Appendix L

Drywell Fact Sheet: Guidance for the ARB Region

Introduction

This Drywell Fact Sheet was created by a team of regional stakeholders during development of the American River Basin (ARB) Stormwater Resource Plan (SWRP; OWP 2018). The purpose of the ARB SWRP is to promote planning and implementation of projects and programs that capture and use stormwater to augment surface water supplies, recharge groundwater, and support ecosystems. Priority is given to projects that achieve multiple benefits associated with improving water quality, increasing water supply, reducing flood risk, protecting the environment, and enhancing communities. As identified in the SWRP, drywells are considered to be a key tool in the development and implementation of such priority projects.

Advantages of Drywells

Drywells are gravity fed cylinders that capture and infiltrate stormwater and dry weather runoff into the vadose zone. They are particularly useful in urbanized environments where existing development has reduced natural infiltration capacities and new development has the potential to continue this trend. Inclusion of drywells in retrofit projects and in the design of new subdivision projects can amplify the accomplishments of other stormwater best management practices (BMP's) and contribute to the multiple water-related benefits associated with capturing and infiltrating or otherwise using stormwater and dry weather runoff. These benefits include increased groundwater recharge, leading to more available water supplies, and reduced discharges into streams and rivers, resulting in improved surface water quality and aquatic habitat through reductions in erosion, channel incision, and pollutant transport. Reduced runoff flow rates and volumes can also reduce flood risk and lower energy use and greenhouse gas emissions (if pumping is used to manage conveyance). Finally, drywells can be incorporated into stormwater BMPs that are designed to beautify the landscape, promoting community stewardship.

Because of these multiple benefits, stakeholders in the ARB region consider capture and infiltration to be the ideal approach to managing runoff. However, the prominence of clay soils in the ARB region impedes surface infiltration of stormwater and dry weather runoff. Conventional infiltrating BMPs rely on surface infiltration, typically within the top four feet of ground level. Clay soils limit the percolation that occurs in this stratum and constrain the resulting benefits of these BMP's. Drywells, however, can extend deep into the subsurface with an open shaft completed below a confining layer. The resulting storage and elevation head combined with increased soil conductivity promotes higher infiltration rates, faster drainage and deeper subsurface infiltration. Another advantage of drywells is that they can be installed in a relatively small and/or narrow footprint, which is useful in existing development settings.

Barriers to Drywell Implementation in the ARB Region

The federal requirements for owning and operating drywells were adopted as part of the Safe Drinking Water Act which established the Underground Injection Control (UIC) Program. Drywells are Class V UICs. Owners of such facilities are responsible for ensuring that fluids containing contaminants do not degrade groundwater quality or violate safe drinking water standards. In California, anyone intending to operate a drywell must provide basic "inventory information" about their well to the appropriate EPA regional office using an online form. The filing of this basic inventory information meets the minimum federal requirements for drywell construction and operation.

States retain the authority to assume primacy for oversight of the UIC Program, although California has not assumed this authority for Class V wells. Nevertheless, the State's Porter Cologne Act (Act) covers "injection wells" meaning "any bored, drilled, or driven shaft, dug pit, or hole in the ground into which waste or fluid is discharged, and any associated subsurface appurtenances, and the depth of which is greater than the circumference of the shaft, pit, or hole". The Act requires all persons operating, or proposing to construct, an injection well to file a report of the discharge with the appropriate Regional Water Quality Control Board containing the information that may be required by the Regional Board. Once the report is filed, construction of an injection well is prohibited until either: (1) the Regional Board issues a permit with waste discharge requirements; (2) the Regional Board issues a waiver from its discharge requirements; or (3) if the discharge does not create a threat of pollution, by rule the discharge may proceed after at least 140 days have expired since the filing of the report and at least 90 days have expired since approval of the CEQA document by the lead agency. The Regional Board has not issued guidance on the information to be contained in an injection well report.

No other State law or regulation directly applies to drywells. However, the Department of Water Resources Bulletins 74-81 and 74-90 (bulletins) describe standards and practices for the maintenance of water and monitoring wells and other types of wells. The bulletins define wells as "any artificial excavation constructed by any method for the purpose of extracting water from, or injected water into, the underground". These bulletins have caused some confusion regarding their applicability to drywells. However, managers and staff of the Water Well Program at DWR have indicated that the bulletins are not intended to apply to drywells.

Sacramento County's Environmental Management Division (EMD) permits all wells, including drywells, within the County's jurisdiction. Other municipalities within the County defer to EMD for well permitting, including drywells. EMD considers drywells to be a type of injection well covered by Bulletin 74-81. Accordingly, all wells, including drywells, are required to follow specific design standards based on those that apply to drinking water wells. Many of these standards are at odds with the intent of drywells, which is to maximize recharge, not restrict it. For example, EMD requires an annular seal 50 feet deep along the length and diameter of well, which, for most drywells would drastically reduce the infiltration ability. EMD is reluctant to write any interim drywell guidelines to address their concern for groundwater protection.

With the exception of the City of Roseville, municipalities within Placer County defer to Placer County Environmental Health Department (EHD) for well permitting. The City of Roseville does the water well permitting within its jurisdictional boundaries and follows DWR"s Bulletin 74-90. Use of drywell has not been proposed within Placer County of the City of Roseville, but it is anticipated that the well permitting agencies would have an approach similar to Sacramento County EMD.

Support for Drywells Use

The Central Valley Regional Water Board (Regional Board) has offered to write support letters to EMD for specific projects that have a research orientation. In the past, this type of support has been acceptable to EMD. The Central Valley Regional Board does not currently issue a Waste Discharge Requirement (WDR), waiver, or letter of support for all drywell use, in the absence of statewide guidance, which they defer to the State Water Board. Recently, the State Board began drafting a General Order under the WDR permit program, to develop a permit for drywells. It is anticipated the new WDR permitting system for drywells will be completed by late winter, 2019. The State Water Resources Control Board (Water Board) is also working on general statewide guidance on drywells design, siting, monitoring, and maintenance, with an estimated completion date of 2022 or later.

Need for Interim Drywell Guidance

There is presently no guidance on the design and use of drywells specific to the ARB region, or even most other areas of California. The one exception is Orange County, which is currently drafting local drywell guidelines. As noted above, the State Water Board is beginning to develop statewide guidance, with a target date of issuance of 2022. This Drywell Fact Sheet and the drywell guidelines are meant for interim use by ARB stakeholders, as we await issuance of statewide guidance. By establishing standards of practice, these guidelines serve to educate stakeholders on drywell components, barriers to their use, and how they can be designed and implemented to be protective of groundwater quality. In this way, the guidelines may promote informed discussions with local, regional, and state agencies regarding permitting and approval of their use.

Drywell Fact Sheet:

Guidelines for the American River Basin (ARB) Region

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General Description

Drywells, also known as underground injection control (UIC) systems, are stormwater infiltration devices typically constructed of a vertical pipe that extends deep into the subsurface (e.g., 3 foot-diameter with a depth of 20 – 50 feet). The US EPA defines them as infiltration facilities that are deeper than they are wide. Perforations are located along the length of the pipe and/or at the bottom to permit stormwater to flow from various parts of the well into the surrounding soils. (Figure 1). There are many varieties in construction and design including the placement of perforations, use of geotextiles, and the use of internal gravel or rocks.

Drywells can be used in a variety of situations, but are especially useful in areas with shallow clay or hardpan soils because they facilitate the movement of stormwater runoff below these types of constricting layers to facilitate infiltration. In the Sacramento region, soils with a high content of silt and/or clay reduce the rate of surface infiltration to the point that meeting current stormwater management requirements is challenging. In addition to addressing this challenge, drywells can also be a useful tool for enhancing aquifer recharge as well as furthering the use stormwater as a resource. Some communities in California are considering using drywells to help achieve groundwater sustainability under the requirements of the Sustainable Groundwater Management Act (SGMA). Drywells can also be used in conjunction with low impact development (LID) practices and runoff detention/retention systems to reduce the adverse effects of stormwater hydromodification on aquatic habitat, surface water quality, and downstream flood risk. They can be used in large and small spaces in a variety of land use types. Drywells help to adapt to the effects of drought and climate change by providing additional recharge to groundwater resources. However, the use of drywells has raised concerns that contaminants in stormwater could be transported to groundwater and compromise groundwater quality.

