CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

CHARACTERIZATION OF VADOSE ZONE AND ASSESSING ENHANCED RECHARGE POTENTIAL IN CANYONS AND HEADWATER AREAS OF WESTERN SAN FERNANDO VALLEY, CALIFORNIA

A thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science in Geology

By

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ABSTRACT

CHARACTERIZATION OF VADOSE ZONE AND ASSESSING ENHANCED RECHARGE POTENTIAL IN CANYONS AND HEADWATER AREAS OF WESTERN SAN FERNANDO VALLEY, CALIFORNIA

By

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Master of Science in Geology

For its water needs, the City of Los Angeles relies on imported water (the Colorado River, Owens Valley/Mono Lake Basin and the State Water Project) and local groundwater resources. In particular, the City on average gets about 15% of its water from the San Fernando Valley Groundwater Basin (SFVGB). In order to prolong and to enhance the groundwater resources of the SFVGB, several spreading grounds, which are located in the valley floor areas, have been developed since the 1930s. The existing spreading grounds are mostly located in the central and north central areas of the valley floor where alluvial units and fans are thick and rich with sand and gravel deposits. As the City's demand for water has increased and the availability of imported water has been constrained, and in order to impose less stress on water resources and ecology of the areas where water has been imported from, support in capturing and utilizing local water resources (e.g., treated wastewater recycling and enhancement of groundwater recharge rates using local runoff waters) has been increased in recent years. Specially, water availability and its quality and potential for enhanced recharge activities in over twenty

canyons associated with upper portions of the Los Angeles River was initiated in 2005. The canyons are located within the mountainous and hilly areas of Western San Fernando Valley. Based on geologic settings of the canyons, several infiltration tests using double ring infiltrometers, soil sampling and its characterization and comprehensive water quality data collection, it has been determined that the potential for artificial recharge in some canyons is warranted.

1. INTRODUCTION

Background

Groundwater is an important source of fresh water throughout the world. More than 1.5 billion people world wide and more than 50% of the U. S. population rely on groundwater for their primary source of drinking water (Alley et. al., 2002). Groundwater is an essential part of hydrological cycle and it is important in sustaining streams, lakes, wetlands and aquatic communities.

San Fernando Basin (SFB) is a major source of groundwater for city of Los Angles. The SFB lies within the watershed of the Los Angeles River (known as the Upper Los Angeles River Area). The San Fernando Valley and its surrounding hills and mountains make up the Upper Los Angeles River Area (ULARA), which constitutes the entire watershed for the Los Angeles River. This basin is bounded on the northeast and east by San Gabriel Mountains, Verdugo Mountains and San Rafael Hills, on the south by Santa Monica Mountains, and on the west and northwest by the Simi Hills and Santa Susana Mountains (SWRB. 1962).

A major portion of water consumed in City of Los Angeles is imported from other regions and the only domestic water resource is the water extracted from groundwater basins. The four sources of water in Los Angeles City are from State Water Project through California Aqueduct, Colorado River through Colorado Aqueduct, Mono Lake in Eastern Sierra Nevada and groundwater from Owens Valley through Los Angeles Aqueduct and the San Fernando Groundwater Basin. The San Fernando Groundwater

Basin not only supplies 15% of the City's domestic needs, but it also acts as a vast underground reservoir where water accumulates during years of abundant rainfall and is stored for use in the future (LADWP, 2002).

Approximately 82% of groundwater extracted in the City of Los Angeles comes from the ULARA, while the remainder comes from the Central and West Basins (Fig. 1), both of which are outside the ULARA (ULARAW, 2006). Four distinct groundwater basins make up the ULARA – the San Fernando, Sylmar, Verdugo, and Eagle Rock Groundwater Basins. The San Fernando Groundwater Basin is the largest in the ULARA and supplies most of the City's groundwater. The Eagle Rock Basin is the smallest and, as it has no significant native yield, is not used by the City for groundwater supply (ULARAW, 2006). These groundwater basins are replenished artificially by six spreading facilities operated by City of Los Angeles and Los Angeles County Department of Public Works (LACDPW) as well as naturally from rain and imported water used within the basin (e.g. irrigation return flow) (ULARAW, 2006).

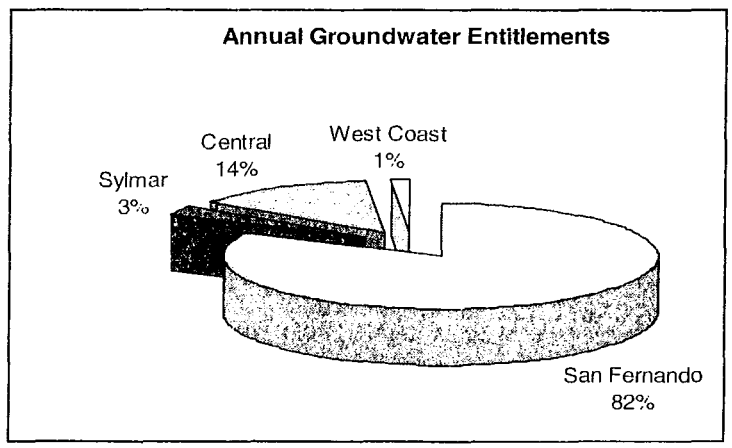

Figure 1: Groundwater Entitlements of Four Groundwater Basins. (Data Source: LADWP, 2002)

Los Angeles Department of Water and Power (LADWP) has 64 active wells that annually deliver approximately $1.13 * 10^7 m^3$ or 15 percent of the City's total water needs, over the last ten years, primarily located in the San Fernando Basin. As water demand is increasing, artificial recharge of the San Fernando Groundwater Basin can reduce the City's dependency on imported water. Previous work on water storage program and enhanced recharge activities have been focused only on the valley floor areas due to limitations on proper porous media storage. Hence this study is a preliminary research on the recharge potential for Western San Fernando Basin in general and the local canyons in particular.

Purpose and Scope

Artificial recharge projects are inherently interdisciplinary and this report illustrates a geological approach to artificial recharge site selection for Western San Fernando Basin. This report documents: (1) the preliminary assessment of vadose zone with regard to the potential for artificial recharge; (2) a review of artificial recharge technique from existing literature and evaluation of selected artificial recharge methods as to their relative feasibility for recharging Western San Fernando Basin; and (3) a preliminary evaluation of baseline water quality conditions for alternative artificial recharge sites.

Enhanced recharge activities in arid and semi-arid region represents a challenging topic. The conditions required for successful artificial groundwater recharge are geologically site specific. The specific site's surface and subsurface geology and the geologic relationship to the configuration and hydraulics of an aquifer system determine where in

the basin the optimum benefit of artificial recharge will be found. Furthermore, there is a major limitation on availability of spaces for such activities in urbanized areas because most of the valley floor areas are now overlain by urban developments, and the cost and ability to acquire land and to access for artificial recharge activities may override the geologic and hydraulic acceptability of the site.

Description of Study Area

Study Area

Study area is located in the western part of San Fernando Valley, about 56km northwest of the downtown Los Angeles. This study was focused on the western part of the ULARA, confined to the canyons associated with hills and mountainous areas. In general the study area includes the southern part of Santa Susana Mountains, eastern part of Simi Hills and northern part of Santa Monica Mountains (Fig. 2). Within the study area land surface elevation ranges from 275m to 460m.

Valley Floor

San Fernando Valley is a closed structural and topographic basin except for a narrow stream-cut outlet located at the southeastern end. The valley floor has been built up by sediments that were washed down from the surrounding highlands. These sediments are in the form of coalescing alluvial fans (Wozab, 1952), with the larger fans from the northern mountains sloping toward the southern border. Except for some of the foothills, the valley floor appears flat, gently sloping toward the southeast.

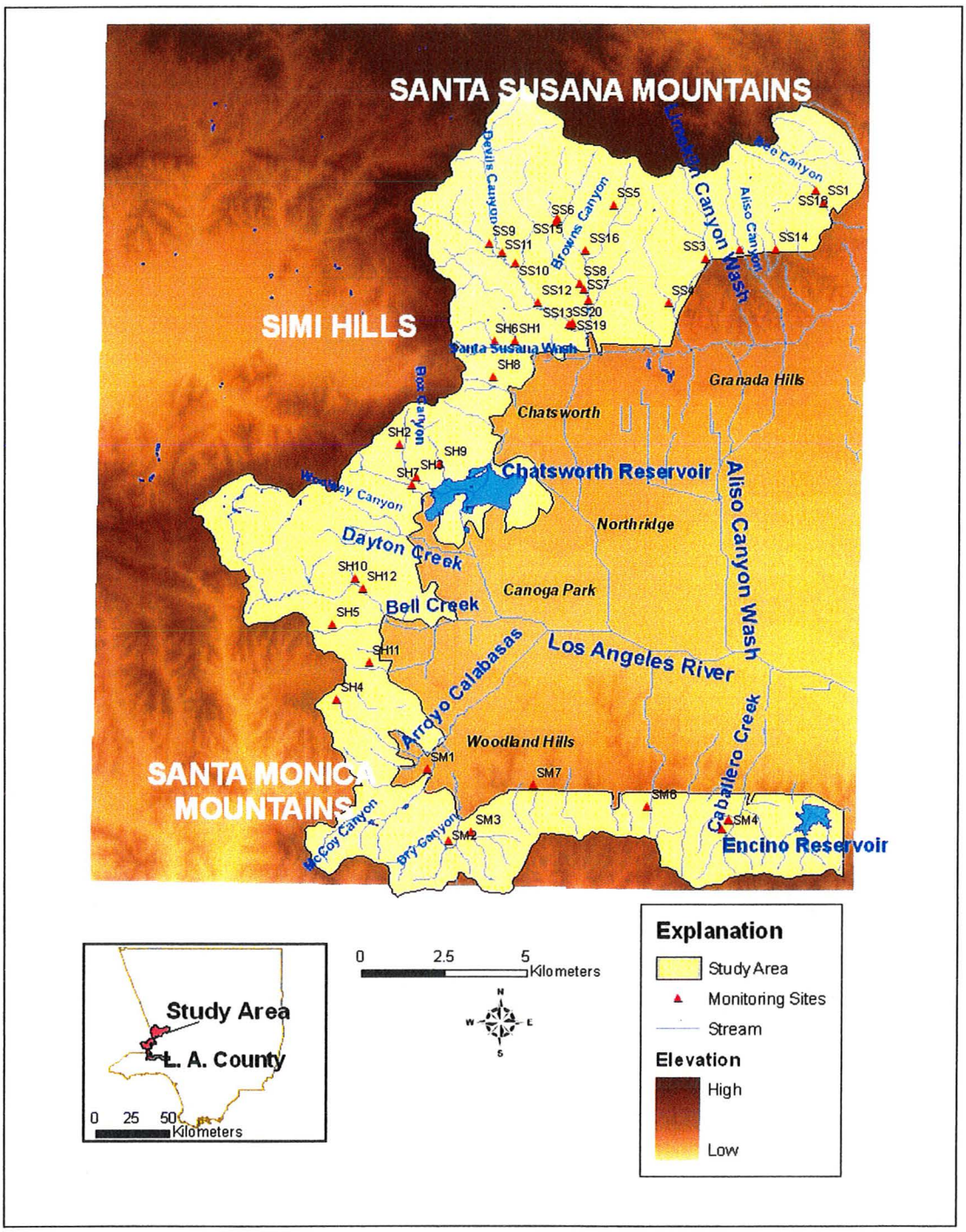

Figure 2: Study Area and Monitoring Sites (Data Source: USGS, 1998 & MRT Geodatabase).

Surrounding Highlands

Along the southern border of the valley, and separating it from the Pacific Ocean, lie the Santa Monica Mountains. The range has a general east-west trend, with elevations ranging from about 300m to 600m. High points of this range are Cahuenga Peak near the south-eastern portion of the valley, and Calabasas Peak near the extreme western end of the valley, having elevations of 555m and 658m respectively (USGS, 1998). Trending in a nearly easterly direction, are the Simi Hills which form the western border of the valley. Elevations of the higher points of these hills are above 600m.

Forming the north border are the Santa Susana Mountains that trend in a west-northwesterly direction. These mountains range in elevation from 365m to over 900m. Portions of this range project out into the valley through eroded younger formations.

Monitoring Sites

Twenty sites (Table 1, Fig 2) were selected for surface water quality monitoring and field investigation. The site selection was primarily based on accessibility, availability of water in the canyons, geomorphology suitable to develop recharge basin and future study needs. Access to private property limited site location in several instances; therefore less desirable nearby sites, such as those along roadways, were used as alternatives. In all instances, sites were selected to represent the typical land use and surface conditions of the surrounding area.

Table 1. Location of Water Quality Monitoring Sites

Station Identification No.	Sampling Site Designation	Station Latitude	Station Longitude	Approximate Site Elevation (m)
SS1	Bee Canyon	N34.31121	W118.51355	386
SS2	Aliso Canyon	N34.29767	W118.54028	424
SS3	Limekiln Canyon	N34.29557	W118.55182	484
SS4	Limekiln Canyon	N34.28331	W118.56383	372
SS7	Browns Canyon East	N34.28678	W118.59184	368
SS8	Browns Canyon West	N34.28685	W118.59203	384
SS15	Browns Canyon North	N34.30573	W118.60115	475
SS17	Lower Browns Canyon	N34.28382	W118.59007	374
SS19	Devils Canyon	N34.27724	W118.59628	359
SH2	Box Canyon	N34.24330	W118.65143	406
SH6	Santa Susana Wash	N34.27238	W118.62040	362
SH7	Woolsey Canyon	N34.23472	W118.64534	279
SH8	LACO PW DRAIN 3863	N34.26225	W118.62076	310
SH9	Lake Manor	N34.23846	W118.63763	282
SH12	Bell Creek	N34.20427	W118.66264	286
SM1	McCoy Canyon	N34.15459	W118.63984	286
SM2	Dry Canyon	N34.13553	W118.63174	318
SM3	Dry Canyon Southfork	N34.13759	W118.62492	317
SM7	LACO PW DRAIN 5229	N34.15060	W118.60513	308
SM8	Caballero Creek	N34.14243	W118.54045	294

SS = Santa Susana Mountains
SH = Simi Hills
SM = Santa Monica Mountains

Geologic Setting

The geologic settings as determined by SWRB (1962) may be divided into two groups, the non water-bearing series and the water bearing series. The non water-bearing series do not, transmit or yield water readily. They are the basement Complex Rocks and the Cretaceous and Tertiary Sediments of the Chico, Topanga, and Modelo Formations (SWRB, 1962). The water bearing series which absorbs, transmit and yield water readily, consist of the alluvial and alluvial fan deposits of Quaternary age and are classified as the Saugus Formation, Older Alluvium (terrace deposits), and Recent Alluvium (SWRB,

1962). This study deals mainly with characterization and infiltration rate investigation of selected areas involving upper portions of alluvial deposits.

Alluvial Fans and Fan Heads

Alluvial fans and fan heads are favorable areas for artificial recharge of groundwater basin. Some of the monitoring sites have alluvial fan deposit which might hold better potential for artificial recharge activities. As the monitoring sites are located in the vicinity of canyons, one of the best methods of artificial recharge could be enhanced streambed infiltration.

The study sites McCoy Canyon (SM1) and Devils Canyon (SS19) have the alluvial fan deposits. McCoy Canyon (SM1) is located in highly urbanized area and the canyon is channelized downstream from the study site. So this site does not hold any potential for the development of recharge basin.

The alluvial fans deposit at Devils Canyon site is gently sloping, and also has fan-shaped landform, at the base of mountain range. The landform at this site has a sedimentary deposit composed of alluvium or debris flow deposits. It is located at the topographic break but this landform is not large enough to be identified through the small scale topographical map. This site seems to have prospective for the recharge suitability analysis if other major factors such as availability of water for recharge and underground geology are suitable.

Climate

The study area has the climate of an interior coastal valley (semi arid) and is hotter in the summer and wetter in the winter than the coastal area which has a Mediterranean type climate (SWRB, 1962). January and July are the coldest and warmest months of the year, respectively (NWS, 2007). The range of temperature and occurrence of fog and frost vary with the valley with the west and north sections being subject to the highest temperatures. The northern perimeter of the valley along the base of the mountains is warmer and more frost free than areas of lower elevations in the western portions (Wozab, 1952).

Most precipitation occurs between December and March due to extratropical cyclones from the North Pacific (WRCC, 2007). Precipitation during summer months is infrequent, and rainless periods of several months are common (Wozab, 1952). Precipitation in the San Fernando Valley ranges from 38 cm to 58 cm per year and averages about 43cm. The average minimum and average maximum temperature are 9.4^{o} C and 25.5^{o} C respectively (NWS, 2007).

Vegetative Cover and Urban Land Use

The principal vegetative cover of upper mountain areas consists of various species of brush and shrubs known as chaparral. Most trees found on mountain slopes are oak. Pine, cedar, and juniper are found in ravines at higher elevations and along high mountain summits. Alder, willow, and sycamore are found along streambeds at lower elevations (Wozab, 1952). The chaparral is extremely flammable, and extensive brush fire frequently occurs during dry, windy weather. Chaparral depends on fire to germinate and

has the ability to sprout quickly after fire, reestablishing the watershed cover within a period of five to ten years. Grasses are the principal vegetation on the low elevation hills. Approximately 25% of the land in the study area has been converted to urban and suburban use (CASIL, 1977) (Fig 3).

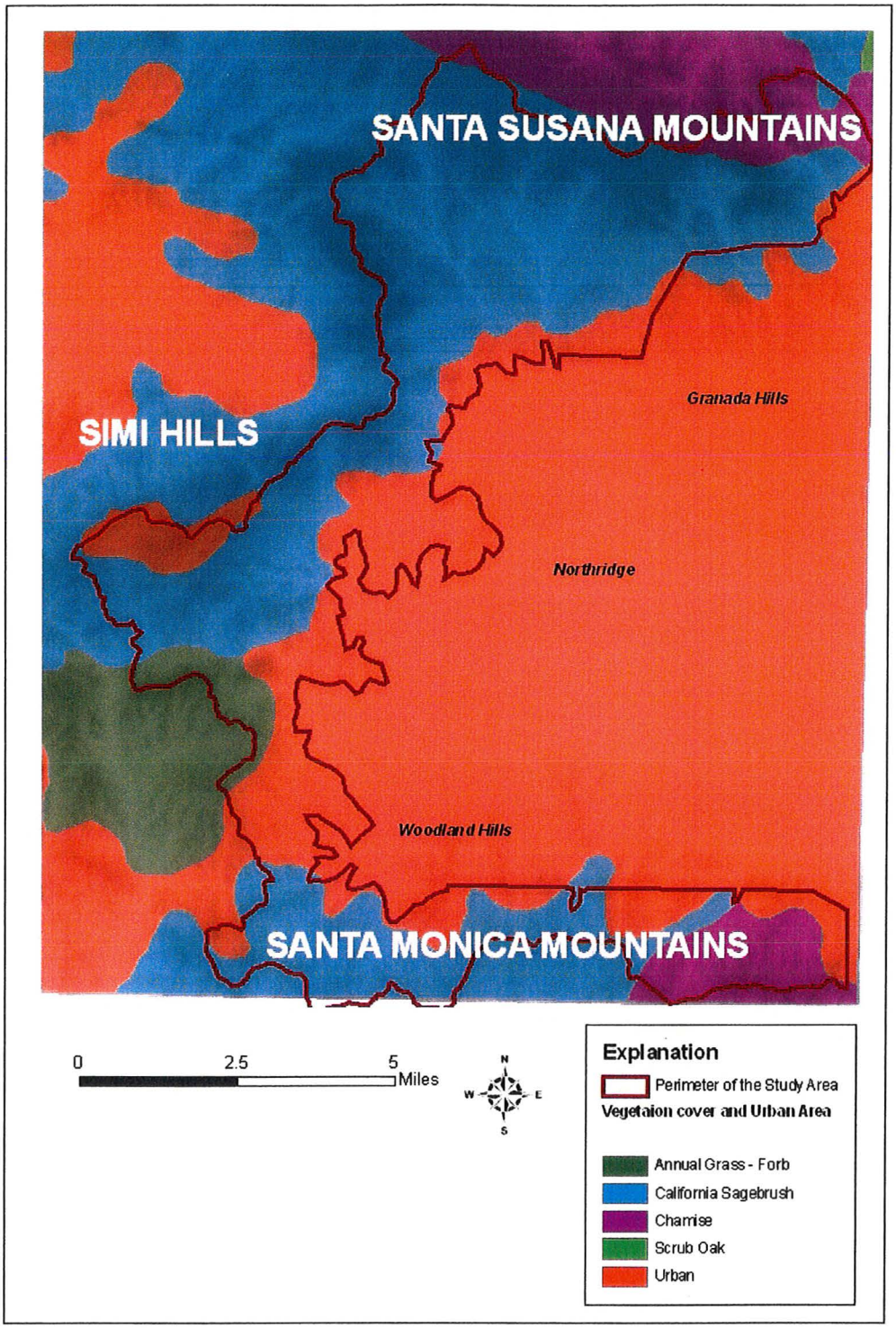

Figure 3: Generalized Land Cover and Distribution of Urban Land in the Study Area (Data Source: CASIL, 1977 & MRT Geodatabase).

2. HYDROLOGICAL SETTING AND HYDROGEOLOGY

Drainage System

The Los Angeles River system drains the study area. The Los Angeles (LA) River watershed is one of the largest in the region. It is also one of the most diverse in terms of land use patterns. Approximately 324 square miles of the watershed are covered by forest or open-space land including the area near the headwaters which originate in the Santa Monica, Santa Susana, and San Gabriel Mountains (LACDPW, 2007). The rest of the watershed is highly developed. The river flows through the San Fernando Valley past heavily developed residential and commercial areas (LACDPW, 2007).

The major drainage network is composed of the main stream, and its principal tributaries are Aliso, Browns, Bell, Box, Dayton, Woolsey, Dry, McCoy and Arroyo Calabasas canyons. The study area represents portion of headwater area of Los Angeles River located in the Western San Fernando Valley. (Fig. 4)

Stream Bed Characteristics

The information on streambed characteristics presented here was obtained by plotting the monitoring sites on geologic map by Diblee (1960) which was digitized by USGS (1998). The stream beds of most of the canyons are made up of marine sedimentary rocks, basically sandstone and shale (Fig.5). Dry Canyon, LACO PW DRAIN 5229, Caballero Creek, and upstream areas of Bee Canyon are composed of alternating shale and massive sandstone units, diatomaceous shale, and brown earthy shale. Downstream areas of the Bee Canyon consist of alluvium (Dibblee, 1960).

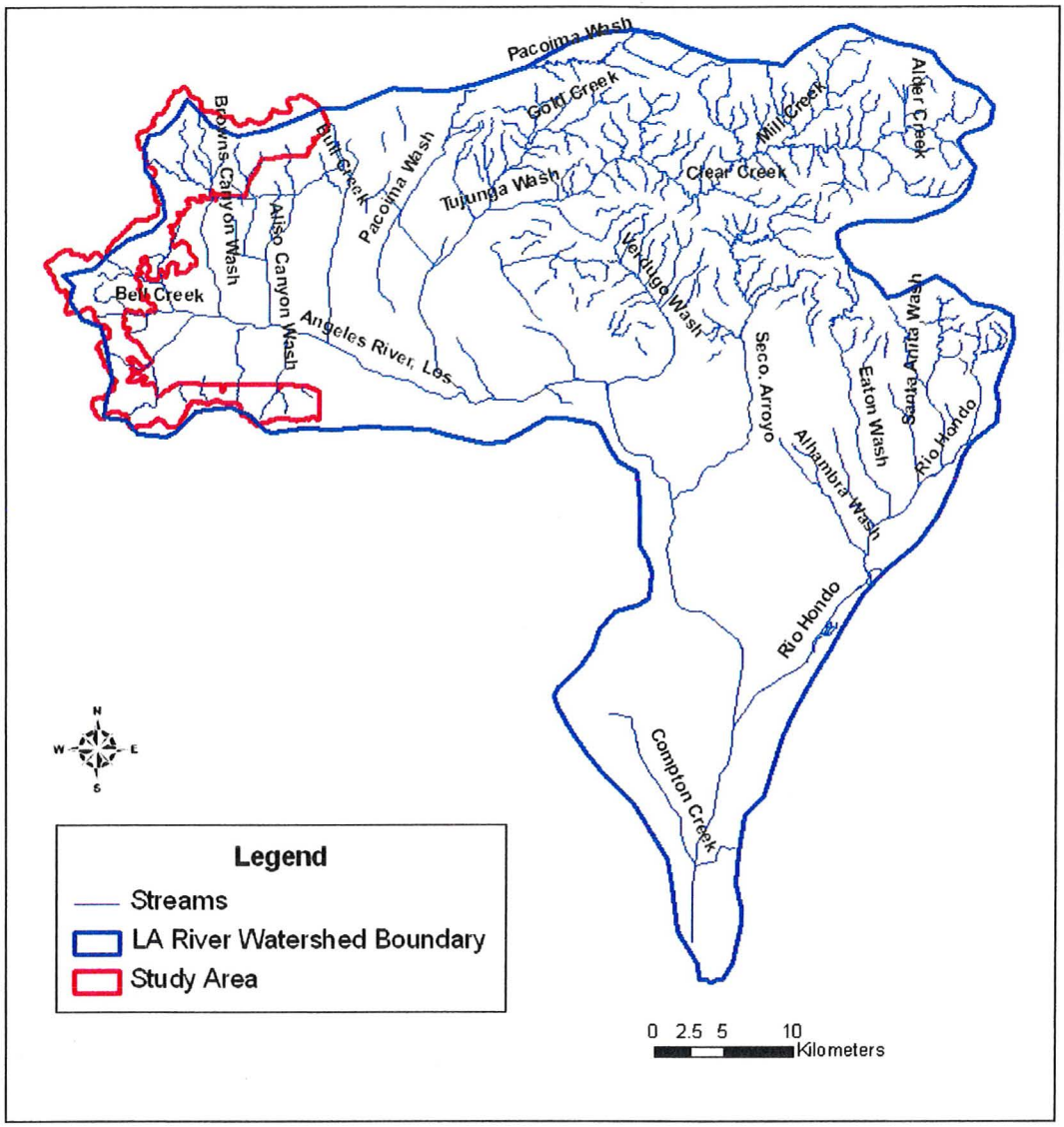

Figure 4: Los Angeles River Watershed and the Tributaries of the Los Angeles River in the Study Area (Source: USGS, 1998 & MRT Geodatabase).

