

POTENTIAL EFFECTS OF A LARGE-SCALE HOUSING DEVELOPMENT AND
ASSOCIATED GOLF COURSE ON THE EDWARDS AQUIFER
IN SAN MARCOS, TEXAS

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Laura B. McCalla, B.S.

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POTENTIAL EFFECTS OF A LARGE-SCALE HOUSING DEVELOPMENT AND
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Committee Members Approved:

Glenn Longley, Chair

Walter Rudzinski

Benjamin Schwartz

Approved:

J. Michael Willoughby
Dean of the Graduate College

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ABSTRACT

POTENTIAL EFFECTS OF A LARGE-SCALE HOUSING DEVELOPMENT AND ASSOCIATED GOLF COURSE ON THE EDWARDS AQUIFER IN SAN MARCOS, TEXAS

by

Laura Betty McCalla, B.S.

Texas State University-San Marcos

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SUPERVISING PROFESSOR: DR. GLENN LONGLEY

A large-scale housing development, Paso Robles, is planned for construction in the southwest outskirts of San Marcos, Texas, and will result in the placement of residential homes, small commercial businesses, new roads, and a golf course adjacent to and on the sensitive Edwards Aquifer recharge zone where surface water enters the aquifer system. There is concern that the construction process and subsequent residential use of lawn chemicals such as herbicides and insecticides will adversely influence the water quality of surrounding areas. Further concern lies with the planned application of effluent, or reclaimed wastewater, from the San Marcos Wastewater Treatment Plant for irrigation of the golf course.

This research sought to establish a pre-construction baseline understanding of water quality conditions in the region around the future Paso Robles development and associated golf course. To accomplish this, water samples from nine groundwater wells in the vicinity of the future development were monitored bimonthly, beginning in January 2011 and continuing through July 2012.

GC-MS-MS (gas chromatography-mass spectrometry-mass spectrometry) analysis of groundwater samples detected the presence of select compounds typically found to persist in treated wastewater: triclosan (11% detection frequency), triethyl citrate (4%), and TCEP (2%). Common insecticides and herbicides detected with this method include DEET (28%), malathion (4%), permethrin (1%), and atrazine (2%). The use of passive sampling semi-permeable membranes assisted the sampling for and analysis of volatile and semi-volatile organic compounds at select wells. Detections through this method included the following: total petroleum hydrocarbons (73%), PCE (12%), undecane (10%), benzene (5%), fluorine (5%), and tridecane (2%). Although these detections occurred at extremely low levels (ppb and ppt), their presence in the Edwards Aquifer groundwater supports the need for continuous monitoring of well water samples; particularly during the construction process and upon completion of the Paso Robles housing development and associated golf course.

CHAPTER I

INTRODUCTION

1.1. Structure of the Edwards Aquifer

The Edwards Aquifer, which underlies approximately 4,000 square miles (10,360 square kilometers), is a karst aquifer composed of faulted and fractured Cretaceous-age carbonate rocks (Figure 1) (Ryder 1996; Smith et al. 2005). Over an extended period of time, flowing water containing carbonic acid can chemically dissolve carbonate rocks, such as limestone and dolomite. Carbonic acid in groundwater arises from the accumulation of atmospheric carbon dioxide as precipitation infiltrates and moves downwards through the soil and epikarst. The dissolution of carbonate rocks creates pipe-like channels called conduits, and enlarges pores and fractures through which water flows. These processes have produced the karstic Edwards Aquifer, which is highly porous and permeable in nature (Abbott 1977; Hovorka et al. 2004; Hamilton et al. 2010). Over time, the permeability and porosity of karst increases and enhances the storage capacity of the groundwater system (Abbott 1977; Ford and Williams 2007). The residence time for water in the Edwards Aquifer has been found to range from hours or days to hundreds of years. Residence time is directly related to the depth of circulation, location in the Edwards, and other aquifer parameters such as size and distribution of

pores and fissuring (Hanson and Small 1995; Stone and Schindel 2002; Hamilton et al. 2006).

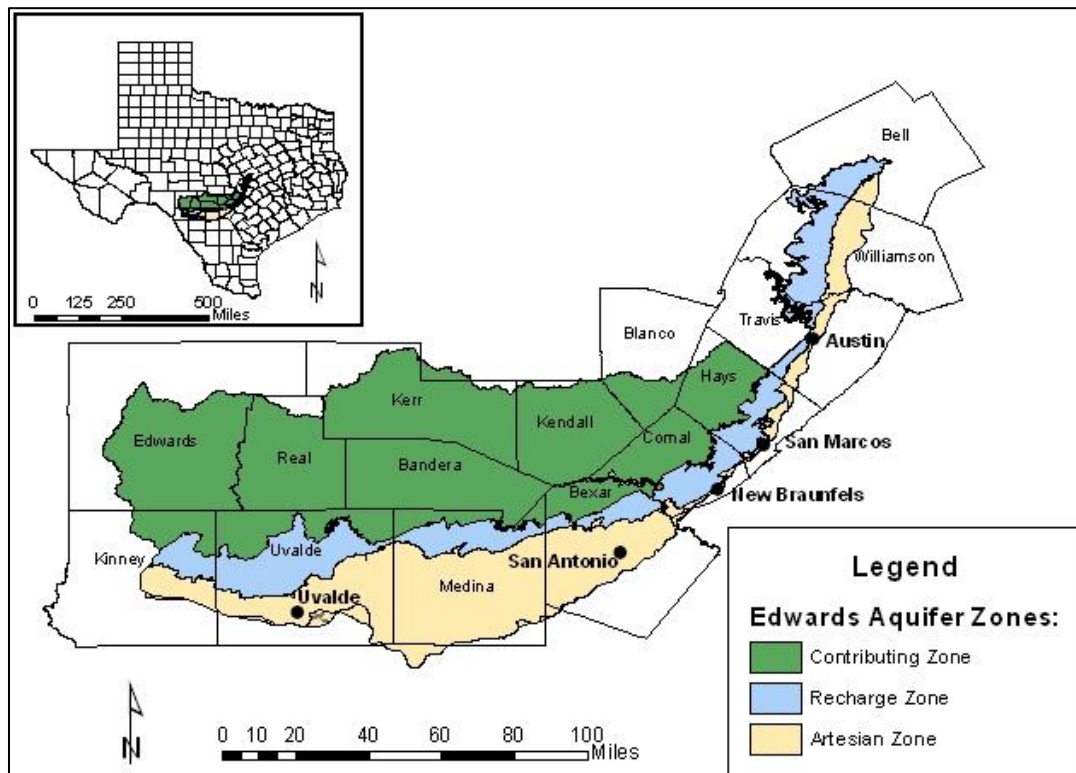


Figure 1. Zones of the Edwards Aquifer in central Texas.

Large quantities of water recharge the Edwards Aquifer as streams flowing south or east from the Texas hill country contributing zone cross the faulted recharge zone (Figure 2). The contributing, or drainage, zone is composed primarily of Cretaceous rocks containing the Trinity Aquifers. These are formed in the Glen Rose and Pearsall formations which are Lower Cretaceous rocks lying stratigraphically beneath the Edwards Group. Additionally, rainwater infiltrates diffusely and directly (via surface openings in the karst) in the upland areas between the streams, and contributes to recharge in the Edwards Aquifer via cross-formational flow (Ogden et al. 1986; Hanson and Small 1995; Kuniansky et al. 2001; Ferril et al. 2004; Blome et al. 2007).

The Edwards Aquifer recharge zone includes approximately 1,700 square miles (4,400 square kilometers) and occurs along the Balcones Fault Zone. Extensive faulting in this region is the result of uplift and down-dropping, as well as the shifting of large limestone blocks towards the southeast. Millions of years of erosion exposed the uplifted Edwards Limestone at the ground surface along the southern boundary of the Texas hill country (Figure 2) (Ross and Rice 2005; Johnson et al. 2009; Hamilton et al. 2010). As blocks within this system were downthrown along faults to the south and toward the Gulf of Mexico, the Balcones Fault Zone created fracture networks that increased the permeability of the Edwards Aquifer. In addition, this fault system has increased the hydrologic gradient through uplift of the base of the Edwards Group (Hovorka et al. 2004; Johnson et al. 2009).

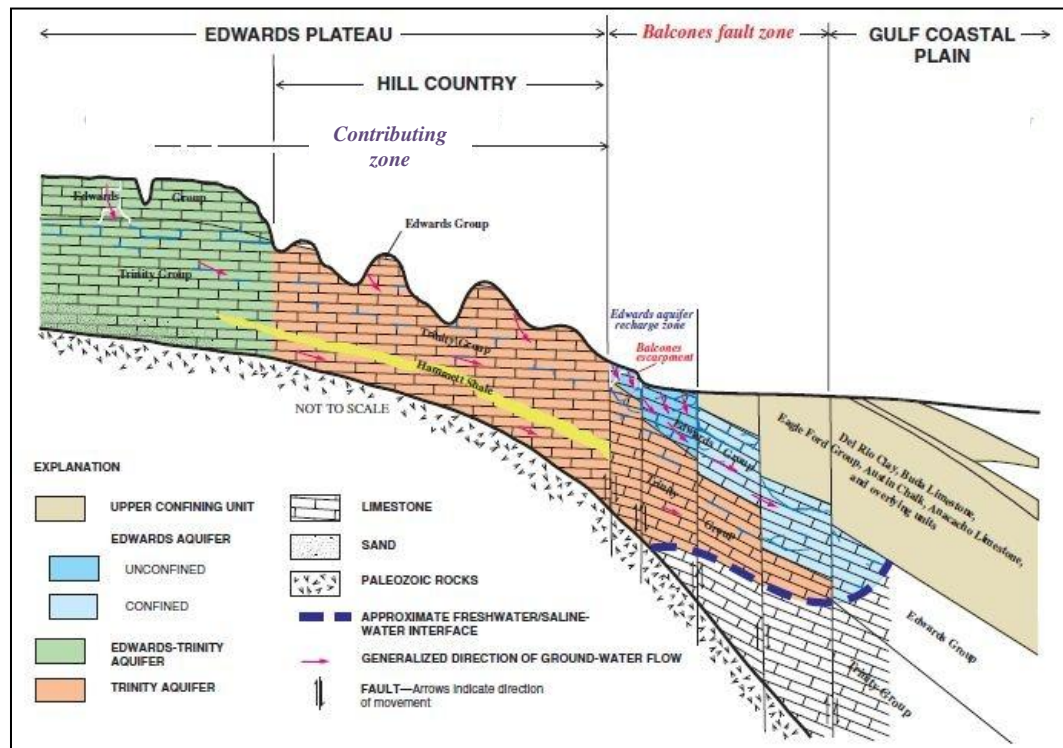


Figure 2. Structural cross-section of the Edwards Aquifer (modified from Barker and Ardis 1996).

The Balcones Fault Zone of the Edwards Aquifer crosses portions of nine counties of south central Texas. These include Kinney, Uvalde, Medina, Bexar, Comal, Hays, Travis, Williamson, and Bell counties (Figure 1). Water flows along and through this recharge zone consisting of echelon, high-angle normal faults parallel to the Balcones Escarpment, which divides two major physiographic eco-regions of Texas: The karstic Edwards Plateau to the west, and the Blackland Prairie of the Gulf Coastal Plains to the south/southeast (Figure 2) (Ogden et al. 1986; Hanson and Small 1995; Kuniansky et al. 2001; Ferrill et al. 2004).

The highly fractured recharge zone of the Edwards Aquifer received an average annual recharge of approximately 560,900 acre-feet for the period of 1934 to 2010. Total recharge in 2010 was 813,400 acre-feet. An acre-foot is the volume of water needed to cover 1 acre to a depth of 1 foot, and is a common unit of measurement for groundwater discharge and recharge values (Hamilton et al. 2011). Average discharges from the aquifer via springs and wells are approximately equivalent to the average amount of recharge (Grubb 1997). For instance, in 2010 the total discharge from both springs and wells was 862,831 acre-feet (Hamilton et al. 2011).

Water generally moves from the unconfined recharge zone of the Edwards Aquifer to the south and/or east towards the narrow faulted and fractured transition zone. Immediately down-dip of the transition zone is the artesian zone, which is fully saturated and confined by the upper Del Rio Clay and overlying younger rocks, and the lower Glen Rose formation, which is part of the Trinity Group of Lower Cretaceous rocks (Figure 2) (Hanson and Small 1995; Hamilton et al. 2006; Blome et al. 2007; Johnson et al. 2009). Water gravitationally flows downward into this zone, allowing for the buildup of

sufficient hydraulic pressure to force water from the Edwards Aquifer up through faults and wells to the surface (Ogden et al. 1986). In general, groundwater in the Edwards Aquifer moves in a southwest to northeast direction through a highly permeable system of fractures, faults, solutionally enhanced porosity, and conduits which make up the aquifer (Ogden et al. 1985; Smith et al. 2005; Hamilton et al. 2006; Murray et al. 2007; Hamilton et al. 2010).

In an unconfined aquifer setting, or one that possesses no confining layer, as with some sections of the Edwards Aquifer (Figure 2), water infiltrates and moves vertically downward through rocks that are only partially saturated. This unsaturated area is referred to as the vadose zone, and is in relatively free communication with the surface (Ford and Williams 2007). Under the influence of gravity, water moves vertically until it reaches the level at which all pores are filled with water, or are saturated. This area is referred to as the phreatic zone. The level, or elevation, of the transition from the unsaturated zone to the phreatic zone is called the water table. The elevation of the water table at any given point and time is related to both the aquifer properties and the amount of water infiltrating the vadose zone and reaching the water table, which is called recharge (White 1988). The depth of the vadose zone is thus determined by the relative lowering of surface water as permeability increases through time, and also by the variable height of the water table (Ford and Williams 2007).

In a confined aquifer system, however, surface water and precipitation are unable to directly recharge the aquifer by means of percolation through overlying soil and rock. This is due to the presence of an overlying confining bedrock unit that has very low hydraulic conductivity, or the ability to transmit water under a given hydraulic gradient.

This confining unit therefore restricts the vertical movement of groundwater either into or out of the aquifer (Heath 1987).

The geology of the Edwards Aquifer beneath the San Marcos area in Hays County, Texas is composed of three stratigraphic units with a combined thickness of approximately 430 – 660 feet (131 – 200 meters). The deepest and oldest unit is referred to as the Kainer Formation, and has an approximate thickness of 240 – 330 feet (73 – 100 meters). Above that unit is the Person Formation with an approximate thickness of 170 – 270 feet (52 – 82 meters). Collectively, these two formations create the Edwards Limestone Group. The third stratigraphic unit, which lies above the Person Formation, is known as the Georgetown Limestone, and has an approximate thickness of 20 – 60 feet (6 – 18 meters). The Kainer and Person formations are further divided into seven hydrostratigraphic subunits as determined by their transmissivity and other physical characteristics (Figure 3) (Ogden et al. 1985; Bluntzer 1992; Barker et al. 1994; Hanson and Small 1995; Barker and Ardis 1996).

Era	System	Series	Stage	Stratigraphic Unit (group, formation, or member)			Approximate Thickness (feet)	Lithology	Hydrologic Function	
Mesozoic	Upper Cretaceous	Gulfian	Navorroan	Navarro Group			300 - 500	Clay, chalky limestone	Confining Units	
			Tayloran	Taylor Group			300 - 500			
			Austinian	Austin Group			200 - 350			
			Eaglefordian	Eagle Ford			50 - 250	Brown, flaggy, sandy shale and argillaceous limestone		
	Lower Cretaceous	Comanchean	Washitan	Buda Limestone			100 - 200	Buff, light gray, dense mudstone	Confining Unit	
				Del Rio Clay				Blue-green to yellow-brown clay		
				Georgetown Formation				20 - 60		
				Edwards Group	Person Formation	Cyclic and marine members, undivided	90 - 150	Mudstone to packstone, miliolid grainstone, chert	Edwards Aquifer	
						Leached and collapsed members, undivided	60 - 90	Crystalline limestone, mudstone to grainstone, chert, collapsed breccia		
						Regional dense member	20 - 30	Dense, argillaceous mudstone		
			Fredericks-burgian	Kainer Formation	Grainstone member	50 - 60	Miliolid grainstone, mudstone to wackestone, chert			
					Kirschberg evaporite member	150 - 200	Crystalline limestone, chalky mudstone, chert			
					Dolomitic member		Mudstone to grainstone, crystalline limestone, chert			
					Basal nodular member	40 - 70	Shaly, nodular limestone, mudstone miliolid grainstone			
			Trinitian	Upper Glen Rose			300 - 400	Alternating beds of nodular marl, fossiliferous limestone, porous dolomite	Upper Trinity Aquifer Unit (lower confining unit to Edwards Aquifer)	Trinity Aquifer
				Lower Glen Rose			200 - 250	Limestone, dolostone, dolomitic limestone beds; mollusk assemblages and local rudist reefs		
				Pearsall Formation	Hensel Sand Member (Bexar Shale Member)		± 210	Red to gray clay, silt, calcareous sand, chert, quartz, thin limestone beds	Middle Trinity Aquifer Unit	
					Cow Creek Member		± 88	Calcarenite, carbonate concretions, sand, shale, lignite, gypsum, anhydrite		
					Hammett Shale Member (Pine Island Shale Member)		± 130	Fossiliferous, calcareous and dolomitic shale; limestone, sand	Confining Unit	
				Sligo Formation			800 - 1500	Sandy dolomitic limestone, limestone, dolomite and shale	Lower Trinity Aquifer Unit	
			Hosston (Sycamore) Formation			Sandstone, siltstone, claystone, shale, dolomite, limestone and basal conglomerate				
Paleozoic			Undifferentiated Paleozoic Rocks						Paleozoic Aquifers	

Figure 3. Generalized representation of the stratigraphic section for Hays County.

1.2. Importance of the Edwards Aquifer

Groundwater from the Edwards Aquifer is heavily used for municipal, agricultural, and recreational purposes (Longley and Jordan 1996; Hamilton et al. 2011). Nearly two million residents in Hays County and the New Braunfels/San Antonio region rely on the Edwards Aquifer as their sole-source of public water (Ogden et al. 1986; Hanson and Small 1995; Hamilton et al. 2011). Historically, the high-quality water of the Edwards Aquifer prompted the cities of New Braunfels, Uvalde, San Antonio, and San Marcos to be founded near the springs that discharge from the aquifer (Hamilton et al. 2009). The two largest spring groups in the state of Texas, Comal and San Marcos springs, are sustained by water discharged from the Edwards Aquifer. Additional springs that discharge from the aquifer include Hueco, San Pedro, San Antonio, and Leona springs (Ogden et al. 1986).

Furthermore, there are over 40 specialized surface and subsurface aquatic species associated with the Edwards Aquifer and connected streams. Of these, seven are listed as endangered (Longley 1986). They include the fountain darter (*Etheostoma fonticola*), Texas blind salamander (*Eurycea rathbuni*), Comal Springs riffle beetle (*Heterelmis comalensis*), Comal Springs dryopid beetle (*Stygoparnus comalensis*), Peck's Cave amphipod (*Stygobromus pecki*), and Texas wild rice (*Zizania texana*). The San Marcos salamander (*Eurycea nana*) inhabits San Marcos Springs, which discharges from the Edwards Aquifer, and is listed as threatened under the US Fish and Wildlife Service's endangered and threatened species report (USFWS 2012).

1.3. Vulnerability of the Edwards Aquifer

Although the karstic Edwards Aquifer generally exhibits very high water quality, its high porosity and permeability can allow for fluctuation as a result of rapid recharge events which often introduce municipal, industrial, or agricultural land runoff (Hamilton et al. 2010). Historically, water quality was better because the contributing and recharge zones were primarily undeveloped (Hamilton et al. 2010). Currently, however, sprawling development is occurring at a rapid rate in central Texas and is perhaps the biggest threat to the Edwards Aquifer as a result of surface contamination (Hanson and Small 1995; Ferrill et al. 2004).

Anthropogenic activities in the contributing and recharge zones of the Edwards can greatly contribute to degrading water quality in areas where land use is being transformed from ranching to residential and/or commercial development (Stone and Schindel 2002). Development on the extremely faulted and fractured karst limestone in the Balcones Fault Zone results in the increased likelihood of leakage or spilling of hazardous materials, which would enter the aquifer with little to no filtration (Hanson and Small 1995). In addition, increases in the amount of impervious cover, such as residential streets, sidewalks, parking lots, concrete-lined channels, and rooftops; also disrupt the relationship between rainfall and the local soil and vegetation. As a result, rainfall drains quickly into recharge features and carries increased contaminant loads relative to natural runoff and recharge (Ross and Rice 2005).

The average annual withdrawal of groundwater from the Edwards Aquifer over the past ten years has been estimated by the Edwards Aquifer Authority to be 378,000

acre-feet. This estimated ten-year average withdrawal was calculated based on metered use throughout the region and does not account for unmetered use, such as that of smaller residential wells. The average withdrawal rate for domestic stock use within this same ten year period was found to be 14,000 acre-feet, and an average of 88,000 acre-feet was estimated to be used for irrigation. Industrial and commercial use contributed to an estimated average withdrawal of 30,000 acre-feet, and municipal use created an average estimated withdrawal of 246,000 acre-feet.

The total withdrawal amount coupled with the estimated spring discharge creates an average groundwater discharge value of 894,000 acre-feet over the past ten years. The estimated total groundwater recharge value of the Edwards Aquifer for the same time period was calculated as 985,000 acre-feet (Hamilton et al. 2011). Along with an increased likelihood of groundwater contamination, there is concern throughout the region that without proper management, the Edwards Aquifer will not contain sufficient water to support the demands of a growing population without detrimental effects to spring flows. In addition to a larger demand on the aquifer, the development process, particularly over portions of the recharge zone, could ultimately reduce the number of recharge features that are so crucial for the replenishment of the Edwards Aquifer to support the growing demand.

1.4. Location and Geology of the Study Area

The San Marcos area in south-central Texas is characterized by a moderate to humid subtropical climate with hot summers and relatively mild winters. Average

maximum temperature for August, which is typically the warmest month, is 95.4⁰F (35.2⁰C), and the average minimum temperature in the coldest month, January, is 38.6⁰F (3.7⁰C). Average annual precipitation for the area is 37.19 in (94.46 cm), often with the wettest month being May. However, the yearly distribution of precipitation can be highly variable and irregular (NOAA NWSFO 2012).

The karstic Edwards Plateau lies to the northwest of the San Marcos area, and is characterized by thin to non-existent soils over bedrock. To the south/southeast, the topography transitions into the Blackland Prairie of the Gulf Coastal Plains with flat to low, hilly prairie. This region consists primarily of clay-rich soils that are locally silty and calcareous (BEG-UT 1999).

The United States Department of Agriculture Natural Resource Conservation Service has identified various soil groups in the San Marcos area: Comfort-Rumple-Eckrant, Lewisville-Gruene-Krum, Heiden-Houston Black, and some Drum-Medlin-Eckrant. The Comfort-Rumple-Eckrant group is characterized by shallow to moderately deep, steep to hilly soils over limestone on the Edwards Plateau, and the Lewisville-Gruene-Krum group is composed of deep to very shallow gently sloping soils over loamy, clayey gravel sediments of stream terraces and valleys of the Edwards Plateau and Blackland Prairie. Similarly, the Krum-Medlin-Eckrant group has deep to very shallow, undulating to steep hilly soils over clay, shale, and limestone of the stream terraces and valleys of the Edwards Plateau. The Heiden-Houston Black group consists of deep, gently sloping soils over clay and shale of the Blackland Prairie (USDA Bureau of Soils 1906). Vegetation in the San Marcos area is dominated by the presence of Live Oak,

Ashe Juniper, Cedar Elm, and Honey Mesquite trees. Prevalent land use in this area includes sprawling development and agriculture (Hill Country Alliance 2012).

The area of interest for this study is the future site of the Paso Robles housing development and associated golf course. This development of approximately 1,452 acres will lie just north of Hunter Road/FM 2439 in the southwestern outskirts of San Marcos, Texas, and will result in the placement of approximately 3,600 residential homes, small commercial businesses, new roads, and a golf course adjacent to and over portions of the Edwards Aquifer crucial recharge zone where water enters the aquifer system (Figures 4 and 5).

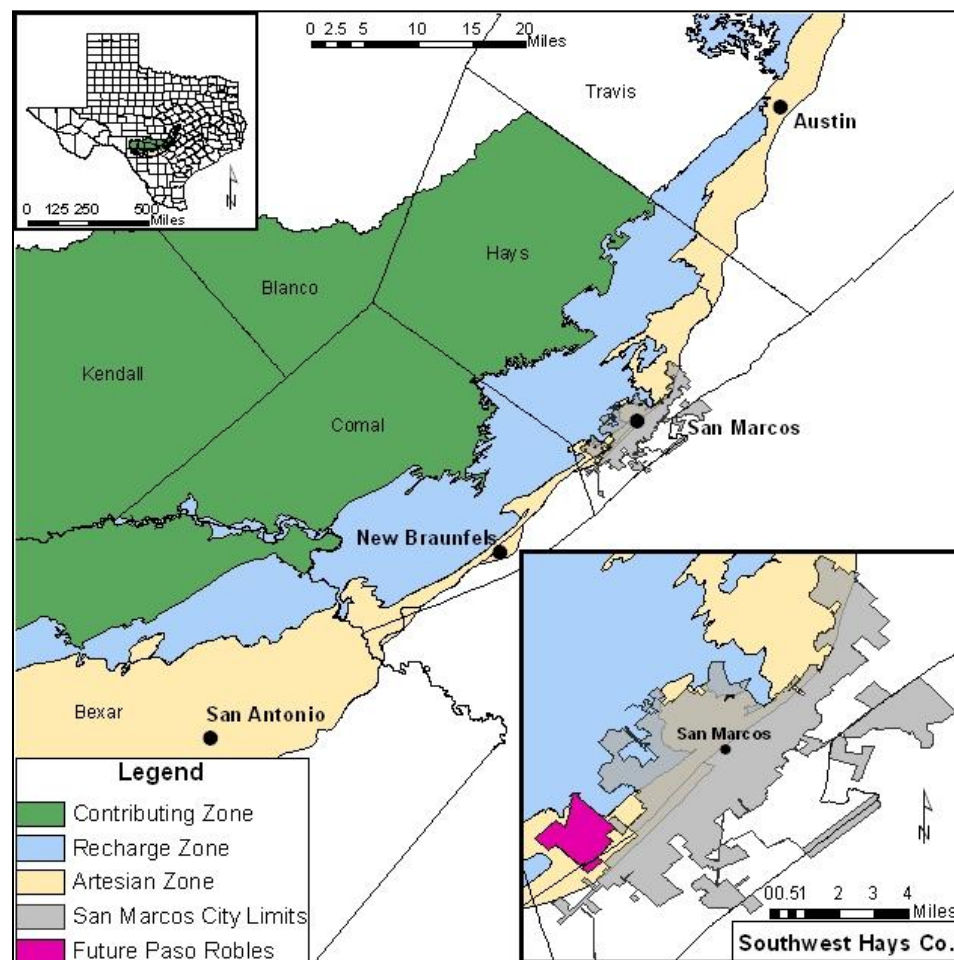


Figure 4. Location of the future Paso Robles housing development in the southwest outskirts of San Marcos, Texas, Hays County.

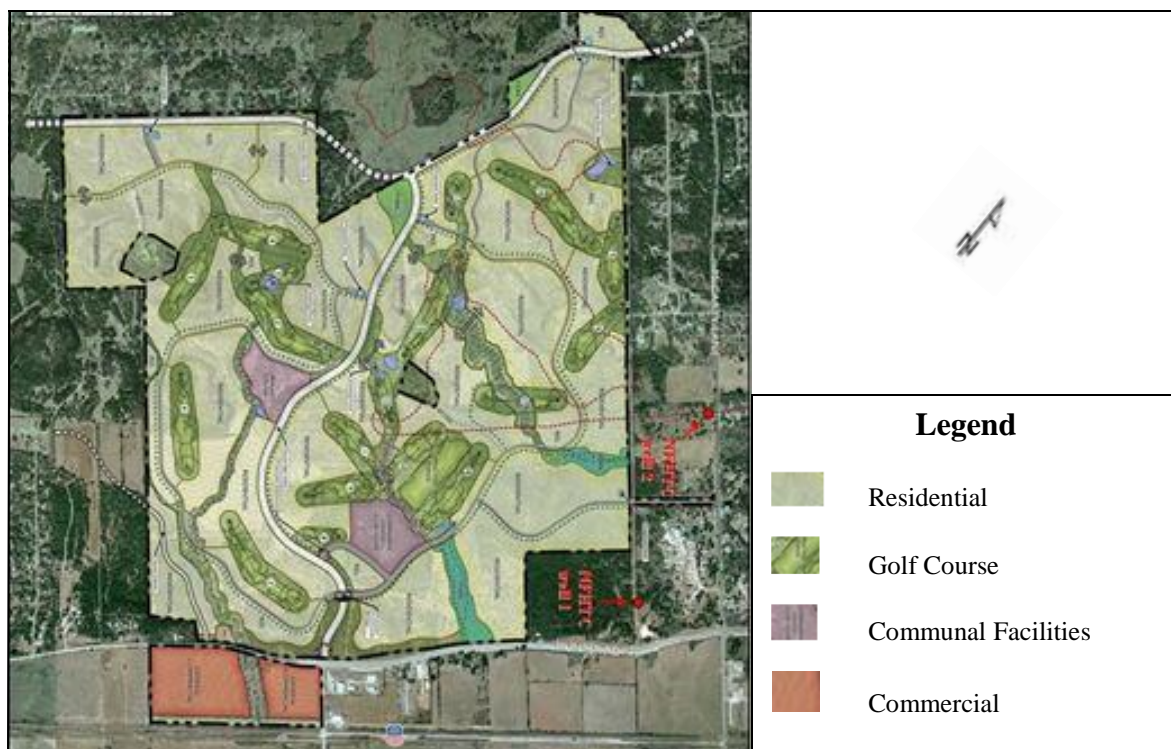


Figure 5. Paso Robles land use plan, courtesy of the City of San Marcos, Texas.

