1

			Monitoring Station[2]								
Constituent	**Units[1]**	**Fraction**	**S-SW-01**	**S-SW-02**	**S-SW-03**	**S-LS-01**	**S-LS-02**	**S-LS-03**	**S-LS-04**	**S-LS-05**	**EV-10**
Diethyl Ether	µg/L	N/A	ND	ND - 0.94	ND - 0.78	ND	ND	ND	ND	ND	ND
Ethanol	µg/L	N/A	ND - 290	130 - 1900	ND - 840	ND	ND	ND	ND	ND	ND
Methyl Chloride	µg/L	N/A	ND - 0.56	ND	ND	ND	ND	ND	ND	ND	ND
Tert-Butyl Alcohol (TBA)	µg/L	N/A	ND	ND	ND	ND - 24	ND - 23	ND	ND - 54	ND	ND
Trichlorofluoromethane	µg/L	N/A	ND	ND	ND	ND	ND	ND	ND	ND	1.1
Semi-Volatile Organic Compounds											
2-Methylphenol (o-Cresol)	µg/L	N/A	ND	ND - 12	ND - 19	--	--	--	--	--	ND
Benzoic acid	µg/L	N/A	ND	ND	150 - 280	--	--	--	--	--	ND
Benzyl alcohol	µg/L	N/A	ND	ND	ND - 12	--	--	--	--	--	ND
Bis(2-Ethylhexyl) Phthalate	µg/L	N/A	ND	ND	13 - 32	--	--	--	--	--	ND
Diethyl Phthalate	µg/L	N/A	ND	ND - 12	18 - 21	--	--	--	--	--	ND
Di-n-Butyl Phthalate	µg/L	N/A	ND	ND	ND - 16	--	--	--	--	--	ND
Biological Parameters											
Total Coliforms	MPN/100 mL	N/A	2300	> 160000	> 160000	ND	ND	ND	ND	--	--
Fecal Coliform	MPN/100 mL	N/A	2300	90000	160000	ND	ND	ND	ND	--	--
E. coli	MPN/100 mL	N/A	5040	73800	18500	ND	ND	ND	ND	--	--
1. Units of measure: mg/L = milligrams per liter, µg/L = micrograms per liter, MPN/100 mL = most probable number per 100 milliliters.											
2. "--" indicates the constituent was not analyzed for. Analytes not detected are indicated by ND.											

Table 11 Summary Results - Veterans Park

			Monitoring Station[2]							
Constituent	**Units[1]**	**Fraction**	**V-SW-01**	**V-SW-02**	**V-LS-01**	**V-LS-02**	**V-MW-01**	**V-MW-02**	**V-MW-03**	**V-MW-04**
General Monitoring Parameters										
Nitrate (as N)	mg/L	N/A	0.11 - 0.95	ND - 1.9	1.6 - 4.4	0.91 - 8.9	2.3 - 4.7	0.56 - 3.7	2.1 - 6	20 - 44
Total Kjeldahl Nitrogen	mg/L	N/A	2.5 - 10	4.2 - 6.6	0.56 - 1.4	0.98 - 3.4	0.42 - 0.84	ND - 0.98	ND - 0.98	0.98 - 1.7
Ammonia-Nitrogen	mg/L	N/A	0.6 - 1.6	0.21 - 1.8	ND	ND - 0.56	ND	ND	ND	ND
Total Dissolved Solids	mg/L	N/A	20 - 290	130 - 470	610 - 2700	2200 - 4000	4200 - 6000	1500 - 2900	1300 - 2100	4300 - 6600
Total Suspended Solids	mg/L	N/A	20 - 390	42 - 210	--	--	4.1 - 43	ND - 28	ND - 110	ND - 230
Chemical Oxygen Demand	mg/L	N/A	53 - 530	150 - 690	ND - 23	41 - 250	61 - 90	13 - 75	ND - 94	46 - 160
Chloride	mg/L	N/A	1.6-26	5.2-31	12-240	180-440	1000-1400	130-180	130-180	820-1400
Metals										
Aluminum	µg/L	Dissolved	ND - 67.7	ND - 120	ND	ND	ND - 65.3	ND	ND - 141	ND - 218
Aluminum	µg/L	Total	302 - 2140	491 - 2740	ND	ND	108 - 612	51.4 - 805	ND - 1440	55.7 - 1900
Arsenic	µg/L	Dissolved	ND - 1.03	ND - 1.94	16.1 - 29	5.34 - 8.16	2.41 - 19.6	5.32 - 10.6	1.9 - 5.83	5.17 - 17.7
Arsenic	µg/L	Total	ND - 1.79	0.584 - 2.54	16 - 29.3	5.22 - 9.28	4.85 - 19.6	6.03 - 12.1	1.96 - 6.03	5.79 - 17.5
Cadmium	µg/L	Dissolved	ND	ND - 0.316	0.23 - 0.41	ND - 0.306	ND - 0.285	ND	ND	ND
Chromium, Hexavalent	µg/L	Dissolved	ND - 0.67	0.29 - 1.4	0.88 - 1.3	ND	ND - 0.27	0.51 - 2.9	ND - 2.7	ND
Copper	µg/L	Dissolved	7.37 - 24.1	8.77 - 33.8	3.26 - 6.49	9.03 - 20.7	2.93 - 5.04	2.27 - 6.74	2.14 - 3.57	4.82 – 200
Copper	µg/L	Total	11.4 - 45.9	23 - 52.3	3.18 - 7.76	9.41 - 23.6	2.72 - 6.2	2.37 - 7.94	2.13 - 5.39	6.01 – 228
Lead	µg/L	Dissolved	ND - 3.41	0.954 - 3.3	ND	ND	ND	ND	ND	ND - 0.536
Lead	µg/L	Total	3.96 - 27.8	4.59 - 22.6	ND	ND	ND	ND - 0.712	ND - 1.89	ND - 2.24
Mercury	µg/L	Dissolved	ND - 0.111	ND - 0.117	ND	ND	ND	ND - 0.105	-0.1 - 0.164	ND - 0.149
Zinc	µg/L	Dissolved	38.2 - 114	34.5 - 207	ND -	ND - 25.8	ND	ND - 9.9	ND - 5.51	ND - 25.3

			Monitoring Station[2]							
Constituent	**Units[1]**	**Fraction**	**V-SW-01**	**V-SW-02**	**V-LS-01**	**V-LS-02**	**V-MW-01**	**V-MW-02**	**V-MW-03**	**V-MW-04**
					19.1					
Zinc	µg/L	Total	59.4 - 221	73.5 - 157	ND - 27.3	13.2 - 26.2	ND	ND - 11.7	ND - 22.8	ND - 28.5
Other Constituents										
MBAS (Surfactants)	mg/L	N/A	0.24 - 1.1	0.11 - 0.77	--	--	ND - 0.21	ND - 0.13	ND - 0.11	ND - 0.35
Oil and Grease	µg/L	N/A	1.5	2.1 - 6.1	--	--	ND - 1.2	ND - 3.5	ND - 7.4	ND - 19
Perchlorate	µg/L	N/A	ND	ND	ND	ND	ND - 9	ND	ND - 4.5	ND - 8.3
Glyphosate	µg/L	N/A	ND - 16.2	ND	ND	ND	ND	ND	ND	ND
Volatile Organic Compounds										
2-Butanone (Methylethyl ketone)	µg/L	N/A	ND - 2.9	ND - 4.3	ND	ND	ND	ND	ND	ND
Acetone	µg/L	N/A	5.8 - 19	2.6 - 18	ND - 2.5	ND	ND	ND - 2.7	ND	ND - 4.1
Chloroform	µg/L	N/A	ND	ND	ND - 1.7	ND - 0.95	ND	ND	ND - 0.61	ND
Dibromochloromethane	µg/L	N/A	ND	ND - 0.69	ND	ND	ND	ND	ND	ND
Dichlorobromomethane	µg/L	N/A	ND	ND - 0.51	ND	ND	ND	ND	ND	ND
Diethyl Ether	µg/L	N/A	ND - 0.97	ND - 0.71	ND	ND	ND	ND	ND	ND
Ethanol	µg/L	N/A	ND	ND - 250	ND	ND	ND	ND	ND	ND
Methyl Chloride	µg/L	N/A	ND	ND	ND - 0.6	ND - 0.72	ND	ND	ND	ND
Semi-Volatile Organic Compounds										
Bis(2-Ethylhexyl) Phthalate	µg/L	N/A	ND - 18	ND - 20	--	--	ND	ND	ND	ND
Biological Parameters										
Total Coliforms	MPN/100 mL	N/A	30000	30000	ND	ND	ND	ND	ND	--
Fecal Coliform	MPN/100 mL	N/A	ND	700	ND	ND	ND	ND	ND	--
E. coli	MPN/100 mL	N/A	200	100	ND	ND	ND	ND	ND	--

1. Units of measure: mg/L = milligrams per liter, µg/L = micrograms per liter, MPN/100 mL = most probable number per 100 milliliters.

2. "--" indicates the constituent was not analyzed for. Analytes not detected are indicated by ND.

5. DISCUSSION

The potential influence of stormwater infiltrated during this project on soil pore fluid and groundwater quality beneath the site is discussed in this section. The following discussion focuses on analytical results for typical constituents of concern for stormwater and groundwater, including COD, copper, lead, zinc, and arsenic. Additionally, analytical results for other groundwater constituents of concern (TDS, nitrate, chloride, perchlorate, and MtBE) are discussed in detail. PAHs are not discussed as they were not detected in any sample.

TSS, a stormwater constituent of concern, and other metals are not discussed in detail because they are typically not of concern in groundwater. Cadmium, for example, was detected at low concentrations in some stormwater samples, but was not detected in groundwater with the exception of low levels in one well sample at IMAX and Veterans Park.

Analytical results are analyzed both temporally and spatially. Time-concentration charts and the results of Mann-Kendall trend analysis are contained in **Appendix F**. Depth-concentration charts, which show the variation in concentrations between each sampling point by depth, are contained in **Appendix G**. Examples of the time-concentration and depth-concentration charts are included for chloride at Veterans Park, at the end of this discussion.

5.1 Broadous Elementary School

Based on the relative locations and distances of the on-site groundwater monitoring wells, monitoring well B-MW-01 is considered to represent a background well in the site monitoring network. Groundwater quality at B-MW-02 is considered more likely to have been subject to potential influence by stormwater infiltrated during this study.

Nitrate

Concentrations of nitrate in stormwater samples were generally consistent and relatively lower than those in lysimeter and groundwater samples. Concentrations in lysimeter samples remained relatively consistent and low with the exception of the 2002/2003 season where nitrate concentrations were significantly higher. Nitrate concentrations in groundwater samples were slightly higher than concentrations in the lysimeters except for the noted 2002/2003 season. Nitrate concentrations in samples collected from the two groundwater wells were similar. Based on these results, stormwater infiltration has not had an adverse effect on nitrate concentration in groundwater.

TDS

TDS concentrations in stormwater samples were significantly lower than those in lysimeter and groundwater samples. TDS concentrations in lysimeter samples were variable and exhibited concentrations over a broader range. TDS concentrations in groundwater were generally consistent, decreasing slightly during the study period. Groundwater at

monitoring wells B-MW-01 and B-MW-02 had similar TDS concentrations. Based on these results, stormwater infiltration has not had an adverse effect on TDS concentration in groundwater, and may have slightly improved groundwater quality as measured by TDS concentration.

Chloride

In general, chloride concentrations in stormwater samples were low and decreased slightly during the study period. Groundwater samples had slightly higher concentrations than those in stormwater samples and were generally consistent or decreased slightly. Chloride concentrations were higher in B-MW-01 than those in B-MW-02 at the beginning of the study, but then were relatively similar subsequently. Chloride concentrations in lysimeter samples were higher than those in the stormwater and groundwater samples and showed more variability but appeared to decrease slightly over the course of the study. Groundwater degradation by chloride from stormwater infiltration during the study does not appear to have occurred at this site.

Chemical Oxygen Demand

Stormwater samples generally had higher concentrations of COD than groundwater and lysimeter samples and were the most variable. COD in the lysimeter samples was higher initially and lowers toward the end of the study. Groundwater samples were slightly more consistent and had lower COD concentrations than the stormwater and lysimeter samples. COD concentrations in the groundwater samples appeared to decrease during the study. COD was slightly higher in samples from B-MW-02 than in those from B-MW-01. Although no significant trends were seen, COD concentrations appeared to decrease in all types of samples during the study period. Based on these results, stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by COD.

Total Copper

Total copper concentrations in stormwater and lysimeter samples were generally variable and within similar ranges. Total copper concentrations in groundwater samples were higher initially, but subsequently decreased and were generally lower than those in stormwater and lysimeter samples. Although total copper concentrations in stormwater samples were generally higher, it does not appear that total copper concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Copper

Concentrations of dissolved copper in stormwater samples were generally consistent or decreased slightly over the course of the study. Concentrations of dissolved copper in lysimeter samples were more variable and periodically were higher than those in stormwater samples; but these concentrations also decreased slightly during the study. In groundwater samples, dissolved copper concentrations were generally lower than in the other types of samples except in the first season of monitoring when the dissolved copper concentration for B-MW-02 was much higher than that for B-MW-01. Dissolved copper concentrations in groundwater samples appeared to decrease during the study. Although

dissolved copper concentrations in stormwater and lysimeter sample concentrations were generally higher than those in groundwater, it does not appear that dissolved copper in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Total Lead

Total lead was detected in all of the stormwater samples collected at Broadous, but concentrations were generally variable. Total lead was detected in only three of the lysimeter samples and, in general, total lead concentrations in lysimeter samples were lower than stormwater samples. Total lead was detected in approximately half of the groundwater samples and decreased during the study. Because concentrations of total lead decreased in groundwater samples and were not detected in most of the lysimeter samples, it does not appear that total lead in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Lead

Dissolved lead was detected in only one stormwater sample, at a low concentration. Dissolved lead was detected in only one groundwater sample collected at the beginning of the study from B-MW-02. Three lysimeter samples had detected concentrations of dissolved lead during the middle of the study. Based on the limited number of detected concentrations, it does not appear that dissolved lead in groundwater or soil pore water increased as the result of stormwater infiltration.

