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.

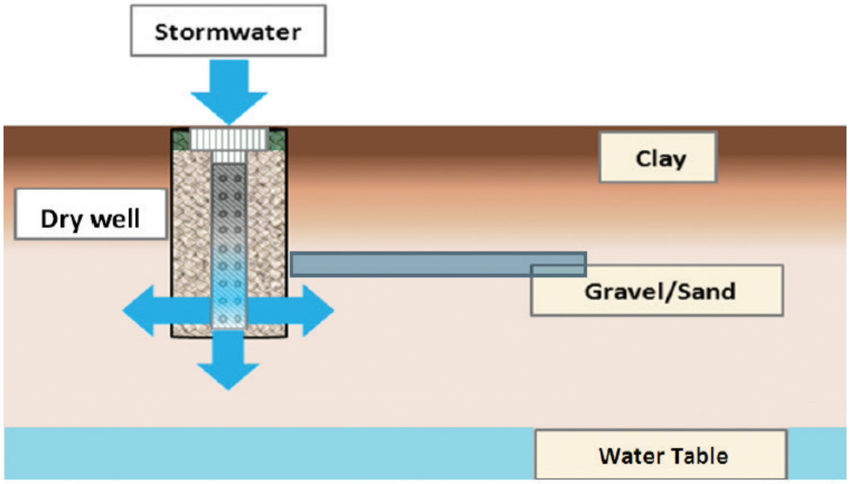

Figure 1. Idealized drawing of stormwater infiltration using dry wells.

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.

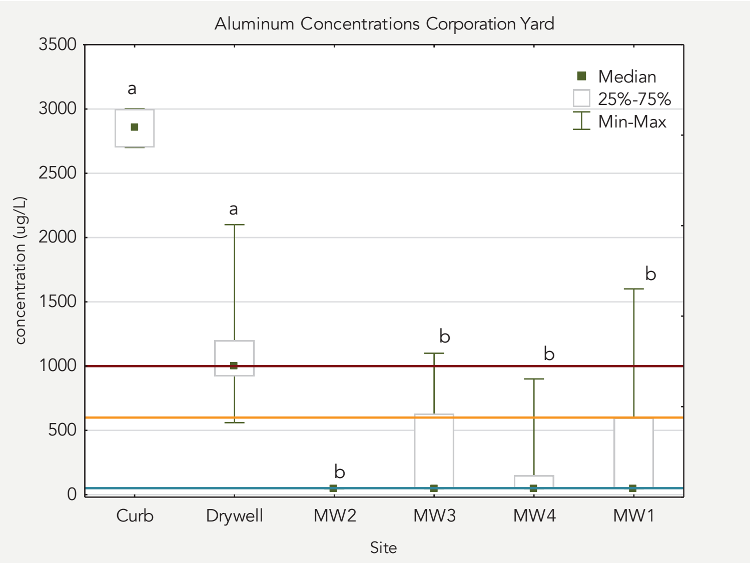

Figure 2. Aluminum concentrations in stormwater and groundwater at the Corporation Yard. Units of concentration are µg/L or ppb. Notations: Box and whiskers labeled with different letters are significantly different from each other. The red line indicates the MCL; the orange line is the Public Health 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.