Although the Paso Robles Best Management Practices state that only organic compounds are to be used for treatment of the associated golf course, there is concern that the construction process and subsequent residential use of lawn chemicals such as herbicides and insecticides will adversely influence the water quality of surrounding areas, particularly downgradient (south and northeast) of the Paso Robles site (Ogden et al. 1985; Smith et al. 2005; Murray et al. 2007; Hamilton et al. 2009).

Additional concerns have been raised over the planned application of effluent, or reclaimed wastewater, from the San Marcos Wastewater Treatment Plant on the golf course for irrigation. A holding pond is to be constructed on-site into which treated effluent will be directly pumped from the City of San Marcos Wastewater Treatment Plant via underground pipelines that will be constructed. According to the Paso Robles Best Management Practices, the pond will be surrounded with native vegetation to

theoretically act as a buffer and aid in the confinement of the effluent within the pond. The effluent will then be piped throughout the development for golf course irrigation. The Paso Robles Best Management Practices have identified only three holes of the golf course that will lie over a portion of the recharge zone. High quality drinking water supplied by the City of San Marcos is to be used to irrigate the sections of the course containing these three holes.

Contamination of the underlying local groundwater could occur through the introduction of endocrine-disrupting compounds associated with some herbicides and insecticides, excess nutrients, and compounds that have been found to remain in reclaimed wastewater. For instance, a previous study assessing the efficiency of the San Marcos Wastewater Treatment Plant found that more than 90% of compounds that are known health risks, and are found initially in untreated influent, are removed by the treatment process. However, some potentially harmful residuals, including known or suspected endocrine disruptors, were detected in more than 60 percent of samples of the city's treated effluent, or reuse water. These included carbamazepine, triethyl citrate, tris (2-chloroethyl) phosphate (TCEP), triclosan, and caffeine. Other known or suspected endocrine-disrupting compounds that were detected in less than 60 percent of the City's effluent samples included sulfamethoxazole, coprostanol, N,N-diethyl-meta-toluamide (DEET), nonylphenol, diltiazem, and estradiol. Many of these compounds are associated with pharmaceuticals, and some are classified as insecticides or flame retardants (Foster 2007).

Endocrine disruptors can interfere with the production and function of natural hormones produced in organisms, including humans. The recycling of wastewater onto

the Paso Robles golf course and the residential use of herbicides and insecticides could allow such compounds to contaminate the near-surface environment and ultimately the groundwater. Prolonged exposure to these compounds could detrimentally affect groundwater fauna. The effects of such exposure on humans are not sufficiently understood or adequately studied (Foster 2007).

A further potential source of contamination concerning the development of Paso Robles could lie within the construction processes. For instance, polycyclic aromatic hydrocarbons (PAHs) can be formed during the incomplete burning of oil, coal, or gas. They are also found in construction materials such as asphalt, and are thought to be fairly insoluble in water and hazardous to aquatic life (Barrett et al. 1995). Throughout the entire construction process, the aquifer may be exposed to numerous volatile and semi-volatile organic compounds, such as PAHs, which can be associated with products such as gasoline, paints, adhesives, and plastics. Many of these compounds are known or suspected carcinogens, and may enter the Edwards Aquifer through pathways such as urban runoff following rain events, leaks, spills of fuels or lubricants, and exhaust from gasoline engines (Moran et al. 2006).

Both organic and inorganic water soluble compounds will move with the water within an aquifer system. Organic compounds which are less dense than water and are slightly soluble, such as petroleum hydrocarbons, will float on the water and often accumulate behind obstructions within the conduit systems. Organic compounds that are slightly soluble but denser than water, such as chlorinated hydrocarbons, often sink to the bottom of an aquifer and may even adhere to sediments. Over time, these compounds may degrade and dissolve or become entrained into the moving water (Ford and Williams

2007). It is thus imperative that routine water analyses be conducted in order to aid in the early detection and prevention of contamination to groundwater.

In addition to occurring adjacent to and over portions of the sensitive recharge zone, the large-scale Paso Robles housing development and associated golf course will occur near two wells that supply water to the San Marcos National Fish Hatchery and Technology Center. This facility maintains captive populations of most of the associated Edwards Aquifer listed species. The construction of the housing development, subsequent chemical treatment of lawns, and application of wastewater effluent on the golf course may ultimately impact the quality of groundwater utilized by downgradient wells. The severity of these impacts will be unknown unless adequate post-construction analyses are performed.

This research sought to establish a pre-construction baseline understanding of water quality in the region of the future Paso Robles development and associated golf course. This was done through the analysis of water samples from nine wells immediately surrounding, or in some cases within the future development site, that were inferred to be either upgradient or downgradient from Paso Robles based on the general southwest to northeast directional flow paths of the Edwards Aquifer (Ogden et al. 1985; Smith et al. 2005; Hamilton et al. 2006; Murray et al. 2007; Hamilton et al. 2009).

The goal of this research was to ultimately aid in characterizing the vulnerability of the Edwards Aquifer within this region to actions which may introduce contaminants. Baseline data acquired prior to construction can be applied to future studies, and ultimately enhance the likelihood of timely identification of potential contamination and promote further investigation of the effects of anthropogenic surface activity on

subsurface aquatic environments such as the Edwards Aquifer. The research may also aid in future modifications of management practices for Paso Robles and its associated golf course, and help protect crucial environmental aspects of the aquifer and its sources of recharge from potential future contamination.

CHAPTER II

METHODS AND MATERIALS

Nine groundwater wells in the vicinity of the future Paso Robles housing development and associated golf course were monitored bimonthly from January 2011 through July 2012 to establish a local baseline water quality profile prior to construction (Figure 6). Four of the nine wells are owned and operated by the City of San Marcos for municipal purposes (labeled CSM-m, -s, -k, and -h), two are owned by the San Marcos National Fish Hatchery and Technology Center (FH 1 and 2) and are used to supply water to captive populations of most of the associated Edwards Aquifer listed species. The remaining three wells used for this study are privately owned (labeled P-a, b, and c). In addition to a bimonthly sampling schedule, groundwater samples were also collected following rain events large enough to produce a recharge response. In some cases, noteworthy rain events fell near enough to scheduled sampling to be combined during a scheduled bimonthly sample event.

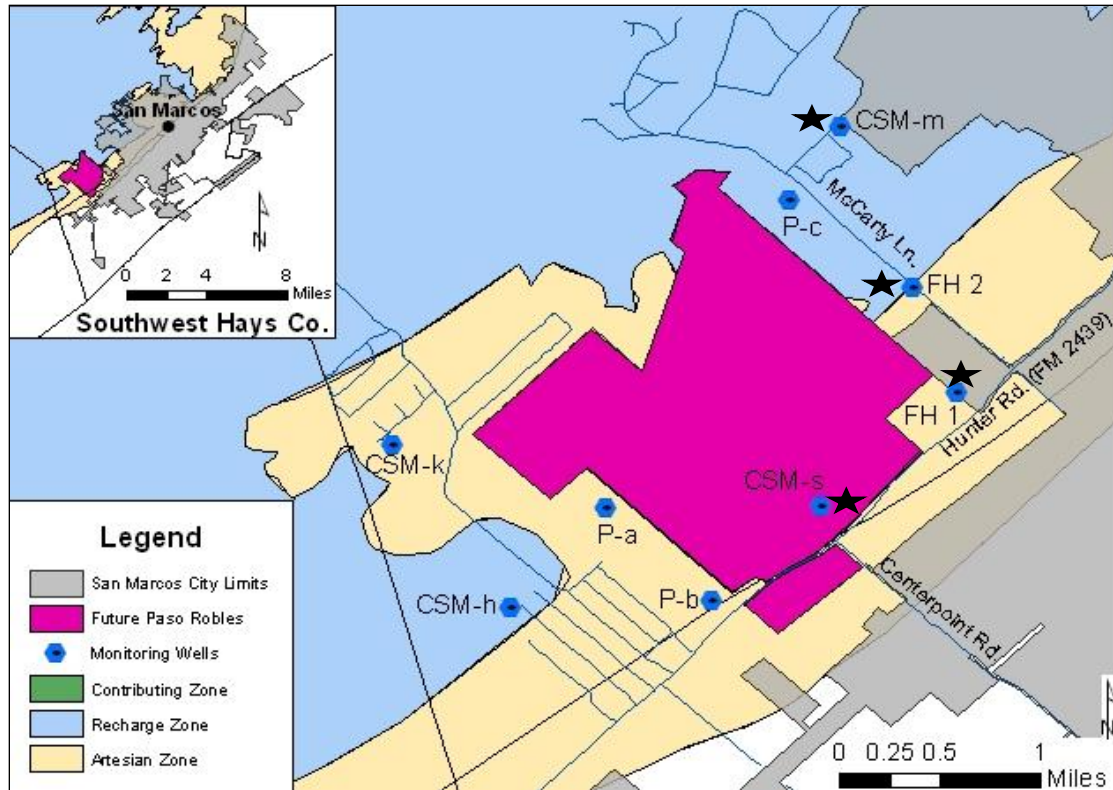


Figure 6. Monitoring well locations and identification names around the future Paso Robles housing development (★ = monitoring well equipped with W.L. Gore passive sampling module).

2.1. Sampling Methods

2.1.1. Water Level Measurements. Measured water level values for accommodating monitoring wells were determined with an electronic Solinst Water Level Indicator prior to well pumping at the start of each sampling event. All wells were purged for approximately 10 to 15 minutes prior to sample acquisition. This amount of time was deemed sufficient as each well monitored for this project is used on a daily basis.

2.1.2. Basic Water Chemistry. Field parameters were collected at each well with the use of a Hydrotech datasonde 5 multiprobe and surveyor recorder, and included

water temperature, pH, dissolved oxygen, and specific conductance (Table 1). The datasonde was calibrated the morning of each sampling event.

Table 1. Field parameters collected at ever sampling event for each monitoring well.

Parameter	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards	Sources of Contamination in Drinking Water	Analytical Method used in this research
Temperature (°C)	NE	---	Field Hydrolab
pH	6.5-8.5 *	Dissolution of acids and bases; dissociation of water molecules	Field Hydrolab
Dissolved Oxygen (mg/L)	NE	---	Field Hydrolab
Specific Conductance (µS/cm)	NE	Natural mineral dissolution	Field Hydrolab

* = National Secondary Drinking Water Regulations; *Source:* (USEPA 2012)

NE = No established MCL or secondary standard

Groundwater collection methods were modeled after USGS ground-water collection protocols and procedures found in the USGS Open-File Report 95-399 (Koterba et al. 1995). Kimberly-Clark Nitrile gloves were worn at each monitoring well, and the use of personal hygiene products, such as lotion, deodorant, and sunscreen; was prohibited. Water samples were obtained directly from a faucet close to the well head at each monitoring site. Half gallon high density polyethylene (HDPE) plastic jugs were filled at each well for the analysis of basic water quality parameters such as cation/anion concentrations, total hardness, total alkalinity, and total dissolved solids (Table 2). Samples were also obtained in 150 mL polystyrene plastic bottles sterilized with sodium thiosulfate to determine the presence of total coliform bacteria and *E. coli* (Table 2). All basic water quality and bacteria samples were kept on ice and submitted to the Edwards Aquifer Research and Data Center without adjustments to pH.

2.1.3. Target Effluent, Insecticide and Herbicide Compounds. For analysis of the targeted known or suspected endocrine disruptors found to frequently persist in treated wastewater from the San Marcos Wastewater Treatment Facility, as well as select insecticides and herbicides (Tables 3 and 4); pre-cleaned 1-liter amber glass bottles were

used to collect water samples at each monitoring wellhead. Each bottle was rinsed with the well water three times prior to collection. Samples were kept on ice and transported to the Bio Assay Laboratory at the Edwards Aquifer Research and Data Center where they are immediately filtered, and their pH was adjusted to 2 with concentrated sulfuric acid (Zaugg et al. 2006). All samples were then stored in a refrigerator at 4°C until analysis, which took place as soon as possible.

2.1.4. Volatile and Semi-Volatile Organic Compounds. This study also utilized passive sampling modules from W.L. Gore & Associates, Inc. Survey Products Group for further groundwater analysis to detect the presence of volatile and semi-volatile organic compounds at select wells (Table 5). Each Gore survey module, approximately 0.25 in (0.64 cm) in diameter and 13 in (33 cm) in length, consisted of a semi-permeable membrane surrounding a series of sorbent packets. The hydrophobic but permeable properties of the modules allowed dissolved volatile contaminants to pass through the membrane and bind with the inner packets (ITRC 2005).

The two San Marcos National Fish Hatchery and Technology Center wells, and two wells owned by the City of San Marcos were each equipped with an airtight flow-through chamber to house the modules (Figure 7). As water was pumped from the well, some was diverted into the flow-through chamber, allowing for a continuous air-tight flow of representative groundwater. With regards to the City wells, the chambers were positioned so as to receive water pumped directly from the well prior to the chlorination process.

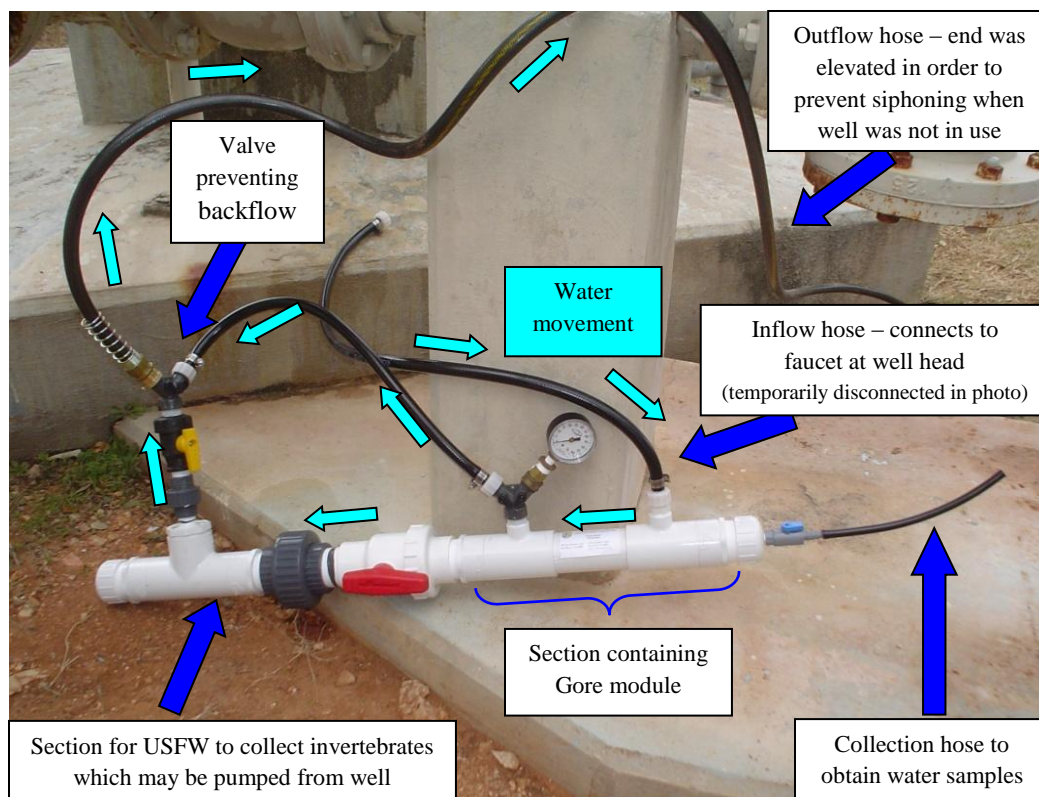


Figure 7. An airtight flow-through chamber for Gore module containment (pictured at a select wellhead owned and operated by the City of San Marcos, Texas).

At the time of each sampling event, a Gore survey module was placed inside each chamber for approximately two to three days to ensure adequate exposure, as the City's wells ran on an 'as needed' basis. Prior to installation of each Gore module, the flow-through chambers were purged for approximately 5 minutes to ensure representative groundwater from each well filled the chamber. The module was then carefully and quickly attached to one end of the chamber and submerged so as to minimize atmospheric contact. Once fully intact, each chamber was purged of air. The chambers were designed to ensure that the modules remained in constant contact with groundwater, even when the wells were not running. This was accomplished through the installation of backflow prevention valves. After adequate exposure, the modules were shipped overnight to the

manufacturer's laboratory for analysis in Elkton, Maryland. A trip blank accompanied each sample module at the time of installation and retrieval for quality assurance.

2.1.5. Precipitation and Storm Water Runoff. Precipitation was measured throughout the study period with the use of an Oregon Scientific wireless rain gauge, as well as with a simple glass gauge in case of instrument failure. Each gauge was positioned clear of overhanging obstacles at the study site. Extensive rainfall can produce a rapid rise of the water table in the karstic Edwards Aquifer in a relatively short amount of time due to areas of high permeability within the aquifer's recharge setting (Hamilton et al. 2011). This often results in variability of the concentrations of compounds and suspended particles within the water (Goldscheider and Drew 2007). As mentioned, scheduled sampling events were accompanied with sampling following rain events that were presumed to have a notable influence on aquifer recharge. This supposition was based on real-time local spring discharge values obtained from the Edwards Aquifer Authority website in partnership with the U.S. Geological Survey, as well as on the general knowledge of recent rain activity, if any, which could influence the permeability of the surface and subsurface (EAA 2012).

Discharge from a tributary of Cottonwood Creek in the site of the future Paso Robles development was measured during storm events capable of creating sufficient surface runoff. This tributary of Cottonwood Creek, which is predominately a dry creek bed, fills with water during heavy rainfall events as surface runoff drains from approximately 300 acres. The creek then flows through a culvert designed to carry the runoff under Hunter Road. Discharge measurements were calculated for each surface

water runoff event by using a sharp-crested, V-notch weir that was installed to the culvert on the upstream side of Hunter Road.

A weir is a common tool that can be used to measure flow in various channel types. There are many forms of the weir, and discharge measurements can be obtained with the use of equations or tables most appropriate to the particular size and shape of the weir. Placed perpendicular to channel flow, a weir contains a notch, or overflow section, of various shapes such as a rectangular or V-shape. Often the notch is created in a plate mounted on the upstream portion of the weir to prevent water clinging to the downstream side of the weir as it flows over the notch, which could result in inaccurate flow measurements. To accurately calculate discharge, the depth, or head of the water flowing over the notch needs to be continuously measured. The base of the notch, also known as the weir crest, provides a baseline measurement of depth zero. The appropriate equation or table is then used to determine the discharge value for each measured depth (USBR 2011).

The weir used for this research, which stood 2 feet in total height, was made of treated plywood securely attached to the 8 x 4 ft (2.4 x 1.2 m) opening of the culvert with the use of angle iron, anchor bolts, and weather-resistant caulking. Two braces were placed on the downstream side of the weir to ensure additional support, should large debris be washed from the drainage basin during strong runoff events. In addition, four weep holes half an inch (1.3 cm) in diameter were drilled across the base of the weir to reduce the accumulation of stagnant water once the water level has receded below the weir crest, or from runoff events not capable of breaching the V-notch.

The base of the notch, or weir crest, measured 0.5 ft (0.2 m) above the ground and created an angle of 130 degrees. V-notch weirs typically have an angle ranging from 25 degrees to 100 degrees, with a 90 degree notch perhaps being one of the more common types (USBR 2011). However, the angle on this particular weir had to be widened in an attempt to appease the Texas Department of Transportation, who regulates the culvert in which the weir was anchored, as well as the landowner of the property on which that portion of Cottonwood Creek drained after emergence from the culvert. The sharp crest of the notch was formed with 2 inch flat iron bars anchored to the upstream side of the weir (Figure 8).



Figure 8. a) Upstream side of the sharp-crested, v-notch weir and staff gage at the base of Cottonwood creek. b) Downstream side of the weir, showing the base of the drainage site.

A crest-stage gage is a useful tool to couple with a weir as it easily allows for the acquisition of water level measurements within the weir pool upstream of the notch. However, the gage should never be placed directly in front of the notch where water can curve as it flows over the crest, which would result in inaccurate head measurements. This gage also allows for the determination of peak flow for each runoff event. The crest-stage gage in this study consisted of a pipe containing a wooden staff marked with a graduated scale. The zero value of the scale was aligned with the weir crest so as to obtain accurate head measurements of surface runoff flowing over the weir. The base of

the pipe contained intake holes to allow for the inflow of water during surface runoff events, and the cap of the pipe contained ventilation holes for the escape of air as the water level began to rise inside the crest-stage gage. Situated inside of the pipe at the base was a perforated tin cup containing granulated cork. As runoff built up in front of the weir, water entered the pipe and allowed the granulated cork to rise as it floated on the water surface. When the water level began to diminish following the peak of the storm, the cork attached to the wooden graduated scale, thus marking the highest water level of each surface water runoff event.

The gage was placed approximately 1 ft (0.3 m) in front of the weir and approximately 2 ft (0.6 m) to the side of the weir crest. In addition, a staff gage was placed on the outside of the crest-stage gage to allow for the easy acquisition of continuous water level measurements during the rise and fall of surface water runoff events. This method of head measurement was performed for the first two storm water runoff events captured during the study period. Measurements were usually verified with the use of an engineer's folding wooden tape measure, which was placed in line with the notch approximately 1 ft (0.3 m) in front of the weir. Measurements were taken every 5 to 10 minutes during runoff events. The latter two recorded storm runoff events for the study period implemented the use of a HOBO U20 Water Level Logger with HOBOWare software, which automatically recorded the absolute pressure (PSI) of the water as it flowed over the notch every five minutes. These pressure values were later converted to feet of water and used to obtain the appropriate head values for each measurement after accounting for the height of the weir crest.

Lastly, an ISCO-6712 Portable Storm Water Sampler was deployed at location of the sharp-crested, V-notch weir. The end of the ISCO sampler collection hose was attached to the weir just below the notch, which insured the acquisition of a representative surface runoff sample as water levels were recorded over the notch. When a sufficient storm event initiated surface runoff through the drainage basin, the ISCO sampler was activated as soon as a liquid level actuator, positioned next to the base of the collection hose, came in contact with water. The sampler was programmed to collect 1 L water samples at intervals of 6 bottles every 5 minutes, 6 bottles every 15 minutes, 6 bottles every 30 minutes, and 6 bottles every hour. Upon conclusion of the sampling event, all sample bottles were removed from the ISCO sampler, packed in ice and transported to the Edwards Aquifer Research and Data Center for analysis. Of the 24 sample bottles collected throughout each surface water runoff event, approximately 10 samples were chosen to represent as much of the rise and fall of each storm event as possible.

2.2. Analytical Methods

2.2.1. Water Level Measurements. Measurements obtained at select wells were compared with historic water level measurements obtained from the Texas Water Development Board for wells in the surrounding area during similar annual weather patterns (TWDB 2011). Latitude and Longitude, as well as land elevation, collection dates, and depth to water measurements were recorded for each well. The historic values were ultimately used to characterize the general groundwater flow patterns surrounding the future site of the Paso Robles housing development and associated golf course

through the construction of a potentiometric map for southwest Hays County. This was accomplished with the utilization of the Spatial Analyst tool in ArcMap 10.

For the construction of the potentiometric map, the water level measurements were used to calculate the hydraulic head of each well, which refers to the energy available for flow at each location in the aquifer system. In general, groundwater flow through an aquifer system is dependent on the aquifer's physical properties, such as hydraulic conductivity, or how easily water moves through the aquifer's material; and effective porosity. Flow within a system occurs from regions of higher mechanical energy to regions of lower mechanical energy within a saturated zone (Hudak 2005).

The flow patterns of an aquifer can be mapped based on changes in hydraulic head, however, it should be noted that the magnitude and direction of flow varies over time at any given location. In addition, heterogeneities and anisotropy caused by faults and fractures can often make the interpretation of this mapping technique somewhat subjective. Nonetheless, under homogenous and isotropic conditions, groundwater will flow in a direction parallel to the steepest energy gradient. This hydraulic gradient can be defined as the difference in hydraulic head between two points in an aquifer divided by the distance between the points (Hudak 2005).

Hydraulic head values were calculated by subtracting the measured depth to water value from the recorded land surface elevation, and plotted for each well of interest within the southwest Hays County potentiometric map. Equipotential lines, similar to the contours of a topographic map, were inserted so as to connect the plotted head measurements of equal values; creating the potentiometric surface (Artiola et al. 2004). From this map, the hydraulic gradient and a generalized direction of groundwater flow

within the vicinity of the future housing development in southwest Hays County were derived. This localized understanding of groundwater movement could ultimately aid in identifying potential contamination pathways throughout and upon the completion of the construction process for the Paso Robles housing development and associated golf course.

2.2.2. Basic Water Chemistry. Procedures to assess basic chemical parameters for water quality analysis of groundwater samples collected throughout the study period were performed by the Edwards Aquifer Research and Data Center located at Texas State University-San Marcos. The following major ions were analyzed: barium, calcium, iron, magnesium, manganese, potassium, silica, sodium, strontium, chloride, fluoride, and sulfate. In addition, concentrations of the nutrients ortho-phosphate as P, nitrite as N, and nitrate-nitrite as N were determined. Additional parameters included total alkalinity, total dissolved solids, total hardness, and the presence of total coliform bacteria and *E. coli*. For each chemical parameter, Table 2 displays the analytical method applied, the U.S. Environmental Protection Agency drinking water maximum contaminant level or secondary standard, and possible sources of contamination in drinking water. The maximum contaminant level (MCL) refers to an enforceable primary standard for the greatest permitted level of a given contaminant in public drinking water for the safeguard of human health. Secondary drinking water standards are non-enforceable standards for concentrations of a given contaminant that may affect aesthetic properties of drinking water, which include odor and appearance (USEPA 2012).

Table 2. Basic water chemistry parameters analyzed for each groundwater sample.

Parameter (mg/L)	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards* (mg/L)	Sources of Contamination in Drinking Water	Analytical Method used in this research
Barium	2	Drilling waste discharge; Industrial discharge; natural erosion deposits	U.S. EPA Method 200.7 (Rev. 4.4)
Calcium	NE	Natural dissolution of carbonate rocks	U.S. EPA Method 200.7 (Rev. 4.4)
Iron	0.3*	Natural dissolution and erosion deposits; Industrial discharge; corrosion of iron containing metals	U.S. EPA Method 200.7 (Rev. 4.4)
Magnesium	NE	Natural mineral dissolution and erosion deposits; industrial discharge	U.S. EPA Method 200.7 (Rev. 4.4)
Manganese	0.05*	Natural dissolution and erosion deposits; Industrial discharge; pesticide runoff	U.S. EPA Method 200.7 (Rev. 4.4)
Potassium	NE	Natural mineral dissolution and erosion deposits; fertilizer runoff; water treatment	U.S. EPA Method 200.7 (Rev. 4.4)
Silicon	NE	Natural mineral dissolution and erosion deposits	U.S. EPA Method 200.7 (Rev. 4.4)
Sodium	NE	Natural mineral dissolution and erosion deposits	U.S. EPA Method 200.7 (Rev. 4.4)
Strontium	NE	Natural mineral dissolution and erosion deposits; industrial processes	U.S. EPA Method 200.7 (Rev. 4.4)
Ortho-phosphate-P	NE	Sewage; fertilizers; decaying organic matter	Standard Method 4500-P E, 21st ed.
Nitrite-N	1	Sewage; fertilizers; decaying organic matter; natural erosion deposits	U.S. EPA Method 353.2 (Rev 2.0)
Nitrate+ Nitrite-N	10	Sewage; fertilizers; decaying organic matter; natural erosion deposits	U.S. EPA Method 353.2 (Rev 2.0)
Chloride	250*	Oil field and industrial brines; natural dissolution; sewage and garbage dump leaching	U.S. EPA Method 300.0 (Rev 2.1)
Fluoride	4	Water treatment additive; natural deposit erosion; fertilizer runoff	Standard Method 4500-F C, 21st ed.
Sulfate	250*	Industrial waste; natural dissolution	U.S. EPA Method 300.0 (Rev 2.1)
Total Alkalinity	NE	Natural dissolution of carbonate rocks (particularly limestone and dolomite)	Standard Method 2320 B, 21st ed.
Total Dissolved Solids	500 *	Natural mineral dissolution	Standard Method 2540 C, 21st ed.
Total Hardness	>180	Natural dissolution of carbonate rocks; presence of calcium and magnesium	Standard Method 2340 C, 20th ed.
Total Coliform Bacteria (MPN/100 mL)	<1	Mammalian and avian feces; leaching sewer lines and septic systems; land runoff	Standard Method 9223 B, 21st ed.
<i>E. coli</i> (MPN/100 mL)	<1	Mammalian and avian feces; leaching sewer lines and septic systems; land runoff	Standard Method 9223 B, 21st ed.

* = National Secondary Drinking Water Standards; *Source:* (USEPA 2012)

NE = No established MCL or secondary standard

2.2.3. Target Effluent, Insecticide and Herbicide Compounds. In partnership with the Environmental Contaminants Lab at the A.E Wood State Fish Hatchery in San Marcos, Texas, gas chromatography-mass spectrometry-mass spectrometry (GC-MS-MS) analysis was used to analyze groundwater samples for compounds that a previous study found to be most frequently detected in 60% of effluent samples obtained from the City of San Marcos Wastewater Treatment Plant (Foster, 2007). These compounds were included in this groundwater analysis project as the Paso Robles golf course best management practices plans to reuse water from the San Marcos Wastewater Treatment Facility for irrigation of the associated golf course. These compounds, which are known or suspected endocrine disruptors, are listed in Table 3. Additional compounds found to frequently persist in local treated effluent samples, carbamazepine and sulfamethoxazole, were planned for analysis with the use of liquid chromatography-mass spectrometry-mass spectrometry (LC-MS-MS), and all samples were prepared accordingly. However, ultimately the LC-MS-MS instrumentation (Thermo Finnigan Surveyor LC 2000 liquid chromatograph equipped with LC Q MSⁿ advantage ion trap mass spectrometer and a surveyor 2000 autosampler) remained inoperable for the duration of the study.

Table 3. Target effluent compounds analyzed with GC-MS-MS for each groundwater sample.