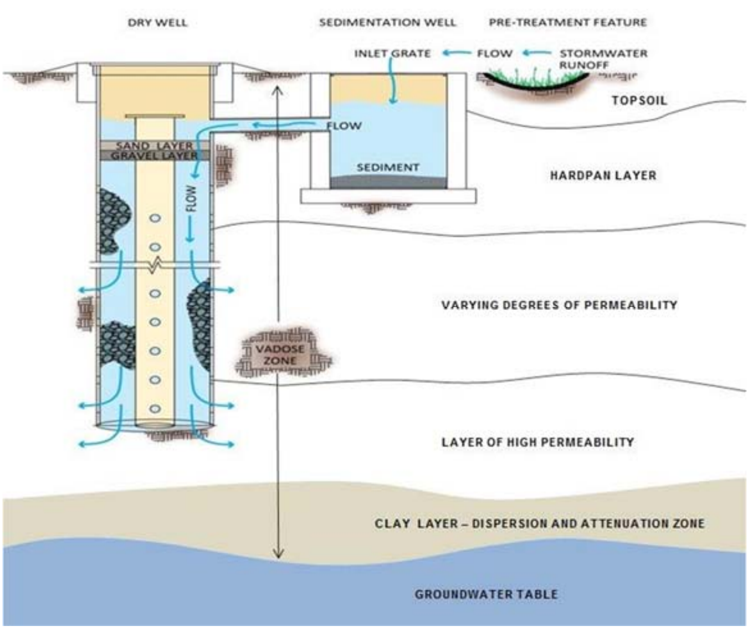

Figure 1. Drawing of a drywell system including key features.
(Not to scale)

How Does a Drywell Work?

Drywells function by providing a conduit for stormwater to infiltrate into the vadose zone at an accelerated rate. Typically, runoff is initially directed to a pretreatment facility to remove sediment and other pollutants that could clog the well or subsurface soils, or pose risks to groundwater. Bioretention planters, biostrips and swales, proprietary devices, or sedimentation chambers (sometimes with screens or hydrophobic sponges or pillows) can serve as the pretreatment facility. While pretreatment can reduce the load of particles and adsorbed pollutants by 50-75% (Elk Grove and CalEPA OEHHA 2016), existing forms of pretreatment typically will not reduce the concentrations of water soluble contaminants such as nitrate and neonicotinoids. After pretreatment, a conveyance pipe directs treated runoff into the system's secondary chamber, the drywell.

Drywells are constructed of concrete or other material. The lower section includes a pervious shaft which can be comprised of a perforation within the casing material or merely be an open shaft, with or within aggregate backfill. Drywells can penetrate confining clay layers. Where sand or gravel exist in the vadose zone profile, water can readily leave the drywell itself, moving horizontally and vertically until it reaches groundwater. Before reaching groundwater, it is beneficial for runoff to pass through layers of silt and clay to help sequester contaminants in the water before they reach groundwater.

Advantages and Limitations of Drywells

Like all devices, drywells can provide useful benefits for water supply and surface water quality but have associated risks and tradeoffs as well. These are summarized below.

Advantages

- Drywells generally have a small footprint, depending on the type of pretreatment, so they can be suitable for sites with limited space.
- Drywells can help to manage hydromodification effects in densely developed areas.
- Drywells provide an opportunity to enhance groundwater recharge.
- Drywells can help reduce or eliminate localized flooding.
- Drywells can be placed within streets and combined with existing drainage systems. They can be especially useful for green streets projects and can be combined with bioretention or other type of vegetated pretreatment.
- Drywells are relatively easy to maintain but do require periodic inspections and removal of particulate material collected in the pretreatment features.

Limitations

- Infiltration rates are location specific – their performance depends on the local subsurface geology. Local percolation tests must be performed prior to construction to determine suitability.
- Currently available drywell technology is not efficient at sequestering water soluble contaminants, such as nitrate, certain pesticides (e.g., neonicotinoids), and some non-aqueous phase liquids (e.g. toluene).
- Drywells are not suitable for steeply sloping areas (slope > 25 degrees)
- Drywells can become clogged with particulates if appropriate pretreatment and regular maintenance practices are not performed.

- Drywells should not be used in areas with shallow groundwater.

Drywell Vector Considerations

Drywells create the potential for mosquitoes to grow due to standing water. This risk will be greatly reduced or eliminated if the well is properly designed, constructed, and maintained. Water within the drywell and associated pretreatment systems should be draw down within 48 hours. (CDPH 2017).

Siting Considerations

The following recommendations are based on siting restrictions commonly used in Washington, Oregon, and Arizona, as well as professional judgement based on the needs, interests, and site characteristics within the ARB region.

- Locate drywells sufficiently far away from public and private drinking water wells to provide a two-year time-of-travel (City of Portland, 2008) or 150 feet, the required setback of septic systems from a domestic well in the Sacramento region (County of Sacramento, Environmental Management District). The two-year time-of-travel distance will vary based on the local soils and geology as well as constituents of concern. This avoids the risk of transferring contaminants to the boreholes of drinking water wells.
- Installation of drywells should not be permitted in contaminated soils or near contaminated groundwater plumes. Drywells should be a minimum of 250 feet from an area with contaminated soils. Some jurisdictions in the Bay Area require a 1500-foot setback (Santa Clara Valley, 2016). This reduces the risk of mobilizing contaminants already present in soil. A site assessment should be conducted to determine if contaminants are an issue.
- Installation of drywells should not be permitted within 250 feet of auto repair shops, nurseries, or industrial sites that use hazardous materials[1]. This is a restriction common in other western states. If state policy permits the use of drywells at industrial sites, special requirements should be followed, outlined in Table 1.
- Drywells should not be used on roads with greater than 30,000 average annual daily trips (AADT) without additional pretreatment features (See Table 1). Roads with this type of traffic are associated with higher concentrations of contaminants and are at greater risk for a spill.
- Require a minimum 10 to 25 feet of vertical separation from the bottom of the drywell and the seasonal high water table[2] and a 5 foot treatment zone. Ten feet of vertical separation is recommended by the US EPA and practiced in many other states. Twenty-five feet is recommended by the State of Washington in some circumstances. A treatment zone is an area beneath the permeable layers in the subsurface that serves to sequester contaminants due to its geologic composition.

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[1] Gas stations and car washes were not included among the prohibited sites due to current regulations that provide for containment of spills and runoff on the site.

[2] This is typically interpreted to mean based on historical data. If it is unavailable, then using at least 1 year's worth of data along with redoximorphic analysis (based on mottling of lithologic layers associated with redox reactions associated with saturation)

- Conduct appropriate evaluations such as soil borings to ensure the site contains permeable unit in the subsurface that are conducive to infiltration.
- Select sites with a combination of sand, gravel, and clay. This can be determined by exploratory borings. It is preferable to have some clay between the bottom of the drywell and the water table to enhance pollutant attenuation.
- Drywells should be spaced approximately 100 feet apart.
- Do not place drywells closer than 20 feet downslope or 100 feet upslope from a building's foundation.
- Do not install on slopes greater than 15% (13.5 degrees) without a geotechnical review and avoid slopes with greater than 28.5% grade (25 degrees).

Design Criteria

A two-stage UIC is the preferred standard for most sites where drywells are used. The exception is for drywells that are used to capture roof runoff only. To capture suspended sediment that might cause clogging as well as introduce pollutants to the subsurface, stormwater should be pretreated (Stage 1) in in a vegetated stormwater treatment device, a sedimentation chamber, and/or a proprietary device. Stage 2 of the system is composed of the actual drywell. Some designs combine the pretreatment facility within the drywell to form a single unit. If a sedimentation chamber is used, it should be sufficiently deep, usually 10 feet minimum (see Table 1), to permit particulates to settle. Often the elbow of the pipe connecting the pretreatment facility to the drywell is inverted to promote the collection of floatables.

Risk Reduction and Design Requirements

Drywell design and siting are guided by two key factors: the concentration of pollutants associated with various land uses that determine risk categories and the potential of the vadose zone to sequester pollutants that enter the drywell. Table 1 (below) identifies the design features and vertical separation distance from the bottom of the drywell to the seasonal high water table associated with the risk categories.

