CITY OF ELK GROVE

SEPARATING FACT FROM FICTION: Assessing the use of Dry Wells as an Integrated Low Impact Development (LID) Tool for Reducing Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds

FINAL REPORT

March 21, 2017

Final Report

Separating Fact from Fiction: Assessing the Use of Dry Wells as an Integrated Low Impact Development (LID) Tool for Reducing Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds

City of Elk Grove, California

Title Page

Title:	Final Report Separating Fact from Fiction: Assessing the Use of Dry Wells as an Integrated Low Impact Development (LID) Tool for Reducing Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds City of Elk Grove, California
Agreement No:	12-452-550
Date:	March 17, 2017
Watersheds:	Strawberry Creek and Grant Line Channel Watersheds
Project Type:	Stormwater Contamination Reduction/Prevention and Groundwater Recharge
Funding Source:	Proposition 84 (Prop 84) Storm Water Grant Program (SWGP) Planning Grant
Total Project Cost:	$850,000
Prepared By:	Connie Nelson, City of Elk Grove/Willdan Engineering, Barbara Washburn, California Office of Environmental Health Hazard Assessment (OEHHA), and Bennett Lock, (OEHHA)

Table of Contents

List of Tables

List of Figures

List of Appendices

Acknowledgements

The City would like to express appreciation to the following individuals who contributed to this project:

Project Team:

cbec eco-engineering: Chris Bowles, Ben Taber, Rafael Rodriguez, Chris Campbell

Ludhorff & Scalmanini Consulting Engineering: Reid Bryson, Vicki Kretsinger, John Fawcett, Casey Meirovitz

OEHHA: Bennett Lock, Ary Ashoor, Kathleen Doran, David Katz, Hamad Hamad, Alena Dubrovsky, David Siegel

UC Davis Land Air and Water Resources: Emily Edwards, Graham, Fogg, Thomas Harter

Private contractor: Xue Li, Geochemical Engineer

City of Elk Grove: Darren Wilson, Brian Fragiao, Jeff Werner, Fernando Duenas

Member of the Technical Advisory Committee (TAC):

Annalisa Kihara, State Water Resources Control Board, Division of Water Quality

Dana Booth, Sacramento County Department of Water Resources and Sacramento Stormwater Quality Partnership

Darrell Eck, Sacramento County Water Agency, Water Supply Planning and Development

John Borkovich, State Water Resources Control Board, Division of Water Quality

Julie Haas, California Department of Water Resources, Division of Integrated Regional Water Management

Mark Madison, Elk Grove Water

Paul Marshall, Laguna Creek Watershed Council

Rob Swartz, Regional Water Authority, Sacramento Groundwater Authority

Chris Hunley, Sacramento County Environmental Health Department, Well Program – Permitting and Enforcement

Elaine Khan, Chief, Water Toxicology Branch, OEHHA

Special Thanks To:

Barbara Washburn, Science Advisor/Aquatic Toxicologist, OEHHA
Connie Nelson, Project Manager, City of Elk Grove/Willdan Engineering

This project would not have been possible without the funding from the Proposition 84 (Prop 84) Storm Water Grant Program (SWGP) Planning Grant. The City would like to extend our sincere thanks to the staff at the State Water Quality Resources Control Board, Department of Financial Assistance and to Kelley List, Grant Manager.

Funding was also provided by OEHHA and the City of Elk Grove as in-kind services and match.

Acronyms

bgs – below ground surface
BMPs – best management practices
Cfs – cubic feet per second
City – City of Elk Grove
CY – City of Elk Grove Corporation Yard
EIR - Environmental Impact Report
EMD - Environmental Management Department
EPA - Environmental Protection Agency
gpm – gallons per minutes
GPS – Global positioning system
GW - groundwater
LASGRWC **–** Los Angeles and San Gabriel Rivers Watershed Council
LID – low impact development
MCL – Maximum Contaminant Level
MOU - Memorandum of Understanding
MP - Monitoring Plan(s)
MPN – most probable number
MW1 – Monitoring well 1 (upgradient well)
MW2 – Vadose zone well
MW3 – Monitoring well 3 (downgradient well)
MW4 – Monitoring well 4 (downgradient well)
NPDES - National Pollutant Discharge Elimination System MS4 Permit
NRPI - Natural Resource Projects Inventory
O&M - Operation and Maintenance
OEHHA - Office of Environmental Health Hazard Assessment
PAEP - Project Assessment and Evaluation Plan
PAHs – polycyclic aromatic hydrocarbons
PCE - perchloroethylene
perc - perchloroethylene
PHG – Public Health Goal
Prop 84 – Proposition 84
ppm - part per million
QAPP - Quality Assurance Project Plan
SDB – Strawberry Creek Water Quality Detention Basin
SDMP - Storm Drainage Master Plan
SW – stormwater
SWGP – Storm Water Grant Program
TAC - Technical Advisory Committee
TMDLs - Total Maximum Daily Loads
TSS - total suspended solids

UICs – Underground Injection Control Systems
UPRR - Union Pacific Railroad
USGS – United States Geological Survey

Glossary

Chlorophenoxy herbicides: This class of widely used broadleaf weed herbicides includes pesticides such as 2,4-D and MCPA. Most form are highly soluble in water therefore potentially a risk to groundwater quality. Chlorophenoxy herbicides have been classified by the International Agency for Research on Cancer (IARC) as possibly carcinogenic to humans.

Best Management Practices (BMPs): Refers to a type of water pollution control to reduce pollutants in stormwater runoff.

Climate Change: Climate change refers to the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. These changes are associated with alterations in weather patterns, including the form of precipitation.

Coliforms (total coliforms): A group of related bacteria that are (with few pathogen exceptions) not harmful to humans, but act as indicators of other pathogens in drinking water and the efficacy water treatment.

Dry wells: Dry wells are gravity-fed excavated pits deeper than they are wide. They are constructed using perforated casing and can be filled with gravel and rocks. Dry wells penetrate layers of clay soils with poor infiltration rates to permit stormwater to reach more permeable layers of soil, allowing for more rapid infiltration.

Low Impact Development (LID): A land planning and engineering design approach to manage stormwater runoff that emphasizes conservation and use of on-site natural features. These practices are designed to minimize the hydrologic changes associate with urbanization.

Metals (drinking water metals): Metals are inorganic substances that are found in the geologic formations of the earth. While most are required for good health, in excess they can be toxic. The drinking water metals are a group of regulated metals that includes arsenic, chromium, copper, and lead.

Motor oil: A mixture of petroleum hydrocarbons and additives used to lubricate clean, cool, and protect vehicle engines. Motor oil's chemical composition and broad use make it a serious environmental concern.

Pretreatment: Reduction or removal of pollutants in stormwater runoff before it is discharged into the dry well. Pretreatment includes structural pretreatment, such as a sedimentation well, and vegetative pretreatment, such as a vegetated swale, bioretention cell, or water quality basin.

Pyrethroids: Synthetic derivatives of naturally-occurring pyrethrins, insecticides derived from the chrysanthemum flowers. Pyrethroid pesticides are used widely to control pests in both

agricultural, commercial, and residential areas, including for the treatment of head lice and fleas in humans and pets.

Pyrogenic polycyclic aromatic hydrocarbons (PAH): Ubiquitous environmental pollutants that are typically formed by incomplete combustion of organic materials such as coal, oil, and wood. PAHs are lipid soluble and can have toxic, mutagenic, and/or carcinogenic effects.

Semi-volatile organics (SVOCs): A group of organic compounds that have low volatility, due to their high molecular weights. They include PAHs and have been linked to a variety of serious health effects. Examples include phthalates, brominated flame-retardants, polychlorinated biphenyls, and some pesticides.

Total petroleum hydrocarbons (TPH): A term used to describe a large family of several hundred chemical compounds that originally come from crude oil, used to make petroleum products, which can contaminate the environment. Because there are so many different chemicals in crude oil, it is not practical to measure each one separately and so the total amount of petroleum hydrocarbons is measured instead.

Total suspended solids (TSS): All particles suspended in water which can be trapped with a filter that is 0.7 – 1.5 µm in size. High TSS in a water body increases turbidity and often means higher concentrations of bacteria, nutrients, pesticides, and metals in the water.

Underground Injection Controls (UICs): Individual dry wells are often referred to as UIC because the US EPA's UIC program regulates them as Class V wells as required by the Safe Drinking Water Act.

Volatile organic compounds (VOCs): Organic chemical compounds that will evaporate readily at room temperature. They are often released from solvents, paints, glues, and other commonly used products.

Executive Summary

Separating Fact from Fiction: Assessing the Use of Dry Wells as an Integrated Low Impact Development (LID) Tool for Reducing Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds.

Background

Stormwater produced by urban hardscape has degraded water quality and aquatic habitat in California's rivers and streams. Traditional stormwater management practices have not adequately addressed this problem. A six year drought has highlighted the need to view stormwater as an untapped source of groundwater recharge. Further, climate change research indicates that reduced volumes of precipitation are more than twice as likely to result in drought conditions in the future. To address these challenges, new ways to manage stormwater have evolved. One practical solution is the use of dry wells with LID features to help reduce stormwater waste, the adverse impacts of hydromodification, and to recharge the aquifer.

The Elk Grove Dry Well project (project) was designed to evaluate the risk of groundwater degradation associated with infiltrating stormwater runoff through dry wells. Dry wells, also known as recharge wells or underground injection control (UIC) systems, are stormwater infiltration devices that are deeper than they are wide. Typically, they are constructed of a pipe about 3 feet wide and 20 to 50 feet deep, containing perforated holes through much of the length and/or at the bottom. They are particularly useful to quickly infiltrate stormwater runoff and recharge the aquifer especially in areas with soil with high clay content. However, use of this technology has raised concerns that releasing stormwater into to the aquifer could compromise groundwater quality.

Three specific project goals and relevant benchmarks that guided the project were:

- To assess the potential for groundwater contamination associated with the use of dry wells. Benchmarks: contaminants in groundwater do not exceed the Maximum Contaminant Level (MCL) and that the contaminant concentrations in upgradient water table wells are not different than downgradient wells.
- To assess the efficacy of the pretreatment features. Benchmark: the concentration of selected contaminants will be significantly reduced by pretreatment.
- To conduct as broad an educational and outreach effort as possible in order to make the best available science accessible to local and state decision makers. Benchmarks: numeric targets for distribution of outreach materials, presentations, etc. were established.

Project Methods and Approach

To address these questions, two dry wells systems and associated monitoring well networks were constructed at two locations in the Elk Grove, California: 1) the Strawberry Creek water quality basin, which collects runoff from a 168 acre residential neighborhood and 2) the City's Corporation Yard, which serves as a bus parking and service center with a drainage area of 0.6

acres. At each site, a dry well approximately 40 feet deep was constructed along with vegetated and structural pretreatment features. Each dry well was connected to a sedimentation well that was intended to remove sediment and associated pollutants from the stormwater before it flowed into the dry well. However, the sedimentation wells were not sufficiently deep to perform this function. As a consequence, vegetated pretreatment, i.e., the vegetation in the water quality basin and the grassy swale at the Corporation Yard was the primary means of removing particles and associated pollutants from stormwater runoff. A groundwater monitoring well network, composed of a vadose zone well, as well as one upgradient well (to determine baseline conditions) and two downgradient wells (to determine the influence of stormwater runoff passing through the dry well on groundwater) were also constructed.

Monitoring of over 200 contaminants in stormwater and groundwater was performed five times over two years. Groundwater monitoring also occurred prior to the dry well construction and after the first and second year of monitoring. Measurement were made of stormwater runoff as it entered the dry well (after pretreatment) and in all subsurface monitoring wells. Twice during the study, the full suite of contaminants were also monitored in influent stormwater. Flow-weighted composite stormwater samples were used for most analyses. Contaminant data was analyzed, comparing concentrations at different sites at both locations using non-parametric statistical methods. A preliminary analysis was also made of the likelihood that arsenic and chromium, naturally occurring at the project sites, could be mobilized by constituents commonly found in stormwater, such as calcium carbonate, iron, or other metals.

Additionally, flow rates and total volume of runoff infiltrated were quantified. Fate and transport modeling was also performed to evaluate the long term potential for contaminants to reach the water table. HYDRUS 1D was used to predict the travel time of selected contaminants vertically downward from the bottom of dry well to the top of the seasonal high water table.

Finally, extensive education and outreach efforts, aimed primarily at stormwater and groundwater managers, were made throughout the project.

Project Findings

Results of the project showed that with rare exception, none of the 200+ contaminants that were analyzed were detected in stormwater or groundwater. Specifically, volatile and semi-volatile organics were rarely detected. Polycyclic aromatic hydrocarbons were never detected in water, and there was a single detection of an herbicide in groundwater during the entire project. The class of contaminants that were regularly detected in stormwater were metals and pyrethroid pesticides. At the Corporation Yard, the concentration of aluminum in influent stormwater exceeded the MCL by three-fold. Vegetated pretreatment reduced the concentration from 3 mg/L to 1 mg/L. Although the median concentration of aluminum in groundwater was below the reporting limit, it was occasionally quantifiable. However, the fact that there were no differences in concentration between the upgradient and downgradient wells suggests that runoff passing through the dry well was not the source of this metals. One dimensional vadose zone modeling suggested that even using a worst-case scenario,

quantifiable concentrations of aluminum would not reach the vadose zone within the modeling timeframe of 3,000 years. A similar pattern of detections in stormwater was observed for a number of pyrethroid pesticides, including bifenthrin, at the Strawberry Creek water quality basin. However, none was detected in groundwater. Vadose zone modeling suggested that most metals and hydrophobic pesticides would not reach the water table at quantifiable levels within the modeling timeframe.

In contrast to metals and organics, a few class of contaminants were detected at elevated levels in the groundwater. At both sites, nitrate concentrations exceeded the MCL in both upgradient and downgradient water table wells with low levels in stormwater. This pattern can be explained by long term leaching of nitrate out of the soil related to the historic agricultural uses of the land. A handful of detections of coliform bacteria was also measured in groundwater at the Strawberry Creek water quality basin, but these appear to be linked to infiltration through the entire water quality basin, not the dry well.

While fate and transport modeling did not suggest a risk to groundwater quality from any of the contaminants measured in this project, analysis was also performed on water soluble pesticides such as imidacloprid. In contrast to hydrophobic pollutants, water soluble pesticides could pass quickly through the vadose zone. Additional research on potential risks linked to neonicotinoids and fipronil is recommended.

In addition to investigating potential effects on groundwater quality, estimates of the effectiveness of vegetated pretreatment were made. There was a 50-65% reduction in total suspended solid (TSS) concentration as it passed through the grassy swale or water quality basin. If the sedimentation well had been functioning properly, the removal efficiency would have likely been greater.

Stormwater recharge capacity through the two dry wells was also evaluated. The estimated mean volume of water that passed through the dry well at the water quality basin was 0.7 acre/feet (AF), while at the Corporation Yard, it was 0.2 AF. At the Corporation Yard, the small volume of runoff in the 0.6 acre drainage shed accounted for the low volumes. These estimates were based on the 2015-16 rain fall of 13 ½ inches. In a typical year of precipitation (about 18 inches), approximately 1 AF would have passed through the dry well. This volume can be used as an modest estimate; the actual amount would vary based on local soils and lithology.

Lastly, the results of reviewing scientific literature on dry wells presents a picture consistent with these results. The higher quality studies suggested that with proper pretreatment, siting and maintenance that dry wells pose minimal risk to groundwater quality.

Project Performance Measures

The main goal of the project was to assess the potential for groundwater contamination associated with the use of dry wells. Results of this project as well as studies and government reports that were reviewed all pointed to the same conclusion – there was no evidence that dry wells with pretreatment features posed a threat to groundwater quality. Another performance goal was to assess the effectiveness of various pretreatment features at

removing suspended solids and contaminants from stormwater. Results of this project showed that between 50-65% of solids and associated pollutants were removed by the vegetated pretreatment features. The third goal of the project was to determine how often the dry well system would require cleaning. This goal was not addressed because the sedimentation well did not function properly, little sediment accumulated, requiring no maintenance. As a result, no specific recommendations can be made. Education and outreach was another major focus of this project. Much of the concern regarding the use of dry wells stems from a lack of information and knowledge on the results of studies and the practices in other states. To address this issue, education and outreach efforts were conducted to reach a broad audience. These efforts included the development of fact sheets, a review of the literature, and multiple presentations in a variety of venues.

Conclusions

The risks associated with the use of dry wells are primarily linked to the potential to introduce pollutants into the aquifer. Data collected at the two project sites in Elk Grove combined with modeling results did not provide evidence that groundwater quality would be degraded by the use of dry wells. Practices in other states and conclusions reached by US EPA suggest that with proper dry well siting, design, and maintenance, dry wells can be used safely. Results from this project are consistent with these conclusions.

All goals for the project were met and the City will continue to monitor and maintain the Strawberry Creek water quality basin dry well system for at least 20 years.

Chapter 1. Project Background

1.1 Definition of a Dry Well

Dry wells, also known as underground injection control (UIC) systems, are stormwater infiltration devices typically constructed of a pipe approximately 3 feet wide and 20 to 50 feet deep, containing perforation at various locations along the pipe and/or at the bottom (**Figure 1.1**). Dry wells can be used in a variety of situations, but are especially useful in areas with clay soils to help facilitate the movement of stormwater runoff below the constricting clay layers. They are a stormwater best management practices (BMPs) to infiltrate water into the ground to reduce runoff; are relatively easy to construct; and require little land area. Dry wells can be used in conjunction with low impact development (LID) practices to reduce the adverse effects of hydromodification on surface water quality and aquatic habitat. They can also provide additional benefits such as localized flood reduction and groundwater recharge; and help to adapt to the effects of drought and climate change. However, the use of this technology has raised concerns that contaminants in stormwater could compromise groundwater quality.

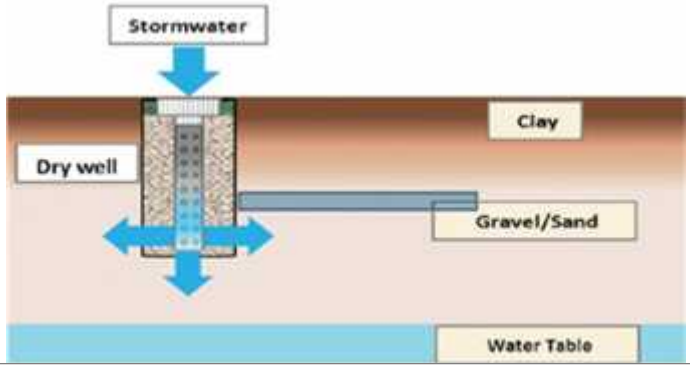


Figure 1.1. Idealized Drawing of Stormwater Infiltration Using a Dry Well

1.2 Project Purpose

This Elk Grove Dry Well Project (project) was designed to evaluate the risk of groundwater quality degradation associated with infiltrating stormwater runoff through dry wells. The project quantified the risk of groundwater contamination; investigate the effectiveness of vegetated pretreatment and natural contaminant attenuation; and researched studies and government reports which included other state's dry well and UIC programs.

1.3 Relationship between Stormwater Management, Low Impact Development and Dry Wells

The report issued by the National Academy of Sciences (2008) on the failure of the current National Pollution Discharge Elimination System (NPDES) to protect the beneficial uses of the nation's waters put into context what many environmental organizations and stormwater managers had known for years – that the NPDES system as it was interpreted at the time was not protecting water quality or aquatic habitat from degradation. The report pointed to the need to manage the hydrologic cycle in a way that mimicked its historic local pattern. The dramatic hydrologic changes that resulted from urbanization and associated storm drain system played a major role in the impairment of beneficial uses. A set of LID practices were

developed to compensate for these alterations. These practices worked by increasing pervious areas, promoting the infiltration of stormwater runoff, and decreasing runoff volume. LID and hydromodification management practices are now required for new development in most major urban areas of California.

One challenge in implementing LID practices in the Central Valley is the presence of clay in soils that inhibits infiltration. The geology of the Sacramento region, in particular, is known for its thick clay layer, sometimes referred to as hardpan, approximately 2 to 8 feet below ground surface (bgs). The hardpan layer reduces infiltration of rain and stormwater runoff, making LID practices difficult to implement. Dry wells offer a solution to this problem because they allow runoff to bypass the upper layers of clay, thus avoiding a major obstacle to infiltration.

1.4 Drought and Climate Change

Dry wells not only are a useful tool for managing stormwater runoff, but are also useful as an adaptation practice in response to drought and climate change. California is just now coming out of a 5 year drought that exacerbated the over draught of the aquifer. During this time, the State established new programs to identify ways to use stormwater as a resource to help offset the impacts of the drought. At the same time, the effects of climate change on the precipitation pattern have become clearer. Efforts are being undertaken to identify ways to capture rain and stormwater since less precipitation will be stored in the mountains as snow. Dry wells can play a role in capturing stormwater runoff and storing it in underground basins.

1.5 Risk of Groundwater Quality Degradation Associated with Dry Wells Use

A major barrier to incorporating dry wells into stormwater capture practices across the State is the view that groundwater might be contaminated if pollutant-laden stormwater is permitted to bypass some of the natural filtration and attenuation of the upper aerobic units of the soil. This concern is, without question, legitimate. However, to some extent, misinformation has generated an unwarranted degree of concern.

A number of factors contribute to this view. Historically, dry wells have been used by agriculturists to drain tailwater carrying nutrients and pollutants from a field. Many rural aquifers have been contaminated as a result of this and related practices. Additionally, some industries have used dry wells to dispose of waste. For example, contaminant has polluted some groundwater basins south of San Francisco as a result of irresponsible industry practices that included the use of dry wells. Groundwater contamination with the dry cleaning solvent perchloroethylene (perc) in Modesto in the 1990s is frequently cited as an example of the risk of using dry wells. In this case, a dry cleaning establishment released contaminated wastewater into the sanitary sewer system for about 50 years, resulting in the establishment of a Superfund site. Details of this incident, for which clean-up is still ongoing, is posted on the US EPA's website: (https://cumulis.epa.gov/supercpad/cursites/dsp_ssppSiteData1.cfm?id=0902527#Status).

Due to the fact that un-engineered dry wells have been used in Modesto for 60 + years, some assumed that the dry wells were the source of the solvent perc. This was not the case, but has

been a commonly held view. As a consequence, many water resource managers are reluctant to use dry wells with the view that they may incur risks to groundwater quality (a public health and safety issue) in order to improve stormwater management (an environmental issue). This perceived conflict of public purposes was heightened by the institutional separation of stormwater and groundwater management responsibilities which has yet to be replaced by a more integrated approach to water resource management.

1.6 Project Description

The origins of Elk Grove project stemmed from the need to provide a local and regional example of dry well use that would address the concerns of regional stakeholders. To this end, a team led by the City of Elk Grove (City) applied for and received Proposition 84 (Prop 84) Storm Water Grant Program (SWGP) Planning Grant from the California State Water Resources Control Board. Using resources from the water bond along with significant contributions from project partners, the Elk Grove dry well project was implemented. The project designed and constructed a dry well system with a groundwater monitoring well network at two locations in Elk Grove, California. The dry well system was designed as a treatment train of three features: 1) a vegetated pretreatment area that infiltrates and/or slows and filters sediment and associated pollutants out of stormwater runoff, 2) a sedimentation well that permits particles and associated pollutants to settle, and 3) the dry well that conveys stormwater runoff below restricting clay layers.

At each site, four monitoring wells were also constructed. A vadose zone well was constructed 15 feet downgradient of the dry well to trace the movement of contaminant, if present. One upgradient and two downgradient water table wells were also constructed. The upgradient well was approximately 150 to 300 feet from the dry well and provided information on the baseline groundwater quality. The two downgradient wells, located about 100 feet from the dry well, permitted the assessment of the affects, if any, of influent stormwater on groundwater quality.

Monitoring of over 200 contaminants in stormwater and groundwater was performed five times over two years. Groundwater monitoring also occurred prior to the dry well construction and after the first and second year of monitoring. Measurement were made of stormwater runoff as it entered the dry well (after pretreatment) and in all subsurface monitoring wells. Twice during the study, the full suite of contaminants were also monitored in influent stormwater. Flow-weighted composite stormwater samples were used for most analyses. Contaminant data was analyzed, comparing concentrations at different sites at both locations using non-parametric statistical methods. A preliminary analysis was also made of the likelihood that arsenic and chromium, naturally occurring at the project sites, could be mobilized by constituents commonly found in stormwater, such as calcium carbonate, iron, or other metals.

Additionally, flow rates and total volume of runoff infiltrated were quantified. Fate and transport modeling was also performed to evaluate the long term potential for contaminants to reach the water table. HYDRUS 1D was used to predict the travel time of selected

contaminants vertically downward from the bottom of dry well to the top of the seasonal high water table.

Finally, extensive education and outreach efforts, aimed primarily at stormwater and groundwater managers, were made throughout the project.