Parameter	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards* (ug/L)	Sources of Contamination in Drinking Water	Analytical Method used in this research
Triclosan	NE	Anti-microbial carried through effluent	GC-MS-MS
Triethyl Citrate	NE	Cosmetics; food additive carried through effluent	GC-MS-MS
Tris (2-chloroethyl) posphate (TCEP)	NE	Fire retardant; manufacturing additive carried through effluent	GC-MS-MS
Carbamazepine	NE	Anti-epileptic carried through effluent	LC-MS-MS
Sulfamethoxazole	NE	Antibiotic carried through effluent	LC-MS-MS

* = National Secondary Drinking Water Standards; *Source:* (USEPA 2012); NE = No established MCL or secondary standard; = LC-MS-MS Compounds that could not ultimately be analyzed for this project.

In addition, Table 4 lists target insecticide and herbicide compounds, many of which are also known or suspected endocrine disruptors, which were analyzed for this study using GC-MS-MS. There were also initial target compounds planned for LC-MS-MS analysis. Again, these could ultimately not be targeted due to equipment failure. These compounds were chosen based on their commercial availability in local stores and the inferred likelihood of their use within the Paso Robles housing development.

Table 4. Target insecticide and herbicide compounds analyzed with GC-MS-MS for each groundwater sample.

Parameter	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards* (ug/L)	Sources of Contamination in Drinking Water	Analytical Method used in this research
Malathion	100**	Insecticide runoff	GC-MS-MS
Permethrin	NE	Insecticide runoff	GC-MS-MS
N, N-diethyl-meta-toluamide (DEET)	NE	Insecticide runoff	GC-MS-MS
Atrazine	3	Herbicide runoff	GC-MS-MS
Carbaryl	NE	Insecticide runoff	LC-MS-MS
Imidacloprid	NE	Insecticide runoff	LC-MS-MS
2,4-Dichlorophenoxyacetic acid (2, 4-D)	70	Herbicide runoff	LC-MS-MS
Triclopyr	NE	Herbicide runoff	LC-MS-MS

* = National Secondary Drinking Water Standards; *Source:* (USEPA 2012); ** = U.S. EPA Lifetime Health Advisory; *Source:* (USEPA 2012); NE = No established MCL or secondary standard; = LC-MS-MS Compounds that could not ultimately be analyzed for this project.

Analysis of samples using GC-MS-MS have been developed based on USGS analytical methods found in Open-File Report 95-181 (Zaugg et al. 1995), and Water-Resources Investigations Report 01-4186 (Zaugg et al. 2006). LC-MS-MS analysis was to be modeled after previously developed analytical methods described by Vanderford et al. (2003). Groundwater samples were prepared for GC-MS-MS and LC-MS-MS through solid phase extraction. Analytes for GC-MS-MS were extracted in batches of five samples using 6 mL/200 mg hydrophilic-lipophilic balance (HLB) cartridges from the Waters Corporation using a BAKER SPE-12G Column Processor. Each cartridge was preconditioned with 5 mL of ethyl acetate, 5 mL of methanol, and 5 mL of reagent

water. Each 1 L (1000 mL) groundwater sample was spiked with the surrogates Atrazine- ^{13}C 3 and Fluoranthene- d 10 to indicate the efficiency of individual sample extraction and aid in the calculation of percent recovery. The samples were then loaded onto the cartridges at a rate of approximately 15 mL/min. After extraction, the cartridges were rinsed with 5 mL of reagent water and dried with a gentle stream of nitrogen for approximately 60 minutes.

The cartridges were then eluted with 10 mL of ethyl acetate and 10 mL of dichloromethane into 40-mL glass vials at a flow rate of approximately 1 mL/min. A small amount of sodium sulfate was added to the sides of each vial to remove any excess water. The extracts were then concentrated to approximately 750 μL with a gentle stream of nitrogen. The concentrated samples were transferred to 2 mL amber glass vials with Teflon® lined septa using a glass Pasteur pipet, and brought to approximately 1 mL with dichloromethane. To each vial, 10 μL of a 100 $\mu\text{g/mL}$ solution of Chrysene- d 10 were added as an internal standard.

The samples were analyzed on a Thermo Scientific TRACE GC ultra-gas chromatograph equipped with a LTQ MSⁿ ion trap mass spectrometer and TriPlus autosampler. Thermo EnviroLab Forms software from Thermo Scientific was used for data processing. A Resteck RTX®-XLB capillary column, 30 m by 0.25 mm id with 25 μm film thickness, was used to separate all analytes. In addition, a Resteck IP Deactivated guard column, 5 m by 0.53 mm, was installed at the front of the analytical column with a Valco internal union. The following column temperature program was used for analysis: an initial temperature of 35°C was held for 3.5 minutes, the first temperature ramp was 100°C/min up to 150°C, and the second temperature ramp was

5°C/min up to 300°C. The total run time was 35 minutes. The carrier gas used for this analysis was helium at a constant flow rate of 1.2 mL/min. The injection port tracked the column oven with no additional heating through the use of cool on-column injection.

The injection volume for this analysis was 1 µL.

The mass spectrometry analysis was conducted by electron impact ionization and operated in tandem (MS-MS) with a source temperature of 250°C. Selection and fragmentation of ions was performed with collision-induced dissociation with helium gas in the ion trap using a range of collision excitation voltages. Conditions for isolation and fragmentation were optimized for each analyte, and can be found in Table 5. Scan intervals generally ranged from approximately 10 m/z greater than precursor ions to approximately 30 m/z less than the product ions. Table 5 also lists precursor ions used for confirmation and quantitation of each compound.

Peak assignment for GC-MS-MS was determined through the comparison of peak retention times and mass spectra produced by known standards with an internal standard of Chrysene-*d*10. A signal to noise ratio (S/N) of 3 was used for each ion when confirming compounds.

Table 5. General conditions used for GC-MS-MS analysis.

Compound	Average MW	GC-MS ² Precursor Ions	Product Ions	MS ² full scan interval
Triclosan	289.55	290, M ⁺	148, 218, 255	100-300
Triethyl Citrate	276.29	203, M ⁺	111, 115, 129	105-210
TCEP	285.49	249, [M-Cl] ⁺	125, 143, 187	100-260
Malathion	330.36	173, M ⁺	127, 145	60-180
Permethrin (2 isomers)	391.29	183, M ⁺	155, 165	95-190
DEET	191.27	190, M ⁺	145, 162, 175	100-200
Atrazine	215.69	215, M ⁺	173, 200	125-225
Chrysene- <i>d</i> 12 (IS)	240.00		240	120-400
Atrazine- ¹³ C3 (SS)	148.53	218, M ⁺	176, 203	125-225
Fluoranthene- <i>d</i> 10 (SS)	212.26		212	106-220

To ensure quality assurance of the GC-MS-MS analysis performed in this research, each sampling event included the following: lab blank, lab control spike, matrix spike, matrix spike duplicate, field blank, and sample duplicates at randomly selected sites to indicate reproducibility. In addition, standards of each GC target compound were prepared at various concentrated levels to create the following calibration curve: 2.5, 5, 50, 100, 250, 500, and 1000 ng/mL. For each batch of analytical samples, a continuing calibration verification was run to validate instrument performance. There were three samples in which TCEP concentrations fell outside of the established curve. These samples were diluted 10x and rerun. Figure 9 represents the chromatogram of the GC compound stock mix.

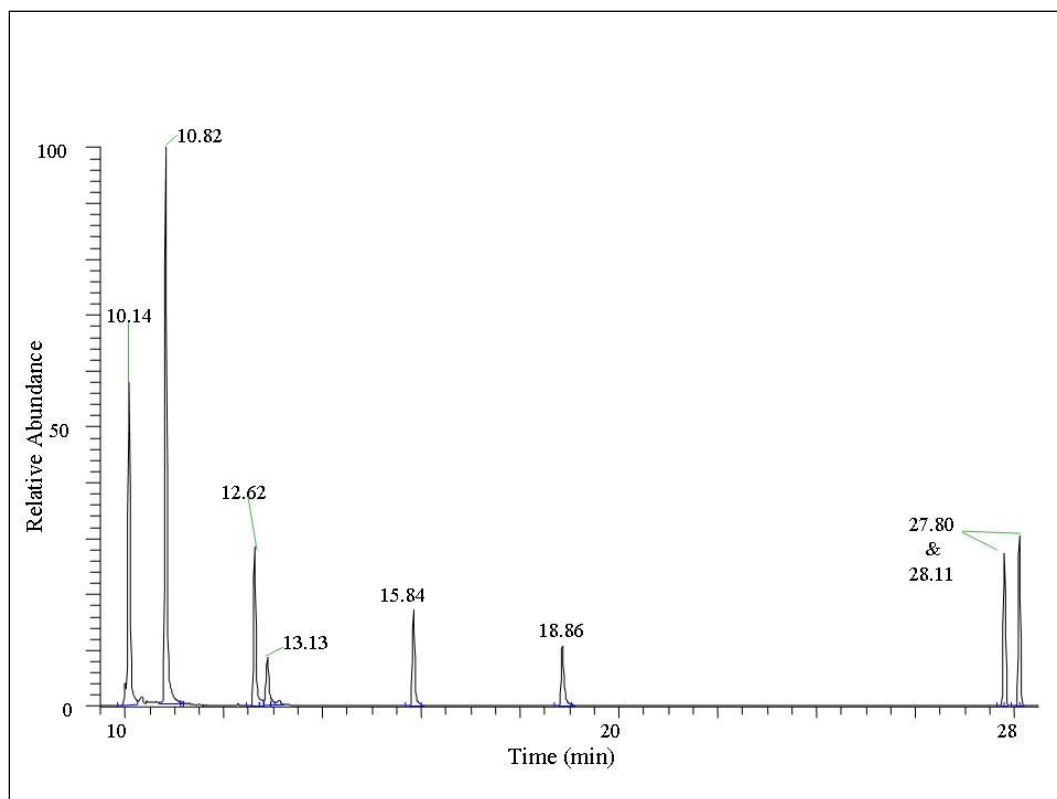


Figure 9. GC-MS-MS total ion chromatograph generated from an analysis of the GC standard mix under optimized conditions. Peak identifications: (10.14) DEET, (10.82) triethyl citrate, (12.62) atrazine, (13.13) TCEP, (15.84) malathion, (18.86) triclosan.

Lastly, a method validation was performed to ensure success and reproducibility of analytical techniques, including extraction and elution of each sample. This involved spiking replicates for GC-MS-MS with all compounds that were analyzed with this chromatographic technique, as well as with the appropriate surrogates. A blank was also extracted and eluted with the replicate validation samples.

Solid phase extraction of groundwater samples for LC-MS-MS analysis was also conducted. However, the surrogates used in this case were 2, 4-D- $^{13}\text{C}_6$ and Acetaminophen- d_4 , which would have been used to validate the efficiency of analyte extraction. Each cartridge for this method was preconditioned with 5 mL of methyl tertiary-butyl ether, 5 mL of methanol, and 5 mL of reagent water. The samples were then loaded onto the cartridge at a flow rate of approximately 15 mL/min, after which the cartridges were rinsed with 5 mL of reagent water and dried with a gentle stream of nitrogen for approximately 60 minutes.

The cartridges were eluted with 5 mL of 10/90 (v/v) methanol/methyl tertiary-butyl ether followed by 5 mL of methanol at a flow of about 1 mL per minute into 40-mL glass vials. The contents were then concentrated to approximately 750 μL with a gentle stream of nitrogen, and transferred to 2 mL amber glass vials with Teflon® lined septa using a glass Pasteur pipet. The samples were brought to approximately 1 mL with methanol. Each vial was then injected with 10 μL of 100 $\mu\text{g/mL}$ solution of caffeine- $^{13}\text{C}_3$ as an internal standard. As mentioned previously, though, final analysis could not be completed for LC-MS-MS.

2.2.4. Volatile and Semi-Volatile Organic Compounds. The use of W.L. Gore passive sampling modules in two wells owned by the City of San Marcos and the two San

Marcos National Fish Hatchery and Technology Center wells aided in the detection of volatile and semi-volatile organic compounds, including polycyclic aromatic hydrocarbons; which could become more prevalent in local groundwater samples once the construction process is underway. As mentioned previously, polycyclic aromatic hydrocarbons may be formed during the incomplete burning of oil, coal, or gas. In addition, these compounds can be found in construction materials such as asphalt (Barrett et al. 1995). Volatile and semi-volatile organic compounds are often associated with products such as gasoline, paints, adhesives, and plastics. Table 6 lists all volatile and semi-volatile organic compounds that each Gore module was designed to detect during each sampling event. Many of these compounds are known or suspected carcinogens (Moran et al. 2006).

Table 6. Target volatile and semi-volatile organic compounds analyzed with passive sampling W.L. Gore modules at select wellheads for each sampling event.

	Parameter	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards (µg/L)	Sources of Contamination in Drinking Water	Analytical Method used in this research
Volatile Organic Compounds (VOCs)	Total Petroleum Hydrocarbons	500 ppm	Industrial discharge; oil spills or leaks; chemical leaching	TD-GC-MS following U.S. EPA Method 8260 (SPG-WI-0292)
	Benzene	5	Factory discharge, gasoline storage tank and landfill leaching	
	Toluene	1000	Petroleum factory discharge	
	Ethylbenzene	700*	Leaching from underground gasoline storage tanks and landfill sites; pesticide use; municipal and industrial waste discharge	
	m-, p-xylene	10,000*	Petroleum factory discharge; chemical factory discharge	
	o-xylene	10,000*	Petroleum factory discharge; chemical factory discharge	
	Methyl t-butyl ether	200***	Leaching from underground gasoline storage tanks	
	Octane	NE	Leaching from underground gasoline storage tanks	
	Chloroform	80	Disinfection by-product; precursor to Teflon and refrigerants	
	Carbon tetrachloride	5	Industrial and chemical facility discharge; cleaning agent	
	Chlorobenzene	100	Chemical and agricultural chemical factory discharge	
	1,1-Dichloroethane	2,400**	Industrial and chemical facility discharge; pesticide runoff	
	1,2-Dichloroethane	5	Industrial and chemical facility discharge	
	1,1,1-Trichloroethane	200	Industrial and chemical facility discharge	
	1,1,2-Trichloroethane	5	Industrial and chemical facility discharge	
	1,1,1,2-Tetrachloroethane	35**	Industrial and chemical facility discharge	
	1,1,2,2-Tetrachloroethane	0.3***	Chemical facility discharge	
	Cis-1,2-Dichloroethene	7	Industrial and chemical facility discharge	
	Trans-1,2-Dichloroethene	100	Industrial and chemical facility discharge	
	Trichloroethene	5	Factory discharge; discharge from metal degreasing sites	
	Tetrachloroethene (PCE)	5	Factory and dry cleaners discharge	

Table 6. Continued.

	Parameter	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards (µg/L)	Sources of Contamination in Drinking Water	Analytical Method used in this research
Semi-Volatile Organic Compounds (SVOCs) & Polycyclic Aromatic Hydrocarbons (PAHs)	1,2,4-Trimethylbenzene	70***	Petroleum, Industrial, and Chemical factory discharge; underground gasoline storage leaching	TD-GC-MS following U.S. EPA Method 8260 (SPG-WI-0292)
	1,3,5-trimethylbenzene	40***	Petroleum, Industrial, and Chemical factory discharge; underground gasoline storage leaching	
	1,2-Dichlorobenzene	600**	Industrial and chemical facility discharge; pesticide runoff	
	1,3-Dichlorobenzene	730**	Industrial and chemical facility discharge; pesticide runoff	
	1,4-Dichlorobenzene	75	Industrial and chemical facility discharge; pesticide runoff	
	Undecane	NE	Industrial, and Chemical factory discharge; underground gasoline storage leaching	
	Tridecane	NE	Industrial and chemical facility discharge	
	Pentadecane	NE	Industrial and chemical facility discharge	
	Naphthalene	100***	Combustion byproduct; moth repellant; PAH	
	2-methyl naphthalene	98**	Pesticide adjuvant; PAH	
	Acenaphthene	1,500**	Industrial and chemical facility discharge; pesticide runoff; PAH	
	Acenaphthylene	1,500**	Industrial and chemical facility discharge; pesticide runoff; PAH	
	Fluorene	980**	Industrial and chemical facility discharge; pesticide runoff; PAH	
	Phenanthrene	730**	Industrial and chemical facility discharge; pesticide runoff; PAH	
	Anthracene	7,300**	Industrial and chemical facility discharge; pesticide runoff; PAH	
	Fluoranthene	980**	Combustion byproduct; PAH	
	Pyrene	730**	Combustion byproduct; PAH	

* = National Secondary Drinking Water Standards; *Source:* (USEPA 2012); ** = U.S. EPA Lifetime Health Advisory; *Source:* (USEPA 2012) ;

*** = Texas Risk Reduction Program (TRRP) rules; *Source:* (TCEQ 2012); NE = No established MCL or secondary standard

Once the modules were exposed to representative groundwater from within the constructed airtight flow-through chambers for an adequate amount of time, they were retrieved and gently dried with a paper towel. They were then placed in a specified glass container for overnight shipment to the W.L Gore & Associates Survey Products Laboratory. A field blank was implemented during each installation and retrieval event. The analytical method employed was a modified EPA method 8260. Instrumentation consisted of gas chromatographs equipped with mass selective detectors coupled with automated thermal desorption units. For sample preparation, the tips of each Gore module were cut off and one or more exposed sorbent containers, or sorbers, containing engineered adsorbents were transported from the module to a thermal desorption tube for analysis.

For quality assurance, two instrument blanks, a sorber containing 5 µg of bromofluorobenzene (BFB), and a method blank were analyzed before each run sequence. Standards containing the selected target compounds at five calibration levels were also analyzed at the beginning of each run. For each target compound (Table 6), the criterion was less than 25% relative standard deviation. If this criterion was not met for any target compound, the analyst had the option of generating second- or third-order standard curves, as appropriate. A second-source reference standard, at a level of 10 µg per target compound, was analyzed after every ten samples and/or trip blanks, and at the end of the run sequence. Positive identification of target compounds was determined by 1) the presence of the target ion and at least two secondary ions; 2) retention time versus reference standard; and 3) the analyst's judgment. The equation used to determine concentrations of analytes found within each sorbent of the modules is as follows:

Conc., $\mu\text{g/L}$ = mass, μg x (Exposure Time, Hour/ Adjusted Uptake Rate, L/Hour).

2.2.5. Storm Water Runoff. The equation used to calculate discharge from a triangular weir was derived from the USGS Water Supply Paper 200 (Horton 1907):

$$Q = (1.32)(L)(H^{3/2})$$

where: Q = volume of discharge per second, (ft^3/sec); 1.32 = constant; L = width of the water surface on the weir, (ft); H = head, or depth of water over the crest of the weir, (ft). This discharge formula has been verified by similar approaches found in the Handbook of Hydraulics (Brater et al. 1996).

Each surface runoff sample collected with the automated ISCO surface water sampler after a substantial rain event was analyzed for all parameters listed in Table 7 at the Edwards Aquifer Research and Data Center. This data was plotted against discharge values for each storm event to assess concentrations prior to construction during the rise and fall of storm events analyzed during the study period. Once the construction process of the future Paso Robles housing development and associated golf course has begun, there may be a substantial change in water chemistry as the land is disturbed over the recharge and contributing zones of the Edwards Aquifer.

Table 7. Chemical parameters analyzed for each storm water runoff sample.

Parameter	U.S. EPA Drinking water Maximum Contaminant Level (MCL) or Secondary Standards* (mg/L)	Sources of Contamination in Drinking Water	Analytical Method used in this research
Calcium	NE	Natural dissolution of carbonate rocks	U.S. EPA Method 200.7 (Rev. 4.4)
Magnesium	NE	Natural mineral dissolution and erosion deposits; industrial discharge	U.S. EPA Method 200.7 (Rev. 4.4)
Potassium	NE	Natural mineral dissolution and erosion deposits; fertilizer runoff; water treatment	U.S. EPA Method 200.7 (Rev. 4.4)
Sodium	NE	Natural mineral dissolution and erosion deposits	U.S. EPA Method 200.7 (Rev. 4.4)
Total Phosphorus	NE	Sewage; fertilizers; decaying organic matter	Standard Method 4500-P E, 21st ed.
Nitrite-N	1	Sewage; fertilizers; decaying organic matter; natural erosion deposits	U.S. EPA Method 353.2 (Rev. 2.0)
Nitrate+ Nitrite-N	10	Sewage; fertilizers; decaying organic matter; natural erosion deposits	U.S. EPA Method 353.2 (Rev. 2.0)
Total Kjeldahl Nitrogen	NE	Sewage; fertilizers; decaying organic matter; natural erosion deposits	U.S. EPA Method 351.2 (Rev. 2.0)
Ammonia as N	NE	Sewage; fertilizers; decaying organic matter	U.S. EPA Method 350.1 (Rev. 2.0)
Chloride	250*	Oil field and industrial brines; natural dissolution; sewage and garbage dump leaching	U.S. EPA Method 300.0 (Rev. 2.1)
Sulfate	250*	Industrial waste; natural dissolution	U.S. EPA Method 300.0 (Rev. 2.1)
Total Alkalinity	NE	Natural dissolution of carbonate rocks (particularly limestone and dolomite)	Standard Method 2320 B, 21st ed.
Total Suspended Solids	NE	Natural erosion deposits; agricultural and construction sites; untreated sewage; general land runoff	Standard Method 2540 D, 21st ed.
Dissolved Organic Carbon	NE	Decaying organic matter	Standard Method 5520 D, 21st ed.
Biochemical Oxygen Demand	NE	Organic pollution can cause high numbers of aerobic bacterial activity	Standard Method 5210 B, 21st ed.
Turbidity (NTU)	NE	Erosion; land runoff; anthropogenic activities	U.S. EPA Method 180.1 (Rev. 2.0)

* = National Secondary Drinking Water Regulations; *Source:* (USEPA 2012); NE = No established MCL or secondary standard.

2.2.6. Statistical Tests. Nonparametric statistical techniques were applied to this study. This approach was appropriate as the data did not exhibit normal distributions, and many observations were found to be below the analytical detection limits and were therefore censored. Distribution-free nonparametric statistical techniques utilize the ranks of the data rather than actual concentrations and are therefore not affected by censored data (Helsel 2012).

The generalized Wilcoxon score test was used to test whether the distributions of detected compound concentrations among the monitoring wells were the same, or if at least one was significantly different. If the overall test was found to be significant, supporting that at least one well was found to have a significantly different distribution of the compound in question, then a multiple comparison procedure was applied to assess which wells differed in compound detection distribution. For nonparametric comparison analyses of censored data, the best method involves a series of two-group score tests between each possible pair with the use of the Wilcoxon score test (Helsel 2012). This study involved the monitoring of 9 wells for target effluent compounds, insecticides, and herbicides; and 4 wells for the analysis of volatile and semi-volatile organic compounds via the W.L. Gore passive sampling modules. Nine monitoring wells yield 36 possible pair-wise comparisons, while 4 monitoring wells give way to 6 possible pairs. For the determination of significant differences within a multiple comparison pair-wise test, the p-value must be adjusted to the Bonferroni individual comparison level. This adjusted p-value can be calculated with the following equation:

$$\text{Individual error rate} = \alpha / g$$

where α is the overall desired error rate, usually 0.05, or 5%; and g is the number of possible comparisons to be made (Helsel 2012). The Bonferroni-adjusted level for the monitoring of 9 wells was calculated as 0.0014, while the adjusted level for 4 monitoring wells was found to be 0.0083. For each comparison test, if the p-value was below the Bonferroni adjusted comparison level, then the two wells were declared to have significantly different distributions of the compound of interest.

In addition, Kendall's tau correlation test was applied to each detected compound. This test was used to investigate the presence of a significant relationship between detected concentrations with the amount of precipitation received the week prior to each sampling event. A significance level of 0.05 was used for all statistical tests in this study, except for the multiple comparison pair-wise tests in which the Bonferroni adjusted p-value was applied.

CHAPTER III

RESULTS AND DISCUSSION

3.1. Water Level Measurements

Historic water level measurements obtained from the Texas Water Development Board for wells in the surrounding area during a period of minimal rainfall were used to characterize the general groundwater flow patterns surrounding the future site of the Paso Robles housing development and associated golf course. This was accomplished through the construction of a potentiometric map for southwest Hays County. A fairly dry period was chosen so as to reduce the occurrence of rapid fluctuations in water level measurements, which could have reduced the accuracy of this groundwater modeling technique. Figure 10 depicts the calculated potentiometric surface for southwest Hays County.

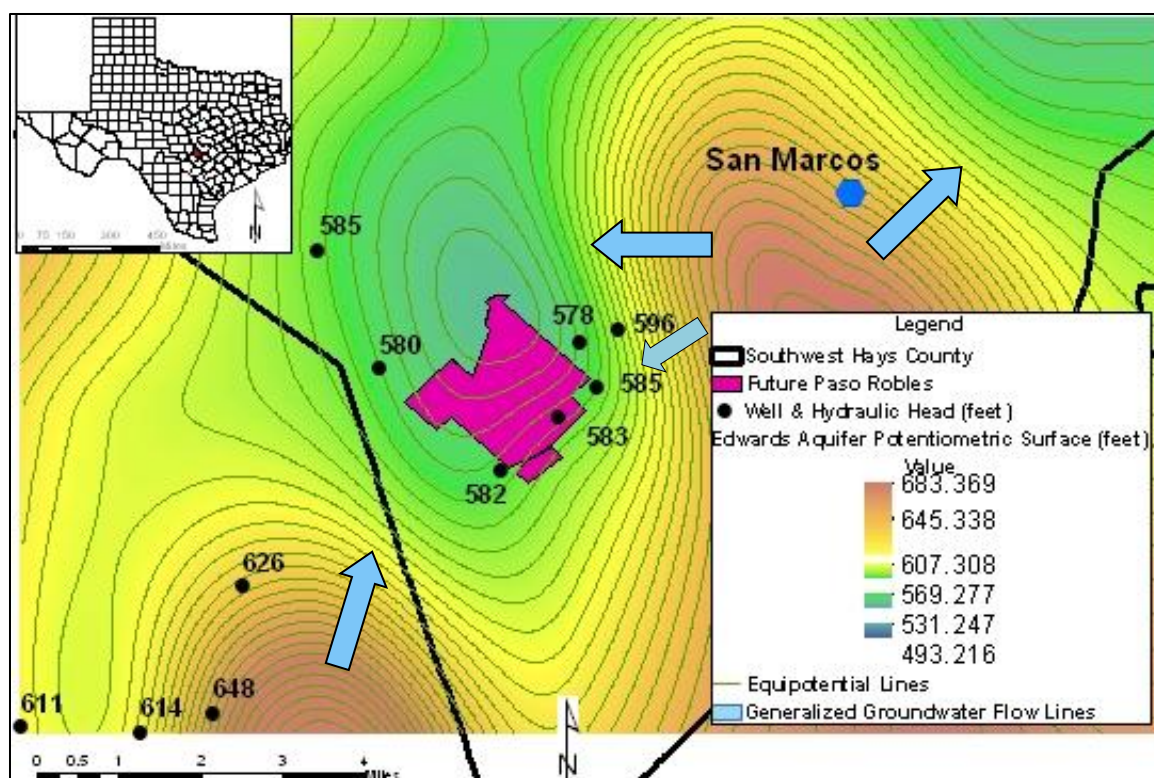


Figure 10. Potentiometric map of the immediate area surrounding the future Paso Robles housing development with equipotential lines and generalized flow arrows.

Equipotential lines, similar to the contours of a topographic map, were used to connect the plotted hydraulic head measurements of equal values. Blue arrows depict the generalized directional flow paths of groundwater, which moves from higher mechanical energy to regions of lower mechanical energy within a saturated zone (Hudak 2005). It should be noted that this inferred hydraulic gradient only applies to portions of the map with plotted hydraulic head values, and the remainder areas represent calculated values of the GIS programming rather than accurately measured values. The localized potentiometric surface portrayed in Figure 10, however, does seem to generally coincide with documented reports outlining inferred direction groundwater movement in Hays County and surrounding areas (Maclay and Small 1984; Ogden et al. 1986; Maclay and Land 1988; Groschen 1996). For instance, a synoptic water level report released by the

Edwards Aquifer Authority in 2006 produced similar potentiometric maps for the area, as did maps from a final contract report of the Bureau of Economic Geology through The University of Texas at Austin (Hovorka et al. 2004; Hamilton et al. 2006). However, these maps were showing values on a much broader scale that depicted the entire Edwards Aquifer, which could thus lead to some discrepancies in comparisons with Figure 10, which is limited to the San Marcos region. The potentiometric map constructed for this research does follow maps created by Ogden et al. of the San Marcos area specifically (1986).

The presence of such an extensive fault system, the Balcones Fault Zone, creates a very complex potentiometric surface as faults can greatly impede or enhance directional movement. When estimating a generalized groundwater flow pattern, it is crucial to take into account the location of known, as well as inferred fault lines within the aquifer system (Abbott 1977). The presence of intense faulting within the San Marcos area undoubtedly affects water movement. As the Edwards Aquifer is a karst aquifer, it is thus heterogeneous and never uniform in flow. Groundwater flow within a karst system can be generally characterized as a slow-moving matrix flow, flow through fractures, or fast flow through large conduits. A matrix or diffuse flow is more representative of flow patterns through a porous medium, as outlined with Darcy's Law; whereas fast flow through conduits can be turbulent and restricted to isolated paths (Lindgren et al. 2004). Figure 11 depicts local faults within the San Marcos region.

