California Drywell Guidance Research and Recommendations

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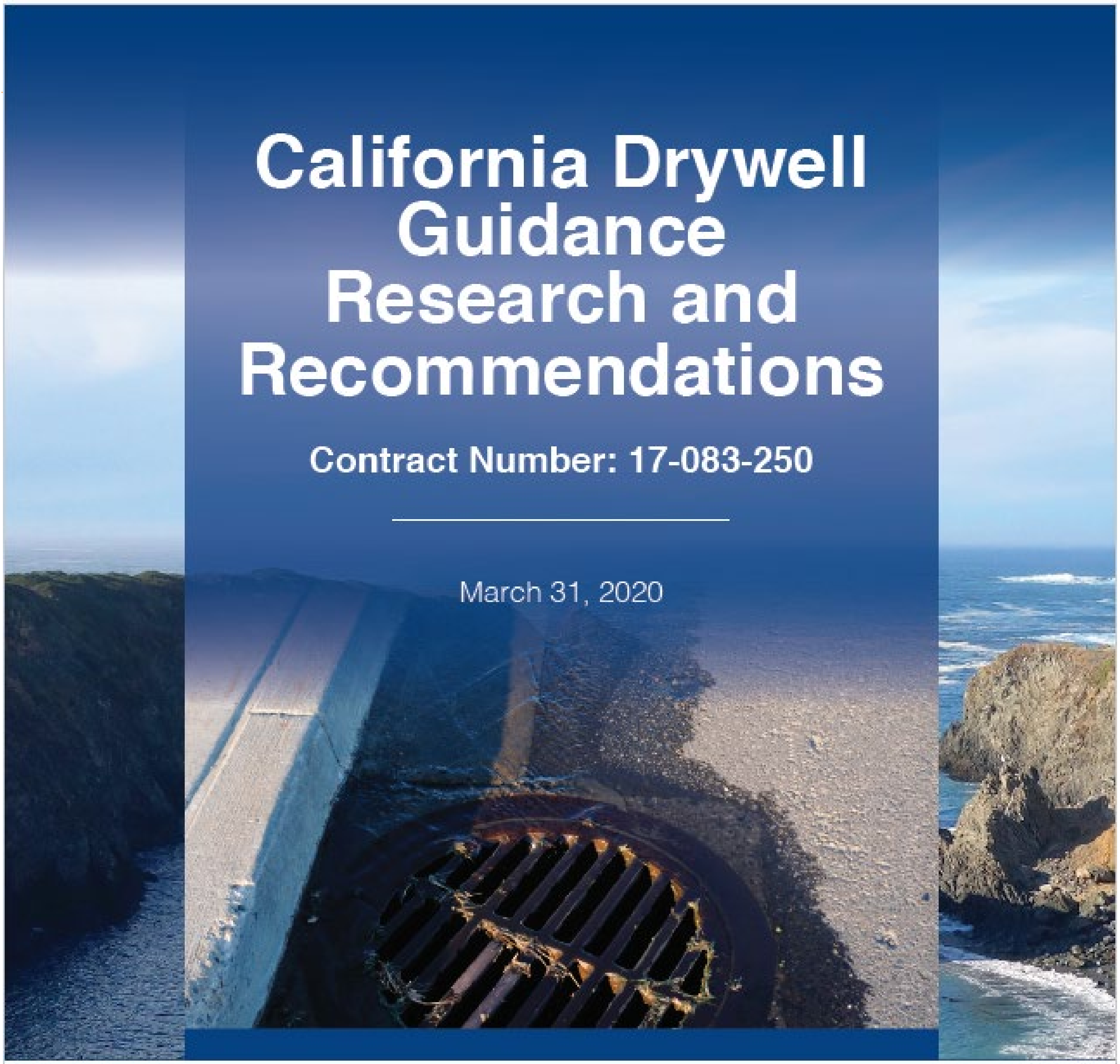

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ACRONYMS AND ABBREVIATIONS

ARB	American River Basin
ARG	antibiotic resistant gene
Basin Plans	Water Quality Control Plans
BMP	best management practice
Bti	bacillus thuringiensis israelensis
Bulletin	DWR *Bulletin 74 California Well Standards*
CEDEN	California Environmental Data Exchange Network
DEHP	Di(2-ethylhexyl)phthalate
DPR	Department of Pesticide Regulation
DWR	Department of Water Resources
USEPA	United States Environmental Protection Agency
ESA	Environmental Site Assessment
FIB	fecal indicator bacteria
Geosyntec	Geosyntec Consultants, Inc.
GSA	GeoSystems Analysis, Inc
GULD	General Use Level Designation
IGP	Industrial General Permit
LASAN	Los Angeles Bureau of Sanitation
LEAs	Local Enforcing Agencies
MCL	Maximum Contaminant Level
mg/L	milligrams per liter
MS4	Municipal Separate Storm Sewer System
NEC	no exposure certification
O&M	operations and maintenance
PAHs	polycyclic aromatic hydrocarbons
PCA	Porter Cologne Act
PFAS	per- and polyfluoroalkyl substances
PPCPs	pharmaceuticals and personal care products
QSD/QSP	Qualified Stormwater Developer and Practitioner

Regional Water Boards	Regional Water Quality Control Boards
SDWA	Safe Drinking Water Act
SSOs	Sanitary Sewer Overflows
State Water Board	State Water Resources Control Board
SWRP	Stormwater Resource Plan
TAC	technical advisory committee
TAPE	Technology Assessment Protocol – Ecology
TGD	Technical Guidance Document
TSS	total suspended solids
UIC	Underground Injection Control
USDW	underground source of drinking water
Water Boards	State and Regional Water Boards
WDR	Waste Discharge Requirements
WQMP	Water Quality Management Plan

1. INTRODUCTION

1.1 Purpose and Organization

The purpose of this report is to provide guidance on stormwater infiltration drywells (referred to as "drywells" throughout this report) as their use continues to increase throughout California. Depending on local conditions, drywells can provide high stormwater infiltration capacity while only requiring a limited footprint area and can take advantage of deeper layers of infiltrative soil. As a result, drywells are advantageous where space is constrained (e.g., industrial facilities where operations occupy the majority of the site or in the public right of way) or where shallow soils are not sufficiently infiltrative. The State Water Resources Control Board (State Water Board) and nine Regional Water Quality Control Boards (Regional Water Boards; collectively Water Boards) have identified the need for this guidance document in order to continue the use of this effective infiltration tool, while also being protective of California's water resources and public health. The report describes a risk-based framework for siting, design, installation, and maintenance of drywell projects to accomplish these goals. The risk-based framework was developed to identify (a) scenarios where infiltration of stormwater through drywells could negatively impact groundwater quality and (b) solutions to mitigate scenarios that pose a high risk to groundwater quality. The intended audiences of this report are the Water Boards, Municipal Separate Stormwater System (MS4) permittees, Department of Water Resources (DWR), Local Enforcing Agencies (LEAs)[1], as well as consultants who may be supporting local public agencies.

This guidance was written by Geosyntec Consultants, with the content developed based on the cumulative input received from the State Water Board, the technical advisory committee (TAC) (Section 1.4), Dr. Robert E. Pitt (University of Alabama Expert Adviser), and O'Day Consultants. While Geosyntec provided a preliminary data analysis, with support from GeoSystems Analysis, Inc. (GSA), to begin filling a limited subset of the identified research needs and data gaps (Section 2), the risk-based framework presented herein is mostly based on the input received (as describe above) coupled with a review of existing drywell guidance and drywell-specific literature (Section 3 and Section 4). This report also identifies future research and data analyses required to sufficiently quantify the potential risk to groundwater contamination posed by drywells and thus develop appropriate mitigation strategies in the future as more data are collected and analyzed (Section 5).

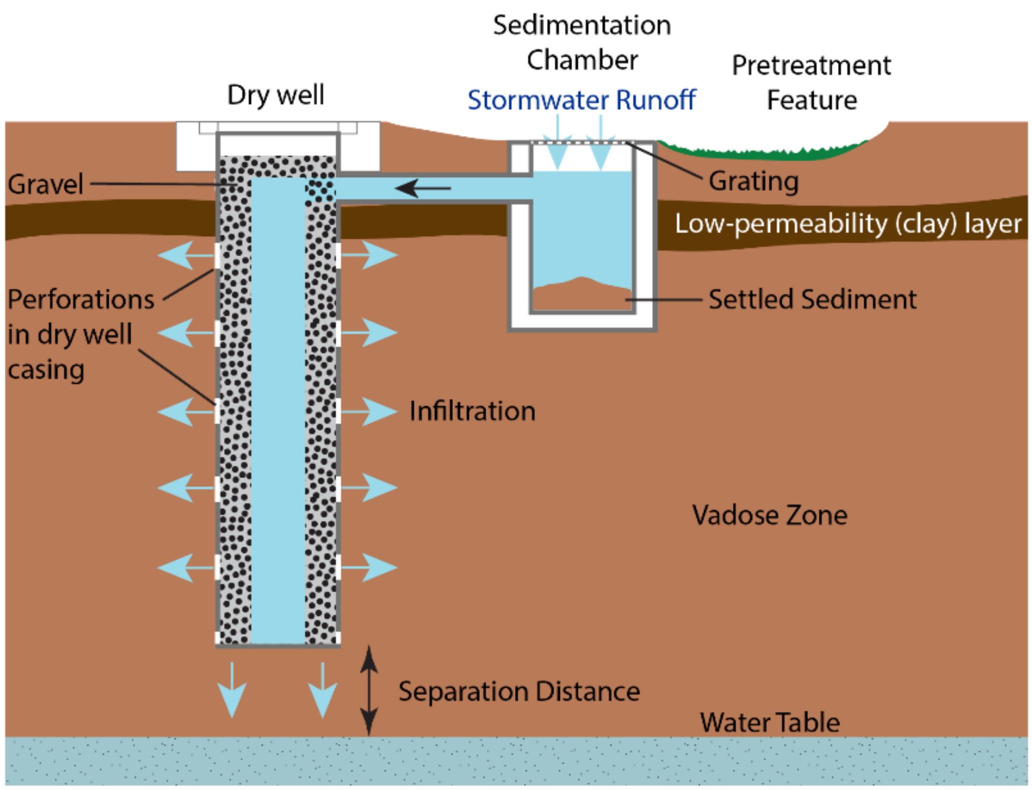
Regional Water BoardsThe remaining introductory sections provide an overview of drywells and their historical regulation, a summary of the TAC, and a summary of how this guidance was developed.

[1] Designated City and County officials responsible for administering the DWR Well Standard, including reviewing and approving well permit applications for drywells.

1.2 Drywell Overview

Drywells are stormwater management best management practice (BMP) infiltration devices that capture and infiltrate stormwater and incidental dry weather runoff into the unsaturated zone above the groundwater table (i.e., the vadose zone). Drywells typically include a perforated concrete chamber surrounded by gravel with a perforated pipe. Typical chamber or pipe dimensions are up to 4 feet in diameter and 20 to 50 feet deep, and can be greater than 100 feet deep. The pipe is commonly (and is recommended to be) preceded by a pretreatment BMP or sediment chamber. Drywells can provide an effective means of stormwater runoff capture and infiltration in urban space-constrained environments when subsurface conditions are suitable. Where near-surface soils are less infiltrative, drywells can provide a means to bypass those layers to infiltrate water into deeper subsurface soil horizons with higher infiltration capacity. Deep infiltration is a natural process that provides critical groundwater recharge and has been greatly reduced due to land development. Drywells help to restore this natural process and mimic pre-development conditions. A schematic drawing of a typical drywell shown in Figure 1 contains a vegetated pretreatment feature, a structural sedimentation chamber, and a drywell; however, different configurations have been implemented.

Figure 1. Schematic Drawing of a Drywell System



Source: americangeosciences.org

1.3 Regulatory Overview

1.3.1 Federal

Drywells in the United States are regulated as Class V wells under the Underground Injection Control (UIC) program, which is authorized by the Safe Drinking Water Act (SDWA) and requires the injection does not endanger a underground source of drinking water (USDW) and is registered with the United States Environmental Protection Agency (USEPA). USEPA regulations on drywell guidance do not include specific design requirements. Design standards are more often found in state and local guidance, as introduced in the following sections.

The USEPA

definition of Class V UIC wells can include shallow and deep vertical drywell systems as well as some infiltration galleries, that are "deeper than its widest surface dimension" (USEPA, 2008). The recommendations presented herein are focused on deeper vertical drywell systems, those which match the general description provided in Section 1.2 and shown in Figure 1, rather than shallow wells or infiltration galleries. Even though this guidance focuses on deeper systems, most of the recommendations provided are also applicable to shallow drywell systems and applicable infiltration galleries (i.e., all Class V UIC wells).

1.3.2 State of California

Porter Cologne Act. California's Porter Cologne Act (PCA) Section 13260 requires that all persons proposing to construct an "injection well"[2] file a report of waste discharge (ROWD) with the applicable RWQCB. The guidelines presented herein do not provide recommendations for permitting drywells throughout the state; however, it is recommended that the State Water Board and Regional Water Boards work together to identify a streamlined approach.

At the regional level, Regional Water Boards are authorized to permit waste to permit waste discharges to both surface and groundwaters of the state. Regional MS4 permits reflect specific guidelines for stormwater discharge. However, they are not usually for discharges to groundwater except in some instances through post-construction requirements, and these typically do not specifically address drywells.

Well Standards Bulletin 74-81. The California Department of Water Resources (CA DWR) Well Standards (Bulletin 74-81) provide requirements to protect wells used to supply drinking water. The CA DWR Well Standards include elements to prevent the contamination of groundwater and inflow of surface water into wells. However, drywells represent a unique case where inflow of surface water is an intended function of the

[2] An injection well is defined under the PCA as "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."

drywell. Thus, the goals of Well Standards appear to stand in contradiction to the very purpose of the drywell and there is confusion on the extent to which these regulations apply to drywells. CA DWR is in the process of revising the Well Standards and the revision is anticipated to consider the application of drywells. Status of the effort to update the Bulletin can be tracked at: https://water.ca.gov/Programs/Groundwater-Management/Wells/Well-Standards.

