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Attenuation of PPCPs Through Golf Courses Using Recycled Water

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ATTENUATION OF PPCPS THROUGH GOLF COURSES USING RECYCLED WATER

by

Michael D. McCullough
Northern California Golf Association

2012

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This report was co-published by the following organization.

IWA Publishing
Alliance House, 12 Caxton Street
London SW1H 0QS, United Kingdom
Tel: +44 (0) 20 7654 5500
Fax: +44 (0) 20 7654 5555
www.iwapublishing.com
publications@iwap.co.uk

Library of Congress Catalog Card Number: 2011929585
Printed in the United States of America
IWAP ISBN: 978-1-78040-023-5/1-78040-023-3

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ACKNOWLEDGMENTS

The research team wishes to thank these individuals for their contributions and dedication to the project: Svetlana Bondarenko, Laurel Dodgen, Fred Ernst, Dr. Jim Baird, Janie Zeigler, Doug Mawhinney, Oscar Quiñones, Linda Parker, Dave Rexing, Lena Wright, Cary Lee, Kathy Carter, Adam Kloster, Nick Checklenis, Chris Dubridge and John Healey. A special note of gratitude goes to Debi Noack for working her magic on the final report. The authors also wish to thank the project subcommittee and program director for their valuable input, which helped make this a useful product for WERF and WateReuse Research Foundation subscribers. To all of the supporting agencies, this research could not have been performed without your support. Thank you very much.

The following organizations provided funding for this project:

- California Association of Sanitation Agencies
- California Golf Course Superintendents Association
- California Golf Course Owners Association
- City of Santa Rosa
- Coachella Valley Water District
- Contra Costa Water District
- Delta Diablo Sanitation District
- Denver Water
- Dublin San Ramon Sanitation District
- Environmental Institute of Golf
- Inland Empire Utility Agency
- Irvine Ranch Water District
- Las Vegas Valley Water District
- Los Angeles Department of Water and Power
- Monterey County Water Resource Agency
- Monterey Regional Water Pollution Control Agency
- PhRMA
- Reedy Creek Energy Services
- San Francisco Public Utilities Commission
- Sanitation Districts of Los Angeles County
- Santa Clara Valley Water District
- Sonoma County Water Agency
- South Bay Recycling
- Toro Company
- Toro Foundation
- United States Golf Association
- Water Environment Research Foundation,
- WateReuse Research Foundation

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ABSTRACT AND BENEFITS

Abstract:

A multi-year, collaborative research project was conducted to investigate the fate and transport of pharmaceuticals and personal care product chemicals (PPCPs) in turfgrass/soil systems irrigated with recycled water. The project involved laboratory adsorption and degradation experiments, controlled lysimeter experiments, field-scale controlled plot monitoring of drainage concentrations, and mass flux below fairways on four different golf courses. Fourteen different compounds were monitored in the irrigation and drainage waters in these studies.

The laboratory experiments indicated only a few PPCPs were susceptible to biodegradation under aerobic conditions, while the other target compounds were relatively persistent, with half-lives longer than 100 days (d). The low sorption and long persistence of some PPCPs suggest potentially high mobility in sandy soils. However, the absence of plants in the laboratory degradation experiments and the use of extremely sandy soils may have contributed to the observed persistence, indicating a need for evaluation of the attenuation of PPCPs under more representative simulated or field conditions.

The lysimeter experiment revealed breakthrough of nine of 14 compounds in the drainage water, after migrating through 120 cm soil profiles. The experiment lasted 745 days, and varied by leaching fractions (0.05 vs. 0.25), soil type (loamy sand vs. sandy loam), and treatment of the soil surface (turfgrass vs. bare soils). Only primidone, sulfamethoxazole, and carbamazepine concentration patterns correlated with the number of unsaturated pore volumes displaced from the soil profile. In the case of primidone, 94% of the variation in mass flux could be described by soil conditions (e.g., number of unsaturated pore volumes drained, the percent sand in the soil, and the average redox potential at the 105 cm depth).

The controlled plot experiment showed that after irrigation with recycled water for six months on mature turfgrass plots, only a few PPCPs were detected in the drainage water collected at the 90-cm depth. Primidone, trimethoprim, and carbamazepine were the only compounds appearing in the drainage water. Despite the heavy irrigation rates (100% and 130% of reference evapotranpiration or ETo), most PPCPs were completely removed by the turfgrass/soil system. After correcting for leaching fractions, the removal was greater than 75% even for the few compounds that were detected in the drainage water. Therefore, the plot experiment validated the lysimeters experiment and clearly demonstrated that turfgrass has an outstanding capacity to attenuate PPCPs introduced via irrigation with recycled water.

In the golf course experiments, sulfamethoxazole, meprobamate, and carbamazepine were the most commonly found PPCPs in drainage water; however, when concentrations of samples taken from the drain gauges were normalized to the hectare scale, the researchers found that fluxes for all compounds were less than 0.100 grams/hectare, and the majority of all fluxes were recorded during the second year of the field monitoring.

In summary, the results support the use of recycled water for irrigation purposes, as long as sound, science-based irrigation management practices (e.g., cycle and soak irrigation) are implemented. The use of recycled water allows communities to extend their water resources

while minimizing the discharge of such waters into aquatic systems.

Benefits:

- Demonstrates that turfgrass/soil systems can be effective for attenuating downward movement of PPCPs introduced through recycled water irrigation.
- Demonstrates that turfgrass/soil systems are a suitable location for applying recycled water as turf managers normally irrigate to moisten only the root zone, and most roots occur in the upper 30 cm of soil; however, additional water is often added to incorporate a leaching fraction because of the elevated salinity in recycled water.
- Suggests that there could be some caution about using recycled water on bare, sandy soils with little or no organic material in the soil as downward movement of PPCPs toward groundwater sources is possible.
- Shows that PPCPs mass flux needs to be calculated and measured versus analyzing only PPCPs concentrations, because the mass flux represents the actual compound load leaving the turfgrass/soil system. Concentration alone does not provide information on possible environmental impacts (i.e., high concentration with low water flux will have negligible effect on the environment).
- Provides a successful example of a regional project involving multiple universities and researchers, public and private funding partners and third party project supervision.

Keywords: PPCPs, sorption, leaching, drainage water, flux measurements, attenuation, recycled water irrigation.

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LIST OF ACRONYMS

ANOVA	analysis of variance
BC	Boulder City, Nevada
CC	Country Club
CEC	cation exchange capacity
DCT	divergence control tube
ET	evapotranspiration
ETo	Reference evapotranspiration
GC	Golf Course
LF	leaching fraction
NLV	North Las Vegas, Nevada
PPCPs	pharmaceuticals and personal care product chemicals
RAWS	remote automated weather station
SPE	solid phase extraction
UPLC	ultra performance liquid chromatography system
WWTPs	wastewater treatment plants

EXECUTIVE SUMMARY

Introduction

The scarcity of water supplies in various portions of the United States, and in particular arid and semi-arid regions, make landscape irrigation with recycled water a highly viable and beneficial practice. An increasing number of studies show that some pharmaceuticals and personal care product chemicals (PPCPs) are resistant to chemical or biological treatment processes and are ubiquitously found in recycled water. Assessing attenuation processes in the vadose (i.e., unsaturated) zone helps determine whether compounds could potentially contaminate groundwater from irrigation with recycled water. Many studies conducted over the last two decades have shown the turfgrass/soil system effectively retains and biodegrades trace contaminants, such as pesticides. However, specific studies involving PPCPs are relatively sparse.

ES.1 Objectives

The intent of this research was to address these specific objectives:

- To understand the fate and transport of PPCPs in turfgrass/soil systems when recycled water was used as the sole source of irrigation water.
- To evaluate the biological degradation capacity of turfgrass/soil systems for removing PPCPs found in recycled water.
- To extend knowledge to stakeholders and reduce the uncertainty of how long-term use of recycled water for irrigation may impact groundwater quality.

ES1.1 Hypotheses

- Turfgrass/soil systems can function effectively to reduce PPCPs when recycled water is used as the primary irrigation source.
- Significant attenuation of these compounds occurs in the root zone, minimizing the likelihood for PPCPs to reach the water table.
- Use of concentration and water flux to determine mass flux provides a more complete picture of PPCPs attenuation or leaching potential.
- The potential of PPCPs to move downward in the soil profile is a function of the chemical compound characteristics, soil type, and irrigation-induced leaching fractions.

ES.2 Experimental Methods

The following PPCPs were studied in this project. These compounds represent some of the most frequently occurring PPCPs in recycled water. Metabolites of these compounds were not analyzed in the project. The cost of performing the analysis of transformation products was a limiting factor.

Atenolol - beta-blocker; cardiovascular disease and hypertension
Atorvastatin - blood pressure regulation
Carbamazepine - anticonvulsant
Diazepam - sedative and anticonvulsant
Diclofenac - anti-inflammatory
Dilantin - anticonvulsant and seizure treatment
Fluoxetine - antidepressant
Gemfibrozil - lipid regulation
Ibuprofen - anti-inflammatory
Meprobamate - tranquilizer
Naproxen - anti-inflammatory
Primidone - anticonvulsant and seizure treatment
Sulfamethoxazole - antibiotic
Triclosan - antimicrobial
Trimethoprim - antibiotic

The following experiments were completed to address the above objectives:

- Controlled Laboratory Scale Experiments – bench-scale experiments to obtain information on the sorption and degradation of selected PPCPs in soils used in the subsequent lysimeter study. Sorption and degradation parameters were used to interpret observations from the lysimeter and field studies.
- Lysimeter Experiments – large columns used to evaluate the leaching potential of targeted PPCPs under simulated (unsaturated) conditions. Results enabled model simulation transport of PPCPs in irrigated turfgrass settings (golf courses) and connected the small scale laboratory experiments to the larger-scale complex field experiments.
- Field Plot Experiments – mature turf plots with drainage lysimeters irrigated with tertiary recycled water for six months at 100 or 130% of reference evapotranspiration (ETo). These experiments represented “worst-case scenarios,” meaning irrigation rates well above normal practices, aimed to screen compounds susceptible to downward movement during recycled water irrigation.
- Operational Golf Course Monitoring Experiments – three drain gauges installed at each of four operational golf courses receiving recycled water for irrigation. Water flux data and drainage water samples were collected periodically to understand occurrence of PPCPs under field conditions.

ES.3 Research Findings and Conclusions

The measured concentrations of the PPCPs in the irrigation (feed) water and in the drainage water for the lysimeter, controlled field plot and golf course experiments are presented in Table ES-1. The mass removal (attenuation) of the PPCPs under low and high leaching conditions in the controlled field plot experiment, and under low and high leaching conditions in both loamy sand and sandy loam soil in the lysimeter experiments are presented in Table ES-2. The findings are discussed below for each of the experiments.

ES3.1 Controlled Laboratory Scale Experiments

Attenuation of concentrations are dominated by sorption and biodegradation processes. Results indicated that many of the PPCPs compounds considered in this study exhibited little to moderate sorption in soils. A few PPCPs were somewhat susceptible to degradation, but most of the selected PPCPs were relatively persistent with half-lives longer than 100 d. The low sorption and long persistence would suggest that the selected PPCPs may have high mobility in sandy soils found on some golf courses and therefore may move downward to pose a risk for groundwater contamination where recycled water is used for irrigation. However, it must be noted that the overall long persistence may be due to low organic matter contents of these arid and semi-arid soils. Moreover, plants were absent under these experimental conditions, lowering microbial diversity/activity and potentially explaining the lack of degradation. Information from laboratory experiments pointed to a need for further evaluation under field conditions with realistic agronomic maintenance practices and water management schemes.

ES3.2 Lysimeter Experiments

After over two years of irrigation with recycled water on both turfgrass and bare soils, nine of 14 PPCPs were detected in the drainage water (ibuprofen was not included in the lysimeter experiments). Significantly higher leaching was typically linked to the loamy sand soil and to the higher leaching fraction (LF) treatment on bare soil. Comparing concentrations of PPCPs in the drainage water, relative to that in the irrigation water, was a poor predictor of the percentage of mass of the compound drained relative to mass loading of the compound in the irrigation. Knowing the drainage flux associated with the concentration is critical for better assessing the leaching risk of PPCPs. It was concluded that only small amounts of PPCPs would drain under typical golf course conditions, similar to those encountered in southern Nevada, especially on soils with lower sand contents than those associated with this experiment and under lower leaching conditions.

ES3.3 Field Controlled Plot Experiments

Turfgrass plots were irrigated with recycled water for over six months at elevated irrigation rates. Leaching of select PPCPs was evaluated based on their presence in the source water (i.e., recycled water) and drainage water collected at 90 cm depth. Results show that, with the exception of a few compounds, most PPCPs did not appear in the drainage water under conditions used in this experiment. Trimethoprim and primidone were frequently found in the drainage water for both soil types and both irrigation rates. However, after accounting for leaching fractions, the mass removal for these PPCPs was always greater than 80%. Therefore, it may be concluded that the turfgrass/soil system served to effectively reduce PPCPs after recycled water irrigation, despite the persistence and/or weak adsorption of many PPCPs in soil. The conditions used in this experiment simulated worst-case scenarios; meaning irrigation rates were above normal practices and drainage water was monitored at 90 cm below ground surface.

The actual leaching risk for PPCPs may be less under typical turfgrass management practices and conditions, where water tables are deeper.

ES3.4 Operational Golf Course Monitoring Experiments

The field experiment at operational golf courses lasted approximately two years. During that time, drainage water was collected periodically and analyzed for concentrations of 13 compounds (atorvastatin and ibuprofen were not included in these experiments). Mass flux of compounds was obtained by multiplying water flux with the observed concentration. Mass flux is more appropriate for assessing potential environmental impacts and risks as high concentrations with low flux indicates that contaminants are remaining in the soil profile and not migrating toward receiving waters. The mass fluxes were converted into units of grams per hectare (g/ha) and were all less than 0.1 g/ha. Most were below 0.001 g/ha, indicating a relatively low mass loading away from turfgrass. The results also indicate a stronger (and perhaps more predictable) correlation between higher mass flux at arid sites when higher irrigation rates are needed for overseeding winter turfgrass and when winter rainfall periods are common. This would be particularly important for soils with low organic matter or sorption capacity. Courses in arid climates that deficit irrigate during most of the calendar year and then heavily irrigate during winter overseeding are more likely to experience deeper PPCPs migration, than those courses either irrigated with positive leaching fractions or that have more evenly distributed precipitation patterns. This would be especially true at golf courses with sandy soils.

ES.4 Project Summary

ES4.1 Answering Project Objectives

- To evaluate the biological degradation capacity of turfgrass/soil systems for removing PPCPs found in recycled water.

As golf courses age, the amount of organic matter in the vadose zone will increase unless a regimented schedule of specific maintenance practices are being implemented. Common golf course maintenance practices such as aerification and top dressing help reduce organic matter in the top 10 cm (4 inches) of the soil surface. These practices regularly occur on greens and tees and less frequently on fairways and roughs. The greens and tees typically make up less than 10% of the irrigated area on a golf course whereas fairways and roughs are in the 65-70% range of irrigated turf acreage on a typical golf course.

The root zone (top 30 cm of soil) area is generally characterized with substantial biological activity that can aid in the attenuation process of PPCPs. The Controlled Laboratory Experiments demonstrated that adsorption of compounds in soil is not likely when organic matter or plant material is either limited or absent. Results from the Field Plot Experiment also confirmed the ability of turfgrass/soil system to aid in reducing the concentrations of PPCPs as they pass through the root zone and into deeper soil. When the mass flux data from the Operational Golf Course Experiments were scaled up to create a meaningful sample size (i.e., hectare scale), the results again confirmed that less than one gram of some compounds were transported downward per year and away from the root zone area of the turfgrass.

- To understand the fate and transport of PPCPs in turfgrass/soil systems when recycled water is used as the sole source of irrigation water.

Results from the lysimeter experiment provided realistic estimates of leaching potential of many PPCPs compounds found in recycled water. All experimental factors (soil texture, soil cover, and irrigation amounts) affected how these compounds were transported and degraded through a subsurface, biological system. These results should be valuable to water managers who must evaluate potential risks of using recycled water as an irrigation source.

To fully understand the fate and transport of PPCPs, additional research is needed for longer durations with multiple sites (see Future Research Needs section in Chapter 6.0) to accurately describe how these compounds react as they move through soil profiles with different texture and characteristics.

Based on this research, golf courses provide a suitable location for recycled water application. This practice will reduce the use of potable or groundwater supplies for irrigating large outdoor landscapes.

Table ES-1. Compound Concentrations in Water Sources (ranges in ng/L)

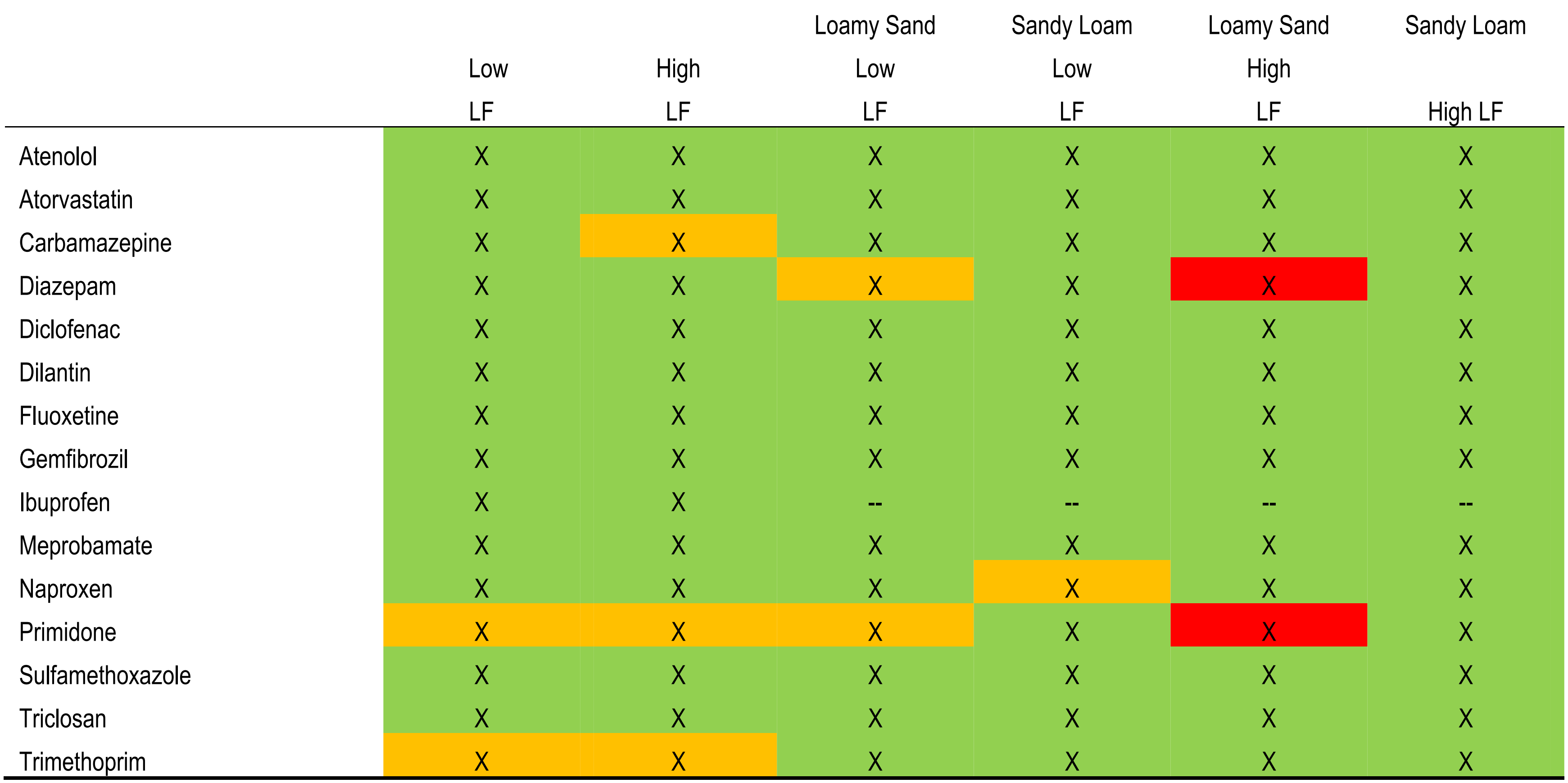
	Feed Water Samples			Drainage Water Samples						
						Lysimeters				
	Field Plots	Lysimeter	Golf Courses	Field Plots	Golf Courses	Low LF/ Bare Soil*	High LF/ Bare Soil*	Low LF/ Turf*	High LF/ Turf*	Human Health Threshold**
Atenolol	66-320	27-430	20-600	<RL	<RL	N/A	N/A	N/A	N/A	70,000
Atorvastatin	2-5	1-65	<RL - 1300	<RL	<RL	N/A	N/A	N/A	N/A	5,000
Carbamazepine	206-416	130-635	3.7-220	<RL-164.7	<RL - 78	<RL - 10	<RL - 68	N/A	<RL - 81	1,000
Diazepam	1-7	2-13	<RL-44	<RL	<RL	<RL - 18	<RL - 22	<RL - 46	N/A	N/A
Diclofenac	2-31	32-104	<RL-1700	<RL	<RL - 74	<RL - 21	<RL - 78	<RL - 85	<RL - 150	N/A
Dilantin	9-23	<RL-26	N/A	<RL	N/A	<RL - 7.7	<RL - 7.6	N/A	N/A	N/A
Fluoxetine	7-43	4-58	<RL-240	<RL	<RL	N/A	N/A	N/A	N/A	10,000
Gemfibrozil	25-262	<RL - 165	<RL - 69	<RL	<RL - 15	N/A	N/A	N/A	N/A	45,000
Ibuprofen	N/A	N/A	<RL-5.0	<RL	<RL - 13	N/A	N/A	N/A	N/A	34,000
Meprobamate	231-963	210-621	67-2100	<RL-63.3	<RL - 300	<RL - 15	<RL - 54	N/A	N/A	260,000
Naproxen	5-90	<RL - 146	<RL-14	<RL	<RL - 9.8	<RL - 73	<RL - 48	<RL - 34	<RL - 128	220,000
Primidone	18-53	17-65	N/A	<RL-44.6	N/A	<RL - 39	<RL - 38	<RL - 33	<RL - 48	N/A
Sulfamethoxazole	80-1255	940-2168	<RL-160	<RL-92.8	<RL - 75	<RL - 266	<RL - 657	<RL - 69	<RL - 60	35,000
Triclosan	21-146	10-149	<RL -140	<RL	<RL - 170	<RL - 152	<RL - 69	N/A	N/A	350
Trimethoprim	6-128	9-243	<RL - 320	<RL-113.1	<RL - 1.8	N/A	N/A	N/A	N/A	61,000

*It should be noted that this data set was generated by combining both soil types. A clearer understanding of the interaction between LF, soil type and cover can be found in the report.

**This list was included to provide some perspective of the compound concentrations for the relevance of Public Health. A recent report to the California State Water Resources Control Board (Anderson et al., 2010) reported the Monitoring Triggering Levels (MTLs) for many of the compounds for Potable Reuse.

N/A = not applicable, <RL = less then reportable limits

Table ES-2. Mass Removal (attenuation) of PPCPs in Controlled Field Plots and Lysimeters Irrigated with Recycled Water.



	Field Plots		Lysimeter			
			Loamy Sand	Sandy Loam	Loamy Sand	Sandy Loam
	Low LF	High LF	Low LF	Low LF	High LF	High LF
Atenolol	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Atorvastatin	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Carbamazepine	🟩 X	🟨 X	🟩 X	🟩 X	🟩 X	🟩 X
Diazepam	🟩 X	🟩 X	🟨 X	🟩 X	🟥 X	🟩 X
Diclofenac	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Dilantin	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Fluoxetine	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Gemfibrozil	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Ibuprofen	🟩 X	🟩 X	🟩 --	🟩 --	🟩 --	🟩 --
Meprobamate	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Naproxen	🟩 X	🟩 X	🟩 X	🟨 X	🟩 X	🟩 X
Primidone	🟨 X	🟨 X	🟨 X	🟩 X	🟥 X	🟩 X
Sulfamethoxazole	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Triclosan	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X	🟩 X
Trimethoprim	🟨 X	🟨 X	🟩 X	🟩 X	🟩 X	🟩 X

Green cell - 98% or more compound attenuation
Yellow cell – 85 - 98% compound attenuation
Red – 84-80% compound attenuation
-- Not measured

- To extend knowledge to stakeholders and reduce the uncertainty of how long-term use of recycled water for irrigation may impact groundwater quality.

Personnel at facilities that use recycled water should understand water quality issues related to recycled water such as high salts, additional nutrients, and other similar issues. These topics play a major factor in how turf managers should strategically apply recycled water as irrigation to golf courses or large landscaped areas. Other factors such as soil type, turf type, and evapotranspiration rate also determine how much water is applied to the turf. For golf courses using recycled water, playing conditions are an integral part of the water management philosophy (courses with wet playing conditions during the growing season are not the preferred choice of golfers).

Golf courses irrigating with recycled water should use a leaching fraction as a tool to aid in addressing excessive salts in recycled water. Typically, golf courses should implement a leaching fraction of 10-15%. However, deficit irrigation (replacing less water than the amount the plant actually needs) is a common practice with golf courses, even those that use recycled water.

As more and more communities add recycled water to their water portfolios, the possibility of PPCPs contamination of surface and ground waters will increase. PPCPs in irrigation water used on large outdoor landscapes should move through a highly reactive turfgrass/soil system that can retain and reduce these compounds. Many communities have chosen to use recycled water as a source of irrigation water for large turfgrass areas (like golf courses, parks, schools, roadsides). While some of the compounds do have the potential to move downward and possibly contaminate groundwater supplies, the likelihood of risk to humans and or the environment is considered minimal as long as sound irrigation management practices are implemented based upon the local conditions. This underscores the importance of understanding irrigation management techniques and strategies for using recycled water.

CHAPTER 1.0

INTRODUCTION

The scarcity of water supply in many arid and semi-arid regions, when coupled with the necessity for disposing of large volumes of recycled water, makes landscape irrigation with recycled water[1] a highly viable and beneficial practice. However, an increasing number of studies show that many pharmaceutical and personal care product chemicals (PPCPs) and endocrine disrupting compounds (EDCs)[2] are resistant to chemical or biological treatment processes and are ubiquitously found in recycled water (Tabak and Bunch, 1970; Hignite and Azarnoff, 1977; Tabak et al., 1981; Eckel et al., 1993; Halling-Sorensen et al., 1998; Daughton and Ternes, 1999; Kolpin et al., 2002). As several studies have shown, exposure to trace levels of certain PPCPs may cause adverse impacts to aquatic species (e.g., feminization) (Bevans et al., 1996; Harries et al., 1996; Jobling et al., 1998; Jobling and Tyler, 2003; Snyder et al., 2004; Tyler et al., 2005). The perceived human and ecological risks of PPCPs and the concern for potential groundwater contamination, if not properly addressed, could negatively affect the acceptance and adoption of large scale landscape irrigation uses of recycled water.

Large communities in the arid southwest (e.g., Las Vegas, NV, Los Angeles, CA, and Phoenix, AZ) use the majority of their potable water supply to irrigate urban landscapes. With these communities, turfgrass is the single most important landscape constituent. For instance, turfgrass occupies an area that is equivalent to the fifth largest crop in California. Irrigation rates on turf can surpass those of most agricultural crops due to the very high plant density and the need to maintain high aesthetic standards. The availability of recycled water, the high cost and lower availability of potable water, and many communities' desire to cultivate high-water use landscapes are driving interest on incorporating recycled water in water supply planning. Although preliminary data show that turfgrass/soil systems can be highly effective in removing the majority of PPCPs from recycled water (Snyder et al., 2004), understanding the fate and transport of these compounds may allow more effective optimization of turf irrigation for contaminant attenuation, thereby enhancing water resource availability and improving both public and regulatory acceptance of recycled water.

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[1] Recycled water is the term that will be used throughout this report. Other words to describe the water that is produced from wastewater treatment plants are reclaimed water, reuse water, treated wastewater, and tertiary treated effluent just to name a few.

[2] Wastewater contains a wide diversity of trace organic compounds. Among these organic compounds includes pharmaceuticals, personal care products, steroid hormones, and others. Some of these compounds have been shown to impact the endocrine system of animals and are commonly referred to as endocrine disrupting compounds (EDCs). The most commonly studied EDCs are estrogen hormones and compounds which can mimic the biological action of estrogen (estrogenic compounds). However, estrogenic EDCs are only one class of EDCs. The project team originally considered including natural and synthetic estrogen hormones during the project. However, considering the relatively low occurrence and previously demonstrated attenuation during water infiltration, the team decided not to pursue these compounds within this project. It is important to note that the term EDC is not synonymous with PPCPs, even though some PPCPs are considered to be EDCs. For the purpose of this study, we will only use the term PPCPs, while acknowledging the some of our target compounds also could be considered EDCs depending on exposure concentration.

Golf courses represent excellent sites for examining the potential migration of PPCPs toward the water table. Frequently, many golf courses are located in close proximity to wastewater treatment plants (WWTPs) which, when combined with their high demands for irrigation water, makes the use of recycled water for irrigation economically feasible. Recently, arid southwestern cities like Las Vegas, NV, Phoenix, AZ, Tucson, and Palm Springs, CA have been installing distribution systems that allow golf courses to utilize recycled water. Additionally, recycled water is sometimes supplied to infiltration basins that augment natural recharge to phreatic aquifers. Assessing and evaluating the vadose-related attenuation processes may help determine whether accumulation of these compounds occurs in shallow groundwater systems. Many studies over the last two decades show that turfgrass is extremely effective in retaining and biodegrading trace contaminants such as many pesticides (Wu et al., 2002). In particular, research shows that the thatch layer, which is the matted layer of grass debris and soil organic matter near the surface, has high amounts of biological activity. For instance, in a recent study funded through the WateReuse Research Foundation, golf course turf was found to be very effective in attenuating *N*-nitrosodimethylamine (NDMA) introduced through irrigation with recycled water (Gan et al., 2006; Arienzo et al., 2006). Although NDMA is known for its mobility and persistence, no NDMA was found in the drainage water of a 1-m profile when turf plots were intensively irrigated with recycled water for four months. However, the efficiency of turfgrass/soil systems to attenuate commonly occurring PPCPs is largely unknown, and must be experimentally evaluated.

To assess the environmental risks of irrigating with recycled water that contains PPCPs, fate and transport experiments were conducted in the laboratory, with lysimeters, with controlled field plots, and at golf courses. The underlying hypothesis is that turfgrass/soil systems on irrigated landscapes have the capacity to attenuate or otherwise remove the various biological and chemical contaminants, preventing them from reaching drinking water sources (e.g., groundwater) or surface aquatic ecosystems. To date little is known about the fate and transport of emerging contaminants such as PPCPs from recycled water used for landscape irrigation. Therefore, this project investigated the fate and transport of PPCPs in turfgrass/soil systems with the goal to evaluate its effectiveness in mitigating vertical movement of compounds (i.e., leaching). The transport behavior of such contaminants needs to be described and taken into account in the formulation of recycled water management strategies. That way communities and end users will continue to embrace the use of recycled water for irrigation purposes and for contributing to the continued conservation of freshwater sources. Note that the project did not isolate the fate and transport for each possible pathway (e.g., sorption, microbial degradation, uptake by turfgrass, etc.), given the significant complexity and cost for analyzing compounds according to each treatment. Rather, the project focused on overall attenuation and assumed that reduction in mass of each compound was due to several possible processes, although they were not individually studied. Laboratory experiments were conducted to evaluate sorption and degradation of the PPCPs in soil.

1.1 Research Intent, Objectives, and Hypotheses

The intent of this research project was to address specific objectives and test appropriate hypotheses. This was accomplished by reviewing and identifying the most prevalent PPCPs in recycled water, developing reliable sampling and analytical methods, and carrying out laboratory, plot-scale, and field experiments.

1.2 Research Objectives

The objectives of this research were to:

- To understand the fate and transport of PPCPs in turfgrass/soil systems when recycled water was used as the sole source of irrigation water;
- To evaluate the biological degradation capacity of turfgrass/soil systems for removing PPCPs found in recycled water;
- To extend knowledge to stakeholders and reduce the uncertainty of how long-term use of recycled water for irrigation may impact groundwater quality.

1.3 Research Hypotheses Tested

The hypothesis this research sought to test were:

- Turfgrass/soil systems can function effectively to reduce PPCPs when recycled water is used as the primary irrigation source.
- Significant attenuation of these compounds occurs in the root zone, minimizing the likelihood for PPCPs to reach the water table.
- Use of concentration and water flux to determine mass flux provides a more complete picture of PPCPs attenuation or leaching potential.
- The potential of PPCPs to move downward in the soil profile is a function of the chemical compound characteristics, soil type, and irrigation-induced leaching fractions.

1.4 Target Compounds Studied

The target compounds, listed below, represent PPCPs that are likely to appear in recycled water used for landscape and golf course irrigation. These compounds formed the target list for laboratory, plot-scale, and field studies.

Atenolol - beta-blocker; cardiovascular disease and hypertension
Atorvastatin - blood pressure regulation
Carbamazepine - anticonvulsant
Diazepam - sedative and anticonvulsant
Diclofenac - anti-inflammatory
Dilantin - anticonvulsant and seizure treatment
Fluoxetine - antidepressant
Gemfibrozil - lipid regulation
Ibuprofen - anti-inflammatory
Meprobamate - tranquilizer
Naproxen - anti-inflammatory
Primidone - anticonvulsant and seizure treatment
Sulfamethoxazole - antibiotic
Triclosan - antimicrobial
Trimethoprim - antibiotic

1.5 Research Tasks

Many research tasks were performed to meet the objectives of the project. Each task is discussed individually in this report.

- Laboratory-Scale Experiments
- Lysimeter Experiments
- Controlled Field Plot Experiments
- Experiments at Active Golf Courses

CHAPTER 2.0

LABORATORY-SCALE EXPERIMENTS

2.1 Introduction

Soil sorption and degradation are two major processes that may influence the attenuation of PPCPs after they enter the vadose zone through irrigation of recycled water. A limited number of studies so far have shown inconclusive evidence. For example, a soil column leaching experiment showed that carbamazepine and diclofenac were significantly retarded in the 0-5 cm soil sample rich in soil organic matter, while naproxen was highly mobile (Chefetz et al., 2008). Kinney et al. (2006) investigated the occurrence and distribution of 19 pharmaceuticals in soil samples collected from three sites irrigated with recycled water and found that some pharmaceuticals accumulated in soil and could persist in soil for months after irrigation. For those compounds susceptible to soil sorption, they are prone to accumulated in the top soil layer and subsequently affect the soil microbial community and may be taken up by plants (Thiele-Bruhn, 2003). For instance, Snyder et al. (2004) showed that many pharmaceuticals and endocrine disrupting chemicals could be efficiently removed by turfgrass/soil systems due mainly to soil sorption and microbial degradation. These studies suggest that the sorption and degradation of pharmaceuticals in soil are highly compound- and site-specific. Therefore, it is necessary to examine the attenuation of wastewater-borne pharmaceuticals in soils irrigated with recycled water.

The objective of the laboratory-scale experiments was to evaluate the sorption and degradation of a list of PPCPs in two sandy soils from Nevada. The selected PPCPs have been frequently detected in recycled water (Benotti et al., 2009; Kolpin et al., 2002; Snyder et al., 2004). The soils were representative of soil types found in golf courses in the general southwestern area of the United States, where recycled water is increasingly used for irrigation.

2.2 Experimental Approach

As described below, chemicals were purchased, soils were collected, and various experiments and analyses conducted to complete this research.

2.2.1 Chemicals

Standards of unlabeled pharmaceuticals (carbamazepine (> 98%), diazepam (> 98%), dilantin (99%), gemfibrozil (> 99%), meprobamate (> 99%), primidone (> 98%), diclofenac sodium (> 98%), ibuprofen (> 97%), naproxen (98%), sulfamethoxazole (> 98%), and trimethoprim (98%)) were purchased from Sigma-Aldrich (St. Louis, MO). Standards of deuterium-labeled compounds (gemfibrozil-*d*3 (98%), primidone-*d*5 (98%) meprobamate-*d*6 (98%), ibuprofen-*d*3 (98%), sulfamethoxazole-*d*4 (99%), and trimethoprim-*d*9 (98%)) were purchased from Toronto Research Chemicals (North York, Ontario, Canada). A standard of diazepam-*d*5 (99%) was purchased from Cambridge Isotope Laboratories (Andover, MA). Standards of carbamazepine-*d*10 (> 99%), dilantin-*d*10 (> 99%), diclofenac-*d*4 (> 99%), and naproxen-*d*3 (98.1%) were purchased from C/D/N Isotopes (Pointe-Claire, Quebec, Canada).

2.2.2 Soils

Two soils separately collected from Boulder City, Nevada (BC) and North Las Vegas, Nevada (NLV), were used in this study. After collection, the soil samples were stored at 4°C until use. Physicochemical properties of the soils are given in Table 2-1.

Table 2-1. Textural and Chemical Properties of Soils Used.

Soil	Soil type	Sand, %	Silt, %	Clay, %	OC, %	pH	CEC, meq/100g
BC	sand	91	5	4	0.16	9.23	8.2
NLV	loam	31	44	25	0.33	8.73	22.2

2.2.3 Sorption Experiments

Sorption of PPCPs in the soils was measured using a batch equilibrium method at room temperature (21 ± 1°C). Briefly, an aliquot of 5.0 g soil (dry weight equivalent) was weighed into a 40-mL Teflon centrifuge tube and 25 mL of 0.01 M $CaCl_2$ solution was added to arrive at a soil/solution ratio of 1:5 (w/w). The $CaCl_2$ solution also contained sodium azide at 200 mg/L to suppress microbial activity during the equilibration. The soil samples were spiked with 20 µL standard solution in methanol solution. The nominal initial concentrations for each compound in these treatments were 2, 5, 10, 20, 30, 40, and 50 µg/L, respectively. The sample tubes were closed with Teflon-lined caps, and shaken reciprocally on a mechanical shaker for 24 h. After shaking, the tubes were centrifuged for 10 min at 8820 *g*, and the supernatant was removed by pipetting. An aliquot of the supernatant was passed through a 0.45 µm glass fiber microfilter (Fisher Scientific) and 1.0 mL of the filtrate was directly subjected to analysis to obtain the concentration in the aqueous phase (C_w, µg/L). To calculate the sorbed concentration (C_s, µg/kg), a soil-less control (0.01 M $CaCl_2$ solution) with only the spiked chemicals was included for each treatment. The concentration of each compound after equilibration was similarly measured and defined as C_{ck} (µg/L). When noticeable sorption occurred, the difference between C_w and C_{ck} was used to estimate C_s. All tests were done in triplicates. The sorption coefficient (K_d, L/kg) was calculated as the ratio of C_s over C_w, from which the organic carbon–normalized sorption coefficient K_{OC} was further estimated by normalizing K_d over the soil organic carbon content.

2.2.4 Degradation Experiments

In the aerobic degradation experiment, aliquots of 5.0 g soil (dry weight equivalent) were weighed into small glass jars (5.4 cm diameter × 4.6 cm height) and a given amount of deionized water was added to each jar to keep the soil water content at 75% of maximum water-holding capacity. The soil samples were then spiked with 10 µL of methanol solution containing 0.2 µg of each pharmaceutical to generate an initial nominal concentration of 40 µg/kg for each compound. The treated samples were incubated in a dark and airy cabinet at room temperature (21 ± 1°C). The samples were checked daily for water loss by weighing, and deionized water was added to compensate for water loss when necessary.

In the anaerobic degradation experiment, aliquots of 5 g soil (dry weight equivalent) were weighed into 40-mL glass vials (2.8 cm diameter × 9.5 cm height) and a given amount of deionized water was added to achieve a soil water content of 75% of maximum water-holding capacity. The anaerobic microcosm was built according to a previous study (Lin et al., 2008). Briefly, the sample vials were transferred into an airtight inflatable plastic glove chamber (Cole Parmer, Vernon Hill, IL) inflated with nitrogen gas (99.99%). The sample vials were flushed with nitrogen by alternately inflating and deflating the glove chamber, and equilibrated in the inflated glove chamber for 1 d, followed by sealing with screw caps with Teflon-lined butyl rubber septa. The soil samples were removed from the glove chamber and immediately spiked with 10 μL acetone solution containing 0.2 μg of each compound using a micro-syringe. The treated samples were vortexed for 30 s and returned to the nitrogen-filled chamber for incubation at room temperature (21 ± 1°C). The anaerobic conditions inside the vials were maintained by adding nitrogen into the plastic glove when noticeable deflation occurred.

For both aerobic and anaerobic degradation experiments, triplicate samples were removed on 0, 14, 28, 42, 56, 70, and 84 d after the treatment and stored at -22°C until extraction and analysis.

2.2.5 Chemical Analysis

To determine the remaining concentration of PPCPs in the incubated soil samples, the frozen samples were thawed at room temperature and spiked with a known amount of the mixture of the deuterium labeled standards as internal standards. The extraction procedure followed a modified EPA Method 1694. Briefly, the soil samples were transferred to 50-mL centrifuge tubes and extracted with 35 mL of 3/4 (v/v) pH 2.0 phosphate buffer solution/methanol by mixing on a shaker for 60 min. The slurry samples were centrifuged at 8820 *g* for 10 min and the supernatant was filtered through Whatman No. 41 filter paper (Whatman, Maidstone, UK). The same extraction step was repeated two more times with 35 mL of 3/4 (v/v) pH 2.0 phosphate buffer solution/methanol and 20 mL methanol. The combined extracts were concentrated to about 20-30 mL on a vacuumed rotary evaporator at 60°C. Immediately after the volume reduction, 250 mL of reagent water was added to the extract to reconstitute it to an aqueous solution suitable for further cleanup.

The cleanup procedure was based on methods from Vanderford and Snyder (2006). Briefly, the extract was passed through a 6-mL (150 mg) Oasis hydrophilic-lipophilic balance solid-phase extraction (SPE) cartridge (Waters, Millford, MA). The SPE cartridges were sequentially preconditioned with 5 mL MTBE, 5 mL methanol, and 5 mL reagent water. The diluted samples were then loaded onto the SPE cartridge at 10 mL/min using a Supelco vacuum manifold (Bellefonte, PA), after which the cartridges were rinsed with 5 mL reagent water and then dried with a stream of nitrogen for 30 min. The cartridges were eluted with 5 mL methanol followed by 5 mL of 10/90 (v/v) methanol/MTBE mixture. The resulting eluent was further condensed to near dryness under a gentle stream of nitrogen at 40°C. The extract was finally dissolved in 1.0 mL methanol for analysis.

Analysis of PPCPs was carried out on an Aquity ultra performance liquid chromatography system (UPLC) coupled with a Trinity triple quadrupole mass spectrometer equipped with an electrospray ionization source (ESI) (Waters). The separation was achieved using a BEH C18 column (100 mm × 2.1 mm i.d. with 1.7 μm particle size, Waters). Individual tune files were created by infusing the individual compounds to determine the optimum capillary and cone voltages, collision energies, and product ions. The MS/MS parameters, precursor and product ions are listed in Table 2-2. The instrumental detection limit ranged from 0.2 to 0.7 ng/L for the different analytes.

Table 2-2. MS/MS Parameters, Precursors, and Product Ions.

Compound	Precursor ion	Cone voltage	Product ion	Collision energy
ESI Positive				
Trimethoprim	291	50	230	26
Trimethoprim-*d9*	300	50	234	25
Sulfamethoxazole	254	30	156	15
Sulfamethoxazole-*d4*	258	25	160	15
Primidone	219	30	162	15
Primidone-*d5*	224	30	167	10
Meprobamate	219	25	158	10
Meprobamate-*d3*	222	20	161	10
Dilantin	253	30	182	20
Dilantin-*d10*	263	40	192	15
Carbamazepine	237	41	194	20
Carbamazepine-*d10*	247	40	204	20
Diazepam	285	50	154	44
Diazepam-*d5*	290	50	154	25
ESI Negative				
Naproxen	229	25	170	22
Naproxen-*d3*	232	30	171	45
Diclofenac	294	17	250	15
Diclofenac-*d4*	298	30	217	25
Ibuprofen	205	25	161	30
Ibuprofen-*d4*	208	30	164	15
Gemfibrozil	249	27	121	25
Gemfibrozil-*d6*	255	35	121	16

2.3 Results and Discussion

Sorption of the compounds in the soil was relatively weak. The results leading to that conclusion are presented below. In addition, results of degradation testing of the compounds follow.

2.3.1 Sorption of PPCPs in Soils

A total of 11 compounds were included in the adsorption experiments. Overall, most of the compounds showed no appreciable or very weak sorption in the soils (Table 2-3). For those compounds with non-observable sorption, results were demonstrated by the relationship of C_w and C_{ck}, constantly showing a close slope to 1.0. For those compounds (atenolol, diazepam, trimethoprim, and gemfibrozil) with significant sorption, K_d values were calculated by the ratio of C_s to C_w.

Table 2-3. Sorption Coefficients (K_d) of Selected PPCPs in BC and NLV Soils. (NS denotes no sorption)

Compound	BC soil			NLV soil		
	K_d, L/kg	K_{oc}, L/kg	R^2	K_d, L/kg	K_{oc}, L/kg	R^2
Primidone	NS	NS	-	NS	NS	-
Meprobamate	NS	NS	-	NS	NS	-
Carbamazepine	NS	NS	-	7.1	2152	0.96
Dilantin	NS	NS	-	NS	NS	-
Sulfamethoxazole	NS	NS	-	NS	NS	-
Atenolol	27.1	16938	0.93	>195	-	-
Diazepam	6.0	3750	0.96	>195	-	-
Trimethoprim	7.4	4625	0.96	>195	-	-
Ibuprofen	NS	NS	-	NS	NS	-
Gemfibrozil	NS	NS	-	2.6	485	0.91
Diclofenac	NS	NS	-	NS	NS	-

Primidone

No sorption was observed in both BC and NLV soils (Figure 2-1).

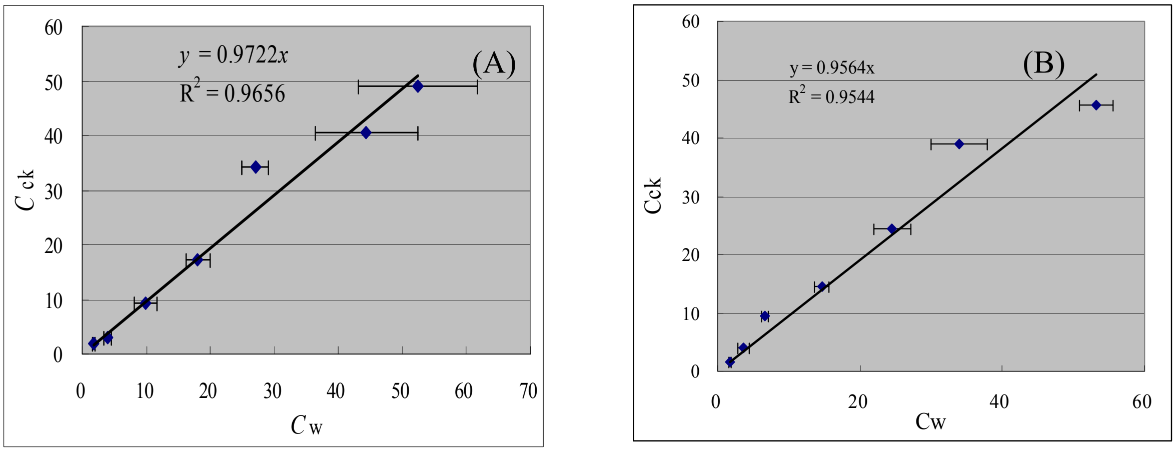


Figure 2-1. Sorption of Primidone in (A) BC and (B) NLV Soils.

Meprobamate

No sorption was observed in both BC and NLV soils (Figure 2-2).

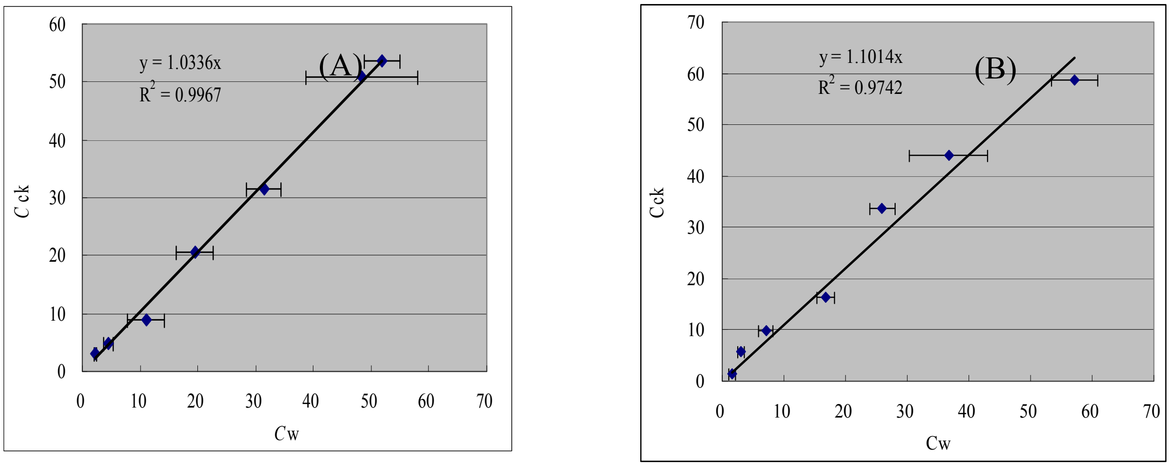


Figure 2-2. Sorption of Meprobamate in (A) BC and (B) NLV Soils.

Carbamazepine

No sorption was observed in the BC soil (Figure 2-3). However, the NLV soil displayed weak sorption for carbamazepine. A linear sorption trend was observed in the NLV soil between 2.1 µg/L and 11.3 µg/L aqueous phase concentrations. The corresponding sorption coefficient K_d was estimated to be 7.1 L/kg with an R^2 of 0.96. When the aqueous-phase concentrations were higher than 11.3 µg/L, the sorption amounts of carbamazepine in the soil phase remained approximately the same, suggesting likely saturation of sorption capacity for the NLV soil. The maximum sorption capacity of the NLV soil for carbamazepine was estimated to be approximately 84 µg/kg.

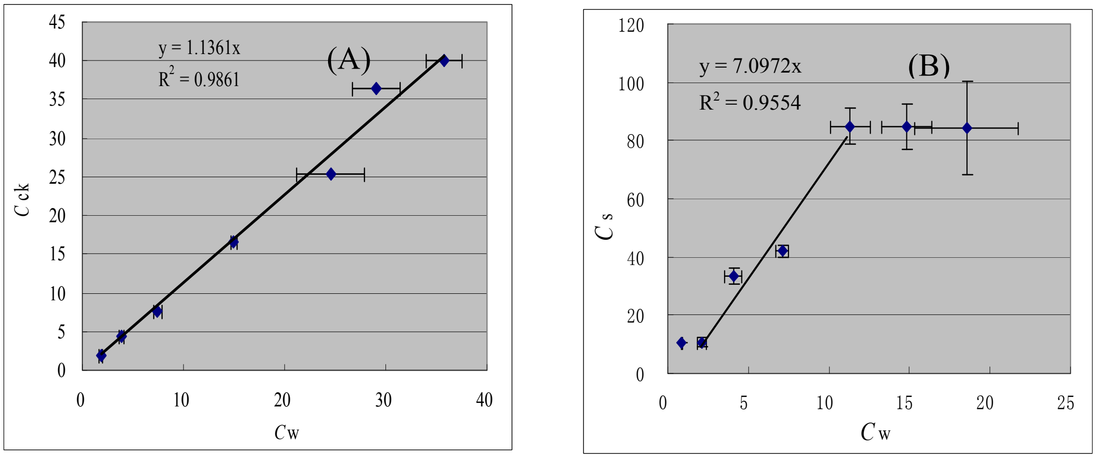


Figure 2-3. Sorption of Carbamazepine in (A) BC and (B) NLV Soils.

Dilantin

No sorption was observed in both BC and NLV soils (Figure 2-4).

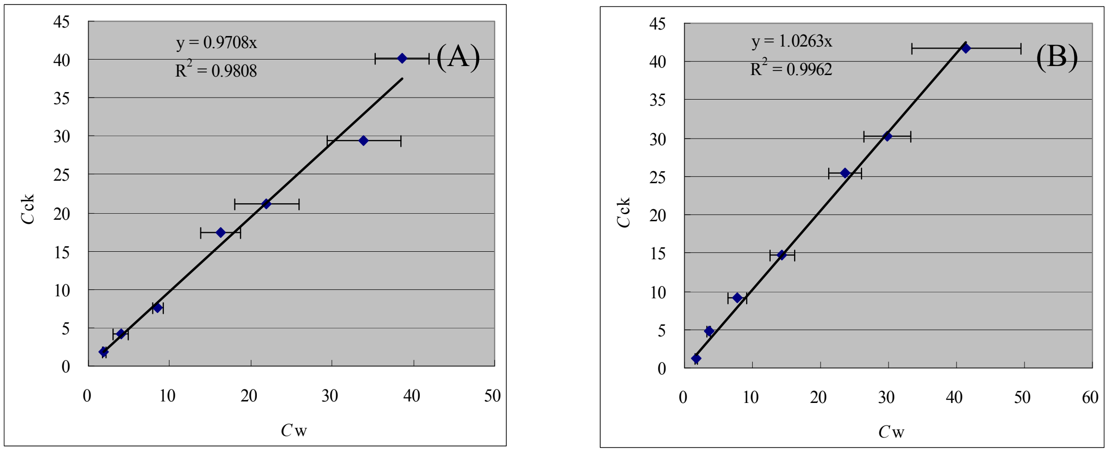


Figure 2-4. Sorption of Dilantin in (A) BC and (B) NLV Soils.

Sulfamethoxyazole

No sorption was observed in both BC and NLV soils (Figure 2-5).