Total Zinc

Total zinc was detected in all of the stormwater samples and most of the lysimeter and groundwater samples. Concentrations of total zinc in stormwater were higher than those in lysimeter or groundwater samples. Total zinc concentrations in lysimeter samples were generally low except for during the 2002/2003 season when the concentrations were significantly higher than in stormwater or groundwater samples. In the first part of the study, lysimeter and groundwater samples were higher in total zinc concentrations than that the stormwater samples, but lower than stormwater samples in the second half of the study. By the second half of the study, total zinc decreased to low levels in all samples. Total zinc in the two groundwater monitoring wells were generally similar except in the initial part of the study when concentrations in B-MW-01 were higher than those in B-MW-02. Based on these results, it appears that stormwater infiltration does not have an adverse affect on total zinc concentrations in groundwater.

Dissolved Zinc

Dissolved zinc was detected in all of the stormwater samples and in most of the groundwater and lysimeter samples. Dissolved zinc concentrations in stormwater were generally consistent although slightly higher in the 2001/2002 and 2003/2004 season and in lysimeter samples were generally low except for the 2002/2003 season when the concentrations were significantly higher than any of the other dissolved zinc concentrations detected in any of the sample types. Dissolved zinc concentrations were generally similar in groundwater samples from the two monitoring wells except in the initial part of the study when groundwater samples from B-MW-01 were slightly higher.

In general, concentrations of dissolved zinc in all three types of samples appeared to decrease during the study. Based on these results, it does not appear that dissolved zinc in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Arsenic

Arsenic was periodically detected in the stormwater samples from this site. Arsenic concentrations in the lysimeter samples were higher than those in the stormwater samples and were more variable during the study with a significantly higher concentration detected during the 2003/2004 season. Arsenic concentrations in groundwater samples were mainly below detection except in the samples from B-MW 01 in the beginning of the study and in samples from both B MW 01 and B-MW-02 at the end of the study. Based on these results, it does not appear that arsenic present in the stormwater or pore water has affected the water quality in the groundwater wells.

Perchlorate

Perchlorate was not detected in any lysimeter or groundwater samples. Perchlorate was detected in one stormwater sample collected during the 2003/2004 season, but not in any of the other stormwater samples. Because perchlorate was not detected in lysimeter or groundwater samples collected for this study, it does not appear that stormwater infiltration from this study has contributed to degradation of groundwater.

5.2 Hall House

A single lysimeter, H-LS-01, is present at the site beneath the edge of the infiltration lawn area. Because there are no groundwater monitoring wells at this site, soil pore fluid quality may be used as an indicator of potential influence on groundwater quality.

Nitrate

Concentrations of nitrate in stormwater were consistently low or not detected at H SW 01 and variable at H-SW-02. Nitrate concentrations in surface water samples collected during 2003 and 2004 were variable in comparison with those detected in lysimeter samples; surface water and lysimeter samples results for samples collected in 2005 were similar. Nitrate concentrations in lysimeter samples were relatively higher during the initial sampling event and low or non-detected and generally consistent during subsequent events. Based on these results, soil pore fluid does not appear to have been degraded by nitrate from stormwater infiltrated as part of this study.

TDS

TDS concentrations in stormwater samples were significantly lower than those in lysimeter samples. TDS data from the lysimeter were not available for the 2002/2003 season. TDS concentrations in lysimeter samples were relatively consistent during the two sampling events in the 2003/2004 season and the first event in the 2004/2005 season, then decreased during the final two events of the study. Based on these results, soil pore fluid does not appear to have been degraded by TDS from stormwater infiltrated as part of this study.

Chloride

Chloride concentrations in stormwater samples were significantly lower than those in lysimeter samples during most of the study period. TDS concentrations in lysimeter samples were variable from the initial sampling event through the first event in the 2004/2005 season, then, similar to TDS, decreased during the final two events of the study. Chloride was not detected in the lysimeter sample from the final sampling event. Based on these results, soil pore fluid does not appear to have been degraded by chloride from stormwater infiltrated as part of this study.

Chemical Oxygen Demand

COD values in stormwater were relatively consistent at H-SW-01 and variable at H-SW-02. Stormwater samples had higher concentrations of COD than did lysimeter samples. COD in lysimeter samples was not detected during the three initial sampling events for which data are available, and was detected at concentrations at or only very slightly greater than the reporting limit during the two subsequent monitoring events. Based on these results, stormwater infiltration for this project does not appear to have resulted in degradation of soil pore fluid by COD.

Total Copper

Concentrations of total copper in stormwater samples were variable and generally higher than those in lysimeter samples. Lysimeter sample concentrations of total copper were low and showed a statistically significant decreasing trend. Based on these results, soil pore fluid does not appear to have been degraded by chloride from stormwater infiltrated as part of this study.

Dissolved Copper

Concentrations of dissolved copper in stormwater samples were variable. Concentrations at H-SW-02 were in all cases higher than those in lysimeter samples; concentrations at H-SW-01 were higher than those in lysimeter samples during three sampling events and lower during three sampling events. Lysimeter sample concentrations of dissolved copper showed a statistically significant decreasing trend during the study period. Based on these results, soil pore fluid does not appear to have been degraded by chloride from stormwater infiltrated as part of this study.

Total Lead

Concentrations of total lead in stormwater samples were variable but significantly greater than those in lysimeter samples. The initial lysimeter sample for which total lead results are available (February 2004) showed a total lead concentration slightly above its reporting limit; total lead was not detected in any of the subsequent lysimeter samples from this site. Based on these results, stormwater infiltration for this project does not appear to have resulted in degradation of soil pore fluid by total lead.

Dissolved Lead

Concentrations of dissolved lead in stormwater samples were variable but significantly greater than those in lysimeter samples during most sampling events. The initial lysimeter sample (December 2002) showed a dissolved lead concentration slightly above its

reporting limit; dissolved lead was not detected in any of the subsequent lysimeter samples from this site. Based on these results, stormwater infiltration for this project does not appear to have resulted degradation of soil pore fluid by dissolved lead.

Total Zinc
Concentrations of total zinc in stormwater samples were variable but significantly greater than those in lysimeter samples. Lysimeter samples were analyzed for total zinc during February 2004 and subsequent monitoring events, and showed total zinc concentrations that were variable but did not show a clear trend. Based on these results, stormwater infiltration for this project does not appear to have resulted in degradation of soil pore fluid by total zinc.

Dissolved Zinc
Dissolved zinc was detected in all of the stormwater samples. For all sampling events, concentrations of dissolved zinc were higher at surface water sampling point H-SW-01 than at surface water sampling point H-SW-02 or in the lysimeter sample. Concentrations at H-SW-02 were generally more similar to those in the lysimeter samples. Lysimeter sample concentrations of dissolved zinc showed a statistically significant decreasing trend during the study period. Based on these results, stormwater infiltration for this project does not appear to have resulted in degradation of soil pore fluid by dissolved zinc.

Arsenic
Arsenic was detected in only one of the stormwater samples from this site (the sample collected in February 2004 from H-SW-02) and in only the initial lysimeter sample (from December 2002). Consequently, stormwater infiltration for this project does not appear to have resulted in degradation of soil pore fluid by arsenic.

Perchlorate
Perchlorate was not detected in stormwater samples from this site. Lysimeter samples from this site were not analyzed for perchlorate.

5.3 IMAX

Based on the relative locations and distances of the on-site groundwater monitoring wells, monitoring well I-MW-01 represents an "upgradient background" well in the site monitoring network. Groundwater quality at I-MW-02 is considered much more likely than that at I-MW-01 to have been subject to influence by stormwater infiltrated during this study.

Nitrate
Concentrations of nitrate in stormwater samples were typically lower than those in lysimeter and groundwater samples. Nitrate concentrations in lysimeter samples from I-LS-01 and I-LS-02 were significantly different, with higher concentrations in I-LS-01 (area of roof runoff). Concentrations of nitrate in I-LS-02 were typically low and decreased slightly over the study period. The decreasing concentration trend in I-LS-02 is statistically significant. Groundwater samples from both wells were similar, with slightly

higher concentrations in I-MW-02 during the first two years of the study. Based on these results, stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by nitrate.

TDS

Concentrations of TDS in stormwater samples were typically lower than those in lysimeter and groundwater samples. TDS concentrations in lysimeter samples from I-LS-01 and I-LS-02 were significantly different, with higher concentrations in I-LS-01 (area of roof runoff). Lysimeter sample concentrations did not exhibit statistically significant trends over time. Concentrations from the two groundwater monitoring wells appeared to have similar concentrations with no statistically significant trends. The most recent TDS concentration from I-MW-02 (potentially influenced by infiltrated stormwater) was the lowest observed during the study period. Based on these results, stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by TDS.

Chloride

Concentrations of chloride in stormwater were typically lower than both those in lysimeter and groundwater samples. Chloride concentrations in lysimeter samples from I-LS-01 and I-LS-02 were significantly different, with higher concentrations in I-LS-01 (area of roof runoff). Lysimeter sample concentrations did not exhibit statistically significant trends over time. Samples from the groundwater monitoring well nearest the infiltrator (I-MW-02) exhibited typically higher concentrations than samples from I-MW-01 but showed a statistically significant slightly decreasing trend over the study period. Concentrations of chloride in I-MW-01 appeared relatively consistent throughout the study period. Stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by chloride.

Chemical Oxygen Demand

Concentrations of COD in stormwater appeared variable. COD in lysimeter samples were variable with slightly higher concentrations in samples from I-LS-01 over the last two years of the study. COD concentrations in groundwater were generally higher in I-MW-02 than in I-MW-01, including a notably higher concentration in the initial sample collected in 2001. No trends for COD in groundwater or lysimeter samples were apparent. Based on these results, stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by COD.

Total Copper

Concentrations of total copper in stormwater samples from I-SW-02 (parking lot runoff) were variable and typically higher than those in groundwater samples. Lysimeter sample concentrations appeared variable with slightly decreasing concentrations during the 2004/2005 wet season. Except for the initial samples collected in 2001, total copper concentrations in groundwater samples were typically low and lower than lysimeter and stormwater samples during the last two years of the study. While stormwater and lysimeter sample concentrations are generally higher than groundwater, it does not appear that total copper concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Copper

Concentrations of dissolved copper in stormwater samples from I-SW-02 (parking lot runoff) were variable and typically higher than those in groundwater samples. Lysimeter sample concentrations appeared variable with slightly decreasing concentrations over the study period. Except for the initial samples collected in 2001, groundwater samples were typically low and lower than both lysimeter and stormwater samples during the last two years of the study. While stormwater and lysimeter sample concentrations were generally higher than groundwater, it does not appear that total copper concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Total Lead

Concentrations of total lead in stormwater samples were typically higher than those in lysimeter or groundwater samples. One notably higher concentration was detected at I-SW-01 during the storm event sample collected on February 18, 2005. Concentration of total lead from both lysimeter locations showed low and generally decreasing concentrations, with total lead not detected in the last two sampling events. The decreasing concentration trend in I-LS-01 is statistically significant. Total lead concentrations in groundwater were generally lower, except for the initial sampling event, in groundwater well I-MW-02 (potentially influenced by infiltrated stormwater). I-MW-02 also had a higher percentage of non-detect samples during the study period. Although concentrations of total lead were generally higher in stormwater samples than in groundwater, it does not appear that total lead in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Lead

Dissolved lead was detected in only one stormwater sample, one lysimeter sample, and one groundwater sample during the study. Based on the limited number of detected concentrations, it does not appear that dissolved lead in groundwater or soil pore water increased as the result of stormwater infiltration.

Total Zinc

Total zinc was detected in all of the stormwater samples. Concentrations of total zinc in stormwater were typically similar to or higher than those in groundwater samples. Lysimeter sample concentrations from I-LS-02 were highly variable with the lowest concentrations detected in the last three sample events. I-LS-01 remained generally consistent over the study duration. Total zinc concentrations in groundwater samples were typically lower than those in stormwater and in the majority of lysimeter samples. Total zinc concentrations were generally lower in groundwater well I-MW-02 than in I-MW-01 in all but the initial and most recent samples. Although concentrations of total zinc were generally higher in stormwater samples than in groundwater, it does not appear that total zinc in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Zinc

Dissolved zinc was detected in all of the stormwater samples. Concentrations of dissolved zinc in stormwater were typically higher than those in groundwater samples. Lysimeter sample concentrations in I-LS-02 appeared variable with slightly decreasing concentrations during the 2004/2005 wet season. Lysimeter sample concentrations in I-LS-02 appeared variable with slightly increasing concentrations during the 2004/2005 wet season. Dissolved zinc concentrations in groundwater samples were typically lower than those in stormwater and in the majority of lysimeter samples. Dissolved zinc concentrations were generally lower in groundwater well I-MW-02 than in I-MW-01 in all but the initial and most recent samples. Although concentrations of dissolved zinc were generally higher in stormwater samples than in groundwater, it does not appear that dissolved zinc in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Arsenic

Arsenic was not detected in stormwater samples collected from I-SW-01 (roof runoff). Arsenic concentrations in stormwater from I-SW-02 (parking lot runoff) were variable but generally higher than groundwater and lysimeter sample concentrations. Lysimeter sample concentrations from I-LS-02 remained relatively consistent or decreased slightly over the study period. Lysimeter sample concentrations from I-LS-01 were relatively low but may have increased slightly. Samples from both groundwater monitoring wells showed similar concentrations with no statistically significant trends. While stormwater sample concentrations are generally higher than soil pore water and groundwater, it does not appear that arsenic concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Perchlorate

Perchlorate was detected in only one stormwater sample and was not detected in lysimeter samples from this site. Perchlorate concentrations in I-MW-02 were typically higher than at I-MW-01 but appeared to decrease slightly over the study duration. Perchlorate concentrations in I-MW-01 were variable with a slightly increasing trend over the duration of the study. Perchlorate was also detected in groundwater samples taken at the beginning of the study, thus it is likely a pre-existing condition and not a result of stormwater infiltration.