Upstream and downstream sections of Limekiln Canyon site (SS3) are mostly composed of colluvium and Saugus Formation respectively. The upper sections of Browns Canyon sites (SS7, SS8, SS15) are also composed of Saugus Formation which is composed of light grey arkosic sands and gravel.

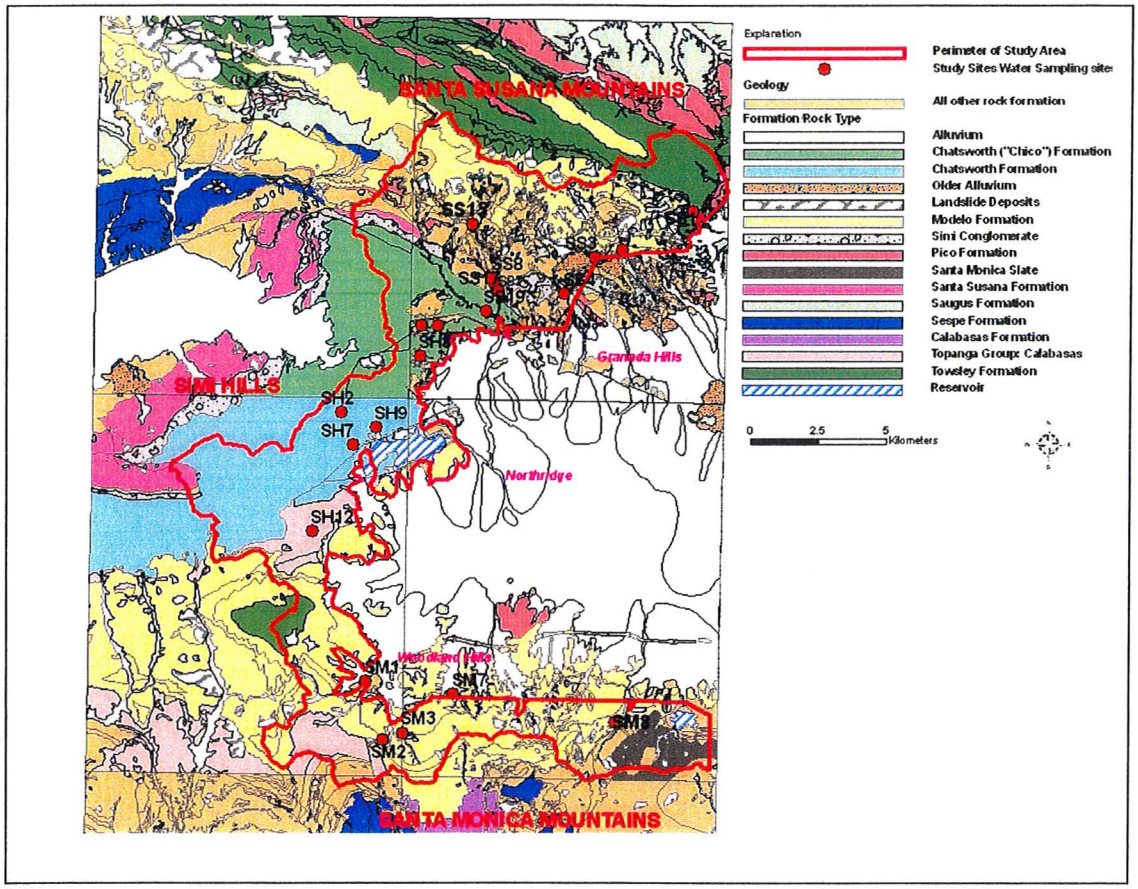

Figure 5: General Geology of the Study Area (Base Map: Modified after USGS-Digitized Dibblee (1960) Map, 1998, & MRT Geodatabase).

Lower sections of Browns Canyon sites (SS17) and Devils Canyon sites (SS19) are composed of alluvium but the surrounding areas are comprised of rocks of the Chico Formation. The rocks of LACO PW DRAIN 3863 site (SH8) and Santa Susana Wash site (SH6) are also composed of Chico Formation. Medium to coarse grained sandstone of the Chico Formation are dark grey to olive brown in color. Thick beds of sandstone are separated by thin layers of dark grey fissile shale.

Box Canyon, Woolsey Canyon, Lake Manor at study sites (SH1), (SH7), (SH9), are comprised of, Chatsworth Formation, which is a marine turbidite sequence primarily comprised of medium-grained sandstone with interbedded siltstone and shale units. The Chatsworth Formation is highly fractured and faulted in places (USGS, 1998).

Topanga Formation, a group of light colored, thick-bedded sandstones, shales and assorted pebbly formations are found along Bell Creek near the study site (SH12). McCoy Canyon (SM1) site, which is located in a highly urbanized area is consisted of older Terrace Deposits, which are the remnant of older alluvial deposits, uplifted and eroded to form terraces.

Stream Gradient

Stream gradient directly influences stream velocity and in turn stream discharge. High gradient streams have higher velocity, which reduces the potential for recharge through the stream bed; in such conditions it may be necessary to reduce the stream gradient in order to reduce the velocity and increase infiltration. The average hydraulic gradient of the stream in each canyon was calculated using National Geographic Topo software. Streams were traced along its path from its lowest elevation to the highest point within the study area. The software provides the linear distance, in miles, and the change in elevation, in feet. After converting the linear distance into feet, the elevation change was divided by the linear distance to produce an approximate hydraulic gradient (*dh/dl*) for the stream (Table 2).

Table 2: Stream Gradient in the Study Area

Mountain Range	Watershed	Monitoring Sites	Flow pattern	Gradient dh/dl
Santa Susana Mountains	Bee Canyon	SS1	Seasonal	0.076
	Aliso Canyon	SS2	Seasonal	0.04
	Limekiln Canyon	SS3, SS4	Perennial	0.055
	Devils Canyon	SS19	Seasonal	0.04
	Browns Canyon	SS7, SS8, SS15, SS17	Perennial	0.07
Simi Hills	Box Canyon	SH1	Seasonal	0.077
	Santa Susana Wash	SH6	Perennial	0.063
	Woolsey Canyon	SH7	Seasonal	0.079
	Chatsworth Park (LACO PW DRAIN 3863)	SH8	Perennial	0.062
	Lake Manor	SH9	Seasonal	0.89
	Bell Creek	SH12	Seasonal	0.029
Santa Monica Mountains	McCoy Canyon	SM1	Perennial	0.020
	Dry Canyon	SM2	Perennial	0.035
	Dry Canyon Southfork	SM3	Perennial	0.031
	Topanga Canyon (LACO PW DRAIN 5229)	SM7	Perennial	0.058
	Caballero Creek	SM8	Perennial	0.076

As shown in Table 2, the canyons at the heads of watershed have relatively higher gradients (>0.04) in the study area as. Most of the calculated stream gradients in the Santa Susana Mountains and Simi Hills areas are higher than calculated stream gradients in Santa Monica Mountains area. One of the reasons is that Santa Monica Mountains area, particularly the area near the monitoring sites McCoy Canyon (SM1), Dry Canyon (SM2) and Dry Canyon Southfork (SM3), is highly developed. As a result, the area has gone through multiple cut and fills operations (USDA, 1980).

Stream Discharge

Stream discharge rates were measured at all twenty monitoring sites on a monthly basis using a handheld flow meter as all of the canyons are un-gauged (Miles, 2006). The flow

data were collected from March 2006 to February 2007 as is documented by Miles, 2006 in Water Quality and Land Use in Western San Fernando Valley Tributaries. The majority of the canyon streams in the study area are intermittent and the measured discharge rates were not significant during the course of present study (Miles, 2006). The primary reason for these low flow rates is lower precipitation: water year 2006-2007 was one of the driest year in Los Angeles with 8.15 cm of rainfall till May 1, 2007. So the stream discharge for years with normal precipitation would be expected to be much higher than discharge rates measured in this study.

Generally the flow rates in the canyons within the project area are not significant hence only the perennial streams appear to be economically viable for enhanced recharge. The higher flow rates were observed in the Limekiln Canyon and Browns Canyon East (Santa Susana Mountains) and McCoy and Dry Canyons (Santa Monica Mountains). Water quality and the site specific recharge methods of the aforementioned canyons will be discussed later.

3. SOIL PROPERTIES CHARACTERIZATION

The soil component of the study area includes all the soil horizons and the unsaturated zone. With respect to infiltration rates and groundwater recharge, soil characteristics can play a major role. Information used to determine the soil characteristics at the study area were obtained from soil survey report of western San Fernando Valley prepared by USDA (USDA, 1980), through soil sampling using a hand auger, and from field observation. Site specific soil characteristics data were obtained by augering, infiltration tests, field observations, and laboratory analysis of the soil samples. From the data analysis and field observations it is evident that the soil survey mapping scale is not detailed enough to show the soil variability and characteristics especially in the vicinity of the canyons. The general and site specific information are integrated to provide a comprehensive and site by site characterization of Western San Fernando soils.

Soil Types, Characteristics and Distribution

The basic soil characteristics such as vertical extent; physical, hydrologic, and engineering properties as determined by the USDA (1980) are illustrated in the following tables. The USDA soil units discussed here are associated with the specific study sites and the monitoring stations (Fig 6) and detailed information on these soil units are available in soil survey report by USDA (1980). The field activities and the laboratory analyses of soil samples for areas with a mixture of several soil types provided reliable data on soil properties.

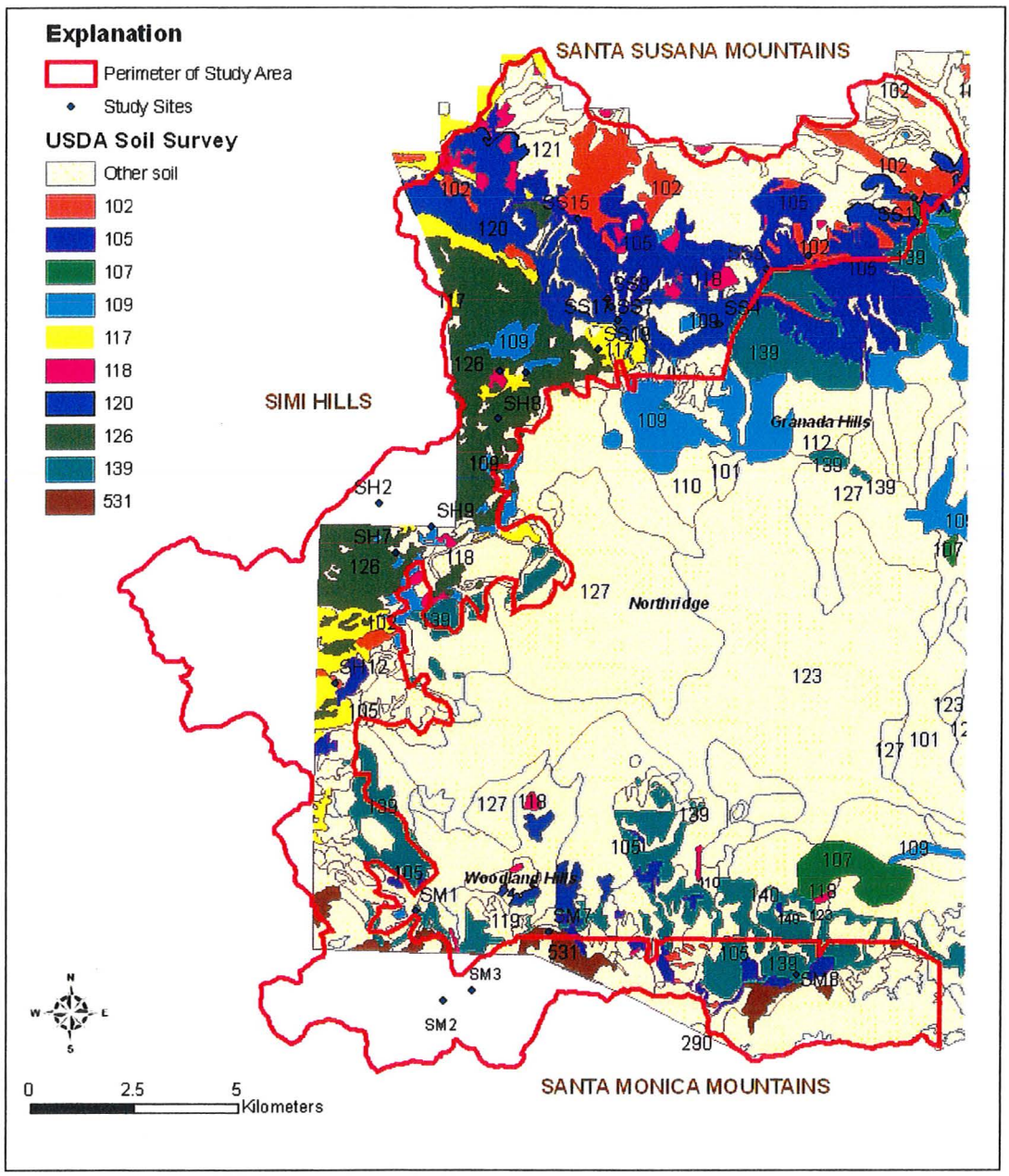

Figure 6: Spatial Distribution and Soil Types in the Study Area According to USDA Soil Survey Report (USDA, 1980 & MRT Geodatabase).

Some physical characteristics and features that affect soil behavior as described by USDA (1980) are given in Table 3. Monitoring stations are the field study sites for this project shown in Fig 6. Soil type is the soil survey series described in the soil survey report of western San Fernando Valley area (USDA, 1980). Depth is the average thickness of the each unit. Clay is the soil particles that are less than 0.002 millimeter in diameter. In this table, the estimated clay content of each soil layer is given as a percentage, by weight, of thesoil material that is less than 2 millimeters in diameter. Moist bulk density is the weight of soil (ovendry) per unit volume and volume is measured when the soil is at field moisture capacity. Surface runoff refers to the loss of water from an area by flow over the land surface. Surface runoff classes are based on slope, climate, and vegetative cover.

Table 3: Physical Properties of Soil in the Study Area (USDA, 1980)

Monitoring Station	Soil Type (Soil Survey Series)	Depth (m)	Percent Clay	Moist Bulk Density	Surface Runoff
SS18	102	0-1.52	-	-	Very High
SS2, SS15, SH12	105	0-1.04	27-35	1.45-1.6	Very High
SS1	107	0-1.82	8-18	1.5-1.65	Very Low
SH7	109	0-1.78	10-30	1.4-1.65	Low
SH9	117	0-0.48	10-18	1.5-1.65	Medium
SH6	118	0-0.81	27-30	1.45-1.6	Very High
SS3, SS4, SS7, SS8, SS17	120	0-1.04	27-35	1.45-1.6	Very High
SS19,SH1,SH8	126	0-0.48	10-18	1.5-1.65	Medium
SM1	139	0-1.63	27-35	1.45-1.6	Very High
SM7,SM8	531	0-1.57	18-35	1.4-1.55	Medium to Very High

Engineering classification and range of hydrogeological properties of the soil in the study area as measured by USDA (1980) are given in Table 4. Texture is given in the standard terms used by the U.S. Department of Agriculture (USDA, 1980). These terms are defined according to percentages of sand, silt, and clay in the fraction of the soil that is

less than 2 millimeters in diameter. The Unified system classifies according to particle-size distribution of the fraction less than 7.62 cm in diameter and according to plasticity index, liquid limit, and organic matter content.

Table 4: Hydrogeological Properties of Soil in the Study Area (USDA, 1980)

Monitoring Station	USDA Texture	Unified Soil Classification System	Saturated Hydraulic Conductivity (micro m/sec)	Hydrologic Group
SS18	Weathered Bedrock	-	-	D
SS2, SS15, SH12	Silty Clay Loam	CL	1.4-4.0	B
SS1	Loam to Fine Sandy Loam	ML-SM	4-42	B
SH7	Sandy Loam to Sandy Clay Loam	SC-SM	1.4-14	B
SH9	Sandy Loam	SM	14.0-42.0	D
SH6	Silt Clay Loam	CL	1.4-4.0	C
SS3, SS4, SS7, SS8, SS17	Silt Clay Loam	CL	1.4-4.0	C
SS19,SH1,SH8	Sandy Loam	SM	14.0-42.0	D
SM1	Silt Clay Loam	CL	1.4-4.0	B, C
SM7,SM8	Loam to Silt Clay Loam	CL	0.00-4.00	C,D

where, CL= Clay with low plasticity, ML=Silt with low plasticity

SC=Sandy Clay, SM=Sandy Silt

Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water. The USDA estimates in Table 4 are expressed in terms of micrometers per second. Hydrologic soil groups are based on estimates of runoff potential. Soils were assigned by USDA to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms. The four hydrologic soil groups are:

Group A. Soils having a high infiltration rate (low runoff potential)

Group B. Soils having a moderate infiltration rate

Group C. Soils having a slow infiltration rate

Group D. Soils having a very slow infiltration rate (high runoff potential)

Soil Sampling

Soil samples (using a hand auger) were collected from four different monitoring sites near the infiltration tests sites within the study area (Fig 11). These soil samples were collected to identify the hydraulic properties of the soil through laboratory analysis. Hydraulic properties of soil such as grain size distribution, moisture content, porosity, etc. governs the transmission characteristics of soil and artificial recharge process.

Soil samples may be recovered using a variety of methods and equipments depending on depth of sampling (surface versus subsurface), the type of sample required (disturbed versus undisturbed) and the soil composition. For this study subsurface and undisturbed soil samples were collected directly, using a hand-held auger.

Equipments/Apparatus

1. Maps
2. GPS
3. Tape measure
4. Survey stakes
5. Camera and film
6. Plastic bucket
7. Ziploc plastic bags
8. logbook

9. Field data sheets
10. Shovel
11. Scoop

For soil sampling a hand auger with a series of extension rods and a thin-wall tube sampler were used. The auger bores a hole to a desired sampling depth and then is withdrawn. The auger tip is then replaced with a tube core sampler, lowered down the borehole, and driven into the soil to a predetermined depth. The core is then withdrawn and the sample collected.

The following procedure was used to collect soil samples with a hand auger:

1. The auger bit was attached to a drill extension rod, and then attached to the "T" handle to the drill extension rod.
2. The sampling area was cleared of any surface debris before augering was started.
3. After reaching the desired depth, slowly and carefully the auger was removed from boring.
4. The auger tip was replaced with a pre-cleaned thin-wall tube sampler.
5. The tube sampler was lowered carefully down borehole. Tube sampler was gradually forced into soil. Care was taken to avoid scraping the borehole sides.
6. The tube sampler was removed and the drill rods were unscrewed.
7. Top of the core (approximately 2.54cm) was discarded as this represents material collected by the tube sampler before penetration of the layer of concern.
8. The samples were preserved in Ziploc bag and then transferred to lab for testing.

9. The process was repeated to collect the samples from different depths.

Soil Descriptions

Soil thickness was found to be about 0.45m at the Lower Limekiln Canyon (SS4) monitoring site. The soil was calcareous, dark brown in color, silty, gravelly, fine to coarse sand with shale pieces.

In Browns Canyon East (SS7) monitoring site, saturated material was encountered at a depth of 25.4cm. The soil was grey in color with silty sand texture. A more complete soil profile was obtained in Lower Browns Canyon (SS17) site where the depth of the soil was found to be 8.5m. The hand augering was very challenging at this site because of the presence of larger diameter sediment particles such as gravel. The soil was grey in color, calcareous, and fine to coarse gravelly sand.

The depths of soil for the Lower Limekiln Canyon (SS4), Browns Canyon East (SS7), and Lower Browns Canyon (SS17) sites are given as 0-71cm for Gazos soil and 0-94cm for Balcom soil in the soil survey report (USDA, 1980). This uniformity in soil depth was not observed during this site specific study.

At the Devils Canyon (SS19) site the soil profile was found to be less than a 30cm thick and saturated soil were encountered at shallow depth of about a 30cm. The Soil Survey Report (USDA, 1980) describes the depth of soil at this site to be 38 cm. The soil sample collected was saturated soil and grey in color. Texture was dominantly sandy and the soil was non-calcareous.

Moisture Content

The initial moisture content of soil affects infiltration rates. When the initial soil moisture content is low, the soil can absorb more water, hence the rate of initial infiltration is higher for dry soil. The soil infiltration rate generally decreases as the soil becomes wet. Initially pores and cracks are wider in a dry soil. With increasing soil moisture, through sediment grain (e.g. clay minerals) swelling, porous media openings become smaller. As a result, infiltration rates decrease.

Soil samples collected were analyzed in the laboratory to calculate moisture content using both the gravimetric and volumetric methods.

a) Gravimetric Method

A gravimetric method was used to calculate soil moisture content in which a soil sample was dried at 105°C until the weight is reduced to a constant value.

Equipment

1. Drying Oven
2. Bowls
3. Soil Analysis Data Sheets
4. Balance

Procedure

1. The empty bowls were weighed and the weight was recorded in data sheet.
2. After placing the soil sample in the bowl the bowl was weighed again and the weight was recorded.

3. Bowls were placed in 105°C oven and were dried for 24 hours (until weight becomes constant).
4. Samples were removed from oven, and the dry weight was recorded.
5. Gravimetric Moisture Content is calculated (Table 5) using the following formula:

   Gravimetric moisture content (Θ_m) = (M_w-M_d)/M_d * 100

   M_w = Mass of wet soil sample (wet weight - bowl weight), [grams]

   M_d = Mass of dry soil sample (dry weight - bowl weight), [grams]

Table 5: Gravimetric Moisture Content in Percentage

Sample Site / Sample ID	Sampling Depth (m)	Wt. of wet sample -M_w (g)	Wt. of dry sample -M_d (g)	Wt. of water (g)	Gravimetric Moisture Content (%),Θ_m
SS4	0.3	246.5	226.5	20.0	8.8
SS17	0.3	529.0	490.0	39.0	8.0
SS17	0.6	438.0	403.0	35.0	8.7
SS19	0.3	601.5	482.0	119.5	24.8

b) Volumetric Method

Volumetric moisture content can be calculated after obtaining the bulk density data. Bulk density is a measure of the weight of the soil per unit volume (M/L^3).

$\rho_B = W_t / V_t$ where:

ρ_B = Dry Bulk density, W_t = Weight of sample, V_t = Volume of sample

Variation in bulk density is attributable to the specific gravity of solid organic and inorganic particles and to the porosity of the soil. Most soils have bulk densities between 1.0 and 2.0 g/cm^3. The determination of bulk density usually consists of drying and

weighing a soil sample, the volume of which is known. The volumetric moisture content can be calculated by using the formula given below.

$\Theta_v=(\Theta_m) * \rho_B$ where:

Θ_v = *Volumetric moisture content*

(Θ_m) = *Gravimetric moisture content*

ρ_B =*Dry bulk density [M/L]*

Table 6: Bulk Density of the Soil Sample and Volumetric Moisture Content Analysis

Sampling Site/ Sample ID	Sampling Depth (m)	Wt. of dry sample (g)	Vol. of dry sample (cm^3)	Dry Bulk density (g/cm^3)	Volumetric Moisture Content (%)
Lower Limekiln Cyn (SS4)	0.3	250.9	181.13	1.39	12.2
Lower Browns Cyn (SS17)	0.3	277.7	181.13	1.53	12.2
Lower Browns Cyn (SS17)	0.6	277.7	181.13	1.53	17.6
Devils Cyn (SS19)	0.3	293.6	181.13	1.62	40.2

Both the gravimetric as well as the volumetric moisture content are higher for the soil sample collected from Devils Canyon (SS19), where a saturated geologic unit was very close to surface (Table 4, 5 & 6). The bulk density data (Table 6) were used to calculate porosity of the soil samples (Table 7).

Porosity

Porosity of a soil is the volume of all the open spaces (pores) between the solid grains of soil. For artificial recharge of groundwater by storing the surface water in subsurface soil, the porosity is important as it defines the volume of water that can be held in a given

volume of the soil. Porosity is a value that expresses the relative amount of pore space in the soil. It is calculated using the following formula (Brady & Weil, 1996):

$\eta = \{(1 - \rho_B)/\rho_d\} * 100$ where:

η = Porosity [1], ρ_B = Bulk density [μ/L^3], ρ_d = Particle density [μ/L^3]

Particle density was calculated after finding the mass of solid (soil) and volume of soil by using the following formula:

$\rho_d = W_t / V_s$ where:

ρ_d = Particle density, W_t = Weight of sample, V_s = Volume of solids

Table 7: Porosity of the Soil Samples

Sample Location (Sample ID)	Depth (m)	Particle density (g/cm^3)	Bulk density (g/cm^3)	Porosity (%)
Lower Limekiln Canyon (SS4)	0.3	2.65	1.39	47.7
Lower Browns Canyon (SS17)	0.3	2.65	1.53	42.2
Lower Browns Canyon (SS17)	0.6	2.65	1.53	42.2
Devils Canyon (SS19)	0.3	2.65	1.62	38.8

Porosities of the soil samples from the study sites were calculated and are compiled in Table 7. The calculated results show that the soil samples from Devils Canyon (SS19) and Limekiln Canyon (SS4) have the lowest and the highest porosity values respectively.

Grain Size Analysis

The grain-size analysis is used for engineering purposes including artificial recharge activities. The resulting grain-size distribution curves are used in conjunction with infiltration tests to ascertain the hydraulic properties of soil for artificial recharge activities. The grain-size analysis is an attempt to determine the relative proportions of the different grain-sizes which make up a given soil mass so as to relate them to soil hydraulics and characteristics.

Particle size and shape play a key role in determining the hydraulic permeability of soil. The packing of larger grains result in larger pore openings, reducing the affect of friction caused by surface tension, resulting in greater sediment permeability. An increase in mean grain size correlates with an increase in infiltration rates. Some soils with finer particle size (clay), have much lower infiltration rates compared soil with a higher proportion of sand and gravel. As a result soils with lower infiltration rates generate more runoff water. In general, the area with large grained well sorted sediments holds better potential for artificial recharge activities.