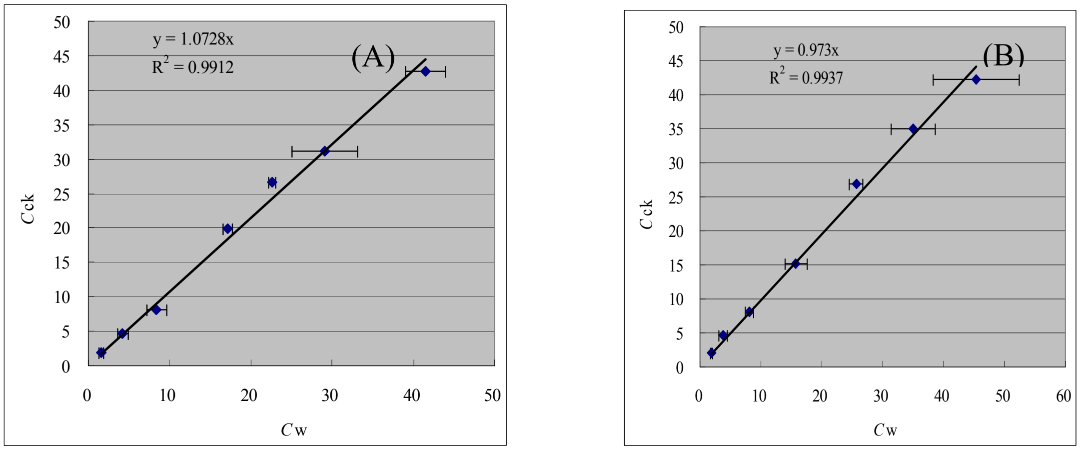


Figure 2-5. Sorption of Sulfamethoxylazole in (A) BC and (B) NLV Soils.

Atenolol

Sorption of atenolol in the BC soil could be described by a linear model. The estimated K_d was 27.1 L/kg with an R^2 of 0.93, suggesting rather strong sorption (Figure 2-6). For the NLV soil, the soil-less control showed good recoveries, but no atenolol was detected in the solution phase at equilibrium, suggesting exceedingly strong sorption for this compound in this soil. Using the spiked concentrations and the detection limit of the analytical method, K_d of atenolol in the NLV soil was estimated to be higher than 195 L/kg. Such an unexpected high K_d of atenolol in the NLV soil may be attributable to the high soil cation exchange capacity (with a CEC of 22.2 meq/100g). Similar results were found for the sorption of diazepam and trimethoprim in the NLV soil.

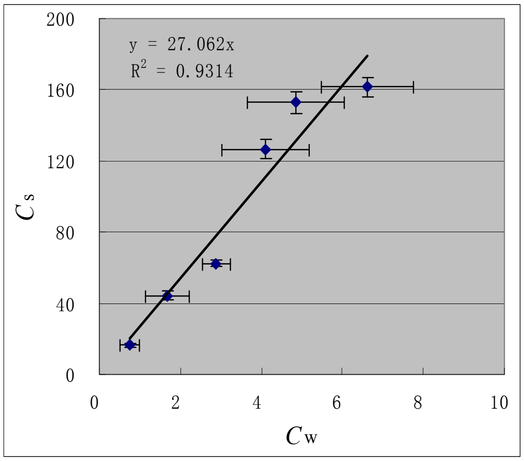


Figure 2-6. Sorption of Atenolol in BC Soil.

Diazepam

Sorption of diazepam in the BC soil could be described by a linear model. The estimated K_d was 6.0 L/kg with an R^2 of 0.96, suggesting moderate sorption (Figure 2-7). Although the soil-less control showed good recoveries, diazepam became non-detectable in the solution of NLV upon equilibrium, suggesting exceedingly strong sorption. The sorption coefficient K_d of diazepam in the NLV soil was therefore estimated to be higher than 195 L/kg.

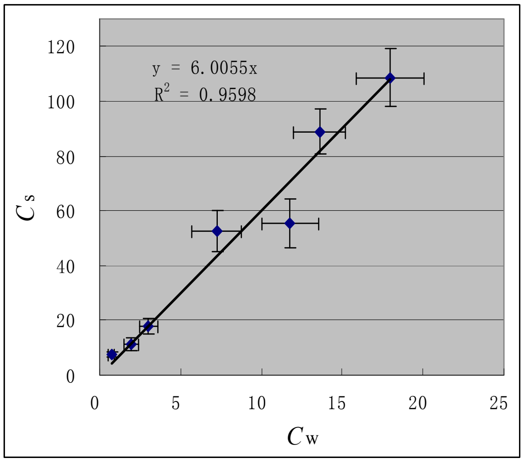


Figure 2-7. Sorption of Diazepam in BC Soil.

Trimethoprim

Sorption of trimethoprim in the BC soil could be described by a linear model. The estimated K_d was 7.4 L/kg with R^2 of 0.96, suggesting moderate sorption. Again, although the soil-less control showed good recoveries, no detectable concentration of trimethoprim was found in the solution of NLV at equilibrium, suggesting exceedingly strong sorption. The sorption coefficient K_d of trimethoprim in the NLV soil was also estimated to be higher than 195 L/kg.

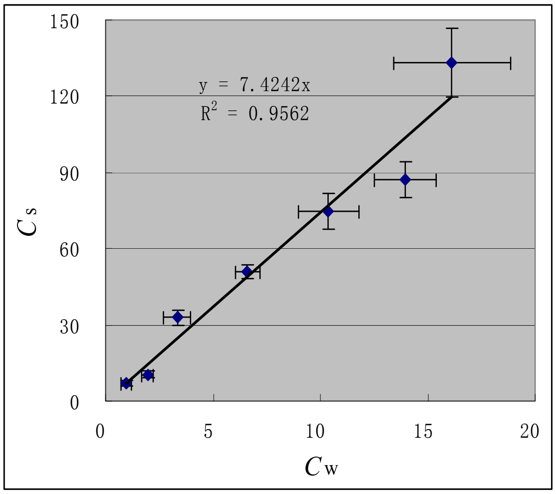


Figure 2-8. Sorption of Trimethoprim in BC Soil.

Ibuprofen

No sorption was observed in both BC and NLV soils (Figure 2-9).

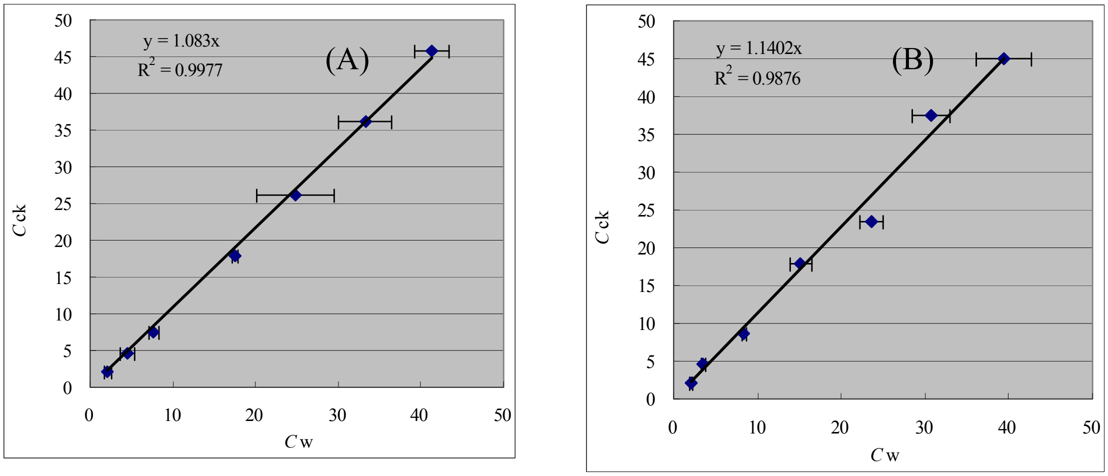


Figure 2-9. Sorption of Ibuprofen in BC and NLV Soils.

Gemfibrozil

No sorption was observed in the BC soil (Figure 2-10). Sorption of gemfibrozil in the NLV soil could be described by a linear model. The estimated K_d was 2.6 L/kg with R^2 of 0.91 (Figure 2-10).

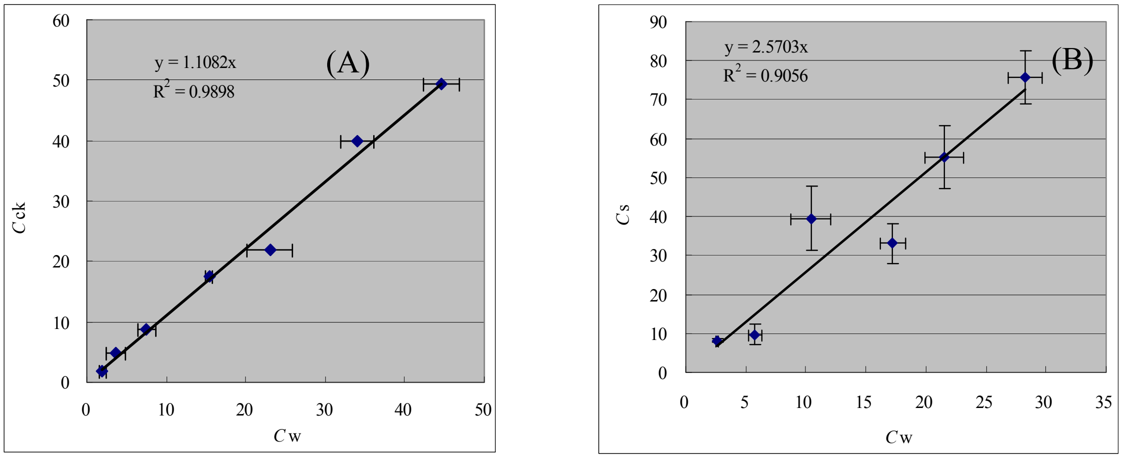


Figure 2-10. Sorption of Gemfibrozil in BC and NLV Soils.

Diclofenac

No sorption was observed in both BC and NLV soils (Figure 2-11).

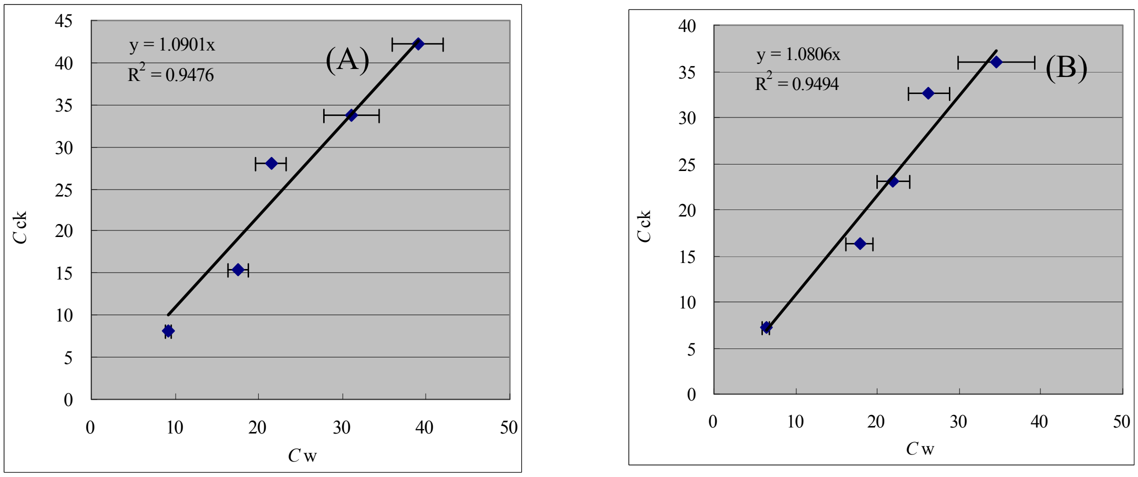


Figure 2-11. Sorption of Diclofenac in BC and NLV Soils.

2.3.2 Degradation of PPCPs in Soils

The decline of PPCPs concentrations in the soils over time is plotted in Figures 2-12 and Figure 2-13. For those compounds with appreciable degradation, the disappearance curves were fitted to an exponential decay model to estimate the first-order degradation rate constant k (d^{-1}) and half-life $T_{1/2}$ (d). In this study, only the degradation of some PPCPs under specific soil or incubation (aerobic, anaerobic) conditions could be successfully fitted to the exponential decay model (Table 2-4). Model fit for all other treatments yielded either zero or very small R^2 values, suggesting that many PPCPs were highly persistent in soil under the experimental conditions.

Gemfibrozil, Dilantin, Meprobamate

Under aerobic conditions, $T_{1/2}$ values of gemfibrozil in the BC and NLV soils were estimated to be 27 and 94 d, respectively. The respective $T_{1/2}$ values for dilantin were 44 and 74 d. The $T_{1/2}$ values of meprobamate in the BC soil incubated under aerobic and anaerobic conditions were estimated to be 33 and 54.6 d, respectively. Gemfibrozil, dilantin and meprobamate were relatively stable in the sterilized soil, suggesting that microbial degradation played an important role in the dissipation of these three compounds in the soils. For gemfibrozil and dilantin, degradation in the same soil appeared to be faster under aerobic conditions than under anaerobic conditions. For instance, over 90% of the initially spiked gemfibrozil was degraded in the BC soil after 84 d of incubation, while only 28% was lost under anaerobic conditions.

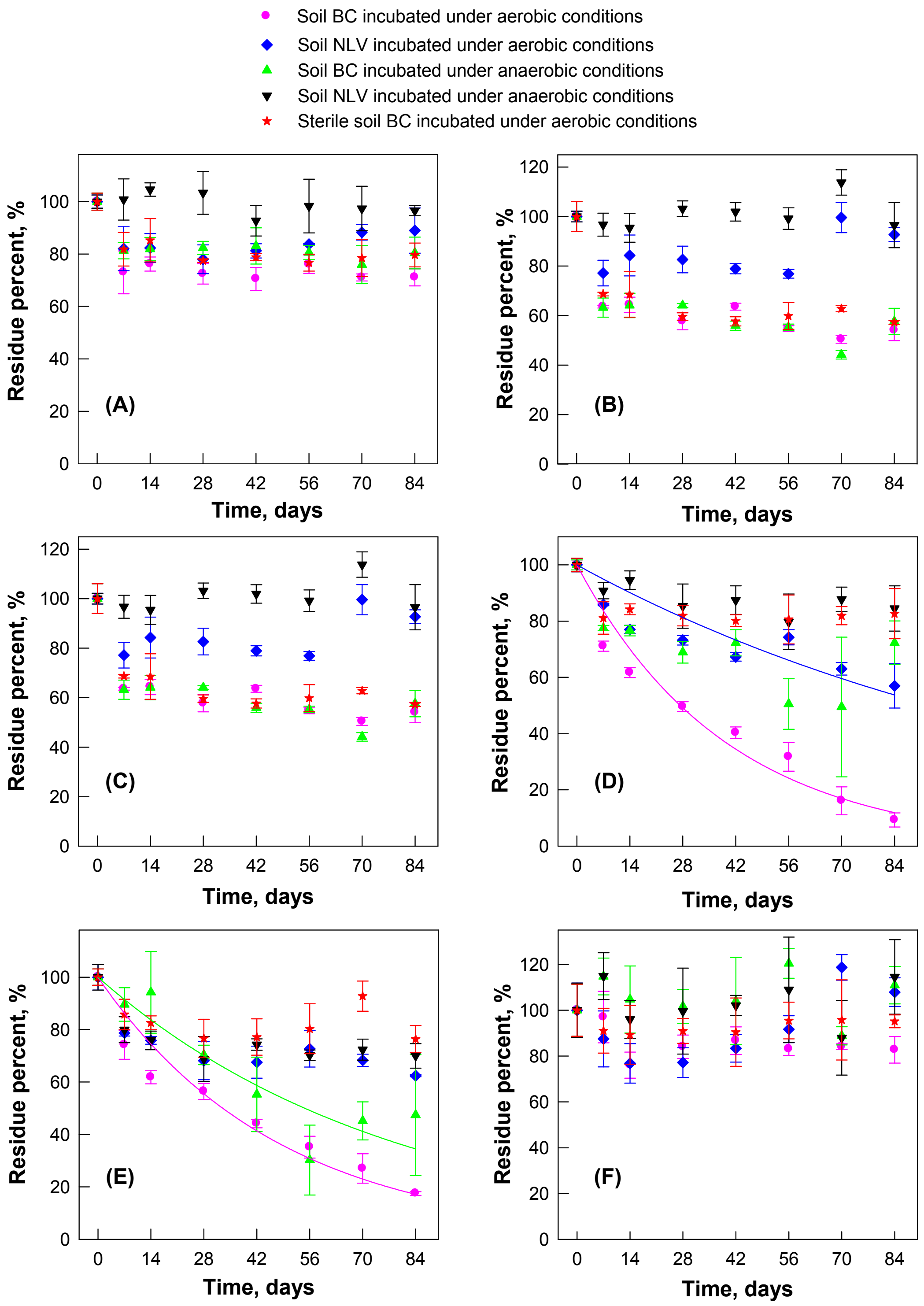


Figure 2-12. Degradation of Selected PPCPs in Soils Under Different Conditions.
The selected PPCPs are (A) carbamazepine, (B) diazepam, (C) dilantin, (D) gemfibrozil, (E) meprobamate, and (F) primidone.

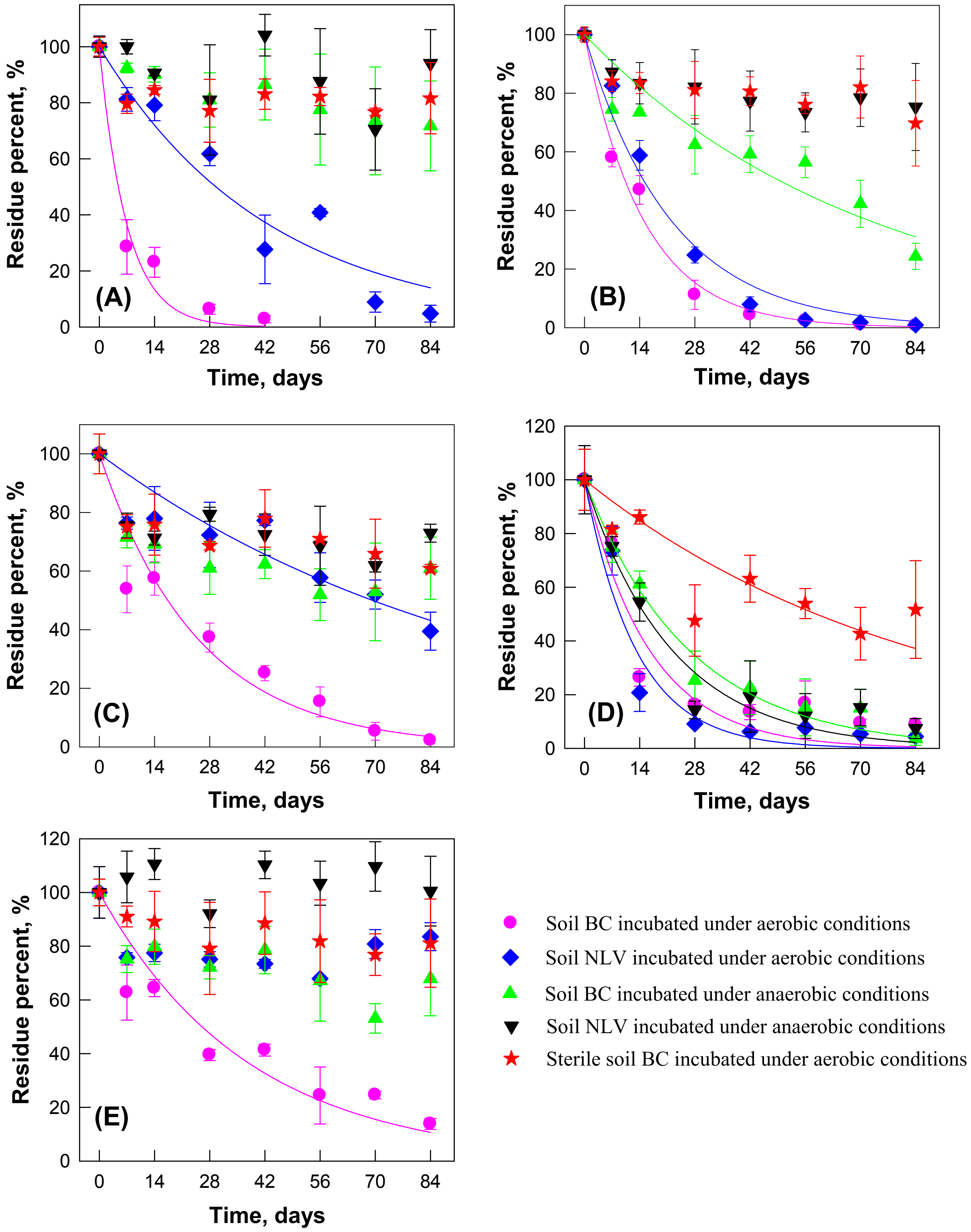


Figure 2-13. Degradation of Selected PPCPs in Soils Incubated Under Different Conditions.
The selected PPCPs are (A) diclofenac, (B) ibuprofen, (C) naproxen, (D) sulfamethoxazole, and (E) trimethoprim.

Table 2-4. First-Order Degradation Rate Constants (k) and Half-Life Values of Selected PPCPs with Appreciable Degradation in Soils Under Experimental Conditions.

Compound	Soil	Conditions	k, d^{-1}	$t_{1/2}$, d	R^2
Diclofenac	BC	Aerobic	0.1434 ± 0.0211	4.8	0.970
	NLV	Aerobic	0.0234 ± 0.0028	29.6	0.927
Gemfibrozil	BC	Aerobic	0.0254 ± 0.0022	27.3	0.95
Gemfibrozil	NLV	Aerobic	0.0074± 0.0010	93.7	0.65
Ibuprofen	BC	Aerobic	0.0668 ± 0.044	10.4	0.989
	NLV	Aerobic	0.0457 ± 0.0039	15.2	0.980
	BC	Anaerobic	0.0139 ± 0.0016	49.9	0.844
Meprobamate	BC	Aerobic	0.0210 ± 0.0019	33.0	0.93
Meprobamate	BC	Anaerobic	0.0127 ± 0.0016	54.6	0.86
Naproxen	BC	Aerobic	0.0399 ± 0.0052	17.4	0.925
	NLV	Aerobic	0.0100 ± 0.0012	69.3	0.785
Sulfamethoxazole	BC	Aerobic	0.0609 ± 0.0104	11.4	0.913
	NLV	Aerobic	0.0766 ± 0.0115	9.0	0.948
	BC	Anaerobic	0.0379 ± 0.0027	18.3	0.979
	NLV	Anaerobic	0.0452 ± 0.0050	15.3	0.955
	BC	Aerobic	0.0118 ± 0.0018	58.7	0.695
Trimethoprim	BC	Anaerobic	0.0266 ± 0.0033	26.1	0.880

Carbamazepine

Carbamazepine did not undergo appreciable degradation in the NLV soil during 84 d incubation under either aerobic or anaerobic conditions. The final residue accounted for 78-105% of the initial treatment. In the BC soil, carbamazepine decreased to about 70% of the initial level after 7 d of incubation under both aerobic and anaerobic conditions, but no further significant decrease occurred thereafter ($p > 0.05$). A similar initial loss was also found for most of the other compounds in this study. This loss may be attributed to the formation non-extractable residues. Although the formation of non-extractable residues was not considered in this study due to the use of non-labeled compounds, other studies using radioisotope labeling techniques showed the widespread occurrence of non-extractable or bound residues of pharmaceutical and PPCPs in soils or sediments (Heise et al., 2006; Höltge and Kreuzig, 2007; Richter, 2007; Al-Rajab et al., 2009). For example, 93% of sulfamethoxazole became non-extractable after 102 d incubation in soil (Heise et al., 2006). Similarly, more than 15% of diazepam was found to be non-extractable after 55 d of incubation in soils (Richter et al., 2007). Furthermore, the dissipation curve of carbamazepine in the sterilized BC soil followed a very similar pattern to that in the non-sterile BC, suggesting that microbial transformations did not contribute to the observed loss. Several studies also showed the low biodegradability of carbamazepine (Clara et al., 2004; Miao et al., 2005; Matamoros et al., 2008; Benotti and Brownawell, 2009; Monteriro and Boxall, 2009). For example, degradation of carbamazepine was very limited in agricultural soils with or without biosolid amendment over 60 d (Monteriro and Boxall, 2009). Similarly, only 5% of carbamazepine was removed in a subsurface flow constructed wetland (Matamoros et al., 2008). Benotti and Brownawell (2009) also showed that carbamazepine was resistant to microbial transformations in estuarine and coastal seawater with estimated half-lives over 100 d.

Diazepam

Diazepam followed a dissipation pattern similar to carbamazepine. Like carbamazepine, diazepam did not dissipate significantly in the NLV soil under either aerobic or anaerobic conditions (Figure 2-12 C) ($p > 0.05$). Diazepam showed a substantial initial loss in non-sterile and sterilized BC soil after 7 d of incubation, which was followed by a very slow decline. The similarity between sterilized and non-sterile soils also suggested a lack of microbial involvement in the dissipation of diazepam in the BC soil. Similar to our finding, diazepam was demonstrated to be refractory to biodegradation in two previous studies (Richter et al., 2007; Redshaw, et al., 2008).

Primidone

The remaining concentrations of primidone in the incubated samples were found to fluctuate between 76 and 120% of the initial level with no discernable trend (Figure 2-12F), suggesting its persistence in the soils. This observation coincided with the finding of a recent study (Kahle et al., 2009) that also showed relative stability of primidone in natural and domestic waters. The stability of primidone was even suggested as a characteristic allowing it to be used as a possible marker for tracing the contamination of natural waters by domestic wastewater.

Diclorfenac

Under aerobic conditions, degradation of diclofenac in BC and NLV soils followed the exponential decay model and the estimated $t_{1/2}$ was 4.8 d for BC soil and 29.6 d for NLV soil. This result was consistent with a previous study where $t_{1/2}$ of diclofenac varied from 3.1 to 20.4 d in different soils (Xu et al., 2009). However, under anaerobic conditions, most of the diclofenac remained in the soils after 84 d (Figure 2-13A), suggesting negligible dissipation. Similarly, diclofenac did not show appreciable reduction in concentration in the sterilized BC soil, suggesting that microorganisms played an important role in the degradation of diclofenac in BC and NLV soils under aerobic conditions.

Ibuprofen, Naproxen

Ibuprofen showed apparent dissipation in BC soil under both aerobic and anaerobic conditions and in NLV soil under aerobic conditions, with the corresponding $t_{1/2}$ values to be 10, 50, and 15 d, respectively (Table 2-3). After 84 d of incubation, about 70% of the spiked ibuprofen was in NLV soil under anaerobic conditions and 75% in the sterilized BC soil under aerobic conditions. In addition, the observed reduction mainly occurred during the first 7 d, with little decreases observed thereafter (Figure 2-13B). The initial decrease was likely due to the formation of non-extractable residues, as demonstrated using ^{14}C-labeled compounds (Richter et al., 2007). A few other treatments in this study also displayed a similar behavior. For example, following the initial decrease, naproxen levels remained unchanged in BC and NLV soils under anaerobic conditions or in the sterile BC soil under aerobic conditions (Figure 2-13C). However, under aerobic conditions, $t_{1/2}$of naproxen was estimated to be 17.4 d in BC soil and 69 d in NLV soil. Monteiro and Boxall (2009) reported that naproxen degraded rapidly in a range of agricultural soils with $t_{1/2}$ ranging from 3.1 to 6.9 d.

Sulfamethoxazole

Dissipation of sulfamethoxazole in BC and NLV soils under both aerobic and anaerobic conditions was well described by the exponential decay model with R^2 between 0.91 and 0.98 (Figure 2-13D). The $t_{1/2}$ values of sulfamethoxazole in BC and NLV soils were 11.4 and 9.0 d, respectively, under aerobic conditions, and 18.3 and 15.3 d, respectively, under anaerobic conditions. The persistence of sulfamethoxazole in the sterilized BC soil ($t_{1/2} = 59$ d) was substantially longer, suggesting the contribution from biotic transformations. Other studies (Mohring et al., 2009; Wu et al., 2009) also showed that sulfamethoxazole was readily biodegradable under either aerobic or anaerobic conditions.

Trimethoprim

The half-life of trimethoprim in BC soil under aerobic conditions was 26 d. However, there was no discernible dissipation for trimethoprim in the other treatments (Figure 2-13E). For example, the level of trimethoprim remaining in NLV soil under aerobic conditions fluctuated from 68-84% between 7 d and 84 d. In a previous study (Benotti and Brownawell, 2009), trimethoprim was also found to be recalcitrant to microbial degradation in estuarine and coastal surface waters, showing $t_{1/2} > 100$ d. On the other hand, Mohring et al. (2009) showed that trimethoprim was completely removed through anaerobic fermentation within 8 d.

2.4 Conclusions

Except for a limited few PPCPs, many of the PPCPs considered in this experiment generally showed little to moderate sorption in soils. In addition, only a relatively few PPCPs were somewhat susceptible to biodegradation under some conditions, while the other PPCPs considered in this experiment were all relatively persistent with half-lives longer than 100 d. The low sorption and long persistence of the selected PPCPs would suggest that they may have a high mobility in sandy soils commonly found on some golf courses in arid and semi-arid regions and therefore may move downward to pose a risk for groundwater contamination where recycled water is used for irrigation. However, it must be noted that the overall long persistence may be due to the very low organic matter contents of these soils. Moreover, unlike actual turfgrass/soil systems such as golf courses, plants were absent under the experimental conditions, which could have contributed to the lack of degradation due to lower microbial diversity/activity. Information from this laboratory experiment points to a need for further evaluating the leaching risk of these and other trace contaminants under field conditions with realistic agronomic and water management practices.

CHAPTER 3.0

FATE AND TRANSPORT OF PPCPS – LYSIMETER STUDY

3.1 Introduction

Recycled water is used in communities throughout the United States to augment existing water resources (Devitt et al., 2007; USGA, 1994). Using recycled water allows communities to diversify their water resource portfolios while at the same time utilizing such water in an environmentally acceptable and responsible fashion. In Las Vegas NV, over 30 of the existing 53 golf courses utilize recycled water to irrigate fairways and greens. However, such water contains elevated soluble salts that require an irrigation management strategy that incorporates effective leaching to maintain soil salinity below threshold levels (Devitt et al., 2007). Such leaching is critical for the maintenance of favorable long term salt balances but also provides an opportunity for other soluble compounds to be leached from the soil profile. This has long been a concern with nitrates in recycled water but more recently with pharmaceuticals and personal care product chemicals (PPCPs).

Unlike nitrates which are known to move with water in a one to one fashion (Devitt et al., 1976), PPCPs are organic in nature, having higher octanol-water partition coefficients (Yoon et al., 2006). Some PPCPs are known to undergo adsorption reactions on the surfaces of clay particles and organic matter in the soil (Xu et al., 2009). Some PPCPs are also acted upon by microbes in the soil profile as a source of energy, leading to full or partial degradation (Carr et al., 2011). As such, studies in the field rarely detect concentrations of PPCPs in drainage or ground water that are similar to concentrations found in the source water (Gibson et al., 2010).

The biological significance of such compounds found in water even at concentrations measured in parts per billion is not fully understood (Pal et al. 2010). At the same time, emphasis needs to be placed not on the concentration but the mass discharge of PPCPs from known points of application. This is because low concentrations associated with high volumes of discharge can be associated with a high mass discharge of PPCPs. Concentration and total discharge are necessary for a more complete understanding of PPCPs environmental mobility. As such, it is important that the scientific community more fully understand the fate and transport of PPCPs in irrigated turfgrass/soil systems.

No studies that have been conducted on PPCPs under conditions in which water balances have been maintained over a 745-day period. The goal of this phase of the project was to assess the long-term mobility of PPCPs under realistic field conditions, in which leaching fractions (drainage volume divided by the irrigation volume), soil type, and cover varied. In particular, the experiment focused not only on the monitoring of PPCPs concentration in drainage water, but also the quantification of the mass discharge of PPCPs in water draining from soil profiles. It then related this to the main treatment effects and to additional soil, plant, and water variables assessed over time.

3.2 Experimental Design

The experiment was conducted outdoors at the University of Nevada Las Vegas Center for Urban Water Conservation in North Las Vegas, NV. The experiment was set up in a randomized block design, allowing results to be assessed using analysis of variance (ANOVA). The main treatments were soil type (sandy loam or loamy sand), leaching fractions (0.05 or 0.25) and cover (bare or turfgrass). It comprised the following eight treatments with BC indicating the loamy sand, NLV indicating a sandy loam, 0.05 and 0.25 indicating the leaching fraction and B indicating bare soil, and G indicating turfgrass covered lysimeter: BC 0.05 B, BC 0.25 B, BC 0.05 G, BC 0.25 G, NLV 0.05 B, NLV 0.25 B, NLV 0.05 G, and NLV 0.25 G. Treatments were replicated in triplicate yielding 24 experimental units. These 24 experimental units were lysimeters constructed of pvc pipe with bottom end caps. Each lysimeter was approximately 61 cm in diameter and 129 cm in depth. An experimental area was leveled and fenced to contain the lysimeters (Figure 3-1). Holes were augured into the soil within the experimental area such that each lysimeter could be positioned at ground level. Lysimeters were spaced approximately 3.7 m apart in four rows of six lysimeters.

Figure 3-1. Research Plot at the Center for Urban Water Conservation.

The lower 7 cm of all lysimeters was packed with diatomaceous earth in which two ceramic samplers were placed for evacuating drainage water. Tubing inserted into the ceramics was positioned along the walls of each lysimeter. Each lysimeter was then hand packed with either a Boulder City loamy sand or a Las Vegas sandy loam soil (Table 3-1) at bulk densities of 1.7 g/cm and 1.5 g/cm respectively. Total soil depth in each lysimeter was maintained at 120 cm, allowing for approximately 2 cm for containment of irrigation water. Each soil filled lysimeter had an access tube placed in the center of the lysimeter to a depth of 100 cm. The access tubes allowed the insertion of a soil water profiler probe (Dynamax Inc., Houston, TX) for monitoring soil volumetric water content with depth over time. Redox probes were inserted to depths of 15 and 105 cm for assessing the reduction oxidation potential within the soil profile over time. Six lysimeters of each soil type were planted with hybrid Bermuda grass (Tifway sod) and overseeded with perennial ryegrass (Palmer III) each winter. Area surrounding lysimeters were also planted to hybrid Bermuda grass/ryegrass to minimize an oasis effect on the turfgrass growing in the lysimeters. This buffer area was irrigated with subsurface drip irrigation to avoid any water reaching the lysimeter surfaces.

Table 3-1. Soil Classification and Soil Properties.

Location	Soil Classification	Soil Type	% Sand	% Silt	% Clay	CEC (meq/100g soil)	pH	Organic Matter (%)
Boulder City	Arizo Series, a mixed, sandy-skeletal, typic torriorthent	Loamy Sand	86	4	9	11.6	8.0	0.3
North Las Vegas	Loamy carbonitic, thermic shallow typic petrocalcid	Sandy Loam	72	8	19	23.2	7.6	0.8

Irrigation water was pumped from a post UV water collection chamber at the Clark County Wastewater Treatment Facility. The recycled water underwent a tertiary treatment process including primary treatment using screening to remove large debris and primary clarification, secondary treatment using aeration and secondary clarification, and tertiary treatment using dual media filtration and UV disinfection. Water was collected from a discharge point before the addition of chlorine. The water was pumped into a 300-gallon carboy that was transported to the center every two weeks (placed under shade). Irrigations occurred based on closing a water balance on each lysimeter on a weekly basis. The hydrologic balance was based on estimating evapotranspiration using Equation 3.2-1.

$$(ET) = (I) - (D) - (\Delta S) \qquad (3.2\text{-}1)$$

where: ET = evapotranspiration (cm)

I = irrigation

D = drainage

ΔS = change in storage

Drainage was obtained by hooking up the tubing to each ceramic sampler to a vacuum collection system which diverted water to designated four liter bottles confined in an underground storage vault. Drainage was evacuated six days per week for approximately 60 minutes; however these times would vary slightly based on drainage volumes collected and soil volumetric water contents estimated at 100 cm. Weekly irrigations were then estimated by incorporating a leaching fraction (LF = D/I). Two different leaching fractions were imposed on each soil type (0.25 or 0.05). Irrigations amounts were then calculated by using Equation 3.2-2.

$$(I) = (ET) / (1-LF) \qquad (3.2\text{-}2)$$

Once per week, turfgrass was cut to a height of approximately 2.5 cm. However during the colder winter months, reduced growth rates led to cuttings occurring on a bimonthly basis. Cuttings were removed from the lysimeters and brought back to the lab where tissue moisture content and dry biomass were assessed. On days in which turfgrass was cut, redox potential was measured using a pH millivolt meter and a calomel electrode. To avoid platinum poisoning (Devitt et al., 1989), probes were slowly removed from the soil once per year, if coatings were observed (only in a few cases) they were removed with sandpaper and probes were gently placed back into position. In addition, probes were slowly rotated in place every six months.

To assess environmental demand during the experimental period, weather parameters (temperature, relative humidity, solar radiation, and wind speed) were monitored with an automated weather station located within 200 m of the experimental plot. These values were used to estimate daily Penman Monteith Reference ET estimates (Allen et al., 2006). Rainfall was measured with a tipping bucket.

Irrigation water was analyzed for electrical conductivity, pH, and all major cations and anions (ion chromatograph) on a monthly basis. Irrigation water was also analyzed for PPCPs every two weeks when new water was obtained. Because ibuprofen was always below detection levels in the source water, only the remaining 14 target compounds listed in the Introduction were reported. Sampling protocol followed that outlined in Chapter 2.0. Samples were placed in amber one liter bottles with sodium azide and ascorbic acid to inhibit microbial activity. Samples were kept at 4^oC until they were brought to the Southern Nevada Water Authorities water chemistry laboratory for analysis, usually occurring within a two-day period, until January of 2009. After that date, Dr. Jay Gan's laboratory at the University of California, Riverside performed analysis of PPCPs in irrigation water samples using a method similar to that mentioned in Vanderford and Snyder (2006).

Drainage water from the lysimeters was collected based on the number of unsaturated pore volumes draining, where an unsaturated pore volume was based on the amount of water in storage that stabilized under the influence of the imposed treatments, not including the initial wet-up or over-seed period. Samples were taken upon the first drainage collected and then at increments of approximately 0.5 pore volumes of drainage thereafter. In the loamy sand lysimeters under the highest leaching fraction, over 5 pore volumes of drainage occurred over the two-year period.

Under the sandy loam soil at the lowest leaching fraction, less than 1 pore volume was collected. Drainage samples were placed in one liter amber bottles containing sodium azide and ascorbic acid. Samples were refrigerated at 4^oC until at least six samples were obtained (typically within 10 to 14 days). Samples were then packed in reusable ice packs and shipped over night to the analytical laboratory at the University of California Riverside.

Soil samples were collected in all turf lysimeters and in representative bare lysimeters at the end of the experiment. Samples were taken in increments of 0-15 cm, 15-30cm, and 30-60 cm for analysis of organic matter content. Soils were sent to a private laboratory where organic matter content was analyzed according to the combustion method.

Data were analyzed using general descriptive statistics, one way ANOVAs for repeated measurements, three way ANOVAs and backward stepwise regression analysis (SigmaStat). Terms were deleted in the backward regressions when p values for the t test exceeded 0.05. To eliminate the possibility of co-correlation, parameters were included only if variance inflation factors were less than 3 and the sum total was less than 10 (Systat Software, 2004).

3.3 Results

The lysimeter study produced a number of results. Those are presented below. Conclusions that can be drawn from those results are presented in Section 3.4.

3.3.1 Irrigation, Evapotranspiration, and Biomass

Under irrigated conditions, water movement in soils is dictated not only by the hydraulic conductivity of the soil but also by the rate at which water is applied relative to the rate at which water is lost through the process of evaporation and transpiration, collectively referred to as evapotranspiration (ET). This balance is influenced by soil type (structure, texture, etc.) and the overall growth and productivity of the plants being grown (or lack of plants).

Under turfgrass conditions, the entire surface area is covered, significantly reducing the evaporation component of the ET total. Based on the results in this experiment, irrigation amount accounted for 90% of the variability in ET (ET (cm) = 1.84 + 0.77(I), R^2=0.90***). Level of significance, * indicates $p < 0.05$, ** indicates $p < 0.01$ and *** indicates $p < 0.001$, with highest ET rates associated with lysimeters growing turfgrass (Table 3-2). Turfgrass biomass, in turn, was also correlated with ET (R^2=0.44*), with highest biomass in the sandy loam 0.25 LF lysimeters, with variability occurring based on soil type and LF. Analysis of variance revealed significant cover and soil by LF interactions on ET. The least square means for ET associated with turfgrass was 32% higher than that for bare soil lysimeters (368 cm vs.251 cm). Little difference in ET was observed between loamy sand lysimeters irrigated with either a 0.05 or 0.25 LF. A 40% difference in the least square means of ET for the sandy loam lysimeters irrigated at 0.05 vs. 0.25 was observed (277 cm vs. 389 cm). When just the turfgrass lysimeters were considered, soil and LF accounted for 89% of the variability in ET ($p<0.001$) with biomass deleted from the stepwise regression. Biomass was not a major driving force in ET within the turfgrass lysimeters because the lysimeters always had 100% turfgrass cover and weekly cuttings did not allow for significant changes in plant canopy architecture or aerodynamic resistances to occur.

Table 3-2. Cumulative Irrigation, Rainfall, Drainage, LF, ET, and ET_0 for all Lysimeters from 11/18/08-12/2/10.

Lysimeter	Soil Type	Grass/ Bare	LF (imposed)	Irrigation (cm)	Rain (cm)	Drainage (cm)	Pore Volumes Drainage	LF (actual)	ET (cm)	ET_0 (cm)
1	BC	G	0.05	386.5	18.8	55.5	2.3	0.14	329.9	354.3
2	NLV	B	0.05	278.3	18.8	31.4	0.8	0.11	228.9	354.3
3	NLV	G	0.25	548.8	18.8	78.9	1.6	0.14	434.6	354.3
4	NLV	B	0.05	235.3	18.8	35.8	1.0	0.14	178.8	354.3
5	NLV	G	0.25	549.9	18.8	97.1	2.0	0.17	428.1	354.3
6	BC	B	0.25	335.2	18.8	120.6	5.4	0.34	212.4	354.3
7	NLV	B	0.05	275.6	18.8	33.8	0.9	0.12	225.4	354.3
8	BC	B	0.05	281.0	18.8	32.7	0.9	0.11	226.6	354.3
9	BC	B	0.25	315.6	18.8	90.4	4.0	0.27	213.3	354.3
10	BC	G	0.05	401.3	18.8	34.7	1.5	0.08	349.9	354.3
11	BC	B	0.05	276.8	18.8	52.1	2.3	0.18	215.0	354.3
12	BC	G	0.05	420.2	18.8	38.6	1.7	0.09	367.5	354.3
13	BC	G	0.25	488.4	18.8	128.2	5.2	0.25	343.3	354.3
14	BC	B	0.05	251.9	18.8	60.1	2.7	0.22	191.5	354.3
15	NLV	G	0.05	419.2	18.8	29.8	0.7	0.07	370.9	354.3
16	NLV	B	0.25	423.0	18.8	96.6	2.0	0.21	309.6	354.3
17	NLV	G	0.25	541.1	18.8	99.8	2.0	0.17	417.2	354.3
18	NLV	G	0.05	401.3	18.8	31.5	0.8	0.08	309.0	354.3
19	NLV	B	0.25	504.6	18.8	109.0	2.3	0.21	404.1	354.3
20	NLV	B	0.25	460.9	18.8	89.9	1.8	0.19	344.1	354.3
21	BC	G	0.25	480.5	18.8	123.9	5.0	0.25	342.2	354.3
22	BC	B	0.25	386.0	18.8	111.1	4.9	0.28	263.8	354.3
23	NLV	G	0.05	411.0	18.8	34.6	0.9	0.08	349.1	354.3
24	BC	G	0.25	509.2	18.8	114.7	4.7	0.22	379.0	354.3

3.3.2 Soil Water Content and Soil Water in Storage

Soil water content was assessed at depths of 10, 20, 40, 60, and 100 cm on a weekly basis in each lysimeter. These values were then used to estimate soil water in storage. Changes in soil water in storage from week to week were then inserted into Equation 3.2-1 to close water balances and estimate weekly ET totals.

Figure 3-2 shows the soil volumetric water contents at 100 cm over time for all treatment combinations. Arrival of water at this lower depth took longer in the sandy loam soil under the lowest LF. In fact, water content at the 100 cm depth did not approach saturation until the first overseed period in which LF treatments were discontinued during ryegrass establishment.

During the overseed period all lysimeters received daily irrigation at a rate that maintained moist seedbed conditions, a practice imposed on local golf courses. The soil water content data was utilized at the deepest depth to help adjust drainage evacuation times, with the aim of minimizing water contents above the saturation level at this depth. In the loamy sand soil, volumetric water contents were kept below the saturation level except during the overseed periods. However, in the sandy loam soil, volumetric water contents oscillated around the saturation level in the bare 0.25 lysimeters throughout the experimental period. This did not occur in the turfgrass 0.25 lysimeters because of root water extraction throughout the soil profile.

Soil water in storage revealed a clear increase in storage associated with the overseeding period (especially the 0.05 LF treatments), with storage values declining during the spring and summer periods, as the lysimeters came back under the influence of the lower imposed LFs. It was during the higher soil water in storage periods that the sandy loam 0.05 LF lysimeters drained.

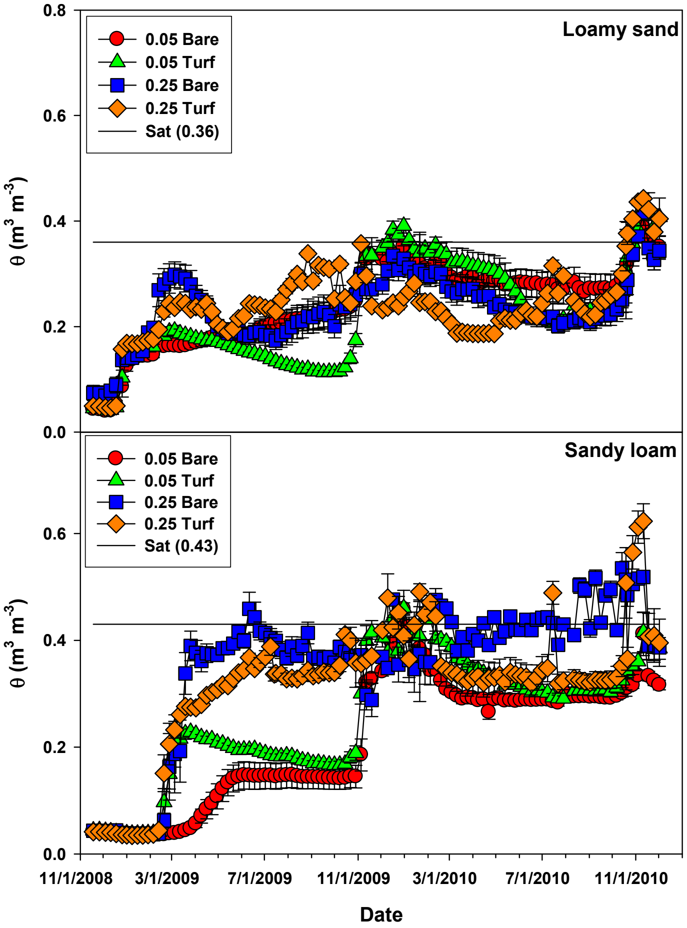


Figure 3-2. Volumetric Water Content at 100 cm for All Lysimeter Treatments with Loamy Sand Treatments in Top Graph and Sandy Loam Treatments in Lower Graph.
Saturation for Each Soil Shown as a Solid Horizontal Line.

3.3.3 Leaching Fractions and Unsaturated Pore Volumes of Drainage

The leaching fractions imposed and those that were achieved at the end of the experiment are reported in Table 3-2. Deviations from the imposed LF were associated with the additional irrigation applied during each year's overseed period, which typically lasted for approximately four weeks. This deviation from the imposed LF prevented chloride from attaining steady state conditions. That prevented the ability to utilize chloride ratios based on irrigation and drainage concentrations to predict LF. Prior to the first overseed period, the relationship between the actual LF and the LF predicted based on chloride ratios was highly linear (R^2=0.72***) and moving toward a 1:1 relationship. However, after the first overseed period, this same relationship became non-significant (R^2=0.05). This uggests that chloride ratios under golf course conditions in which overseeding occurs, should not be considered very accurate in predicting LFs even under low rainfall conditions.

Although utilizing LF as a management tool to achieve acceptable leaching of soluble salts is a standard practice, it is the amount of drainage that drives the displacement of soluble compounds. To be precise, the amount of unsaturated pore volumes leaving the soil profile drives the displacement of soluble compounds. Because irrigation volumes go up as ET goes up (Equation 3.2-2), if the goal is to impose a constant LF, then, by definition, actual volumes of D must go up as I goes up with increasing ET. However, these volumes differ significantly between turfgrass and bare lysimeters. In turn, as D goes up, the amount of unsaturated pore volumes must also go up. Thus anything that drives ET up, such as turfgrass vs. no turfgrass under LF irrigation management, regardless of soil type, will contribute to larger pore volumes being displaced from the soil profile. Figure 3-3 shows that at a given LF, higher unsaturated pore volumes of drainage would be predicted under turfgrass conditions. Although this is counter to what is desired, growing turfgrass allows for greater utilization of recycled water (least square means for cover; 463 cm turfgrass vs. 335 cm bare soil, 28% difference). Turfgrass also provides possible uptake of contaminants and contributes carbon to the soil via root turnover, which can help support a larger more diverse microbial population. However, additional research is needed to confirm that turfgrass does perform that function.

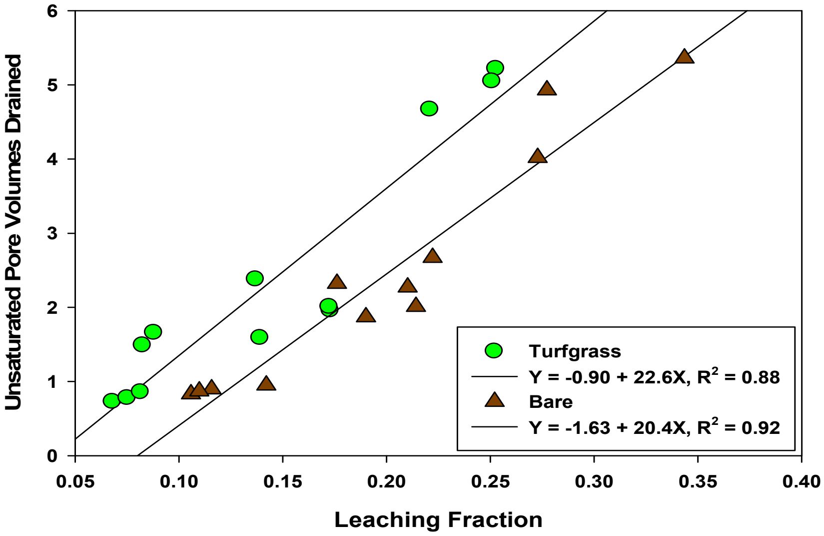


Figure 3-3. Unsaturated Pore Volume of Drainage as a Function of Leaching Fraction for Bare and Turfgrass Covered Lysimeters.

The total number of unsaturated pore volumes draining from each lysimeter is reported in Table 3-2 and plotted as cumulative unsaturated pore volumes in Figure 3-4. Values for unsaturated pore volumes drained ranged from 0.8 to 5.4, with higher values in the loamy sand soils under high LF. The shape of the pore volume time curves all shifted during the over-seed periods. After a 745-day experimental period, the sandy loam 0.05 LF bare and turf covered lysimeters averaged less than one pore volume of drainage, demonstrating the impact of lower leaching conditions on lower sand content soils.

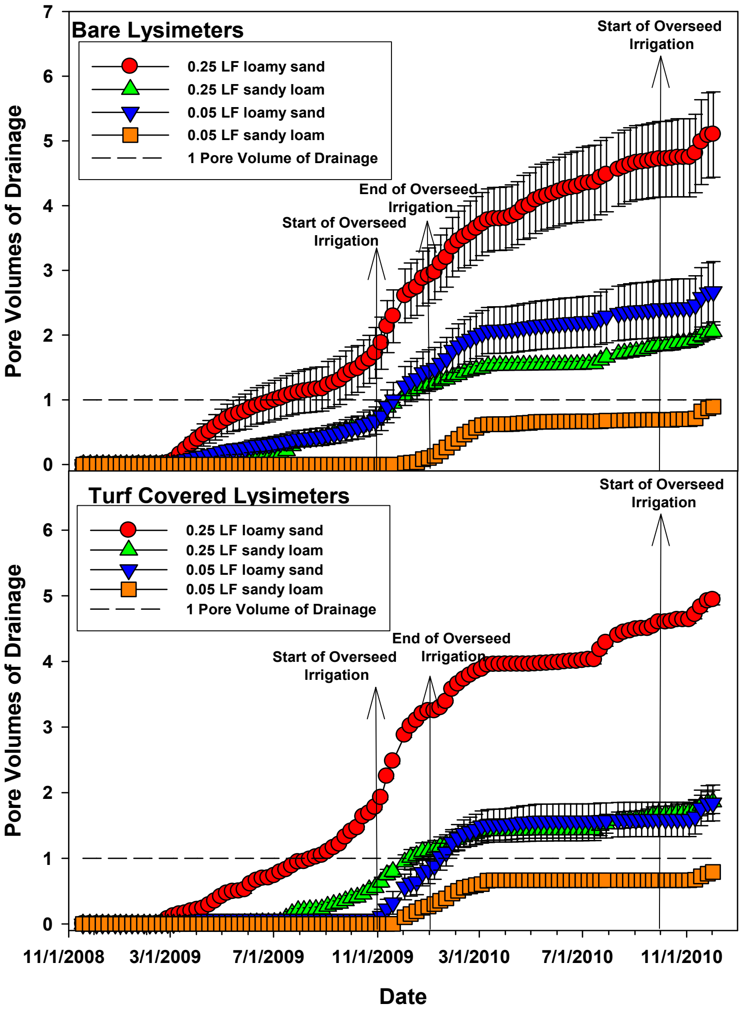


Figure 3-4. Pore Volumes of Drainage for All Lysimeter Treatments Shown Cumulatively Over Time. Bare lysimeters are shown in above graph and turf covered treatments are shown in the lower graph with arrows indicating start and stop of overseed irrigation. One pore volume of drainage is indicated with a dashed line.

3.3.4 Redox Potentials

Redox potentials were measured at the 15 and 105 cm depth in all lysimeters on a weekly basis. Appendix A reports average values, standard deviations and coefficients of variation for both the entire two year period and for the extended periods in which values shifted downward and stabilized (Figures 3-5 and 3-6). The entire two-year data sets are also plotted in Figures 3-5 and 3-6 which show a downward shift at the 15 cm depth based on nine of the 12 turfgrass lysimeters. However, in only one of the bare soil lysimeters had such a shift occur. The timing of the downward shift and the extent of the shift varied in each lysimeter. The shift occurred under both high and low leaching conditions. However, in all lysimeters which showed a shift, the before and after values were significantly different at the $p<0.05$ level.

