Appendix 5.4

Technical Memorandum

Mobilization of arsenic and chromium in the groundwater due to storm water infiltration through dry wells

Dr. Xue Li

Abstract

Stormwater and groundwater data from two dry well study sites in Elk Grove, California were analyzed to assess the likelihood of arsenic and chromium mobilization in geologic units due to stormwater infiltration. Arsenic and chromium concentrations in the upgradient and downgradient monitoring wells were compared using boxplot. Strength of correlation for common arsenic or chromium ion couples were calculated using Spearman's rho to distinguish naturally occurring mechanisms. During the monitoring period, no significant increased concentrations of arsenic or chromium were measured downgradient of the storm water recharge point. There was not enough data to determine whether mixing of storm water will eventually change local groundwater geochemistry and lead to metal release. No significant correlation was found between arsenic and its potentially related ions, but a positive correlation was found between chromium and iron, suggesting that chromium may be associated with labile iron oxides.

Introduction

The infiltration of stormwater through dry wells is a cost-effective way to recharge groundwater. One of the concerns is whether the introduction of stormwater will adversely affect groundwater quality. For example, the potential for sediment-associated metals to re-dissolve into groundwater or release metals has not been thoroughly studied and remains unclear. Because stormwater represents a very different aqueous environment than groundwater, the alteration of local groundwater geochemistry is possible and thus studying the issue of metal mobilization is warranted.

The Elk Grove dry well project evaluated two types of stormwater drainage areas: Corporation Yard (CY), which is a bus parking area with a drainage area about 0.6 acres, and Strawberry Detention Basin (SDB), which receives stormwater from residential neighborhood and has a drainage area about 160 acres. Because stormwater runoff often contains high concentrations of dissolved oxygen, anions (e.g., sulfate, phosphate, bicarbonate, etc) or has a different pH than groundwater, infiltrating stormwater into oxygen-depleted or anoxic native groundwater will possibly change the local redox condition, promoting the release of various metal ions.

For example, arsenic and chromium, two metals of concern, were detected in both CY and SDB's groundwater and stormwater. This report focuses exclusively on quantifying these two metals' mobilization evidence, and aims to identify their natural occurring mechanisms by analyzing strength of correlation between (redox) ion couples, which in turn can shed lights on metal mobilization potential.

Methods

If storm water recharge causes metal mobilization, a significant increase of metal concentration may be noticed down gradient of the storm water recharge point. Accordingly, metals were grouped per type of well from which they were collected, and boxplots were used to quantify any significant differences between monitoring wells. The results of boxplots could be viewed as direct evidences of metal release. The second approach concerns finding potential correlated ion couples: Spearman's rho and p-value were calculated; a significant correlation between an ion couple signals a natural occurring mechanism. Thus, if one of the correlated ion is introduced through stormwater, it could possibly lead to release of its coupled ion.

Results and Discussion

Figure 1 to 2 show datasets of arsenic and chromium concentration in different monitoring wells (MW1, 3 & 4, representing upgradient and downgradient water table wells) at the two study sites (CY and SDB). The range of different metal concentration in each monitoring well is thus readable from the plot. There was no significant difference found between groups, indicating that during the monitoring period, no arsenic or chromium release was found. It is worth noting that there was not enough data to determine whether the introduced stormwater will cause metal mobilization in the long term due to the short period of monitoring.

A further investigation on arsenic and its potentially related ions was conducted; the results are summarized in Table 1. The Spearman's rho and p value were calculated and shown in Figure 3 to 6. No significant correlation was found between arsenic and sulfate, bicarbonate, or manganese. But in the case of arsenic and iron, there was an environmentally significant ($p = 0.056$, just above the cutoff for statistical significance) relationship between these metals. A positive correlation between arsenic and iron could suggest natural occurring mechanism due to reduction of arsenic-bearing iron oxides, during which process arsenic was released (Table 1). However, further monitoring on the sediment iron oxides is needed to confirm the finding. Mobilization due to competing effects could not be excluded, and therefore further monitoring on common competing anions such as phosphate, silicate or vanadate is needed.

The results of correlation between chromium and its potentially related ions is shown in Table 2. No significant correlation was found between chromium and manganese (Figure 7), despite the fact that manganese oxides are recognized to be the major viable oxidants which oxidize insoluble trivalent chromium [Cr(III)] to soluble hexavalent chromium [Cr(VI)] under a range of environmental conditions (Eary and Rai, 1987; Guha *et al*., 2001). Further monitoring of manganese's species is needed to confirm the finding.

A positive correlation was found between chromium and dissolved iron (Figure 8). A negative correlation may suggest the natural attenuation of chromium due to iron reduction of Cr(VI) to form insoluble Cr(III) species (thus removed from the aqueous phase) (Rai *et al*., 1989; Buerge and Hug, 1997; Lawniczak *et al*., 2001). The opposite finding, however, suggests that iron was possibly involved in chromium mobilization in a different mechanism, e.g., chromium was associated with labile iron oxides. Further monitoring on the iron species and iron oxides is needed to confirm the finding.

Conclusions

No arsenic or chromium release was found downgradient of the stormwater recharge point during the monitoring period. There was not enough data to determine whether stormwater recharge will cause metal mobilization in the long term. No significant correlation was found between arsenic and iron, sulfate, bicarbonate or manganese; the natural occurring mechanism for arsenic remains unclear. No significant correlation was found between chromium and manganese but a positive correlation was found between chromium and iron. This is contrary to the natural attenuation mechanism of chromium, suggesting chromium release may be due to desorption from labile iron oxides.

Tables and figures

Table 1 Summary of arsenic mobilization mechanisms and findings

Potentially correlated ion couples	**Mobilization mechanism**	**Possible reactions**	**Significant correlation found?**
A positive correlation between dissolved arsenic and iron or manganese	Iron or manganese (Fe/Mn) oxides are common sinks for arsenic. Under reducing aquifers, reduction of Fe/Mn oxides may result in releasing its adsorbed load of arsenic (Bose and Sharma, 2002; Pierce and Moore, 1982).	$8FeOOH + CH_3COO^-$ (organic matter) $+ 15H_2CO_3 = 8 Fe^{2+} + 17HCO_3^- + 12H_2O$ (McArthur *et al.*, 2001)	No
A positive correlation between arsenic and dissolved sulfate concentration (and a negative correlation with sulfide) (Tabelin *et al.*, 2012; Lazareva *et al.*, 2015)	Arsenic-rich sulfide minerals (e.g., pyrite or Fe-containing biotite) are also common sinks for arsenic. Under oxidizing conditions, oxygen or ferric iron can oxidize these arsenic-rich minerals and release arsenic to the groundwater	$4FeAs_xS_{2-x} + 7/2O_2 + 6H_2O = Fe^{2+} + xAsO_4^{3-} + (2-x)SO_4^{2-} + 2H^+$ (Lazareva *et al.*, 2015)	No
A negative correlation between dissolved arsenic and common competing anions such as phosphate (PO_4^-), bicarbonate (HCO_3^-), silicate or organic matter (Ujevic *et al.*, 2010; Piqué *et al.*, 2010)	Competition for surface sites due to ion exchange/ desorption processes from common anions that is several magnitudes higher in concentration than arsenic	$PO_4^- + \equiv S\text{-}As = S\text{-}PO4- + As$ ($\equiv S$ represent surface site)	No

Table 2 Summary of chromium mobilization mechanisms

Mobilization mechanism	**Mobilization evidence**	**Possible reactions**	**Significant correlation found?**
Oxidation of relatively insoluble Cr(III) to soluble Cr(VI) at circumneutral pH by Mn(III,IV) oxides (Eary and Rai, 1987; Guha *et al*., 2001; Szalinska *et al*., 2010; Ndung'u *et al*., 2010; Mills *et al*., 2011)	A positive correlation between dissolved Cr(VI) and dissolved manganese concentration	MnO_2 (s) + $2H^+$ = Mn^{2+} + H_2O + ½ O_2 (aq) (low pH) $CrOH^+$ + $3MnO_2$ (s) + $3H_2O$ = $HCrO_4^-$ + 3MnOOH (s) + $3H^+$ (relatively higher pH) (Eary and Rai, 1987)	No
Iron or aluminum oxides have active sorption capability for chromium. However, increasing the pH could enhance desorption of Cr(VI) from these oxides (Ajouyed *et al*., 2010, Rai *et al*., 1989)	A positive correlation between dissolved chromium and increasing pH	≡SOH + H^+ + CrO_4^{2-} ↔ ≡SOH_2^+-CrO_4^{2-} (≡SOH represent inorganic hydroxyl site either on iron or aluminum oxides, and ≡SOH_2^+-CrO_4^{2-} is the adsorbed chromium surface complex. (Rai *et al*., 1989)	Not available

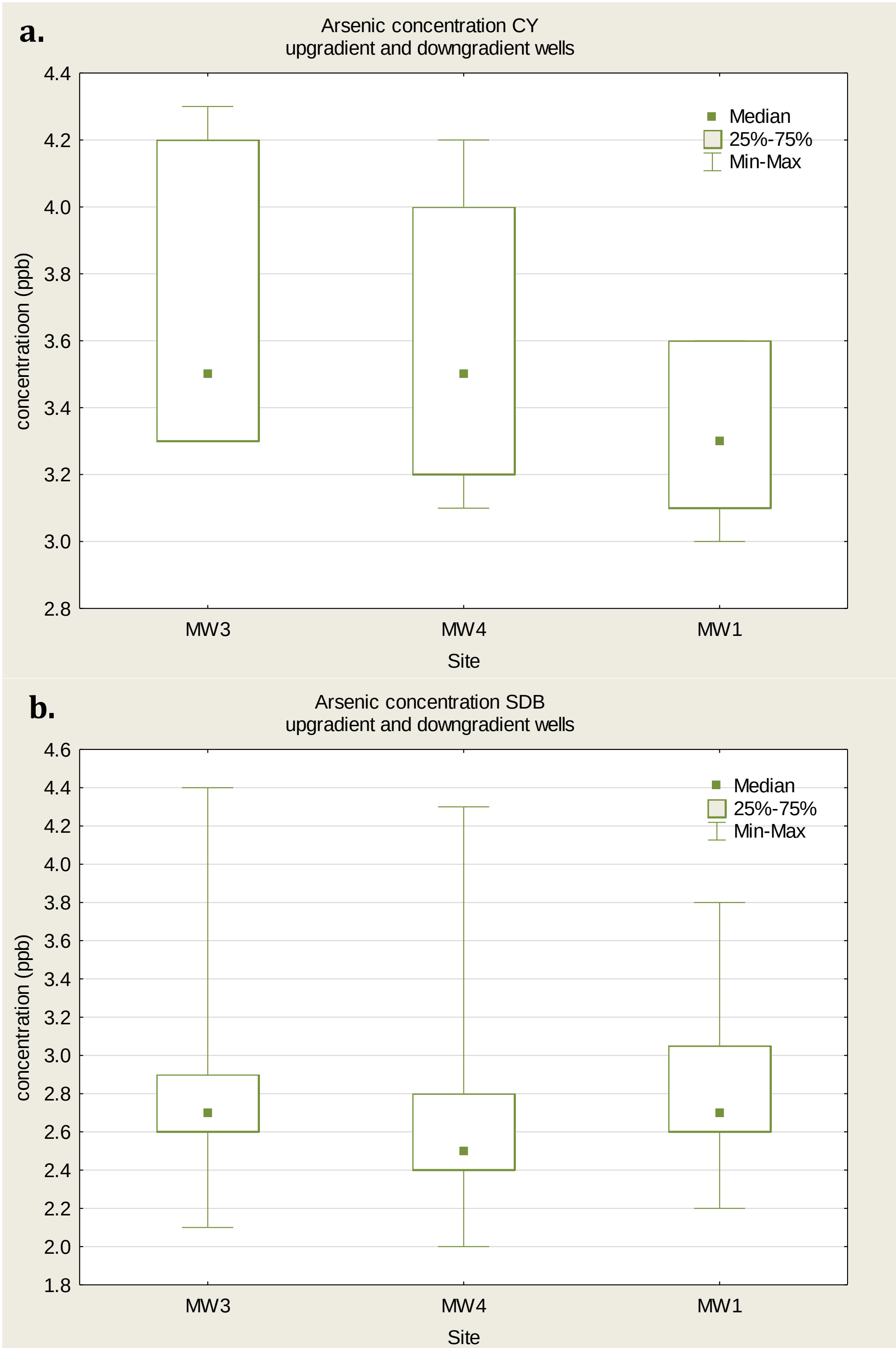
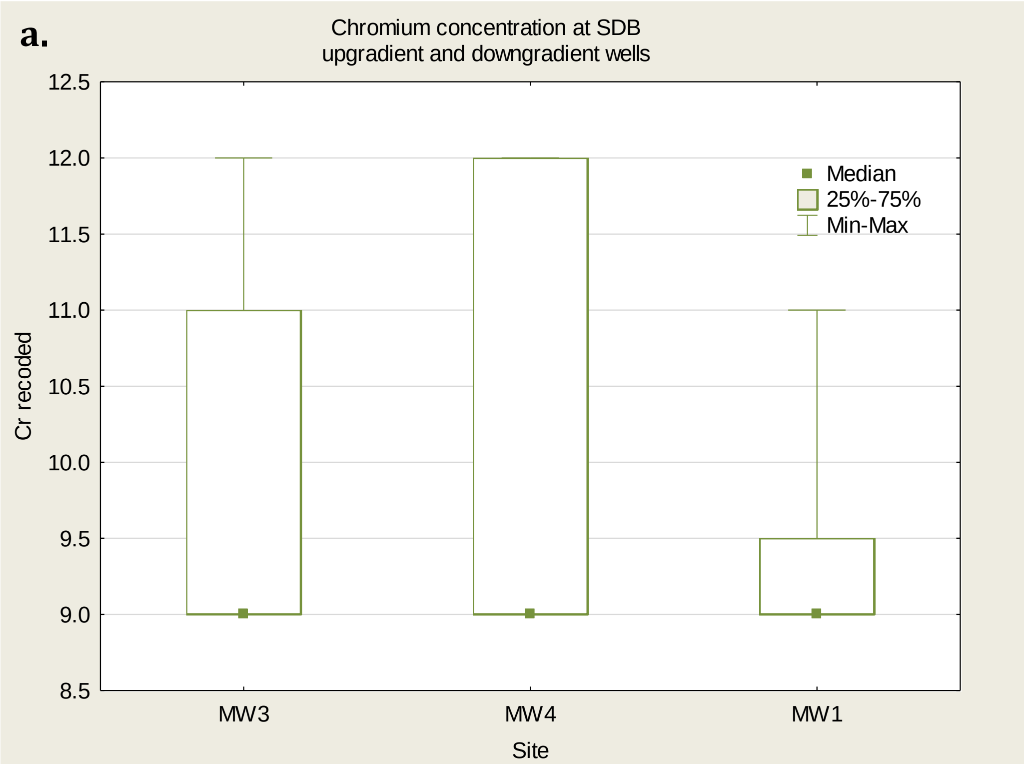


Figure 1 Boxplot of arsenic concentration in different monitoring wells (MW1, up gradient; MW3 and 4, down gradient of the storm water recharge point) at different sites: a) arsenic

Corporation Yard (CY) and b) Strawberry Detention Basin (SDB). No significant difference was found between groups.



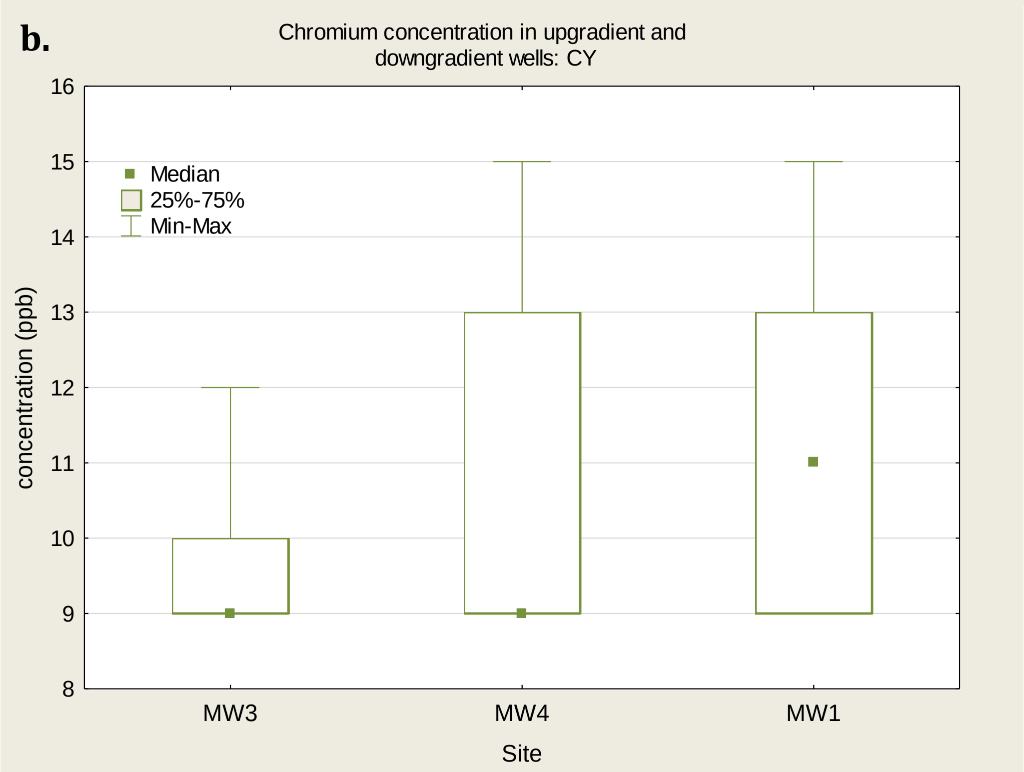


Figure 2 Boxplot of chromium concentration in different monitoring wells at different sites: a) CY and b) SDB. No significant difference was found between groups.

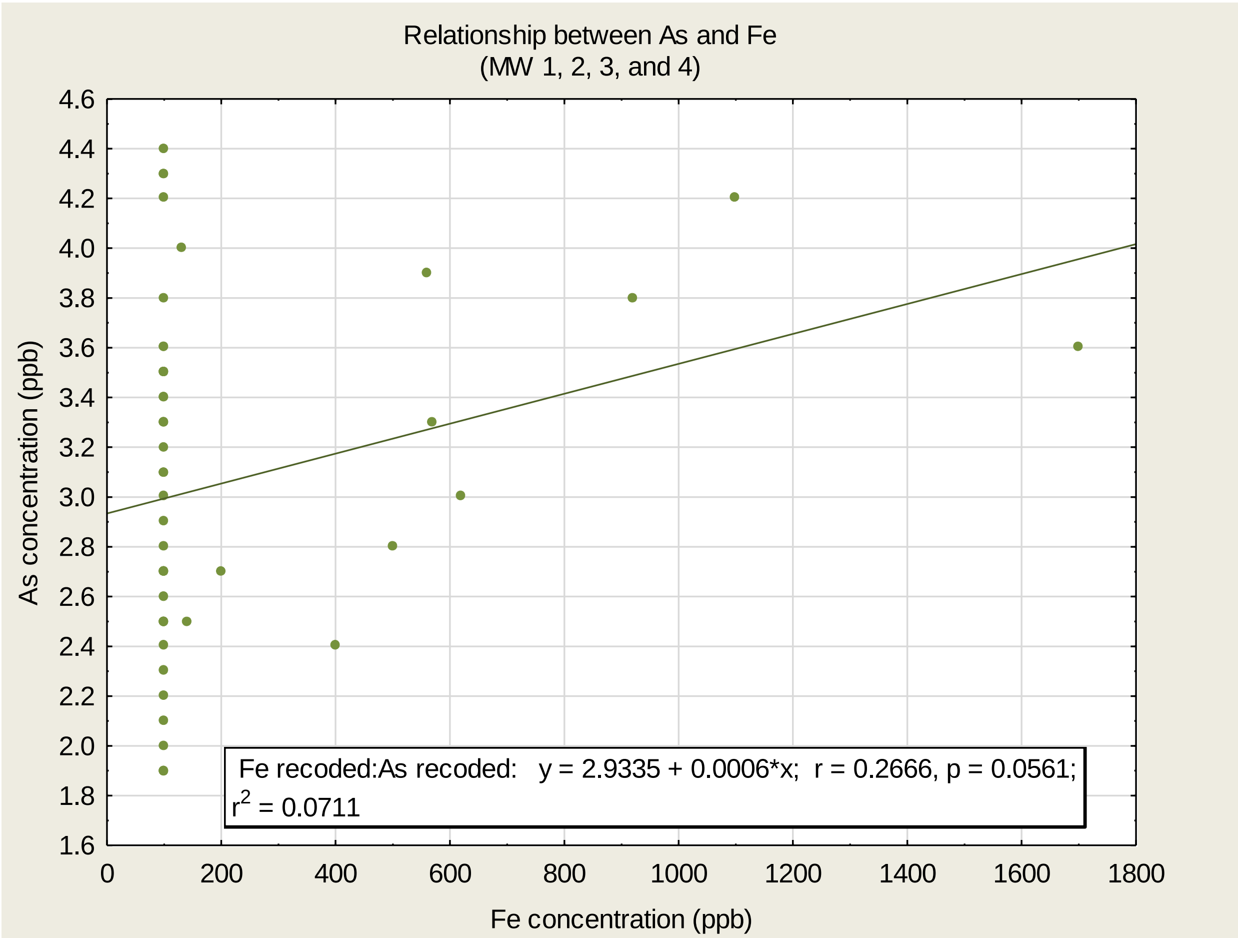


Figure 3 Relationship between concentration of arsenic and dissolved iron in groundwater samples collected from monitoring wells. No significant correlation was found between the two ions.

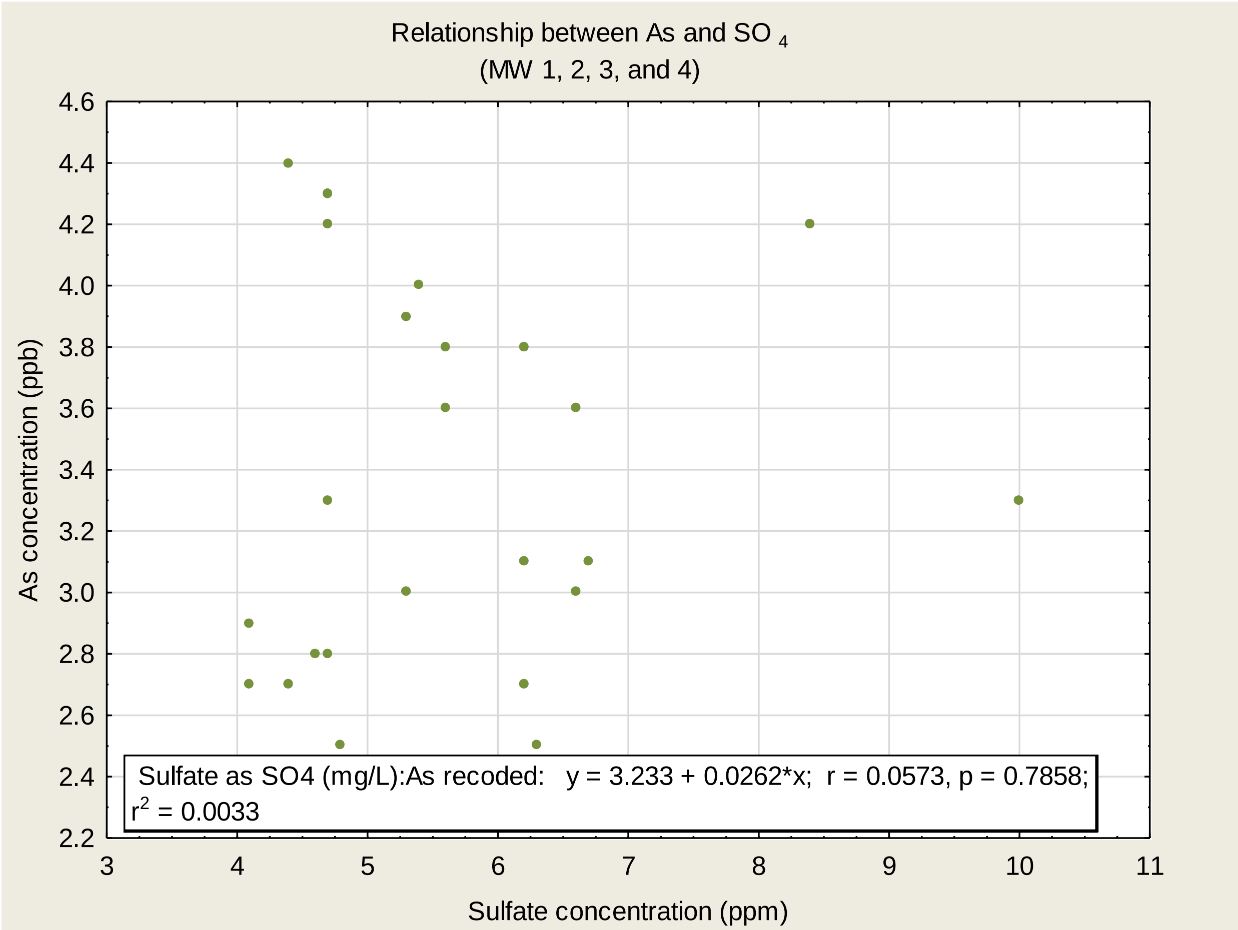


Figure 4 Relationship between concentration of arsenic and sulfate (SO_4) in groundwater samples collected from monitoring wells. No significant correlation was found between the two ions.

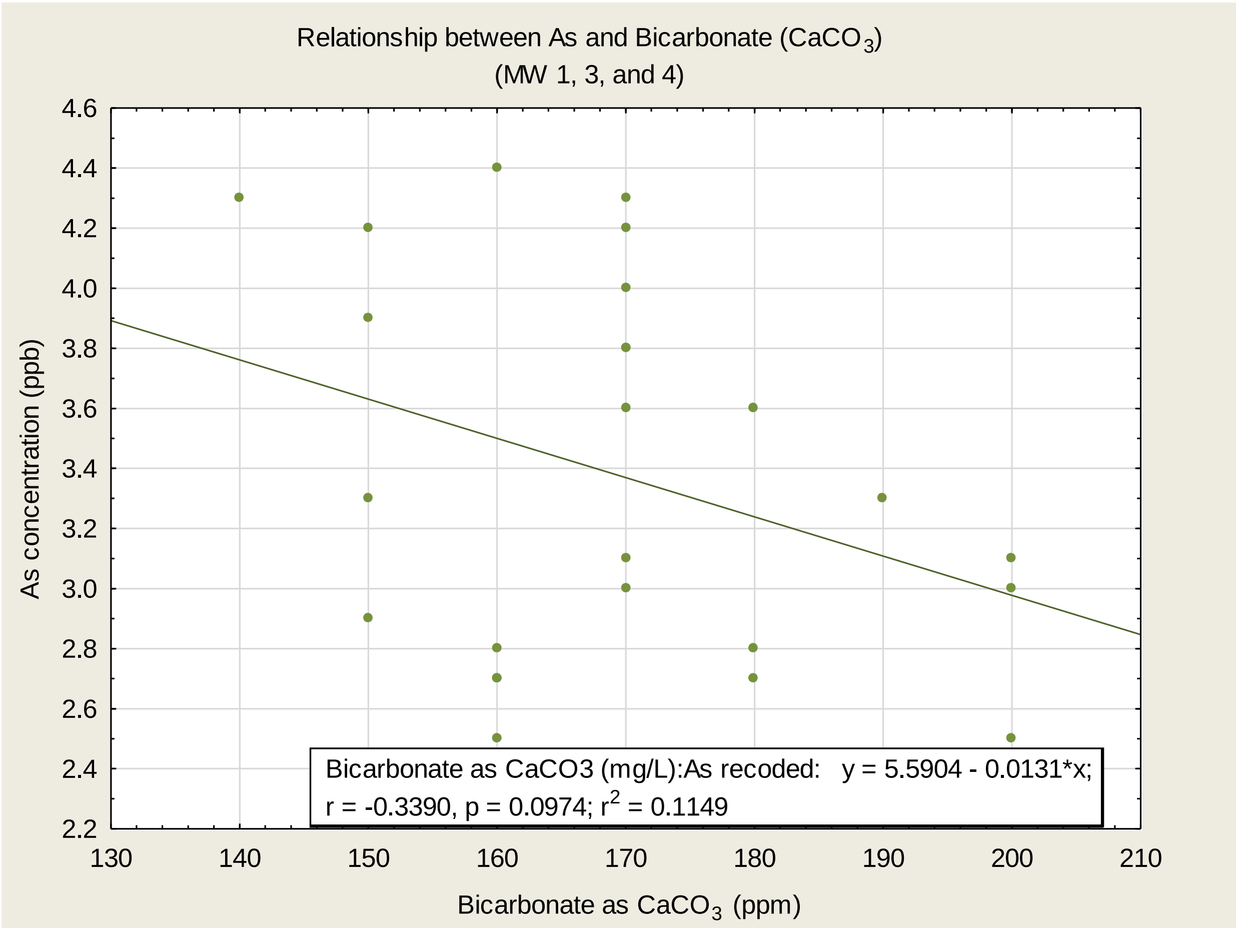


Figure 5 Relationship between concentration of arsenic and bicarbonate in groundwater samples collected from monitoring wells. No significant correlation was found between the two ions.

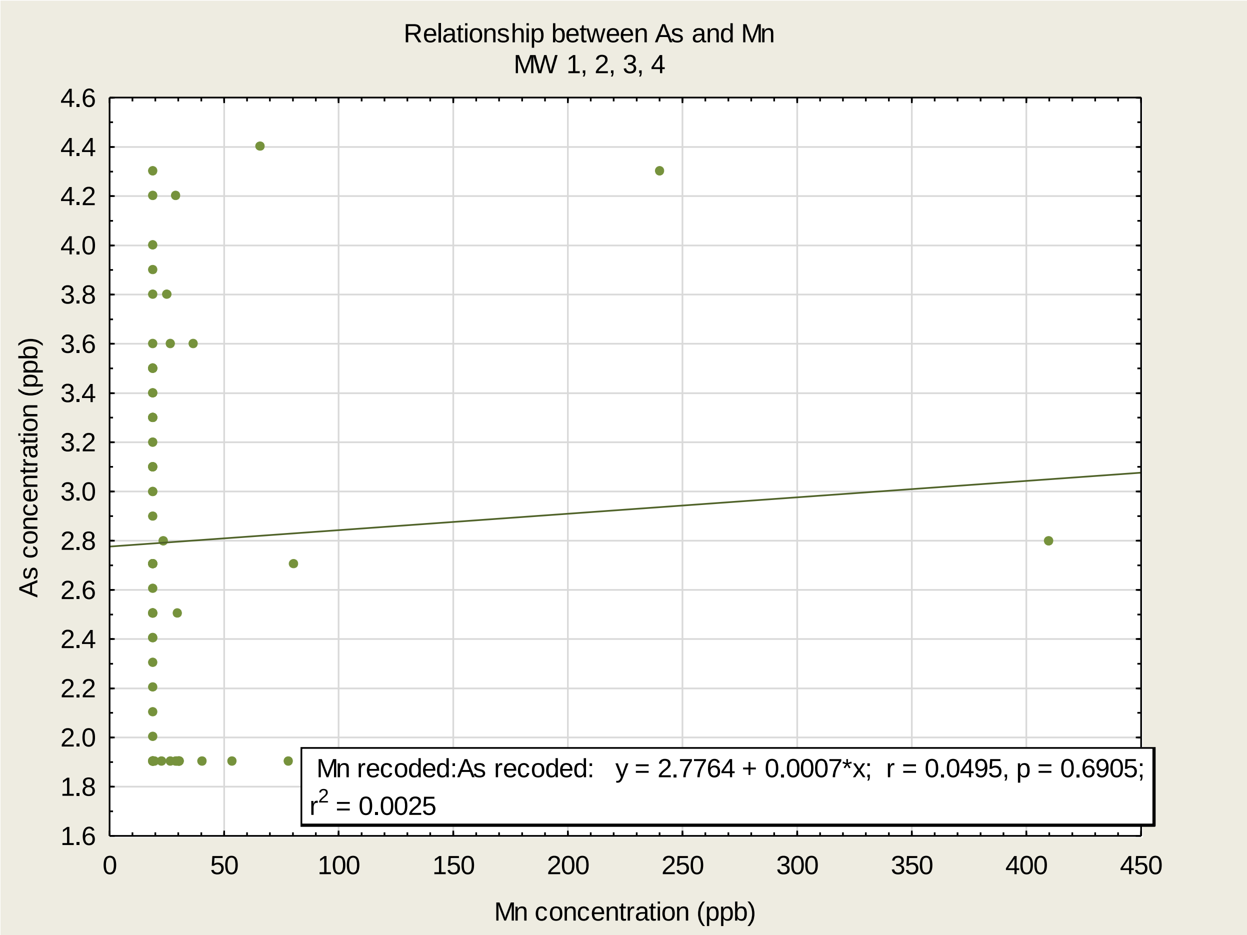


Figure 6 Relationship between concentration of arsenic and manganese in groundwater samples collected from monitoring wells. No significant correlation was found between the two ions.

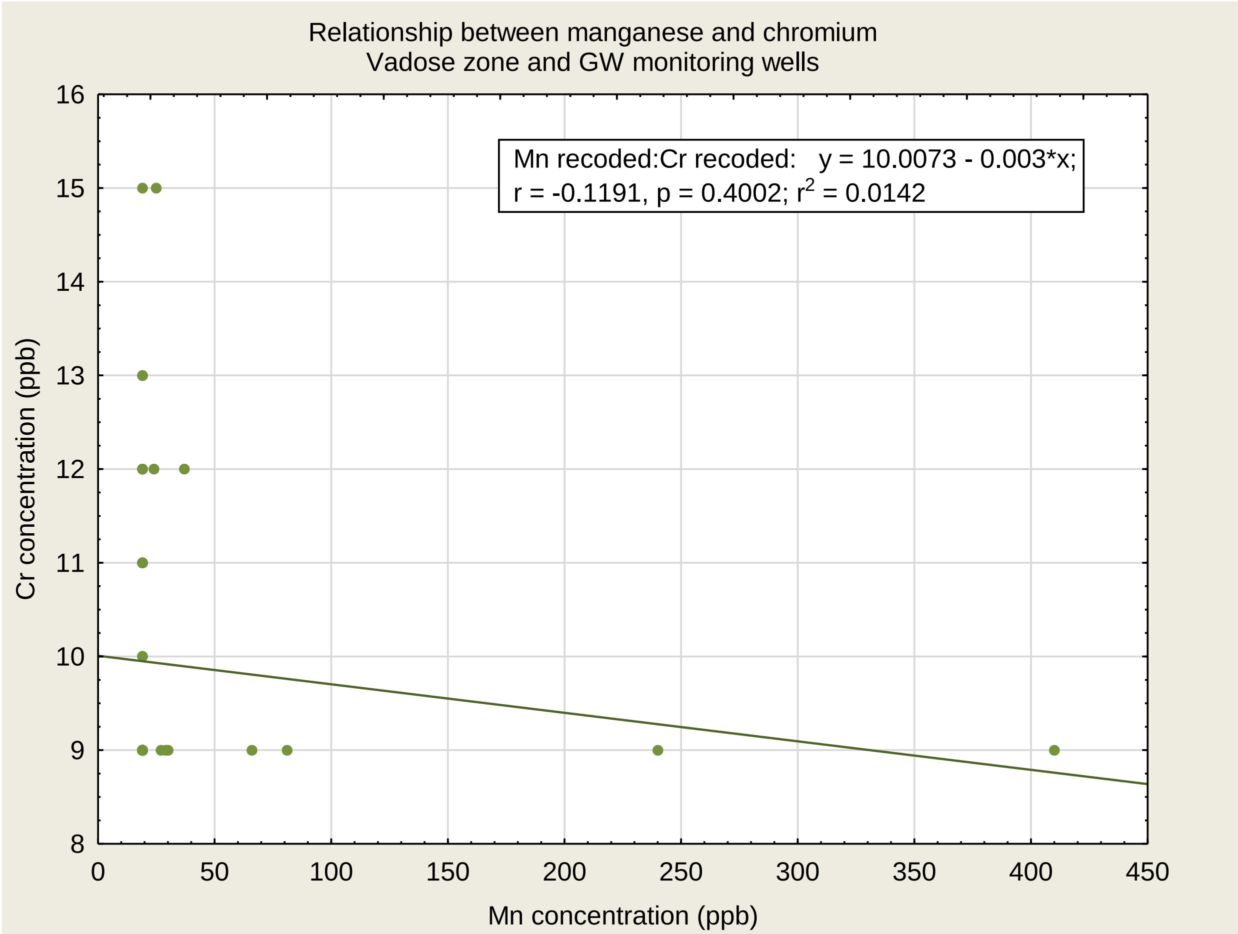


Figure 7 Relation between concentration of chromium and mangagnese. No significant correlation was found.

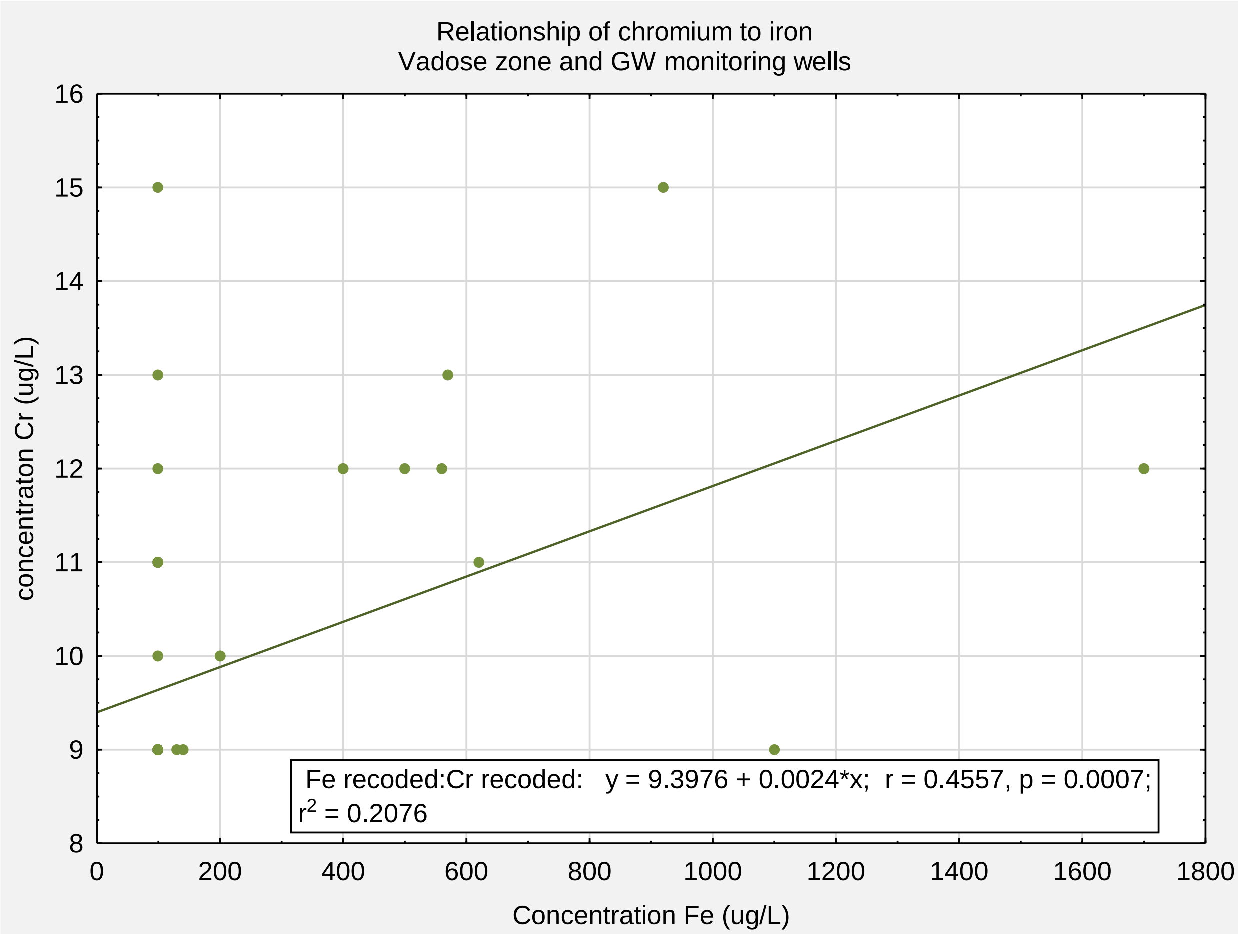


Figure 8 Relation between concentration of chromium and dissolved iron in groundwater samples. A positive correlation was found (Spearman's rho = 0.456, *p*-value= 0.007).

Reference

Ajouyed, O.; Hurel, C.; Ammari, M.; Allal, L.B.; & Marmier, N., 2010. Sorption of Cr(VI) onto natural iron and aluminum (oxy)hydroxides: Effects of pH, ionic strength and initial concentration. *Journal of Hazardous Materials,* Vol. 174, pp. 616-622.

Bose, P. & Sharma, A., 2002. Role of iron in controlling speciation and mobilization of arsenic in subsurface environment. *Water Research,* Vol. 36, pp. 4916-4926.

Buerge, I.J. & Hug, S.J., 1997. Kinetics and pH dependence of chromium(VI) reduction by iron(II). *Environ. Sci. Technol.,* Vol. 31, pp. 1426-1432.

Eary, L.E. & Rai, D., 1987. Kinetics of chromium(III) oxidation to chromium(VI) by reaction with manganese dioxide. *Environ. Sci. Technol.,* Vol. 21, pp.1187-1193.

Guha, H.; Saiers, J.E.; Brooks, S.; Jardine, P.; & Jayachandran, K., 2001. Chromium transport, oxidation, and adsorption in manganese-coated sand. *Journal of Contaminant Hydrology,* Vol. 49, pp. 311-334.

Lawniczak, S.; Lecomte, P.; & Ehrhardt, J.J., 2001. Behavior of hexavalent chromium in a polluted groundwater: Redox processes and immobilization in soils. *Environ. Sci. Technol.,* Vol. 35, pp. 1350-1357.

Lazareva, O.; Druschel, G.; & Pichler, T., 2015. Understanding arsenic behavior in carbonate aquifers: Implications for aquifer storage and recovery (ASR). *Applied Goechemistry,* Vol. 52, pp. 57-66.

McArthur, J.M.; Ravenscroft, P.; Safiulla, S.; & Thirlwall, M.F., 2001. Arsenic in groundwater: Testing pollution mechanisms for sedimentary aquifers in Bangladesh. *Water Resources Research,* Vol. 37, No. 1, pp.109-117.

Mills, C.T.; Morrison, J.M.; Goldhaber, M.B.; & Ellefsen, K.J., 2011. Chromium(VI) generation in vadose zone soils and alluvial sediments of the southwestern Sacramento Valley, California: A potential source of geogenic Cr(VI) to groundwater. *Applied Geochemistry,* Vol. 26, pp. 1488-1501.

Ndung'u, K.; Friedrich, S.; Gonzalez, A.R.; & Flegal, A.R., 2010. Chromium oxidation by manganese (hydr)oxides in a California aquifer. *Applied Geochemistry,* Vol. 25, pp. 377-381.

Pierce, M. & Moore C., 1982. Adsorption of arsenite and arsenate on amorphous iron hydroxide. *Water Research,* Vol. 16, pp. 1247 to 1253.

Piqué, A.; Grandia, F.; & Canals, À., 2010. Processes releasing arsenic to groundwater in the Caldes de Malavella geothermal area, NE Spain. *Water Research*, Vol.44, pp. 5618-5630.

Rai, D.; Eary, L.E., & Zachara, J.M., 1989. Environmental chemistry of chromium. *The Science of the Total Environment*, Vol. 86, pp. 15-23.

Szalinska, E.; Domink, J.; Vignati, D.A.L.; Bobrowski, A.; & Bas, B., 2010. Seasonal transport pattern of chromium(III and VI) in a stream receiving wastewater from tanneries. *Applied Geochemistry,* Vol. 25, pp.116-122.

Tabelin, G.B.; Igarashi, T.; Tamoto, S.; & Takahashi, R., 2012. The roles of pyrite and calcite in the mobilization of arsenic and lead from hydrothermally altered rocks excavated in Hokkaido, Japan. *Journal of Geochemical Exploration,* Vol. 119, pp. 17-31.

Ujević, M.; Duić, Ž.; Casiot, C.; Sipos, L.; Santo, V.; Dadić, Ž.; & Halamić, J., 2010. Occurrence and geochemistry of arsenic in the groundwater of Eastern Croatia. *Applied Geochemistry,* Vol. 25, pp. 1017-1029.

Appendix 6.1

Fact Sheets

Assessing the Risks of Using Dry Wells for Stormwater Management and Groundwater Recharge:
The Results of the Elk Grove Dry Well Project

PROJECT PURPOSE

The Elk Grove Dry Well project was designed to evaluate the risk of groundwater quality degradation associated with infiltrating stormwater runoff through dry wells.

BACKGROUND

Dry wells, also known as underground injection control (UIC) systems, are stormwater infiltration devices typically constructed of a pipe approximately 3 feet wide and 20 to 50 feet deep, containing perforation at various locations along the pipe and/or at the bottom (Figure 1). Dry wells can be used in a variety of situations, but are especially useful in areas with clay soils because they facilitate the movement of runoff below the constricting clay layers. Dry wells can be used in conjunction with low impact development (LID) practices to reduce the adverse effects of hydromodification on surface water quality, aquatic habitat, and downstream flood risk. They help to adapt to the effects of drought and climate change. However, the use of this technology has raised concerns that contaminants in stormwater could compromise groundwater quality.

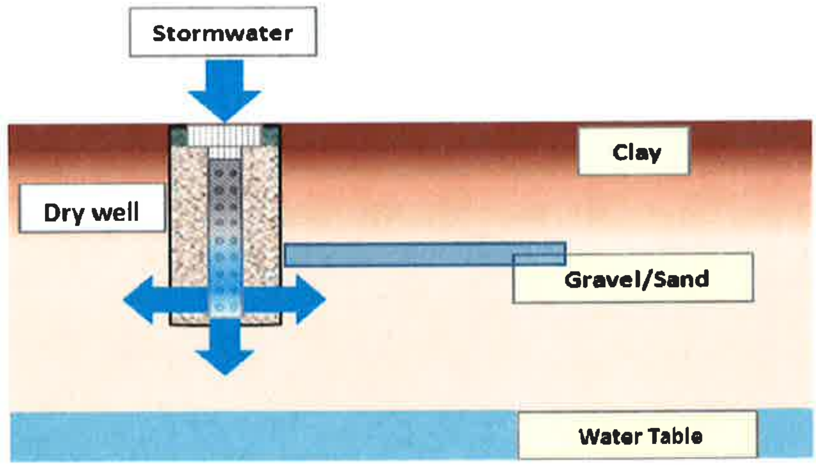


Figure 1. Idealized drawing of stormwater infiltration using dry wells.

In California, dry wells are used under the regulatory authority of the US Environmental Protection Agency's Underground Injection Control Program. Dry wells are categorized as Class V injection wells. Thousands of engineered dry wells have been installed in southern California as part of that region's extensive stormwater capture efforts whereas in northern California, they are used much less frequently. In neighboring states, such as Arizona, Washington, and Oregon, dry wells are used extensively as stormwater and flood control management tools. In these states as well as within California, protection of groundwater quality is of paramount importance. Results of data collection and fate and transport modeling for this project, along with a comprehensive literature review, provided scientific information on the risk to groundwater quality associated with dry well use in urban areas.

PROJECT APPROACH AND PROCEDURES

Two dry wells systems and an associated monitoring well network were constructed at two locations in the City of Elk Grove, California: 1) the Strawberry Creek water quality basin that collects stormwater runoff from a 168-acre residential neighborhood and 2) the City's Corporation Yard which serves as a bus parking and service center with a drainage area of 0.6 acres. At each site, a dry well approximately 40 feet deep was constructed and completed 10-15 feet above the high water table. Before reaching the dry well, stormwater runoff would pass through the vegetated and structural pretreatments. The grassy swale at the Corporation Yard and the vegetation in the water quality basin served as the vegetated pretreatment and were the primary means of removing particles and associated pollutants from stormwater. Due to design issues, the sedimentation well that was intended to sequester sediment before it flowed into the dry well was not sufficiently deep to perform this function. A groundwater monitoring well network, composed of a vadose zone well as well as one upgradient well (to determine background condition) and two downgradient wells (to determine groundwater influenced by the dry well), were also constructed.

Monitoring of over 200 contaminants in stormwater and groundwater was performed five times over two years. Groundwater monitoring also occurred prior to the dry well construction and after the first and second year of monitoring. The following classes of contaminants were analyzed (Table 1 on the following page):

Class (Number Tested)	Examples	Frequency of Detection Above Reporting Limit	Reporting Limits
Volatile organics (65)	Toluene, ethylbenzene, naphthalene	infrequent	low ppb (µg/L)
Semi-volatile organics (65)	Dichlorobenzene, benzo[a]pyrene, phthalates, naphthalene, benzoic acid	rare	low ppb (µg/L)
Polycyclic aromatic hydrocarbons (16)	Benzo[a]pyrene, anthracene, pyrene	none	low ppb (µg/L)
Chlorophenoxy herbicides (11)	2,4-D, dalaphon, pentachlorophenol	rare	low ppb (µg/L)
Pyrethroid pesticides (9)	Bifenthrin, permethrin, cyfluthrin	frequent	low pptr (ng/L)
Drinking water metals (20)	Total chromium, arsenic, lead	frequent	low ppb (µg/L)
Bacteria (3)	Total coliform, fecal coliform, e.coli	frequent	1.8 (low) and 1600 (high) most probable number/100 ml
Total petroleum hydrocarbons	Diesel, gas, motor oil	infrequent	low ppm (mg/L)
Special testing (3)	Hexavalent chromium, glyphosate, total suspended solids	Chromium6+: none Glyphosate: rare Total Suspended Solics (TSS): n/a	low ppb (µg/L) ppm (mg/L)
Conventional parameters (20)	Calcium, specific conductance, total alkalinity	n/a	ppm (mg/L)

Table 1. Contaminants analyzed and frequency of detection. The minimum concentrations that could be quantified with the analytical methods used are listed in the reporting limits column. Frequency of detection in stormwater: rare - < 5 times; infrequent - < 10 times; frequent – some in the class detected in all stormwater samples.

Measurement were made of stormwater runoff as it entered the dry well (after pretreatment) and in all subsurface monitoring wells. Twice during the study, the full suite of contaminants was also monitored in influent stormwater. Flow-weighted composite stormwater samples were used for most analyses. Contaminant data was analyzed, comparing concentrations at different locations at both sites and over time, using non-parametric statistical methods.

Additionally, flow rates and total volume of runoff infiltrated were quantified. Fate and transport modeling was also performed to evaluate the long term potential for contaminants to reach the water table. The modeling effort utilized data from the well boring logs to assess subsurface composition as well as a range of values for hydraulic conductivity, fractional organic carbon, and other parameters. HYDRUS 1D was used to estimate the travel time of selected contaminants vertically downward from the bottom of dry well to the top of the seasonal high water table. Eight scenarios were run for the dissolved concentration of each contaminant at both project sites.

Looking inside the dry well. On the left, runoff from the sedimentation well can be seen spilling into the dry well.

Finally, a review of the literature was performed to examine studies and government reports published over the past 30 + years that addressed the risk of groundwater contamination associated with dry well use.

KEY PROJECT FINDINGS

Analysis of data from stormwater and groundwater monitoring showed no evidence of contamination of the aquifer linked to the two dry wells. Of the chemicals analyzed (Table 1), most were detected rarely or at low frequency, as described below.

Chemicals Infrequently Detected

Chemicals in the volatile and semi-volatile organics and polycyclic aromatic hydrocarbons (PAH) classes were detected in stormwater a handful of times, at levels just above the reporting limits for the analytical methods. Toluene, acetone, and tert-butyl alcohol were detected near their reporting limits in influent stormwater. Pretreatment reduced their concentrations to near/below the reporting limits in samples collected at the dry well. The only semi-volatile detected was diethylhexyl phthalate, a ubiquitous plasticizer, just above the reporting limit. None were detected in groundwater.

Chemicals Frequently Detected

The main classes of contaminants that were detected regularly in stormwater included metals, pyrethroid pesticides, and bacteria. Aluminum was the main metal contaminant in stormwater found at the Corporation Yard (Figure 2); present at concentrations three times the MCL (Maximum Contaminant Level) for drinking water. The median concentration was reduced approximately three-fold as stormwater runoff traveled through the grassy swale; none was found in the subsurface monitoring wells. Using conservative assumptions, the fate and transport model indicated that it would take aluminum 500 years to reach 0.04 mg/L, below the quantifiable level of 0.05 mg/L; and it would never reach the MCL.

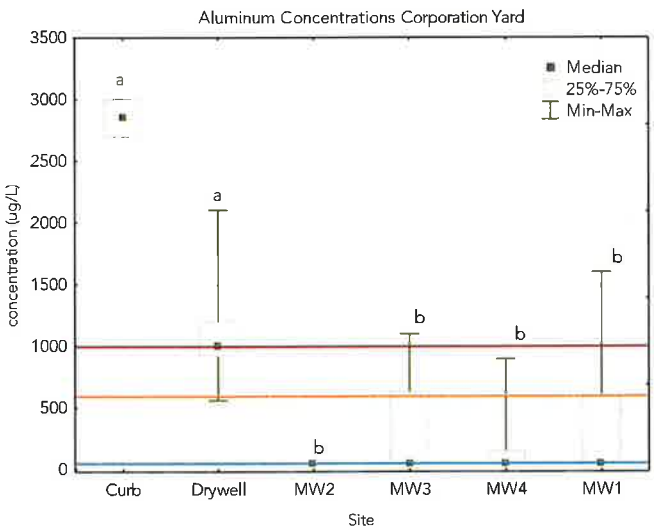


Figure 2. Aluminum concentrations in stormwater and groundwater at the Corporation Yard. Units of concentration are μg/L or ppb. Notations: Box and whiskers labeled with different letters are significantly different from each other. The red line indicates the MCL; the orange line is the Public Health Goal (PHG); and the blue line reflects the analytical reporting limit. Curb = curb cut where influent stormwater enters the dry well system. MW2 = vadose zone well. MW3 and 4 = downgradient water table wells. MW1 = upgradient water table well. Concentrations at water quality basin were about 3 fold lower than at the Corporation Yard, but the patterns were similar.

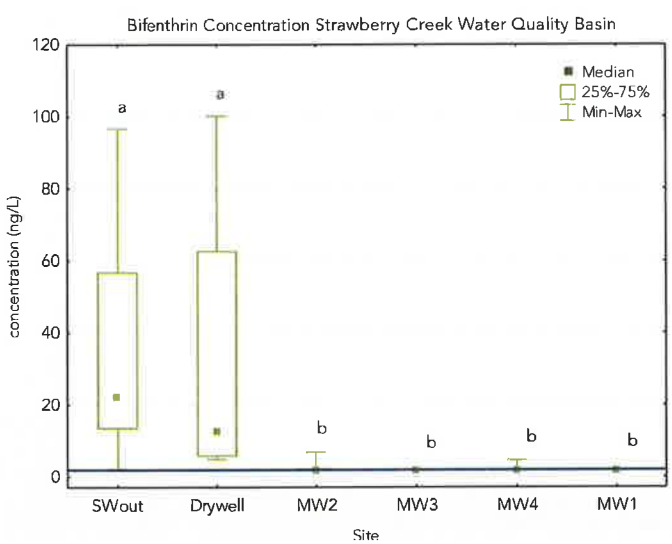


Figure 3. Bifenthrin concentration in stormwater and groundwater at the water quality basin. Notations are the same as described in Figure 2. None was detected below the ground surface.

Other metals were detected at concentrations that were not quantifiable (below the reporting limit). Some metals known to occur naturally in the Sacramento region, such as arsenic and hexavalent chromium, were detected in groundwater below the MCL (10 μg/L) for both metals. Concentrations were not quantifiable in stormwater.

The other major class of contaminants detected with regularity, but at ultra-low levels (generally <20 ng/L), were pyrethroid pesticides. Bifenthrin was the major pyrethroid detected (Figure 3). It is commonly used to control ants and other pests around residences. This was particularly an issue at the Strawberry Creek water quality basin, located in a residential neighborhood. None was detected in groundwater at either location.

Another pyrethroid, permethrin, was detected on a single occasion at the Corporation Yard. It was sprayed around the perimeter of the Corporation Yard office building and, when it rained a week later, it was detected in the vadose zone well (data not shown). None was found in water table samples. Vadose zone modeling suggests that this contaminant would not reach the water table at quantifiable levels within the 3000 year modeling timeframe.

Nitrate presented a different pattern of detection in stormwater and groundwater. Its concentration in groundwater exceeded the MCL and Public Health Goals (PHG) (10 mg/L as nitrogen) at both project locations, but there were low concentrations in stormwater. While nitrate is very water soluble, its concentration in stormwater is not sufficiently high to account for the concentration in groundwater. Water collected from the two downgradient water table wells had significantly higher concentrations than stormwater and the vadose zone well at the Corporation Yard (Figure 4 on the following page). These concentrations are likely the result of nitrates that have accumulated in the soil over many decades, when the lands surrounding both project sites were used for agricultural production.

Total coliform, an indicator of bacterial contamination, was detected in both stormwater and groundwater (data not shown). At the Corporation Yard, where the only source of stormwater in the subsurface was the dry well, coliform was confined to the vadose zone well; none was detected at the water table. In contrast, at Strawberry

[1] MPN = most probable number

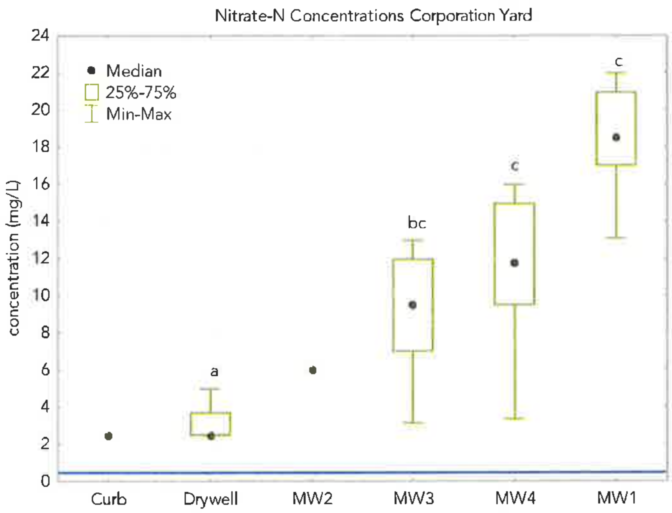


Figure 4. Nitrate (as N) concentration at the Corporation Yard in stormwater and groundwater. Notations are the same as described in Figure 2.

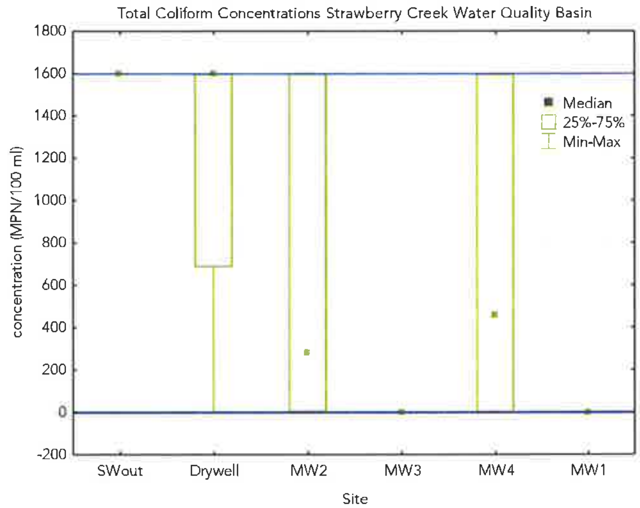


Figure 5. Coliform bacteria concentrations at Strawberry Creek water quality basin. Notations are the same as described in Figure 2.

Creek water quality basin, where stormwater could infiltrate through both the the large water quality basin and the dry well, coliform was detected at >1600 MPN[1]/100 ml in the vadose zone and downgradient water table well (Figure 5). The high concentrations of coliform in both the upgradient and downgradient water table wells is likely due to the ability of stormwater to percolate through the water quality basin as well as the dry well.

Contaminant Removal by Pretreatment

Pretreatment removal of pollutants prior to entering the subsurface is a key factor in preserving the quality of groundwater. To assess the effectiveness of pretreatment, estimates of percent removal efficiency are often made. Many factors can influence these estimates, most notably the influent stormwater concentration (Wright Water Engineers and Geosyntec, 2007). Given this caveat, rough estimates were calculated of contaminants removed by pretreatment at both sites (Table 2).

The efficiency of contaminant removal by the vegetated pretreatment feature was similar to the values reported in the International Stormwater BMP database. Higher removal efficiency at the Corporation Yard is likely associated with the use of geotextiles to stabilize the soil and the uniform pattern of long grass that grew in the swale. A study by Torrent Resources[2], a stormwater infiltration consultant with extensive experience with dry wells, reported approximately 90% removal efficiency of TSS (total suspended solids) in a two chambered dry well system, where both chambers sequestered sediment. While water soluble contaminants such as nitrate and neonicotinoids would likely escape sequestration, most metals and organics would be captured. If the project's sedimentation well had functioned properly, it is likely that additional pollutant removal could have been achieved.

Contaminant	Corporation Yard	Water Quality Basin
Total suspended solids	63%	50%
Bifenthrin	--	42%
Aluminum	65%	50%
Estimated average efficiency	64%	47%

Table 2. Estimated removal efficiency of selected constituents by the vegetated pretreatment feature. Note: Inadequate data was available at the Corporation Yard to estimate changes in bifenthrin concentrations.

Flow Rates and Stormwater Recharged through the Dry Wells

Infiltration rates through the dry wells were estimated to average 15 gpm (gallons per minute) at the Corporation Yard and 31 gpm at Strawberry Creek water quality basin. The highest infiltration rate, 47 gpm or 0.1 cfs, was achieved early in the season at the water quality basin. A 0.1 cfs rate is used by some as the 'design' infiltration rate; the project wells did not meet this standard likely due to the dry well design and location. Factors that affected the rate of flow through the dry well included the size of the drainage area (volume of runoff), the size and intensity of any individual storm event, and the degree of saturation in the vadose zone. Estimates were also made of the total volume of runoff infiltrated during the rainy season. Based on total precipitation in 2015-16, 13.72 inches, the Corporation Yard dry wells infiltrated approximately 0.4 AF (acre/feet) and the Strawberry Creek water quality basin 0.7 AF of stormwater. In a normal year, when approximately 18" of rain falls in the region, an estimated 1 AF would likely pass through the dry well at the water quality basin.

2 This reference does not constitute an endorsement of products or services.

Fate and Transport Modeling

Contaminant transport modeling, using HYDRUS 1D, was performed to estimate the long-term risks to groundwater quality associated with the use of dry wells. Eight scenarios were assessed for each stormwater contaminant at concentrations measured at the dry well, using a range of values for key modeling parameters. Most of the variables used were sediment hydraulic or contaminant chemical properties that affect transport through the vadose zone, such as fractional organic carbon and hydraulic conductivity. Table 3 contains results for key contaminants using the most conservative set of assumptions (i.e., lower organic carbon, higher hydraulic conductivity).

Site	Contaminant Concentration Measured at Dry Well	Estimated Time to Detection	Estimated Time to PHG/MCL Concentration
Corporation Yard	Aluminum – 0.042 µg/L	φ	φ
	DEHP – 3.01 µg/L	φ	*
	Permethrin – 12.2 ng/L	φ	n/a
	Fipronil – 0.5 µg/L	133 days	n/a
	Imidacloprid – 0.9 µg/L	16 days	n/a
Strawberry Creek Water Quality Basin	Aluminum – 0.006 µg/L	φ	n/a
	Bifenthrin – 11 ng/L	φ	n/a
	Fipronil – 0.5 µg/L	18 days	n/a
	Imidacloprid – 0.9 µg/L	3 days	n/a

Table 3. Estimated travel time of observed and hypothetical contaminants to reach the water table at the Corporation Yard and Strawberry Creek water quality basin. Results based on 1 dimensional vadose zone modeling. Highlighted cells reflect estimates developed for contaminants not measured in this study, but reported by the Department of Pesticide Regulation as pesticides of particular concern due to their increased use. All input concentration reflect calculated dissolved concentrations based on the measurement of total concentration in stormwater measured at the dry well. Estimated detection time refers to model estimates of the time it would take to first be able to quantify the contaminant. Notations: φ = input concentration is insufficient to reach the reportable values. DEHP = diethylhexy phthalate. n/a = No PHG or MCL exists for the contaminant.