The risk categories were developed by surveying existing drywell guidance documents, speaking with experts currently involved in drywell planning, and reviewing scientific research and databases that characterized runoff associated with different land use types, including roads. The risk categories in Table 1 are defined in the footnotes. The two classifications of vadose zone treatment potential (defined in Table 2) were identified based on estimates of treatment capacity of subsurface geology. The treatment zone (Figure 2), which lies between the bottom of the drywell and the water table, is a five-foot thick unit that has the greatest capacity within the subsurface profile to sequester contaminants (Washington Dept of Ecology, 2006).

Table 1. Required drywell features, based on risk of pollution and vadose zone treatment potential

Risk Category[1]	Vadose zone treatment layer classifications	
	Medium – high treatment potential	*Low treatment potential*
Insignificant risk	Pretreatment facility, 10 feet vertical separation,	
Low risk	Pretreatment facility, shut off valve, 10 feet vertical separation,	Pretreatment facility, shut off valve, 25 feet vertical separation.

Medium risk	Pretreatment facility, shut off valve, 10 feet vertical separation,	Pretreatment facility, shut off valve, 25 feet vertical separation
High risk	Pretreatment facility, shut off valve, 25 feet vertical separation	

[1]Risk categories

These risk categories were developed with input from the Mary Shaleen-Hansen (UIC Program, Washington state), and Aaron Poresky (Geosyntec, Portland, OR).

Insignificant: Source of stormwater is rooftops from single family residential neighborhoods.

Low: Residential, office park, small retail, and associated parking areas; streets with <15,000 average annual daily trips (AADT).

Medium: Medium and high density residential, institutional and commercial land uses, major retail and office land uses, such as downtown Sacramento or large retail malls (e.g., Galleria in Roseville), and associated parking lots. Roadways with 15- 30,000 AADT. Parking lots in light or heavy industrial areas if hydrologically isolated from areas where hazardous chemicals are used or activities performed. Any land use where pesticides and fertilizers are regularly used (ball fields, some residential land uses, etc.)

High: Industrial land uses, gas stations, nurseries, auto repair shops, car washes, arterial and other streets with AADT >30,000.

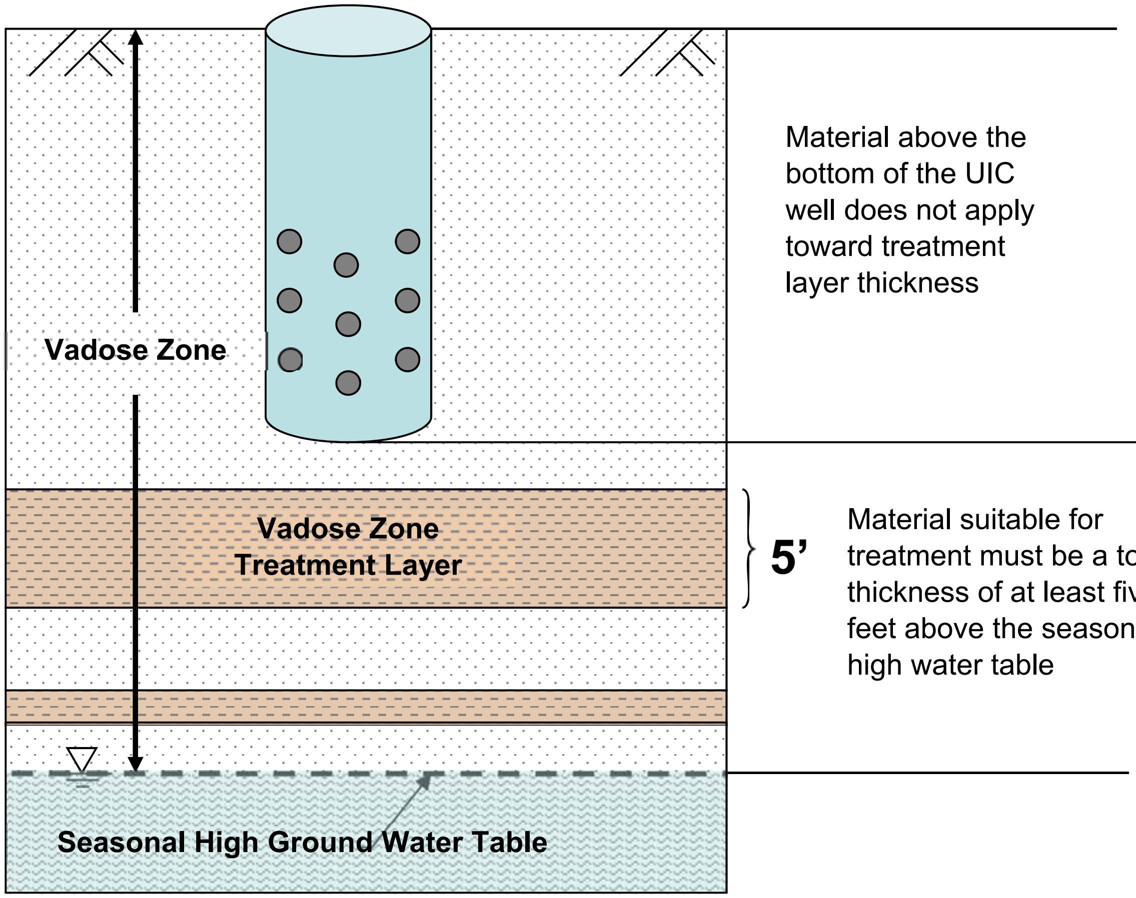


Figure 2. Illustration of the vadose zone treatment (Washington DOE 2006)

Table 2 describes the characteristics of the vadose zone treatment layer for the difference treatment classifications. The task of defining treatment potential for geologic units in the subsurface has many uncertainties. Key factors of the subsurface lithology that define sequestration or treatment capacity are its fractional organic carbon content (f_{oc}), percent silt and clay, and the cation exchange capacity (pers. comm., T. Ginn). However, the criteria separating medium-high potential from low potential are best estimates, not definitive values. Drywell planning should carefully examine the subsurface characteristics to determine treatment potential.

Table 2. Classification of treatment potential within the vadose zone

Treatment Classification	Description of Treatment Zone[a]
MEDIUM - HIGH	Treatment zone dominated by silt and/or clay. High cation exchange capacity (estimated to be >20 meq/100 g dry soil)[b] High fractional organic carbon (>0.01)[c] *This category generally includes till, hardpan, clay, silty clay, and silt*
LOW	Treatment zone dominated by sand, gravel, and other coarser grained material Low cation exchange capacity (estimated to be <20 meq/100 g dry soils) Low fractional organic carbon (<0.01) *This category includes poorly-sorted silty or muddy gravel, sandy gravel, gravelly sand, sand, and/or gravel, might contain some alluvium and outwash deposits*

[a] This approach is used by the Dept. of Ecology, Washington state. Washington's guidance identifies 3 classifications. These guidelines are posted at: https://fortress.wa.gov/ecy/publications/documents/0510067.pdf.
[b] Ginn 2018.
[c] Estimates of high and low f_{oc} values were drawn from MS thesis (UC Davis, Graduate Group in Hydrology) of Emily Edwards, based on her review of the literature.

Design Procedures

The basic steps for designing drywells systems are outlined below. Refer to Attachment 1 for specific calculations.

1. **Design the drywell system.**
    a. **Design the pretreatment facility.** The pretreatment facility serves to remove particulates, associated pollutants, and sometimes additional pollutants. Types of facilities include structural pretreatment (e.g., sedimentation chambers or proprietary devices) or vegetated pretreatment such as biostrips/swales or stormwater/bioretention planters.
    b. Design the drywell. The drywell carries treated runoff into the subsurface to permeable units of sand and/or gravel. This step involves drilling an investigative boring, conducting permeability testing, and establishing the depth of the drywell as well as the height of its pervious shaft.
    c. Design the conveyance between the pretreatment facility and the drywell. This involves properly sizing a pipe that connects the two parts of the drywell system.

2. **Determine the number of drywells required for the given drainage area.** Factors of importance for this calculation include the runoff volume and infiltration rate of the drywell(s). The minimum number of drywells should meet water quality design requirements for the drainage area, although more may be added if the project goal is to alleviate flooding or increase aquifer recharge.