MtBE

MtBE was not detected in the majority of the stormwater and lysimeter samples. MtBE concentrations were variable in groundwater well I-MW-02 with no detections since 2003. MtBE was not detected in I-MW-01. Because MtBE was only detected in one stormwater and lysimeter sample, it does not appear that stormwater infiltration from this study has contributed MtBE to groundwater.

5.4 Metal Recycler

At the metal recycler site, groundwater occurs at more than 200 feet bgs. A single groundwater monitoring well, M-MW-01, was constructed approximately 25 feet south of the infiltrator.

Nitrate

Concentrations of nitrate in stormwater were generally near the lower portion of the range of concentrations in lysimeter samples. Nitrate was detected in the baseline sample from well M-MW-01 at a concentration just above its detection limit. Nitrate was not detected in any of the subsequent groundwater samples. There was not a consistent concentration trend with depth in samples collected from the two sets of shallow/deep paired lysimeters at the site. Nitrate concentrations in samples from deep lysimeter M-LS-01 were generally similar to or greater than those in samples from its paired shallower lysimeter, M-LS-02. However, both samples collected from deep lysimeter M-LS-03 had lower concentrations than those in samples from its shallower companion, M-LS-04. Concentrations in stormwater and lysimeter samples remained relatively consistent during the study, and nitrate was not detected in groundwater samples after the initial sampling event.

TDS

TDS concentrations in stormwater samples had an average concentration of about 1000 mg/L. TDS concentrations in lysimeter and groundwater samples were similar. There is no apparent trend in concentration with depth in samples collected from the two sets of paired lysimeters. Concentrations in stormwater, lysimeter, and groundwater samples remained relatively consistent during the study.

Chloride

Chloride concentrations were generally similar in stormwater, lysimeter, and groundwater samples. Chloride concentrations in samples collected from deep lysimeter M-LS-03 were consistently higher than those in samples from its shallow pair, M-LS-04. Concentrations in stormwater and lysimeter samples remained relatively consistent during the study. An increasing trend in chloride concentration in groundwater samples collected from M-MW-01 is statistically significant. Because groundwater is deep and because chloride concentrations in stormwater and lysimeter samples is similar to those in groundwater, it is likely that the increasing trend in chloride in groundwater samples is due to factors other than stormwater infiltration.

Chemical Oxygen Demand

Stormwater samples generally had higher concentrations of COD than groundwater and lysimeter samples. No time or depth trends for COD in groundwater or lysimeter samples are evident. Based on these results, stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by COD.

Total Copper

Concentrations of total copper in stormwater samples were variable and consistently higher than those in lysimeter samples and groundwater. Concentrations in lysimeter samples

were variable and consistently higher than those in groundwater samples. Samples collected from deep lysimeter M-LS-03 had a consistently lower concentration than did those in samples collected from its shallower companion, M-LS-04. No concentration trends are evident for the study period. While stormwater and lysimeter sample concentrations are consistently higher than groundwater concentration, it does not appear that total copper concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Copper

Concentrations of dissolved copper in stormwater samples were variable and consistently higher than those in lysimeter samples. Concentrations in lysimeter samples were variable and consistently higher than those in groundwater samples. Samples collected from deep lysimeter M-LS-03 had a consistently lower concentration than detected in samples collected from its shallower companion, M-LS-04. No concentration trends are evident for the study period. While stormwater and lysimeter sample concentrations were consistently higher than groundwater concentrations, it does not appear that dissolved copper concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Total Lead

Concentrations of total lead in stormwater samples were variable and consistently higher than those in lysimeter samples. Concentrations in lysimeter samples were variable and consistently higher than those in groundwater samples. No concentration trends with depth are evident in the paired lysimeters, but concentrations in samples from the M-LS-01/M-LS-02 pair were consistently higher than those in samples from the M-LS-03/M-LS-04 pair. No concentration trends with time were evident for the study period. Although stormwater and lysimeter sample concentrations were consistently higher than groundwater concentrations, it does not appear that total lead concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Lead

Dissolved lead was detected in all stormwater samples at concentrations ranging from about 3 to 180 µg/L. Dissolved lead was detected in lysimeter samples at concentrations less than 7 µg/L, and was not detected in about half the samples. Dissolved lead was not detected in groundwater samples. Based on the limited number of detected concentrations, it does not appear that dissolved lead in groundwater or soil pore water increased as the result of stormwater infiltration.

Total Zinc

Concentrations of total zinc in stormwater samples were variable and consistently much higher than those in lysimeter or groundwater samples. Concentrations in lysimeter samples were variable and consistently higher than those in groundwater samples. There are no evident concentration trends with depth in the paired lysimeters, but concentrations in samples from the M-LS-01/M-LS-02 pair were consistently higher than those in samples from the M-LS-03/M-LS-04 pair. There are no evident concentration trends over time

during the study period. While stormwater and lysimeter sample concentrations are consistently higher than groundwater concentrations, it does not appear that total lead concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Zinc

Dissolved zinc was detected in all of the stormwater samples. Concentrations of dissolved zinc in stormwater were variable and were similar to or higher than those in lysimeter samples. Concentrations in the lysimeter samples were consistently higher than those in groundwater samples. Although concentrations of dissolved zinc were generally higher in stormwater samples than in groundwater, it does not appear that dissolved zinc in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Arsenic

With the exception of two samples from M-LS-03, dissolved arsenic concentrations in stormwater, lysimeter, and groundwater samples were similar at approximately 6 µg/L or less. There are no evident trends in concentration during the study period. Concentrations in samples from the deep lysimeters (M-LS-01 and M-LS-03) were generally greater than concentrations in samples from the shallow lysimeters (M-LS-02 and M-LS-04).

Perchlorate

Perchlorate was detected in most stormwater and lysimeter samples from this site. Perchlorate was not detected in groundwater samples. Although a statistically significant trend was not evident, the perchlorate data from M-LS-01 suggests greater variability and detection of sporadically higher concentrations during the later times of the study.

MtBE

MtBE was detected in a few stormwater samples in concentrations consistently less than those in lysimeter samples. The highest concentrations were detected in samples collected from the M-LS-01/M-LS02 lysimeter pair. An increasing trend in MtBE concentration in M-LS-01 is statistically significant. Because of low stormwater MtBE concentration, infiltrating stormwater is not the likely source of increasing MtBE concentration in soil pore water.

5.5 Sun Valley

At the Sun Valley site, groundwater occurs at more than 300 feet bgs. The potential influence of stormwater infiltrated during this project on groundwater quality in off-site well EV-10 is not considered likely. However, groundwater quality conditions in EV-10 may represent background groundwater quality conditions for the site.

Nitrate

Concentrations of nitrate detected in stormwater samples were generally low and consistent during the study. Nitrate concentrations were slightly higher in most of the lysimeters than in the stormwater samples. Nitrate concentrations in samples from shallow

lysimeters S-LS-01 and S-LS-03 showed a statistically significant decrease during the study; concentrations in mid-depth lysimeter S-LS-04 were more erratic but also appeared to decrease. Nitrate concentrations in S-LS-02 were variable. Nitrate concentrations in S-LS-05 were non-detect to low. Nitrate concentrations generally were lower in the shallower lysimeters than in the mid-depth lysimeters, but the deep lysimeter S-LS-05 had very low concentrations. Nitrate was detected in well EV-10 at similar and low concentrations the two times it was sampled.

TDS

TDS concentrations in stormwater samples were generally low with the exception of one sample each from S-SW-02 and S-SW-03 during the second year of monitoring, when concentrations were much higher (near 1000 mg/L). Concentrations in S-SW-01, from the roof sampling point, were generally low and decreased during the study. TDS concentrations in the shallow lysimeters S-LS-01 and S-LS-03 and in the mid-depth lysimeter S-LS-04 decreased during the study but were variable in S-LS-02. The decreasing trends in TDS concentration in samples from S-LS-01 and S-LS-03 were statistically significant. Deep lysimeter S-LS-05 had an initially high TDS concentration, but the concentration decreased in the next two sampling events. The initially high TDS concentration may have been caused by dewatering of grout from this recently installed lysimeter. TDS concentrations in well EV-10, which was only sampled twice, were generally low. Based on these results, there may be a trend in depth for TDS in soil pore concentrations where TDS increases in depth, particularly at lysimeter pair S-LS-01/S-LS-02. It appears that stormwater infiltration does not have an adverse effect on pore water at the site.

Chloride

Chloride concentrations in stormwater samples were generally similar to or lower than those in lysimeter samples. In stormwater samples collected at S-SW-01, chloride concentrations were mainly below detection but concentrations in stormwater samples S-SW-02 and S-SW-03 were more variable. Chloride concentrations in shallow and mid-depth lysimeter samples generally decreased during the study; decreasing trends in S-LS-02 and S-LS-03 were statistically significant. Chloride concentrations in deep lysimeter S-LS-05 were significantly higher than those in the other lysimeters. In general, chloride concentrations were slightly higher in the mid-depth lysimeters versus the shallow lysimeter pairs. Chloride concentrations in samples collected from deep lysimeter S-LS-04 were consistently higher than those in samples from its shallow pair, S-LS-03. In the groundwater samples collected from EV-10, chloride concentrations were generally low and consistent.

Chemical Oxygen Demand

Stormwater samples generally had higher concentrations of COD than groundwater and lysimeter samples. Of the three stormwater locations, S-SW-01 had the lowest and most consistent COD concentrations with a slight decreasing trend over the course of the study. COD was detected in approximately half of the lysimeter samples. No time or depth trends for COD in lysimeter samples are evident. COD concentrations detected in groundwater samples from EV-10 were just above the reporting limit.

Total Copper

Concentrations of total copper in stormwater samples were variable and consistently higher than those in lysimeter samples. Concentrations in lysimeter samples were similar to those in groundwater samples from EV-10 except that S-LS-04, a mid-depth lysimeter, had relatively high total copper concentrations in the first year of monitoring. Total copper concentrations appeared to increase slightly in the lysimeters. A slight but statistically significant increasing trend was noted in samples from S-LS-03. No significant differences in concentrations were noted between the different lysimeters, except that the deeper lysimeter S-LS-05 had slightly lower concentrations than the other lysimeters. Because total copper concentration in lysimeter samples was low and generally remained stable or increased slightly, it does not appear that soil pore water quality was adversely impacted by total copper.

Dissolved Copper

Concentrations of dissolved copper in stormwater samples were generally higher in the samples from S-SW-02 and S-SW-03. Concentrations were variable from S-SW-02, and concentrations from S-SW-03 showed a decreasing trend. Concentrations from S-SW-01 (roof run-off), were generally consistent and low. Dissolved copper concentrations in stormwater samples were generally higher than those in lysimeter samples with the exception of S-LS-04, a mid-depth lysimeter, which had relatively high dissolved copper concentrations in the first year of monitoring. The deep lysimeter S-LS-05 had slightly lower concentrations than the other lysimeters. Dissolved copper concentrations appeared to increase slightly in the lysimeters. A slight but statistically significant increasing trend was noted in concentrations from S-LS-01 and S-LS-03. Concentrations in lysimeter samples were higher than those in the groundwater samples collected from EV-10. While stormwater concentrations are higher than lysimeter sample concentrations, it does not appear that dissolved copper concentrations in soil pore water increased significantly as the result of stormwater infiltration over the study period.

Total Lead

In general, concentrations of total lead in stormwater samples were higher than those in lysimeter samples. Concentrations of total lead in stormwater samples at S-SW-02 and S-SW-03 were variable and consistently higher than those in the stormwater samples at S-SW-01, in which they appeared to decrease slightly and were generally more consistent. Total lead was detected in approximately half of the lysimeter samples, and when detected, were generally low. No concentration trends were evident with depth in the lysimeters. Total lead in the groundwater samples collected from EV-10 also was low. While stormwater concentrations are consistently higher than lysimeter concentrations, it does not appear that total lead concentrations in soil pore water increased significantly as the result of stormwater infiltration over the study period.

Dissolved Lead

Dissolved lead was detected in most of the stormwater samples, but at generally low concentrations except in one sample at S-SW-03, which was significantly higher than the other concentrations. Dissolved lead was detected in lysimeter samples at concentrations

less than 2 µg/L and was not detected in most of the samples. Dissolved lead was not detected in the groundwater samples collected from EV-10. Based on the relatively few detections of dissolved lead, it does not appear that dissolved lead in soil pore water increased as the result of stormwater infiltration.

Total Zinc

Concentrations of total zinc in stormwater samples were variable and consistently much higher than those in lysimeter samples. Concentrations in groundwater samples from EV-10 were similar to those in the lysimeter samples. Concentrations of total zinc were generally lower in the shallower lysimeters than in the deeper lysimeters. While stormwater concentrations are consistently higher than lysimeter concentrations, it does not appear that total zinc concentrations in soil pore water increased as the result of stormwater infiltration over the study period. Samples from EV-10 appear to indicate that zinc is present in regional groundwater at higher concentrations than what is detected in the lysimeters.