Although not analyzed in stormwater, imidacloprid and fipronil were included in the modeling effort due to their growing use in California and elsewhere. Both pesticides are used in urban settings with increasing frequency. Given their high water solubility, these pesticides are unlikely to be adsorbed by particles, thus not removed from stormwater via sedimentation. Modeling results suggests they have a very short transit time to the water table. There is a need for additional investigation to determine their concentration and distribution in stormwater runoff and the most effective pretreatment. Further analysis is needed to understand the risk they might pose to groundwater quality.

LITERATURE REVIEW

The literature on dry wells and their potential link to groundwater contamination is relatively small. Of the studies and reports that have been published, most have drawn similar conclusions – that dry wells do not pose a risk to groundwater quality. One study observed that metal pollutants are likely retained in the vadose zone while organic pollutants are degraded by bacteria, thus both unlikely to reach the water table. In another study, the USGS performed a detailed analysis in Modesto to assess groundwater quality. Dry wells have been used in Modesto as a stormwater management tool for over 50 years. The research team found little evidence of groundwater contamination from urban uses. The study did find, however, that naturally-occurring uranium was solubilized by increased alkalinity associated with irrigation practices. Groundwater modeling performed in Portland and numerous other cities in Oregon suggests that the risk of groundwater contamination is attenuated by the vadose zone, assuming contaminant concentrations entering the dry well are below the MCL or equivalent. Some researchers have recommended limitations on how and where dry wells should be utilized. For example, most suggested that dry wells should not be sited where toxic material is used (e.g., gas stations, vehicle maintenance areas, industrial areas) or near public supply wells. Many have suggested that vegetated or structural pretreatment should be incorporated into the dry well design, as it serves to prevent clogging of the dry well and sequester sediment and associated pollutants. One study by stormwater experts (Talebi & Pitt, 2014) suggested that pollutants with high concentrations in stormwater, high mobility in the vadose zone, and/or high water solubility pose the greatest risk to groundwater quality. This reflects the importance of understanding the stormwater contaminants present when siting a dry well to ensure the dry well and pretreatment features can effectively manage relevant contaminants at the site.

Corporation Yard monitoring event.

The literature has also pointed to the benefits of dry wells as an aquifer recharge tool. Studies suggest that the use of dry wells can have significant recharge potential. In 2005, the Los Angeles and San Gabriel Rivers Watershed Council, in a ten year study in the Los Angeles region found that recharge could provide for the water needs for 750,000 households. In light of the recent history of drought and increasing water challenges from climate change, dry wells could serve as one valuable tool to optimize groundwater recharge.

CONCLUSIONS

Data collected at the two project sites in Elk Grove did not show evidence of groundwater contamination linked to the dry wells, even given the fact that the majority of pretreatment depended only on vegetated features. With adequate structural pretreatment, a higher level of pollutant removal could have been achieved. Modeling suggested there are only minimal risks of groundwater contamination associated with common urban contaminants -- such as combustion by-products, copper, zinc, and other metals associated with brake pads and tire wear, and pyrethroid pesticides. Practices in other states and conclusions reached by US EPA suggest that with proper dry well siting, design, and maintenance, dry wells can be used safely. Results from this project are consistent with these conclusions.

Attention should be given to the following set of criteria (Table 4) which are widely used in neighboring states and evaluated in the scientific literature and government reports:

Management Practice	What It Achieves
Siting: Locate dry wells away from public supply wells	Avoids risk of transfer of contaminants to the boreholes of drinking water wells
Siting: Do not permit installation in contaminated soils	Avoids risk of mobilizing contaminants already present in soil
Siting: Do not permit installation near gas stations, vehicle servicing facilities, or businesses that use hazardous materials	Avoids risk of spills or stormwater runoff entering the subsurface through the dry well
Siting: Require a minimum vertical separation, commonly 10 feet, from the aquifer	Utilizes the vadose zone material to attenuate pollutants
Design: Require pretreatment to reduce the concentration of contaminants in stormwater entering the dry well	Reduces the concentration of pollutants entering the subsurface to a level that mitigates against degradation of the aquifer
Monitoring: Periodic monitoring for key contaminants collected as runoff enters the dry well	Ensures that pretreatment is effective and stormwater does not exceed criteria values
Maintenance: Periodic inspections and maintenance	Insures proper functionality and infiltration rates

Table 4. Best management practices for dry wells.

References:

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

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

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

Talebi, L and R. Pitt. 2014. Evaluation and demonstration of stormwater dry wells and cisterns in Millburn Township, New Jersey. J. Water Management Modeling.

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

Prepared by: B. Washburn, barbara.washburn@oehha.ca.gov, B. Lock, bennett.lock@oehha.ca.gov, and C. Nelson, cnelson@elkgrovecity.org.

For more information on the project's final results visit http://www.elkgrovecity.org/drywell

Project website: http://www.elkgrovecity.org/drywell

The Project was funded by a State Water Resources Control Board Proposition 84 (Prop 84) Storm Water Grant Program (SWGP) Planning Grant

DRY WELLS

USES, REGULATIONS, AND GUIDELINES IN CALIFORNIA AND ELSEWHERE

Dry Well Description and Challenges to Use

Dry wells are gravity-fed excavated pits lined with perforated casing and backfilled with gravel or stone (Fig. 1). Dry wells penetrate layers of clay soils with poor infiltration rates to reach more permeable layers of soil, allowing for more rapid infiltration of stormwater. They can be used in conjunction with low impact development (LID) practices to reduce the harmful effects that traditional stormwater management practices have had on the aquatic ecosystem. Dry wells not only aid in stormwater runoff reduction, but they can also increase groundwater recharge, are economical, and have minimal space requirements.

Figure 1. Idealized drawing of stormwater infiltration using a dry well

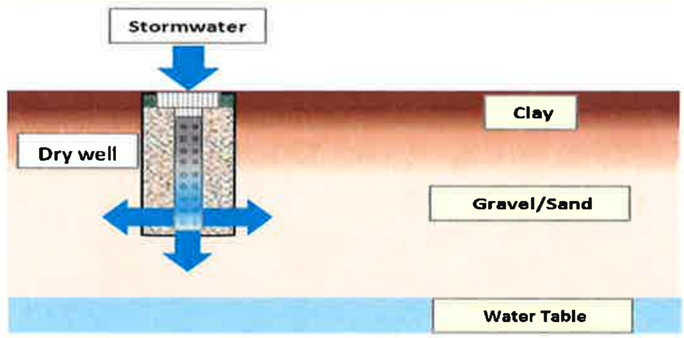


Figure 2. Dry well installed to receive runoff flowing through a lawn (Source: R. Pitt)

In California, dry wells are used frequently in the southern part of the State but with caution in northern California due to the concern that they might provide a conduit for contaminants to enter the groundwater. Regional Water Quality Control Boards' Stormwater Management Plans often differ in technical specifications for dry well construction. The CA Department of Water Resources' well water regulations imply that dry wells should be constructed to water well standards. Varying design and technical specifications, poorly disseminated information about studies of the risks of using dry wells, and lack of clarity on the need to register or permit dry wells has left many reluctant in some parts of California to use dry wells.

U.S. Environmental Protection Agency (EPA) - Region 9 Regulations

Dry wells and other buried infiltrative devices are subject to the U.S. Environmental Protection Agency (US EPA) Underground Injection Control (UIC) regulations. A dry well is a Class V injection well, defined as a conduit for non-hazardous fluids that is deeper than it is wide. Dry wells can be used for stormwater infiltration as long as they are: 1) registered with the EPA using their online form on the UIC Region 9 website, and 2) do not threaten drinking water sources by ensuring that runoff entering the dry well does not exceed primary drinking water standards (Maximum Contaminant Levels or MCL; 40 CFR part 144.82). A permit is not required.

The EPA's UIC Program was established in 1979 as part of the Safe Drinking Water Act. In California, the EPA maintains 'primacy' over the UIC program, unlike most other states who set guidelines and overseeing Class V wells. California has primacy only for wells that are used to inject oil and gas waste products (Class II wells). However, the EPA specifically allows the Regional Water Quality Control Boards and/or local governments to set requirements or standards that are more stringent than EPA regulations (posted at: *http://www.epa.gov/region9/water/groundwater/uic-pdfs/calif5d-muniguide.pdf*).

The US EPA has not imposed design requirements for dry wells in California; that responsibility is left to local authorities. However, the following design practices are encouraged:

- Site evaluation prior to construction to assess geological conditions, the ability of the subsurface to infiltrate stormwater, proximity to public supply wells, and local use of hazardous chemicals,
- Incorporation of a pretreatment feature to remove sediment and associated pollutants,
- Maintenance of minimum distance, commonly 10 feet, from the bottom of the dry well to the water table, and
- Incorporation of any measures, such as siting and design requirements, needed to protect drinking water.

The Role of the California Regional Water Quality Control Board

The State Water Resources Control Board and the Regional Water Quality Control Boards in California can prescribe requirements for discharges into California waters or on to the land. Although not widely used, under California's Porter-Cologne Act, Regional Boards can require that a Waste Discharge Report be submitted when dry wells used for stormwater management are constructed. The requirements must take into consideration the beneficial uses (water supply, irrigation, etc.) of the affected water and the water quality objectives necessary to protect these beneficial uses, as well as the need to prevent a nuisance.

California's Anti-Degradation Policy

When evaluating the risk and benefits of using dry wells, California's anti-degradation policy (State Water Resources Control Board Resolution No. 68-16) is also considered. The anti-degradation policy protects high quality water (water that is higher in quality than that prescribed by the Water Boards' plans and policies). Degradation of high quality water is permitted only if the discharge provides a maximum benefit to the people of the State, does not violate the Boards' Basin Plans and policies, and when the discharge is controlled by the best practicable treatment. The maximum benefit to the State is determined on a case by case basis taking into account the beneficial uses of the water, economic and social costs, the environmental aspects of the proposed discharge, and the implementation of feasible alternative treatment or control methods. Factors to be considered when evaluating the use of dry wells for stormwater management could involve determining if they:

- Provide an additional source of water to augment the water supply,
- Reduce the negative effects of stormwater runoff flowing to surface waters, and
- Minimally impact groundwater quality.

Consideration and interpretation of these and related factors are the basis on which the State's anti-degradation policy is applied to dry well use and siting.

Typical Dry Well Guidelines at the Local Level

Dry Wells and California Water Well Protection Policies

Throughout California, county environmental management departments are charged with implementing California DWR regulations (Bulletins 74-81, 74-90) to protect wells used to supply drinking water, groundwater monitoring wells, etc. These regulations are designed to prevent contamination of groundwater through improperly constructed or decommissioned wells. County staff regularly inspect wells and the area around them to evaluate compliance with regulations. These regulations apply to "waste" and, if stormwater is classified as such, then Bulletin 74 would apply to dry wells. Yet, the process that dry wells are designed to facilitate, namely the infiltration of stormwater, is stymied if the rules identified in Bulletin 74 prohibits surface water from entering injection wells. Currently, individual county environmental health departments in California use their best professional judgment to evaluate how to manage this challenge. Within the State, some communities follow DWR's guidelines while others do not, deferring to the guidance of the US EPA Region 9.

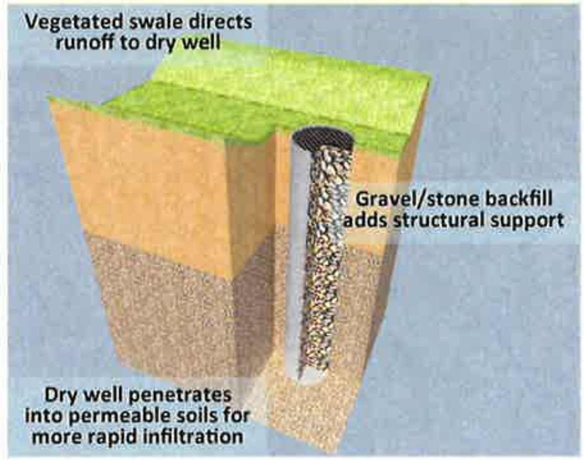
Local Guidelines

Many requirements and design specifications for dry wells come from guidelines linked to the NPDES (National Pollution Discharge Elimination System) permits, issued by the State or Regional Water Boards. In a few locales, city or county requirements also exist. In Los Angeles County, for example, information on placement and design of dry wells must be submitted as part of the permitting process for new development. Not all cities and counties have such requirements. In some cases, inclusion of dry wells in local Low Impact Development Design Guidelines serves as a 'de facto' source of guidance for local municipalities and the development community. For example, a number of cities in the SF Bay Area (San Mateo, Santa Clara, etc.) include dry wells as one LID tool that can be used to reduce the effects of hydromodification.

Local Guidelines (continued)

Design specifications differ by city/county, with some standards varying significantly. Local authorities should be consulted for specific guidelines. The following list includes some of the common standards of the California Standard Urban Stormwater Management Plans and LID Manuals (documents related to NPDES permits):

Figure 3. Example dry well system design



- Building setback: 10 – 20 feet minimum,
- Water table: 10 feet vertical separation between dry well bottom and seasonal high water table,
- Public supply wells: 100 feet minimum setback,
- Separation (center to center): 100 feet minimum,
- Penetration: 10 feet minimum into permeable porous soils,
- Dry well surface inlet: 3 inch minimum above bottom of retention basin,
- Restriction of use near vehicle maintenance sites, industrial areas, and other high risk locations, and
- Should not be used at sites with a slope >15%. (For example, San Diego does not recommended sites with slopes >40%).

There are no commonly applied monitoring or design requirements in California. The role of the vadose zone in the attenuation of contaminants is not a design or siting consideration. A challenge for some in the development community is gaining an understanding of local practices in order to meet stormwater runoff management requirements (i.e., hydromodification requirements) associated with NPDES permits.

Dry Well Regulations in Other States

Most states have assumed responsibility for overseeing dry well programs in their state. Some have minimal requirements while others have a complex set of standards and monitoring requirements. Two of the states with the most well defined programs are those in Oregon and Washington. Some of the common characteristics of these two programs are the requirement that runoff entering the dry well have concentrations of contaminants below the MCL, the regulatory standard for contaminants in drinking water. The following table summarizes key aspects of the programs in these two states:

Issue	Oregon	Washington
Design & Pretreatment	Pretreatment reqd. (vegetated or structural) for all except those with roof-runoff only; spill containment system must be incorporated into system; runoff entering UIC must be < MCL. Vadose zone modeling of stormwater contaminants required for most UICs.	Need for pretreatment based on pollutant load and vadose zone treatment capacity except for roof runoff; runoff < MCL as it enters UIC; spill containment if UIC at industrial or commercial site.
Siting	> 500 feet from any water well, none allowed where soils already contaminated, > 5 feet vertical separation from water table, commonly used in roadway right of ways.	Prohibited in vehicle servicing/washing facilities, areas with hazardous materials, others specified; > 100 feet from drinking water wells; restrictions on slopes > 25%, setback 100 feet upslope and 20 feet downslope from buildings.
Monitoring	Required in most circumstances, measured in stormwater as it enters UIC. Includes metals, volatiles, semi-volatiles, combustion by-products, coliform, etc.	Not generally required.
Permitting or Registration	Registration for rooftop runoff; others must obtain permit from local or state government.	Registration required for all but roof-runoff only UICs; permits integrated into stormwater permit.
Other points of interest	Stormwater management plan must be prepared, operations and maintenance plan frequently required.	

Regulations in Other States (continued)

Pennsylvania, New Jersey, and Arizona, and Hawaii are a few of the others states with dry well regulations and guidelines. In New Jersey, some communities require dry well installation for all new and major remodels related to residential construction. They are typically designed to temporarily store and infiltrate roof runoff. Dry wells in New Jersey are prohibited in industrial or other areas where toxic chemicals might be used. In contrast, in Pennsylvania dry wells are permitted in industrial areas with restrictions, but not along roadways. Arizona requires dry wells in all new development to control runoff produced by the 100 year storm over 24 hours. The regulations of these states vary with respect to dry well design, use of pretreatment, separation from drinking water sources, distance from the water table, and other factors.

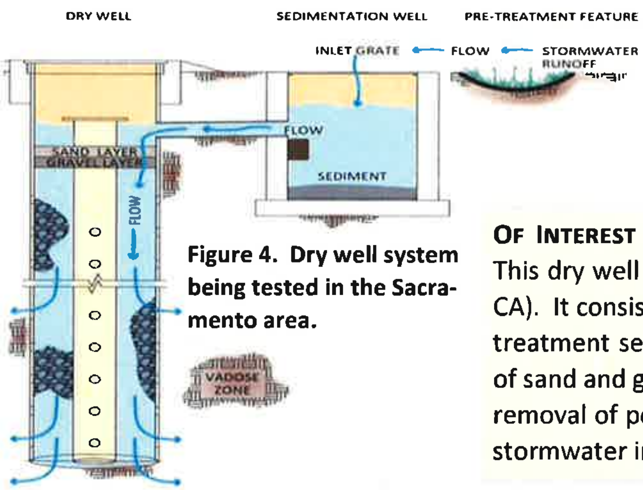


Figure 4. Dry well system being tested in the Sacramento area.

OF INTEREST Most dry wells are not holes in the ground filled with rocks. This dry well system (left) is being tested in the Sacramento area (Elk Grove, CA). It consists of 3 parts: a vegetated pretreatment feature, a structural pretreatment sedimentation well, and the dry well itself, which contains layers of sand and gravel above the rocks. The goal of this design is to maximize the removal of pollutants, reduce clogging of the dry well, and promote efficient stormwater infiltration.

Conclusions

Currently, there are no uniform State regulations or guidelines for dry wells in California. However, the Regional Water Quality Control Boards have the discretion to issue waste discharge requirements and to interpret and apply the anti-degradation policy to the construction of new dry wells. Therefore, most regulations and guidelines occur at the city or county level and vary by region. Available information suggests that dry wells can be used safely if careful site evaluations are performed to determine if a dry well is suitable for the location. They can be an alternative to typical storm drainage systems that provide numerous benefits, including reducing localized flooding, recharging the aquifer, supporting the implementation of LID practices in areas with clay soils, thereby minimizing the damaging effects of hydromodification on aquatic resources.

Useful Links and References

General Information

US EPA Class V Injection Well Info: *https://www.epa.gov/uic/class-v-wells-injection-non-hazardous-fluids-or-above-underground-sources-drinking-water*

US EPA Region 9 Injection Well Guidelines

http://www.epa.gov/region9/water/groundwater/uic-pdfs/calif5d-muniguide.pdf

Forms and Registration

EPA Region 9 Injection Well Registration

http://www.epa.gov/region09/water/groundwater/injection-wells-register.html

Information about programs in other states:

Oregon: *http://www.deq.state.or.us/wq/uic/uic.htm*

Washington: *http://www.ecy.wa.gov/PROgrams/wq/grndwtr/uic/index.html*

References

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

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

This factsheet was prepared by the California Office of Environmental Health Hazard Assessment, working with the City of Elk Grove, on the Elk Grove Dry Well project to investigate the risks associated with the use of dry wells. Written by Nelson Pi, Ary Ashoor, and Barbara Washburn. For more information, contact Barbara Washburn at barbara.washburn@oehha.ca.gov or Connie Nelson at cnelson@elkgrovecity.org.

(vers. 2)

Oregon's Experience with Dry Wells: The Underground Injection Control Program

Background

While over a dozen states around the country oversee dry well programs, one of the most developed programs is in Oregon. The Oregon Department of Environmental Quality (DEQ) issues permits to municipalities to operate underground injection control (UIC) devices or dry wells. Portland manages about 9,000 public UICs which collect stormwater in a catch basin, filter it through a sedimentation manhole, and release the runoff into a dry well for infiltration 20—40 feet below the ground. Portland developed UICs as a best management practice to minimize the damaging effects of increased stormwater runoff volumes on the aquatic ecosystem as well as to recharge the aquifer. In Portland, the public UICs typically collect stormwater in drainage inlets along the side of the street from the public rights-of-way. In some areas of the City, UICs are the only form of stormwater disposal. Portland's program stands out among others around the country due to the extensive oversight and monitoring performed in an effort to protect groundwater quality. This fact-sheet describes Oregon's UIC Program.

The role of stormwater monitoring in Oregon's UIC Program

The protection of groundwater in Oregon's program rests on monitoring the quality of stormwater. Drinking water standards such as MCLs (maximum contaminant levels) are used to determine the maximum allowable concentration of contaminants in stormwater. Oregon assumes that if stormwater entering the UIC does not exceed drinking water standards, groundwater quality is likely to be protected. Municipalities in Oregon operate their UIC Program under a permit from the Oregon DEQ. In June 2005, the DEQ issued a 10 year permit to Portland, which allowed stormwater discharges into city-owned UICs – the first permit of its kind in the nation. The permit established construction, operation and maintenance, and monitoring mandates for the UICs to ensure contamination prevention and groundwater replenishment.

Figure 1. A UIC located in a public right of way. *Source: Oregon DEQ UIC program.*

UICs: Construction and Design

The main component of a UIC is the dry well, which is typically a precast, reinforced, concrete cylinder that contains numerous perforations, allowing stormwater to infiltrate into the surrounding subsurface (Fig. 1 & 2). Specific features of UICs can vary by site to account for local geologic and hydrological conditions. The drywell is not filled with gravel or other material that might impede the flow or become clogged with fine sediment over time. Most have a solid bottom to permit periodic vacuuming of accumulated sediment. The size and depth of the dry well depends on the amount of infiltrating stormwater, subsurface conditions, and distance to the water table.

A second component of the UIC is the sedimentation manhole, a solid concrete cylinder generally 3-4 feet in diameter and 10 feet deep, 4 feet of which extends below the pipe that transfers stormwater to the dry well (Fig. 3). The sedimentation manholes provide pretreatment by allowing sediment in stormwater to settle, thus minimizing suspended solids, and the pollutants they carry, from entering the dry well.

The third component of the system is a catch basin. The design of catch basins vary, from a street gutter to a vegetated swale or bioretention cell or some combination of the two (Fig. 3). The function of this portion of the UIC system is to collect water and, in some cases, provide additional pretreatment.

Figure 2. Schematic of typical city UIC system in Portland. *Source: Portland Bureau of Environmental Services*

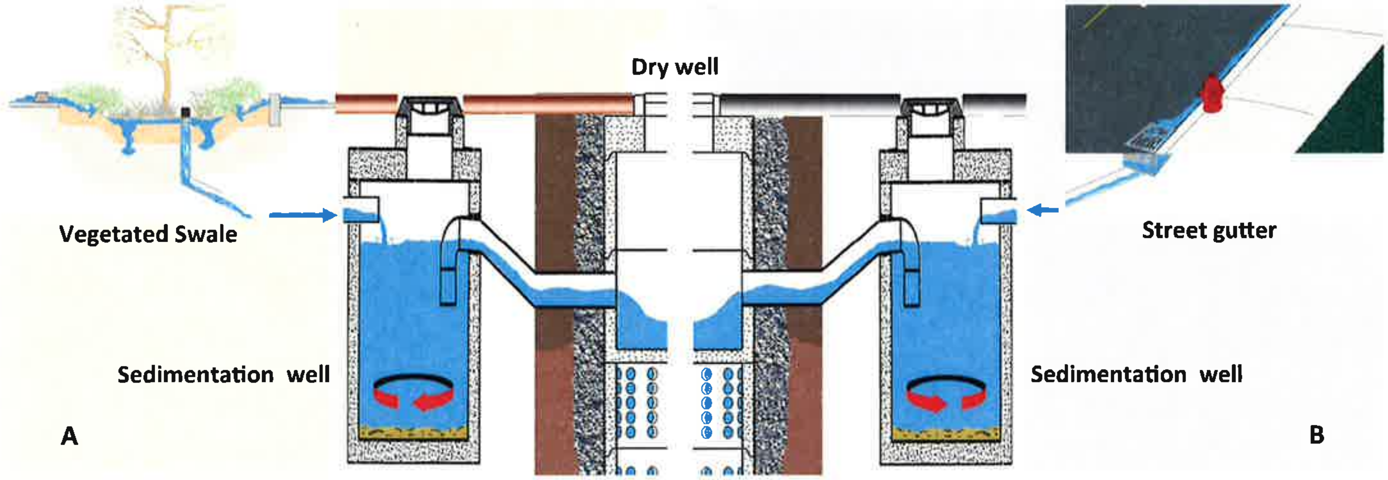


Figure 3. Typical UIC systems used in Oregon. In Oregon, the drywell (center) can extend up to 40 ft. below ground surface, depending on the depth of groundwater. Panel A shows a system more commonly seen in Bend, OR with a vegetated swale collecting stormwater, followed by a sedimentation well, where particulates in the water can settle to the bottom. This promotes an efficient and sustainable system because sediment and associated pollutants are removed as runoff passes through the system. Panel B shows a system commonly seen in Portland. Street gutters collect the stormwater runoff and transport it to the sedimentation well directly. Because Portland receives much more rain than Bend, concentrations of contaminants in stormwater are diluted. This two part UIC has been shown to efficiently remove pollutants from runoff.

Regulations and Permitting

Both public and private UICs must comply with a common set of restrictions. These restrictions affect the placement of UICs, including prohibition of UICs near vehicle maintenance areas and gas and fire stations, as well as within 500 feet of a water supply well. Permit holders must conduct a minimum of two years of stormwater monitoring to verify that run-off entering the UIC does not exceed criteria values. Permittees also must perform groundwater fate and transport modeling to ensure groundwater quality will not be compromised. Lastly, an annual report must be submitted to Oregon DEQ describing the location and monitoring results. If exceedances do occur, source control measures are the first corrective action, followed by retrofitting the UIC to capture the contaminant(s) of concern. If neither is effective, the UIC is decommissioned. There are no requirements for pretreatment, although the majority of UICs include some type of sediment trap (e.g., manhole or swale).

Monitoring Program

The monitoring program in Oregon focuses on analyzing stormwater samples collected after pretreatment, just prior to entering the dry-well (Table 1). Groundwater monitoring is not an active component of Oregon's UIC programs. Instead, vadose zone modeling is used to estimate the migration of contaminants through the subsurface. Portland, for example, monitors a randomly selected set of 30 UICs five times each year. Contaminants that are analyzed include metals, volatile and semi-volatile organics, polycyclic aromatic hydrocarbons, and pesticides/herbicides, as well as others. Owners of private UICs are also responsible for monitoring and ensuring the safety of groundwater. They must identify pollution sources, prevent stormwater pollution from reaching groundwater, and ensure UIC stormwater discharge receives the appropriate pretreatment. Results of the stormwater monitoring suggest that, in almost all cases, pretreated stormwater met federal, state, and local standards .

Analyte	MCL (µg/L)	Exceedances
Antimony	6	1
Arsenic	10	2
Benzo[a]pyrene	0.2	2
Cadmium	5	8
Chromium	100	3
Di(2-ethylhexyl) phthalate (DEHP)	6	30
Lead	50	78
NO3-N	10000	2
Pentachlorophenol	1	79
Zinc	5000	1

Table 1. Number of Exceedances of the Maximum Contaminant Level (MCL) in Stormwater. Over 25,000 runoff samples were collected prior to entering the dry well between 1990-2008 throughout Oregon. Of the 45 analytes tested, 10 exceeded screening levels. Pentachlorophenol, lead, and phthalate were the most common exceedances.

Modeling the Risk of Groundwater Contamination

Each UIC permit holder has to assess the potential risk to groundwater posed by the discharge of urban stormwater into UICs. Part of this process involves using a solute-based, one-dimensional model, known as the Groundwater Protectiveness Demonstration Tool (GWPD), that estimates how much a pollutant's concentration in stormwater will decrease as stormwater flows out of the UIC and infiltrates through the vadose zone to the water table. Physical, chemical, and biological characteristics of both the pollutants and the unsaturated soil are used as input parameters. Porosity, soil moisture content, percent organic carbon, and degradation rate, gathered from literature values for the area, are some of the input parameters (Fig. 4). The pollutants selected for analysis were chosen based on their frequency of detection, mobility, persistence, and toxicity. Because hydrogeological systems are highly complex, scenarios depicting average and worst-case conditions were created.

The values used for the various parameters are conservative. By using a one-dimensional equation for fate and transport, the tool assumes that the stormwater pollutants migrate vertically, whereas lateral movement often predominates, resulting in significant pollutant attenuation. The use of a one-dimensional model both simplifies the calculations as well as assumes a worst-case scenario. Additionally, the pollutant concentrations used in the model were equal to or 10 times higher than those actually measured. Data from Bend and Portland show that modeled pollutant concentrations in stormwater were often 10 to 1000 fold lower than the MCL. Lastly, the GWPD tool input assumes a 5 foot separation distance from the bottom of the UIC and the groundwater. In some cases, the separation distance was 5 feet, but in many others it was as great as 100 feet. Taken together, numerous highly conservative factors have been built into the model to promote protection of groundwater quality.

Modeling results for a variety of locations produced similar findings—even with a 5 foot separation distance and highly permeable geologic material, the great majority of pollutants would be reduced by more than 99% before they reach the water table. There were a few pollutants that commonly varied from this general finding, notably 2,4-D and toluene.

Modeling results can best be understood by examining output from two cities: Bend and Portland. Table 2 summarizes key findings of the modeling efforts worst-case conditions. For each of the measured stormwater concentrations (Col. A), a safety factor was applied (Col. B). The model input concentration represents the theoretical concentration of the contaminant discharged from the UIC (Col. C). Most of these values are equal to 10 times the contaminant's MCL, while others are equal to the MCL. The model output concentration reflects the theoretical contaminant concentration 5 feet below the bottom of the UIC (Col. D). Most concentrations of pollutants would be less than the reporting limit (RL). Notably, for 2,4-D and toluene, the concentrations 5 feet below the UIC were measurable. The percent reduction (Col. E) refers to the change in concentration of each contaminant from samples collected as runoff entered the dry well (immediately after pretreatment) and at 5 feet below the UIC.

In Bend, for example, the concentrations of 2,4-D and toluene were reduced by 44% and 47% respectively. Although their output concentrations were still far below the MCL, the concentrations of these pollutants would actually be attenuated below detection limits within 40 feet of the bottom of the UIC (based on modeling). The majority of UICs in Bend have greater than 100 feet of separation from the water table.

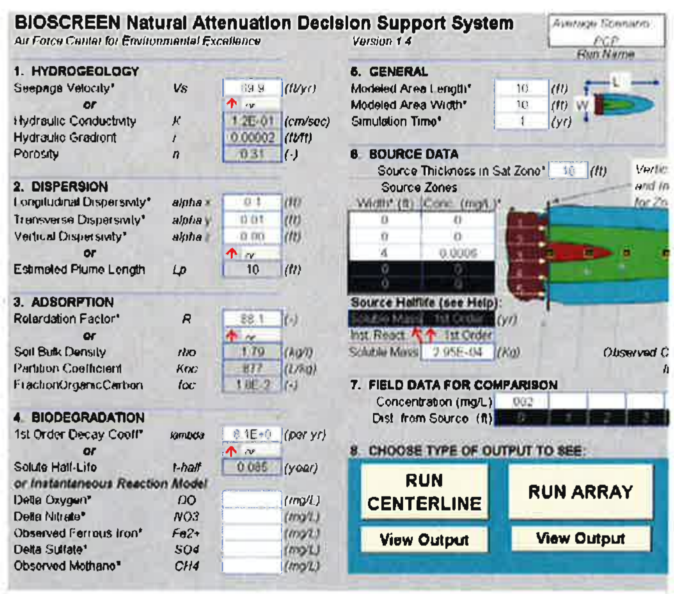


Figure 4. Screenshot of modeling input parameters. This model factors advection, dispersion, adsorption, and aerobic decay into the analysis. It is based on the advection dispersion equation programmed in an Excel spreadsheet. An example is posted at: *http://www.deq.state.or.us/wq/uic/docs/template/ClackamasCoReport.pdf*

		A	B	C	D	E
Analyte	**Study City**	**Estimated Conc. in SW (µg/L)**	**Safety Factor Applied for Modeling**	**Model Input Conc. (µg/L)**	**Model Output Conc. @ 5 ft. below UIC (µg/L)**	**Percent Reduction**
Copper	*Bend*	43.6	30	1300	<RL	100
Lead	*Bend*	10.1	50	500	<RL	100
Benzo(a) pyrene	*Bend*	No Detections	-	2	<RL	100
	Portland	0.02	100	2	<RL	100
Napthalene	*Bend*	No Available Data	-	10	<RL	100
	Portland	0.05	1240	62	<RL	100
PCP	*Bend*	0.05	200	10	<RL	100
	Portland	0.6	17	10	<RL	100
DEHP	*Bend*	0.6	100	60	<RL	100
	Portland	3.8	16	60	<RL	100
2,4-D	*Bend*	No Detections	-	70	39.2	44
	Portland	0.68	1029	700	2.5	99.6
Toluene	*Bend*	2	500	1000	525.7	47
	Portland	2.1	476	1000	76.7	99.2
Methoxychlor	*Portland*	0.1	4000	400	<RL	100

Table 2. Estimated Maximum Concentration of Key Contaminants in the Vadose Zone. The estimated concentration of each contaminant was multiplied by a safety factor in the modeling to account for uncertainty. Bend data represents the mean value over 5 years while Portland data is the 95th upper confidence limit of the mean.

Conclusions

Oregon's UIC Program is a regulatory program designed to oversee the use of UICs for stormwater infiltration. Active UIC programs are found throughout the state: from wet, rainy areas with a high water table, such as Portland and Eugene, to the high desert areas with low amounts of precipitation, such as Bend. Through a combination of monitoring and modeling, the Dept. of Environmental Quality, which oversees these programs, endeavors to protect groundwater resources while benefitting from the value of UICs. Recently, Portland's monitoring data was reviewed by the DEQ and their permit to continue to operate UICs was renewed for another 10 years. Some of the keys to the success of Oregon's UIC programs appear to include both thoughtful UIC design and verification components. The use of a variety of pretreatment facilities, designed to capture pollutant-laden sediment, is a key design feature that has led to the low levels of pollutants entering the UICs. Extensive monitoring of stormwater is performed to ensure it meets regulatory levels. Lastly, the use of a conservative one-dimensional model to estimate subsurface fate and transport of pollutants helps to verify that the handful of pollutants that are not removed by pretreatment will not contaminate the aquifer. The combination of these three program components, as well as other requirements and restrictions, has led to the widespread use of one of the newer low impact development practices - drywells.

OEHHA Note: While Oregon uses the MCL as the criteria for contaminants entering a dry well, other health-related, risk-based criteria might be appropriate for this use.

Useful Links and References

Portland UIC Program Overview
http://www.portlandoregon.gov/bes/48213
City of Portland Underground Injection Controls (UICs) Factsheet
http://www.portlandoregon.gov/bes/article/436258
Groundwater Protectiveness Demonstration Tool
https://www.portlandoregon.gov/bes/article/430383
UIC Management Plan *http://www.portlandoregon.gov/bes/article/250334*

Acknowledgements

Prepared by the Ecotoxicology Program, Office of Environmental Health Hazard Assessment, Cal/EPA. Contributors: A. Ashoor, J. James, A. Bates, & N. Pi; Student Interns; and E. Edwards, Grad. Student, LAWR, UC Davis. Prepared as part of a grant to the City of Elk Grove from the State Water Resources Control Board, Prop. 84 Water Bond Funds. For more information, contact Barbara Washburn, PhD, barbara.washburn@oehha.ca.gov.

ELK GROVE

Appendix 6.2

Guidance Document

City of Elk Grove Dry Well Project

Guidance and Lessons Learned Document

2/28/2017

Guidance and Lesson Learned from the Elk Grove Dry Well Project

The Elk Grove Dry Well Project (project) was a four-year study to investigate the risk of groundwater contamination associated with the use of infiltrating stormwater through dry wells. The project involved a large field component that included the installation of two dry wells with pretreatment and a network of groundwater monitoring wells. The project has two study sites located in Elk Grove, California. The first site was the City of Elk Grove's Corporation Yard, a 0.6-acre parking facility that is a bus fleet servicing area and maintenance yard, and the second site was the Strawberry Detention Basin, a water quality basin that collects stormwater from a 168-acre residential neighborhood.

As part of the project study, stormwater and groundwater samples were collected for two years and analyzed for over 200 contaminants. Estimates of infiltration rates were also made. A companion modeling study of the fate and transport of contaminants through the vadose zone was performed. Scientific and government reports evaluating the risk to groundwater quality associated with dry well use were reviewed and compiled in a literature review (annotated bibliography). Lastly, information from other states with developed dry well programs, often known as underground injection control systems, was summarized in fact sheets with the goal of understanding the regulations, permitting, siting, and design guidelines used elsewhere.

This guidance document summarizes some of the key lessons learned from this work.

1. Siting

The siting of a dry well involves consideration of the land use and types of contaminants that are likely to be associated with any particular land use, the location of other public infrastructure, such as public supply wells, presence of any existing contaminants in the soils, and subsurface lithology. The following are key siting considerations:

- **Avoid sites where hazardous chemicals are used or handled.** It is wise to avoid installing dry wells where hazardous chemicals are used, even if control measures are in place. Stormwater runoff from the Corporation Yard contained very high levels of some metals as well as motor oil. In retrospect this is not surprising given the activities at the site. The washing of buses and their undercarriage, and servicing the vehicles, is likely the source of these contaminants. As a result of finding elevated levels of stormwater contaminants and the challenges of managing runoff at such a busy site, the City of Elk Grove decided to decommission this dry well at the completion of the project. Most other states with developed underground injection control programs, such as Washington and Oregon, do not allow dry wells to be located at vehicle servicing areas, gas stations, and other locations where hazardous chemicals could enter stormwater. They do permit dry wells, however, in the parking lots of such sites if there is no route for the hazardous chemicals to reach the dry well if a spill should occur.
- **Avoid sites where soils are contaminated.** Leaching of hazardous chemicals from soils and entrainment in stormwater runoff also poses a risk. Soils at contaminated sites

require containment and mitigation, making dry well use inappropriate. Although soils at the two project sites in Elk Grove did not contain contaminants, this prohibition is commonly enforced in other states where dry wells are used.

- **Avoid sensitive areas**. It is prudent to avoid placing dry wells near public supply wells, water lines, creeks, and other sensitive areas. In Washington, for example, a 500-foot setback from public supply wells and a 100 foot setback from a domestic well are required. By following these precautions, if contaminants get into a dry well, adjacent infrastructure or natural areas are unlikely to be adversely affected.
- **Land ownership matters**. It is simpler to place dry wells on public lands than on private lands. Oversight of construction, operation and maintenance, and monitoring of influent stormwater can be accomplished more easily if dry wells are sited on public lands such as within the public right of way, in parks, or other public holdings. City or county maintenance staff can oversee dry well maintenance when the dry wells are easily accessible. The long-term concern is proper maintenance and cleaning to prevent clogging with sediment and debris. For example, in Portland, about half of their 20,000 dry wells are located within the public right of way, collecting runoff from sidewalks and streets. However, dry wells have been successfully located on private lands as well. Usually a covenant agreement is required when the development is first constructed that spells out the terms of maintenance and monitoring for these privately owned dry wells. In Oregon and Washington for example, dry wells that only receive roof runoff, from a private home or business, typically containing few or no contaminants, do not require such agreements. For the Elk Grove project, both study sites were located on public lands which facilitated construction oversight, maintenance, and monitoring at odd hours.
- **Use of dry wells in detention basins should be assessed on a case-by-case basis.** Detention basins are not necessarily the ideal location for dry wells. At the Strawberry Detention Basin (water quality basin), the rate of stormwater infiltration through the dry well decreased over the course of the winter, from 46 to 21 gallons per minute. An important factor linked to this decline was saturation of the vadose zone. The rate at which runoff moved through the dry well decreased as the rainy season progress, the water table rose, and presumably the degree of saturation in the vadose zone increased, although this was never directly measured. In contrast, there was not a declining rate of infiltration at the Corporation Yard site, an expansive paved area where the only path for stormwater to enter the subsurface was the single project dry well. However, if a greater amount of sand and gravel, material that can infiltrate large volumes of water, had characterized the lithology at Strawberry Detention Basin, the behavior of the dry well might have been quite different. The subsurface conditions at any prospective dry wells location, including detention basins, is the key factor in assessing if the site is likely to support reliable rates of infiltration throughout the rainy season.
- **Treat clay soils as an asset**. Clay soils are usually viewed as a problem when it comes to infiltrating stormwater. When clay is near the land surface, it acts as a barrier to

infiltration, and is the reason dry wells are needed to obtain meaningful infiltration rates. However, in the vadose zone, clay units serve a valuable function by retarding the movement of contaminants. For the Elk Grove project both dry wells were completed above a clay unit, forcing runoff to leave the dry well through boreholes in the sides and releasing the water above the clay layer. Compared to sand or silt, clay has a very large surface areas (10 m^2/g) and adsorptive capacity. Thus, clay can play a role in attenuating the movement of pollutants, decreasing the risk of groundwater quality degradation. In the state of Washington, this factor is considered when determining required pretreatment. The amount of clay in the vadose zone and the concentration of stormwater pollutants are used to determine the type of pretreatment required for new dry wells.

2. Design and Construction

The design of the dry well system has a major influence on its functionality, especially its ability to capture pollutants and prevent them from entering the subsurface. Pretreatment features, both structural and vegetated, are important design factors. Similarly, in the actual construction of dry wells, it is important to ensure that the plans are implemented as designed and unanticipated issues are properly addressed. This is especially important because dry wells are a relatively new technology in California and many construction contractors do not have significant dry well experience. The following are important design and construction considerations:

- **Pretreatment of stormwater is essential.** Pretreatment can occur in the form of vegetated swales, bioretention cells, or a water quality basin. Structural pretreatment usually refers to a sedimentation well or manhole; usually a deep concrete vault designed to capture sediment. Experiences performing this study as well as information from elsewhere suggests that pretreatment is essential to protect groundwater.
  - ***Vegetated Pretreatment***. Pretreatment for the Elk Grove project consisted of a deep grassy swale at one site and an existing water quality basin at the other site. Both were effective at removing sediment, measured as total suspended solids, from stormwater; approximately 50% removal efficiency was measured for the water quality basin and 65% for the grassy swale at the Corporation Yard. Given that up to 70% of metals and organics in stormwater are found adsorbed to sediment, preventing sediment from entering the dry well not only prevents clogging, but also reduces the pollutant load. Vegetated pretreatment might be especially important to sequester (via foliar absorption) some of the water soluble pesticides such as the neonicotinoid pesticides. This is an area that requires additional research.
  - ***Structural Pretreatment.*** Sedimentation wells/manholes are the main form of structural pretreatment. The sedimentation well design for the Elk Grove project did not function as planned due to design flaws. The 1 – 2 feet of depth beneath the pipe connecting the sedimentation well to the dry well was insufficient to permit sediment to settle. In Portland, their sedimentation manholes are typically 3 feet wide and 10

feet deep. Torrent Resources, who manufactures and installs dry wells in the western United States, designs their sedimentation wells about 15 feet deep. Unfortunately, when the design of the sedimentation well was developed at the beginning of the project, the team lacked this information. Torrent Resources[1] has estimated that their system, composed of two sedimentation wells, with the dry well housed within the second, removes about 90% of particulates. Given the Elk Grove team's experience with vegetated pretreatment, which removed about 55-60% of suspended sediment, a rough estimate was made that a properly design sedimentation well could remove an additional 30% of suspended sediments. Structural pretreatment is the primary means of removing sediment and associated pollutants in major cities such as Phoenix, Arizona and Portland, Oregon. Monitoring in Portland, in particular, has shown that their sedimentation manholes remove the large majority of metals and organic contaminants, such as polycyclic aromatic hydrocarbons, from stormwater runoff.

- **A minimum vertical separation from the water table should be maintained.** Other states often use a10-foot vertical separation distance between the bottom of the dry well and the seasonal high water table as a benchmark. In some cases, the distances are as small as 5 feet or less. The depth of the water table is an important factor to consider in siting and constructing a dry well to permit a minimum amount of pollutant attenuation. In some circumstances, the water table might be so high that dry wells might not be useful. In other cases, the depth of the dry well might need to be reduced to account for shallower depths of the water table.
- **Dry well construction requires careful management.** The use of highly-engineered dry wells is relatively new in California and as such, there is not an abundance of experienced consultants and construction contractors. Some experienced design/build firms do exist. However, should a local construction contractor be selected to perform the installation of dry well system, careful oversight of the project is essential to avoid future problems. Problems were experienced with dry well construction in the Elk Grove project that required removing 5 feet of sand from the dry well and replacing it with the correct ratio of sand to gravel as indicated in the design plans. The contractor did not follow the design details, which lead to stormwater flows and infiltration being impeded. More careful oversight could have avoided this problem.
- **Dry wells should be constructed with a shut off valve.** The dry wells used in the project were designed with a shut off valve that was placed in the pipe connecting the sedimentation well and the dry well that could stop flow into the dry well in an emergency. This valve could be used if a chemical spill occurred, if a large amount of debris generated from a large storm might clog the well, or other unexpected circumstance developed. In the Elk Grove project, the shut off valve was used a few times when large amounts of debris were entrained in stormwater runoff. If dry wells were constructed in the public right of way, and should an accident occur, emergency

[1] References to Torrent Resources do not constitute an endorsement of their products or services.

responder would be able to prevent chemicals from entering the system by closing the valve.

3. Monitoring

- **Stormwater entering the dry well should be monitored**. The only way to know if contaminants are entering the dry well at a level that may pose a risk to groundwater quality is to test the stormwater entering the well. In the Elk Grove project, monitoring was performed at the first flush of the rainy season, and multiple times during the water year. Over 200 contaminants were evaluated in the classes of volatile and semi-volatile organics, herbicides, pyrethroid pesticides, metals, and general mineral and physical parameters. In Oregon, sites that are considered 'low-risk', newly installed wells are monitored twice a year for the first two years, then yearly thereafter. In Portland, however, where the city owns 9000 dry wells, wells at 15 fixed sites and 15 rotating sites are monitored six times per year for a set of priority pollutants. If the concentration exceeds their criteria value, usually the Maximum Contaminant Levels (MCL), a series of control steps are taken that include reducing or eliminating the source of the contaminant, adding additional pretreatment, or in the worst cases, decommissioning the dry well. Based on the experience gained from this project, the contaminants that appeared to warrant regular monitoring would include metals, a small list of semi-volatile organics, pyrethroid pesticides, and total suspended solids. In addition, pesticides which are increasing in use, especially those that are more water soluble than pyrethroids, should be included, specifically imidacloprid and fipronil.
- **Groundwater quality should primarily be evaluated with appropriate vadose zone modeling.** Extensive groundwater monitoring was performed as part of the Elk Grove project. Most of the well samples showed no evidence of contaminants, except for arsenic and chromium, which are naturally occurring. Vadose zone modeling that was also performed helped to explain the reason for the lack of detections. Most pollutants would not reach the water table at detectible levels for many years, decades, or, in some cases, centuries. Exceptions to this general rule were water soluble pesticides such as imidacloprid. Given these facts, and the expense of performing groundwater monitoring, regular groundwater monitoring from a network of wells does not appear to be a useful investment. Instead, limited groundwater monitoring, using a small number of strategically placed wells, could serve as a safeguard. As required in Oregon, vadose zone modeling can serve as useful alternative that can provide valuable information on the fate and transport of contaminants that might have entered the dry well. One dimensional vadose zone modeling can be performed with either a spreadsheet or the open source software Hydrus. University of California at Davis hydrologists is preparing guidance on the methods for performing this analysis.

4. Regulatory Issues

- **Dry well permitting and use varies widely in California**. Significant effort was invested in obtaining permits to install the two dry wells used in this project. The construction of the dry wells had to be modified to meet certain requirements applied to water wells. This experience reflects on the broader issue of the different regulatory environments in California. In Southern California, over 10,000 dry wells have been installed. Permitting is handled at the local level, where specific conditions of construction and management are agreed upon with the contractor. In contrast, in Northern California, relatively few dry wells have been constructed. The regulatory climate is much more cautious than in the Los Angeles/San Diego area, likely due to the differences in the water resources. In the Sacramento region, the County permits dry wells as water wells, following the guidelines of Department of Water Resources (DWR) Bulletin 74-81 and 74-90. This bulletin identifies stormwater as a waste product and dry wells as one type of well to which water well standards apply. While permitting in Northern California serves as a barrier to using dry well technology, in Southern California, the interpretation of DWR's bulletins does not hinder permitting and construction. Requirements for construction and maintenance are applied in a piecemeal fashion in California. The need for state oversight of a dry well program to establish consistent standards for construction, siting, design, and maintenance is clear.

Conclusions

The Elk Grove dry well project team learned valuable lessons about dry well siting, design, construction, overcoming permitting challenges, and the value of stormwater and groundwater monitoring and modeling that have been summarized above. Additionally, the practices followed in neighboring states, all of which have had wide-reaching underground injection control programs in existence for over a decade, have been reviewed. The conclusions drawn from the Elk Grove project are consistent with many of the practices in other states: that is, dry wells can be safely used to manage urban runoff and recharge the aquifer when appropriate safeguards are in place through siting, design and maintenance.

Guidance and Lesson Learned from the Elk Grove Dry Well Project

The Elk Grove Dry Well Project (project) was a four-year study to investigate the risk of groundwater contamination associated with the use of infiltrating stormwater through dry wells. The project involved a large field component that included the installation of two dry wells with pretreatment and a network of groundwater monitoring wells. The project has two study sites located in Elk Grove, California. The first site was the City of Elk Grove's Corporation Yard, a 0.6-acre parking facility that is a bus fleet servicing area and maintenance yard, and the second site was the Strawberry Detention Basin, a water quality basin that collects stormwater from a 168-acre residential neighborhood.

As part of the project study, stormwater and groundwater samples were collected for two years and analyzed for over 200 contaminants. Estimates of infiltration rates were also made. A companion modeling study of the fate and transport of contaminants through the vadose zone was performed. Scientific and government reports evaluating the risk to groundwater quality associated with dry well use were reviewed and compiled in a literature review (annotated bibliography). Lastly, information from other states with developed dry well programs, often known as underground injection control systems, was summarized in fact sheets with the goal of understanding the regulations, permitting, siting, and design guidelines used elsewhere.

This guidance document summarizes some of the key lessons learned from this work.

1. Siting

The siting of a dry well involves consideration of the land use and types of contaminants that are likely to be associated with any particular land use, the location of other public infrastructure, such as public supply wells, presence of any existing contaminants in the soils, and subsurface lithology. The following are key siting considerations:

- **Avoid sites where hazardous chemicals are used or handled.** It is wise to avoid installing dry wells where hazardous chemicals are used, even if control measures are in place. Stormwater runoff from the Corporation Yard contained very high levels of some metals as well as motor oil. In retrospect this is not surprising given the activities at the site. The washing of buses and their undercarriage, and servicing the vehicles, is likely the source of these contaminants. As a result of finding elevated levels of stormwater contaminants and the challenges of managing runoff at such a busy site, the City of Elk Grove decided to decommission this dry well at the completion of the project. Most other states with developed underground injection control programs, such as Washington and Oregon, do not allow dry wells to be located at vehicle servicing areas, gas stations, and other locations where hazardous chemicals could enter stormwater. They do permit dry wells, however, in the parking lots of such sites if there is no route for the hazardous chemicals to reach the dry well if a spill should occur.
- **Avoid sites where soils are contaminated.** Leaching of hazardous chemicals from soils and entrainment in stormwater runoff also poses a risk. Soils at contaminated sites

require containment and mitigation, making dry well use inappropriate. Although soils at the two project sites in Elk Grove did not contain contaminants, this prohibition is commonly enforced in other states where dry wells are used.

- **Avoid sensitive areas.** It is prudent to avoid placing dry wells near public supply wells, water lines, creeks, and other sensitive areas. In Washington, for example, a 500-foot setback from public supply wells and a 100 foot setback from a domestic well are required. By following these precautions, if contaminants get into a dry well, adjacent infrastructure or natural areas are unlikely to be adversely affected.
- **Land ownership matters.** It is simpler to place dry wells on public lands than on private lands. Oversight of construction, operation and maintenance, and monitoring of influent stormwater can be accomplished more easily if dry wells are sited on public lands such as within the public right of way, in parks, or other public holdings. City or county maintenance staff can oversee dry well maintenance when the dry wells are easily accessible. The long-term concern is proper maintenance and cleaning to prevent clogging with sediment and debris. For example, in Portland, about half of their 20,000 dry wells are located within the public right of way, collecting runoff from sidewalks and streets. However, dry wells have been successfully located on private lands as well. Usually a covenant agreement is required when the development is first constructed that spells out the terms of maintenance and monitoring for these privately owned dry wells. In Oregon and Washington for example, dry wells that only receive roof runoff, from a private home or business, typically containing few or no contaminants, do not require such agreements. For the Elk Grove project, both study sites were located on public lands which facilitated construction oversight, maintenance, and monitoring at odd hours.
- **Use of dry wells in detention basins should be assessed on a case-by-case basis.** Detention basins are not necessarily the ideal location for dry wells. At the Strawberry Detention Basin (water quality basin), the rate of stormwater infiltration through the dry well decreased over the course of the winter, from 46 to 21 gallons per minute. An important factor linked to this decline was saturation of the vadose zone. The rate at which runoff moved through the dry well decreased as the rainy season progress, the water table rose, and presumably the degree of saturation in the vadose zone increased, although this was never directly measured. In contrast, there was not a declining rate of infiltration at the Corporation Yard site, an expansive paved area where the only path for stormwater to enter the subsurface was the single project dry well. However, if a greater amount of sand and gravel, material that can infiltrate large volumes of water, had characterized the lithology at Strawberry Detention Basin, the behavior of the dry well might have been quite different. The subsurface conditions at any prospective dry wells location, including detention basins, is the key factor in assessing if the site is likely to support reliable rates of infiltration throughout the rainy season.
- **Treat clay soils as an asset.** Clay soils are usually viewed as a problem when it comes to infiltrating stormwater. When clay is near the land surface, it acts as a barrier to

infiltration, and is the reason dry wells are needed to obtain meaningful infiltration rates. However, in the vadose zone, clay units serve a valuable function by retarding the movement of contaminants. For the Elk Grove project both dry wells were completed above a clay unit, forcing runoff to leave the dry well through boreholes in the sides and releasing the water above the clay layer. Compared to sand or silt, clay has a very large surface areas (10 m^2/g) and adsorptive capacity. Thus, clay can play a role in attenuating the movement of pollutants, decreasing the risk of groundwater quality degradation. In the state of Washington, this factor is considered when determining required pretreatment. The amount of clay in the vadose zone and the concentration of stormwater pollutants are used to determine the type of pretreatment required for new dry wells.

2. Design and Construction

The design of the dry well system has a major influence on its functionality, especially its ability to capture pollutants and prevent them from entering the subsurface. Pretreatment features, both structural and vegetated, are important design factors. Similarly, in the actual construction of dry wells, it is important to ensure that the plans are implemented as designed and unanticipated issues are properly addressed. This is especially important because dry wells are a relatively new technology in California and many construction contractors do not have significant dry well experience. The following are important design and construction considerations:

- **Pretreatment of stormwater is essential.** Pretreatment can occur in the form of vegetated swales, bioretention cells, or a water quality basin. Structural pretreatment usually refers to a sedimentation well or manhole; usually a deep concrete vault designed to capture sediment. Experiences performing this study as well as information from elsewhere suggests that pretreatment is essential to protect groundwater.
    - ***Vegetated Pretreatment***. Pretreatment for the Elk Grove project consisted of a deep grassy swale at one site and an existing water quality basin at the other site. Both were effective at removing sediment, measured as total suspended solids, from stormwater; approximately 50% removal efficiency was measured for the water quality basin and 65% for the grassy swale at the Corporation Yard. Given that up to 70% of metals and organics in stormwater are found adsorbed to sediment, preventing sediment from entering the dry well not only prevents clogging, but also reduces the pollutant load. Vegetated pretreatment might be especially important to sequester (via foliar absorption) some of the water soluble pesticides such as the neonicotinoid pesticides. This is an area that requires additional research.
    - ***Structural Pretreatment.*** Sedimentation wells/manholes are the main form of structural pretreatment. The sedimentation well design for the Elk Grove project did not function as planned due to design flaws. The 1 – 2 feet of depth beneath the pipe connecting the sedimentation well to the dry well was insufficient to permit sediment to settle. In Portland, their sedimentation manholes are typically 3 feet wide and 10

feet deep. Torrent Resources, who manufactures and installs dry wells in the western United States, designs their sedimentation wells about 15 feet deep. Unfortunately, when the design of the sedimentation well was developed at the beginning of the project, the team lacked this information. Torrent Resources[1] has estimated that their system, composed of two sedimentation wells, with the dry well housed within the second, removes about 90% of particulates. Given the Elk Grove team's experience with vegetated pretreatment, which removed about 55-60% of suspended sediment, a rough estimate was made that a properly design sedimentation well could remove an additional 30% of suspended sediments. Structural pretreatment is the primary means of removing sediment and associated pollutants in major cities such as Phoenix, Arizona and Portland, Oregon. Monitoring in Portland, in particular, has shown that their sedimentation manholes remove the large majority of metals and organic contaminants, such as polycyclic aromatic hydrocarbons, from stormwater runoff.

- **A minimum vertical separation from the water table should be maintained.** Other states often use a10-foot vertical separation distance between the bottom of the dry well and the seasonal high water table as a benchmark. In some cases, the distances are as small as 5 feet or less. The depth of the water table is an important factor to consider in siting and constructing a dry well to permit a minimum amount of pollutant attenuation. In some circumstances, the water table might be so high that dry wells might not be useful. In other cases, the depth of the dry well might need to be reduced to account for shallower depths of the water table.
- **Dry well construction requires careful management.** The use of highly-engineered dry wells is relatively new in California and as such, there is not an abundance of experienced consultants and construction contractors. Some experienced design/build firms do exist. However, should a local construction contractor be selected to perform the installation of dry well system, careful oversight of the project is essential to avoid future problems. Problems were experienced with dry well construction in the Elk Grove project that required removing 5 feet of sand from the dry well and replacing it with the correct ratio of sand to gravel as indicated in the design plans. The contractor did not follow the design details, which lead to stormwater flows and infiltration being impeded. More careful oversight could have avoided this problem.
- **Dry wells should be constructed with a shut off valve.** The dry wells used in the project were designed with a shut off valve that was placed in the pipe connecting the sedimentation well and the dry well that could stop flow into the dry well in an emergency. This valve could be used if a chemical spill occurred, if a large amount of debris generated from a large storm might clog the well, or other unexpected circumstance developed. In the Elk Grove project, the shut off valve was used a few times when large amounts of debris were entrained in stormwater runoff. If dry wells were constructed in the public right of way, and should an accident occur, emergency

[1] References to Torrent Resources do not constitute an endorsement of their products or services.

responder would be able to prevent chemicals from entering the system by closing the valve.

3. Monitoring

- **Stormwater entering the dry well should be monitored.** The only way to know if contaminants are entering the dry well at a level that may pose a risk to groundwater quality is to test the stormwater entering the well. In the Elk Grove project, monitoring was performed at the first flush of the rainy season, and multiple times during the water year. Over 200 contaminants were evaluated in the classes of volatile and semi-volatile organics, herbicides, pyrethroid pesticides, metals, and general mineral and physical parameters. In Oregon, sites that are considered 'low-risk', newly installed wells are monitored twice a year for the first two years, then yearly thereafter. In Portland, however, where the city owns 9000 dry wells, wells at 15 fixed sites and 15 rotating sites are monitored six times per year for a set of priority pollutants. If the concentration exceeds their criteria value, usually the Maximum Contaminant Levels (MCL), a series of control steps are taken that include reducing or eliminating the source of the contaminant, adding additional pretreatment, or in the worst cases, decommissioning the dry well. Based on the experience gained from this project, the contaminants that appeared to warrant regular monitoring would include metals, a small list of semi-volatile organics, pyrethroid pesticides, and total suspended solids. In addition, pesticides which are increasing in use, especially those that are more water soluble than pyrethroids, should be included, specifically imidacloprid and fipronil.
- **Groundwater quality should primarily be evaluated with appropriate vadose zone modeling.** Extensive groundwater monitoring was performed as part of the Elk Grove project. Most of the well samples showed no evidence of contaminants, except for arsenic and chromium, which are naturally occurring. Vadose zone modeling that was also performed helped to explain the reason for the lack of detections. Most pollutants would not reach the water table at detectible levels for many years, decades, or, in some cases, centuries. Exceptions to this general rule were water soluble pesticides such as imidacloprid. Given these facts, and the expense of performing groundwater monitoring, regular groundwater monitoring from a network of wells does not appear to be a useful investment. Instead, limited groundwater monitoring, using a small number of strategically placed wells, could serve as a safeguard. As required in Oregon, vadose zone modeling can serve as useful alternative that can provide valuable information on the fate and transport of contaminants that might have entered the dry well. One dimensional vadose zone modeling can be performed with either a spreadsheet or the open source software Hydrus. University of California at Davis hydrologists is preparing guidance on the methods for performing this analysis.

4. Regulatory Issues

- **Dry well permitting and use varies widely in California.** Significant effort was invested in obtaining permits to install the two dry wells used in this project. The construction of the dry wells had to be modified to meet certain requirements applied to water wells. This experience reflects on the broader issue of the different regulatory environments in California. In Southern California, over 10,000 dry wells have been installed. Permitting is handled at the local level, where specific conditions of construction and management are agreed upon with the contractor. In contrast, in Northern California, relatively few dry wells have been constructed. The regulatory climate is much more cautious than in the Los Angeles/San Diego area, likely due to the differences in the water resources. In the Sacramento region, the County permits dry wells as water wells, following the guidelines of Department of Water Resources (DWR) Bulletin 74-81 and 74-90. This bulletin identifies stormwater as a waste product and dry wells as one type of well to which water well standards apply. While permitting in Northern California serves as a barrier to using dry well technology, in Southern California, the interpretation of DWR's bulletins does not hinder permitting and construction. Requirements for construction and maintenance are applied in a piecemeal fashion in California. The need for state oversight of a dry well program to establish consistent standards for construction, siting, design, and maintenance is clear.

Conclusions

The Elk Grove dry well project team learned valuable lessons about dry well siting, design, construction, overcoming permitting challenges, and the value of stormwater and groundwater monitoring and modeling that have been summarized above. Additionally, the practices followed in neighboring states, all of which have had wide-reaching underground injection control programs in existence for over a decade, have been reviewed. The conclusions drawn from the Elk Grove project are consistent with many of the practices in other states: that is, dry wells can be safely used to manage urban runoff and recharge the aquifer when appropriate safeguards are in place through siting, design and maintenance.

Appendix 6.3

Website Tracking Report

http://www.elkgrovecity.org
www.elkgrovecity.org

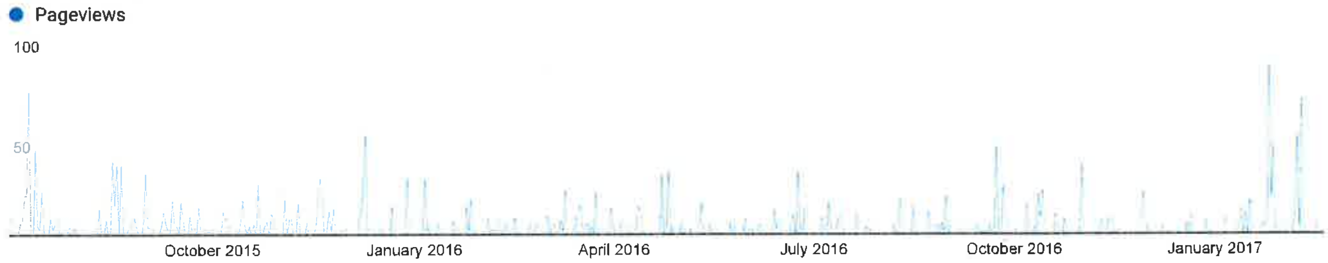
GO TO REPORT

Page Tracking

Jul 1, 2015 - Feb 20, 2017

All Users
100.00% Sessions

Dry Well



Dry Well Pageviews and Unique Pageviews by Page

Page	Pageviews	Unique Pageviews
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/	498	296
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/elk_grove_dry_well_project/	426	207
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/project_factsheets__presentations_and_documents/	304	140
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/all_about_dry_wells/what_is_a_dry_well_/	209	162
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/project_team/	203	165
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/elk_grove_dry_well_project/project_stormwater_and_groundwater_monitoring/	168	132
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/all_about_dry_wells/	145	81
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/all_about_dry_wells/links_to_more_information_about_dry_wells/	139	101
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/elk_grove_dry_well_project/project_design/	135	96
/city_hall/departments_divisions/public_works/dry_well_project___prop_84/elk_grove_dry_well_project/about_the_project/	133	116

Total 2,360

Appendix 6.4

Presentations and Poster Sessions (Handout Format)

Presentation 1: The Risk of Groundwater Quality Degradation from the Use of Dry wells: What We Know Today?