1.7 Project Sites

The two project sites were selected to represent different types of land uses: Site 1: Strawberry Creek Water Quality Basin (SDB) and Site 2: City's Corporation Yard (CY). A detailed description of each project site are presented on the following pages (**Tables 1.1 and 1.2**).

1.8 Project Watersheds

The project sites are located within the Strawberry Creek and Grant Line Channel watersheds. While the Strawberry Creek watershed is a natural system, the Grant Line channel is a primarily a constructed drainage shed of canals originally developed for agricultural drainage. These watersheds were developed as part of the City's Storm Drainage Master Plan (SDMP), and are not USGS watersheds.

Strawberry Creek Watershed: SDB site is located in the Strawberry Creek watershed. This watershed is located in the northern portion of the City and flows generally from east to west, beginning in the County of Sacramento, flowing through the City, and then into the City of Sacramento before joining Unionhouse Creek. The watershed covers approximately 3,700 acres with elevations ranging from 30 feet in the west to 72 feet in the east. There are two upper branches, the North Fork and the Middle Branch. The North Fork begins in Sacramento County and flows into the City at Calvine Road, just west of the Union Pacific Railroad (UPRR). **Figure 1.2** depicts the location of the watershed within the City limits.

The Strawberry Creek watershed is well-developed with many residential subdivisions, parks, and schools. This watershed is listed on the 303(d) list[1] for diazinon, pyrethroid, pentachlorophenol, and sediment toxicity. Runoff from the 168 acre drainage shed enters the water quality basin through two large storm drains (36" and 72" in diameter). Stormwater and groundwater data collected from this location will provide insight into the feasibility of retrofitting water quality or detention basins with dry wells to increase groundwater recharge and reduce or eliminate the runoff (and contaminants) associated with smaller rain events, which are damaging to the aquatic ecosystem. Contaminants commonly found in a residential neighborhood include nitrogen, phosphorus, metals, combustion by-products, and pesticides (US EPA, National Stormwater Quality Database).

[1] 303d List: Listing a water body as impaired in California is governed by the Water Quality Control Policy for developing California's Clean Water Act Section 303(d).

Table 1.1. Site 1: Strawberry Creek Water Quality Basin

Location	SDB is south of Calvine Road and east of Highway 99.
Watershed	Strawberry Creek Watershed (part of Morrison Creek Watershed)
Land Use	Residential
Ownership of Study Site	Public - City of Elk Grove
Depth to Groundwater	48.3 feet to the high water table; 51.2 feet to the low water table
Description	This site receives runoff from various surrounding residential subdivisions to the east and south. The drainage catch basin is approximately 168 acres. Stormwater runoff enters the south end of the water quality basin via 2 existing 72" and 30" pipes/culverts. The map below depicts an aerial photograph of the SDB site.  Site 1: Strawberry Creek Water Quality Basin
GPS Coordinates of Project	Latitude 38° 27' 4 ", Longitude 121° 23' 29"

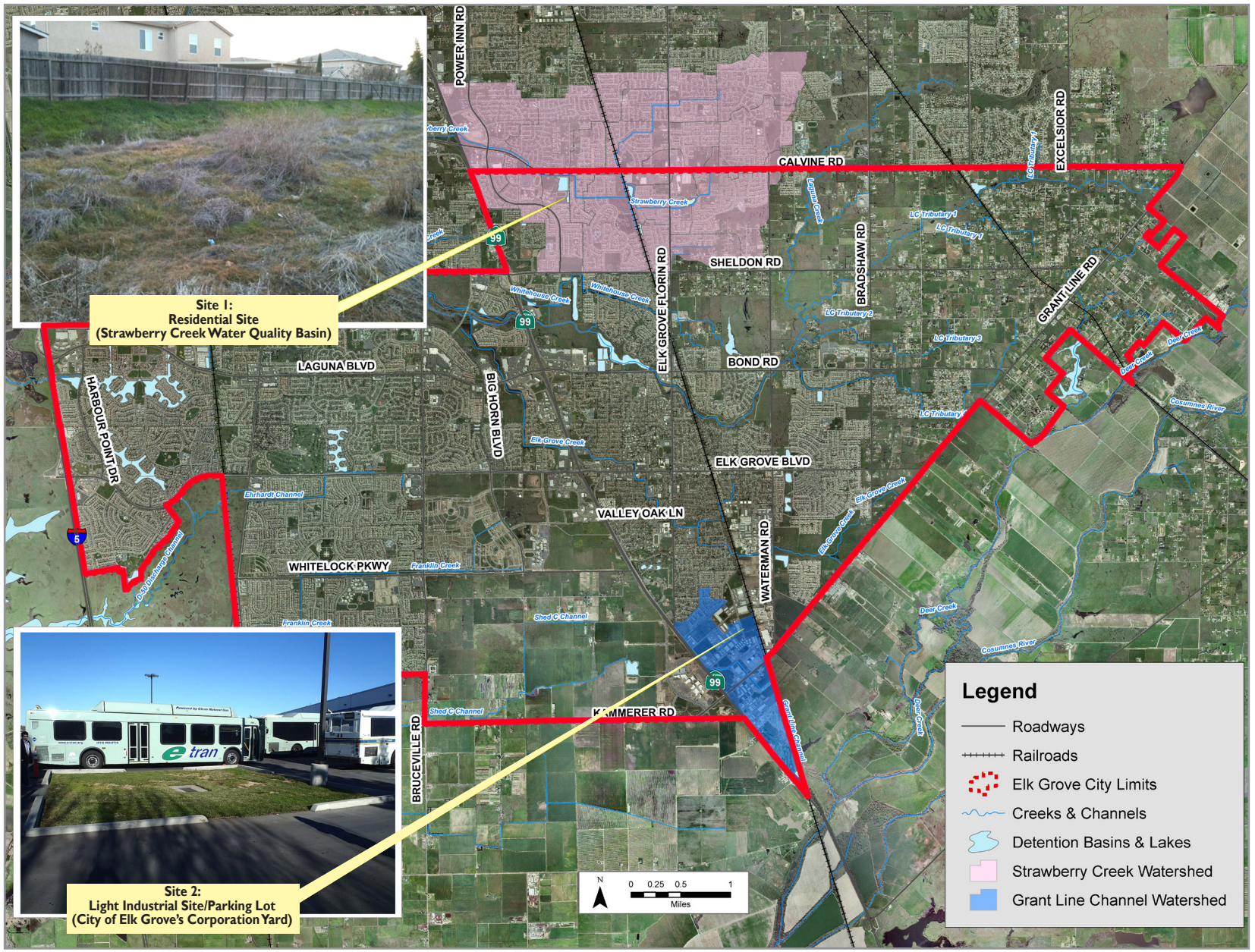
Table 1.2. Site 2: City of Elk Grove Corporation Yard

Location	10250 Iron Rock Way, Elk Grove, CA 95624
Watershed	Grant Line Channel Watershed (part of Laguna Creek Watershed)
Land Use	Light Industrial
Ownership	Public - City of Elk Grove
Depth to Groundwater	74.6 feet to the high water table; 83.4 feet to the low water table
Description	This site receives stormwater runoff from the City's CY large parking lot. The catchment size for this site is approximately 0.64 acres. This site houses the City's transit fleet, and Public Work's maintenance material/equipment/trucks. Transit and Public Works operations and maintenance are conducted at this site. The map below depicts an aerial photograph of the CY site.  Site 2: City's Corporation Yard
GPS Coordinates of Project	Latitude 38° 23' 8", Longitude " -121° 21' 37"

Grant Line Channel Watershed: The CY site is located in the Grant Line channel watershed, which lies in the southern part of the City and covers nearly 550 acres. The watershed is generally bound by Highway 99 to the south and west, the UPRR to the east, and Elk Grove Regional Park to the north. The northern part of the watershed is drained by an underground pipe system that delivers runoff to the Grant Line channel. The Grant Line channel is a man-made trapezoidal channel that begins north of Grant Line Road and carries runoff for approximately 7,800 feet to the south end of the watershed. The channel exits the City in a 60-inch reinforced concrete culvert that carries runoff southeast under the UPRR to an outlet channel that continues to the east for approximately 1,500 feet before joining with Deer Creek. **Figure 1.2** depicts the location of the watershed within the City limits.

Much of the land use within the watershed is industrial and over half of the available industrial land is already developed. Some open space areas and residential land uses are also present. There are a few commercial properties adjacent to Highway 99 that are mostly undeveloped. In addition, there is a golf course at the southern end of the watershed.

Figure 1-2
Project Site Locations and Watersheds Map



Chapter 2. Project Administration

2.1 Project Management and Grant Administration

The project management included managing all staff, consultants and subcontractor work, and interagency coordination through the project grant term. It also included coordination of day-to-day work to successfully complete the project on time and within budget. The grant administration included quality assurance/quality control of work products, timely submittal of project deliverables, and oversight of the project to ensure conformance with the grant requirements and effective outcomes.

2.2 Invoices and Reports

Prepared and submitted sixteen quarterly progress reports and invoices, budget projections, annual progress reports, and Project Assessment and Evaluation Plan (PAEP).

2.3 Agreements

Executed State Water Resources Control Board agreements, task orders and agreements for subconsultant, and Memorandum of Understanding (MOU) with Project team organizations. The Project was adopted through Elk Grove's City Council.

2.4 Amendments and Deviations

Requested and was granted amendments and deviations to grant agreement as follows:

- *Amendment and Deviation 1*: The City requested and was granted a deviation to the grant agreement and one year time extension for the project as recommended by the State Water Resources Control Board and Technical Advisory Committee (TAC). The City amended the scope of work to accommodate the recommended investigation boring/monitoring layout design changes, additional sampling of contaminants to produce better project results, scheduled changes to come into compliance with deliverable dates, one year extension to approve design, modifications to timing for groundwater baseline monitoring, and additional time to go through a public bid process to construct the project following design and the Quality Assurance Project Plan (QAPP) and Monitoring Plan (MP) approval. Amended agreement was executed on December 30, 2013.
- *Amendment and Deviation 2:* The City requested to remove item 8.4 from the Scope of Work (Project Specific Requirements) to complete a draft scientific paper and present the paper at a minimum of one (1) professional meeting, provide the draft scientific paper to the TAC members for peer review, summarize the TAC peer review comments, and submit the draft scientific paper to the Grant Manager as a deliverable. Also, the language under 6.1 was removed for the submittal of monitoring results to the Natural Resource Project Inventory (NRPI) survey form. The NRPI site is not currently operating. Amended agreement was executed on December 16, 2016.

2.5 Project Scope of Work

Task 1. Project Management

1.1 Provide all technical and administrative services as needed for project completion; monitor, supervise, and review all work performed; and coordinate budgeting and

scheduling to ensure the project is completed within budget, on schedule, and in accordance with the approved procedure, applicable laws, and regulations.

1.2 10-day notification of upcoming meetings, workshops, and trainings.

Task 2. Technical Advisory Committee (TAC)

2.1 Create, coordinate, and convene a TAC. Ensure that a representative from the Region 5, Regional Water Quality Control Board and/or State Water Resources Control Board's Division of Water Quality is invited to be involved on the TAC.

2.2 Determine the roles and responsibilities for the TAC members. Submit the final list of the TAC members, their roles and responsibilities to Grant Manager

Task 3. Final Site Selection and Monitoring Study Design

3.1 Conduct initial subsurface investigation borings, including a minimum of four boreholes at a minimum of two separate sites, to verify site suitability. Record and complete soil boring logs for monitoring wells.

3.2 Prepare dry well designs based on the subsurface investigation boring results and make field adjustments, as needed.

3.3 Assess existing pretreatment (e.g., vegetative swales, filter strips, etc.) and prepare additional pretreatment designs, as needed, at each site.

3.4 Design hydrologic and water quality monitoring facilities for each site.

3.5 Design groundwater quality monitoring wells for each site taking into account the site geology and groundwater gradients.

3.6 Submit the designs in items 3.2, 3.3, 3.4 and 3.5 to the TAC for review and feedback.

Task 4. Dry Wells, Sedimentation Wells, and Pretreatment Features

4.1 Prepare specifications and bid documents to select contractor(s) to install a minimum of one dry well, one sedimentation well, and pretreatment features at each site based on the site-specific designs.

4.2 Install a minimum of two dry wells, two sedimentation wells, and pretreatment features. Record and complete soil sample logs for dry wells.

Task 5. Stormwater Quality Monitoring

5.1 Review the preliminary plan for surface water monitoring and make edits to the MP, as necessary, based on the sampling results obtained from previous sampling activities.

5.2 Submit the MP to the TAC for review and feedback. Edit the MP, as necessary, based on TAC feedback.

5.3 Collect and analyze the surface water samples in accordance with the MP. The list of analytes can be modified based on results of the first year's collections.

Task 6. Groundwater Quality Monitoring

6.1 Collect groundwater quality samples from the groundwater monitoring wells completed in the vadose zone and water table at each location approximately four times per year for two consecutive years. The sample collection and analysis will follow the procedures described in the approved QAPP and MP or an equivalent document.

Task 7. Data Analysis and Interpretation

7.1 Analyze groundwater and surface water quality sample results using appropriate statistical methods.

7.2 Interpret the water quality and geologic data to evaluate the efficacy of the dry well at infiltrating stormwater into the aquifer and determine/evaluate if the groundwater aquifer is impacted by infiltration. Assess the potential for deployment of dry wells as a stormwater management tool.

7.3 Review and discuss the results and interpretations from Item 7.2 with the TAC.

Task 8. Education, Outreach and Organization Capacity Building

8.1 Present results at a minimum of three stormwater and groundwater meetings to share information gathered from the project to TAC members, NPDES permittees, and other interested parties.

8.2 Prepare two fact sheets documenting findings of the project, regulatory infrastructure surrounding dry well use, and other topics as deemed appropriate by the TAC and Project Team.

8.3 Provide a guidance document for feasibility analysis, site selection, design and construction of the dry well and associated monitoring network, suggested sampling, and monitoring regimen.

8.4 Work with regional stakeholders to establish a consortium of stormwater and groundwater management agencies willing to discuss methods to sustain the dry well and groundwater monitoring effort beyond the four year period of the project.

8.5 Prepare a Well Closure/Abandonment Plan at the close of the monitoring effort and an Operation and Maintenance (O&M) Plan for the monitoring, sedimentation and dry wells.

Task 9. Project Assessment and Reporting

9.1 Assess the project after the first sampling season, at the midway point, and four years into the grant.

2.6 Project Cost – Total Cost, Matching Funds and Grant Funds

The total cost of the project was $854,581 including in-kind and match funding of 43% from the City (in-kind and match) and California Office of Environmental Health Hazard Assessment (OEHHA) (in-kind) in the amount of $364,761. Below is a summary of costs for each budget category **Table 2.1,** on the following page.

Table 2.1. Budget Summary

Prop 84 Stormwater Grant Program - Budget Summary[1]				
Applicant: City of Elk Grove			**Agreement No. 12-424-550**	
Project: Separating Fact from Fiction: Assessing the Use of Dry Wells as an Integrated LID Tool for Reducing Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds				
	Requested Grant	**Local Match**	**Total**	**% Local Match**
1. Direct Project Administration Costs	$28,087	$4,986	$33,073	15%
2. Planning/Design/Engineering/ Environmental	$131,907	$102,392	$234,299	44%
3. Construction/Implementation	$45,997	$109,421	$155,418	70%
4. Monitoring/Performance	$276,124	$94,480	$370,604	25%
5. Education/Outreach	$7,705	$53,482	$61,187	87%
Total:	**$489,820**	**$364,761**	**$854,581**	**43%**

[1]Budget revised August 31, 2016.

During the term of the grant, the City requested approximately 12% in line item shifts. The cumulative request for the grant was still below the maximum amount of 15% per the grant agreement. Also, match funds were increased by the City to accommodate the modifications in the agreement, additional work and contaminants to be analyzed (i.e. volatile organics and chlorophenoxy herbicides such as 2,4-D), the one year time extension, and design changes (i.e. sedimentation well and refined cost estimates for borings/monitoring wells and dry wells).

Table 2.2 and 2.3 provides a summary of the original budgets for the grant and match funds and budgets for Amendments 1 and 2.

Table 2.2. Grant Funding

Line Item Number	Original Amount	Amendment 1 12/30/13	Amendment 2 12/16/16
1. Project Administration	$27,644	$31,572	$28,087
2. Planning/Design/Engineering/Environmental	$99,670	$131,907	$131,907
3. Construction/Implementation	$82,980	$45,997	$45,997
4. Monitoring/Performance	$229,502	$259,502	$276,124
5. Education/Outreach	$20,024	$20,842	$7,705
Total	$489,820	$489,820	$489,820

Table 2.3. Match Funding

Line Item Number	Original Amount	Amendment 1 12/30/13	Amendment 2 12/16/16
1. Project Administration	$5,070	$5,070	$4,986
2. Planning/Design/Engineering/Environmental	$23,560	$135,753	$102,392
3. Construction/Implementation	$109,800	$67,298	$109,421
4. Monitoring/Performance	$52,76	$66,191	$94,480
5. Education/Outreach	$60,338	$60,388	$53,482
Total	$251,294	$334,700	$364,761

2.7 Project Schedule

The project agreement was executed on January 1, 2013 and the four year grant term was terminated on April 1, 2017. The project schedule is provided in **Table 2.4.**

Table 2.4. Project Schedule

Item	Description	Critical Due Dates	Estimated Due Dates
Exhibit A – Scope of Work to be Performed by Grantee			
A.	PLANS AND GENERAL COMPLIANCE REQUIREMENTS		
1.	GPS information for project site and monitoring locations	Prior to First Disbursement	
2.	PAEP	Day 30	
3.	MP(s)	Day 90	
4.	QAPP	Day 90	
5.	Proof of Water Quality Data Submission to CEDEN	Before Final Invoice	
6.	Copy of final CEQA/NEPA Documentation – Notice of Exemption Environmental Impact Report/Notice of Determination	Day 30	
7.	Public Agency Approvals, Entitlements, or Permits		As Needed
B.	PROJECT-SPECIFIC REQUIREMENTS		
1.	Project Management		
1.2	10-day Notification of Upcoming Meetings, Workshops, and Trainings		Ongoing
2.	TAC		
2.2	Final List of TAC Members, Their Roles and Responsibilities, and Commitment Letters		May 2013
3.	Final Site Selection and Monitoring Study Design		
3.1	Boring Logs		January 2014
3.2	Dry Well Designs		May 2013
3.3	Pretreatment Designs		May 2013
3.4	Hydrologic and Water Quality Monitoring Designs and Specifications		May 2013
3.5	Groundwater Quality Monitoring Design Plans and Specifications		June 30, 2013
4.	Dry Well, Sedimentation Well and Pretreatment Features Installation		
4.1.1	A Copy of Bid Summary and Proof of Advertising		August 2014
4.2	Well Completion Logs		October 2014

Item	Description	Critical Due Dates	Estimated Due Dates
Exhibit A – Scope of Work to be Performed by Grantee			
5.	Stormwater Quality Monitoring		
5.1	Stormwater Monitoring Reports and Proposed Edited Sampling Protocol Revisions		90 Days Following Each Sampling Season
6.	Groundwater Quality Monitoring		
6.1	Groundwater Monitoring Reports and Proof of Submittal to GAMA		90 Days Following Each Sampling Season
7.	Data Analysis and Interpretation		
7.1	Project Team and TAC Report of Results and Interpretations		December 2016
8.	Education, Outreach and Organization Capacity Building		
8.1	Meeting Materials		December 2016
8.2	Fact Sheets (two)		December 2016
8.3	Literature Review		December 2016
8.4	Guidance Document		January 2017
8.5	Monitoring, Sedimentation, and Dry Wells Closure/Abandonment Plan and Operations and Maintenance (O&M) Plan		December 2016
9.	Project Assessment and Reporting		
9.1	Project Assessment and Reporting Results		December 2016
Exhibit B – Invoicing, Budget Detail, and Reporting Provisions			
A.	Invoicing		Quarterly
G.	Reports		
1.	Progress Reports		Quarterly
2.	Annual Progress Summaries and PAEP Status Update		Annually by 9/30
3.	Draft Project Report	November 1, 2016	
4.	Final Project Report	February 1, 2017	
5.	Final Project Summary	Before Final Invoice	

2.8 Project Technical Advisory Committee (TAC)

A TAC was convened to provide guidance and input on the project. The TAC members were selected based on their expertise and their diverse interests and perspectives in groundwater and stormwater management, and environmental protection. A representative from the Regional Water Control Board and State Water Resources Control Board, Division of Water Quality were included on the TAC. A list of the TAC member and their roles and responsibilities are included in **Appendix 2.1**.

A TAC kick-off meeting was held on June 25, 2013. The meeting agenda included a discussion and a presentation on roles and responsibilities of TAC members, an overview of the project, proposed draft MP, review of the 60% design plans, discussions on permitting for the dry wells, the project schedule, and possible design options for study.

Specific changes that were suggested during the TAC meeting for the project were to include an upgradient and a vadose zone monitoring well and sedimentation well to the design plans, and, add volatile organics to the list of contaminants to be analyzed during monitoring. Most of the TAC members actively participated in the meeting and a number of changes were made to the plans as a result of suggestions offered. The TAC members were also given the opportunity to review the 90% design plans, and the City received minor comments from two TAC members.

Throughout the project, the TAC members were updated through emails, meetings and/or project bulletins. The bulletins summarized the status of the project and milestones. The project bulletins are presented in **Appendix 2.2**. In addition, individual meetings with TAC members were conducted to update them on the project's progress and first year of monitoring results. These meetings helped to obtain the TAC's input/suggestions on dry well guidelines and any issue related to dry well use in the Sacramento region. In addition, project fact sheets have been circulated to TAC members for review and comments.

Chapter 3. Planning/Design/Engineering/Environmental

3.1 Planning

The planning efforts of the project included site selection, review of geologic and hydrogeologic data, review of hydrologic data, existing utility research and field verification, the design and construction of the monitoring well network, which included geotechnical investigation (soils and groundwater depth), permitting, design of the dry well system, and CEQA review.

3.1.1 Site Selection

The City worked with members of the project team to make field visits to candidate sites and conducted related research to select two sites representing different land uses. Public ownership was a key factor in making the determination for the sites, along with the presence of pretreatment and access/safety. The site selection was a difficult process. Initially the project proposed three sites; however, due to budget constraints, schedule, and logistical problems with the proposed third roadway site, two study sites were selected.

Some of the criteria considered during the site selection were as follows:

1. 150 foot setback from any domestic wells.
2. 500 foot setback from any public supply well.
3. 5 foot setback from utility lines.
4. Parcel large enough to accommodate the dry well and pretreatment facility with monitoring well network.
5. Adequate watershed size and flow volume to produce sufficient surface water volumes to perform monitoring.
6. Site access to conduct construction and monitoring. There was an access issue with SDB site. The City was granted a right-to-enter from Elk Grove Unified School District until the 50' drainage easement was dedicated to the City.
7. Assessment of existing pretreatment (natural vegetation).
8. Have a willing property owner. For example, if a dry well site is located in a public ditch next to a business or residential property, will the property owner oppose the project? The project team had an issue with the proposed public roadway site and business owner. At first, he supported the project, and then opposed the project after he learned more about dry wells.

Each site was evaluated during the preliminary investigation stage to ensure that the final determination of the sites selected would meet the projects goals and objectives for construction/implementation and monitoring/performance. The final site selection determined that the SDB and CY would be sufficient sites for this demonstration project.

3.1.2 Geologic and Hydrogeologic Data Review

Geologic and hydrogeologic data related to groundwater conditions at, and surrounding, the two sites was collected. Specifically, this included gathering information such as existing designs of the facilities at the two sites, associated hydrogeologic information, such as lithologic logs, well completions records, infiltration tests, and groundwater quality data. In addition, available groundwater elevation data was compiled and a review was performed around the surrounding areas of the study sites. The primary purpose of the review was to delineate the vadose zone and uppermost aquifer units, estimate aquifer properties, and determine/estimate the direction and velocity of groundwater flow at each site.

3.1.3 Hydrologic Data Review

Available information was collected to help with the design of hydrologic and surface water monitoring facilities and dry well installation. Specifically, this included gathering information such as existing designs for the facilities at the two study sites, and associated hydrologic information, such as precipitation records, impervious cover data, watershed boundary data, drainage designs, water quality data, etc.

3.1.4 Existing Utility Research and Field Verification

Existing Improvement Plans were checked for utilities within the project site areas. Also, utility contact letters were emailed to utility agencies requesting any AsBuilt plans of their facilities that may have been within the project site areas.

3.2 Groundwater Monitoring Network Design/Engineering

The project team developed and designed a network of monitoring wells suited for each study site to delineate the movement of potential contaminants through the dry well and vadose zone, and into the groundwater. Design for the monitoring well network was completed at 30%, 60%, 90%, and 100% design stages and a bid package with technical specifications was developed.