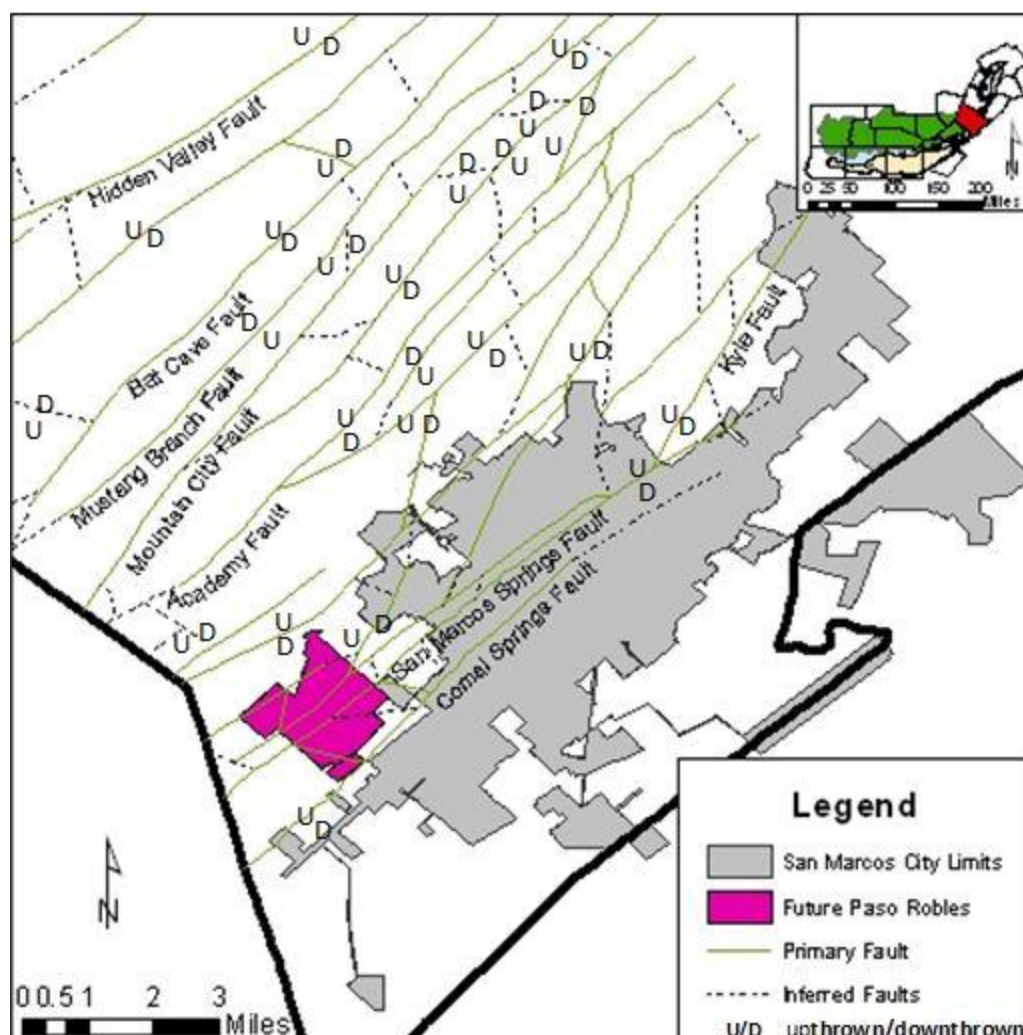


Figure 11. Primary and inferred faults in southwest Hays County.

The faults within the Balcones are echelon, high-angled faults that are generally downthrown to the southeast. However, there are some faults in the region that are downthrown to the northwest (Kuniansky 2001; Ferrill 2004). The area between the San Marcos Springs and Comal Springs faults encompasses roughly half of future Paso Robles housing development and associated golf course location. As described by Ogden et al., this zone exhibits faults which seem divergent to the overall trend of the main faults within the area, ultimately further complicating the localized flow pattern (1985). In addition, while groundwater generally moves from the unconfined recharge zone of

the Edwards Aquifer southeast towards the confined zone, Figures 10 and 11 also support supports speculations made in previous work of the San Marcos Springs and Comal Springs faults acting as hydrologic barriers to localized flow as intense lateral displacement has disconnected these Edwards limestones. Displacement of groundwater flow north of this area along the Bat Cave fault is thought to contribute to a directional shift in water movement more toward the south and to the San Marcos Springs (Ogden et al. 1986).

In addition, development in the area must be taken into account while assessing this conceptual perspective of groundwater flow within the Paso Robles site location. That is, numerous municipal and private wells are located throughout this area and contribute to localized drawdown in the water table. It is also important to remember that hydraulic properties of the Edwards aquifer, such as hydraulic conductivity, transmissivity, and storativity are not homogenous throughout the system and can thus contribute to differences in flow patterns (Lindgren et al. 2004). Nonetheless, Figures 10 and 11 collectively portray a generalized, conceptual look at the flow patterns under and around the Paso Robles location. This understanding of groundwater movement will prove beneficial in assessing and identifying potential contamination in a timely manner of the Edwards Aquifer once the construction process is underway, and upon the completion of the large-scale housing development and associated golf course.

3.2. Basic Water Chemistry

Karst aquifers such as the Edwards can exhibit variable water quality through rapid changes in environmental and hydrologic conditions (Musgrove et al. 2010). This research has provided an assessment of the Edwards Aquifer water quality within the southwestern portion of San Marcos relative to the time and date that samples were collected. Table 8 provides the minimum and maximum water chemistry concentrations for each monitoring well throughout the study period, as well as values typical of Edwards Aquifer freshwater.

Table 8. The range of general water chemistry concentrations from the study in comparison with typical values for Edwards Aquifer freshwater (Hamilton et al. 2010).

Parameter	Range of Detected Concentrations									Typical Concentration Range for Edwards Aquifer Freshwater
	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c	
Field Water Temperature (°C)	17.8 - 24.3	20.0 - 24.9	20.0 - 25.0	15.2 - 24.2	21.3 - 25.1	20.6 - 24.9	16.7 - 26.6	19.9 - 26.7	14.9 - 29.7	20 - 30
Field pH (Units)	6.5 - 7.3	6.5 - 7.3	6.5 - 7.4	6.4 - 7.3	6.5 - 7.3	6.5 - 7.3	6.5 - 7.3	6.2 - 7.3	6.7 - 7.4	6.5 - 8.0
Field Dissolved Oxygen (mg/L)	5.6 - 9.6	3.6 - 6.0	3.9 - 6.7	5.6 - 9.2	4.3 - 8.0	4.9 - 7.0	5.2 - 8.5	1.7 - 4.8	5.4 - 7.9	2.0 - 4.0
Field Specific Conductance (µS/cm)	432 - 613	495 - 698	470 - 657	428 - 596	483 - 673	467 - 662	408 - 621	1252 - 1850	433 - 615	--
Total Barium (mg/L): MDL = 0.033	<0.033 - 0.046	0.034 - 0.052	<0.033 - 0.056	<0.033 - 0.058	<0.033 - 0.079	<0.033 - 0.052	<0.033 - 0.055	<0.033 - 0.042	0.046 - 0.069	0.01 - 0.1
Total Calcium (mg/L): MDL = 0.929	64.85 - 117.66	54.49 - 118.28	66.48 - 124.15	71.69 - 116.37	76.80 - 125.34	52.89 - 121.07	56.23 - 123.10	132.56 - 188.70	35.67 - 108.62	50 - 100
Total Iron (mg/L): MDL = 0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054 - 0.205	<0.054	<0.054	<0.054 - 0.071	ND - 0.006
Total Magnesium (mg/L): MDL = 0.443	16.80 - 24.96	12.50 - 22.87	15.61 - 24.25	15.01 - 23.45	17.09 - 24.62	16.91 - 24.99	14.98 - 22.78	60.93 - 94.90	17.45 - 30.75	ND - 4
Total Manganese (mg/L): MDL = 0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	ND - 4
Total Potassium (mg/L): MDL = 0.127	1.30 - 2.10	2.25 - 3.50	1.81 - 3.88	1.02 - 1.86	1.93 - 3.25	1.76 - 3.51	1.55 - 2.84	10.71 - 16.91	1.18 - 1.95	5.0 - 15.0
Total Silica (mg/L): MDL = 0.248	4.92 - 6.41	5.20 - 6.21	4.13 - 6.47	4.96 - 6.32	4.84 - 6.01	4.92 - 6.20	5.04 - 6.39	4.69 - 7.04	5.01 - 6.04	10.0 - 20.0
Total Sodium (mg/L): MDL = 0.054	7.08 - 8.79	10.58 - 18.32	9.25 - 18.45	5.88 - 7.05	11.23 - 18.65	10.51 - 13.75	7.22 - 10.07	3.29 - 141.50	6.53 - 10.98	5.0 - 15.0
Total Strontium (mg/L): MDL = 0.2	0.42 - 0.63	0.58 - 0.69	0.45 - 0.71	0.45 - 0.62	0.52 - 0.66	0.48 - 0.66	0.44 - 0.64	1.68 - 3.28	1.04 - 1.62	0.2 - 0.5

Table 8. Continued.

Parameter	Range of Detected Concentrations									Typical Concentration Range for Edwards Aquifer Freshwater
	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c	
Ortho-P-Phosphate (mg/L): MDL<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	ND - 0.03
Nitrite-N (mg/L): MDL = 0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	ND - 0.02
Nitrate+ Nitrite-N (mg/L): MDL = 0.1	1.29 - 1.48	1.68 - 2.34	1.58 - 2.43	0.89 - 1.14	1.57 - 2.01	1.53 - 2.19	1.57 - 2.04	<0.1	1.12 - 1.48	ND - 2.5
Chloride (mg/L): MDL = 0.76	9.96 - 13.10	25.10 - 31.00	<1.21 - 24.00	8.00 - 11.60	<1.21 - 26.00	18.00 - 23.00	14.00 - 17.00	205.00 - 326.00	8.85 - 12.60	15 - 50
Fluoride (mg/L): MDL = <0.1	0.2 - 0.3	0.2 - 0.3	0.2 - 0.3	0.2 - 0.3	0.2 - 0.3	0.2 - 1.7	0.2 - 0.3	1.8 - 2.2	0.2 - 0.3	0.02 - 0.4
Sulfate (mg/L): MDL = 1.8	11.0 - 25.1	27.0 - 43.0	23.0 - 43.4	9.0 - 24.4	<3.01 - 36.0	20.0 - 30.0	14.0 - 25.0	233.0 - 355.0	10.0 - 24.2	30 - 60
Total Alkalinity (mg/L): MDL = 20	260 - 278	252 - 270	248 - 262	260 - 266	256 - 286	260 - 270	258 - 274	274 - 296	264 - 278	200 - 400
Total Dissolved Solids (mg/L): MDL = 10	273 - 358	306 - 367	256 - 384	239 - 337	286 - 362	291 - 392	250 - 332	863 - 1208	248 - 328	200 - 400
Total Hardness (mg/L): MDL = 10	286 - 312	306 - 332	298 - 320	300 - 324	306 - 320	298 - 320	290 - 310	626 - 660	294 - 316	--
Total Coliform (MPN/100mL): MDL = 1	<1	<1 - 64	11 - 649	<1 - >2419	<1 - >2419	<1 - 131	<1 - 23	<1 - >2419	<1	--
<i>E. coli</i> (MPN/100mL): MDL = 1	<1	<1 - 2	<1 - 17	<1	<1 - 38	<1	<1	<1 - 5	<1	0 - 3

ND = not detected.

Water quality samples from most of the monitoring wells depicted chemical parameter values within or near the expected range of Edwards Aquifer freshwater. However, the privately-owned well labeled P-b generally had higher concentrations of select major ions. These included calcium, magnesium, potassium, sodium, chloride, and sulfate. In addition, the water quality of this well consistently had much higher field specific conductance values, as well as total dissolved solids and total hardness. The groundwater obtained from this well, which is located within the confined portion of the Edwards Aquifer, may thus be mixing with more saline water as the fresh/saline water interface, known as the “bad water line,” is located immediately south of the study site as depicted in hydrogeologic maps of other work investigating this boundary (Longley et al. 1998; Hovorka et al. 2004; Lindgren 2006; Hamilton et al. 2010; Musgrove et al. 2010). According to R.J. Lindgren, freshwater within the confined zone of the Edwards Aquifer can exist in extremely narrow sections between the San Marcos and Comal Springs, which could further account for an intrusion of saline water within the vicinity of the P-b well. Additionally, the unique faulting and displacement of Edwards rocks in this area could influence the position of the freshwater/saline water interface (2006).

Groundwater inferred to be in contact with the saline zone is characterized by higher conductivity values and levels of total dissolved solids ($\geq 1,000$ mg/L), which is thought to be the result of a longer residence time within the aquifer (Ogden et al. 1986; Longley et al. 1998; Hamilton et al. 2010). South of the interface, groundwater is also generally more saline and contains higher concentrations of dissolved chloride, sulfate, and sodium (Hamilton et al. 2010; Musgrove et al. 2010). Saline-influenced groundwater samples obtained from within the Edwards Aquifer have even at times exhibited lower

dissolved oxygen concentrations than typically found throughout the aquifer (Musgrove et al. 2010). These conditions were characteristic of the ground water samples obtained from the P-b monitoring well throughout the study period, and further support the inferred likelihood of this well's association to saline groundwater along the interface of this confined zone.

The presence of coliform bacteria within groundwater samples of the Edwards Aquifer is to some extent expected. During recharge events, fecal coliform bacteria, which reside in the intestines of warm-blooded animals, can enter the aquifer with little filtration. Coliform bacteria can also leach from buried septic tank drainfields over the recharge zone. High levels of coliform bacteria could indicate the possible presence of waterborne diseases such as typhoid, hepatitis, dysentery, or eye, nose and throat infections (USEPA 2012).

Total coliform bacteria were detected in seven of the nine monitoring wells (CSM-s, CSM-h, CSM-k, FH 1, FH 2, P-a, and P-b). The monitoring wells CSM-h, CSM-k, FH1, and P-b had total coliform concentrations detected at the highest levels; with the CSM-k, FH 1, and P-b wells containing detections above the reporting limit of 2,419 most probable number (MPN) per 100 mL (Figure 12). As previously stated, land use in this area consists of rural development and agriculture. There are cattle and wildlife in this area, and in some instances the cattle are found in the same field as the wellhead. In addition, it should be noted that water samples were obtained at wells prior to any chlorination process.

A statistical analysis was conducted for the occurrence of total coliform bacteria within the majority of the monitoring wells. The general Wilcoxon score test revealed

that at least one of the monitoring wells possessed a significantly different distribution of total coliform bacteria detections than the others ($\chi^2 = 56.5$, $df = 8$, $p = 2.27\text{e-}09$). A multiple comparison approach was then applied to each possible pair of monitoring wells, 36 pairs total, in order to assess which wells differed significantly. The adjusted Bonferroni p-value used was 0.0014. Any p-value reported below this adjusted level indicates significant differences between the two wells compared. The results are summarized in Table 9.

Table 9. Summary of multiple comparison analysis for total coliform bacteria detection between all possible comparison pairs of monitoring wells.

Well Comparison	Chi-Square	Degrees of Freedom	P-Value
CSM-m versus CSM-s	4.2	1	0.0396
CSM-m versus CSM-h	16.3	1	5.24E-05 *
CSM-m versus CSM-k	4.2	1	0.0396
CSM-m versus FH 1	13.9	1	0.0000 *
CSM-m versus FH 2	13.8	1	0.0000 *
CSM-m versus P-a	3.8	1	0.0511
CSM-m versus P-b	11.6	1	0.0007 *
CSM-m versus P-c	n/a	1	n/a
CSM-s versus CSM-h	4.8	1	0.0290
CSM-s versus CSM-k	0.0	1	1.0000
CSM-s versus FH 1	6.5	1	0.0108
CSM-s versus FH 2	1.1	1	0.2980
CSM-s versus P-a	0.4	1	0.5160
CSM-s versus P-b	2.8	1	0.0966
CSM-s versus P-c	5.2	1	0.0229
CSM-h versus CSM-k	6.1	1	0.0137
CSM-h versus FH 1	1.0	1	0.3230
CSM-h versus FH 2	6.5	1	0.0107
CSM-h versus P-a	10.7	1	0.0011 *
CSM-h versus P-b	1.7	1	0.1940
CSM-h versus P-c	19.9	1	8.25E-06 *
CSM-k versus FH 1	5.5	1	0.0190
CSM-k versus FH 2	3.9	1	0.0489
CSM-k versus P-a	0.0	1	0.9320
CSM-k versus P-b	3.5	1	0.0616
CSM-k versus P-c	5.2	1	0.0231
FH 1 versus FH 2	6.4	1	0.0117
FH 1 versus P-a	11.1	1	0.0009 *
FH 1 versus P-b	1.8	1	0.1750
FH 1 versus P-c	16.9	1	3.87E-05 *
FH 2 versus P-a	5.2	1	0.0220
FH 2 versus P-b	1.2	1	0.2760
FH 2 versus P-c	16.8	1	4.17E-05 *
P-a versus P-b	5.8	1	0.0165
P-a versus P-c	4.6	1	0.0313
P-b versus P-c	14.1	1	0.0002 *

* indicates a significant difference in distribution between the compared wells; n/a = both wells contained only censored non-detect values.

In addition, the Kendall's tau rank correlation test was used to investigate a potential significant relationship between the occurrence of total coliform bacteria with the amount of precipitation received the week leading up to each sampling event. However, the data collected in this study supported that there was no significant correlation between the detection of total coliform bacteria and precipitation ($z = 1.3$, $p = 0.2770$).

The bacterium *Escherichia coli* was detected in four of the nine wells: CSM-s, CSM-h, FH 1, and P-b. The CSM-s and P-b wells had extremely low concentrations, while the remaining two had levels of concern. The highest concentration reported throughout these four wells was 38 MPN/100 mL, and was detected in the FH 1 well. The occurrence of septic tanks, cattle, and wildlife in the immediate area could greatly account for these detections. Many strains of *E. coli* are actually fairly harmless and can be found in the intestines of healthy animals, including humans. However, some can cause severe illness, and the detection of *E. coli* can be used as an indicator to the presence of potentially harmful bacteria (USEPA 2012).

A statistical analysis of the *E. coli* detections revealed that at least one of the wells had a significant difference in the distribution of *E. coli* occurrence ($\chi^2 = 17.2$, $df = 8$, $p = 0.0278$). Table 10 summarizes the multiple comparison approach for assessment of which wells differed, with the adjusted Bonferroni p-value of 0.0014. It should be noted that although the generalized Wilcoxon rank test revealed that at least one well had a significantly different distribution of *E. coli* detections, the multiple comparisons tests did not reveal significant differences between any of the tested pairs of wells. While some wells possessed detections and others had none, the actual number of detections was

perhaps too low to produce significant differences through the pair-wise comparison analysis.

Table 10. Summary of multiple comparison analysis for *E. coli* detection between all possible comparison pairs of monitoring wells.

Well Comparison	Chi-Square	Degrees of Freedom	P-Value
CSM-m versus CSM-s	4.3	1.0	0.0
CSM-m versus CSM-h	1.9	1.0	0.2
CSM-m versus CSM-k	n/a	1.0	n/a
CSM-m versus FH 1	1.7	1.0	0.2
CSM-m versus FH 2	n/a	1.0	n/a
CSM-m versus P-a	n/a	1.0	n/a
CSM-m versus P-b	0.8	1.0	0.4
CSM-m versus P-c	n/a	1.0	n/a
CSM-s versus CSM-h	0.3	1.0	0.6
CSM-s versus CSM-k	4.7	1.0	0.0
CSM-s versus FH 1	0.5	1.0	0.5
CSM-s versus FH 2	5.2	1.0	0.0
CSM-s versus P-a	5.2	1.0	0.2
CSM-s versus P-b	2.0	1.0	0.2
CSM-s versus P-c	5.2	1.0	0.0
CSM-h versus CSM-k	2.1	1.0	0.1
CSM-h versus FH 1	0.0	1.0	1.0
CSM-h versus FH 2	2.3	1.0	0.1
CSM-h versus P-a	2.3	1.0	0.1
CSM-h versus P-b	0.7	1.0	0.4
CSM-h versus P-c	2.3	1.0	1.3
CSM-k versus FH 1	1.9	1.0	0.2
CSM-k versus FH 2	n/a	1.0	n/a
CSM-k versus P-a	n/a	1.0	n/a
CSM-k versus P-b	0.9	1.0	0.3
CSM-k versus P-c	n/a	1.0	n/a
FH 1 versus FH 2	2.1	1.0	0.1
FH 1 versus P-a	2.1	1.0	0.1
FH 1 versus P-b	2.1	1.0	0.1
FH 1 versus P-c	2.1	1.0	0.1
FH 2 versus P-a	n/a	1.0	n/a
FH 2 versus P-b	n/a	1.0	n/a
FH 2 versus P-c	n/a	1.0	n/a
P-a versus P-b	n/a	1.0	n/a
P-a versus P-c	n/a	1.0	n/a
P-b versus P-c	n/a	1.0	n/a

n/a = both wells contained only censored non-detect values.

In addition, the Kendall's Tau statistical test of correlation revealed that this data does not support a significant relationship between *E. coli* detection and the amount of precipitation received one week prior to each sampling event ($z = 1.3$, $p = 0.2043$). Lastly, Figure 12 summarizes the frequency of detection for both total coliform bacteria and *E. coli* across all nine monitoring wells.

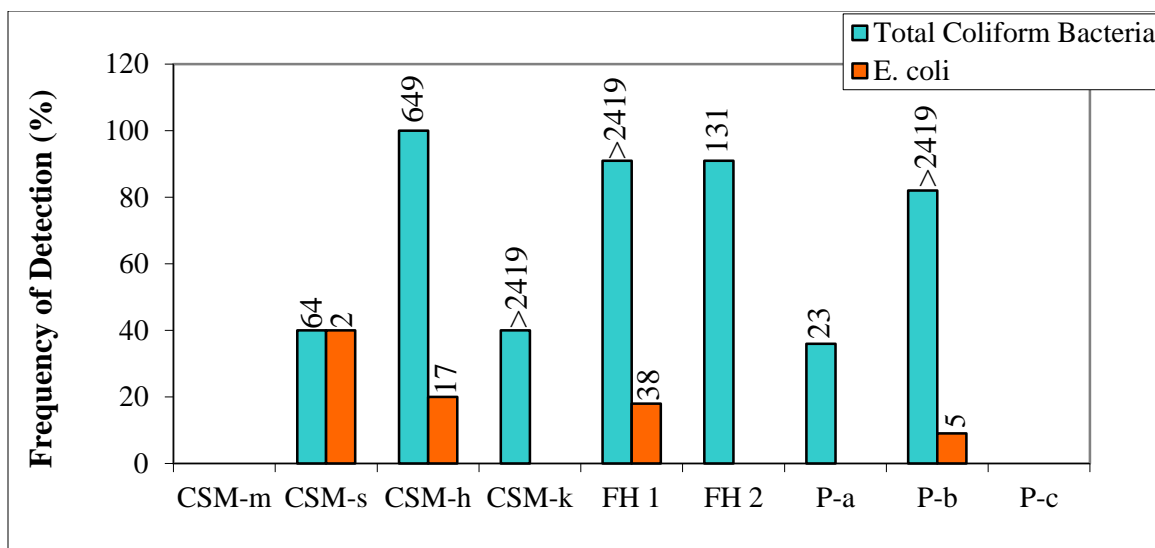


Figure 12. Frequency of detection of total coliform bacteria and *E. coli* in the nine monitoring wells. The maximum concentration detected (MPN/100 mL) for each well is shown above the frequency bars.

3.3. Target Effluent, Insecticide and Herbicide Compounds

The presence of select compounds, which are known or suspected endocrine disruptors found to persist in the treated effluent of the San Marcos Wastewater Treatment Plant, was assessed through GC-MS-MS analysis of groundwater samples collected within the vicinity of the future Paso Robles housing development. These compounds included triclosan, triethyl citrate, and tris(2-chloroethyl)phosphate (TCEP). This technique was also used to evaluate the presence of select insecticide and herbicide compounds commonly used in residential and agricultural settings. These compounds were malathion, permethrin, which has two isomers (cis and trans) that chromatograph separately; n,n-diethyl-meta-toluamide (DEET), and atrazine.

For replicate samples, the relative standard deviation (RSD) was used to evaluate differences in individual paired replicates. The RSD can be defined with the following equation:

$$\text{RSD} = 100 (S / \bar{x})$$

where S is the standard deviation of the two concentrations, and \bar{x} is their average.

Table 11 summarizes the GC-MS-MS analytical results of groundwater samples obtained at all nine monitoring wells throughout the study period.

Table 11. Summary of GC-MS-MS analytical results across all monitoring wells.

Compound	Sample Well ID											
	CSM-m			CSM-s			CSM-h			CSM-k		
	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)
Triclosan	11	18	15.0	12	0	n/a	12	0	n/a	13	15	8.7
Triethyl Citrate	11	9	3300.0	12	8	2500.0	12	0	n/a	13	0	n/a
TCEP	11	0	n/a	12	0	n/a	12	0	n/a	13	0	n/a
Malathion	11	9	9.5	12	8	5.8	12	0	n/a	13	8	3.0
Permethrin Isomer 1	11	0	n/a	12	0	n/a	12	0	n/a	13	0	n/a
Permethrin Isomer 2	11	0	n/a	12	0	n/a	12	0	n/a	13	0	n/a
DEET	11	27	36.0	12	25	110.0	12	25	7.7	13	31	35.0
Atrazine	11	0	n/a	12	8	30.0	12	0	n/a	13	0	n/a

Table 11. Continued.

Compound	Sample Well ID											
	FH 1			FH 2			P-a			P-b		
	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)	<i>n</i>	Percent Detected	Maximum Conc. (ng/L)
Triclosan	13	31	19.0	13	8	96.0	13	15	49.0	13	8	9.1
Triethyl Citrate	13	8	660.0	13	8	5100.0	13	8	19.0	13	0	n/a
TCEP	13	0	n/a	13	0	n/a	13	0	n/a	13	15	250.0
Malathion	13	0	n/a	13	8	3.6	13	8	83.0	13	0	n/a
Permethrin Isomer 1	13	0	n/a	13	0	n/a	13	8	50.0	13	0	n/a
Permethrin Isomer 2	13	0	n/a	13	0	n/a	13	8	26.0	13	0	n/a
DEET	13	38	93.0	13	8	22.0	13	46	75.0	13	15	39.0
Atrazine	13	8	32.0	13	0	n/a	13	0	n/a	13	0	n/a

n/a = not applicable (not detected).

As noted in Figure 13, which depicts the frequency of detection for these compounds across the nine monitoring wells, DEET was most frequently detected with an overall detection frequency of 28% ($n = 114$). Triclosan had an overall detection

frequency of 11% across all nine monitoring wells, followed by triethyl citrate at 4%, malathion at 4%, tris (2-chloroethyl) phosphate (TCEP) at 2%, atrazine at 2%, and each isomer of permethrin at 1%.

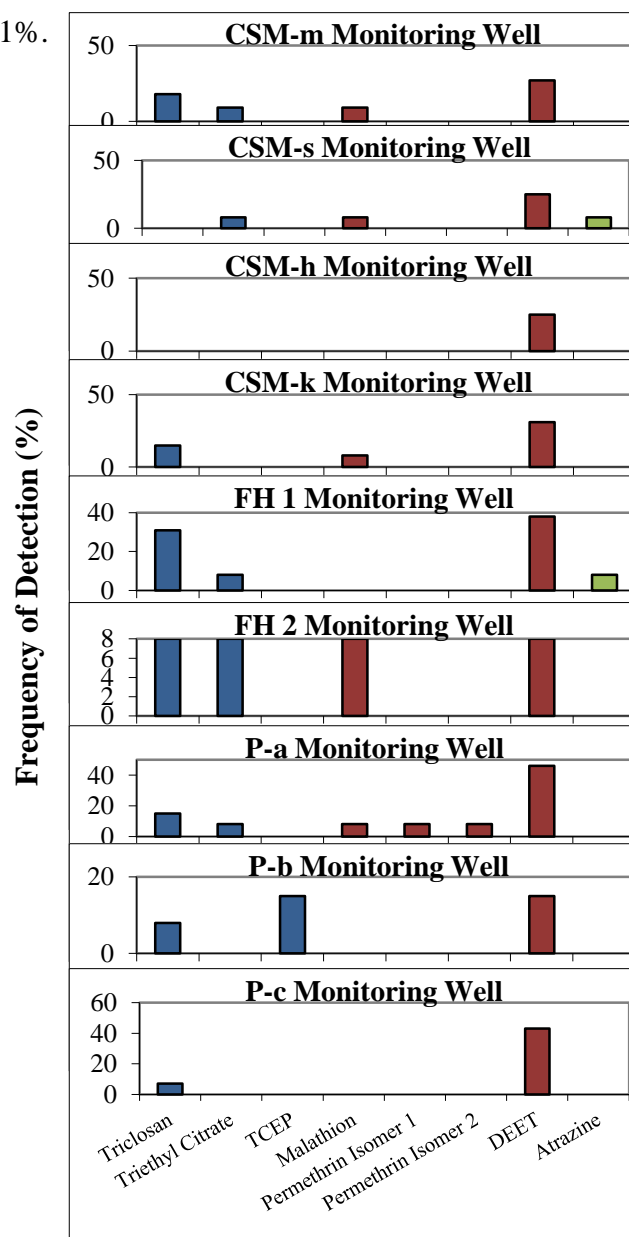


Figure 13. Frequency of detection for target compounds detected with GC-MS-MS analysis across all monitoring wells. Column identification: blue = compound frequently detected in effluent, red = insecticide compound, green = herbicide compound.

A statistical analysis of the occurrence of each target effluent compound and the select insecticides and herbicides revealed that TCEP was the only compound of which the test revealed that at least one well significantly differed in detection distribution ($\chi^2 =$

16.2 , $df = 8$, $p = 0.0401$). As observed in Table 11 and Figure 13, TCEP was actually only detected in one well, P-b, throughout the entire study period. A multiple comparison analysis was thus unnecessary.

The Kendall's tau rank correlation test was applied to each compound in order to test for a significant relationship between its occurrence with the amount of precipitation received the week leading up to each sampling event. Only two compounds revealed significant results that support a relationship, or correlation, between their detection and precipitation. The first compound was the insecticide DEET ($z = 2.0$, $p = 0.0435$), and the second was triclosan, an anti-microbial found to persist in treated wastewater ($z = 2.1$, $p = 0.0323$).

The most frequently detected compound, DEET, is an extremely common insecticide used throughout the world, and is typically applied to human skin and clothing, or even pets, in the form of aerosol, liquid, and lotion products. According to the U.S. Environmental Protection Agency, the toxicity of DEET on humans is of little concern when used properly. DEET was found to be slightly more toxic to rats in laboratory studies, however, when ingested or applied to the skin. It has also been found to be marginally toxic to aquatic invertebrates, fish, and birds (USEPA 1998).