California Environmental Health Association 61st Annual Educational Symposium, Department of Pesticide Regulations Seminar

April 4, 2012

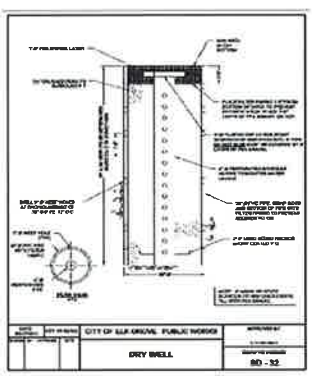
THE RISK OF GROUNDWATER QUALITY DEGRADATION FROM THE USE OF DRY WELLS: WHAT WE KNOW TODAY

A. ASHOOR, N. PI & B. WASHBURN
OFFICE OF ENVIRONMENTAL HEALTH HAZARD ASSESSMENT
CAL/EPA

CEHA, APRIL 4, 2012

OUTLINE

- Why are drywells an issue of concern today?
  - Background on stormwater management issues; low impact development practices; drywells.
- Common pollutants in stormwater
- Major studies of the use of infiltration practices and the results
  - Los Angeles Water Augmentation Study
  - USGS Modesto Study
- Regulation/guidelines relevant to drywells
- Climate change
- Conclusions

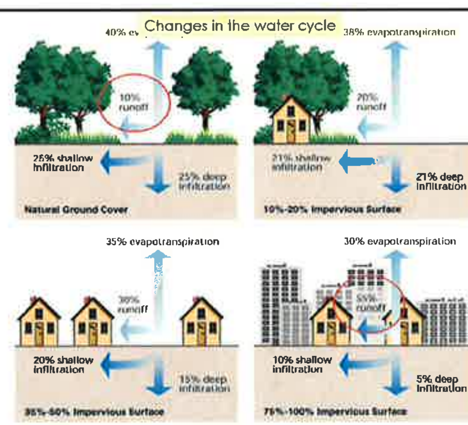


STORMWATER MANAGEMENT

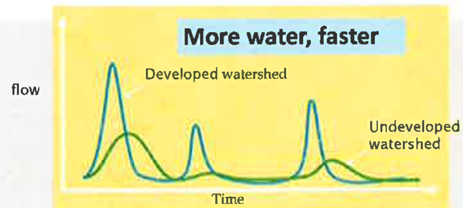
MODERN PRACTICES & THE NEED FOR NEW TOOLS

CHANGES IN STORMWATER MANAGEMENT PRACTICES

- Historically, stormwater = a problem
  - Solution: get rid of it asap
  - Results: a system of grey infrastructure that has greatly altered ecological resources
- Today, stormwater = resource
  - Multiple benefits, including water to support aquatic life and recharge aquifer (drinking water)
  - Results: low impact development management practices
    - Drywells are one of the LID tools
- Begin with a look at the past......................



The hydrograph: pre & post development



The urban hydrograph:
- Increases flow rates
- Increases runoff volume
- Increases the number of runoff events
- Increases in long-term flow duration

= **Hydromodification**

Consequences of too much water and insufficient sediment on aquatic habitat

- Change in the physical structure of waterways


Natural, non-urban


Urban, highly altered

Consequences of hydromodification: alters aquatic habitat & reduces aquatic life

- Increased % fines sediment in streambed
- Reduced oxygen
- Reduced diversity of bugs
- Death of salmon fish eggs/babies


Healthy assortment of bugs

Low biodiversity associated with degraded conditions

Reproductive success of salmon is jeopardized

Water quality effects of hydromodifcation

- Increases in pesticides in waterway, today...pyrethroids
- Increases in metals such as copper and zinc
- Increases in PAHs
- Increases in turbidity
- Increases in trash
- Legacy contaminants: PCBs, DDT & other chlorinated pesticides
- Multiple violations of the Clean Water Act

The contemporary approach to stormwater management: Low Impact Development (LID)

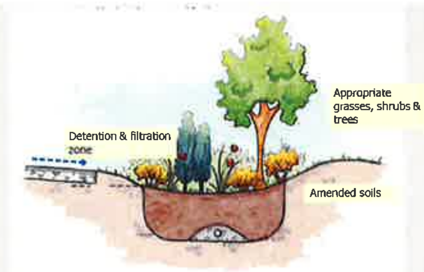
- LID = set of practices that promote capturing runoff at its source through a variety of *infiltration* methods.
- Benefit: Flows in waterways not altered; pollutants do not reach aquatic habitat.

BASIC PRINCIPLES OF LID

1. Work with natural topography and soil types to protect high infiltration areas and natural drainage patterns.
2. Maintain site runoff rate post development to mimic actual hydrograph. Accomplished by using a variety of infiltration practices.
3. Implement pollution prevention, proper maintenance and public education programs.

Can be as simple as disconnecting the downspouts from the stormdrain system

BIORETENTION CELLS OR RAIN GARDENS



NATIONAL POLLUTION DISCHARGE ELIMINATION SYSTEM (NPDES) PERMITS & LID

- Clean Water Act: mandates a system of permits for release of stormwater into waterbodies
  - Require management of stormwater to protect beneficial uses of water (recreation, aquatic life, fishability, etc.)
- Local jurisdictions responsible for implementation and oversight of permit requirements
- Currently, requirements being rolled out to implement hydromodification management and low impact development practices.
  - LID is becoming part of statewide regulations.

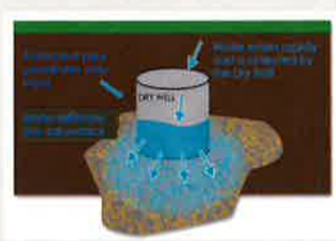
CHALLENGE TO IMPLEMENTATION OF HYDROMODIFICATION REQUIREMENTS AND LID

- Many places have soils with poor infiltration rate (e.g. Central Valley)
- Stormwater created faster than the soil can absorb it!
- Bioretention doesn't operate efficiently

Soil Type	Texture	Infiltration Rate
A	Sand, loamy sand	> 0.3"/hr
B	Silt loam or loam	0.15 - 0.3"/hr
C	Sandy clay loam	0.05 - 0.15"/hr
D	Clay loam, silty clay, sandy clay	0 - 0.05"/hr (about 1/32")

CHALLENGE: HOW TO MIMIC NATURAL HYDROGRAPH IN POORLY INFILTRATING SOILS?

- **Dry wells**
- They can increase infiltration rate, but questions have been raised about their safety.



STORMWATER QUALITY AND HIGH RISK POLLUTANTS

POTENTIAL IMPACTS ON GROUNDWATER

ARE THERE RISKS TO GROUNDWATER QUALITY WITH USE OF DRYWELLS?

- Reason for concern
  - Drywells allow stormwater to bypass treatment in upper (highly aerobic) portions of the soil
    - Microbes degrade many organic compounds
    - Plants bind many metals
  - Question raised by stormwater engineers and environmental management professionals....
    - Is there enough info to know if use of drywells is safe?
    - How are drywells regulated?
- **The remainder of this presentation will focus on these questions.**

STORMWATER CONTAMINANTS WITH GREATEST LIKELIHOOD OF CONTAMINATING GROUNDWATER

- **Key criteria:**
  - High mobility in sub-soil (vadose zone)
  - High concentration in stormwater
  - High soluble fractions (low % associated with particles)
- **Key contaminants that meet these criteria:**
  - Nitrates - most frequently encountered contaminants
  - Some pesticides – especially a problem with sandy soils without a hardpan layer
  - Phthalates – plasticizers used to soften rubber
  - Viruses - due to small size and resistance to degradation
  - Zinc (most mobile of metals), nickel, and copper (ubiquitous)

Pitt et al., 1999, Urban Water 1: 217-236

COMMON CONTAMINANTS IN STORMWATER: METALS

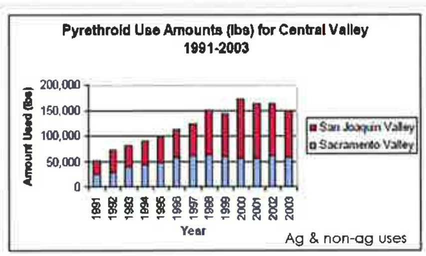
Toxicant	Highest observed location	Conc. (ppb)
Cadmium	Street runoff	220
Chromium	Roof runoff	510
Copper	Street runoff	1250
Lead	Storage area runoff	350
Nickel	Landscaped area runoff	130
Zinc	Roof runoff	1580

http://unix.eng.ua.edu/~rpitt/
Pitt, Clark, and Parmer, 1994, Potential Groundwaer Contamination from intentional and nonintentional stormwater infiltration.

CONTAMINANTS IN STORMWATER: ORGANICS

Toxicant	Maximum (ppb)	Detection frequency	Significant sources
PAHs	60-300	12-23%	Coal tar sealers, asphalt, wood preservative
Pyrene	102	19%	Combustion byproducts
Phthalate	128	13%	Plasticizers in hoses, etc.
1,3-dichlorobenzene	120	23	pesticide

PESTICIDES IN STORMWATER: PYRETHROIDS COMMONLY FOUND IN CALIFORNIA WATERWAYS



http://www.nwp.usace.army.mil/docs/d_sediment/papers/pyrethroids_final.pdf

STUDIES OF DRYWELLS AND OTHER LID INFILTRATION PRACTICES

KEY STUDIES: LOS ANGELES & MODESTO

Los Angeles Water Augmentation Study

- Part of a ten year study by the Los Angeles and San Gabriel Rivers Watershed Council, in conjunction with numerous partners, including:
  - City of Los Angeles Department of Water and Power
  - Metropolitan Water District of Southern California
  - United States Bureau of Reclamation
- Overall goal: Assesses feasibility of the capture and infiltration of stormwater as a means of augmenting local water supplies
- ***Specific Goal: Assess effects of infiltrating stormwater on groundwater quality***

Project Goals

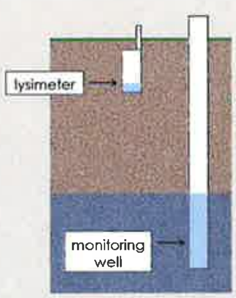
- Assess various infiltration practices:
  - Drywells
  - Vegetated swales
  - Vegetated strips
  - Bioretention areas
- Assess most favorable geographic, geologic, and hydrologic conditions for infiltration

Site Overview

- Six sites selected representing a diversity of land uses
  - A school
  - Office building
  - Residence
  - Two industrial sites
  - Public Park
- Drywells installed at:
  - Office building
  - Private residence

Lysimeters and Monitoring Wells

- Samples collected to determine water quality in areas below ground surface
- Lysimeters
  - Water samples from soil pore spaces in unsaturated zone of soil below ground surface
- Monitoring Wells
  - Water samples from aquifer



Site Overview – Office Building

- LID Practices
  - Roof drain to drywell
  - Sheetflow to landscaped strip
- 31 foot depth to groundwater
- Slow infiltration rate soils
- Monitoring wells and lysimeters installed

Site Overview – Private Residence

- LID Practices
  - Roof drain to landscaping
  - Sheetflow to driveway drywell
- 200 foot depth to GW
- Slow-moderate infiltrating soils
- Lysimeters installed

Monitoring Program

- Stormwater samples taken during storm events for 5 years
- Post-storm samples taken from lysimeters and monitoring wells
- Used soil moisture sensors to determine infiltration rates and sampling lag times
- Samples analyzed for:
  - General monitoring parameters
  - Metals
  - Oil, grease, and perchlorate
  - Volatile and semi-volatile organic compounds
  - Bacteria

Constituent List

General
- Carbon, Dissolved Organic
- Nitrogen, Organic
- Ammonia-Nitrogen
- pH

Metals

Volatile Organic Compounds
- Methyl Bromide
- BTEX
- MTBE
- DIPE
- ETBE
- TAME
- TBA
- Ethanol
- TCE
- PCE
- Disinfection Byproducts (THMs)
- 1,2,3-TCP
- 2,4-D

Semi-Volatile Organic Compounds

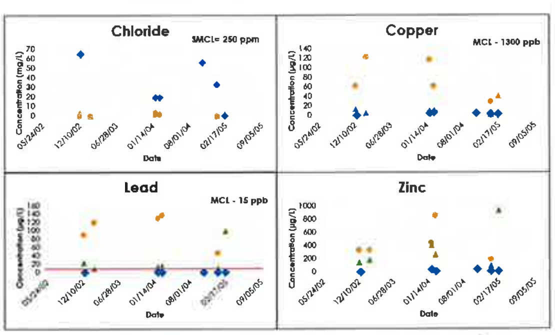
Biological Parameters
- Heterotrophic Plate Count
- Total Coliform
- Fecal Coliform
- E. coli

Other Constituents
- Oil and Grease
- Perchlorate
- N-Nitrosodimethylamine (NDMA)
- Glyphosate
- 1,4-Dioxane
- 1,2-Dibromo-3-chloropropane (DBCP)

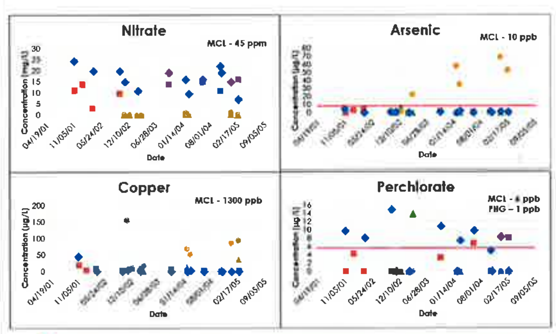
Constituents of Concern in Stormwater at Drywell Sites

- Detected at high levels:
  - Suspended solids
  - Aluminum
  - Arsenic
  - Chromium
  - Copper
  - Lead
  - Zinc
  - Acetone
  - Total coliform

Results – Private Residence



Results – Office Building



Results

- Office building
  - Volatile or semi-volatile organics rarely detect in GW and SW; mainly no detects
  - Trivial amounts of total coliform (<0.8%) of concentration in SW was found in groundwater
  - Most metals not detected in groundwater, although present in SW
    - Exception: zinc
  - Perchlorate present in both 1 SW sample and >10 GW samples collected before and after detection in SW
    - As high as 14 ppb in GW, above MCL of 6 ppb; draft PHG = 1 ppb
    - Since present in only a single SW sample, GW detection not associated with SW

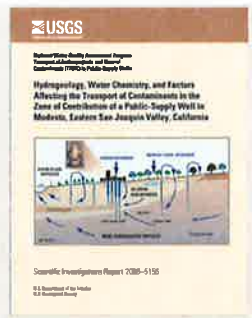
Overall Results

Constituents	Private Residence	Office Building
Chloride and Nitrate	High levels in GW	
Metals	High levels in SW Few detects in GW	
Oil and grease	High levels from driveway ND – low levels in GW	
Perchlorate	No detects SW or GW	One SW detections Numerous GW detections
Volatile and Semi-Volatile Organic Compounds	No consistent sources in SW ND – low levels in GW	
Bacteria	ND in soil pore water or GW	

Conclusions

- Data collected shows that there is no statistically significant degradation of groundwater quality from the infiltration of stormwater at either site
  - No evidence of groundwater contamination from stormwater infiltration at drywell sites
- Sites with shallow groundwater saw some improvement in groundwater quality for most constituents
  - Infiltration of relatively high quality stormwater can improve groundwater conditions

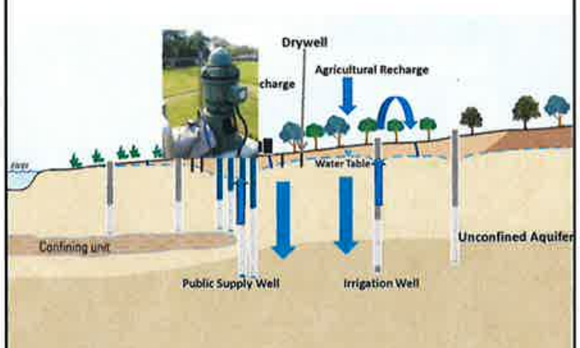
Drywell impact on drinking water: The USGS study in Modesto

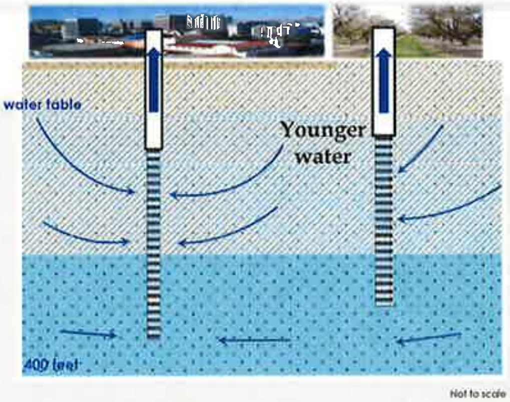


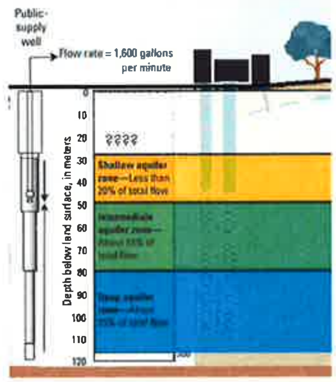
Background of Study

- In 2002, the USGS began studies of contaminants affecting public-supply wells in Modesto, California.
- Previous studies suggest long term agricultural development and more recent urbanization resulted in increased levels of natural and anthropogenic contaminants in the aquifer
- Goal of study: Determine whether and how contaminants entered the Modesto public supply wells
- Relevance of study for our purposes: Long term use of drywells in Modesto. Detection of potential effects on groundwater quality.







USGS Modesto Study

Study Design

- **Depth of monitoring wells**
  - ***Water-table wells:*** Within 5 meters of the water table.
  - ***Shallow wells:*** Represent the chemistry of the groundwater below the water table down to 50 meters
  - ***Intermediate wells:*** Represent the chemistry of groundwater between 50 and 70 meters.
  - ***Deep wells:*** Represent the chemistry of groundwater below 70 meters.
- **Overlaying Land Use**
  - ***Urban***: Residential and commercial land along
  - ***Agricultural:*** Farmed land
  - ***Recently Urban***: Land that had been agricultural within the last 10 to 20 years, but has been or is being currently developed

Water Chemistry Analysis

- Conventional water parameters
  - pH, dissolved oxygen, major ions, water age
- Gasoline related compounds (BTEX)
  - Benzene, toluene, ethylbenzene, xylenes
- Pesticides
  - About a dozen pesticides including simazine and atrazine
- Volatile organic compounds
- Refrigerants

Results: Pesticides Detected in Monitoring Wells

	Pesticides									
	2-Chloro-4-isopropylamino-6-amin-s-triazine	Simazine	Atrazine	Prometon	3,4-Dichloroaniline	Penda-methalin	Metolachlor	Diazinon	Dieldrin	DCPA
# of wells with detection	[illegible]	9	8	2	2	1	1	1	1	1
Water table & Shallow	9	9	7	2	2	1	1	1	1	1
Intermediate	[illegible]	0	1	0	0	0	0	0	0	0
Deep	[illegible]	0	0	0	0	0	0	0	0	0
Max Detect	0.096	0.108	0.059	0.01	0.015	0.014	0.004	0.006	0.006	0.002
MCL (ug/L, ppb)	na	4	1	na	na	na	na	na	na	na

Results: volatile organic compound detected in monitoring wells

Two problems detected:

- Nitrate
  - Likely associated with agriculture
  - Exceeded MCL
- Uranium
  - Naturally occurring, mobilized by urban inputs ($NaHCO_3$, etc.)
  - Exceeded MCL
- In both cases, shallow aquifer reflected higher concentrations of contaminants than deeper levels

Nilrate concentration at various siles

Monitoring well	FPA	FPB	FPE	OFPA	SA	SB	SC
Water table	1.49	3.15	1.77	3.1	2.4	6.46	11.1
Shallow	11.8	ns	12.9	12.5	ns	ns	ns
Intermediate	3.02	3.96	5.58	4.42	ns	ns	ns
Deep	2.39	1.02	ns	ns	ns	ns	ns

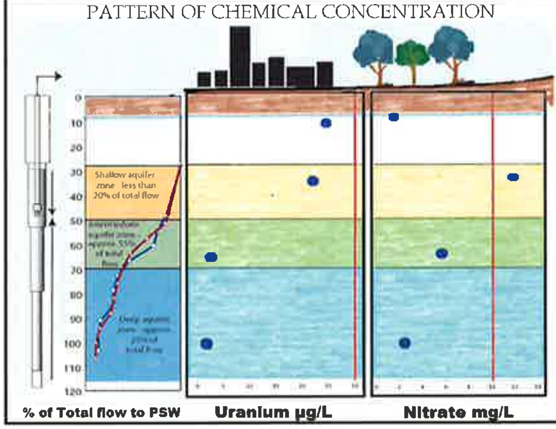
MCL = 10 ppb

Uranium concentrations al various sites

Monitoring well	FPA	FPB	FPE	OFPA	SA	SB	SC
Water table	24.5	11.1	4.76	24.9	29.9	32.2	28.5
Shallow	21.5	ns	21.5	45.3	ns	ns	ns
Intermediate	2.56	6.57	4.33	3.74	ns	ns	ns
Deep	1.52	0.32	ns	ns	ns	ns	ns

MCL = 30 ppb

Pattern of chemical concentration



Results & conclusions

- Younger water in shallow zones more susceptible to contamination
  - Primarily influenced by agriculture
  - Scant evidence of typical urban contaminants
- Water in deep zones had no anthropogenic contaminants
- Even with high levels of contaminants in shallow and intermediate zone, the public supply well water quality met drinking water standards
- Caveat: not all common stormwater contaminants evaluated, ie., pyrethroids, PAHs, copper, zinc.

Conclusions from LA and Modesto studies

- No evidence for contaminants associated with urban runoff in aquifer at a level of concern (near the MCL).
- Need for further studies to investigate pesticides and other pollutants not included in these studies.

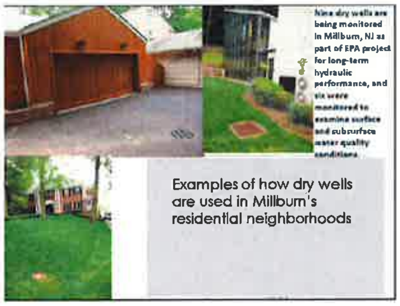
Study of groundwater recharge benefits of drywells

(Robert Pitt, U. Alabama)

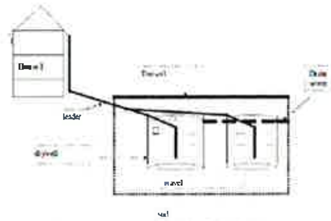
Millburn, NJ

Dry well disposal of stormwater for groundwater recharge in conjunction with irrigation beneficial use

- For the past several years, the city of Millburn has required dry wells to infiltrate increased flows from newly developed areas.
- There are some underground water storage tanks now being installed to use stormwater for irrigation.
- Our current project, supported by the Wet Weather Flow Research Program of the US EPA, is investigating the performance of this shallow groundwater recharge (including groundwater contamination potential) in conjunction with irrigation beneficial uses of the stormwater.



Schematic of Millburn Dry Wells



Monitoring water quality 2 ft. below dry wells

- Monitoring occurred after 10 rain events (0.1-9 inches, median 0.15 inches)
- Three drywells monitored and 1 cistern
  - Total N, total P04,, chemical oxygen demand, copper, lead, zinc, e.coli for all events
  - Herbicides/legacy pesticides (not pyrethroids) for 1 event
  - Results from 2 drywells no different
  - Exceedances of New Jersey standards: bacterial and lead

General conclusions from study

- No difference between stormwater and water collected 2 feet below dry well.
  - Only roof runoff should be passed through drywell
- Raingardens best suits for collection of driveway and road runoff
- Use of cisterns permits irrigation use of stormwater
- Unclear what quality of water would be 10,20, 50 feet below drywell. Look to Modesto study for answers.

Regulations

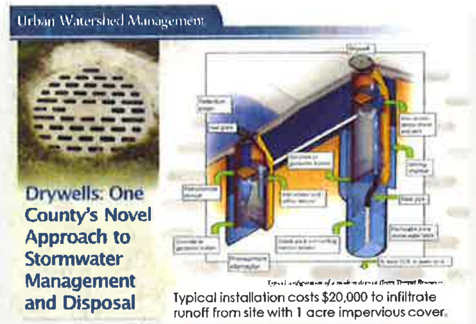
Regulations pertaining to drywells in California and elsewhere

- Examples from other states
- Examples from cities within California
- Water Board's Anti-degradation policy
- US EPA Underground Injection Wells

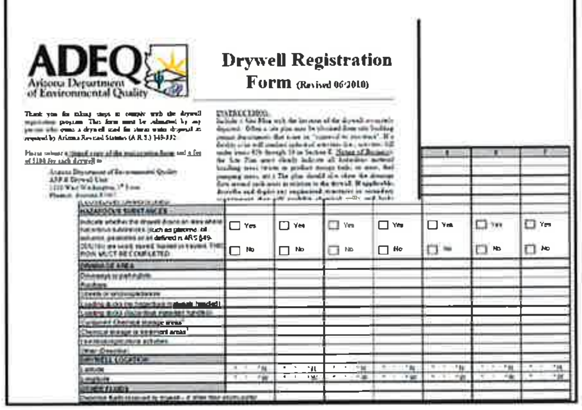
How does our neighbor, Arizona, manage drywells?

- History – Maricopa County/Phoenix
  - Simple rock wells used since 1930s as major stormwater management practice
  - 1970s – required use of LID to retain stormwater onsite
  - 1987 – Formal regulation of drywells, established Aquifer Protection Program
    - License drywell installers
    - Drywell registration for all, permits required in specific situations
  - 2008 – 40,500+ registered drywells in Arizona, 3000+ new ones/yearly
  - Depth: Median = 20 feet (19-120 ft)

Design of drywells in Arizona



Southwest Hydrology, Jan/Feb, 2010



Dry well guidelines – Los Angeles County

- Standard Urban Stormwater Mitigation Plan (SUSMP)
  - Drywells requirements
    - 3-4 feet minimum space between drywell bottom and seasonal high water table
    - Surface grate should be a minimum 3 inches above landscaped retention basin to facilitate settling of sediment
    - Screening to retain larger debris
    - Use of hydrophobic petrochemical absorbent
- No individual dry well permits are issued

Dry wells guidelines – Los Angeles County

US EPA Groundwater Injection Program

- Drywells classified as Class V groundwater injection wells
  - Deeper than wider
  - Used to inject non-hazardous fluids underground.
- Registration of new drywells (online) recommended
- BMPs for drywells: http://www.epa.gov/ogwdw/uic/class5/pdf/page_uic-class5_storm_water_bmps.pdf

California's Anti-degradation Policy

- Restricts degradation of surface and ground water
  - Policy protects water bodies where existing quality is higher than necessary for the protection of beneficial uses
- Any waste producing activities which discharge to existing high quality waters will meet waste discharge requirements to assure
  - A pollution or nuisance will not occur,
  - Discharge does not unreasonably affect present and anticipated beneficial use of the water,
  - Highest water quality consistent with the maximum benefit to the people will be maintained
- Any plans that may affect surface waters are subject to the Federal Anti-degradation Policy
- **Unclear at this point how this policy will be applied to drywells**

http://www.waterboards.ca.gov/water_issues/programs/nps/encyclopedia/0a_laws_policy.shtml; http://water.epa.gov/scitech/swguidance/standards/wqslibrary/ca_9_68_16.cfm

Drywells and Climate Change

- Some have suggested that drywells might be one solution to the expected shortages of water associated with climate change
  - More precipitation as rain not snow
  - Limited capacity to store rain behind system of dams along western slope of Sierras
  - Some experts have hypothesized that a large system of drywells could recharge the aquifer in Central Valley and elsewhere, thereby protecting drinking water sources.

Take Home: Preliminary Conclusions

- No evidence from studies performed so far that dry wells contribute to groundwater quality degradation
  - Could be an cost-effective tool in the LID toolbox
  - Benefits
    - Protection of surface water and aquatic habitat
    - Recharge aquifer (need quantification for most places)
- Use of dry wells might be considered on a site by site basis. Factors to consider
  - Soil characteristics
  - Depth to groundwater
  - Hydrology of aquifer
- Need for statewide guidance on design criteria and siting.
- Need to fill in data gaps on fate and transport of certain metals and pyrethroids

Source of Useful Information on Stormwater Quality

- National Stormwater Quality Database, 2004
- http://rpitt.eng.ua.edu/Research/ms4
  - Covers a wide variety of potential contaminants
- www.oehha.ca.gov
  - Ecotoxicology
    - Annotated bibliography
    - New Jersey study
    - Links to useful websites

Thank You

Contact info:

Drywell / Groundwater Quality Project staff:

- Barbara Washburn,
  barbara.washburn@oehha.ca.gov
- Ary Ashoor
  ary.ashoor@oehha.ca.gov
- Nelson Pi
  nelson.pi@oehha.ca.gov

Presentation 2: Dry Wells and Groundwater Quality

State Water Resources Control Board, Division of Water Quality – Statewide Meeting

April 25, 2013

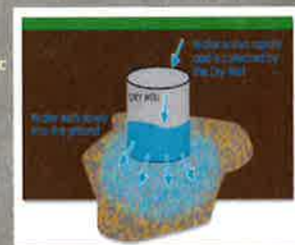
Dry Wells and Groundwater Quality

C. Bowles[1], M. Carr[1], F. Duenas[2], V. Kretsinger[3], C. Meirovitz[1], C. Nelson[2], N. Pi[4], B. Washburn[4], D. Wilson[2]

- [1] cbec eco engineering: surface water hydrology
- [2] City of Elk Grove & Willdan: Project recipient, stormwater engineering
- [3] Luhdorff & Scalmanini: groundwater hydrology
- [4] Office of Environmental Health Hazard Assessment: aquatic toxicology; QA/QC

Basis for interest in dry wells: Identify tools to protect aquatic ecosystem in the face of urbanization

- LID Goal
  - Mimic natural hydrology
  - Reduce damage to aquatic ecosystem
- Challenge
  - Achieving infiltration in clay soils
- One solution: dry wells
  - Increase infiltration rate
  - Questions about risk to groundwater quality



Dry Wells

- Gravity fed excavated pits lined with perforated casing filled with gravel
- Can be used in conjunction with LID systems to improve rate of stormwater infiltration

Dry Wells

Uses, Regulations, and Guidelines in California and Elsewhere

Dry Well Description and Use

U.S. Environmental Protection Agency (EPA) - Region 9 Regulations

Outline

- The issue
- Dry Well Regulations & Guidelines CA & Elsewhere
- Key studies
  - Los Angeles – Water Augmentation Study
  - Modesto – USGS
- Prop. 84 Dry Well Project

EPA Recommendations

- Class V injection wells (deeper than wider)
- Subject to US EPA Underground Injection Control regulations
  - Register dry wells if serves > 1 house
  - Only infiltrate uncontaminated stormwater
- Website contains a list of recommendations for appropriate uses (http://water.epa.gov/type/groundwater/uic/class5/index.cfm)
  - Constructed more than 10 ft above the seasonal high water table
  - Use pre-treatment

Use of Dry Wells in California

- Not widely used in California
  - Concerns about groundwater quality
  - Unclear how State regulations apply to dry wells
- Falls under California's Porter-Cologne Act and anti-degradation policy
- California DWR regulations, Bulletin 74
  - "Prevent surface water from entering injection wells"
  - Contradicts the purpose of dry wells (infiltration of stormwater)
- No uniform guidelines or regulations in California

Key studies of dry wells and groundwater contamination risks

In Other Places

- Thirteen states have dry well regulations
  - New Jersey
    - Guidelines and specifications, infiltrates roof runoff at new residential developments
  - Arizona
    - Registration required, payment of fee, design guidelines
  - Portland
    - Guidelines, permit required except if input is only from rooftops
  - Washington
    - Guidance on design, siting, contaminants of risk, treatment by vadose zone, distance from water table, etc.

Impacts of Dry Wells on Drinking Water Quality in Modesto

Summary of Arizona's Management of Dry Wells

Arizona dry well requirements	CA dry well regulations
Must be registered with AZ Dept of Envir. Quality. Fee must be paid	Regional Board can prescribe discharge requirements for injection wells
Requires Aquifer Protection Permit and approval by DEQ prior to construction	No direct requirements
Requires information on design, pollutant characteristics, and closure strategy	Region Boards may require a report of discharge. No formal statewide process.
A general permit covers facilities that have obtained a NPDES permit and have a stormwater pollution prevention plan in place.	Requirements may vary by region and municipality.

Background on Modesto

- Over 11,000 dry wells since the 1950s
- 1985 - PCE spill at Halford's Cleaners contaminated groundwater detected
  - Associated with defective dry cleaning machines
  - PCE entered leaking sewer line
- Public supply well 11 contaminated

Background on Modesto

- Superfund site late 1990s
- Clean up & monitoring...... 2000+
- Some made the linkage: dry wells = groundwater contamination?
  - US EPA reports: no association
  - Conduit for PCE: sanitary sewer lines, not dry wells

Water Chemistry Analysis

- Conventional water parameters
  - pH, dissolved oxygen, major ions, water age
- Gasoline related compounds (BTEX)
  - Benzene, toluene, ethylbenzene, xylenes
- Pesticides
  - About a dozen pesticides including chlorinated forms, simazine and atrazine
- Volatile organic compounds
  - Chloroform, PCE, TCE, ethyl benzene, xylene, etc.
- Refrigerants

USGS Study

- Study goal
  - Determine whether and how contaminants might enter drinking water supply wells.
- Relevance of study for our purposes
  - Given long history of dry well use – assess **long term** potential risks to groundwater quality.

Brief Summary of Results

- Younger water (shallow depths) more susceptible to contamination
  - Mainly agriculture influences, e.g. nitrate
  - Some evidence of typical urban contaminants, but below MCLs
- Older water (deep zones)
  - No anthropogenic contaminants
  - Uranium and arsenic contamination

Study Design

- Analyzed water quality from 1 drinking water well
- Series of monitoring wells at various depths
  - Water table – up to 38 ft.
  - Shallow zone – 115 ft.
  - Intermediate zone – 200 ft.
  - Deep zone – 300 + ft.
- Monitoring wells along a gradient of agricultural and urban land uses as well as groundwater gradient

Summary of Monitoring Well Detections of Selected Pesticides

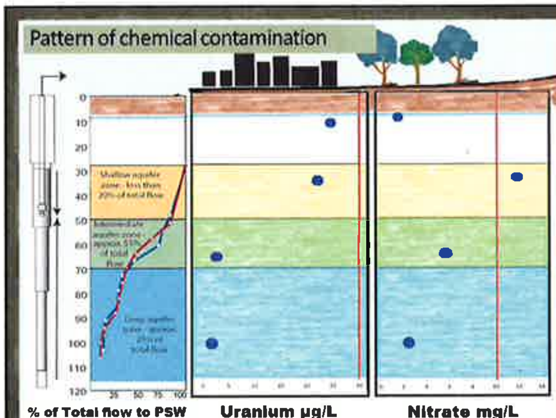
All units ppb	Triazine	Simazine	Atrazine	Metola-chlor	Diazinon	Dieldrin
Detection Freq.	39	39	35	4	4	4
Median	0.0079	0.028	0.013	0.004	0.006	0.006
Max. Conc.	0.096	0.108	0.059	0.006	0.006	0.006
MCL	n/a	4	1	3.5*	0.007*	0.002*
MCL/Max Conc.	-	40	16	580	1	0.3

* US EPA health advisory drinking water equivalent level, guidance values, non-cancer health effects

Summary of Monitoring Well Detections of Selected Volatile Organics

All units ppb	Chloroform	PCE	Ethyl benzene	Xylene
Detection Freq. (%)	61	26	13	4
Median	0.1423	0.08	0.02	0.02
Max. Conc.	3.534	1.21	0.02	0.02
MCL	80	5	1000	600
MCL/Max. Conc.	23	4	50,000	30,000

Los Angeles Water Augmentation Study



Background

- Ten year study by the Los Angeles and San Gabriel Rivers Watershed Council (Council on Watershed Health) and partners
  - City of Los Angeles Department of Water and Power
  - Metropolitan Water District of Southern California
  - United States Bureau of Reclamation
- Overall goal
  - Assesses feasibility of the capture and infiltration of stormwater to augment local water supply (reduce dependency in imported water)
- *One specific goal*
  - *Assess effects of infiltrating stormwater on groundwater quality*

Main Message from USGS Study

- No contaminants associated with urban runoff near the MCL in public supply well water
  - Some urban contaminants present in shallow aquifer

Study Sites Overview

- Six sites - diversity of land uses
  - School
  - Office building
  - Residence
  - Two industrial sites
  - Public park
- Dry wells installed at:
  - Office building
  - Private residence

Office Building

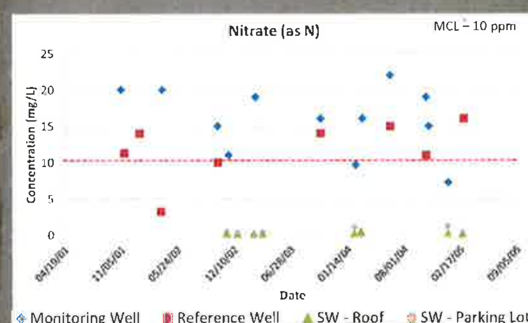
- Roof runoff drained to dry well
- 31 ft. depth to water table
- Poorly infiltrating soils
- Monitoring wells and lysimeters (monitors pore water in vadose zone) installed

Summary of Results – Los Angeles Study

- Contaminants detected at high levels in groundwater were at low levels in SW
- Contaminants at high levels in stormwater were at low levels in GW

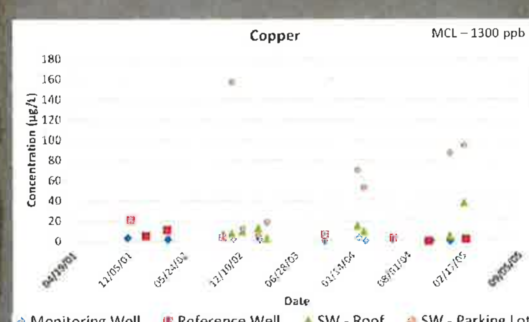
Private Residence

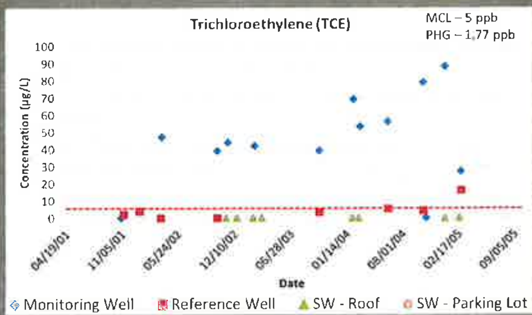
- Driveway sheet flow to dry well
- 200 ft. depth to water table
- Slow-moderate infiltrating soils
- Lysimeters installed



Monitoring Program

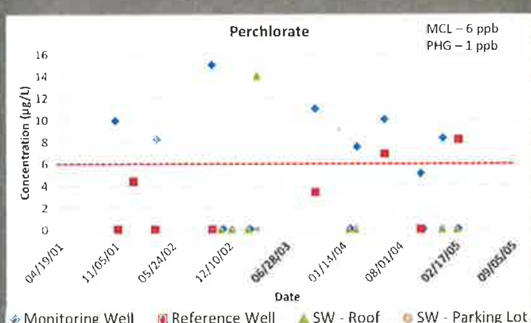
- Stormwater samples taken during storm events for 3-4 years
- Post-storm samples taken from lysimeters and monitoring wells
- Endpoints
  - General physical & chemical
  - Metals
  - Oil, grease, and vehicle-related contaminants
  - Volatile and semi-volatile organic compounds
  - Bacteria





Limitation of Studies

- Los Angeles – Water Augmentation Study
  - Samples not tested for some contaminants: pesticides in current use
  - Monitoring wells not installed at all sites
  - Some monitoring wells up-gradient of dry well
- USGS – Modesto Study
  - Samples not tested for some important stormwater contaminants: metals, pyrethroids, PAHs
  - Limited stormwater analysis



Prop. 84 Dry Well Project

Summary of Results – Los Angeles Study

- Contaminants detected at high levels in groundwater were at low levels in SW
- Contaminants at high levels in stormwater were at low levels in GW

Background

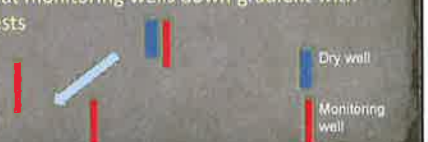
- Main purpose: Assess risk, if any, of groundwater contamination associated with use of dry wells
  - Secondary: Assess role of pre-treatment
- Dry wells with associated monitoring wells
- Different land uses: roadway, residential, commercial/light industrial
  - Location: Elk Grove
  - Pre-treatment: grassy/vegetated swales/rain garden

Data Analysis

- Assess changes in GW constituents over time
- Assess contaminant removal efficiency over time
  - Swales (solids, pyrethroids)
  - Dry wells & vadose zone (all contaminants)
- Determine if any contaminants exceed MCL or PHG

Dry Well System Design

- Dry wells installed at a depth to:
  - Promote infiltration into more pervious soil layers
  - Use vadose zone for some treatment
- Monitoring well clusters around the dry wells to detect contaminants
  - Verify that monitoring wells down gradient with tracer tests



Deliverables

- Factsheets
  - Summary of guidelines & regulations
  - Key findings of the project
- Annotated bibliography
- Education & Outreach
  - Scientific paper
  - Presentations
  - Outreach to school near sampling site
- Summary of Project Experiences (Guidance Manual)
  - Design of dry wells
  - Effectiveness/design of pre-treatment
- Results entered into CEDEN and GAMA
- Website with all products and general information

Monitoring Plan

- Stormwater and groundwater samples collected over a period of two years
  - Three wet weather stormwater samples
    - TSS & pyrethroids at beginning and end of swale/rain garden
  - Three wet and one dry weather monitoring well samples
- Constituents to be tested
  - General physical & chemical
  - Metals (EPA 200)
  - Semi-volatiles (EPA 625)
  - Herbicides (EPA 515)
  - Pyrethroids (WPCL, DFW method)
  - TPH (EPA 8015)
  - Pyrogenic PAHs (EPA 8310)
  - Total coliform

Take Home Thoughts

- Back to the beginning
  - LID offers stormwater management option that protect valuable aquatic resources
  - Dry wells could be a useful tool in the LID tool box
  - Could increase options for groundwater recharge
  - Could reduce flood risk at low cost
- Results from this study and companion study in L.A. will help fill in data gaps to support
  - Development of sound, science-based policies for California
  - Help local municipalities make wise decisions regarding siting/use of dry wells

Thank you

- Contacts
  - Project director: Darren Wilson
    dwilson@elkgrovecity.org
  - Project manager: Connie Nelson
    cnelson@elkgrovecity.org
  - Toxicology/QA officer: Barbara Washburn
    barbara.washburn@oehha.ca.gov
  - Surface water hydrology: Chris Bowles
    c.bowles@cbecoeng.com
  - Groundwater hydrology: Casey Meirovitz
    cmeirovitz@lsce.com

Presentation 3: TAC Kick-off Meeting

1. Proposition 84 Stormwater Grant Program – An In Depth Look at Next Steps
2. Separating Fact from Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds (Project Overview and TAC Roles and Responsibilities)
3. Pretreatment Features – Project Sites

City of Elk Grove and TAC Members

June 25, 2013

PROPOSITION 84 STORMWATER GRANT PROGRAM

An In-Depth Look at the Next Steps

April 4, 2013

Water Boards

Roles of GM, PA, and PD

- Grant Agreement between State Water Board and Grantee (City of Elk Grove)
  - State Water Board does not have agreements with contractors or cooperating agencies
  - The GM should only have one representative contacting them concerning the project.

Introductions

- Grant Manager Background
  - Started at State in March 2008
  - BS in Geology from CSU Sacramento in 2003
  - Previous experience:
    - Student at: DTSC and Region 5
    - Environmental Company
    - Geotechnical Engineering Firm
    - State Water Board

Grant Manager (GM) Roles

- Site Visits and Field Reports
- Keeps State Water Board's records and is Grantee's main contact
- Keeps grant on schedule
- Review, comment, and/or accept reports and work products as required in agreement
- Review and approves invoice

Important Due Dates

- Start Dates
- Critical Due Dates
- Estimated Due Dates
- Work Completion Date
- Final Invoice Date

Program Analyst's (PA's) Role

- Reviews invoice
- Creates project-specific tracking spreadsheet for expenditures
- Track expenditures
- Ensure reimbursement is not over 90% of the grant dollars
- Process approved invoices
- Prepares/Processes amendments

Project Director's (PD's) Role

- Maintains schedule per negotiated time lines
- Keep lines of communication open with GM
- Prepare and submit invoices and reports
- Grantee maintains auditable file for 35 years
- Ensure tasks listed in grant are completed as specified

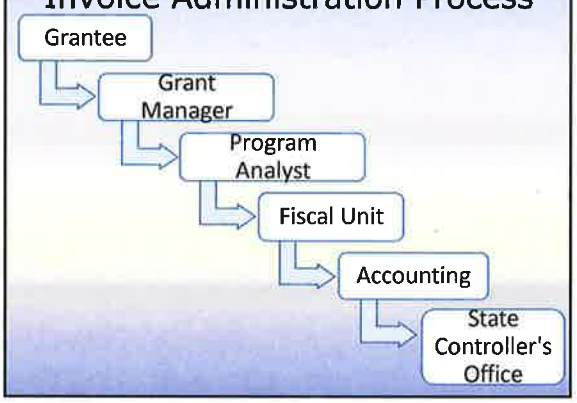
Invoice Formatting

- PA provides Excel file Invoice Template
- Invoices will have names, addresses, and the dollar amounts filled out
- **<u>GM will not accept any other invoice template for reimbursement and will reject any other version of the invoice</u>**

Auditable File – 35 Years

- Application
- *State Water Board Resolution & Approved Funding List*
- Grantee Resolution
- Amendments, Deviations, Reductions, & Extensions
- Significant Correspondence/Notes
- Invoices
- Backup documentation to support all project costs (reimbursed and match)
- Deliverables

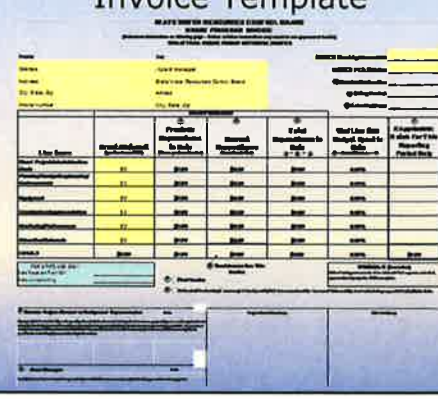
Invoice Administration Process



Invoice Due Dates

- Invoices are due on GM's desk 45-days following end of quarter – **CAN BE EARLIER!!**
- Your accounting department should already be working on 1st invoice
- Late invoices may trigger a Breach of Agreement

Invoice Template



Supporting Documentation

- Invoice Submittal Summary Sheet
- Receipts
- Grantee Labor Certification Form
- Progress Report
- Other Deliverables

Progress Reports

- Used to document progression of project
- Supports expenditures invoiced
- Submitted quarterly
- Provides description of work performed, accomplishments/setbacks during reporting period, and milestones
- Must be sent with quarterly invoice

Common Invoice Mistakes

- Lack of supporting documentation
- Incorrect calculations on invoice
- Incorrect roll-over amounts from previous invoice
- **Lack of organization**
- Asking for reimbursement or match on items that do not pertain to project
- **Poor Progress Reports**
- Overhead/Indirect Charges

Project Assessment and Evaluation Plans (PAEPs)

- Provides framework for assessment and evaluation of project performance
- Identifies measures to monitor progress
- Provides a tool to monitor and measure progress and guide final project performance
- Provide info to help improve current and future projects
- To maximize value of public expenditures

Invoice Disputes

- Will be sent via e-mail
- Stops "clock" on payment of invoice
- "Clock" does not restart until revised invoice or documentation received by GM
- Takes few hours to a few days to address issues in dispute

CEQA

- Provide electronic copy
- State Water Board must develop its own independent CEQA findings for every funded project
- Project cannot begin without State Water Board clearance

Questions?

Welcome

CITY OF ELK GROVE

PROUD HERITAGE BRIGHT FUTURE

Technical Advisory Committee Members

1.	Annalisa Kihara, PE, Water Resource Control Engineer, Stormwater Unit	State Water Resources Control Board, Division of Water Quality
2.	Dana Booth, PG, QSD, Program Manager, Stormwater Quality	Sacramento County Department of Water Resources and Sacramento Stormwater Quality Partnership
3.	Darrell Eck, Senior Civil Engineer	Water Supply Planning and Development Sacramento County Water Agency
4.	Genevieve Sparks, Environmental Scientist	Central Valley Regional Water Quality Control Board, Stormwater MS4 Program
5.	John Borkovich, P.G., GAMA Program Manager, QA/QC	State Water Resources Control Board, Division of Water Quality
6.	Julie Haas, PE, Senior Engineer	California Department of Water Resources, Division of Integrated Regional Water Management
7.	Mark Madison, General Manager	Elk Grove Water
8.	Paul Marshall, P.G.	Laguna Creek Watershed Council
9.	Rob Swartz, PG, CHG	Regional Water Authority, Sacramento Groundwater Authority
10.	Susan Williams, M.S.	Sacramento County Environmental Health Department, Well Program – Permitting & Enforcement, Environmental Compliance Division
11.	Elaine Khan, PhD	Chief Water Toxicology Section, Office of Environmental Health Hazard Assessment (OEHHA)

Separating Fact from Fiction:

Assessing the Use of Dry Wells to Reduce Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds

ELK GROVE

WILLDAN

cbec

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

Background

- Proposition 84 Stormwater Grant Program
- Applied for grant January 2012
- Awarded grant June 2012
- Received grant funding amount $489,820
- Match of in-kind services
  - City of Elk Grove $110,000
  - OEHHA $140,000
- Total project cost $740,349
- Grant term 3-years (ends April 2016)
- Convene a TAC

Project Team

Darren Wilson, P.E., Project Director[1]
Connie Nelson, CFM, Project Manager[2]
Fernando Duenas, P.E., Design Manager[2]
Barbara Washburn, PhD, QA/QC[3]
Casey Meirovitz, P.G., Consultant[4]
Scott Lewis, P.G., Consultant[4]
John Fawcett, P.E. Consultant[4]
Chris Bowles, PhD, P.E., Consultant[5]
Melanie Carr, P.E., Consultant[5]
Nelson Pi, M.S. Consultant[5]

[1] *City of Elk Grove: Project Director and grant recipient*
[2] *Willdan Engineering: Project management and dry well design*
[3] *Office of Environmental Health Hazard Assessment: aquatic toxicology*
[4] *Ludhorff & Scalmanini Consulting Engineering: groundwater hydrology and monitoring well design*
[5] *cbec eco-engineering: surface water hydrology and vegetated swale design*

Meeting Outline

- TAC Roles and Responsibilities
- Ground Rules
- Project Purpose
- Project Goals
- Proposed Project
- Monitoring Plan
- 60% Design Plans

TAC'S Roles and Responsibilities

Convene a TAC of experts in groundwater protection, stormwater management and environmental protection to provide feedback and oversight of the Project

Attend kick-off meeting; and provide feedback on Monitoring Plan and dry well and monitoring wells 60% design[1]	June 25, 2013
Review and provide feedback on 90% design[2]	June 26, 2013
Attend meeting and review results of first year of monitoring[1]	October 2014
Review and provide feedback on fact sheets •Dry Well Fact Sheet[2] •Project Results Fact Sheet[2]	 August 2013 November 2015
Attend meeting and review Project results and interpretation[1]	November 2015
Review and provide feedback on *draft* scientific paper[2]	November 2015
Attend presentation on Project results[3]	December 2015

[1] Attend meetings in person or conference call
[3] Attend presentations or webinar.
[2] Review and provide feedback through email.

Project Purpose

Evaluate the potential for using dry wells, in combination with low impact development practices, to infiltrate stormwater runoff, alleviate localized flooding, and recharge groundwater without negatively impacting groundwater quality

Ground Rules

1. Attendance
Attendance is important to the continuity of the group. Members should make every attempt to attend in person. Topics covered in one TAC meeting will not be revisited in subsequent meetings for members that were absent in meeting they missed.

2. Honor Time
We have an ambitious Project schedule and agenda. In order to meet our Project goals it will be important to follow the strict Project timelines given by the Project Director/ Manager.

3. Decision Making
The TAC will operate as a consensus seeking body that provides oversight and technical advice for the Project. All comments and suggestions may be considered.

4. Use Common Conversational Courtesy
Don't interrupt; use appropriate language, no third party discussions, etc.

5. Humor Is Welcome and Important, but humor should never be at someone else's expense.

Project Goals

- Assess the potential for contamination of groundwater associated with the use of dry wells for infiltrating stormwater
- Assess the ability of the various pre-treatment facilities to remove suspended solids from stormwater
- Provide education and outreach on the use and benefits of dry wells

Ground Rules

6. All Ideas and Points Have Value
You may hear something you do not agree with. Please remember that the purpose of these meetings are to share ideas and be courteous to others.

7. Cell Phone Courtesy
Please turn cell phones, or any other communication item with an on/off switch to "silent."

8. Be Comfortable
Please help yourself to refreshments or take personal breaks. If you have other needs please let City staff know.

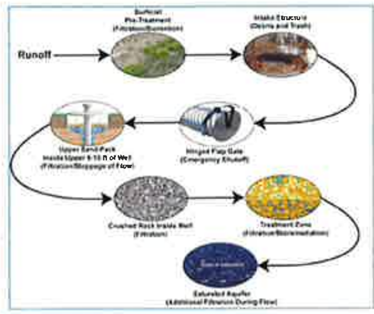
9. Project Website
City of Elk Grove will maintain a Project webpage accessible to the TAC and public.

Proposed Project

- Install 3 dry wells with a series of monitoring wells
- 3 sites representing different land uses
  - Residential
  - Commercial / Light Industrial
  - Major Road

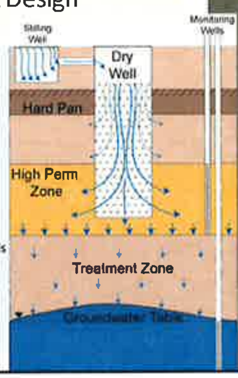
Proposed Site Locations

Proposed Project Stormwater Treatment



Proposed Project Design

- Enhance or modify existing pre-treatment/BMPS
  - Vegetated swales
  - Amended soils
- Stilling well/Sump
  - Capture additional debris/trash
  - Emergency shut-off valve
- Dry wells
  - 12" sand pack to capture suspended solids
  - Promote infiltration into more pervious soil layers
  - Crush rock for filtration



Proposed Monitoring Plan

Presentation by Barbara Washburn

Proposed Project Design

- Monitoring well clusters
  - Detect contaminants down-gradient from dry well
  - Perform tracer tests

Proposed Data Analysis

- Assess changes in groundwater constituents over time
- Assess contaminant removal efficiency over time
  - Vegetated swale (solids and pyrethroids)
  - Dry wells and vadose zone (all contaminants)
- Determine if any contaminants exceed MCLs or PHGs
- Build upon previous studies/investigations

Previous Studies/Investigations

USGS-Modesto Study

Background

- Used dry wells to manage stormwater for more than 50 year
- Currently more than 11,000 wells in operation

Previous Studies/Investigations

Los Angeles Water Augmentation Study

Background

- Study to evaluate feasibility of promoting stormwater recharge using LID practices without impacting groundwater quality

Previous Studies/Investigations

Study Design

- Installed 23 monitoring wells to various depths
- Groundwater quality sampled for general parameters, inorganic, pesticides, BTEX, VOC's, and refrigerants. Did not measure metals, pyrethroid pesticides, or PAHs

Previous Studies/Investigations

Study Design

- Dry wells and monitoring wells at 1 residential and 1 commercial site
- Groundwater quality sampled for general parameters, metals, oil and grease, VOC's, Semi volatiles, organic compounds, and bacteria. Omitted pyrethroid and other pesticides

Previous Studies/Investigations

Results

- The shallow aquifer showed elevated concentrations of nitrate and uranium attributed to agricultural and natural sources
- No contaminants were detected in the public supply well completed in multiple aquifers units
- After 50 years of dry well use, no contaminants were detected in public supply well that exceeded the MCLs

Previous Studies/Investigations

Results

- At both sites, contaminants detected at high concentrations in stormwater were detected at low concentrations near dry well, suggesting effectiveness of pre-treatment and aquifer attenuation
- Sites with elevated concentrations of contaminants in groundwater had low levels of those contaminants in stormwater
  - ✓ Source of contaminants not linked to infiltration practices

Data Gaps

- Some contaminants common today were not used extensively when studies were performed
  - Pyrethroids will be analyzed
- Other contaminants not included in analysis
  - Metals, some PAHs, some pesticides
- Not all monitoring wells reported on dry wells
  - Will perform tracer studies to verify relationship between dry well and monitoring wells

Questions and Comments

CITY OF ELK GROVE

PROUD HERITAGE. BRIGHT FUTURE.

Thank You

Anticipated Project Outcomes

- Maintain a high quality of groundwater while infiltrating stormwater through dry wells
- Assess the role of various types of pre-treatment at removing pollutants-laden sediment in stormwater
- Successfully develop/adapt a design for dry wells that minimize clogging and maintenance
- Assess the volume of stormwater that a dry well can infiltrate to help reduce localized flooding (Grant Line Road/ Bond Road site)

Anticipated Project Outcomes

- Provide education and outreach on the use of dry wells as part of a suite of LID management tools with scientifically sound information and data
- Increase knowledge of dry wells and their effects on groundwater quality, their design, registration requirements, and overall regulatory infrastructure
- Develop a list of interested stakeholders on the Project and keep them informed of Project outcomes
- Develop working relationships among regional stakeholders to encourage future monitoring after the term of the grant

Vegetated Swale
General Description

- Vegetated swales are stormwater conveyance and soil filter systems that temporarily store and then filter the desired water quality volume
- Stormwater is conveyed slowly through a vegetated swale due to roughness associated with plants

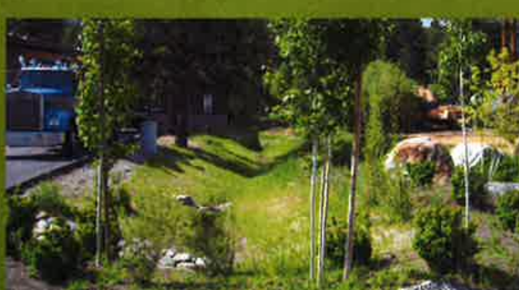
Vegetated Swale Example

Vegetated Swale
Function

- Provide water quality treatment through filtration
- Increase groundwater recharge through infiltration
- Reduce peak discharge rates and total runoff volume
- Provides a location for temporary water storage

Vegetated Swale Example

Vegetated Swale Example



Vegetated Swale Example

Vegetated Swale Example

Project Hydrology and Vegetated Swale Design

- Hydrology
- Vegetated swale design

Hydrology
Site 1: Residential - Strawberry Creek Detention Basin

- Land use: Single family residential (C = 0.50)
- Rainfall intensity: 0.18 inches/hour
- Watershed size: 168 acres
- Design flow: 15 cfs

Hydrology
Site 2: Commercial/Light Industrial - City of Elk Grove Corporation Yard

- Land use: Commercial/Light Industrial (C = 0.90)
- Rainfall intensity: 0.18 inches/hour
- Watershed size: 0.64 acres
- Design flow: 0.1 cfs

Hydrology
Site 3: Major Road – Grant Line Road/Bond Road

- Land use: Roadway (weighted average C = 0.55)
- Rainfall intensity: 0.18 inches/hour
- Watershed size: 1.9 acres
- Design flow: 0.19 cfs

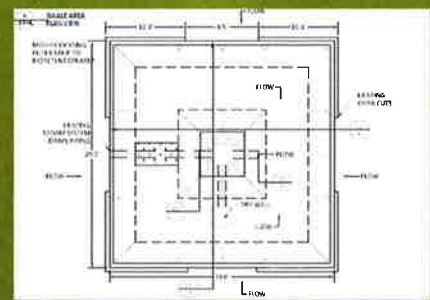
Vegetated Swale Design Using Flow-Based Design Criteria

- Flow-based control measure design standards apply to control measures whose primary mode of pollutant removal depends on the rate of flow of runoff through the facility or device (e.g. swale)
- Typically, flow-based design criteria calls for the capture and infiltration or treatment of the flow runoff produced by rain events of a specified magnitude
- For the local area, the intensity of such a rain event is 0.18 inches/hour for other cities in Sacramento County and unincorporated Sacramento County

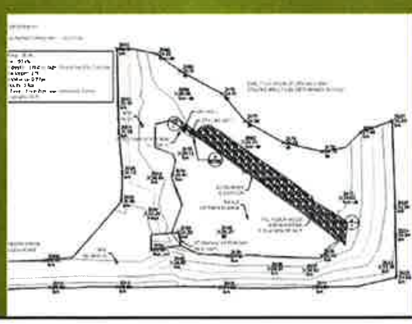
Vegetated Swale Design
Using Flow-Based Design Criteria

- This method satisfies the provisions of the Sacramento Area wide and City of Roseville NPDES Municipal Stormwater Permits, which requires that flow-based measures be designed for at least the maximum (peak) flow rate of runoff produced by the 85th percentile hourly precipitation intensity multiplied by a factor of two, referred to here as the flow-based 85th percentile method (CDM, 2003)
- This criterion is the same as the one prescribed by the 2003 California BMP Handbook. From Appendix D of that handbook, the 85th percentile hourly precipitation intensity for the Sacramento gage is approximately 0.09 inches/hour
- Multiplying by two, the required intensity is at least 0.18 inches/hour. The factor of two specified for this method by the municipal stormwater permits appears to be provided as a factor of safety; therefore, caution should be exercised when applying additional factors of safety during the design process so that over design can be avoided. (CASQA, 2003)

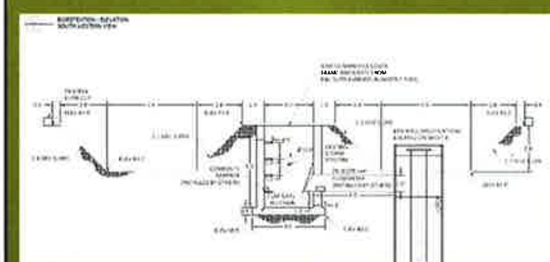
Vegetated Swale Design
Site 2: Commercial/Light Industrial - City of Elk Grove Corporation Yard



Vegetated Swale Design
Site 1: Residential - Strawberry Creek Detention Basin



Vegetated Swale Design
Site 2: Commercial/Light Industrial - City of Elk Grove Corporation Yard



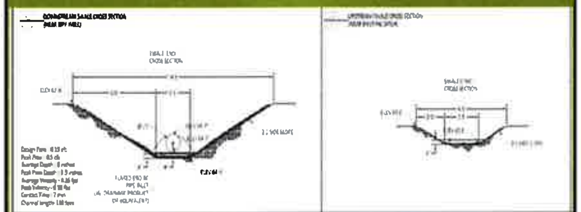
Vegetated Swale Design
Site 1: Residential - Strawberry Creek Detention Basin

- Water quality volume (WQV) = 12 hour storm: 169,130 cu ft
- Vegetated swale design volume: 18,792 cu ft
- Length of channel: 75 feet
- Contact time: 2 min
- Design depth goal: 3-6 inches

Vegetated Swale Design
Site 2: Commercial/Light Industrial - City of Elk Grove Corporation Yard

- Water quality volume (WQV) = 12 hour storm: 1,319 cu ft
- Vegetated swale design volume: 18,792 cu ft
- Effective length of channel: 64 feet
- Contact time: 6.4 min
- Design depth goal: 3-6 inches

Vegetated Swale Design
Site 3: Major Road - Grant Line Road/ Bond Road



Vegetated Swale Design
Site 3: Major Road - Grant Line Road/ Bond Road

- Water quality volume (WQV) =
  12 hour storm: 2,413 cu ft
- Vegetated swale design volume: 1,650 cu ft
- Length of channel: 110 feet
- Contact time: 7 min
- Design depth goal: 3-6 inches

Presentation 4: Assessing the Use of Dry Wells as an Integrated LID Tool for Reducing Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds

Sacramento Central Groundwater Authority

November 13, 2013

Assessing the Use of Dry Wells as an Integrated LID Tool for Reducing Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds

C. Bowles[1], M. Carr[1], F. Duenas[2], V. Kretsinger[3], C. Meirovitz[1], C. Nelson[2], N. Pi[4], B. Washburn[4], D. Wilson[2]

- [1] cbec eco engineering: surface water hydrology
- [2] City of Elk Grove & Willdan: Project recipient, stormwater engineering
- [3] Ludhorff & Scalmanini: groundwater hydrology
- [4] Office of Environmental Health Hazard Assessment: aquatic toxicology, QA/QC

Dry Wells

- Gravity fed excavated pits lined with perforated casing filled with gravel
- Can be used in conjunction with LID systems to improve rate of stormwater infiltration

Class V Injection Wells

By definition, a well is "any bored, drilled, driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system".

An "injection well" is a "well" into which "fluids" are being injected (40 CFR §144.3).

Class V injections Well Defined

- NO
  - Rain gardens
  - Tree boxes
  - Swales
  - Bioretention Areas
  - A dry well that collects ONLY roof runoff
- YES
  - Infiltration trench, if it includes "an assemblage of perforated pipes, drain tiles, etc. intended to distribute fluids below the surface of the ground"
  - Dry wells, which are deeper than they are wide

As such, dry wells must be registered (not permitted) with the US EPA.