3.2.1 Design/Engineering

At each site a network of groundwater monitoring wells were designed, i.e. one upgradient and two downgradient of the dry well and one vadose zone well. The upgradient well provided information on the baseline water quality while the two downgradient wells assessed the effects, if any, of the dry well on downgradient groundwater quality. The three-point layout facilitated the delineation of geologic units and groundwater gradients while increasing the probability of capturing the movement of any contaminants which entered the groundwater. The two monitoring wells located downgradient from the dry well(s) were completed at the water table and with a sufficient screen interval to detect seasonal water table fluctuations. The monitoring well cluster also had one downgradient vadose zone well 15 feet from the dry well. The vadose zone well aided in tracing the movement of contaminants that passed through the dry well. Chapter 5, Section 5.6 discusses how the hydraulic connection between the dry well and groundwater was established and helped facilitate the tracing of contaminants through the system.

Figures 3.1 and 3.2 show the layout of the dry well and monitoring networks at Site 1: SDB and Site 2: CY. In addition, the monitoring well design plans are available in **Appendix 3.1** and on the project website at:

http://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/WDR019_Investigation%20Wells_100%20Submittal_09.04.2013_signed.pdf

3.3 Monitoring Well Construction/Implementation

3.3.1 Permitting

Permits were obtained from the County of Sacramento, Environmental Management Department for the monitoring well networks. The permits for the monitoring well network are included in **Appendix 3.2** Dry Well Feasibility Study – Monitoring Well Construction Report.

3.3.2 Geotechnical Investigation

The project conducted subsurface investigation borings (continuous core) at the two sites to determine the locations of the monitoring wells and dry well, and to assess potential impacts related to the operation of the dry well system. It was understood that the monitoring network would be constructed as part of the initial data collection and design phases to be used in the project design of the dry well system, and to establish baseline groundwater conditions. To reduce project costs, these subsurface investigation borings were converted to the project's eight groundwater monitoring wells.

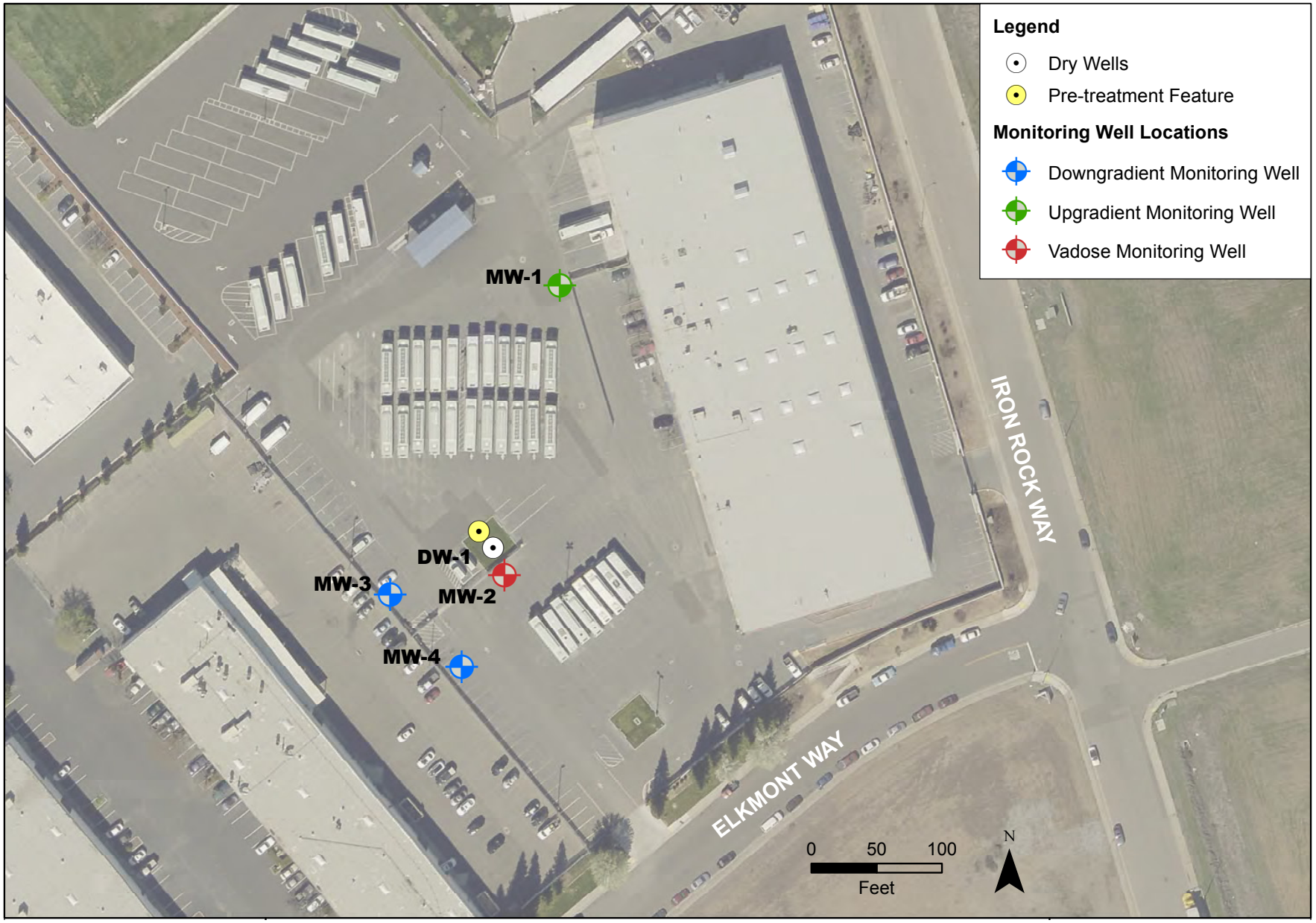
Data required for the project design included the occurrence and composition of underlying sediments (both for infiltration calculations and physical design of dry well openings and gravel packs to avoid clogging), current groundwater levels, groundwater gradients, and the definition of a treatment zone between the bottom of the dry wells and the uppermost aquifer. This data was necessary to produce an efficient design suited to the needs of each project site to ensure continued performance of the dry well on the long-term basis. This data was also necessary to develop specifications and cost estimates as part of the public bidding process to construct the dry well system.

From a regulatory stand point, this data was also necessary to document conditions before, during, and after the operation of dry wells, protecting the City from false claims of impacts, to adjust dry well placement to ensure groundwater samples were obtained within the influence of the dry wells, and to gain approval from local regulators. The drilling of test holes and construction of a monitoring well network (monitoring wells constructed within the test holes) at each site were an essential component of the planning and design phases and were completed simultaneously at the beginning of the project.

Appendix 3.2 provides the Dry Well Feasibility Study – Monitoring Well Construction Report which includes the test hole lithologic descriptions and diagram of the soil types.

Figure 3-1
Location of Dry Well and Monitoring Well Network
Site 1: Strawberry Creek Water Quality Basin

Figure 3-2
Location of Dry Well and Monitoring Well Network
Site 2: City of Elk Grove Corporation Yard



3.3.3 Construction/Implementation

The project constructed eight investigation borings/monitoring wells at both sites. Initially, investigation borings were completed to characterize the composition of the subsurface and determine the depth of the water table at both the CY and SDB sites. The information from the investigative borings was used to determine completion depths and intake screen intervals of the vadose zone and groundwater table monitoring wells. The monitoring wells were constructed prior to the pretreatment system to obtain background data. This phased construction approach was used to address the concern that water might have potentially entered the subsurface through the dry well and altered the baseline conditions.

A drilling contractor was obtained to construct the test hole borings and the monitoring well networks. Oversight by the project team members' inspector ensured that the project was administered and constructed in accordance with the project plans and specifications.

The groundwater wells were constructed at approximately 115-120 feet bgs while the vadose zone well was completed at 55-58 feet bgs. **Table 3.1** summarizes the type of improvements and the depth of the various wells for both sites, and **Appendix 3.3** provides the additional survey information and GPS coordinates.

Table 3.1. Well Head Survey and Construction Summary

	Sites	
Improvements for Each Site	**Strawberry Creek Water Quality Basin**	**Corporation Yard**
Vadose Zone Well (MW2)	58 bgs	55 bgs
Screen	22.5-52.5 bgs	20-50 bgs
Downgradient Well (MW3)	120 bgs	120 bgs
Screen	105-115 bgs	90-115 bgs
Downgradient Well (MW4)	120 bgs	120 bgs
Screen	100-115 bgs	90-115 bgs
Upgradient Well (MW1	120 bgs	115 bgs
Screen	100-115 bgs	80-110 bgs

The construction of the eight monitoring well took approximately one month to complete and was completed at the end of November 2013. Construction photographs are the following page.

3.3.4 Inspections

Monitoring well inspections were performed by the County of Sacramento, Environmental Management Department. The County requested that minor concrete repairs be completed at the SDB for monitoring well 4 (MW4), and that dolphin locks be installed on all monitoring wells at both sites.

Strawberry Creek Water Quality Basin Investigation Borings/Monitoring Wells

Drilling Monitoring Wells

Logging Boring Soil Samples

Completed Downgradient Well (MW3)

City's Corporation Yard Investigation Borings/Monitoring Wells

Drilling Monitoring Wells

Completed Downgraident Well (MW4)

3.4 Project Design/Engineering (Pretreatment Features and Dry Wells)

Research on dry well design yielded few results on how to design a dry well system. This was due to the fact that, in California, other projects referred to dry wells with different names, such as infiltration basins or trenches, to get around permitting requirements and regulatory obstacles. Therefore, the project team conducted a series of meetings to develop the design plans for the dry well system.

During the kick-off meeting with the TAC and State Water Resources Control Board staff, it was suggested that sedimentation well be included in the design of the dry well system for additional pretreatment. Also, during the course of the design process, it was recommended that a bee-hive grate be placed on the top of the sedimentation well to alleviate sedimentation and debris accumulation.

The design plans for the dry well system were prepared at the 30%, 60%, 90%, and 100% plan submittals. The design plans were reviewed by the TAC at the 60% and 90% plan stage. The City received comments from two TAC members at the 90% stage. The TAC comments were minor and most of the comments were incorporated into the 100% design phase.

The dry well design plans are included in **Appendix 3.4** and available on the project website at:

http://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/dry-well-doc-14-2.pdf

3.4.1 Geotechnical Investigation/Hydrogeologic

The dry well design plans were developed based results of the subsurface testing and review of the project's data. A major part of the success of a dry well is the local subsurface composition of its installation site. Dry wells by design are intended to transfer water from poorly drained or low permeability areas to subsurface areas where infiltration and storage of water is possible. However, once influent stormwater has passed the low-permeability surface layer and entered the vadose zone, its transport and fate are dependent on the subsurface hydrogeology.

The key characteristics of the dry well site's underlying hydrogeology include the hydraulic conductivity of its material, the layering structure and composition of layers, and factors that indicate attenuation potential (such as the presence of clays and organic matter). If the effective hydraulic conductivity is too high, contaminants will be transported quickly without much attenuation, and, if the effective hydraulic conductivity is too low, stormwater infiltration will not occur quickly and the dry well will not serve either a stormwater runoff management or aquifer recharge function. What values quantify an effective hydraulic conductivity as either too high or too low cannot be broadly defined and should be determined on a site-by-site basis depending on the quality of stormwater runoff and the amount of runoff a dry well is receiving.

Figures 3.3 and 3.4 illustrate the lithologic description and the composition of the underlying sediments at the two project sites. The sediment layer positions are identified using 55-120 feet long undisturbed cores taken at each of the six monitoring well and two water table well locations.

Figure 3-3
Strawberry Creek Water Quality Basin Lithology Cross Section

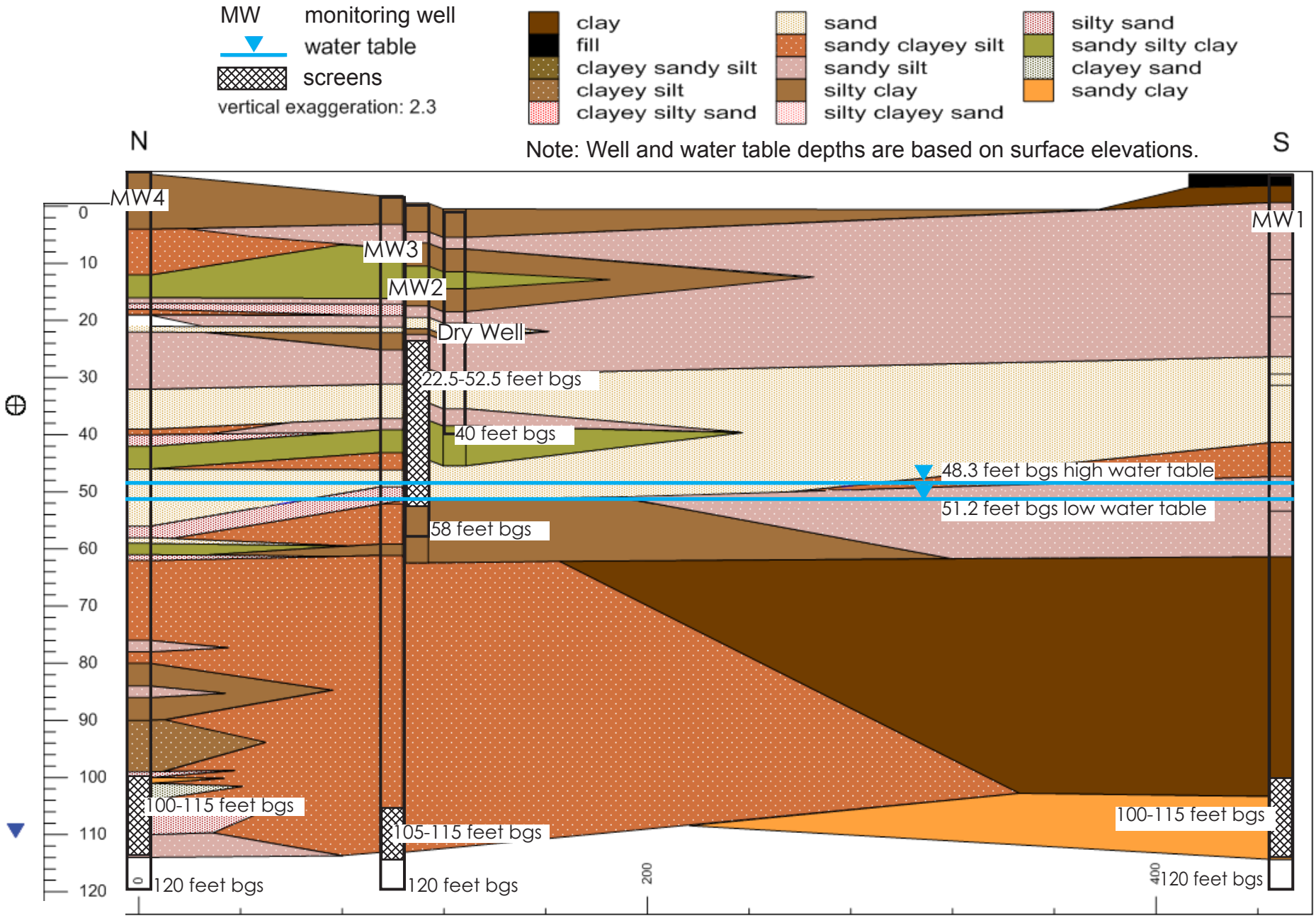
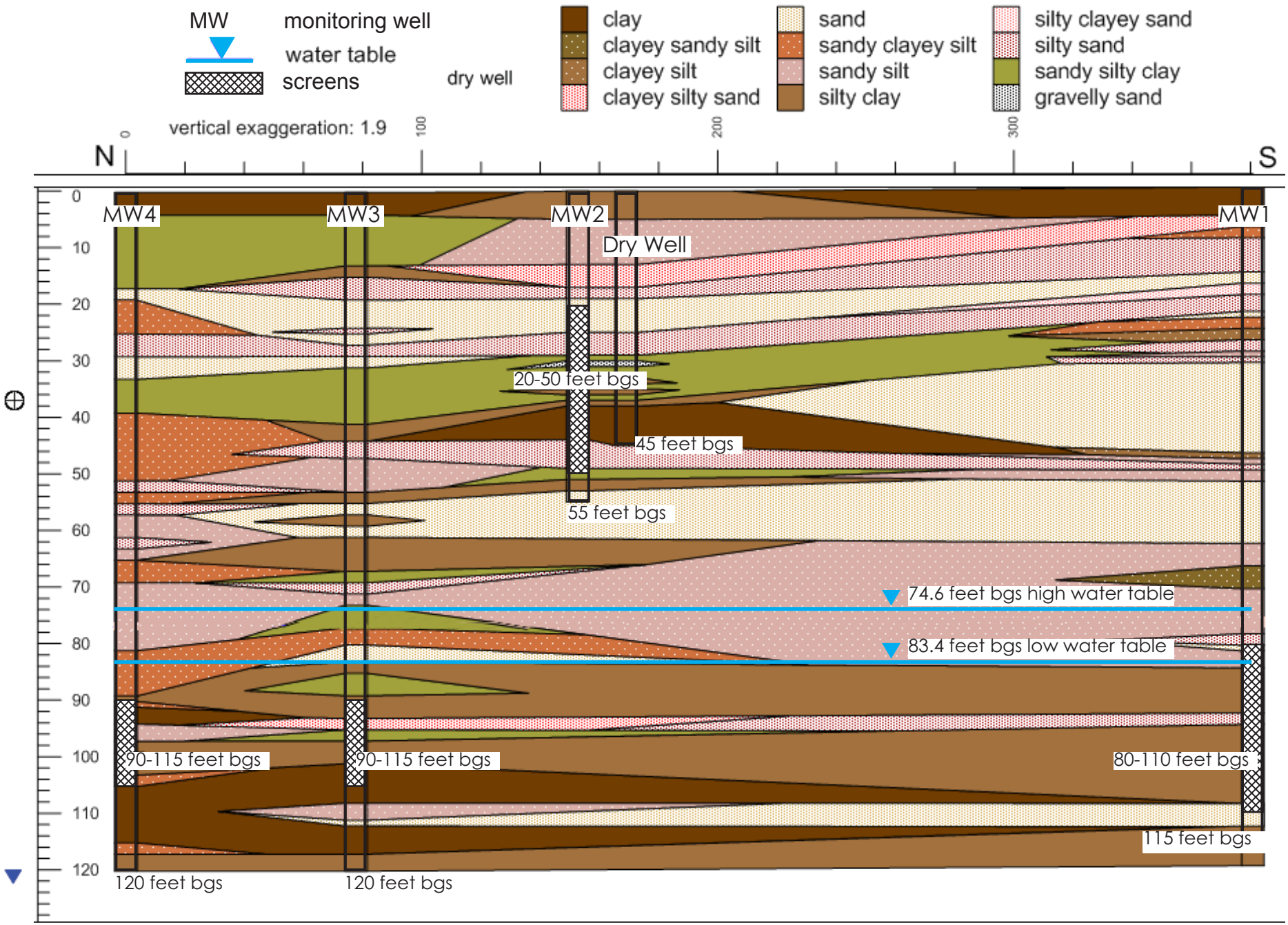


Figure 3-4
City's Corporation Yard Lithology Cross Section



There is a vertical separation between the bottom of the dry well and the high water table of approximately 10 feet bgs at SDB and 30 feet bgs at CY.

3.4.2 Dry Well System Design

The design of the dry well system consists of a treatment train of three components:

1. Vegetated pretreatment features: Traps sediment and associated pollutants and adsorbs some pollutants.
2. Sedimentation well: Traps and filter additional sediment before stormwater runoff is discharged into the dry well.
3. Dry well: Captures remaining suspended solids by including both sand and gravel layers at the top of the dry well.

Figure 3.5 depicts a schematic of the project's dry well system design and the three key components.

The dry well design system collects stormwater runoff in a vegetated pretreatment feature, i.e. the grassy swale at the CY or water quality basin at SDB. The vegetated portion at each site was designed with the goal of holding runoff for approximately seven minutes to meet the recommended contact time for filtering stormwater per the Sacramento Stormwater Quality Partnership Design Guide Manual[1]. The vegetated pretreatment system conveys runoff to a structural pretreatment feature, a concrete sedimentation well, which then conveys water via a pipe that was constructed approximately 1-2 feet above the bottom to the dry well.

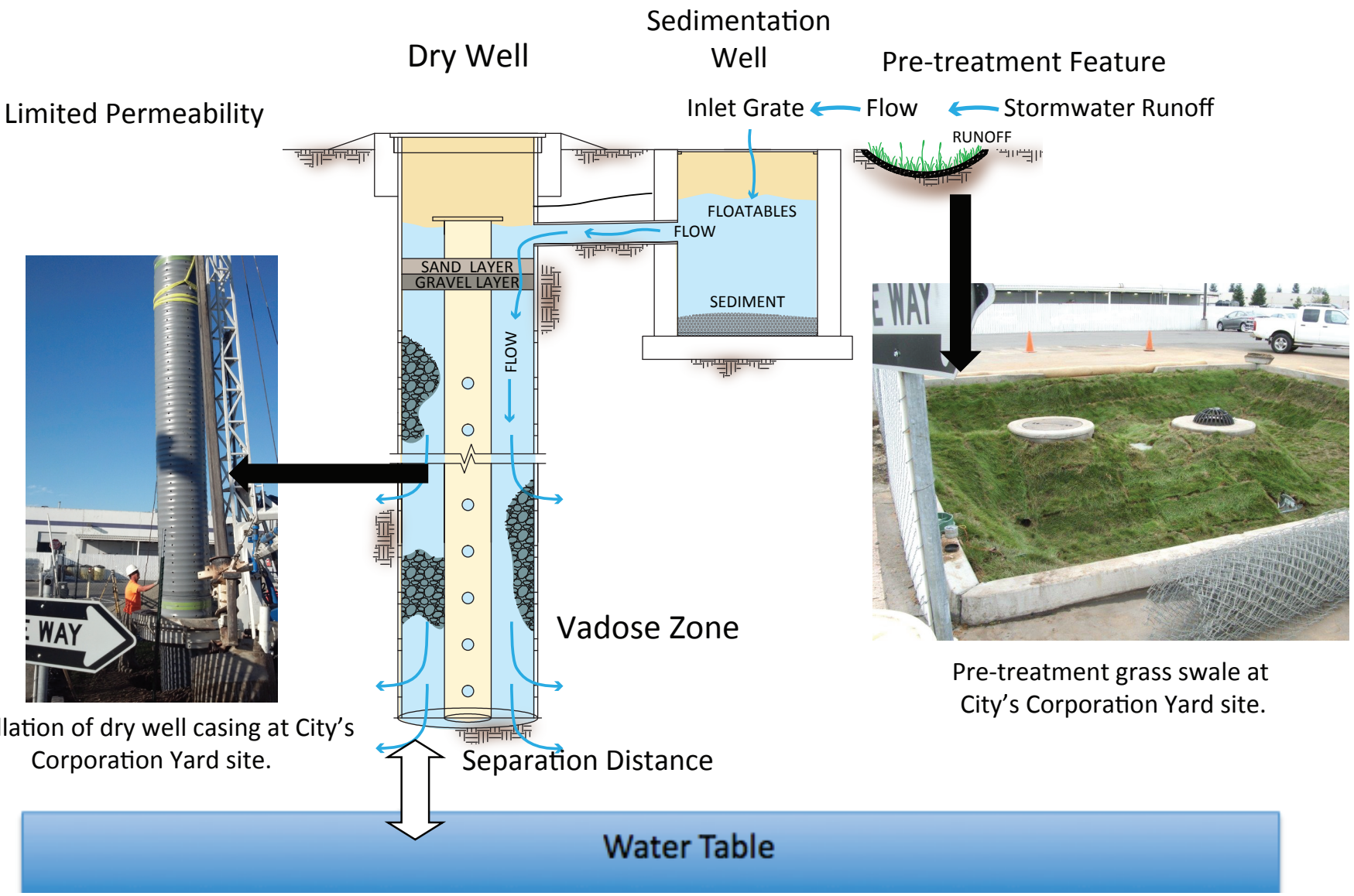
The pictures below illustrate the location of the three components: vegetated pretreatment, sedimentation well, and dry well at each site.

Corporation Yard Drywell

Strawberry Detention Basin Drywell

[1] Posted at: http://www.cityofsacramento.org/utilities/media-room/documents/SWQ_DesignManual_May07_062107.pdf

Figure 3-5
Dry Well Schematic



Installation of dry well casing at City's Corporation Yard site.

Pre-treatment grass swale at City's Corporation Yard site.

A shut-off value is located in the pipe to allow for sealing of the dry well in case of an emergency (not shown in **Figure 3.5**). The dry well design includes a continuous 30-inch diameter outer plastic casing with 1-inch weep holes that will release stormwater into pervious lithologic layers underlain by a clay layer. Pea gravel was installed both in the annular space and within the 30-inch casing. Within the 30-inch casing a layer of sand was placed above the pea gravel to provide additional filtration of incoming stormwater. The dry well was completed at a depth of 40 to 45 feet bgs to optimize infiltration based on information gained from exploratory borings. The pervious layer facilitates a high infiltration rate while the clay layer causes stormwater to move horizontally to obtain further treatment of potential contaminants and functions as a final step of attenuation.