Eh values below 300 mv are considered to represent reducing conditions. They have been linked to the denitrification of nitrate (Wodarczyk, 2000; Sparks, 2003). All nine of the turfgrass lysimeters that revealed a shift, had average redox potentials below 300 mv during this extended downward shift period. At the 105 cm depth the Eh response was more varied with 14 of the 24 lysimeters maintaining Eh values below 300 mv. However, five of the six 0.25 LF sandy loam lysimeters maintained negative Eh values at the deeper depth after the downward shift. That suggests poorer aeration with the lower sand content soil under the higher leaching conditions.

Although root length density was not assessed in the lysimeters, the correlation between shifts in redox potential at the 15 cm depth being primarily associated with turfgrass would suggest a possible link between redox potential and plant activity. At the end of the experiment, soil organic matter content was measured in the lysimeters. Measurements compared statistically higher % OM in the 0-15 cm depth increments to the deeper depths (Table 3-3. However, this did not correlate with elevated soil moisture content.

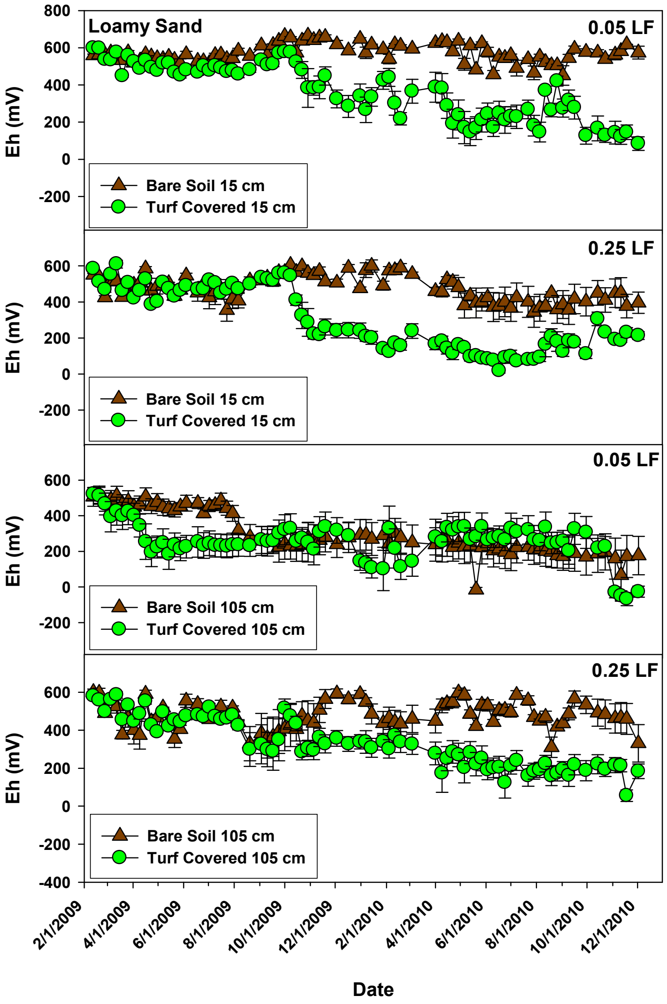


Figure 3-5. Redox Potential for all Loamy Sand Lysimeters at 15 and 105 cm.

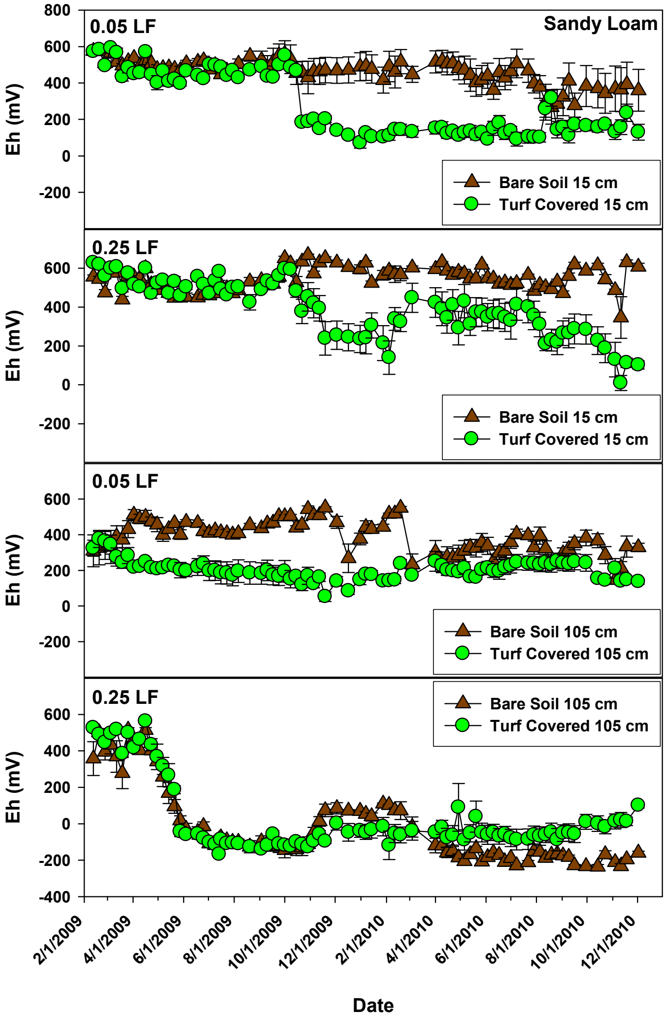


Figure 3-6. Redox Potential for all Sandy Loam Lysimeters at 15 and 105 cm.

Table 3-3. Average, Standard Deviation, and Coefficient of Variation of Soil Organic Matter in Turfgrass Lysimeters.
Listed by Treatment and Depth (in percent organic matter).

Treatment	Depth	Average	SD	CV
BC 0.05 G	0-15	0.47	0.06	0.12
BC 0.05 G	15-30	0.27	0.06	0.22
BC 0.05 G	30-60	0.23	0.12	0.49
BC 0.25 G	0-15	0.73	0.12	0.16
BC 0.25 G	15-30	0.30	0.17	0.58
BC 0.25 G	30-60	0.40	0.10	0.25
NLV 0.05 G	0-15	0.83	0.06	0.07
NLV 0.05 G	15-30	0.53	0.31	0.57
NLV 0.05 G	30-60	0.27	0.21	0.78
NLV 0.25 G	0-15	0.67	0.12	0.17
NLV 0.25 G	15-30	0.33	0.15	0.46
NLV 0.25 G	30-60	0.43	0.15	0.35

Average values for soil organic matter in bare lysimeters, BC soil - 0.25B (0-15, 15-30 and 30-60 cm); 0.4, 0.2 and 0.3.
Average values for soil organic matter in bare lysimeters, NLV soil - 0.25 B (0-15, 15-30 and 30-60 cm); 0.5, 0.5 and 0.5

3.3.5 PPCPs in Irrigation Water

All 15 PPCPs listed in the introduction were analyzed in the irrigation water on a bi-monthly basis. However, because ibuprofen was always below detection levels in the source water, only the remaining 14 compounds were reported on in this experiment. Average PPCPs concentrations in the irrigation water are reported in Table 3-4, along with standard deviations and coefficients of variation. Compounds that varied little over time (CV $\leq$ 0.45) were diazepam, carbamazepine, diclofenac, dilantin, fluoxetine, meprobamate, primidone and sulfamethoxazole. Compounds that revealed intermediate variation over time (CV > 0.45 but $\leq$ 1.05) were: triclosan, naproxen, atorvastatin, trimethoprim and atenolol. The compound that revealed the highest variability over time (CV >1.05) was gemfibrozil. Although primidone, carbamazepine and diclofenac, had relatively low coefficients of variation, they revealed general increasing or decreasing trends over time (R^2 0.26-0.45, $p<0.05$). Diclofenac increased in an oscillating fashion from approximately 35 ng/L in the first sampling to over 100 ng/L later in the experiment. Whereas primidone decreased in an oscillating fashion from approximately 65 ng/L early in the experiment to approximately 5 ng/L by the end of the experiment, carbamazepine oscillated in an upward fashion from just over 150 ng/L to over 300 ng/L later in the experiment. The cause of these upward and downward trends is not known but must reflect either increased or decreased usage of these compounds in the community or an increased or decreased removal rate at the wastewater treatment facility. Conversations with facility personnel suggested no change in plant operations during the experimental period.

Table 3-4. Concentration of Pharmaceuticals in Irrigation Water (ng/L).

Analyte	Average*	SD	CV
Atenolol	143.59	139.96	0.97
Atorvastatin	16.44	13.79	0.84
Carbamazepine	256.71	80.98	0.32
Diazepam	4.41	1.99	0.45
Diclofenac	70.76	19.28	0.27
Dilantin	13.03	3.36	0.26
Fluoxetine	33.90	9.04	0.27
Gemfibrozil	19.86	33.03	1.66
Meprobamate	395.87	100.91	0.25
Naproxen	21.84	16.57	0.76
Primidone	26.01	11.63	0.45
Sulfamethoxazole	1611.62	250.00	0.16
Triclosan	62.96	34.33	0.55
Trimethoprim	35.44	36.60	1.03

* Average based on 45 sampling dates over the 745 day monitoring period

SD = Standard Deviation

CV = Coefficient of Variation

3.3.6 PPCPs in Drainage Water

The same 14 PPCPs analyzed in the irrigation water were also analyzed in the drainage water collected from the lysimeters. Average concentrations of PPCPs in the drainage water are reported in Appendix B, along with standard deviations and coefficients of variation. The PPCPs concentration data is reported based on the inclusion of all data, assuming values of 0.0 ng/L for analytical results reported below the detection level and also for concentration data confined to all values above the detection level. Many compounds were reported below the detection level for various sampling dates during the experiment. Sampling was based on unsaturated pore volumes being displaced from the lysimeters. Loamy sand lysimeters under the 0.25 LF treatment (bare and turfgrass) were sampled between eight and 12 times during the experiment. Whereas in the sandy loam soil under the 0.05 LF treatment (bare and turfgrass) sampling occurred only two to four times during the experiment. Five compounds were never detected in any of the samples collected during the two-year experiment, these were; atenolol, atorvastatin, fluoxetine, gemfibrozil, and trimethoprim. Three compounds revealed a much higher detection rate: primidone, sulfamethoxazole, and carbamazepine (Figure 3-7). The detection rate varied based on soil type, cover, and LF.

In the 0.25 LF loamy sand lysimeters the detection rate averaged 74% for sulfamethoxazole, 72% for primidone and 40% for carbamazepine. ANOVA’s indicated significant soil by LF interactions on the number of detections during the experiment for both sulfamethoxazole (7.2 sampling detections in the loamy sand at 0.25 LF vs. 3.3 detections at 0.05 LF) and carbamazepine (4.0 sampling detections, in the loamy sand at 0.25 LF vs. 0.2 detections at 0.05 LF) whereas primidone revealed no interactions but did reveal significant main effects (soil type, LF and cover) for both soil (5.5 sampling detections in the loamy sand vs. 1.2 detections in the sandy loam) and LF (4.3 sampling detections in the 0.25 LF treatment vs. 2.3 detections at 0.05 LF).

ANOVA's were also run on the final drainage concentrations at the end of the experiment. The results vary by compound. Primidone revealed only a soil effect, with least square means for the loamy sand at 14.3 ng/L and 7.0 ng/L for the sandy loam soil. Carbamazepine and dilantin both revealed soil by LF interactions. Meprobamate revealed a soil by cover interaction. Sulfamethoxazole, which had a very high detection rate, revealed no separation in drainage concentration at the end of the experiment based on main treatment or interaction effects. This indicates that concentration at a single point in time is often difficult to interpret.

During the fall of the first year, possible interference issues with the sampling set up in the lysimeters was discussed among the research team. In response to concerns about possible interference, stainless steel samplers with Teflon tubing were inserted into all lysimeters at a depth of 110 cm (just above the soil – diatomaceous earth interface). In addition, SNWA conducted a laboratory interference experiment by placing diatomaceous earth, ceramic samplers and stainless steel samplers into known concentrations of PPCPs. They analyzed the PPCP concentration in the water over a three-day period. Figure 3-8 indicates that fluoxetine was significantly reduced when it remained in contact with diatomaceous earth, whereas atorvastatin, atenolol, fluoxetine and trimethoprim all showed significant interaction with the ceramic sampler. In the case of the stainless steel sampler, naproxen and meprobamate showed reductions in concentrations between 30 and 40% after one day. Only fluoxetine revealed a dramatic decline in concentration over time. Although such results are of concern, the drainage water was pumped six days out of seven and would therefore only remain in contact with the diatomaceous earth for periods of one day with maximum exposure for two days (Saturday morning through Monday morning), whereas contact with the ceramics and stainless steel samplers would be primarily confined to the time water was actually evacuated through the samplers from adjacent regions of diatomaceous earth or soil (one hour for ceramics, up to four hours for the stainless steel samplers). Once the drainage or soil water passed though the samplers, arrival in the collection bottles occurred in a period of less than one minute.

Results from the soil solution evacuated from the stainless steel samplers also indicated that fluoxetine, atorvastatin, atenolol, and trimethoprim were not detected. This suggests that the later three PPCPs had not yet arrived at the 110 cm depth, perhaps as a result of undergoing significant adsorption interactions with the soil. However, in the case of fluoxetine, removal occurred with all sampling devices, so no valid conclusions can be made concerning this compound.

The PPCPs results obtained from the stainless steel samplers were compared with those from the existing lysimeter sampling system at the end of the experiment. Seven compounds were detected, of which five showed no statistical difference in results (primidone, sulfamethoxazole, carbamazepine, triclosan, and naproxen). Only in the case of diazepam and diclofenac was there a statistical difference. In both cases it was associated with no detections in the stainless steel samplers. The existing lysimeter values were reported over the concentrations from the stainless steel samplers because of the extended data set with the ceramic samplers in the diatomaceous earth that could be paired with drainage volumes and because the diatomaceous earth ceramic sampling system had specific effects on only a few compounds. This eliminated a few of the compounds entirely and was limited to the final sampling. Although the possibility cannot be ruled out that system interference reduced the concentration of some compounds, it is believed that it was only a potential issue under the conditions of this experiment, with fluoxetine (100% reduction), carbamazepine (possible 18% reduction in diatomaceous earth) and diazepam (possible 4% reduction in contact with the ceramic samplers). Thus, estimates would error on the low side with a recommendation that no estimate be made for fluoxetine but only slight upward adjustments be made to leaching losses associated with carbamazepine and diazepam.

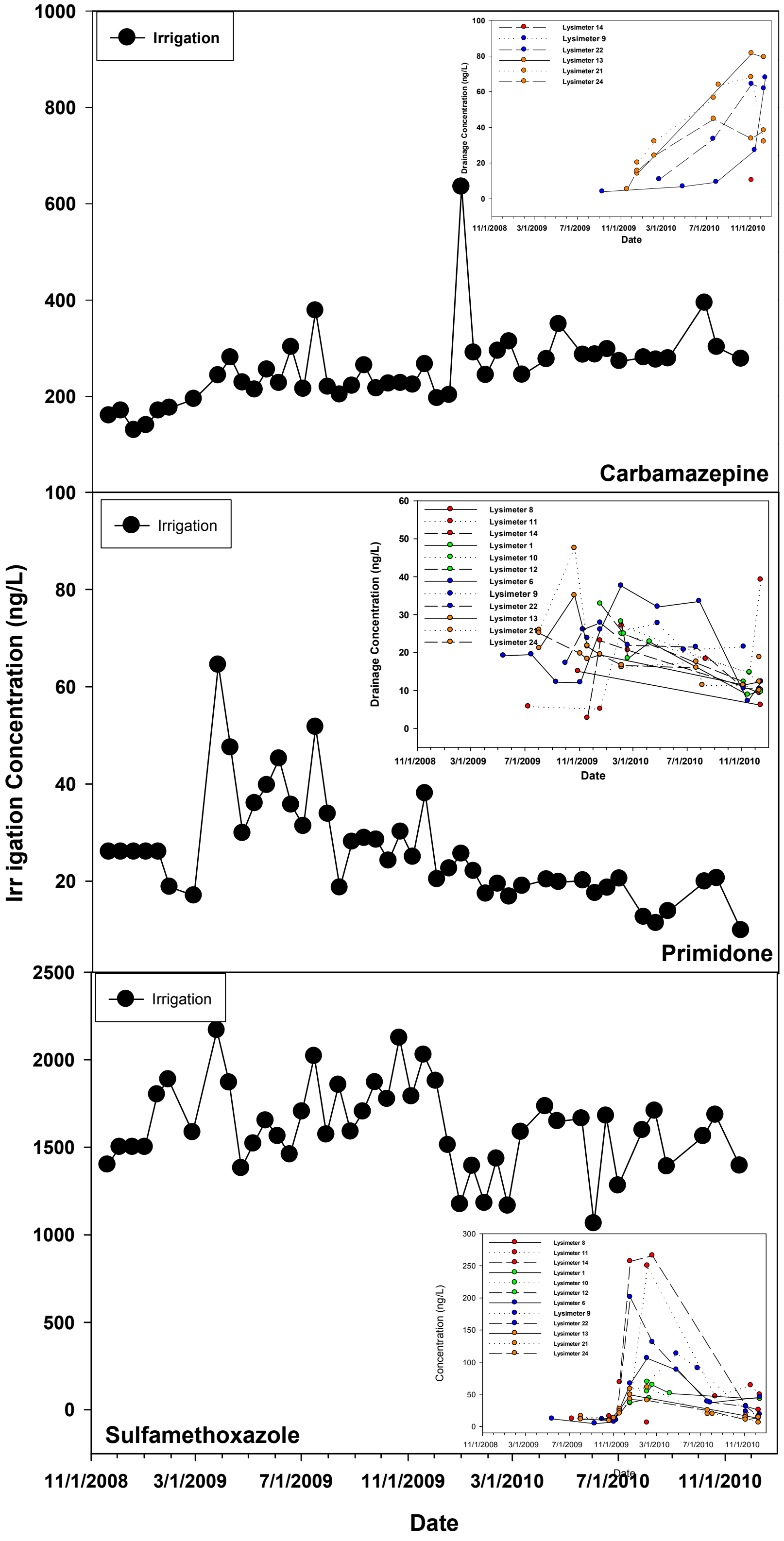


Figure 3-7. Concentration of Selected PPCPs in Irrigation and Drainage (inset) Over Time.
Carbamazepine shown in the top graph, primidone in the middle graph and sulfamethoxazole is shown in the lowest graph.

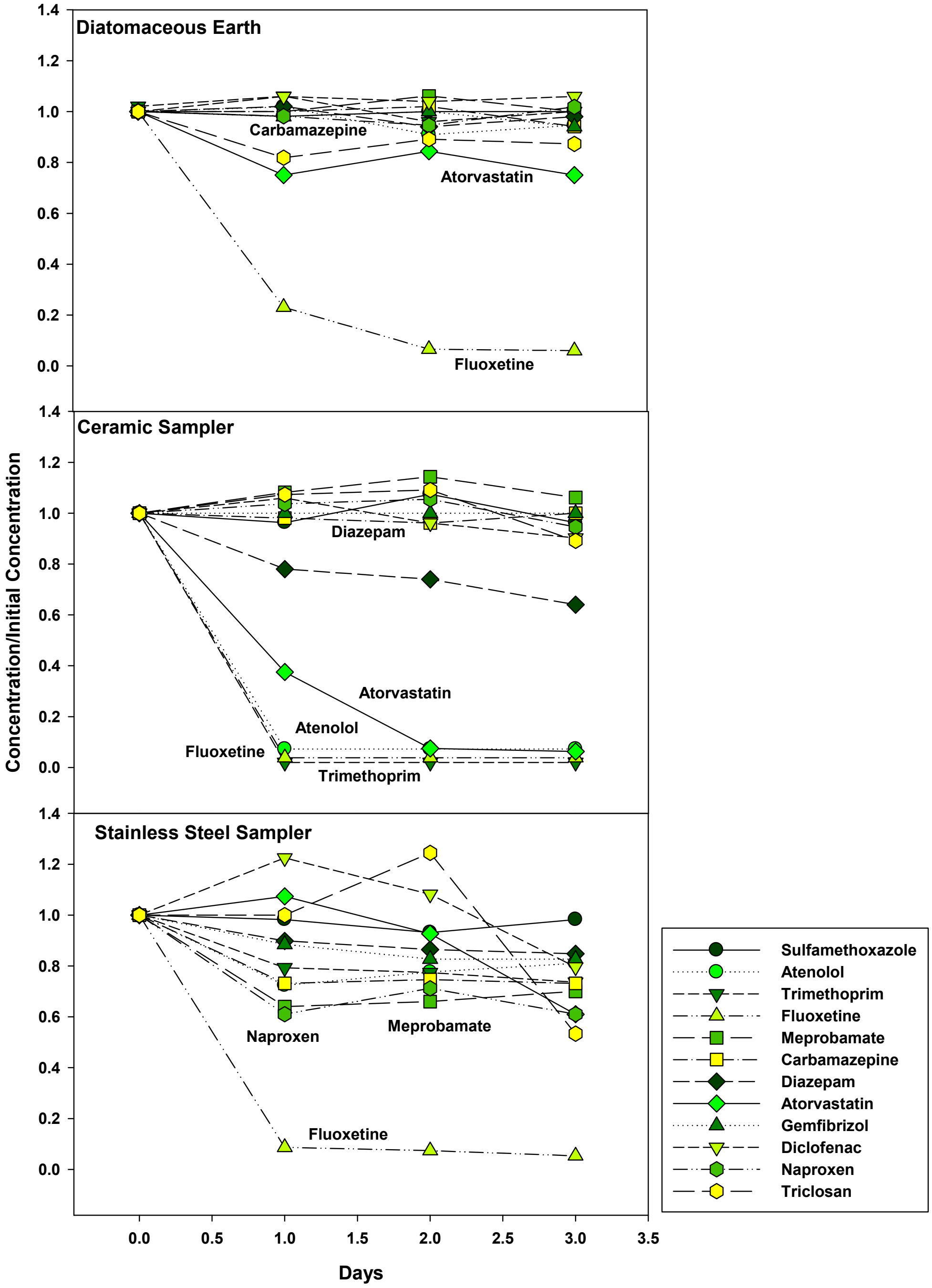


Figure 3-8. Concentration Ratios over Time for PPCPs for Laboratory Testing of Interference for Diatomaceous Earth, Ceramic Sampler and Stainless Steel Sampler.

Compounds of interest are labeled next to the appropriate trend line.

3.3.7 Mass Discharge of PPCPs and PPCPs Discharge Relative to Chloride

Mass discharge estimates for PPCPs required weighting the drainage volumes with measured concentrations. In one lysimeter, no PPCPs were detected at any time during the experiment (lysimeter 18, sandy loam, 0.05 LF, grass). In other lysimeters, the drainage volumes were quite small and sporadic, presenting a challenge to estimate mass discharge. Although increasing the sampling frequency would improve the accuracy of such estimates, the cost was prohibitive in such a large scale experiment.

PPCPs mass discharge (µg) for the entire experimental period is reported in Appendix C. The number of lysimeters with drainage estimates greater than zero is plotted for all PPCPs compounds in Figure 3-9. 100% of the loamy sand lysimeters had drainage estimates greater than zero for both primidone and sulfamethoxazole. No estimates occurred for fluoxetine (interference), gemfibrozil, atorvastain, trimethoprim, or atenolol in either soil. Discharge estimates revealed three PPCPs with higher mobility under the irrigated conditions of this experiment; these were primidone, sulfamethoxazole, and carbamazepine. All three of these compounds were found to have significant correlations between the mass discharge from the lysimeters and the number of unsaturated pore volumes that had drained. In the case of primidone (Figure 3-10), a clear separation was found between the two soil types. Up to 28% of the applied primidone was detected in the drainage of one of the 0.25 LF loamy sand lysimeters. 82% of the variation in the percentage of primidone discharged could be accounted for based on the number of unsaturated pore volumes draining in the loamy sand lysimeters. A clear separation in the mass discharge of the sulfamethoxazole was also observed based on soil types and unsaturated pore volumes draining ($R^2 = 0.52$***, Figure 3-10). However, maximum discharge in one of the 0.25 lysimeters was less than 1.2%. Carbamazepine revealed a curvilinear relationship ($R^2=0.71$***) between discharge and unsaturated pore volumes draining, with no discharge observed from the sandy loam soils even at the higher LF (Figure 3-10). Although other factors may be at play with carbamazepine movement in the sandy loam soil, these results would suggest that the number of unsaturated pore volumes draining was too small, as even within the loamy sand lysimeters, detection did not occur until greater than 2.5 unsaturated pore volumes drained.

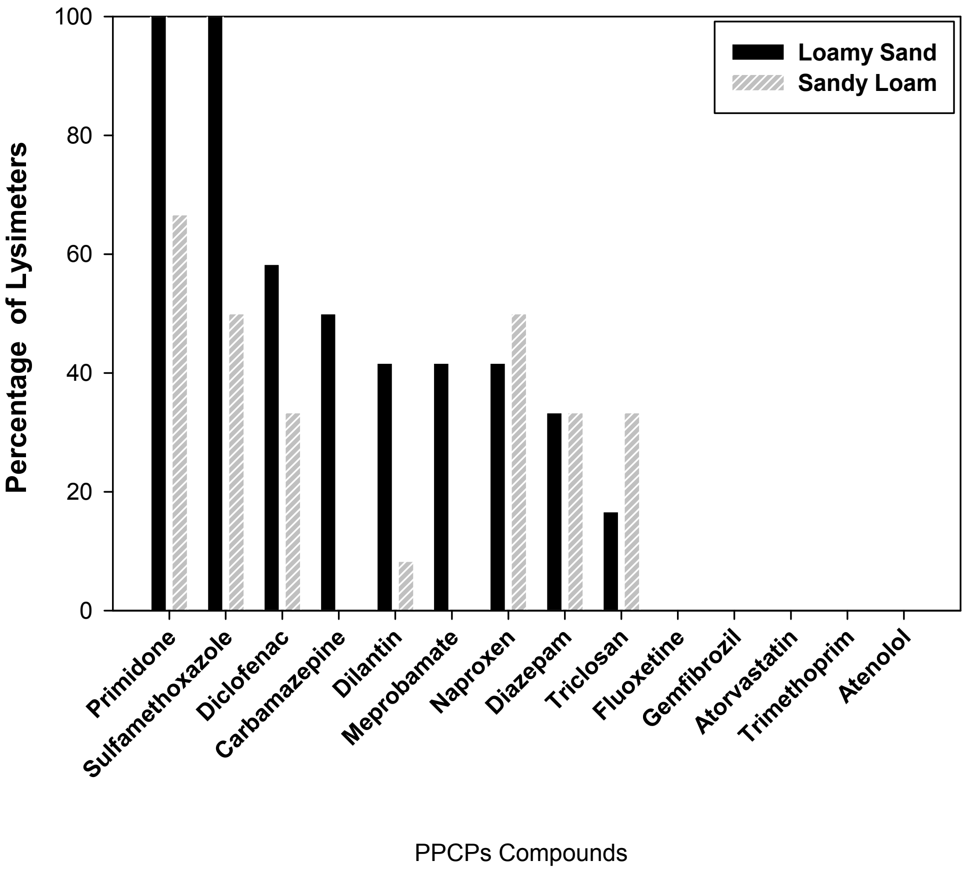


Figure 3-9. Percentage of Lysimeters in Which PPCPs Drainage Estimates Greater than Zero Occurred.

Mobility of the PPCPs was further evaluated by comparing the discharge of the PPCPs with that of chloride, a conservative highly mobile nonreactive ion. The mass discharge of the three PPCPs compounds (primidone, sulfamethoxazole and carbamazepine) that demonstrated a structured relationship with the number of unsaturated pore volumes of drainage were divided by the percentage of chloride that drained (Figure 3-11). This normalized assessment indicated that primidone reached as high as 37% of the mobility of chloride in the loamy sand lysimeters under the highest LF. Carbamazepine approached 3% and sulfamethoxazole only 1.6% of the mobility of chloride in the loamy sand lysimeters under the highest LF. However, in the sandy loam lysimeters all three compounds showed significantly lower mobility's relative to chloride, such as the less than 2% mobility for primidone. These results suggest even lower mobilities in higher clay content soils that have prolonged travel times. Only in the case of primidone could the average travel times between soil types be statistically separate ($p<0.05$) even between LFs within the loamy sand lysimeters. There was a greater than two fold increase in the time it took primidone to be detected in the sandy loam soils compared to the loamy sand lysimeters (> 745 days vs. 322 days). In the loamy sand lysimeters a statistical separation in the travel time occurred between the 0.05 LF and the 0.25 LF turfgrass lysimeters (427 days vs. 258 days).

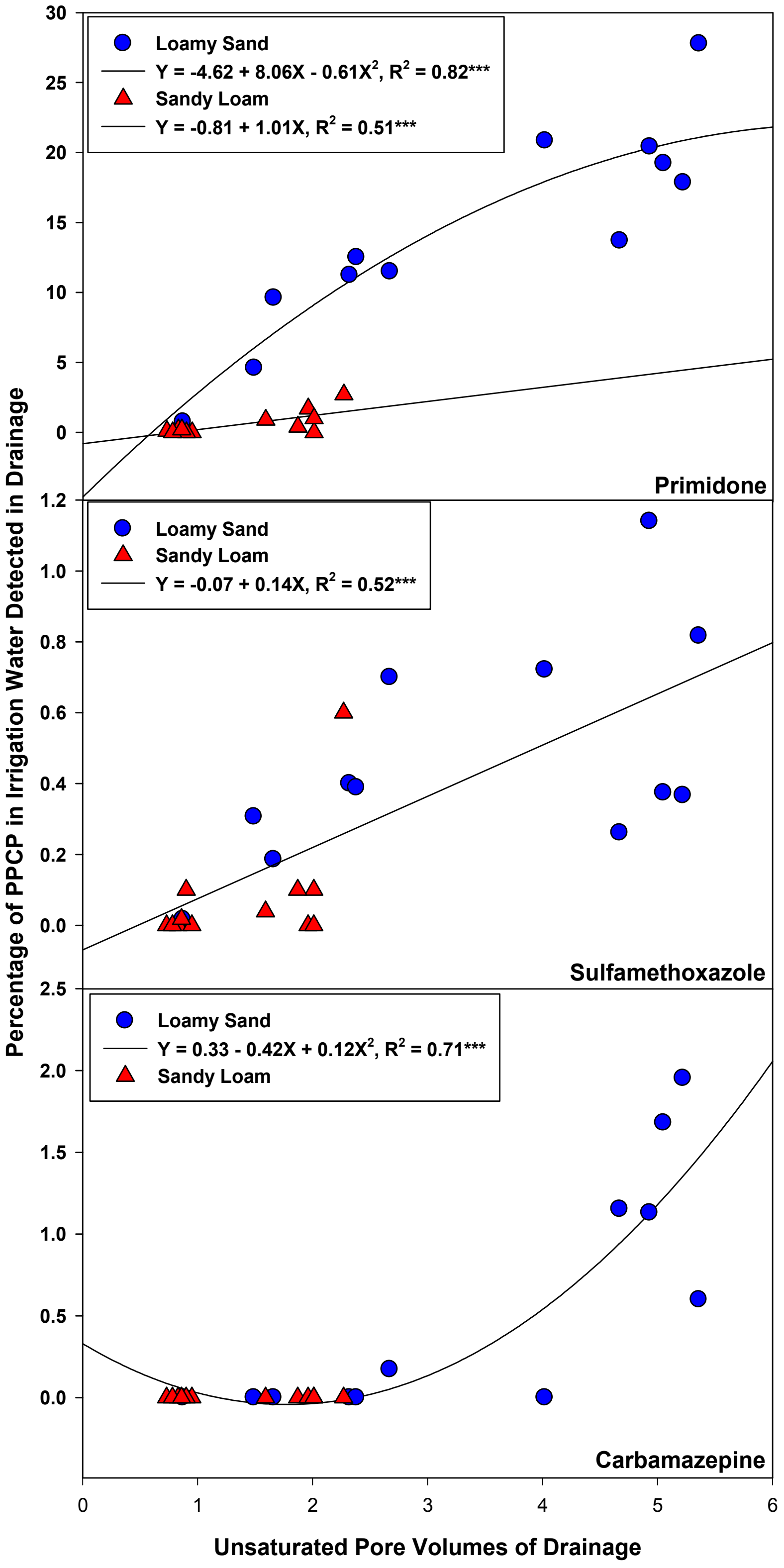


Figure 3-10. Percentage of PPCPs Detected in Drainage for Carbamazepine, Primidone and Sulfamethoxazole as a Function of Pore Volumes of Drainage.

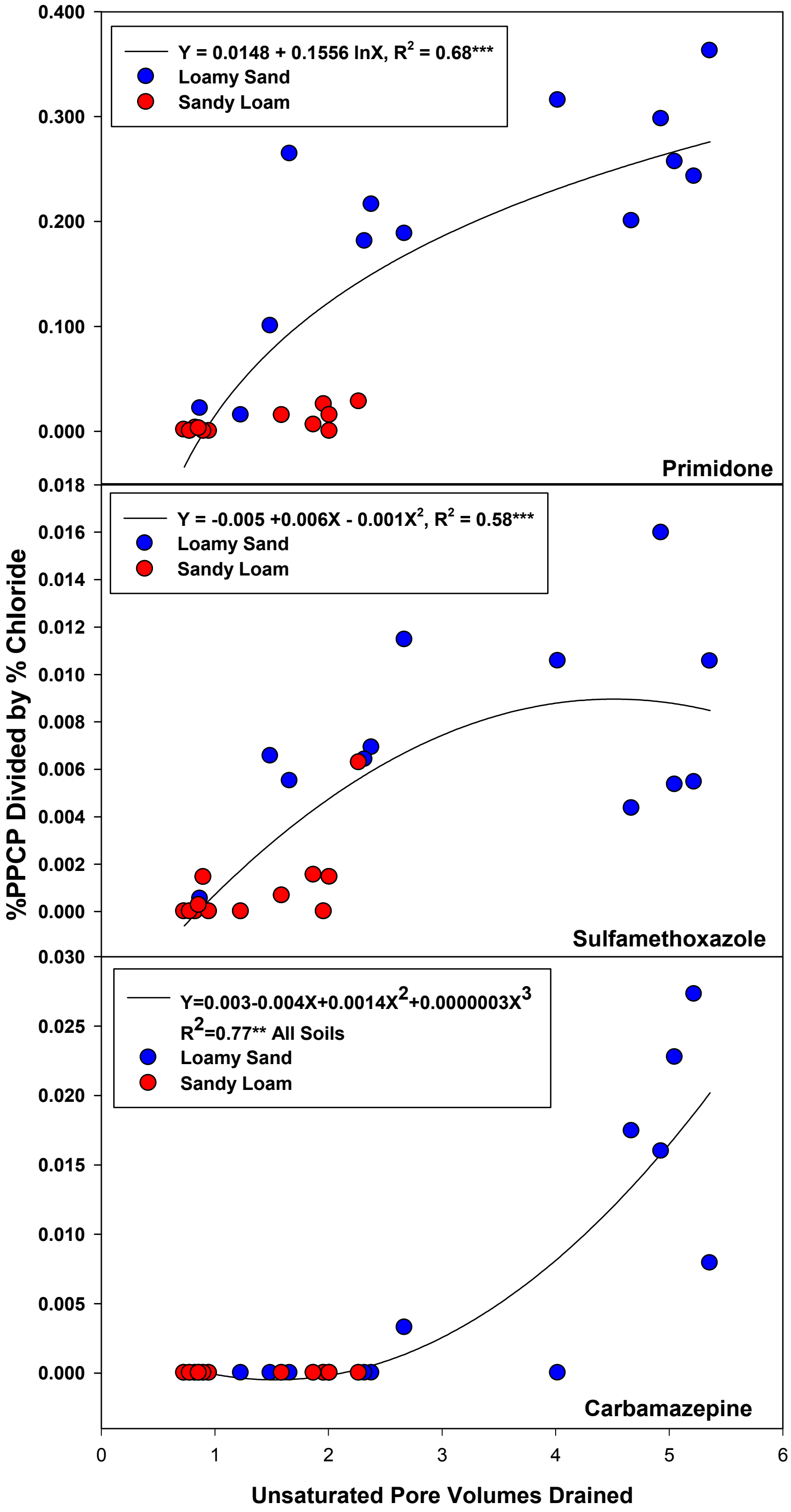


Figure 3-11. Percent of PPCPs Divided by Percent Chloride as a Function of Pore Volumes Drained to Show Relative Mobility to a Conservative Tracer (chloride ion).

3.3.8 Factors Influencing PPCPs Fate and Transport

Each PPCPs compound responded differently under the experimental conditions imposed. Many of the compounds did not behave in a consistent fashion to generate statistically significant results via analysis of variance. In fact only primidone, sulfamethoxazole, carbamazepine, and dilantin demonstrated significant main treatment (soil type, LF, and cover) or treatment interaction effects. With regards to the percentage of primidone drained, only a soil by LF interaction was observed, while sulfamethoxazole revealed a soil effect and a cover by LF interaction effect. Carbamazepine revealed a soil by cover interaction effect, while dilantin revealed both a soil by cover and soil by LF interaction effect. In all cases the results supported higher PPCPs leaching from soil profiles in the loamy sand lysimeters and at higher LFs. Although leaching losses were almost always higher under bare soil conditions, carbamazepine revealed the highest leaching losses in the loamy sand 0.25 LF lysimeters under turfgrass.

Seven compounds revealed significant multiple regression results with regards to explaining variation in leaching losses relative to a mix of soil plant and water variables. A series of statistical analysis were run to generate a list of variables for consideration in the backward stepwise regression analysis. The variables selected for testing included:

- Number of unsaturated pore volumes drained
- ET
- I
- Cover
- % Sand
- Biomass
- Average redox potential during the downward shift period at both the 15 and 105 cm depths
- % Organic matter (OM) content in the 0-15 cm depth
- Average % OM in the 0-60 cm depth

Table 3-5 reports the variables that were accepted in the regression analysis, along with R^2 and p values. The amount of variation that could be accounted for ranged from a low of 17% with diclofenac to 94% with primidone. Because many of the compounds were not detected or only detected on a few occasions (Atenolol, Atorvastatin, Fluoxetine, Gemfibrozil, Ibuprofen, and Trimethoprim), only with three of the compounds could greater than 50% of the variation in the percentage of the compound drained be accounted for. Once again, these were primidone, sulfamethoxazole, and carbamazepine. In the case of primidone, 94% of the variation in the amount leached could be described by the number of unsaturated pore volumes drained, the % sand in the soil, and the average redox potential during the downward shift period at the 105 cm depth. It was interesting to note that four of the seven compounds included redox potential as a significant variable. Primidone leaching was predicted to go up with increased redox potentials at 105 cm and increased leaching of dilantin as redox at both the 15 and 105 cm depths increased. However, with both naproxen and triclosan, as the redox potential went up at 15 cm, leaching losses were predicted to decline. Only in the case of carbamazepine was % organic matter (OM) (0-15 cm depth) accepted as a significant variable in the regression analysis, with increased leaching losses associated with higher % OM, substantiating the higher leaching losses associated with the turfgrass lysimeters.

Table 3-5. Results of Multiple Regression Analysis Describing the Influence of Soil Plant Water Variables on Percent Discharge of PPCPs.

PPCP	Variables Accepted	R^2	p value
Primidone	Y=-27.9 + 0.008 Redox 105 cm + 0.317 % Sand + 3.69 PV	0.94	0.001
Carbamazepine	Y=-1.068 + 0.314PV +1.086 % OM	0.73	0.001
Sulfamethoxazole	Y= 0.037 – 0.001Biomass + 0.145PV	0.67	0.001
Dilantin	Y= -2.26 +0.003 Redox 15 cm + 0.003Redox 105 cm +0.577PV	0.46	0.001
Naproxen	Y= -4.87 -0.41Redox 15 cm + 15.142 Cover	0.35	0.01
Triclosan	Y= -1.12 – 0.004Redox 15 cm + 2.002Cover	0.28	0.05
Diclofenac	Y= 0.251 +0.003Biomass	0.17	0.05

PV = number of unsaturated pore volumes drained reported from data located in Table 3-2.

Cover = assigned a value of 1 for turfgrass and 2 for bare soil

3.4 General Conclusions

Results from the lysimeter study would suggest that most PPCPs are not very mobile. After a 745-day (2+ year) period in which leaching fractions were imposed on two different soil types while irrigating with recycled water on both turfgrass and bare soils, nine of the 14 compounds were detected in the drainage water. Of these compounds, only three revealed a consistent pattern, which was correlated with the number of unsaturated pore volumes being displaced from the 120 cm soil profiles. These three compounds were primidone, sulfamethoxazole, and carbamazepine. Only primidone revealed a significant mass discharge relative to the irrigation load, with percent discharge as high as 30% in the bare loamy sand soil under high LF. When the primidone discharge percentage was normalized with the percent chloride discharge, the mobility of primidone was shown to be as high as 37% of that of chloride. The other two compounds had mobility's relative to chloride of only 1-3% under the highest leaching in the loamy sand soil. Depending upon the compound, soil, cover, LF, and interactions of these three factors, each compound was influenced in a different way. Significantly higher leaching losses were typically linked to the loamy sand soil and to the higher LF treatment on bare soil. In the case of primidone, 94% of the variation in the amount leached could be described by the number of unsaturated pore volumes drained, the percent sand in the soil and the average redox potential during the downward shift period at the 105 cm depth.

Although low percent leaching losses of sulfamethoxazole were reported, this was assessed relative to the irrigation mass loading. In the case of sulfamethoxazole, the concentration in the irrigation water averaged over 1600 ng/L, which was four times higher than any other compound (Table 3-3). When the discharge from the lysimeters was scaled up on a hectare basis, sulfamethoxazole averaged 0.254 g leached from the soil profile on a yearly basis (Appendix D). That was higher than any other compound and in fact was almost three times higher than the highest estimate for primidone. In the sandy loam lysimeters growing turfgrass under the lowest leaching regime, the drainage estimates for sulfamethoxazole averaged below 0.002 g on a yearly basis. Unfortunately, comparing the concentration of the PPCPs in the drainage water relative to that in the irrigation water is a very poor predictor of the percentage of the mass of the compound drained relative to the mass loading of the compound in the irrigation water (R^2 =0.08 NS sandy loam, R^2 =0.18 NS loamy sand). Clearly knowing the drainage flux associated with the concentration is critical in any environmental assessment associated with PPCPs, especially in the assessment of groundwater contamination.

The researchers conclude that only small amounts of PPCPs would drain under typical golf course conditions in Southern Nevada, especially on soils with lower sand contents than those associated with this experiment and under lower leaching conditions. These leaching losses still deserve greater attention by the scientific community until the full implications of such leaching losses can be put into proper biological context (do the concentrations and/or mass discharges have biological significance – impact on growth, reproduction, and/or overall health of organisms). Utilizing recycled water for irrigation purposes while implementing sound science-based irrigation management practices allows communities to extend their water resources, while minimizing the discharge of such waters directly into aquatic systems, where elevated PPCPs have already been documented to cause problems (Santos et al., 2010).

CHAPTER 4.0

CONTROLLED FIELD-PLOT STUDY

4.1 Introduction

The primary objective of the controlled field-plot experiment was to evaluate leaching risks of PPCPs in turfgrass/soil systems when recycled water is used for irrigation. The experiment made use of turfgrass plots that were originally constructed in 1995 with individual lysimeters (Gan et al., 2006). Recycled water was transported from Western Riverside County Regional Wastewater Treatment Plant in Corona, CA, and used as the sole source of irrigation water for over five months. Irrigation rates were 100% and 130% ETo, which simulated worst-case scenarios in terms of above normal rates of irrigation with recycled water. The drainage water was collected at 90 cm depth and was analyzed for breakthrough of 15 PPCPs on a weekly basis. The results of the controlled field-plot experiments provide information for screening those PPCPs that have a tendency to transport downward and for characterizing turfgrass/soil systems to degrade PPCPs during recycled water irrigation.

4.2 Experimental Approach

An intentional approach was applied to the controlled field-plot study. It took site design, water sources, and sample collection into consideration.

4.2.1 Site Description

The turf plots were transplanted with new Bermuda grass at the beginning of 2009. The plots contained either a loamy sand soil or a sandy loam soil. Each plot is 4 × 4 m in dimension. At the four corners of each plot, above-ground sprinklers were placed, and PVC pipes were used to deliver the recycled water from an onsite storage tank to the turf plots at 100% or 130% ETo (Figure 4-1). The ETo values were from the previous week's data recorded at a local CIMIS station. At the center of each plot, a cluster of five 50-gallon drums were installed at the time of plot construction. The bottom of each drum was connected to a galvanized pipe that was extended to the side of the elevated plots, allowing easy access for the collection of drainage water (Figure 4-2).

Table 4-1. Basic Physiochemical Properties of Soils from Turfgrass Plots Used in the Study.

Depth (cm)	pH	Organic C (%)	Sand (%)	Silt (%)	Clay (%)
			Sandy loam, Bermuda grass		
0-10	6.6	1.33	76	20	4
10-20	7.5	0.40	76	17	7
20-30	7.0	0.33	78	16	6
			Loamy sand, Bermuda grass		
0-10	5.8	0.65	81	15	4
10-20	7.1	0.27	97	2	1
20-30	6.9	0.18	97	1	2

Figure 4-1. Turfgrass Plots and Irrigation Setup.

Figure 4-2. Collection of Drainage Water from Individual Turfgrass Plots.

4.2.2 Source of Recycled Water

Recycled water was obtained from the Western Riverside County Regional Wastewater Treatment Plant in Corona, CA. Recycled water was stored in a 6,000-gallon opaque polyethylene tank at the study site (Figure 4-1) and used as the irrigation water. The water tank was replenished once every two weeks using a water truck. Concentrations of PPCPs in the source water were measured once a week, at the same time of collecting drainage water samples.

4.2.3 Irrigation Treatment and Sample Collection

A total of eight Bermuda grass plots were used for the irrigation study. Two irrigation rates (100 and 130% ETo) were used. Two replicate plots for each soil type-irrigation rate combination were used. Irrigation occurred three times a week. Drainage water from each plot was collected into a 4-L amber glass container by free draining once a week and the samples were transported to the laboratory within 2 h of sample collection. The drainage water samples were transferred into 1-L amber glass bottles for analysis. Samples were preserved with ascorbic acid and sodium azide and stored at 4°C if not immediately analyzed. Most samples were extracted with solvents on the same day of sample collection. For quality control, a blank was used for each sample set, and a matrix spike sample was used for each 20 samples.

The method used for analyzing PPCPs in the recycled water and drainage water samples was similar to the method developed by Vanderford et al. (2006).

4.3 Results and Discussion

The experiment produced a number of results. They indicated relatively high removal rates for several PPCPs. The results are described below.

4.3.1 PPCPs in Recycled Water

The levels of PPCPs in the storage tank were monitored once a week for 26 consecutive weeks. The levels of PPCPs were expected to vary due to degradation while the water was sitting under outdoor conditions and also due to periodical replenishments of new recycled water. The concentrations of atenolol, sulfamethoxazole, meprobamate, carbamazepine, and gemfibrozil were relatively high in the recycled water (Figure 4-3). The median concentration was 875 ng/L (94-1220) for sulfamethoxazole, 670 ng/L (230-857) for meprobamate, 338 ng/L (206-416) for carbamazepine, 123 ng/L (38-362) for gemfibrozil, and 142 ng/L (66-240) for atenolol. Trimethoprim, primidone, dilantin, fluoxetine, diclofenac, bisphenol A, naproxen, and triclosan were detected at levels less than 100 ng/L (Figure 4-4 and Figure 4-5). Their median concentrations were 31 ng/L (8-75), 30 ng/L (20-53), 13 ng/L (9-20), 15 ng/L (9-43), 31 ng/L (5-76), 28 ng/L (5-89), and 66 ng/L (23-146), respectively. Diazepam and atorvastatin were found at relatively low concentrations, at less than 10 ng/L. Ibuprofen and estrone were not detected in the recycled water. The levels of bisphenol A was determined to be unacceptable due to detection of this compound in blanks. It is likely that bisphenol A was present in the PVC pipes and/or sprinklers and contributed to its detection in the samples.

The highest concentrations of PPCPs were observed after the tank was just replenished with fresh recycled water, suggesting that some PPCPs were not stable in the storage tank. The stability of the test compounds during storage was not determined, because water was replenished once every two weeks, before the tank was completely dry.

Concentrations of the monitored PPCPs are shown in Table 4-2.

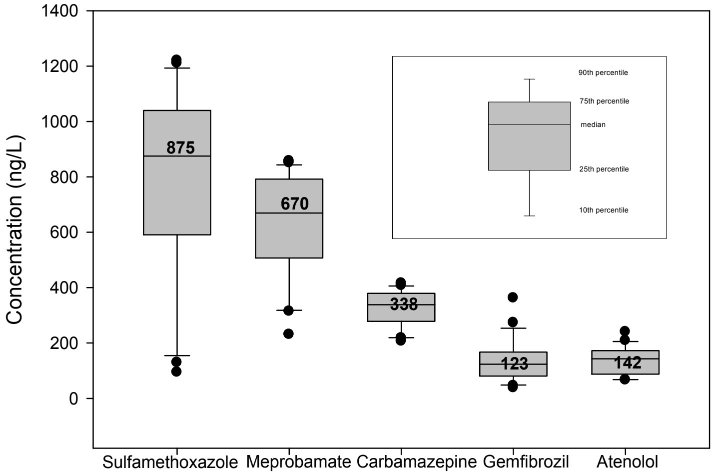


Figure 4-3. Concentrations of Selected PPCPs in Recycled Water Used for Irrigation during the Turfgrass Plot Experiment (ng/L).

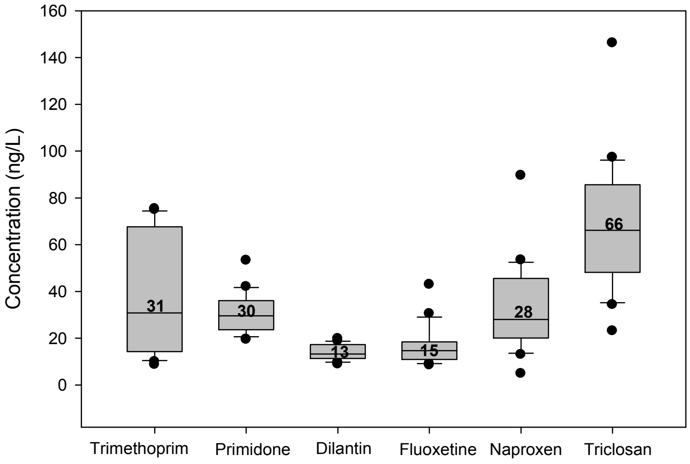


Figure 4-4. Concentrations of Selected PPCPs in Recycled Water Used for Irrigation during the Turfgrass Plot Experiment (ng/L).

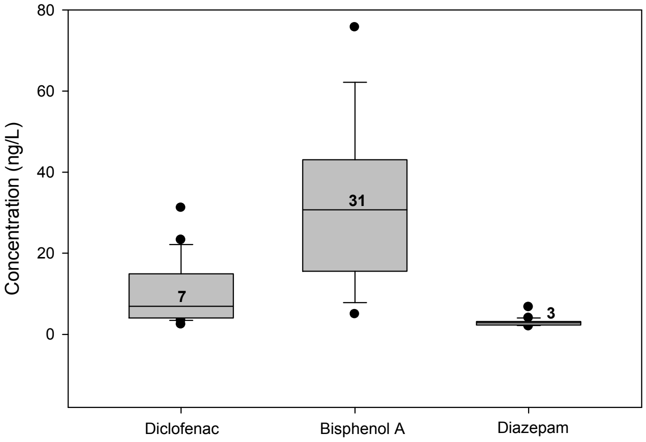


Figure 4-5. Concentrations of Selected PPCPs in Recycled Water Used for Irrigation during the Turfgrass Plot Experiment (ng/L).

Table 4-2. Ranges and Mean Concentrations of Selected PPCPs in the Recycled Water Used for Irrigation in the Turfgrass Plot Experiment.

Compound	Range	Mean±std	Classification
Atenolol	66-320	148.2±62.2	beta-blocker; cardiovascular disease and hypertension
Atorvastatin	2-5	2.7±1.4	Blood pressure regulation
Carbamazepine	206-416	321.9±61.9	Anticonvulsant
Diazepam	1-7	3.0±1.0	Sedative and anticonvulsant
Diclofenac	2-31	9.3±7.3	Anti-inflammatory
Dilantin	9-23	14.6±3.8	Anticonvulsant and seizure treatment
Fluoxetine	7-43	16.2±7.8	Antidepressant
Gemfibrozil	25-262	122.5±76.7	Lipid regulation
Meprobamate	231-963	622.7±205.6	Tranquilizer
Naproxen	5-90	32.3±19.1	Anti-inflammatory
Primidone	18-53	29.9±8.2	Anticonvulsant and seizure treatment
Sulfamethoxazole	80-1255	752.5±373.7	Antibiotic
Triclosan	21-146	60.2±29.4	Antimicrobial
Trimethoprim	6-128	40.1±29.4	Antibiotic

4.3.2 Leaching of PPCPs

The irrigation was started on April 27, 2009 and ended on November 3, 2009. The entire study spanned over six months. Drainage water samples were collected once a week and analyzed for the appearance of the candidate compounds. It must be noted that during the month of September, there were days that the temperature was very high. Since the irrigation rates were based on the previous week's weather conditions, some test plots did not produce sufficient drainage water on some sampling days. Therefore, there are missing data points for some of the test plots due to the lack of samples.

Sandy Loam Soil

The concentrations of PPCPs in the drainage water samples for the sandy loam soil plots are shown in the Figures 4-6 through 4-10 (only for PPCPs with detectable levels in the leachate). At the lower irrigation rate (100% ETo), most of the candidate PPCPs did not appear in the drainage water. Only trimethoprim (Figure 4-6), primidone (Figure 4-8), and carbamazepine (Figure 4-10) were consistently detected. Trimethoprim was frequently found in the drainage water samples with concentrations ranging from below detection limit to 113 ng/L with median concentrations of 9.3 and 37.5 ng/L for the two replicate plots.

Due to evapotranspiration, the actual amount of water leached through the soil profile would be smaller than the amount of water applied onto the surface. This fraction (i.e., drainage or leaching fraction) was estimated using the prevalent weather conditions (CIMIS) and literature for the turfgrass. PPCPs removal (%) was then calculated based on differences between the concentrations in the source water and the leachate (Figure 4-11) or the chemical fluxes by considering the drainage fraction (Figure 4-12).

At 100% ETo, trimethoprim was frequently detected in the drainage water, with one test plot consistently showing higher levels of trimethoprim than the other. The removal calculated from the differences of input and drainage water concentrations was only 28%. However, after accounting for the leaching fraction, the removal was estimated to be >82% (Figure 4-11).