1.3.3 Local Agencies and Municipalities

Local municipalities are regulated under MS4 permits. These permits require BMPs for new development and significant redevelopment projects. They also typically include criteria for groundwater protection. As part of implementing these requirements, local permittee groups typically develop BMP design manuals and, in many cases, these design manuals (e.g. counties of Los Angeles, Riverside, San Bernardino, and San Diego) include criteria for groundwater quality protection and may include guidance for drywell siting and design. Some permittee groups, such as the American River Basin (ARB) and Orange County have developed guidelines for the installation of drywells to manage stormwater in their communities.

LEAs are responsible for implementing the CA DWR Well Standards and for well permitting, which would include drywells. The Well Standards give authority to these LEAs to develop standards for special cases, such as drywells. Examples of LEAs may be County environmental health agencies or municipal well permitting authorities. A list of LEAs by County is available at: https://water.ca.gov/Programs/Groundwater-Management/Wells/Permitting-Agencies.

1.3.4 Example Local Drywell Regulation Approach

Orange County represents an example of how the regulations described above are implemented at a local level and is provided here for informational purposes. This specifically considers the portion of Orange County within the Santa Ana Regional Water Quality Control Board (referred to as North Orange County). The North Orange County MS4 Permit (Order No. R8-2009-0030, Amended by Order No. R8-2010-0062) was issued to the County of Orange and municipal co-permittees by the Santa Ana Regional Water Board. It included criteria for groundwater protection and required the development of a Technical Guidance Document (TGD) for BMP siting, selection and design. The municipal co-permittees developed the TGD, which includes criteria for protecting groundwater quality applicable to any type of infiltration BMPs. The municipal co-permittees apply the TGD standards as part of reviewing and approving land development and retrofit projects.

The Orange County Well Standards Advisory Board includes representatives from Orange County Water District (OCWD), Orange County Health Care Agency (OCHCA), and Orange County Public Works (OCPW). OCWD manages much of the groundwater in Orange County. For drywell projects within the OCWD groundwater basin, the TGD states that infiltration activities should be coordinated with the applicable groundwater management agency. OCHCA is the well permitting authority for much of the County, except for some cities who have their own well permitting authority. As a result, drywell proponents need to receive a well permit from OCHCA or the local well permitting authority (in addition to registering with USEPA).

The Well Standards Advisory Board received input from stakeholders that the process and criteria for drywell design and permitting was not clear and created barriers for permitting of projects with drywells. Representatives of the Board also performed a review of existing criteria and guidance in the TGD, the Orange County Well Ordinance, and the CA DWR Well Standards. From this, they identified opportunities to improve alignment in criteria and guidance.

In response, the Board authorized OCPW to develop guidelines for drywell siting, design, permitting, and construction that can be used by project applicants and reviewers since OCPW is the principal permittee under the MS4 Permit and administers the Orange County Stormwater Program on behalf of the local municipal permittees. The resulting "Guidelines for Use of Drywells as in Stormwater Management Applications" (Orange County Guidelines) (in draft) were developed with input from local municipalities and members of the Well Standards Advisory Board. The Orange County Guidelines are intended to be specific to drywells while being consistent with the MS4 Permit requirements, TGD criteria and CA DWR Well Standards. The guidelines are most directly relevant to private and municipal projects that include drywells for stormwater management. They are intended to support a common interpretation of criteria between OCWD, OCHCA and the local municipal MS4 permittee responsible for review of project plans that involve drywells. Key areas of focus in the Orange County Guidelines include pretreatment requirements, infiltration testing methods, and siting-related criteria that preclude the use of drywells. The Orange County Guidelines also define a local process for coordinating the review and permitting activities between OCWD, OCHCA, and the local municipal MS4 permittee.

1.4 Technical Advisory Committee

The TAC was convened by the State Water Board to serve as expert advisors during the development of this drywell guidance and to provide review of critical items and deliverables based on their individual experience. The TAC members were selected to provide a group with diverse backgrounds and expertise and included representatives from regulatory agencies, municipalities, research institutes, and vendors. A list of the TAC members and their respective affiliations is provided in Table 1.

Table 1. List of TAC Members and Affiliations

Name	Affiliation	Organization Type
John Ricker	California Conference of Directors of Environmental Health	Regulatory Agency
Lani Andam	Central Valley Regional Water Board, Waste Discharge to Land Permitting	Regulatory Agency

Name	Affiliation	Organization Type
Scot Stormo	Colorado River Regional Water Board, Groundwater Protection/Waste Discharge Requirements (WDR)	Regulatory Agency
Julie Haas	Department of Water Resources	Resource Agency
Barbara Washburn	Office of Environmental Health Hazard Assessment (OEHHA)	Regulatory Agency
Scott Bradford	United States Department of Agriculture	Regulatory Agency
Andrew Renshaw	State Water Board, Groundwater Management/Sustainable Groundwater Management Act (SGMA)	Regulatory Agency
Jan Stepek	State Water Board, Groundwater Monitoring/Groundwater Ambient Monitoring and Assessment (GAMA)	Regulatory Agency
Cabe Silverhame	State Water Board, Stormwater Permitting (Industrial, Construction)	Regulatory Agency
Wing Tam	City of Los Angeles, Bureau of Sanitation	Municipality
Paul Alva[1]	County of Los Angeles	Municipality
Adam Hutchinson	Orange County Water District	Municipality
Jill Bicknell	Santa Clara Valley Urban Runoff Pollution Prevention Program / EOA, Inc.	Municipality
Suzanne Sharkey	National Water Research Institute	Research Institute
Maureen Kerner[2]	Sacramento State - Office of Water Programs	Research Institute
Prof. Graham Fogg	U.C. Davis, Department of Land, Air, and Water Resources	Research Institute
Jim Mayer[3]	Torrent Resources	Vendor

Notes:

Alternate TAC members include:

[1]TJ Moon, County of Los Angeles;

[2]Brian Currier, Sacramento State – Office of Water Programs;

[3]Travis Pacheco, Torrent Resources.

The TAC was involved throughout the development of these recommendations through attendance at two in-person meetings in Sacramento, review of deliverables, and providing responses to survey questions. Results from the TAC surveys are provided in Appendix A. Highlights from two example drywell case studies in California that some of the TAC members listed above were involved with are provided in Appendix B.

1.5 Approach for Developing Guidance

This guidance was developed over several months beginning in May 2018 and included two TAC surveys and in-person meetings, background literature and existing guidance document review, as well as limited new technical research. A brief summary of the overall approach to the development of this guidance is provided below.

- **TAC Surveys and In-Person Meetings**: The first TAC survey and in-person meeting was conducted in August 2018 to better understand the strengths and weakness of existing drywell guidance documents and to identify high priority data gaps and research needs. The second TAC survey was conducted in January 2019, after submittal of the Needs and Data Gaps Memorandum (see below and Section 2.1) to review and identify the focus for the next technical research task. The second TAC meeting was conducted on June 2019 to provide an update on the technical research tasks performed and to seek consensus on the revised final report outline, content, and structure. Results from the TAC surveys are provided in Appendix A.

- **Research Needs and Data Gaps**: A memorandum was drafted in November 2018 to provide a high-level overview of relevant existing drywell guidance from California and nearby states as well as a summary of the drywell implementation research needs and data gaps that still exist based on a review of relevant stormwater drywell literature studies. The memo's focus was based on priorities identified by the TAC and the State Water Board to better understand what scenarios for drywell implementation may present a groundwater contamination risk and whether emerging contaminants[3] present additional contamination risk. The Needs and Gaps Memo is included in Appendix C and the key findings are summarized below in Section 2.1. Due to scope limitations, the comments received from the TAC on this draft memo were not incorporated into a final version, but they have been addressed, as feasible, during the development of this guidance document.
- **New Technical Research**: Based on the Needs and Gaps Memo, new analyses were conducted to address a subset of the prioritized research needs and data gaps. The technical analysis included two tasks: (1) a survey of stormwater quality data and statistical analysis to identify land use-pollutant combinations that could pose a risk to groundwater quality; and (2) an analysis of the BMPs that could most effectively mitigate these pollutants. This technical research is presented in Section 2.2.
- **Development of a Risk-Based Framework**: Relying mostly on the Needs and Gaps Memo's summary of existing drywell literature and guidance, as well as input from the TAC and State Water Board, and to a lesser extent based on the new technical analyses performed, a risk-based framework for drywell implementation was developed. The risk-based framework and risk-based pretreatment recommendations for medium and low risk scenarios are described in Section 3. Recommendations for high-risk scenarios are presented in Section 4.

[3] Stormwater emerging contaminants are pollutants that are not typically monitored in stormwater, but initial data collection or research has identified these pollutants as a possible risk of surface water and groundwater contamination if transported by stormwater.

2. SUMMARY OF RESEARCH AND TECHNICAL ANALYSES

A high-level review of relevant existing drywell guidance documents, literature, and publications (limited only to those focused on stormwater and drywells) was conducted to identify research needs and data gaps that should be addressed to understand the potential risk posed by drywell implementation. A summary of this review and the identified needs and gaps are provided in a technical memorandum prepared by Geosyntec Consultants, Inc. (Geosyntec) titled *Drywell Standards Research Needs and Gaps,* dated November 29, 2018 (Needs and Gaps Memo; Appendix C).

A general finding from this review was that available stormwater drywell guidance and literature typically addresses groundwater contamination risk potential from traditionally-studied urban stormwater pollutants (e.g., metals, total suspended solids [TSS], nutrients, bacteria) and does not typically address emerging contaminants or current use pesticides, some of which may represent the highest risk pollutant types. This is particularly the case where they have the following four key attributes: toxic (i.e., responsible for human health impact endpoints), abundant (i.e., present at levels in stormwater above health thresholds), mobile (i.e., highly dissolved[4]), and persistent (i.e., not subject to decay over groundwater travel timeframes). This summary and the recommendations that follow focus on risk mitigation strategies for traditionally-studied urban stormwater pollutants for which data are available; however, few if any of these pollutants represent all four necessary attributes. Therefore, to address this limitation, as described below and in later sections, a general recommendation is to continue data collection and perform additional research to quantify and understand how to appropriately mitigate the potential groundwater contamination risk from pollutants in stormwater that are toxic, abundant, mobile, and persistent.

A summary of the key findings from the Needs and Gaps memo is provided in Section 2.1. These findings were then prioritized based on guidance from the TAC and State Water Board. Two top priority technical analyses were performed to begin addressing the identified needs and gaps, consistent with the scope of the guidance document and are described in Section 2.2. However, not all research needs could be addressed at this time. A summary of the research efforts is described in Section 2.3.

2.1 Research Needs and Data Gaps

A review of existing drywell guidelines and relevant drywell literature studies was conducted to better understand the groundwater contamination risk from stormwater infiltration through drywells. As part of this evaluation, stormwater emerging contaminant literature was also reviewed, based on recommendations from the TAC, to better

[4] The term “dissolved” when used in this report is intended to represent the filtered form of pollutants.

understand stormwater pollutant concentrations and whether these contaminants pose a risk to human health via groundwater contamination through drywell infiltration.

The classes of chemicals that were specifically researched as part of this project included:

- Per- and polyfluoroalkyl (PFAS),
- Antibiotic resistant genes (ARGs), and
- Some current use pesticides, pharmaceuticals and personal care products (PPCPs).

Viruses and additional pesticides are other classes of emerging contaminants that could impair groundwater quality when present in stormwater. However, they were not investigated as part of this project due to limited current stormwater data availability or because the available data lack land use information or regulatory thresholds for comparison. For these emerging contaminants, there is a need for additional studies and research to compare detected concentrations in stormwater to regulatory and health advisory thresholds where they exist.

The following summarizes the general findings from this research:

- Existing guidance documents generally have a similar scope and structure, with variation in the details. Most of the guidance documents reviewed do not include citations or numerical analyses to justify the recommendations; therefore, the guidelines do not necessarily demonstrate a reliable protection of groundwater quality in all drywell implementation circumstances or have a rigorous scientific basis. However, existing guidelines do provide a useful reference for how current and past drywells have been sited and designed.
- There are several datasets available to assess stormwater pollutant concentration ranges relative to human health thresholds and the performance of pretreatment stormwater BMPs relative to these thresholds. However, these datasets tend to be limited to traditionally-studied urban stormwater pollutants and do not include sufficient data to understand typical stormwater concentrations of emerging contaminants or current use pesticides, which may represent the highest risk pollutant types since they are typically toxic, abundant, mobile, and persistent.
- Various factors that contribute to risks to groundwater should be examined in combination, these factors include, but are not limited to:
    - Water quality of flows discharging into drywells, which may vary based on contributing land uses as well as other factors;
    - Pretreatment effectiveness prior to infiltration;
    - Groundwater quality objectives including drinking water standards, other human health thresholds (for non-regulated pollutants), antidegradation

considerations, drywell proximity to downgradient water supply wells, and ambient groundwater quality.

Stormwater quality monitoring and modeling studies have demonstrated low potential incidence of groundwater contamination resulting from stormwater infiltration through drywells (see the Needs and Gaps Memo, Appendix C, and references therein). However, there are certain scenarios that pose a higher risk to groundwater contamination; therefore, it is important to identify a risk-based framework for drywell implementation guidance so that these scenarios are properly mitigated.