The dry well design also includes a 2" stilling pipe, installed in the middle of the dry well, that was used to lower a pressure transducer/electric conductivity meters to monitor conditions in the well during and after storm events.

3.4.3 Vegetated and Structural Pretreatment Design

The vegetated pretreatment was designed to promote retention/detention of particulate matter and associated contaminants. Since approximately 70% of stormwater contaminants are sorbed to particles, removal of particulate matter aides not only in reducing clogging of the dry well, but also in reducing the quantity of contaminants that enter the dry well. The two types of vegetated pretreatment that were used for the project are a water quality basin, filled with large amounts of vegetation, including trees and bulrush that has grown in the basin over the past 15 years at the SDB site, and a grassy swale that was constructed for the project at the CY site.

The dry well system also contained structural pretreatment; i.e. a sedimentation well. This concrete well slows the movement of water, allowing sediment and associated pollutants to fall out of the stormwater runoff. As solids settle to the bottom of the chamber, the stormwater flows through a 12" diameter PVC pipe into the dry well. However, the sedimentation well that was constructed at both project sites was too shallow and did not function properly to remove contaminants.

In addition, there were extensive modifications to the simple dry well design to ensure minimal clogging of the dry well system and the reduction of contaminants entering the dry well. This involved the intense review of literature and practices around the world to ultimately arrive at the current three-part design system.

3.4.4 Dry Well Design Issues

At the CY, the slopes to the grassy swale were designed at 1:1 and during construction to approximately 0.5:0.5 by an omission of the construction contractor. The construction of the dry well system began in early October and was completed in early November, just prior to heavy rain events. Unfortunately, the sod placed in the grassy swale did not have time to establish its roots into the soil causing sloughing and erosion from the steep slopes. To address this issue, the team consulted with one of the State's recognized experts on erosion issues, John McCullah of Salix Applied Earthcare. Following his recommendation, a geotextile fabric was installed to stabilize the slope and sod, and prevent further erosion and sloughing.

However, on the northwest side of the grassy swale, where most of the stormwater enters the dry well system from the large parking lot, the slope continued to erode. Rock was placed on the slope to stabilize it; however the sod continued to have a difficult time establishing at that location.

There were also design issues during the permitting of the dry wells system with the County of Sacramento, Environmental Management Department. The County had comments to redesign the intake valves with a shut off value. Revisions to the plans were made to receive the permits and future dry well systems should include this mechanism as a safety precaution.

Another design issue was the pipe between the sedimentation well and dry well. The pipe's circumference was too large, creating insufficient flow, which prevented the flow meters from working for automatic sampling at the CY. Challenges also occurred with stormwater equipment at SDB. The flow meter did not function properly due to the backwater effect caused by the confluence of the two storm drain outfalls coming into the water quality basin from the residential neighborhood. The outflow from the larger storm drain pipe inhibited the flow from the smaller, 36" pipe to the point that flow was not measureable with the automated equipment.

Since the automatic sampler was triggered by the flow meters that did not function properly at both sites, it necessitated manual sample collection to be performed and flow-weighted volumes calculated during the stormwater monitoring events. In addition, an orifice retrofit was performed to calculate infiltration volumes. This is further discussed in Chapter 4 –Section 4.4.8.

The last design issue was the sedimentation well. The design did not retain runoff for a sufficient period of time to permit settling of suspended material, and therefore did not adequately remove contaminants. The sedimentation well should have been designed to be deeper. The depths ranged from only 1-2 feet below the invert pipe connecting the sedimentation well to the dry well.

3.5 Environmental

The City prepared a Programmatic EIR (SCH: 2011012035) to cover the requirements of CEQA as they related to adopted SDMP. The EIR analyzed operational water quality impacts for projects included in the SDMP (which included groundwater recharge projects). The EIR found operational water quality impacts to be less than significant with no mitigation measures required per:

"LID practices are tools that can be used to reduce stormwater runoff by holding and/or infiltrating runoff at its source. These BMPs reduce pollutants entering local waterways. In addition, the SDMP includes a number of candidate watershed projects that will improve water quality through the creation of multi-functional drainage facilities in place of traditional stormwater conveyance."

This EIR was used for the environmental requirements of the project and it was determined by the State Water Resources Control Board that no other supplemental environmental documentation was required. The project went to the City's Planning Commission on January 3, 2013 for the NOE.

The project was found to be exempt from CEQA pursuant to CEQA guidelines and finding the project consistent with the City's General Plan.

The NOE and NOE Concurrence form was submitted to the State Water Resource Control Board on April 17, 2013 for signature. The NOE Form was filed February 11, 2013 with the State Clearing House. An executed NOE Concurrence form was received April 29, 2013 for the Planning/Design/Engineering/Environmental phases of the project.

Chapter 4. Construction and Implementation

The construction and implementation was on an aggressive schedule to construct the project prior to the 2014-16 rainy seasons. A schedule was developed to strategize internal City review of design plans and specifications, City Attorney review, advertisement, bid opening, City Council award, and start date of construction.

4.1 Technical Specifications/Bid Package/Advertisement

The project team prepared technical specifications for the public bid process for the dry wells and pretreatment features. The project went out to public bid on June 25, 2014 and a pre-bid meeting was held on June 30, 2014. There were no contractors in attendance at pre-bid meeting.

4.2 Contract Award

Bid openings for the project were July 8, 2014 and the City received one bid from Fox Loomis, Inc. in the amount of $108,374.00. A resolution and staff report was prepared to award the contract. Contract was awarded to Fox Loomis, Inc. on July 23, 2014 by the Elk Grove City Council. The project team set up and executed contracts, bonds, and insurance with Contractor. The Contractor was given the notice to proceed on September 9, 2014.

4.3 Well Permits

The City obtained dry well permits from the County of Sacramento, Environmental Management Department. The County made comments to the plans to redesign the intake values. Revisions to the plans were made and the City received the permits on September 30, 2014 with project conditions.

The County was reluctant to permit the dry wells and special provisions were included with the permits. The County had no regulatory guidelines on permitting dry wells; therefore, they permitted the dry wells as water wells.

This project received the first dry well permits *from the County of Sacramento, Environmental Management.*

The dry well permits are included in **Appendix 4.1**. In addition, a representative from the County of Sacramento, Environmental Management Department was on the project's TAC.

4.4 Construction

4.4.1 Pre-Construction Meeting

Prepared for and had pre-construction meeting with the Contractor and subconsultants on September 15, 2014. Prepared to begin construction at the beginning of October, 2014 and began receiving engineering submittals from the Contractor.

4.4.2 Construction

Construction began on October 1, 2014 for the dry well system and construction pictures are below. The project team had weekly meetings with the Contractor on progress of construction. The project team processed three change orders with the Contractor during the construction phases for the following:

1. Intake valves at both sites.
2. Installation of CSP to accommodate drainage within bioswale.
3. Four 12" pop-up sprinklers at CY site, and two stainless steel eyebolts and chain to secure beehive grates to adjacent concrete collar at both sites.

The construction of the dry well system was completed by November, 2014. Below are pictures of the construction.

Strawberry Creek Water Quality Basin – Drilling Dry Well

Corporation Yard – Dry Well Casing Installation

Corporation Yard – Sedimentation Basin, Dry Well and Bioswale Construction

Corporation Yard – Bio Sod Placement

After construction, some challenges arose which are described below along with how each issue was rectified.

Site2: Strawberry Creek Water Quality Basin: At SDB, the intake valve was clogged and sinking. Also, there was some settling and erosion around the sedimentation well and dry well (see picture right). Both issues were repaired by the Contractor.

Dry Well - Erosion

Site 2: Corporation Yard: It was difficult to establish the sod placed in the bioswale due to heavy rains after installation. Continuous rain events in November created sloughing and erosion issues. To address this issue, the project team consulted with one of the State's recognized experts on erosion issues, John McCullah, Salix Applied Earthcare. Following his recommendation, the erosion and sloughing was repaired by installing a turf reinforcement mat to stabilize the slope and sod.

4.4.3 Inspections

The County of Sacramento, Environmental Health completed inspection during construction of the dry well for the concrete collar. Also, the County completed final inspections at both project sites on February 5, 2015 for the dry wells.

4.4.4 Well Completion Logs

The well completion logs (**Appendix 4.2**) were submitted on October 29, 2014 to State Water Resources Control Board and the County of Sacramento, Environmental Management Department as a project deliverable.

4.4.5 Stormwater and Groundwater Equipment Installation

The stormwater and groundwater equipment (i.e. flow meters, composite samplers, electrodes/probes, and telemetry equipment) was installed at both sites. Issues occurred with the flow meters and composite samplers which were discussed in Chapter 3, Section 3.4.4.

4.4.6 EPA Well Registration

On January 28, 2015, the project team registered the wells with EPA's UIC registration web portal for both dry well sites. A pdf of EPAs registration form was submitted to the County of Sacramento, Environmental Health as part of the County's permit requirements.

4.4.7 Improvements

Table 4.1 below summarizes the type of improvements and the depth of the various wells for both sites, and **Appendix 3.3** provides the additional survey information and GPS coordinates.

Table 4.1. Construction Summary

Improvements for Both Sites	Well	Well Depth (feet)	Pervious Area
Dry Wells[1]	2		
CY	1	45	
SDB	1	40	
Sedimentation Wells	2	4.5	N/A
Pretreatment Features			
CY	1	N/A	841 square feet grassy swale
SDB	1	N/A	Existing Water Quality Basin

There is a vertical separation between the bottom of the dry well and the high water table of approximately 10 feet bgs at SDB and 30 feet bgs at CY.

4.4.8 Dry Well System Repairs/Maintenance

After the first year of monitoring, repairs were completed to ensure the projects effectiveness. Infiltration rate testing on April 7, 2015 indicated that at Strawberry Creek water quality basin infiltration was under performing. The project team evaluated the situation and repairs/maintenance was completed.

There were several retrofits/repairs to the dry well system to improve infiltration and other repairs and maintenance were completed as follows:

1. *Infiltration Rate Retrofit #1/Construction Inspections:* The inability to directly monitor dry well inflows with a flow meter throughout the 2014-15 water seasons limited the ability to quantify dry well infiltration rates. In response to this, a falling head infiltration test was

performed during April 7, 2015 storm event to obtain data on saturated hydraulic conductivity and estimates of infiltration rates at each dry well site. The limited falling head test results were compared with anticipated values based on site-specific lithology, and it appears that the SDB dry well was impacted by some degree of clogging or impedance to flow within the upper portion of the gravels within the dry well casing or the subsurface materials. Data from April 7th also indicated that the upper sand layer at the CY dry well was not restricting inflow beyond the capacity of the subsurface to receive flow under steady-state conditions. **Appendix 4.3** includes the analysis and findings from the infiltration test for the April 7, 2015 rain event in a 90-Day Stormwater and Groundwater Monitoring Summary Report.

The reason behind the restricted infiltration rates was unclear. The project team took an adaptive management approach to resolve the apparent clogging within the dry well as follows:

a. Research was completed to better understand how the dry well system was working and why infiltration rates were reduced.
b. Research was conducted on the potential for restricted air displacement in structural pretreatment (sedimentation well) and how to improve performance.
c. A field test was conducted to determine the extent of clogging.
d. Sand and gravel was replaced in SDB dry well to address clogging.

Specifically, at SDB, it was determined that the most cost effective approach was to vacuum out the dry well down 7-15 feet bgs and replace the sand and gravel layer and install a stilling well vent (retrofit #2, below) to improve the infiltration rates. During this process, it was discovered that that over five feet of sand had been added to this dry well during construction instead of the one foot called for in the design plans. This excess sand was removed and replaced with 4' of pea gravel and 1'of sand. After this retrofit, the infiltration rates increased significantly. The infiltration rate at the SDB was about 70 gallons per minute (gpm) (0.16 cubic feet per second (cfs)) over the course of the next rain event on November 2, 2016. Approximately 28,000 gallons passed through the dry well during this rain event.

The issue at SDB could have been avoided if a proper inspection was completed during the construction phase of the project. The construction inspector should have been on site when material was being added to the dry well casing.

2. *Infiltration Rate Retrofit #2/Sedimentation Well:* The project team also completed a retrofit to the sedimentation well at both sites to better manage flows as follows:

Strawberry Creek Water Quality Basin: One of the challenges with measuring infiltration at SDB was the misfit between the large amount of water entering the water quality basin and the small capacity of the single dry well in that basin. This meant that influent stormwater quickly overwhelmed the dry well, backing up inflow and making flow measurements challenging. To address this issue, the project's team developed a

retrofit that controlled water entering the dry well to simulate the conditions used in a constant-head infiltration test, i.e., Inflow approximated the infiltration. By retrofitting the connector pipe with a new elbow and pipe containing orifices, inflow could be managed and flow measurement collected (**Figure 4.1**).

Figure 4.1. Retrofit #2 at Strawberry Creek Water Quality Basin

As long as there was a slight head above the top of the open orifice, equations could be used to calculate inflow. This retrofit was inexpensive.

City's Corporation Yard: To better manage flow measurements into the dry well at the CY, a flange on the 6" inlet pipe in the swale that leads to the sedimentation well was removed and replaced with an elbow, with three or four 6" high risers with couplers that could be added to as needed. This increased residence time of runoff in the grassy swale which allowed sediment/particles to settle to the bottom of the grassy swale. A set of orifices were also retrofitted at the CY to control inflow to the dry well so that flow measurements could be made.

The orifice plate used at the CY was a cap placed on the sedimentation well connector pipe (**Figure 5.2**). The cap contained holes with a diameter of 0.75", 1.00", 1.25", 1.75", and 2.5." When the water level rose and covered any one orifice, the plug was removed to permit runoff to flow into the dry well. With this knowledge, the volume of flow into the dry well can be calculated using the free outfall orifice equation.

Figure 5.2. Office Retrofit. Orifices in a pipe cap that controlled water flowing into the dry well at the Corporation Yard. Knowledge of the flow rate each orifice permitted with a given head supported the calculation of infiltration volume.

By implementing the orifice solution, a constant head could be maintained at the dry well systems at both sites.

3. Maintenance Repairs: Other repairs/maintenance were completed after the first year of sampling at both sites as follows:
   - Replaced manhole lid with lighter duty lid at dry well. This made it easier for the project team to lift the manhole lid during monitoring events.
   - Added rock at access road entrance to detention basin at Power Inn Road to eliminate any tracking.

4.5 Operations and Maintenance (O&M) and Monitoring Plan

To keep the dry well systems functioning as designed, an O&M and Monitoring Plan (**Appendix 4.4**) was developed. The O&M of the project included recommendations for pressure washing and vacuuming out the dry well system, i.e. sedimentation well and dry well, once a year prior to the rainy season. This has been added to the City's O&M for drainage inlets program. Additionally, inspections of the SDB have been added to the existing O&M Program for detention basins

Monitoring will also be performed as part of the O&M. The monitoring efforts will include stormwater and groundwater monitoring once a year for identified contaminants per the project's O&M and Monitoring Plan. The monitoring efforts will be part of the City's Aquatic Resources and Water Quality Protection Management Program. There is adequate funding in this Program to complete stormwater monitoring efforts at the SDB site.

The O&M and monitoring will be in place for 20-years for the SDB project site.

Chapter 5. Monitoring, Analysis and Performance

5.1 Overview

During the 2014-15 and 2015-16 water years, stormwater and groundwater data were collected at the two dry well sites. Monitoring for a wide variety of contaminants was performed during the dry and wet seasons for these two consecutive years. The analysis included examining the following:

- A difference in stormwater quality before and after runoff has passed through the pretreatment features in order to evaluate the effectiveness of removing sediment from runoff.
- The differences between contaminant concentrations in stormwater as it entered the dry well, in the vadose zone, and at the groundwater water table which provided insight into contaminant sequestration in the vadose zone.
- The differences in groundwater quality upgradient and downgradient of the dry wells which helped to identify the source of contaminants in groundwater, should any be detected.

To address these concerns, stormwater and groundwater samples were collected during and after five rain events; and dry season groundwater samples were collected three times. Water was analyzed for over 200 contaminants. In addition, flow measurements were calculated and vadose zone modeling was performed to assess the fate and transport of key contaminants.

5.2 Quality Assurance Project Plan (QAPP) and Monitoring Plan (MP)

The work conducted during this project followed the protocols described in an approved QAPP/MP. These protocols and standards included data quality objectives, sampling schedules, sample collection and documentation forms, including chain of custody, analytical chemistry reporting limits, and the use of appropriate field and laboratory quality control measures, such as field blanks, field duplicates, matrix spikes, and laboratory control samples. The lists of analytes were modified based on the results of the first years sampling collections. In addition, edits were made to the MP, as necessary, based upon the sampling results obtained from previous sampling activities.

The project's QAPP and MP are on the project website at:

http://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/dry-well-doc-13.pdf

5.2.1 Collection of Stormwater and Groundwater Samples

A total of five stormwater monitoring events occurred during the project, from the first flush event and from one-three additional events each year. One additional monitoring event was performed for infiltration testing. Samples were collected to obtain flow-proportional composites for approximately 80% of the storm volume with

one exception; at the April 24, 2105 event, only grab samples were collected due to the very short duration of the storm.

Stormwater samples were collected at the storm drain outfall (SDB) or curbcut (CY), where runoff first entered the pretreatment feature, and as water flowed into the dry well (**Figure 5.1**). Five composite stormwater samples were collected at the dry well and at two event, composite samples were also collected at the stormwater outfall or curbcut. The remainder of the samples collected at the curbcut/outfall were grab samples used for the analysis of pyrethroids and TSS only. Stormwater was collected every 15 – 60 minutes, depending on the intensity of the precipitation and duration of the storm.

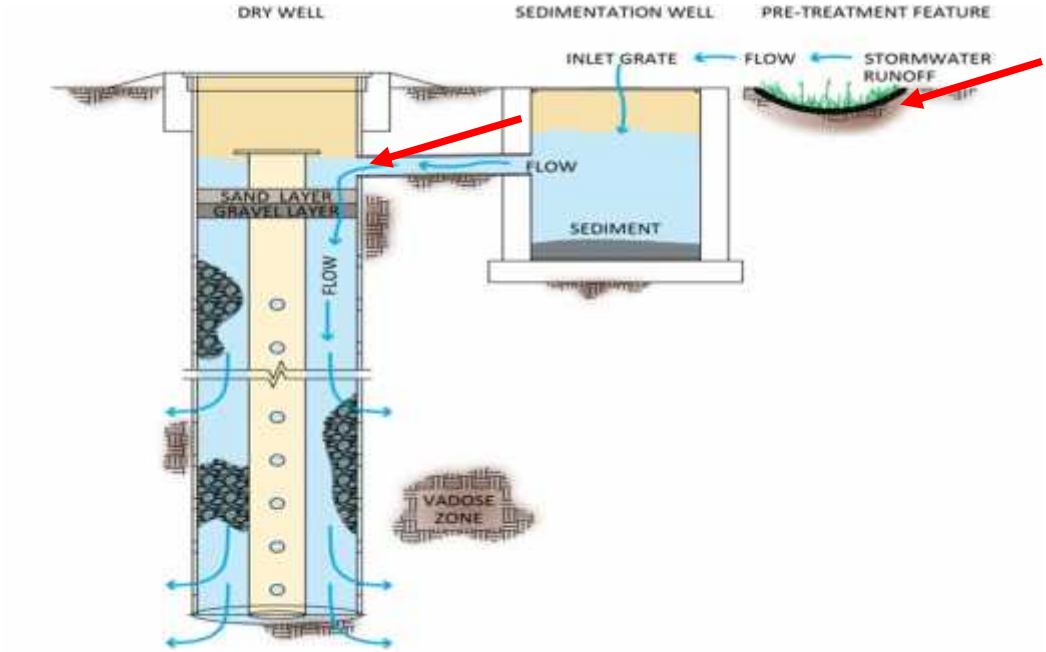


Figure 5.1. Sampling Locations. Composed of a vegetated and structural pretreatment feature in addition to the dry well. Locations from which stormwater samples were collected are highlighted with red arrows.

During the rainy season, groundwater samples were collected approximately one to two days after the storm event from the vadose zone well and about two to seven days after each rain event from the groundwater wells. Water level rises in the wells, which were continuously monitored using pressure transducers, informed the timing of these collections. In addition to the wet season monitoring, three groundwater monitoring events occurred during the dry season for post construction and baseline monitoring. The vadose zone well did not have sufficient water present to collect samples during the dry season monitoring.

All groundwater samples that were used for analysis of metals were filtered in the field, and the analysis reflects dissolved concentrations. This was not the case with

stormwater samples, which were not filtered. Outside of this issue, all other sample were collected in the same manner.

5.2.2 Analysis of Contaminants

Stormwater and groundwater samples were analyzed for the following contaminants:

- Total suspended solids (US EPA 160.2)
- Pyrethroid pesticides (WPCL #53)
- Chlorophenoxy herbicides (US EPA 8151A)
- Total petroleum hydrocarbons and motor oil (US EPA 8015-diesel and gas)
- Pyrogenic polycyclic aromatic hydrocarbons (US EPA 8310)
- Semi-volatile organics (US EPA 625)
- Volatile organics (US EPA 8260B)
- Drinking water metals and hexavalent chromium when indicated (US EPA 200 series)
- General physical (US EPA STDM)
- General mineral (US EPA STDM)
- Total coliform (SM 9221)
- Glyphosate (final monitoring event only)

5.2.3 Statistical Methods

Kruskal-Wallis and other non-parametric tests were performed to analyze differences in contaminants in groundwater collected from upgradient and downgradient wells as well as stormwater as it entered the vegetated pretreatment feature and the dry well. Correlation analysis was performed on data used to investigate the relationship between ions present in stormwater and arsenic and hexavalent chromium in the groundwater. Statistical analysis was not performed on the hydrologic data.

5.3 Results of Stormwater and Groundwater Contaminant Monitoring

5.3.1. Organic Contaminants

The project results indicated that, outside of pesticides, few organic contaminants were detected in stormwater. The specific contaminants detected were motor oil, diethylhexyl phthalate, toluene, acetone, tert-butyl alcohol, and glyphosate. Of those, only diethylhexyl phthalate, detected at 6.01 µg/L, exceeded the MCL of 6.0 µg/L. No quantifiable organics were detected in groundwater. There was a single detection below the MCL of dalapon, a chlorophenoxy herbicide, in a downgradient water table well at SDB. In contrast, pyrethroids pesticides were consistently detected in stormwater at both project sites. Stormwater collected at the SDB had more frequent detections of pyrethroids than samples from the CY. The primary pyrethroid of concern was bifenthrin.

Bifenthrin: This pyrethroid was detected at both sites. At the CY (**Figure 5.2**), the median concentration of bifenthrin was 3 ng/L in stormwater as it entered the grassy swale. None was detected by the time the stormwater reached the dry well or in the subsurface water sample. In contrast at SDB, concentrations of bifenthrin were much higher, reaching as high as 100 ng/L in stormwater (**Figure 5.3,** on the following page). Vegetated pretreatment was effective at reducing bifenthrin concentrations by about 40% and it was not detected in groundwater samples. As a widely used pesticides for the control of ants and other insects in residential and commercial settings, its elevated concentration at SDB is consistent with common use by consumers. Based on results of the vadose zone modeling (see **Section 5.7**), bifenthrin is unlikely to pose a risk to groundwater quality due to its hydrophobic nature and degradation rate in the subsurface. Results suggest that it would not reach the water table at quantifiable levels within the 3,000 year modeling timeframe. Other pyrethroids were detected and details are contained in OEHHA's Technical Memorandum (**Appendix 5.1**). Pyrethroid data suggests that hydrophobic pesticides in general are highly unlikely to pose a risk to groundwater quality.