3. **Check that hydromodification management requirements are met.** These requirements are outlined in the stormwater quality design manual appropriate to the project jurisdiction.

Water Quality Monitoring

Monitoring the quality of stormwater at the point of entry into the drywell is a critical part of ensuring that groundwater quality is protected. A schedule for the recommended monitoring frequency of priority pollutants is provided below (Table 3).

Table 3. Recommended monitoring frequency

Risk Categories	**Recommended monitoring**	
	Medium-high treatment potential	Low treatment potential
Insignificant risk	None	
Low risk	First flush and 1 other wet season event for the first 2 years of operation only, unless exceedances are detected	
Moderate risk	First flush and 1 other wet season event for the first 2 years of operation only, unless exceedances are detected	Yearly, first flush and 1 additional wet weather event
High risk	Yearly, first flush and 1 additional wet weather. In additional to priority pollutants, any specific pollutants unique to the site should be analyzed. Additional special requirements may be developed.	

In most cases a cluster of drywells will be installed in a new development or retrofit project. A subset of these drywells should be identified that can serve as a representative sub-sample to report on the concentration of contaminants in runoff as it enters the drywells. Analytical work should be performed at an ELAP (Environmental Laboratory Accreditation Program) certified laboratory. In addition to priority pollutants, contaminants of special concern should also be analyzed, based on the presence of specific contaminants in the area or in the event of a spill. When possible, a water quality monitoring plan should be prepared that includes a list of analytes, sample collection and handling procedures, analytical methods, and relevant criteria values.

Requirements for infiltration at industrial sites, including the use of drywells, are being developed by the State Water Resources Control Board as part of an Amendment to the Industrial General Permit. Once approved, use those requirements for applicable projects in addition to or in lieu of those noted in Table 3.

The process for selecting the priority pollutants that should be analyzed was based on the approach used by Portland's UIC Program (City of Portland, 2008). The key selection criteria were:

- Frequency of detection, based on data from the Sacramento Stormwater Quality Partnership's (SSQP's) discharge monitoring program (SSQP, 2013)
- Mobility
- Persistence in the environment
- Toxicity to humans.

Pollutants were selected from the following four broad categories.

- Semi volatile organic compounds (SVOCs)/ Polycyclic aromatic hydrocarbons (PAHs)
- Pesticides/Herbicides
- Metals
- Miscellaneous pollutants (emerging contaminants of concern)

Volatile organics were not included because they have rarely been detected in local stormwater.

The criteria values should be used in two different ways, depending on whether an MCL has been established for the pollutants of concern. If so, the MCL value should be compared to the concentration of the relevant contaminant as runoff enters the drywell. If the concentration is less than the MCL, then there is reasonable assurance that drinking water will be protected. The use of the MCL for this purpose is a federal standard as well as one used in many states. Three of the pollutants, however, commonly measured in stormwater in the Sacramento region do not have MCLs. Two of these contaminants are pesticides. As an alternative to the MCL, the Human Health Benchmarks for Pesticides (HHBP), developed by the US EPA, should be used as the criteria value. In these cases, one dimensional vadose zone modeling should be used to identify the maximum concentration of a contaminant *at the water table* after 200 years. This concentration should remain below the HHBP concentration. Once established, the concentration of the contaminant at the drywell can be back-calculated to determine the maximum concentration at the point of entry to minimize the need for future modeling. If used in this way, the HHBP will be highly protective of drinking water.

Table 4 presents criteria values for the selected pollutants. Attachment 2 contains additional details regarding the selection of the priority pollutants. Within each pollutant class, pollutants with the greatest frequency of detection were selected from SSQP data collected from three sites representing new development, old development, and a mix of the two over many years. The highest concentration of the median values from multiple years of monitoring was selected as the representative value. The criteria value is a reference value against which monitoring or modeling data can be compared.

Finally, if the criteria value has been exceeded for 3 or more monitoring events over a 2 year period, and other corrective actions such as source control, have been ineffective, then modeling should be performed to assess the concentration at the water table. This concentration should remain below health based standards (e.g., Public Health Goal).

Additional contaminants could be added to the above list if the land use or regional runoff characteristics warrant such addition. Further, if TMDLs are applicable to the watershed in which the drywells are located, it is recommended that the listed contaminants be analyzed along with the priority pollutants. This will provide useful data to the municipalities regarding load reduction in addition to providing a better understanding of pollutant concentrations entering the drywell.

Table 4. List of Priority Pollutants and Criteria Values

Pollutant class	Constituent	Concentration[a] (ug/L),	Criteria Value (ug/L)
Metals	Pb	0.79	15[b]
	Hg total	0.051	2[b]
SVOC/PAH	Chrysene	1.8	0.6[c]
	DEHP	2.43	4[b]
Pesticides	Bifenthrin	0.061	0.64[d]
	Fipronil	0.5	1[e]
Other	NO3 as N	0.58	10[b]

[a] SSQP Monitoring Data, maximum median value (SSQP 2013)

[b] Maximum Contaminant Level (MCL), a regulatory value established by the State Water Resources Control Board.

[c] No MCL exists for chrysene. The health protective value for drinking water was calculated based on OEHHA's oral cancer slope factor of 0.12 mg/kg-day. The method used for to estimate the health protective value is similar to that used to develop Public Health Goals, with the exception that a lifetime risk of 1 x 10^{-5} was used as the protective standard.

[c] The HHBP database identifies an acute value for bifenthrin. This value was converted to a chronic value by initially dividing by an uncertainty factor of 3000 to account for inter and intra species variability and uncertainty as well as the use of an acute study to develop a chronic value. This value was then divided by the average daily water intake value of 3.71 liters, which is adjusted for intake variability over a 70 year life span. Information on HHBP can be found at: https://iaspub.epa.gov/apex/pesticides/f?p=HHBP:home.

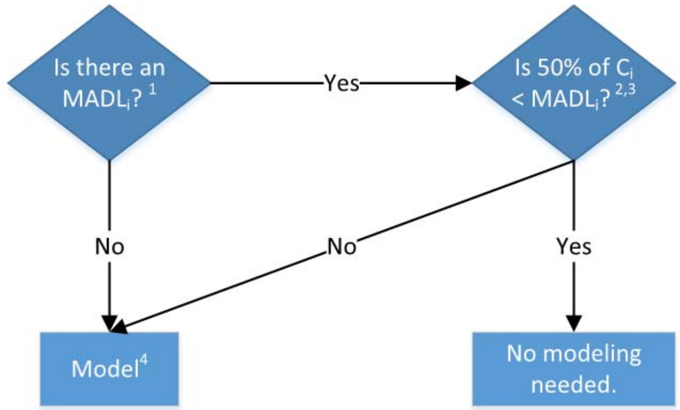
[d] Chronic value for a lifetime exposure via drinking water to fipronil; Source: HHBP.

Contaminant Modeling

In a number of different circumstances, modeling is recommended to ensure groundwater quality is protected:

- If no MCL exists for a contaminant, modeling should be performed to determine the maximum allowable concentration of a contaminant at the water table that would protect groundwater quality,
- If there are stormwater quality exceedances for priority pollutants for samples collected at the entrance to the drywell (after pretreatment) two years in a row, and
- If unique chemicals are used at the site, related to the function of the relevant land use.

The process for determining if modeling is required is illustrated in Figure 3. Procedures for modeling drywells range from relatively simple to complex. Conceptually, drywell operations can be modeled as a simple linear rate, with infiltration flowing to a "bucket" of groundwater based on an estimated rate of infiltration associated with soil and geologic classifications. Flow or transport of contaminants in this modeling approach would be *one-dimensional* (1D), moving vertically from the drywell through soils to the groundwater below. The soil profile can be simplified and represented as a single, homogeneous column, or it can reflect a more realistic picture that involves a profile with varying soil types and properties. Drywell operations could also be modeled using a *two-dimensional* (2D) approach, reflecting both vertically and horizontal movement of contaminants. While this is a more realistic representation that 1-D modeling, two dimensional modeling is resource intensive and costly. Descriptions of a number of different approaches to modeling is provided in Attachment 3.



[1] Maximum Allowable Discharge Level (MADL) for pollutant “i". See values in Table 4.