As a result of this review, the following research needs and data gaps were identified:

1. **Statewide stormwater pollutant groundwater contamination risk data analysis**. A statewide analysis of recently available stormwater runoff data is needed to identify the pollutants or land use-pollutant combinations that pose a higher risk to groundwater contamination. Pollutant concentrations could be compared to Maximum Contaminant Levels (MCLs), human health drinking water thresholds, and other groundwater quality objectives that stormwater pollutants may be expected to exceed.
2. **Vadose zone pollutant attenuation studies**. For pollutants or land use-pollutant combinations that pose a high risk to groundwater contamination identified in the bullet above, research is needed to identify a method for determining redox conditions and site-specific vadose zone pollutant attenuation potential for sites with potential for groundwater contamination.
3. **Pretreatment guidance and effectiveness studies**. For pollutants or land use-pollutant combinations that pose a high risk to groundwater contamination, a summary of how potential pretreatment BMPs may reduce groundwater contamination risk is needed, which could be developed by summarizing BMP performance results from the International BMP Database (www.bmpdatabase.org) to evaluate how certain BMPs perform at expected influent concentration under varying influent ranges.
4. **Infiltration testing guidance**. Research is needed to determine the infiltration testing methods prior to drywell installation that are most reliable and predictive of long-term conditions. The results of this research should be distilled into guidance for practitioners as part of the drywell siting and construction process.
5. **Long-term groundwater impact studies**. An assessment of the long-term groundwater impact potential of stormwater infiltration through drywells is needed. The studies could be conducted at existing drywells by evaluating upgradient and downgradient groundwater quality. This assessment would need to occur over several years at a minimum.
6. **Drywell lifecycle research**. Research is needed to better understand drywell lifecycles, mitigate potential functionality risks, and plan for drywell deconstruction, abandonment, or refurbishment. This research could be based primarily on data and other input provided by cities and counties.

The Needs and Gaps Memo also provides a summary of publicly available stormwater datasets that can be used by practitioners to characterize typical urban stormwater concentrations that may be entering drywells, along with effluent concentrations expected from certain stormwater BMPs that could be used as drywell pretreatment devices. These datasets were used in the technical analysis. Scope and budget limitations restricted this analysis to an introductory or preliminary investigation of the above research needs and gaps as described in the next section.

2.2 Technical Analysis Summary

After completion of the previous task reviewing gray and peer-reviewed literature, additional technical analysis was performed to begin addressing a subset of the research needs and data gaps identified above. Based on guidance from the State Water Board and TAC, the technical analysis began addressing research tasks 1 and 3 summarized in Section 2.1. Based on these two research needs, analyses were performed to begin answering the following questions:

1. Are there combinations of land uses and concentrations of pollutants originating from those land uses that pose a higher risk to groundwater contamination (relative to drinking water standards)?
2. What types of pretreatment BMPs are effective for removal of these land use-pollutant combinations? Additionally, what types of pretreatment BMPs are effective for removal of solids to reduce the rate of clogging?

The approach and results of these additional technical analyses are summarized below.

2.2.1 Land Use-Pollutant Combination Risk Analysis

A statistical analysis of land use-based stormwater quality data was conducted to evaluate the degree of risk to groundwater contamination from various land use-pollutant combinations. The overall approach included using publicly available statewide stormwater runoff data and comparing observed concentrations with USEPA or California drinking water standards, or MCLs, to identify the land use-pollutant combinations that have a higher probability of exceeding MCLs and thus pose a higher groundwater contamination risk[5]. Therefore, this evaluation mainly identified pollutants that are toxic (i.e. have an MCL), abundant (i.e. likely to exceed the MCL), persistent (i.e. resistant to decay), but typically particulate-bound[6], which would be removed by conventional pretreatment and vadose zones with fine soils.

A limitation of the study was that this evaluation did not include some mobile pollutants (e.g. viruses and some pesticides) due to a lack of available data or data with land use

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[5] While other water quality criteria do exist, this analysis was limited to comparing stormwater concentrations to applicable MCLs due to scope limitations.
[6] The term "particulate" as used in this report does not include colloids or colloid-associated pollutants. Colloids are assumed to be in the dissolved (or filtered) fraction for the purposes of this report.

information and limited available data for other mobile pollutants (e.g. PFAS, ARGs, and some PPCPs). These mobile pollutants could be expected to travel through typical pretreatment devices and the vadose zone. Recommendations for future research (Section 5) have identified a need to perform additional groundwater contamination risk analyses including these more mobile pollutants.

Mobile pollutants with sufficient data that may be toxic, abundant, or persistent and were incorporated into the analysis include some dissolved metals as well as nitrate and nitrite. In addition to potentially mobile pollutants passing through the vadose zone, redox conditions and other soil characteristics such as intrinsic permeability, hydraulic conductivity, pH, organic content, and cation exchange capacity also play an influential role in the attenuation and movement of pollutants in the vadose zone.

The datasets analyzed were limited to those with land use-specific information for each result to understand the relationship between pollutant concentration and tributary land use. Other human health thresholds besides MCLs, such as the California Human Health Screening Levels or Health Protective Screening Levels from Office of Environmental Health Hazard Assessment (OEHHA)[7], could be evaluated in future investigations. Due to the nature of available datasets, the stormwater quality data used in this analysis are heavily weighted to studies conducted in southern California.

Regional land use-specific stormwater quality data from seven stormwater quality databases[8] were used in this analysis and are summarized in Table 2.

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[7] https://oehha.ca.gov/risk-assessment/california-human-health-screening-levels-chhsls

[8] Many of these databases rely on user-input and therefore some human error is expected (e.g., incorrect units or data entry errors). These errors were corrected to the extent feasible, but not all could be easily diagnosed.

Table 2. Stormwater Quality Databases Used in the Technical Analyses

Database	Years	Number of Records	Number of Locations	Source
Stormwater Multiple Application and Report Tracking System (SMARTS)[1]	2001 to 2019	561,884	11,542	https://smarts.waterboards.ca.gov
National Stormwater Quality Database (NSQD)[1] - *California only*	1977 to 2002	946	43	http://www.bmpdatabase.org
Southern California Coastal Water Research Project (SCCWRP)	2001 to 2005	66,065	32	http://www.sccwrp.org/about/research-areas/data-portal/
Santa Barbara County land use-based stormwater monitoring data	2016 to 2018	1,679	6	Data provided by Santa Barbara County
Ventura County land use-based stormwater monitoring data	1993 to 2004	9,251	3	Data provided by Ventura County
Los Angeles County land use-based stormwater monitoring data	1994 to 2001	4,889	28	Data provided by Los Angeles County
San Diego County land use-based stormwater monitoring data	2009 to 2011	13,729	30	Data provided by San Diego County

Notes:
[1]Data were downloaded in April 2019.

The following reports prepared by GSA identify the land use-pollutant combinations used for the statistical analysis and are included in Appendix D:

- The California Stormwater Quality Data Compilation and Statistical Analysis (May 30, 2019); and
- The Addendum Summary of Selected Land Use Pairs (June 12, 2019).

Available data were compiled and pollutants with MCLs were filtered from the larger datasets. All possible land use-pollutant combinations were then further filtered to only include combinations with enough data points to estimate central tendency within an acceptable margin of error (50%), degree of confidence (95%) and power (80%)[9]. Results for non-detect records were included in the analysis as equal to reported laboratory

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[9] Additional assumptions were based on the central limit theorem, which has a general rule of thumb that at least 30 datapoints are necessary to estimate the central tendency of the underlying population. The coefficient of variation (CV) of the sample data is used to estimate the actual sample size needed for the cumulative distribution function (CDF), which, in turn, was used to estimate the probability of exceeding the MCL.

detection limits. Following this method, there were 55 unique land use-pollutant combinations with enough data and MCLs to perform statistics; these combinations are listed in Table 3.

Table 3. Land Use-Pollutant Combinations with Enough Data for Statistical Analyses and MCLs for Comparison

Land Use	Potential Pollutant Risks[1]	Pollutants with Limited Risk Identified
Industrial	Total Aluminum	Gross Alpha particle activity (excluding radon and uranium), Gross Beta particle activity, 1,1,2-Trichloro, Dichloromethane, Dissolved Antimony, Total Arsenic, Dissolved Barium, Dissolved Cadmium, Fluoride, Dissolved Nickel, Nitrate + Nitrite as N, Nitrate as NO_3
Institutional	Total Aluminum	Dissolved Aluminum, Dissolved Barium, Total Barium, Nitrate as N, Nitrite as N
Residential	Di-2-ethylhexyl phthalate (DEHP), Total Lead	Total Aluminum, Dissolved Barium, Total Barium, Total Chromium, Nitrate + Nitrite as N, Nitrate as N, Nitrite as N
Transportation/ Highway	DEHP, Total Lead	Total Aluminum, Dissolved Barium, Total Barium, Total Cadmium, Dissolved Nickel, Total Nickel, Nitrite as N
Commercial	Total Lead	Dissolved Barium, Total Chromium, Total Nickel, Nitrate + Nitrite as N, Nitrate as N, Nitrite as N
Agricultural	None identified	Total Arsenic, Total Chromium, Total Nickel, Nitrate + Nitrite as N
Vacant/Open Space	None identified	Dissolved Barium, Total Barium, Dissolved Chromium, Fluoride, Nitrate + Nitrite as N, Nitrate as N

Notes:

[1]Potential Pollutant Risks are the pollutants associated with respective land use that are more likely to exceed MCLs.

Data associated with these land use-pollutant combinations were compared to applicable MCLs to determine the combinations likely to exceed the MCLs some portion of the time (e.g., 25th percentile, median, or 75th percentile concentration is above the MCL). The seven unique land use pollutant combinations that were identified as potentially likely to exceed the MCLs are shown in Table 4.

Table 4. Land use – Pollutant Combinations Identified as Potentially Likely to Exceeded MCLs

Exceedance Threshold	Pollutant	Land Use
Exceeds MCL 75% of the time	DEHP	Transportation/Highway
Exceeds MCL 50% of the time	DEHP	Residential
Exceeds MCL 25% of the time	Total Aluminum	Industrial
		Institutional
	Total Lead	Commercial
		Residential
		Transportation/Highway

Pollutants Analyzed Quantitively

DEHP. Di-2-ethylhexyl phthalate (DEHP) belongs to a family of chemicals called phthalates, which are added to some plastics to make them flexible. It has been one of the most frequently used chemicals in this class. Among the pollutants with enough data for analysis, DEHP shows the greatest probability of exceeding MCLs in raw stormwater. However, DEHP, as an organic compound itself, is also expected to be strongly adsorbed into organic matter based on the partition coefficient (European Communities, 2008). DEHP is expected to be partitioned with particles in stormwater and may be effectively removed in pretreatment systems and the vadose zone. It is also subject to microbial degradation.

Aluminum and Lead. Total aluminum and total lead were evaluated in the analysis. These measures include both particulate-bound and dissolved forms. Since particulate-bound pollutants are expected to be filtered by pretreatment media or the vadose zone (i.e., most particles are unable to pass through pore space), the remaining mass of pollutant leaving the drywell and potentially entering groundwater would be in the dissolved form. Dissolved concentrations of lead and aluminum were not preliminarily identified as potentially likely to exceed MCLs. While there was insufficient data to rigorously evaluate dissolved aluminum or lead, the results showed that concentrations of both pollutants at the 90th percentile of detected values fell below the MCL. This may warrant further investigation.

Remaining Analyzed Pollutants. There were also 48 land use-pollutant combinations with sufficient data for statistics that, when compared to MCLs, did not suggest a potential groundwater quality impact. These land use-pollutant combinations are shown in Table 3 Table 3 (pollutants with limited risk identified).

Pollutants not Analyzed Quantitatively

Fecal Indicator Bacteria. One commonly measured pollutant not included in this stormwater data risk analysis was fecal indicator bacteria (FIB). Though ubiquitously high in the environment, FIB are not always the best indicators of human health risk as there are many non-human and non-fecal FIB sources. Additional research into specific human waste DNA marker and virus levels in typical urban stormwater may be more appropriately to assess the human health risk from drywells.

Pesticides and Emerging Contaminants. Emerging contaminants are contaminants that are not commonly monitored or regulated but are suspected to have harmful effects on humans or the environment. Current measurements of emerging contaminants in stormwater broken out by land use are lacking and many pollutants did not have enough data to conduct statistical analyses. Furthermore, only a few emerging contaminants have established regulatory thresholds. Analyses conducted herein were focused on pollutants with MCLs and land use information, thus excluding many pesticides such as pyrethroids which are commonly used in residential land uses. Lack of existing data limited the extent to which the risk of these pollutants could be evaluated. As more data becomes available in the future, similar analyses on emerging contaminants is recommended.

Summary

To answer the question "which land use-pollutant combinations pose a higher risk to groundwater contamination", the analysis identified 7 of the 55 land use-pollutant combinations that could potentially be expected to exceed the MCLs some portion of the time. It is important to note that each major urban land use category was found to have at least one pollutant that had the potential to exceed an MCL. Future analysis of the California Environmental Data Exchange Network (CEDEN) database, which may include more robust and recent urban stormwater datasets with a broader suite of pollutants (although less land use-specific data), is recommended to expand the number of data points and identify other land use-pollutant combinations with a sufficient amount of data to understand if other groundwater contamination risks exist.

2.2.2 BMP Effectiveness Analysis for Pollutants Likely to Exceed MCLs

An analysis was conducted to evaluate BMP effectiveness at reducing the pollutants identified above as likely to exceed the MCLs (i.e., total aluminum, total lead, and DEHP; Table 4). Available influent and effluent data included in the International Stormwater BMP Database[10] for the identified pollutants more likely to exceed their MCLs were analyzed for a range of BMP types. This BMP performance analysis was limited to influent-effluent data pairs for which influent values exceeded the MCLs. It should be noted that BMPs are not uniform in size, geometry, and design specifications. In addition, variable climate conditions at the different BMP locations may also impact the reported influent and effluent concentrations.

For both aluminum and lead, a few BMP types analyzed demonstrated a reduction of concentrations in effluent as compared to influent. For total lead, more robust BMP types utilizing filtration through engineered media (i.e., media filters and bioretention) were found to reduce high influent concentrations consistently below MCLs (Figure 2). Grass strips, grass swales, manufactured device BMPs (e.g., proprietary media filters or treatment trains), and detention basin BMPs also demonstrated reductions in total lead concentrations when comparing influent to effluent, though effluent concentrations were below the MCLs approximately 50% of the time. Additional figures showing BMP-specific results are provided in Appendix E. For total aluminum, manufactured device BMPs (proprietary media filters or treatment trains) effectively reduced concentrations in effluent to levels below MCLs, as shown in Figure 3. All other BMPs included in the BMP Database had five or fewer associated aluminum influent measurements above the MCL and were therefore not analyzed.