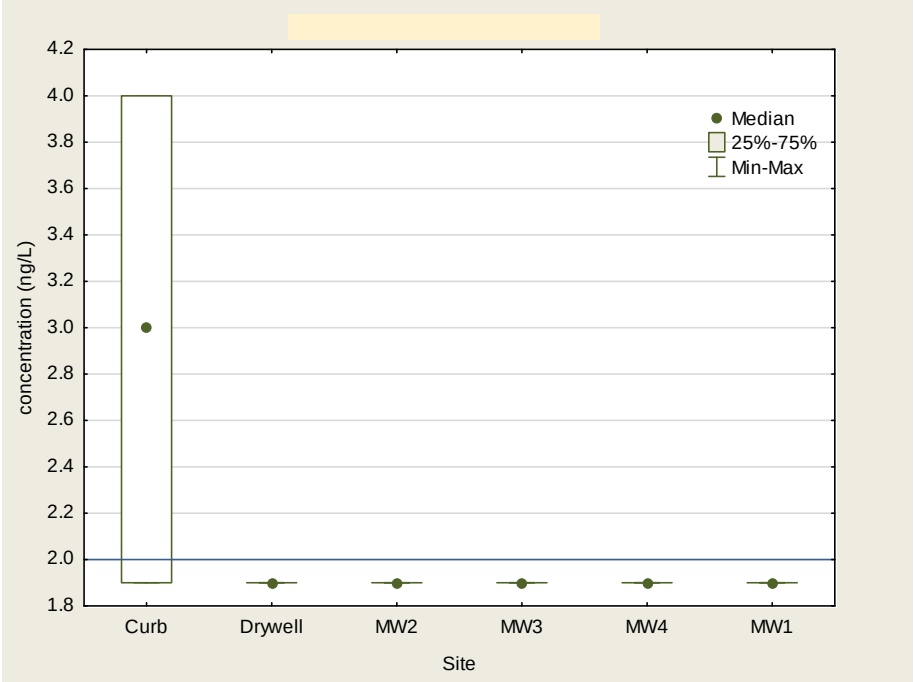


Figure 5.2. Bifenthrin Concentrations in Stormwater and Groundwater at the Corporation Yard. Each point represents the median concentration, the box reflects the 25th and 75th percentile values, and the whiskers represent the minimum and maximum values measured. n = 2 – 5. Units of concentration (y-axis) are ng/L. Sampling groups are as follows: Curb=curbcut where stormwater first entered the dry well system at the CY; Drywell, as runoff entered the well; MW2=vadose zone well; MW3 and MW4=downgradient water table; MW1=upgradient well. The blue line indicates the reporting limit.

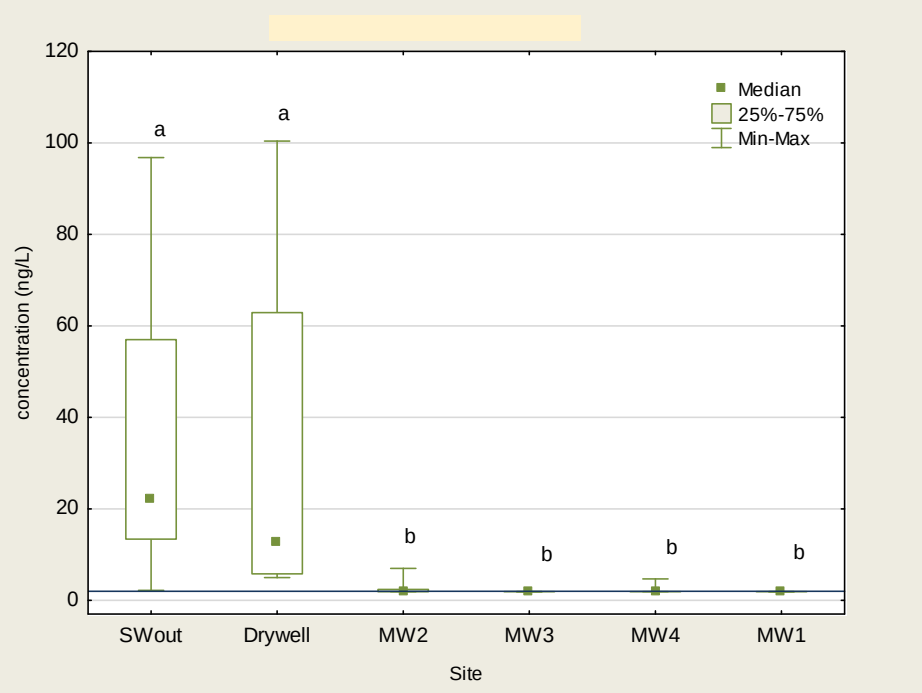


Figure 5.3. Bifenthrin Concentrations in Stormwater and Groundwater at the Strawberry Creek Water Quality Basin. Notations are the same as for Figure 5.2.

Motor Oil: One of the few organic contaminants, outside of pesticides, that was regularly detected at both sites was motor oil. The concentrations observed in stormwater at the CY were ten-fold higher than at SDB (**Figure 5.4**). Visible oil sheens

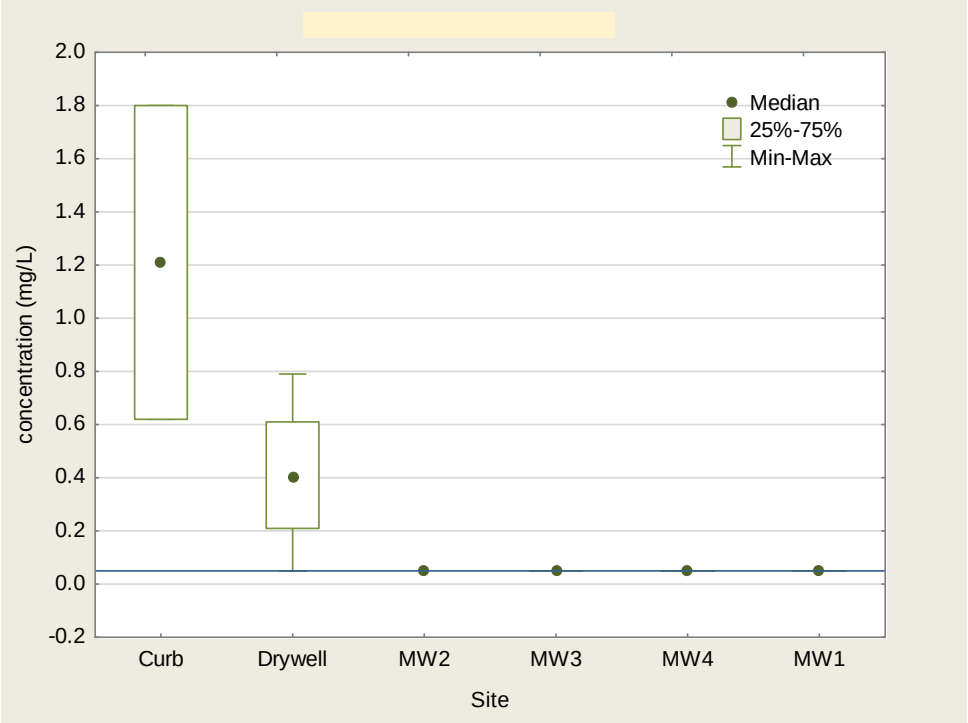


Figure 5.4. Concentration of Motor Oil at the Corporation Yard. Notations are the same as Figure 5.2. Motor oil concentrations in stormwater and groundwater were not significantly different at the CY ($p = 0.10$) due to the small sample size (n=2--5).

were commonly observed during monitoring events at the CY. None was detected in groundwater. The median concentration declined three-fold as runoff moved through the grassy swale (difference between curb and dry well as presented **Figure 5.4)**. None was detected in the subsurface samples (MW2, 3, and 4) downgradient of the dry well. The pattern of motor oil detections were similar at SDB (not shown). Motor oil concentrations were effectively diminished by the vegetated pretreatment features and are unlikely to pose a risk to groundwater quality.

Acetone: Elevated concentrations of the volatile organic acetone was detected in stormwater entering the grassy swale at the CY, but fell to just above the reporting limit by the time stormwater entered the dry well (**Figure 5.5**). None was detected at SDB or in groundwater at the CY. Acetone is a highly water soluble volatile organic compound, therefore this significant reduction is most probably due to volatilization that occurred as stormwater flowed through the grassy swale and sedimentation well. The source of acetone at the CY is likely gasoline or solvents used during vehicle maintenance. The high concentrations of both acetone and motor oil detected in stormwater at the CY suggests that vehicle maintenance facilities might not be appropriate places to use dry wells. In states with established dry wells/UIC programs such as Washington and Oregon, dry wells are not permitted in such locations.

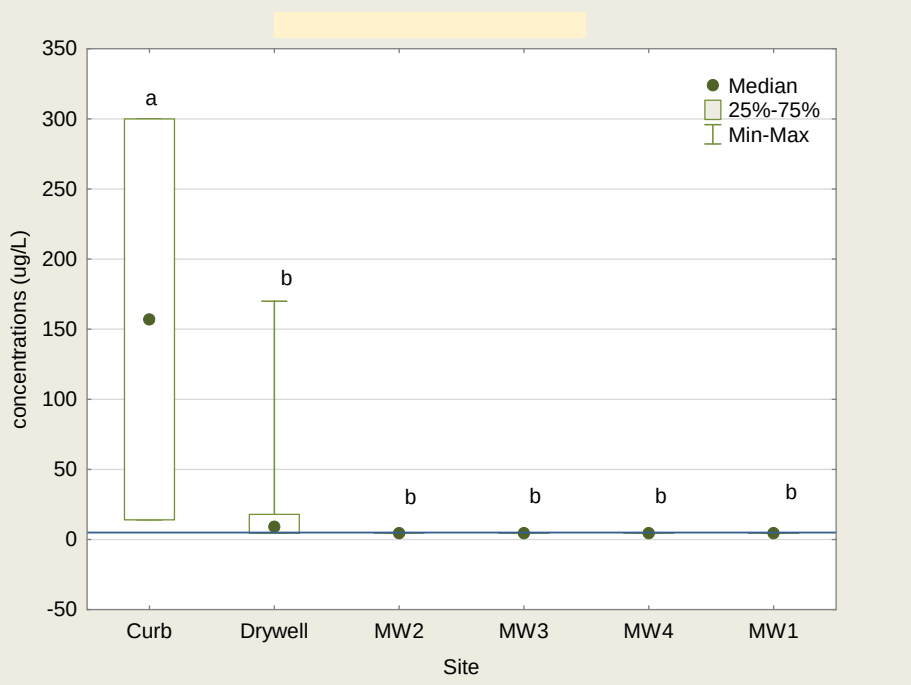


Figure 5.5. Concentration of Acetone at the Corporation Yard. Notations are the same as Figure 5.2 No regulatory or advisory values have been established for acetone.

5.3.2 Metals

Metals were the primary class of contaminants detected in stormwater and groundwater samples at both sites. Of the 20 drinking water metals analyzed, numerous metals were detected at concentrations that fell below the reporting limits. A smaller number were detected at quantifiable concentrations. These metals can be

grouped into two categories: 1) contaminants that are anthropogenic and were elevated in stormwater and 2) contaminants that are naturally occurring and were elevated in groundwater. Aluminum was the primary metal that fell into the first group while arsenic and chromium fell into the second group.

In many cases, the concentrations of metals dropped by greater than 50%, in some cases by as much as 300% as the contaminants passed through the vegetated pretreatment features. Due to the limited number of composite samples collected at the curbcut and stormwater outfall (n=2), the ability to identify statistical significance was challenging. While statistically significant differences in concentrations of various metals and other contaminants could not be documented, the differences were nonetheless environmentally meaningful. Metals are typically particle-bound, and therefore tend to follow a similar pattern of removal as TSS, as is the case with aluminum.

Aluminum: Significant concentrations of aluminum were detected in stormwater at the CY. On multiple occasions, aluminum levels exceeded the MCL of 1,000 µg/L in stormwater, reaching as high as 3000 µg/L (**Figure 5.6**). After passing through the grassy swale, the concentration decreased by greater than two-fold, although median concentration remained elevated. Only occasional detections were observed in upgradient and downgradient water table wells at the CY.

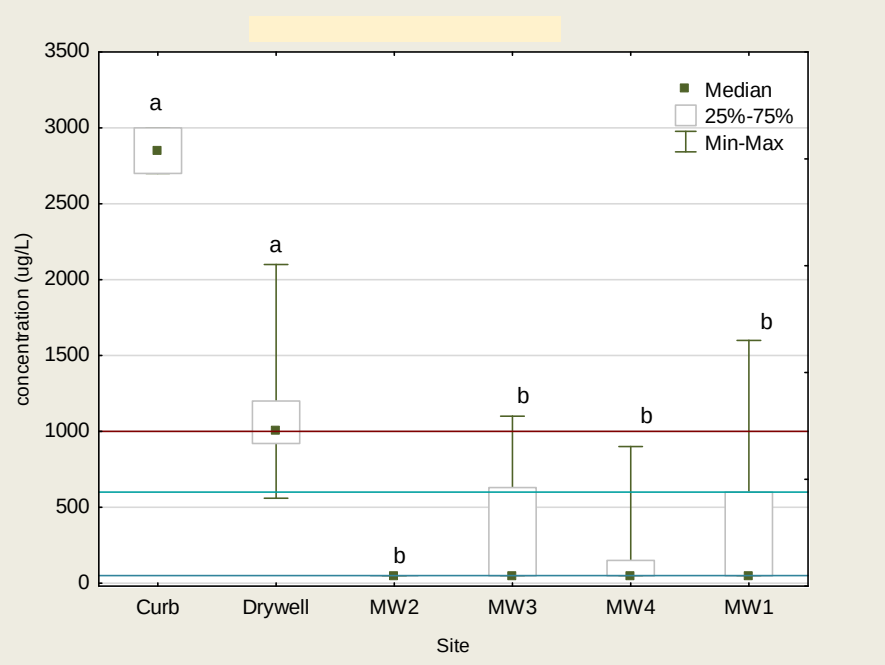


Figure 5.6. Aluminum Concentrations in Stormwater and Groundwater at the Corporation Yard. Units of concentration are µg/L. The blue line indicates the reporting limit; the red line indicates the MCL; and the teal blue line is the PHG. Other notations are the same as Figure 5.2.

At SDB, the stormwater samples with detectable concentrations of aluminum were about 1/3 of those at the CY (**Figure 5.7**). The vegetated pretreatment was effective at sequestering aluminum in stormwater, reducing its concentration by about 50%. As observed at the CY, only occasional detections in groundwater were observed in both upgradient and downgradient wells. On a few occasions, the concentration of aluminum at the water table exceeded the Public Health Goal (PHG), but these were upgradient wells at both the CY and SDB, suggesting the source of aluminum was not stormwater infiltrated through the dry wells.

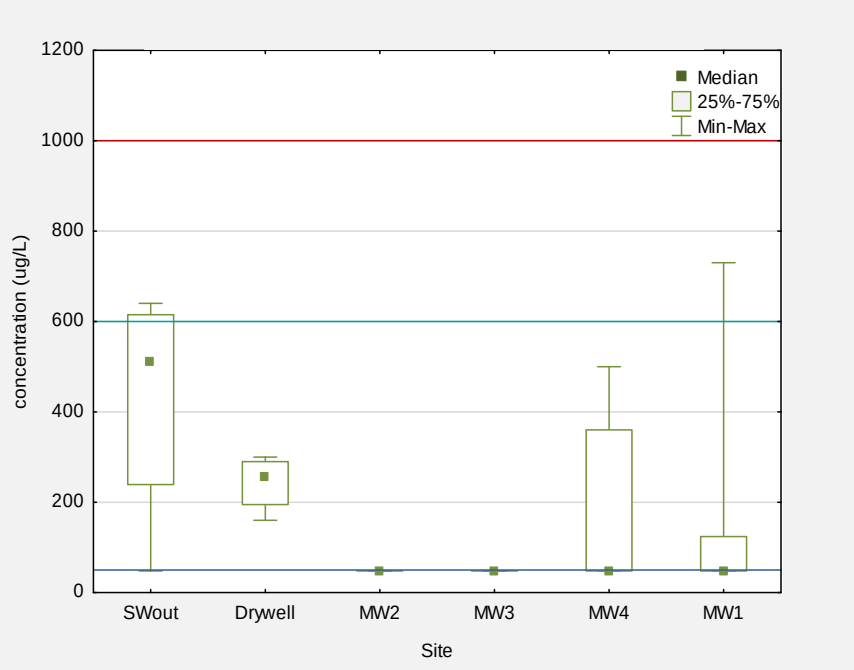


Figure 5.7. Aluminum Concentrations in Stormwater and Groundwater at the Strawberry Creek Water Quality Basin. Notations are the same as Figure 5.6. Units of concentration are µg/L.

Modeling results suggest that aluminum would not reach the aquifer at detectable levels for greater than 3,000 years (see **Section 5.7**). The results of contaminant monitoring and modeling both suggest that it is highly unlikely that aluminum would pose risk to groundwater quality.

Chromium and Arsenic: The second group of metals, arsenic and chromium, are naturally occurring and have a higher concentration in groundwater than stormwater. Both contaminants followed the same pattern and neither were detected in stormwater at either site. For example, total chromium concentration fell at or below 10 µg/L in groundwater, the MCL for hexavalent chromium. Because the ratio of hexavalent : trivalent chromium can be as high as 95:5, when chromium concentrations reach 10 µg/L, it would be possible for 95% to be present as hexavalent chromium. Thus 10 µg/L served as the trigger for the analysis of hexavalent chromium (**Figure 5.8,** on the following page).

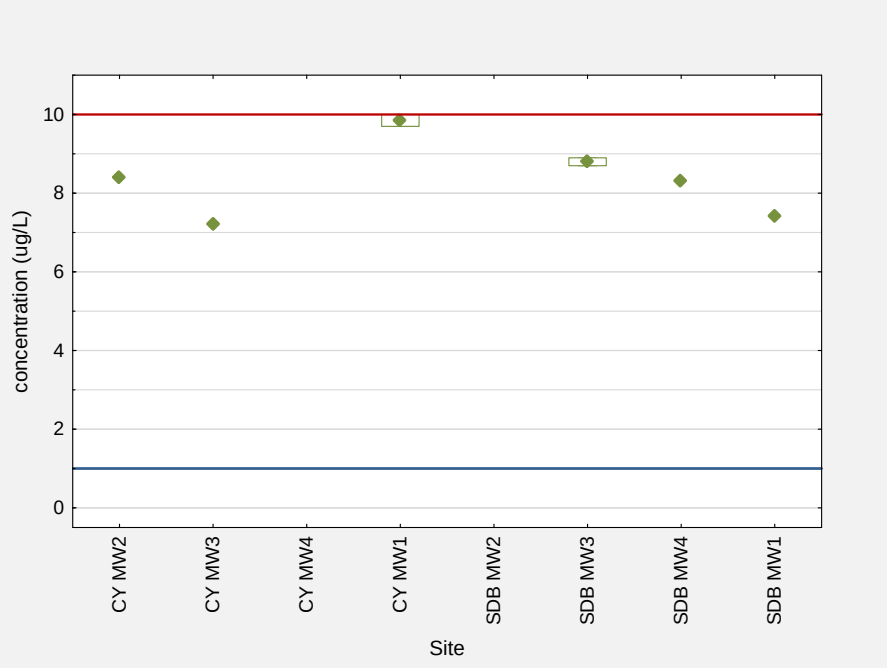


Figure 5.8. Hexavalent Chromium Concentrations in Groundwater at Both Sites. Notations are the same as Figure 5.6. The highest concentration, 10 ug/L, was measured on a single occasion in a sample from the upgradient monitoring well at the CY. The MCL for hexavalent chromium is 10 µg/L.

The other major toxic metal found in groundwater was arsenic. The pattern of arsenic concentrations in runoff and groundwater followed that of chromium; it was significantly higher in groundwater than stormwater (**Figure 5.9**). No differences were seen in any of the monitoring wells at the CY as was the case at SDB (data not shown). Typical groundwater concentrations were four-fold below the MCL.

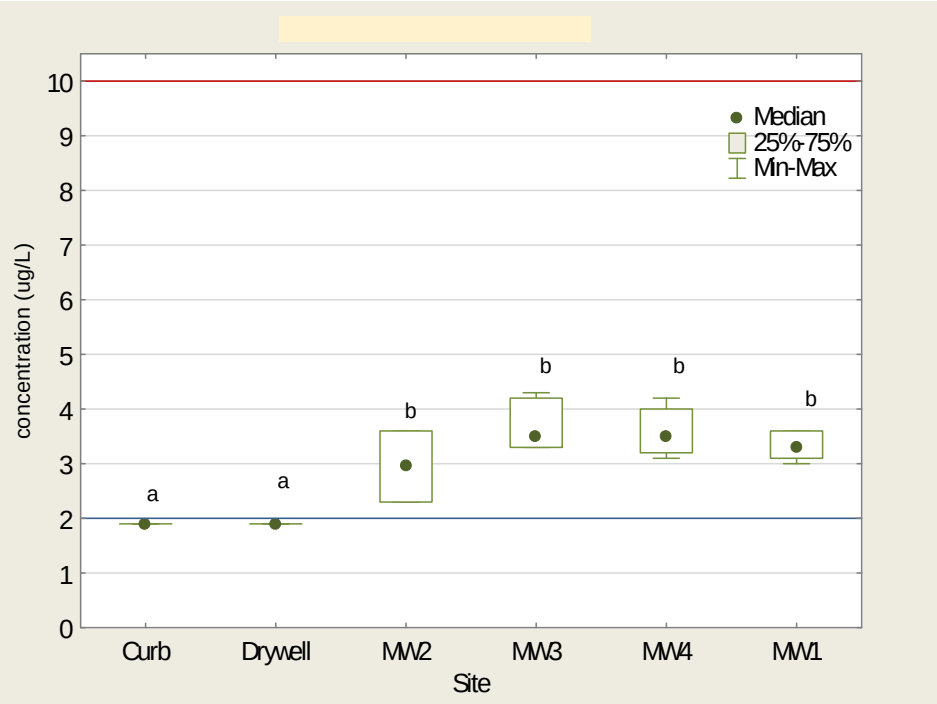


Figure 5.9. Arsenic Concentrations in Stormwater and Groundwater at the Corporation Yard. Notations are the same as Figure 5.6.

Arsenic concentrations ranging from 0.50 to 4.4 µg/L were measured at both sites. This range of concentrations is common in the Sacramento region (based on review of the GAMA database) and does not exceed the MCL of 10 µg/L for As.

In summary, there is no evidence that metals posed a risk to groundwater quality. Further, modeled simulations extended for up to 3,000 years suggested that metals are unlikely to reach the aquifer at levels that are detectable (see **Section 5.7**). The details of this analysis can be found in the UC Davis Technical Memorandum (**Appendix 5.2**).

5.3.3 Coliform Bacteria

High levels of coliform were reported at both sites in stormwater and groundwater. In stormwater, bacteria concentrations >1600 MPN[1]/100 ml were reported on more than one occasion (**Figure 5.10**). Most of the detections of coliform in subsurface water samples that came from the vadose zone well, with three exceedances in a groundwater table well at SDB. While the dry well could serve as a conduit, infiltration of stormwater through the large water quality basin in which the dry well was situated is just as likely a source.

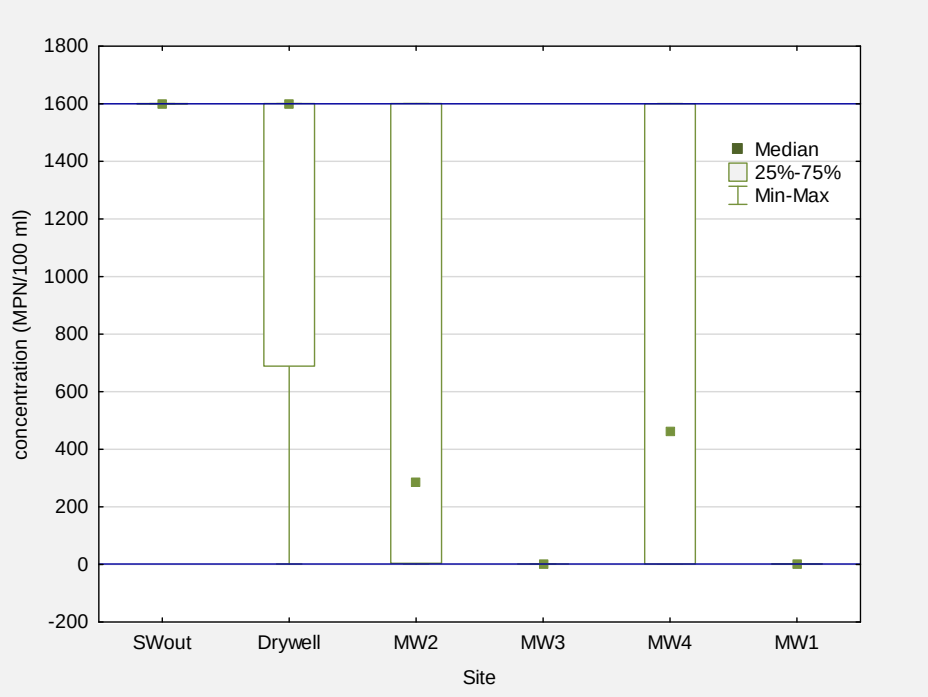


Figure 5.10. Total Coliform Concentration in Stormwater and Groundwater at Strawberry Creek Water Quality Basin. Notations are the same as Figure 5.6. n=5-10. Units are in MPN/100 ml. However, because there is an upper limit to the measurement of coliform, the blue lines reflect the lower and upper limits of quantification of total coliform.

Furthermore, dry wells are used in septic systems in the Sacramento region's rural areas which transports viable microbes in the vadose zone. This does not occur often, in fact, this is one of the reasons that dry wells should be sited a considerable distance from water supply wells to reduce risk of contamination. A more detailed summary is contained in OEHHA's Technical Memorandum (**Appendix 5.1**).