[2] Concentration of pollutant “i" (C_i) discharged from the drainage catchment. If site specific monitoring data is available, set C_i as the 90% upper confidence limit of the data. Otherwise, use the C_i value from Table 4.

[3] It is assumed that the sediment capture facility will have a minimum treatment potential of 50% removal. Therefore, the concentration of pollutant “i" entering the dry well can be calculated as 50% of C_i.

[4] Based on C_i and MADL$_i$ values from Table 4, DEHP and Chrysene will need to be modeled.

Figure 3. Flow chart for determining whether modeling is required to demonstrate groundwater protection.

General Maintenance

Maintenance activities for drywell systems should be specifically developed based on the design characteristics and configuration of the installation. An Operations and Maintenance Plan should be developed for all categories of drywells except those with rooftop runoff only. This plan should follow these general guidelines:

- Yearly inspections of the sedimentation chamber and/or bioretention cell and drywell should be conducted.
- Regular street sweeping should be performed on the roads to remove accumulated dirt and particulates (primarily arterials).
- Record keeping procedures, including inventory records, inspection records and maintenance work should be documented.

The primary maintenance activity is sediment removal - a cleaning procedure aimed at restoring the UIC to the designed treatment and storage capacity. Maintenance is typically performed on the sedimentation chamber and drywell, depending on the design.

Maintenance

Maintenance requirements are specific to the drywell itself and pretreatment sediment capture facilities. This should include a schedule for regular vacuuming of debris and accumulated sediment from the sedimentation chambers[3]. Replacement of adsorptive material such as hydrophobic pillows that may be used should also be performed at this time. A general inspection of the drywell system, including inspecting the operation of the shut off valve and cleaning of any filters or screens, should also be performed. For vegetated pretreatment, follow the relevant stormwater design manual standards. Check the condition of the conveyance pipe and remove material if necessary.

Long-term Maintenance and Management

Long term maintenance and management of drywells can help prevent accidental release of contaminants into the subsurface and prevent clogging. In addition to the regular cleaning and inspections procedures described above, source control practices and public outreach can help improve the performance of drywells.

Source control involves spill prevention and protection and well as reduced use of pesticides and other pollutants, including the following activities:

- Outreach to fire departments and other first responders to inform them of the location of drywells and spill management, including proper type and use of spill control kits and operation of shut off valves
- Outreach to contractors performing construction in the vicinity of drywells, as well as their Qualified Stormwater Developers and Practitioners (QSDs and QSPs) performing construction to ensure the use of proper construction best management practices to prevent sediment and debris from entering drywells, as well as disconnection or use of the shutoff valve during construction activities. To support this effort, drainage maps that include dry well locations should be developed in the future, allowing plan checkers to issue such conditions with grading permits.
- Continued efforts to reduce use of chemicals, such as pesticides, that pose risks to surface and groundwater quality

Public education and outreach can increase community awareness and stewardship of drywells, thereby preventing illegal disposal, minimizing spills, helping reduce the use of pesticides and other pollutants, and minimizing the accumulation of trash. Such activities can include:

- Public service announcements
- Signage
- Training of municipal staff, including community service districts that maintain parks, rights-of-way, and other landscaped areas, and relevant businesses on spill prevention and response, erosion control, hazardous materials reduction, and operations and maintenance

[3] The City of Portland has found that accumulation of up to 2 feet of sediment in the bottom of their 10 foot deep sedimentation manhole does not compromise the operations. Most others states and manufacturers of drywell systems suggest checking drywells annually and vacuuming the sedimentation and/or drywell as needed. The frequency of vacuuming will vary with the associated land uses, frequency and intensity of storms, but most service drywells on a 1 – 2 year cycle.

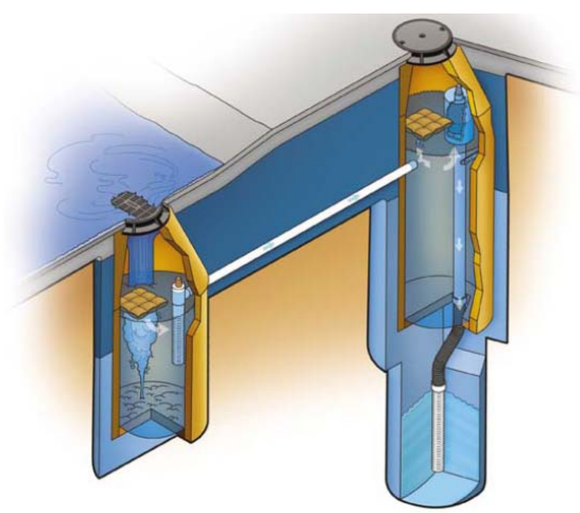
Construction Considerations

The following recommendations inform planning for construction of a drywell system:

- Drill drywell hole within the same drainage shed and general vicinity (500 feet) of the investigative boring to ensure consistency in soils types previously identified and used in design
- Provide careful oversight of excavation crew and structure installation crew to ensure depths, materials, and other design details are properly followed
- Log drill cuttings and compare to investigative boring records to assess whether design details need adjustment
- Watch and smell for unexpected colors, fluids, or odors to prevent installation in unknown contaminated area
- Prevent contamination and clogging of the borehole during drilling by preventing providing appropriate erosion control materials and practices
- Conduct well development after installation to remove fine particles and fluids that may have entered well during drilling
- Ensure proper handling and disposal of excavated materials

Examples of Drywell Systems

The follow figure illustrate a range of designs for drywell systems.



Maxwell Plus Drywell. This is a 2-stage drywell sold by Torrent Resources. Water enters the sedimentation chamber, oil and grease are captured by the hydrophobic pillow, while particulates settle to the bottom of the chamber. When sufficient water accumulates, it is transferred to the drywell, which contains a second oil/grease pillow, further settling occurs, then stormwater enters a pipe which carries it into the vadose zone, beneath confining layers of clay.

The use of this diagram does not represent an endorsement of Torrent Resources. This drywell design is used as a standard by other municipalities in southern California.

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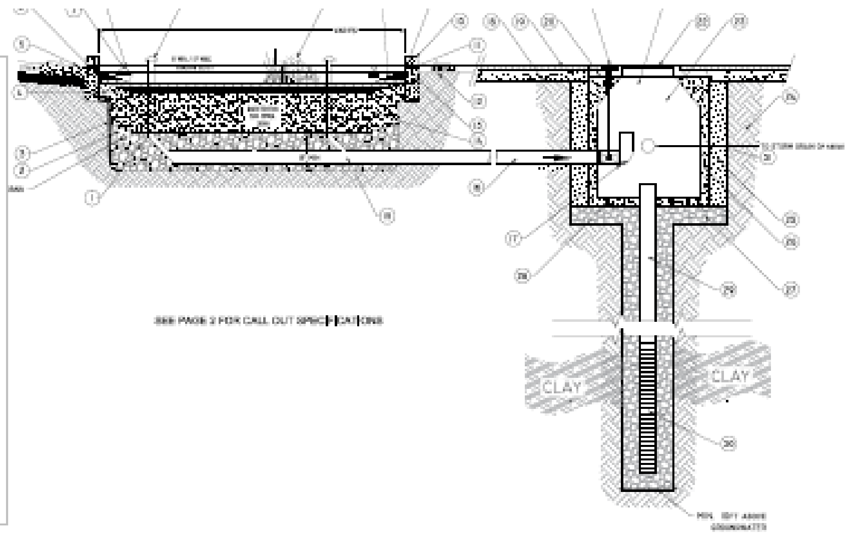
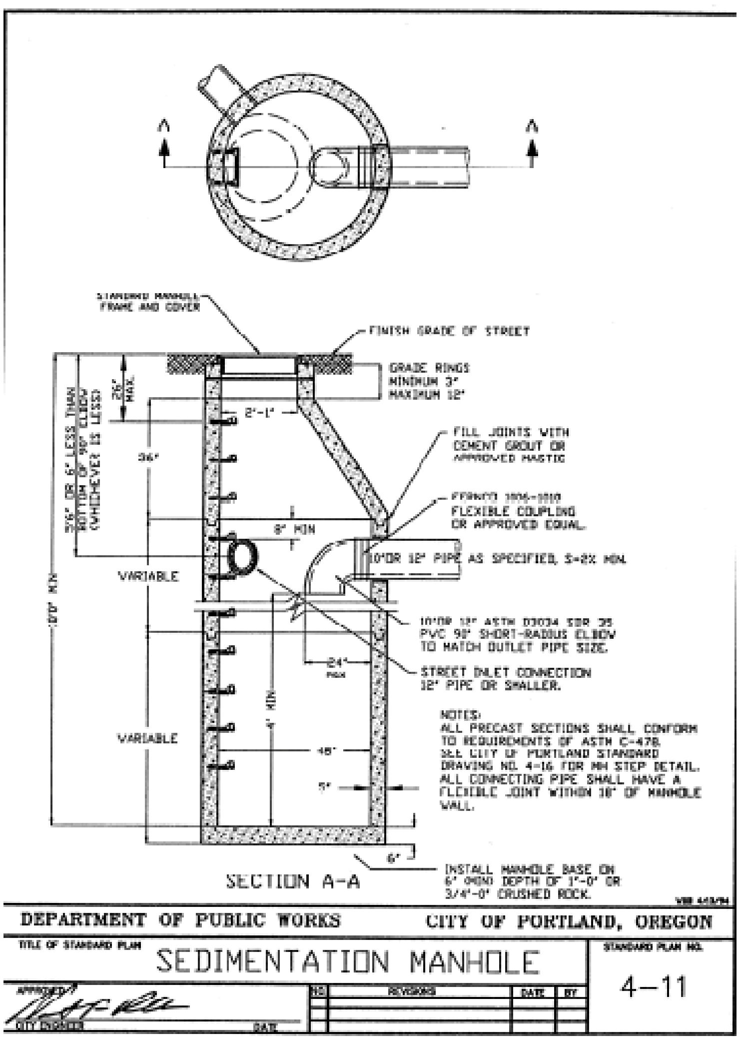
Drywell with vegetated pretreatment. In this example, drawn from the Central Coast Low Impact Development Initiative, a bioretention cell captures particulates and associated pollutants. Then treated runoff is transferred via a connecting pipe to the drywell.