Apparatus and Materials

1. Sieves and a collection pan (20 cm diameter). ASTM Sieve; sizes No. 3/4", No. 3/8", No. 5 (4.00 mm), No. 10 (2.00 mm), No. 40 (0.42 mm). No. 60 (0.250mm), No. 100 (0.149mm) and a No. 200 (0.074mm)
2. Sieve brush.
3. Balance (capacity 1000 g; sensitivity 0.1 g).

4. Mortar and rubber-tipped pestle.
5. Drying oven (Capable of 105^{0}C).
6. Sieve shaker.

Procedure

1. Sieves were thoroughly brushed clean from the bottom side and weighed.
2. A representative soil sample of approximately 500gm was selected and weighed, the soil was broken into individual particles by crushing by hand and a rubber-tipped pestle.
3. The sample was passed through the stack of sieves, using all of the following sieve sizes, #3/4", #3/8", # 5, # 10, # 40, #60, #100, # 200.
4. Following 10 minutes of shaking, each sieve was weighed and the gross weight of the sieve plus soil was recorded. Weight of the sieve was subtracted as determined previously and the amount of the total sample retained on each sieve was determined.
5. The weight of the residue collected on each sieve was summed and this was compared to the sample weight recorded. A discrepancy of more than 2% by weight was considered unsatisfactory and the test was repeated in such cases.
6. The percentage of sample passing each sieve was computed by starting with 100% and subtracting the percent retained on each sieve as a cumulative procedure.
7. The cumulative grain-size distribution was graphed on a semi-logarithmic paper.

8. From the grain-size distribution graph, uniformity coefficient (Cu) was computed using the following formula:

   ($C_u = D_{60}/D_{10}$) where:

   D refers to the diameter of the soil particles and the subscripts (10 and 60) denote the cumulative percent which is smaller than the given size. An indication of the spread or range of grain sizes is given by C_u, with a large C_u value indicating that the D_{60} and D_{10} sizes differ appreciably and the related soil sample is poorly sorted. A uniformity coefficient of 1.00 denotes a material having a particle grains all the same size; numbers increasingly greater than one denote increasingly less uniformity.

Unified Soil Classification and Uniformity Coefficient

The uniformity coefficients and median grain sizes of soil samples from four different sites are given in Table 8.

Table 8: Uniformity Coefficient and Median Diameter of the Soil Samples

Canyons	Soil Sampling Site	d_{10} (mm)	d_{50} (mm)	d_{60} (mm)	C_u
Lower Limekiln Canyon	SS4	0.08	0.57	1	12.5
East Browns Canyon	SS7	0.26	0.95	1.3	5
Lower Browns Canyon	SS17	0.165	0.86	1.25	7.6
Devils Canyon	SS19	0.12	0.27	0.3	2.5

Soil samples collected near the Limekiln Canyon (SS4) monitoring stations contained 73% sand with a uniformity coefficient of 12.5 (Fig 7). According to Unified Soil Classification, the soil can be classified as well graded sand (SW).

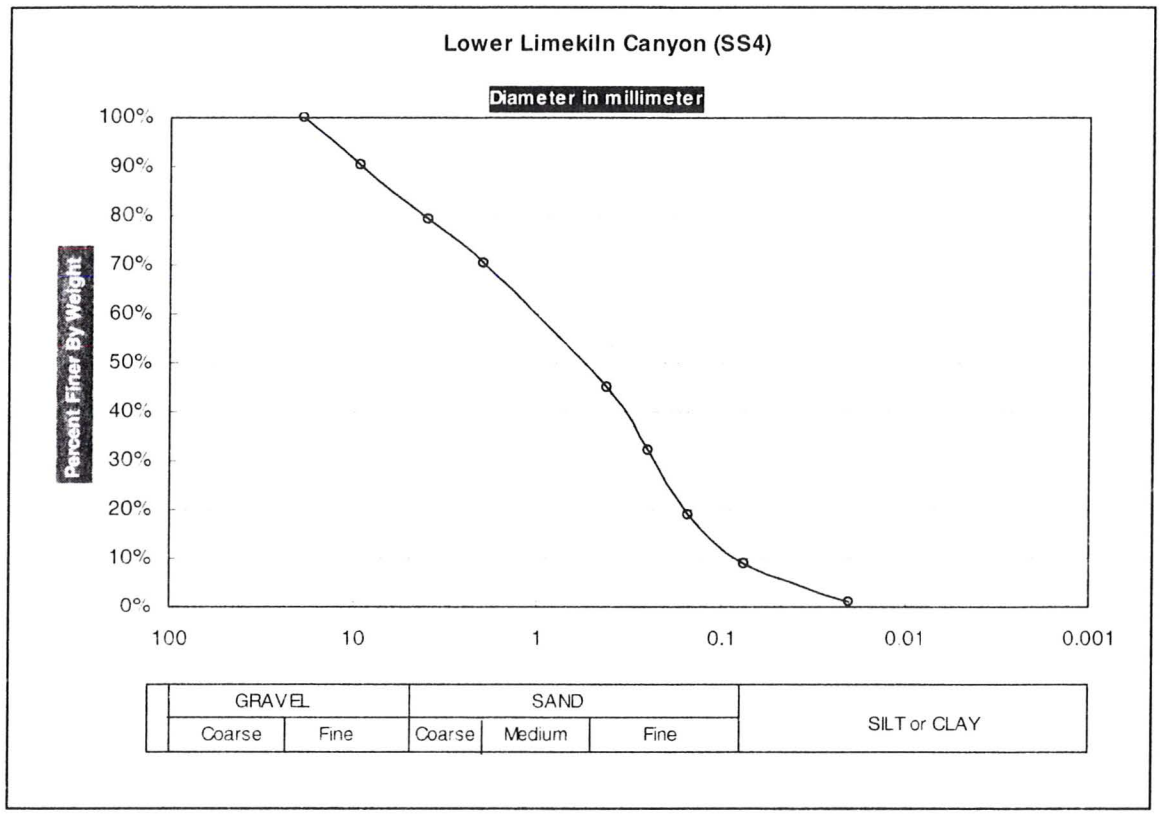

Figure 7: Grain Size Distribution Curve for Lower Limekiln Canyon (SS4) Soil Sample.

The uniformity coefficient for the Browns Canyon East (SS7) soil sample is 5.0, which means the soil is uniformly graded. Eighty-six percent of the sample is composed of sand (Fig 8). Hence the soil can be classified as, uniformly graded sand.

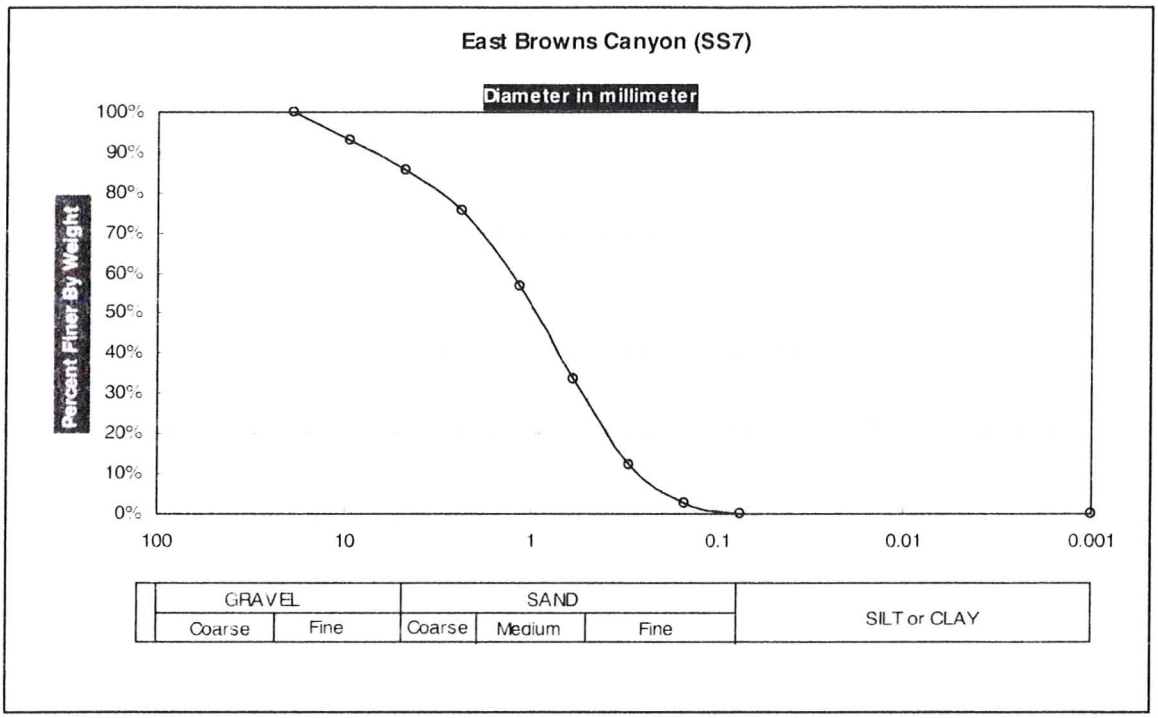

Figure 8: Grain Size Distribution Curve for East Browns Canyon (SS7) Soil Sample

In Lower Browns Canyon (SS17) site, 82% of the soil sample is sand (Fig. 9) and based on its calculated uniformity coefficient (7.6) it is well graded. Based on the Unified Soil Classification this sample can be classified as well graded sand (SW).

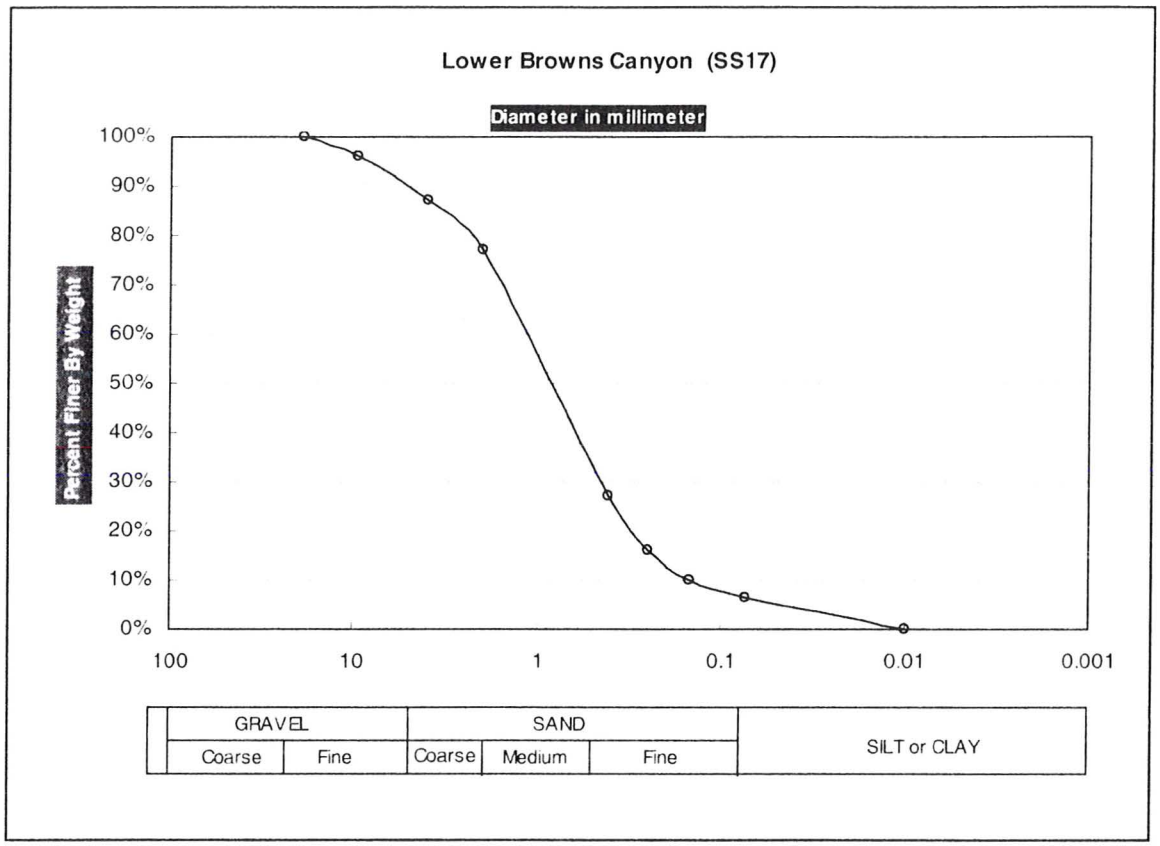

Figure 9: Grain Size Distribution Curve for Lower Browns Canyon (SS17) Soil Sample

The soil samples obtained from all of the above mentioned sites (SS4, SS7, SS17) have been classified as clay with low plasticity (CL) according to the soil survey report prepared by USDA (USDA,1980). The contradiction between my results and soil survey (USDA, 1980) report is due to map scale of the soil survey. It has been stated in the report that "there are many smaller areas which are not possible to map properly because the scale is not large enough to cover them". Further all the sites that have been sampled for this project are in the proximity of the canyons and hence consist of alluvium.

The soil samples collected at the Devils Canyon (SS19) site have uniformity coefficient of 2.5, so the soil sample is fairly well sorted. The sand size portion of the sample is as high as 95% (Fig. 10). The soil from this site can be classified as poorly graded sand (SP). However, according to Soil Survey Report (USDA, 1980), the soil type of the Devils Canyon (SS19) site has been classified as silty sand (SM). Once again, the results are contradictory due to the sampling and mapping scale.

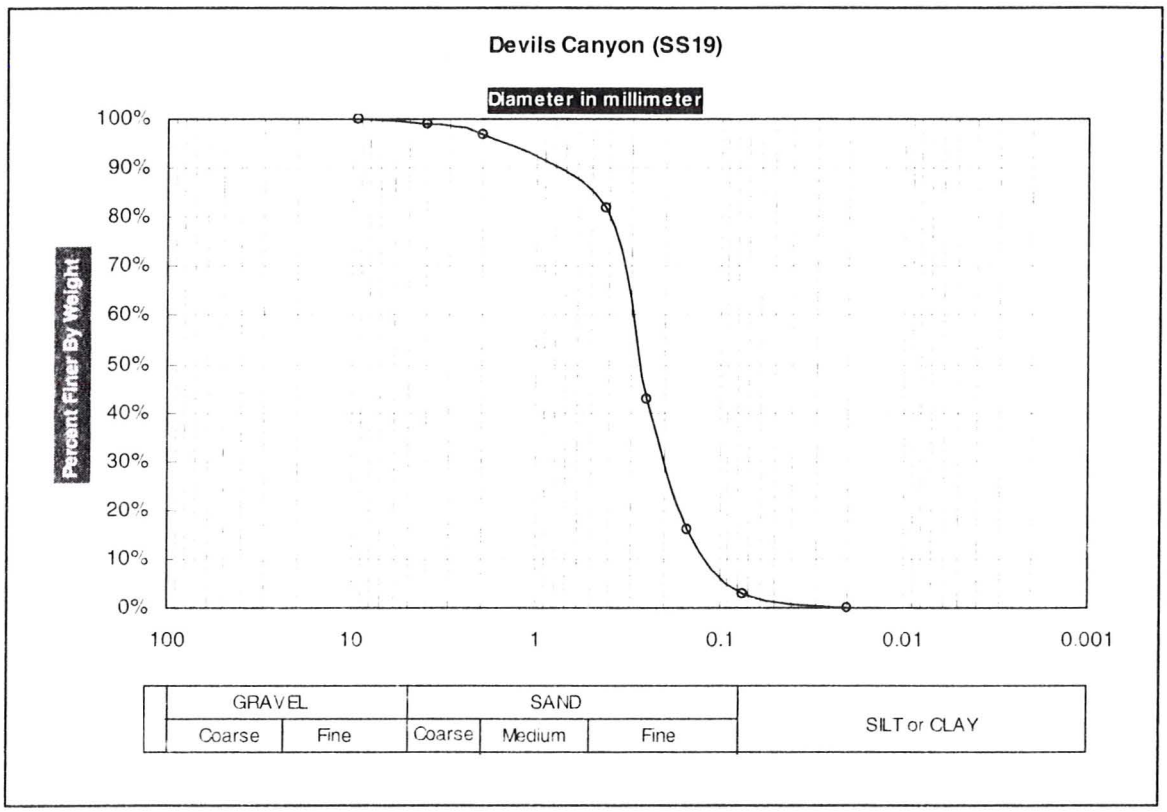

Figure 10: Grain Size Distribution Curve for Devils Canyon (SS19) Soil Sample

Estimated Hydraulic Conductivity

Hydraulic conductivity is the rate at which water moves through the soil under a hydraulic gradient. In general, higher infiltration rate correlates with higher hydraulic conductivity. Particularly, the later, steady-state readings from the infiltration tests provide an estimate of the saturated hydraulic conductivity. Hydraulic conductivity depends on the properties of porous medium (soil) and fluid (water). The coarser the material higher will be the hydraulic conductivity. Soil with higher hydraulic conductivity is ideal for an artificial recharge site.

Hydraulic conductivity can be calculated from field pump tests and in laboratory using permeameter. In addition, there are empirical formulas that relate grain size distribution data to hydraulic conductivity values such as the Hazen method. For example, for sandy sediments with an effective grain size (d_{10}) of between approximately 0.1 and 3.0 mm, the following equation can be used:

$K = C(d_{10})^2$ where:

K = hydraulic conductivity [L/T]

C = coefficient based on sorting and texture (Table 5) [1]

d_{10} = effective grain size [L]

Table 9: Coefficient Values Based on the Sorting and Texture of Soil (Fetter, 2001)

Soil Type	Coefficient (C)
Very fine sand, poorly sorted	40-80
Fine sand with appreciable fines	40-80
Medium sand, well sorted	80-120
Coarse sand, poorly sorted	80-120
Coarse sand, well sorted, clean	120-150

Hydraulic conductivity is a unique physical parameter, as it can have values that range over 13 orders of magnitude. Typical values for sediments in cm/sec are:

Clay-10^{-10} to 10^{-6} , Silt-10^{-6} to 10^{-4} , Sand-10^{-5} to 10^{0}, and Gravel 10^{0} to 10^{2}.

Table 10: Calculated/Estimated Hydraulic Conductivity Values Using Hazen Method

Sampling Site (Canyons)	Site ID	Effective grain size (d_{10}) (cm)	Coefficient (C)	$K=C(d_{10})^2$ (cm/sec)
Lower Limekiln Canyon	SS4	0.008	80	0.005
East Browns Canyon	SS7	0.026	40	0.027
Lower Browns Canyon	SS17	0.0165	80	0.022
Devils Canyon	SS19	0.012	120	0.017

The calculated/estimated hydraulic conductivity of the soil samples obtained from the study sites are complied in Table 10. The table shows that the hydraulic conductivity is directly proportional to the effective grain size of the material, so the higher the effective grain size value, the higher is the hydraulic conductivity value. The calculation shows that K value for East Browns Canyon sampling site has the highest hydraulic conductivity value. The K values compiled here should be considered preliminary. Through application of alternative methods such as application of Darcy's law using constant head method or falling head method or aquifer test such as pumping test or slug test. can give more accurate values.

4. INFILTRATION RATES THROUGH SOIL PROFILE

The vadose zone and its hydrologic characteristics directly influence infiltration, evapotranspiration, interflow and aquifer recharge rates. Understanding the nature of water movement in the vadose zone and its quantification is essential in estimation of infiltration and recharge rates.

A portion of precipitation enters the soil through the process of infiltration. If the rate of precipitation is greater than the soil's infiltration rate, excess water will either accumulate on the soil's surface or become runoff. A portion of infiltrated water may remain in the vadose zone and some may percolate further down, recharging groundwater aquifer systems.

Factors Affecting Infiltration Rate

■ **Hydraulic Conductivity**: Infiltration rate correlates with saturated hydraulic conductivity. The infiltration data obtained later during a test are comparable to hydraulic conductivity. Lower Browns Canyon site (SS17) with higher hydraulic conductivity also gives the higher rate of infiltration.

■ **Initial Moisture Content**: The initial moisture content of soil affects the infiltration rates. When soil moisture content is high, the soil cannot absorb more water, hence the rate of infiltration is lower for moist soil. Similar condition was found in Browns Canyon East (SS7) site, where the soil was moist to wet and hence gives the lower rate of infiltration.

■ **Organic Matter:** Generally as the amount of organic material increases the infiltration rate is increased. Organic matter increases the entry of water by protecting the soil aggregates from breaking down during the impact of raindrops. Particles broken from aggregates can clog pores and seal the surface and decrease infiltration during a rainfall event (USDA, 1998). In the present study, Lower Limekiln Canyon (SS4) site is composed of organic soil hence gives the higher rate of infiltration.

■ **Slope of the Land**: Water falling on steeply-sloped land runs off more quickly and infiltrates less than water falling on more gentle topography. Devils Canyon (SS19) site has the gentler slope with higher rate of infiltration.

Horton's Model

The infiltration process is a complex interaction among rainfall intensity and duration, soil type, surface geology and landuse. Soil surface conditions govern the ability or rate at which water passes into the soil, whereas subsurface soil properties govern the rate at which water percolates through the unsaturated zone. Horton (1940) showed that when rainfall rate exceeds the infiltration rate, the infiltration rate decreases with time. According to Horton's equation:

$$f_p = f_c + (f_o - f_c)e^{-kt}$$

where,

f_p is the maximum infiltration rate at time t, [L/T],

f_o is the initial infiltration rate at time equals zero, [L/T]

k is a constant that defines function f, [1], t is time, [T]

Ultimately, as precipitation continues with an intensity of greater than infiltration rate, the infiltration rate reaches a constant value known as the saturated soil infiltration rate. Rubin and Steinhardt (1963) and Rubin and others (1964) showed that the final infiltration rate reached under the condition that precipitation exceeds the infiltration rate is equal to the vertical hydraulic conductivity of a saturated soil. Several assumptions about boundary conditions must be met, including a constant vertical hydraulic gradient and flow rates with no lateral flow component.

Soil Infiltration Measurements

Based on general soil and hydrologic investigation of the foothills of Santa Susana, Simi Hills and Santa Monica Mountains and in order to quantify infiltration rates within the project area, four sites in the headwater area of Los Angeles River Basin were chosen. All four sites are located in the Santa Susana Mountains area (Fig. 11). The selection of the test sites was based on the discharge analysis of the canyons, geomorphology suitable to develop an artificial recharge basin, proximity to water source and site accessibility as access to private property was a limiting factor. In all instances, sites were selected to represent the typical land use and surface conditions of the surrounding area. At three of the infiltration test sites, a second measurement was made in proximity to the first measurement to test the reproducibility of the results and to gain further insight about spatial and temporal variability in soil infiltration rates.

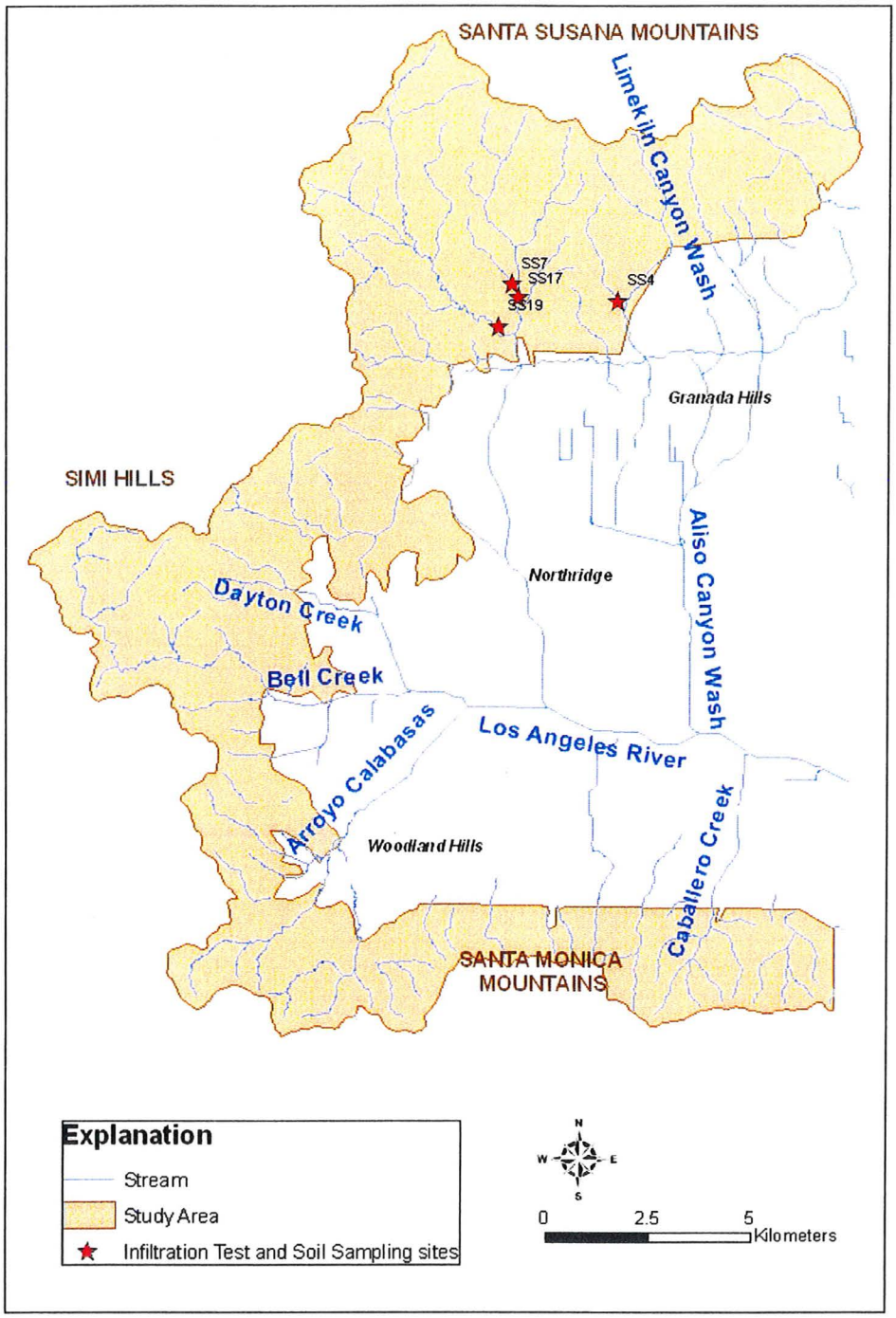

Figure 11: Infiltration and Soil Sampling Sites (Base map is based on USGS, 1998 & MRT Geodatabase)

Soil infiltration was measured by using two standard double-ring infiltrometers with diameters 15.2 cm and 30.4 cm (American Society for Testing and Materials, 1994), which consists of two concentric rings and the larger one also consists of two calibrated Marriotte tubes assemblies to deliver water to the rings during the measurement (Fig 12). The saturated soil between the inner and outer rings vertically constrains flow through the inner ring. Water used for the soil infiltration tests was taken from the local public supply for one test and from nearby canyons for other tests.