At 100% ETo, median sulfamethoxazole concentrations in the drainage water (3.3 and 2.0 ng L^{-1}) were significantly lower than that in the source water (866 ng/L). Therefore, although sulfamethoxazole was detected in the drainage water, there was at least 99% removal, based on either concentration differences or chemical fluxes.

At 100% ETo, primidone concentrations in the drainage water ranged from below detection limit to 28 ng/L, and median concentrations found in the drainage water samples were only 5.1 and 9.7 ng/L for the two replicate plots. Removal efficiency of primidone by the sandy loam soil plot was estimated to be > 75% based on the concentration differences. After taking leaching fluxes into consideration, however, the removal was >94%.

At 100% ETo, median carbamazepine concentrations in the drainage water samples were 2 and 4 ng/L for the two replicate plots. The removal efficiency was estimated to be >99% for carbamazepine, based on either concentration differences or chemical fluxes.

At 100% ETo, meprobamate was only occasionally detected at concentration levels less than 17 ng/L. Its input concentrations were always magnitudes greater than the concentrations found in the drainage water. The removal was >99% for meprobamate based on either concentration differences or chemical fluxes.

From the plots that received irrigation at 130% ETo, similar PPCPs compounds were found in the drainage water. The median concentration of trimethoprim, sulfamethoxazole, primidone, meprobamate, and carbamazepine was 3.3 and 2.0, 4.7 and 1.0, 10.6 and 6.5, 2.9 and 1.0, and 37 and 10 ng/L, respectively for the two plots. The highest concentration observed for those compounds were 8.1, 93, 36, 63, 165 ng/L, respectively. Based on changes in concentrations, the removal was estimated to be 91% for trimethoprim, 71% for primidone and 93% for carbamazepine. With consideration of leaching fractions, the removal was estimated to be 96% for trimethoprim, 89% for primidone, and 97% for carbamazepine. For all the other PPCPs, the removal based on either concentration or chemical fluxes was >99%.

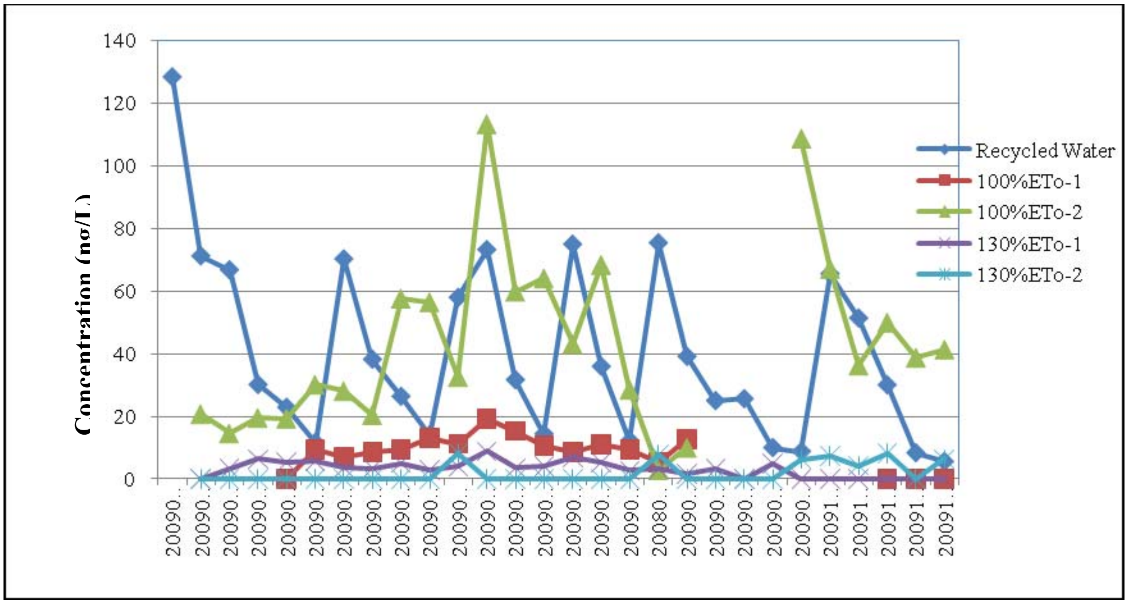


Figure 4-6. Levels of Trimethoprim in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Sandy Loam Plots.

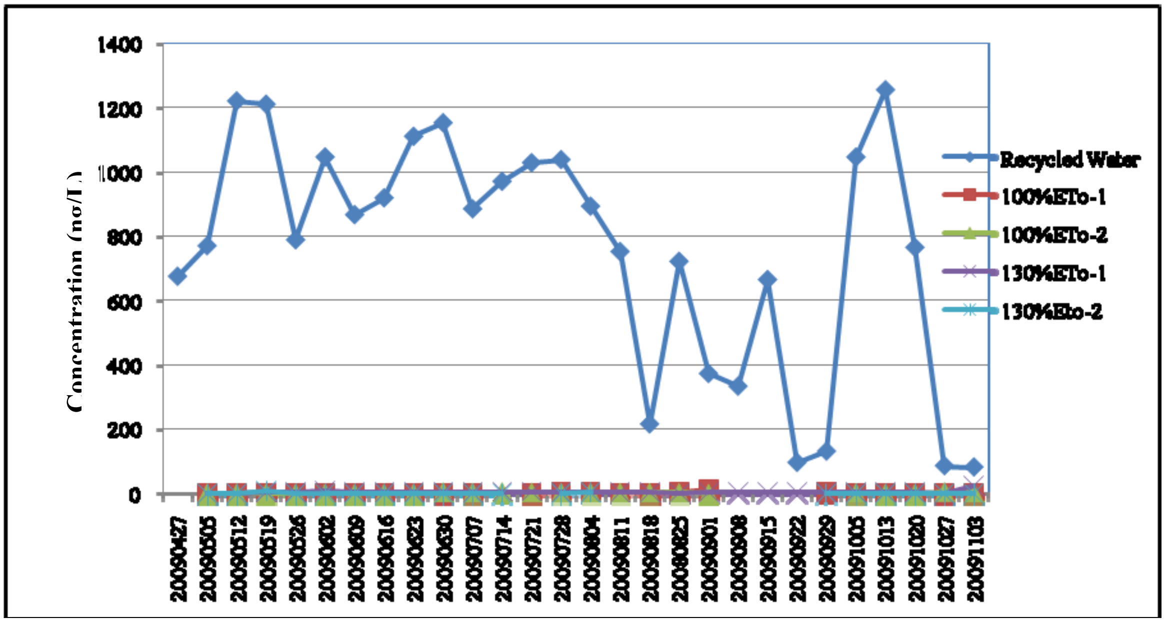


Figure 4-7. Levels of Sulfamethoxazole in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Sandy Loam Plots.

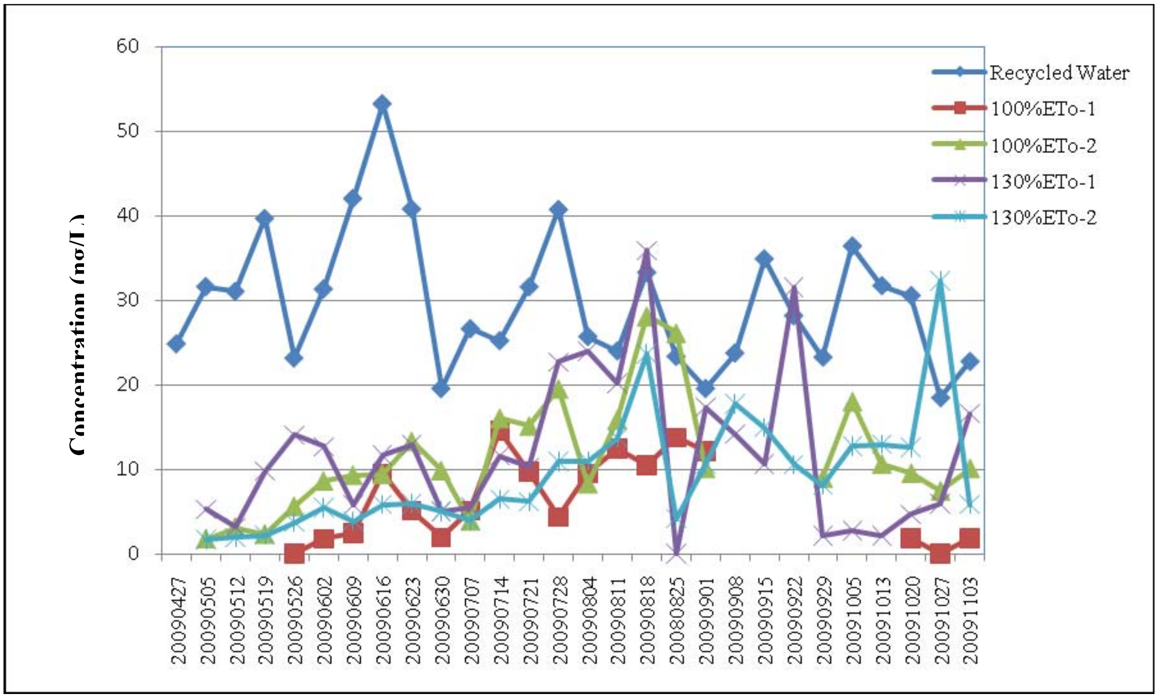


Figure 4-8. Levels of Primidone in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Sandy Loam Plots.

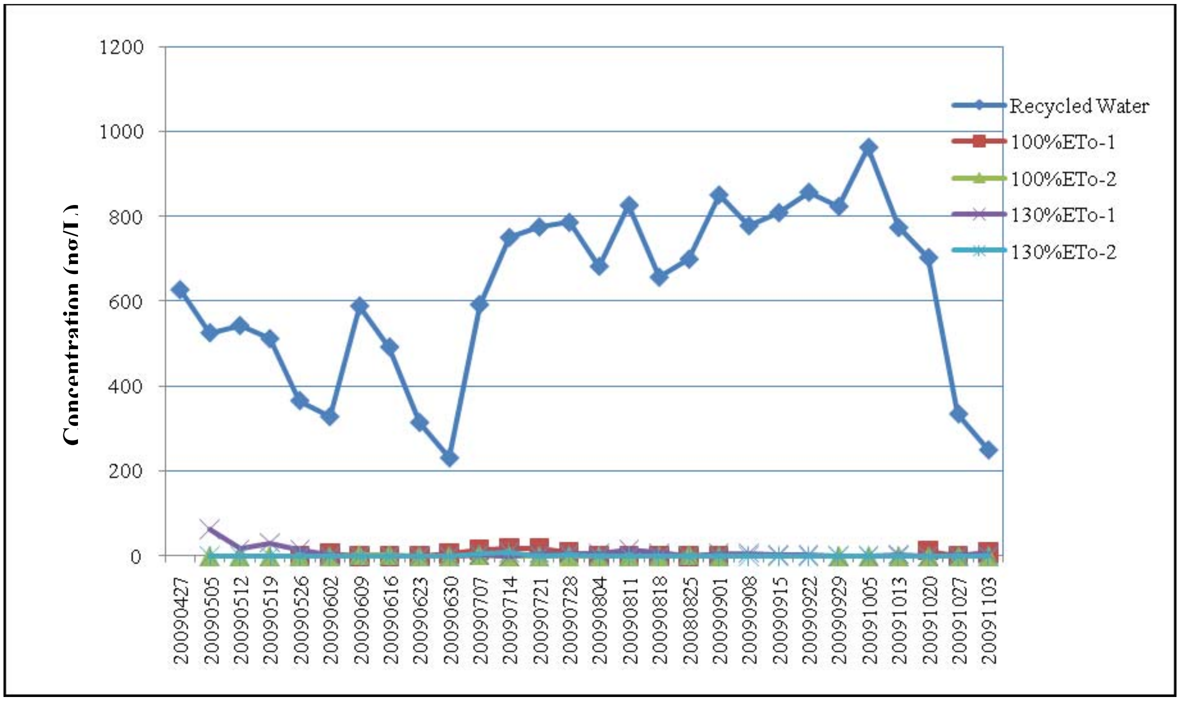


Figure 4-9. Levels of Meprobamate in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Sandy Loam Plots.

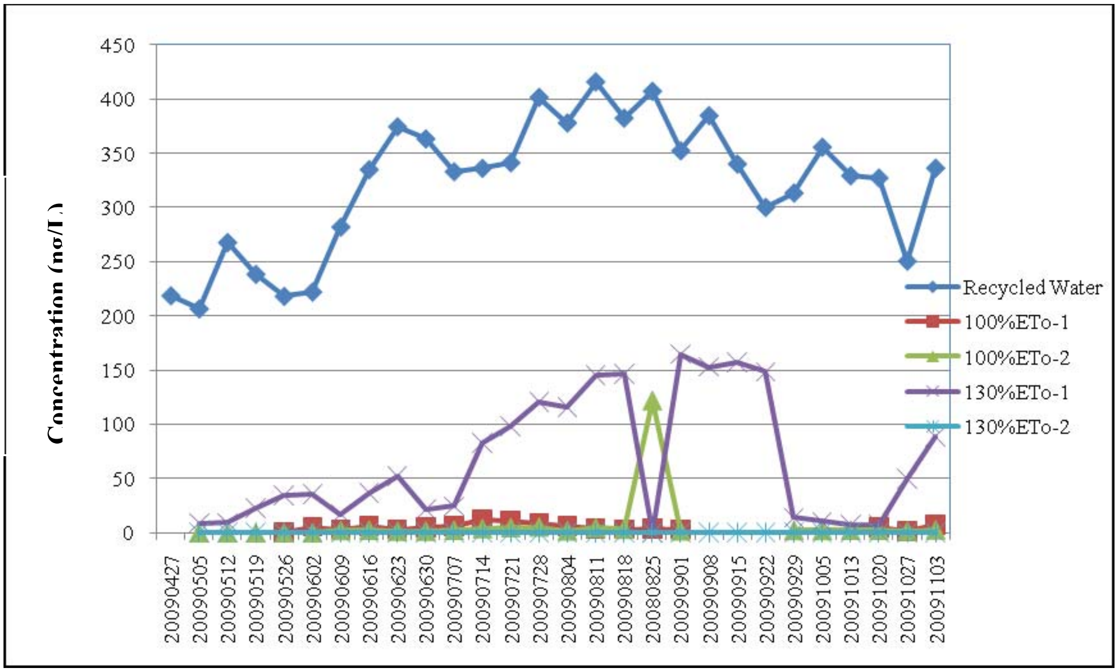
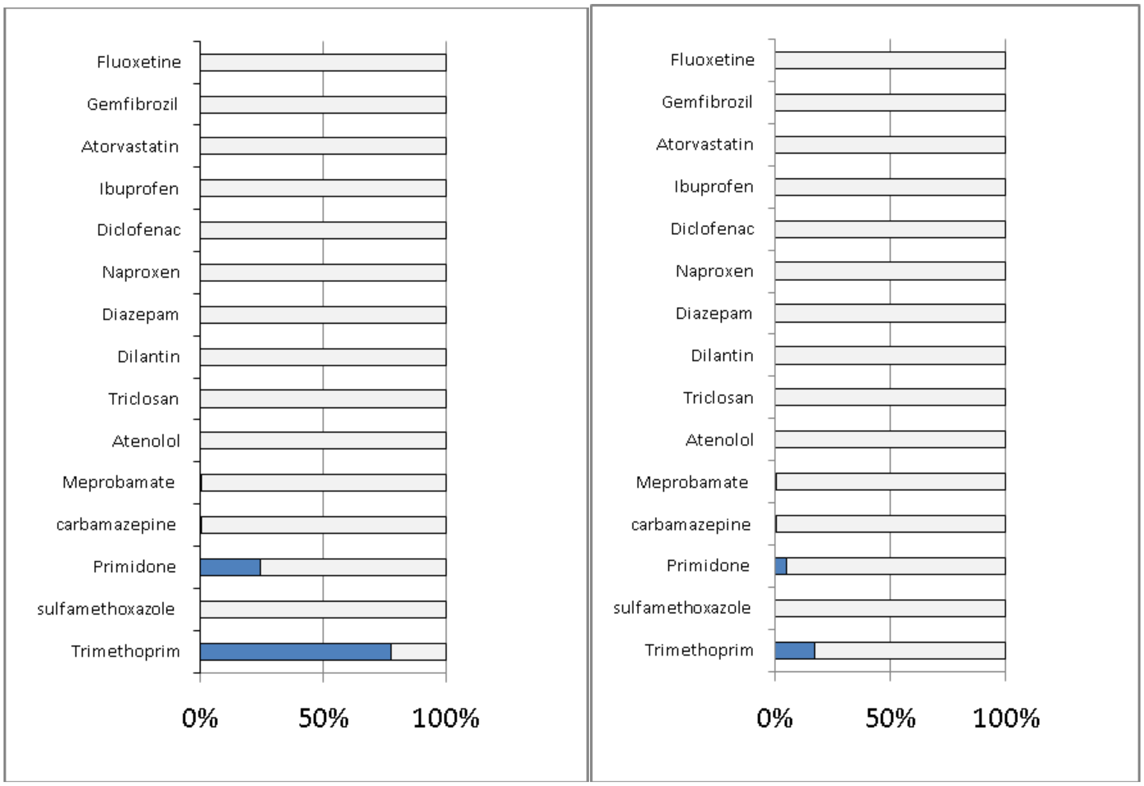
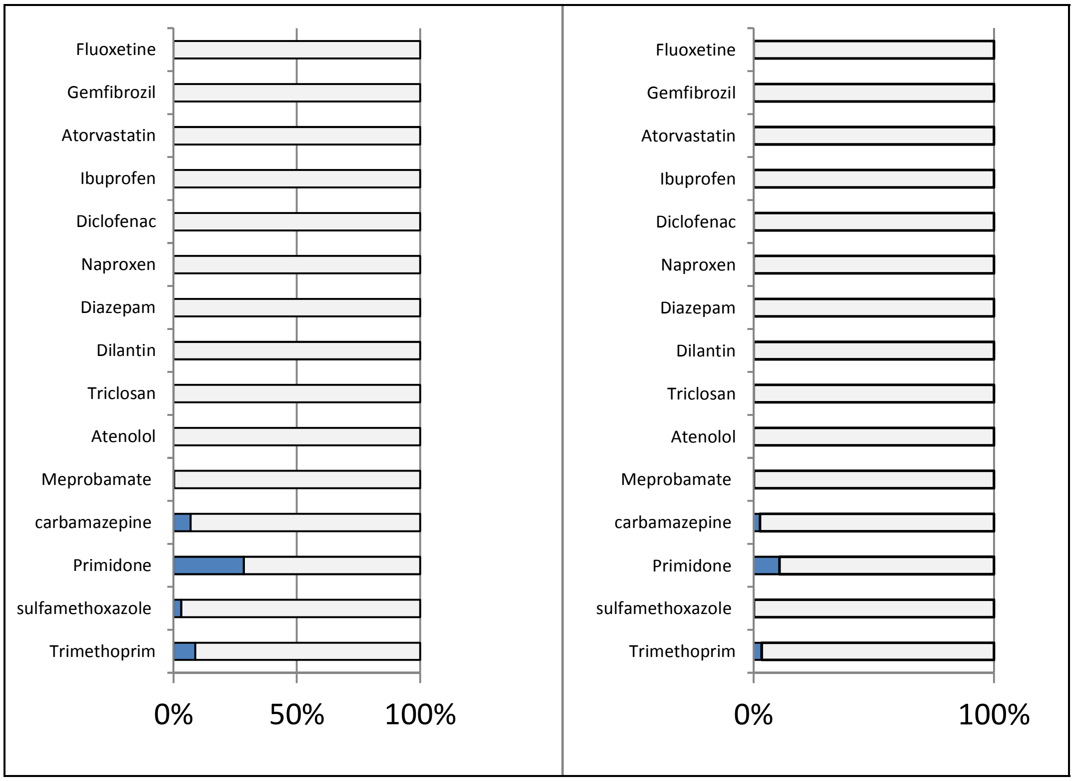


Figure 4-10. Levels of Carbamazepine in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Sandy Loam Plots.



(A) **(B)**

Figure 4-11. Leached Fractions Calculated from (A) Concentration Changes and (B) Chemical Fluxes Based on Drainage Fractions (Sandy loam plots, irrigated at 100% ETo).



(A) **(B)**

Figure 4-12. Leached Fractions Calculated from (A) Concentration Changes and (B) Chemical Fluxes Based on Drainage Fractions (Sandy loam plots, irrigated at 130% ETo).

Loamy Sand Soil

The concentrations of PPCPs in the drainage water samples for loamy sand plots at two different irrigation rates are shown in Figures 4-13 through 4-16. Only trimethoprim, and primidone were frequently detected in the drainage water samples collected from the loamy sand plots at the low irrigation rate. Sulfamethoxazole, carbamezapine, and meprobamate were detected infrequently towards the end of the study. When detected, trimethoprim, and primidone concentrations were generally low. The median concentrations (for the replicate plots) of trimethoprim, and primidone were only 7.9 and 8.2, and 2 and 3.9 ng/L, respectively. High spikes in trimethoprim and primidone concentrations were only observed when the drainage water volume was exceptionally low.

At 100% ETo, the removal of trimethoprim was 71% based on the differences in concentration between the source water and drainage water. After correcting for leaching fraction, the removal was estimated to be 97% (Figure 4-18). The removal of primidone was about 90% based on concentration reductions, but was >99% after accounting for leaching fraction. For all other PPCPs, the removal was >99%, based on either concentrations or chemical fluxes.

At 130% ETo, the removal of both trimethoprim and primidone was about 90%. However, after accounting for leaching fractions, the removal was found to be >95% for both chemicals. The removal efficiency for all other PPCPs was >98% (Figure 4-19).

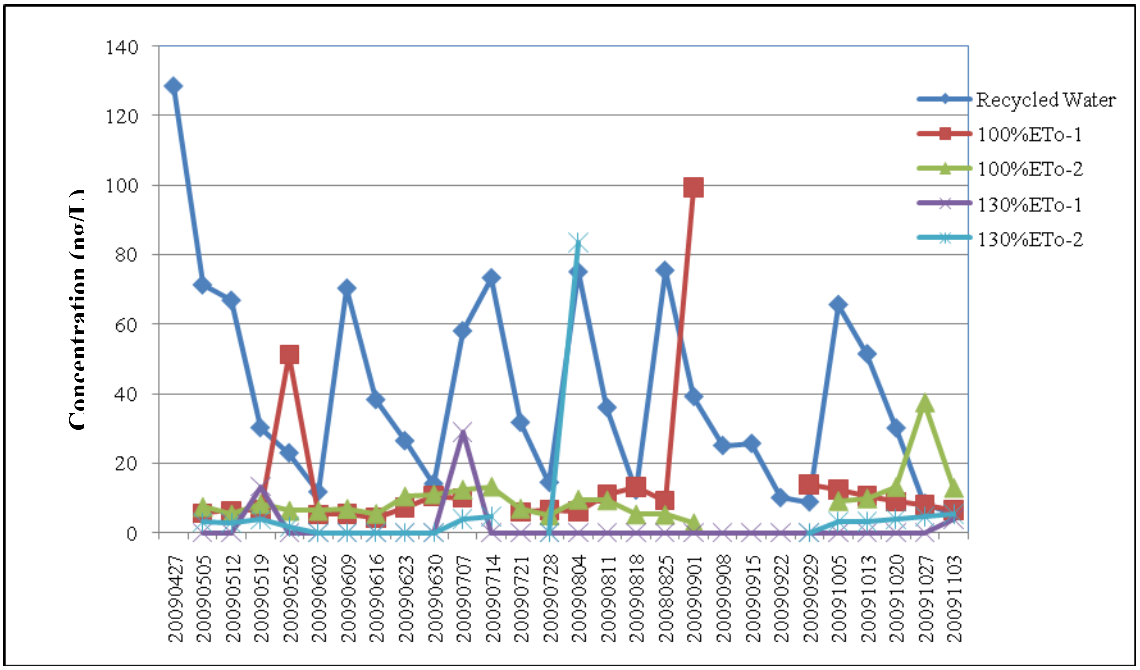


Figure 4-13. Levels of Trimethoprim in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo (and 130% ETo of Loamy Sand Plots.

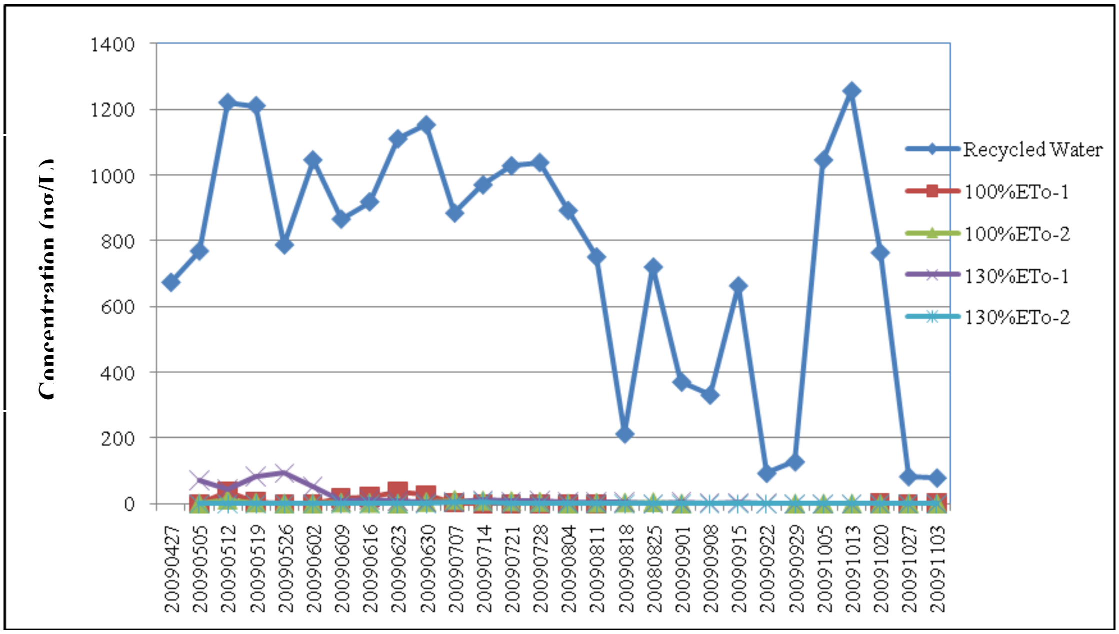


Figure 4-14. Levels of Sulfamethoxazole in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Loamy Sand Plots.

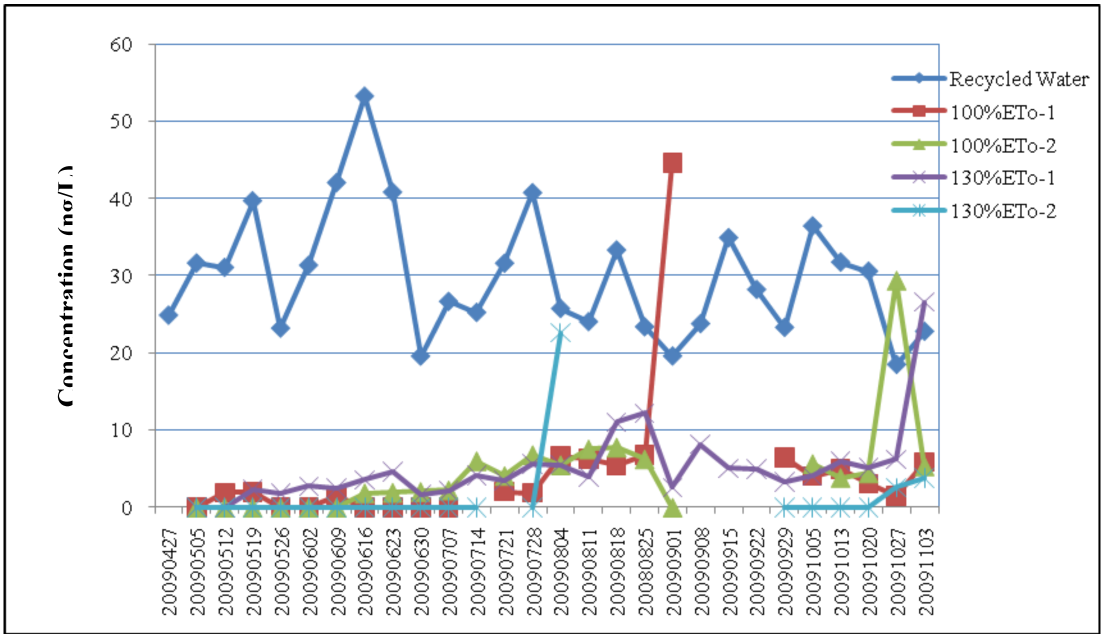


Figure 4-15. Levels of Primidone in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Loamy Sand Plots.

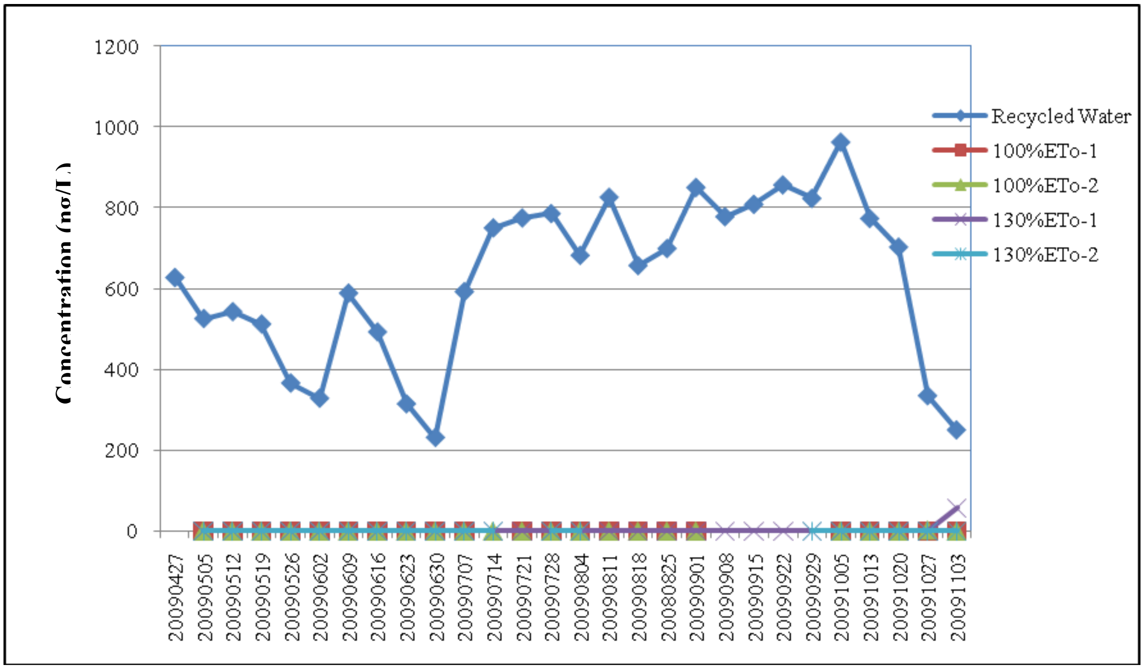


Figure 4-16. Levels of Trimethoprim in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Loamy Sand Plots.

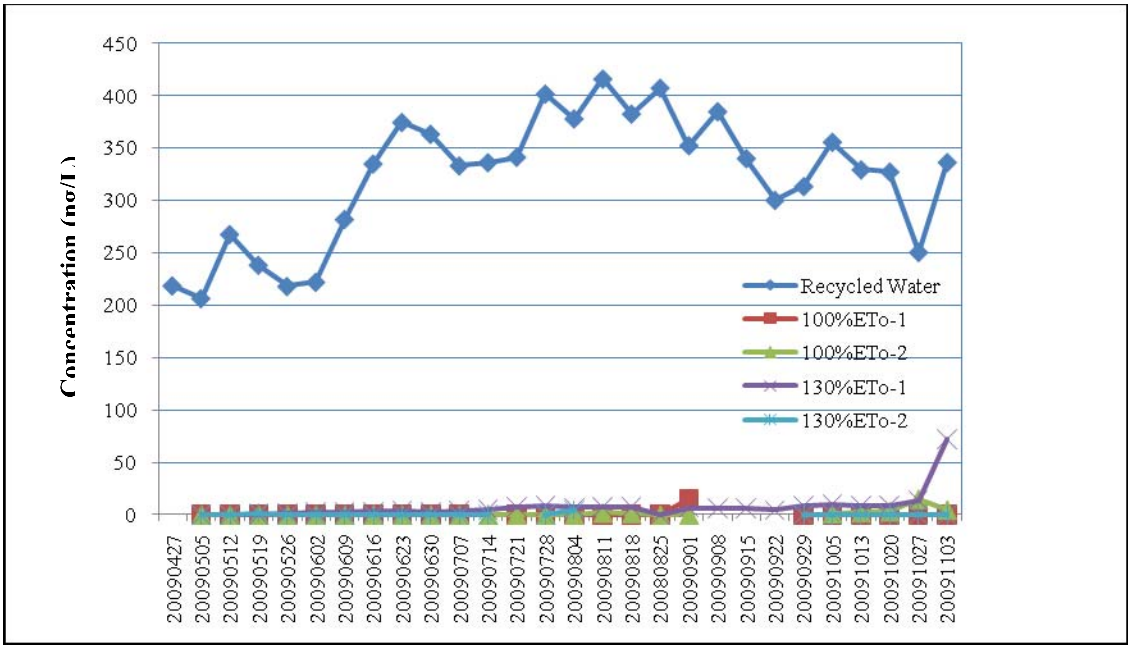
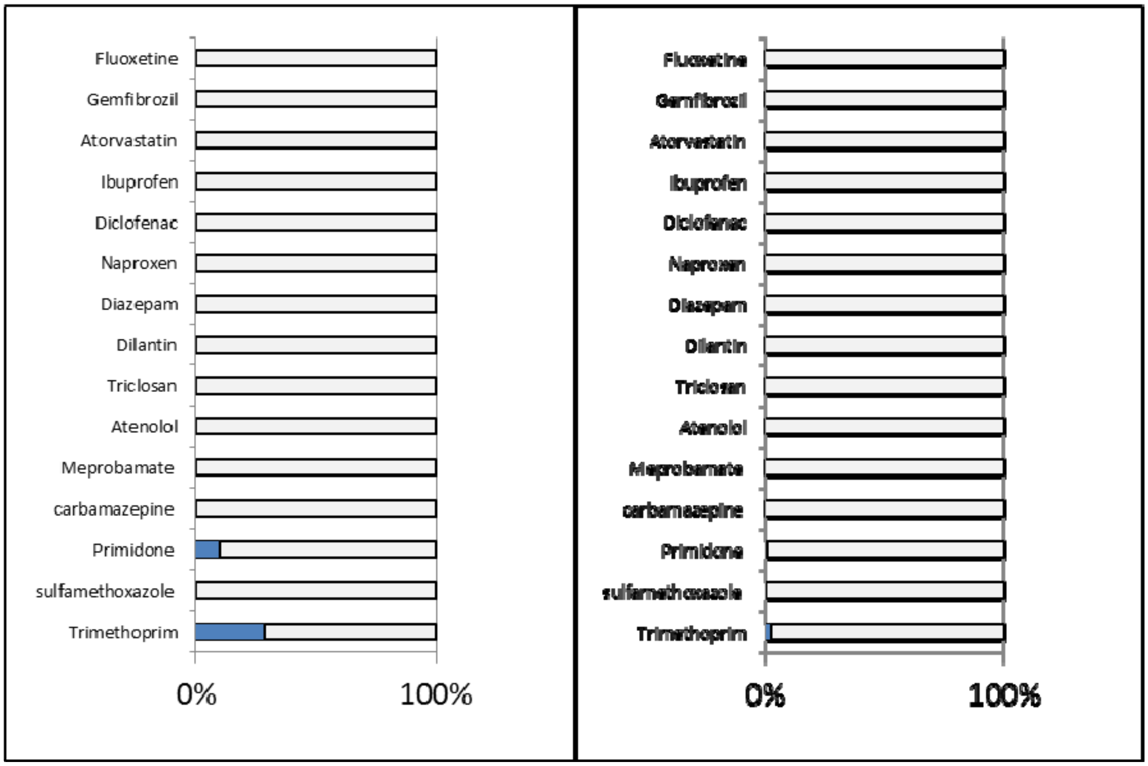
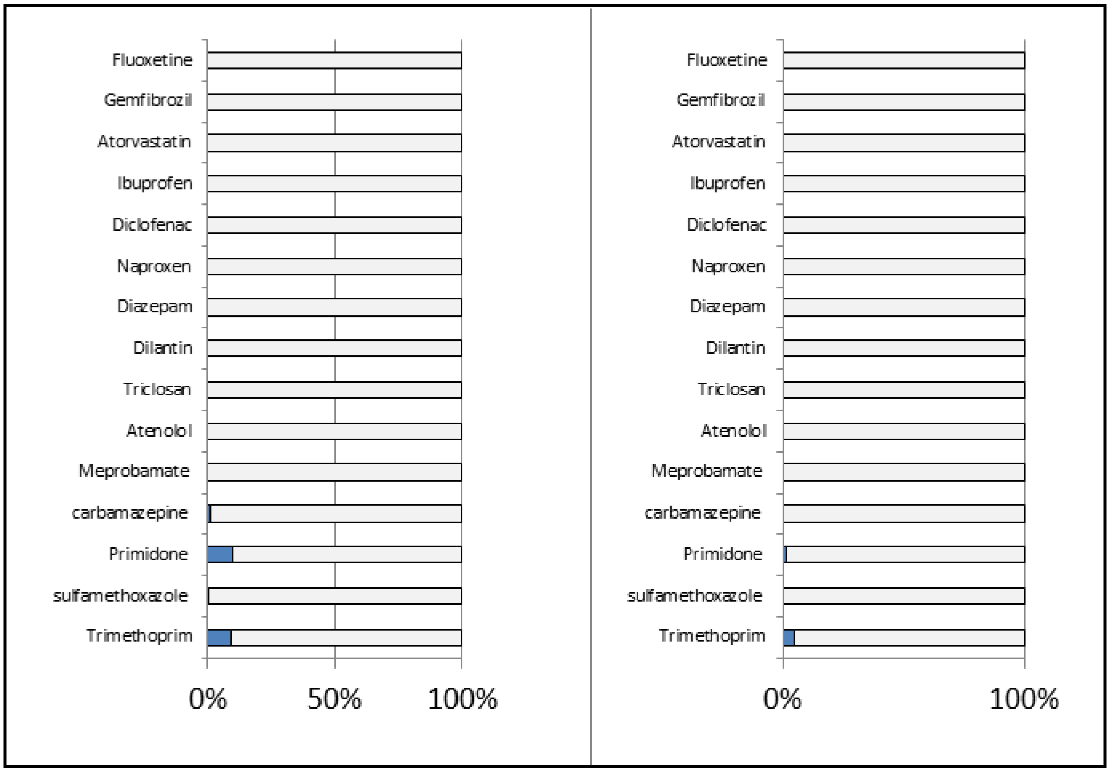


Figure 4-17. Levels of Carbamazepine in the Source Water (recycled water) and Drainage from Irrigation at 100% ETo and 130% ETo of Loamy Sand Plots.



(A) (B)

Figure 4-18. Leached Fractions Calculated from (A) Concentration Changes and (B) Chemical Fluxes Based on Drainage Fractions (Loamy sand plots, irrigated at 100% ETo).



(A) (B)

Figure 4-19. Leached Fractions Calculated from (A) Concentration Changes and (B) Chemical Fluxes Based on Drainage Fractions (Loamy sand plots, irrigated at 100% ETo).

4.4 Conclusions

Turfgrass plots were irrigated with recycled water for over six months at elevated irrigation rates. Leaching risks of a range of PPCPs were evaluated based on their presence in the source water (i.e., recycled water) and drainage water occurring at the 90 cm depth. Results clearly show that with the exception of a few compounds, most PPCPs did not appear in the drainage water under the conditions employed in this experiment. Trimethoprim and primidone were frequently found in the drainage water for both soil types and at both irrigation rates. However, after accounting for leaching (or drainage) fractions, the mass removal for these PPCPs was always greater than 80%. Therefore, it may be concluded that turfgrass/soil systems effectively attenuate PPCPs during recycled water irrigation, despite the fact that many PPCPs are persistent and/or weakly adsorbing in soil. It should be noted that the levels of trimethoprim and primidone were relatively low in the recycled water, with median concentrations at 30 ng/L. Even though these two compounds were detected in the drainage water, the levels were always very low, with median concentrations ranging from 2 to 23.4 ng/L for trimethoprim, and less than 1 to 8.6 ng/L. In addition, the conditions used in this study were simulations of worst-case scenarios in that the irrigation rates were above normal practices and that the drainage water was monitored at 90 cm below the surface. The actual leaching risk for PPCPs may be less under typical turfgrass management practices and conditions.

CHAPTER 5.0

EXPERIMENTS AT ACTIVE GOLF COURSES

5.1 Introduction

This chapter reports on experiments conducted at operational golf courses, in which monitoring of water flux and target PPCPs concentration were undertaken. Field monitoring of water movement and compound concentration was conducted using the same sampling and experimental methodologies at each site. Four golf courses were chosen, one in Nevada and three in California, all of which have histories of using recycled water on their fairways. Monitoring periods lasted approximately two years at each site, spanning two winter overseeding periods.

5.2 Materials and Methods

Specifically tailored monitoring equipment was installed at four golf courses. Each course had unique characteristics. The nature of these courses and their equipment, as well as the challenges they presented are described below.

5.2.1 Field Locations

- Wildhorse Golf Course is an 18-hole golf course located in the City of Henderson, NV. The soil on the course is classified as a McCarran fine sandy loam (Coarse-loamy, mixed, thermic, CambicGypsiorthids). The fairways are planted to a hybrid bermudagrass (Tifway/TifEagle) and overseeded with perennial ryegrass. The course has been using recycled water since the early 1960s.
- Silver Creek Valley Country Club (CC) is an 18-hole golf course in San Jose, Santa Clara County, CA. The soil is part of the Santerhill complex, characterized by clay texture formed from residuum of serpentine and/or slope alluvium. The site has been irrigated with recycled water since 1999.
- Babe Zaharias Golf Course is an 18-hole golf course located in City of Industry, Los Angeles County, CA. The soil is part of the Yolo Association, found on gently sloping alluvia fans, with a silt loam texture. The course was built on a landfill in the early 1980s. Note that the study site was on a portion of the golf course built on native soil. Since August 1983, 600 acres have been irrigated with recycled water, which is supplied by the San Jose Creek East Water Treatment Plant operated by the Sanitation Districts of Los Angeles County.
- Palm Desert Country Club is located in Palm Desert, Riverside County, CA. The soil on the course is classified as Myoma fine sand (Mixed, hyperthermic Typic Torripsamments). Since 1968, a portion of the golf course, including the study site, has been irrigated with recycled water, which is supplied by Water Reclamation Plant No. 9 of the Coachella Valley Water District.

Wastewater treatment methods for each golf course used in this experiment are included in Table 5-1.

Table 5-1. Methods of Wastewater Treatment for Input Water Used at Golf Courses.

Site and Facility	Description of Water Treatment
Wildhorse GC Source: Clark County Water Reclamation District	This plant collects sewage entering the preliminary treatment facility that screens out objects and allows sand and gravel to settle from the wastewater. Secondary treatment includes aeration and secondary clarifiers, where bacteria break down or stabilize organic materials. Tertiary treatment includes chemical addition, filtration and disinfection.
Silver Creek Valley CC Recycled water wholesaler: SBWR Source: San Jose/Santa Clara Water Pollution Control Plant	South Bay Water Recycling is a regional program that provides recycled water from San Jose/Santa Clara Pollution Control Plant (Plant) for non-potable uses in the cities of San Jose, Milpitas and Santa Clara. Treatment consists of screening, grit removal, primary sedimentation, secondary treatment (activated sludge biological nutrient removal or BNR) followed by the secondary clarification, gravity filtration (dual media, anthracite, and sand) and disinfection (liquid Sodium Hypochlorite plus ammonia). After disinfection, about 10% of the recycled water is diverted to the transmission pump station for distribution as recycled water for non-potable uses.
Babe Zaharias GC Source: The San Jose Creek WRP East facility	This plant provides tertiary treatment using the following treatment process sequence: primary sedimentation, activated sludge nitrification/denitrification biological treatment, secondary clarification, coagulation with alum (when needed), inert dual-media (sand and anthracite coal) gravity filtration, and disinfection with chlorine gas. Recycled water produced by this plant and not delivered for beneficial reuse is dechlorinated with sulfur dioxide gas prior to discharge to the river. All primary and waste activated sludge from the San Jose Creek WRP East is returned to the sewer for transport to and further processing at the District's Joint Water Pollution Control Plant in Carson.
Palm Desert CC Source: WRP9	This plant is located in the city of Palm Desert, California, and consists of the following treatment units: a grit chamber, two basin aeration basins, two secondary clarifiers, one chlorine contact chamber, and one aerobic digester, and two infiltration/storage basins. One basin is lined for storage of recycled water. Treated and chlorinated effluent from the lined storage basin is pumped to the Palm Desert Country Club mixed with pumped ground water in the irrigation system, and used for golf course irrigation. The recycled water use areas are the driving range holes seven, eight and nine of the executive golf course, and the centerline areas of holes six, seven, eight and nine of the championship golf course. In 2008, the plant received 108.257 MG of influent and treated 71%. 76.673 MG were used for golf course and landscape irrigation by Palm Desert Country Club and the remainder was percolated or used as wash water at the plant. WRP9 was able to provide approximately 18% of the total irrigation water used (Recycled + Ground Water) for golf course irrigation.

5.2.2 Installation of Monitoring Equipment at Golf Course Sites

The monitoring program at golf course sites was centered on the use of the passive capillary drain gauges (model G2, Decagon Devices, Pullman, WA). These devices were originally developed by Gee et al. (2002) and have since been modified to allow sampling of percolate that collects in inert containers at the base of the device. A full description can be found at the Decagon website (accessed February 2011, http://www.decagon.com/products/lysimeters-and-infiltrometers/drain-gauge-passive-capillarylysimeter/drain-gauge-g2/). In addition to use of drain gauges to measure water flux, water content was measured in undisturbed soil outside of the gauges at two locations (Zaharias GC and Palm Desert CC), so that water status could be correlated to flux. Water content was measured (model 5TE, Decagon Devices) at 15 cm and 75 cm depths. Water content sensors were not available at the time of installation for Wildhorse GC or Silver Creek Valley CC. All sensor wires were connected to a datalogger (EM50, Decagon Devices) which collected data hourly throughout the study period. The datalogger was stored below ground in a water tight case (model 1450 [or equivalent], Pelican Products, Inc. Torrance, CA), protected by an irrigation valve box. Table 5-2 provides ancillary information on field site locations and installation.

Table 5-2. Background Information for Installation.

Site	City, State	Installation Date	Fairway/Hole
Wildhorse GC	Henderson, NV	November 12, 2008	3
Silver Creek Valley CC	San Jose, CA	December 7-8, 2008	18
Babe Zaharias GC	City of Industry, CA	March 17, 2009	4
Palm Desert CC	Palm Desert, CA	March 18, 2009	8

The specific method to install these gauges was nearly identical at all sites. Differences in installation procedure are noted when necessary. Soil material for the divergence control tube (DCT), which is the uppermost component in the drain gauge, was harvested using at area adjacent to where drain gauges were installed. Though the locations for sample recovery and gauge installation differed slightly, the soil treatment and irrigation regime were identical; using this alternative area allowed the researchers to concentrate soil collection in one location for the replicate drain gauges. Several methods to recover intact soil cores were attempted. The most promising method was to connect the DCT to a skid steer using a drilling attachment, and then to “drill” down the DCT under the weight of the machine. The attachment was built specifically for this project. After repeated efforts at several sites, it was determined that collecting undisturbed soil would not be possible due to the clayey-textured nature of the soils. The field crew then excavated soil in layers of about 7 to 10 cm (3 to 4 inches) thick using another cutting tool with a cutting shoe welded to the base of the auger. Soil was removed by hand and transferred into the DCT of interest. All efforts were made to avoid any air gaps or preferential flow paths inside the DCT, and to repack soil into the original layering. In general, though, the repacked soil in the DCT was about 5 to 7 cm (2 to 3 inches) thicker than the depth of the excavated borehole. Therefore, the final bulk density in the DCT was slightly lower than undisturbed soil.

Boreholes were excavated using a solid stem auger (between 25-cm and 30-cm diameter depending on the site) attached to the skid steer. Boreholes were advanced to ~200 to 210 cm (79 to 82 inches) below ground surface. Gravel was used to raise the base of the borehole to approximately 185 cm (72 inches) below ground surface. The gravel base also serves as a sump for discharge water from the sample chamber, thereby, preserving the integrity of the water samples collected. Table 5-3 has specific depths of boreholes and completion depths of the drain gauges. Before installation, the bottom of the DCT was coated with diatomaceous earth and then attached to the drain gauge using clamps (diatomaceous earth was used to enhance contact between the DCT and the drain gauge assembly). The entire assembly was then lowered into the borehole, with the top of the drain gauge positioned to between 7 and 15 cm below ground surface (gauges were placed below verticutting and aeration depths, at the request of the superintendents). Soil was backfilled around the DCT, ensuring that the DCT and drain gauges were vertically oriented. Turf was replaced on top of the drain gauge by field personnel.

Wires and tubing from the drain gauges and water content sensors (when used) were contained in rigid conduit from the installation site, to a circular valve box, where the fluid removal tubes terminated. Wires used for monitoring water depth in the drain gauge were conveyed to the central valve box, fed into a water proof case and terminated at the EM50R logger. All conduit runs were sealed using plumber's putty to prevent water from entering the conduit. All drain gauges were checked for operation before site completion and cleanup and no problems were detected. Figures showing locations map installation specifications for each of the four golf course sites and are found in Appendix E.

Table 5-3. Depths for Completion of Drain Gauges at Golf Course Sites.

Site and gauge	Depth of borehole (cm bgs†)	Depth to bottom of DCT (cm bgs)	Depth to top of DCT (cm bgs)
Wildhorse GC#1	199.8	81.0	15.0
Wildhorse GC#2	191.8	81.4	15.4
Wildhorse GC#3	202.2	84.4	18.4
Silver Creek Valley CC#1	207.7	80.9	14.9
Silver Creek Valley CC#2	207.1	80.3	14.3
Silver Creek Valley CC#3	204.1	77.4	11.4
Babe Zaharias GC #1	207.8	81.0	15.0
Babe Zaharias GC #2	207.8	81.0	15.0
Babe Zaharias GC #3	207.8	81.0	15.0
Palm Desert CC #1	207.8	81.0	15.0
Palm Desert CC #2	197.8	71.0	5.0
Palm Desert CC #3	211.4	84.4	18.4

† - bgs – below ground surface

In addition to the monitoring equipment described above, a monitoring well was installed adjacent to the drain gauges at Wildhorse GC, for the purpose of observing groundwater levels and occasional sampling of well water. The monitoring well was installed using a solid stem auger (15 cm diameter) to advance the borehole to a depth of 4.10 meters. Hand-cut slots were added to the bottommost section of the well, which was made of Schedule 40 PVC material (5 cm diameter). Sandy material was used to backfill the well screen, and then native material was used in the remaining annular space to ground surface. The well was not completed using fully standardized methods (e.g., grout cement, steel collar, etc.), as data from the well was intended to provide general information on water level and water quality.

5.2.3 Operation and Maintenance of Drain Gauges

The drain gauges and sensors were designed to operate remotely and with little need for intervention. The data loggers themselves were powered by 9-volt batteries that obviate the need for external power (and associated complications). During the approximate two-year monitoring period of this project, batteries were changed only at Palm Desert CC. No data were lost because of power issues. A "Drain Gauge Monitoring Guide" was written for each field site to ensure uniform practices and to assist field personnel. The guide included site-specific specifications for drain gauges, depths of installation, and step-by-step instructions for downloading data and collecting water samples. As an example, the Guide for Silver Creek Valley CC is included as Appendix F (general information on operation and maintenance for the other sites is identical; only Silver Creek Valley CC is included as an example).

During the field project, three broad maintenance issues were encountered that led to some data loss or issues with accuracy. These issues included periodic flooding in the annular space around the drain gauges, corrosion of wiring connecting drain gauges to the loggers and flooding of the logger boxes. The issues and resolutions are described below.

Annular space flooding – During summer 2010 (and potentially in 2009), it was noted that the drain gauges were potentially flooded at Silver Creek Valley CC (water flux measurements were not recorded but anomalously high volumes of water were found in the upper and lower sampling chambers). After several discussions, it was felt that water from the annular space was flowing back into the drain gauges through a drain hole drilled in the gauges themselves (no one-way check valves are present to prevent this from occurring). Accumulation of water at the base of the gauge could be from either a shallow groundwater table created as a result of either drainage from the drain gauge or from the irrigation scheduling used by the golf course. In either case, the very low hydraulic conductivity clay-rich soil at the site prevented water drainage, which in turn caused backflushing to occur. To solve the problem, on July 7, 2010, John Healey (DRI), Mike McCullough (NCGA), and representatives from Silver Creek Valley CC drilled a 2.54-cm (1-inch) diameter borehole outside of each drain gauge, and installed a PVC pipe that terminated in the gravel sub-base below the drain gauge. A portable pump was then used to remove any ponded water. Volumes of water removed were not immediately measured, but they were in the multiple liter range. Removing the fluid effectively isolates the drain gauge from the shallow water and allows the system to operate correctly. All three gauges at Silver Creek Valley CC were modified in this way. Field personnel consistently pumped water from the annular spaces of the drain gauges throughout the remainder of the field project, and the data collected was within the ranges expected.

Drain gauges were also flooded by precipitation at Zaharias from late January 2010 through mid-March 2010 for gauges 2 and 3, and until approximately late June 2010.

Wiring at Zaharias – A problem with the wiring on the ECH2O probe, installed at 75-cm depth, was discovered and repaired on June 30, 2009 (ED 180). The problem dates back to the original installation and involved the water content, soil temperature and bulk electrical conductivity of soil. The wiring was repaired by Robert Green and Kathy Carter (UC Riverside) and the system appeared back on line. A second problem was encountered during summer 2010 with Drain Gauge #2. The error manifested in a cyclic recording of increases and decreases in water volume in the upper chamber, an observation that was not physically possible. Multiple discussions with Decagon Devices, and attempts at field repair by Robert Green and others, led to the conclusion that the electronic sensor in the gauge was malfunctioning. Because this drain gauge model cannot be repaired without excavating the entire sensor, the project team decided to abandon the collection of flux data from this gauge, though fluid collection was continued as before.