Design of the sedimentation manhole used in Portland. Similar designs are used by others. The key aspect of the design is that the chamber is sufficiently deep to permit all but the finest particles to settle to the bottom and not be resuspended when runoff enters the chamber. This helps to avoid clogging of the drywell as well as removal of sediment-bound pollutants such as metals and organics.

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Attachment 1: Drywell system design procedures (for drywells with a barrier above the pervious shaft

Figure A1-1 depicts a drywell system and the design parameters used in the calculations provided on the following pages.

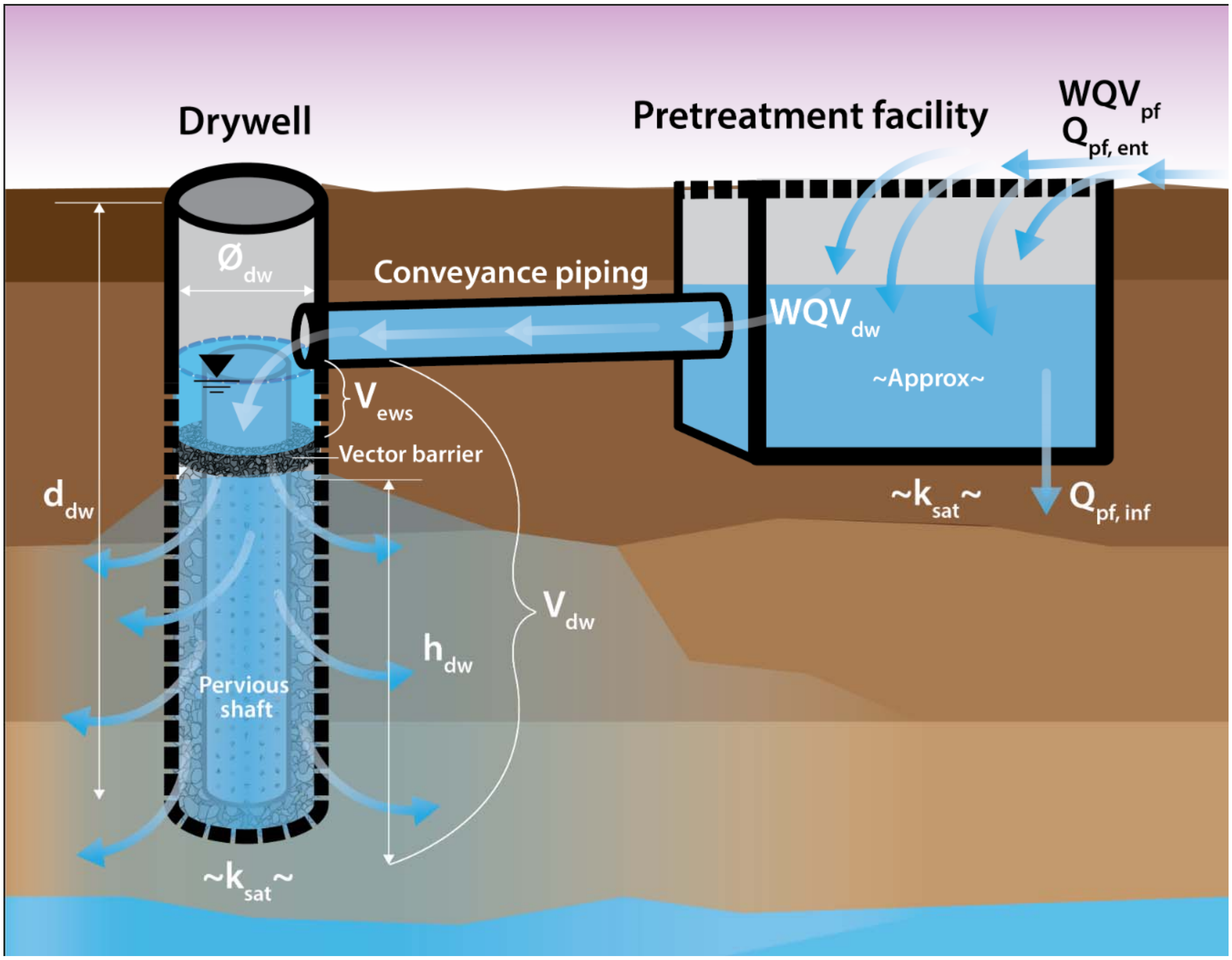

Figure A1-1. Schematic of drywell system and design parameters *(used in equations presented herein)*

d_{dw} = depth of drywell (ft)
h_{dw} = height of drywell's pervious shaft (ft)
Φ_{dw} = drywell diameter (ft)
V_{ews} = exposed water storage volume above the barrier above the drywell's pervious shaft (ft^3)
k_{sat} = hydraulic conductivity (in/hr).
$Q_{pf,ent}$ = flow rate of runoff entering the pretreatment facility (cfs)
$Q_{pf,inf}$ = rate of infiltration below the pretreatment facility (cfs)
WQV_{dw} = water quality volume entering the drywell (ft^3)
WQV_{pf} = water quality volume entering the pretreatment facility (ft^3)
V_{dw} = total volume of drywell storage (ft^3) (may include volume within the pervious shaft if drywell is designed to empty this volume in the time period associated with the design storm (e.g., 48 hours is often used to determine a design storm))

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1. **Design the drywell system.**
   a. **Design the pretreatment facilities.**
      - Types of facilities include sedimentation chambers, proprietary devices, or vegetated devices such as biostrips/swales or stormwater/bioretention planters.
      - Sedimentation chambers should be of sufficient depth to allow settling of particles prior to entering the drywell. The depth is frequently 10 feet or greater, with a 2-4 foot diameter width.
      - Other pretreatment facilities should be designed following the stormwater design manual relevant to the project jurisdiction:
        - City of Rocklin Post-Construction Manual (City of Rocklin 2015)
        - West Placer Storm Water Quality Design Manual (Placer County et al. 2016)
        - West Slope Development and Redevelopment Standards and Post Construction Storm Water Plan Requirements webpage (El Dorado County 2018).
        - Sacramento Stormwater Quality Partnership Stormwater Quality Design Manual (SSQP 2018b).