Figure 12: Double-Ring Infiltrometer with Marriotte Tubes

For operating the larger diameter infiltrometer, the rings were filled with water and constant head was maintained by using a floater. The calibrated marking on the Marriotte tube generally is read at timed intervals to calculate the delivery rate of water to the inner ring. If a constant head is maintained in the inner ring, the delivery rate is the incremental infiltration rate. At some sites, where the infiltration rates were higher than the maximum delivery rates of the tube to the inner ring, water was added directly to the inner ring. The

volume of added water was recorded by measuring down to the water surface from the top of the inner ring at timed intervals. (To maintain a saturated barrier, water also had to be added directly to soil through the space between the inner and outer rings.)

Testing infiltration rates in the soil with higher moisture content and thin soil profile was difficult. As a result, assumptions of vertical flow through the soil column were uncertain in the East Browns Canyon (SS7) site. A more detailed evaluation of infiltration rates in this compacted disturbed soil of East Browns Canyon (SS7) site could validate or clarify rates reported herein.

Infiltration Rate Data Analysis and Interpretation

Incremental soil infiltration rates as a function of time were plotted for each test and Horton's equation was fitted through the data (Table 11, Fig 13-15). According to Horton's equation, infiltration rates become constant with time as the soil reaches fully saturated conditions. At most sites, it took about 10 to 50 minutes for infiltration rates to become constant.

Table 11: Field Infiltration Data Fitted to Horton's Equation

Canyons	Weather	Sampling Site	k	f_0	f_c	Fitted to Horton's Equation
Lower Limekiln Canyon	Dry	SS4	0.0648	230.3	63.16	$f_p=63.16+(230.33-63.16)*e^{-0.0648*t}$
	Wet		0.09	76.19	48	$fp= 48+(76.19-48)*e^{-0.09t}$
East Browns Canyon	Dry	SS7	0.063	15.66	4.29	$fp= 4.29+(15.662-4.29)*e^{-0.063t}$
Lower Browns Canyon	Dry	SS17	0.211	506.3	52.5	$fp= 52.5+(506.33-52.5)*e^{-0.211t}$
Devils Canyon	Dry	SS19	0.1557	164.7	45	$fp= 45+(164.74-45)*e^{-0.1557*t}$
	Wet		0.214	83.05	44.31	$fp= 44.31+(83.055-44.31)*e^{-0.214t}$

The measured infiltration rates ranged from 4.29cm/hr for Browns Canyon East, SS7 to 63.2cm/hr Lower Limekiln Canyon, SS4) and the data are plotted on Fig 13-15. Infiltration rate was greatly reduced due to the higher moisture condition at the Browns Canyon East (SS7) site. The infiltration rates obtained during this study are in compliance with the rates reported in published document such as one published by U.S. Geological Society (Telis, 2000).

The infiltration rates for some of the successfully operating spreading grounds such as Pacoima and Tujunga are documented as low as 1.5 cm/hr and 3cm/hr respectively (LACDPW, 2003). The infiltration rates reported here are relatively higher when compared with Pacoima and Tujunga spreading ground values. The reason for such a big difference in infiltration rate is the infiltration time period. The infiltration data from present study represents a short term rate and the rates reported in the abovementioned spreading grounds are the long term rates when the soil becomes saturated.

Initial soil moisture content affects the rate of infiltration. To understand the role of initial soil moisture content on infiltration rate, a comparative study of infiltration rates during different seasons was carried out for the, Devils Canyon and Lower Limekiln Canyon sites. The results obtained showed that although the initial rates are different under dry and wet weather conditions, the final rates of infiltration are comparable. (Figs. 13-14).

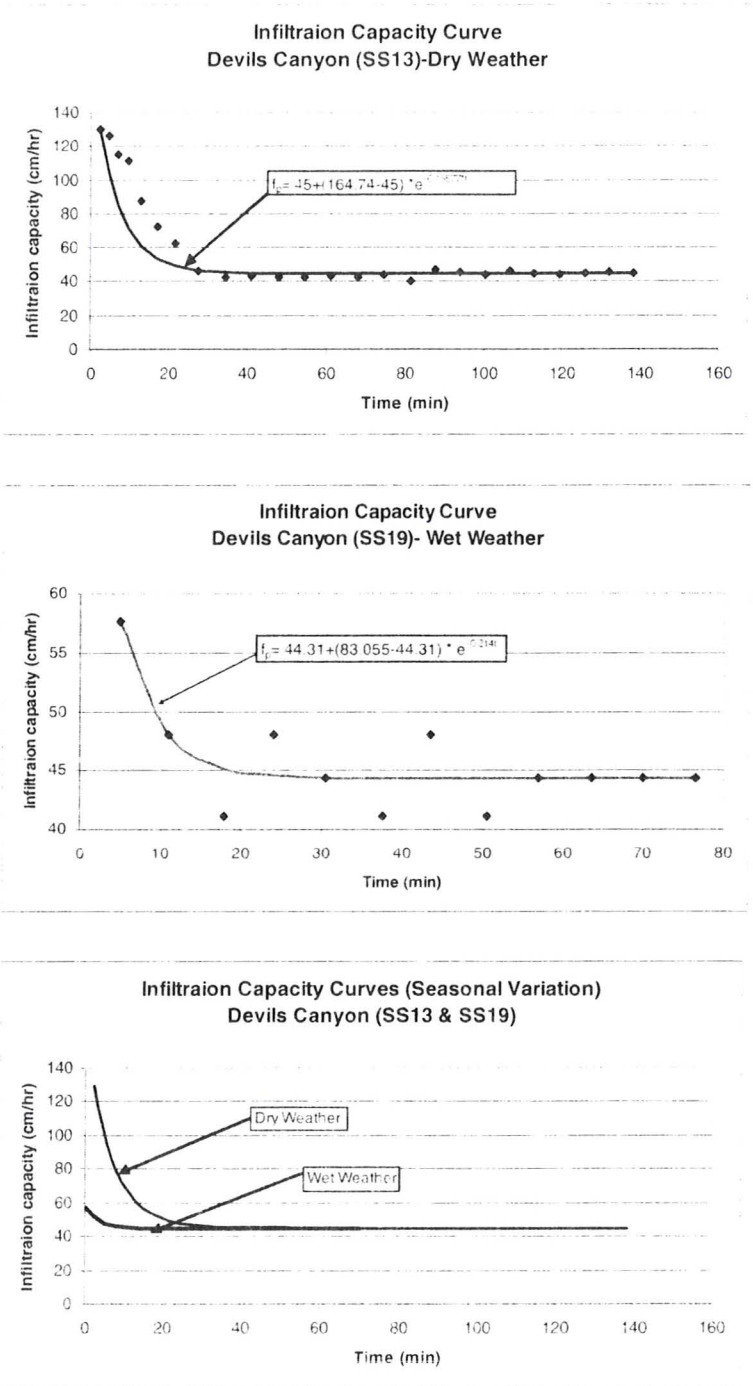

Figure 13: Soil Infiltration Rate as a Function of Time for Devils Canyon Testing Site (Data are Fitted to Horton's Equation)

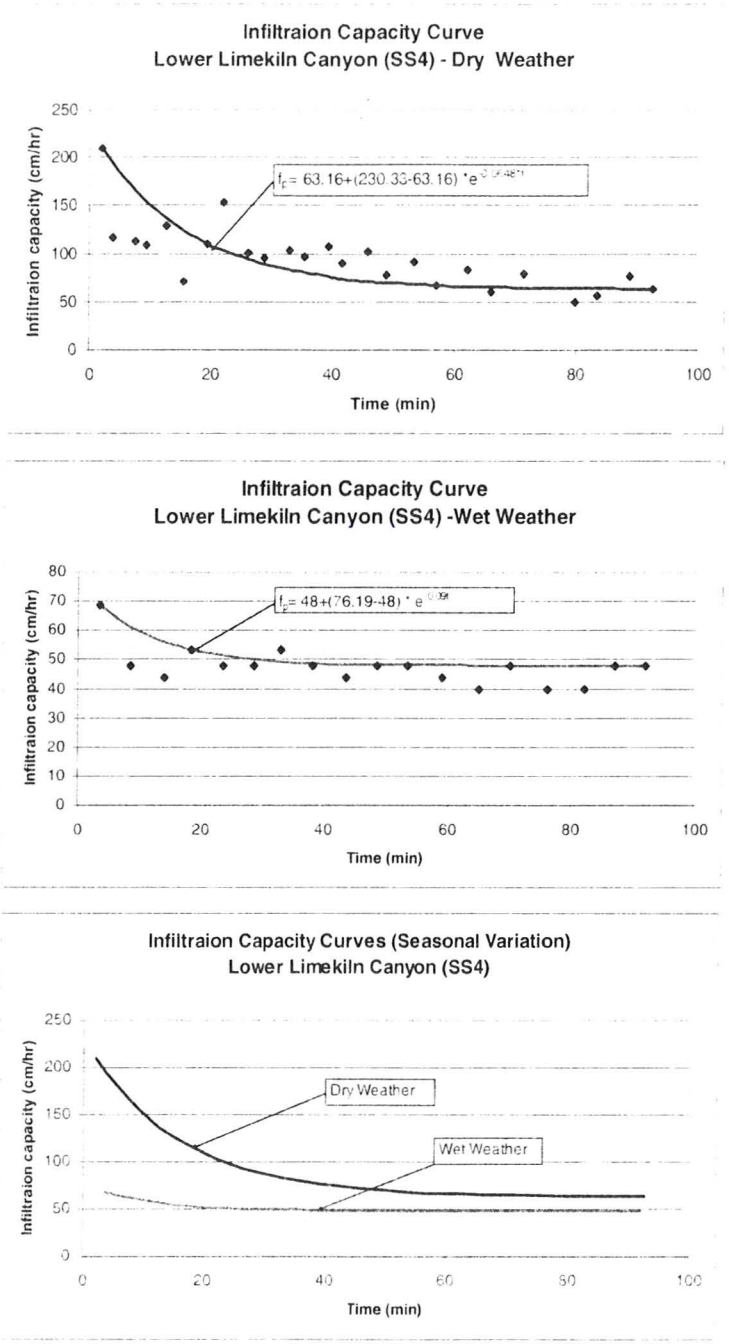

Figure 14: Soil Infiltration Rate as a Function of Time for Lower Limekiln Testing Site (Data are Fitted to Horton's Equation)

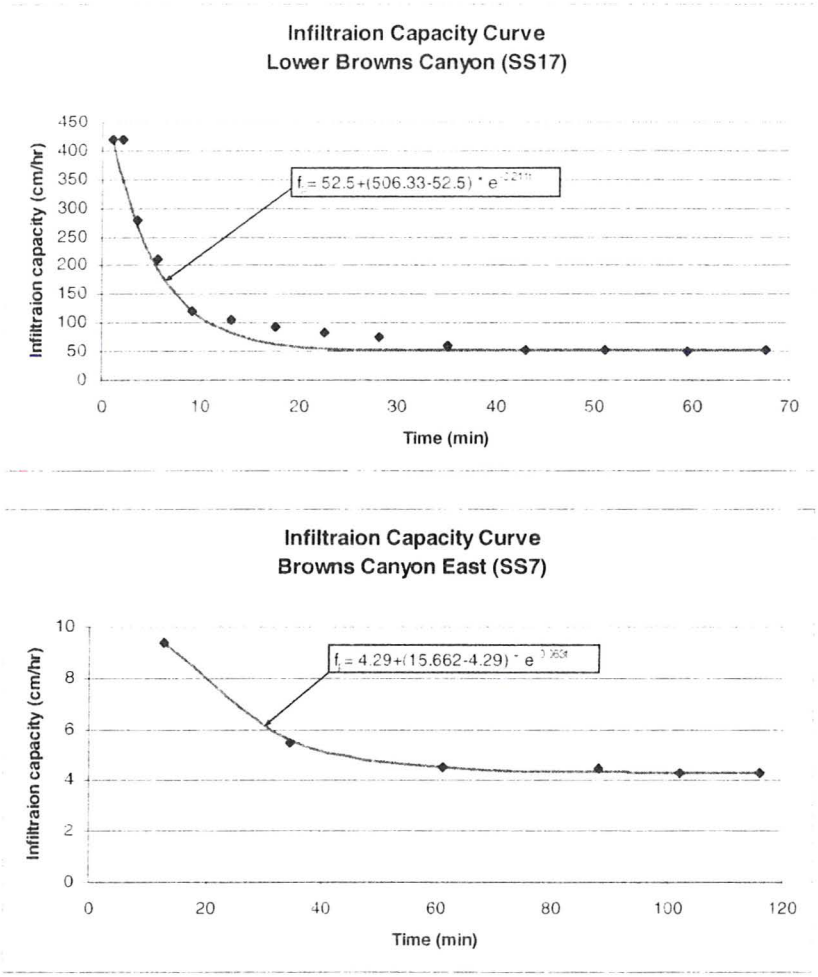

Figure 15: Soil Infiltration Rate as a Function of Time for Lower Browns Canyon and Browns Canyon East Testing Sites (Data are Fitted to Horton's Equation)

It should be mentioned that smaller diameter infiltrometer was used in the dry weather testing while larger diameter infiltrometer was exercised in the wet weather testing. The larger diameter infiltrometer has a numbers of operational difficulties such as its greater weight, and its requirement for a larger volume of water. It may introduce error into the test such as the condition when the infiltration rate was higher than the water delivery

rate of the marriotte tube and additional water was added directly into the ring. However, if the testing is conducted properly, the data obtained from the smaller diameter infiltrometer is as reliable as the one from larger diameter infiltrometer. The aforementioned is supported by the analogous final rates of infiltration obtained for two different seasons (Fig. 13-14).

The results obtained from the infiltration tests illustrate that Lower Browns Canyon (SS17) and Lower Limekiln Canyon (SS4) testing site have the higher infiltration rates (52.5cm/hr and 63.2cm/hr respectively). The infiltration rates were lowest for Browns Canyon East (SS7) with 4.3cm/hr.

The infiltration rates complied in LACDPW, 2006 a,b (Fig. 16) are based on theoretical /mathematical formula and are drastically different than those infiltration rates obtained through field testing in this study.

The contradictory infiltration rate results compiled in Table 12 are primarily due to testing sites scale and difference in methodologies/techniques.

Table 12: Comparison of Field Infiltration Rate Measurement with Published Data (USDA, 1980 and LACDPW, 2006 a,b)

Study Site	Infiltration Rate (Measured, cm/hr))	Infiltration Rate (Soil Survey, USDA)	Infiltration Rate (LACDPW, cm/hr)
Lower Limekiln Canyon (SS4)	48-63.2	Moderate-Slow	1.12
Browns Canyon East (SS7)	4.3	Moderate-Slow	1.12
Lower Browns Canyon (SS17)	52.5	Moderate-Slow	1.12
Devils Canyon (SS19)	44.3-45	Very Slow	0.54

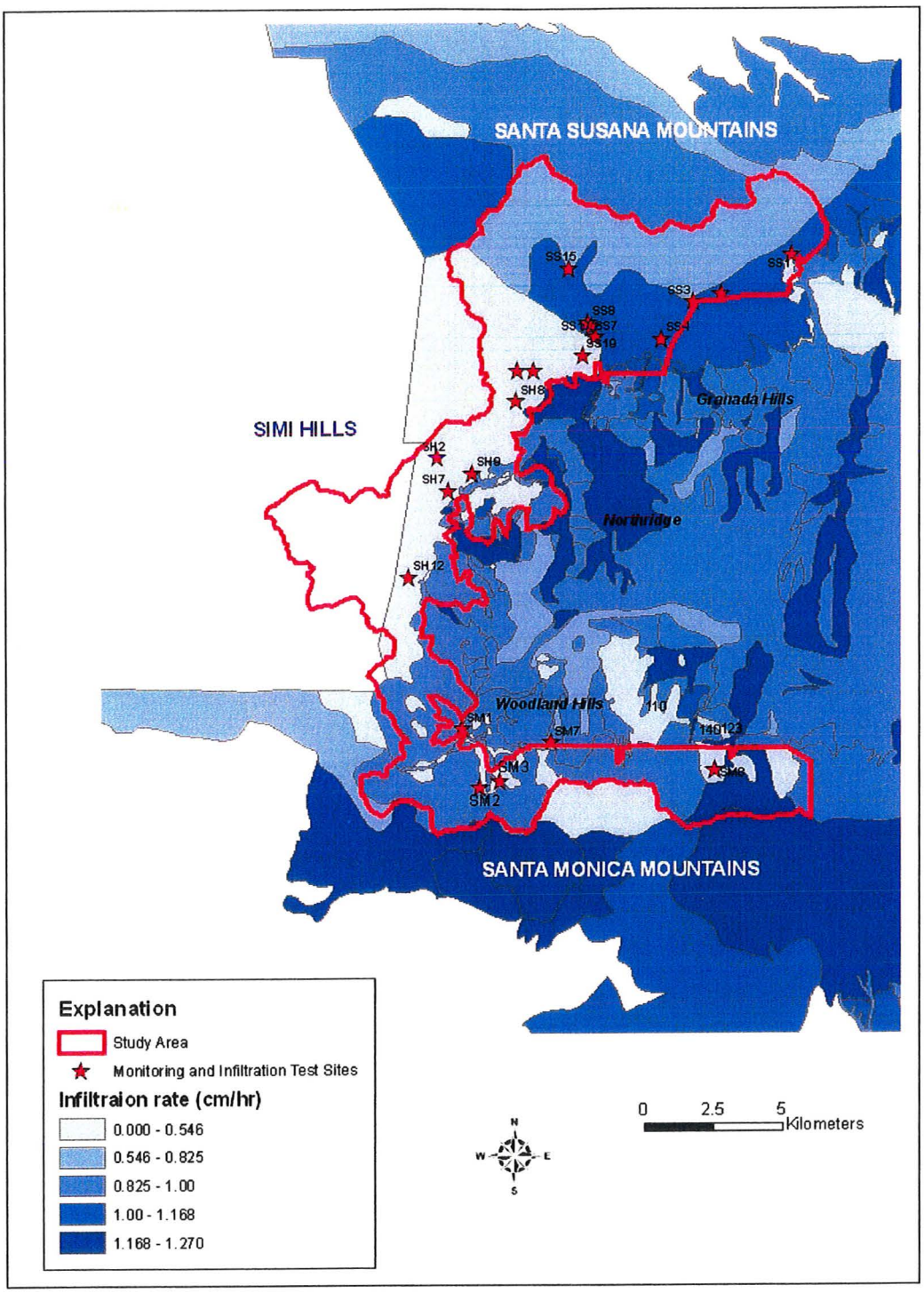

Figure 16: Calculated Infiltration Rates (Modified after LACDPW, 2004)

5. WATER QUALITY ASPECTS OF GROUNDWATER RECHARGE

Effectiveness of an artificial groundwater recharge project requires in-depth assessment of the vadose zone hydrologic characteristics, water availability and its quality, the impact of artificial recharge on local aquifers and ultimate recovery of the recharge water. Another important issue in any artificial recharge activity is to evaluate potential near term and long-term impact of recharge water on the receiving aquifer system.

One of the major focuses of this study is to ascertain the quality of surface water that potentially could be used for artificial recharge activities. The suitability of water for a particular purpose depends on the kinds and amounts of chemical species and organic materials.

Sources of Data

In order to evaluate the suitability of surface water of the project area for artificial recharge activities, twenty water quality sampling stations were established and the surface water quality of the area was characterized based on results of monthly sampling at twenty locations. Surface Water Ambient Monitoring Program (SWAMP,2005) protocol was followed for the sampling which began in March 2006 and was continued until April 2007. An effort was made to present both the dry and wet weather characteristics of surface water quality. The sampling sites are mostly located on the foothills of Santa Susana and Santa Monica Mountains and Simi Hills (Fig. 17). The collected water samples were analyzed by a state certified lab, American Analytics located at Chatsworth, California following standard EPA methods (Appendix C).

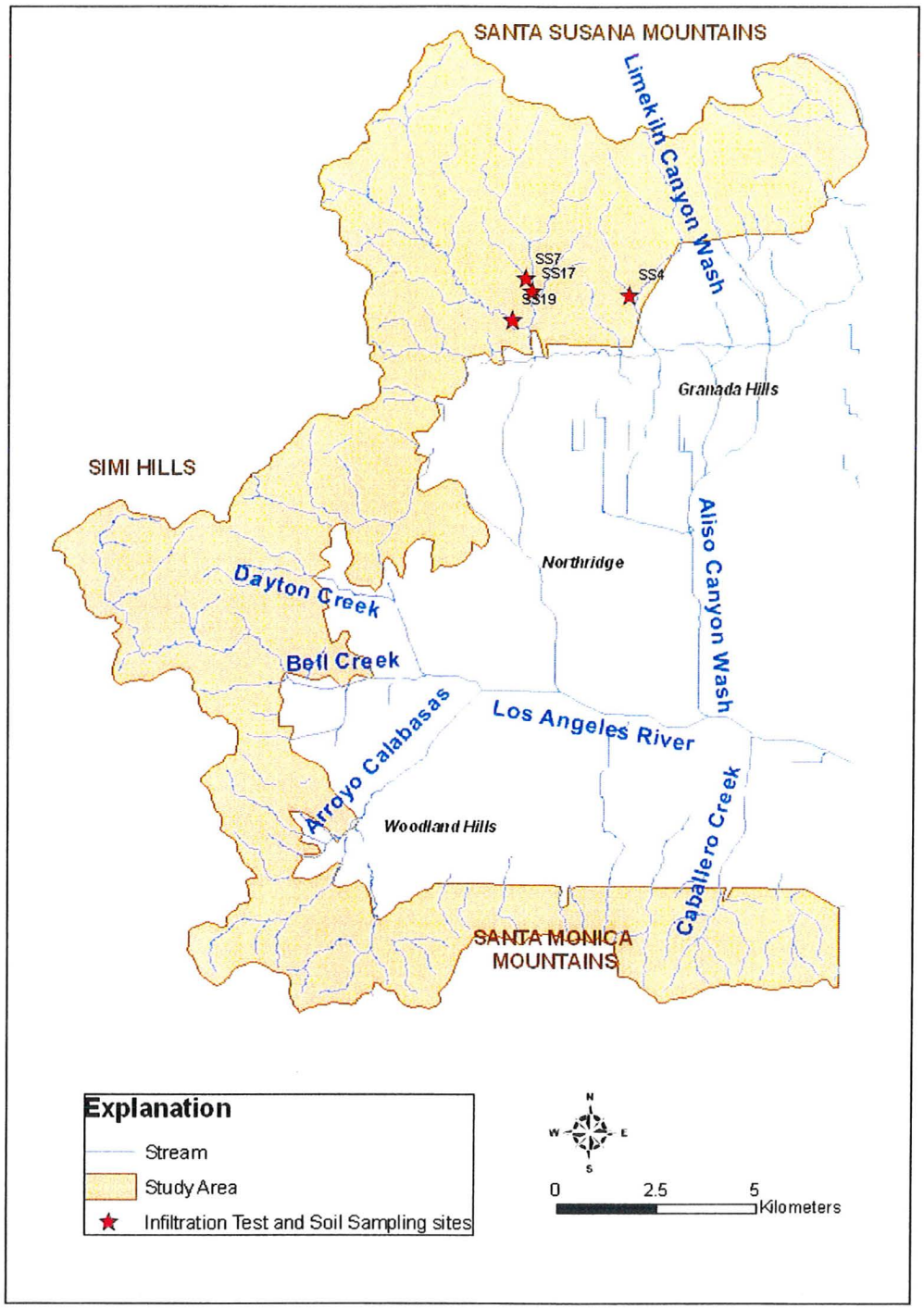

Figure 17: Water Quality Monitoring Sites (Base Map: Modified After USGS, 1998 & MRT Geodatabase)

Baseline Water Quality Assessment

Analysis of water samples included tests for alkalinity, calcium, magnesium, potassium, sodium, chloride, fluoride, nitrate, total dissolved solid, total hardness, aggressive index, specific conductance, pH, langelier index, sodium adsorption ratio, arsenic, boron, copper, iron, manganese, selenium and zinc (Appendix C). The aforementioned water quality data were used to identify type of water, to compare water quality characteristics of potential areas for artificial recharge activities and an attempt was made to relate the quality of water with respect to its use for artificial recharge of Western San Fernando Basin.

Water Type

The ionic composition of water samples can be represented by a water-quality diagram - the stiff diagram. Stiff diagrams are used to compare the ionic composition of water samples between different locations, depths, or aquifers. The stiff diagram is a polygon created from three horizontal axes extended on both sides of a vertical axis. Cations are plotted on the left side of the axis and anions are plotted on the right side, both in meq/L.

A greater distance from the vertical axis represents a larger ionic concentration. The cation and anion concentrations are connected to form an asymmetric polygon known as a stiff diagram, where the size is a relative indication of the dissolved-solids concentration. The stiff diagrams constructed for selected water samples collected as part of this study are shown in Fig. 18. Following stiff diagrams give the average water type of the canyons those considered as most suitable for artificial recharge.