Once DEET enters the body, it is broken down and mostly expelled in urine. Trace amounts may remain in the tissues, although the buildup up DEET in our bodies is poorly studied (Hays et al. 1991). The U.S. EPA has classified DEET as a group D carcinogen, or not classifiable to human carcinogenicity. For compounds in this classification group, there is generally insufficient evidence to indicate carcinogenicity in

humans, or there simply may not be available data to properly assess the effects (USEPA 1998).

Overall, further testing needs to be conducted to assess the long-term effects DEET could have on the environment. It has been determined, however, that DEET degrades fairly quickly in the atmosphere, but typically breaks down very slowly when it enters soils (Hays et al. 1991). Its persistence in the soil environment could allow it to effectively enter the groundwater, in some cases with little to no filtration such as over the recharge zone of the Edwards Aquifer. This could also account for the significant relationship found between the occurrence of DEET in the nine monitoring wells with the amount of precipitation received the week prior to each sampling event as increased recharge could allow for elevated trace amounts of DEET to be washed into the aquifer.

Triclosan, the second most frequently detected compound, was also found to have a significant relationship between its detection throughout the nine monitoring wells with precipitation. This compound is an anti-microbial that is found in many products used by humans on a daily basis such as face wash, toothpaste, deodorants, body lotion, soap, cosmetics, and dishwashing liquids. It may enter the body in small amounts through the skin or mouth, and be dispelled into the environment through effluent discharge, or septic tank leachates.

Unfortunately little is known of the risks of low environmental levels of triclosan to human health, but it has been linked to endocrine, or hormone disruption. More research needs to be conducted to effectively assess its impacts on our bodies and the environment. This need is evident in the results of a National Health and Nutrition Examination Survey carried out from 2003 to 2004 by the Centers for Disease Control

and Prevention, which found that triclosan was detected in 75% of the urine samples analyzed from 2,517 participants aged 6 years and older (USEPA 2010). In addition, research conducted by the U.S. EPA has found that triclosan will typically not volatilize from soil environments or water surfaces. In aquatic environments, it will typically attach to sediments and suspended solids. There is also a low-to-moderate potential of bioaccumulation through aquatic organisms, but more research is needed (USEPA 2010).

3.4. Volatile and Semi-Volatile Organic Compounds

The use of W.L. Gore passive sampling modules in airtight flow-through chambers attached to select wellheads allowed for an analysis of volatile and semi-volatile organic compounds during each sampling event. Unfortunately only 4 of the 9 wells could be utilized for this analysis: CSM-m, CSM-s, FH 1, and FH 2. Table 12 summarizes the detection results for each of these wells.

Table 12. Summary of W.L. Gore passive sampling analytical results across the 4 selected monitoring wells.

Compound	Sample Well ID											
	CSM-m			CSM-s			FH 1			FH 2		
	<i>n</i>	Percent Detected	Maximum Conc. (µg/L)	<i>n</i>	Percent Detected	Maximum Conc. (µg/L)	<i>n</i>	Percent Detected	Maximum Conc. (µg/L)	<i>n</i>	Percent Detected	Maximum Conc. (µg/L)
Total Petroleum Hydrocarbons	6	100	18.29	11	82	13.20	12	67	6.52	12	58	7.63
Benzene	6	0	n/a	11	9	0.05	12	0	n/a	12	8	0.18
Undecane	6	0	n/a	11	18	0.03	12	17	0.02	12	0	n/a
Tridecane	6	17	0.03	11	0	n/a	12	0	n/a	12	0	n/a
Fluorene	6	17	0.02	11	9	0.02	12	0	n/a	12	0	n/a
Tetrachloroethene (PCE)	6	0	n/a	11	9	0.36	12	25	0.29	12	8	0.72

n/a = not applicable (not detected).

Figure 14 provides an additional view of detection frequencies across the 4 wells. Total Petroleum hydrocarbons (TPH) are volatile organic compounds that were the most commonly detected with an overall detection frequency of 73% (*n* = 14). The second

most frequently detected compound was tetrachloroethene (PCE) at 12% detection, followed by undecane at 10%, benzene at 5%, fluorine at 5%, and tridecane at 2%.

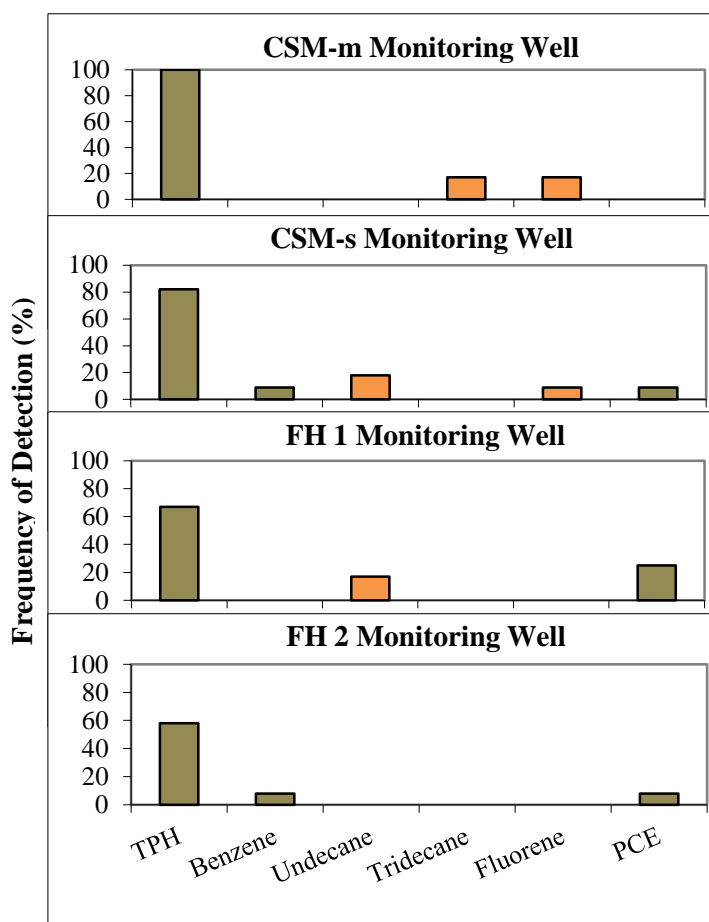


Figure 14. Frequency of detection for target compounds detected with the W.L. Gore passive sampling modules across the 4 selected wells. Column identification: tan = volatile organic compound, orange = semi-volatile organic compound.

A statistical analysis to assess similarities or differences between the distributions of each detected target compound across the 4 wells was conducted with the general Wilcoxon rank test. The test for each detected compound yielded non-significant results. That is, the distribution of detection for each compound across all 4 wells was not significantly different from well to well. The Kendall's tau rank correlation test, however, found that there was a significant relationship between the detection of TPH

and the amount of precipitation received the week leading up to each sampling event ($z = 1.0$, $p = 0.0082$).

The assessment of total petroleum hydrocarbons for this study involved the analysis of petroleum hydrocarbon constituents within well water. One of the most common sources of contamination to the environment is leaking underground storage tanks, which allow TPH components to leach into soils and ultimately groundwater. TPH may also enter the environment through spilled oil, or chemicals used in residential or industrial settings. Once in the environment, TPH may bind to soil and persist for years. In aquatic environments, some of these petroleum components may float on the surface while others bind to sediments (ATSDR 1999).

According to the U.S. Department of Health and Human Services, TPH can affect the central nervous system, blood, immune system, lungs, skin, and eyes at elevated levels. Some constituents of TPH have also affected reproduction in developing animal fetuses in laboratory studies. In addition, some TPH compounds have been found to be likely carcinogens to humans. To date, however, the government has implemented no regulations or advisories for TPH (ATSDR 1999).

Aside from TPH, the second most frequently detected compound was tetrachloroethene (PCE), which was detected in 3 of the 4 wells. PCE is a common dry-cleaning solvent used in the textile industry. It may enter the environment through leaks or spills, and, according to the U.S. EPA, has been detected at more than 1,500 hazardous waste sites. This compound is slow to break down when released into soil and thus poses a high risk of leaching into groundwater. PCE is toxic to the central nervous system, kidneys, and liver; and is likely a carcinogen (USEPA 2012). It should be noted,

however, that the samples collected during this study did not yield PCE concentrations above the maximum contaminant level of 5 µg/L established by the U.S. EPA.

An accurate assessment, or conclusion from quantifying non-naturally occurring compounds within a karst groundwater system, such as the Edwards Aquifer, is often difficult. Contaminants may pass through the system fairly quickly, and even transform or degrade as they move through the water (Focazio et al. 2008). Grab samples for this study were obtained at two-month intervals, as well as after substantial rain events. This method of sampling may not actually have been sufficient in capturing a flux of contaminant within the aquifer, and it is thus unknown whether the detected concentrations are representative of the low or high end of a potential pulse.

Rather than merely make quantitative observations, the focus of this study was to primarily assess detection versus non-detection for target compounds. In addition, it is important to remember that while the target compounds were detected at extremely low levels, they were detected even so. The concentrations of compounds detected with the W.L. Gore passive sampling modules were reported in parts per billion (ppb), or µg/L, and the compounds detected with GC-MS-MS were conveyed in parts per trillion (ppt), or ng/L. The expansive Edwards Aquifer has adequate dilution abilities, which thus puts into question the amount of contaminant needed to enter the aquifer in order to be at all detected. Some more insoluble contaminants may simply accumulate in the aquifer system and be detected periodically. Nonetheless, the detected concentrations of target compounds in this study have contributed to constructing a baseline profile for the immediate area of the future Paso Robles housing development, and can be compared to samples obtained during and upon the completion of the construction process. Figure 15

summarizes the frequency of detection for all of the detected compounds analyzed with both GC-MS-MS and the W.L. Gore passive sampling modules.

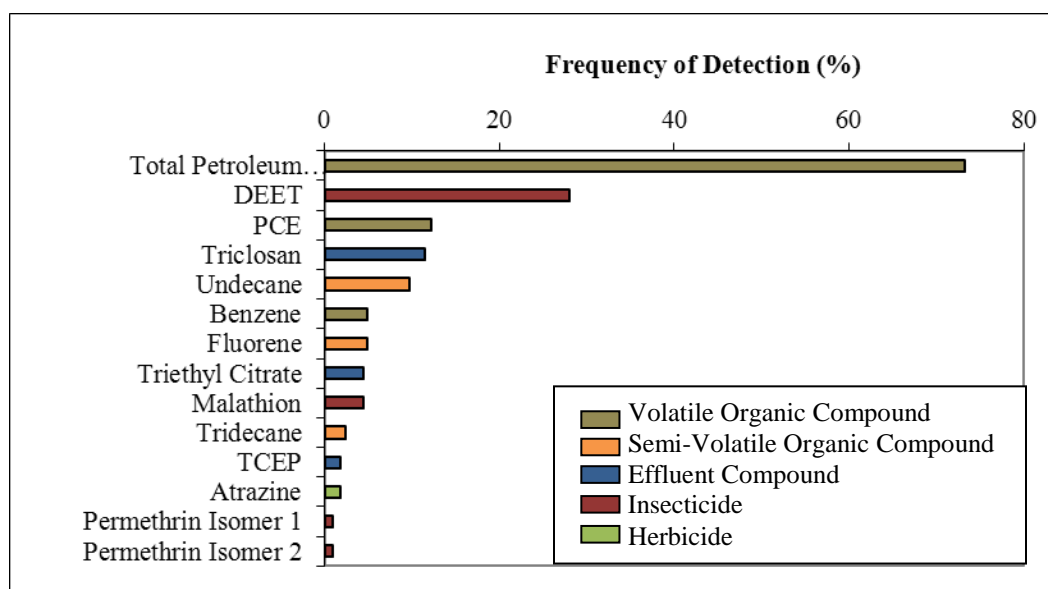


Figure 15. Frequency of detection for all detected target effluent, insecticide, herbicide, volatile, and semi-volatile organic compounds.

3.5. Precipitation & Storm Water Runoff

Precipitation was measured throughout the study period of January 2011 through July 2012, and is presented in Figure 16.

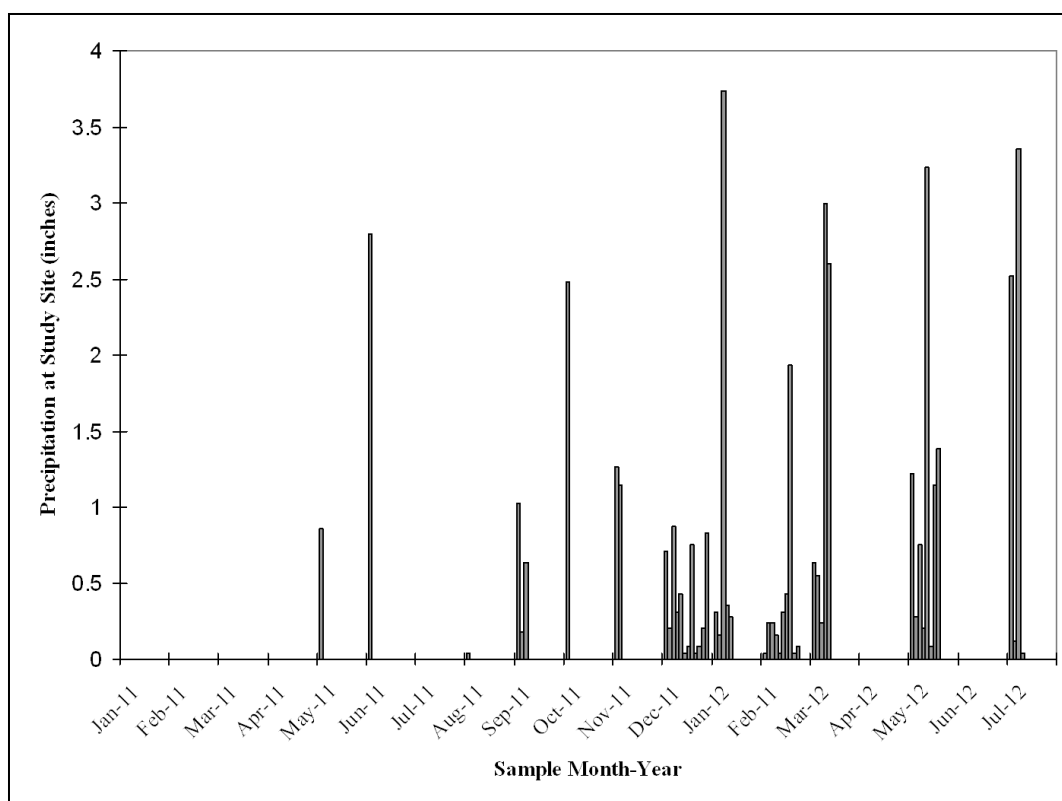


Figure 16. Precipitation during the study period: January 25, 2011 – July 12, 2012.

A significant portion of this study was conducted during drought conditions, and in some instances substantial rainfall merely soaked into the dry soils and did not produce runoff. There were four instances throughout this study for which rain events produced enough discharge from a tributary of the Cottonwood Creek drainage basin within the study site from which surface runoff samples were collected. These events occurred on the following dates: January 25, 2012 (3.3 in, or 9.4 cm); February 18, 2012 (1.9 in, or 4.8 cm); March 20, 2012 (3.0 in, or 7.6 cm); and July 11, 2012 (3.4 in, or 8.6 cm). During the latter storm event, samples were only collected on the fall of the storm hydrograph (after peak discharge). The discharge of each storm event was calculated based on water level, or head values, over the sharp-crested, V-notch weir. The chemical properties of the runoff were assessed and plotted against the calculated discharge. This

information can be beneficial for future assessments of storm runoff during and upon the completion of the Paso Robles housing development and associated golf course. In comparing water quality parameters such as major ion concentrations, total suspended solids, and dissolved organic carbon under various flow conditions; the effects of the development over and within the vicinity of the sensitive Edwards Aquifer recharge zone with groundwater quality can be further determined. Figures 17 through 20 provide comparisons of turbidity, total dissolved solids, biological oxygen demand, and total alkalinity values of surface runoff samples to discharge for each sampling event.

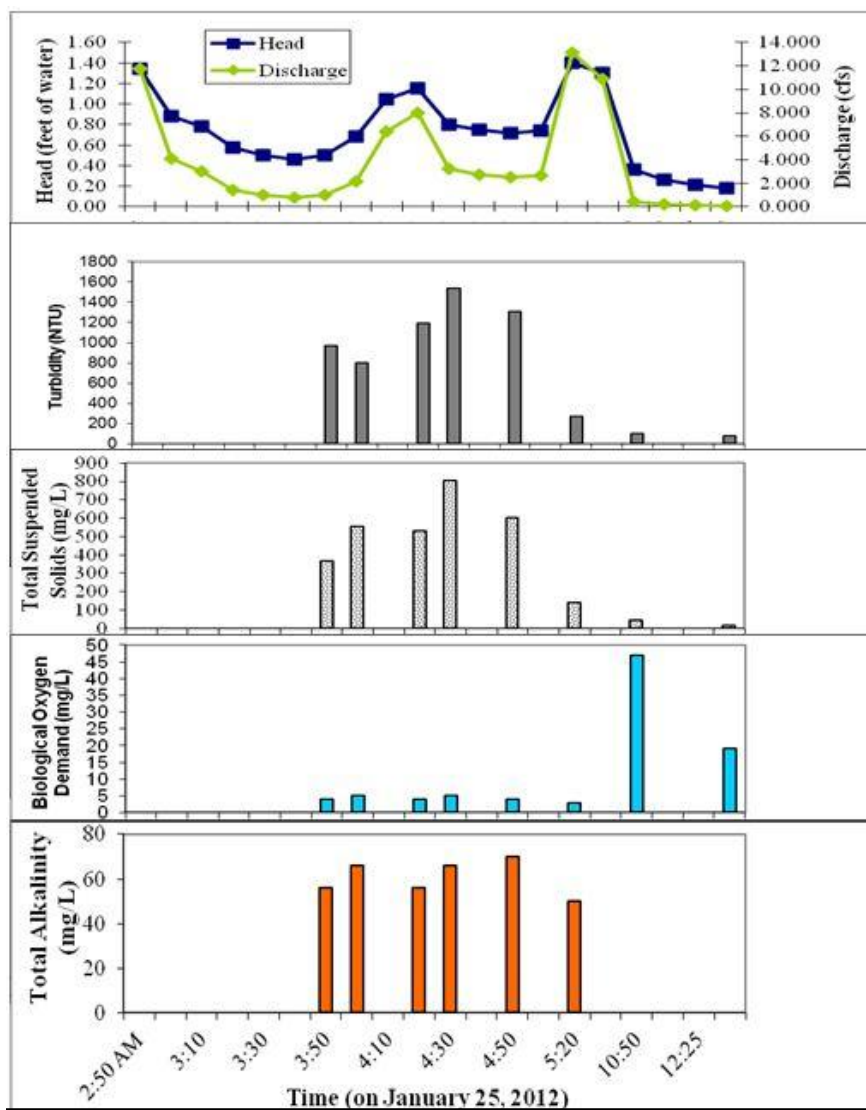


Figure 17. Turbidity, total suspended solids, biological oxygen demand, and total alkalinity concentrations of storm water runoff relative to the calculated drainage basin discharge during the January 25, 2012 rain event.

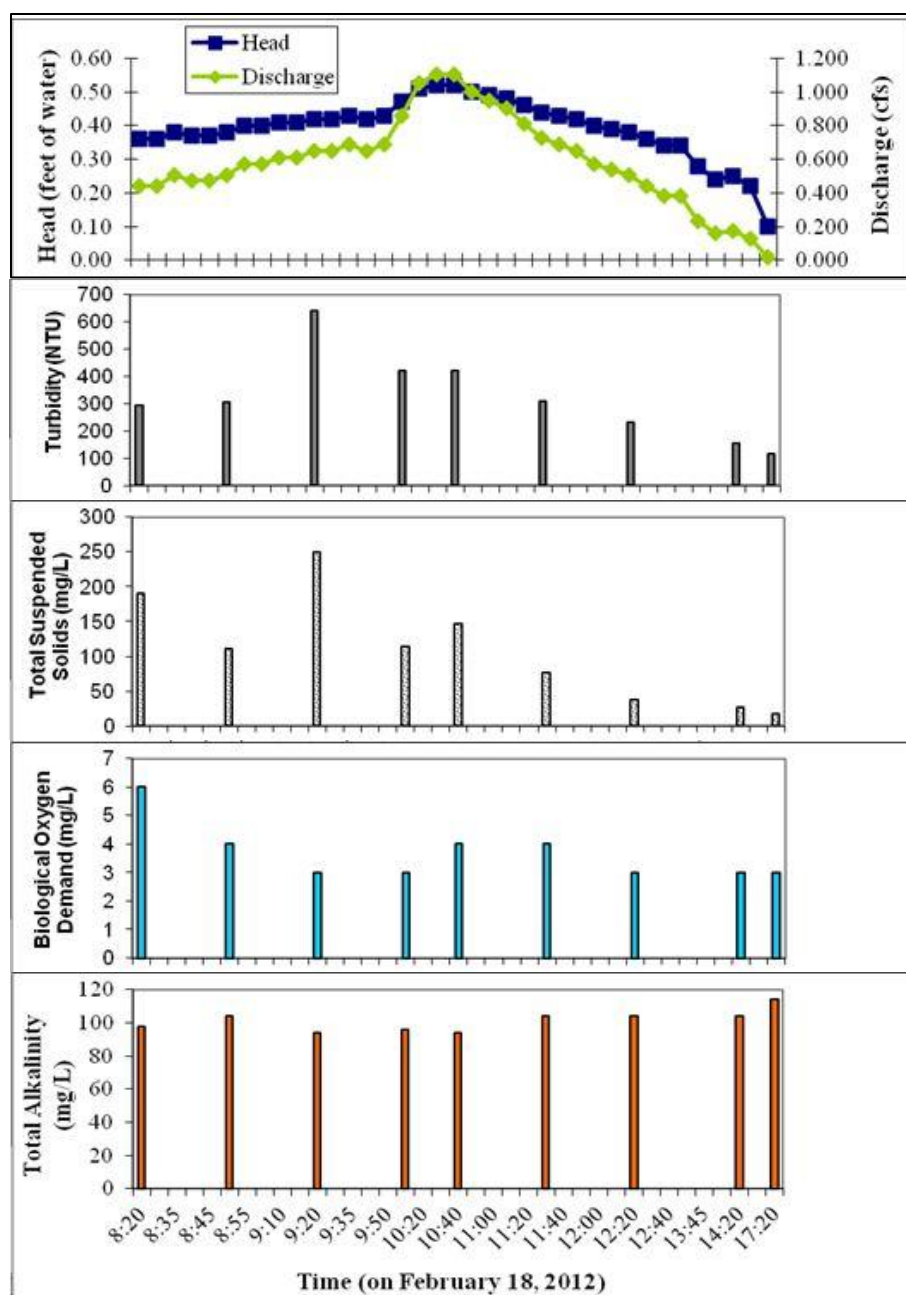


Figure 18. Turbidity, total suspended solids, biological oxygen demand, and total alkalinity concentrations of storm water runoff relative to the calculated drainage basin discharge during the February 18, 2012 rain event.

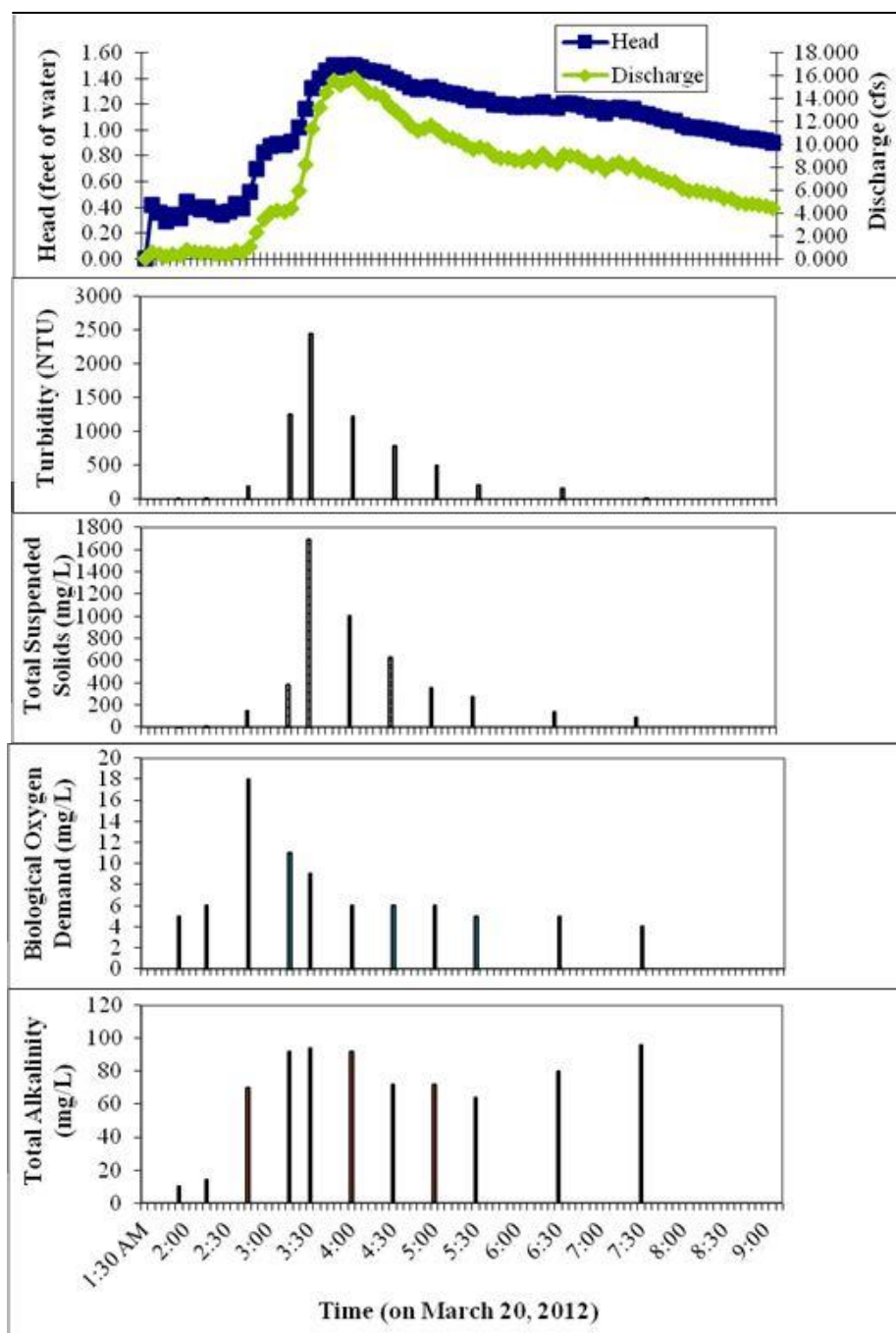


Figure 19. Turbidity, total suspended solids, biological oxygen demand, and total alkalinity concentrations of storm water runoff relative to the calculated drainage basin discharge during the March 20, 2012 rain event.

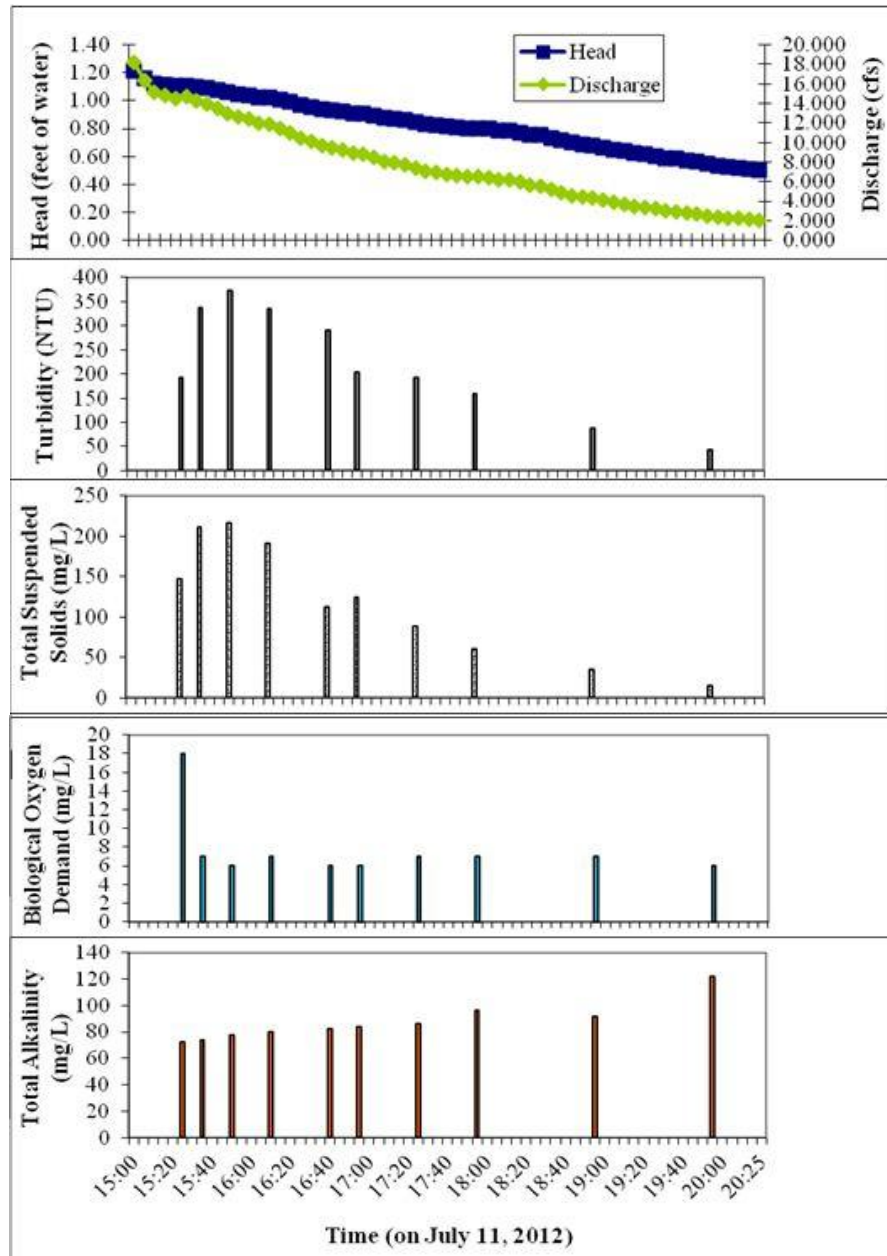


Figure 20. Turbidity, total suspended solids, biological oxygen demand, and total alkalinity concentrations of storm water runoff relative to the calculated drainage basin discharge during the July 11, 2012 rain event.