   b. **Design the drywell.**
      - Drill investigative boring.
        - Drill boring in vicinity (within 500 feet) of proposed drywell location to assess local geology and suitability for drywell installation. Boring logs should include soil classification.
        - Drill to depth to achieve a minimum of 5 foot "vadose zone treatment layer" below the bottom of the drywell. (See Figure 2 of Fact Sheet).
      - If the depth of the high seasonal groundwater table cannot be determined by boring, it can be approximated from the following sources:
        - ARB SWRP web map, depth to groundwater layer: http://www.owp.csus.edu/ARBSWRP/map.htm
        - Sacramento Central Groundwater Authority
        - Sacramento Groundwater Authority
        - Western Placer County Groundwater Management Plan
      - Establish the drywell depth (d_{dw}).
        - Using the boring data, determine (from Table 2) the treatment classification category of the "vadose zone treatment layer".
        - Using the treatment classification category, look up (in Table 1) the minimum required vertical separation between the bottom of the drywell and the high seasonal groundwater table.
        - Establish d_{dw} (the depth from the ground surface to the bottom of the well) to achieve the minimum required vertical separation between the bottom of the drywell and high seasonal groundwater table and to maximize infiltration capacity.
      - Conduct permeability testing in the bore hole using a falling head or constant head test method. Chapter 17 of the Engineering Geology Field Manual contains guidance for selecting among various methods for both gravity and pressure permeability tests (USBR 2001)
        - Assume the test results represents the saturated hydraulic conductivity (k_{sat}) of the soil at d_{dw}.

- Establish a height of the drywell's pervious shaft (h_{dw}, the lower portion of d_{dw} where water is allowed to infiltrate laterally) to achieve maximum drawdown time of 48 hrs. (Derivation provided at end of this attachment. Note that this equation assumes h_{dw} does not decrease with time as water infiltrates from the drywell).

$$h_{dw} \geq \frac{\Phi_{dw}}{4 * c} * \left[\frac{V_{ews}}{\pi * {\Phi_{dw}}^2 * k_{sat}} - 1\right]$$

Where h_{dw} *= height of drywell's pervious shaft (ft)*
Φ_{dw} *= drywell diameter (ft)*
c = fraction of pervious shaft's surface area available to seepage.
If no casing, c = 1.
V_{ews} *= exposed water storage volume above the barrier above the pervious shaft drywell* *(ft^3)*
k_{sat} *= hydraulic conductivity (in/hr). Apply a safety factor if desired.*
4: conversion factor

c. Design the conveyance between the pretreatment facility and the drywell.

- The conveyance piping must have a diameter/orifice sized to convey the rate of runoff leaving the pretreatment facility. The rate is often less than the rate entering the pretreatment facility. The rate of runoff infiltrating below the pretreatment facility ($Q_{pf,inf}$) can be considered in reducing the flow rate requirement for the conveyance pipe.
- Consider a slotted downturned influent or other screening mechanism to reduce clogging
- The flow rate entering the pretreatment facility ($Q_{pf,ent}$) can be calculated from the Rationale method:

$$Q_{pf,ent} = \frac{\mathrm{C} * \mathrm{i} * A_{catchment}}{12}$$

Where $Q_{pf,ent}$ *= flow rate of runoff entering the pretreatment facility (cfs)*
*C = Rationale coefficient **
*i = design storm intensity (in/hr)**
$A_{catchment}$ *= area of drainage catchment* *(ft^2)*
1/12: unit conversion factor (ft/in)
**Refer to the relevant stormwater design manual for C and i values. See Step 1.a for a list of the manuals relevant to each region. Note that i is for water quality treatment, but may need to be increased for drainage designs.*

- $Q_{pf,inf}$ can be calculated from k_{sat} (assumed to be the same as that measured for the drywell) and the cross sectional area of the pretreatment facility across which infiltration occurs (V_{pf}):

$$Q_{pf,inf} = A_{pf} * \frac{k_{sat}}{12}$$

Where $Q_{pf,inf}$ *= rate of infiltration below the pretreatment facility (cfs)*
A_{pf}*= cross sectional area of pretreatment facility, across which infiltration occurs* *(ft^2)*
k_{sat} *= saturated hydraulic conductivity (in/hr). Assume rate determined from drywell percolation testing.*
1/12: unit conversion factor (ft/in)

- The flow through the conveyance pipe (Q_p) is then equivalent to the difference between the inflow to and infiltration from the pretreatment facility:

$$Q_p = Q_{pf,ent} - Q_{pf,inf}$$

  - Culvert design or orifice flow equations should be selected based on the flow regime. Culvert design is covered in the Federal Highway Administration's Hydraulic Design of Culverts (FHWA 2012). NRCS also provides an MS Excel-based tool for designing culverts (NRCS 2015).

2. Calculate the number of drywells (N_{dw}) required for full on-site retention of design storm.

- If not calculated under Step 1, calculate the water quality volume (WQV_{pf}) entering the pretreatment facility using the method cited in the stormwater design manual appropriate for the project jurisdiction. See references for manuals listed in Step 1.a.
- Calculate the water quality volume entering the drywell (WQV_{dw}) from the pretreatment facility:

$$WQV_{dw} = \mathrm{WQV}_{pf} - \Delta \mathrm{V}_{pf}$$

Where WQV_{dw} *= water quality volume entering the drywell (ft³)*
WQV_{pf} *= water quality volume entering the pretreatment facility (ft³)*
ΔV_{pf} *= water quality volume lost (evapotranspired/stored/infiltrated) within pretreatment facility (ft³). The volume may be set to 0 as a conservative approach, or determined from the Sacramento Hydrologic Model (SAHM, SSQP 2014), the Phase II LID sizing tool (OWP 2017), or the National Stormwater Calculator (USEPA 2017). Appendix H of the American River Basin Stormwater Resource Plan (ARB SWRP, OWP 2018) provides instructions for determining these volumes.*

- Calculate N_w:

$$N_{dw} = \mathrm{Roundup}\left(\frac{WQV_{dw}}{V_{dw}}\right) = \mathrm{Roundup}\left(\frac{WQV_{dw}}{\mathrm{d}_{dw} * \frac{\pi * \Phi_{dw}}{4} * \eta_{dw}}\right)$$

Where N_{dw}*= number of drywells, rounded up to nearest integer*
V_{dw} *= total volume of drywell storage (ft³) (may include volume within the pervious shaft if drywell is designed to empty this volume in the time period associated with the design storm (e.g., 48 hours is often used to determine a design storm))*
d_{dw} *= depth of drywell (ft), from Step 1.b*
Φ_{dw}*= drywell diameter (ft). Typically 3-4 ft.*
η_{dw} *= porosity of drywell material fill (if applicable)*

3. Check that hydromodification management requirements are met.

- Follow the hydromodification management requirements from the storm water quality design manual relevant to the project jurisdiction.

Derivation of h_{dw} for draining of the exposed water surface for vector control

The surface area across which infiltration may occur includes the bottom of the drywell as well as the perimeter of the pervious shaft portion of the well:

$$A_{inf} = 2 * \pi * \frac{\Phi_{dw}}{2} * h_{dw} * c + \pi * \frac{(\Phi_{dw})^2}{4}$$

Where A_{inf} *= surface area of drywell across which infiltration can occur (sf)*
Φ_{dw}*= drywell diameter (ft)*
h_{dw} *= height of pervious shaft of drywell (ft)*
c = fraction of pervious shaft's surface area available to seepage.
If no casing, c = 1.