[1] MPN – most probable number of bacteria

5.3.4 Nitrate

Nitrate-nitrogen (NO_3-N) concentrations that exceeded the MCL of 10 mg/L were found consistently in groundwater sampled at the CY and SDB (**Figure 5.11 and 5.12**). At both sites, concentrations were low in stormwater, were elevated in the vadose zone well (MW2), and were significantly higher in groundwater compared to stormwater. This suggests that sources other than stormwater infiltrating through the

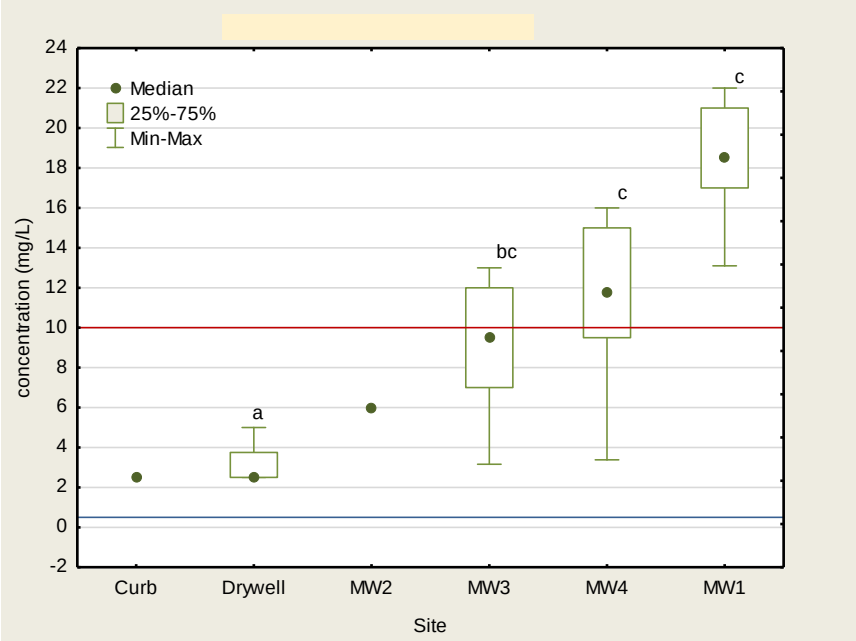


Figure 5.11. Nitrate Concentration in Stormwater and Groundwater Corporation Yard. Notations are the same as Figure 5.6. n=1-10.

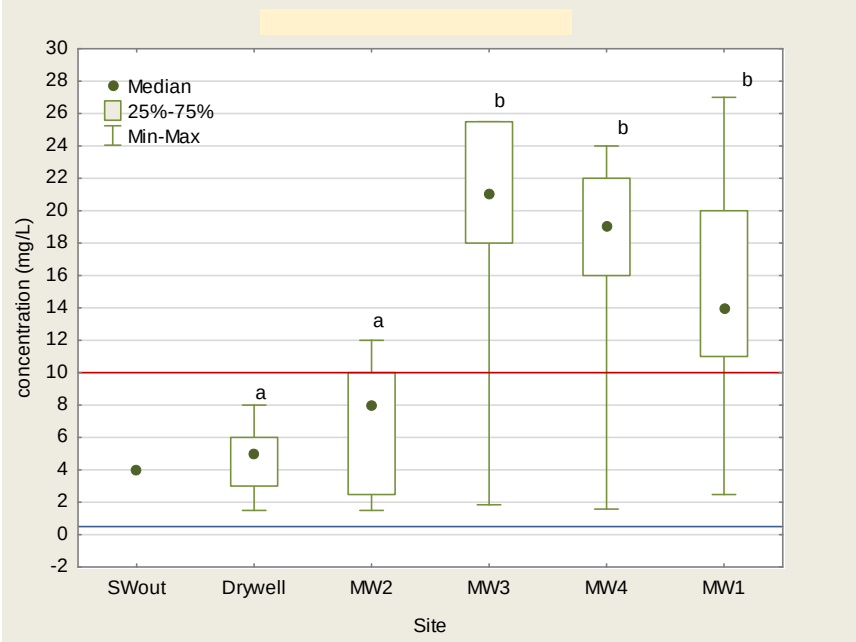


Figure 5.12. Nitrate Concentration in Stormwater and Groundwater Strawberry Creek Water Quality Basin. Notations are the same as Figure 5.6. n=1-10.

dry wells were the origin of nitrate. While we did not measured nitrate in the subsurface soils, the most likely source is legacy nitrate associated with historic agricultural activities in the Elk Grove area. Nitrate can leach out of the soil for decades after its local use ceases (Tesoriero et al. 2013; Dubrovsky et al. 2010).

In summary, the results of the analysis for nitrate in stormwater, the vadose zone, and groundwater do not suggest that runoff that passes through the dry wells contribute to the degradation of groundwater quality. Generally, nitrate was detected in the upgradient wells as frequently and at similar concentrations as in downgradient water table wells. In some cases, it appeared that stormwater had actually reduced the concentration of nitrate in the downgradient wells, which was observed at the CY, where the dry well served as the primary source of recharge. These findings are consistent with those described in scientific studies and government reports reviewed in the project's literature review (annotated bibliography) (**Section 5.11**).

5.4 Results of Groundwater Gradient Analysis

The network of water table wells that were used to obtain samples for contaminant analysis were assigned an upgradient or downgradient relationship to the dry well based on existing information from previous studies in the region. Knowledge of which wells were downgradient to the dry well affects how the results of contaminant monitoring were interpreted. To confirm these initial estimates, groundwater level data was interpolated to calculate gradients. At the CY and SDB sites, the relationship of the monitoring wells to the dry wells was categorized as the upgradient well as MW1; and the two downgradient wells, MW3 and MW4 (**Table 5.1**). However, results of the gradient analysis showed that at SDB (**Table 5.2**, on the following page), MW1 was upgradient to the dry well in the wet season, but was downgradient in the dry season. MW3 had the inverse relationship to the dry well (**Appendix 5.3 technical email**). MW4 remained the most downgradient throughout the year. This difference altered the interpretation of nitrate data, as discussed in the previous section.

Table 5.1. Calculated Gradient Between Dry Well and Monitoring Wells at the Corporation Yard. Gradients were calculated when mounding near the dry well was observed in the interpolated groundwater level data. These data were based on the high point of the interpolated groundwater surface in the vicinity of the dry well. The slope of the upgradient wells is not identified, just referred to as upgradient.

	Distance to Dry Well (feet)	2/1/2015	5/16/2015	10/1/2015	2/15/2016	5/9/2016
CY-MW1	191.4	Upgradient				
CY-MW3	76.71	0.000417	0.000534	0.000612	0.000646	0.000557
CY-MW4	84.39	0.000712	0.000932	0.000898	0.00051	0.000113

Table 5.2. Calculated Gradient Between Dry Well and Monitoring Wells at Strawberry Creek Water Quality Basin.

	Distance to Dry Well (feet)	2/1/2015	5/16/2015	10/1/2015	2/15/2016	5/9/2016
SDB-MW1	325.04	upgradient	0.000196	0.000241	Upgradient	0.000244
SDB-MW3	58.69	0.001547	upgradient	upgradient	0.001635	upgradient
SDB-MW4	44.08	0.002068	0.000075	0.000122	0.002257	0.000147

5.5 Flow Measurement Methods and Results

To measure water levels in the dry well and monitoring wells, pressure transducers (water level gauges) were installed at three locations at each site. The locations were 1) within the pipe in the middle of the dry well, 2) at the top of the dry well within the gravel layer, and 3) within the sedimentation well. Data from the pressure transducers was used to determine stage and flow through the dry well. In addition, pipes with orifices, holes ranging between 0.5-2.5" were used to control inflow into the dry well, described in detail in OEHHA's Technical Memorandum (**Appendix 5.1**).

Flow measurements, the rate at which water moved through the dry well, were calculated for each rain event (**Table 5.3**). The average flow rate at the CY was 15 gpm with a high of 26.38 gpm (0.06 cfs). This very modest rate of

Table 5.3. Flow Rates and Infiltration Volumes through the Dry wells, 2015-16 Water Year. Average flow rates through the dry wells at the CY and SDB, based on estimates made under near-static conditions. Estimates for total precipitation were made from rain gauges at each site, except at SDB in March and April, 2016 when rain gauges were vandalized. In these cases, rain amounts were collected from the closest county monitoring gauge (Laguna at Waterman).

Monitoring Event Date	Corporation Yard			Strawberry Creek Water Quality Basin		
	Average Flow (gpm)	Total Volume Infiltrated (gallons)	Total Rainfall (inches)	Average Flow (gpm)	Total Volume Infiltrated (gallons)	Total Rainfall (inches)
11/2/2015	8.46	1,100	0.085	46.72	28,400	0.53
1/5/2016	26.38	8,400	0.93	36.09	9,200	1.09
3/4/2016	10.41	1,600	0.20	21.54	3,200	0.2
4/22/2016	14.29	1,300	0.22	20.15	2,500	0.2

flow was associated with a number of factors including: 1) the small volume of runoff in the drainage shed (parking lot), 0.64 acres, 2) the relatively small size of many rain events, and 3) the composition of the vadose zone, which had only a few geologic units that could accept water.

The average flow rate at SDB was 31 gpm. The highest rate was 47 gpm, or about 0.1cfs, the rate used by some professionals as the design standard. As the rainy season progressed, the flow measurements through the dry well decreased by greater than 50%, with a concomitant decline in the volume of stormwater that passed through the dry well (**Table5. 3**). These decreases appear to be primarily linked to saturation of the vadose zone associated with infiltration into the water quality basin independent of the dry well, although soil saturation was not directly measured at SDB. The lithology at SDB was comprised of many clay layers and minimal gravel and sand layers. In an area with greater number of gravel and sand layers, subsurface saturation might not become an issue. Data from SDB calls into question the value of using dry wells in locations that are likely to become saturated quickly.

In contrast to the SDB, the area surrounding the dry well at the CY was 95% impervious, providing little opportunity for water to enter the subsurface unless it flowed through the dry well. Therefore, it was highly probable that the vadose zone remained unsaturated throughout the winter, playing little role in limiting the infiltration rate. At the CY, the size of any single storm event was the primary driver of infiltration rate and volume.

5.6 Stormwater and Groundwater Connectivity Modeling and Results

Verification of a hydraulic connection between the dry well and the water table, where samples were collected, was important. This connection helped to validate a possible pathway for contaminants present in runoff to reach the water table. One dimensional modeling (described in **Section 5.7**) of chloride movement through the vadose zone was used to make this assessment. Since chloride travels with water, it can serve as a useful marker for the movement of water. Results suggested it would take one to three days at the SDB and three days at CY for runoff released from the dry well to reach the water table. The travel time is presented as a range, dependent upon values used to estimate hydraulic conductivity of the various geologic units. In other words, in less than 1 week at both sites, water that infiltrated through the dry well is likely to reach the water table. Factors such as runoff volume, rain intensity, and degree of saturation in the vadose zone would also influence the timing.

5.7 Fate and Transport Modeling and Results

Contaminant transport modeling, using HYDRUS 1D for a 3,000 year timeframe, was performed to estimate the long-term risks to groundwater quality associated with the use of dry wells. Eight scenarios were assessed for each stormwater contaminant at concentrations measured at the dry well, using a range of values for key parameters. Most of the variables used were sediment hydraulic or contaminant chemical properties

that affect transport through the vadose zone, such as fractional organic carbon and hydraulic conductivity.

Results of the vadose zone modeling suggested that most contaminants are unlikely to ever reach the water table (**Table 5.4**). Included in this group are aluminum, bifenthrin,

Table 5.4. Modeling Results for Selected Contaminants at the Corporation Yard and Strawberry Creek Water Quality Basin

Contaminant and Input Concentration Corporation Yard	Travel Time to water Table (Reporting Limit)	Worst Case Time to Regulatory Level	Worst Case Peak Concentration at Water Table in 500 Years
Aluminum 0.042 mg/L	ψ	ψ	0.04 mg/L
Diethylhexyl phthalate 0.062 ug/L	ψ	ψ	0.06 ug/L
Iron 0.16 mg/L	7 years	ψ	0.160 mg/L
Mamganese 10 ug/L	ψ	ψ	10 ug/L
Permethrin 2.4 ng/L	ψ	n/a	1.70 ng/L
Tert-butyl alcohol 19 ug/L	12 days	12 days*	18 ug/L
Fipronil 0.5 ug/L	134 days	n/a	0.47 ug/L
Imidacloprid 0.9 ug/L	17 days	n/a	0.85 ug/L
Strawberry Creek Water Quality Basin			
Aluminum 0.006 mg/L	ψ	ψ	0.006 mg/L
Bifenthrin 11 ng/L	470 years	n/a	10 ng/L
Iron 42 µg/L	ψ	ψ	42 µg/L
Mamganese 14 ug/L	ψ	ψ	14 ug/L
Tert-butyl alcohol 20 ug/L	19 days	4 days*	20 ug/L
Fipronil 0.5 ug/L	154 days	n/a	0.47 ug/L
Imidacloprid 0.9 ug/L	20 days	n/a	0.89 ug/L

their high water solubility, these pesticides are unlikely to be adsorbed by particles, thus not removed from stormwater via sedimentation. Modeling results suggests they have a very short transit time. There is a need for additional analysis to determine their concentration and distribution in stormwater runoff and the most effective pretreatment as well as to understand the risk they might pose to groundwater quality. The majority of common urban contaminants (i.e., metals, most pesticides, volatile and semi-volatile organics, motor oil) will either degrade, volatilize, or be sequestered in the vadose zone and do not pose a risk to groundwater quality for the indefinite future. Further discussion of modeling results is presented in OEHHA's Technical Memorandum (**Appendix 5.1**) and UC Davis Technical Memorandum (**Appendix 5.2**)

5.8 Mobilization of Naturally Occurring Contaminants

In a study performed in Modesto by the USGS, Jurgens et. al. (2008), reported that the naturally-occurring uranium was mobilized by constituents in stormwater. This report raised concerns that similar processes might affect arsenic or chromium at the project locations. Both metals are found in geological units bound to commonly occurring metals such as iron and aluminum. Oxidation-reduction reactions associated with influent bicarbonate, oxygen, iron, and/or manganese can alter the valence state of the metals that arsenic or chromium are bound to, thus releasing these toxic compounds. Ion exchange reactions associated with sulfides or iron can also cause mobilization of aluminum and chromium. To investigate this possibility, the concentrations of aluminum and chromium in upgradient and downgradient water table wells was compared as well as the relationship between key redox metals such as iron and manganese, and aluminum and chromium (**Appendix 5.4, Technical Memorandum**).

No significant differences in upgradient and downgradient wells were found for either metal, suggesting that mobilization of aluminum and chromium as a result of stormwater influx was unlikely. Correlation analysis was used to assess the relationship between metals involved in aluminum or chromium mobilization. Concentrations of aluminum or chromium in groundwater revealed no significant relationship with one exception; a weak correlation, influenced by a few data points, was detected between iron and arsenic and is presented in **Figure 5.13**, on the following page. This finding suggests further analysis of the potential for metal mobilization would be warranted.

5.9 Effectiveness of Vegetated Pretreatment Features

In most cases, vegetated pretreatment was effective at reducing contaminant concentrations before stormwater runoff entered the dry well. The structural

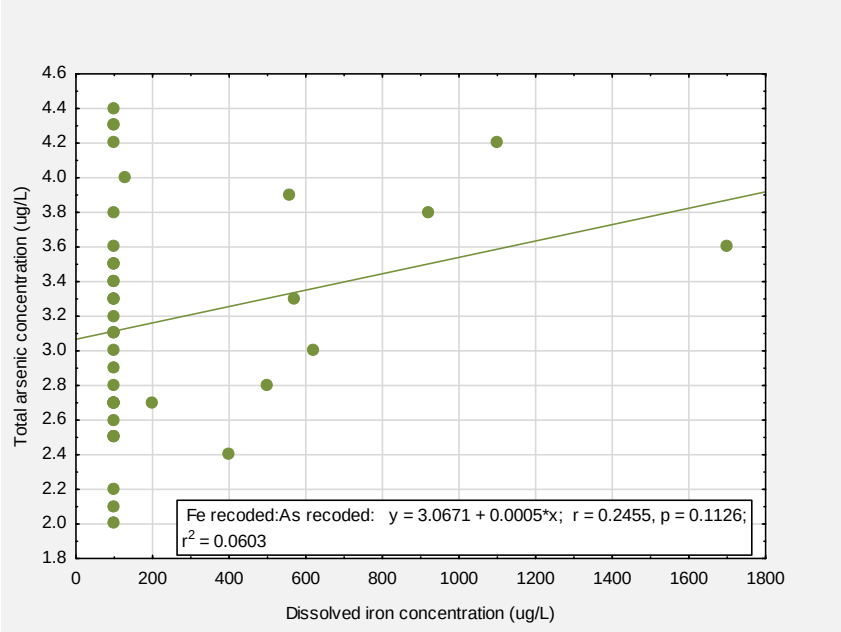
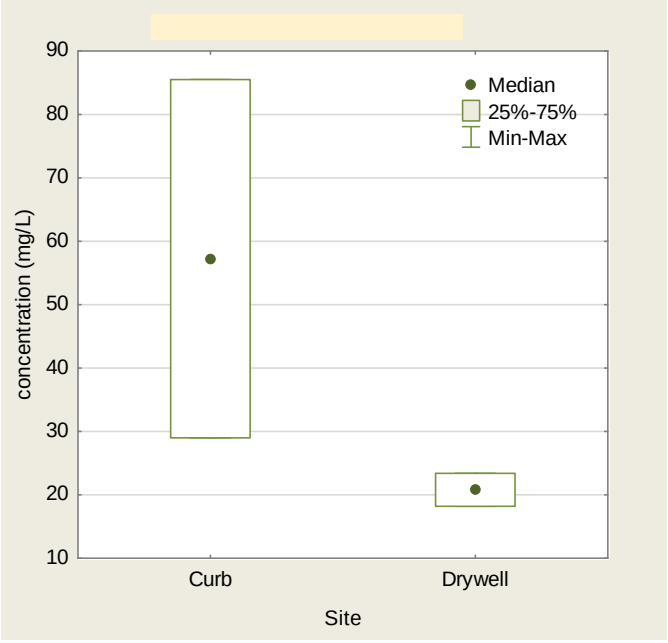
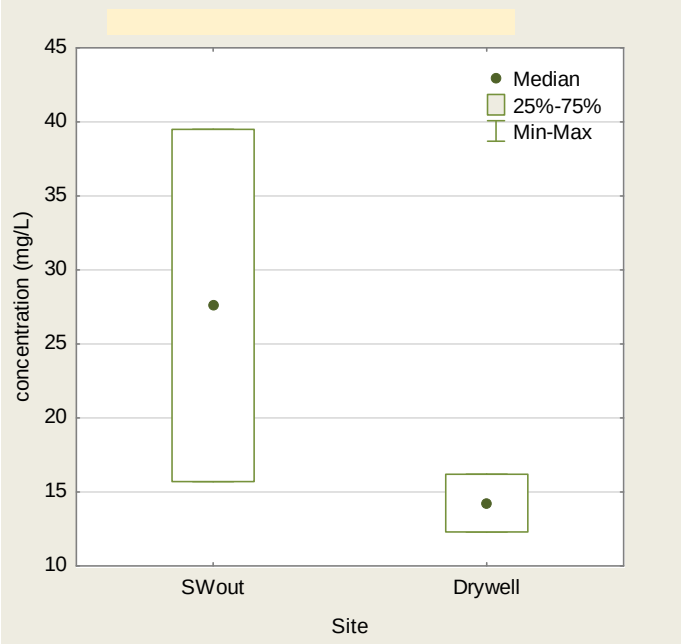


Figure 5.13. Relationship Between Dissolved Iron and Total Arsenic in Samples Collected from Water Table Wells at the Corporation Yard and Strawberry Creek Water Quality Basin. A weak correlation was detected, strongly influenced by a few data points.

pretreatment feature, i.e., sedimentation well, was ineffective at capturing sediment due to insufficient depth. Therefore, the assumption was made that the overwhelming majority of pollutant load reduction that was observed was associated with either the grassy swale at the CY or the water quality basin at the SDB. TSS concentration was the primary marker used to assess pretreatment efficiency (**Figures 5.14 and 5.15**).





Figures 5.14 and 5.15. Total Suspended Solids at the Corporation Yard (left) and Strawberry Creek Water Quality Basin (right). TSS concentration at the curbcut (Curb) or stormwater outfall (SWout) at the CY and SDB. Notations are the same as Figure 5.2.

The water quality basin removed about 50% of TSS, which is in the lower 25th percentile of national data (median value = 65%; International Stormwater BMP database, 2014). TSS were reduced by 63% while passing through the grassy swale at the CY, similar to national averages. Whereas the vegetation in the water quality basin varied with inconsistent coverage, vegetation in the swale was composed of long grass with uniform coverage. This might explain the higher TSS removal efficiency at the CY.

In general, removal efficiency is not a reliable metric due to the multiple confounding factors that influence the estimate (Wright Water Engineers and Geosyntec Consultants, 2007). Percent removal is often more reflective of how "dirty" the influent stormwater runoff is rather than how well the BMP is actually performing, Further, outliers often dominate the averages used in the calculation. Given these limitations, the results for percent removal at the CY and SDB should be viewed as rough estimates.

5.10 Volume and Pollutant Load Reduction Results

The total cumulative volume of stormwater that was captured in the dry wells at each site during the 2015-16 water year was estimated to be 61,200 gallons at the CY and 216,900 gallons at the SDB. This is equivalent to approximately 0.2 AF/year at the CY and 0.7 AF/year at SDB. This very large difference is primarily related to the volume of runoff, which is linked to the size of the two drainage sheds. Therefore, the mass of pollutants diverted from local waterways, based on one year's worth of data (2015-16) was significant. A total of 1,850 grams of aluminum, about 2,000 grams of iron, almost 14 mg of bifenthrin, and about 46 kg of sediment were diverted. Detailed information on pollutant reduction is contained in OEHHA's Technical Memorandum (**Appendix 5.1**).

5.11 Scientific Literature (Annotated Bibliography)

Part of the analytical work performed for this project involved reviewing the scientific literature and government reports.

A scientific literature review (annotated bibliography) was prepared that reviewed literature from the 1980s to the present on the risks of groundwater quality degradation associated with the use of dry wells. Three high quality studies stood out among those reviewed. The first was conducted by the US EPA to determine if existing federal UIC regulations were sufficient to mitigate risks to underground sources of drinking water (USDW), if additional federal regulations were necessary, and how each type of well should be regulated (US EPA, 1999). Existing literature was reviewed, contaminant spills linked to dry well documented, and practices in various states assessed. Documented cases of USDW contamination associated with dry wells were rare. The conclusion drawn was that dry wells do not pose a threat to USDW and that additional Federal UIC regulations were not warranted (Federal Register, 2002).

The second important study was in-depth analysis of groundwater and drinking water quality in Modesto, CA (Jurgens et al., 2001). Dry wells without pretreatment have been

in use in Modesto since the 1950s, and as a consequence, this study sheds light on the potential long-term effects of infiltrating runoff through dry wells. The investigators found that common urban contaminants analyzed in groundwater did not exceed their MCLs. The only two contaminants detected above the MCLs, uranium and nitrate, were associated with the geology of the region and historic agricultural practices, respectively. Key organic and metal contaminants examined in the shallow and intermediate aquifer zones were associated with agriculture, not urban land use. However, elevated alkalinity, a product of both agricultural and urban irrigation practices, increased desorption of uranium from aquifer sediments. This observation raised the question of mobilization of harmful metals such as arsenic or chromium with long-term use of dry wells.

The third, the Water Augmentation study (The Los Angeles and San Gabriel Rivers Watershed Council (LASGRWC), 2005) was conducted to assess the potential for stormwater infiltration practices to contaminate groundwater as well as to assess the volume of water that could be collected for recharge. The study included two sites with dry wells: one commercial and one residential. All pollutant concentrations in groundwater at the commercial site showed variable or statistically significant negative trends over time, suggesting that pollutant concentrations did not build up in the groundwater over the six year period of the study. Furthermore, the negative trends observed suggest that pollutants might actually be diluted by influent stormwater. At the residential site, a few contaminants were detected at higher concentrations in the vadose zone than in stormwater, however, their concentrations declined over the course of the study, suggesting that stormwater infiltration was not responsible for their presence. Groundwater samples were not collected at the residential site.