Dissolved Zinc

Dissolved zinc was detected in all of the stormwater samples. Concentrations of dissolved zinc in stormwater samples were variable except for samples at S-SW-01, which were fairly consistent, and were similar to or higher than those in lysimeter samples. Concentrations of dissolved zinc in lysimeter samples were generally low and consistent. Concentrations of dissolved zinc were generally lower in the shallower lysimeters than in the deeper lysimeters. Groundwater samples from EV-10 were lower in the first sampling event than the samples collected at the site and higher than most of the lysimeter samples and lower than the stormwater samples in the second sampling event. Although concentrations of dissolved zinc were generally higher in stormwater samples than in lysimeter samples, it does not appear that dissolved zinc in soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Arsenic

Dissolved arsenic concentrations in stormwater samples were generally similar to or lower than those in lysimeter samples. Dissolved arsenic was not detected in any samples from S-SW-01 and, for the other stormwater locations, the concentrations were lower in the samples collected in the second season of monitoring than in the first season of monitoring. Dissolved arsenic concentrations in lysimeter samples were consistent or decreased slightly, except for the deepest lysimeter S-LS-05, which had increasing concentrations of which the last two concentrations were significantly higher than any of the other samples for the other lysimeters. The slightly decreasing trends in dissolved arsenic concentrations in S-LS-01 and S-LS-04 were statistically significant. No evident trends were noted with depth for the lysimeters. Dissolved arsenic was not detected in groundwater from EV-10 during the initial monitoring event and was detected at a concentration only slightly above the reporting limit in the second monitoring event.

Perchlorate

Perchlorate was detected in the initial stormwater samples from S-SW-02 and S-SW-03 but was not detected in any of the subsequent samples or in any of the samples from

S-SW-01. Perchlorate was detected sporadically in lysimeters S-LS-03 and S-LS-04, with concentrations decreasing with depth. Perchlorate concentrations detected in the stormwater samples were similar to those detected in the lysimeter samples. Perchlorate was not detected in the deepest lysimeter or in groundwater samples collected at EV-10.

MtBE
MtBE was not detected in any of the stormwater samples or in the groundwater samples from EV-10. MtBE was detected in only two lysimeters (lysimeter pair S-LS-02 and S-LS-04) during the first year of monitoring. Because MtBE was not detected in any stormwater samples, infiltrating stormwater is not a likely source of MtBE concentrations in soil pore water.

TKN
TKN was detected in all of the stormwater samples and in most of the lysimeter samples. TKN concentrations generally were higher in the stormwater samples than in the lysimeter samples with the exception of one lysimeter sample (S-LS-05). TKN concentrations in the lysimeter samples were consistent and low. TKN was detected in only one of the two groundwater samples collected from EV-10 at a concentration just above the reporting limit.

5.6 Veterans Park

Based on the relative locations and distances of the on-site groundwater monitoring wells, there is not a clear "background" well in the site monitoring network. The monitoring wells at the site were used for interpretation of groundwater quality data in the following context:

- Based on its distance from the infiltrator, groundwater at monitoring well V-MW-01 is considered less likely to have been subject to influence by stormwater infiltrated during the study.
- Because of its proximity to the infiltrator, groundwater quality at V-MW-02 is considered more likely to have been subject to influence by stormwater infiltrated during this study.
- Groundwater quality at V-MW-03 is considered to have a moderate likelihood to have been subject to influence by stormwater infiltrated during this study.
- Groundwater quality at V-MW-04 is considered to have a moderate likelihood to have been subject to influence by stormwater infiltrated during this study.

Nitrate
Concentrations of nitrate in stormwater were relatively lower than those in lysimeter and groundwater samples. Concentrations in lysimeter samples remained relatively consistent or may have decreased slightly during the study. Groundwater samples from the well nearest the infiltrator (V-MW-02) showed concentrations of nitrate that were lower than those in samples from other wells but increased slightly during the study. Groundwater samples from V-MW-04 showed nitrate concentrations that were much higher than those

from other wells but decreased during the study. Using the Mann-Kendall test for trend, decreasing concentration trends in samples collected from V-LS-02, V-MW-03, and V-MW-04 are statistically significant. The observed increasing trend in samples collected V-MW-02 is also statistically significant. The relationships, if any, between the changes in nitrate concentrations at these monitoring wells and the infiltration of stormwater for this project, were not apparent from the data reviewed.

TDS

TDS concentrations in stormwater samples were significantly lower than those in lysimeter and groundwater samples. TDS concentrations in lysimeter samples generally decreased over the study period. Groundwater at monitoring wells V-MW-01 and V-MW-04 had significantly higher concentrations of TDS than did groundwater at monitoring wells V-MW-02 and V-MW-03; this relationship was apparent in initial samples as well as samples collected later during the study. Similar to the lysimeter samples, TDS concentrations at all four groundwater monitoring wells decreased over the study period. These concentration decreases may have been the result of infiltration of relatively low-TDS stormwater to shallow groundwater, both through the project infiltrator and through the landscaped area comprising much of the site. Decreasing concentration trends in samples collected from V-LS-02, V-MW-02, and V-MW-04 are statistically significant.

Chloride

Time-concentration and depth-concentration charts for chloride are presented in Figures 10 and 11. Chloride was not detected in stormwater samples from this site during the study period. Samples from both lysimeters showed decreasing chloride concentrations. Groundwater samples from wells V-MW-01 and V-MW-04 had significantly higher concentrations of chloride than did those from V-MW-02 and V-MW-03; these differences were apparent in data from the initial sampling and subsequent events. Chloride concentrations in groundwater at V-MW-04 and V-MW-02 decreased over the duration of the study, while those at V-MW-03 were relatively consistent, and those at V-MW-01 appeared variable. Decreasing concentration trends in samples collected from V-LS-01, V-LS-02, V-MW-02, and V-MW-04 were statistically significant. Groundwater degradation by chloride from stormwater infiltration during the study does not appear to have occurred at this site, and some improvement to groundwater quality may have occurred .

Chemical Oxygen Demand

Stormwater samples generally had higher concentrations of COD than groundwater and lysimeter samples. COD in lysimeter samples were variable, with slightly higher concentrations in V-LS-02. COD concentrations in groundwater also were variable, with slightly higher concentrations in V-MW-04. No trends for COD in groundwater or lysimeter samples are evident. Based on these results, stormwater infiltration for this project does not appear to have resulted in groundwater quality degradation by COD.

Total Copper

Concentrations of total copper in stormwater samples were variable and generally higher than those in groundwater samples and the majority of those in the lysimeter samples.

Lysimeter sample concentrations of total copper were generally slightly higher in V-LS-02 than V-LS-01, with V-LS-02 concentrations typically higher than concentrations found in groundwater. V-MW-04 had slightly higher concentrations of total copper than the other three groundwater wells. V-MW-03 sample concentrations were generally lower than the other groundwater wells and concentrations at V-MW-02 showed a slight but statistically significant decreasing trend over the project period. Although stormwater and lysimeter sample concentrations are generally higher than groundwater, it does not appear that total copper concentrations in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Copper

Concentrations of dissolved copper in stormwater samples were variable and generally higher than those in groundwater samples and those in the majority of the lysimeter samples. Lysimeter sample concentrations of dissolved copper were generally slightly higher in V-LS-02 than in V-LS-01, with V-LS-02 concentrations typically higher than concentrations found in groundwater. V-MW-04 had slightly higher concentrations of dissolved copper than the other three groundwater wells. Dissolved copper concentrations in samples from V-MW-03 were generally lower than those in samples from the other groundwater wells, and concentrations at V-MW-02 showed a slight but statistically significant decreasing trend over the project period. Although dissolved copper concentrations in stormwater and lysimeter sample concentrations were generally higher than those in groundwater, it does not appear that dissolved copper in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Total Lead

Concentrations of total lead in stormwater samples from V-SW-02 were typically higher than those in groundwater samples, as were the most recent samples from V-SW-01. Total lead was not detected in any lysimeter samples collected. Total lead was also not detected in groundwater samples from V-MW-01. Concentrations of total lead detected in groundwater samples from the other three wells were generally low and varied through the study period. Although concentrations of total lead were generally higher in stormwater samples than in groundwater, it does not appear that total lead in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Lead

Dissolved lead was detected at low concentrations in the majority of stormwater samples. Dissolved lead was detected in only one of the groundwater samples, and was not detected in any of the lysimeter samples. Based on the limited number of detected concentrations, it does not appear that dissolved lead in groundwater or soil pore water increased as the result of stormwater infiltration.

Total Zinc

Total zinc was detected in all of the stormwater samples. Concentrations of total zinc in stormwater were higher than those in lysimeter or groundwater samples. Total zinc concentrations in lysimeter samples remained generally consistent over the study duration. Total zinc was not detected in groundwater samples from V-MW-01, and concentrations in

V-MW-04 were generally higher than those in V-MW-02 and V-MW-03, but concentrations at each monitoring well remained relatively consistent during the study. Although concentrations of total zinc were generally higher in stormwater samples than in groundwater, it does not appear that total zinc in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Dissolved Zinc

Dissolved zinc was detected in all of the stormwater samples. Concentrations of dissolved zinc in stormwater were higher than lysimeter and groundwater sample concentrations in all cases. Some lysimeter sample concentrations were slightly higher than those in the groundwater samples. Concentrations of dissolved zinc were generally similar in groundwater samples from the four monitoring wells. Lysimeter and groundwater sample concentrations were fairly stable over the study duration. Although concentrations of dissolved zinc were generally higher in stormwater samples than in groundwater, it does not appear that dissolved zinc in groundwater or soil pore water increased as the result of stormwater infiltration over the study period.

Arsenic

Arsenic was not detected in most of the stormwater samples; low concentrations were detected during the two most recent sampling events. Arsenic concentrations in lysimeter samples remained relatively consistent over the study period. Arsenic concentrations in groundwater samples from V-MW-01 and V-MW-04 were slightly higher than those from V-MW-02 and V-MW-03 during the 2004/2005 wet season, and concentrations at V-MW-02 and V-MW-03 showed a slight decrease during the study period. Based on these results and the groundwater flow and monitoring well location conditions summarized previously, it does not appear that the increase in arsenic concentrations in groundwater at V-MW-01 and V-MW-04 is the result of arsenic concentrations in stormwater infiltrated during this study. Decreasing concentration trends in samples collected from V-MW-02 and V-MW-03 are statistically significant.

Perchlorate

Perchlorate was not detected in stormwater or lysimeter samples from this site. Concentrations of perchlorate in groundwater were sporadic and variable, and included some relatively higher values in samples from V-MW-01 and V-MW-04. Because perchlorate was not detected in lysimeter or stormwater samples, it is unlikely that stormwater infiltration has contributed perchlorate to groundwater.

MtBE

MtBE was not detected in any of the samples.