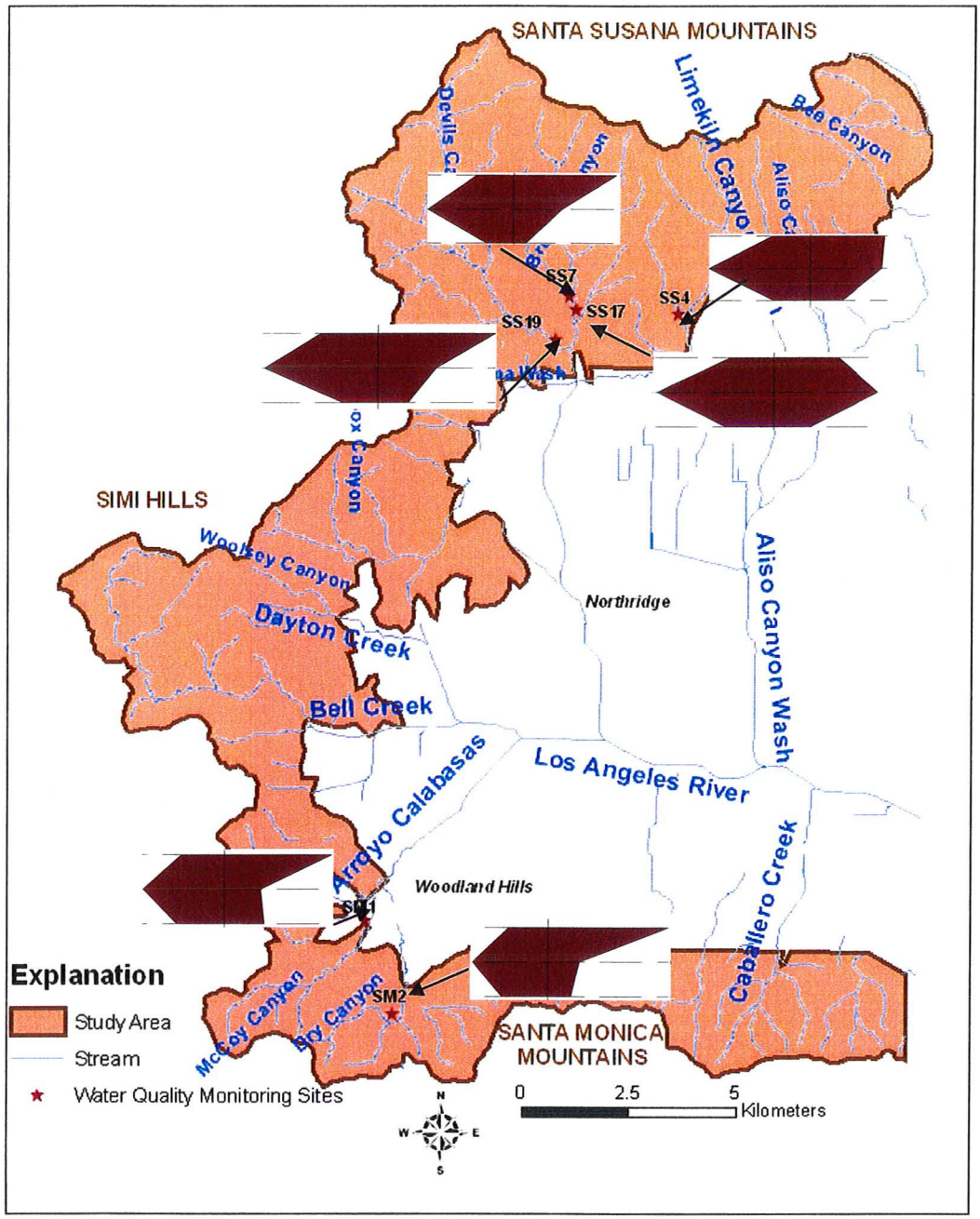

Figure 18: Stiff Diagrams to Display Spatial Variations of Water Type (Base Map: Modified After USGS, 1998 & MRT Geodatabase)

The stiff diagrams show the similarity in ionic composition (calcium-sulfate-type water) observed in most water samples, regardless of areal distribution of the monitoring sites. Most of the water samples exhibited water type as calcium sulfate, which is consistent with the local geology (presence of sulfate bearing rocks). For samples collected from Lower Browns Canyon (SS17), stiff diagrams show little variation in water type and which is found to be calcium bicarbonate.

Temporal Variation of Water Quality Characteristics

Trilinear diagrams are used to show the relative proportion of common cations and anions, thereby allowing comparisons and classification of water samples with different concentrations (Hem, 1985). Samples that represent the range of water quality condition for 12 months are shown in trilinear diagrams (Fig 19). The water type of the surface water samples in the Western San Fernando Valley is consistent throughout the year though there are some seasonal variations in the concentration of major anions and cations.

Quality of Surface Water for Recharge Purpose

The water in canyons must meet the federal and/or state water quality limits before using them for artificial recharge. Water quality data obtained from this study are compared to water quality limits established by regulating agencies such as U.S. Environmental Protection Agency (USEPA), and Los Angeles Regional Water Quality Control Board (LARWQCB).

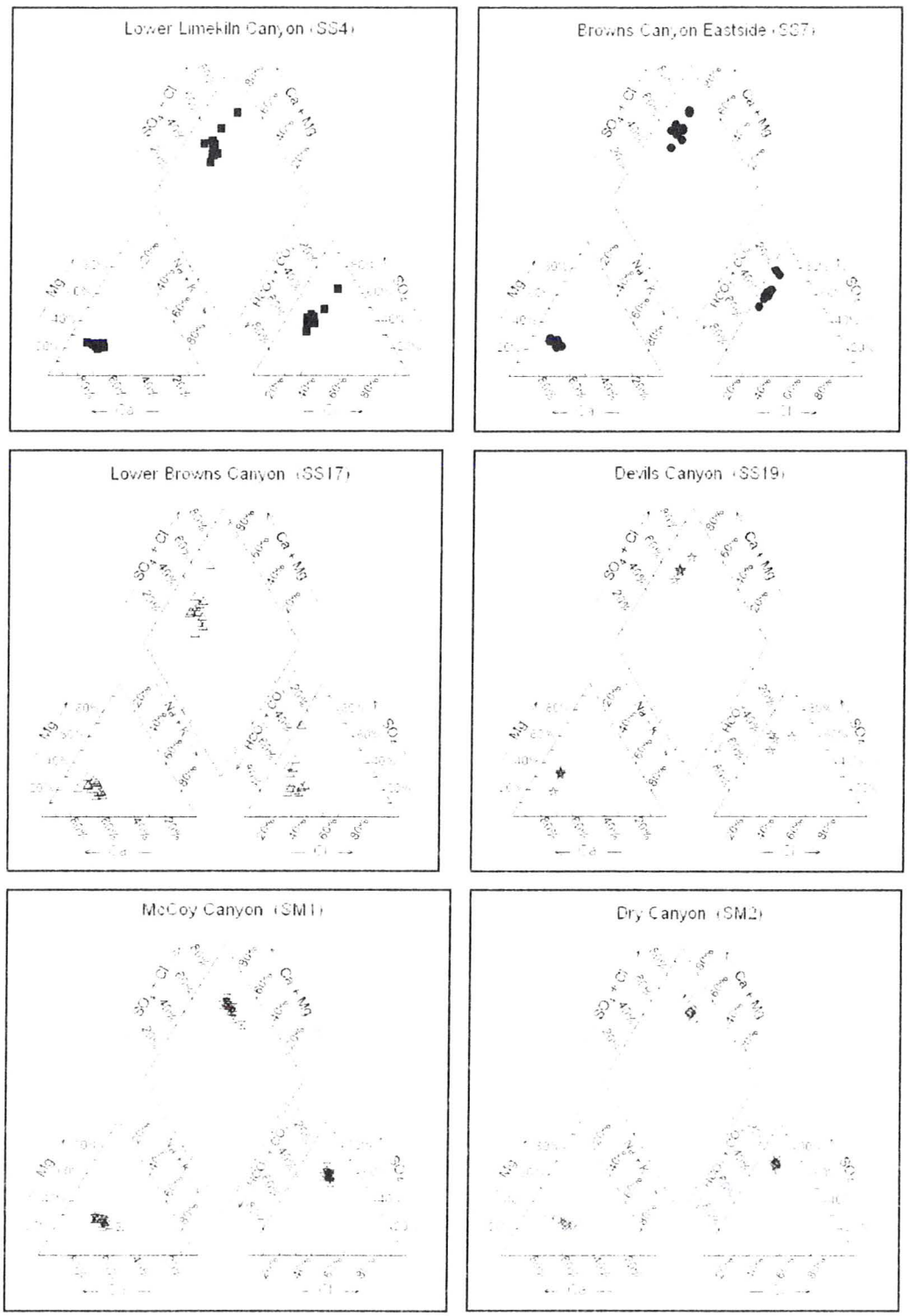

Figure 19: Trilinear Diagrams Showing the Consistency (Temporal) in Water Type and Water Quality

The best suited water quality standard for this study is the one defined by LARWQCB for Los Angeles River and its tributaries which is known commonly as Basin Plan (1994). However establishing water quality limits is a continuous process and none of the water quality standards is comprehensive enough to cover all the chemical constituents of interest. So other water quality standards such as the California Toxic Rule (CTR) and the water quality limit for drinking water purpose the Maximum Contaminant Limit (MCL) and the Secondary Maximum Contaminant Level (SMCL) are also used for the purpose of comparing water quality.

Arsenic

Arsenic is considered as a highly undesirable element in drinking water supplies because it is a carcinogen to humans. Exposures to arsenic are additive, and prolonged exposure to small concentrations may have adverse health effects including skin, liver, lung, and bladder cancer (Hem, 1985). Arsenic is a regulated contaminant, and in 2001 U.S. Environmental Protection Agency reduced the drinking water maximum contaminant level (MCL) from 50 to 10 micrograms per liter (USEPA, 2003a).

Arsenic has been used as a component of pesticides and thus may enter streams or ground water through improper waste disposal practices or agricultural usage. Arsenic is present in volcanic gases and is a common constituent of geothermal water (Hem, 1985). An important factor in the natural circulation of arsenic, however, is the volatility of the element and some of its compounds.

The lab data presented here (Fig. 20, the symbol used signifies < value) shows that arsenic concentrations in the runoff of the monitoring sites are well below the MCL. The water quality data obtained from lab shows that the concentrations are less than 0.007 mg/L for all the samples. The levels of arsenic concentration are lower than MCL for the entire sampling period and are not a limiting factor in artificial recharge activities.

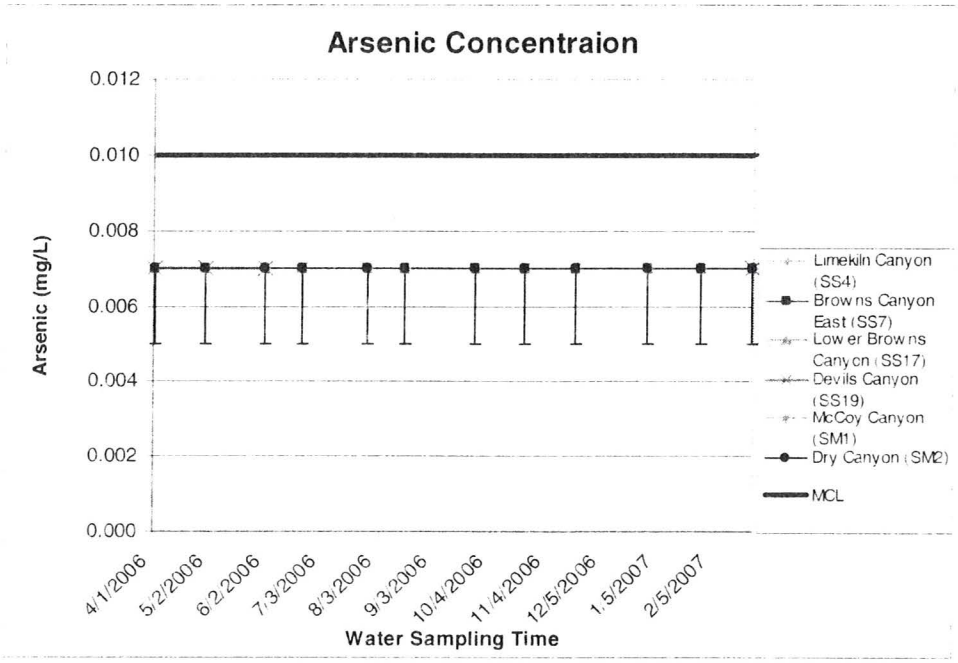

Figure 20: Concentration of Arsenic in the Water Samples

Selenium

The sources of selenium in water have been identified as discharge (waster water) from petroleum refineries, erosion of natural deposits, and discharge from mines. Although selenium plays no role in plant nutrition, it is taken up by plants and thus concentrated in the areas where organic matter has accumulated; for example, in coals and black shales where it is often associated with iron pyrite. Black shales may contain as much as 20 ppm

selenium regionally and up to 1,500 ppm locally. Coals average 1.5 ppm selenium and coals generally contain from 0.5 to 12 ppm selenium (Hem, 1985).

Selenium is an essential nutrient at low levels for living beings. However, the EPA has found selenium to potentially cause the following health effects when people are exposed to it at levels above the MCL for relatively short periods of time: hair and fingernail changes; damage to the peripheral nervous system; fatigue and irritability. Selenium has the potential to cause hair and fingernail loss; damage to kidney and liver tissue, and the nervous and circulatory systems from a lifetime exposure at levels above the MCL. (USEPA, 2003)

Total Maximum Daily Load (TMDL) report for metals including selenium for the Los Angeles River shows that some of the water samples from Dry Canyon (SM1) and McCoy Canyon (SM2) sites exceeded CTR values of 0.005 mg/L for selenium (LARWQCB, 2005). The water quality data collected by the City of Calabasas during the period of July 2000 to July 2002 showed the maximum measured values for selenium were 0.044 mg/L for McCoy Canyon.

The selenium data obtained during this study shows that the 2 out of 12 samples exceeded the California Toxic Rule (CTR) for McCoy Canyon (SM2), and the maximum concentration value was 0.013 mg/L (Fig. 21, the symbol used signifies < value). None of the samples from Dry Canyon (SM1) had higher selenium values during this period of monitoring. However the Limekiln Canyon (SS4) site, which is not listed in the 303 (d) list of 2002 and 2006 had selenium values higher than CTR during the same time periods

that when the values were also higher for McCoy Canyon(SM2). It has been discussed in the TMDL report (LARWQCB, 2005) that there are very little industrial activities in the upper reaches of Los Angeles River Watershed. This fact directs the source of selenium towards natural deposits such as occurrence of marine shales (EDAW, 2003). Due to occurrence of selenium at high concentration, the water of Limekiln Canyon (SS4) and McCoy Canyon (SM2) needs suitable means of treatment before using them for groundwater recharge.

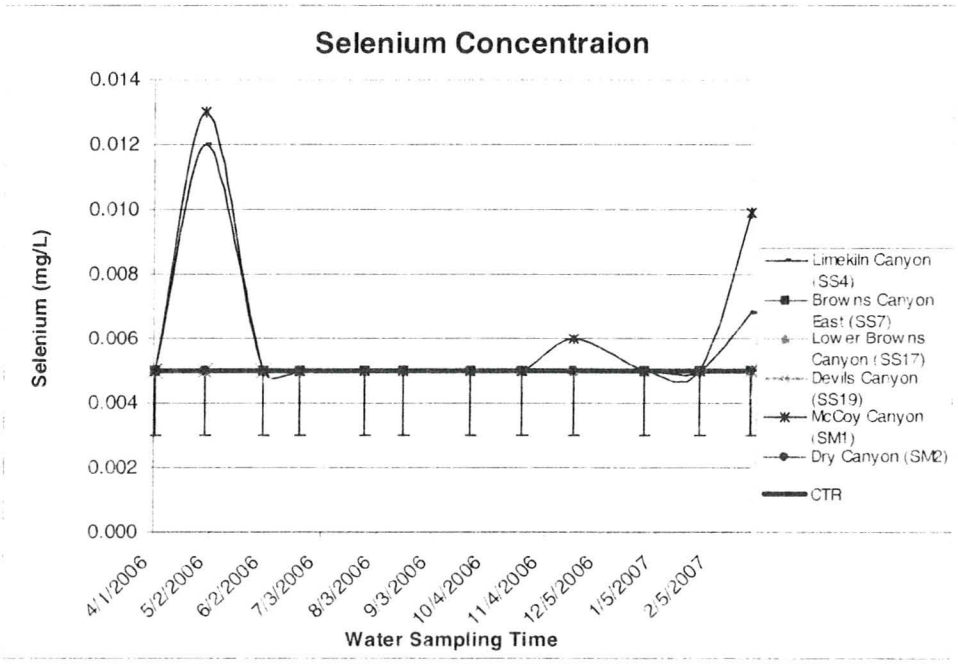

Figure 21: Concentration of Selenium in the Water Samples

Sulfate

Sulfates can be naturally occurring or they can also occur as the result of municipal or industrial discharges. When naturally occurring, they are often the result of the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals, or of atmospheric deposition. They may also form by the oxidation of iron sulfides or of native sulfur. Point sources include

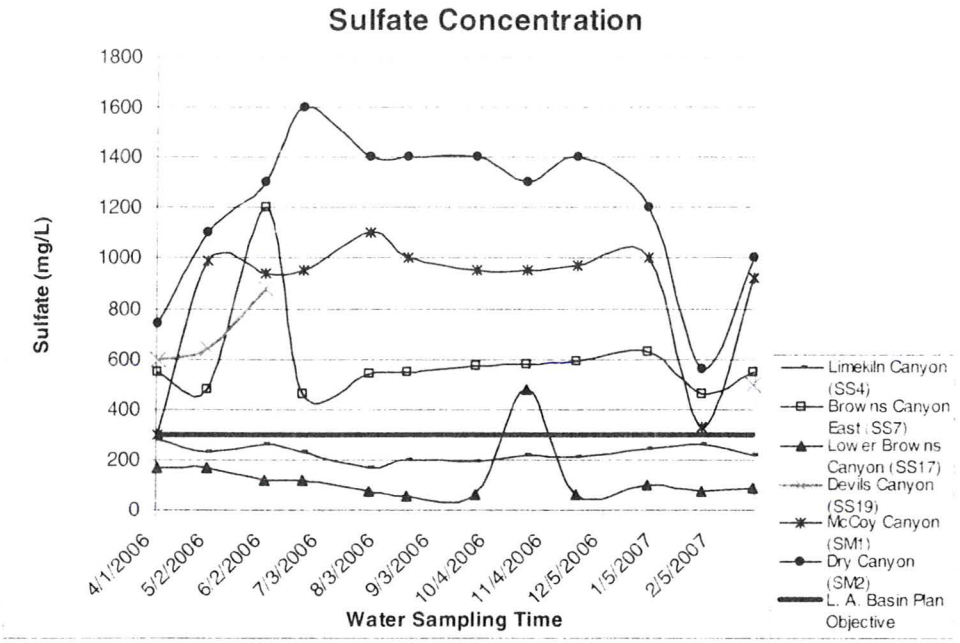

Figure 22: Concentration of Sulfate in the Water Samples

Calcium

Calcium salts and calcium ions are among the most commonly occurring in nature and hence are the predominant cations in river water. They may result from the leaching of soil and other natural sources or may come from man-made sources such as sewage and some industrial wastes. Calcium is usually one of the most important contributors to water hardness. Even though the human body requires approximately 0.7 to 2.0 grams of calcium per day as a food element, excessive amounts can lead to the formation of kidney or gallbladder stones. High concentrations of calcium can also be detrimental to some industrial processes. Thus, both domestic and industrial water users have to consider calcium concentrations. Calcium also serves an important role in the health of bodies of water. In natural water it is known to reduce the toxicity of many chemical compounds on fish and other aquatic life (Hem, 1985).

Rivers in more arid regions, especially where some of the more soluble rock types are exposed, tend to have much higher dissolved-calcium concentrations. When river water is impounded in a storage reservoir, changes may occur in calcium content as a result of calcium carbonate precipitation (Hem, 1985).

Calcium is defined as a secondary contaminant by EPA and it SMCL is 250mg/L. Concentrations of calcium in three canyons are within EPA guidelines whereas McCoy Canyon and Dry Canyon values exceeded the SMCL (Fig. 23). The higher values seem to be consistent with the climatic conditions (semi-arid) and geology (soluble sedimentary rocks) of the area.

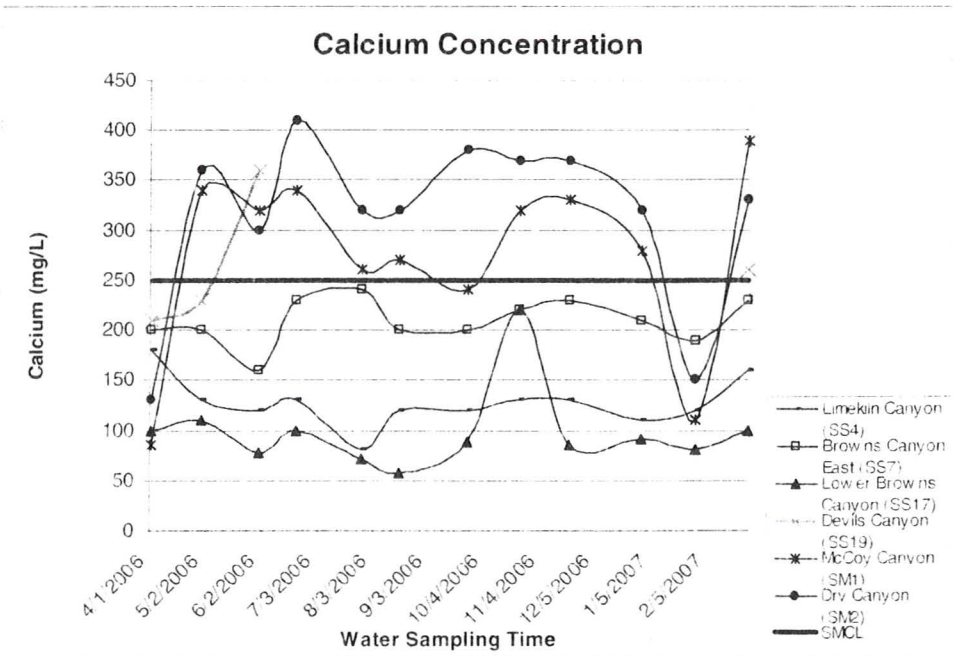

Figure 23: Concentration of Calcium in the Water Samples

Chloride

Chlorides are salts resulting from the combination of the gas chlorine with a metal. Some common chlorides include sodium chloride (NaCl) and magnesium chloride ($MgCl_2$). Chlorine alone as Cl_2 is highly toxic and it is often used as a disinfectant. In combination with a metal such as sodium it becomes essential for life. Small amounts of chlorides are required for normal cell functions in plant and animal life (Hem, 1985). Chlorides are not usually harmful to people; however, the sodium part of table salt has been linked to heart and kidney disease. Sodium chloride may impart a salty taste at 250 mg/L; however, calcium or magnesium chloride is not usually detected by taste until levels of 1000 mg/L are reached.

Chlorides may get into surface water from several sources including: rocks containing chlorides; agricultural runoff; wastewater from industries; oil well wastes; effluent wastewater from wastewater treatment plants; road salting. Public Drinking Water Standards require chloride levels should not exceed 250 mg/L. Criteria for protection of aquatic life require levels of chloride less than 600 mg/L for chronic (long-term) exposure and 1200 mg/L for short-term exposure.

Chloride is present in all natural waters, but usually the concentrations are low. In most surface streams, chloride concentrations are lower than those of sulfate or bicarbonate. Exceptions occur where streams receive inflows of high-chloride ground water or industrial waste or are affected by oceanic tides.

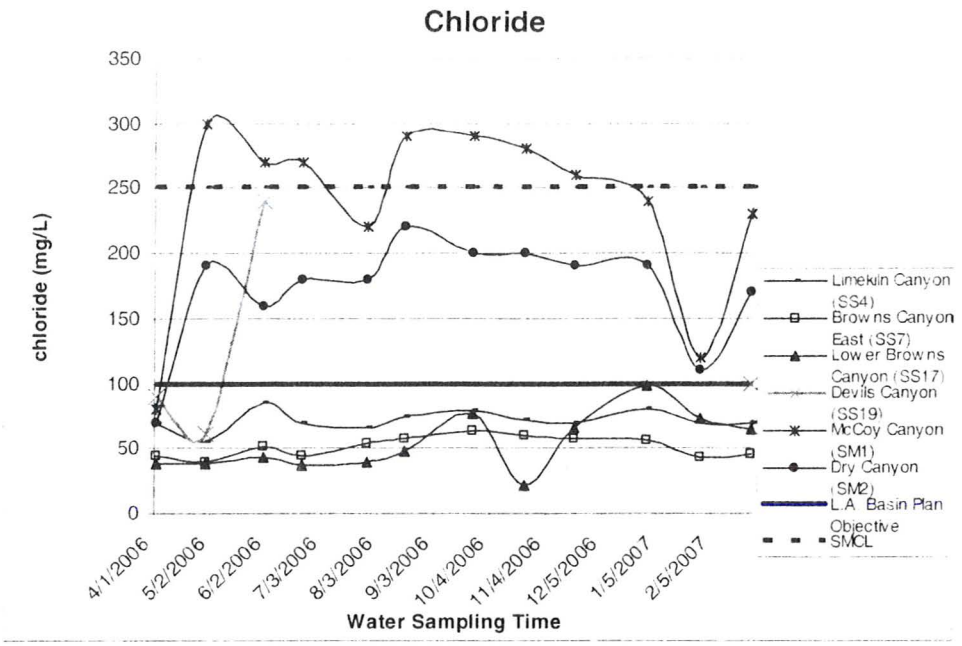

Figure 24: Concentration of Chloride in the Water Samples

Quality of water is relatively better with respect to the presence of chloride. Runoff samples from all the canyons contain chloride below the SMCL except that it is higher in samples collected from McCoy Canyon (SM1) (Fig. 24). The concentrations also meet the L.A. basin plan objective for three canyons as shown in the Figure 24. Hence the chloride concentration doesn't hamper the beneficial use of water for groundwater recharge.

Total Dissolved Solids

The Total Dissolved Solid (TDS) is a measure of all constituents dissolved in water. The principal inorganic anions dissolved in water include carbonates, chlorides, sulfates and nitrates. The principal cations are sodium, potassium, calcium and magnesium.

Dissolved-solids values often are used to compute rates at which rivers transport weathering products to the ocean and to compute the rate at which rock weathering is lowering the land surface. It is an interesting fact, however, that a considerable part of the dissolved-solids load of a stream draining an igneous terrain represents bicarbonate ions that were derived from the atmosphere rather than from rocks. The value of dissolved solid depends on the concentration of ion and on water temperature (Hem, 1985).