Failed data loggers at Silver Creek Valley CC and Zaharias GC – Two EM50 data loggers that collect and store data from the three drain gauges failed during the second quarter in 2009. Specifically, the loggers at Silver Creek Valley CC and Zaharias GC failed due to water leakage into the logger boxes. Data from Silver Creek Valley CC was recoverable, but data from Zaharias GC was lost between May 5, 2009 (ED 134) and August 11, 2009 (ED 223). These leakages occurred even though the EM50 logger box (already resistant to water leaks) was placed into the waterproof case and sealed with rubber stoppers. In the case of Zaharias, the valve box was found to be flooded on May 5 (ED 124) and water subsequently leaked into the logger container, destroying the logger. A new EM50 logger was drop shipped to UC Riverside and installed one week later (ED 138). A field drain was installed to remove excess water collecting in the main valve box where the data logger was stored. The top of the valve box lid was sealed to limit water from directly entering the box. These steps proved successful and data collection has been continuous since the completion. In the case of Silver Creek Valley CC, communication with the logger became problematic on or about May 15, 2009 (ED 134). After discussing the situation with Decagon Devices, they dropshipped a loaner unit while repairing the damaged logger. The replacement logger was resealed into the waterproof case and no future logger issues were encountered.

5.2.4 Fluid Collection

Table 5-4 shows dates for fluid collection at all golf course sites, including drain gauges and irrigation sources (i.e., storage ponds or from irrigation lines), and a water well installed by Dale Devitt and students, and a decorative pond located near the drain gauges but not used as an irrigation source. Water quality results from the decorative pond provide general information about water management at the site). Differences in fluid collection scheduling reflect the time needed for water to percolate through the 60-cm diversion control structure and into the sampling containers. In the case of Wildhorse GC, more than 14 months was needed for enough water to initiate vertical flow, illustrating the small amount of excess water being applied to the soil, and the importance of winter precipitation to initiate flow. The time needed at other sites was less, ranging from about 3-9 months. Variability was due to differences in rainfall patterns and irrigation depths during the year. It is apparent that once the soil water deficit was diminished and flow began, soil water continued to be released into the sampling chambers and be available for sampling.

Table 5-4. Dates for Fluid Collection at Golf Course Sites.†

Wildhorse GC	Silver Creek Valley CC	Zaharias GC	Palm Desert CC
7/27/2009 - 2, 3, 4	6/2/2009 - 1	11/13/2009 - 1	12/4/2009 - 1
10/7/2009 - 2, 3, 4	6/26/2009 - 1	12/2/2009 - 1, 2	12/31/2009 - 1
2/1/2010 - 2, 3, 4	7/23/2009 - 1	12/30/2009 - 1	1/29/2010 - 1,2
2/26/2010 - 1	8/27/2009 - 1, 2	1/28/2010 - 1	2/19/2010 - 1
5/4/2010 - 1, 2, 3, 4	10/9/2009 - 1	4/2/2010 - 2	3/19/2010 - 1
9/22/2010 - 1, 2, 3, 4	10/29/2009 - 1, 2	4/23/2010 - 1	4/30/2010 - 2
11/10/2010 - 1, 3	12/14/2009 - 1	7/26/2010 - 2	10/15/2010 - 2
11/16/2010 - 2, 4	1/11/2010 - 1	10/22/2010 - 1, 2	1/7/2011 - 1, 2
12/14/2010 - 1, 2, 3, 4	2/1/2010 - 1	11/19/2010 - 1	
	3/26/2010 - 1	12/13/2010 - 1	
	4/30/2010 - 1	1/5/2011 - 1, 2	
	5/20/2010 - 1		
	6/25/2010 -1		
	7/22/2010 - 1, 2		
	8/23/2010 - 1, 2		
	9/29/2010 - 1		
	10/21/2010 - 1		
	11/30/2010 - 1		
	12/8/2010 - 1		
	12/21/2010 - 1		

† - 1 – Drain gauges; 2 – Irrigation source; 3 – Water well (Wildhorse only); 4 – Decorative pond (Wildhorse only)

In many cases, samples were consolidated before analysis (i.e., from chambers between drain gauges). This was done to increase the volumes of fluid, thus allowing lower detection limits (in the ng/L [part per trillion] level) for many of the constituents on the target list. During the field project, the preference was to sample only the upper chamber of each drain gauge individually. The challenge, though, was arriving at the site just before the upper chamber was full and fluid was siphoned to the lower chamber. Recalling, when the upper chamber (containing about 35 mL of water) becomes full, a dosing siphon installed in the chamber removes the fluid and conveys it to a lower chamber. When the lower chamber (which contains about 100 mL of water) becomes full, fluid seeps from a drain hole installed in the side of the gauge and into the annular space. Analytical results (provided in Appendix H) obtained on samples collected independently from upper and lower chambers showed nearly identical results. Therefore, if volumes of fluid collected from upper chambers were sufficient for laboratory analyses, then the samples were shipped to the laboratory separately. If sample volumes from the upper chambers were not sufficient, then fluid collected from upper and lower chambers was consolidated for analyses.

Individual concentration values measured by SNWA were ultimately converted to mass flux throughout the study period:

$$Mass\ flux\ (ng) = Water\ flux\ (cm^3) \times \left(\frac{1\ L}{1000\ cm^3}\right) \times concentration\ \left(\frac{ng}{L}\right) \quad (5\text{-}1)$$

The values of mass flux were then upscaled from the drain gauge scale (314 cm^2) to the hectare scale (10,000 m^2), which provides a better physical basis for comparison between golf courses and with the drainage lysimeter data described in Chapter 4.0. The conversion factor from mass flux at the drain gauge scale (ng) to kilograms/hectare is:

$$Mass\ (g/ha) = \frac{Mass\ flux\ (ng)}{Area\ (cm^2)} \times \left(\frac{100\ cm}{1\ m}\right)^2 \times \left(\frac{10{,}000\ m^2}{1\ ha}\right) \times \left(\frac{1\ g}{10^9 ng}\right) \quad (5\text{-}2)$$

5.3 Results and Discussions

The experiment generated a number of results. They pertain to soil types, watering and weather variations, and how those affect absorption and movement of PPCPs. Those results are described in this section.

5.3.1 Soil Analyses

Soil samples collected at each golf course site were sent to A&L Labs (Modesto, CA) for analyses of soil texture, and basic anions and cations. All analyses are provided in Appendix G. The textural components (e.g., sand and clay) are shown as functions of depth in Figure 5-1. The results show relatively clay-rich soils at the sites, except for Palm Desert CC, which was classified as a textural sand throughout the profile. Soil materials at the other three sites were mostly classified as loam and clays. Because soil hydraulic conductivity and downward flow of water through soils depend substantially on soil texture, the results for Wildhorse GC, Silver Creek Valley CC, and Zaharias GC courses highlight the expectation that soil water will move relatively slowly compared to Palm Desert CC, all other factors held equally. The presence of significant percentages of clay – especially at Silver Creek Valley CC – also indicate a higher likelihood that dissolved compounds will sorb onto the soil, thus further reducing transport rates. This can be seen from the analytical results shown in Appendix G, where the cation exchange capacity (CEC) varies with clay percentage. For example, Palm Desert soils have an average CEC of 2.9 meq/100g soil, versus Silver Creek Valley CC soils that showed an average CEC of 31.7 meq/100g soil. Though sorption onto soils depends on the constituent characteristics (e.g., polarity, size, etc.), the differences in CEC provides a reasonable estimate of the capacity of the soil material itself to remove or reduce aqueous concentrations of dissolved constituents.

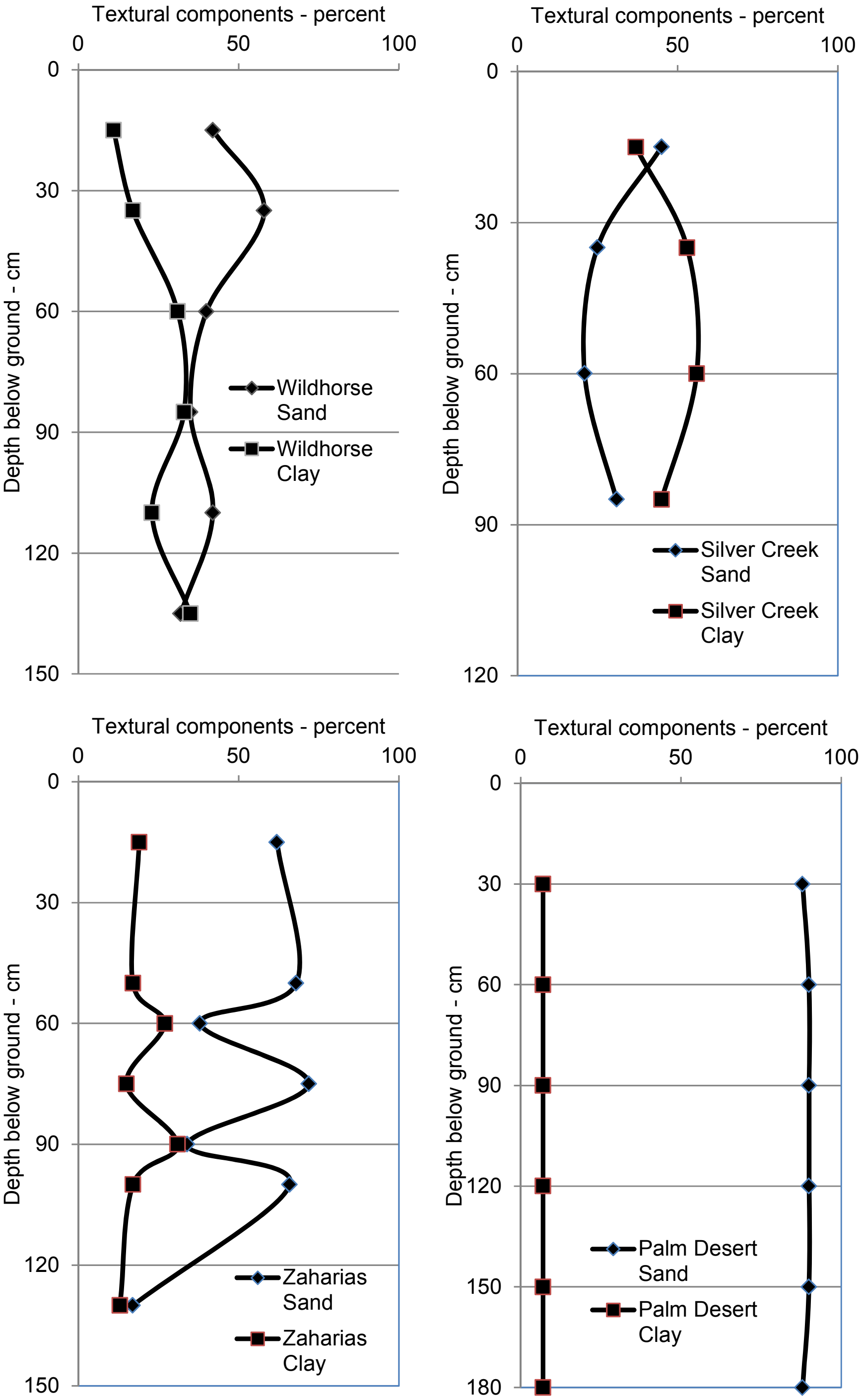


Figure 5-1. Textural Components of Soils at Golf Course Sites (note different y-axis scales).

5.3.2 Water Flux Measurements

During the experimental period, especially during the early part of the first field season in 2009, flux was recorded only at Silver Creek Valley CC (Figure 5-2). During the first six months in 2009, nearly 19 mm flux was recorded. Other sites in drier climes were still equilibrating during this initial period. As the experiment progressed into 2010, the 60 cm thick soil column (stored within the DCT) was sufficiently saturated to allow vertical drainage. The values in Figure 5-2 are the geometric mean of the three drain gauges at each site. The geometric mean is used because drainage rates depend on the soil hydraulic conductivity, which is often represented by a right-skewed log-normal distribution. The use of the geometric mean tends to place the average value closer to the mass of data (Zhu and Mohanty, 2002), rather than closer to outliers. In the case of infiltration behavior in soils, the geometric mean provides a good effective value for soil hydraulic properties (Renard et al., 2000), especially when considering spatially variable soils.

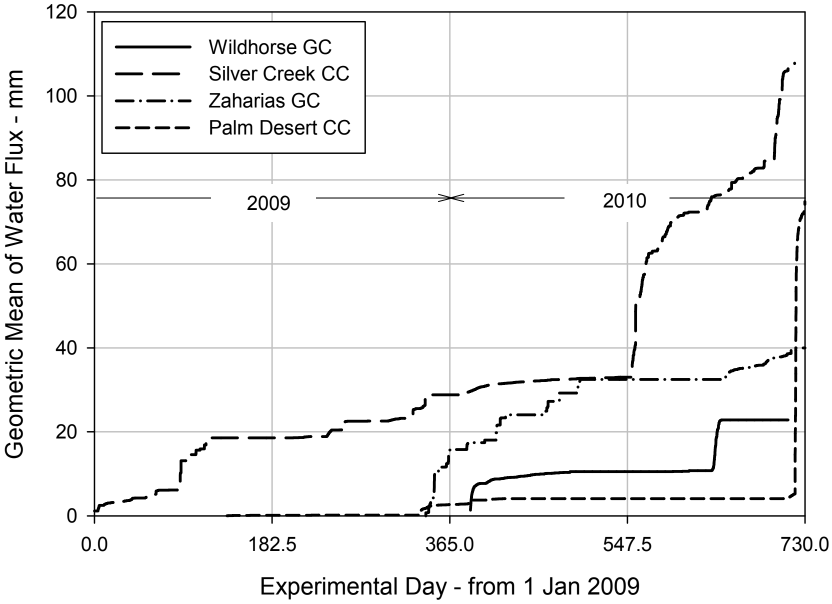


Figure 5-2. Geometric Mean of Flux from All Drain Gauges Used in the Field Study.

5.3.2.1 Flux Measurements at Wildhorse Golf Course

The lowest mean flux was recorded at Wildhorse GC (Henderson, NV), which required more than 1 year to equilibrate and ultimately yielded only 22.8 mm, or less than 1 inch of vertical drainage. Flux varied from a low of 7 mm recorded in gauge 3 to a high of 48 mm recorded in gauge 1 (Figure 5-3). The corrected value of gauge 2 considers a spurious flux spike that occurred early in the monitoring period, without any significant precipitation or irrigation events or similar responses from the other gauges. When this spike was removed from the total, the general trends were similar to the other gauge readings. Generally, more than 50% of all the recorded flux occurred toward the end of September 2010 from summer thunderstorms, over-irrigation of turf, or a combination of both. During this entire two-year time period, total precipitation recorded at a remote automated weather station (RAWS) located in Henderson, NV (and maintained by DRI) was 226.05 mm (Figure 5-4). The data show the typical pattern of higher precipitation during the winter months, with occasional summer storms. Unfortunately, daily irrigation depths were not recorded and maintained, so comparing flux to total water input is not possible. In any case, though, it is clear that the significant precipitation that was recorded near the site, especially surrounding ED 365 (end of 2009) triggered downward percolation below 60 cm depth and water flux being recorded by the gauge.

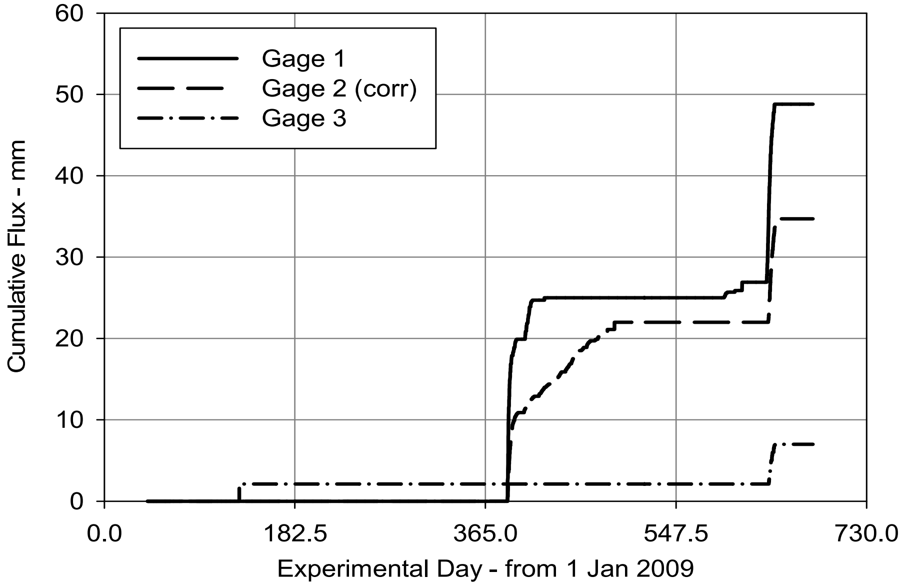


Figure 5-3. Cumulative Flux Recorded at Wildhorse GC.

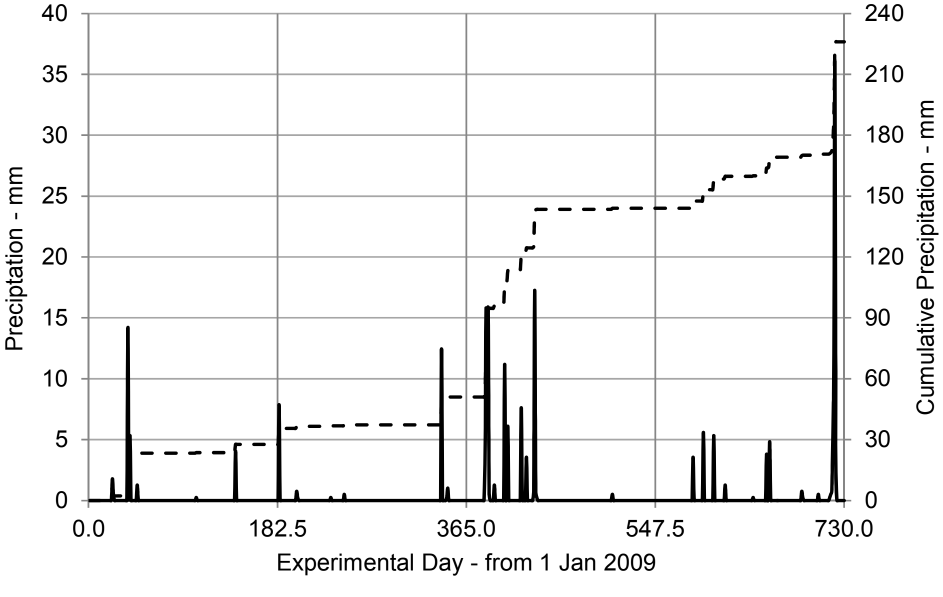


Figure 5-4. Precipitation Recorded at Wildhorse GC.

5.3.2.2 Flux Measurements at Silver Creek Valley Country Club

Fluxes measured at Silver Creek Valley CC also varied significantly, with values from gauge 3 significantly higher than the fluxes recorded from the other gauges (Figure 5-5). As indicated above, some issues with flooding in the annular space were observed and this could explain the higher values. Focusing on gauges 1 and 2, they show an increase in late March 2009 and a second substantial increase in flux around July 2010, as irrigation was needed to supplement the lack of summer rainfall. If the geometric mean of flux was calculated without the results from gauge 3, the total cumulative flux would be 68.8 mm, or about 57% of the geometric mean shown in Figure 5-2. As seen in Figure 5-6, increases in flux do show some connection to irrigation patterns at the site (unfortunately daily ambient precipitation is not available, as no RAWS stations are close to this golf course).

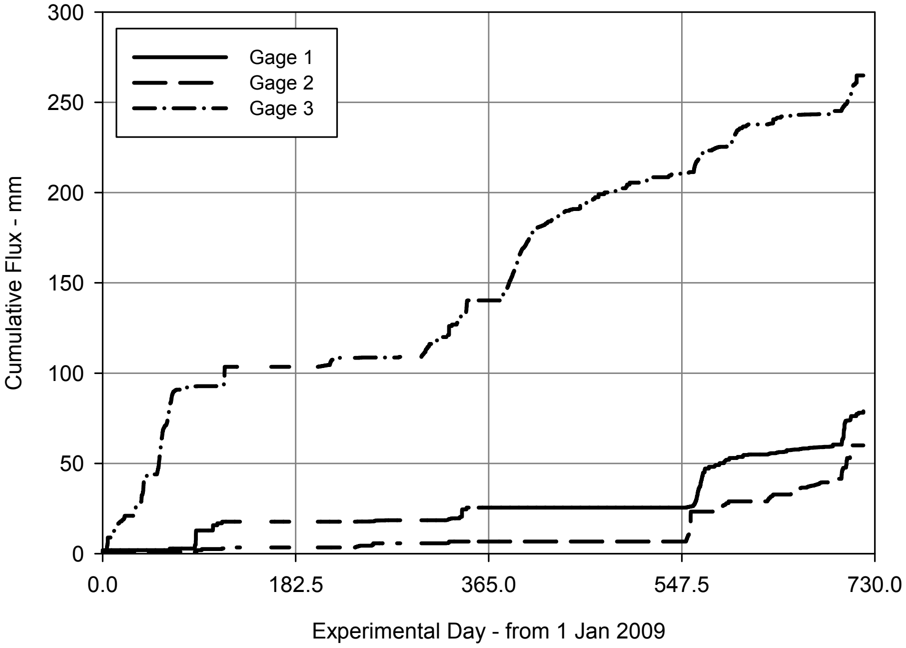


Figure 5-5. Cumulative Flux Recorded at Silver Creek Valley CC.

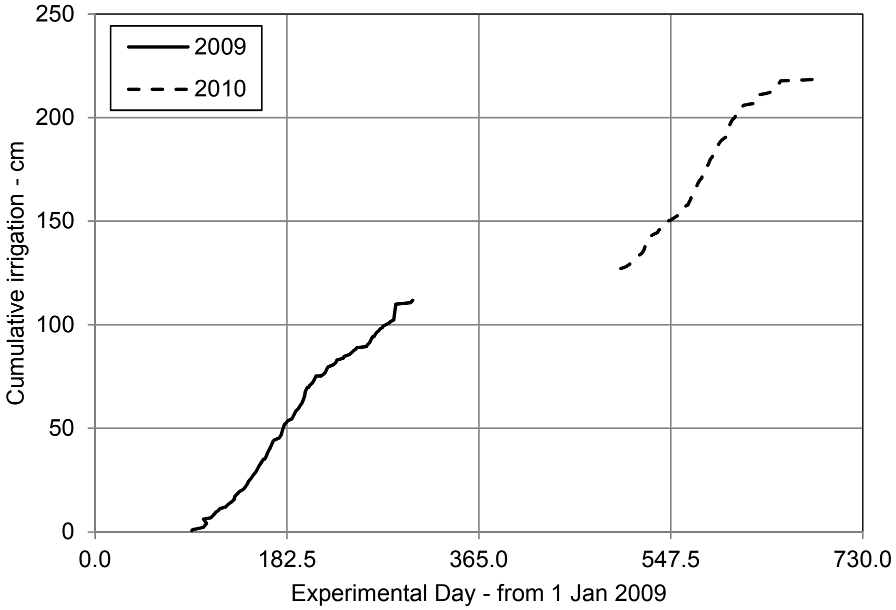


Figure 5-6. Cumulative Irrigation Applied to the 18th Fairway at Silver Creek Valley CC.

5.3.2.3 Flux Measurements at Zaharias Golf Course (Industry, CA)

Drain gauges at Zaharias GC began operating consistently after precipitation events were recorded after about three months (Figures 5-7 and 5-8), but fluxes increased considerably from the heavy precipitation experienced in the desert southwest U.S. during winter of 2009-2010. Toward December 2009, significant fluxes were measured in all drain gauges. Given the small fluxes measured prior to mid-July when the data logger was flooded, and the lack of significant precipitation until the end of 2009, the research team suggests that the data gap from instrument failure in mid-late 2009 did not miss significant flux. As described above, fluxes were not recorded from gauge 2 in early-mid 2010 because of corrosion of wiring.

It is apparent that fluxes are tied directly to ambient precipitation as the irrigation rates are likely near or below reference evapotranspiration (ETo), especially during 2010. Thus, precipitation – particularly winter precipitation – drives downward percolation of water and thus increases the potential for transport of target compounds.

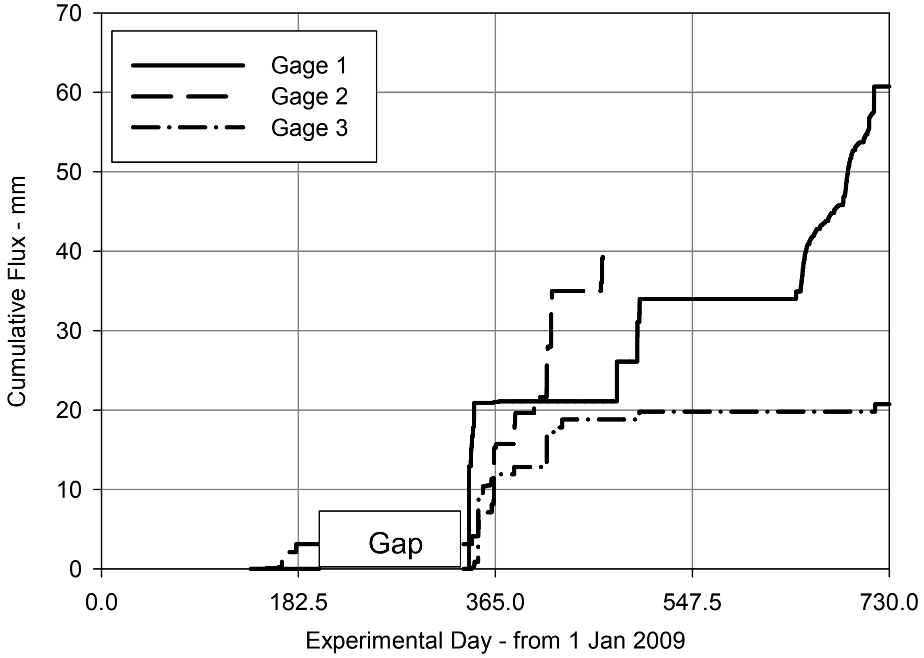


Figure 5-7. Cumulative Flux Recorded at Zaharias GC.

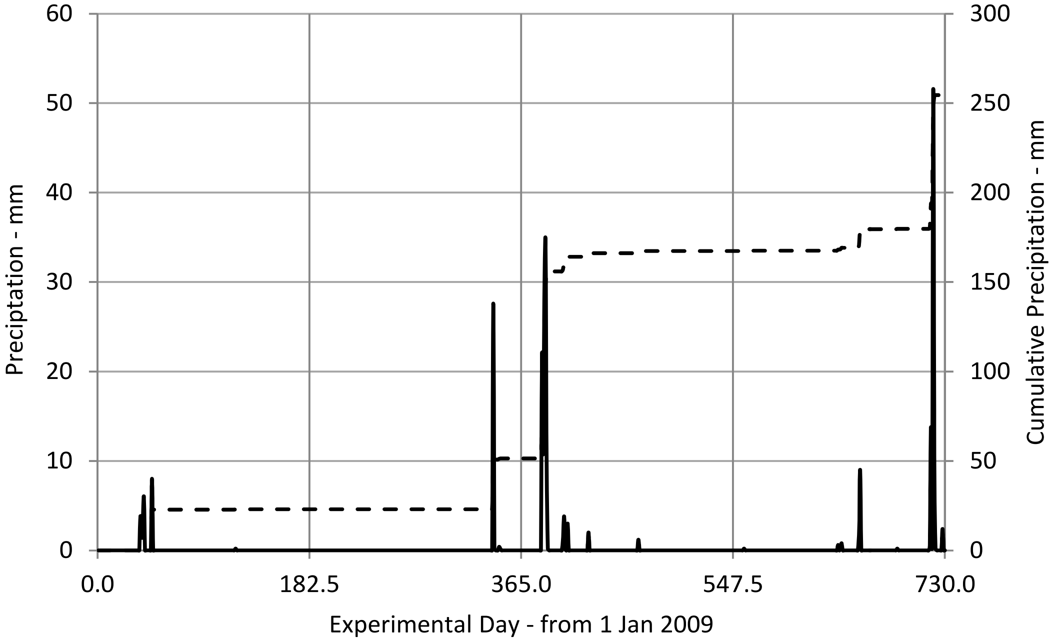


Figure 5-8. Precipitation Recorded at the Whittier Hill, CA RAWS Station, Approximately 14.5 km from Zaharias GC.
Daily irrigation records were not available.

5.3.2.4 Flux Measurements at Palm Desert Country Club

Sustained downward flux of water was disrupted by two closures of the country club: from September 22, 2009 to October 11, 2009 (ED 264-283), and from June 21, 2010 to December 7, 2010 (ED 536-705). The second closure was significant, lasting more than five months. During this time, the turf underwent limited irrigation and maintenance. Project researchers viewed the turf above the drain gauges and in the general vicinity during periodic visits and determined that the turf was still viable, though becoming patchy. The lack of irrigation during these downtimes can partially explain the lack of flux measured in the fairway (Figure 5-9), although the golf course superintendent would likely deficit irrigate during the warm summer months, and wait for winter ambient precipitation to remove any salt buildup in the soil. Note for example the significant precipitation event recorded on December 21, 2010 (ED 720), when 74.16 mm (2.92 inches) was recorded during a span of four days.

The fluxes measured at Palm Desert CC were highly variable, especially the fluxes recorded on gauge 2. In this case, a rapid increase in flux was noted on 12/13/10 (ED 711), a steady increase in cumulative flux for the next two weeks, and a tapering of flux on the remaining several days of the month. The high flux is unusual and somewhat suspect, although analysis of the raw data indicates quality data and field personnel tested the gauges to ensure correct operation.

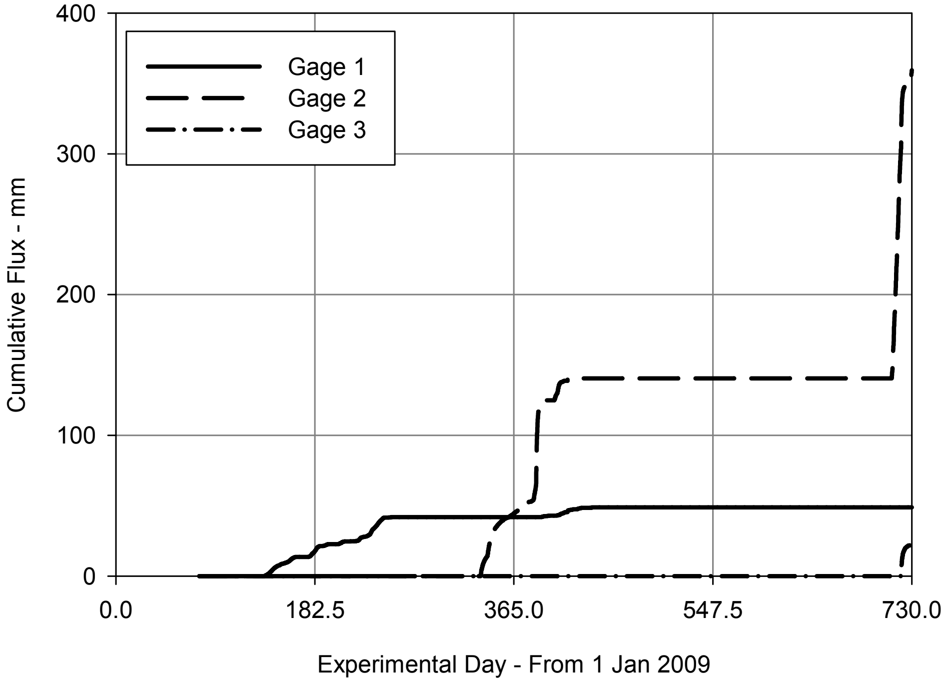


Figure 5-9. Cumulative Flux Recorded at Palm Desert CC.

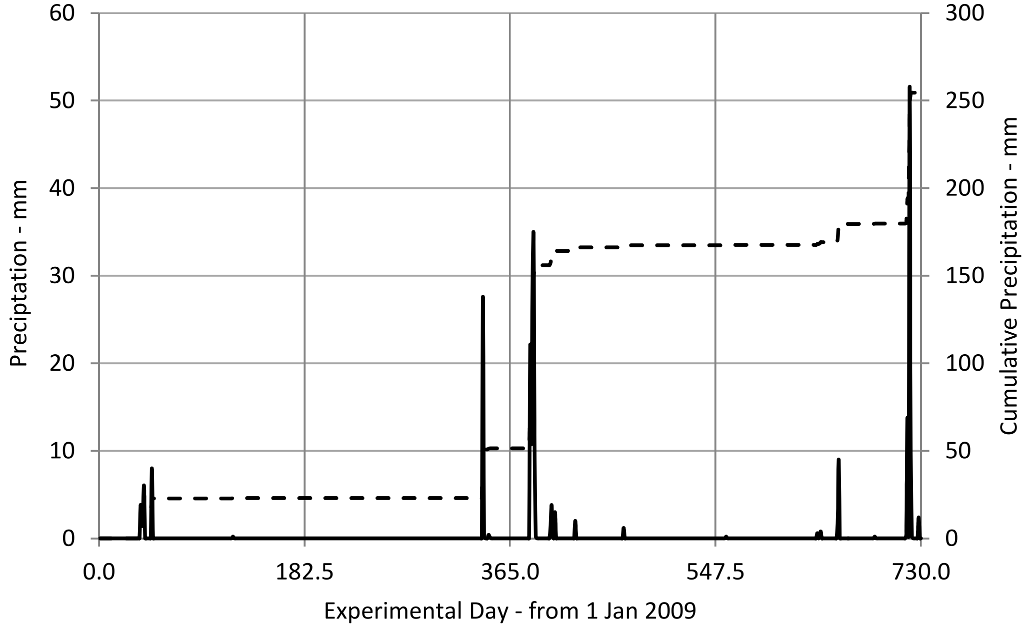


Figure 5-10. Precipitation Recorded at Cathedral City, CA, Approximately 12 km from Palm Desert CC.
Daily irrigation records were not available.

5.3.3 Analytical Results of Samples Collected at Golf Course Sites

During the two-year field study, a total of 84 samples were collected and analyzed by SNWA for the 14 original PPCPs (as noted below, Bisphenol A was dropped in mid-study because the concentration levels were impacted by either the irrigation system or the sampling equipment). The sample breakdown was 30, 39, 17, and 12 for Wildhorse Golf Course, Silver Creek Valley Country Club, Zaharias Golf Course, and Palm Desert Country Club, respectively. Samples were collected from a variety of sources, including drain gauges (52), decorative/storage ponds (20), groundwater wells (7; Wildhorse only), and directly from the distribution networks that feed the irrigation system (5). All results are shown in Appendix H, with values above reportable limits highlighted. Of the samples collected from drain gauges, a total of 111 instances of compounds above reportable limits were observed (note that the term 'reportable limits' is used by the analytical lab at SNWA to indicate concentrations that can be reported with a reasonable degree of accuracy and precision). The breakdown is found below in Table 5-5. The results show that four compounds were not found in any samples collected with drain gauges (Atenolol, Fluoxetine, Diazepam, and Atorvastatin), but that the other nine PPCPs were found in instances that ranged from once (Trimethoprim and Ibuprofen) to more than 30 times (Meprobamate and Carbamazepine). Concentrations above reportable limits were most common at Silver Creek Valley CC (60% of all occurrences) and least common at Wildhorse (7.2% of all occurrences), with Zaharias and Palm Desert in between (18.9% and 13.5%, respectively). The prevalence of PPCPs found at Silver Creek Valley CC is contrary to the earlier discussion, which stated that clayey soils more commonly retard the transport of compounds.

Table 5-5. Instances of Compounds Above Reportable Limits.

Compound	Wildhorse GC	Silver Creek Valley CC	Zaharias GC	Palm Desert CC	Total
Sulfamethoxazole	1	16	3	3	**23**
Atenolol	0	0	0	0	**0**
Trimethoprim	0	1	0	0	**1**
Fluoxetine	0	0	0	0	**0**
Meprobamate	2	20	7	2	**31**
Carbamazepine	1	20	8	5	**34**
Diazepam	0	0	0	0	**0**
Atorvastatin	0	0	0	0	**0**
Gemfibrozil	0	6	0	0	**6**
Diclofenac	1	1	1	0	**3**
Naproxen	0	0	1	2	**3**
Triclosan	2	3	1	3	**9**
Ibuprofen	1	0	0	0	**1**
Total	**8**	**67**	**21**	**15**	**111**

The results show a few distinct trends. First, as noted from data in Appendix H, source waters (i.e., used in irrigation) contained substantially higher concentrations of PPCPs on the target list than did samples that percolated through the soils and into the drain gauges. Thus, substantial levels of “treatment” occurred through the turfgrass/soil system, leading to either retardation (i.e., sorption), degradation of the PPCPs by either chemical or biological processes, or transformation of the PPCPs to a daughter or breakdown product. Post-experiment soil sampling was not done to quantify the different processes that led to the reduction. Also, though it is tempting to examine the reduction in PPCPs concentration in samples collected from source waters (e.g., ponds) and drain gauges on the same day, the long delay in arrival of water at the base of the drain gauges alters the ability to make side-by-side comparisons of before “treatment” with soil and after “treatment” with soil.

The second trend to note is the potential existence of cycles in the concentration. Figure 5-11 shows the time series of concentrations for sulfamethoxazole, meprobamate, and carbamazepine recorded in soil water at Silver Creek Valley CC and Zaharias GC (data were too sparse at Wildhorse GC and Palm Desert CC to generate meaningful charts). In the case of Silver Creek Valley CC, the time series indicates higher concentrations in the latter half of the year (July-December) and lower concentrations in the first half (January-June), although the total monitoring period did not fully capture a two-year period (soil equilibration was needed). If the trends hold up over time, this would indicate an unusually close connection between irrigation activity and higher compound concentrations in percolate. Note in particular the higher irrigation activity at Silver Creek Valley CC between April and September (Figure 5-6) and the higher concentrations in water collected with the drain gauge (Figure 5-11). As stated above, the close connection between above-ground activity and below-ground percolate indicates a potential short-circuiting of water around the soil in the DCT and into the sampling chambers (a phenomenon that required field activities to rectify). The higher concentrations at Zaharias GC, particularly around ED 365 correspond to periods of higher winter precipitation (Figure 5-8). Given the water hold capacity of the predominantly sandy loam soil at this site, it is likely that the compounds flushed into the chambers stems from earlier irrigation during the late summer periods when the golf course is deficit irrigating.

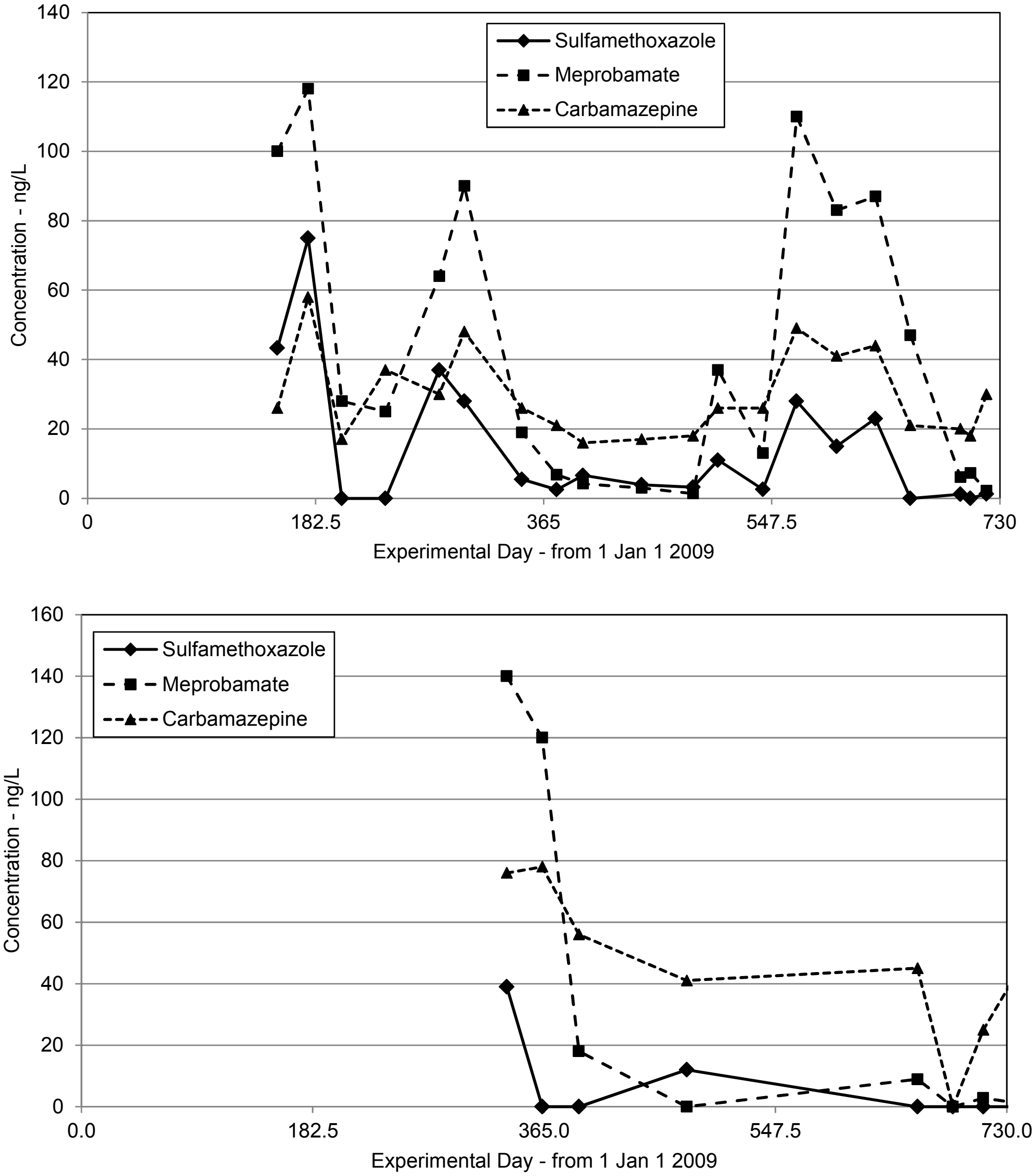


Figure 5-11. Time Series of Concentrations in Soil Water for Three Target Compounds at Silver Creek Valley CC (upper chart) and Zaharias GC (lower chart).

5.3.4 Mass Flux of Target Compounds

Table 5-6 presents the total mass flux of target compounds observed throughout the study. It is clear that eight target compounds were detected at the golf course sites and five compounds were not detected in water samples collected from any drain gauge. Mass fluxes varied across the golf courses, but values were all less than 1 gram/hectare, and often values were less than 1 milligram/hectare. Mass fluxes of individual compounds at Silver Creek Valley CC tended to be the highest of the four courses studied (except for diclofenac and naproxen), and least at Wildhorse GC, although naproxen was highest at this site. Meprobamate, carbamazepine, and naproxen were recorded at all sites, illustrating either the difficulty in removing this compound from wastewater or the ubiquitous nature of these compounds at cities across the southwestern U.S.

Estimating the mass flux of target compounds that could potentially transport away from each golf course through downward percolation can be calculated as the product of the values in Table 5-6 and total irrigated area.

Table 5-6. Mass Flux of Target Compounds during Field Period.
All units are in grams/hectare.† ‡

Site	Sulfamethoxazole	Trimethoprim	Meprobamate	Carbamazepine
Wildhorse GC	0‡	0	1.820e-3	2.670e-4
Silver Creek Valley CC	0.014	4.788e-4	0.060	0.034
Zaharias GC	1.007e-3	0	0.014	0.020
Palm Desert CC	0.013	0	3.962e-3	0.028

Site	Gemfibrozil	Diclofenac	Naproxen	Triclosan
Wildhorse GC	0	4.490e-4	0.0209	0
Silver Creek Valley CC	7.028e-3	0	1.106e-4	2.880e-4
Zaharias GC	0	3.377e-4	4.853e-4	9.061e-4
Palm Desert CC	0	0	4.826e-4	3.451e-4

† - Atenolol, Fluoxetine, Diazepam, Atavorstatin, and Ibuprofen were not recorded at any site.

‡ - Zero mass fluxes were used for compounds with concentrations below reportable limits.

Mass fluxes of target compounds at each golf course site are shown in Figures 5-12 through 5-15. When appropriate to facilitate graphing, the y-axis was shown in log scale. As above, the time (x-) axis is subdivided into six month increments, spanning the entire field period.

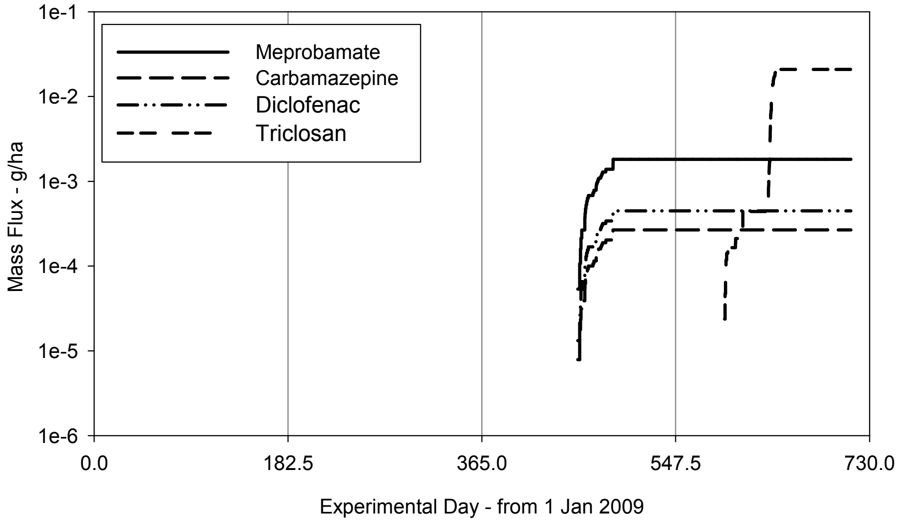


Figure 5-12. Mass Flux of Target Compounds (grams/hectare) at Wildhorse GC.

Several important trends are evident when looking at these graphs. First, most of the downward movement of target compounds occurred in the second year of the field monitoring. This trend is almost certainly an artifact of the monitoring program using drain gauges, which normally appeared to have required a full year to equilibrate (see above notes on drainage water). This means that, in general, the results shown in Table 5-4 would be more appropriately used to estimate yearly mass fluxes through undisturbed soil on active fairways at these sites. Second (and not surprisingly), the mass fluxes are strongly dependent on the downward percolation rates of water, which is the carrier of the target compounds. Using concentrations alone is not appropriate – both concentrations and water flux are needed to assess potential environmental impacts and risks.

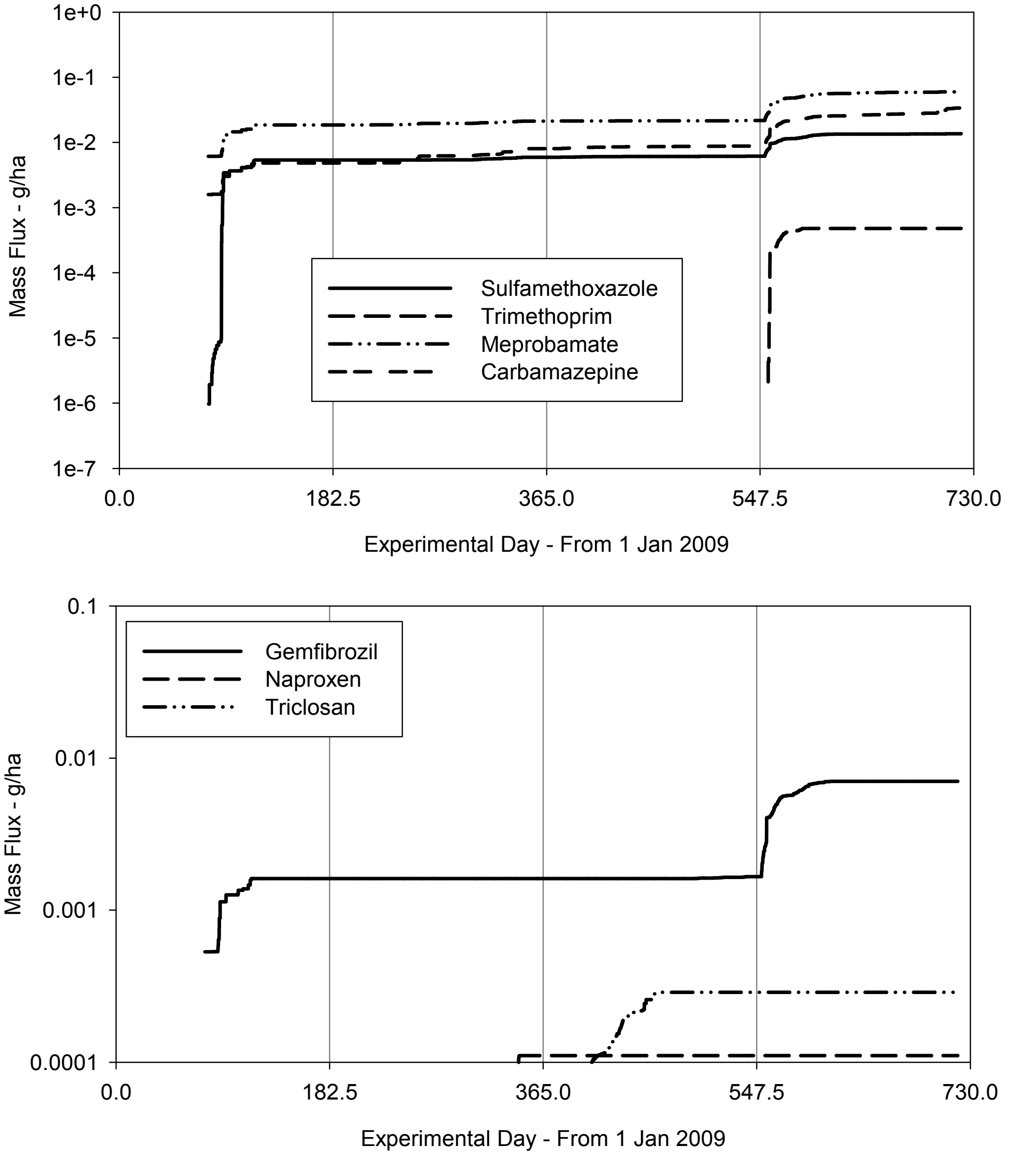
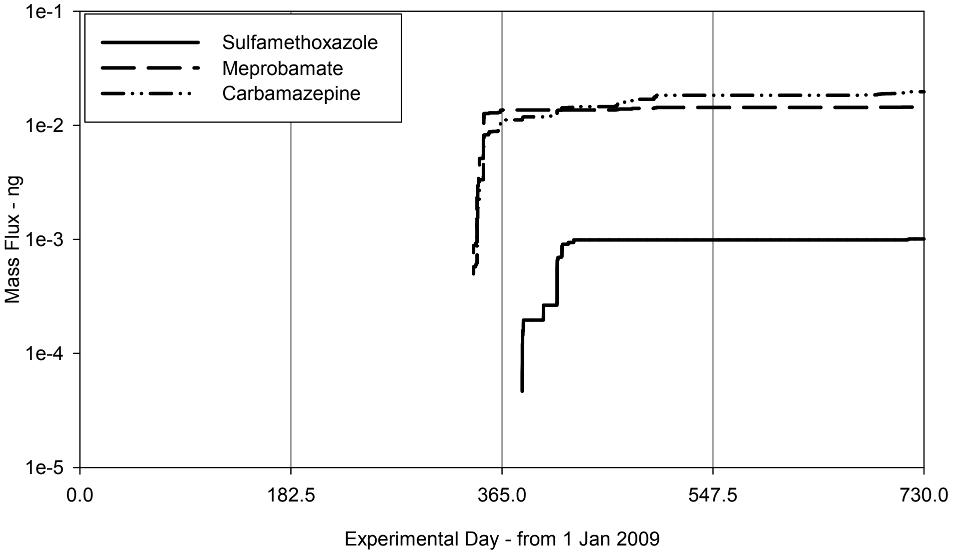


Figure 5-13. Mass Flux of Target Compounds (grams/hectare) at Silver Creek Valley CC.
Multiple charts were used to simplify the presentation.



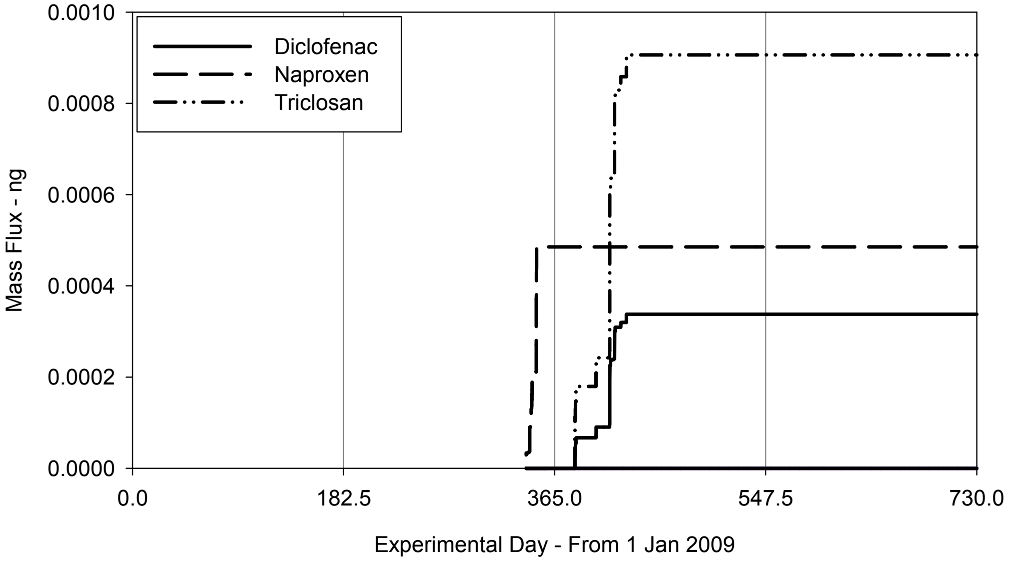


Figure 5-14. Mass Flux of Target Compounds (grams/hectare) at Zaharias GC.
Multiple charts were used to simplify the presentation.