The concentrations of turbidity, total suspended solids, biological oxygen demand, and total alkalinity throughout the discharge of each storm event provide insight into storm runoff during various weather conditions. For instance, turbidity and total suspended solid values were relatively higher for runoff events for which there had not

been recent substantial rain events prior to sampling. The January 25, 2012 runoff, for example, had higher values than the February 18, 2012 event. The March 20, 2012 runoff, however, had substantially higher turbidity and total suspended solids concentrations. This could have been the result of higher productivity in the spring, as well as the fact that the March storm event yielded more precipitation than the February rainstorm, thus allowing for a greater amount of runoff. Furthermore, these values will likely increase for each storm event once construction has begun. Erosion throughout construction sites can be a major contributor of solids to storm runoff, which ultimately aids in recharging the aquifer. An increase in solids allows for a higher risk of other contaminants, which may bind to soil particles such as herbicides, insecticides, and compounds found to persist in treated effluent; to enter the aquifer through storm runoff recharge events (USEPA 2012).

The following Figures 21 through 24 provide nutrient levels of total phosphorous and nitrate + nitrite-N through each runoff event. As expected, peaks of nutrient levels were congruent with peak discharge. That is, as the amount of surface runoff increased throughout the storm event, more nutrients were washed through the drainage basin. During and upon the completion of the Paso Robles construction process for the Paso Robles housing development, nutrient levels may likely increase through urban landscape and fertilizer runoff (USEPA 2012).

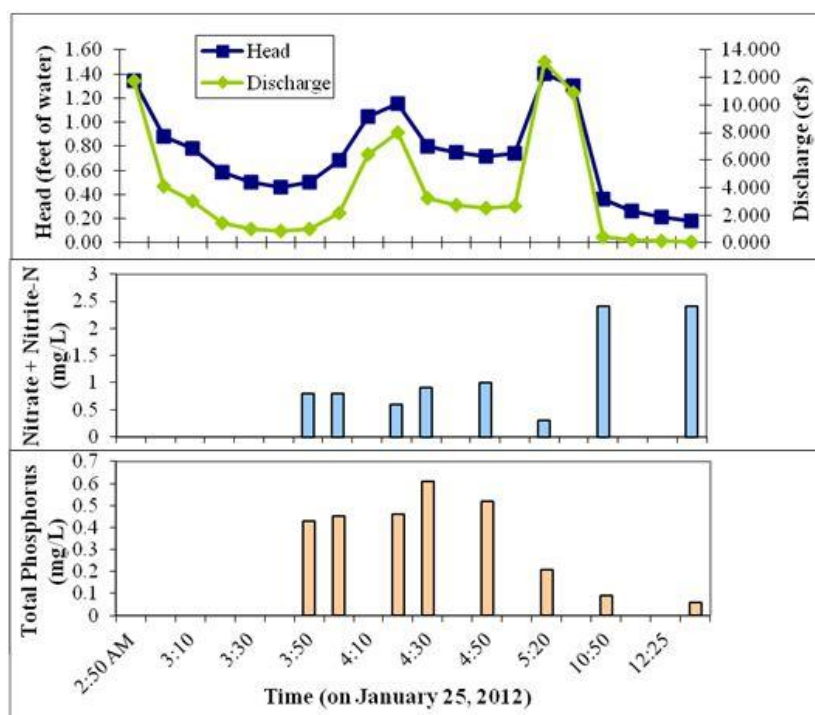


Figure 21. Nitrate + nitrite-N and total phosphorus concentrations of storm water runoff relative to the calculated drainage basin discharge during the January 25, 2012 rain event.

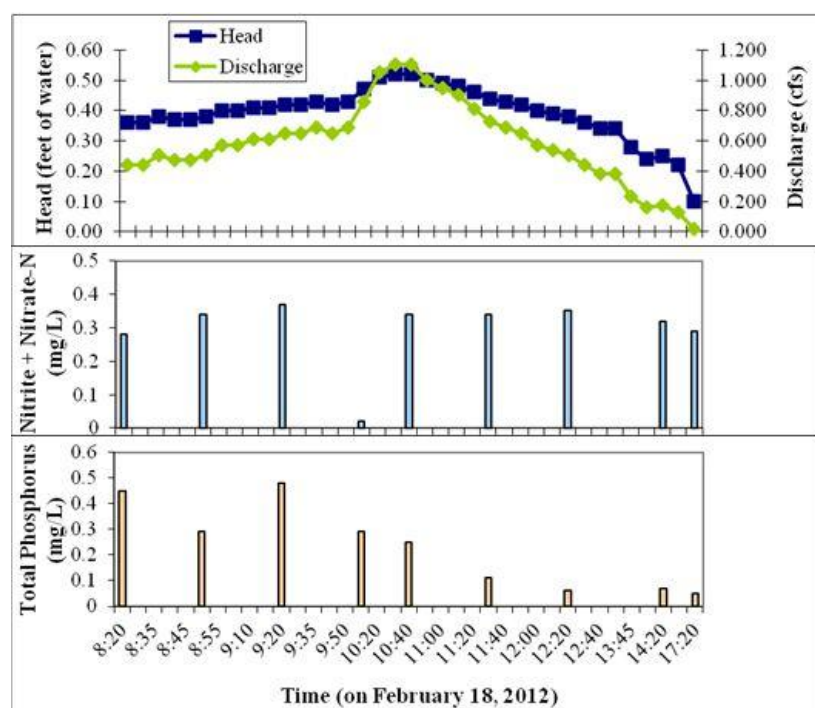


Figure 22. Nitrate + nitrite-N and total phosphorus concentrations of storm water runoff relative to the calculated drainage basin discharge during the February 18, 2012 rain event.

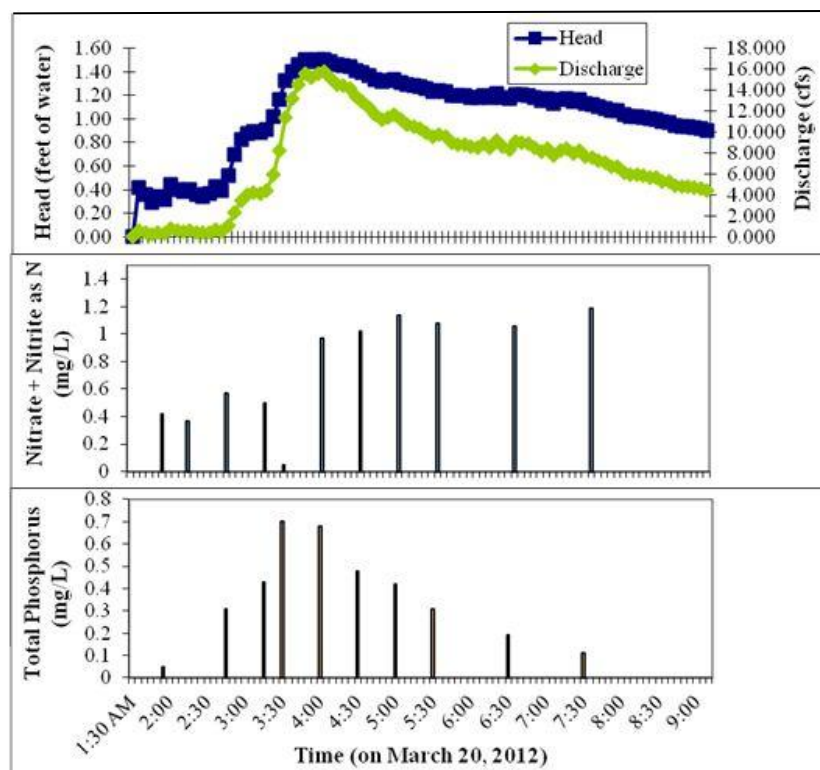


Figure 23. Nitrate + nitrite-N and total phosphorus concentrations of storm water runoff relative to the calculated drainage basin discharge during the March 20, 2012 rain event.

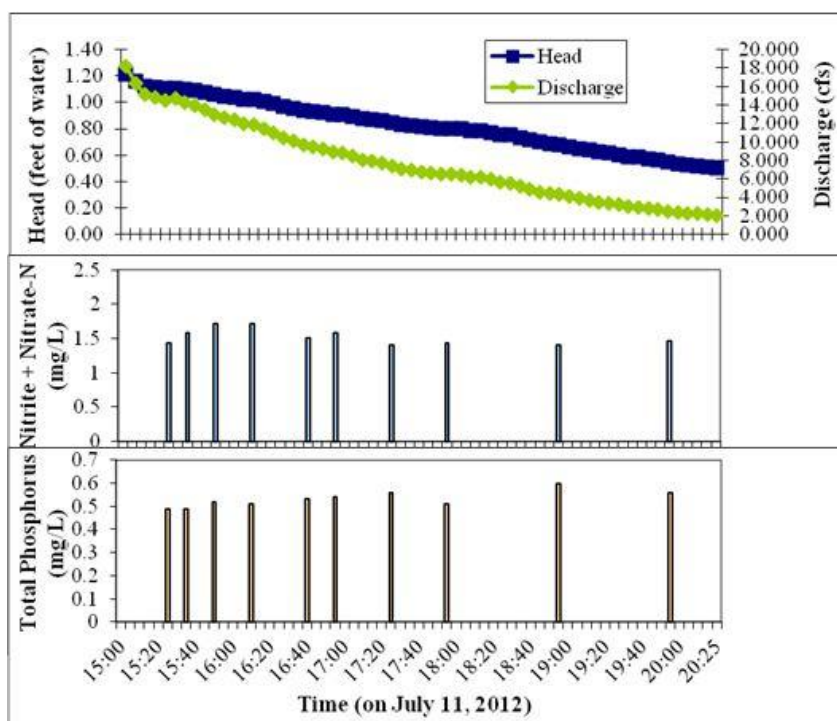


Figure 24. Nitrate + nitrite-N and total phosphorus concentrations of storm water runoff relative to the calculated drainage basin discharge during the July 11, 2012 rain event.

Figures 25 through 27 display levels of the chloride and sulfate ions for the February, May, and July 2012 storm runoff events. Chloride and sulfate values were each only detected once throughout all samples obtained during the January 25, 2012 runoff event, and therefore are not displayed. This could have been the result of the instrument failure encountered during the analysis of this runoff storm event.

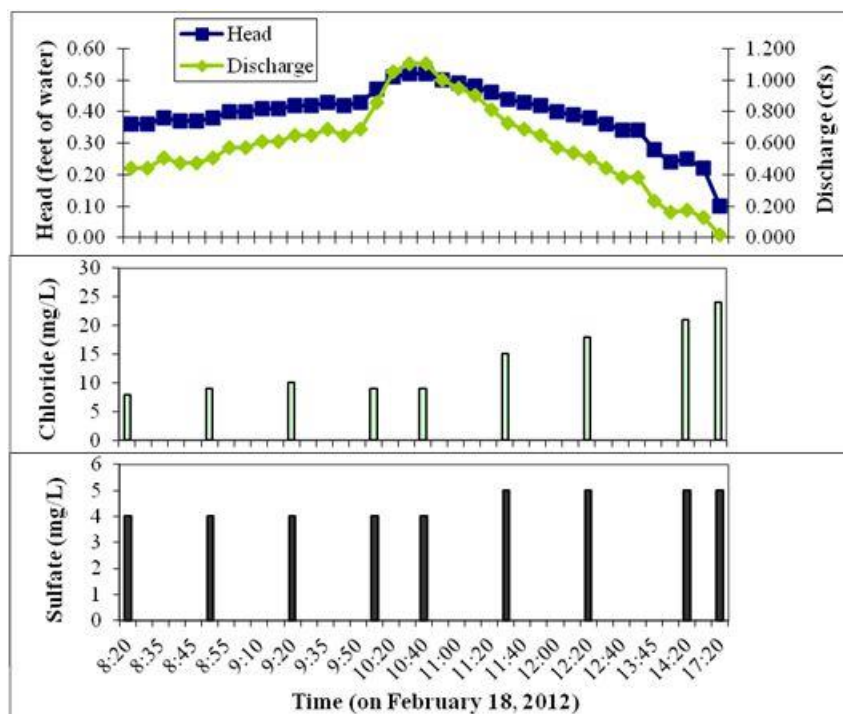


Figure 25. Chloride and sulfate concentrations of storm water runoff relative to the calculated drainage basin discharge during the February 18, 2012 rain event.

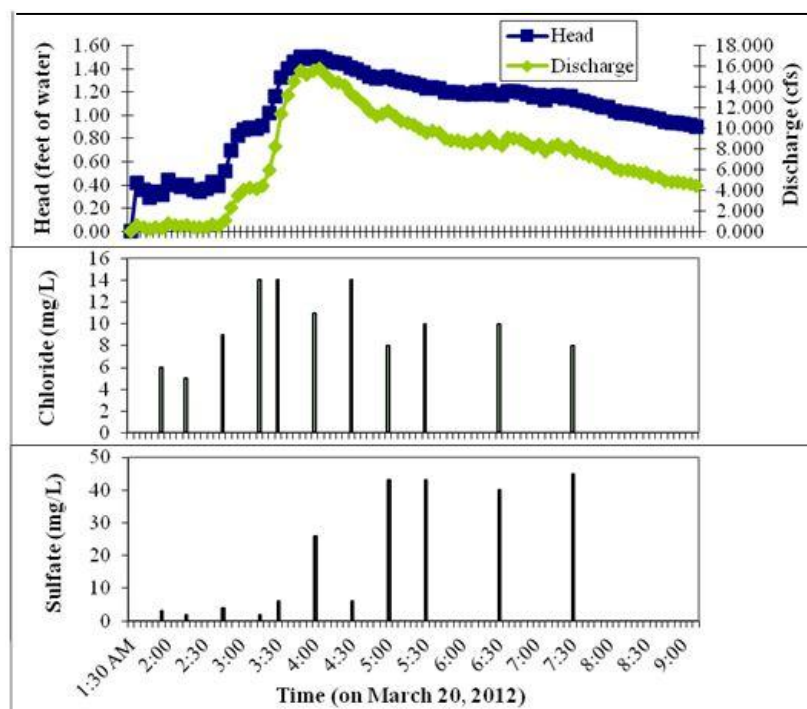


Figure 26. Chloride and sulfate concentrations of storm water runoff relative to the calculated drainage basin discharge during the March 20, 2012 rain event.

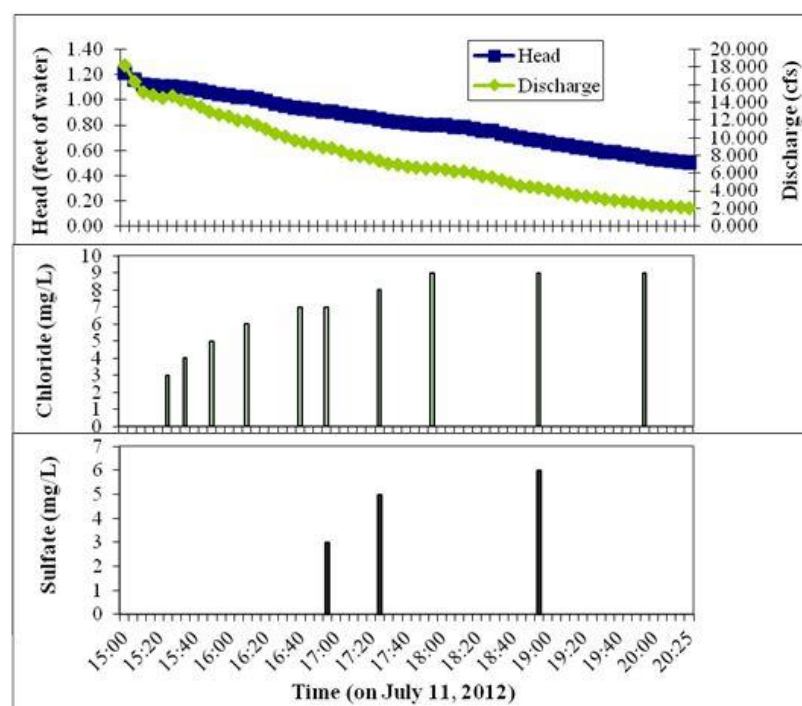


Figure 27. Chloride and sulfate concentrations of storm water runoff relative to the calculated drainage basin discharge during the July 11, 2012 rain event.

The following graphs, Figures 28 through 31, present the detected concentrations of select metals during each storm runoff event. Major cation concentrations could increase overall during and upon the completion of Paso Robles. The primary source of metals in runoff is often automobiles and various industries (USEPA 2012).

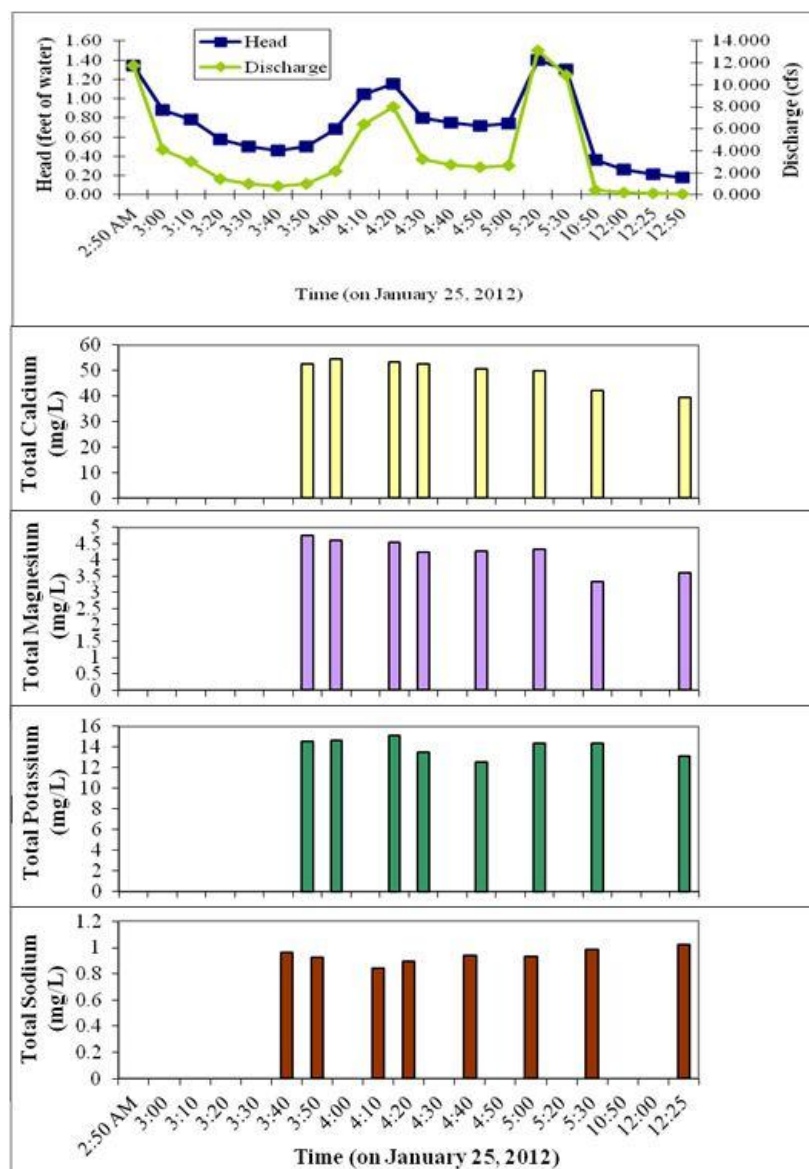


Figure 28. Total calcium, magnesium, potassium, and sodium concentrations of storm water runoff relative to the calculated drainage basin discharge during the January 25, 2012 rain event.

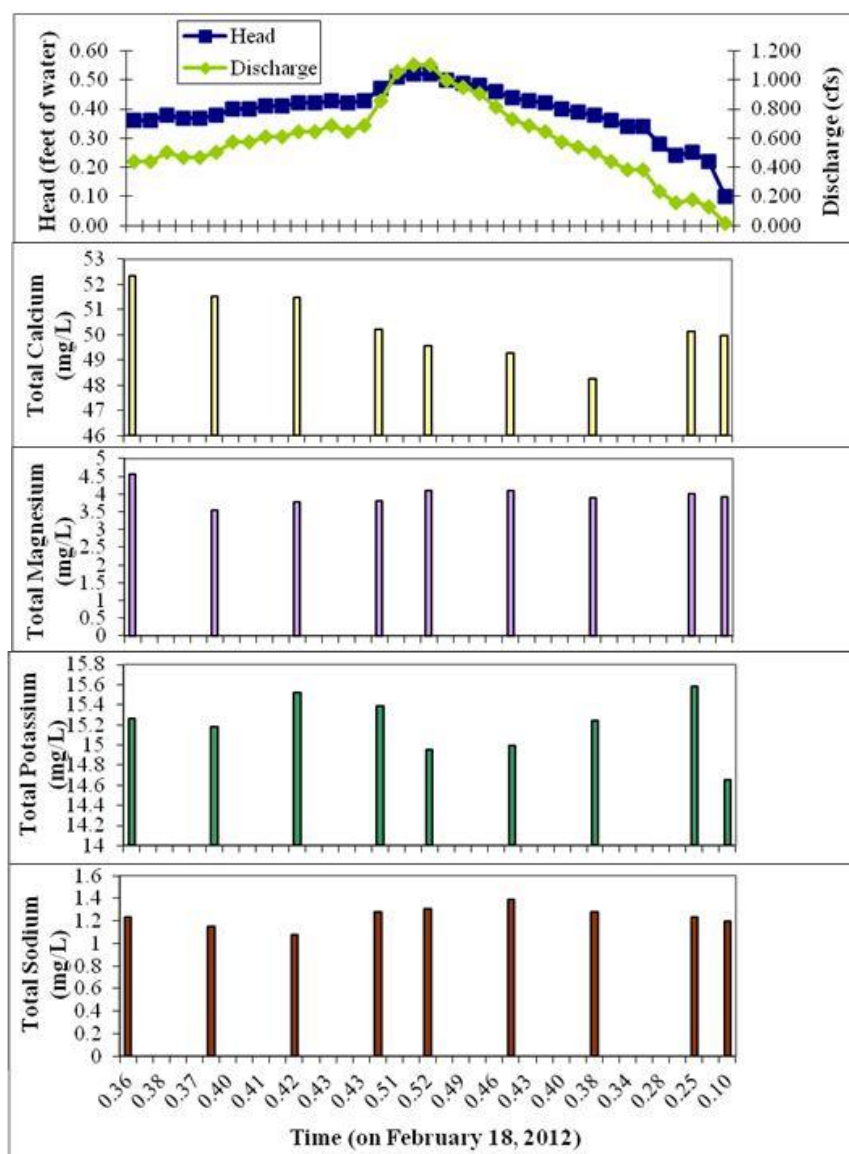


Figure 29. Total calcium, magnesium, potassium, and sodium concentrations of storm water runoff relative to the calculated drainage basin discharge during the February 18, 2012 rain event.

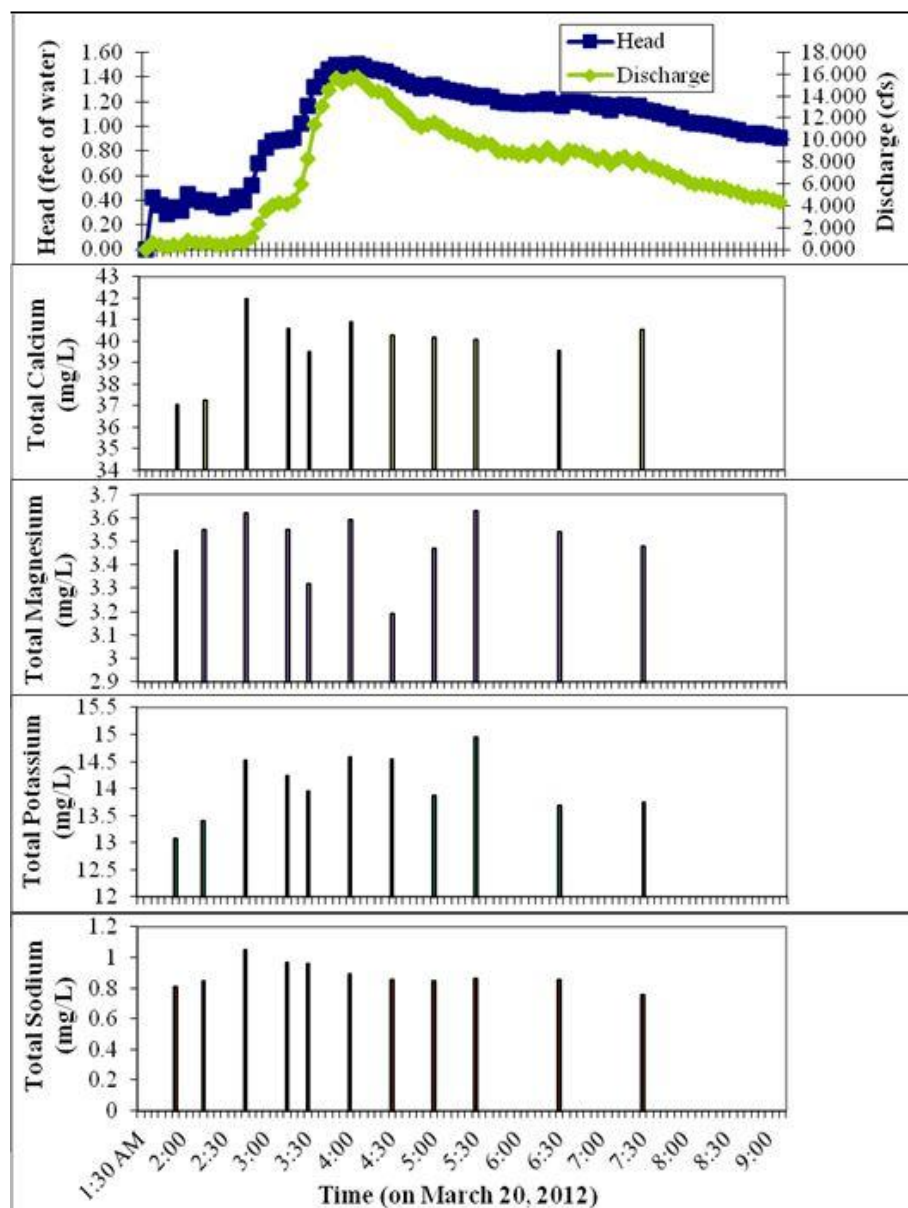


Figure 30. Total calcium, magnesium, potassium, and sodium concentrations of storm water runoff relative to the calculated drainage basin discharge during the March 20, 2012 rain event.

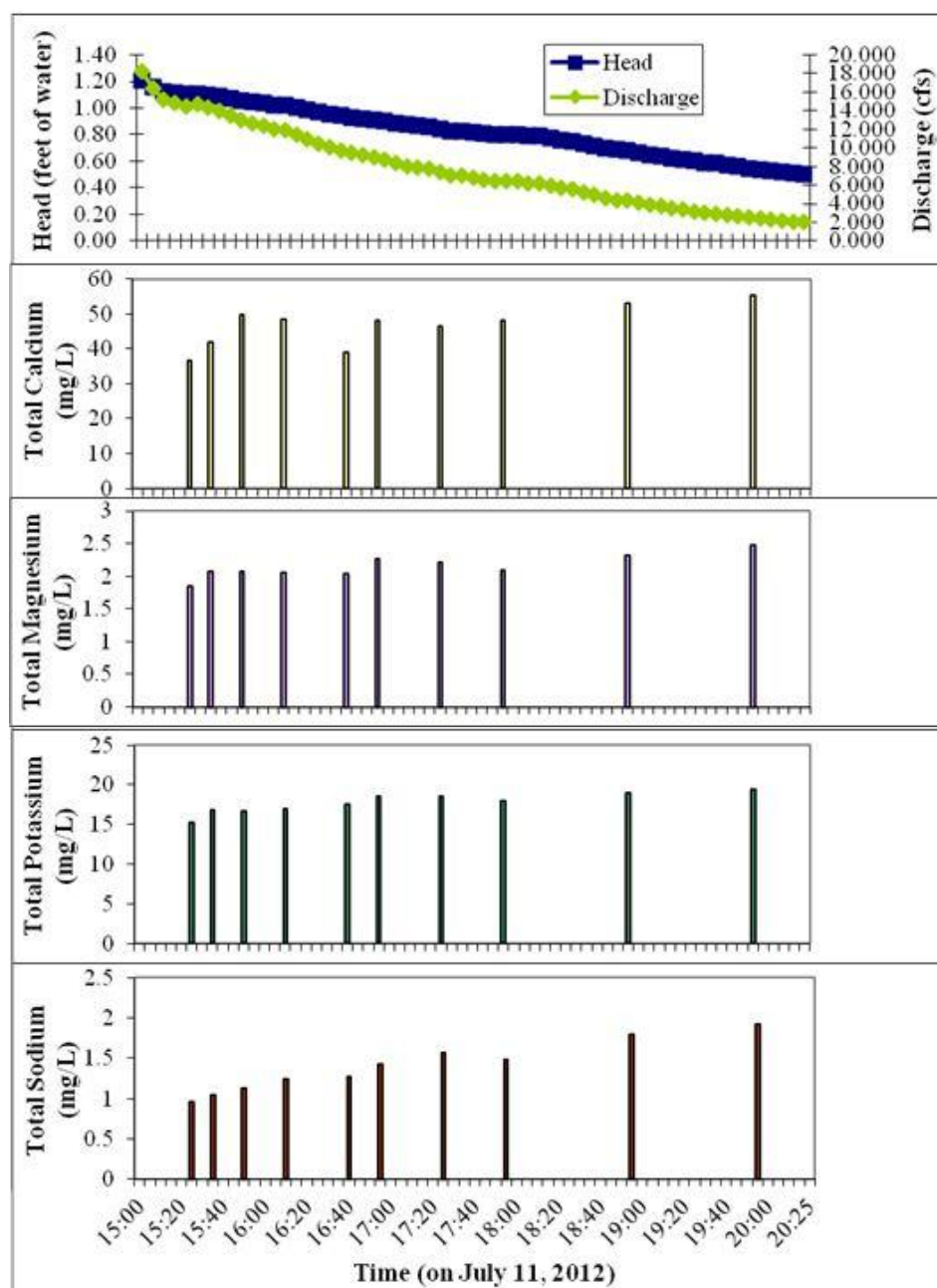


Figure 31. Total calcium, magnesium, potassium, and sodium concentrations of storm water runoff relative to the calculated drainage basin discharge during the July 11, 2012 rain event.