Figure 10
Depth Concentrations for Chloride - Veterans Park

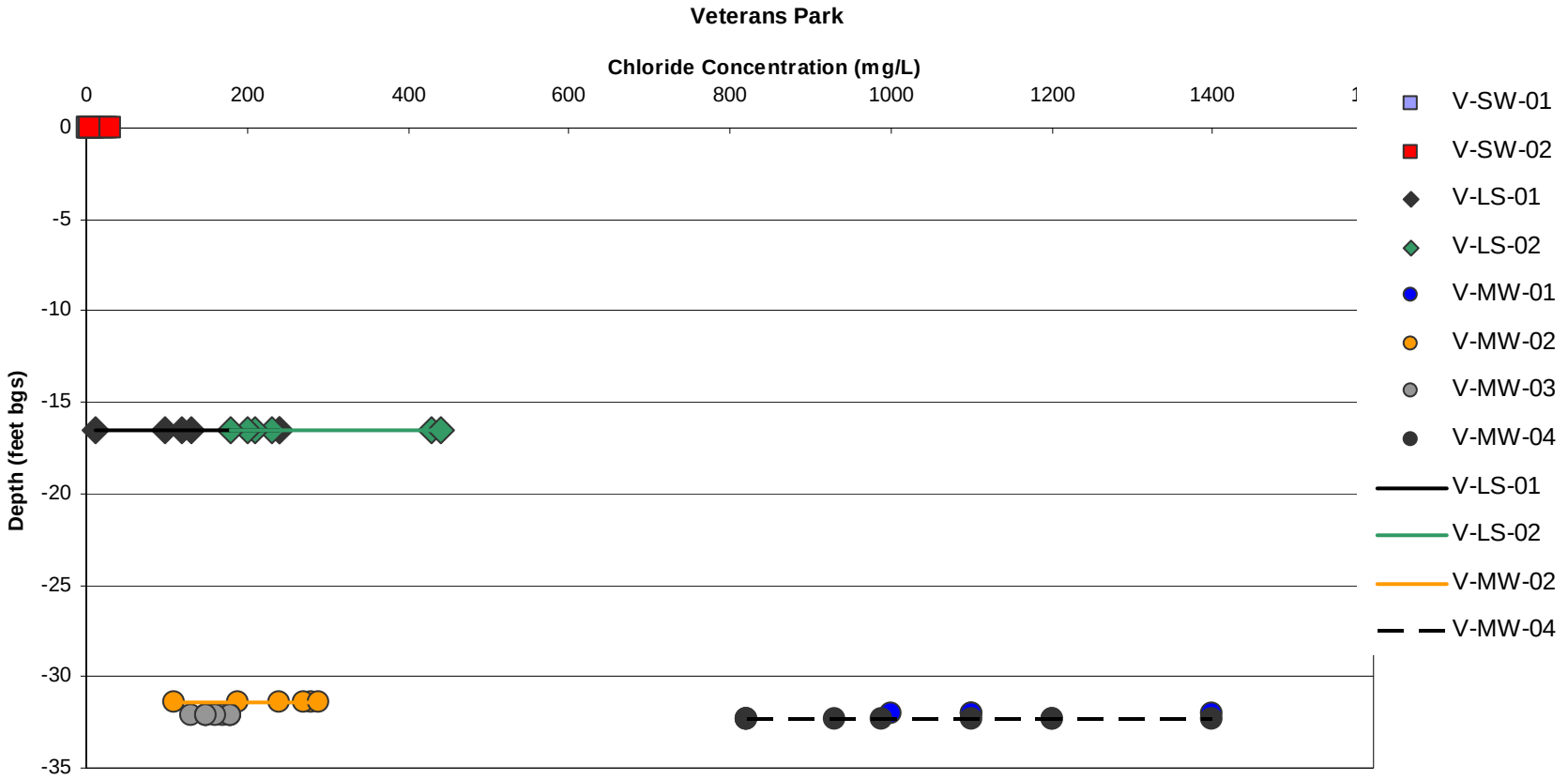
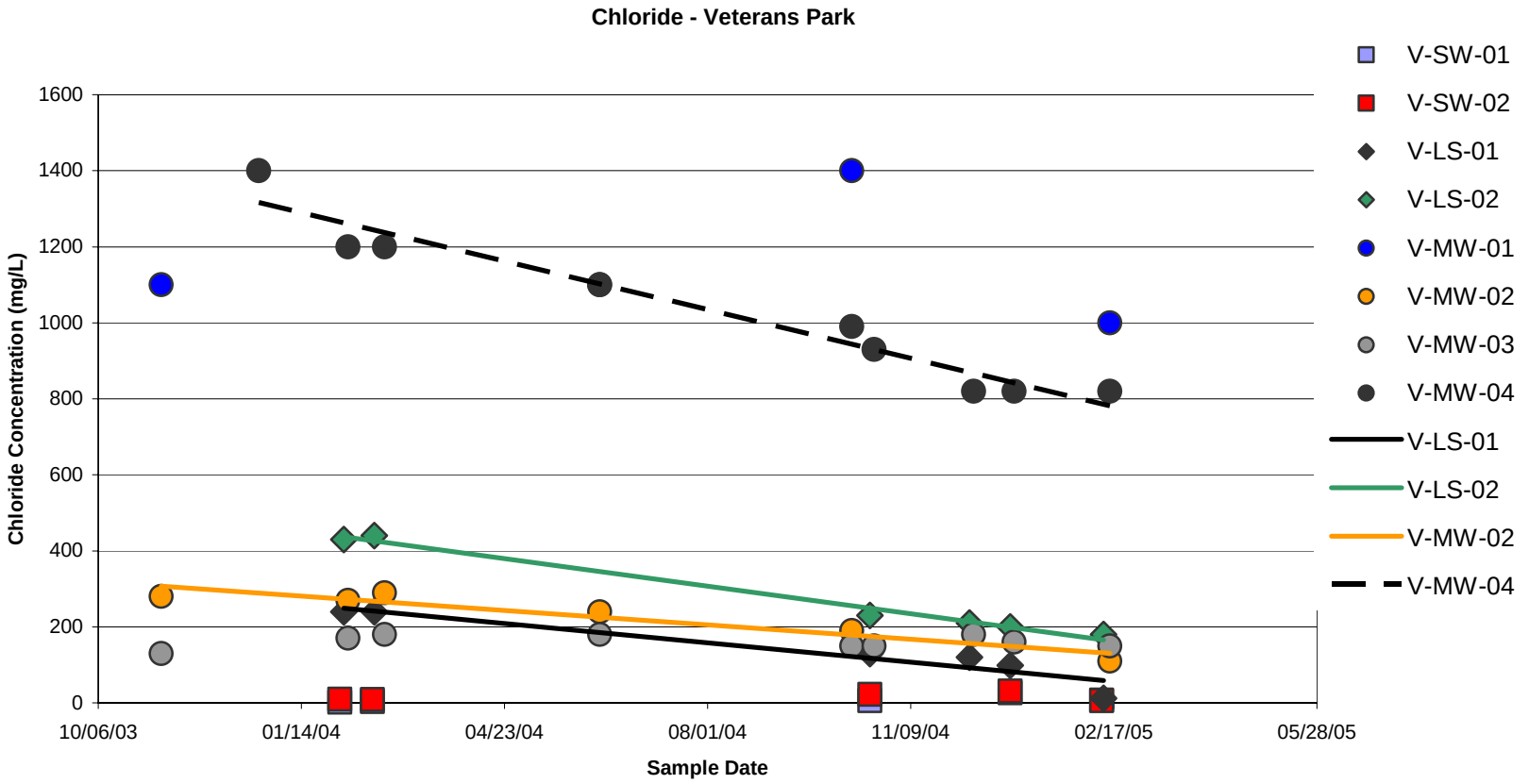


Figure 11
Chloride Concentrations Over Time - Veterans Park



5.7 Land Use Variation

The biggest difference in constituents detected between the sites that can be attributed to land use is in the organic compounds. Some VOCs were detected in stormwater collected at all sites, but were much more abundant in the samples collected at the industrial sites. Organics detected at the non-industrial sites were primarily acetone, MEK and oil and grease. The industrial sites had higher concentrations of those constituents, plus other compounds such as benzene, toluene, ethanol, and phthalates. Petroleum hydrocarbons were also detected in small quantities at the industrial sites, but not at the other sites.

Nitrate in stormwater was low at all sites. Concentrations of metals, dissolved solids and suspended solids were higher at the industrial sites than at the other sites, undoubtedly related to the business activities conducted at those sites. Total copper and zinc were lowest at the Broadous School. Concentrations of TDS at Veterans Park were higher in lysimeters and groundwater than samples collected at the industrial sites, which may be the result of pre-study infiltration from irrigation and the application of fertilizer that does not occur at industrial sites. No other significant differences in constituent concentrations were discernable between the commercial, educational, and residential land uses.

Total coliform bacteria concentrations were high in most stormwater samples. Detections of total coliform were highest at Sun Valley and lowest at the residential site and the metal recycler. Differences in the two industrial sites may be attributed to the types of material handled. Beverage containers brought in for sorting at the Sun Valley site may contain residual liquid that would promote bacterial growth, as opposed to the relatively dry scrap metal handled at the metal recycler.

At the three sites where roof runoff was sampled (IMAX, Hall House and Sun Valley), concentrations of most constituents were lower in roof samples than in samples taken from the ground surface. Concentrations of metals (especially total aluminum, lead and zinc), TDS, TSS and acetone in roof runoff were not insignificant however, indicating that atmospheric deposition may be a major contributor to stormwater pollution.

5.8 CONCLUSIONS

Soil appears to be very efficient at removing bacteria from stormwater. Fecal coliform and E. coli were detected in at least one stormwater sample from each site except Hall House, and total coliforms were detected at high levels in nearly all stormwater samples at all sites. With the exception of one sample at the Broadous School, bacteria were not detected, or detected at very low concentrations, in lysimeter and groundwater samples.

Concentrations of metals tended to be higher in stormwater than in subsurface water samples. Concentrations in subsurface samples were variable and generally stable or decreasing. Exceptions are increasing trends of copper in lysimeter samples collected at the Sun Valley site that could be associated with infiltration of storm water with relatively

higher concentrations of copper. Most inorganic groundwater quality constituents do not show clear trends or show decreasing concentrations over the study period. In only one instance, involving low concentrations of nitrate, did concentrations of a constituent show a statistically significant, although slight, increase. Groundwater quality data from the shallow groundwater sites show groundwater quality improvement (decreasing salt concentrations) potentially associated with dilution by infiltrating stormwater.

At the non-industrial sites the concentrations of general monitoring parameters such as TDS and chloride tended to be less than or similar to concentrations in lysimeter and groundwater samples. This suggests that the infiltration of stormwater is not likely to have a significant negative impact to groundwater from these constituents. At the Veterans Park site, concentrations of TDS, nitrate, chloride, and other salts in groundwater samples (including pre-infiltration background samples) was much higher than concentrations in stormwater samples. This result is likely due to historical application of fertilizers. Data collected to date suggest that concentrations of many of these constituents in lysimeter and groundwater samples are decreasing with time, possibly due to dilution by infiltrated stormwater.

Other than acetone, VOCs and SVOCs detected in storm water are different than VOCs detected in subsurface samples. VOCs detected in groundwater samples during the monitoring period were also detected in initial background samples. With the possible exception of occasional low level detections of acetone, VOCs in stormwater do not appear to impact groundwater at all. At the industrial sites, groundwater constituents such as MtBE and chlorinated solvents were present in some lysimeter samples at greater concentrations than present in any stormwater samples. This finding suggests the presence of subsurface contamination prior to stormwater infiltration.

The industrial sites had detections of more organic compounds and higher concentrations of metals than the non-industrial sites. The filtration system in the detention basins at Sun Valley and the Metal Recycler site was somewhat effective at reducing concentrations of certain constituents, particularly the dissolved metals. For example, at the Metal Recycler site, concentrations of dissolved arsenic, copper, chromium VI and lead were lower after filtration. The sedimentation basin at Veterans Park and the soil layers at the other sites would also be expected to reduce concentrations of metals and other solids, although effluent was not analyzed separately to verify this.

Although perchlorate was detected in some stormwater samples, there is no evidence of groundwater degradation by perchlorate from stormwater infiltration during this study. The occurrence of perchlorate in stormwater samples was unexpected, as the focus is typically on subsurface sources of perchlorate contamination. Perchlorate is a salt, which in addition to being a component of solid rocket fuel, is also an ingredient in fireworks and road flares. Other constituents of concern for groundwater (disinfection byproducts, 1,4-Dioxane, PAHs and DBCP) were not detected in stormwater.

Soil samples collected from four of the sites at the conclusion of the study indicated no significant increases in parameters monitored, and in many cases constituent concentrations were reduced.

The concentrations of many constituents vary throughout the sampling period, but there is no apparent pattern that can be tied to effects from infiltration. As stated above, VOCs detected in groundwater are routinely different than those in stormwater. VOCs detected in groundwater samples collected during the storm season were also detected in pre-season background samples, thus they do not appear to be the result of infiltration. Given the depth to groundwater at the two industrial sites and at Broadous, it seems unlikely that constituents introduced into the soil from stormwater infiltration would migrate all the way to the groundwater at a detectable concentration.

Data collected to date indicate that there is no statistically significant degradation of groundwater quality from the infiltration of stormwater-borne constituents. Groundwater quality has generally improved for most constituents at sites with shallow groundwater.

6. SUMMARY

6.1 Evaluation of Project Success

The data collected during this study show no immediate impacts, and no apparent trends to indicate that stormwater infiltration will negatively impact groundwater at these sites. While variations in stormwater and groundwater constituents between types of land use were apparent, they may not be a barrier to infiltration. Filtration methods employed at the industrial sites seemed to be effective at removing certain constituents prior to entering the infiltration system, which may make infiltration more feasible at these more contaminated sites. However, site characterization of surface and soil constituents at industrial sites should be conducted prior to implementing infiltration strategies.

Overall the goals of our Phase II study have been met. The specific goals of Phase II were to assess the cumulative impact of infiltration on soil and groundwater, and evaluate the effects of different land uses on constituent types and concentrations. While we see the value in long-term monitoring to better characterize these issues, the data so far have shown positive results for infiltration potential.

6.2 Next Steps

6.2.1 Long-term Monitoring Program

While the data collected during this program do provide significant information, monitoring will continue in order to better assess the cumulative effects of infiltration. A reduced program of subsurface monitoring is under currently development. This program will likely include annual or bi-annual monitoring of lysimeters and groundwater wells at four or five sites. No stormwater samples will be collected, as surface runoff quality has been well-characterized at these sites. Monitoring will be scheduled after significant storm events and late in the storm season, to ensure that infiltration to the deepest lysimeters has occurred. The analytical suite will be reduced but should include metals, general parameters, some organics, and perchlorate. We expect to continue monitoring for at least two additional years, and possibly longer if funding is available.

6.2.2 Phase III Work Plan

Infiltration is not the only means of addressing water supply and water quality issues. We believe that an integrated, comprehensive approach to water management is necessary to maximize efficient use of our water resources. Thus the third phase of the study will incorporate demonstration projects on a neighborhood scale. We propose to retrofit one or more small neighborhoods with state of the art Best Management Practices to address stormwater infiltration as well as water conservation, pollution reduction and treatment, flooding, and habitat and stream restoration. Specific techniques will depend upon the sites selected, but may include conversion to native drought-tolerant landscapes, use of

irrigation controllers, facilities to capture runoff for infiltration and/or reuse, restoring buried stream channels, and adding green space and habitat areas. The demonstration projects will be monitored for water quality as well as for reduction of runoff and water use, changes in property values, and other potential benefits. These neighborhood projects will provide real-world models of addressing existing infrastructure and will serve to integrate many on-going efforts in the region to address flood management, water quality, water supply and environmental restoration. Our goal is to demonstrate how these approaches can be applied on a regional scale in Southern California as well as in other geographic regions.

In addition to the demonstration project, we are assessing the overall feasibility of utilizing infiltration techniques to capture stormwater for groundwater recharge. The Bureau of Reclamation is currently developing a groundwater augmentation model to predict the amount of additional water that could be available for deep percolation if infiltration is increased. They are also developing a regional cost and benefit assessment to determine the real cost of this new water supply. Researchers at UC Riverside are assessing costs on a site-specific scale. The long-term goal of this project is a regional strategy for implementation.