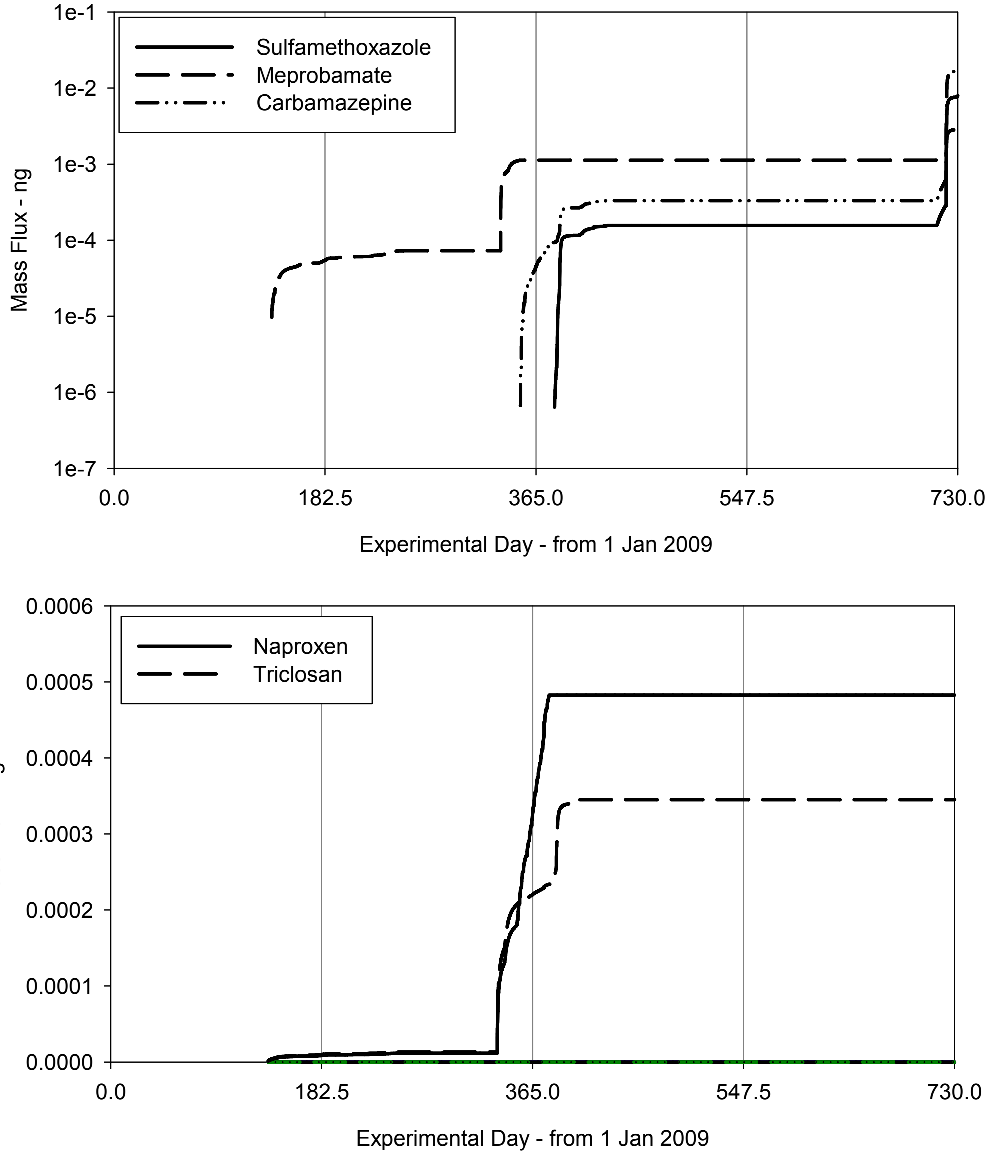


Figure 5-15. Mass Flux of Target Compounds (grams/hectare) at Palm Desert CC.
Multiple charts were used to simplify the presentation.

5.4 Conclusions

The results indicate movement of several PPCPs on the target list beyond a depth 60 cm, which was the thickness of the soil connected to the drain gauges. The two-year field portion of this overall study was sufficiently long to obtain a full year of good data – approximately one year was needed for the system to equilibrate before connections between irrigation/precipitation patterns at ground surface would lead to downward flux of water and target PPCPs. Longer monitoring time frames would allow understanding of the connections to strengthen.

As described in Section 5.3, more than 100 instances of target compounds were detected in the soil water, most of them at Silver Creek Valley CC (though likely some of these hits were the result of short-circuiting of flow around the soil and into the drain gauge). The results indicate that sulfamethoxazole, meprobamate, and carbamazepine were most commonly found in drainage water. The other five compounds that were identified in drainage water occurred between 1 and nine times; four compounds were not detected in any samples.

When water flux was multiplied by concentration, mass flux of compounds is obtained. Mass flux is more appropriate for assessing potential environmental impacts and risks as high concentration with low flux indicates that contaminants are remaining in place in the soil column, not migrating toward receiving waters or impacting the environment. The mass fluxes were converted into units of grams per hectare (g/ha), a more meaningful scale for comparison. The mass fluxes at this scale were all less than 0.1 g/ha, and most were below 0.001 g/ha, indicating a relatively low mass loading away from the turfgrass/soil systems. Potential environmental and human impacts require that these mass fluxes be assessed at the field scale, and at a point where shallow groundwater (typically the receiver for soil water) intersects surface water bodies or shallow pumping wells. Depending on site water management at the golf courses used in this study, shallow ground water could flow back to storage ponds, where the water is again used for irrigation.

Site conditions varied substantially; however, conditions do not span the full gamut of possible combinations of field conditions, and thus extrapolating results to sites outside of this study is conjectural. For example, the golf courses chosen in this study varied primarily by climate (arid to Mediterranean), soil type (sandy to clayey), and depth to groundwater (shallow and deep, relative to the base of the drain gauges). These combinations are shown as:

Wildhorse GC – arid climate, sand/clay loam soil, deep groundwater

Silver Creek Valley CC – Subtropical/Med. climate, clay soil, shallow groundwater

Zaharias GC – Subtropical/Med. climate, sand/clay loam soil, shallow groundwater

Palm Desert CC – arid climate, sandy soil, deep groundwater

A broader study that further varied site conditions, and combined them uniquely would allow more generalizations to be made, though the researchers stress that results are highly site specific, and are particularly connected to irrigation management. The study results showed higher occurrences of compound mass flux at Silver Creek Valley CC than other sites, even though soil had the highest clay content. These results are counter-intuitive (one could predict that clayey soils would limit downward flux) and suggest that compounds are not fully degraded in the soil water before being transported downward from either precipitation or irrigation. It is also likely that the clayey soils, with higher water holding capacity, would maintain a shallower root zone; thus, compounds need to migrate less distance to reduce their exposure to the biological activity in the soil/root environment. Further study would be needed to fully connect retardation and microbial degradation rates as a function of depth at this site, to validate this possibility. The researchers noted that differences in compound breakthrough were not correlated to the wastewater treatment processes, in part because treatment processes were similar (see Table 5-1), and in part given the substantial differences in soil texture, climate and depth to groundwater existing at these four field sites.

The results also indicate a stronger (and perhaps more predictable) connection between mass flux at arid sites, winter rainfall periods and higher irrigation rates needed for overseeding of winter turfgrass. This would be particularly important for soils with very low organic matter or sorption sites. It was noted that the CEC at Palm Desert CC was about 10 times less than that recorded at Silver Creek Valley CC, implying a great potential for rapid downward migration of compounds with large influxes of water from either overseeding activities or above average storm events. Thus, sites in arid climates that deficit irrigate during most the calendar year, but then over-irrigate during winter overseeding and spring revival of summer turfgrass, are more likely to experience larger, more intense, flushes of PPCPs compounds, than those sites that irrigate with positive leaching fractions or that have more evenly distributed precipitation patterns.

Locations with very shallow water tables and sandy-textured soils can benefit from efficient irrigation scheduling practices that minimize the potential negative effects of golf course drainage water discharging into surface or ground waters. The “cycle and soak” features of many irrigation control systems divide the total irrigation runtime into several small application “cycles.” Each of these “cycles” is short enough in duration so that the amount of water applied does not exceed the infiltration rate of the soil. A “soak” time follows each “cycle” application in order to allow the water to completely infiltrate into the soil and avoid runoff into surface water, storm sewers, etc.

CHAPTER 6.0

CONCLUSIONS

This project was unique in that it combined laboratory (bench), meso-, and field-scale experiments of PPCPs fate and transport, using the same target compounds in similar environmental conditions. Several pertinent results were similar across all three scales of interest, which illustrates that the experimental results are relatively independent of scale.

At the laboratory scale (conducted by the University of California, Riverside), most target compounds showed low to moderate sorption in soils. In addition, only a few PPCPs were susceptible to degradation under aerobic conditions, while other target compounds were relatively persistent with half-lives longer than 100 d. The low sorption and long persistence of some PPCPs would suggest a potentially high mobility in sandy soils; therefore, these compounds could pose a risk for groundwater contamination where recycled water is used for irrigation. However, the conditions used in the laboratory experiments are quite different from those in the field. For example, the laboratory experiments used bare soils originating from desert environments that have very low organic matter content. Soil organic matter serves as sorption sites for chemicals and supports microbial diversity and function. In actual turfgrass/soil systems (e.g., golf courses), there is a thatch layer enriched in organic matter. Therefore, microbial activity is enhanced in the root zone, when compared to bare soil. These processes, along with other factors (e.g., sunlight), may accelerate degradation of PPCPs under field conditions, decreasing their leaching potential.

As interest increased from the laboratory-scale to the lysimeter-scale (UNLV), the research team was able to control the conditions of the soil material, while imposing an experimental design that would allow the research team to isolate variables that dominated the fate and transport of target compounds. Though the lysimeters were 120 cm deep, shallower than many other soils, the experimental factors (soil type, soil surface treatment [bare versus turfgrass], and leaching fraction) dominate the factors at typical parks and golf courses where recycled water would be expected to be used. In combination, some of the treatments were closely aligned with “typical” turfgrass environments that are the focus of much of the public concern about recycled water.

As discussed in Chapter 3.0, results from the lysimeter experiment suggest a low mobility of most PPCPs, especially when the soil surface is planted with turfgrass. The experiment did show breakthrough of nine of 14 compounds in the drainage water that after a 745 day period in which leaching fractions were imposed on two different soil types while irrigating with recycled water on both turfgrass and bare soils. Of these compounds, only three revealed a concentration pattern that correlated with the number of unsaturated pore volumes displaced from the soil profile of the lysimeter, namely primidone, sulfamethoxazole, and carbamazepine. However, only primidone revealed a significant mass flux relative to the irrigation load (as high as 30% in the bare loamy sand soil under high leaching fraction). The results showed that each compound was influenced differently, given different combinations of soil type, cover, leaching fraction, and the interactions of these three factors. However, when bare, loamy sand soil was subjected to the higher leaching fraction treatment (considered as “worst-case scenario”), mass flux of target compounds was highest and explainable by the treatments. For example, in the case of primidone, 94% of the variation in the mass flux could be described by the soil conditions – specifically, the number of unsaturated pore volumes drained, the percent sand in the soil, and the average redox potential at the 105 cm depth. These soil conditions are strongly influenced by management practices at the soil surface.

Also of importance is the percentage of compounds leached from the soil, versus the mass applied to the soil through irrigation. For example, although low leaching losses of sulfamethoxazole were reported, they need to be assessed relative to the irrigation mass loading. Here, concentrations in irrigation water averaged over 1600 ng/L, which was four times higher than any other compound (Table 3-3). When scaled to the hectare, highest leaching losses averaged 0.254 g per year. This mass flux was higher than any other compound, and was almost three times higher than the highest estimate for primidone. Unfortunately, knowing the concentration of these target compounds in irrigation water or in the drainage water, were poor predictors of mass discharge from the root zone, which is vital for any environmental assessment of PPCPs. As shown earlier, soil conditions and irrigation management are the main driving forces behind the drainage concentration and rates of mass discharge.

As the scale increased to the meso-scale with controlled turfgrass plots in Riverside, California, the results clearly showed that most PPCPs did not appear in the drainage water when sandy loam and loamy sand plots were irrigated exclusively with recycled water for six months at relatively high irrigation rates (leaching fractions of 1.00 and 1.30). Target PPCPs were invariably present in the recycled water. Therefore, the absence of most of the target PPCPs in the drainage water suggested complete removal. However, trimethoprim and primidone did frequently appear in the drainage water for both soil types and at both irrigation rates. After accounting for leaching fraction, mass removal of all PPCPs still exceeded 80%. Meso-scale conditions used in this study are viewed as being worst-case scenarios by the researchers. This was because the irrigation rates were high in comparison to normal practices, the soil texture was very sandy, and the drainage water collection depth (90 cm) represented an extremely shallow groundwater table. The actual mass fluxes for PPCPs would likely have been lower with deeper drainage water collection, as it would provide longer contact time for PPCPs to be sorbed and degraded in the soil profile. Therefore, using these meso-scale lysimeters under normal field conditions, it was demonstrated that turfgrass/soil systems effectively filtered out most PPCPs from recycled water irrigation, despite the persistence of many PPCPs and the weak sorption capacity of the soil.

The field-scale experiments were conducted at active golf courses. In general, sulfamethoxazole, meprobamate, and carbamazepine were the PPCPs most commonly found in drainage water. The other five compounds that were identified in drainage water occurred far less frequently. Four compounds were not detected in any samples. Because of slight differences in compounds analyzed at the University of California, Riverside and SNWA, primidone was not measured in any samples obtained from the golf courses. However, similar to the results obtained at the laboratory- and meso-scale experiments, of the compounds tested, sulfamethoxazole and carbamezapine were most commonly found. Also similar between scales in this project were the mass fluxes measured in drainage waters. For example, as the concentrations of samples taken from the drain gauges were normalized to the hectare scale, fluxes found for all compounds were less than 0.1 g/ha (noting that almost all of the fluxes were recorded during the second year of the field monitoring). No differences in compound breakthrough could be correlated to the wastewater treatment processes, in part because the processes were quite similar (Table 5-1), and in part given the substantial differences in soil texture, climate and depth to groundwater existing at these four field sites.

Ultimately, environmental and human impacts are less likely to occur if drainage water remains onsite after downward transport beyond the rootzone. Therefore, site water management at facilities using recycled water is vital. In the case of the Wildhorse GC site, compounds were found in groundwater samples collected from a well installed adjacent to the drainage gauges, the researchers cannot determine whether the compounds were from sources offsite from Wildhorse, or from the golf course itself. Although small amounts of PPCPs were detected in drainage water in this study, they can be further reduced by imposing low leaching fractions and avoiding high sand content soils.

Finally, this project, as broad as it was with respect to spatial scaling, did not fully deal with the significant spatial variability of soil properties and conditions known to exist at the field scale. One path forward would be to further investigate differences in treatments and how they translate to potential mass flux, and then to translate those findings in the best management practices that will minimize, to the extent possible, release of these compounds to the environment. The research team believes using recycled water for irrigation purposes is recommended, while implementing sound, science-based irrigation management practices. It would allow communities to extend their water resources while minimizing the unintended discharge into aquatic systems where elevated PPCPs have already been documented to cause problems (Santos et al., 2010).

6.1 Future Research Needs

Based on research findings from this project, the following additional studies are proposed for future investigations:

- A study to assess the uptake of PPCPs into plant foliage from recycled water irrigation would determine how or if the cover plants significantly absorb these compounds as a removal pathway. For food crops, especially vegetables or fruits that are consumed raw, measurement of plant accumulation would provide baseline information for future human risk assessment.
- Longer time frames for field monitoring studies would allow for equilibration of soil inside the various equipment devices and a more accurate understanding of chemical fluxes. Compounds such as sulfamethoxazole, carbamazepine, meprobamate, and primidone should be targeted as the primary PPCPs for future field monitoring efforts due to their high mobility.
- To better understand leaching risks of PPCPs, researchers should consider closer monitoring of irrigation management on golf courses (or other field sites). Collecting water application, site-specific evapotranspiration data; measuring irrigation distribution uniformity; measuring infiltration rates; and, accurately accounting for any hand watering in and around field equipment sites.
- Leaching behaviors of PPCPs will vary with site and management-specific conditions. Therefore, future studies should use a range of field sites differing in soil textures, groundwater table depths, and different management practices.

APPENDIX A

AVERAGES, STANDARD DEVIATION, AND COEFFICIENT OF VARIANCE FOR REDOX AT 15 AND 105 CM FOR ALL MEASUREMENTS AND AFTER DOWNWARD SHIFT AND STABILIZATION

All Lysimeter	15 cm Average	SD	CV	After Stabilization Lysimeter	15 cm Average	SD	CV
8	567.20	61.57	0.11	8	567.20	61.57	0.11
11	569.63	59.04	0.10	11	569.63	59.04	0.10
14	572.17	79.60	0.14	14	572.17	79.60	0.14
1	283.20	229.10	0.81	1	96.85	106.70	1.10
10	475.40	82.63	0.17	10	448.40	92.35	0.21
12	350.14	194.38	0.56	12	219.53	162.77	0.74
6	527.12	74.88	0.14	6	527.12	74.88	0.14
9	356.93	194.77	0.55	9	356.93	194.77	0.55
22	536.23	73.91	0.14	22	536.23	73.91	0.14
13	349.93	151.34	0.43	13	243.23	104.43	0.43
21	286.34	203.38	0.71	21	126.42	88.55	0.70
24	273.61	199.84	0.73	24	111.93	66.37	0.59
2	554.60	60.03	0.11	2	554.60	60.03	0.11
4	241.87	191.71	0.79	4	128.30	128.55	1.00
7	585.15	87.40	0.15	7	585.15	87.40	0.15
15	260.19	230.67	0.89	15	71.28	76.87	1.08
18	323.89	117.66	0.36	18	234.71	49.51	0.21
23	270.09	187.14	0.69	23	124.39	84.73	0.68

16	552.30	98.70	0.18	16	552.30	98.70	0.18
19	535.91	78.13	0.15	19	535.91	78.13	0.15
20	544.77	64.69	0.12	20	544.77	64.69	0.12
3	474.51	176.45	0.37	3	408.48	206.31	0.51
5	276.03	227.62	0.82	5	86.91	50.71	0.58
17	441.39	169.23	0.38	17	396.87	208.87	0.53

SD = Standard Deviation

CV = Coefficient of Variation

APPENDIX A (continued)

All Lysimeter	105 cm Average	SD	CV	After Stabilization Lysimeter	105 cm Average	SD	CV
8	190.62	255.96	1.34	8	31.73	106.62	3.36
11	147.36	115.00	0.78	11	75.09	53.70	0.72
14	558.35	85.60	0.15	14	563.15	96.94	0.17
1	190.75	138.06	0.72	1	154.16	72.18	0.47
10	79.99	113.86	1.42	10	71.02	106.17	1.50
12	510.84	179.46	0.35	12	538.99	97.54	0.18
6	551.27	116.31	0.21	6	551.27	116.31	0.21
9	512.99	140.21	0.27	9	512.99	140.21	0.27
22	367.58	180.82	0.49	22	384.91	172.18	0.45
13	319.35	192.48	0.60	13	176.01	128.25	0.73
21	393.06	151.93	0.39	21	424.58	103.69	0.24
24	289.11	204.11	0.71	24	126.22	70.77	0.56
2	368.51	171.60	0.47	2	368.51	171.60	0.47
4	408.95	106.95	0.26	4	408.95	106.95	0.26
7	384.44	147.88	0.38	7	414.44	109.43	0.26
15	312.37	106.29	0.34	15	312.37	106.29	0.34
18	178.27	57.76	0.32	18	178.27	57.76	0.32
23	117.20	101.99	0.87	23	117.20	101.99	0.87
16	43.06	232.39	5.40	16	-57.39	110.05	-1.92
19	-86.54	205.41	-2.37	19	-160.61	115.81	-0.72
20	-9.87	226.91	-23.00	20	-107.40	104.90	-0.98
3	-19.15	242.28	-12.65	3	-128.50	76.26	-0.59
5	2.64	241.56	91.48	5	-109.07	78.37	-0.72
17	107.99	179.99	1.67	17	55.02	133.71	2.43

SD = Standard Deviation

CV = Coefficient of Variation

APPENDIX B

DRAINAGE SAMPLE PHARMACEUTICAL ANALYSIS IN NG/L

ALL – INDICATES AVERAGE OF ALL SAMPLES FROM LYSIMETER WITH THOSE LESS THEN REPORTABLE LIMIT AS ZERO,
DETECT – INDICATES AVERAGE ONLY FROM SAMPLES GREATER THEN REPORTABLE LIMIT

0.05 bare loamy sand			**Lysimeter 8**						**Lysimeter 11**						**Lysimeter 14**			
	Average		**SD**		**CV**		**Average**		**SD**		**CV**		**Average**		**SD**		**CV**	
Analyte	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**
Carbamazepine	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	10.23	<RL	N/A	<RL	N/A
Diazepam	<RL	<RL	<RL	<RL	<RL	<RL	4.43	15.52	7.57	0.59	1.71	0.04	<RL	<RL	<RL	<RL	<RL	<RL
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	2.92	20.43	7.72	N/A	2.65	N/A	9.60	21.44	16.06	N/A	1.67	N/A
Dilantin	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	5.80	<RL	N/A	<RL	N/A
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	2.14	14.99	5.67	N/A	2.65	N/A	<RL	7.64	<RL	2.34	<RL	0.31
Naproxen	5.25	15.74	9.09	N/A	1.73	N/A	8.03	28.12	15.04	15.07	1.87	0.54	2.17	<RL	5.32	<RL	2.45	<RL
Primidone	7.05	10.58	7.57	6.32	1.07	0.60	15.70	18.31	13.83	13.11	0.88	0.72	14.69	13.32	10.31	8.42	0.70	0.63
Sulfamethoxazole	1.77	5.31	3.07	N/A	1.73	N/A	67.29	67.29	82.56	82.56	1.23	1.23	35.27	129.44	28.19	121.40	0.80	0.94
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	21.70	151.88	57.41	N/A	2.65	N/A	<RL	<RL	<RL	<RL	<RL	<RL

0.05 turf loamy sand			**Lysimeter 1**						**Lysimeter 10**						**Lysimeter 12**			
	Average		**SD**		**CV**		**Average**		**SD**		**CV**		**Average**		**SD**		**CV**	
Analyte	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**
Carbamazepine	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diazepam	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	21.28	28.37	18.85	15.21	0.89	0.54
Diclofenac	9.60	28.79	16.06	13.59	1.67	0.47	<RL	<RL	<RL	<RL	<RL	<RL	10.94	21.88	12.64	0.59	1.16	0.03
Dilantin	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Naproxen	2.17	13.03	5.32	N/A	2.45	N/A	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Primidone	14.69	17.63	10.31	8.26	0.70	0.47	16.40	16.40	7.81	7.81	0.48	0.48	17.49	23.32	14.42	10.40	0.82	0.45
Sulfamethoxazole	35.27	52.90	28.19	8.97	0.80	0.17	22.97	68.91	39.79	N/A	1.73	N/A	20.07	40.15	23.34	4.74	1.16	0.12
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL

Atenolol, Atorvastatin, Fluoxetine, Gemfibrozil, Ibuprofen, and Trimethoprim not shown due to consistent <RL for all lysimeter.

N/A = not applicable, <RL = less then reportable limits, SD = Standard Deviation, CV = Coefficient of Variation

APPENDIX B (continued)

0.25 bare loamy sand	Lysimeter 6						Lysimeter 9						Lysimeter 22					
	Average		SD		CV		Average		SD		CV		Average		SD		CV	
Analyte	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect
Carbamazepine	9.56	22.95	19.95	26.65	2.09	1.16	<RL	<RL	<RL	<RL	<RL	<RL	18.89	42.51	27.25	25.33	1.44	0.60
Diazepam	6.23	12.46	7.78	6.32	1.25	0.51	1.95	15.56	5.50	N/A	2.83	N/A	<RL	<RL	<RL	<RL	<RL	<RL
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	3.48	13.94	6.97	6.99	2.00	0.50	<RL	<RL	<RL	<RL	<RL	<RL
Dilantin	0.63	7.60	2.19	N/A	3.46	N/A	1.50	6.00	2.79	0.71	1.86	0.12	2.86	6.43	3.44	0.92	1.20	0.14
Meprobamate	0.50	5.96	1.72	N/A	3.46	N/A	2.46	9.85	5.07	5.87	2.06	0.60	14.66	32.99	22.08	22.22	1.51	0.67
Naproxen	<RL	<RL	<RL	<RL	<RL	<RL	3.08	24.66	N/A	N/A	N/A	N/A	8.03	36.14	16.97	16.50	2.11	0.46
Primidone	17.61	21.13	12.62	10.58	0.72	0.50	11.70	23.40	12.67	3.15	1.08	0.13	15.02	19.31	10.43	6.96	0.69	0.36
Sulfamethoxazole	30.44	45.65	37.96	38.34	1.25	0.84	33.64	53.82	43.66	44.47	1.30	0.83	48.44	62.28	70.03	74.38	1.45	1.19
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	1.29	11.65	3.88	N/A	3.00	N/A

0.05 turf loamy sand	Lysimeter 13						Lysimeter 21						Lysimeter 24					
	Average		SD		CV		Average		SD		CV		Average		SD		CV	
Analyte	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect
Diazepam	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	4.69	12.89	6.83	3.79	1.46	0.29	4.11	10.28	5.49	2.41	1.33	0.23
Dilantin	1.12	8.93	3.16	N/A	2.83	N/A	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Naproxen	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	6.49	32.47	15.14	19.38	2.33	0.60
Primidone	15.09	20.12	11.77	8.52	0.78	0.42	14.66	20.16	13.98	12.34	0.95	0.61	13.37	19.10	9.55	3.00	0.71	0.16
Sulfamethoxazole	15.64	20.85	15.97	15.06	1.02	0.72	20.20	24.69	20.66	20.21	1.02	0.82	17.32	21.65	14.59	12.90	0.84	0.60
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL

Atenolol, Atorvastatin, Fluoxetine, Gemfibrozil, Ibuprofen, and Trimethoprim not shown due to consistent <RL for all lysimeter.

N/A = not applicable, <RL = less then reportable limits, SD = Standard Deviation, CV = Coefficient of Variation

APPENDIX B (continued)

0.05 turf sandy loam	Lysimeter 15						Lysimeter 18						Lysimeter 23					
	Average		SD		CV		Average		SD		CV		Average		SD		CV	
Analyte	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect
Carbamazepine	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diazepam	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	3.88	7.76	4.68	2.31	1.20	0.30
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	37.96	75.93	44.46	12.91	1.17	0.17
Dilantin	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Naproxen	11.31	33.93	19.59	N/A	1.73	N/A	<RL	<RL	<RL	<RL	<RL	<RL	6.45	25.80	12.90	N/A	2.00	N/A
Primidone	5.39	16.16	9.33	N/A	1.73	N/A	<RL	<RL	<RL	<RL	<RL	<RL	3.70	14.78	7.39	N/A	2.00	N/A
Sulfamethoxazole	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	5.44	21.75	10.87	N/A	2.00	N/A
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL

0.05 bare sandy loam	Lysimeter 2						Lysimeter 4						Lysimeter 7					
	Average		SD		CV		Average		SD		CV		Average		SD		CV	
Analyte	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect	All	Detect
Carbamazepine	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diazepam	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	8.91	17.81	12.60	N/A	1.41	N/A
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Dilantin	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	3.84	7.67	5.43	N/A	1.41	N/A
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Naproxen	<RL	<RL	<RL	<RL	<RL	<RL	30.91	61.83	36.74	15.09	1.19	0.24	<RL	<RL	<RL	<RL	<RL	<RL
Primidone	3.41	13.6	6.81	N/A	2.00	N/A	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Sulfamethoxazole	1.38	5.5	2.75	N/A	2.00	N/A	<RL	<RL	<RL	<RL	<RL	<RL	39.02	78.05	55.19	N/A	1.41	N/A
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	36.09	144.37	72.19	N/A	2.00	N/A	<RL	<RL	<RL	<RL	<RL	<RL

Atenolol, Atorvastatin, Fluoxetine, Gemfibrozil, Ibuprofen, and Trimethoprim not shown due to consistent <RL for all lysimeter.

N/A = not applicable, <RL = less then reportable limits, SD = Standard Deviation, CV = Coefficient of Variation

APPENDIX B (continued)

0.25 bare sandy loam	**Lysimeter 16**						**Lysimeter 19**						**Lysimeter 20**					
	Average		**SD**		**CV**		**Average**		**SD**		**CV**		**Average**		**SD**		**CV**	
Analyte	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**
Carbamazepine	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diazepam	2.05	7.18	3.51	0.45	1.71	0.06	1.76	12.33	4.66	N/A	2.65	N/A	<RL	<RL	<RL	<RL	<RL	<RL
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	13.07	78.43	32.02	N/A	2.45	N/A
Dilantin	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Naproxen	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	1.05	6.30	2.57	N/A	2.45	N/A
Primidone	<RL	<RL	<RL	<RL	<RL	<RL	4.73	11.03	5.92	0.89	1.25	0.08	0.85	5.13	2.09	N/A	2.45	N/A
Sulfamethoxazole	4.22	14.77	7.34	3.45	1.74	0.23	95.91	223.80	247.51	375.30	2.58	1.68	8.05	48.30	19.72	N/A	2.45	N/A
Triclosan	2.16	15.11	5.71	N/A	2.65	N/A	17.74	62.10	30.55	9.51	1.72	0.15	<RL	<RL	<RL	<RL	<RL	<RL

0.25 turf sandy loam	**Lysimeter 3**						**Lysimeter 5**						**Lysimeter 17**					
	Average		**SD**		**CV**		**Average**		**SD**		**CV**		**Average**		**SD**		**CV**	
Analyte	**All**	**Detect**	**All**	**Detect**	All	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	**All**	**Detect**	All	**Detect**
Carbamazepine	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diazepam	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Diclofenac	<RL	<RL	<RL	<RL	<RL	<RL	37.16	74.32	58.93	67.37	1.59	0.91	19.95	46.54	30.60	30.86	1.53	0.66
Dilantin	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Meprobamate	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Naproxen	<RL	<RL	<RL	<RL	<RL	<RL	3.02	18.10	7.39	N/A	2.45	N/A	20.45	71.56	47.86	80.15	2.34	1.12
Primidone	3.55	8.87	4.86	0.18	1.37	0.02	3.69	11.08	5.85	2.72	1.58	0.25	1.60	5.61	2.76	0.73	1.72	0.13
Sulfamethoxazole	1.10	5.48	2.45	N/A	2.24	N/A	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL	<RL
Triclosan	<RL	<RL	<RL	<RL	<RL	<RL	5.07	30.4	12.41	<RL	2.45	<RL	<RL	<RL	<RL	<RL	<RL	<RL

Atenolol, Atorvastatin, Fluoxetine, Gemfibrozil, Ibuprofen, and Trimethoprim not shown due to consistent <RL for all lysimeter.

N/A = not applicable, <RL = less then reportable limits, SD = Standard Deviation, CV = Coefficient of Variation

APPENDIX C

PHARMACEUTICAL MASS BALANCE (μG) FOR DRAINAGE SAMPLES

0.05 Bare Loamy Sand	Analyte	Average (μg)	SD (μg)	CV
	Carbamazepine	0.11	0.19	1.73
	Diazepam	0.11	0.19	1.73
	Diclofenac	0.36	0.34	0.96
	Dilantin	0.10	0.17	1.73
	Meprobamate	0.50	0.45	0.91
	Naproxen	0.37	0.40	1.09
	Primidone	1.53	1.20	0.78
	Sulfamethoxazole	4.98	4.38	0.88
	Triclosan	0.56	0.97	1.73

0.05 Turf Loamy Sand	Analyte	Average (μg)	SD (μg)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	0.37	0.64	1.73
	Diclofenac	0.53	0.47	0.88
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	<RL	<RL	<RL
	Primidone	2.60	1.13	0.44
	Sulfamethoxazole	5.50	1.73	0.31
	Triclosan	<RL	<RL	<RL

0.25 Bare Loamy Sand	Analyte	Average (μg)	SD (μg)	CV
	Carbamazepine	1.58	1.62	1.03
	Diazepam	0.82	1.14	1.39
	Diclofenac	0.29	0.51	1.73
	Dilantin	0.64	0.45	0.70
	Meprobamate	2.45	3.42	1.40
	Naproxen	0.37	0.32	0.87
	Primidone	5.77	1.05	0.18
	Sulfamethoxazole	14.91	5.33	0.36
	Triclosan	0.23	0.40	1.73

0.25 Turf Loamy Sand	Analyte	Average (μg)	SD (μg)	CV
	Carbamazepine	5.91	1.38	0.23
	Diazepam	<RL	<RL	<RL
	Diclofenac	0.94	0.86	0.91
	Dilantin	0.12	0.21	1.73
	Meprobamate	<RL	<RL	<RL
	Naproxen	0.33	0.58	1.73
	Primidone	6.01	0.86	0.14
	Sulfamethoxazole	7.69	1.28	0.17
	Triclosan	<RL	<RL	<RL

APPENDIX C (continued)

0.05 Bare Sandy Loam	Analyte	Average (µg)	SD (µg)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	0.10	0.17	1.73
	Diclofenac	<RL	<RL	<RL
	Dilantin	0.04	0.07	1.73
	Meprobamate	<RL	<RL	<RL
	Naproxen	1.58	2.74	1.73
	Primidone	0.01	0.03	1.73
	Sulfamethoxazole	0.43	0.74	1.73
	Triclosan	0.77	1.33	1.73

0.05 Turf Sandy Loam	Analyte	Average (µg)	SD (µg)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	0.05	0.08	1.73
	Diclofenac	0.54	0.94	1.73
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	0.34	0.53	1.58
	Primidone	0.03	0.03	1.04
	Sulfamethoxazole	0.11	0.20	1.73
	Triclosan	<RL	<RL	<RL

0.25 Bare Sandy Loam	Analyte	Average (µg)	SD (µg)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	0.18	0.17	0.90
	Diclofenac	0.09	0.16	1.73
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	0.06	0.11	1.73
	Primidone	0.38	0.55	1.43
	Sulfamethoxazole	5.21	6.92	1.33
	Triclosan	0.90	0.91	1.02

0.25 Turf Sandy Loam	Analyte	Average (µg)	SD (µg)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	<RL	<RL	<RL
	Diclofenac	2.81	2.46	0.88
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	0.65	0.75	1.15
	Primidone	0.47	0.18	0.37
	Sulfamethoxazole	0.33	0.58	1.73
	Triclosan	0.27	0.47	1.73

SD = Standard Deviation

CV = Coefficient of Variation

APPENDIX D

PHARMACEUTICAL MASS BALANCE (G) FOR DRAINAGE SAMPLES OVER 1 HECTARE PER YEAR

0.05 Bare Loamy Sand	**Analyte**	**Average (g)**	**SD (g)**	**CV**
	Carbamazepine	1.84E-03	3.19E-03	1.73
	Diazepam	1.83E-03	3.17E-03	1.73
	Diclofenac	6.07E-03	5.81E-03	0.96
	Dilantin	1.67E-03	2.90E-03	1.73
	Meprobamate	8.50E-03	7.70E-03	0.91
	Naproxen	6.24E-03	6.83E-03	1.09
	Primidone	2.60E-02	2.04E-02	0.78
	Sulfamethoxazole	8.49E-02	7.47E-02	0.88
	Triclosan	9.57E-03	1.66E-02	1.73
0.05 Turf Loamy Sand	**Analyte**	**Average (g)**	**SD (g)**	**CV**
	Carbamazepine	<RL	<RL	<RL
	Diazepam	6.28E-03	1.09E-02	1.73
	Diclofenac	9.02E-03	7.96E-03	0.88
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	<RL	<RL	<RL
	Primidone	4.43E-02	1.93E-02	0.44
	Sulfamethoxazole	9.36E-02	2.94E-02	0.31
	Triclosan	<RL	<RL	<RL
0.25 Bare Loamy Sand	**Analyte**	**Average (g)**	**SD (g)**	**CV**
	Carbamazepine	2.68E-02	2.75E-02	1.03
	Diazepam	1.39E-02	1.94E-02	1.39
	Diclofenac	4.98E-03	8.62E-03	1.73
	Dilantin	1.09E-02	7.62E-03	0.70
	Meprobamate	4.18E-02	5.83E-02	1.40
	Naproxen	6.24E-03	5.42E-03	0.87
	Primidone	9.83E-02	1.79E-02	0.18
	Sulfamethoxazole	2.54E-01	9.08E-02	0.36
	Triclosan	3.89E-03	6.74E-03	1.73
0.25 Turf Loamy Sand	**Analyte**	**Average (g)**	**SD (g)**	**CV**
	Carbamazepine	1.01E-01	2.35E-02	0.23
	Diazepam	<RL	<RL	<RL
	Diclofenac	1.60E-02	1.46E-02	0.91
	Dilantin	2.09E-03	3.63E-03	1.73
	Meprobamate	<RL	<RL	<RL
	Naproxen	5.69E-03	9.85E-03	1.73
	Primidone	1.02E-01	1.47E-02	0.14
	Sulfamethoxazole	1.31E-01	2.17E-02	0.17
	Triclosan	<RL	<RL	<RL

APPENDIX D (continued)

0.05 Bare Sandy Loam	Analyte	Average (g)	SD (g)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	1.66E-03	2.88E-03	1.73
	Diclofenac	<RL	<RL	<RL
	Dilantin	7.17E-04	1.24E-03	1.73
	Meprobamate	<RL	<RL	<RL
	Naproxen	2.69E-02	4.66E-02	1.73
	Primidone	2.52E-04	4.37E-04	1.73
	Sulfamethoxazole	7.29E-03	1.26E-02	1.73
	Triclosan	1.31E-02	2.26E-02	1.73

0.05 Turf Sandy Loam	Analyte	Average (g)	SD (g)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	7.78E-04	1.35E-03	1.73
	Diclofenac	9.21E-03	1.60E-02	1.73
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	5.77E-03	9.10E-03	1.58
	Primidone	5.33E-04	5.52E-04	1.04
	Sulfamethoxazole	1.93E-03	3.34E-03	1.73
	Triclosan	<RL	<RL	<RL

0.25 Bare Sandy Loam	Analyte	Average (g)	SD (g)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	3.14E-03	2.83E-03	0.90
	Diclofenac	1.54E-03	2.67E-03	1.73
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	1.06E-03	1.83E-03	1.73
	Primidone	6.53E-03	9.35E-03	1.43
	Sulfamethoxazole	8.88E-02	1.18E-01	1.33
	Triclosan	1.53E-02	1.56E-02	1.02

0.25 Turf Sandy Loam	Analyte	Average (g)	SD (g)	CV
	Carbamazepine	<RL	<RL	<RL
	Diazepam	<RL	<RL	<RL
	Diclofenac	4.78E-02	4.19E-02	0.88
	Dilantin	<RL	<RL	<RL
	Meprobamate	<RL	<RL	<RL
	Naproxen	1.11E-02	1.27E-02	1.15
	Primidone	8.09E-03	3.01E-03	0.37
	Sulfamethoxazole	5.66E-03	9.81E-03	1.73
	Triclosan	4.62E-03	8.00E-03	1.73

<RL = less then reportable limits

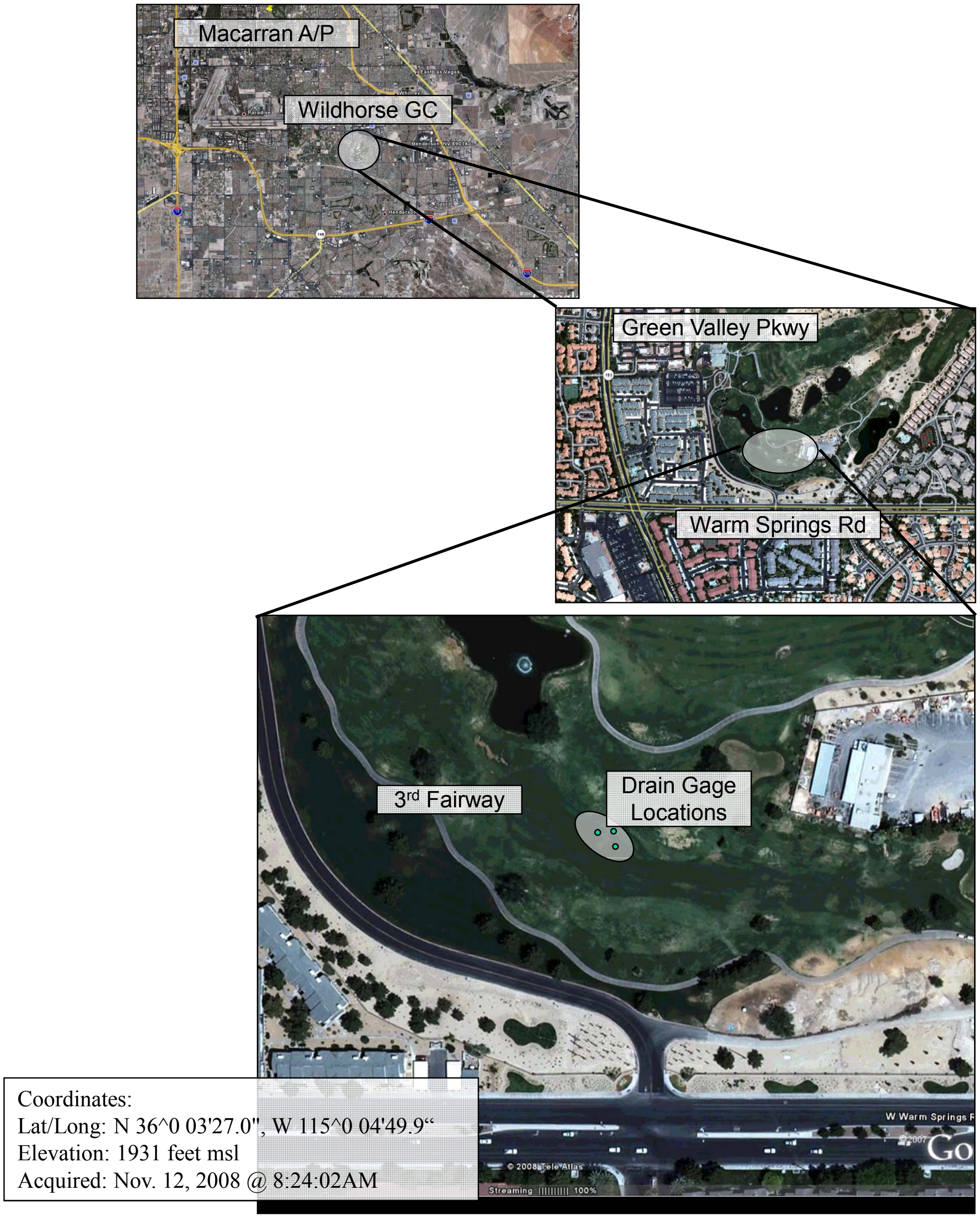
<RL for replicate calculated as zero for average and standard deviation

SD = Standard Deviation, CV = Coefficient of Variation

APPENDIX E

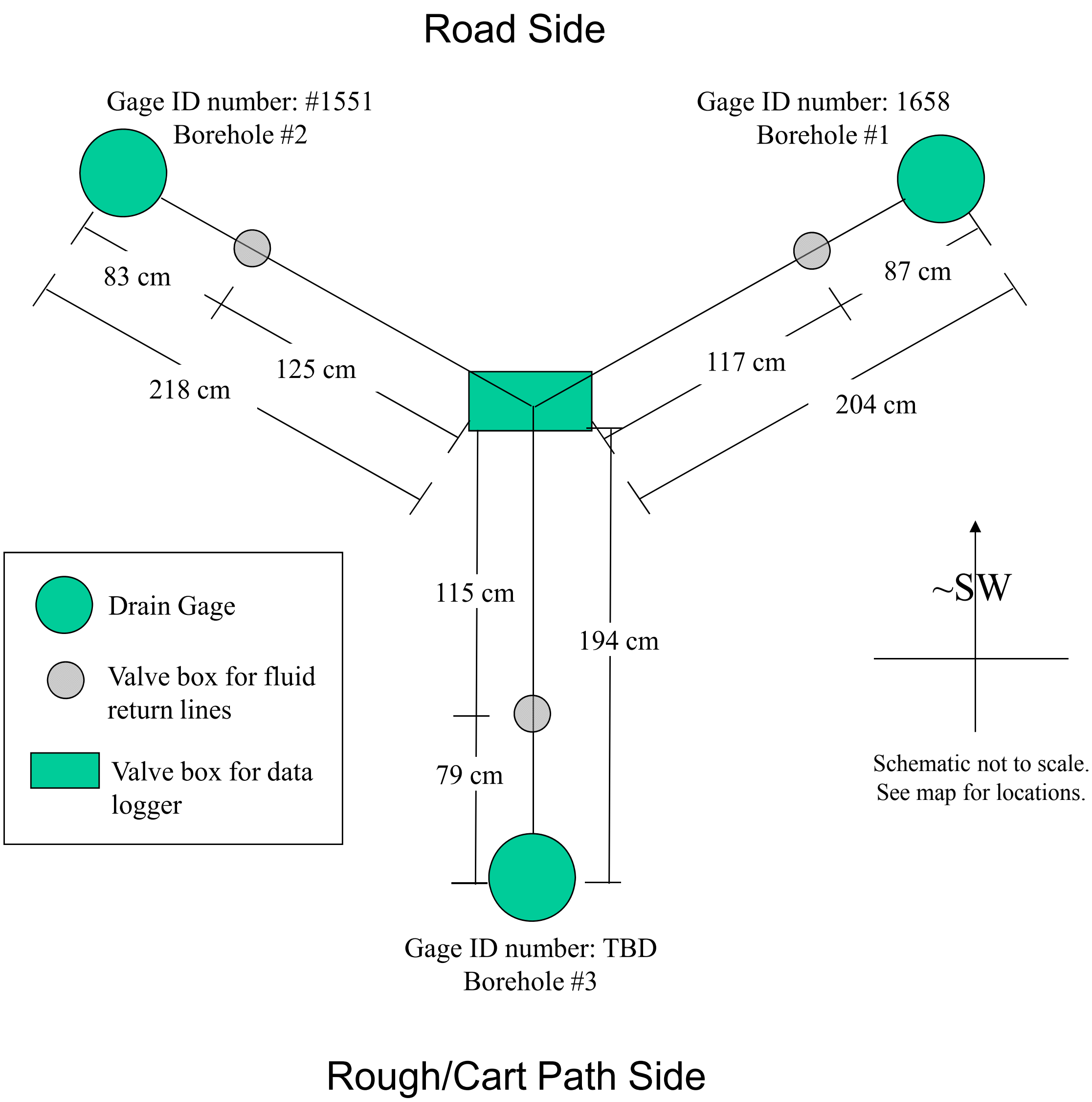
LOCATION MAPS AND INSTALLATION SCHEMATICS

Location of Wildhorse GC and Drain Gauges



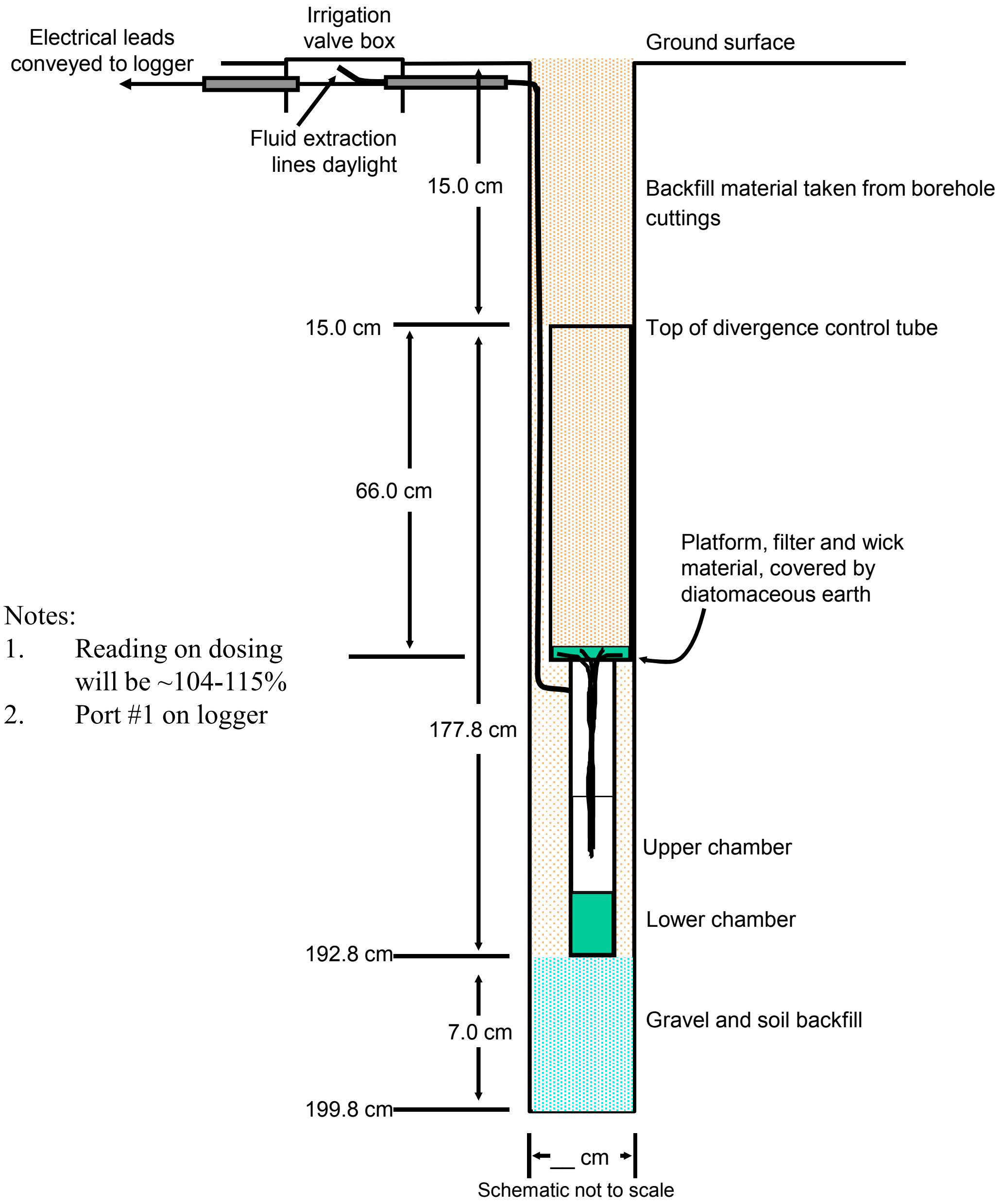
Coordinates:
Lat/Long: N 36^0 03'27.0", W 115^0 04'49.9“
Elevation: 1931 feet msl
Acquired: Nov. 12, 2008 @ 8:24:02AM

Drain gauge installation schematic - Map View



Date: 12 November 2008 Site: Wildhorse GC
Personnel: Young, Healey, Devitt, Meyer, Wright

Drain gauge installation schematic: #1658 (BH #1)



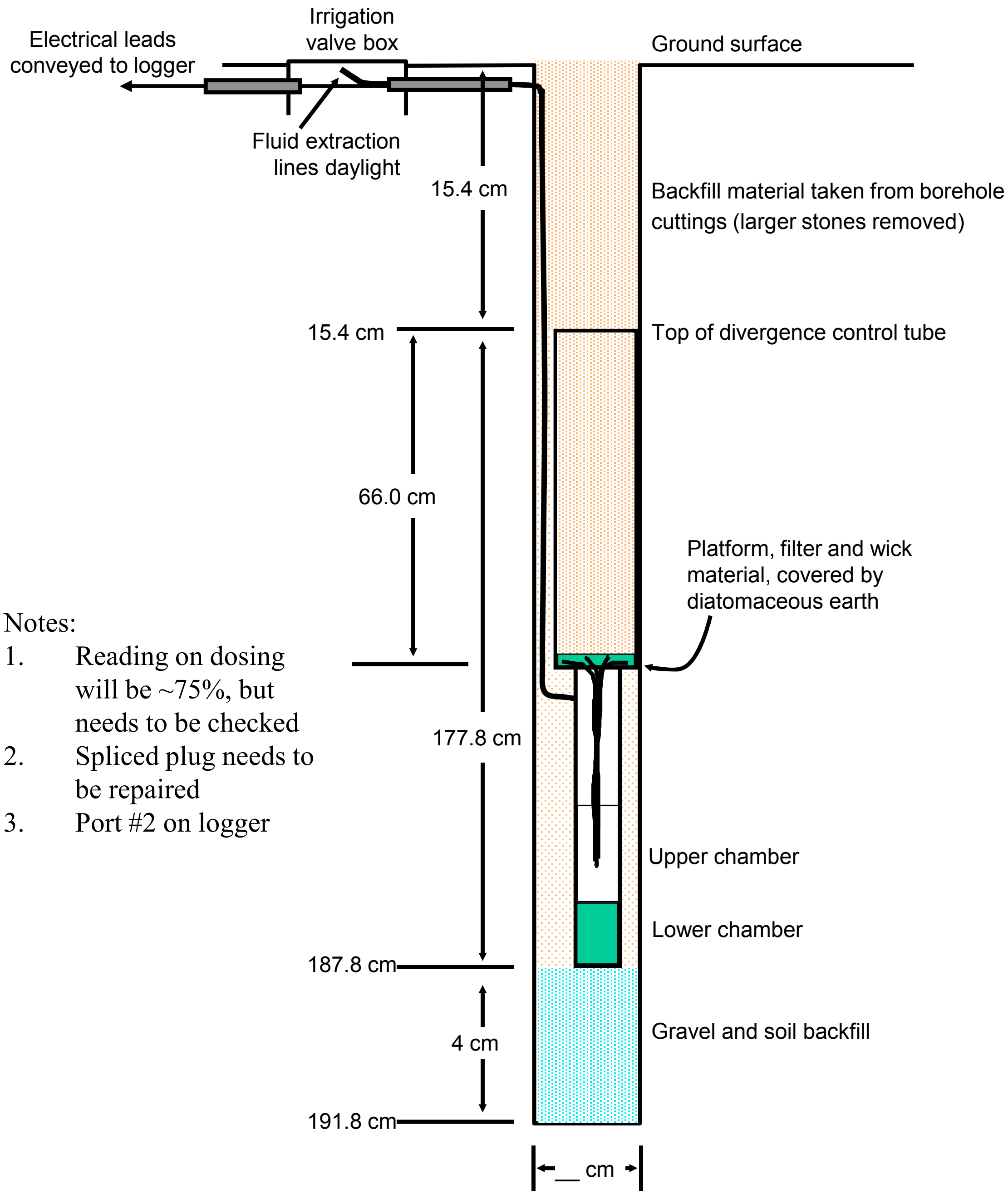
Notes:

1. Reading on dosing will be ~104-115%
2. Port #1 on logger

Date: 12 November 2008 Site: Wildhorse GC

Personnel: Young, Healey, Devitt, Meyer, Wright

Drain gauge installation schematic: #1551 (BH #2)