CHAPTER IV

CONCLUSION

The Paso Robles housing development and associated golf course in the southwestern outskirts of San Marcos, Texas, will result in the placement of residential homes, some small commercial businesses, new roads, and a golf course adjacent to and over portions of the Edwards Aquifer sensitive recharge zone (Balcones Fault Zone) where water enters the aquifer system. Anthropogenic activities in the contributing and recharge zones of the Edwards can greatly contribute to degrading water quality in some regions where land use is transformed from ranching/residential areas to commercial development (Stone and Schindel 2002). Development on extremely faulted and fractured karst limestone, as that found within the Balcones Fault Zone, will increase the likelihood of leakage or spilling of hazardous materials which would enter the aquifer with little to no filtration (Hanson and Small 1995). In addition, increases in the amount of impervious cover, such as residential streets, sidewalks, parking lots, concrete-lined channels, and rooftops, disrupts the relationship between rainfall and the local soil and vegetation. As a result, rainfall drains quickly to areas of recharge features, picking up increased concentrations of contaminants along the way (Ross and Rice 2005).

This research sought to establish a baseline understanding of groundwater quality within the immediate vicinity of the future Paso Robles housing development and associated golf course. This was accomplished through a bimonthly monitoring program of nine wells around the site location.

GC-MS-MS analysis of groundwater samples detected the presence of select compounds typically found to persist in treated wastewater: triclosan (11% detection frequency), triethyl citrate (4%), and TCEP (2%). Common insecticides were also detected with this method: DEET (28%), malathion (4%), and permethrin (1%); along with the herbicide atrazine (2%).

The use of passive sampling semi-permeable membranes allowed for the analysis of volatile and semi-volatile organic compounds at select wells. Detections through this method included the following: total petroleum hydrocarbons (73% detection frequency), PCE (12%), undecane (10%), benzene (5%), fluorine (5%), and tridecane (2%). As noted previously, though, these detections occurred at extremely low levels. However, their presence in the Edwards Aquifer groundwater supports the need for continuous monitoring of well water samples, particularly during the construction process and upon the completion of the Paso Robles housing development and associated golf course. Lastly, total coliform bacteria and *E. coli* were also detected throughout the study. Sources of bacteria within this relatively rural area are likely cattle, wildlife, and septic tanks.

In addition, the comparison of the calculated discharge with water quality parameters such as major ions concentrations, total suspended solids, and dissolved organic carbon under various flow conditions of each storm event can be beneficial for

future assessments of storm runoff during the construction of Paso Robles. That is, effects of the development over and within the vicinity of the sensitive Edwards Aquifer recharge zone with groundwater quality can be further determined using these baseline data.

This baseline research will ultimately aid in characterizing the effects of regional development on the vulnerable Edwards Aquifer within this region to actions which will increase the likelihood of introducing contaminants. This data acquired prior to construction could be applied to future studies and enhance the likelihood of timely identification of potential contamination and promote further investigation of the effects of anthropogenic surface activity on subsurface aquatic environments such as the Edwards Aquifer. This research may also aid in future modifications of management practices for Paso Robles and its associated golf course if needed, and help minimize deleterious effects on crucial environmental aspects of the aquifer and its sources of recharge from potential future contamination.

APPENDICES

Appendix 1. Basic water chemistry parameter analysis for each monitoring well.

Field Water Temperature (°C)					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	19.9	20.0	20.0	15.2	21.7	21.0	21.5	21.9	20.5
March-11	20.9	22.0	22.1	21.8	22.5	22.6	19.7	19.9	21.6
May-11	24.3	24.9	25.0	24.2	25.1	23.3	24.7	26.2	24.7
June-11 (rain event)	23.6	24.7	23.7	24.0	24.2	24.9	25.1	26.5	27.0
July-11	23.1	23.5	23.5	23.7	23.3	23.1	26.6	25.2	29.7
September-11	22.6	23.0	23.0	22.9	23.6	23.4	24.6	23.9	23.7
November-11	17.8	20.8	20.6	19.9	20.5	20.6	18.8	21.0	14.9
January-12	21.5	21.9	22.3	22.2	21.3	21.9	16.7	22.2	17.9
March-12	---	23.7	24.2	23.2	22.4	22.2	19.8	22.3	19.6
May-12 (rain event)	---	---	---	---	22.6	22.5	20.8	22.3	20.4
May-12	22.2	22.7	22.7	22.7	22.8	24.0	24.0	23.6	24.5
July-12	23.1	23.8	23.7	23.2	23.7	24.0	24.5	26.7	24.8
Field pH (Units)									
January-11	7.3	7.3	7.4	6.8	7.3	7.3	7.3	7.3	7.4
March-11	7.2	7.2	7.3	7.3	7.2	7.2	7.3	7.3	7.3
May-11	6.8	6.8	6.8	6.8	6.8	6.7	6.8	6.6	6.9
June-11 (rain event)	6.5	6.5	6.5	6.4	6.6	6.6	6.5	6.5	6.6
July-11	7.2	7.1	7.1	7.1	7.2	7.2	7.2	7.2	7.4
September-11	6.6	6.6	6.6	6.7	6.6	6.7	6.6	6.4	6.8
November-11	6.6	6.5	6.6	6.5	6.5	6.5	6.5	6.2	6.7
January-12	6.8	6.8	6.9	6.9	6.9	6.9	7.0	7.0	7.1
March-12	---	6.9	6.9	6.9	6.9	6.9	6.9	6.9	7.1
May-12 (rain event)	---	---	---	---	7.1	7.1	7.2	7.2	7.4
May-12	7.0	6.9	6.9	6.9	6.9	7.0	7.0	7.0	7.1
July-12	6.9	6.9	7.0	6.9	7.0	7.1	7.0	7.1	7.3

Appendix 1. Continued.

Field Specific Conductance (µS/cm)					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	433	496	470	430	483	467	454	1367	433
March-11	432	495	463	428	483	467	408	1252	435
May-11	494	559	514	486	539	521	504	1552	502
June-11 (rain event)	567	634	657	556	613	607	579	1771	581
July-11	512	576	542	501	561	542	529	1614	523
September-11	497	561	519	486	533	517	501	1538	490
November-11	526	615	566	530	593	573	547	1684	535
January-12	544	620	572	533	590	574	548	1692	547
March-12	---	668	651	570	625	604	587	1797	579
May-12 (rain event)	---	---	---	---	664	648	613	1830	608
May-12	613	698	657	596	673	662	621	1850	615
July-12	583	668	630	569	628	613	589	1793	586
Field Dissolved Oxygen (mg/L)									
January-11	5.6	3.6	3.9	6.0	4.3	4.9	5.2	3.6	6.6
March-11	9.6	5.5	6.7	9.2	8.0	7.0	5.4	1.7	5.4
May-11	7.0	6.0	5.8	7.7	6.2	5.8	6.8	3.4	7.2
June-11 (rain event)	7.1	4.3	5.5	5.6	6.6	5.8	5.5	3.1	6.5
July-11	6.8	5.4	5.7	7.1	5.6	5.9	6.9	3.4	7.0
September-11	6.7	4.8	5.7	6.9	5.4	5.9	7.8	3.5	7.3
November-11	6.9	5.5	5.7	6.4	6.0	5.9	6.5	4.5	7.2
January-12	7.2	5.2	6.2	7.4	6.1	5.9	8.5	3.8	7.5
March-12	---	5.9	5.8	7.2	5.8	6.0	6.8	3.8	7.9
May-12 (rain event)	---	---	---	---	6.2	5.3	6.7	3.5	7.0
May-12	6.3	5.7	5.8	6.1	6.0	5.0	5.8	4.8	6.4
July-12	6.8	5.3	5.7	7.2	5.5	6.0	6.5	3.6	7.3

Appendix 1. Continued.

Total Coliform (MPN/100mL): MDL = 1					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	---	---	---	---	---	---	---	---	---
March-11	<1	<1	11	<1	>2419	2	23	2	<1
May-11	<1	<1	12	1	<1	6	23	64	<1
June-11 (rain event)	<1	<1	15	1	435	3	3	6	<1
July-11	<1	<1	60	<1	21	19	<1	<1	<1
September-11	<1	<1	32	<1	>2419	3	<1	<1	<1
November-11	<1	<1	19	<1	93	<1	<1	8	<1
January-12	<1	59	73	<1	91	4	<1	435	<1
March-12	---	57	649	457	5	1	<1	9	<1
May-12 (rain event)	---	---	---	---	10	4	1	1300	<1
May-12	<1	6	14	>2419	1414	29	<1	5	<1
July-12	<1	64	15	<1	24	131	<1	>2419	<1
<i>E. coli</i> (MPN/100mL): MDL = 1									
January-11	---	---	---	---	---	---	---	---	---
March-11	<1	<1	<1	<1	<1	<1	<1	<1	<1
May-11	<1	<1	<1	<1	<1	<1	<1	<1	<1
June-11 (rain event)	<1	<1	<1	<1	<1	<1	<1	<1	<1
July-11	<1	<1	<1	<1	<1	<1	<1	<1	<1
September-11	<1	<1	<1	<1	38	<1	<1	<1	<1
November-11	<1	<1	<1	<1	<1	<1	<1	<1	<1
January-12	<1	1	17	<1	<1	<1	<1	<1	<1
March-12	---	1	9	<1	<1	<1	<1	<1	<1
May-12 (rain event)	---	---	---	---	<1	<1	<1	<1	<1
May-12	<1	1	<1	<1	15	<1	<1	<1	<1
July-12	<1	2	<1	<1	<1	<1	<1	5	<1

Appendix 1. Continued.

Total Alkalinity (mg/L): MDL = 20					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	266	264	262	266	262	260	262	282	270
March-11	266	252	258	266	260	260	258	282	270
May-11	260	258	256	262	286	260	258	274	268
June-11 (rain event)	268	260	256	264	266	264	262	282	274
July-11	264	258	258	264	260	266	266	292	272
September-11	264	258	258	260	256	264	264	284	264
November-11	260	256	254	260	258	260	262	282	268
January-12	264	264	248	266	262	262	262	296	278
March-12	---	264	256	264	260	262	260	290	272
May-12 (rain event)	---	---	---	---	256	260	260	286	266
May-12	278	270	260	264	260	270	270	290	276
July-12	276	268	256	264	258	262	274	286	276
Total Dissolved Solids (mg/L): MDL = 10									
January-11	358	356	367	322	362	339	332	1079	323
March-11	295	364	334	337	316	291	325	1047	254
May-11	322	346	350	329	309	392	300	1207	343
June-11 (rain event)	327	345	376	317	327	317	306	1083	340
July-11	254	314	371	239	310	355	291	1004	303
September-11	329	361	229	276	325	296	291	1164	328
November-11	295	322	256	281	288	299	276	1208	319
January-12	294	331	340	321	379	359	294	1148	364
March-12	---	367	384	288	286	283	282	1038	292
May-12 (rain event)	---	---	---	---	311	321	290	960	248
May-12	317	306	355	289	311	308	250	863	283
July-12	273	316	295	250	297	296	299	992	294

Appendix 1. Continued.

Total Hardness (mg/L): MDL = 10									
Sample Well ID									
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	312	326	304	300	320	310	310	640	314
March-11	312	326	312	300	320	312	308	660	314
May-11	286	306	304	300	320	320	298	648	310
June-11 (rain event)	310	320	320	324	306	310	300	640	310
July-11	302	322	304	304	312	310	306	644	294
September-11	304	316	308	306	308	306	300	660	306
November-11	312	316	298	310	318	314	310	650	310
January-12	304	322	302	302	314	306	310	626	310
March-12	---	320	314	306	316	298	298	640	310
May-12 (rain event)	---	---	---	---	314	306	290	628	316
May-12	308	326	314	304	316	310	304	650	300
July-12	302	332	310	308	312	304	308	642	304
Nitrate+ Nitrite-N (mg/L): MDL = 0.1									
January-11	1.48	1.99	1.78	1.04	1.83	1.67	1.79	<0.1	1.33
March-11	1.30	1.68	1.59	0.92	1.61	1.60	1.59	<0.1	1.16
May-11	1.32	1.75	1.61	0.98	1.58	1.66	1.59	<0.1	1.23
June-11 (rain event)	1.33	1.72	1.58	0.95	1.61	1.61	1.62	<0.1	1.21
July-11	1.32	1.69	1.60	0.93	1.57	1.57	1.57	<0.1	1.21
September-11	1.38	1.90	1.66	0.98	1.63	1.67	1.78	<0.1	1.25
November-11	1.40	2.10	1.70	1.00	1.70	1.70	1.70	<0.1	1.30
January-12	1.40	2.00	1.80	1.00	1.60	1.60	1.60	<0.1	1.30
March-12	---	3.01	2.43	1.14	2.01	2.19	2.04	<0.1	1.48
May-12 (rain event)	---	---	---	---	1.78	1.74	1.85	<0.1	1.21
May-12	1.33	2.34	1.80	0.97	1.73	1.60	1.72	<0.1	1.17
July-12	1.29	2.05	1.60	0.89	1.61	1.53	1.72	<0.1	1.12

Appendix 1. Continued.

Nitrite-N (mg/L): MDL = 0.1									
Sample Well ID									
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
March-11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
May-11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
June-11 (rain event)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
July-11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
September-11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
November-11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
January-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
March-12	---	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
May-12 (rain event)	---	---	---	---	<0.1	<0.1	<0.1	<0.1	<0.1
May-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
July-12	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Chloride (mg/L): MDL = 0.76									
January-11	10.60	27.40	20.20	8.92	22.40	19.60	14.30	262.00	9.63
March-11	11.60	28.60	20.50	9.68	22.80	19.40	13.70	219.00	10.10
May-11	13.10	27.80	20.20	11.60	25.10	21.90	16.60	230.00	12.60
June-11 (rain event)	9.96	25.10	30.50	8.16	21.10	18.10	13.50	205.00	8.85
July-11	11.00	27.70	22.00	8.97	23.30	19.50	14.50	269.00	10.10
September-11	11.10	27.50	19.20	9.50	23.40	19.60	15.00	326.00	9.97
November-11	12.00	30.00	24.00	11.00	<1.21	23.00	17.00	216.00	12.00
January-12	13.00	31.00	<1.21	9.00	23.00	20.00	15.00	206.00	10.00
March-12	---	24.00	25.00	8.00	21.00	18.00	14.00	225.00	9.00
May-12 (rain event)	---	---	---	---	26.00	22.00	15.00	241.00	10.00
May-12	12.00	27.00	22.00	9.00	26.00	22.00	16.00	313.00	11.00
July-12	11.00	27.00	23.00	9.00	22.00	20.00	14.00	325.00	10.00

Appendix 1. Continued.

Sulfate (mg/L): MDL = 1.8									
Sample Well ID									
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	23.9	41.9	31.4	23.4	34.0	30.0	24.0	310.0	24.2
March-11	25.1	43.0	32.3	24.4	30.0	25.7	20.7	269.0	21.2
May-11	19.1	33.3	24.2	19.1	29.1	25.6	19.8	265.0	20.3
June-11 (rain event)	21.9	37.6	43.4	21.5	31.0	27.5	22.6	253.0	22.3
July-11	21.4	37.8	31.0	21.1	31.5	27.1	21.8	275.0	22.2
September-11	20.6	35.6	26.7	20.2	29.6	25.5	21.5	249.0	21.0
November-11	18.0	37.0	28.0	20.0	<3.01	26.0	21.0	258.0	20.0
January-12	23.0	39.0	33.0	22.0	28.0	25.0	20.0	233.0	19.0
March-12	---	37.0	39.0	21.0	31.0	27.0	23.0	245.0	21.0
May-12 (rain event)	---	---	---	---	35.0	30.0	24.0	261.0	22.0
May-12	25.0	37.0	32.0	22.0	36.0	29.0	25.0	355.0	22.0
July-12	11.0	27.0	23.0	9.0	22.0	20.0	14.0	325.0	10.0
Fluoride (mg/L): MDL = <0.1									
January-11	0.2	0.3	0.3	0.2	0.3	0.2	0.2	2.2	0.3
March-11	0.3	0.3	0.3	0.2	0.2	0.2	0.3	2.2	0.3
May-11	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.9	0.3
June-11 (rain event)	0.2	0.3	0.3	0.2	0.3	0.2	0.2	2.0	0.3
July-11	0.2	0.3	0.3	0.3	0.3	0.2	0.3	2.0	0.3
September-11	0.2	0.3	0.3	0.2	0.3	0.3	0.3	2.1	0.3
November-11	0.2	0.3	0.2	0.2	0.3	0.3	0.2	2.1	0.3
January-12	0.2	0.3	0.3	0.2	0.3	0.3	0.2	2.0	0.3
March-12	---	0.3	0.3	0.2	0.2	0.2	0.2	1.9	0.3
May-12 (rain event)	---	---	---	---	0.2	1.7	0.2	1.8	0.2
May-12	0.2	0.3	0.2	0.2	0.2	0.2	0.2	1.8	0.3
July-12	0.2	0.3	0.3	0.2	0.2	0.2	0.2	1.9	0.3

Appendix 1. Continued.

Ortho-P-Phosphate (mg/L): MDL<0.02					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
March-11	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
May-11	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
June-11 (rain event)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
July-11	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
September-11	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
November-11	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
January-12	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
March-12	---	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
May-12 (rain event)	---	---	---	---	<0.02	<0.02	<0.02	<0.02	<0.02
May-12	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
July-12	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total Barium (mg/L): MDL = 0.033									
January-11	0.041	0.034	0.038	0.046	0.036	<0.033	<0.033	<0.033	0.046
March-11	<0.033	0.036	0.034	<0.033	0.036	<0.033	0.039	<0.033	0.064
May-11	0.036	0.038	0.036	<0.033	0.034	0.039	0.040	<0.033	0.047
June-11 (rain event)	<0.033	0.037	0.040	0.034	0.037	<0.033	0.035	<0.033	0.049
July-11	<0.033	0.036	<0.033	<0.033	<0.033	<0.033	0.035	<0.033	0.057
September-11	0.045	0.052	0.049	0.043	0.051	0.052	0.047	0.037	0.061
November-11	<0.033	0.041	<0.033	<0.033	0.044	<0.033	0.052	0.034	0.055
January-12	0.044	0.052	0.051	0.054	0.077	0.049	0.049	0.042	0.060
March-12	---	0.049	0.054	0.058	0.074	0.046	0.043	0.036	0.059
May-12 (rain event)	---	---	---	---	0.046	0.044	0.055	0.034	0.069
May-12	0.046	0.051	0.053	0.056	0.079	0.050	0.046	0.038	0.062
July-12	0.042	0.050	0.056	0.040	0.049	0.047	0.054	0.039	0.069

Appendix 1. Continued.

Total Calcium (mg/L): MDL = 0.929					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	64.85	54.49	66.48	73.60	76.80	52.89	56.23	132.56	35.67
March-11	92.48	97.58	92.88	85.21	100.72	83.43	123.10	139.90	85.98
May-11	102.82	100.10	99.30	71.69	113.79	78.23	91.47	163.94	98.58
June-11 (rain event)	117.66	113.94	113.40	110.87	125.34	112.51	105.51	188.70	99.45
July-11	104.32	77.18	91.30	109.18	106.55	107.83	83.19	133.98	79.95
September-11	105.03	113.78	116.98	89.02	113.03	98.47	107.24	166.57	99.22
November-11	102.35	75.25	92.5	105.26	104.25	105.78	84.21	132.58	78.85
January-12	106.54	117.79	123.85	115.85	112.95	103.25	108.48	168.25	99.42
March-12	---	117.99	124.15	115.73	113.65	104.56	109.15	162.25	99.45
May-12 (rain event)	---	---	---	---	115.21	121.07	108.25	161.71	105.11
May-12	107.54	118.28	124.01	116.37	113.46	105.12	109.26	164.03	100.70
July-12	110.80	110.73	105.59	110.97	102.53	104.87	93.78	165.79	108.62
Total Iron (mg/L): MDL = 0.054									
January-11	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
March-11	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
May-11	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
June-11 (rain event)	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
July-11	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
September-11	<0.054	<0.054	<0.054	<0.054	<0.054	0.057	<0.054	<0.054	<0.054
November-11	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
January-12	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
March-12	---	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
May-12 (rain event)	---	---	---	---	<0.054	<0.054	<0.054	<0.054	<0.054
May-12	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054	<0.054
July-12	<0.054	<0.054	<0.054	<0.054	<0.054	0.205	<0.054	<0.054	0.071

Appendix 1. Continued.

Total Magnesium (mg/L): MDL = 0.443									
Sampe Well ID									
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	18.18	17.11	17.55	18.95	19.28	17.35	14.98	73.13	21.94
March-11	18.50	18.25	19.54	16.38	18.30	17.85	20.63	65.69	17.45
May-11	17.98	18.56	18.87	15.43	18.12	17.64	16.49	72.31	21.91
June-11 (rain event)	19.41	17.88	19.46	15.01	20.00	17.70	16.70	81.54	20.41
July-11	16.80	12.50	15.67	16.36	17.12	16.91	14.84	60.93	16.59
September-11	22.25	22.87	24.81	17.44	23.17	20.96	21.77	90.74	26.07
November-11	16.90	13.52	15.61	16.52	17.09	17.11	22.52	20.52	20.99
January-12	22.95	21.79	23.45	23.45	23.85	19.52	21.88	90.22	26.85
March-12	---	22.24	24.25	21.85	24.06	20.87	21.88	90.56	27.58
May-12 (rain event)	---	---	---	---	24.62	24.99	22.35	88.86	28.10
May-12	23.38	22.14	24.09	22.39	24.18	20.78	22.78	91.05	27.77
July-12	24.96	22.34	22.63	22.19	22.27	22.42	20.07	94.90	30.75
Total Manganese (mg/L): MDL= 0.035									
January-11	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
March-11	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
May-11	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
June-11 (rain event)	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
July-11	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
September-11	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
November-11	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
January-12	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
March-12	---	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
May-12 (rain event)	---	---	---	---	<0.035	<0.035	<0.035	<0.035	<0.035
May-12	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
July-12	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035

Appendix 1. Continued.

Total Potassium (mg/L): MDL= 0.127					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	1.58	2.29	2.05	1.11	2.18	1.76	1.55	12.85	1.18
March-11	1.32	2.30	1.81	1.17	2.08	1.80	1.79	12.01	1.19
May-11	1.33	2.36	1.84	1.02	2.07	1.84	1.74	12.20	1.26
June-11 (rain event)	1.30	2.30	2.16	1.19	2.17	1.84	1.73	12.56	1.19
July-11	1.30	2.25	1.66	1.10	1.93	1.83	1.72	10.71	1.36
September-11	2.07	3.38	2.70	1.75	3.13	2.99	2.44	15.96	1.86
November-11	1.45	2.75	1.85	1.82	3.15	2.94	1.75	11.52	1.95
January-12	2.10	3.42	3.65	1.86	3.25	3.09	2.45	16.85	1.86
March-12	---	3.46	3.88	1.79	3.14	3.51	2.45	15.98	1.88
May-12 (rain event)	---	---	---	---	3.06	2.68	2.82	15.48	1.89
May-12	2.06	3.50	3.78	1.81	3.20	3.15	2.54	16.74	1.82
July-12	1.92	3.50	3.35	1.67	3.02	2.80	2.84	16.91	1.83
Total Silica (mg/L): MDL= 0.248									
January-11	6.41	5.55	5.67	5.32	5.67	5.13	5.04	6.25	5.36
March-11	4.92	5.45	4.92	5.44	5.02	5.05	5.42	5.80	5.16
May-11	5.21	5.43	5.18	4.96	5.02	5.12	5.19	5.75	5.24
June-11 (rain event)	4.97	5.24	5.15	4.99	5.44	4.92	5.15	5.92	5.01
July-11	5.12	5.20	4.13	5.07	4.84	4.95	5.13	4.69	5.07
September-11	5.99	5.83	5.61	6.05	6.01	6.24	5.59	6.41	5.79
November-11	5.12	5.88	5.65	6.11	5.92	6.20	5.82	6.51	5.78
January-12	6.09	5.81	5.98	6.32	5.96	6.01	5.61	6.85	5.66
March-12	---	6.01	6.47	6.24	5.75	5.95	5.35	6.95	5.64
May-12 (rain event)	---	---	---	---	5.69	5.43	6.39	6.29	6.04
May-12	6.13	6.21	6.04	6.21	5.89	6.10	5.72	7.04	5.76
July-12	5.47	5.67	6.03	5.48	5.60	5.51	6.04	6.76	5.59

Appendix 1. Continued.

Total Sodium (mg/L): MDL= 0.054					Sample Well ID				
Sample Month-Year	CSM-m	CSM-s	CSM-h	CSM-k	FH 1	FH 2	P-a	P-b	P-c
January-11	8.79	16.86	14.19	6.25	17.06	11.48	8.82	127.88	6.53
March-11	7.08	17.51	11.82	6.48	18.65	11.70	10.07	113.04	6.83
May-11	7.49	18.32	11.57	5.88	15.80	11.63	9.68	125.49	7.00
June-11 (rain event)	7.19	16.69	18.45	6.24	15.85	11.80	10.05	141.19	6.71
July-11	7.51	12.89	11.02	6.19	14.23	11.66	10.07	111.18	6.84
September-11	7.74	11.54	10.15	6.81	13.48	10.87	8.94	141.50	7.09
November-11	7.81	10.58	9.25	6.65	13.38	13.75	7.22	109.68	10.98
January-12	7.94	11.85	11.25	6.84	11.85	10.92	9.90	137.55	6.95
March-12	---	11.76	11.45	7.05	11.55	11.54	9.64	138.24	6.94
May-12 (rain event)	---	---	---	---	11.93	10.51	10.04	135.00	7.16
May-12	8.21	11.80	11.37	6.91	11.69	11.31	9.71	139.21	7.03
July-12	7.58	11.58	11.67	6.49	11.23	10.53	9.64	3.29	7.09
Total Strontium (mg/L): MDL= 0.2									
January-11	0.58	0.58	0.59	0.47	0.57	0.48	0.44	2.47	1.11
March-11	0.48	0.60	0.53	0.49	0.53	0.49	0.51	2.05	1.21
May-11	0.48	0.60	0.56	0.45	0.55	0.50	0.49	2.12	1.04
June-11 (rain event)	0.48	0.60	0.64	0.48	0.58	0.50	0.50	2.20	1.06
July-11	0.49	0.60	0.47	0.48	0.52	0.50	0.50	1.68	1.05
September-11	0.58	0.67	0.63	0.57	0.65	0.63	0.54	2.34	1.21
November-11	0.42	0.64	0.45	0.47	0.53	0.54	0.61	1.85	1.11
January-12	0.61	0.67	0.62	0.61	0.64	0.64	0.61	3.22	1.34
March-12	---	0.59	0.64	0.62	0.61	0.60	0.62	3.09	1.52
May-12 (rain event)	---	---	---	---	0.63	0.57	0.64	3.04	1.16
May-12	0.63	0.69	0.67	0.59	0.66	0.66	0.58	3.12	1.45
July-12	0.56	0.67	0.71	0.54	0.63	0.58	0.62	3.28	1.62

Appendix 2. Detected target effluent, insecticide, and herbicide compounds for each monitoring well.

Triclosan			Sample Well ID																								
	CSM-m			CSM-s			CSM-h			CSM-k			FH 1			FH 2			P-a			P-b			P-c		
	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)
Sample Month-Year																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	96.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	15.0	16.0	4.6	<2.5	n/a	n/a	<2.5	n/a	n/a	8.7	n/a	n/a	19.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	8.1	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	3.1	n/a	n/a	<2.5	n/a	n/a	5.6	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	4.2	n/a	n/a	6.4	7.8	13.9	<2.5	n/a	n/a	49.0	n/a	n/a	9.1	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
Triethyl Citrate																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	19.0	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a
January-12	3300	n/a	n/a	2500	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	660	n/a	n/a	5100	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
TCEP																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	250.0	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	72.0	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a

Appendix 2. Continued.

Malathion				Sample Well ID																							
	CSM-m			CSM-s			CSM-h			CSM-k			FH 1			FH 2			P-a			P-b			P-c		
	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)
Sample Month-Year	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	<2.5	9.5	n/a	5.8	n/a	n/a	<2.5	n/a	n/a	3.0	n/a	n/a	<2.5	n/a	n/a	3.6	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	83.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
Permethrin Isomer 1																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	50.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
Permethrin Isomer 2																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	26.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a

Appendix 2. Continued.

DEET			Sample Well ID																								
	CSM-m			CSM-s			CSM-h			CSM-k			FH 1			FH 2			P-a			P-b			P-c		
	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)	Conc. (ng/L)	Sample Duplicate	RSD (%)
Sample Month-Year																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	36.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	6.5	n/a	n/a	39.0	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	11.0	n/a	n/a	<2.5	n/a	n/a	8.7	n/a	n/a
June-11 (rain event)	<2.5	<2.5	n/a	<2.5	n/a	n/a	7.7	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	16.0	n/a	n/a	<2.5	n/a	n/a	7.8	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	35.0	n/a	n/a	93.0	n/a	n/a	<2.5	<2.5	n/a	4.5	n/a	n/a	<2.5	n/a	n/a	30.0	n/a	n/a
September-11	4.3	n/a	n/a	110.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	6.6	n/a	n/a	3.7	n/a	n/a	5.4	n/a	n/a	3.1	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	4.7	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	9.6	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	23.0	23.0	0.0	<2.5	n/a	n/a	53.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	75.0	n/a	n/a	7.7	n/a	n/a	19.0	12.0	31.9
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	7.2	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	3.5	n/a	n/a	4.4	5.9	20.6	6.7	n/a	n/a	22.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
Atrazine																											
January-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
June-11 (rain event)	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
September-11	<2.5	n/a	n/a	30.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
November-11	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a
January-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
March-12	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
May-12 (rain event)	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	--	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a
May-12	<2.5	n/a	n/a	<2.5	<2.5	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a
July-12	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	<2.5	n/a	32.0	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a	<2.5	n/a	n/a

Appendix 3. Detected volatile and semi-volatile organic compounds for each selected monitoring well.