In regions of high rainfall and relatively insoluble rocks, dissolved-solids concentrations in runoff may be as low as 25 mg/L. Saturated sodium chloride brine, on the other hand, may contain more than 300,000 mg/L (Hem, 1985). The safe limit (SMCL) of dissolved solid has been established as 500mg/L.

The study area is a region of low annual rainfall and consists of relatively water soluble rocks such as sandstone, shale, and conglomerate so the higher concentration of TDS is reasonable. During the year round monitoring, four canyons, Dry, McCoy, Devils and Browns East were found to be exceeding L A. basin plan objective of 800mg/L for TDS (Fig 25). In the Lower Browns Canyon (SS17) and Limekiln Canyon (SS4), TDS was found to be lower, meeting the basin plan objective and also below SMCL in some water samples. The highest concentration of TDS for Dry Canyon (SM2) was 2900 mg/L. The water of the canyons exceeding the basin plan objective need to be treated before using them as recharge water.

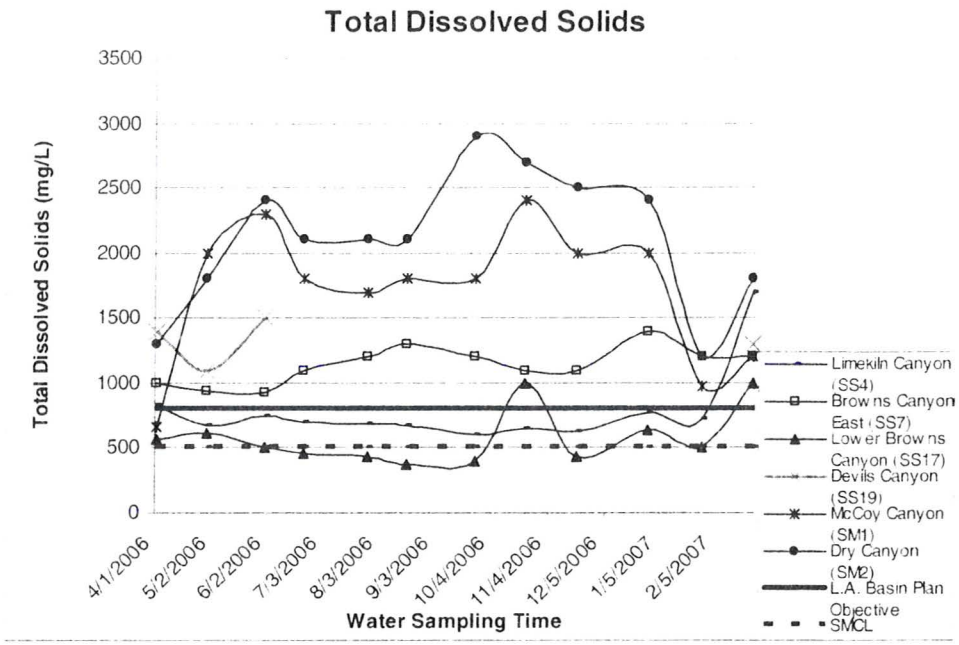

Figure 25: Concentration of TDS in the Water Samples

Copper

Copper may occur in the Earth's crust as the free native metal. It may be dissolved from water pipes and plumbing fixtures, especially by water whose pH is below 7. Copper salts are sometimes purposely added in small amounts to water-supply reservoirs to suppress the growth of algae (Hem, 1985). Organic and inorganic compounds of copper have been used extensively in agricultural pesticide sprays. The element is therefore likely to be more readily available for solution in surface and ground water than its low average abundance in rocks might imply.

Copper may be present in concentrations as great as a few hundred mg/L in acid drainage from metal mines. When the acidity of such solutions is neutralized, the copper is mostly precipitated. Levels of copper found naturally in ground water and surface water are generally very low: about 0.004 milligrams of copper in one liter of water (0.004 mg/L)

or less (Hem, 1985). Copper is a regulated metal by the EPA and its MCL is 1.3mg/L (Fig 26). The concentrations of copper in all the samples during the entire monitoring time were well below the MCL.

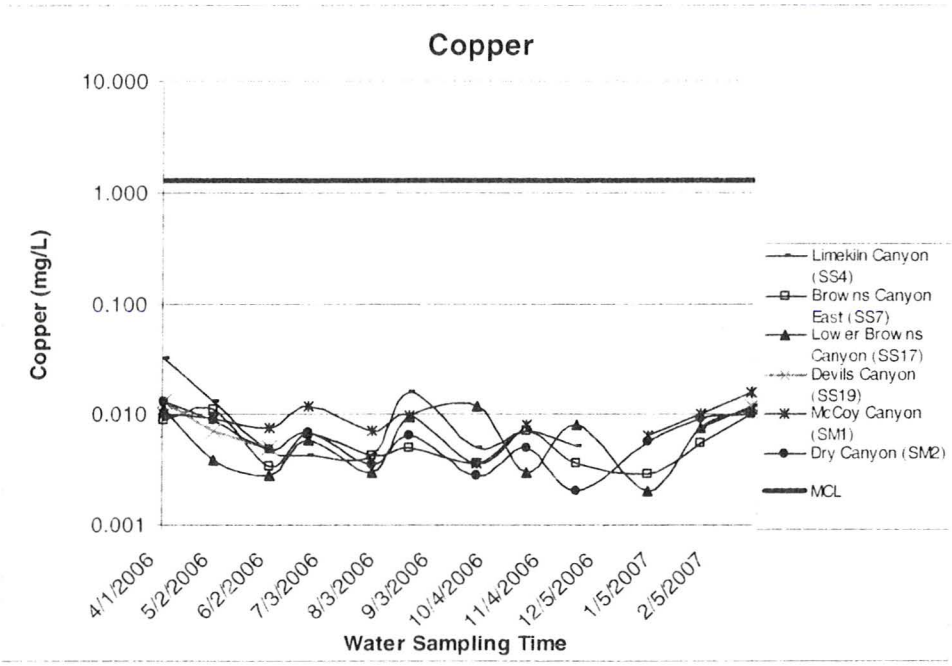

Figure 26: Concentration of Copper in the Water Samples

Boron

The most widely distributed mineral of igneous rocks in which boron is an essential constituent is tourmaline. This mineral is highly resistant to chemical attack and may appear in resistant sediments as well as in original igneous rock (Hem, 1985). Boron, however, also may be present as an accessory constituent of biotite and amphibole.

Evaporite deposits of certain closed basins, especially in southeastern California, contain considerable amounts of boron and constitute ores from which boron salts are extracted (Hem, 1985). The high boron content of water from thermal springs has been noted.

Boron in concentrations up to a few tenths of a milligram per liter can be expected in a good many types of surface and ground water.

The upper limit of boron concentration for Western San Fernando Basin is given as 1.5 mg/L in the Los Angeles Basin Plan. All the water samples collected from the study area have boron concentration within the limit for L.A. basin plan (Fig. 27). Hence the concentration of boron allows using the surface water of this area for groundwater recharge activities.

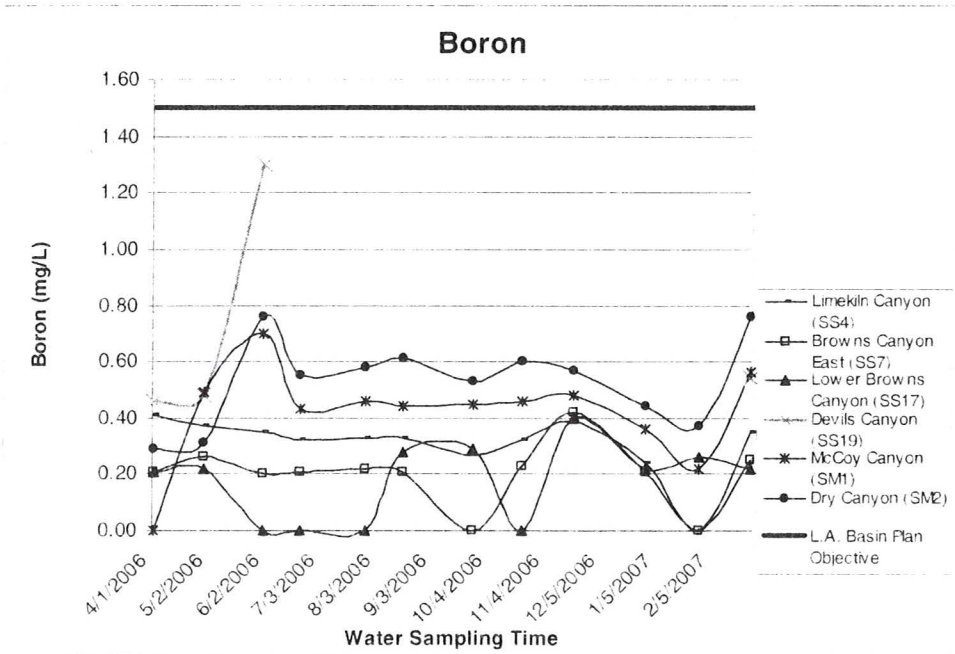

Figure 27: Concentration of Boron in the Water Samples

Fluoride

Fluoride has a rather low solubility and occurs in both igneous and sedimentary rock. The concentration of fluoride in most natural water, which has a dissolved-solids concentration of less than 1,000 mg/L, is less than 1 mg/L (Hem, 1985).

Fluoride ions maybe present either naturally or artificially in drinking water and are absorbed to some degree in the bone structure of the body and tooth enamel. Fluoride at extremely high levels can cause mottling (discoloration) of the teeth. Some fluoride compounds may also cause corrosion of piping and other water treatment equipment. Natural fluorides occur in rocks in some areas. Another source of fluorides in streams and reservoirs is releases from sewage treatment plants, since most public water supplies add fluoride to drinking water to reduce dental decay (Hem, 1985).

The Water Quality Standards maximum for fluoride in streams is a concentration of 1 mg/L or 1 part per million. Higher levels may be harmful to aquatic life. Fluoride concentration in water to be used for domestic water supply should not exceed 1.0 mg/L. Fluoride is a regulated contaminant and it is recognized as primary as well as secondary contaminant by EPA for different level of concentrations. The concentration of >4 mg/L makes fluoride a primary contaminant and if it is >2 mg/L, fluoride will be treated as secondary contaminant. The concentration of fluoride in the study area is below 4mg/L (Fig. 28). Hence it is a secondary contaminant for this area and the fluoride concentration is higher than SMCL for samples collected from Dry Canyon and McCoy Canyon. Limekiln Canyon had a higher concentration of fluoride only once during the 12-month sampling period.

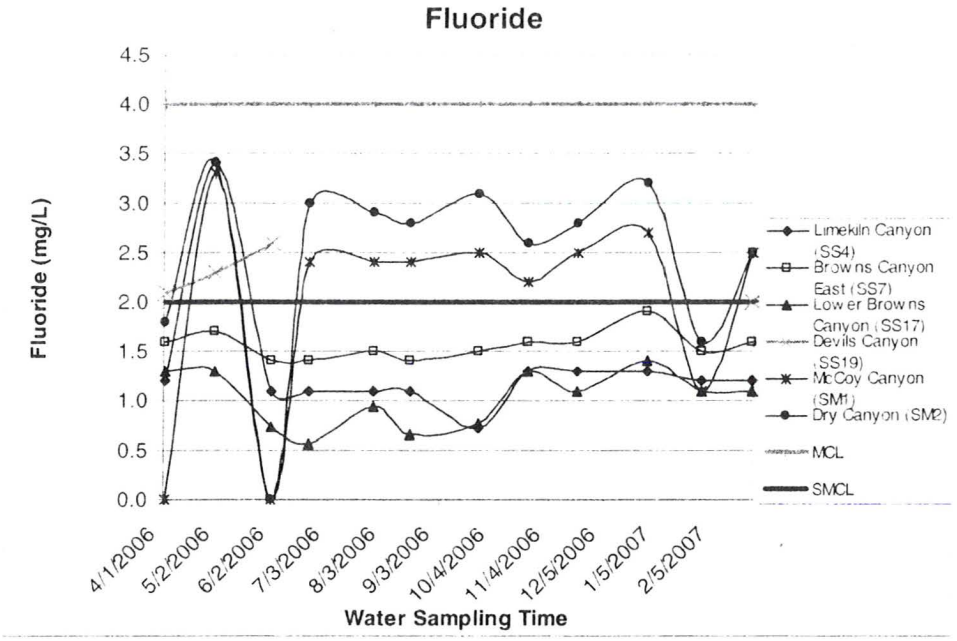

Figure 28: Concentration of Fluoride in the Water Samples

Nitrate and Nitrite

The occurrence of high nitrate concentrations in the majority of water sources is caused by leaching of irrigated soil which has nitrogen fertilizer. Limestone caves that are used for shelter by large numbers of bats may accumulate guano that serves as a nitrogen source to ground water in the vicinity (Hem, 1985).

Excessive concentrations of nitrites can produce a serious condition in fish called "brown blood disease." Nitrites also can react directly with hemoglobin in the blood of humans and other warm-blooded animals to produce methemoglobin (USEPA, 2003a). Methemoglobin destroys the ability of red blood cells to transport oxygen. This condition is especially serious in babies under three months of age. It causes a condition known as methemoglobinemia or "blue baby" disease. Water with nitrate levels exceeding 1.0 mg/L

should not be used for feeding babies. High nitrates in drinking water can cause digestive disturbances in people. Nitrite/nitrogen levels below 90 mg/L and nitrate levels below 0.5 mg/L seem to have no affect on warm water fish.

The major impact of nitrates/nitrites on fresh water bodies is that of enrichment or fertilization called eutrophication. Nitrates stimulate the growth of algae and other plankton which provide food for higher organisms (invertebrates and fish); however an excess of nitrogen can cause over-production of plankton, and as they die and decompose they use up the oxygen which causes other oxygen-dependent organisms to die (Hem, 1985).

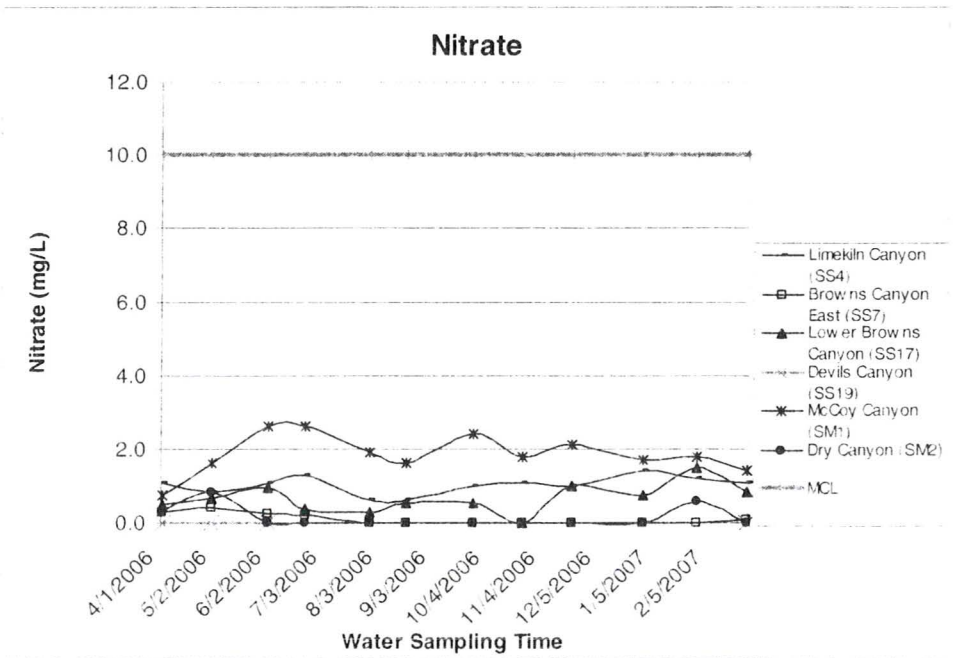

Figure 29: Concentration of Nitrate in the Water Samples

Nitrates should remain below 10 mg/L in water to be used as a domestic water supply as guided by EPA as a primary contaminant. As shown in the Fig. 29 the concentration of nitrate is within the EPA guidelines through out the year for all the monitoring sites.

The MCL for nitrite is given by EPA as 1mg/L. The nitrite values obtained from the lab were provided as less than numbers (e.g. < 0.5) rather than the absolute values. Hence those less then values are plotted in the graph (Fig. 30, the data symbol signifies < values) which shows that values for McCoy Canyon (SM1) and Dry Canyon (SM2) are above the safe limit for most of the year. The values are higher for Browns Canyon East (SS7) during the later period of the monitoring. Nitrite above the MCL in the water of McCoy, Dry and Browns East canyons could hamper the beneficial use of this water for artificial recharge purpose.

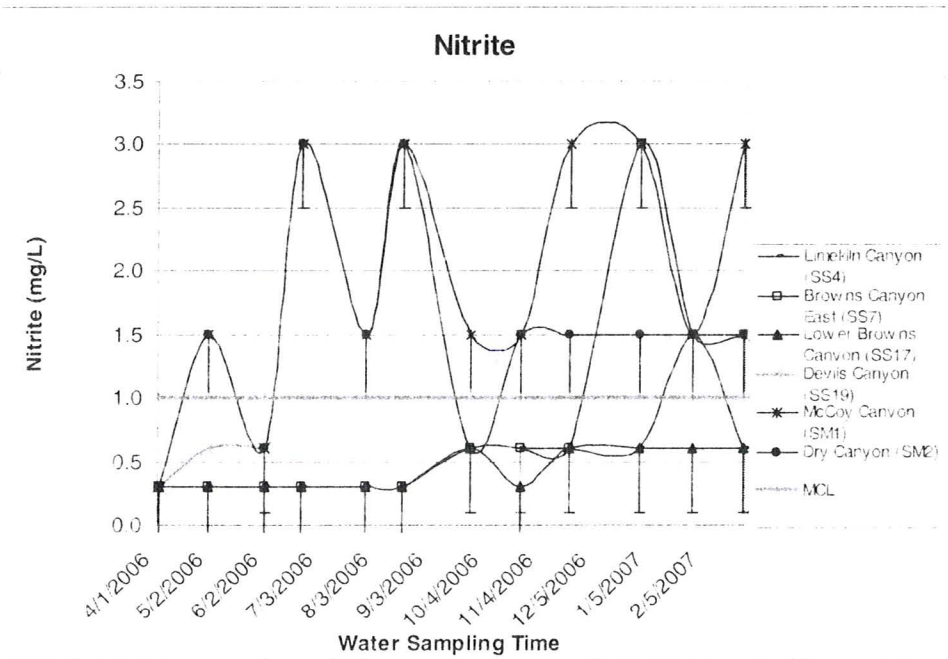

Figure 30: Concentration of Nitrite in the Water Samples

pH

The effective concentration (activity) of hydrogen ions could be expressed in the same kinds of units as other dissolved species, but H' concentrations in milligrams per liter or moles per liter are very low for water solutions that are not strongly acid. The activity of hydrogen ions can be expressed most conveniently in logarithmic units, and the abbreviation "pH" represents the negative base-10 log of the hydrogen-ion activity in moles per liter. The pH of pure water at 25°C is 7.00 (Hem, 1985).

River water in areas not influenced by pollution generally has a pH in the range 6.5 to 8.5., but water having lower pH is not uncommon in thermal springs. Water having a pH much greater than 9.0 is unusual but by no means unknown. Higher pH values have been observed in springs and were ascribed to reactions of meteoric water with ultramafic rock in which serpentinite was produced (Hem, 1985). pH is a regulated contaminant and its SMCL is defined as 6.5-8.5. The water samples collected from all the monitoring sites are within the safe limit as shown in the Figure 31.

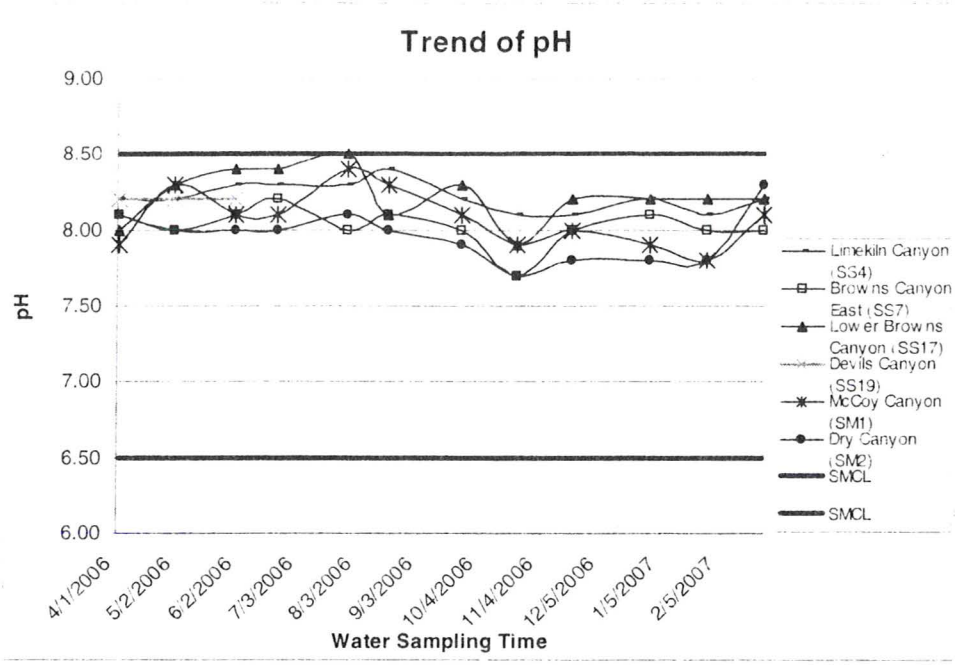

Figure 31: Trend of pH in the Water Samples

Alkalinity

The alkalinity of a solution may be defined as the capacity for solutes it contains to react with and neutralize acid. In almost all natural waters, the alkalinity is produced by the dissolved carbon dioxide species, bicarbonate and carbonate. The principal source of carbon dioxide species that produce alkalinity in surface or ground water is the CO_2 gas fraction of the atmosphere, or the atmospheric gases present in the soil or in the unsaturated zone lying between the surface of the land and the water table. Possible major local sources include biologically mediated sulfate reduction and metamorphism of carbonate rocks (Hem, 1985).

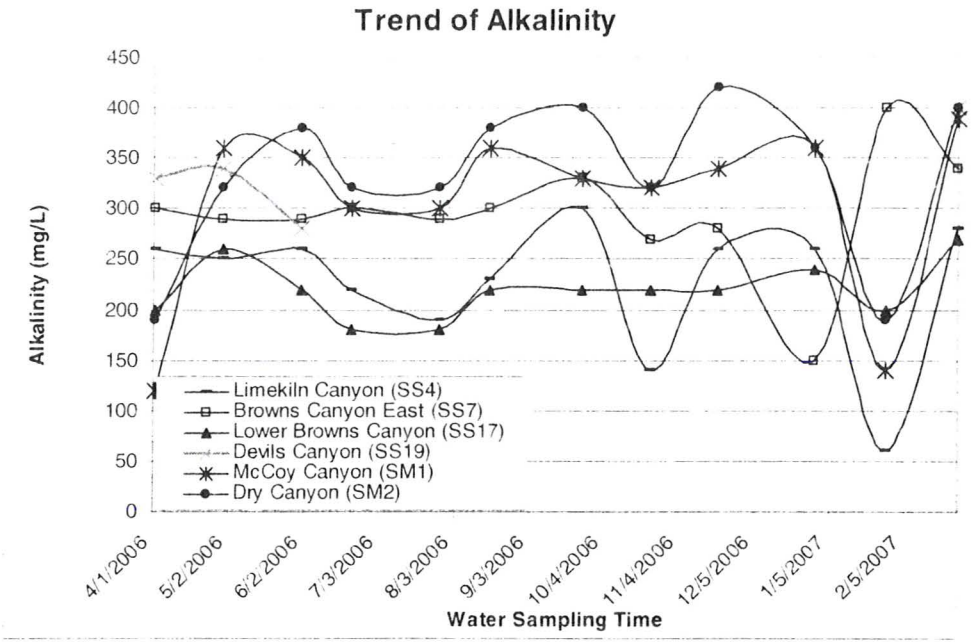

Figure 32: Trend of Alkalinity in the Water Samples

Most surface streams contain alkalinity less than 200 mg/L, but in ground waters somewhat higher concentrations are not uncommon. Concentrations over 1,000 mg/L occur in some waters that are low in calcium and magnesium, especially where processes releasing carbon dioxide (such as sulfate reduction) are occurring in the ground-water reservoir. For protection of aquatic life the buffering capacity should be at least 20 mg/L (Hem, 1985).

The alkalinity reported here is the bicarbonate alkalinity. The result shows that alkalinity of the canyon water shows a decrease during summer which is followed by cycles of increase and decrease. (Fig. 32). Dry Canyon (SM1) has the higher values of alkalinity and Lower Browns Canyon has the lower values.

6. GEOLOGIC LOG INTERPRETATION

The lithologic well log data used here for acquiring the subsurface geologic information are derived from pre-existing logs on file with Los Angeles County Department of Public Works (LACDPW) and Department of Water Resources (DWR). There are abundant well with geologic log data in the study area but obtaining the data was challenging and limited; old data which are available to public have been used here.

Selection of suitable site and recharge method depends primarily on the subsurface geology. Geologic details are essential for the recharge well method as well as for other methods like spreading basin and recharge pits. Successful operation of a groundwater recharge project is possible only when units which can store and transmit water such as sand and gravel are present in the subsurface area.

Individual well logs presented here, were constructed from drill core and illustrate major zonations, lithology and water bearing strata. Three lithological logs are used for the interpretation of the subsurface geology. These logs were drilled in the Santa Susana Mountains, Simi Hills and Santa Monica Mountains areas (Fig. 33). In general the underground geology of Santa Monica Mountains seems to be less suitable for groundwater storage whereas the Simi Hills and Santa Susana Mountains study areas have material with higher transmissivity and hydraulic conductivity.

Please note that the geologic logs presented here are located in the vicinity of the sites but they do not precisely represent the subsurface geology of these sites. These logs can

provide only a rough estimation of subsurface geology of monitoring sites. Only onsite drilling can provide exact geological detail of these sites.