There were limited DEHP data in the BMP database. BMP studies with measured influent concentrations less than the MCL were not analyzed. As reported in the BMP database, a multi-chambered treatment train BMP study located in Alabama included 12 influent-effluent data pairs. Of the 12 influent-effluent pairs, 10 reported influent concentrations

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[10] International Stormwater BMP Database, Version 2018-08-22, accessed at www.bmpdatabase.org

were below the MCL, and 11 effluent concentrations were below the detection limit associated with the laboratory analytical method. Additional DEHP studies not included in the BMP Database were also reviewed. A fate and transport study using the HYDRUS 1D model was undertaken by the City of Elk Grove (Nelson, 2017; case study example in Appendix B) to evaluate the long-term potential for pollutants to reach the groundwater table. The modeling included DEHP, among other pollutants, and results showed that measured concentrations at the drywell were insufficient to reach reportable values in groundwater over **0**the model timeframe of 500 years. Results from these limited studies along with considerations of DEHP physiochemical properties, including its high soil adsorption coefficient (European Communities, 2008), suggest that removal of this pollutant within BMP media and/or vadose zone is likely, though more data are needed to confirm this.

Figure 2. Bioretention and Media Filter Removal of Total Lead

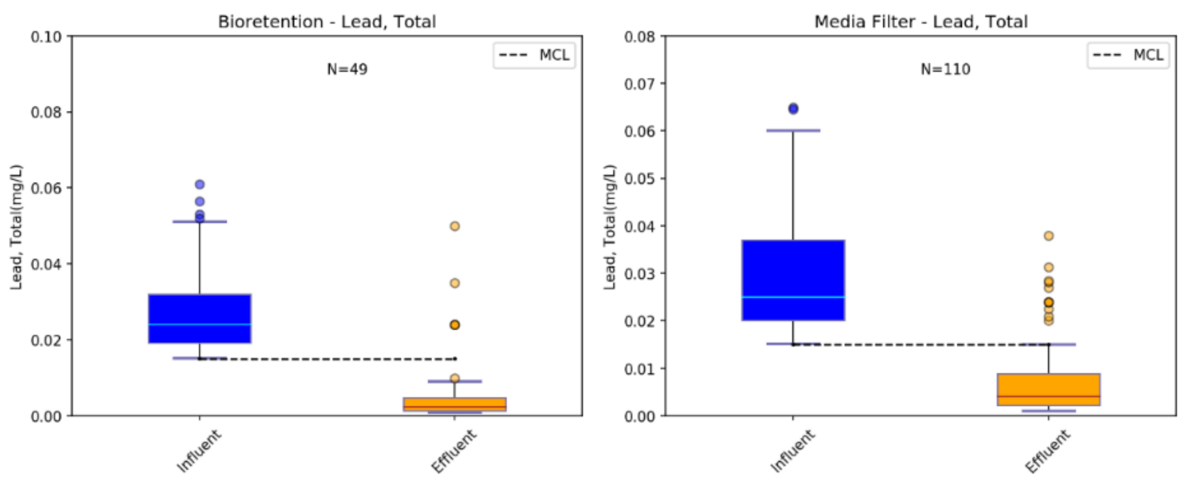
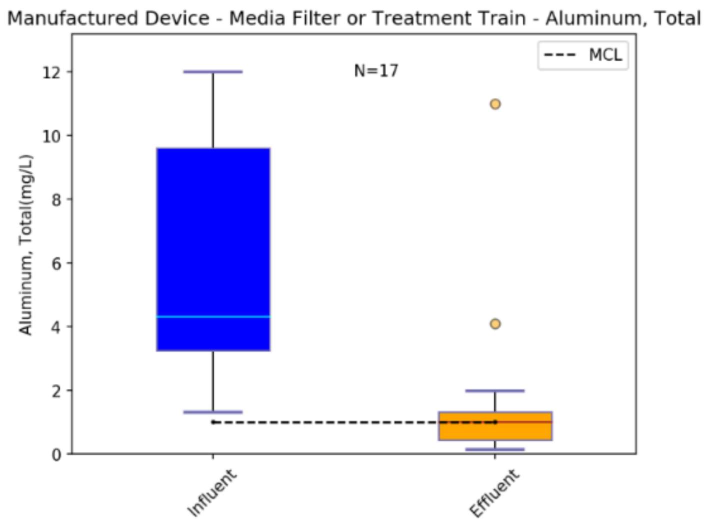
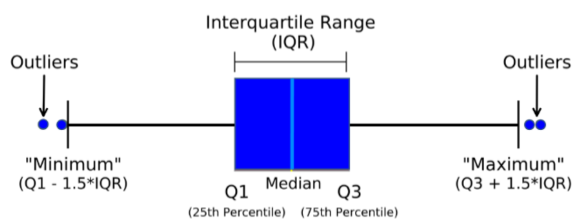


Figure 3. Media Filter or Treatment Train Removal of Total Aluminum



Legend for box and whisker plots



Summary

To answer the question "what type of pretreatment BMPs are effective at reducing the land use-pollutant combinations more likely to exceed their MCLs", most BMPs examined were effective at reducing concentrations for total metals and similar particulate-based pollutants analyzed as part of this study. Available data suggests that bioretention or engineered media filter BMPs more reliably remove lead than grass strips, grass swales, manufactured device BMPs (e.g., proprietary media filters or treatment trains), and detention basin BMPs. For total aluminum, manufactured device BMPs (proprietary media filters or treatment trains) effectively reduced concentrations in effluent to levels below MCLs but no other BMPs had sufficient data to analyze at this point in time. For DEHP, it is projected that removal within BMP media and/or the vadose zone is likely, but more research is needed to confirm.

This evaluation was limited to the parameters identified in the previous analysis and did not include emerging or other contaminants. The pretreatment recommendations developed below are intended to target conventional, particulate-bound pollutants, which may be toxic, abundant, and persistent, but likely not mobile. Additional educational and outreach efforts are provided below to minimize the impact of emerging and other contaminants that may be toxic, abundant, mobile, and persistent.

2.2.3 BMP Effectiveness Analysis for TSS

In addition to evaluating pollutants more likely to exceed their MCLs, BMP TSS concentration influent-effluent data pairs with influent concentrations greater than 100 milligrams per liter (mg/L) were analyzed to identify BMPs that could sufficiently remove TSS to below this threshold[11] to delay drywell clogging. Multiple evaluated BMPs were found to be effective at reducing TSS concentrations. TSS effluent concentrations were consistently lower than influent concentrations for multiple BMP types evaluated including bioretention, detention, grass strips, grass swales, manufactured inlet devices, and media filters. This suggests that most conventional stormwater BMPs are capable at delaying clogging to some degree when sized appropriately. Figures showing TSS removal efficiency for the BMPs evaluated are provided in Appendix E.

2.3 Summary of Research

The results of the technical analyses described above are summarized below.

- Conventional stormwater pollutants (e.g., metals, TSS, nutrients, bacteria) typically pose a low risk to groundwater contamination when infiltrated through drywells (noting that exceptions exist and are dependent on the siting and design of drywells). Two of three of the identified pollutants more likely to exceed their MCLs (e.g., total lead and total aluminum) are also associated with particulates. Comparison of influent and effluent concentrations of these pollutants show a consistent reduction in pollutant concentrations when filtered through bioretention or other engineered soil media (Section 2.2.2). DEHP is expected to be partitioned with particles in stormwater and may be effectively removed in pretreatment systems and the vadose zone; however, more data analysis is needed to confirm.
- For those conventional and priority pollutants with available data, specific land use-pollutant combinations within the urban environment do not present a high risk to groundwater contamination when runoff is treated through well-maintained pretreatment BMPs prior to entering the drywell and filters through suitable vadose zone soils upon exiting the drywell. **Specific pretreatment recommendations based on the vadose zone composition are provided in Section 3.4.**
- Emerging contaminants that are toxic, abundant, mobile, and persistent, pose a potential risk to groundwater contamination. Conventional BMPs may be generally ineffective at treating this class of pollutants given their inherent properties of being mobile, resistant to decay and/or not being affiliated with particulates. Additionally, due to limited data or data with land use information, a thorough evaluation of these contaminants was not feasible when developing

[11] This methodology was selected as a simplified approach to evaluating BMP effectiveness at delaying clogging. Other approaches may be needed to account for site specific conditions to predict clogging delay.

the recommendations presented in this report. Limited research and input from the TAC and State Water Board indicate that, when present in stormwater, these contaminants pose a potential risk to groundwater. All potential sources of emerging contaminants cannot be identified here. The consensus from TAC members was that industrial facilities, particularly those including manufacturing activities, firefighting activities, and/or storage of solvents and other chemicals, are more likely to present sources of some of these contaminants. **Based on this input, industrial facilities have been categorized as a high-risk in this report. In addition, specific requirements are included for other urban areas with potential for human waste and sewage overflows. Additional research to quantify and understand how to appropriately mitigate the groundwater contamination risk due to other emerging contaminants is still needed.**

- Based on limited research and input from the State Water Board and TAC, soluble pesticides pose a risk to groundwater contamination and are common in urban drainage areas. The Department of Pesticide Regulation (DPR) is continuing to collect stormwater data to develop appropriate regulation and/or ordinances. **As noted above, additional research to quantify and understand how to appropriately mitigate the groundwater contamination risk due to soluble pesticides is still needed.**
- Industrial facilities and heavily trafficked (>25,000 average annual daily trips) arterials and roadways pose a higher risk of spills, which could result in large volumes of contaminants entering nearby drywells. **To mitigate the risk of spills, this report recommends providing a sump[12] prior to the drywell to capture potential spills, secondary containment of chemicals at industrial facilities, or documenting that a Spill Response Plan is in place with appropriately trained personnel. An alternative voluntary measure could include an automatic shut off valve that closes when spills are detected if enough storage is provided to capture and detect the spill.**

Finally, it is acknowledged that mobilization of existing contaminants in the vadose zone could occur as a result of the increased contact with stormwater infiltration. If a site has known legacy contaminants in the vadose zone, dry wells should not be sited at these locations (see Section 3.1). In addition, naturally occurring contaminants such as arsenic could be present at potential dry well sites. Mobilization of these naturally occurring contaminants could occur as a result of the increased contact with infiltrated stormwater and potential changes in pH or chemical oxidation-reduction (redox) conditions. Redox or pH changes have been a concern for aquifer recharge since treated wastewater typically has low dissolved oxygen and high carbon, creating anaerobic environments. However, stormwater typically has high dissolved oxygen and low carbon, resulting in aerobic environments. Stormwater is not expected to alter redox conditions to the same extent as

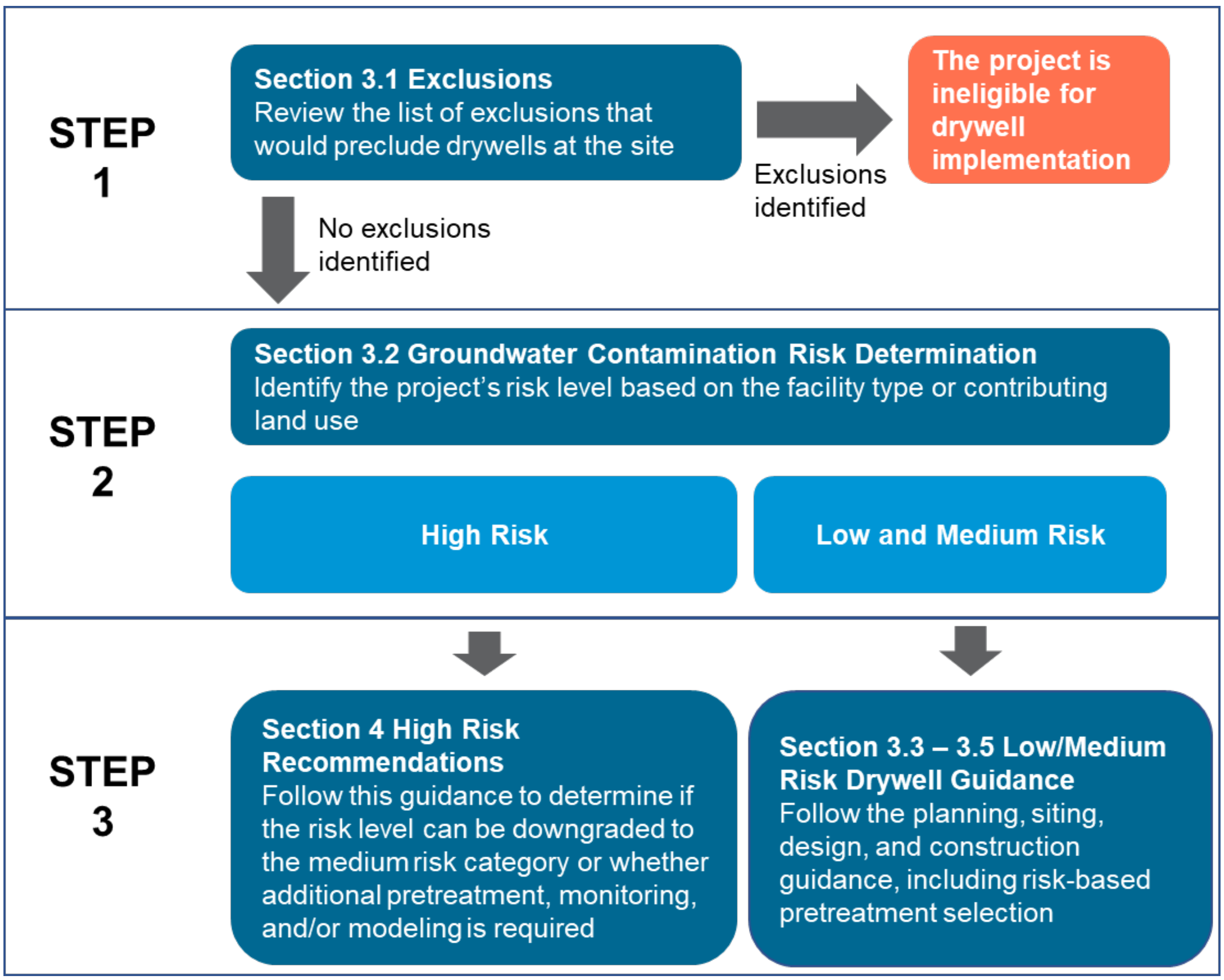
[12] A sump is any structure with a closed bottom and an elevated outlet that is designed to capture and store the full volume of a spill that is likely to occur in the upstream drainage area.

treated wastewater. **Future research on redox conditions is recommended to sufficiently protect this from occurring and the Water Boards may provide additional guidance on the feasibility and siting of drywells if remobilization of naturally occurring contaminants has the potential to exist**.