In addition to the three studies evaluated, two field studies in Arizona performed stormwater, sediment, vadose zone, and groundwater monitoring to assess potential risks linked to stormwater infiltrated via dry well. Both studies found that metals were adsorbed or attenuated in the vadose zone and that pollutants, particularly semi-volatiles, appeared to undergo adsorption or volatilization in the dry well settling chamber over time (Wilson et al., 1989; Olson, 1987). Additional reports included studies in Arizona, Hawaii, Montana, New Jersey, Oregon, Washington, and Wisconsin. These reports addressed issues of dry well design, siting, hydrogeology, lithology, common contaminants, pretreatment, and monitoring. The quality of these studies varies greatly. They have all been summarized in the Annotated Bibliography, available on the project's website (link below). A more detailed summary is presented in OEHHA's Technical Memorandum (**Appendix 5.1**).

http://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/Annot%20Biblio%20Dry%20Wells%20Final%2012_18_14.pdf

5.12 Fact Sheets

A fact sheet was written that summarizes regulations and guidelines on the use of dry well in California and other states (Dry Wells: Uses, Regulations, and Guidelines in California and Elsewhere). The key point cited in this fact sheet is that, in contrast to neighboring states that have developed programs that govern the siting, design, and permitting of dry wells, California has not yet developed a statewide program. A second fact sheet, Oregon's Experience with Dry Wells, reviewed the approach to managing underground injection control systems, including, regulations, guidelines, and the results of monitoring and vadose zone modeling. A final fact sheet was prepared summarizing the results of the project. Fact sheets are available on the project website:

http://www.elkgrovecity.org/cms/One.aspx?portalId=109669&pageId=229957

5.13 Goals and Performance Targets

5.13.1 Goal No. 1

The project met the goal of assessing the potential for groundwater contamination associated with the use of dry wells, as described in this chapter. There was no evidence that stormwater passing through the dry wells introduced contaminants into groundwater (**Table 5.5**).

Table 5.5. Contaminants in Groundwater that Exceeded the Criteria Values.

Contaminant	Location of Detection Above Criteria Value	Explanation	Evidence for Dry Well Linked Degradation
Aluminum	CY MW1 and MW3	Both upgradient and downgradient wells had a single measurement above the MCL. Aluminum was unlikely to reach aquifer at detectable levels within the modeling timeframe (3,000 years).	Negative
Iron	CY MW1, MW3, and MW4; SDB MW1 and MW4	Both upgradient and downgradient water table wells had some detections above the secondary MCL. Modeling suggested that it would take a 7 year travel time to reach aquifer at detectable levels at the CY and >3000 years at SDB.	Negative
Vanadium	All water table wells at CY and SDB	Upgradient and downgradient water table wells exceeded notification levels and the concentration similar to other wells in region.	Negative
Manganese	SDB MW3 and MW4 (downgradient)	Median values in stormwater and down-gradient wells were < reporting limits and a few values exceed the secondary MCL in groundwater; which is unlikely to reach the	Negative

		aquifer at detectable levels.	
Nitrate	SDB and CY MW1, MW3, and MW4	All water table wells exceeded MCL. Very low concentrations in stormwater and historic agricultural use in area suggests legacy nitrate.	Negative

5.13.2 Goal No. 2

The second goal was to assess the effectiveness of various pretreatment features at removing suspended solids and associated contaminants from stormwater. As noted earlier, the sedimentation well was not sufficiently deep to permit settling of suspended material. Therefore, vegetated pretreatment was the primary mechanism of pollutant removal prior to water entering the dry well. Decreases in concentration of contaminants as water passed through the grassy swale or water quality basin were observed with almost all of the contaminants detected. There were numerous cases where a large reduction in concentrations, on the order of two-three-fold, was observed. However, due to the small sample size (n=2 where influent stormwater was measured), statistical analysis could not be performed on the data so statistically significant differences could not be evaluated.

Another aspect of Goal No. 2 was to determine how often the dry well system would require cleaning. Because the sedimentation well did not function properly, sediment did not accumulate and no maintenance was required. The experience of those in neighboring states suggests that vacuuming the sedimentation well to remove accumulated sediment and debris would be required every few years. In the dry well itself, small amounts of debris accumulated on the top of the gravel layer. It was estimated that yearly inspections to assess the need for debris removal from the top of the dry well should be sufficient.

5.14 Discussion and Conclusion

Two different stormwater and groundwater contaminant patterns were observed: one in which the concentration of contaminants were elevated in stormwater but low in groundwater and the reverse, where contaminants were elevated in groundwater but detected at low levels or not at all in stormwater. These patterns are consistent with the findings of LASGRWC's Water Augmentation Study (2005). The first pattern was observed for metals such as aluminum and manganese (at the CY); both were detected in stormwater above criteria levels but were not detected in groundwater monitoring wells. The failure to detect contaminants in groundwater samples is linked to both effective sequestration by the pretreatment feature and attenuation in the vadose zone primarily by clay units.

Vadose zone modeling suggested that it would take many hundreds of years for some contaminants to reach the water table and others contaminants never will. For example, modeling results indicated that aluminum and manganese would not reach

the water table at detectable levels within the 3,000 year model timeframe. These and similar findings raise a question of the value of monitoring the groundwater given the extended, in some cases indefinite, period of migration of many contaminants. This appears to be the conclusion that the Department of Environmental Quality in Oregon has reached. They require vadose zone modeling and stormwater sampling, but not groundwater monitoring to ensure groundwater safety for their UIC systems.

The second pattern observed was that of the naturally-occurring metals such as arsenic and chromium. Concentrations of these metals was higher in groundwater than In stormwater. While stormwater did not contribute to their elevated concentrations, it could increase the risk of desorption due to exposure to constituents such as bicarbonate and iron in stormwater. A preliminary analysis of redox reactions that could result in increased solubility of arsenic or chromium was performed. Results suggest that it is desorption is unlikely to occur because the relevant constituents in stormwater are not present at the sufficiently high concentrations to cause solubilization or desorption reactions. However, this analysis had a number of limitation. Additional analysis is recommended to determine the likelihood these reaction might occur over many years.

Additional research on two contaminant-related issues would be useful to further characterize the risks associated with dry well use. First, development of risk reduction strategies related to water soluble pesticides such as fipronil and imidacloprid would be valuable. These pesticides appear to have short transit times through the vadose zone; therefore removal prior to entering the dry well (pretreatment) is the key to protecting the aquifer. Further information is needed on their concentration and association with various urban land uses. Since these pesticides are unlikely to be captured by sedimentation, identification of the nature of vegetated pretreatment that would work best to reduce their concentration in stormwater runoff would be very useful. Second, greater knowledge of the risk of desorption of naturally-occurring arsenic and chromium would also increase confidence in using dry wells. While the preliminary analysis performed as part of this project did not find evidence of desorption, a longer-term and more carefully-crafted study would be helpful to bolster this preliminary data.

Infiltration rates at the two sites varied. At the CY, they were quite modest, while at SDB they reached rates used as industry standards (0.1 cfs). An estimate of the average amount of stormwater that might be infiltrated in a historically average winter, 18 inches of precipitation in the Sacramento region, suggested that approximately 1 acre/foot/year per dry well could be recharged. If the highest infiltration rate was used to make this estimate, greater than 3 AF/year per dry well could be recharged. This is not an unrealistic estimate because saturation of the vadose zone likely reduced the rate of infiltration at SDB. Although this value would vary depending on the lithology at a site, the drainage shed area, and the actual

amount of precipitation, it suggests that dry wells can be used to obtain meaningful recharge volumes.

References:

Bandeen, R.F. 1987. Additional case study simulations of dry well drainage in the Tucson basin." Pima County Transportation and Flood Control District. Tucson, Posted at: http://arizona.openrepository.com/arizona/bitstream/10150/306934/1/wrrc_219.pdf

Barraud, S., Gautier, A., Bardin, J.P., and V. Riou. 1999. The impact of intentional stormwater infiltration on soil and groundwater. Wat. Sci. Tech 39 (2): 185-192.

City of Portland Underground Injection Control Program documents. Posted at: https://www.portlandoregon.gov/bes/50442

Dallman, S. and M. Spongberg. 2012. Expanding local water supplies: Assessing the impacts of stormwater infiltration on groundwater quality. The Prof. Geographer. 64: 1 – 18.

Dubrovsky NM, Burow KR, Clark GM, Gronber JM, Hamilton PA, et al.. 2010. The quality of our nation's waters: Nutrients in the nation's streams and groundwater, 1992–2004. Circular 1350. Reston, VA: U.S. Geological Survey. Posted at: http://pubs.usgs.gov/circ/1350/.

Federal Register. 2002. Underground Injection Control Program—Notice of Final Determination for Class V Wells; Final Rule. 40 (144): 39584-39593.

HydroSystems Inc. 2011. Advances in Stormwater Drainage - The MaxWell Plus Drywell; A Case Study in Phoenix Arizona. Consultant report prepared for Torrent Resources.

Jurgens, B.C., K.R. Burow, B.A. Dalgish, & J.L. Shelton. 2008. Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public-supply well in Modesto, eastern San Joaquin Valley, California. National Water Quality Assessment Program, U.S. Geological Survey, Scientific Investigation Report 2008-5156.

Li, X. 2017. Possible mechanisms for the mobilization of arsenic and chromium in the groundwater due to stormwater infiltration through dry wells. Technical Memorandum submitted to OEHHA.

Lindemann, J. 1999. Evaluation of Urban Runoff Infiltration and Impact to Groundwater Quality in Park Ridge, Wisconsin. Master's Thesis, College of Natural Resources, University of Wisconsin, Stevens Point, Wisconsin.

Office of Environmental Health Hazard Assessment. 2016. Dry Wells and the Risk of Groundwater Contamination: An Annotated Bibliography. California Environmental Protection Agency. Posted at: http://oehha.ca.gov/media/downloads/ecotoxicology/document/annotbibliodrywells2015.pdf

Olson, K.L. 1987. Urban stormwater injection via dry wells in Tucson, Arizona and its effect on groundwater quality. Master's Thesis, Department of Hydrology and Water Resources, University of Arizona. Posted at: http://watershedhealth.org/programsandprojects/was.aspx

Tesoriero, A.J., Duff, J.H., Saad, D.A., Spahr, N.E., Wolock, D.M. 2013. Vulnerability of Streams to Legacy Nitrate Sources. Env Sci Tech, 47(8), 3623-3629.

The Los Angeles and San Gabriel Rivers Watershed Council. 2005. Los Angeles Basin Water Augmentation Study, Phase II Final Report. Los Angeles, CA. Posted at: http://watershedhealth.org/Files/document/265_2005_WAS%20Phase%2011%20Final%20Report_2005.pdf

US EPA. 1999. The Class V Underground Injection Control Study: Volume 3, Stormwater Drainage Wells Office of Ground Water and Drinking Water. 96 pgs. Posted at: https://www.epa.gov/uic/class-v-underground-injection-control-study

Wilson, L.G., Osborn, M.D., Olson, K.L., Maida, S.M., and L.T. Katz. 1989. The groundwater recharge and pollution potential of dry wells in Pima County, Arizona. Groundwater Monitoring & Remediation. Summer: 114-121. Posted at: http://arizona.openrepository.com/arizona/bitstream/10150/306470/1/wrrc_250_w.pdf

Wright Water Engineers and Geosyntec Consultants, 2007. Frequently Asked Questions Fact Sheet for the International Stormwater BMP Database: Why does the International Stormwater BMP Database Project omit percent removal as a measure of BMP performance? (Posted at: www.bmpdatabase.org)

Chapter 6. Education, Outreach and Capacity Building

Over the course of the project, a variety of outreach tools were developed to share information about the results of the project, as well as the findings from other government reports, studies, and programs. These outreach tools included:

1. Fact Sheets
2. Literature Review (Annotated Bibliography)
3. Guidance Document
4. Project Website
5. Presentations and Poster Sessions
6. Project Flyer/Description
7. Publications
8. Meetings with the TAC
9. Project Bulletins
10. Interested Stakeholders
11. Extended Monitoring/Capacity Building
12. Regulatory Environment

6.1 Project Goals

The goals for the Education, Outreach and Capacity Building are provided in **Table 6.1** below:

Table 6.1. Summary of Project Goals

Goals	Performance Targets
1. Conduct education and outreach to a broad audience on the use, benefits, and limitations of dry wells with pretreatment features.	1. 500 fact sheets distributed and/or downloaded. 2. 100 literature reviews (annotated bibliography) distributed and/or downloaded. 3. 100 guidance documents distributed and/or downloaded. 4. 500 visits to project website. 5. List of > 100 interested stakeholders. 6. Presentations given to a minimum of 1,000 people in a targeted audience. 7. Two or more meetings with the TAC. 8. Monitoring efforts continue past the term of the grant. 9. Analysis/reporting of project results delivered to 5 regional or state decision making bodies for the development of guidelines for dry well systems in California.

6.2 Fact Sheets

As part of the project's deliverables, two fact sheets were developed documenting findings of the project, i.e., one outlining regulatory environment for dry wells in California, and the other

fact sheet summarized the results of the project. An additional fact sheet was developed on Oregon's Underground Injection Control Program. There have been over 500 fact sheets distributed at meetings and conferences and/or downloaded from the project's website. In addition, the fact sheets have been circulated to TAC members for review and comment.

The fact sheets are included in **Appendix 6.1** and are posted on the project website. A web link is provided below for the fact sheets:
http://www.elkgrovecity.org/cms/One.aspx?portalId=109669&pageId=229957

6.3 Literature Review (Annotated Bibliography)

A literature review (annotated bibliography) of scientific and government reports on the relationship between dry well systems and groundwater quality was developed. A web link is provided below for this document and a summary of the literature review is included in Chapter 5, Section 5.11.
http://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/Annot%20Biblio%20Dry%20Wells%20Final%2012_18_14.pdf

There have been over 100 documents distributed and/or downloaded from the project website.

6.4 Guidance Document

A guidance and lessons learned document was developed to summarize the siting, design, construction, monitoring, and key findings of the project. The guidance document is included in **Appendix 6.2** and a web link is provided below.

http://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/8.4%20Guidance%20Document%2012-424-550%20City%20of%20Elk%20Grove%201_31_17.pdf

There have been over 100 documents distributed and/or downloaded from the project's website.

6.5 Project Website

A project website was developed. The website includes information about the project, including updates and notifications, project documents, and results as they became available. The documents are posted at:

http://www.elkgrovecity.org/dry well

There have been 2,360 hits to the project website as of February 20, 2017. **Appendix 6.3** provides the website tracking report.

6.6 Professional Presentations and Poster Sessions

Presentations (oral and posters) were made at various meetings and conferences. **Table 6.2** identifies each presentation and poster session and the number of attendees at the meeting or

Table 6.2. Project Presentations and Poster Sessions

	Date	Presentation Name	Venue	Attendees
1	April 4, 2012[1]	The Risk of Groundwater Quality Degradation from the Use of Dry Wells: What We Know Today	California Environmental Health Association 61st Annual Educational Symposium, Department of Pesticide Regulations Seminar	30
2	April 25, 2013	Dry Wells and Groundwater Quality	State Water Resources Control Board, Division of Water Quality – Statewide Meeting	100
3	June 25, 2013	TAC Kick-off Meeting 1. Proposition 84 Stormwater Grant Program – An In Depth Look at Next Steps 2. Separating Fact from Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds (Project Overview and TAC Roles and Responsibilities) 3. Pretreatment Features – Project Sites	City of Elk Grove and TAC Members	18
4	November 13, 2013	Assessing the Use of Dry Wells as an Integrated LID Tool for Reducing Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds	Sacramento Central Groundwater Authority	14
5	May 7, 2014	Stormwater Infiltration using Dry Wells as a Possible Adaptation to Climate Variability	24th Meeting of Society of Environmental Toxicology and Chemistry (NorCal SETAC), UC Berkeley	75
6	June 4, 2014	Stormwater Infiltration using Dry Wells as a Low Impact Development (LID) Tool	Association of State Floodplain Managers (ASFPM) 2014 Conference, Seattle, Washington	70
7	October 1, 2014	Stormwater and Groundwater Issues and Elk Grove Dry Well Project	Regional and State Water Board Member's Annual Meeting/Tour – Educational Forum	80
8	June 30, 2014	Pre-Bid Meeting – Dry Wells as a Low Impact Development (LID) Improvement Project (WDR019)	City of Elk Grove and Contactors	5[2]
9	October 23, 2014	Stormwater Infiltration using Dry Wells as Low Impact Development (LID) Tool – Project Overview and Construction Presentation/Tour	State Water Resource Control Board	12
10	November 5, 2014	Using Dry wells for Stormwater Infiltration: Assessing the Risk of Groundwater Contamination	American Basin Council for Watersheds Meeting	15
11	May 14, 2015	Dry Wells and Rain Gardens: Eco-Friendly Ways to Manage Stormwater	Stormwater Detectives Program, City of Lodi	35
12	November 4, 2015	Stormwater Infiltration using Dry Wells as a Low Impact Development Tool	Low Impact Development Conference, American Basin Council for Watersheds and CSUS's Office of Water Program	200
13	November 5, 2015	Summary of Dry Well Guidelines and Regulations in California	Central Valley Regional Board	10
14	October 19 - 20, 2016	An Evaluation of Dry Wells as Tools for Stormwater Management and Aquifer Recharge	NWRI/DWR Workshop on Drought Vulnerability and Tools for Improving Water Resilience, Los Angles	100
15	November 8, 2016	Dry Well Use for Groundwater Recharge and Stormwater Management: Lessons Learned From the Elk Grove Dry Well Project	Sacramento Chapter Groundwater Resources Association Meeting	30
16	January 9, 2017	Dry Well Use for Groundwater Recharge and Stormwater Management: Lessons Learned from the Elk Grove Dry Well Project	OEHHA and State Water Control Board	15
17	January 17, 2017	TAC Final Result Meeting - Separating Fact from	City of Elk Grove and TAC Members	14

		Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds - Final Results		
18	March 15, 2017	Stormwater Infiltration Using Dry Wells and the Elk Grove Dry	Practical Stormwater Management and Beyond the Regulations SAGE, Surveyors, Architects, Geologist, and Engineers	60
19	April 5, 2017	Elk Grove Dry Well Project	Sacramento Stormwater Quality Partnership	
20	March 16, 2017	Elk Grove Dry Well Project	Regional American River Basin Stormwater Resource Plan Collaborator Meeting	
Poster Sessions				
1	May, 2012[1]	Fact or Fiction: Is there a link between dry wells and groundwater contamination?	2012 NorCal Society of Environmental Toxicology and Chemistry 22nd Annual Meeting	75
2	May 22 - 23, 2013	Separating Fact from Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds	2013 Managed Aquifer Recharge in the Urban Environment Technical and Policy Challenges Symposium	80
3	April 16, 2014	Stormwater Infiltration using Dry Wells as a Possible Adaptation to Climate Variability	Climate Change and the Future of Groundwater in California Conference, UC Davis	120
4	December 15 -19, 2014	Assessing the Use of Dry Wells as a Tool for Stormwater Management and Groundwater Recharge in Urban Areas	2014 American Geological Union Fall Meeting	24,000[3]
5	December 14 - 18, 2015	Numerical Model Assessment of the Effects of Dry Well Facilitated Stormwater Infiltration	2015 American Geological Union Fall Meeting	24,000[3]
6	April 30, 2015	Assessing the Effect of Dry Well Aided Stormwater Infiltration on Groundwater Quality	2015 NorCal Society Environmental Toxicology and Chemistry 25th Annual Meeting	80
7	December 12 - 16, 2015	Assessment of Dry Wells as Effective Tools for Stormwater Management and Aquifer Recharge: Results of a Two-Year Field and Numerical Modeling Study	2016 American Geological Union Fall Meeting	24,000[3]

[1]Prior to Project beginning.

[2]No contractors attended the pre-bid meeting. Only City staff was in attendance.

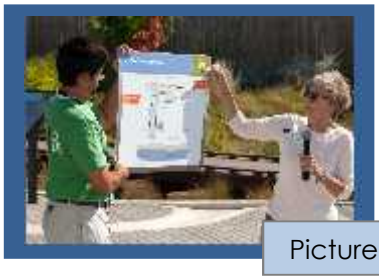
[3]Attendees for the entire conference.

conference. **Appendix 6.4** contains the presentations in handout format. The presentations and poster sessions were given to more than 1,000 people in a targeted audience. Notable presentations include:

1. ***November 13, 2013*** – Presentation to the Board of Directors of the Sacramento Central Groundwater Authority. This was an important meeting to highlight the possible uses of dry wells in the Sacramento region and initiate capacity building with this organization.
2. ***October 1, 2014*** – Presentation and annual tour for the Regional and State Water Resources Control Boards members. Speakers at this event addressed issues related to climate change, the drought and the ways in which dry wells might be useful as an adaptation tools, as well as reviewed the details of the Elk Grove Dry Well project. Pictures of the event are presented below. with opening remarks from Steve Moore, State Water Board Member (picture 1); Kelly Rivas, Field Director for Congressman Ami Bera, Senator Richard Pan, and Mayor Gary Davis, City of Elk Grove (picture 2) and project team member Barbara Washburn, OEHHA (picture 3).


Picture 1


Picture 2


Picture 3

3. ***November 4, 2015*** – Presentation at the regional LID conference. This biennial conference is for local government, planners, designers, developers, and environmental organizations to learn about strategies for integration of LID practices with sustainable planning, design, and construction.
   January 17, 2017 – Presentation and discussion on project's conclusions and findings to project's TAC.

6.7 Technical Advisory Committee (TAC) Meetings

There were two TAC meetings held. The first meeting was a kick-off meeting to describe the project, and present the TAC's roles and responsibilities. The second meeting was at the end of the project. This meeting presented the project's findings and conclusions. There were also individual meetings with TAC members throughout the project to discuss the project's findings of the first and second year of monitoring results.

6.8 Project Flyer/Description

A project description/flyer was created for the State Water Resources Control Board's Annual meeting and was distributed at that event along with other various events, conferences, presentations, and meetings. A copy of the flyer is included in **Appendix 6.5.**

6.9 Publications

A publication was published in 2016 for citation: Edwards, Emily C., Thomas Harter, Graham E. Fogg, Barbara Washburn, and Hamad Hamad. "Assessing the Effectiveness of Dry Wells as Tools for Stormwater Management and Aquifer Recharge and Their Groundwater Contamination Potential". Journal of Hydrology 539 (2016): 539-553.

6.10 Project Bulletins

Project bulletins were developed to keep the TAC updated and informed on the project's progress. Project bulletins are included in **Appendix 2.2**.

6.11 Project Contacts and Interested Stakeholders

Over the course of the project, a list of project contacts and interested parties was developed. This list is included in **Appendix 6.6**.

6.12 Extended Monitoring/Capacity Building

The project worked with regional stakeholders and TAC members to establish a consortium of stormwater and groundwater management agencies willing to discuss methods to sustain the dry well and groundwater monitoring effort beyond the four year period of the project. The conclusion of that discussion was to decommission the CY site and continue monitoring at the SDB site.

A Well Closure/Abandonment Plan (**Appendix 6.7**) was developed and will be implemented at the CY site and an O&M and Monitoring Plan (**Appendix 4.4**) for the SDB site is in place to continue monitoring and maintenance of the dry well system and groundwater monitoring well network past the term of the grant. The monitoring and O&M efforts will be part of the City's Drainage Maintenance and Aquatic Resources and Water Quality Protection Management Programs. The O&M for the dry well system at SDB will be maintained for 20 years.

6.13 Regulatory Environment

The main impetus for this project was the desire to gain greater clarity about the potential impacts of dry wells on groundwater quality. While great interest in the data of this study was expressed at the beginning of the project, some declined to support the project. This exposed the existing barriers to the widespread use of dry wells in the Sacramento region and the State. However, over time and through significant public outreach, the regulatory environment has changed as stormwater and groundwater managers have become more familiar with dry wells and their widespread use in other areas of California and other states. Stakeholders and regulators became interested in the use of dry wells as stormwater BMPs and as a tool to address the impacts of drought, climate change, and meeting the requirements of the NPDES permit.

Staff at the State Water Resources Control Board Division of Water Quality is investigating the options to develop statewide standards for stormwater capture and injection wells. In addition, discussions about the Elk Grove Dry Well Project occurred with staff at US EPA Region 9 and the

Central Valley Regional Water Quality Control Board; and as a result of these discussions, language was put into the Sacramento Region-Wide NPDES permit (Order No. R5-2016-0040) for BMP infiltration.

6.14 Results

Education and outreach was a major focus of this project. A considerable portion of the resistance to the use of dry wells among stakeholders was the lack of information and knowledge. Therefore, the goal of the Education, Outreach and Capacity Building was to develop outreach tools to share information and educate key audiences about the use of dry wells elsewhere and project research results.

Highlighted below are the materials produced to accomplish the project goals and objectives:

- Fact sheets on the project and the existing regulations in California (Section. 6.2).
- Annotated bibliography reviewing peer-reviewed publications and government reports that addressed the risks of groundwater contamination associated with dry well use (Section 6.3).
- Guidance and lessons learned document on describing project key findings as well as siting, design, construction and monitoring. (Section 6.4).
- Twenty professional presentations attended by at least 10 professionals each (Section 6.6).
- Poster presentations attended by between 20 – 5000 professionals at each event (Section 6.6).

In addition, the results of this project were useful to the following audiences:

- Local health and environmental management departments that oversee drinking water quality.
- Water supply agencies interested in protecting groundwater quality and promoting groundwater recharge.
- Stormwater and groundwater program managers and members of the development community looking for cost-effective LID solutions.