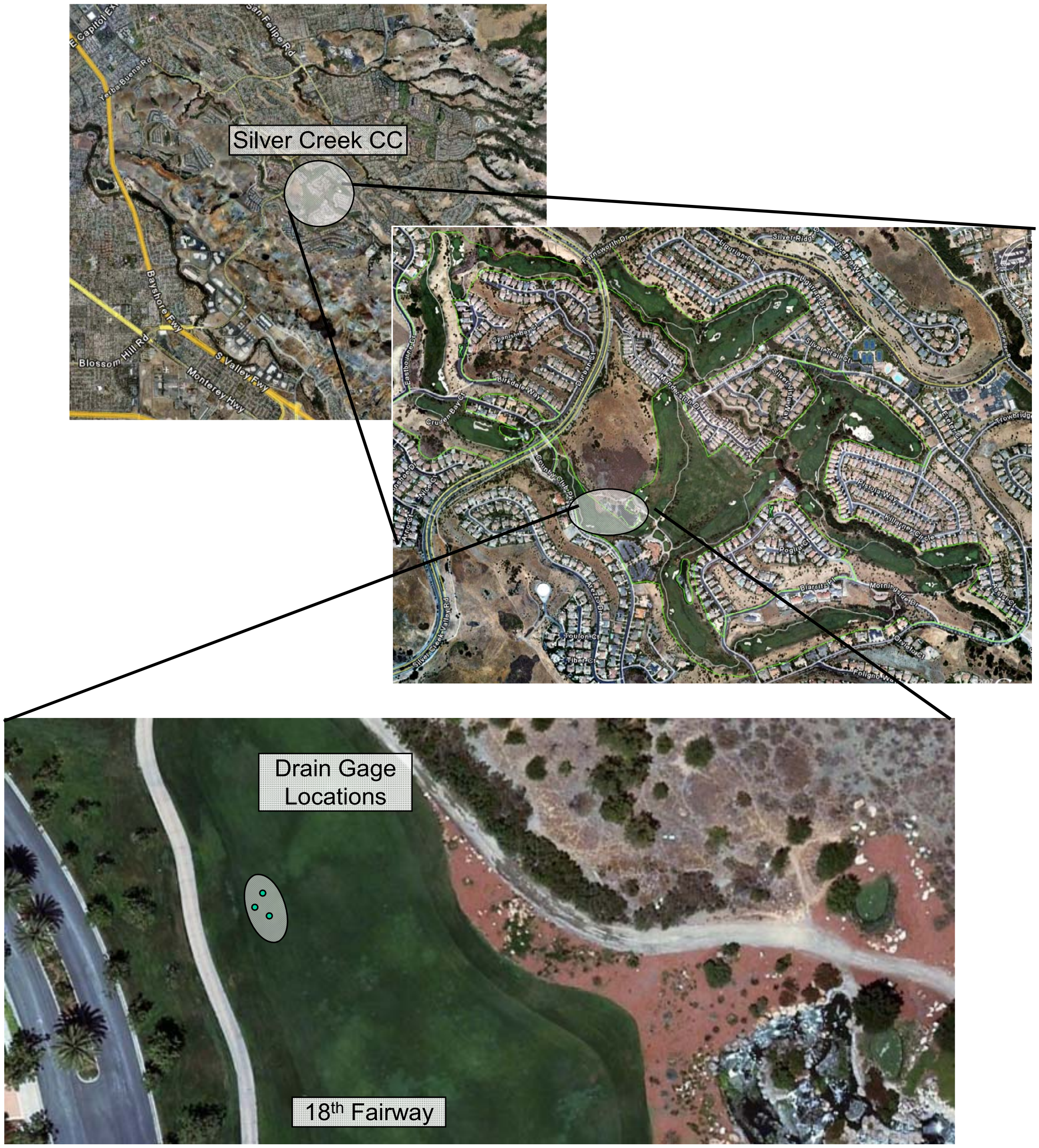


Schematic not to scale

Notes:
1. Reading on dosing will be ~75%, but needs to be checked
2. Spliced plug needs to be repaired
3. Port #2 on logger

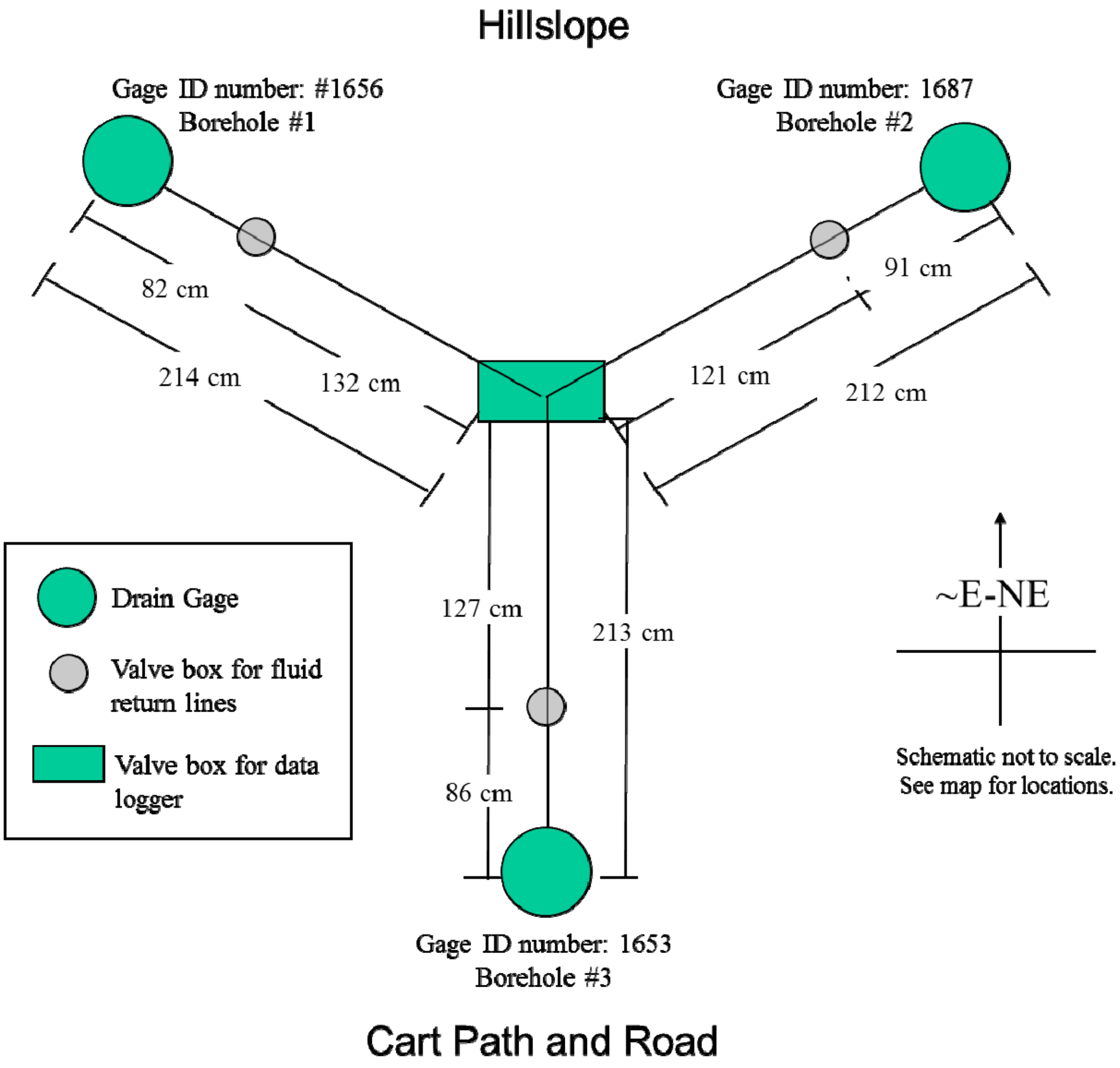
Date: 12 November 2008 Site: Wildhorse GC
Personnel: Young, Healey, Devitt, Meyer, Wright

Location of Silver Creek Valley CC and Drain Gauges



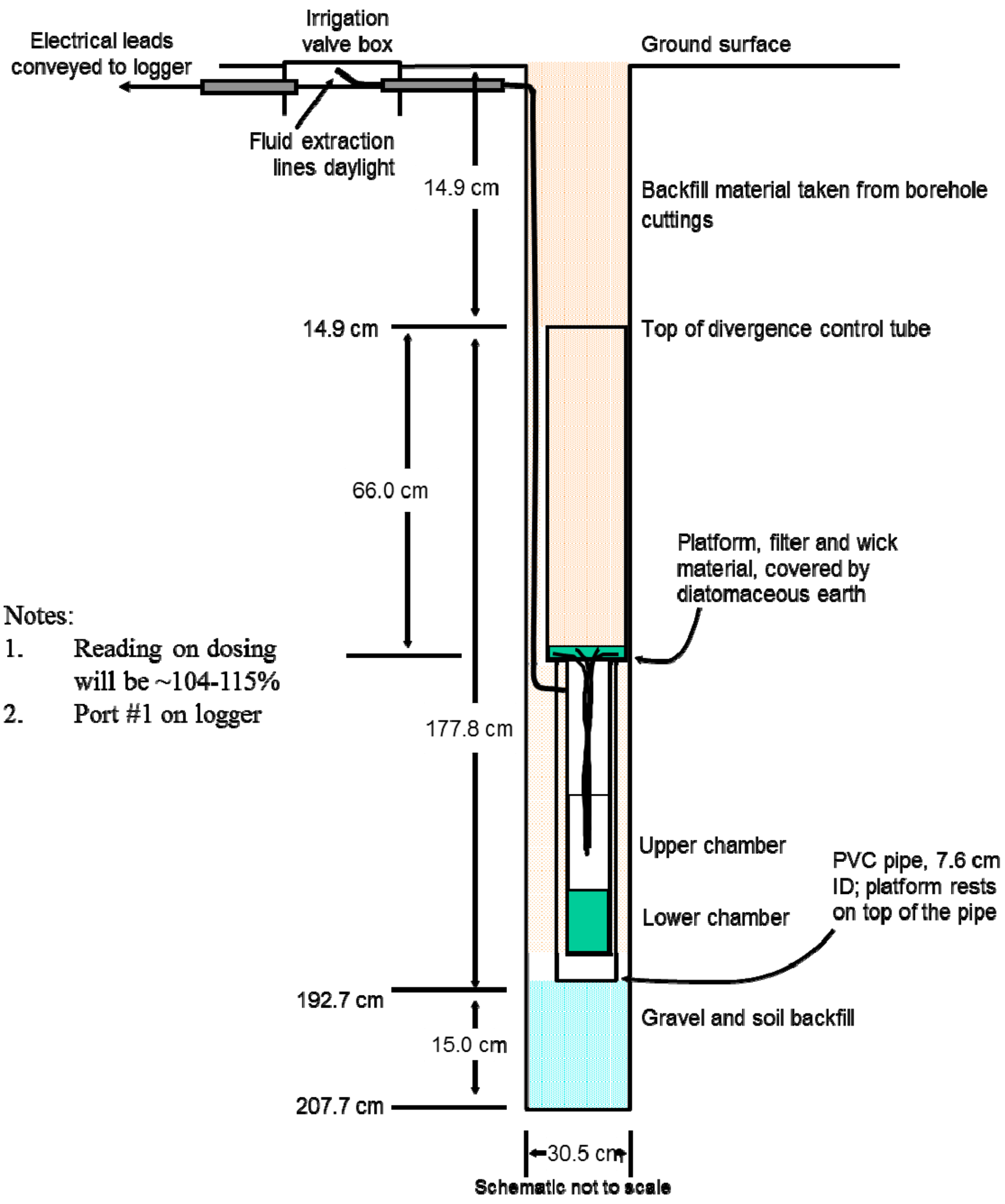
Coordinates:
Lat/Long: 37º16' 35.55"N, 121º 46' 25.00"W
Elevation: 633 feet msl
Acquired: 8 Dec 2008

Drain gauge installation schematic - Map View



Date: 7-8 December 2008 Site: Silver Creek Valley CC
Personnel: Young, Healey, Checklenis, McCullough

Drain gauge installation schematic: #1656 (BH #1)



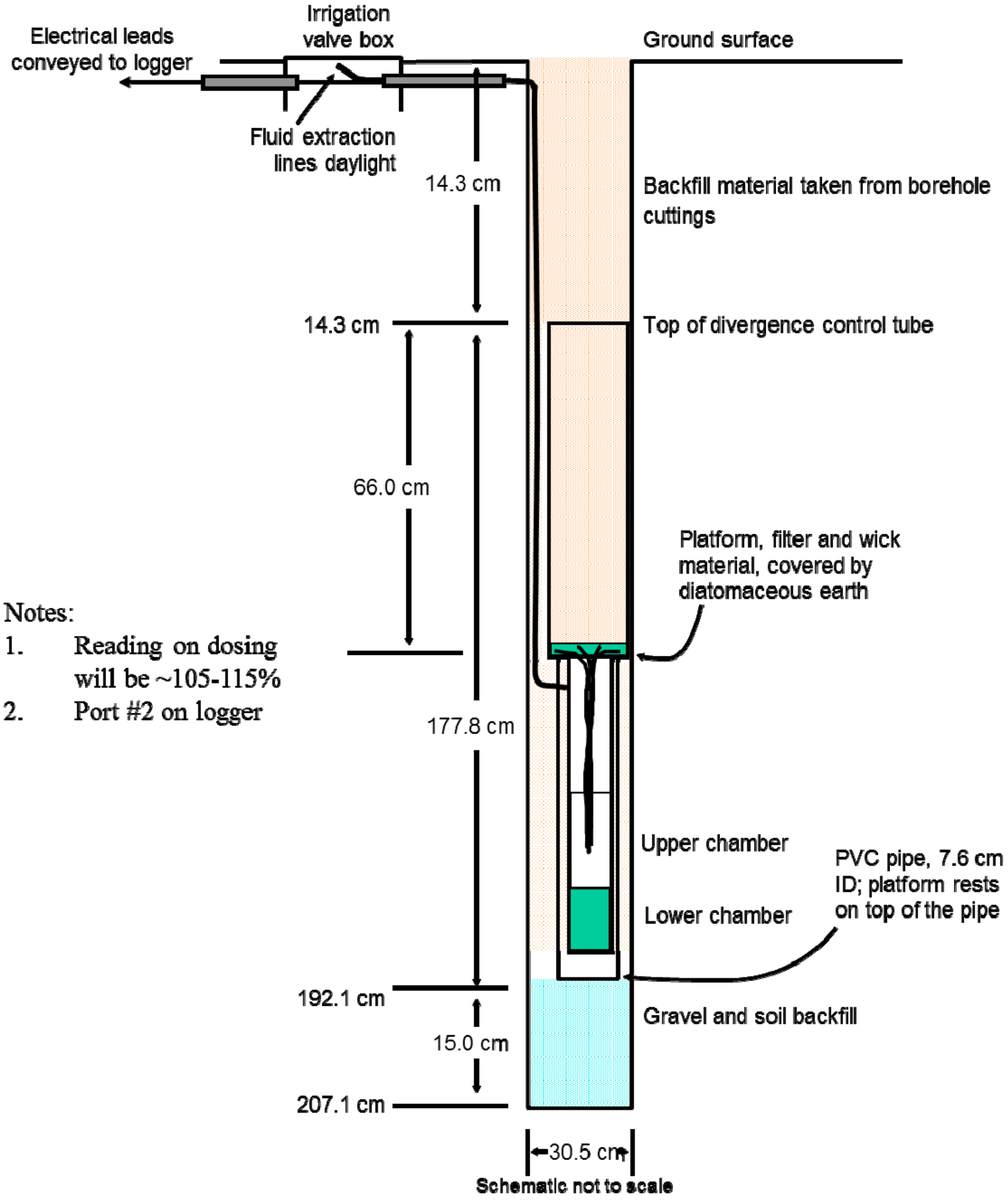
Notes:

1. Reading on dosing will be ~104-115%
2. Port #1 on logger

Date: 7-8 December 2008 Site: Silver Creek Valley CC

Personnel: Young, Healey, Checklenis, McCullough

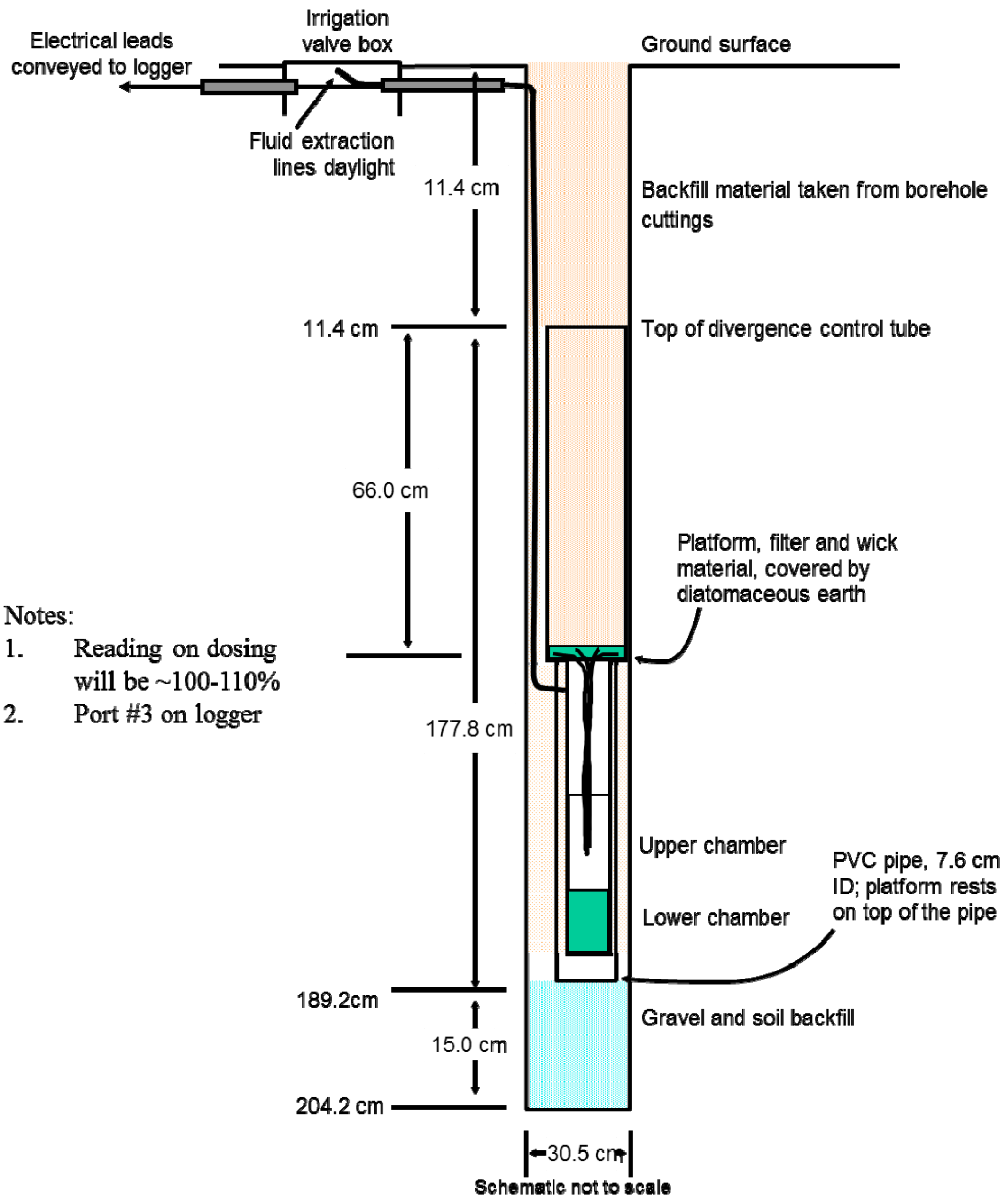
Drain gauge installation schematic: #1687 (BH #2)



Notes:
1. Reading on dosing will be ~105-115%
2. Port #2 on logger

Date: 7-8 December 2008 Site: Silver Creek Valley CC
Personnel: Young, Healey, Checklenis, McCullough

Drain gauge installation schematic: #1653 (BH #3)



Notes:

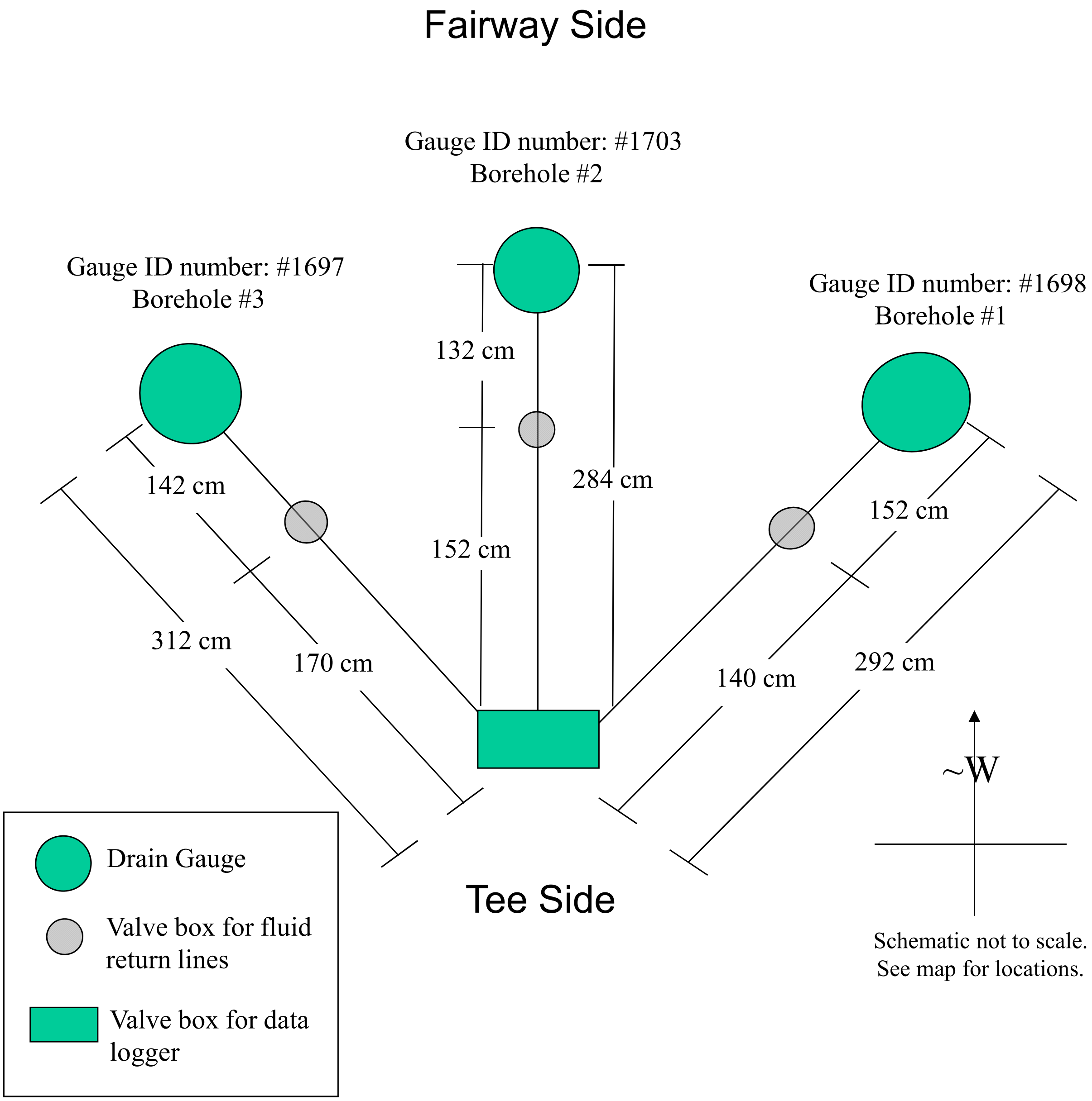
1. Reading on dosing will be ~100-110%
2. Port #3 on logger

Date: 7-8 December 2008 Site: Silver Creek Valley CC

Personnel: Young, Healey, Checklenis, McCullough

Location of City of Industry, CA; Zaharias GC and Drain Gauges

Coordinates:
Lat/Long: 34 00’55.77”N; 117 55’26.6”W
Elevation: 138 m msl

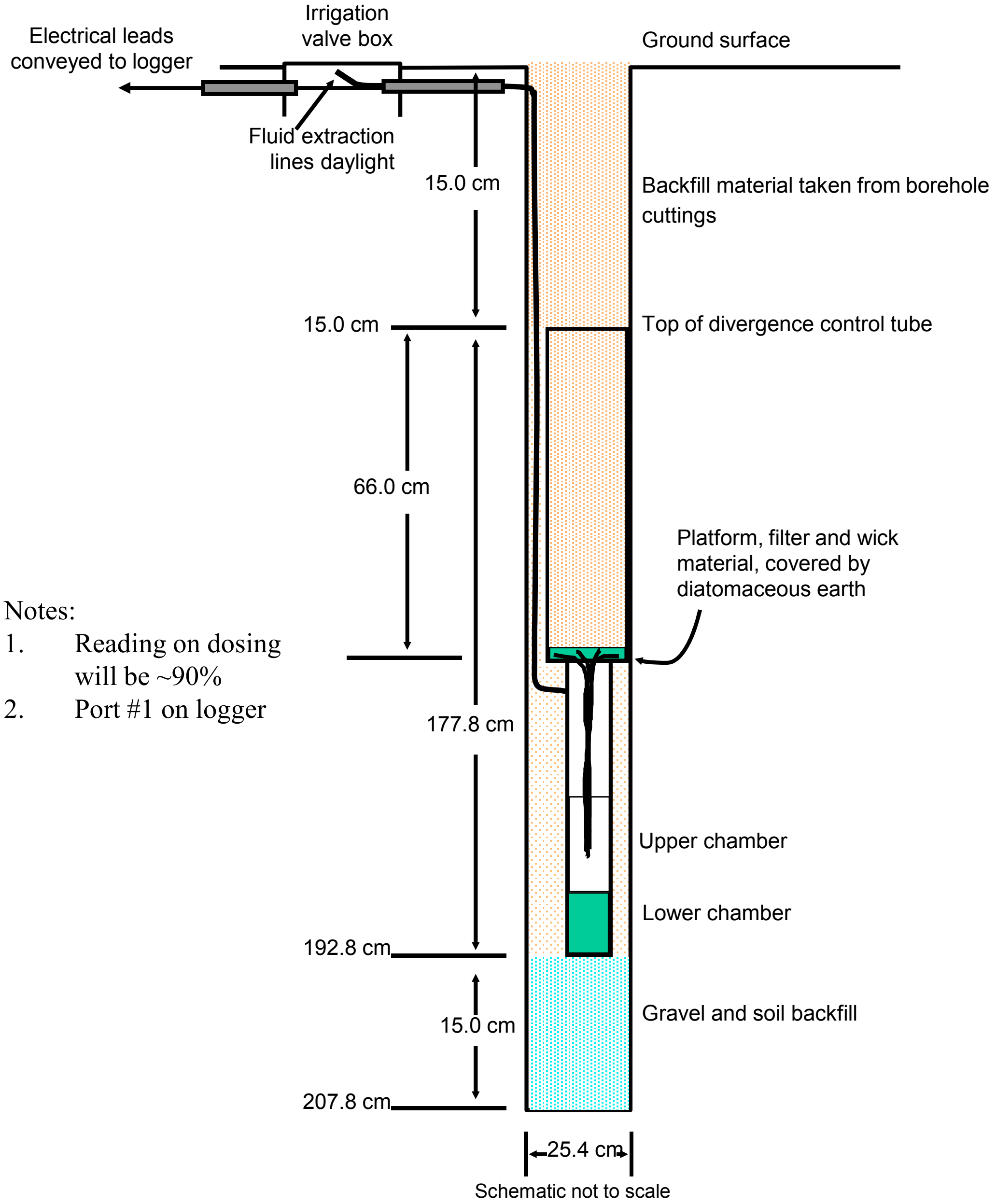


Schematic not to scale.
See map for locations.

Date March 17, 2009 Site: Zaharias GC

Personnel: Young, Devitt, Healey, Green, Carter, Wu

Drain gauge installation schematic: #1698 (BH #1)



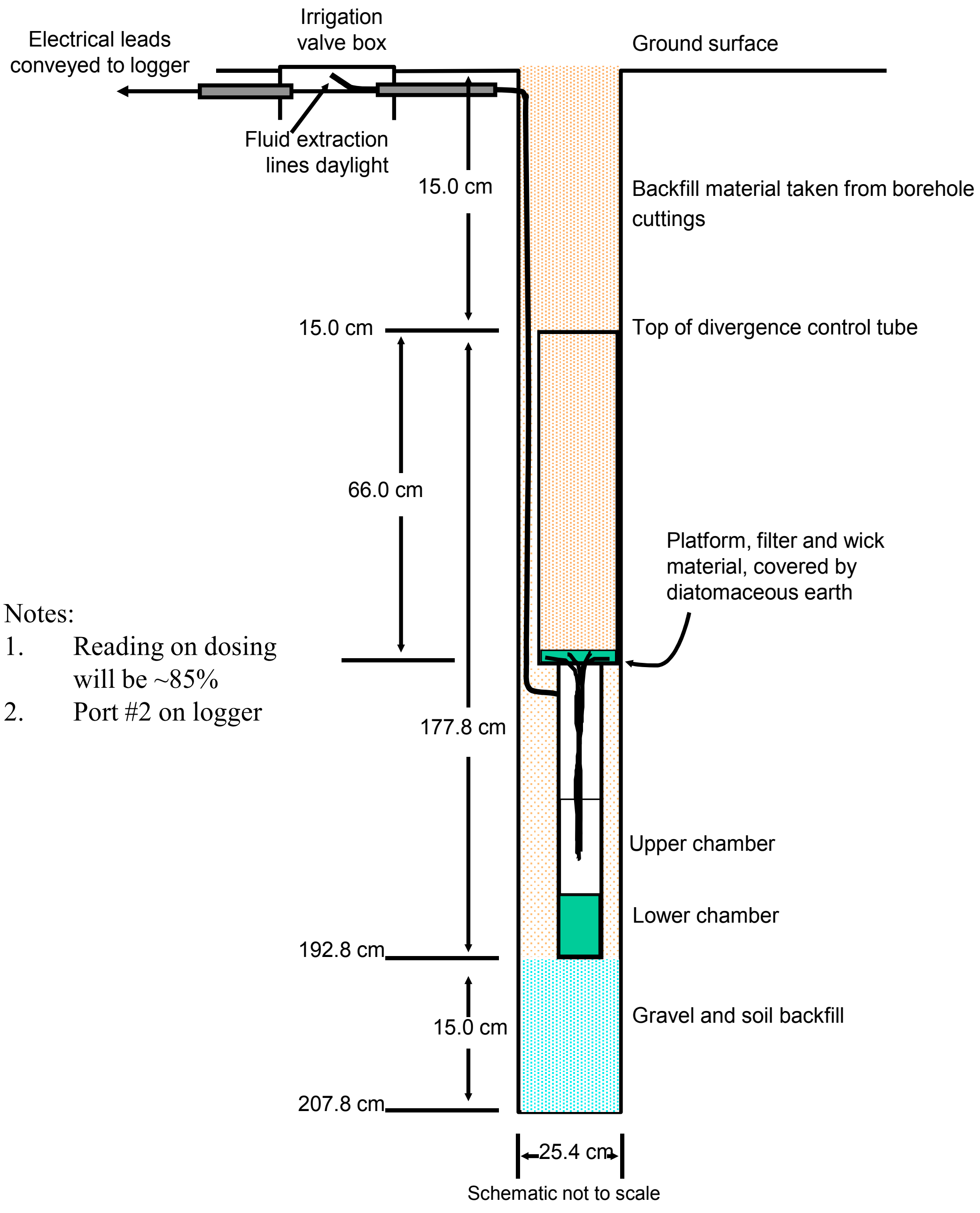
Notes:

1. Reading on dosing will be ~90%
2. Port #1 on logger

Date March 17, 2009 Site: Zaharias GC

Personnel: Young, Devitt, Healey, Green, Carter, Wu

Drain gauge installation schematic: #1703 (BH #2)



Notes:

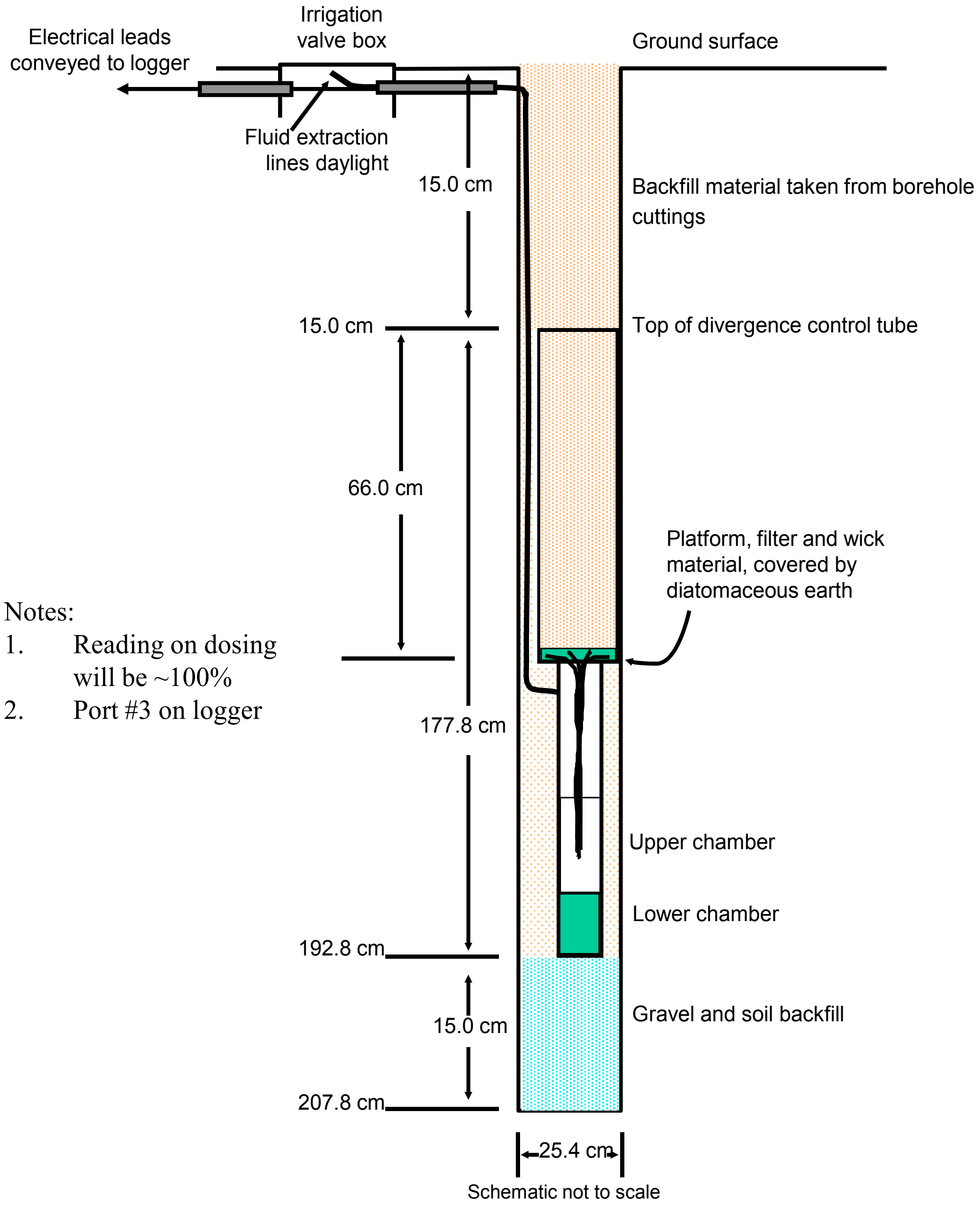
1. Reading on dosing will be ~85%
2. Port #2 on logger

Schematic not to scale

Date March 17, 2009 Site: Zaharias GC

Personnel: Young, Devitt, Healey, Green, Carter, Wu

Drain gauge installation schematic: #1697 (BH #3)



Notes:

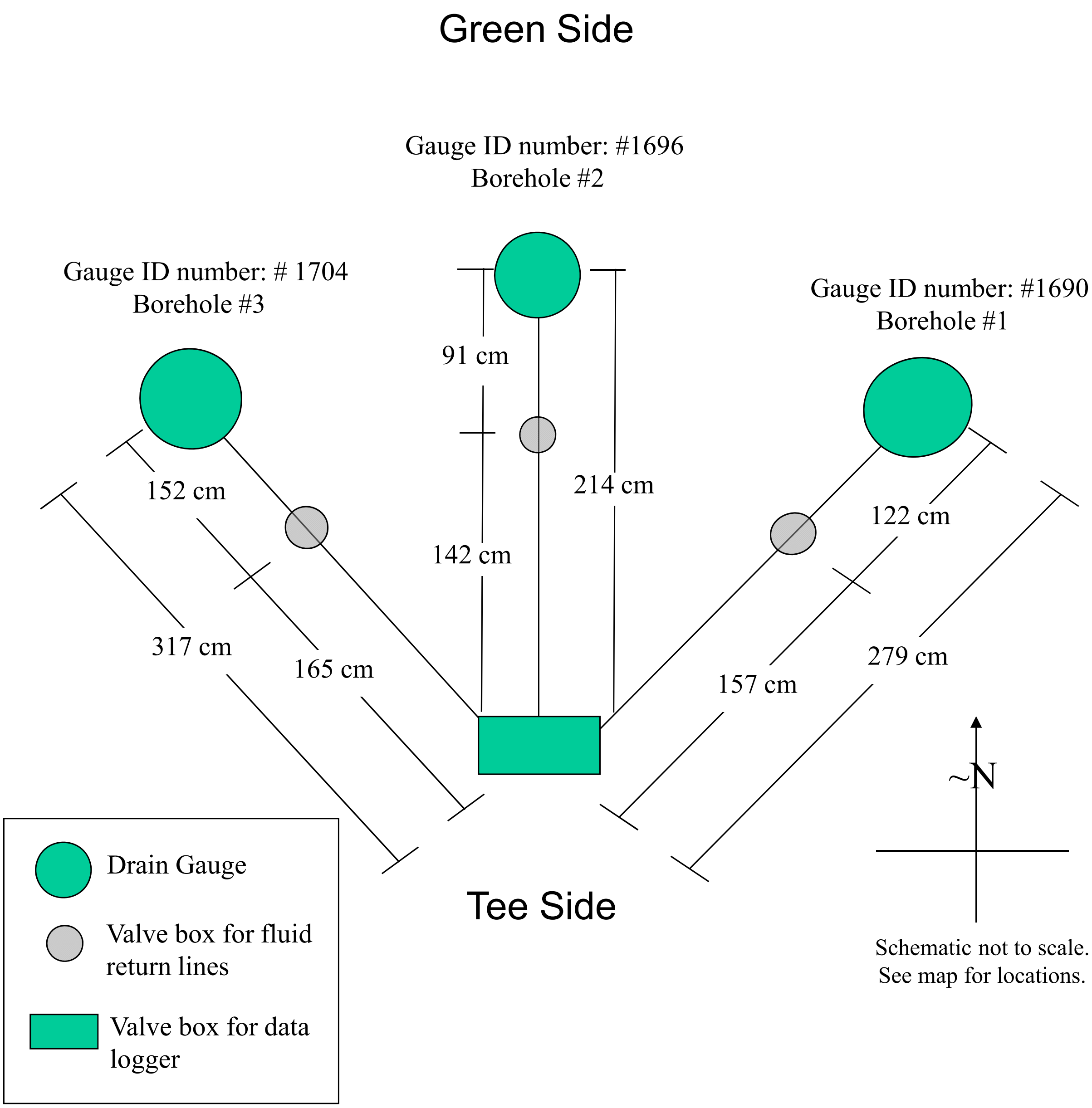
1. Reading on dosing will be ~100%
2. Port #3 on logger

Date March 17, 2009 Site: Zaharias GC

Personnel: Young, Devitt, Healey, Green, Carter, Wu

Location of Palm Desert CC and Drain Gauges

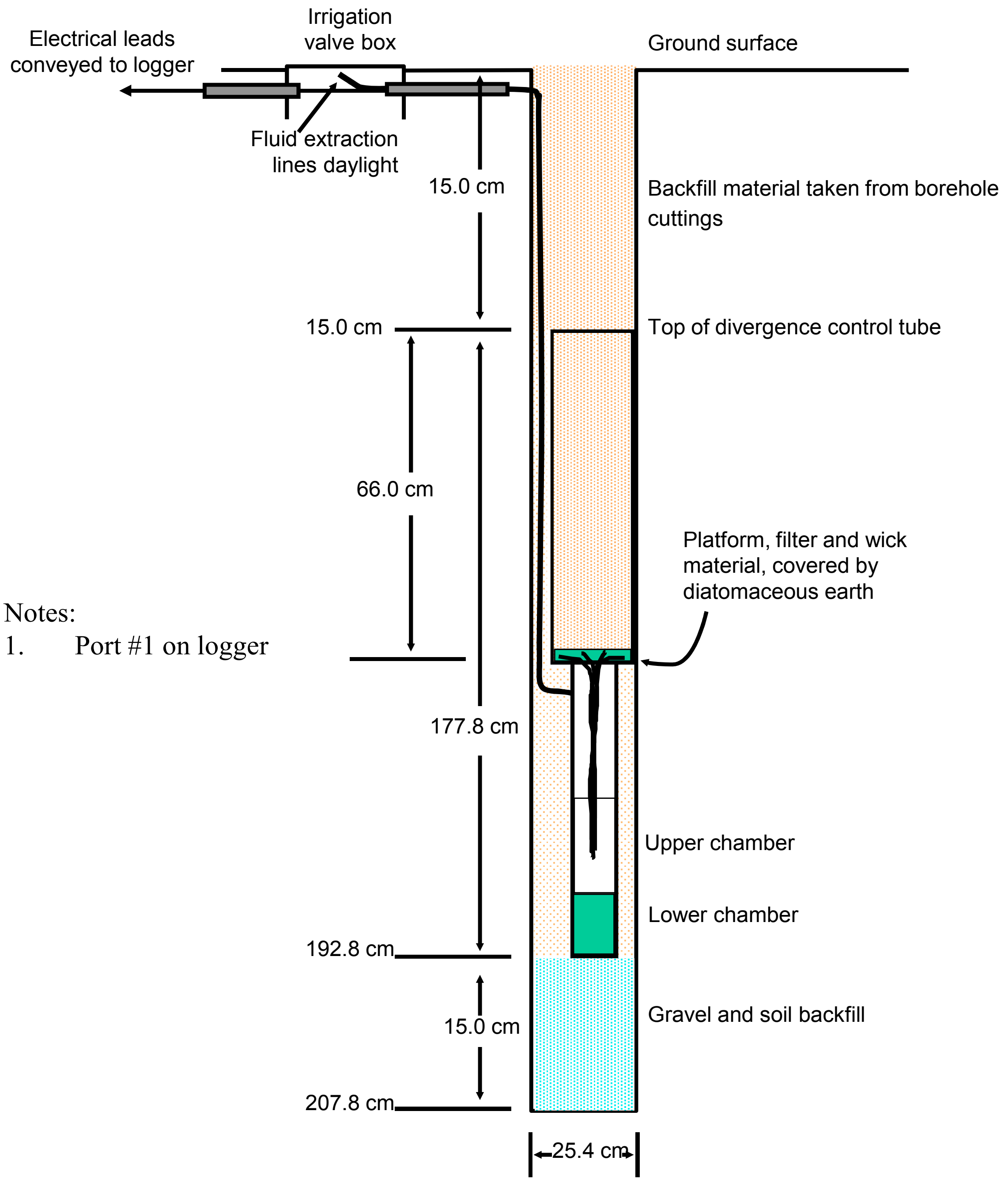
Coordinates:
Lat/Long: N 33º 43’ 58.86”; W 116º18; 45.36”
Elevation: 54 feet msl



Schematic not to scale.
See map for locations.

Date March 18, 2009 Site: Palm Desert CC
Personnel: Young, Devitt, Healey, Green, Carter

Drain gauge installation schematic: #1690 (BH #1)



Notes:

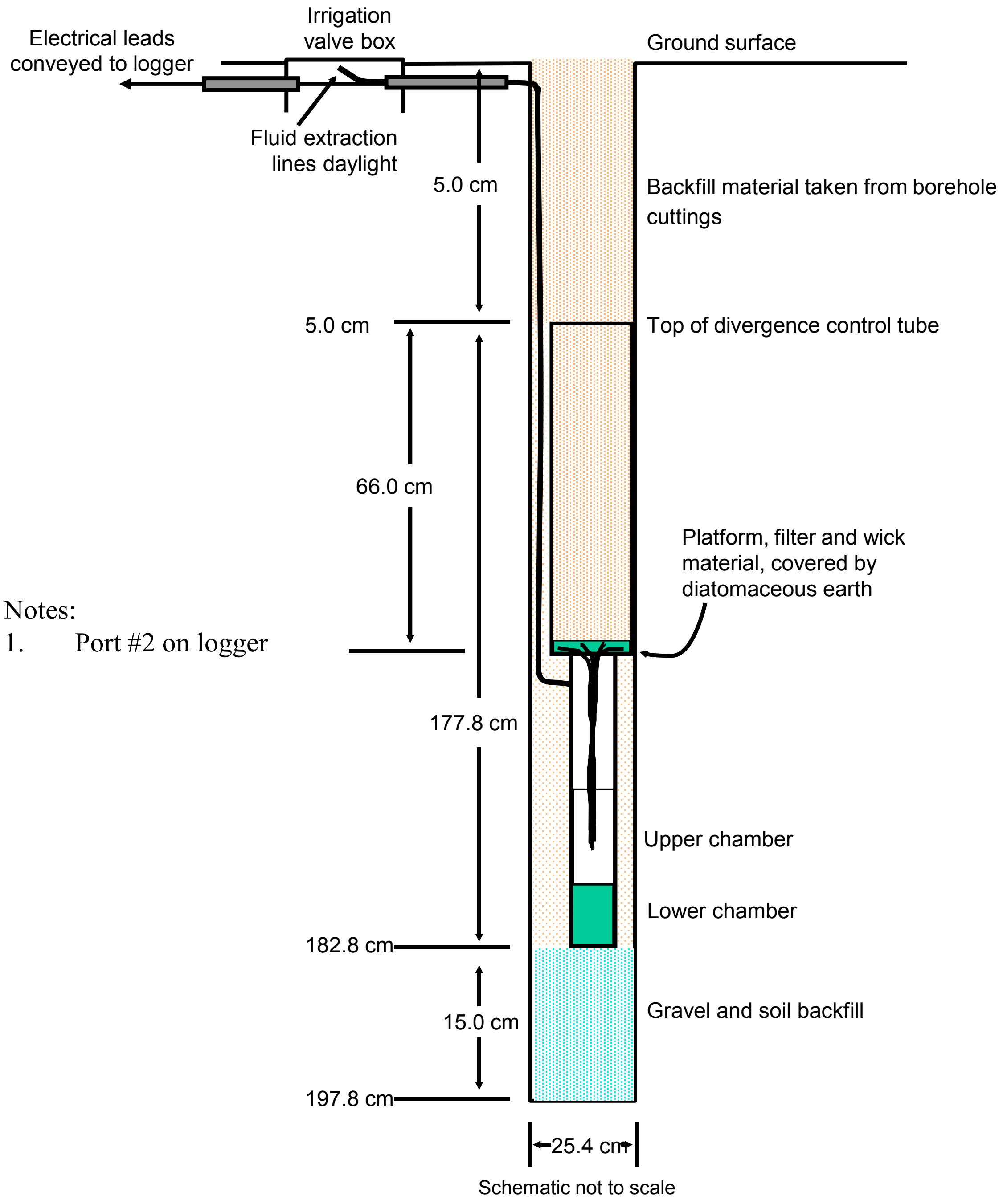
1. Port #1 on logger

Schematic not to scale

Date March 18, 2009 Site: Palm Desert CC

Personnel: Young, Devitt, Healey, Green, Carter

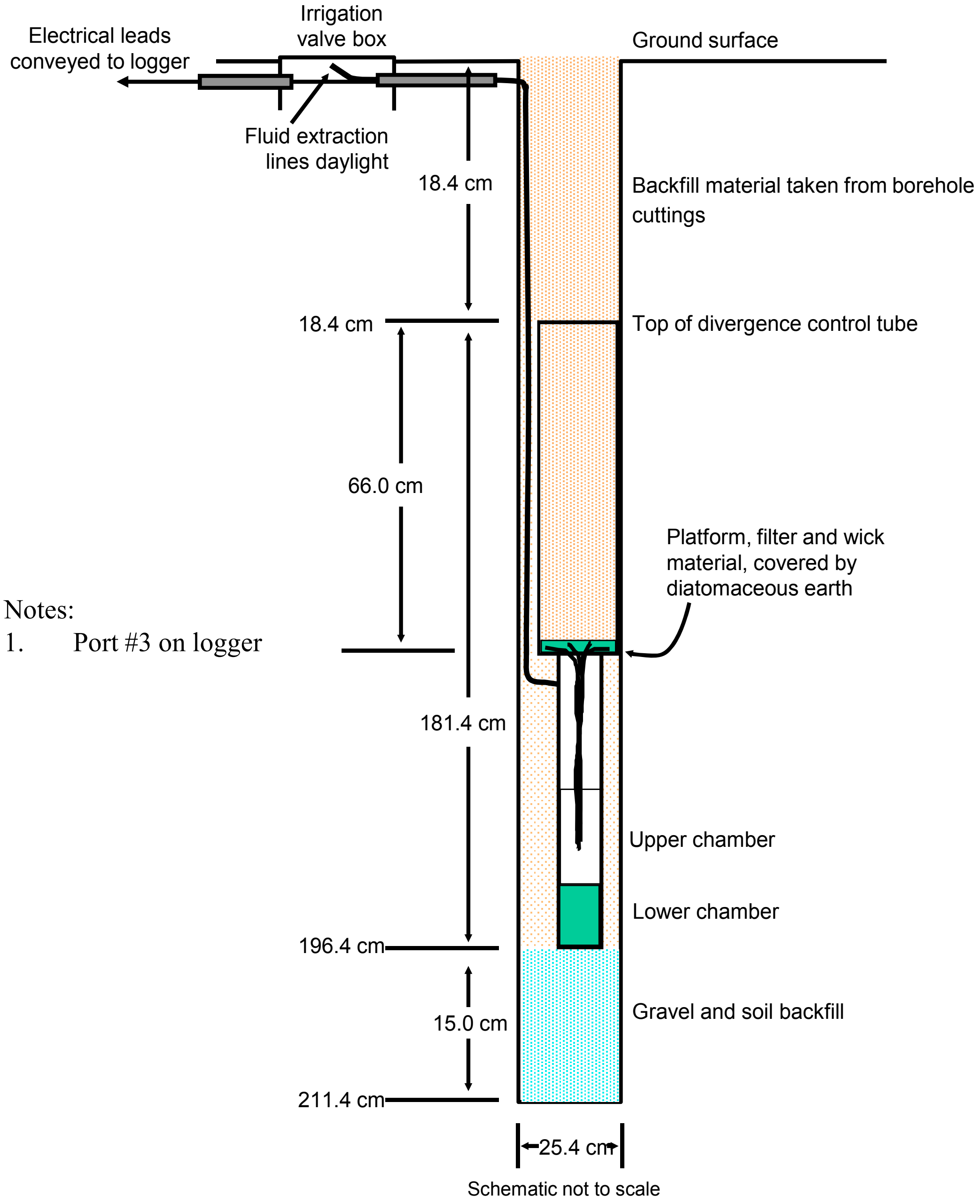
Drain gauge installation schematic: #1696 (BH #2)



Notes:
1. Port #2 on logger

Date March 18, 2009 Site: Palm Desert CC
Personnel: Young, Devitt, Healey, Green, Carter

Drain gauge installation schematic: #1704 (BH #3)



Notes:

1. Port #3 on logger

Date March 18, 2009 Site: Palm Desert CC
Personnel: Young, Devitt, Healey, Green, Carter

APPENDIX F

FATE AND TRANSPORT OF PPCPS IN GOLF COURSES IRRIGATED WITH REUSE WATER

Drain Gauge Monitoring Guide for:

Silver Creek Valley Country Club, San Jose, CA

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

DRI Desert Research Institute

UNLV

SOUTHERN NEVADA WATER AUTHORITY

NORTHERN CALIFORNIA GOLF ASSOCIATION • 1901 •

Introduction

This site has been instrumented with drainage flux meters, manufactured by Decagon Devices (Pullman, WA). Drainage flux is defined as the depth of water that percolates below the root zone in a particular time period. These instruments are also designed for recovering soil pore water for future analysis of different PPCP/ED compounds. The product of the flux and concentration provides the mass flux of the constituent, which is of primary interest in the project because, ultimately, this determines the constituent concentration that could migrate downward to the water table. Three flux meters were installed on the western portion of 18th fairway. These devices measure the water flux below the root zone of the turf. Combined with the water quality results, these measurements can provide mass flux of compounds that migrate below the root zone of the turfgrass and downward toward the water table.

This short document provides the specifications for the instruments installed at this site, including the depth of installation, location of conduits, schematics of instrument location, etc. This document also describes the procedures for using the monitoring systems. Additionally, a copy of the User's Manuals for the drain gauge and the data logger (Decagon Devices, Pullman, WA) are included in the appendix. The User's Manuals provide significant background information that may not be needed for simply operating the drain gauges and data logger. Thus, this shorter document should provide the information needed for routine activities. Users are referred to the Decagon manuals for more information.

Materials and Methods for Installation and Monitoring

Installation

Drain gauges were installed at the Silver Creek Valley CC on 7-8 December 2008. Weather was partly sunny and ~50-60F. Figures 5B-1 and 5B-2 (all figures are shown at the back of this appendix) show the overall site location and a schematic of the location of gauges and valve boxes, which are used for storing the data logger and fluid removal tubes. The site was located near the fringe of the 18th fairway centered on a triangle formed by three irrigation heads. The site selection was primarily based on watering criteria and represents the maximum application of recycled water.

Soil material for the divergence control tube (DCT) was harvested using an area approximately 5 meters west of the location where drain gauges were installed. Though the locations for sample recovery and gauge location are slightly different, the soil treatment and irrigation regime are identical, and using this alternative area allowed us to concentrate soil collection in one location for the replicate drain gauges. Several methods were used to recover intact soil cores at the site, but the clayey-textured soil precluded all methods. The field crew was then forced to excavate soil in layers of about 7-10 cm (3-4 inches) thick using a specifically designed DCT with a cutting shoe welded to the base. Soil was removed by hand and transferred into the DCT of interest. In general, the repacked soil in the DCT was about 5-7 cm (2-3 inches) thicker than the depth of the excavated borehole. Therefore, the final bulk density was slightly lower than undisturbed soil.