3. DRYWELL IMPLEMENTATION GUIDANCE – RISK BASED FRAMEWORK

A risk-based framework for statewide drywell guidance was developed based on the results provided in the previous sections. The framework and associated guidance provided herein are intended to be used by municipalities, private developers, and LEAs to site, design, review, construct, and maintain drywell systems in the urban environment. The framework is organized in a step-by-step manner to guide users in the drywell development process as shown in the flowchart below (Figure 4).

Figure 4. Flowchart Describing How to Use this Guidance



First review Section 3.1 Exclusions to determine if they apply to your site. There are two possible answers, "exclusions identified" and "no exclusions identified."

If "exclusions identified," then the project is ineligible for drywell implementation.

If "no exclusions identified," then review Section 3.2 Groundwater Contamination Risk Determination and identify the project's groundwater contamination risk level based on the facility type or contributing land use. There are two possible answers: "high risk" and "low and medium risk."

If "high risk," then review the requirements in Section 4 High Risk Recommendations to determine if the risk level can be downgraded to the medium risk category or whether additional pretreatment, monitoring, and/or modeling is required.

If "low and medium risk," then review the requirements in Section 3.3-3.5 Low/Medium Risk Drywell Guidance: including planning, siting, design, and construction guidance, with risk-based pretreatment selection guidance.

The recommendations provided in this section were developed with considerations of requirements and guidelines contained in the following existing drywell guidance documents:

- The American River Basin (ARB) *Stormwater Resource Plan* (SWRP) – Appendix L Drywell Fact Sheet (2018);
- Portland Stormwater Management Manual (2016);
- Oregon UIC - Permit Evaluation Report General Permit for Class V Stormwater UIC Systems (2015);
- The Los Angeles County Low Impact Design Standards Manual (2014);
- Orange County Guidelines for Permitting, Construction, and Use of Drywells in Stormwater Management Applications (2019); and
- Washington State Department of Ecology, *Guidance for UIC Wells that Manage Stormwater* (2006).

A Note on Groundwater Designation, Use, and Existing Quality: The consensus of the TAC and the State Water Board is that all groundwater basins may be potentially used for municipal water supply (public or private) and therefore are assumed to be classified with a "MUN" beneficial use category, the Water Boards' classification for "*uses of water for community, military, or individual water supply systems, including, but not limited to, drinking water supply*." Groundwater basins with a "MUN" beneficial use are subject to specific groundwater quality objectives as defined in the Water Quality Control Plan(s) (Basin Plans) for each region. Since all groundwater basins are assumed MUN beneficial uses, even where the MUN does not exist, the MCLs are the prevailing regulatory thresholds. This was the underlying assumption throughout the development of this risk-based framework and the relative risk levels are based on the likelihood to exceed the MCLs.

In addition, antidegradation policies may need to be considered under site-specific conditions. When siting drywells in specific regions, the local Regional Water Board or a local groundwater basin manager (e.g. City of Los Angeles, Orange County Water

District) may identify areas with higher quality groundwater so that drywell owners are aware that additional pretreatment may be needed for protection of these resources (such requirements would be subject to discussion with the local Regional Water Board). Additionally, for aquifers that are designated as Sole Source Aquifers by USEPA, local groundwater protection criteria may also exist.

3.1 Exclusions

During the BMP selection process or consideration of drywells for a site, it is recommended that sites with at least one the following conditions are NOT suitable for drywells:

- Sites with less than a 10-foot separation between the base of the drywell to the seasonally high groundwater table, regardless of the extent of pretreatment. This exclusion is to provide a buffer from potential mounding[13] of the groundwater table as well as possible loss of the oxidation zone that provides contaminant attenuation and reduction.
- Sites within contaminated soils or contaminated groundwater plumes.[14]
- Sites with risk of septic effluent mobilization (i.e., within 100 feet of septic tanks or fields).
- Sites within 150 feet of a drinking water well.
- Sites with slopes greater than 15% without geotechnical review. A geotechnical review should be conducted by a licensed geotechnical engineer to confirm that a drywell can be implemented without impacting slope stability or other nearby foundations or structures.

Recommended setbacks, soil and geologic characteristics are discussed in more detail in Section **0**.

3.2 Groundwater Contamination Risk Determination

After confirming that exclusions are not present, the next step is to determine the potential risk to groundwater contamination based on the land use surrounding or contributing to the project. Three risk categories (i.e., low, medium, high) for groundwater contamination potential are presented in Table 5Table 5 and are further described below:

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[13] Groundwater mounding may occur beneath stormwater management BMPs designed to infiltrate stormwater (Carleton, 2010).

[14] If a Phase I Environmental Site Assessment (ESA) has been completed and a historical recognized environmental condition (HREC) has been classified, then this site may include implementation of a drywell but is subject to the discretion of the RWQCB. Per the American Society of Testing and Materials, a HREC refers to a past spill release that has been remediated to below residential standards and given regulatory closure with no use restrictions.

- **High-Risk:** While the additional technical analysis did not find industrial land uses to present a higher risk of potential groundwater contamination for the pollutants evaluated, the general consensus from existing guidance, the TAC, and State Water Board was that these sites inherently pose a higher risk due to the higher likelihood of storing chemicals and solvents, the potential exposure of toxic, abundant, mobile, and persistent pollutants, and the higher potential for spills to occur. As a result, all industrial facilities[15] were provided a "High-Risk" classification. In addition, drywell projects with industrial facilities located in the upstream drainage area would also fall into the same "High-Risk" classification. Therefore, if a proposed drywell project is located at an industrial facility or an industrial facility is located within a proposed drywell's drainage area, the project proponent would skip to Section 4 to identify what pathways are available for implementation of a drywell. As described in Section 4 and Figure 5, there is a pathway to be downgraded to the medium-risk category if pollutants posing a higher risk to groundwater contamination are not present at the industrial facility.
- **Low-Risk:** The consensus within the existing literature and among the TAC members was that stormwater runoff from non-industrial rooftops[16] and open space (parks or other undeveloped land not impacted by pesticide application) pose a low risk to groundwater contamination. Therefore, sites draining 100% non-industrial rooftop or open space were provided a "Low-Risk" classification. If a proposed drywell project only captures runoff from non-industrial rooftops and/or open space, then the project proponent would move to Sections 3.3 – 3.5 for drywell design requirements and refer to the "Low-Risk" pretreatment design recommendations with the goal of providing clogging delay.
- **Medium-Risk:** Since the additional technical analyses and research were unable to identify land use-pollutant combinations posing a higher risk to groundwater contamination, the remaining sites (i.e., drainage areas consisting of urban[17] and agricultural land uses), were provided a "Medium-Risk" classification. The pollutant loading from these drainage areas is expected to consist of mostly particulate-bound, or highly adsorbed pollutants, that would be removed by pretreatment and possibly by the vadose zone (depending on the composition). Other pollutants, as well as risk of spills, may be applicable to these project sites. Therefore, the project

[15] Industrial facilities are defined, for this guidance, according to the Standard Industrial Classification (SIC) code requirements in the Industrial General Permit (IGP), California's General Permit for Stormwater Discharges Associated with Industrial Activities Order No. 2014-0057-DWQ (NPDES No. CAS000001). However it is recommended that the Water Boards also evaluate the Drinking Water Source Assessment and Protection Program Table 7-2 (https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/dwsapguidance/DWSAP_document.pdf) to identify other facilities that may pose a similarly high risk to groundwater contamination during subsequent guidance.

[16] Non-industrial rooftops are those that are low risk to groundwater contamination meaning they are well maintained, there is no visual staining or deposits, there is no storage or equipment other than typical HVAC equipment and the facility does not have an air quality permit.

[17] Urban land uses include any land use not categorized as open space, agricultural, or solely non-industrial rooftops.

proponent would move to Sections 3.3 – 3.5 for drywell design requirements and adhere to the "Medium-Risk" pretreatment design recommendations. Additional research to quantify and understand how to appropriately mitigate the groundwater contamination risk due to other emerging contaminants, in addition to soluble pesticides, is still needed.

The goal of this scenario is to provide clogging delay and water quality improvement, as well as education/outreach and spill control/response requirements. Education and outreach recommendations are provided for municipal drywell owners to address potential virus sources such as sanitary sewer overflows and homeless encampments in the drainage area (Section 3.4.1.2). Spill control and spill response may also be required design elements depending on the upstream land uses.

It is recommended that this framework be revised as more data are collected and other high or low risk land uses, or specific elevated-risk scenarios are identified.

Table 5. Risk-Based Framework

Risk (Potential for Groundwater Contamination)	Location or Drainage Area Land Uses	Pretreatment/Risk-specific Requirements
Low	Drainage area is entirely open space or non-industrial rooftops	Delay clogging from sediment or other particulates.
Medium	Drainage area includes all other urban land uses for projects not designated "high" or "low" risk	Delay clogging from sediment or other particulates and attenuate particulate-bound pollutants. Education outreach for viruses, as well as additional spill control measures.
High	Industrial facilities[18] or drainage areas with industrial facilities	Discuss with the Regional Water Board unless the facility has obtained a No Exposure Certification (NEC) or a pollutant source assessment demonstrates that the Section 4 Table 7 parameters are not present in industrial activities/material or exposed to precipitation at the site. See Section 4 for more information.

[18] Industrial facilities are defined, for this guidance, according to the SIC code requirements in the IGP. However, it is recommended that the Water Boards also evaluate the Drinking Water Source Assessment and Protection Program Table 7-2 (https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/dwsapguidance/DWSAP_document.pdf) to identify other facilities that may pose a similarly high risk to groundwater contamination during subsequent guidance.

3.3 Drywell Design Recommendations

The following sections summarize recommendations for planning, siting, and designing drywells.

3.3.1 Establish design criteria/metrics

Drywells (and their pretreatment) should be sized using either volume-based or flow-based methods. Design specifications will be dependent on the intent of the drywell (e.g., sized to meet post-construction permit requirements, Industrial General Permit (IGP) requirements, or water supply augmentation goals). Refer to applicable local BMP technical guidance manuals for infiltration facilities for additional sizing and design requirements.

3.3.2 Perform subsurface testing

Soil testing should be performed in the vicinity of the project site to characterize chemical and physical properties of the vadose zone. Infiltration testing should also be performed by a licensed engineer or geologist to provide results representative of the field-scale drywell conditions. Local technical guidance (e.g. BMP design manuals, geotechnical criteria manuals) may dictate minimum infiltration rates and testing procedures. These procedures may need to be adapted to account for the relatively unique geometry of drywells. A geotechnical evaluation should be performed and a professional engineer should confirm that there is sufficient infiltration capacity to meet the design flow rates and drawdown requirements. One infiltration test can be used for one or multiple drywells to be installed within a 500-foot radius, or greater if approved by a professional engineer or geologist. The soil and infiltration testing should confirm that the following requirements can be achieved.

Groundwater separation distance. Maintain at least 10 feet of separation between the bottom of the drywell and the top of the seasonally high groundwater table[19]. The depth of the seasonally high groundwater table should be determined using historical records, over approximately the last 5 years, and in coordination with a professional geologist or certified hydrogeologist. This minimum separation depth is intended to provide adequate space for hydraulic mounding, which would reduce the depth between the base of the drywell and the groundwater table.

Drawdown time. Drawdown time limits are based on vector control considerations. Drywell drawdown times[20] should not exceed 96 hours, unless superseded by more stringent requirements provided in local BMP manuals or vector control regulations. Where sump manholes are used for pretreatment and spill containment, approaches such

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[19] The seasonally high groundwater table is the highest elevation of the water table during the wettest season of the year with above average precipitation.
[20] The drawdown period is calculated as the duration of time to drain the full volume of a system when inflows are not occurring.

as bacillus thuringiensis israelensis (Bti),[21] may be needed to control vectors in the ponded water.

Soil characteristics. Soil chemical and physical properties affect the pollutant attenuation capacity of soils and should be determined as part of selecting appropriate pretreatment. Use the soil characteristics to select appropriate pretreatment in Section 3.4.

Geology. Maintain a separation distance of at least 10 feet between the bottom of the drywell and bedrock. Limiting layers, such as bedrock or fine soils, should be considered when determining the reliable infiltration rate.

Geotechnical Evaluation The geotechnical basis for the drywell design should be approved by a professional geologist, civil engineer, and/or geotechnical engineer. The geotechnical evaluation should provide infiltration rate and depths (e.g. depth of target infiltration zone), evaluation of drywell placements with respect to existing structures and foundations, potential liquefaction issues and slope stability issues.

3.3.3 Determine the number of drywells required

Hydrologic models or calculations (e.g., Rational method depending on drainage area size) can be used to estimate the design flowrate expected from the drywell's drainage area. Based on the infiltration testing results and soil characteristics, the estimated flowrate provided by the drywell can be calculated. There are many methodologies to determine the appropriate number of drywells statewide and the most relevant approach may be applied. An example provided in the ARB SWRP Drywell system design procedures is attached as Appendix F. The design flowrate, which will vary based on local BMP guidance and site-specific goals, should then be divided by the estimated drywell flowrate to determine the required number of drywells for each drainage area. More drywells may be added, with analysis of potential interference between adjacent drywells, if the intent of the drywell system is to alleviate flooding or increase aquifer recharge.