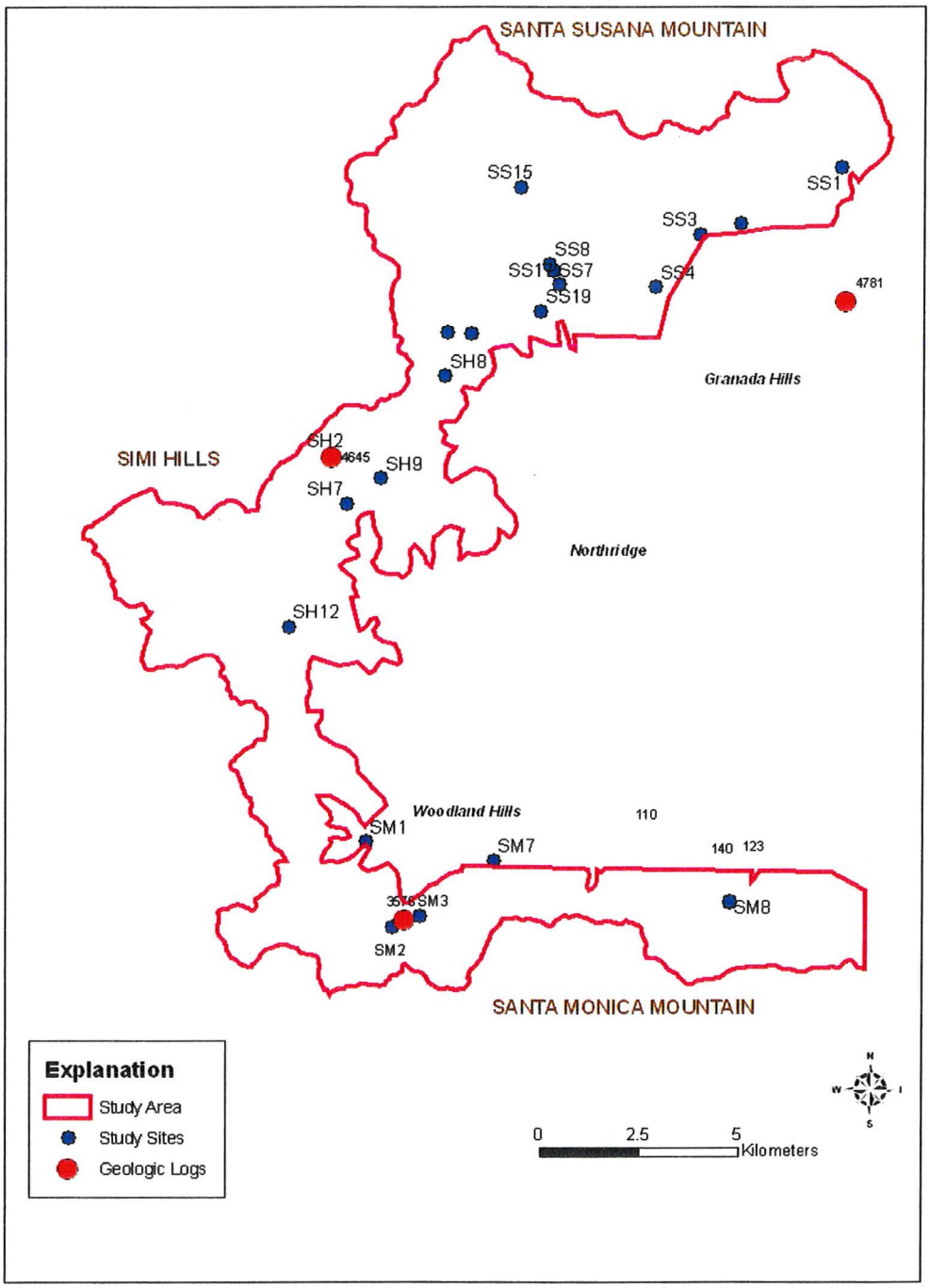

Figure 33: Location of Lithologic Logs used to examine the Subsurface Geology (Base Map: Modified After LACDWP, 1966 & MRT Geodatabase).

Santa Monica Mountains Area

The lithologic log in Fig. 34 is derived from a well drilled in the Santa Monica Mountains study area. The site is drilled up to depth of 62.8ft. The major lithology present at this drill site is shale, which is not a suitable unit for groundwater storage. A small unit of sandstone of thickness 2.13 is located at the depth of 18.6m. Another unit of boulder is present at a depth of 5.8m but this unit is too thin to act as an aquifer. Hence the most suitable unit for surface water storage is the fine blue sandstone but the thickness and extent of this unit should be examined well before considering any artificial method of recharge. Water table was not found through the entire drilled depth and also no water-bearing strata were observed.

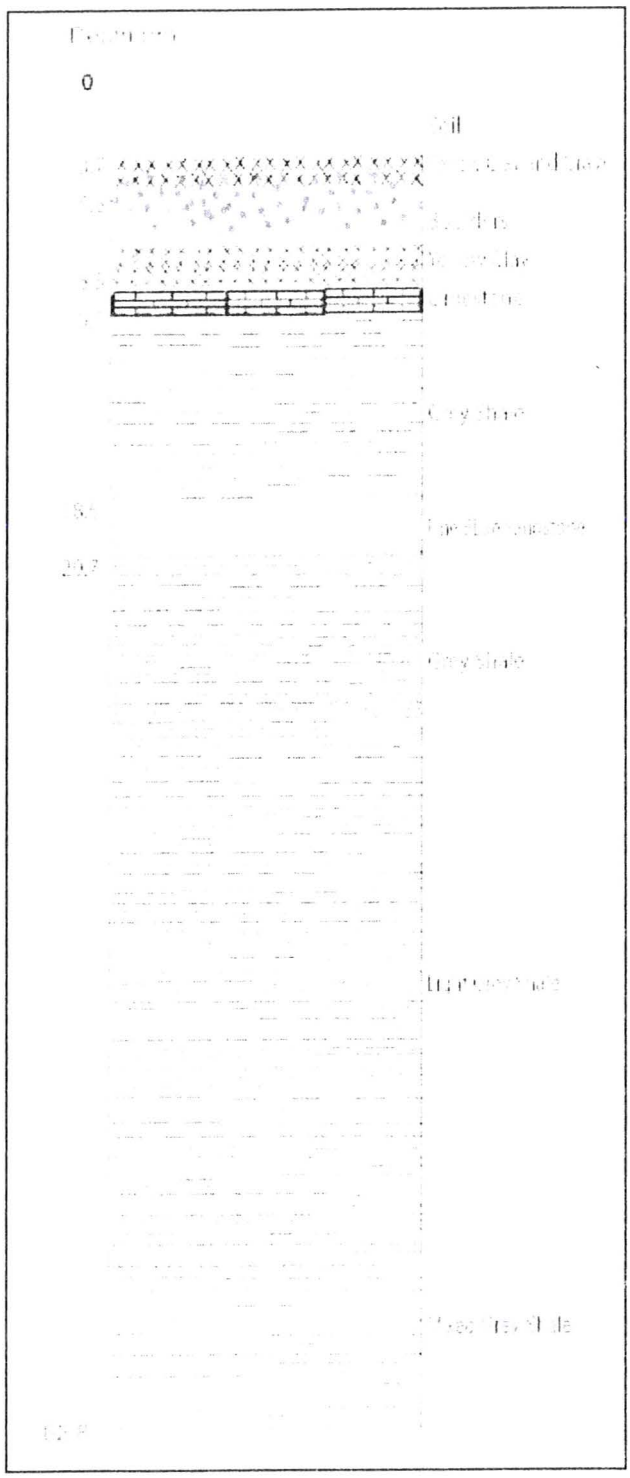

Figure 34: Geologic Log Describing the Geology of Santa Monica Mountains Area in the Vicinity of McCoy Canyon Site.

This well log which represents the subsurface geology of McCoy and Dry Canyons suggest that storage of small amount of water is possible but provides no direct way to recharge the deeper aquifer of San Fernando Basin.

Santa Susana Mountains Area

The well log data from Santa Susana Mountains area (Fig. 35) suggests better opportunity for artificial recharge as there are numerous permeable units present. This lithologic log represents the geology of Aliso, Bee and Limekiln Canyons site study area sites. The top layer consists of clay 15.24m thick which avert the possibility of using direct method of recharge like spreading basin and recharge pits. There are no water bearing strata present but the alternating layering of good aquifer material (coarse sand, conglomerate, sand and gravel) offers an opportunity to store water in these units.

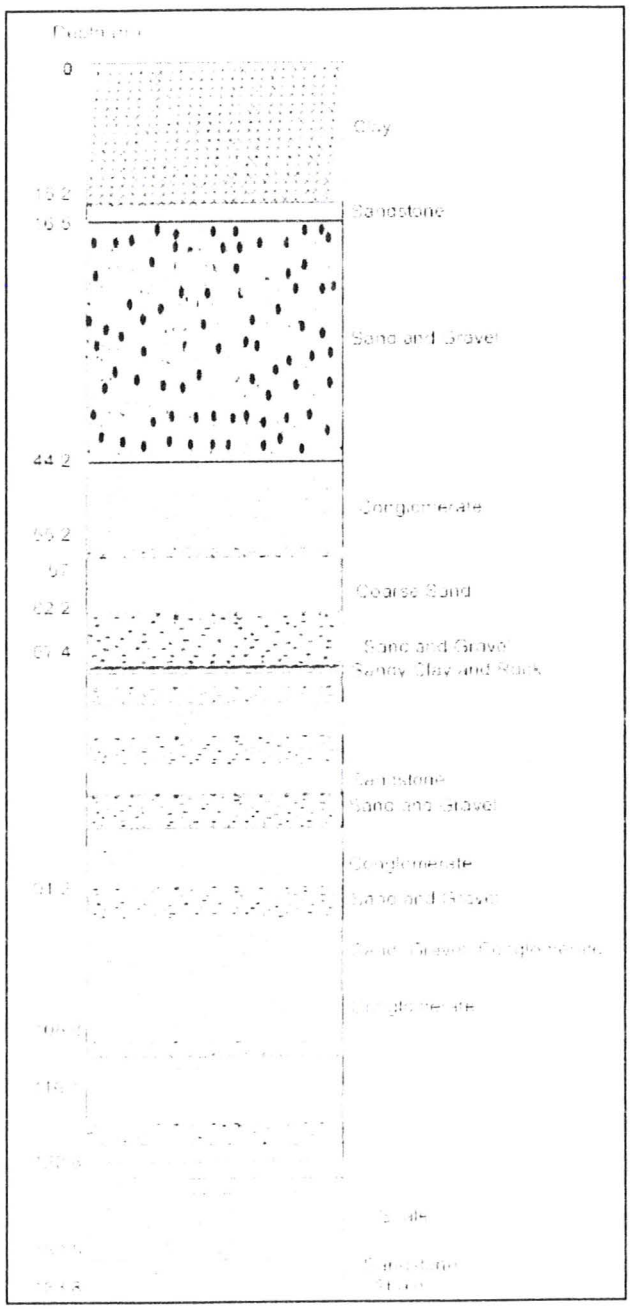

Figure 35: Geologic Log Describing the Geology of Santa Susana Mountains Area.

The unit that is adjacent to surface and have potential of storing water is present at the depth of 15.24m. There are many layers of sand, gravel and conglomerate up to the depth of 122.8m. Hence all of these units offer better prospective to store surface water.

Simi Hills Area

The subsurface geologic information of the Simi Hills sites is provided by the lithologic log in Figure 36. This well log provides the lithological details up to the depth of 126.5m. There are many water-bearing units at this site. First suitable unit, sandstone, is located adjacent to surface at a depth of 1.5m.

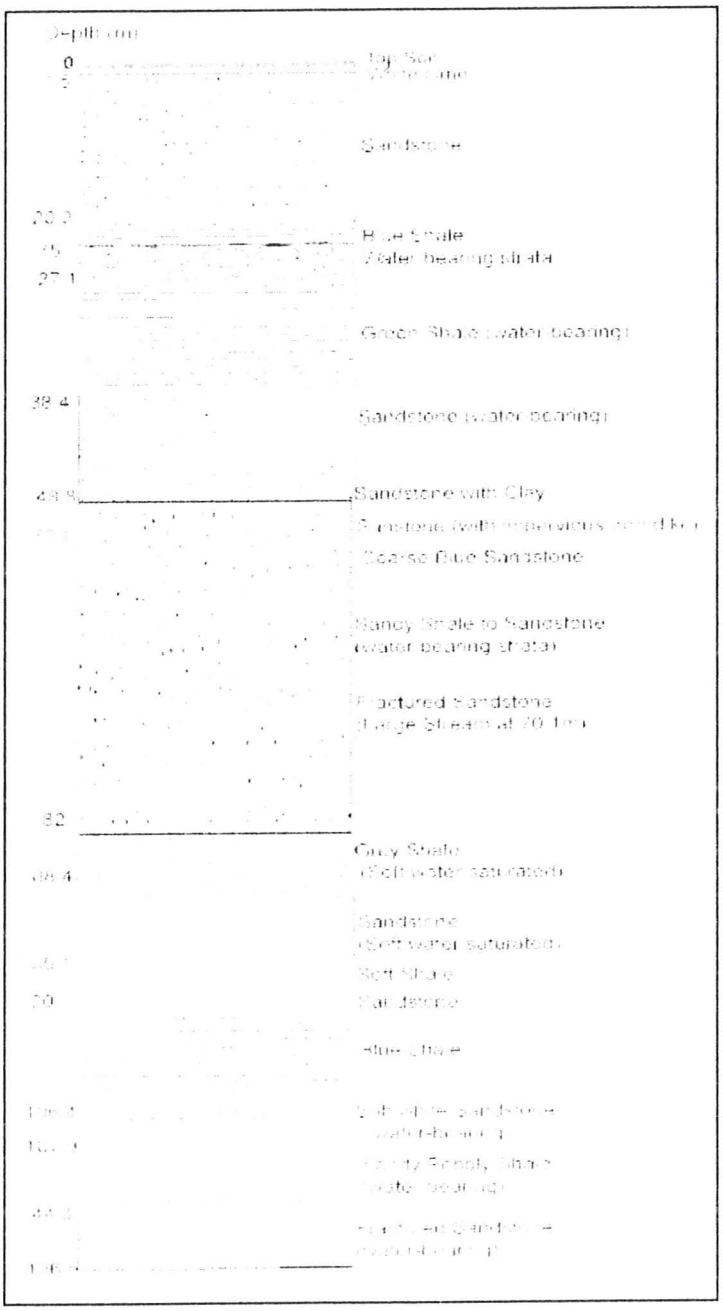

Figure 36: Geologic Log Describing the Geology of Simi Hills Area in the Vicinity of Box and Woolsey Canyon Sites.

Furthermore the lithological log reports the presence of underground stream at the depth of 70.1m, in fractured greystone, or quartz sandstone. Hence this site is very suitable to operate aquifer storage and recovery well, provided that surface water is available for storage. This site is located in the vicinity of Box Canyon, which is an intermittent stream and has very low seasonal flow.

7. OVERVIEW OF ARTIFICIAL RECHARGE METHODS AND PHENOMENA

Stated simply, artificial recharge is a process by which excess surface water is directed into the ground – either by spreading on the surface, by using recharge wells, or by altering natural conditions to increase infiltration – to replenish an aquifer. It refers to the movement of water through man-made systems from the surface of the earth to underground water-bearing strata where it may be stored for future use. Artificial recharge (sometimes called planned recharge) is a way to store water underground in times of water surplus to meet demand in times of shortage. Groundwater recharge may also be used to mitigate or control saltwater intrusion into coastal aquifers.

Factors to Consider for Artificial Recharge

Artificial recharge is a complex phenomenon, cutting across many disciplines and a number of factors play key roles. The major factors that govern artificial recharge site selection are in Table 13. The present study is a geological approach to artificial recharge site selection. Hydrogeologic properties of soil, quality and quantity of recharge water were discussed in previous sections. This section of the report focuses on identifying the potentially suitable recharge method. The legal/institutional constraints, cost and cultural/social considerations of groundwater recharge project are beyond the scope of this study.

Table 13: Research Inventory for Artificial Recharge Site Selection (O'Hare et. al., 1986).

1.	Availability of water
2.	Quantity of source water available
3.	Quality of source water available
4.	Resulting water quality (reactions with native water and aquifer materials)
5.	Clogging potential
6.	Underground storage space available
7.	Depth to underground storage space
8.	Transmission characteristics
9.	Topography/applicable methods (injection or infiltration)
10.	Legal/institutional constraints
11.	Costs
12.	Cultural/social considerations

Methods of Artificial Recharge

Direct Artificial Recharge

Spreading basins

This method involves surface spreading of water in basins that are excavated in the existing terrain. For effective artificial recharge highly permeable soils are suitable and maintenance of a layer of water over the highly permeable soils is necessary. When direct discharge is practiced, the amount of water entering the aquifer depends on three factors - the infiltration rate, the percolation rate, and the capacity for horizontal water movement (O'Hare et. al. 1986).

In a homogenous aquifer the infiltration rate is equal to the percolation rate. At the surface of the aquifer however, clogging occurs by deposition of particles carried by

water in suspension or in solution, by algal growth, colloidal swelling and soil dispersion, microbial activity etc. Recharge by spreading basins is most effective where there are no impending layers between the land surface and the aquifer and where clear water is available for recharge; however, more turbid water can be tolerated than with well recharge. The common problem in recharging by surface spreading is clogging of the surface material by suspended sediment in the recharge water or by microbial growth. In coarse grained materials removal of fine suspended sediment is difficult (O'Hare et. al. 1986).

Infiltration tests carried out in potentially suitable sites in the study area showed that the rates are generally high for the short term test. However, subsurface geology, a major governing factor for the successful operation of spreading basins, seems to be unfavorable. The analysis of the geologic logs in the vicinity of the potential sites indicated the presence of impermeable layers. Hence this method is not recommended for any of the study sites.

Recharge Pits and Shafts

Conditions that permit surface spreading methods for artificial recharge are relatively rare and this applies to the present study area as well. Often lenses of low permeability lie between the land surface and water table. In such situations artificial recharge systems such as pits and shafts could be effective to penetrate the less permeable strata in order to access the dewatered aquifer. The rate of recharge has been found to increase as the side slopes of the pits increased (O'Hare et. al. 1986).

Unfiltered runoff water leaves a thin film of sediment on the sides and bottom of the pits which requires maintenance in order to sustain high recharge rates. Shafts may be circular, rectangular, or of square in cross-section and may be backfilled with porous material. Excavation may terminate above the water table level or may be hydraulic connectors and extend below the water table. Recharge rates in both shafts and pits may decrease with time due to accumulation of fine grained materials and the plugging effect brought about by microbial activity (O'Hare et. al. 1986).

It is likely that this method can be adopted for at least one of the study sites, Devils Canyon (SS19), where the infiltration rate is moderate. Subsurface geology is not confirmed at this site but the presence of impermeable layers has been reported (USDA, 1980). Before implementation of this method, drilling of the site is warranted.

Aquifer Storage and Recovery (ASR) Wells

Aquifer storage and recovery is a technique whereby freshwater is pumped into an aquifer through a well, the pumped water is stored in aquifer material and ultimately is recovered from the aquifer by pumping it out through the same well or by a nearby well. It is a relatively new and rapidly-spreading practice in artificial recharges, which are a combination of recharge and pumped wells. They are used for recharge when surplus water is available and for pumping when the water is needed (O'Hare et. al. 1986).

ASR wells typically are used for seasonal storage of water in areas where water demands are much greater in summer than in winter, and where surface storage of water is not

possible or is too expensive. In the study area availability of surface water is significantly high during winter and the many of the canyons dried out partially to completely during summer. The winter surplus is then stored underground with ASR wells, which are pumped in summer to augment production from the water-treatment plant. ASR wells make it possible to design and operate water-treatment plants for mean daily demand (O'Hare et. al. 1986).

The site SS4 (Limekiln Canyon) is the most suitable for using the ASR method. The geologic log data available in the vicinity of the site suggest the presence of an impermeable clay layer near the surface unto the depth of 16.5m and sand and gravel material from the depth of 16.5m to 44.2m. The material beneath this unit is also composed of ideal aquifer materials such as conglomerate, sand, gravel and boulder up to the depth of 122.8m besides few thin impermeable clay and rock layers. Even though groundwater is not present, these units are the most suitable aquifer material to store the water available in the Limekiln Canyon, especially during the winter, when the flow is much higher.

Indirect Artificial Recharge

Conjunctive Wells

A conjunctive well is one that is screened in both a shallow confined aquifer and a deeper artesian aquifer. Water is pumped from the deeper aquifer and if its potentiometric surface is lowered below the shallow water table, water from the shallow aquifer drains directly into the deeper aquifer (O'Hare et. al. 1986).

The study area is located on the foothills of mountain, so the depth to water table is higher. According to the geologic log data, no distinct aquifer is present in the study area. For these reasons method of using conjunctive well is not recommend for the study area.

Enhanced Streambed Infiltration (Induced Infiltration)

This method of induced recharge consists of setting a gallery or a line of wells parallel to the bank of a river and at a short distance from it. Without the wells there would be unimpeded outflow of groundwater to the river. When small amounts of groundwater are withdrawn from the gallery parallel to the river, the amount of groundwater discharged into the river decreases. The water recovered by the gallery consists wholly of natural groundwater. Each groundwater withdrawal is accompanied by a drawdown in the water table. Thus, surface water from the river will be induced to enter the aquifer and to flow into the gallery (O'Hare et. al. 1986).

As the study area is located in the semi-arid area, the flow in the canyons during the summer is essentially groundwater. Many canyons such as McCoy (SM1), Dry Canyon (SM2), Dry Canyon Southfork (SM3), Santa Susana Wash (SH6), and Browns Canyons have runoff also during summer. Parts of the water in those canyons are lost by evaporation due to the extreme heat of summer. In this background, adopting enhanced streambed infiltration method is very useful to preserve the existing groundwater in the sites as stated earlier. One of the constrains for adopting this method, could be the high urban development in the Santa Monica Mountains area. More study is required to ascertain the landuse and landownership before implementing this method.

8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The flow data that were collected in this study suggest that Lower Limekiln Canyon in the Santa Susana Mountains and the McCoy and Dry Canyons in the Santa Monica Mountains would be better candidates for an enhanced recharge project. Devils Canyon, an intermittent stream, which has higher flow rates during winter, also offers better opportunity for artificial recharge activities with its larger undeveloped area, gentler slope and alluvial fan type structure.

Infiltration tests that were conducted in four different sites in two seasons illustrate that the Lower Browns Canyon (SS17) and Lower Limekiln Canyon (SS4) soils have the higher rates of infiltration, 52.5cm/hr and 63.2cm/hr, respectively. The infiltration rates were lowest for Browns Canyon East (SS7) with 4.3cm/hr because the moisture content was higher. The infiltration rates obtained during this study were much higher when compared to the rates from the successfully operated spreading grounds like Pacoima and Tujunga. The reason for such a difference is likely to be the short term infiltration rate of present study as compared to the long term and continuous infiltration rate of spreading basins.

The water samples collected during a twelve-month period suggest that some of their chemical constituents do not meet the state water quality standards. The water samples of McCoy and Dry Canyons have higher concentrations of sulfate, TDS, chloride, calcium and nitrite. In a few samples collected from Lower Limekiln and McCoy

Canyons, concentration of selenium was higher than the California Toxic Rules (CTR). In one sample collected from Lower Limekiln Canyon and Browns Canyon East, nitrite concentration was higher than the Maximum Contaminant Level (MCL). It is suggested that the surface water of these canyons should be treated with appropriate and updated technology prior to using them as recharge water.

Subsurface geology information obtained from available well log data suggests the presence of thicker sand and gravel units in the Simi Hills and the Santa Susana Mountains area. These sand and gravel units offer better opportunity to execute aquifer storage and recovery (ASR) projects. Few and scattered well log data prevented better characterization of subsurface geology and identification of suitable artificial recharge technology.

Recommendations

Present study opens and expands the avenue of research on different components of artificial recharge projects in the San Fernando Valley area. The water quality monitoring scheme for artificial recharge activities initiated in this study could be expanded to include other constituents regulated by U.S. Environmental Protection Agency such as microorganism, disinfectants, disinfection byproducts, organic chemicals and radionuclides. If any of these appeared in high concentration, conclusion from this study would be reversed.

There is no better option than onsite drilling to get precise information on subsurface geology to ascertain the depth and availability of underground storage space and transmission characteristics of subsurface soil. If onsite drilling will give information on subsurface geology different than available lithologic log data, the recommended artificial recharge method would be entirely different or the possibility of artificial recharge might be overturned.

Discharge data during rain events and the associated water quality data could give better insight in terms of water quantity and quality available for artificial recharge activities. More site specific data on the transmission characteristics of vadose zone such as percolation, permeability and hydraulic conductivity could guide an investigator to identify the most suitable artificial recharge method. Significant concentration of chemical constituents during rain events, even higher concentration of TDS and/or slow water transmission rates would reverse the conclusion from this study.