Figures A5-3 through A5-5 show schematics of installation of the drain gauges including the depths of the top of the DCT and other internal dimensions. Soil was backfilled around the DCT, ensuring that the DCT and drain gauges were vertically oriented. Turf patches (~60 cm by 60 cm) in size were placed on top of the drain gauge by Silver Creek Valley CC personnel.

Wires and tubing from the drain gauges were contained in rigid conduit from the installation site, to a circular valve box, where the fluid removal tubes terminated. Wires used for monitoring water depth in the drain gauge were conveyed to the central valve box (Figure 5A-2), fed into a water proof case and terminated at the EM50R logger. All conduit runs were sealed using plumber's putty to prevent water from entering the conduit and moving laterally across the site.

Monitoring –

Two key monitoring tasks are needed for the drain gauge: checking and downloading data, and withdrawing fluids from the upper chamber of the gauge. Both aspects of monitoring are fully described in the manufacturers' users manuals for the drain gauge and data logger, but they are briefly described here in a series of steps.

Downloading Data

1. To check the functionality and condition of the drain gauge, the EM50R datalogger needs to be connected to the computer. First, remove it from the yellow Pelican Case found inside the large valve box that connects the three drain gauges. The EM50R is then connected to a personal computer by either a direct connection to the computers' serial or USB port, or the RM-1 wireless module that was purchased for each of the field sites.

a. If the direct connection method is used, use Decagon's serial-to-radio-plug cable, open up the datalogger and plug the radio-plug side into the far right port, labeled as serial communication port. The other side of the cable is connected to the computer.

b. If the RM-1 wireless system is used, start the ECH2O utility program, and connect to the logger by pulling down the menu under "Connect Via:" and choose the appropriate option (the manual has a complete description in Chapter 6).

2. After the logger is connected to the personal computer, Scan the three drain gauges and record the percent full values on the field form (found in the back of this document). Then download data by clicking on the "Download" button. Several choices are provided for downloading, but it is best to use the "Processed Data Excel File" option and the suggested filename which uses the site name download date. This file needs to be emailed to the Research group as soon as possible after collecting. It is recommended that data from the drain gauge be downloaded every two weeks, immediately after installation, until project personnel can examine instrument performance.

3. Fill out the Drain Gauge Monitoring Form, which is attached at the back of this report. This report should be kept in a notebook and periodically copied and sent to Michael Young at DRI (A full address is found below).

4. When data have been downloaded, disconnect the computer cable from the EM50R

logger, replace it in the yellow Pelican Case and secure it inside the valve box.

Fluid Collection

Fluid collects in two chambers in the drain gauge, an upper and lower chamber. The upper chamber collects water directly from the wick material inside the drain gauge. This chamber is also monitored by the EM50R logger. When the upper chamber becomes full, a dosing siphon installed in the chamber removes the fluid and conveys it to a lower chamber. When the lower chamber becomes full, fluid seeps from a drain hole installed in the side of the gauge. Because the lower chamber does not fully mix the fluid being collected, the upper chamber should be used for fluid sampling.

The decision on when to remove fluid from the drain gauge will be based on the flux measured by the gauge. Generally, if the upper chamber is more than 50% full, the fluid should be removed, otherwise no other action is needed.

1. Two different tubes are used to remove fluid from the drain gauges, a clear tube and a blue tube. The clear tube connects to the upper chamber and the blue tube connects to the lower chamber. Connect the syringe to the fitting on the clear tubing and pull back gently on the syringe plunger until fluid is seen collecting in the syringe. Continue pulling back on the syringe until the upper chamber is fully evacuated (air bubbles will be withdrawn from the sampler).
2. The fluid in the syringe should be pushed back into the sampling bottles supplied by the researchers, using the accompanying labels, and following appropriate preservation and shipping instructions (found below or sent to the GC under separate cover).
3. The syringe should be cleaned by triple rinsing with deionized water, air dried and then stored in the plastic case that was supplied with the drain gauge.

Fluid Handling and Preservation

Immediately after the samples are collected, they must be preserved and shipped to the laboratory for analysis. The bulleted list describes the step-by-step procedures for preservation and shipping.

Place ice packs into freezer upon arrival and ensure that they are frozen before sampling begins.

Wear gloves, at all times, during sampling and avoid touching or even breathing on the samples (compounds are being measured at part per trillion levels, so it is very prone to contamination). Gloves here should be common medical examination gloves, rather than construction gloves that might have soil or other chemicals on them.

Sample bottle contains toxic preservative, so use caution. A Material Safety Data Sheet will be supplied with the sample bottles. These should be read and understood before using the sample bottles.

Do not rinse or overfill container.

TRAVEL BLANK: Water will be supplied by SNWA that is used as a travel blank. These samples are used to ensure that fluids do not inadvertently transfer between bottles during shipping. Please transfer water into travel blank sample bottle, which is also supplied by SNWA.

Make sure caps on sample bottles are tightly sealed.

Fill out Sample Information Sheet and Chain of Custody sheets, supplied by SNWA, and include any additional water quality data available (i.e., temperature), if other data are collected. Remember to fill out the

Place sample in 1-4°C refrigerator to cool samples prior to shipping.

When ready to ship, place sample bottles into cooler and include ice packs and place Sample Information Sheet/Chain of Custody in a sealed plastic bag. The sealed bag should be taped to the cooler lid.

Send return shipment Priority/Next Day Air, and only send out Mon through Wed.

Send to:

Janie Zeigler
River Mountains WTF
1299 Burkholder Blvd.
Henderson, NV 89015

Send confirmation e-mail to janie.zeigler@lvvwd.com, and include any tracking numbers that are associated with the shipment.

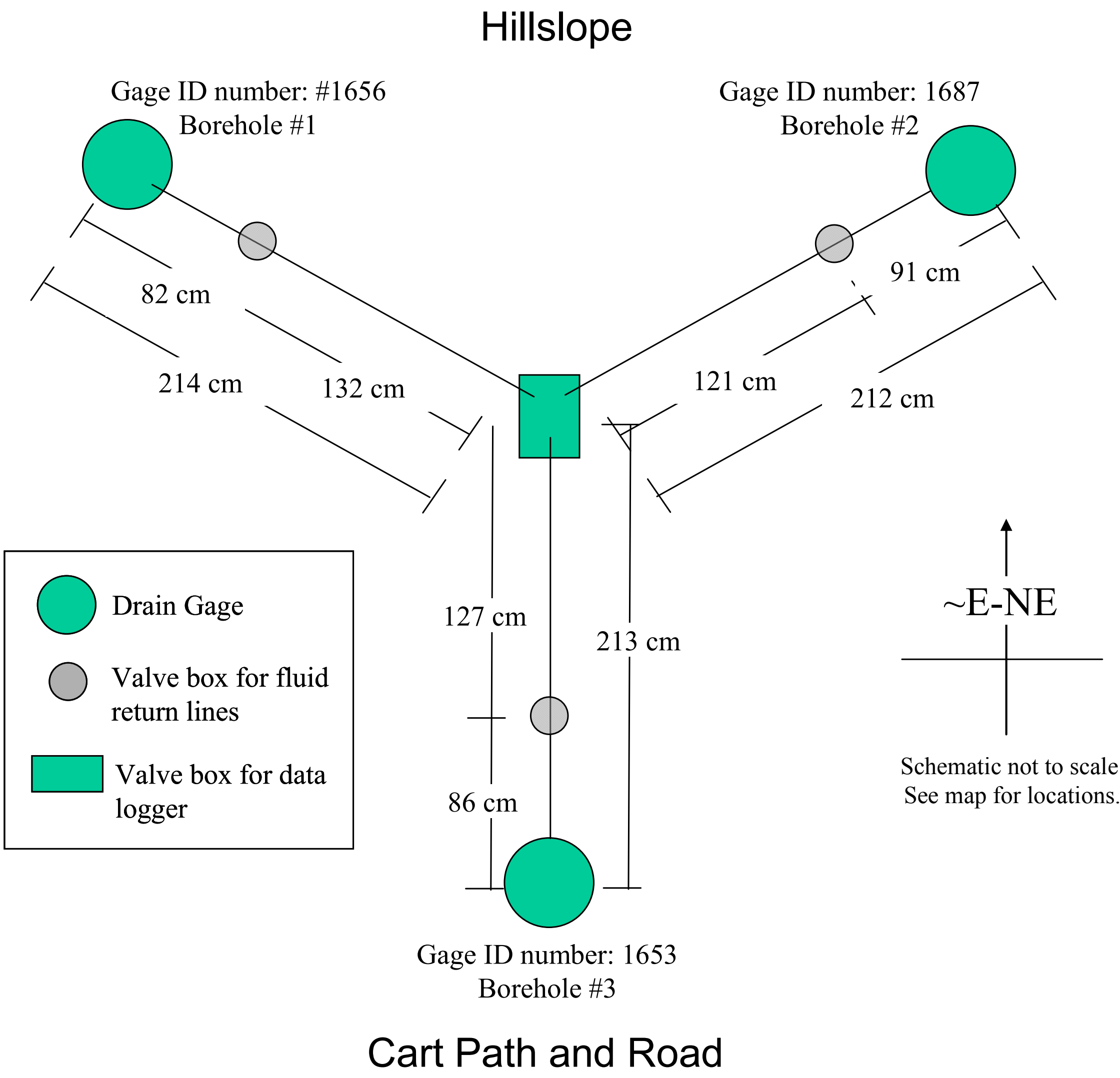
Questions

Any questions regarding the operation of the drain gauge should be directed to:

Michael Young, Bureau of Economic Geology
University of Texas at Austin
University Station, Box X
Austin, TX 78712-8924
Phone: 512-75-8830
Email: michael.young@beg.utexas.edu

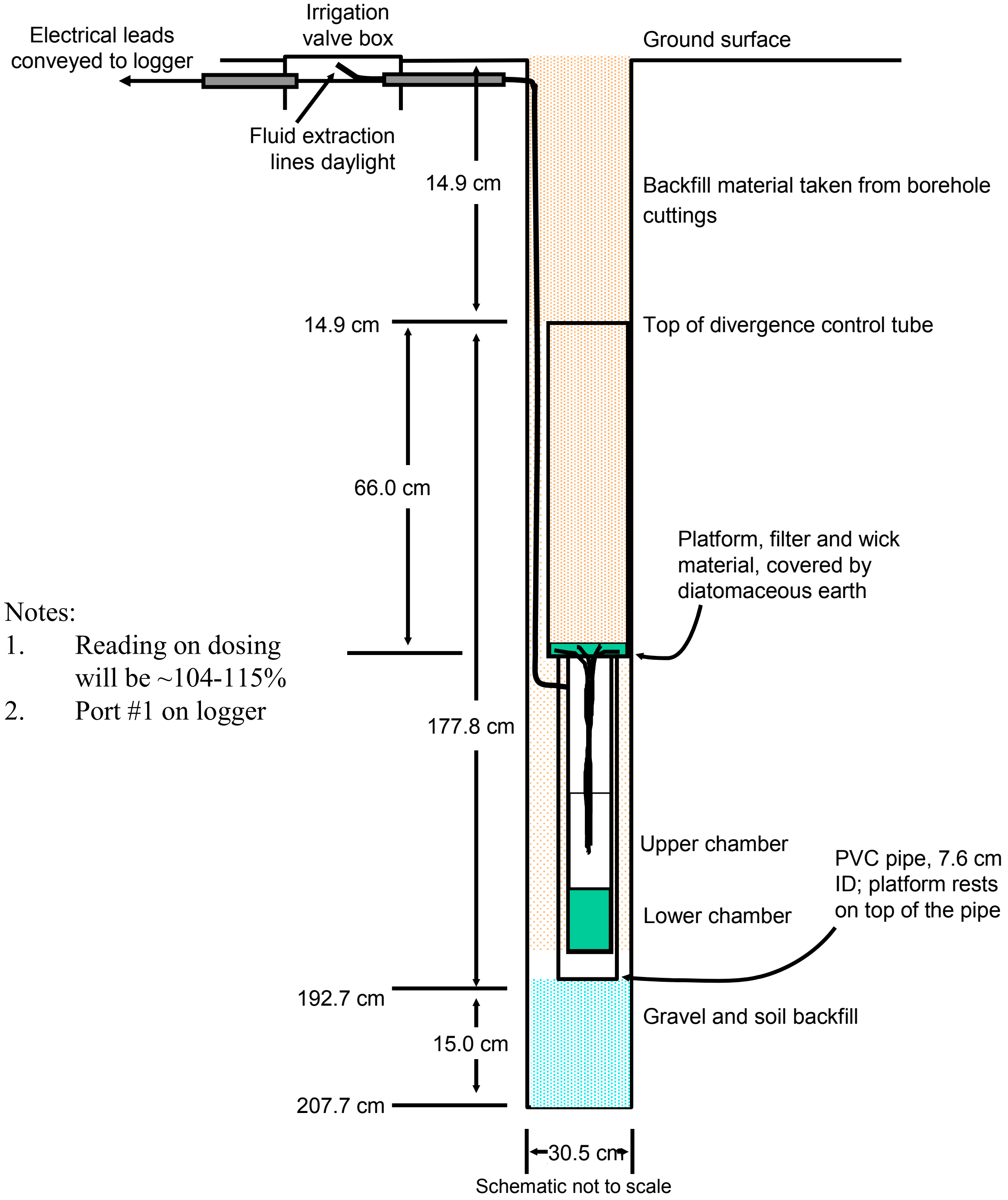
Coordinates:
Lat/Long: N37 16’37.9”, W121 46’26.5”
Elevation: 554 feet msl
Acquired: Date: 07-DEC-08 Time: 3:38:24 PM

Figure F-1. Location Maps of Drain Gauges Installed at Silver Creek Valley CC.



Date: 7-8 December 2008   Site: Silver Creek CC
Personnel: Young, Healey, Checklenis, McCullough

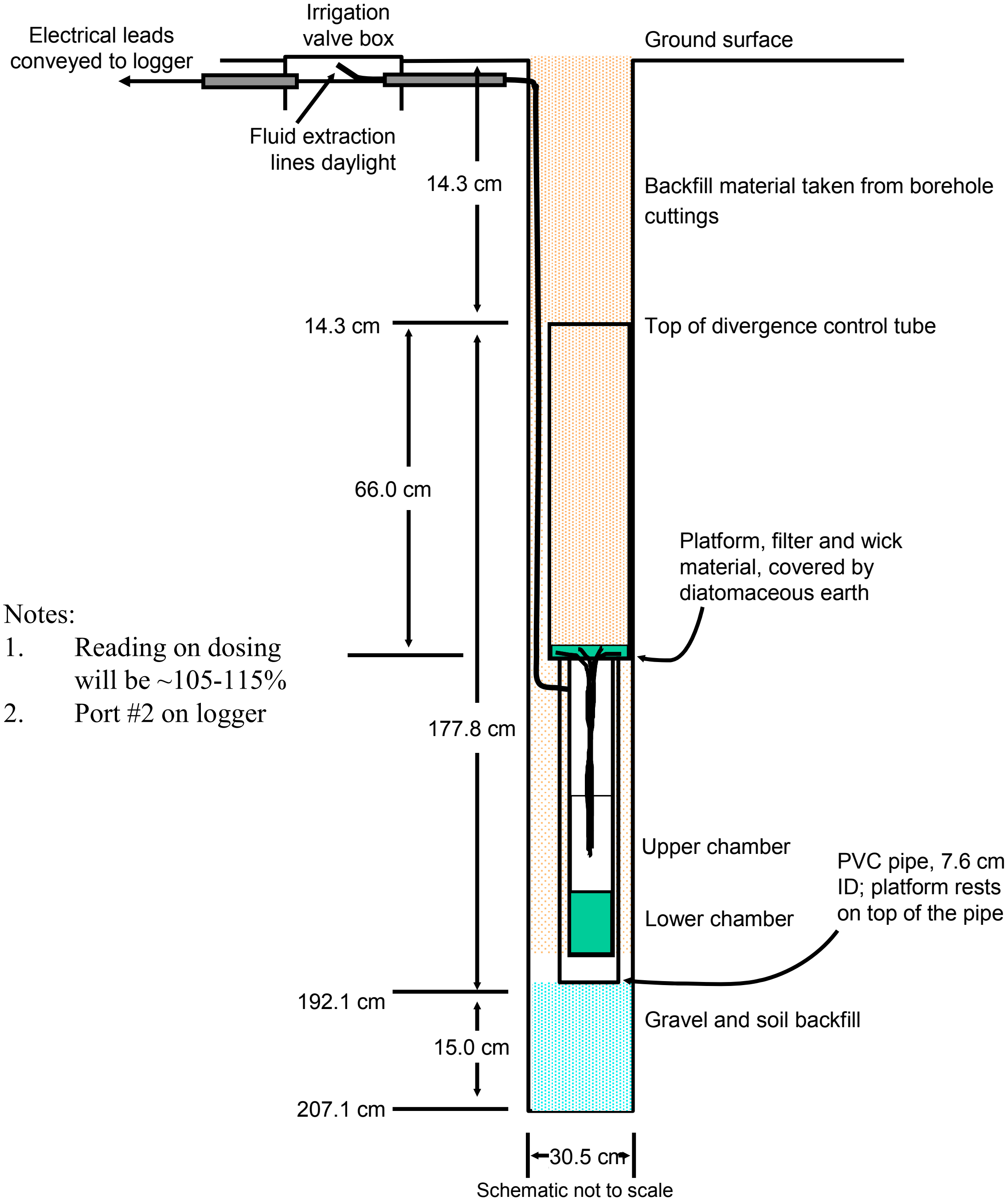
Figure F-2. Map View Schematic of Drain Gauges and Utility Boxes, Silver Creek Valley CC.



Notes:
1. Reading on dosing will be ~104-115%
2. Port #1 on logger

Schematic not to scale

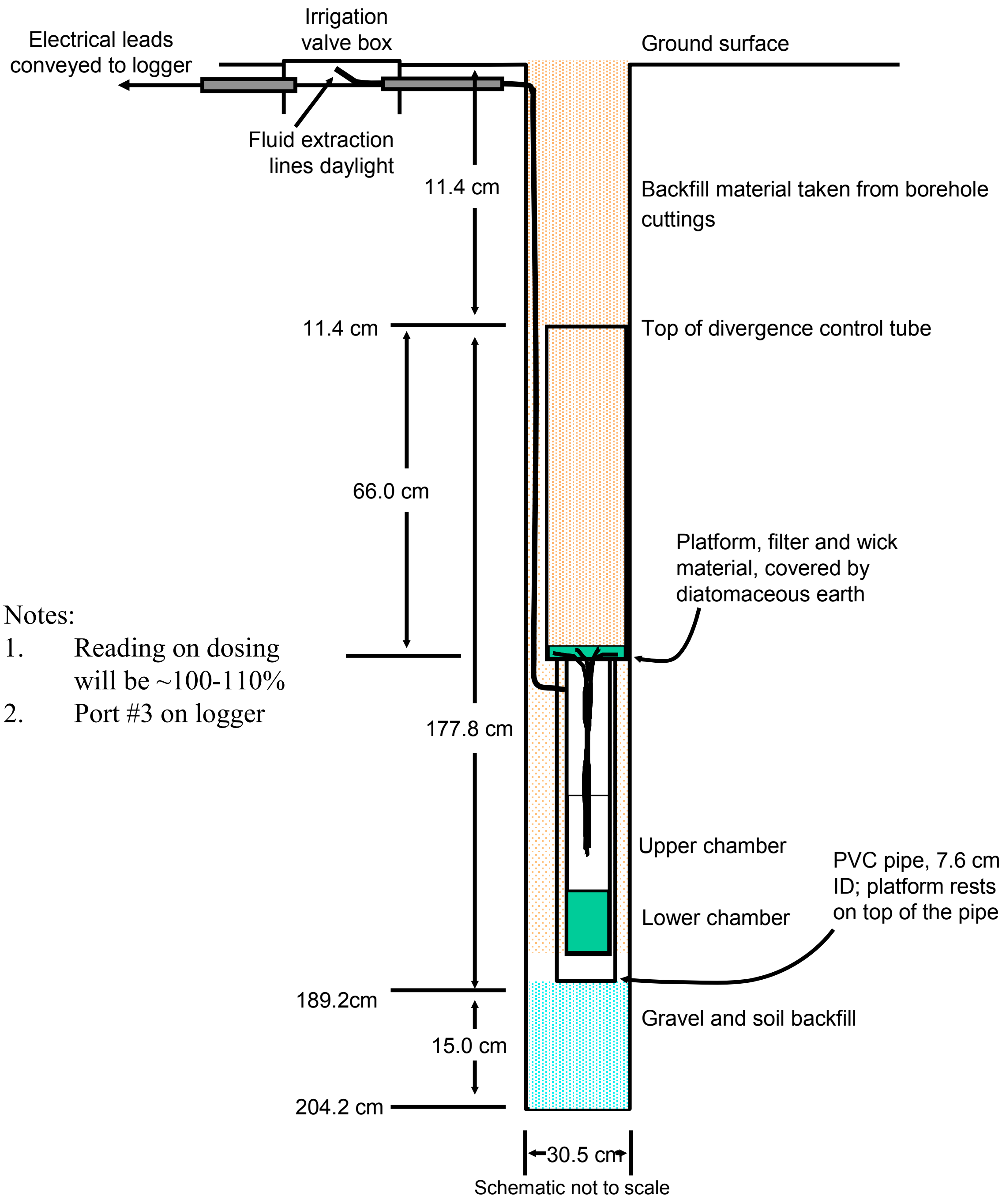
Figure F-3. Drain Gauge Schematic for Gauge #1656.



Notes:

1. Reading on dosing will be ~105-115%
2. Port #2 on logger

Figure F-4. Drain Gauge Schematic for Gauge #1687.



Notes:

1. Reading on dosing will be ~100-110%
2. Port #3 on logger

Figure F-5. Drain Gauge Schematic for Gauge #1653.

APPENDIX G

SOIL ANALYSES

Wildhorse GC

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 10-309-058

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUTE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER:

DATE OF REPORT: 11/09/10

SOIL ANALYSIS REPORT

PAGE: 1

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	NaHCO$_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
WH-15	54785	2.7M	84	7 *	5L	659M	442M	5431VH	720H	7.9		0.0	35.5	4.7	10.2	76.2	0.0	8.8
WH-35	54786	1.8L	65	2 *	3VL	854VH	518H	1939L	934VH	8.0		0.0	20.2	10.8	21.1	47.9	0.0	20.1
WH-60	54787	1.8L	65	1 *	5L	513H	421M	2743L	1075VH	8.1		0.0	23.1	5.7	15.0	59.2	0.0	20.2
WH-85	54788	1.9L	68	1 *	4L	744H	643M	2543L	1564VH	8.0		0.0	26.7	7.1	19.8	47.6	0.0	25.5
WH110	54789	1.7L	65	1 *	3VL	731H	738H	2710L	1643VH	8.0		0.0	28.6	6.5	21.2	47.3	0.0	25.0

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO$_3$-N ppm	Sulfur SO$_4$-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS SAND %	SILT %	CLAY %	SOIL TEXTURE
WH-15	25M	3253VH	5.8H	1VL	2VL	0.1VL	1.8H	H	3.3H			42	46	11	LOAM
WH-35	23M	1214VH	0.4VL	1VL	1VL	0.1VL	3.8VH	L	3.2H			58	24	17	SANDY LOAM
WH-60	31H	1171VH	0.4VL	1VL	2VL	0.1VL	3.2VH	H	5.2VH			40	28	31	CLAY LOAM
WH-85	46VH	1110VH	0.2VL	1VL	2VL	0.1VL	2.8VH	H	7.1VH			34	32	33	CLAY LOAM
WH110	43VH	1340VH	0.2VL	1VL	3VL	0.3VL	4.2VH	H	7.9VH			42	34	23	LOAM

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
** ENR - ESTIMATED NITROGEN RELEASE
*** MULTIPLY THE RESULTS IN ppm BY 2 TO CONVERT TO LBS. PER ACRE OF THE ELEMENTAL FORM
**** MULTIPLY THE RESULTS IN ppm BY 4.6 TO CONVERT TO LBS. PER ACRE P_2O_5
***** MULTIPLY THE RESULTS IN ppm BY 2.4 TO CONVERT TO LBS. PER ACRE K_2O
MOST SOILS WEIGH TWO (2) MILLION POUNDS (DRY WEIGHT) FOR AN ACRE OF SOIL 6-2/3 INCHES DEEP

This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

M Buttress

Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

Wildhorse GC (continued)

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 10-309-058

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUTE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER:

DATE OF REPORT: 11/09/10

SOIL ANALYSIS REPORT

PAGE: 2

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	NaHCO$_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
WH135	54790	1.9L	68	1 *	7L	696H	847H	3102L	1846VH	8.1		0.0	32.2	5.5	21.6	48.0	0.0	24.9

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO$_3$-N ppm	Sulfur SO$_4$-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS			
												SAND %	SILT %	CLAY %	SOIL TEXTURE
WH135	55VH	1774VH	0.3VL	1VL	3VL	0.2VL	3.0VH	H	7.7VH			32	32	35	CLAY LOAM

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
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This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

M Buttress
Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

Silver Creek Valley CC

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 ● MODESTO, CALIFORNIA 95351 ● (209) 529-4080 ● FAX (209) 529-4736

REPORT NUMBER: 10-340-044

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUTE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER: SILVER CREEK

DATE OF REPORT: 12/10/10

SOIL ANALYSIS REPORT

PAGE: 1

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	$NaHCO_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
SC-15	56493	3.5M	100	27 *	43VH	478M	1261VH	3152L	1158VH	7.9		0.0	32.4	3.8	32.1	48.6	0.0	15.6
SC-35	56494	1.9L	68	17 *	17H	146L	1734VH	2171L	675VH	8.0		0.0	28.4	1.3	50.2	38.1	0.0	10.3
SC-60	56495	1.4L	58	12 *	9M	84L	2612VH	1900VL	772H	8.4		0.0	34.5	0.6	62.2	27.5	0.0	9.7
SC-85	56496	1.3L	56	9 *	10M	70VL	2316VH	1899VL	677H	8.5		0.0	31.6	0.6	60.2	29.9	0.0	9.3

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO_3-N ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS SAND %	SILT %	CLAY %	SOIL TEXTURE
SC-15	10L	330VH	6.6VH	10M	45VH	4.6VH	3.3VH	L	1.7M			45	18	37	CLAY LOAM
SC-35	3VL	220VH	1.6M	4M	20H	1.3H	1.1M	H	1.5M			25	22	53	CLAY
SC-60	2VL	185VH	0.7L	2L	11M	1.0M	1.0M	H	1.5M			21	23	56	CLAY
SC-85	2VL	116VH	0.2VL	1VL	8L	0.9M	0.8M	H	1.3M			31	24	45	CLAY

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
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This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

M Buttress
Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

Zaharias GC (Industry, CA)

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 ● MODESTO, CALIFORNIA 95351 ● (209) 529-4080 ● FAX (209) 529-4736

REPORT NUMBER: 10-309-056

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUTE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER:

DATE OF REPORT: 11/09/10

SOIL ANALYSIS REPORT

PAGE: 1

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	$NaHCO_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
IH-15	54772	2.0L	70	20 *	10M	108L	673M	3627M	1095VH	7.8		0.0	28.7	1.0	19.3	63.1	0.0	16.6
IH-50	54773	2.1L	72	20 *	12M	97L	729M	3953M	992VH	7.6		0.0	30.3	0.8	19.8	65.1	0.0	14.3
IH-60	54774	2.9M	88	1VL	7L	233L	1236M	7589H	1160H	7.5		0.0	53.7	1.1	18.9	70.6	0.0	9.4
IH-75	54775	2.0L	70	9L	13M	76L	704H	3237M	651VH	7.5		0.0	25.0	0.8	23.2	64.7	0.0	11.3
IH-90	54776	2.7M	84	14L	5L	103L	820M	5333H	677H	7.5		0.0	36.6	0.7	18.4	72.8	0.0	8.1

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO_3-N ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS SAND %	SILT %	CLAY %	SOIL TEXTURE
IH-15	3VL	269VH	0.4VL	3M	9L	1.1M	1.6H	H	2.2H			62	18	19	SANDY LOAM
IH-50	6L	517VH	0.6L	3M	10L	1.3H	1.0M	L	2.9H			68	14	17	SANDY LOAM
IH-60	2VL	212VH	0.4VL	1VL	6L	1.4H	0.9M	L	1.8M			38	34	27	CLAY LOAM
IH-75	4VL	262VH	0.4VL	2L	7L	1.7H	0.4L	L	2.6H			72	12	15	SANDY LOAM
IH-90	2VL	124VH	0.2VL	1VL	3VL	0.9M	0.4L	L	1.4M			34	34	31	CLAY LOAM

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
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This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

M Buttress
Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

A & L WESTERN AGRICULTURAL LABORATORIES
1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 10-309-056

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUTE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER:

DATE OF REPORT: 11/09/10

SOIL ANALYSIS REPORT

PAGE: 2

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	$NaHCO_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
IH100	54777	1.8L	65	15 *	7L	71L	679H	3653M	729VH	7.6		0.0	27.2	0.7	20.6	67.1	0.0	11.7
IH130	54778	1.8L	65	14L	4L	69L	694H	3061M	475H	7.5		0.0	23.2	0.8	24.6	65.8	0.0	8.9

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO_3-N ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS			
												SAND %	SILT %	CLAY %	SOIL TEXTURE
IH100	8L	398VH	0.5VL	3M	8L	10.3VH	0.6M	L	1.7M			66	16	17	SANDY LOAM
IH130	5L	151VH	0.5VL	7M	8L	3.6VH	0.5L	L	1.9M			74	12	13	SANDY LOAM

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
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MOST SOILS WEIGH TWO (2) MILLION POUNDS (DRY WEIGHT) FOR AN ACRE OF SOIL 6-2/3 INCHES DEEP

This report applies only to the sample(s) tested. Samples are retained a maximum of thirty days after testing.

Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

Palm Desert CC

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 10-309-057

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER:

DATE OF REPORT: 11/10/10

SOIL ANALYSIS REPORT

PAGE: 1

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	$NaHCO_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
PD-30	54779	0.6L	42	11 *	5L	109	53	443	54	7.8		0.0	3.2	8.8	13.7	69.9	0.0	7.5
PD-60	54780	0.7L	43	10 *	7L	79	36	331	26	7.7		0.0	2.3	8.9	13.0	73.1	0.0	5.0
PD-90	54781	0.4L	39	17 *	6L	73	38	309	20	7.8		0.0	2.1	8.7	14.8	72.3	0.0	4.2
PD120	54782	0.7L	43	26 *	5L	95	52	407	49	7.6		0.0	2.9	8.4	14.7	69.6	0.0	7.4
PD150	54783	0.6L	42	4 *	6L	124	63	591	57	8.1		0.0	4.0	7.9	12.8	73.1	0.0	6.1

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO_3-N ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS			
												SAND %	SILT %	CLAY %	SOIL TEXTURE
PD-30	3VL	14M	0.2VL	2L	10L	0.5L	0.2VL	L	0.2VL			88	4	7	SAND
PD-60	6L	7L	0.1VL	2L	12M	0.3VL	0.1VL	L	0.2VL			90	2	7	SAND
PD-90	7L	5L	0.1VL	1VL	8L	0.1VL	0.2VL	L	0.2VL			90	2	7	SAND
PD120	7L	8L	0.4VL	2L	9L	0.3VL	0.2VL	L	0.2VL			90	2	7	SAND
PD150	5L	14M	0.1VL	1VL	11M	0.2VL	0.2VL	L	0.3L			90	2	7	SAND

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
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M Buttress

Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

Palm Desert CC (continued)

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 10-309-057

CLIENT NO: 9999-D

SEND TO: DESERT RESEARCH INSTITUTE
755 EAST FLAMINGO RD
LAS VEGAS, NV 89119-

SUBMITTED BY: JOHN M HEALEY

GROWER:

DATE OF REPORT: 11/10/10

SOIL ANALYSIS REPORT

PAGE: 2

SAMPLE ID	LAB NUMBER	Organic Matter		Phosphorus		Potassium	Magnesium	Calcium	Sodium	pH		Hydrogen	Cation Exchange Capacity	PERCENT CATION SATURATION (COMPUTED)				
		* % Rating	** ENR lbs/A	P1 (Weak Bray) **** * ppm	$NaHCO_3$-P (OlsenMethod) **** * ppm	K ***** * ppm	Mg *** * ppm	Ca *** * ppm	Na *** * ppm	Soil pH	Buffer Index	H meq/100g	C.E.C. meq/100g	K %	Mg %	Ca %	H %	Na %
PD180	54784	0.6L	42	11 *	8M	84	39	436	88	8.1		0.0	3.1	6.9	10.4	70.3	0.0	12.4

* Weak Bray unreliable at M or H excess lime or pH > 7.5

SAMPLE NUMBER	Nitrogen NO_3-N ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Excess Lime Rating	Soluble Salts mmhos/cm	Chloride Cl ppm		PARTICLE SIZE ANALYSIS			
												SAND %	SILT %	CLAY %	SOIL TEXTURE
PD180	7L	6L	0.1VL	1VL	9L	0.1VL	0.2VL	L	0.2VL			88	4	7	SAND

* CODE TO RATING: VERY LOW (VL), LOW (L), MEDIUM (M), HIGH (H), AND VERY HIGH (VH).
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Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC.

APPENDIX H

ANALYTICAL RESULTS OF SAMPLES COLLECTED AT GOLF COURSE SITES

Notes:

- Trip blanks are not included

Wildhorse GC

Collection Date	7/27/2009	7/27/2009	7/27/2009	10/7/2009	10/7/2009	10/7/2009	2/1/2010	2/1/2010
Description	Irrigation Pond	Well	Decorative Pond	Irrigation Pond	Well	Decorative Pond	Well	Irrigation Pond
Analyte	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L
Sulfamethoxazole	190	<6.8	11	160	<6.4	15	5.4	22
Atenolol	35	<27	<29	33	<26	<26	<1.0	24
Trimethoprim	10	<6.8	<7.2	<7.0	<6.4	<6.4	<0.25	3.3
Fluoxetine	<13	<13	<14	<14	<13	<13	<0.50	<0.50
Meprobamate	700	<6.8	90	810	<6.4	130	<0.25	580
Carbamazepine	150	<13	<14	170	<13	20	<0.50	75
Diazepam	<6.6	<6.8	<7.2	<7.0	<6.4	<6.4	<0.25	5.9
Atorvastatin	<13	<13	<14	<14	<13	<13	<0.50	<0.50
Gemfibrozil	16	<6.8	<7.2	69	<6.4	<6.4	<0.25	13
Diclofenac	120	<14	250	<14	<13	<13	<0.50	60
Naproxen	<13	<14	<14	<14	<13	<13	<0.50	<0.50
Triclosan	78	57	160	120	270	300	30	32
Ibuprofen	<26	<27	<29	<28	<26	<26	<1.0	<1.0

APPENDIX H (continued)

Wildhorse GC (continued)

Collection Date	2/1/2010	2/26/2010	5/4/2010	5/4/2010	5/4/2010	5/4/2010	5/4/2010	9/22/2010
Description	**Decorative Pond**	**Flux 1/Flux 2**	**Decorative Pond**	**Irrigation Pond**	**Well**	**Lower Chamber (WH3)**	**Upper/Lower Chamber (WH2)**	**Decorative Pond**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	5.0	<3.5	4.1	8.1	5.6	<3.4	<3.0	4.3
Atenolol	<1.0	<14	<1.0	25	<1.0	<14	<12	<1.0
Trimethoprim	<0.25	<3.5	<0.25	<0.25	<0.25	<3.4	<3.0	<0.25
Fluoxetine	<0.50	<7.0	<0.50	3.1	<0.50	<6.8	<6.0	<0.50
Meprobamate	24	<3.5	28	540	<0.25	300	<3.0	100
Carbamazepine	5.3	<7.0	9.0	95	<0.50	44	<6.0	15
Diazepam	0.49	<3.5	0.38	4.0	<0.25	<3.4	<3.0	<0.25
Atorvastatin	<0.50	<7.0	<0.50	<0.50	<0.50	<6.8	<6.0	<0.50
Gemfibrozil	0.83	<3.5	1.8	3.9	<0.25	<3.5	<3.0	0.60
Diclofenac	28	<7.0	<0.50	<0.50	<0.50	74	<60	<0.50
Naproxen	<0.50	<7.0	4.1	<0.50	<0.50	<7.0	<60	<0.50
Triclosan	5.5	<14	6.0	140	270	<14	<12	53
Ibuprofen	<1.0	<14	<1.0	<1.0	2.9	<14	<120	<1.0

APPENDIX H (continued)

Wildhorse GC (continued)

Collection Date	9/22/2010	9/22/2010	9/22/2010	11/10/2010	11/10/2010	11/16/2010	11/16/2010	11/10/2010	11/10/2010
Description	**Well**	**Irrigation Pond**	**Flux Upper/Lower**	**Well**	**WD 0.0**	**Decorative Pond**	**Irrigation Pond**	**Upper 1**	**Upper 2/3**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	4.5	9.5	<3.0	4.7	7.8	24	9.4	<4.0	<3.1
Atenolol	<1.0	20	<12	<1.0	<1.0	2.1	14	<16	<12
Trimethoprim	<0.25	<0.25	<3.0	<0.25	<0.25	<0.25	<0.25	<4.0	<3.1
Fluoxetine	<0.50	3.7	<6.0	<0.50	<0.50	<0.50	3.4	<8.0	<6.2
Meprobamate	0.32	540	<3.0	0.43	13	340	700	<4.0	<3.1
Carbamazepine	<0.58	110	<6.0	<0.50	4.8	54	86	<8.0	<6.2
Diazepam	<0.25	7.3	<3.0	<0.25	<0.25	1.2	5.1	<4.0	<3.1
Atorvastatin	<0.50	<0.50	<6.0	<0.50	<0.50	<0.50	<0.50	<8.0	<6.2
Gemfibrozil	<0.30	8.1	<3.0	<0.25	<0.25	8.5	11	<4.0	<3.1
Diclofenac	<0.50	<0.50	<30	0.51	<0.50	<0.50	<0.50	<80	<62
Naproxen	<0.50	<0.50	<6.0	<0.50	<0.50	<0.50	<0.50	<8.0	<6.2
Triclosan	130	35	170	68	2.3	89	68	<16	46
Ibuprofen	6.2	5.0	<12	2.6	<1.0	<1.0	<1.0	<80	<62

Wildhorse GC (continued)

Collection Date	12/14/2010	12/14/2010	12/14/2010	12/14/2010	12/14/2010
Description	**Well**	**Decorative Pond**	**Irrigation Pond**	**Lower 2**	**Lower 3**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	4.1	21	41	4.4	<0.50
Atenolol	<1.1	<1.1	76	<12	<12
Trimethoprim	0.32	<0.28	4.4	<3.1	<0.50
Fluoxetine	<0.53	<0.57	1.8	<6.2	<6.2
Meprobamate	<0.26	400	770	<3.1	4.8
Carbamazepine	<0.53	65	140	<6.2	<6.2
Diazepam	<0.26	1.7	6.2	<3.1	<3.1
Atorvastatin	<0.53	<0.57	<0.55	<6.2	<6.2
Gemfibrozil	<0.26	4.7	27	<3.1	<3.1
Diclofenac	0.60	<0.57	<0.55	<6.2	<6.2
Naproxen	<0.53	<0.57	14	<6.2	<6.2
Triclosan	120	14	2.0	<12	<12
Ibuprofen	<1.1	<1.1	<1.1	<125	13

APPENDIX H (continued)

Silver Creek Valley CC

Collection Date	6/2/2009	6/2/2009	6/2/2009	6/26/2009	7/23/2009	8/27/2009	8/27/2009	10/9/2009
Description	**Gauge 1**	**Gauge 2**	**Gauge 3**	**Consolidated Sample**	**Consolidated Sample**	**Upper Silver Creek**	**Recycled Water**	**Consolidated Sample**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	<14	130	<33	75	<7.2	<12.5	380	37
Atenolol	<56	<38	<130	<77	<29	<50	130	<26
Trimethoprim	<14	<9.5	<33	<19	<7.2	<12.5	37	<6.4
Fluoxetine	<28	<19	<65	<38	<14	<25	<13	<13
Meprobamate	<14	170	130	118	28	25	300	64
Carbamazepine	<28	78	<65	58	17	37	210	30
Diazepam	<14	<9.5	<33	<19	<7.2	<12.5	<6.4	<6.4
Atorvastatin	<28	<19	<65	<38	<14	<25	<13	<13
Gemfibrozil	<14	26	<33	<19	<7.2	<12.5	160	<6.4
Diclofenac	<28	<19	<65	<38	<14	<25	<13	<13
Naproxen	<28	<19	<65	<38	<14	<25	<13	<13
Triclosan	<56	<38	<130	<77	<29	<50	<26	<26
Ibuprofen	<56	<38	<130	<77	<29	<50	<26	<26

Silver Creek Valley CC (continued)

Collection Date	**10/29/2009**	**10/29/2009**	**12/14/2009**	**12/14/2009**	**1/11/2010**	**2/1/2010**	**3/8/2010**	**3/8/2010**
Description	**Fairway #18 Consolidated Sample**	**Recycled Water**	**Consolidated Sample, Lower Chamber**	**Consolidated Sample, Upper Chamber**	**Upper/Lower Chamber**	**Upper/Lower Chamber**	**Upper Chamber**	**Lower Chamber**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	28	240	6.0	5.0	2.5	6.6	3.2	<1.2
Atenolol	<24	470	<4.6	<3.9	<2.9	<2.1	<3.9	<5.0
Trimethoprim	<6.1	42	<1.2	<0.98	<0.72	<0.52	<0.98	<1.2
Fluoxetine	<12	<12	<2.3	<2.0	<1.4	<1.0	<2.0	<2.5
Meprobamate	90	290	18	20	6.8	4.2	1.4	1.5
Carbamazepine	48	180	18	34	21	16	18	16
Diazepam	<6.1	<6.2	<1.2	<0.98	<0.72	<0.52	<0.98	<1.2
Atorvastatin	<12	<12	<2.3	<2.0	<1.4	<1.0	<2.0	<2.5
Gemfibrozil	<6.1	110	<1.2	<0.98	<0.72	<0.52	<0.98	<1.2
Diclofenac	<12	<12	<2.3	<2.0	<1.4	<1.0	<2.0	<2.5
Naproxen	<12	<12	<2.3	<2.0	<1.4	<1.0	<2.0	<2.5
Triclosan	<24	<25	<4.6	2.0	<2.9	6.5	<3.9	<5.0
Ibuprofen	<24	<25	<4.6	<3.9	<2.9	<2.1	<3.9	<5.0

Silver Creek Valley CC (continued)

Collection Date	3/26/2010	3/26/2010	4/30/2010	4/30/2010	5/20/2010	5/20/2010	6/25/2010	6/25/2010	7/22/2010	7/22/2010	7/22/2010
Description	**Upper Chamber**	**Lower Chamber**	**Upper Chamber**	**Lower Chamber**	**Upper Chamber**	**Lower Chamber**	**Upper Chamber**	**Lower Chamber**	**Upper Chamber**	**Lower Chamber**	**Recycled Water**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	3.9	2.2	1.6	<0.82	11	6.7	2.6	1.4	28	8.5	97
Atenolol	<4.5	<5.3	<4.5	<3.3	<2.0	<2.4	<2.7	<4.4	<4.8	<5.0	170
Trimethoprim	<1.1	<1.3	<1.1	<0.82	<0.50	0.86	<0.67	<1.1	<1.2	<1.2	67
Fluoxetine	<2.2	<2.7	<2.2	<1.6	<1.0	<1.2	<1.3	<2.2	<2.4	<2.5	15
Meprobamate	3.0	2.7	6.6	3.1	37	22	13	14	110	32	160
Carbamazepine	17	17	15	15	26	20	26	16	49	19	120
Diazepam	<1.1	<1.3	<1.1	<0.82	<0.50	<0.61	<0.67	<1.1	<1.2	<1.2	2.2
Atorvastatin	<2.2	<2.7	<2.2	<1.6	<1.0	<1.2	<1.3	<2.2	<2.4	<2.5	<1.0
Gemfibrozil	<1.1	<1.3	<1.1	<0.82	13	6.9	1.2	2.0	15	3.2	110
Diclofenac	<2.2	<2.6	<2.2	1.7	<5.0	<2.5	15	26	<12	<12	<5.0
Naproxen	<2.2	<2.6	<2.2	<1.6	<1.0	<1.2	<1.4	<2.2	<2.4	<2.5	<1.0
Triclosan	23	<5.3	<4.5	<3.3	<2.0	<2.4	9.1	25	<4.8	<5.0	<2.0
Ibuprofen	<4.5	<5.3	<4.5	<3.3	<2.0	3.0	<2.7	<4.4	<4.8	<5.0	<2.0

Collection Date	**8/23/2010**	**8/23/2010**	**8/23/2010**	**9/29/2010**	**9/29/2010**	**9/29/2010**	**10/21/2010**	**11/30/2010**	**11/30/2010**
Description	**Upper Chamber**	**Lower Chamber**	**Recycled Water**	**18th Fairway, Upper Consolidated**	**18th Fairway, Lower Consolidated**	**Upper 1, 2 and 3**	**18th Fairway, Upper/Lower Consolidated**	**18th Fairway Upper**	**18th Fairway Lower**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	15	7.5	100	23	42	11	<3.8	1.2	<5.4
Atenolol	<2.8	<2.4	240	<4.0	<5.0	<16	<15	<2.5	<22
Trimethoprim	1.8	<0.61	42	<1.0	1.5	<3.9	<3.8	<0.62	<5.4
Fluoxetine	<1.4	0.55	17	<2.0	<2.5	<7.8	<7.5	<1.2	<11
Meprobamate	83	44	290	87	150	42	47	6.1	<5.4
Carbamazepine	41	23	110	44	78	21	21	20	22
Diazepam	<0.70	<0.61	1.9	<1.0	<1.2	<3.9	<3.8	<0.62	<5.4
Atorvastatin	<1.4	<1.2	<0.91	<2.0	<2.5	<7.8	<7.5	<1.2	<11
Gemfibrozil	13	<0.60	95	15	27	6.3	<3.8	<0.62	<5.4
Diclofenac	<1.4	<1.2	<0.90	<2.0	<2.5	<8.0	<38	<12	<11
Naproxen	<2.5	<2.5	<2.5	<2.0	<2.5	<8.0	<7.5	<1.2	<11
Triclosan	<2.8	<2.4	5.9	<4.0	<5.0	<16	<15	<2.5	<22
Ibuprofen	<5.0	<5.0	<5.0	<4.0	<5.0	<16	<15	<2.5	<22

Silver Creek Valley CC (continued)

Collection Date	12/8/2010	12/8/2010	12/21/2010
Description	18th Fairway Upper	18th Fairway Lower	18th Fairway Upper/Lower
Analyte	ng/L	ng/L	ng/L
Sulfamethoxazole	<3.0	<0.82	1.3
Atenolol	<12	<3.3	<3.5
Trimethoprim	<3.0	<0.82	<0.88
Fluoxetine	<6.0	<1.6	<1.8
Meprobamate	7.3	7.7	2.2
Carbamazepine	18	14	30
Diazepam	<3.0	<0.82	<0.88
Atorvastatin	<6.0	<1.6	<1.8
Gemfibrozil	<3.0	<0.82	<0.88
Diclofenac	<60	<16	<1.8
Naproxen	<6.0	<1.6	<1.8
Triclosan	<12	<3.3	<3.5
Ibuprofen	<12	<3.3	<3.5

Zaharias GC (Industry Hills)

Collection Date	**11/13/2009**	**11/13/2009**	**12/2/2009**	**12/2/2009**	**12/30/2009**	**1/28/2010**	**4/2/2010**	**4/23/2010**	**7/26/2010**
Description	**Upper chamber**	**Lower chamber**	**Upper chamber**	**Irrigation Pond**	**Upper/Lower Chamber**	**Upper/Lower Chamber**	**Irrigation Pond**	**Lower Chamber**	**Irrigation Pond**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	39	35	<5.2	270	<1.3	12	140	<3.4	58
Atenolol	<17	<13	<21	170	<5.3	<6.4	85	<14	29
Trimethoprim	<4.3	<3.2	<5.2	35	<1.3	<1.6	32	<3.4	3.7
Fluoxetine	<8.6	<6.4	<10	14	<1.3	<3.2	13	<6.8	2.9
Meprobamate	140	140	120	440	18	<1.6	400	8.9	420
Carbamazepine	76	81	78	220	56	41	180	45	240
Diazepam	<4.3	<3.2	<5.2	<5.0	<1.3	<1.6	2.8	<3.4	4.0
Atorvastatin	<8.6	<6.4	<10	<10	<2.6	<3.2	<0.50	<6.8	<0.50
Gemfibrozil	<4.3	<3.2	<5.2	340	<1.3	<1.6	430	<3.4	67
Diclofenac	<8.6	<6.4	<100	2.3	<2.6	4.1	6.2	<6.8	<2.5
Naproxen	<8.6	<6.4	4.6	14	<2.6	<3.2	7.1	<6.8	<0.50
Triclosan	<17	<13	<21	14	<5.3	11	2.3	<14	3.1
Ibuprofen	<17	<13	<21	<20	<5.3	<6.4	<5.0	<14	<1.0

Zaharias GC (Industry Hills) (continued)

Collection Date	**10/22/2010**	**10/22/2010**	**10/22/2010**	**11/19/2010**	**12/13/2010**	**1/5/2011**	**1/5/2011**	**1/5/2011**
Description	**Irrigation Pond**	**Upper Chamber**	**Lower Chamber**	**Upper/Lower Chamber**	**Upper/Lower Chamber**	**Upper Chamber**	**Lower Chamber**	**Irrigation Pond**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	180	<5.0	<1.2	<1.2	<1.0	1.3	0.73	190
Atenolol	27	<20	<5.0	<4.6	<4.2	<2.0	<2.0	31
Trimethoprim	18	<5.0	<1.2	<1.2	<1.0	<0.50	<0.50	26
Fluoxetine	6.6	<10	<2.5	<2.3	<2.1	<1.0	<1.0	6.3
Meprobamate	450	<5.0	10	2.8	1.4	0.88	0.44	380
Carbamazepine	200	<10	20	25	41	27	10	150
Diazepam	3.2	<5.0	<1.2	<1.2	<1.0	<0.50	<0.50	1.6
Atorvastatin	<0.50	<10	<2.5	<2.3	<2.1	<1.0	<1.0	<0.50
Gemfibrozil	170	<5.0	<1.2	<1.1	<1.0	<0.50	<0.50	140
Diclofenac	8.4	<10	<5.0	<23	<21	<1.0	<1.0	<0.50
Naproxen	16	<10	<2.5	<2.3	<2.1	<1.0	<1.0	<0.50
Triclosan	6.2	<20	<5.0	<4.6	<4.2	<2.0	<2.0	3.9
Ibuprofen	<20	<20	<5.0	<46	<4.2	<2.0	<2.0	<1.0

APPENDIX H (continued)

Palm Desert CC

Collection Date	12/4/2009	12/4/2009	12/31/2009	1/29/2010	1/29/2010	2/19/2010	3/19/2010	4/30/2010
Description	**Upper chamber**	**Lower Chamber**	**Upper/Lower Chamber**	**Upper/Lower Chamber**	**WRP #9**	**Upper/Lower Chamber**	**Upper/Lower Chamber**	**Irrigation Pond**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	<6.2	22	<1.1	12	520	13	<1.6	270
Atenolol	<25	34	<4.4	<3.6	780	<3.3	<6.2	430
Trimethoprim	<6.2	<1.2	<1.1	<0.89	220	<0.82	<1.6	66
Fluoxetine	<12	<2.4	<2.2	<1.8	44	<1.6	<3.1	7.4
Meprobamate	45	<1.2	<1.1	<0.89	1700	<0.82	<1.6	1400
Carbamazepine	<12	24	30	18	14	21	4.0	3.4
Diazepam	<6.2	<1.2	<1.1	<0.89	5.9	<0.82	<1.6	3.8
Atorvastatin	<12	<2.4	<2.2	<1.8	0.64	<1.6	<3.1	<0.50
Gemfibrozil	<6.2	<1.2	<1.1	<0.89	2000	<0.82	<1.6	2100
Diclofenac	<12	<24	<2.2	<1.8	1.9	<1.6	<3.1	2.5
Naproxen	7.2	<2.4	98	<1.8	47	<1.6	<3.1	81
Triclosan	8.3	<4.8	8.6	11	5.4	<3.3	<6.2	5.7
Ibuprofen	<25	<4.8	<4.4	<3.6	320	<3.3	<6.2	<1.0

Palm Desert CC (continued)

Collection Date	10/15/2010	1/7/2011	1/7/2011	1/7/2011
Description	**WRP 9**	**Upper Chamber**	**Lower Chamber**	**WRP #9**
Analyte	**ng/L**	**ng/L**	**ng/L**	**ng/L**
Sulfamethoxazole	600	11	11	41
Atenolol	710	<14	<2.4	1300
Trimethoprim	62	<3.5	<0.60	14
Fluoxetine	15	<7.0	<1.2	39
Meprobamate	1400	2.5	1.5	880
Carbamazepine	45	24	22	15
Diazepam	4.4	<3.5	<0.60	3.1
Atorvastatin	<0.50	<7.0	<1.2	<0.50
Gemfibrozil	2100	<3.5	<0.60	400
Diclofenac	8.5	<7.0	<1.2	9.0
Naproxen	100	<7.0	<1.2	<0.0
Triclosan	7.2	<14	<2.4	8.2
Ibuprofen	69	<14	<2.4	92

GLOSSARY OF TERMS

Adsorption:	The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surfaces of solids by chemical or physical binding.
Degradation:	The process whereby a compound is transformed into simpler compounds.
Evapotranspiration (ET):	The combined loss of water from a given area, and during a specified period of time, by evaporation from the soil surface and by transpiration from plants.
Flux:	The time rate of transport of a quantity across a given area.
Leaching Fraction:	The fraction of infiltrated irrigation water that percolates below the rootzone.
Redox Potential:	Measurement to assess the aeration status of soil.
Unsaturated Pore Volume:	The amount of water held in a given profile relative to the total pore space that has reached stable conditions under an imposed irrigation treatment.
Reference ET:	Calculated ET rate of an actively growing reference crop, not limited by soil water content, and having specified plant and biophysical characteristics. Reference ET from clipped, cool-season grass is denoted ETo and while the same from full-cover alfalfa is denoted as ETr.
Soil Water Content:	The water lost from the soil upon drying to constant mass at 105ºC; expressed either as the mass of water per unit mass of dry soil or as the volume of water per unit bulk volume of soil.

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Co-published by

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Email: publications@iwap.co.uk
Web: www.iwapublishing.co
IWAP ISBN: 978-1-78040-023-5/1-78040-023-3

Feb 2012