Outline

- The issue
- What we have learned about dry well use from others
  - Los Angeles – Water Augmentation Study
  - Modesto – USGS
  - Portland – Underground Injection Control System (UICS) Program
- Proposition 84 Project

Basis for Interest in Dry Wells

- Requirement of NPDES permit:
  - Mimic natural hydrology
  - Reduce damage to aquatic ecosystem
  - Use LID practices
- Challenge
  - Achieving infiltration in clay soils
- One solution: dry wells
  - Increase infiltration rate
  - Questions about risk to groundwater quality

Dry Wells
Uses, Regulations, and Guidelines in California and Elsewhere

Dry Well Description and Use

U.S. Environmental Protection Agency (EPA): Region 9 Regulations

EPA Recommendations

- Class V injection wells (deeper than wider)
- Subject to US EPA Underground Injection Control regulations
  - Register dry wells if serves > 1 house
  - Only infiltrate uncontaminated stormwater
- Website contains a list of recommendations for appropriate uses (http://water.epa.gov/type/groundwater/uic/class5/index.cfm)
  - Constructed more than 10 ft above the seasonal high water table
  - Use pre-treatment

Use of Dry Wells in California

- Not widely used in California
  - Concerns about groundwater quality
  - Unclear how State regulations apply to dry wells
- Falls under California's Porter-Cologne Act and anti-degradation policy
- California DWR regulations, Bulletin 74
  - "Prevent surface water from entering injection wells"
  - Contradicts the purpose of dry wells (infiltration of stormwater)
- No uniform guidelines or regulations in California

Dry Well Use in Other Places

- Thirteen states have dry well regulations
- One of the most developed programs is in Portland, OR
  - 20,000 UICS in City – in some place, only stormwater management system
  - Principle underlying their program: If contaminants in stormwater are below the MCL levels, do not need to worry about groundwater contamination
  - Elaborate monitoring stormwater system
  - Modeling of fate and transport of most common contaminants in the vadose zone

Typical UICS in Portland

- Catch basin
- Sedimentation manhole
- Dry well (UIC)

http://www.portlandoregon.gov/bes/48213

Portland UICS Program

- Insert here some graphs showing low levels of contaminants
- Subsurface transport: PCP = 4 feet

Lessons from Portland

- Stormwater from streets might not be as contaminated as typically assumed
- Settling of solids important
- Appears to be a successful program
- Caveat:
  - CA geology: Contains many toxic metals (As, Cr) which could be mobilized by high specific conductivity, alkalinity of SW.
  - Need to investigate this potential by-product of UICS use.

Key studies of dry wells and groundwater contamination risks

Impacts of Dry Wells on Drinking Water Quality in Modesto


USGS

Hydrogeology, Water Chemistry, and Factors Affecting the Transport of Contaminants in the Zone of Contribution of a Public-Supply Well in Modesto, Eastern San Joaquin Valley, California

Background on Modesto

- Over 11,000 dry wells since the 1950s
- 1985 - PCE spill at Halford's Cleaners contaminated groundwater detected
  - Associated with defective dry cleaning machines
  - PCE entered leaking sewer line
- Public supply well 11 contaminated

Background on Modesto

- Superfund site late 1990s
- Clean up & monitoring...... 2000+
- Some made the linkage: dry wells = groundwater contamination?
  - US EPA reports: no association
  - Conduit for PCE: sanitary sewer lines, not dry wells

USGS Study

- Study goal
  - Determine whether and how contaminants might enter drinking water supply wells.
- Relevance of study for our purposes
  - Given long history of dry well use – assess **long term** potential risks to groundwater quality.

Study Design

- Analyzed water quality from 1 drinking water well
- Series of monitoring wells at various depths
  - Water table – up to 38 ft.
  - Shallow zone – 115 ft.
  - Intermediate zone – 200 ft.
  - Deep zone – 300 + ft.
- Monitoring wells along a gradient of agricultural and urban land uses as well as groundwater gradient

Water Chemistry Analysis

- Conventional water parameters
  - pH, dissolved oxygen, major ions, water age
- Gasoline related compounds (BTEX)
  - Benzene, toluene, ethylbenzene, xylenes
- Pesticides
  - About a dozen pesticides including chlorinated forms, simazine and atrazine
- Volatile organic compounds
  - Chloroform, PCE, TCE, ethyl benzene, xylene, etc.
- Refrigerants

Brief Summary of Results

- Younger water (shallow depths) more susceptible to contamination
  - Mainly agriculture influences, e.g. nitrate
  - Some evidence of typical urban contaminants, but below MCLs
- Older water (deep zones)
  - No anthropogenic contaminants
  - Uranium and arsenic contamination

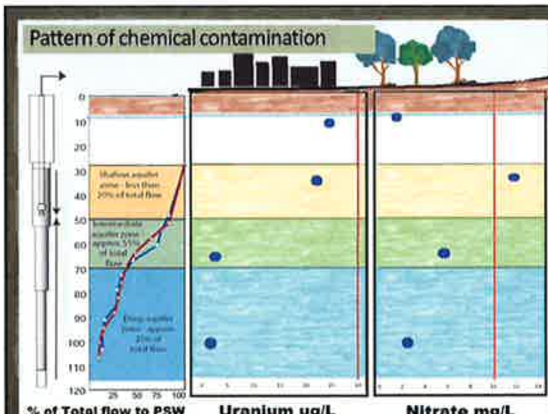
Summary of Monitoring Well Detections of Selected Pesticides

All units ppb	Triazine	Simazine	Atrazine	Metolachlor	Diazinon	Dieldrin
Detection Freq.	39	39	35	4	4	4
Median	0.0079	0.028	0.013	0.004	0.006	0.006
Max. Conc.	0.096	0.108	0.059	0.006	0.006	0.006
MCL	n/a	4	1	3.5*	0.007*	0.002*
MCL/Max Conc.	-	40	16	580	1	0.3

* US EPA health advisory drinking water equivalent level, guidance values, non-cancer health effects

Summary of Monitoring Well Detections of Selected Volatile Organics

All units ppb	Chloroform	PCE	Ethyl benzene	Xylene
Detection Freq. (%)	61	26	13	4
Median	0.1423	0.08	0.02	0.02
Max. Conc.	3.534	1.21	0.02	0.02
MCL	80	5	1000	600
MCL/Max. Conc.	23	4	50,000	30,000



Main Message from USGS Study

- No contaminants associated with urban runoff near the MCL in public supply well water
  - Some urban contaminants present in shallow aquifer
  - Some mobilization of naturally occurring toxic metals

Los Angeles Water Augmentation Study

Background

- Ten year study by the Los Angeles and San Gabriel Rivers Watershed Council (Council on Watershed Health) and partners
  - City of Los Angeles Department of Water and Power
  - Metropolitan Water District of Southern California
  - United States Bureau of Reclamation
- Overall goal
  - Assesses feasibility of the capture and infiltration of stormwater to augment local water supply (reduce dependency in imported water)
- *One specific goal*
  - *Assess effects of infiltrating stormwater on groundwater quality*

Study Sites Overview

- Six sites - diversity of land uses
  - School
  - Office building
  - Residence
  - Two industrial sites
  - Public park
- Dry wells installed at:
  - Office building
  - Private residence

Office Building

- Roof runoff drained to dry well
- 31 ft. depth to water table
- Poorly infiltrating soils
- Monitoring wells and lysimeters (monitors pore water in vadose zone) installed

Private Residence

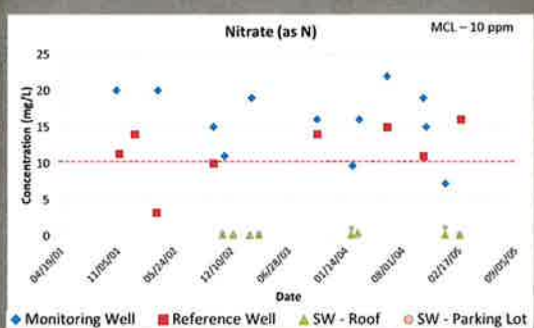
- Driveway sheet flow to dry well
- 200 ft. depth to water table
- Slow-moderate infiltrating soils
- Lysimeters installed

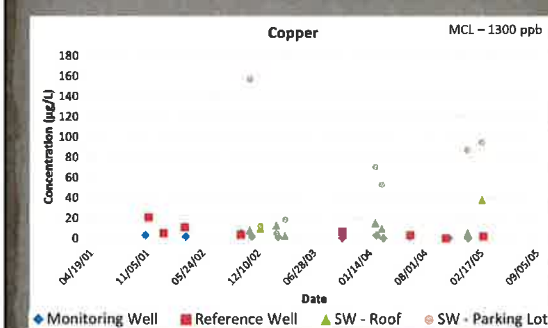
Monitoring Program

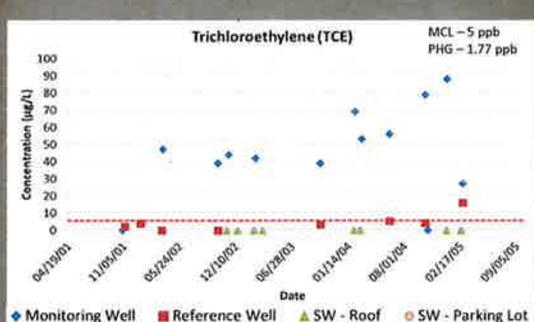
- Stormwater samples taken during storm events for 3-4 years
- Post-storm samples taken from lysimeters and monitoring wells
- Endpoints
  - General physical & chemical
  - Metals
  - Oil, grease, and vehicle-related contaminants
  - Volatile and semi-volatile organic compounds
  - Bacteria

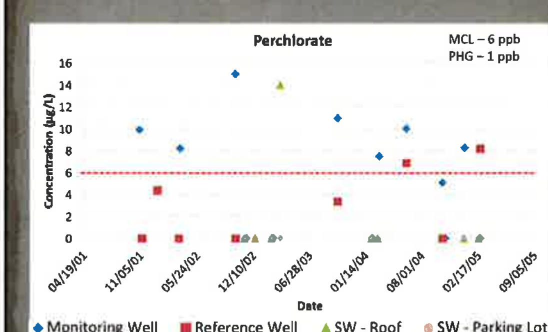
Summary of Results – Los Angeles Study

- Contaminants detected at high levels in groundwater were at low levels in SW
- Contaminants at high levels in stormwater were at low levels in GW









Summary of Results – Los Angeles Study

- Contaminants detected at high levels in groundwater were at low levels in SW
- Contaminants at high levels in stormwater were at low levels in GW

Limitation of Studies

- Los Angeles – Water Augmentation Study
  - Samples not tested for some contaminants: pesticides in current use
  - Monitoring wells not installed at all sites
  - Some monitoring wells up-gradient of dry well
- USGS – Modesto Study
  - Samples not tested for some important stormwater contaminants: metals, pyrethroids, PAHs
  - Limited stormwater analysis

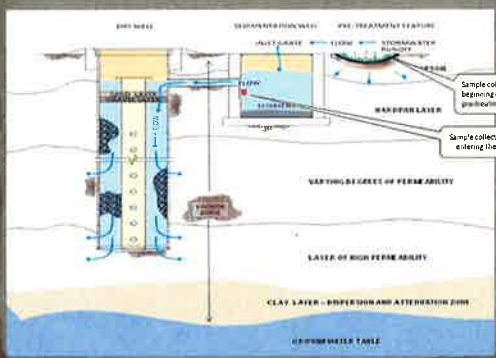
Prop. 84 Dry Well Project

Location

Vadose zone well: 55 ft bgs; water table wells: 120 ft bgs

Monitoring wells: vadose zone & water table

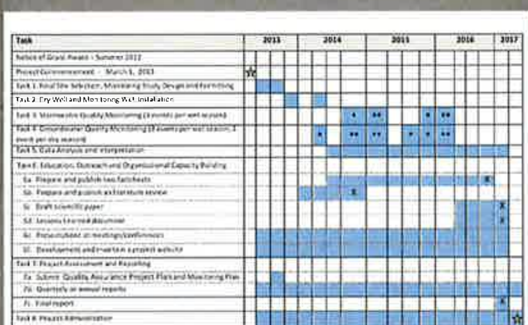
DRY WELL SYSTEM



Overview of Monitoring Plan

- Stormwater and groundwater samples collected over a period of two years
  - Three wet weather stormwater samples
    - TSS & pyrethroids at beginning and end of swale/rain garden
  - Three wet and one dry weather monitoring well samples
- Constituents to be tested
  - General physical & chemical
  - Metals (EPA 200)
  - Semi-volatiles (EPA 625)
  - Herbicides (EPA 515)
  - Pyrethroids (WPCL, DFW method)
  - TPH (EPA 8015)
  - Pyrogenic PAHs (EPA 8310)
  - Total coliform

Project Timeline



Data Analysis

- Assess changes in GW constituents over time
- Assess contaminant removal efficiency over time
  - Swales (solids, pyrethroids)
  - Dry wells & vadose zone (all contaminants)
- Determine if any contaminants exceed MCL or PHG

Deliverables

- Factsheets
  - Summary of guidelines & regulations
  - Key findings of the project
- Annotated bibliography
- Education & Outreach
  - Scientific paper
  - Presentations
  - Outreach to school near sampling site
- Summary of Project Experiences (Guidance Manual)
  - Design of dry wells
  - Effectiveness/design of pre-treatment
- Results entered into CEDEN and GAMA
- Website with all products and general information

Thank you

- Contacts
  - Project director: Darren Wilson
    dwilson@elkgrovecity.org
  - Project manager: Connie Nelson
    cnelson@elkgrovecity.org
  - Toxicology/QA officer: Barbara Washburn
    barbara.washburn@oehha.ca.gov
  - Surface water hydrology: Chris Bowles
    c.bowles@cbecoeng.com
  - Groundwater hydrology: Casey Meirovitz
    cmeirovitz@lsce.com

Presentation 5: Stormwater Infiltration using Dry Wells as a Possible Adaptation to Climate Variability

24th Meeting of Society of Environmental Toxicology and Chemistry (NorCal SETAC), UC Berkeley

May 7, 2014

Stormwater Infiltration using Dry Wells as a Possible Adaptation to Climate Variability

C. Bowles[1], M. Carr[1], F. Duenas[2], V. Kretsinger[3], C. Meirovitz[4], C. Nelson[2], N. Pi[4], B. Washburn[4], D. Wilson[2]

[1] cbec eco engineering: surface water hydrology
[2] City of Elk Grove & Willdan: Project recipient, stormwater engineering
[3] Ludhorff & Scalmanini: groundwater hydrology
[4] Office of Environmental Health Hazard Assessment, aquatic toxicology; QA/QC

Overview

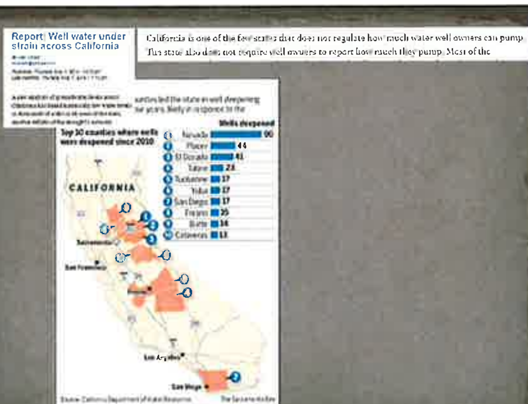
- Background
- Elk Grove Dry Well Project
- Other studies

What are Dry Wells

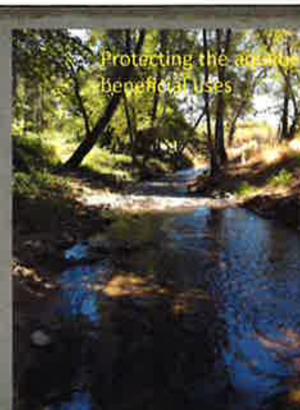
- Gravity fed excavated pits lined with perforated casing filled with gravel
- Deeper than wide
- Used in conjunction with LID systems to improve rate of stormwater infiltration and groundwater recharge

Value of using dry wells in California

- Stormwater:
  - Facilitate stormwater infiltration even in clay soils
    - Helps to meet hydromodification management
    - Protects aquatic ecosystem
- Climate change / drought:
  - Facilitates aquifer recharge



Protecting the aquatic ecosystem and its beneficial uses



Stormwater BMP installation in major cities

- TMDL control
- MS4 permits
- First flush capture
- Groundwater augmentation
- Urban aesthetics

http://www.nwri-usa.org/documents/Boehm.pdf

Role of Dry Wells

- Can facilitate the use of LID practices where soils have poor permeability (Soil Groups C and D)

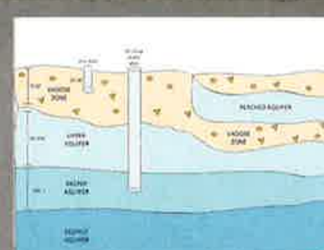
The Challenge

- DWR Bulletin 74-81/90: guidelines to prevent surface water entering water well (Water Code Sect 13710).
  - Dry wells: Class V injection wells
- BUT......... LID and hydromodification rules encourage or require infiltration of stormwater
- Perception that dry wells contribute to groundwater contamination (e.g. Modesto)
- Need for additional information to inform policy

Elk Grove Dry Well Project

Elk Grove Project: 3 parts

- Field study
- Contaminant fate and transport modeling
- Education and outreach



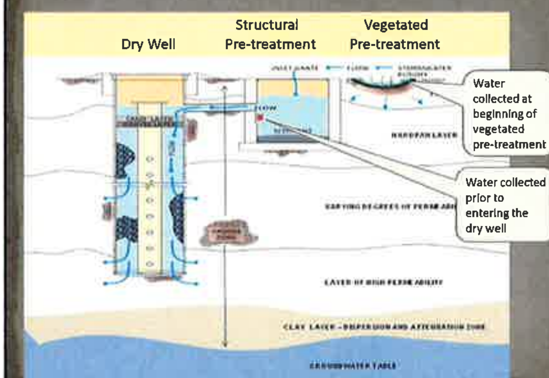
Field Study

Begins Fall, 2014

Location

Vadose zone well: 55 ft. bgs; water table wells: 120 ft. bgs

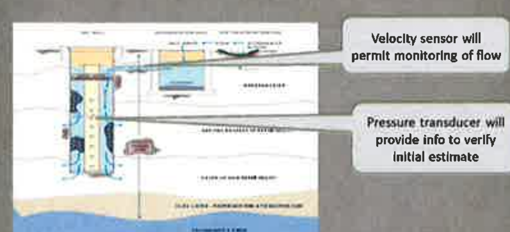
Monitoring wells: Vadose Zone and Water Table



Water Quality Monitoring Plan

- Stormwater and groundwater samples collected for two years
  - Three wet weather stormwater samples
  - Three wet and one dry weather groundwater well samples
- Constituents to be tested
  - General physical & chemical
  - Metals (EPA 200)
  - Volatiles (EPA 8260)
  - Semi-volatiles (EPA 625)
  - Herbicides (EPA 515)
  - Pyrethroids (WPCL, DFW method)
  - TPH (EPA 8015)
  - Pyrogenic PAHs (EPA 8310)
  - Total coliform

Estimates of Recharge



Questions that will be addressed

- Primary question:
  - Are contaminants introduced into groundwater through the dry wells?
- Secondary questions:
  - How effective is pre-treatment at removing contaminants and sediment from stormwater?
  - What is recharge potential?
  - What are maintenance requirements?

Logging boring soil samples at well sites

Fate and Transport of Contaminants

Contaminant modeling

- Addresses two major concerns:
  - How far might contaminants migrate from bottom of dry well over many years?
  - Could naturally occurring metals (e.g. As, U) be mobilized as a result of high specific conductivity often found in stormwater?
- UCD LAWR faculty and a grad student will address

Education and Outreach

Literature Review
Factsheets
Reports
Website

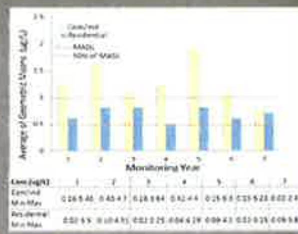
Portland: Underground Injection Control Program

- 9,000 publicly owned dry wells
  - Located in streets
- 10,000 privately owned

Contaminant Monitoring Program

- Multi-million dollar effort over 7 years
- Stormwater only, little groundwater
- Contaminants evaluated
  - Metals
  - Volatile organics and semi-volatiles
  - PAHs
  - Pesticides and herbicides
- Key benchmark
  - Maximum allowable discharge level = MCL

- Common pollutants
  - DEHP
  - B[a]P
  - PCP
- Pentachlorophenol – pesticide, preservative on utility poles
- Fate and transport modeling: Soil binds PCP, limiting migration to < 10 feet



Average geometric mean (min/max) PCP; Sample size = 30

Lessons from Portland

- Stormwater from streets does not appear to be as contaminated as typically assumed
- No evidence for groundwater contamination
- Caveat:
  - California geology and climate very different than Portland

Impacts of Dry Wells on Drinking Water Quality in Modesto

USGS: Background on Modesto Perc Spill

- Over 11,000 dry wells since the 1950s
- 1985 - PCE spill at Halford's Cleaners contaminated groundwater detected
  - Associated with defective dry cleaning machines
  - PCE entered leaking sewer line

Background on Modesto

- Superfund site late 1990s
- Clean up and monitoring...... 2000+
- Some made the linkage: dry wells = groundwater contamination?
  - US EPA reports: conduit for PCE - sanitary sewer lines, not dry wells

USGS Study

- Study goal
  - Determine whether and how contaminants might enter drinking water supply wells
- Relevance of study for our purposes
  - Given long history of dry well use – assess long term potential risks to groundwater quality

USGS Study Design

- Analyzed water quality from one drinking water well
- Series of monitoring wells at various depths
  - Water table – up to 38 ft.
  - Shallow zone – 115 ft.
  - Intermediate zone – 200 ft.
  - Deep zone – 300 + ft.
- Monitoring wells along a gradient of agricultural and urban land uses as well as groundwater gradient

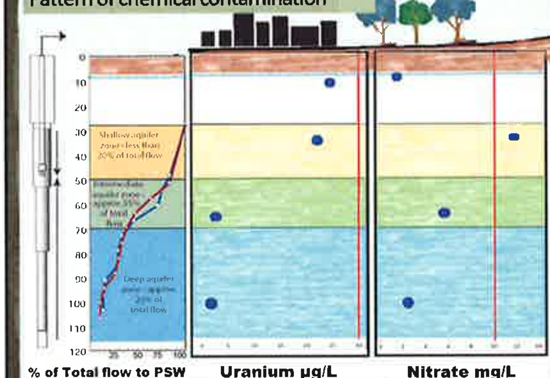
USGS: Water Chemistry Analysis

- Conventional water parameters
  - pH, dissolved oxygen, major ions, water age
- Gasoline related compounds (BTEX)
  - Benzene, toluene, ethylbenzene, xylenes
- Pesticides
  - About a dozen pesticides including chlorinated forms, simazine and atrazine
- Volatile organic compounds
  - Chloroform, PCE, TCE, ethyl benzene, xylene, etc.
- Refrigerants

USGS: Summary of Key Results

- Younger water (shallow depths) more susceptible to contamination
  - Key problems:
    - Nitrate: Agricultural activity
    - Uranium and arsenic: Natural
  - Some evidence of typical urban contaminants, but below MCLs
- Older water (deeper zones)
  - No anthropogenic contaminants

Pattern of chemical contamination



Main Message from USGS Study

- No contaminants associated with urban runoff near the MCL in public supply well water
  - Some urban contaminants present in shallow aquifer
  - Possible mobilization of naturally occurring toxic metals with high alkalinity ....

Los Angeles Water Augmentation Study

Background on LA Study

- Ten year study by Council on Watershed Health and partners
- Goals
  - Assesses feasibility of stormwater capture to augment local water supply
  - Assess effects of infiltrating stormwater on groundwater quality

Study Sites with Dry Wells

- Site 1: Office building
  - Groundwater and vadose zone monitoring wells
- Site 2: Residence
  - Vadose zone wells only

LA Study: Monitoring Program

- Stormwater samples taken during storm events for 5+ years
- Post-storm samples taken 2 – 10 days after event
- Analytes
  - General physical and chemical
  - Metals
  - Oil, grease, and vehicle-related contaminants
  - Volatile and semi-volatile organic compounds
  - Bacteria

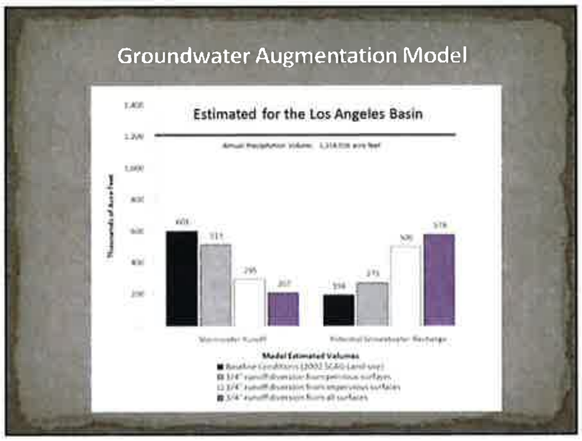
Key Results : Los Angeles Study

- Contaminants detected at high levels in groundwater were at low levels in SW
- Contaminants at high levels in stormwater were at low levels in GW
- Little evidence for a groundwater contamination

LA Study - Groundwater Augmentation Model

- Worked with Bureau of Reclamation to develop model to:
  - Estimate the maximum amount of recharge that might occur in area of study
  - Currently ~600,000 acre/ft. becomes runoff
  - **Key finding:** if 1st ¾" rain of every storm on all property captured, about 47% of precip could be infiltrated, or ~578,000 a/f; enough for ¾ million households

Area included in the GWAM


Groundwater Augmentation Model
Estimated for the Los Angeles Basin
295
207
Model Estimated Volumes


http://www.egpublicworks.org: Dry Well tab
Contacts
Project director: Darren Wilson
dwilson@elkgrovecity.org
Project manager: Connie Nelson
cnelson@elkgrovecity.org
Toxicology/QA officer: Barbara Washburn
barbara.washburn@oehha.ca.gov
Surface water hydrology: Melanie Carr
m.carr@cbecoeng.com
Groundwater hydrology: Casey Meirovitz
cmeirovitz@lsce.com
Thank You

Presentation 6: Stormwater Infiltration using Dry Wells as a Low Impact Development (LID) Tool

Association of State Floodplain Managers (ASFPM) 2014 Conference, Seattle, Washington

June 4, 2014

Stormwater Infiltration using Dry Wells as a Low Impact Development (LID) Tool

Presented by:
Connie Nelson, CFM
City of Elk Grove/Willdan Engineering

June 4, 2014

ELK GROVE

Today's Discussion

- Background
  - California's water situation
  - Groundwater recharge (hydrologic cycle)
  - Effects of urbanization
  - Stormwater as a resource
- Use of Dry Wells as a Low Impact Development Tool
  - What is Low Impact Development?
  - What are dry wells?
- Elk Grove Dry Well Projects
  - State funded projects
  - Other projects

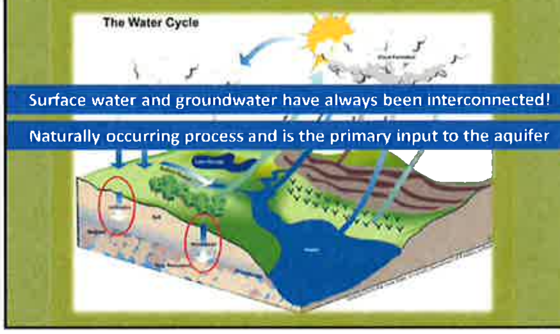
ELK GROVE

Background

- California is in a severe drought
- Legislation is calling for:
  - Water reuse
  - Treating stormwater as a resource
  - Strengthen groundwater management
- A solution may be the use of dry wells for these challenges

ELK GROVE

Groundwater recharge is a hydrologic process where water moves downward from the surface water to groundwater.



Surface water and groundwater have always been interconnected!

Naturally occurring process and is the primary input to the aquifer

Effects of Urbanization

- Decrease in the infiltration of rain water due to hardscapes such as building and roads
- This alteration in the natural flow patterns is called hydromodification
  - Impacts aquatic ecosystem
  - Increased flood risk

ELK GROVE

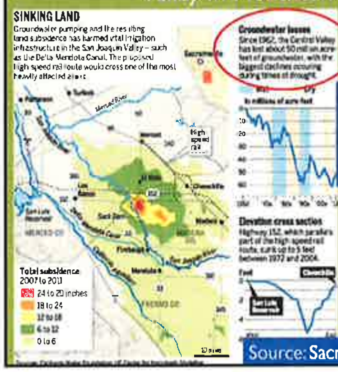
Effects of Urbanization

Typical cycle in an undeveloped area.

Typical cycle in an developed area.

5-fold increase in urban runoff in a developed area.

Groundwater Supplies Depleting in Central Valley in Northern California



- Sinking Land
- 50 million acre feet groundwater lost

Source: Sacramento Bee, April 2014

One Solution is to Treat Stormwater as a Resource

- Improve water quality
- Reduce urban runoff
- Provide groundwater argumentation
- Reduce localized flooding
- Provide habitat enhancement and protects aquatic resources
- Aesthetically pleasing

http://www.nwri-usa.org/documents/Boehm.pdf

"Greener approach…return to natural hydrologic regime."

Dry Wells as a Low Impact Development Tool

What is Low Impact Development?

Innovative stormwater management approach

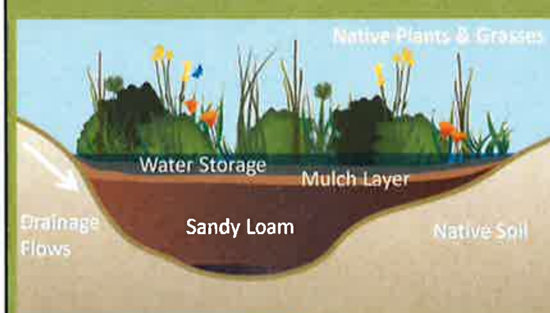
- Mimics natural hydrology
- Manage stormwater at the source
- Captures, stores, cleanses and slowly releases stormwater (reducing peak flows)
- Water quality treatment through filtration
- Recharges stormwater to groundwater
- Treats small to medium storm events
- Mitigate flooding, erosion and reduction in sedimentation

ELK GROVE

Example of Low Impact Development

Bioretention and grassy swale

Example of Low Impact Development



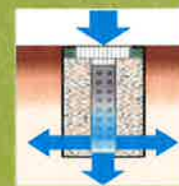
Rain gardens

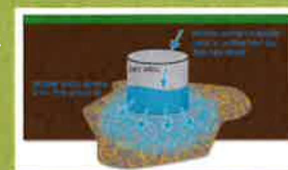
What are Dry Wells?

- Promote infiltration of stormwater runoff to recharge groundwater
- Can infiltrate stormwater through clay soils
- Use in conjunction with Low Impact Development practices

How does it Work?

- Receives water from one or more entry points
- Collect, store and disburse water
- Discharges water through small openings
- Bottom of dry well is placed at permeable soils





Example Grassy Swale and Dry Well

Bioretention and grassy swales

Challenges

- Competing regulations:
  - Water Code 13710: guidelines to prevent surface water entering water well (DWR Bulletin 74-81/90)
  - State Water Board promotes stormwater infiltration and dry wells are an important tool in the Low Impact Development tool kit
- Perception that dry wells contribute to groundwater contamination

ELK GROVE

Elk Grove Dry Well Projects

City of Elk Grove, California

Project 1: Dry Wells as Low Impact Development

Background

- State funded Stormwater Grant Program
- Total project budget $825,000
- Received grant funding amount $489,820
- In-kind services $335,180

ELK GROVE

Project Purpose

Evaluate the potential for using dry wells, in combination with low impact development practices to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

...without negatively impacting quality of groundwater.

ELK GROVE

Project Team

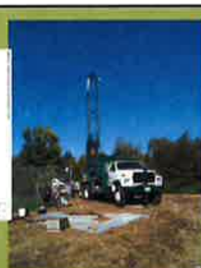
WILLDAN extending your reach

cbec

UC DAVIS

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

CITY OF ELK GROVE

Phase 1: Site Selection, Design and Construction

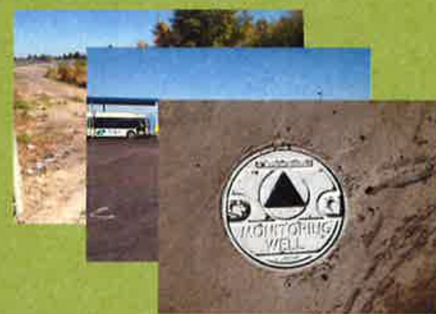
2012 - 2014

Project Site Locations

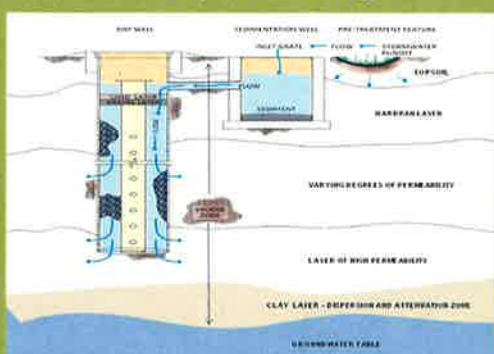
Project Site Schematic

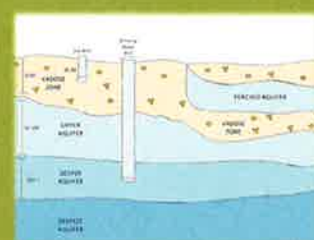
Shallow groundwater well: 55 feet
Deep groundwater wells: 110 feet

Monitoring Well Network



Dry Well Design





Phase 2: Field Study

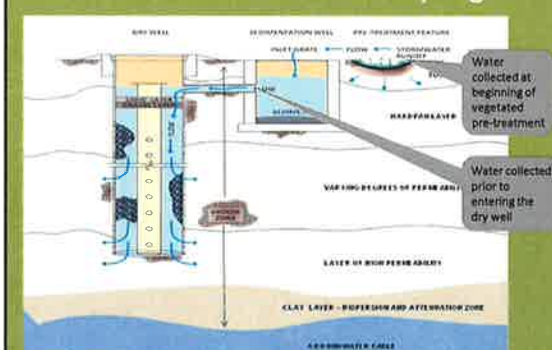
Begins Fall, 2014

Field Study

- Collect and sample stormwater and groundwater for 2 years
  - 3 wet weather stormwater samples
  - 3 wet and I dry weather groundwater samples

ELK GROVE

Stormwater Water Sampling



Water Quality Chemistry

- Constituents to be tested in stormwater and groundwater
  - General physical & chemical
  - Metals (EPA 200)
  - Volatiles (EPA 8260)
  - Semi-volatiles (EPA 625)
  - Herbicides (EPA 515)
  - Pyrethroids (WPCL, DFW method)
  - TPH (EPA 8015)
  - Pyrogenic PAHs (EPA 8310)
  - Total coliform

ELK GROVE

Estimate Recharge and Infiltration Capacities

Velocity sensor to monitor flow

Pressure transducer to estimate the volume of flow

Logging boring soil samples at well sites

Phase 3: Fate and Transport Modeling

2014 - 2015

Phase 4: Education and Outreach

Literature Review
Factsheets
Reports
Website

Questions that will be Addressed

- Primary question:
  - Are contaminants introduced into groundwater through dry wells?
- Secondary questions:
  - How effective is pre-treatment at removing contaminants and sediment from stormwater?
  - What is groundwater recharge potential?
  - What are maintenance requirements?

ELK GROVE

Project 2: Sleepy Hollow Detention Basin Retrofit

Background

- State funded Implementation Grant
- Total project budget $850,000
- Received grant funding amount $240,000
- In-kind services $610,000

ELK GROVE

Project Purpose

Retrofit an existing detention basin for multifunctional purposes to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater
- Improve water quality
- Provide habitat enhancement/riparian zones

ELK GROVE

Sleepy Hollow Detention Basin

Other Elk Grove Dry Well Projects

Dry Wells Rural Roadway

- **Alternative to typical storm drain system**
- **Localized flood control**
- **Less expensive**
- **Groundwater recharge potential**

Elk Grove Rain Garden Plaza

- **Largest rain garden in California**
- **Educates sustainable stormwater practices**
- **Demonstrates Low Impact Development techniques**

"9 State and Regional Awards"

http://www.elkgrovecity.org/rain-garden/

Conclusion

- Sustainable Water Resource Management
  - Multiple purposes and beneficial uses
- Incorporate into any project
- Maintain groundwater quality
- Proposition 84 Projects
  - Provide scientific data to help local and State agency on the beneficial uses of dry wells as a Low Impact Development tool

ELK GROVE

Contacts

Project Manager: Connie Nelson, CFM
City of Elk Grove/Willdan Engineering
cnelson@elkgrovecity.org

Q/A Officer: Barbara Washburn, PhD
Office of Environmental Health Hazard Assessment, California EPA
Barbara.Washburn@oehha.ca.gov

CITY OF ELK GROVE

Questions?
Thank you

Presentation 7: Stormwater and Groundwater Issues and the Elk Grove Dry Well Project

Regional and State Water Board Member's Annual Meeting/Tour – Educational Forum

October 1, 2014

Elk Grove Dry Well Project
Strawberry Creek Water Quality Basin

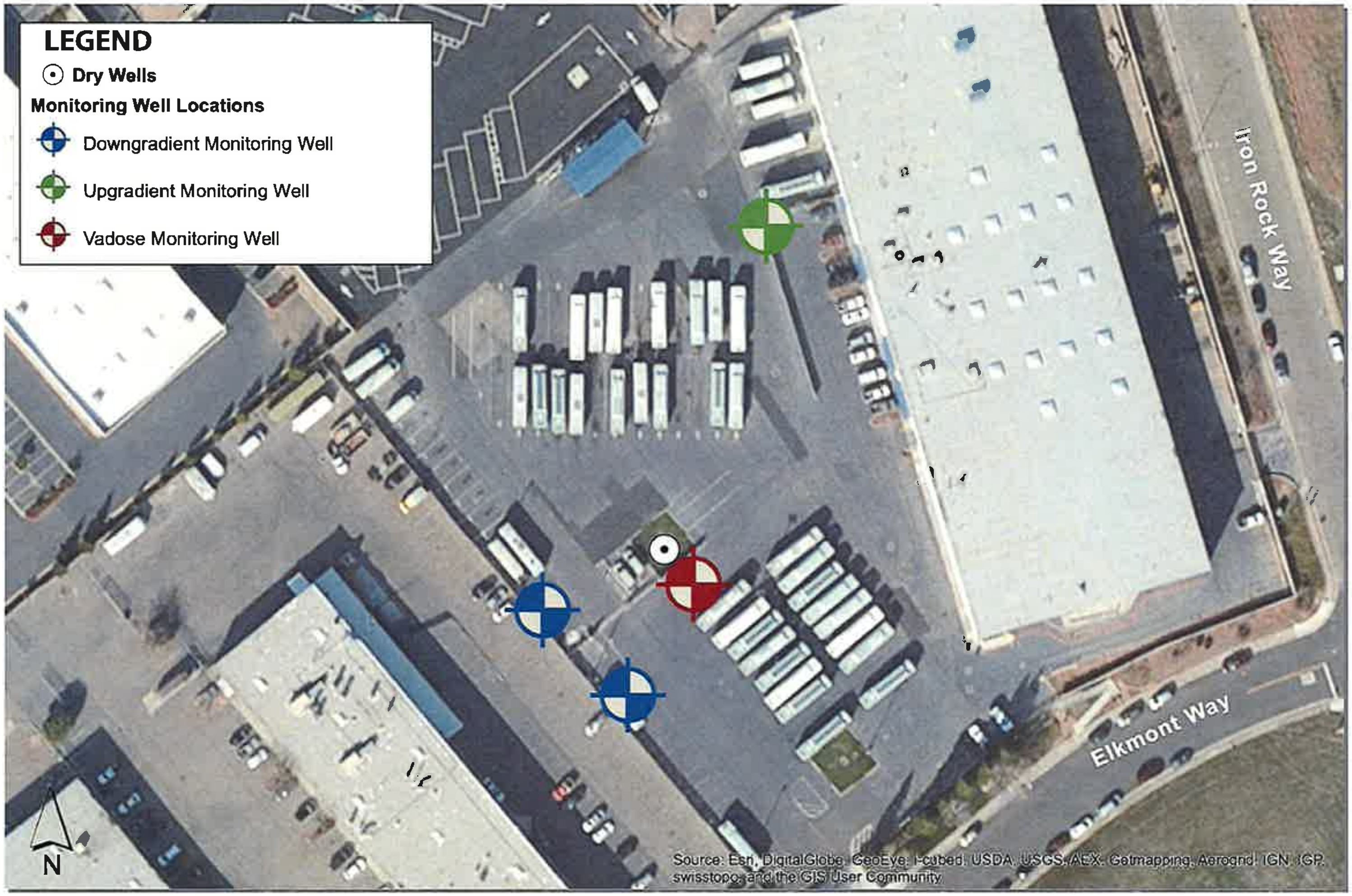
City of Elk Grove

Path: X:\2012 Job Files\12-001\GIS\mapfiles\MW locations not survey.mxd

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

Elk Grove Dry Well Project
Elk Grove Corporation Yard

City of ELK GROVE

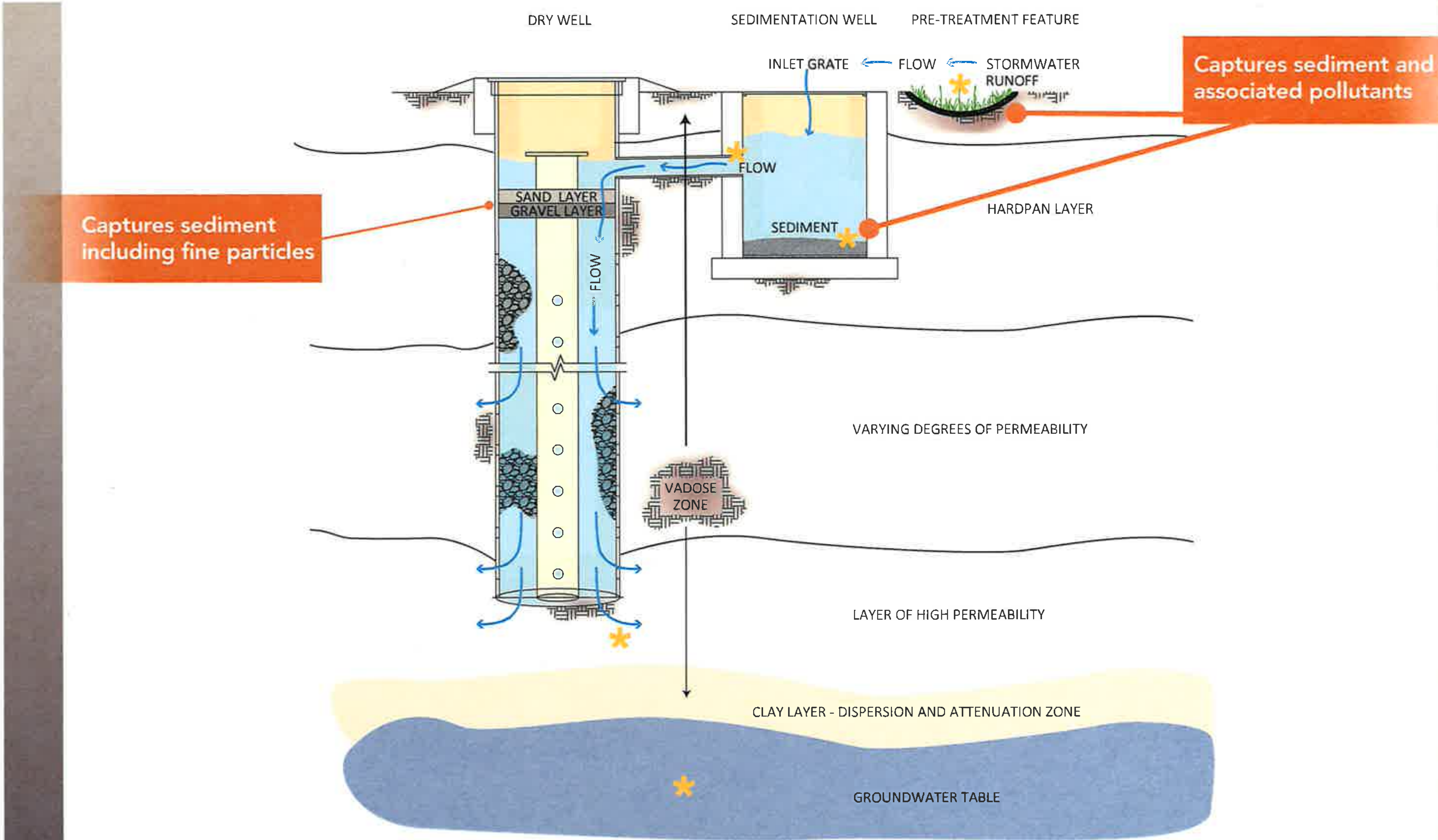


Path: X:\2012 Job Files\12-001\GIS\mapfiles\MW locations not survey.mxd

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

Dry Well Treatment Train

CITY OF ELK GROVE



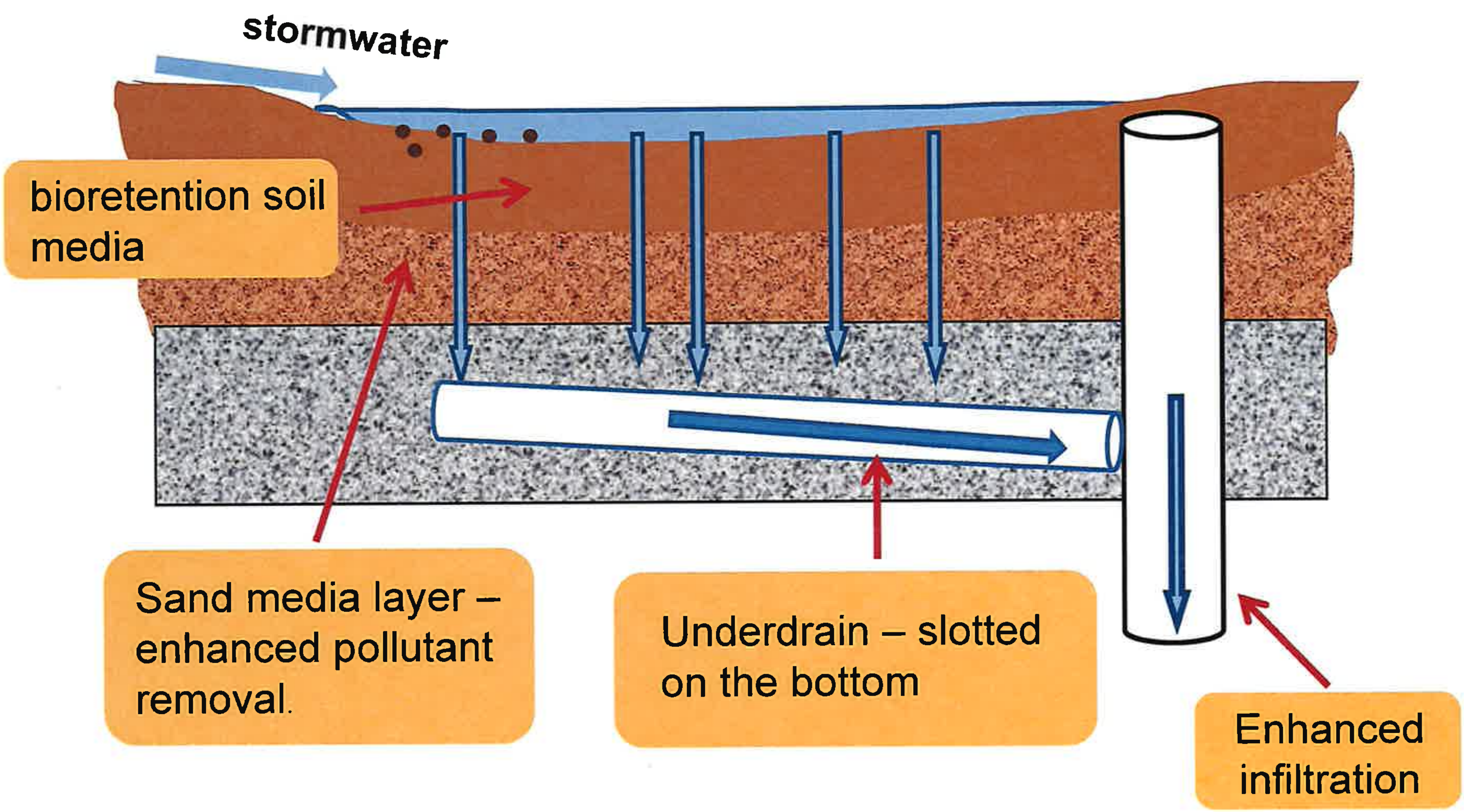
* Location for sample collections.

Constituents to be tested in stormwater and groundwater:

CITY OF ELK GROVE

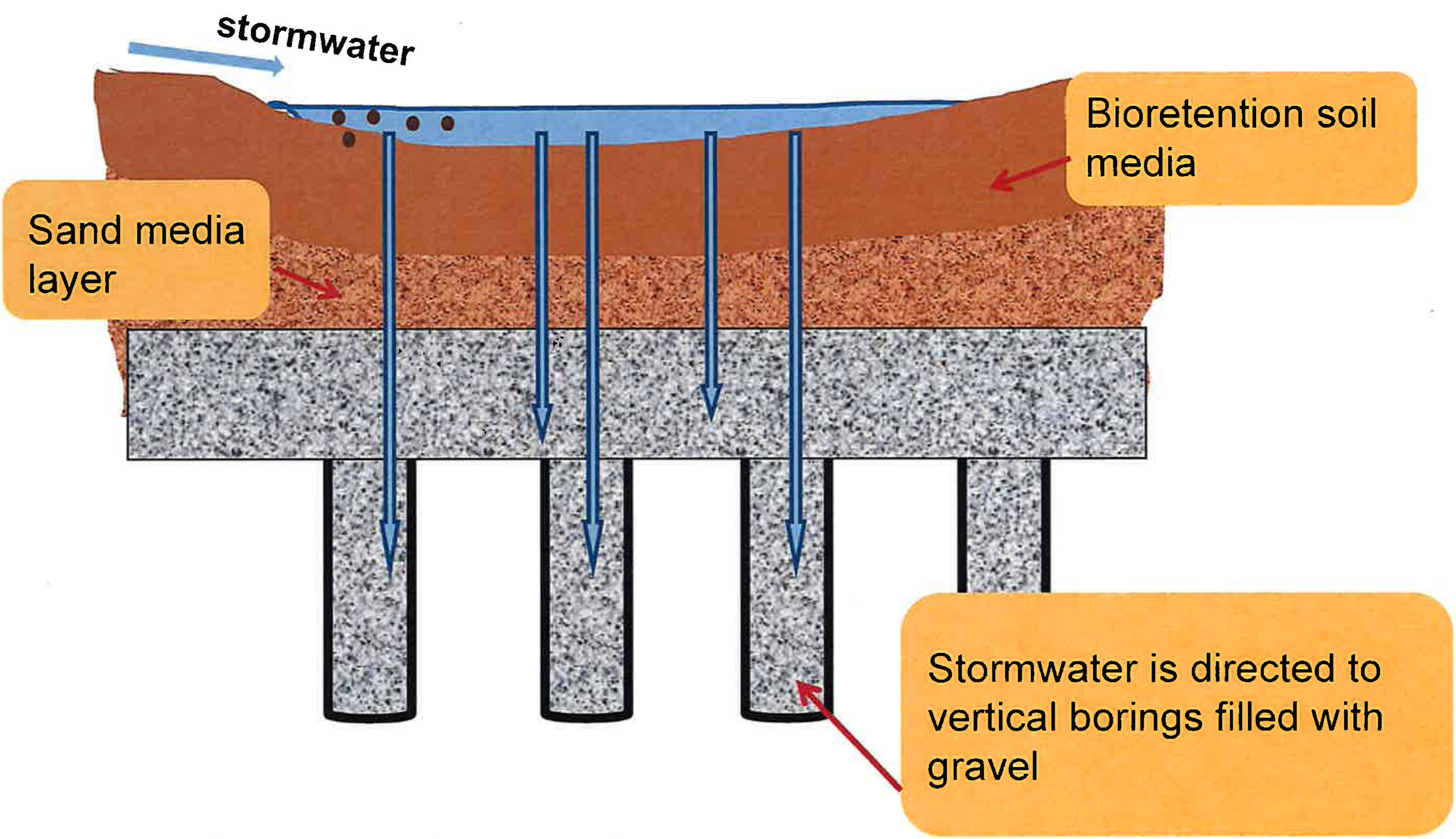
- Pyrogenic PAHs
- Volatile and semi-volatile organics
- Chlorophenoxy herbicides
- Pyrethroids
- Gas and diesel by-products (TPH)
- Drinking water metals
- Coliform
- General physical/chemical parameters

City of Gonzales: Proposed Enhanced Treatment and Infiltration



Contact: Darla Inglis, Low Impact Development Initiative, dainglis@ucdavis.edu

City of Palo Alto's Southgate Neighborhood Green Street Project



Contact: Daniel Apt, RBF Consulting, DApt@mbakerintl.com

Sleepy Hollow Detention Basin Retrofit Project

CITY OF ELK GROVE

Sleepy Hollow Detention Basin Improvements

CITY OF ELK GROVE

Welcome to the Award Winning Elk Grove
RAIN GARDEN PLAZA

CITY OF ELK GROVE

Presentation 8: Pre-Bid Meeting – Dry Wells as a Low Impact Development (LID) Improvement Project (WDR019)

City of Elk Grove and Contractors

June 30, 2014

Pre-Bid Meeting

Dry Wells as Low Impact Development (LID) Improvement Project (WDR019)

Connie Nelson, CFM
Project Manager
City of Elk Grove

June 30, 2014

ELK GROVE

Project/Construction Site Locations

Project Purpose

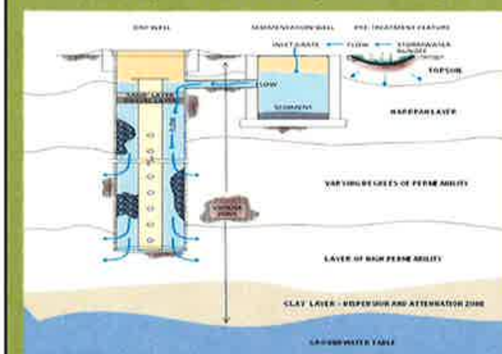
Evaluate the potential for using dry wells, in combination with low impact development practices to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

…without negatively impacting quality of groundwater.

ELK GROVE

Dry Well Design Concept



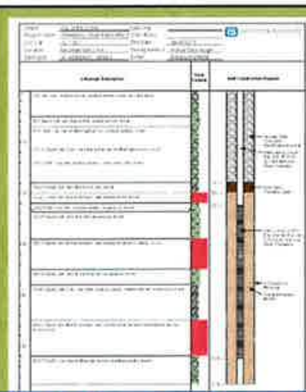
Background

- State funded Stormwater Grant Program
- Construct two dry wells with pre-treatment features
- Two locations

ELK GROVE

Project Site Schematic

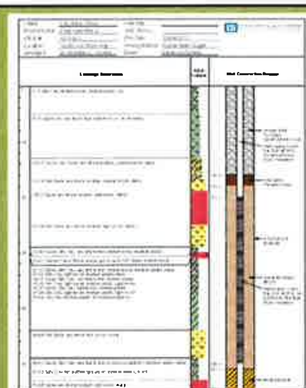
Shallow groundwater well: 55 feet
Deep groundwater wells: 110 feet



Lithology Report – Strawberry Creek Water Quality Basin

Key Points

- Have submittals ready as soon as possible to ensure on-time start.
- Drill cuttings collected: 5 foot intervals, at formation changes or as directed by Engineer.



Lithology Report – Corporation Yard

Key Points

- County of Sacramento Well Permits and Well Completion Records
- Corporation Yard: Excavation/spoils shall be removed daily
- Grassy Swale Establishment: 90 Calendar Days
  - ✓ Preference to begin at Corporation Yard
- Full Retention: Cannot release full retention until 35 days after the Notice of Completion is filed and recorded with the County. This occurs after the City Council "Accepts" the project.

Key Dates

- Bid Opening: July 8, 2014 2:00 PM **2:00 PM**
- City Council Award: July 23, 2014
- Contract Approved (turn in submittals): August 18, 2014
- Pre-Construction Meeting: August 22, 2014
  - ✓ Staging at Corporation Yard
- Construction

  Start Date: week of August 25, 2014
- Working Days: 20 days

Contacts

Project Manager: Connie Nelson, CFM
City of Elk Grove
(916) 478-3638
cnelson@elkgrovecity.org

Project RE: Paul Sipple
City of Elk Grove
(916) 478-3647
psipple@elkgrovecity.org

Questions?
Site Visit (optional)
Thank you

Site Visit

Edward Harris Middle School
8691 Power Inn Road
Elk Grove, CA 95624
Parking Lot

City's Corporation Yard
10250 Iron Rock Way
Elk Grove, CA 95624
Park at entrance, west side next to fence

CITY OF ELK GROVE

Presentation 9: Stormwater Infiltration using Dry Wells as Low Impact Development (LID) Tool – Project Overview and Construction Presentation/Tour

State Water Resource Control Board

October 23, 2014

Stormwater Infiltration using Dry Wells as a Low Impact Development (LID) Tool

Presented by:
Connie Nelson, CFM
Fernando Duenas, P.E.
City of Elk Grove/Willdan Engineering

October 23, 2014

ELK GROVE

Today's Discussion

- Background
  - California's water situation
  - Groundwater recharge (hydrologic cycle)
  - Effects of urbanization
  - Stormwater as a resource
- Use of Dry Wells as a Low Impact Development Tool
  - What is Low Impact Development?
  - What are dry wells?
- Elk Grove Dry Well Project
  - Project overview
  - Dry well construction
  - Site visits

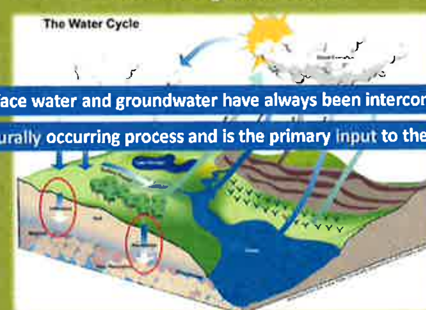
ELK GROVE

Background

- California is in a severe drought
- Legislation is calling for:
  - Water reuse
  - Treating stormwater as a resource
  - Strengthen groundwater management
- A solution may be the use of dry wells for these challenges

ELK GROVE

Groundwater recharge is a hydrologic process where water moves downward from the surface water to groundwater.



Surface water and groundwater have always been interconnected!

Naturally occurring process and is the primary input to the aquifer

Effects of Urbanization

Typical cycle in an undeveloped area.

Typical cycle in an developed area.

5-fold increase in urban runoff in a developed area.

One Solution is to Infiltrate Stormwater

- Reduce urban runoff
- Improve water quality
- Provide groundwater argumentation
- Reduce localized flooding
- Provide habitat enhancement and protects aquatic resources
- Aesthetically pleasing

http://www.nwri-usa.org/documents/Boehm.pdf

"Greener approach…return to natural hydrologic regime."

Dry Wells as a Low Impact Development Tool

What is Low Impact Development?

Innovative stormwater management approach

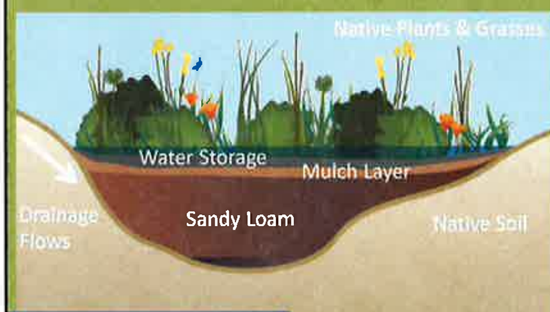
- Manage stormwater at the source
- Mimics natural hydrology
- Captures, stores, cleanses and slowly releases stormwater (reducing peak flows)
- Recharges stormwater to groundwater

ELK GROVE

Example of Low Impact Development

Bioretention and grassy swale

Example of Low Impact Development



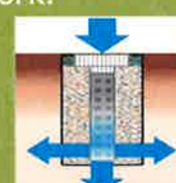
Rain gardens

What are Dry Wells?

- Promote infiltration of stormwater runoff to recharge groundwater
- Can infiltrate stormwater through clay soils
- Use in conjunction with Low Impact Development practices

How does it Work?

- Receives water from one or more entry points
- Collect, store and disburse water
- Discharges water through small openings
- Bottom of dry well is placed at permeable soils



Example Grassy Swale and Dry Well

Bioretention and grassy swales

Elk Grove Dry Well Project

Project Purpose

Evaluate the potential for using dry wells, in combination with low impact development practices to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

…without negatively impacting quality of groundwater.

ELK GROVE

Project Overview

- Conducting 3-year study
- 2 project sites: residential and commercial
- Construction of 2 dry wells with vegetated and structure pre-treatment features (LID)
- Construction of network of monitoring wells
- Perform stormwater and groundwater sampling
- Estimate groundwater recharge capacity and percentage of stormwater captured
- Education and outreach
- Reporting mechanisms

ELK GROVE

Project Team

WILLDAN | extending your reach

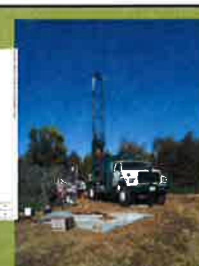
cbec

UCDAVIS

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

CITY OF ELK GROVE

PROUD HERITAGE. BRIGHT FUTURE.



Phase 1:
Site Selection, Design and Construction

2012 - 2014

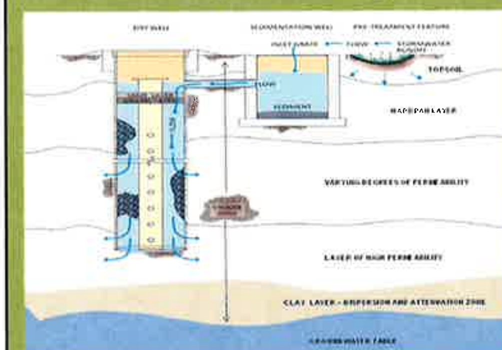
Project Site Locations

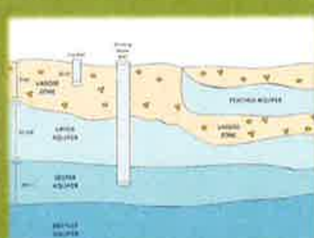
Project Site Schematic

Shallow groundwater well: 55 feet
Deep groundwater wells: 110 feet
Dry well: 40-45 feet

Monitoring Well Network

Dry Well Design





Phase 2: Field Study

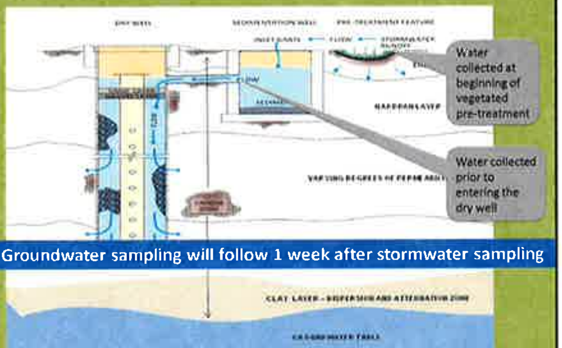
Begins Fall, 2014

Field Study

- Collect and sample stormwater and groundwater for 2 years
  - 3 wet weather stormwater samples
  - 3 wet and 1 dry weather groundwater samples

ELK GROVE

Stormwater Water Sampling



Water Quality Chemistry

- Constituents to be tested in stormwater and groundwater
  - General physical & chemical
  - Metals (EPA 200)
  - Volatiles (EPA 8260)
  - Semi-volatiles (EPA 625)
  - Herbicides (EPA 515)
  - Pyrethroids (WPCL, DFW method)
  - TPH (EPA 8015)
  - Pyrogenic PAHs (EPA 8310)
  - Total coliform

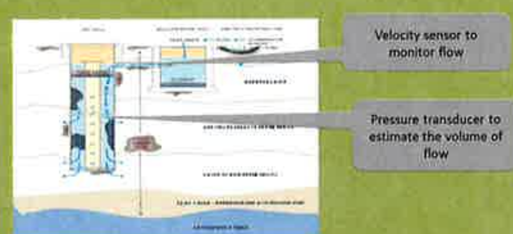
ELK GROVE

Water Quality Chemistry

- Constituents at Corporation Yard
  - Oil and Grease
  - Volatiles and Semi-volatiles compounds
  - Pyrogenic PAHs
- Constituents at Water Quality Basin
  - Pyrethroid pesticides
  - Herbicides such as 2,4-D
  - Nutrients (nitrogen and phosphates)
  - Semi-volatiles (possibly)
  - Oil and grease (possibly)

ELK GROVE

Estimate Recharge and Infiltration Capacities



Logging boring soil samples at well sites

Phase 3:
Fate and Transport Modeling

2014 - 2015

Phase 4:
Education and Outreach

Literature Review
Factsheets
Reports
Website


Construction – Corporation Yard


Construction – Corporation Yard


Construction – Corporation Yard
WAY


Construction – Corporation Yard


Construction – Corporation Yard


Construction – Corporation Yard


Construction – Corporation Yard


Construction – Strawberry Creek Water Quality Basin


Construction – Strawberry Creek Water Quality Basin


Construction – Strawberry Creek Water Quality Basin


Construction – Strawberry Creek Water Quality Basin


Construction – Strawberry Creek Water Quality Basin

Construction – Strawberry Creek Water Quality Basin

Construction – Strawberry Creek Water Quality Basin

Construction – Strawberry Creek Water Quality Basin

Contacts

Project Manager: Connie Nelson, CFM
City of Elk Grove/Willdan Engineering
cnelson@elkgrovecity.org

Q/A Officer: Barbara Washburn, PhD
Office of Environmental Health Hazard Assessment, California EPA
Barbara.Washburn@oehha.ca.gov

ELK GROVE

Questions?
Thank you

Presentation 10: Using Dry wells for Stormwater Infiltration: Assessing the Risk of Groundwater Contamination

American Basin Council for Watersheds Meeting

November 5, 2014

Using Dry Wells for Stormwater Infiltration: Assessing the Risk of Groundwater Contamination

Project Team – Key Staff:

City of Elk Grove/Willdan Engineering: Connie Nelson, Fernando Duenas

OEHHA: Barbara Washburn

cbec eco engineering: Melanie Carr

Ludhorff & Scalmanini: Reid Bryson

November 5, 2014

Background

- Groundwater recharge
  - Recent report (Stanford Woods Institute of the Environment) identified the aquifer as cheapest and easiest way to store water
  - Recharge stormwater to groundwater
  - Manage stormwater at the source
- Water Quality
  - Implementation of LID practices
    - Mimics natural hydrology "greener approach"
    - Capture, stores, cleanse and slowly release stromwater (reducing peak flows)

Today's Discussion

- Background
- Dry wells
- Elk Grove Dry Well Project

What are Dry Wells?