7. REFERENCES

Ackerman, D. and K. Schiff. 2003. Modeling Stormwater Mass Emissions to the Southern California Bight. Journal of Environmental Engineering, 129(4): 308-317.

Anders, R., Yanko, W.A., Schroeder, R.A., and J.L. Jackson. 2003. *Virus Fate and Transport During Recharge Using Recycled Water at a Research Field Site in the Montebello Forebay, Los Angeles County, California, 1997-2000*. (http://ca.water.usgs.gov/issues/6.html) (Accessed 18 October, 2004).

Barraud, S., Gautier, A., Bardin, J.P., and V. Riou. 1999. The Impact of Intentional Stormwater Infiltration on Soil and Groundwater. *Water Science and Technology* 39 (2): 185-192.

Bhaduri, B., Minner, M., Tatalovich, S., and J. Harbor. 2001. Long-term Hydrologic Impact of Urbanization: A Tale of Two Models. *Journal of Water Resources Planning and Management* 127 (1): 13-19.

Bouwer, H. 1996. Issues in Artificial Recharge. *Water Science and Technology* 33: 381-390.

Brattebo, B.O. and D.B. Booth. 2003. Long-term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. *Water Research* 37 (18): 4369-4376.

Bucheli, T., Muller, S., Herberle, S., and T. Schwarzenbach. 1998. Occurrence and Behavior of Pesticides in Rainwater, Roof Runoff, and Artificial Stormwater Infiltration. *Environmental Science and Technology* 32: 3457-3464.

Cox, J. and E. Livingston. 1997. Stormwater Sediments: Hazardous Waste or Dirty Dirt. Fifth Biennial Stormwater Research Conference, Florida. November 5-7, 1997.

Datry, T., F. Malard and J. Gilbert. Dynamics of Solutes and Dissolved Oxygen in Shallow Urban Groundwater Below a Stormwater Infiltration Basin. 2004. *Science of the Total Environment* 329 (1-3): 215-229.

_____. 2003. Solute Dynamics in the Bed Sediments of a Stormwater Infiltration Basin. *Journal of Hydrology* 273 (1-4): 217 - 233.

Dechesne, M., S. Barraud and J. Bardin. 2004. Spatial Distribution of Pollution in an Urban Stormwater Infiltration Basin. *Journal of Contaminant Hydrology* 72 (1-4): 189-205.

Dierkes, C. and W.F. Geiger. 1999. Pollution Retention Capabilities of Roadside Soils. *Water Science and Technology* 39: 201-208.

Downs, T., Cifuentes, E., Ruth, E., and I. Suffet. 2000. Effectiveness of Natural Treatment in a Wastewater Irrigation District of the Mexico City Region: A Synoptic Field Survey. *Water Environment Research* 72 (1).

Dunne, T. and L. Leopold. 1979. *Water in Environmental Planning*. New York: W.H. Freeman and Company.

Dunning, C. and R. Bannerman. 1993. *Monitoring Contaminant Transport from a Stormwater Infiltration Facility to Ground Water*. Wisconsin Department of Natural Resources Project #168, December 2003.

Ferguson, B. 1998. *Introduction to Stormwater*. New York: John Wiley & Sons.

_____. 1994. *Stormwater Infiltration*. Florida: Lewis Publishers.

Fisher, D., Charles, E.G., and A.L. Baehr. 2003. Effects of Stormwater Infiltration on Quality of Groundwater Beneath Retention and Detention Basins. *Journal of Environmental Engineering* 129 (5): 464 - 471.

Flint, A. 2002. *The Role of Unsaturated Flow in Artificial Recharge Projects*. *in* U.S. Geological Survey Artificial Recharge Workshop Proceedings. G.R. Aiken and E.L. Kuniansky, Ed. Sacramento, California. April 2-4, 2002.

Freeze, R.A and J. A. Cherry. 1979. *Groundwater*. Prentice-Hall Inc.

Glick, R., Chang, G. and M. Barrett. 1998. *Monitoring and Evaluation of Stormwater Quality Control Basins*. Proceedings of the Water Environment Federation Conference. Denver, CO. May 3-6, 1998.

Hathhorn, W. and D. Yonge. 1995. *The Assessment of Groundwater Pollution Potential Resulting from Stormwater Infiltration BMPs*. Washington State Transportation Center, Washington State University. Final Technical Report. August, 1995.

Lazaro, T., 1990. *Urban Hydrology – A Multidisciplinary Perspective*. Lancaster, PA: Technomic Publishing Co, Inc.

Lee, G., Jones-Lee, A. and S. Taylor. 1998. Development of Appropriate Stormwater Infiltration BMPs: Part I, Potential Water Quality Impacts, Monitoring and Efficacy Evaluation. Presented at the Ground Water Protection Council 98 Annual Forum. September, 1998.

Lee, G. 2000. Overview of Conventional Stormwater Runoff Water Quality BMP Characteristics and Performance *in Stormwater Runoff Water Quality Science/Engineering Newsletter*. 3 (2). May 19, 2000.

_____. 2004. Unrecognized Environmental Pollutants *in Stormwater Runoff Water Quality Science/Engineering Newsletter*. 7 (3). March 12, 2004.

Legret, M. and V. Colandini. 1999. Effects of a Porous Pavement with Reservoir Structure on Runoff Water: Water Quality and Fate of Heavy Metals. *Water Science and Technology* 39:111-117.

Lindemann, J. 1999. *Evaluation of Urban Runoff Infiltration and Impact to Groundwater Quality in Park Ridge, Wisconsin*. Masters Thesis. University of Wisconsin, College of Natural Resources.

Lopes, T., J. Fallon, D. Rutherford and M. Hiatt. 2000. *Quantifying non-point sources of volatile organic compounds in stormwater from a parking lot*. Journal of Environmental Engineering, December, 1137-1143.

Los Angeles County Department of Public Works (LACDPW). 2000. Annual Hydrologic Report. 1999-2000.

_____, 2002. Table 4-12 Summary of 1994-2000 Land Use Results by Site, in 1994-2000 Stormwater Quality Data Tables
(http://www.LACDPW.org/WMD/npdes/9400_tbl_list.cfm)

_____, 2005. Unpublished rainfall data.

Metge, D. 2002. *Fate and Transport of Bacterial, Viral, and Protozoan Pathogens During ASR Operations—What Microorganisms Do We Need to Worry About and Why? in* U.S. Geological Survey Artificial Recharge Workshop Proceedings. G.R. Aiken and E.L. Kuniansky, Ed. Sacramento, California. April 2-4, 2002.

Mikkelsen, P., Hafliger, M., Ochs, M., Jacobsen, P., Tjell, J.C., and M. Boller. 1997. Pollution of Soil and Groundwater from Infiltration of Highly Contaminated Stormwater – A Case Study. *Water Science and Technology* 36: 325-330.

Mikkelsen, P., Jacobsen, P., and S. Fujita. 1996. Infiltration Practice for Control of Urban Stormwater. *Journal of Hydraulic Research* 34:827-840.

Mount, J. 1995. *California Rivers and Streams: The Conflict Between Fluvial Process and Land Use*. Berkeley: University of California Press.

Novotny, V. and H. Olem. 1994. *Water Quality: Prevention, Identification, and Management of Diffuse Pollution*. New York: Van Nostrand Reinhold.

Pitt, R., Clark, S., Parmer, K., and R. Field. 1996. *Groundwater Contamination from Stormwater Infiltration*. Michigan: Ann Arbor Press.

RBF Consulting. June, 2003. *BMP Effectiveness and Applicability for Orange County*. Irvine, California.

Rourke, D. November, 2004. Coordinator, Fresno Metropolitan Flood Control District. Personal Communication.

Schroeder, E. et al. 2002. *Management of Pathogens Associated with Storm Drain Discharge*. Division of Environmental Analysis, California Department of Transportation Report CTSW-TR-02-05, May 2002.

Schroeder, R. 1995. *Potential for Chemical Transport Beneath a Storm-Runoff Recharge (Retention) Basin for an Industrial Catchment in Fresno, California*. U.S. Geological Survey Water Resources Investigations Report 93-4140.

Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Washington, DC: Washington Metropolitan Water Resources Planning Board.

Shelton, J. et al. 2001. *Low-Level Volatile Organic Compounds in Active Public Supply Wells as Ground-Water Tracers in the Los Angeles Physiographic Basin, California*. U.S. Geological Survey Water Resources Investigations Report 01-4188.

Strecker, E. 1994. *Considerations and Approaches for Monitoring the Effectiveness of Urban BMPs.* Portland: Woodward-Clyde.

Strecker, E., Quigley, M., Urbonas, B., Jones, J. and J. Clary. 2001. Determining Urban Stormwater BMP Effectiveness. *Journal of Water Resources Planning and Management* 127 (3): 144-49.

Santa Monica Bay Restoration Project (SMBRP). (1992) *Pathogens and Indicators in Storm Drains within the Santa Monica Bay Watershed.*

Tiefenthaler, L., K. Schiff, S. Bay, and D. Greenstein. 2002. *Effect of antecedent dry periods on the accumulation of potential pollutants on parking lot surfaces using simulated rainfall*. Southern California Coastal Water Research Project Annual Report, 2001-2002.

Tiefenthaler, L. and K. Schiff, 2002. *Effects of rainfall intensity and duration on first flush of stormwater pollutants*. Southern California Coastal Water Research Project Annual Report, 2001-2002.

Tipton, D. K., 2003. Transport and Biodegradation of Perchlorate in Soils. *Journal of Environmental Quality,* 32: 40–46.

Urbonas, B. and P. Stahre. 1993. *Stormwater Best Management Practices and Detention for Water Quality, Drainage, and CSO Management*. New Jersey: Prentice Hall.

United States Environmental Protection Agency (EPA), 1983. *Results of the Nationwide Urban Runoff Program*. Volume 1 – Final Report. Washington, DC: U.S. EPA Water Planning Division. WH-554. December, 1983.

_____, 1994. Potential Groundwater Contamination from Intentional and Non-intentional Stormwater Infiltration. U.S. EPA Center for Environmental Research Information. May, 1994.

_____, 1999. *Preliminary Data Summary of Urban Stormwater Best Management Practices*. Washington, D.C.: US EPA Office of Water. August, 1999.

United States Geological Survey (USGS), 2001. A Historical Overview of Hydrologic Studies of Artificial Recharge in the U.S. Geological Survey. Lakewood, Colorado.

_____. 2004. Aquifer Storage and Recovery. USGS Water Resources of California. (http://ca.water.usgs.gov/issues/6.html) (Accessed 18 October, 2004).

Water Environment Federation and American Society of Civil Engineers. 1998. *Urban Runoff Quality Management*. WEF Manual of Practice No. 23, ASCE Manual and Report on Engineering Practice No. 87.

Water Replenishment District. 2001. Regional Groundwater Monitoring Report for Water Year 2000-2001.

_____. Information Fact Sheet. (http://www.wrd.org/broch_new.htlm) (Accessed 15 October, 2004).

8. APPENDICES

Appendix A Site Location Maps
Appendix B Analytical List

On cd:
Appendix C Complete Stormwater, Lysimeter, and Groundwater Water Quality Results.
Appendix D Comparative Water Quality Results
Appendix E Soil Analytical Results
Appendix F Time-Concentration Charts and Results of Trend Analysis
Appendix G Depth-Concentration Charts
Appendix H Boring logs
Appendix I Groundwater Hydrographs