Chapter 7. Project Evaluation and Effectiveness

The PAEP describes the manner in which the project was effective in preventing or reducing pollution and in demonstrating the desired environmental results. The approved PAEP (**Appendix 7.1**) details the methods of measuring project benefits and reporting.

7.1 Project Goals and Performance Targets

Table 7.1 presents the project's approved PEAP table which includes project's goals, outcomes, indicators, measurement tools/methods, and targets.

7.2 Planning, Research, Monitoring, and Assessment

The project's goals and performance targets for Planning, Research, Monitoring, and Assessment are indicated below.

7.2.1 Project Goals

1. Assess the potential for contamination of groundwater associated with the use of dry wells with pretreatment features for infiltrating stormwater runoff from different land uses.
2. Assess the ability of the various pretreatment features to remove suspended solids and contaminants from stormwater.

7.2.2 Project Performance Targets

1. Concentrations of contaminants in the aquifer downgradient of the dry wells will remain below the MCLs for all anthropogenic contaminants.
2. There will be no statistically significant difference in the groundwater quality in the upgradient and downgradient monitoring wells.
3. Statistically significant reduction in TSS and pyrethroids in stormwater by the pretreatment features.
4. Sedimentation well and dry well requires cleaning to remove sediment less than one time per year.

7.2.3 Project Results

The project performance targets were met for all, except for the fourth target related to cleaning of the sedimentation well. Specifically:

1. Concentrations of contaminants in downgradient water table wells were in all cases at or below the concentrations in the upgradient wells and below the MCL (Goals 1 and 2). This suggests that influent stormwater did not introduce contaminants into the aquifer. However, given the fact that in almost all cases, modeling results suggested that the contaminants examined would take decades – centuries to reach the aquifer, meeting these targets did not provide great insight into the risk of degrading groundwater quality. What provides greater insight into the performance goal of assessing the potential for groundwater contamination were the results of vadose zone modeling. These results suggest that for the overwhelming majority of urban contaminants, including most pyrethroid pesticides, PAHs, most metals, as well as volatile and semi-volatile organics, would not reach the water table at

Table 7.1 Project Assessment and Evaluation Plan
Planning, Research, Monitoring, and Assessment

Project Goals	Desired Outcomes	Output Indicators	Outcome Indicators	Measurement Tools and Methods	Targets
1. Assess the potential for contamination of groundwater associated with the use of dry wells with pretreatment features for infiltrating stormwater runoff from different land uses.	1. Infiltrate stormwater through dry well system without degrading the quality of groundwater.	1. Data on pollutant concentrations for stormwater and groundwater will be produced, as defined in the Project's QAPP.	1. Infiltrate stormwater to recharge the aquifer while maintaining the concentration of pollutants below the California Maximum Contaminant levels for all anthropogenic contaminants.	1. **Tools:** Analytical instrumentation (e.g. HPLC, GC/MS), flow meters, monitoring wells, and pressure transducers. **Methods**: Established methods for analysis of contaminants and conventional water quality parameters, as defined in the Project's QAPP.	1. Concentrations of contaminants in the aquifer will remain below the California Maximum Contaminant Levels for all anthropogenic contaminants. 2. There will be no statistically significant difference in the groundwater quality in the upgradient and downgradient monitoring wells (using Kruskal-Wallis statistic).
2. Assess the ability of the various pretreatment features to remove suspended solids and contaminants from stormwater.	1. Develop a design for a dry well system, composed of a vegetated pretreatment feature, a structural pretreatment feature (sedimentation well), and dry well that remove suspended solids and pyrethroids to the maximum degree practical. 2. Assess the effectiveness of pretreatment features at removing pollutant-laden sediments in stormwater. 3. Develop a design for a dry well system that minimizes clogging and maintenance.	1. Dry wells with vegetated and structural pretreatment features constructed according to approved design/ specifications at two sites. 2. Data on total suspended solids and pyrethroids collected at the entrance and end of the pretreatment features at each site. 3. Analysis of data related to clogging of system with sediment and frequency of maintenance for sedimentation well and dry well.	1. Pollutant levels significantly reduced after pretreatment of stormwater. 2. Development of guidelines on required maintenance of pretreatment facilities and dry well.	1. **Tools**: Analytical instrumentation (e.g. HPLC, GS/MS, etc.). **2. Methods:** Measurement of total suspended solids in stormwater collected from two locations in the dry well system, using established methods as described in Project's QAPP.	1. Statistically significant reduction in TSS and pyrethroids in stormwater by the pretreatment features (using Mann Whitney U test). 2. Sedimentation well and dry well requires cleaning to remove sediment less than one time per year.

Education, Outreach and Capacity Building

Project Goals	Desired Outcomes	Output Indicators	Outcome Indicators	Measurement Tools and Methods	Targets
1. Conduct education and outreach to a broad audience on the use, benefits, and limitations of dry wells with pretreatment features.	1. Improved knowledge among scientists, engineers, stormwater/ groundwater managers, and other interested stakeholders on the uses of dry wells with pretreatment features and their effects on groundwater quality, accomplished through education and outreach efforts. 2. Develop an interest among a broad range of stakeholders in the Project. 3. Cultivate working relationships with stakeholders to encourage future monitoring after the term of the grant expires. 4. Provide Project results that can be used by regulators and decision makers for the development of guidelines for dry well systems in California.	1. Two fact sheets produced: (a) describing the use of dry wells and the regulatory environment for dry wells in California, and (b) summarizing the results of the Project (i.e., summarize stormwater/ groundwater monitoring results and potential risk to drinking water quality). 2. A literature review (annotated bibliography) of scientific and government reports on the relationship between dry well systems and groundwater quality. 3. A guidance document summarizing site selection, design, construction, sampling and monitoring, and key findings of the Project. 4. A Project's website with information regarding dry wells, the Project, the Project team, etc. 5. A list of interested stakeholders. 6. Presentations and poster sessions at meetings and conferences. 7. Multiple meetings with stakeholders. 8. Extend monitoring efforts past the term of the grant. 9. Project results provided to decision makers and regulators for the development of guidelines for dry well systems in California.	1. Knowledge of appropriate and inappropriate uses of dry wells among engineers, scientists, managers, and stakeholders. 2. Interest among a broad range of stakeholders in Project. 3. Interest among stakeholders to continue monitoring past the term of Project. 4. Use of Project results in the development of dry well system guidelines and regulations for California.	**Tools/Methods:** 1. Fact sheets distributed and/or downloaded. 2. Literature review (annotated bibliography) distributed and/or downloaded. 3. Guidance document distributed and/or downloaded. 4. Visits to Project website. 5. Number of names on list of interested stakeholders. 6. Number of people attending presentations at meetings and conferences. 7. Meetings of stakeholders' working group with plans to extend monitoring efforts for existing wells. 8. Cultivate interest to extend monitoring efforts past the term of the grant. 9. Analysis/reporting of Project results to decision makers and regulators for the development of guidelines for dry well systems in California.	1. 500 fact sheets distributed and/or downloaded. 2. 100 literature reviews (annotated bibliography) distributed and/or downloaded. 3. 100 guidance documents distributed and/or downloaded. 4. 500 hits to Project website. 5. List of > 100 interested stakeholders. 6. Presentations given to a minimum of 1,000 people in target audience. 7. Two or more meetings with the Technical Advisory Committee (TAC). 8. Monitoring efforts continues past the term of the grant. 9. Analysis/ reporting of Project results delivered to 5 regional or state decision making bodies for the development of guidelines for dry well systems in California.

measureable levels within the modeling timeframe of 3,000 years. However, the extensive groundwater monitoring effort was probably not the best measure of groundwater contamination due to the short duration of the project. The limitation of groundwater monitoring is likely the reason why Oregon performs vadose zone modeling and not groundwater monitoring as the best indicator of risk to groundwater quality associated with dry well use.

The one exception to this general rule was water soluble contaminants. Modeling results for tert-butyl alcohol, fipronil, and imidacloprid suggested they could reach the water table in a short timeframe, on the order of days – weeks. Tert-butyl alcohol was detected at SDB above the notification level on one occasion, but it was never detected in any subsurface water sample even though modeling results suggest it should reach the water table within 20 days. On the other hand fipronil and imidacloprid were not part of the suite of contaminants analyzed, but included in the modeling effort due to their increased detection in urban waterways.

Fortunately, comparison of results of groundwater monitoring and modeling helped to clarify the limitations of using monitoring to assess risk to groundwater quality and pointed to the strength of using vadose zone modeling to understand the movement of all types of contaminants. Modeling results suggested that vadose zone is unlikely to sequester water soluble pesticides, therefore future attention should be given to pretreatment as means of addressing those containments.

2. The goal of identifying a statistically significant reduction in TSS and pyrethroids as they passed through the pretreatment features was met in large part. Due to the small sample size (n=2), statistical significance could not be identified. However, there was a 50 – 65% reduction in TSS concentration linked to the vegetated pretreatment feature. Reducing the concentration by 50+% is significant. The changes in bifenthrin, the main pyrethroid for which calculations could be made, also declined by 42% at SDB and 100% at the CY.

3. The goal of yearly cleaning frequency of the sedimentation well was partially met. The sedimentation well did not require cleaning because it failed to capture sediment as a result of design flaws. It was not designed sufficiently deep to allow suspended material to fall out of the water column. The dry well was cleaned once during the project probably due to the efficiency of the vegetated pretreatment feature.

7.3 Education, Outreach and Capacity Building

Another goal of the project was focused on the goals and performance targets for Education, Outreach and Capacity Building, as discussed below:

7.3.1 Project Goals

Conduct education and outreach to a broad audience on the use, benefits, and limitations of dry wells with pretreatment features.

7.3.2 Project Performance Targets

1. 500 fact sheets distributed and/or downloaded.
2. 100 literature reviews (annotated bibliography) distributed and/or downloaded.
3. 100 guidance documents distributed and/or downloaded.
4. 500 hits to project website.
5. List of > 100 interested stakeholders.
6. Presentations given to a minimum of 1,000 people in target audience.
7. Two or more meetings with the TAC.
8. Monitoring efforts continues past the term of the grant.
9. Analysis/reporting of project results delivered to 5 regional or state decision making bodies for the development of guidelines for dry well in California.

7.3.3 Project Results

The project goals for Education, Outreach, and Capacity Building portion of the project were met or exceeded as described in Chapter 6 of this report. The ultimate goal of the project was achieved by providing the best available science to decision makers to support the development of technical standards and policy on dry wells to advance widespread implementation of dry wells and green technologies (LID) in stormwater and groundwater management. These technical standards could include guidance on appropriate siting, design and pretreatment. Information in the Guidance Document report addressed these issues. These recommendations were based on data generated by this project, the scientific literature (project's annotated bibliography), and practices in other states.

As equally important, the audience for the outreach efforts was stormwater and groundwater managers at the local and regional levels. These individuals represent municipalities and counties that may use dry well as part of their aquifer recharge or stormwater management programs. In addition, the project's outreach material was distributed at meetings and conferences, and downloaded from the project website. There were approximately 2,360 hits to the project website. In addition, two TAC meetings were held for the project.

Chapter 8. Project Conclusion

8.1 Overview

The goal of the project was to assess the risks to groundwater quality associated with the use of dry wells to infiltrate stormwater. The results of the project suggest that dry wells with pretreatment can manage hydromodification as well as increase infiltration and groundwater recharge with little risk of degrading groundwater quality.

8.2 Project Key Findings

Results of this project are based on stormwater and groundwater monitoring, vadose zone modeling, research of other state's dry well/UIC programs, scientific literature, and government reports. Some of the key findings generated by the monitoring and modeling efforts include the following:

- Volatile and semi-volatile organics and PAHs were rarely detected in stormwater. When they were detected it was at concentration near the reporting limit.
- Aluminum was found at the CY, present at concentrations three times the MCL. Vegetated pretreatment reduced the concentration three-fold and was below the reporting limits in groundwater. Modeling results indicated that aluminum would not reach the aquifer at detectable levels for more than 3,000 years, the modeling timeframe.
- Coliform bacteria were found in both stormwater and groundwater in upgradient and downgradient wells at both project sites. There is no evidence that the dry wells were uniquely responsible for this problem.
- The most commonly detected pyrethroid in stormwater was bifenthrin. The combination of pretreatment and vadose zone attenuation effectively sequestered the contaminant, and none was detected in groundwater. Vadose zone modeling suggested it would take close to 500 years for it to reach quantifiable levels in groundwater.
- Naturally-occurring chromium and arsenic was detected in groundwater at levels below the MCL. None was found in stormwater.
- Nitrate concentrations in groundwater were elevated above the MCL. Small quantities were found in stormwater. The source of nitrate in groundwater was likely leaching from the soil linked to historic agricultural activities throughout the region. At the SDB, stormwater actually might have diluted the concentration of nitrate in groundwater.
- Chlorophenoxy herbicides, were not detected in stormwater or groundwater, except for a single detection of dalaphon measured just above the reporting limit at SDB.
- Fate and transport modeling suggested that most metals carried in stormwater runoff would not reach the water table at measurable levels during the modeling timeframe of 3,000 years. An exception was iron, which is much more mobile.

Similarly, the pyrethroids travel time is very slowly, on the order of decades or greater than 3,000 years, depending on the specific species. The volatile organic compound tertiary butyl-alcohol is likely to move through the vadose zone in less than 10 years.

- Fipronil and imidacloprid were two pesticides that were not measured at either project site, but were included in the modeling efforts due to their increased use. These pesticides are more water soluble than pyrethroids and could move to the water table on the order of days to months.

Additional findings not related to contaminants or modeling include:

- An assessment of the effectiveness of vegetated pretreatment showed that the grassy swale at the CY was slightly better at removing suspended solids (65% efficiency) than the water quality basin (50% efficiency). This was most likely due to the uniform growth of long grasses and the geotextile base used to stabilize the steep slopes at the CY.
- Infiltration rates at the CY averaged 15 gpm and at SDB 57 gpm. Many factors influenced these numbers, including the depth to groundwater, the size of the drainage shed, the saturation of the vadose zone, and the intensity of each rain event.
- The total amount of runoff infiltrated during a single rain event was a maximum of 8,400 gallons at the CY and 28,500 gallons at SDB. An estimate of the total amount of water that flowed through each dry well for the 2015-16 water year was approximately 0.2 AF at the CY and 0.7 AF at SDB. Using conservative estimates of total rainfall at SDB, approximately 116 AF would have been available for aquifer recharge, assuming 50% of the runoff was protected for environmental flows to the creek. These estimates were based on the 2015-16 water year with a rainfall total of about 13 ½ inches. If the historic average was 18 inches, approximately 1 AF would have passed through the dry well at SDB. If the maximum infiltration rate of 46 gpm measured at SDB had been sustained throughout the winter, upwards of 3 acre/feet could have been recharged. This rate was not sustained however, due to vadose zone saturation at SDB.
- Approximately 14 kg (30 lbs) of suspended sediment at the CY and 727 kg (60 lbs) of suspended sediment at SDB were diverted from local waterways in 2015-16.
- An extensive search of the scientific literature and government reports did not identify evidence for the degradation of groundwater quality associated with infiltrating stormwater through dry wells. Dry wells have been used successfully in Arizona, Oregon, and Washington for decades.

8.3 Data Gaps

A number of data gaps were identified during this project. The primary gap identified was the need to better understand the distribution, concentration, and risk to groundwater quality of water soluble pesticides. Unlike most urban contaminants, which are hydrophobic and bound to particles, the neonicotinoids and fipronil are not hydrophobic and not easily sequestered

through the management of particles. Modeling results suggest they pass through the vadose zone in a short period of time. The key to their management appears to be vegetated pretreatment, and it is unlikely sedimentation will be effective at capturing these pollutants. A cursory literature review and conversations with two UC Davis faculty members turned up little information on the issue of how to use plants and which plants/grasses might be efficient at sequestering water soluble pesticides from stormwater. One of the reasons neonicotinoids are effective pesticides is the ease with which they move into the leaves and root of plants. This behavior could possibly be exploited to reduce their concentration in stormwater during pretreatment. Additional research on their prevalence in urban runoff and the type of pretreatment that could sequester them would help to manage the risk posed by these pesticides.

A second data gap identified was the need for more information on the risk of mobilization of naturally-occurring metals. Arsenic and chromium have been found at elevated levels in drinking water throughout California. Both were detected in groundwater at the project sites. Based on a USGS report of uranium mobilization by constituents in stormwater, concerns that similar processes might affect arsenic or chromium at the project locations arose. A preliminary analysis of this risk did not provide evidence of mobilization of either metal (**Appendix 5.4, Technical Memorandum**). However, this analysis did identify some correlations between iron and arsenic and chromium that would be worth exploring further. Additional analysis would provide more conclusive information regarding the long term risks of metal mobilization.

8.4 Recommendations

The following recommendations evolved from experience and knowledge gained during this project:

1. *Siting:* Land use is an important consideration in siting a dry well. Vehicle servicing areas (such as gas stations, etc.) or industrial areas are probably not appropriate sites for dry wells. These areas have a potential to contain elevated levels of contaminants in stormwater runoff. This recommendation stems from the experiences at the CY. Elevated concentrations of some metals and motor oil were regularly found from stormwater samples at the CY. Further, the risk of a spill was always present.

   In addition, the placement of dry wells within water quality basin/detention basins may not be ideal. At SDB, the infiltration rates decreased over the course of the water year as the subsurface became saturated. For example, the estimated 116 AF potentially available for recharge would require over 100 dry wells to accommodate that volume of water at the infiltration rates observed. If those dry wells were distributed throughout the neighborhood, the likelihood that they would function with higher efficiency throughout the water year would be greater than if they were all placed in and around the water quality basin, where saturation of the vadose zone appeared to impede infiltration. Siting dry wells in water quality basin or a detention basin should be

evaluated on a case-by-case basis, considering local lithology, runoff volumes, and depth to water table along with other factors.

Additional considerations for siting include:

- Avoid sites where hazardous chemicals are used or handled. This reduces the risk of spilled chemicals entering the subsurface through the dry well.
- Avoid sites where soils are contaminated. This reduces the risk of mobilizing contaminants already present in soil.
- Avoid sensitive areas such as placing dry wells near public supply wells, water lines, creeks and other sensitive areas.
- Optimize placements on public lands. When land is in public ownership, the local municipality can take responsibility for oversight of dry well construction, O&M, and long term monitoring.

2. *Subsurface Composition*: Another aspect of siting is local lithology. While clay presents challenges for surface infiltration, it offers some advantages when used with deep infiltration. It can contribute to the attenuation and reduction of pollutants, especially metals and many organics. In Washington State, for example, vadose zone attenuation and pollutant concentration determines what type of pretreatment is needed. If clay units lay beneath the bottom of the dry well, additional attenuation of pollutants can be obtained.
3. Vertical Separation Distance: Other states with developed UIC programs frequently require a 10 foot vertical separation distance between the bottom of the dry well and seasonal high water table. At the two project sites, vertical separation distances were approximately 10 feet bgs at the SDB and 30 feet bgs at the CY. Because the vadose zone serves as a 'safety net' for those contaminants that are not removed by pretreatment, larger distances can be more protective.
4. *Pretreatment*: Effective pretreatment is the key to protecting groundwater quality. Pretreatment can take the form of vegetated swales, bioretention cells, or other vegetated feature. Structural pretreatment refers to an engineered structure such as a sedimentation well or manhole; usually a 10– 20 foot deep concrete vault designed to capture sediment.

   If the pollutant concentration in stormwater runoff can be significantly reduced with pretreatment prior to entering the dry well, the risk of introducing contaminants into the aquifer is greatly diminished. Although pretreatment cannot serve as a substitute for avoiding inherently high risk land uses, for everyday circumstances such as stormwater runoff from streets, parking lots, turf, downspouts, etc., it can be very effective. The single vegetated pretreatment at the two project sites removed 50-65% of suspended solids. The addition of a functioning sedimentation well would have removed additional

amounts of TSS and associated pollutants. It has been estimated that the two-chambered Torrent Resources dry well removes about 90% of TSS[1].

5. *Shut off Value*: The dry wells used in this project were designed with an emergency shut off valve that was placed in the pipe connecting the sedimentation well and the dry well. This valve could be used if a chemical spill occurred, if a large amount of debris generated from a large storm might clog the well, or other unexpected circumstance developed. If dry wells were constructed in the public right of way, and if an accident should occur, emergency responder would be able to prevent chemicals from entering the system by closing the valve.
6. *Construction Oversight and Inspections*: Inspections are a key to the successful construction of dry well systems. The use of highly-engineered dry wells is relatively new in California, and as such, there are not an abundance of experienced consultants and construction contractors. In this project, problems were encountered with dry well construction at both sites. At SDB, as a result of insufficient oversight, excess sand was added to the dry well that dramatically reduced the infiltration rate, causing delays and added expenses associated with identifying and rectifying the problem. Over 5 feet of sand had to be removed and replaced with the correct ratio of sand to gravel. Careful oversight of construction could have avoided the problem in the first place.
7. *Lack of Qualified Professionals*: Finding experienced professionals to design and construct the dry well systems was not easy. At the outset of the project, there were very few consultants and contractors in the Sacramento region who were knowledgeable in dry well design and construction. Had there been knowledgeable professional in the region, significant time and money could have been made. Even though dry wells with LID features are being used more frequently, the lack of qualified professionals to design and construct green infrastructure projects makes these types of projects hard to scale and implement on a broad basis. Costs would also be expected to decline as more and more dry wells are installed, assuming qualified professionals are available.
8. *Groundwater and Stormwater Monitoring*: Periodic monitoring of key contaminants will help ensure that stormwater does not exceed criteria values. Whether the MCL or another benchmark is used as the criteria value, evaluating contaminant concentration at the entry into the subsurface is essential for determining the potential for changes in groundwater quality. For this project, monitoring of groundwater quality did not lend great insight into the assessment of risk. Given that modeling results suggested that most contaminants would not reach the water table for many decades or more, it was unlikely that most pollutants would be detected during the two-year monitoring period. Therefore, the value of groundwater monitoring as a general practice is questionable,

[1] This mention does not constitute and endorsement of products or services of this company.

especially considering its cost. Other states with established dry well/UIC programs use a combination of influent stormwater monitoring and vadose zone modeling to assess groundwater protectiveness.

9. *Operation and Maintenance*: Establishing O&M procedures to ensure dry wells are maintained in a functional state is important. Such protocols ensure that pretreatment features remain effective and the dry well is performing as designed.
10. *Need for Statewide Guidelines*: California does not currently have a statewide set of standards or guidelines governing the use of dry wells. The US EPA maintains oversight of dry well use in California. They post guidelines for construction and require that dry wells be registered (not permitted) on their website. They also specify that local jurisdictions and/or the Regional Water Quality Control Boards have the authority to promulgate additional and more restrictive regulations, if deemed necessary.

    To the degree that California does not have general standards, policy, registration, and/or permitting processes, dry well use will be challenging, requiring negotiations on a project by project basis with one or another government agencies. The experiences of the project team and other information gained over the course of the project point to the need for a uniform statewide standards and policy on dry well use to track locations as well as ensure that design standards, siting, and maintenance requirements are implemented. Such programs in other states are revenue-generators as well. Statewide guidelines will help ensure that dry wells are being used in a safe and proper manner.

8.5 City's Commitment

The City is committed to maintaining the SDB dry well system to capture and treat stormwater as designed. The City will continue to maintain and monitor the performance of the dry well system per the project's O&M and Monitoring Plan; and maintain the system for a minimum of 20 years per the grant agreement terms. The City will continue to build on the Elk Grove dry well project and related LID projects to quantify the costs, benefits, and potential risks of using dry wells to accomplish multiple objectives, including helping to develop the Regional Stormwater Resource Plan, complying with the NPDES permit, and multiple City planning efforts in the future. The City will share their experience with others with the goal of advancing the wise use of dry wells to manage stormwater and recharge aquifers.

In addition, based on the experience gained from this project, it was determined that the CY wells should be decommissioned due to the risk associated with a site that involves vehicle servicing and maintenance. This reasoning is consistent with practices with states of Washington and Oregon's Dry Well Programs. This approach was vetted through the TAC, and the TAC members agreed that the wells at the CY should be closed per the Well Closure/ Abandonment Plan (**Appendix 4.4**).

8.6 Conclusion

Dry wells are beginning to become a viable option for infiltration in northern California. The risks associated with the use of dry wells are primarily linked to the potential to introduce pollutants into the aquifer. Data collected at the two project sites in Elk Grove did not show evidence of groundwater contamination linked to the dry wells. Modeling suggested there is only minimal risk of groundwater contamination associated with common urban contaminants -- such as PAHs, metals, and pyrethroid pesticides. Practices in other states and conclusions reached by US EPA suggest that with proper dry well siting, design, and maintenance, dry wells can be used safely. Results from this project are consistent with these conclusions and will be helpful in any future development of statewide standards for recharge or injection wells.

All goals for the project were met and the City will continue to monitor and maintain the Strawberry Creek water quality basin dry well system for at least 20 years.