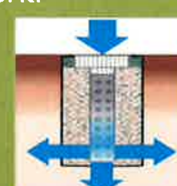
- Promote infiltration of stormwater runoff to recharge groundwater
- Can infiltrate stormwater through clay soils
- Use in conjunction with LID practices

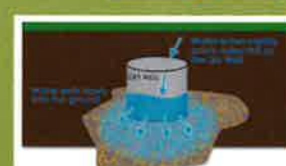
Background

- Uncertain water future
  - Severe drought
  - Climate change
- Legislation is calling for:
  - Water reuse
  - Treating stormwater as a resource
  - Strengthen groundwater management
- A solution may be the use of dry wells for these challenges

How does it Work?

- Receives water from one or more entry points
- Collect, store and disburse water
- Discharges water through small openings
- Bottom of dry well is placed at permeable soils





Example Grassy Swale and Dry Well

Bioretention and grassy swales with dry well

Project Purpose

Evaluate the potential for using dry wells, in combination with low impact development practices to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

...without negatively impacting quality of groundwater.

Elk Grove Dry Well Project

Project Overview

- Conducting 3-year study
- 2 project sites: residential and commercial
- Construction of 2 dry wells with vegetated and structure pre-treatment features (LID)
- Construction of network of monitoring wells
- Perform stormwater and groundwater sampling
  - 8 times over 2 year period
- Estimate groundwater recharge capacity and percentage of stormwater captured
- Education and outreach
- Reporting mechanisms

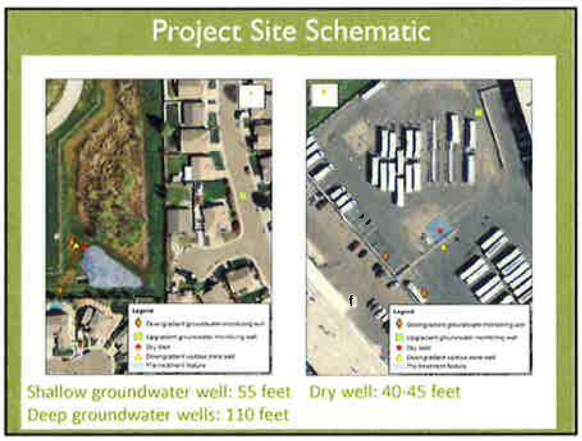
Background

- State funded Stormwater Grant Program
- Total project budget $825,000
- Received grant funding amount $489,820
- In-kind services $335,180
- Awarded grant January 2013

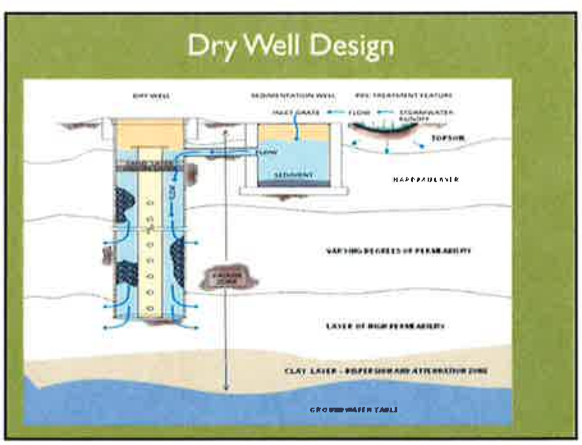
Phase 1:
Site Selection, Design and Construction
2012 - 2014


Project Site Locations
Legend
Roadways
Railroads
Elk Grove City Limits
Strawberry Creek Watershed
Detention Basins & Lakes
Creeks & Channels
Grant Line Channel


Construction – Corporation Yard


Project Site Schematic
Shallow groundwater well: 55 feet
Deep groundwater wells: 110 feet
Dry well: 40-45 feet


Construction – Corporation Yard
WAY


Dry Well Design
TOPSOIL
VARYING DEGREES OF PERMEABILITY
LAYER OF HIGH PERMEABILITY
GROUNDWATER TABLE


Construction – Corporation Yard


Construction – Corporation Yard


Construction – Strawberry Creek Water Quality Basin


Construction – Corporation Yard

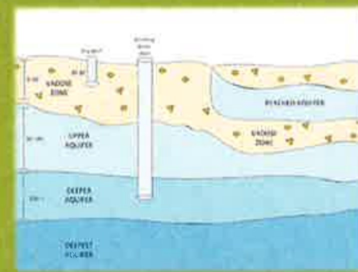

Construction – Strawberry Creek Water Quality Basin


Construction – Corporation Yard


Construction – Strawberry Creek Water Quality Basin

Construction – Strawberry Creek Water Quality Basin

Phase 2: Field Study Begins Fall, 2014



Construction – Strawberry Creek Water Quality Basin

Study Design

- Collect and sample stormwater and groundwater for 2 years
  - 3 wet weather stormwater samples
  - 3 wet and 1 dry weather groundwater samples
- Comparisons to be made:
  - Groundwater quality upgradient and downgradient of dry well
  - Stormwater, vadose zone, and groundwater quality
  - Changes over time – groundwater and vadose zone

Construction – Strawberry Creek Water Quality Basin

Water Quality Chemistry

- Constituents to be tested in stormwater and groundwater
  - General physical & chemical
  - Metals (EPA 200)
  - Volatiles (EPA 8260)
  - Semi-volatiles (EPA 625)
  - Herbicides (EPA 515)
  - Pyrethroids (WPCL, DFW method)
  - TPH (EPA 8015)
  - Pyrogenic PAHs (EPA 8310)
  - Total coliform

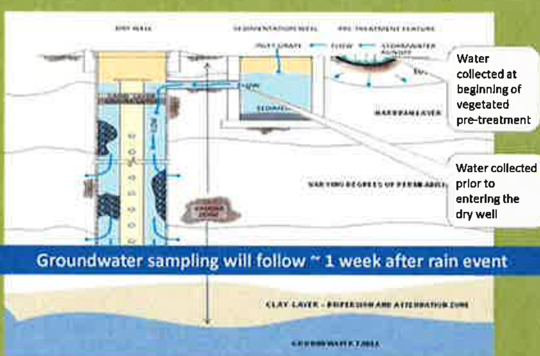
Water Quality Chemistry

- Constituents at Corporation Yard
  - Oil and Grease
  - Volatiles and Semi-volatiles compounds
  - Pyrogenic PAHs
- Constituents at Water Quality Basin
  - Pyrethroid pesticides
  - Herbicides such as 2,4-D
  - Nutrients (nitrogen and phosphates)
  - Semi-volatiles (possibly)
  - Oil and grease (possibly)

Groundwater – Reference Conditions Watch List - Corporation Yard

Analyte	Value Range	MCL	PHG
Arsenic µg/L	ND - 4.7	10	0.004
Antimony µg/L	ND - 4.3	--	0.7
Chromium µg/L	ND - 15	50	Chrome 6: 10
Nitrate mg/L	15 - 57	45	45

Stormwater Water Sampling



Groundwater sampling will follow ~ 1 week after rain event

Groundwater – Reference Conditions Watch List – Strawberry Water Quality Basin

Analyte	Value Range	MCL	PHG
Arsenic µg/L	ND - 4.4	10	0.004
Cadmium µg/L	ND – 4.3	5	0.04
Chromium µg/L	ND	50	Chrome 6: 10
Thallium µg/L	ND - 16	2	0.1

Estimate Recharge and Infiltration Capacities

Velocity sensor to monitor flow

Pressure transducer to estimate the volume of flow

Logging boring soil samples at well sites

Phase 3:
Fate and Transport Modeling
2014 - 2015

Key Questions Fate and Transport Modeling

- How long will it take contaminants detected near the bottom of the dry well to reach the water table?
- Could the elevated concentrations of salts usually found in stormwater have the effect of dissolving naturally occurring toxic metals such as arsenic?

Summary of Key Findings Review of the Literature

- Lack of a clear link between dry well use and groundwater contamination
- Pretreatment important – reduces clogging and removes contaminants associated with sediments
- Don't use at high risk sites (industrial, etc.)
- Keep away from public supply wells (>150 ft.??)
- Water soluble constituents pose a risk (nitrate)
- Sedimentation wells and vadose zone trap many contaminants

Phase 4:
Education and Outreach
2013 - 2017

Contacts

Project Manager: Connie Nelson
City of Elk Grove/Willdan Engineering
cnelson@elkgrovecity.org

Barbara Washburn
Office of Environmental Health Hazard Assessment, Cal/EPA
barbara.washburn@oehha.ca.gov

Education and Outreach

- Series of factsheets
- Annotated bibliography on dry wells and influence on groundwater quality
- Lessons Learned Report
- Peer-reviewed publication
- Presentations (such as this!!)

Questions?

Thank you

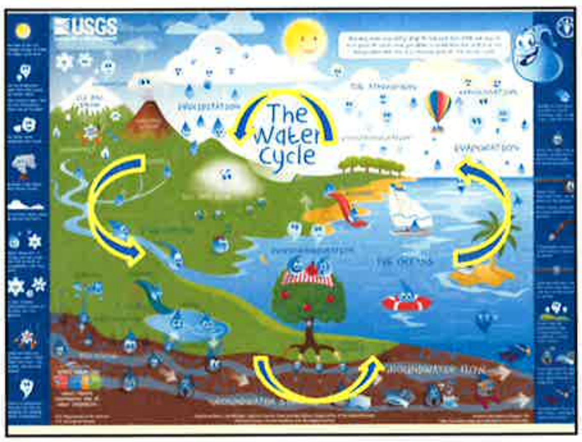
Presentation 11: Dry Wells and Rain Gardens: Eco-Friendly Ways to Manage Stormwater

Stormwater Detectives Program, City of Lodi

May 14, 2015

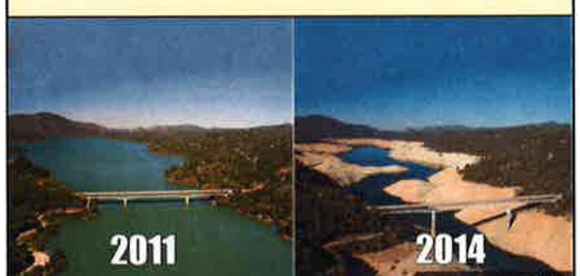
DRY WELLS AND RAIN GARDENS: ECO-FRIENDLY WAYS TO MANAGE STORMWATER

WHAT IS STORMWATER?



WHY DO ALL THIS?

LAKE OROVILLE



FOLSOM LAKE

KEEP RAIN WHERE IT FALLS!

Retain all the water that falls on your property. This can be done with by a variety of approaches, you are only limited by your creativity:

Rain Gardens
Rain Barrels/Cisterns
Rain Chains
Driveway Material
Innovative Ideas

RAIN GARDENS AND BIOSWALES

Present a great opportunity to retain stormwater on site in an aesthetically pleasing manner.

DISCONNECT

Disconnect rain gutters that run to the street or piped stormwater systems.

Celebrate stormwater, replace traditional gutters with…

ALTERNATIVE PAVEMENTS

Reduce the amount of paving.

Use gravel, Hollywood Driveways, permeable pavements!

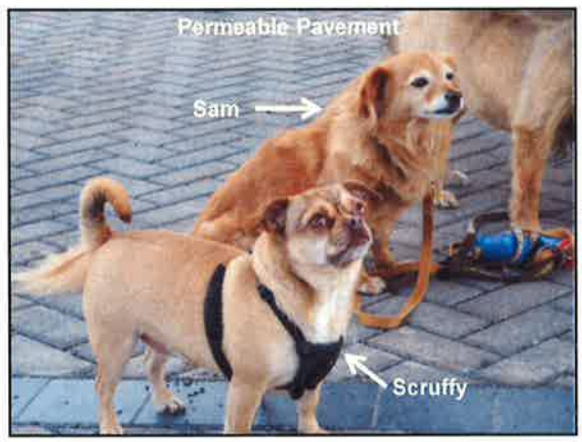
Site Design: Material Choices

Choose pervious materials, that allow rain water to infiltrate.


ELK GROVE
RAIN GARDEN PLAZA


City Employee Parking Lot
Elk Grove PD
Colton Park
EXISTING 1 ACRE SITE
ELK GROVE
RAIN GARDEN PLAZA

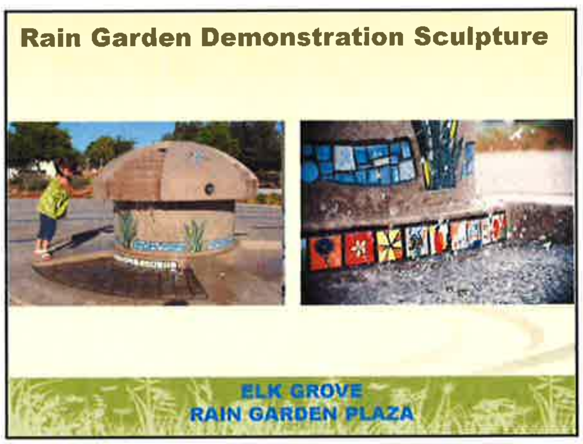

PERMEABLE PAVERS


Permeable Pavement
Sam
Scruffy

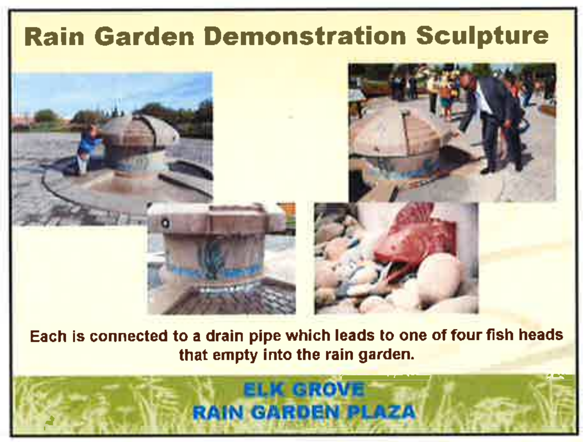

Charlie
Permeable Pavement


Rain Water Harvesting
Shade canopy not only provides a shaded area to sit and have lunch but includes rain harvesting techniques such as rain barrels and rain chains.
ELK GROVE
RAIN GARDEN PLAZA
CSD

Rain Garden Art
ELK GROVE
RAIN GARDEN PLAZA

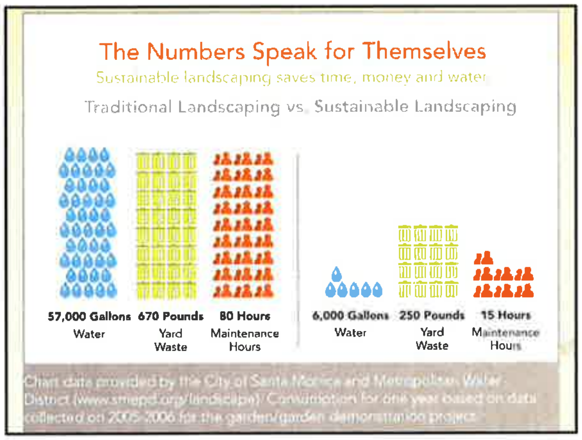


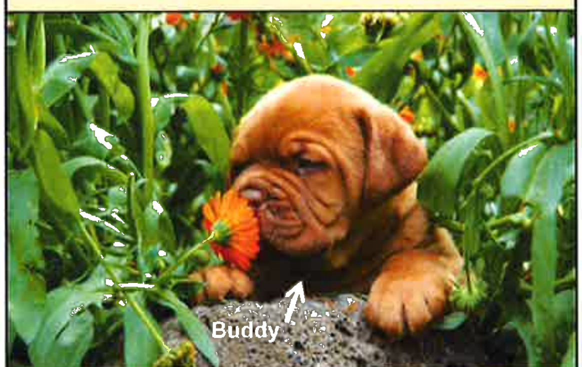
Rain Garden Demonstration Sculpture
ELK GROVE
RAIN GARDEN PLAZA



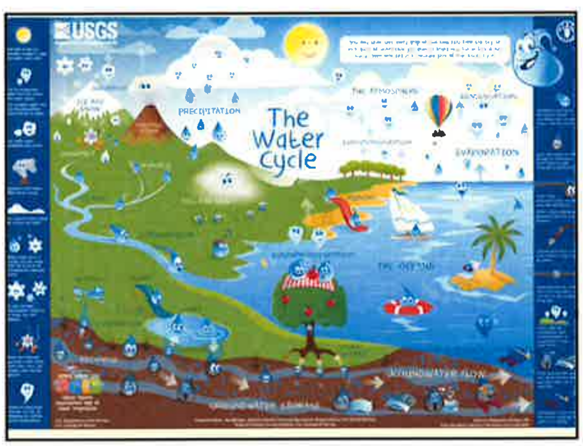
Rain Garden Demonstration Sculpture
Each is connected to a drain pipe which leads to one of four fish heads that empty into the rain garden.
ELK GROVE
RAIN GARDEN PLAZA

Adult Fitness





WHAT
IS
A DRY WELL?

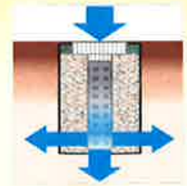


What Are Dry Wells?

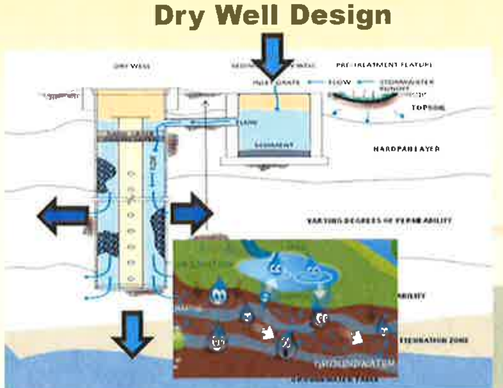
- Promote infiltration of stormwater runoff to recharge groundwater
- Can infiltrate stormwater through clay soils

How Does It Work?

- Receives water from one or more entry points
- Collect, store and disburse water
- Discharges water through small openings
- Bottom of dry well is placed at permeable soils



Dry Well Design



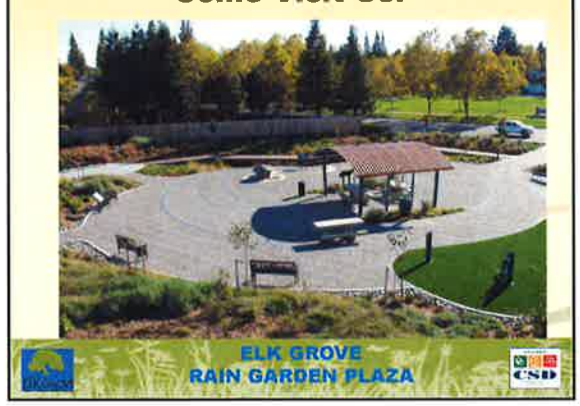
Construction – Strawberry Creek Water Quality Basin

Construction – Corporation

DRY WELL AT RAIN GARDEN

WHAT CAN YOU DO?

Come Visit Us!



Presentation 12: Stormwater Infiltration using Dry Wells as a Low Impact Development Tool

Low Impact Development Conference, American Basin Council for Watersheds and CSUS's Office of Water Program

November 4, 2015

Stormwater Infiltration using Dry Wells as a Low Impact Development Tool

Connie Nelson, CFM[1]
Barbara Washburn, PhD[2]

[1]*City of Elk Grove/Willdan Engineering*
[2]*Office of Environmental Health Hazard Assessment, California EPA*

ELK GROVE

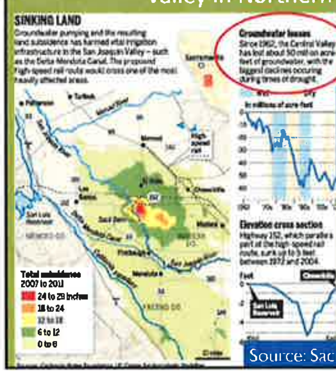
Today's Discussion

- California water situation and recharge opportunities
- What are dry wells
- How to integrate low impact development (LID) practices with dry wells
- Elk Grove Dry Well Project and results to date
- Regulations and permitting issues with dry wells

Background

- California is in a severe drought
- Legislation is calling for:
  - Water reuse
  - Treating stormwater as a resource
  - Strengthening groundwater management
- A solution may be the use of dry wells with LID practices for these challenges

Groundwater Supplies Depleting in Central Valley in Northern California



- Sinking Land
- 50 million acre feet groundwater lost

Source: Sacramento Bee, April 2014

Groundwater provides 30 percent of the California's water supply

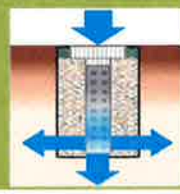
- 431 groundwater basins
- Covers 40% of the State
- Storage capacity:
  - ✓ 851 million acre-feet (not all useable)

What are Dry Wells?

- Gravity fed excavated pits lined with perforated casing filled with gravel
- Deeper than width
  - 3 feet wide
  - 20 to 60 feet
- Can be used in conjunction with LID practices

How do they work?

- Receives water from one or more entry points
- Collects, stores, and disburses water
- Discharges water through small openings
- Bottom/sides of dry well placed at permeable soils



Value of Using Dry Wells in California

- Captures and stores urban stormwater runoff
- Facilitates stormwater infiltration **even in clay soils**
- Can improve surface water quality
- Facilitates groundwater recharge
- Helps meet hydromodification management goal
- Reduces localized flooding
- Sustainable change

General Concept of LID Features with a Dry Well

Elk Grove Dry Well Project

- Background
- Stormwater and groundwater monitoring
- Fate and transport of contaminants
- *Education and outreach*

Monitoring event November 2, 2014 at Strawberry Creek Water Quality Basin

Background

- State funded Stormwater Grant Program
- Total project budget $825K
- Received grant funding amount $490K
- In-kind services $335K
  - City of Elk Grove $195K
  - OEHHA $140K
- Fate and Transport Modeling (complementary, $135K)
- Grant term 4-years

Project Team

City of Elk Grove

WILLDAN

cbec

UC DAVIS

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

OEHHA

California Water Boards

Project Purpose

Evaluate the potential of using dry wells, in combination with low impact development practices, to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

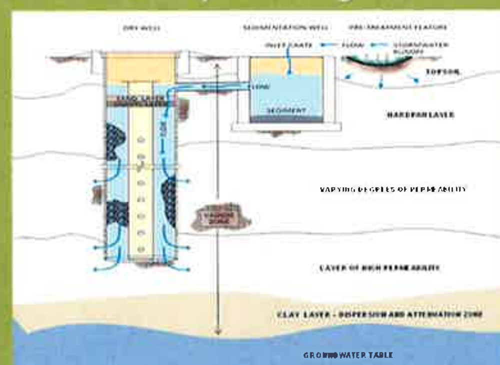
without negatively impacting groundwater quality

Project Site Locations

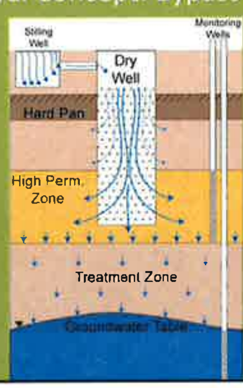
Project Site Schematic

Vadose zone well: 55 feet, water table wells: 110 feet

Dry Well Design



General Concept: Bypass Hardpan



Monitoring event November 2, 2014 at Strawberry Creek Water Quality Basin

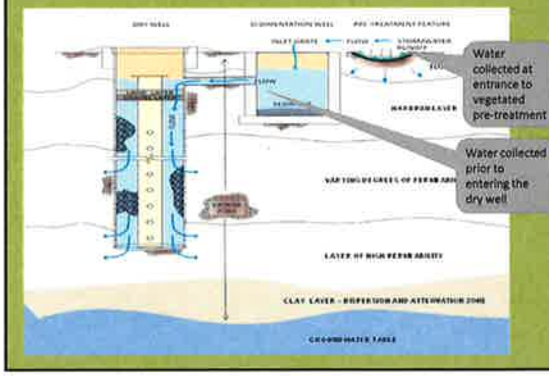
Stormwater and Groundwater Monitoring

Fall 2014 – Spring 2016

Water Quality Monitoring Plan

- Collect and sample stormwater and groundwater for 2 years
  - 6 wet weather stormwater samples
  - 6 wet and 2 dry weather groundwater samples
- Flow weighted composite samples collected over 80% of storm volume

Stormwater Sampling



Water Chemistry

- Constituents to be tested in stormwater and groundwater
  - General physical and chemical
  - Metals
  - Volatiles
  - Semi-volatiles
  - Herbicides
  - Pyrethroids
  - Total petroleum hydrocarbons - gas diesels
  - Pyrogenic polycyclic aromatic hydrocarbons
  - Total coliform

Water Quality Monitoring Findings: Year 1

Date	Strawberry Creek Water Quality Basin
8/4/14 Groundwater	Mn: 240 ppb (50; aesthetics)

2/6/15 Stormwater (composite collected at stormwater outfall)	• Organoleptic metals stormwater outfall (Al, Fe)
	• Bifenthrin:
	  • Stormwater outfall: 97 pptr
	  • Sedimentation well: 63 pttr
	• Trace amts other pyrethroids

2/6/15 Groundwater	• Bifenthrin: 7 pptr vadose zone • Dalaphon: 3 ppb downgradient • Total coliform: 1600 MPN/100 ml vadose & downgradient wells

Results: Year I

Date	Strawberry Water Quality Basin

4/24/15 Stormwater (composite collected at outfall)	• Toluene 0.84 ppb (150)
	• Coliform >1600
	• Bifenthrin:
	  • Stormwater outfall: 2.2
	  • Sedimentation well: 5

4/24/15 Groundwater	• No collection
8/4/14 Groundwater	NO_3: 57 ppm (45)

Results: Year I

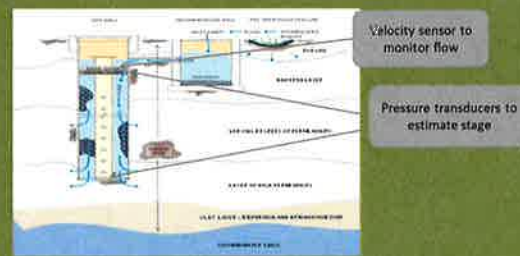
Date	Corporation Yard
4/24/15 Stormwater (composite collected at sedimentation well)	• Organoleptic metals (Fe, etc.) • Coliform: >1600 MPN;/100 ml • Bifenthrin: • Curbcut: 4 pptr

Few contaminants detected in dry well system
- Pretreatment removes over 50% of suspended solids
- Subsurface attenuation

Monitoring Plan: 2015-2016

- 5 monitoring events
- 1st flush event includes 2 flow-weighted composites
  - Early phase of runoff (highest contaminants)
  - Middle-later phase up to 80% of total
- 3 monitoring events
  - Flow weighted composites
    - ✓Modify analytes:
      - Remove VOCs, SVOCs, PAHs, herbicides
      - Add neonicitinoids (imidacloprid) and phenylpyrazoles (fipronil, and/or PPCPs)

Recharge and Infiltration Capacities



Preliminary infiltration rate:
Corporation Yard: 20 - 97 gpm (varies by intensity of storm event)
Strawberry Creek Water Quality Basin: 70 - 80 gpm


Logging boring soil samples at well sites

Fate and Transport of Contaminants

Fate and Contaminant Modeling

- UCD hydrologists (G. Fogg, T. Harder and E. Edwards)
- Address two major concerns:
  - How far might contaminants migrate from bottom of dry well over many years?
  - Could naturally occurring metals (e.g. As, U) be mobilized as a result of stormwater influx?


City of Elk Grove Corporation Yard dry well system

Education and Outreach

Education and Outreach

- Factsheets
  - Regulations
  - Dry well programs other states
  - Findings of the project
- Annotated Bibliography
- Lessons Learned Report
- Journal article

Dry Well Regulations and Permitting

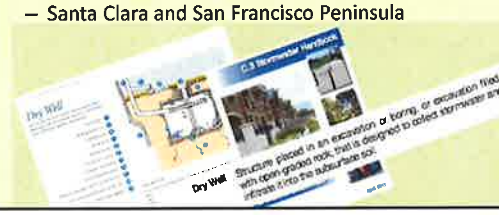
US EPA Underground Injection Control (UIC) Program

- 1989: Authorized use of UICs but runoff entering dry well cannot exceed MCL
- 1999: Performed large study, concluded:
  - Additional regulations unnecessary
  - No evidence of contamination problems
- 2002: EPA Region 9 Factsheet
  - EPA primary agency for overseeing Class V Injection Well Program in California
  - Identified Regional Boards and local agencies to promulgate additional regulations and guidelines

Dry Well Regulations and Permitting

Municipalities follow two different set of rules:

1. US EPA guidelines for UIC wells:
   - Southern California and San Francisco:
   - Southern California 10,000 dry wells
   - Santa Clara and San Francisco Peninsula



Dry Well Regulations and Permitting

2. Follows DWR Bulletin 74-81 and 74-90 – guidelines for drinking water wells; prevent surface water from entering subsurface to protect groundwater

   Sacramento region and other areas:
   - Interpretation assumes stormwater is a waste product
   - Wells "used for the injection of reclaimed waste water" including "dry wells," "drainage" wells and sewer wells
   - Waste defined as "sewage and all other waste substances of human or animal origin...."
   - Waste defined as Local interpretation: Dry well should be constructed to drinking water well standards and permitted as such

Dry Well Regulations and Permitting

Challenges

- Dry wells not commonly used in Sacramento region; difficult to obtain permit
- No regional guidelines for design, placement, monitoring, etc.
- Caution among stormwater managers

BUT.....

- LID/hydromodification requirements
- Water Board "Stormwater Initiative"
- Drought, climate change - all push for more infiltration and groundwater recharge

Dry Well Regulations and Permitting

Summary

- Sacramento region and other areas of California:
  - No streamlined municipalities guidelines
  - Lack of State Class V UIC Program: a barrier to effective use of dry wells for stormwater as a resource

Primary Enforcement Responsibility throughout United States

Lack of statewide UIC program has led to piecemeal practices around the State

Oregon's Underground Injection Control Program

- Good example of a carefully designed program
- Permits given by Oregon Department of Environmental Quality (DEQ)
- Requirements of permit
  - Monitoring of runoff just prior to entering dry well to determine that it meets drinking water standards
  - Modeling of fate and transport
  - Prohibition of use of dry wells in high risk areas: industrial, gas stations, etc.

Oregon's Underground Injection Control Program: Portland

- 20,000 UICs – public and private
- Ten year Monitoring Program
  - 30 sites, 6 times/year, and extensive list of contaminants
- Model to determine fate and transport
- Received renewal of 1st 10 year permit
- Beginning second decade of UIC Program
- Identified little evidence of groundwater contamination

Elk Grove Dry Well Project

Preliminary Lessons Learned

- No evidence that dry wells contributed to groundwater contamination
  - Consistent with literature and experiences from other States
- Challenges to placement and construction of dry well systems

Bigger Picture

- Dry wells serves multiple benefits:
  - Aquatic ecosystem protection
  - Improved water quality
  - Groundwater recharge
- Need to use stormwater as a resource
- A key driver for use of dry wells with LID practices is drought and climate change

Contact

Connie Nelson, Project Manager
cnelson@elkgrovecity.org
(916) 478-3638
www.egpublicworks.org......click the dry well tab

THANK YOU!

Presentation 13: Summary of Dry Well Guidelines and Regulations in California

Central Valley Regional Board

November 5, 2015

SUMMARY OF DRY WELL GUIDELINES AND REGULATION IN CALIFORNIA

November 2015

Barbara Washburn
Office of Environmental Health Hazard Assessment (OEHHA)
barbara.washburn@oehha.ca.gov
916-316-7982

US EPA UIC Program

- 2002: EPA Region 9 Factsheet:
  - ✓ EPA primary agency for overseeing Class V Injection Well Program in California
  - ✓ Identified Regional Boards and local agencies to promulgate additional regulations and guidelines

Dry Well Regulations and Permitting Background

US EPA Underground Injection Control (UIC) Program

- 1974: Passed and amended several times State Drinking Water Act
- 1980: Authorized use of UICs but runoff entering dry well cannot exceed MCLs (maximum contaminant levels)
- Section 1422: States may apply to EPA for primacy to administer UIC program
- 1983: California and US EPA agreed to split primary responsibility:
  - ✓ California: Class II: gas/oil production waste
  - ✓ US EPA: Class I, III, IV, V, and now VI

Dry Well Regulations and Permitting

Municipalities follow two different set of rules:

1. Allow use of dry wells following US EPA reporting requirements:
   - Southern California 10,000 dry wells
   - *Santa Clara* and *San Francisco* Peninsula

US EPA UIC Program

- 1987: Report to Congress on Class V wells:
  - ✓ Stormwater drainage: moderate risk
  - ✓ Need to inventory all existing and future wells
- 1993: Suit against EPA by Sierra Club asserting inadequate regulation of Class V wells to protect groundwater:
  - ✓ One outcome: fluids entering wells not to exceed MCLs (drinking water standards) or other health based standard
- 1999: Performed large review of Class V wells:
  - ✓ Additional regulations unnecessary
  - ✓ No evidence of contamination problems

Dry Well Regulations and Permitting

2. Require permit based on DWR Bulletin 74-81 and 74-90:
   - Guidelines for drinking water wells; prevent surface water from entering subsurface to protect groundwater
   - Wells "used for the injection of reclaimed waste water" including "dry wells," "drainage" wells and sewer wells
   - Waste defined as "sewage and all other waste substances of human or animal origin…."
   - Sacramento region: Dry well should be constructed to drinking water well standards and permitted as such

Dry Well Regulation and Permitting

Challenges

- Dry wells not commonly used in Sacramento region; difficult to obtain permit
- No regional guidelines for design, placement, monitoring, etc.
- Caution among stormwater managers in Sacramento and throughout California

BUT

- LID/hydromodification requirements
- Water Board "Stormwater Initiative"
- Drought, climate change - all push for more infiltration and groundwater recharge

Primary Enforcement Responsibility throughout United States

Lack of statewide UIC program has led to piecemeal practices around the State

Some might put groundwater quality at risk

In addition, consider California Water Code: Waste Discharge Requirements

- Anyone seeking to discharge "waste" to the land or water must submit a Waste Discharge Report to the Regional Board, including construction of an "injection well:"
  - ✓ Fill out report
  - ✓ Wait 140 days, if not contacted by Regional Board…OK to proceed
  - ✓ Must also submit CEQA documentation
  - ✓ For Region 5, does not appear Waste Discharge Report utilized
  - ✓ Other regions????
  - ✓ California Water Code Sections13263.5, 13264

Dry Well Regulation and Permitting

What we've learned so far….

- No streamlined municipalities guidelines
- Lack of State Class V UIC Program - a barrier to effective use of dry wells to use stormwater as a resource

Lastly, State's Anti-Degradation Policy

- Discharges that could affect surface or groundwater not permitted if degradation of high-quality water
- Some degradation of high quality water is permitted if there are maximum benefits to the people of the State
- Determined case by case basis taking into account
  - ✓ Beneficial uses
  - ✓ Economic costs
  - ✓ Social costs
  - ✓ Environmental impacts
  - ✓ Alternatives
- In the current context:
  - ✓ Would dry wells degrade groundwater quality?
  - ✓ Do the benefits offset the risks?

Oregon's Underground Injection Control Program

- Good example of a carefully designed program
- Permits given by Oregon Department of Environmental Quality (DEQ)
- Requirements of permit
  - ✓ Monitoring of runoff just prior to entering dry well to determine that it meets MCLs (drinking water standards)
  - ✓ Modeling of fate and transport
  - ✓ Prohibition of use of dry wells in high risk areas: industrial, gas stations, etc.

Oregon's Underground Injection Control Program: Portland

- 20,000 UICs – public and private
- Ten year Monitoring Program
  - ✓ 30 sites, 6 times/year, and extensive list of contaminants
- Model fate and transport
- Received renewal of 1st 10 year permit recently
- Identified little evidence of groundwater contamination

Information on Elk Grove Dry Well Project

Connie Nelson, Project Manager
cnelson@elkgrovecity.org
(916) 478-3638
www.egpublicworks.org......click the dry well tab

Elk Grove Dry Well Project

Preliminary Lessons Learned

- No evidence that dry wells contributed to groundwater contamination
  - ✓ Consistent with literature and experiences from other States
- Challenges to placement and construction of dry well systems

Bigger Picture

- Dry wells serves multiple benefits
  - ✓ Aquatic ecosystem protection
  - ✓ Improved water quality
  - ✓ Groundwater recharge
- Need to use stormwater as a resource
- A key driver for use of dry wells and Low Impact Development (LID) in general is drought and climate change

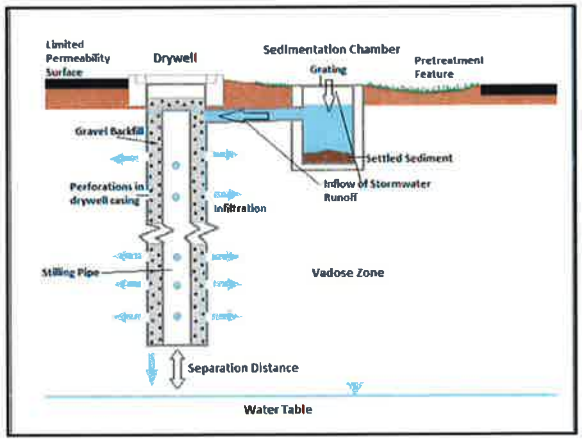
Presentation 14: An Evaluation of Dry Wells as Tools for Stormwater Management and Aquifer Recharge

NWRI/DWR Workshop on Drought Vulnerability and Tools for Improving Water Resilience, Los Angles

October 19 - 20, 2016

An Evaluation of Drywells as Tools for Stormwater Management and Aquifer Recharge

Emily Edwards
University of California, Davis
Department of Land, Air and Water Resources
10/20/2016



Talk Overview

- Drywell definition and description
- Significance of drywell technology in CA
- Drywell infiltration quantity studies
- Drywell infiltration quality studies
- Drywell numerical modeling
- Recommendations and takeaways

Drywell Prevalence

- Approximately 250,000 drywells in the US in 1999
- Currently:
  - 100,000 in Washington state
  - 19,000 in Portland, OR
  - 52,000 in AZ
  - At least 35,000 in CA
- 11,000 drywells used for 50 plus years in Modesto, CA

What is a drywell?

- A well that is deeper than its widest surface dimension used to transmit surface water to the subsurface (EPA, 1999)

Why evaluate drywell technology?

- Drywells have been in use across the world for more than half a century
- Used extensively in Arizona, Oregon, and Washington
- Some reluctance to use in California due to concerns about potential for groundwater contamination
- Scientific studies performed in other states have lead to drywell regulation reform

Why now?

- CA currently entering sixth year of severe drought
- Subsurface storage increasingly looked to as solution for water availability and timing issues
- Drywells evaluated as tools to significantly and safely recharge aquifers in CA

National Stormwater Quality

Land Use Type	Commonly Detected SW Contaminant Categories	Possible Sources of Contaminants
Agricultural	Herbicides, insecticides, nutrients, VOCs	Crop applications, fertilizers, livestock and dairy production
Urban: Commercial	Bacteria, metals, nutrients, petroleum by-products	Pavement runoff
Urban: Industrial	Bacteria, metals, nutrients, PAHs, petroleum by-products	Pavement runoff, industrial processes
Urban: Residential	Bacteria, dissolved minerals, herbicides, metals, nutrients, petroleum by-products	Pavement runoff, yard applications, septic systems, household usage

Infiltration Quantity Studies

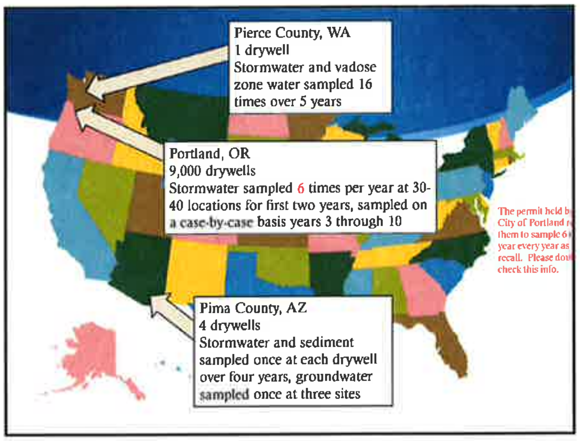
- Portland, OR (1994), 5,700 drywells this contradicts previous slide info (19000) Maybe reflects number of UICs in 1994. Consider referencing more recent work (this is about 20 years old)
  - 75% of precipitation falling on paved surfaces enters drywells
  - 126,600 acre-feet per year
  - 38% of total groundwater recharge unclear what this means – 38% of total recharge is through UICs? Or 38% of total runoff is recharged
- Bend, OR (2011), 5,000 drywells
  - 63% of precipitation falling within city enters drywells
  - 13,400 acre-feet per year
  - 12% of total groundwater recharge
- Los Angeles, CA (2010)
  - 384,000 acre-feet per year ????

Drywell Studies

- Goals of studies: quantify recharge volume, or determine recharge quality and possible effects to hydrologic system
- Study Types: pilot scale and full scale field studies, analytical and numerical modeling studies
- Study Locations: mostly U.S. (Arizona, California, Hawaii, Montana, New Jersey, Oregon, Washington, Wisconsin), also France and U.K.

Infiltration Quality Studies

- General design of field studies:
  - Stormwater monitoring
  - Groundwater monitoring
  - Criteria for groundwater risk decision-making process
- Differences between studies:
  - Scale of study
  - Drywell design
  - Rigor of monitoring and water quality analysis
  - Subsurface conditions
  - Land use of sites



Contaminants Above MCLs

Contaminant Category	Metals	SVOCs and VOCs	PAHs	Nutrients/Minerals
Contaminants detected in stormwater	Arsenic, cadmium, chromium, copper, lead (3), nickel, thallium, zinc	Benzene, carbon tetrachloride, pentachloro-phenol	Benzo(a)pyrene (3), benzo(b)fluor-anthene, chrysene	Nitrogen, sodium (2)
Contaminants detected in groundwater	arsenic, uranium			Nitrogen (3), sodium (2)
Land use	Residential, commercial, agricultural	residential	residential	Agricultural, road-side

Factors that Affect Field Study Results

- Rigor of monitoring efforts
- Thoroughness of water analysis
- Duration of study
- Subsurface conditions
- Regulatory environment

Groundwater Contamination Risk

- Groundwater protectiveness of drywells dependent on:
  - Contaminants in stormwater and their concentrations
  - Composition of subsurface (presence of clay layers below drywell)
  - Separation distance between drywell bottom and seasonal high water table
  - Use of pretreatment in design (only 6 of 13 studies)

Contaminants Detected in Stormwater and Groundwater

- Metals (11/12)
- SVOCs and VOCs (5/12)
- PAHs (4/12)
- Pesticides (4/12)
- Other organics (5/12)
- Nutrients/minerals (7/12)
- Biological contaminants (3/12)

Conclusions from Field Studies

- Majority of studies (9 out of 13) concluded drywells do not pose threat to groundwater and drinking water quality
  - What did the other studies conclude?
- Studies that incorporated pretreatment into design (6 out of 13) concluded it helped reduce contaminant concentrations and prevent clogging
- Some studies indicated that a longer study period was needed to reach final conclusions

Recent project in Elk Grove, CA?

- Two year study conducted by OEHHA CalEPA and City of Elk Grove, two different land uses.
  - Residential neighborhood
  - Vehicle servicing site (City Corporation Yard)
- Dry well system composed of swale (Corp Yard) or water quality basin (residential site) and dry well. Sedimentation well constructed but functioned poorly as a result of design limitations.

Take Aways

- Drywells can be an effective means to safely manage stormwater runoff and significantly recharge groundwater as long as:
  - Influent stormwater is not heavily contaminated
  - Appropriate pretreatment is used
  - Sufficient separation distance to groundwater is allowed
  - Subsurface provides adequate contaminant attenuation over time

Elk Grove Study

- Stormwater, vadose zone, and groundwater monitoring performed 6 times in two years
- Contaminants used in numerical modeling: Al, bifenthrin, Cr (total and VI), di-ethyl hexyl phthalate (DEHP), Fe, Mn, permethrin, TBA
- Results: no contaminants exceeded MCLs in groundwater after 500 years of 220 days of stormwater infiltration/year except Al after 318 years
  - Al: detected at Corporation Yard (bus servicing station). Results suggest a combination of either improved pretreatment needed and/or restricted use of dry wells at vehicle servicing/washing facilities (these restrictions apply in WA, for example).
- Conclusions: with adequate pretreatment and in the presence of clay units in the vadose zone, dry wells use does not appear to pose risk to groundwater quality, even with long term use.

DE
fan

References

- Edwards, Emily C., Thomas Harter, Graham E. Fogg, Barbara Washburn, and Hamad Hamad. "Assessing the Effectiveness of Drywells as Tools for Stormwater Management and Aquifer Recharge and Their Groundwater Contamination Potential". Journal of Hydrology 539 (2016): 539-553.
- Access online at http://dx.doi.org/10.1016/j.jhydrol.2016.05.059

Recommendations for Drywell Use

- Assess nature and concentration of contaminants in stormwater, using existing data or perform new studies.
- Include pretreatment (vegetative and/or structural)
  - Subsurface conditions helps to inform extent of pretreatment needed
  - Optimal conditions: some clay
- Monitor groundwater for changes in quality
- Regular monitoring of stormwater entering dry well
  - Benchmark: MCL
- Proper maintenance to avoid clogging

Presentation 15: Dry Well Use for Groundwater Recharge and Stormwater Management: Lessons Learned From the Elk Grove Dry Well Project

Sacramento Chapter Groundwater Resources Association Meeting

November 8, 2016

DRY WELL USE FOR GROUNDWATER RECHARGE AND STORMWATER MANAGEMENT: LESSONS LEARNED FROM THE ELK GROVE DRY WELL PROJECT

Barbara Washburn, PhD
Ecotoxicology Program
Office of Environmental Health Hazard Assessment, Cal/EPA

TEAM PARTNERS AND ACKNOWLEDGEMENTS

Connie Nelson, Project Manager, City of Elk Grove and Willdan Engineering

cbec ecoengineering: Chris Bowles, Ben Taber, Rafael Rodriguez, Chris Campbell

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

Ludhorff/Scalmanini: Reid Bryson, Vicki Kretsinger

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

Funded by Proposition 84 Stormwater Grant to the City of Elk Grove, State Water Resources Control Board, Division of Financial Assistance, Grant Manager: Kelley List

TODAY'S DISCUSSION

- What are dry wells and how might they be useful
- How to integrate dry wells with low impact development (LID) practices
- Background of Elk Grove Dry Well Project
- Project description and results
- Lessons learned
- Use of dry wells in other states
- Future for use of dry wells in California

DRY WELL OR UNDERGROUND INJECTION CONTROL SYSTEM

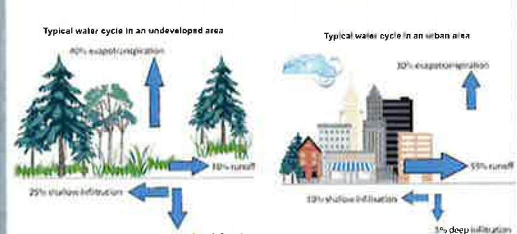
- Gravity fed excavated pits lined with perforated casing filled with gravel
- Deeper than width
  - 3 feet wide
  - 20 to 60 feet
- Can be used in conjunction with LID practices

- Receives water from one or more entry points
- Collects, stores, and distributes stormwater
- Discharges water through small openings
- Bottom/sides of dry well placed at permeable soils

Two chambered Maxwell Plus, Torrent Resources

VALUE OF USING DRY WELLS

- Management of urban stormwater runoff
- Localized flooding
- Damage to aquatic ecosystem – scour and pollutants



DRY WELLS CAN BE INTEGRATED INTO LID FEATURES

LID practices that capture and infiltrate stormwater at or near where rain falls. Ex: swales, rain gardens, pervious pavement

Challenge in our region: CLAY SOILS (Class C and D) that make infiltration difficult

Dry wells can be constructed to bypass clay layers and reach units with high % sand and gravel

GRASSY SWALE WITH DRY WELL

VALUE OF USING DRY WELLS

Facilitates groundwater recharge and addresses:

- Efforts of State Water Resources Control Board to use stormwater as a resource, one of which is aquifer recharge
- Water shortages caused by drought
- Water storage challenges linked to changing climate

ELK GROVE DRY WELL PROJECT

CITY OF ELK GROVE

WILLDAN | extending your reach

cbec

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

PROJECT PURPOSE

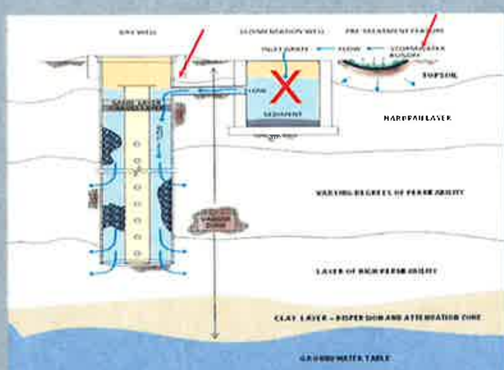
Assess risk to groundwater quality associated with infiltrating stormwater through dry wells

- Estimate recharge capacity
- Understand practices in other states
- Provide information to stormwater and groundwater managers and the public in general

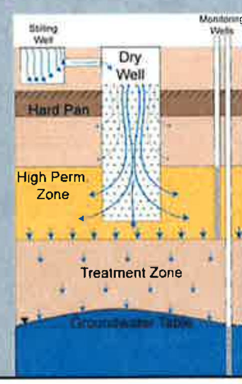
ELK GROVE DRY WELL PROJECT LOCATIONS

MONITORING WELL NETWORK AND DRY WELL

Vadose zone well: 55 feet, water table wells 110 feet

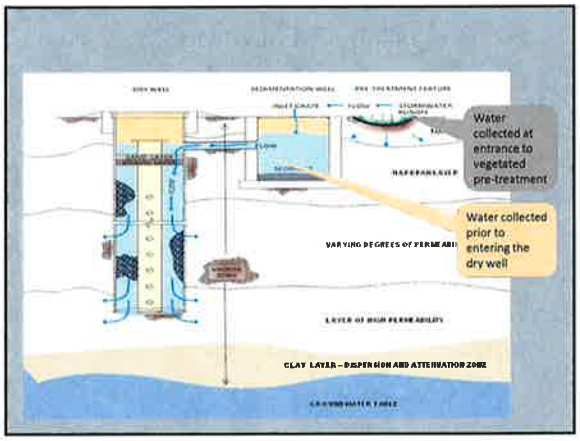


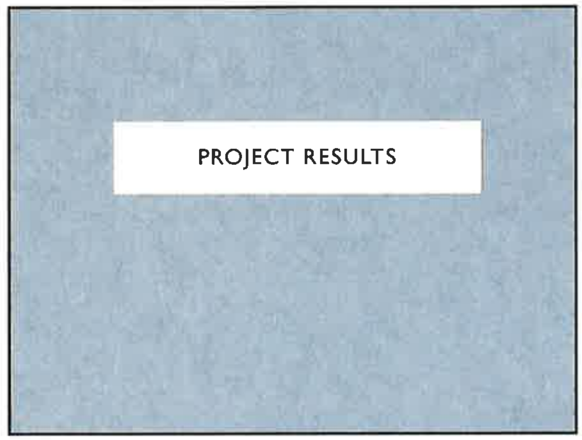
General Concept: Bypass Hardpan

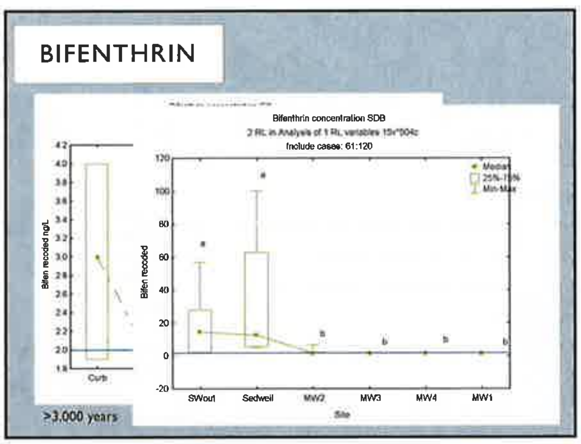


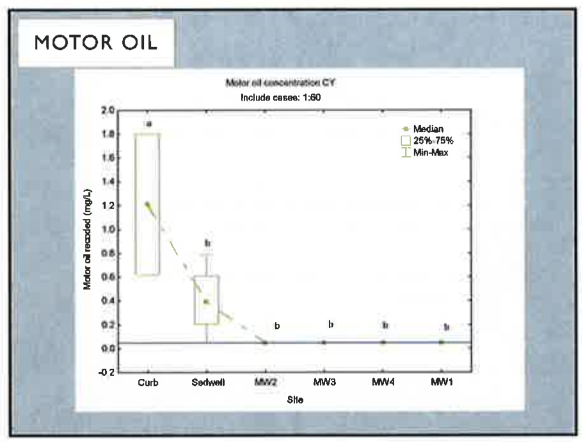
WATER QUALITY MONITORING PLAN

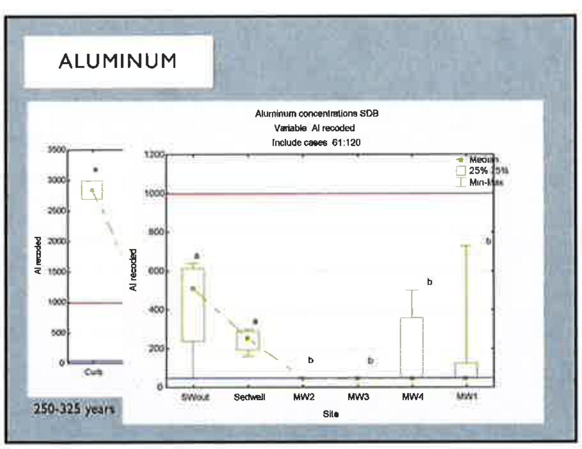
- Collect stormwater and groundwater for 2 years
  - 5 wet season stormwater and groundwater
  - Groundwater: pre-construction, 2 dry season
  - Contaminant analysis:
    - Organics (VOCs, SVOC, PAHs, gas, diesel, etc.)
    - Pesticides/Herbicides
    - Metals
    - Bacteria

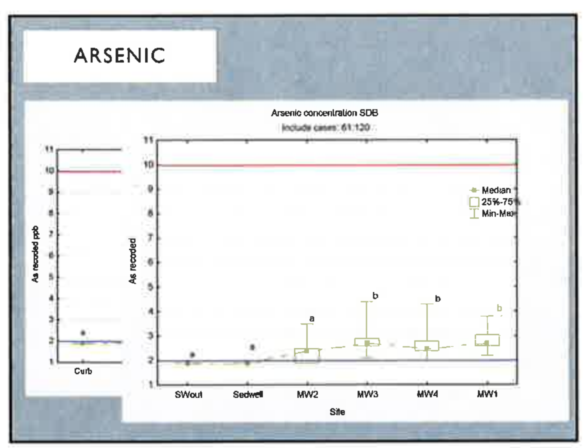

Water collected at entrance to vegetated pre-treatment
Water collected prior to entering the dry well
CLAY LAYER – DISPERSION AND ATTENUATION ZONE


PROJECT RESULTS

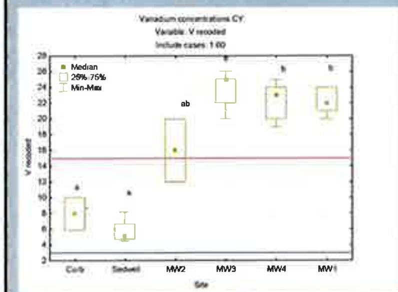

BIFENTHRIN
Bifenthrin concentration SDB
Include cases: 61:120
Bifen recoded
Site
SWout
Sedwell
MW2
MW3
MW4
MW1
Curb
>3,000 years


MOTOR OIL
Motor oil concentration CY
Include cases: 1:60
Median
25%-75%
Min-Max
Motor oil recoded (mg/L)
Curb
Sedwell
MW2
MW3
MW4
MW1
Site

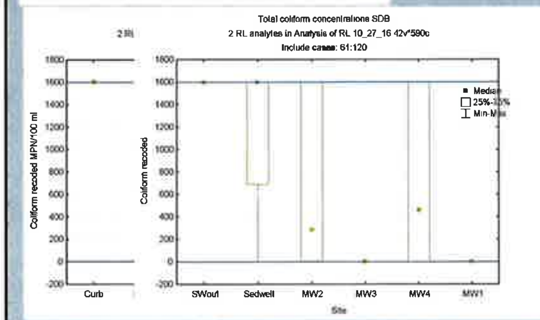

ALUMINUM
Aluminum concentrations SDB
Variable: Al recoded
Include cases: 61:120
Al recoded
SWout
Sedwell
MW2
MW3
MW4
MW1
Site
Curb
250-325 years


ARSENIC
Arsenic concentration SDB
Include cases: 61:120
As recoded
SWout
Sedwell
MW2
MW3
MW4
MW1
Site
Curb

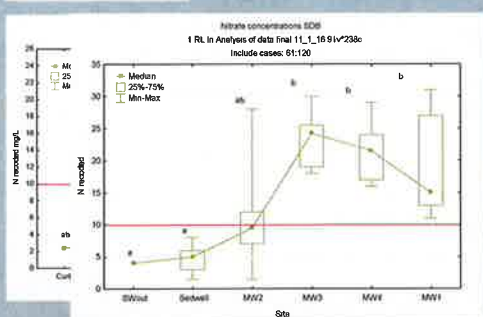
VANADIUM



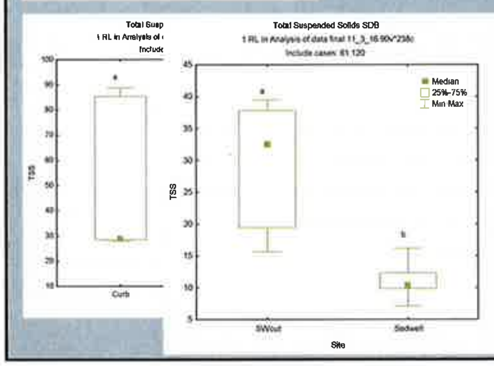
TOTAL COLIFORM BACTERIA



NITRATE



PRETREATMENT EFFICIENCY



HOW MUCH WATER INFILTRATED?

Date	CY Avg Flow (gpm)	CY Total Vol (gal)	SDB Avg. Flow (gpm)	SDB Total Vol (gal)
11/2/15	8.46	1,017	46.72 (0.1 CFS)	28,437
1/5/16	26.38 (0.06 CFS)	8,364	35.09	9,169
3/4/16	10.41	15,800	21.54	3,241
4/22/16	14.29	1,286	21.3	2,534

0.4-0.7 AF WATER FROM EACH DRY WELL PUT INTO THE GROUND DURING THE 2015-16 WATER YEAR

FATE AND TRANSPORT MODELING

- Examine long term effects of using dry wells – out to 3,000 years to understand the risk of groundwater degradation
  - ID model
  - Used data from boring logs
  - Used range of hydraulic conductivity values for clay
  - A variety of distribution coefficients specific to pollutants
  - Aluminum, bifenthrin, chromium (total and hexavalent), DEHP, iron, manganese, permethrin, and TBA (tert-butyl alcohol) – all found at 2 sites; also fipronil and imidacloprid

MODELING RESULTS

- Bifenthrin, TBA, total Cr, DEHP, permethrin, and fipronil unlikely to ever reach the water table
- Al would reach water table between 200-400 years
- Mn and Fe, <5 years
- Imidacloprid, days
- Assumption: the Elk Grove dry well system was used in modeling. Concentration of contaminants likely greater than if sedimentation well working properly

OTHER STATES – WHAT DO THEY DO

- Oregon and Washington have state regulated systems for using UIC (underground injection control systems)
- Examples of their guidelines:
  - Minimum 10 foot separation from high water table
  - 500 feet setback from public supply well
  - Not to be used near gas stations, vehicle servicing facilities
  - Not to be used where contaminated soils are found
  - Monitoring as water enters the dry well 6 x year

UIC COMMONLY USED IN PORTLAND

- 10,000 public, same number private UICs
- Monitor 6 x year/30 wells
  - Guideline: If stormwater entering UIC < MCL, good to go
- Modeling to demonstrate groundwater is protected (1 D vadose zone)
- Requires pretreatment and annual inspections

Figure 2. Schematic of typical city UIC system in Portland. Source: Portland Bureau of Environmental Services

WASHINGTON: GUIDANCE FOR PRETREATMENT

Pollutant loading \ Treatment capacity	*High*	*Medium*	*Low*	*None*
Insignificant	None	None	None	None
Low	None	None	None	Remove solids[2]
Medium	Two-stage drywells[1]	Two-stage drywells[1]	Remove solids[2]	Remove solids[2]
High	Remove oil[3]	Remove oil[3]	Remove oil and solids[2,3]	Remove oil and solids[2,3]

Guidance for UIC Wells that Manage Stormwater, Department of Ecology Washington State

DRY WELL REGULATIONS AND PERMITTING

- Follows DWR Bulletin 74-81 and 74-90 – guidelines for drinking water wells; prevent surface water from entering subsurface to protect groundwater
  - Sacramento region and other areas
  - Interpretation assumes stormwater is a waste product
  - Wells "used for the injection of reclaimed waste water" including "dry wells," "drainage" wells and sewer wells
  - Waste defined as "sewage and all other waste substances of human or animal origin…."
- Local interpretation: Dry well should be constructed to drinking water well standards and permitted as such

ELK GROVE DRY WELL PROJECT LESSON LEARNED

DRAFT

- No evidence that dry wells contributed to groundwater quality degradation
  - Consistent with literature and experiences from other States
- Use of pretreatment very important
- Placement in vehicle servicing areas (gas stations) not advisable. High risk areas should be avoided
- Registration/permitting process remains challenging, although this appears to be changing due to State Water Resources Control Board initiatives
- Need for more dry well professionals to oversee design and construction
- Dry wells have a bright future for: stormwater and groundwater management and aquifer recharge needs
- **Benefits clearly outweigh risks**

Contact info:

Barbara Washburn, 916-316-7982, barbara.washburn@oehha.ca.gov

Connie Nelson, 916-478-3638, cnelson@elkgrovecity.org

Project website:
http://www.elkgrovecity.org/city_hall/departments_divisions/public_works/
Select Dry Well project in menu on left.

THANK YOU!