Appendix A. Site Location Maps

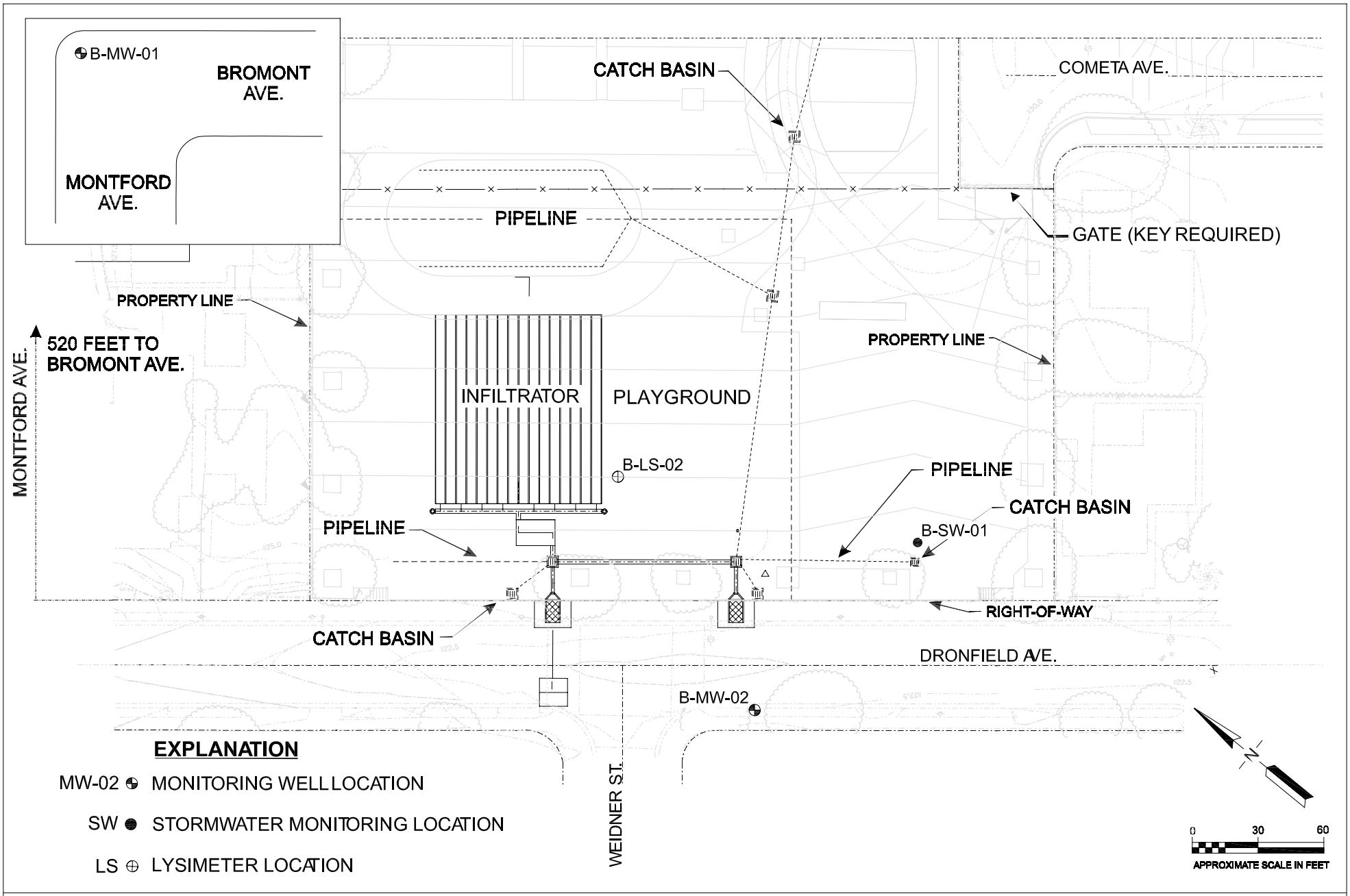
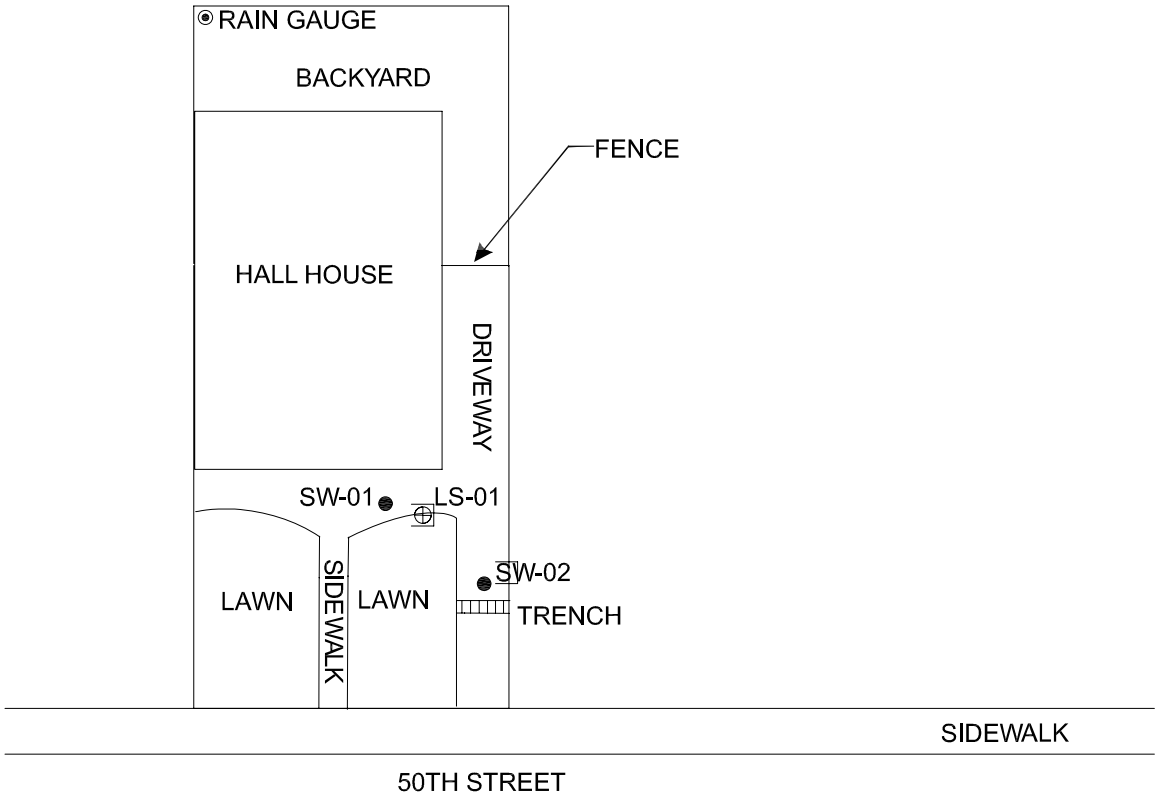


FIGURE A-1

INFILTRATION AND BMP MONITORING SYSTEM - BROADUS SCHOOL SITE



EXPLANATION

SW-01 ● STORMWATER MONITORING LOCATION

LS-01 ⊕ LYSIMETER LOCATION

N

NOT TO SCALE

FIGURE A-2
MONITORING LOCATION MAP - HALL HOUSE

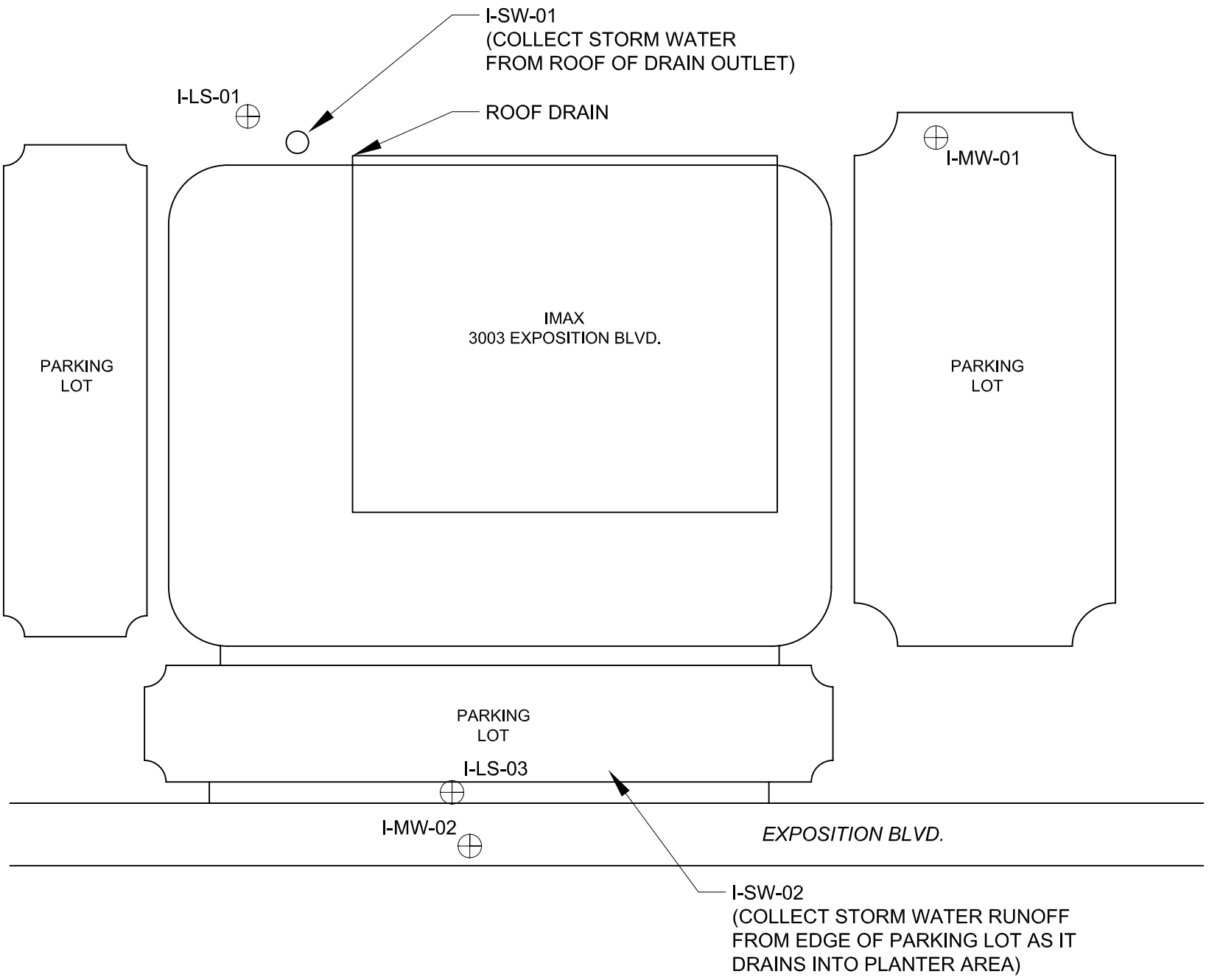


FIGURE A-3

MONITORING LOCATION MAP - IMAX BUILDING

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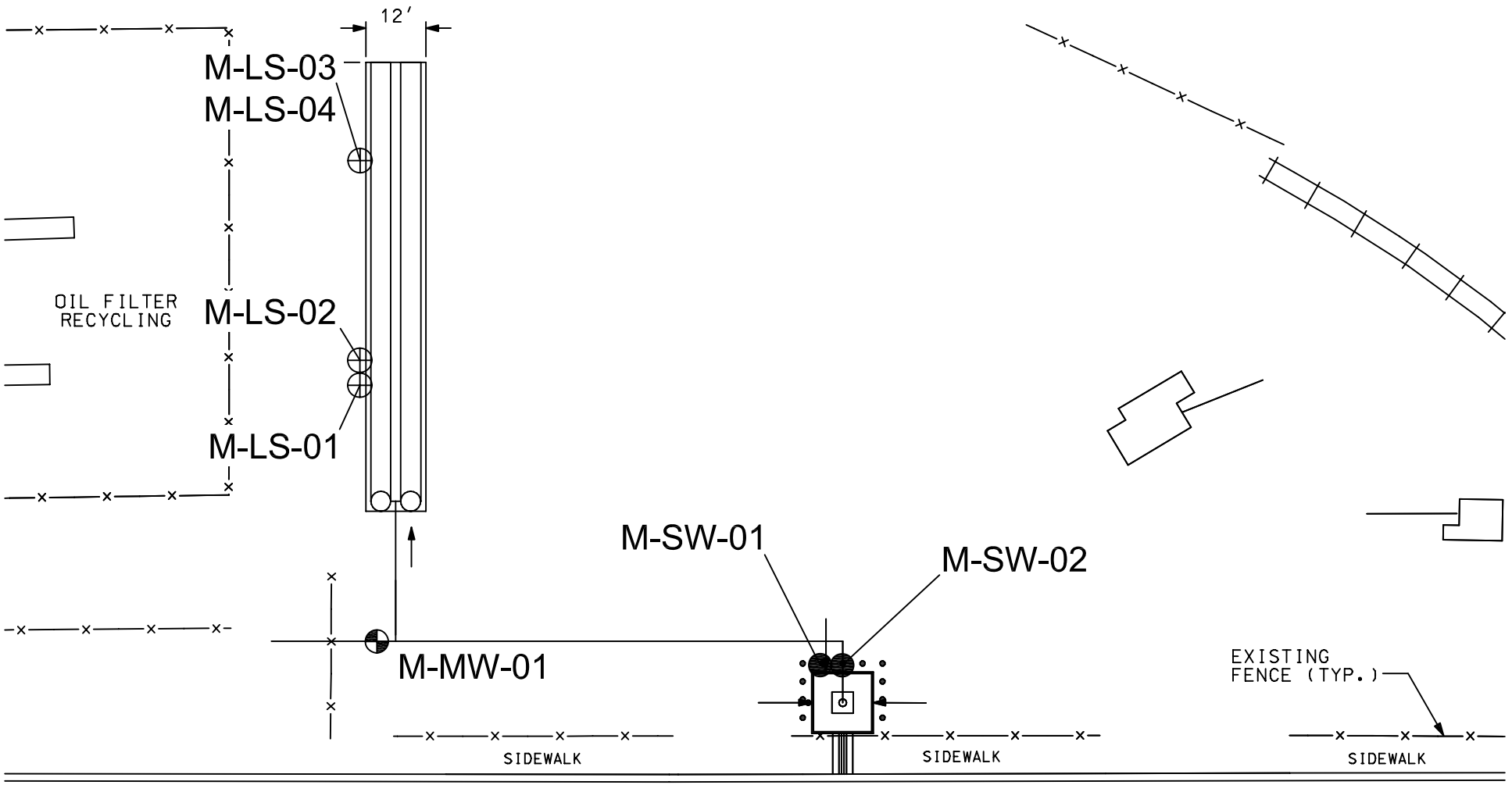