Hydrologic models can also be used to run long-term historical continuous simulations to estimate the average annual water supply benefit of installing one or multiple drywells to capture and infiltrate stormwater from each drainage area after the previous sizing is complete. The installation of drywells should not create an opportunity for hydraulic impediments to the main storm drainage system. If drywell systems clog, then flows should be able to bypass the system without affecting existing hydraulics.

Refer to local sizing and design guidance, if available. For additional detailed guidance on drywell sizing and design, as an example, refer to the ARB SWRP Drywell System Design Procedures (ARB SWRP, 2018) included herein as Appendix F.

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[21] Bti is a bacterium found in soils and whose spores produce toxins that specifically target mosquito, black fly, and fungus gnat larvae. EPA has approved 48 pesticide products that contain Bti and are approved for residential, commercial, and agricultural settings. EPA has also concluded that Bti does not pose a risk to human health.

3.3.4 Plan for Setbacks, Spacing, and Mounding Recommendations

Based on requirements and guidelines from existing drywell guidance documents listed at the beginning of Section 3, it is recommended that drywell placement observe the following setbacks, noting that deviations to these setbacks may be acceptable if approved by a licensed professional after performing site-specific evaluations:

- Drinking water wells: 150 feet.
- Building foundations: 20 feet downslope and 100 feet upslope;
- Slopes: if located upslope or located behind a slope > 15%, the minimum setback is equal to height of the slope;
- Other sources of surface water contamination[22] (e.g., auto shops, nurseries, contaminated soils, hazardous materials sites, contaminated groundwater plumes): 250 feet.

Where drywells are spaced less than 30 feet apart, and groundwater is less than 20 feet below the bottom of the drywell, overlaps in hydraulic mounding should be considered. The effects can be estimated using the Hantush (1967) method[23] or other analytical methods.

3.3.5 Additional Design Considerations

Additional detailed design requirements include the following:

- Drywell structure including frame and cover should be designed to meet appropriate structural loading (e.g., traffic) and local jurisdictional requirements for standard materials and specifications.
- Drywells should include a minimum 5 foot thick annular well seal that is placed within the upper 10 feet from the ground surface. Seal material should be approved to avoid water entering the well that is not pre-treated.

3.4 Pretreatment Selection and Design

The recommended pretreatment facilities associated with each risk classification and according to vadose zone characteristics is provided in Table 6 and are discussed below. The pretreatment technologies recommended below are intended to target particulate-bound or highly adsorbed pollutants, such as those identified in Section 2.2.2, which are

[22] Future drywell regulatory requirements should review the Drinking Water Source Assessment and Protection Program Table 7-2 for a list of other potential sources of surface water contamination to be included in this list (https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/dwsapguidance/DWSAP_document.pdf)

[23] Several online calculators are available for this estimation, including a United States Geological Survey spreadsheet available at: https://pubs.usgs.gov/sir/2010/5102/.

toxic, abundant, persistent but not mobile. Vadose zones with fine soils are expected to remove these pollutants, therefore the recommendations below for this vadose zone type are designed only to minimize clogging (i.e., not necessarily for pollutant removal). Vadose zones with sandy soils are not expected to remove these pollutants as effectively, therefore the recommendations below for this vadose zone type are intended to minimize clogging and provide removal of these particulate-based pollutants through filtration. Emerging and other contaminants that are toxic, abundant, mobile, and persistent (e.g., soluble pesticides, soluble PFAS, and viruses) are expected to pass through conventional pretreatment and vadose zones of various types. Other drywell guidance has identified these contaminants as posing a potential risk to groundwater contamination, but this risk has not been sufficiently quantified. Therefore, evaluation of additional data is recommended to quantify and identify whether additional measures are required to mitigate this potential risk and meet the federal USEPA Class V well requirement to prevent contamination of underground sources of drinking water. For areas of potentially elevated human waste (e.g., sources of viruses/pathogens), education and outreach recommendations are provided. Additional research to quantify and understand how to appropriately mitigate the groundwater contamination risk due to other emerging contaminants, in addition to soluble pesticides, is still needed.

Pretreatment recommendations include non-proprietary BMPs, as well as proprietary BMPs certified by the Technology Assessment Protocol – Ecology (TAPE) Program[24] supported by the Washington State Department of Ecology. This program was established to evaluate and approve emerging stormwater treatment BMPs and is referenced nationwide. If using a TAPE technology, only General Use Level Designation (GULD) technologies should be considered. The table and following sections outline the risk-level pretreatment recommendations. If vadose zone composition is not characterized, then the BMP recommendations corresponding to a vadose zone dominated by sand, gravel, and coarse-grained material, as defined in the table below, may be used by default.

In addition to the recommendations in the table below, pretreatment facility overflow structures should be designed to convey bypassing runoff around or away from the drywell in order to minimize clogging and promote removal of particulate-bound pollutants from runoff prior to entering the drywell.

[24] https://www.wastormwatercenter.org/tape-program

Table 6. Risk-Based Pretreatment Recommendations

Land Use-Based Contamination Risk	Vadose Zone Characteristics[1]	Pretreatment Goals	Types of BMPs Recommended	Additional Spill Control and Outreach Recommendations
Low	Any	• Manage rate of clogging[4]	• Settling vault/sump, • TAPE Pretreatment GULD[5], or • Alternative pretreatment BMP selected based on clogging considerations (Subject to LEA approval) • Device from the medium risk category	N/A
Medium	Dominated by silt or loam, high cation exchange capacity,[2] and high fractional organic carbon (>0.01).[3]	"Low risk" goals, plus: • Isolate and contain spills, and • Capture trash	• Settling vault/sump, or • Hydrodynamic separator, or • TAPE Pretreatment GULD[5], or • Alternative pretreatment BMP selected based on clogging (Subject to LEA approval)	• Conduct source control investigation and outreach for potential sources of human waste (see Section 3.4.2 below) • Closed bottom sump with elevated outlet, documentation of a spill response plan and adequately trained spill response team, or demonstration of low risk of spills in the drainage area. Alternatively include an automatic shutoff valve.
	Dominated by sand, gravel, and coarse-grained material, low cation exchange capacity[2] or low fractional organic carbon (0.01).[3]	Above "Medium risk" goals, plus: • Provide treatment of particulate-bound pollutants	• Bioretention, or • Media filter, or • TAPE Basic GULD[6] (with sump element), or • Alternative pretreatment BMP selected based on clogging and water quality considerations (Subject to LEA approval)	

Notes:
[1]These requirements apply to the "treatment zone," which is an area within the vadose zone beneath the permeable layers in the subsurface that is at least 5 feet thick and serves to sequester contaminants due to its geologic composition. This approach was used in the ARB SWRP (2018) and by the Washington State Department of Ecology (2006).
[2]Ginn, 2018 and ARB SWRP, 2018. High cation exchange capacity is estimated to be >20 milliequivalents per 100 grams dry soil and low cation exchange capacity is estimated to be <20 milliequivalents per 100 grams dry soil.
[3]Edwards, 2017 and ARB SWRP, 2018.
[4]Clogging is not a groundwater quality risk, however it affects the necessary maintenance intervals and lifecycle cost of a drywell and needs to be considered in selection of pretreatment BMPs.
[5]TAPE Pretreatment General Use Level Designation (GULD) BMPs are BMPs that meet 50% removal of TSS, when influent is between 100 and 200 mg/L.
[6]TAPE Basic GULD BMPs are BMPs that meet 80% removal of TSS when influent is between 100 and 200 mg/L.

3.4.1 Low Risk Pretreatment Recommendations

When a site is considered to have low potential risk for groundwater contamination, the primary goal of pretreatment is solids removal for clogging delay, rather than water quality, to extend the lifetime of the drywell system. Low-risk category recommended options for pretreatment include:

- A settling vault or sump; or
- A TAPE Pretreatment category device; or
- An alternative pretreatment BMP selected based on clogging considerations (subject to LEA approval), or
- A device from the medium-risk category.

3.4.2 Medium Risk Pretreatment Recommendations

Medium risk site pretreatment recommendations are divided into three categories:

- **Pretreatment technology (targeting particulate-bound pollutants):** conventional pretreatment is expected to provide solids removal and remove particulate-bound pollutants, which are expected to be present at medium-risk sites. Depending on the vadose zone's ability to attenuate particulate-bound pollutants, specific treatment technologies are recommended.
- **Education and Outreach (targeting toxic, abundant, mobile, and persistent pollutants):** Other pollutants, including pathogens or viruses, may exist in medium site drainage areas. Therefore, additional education and outreach requirements are provided to minimize the impacts from these pollutants as conventional pretreatment technologies are not expected to address this suite of pollutants.
- **Spill Control:** Depending on the upstream land uses, spill containment or response may also be required. Additional spill control requirements are therefore provided.

Medium Risk Pretreatment Technology Recommendations

For treatment zones dominated by silt or loam, high cation exchange capacity, and high fractional organic carbon, the following devices are recommended to promote solids removal (i.e., clogging risk reduction):

- Settling vault or sump; or
- Hydrodynamic separator; or
- TAPE **Pretreatment** category device; or
- Alternative pretreatment BMP selected based on clogging and water quality considerations (Subject to LEA approval).

For subsurface treatment zones dominated by sand, gravel, and coarse-grained material, low cation exchange capacity or low fractional organic carbon, the following devices are recommended to promote solids removal and water quality pretreatment (with a focus on filtration and removal of particulate-bound pollutants):

- Bioretention or media filter designed to direct treated runoff to the drywell system; or
- A TAPE **Basic** category device; or
- Alternative pretreatment BMP selected based on clogging and water quality considerations (Subject to LEA approval).

Medium Risk Education and Outreach Recommendations

Areas of potentially elevated human waste

Human waste contamination, when present in stormwater runoff infiltrated into underlying groundwater, can also pose a human health risk due to the introduction of pathogens and viruses that are harmful to humans. For medium risk sites, it is recommended that municipal drywell owners conduct the following evaluations:

- Work with local agencies responsible for homeless engagement to determine if there are permanent homeless encampments located in the proposed drywell's drainage area;
- Work with local sewer agencies to identify areas within the proposed drywell's drainage area where sanitary sewer overflows (SSOs) have historically occurred or there is an elevated risk for SSOs to occur; and
- Evaluate whether there are other major sources of human waste contamination present in the proposed drywell's drainage area.

Owners of privately-owned drywell projects should do their own self-evaluation of potential human waste contamination and follow guidelines above for municipal owners to the extent feasible.

If sources of potential human waste contamination area are identified, drywell owners should work with local agencies to mitigate any potential contaminant concerns.

Medium Risk Spill Control Recommendations

The likelihood and consequence of spills occurring in medium-risk drainage areas should be determined by the project proponent. One of the following should be provided according to this evaluation:

- Design the drywell to be preceded by a closed-bottom sump sized to capture a potential spill from the drainage area with an elevated outlet pipe to settle sediments, separate trash and floatables, and capture potential spills. An evaluation of the storage container or vehicle size and frequency should be conducted to understand the likelihood and consequence of certain spills occurring. The sump should be designed to capture a spill volume with a high likelihood of occurring. If a sump with elevated outlet is included, consider using a commercial vector control product that contains Bti to prevent mosquito breeding (consult with local vector control agencies to determine that this application is acceptable). Bti is generally approved by the Water Boards, but it is recommended to consult with local vector control agencies to identify best practices for implementation during drywell planning and design.

- Preparation or submittal of a spill control and response plan, documenting how spills within the drainage area will be reported, the response plan to mobilize staff and contain the spills, and a summary of how staff have been appropriately trained.
- Documentation that an evaluation has been performed and determined that there is a low likelihood of spills within the project's drainage area.
- An alternative voluntary measure could include a system with an automatic shut off valve or oil stop valve that closes when spills are detected if enough storage is provided upgradient of the drywell to capture and detect the spill.

3.5 Construction and Operation and Maintenance Recommendations

The following sections summarize recommendations for implementing and maintaining drywells.

3.5.1 Construction Best Practices

It is recommended that the construction and destruction of drywells meet Department of Water Resources (DWR) *Bulletin 74 California Well Standards* (Bulletin; DWR, 1991). The Bulletin defines wells as "any artificial excavation constructed by any method for the purpose of extracting water from, or injecting water into, the underground." While the Bulletin was not originally developed for drywells, it is currently in the process of being updated and should consider drywells in the update.

The following best practices for drywell construction include:

<u>Construction best practices</u>

- Provide careful oversight of excavation crew and structure installation crew so that 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.
- Conduct proper handling and disposal of excavated materials.
- Aggregate used to fill the annular space or void space shall be washed and free of fines and deleterious material.

Erosion control best practices

- Prevent contamination and clogging of the borehole during drilling by providing appropriate erosion control materials and practices.
- Drywells should not receive any runoff from the site during the construction phase.

Regulatory and procedural items

- Drilling contractors should have a C-57 license.
- Provide educational signage displayed near the drywell consistent with local BMP guidance or MS4 permit requirements.
- Register the proposed drywell(s) with the USEPA Region at: https://www.epa.gov/uic/forms/underground-injection-well-registration-pacific-southwest-region-9.
- To decommission drywell(s), obtain a permit from the applicable local agency, report to DWR, follow USEPA UIC decommissioning guidance, and update the USEPA UIC registration.

It is also important to note that drywells are considered confined space with limited entry and egress and pose a dangerous fall hazard during construction. A health and safety plan should address this issue.

3.5.2 Operations and Maintenance Recommendations

Maintenance activities for drywell systems should be based on the specific design and configuration of the system to minimize clogging in order to extend the lifetime of the drywell system, as well as to detect structural concerns, infiltration limitations, and potential water quality contamination concerns. Since drywells are considered confined space, no one should enter drywells for typical maintenance. If necessary, only trained and qualified professionals in confined space entry should enter with proper health and safety protocols in place. An O&M Plan should be developed for all drywells and include health and safety precautions.

The following O&M guidelines are recommended:

- Conduct regular street sweeping with a vacuum sweeper on all roads in the tributary drainage area to remove accumulated dirt and particulates (as feasible).
- Inspect drainage area for new pollutant source areas and/or eroding soils.
- Conduct yearly inspections of the sump, automatic shut off valve, or review of the Spill Response Plan for the site location.
- Apply Bti or other vector control approach within the sump, as needed.