Presentation 16: Dry Well Use for Groundwater Recharge and Stormwater Management: Lessons Learned from the Elk Grove Dry Well Project

OEHHA

January 9, 2017

DRY WELL USE FOR GROUNDWATER RECHARGE AND STORMWATER MANAGEMENT: LESSONS LEARNED FROM THE ELK GROVE DRY WELL PROJECT

WILLDAN | OEHHA | LUHDORFF & SCALMANINI CONSULTING ENGINEERS | cbec | ELK GROVE

TEAM PARTNERS

City of Elk Grove and Willdan Engineering: Connie Nelson, Project Manager

cbec ecoengineering: Chris Bowles, Ben Taber, Rafael Rodriguez, Chris Campbell

OEHHA: Bennett Lock, Ary Ashoor, Kathleen Doran, David Katz, Hamad Hamad, Barbara Washburn

Ludhorff/Scalmanini: Reid Bryson

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

Funded by Proposition 84 Stormwater Grant to the City of Elk Grove, State Water Board

TODAY'S DISCUSSION

Goal of seminar: Obtain feedback on project results and interpretation.

Topics:

- Overview
- Project methods and results
  - Contaminant data: stormwater and naturally occurring
  - Modeling
- Use of dry wells in other states
- Future use of dry wells in California

DRY WELL OR UNDERGROUND INJECTION CONTROL SYSTEMS

- Receives water from one or more entry points
- Collects, stores, and distributes stormwater to subsurface
- Discharges water through small openings
- Bottom/sides of dry well placed at permeable soils, overcoming clay 'obstacle'

Two chambered Maxwell Plus, Torrent Resources

VALUE OF DRY WELLS: STORMWATER

- Aid in management of urban stormwater runoff
- Reduce localized flooding
- Reduce damage to aquatic ecosystem – scour and pollutants
- Especially useful where clay soils impair infiltration rate.

Dry well system, integrated with LID features

VALUE OF DRY WELLS: GROUNDWATER

- Facilitates groundwater recharge to address:
  - Water shortages caused by drought
  - Water storage challenges linked to changing climate
  - Efforts of Water Board to use stormwater as a resource, one of which is aquifer recharge

ELK GROVE DRY WELL PROJECT

PROJECT GOALS AND OBJECTIVES

- Assess risk to groundwater quality associated with dry well use
  - Collect and analyze stormwater and groundwater samples at two study sites
  - Model fate and transport of contaminants through vadose zone
  - Estimate risk of mobilization of naturally occurring toxic metals
- Additional objectives – inadequate time to discuss today

PROJECT GOALS AND OBJECTIVES

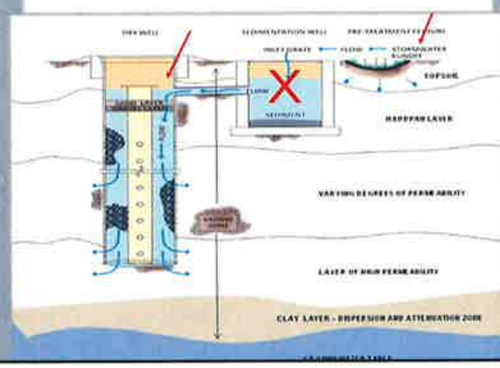
- Estimate recharge rate and capacity
- Review practices in other states and around California
- Learn from studies performed by others
- Provide information to groundwater and stormwater managers and the public

PROJECT LOCATIONS

MONITORING WELL NETWORK

Vadose zone well: 55 feet, screened 20-50 feet
Water table wells: 110 feet, screened 80-15 feet

DRY WELL AND PRETREATMENT FEATURES



WATER QUALITY MONITORING

- Collected stormwater and groundwater for 2 years
  - 5 wet season storms: stormwater & groundwater
  - Additional groundwater: pre-construction, 2 dry season
  - Flow-weighted composite stormwater samples used to analyze over 200 contaminants
  - Groundwater samples collected approx. 24 hours after rain event, based on presence of water in vadose zone well

Class (number tested)	Examples
Volatile organics (65)	Toluene, ethylbenzene, napthalene
Semi-volatile organics (65)	Dichlorobenzene, benzo[a]pyrene, phthalates, napthalene, benzoic acid
Polycyclic aromatic hydrocarbons (16)	Benzo[a]pyrene, anthracene, pyrene
Chlorophenoxy herbicides (11)	2,4-D, dalaphon, pentachlorophenol
Pyrethroid pesticides (9)	Bifenthrin, permethrin, cyfluthrin
Drinking water metals (20)	Total chromium, arsenic, lead
Bacteria (3)	Total coliform, fecal coliform, e.coli
Total petroleum hydrocarbons	Diesel, gas, motor oil
Special testing (3)	Hexavalent chromium, glyphosate, total suspended solids
Conventional parameters	Calcium, specific conductance, total

STATISTICAL METHODS

- Needed special methods due to abundance of non-detects
- For data with a single reporting limit:
  - Kruskal-Wallis test
  - Multiple comparisons: Tukey's using ranked data (not numbers) to minimize false discovery rate
- For data with 2 or more reporting limits:
  - Generalized Wilcoxon test
  - Multiple comparisons: Benjamini and Hochberg test

FLOW AND INFILTRATION CAPACITY

Flow rates into dry wells controlled by 5 orifices (0.75" – 2.5") in pipes leading to sedimentation well.

Opened orifice to maintain constant head over dry well

Estimate of flow through dry well then calculated:

$$C_d = \frac{Q}{A\sqrt{2gh}}$$

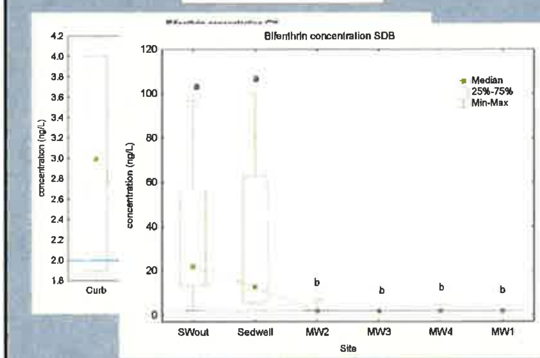
GROUNDWATER LEVEL AND GRADIENT

- Pressure transducers in wells
  - 3 per site to measure water level
  - Used to estimate groundwater gradient
- Electric conductivity transducers
  - One/site – twice during project to estimate surface water-groundwater connectivity

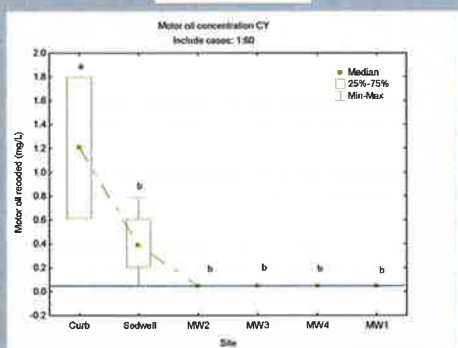
RESULTS – ANALYSIS OF CONTAMINANTS

Class (number tested)	Examples	Frequency of detection > RL in stormwater	Reporting limits
Volatile organics (65)	Toluene, ethylbenzene, napthalene	infrequent	low ppb (µg/L)
Semi-volatile organics (65)	Dichlorobenzene, benzo[a]pyrene, phthalates, napthalene, benzoic acid	rare	low ppb (µg/L)
Polycyclic aromatic hydrocarbons (16)	Benzo[a]pyrene, anthracene, pyrene	none	low ppb (µg/L)
Chlorophenoxy herbicides (11)	2,4-D, dalaphon, pentachlorophenol	rare	low ppb (µg/L)
Pyrethroid pesticides (9)	Bifenthrin, permethrin, cyfluthrin	frequent	low pptr (ng/L)
Drinking water metals (20)	Total chromium, arsenic, lead	frequent	low ppb (µg/L)
Bacteria (3)	Total coliform, fecal coliform, e.coli	frequent	1.8 most probable number/100 ml
Total petroleum hydrocarbons	Diesel, gas, motor oil	Infrequent	low ppm (mg/L)
Special testing (3)	Hexavalent chromium, glyphosate, total suspended solids	Cr^{6+}: infrequent Glyphosate: rare TSS: n/a	low ppb (µg/L) ppm (mg/L)
Conventional parameters	Calcium, specific conductance, total	n/a/	ppm (mg/L)

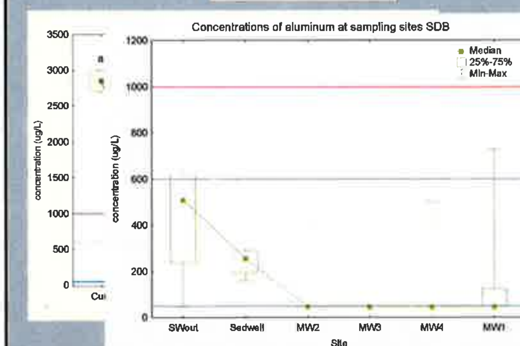
BIFENTHRIN



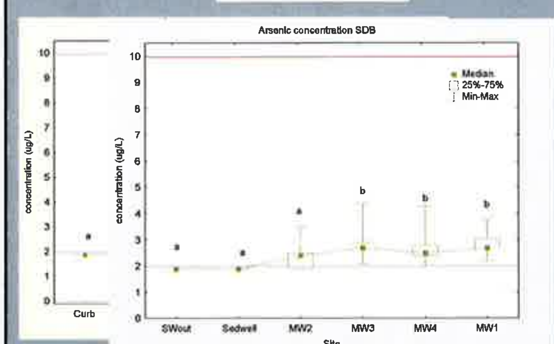
MOTOR OIL



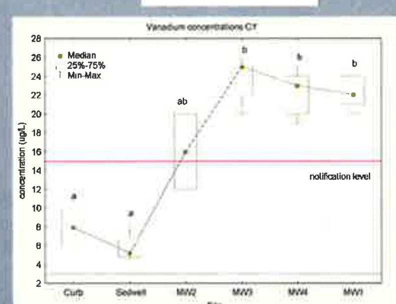
ALUMINUM



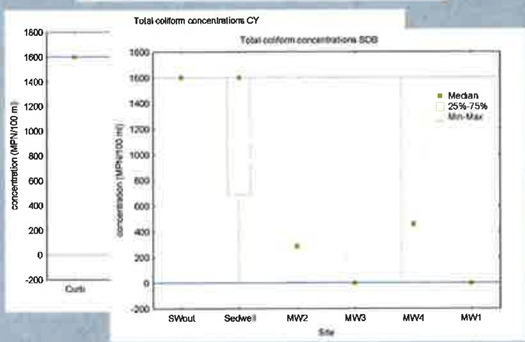
ARSENIC



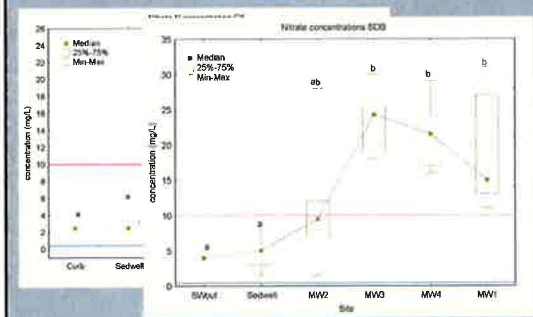
VANADIUM



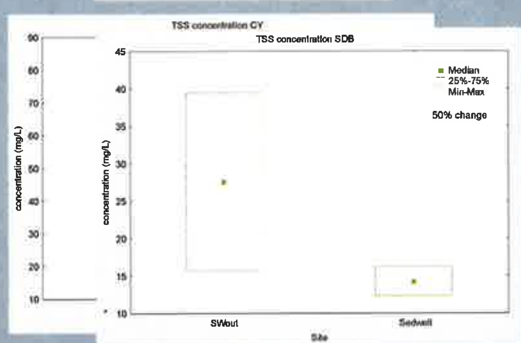
TOTAL COLIFORM BACTERIA



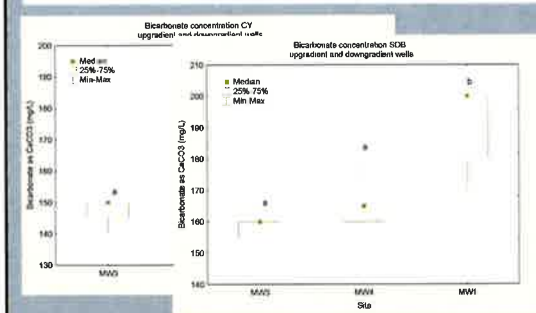
NITRATE



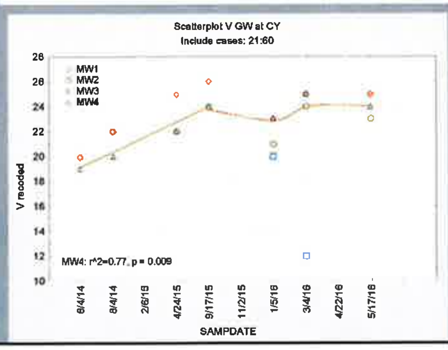
PRETREATMENT EFFICIENCY



IN SOME CASES, STORMWATER DILUTED GROUNDWATER CONSTITUENTS, IMPROVING QUALITY



CHANGES OVER TIME: VANADIUM CY



RESULTS: INFILTRATION CAPACITY

HOW MUCH WATER INFILTRATED?

Date	CY Avg Flow (gpm)	CY Total Vol (gal)	SDB Avg. Flow (gpm)	SDB Total Vol (gal)
11/2/15	8.46	1017	46.72 (0.1 CFS)	28437
1/5/16	26.38 (0.06 CFS)	8364	35.09	9169
3/4/16	10.41	15800	21.54	3241
4/22/16	14.29	1286	21.3	2534

0.4-0.7 AF WATER FROM EACH DRY WELL PUT INTO THE GROUND DURING THE 2015-16 WATER YEAR

METAL MOBILIZATION AND PRELIMINARY RESULTS

Xue Li, PhD
(UCD Environmental Engineering)
Currently CSUS Engineering

BACKGROUND

- **What's metal mobilization**:
  - Metals associated with the solid phase are released into aqueous solution
- **How can it happen**:
  - Changes of geochemical conditions (e.g. pH, Eh) that have the potential to interact with naturally occurring metals in both soils and groundwater and possibly results in metal release
- **Why could it happen**:
  - Mixing of stormwater with groundwater disrupts the local equilibrium or changes local groundwater geochemistry

METHODS

- **To look for direct evidence of metal release**:
- Compare upgradient and downgradient monitoring wells – As and Cr
- If higher metal concentration was found in downgradient, then metal might have been released due to stormwater introduction
  - Assumes metal not introduced by stormwater

METHODS

- **Potential mechanism for metal release**
  - Correlation between ion couples associated with physical-chemical reactions
  - If significant correlation detected between an ion couple, signals a natural occurring mechanism

PHYSICAL-CHEMICAL REACTIONS AFFECTING THE MOBILIZATION OF METALS

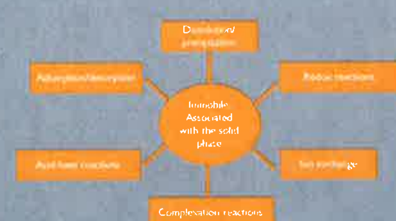
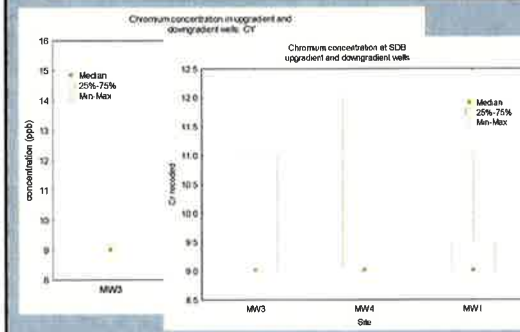


Figure revised from Gardner et al. 2015

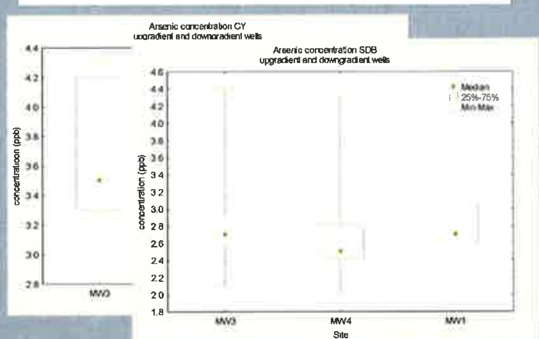
MECHANISMS

Potentially correlated ion couples	Possible mobilization mechanism
Positive correlation between As and Fe or As and Mn	Fe/Mn oxides are common sinks of arsenic (Reduction of Fe/Mn oxides may result in releasing its adsorbed load of arsenic)
Positive correlation between As and SO_4^{2-} and a negative correlation between As and S^{2-}	Sulfide minerals are common sinks of arsenic (oxidizing these minerals can release arsenic to the groundwater)
Negative correlation between As and PO_4^{3-}, HCO_3^-, SiO_4^{2-} or organic matter	Competition for surface sites due to ion exchange/ desorption processes from common anions

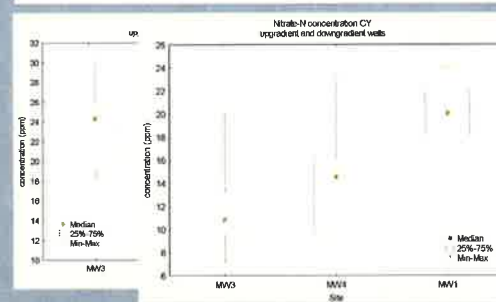
DIRECT EVIDENCE CR: NS DIFFERENCE UPGRADIENT & DOWNGRADIENT WELLS



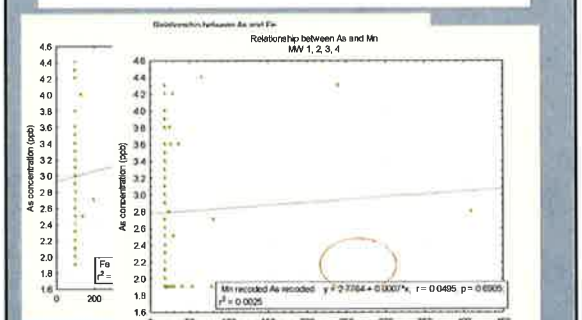
DIRECT EVIDENCE ARSENIC: NS DIFFERENCES UPGRADIENT & DOWNGRADIENT WELLS



PRELIMINARY RESULTS NITRATE-N (DIRECT EVIDENCE)

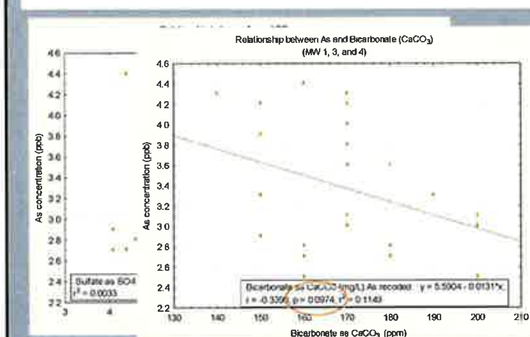


POTENTIAL MECHANISMS ARSENIC: Fe and Mn

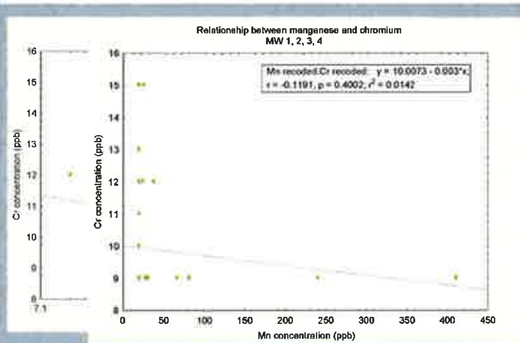


Data from CY and SDB

POTENTIAL MECHANISM ARSENIC: HCO_3^-



POTENTIAL MECHANISM CHROMIUM: pH and Mn



PRELIMINARY CONCLUSIONS

Ion	Boxplot results	Conclusions
Cr	No significant difference between upgradient and downgradient monitoring wells	No evidence for metal mobilization
As		

Ion couple	Scatterplot finding	Conclusions
As with Fe, Mn, SO_4^{2-} or HCO_3^-	No/weak correlation between the proposed ion couples	Within the concentration range detected, no strong evidence for Fe, Mn, $SO4^{2-}$ or HCO^{3-} potential to mobilize As
Cr with Mn or pH	NS	NS

NUMERICAL MODEL ASSESSMENT OF STORMWATER CONTAMINANT TRANSPORT

Emily Edwards
ecedwards@ucdavis.edu
University of California, Davis

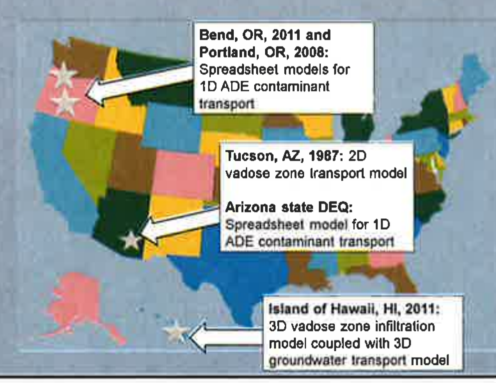
TALK OVERVIEW

- Motivation for numerical model assessment
- Numerical model analyses done for other dry well studies
- Our modeling approach: conceptual model and HYDRUS 1D
- Model domains
- Selected contaminants
- Model inputs and modeled scenarios
- Results
- Discussion and conclusions

MOTIVATION

- Field studies can provide good data on water quality effects of dry well use during monitoring period
  - monitoring period often limited to a few years
  - difficult to perform thorough monitoring for large scale dry well projects
- Numerical models can be used to predict effects of dry well use tens, hundreds, even thousands of years into the future
- Can easily manipulate model domains and inputs to create hypothetical and worst-case scenarios
- Fill in some blanks when long-term, full-scale water quality monitoring is not feasible

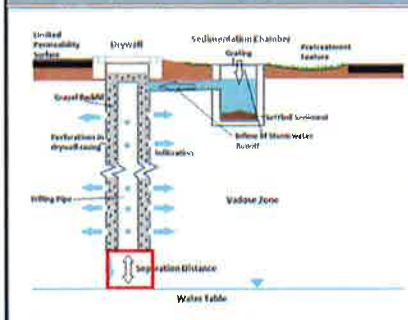
Previous Dry Well Modeling Analyses



BENEFITS AND LIMITATIONS OF PREVIOUS MODELING APPROACHES

Benefits	Limitations
Spreadsheet models are user-friendly and can be run with minimal modeling experience	All domains for spreadsheet models are composed of a single material (no layering)
2D and 3D model domains show extent of lateral contaminant transport	2D and 3D models only run for short time periods (less than 150 days)

CONCEPTUAL MODEL



- 1D vertical transport from bottom of drywell to seasonal high water table
- Shortest path stormwater contaminants travel to reach groundwater

HYDRUS 1D SOFTWARE

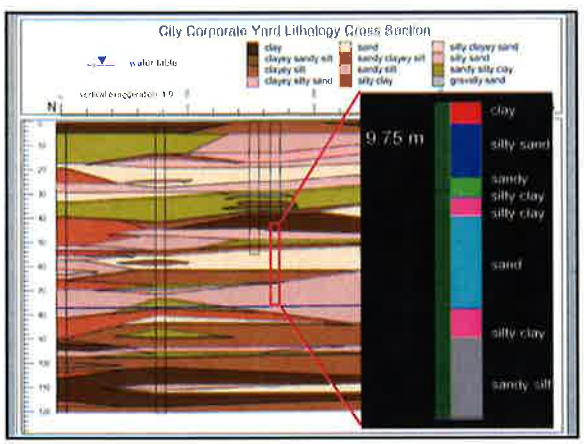
- Public domain 1D vadose zone flow and transport modeling software
- Water flow described by 1D Richards Equation
- Solute transport described by variations of 1D Advection and Dispersion Equation
- Simunek et al., 2013

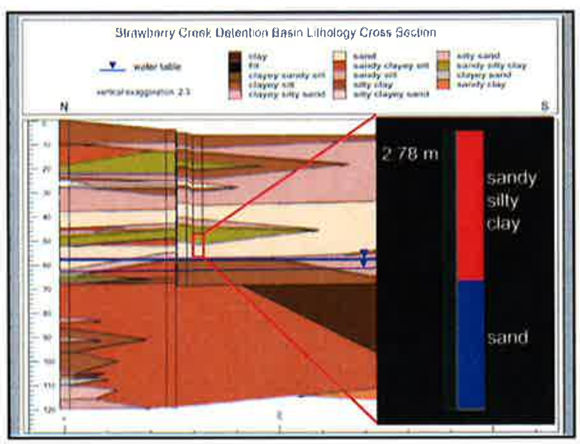
$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\left(\frac{\partial h}{\partial z}+1\right)\right]$$

$$D\frac{\partial^2 c}{\partial x^2} - v\frac{\partial c}{\partial x} = R\frac{\partial c}{\partial t}$$

MODEL DOMAINS

- 1D profile lengths = site separation distances
- Material layering based on data from site dry well and monitoring well driller's logs
- Water and solute enter at top of profile
- Contaminated water is input for 230 days/year, followed by a 135 day dry period (repeated for up to 1000 years)
- Monitor contaminant concentration in water exiting profile

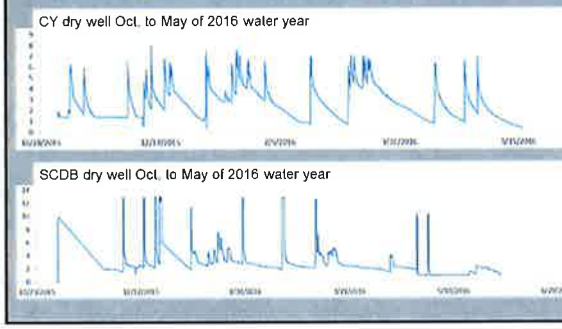




MODEL INPUTS

Type of model input	Examples of parameters	Sources of values
Van Genuchten parameters, other soil charactersitics	Soil hydraulic conductivity, soil bulk density	HYDRUS neural network predictions, site falling head
Contaminant chemical characteristics	Soil-water partitioning coef., Henry's Law constant	Literature values
Annual infiltration record: pressure head and contaminant concentration	Daily pressure head, contam. concentration of influent water	Stage data from pressure transducers at bottom of drywell

STAGE RECORDS



MODELED SCENARIOS

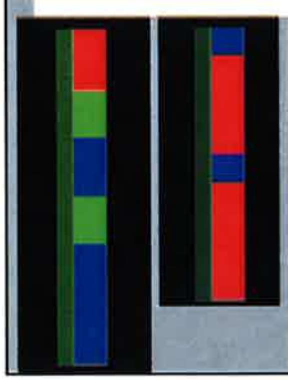
- Eight scenarios run for each contaminant at each site
- Scenarios created by varying the contaminant input concentrations, clay hydraulic conductivities, and Kd values

Scenario	clay layer Ks	foc/Kd
Best Case	low	high
Avg Case 1	low	low
Avg Case 2	high	high
Worst Case	high	low

90% REMOVAL SCENARIOS

- results of stormwater monitoring indicate pretreatment can reduce influent contaminant concentrations by 90%
- select contaminants from both sites were modeled at 10% of their highest pre-pretreatment concentrations

LOS ANGELES SCENARIOS



Average case profile: 10.7 m of clay, sandy loam, and sand

Worst case profile: 2.0 m of loam and sand

Modeled contaminants

Metals: Al, Cu, Fe, Pb, and Zn

VOCs and SVOCs: TBA

PAHs: benzo(a)pyrene and naphthalene

Insecticides and herbicides: bifenthrin, permethrin, fipronil, and imidacloprid

RESULTS

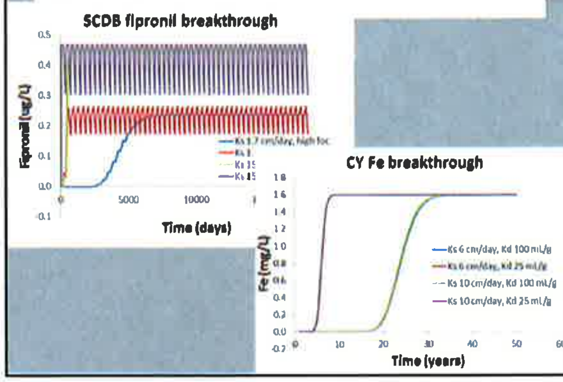
- Types of results:
  - arrival times
  - times of regulatory exceedances
  - peak concentrations at the water table
- Results available in table format
- Also visualized as "breakthrough curves" (conc. at water table as a function of time)

CY Contaminant and input concentration	Worst case travel time to reporting limit at WT	Worst case time to regulatory limit	Worst case peak concentration at WT in 500 yrs
Al 2.1 mg/L	274 yrs	351 yrs MCL	2.07 mg/L
Cr (total) 11 ug/L	doesn't reach WT	n/a	n/a
DEHP 3.01 ug/L	[influent] too low	[in.] too low	2.73 ug/L
Fe 1.6 mg/L	5 yrs	6 yrs to sec std	1.60 mg/L
Mn 31 ug/L	8 yrs	[in.] too low	31.0 ug/L
permethrin 12.2 ng/L	17 yrs	no reg. limits	8.78 ng/L
TBA 19 ug/L	10 days	12 days to not. limit	17.99 ug/L
fipronil 0.5 ug/L	133 days	no reg. limits	0.473 ug/L
imidacloprid 0.9 ug/L	16 days	no reg. limits	0.855 ug/L

SDB Contaminant and input concentration	Worst case travel time to reporting limit at WT	Worst case time to regulatory limit	Worst case peak concentration at WT in 500 yrs
Al 0.3 mg/L	29 yrs	[influent] too low	0.299 mg/L
bifenthrin 100 ng/L	42 yrs	no reg. limits	98.6 ng/L
Fe 0.42 mg/L	190 days	2 yrs to sec std	0.420 mg/L
Mn 41 ug/L	2 yrs	[in.] too low	41.0 ug/L
TBA 20 ug/L	3 days	4 days to not. limit	17.99 ug/L
fipronil 0.5 ug/L	18 days	no reg. limits	0.468 ug/L
imidacloprid 0.9 ug/L	3 days	no reg. limits	0.895 ug/L

SDB Contam. and [input]	Worst case travel time to reporting limit at WT	Worst case time to regulatory limit	Worst case [peak] at WT after 500 yrs
bifenthrin 100 ng/L	42 yrs	no reg. limits	98.6 ng/L
bifenthrin with removal 10 ng/L	53 yrs	no reg. limits	9.87 ng/L
fipronil 0.5 ug/L	18 days	no reg. limits	0.468 ug/L
fipronil with removal 0.05 ug/L	22 days	no reg. limits	0.0468 ug/L

SELECTED BREAKTHROUGH CURVES



DISCUSSION

- Important caveat: most modeled influent contaminant concentrations are highest concentrations detected in stormwater before pretreatment
  - results of modeling 90% removal for all contaminants would indicate lowered risk
- All four modeled scenarios are conservative in terms of transport
- Model results present range of results for possible chemical and subsurface physical conditions
- More physical site data is needed to obtain a narrower range

TAKEAWAYS AND CONCLUSIONS

- Results indicate that Elk Grove drywells pose little risk to local groundwater quality
- Worst case: only four contaminants are predicted to exceed non-MCL regulatory limits
- Worst case: aluminum at the CY is the only contaminant predicted to exceed its MCL after a minimum of 350 yrs
- Some risk to groundwater quality does exist: further site characterization would be needed for improved assessment

REFERENCES

- Šimůnek, J., M. Šejna, H. Saito, M. Sakai, and M. Th. van Genuchten, The Hydrus-1D Software Package for Simulating the Movement of Water, Heat, and Multiple Solutes in Variably Saturated Media, Version 4.17, HYDRUS Software Series 3, Department of Environmental Sciences, University of California Riverside, Riverside, California, USA, pp. 342, 2013.

FATE AND TRANSPORT MODELING

- EMILY slides here

OTHER STATES – WHAT DO THEY DO

- Oregon and Washington have state regulated systems for using UIC (underground injection control systems)
- Examples of their guidelines:
  - Usually minimum 10 foot separation from high water table
  - 500 feet setback from public supply well
  - Not to be used:
    - near gas stations,
    - where hazardous chemicals are used,
    - where contaminated soils are found.
  - Monitoring as water enters the dry well sub-sampled of dry wells 6 x year (Portland) or not at all (most places in Washington state)

UIC COMMONLY USED IN PORTLAND

- 10,000 public, same number private UICs
- Monitor 6 x year/30 wells
  - Guideline: If stormwater entering UIC < MCL, good to go
- Modeling to demonstrate groundwater is protected (1 D vadose zone)
- Require pretreatment and annual inspections

WASHINGTON: GUIDANCE FOR PRETREATMENT

Pollutant loading \ Treatment capacity	*High*	*Medium*	*Low*	*None*
Insignificant	None	None	None	None
Low	None	None	None	Remove solids[3]
Medium	Two-stage drywells[1]	Two-stage drywells[1]	Remove solids[3]	Remove solids[3]
High	Remove oil[1]	Remove oil[1]	Remove oil and solids[2,3]	Remove oil and solids[2,3]

Guidance for UIC Wells that Manage Stormwater, Dept. Ecology, Washington State

DRY WELL REGULATIONS AND PERMITTING

- Follows DWR Bulletin 74-81 and 74-90 – guidelines for drinking water wells; prevent surface water from entering subsurface to protect groundwater
  - Sacramento region and other areas
  - Interpretation assumes stormwater is a waste product
  - Wells "used for the injection of reclaimed waste water" including "dry wells," "drainage" wells and sewer wells
  - Waste defined as "sewage and all other waste substances of human or animal origin…."
- Local interpretation: Dry well should be constructed to drinking water well standards and permitted as such.

KEY IDEAS FROM ELSEWHERE

- Literature review: peer-reviewed, thesises, government reports: Little evidence that dry wells pose a risk to groundwater quality, includes US EPA report and recent NAS report.
- Other states: dry wells widely used in WA, OR, AZ, and 10,000 in SoCal. In WA/OR – in use for over a decade, AZ for much longer. No reported compromises of groundwater quality.

PROPOSED CONCLUSIONS

- Use of pretreatment essential
- Placement in vehicle servicing areas not advisable. Will be closing CY dry well. High risk areas should be avoided.
- Registration/permitting process remains challenging, although this appears to be changing due to Water Board and DWR initiatives
- With proper design, siting, and maintenance, dry well present minimal risk of degrading aquifer
  - Need more info for water soluble pesticides (data gap)

FINAL THOUGHTS

- Reports will be submitted to Water Board and could be used in developing statewide guidelines and standards for dry wells.
- Your thoughts on results and conclusions welcome
- Thank you!

Presentation 17: TAC Final Result Meeting - Separating Fact from Fiction: Assessing the Use of Dry wells to Reduce Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds - Final Results

City of Elk Grove and TAC Members

January 17, 2017

WELCOME

ELK GROVE

Special THANKS!

State Water Resources Control Board for funding the project

Kelley List, Grant Manager

Water Boards

Separating Fact from Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds

WILLDAN | cbec | UC DAVIS | LUHDORFF & SCALMANINI CONSULTING ENGINEERS | OEHHA | ELK GROVE

Today's Discussion

Goal of todays meeting: Obtain input on project findings and degree of risk associated with dry well use.

- Overview
- Project refresher
- Project conclusions and findings
- Next steps

Team Partners

Connie Nelson, Project Manager, City of Elk Grove and Willdan Engineering

OEHHA: Barbara Washburn, Bennett Lock, Ary Ashoor, Kathleen Doran, David Katz, Hamad Hamad

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

Ludhorff and Scalmanini: Reid Bryson

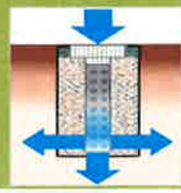
UC Davis Land, Air and Water Resources (LAWR): Emily Edwards, Graham Fogg, Thomas Harter

What are Dry Wells?

- Gravity fed excavated pits lined with perforated casing filled with gravel
- Deeper than width
  - –3 feet wide
  - –20 to 60 deep
- Can be used in conjunction with LID practices

How do they work?

- Receives water from one or more entry points
- Collects, stores, and disburses water
- Discharges water through small openings
- Bottom/sides of dry well placed at permeable soils



Value of Using Dry Wells: Groundwater

Facilitate groundwater recharge to address:

- Water shortages caused by drought
- Water storage challenges linked to changing climate
- Treat stormwater as a resource to recharge groundwater supplies

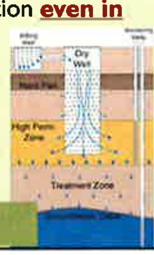
General Concept of LID Features with a Dry Well

Groundwater provides 30 percent of California's water supply

- 431 groundwater basins
- Covers 40% of the State
- Storage capacity:
  - ✓ 851 million acre-feet (not all useable)

Value of Using Dry Wells: Stormwater

- Aids in the management of urban stormwater runoff
- Facilitates stormwater infiltration **<u>even in clay soils</u>**
- Reduces localized flooding
- Reduces damage to aquatic ecosystem – scour and pollutants



General concept:
Bypass hardpan

Questions?

ELK GROVE

Elk Grove Dry Well Project

Monitoring event at Strawberry Creek Water Quality Basin November 2, 2014

Project Site Schematic

Dry wells: 40 feet, Vadose zone wells: 55 feet (screened 20 to 55 feet), water table wells: 120 feet (screened: 80 to 115 feet)

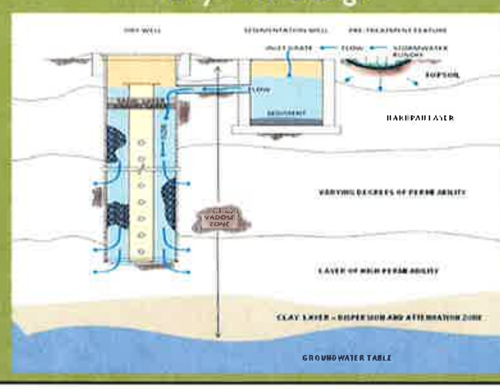
Project Purpose

Evaluate the potential of using dry wells, in combination with low impact development (LID) practices, to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

without negatively impacting groundwater quality

Dry Well Design

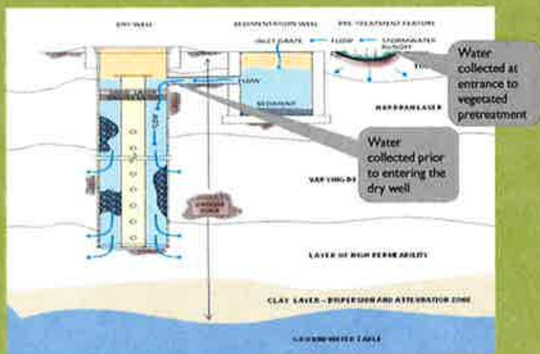


Project Site Locations

Monitoring event at Strawberry Creek Water Quality Basin, November 2, 2014

Stormwater and Groundwater Monitoring Fall 2014 – Spring 2016

Stormwater Sampling



Logging boring soil samples at well sites

Fate and Transport of Contaminants

Water Quality Monitoring

- Collect and sample stormwater and groundwater for 2 years
  - 5 wet weather stormwater samples
  - 5 wet and 2 dry weather groundwater samples
- Flow weighted composite samples collected over 80% of storm volume at the dry well
- Grab samples at curb cut and stormwater outfall (3 events); composites (2 events)

Fate and Contaminant Modeling

- Address two major concerns:
  - How far might contaminants migrate from bottom of dry well over many years?
    - Modeling performed by Emily Edwards, UCD grad student, LAWR
  - Could naturally occurring metals (e.g. As, Cr) be mobilized as a result of stormwater influx?
    - Analysis performed by Xue Li, PhD, CSUS

Water Chemistry

- Constituents to be tested in stormwater and groundwater
  - General physical and chemical
  - Metals
  - Volatiles
  - Semi-volatiles
  - Herbicides
  - Pyrethroids
  - Total petroleum hydrocarbons – gas, diesels
  - Pyrogenic polycyclic aromatic hydrocarbons (PAHs)
  - Total coliform

Annotated Bibliography

Education and Outreach

Education and Outreach

- Factsheets
  - Regulations
  - Oregon UIC Program
  - Project
- Annotated Bibliography
- Guidance/Lessons Learned Document
- Presentations
- Project website

Project Conclusions and Findings

- Siting dry wells where hazardous material are used should be off limits
- Proper design and construction oversight will avoid future problems
- Pretreatment is essential
- Vadose zone provides important attenuation of contaminants
- Stormwater infiltration can dilute groundwater constituents, improving water quality

Questions?

ELK GROVE

Project Conclusions and Findings

- No evidence found for mobilization of naturally occurring metals in subsurface
- Future monitoring of stormwater and groundwater is advised
- Operations and Maintenance Plan should be in place and implemented

Overall, dry wells can be safely used with appropriate siting, design and maintenance

City of Elk Grove Corporation Yard dry well system

Project Conclusions and Findings

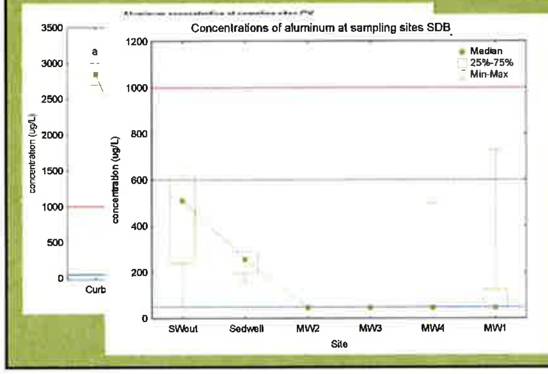
Logging Boring Samples

Finding 1: Siting Considerations Influence the Risk and Performance of the Dry Well

Undesirable and Desirable Siting Considerations

- Undesirable conditions:
  - Areas with hazardous chemicals
    - Vehicle servicing, gas stations, industrial
  - Areas with contaminated soils
  - Proximity to public supply wells
- Desirable conditions:
  - Combination of sand, gravel and clay in the subsurface

Evidence: Aluminum Concentrations High



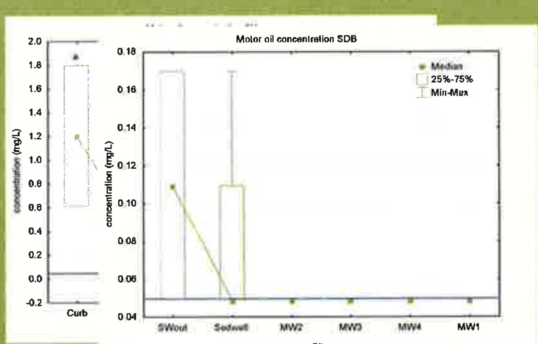
Experience at the Corporation Yard

- CY site not ideal
  - Bus fleet washing and maintenance area
  - Public Works maintenance yard
  - >95% impervious
  - Hazardous materials that could collect and be conveyed on hardscape → dry well

Siting Recommendations from Literature

- Siting based on site-specific hydrogeological conditions (i.e. vadose zone lithology), land use practices, and soil composition (Wilson, Clark, US EPA) should be considered
- High risk areas should be avoided (Olson, US EPA)

Evidence: Motor Oil Concentrations High



Siting Restrictions in Oregon and Washington

- Oregon and Washington have state regulated programs for using UIC
- Examples of their siting guidelines:
  - 500 feet setback from public supply well
  - Not to be located:
    - near gas stations
    - where hazardous chemicals are used
    - where contaminated soils are found

Questions?

ELK GROVE

Questions?

ELK GROVE

City of Elk Grove Corporation Yard dry well system

Findings 2: Design and Construction

City of Elk Grove Corporation Yard Dry Well

Finding 3: Pretreatment is Essential

Design and Construction is Important

- Sedimentation wells designed too shallow
- Swale at CY improperly designed and built
  - Slope of swale too steep
  - Significant erosion
  - Stabilization required
- Poor infiltration at SDB
  - Improper amount of sand, not to specifications
  - Design specified one foot of sand, >5 feet placed in dry well
- Construction inspection critical

Pretreatment

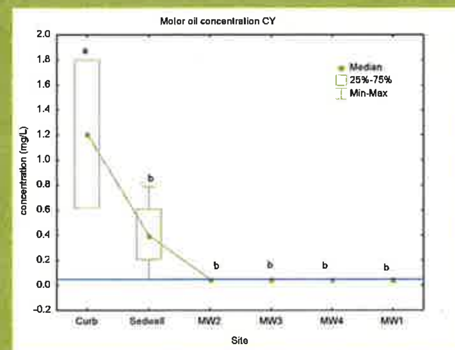
- Combination of vegetated and structural pretreatment reduces risk
- Many studies and reports recommend vegetative and structural pretreatment (Wogsland, Wilson, Pitt, Clark, US EPA)
- Portland, OR requires pretreatment with UICs

Figure 2. Schematic of typical city UIC system in Portland. Source Portland Bureau of Environmental Services

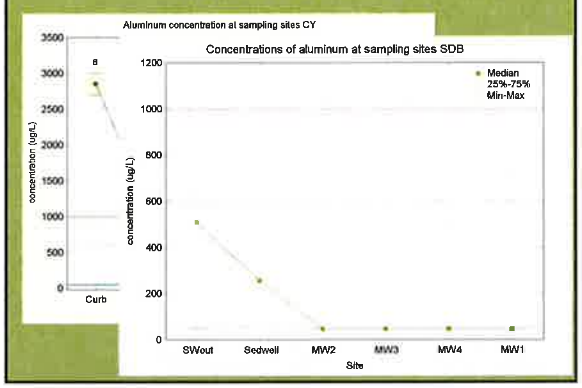
Pretreatment

- Some data suggests as much as 90% removal efficiency can be achieved with pretreatment
- In this project, the structural pretreatment was ineffective due to design issues (discussed later)
- 50 - 65% of suspended sediment and associated pollutants were removed by vegetated pretreatment

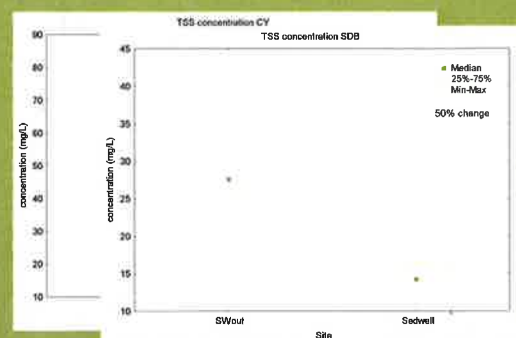
Evidence: Motor Oil



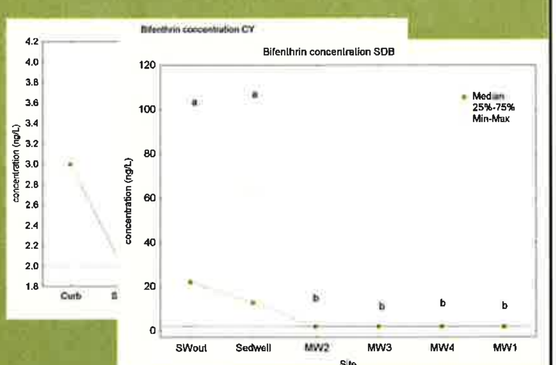
Evidence: Aluminum



Pretreatment Efficiency

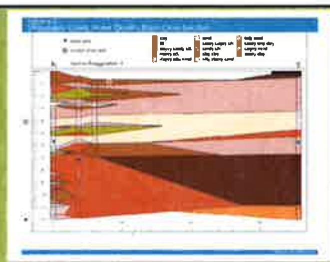


Evidence: Bifenthrin



Questions?

ELK GROVE



Strawberry Creek Water Quality Basin Lithology Cross Section

Finding 4: Vadose Zone Provides Important Attenuation of Contaminants

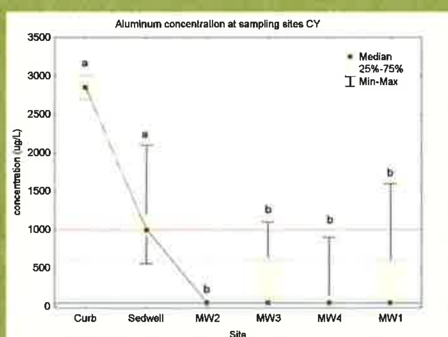
Washington: Role of Vadose Zone in Attenuation

Treatment capacity of vadose zone determines required pretreatment

Pollutant loading \ Treatment capacity	*High*	*Medium*	*Low*	*None*
Insignificant	None	None	None	None
Low	None	None	None	Remove solids[2]
Medium	Two-stage drywells[1]	Two-stage drywells[1]	Remove solids[2]	Remove solids[2]
High	Remove oil[3]	Remove oil[3]	Remove oil and solids[2,3]	Remove oil and solids[2,3]

Guidance for UIC Wells that Manage Stormwater. Dept. Ecology, Washington State

Evidence: Aluminum Concentration



Evidence: Literature

- Physical properties of clay → attenuation
  - Huge surface area (10 m^2/g) compared to sand or silt
  - Adsorptive capacity (non-ionic, electrostatic, pores)
- Metals attenuated in the vadose zone (Olson, Wogsland, Wilson)
  - Olson found metals and organics adsorbed to sediment in dry well itself…did not migrate (2 year study)
  - Wilson found vadose zone with two clay lenses attentuated both metals and organics (3 year study)

Evidence: Fate and Transport Modeling

Input concentration (highest measured at dry well)	Fastest travel time to water table (worst case)	Time to reach MCL at water table (worst case)
Al (2.1 mg/L) CY	270 years	350 years
Fe (1.6 mg/L) CY	5 years	6 years to 2nd MCL
Permethrin (12.2 ng/L) CY	17 years	n/a
Bifenthrin (100 ng/L) SDB	42 years	n/a
Fe (0.42 mg/L) SDB	190 days	2 years to 2nd MCL

Assumptions: low foc, high Ks, highest concentration measured, and contaminant in dissolved form

Questions?

ELK GROVE

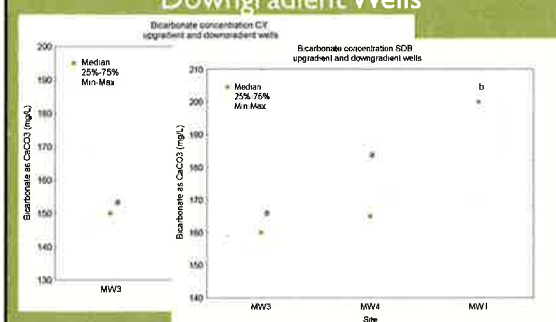
Measuring infiltration rates at the Corporation Yard
April, 2015

Finding 5: Stormwater Can Reduce the Concentration of Groundwater Contaminants

Dilution of Groundwater Contaminants

- Contaminants can be diluted by stormwater from the dry well
- Same phenomena observed in the Los Angeles Water Augmentation Study

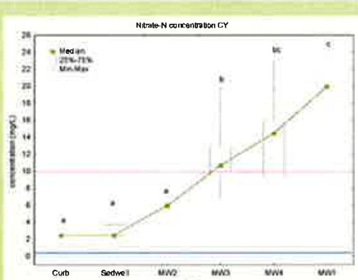
Bicarbonate Concentration Lower in Downgradient Wells



Questions?

ELK GROVE

Nitrate Concentrations Lower in Downgradient Well



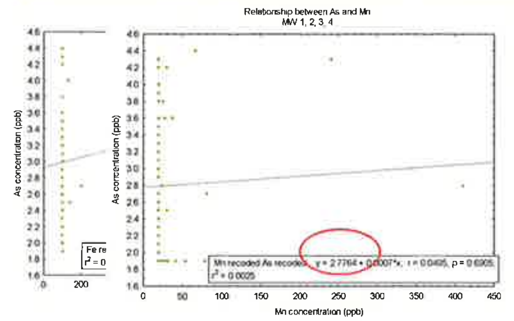
City of Elk Grove Corporation Yard groundwater sampling

Finding 6: Stormwater Does Not Appear to Mobilize Naturally – Occurring Toxic Metals

Preliminary Conclusions

- Over the course of the project, no apparent mobilization of chromium or arsenic
- Evidence:
  - No differences in concentration between up gradient and downgradient wells
  - Weak evidence for mechanisms of desorption

Potential Mechanisms: Arsenic

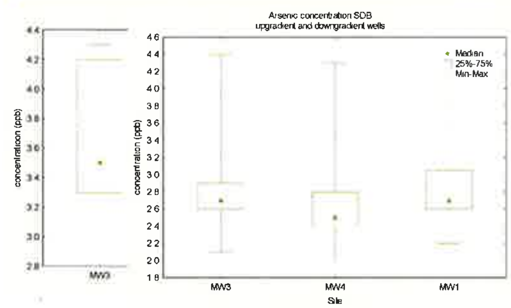


Preliminary Conclusions

Ion	Comparisons between upgradient and downgradient wells	Conclusions
Cr	NS	No evidence for metal mobilization
As	NS	No evidence

Ion couple	Relationship between metals	Conclusions
As with Fe, Mn, SO_4^{2-} or HCO_3^-	No/weak correlation between the proposed ion couples	Within the concentration range detected, no strong evidence for Fe, Mn, SO4[2-] or HCO[3-] potential to mobilize As
Cr with Mn or pH	NS	NS

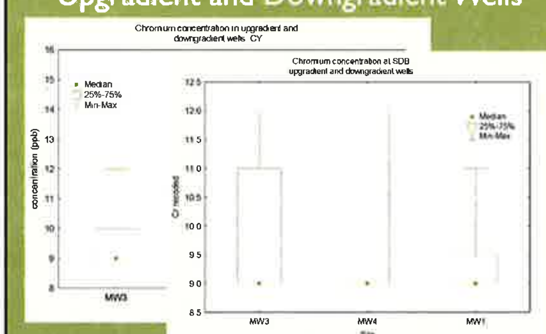
Evidence As: NS Difference Upgradient and Downgradient Wells



Mechanisms

Potentially correlated ion couples	Possible mobilization mechanism
Positive correlation between As and Fe or As and Mn	Fe/Mn oxides are common sinks of arsenic (Reduction of Fe/Mn oxides may result in releasing its adsorbed load of arsenic)
Positive correlation between As and SO_4^{2-} and a negative correlation between As and S^{2-}	Sulfide minerals are common sinks of arsenic (oxidizing these minerals can release arsenic to the groundwater)
Negative correlation between As and PO_4^{3-}, HCO_3^-, SiO_4^{2-} or organic matter	Competition for surface sites due to ion exchange/ desorption processes from common anions

Evidence CR: NS Difference Upgradient and Downgradient Wells



Questions?

ELK GROVE

Next Steps

- Grant is coming to a close
- Review factsheets (project factsheet by January 31st)
- Decommission CY wells (thoughts?)
- Operation and Maintenance and Monitoring Plan
- Scientific paper

Data Gap: Water Soluble Pesticides

CY contaminant and input concentration	Travel time to water table (worst case)	Travel time to reach regulatory level	Peak concentration at 500 years
Fipronil (0.5 ug/L)	133 days	n/a	0.473 ug/L
Imidacloprid (0.9 ug/L)	16 days	n/a	0.855 ug/L

Water soluble pesticides that are not attenuated by pretreatment. Unclear effects of pretreatment.

Bigger Picture

- Dry wells serve multiple benefits:
  - Improved water quality
  - Groundwater recharge
  - Aquatic ecosystem protection
- Stormwater is a resource
- A key driver for use of dry wells with LID practices is drought, climate change, and meeting NPDES requirements

How much water infiltrated?

Date	CY Avg Flow (gpm)	CY Total Volume (gal)	SDB Avg. Flow (gpm)	SDB Total Volume (gal)
11/2/15	8.46	1017	46.72 (0.1 CFS)	28437
1/5/16	26.38 (0.06 CFS)	8364	35.09	9169
3/4/16	10.41	15800	21.54	3241
4/22/16	14.29	1286	21.3	2534

0.7 AF Water from SDB Dry Well (13.5" Rain)
Estimate 1 AF/year with **'NORMAL'** rain

Take Away: Project's Key Conclusion

With proper siting, design and maintenance, dry wells appear to be a valuable tool to reduce stormwater runoff and increase aquifer recharge with little risk to groundwater quality

Contact

Connie Nelson, Project Manager
cnelson@elkgrovecity.org
(916) 478-3638

Barbara Washburn, OEHHA
barbara.washburn@oehha.ca.gov
(916) 316-7982

www.egpublicworks.org.....click the dry well tab

THANK YOU!

Presentation 18: Stormwater Infiltration Using Dry Wells and Elk Grove Dry Well Project

Practical Stormwater Management and Beyond the Regulations

SAGE, Surveyors, Architects, Geologist, and Engineers

March 15, 2017

SAGE

Surveyors Architects Geologists & Engineers

OF EL DORADO COUNTY

SEMINAR

Practical Storm Water Management And Beyond the Regulations

Come learn about the latest regulatory requirements of the Phase II MS4 Permit. Sustainable storm water practices used within the region and local examples will be presented. Methodologies to determine infiltration capacities and alternatives to mimic pre vs post development hydrology will be discussed. Design options to filter, store, and detail storm water will be reviewed and the practical implementation of storm water LID BMP's within the foothill region will be highlighted.

Event details:

Date:	**March 15, 2017**
Cost:	**$125 per person prior to March 15th, $150 cost at the door, and $100 for SAGE members**
Address:	**Holiday Inn Express, 4360 Town Center Blvd, El Dorado Hills, CA 95762**
Time:	**8:00a.m. to 5:00p.m**

Seminar Topics and Speakers

Global Speaker-STORM PROGRAM-Phase II MS4
Mr. Bill Hereth, State Water Resource Control Board

El Dorado County Regulatory Compliance
Mr. Brenden Ferry, El Dorado County

LID Design and Examples
Ms. Dalia Fadl P.E., City of Sacramento, Dept. of Utilities

Achieving LID Standards, CSUS
Ms. Maureen Kerner P.E., Office of Water Programs

Elk Grove Dry Well Project
Ms. Connie Nelson, CFM, Willdan Engineering/City of Elk Grove
Barbara Washburn, PhD, OEHHA

Panel Discussion: Site Characterization Infiltration/Bioretention Design and Challenges in the Foothills
David Sederquist, CEG, CHG, Youngdahl Consulting Group, Inc.
Chris Shulze, P.E., TSD Engineering

Biological Approach to Stormwater Management
Bill Roach, ASLA, LEED AP, Roach + Campbell

Participating Vendors

Basalite ~ Contech ~ Jensen Precast

SIGN UP AT: www.sage-edc.org

PRACTICAL STORM WATER MANAGEMENT
BEYOND THE REGULATIONS

SAGE 2017 Workshop

Wednesday March 15th, 2017,

Holiday Inn, 4360 Town Center Boulevard, El Dorado Hills

Introduction:	8:00-8:15
Speakers 1 & 2:	8:15-9:15
Global Speaker- STORM PROGRAM- Phase II MS4	**Mr. Bill Hereth, SWQCB**
El Dorado County Regulatory Compliance,	**Mr. Brenden Ferry, El Dorado County**
LID Design and Examples	
Bioswales/Bioretention Planters	9:15-10:00
	Ms. Dalia Fadl, P.E., City of Sac, Dept of Utilites
Break /Vendor 1 Presentation	10:00-10:30
Achieving LID Standards, CSUS	10:30- 11:15
	Ms. Maureen Kerner, P.E. Office of Water Programs
Elk Grove Dry Well Project	11:15-12:00
	Ms. Connie Nelson, City of Elk Grove
	Barbara Washburn, OEHHA
Vendor 2 Presentation	12:00- 12:15
Lunch	12:15- 1:30
Infiltration and Bioretention Design	1:30 – 3:00
Site Characterization and Challenges in the Foothills	
Panel Discussion/Forum	**David Sederquist**, CEG, HG, Youngdahl
	Antony Tassano, PE, Warren Consulting
Vendor 3 Presentation	3:00 – 3:15
Break	3:15- 3:30
7. Biological Approach to Stormwater Management	3:30-4:15
	Bill Roach, ASLA, Roach + Campbell

Vendors: **Contech Engineered Solutions/Jensen Precast/Basalite**

Stormwater Infiltration Using Dry Wells and Elk Grove Dry Well Project

Connie Nelson, CFM[1]
Barbara Washburn, PhD[2]

[1]*City of Elk Grove/Willdan Engineering*
[2]*Office of Environmental Health Hazard Assessment, California EPA*

ELK GROVE

Today's Discussion

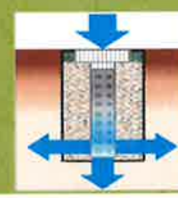
- What are dry wells
- Where dry wells fit in the stormwater BMP toolbox
- Elk Grove Dry Well Project
  - Groundwater quality protection using dry wells
    - Are they a risk?
    - Measures to reduce risk
- Regulatory challenges of using dry wells in the Sacramento region

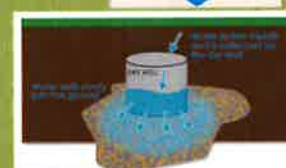
What are Dry Wells?

- Gravity fed excavated pits lined with perforated casing filled with gravel
- Deeper than width
  - 3 feet wide
  - 20 to 60 feet
- Can be used in conjunction with LID practices

How do they work?

- Receives water from one or more entry points
- Collects, stores, and disburses water
- Discharges water through small openings
- Bottom/sides of dry well placed at permeable soils





General Concept of LID Features with a Dry Well

Background

- Uncertain water future
- Climate change alters form of precipitation
  - Drought
  - Extreme climate events
- Need for additional management tools
  - STORMS Program

Groundwater provides 30 percent of the California's water supply

- 431 groundwater basins
- Covers 40% of the State
- Storage capacity:
  - ✓851 million acre-feet (not all useable)

Groundwater Recharge

- Recent report (Stanford Woods Institute of the Environment) identified the aquifer as cheapest and easiest way to store water
- Recharge stormwater to groundwater (conjunctive use)
- Manage stormwater at the source
- Dry wells one tool to help store water

Value of Using Dry Wells in California

- Captures and stores urban stormwater runoff even in clay soils
- Can improve surface water quality
- Facilitates groundwater recharge
- Helps meet hydromodification management goal
- Reduces localized flooding
- Challenge: reluctance to use them due to risks of degrading groundwater quality

Elk Grove Dry Well Project

- Background and project overview
- Project conclusions and findings
- Lessons learned

Monitoring event at Strawberry Creek Water Quality Basin November 2, 2014

Project Background

- Proposition 84 Stormwater Planning Grant
- Grant funding $489K
- Match Funding
  - City of Elk Grove $225K
  - OEHHA $140K
    - Fate and Transport Modeling $135K
- 4-year grant term

Project Team

City of Elk Grove

WILLDAN | extending your reach

cbec

UC DAVIS

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

OEHHA

Water Boards

Project Purpose

Evaluate the potential of using dry wells, in combination with low impact development practices, to:

- Infiltrate stormwater runoff
- Alleviate localized flooding
- Recharge groundwater

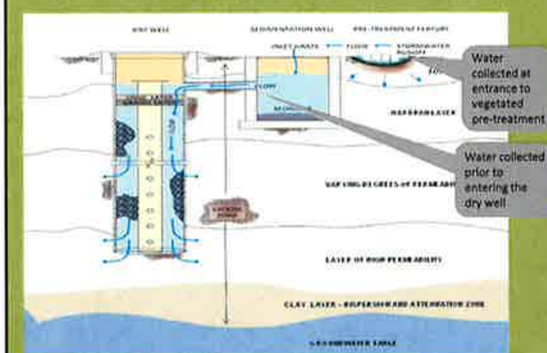
without negatively impacting groundwater quality

Project Site Locations

Project Site Schematic

Dry wells: 40 feet, Vadose zone wells: 55 feet
water table wells: 120 feet

Dry Well Design and Stormwater Sampling



Monitoring event November 2, 2014 at Strawberry Creek Water Quality Basin

Stormwater and Groundwater Monitoring
Fall 2014 – Spring 2016

Water Quality Monitoring

- Collect and sample stormwater and groundwater for 2 years
  - 5 wet weather stormwater samples
  - 5 wet and 2 dry weather groundwater samples
- Flow weighted composite samples collected over 80% of storm volume at the dry well
- Grab samples at curb cut and stormwater outfall (3 events); composites (2 events)

Water Chemistry

- Constituents to be tested in stormwater and groundwater
  - General physical and chemical
  - Metals
  - Volatiles
  - Semi-volatiles
  - Herbicides
  - Pyrethroids
  - Total petroleum hydrocarbons - gas diesels
  - Pyrogenic polycyclic aromatic hydrocarbons
  - Total coliform

Logging boring soil samples at well sites

Fate and Transport of Contaminants

Fate and Contaminant Modeling

- UCD hydrologists (G. Fogg, T. Harder and E. Edwards)
- How far might contaminants migrate from bottom of dry well over many years?
  - Modeling timeframe: 3,000 years

City of Elk Grove Corporation Yard dry well system

Project Conclusions and Findings

Project Conclusions and Findings

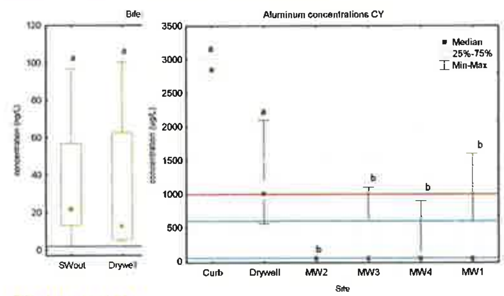
- No evidence that dry wells introduced contaminants into groundwater
- Pretreatment is essential
- Vadose zone provides important attenuation of contaminants
- Stormwater infiltration can dilute groundwater constituents, improving water quality
- Long term stormwater monitoring help ensure groundwater remains high quality

Project Conclusions and Findings

- Groundwater modeling, not monitoring, a better investment of resources
- Siting dry wells where hazardous material are used should be off limits
- Proper design and construction oversight will avoid future problems
- No evidence found for mobilization of naturally occurring metals in subsurface
- Operations and Maintenance Plan should be in place and implemented

Finding 1: Stormwater Doesn't Degrade Groundwater Quality

Evidence: Bifenthrin and Aluminum



Bifenthrin - pesticide

Modeling Results

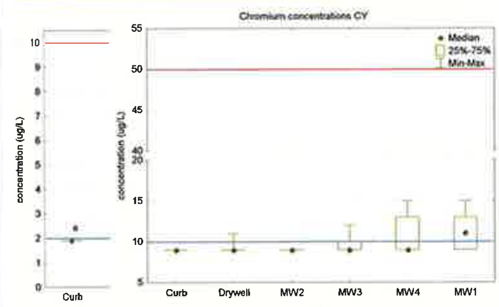
Contaminant input concentr.	Travel time to water table (reporting limit)	Worst case time to regulatory level	Worst case peak concentration at WT in 500 yrs.
Aluminum 0.042 mg/L	ψ	ψ	0.04 mg/L
Bifenthrin 11 ng/L	470 yrs.	n/a	10 ng/L

Dissolved concentrations of contaminants based on measured totals at dry well

Al: will never reach water table in modeling timeframe

Bifenthrin: ~500 years to be able to detect at water table.