A_{inf} is multiplied by the saturated conductivity of the underlying soil to (conservatively) estimate the volumetric draw down rate (volume/time) within the drywell. The volume of exposed water stored within the drywell above the pervious shaft (V_{ews}) is then divided by this product to estimate the time (t_d) required to draw down V_{ews}. For vector control purposes, the draw down time should not exceed 48 hours:

$$\frac{V_{ews}}{k_{sat} * A_{inf}} * 12 = \frac{V_{ews} * 12}{k_{sat} * \left[2 * \pi * \frac{\Phi_{dw}}{2} * h_{dw} * c + \pi * \frac{(\Phi_{dw})^2}{4}\right]} \leq 48$$

Where V_{ews} *= exposed water storage volume above the barrier above the pervious shaft drywell* (ft^3)
k_{sat}*= saturated conductivity of soils below the drywell (in/hr)*
d_{dw} *= depth of drywell from Step 1.b (ft)*

The above equation is rearranged to solve for h_{dw}:

$$h_{dw} \geq \frac{\Phi_{dw}}{4 * c} * \left[\frac{V_{ews}}{\pi * {\Phi_{dw}}^2 k_{sat}} - 1\right]$$

Attachment 2: Characteristics of pollutants selected for the priority pollutant list

Multiple pollutants measured at three long term monitoring sites maintained by the Sacramento Stormwater Quality Partnership were reviewed. The following list of contaminants was selected based on the criteria shown in the table (below). A detailed description of how the criteria values were developed is contained in the footnotes to Table 4.

Pollutant class	Chemical	Concentration (median, ug/L unless otherwise noted)	Frequency of detection (%)	Mobility	Criteria Value (ug/L)
Metals	Pb	.69, .79, 0.05	84, 87, 78	medium	15
	Hg total	0.051, 0.029, 0.004	100, 87, 100	medium	2
SVOC/PAH	Chrysene	0.7, 0.2, 1.8	79, 57, 50	low	0.6
	DEHP	2.25, 2.43,	100, 100	low	4
Pesticides	Bifenthrin	0.061, 0.029, 0.021	100 100 100	low	0.64
	Fipronil	0.5[a]	-	high	1.0
Other	NO3 as N	0.58, 0.56, 0.44 (ppm)	100 100 100	high	10

[a] This concentration reflects upper 95% confidence limit for samples collected from storm drain outfalls at a number of Northern California sites, drawn from a study performed by the California Department of Pesticide Regulation (Budd et. al., 2015). Fipronil has not been part of the suite of contaminants monitored by the SSQP.

Attachment 3: Survey of Modeling Approaches

A variety of models, including simple spreadsheets through custom software packages, have been used to simulate drywell processes as part of current project planning and regulatory studies. Some software models used to date in simulating drywell processes are described below. This is not a comprehensive list, but rather a survey of the range of models in use.

Spreadsheet software: Oregon uses a one dimensional model based on the Advection Dispersion Equation (ADE)[4], which assumes transport under saturated conditions. Pollutant attenuation occurs by advection, dispersion, degradation, and retardation. Model input parameters include the following:

- Initial concentrations are 10x the EPA MCL. Contaminants without MCLs are not included in the list of priority pollutants that are modeled.
- Fraction Organic Carbon has been shown to be an influential factor in contaminant transport. The content of soil includes organic carbon from two sources: (1) naturally-occurring organic carbon in soil and (2) organic carbon in stormwater that filters out in soil surrounding the drywell.
    - Soil permeability is based on infiltration tests, and assumes a horizontal to vertical anisotropy of 1: 100 (if necessary, depending on the direction of permeability that was measured during the infiltration test).
    - Transport time is calculated based on the hours of runoff that flow into a drywell each year.
    - Biodegradation rate, total porosity, effective porosity, bulk density, and dispersivity values are drawn from the scientific literature. As appropriate, the input values reflect soil types (gravel, sand, etc.) and geochemical conditions of shallow soils (e.g., aerobic soils, appropriate pH). Dispersivity is conservatively estimated to be 5% of scale.
    - The model supports input of a single geologic type (e.g., silty clay, sand, etc.). The most permeable of the units in the profile is used in the modeling to arrive at a conservative estimate.

The value of this approach is its simplicity. One of the limitations is that it does not support an accurate representation of the vadose zone profile since it allows input of a single soil type (e.g., silty clay, sand, etc.). To manage this limitation, the most permeable geologic unit (e.g., sand or gravel) is often used in the analysis, therefore providing a more conservative result.

Hydrus: This is a software program that simulates water flow and solute transport in the vadose zone. It will accommodate data that reflects the complexity of the soil profile, so can provide a more realistic representation of local lithology. A public version of the software is available for modeling 1D processes, Hydrus-1D. A commercial version, Hydrus-2D, supports modeling of more complex situations involving two- and three-dimensional processes. In the Sacramento region, HYDRUS 1D was used to estimate drywell operations in a study in Elk Grove. 5 The travel time of selected contaminants moving vertically downward from the bottom of drywell to the top of the seasonal high water table was assessed for eight

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[4] Most of the modeling in Oregon is performed by GSI Consulting. They have provided this summary of the key aspects of the proprietary spreadsheet that is used. Other states had adopted similar approaches.

[5] Assessing the Risks of Using Drywells for Stormwater Management and Groundwater Recharge: The Results of the Elk Grove Drywell Project." City of Elk Grove and the California Office of Environmental Health Hazard Assessment. https://www.elkgrovecity.org/UserFiles/Servers/Server_109585/File/Departments/Public%20Works/Drainage/Dry%20Wells/dry-well-doc-01.pdf

scenarios, thus providing an estimate of concentrations of contaminants at the water table over a range of parameter inputs.

GIFMod: The Green Infrastructure Flexible Model, or *GIFMod*, is EPA-funded, open source software developed for modeling hydrologic, hydraulic, and water quality processes at multiple geographic scales. [6] Like Hydrus, it models The software incorporates many common methods for estimating hydrologic processes, including evapotranspiration, infiltration, and saturated and unsaturated flow, along with water quality considerations for contaminant inflow concentrations and transport. The user interface was designed to be approachable. Users delineate separate infrastructure devices or physical features, such as a swale or a lake, and assign known physical parameters. Model results report simulated flows and contaminant concentrations for an identified time period. Notably, *GIFMod* offers capability to easily simulate a multi-step drywell installation that includes additional features for pre-treatment such as a vegetated swale or sedimentation chamber. It also can perform inverse modeling which could be used to estimate concentrations of contaminants allowable at the entry point into the drywell based on desired maximum allowable concentrations at the water table.

VS2DH 3.0: *VS2DH 3.0* is a software platform for simulating 2-dimensional, saturated-unsaturated flows based on a finite-difference modeling framework.[7] For drywells, this would simulate the radial flow in 2-dimensions, both vertically and laterally, within a soil column of potentially varying composition and areas of saturated and unsaturated movement. *VS2DH 3.0* was used to estimate calibrated steady-state infiltration rates from drywell installations in the state of Washington.[8] The modeling estimated how, over time, infiltration rates decreased as soils became more saturated for multiple types of drywell design and construction.

Custom Operations Research Models: Planning for on-site drywell installations can necessarily include investigating decisions on siting, construction depths, setbacks, and separation between wells. Operations research modeling with simulation and optimization is used in identifying optimal parameters that meet design criteria and constraints. Such methods are useful in planning drywells. For instance, as part of a research project at the Arizona State University, researchers developed non-linear, mixed-integer programming to inform drywell design parameters, including depth, size, and number of wells on a site.[9] The modeling used an objective function (goal) of minimizing total costs of construction, land acquisition, and "hydroseeding" (planting surface vegetation) to infiltrate runoff using the modified rational method. The model only considers water quantities and infiltration and does not simulate water quality processes.

[6] Massoudieh, A., M. Maghrebi, B. Kamrani, C. Nietch, M. Tryby, S. Aflaki, S. Panguluri (2017), A flexible modeling framework for hydraulic and water quality performance assessment of stormwater green infrastructure, *Environmental Modeling and Software*, 92, pp 57–73. http://gifmod.com/

[7] Healy, R.W., and Ronan, A.D., 1996, Documentation of computer program VS2DH for simulation of energy transport in variably saturated porous media -- Modification of the U.S. Geological Survey's computer program VS2DT, U.S. Geological Survey Water Resources Investigations Report 90-4025, 125 pages. https://wwwbrr.cr.usgs.gov/projects/GW_Unsat/vs2di/hlp/energy/vs2dh3p0.html

[8] Massmann (2004). "An Approach for Estimating Infiltrates Rates for Stormwater Infiltration Drywells. Washington State Department of Transportation, Research Office, Olympia, WA. https://trid.trb.org/view/859214

[9] Lacy, Mason. Optimization Model for the Design of Bioretention Basins with Drywells. (2016). Arizona State University. https://repository.asu.edu/attachments/170323/content/Lacy_asu_0010N_15741.pdf