- O&M for the pretreatment systems should follow the manufacturer specifications for proprietary devices and local BMP technical guidance manuals for non-proprietary BMPs.
- Include a regular schedule for checking and vacuuming accumulated trash, debris, and sediment in the sedimentation chamber and drywell. Many manufacturers of drywell systems recommend annual maintenance to check the systems and vacuum as needed. Trash accumulation may be a significant issue depending on the land uses in the drainage area. The frequency of vacuuming will vary depending on the land uses and storm frequency and intensity.
- During regular maintenance inspections, check the condition of the conveyance pipe and remove any accumulated material, as necessary.
- Keep records of all inspections, deficiencies, and corrective actions.

In addition to regular maintenance of the drywell system, additional source control practices and public outreach can help to further extend the lifetime of the drywell and prevent unwanted pollutants from entering the groundwater including:

- Contact local fire departments to inform them of the drywell location and any spill response or containment measures in place.
- Contact contractors conducting construction in the drainage area as well as their Qualified Stormwater Developers and Practitioners (QSDs and QSPs) to encourage the proper use of sediment and erosion control BMPs.
- Continue education and outreach efforts to reduce the presence of contaminants that pose a threat to groundwater quality.

Additional public education and outreach efforts to increase community awareness of drywells may include:

- Public service announcements.
- Signage within the drainage area and/or on drywell components (e.g., “NO DUMPING, DRAINS TO DRYWELL AND GROUNDWATER,” “CLOSE VALVE IN CASE OF SPILL”).
- Training of municipal staff on spill prevention and response, hazardous materials reduction, and O&M.

4. HIGH-RISK RECOMMENDATIONS

For potential drywell projects identified as having a potentially high risk of groundwater contamination, recommendations are based on the type of coverage under the IGP[25] and potential chemical storage or use at the industrial site where drywells are implemented or the industrial site in the upstream drainage area. Figure 5 provides the recommendations for high-risk sites which are described below:

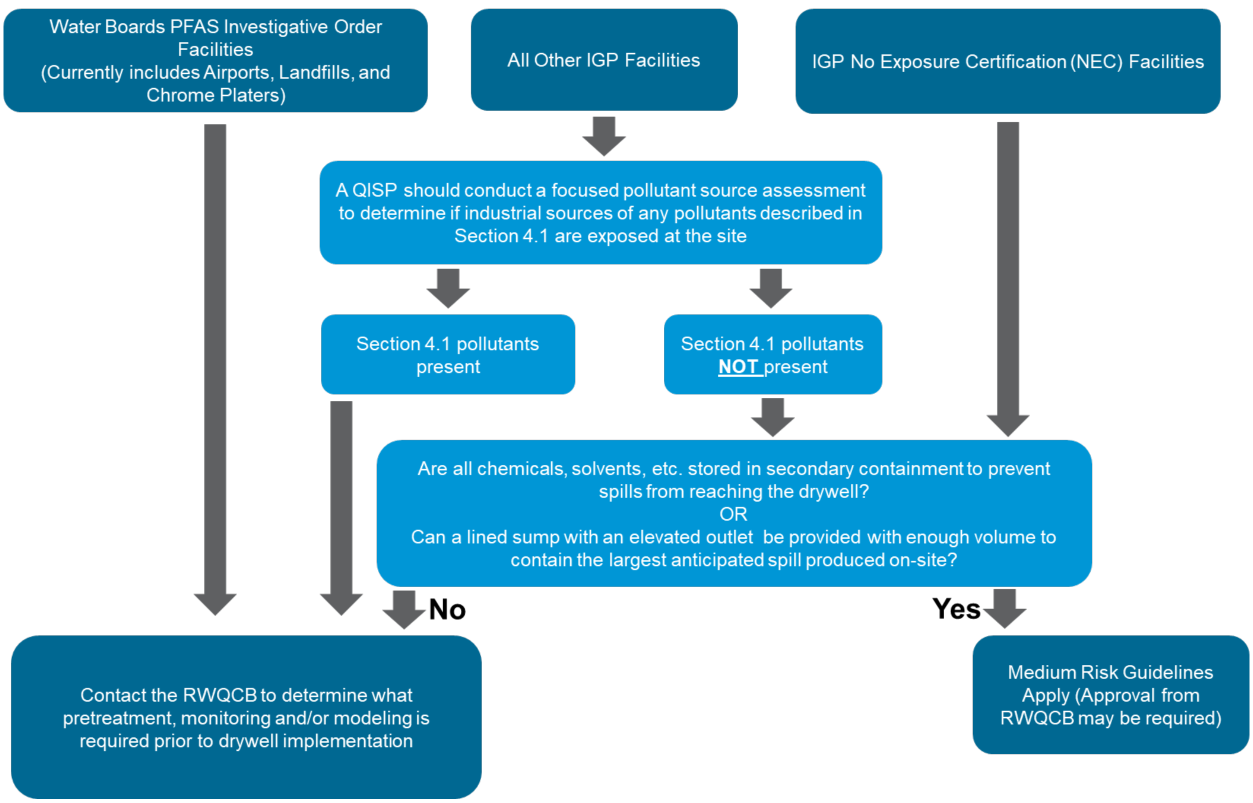
- **For State Water Board's PFAS Investigative Order facilities (e.g., airports, landfills, and chrome platers [as of November 2019]),** discuss with the Regional Water Board whether additional pretreatment, monitoring and/or modeling requirements exist prior to implementation of a drywell. (See Section 4.1 and Section 4.2 for additional monitoring and modeling recommendations.) For these high-risk sites, it is also recommended that the Regional Water Board consider potential pesticide application when determining what treatment or outreach requirements apply.
- **For industrial sites with an IGP no exposure certification (NEC)[26],** follow the medium risk guidelines and confirm that chemicals, solvents, etc. are stored within secondary containment or that a lined sump with an elevated outlet will be provided with enough volume to contain the largest anticipated spill produced on-site.
- **For all other industrial sites covered under the IGP[27],** a Qualified Industrial Stormwater Practitioner (QISP) should conduct a focused pollutant source assessment, even if the facility is in baseline, to determine if industrial sources of any pollutants described in Section 4.1 Table 7 are exposed at the site[28].
    - If the pollutant source assessment confirms that industrial sources of the pollutants listed in Table 7 are potentially exposed to precipitation, further coordination with the Regional Water Board is recommended for pretreatment, monitoring and/or modeling requirements. For these high-risk sites, it is also recommended that the Regional Water Board consider potential pesticide application when determining what treatment or outreach requirements apply.
    - If a high likelihood of uncontained/unmitigated spills are identified, provide secondary containment for all storage materials with potential to spill (e.g., chemicals, solvents, etc.) or a lined sump with an elevated

[25] California's General Permit for Stormwater Discharges Associated with Industrial Activities Order No. 2014-0057-DWQ (NPDES No. CAS000001).
[26] NEC facilities must meet the requirements of IGP section XVII confirming that all industrial activities and materials are not exposed to precipitation. Therefore, the only runoff from these facilities would be generated from non-industrial areas (e.g., rooftops without vents/stacks, administrative parking areas, etc.)
27 Includes facilities that meet the Notice of Non-Applicability (NONA) requirements.
28 If the site is located in the drywell's drainage area, coordination with the site owner or directly with the Water Boards may be required to perform this assessment.

outlet with enough volume to contain the largest anticipated spill produced on-site.

- If the pollutant source assessment does not identify pollutants listed in Table 7 and the spill control requirements are met above, Regional Water Board document the results of the evaluation in the SWPPP, and use the medium risk category guidelines. The Regional Water Board may require review and approval of the pollutant source assessment results depending on local priorities and concerns.

Figure 5. Recommendations for High-Risk Site Locations



State Water Board PFAS Investigative Order Facilities (Currently includes Airports, Landfills, and Chrome Platters) should contact the Regional Water Board to determine what pretreatment, monitoring and/or modeling is required prior to drywell implementation.

All Other IGP Facilities should have a QISP conduct a focused pollutant source assessment to determine if industrial sources of any pollutants described in Section 4.1 are exposed at the site. There are two possible answers, “Section 4.1 pollutants present” and “Section 4.1 pollutants not present.”

If “Section 4.1 pollutants present,” then contact the Regional Water Board to determine what pretreatment, monitoring and/or modeling is required prior to drywell implementation.

If “Section 4.1 pollutants not present,” then determine whether all chemicals, solvents, etc. are stored in secondary containment to prevent spills from reaching the drywell OR if a lined sump with an elevated outlet can be provided with enough volume to contain the largest anticipated spill produced on-site? There are two possible answers, “Yes” and “No.”

If “Yes,” then Medium Risk Guidelines Apply (approval from RWQCB may be required)

If “No,” then contact the Regional Water Board to determine what pretreatment, monitoring and/or modeling is required prior to drywell implementation.

IGP No Exposure Certification (NEC) Facilities need to determine whether all chemicals, solvents, etc. are stored in secondary containment to prevent spills from reaching the drywell OR if a lined sump with an elevated outlet can be provided with enough volume to contain the largest anticipated spill produced on-site? There are two possible answers, “Yes” and “No.”

If “Yes,” then Medium Risk Guidelines Apply (approval from Regional Water Board may be required)

If “No,” then contact the Regional Water Board to determine what pretreatment, monitoring and/or modeling is required prior to drywell implementation.

4.1 Monitoring Recommendations

Depending on requirements established by the Regional Water Board

, monitoring of influent stormwater entering the drywell (after pretreatment) may be recommended or required Regional Water Board. Based on the technical analysis conducted in earlier phases of this project, which examined a subset from the overall list of potential stormwater pollutants (Section 2.2.1), those that were most likely to exceed MCLs were DEHP, total aluminum, and total lead. Most conventional pretreatment facilities or fine-soil vadose zones should provide adequate treatment for solids and particulate-form metals, therefore total aluminum and total lead are not expected to pose a high risk to groundwater contamination. Additionally, DEHP is expected to be partitioned with particles in stormwater and may be effectively removed in pretreatment systems and the vadose zone; however, more data analysis is required before removing this parameter from the list below. The minimum list of pollutants suggested for monitoring (Table 7) are based on the results of the research conducted as part of this project as well as existing drywell guidelines that list pollutants with a higher risk of groundwater contamination, as well as TAC recommendations. The criteria values provided represent maximum expected levels that would reach the groundwater table after pretreatment and filtration through the vadose zone. It is recommended that the Water Boards re-evaluate this list frequently as new data are collected, including a consultation with DPR to revise the list of pesticides included.

Table 7. Minimum Pollutants Suggested for Monitoring at High-Risk Sites

Pollutant	Basis	Criteria Value
DEHP	Statistical analyses conducted as part of this project and ARB SWRP (2018).	4 µg/L[a]
Chrysene	ARB SWRP (2018)	0.6 µg/L[b]
Bifenthrin	Nelson, et al. (2017)	0.64 µg/L[c]
Fipronil	Nelson, et al. (2017)	1.0 µg/L[c]
Imidacloprid	California Stormwater Quality Association Pesticides Subcommittee	360 µg/L[c]
Chloride	TAC Recommendation	250 mg/L[d]
Total Dissolved Solids	TAC Recommendation	500 mg/L[d]
Emerging contaminants that are toxic, abundant, mobile, and persistent	These contaminants are less studied and therefore additional research and data collection is needed to quantify their potential risk. The Regional Water Board may require analyzing for these parameters depending on site-specific concerns and guidance available.	To be established

Notes:
[a]Primary MCL
[b]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 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 (ARB SWRP, 2018).
[c]Human Health Benchmark for Pesticides (HHBP) chronic value. The criteria for bifenthrin was adjusted from an acute value following the ARB SWRP 2018. Information on HHBP can be found at: https://iaspub.epa.gov/apex/pesticides/f?p=HHBP:home.
[d]Secondary MCL.

In addition, some PFAS compounds are also recommended to be monitored at airports, landfills, treatment plants, firefighting training facilities, chrome platers, and manufacturers of fluorinated compounds. At a minimum, the PFAS that should be considered include:

- Perfluorooctane sulfonic acid (PFOS), and
- Perfluorooctanoic acid (PFOA).

It is recommended that the Regional Water Board regularly review the list of PFAS chemicals with screening levels, public health goals, or drinking water standards being developed by the Water Boards, OEHHA, and other agencies throughout the state to determine the final list of PFAS compounds required for assessment here.

Other emerging contaminants that may pose a groundwater contamination risk but where existing data are limited include PPCPs, ARGs, and Viruses.

As new data are collected, if these contaminants are found to pose a contamination risk from stormwater infiltration, then these additional pollutants should be added to the list above for specific areas.

The minimum recommended monitoring frequency is during or directly after a first flush event and three additional wet weather events within a calendar year (additional time may be included to collect the required number of events if enough rainfall does not occur). Additional pollutants and sampling events may be required by the Regional Water Board depending on activities in the drainage area. After the required events are sampled and all concentrations are below the recommended criteria, the proposed drywell project could move forward as a "Medium-Risk" project. If concentrations are not all below the recommended criteria, then it is recommended that the project proponent work with the Regional Water Board to mitigate potential contamination for the exceeding pollutants. This may include, but is not limited to, source controls to abate the source or robust pretreatment (e.g., amended media filtration or active treatment).

4.2 Modeling Recommendations

Modeling may be considered in specific circumstances to protect groundwater quality. For example, if pretreatment is not practicable, modeling could potentially be conducted in place of monitoring to trace the transport of the pollutant in the vadose zone and estimate the concentration of the pollutant at the water table. If there are unique pollutants of concern related to operations within the drainage area and/or no standard criteria are available, modeling may be useful to predict pollutant concentrations in the subsurface, with monitoring suggested to verify. In addition, hydraulic parameters and contaminant transport parameters should be based on measurements from the site to the extent feasible. Ultimately, the Regional Water Board will have jurisdiction to require and approve modeling demonstrations of groundwater quality protectiveness.