Arsenic and Chromium



Conclusions: Risk Groundwater Contamination

- Most contaminants never detected in stormwater or groundwater
  - PAHs, volatile and semi-volatile organics
- Those that were detected in stormwater did not show up in groundwater
  - Even after centuries, unlikely to pose a risk
- One of the keys to protecting groundwater is removing pollutants from stormwater

Finding 2: Pretreatment is Essential

Pretreatment

- Combination of vegetated and structural pretreatment reduces risk
- Many studies and reports recommend vegetative and structural pretreatment (Wogsland, Wilson, Pitt, Clark, US EPA)*
- Portland, OR requires pretreatment with UICs

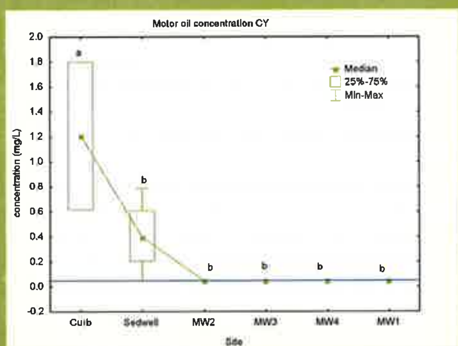
Figure 2. Schematic of typical city UIC system in Portland. Source: Portland Bureau of Environmental Services

* Summarized in annotated bibliography

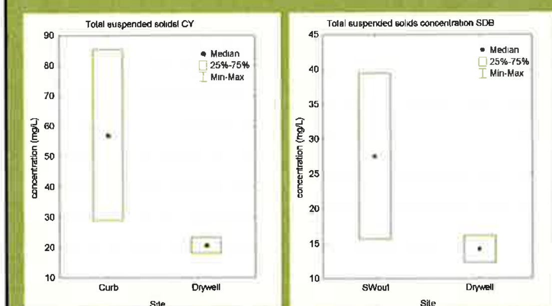
Pretreatment

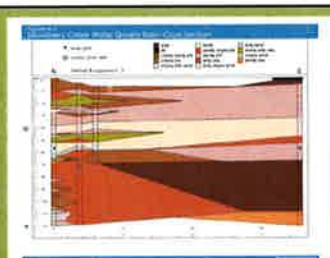
- Some data suggests as much as 90% removal efficiency can be achieved with pretreatment
- In this project, the structural pretreatment was ineffective due to design issues
- 50 - 65% of suspended solids and associated pollutants were removed by vegetated pretreatment

Evidence: Motor Oil



Pretreatment Efficiency

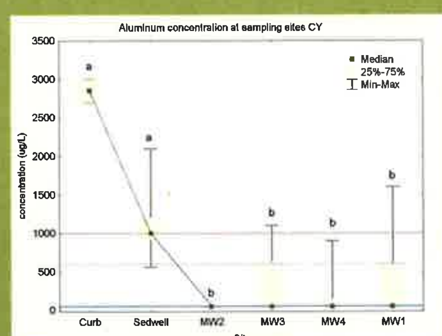




Strawberry Creek Water Quality Basin Lithologic Cross Section

Finding 3: Vadose Zone Provides Important Attenuation of Contaminants

Evidence: Aluminum Concentration



Evidence: Fate and Transport Modeling

Contaminant and input concentration	Travel time to water table (reporting limit)	Worst case time to regulatory level	Worst case peak concentration at WT in 500 yrs.
Corporation Yard			
Aluminum 0.042 mg/L	ψ	Ψ	0.04 mg/L
DEHP 0.062 ug/L	ψ	Ψ	0.06 ug/L
Iron 0.16 mg/L	7 yrs.	Ψ	0.160 mg/L
Manganese 10 ug/L	ψ	Ψ	10 ug/L
Permethrin 2.4 ng/L	ψ	n/a	1.70 ng/L
TBA 19 ug/L	12 days	12 days*	18 ug/L
Fipronil 0.5 ug/L	134 days	n/a	0.47 ug/L
Imidacloprid 0.9 ug/L	17 days	n/a	0.85 ug/L

Evidence: Literature

- Physical properties of clay → attenuation
  - Huge surface area (10 m^2/g) compared to sand or silt
  - Adsorptive capacity (non-ionic, electrostatic, pores)
- Metals attenuated in the vadose zone (Olson, Wogsland, Wilson)
  - Olson found metals and organics adsorbed to sediment in dry well itself…did not migrate (2 year study)
  - Wilson found vadose zone with two clay lenses attentuated both metals and organics (3 year study)

Logging Boring Samples

Finding 4: Siting Considerations Influence the Risk and Performance of the Dry Well

Undesirable and Desirable Siting Considerations

- Undesirable conditions:
  - Areas with hazardous chemicals
    - Vehicle servicing, gas stations, industrial
  - Areas with contaminated soils
  - Proximity to public supply wells
- Desirable conditions:
  - Combination of sand, gravel and clay in the subsurface

Experience at the Corporation Yard

- Corporation Yard site not ideal
  - Bus fleet washing and maintenance area
  - Public Works maintenance yard
  - >95% impervious
  - Hazardous materials that could collect and be conveyed on hardscape → dry well

Siting Recommendations from Literature

- Siting based on site-specific hydrogeological conditions (i.e. vadose zone lithology), land use practices, and soil composition (Wilson, Clark, US EPA) should be considered
- High risk areas should be avoided (Olson, US EPA)

Siting Restrictions in Oregon and Washington

- Oregon and Washington have state regulated programs for using UIC
- Examples of their siting guidelines:
  - 500 feet setback from public supply well
  - Not to be located:
    - near gas stations
    - where hazardous chemicals are used
    - where contaminated soils are found

Interior of dry well, Strawberry Creek Water Quality Basin

Finding 5: Dry Well Useful Tool to Recharge Groundwater

Recharge and Infiltration Capacities

Date	Corporation Yard			Strawberry Detention Basin		
	Average flow (gpm)	Total volume (gallons)	Total rainfall (inches)	Average flow (gpm)	Total volume (gallons)	Total rainfall (inches)
11/2015	8.46	1,000	0.085	46.72 (0.1 cfs)	28,500	0.53
1/2016	26.38	8,400	0.93	36.09	9,200	1.09
3/2016	10.41	1,600	0.20	21.54	3,200	0.2
4/2016	14.29	1,300	0.22	20.15	2,500	0.2

2015-16 precipitation total: 13.5"
With 18" rain, 1 dry well, SDB infiltrate 1 AF; at highest rate, > 3 AF/yr.

Elk Grove Dry Well Project

Lessons Learned

- No evidence that dry wells contributed to groundwater contamination
  - Consistent with literature and experiences from other states
- Challenges to placement and construction of dry well systems

Measuring infiltration rates at the Corporation Yard
April, 2015

Finding 6: Permitting Still Challenging in Sacramento Region

Dry Well Regulations and Permitting

US EPA Underground Injection Control (UIC) Program

- 1989: Authorized use of UICs but runoff entering dry well cannot exceed MCL
- 1999: Performed large study, concluded:
  - Additional regulations unnecessary
  - No evidence of contamination problems
- 2002: EPA Region 9 Factsheet
  - EPA primary agency for overseeing Class V Injection Well Program in California
  - Identified Regional Boards and local agencies to promulgate additional regulations and guidelines

Dry Well Regulations and Permitting

Local authorities follow DWR Bulletin 74-81 and 74-90 guidelines for drinking water wells

- Interpretation assumes stormwater is a waste product
- Wells "used for the injection of reclaimed waste water" including "dry wells," "drainage" wells and sewer wells
- Waste defined as "sewage and all other waste substances of human or animal origin…."
- Waste defined as local interpretation: Dry well should be constructed to drinking water well standards and permitted as such

Dry Well Regulations and Permitting

Challenges

- Dry wells not commonly used in Sacramento region; difficult to obtain permit
- No regional guidelines for design, placement, monitoring, etc.
- Cautious attitude among stormwater managers

BUT…..

- LID/hydromodification NPDES requirements
- Drought, climate change - all push for more infiltration and groundwater recharge
- Water Board STORMS Program – SW = resource
- Future: State establishes guidelines and standards.

Take Away

With proper siting, design and maintenance, dry wells pose little risk to groundwater quality

Provide many benefits:

- *Flood control*
- *Stormwater Management/NPDES*
- *Aquifer recharge*
- *Water quality/aquatic ecosystem protection*

Contact

Connie Nelson, Project Manager
cnelson@elkgrovecity.org
(916) 478-3638

Barbara Washburn, OEHHA
barbara.washburn@oehha.ca.gov
(916) 316-7982

www.egpublicworks.org……click the dry well tab

THANK YOU!

Presentation 19: Stormwater Infiltration Using Dry Wells and Elk Grove Dry Well Project

Sacramento Stormwater Quality Partnership

April, 2017

(Presentation given after final report was submitted)

Presentation 20: Stormwater Infiltration Using Dry Wells and Elk Grove Dry Well Project

American River Basin (ARB) Stormwater Resource Plan

May, 2017

(Presentation given after final report was submitted)

Poster Presentation 1: Fact or Fiction: Is there a link between dry wells and groundwater contamination?

2012 NorCal Society of Environmental Toxicology and Chemistry 22nd Annual Meeting

May, 2012

Fact or Fiction: Is there a link between drywells and groundwater contamination?

Ashoor, A., N. Pi, & B. Washburn

Office of Environmental Health Hazard Assessment, Cal/EPA, Sacramento, CA.

Abstract

Impervious surfaces characteristic of urban areas have resulted in increased stormwater runoff with elevated pollutant levels. In an effort to protect water quality and aquatic habitat, traditional stormwater management systems, which divert stormwater off site, are being replaced with low impact development (LID) practices which infiltrate runoff on site and provide the added benefit of augmenting the aquifer. One challenge to LID practices is poorly-infiltrating soils, common in many parts of California. Drywells can be used to overcome this dilemma. They are typically a 3 foot wide hole in the ground that is filled with rock/gravel which extends down 15-35 feet. Some are concerned that drywells could introduce contaminants into the groundwater and pollute drinking water. To address this issue, OEHHA has reviewed key state and federal reports as well as peer-reviewed literature. There is little data to support this assertion. The data suggests that with proper usage and design, drywells can be used for stormwater management without adverse effects on groundwater quality.

LID Background

Traditional methods of stormwater management have adverse impacts on the aquatic ecosystem:

- Alteration in aquatic habitats
- Reduced aquatic life
- Reduced water quality
- Violations of the Clean Water Act

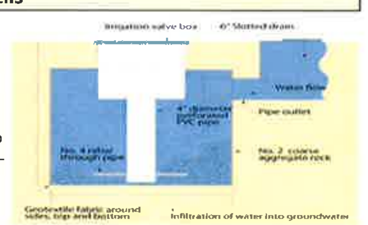
Figure 1: Natural creek affected by channel scouring

Rather than shunting stormwater via pipes to local waterways, LID practices promote capturing runoff at its source through a variety of natural infiltration methods:

- Bioretention (Rain Gardens)
- Green Roofs
- Vegetated Swales
- Permeable Pavement
- Drywells

Drywells

Drywells are typically a 3 foot wide hole in the ground that is filled with rock/gravel which extends down 15-35 feet. In areas containing soils with poor infiltration rates, where stormwater is created faster than the soil can absorb it, drywells can overcome the slow rate of infiltration by penetrating through clay layers to allow access to more permeable soil. Drywells have multiple benefits including stormwater management and groundwater recharge.



Drywell Safety

Some have raised concerns that groundwater could become contaminated with the pollutants present in stormwater runoff. Runoff entering a drywell will often bypass the upper layer of soil where contaminants such as organic compounds and metals are removed by microbes and plants. The drywell itself provides little to no treatment, allowing potentially contaminated stormwater to enter a aquifer. Contaminants which are highly mobile in subsoil, have high concentrations in stormwater, and have high soluble fractions have the greatest potential to contaminate groundwater. These contaminants include nitrates, some pesticides, phthalates, viruses, copper, nickel, and zinc.

Los Angeles Basin Water Augmentation Study

Background: The Los Angeles and San Gabriel Rivers Watershed Council, in conjunction with numerous partners, conducted a long-term study to explore the potential for augmenting local water supplies by increasing infiltration of urban stormwater runoff. The study evaluated the feasibility of promoting infiltration of stormwater through the use of LID practices without adversely affecting groundwater quality. Of the six sites studied, drywells were included in two, one at a private residence and a second at commercial office building.

Figure 2: Pictures of LID practices used at two of the study sites. Figures 2A and B were taken at the office building site. Figures 2C and 2D were taken at the residential site.

Figure 2A. Figure 2B. Figure 2C. Figure 2D.

Los Angeles Basin Water Augmentation Study (cont.)

Monitoring Program: The monitoring program consisted of collecting stormwater runoff samples from the "first-flush" and post-storm samples from the vadose zone (sub-surface unsaturated soil) using lysimeters and from aquifers via monitoring wells. Each sample was analyzed for general monitoring parameters (pH, nitrate, fluoride, temperature, etc.), metals, oil and grease, volatile and semi-volatile organic compounds, and bacteria. Analytes omitted include pyrethroids and some other pesticides.

Results: A general analysis comparing stormwater samples to lysimeters or monitoring well samples was conducted. In a few instances, concentrations of contaminants above the **maximum contaminant level (MCL)** were found in groundwater. However, they appear to reflect pre-existing conditions of the soil and were not statistically linked to the infiltration of stormwater. Selected results, shown below, reflect cases where there were significant differences between groundwater and stormwater samples.

Figure 3 (below). Scatterplot of Contaminants in Stormwater & Pore Water at the Residence. Samples collected from lysimeters at the private residence were compared to runoff from the roof and driveway. If stormwater was contaminating pore water in the vadose zone, levels of both should be elevated. This was not observed for any contaminants. The low levels of chloride found in stormwater samples is not likely to have contributed to the already elevated levels of chloride within the soil. All instances of metals such as copper, lead, and zinc were present at high levels in stormwater, but was not found to affect soil pore water quality.

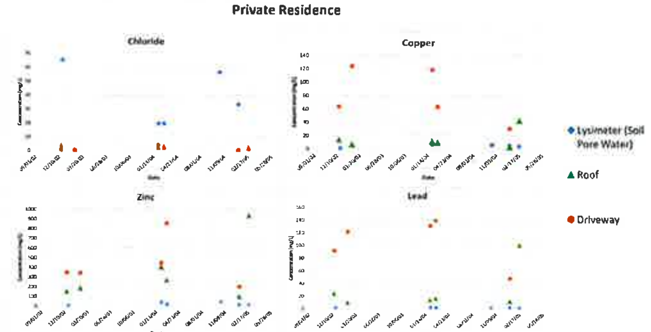
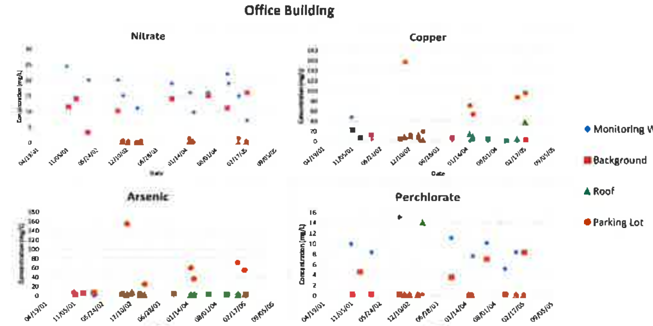


Figure 4 (below). Scatterplot of Contaminants in Stormwater and Groundwater at the Office Building. Unlike the residential site, a control monitoring well (background, red square) was installed to monitor groundwater unaffected by the drywell. Both nitrate and perchlorate concentrations were elevated in groundwater. However, it does not appear that stormwater is responsible for these levels. With respect to nitrate, concentration in water drawn from the control monitoring well and the "experimental" well are similar and stormwater samples had very low levels of nitrate. These finding suggest that existing nitrate in the soil or from elsewhere are the source of elevated nitrate. With respect to perchlorate, only a single stormwater sample had elevated perchlorate levels in contrast to all of the groundwater samples. This suggests that stormwater infiltration is highly unlikely to be the source of the groundwater contamination.

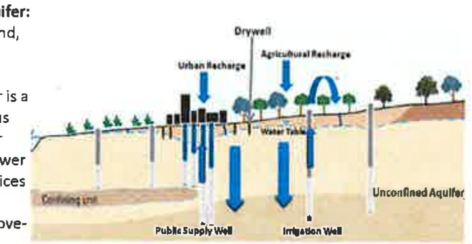


CONCLUSIONS: For all constituents analyzed, there was no statistically significant degradation of groundwater quality due to stormwater infiltration. Roof runoff had lower contaminant levels when compared to those from the driveway and parking lot. Detection of nitrate and chloride in the groundwater likely reflects pre-existing conditions. The detection of perchlorate at the office building also cannot be associated with stormwater infiltration as it was only detected in one stormwater sample. Removal of metals is likely due to adsorption to soil surfaces during infiltration. Groundwater quality saw seasonal improvement for some constituents due to the infiltration of relatively higher quality

USGS Modesto Study

In 2001, the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program began a study to assess the vulnerability of public supply wells to contamination from a variety of constituents. Modesto was selected as a representative of specific geological and aquifer settings for other similar regions in the nation. This study is of particular interest in light of the fact that for the pasat 50 years, Modesto installed over 11,000 drywells that are used to manage stormwater. Although it was not the intended purpose of the USGS study, the data generated from the study can be used to understand the long term risk associated with the use of drywells. **In other words, if drywells have been serving as a conduit for contaminants entering groundwater, the USGS study should reveal this problem.**

Brief background on Modesto's Aquifer: The aquifer is a mixture of gravel, sand, silt, and clay mixed with water. Most drinking water wells in Modesto are 200 to 400 feet deep. Drinking water is a mixture of waters drawn from various depths including deeper, older water and shallower new water. The shallower water reflects current land use practices while water deep can be over 1000 years old. Although groundwater movement is typically slow, irrigation and groundwater pumping in Modesto have increased the rate that water moves through the aquifer by more than 10 times. As a result, water affected by recent land-uses has moved downward to depths of more than 150 feet. Because the aquifer in Modesto is unconfined, water moves relatively freely between different depths. This permits contaminants to mix with older, deeper water without significant constraints. **Bottom line: If drywells were contributing pollutants to the upper aquifer, there is a risk that drinking water could be contaminated.**



Study design: Twenty three monitoring wells were installed at various depths to collect samples from the water table interface with vadose zone, upper, middle, and deep aquifers. Groundwater samples were collected between one to five times during the study (Oct 2003-June 2005) using methods developed by NAQWA. Stormwater runoff was collected in catch basins connected to gutters, and overflow from catch basins was routed to drywells beneath the sidewalk. All water samples were analyzed for conventional water parameters (e.g. pH, dissolved oxygen), inorganic constituents (e.g. uranium), pesticides (e.g sizamine), gas related compounds (BTEX; benzene, toluene, ethylbenzene, and xylenes), volatile organic compounds (VOCs), and refrigerants. Contaminants not measured were 1) metals, 2) pyrethroid pesticides, and 3) PAHs.

Results:

Figure 5 (below). Pesticide detection in groundwater monitoring well samples (23 wells x 1-5 samples/well over the course of the 2 year study). None of the water samples contained pesticides which exceeded their maximum contaminant level (MCL), legal threshold limit on the amount of a substance that is allowed in drinking water.

	Triazine	Simazine	Atrazine	Prometon	Dichloro-aniline	Penda-mithalin	Metolachlor	Diazinon	Dieldrin	DCPA
# of wells with detection	9	9	8	2	2	1	1	1	1	1
Water table & Shallow	8	9	7	2	2	1	1	1	1	1
Intermediate	1	0	1	0	0	0	0	0	0	0
Deep	0	0	0	0	0	0	0	0	0	0
Max Detect	0.096	0.108	0.059	0.01	0.015	0.014	0.004	0.006	0.006	0.002
PSW										
MCL (µg/L, ppb)	na	4	1	na	na	na	na	na	na	na

Figure 6 (below). Volatile Organic Compound detection in groundwater monitoring well samples. Similar sample size as in Figure above. None of the water samples contained pesticides which exceeded their MCLs.

	Trihalomethanes		Solvents					Gasoline-related compounds					
	Chloroform	Bromo-dichlor-ethane	PCE	TCE	Cis- Di-chloro-ethene	Dichlor-ethane	Trichloro-ethane	Methyl tertbutyl ether	m and p Xylene	Ethyl-benzene	1,2,4- Tri-methylbenzene	o-Xylene	1,2-Dichloro-benzene
# of wells with detection	13	4	6	1	1	1	1	5	4	2	2	2	1
Water table & Shallow	11	4	6	1	1	1	1	5	3	2	2	2	0
Intermediate	1	0	0	0	0	0	0	0	1	0	0	0	1
Deep	1	0	0	0	0	0	0	0	0	0	0	0	0
PSW	0.006	0.009	0.013	0	0	0	0	0	0	0	0	0	0
Max Detect	3.534	0.12	1.21	0.03	0.02	0.03	0.02	0.97	0.09	0.02	0.07	0.03	0.02
MCL (µg/L, ppb)	80		5	5	70	7	200	na	1000		700	na	600

USGS Modesto Study (cont.)

In general, drinking water samples contained low concentrations of a variety of contaminants, including uranium, nitrate, volatiles, and pesticides. All values were below the drinking-water MCLs. Depth-dependent sampling indicated that most contaminants in the water came from the shallow aquifer, which provides about 20% of the total volume of water withdrawn from the well. Water in the deep zones of the aquifer contained no anthropogenic contaminants. Although no contaminant from the well exceeded drinking water standards, uranium and nitrogen were detected at concentrations of concern (Figure 7). In water-table and shallow monitoring wells, uranium and nitrogen were detected above their maximum contaminant levels of 30µg/L and 10 mg/L respectively. The likely source of elevated concentration of nitrate is agricultural whereas uranium is a characteristic of the local geology.

Implications on the safety of drywell use: Drywells were initially used in Modesto as an inexpensive way to manage stormwater. Due to the presence of a hardpan layer only small volumes of stormwater will infiltrate through the soil. *Therefore the quality of the groundwater described in USGS study can be viewed as a report card on the risk of contamination associated with long-term drywell use.*

Evidence exists for higher levels of some contaminants in shallow aquifer. However, even at their highest levels, all values were below MCLs. None of these contaminants penetrated into the deep aquifer except in trace amounts. Some have expressed a concern that other studies of drywells did not monitor groundwater for a long enough period of time to detect contamination. However, after 50 years of dry well use, none was observed. The contaminants identified in this study cannot be attributed to drywell use but rather to agricultural (nitrogen) and natural (uranium) sources. Additional studies that investigate contaminants omitted from the Modesto study should be performed.

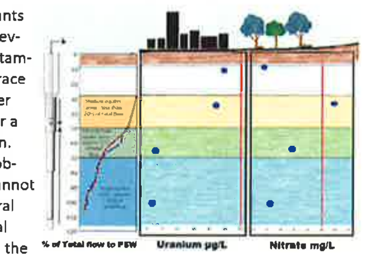


Figure 7: Concentrations of uranium and nitrate drawn from different depths of the aquifer. Contamination was highest in the shallow aquifer.

Sdfdaf sdfadgf gfagafd

Preliminary Conclusions on Drywell Use

Neither the Los Angeles study nor the USGS Modesto study suggest that groundwater quality is degraded by drywells.

Drywells could be a cost-effective tool in the low impact development toolbox. They allow infiltration of stormwater in areas with clay soils. Studies to date do not provide justification for removing them from consideration.

Additional studies are needed to address omissions (e.g. pyrethroids and metals) in both studies. Further, studies on pre-treatment options which would remove sediment that clog drywells as well as carry pollutants would also be helpful.

References

Pitt, R., S. Clark, et al. (1999). "Groundwater contamination potential from stormwater infiltration practices." Urban Water 1(3): 217-236.

The Los Angeles and San Gabriel Rivers Watershed Council, Geomatrix Consultants Inc. (2005). Los Angeles Basin Water Augmentation Study Phase II Final Report. Los Angeles.

Jurgens, B.C., Burrow, K.R., Dalgish, B.A., and Shelton, J.L., 2008 Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public-supply well in Modesto, eastern San Joaquin Valley, California: U.S. Geological Survey Scientific Investigations Report 2008-5156, 78 p.

Poster Presentation 2: Separating Fact from Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff while Protecting Groundwater Quality in Urban Watersheds

2013 Managed Aquifer Recharge in the Urban Environment Technical and Policy Challenges Symposium

May 22 - 23, 2013

Separating Fact from Fiction: Assessing the Use of Dry Wells to Reduce Stormwater Runoff While Protecting Groundwater Quality in Urban Watersheds

MEIROVITZ, Casey[1](cmeirovitz@lsce.com), BOWLES, Chris[2], CARR, Melanie[2], FAWCETT, John[1], KRETSINGER GRABERT, Vicki[1], NELSON, Connie[3], PI, Nelson[2,4], and WASHBURN, Barbara[4],
(1) Luhdorff &Scalmanini, Consulting Engineers, (2) cbec Inc., eco engineering, (3) City of Elk Grove and Willdan Engineering, (4) Office of Environmental Health and Hazard Assessment (California EPA)

Introduction

Watershed urbanization can result in degraded water quality and increased flood risk due to hydromodification (larger peak runoff volume and shorter watershed residence time). Low Impact Development (LID) can reduce these effects by infiltrating and retaining, filtering, or slowly releasing stormwater from a given site or sites. Shallow, low-permeability (clay) soils limit infiltration rates throughout California. Dry wells, constructed above the water table and bypassing these low-permeability zones provide enhanced infiltration, and connection to groundwater storage, benefiting both groundwater and surface water systems. However, there is concern that dry wells could allow stormwater to bypass the natural filtration provided by the uppermost soil units and ultimately impact underlying groundwater quality.

Project Objective: Evaluate the potential for using dry wells, in combination with other LID practices, to infiltrate stormwater runoff, alleviate localized flooding, and recharge groundwater without negatively impacting groundwater quality.

Previous Investigations

USGS Modesto Study

Background
- Modesto began using dry wells to manage stormwater more than 50 years ago.
- Currently more than 11,000 dry wells in operation.

Study Design
- Installed 23 monitoring wells to various depths.
- Groundwater quality sampled for general parameters, inorganics, pesticides, BTEX, VOC's, and refrigerants. Did not measure metals, pyrethroid pesticides, or PAHs.

Results:
- The shallow aquifer showed elevated concentrations of nitrate and uranium attributed to agricultural and natural sources, respectively.
- No contaminants were detected in a monitored public supply well completed in multiple aquifer units.
- After 50 years of dry well use, no contaminants were detected in monitoring wells exceeding MCLs.

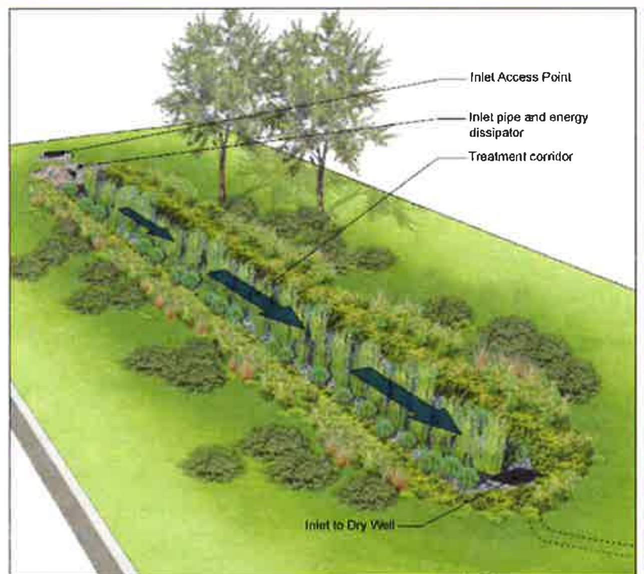
Los Angeles Basin Water Augmentation Study

Background
- Study to evaluate feasibility of promoting stormwater infiltration using LID practices without impacting groundwater quality.

Study Design
- Dry wells and monitoring wells at 1 residential and 1 commercial site.
- Groundwater quality sampled for general parameters, metals, oil and grease, VOCs, Semi-VOCs, organic compounds, and bacteria. Omitted pyrethroids and other pesticides.

Results
- At both sites, contaminants detected at high concentrations in stormwater were detected at low concentrations near the dry well, suggesting effectiveness of pre-treatment and aquifer attenuation.

Surficial Pre-Treatment (Vegetated Swales)



Images adapted from *Low Impact Development Approaches Handbook*, Clean Water Services, 2009.

Design Strategies
- Use vegetation to increase surface roughness.
- Provide water quality treatment through filtration.
- Use soil amendment to increase infiltration.
- Reduce peak discharge rates and total runoff.

Benefits
- Control peak discharges by reducing runoff velocity, lengthening flow paths, and increasing time of conc.
- Trap, filter, and infiltrate particulates and associated pollutants.

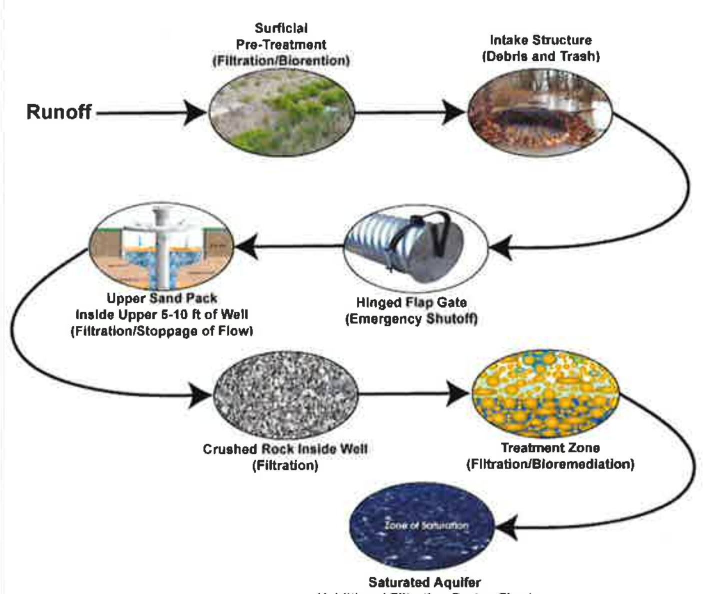
Limitations
- Effectiveness reduced by compacted soils, steep slopes, short flow paths, and large storm/flow events.
- Less effective at removing soluble nutrients like phosphorous.
- Potential vector concerns due to standing water.
- Vegetation may require irrigation/maintenance.

Effectiveness

Pollutant	Total Suspended Solids	Total Phosphorous	Total Nitrogen	Nitrate	Metals	Organics	Bacteria
% Removal	60-95	15-45	16-65	25-65	20-90	75-90	75-90

Dry Well Design and Operation

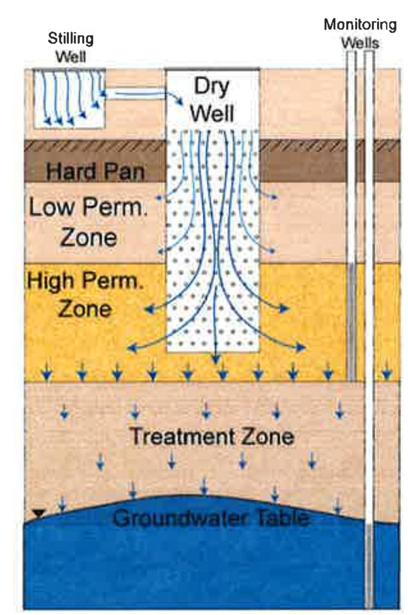
Safety and Treatment "7 Steps to Safety"



Conceptual Design

Design Strategies
- Reduce runoff and enhance groundwater recharge.
- Provide simple, low-cost, broadly applicable design.
- Construct dry well with treatment zone sufficiently above groundwater table.
- Protect groundwater quality through filtration, treatment, and flow control.
- Enhance long-term infiltration through sediment control.
- Reduce maintenance costs.

Limitations/Concerns
- Long-term effectiveness.
- Point-source contamination.
- Natural/anthropogenic groundwater level/quality fluctuations.
- Monitoring network effectiveness.
- Ongoing maintenance costs.



Proposed Study Design

- Install 1 dry well and 4 monitoring wells at each of the 3 sites representing residential, commercial/light industrial, and roadway land uses.
- Enhance or modify existing surficial pre-treatment using vegetated swales and bioretention.
- Continuously monitor flow volumes to the dry wells and groundwater levels in all project wells.
- Water quality sampling 4 times per year for 2 years (following 3 storm events in the rainy season and 1 round of sampling at the end of the dry season).
  - Stormwater quality sampled before and after pre-treatment.
  - Coordinated groundwater and stormwater quality sampling events.
  - Water quality sampling for general parameters, TSS, metals, VOCs, semi-VOCs, PAHs, pyrethroid pesticides, TPH (gas & diesel), and coliform bacteria.
- Perform a tracer test at each site following the first year of sampling to quantify uncertainty relating to the monitoring network design.
- Use appropriate methods to analyze results (contouring, trend analysis and stats).
- Propose monitoring beyond the life of the project.

Anticipated Outcomes

- Determine effectiveness of eco-engineered structures as pre-treatment strategy.
- Develop dry well designs that minimize potential impacts and maintenance.
- Evaluate the efficacy of using dry wells for enhancing groundwater recharge in areas with shallow, low permeability soils/geologic units.
- Quantify potential impacts to groundwater quality resulting from dry well use.
- Develop and provide useful data to cities/counties, health and water agencies, the State Water Resources Control Board, and the U.S. EPA to inform decisions relating to the appropriate use of dry wells in urban watersheds.

References

1. Clean Water Services, 2009. *Low Impact Development Approaches Handbook*. Accessed online at: www.cleanwaterservices.org/PermitCenter/NewsAndResources/LIDAHandbook.aspx
2. Jurgens, B.C., K.R. Burow, B.A. Dalgish, & J.L. Shelton, 2008. *Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public-supply well in Modesto, eastern San Joaquin Valley, California*. National Water Quality Assessment Program. U.S. Geological Survey, Scientific Investigation Report 2008-5156.
3. The Los Angeles and San Gabriel Rivers Watershed Council, 2005. *Los Angeles Basin water augmentation study, Phase II Final Report*. www.watershedhealth.org/Files/document/265_2005_WAS%20Phase%2011%20Final%20Report_2005.pdf

Poster Presentation 3: Stormwater Infiltration using Dry Wells as a Possible Adaptation to Climate Variability

Climate Change and the Future of Groundwater in California Conference, UC Davis

April 16, 2014

Stormwater Infiltration using Dry Wells as a Possible Adaptation to Climate Variability

C. Bowles[A], M. Carr[A], F. Duenas[CE], J. Fawcett[B], V. Kretsinger[B], C. Meirovitz[B], C. Nelson[CE], B. Washburn[D], and D. Wilson[C]

[A] cbec ecoengineering, West Sacramento, CA; [B] Ludhorff Scalmanini Consulting Engineers, Woodland, CA; [C] City of Elk Grove, CA; [D] Ecotoxicology Program, OEHHA, Cal/EPA, Sacramento, CA; [E] Willdan Engineering.

Abstract

Watershed urbanization can result in degraded water quality and increased flood risk due to hydromodification (larger peak runoff volume and shorter watershed residence time). Low impact development (LID) techniques can help reduce these effects by infiltrating and retaining, filtering, or slowly releasing stormwater from a given site. In many areas throughout California, the use of LID practices is challenging due to poor infiltrative capabilities associated with clay soils. Dry wells constructed above the water table and bypassing these low-permeability zones, provide enhanced infiltration and connection to groundwater storage thus benefiting both surface water and groundwater water systems. However, in California, dry wells are used infrequently and with caution due to the concern that they could potentially allow stormwater to bypass the natural filtration provided by the uppermost soil units and ultimately impact underlying groundwater quality. Studies conducted in Los Angeles, Modesto, and Portland suggest that the use of dry wells introduces few, if any, contaminants to the groundwater. To help fill in some data gaps the City of Elk Grove and its partners are conducting a study to evaluate the risk of groundwater contamination by monitoring water collected from dry wells, pre-treatment features and a series of shallow and deep monitoring wells over 2 water years. A wide range of contaminants, including volatile and semi-volatile organics, pyrogenic PAHs, metals, and pesticides will be analyzed in samples collected 3-4 times each year during dry and wet seasons. Estimates of recharge capacity will also be made to determine percent of stormwater captured. Results of this study should provide additional information for decision makers on the safety and efficacy of using dry wells to manage stormwater runoff and recharge the aquifer to mitigate for potential impacts of climate change.

Project Objective: EVALUATE THE POTENTIAL FOR USING DRY WELLS, IN COMBINATION WITH OTHER LID PRACTICES, TO INFILTRATE STORMWATER RUNOFF, ALLEVIATE LOCALIZED FLOODING, AND MAXIMIZE AQUIFER RECHARGE.

Summary of Previous Work

USGS Modesto Study

Background: Modesto began using dry wells to manage stormwater more than 50 years ago. Currently there are more than 11,000 dry wells in operation. They are primarily simple pits filled with rocks with little or no pre-treatment. This design requires high maintenance due to clogging with fine material, requiring regular vacuuming and/or rock replacement.

Study Design: Twenty-three monitoring wells were installed at various depths. Groundwater was sampled for general parameters, inorganics, pesticides, BTEX, VOCs, refrigerants, and naturally occurring toxicants such as arsenic and radionucleides. Samples were collected at various depths and age of the samples were determined. Samples from a single public supply well were also collected.

Results: The shallow aquifer, primarily influenced by agriculture and more recently urban land uses, had elevated concentrations of nitrate and uranium. Samples collected from deeper units contained older water and had little if any contamination of any type. No contaminants were detected in the public supply well completed in multiple aquifer units. After decades of use, no contaminants above MCL were detected in the monitoring wells.

Conclusion: Although the purpose of this study was not to assess the risks of using dry well, the analysis demonstrated that none of the common urban contaminants were detected at levels of concern, suggesting that dry wells did not introduce pollutants into the aquifer.

Water Augmentation Study—Los Angeles

Background: Los Angeles is heavily dependent on imported water. The focus of this 10-year study was to determine if stormwater infiltration could supply the L.A. area with a modest supply of drinking water. Prior to addressing this issue, the risk of groundwater contamination using LID practices, including dry wells, was assessed.

Study Design: Various LID practices were installed at 8 sites; 2 of these, a residential and a commercial site, contained dry wells. Groundwater quality was sampled to determine concentrations of general parameters, metals, oil and grease, VOCs, semi-VOCs, organic compounds, and bacteria.

Results: At both sites, contaminants that were detected at high concentrations in stormwater were detected at low concentrations in vadose zone/groundwater, suggesting that stormwater did not contaminate the aquifer. Conversely, contaminants detected at low levels in stormwater were detected at higher levels in groundwater, suggesting that the contaminants were introduce from other sources.

Conclusion: Dry wells do not appear to contaminate groundwater.

ADDITIONAL BENEFITS OF DRY WELLS

Urbanization has caused dramatic changes in the hydrologic cycle of urban creeks, increasing the volume and timing of stormwater runoff. The effects on the aquatic ecosystem are numerous, including scouring of the bed and banks of creeks and introducing pollutants into the waterways. Another consequence is the smothering of redds with fine sediment. A suite of LID tools have been developed to minimize these changes in the water cycle by infiltrating stormwater where it is created. The clay soils found throughout California pose a challenge to achieving even modest infiltration rates. Dry well are one solution to this problem.

Figure 1. Salmon yolk sac fry in a redd.

Study Design: Overview

- Install 1 dry well and 4 monitoring wells (1 vadose downgradient, 2 water table downgradient, 1 water table upgradient) at 2 sites representing residential and commercial/light industrial land uses.
- Enhance or modify existing surficial pre-treatment using vegetated swales and bioretention.
- Continuously monitor flow volumes to the dry wells and groundwater levels in all project wells.
- Groundwater quality sampling 4 times per year for 2 years (following 3 storm events in the rainy season and 1 round of sampling at the end of the dry season).
- Stormwater quality sampled before and after pre-treatment. 3 times during wet season.
- Coordinated groundwater and stormwater quality sampling events.
- Water quality sampling for general parameters, TSS, metals, VOCs, semi-VOCs, pyrogenic PAHs, chlorophenoxy herbicides, pyrethroid pesticides, TPH (gas & diesel), and coliform bacteria.
- Perform tracer test at each site following the first year of sampling to quantify uncertainty relating to the monitoring network design.
- Use appropriate methods to analyze results (contouring, trend analysis and stats).
- Propose monitoring beyond the life of the project.

Dry Well System Design

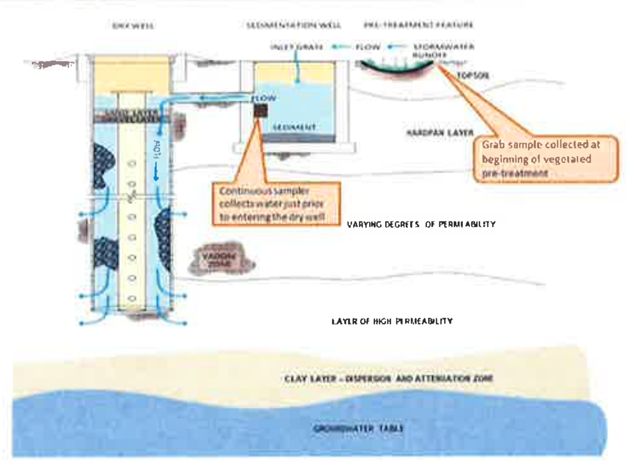


Figure 2. Design of the dry well system. The dry well system is composed of 3 parts:

- A vegetated pre-treatment designed to capture sediment and contaminants adsorbed to particles.
- A structural pre-treatment or sedimentation basin designed to capture additional sediment. The sedimentation basin is approximately 4 feet deep and will be vacuumed periodically to maintain capacity. A sampler will be placed just below the pipe leading to the dry well to facilitate analysis of the effectiveness of contaminant removal using the 2 pre-treatment features.
- The dry well. It is designed with sand and gravel near the top to facilitate trapping of any remaining particles. The dry well will be filled with crushed rocks. It will be completed in a pervious layer of material which is underlain by a clay layer, which will serve as an additional contaminant attenuation and dispersal zone.

Design Considerations

- Capture particulates to the maximum degree possible to avoid contaminating groundwater.
- Minimize clogging of the dry well.
- Minimize long term maintenance costs.

Limitations/Concerns

- Soluble pollutants (N and P) will pass through the dry well system.
- Groundwater monitoring network might not be effective.
- High specific conductivity of stormwater could mobilize naturally occurring metals (arsenic, etc.).

Location of Dry Well Systems

Figure 3. The two sites where dry well systems are being constructed in Elk Grove. The northern site falls within the Strawberry Creek (a tributary of Morrison Creek) subwatershed. The dry well and monitoring network will be located in a large water quality basin that drains a residential neighborhood.

The location to the south falls within the Grantline Channel drainage shed, ultimately draining to the Stone Lakes National Wildlife Refuge. The dry well and associated monitoring network will be constructed in the parking lot of the City's Corporation Yard.

Figures 4a and b. Aerial photographs of the two study sites. The left panel is the Strawberry Creek site; the right panel is the City's Corporation Yard. Location of monitoring wells, dry well, and the vegetated pre-treatment features are shown.

Sample Collection and Analytical Chemistry

Analyte	Method	Detection Limit
Total suspended solids	EPA 160.2	300 µg/L
Pyrethroid pesticides	WPCL PYR_WATER	0.001—0.003µg/L
Chlorinated herbicides	EPA 8151A	0.0005-1.0 µg/L
Total petroleum hydrocarbons	EPA 8015	Gas: 50 µg/L Diesel: 50 µg/L
Pyrogenic polycyclic aromatic hydrocarbons	EPA 8310	10 µg/L
Semi-volatile organics	EPA 625	10 µg/L
Volatile organics	EPA 8260B	0.056-2.2 µg/L
Drinking water metals	EPA 200 series	Varies per metal (0.17-1.35 µg/L)
General physical	EPA STDM	varies
General mineral	EPA STDM	varies
Total coliform	SM 9221	1.1 MPN/100 ml

Table 1. List of contaminants and general constituents that will be monitored in stormwater and groundwater samples. Stormwater samples will be collected at 2 locations: the beginning of the vegetated pre-treatment and just prior to water entering the pipe into the dry well. Three sampling events will occur during the wet season after significant rain events. The groundwater samples will be collected 4 times a year: 3 wet and 1 dry season. In addition to the analysis of these classes of constituents/contaminants, field measurements will be taken that include flow, pH, temperature, electric conductivity, dissolved oxygen, and turbidity (NTU).

Future Results: Questions We Will Address

Research Question	Data that will be used to address this issue
Are the vegetated and structural pre-treatment features effective at removing contaminants and sediment from stormwater?	Differences in turbidity and pyrethroid concentrations of stormwater samples collected at the beginning of the vegetated pre-treatment and just prior to entry into the dry well.
Does the dry well introduce contaminants into the groundwater or vadose zone?	Differences in contaminant concentration between stormwater samples collected just prior to entering the dry well and water collected from the vadose zone and downgradient groundwater monitoring wells. Differences in contaminant concentrations between the upgradient and downgradient water table wells.
Does passage through the vadose zone attenuate contaminant concentration in water infiltrated through the dry well?	Differences in contaminant concentration in samples collected from the downgradient vadose zone well and 2 groundwater monitoring wells.
Does the sedimentation well help to reduce pollutant concentrations in stormwater?	Differences in contaminant concentration in sediment samples collected from the sedimentation well and water that enters the dry well.

Modeling of Possible Long Term Effects and Mobilization of Naturally Occurring Toxic Metals

Working with faculty and students in the Department of Land, Air, & Water Resources, a new task was recently added to this project that will address 2 important issues:

1. Increases in the conductivity of stormwater is among the most well documented stormwater quality changes associated with urban land uses (www.epa.gov/caddis/ssr_urb_wsq2.html). In the Sacramento region, this is often linked to industrial effluent and concrete weathering. High concentrations of these salts can lead to alkaline desorption of arsenic from mineral oxides (Rodriguez-Lado, et al.,2013. Science, 341: 866). It is currently unknown if the concentration of salts in stormwater at the 2 Elk Grove sites is sufficiently high to solubilize these metals.
2. While it is possible contaminants will not reach the water table over the course of 2 years of sampling, it is possible that over 5, 10, or more years, these pollutants might work their way through the vadose zone and reach groundwater. Using contaminant and local stratigraphy data, estimates will be made of the period of time toxicants will need to migrate to the water table. Analysis from the Portland Underground Injection Control Program (https://www.portlandoregon.gov/bes/48213) suggests that there will be only very small migration of chemicals (< 10 feet), data reflecting local soils, geologic formations, and precipitation pattern vary considerably and could produce different results.

Conclusions

Results of this study should fill in existing data gaps and provide information to decision makers regarding the risks associated with using dry wells as a stormwater management, flood control, and climate change adaptation tool. Results will be published in peer-reviewed journals as well as in a Lessons Learned report, available on the project website (http://www.egpublicworks.org. Click the Dry Well Project tab). We welcome feedback and suggestions.

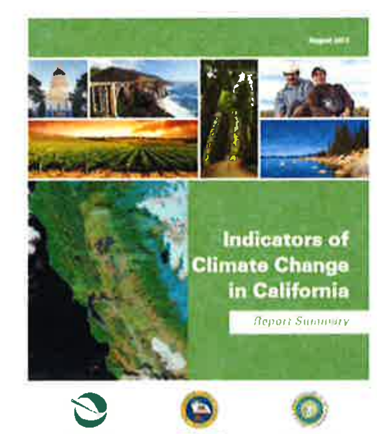


Figure 5. Tracking indicators of climate change. Every 2 years, OEHHA summarizes key literature addressing environmental conditions and effects of climate change. The Executive Summary (left) and full report can be downloaded at: http://www.oehha.org/multimedia/epic/2013EnvIndicatorReport.html.

IF YOU WOULD LIKE TO RECEIVE UPDATES ON THE PROJECT, PLEASE LEAVE YOUR BUSINESS CARD (OR JUST YOUR NAME AND EMAIL) IN THE ENVELOPE BELOW. OR TAKE A BUSINESS CARD OF PROJECT STAFF. WE WELCOME YOUR INPUT.

Poster Presentation 4: Assessing the Use of Dry Wells as a Tool for Stormwater Management and Groundwater Recharge in Urban Areas

2014 American Geological Union Fall Meeting

December 15 - 19, 2014

Assessing the Use of Drywells as a Tool for Stormwater Management and Groundwater Recharge in Urban Areas

H53F-0925

AGU FALL MEETING

Emily C. Edwards[1], Thomas Harter[1], Graham E. Fogg[1], Reid Bryson[3], Casey Meirovitz[3], John Fawcett[3], Chris Bowles[4], Melanie Carr[4], Connie Nelson[5], Fernando Duenas[5], Barbara Washburn[2]

[1] University of California, Davis [2] California EPA, Office of Environmental Health and Hazard Assessment [3] Luhdorff and Scalmanini Consulting Engineers [4] CBEC Ecoengineering [5] City of Elk Grove and Willdan Engineering

Background

California is entering its fourth year of severe drought. During wet and average years, groundwater provides approximately 30% of California's agricultural and urban water use, however during dry years that percentage increases to up to 60%. Recently passed state groundwater legislation has brought groundwater to the forefront of the California water debate. With usage of groundwater at an all-time high and overdraft becoming a serious issue, there is an urgent need for alternative recharge water sources.

Drywells are gravity-fed, excavated pits with perforated casings used to facilitate stormwater infiltration and groundwater recharge in areas comprised primarily of low permeability surfaces or soils. Stormwater runoff that would otherwise be routed to streams or drains in urban areas is used as a source of aquifer recharge. However, the potential for groundwater contamination caused by urban runoff bypassing surface soil filtration has prevented more widespread use of drywells as a recharge mechanism. We present the results of a literature review to assess the potential of drywells for safe stormwater recharge. This work is part of an ongoing pilot study being performed in Elk Grove, CA.

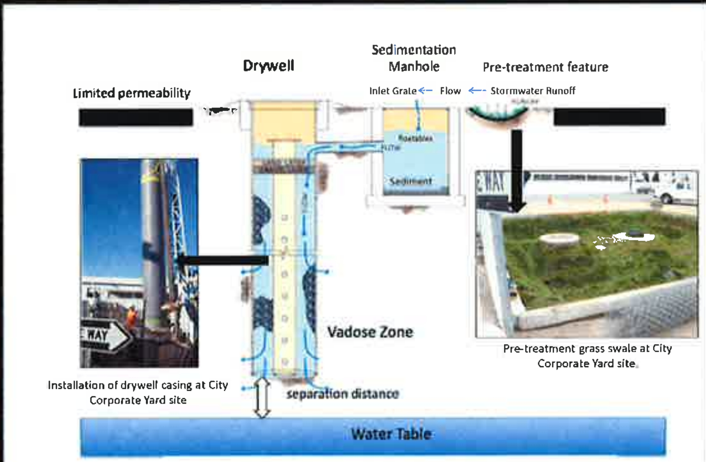


Figure 1. Schematic of a typical drywell (OEHHA, 2007)

State	Estimated Number of Drywells	Mandated Separation Distance (from groundwater)	Other Regulations
Federal	247,522 (1999)	2 feet	Wells under 18 feet deep authorized by rule
Arizona	40,586 (2008)	5 feet (zero feet if no coliforms are detected)	Operate under highly regulated permitting system (regional EPA)
California	11,000 (1999)	5 feet	Operate under permit (Regional EPA)
Hawaii	2,622 (1999)	2 feet	Drywells must accommodate flows of 5 cfs and operate under permit (Regional EPA)
Montana	4,000 (1999)	2 feet	Authorized by rule (Regional EPA)
New Jersey		2 feet	Each well may only drain an area of 1 acre, only roof runoff (State agency)
Oregon	4,148 (1999) Currently 19,000 in Portland alone	zero feet	Authorized by rule (State agency)
Washington	22,700	5 feet high treatment capacity, 10 feet medium treatment capacity, 25 feet low treatment capacity	Authorized by rule (State agency)
Wisconsin	-	-	Construction of new wells banned as of 1994. Wells less than 10 feet deep banned since 1930 (State agency)

Table 1. Key drywell information and regulations in states that served as drywell study locations.

Key Findings

Recharge Potential

Several studies modeled the volume of stormwater entering drywells and consequently recharging underlying aquifers.

Study Location and Year	Method Used	Average Annual Precipitation	Results
Portland Basin, OR, 1994	Performed mass balance (assuming all runoff entering drywells infiltrates to aquifer) for representative area housing 5,700 drywells.	42 inches	21 inches of stormwater per year added to Portland Basin aquifers
Los Angeles, CA, 2010	Theoretical model based on the fact that 48% of LA precipitation falls on impermeable surfaces; assumed ¾ inches of this could be infiltrated through drywells.	18 inches	578,000 acre ft/year could be added to LA aquifers

	Average Scenario			Reasonable Maximum Scenario		
Pollutant	Qfc	Qff	QTg	Qfc	Qff	QTg
Copper	47,000	75,000	460,000	4,500	15,000	45,000
Lead	620,000	1,000,000	6,000,000	90,000	250,000	850,000

Portland 2008 used a 1D spreadsheet model to predict the fate of metals in vasose zones of various compositions.

Table 4 Years for Cu and Pb entering a drywell with 5 ft separation to reach their maximum concentration at the water table.

Study Location	Study Year(s)	Stormwater Contaminants Detected*: metals	Semi-Volatile and Volatile Organic Compounds	Polycyclic Aromatic Hydrocarbons	pesticides	other organics	nutrients/ minerals	biological contaminants
Tucson, AZ	1987	arsenic, cadmium, chromium, lead, mercury, nickel, thallium,	-	anthracene, benzo(A)pyrene, pyrene	-	-	-	-
Los Angeles, CA	2011	various heavy metals, arsenic, copper, lead, zinc,	-	-	-	petroleum hydrocarbons	chloride, nitrogen, salts perchlorate,	bacteria
Modesto, CA	2008	arsenic, uranium	benzene, chloroform, ethylbenzene, tetrachloroethylene, toluene	-	10 total including atrazine and simazine	-	nitrogen	-
Hawaii, HI*	2011	cadmium, chromium, copper, iron, lead, nickel, zinc	-	-	-	-	-	-
Missoula, MT	1988	cadmium, chromium, copper, iron, lead, manganese, nickel, zinc	-	-	-	oil, grease	bicarbonate, calcium, chlorine, manganese, nitrogen, potassium, sodium,	-
Millburn, NJ	2012	lead	-	-	chlordane	endosulfan I, heptachlor epoxide	-	bacteria
Portland, OR	2006-2014	copper, lead	di(2-ethylhexyl) phthalate, pentachlorophenol, toluene	benzo(A)pyrene, naphthalene	2,4-D, methoxychlor	-	-	-
Pierce County, WA	1991-1993	arsenic, copper, lead, zinc	-	-	-	-	nitrogen	fecal coliform
Park Ridge, WI	1999	-	benzene, carbon tetrachloride, naphthalene, trichlorofluoromethane, toluene, xylene	benzo(a)anthracene, benzo(A)pyrene, benzo(b)fluoranthene, chrysene	-	-	chlorine, nitrogen, sodium	-

*stormwater was not sampled for study; contaminants are hypothesized based on results of previous stormwater data collection.
[1] detected in stormwater samples, groundwater monitoring wells, or vadose zone water samples.
[2] detected in elevated levels.
[3] detected in trace amounts

Table 3. Findings of the nine studies reviewed that looked at stormwater contaminants in relation to drywells.

Effects on Water Quality

Nine studies were reviewed that employed both drywells and a water quality monitoring system. The extent of monitoring performed for each study ranged over a broad spectrum, from grab samples being taken from one drywell over the course of a year, to ten years of rotating monitoring of up to thirty wells with vadose zone, groundwater, and surface stormwater samplings taken at regular intervals. Fate and transport modeling was also performed as a part of some studies.

Pollutant	MADL (µg/l) Input conc.	Output conc.	Percent reduction
Benzo[a]pyrene	0.2	0	100
Napthalene	6.2	0	100
DEHP	6	0	100
PCP	1	0	100
2,4-D	70	0.25	99.6

Table 4. Modeled concentrations of common stormwater pollutants after passing through a drywell and immediately above the water table. Model assumptions: 5 feet of separation between the bottom of the drywell and the water table, coarse grained sediments with high permeability in subsurface. MADL is the maximum allowable discharge level in stormwater, the equivalent of the MCL for drinking water.

Table 5. Table taken from Clark and Pitt 2007. Contamination potential for common stormwater pollutants based on their mobility, abundance, and filterable fraction. Potential varies based on soil characteristics such as texture, hydraulic conductivity, pH, and CEC.

Clark and Pitt

Groundwater contamination potential for stormwater pollutants.

Compound class	Compounds	Mobility (worst case: sandy/low organic soils)	Abundance in stormwater	Fraction filterable (dissolved)
Nutrients	Nitrate	[illegible]	[illegible]	High
Pesticides	2,4-D	[illegible]	Low	Likely low
	γ-BHC (lindane)	[illegible]	Moderate	Likely low
	Malathion	[illegible]	Low	Likely low
	Chlordane	[illegible]	Moderate	Very low
	Diazinon	[illegible]	Low	Likely low
Other organics	Volatile organic compounds (VOCs)	[illegible]	Low	Very high
	1,3-Dichlorobenzene	[illegible]	High	High
	Benzo(a)anthracene	[illegible]	Moderate	Very low
	Bis (2-ethylhexyl) phthalate	[illegible]	Moderate	Likely low
	Fluoranthene	[illegible]	High	High
	Naphthalene	[illegible]	Low	Moderate
	Phenanthrene	[illegible]	Moderate	Likely low
	Pyrene	[illegible]	High	High
Pathogens	Enteroviruses	[illegible]	Likely present	Moderate
	Shigella	[illegible]	Likely present	Moderate
	P. aeruginosa	[illegible]	Very high	Moderate
	Protozoa	[illegible]	Likely present	Moderate
Heavy metals	Cadmium	[illegible]	Low	Moderate
	Chromium	[illegible]	Moderate	Very low
	Lead	[illegible]	Moderate	Very low
	Zinc	[illegible]	High	High
Salts	Chloride	[illegible]	Seasonally high	High

[illegible]

Separation Distance

Several model studies evaluated the groundwater protectiveness of various separation distances between the drywell bottom perforation and the seasonal high water table, and the effect of varying storm event intensities.

Study Location and Year	Method Used	Local Geology	Results
Portland, OR, 2006 - 2014	Chose contaminants based on results of 2 years of monitoring. Used 1D spreadsheet model.	Alluvial deposits, gravel, sand, and silt	All contaminants were sufficiently attenuated by 5 foot separation distance through course sediment.
Tucson, AZ, 1987	Used UNSAT 2 modeling software to predict magnitude, direction, and velocity of stormwater infiltration.	Sand, clay, silt interbeded with caliche layers	Contaminants were sufficiently attenuated by 75 foot separation distance; layered subsurface with some clay is preferable.

Conclusions and Future Work

Drywells have been shown to be an effective and practical means by which to manage stormwater runoff and recharge groundwater. Their success, however, is dependent on local subsurface conditions, the land use surrounding the drywells, and the quantity of water infiltrating. A stratified subsurface containing some layers with high clay content is appropriate. Drywells should not be installed in areas that are expected to experience any type of contaminant spills or surface applications of potential contaminants. Runoff from roofs was found to be the most devoid of contaminants. Drywells may be of great use in California as a method of groundwater recharge, however further studies are needed in order to determine localized contamination potential.

Current work includes a comparative pilot study involving a residential site and an industrial site in Elk Grove, CA. The study will use modeling tools to assess the recharge potential and groundwater protectiveness of drywells. Both sites are outfitted with four monitoring wells each: an upgradient monitoring well, two downgradient monitoring wells, and a vadose zone monitoring well. The results of water quality sampling will determine the contaminants of interest. A model of the fate and transport of these contaminants in the vadose zone will be coupled with hydraulic models to estimate the response of the hydrogeologic system to drywell recharge. The study goal is to create a comprehensive planning and assessment tool for the evaluation of future drywell locations.

Figure 2

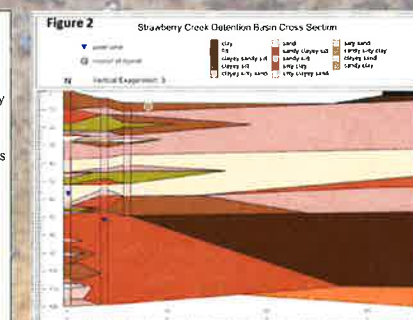


Figure 3

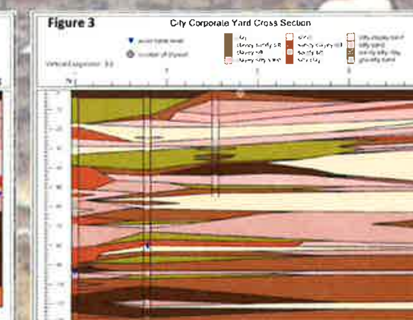


Figure 4

Figure 5

Figure 6

Figures 2, 3, 4, 5, and 6. Locations of comparative pilot study drywells. Figure 5 is a site map of the City of Elk Grove, CA, and our two drywell locations. Figures 2 and 3 depict the composition of the underlying sediments at the two sites located in the Sacramento Valley in Elk Grove. The sediment layers are based off of 120 to 55 foot long undisturbed cores taken from each of the six monitoring well and two vadose zone well locations, and the water table level data is as recorded in June, 2014. Figures 4 and 6 delineate the position of the cross sections. The City Corporate Yard drywell drains an area of 1 acre, while the Strawberry Creek Detention Basin drywell was placed in a pre-existing detention basin that drains 215 acres. Both wells are fully constructed and have begun to infiltrate stormwater.

References and Acknowledgements

Adolfson Associates. 1995. *Pilot Evaluation Subsurface Stormwater Disposal Facilities*. Tacoma Pierce County Health Department, Tacoma Pierce County Washington.

Bandeen, R.F. 1987. *Additional case study simulations of dry well drainage in the Tucson basin*. Pima County Transportation and Flood Control District. Tucson, AZ. Posted at: [illegible]

Clark, S.E. and R. Pitt. 2007. *Influencing factors and a proposed evaluation methodology for predicting groundwater contamination potential from stormwater infiltration activities*. Water Environ. Res. 79(1): 29 – 36.

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

Department of Water Resources. 2014. Groundwater Information Center. [illegible]

Environmental Protection Agency. 1999. *The Class V Underground Injection Control Study. Volume 3: Storm Water Drainage Wells*. Office of Groundwater and Drinking Water.

Izuka, S.K. 2011. *Potential effects of roadside dry wells on groundwater quality on the Island of Hawai'i – Assessment using numerical groundwater models*. U.S.G.S. Scientific Investigations Report 2011-5072, pp. 1 – 30. Posted at: [illegible]

Jurgens, B.C., Burow, K.R., Dalgish, B.A., and J.L. Shelton. 2008. *Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public supply well in Modesto, eastern San Joaquin Valley, California*. USGS Scientific Investigations Report 2008-5156. 78 p. Posted at: [illegible]

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

Lindsey, G., Roberts, L. and W. Page. 1992. *Maintenance of Stormwater BMPs in Four Maryland Counties: A Status Report*. Journal of Soil and Water Conservation. Vol. 47:417-422.