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Appendix A

Grain Size Analysis Data

Site- Lower Limekiln Canyon (SS4)

Sieve No	Diameter (mm)	Wt. Retained (gm)	% Retained	% Retained Cumulative	Cum % Passing
3/4"	19	0.0	0.00%	0.00%	100.00%
3/8"	9.5	49.0	9.81%	9.81%	90.19%
5	4	103.7	20.75%	20.75%	79.25%
10	2	44.9	8.97%	29.72%	70.28%
40	0.42	126.3	25.27%	54.99%	45.01%
60	0.25	63.9	12.78%	67.77%	32.23%
100	0.149	66.5	13.29%	81.06%	18.94%
200	0.074	50.5	10.10%	91.17%	8.83%
PAN	0.00	38.1	7.63%	98.79%	0%

Site- Browns Canyon East (SS7)

Sieve No	Diameter (mm)	Wt. Retained (gm)	% Retained	% Retained Cumulative	Cum % Passing
3/4"	19	0.00	0.00%	0.00%	100%
3/8"	9.5	35.04	7.01%	7.01%	92.99%
#4	4.75	37.74	7.55%	14.56%	85.44%
#8	2.36	49.87	9.97%	24.53%	75.47%
#16	1.18	94.34	18.87%	43.40%	56.60%
#30	0.6	115.90	23.18%	66.58%	33.42%
#50	0.3	106.47	21.29%	87.87%	12.13%
#100	0.15	48.52	9.70%	97.57%	2.43%
#200	0.075	12.13	2.43%	100.00%	0.00%
pass	0.00	0.00	0.00%	100.00%	0.00%

Site-Lower Browns Canyon (SS17)

Sieve No	Diameter (mm)	Wt. Retained (gm)	% Retained	% Retained Cumulative	Cum % Passing
3/4"	19	0.0	0.00%	0.00%	100.00%
3/8"	9.5	20.0	4.01%	4.01%	95.99%
5	4	63.7	12.75%	12.75%	87.25%
10	2	49.9	9.97%	22.72%	77.28%
40	0.42	250.3	50.07%	72.79%	27.21%
60	0.25	55.9	11.18%	83.97%	16.03%
100	0.149	30.5	6.09%	90.06%	9.94%
200	0.074	17.5	3.50%	93.57%	6.43%
PAN	0.00	12.1	2.43%	95.99%	0.00%

Site-Devils Canyon (SS19)

Sieve No	Diameter (mm)	Wt. Retained (gm)	% Retained	% Retained Cumulative	Cum % Passing
3/4"	19	0	0.00%	0.00%	100.00%
3/8"	9.5	0	0.00%	0.00%	100.00%
5	4	5.3	1.06%	1.06%	98.94%
10	2	10.7	2.13%	3.19%	96.81%
40	0.42	75.4	15.08%	18.27%	81.73%
60	0.25	194.4	38.88%	57.16%	42.84%
100	0.149	133.6	26.72%	83.87%	16.13%
200	0.074	66.8	13.36%	97.24%	2.76%
PAN	0.00	13.8	2.76%	100.00%	0.00%

Appendix B

Infiltration Test Data

Site- Lower Limekiln Canyon (SS4)

Dry Weather

Time (minute) Elapsed	Depth(cm)	Time Cumulative (minute)	Infiltration rate (cm/hr)	F_p (cm/hr)
2.00	7.00	2.00	210.00	210.01
1.80	3.50	3.80	116.67	193.84
3.70	7.00	7.50	113.51	165.98
1.93	3.50	9.43	108.81	153.89
3.25	7.00	12.68	129.23	136.66
2.97	3.50	15.65	70.71	123.80
3.80	7.00	19.45	110.53	110.56
2.73	7.00	22.18	153.85	102.88
4.15	7.00	26.33	101.20	93.51
2.50	4.00	28.83	96.00	88.97
4.07	7.00	32.90	103.19	82.99
2.48	4.00	35.38	96.77	80.04
3.90	7.00	39.28	107.69	76.27
2.33	3.50	41.61	90.13	74.44
4.12	7.00	45.73	101.94	71.79
3.08	4.00	48.81	77.92	70.23
4.57	7.00	53.38	91.90	68.42
3.58	4.00	56.96	67.04	67.33
5.04	7.00	62.00	83.33	66.17
4.00	4.00	66.00	60.00	65.48
5.28	7.00	71.28	79.55	64.81
8.40	7.00	79.68	50.00	64.12
3.70	3.50	83.38	56.76	63.91
5.45	7.00	88.83	77.06	63.69
3.80	4.00	92.63	63.16	63.57

Site- Lower Limekiln Canyon (SS4)

Wet Weather

Time (minute) Elapsed	Depth(cm)	Time Cumulative (minute)	Infiltration rate (cm/hr)	F_p (cm/hr)
3.5	4	3.5	68.57	68.57
5	4	8.5	48.00	61.12
5.5	4	14	43.64	56.00
4.5	4	18.5	53.33	53.33
5	4	23.5	48.00	51.40
5	4	28.5	48.00	50.17
4.5	4	33	53.33	49.45
5	4	38	48.00	48.92
5.5	4	43.5	43.64	48.56
5	4	48.5	48.00	48.36
5	4	53.5	48.00	48.23
5.5	4	59	43.64	48.14
6	4	65	40.00	48.08
5	4	70	48.00	48.05
6	4	76	40.00	48.03
6	4	82	40.00	48.02
5	4	87	48.00	48.01
5	4	92	48.00	48.01

Site- Browns Canyon East (SS7)

Dry Weather

Time (minute) Elapsed	Depth(cm)	Time Cumulative (minute)	Infiltration rate (cm/hr)	F_p (cm/hr)
12.75	2	12.75	9.41	9.41
21.83	2	34.58	5.50	5.60
26.42	2	61	4.54	4.54
27	2	88	4.44	4.34
14	1	102	4.29	4.31
14	1	116	4.29	4.30

Site-Lower Browns Canyon (SS17)

Wet Weather

Time (minute) Elapsed	Depth(cm)	Time Cumulative (minute)	Infiltration rate (cm/hr)	F_p (cm/hr)
1	7	1	420.00	420.00
1	7	2	420.00	350.09
1.5	7	3.5	280.00	269.35
2	7	5.5	210.00	194.70
3.5	7	9	120.00	120.45
4	7	13	105.00	81.72
4.5	7	17.5	93.33	63.80
5	7	22.5	84.00	56.44
5.5	7	28	76.36	53.73
7	7	35	60.00	52.78
8	7	43	52.50	52.55
8	7	51	52.50	52.51
8.5	7	59.5	49.41	52.50
8	7	67.5	52.50	52.50

Site-Devils Canyon (SS19)

Wet Weather

Time (min) Elapsed	Depth(cm)	Time Cumulative (min)	Infiltration rate (cm/hr)	F_p (cm/hr)
5	4.8	5	57.60	57.60
6	4.8	11	48.00	47.99
7	4.8	18	41.14	45.13
6	4.8	24	48.00	44.54
6.5	4.8	30.5	44.31	44.37
7	4.8	37.5	41.14	44.32
6	4.8	43.5	48.00	44.31
7	4.8	50.5	41.14	44.31
6.5	4.8	57	44.31	44.31
6.5	4.8	63.5	44.31	44.31
6.5	4.8	70	44.31	44.31
6.5	4.8	76.5	44.31	44.31

Site-Devils Canyon (SS19)

Dry Weather

Time (min) Elapsed	Depth(cm)	Time Cumulative (min)	Infiltration rate (cm/hr)	F_p (cm/hr)
2.22	4.80	2.22	129.73	129.73
2.28	4.80	4.50	126.32	104.40
2.50	4.80	7.00	115.20	85.24
2.60	4.80	9.60	110.77	71.84
3.30	4.80	12.90	87.27	61.05
4.00	4.80	16.90	72.00	53.61
4.62	4.80	21.52	62.34	49.19
6.18	4.80	27.70	46.60	46.60
6.80	4.80	34.50	42.35	45.56
6.60	4.80	41.10	43.64	45.20
6.70	4.80	47.80	42.99	45.07
6.70	4.80	54.50	42.99	45.02
6.60	4.80	61.10	43.64	45.01
6.70	4.80	67.80	42.99	45.00
6.50	4.80	74.30	44.31	45.00
7.10	4.80	81.40	40.56	45.00
6.10	4.80	87.50	47.21	45.00
6.30	4.80	93.80	45.71	45.00
6.50	4.80	100.30	44.31	45.00
6.20	4.80	106.50	46.45	45.00
6.41	4.80	112.91	44.93	45.00
6.49	4.80	119.40	44.38	45.00
6.40	4.80	125.80	45.00	45.00
6.30	4.80	132.10	45.71	45.00
6.40	4.80	138.50	45.00	45.00

Appendix C-Water Quality Data

Site- Lower Limekiln Canyon (SS4)

Date	Date	3/31/06	4/28/06	5/30/06	6/20/06	7/26/06	8/16/06	9/23/06	10/21/06	11/18/06	12/28/06	1/27/07	2/25/07
Bicarbonate	mg/L	317.2	305	317.2	268.4	231.8	280.6	366	170.8	317.2	317.2	73.2	341.6
Alkalinity	mg/L	260	250	260	220	190	230	300	140	260	260	60	280
Calcium	mg/L	180	130	120	130	80	120	120	130	130	110	120	160
Magnesium	mg/L	43	34	30	30	19	27	28	30	26	24	27	37
Potassium	mg/L	4.4	3	3.7	2.1	2.2	2.9	1.8	4.2	3.9	3.2	3.7	1.9
Sodium	mg/L	57	66	49	44	43	49	60	44	57	43	53	39
Chloride	mg/L	70	55	85	69	66	74	79	72	69	80	69	69
Fluoride	mg/L	1.2	3.4	1.1	1.1	1.1	1.1	0.72	1.3	1.3	1.3	1.2	1.2
Nitrate	mg/L	1.1	0.85	1.1	1.3	0.64	0.62	1	1.1	0.99	1.4	1.2	1.1
Nitrite	mg/L	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.6	<0.6	<0.6	<0.6	<1.5	<0.6
Sulfate	mg/L	280	230	260	230	170	200	190	220	210	240	260	220
Dissolved Solids	mg/L	830	670	750	700	690	670	600	650	630	770	720	1700
Hardness	mg/L	570	530	500	490	360	550	410	440	520	490	480	580
Conductivity	µmho/cm	1100	1100	1100	1100	880	940	860	1000	960	1000	1000	1100
pH	pH	8.20	8.2	8.3	8.3	8.3	8.4	8.2	8.1	8.1	8.2	8.1	8.2
Arsenic	mg/L	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Boron	mg/L	0.41	0.37	0.35	0.32	0.33	0.33	0.27	0.32	0.39	0.24	< 0.2	0.35
Copper	mg/L	0.03	0.013	0.0046	0.0042	0.0042	0.016	0.0049	0.007	0.0052	< 0.002	0.0076	0.012
Iron	mg/L	1.20	0.075	0.26	0.39	0.18	0.27	0.29	< 0.05	< 0.05	< 0.05	< 0.05	0.38
Manganese	mg/L	< 0.05	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Selenium	mg/L	<0.005	0.012	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0068
Zinc	mg/L	0.085	0.076	< 0.05	< 0.05	< 0.05	0.084	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

NOTE- micromho per centimeter (µmho/cm) = microSiemen per centimeter (µS/cm)

Site-Browns Canyon Eastside (SS7)

Date	Date	3/31/06	4/28/06	5/30/06	6/20/06	7/26/06	8/16/06	9/23/06	10/21/06	11/18/06	12/28/06	1/27/07	2/25/07
Bicarbonate	mg/L	366	353.8	353.8	366	353.8	366	402.6	329.4	341.6	183	488	414.8
Alkalinity	mg/L	300	290	290	300	290	300	330	270	280	150	400	340
Calcium	mg/L	200	200	160	230	240	200	200	220	230	210	190	230
Magnesium	mg/L	56	56	47	65	62	52	49	57	50	57	50	62
Potassium	mg/L	4	2.6	3.3	2.4	2.4	2.8	2.1	3.4	3.9	6.6	3.1	2.8
Sodium	mg/L	72	73	59	59	61	72	98	84	91	67	76	62
Chloride	mg/L	44	39	51	44	54	58	63	60	57	56	43	45
Fluoride	mg/L	1.6	1.7	1.4	1.4	1.5	1.4	1.5	1.6	1.6	1.9	1.5	1.6
Nitrate	mg/L	0.27	0.42	0.26	0.21	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1
Nitrite	mg/L	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.6	<0.6	<0.6	<3	<1.5	<1.5
Sulfate	mg/L	550	480	1200	460	540	550	570	580	590	630	460	550
Dissolved Solids	mg/L	1000	940	930	1100	1200	1300	1200	1100	1100	1400	1200	1200
Hardness	mg/L	830	790	720	710	710	740	780	720	770	860	760	840
Conductivity	µmho/cm	1500	1500	1500	1400	1600	1600	1400	1600	1600	1600	1600	1600
pH	pH	8.10	8	8.1	8.2	8	8.1	8	7.7	8	8.1	8	8
Arsenic	mg/L	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Boron	mg/L	0.21	0.26	0.2	0.21	0.22	0.21	< 0.2	0.23	0.42	0.21	< 0.2	0.25
Copper	mg/L	0.0088	0.011	0.0034	0.0067	0.0043	0.005	0.0036	0.007	0.0036	0.0029	0.0054	0.01
Iron	mg/L	0.49	0.21	0.33	0.41	0.44	0.26	0.32	< 0.05	< 0.05	< 0.05	< 0.05	0.31
Manganese	mg/L	0.1	0.057	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.057
Selenium	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc	mg/L	< 0.05	< 0.05	< 0.05	0.055	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.099

Site-Lower Browns Canyon (SS17)

Date	Date	3/31/06	4/28/06	5/30/06	6/20/06	7/26/06	8/16/06	9/23/06	10/21/06	11/18/06	12/28/06	1/27/07	2/25/07
Bicarbonate	mg/L	244	317.2	268.4	219.6	219.6	268.4	268.4	268.4	268.4	292.8	244	329.4
Alkalinity	mg/L	200	260	220	180	180	220	220	220	220	240	200	270
Calcium	mg/L	100	110	77	100	72	58	88	220	86	92	80	100
Magnesium	mg/L	29	33	22	31	17	12	15	40	13	19	15	23
Potassium	mg/L	3	2.4	2.2	1.5	2	3.3	3.1	2.1	6	7.6	10	3.5
Sodium	mg/L	52	51	41	34	28	38	62	56	47	38	44	37
Chloride	mg/L	38	38	43	37	40	48	77	21	66	98	73	65
Fluoride	mg/L	1.3	1.3	0.74	0.57	0.94	0.66	0.77	1.3	1.1	1.4	1.1	1.1
Nitrate	mg/L	0.5	0.66	0.95	0.39	0.29	0.53	0.53	< 0.1	1	0.73	1.5	0.83
Nitrite	mg/L	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.6	<0.3	<0.6	<0.6	<0.6	<0.6
Sulfate	mg/L	170	170	120	120	72	56	62	480	65	100	75	85
Dissolved Solids	mg/L	570	610	500	460	430	370	400	1000	430	640	500	1000
Hardness	mg/L	350	370	320	320	290	320	280	720	350	420	350	460
Conductivity	µmho/cm	850	910	780	710	650	600	580	1400	690	900	760	810
pH	pH	8.00	8.3	8.4	8.4	8.5	8.1	8.3	7.9	8.2	8.2	8.2	8.2
Arsenic	mg/L	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Boron	mg/L	0.21	0.22	< 0.2	< 0.2	< 0.2	0.28	0.29	< 0.2	0.4	0.22	0.26	0.22
Copper	mg/L	0.011	0.0038	0.0028	0.0059	0.003	0.0096	0.012	0.003	0.008	0.002	0.0076	0.011
Iron	mg/L	0.75	0.088	0.28	0.35	0.2	0.076	0.26	< 0.05	< 0.05	< 0.05	< 0.05	0.2
Manganese	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Selenium	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc	mg/L	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.078

Site-Devils Canyon (SS19)

Date	Date	3/31/06	4/28/06	5/30/06	6/20/06	7/26/06	8/16/06	9/23/06	10/21/06	11/18/06	12/28/06	1/27/07	2/25/07
Bicarbonate	mg/L	402.6	414.8	341.6	DRY								488
Alkalinity	mg/L	330	340	280									400
Calcium	mg/L	210	230	360									260
Magnesium	mg/L	82	85	62									94
Potassium	mg/L	5.5	4.7	2.9									3.1
Sodium	mg/L	71	82	120									92
Chloride	mg/L	90	61	240									99
Fluoride	mg/L	2.1	2.3	2.6									2
Nitrate	mg/L	< 0.1	< 0.1	< 0.1									< 0.1
Nitrite	mg/L	<0.3	<0.6	<0.6									<1.5
Sulfate	mg/L	600	640	880									500
Dissolved Solids	mg/L	1400	1100	1500									1300
Hardness	mg/L	920	980	1100									1000
Conductivity	µmho/cm	1900	1800	2400									1900
pH	pH	8.20	8.200	8.2									8.1
Arsenic	mg/L	<0.007	<0.007	<0.007									<0.007
Boron	mg/L	0.46	0.480	1.3									0.54
Copper	mg/L	0.013	0.007	0.005									0.012
Iron	mg/L	0.49	0.240	0.4									0.43
Manganese	mg/L	0.2	0.088	< 0.05									0.11
Selenium	mg/L	<0.005	<0.005	<0.005									<0.005
Zinc	mg/L	< 0.05	< 0.05	< 0.05									< 0.05

Site-McCoy Canyon (SM1)

Date	Date	4/1/06	4/29/06	5/31/06	6/21/06	7/27/06	8/17/06	9/24/06	10/22/06	11/19/06	12/29/06	1/28/07	2/26/07
Bicarbonate	mg/L	146.4	439.2	427	366	366	439.2	402.6	390.4	414.8	439.2	170.8	475.8
Alkalinity	mg/L	120	360	350	300	300	360	330	320	340	360	140	390
Calcium	mg/L	85	340	320	340	260	270	240	320	330	280	110	390
Magnesium	mg/L	26	110	110	110	84	97	80	110	87	89	33	120
Potassium	mg/L	6.3	10	7.7	6.1	11	6.9	8.4	9.7	9.6	2.9	7.1	7.4
Sodium	mg/L	73	180	200	170	190	150	300	230	240	150	73	190
Chloride	mg/L	80	300	270	270	220	290	290	280	260	240	120	230
Fluoride	mg/L	< 0.5	3.3	< 0.5	2.4	2.4	2.4	2.5	2.2	2.5	2.7	1.1	2.5
Nitrate	mg/L	0.75	1.6	2.6	2.6	1.9	1.6	2.4	1.8	2.1	1.7	1.8	1.4
Nitrite	mg/L	<0.3	<1.5	<0.6	<3	<1.5	<3	<1.5	<1.5	<3	<3	<1.5	<3
Sulfate	mg/L	300	990	940	950	1100	1000	950	950	970	1000	330	920
Dissolved Solids	mg/L	660	2000	2300	1800	1700	1800	1800	2400	2000	2000	970	1200
Hardness	mg/L	380	1400	1400	1100	1100	1400	1100	1200	1400	1100	500	1400
Conductivity	µmho/cm	960	3100	2800	2600	2500	2700	3000	3000	3100	2700	1300	2900
pH	pH	7.90	8.300	8.1	8.1	8.4	8.3	8.1	7.9	8	7.9	7.8	8.1
Arsenic	mg/L	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Boron	mg/L	< 0.2	0.490	0.7	0.43	0.46	0.44	0.45	0.46	0.48	0.36	0.22	0.56
Copper	mg/L	0.01	0.009	0.0075	0.012	0.007	0.0099	0.0036	0.008	< 0.002	0.0065	0.01	0.016
Iron	mg/L	0.20	0.260	0.46	0.012	0.41	0.45	0.28	1	< 0.05	< 0.05	< 0.05	0.88
Manganese	mg/L	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	0.13	0.069	0.13
Selenium	mg/L	<0.005	0.013	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	<0.005	<0.005	0.0099
Zinc	mg/L	< 0.05	0.06	< 0.05	< 0.05	< 0.05	0.074	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Site-Dry Canyon Main (SM2)

Date	Date	4/1/06	4/29/06	5/31/06	6/21/06	7/27/06	8/17/06	9/24/06	10/22/06	11/19/06	12/29/06	1/28/07	2/26/07
Bicarbonate	mg/L	231.8	390.4	463.6	390.4	390.4	463.6	488	390.4	512.4	439.2	231.8	488
Alkalinity	mg/L	190	320	380	320	320	380	400	320	420	360	190	400
Calcium	mg/L	130	360	300	410	320	320	380	370	370	320	150	330
Magnesium	mg/L	48	120	110	130	97	110	120	120	96	92	47	99
Potassium	mg/L	6.2	7	5	4.5	7.2	4.9	4	6.6	7.4	4.8	5.7	3.5
Sodium	mg/L	130	130	240	220	250	170	280	280	290	240	140	230
Chloride	mg/L	70	190	160	180	180	220	200	200	190	190	110	170
Fluoride	mg/L	1.8	3.4	< 0.5	3	2.9	2.8	3.1	2.6	2.8	3.2	1.6	2.5
Nitrate	mg/L	0.32	0.83	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.57	< 0.1
Nitrite	mg/L	<0.3	<1.5	<0.6	<3	<1.5	<3	<0.6	<1.5	<1.5	<1.5	<1.5	<1.5
Sulfate	mg/L	740	1100	1300	1600	1400	1400	1400	1300	1400	1200	560	1000
Dissolved Solids	mg/L	1300	1800	2400	2100	2100	2100	2900	2700	2500	2400	1200	1800
Hardness	mg/L	680	1500	1400	1300	1400	1500	1300	1300	1300	1300	630	1200
Conductivity	µmho/cm	1600	2800	2900	3100	3100	3200	3300	3500	3500	2900	1700	2800
pH	pH	8.1	8	8	8	8.1	8	7.9	7.7	7.8	7.8	7.8	8.3
Arsenic	mg/L	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Boron	mg/L	0.29	0.31	0.76	0.55	0.58	0.61	0.53	0.6	0.57	0.44	0.37	0.76
Copper	mg/L	0.013	0.0088	0.0048	0.0068	0.0035	0.0064	0.0028	0.005	<0.002	0.0057	0.0091	0.01
Iron	mg/L	0.31	0.29	0.46	0.56	0.4	0.48	0.41	< 0.05	< 0.05	< 0.05	< 0.05	0.78
Manganese	mg/L	0.084	2.1	< 0.05	< 0.05	0.17	0.066	0.058	< 0.05	< 0.05	0.13	0.063	0.15
Selenium	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc	mg/L	0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

SUMMARY OF STANDARD OPERATING PROCEDURES

BY AMERICAN ANALYTICS LABOROTORY

1. SM2320-Alkalinity

The alkalinity of water or an aqueous waste is measured by its concentration of $CaCO_3$ in units of mg/L or parts per million (ppm). The concentration of $CaCO_3$ is determined by potentiometric titration using a standard acid titrant such as HCl or H_2SO_4, to an electrometrically determined end point of pH 4.5. Samples to be tested for alkalinity must not be filtered, diluted, concentrated or altered in any way. The method fits all concentration ranges of alkalinity; however, proper aliquots should be used to avoid having to add more than 50 ml of standard acid solution. Automated titrimetric equipment may be used.

2. EPA 120.1-Conductance (Specific Conductance, µmhos at 25°C)

The specific conductance of a sample is measured by use of a self-contained conductivity meter, Wheatstone bridge-type, or equivalent. Samples are preferably analyzed at 25°C. If not, temperature corrections are made and results reported at 25°C.

3. EPA 130.2-Total Hardness

The total hardness of water or an aqueous waste is represented by its concentration of $CaCO_3$ and $MgCO_3$ in units of mg/L or parts per million (ppm). The concentration of $CaCO_3$ is determined by titration using disodium ethylenediamine tetra acetate (Na_2EDTA) with a known concentration as the standard titrant.Ca^{2+} and Mg^{2+} in the samples are sequestered upon the addition of EDTA. The progress of the chemical reaction is indicated by Eriochrome

Black T indicator, which shows a red color in the presence of Ca^{2+} and Mg^{2+}, and turns to blue when the complex formation reaction is completed. The method fits all concentration ranges of hardness; however, in order to avoid using too much titrant, use a sample aliquot containing not more that 25 mg $CaCO_3$. Automated tiration may be used.

4. EPA 150.1-pH Measurements

This method is used to measure the pH of aqueous and soil samples by EPA 9040 and EPA 9045 respectively. The pH of the sample is determined by using a combined electrode which is calibrated using a series of standard solutions of known pH. In general, for diluted solutions (<0.1 M) the measured pH can be in the range of ~14. At a temperature of 250C, a pH of 7.0 indicates neutrality, a pH >7 alkalinity and a pH <7 acidity. Method 9045 is an electrometric procedure which has been approved for measuring pH in soils. The soil sample is mixed with water and the pH of the solution is then measured with a pH Meter.

Method 9040 is also an electrometric procedure for aqueous samples by which the pH probe is inserted directly into the sample matrix in order to take the reading. As an alternative to method 9040, when accurate pH is not required, Method 9041 using pH paper may be used to measure pH in order to define a corrosive or non-corrosive aqueous waste.

5. EPA 160.1-Total Dissolved Solids

A well-mixed aliquot of the sample is filtered through a glass fiber filter. The filtrate is evaporated and dried to constant weight at 180^{0}C.If Residue, Non-Filterable is being

determined, the filtrate from that method may be used for Residue, Filterable. The practical range of the determination is from 10 mg/L to 20,000 mg/L.

6. EPA 300-Inorganic Anions

A small volume of sample (50 uL) is introduced into an ion chromatograph. The anions of interest are separated and measured, using a system comprised of a guard column, separator column, suppressor device, and conductivity detector.

7. EPA 6010B-Inductively Coupled Plasma (ICP) Atomic Emission Spectroscopy

The method is applicable for elemental determination in drinking water, ground water, other aqueous and liquid samples, TCLP and EP extracts, industrial and organic wastes, soils, sludges, sediments, and other solid wastes. Elements determined by this procedure, observation wavelengths, and detection limits given below.

Analyte	Observation Wavelength (Nm)	Method Reporting Limit Water (Mg/L)
Arsenic (As)	189.042	0.05
Calcium (Ca)	317.933	0.1
Copper (Cu)	324.754	0.05
Iron (Fe)	259 .9 0	0.1
Magnesium (Mg)	279.079	0.1
Manganese (Mn)	257.610	0.05
Potassium (K)		0.1
Selenium (Se)		0.05
Sodium (Na)		0.1
Zinc (Zn)	213.856	0.05

Prior to analysis, samples are solubilized or digested using appropriate EPA sample preparation methods 3005, 3010, 3050, 1311, and Title 22 CAL WET. These methods are

described in detail in the American Analytics SOP's: MET009, MET003, MET005, MET008, and MET007. For the determination of trace elements in drinking water, samples with turbidity measurements of less than 1 NTU are analyzed directly, and samples with turbidity measurements greater than 1 NTU are digested using EPA method 3010A (AA SOP MET003) and analyzed. For the determination of dissolved constituents, acid digestion is not necessary if the samples are filtered and acid preserved prior to analysis. The method measures element-emitted light by optical spectrometry. Samples are nebulized and the resulting aerosol is transported to the plasma torch. Element-specific atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and the intensities of the lines are monitored by photomultiplier tubes.