EXPLANATION

M-MW-01 ⊕ MONITORING WELL LOCATION

M-SW-01 ● STORMWATER MONITORING LOCATION

M-LS-01 ⊕ LYSIMETER LOCATION

N

0 15 30

APPROXIMATE SCALE IN FEET

FIGURE A-4

INSTALLED MONITORING SYSTEM - METAL RECYCLER

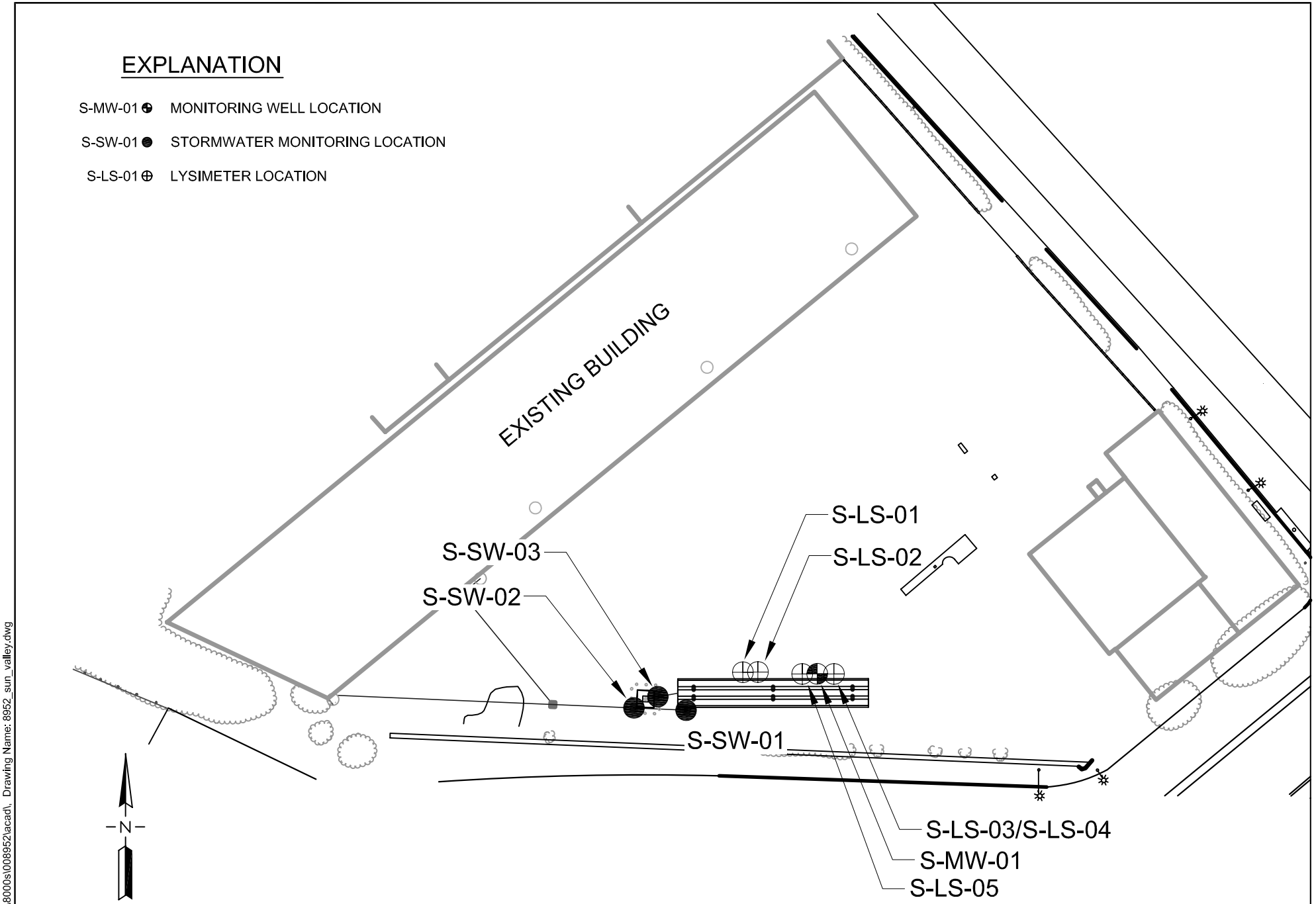

FIGURE A-5
INSTALLED MONITORING SYSTEM - SUN VALLEY

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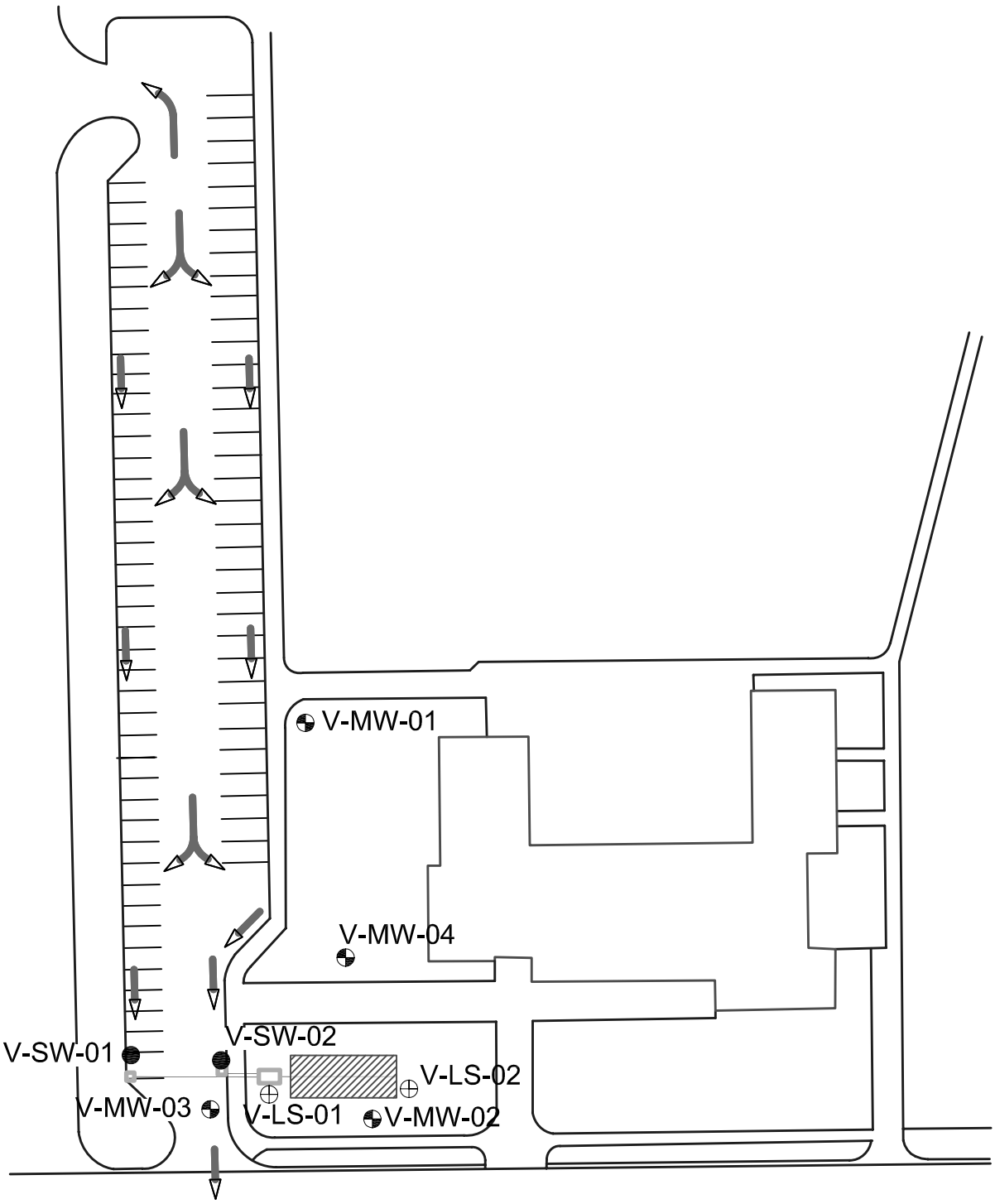

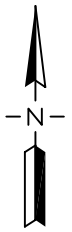

0 30 60

APPROXIMATE SCALE IN FEET

EXPLANATION

V-MW-01 MONITORING WELL LOCATION

V-SW-01 STORMWATER MONITORING LOCATION

V-LS-01 LYSIMETER LOCATION

FIGURE A-6

INSTALLED MONITORING SYSTEM - VETERANS PARK

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Appendix B. Analytical Suite

Constituent	Detect Limit	Lab Method	Surface & GW	Lysimeter List	Soils
General:					
Alkalinity	1 mg/L	SM2320B	Y	N	Y
Bicarbonate	1 mg/L	SM2320B	Y	N	Y
Bromide	0.1 mg/L	EPA 300	Y	Y	Y
Calcium	0.1 mg/L	EPA 200.7	Y	N	Y
Carbonate	1 mg/L	SM2320B	Y	N	Y
Chloride	1 mg/L	EPA 300.0	Y	Y	Y
COD	5 mg/L	EPA 410.4	Y	Y	Y
Fluoride	0.1 mg/L	EPA 340.2	Y	N	Y
Hardness	2 mg/L	EPA 130.2	Y	N	N
Hydroxide	1 mg/L	SM2320B	Y	N	Y
Magnesium	0.1 mg/L	EPA 200.7	Y	N	Y
MBAS	0.1 mg/L	EPA 425.1	Y	N	Y
Nitrate as N	0.1 mg/L	EPA 300	Y	Y	Y
Nitrite as N	0.1 mg/L	EPA 300	Y	Y	Y
Total Organic Carbon	0.5 mg/L	EPA 415.1	Y	Y	Y
Dissolved Organic Carbon	0.5 mg/L	EPA 415.1	Y	N	N
Organic N	0.5 mg/L	SM4500NorgE	Y	Y	Y
NH3	0.1 mg/L	EPA 350.2	Y	Y	Y
pH	na	EPA 150.1	Y	field	Y
Phosphorous - total	0.03 mg/L	EPA 365.3	Y	Y	Y
Phosphorous - dissolved	0.03 mg/L	EPA 365.3	Y	N	N
Potassium	0.5 mg/L	EPA 200.7	Y	N	Y
Sodium	0.5 mg/L	EPA 200.7	Y	N	Y
Specific Conductance	4 umho/cm	EPA 120.1	Y	field	N
Sulfate	1 mg/L	EPA 300	Y	Y	Y
TDS	1 mg/L	EPA 160.1	Y	Y	N
TSS	1 mg/L	EPA 160.2	Y	N	N
Turbidity	0.05 NTU	EPA 180.1	Y	N	N
Metals (total & dissolved)					total
Aluminum	50 µg/L	EPA 200.8	Y	Y	Y
Antimony	1 µg/L	EPA 200.8	Y	Y	Y
Arsenic	2 µg/L	EPA 200.8	Y	Y	Y
Barium	1 µg/L	EPA 200.8	Y	Y	Y
Beryllium	1 µg/L	EPA 200.8	Y	Y	Y
Boron	50 µg/L	EPA 200.8	Y	Y	Y
Cadmium	0.2 µg/L	EPA 200.8	Y	Y	Y
Chromium	1 µg/L	EPA 200.8	Y	Y	Y
Chromium VI	0.2 µg/L	EPA 218.6	Y	Y	Y
Cobalt	1 µg/L	EPA 200.8	Y	Y	Y
Copper	1 µg/L	EPA 200.8	Y	Y	Y
Iron	100 µg/L	EPA 200.8	Y	Y	Y
Lead	0.5 µg/L	EPA 200.8	Y	Y	Y

Constituent	Detect Limit	Lab Method	Surface & GW	Lysimeter List	Soils
Manganese	1 µg/L	EPA 200.8	Y	Y	Y
Mercury	0.1 µg/L	EPA 7470.A	Y	N	Y
Molybdenum	1 µg/L	EPA 200.8	Y	Y	Y
Nickel	1 µg/L	EPA 200.8	Y	Y	Y
Selenium	1 µg/L	EPA 200.8	Y	Y	Y
Silver	1 µg/L	EPA 200.8	Y	Y	Y
Thallium	1 µg/L	EPA 200.8	Y	Y	Y
Zinc	5 µg/L	EPA 200.8	Y	Y	Y
Volatile Organic Compounds (full suite)			Y	Y	EPA 8260
Methyl Bromide	0.5 µg/L	EPA 524.2	inc	inc	inc
BTEX	0.5 µg/L	EPA 524.2	inc	inc	inc
MtBE	1 µg/L	EPA 524.2	inc	inc	inc
DIPE	2 µg/L	EPA 524.2	inc	inc	inc
ETBE	2 µg/L	EPA 524.2	inc	inc	inc
TAME	2 µg/L	EPA 524.2	inc	inc	inc
TBA	10 µg/L	EPA 524.2	inc	inc	inc
Ethanol	100 µg/L	EPA 524.2	inc	inc	inc
TCE	0.5 µg/L	EPA 524.2	inc	inc	inc
PCE	0.5 µg/L	EPA 524.2	inc	inc	inc
Disinfection Byproducts (THMs)	0.5 µg/L	EPA 524.2	inc	inc	inc
1,2,3-TCP	0.005 µg/L	GC/MS Isotope Dilution	Y (1 time)	N	Inc
Trip blanks	N/A	upon request			
Other					
Oil and Grease	1 mg/L	EPA 1664	Y	Y	Y
Perchlorate	2 µg/L	EPA 314	Y	N	Y
Semi-volatile Organics (full suite)	5-50 µg/L	EPA 625/8270C	Y	N	Y
NDMA	.002 µg/L	EPA 1625mod	Y	N	N
Round-up (Glyphosate)	10 µg/L	EPA 547	Y	N	Y
1,4 Dioxane	2µg/L	GC/MS Isotope Dilution	Y	N	N
DBCP	0.02 µg/L	EPA 504.1	Y	N	Y (8260)
Biological:					
HPC	<1 CFU/mL	SMEWW 20th	Y	Y	Y
Total coliforms	1.1 MPN/100ml	SMEWW 20th	Y	Y	Y
Fecal coliform	1.1 MPN/100ml	SMEWW 20th	Y	Y	Y
E. coli	1.1 MPN/100ml	SMEWW 19th	Y	Y	Y