The Los Angeles and San Gabriel Rivers Watershed Council. *The Los Angeles and San Gabriel Rivers Water Augmentation Study*
2005. *Phase II Final Report.*
2008. *Phase II Monitoring Report Update*
2010. *Ground Water Augmentation Model Demonstration Report.*
Posted at: [illegible]

City of Portland Bureau of Environmental Services. 2008. *Decision Making Framework for Groundwater Protectiveness Demonstrations. Underground Injection Control System Evaluation and Response*. Posted at: [illegible]

Snyder, D.T., Morgan, D.S., and T.S. McGrath. 1994. *Estimation of groundwater recharge from precipitations, runoff into drywells, and on-site waste-disposal systems in the Portland basin, Oregon and Washington*. USGS Water Resources Investigations Report 92-4010: 1—24. Posted at: http://pubs.usgs.gov/wri/1992/4010/report.pdf

Wogsland, K.L. 1988. *Effect of urban storm water injection by Class V wells on the Missoula aquifer, Missoula, Montana*. University of Montana: 1-133.

Special thanks to OEHHA staff and student interns for their contribution to this literature review, and to the Prop 84 Water Bond Fund as well as the City of Elk Grove.

Poster Presentation 5: Numerical Model Assessment of the Effects of Dry Well Facilitated Stormwater Infiltration

2015 American Geological Union Fall Meeting

December 14 - 18, 2015

H13L-1743

Numerical Model Assessment of the Effects of Drywell Facilitated Stormwater Infiltration

AGU FALL MEETING
San Francisco | 14–18 December 2015

Emily C. Edwards[1], Thomas Harter[1], Graham E. Fogg[1], and Barbara Washburn[2]
[1] University of California, Davis [2] California EPA, Office of Environmental Health and Hazard Assessment

Motivation and Background

Drywells (Fig. 1):
- gravity-fed, excavated pits with perforated casings
- used to facilitate stormwater infiltration in areas with low permeability surfaces or soils

Benefits:
- decrease surface runoff in urban areas
- enhance groundwater recharge and storage
- influent stormwater contaminants undergo attenuation processes in subsurface

Concerns:
- potential for groundwater contamination

Elk Grove, CA Drywell Study
- two drywell sites (site IDs SCDB and CY) in Elk Grove, CA, one suburban and one industrial
- drywell construction completed Oct. 2014

Study Objectives:
- determine risk of groundwater contamination from drywells
- facilitate development of design criteria for typical California conditions

Figure 1. Typical drywell. Influent stormwater is routed through a pretreatment feature before entering a sedimentation. The drywells built for the Elk Grove study are 0.76 m in diameter and 12.8 m deep with an open bottom, backfilled with pea gravel and encased in perforated concrete. The separation distance is the vertical distance between the bottom of the drywell and the seasonal high water table, and is 4 m and 11 m for the sites involved in this study.

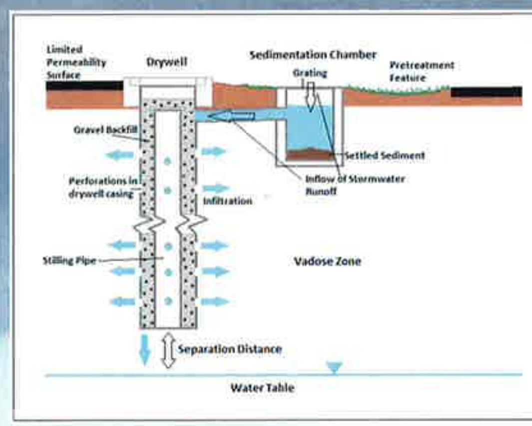


Figure 2 Strawberry Creek Detention Basin Lithology Cross Section

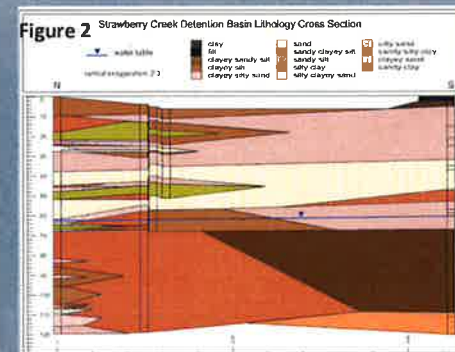


Figure 3 City Corporate Yard Lithology Cross Section

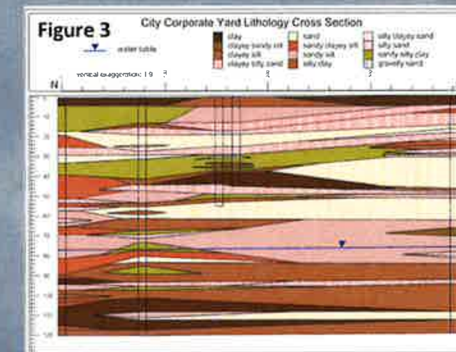
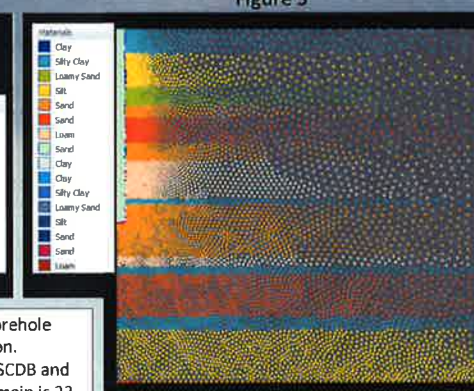


Figure 4

Figure 5



Figures 2 and 3. Lithologic cross-sections created using borehole data taken during monitoring well and drywell construction.
Figures 4 and 5. Axisymmetrical HYDRUS 2D domains for SCDB and CY respectively (SCDB domain is 17 m by 24 m, and CY domain is 23 m by 24 m) created to represent the vadose zone materials portrayed in the cross-sections.

Preliminary Findings and Future Work

Findings:
- contaminants with high Kd values do not reach water table within current simulation period (4 years)
- significant lateral flow through layers with high Ks underlain by layers with low Ks (e.g. sand on clay)
- simulated ponding in drywell resembles ponding observed in field data
- work currently constrained by run-time of simulations

Future Work:
- comparison of constant contaminant loading scenarios with temporally variable contaminant loading scenarios
- groundwater modeling of contaminant plume migration using MODFLOW to represent drywell input as point source to predict any interaction with local municipal wells (Harbaugh, 2005)

Figure 6

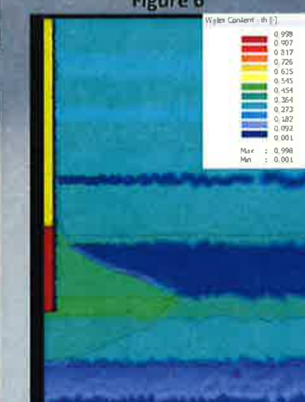


Figure 6. water content distribution through the SCDB domain during an infiltration event. The red in the drywell material indicates ponding inside the drywell.

Figures 7 and 8. contaminant distributions of bifenthrin and a conservative tracer in the SCDB domain after one year of infiltration.

Figure 9 and 10. contaminant distribution of iron in the CY domain as plume enters groundwater and after three years of infiltration

Figure 7

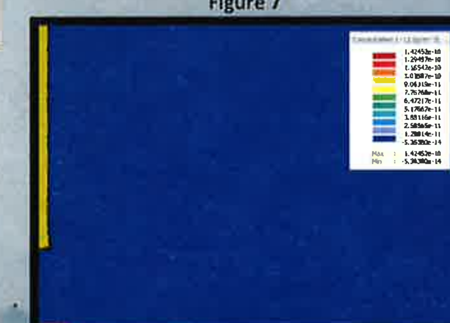


Figure 8

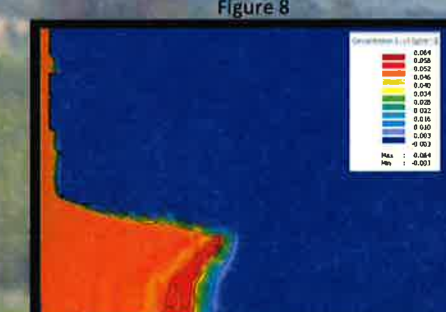


Figure 9

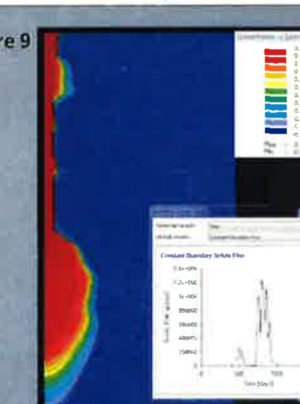
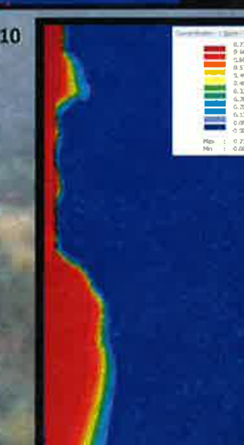


Figure 10



Study Design Part 1. Field Sampling

Sampling Methods:
- hourly, flow-weighted composite samples taken from pipe connecting sed. chamber to drywell
- groundwater samples taken between 2 and 5 days after storm

Water Samples Analyzed For:

-general parameters	-volatile organics	-pyrogenic PAHs	-minerals	-hexavalent chromium
-herbicides	-semi-volatile organics	-pyrethroids	-metals	-total coliform

Table 1. contaminants and concentrations detected at each event. Contaminants exceeding MCLs are indicated with red, upgradient monitoring wells with blue, downgradient monitoring wells with green.

Table 1

Site and Sampling Source	Sampling Event Dates and Contaminants Detected			
	08/04/2014	02/06/2015	04/24/2015	11/02/2015
SCDB stormwater	-	Bifenthrin: 62.9 ng/L Deltamethrin: 17.4 ng/L Permethrin cis: 8.4 ng/L Al: 590 µg/L Fe: 550 µg/L V: 5.5 µg/L NO3: 3.6 mg/L	Toluene: 0.84 µg/L Fe: 190 µg/L Mn: 70 µg/L Total coliform: >1600 MPN/100 mL	B: 130 µg/L Al: 300 µg/L Fe: 340 µg/L Mn: 41 µg/L V: 5.6 µg/L NO3: 4.4 mg/L
SCDB groundwater	Bifenthrin: MW2: 4 ng/L As: MW1: 3.89 µg/L, MW3: 4.4 µg/L, MW4: 4.3 µg/L Mn: MW4: 240 µg/L	Dalaphon: MW3: 3.1 µg/L Bifenthrin: MW2: 7 ng/L V: MW1: 15 µg/L, MW4: 20 µg/L Fe: MW1: 140 µg/L, MW2: 13 µg/L As: MW2: 2.5 µg/L, MW3: 2.7 µg/L, MW4: 2.5 µg/L Mn: MW4: 30 µg/L NO3: MW1: 8.6 mg/L, MW2: 5.8 mg/L, MW3: 8.5 mg/L, MW4: 8.0 mg/L Total coliform: MW4: 1600 MPN/100 mL, MW2: >1600 MPN/100 mL	-	-
CY stormwater	-	-	Fe: 700 µg/L Mn: 23 µg/L V: 4.6 µg/L Total coliform: >1600 MPN/100 mL	Al: 920 µg/L Fe: 1100 µg/L Mn: 30 µg/L Total Cr: 11 µg/L V: 8.2 µg/L NO3: 2.2 mg/L
CY groundwater	Total Cr: MW1: 15µ g/L, MW4:13 µg/L As: MW1: 3.6 µg/L, MW3: 4.3 µg/L	-	Al: MW1: 1600 µg/L, MW3: 1100 µg/L, MW4: 150 µg/L As: MW1: 3.6, MW3: 4.2 µg/L, MW4: 4 µg/L	-

Study Design Part 2. Numerical Modeling

Modeling Method:
- HYDRUS 2D/3D finite element model used to simulate water flow and solute transport in variably saturated media (Simunek, 2011).

Domain Design:
- drywells are very high Ks gravel with low Ks clay perforated linings
- domain materials are constructed from borehole data, and physical parameters inferred from field infiltration tests

Model Inputs:
- physical and chemical subsurface parameters (Van-Genuchten parameters including Ks, ρ, f_{oc})
- solute reaction parameters and influent concentrations
- time variable fluxes (365 day precipitation record repeated over simulation period) inferred from field flow rate data
  - SCDB: 11000 cm/day
  - CY: 4000 cm/day

Table 2. The contaminants and concentrations chosen as inputs into the two site simulations. The input parameters for the contaminants include their diffusivity in water (D_W) and in gas (D_G), their partitioning coefficient (K_d), and their Henry's Law constants. K_d values for organic compounds are the product of their octonol water partitioning coefficient (K_{oc}) and the fraction organic carbon (F_{oc}) of the material through which the contaminant is being transported.

Table 2 Site	Contaminants and Concentrations Modeled	Input Parameters			
		D_W (cm²/day)	D_G (cm²/day)	K_d (cm³/g)	Henry's Constant (-)
SCDB	Bifenthrin @ 1.0E-4 mg/L	0.388	1555.2	2.3E6 $\times F_{oc}$	4.1E-5
	Aluminum @ 0.6 mg/L	0	0	1500	0
CY	Bifenthrin @ 6.3E-8 mg/L	0.388	1555.2	2.3E6 $\times F_{oc}$	4.1E-5
	Iron @ 2.7 mg/L	0	0	25	0

Acknowledgements and References

This project would not be possible without funding from the Proposition 84 Water Bond Fund and cooperation from the City of Elk Grove, CA. Thanks also to Ary Ashoor, Kathleen Doran, Hamad Hamad, and Bennett Lock of CalEPA OEHHA; Chris Bowles, Melanie Carr, Rafael Rodriguez, and Benjamin Taber of CBEC Eco Engineering; Reid Bryson of LSCE; and Connie Nelson and Fernando Duenas of the City of Elk Grove. Special thanks go to Maziar Kandelous of UC Davis LAWR.

Šimůnek, J., M. Th. van Genuchten, and M. Šejna, The **HYDRUS** Software Package for Simulating Two- and Three-Dimensional Movement of Water, Heat, and Multiple Solutes In Variably-Saturated Media, Technical Manual, Version 2.0, PC Progress, Prague, Czech Republic, pp. 258, 2011.
Harbaugh, A.W. MODFLOW-2005, The U.S. Geological Survey modular ground-water model -- the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously p., 2005.

Poster Presentation 6: Assessing the Effect of Dry Well Aided Stormwater Infiltration on Groundwater Quality

2015 NorCal Society Environmental Toxicology and Chemistry 25th Annual Meeting

April 30, 2015

Assessing the Effect of Drywell Aided Stormwater Infiltration on Groundwater Quality

E.C. Edwards[1], B.S. Washburn[2], T. Harter[1] G,E. Fogg[1], H.K. Hamad[2], A. Ashoor[2], & C. Nelson[3]

[1] Dept. Land Air Water Resources, UC Davis; [2] Office of Environmental Health Hazard Assmt.; [3] Willdan Engineering/City of Elk Grove, CA

Abstract

Drywells are gravity-fed, excavated pits with perforated casings used to facilitate stormwater infiltration and groundwater recharge in areas comprised of low permeability soils or cover. Stormwater runoff that would otherwise be routed to streams or drains in urban areas is used as a source of aquifer recharge. However, the potential groundwater contamination caused by runoff bypassing surface soil filtration has prevented widespread use of drywells as a recharge mechanism. There is considerable drywell literature indicating that infiltrating contaminants are adequately attenuated in the vadose zone, leaving groundwater quality uncompromised. A study is currently underway in Elk Grove, CA, where two drywells have been constructed: one in a preexisting drainage basin fed by residential lots, and one at an industrial site. Both sites are outfitted with four monitoring wells each: one upgradient and two downgradient water table wells, and one vadose zone well. Results of water quality sampling will determine contaminants of interest, and a model of the fate and transport of these contaminants in the vadose zone will be coupled with hydraulic models to estimate the response of the hydrogeologic system to drywell recharge, with the goal of creating a tool that can be used to evaluate other drywell locations.

Background

California is entering its fourth year of severe drought. During wet and average years, groundwater provides approximately 30% of California's agricultural and urban water use, however during dry years that percentage increases to up to 60%. Recently passed state groundwater legislation has brought groundwater to the forefront of the California water debate. With usage of groundwater at an all-time high and overdraft becoming a serious issue, there is an urgent need for alternative recharge water sources. Drywells can be installed in areas where available surface area is limited, and have the advantage of storing runoff underground, avoiding water loss due to evaporation. Studies have shown that with adequate pretreatment and careful monitoring, drywells do not pose a threat to groundwater quality.

Study Purpose

The purpose of the study was to assess the risks of groundwater contamination associated with the use of dry wells. Dry wells are a means of infiltrating urban runoff when clay soils reduce infiltration rates. Increasing the infiltration of stormwater reduces runoff volume and the numerous adverse effects on the aquatic ecosystem associated with hydromodification. Further, due to drought and climate change, there is a need to utilize stormwater as a way to recharge the aquifer. By evaluating the risks associated with the use of dry wells, these multiple goals will be addressed.

Study Design & Methods

The dry well is approximately 30" wide x 45 foot deep; filled with gravel with perforations throughout. The dry well was constructed so the bottom releases water into a sandy zone with a high rate of infiltration. Just below is a layer of clay which serves as a final attenuation site for contaminants.

To assess the risk of groundwater contamination, a series of monitoring wells were constructed: 3 completed at the water table and 1 in the vadose (unsaturated) zone (**Figure X**). One water table well is upgradient of the dry well and serves as a control while the other two are downgradient. The vadose zone well is slightly deeper than the dry wells and a short distance downgradient from it.

Figure 1. Schematic of a typical drywell

Figure 2. Dry well sites and monitoring well system. The left panel is the Strawberry Detention Basin site; the right the Corporation Yard site. MW1 is the upgradient water table well; MW2 is the vadose zone well; MW 3 & 4 are downgradient water table wells.

Dry well systems were constructed at two sites in Elk Grove CA reflecting different land uses. One site was a bus parking lot and the second a detention basin in a residential neighborhood. Each dry well system consist of vegetated and structural pretreatment and the dry well itself (Fig.1). The pretreatment portion of the system was designed to remove particles and the contaminants sorbed to them.

To assess the risk of groundwater contamination, a series of monitoring wells were constructed: 3 completed at the water table and 1 in the vadose (unsaturated) zone (Fig.2). One water table well is upgradient of the dry well and serves as a control while the other two are downgradient. The vadose zone well is slightly deeper than the dry wells and a short distance downgradient from it.

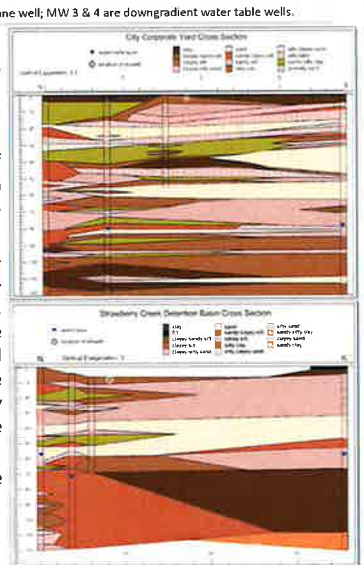


Figure 3 (above) depicts the composition of the underlying sediments at the two sites. The sediment layer positions are identified using 55 -120 feet long undisturbed cores taken at each of the six monitoring well and two water table well locations.

Samples of stormwater and groundwater are analyzed for the following contaminants:

General physical/mineral	Volatile organics
Semi-volatile organics	Pyrogenic PAHs
Pyrethroids	Chlorophenoxy herbicides
Drinking Water Metals	Chrome 6
Total coliform	Conventional parameters

Monitoring is being conducted approximately 4 times each year for 2 years. Stormwater samples are collected if a storm exceeds 0.4" of precipitation. Flow-weighted composites samples of stormwater, collected over 80% of the runoff volume, are the primary type of sampling. At Strawberry Detention Basin, runoff samples are collected at the outfall of two stormdrains while at the Corp Yard, the samples are collected at the entrance of the pipe carrying water from the sedimentation well to the dry well. Within 5 days of the storm event, groundwater samples are collected at each of the 4 monitoring wells. All of the water samples are analyzed for the suite of contaminants listed above.

Results will be analyzed to assess the following:

- Differences in contaminant concentration between the upgradient and downgradient GW to determine if the dry well introduces contaminants;
- Contaminant concentration in the dry well, vadose zone, and downgradient GW to assess the role of the subsurface in sorbing contaminants; and
- For select contaminants, quality of SW entering the vegetated pretreatment and entering the dry well, to assess the effectiveness of the pretreatment features at removing contaminants.

To estimate the risk of groundwater contamination over the long term, the movement of contaminants through the vadose zone will be modeled using HYDRUS 2D and MODFLOW. Additionally, the risk of desorption of naturally occurring toxic metals associated with SW infiltration will also be modelled.

Results

One full round of stormwater and groundwater monitoring and chemical analysis has been performed at both sites as well as infiltration testing. Some of the results from the Strawberry Creek Detention Basin site are shown below:

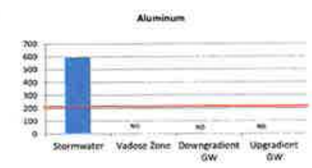


Figure 4. Concentration of aluminum in the stormwater, vadose zone well, downgradient and upgradient groundwater wells (GW). Samples were collected Strawberry Detention Basin site (n=1). Orange line reflects US EPA Secondary Screening Levels (non-regulatory) The Maximum Contaminant Level (MCL; regulatory level) is 1000 µg/L. ND=not detected. Data from this single monitoring event shows that while stormwater contains considerable amounts of Al, none penetrate to the vadose zone or water table. The literature suggests that most metals are sorbed by clays and other particles within the vadose zone.

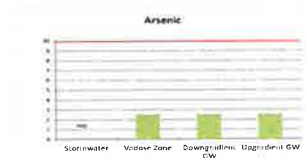


Figure 5. Concentration of aresenic in the stormwater (SW), vadose zone well, downgradientand upgradient groundwater wells (GW). The red line is the Maximum Contaminant Level (MCL; regulatory level). ND=not detected. Data from this single monitoring event shows that stormwater does not contain arsenic but it is present at 1/4 of the MCL in the vadose zone and in groundwater. Arsenic is a naturally occurring metalloid throughout our region and the Southwest in general.

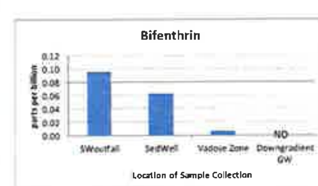


Figure 6. Concentration of bifenthrin measured in the stormwater, sedimentation well, vadose zone, and at the downgradient water table well. SWoutfall = stormwater outfall; SedWell=sedimentation well that captures particulates. As stormwater moved from the outfall to towards the dry well system (SWoutfall —> SedWell) through vegetation in the basin, the concentration of bifenthrin decreased by about 30%. When stormwater moved from the inlet of the SedWell, through the drywell, and into the vadose zone, bifenthrin concentration declined about 6 fold. No bifenthrin was detected in the downgradient water table. This preliminary finding suggests that the dry well system (vegetation and sedimentation well that are designed to trap particulates and the vadose zone which has significant amounts of clay which adsorbs lipophilic contaminants and metals) is working as anticipated.....significantly reducing the concentration of contaminants. Future analysis will either confirm these preliminary findings or reveal a different pattern of pollutant attenuation.

Contaminant Fate & Transport Modeling

In order to estimate potential long-term effects of drywell stormwater infiltration, contaminant fate and transport modeling will be performed for contaminants chosen based on the results of water quality testing. The first step will be to model the transport and fate of contaminants in the vadose zone using HYDRUS 2D. HYDRUS is a finite element modeling software used for variably saturated flow in between ground surface and the water table. The vadose zone will be modeled as a 2D, layered system consisting of clay, silt, sand, and gravel. Inputs needed for this step are properties of the vadose zone including hydraulic conductivity (a property describing the ease with which a fluid flows through a material) and organic content of sediment layers, properties of the recharge including the frequency and intensity of rain storms, the capacity of the drywells, the size of the watershed, and properties of the chosen contaminants including partitioning coefficients and sorption rates. The second step will be to model the fate and transport of contaminants in groundwater using MODFLOW, a finite differences groundwater flow model. The output of the vadose zone modeling will provide the contaminant concentration inputs for the groundwater modeling. Other inputs include local and regional groundwater gradients, aquifer hydraulic conductivity, extent, and dispersivity, and contaminant properties. The results of the modeling will provide average and worst-case scenarios for potential groundwater contamination on both a short-term and long-term scale, and provide information about the effectiveness of vadose zone materials (such as clays) as a means to reduce contaminant concentrations.

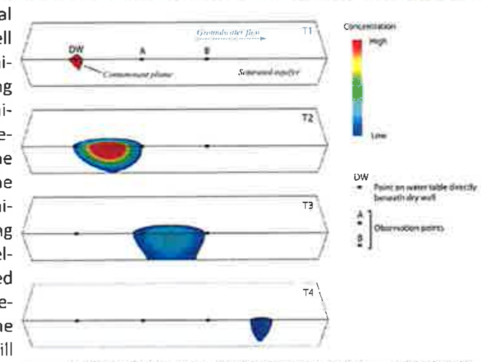


Figure 7 is a contaminant transport simulation done for a USGS drywell study in Hawaii. The simulation was created using MODFLOW-2005, and shows a drywell infiltration contaminant plume travelling with the regional groundwater flow, and the gradual degradation of the plume and decrease in contaminant concentration.

Summary of Literature Review

The literature on dry wells and their potential link to groundwater contamination is relatively small. Of the studies and reports that have been published (Lindemann, 1999; Barraud et al., 1999; Wilson et al., 1989 &1990; Wogsland et al.,1988; Olson et al.,1987; City of Bend, 2011; City of Portland, Bureau of Environmental Services, 2008; & LASGRWC, 2010), most have drawn similar conclusions - that drywells do not appear to contribute to groundwater contamination. Wilson *et al.* (1989) observed that metal pollutants are likely retained in the vadose zone while organic pollutants are degraded by bacteria in the vadose zone. The USGS performed a detailed study of Modesto to assess groundwater quality (Jurgens et al., 2005). While the purpose of their study was not to evaluate dry wells, dry wells have been used in Modesto as a stormwater management tool for over 50 years. The research team found little evidence of groundwater contamination from urban uses. Further, the cities of Bend and Portland Oregon have operated over 20,000 dry wells for over than 5 years. The extensive stormwater monitoring they have performed in conjunction with groundwater modeling suggests that groundwater is protected from the risk of contamination.

Some investigators have suggested limitations on how and where dry wells should be utilized. Olson *et al.* (1987) and Bandeen *et al.* (1984) determined that drywells should not be sited where known toxic material is used or near public-supply wells. Pitt *et al.* (1999) and Clark *et al.* (2007) determined that some type of vegetative or structural pretreatment should be incorporated into the drywell design, as it serves to prevent clogging of the drywell and sequesters sediment and associated pollutants. Pitt et al. (1999) found that pollutants with high abundance in stormwater, high mobility in the vadose zone, and those that are highly water soluble pose the greatest risk to groundwater quality. An example of this is nitrate.

Lastly, the literature has pointed to the benefits of dry wells as an aquifer recharge tool. Snyder et al. (1994) and Bouwer et al. (2002) determined that the use of dry wells can have significant recharge potential. The Los Angeles and San Gabriel Rivers Watershed Council (2010) calculated that if infiltration practices were widely developed in the Los Angeles region, it would result in a 384,000 acre-feet/year increase in groundwater recharge; enough to supply water for three-quarters of a million typical Southern California families each year.

An annotated bibliography that reviews this and other literature is available at: http://oehha.ca.gov/ecotox/drywells/pdf/AnnotBiblioDryWells2015.pdf.

Corporation Yard Drywell

Strawberry Detention Basin Drywell

References

Bandeen, R.F. 1987. *Additional case study simulations of dry well drainage in the Tucson basin.* Pima County Transportation and Flood Control District. Tucson, AZ.

Clark, S.E. and R. Pitt. 2007. *Influencing factors and a proposed evaluation methodology for predicting groundwater contamination potential from stormwater infiltration activities.* Water Environ. Res. 79(1): 29 – 36.

Izuka, S.K. 2011. *Potential effects of roadside dry wells on groundwater quality on the Island of Hawai'i – Assessment using numerical groundwater models.*

Jurgens, B.C., Burow, K.R., Dalgish, B.A., and J.L. Shelton. 2008. *Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public supply well in Modesto, eastern San Joaquin Valley, California.* USGS Scientific Investigations Report 2008-5156. 78 p.Posted at:

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

The Los Angeles and San Gabriel Rivers Watershed Council. *The Los Angeles and San Gabriel Rivers Water Augmentation Study,* 2010. *Ground Water Augmentation Model Demonstration Report.*

City of Portland Bureau of Environmental Services. 2008. *Decision Making Framework for Groundwater Protectiveness Demonstrations: Underground Injection Control System Evaluation and Response*

Wilson, L.G., Osborn, M.D., Olson, K.L., Maida, S.M., and L.T. Katz. *The groundwater recharge and pollution potential of dry wells in Pima County, Arizona.* 1990. Groundwater Monitoring & Remediation. Summer. 114-121.

Wogsland, K.L. 1988. *Effect of urban storm water injection by Class V wells on the Missoula aquifer, Missoula, Montana.* University of Montana: 1-133.

Poster Presentation 7: Assessment of Dry Wells as Effective Tools for Stormwater Management and Aquifer Recharge: Results of a Two-Year Field and Numerical Modeling Study

2016 American Geological Union Fall Meeting

December 12 - 16, 2015

AGU FALL MEETING
San Francisco | 12–16 December 2016

H13M-1606

Assessment of Drywells as Effective Tools for Stormwater Management and Aquifer Recharge: Results of a Two-Year Field and Numerical Modeling Study

Emily C. Edwards[1], Barbara S. Washburn[2], Thomas Harter[1], Graham E. Fogg[1], Xue Li[1], Bennett Lock[2], and Connie Nelson[3]

1. University of California, Davis; 2. California EPA, Office of Environmental Health and Hazard Assessment; 3. Willdan Engineering

Background and Motivation

Climate change and a five year drought have shown California's surface water resources to be less reliable and resilient than they have been in the past. Snowpack from the Sierra Nevada is decreasing and melting earlier in the year, increasing the temporal gap between peak surface water availability and peak water usage. Agricultural and urban water users are turning to groundwater as a more reliable water source. In order to maintain groundwater as a sustainable water resource there is an urgent need for alternative sources of aquifer recharge.

Drywells are gravity-fed, excavated pits with perforated casings used to facilitate stormwater infiltration and groundwater recharge in areas with low permeability soils or cover. Stormwater runoff that would otherwise be routed to streams or drains in urban areas is used instead as a source of aquifer recharge, potentially mitigating the effects of un-sustainable groundwater usage and harm to natural surface water bodies. However, the potential for groundwater contamination caused by urban runoff bypassing surface soil attenuation processes has prevented large scale use of drywells in California. This project was conducted in order to assess the safety of drywell use.

Drywell Design and Site Description

Fig. 1 (above) Grassy swale pretreatment feature at CY site

Fig. 2 (below) Installation of perforated drywell casing at CY site

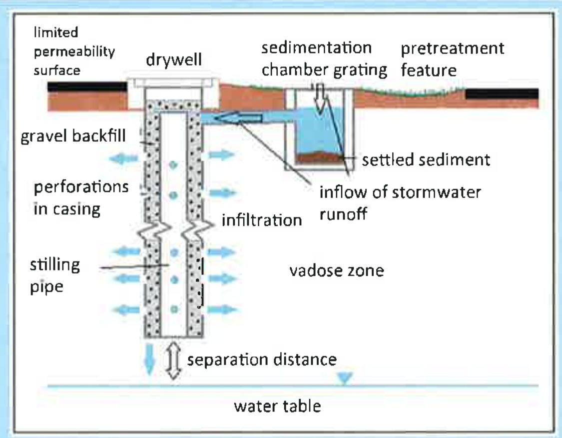


Fig. 3 (at right) Drywell design

The two drywell field sites are located in Elk Grove, CA (see fig.s 4 through 6). The Corporate Yard (CY) site has an industrial land use. The Strawberry Creek Detention Basin (SCDB) site was constructed in a pre-existing stormwater detention basin surrounded by residential land use. The sites' drywells are between 12.2 and 13.7 m in depth and include vegetated pretreatment features and sedimentation chambers. Both field sites include four monitoring wells: a vadose zone monitoring well, an upgradient groundwater monitoring well, and two downgradient groundwater monitoring wells.

Fig. 4 CY site map Fig. 5 Map of CA showing Elk Grove and site locations Fig. 6 SCDB site map

Methods

Field Methods

Site stormwater and groundwater monitoring occurred during the 2015 and 2016 water years. Six stormwater sampling events were conducted at each site with hourly, flow-weighted composite samples taken. Five groundwater sampling events were also conducted at each site between two and five days after each sampled storm, with an additional three dry season sampling events.

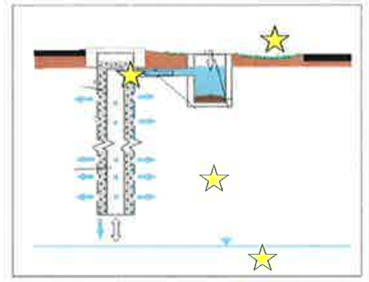


Fig. 7 SW and GW sampling locations

Date	Site	SW or GW
08/4/14	CY and SCDB	GW
02/6/15	SCDB	SW and GW
04/24/15	CY and SCDB	SW and GW (CY)
09/17/15	CY and SCDB	GW
11/02/15	CY and SCDB	SW and GW (SCDB)
01/05/16	CY and SCDB	SW and GW
03/04/16	CY and SCDB	SW and GW
04/22/16	CY and SCDB	SW
05/17/16	CY and SCDB	GW

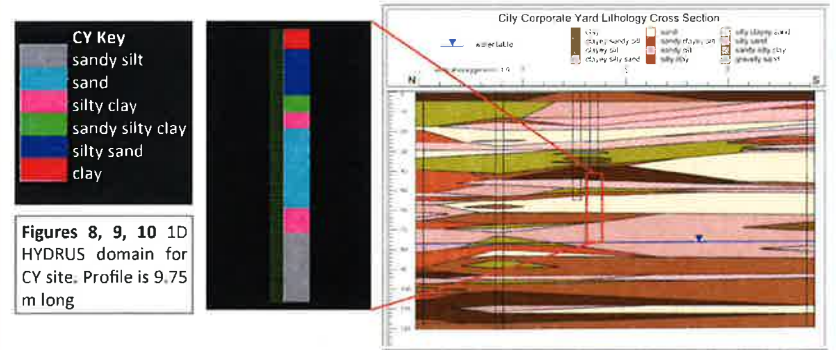
Table 1 sampling dates and locations from monitoring period

Numerical Methods

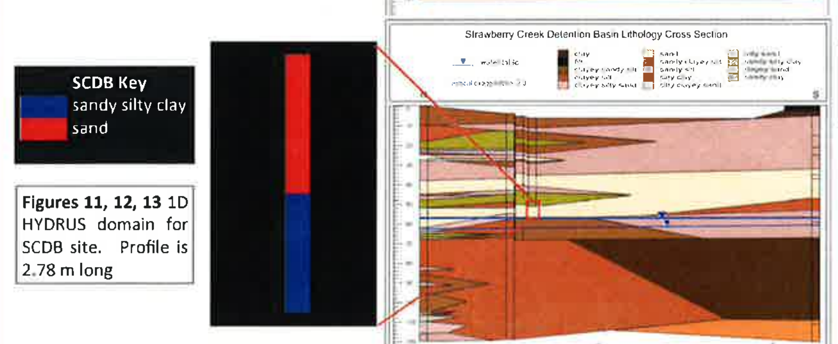
The vadose zone flow and transport modeling software HYDRUS 1D was used to predict the travel times of chosen contaminants vertically downward from the bottom of the drywell to the top of the seasonal high water table. Eight scenarios were run for each contaminant at each site with varying contaminant input concentrations, clay K_s values, and f_{oc} values.

Type of model input	Individual parameters	Sources of values
Van Genuchten parameters, other soil charactersitics	K_s, Q_r, Q_s, α, n, ρ_b	HYDRUS neural network predictions, Falling head tests at sites
Contaminant chemical characteristics	K_d or K_{oc}, H, k, D_g, D_w	Literature values
Annual infiltration record: pressure head and contaminant concentration	Daily Ψ, contam. concentration of influent water	Stage data from pressure transducers at bottom of drywell

Table 2 information on model inputs



Figures 8, 9, 10 1D HYDRUS domain for CY site. Profile is 9.75 m long

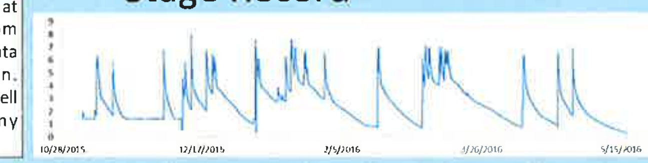


Figures 11, 12, 13 1D HYDRUS domain for SCDB site. Profile is 2.78 m long

Results

Stage Record

Fig. 14 stage in drywell at CY site derived from pressure transducer data for 2016 wet season. Ponding occurs in drywell for most/all of rainy season.

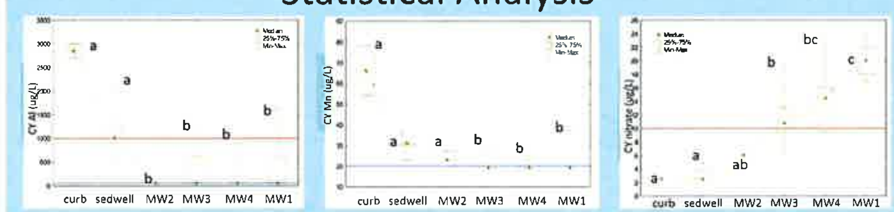


Stormwater and Groundwater Sampling

Analyte category	Volatile organics	Semi-volatile organics	Chlorinated herbicides	PAHs	Pyrethroids	Metals	Minerals	Total coliform
Detected in SW or GW	SW and GW (only detected when RL lowered)	SW and GW	SW only	Not detected	SW only	SW and GW	SW and GW	SW and GW
Reg. limit exceed-ances	yes (TBA notifica-tion level)	no	no	no	no	yes (Al MCL, Fe sec. std)	yes (nitrate MCL GW)	yes
Analytes chosen for modeling	TBA	DEHP	-	-	Bifenthrin and permethrin	Al, total Cr, Fe, and Mn	-	-

Table 3 results of water quality analyses

Statistical Analysis

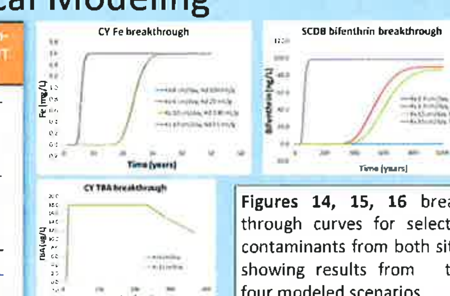


Figures 15, 16, 17 box plots for Al, Mn, and nitrate at CY site combining results of all water sampling events

Numerical Modeling

CY Contaminant and [input]	Travel time to RL at WT	Time to regulatory limit	Peak concentration at WT in 500 yrs
Al 2.1 mg/L	274 yrs	351 yrs MCL	2.07 mg/L
Cr (total) 11 ug/L	β	α	n/a
DEHP 3.01 ug/L	α	α	2.73 ug/L
Fe 1.6 mg/L	5 yrs	6 yrs sec std	1.60 mg/L
Mn 31 ug/L	8 yrs	α	31.0 ug/L
permethrin 12.2 ng/L	17 yrs	ε	8.78 ng/L
TBA 19 ug/L	10 days	12 days NL	17.99 ug/L
fipronil 0.5 ug/L	133 days	ε	0.473 ug/L
imidacloprid 0.9 ug/L	16 days	ε	0.855 ug/L

Table 4 selected results from CY site modeling showing worst case scenario travel times and concentrations. Contaminants in blue were not found in site stormwater, but were modeled at theoretical concentrations.



Figures 14, 15, 16 break-through curves for selected contaminants from both sites showing results from the four modeled scenarios

Conclusions and Recommendations

The results of the field testing and numerical model analyses indicate that the Elk Grove drywells pose little risk to groundwater quality; however, some risk does exist. The worst case scenario modeling results show stormwater contaminants exceeding regulatory limits with prolonged use. The average scenario modeling results show a few of the stormwater contaminants exceeding regulatory limits decades into the future. Stormwater quality analyses show that the designed pretreatment features decrease influent contaminant concentrations by approx. 52%, and literature indicates that with improved pretreatment design this can increase to 90% removal. With adequate vadose zone separation distance and appropriate land use siting, drywells can be a safe means to manage stormwater and provide aquifer recharge.

Appendix 6.5

Project Description/Flyer

Dry Wells: Using Stormwater as a Resource while Protecting Groundwater Quality

CITY OF ELK GROVE

PROJECT PURPOSE

This project will evaluate the risk to groundwater quality associated with infiltrating stormwater runoff through dry wells with pretreatment facilities. To accomplish this goal, the City of Elk Grove has brought together a team of surface water and groundwater hydrologists and toxicologists from Cal/EPA's Office of Environmental Health Hazard Assessment, Willdan Engineering, and local consulting firms. The project is funded by a California State Water Resources Control Board Proposition 84 Stormwater Planning and Monitoring Grant.

Strawberry Creek Water Quality Basin Investigation Boring/Monitoring Wells

KEY ASPECTS OF THE PROJECT

- The project is comprised of two site locations in Elk Grove: a residential neighborhood and a commercial parking lot.
- Monitoring wells are constructed at each site, upgradient and downgradient of the dry well system to monitor groundwater quality (Figure 1).
- Water quality monitoring will be performed four times per year for two years.
- Stormwater samples will be collected from the dry well system at two locations (Figure 1) during significant storm events.
- Post-storm event groundwater samples will be collected from all monitoring wells.
- Analytes to be measured include volatile and semi-volatile organics, pesticides/herbicides, combustion by-products (PAHs), metals, and conventional water quality parameters.
- Flow rates will be measured and estimates of groundwater recharge capacity will be made.
- Risk of groundwater quality degradation associated with dry well use will be determined.
- Potential for long term migration of contaminants through sub-surface and mobilization of naturally occurring metals will be modeled by Land, Air and Water Resource Department, UC Davis.

BACKGROUND

Watershed urbanization can result in increased flood risks and degradation of water quality and aquatic habitat due to hydromodification. Low Impact Development (LID) techniques may help reduce these impacts. However, in many areas throughout California, the use of LID techniques is challenging due to poor infiltrative capabilities associated with clay soils. One solution is to bypass these low-permeability clay zones through the use of dry wells; vertical infiltration pipes which are deeper than they are wide. Studies have shown that when combined with LID pretreatment, dry wells can recharge the aquifer with little, if any risk of groundwater quality. Furthermore, this combined approach will decrease stormwater runoff and may reduce the adverse impacts of hydromodification on receiving water bodies. The goal of this project is to further quantify the benefits and potential risks of using dry wells to accomplish multiple objectives.

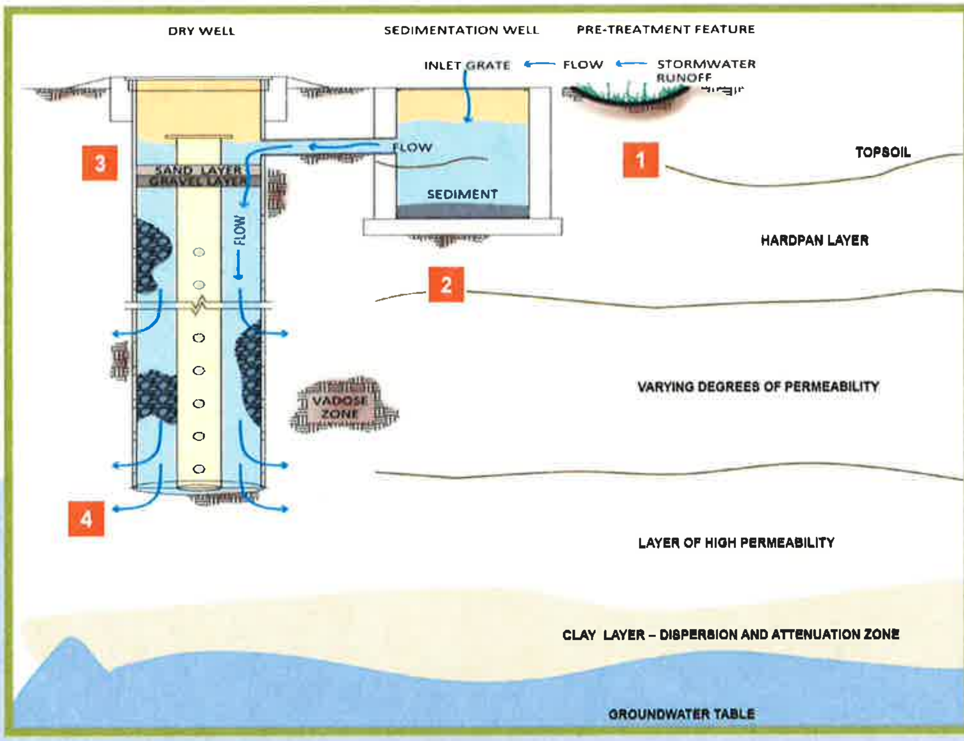


FIGURE 1: DRY WELL SYSTEM UNDER EVALUATION IN THE ELK GROVE PROJECT

1. Stormwater will enter a vegetated pretreatment facility such as a swale or bioretention cell. Sediment will be captured through the swale or bioretention cell. Approximately 70% of stormwater pollutants are associated with sediment; and this is the first step in the treatment train to help reduce the contaminant load prior to entering the dry well.
2. Stormwater will subsequently flow into a sedimentation basin that will further allow particulates to fall out, thereby reducing pollutants entering the dry well. The sedimentation basin is a 3 foot diameter concrete vault that can be cleaned out as sediment accumulates. The volume of sediment that accumulates will also provide data on the effectiveness of the vegetated pretreatment as well as provide information on the maintenance requirements of future dry well systems.
3. The upper layers of the dry well system will contain sand and gravel to further trap fine particulates. This portion of the dry well will be easily accessible for removal and replacement of sand and gravel as necessary for maintenence purposes. The majority of the dry well will be filled with large gravel and stones. The interior pipe will permit access to water in the dry well for sampling and water level determinations.
4. The bottom of the dry well will sit in a layer of permeable sub-surface material to optimize infiltration capacity. Further, beneath this permeable layer, there will be a layer of clay which will function to disperse stormwater horizontally and serve as a final site of pollutant attenuation.

CITY OF ELK GROVE

REGIONAL AND STATEWIDE SIGNIFICANCE

In California, dry wells are used infrequently and with caution due to the concern that they may provide a conduit for contaminants to enter the groundwater. This contrasts with neighboring states such as Arizona and Oregon, where dry wells are used extensively as stormwater and flood control management tools. Results of this project along with a comprehensive literature review should provide scientific information on the risk to groundwater quality associated with dry well use in urban areas. This information may be used by decision makers to determine appropriate guidelines for dry wells in the Sacramento region and throughout the State of California.

This project is in partnership with:

WILLDAN | extending your reach

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

cbec

Contact: Connie Nelson, CFM, Project Manager, (916) 478-3638, cnelson@elkgrovecity.org
or visit us online at: egpublicworks.org/dry-wells/

Appendix 6.6

Project Contacts and Stakeholders

Project Contacts and Interested Stakeholders

Number	Contacts	Name	Phone	Email
1	Luhdorff and Scalmanini Consulting	Reid Bryson	530-661-0109	rbryson@lsce.com
2	Torrent Resources	Travis Pacheco	707-266-2583	tpacheco@torrentresources.com
3	State Water Resources Control Board	Kelley List	916-319-9226	kelley.list@waterboards.ca.gov
4	EPA Region 9	Peter Kozelka	415-972-3448	kozelka.peter@epa.gov
5	Professional Legislative Representation	Jason Gonzales	916-441-0597	gonsalves@gonsalvi.com
6	Elk Grove Unified School District	Bill Heinicke	916-686-7111	wheinick@egusd.net
7	Elk Grove School District	Robert Pierce	916-686-7711	rpierce@egusd.net
8	County of Sacramento Water Agency, Groundwater Section	Kerry Schmitz	916-874-4681	schmitzk@saccounty.net
9	DWR	Carmel Brown	916-591-1324	carmel.brown@water.ca.gov
10	Congress of the United States	Congressman Ami Bera	916-635-0505	ami.bera@mail.house.gov
11	California State Senate	Senator Richard Pan		claire.conlon@sen.ca.gov
12	SACOG	Mike McKeever		mmckeever@sacog.org
13	County of Sacramento	Dana Booth	916-874-4389	boothd@saccounty.net
14	State Water Resource Control Board	Bryan Smith	530-226-3425	bryan.smith@waterboards.ca.gov
15	Elk Grove Unified School District	Ray Pietersen	916-686-7797	rpeter@egusd.net
16	City of Elk Grove	Christopher Jordan	916-478-2222	cjordan@elkgrovecity.org
17	City of Elk Grove	Bob Murdoch	916-478-2287	bmurdoch@elkgrovecity.org
18	Urban I Rain Design	Kevin Robert Perry	503-928-5522	kevin@urbanraindesign.com
19	City of Elk Grove/Willdan Engineering	Tom Metcalf	916-478-2281	tmetcalf@elkgrovecity.org
20	Torrent Resources	Jim Mayer	602-499-5881	jmayer@torrentresources.com

21	Luhdorff and Scalmanini Consulting	Scott Lewis	530-661-0109	slewis@lsce.com
22	State Water Resources Control Board	Chris Beegan	916-341-5912	chris.beegan@waterboards.ca.gov
23	State Water Resources Control Board	Jeff Albrecht	916-322-8569	jeffrey.albrecht@waterboards.ca.gov
24	City of Elk Grove	Councilmember Steve Detrick	916-478-2201	sdetrick@elkgrovecity.org
25	City of Elk Grove	City Manager Laura Gill	916-478-2200	lgill@elkgrovecity.org
26	City of Elk Grove	Councilmember Steve Ly	916-478-2279	stevely@elkgrovecity.org
27	Office of Water Programs CSUS	Maureen Kerner	916-278-8117	maureen.kerner@owp.csus.edu
28	City of Sacramento	Dalia Fadl	916-808-1449	dfadl@cityofsacramento.org
29	City of Elk Grove	Brian Fragiao	916-627-3223	bfragiao@elkgrovecity.org
30	City of Elk Grove/Willdan Engineering	Connie Nelson	916-478-3638	cnelson@elkgrovecity.org
31	City of Elk Grove/Michael Baker International	Gerald Park	916-478-3671	gpark@elkgrovecity.org
32	Sacramento Area Flood Control Agency (SAFCA)	Tim Washburn	916-874-7606	washburnt@saccounty.net
33	Regional Water Authority (RWA)	Rob Swartz	916-967-7692	rswartz@rwah2o.org
34	Laguna Creek Watershed Council	Barbara Washburn	916-316-7982	lagunacreek@gmail.com
35	CA Office of Environmental Health Hazard Assessment (OEHHA)	Barbara Washburn	916-316-7982	barbara.washburn@oehha.ca.gov
36	Sacramento Stormwater Quality Partnership	Sherrill Huun	916-808-1455	shuun@cityofsacramento.org
37	City of Sacramento	Sherrill Huun	916-808-1455	shuun@cityofsacramento.org
38	State Water Resources Control Board	Sean Maguire	916-341-5877	sean.maguire@waterboards.ca.gov
39	County of Sacramento Water Agency, Groundwater Section	Darrell Eck	916-874-5039	eckd@saccounty.net
40	City of Elk Grove	Mayor Gary Davis	916-627-3201	trodriguez@elkgrovecity.org

41	Sacramento Stormwater Quality Partnership	Dana Booth	916-874-4389	boothd@saccounty.net
42	Assembly California Legislature, 9th District	Assemblymember Jim Cooper	916-670-7888	mikey.hothi@asm.ca.gov
43	City of Elk Grove	Councilmember Darren Suen	916-478-2201	dsuen@elkgrovecity.org
44	City of Elk Grove	Councilmember Pat Hume	916-627-3202	phume@elkgrovecity.org
45	City of Sacramento	Fernando Duenas	916-808-4953	fduenas@cityofsacramento.org
46	Larry Walker Associates (LWA)	Brian Laurenson	530-753-6400	brianl@lwa.com
47	County of Sacramento, Environmental Management Department	Susan Williams	Retired	Retired
48	County of Sacramento, Environmental Management Department	Cheryl Hawkins	Retired	Retired
49	County of Sacramento, Environmental Management Department	David Von Aspern	916 -875-8467	vonaspernd&saccounty.net
50	County of Sacramento, Environmental Management Department	Chris Hunley	916-875-8513	hunleyc@saccounty.net
51	State Water Resources Control Board, Division of Water Resources	Annalisa Kihara		
52	Central Valley Regional Water Quality Control Board, Stormwater MS4 Program	Chris Day	916-464-4686	chris.day@waterboards.ca.gov
53	Central Valley Regional Water Quality Control Board, Stormwater MS4 Program	Genevieve Sparks		
54	State Water Resources Control Board, Division of Water Resources	John Borkovich		
55	California Department of Water Resources, Division of Integrated Regional Water Management	Julie Haas		
56	Elk Grove Water	Mark Madison		

57	Laguna Creek Watershed Council	Paul Marshall		
58	OEHHA	Dr. Elain Khan		
59	OEHHA	Ary Ashoor	916-760-6579	aryashoor@gmail.com
60	OEHHA	Bennett Hughes Lock	202-386-1202	bennett.lock@ohha.ca.gov
61	OEHHA	Kathleen Doran	708 846-5375	kathleen.doran@oehha.ca.gov
62	cbec	Chris Bowles	916-243-8290	c.bowles@cbecoeng.com
63	cbec	Ben Taber	530-306-5573	b.taber@cbecoeng.com
64	cbec	Chris Campbell	916-214-3624	c.campbell@cbecoeng.com
65	cbec	Rafael Rodriguez	916-231 6052	r.rodriguez@cbecoeng.com
66	UC Davis	Emily Edwards	925-878 9650	ecedwards@ucdavis.edu
68	UC Davie	Thomas Harter		thharter@ucdavis.edu
69	WPCL	Gail Cho	916-358-2840	Gail.cho@wildlife.ca.gov
70	Confluence Environmental, Inc.	Jason Brown	916 759-8156	jbrown@confluenceenvironmental.com
71	WPCL	Mary Curry	916-358-4398	Mary.curry@wildlife.ca.gov
72	CLS	Scott Furnas	916-638-7301	scottf@californialav.com
73	WPCL	Scott Harris	916-470-6239	
74	City of Elk Grove	Su Mishra	916-627-3434	smishra@elkgrovecity.org
75	City of Elk Grove	Amittoj Thandi	916-478-2252	athandi@elkgrovecity.org
76	City of Elk Grove	Darren Wilson	916-627-3446	dwilson@elkgrovecity.org
77	City of Elk Grove	Jeff Werner	916-478-3602	jwerner@elkgrovecity.org
78	Luhdorff and Scalmanini Consulting	John Fawcet	530-661-0109	jfawcett@lsce.com
79	County of Sacramento	George Booth		
80	Foster Morrison Consulting	Jeanine Foster	303-717-7171	jeanine.foster@fostermorrison.com
81	Office of Water Programs CSUS	Scott Meyer		scott.meyer@owp.csus.edu
82	Amec Foster Wheeler	Kent Parrish	916- 636-3200	Kent.Parrish@amecfw.com

83	cbec	Melanie Carr		'm.carr@cbecoeng.com'
84	State Water Resources Control Board	Robert Reeves		robert.reeves@waterboards.ca.gov
85	State Water Resources Control Board	Wendy Westerman		wendy.westerman@waterboards.ca.gov
86	State Water Resources Control Board	Michele Stebbins	916- 341-5665	michele.stebbins@waterboards.ca.gov
87	State Water Resources Control Board	Reena Jawanda		ranvir.jawanda@waterboards.ca.gov
88	Council of Watershed Health	Greg Bates		jschoonover@folsom.ca.us
89	cbec	Sam Diaz		s.diaz@cbecoeng.com
90	City of Elk Grove	Rick Carter	916-627-3219	rcarter@elkgrovecity.org
91	City of Elk Grove	Richard Shepard	Retired	Retired
92	State Water Resources Control Board	Renee Spears	916-341-5583	Renee.spears@waterboards.ca.gov
93	City of Elk Grove	Ray Manger	916-478-3612	rmanger@elkgrovecity.org
94	Rose's Engineering	Bob Lilly		
95	Elk Grove Water	Bruce Kamilos	916-585-9385	bkamilos@egwd.org
96	Fox Loomis	Arnie		
97	Luhdorff and Scalmanini Consulting	Casey Meirovitz		cmeirovitz@lsce.com
98	Luhdorff and Scalmanini Consulting	Vicki Kretsinger		vkretsinger@lsce.com
99	Willdan Engineering	Mort August		
100	Willdan Engineering	Daniel Chow		
101	State Water Resources Control Board	Erick Ekdahl		Erik.Ekdahl@waterboards.ca.gov
102	OEHHA	Nelson Pi		Nelson.Pi@oehha.ca.gov
103	OEHHA	Hamad Hamad		Hamad.Hamad@oehha.ca.gov
104	City of Sacramento	Hong Lin	916-808-1449	HLin@cityofsacramento.org
105	Salix Applied Earthcare	John McCullah	530-247-1600	john@salixaec.com
106	Fox Loomis	Sam		
107	County of Sacramento Sewer	David Ocenosak		ocenosakd@sacsewer.com

108	City of Lodi	Kathy Grant	209-327-2063	kgrant@lodi.gov
109	Department of Water Resources	Laura McLean	916-651-9212	Laura.McLean@water.ca.gov
110	Willdan Engineering	Jennifer Maxwell	916-478-2233	jmaxwell@willdan.com
111	Willdan Engineering	Gary Grunwald	916-478-2236	ggrundwald@willdan.com

Appendix 6.7

Well Closure/Abandonment Plan for the Corporation Yard

Well Closure/Abandonment Plan for Corporation Yard

1.0 Overview

The City of Elk Grove (City) is planning to abandon the Corporation Yard (CY) site dry well and monitoring wells. This site includes one dry well with pre-treatment features (i.e. sedimentation well and grassy swale), and four monitoring wells, one upgradient and two downgradient wells, and a vadose zone well (**Figure 1**). It was determined that the CY site should be decommissioned for the following reasons:

- Vehicle/bus servicing areas are not appropriate for dry well sites due to multiple chemicals in use.
- Influent stormwater exceed the MCL for aluminum more than once.
- Sedimentation well too shallow and not functioning as designed, therefore pollutants removal was not efficient.
- Challenge with maintaining safety of groundwater without regular monitoring and existing dry well system design shortfalls (sedimentation well).

This reasoning is consistent with practices with States of Washington and Oregon's Dry Well Programs to protect water resources. In those states, dry well use in vehicle servicing areas is not permitted. The Well Closure/Abandonment Plan will be implemented as soon as the City receives approval from the State Water Resources Control Board that the approach of this Plan is acceptable.

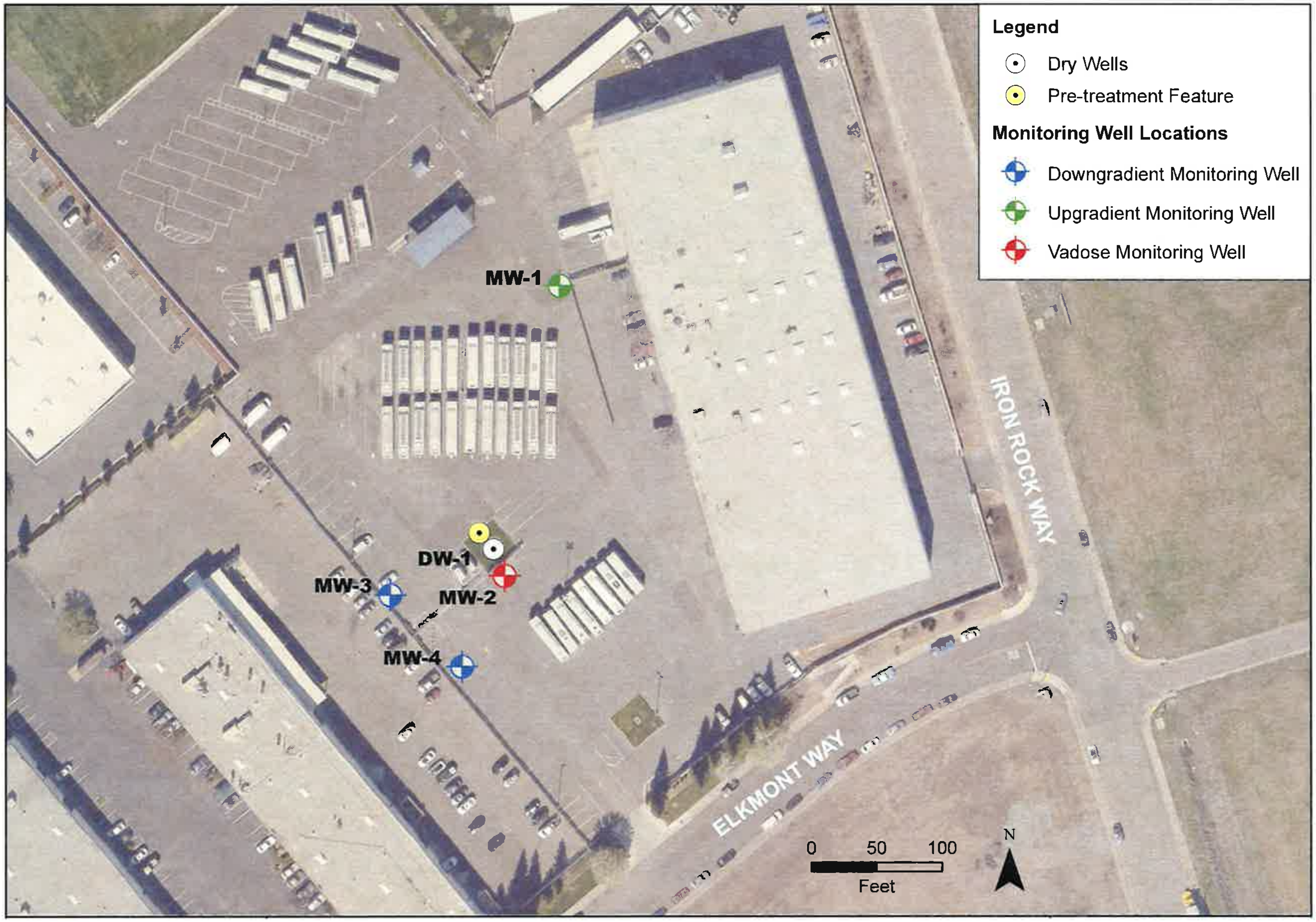
2.0 Implementation

Closure will be accomplished through destruction of each well in accordance with guidelines set forth by the California Water Code, California Department of Water Resources (Bulletins 74-81 and 74-90) and Sacramento County, Environmental Management Department regulations. A brief description of destruction methods for the two types of wells are provided below. These methods are preliminary and will be revised as needed to ensure that correct abandonment/ destruction procedures are completed. In addition, the appropriate permits will be obtained and an experienced dry well drilling contractor (C-57 well contractor) will be used to complete the work.

2. 1 Monitoring Wells

Prior to destruction of each monitoring well, the well will be cleaned out, likely by airlifting, to remove any sediment. After a thorough cleaning, the standard procedures include removal of all internal components such as piping, screens, and shields and pumping grout down the main

Figure 1
Location of Dry Well and Monitoring Well Network
City of Elk Grove Corporation Yard



casing. The contractor will perforate the casing and pressure grout using neat cement. This process will push cement into void spaces in the formation immediately surrounding the well, sealing off the well to limit interaction with surrounding aquifer(s). The top 5 feet below ground surface (bgs) will be backfilled with clean fill such as silt, clay, or engineered material and compacted as it is in place. Land surface surrounding the monitoring well will be restored with similar material, if necessary.

2.2 Dry Well

The dry well is a large diameter (36 inches) perforated pipe filled with sand and gravel. Destruction of this well will occur in the dry months when moisture in and around the well are at a minimum. The gravel, sand, and accumulated sediment will be removed from the well 5 feet bgs using a large vactor truck. Once the material in the chamber has been removed, the resulting hole will be filled with clean fill such as silt, clay, or engineered material and compacted as it is in place. The intake and outfall pipe will be capped at sedimentation well, and dry well (**Figure 2**), respectively. The intake pipe for the dry well incorporated a shutoff valve that will be permanently closed. The grassy swale will remain in place to continue to filter out sediment and contaminants prior to entering the MS4 system.

2.3 Registration with EPA

Within 30 days of decommissioning the wells at the CY, the City will de-active and abandon the wells on EPA's website portal for underground injection wells. The City will also, complete and file with State of California Department of Water Resources (DWR) the Well Completion Report for each destroyed well.

2.4 Financial Responsibility

The City assumes financial responsibility of decommissioning the dry well and monitoring wells at the CY site.

Figure 2
Dry Well Schematic
Close Shutoff Valve and Cap Intake/Outfall Pipe