Total Petroleum Hydrocarbons (µg/L)				
Sample Month-Year	Sample Well ID			
	CSM-m	CSM-s	FH 1	FH 2
January-11	18.29	13.20	1.45	7.63
March-11	0.41	7.49	0.72	0.31
May-11	1.89	0.31	1.25	bdl
June-11 (rain event)	0.27	0.16	1.09	1.37
July-11	1.81	2.24	6.52	1.12
September-11	0.78	0.44	0.40	0.26
November-11	---	0.43	bdl	bdl
January-12	---	3.23	4.35	4.84
March-12	---	bdl	bdl	bdl
May-12 (rain event)	---	---	bdl	bdl
May-12	---	6.05	2.39	3.29
July-12	---	bdl	bdl	bdl
Benzene (µg/L)				
January-11	bdl	0.05	nd	0.18
March-11	nd	nd	nd	nd
May-11	nd	nd	nd	nd
June-11 (rain event)	nd	nd	nd	nd
July-11	nd	nd	nd	nd
September-11	bdl	nd	nd	nd
November-11	---	nd	nd	nd
January-12	---	nd	nd	nd
March-12	---	nd	nd	nd
May-12 (rain event)	---	---	bdl	bdl
May-12	---	nd	nd	nd
July-12	---	nd	nd	nd
Tetrachloroethane (PCE) (µg/L)				
January-11	bdl	bdl	bdl	bdl
March-11	bdl	bdl	0.07	bdl
May-11	bdl	bdl	bdl	bdl
June-11 (rain event)	bdl	bdl	0.05	bdl
July-11	bdl	bdl	bdl	bdl
September-11	bdl	bdl	bdl	bdl
November-11	---	bdl	bdl	bdl
January-12	---	bdl	bdl	bdl
March-12	---	bdl	bdl	bdl
May-12 (rain event)	---	---	bdl	bdl
May-12	---	0.36	0.29	bdl
July-12	---	bdl	bdl	0.72

nd = nondetect

bdl = below detection limit

Appendix 3. Continued.

Fluorene (µg/L)				
Sample Month-Year	Sample Well ID			
	CSM-m	CSM-s	FH 1	FH 2
January-11	0.02	0.02	bdl	bdl
March-11	bdl	bdl	bdl	bdl
May-11	bdl	bdl	bdl	bdl
June-11 (rain event)	bdl	bdl	bdl	bdl
July-11	bdl	bdl	bdl	bdl
September-11	bdl	bdl	bdl	bdl
November-11	---	bdl	bdl	bdl
January-12	---	bdl	bdl	bdl
March-12	---	bdl	bdl	bdl
May-12 (rain event)	---	---	bdl	bdl
May-12	---	bdl	bdl	bdl
July-12	---	bdl	bdl	bdl
Undecane (µg/L)				
January-11	bdl	bdl	bdl	bdl
March-11	bdl	0.03	bdl	bdl
May-11	bdl	bdl	0.02	bdl
June-11 (rain event)	bdl	bdl	bdl	bdl
July-11	bdl	0.03	0.02	bdl
September-11	bdl	bdl	bdl	bdl
November-11	---	bdl	bdl	bdl
January-12	---	bdl	bdl	bdl
March-12	---	bdl	bdl	bdl
May-12 (rain event)	---	---	bdl	bdl
May-12	---	bdl	bdl	bdl
July-12	---	bdl	bdl	bdl
Tridecane (µg/L)				
January-11	0.03	bdl	bdl	bdl
March-11	bdl	bdl	bdl	bdl
May-11	bdl	bdl	bdl	bdl
June-11 (rain event)	bdl	bdl	bdl	bdl
July-11	bdl	bdl	bdl	bdl
September-11	bdl	bdl	bdl	bdl
November-11	---	bdl	bdl	bdl
January-12	---	bdl	bdl	bdl
March-12	---	bdl	bdl	bdl
May-12 (rain event)	---	---	bdl	bdl
May-12	---	bdl	bdl	bdl
July-12	---	bdl	bdl	bdl

nd = nondetect

bdl = below detection limit

Appendix 4. Calculated discharge and chemical parameters of storm water runoff for the January 25, 2012 rain event.

Discharge "Q" (cfs)	Turbidity (NTU)	TSS (mg/L)	Dissolved Organic Carbon (mg/L)	BOD (mg/L)	Total Alkalinity (mg/L)	Nitrate + Nitrite-N (mg/L)	Total Phosphorus (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Calcium (mg/L)	Total Magnesium (mg/L)	Total Potassium (mg/L)	Total Sodium (mg/L)
11.768													
4.113													
3.042													
1.450													
1.001													
0.813													
1.001	972	367	---	4	56	0.8	0.43	<3.01	<1.21	52.35	4.75	14.52	0.966
2.159	800	554	---	5	66	0.8	0.45	<3.01	1.4	54.41	4.59	14.65	0.928
6.396													
8.029	1196	529	---	4	56	0.6	0.46	<3.01	<1.21	53.26	4.52	15.09	0.845
3.241	1538	805	---	5	66	0.9	0.61	<3.01	<1.21	52.65	4.22	13.48	0.898
2.758													
2.490	1310	604	---	4	70	1	0.52	<3.01	<1.21	50.78	4.26	12.55	0.941
2.667													
13.130	269	140	---	3	50	0.3	0.21	<3.01	<1.21	49.98	4.31	14.35	0.932
10.909													
0.440	98.3	43	---	47	---	2.4	0.09	<3.01	<1.21	42.25	3.34	14.32	0.988
0.195													
0.114													
0.078	77	13	---	19	---	2.4	0.06	4	<1.21	39.52	3.61	13.15	1.02

Appendix 5. Calculated discharge and chemical parameters of storm water runoff for the February 18, 2012 rain event.

Discharge "Q" (ft ³)	Turbidity (NTU)	TSS (mg/L)	Dissolved Organic Carbon (mg/L)	BOD (mg/L)	Total Alkalinity (mg/L)	Nitrate + Nitrite-N (mg/L)	Total Phosphorus (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Calcium (mg/L)	Total Magnesium (mg/L)	Total Potassium (mg/L)	Total Sodium (mg/L)
0.440	295	191	29	6	98	0.28	0.45	4	8	52.34	4.56	15.26	1.23
0.440													
0.504													
0.471													
0.471													
0.504	305	112	28	4	104	0.34	0.29	4	9	51.53	3.55	15.18	1.15
0.573													
0.573													
0.609													
0.609													
0.647	640	250	30	3	94	0.37	0.48	4	10	51.47	3.78	15.52	1.08
0.647													
0.686													
0.647													
0.686													
0.857	420	114	29	3	96	0.02	0.29	4	9	50.2	3.81	15.39	1.28
1.052													
1.104													
1.104	420	148	28	4	94	0.34	0.25	4	9	49.56	4.11	14.95	1.31
1.001													
0.952													
0.904													
0.813													
0.727	311	78	31	4	104	0.34	0.11	5	15	49.29	4.09	14.99	1.39
0.686													
0.647													
0.573													
0.538													
0.504	232	39	30	3	104	0.35	0.06	5	18	48.25	3.88	15.24	1.28
0.440													
0.382													
0.382													
0.235													
0.160													
0.177	156	28	29	3	104	0.32	0.07	5	21	50.15	4.02	15.58	1.23
0.129													
0.018	116	18	27	3	114	0.29	0.05	5	24	49.95	3.92	14.65	1.2

Appendix 6. Calculated discharge and chemical parameters of storm water runoff for the March 20, 2012 rain event.

Discharge "Q" (ft ³)	Turbidity (NTU)	TSS (mg/L)	Dissolved Organic Carbon (mg/L)	BOD (mg/L)	Total Alkalinity (mg/L)	Nitrate + Nitrite-N (mg/L)	Total Phosphor us (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Calcium (mg/L)	Total Magnesi um (mg/L)	Total Potassium (mg/L)	Total Sodium (mg/L)
0.000													
0.651													
0.433													
0.254													
0.384													
0.316	5.57	11	17	5	10	0.42	0.05	3	6	37.02	3.46	13.08	0.809
0.760													
0.571													
0.517													
0.568	1.92	4	17	6	14	0.37	<0.05	2	5	37.25	3.55	13.41	0.85
0.441													
0.377													
0.466													
0.685													
0.564													
1.099	182	145	29	18	70	0.57	0.31	4	9	41.95	3.62	14.52	1.05
2.311													
3.484													
4.060													
4.238													
4.178													
4.428	1260	386	66	11	92	0.5	0.43	2	14	40.56	3.55	14.23	0.965
5.943													
8.223													
11.377	2448	1692	36	9	94	0.05	0.7	6	14	39.52	3.32	13.95	0.961
13.151													
14.535													
15.616													
15.211													
15.616													
15.755	1228	1000	36	6	92	0.97	0.68	26	11	40.89	3.59	14.59	0.895
15.211													
14.558													
14.426													
14.170													
13.418													
12.909	784	629	34	6	72	1.02	0.48	6	14	40.29	3.19	14.54	0.856
12.312													
11.622													
11.175													
11.397													
11.622													
11.155	500	356	35	6	72	1.14	0.42	43	8	40.16	3.47	13.87	0.847
10.719													
10.505													
10.293													
9.978													
9.553													
9.751	207	276	36	5	64	1.08	0.31	43	10	40.07	3.63	14.95	0.859
9.553													
8.961													
8.841													
8.841													
8.650													
8.558													
8.939													
8.558													
9.230													
8.650													
8.371													
9.116	157	144	31	5	80	1.06	0.19	40	10	39.57	3.54	13.69	0.852
9.017													
8.922													
8.541													
8.166													
8.445													
7.718													
8.260													
8.445													
7.912													
8.260													
7.643													
7.542	8.04	87	29	4	96	1.19	0.11	45	8	40.53	3.48	13.74	0.755

Appendix 7. Calculated discharge and chemical parameters of storm water runoff for the July 11, 2012 rain event.

Discharge "Q" (ft³)	Turbidity (NTU)	TSS (mg/L)	Dissolved Organic Carbon (mg/L)	BOD (mg/L)	Total Alkalinity (mg/L)	Nitrate + Nitrite-N (mg/L)	Total Phosphor us (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Total Calcium (mg/L)	Total Magnesi um (mg/L)	Total Potassium (mg/L)	Total Sodium (mg/L)
18.254													
16.360													
15.143													
14.795													
14.483													
14.658	192	147	27	18	72	1.43	0.49	<0.4	3	36.83	1.85	15.21	0.963
14.309													
13.974	337	211	31	7	74	1.58	0.49	<0.4	4	42.05	2.08	16.87	1.04
13.483													
12.995													
12.678	374	217	33	6	78	1.72	0.52	<0.4	5	49.72	2.08	16.73	1.13
12.366													
12.018													
11.876													
11.418	335	191	33	7	80	1.71	0.51	<0.4	6	48.41	2.06	16.95	1.25
10.977													
10.409													
10.132													
9.722													
9.456													
9.194	290	112	32	6	82	1.51	0.53	<0.4	7	39.1	2.04	17.49	1.27
8.937													
8.807													
8.436	203	124	30	6	84	1.58	0.54	3	7	48.12	2.27	18.52	1.43
8.069													
7.952													
7.742													
7.394													
7.079													
6.986	192	89	32	7	86	1.41	0.56	5	8	46.49	2.22	18.53	1.57
6.773													
6.578													
6.493													
6.493													
6.414													
6.225	159	61	32	7	96	1.44	0.51	<0.4	9	48.14	2.09	18	1.49
6.225													
5.947													
5.649													
5.555													
5.200													
4.922													
4.592													
4.423													
4.338													
4.097													
3.860													
3.707	88.4	35	29	7	92	1.41	0.6	6	9	52.96	2.31	18.97	1.79
3.484													
3.341													
3.202													
2.998													
2.933													
2.816													
2.679													
2.496													
2.379													
2.265													
2.209													
2.100	42.7	15	27	6	122	1.46	0.56	<0.4	9	55.2	2.48	19.39	1.92

LITERATURE CITED

- Abbot PL. 1977. Effects of Balcones faults on groundwater movement, south central Texas. *The Texas Journal of Science* 29(1,2): 5-14.
- Artiola JF, Pepper IL, Brusseau M. 2004. Environmental monitoring and characterization. Burlington (MA): Elsevier Academic press. p 230-232.
- [ATSDR] Agency for Toxic Substances and Disease Registry. 1999. Total Petroleum Hydrocarbons (TPH) ToxFAQs: U.S. Department of Health and Human Services [cited 2012 Oct 8]. Available from: <http://www.atsdr.cdc.gov/toxfaqs/tfacts123.pdf>
- Barker RA, Ardis AF. 1996. Hydrogeologic framework of the Edwards-Trinity aquifer system, west-central Texas: U.S. Geological Survey. U.S. Geological Survey Professional Paper 1421 – B. 76 p.
- Barker RA, Bush PW, Baker ET, Jr. 1994. Geologic history and hydrogeologic setting of the Edwards-Trinity aquifer system, west-central Texas: U.S. Geological Survey. Water-Resources Investigations Report 94-4039. 51 p.
- Barrett ME, Malina JF, Jr., Charbeneau RJ, Ward GH. 1995. Water quality and quantity impacts of highway construction and operation: summary and conclusions. Bureau of Engineering Research, University of Texas at Austin Technical Report CRWR 266. 35 p.
- [BEG-UT] Bureau of Economic Geology – The University of Texas at Austin [Internet]. Land-Resource Map of Texas;1999 [cited 2012 Aug 20].Available from: http://www.beg.utexas.edu/UTopia/images/pagesizemaps/land_resources.pdf
- Blome CD, Faith KR, Ozuna GB. 2007. Geohydrologic framework of the Edwards and Trinity aquifers south-central Texas: U.S. Geological Survey. Fact Sheet 2006-3145. 4 p.
- Bluntzer RL. 1992. Evaluation of the ground-water resources of the Paleozoic and Cretaceous aquifers in the hill country of central Texas. Texas Water Development board Report 339. 130 p.

- Brater E, King H, Lindell J, Wei C. 1996. Handbook of Hydraulics. 7th ed. Boston (MA): McGraw-Hill Professional. 640 p.
- Clescerl LS, Greenberg AE, Eaton AD, editors. 1999. Standard methods for the examination of water and wastewater. 20th ed. Washington, DC: American Public Health Association. 1325 p.
- Drewes JE, Heberer T, Rauch T, Redderson K. 2003. Fate of pharmaceuticals during ground water recharge. *Ground Water Monitoring & Remediation* 23(3): 64-72.
- [EAA] Edwards Aquifer Authority [Internet]. Spring and well reading charts: interactive well readings; c2012 [cited 2012 Aug 20]. Available from: http://www.edwardsaquifer.org/chart_levels.php
- Eaton AD, Clescerl LS, Rice EW, Greenberg AE, editors. Standard methods for the examination of water and wastewater. 21st ed. Washington, DC: American Public Health Association. 1325 p.
- Ferrill DA, Sims DW, Waiting DJ, Morris AP, Franklin NM, Schultz AL. 2004. Structural framework of the Edwards Aquifer recharge zone in south-central Texas. *Geological Society of America* 116(3/4): 407-418.
- Focazio MJ, Kolpin DW, Barns KK, Furlong ET, Meyer MT, Zaugg SD, Barber LB, Thurman ME. 2008. A national reconnaissance for pharmaceuticals and other organic wastewater contaminants in the United states – II) Untreated drinking water sources. *Science of the Total Environment* 402: 201-216.
- Ford D, Williams P. 2007. Karst Hydrogeology and Geomorphology. London: John Wiley & Sons, Ltd. 562 p.
- Foster AL. 2007. Occurrence and fate of endocrine disruptors through the San Marcos Wastewater Treatment Plant. MA Thesis-Chemistry Department, Texas State University. 68 p.
- Goldscheider N, Drew D, editors. 2007. Methods in karst hydrogeology. London: Taylor & Francis. 264 p.
- Grimshaw TW, Woodruff CM, Jr. 1986. Structural style in an echelon fault system, Balcones Fault Zone, central Texas: geomorphic and hydrologic implications; Abbott PL, Woodruff CM, Jr., editors. *Geological Society of America Annual Meeting*. 200 p.
- Groschen GE. 1996. Hydrogeologic factors that affect the flowpath of water in selected zones of the Edwards Aquifer, San Antonio region, Texas: U.S. Geological Survey. Water-Resources Investigations Report 964046.

- Grubb HW. 1997. The Edwards Aquifer: conflicts surrounding use of a regional water resource. *Journal of Contemporary Water Research and Education* 106(1): 39-45.
- Hamilton JM, Esquilin R, Schindel GM. 2006. Edwards Aquifer Authority synoptic water level program 1999-2004 Report. Edwards Aquifer Authority Report No. 06-02. 114 p.
- Hamilton JM, Johnson S, Esquilin R, Burgoon C, Luevano G, Gregory D, Mireles J, Gloyd R, Schindel GM. 2010. Edwards Aquifer Authority hydrologic data report for 2009. Edwards Aquifer Authority Report No. 10-02. 247 p.
- Hamilton JM, Johnson S, Esquilin R, Burgoon C, Luevano G, Gregory D, Mireles J, Gloyd R, Schindel GM. 2011. Edwards Aquifer Authority hydrologic data report for 2010. Edwards Aquifer Authority Report No. 11-01. 340 p.
- Hanson JA, Small TA. 1995. Geologic framework and hydrogeologic characteristics of the Edwards Aquifer outcrop, Hays County, Texas: U.S. Geological Survey. Water-Resources Investigations Report 95-4265. 10 p.
- Hays WJ, Laws ERJ, editors. 1991. Handbook of pesticide toxicology. Volume 2. San Diego (CA): Academic Press.
- Heath RC. 1987. Basic ground-water hydrology: U.S. Geological Survey. Water- Supply Paper 2220. 84 p.
- Helsel DR. 2012. Statistics for censored environmental data using Minitab and R. 2nd ed. Hoboken (NJ): John Wiley & Sons, Inc. 324 p.
- Hill Country Alliance [Internet]. Hill Country GIS Map Viewer; c2012 [updated 2012; cited 2012 May 05]. Available from: <http://hillcountrymapviewer.org/>
- Horton RE, 1907. Weir experiments, coefficients, and formulas: U.S. Geological survey. Water-Supply Paper 200. 195 p.
- Hovorka S, Phu T, Nicot JP, Lindley A. 2004. Refining the conceptual model for flow in the Edwards Aquifer – characterizing the role of fractures and conduits in the Balcones Fault Zone segment. Bureau of Economic Geology – The University of Texas at Austin Final Contract Report. 52 p.
- Hudak PF. 2005. Principles of hydrogeology. 3rd ed. Boca Raton (FL): CRC Press LLC. p 83-85.
- [ITRC] Interstate Technology and Regulatory Council [Internet]. 2006. Technology overview of passive sampler technologies; c2005 [cited 2010 Sep 22]. Available from: http://www.itrcweb.org/Documents/DSP_4.pdf

- Johnson S, Schindel G, Hoyt J. 2009. Water quality trend analysis of the San Antonio segment, Balcones Fault Zone Edwards Aquifer, Texas. Edwards Aquifer Authority Report No. 09-03. 48 p.
- Katz BG, Griffin DW, Davis JH. 2009. Groundwater quality impacts from the land application of treated municipal wastewater in a large karstic spring basin: chemical and microbiological indicators. *Science of the Total Environment* 407(8): 2872-2886.
- Kegley Se, Hill BR, Orme S, Choi AH [Internet]. Pesticide Action Network Pesticide Database; c2000-2011[cited 2010 Sep 30]. Available from: <http://www.pesticideinfo.org/>
- Koterba MT, Franceska DW, Lapham WW. 1995. Ground-water data-collection protocols and procedures for the National Water-Quality Assessment program, collection and documentation of water-quality samples and related data: US Geological Survey. Open-File Report 95-399. 123 p.
- Kuniansky EL, Fahlquist L, Ardis AF. 2001. Travel times along selected flow paths of the Edwards Aquifer, central Texas. U.S. Geological Survey Karst Interest Group Proceedings; 2001 Feb 13-16; St. Petersburg (FL); Water-Resources Investigations Report 01-4011. p 69-77.
- Larson SJ, Capel PD, Majewski MS. 1997. Pesticides in surface waters: distribution, trends, and governing factors. Volume 3, Pesticides in the hydrologic system. Chelsea (MI): Ann Arbor Press, Inc.
- Lindgren RJ. 2006. Diffuse-flow conceptualization and simulation of the Edwards Aquifer, San Antonio region, Texas: U.S. Geological Survey. Scientific Investigations Report 2006-5319.
- Lindgren RJ, Dutton AR, Hovorka SD, Worthington SRH, Painter S. 2004. Conceptualization and simulation of the Edwards Aquifer, San Antonio region, Texas: U.S. Geological Survey. Scientific Investigations Report 2004-5277. 143 p.
- Longley G. 1986. The biota of the Edwards Aquifer and the implications for paleozoogeography; Abbott PL, Woodruff CM, Jr., editors. Geological Society of America Annual Meeting. p 51-54.
- Longley G, Jordan WR. 1996. Management of the Edwards Aquifer region: how the Endangered Species Act influenced action. Southern IL Univ, Council on Water Resources. Water Resources Update 106(Winter): 53-61.

- Longley G, Jennings M, Wanakule N, Setser R, Ourso R. 1998. Edwards Aquifer saline-zone (“bad-water line”) monitoring program: Edwards Aquifer Research and Data Center, Texas State University-San Marcos. 11 p.
- Maclay RW, Land LF. 1988. Simulation of flow in the Edwards Aquifer, San Antonio region, Texas, and refinement of storage and flow concepts: U.S. Geological survey. Water-Supply Paper 2336-A.
- Maclay RW, Small TA. 1984. Carbonate geology and hydrology of the Edwards Aquifer in the San Antonio area, Texas: U.S. Geological Survey. Open-File Report 83-537. 72 p.
- Martin TD, Brockhoff CA, Creed JT, EMMC Methods Work Group. 1994. Determination of metals and trace elements in water and wastes by inductively coupled plasma-atomic emission spectrometry: U.S. Environmental Protection Agency. Method 200.7, Revision 4.4.
- Moran MJ, Hamilton PA, Zogorski JS. 2006. Volatile organic compounds in the Nation’s ground water and drinking-water supply wells, A summary: US Geological Survey. Fact Sheet 2006-3048. 6 p.
- Murray KE, Straud DR, Hammond WW. 2007. Characterizing groundwater flow in a faulted karst system using optical brighteners from septic systems as tracers. *Environ Geol* 53: 769-776.
- Musgrove M, Falhquist L, Houston NA, Lindgren RJ, Ging PB. 2010. Geochemical evolution processes and water-quality observations based on results of the National Water-Quality Assessment Program in the San Antonio segment of the Edwards Aquifer, Texas, 1996-2006: U.S. Geological Survey. Scientific Investigations Report 2010-5129.
- [NOAA NWSFO] National Oceanic Atmospheric Administration National Weather Service Forecast Office [Internet]. Local South Central Texas Climate Information; [modified 2012 Aug 02, cited 2012 Aug 20]. Available from: <http://www.srh.noaa.gov/ewx/?n=scntrltxclimate.htm>
- O’Dell JW, editor. 1993. Determination of nitrate-nitrite nitrogen by automated colorimetry: U.S. Environmental Protection Agency. Method 353.2, Revision 2.0.
- O’Dell JW, editor. 1993. Determination of turbidity by nephelometry: U.S. Environmental Protection Agency. Method 180.1, Revision 2.0.

- Ogden AE, Spinelli AH, Horton J. 1985. Hydrologic and hydrochemical data for the Edwards Aquifer in Hays and Comal counties – October 1983 to June 1985: Edwards Aquifer Research and Data Center, Texas State University. Report R2-85. 83 p.
- Ogden AE, Quick RA, Rothermel SR. 1986. Hydrochemistry of the Comal, Hueco, and San Marcos Springs, Edwards Aquifer, Texas ; Abbott PL, Woodruff CM, Jr., editors. Geological Society of America Annual Meeting. p 115-130.
- Pfaff JD. 1993. Determination of inorganic anions by ion chromatography: U.S. Environmental Protection Agency. Method 300.0, Revision 2.1.
- Ross L, Rice G. 2005. Protecting the Edwards Aquifer: vulnerability, contamination, effects of development , and inadequacy of engineered controls. Aquifer Guardians in Urban Areas. 20 p.
- Ryder PD [Internet]. U.S. Geological Survey Groundwater Atlas of the United States – Oklahoma, Texas; 1996 [updated 2009 Feb 09; cited 2012 Aug 20]. Available from: http://pubs.usgs.gov/ha/ha730/ch_e/index.html
- Smith BA, Hunt BB, Schindel GM. 2005. Groundwater flow in the Edwards Aquifer: comparison of groundwater modeling and dye trace results. Proceedings of the 10th Multidisciplinary Conference; 2005 Sep 24-28; San Antonio (TX): Geotechnical Special Publication 144: 131-141.
- Stone D, Schindel GM. 2002. The application of GIS in support of land acquisition for the protection of sensitive groundwater recharge properties in the Edwards Aquifer of south-central Texas. Journal of Cave and Karst Studies 64(1): 38-44.
- [TCEQ] Texas Commission on Environmental Quality [Internet]. Texas risk reduction program rule; [cited 2012 Aug 12]. Available from: <http://www.tceq.texas.gov/remediation/trrp/trrprule.html>
- [TWDB] Texas Water Development Board [Internet]. Wells in the Texas Water Development Board groundwater database; c2002 [cited 2011 Oct 15]. Available from: http://wiid.twdb.tx.us/ims/wwm_drl/viewer.htm
- [USBR] U.S. Department of the Interior Bureau of Reclamation [Internet]. Water measurement manual, a water resources technical publication: A guide to effective water measurement practices for better water management [cited 2011 May 10]. Available from: http://www.usbr.gov/pmts/hydraulics_la_b/pubs/wmm/

- [USDA] U.S. Department of Agriculture Bureau of Soils [Internet]. University of North Texas Libraries Government Documents Department: Soil Map, Texas, San Marcos Sheet; 1906 [cited 2012 Aug 18]. Available from: <http://texashistory.unt.edu/ark:/67531/metaph19676/m1/1/>
- [USEPA] U.S. Environmental Protection Agency. 1996. Volatile organic compounds by gas chromatography/mass spectrometry (GC/MS): U.S. Environmental Protection Agency. Method 8260.
- [USEPA] U.S. Environmental Protection Agency. 1998. DEET: Reregistration Eligibility Decision: U.S. Environmental Protection Agency. Washington D.C.
- [USEPA] U.S. Environmental Protection Agency. 2010. Triclosan Facts [cited 2012 Oct 4]. Available from: http://www.epa.gov/oppsrrd1/REDs/factsheets/triclosan_fs.ht
- [USEPA] U.S. Environmental Protection Agency. 2012. 2012 Edition of the Drinking Water Standards and Health Advisories: U.S. Environmental Protection Agency. EPA 822-S-12-001. 12 p.
- [USFWS] U.S. Fish and Wildlife Service [Internet]. Species reports: listings and occurrences in Texas; [updated 2012 Aug, cited 2012 Aug 29]. Available from: http://ecos.fws.gov/tess_public/pub/stateListingAndOccurrenceIndividual.jsp?state=TX&s8fid=112761032792&s8fid=112762573902
- Vanderfod BJ, Pearson RA, Rexing DJ, Snyder SA. 2003. Analysis of endocrine disruptors, pharmaceuticals, and personal care products in water using liquid chromatography/tandem mass spectrometry. *Analytical Chemistry* 75: 6265-6274.
- White WB. 1988. *Geomorphology and hydrology of karst terrains*. New York (NY): Oxford University Press. 464 p.
- Zaugg SD, Sandstrom MW, Smith SG. 1995. Methods of analysis by the US Geological Survey National Water Quality Laboratory – Determination of pesticides in water by C-18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry with select-ion monitoring: U.S. Geological Survey. Open-File Report 95-181. 59 p.
- Zaugg SD, Smith SG, Schroeder MP, Barber LB, Burkhardt MR. 2006. Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory – Determination of wastewater compounds by polystyrene-divinylbenzene solid-phase extraction and capillary-column gas chromatography/mass spectrometry: U.S. Geological Survey. Water-Resources Investigations Report 01-4186. 37 p.

VITA

Laura Betty McCalla, daughter of Clair and Patty McCalla, graduated from Texas A&M University – Galveston in 2008 with a Bachelor of Science degree in Marine Biology. As an undergraduate, Laura volunteered under Dr. Christopher Marshall in the Texas A&M – Galveston Ecomorphology and Comparative Physiology Laboratory where she assisted with research on bite force mechanics and feeding kinematics of loggerhead sea turtles and methods to reduce interactions and mortality with longline fishing gear. Upon the completion of her undergraduate degree, Laura took on the position of an Eco-Art Educator with Artist Boat where she instructed participants on the importance of estuaries via kayak and vessel trips. She later worked as a Marine Science Instructor for the Catalina Island Marine Institute where she conducted marine laboratory programs and led students through outdoor educational activities such as snorkeling, kayaking, and hiking. In 2010, Laura began her graduate career at Texas State University – San Marcos in Aquatic Resources, and won fourth place with a poster presentation of her research at the Third Annual Women in Science and Engineering Conference. She hopes to use the knowledge of aquatic pollution obtained through this research opportunity and apply it to the marine environment in order to better understand contaminant pathways that allow pollution to enter our crucial ocean systems.

Permanent address: 14719 Bernard Timbers Drive
East Bernard, Texas 77435

This thesis was typed by Laura B. McCalla.