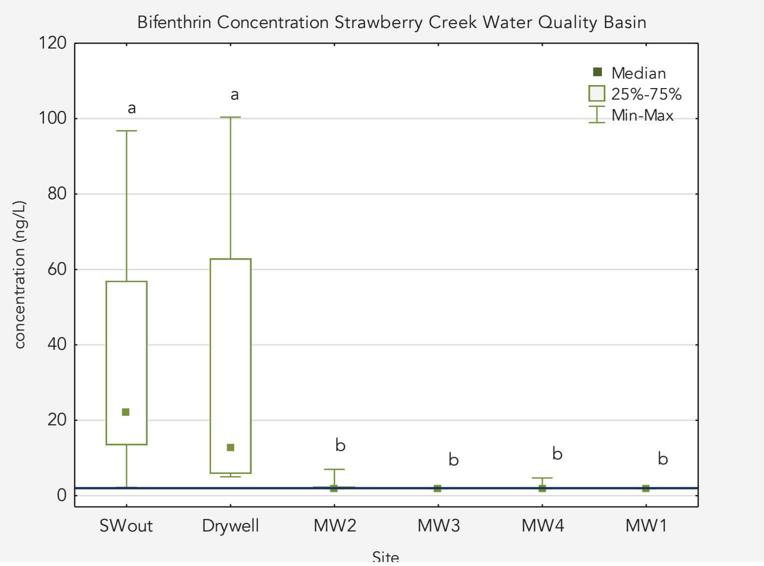

Figure 3. Bifenthrin concentration in stormwater and groundwater at the water quality basin. Notations are the same as described in Figure 2. None was detected below the ground surface.

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

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[1] MPN = most probable number

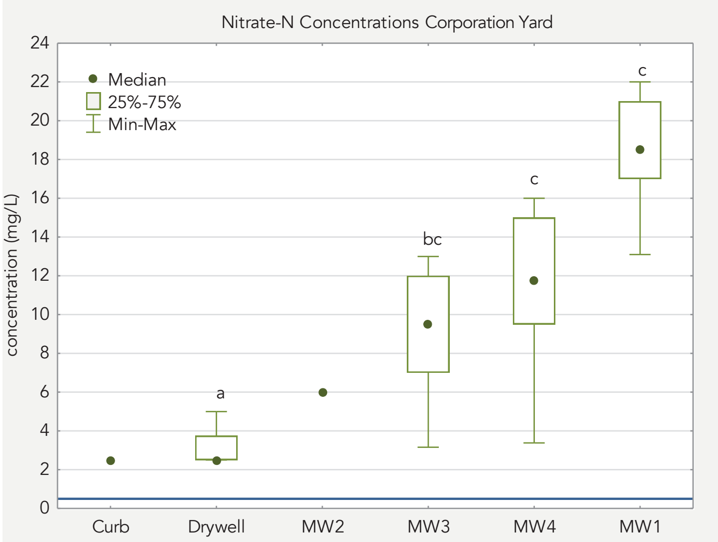

Figure 4. Nitrate (as N) concentration at the Corporation Yard in stormwater and groundwater. Notations are the same as described in Figure 2.

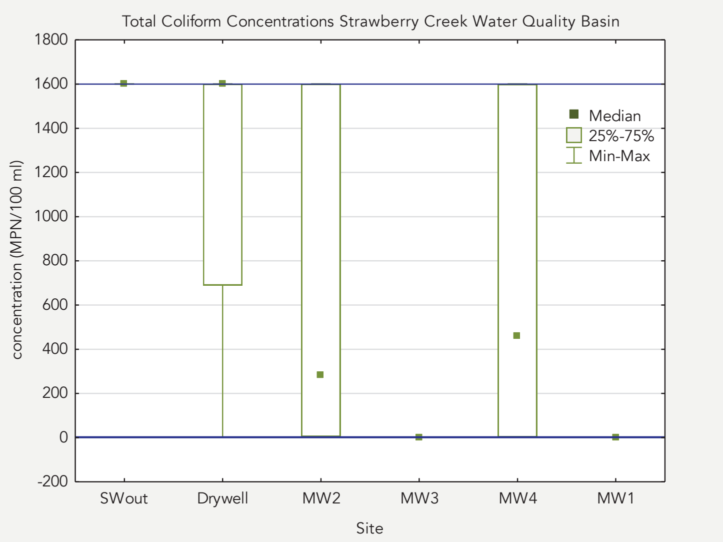

Figure 5. Coliform bacteria concentrations at Strawberry Creek water quality basin. Notations are the same as described in Figure 2.

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).

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.

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.

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.

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[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.

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