The complexity of the model (e.g., one-dimensional or two-dimensional, a single homogeneous soil column or a soil profile with varying soil types) and model selection will be dictated by the purpose and questions to be addressed, as well as the resources available. Developing scenario-specific modeling recommendations is outside the scope of this report; however, a groundwater fate model that has been used with reasonable success is the Seasonal Soil compartment model (SESOIL). Additionally, a description of other applicable modeling options from the ARB SWRP is provided in Appendix G.

5. SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the original research conducted during the development of these recommendations, drywells are generally found to pose a low threat to groundwater contamination with proper siting and design for traditionallystudied urban stormwater pollutants. The following additional research needs were identified for the development of future regulatory guidance and are described further in the Needs and Gaps Memo (Appendix C).

- **Pollutant groundwater contamination risk studies.** Land use-pollutant risk analyses conducted as part of this project (Section 2.2.1) could be further expanded by incorporating data from CEDEN. As more data become available, future studies should include water soluble pesticides. Statewide pesticides datasets from the California Department of Pesticide Regulation should be analyzed and compared with the latest health and human thresholds to identify other specific chemicals of concern. This would also include assessing the cumulative groundwater risk of large-scale implementation of drywells.
- **Vadose zone pollutant attenuation studies**. Research is needed to identify a method for determining site-specific vadose zone pollutant attenuation throughout California for sites classified as having potential groundwater risk. This could include fate and transport modeling to evaluate maximum infiltration rates that should be prescribed to allow for sufficient pollutant attenuation in the vadose zone.
- **Pretreatment guidance**. As described in Sections 2.2.2 and 2.2.3, a BMP effectiveness study for pollutants more likely to exceed their MCLs and TSS removal was initiated as part of this project. As more data become available, additional research is recommended to assess whether typical pretreatment may be able to remove pollutants posing a higher risk to groundwater contamination (e.g., DEHP, soluble pesticides, PFAS).
- **Infiltration Testing Guidance**. An assessment is needed to compare measured or estimated versus actual infiltration capacity of drywells to determine the infiltration testing methods that are most reliable, and what factor of safety is needed to develop reliable capacity estimates from testing data. In addition, infiltration testing may also be used to test the effectiveness of the drywells over time as they clog.
- **Long-term Groundwater Contamination Studies**. An assessment of the long-term groundwater contamination potential of stormwater infiltration through drywells is needed, which could include monitoring drywell field studies in different regions of the state with varying site and geologic conditions.

- **Drywell Lifecycle Research**. Additional research and discussion with cities and counties are needed to establish an understanding of drywell lifecycles and reasons for failure through anecdotal evidence.
- **Mobilization of existing contaminants in the vadose zone.** Future research on potential changes in pH or redox conditions is recommended to sufficiently protect this from occurring as a result of increased soil contact with infiltrating stormwater.
- **Emerging Contaminants Stormwater Data Collection**. Stormwater infiltration studies or additional laboratory research is needed to evaluate the transport of emerging contaminants such as some PFASs, ARGs, current use pesticides, and viruses to understand the associated groundwater contamination risks. There are unknown risks from these contaminants including pesticides and PFAS that need to be investigated prior to establishing final guidance to mitigate these risks. In addition, this research should include evaluating other emerging contaminants data as they are collected in the future to continue identifying high-risk sites and scenarios.

It is recommended that these research needs be addressed to better understand whether other high-risk scenarios exist and how to mitigate them. As many of these research needs depend on additional data, additional field monitoring is also recommended. As more data become available, the framework and risk categorizations may be updated to reflect the most current understanding of groundwater quality risk from infiltrating stormwater through drywells.

6. LIMITATIONS

The information presented in this report rely on published guidance documents, stormwater drywell literature (available in 2019), and information shared by the TAC. Recommendations presented herein were developed under the direction of the State Water Board during the development of this report.

This report satisfies the requirements of Contract 17-083-250 between Geosyntec and the State Water Board, which focused on the researching of available data and identification of data gaps. It is understood that the additional analyses identified in this effort are beyond the project scope. Data analyses were based on publicly available datasets with land use-specific stormwater and applicable MCLs. Due to limited data availability, many land use-pollutant combinations could not be evaluated to make statistical conclusions with respect to their potential groundwater contamination risk. In addition, these datasets did not include emerging and other contaminants that are toxic, abundant, mobile, and persistent, such as some PFASs, soluble pesticides, and viruses. Additional data analysis and research are needed to identify other land use-pollutant combinations that pose a high risk to groundwater contamination using larger datasets (e.g., CEDEN) and to better understand the abundance and transport of emerging and other contaminants to further define and characterize the sources and magnitudes of risks to groundwater contamination.

Currently available data do not support an assessment of the ability of conventional pretreatment stormwater BMPs to address the aforementioned emerging and other mobile contaminants; therefore, this evaluation was not included in the project scope. As such, the approach described in this report focuses on pretreatment recommendations for toxic, abundant, and persistent pollutants, that are not highly mobile. The report also suggests some education and outreach to reduce the potential impacts from toxic, abundant, persistent, and mobile pollutants if they are present in the drainage area. However, more research is required to quantify and understand how to appropriately mitigate this potential risk.

The high-risk site locations in this report are limited to industrial facilities since the general consensus from the TAC was that these facilities inherently pose a higher risk due to the storage of chemicals and solvents, the potential exposure of sources of toxic, abundant, persistent, and mobile pollutants, and potential for spills to occur. A specific emphasis was placed on PFAS investigative order facilities due to the recent heightened concern of PFAS impacts to surface water and groundwater. However, there may be other contaminants present at these facilities and/or other types of facilities that pose additional risks but are currently unknown or not adequately studied. It is recommended that these guidelines be revised as additional data are collected and analyzed to continue to identify those scenarios that pose a higher risk to groundwater contamination.

Finally, these recommendations do not supersede any local authority and are intended to provide general guidance; site-specific concerns or limitations should be evaluated at the local level. In addition, while this report has been developed to be used as guidance for the implementation of drywells, it does not represent specific policy or regulatory recommendations to be used when establishing a permitting framework for drywell implementation throughout California.

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United States Environmental Protection Agency, 2008. Clarification on which stormwater infiltration practices/technologies have the potential to be regulated as "Class V" well by the Underground Injection Control Program Memorandum. June 13. https://www.epa.gov/sites/production/files/2015-10/documents/epamemoinfiltrationclassvwells.pdf

Washington State Department of Ecology. 2006. *Guidance for UIC Wells that Manage Stormwater*. Publication Number 05-10-067.

APPENDIX A
TAC Survey Results

APPENDIX B
Example Drywell Case Studies

California Drywell Case Studies

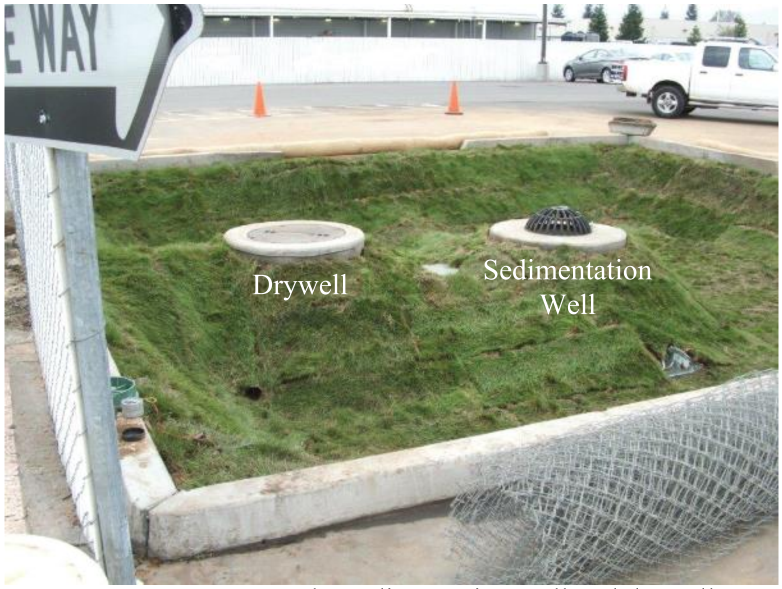
This Appendix includes highlights from two example drywell case studies in California that TAC members were recently involved in. Barbara Washburn, OEHHA and Maureen Kerner, Sacramento State - Office of Water Programs, were involved in the City of Elk Grove Dry Well Project outside of Sacramento. This project was conducted over a four-year period and included monitoring and modeling of two drywell systems in contrasting urban environments. Wing Tam, Los Angeles Sanitation and Environment (LASAN), recently completed a drywell project in a northern Los Angeles residential neighborhood that included the installation of over 20 drywell systems. The project is a case study of a typical medium-risk scenario project. LASAN has installed other drywell projects and is planning to use drywells to provide additional water supply and water quality benefits to the city of Los Angeles through additional installations in the coming years.

City of Elk Grove Dry Well Project

The Elk Grove drywell project in northern California, south of Sacramento, was designed with three major goals: (a) to assess the potential of groundwater contamination associated with infiltrating stormwater through drywells; (b) to assess the effectiveness of typical pretreatment features paired with drywells; and (c) to conduct an educational and outreach effort. The study was conducted between January 1, 2013 and April 1, 2017. To achieve the goals of the study, drywell systems were installed at two locations: (a) the Strawberry Creek water quality basin, which collects runoff from a 168-acre residential neighborhood; and (b) the Elk Grove Corporation Yard, which contains bus parking and service center with a 0.6-acre drainage area. Each drywell system was constructed with two pretreatment components, a vegetated pretreatment swale, and a sedimentation well to trap sediment and associated pollutants (Figure B-1**Error! Not a valid bookmark self-reference.**). Each drywell was approximately 40 feet deep.

Monitoring and modeling were conducted as a part of the study. A groundwater monitoring network was established at each site location and consisted of one upgradient well, one in the vadose zone, and two downgradient wells. Groundwater baseline measurements were taken prior to drywell construction. In a two-year period, monitoring of over 200 pollutants in stormwater and groundwater was performed on five occasions. Stormwater runoff was measured after pretreatment and before entering the drywell and in all subsurface monitoring wells. Fate and transport modeling, using HYDRUS 1D, was also conducted to evaluate the long-term potential for contaminants to reach the water table.

Figure B-1: Constructed Drywell System at the City of Elk Grove's Corporation Yard



Pretreatment grass swale, sedimentation well and drywell at
the City of Elk Grove Corporation Yard site.

The results of the monitoring demonstrated that few of the more than 200 pollutants that were analyzed were detected in stormwater or groundwater. Volatile and semi-volatile compounds were rarely detected above laboratory detection limits and PAHs were never detected in water. The class of contaminants that were consistently detected in stormwater were metals and pyrethroid pesticides (e.g., bifenthrin). At the Corporation Yard, where aluminum was detected in groundwater, concentrations were not significantly different in upgradient wells compared to downgradient wells. Fate and transport modeling suggested that measurable concentrations of most metals and hydrophobic pesticides would not reach the water table within the modeling timeframe of 3,000 years. However, water soluble pesticides, such as imidacloprid, could pass quickly through the vadose zone. Results of pollutant monitoring and the fate and transport modeling for the case study are shown in Table B-1Figure B-2.

Table B-1: City of Elk Grove Case Study Pollutant Monitoring and Fate and Transport Modeling Results

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

φ = input concentration is insufficient to reach the reportable values.

With respect to pretreatment effectiveness, the vegetated swale pretreatment showed a 50 to 65% reduction in TSS. The sedimentation wells were not constructed sufficiently deep and, in turn, did not function properly for TSS removal. The City of Elk Grove Drywell Project concluded that "*data collected at the two project sites in Elk Grove combined with modeling results did not provide evidence that groundwater quality would be degraded by the use of drywells. Practices in other states and conclusions reached by U.S. Environmental Protection Agency (USEPA) 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.*"

The Corporation Yard drywell was decommissioned due to concerns about "heavy metals and motor oil" with the following lessons learned: "difficult to maintain grass; sedimentation well not functional; high concentration of metals; elevated risk for spill; and most states do not permit UICs at vehicle service sites" (City of Elk Grove, 2017).

LASAN Van Nuys Green Streets Drywell Case Study

LASAN has implemented multiple drywells through various projects over the last few years, including the Van Nuys Green Streets Project which was completed in Spring 2019 and included the installation of 21 drywells in an urban, primarily residential, neighborhood in Los Angeles (Figure B-2).

Figure B-2: LASAN Van Nuys Green Streets Drywell Project – Drainage Areas and Drywell Locations

The goals of the Van Nuys Green Streets Project was to implement green stormwater infrastructure to provide groundwater recharge, improve water quality, and increase the greening and community value of the local project area. The project boundary is shown in Figure B-2; the total drainage area available for capture by the drywells is approximately 100 acres. Bioretention planters were used as pretreatment for 9 of the 21 drywells and permeable pavement was used as pretreatment for 12 of the 21 drywells, which are both consistent with the recommendations described for the medium risk category of this report (Note that permeable pavement would require LEA approval to demonstrate equivalent pretreatment benefit). The estimated average annual stormwater capture volume was 86% (58 acre-feet) of the total average annual runoff volume. Construction photos of the drywells, bioretention planters, and permeable pavement pretreatment BMPs are shown in Figure B-3. LASAN worked with Geosyntec and Torrent Resources during the planning and design phase to review available boring logs and infiltration testing results from nearby drywell projects. This review of available geologic and infiltration data helped streamline the geotechnical evaluation and infiltration testing for the project. Therefore, one of the lessons learned from the project was to use nearby boring logs from previous drywell studies to inform and reduce the infiltration testing burden for new projects in the same area. The subsurface soil type was a gravelly sandy loam and field measured infiltration rates, conservatively estimated at 0.15 cubic feet per second, were used to determine the minimum number of drywells required to capture and infiltrate the 85th-percentile, 24-hour storm event ("design storm"). The pretreatment provided according to the subsurface soil type meets the medium risk pretreatment recommendations outlined in this report.

Figure B-3: Construction Photos from the LASAN Van Nuys Green Streets Drywell Project

Bioretention Planter

Permeable Pavement

Drilling of Drywell Shaft

Top of Drywell

APPENDIX C

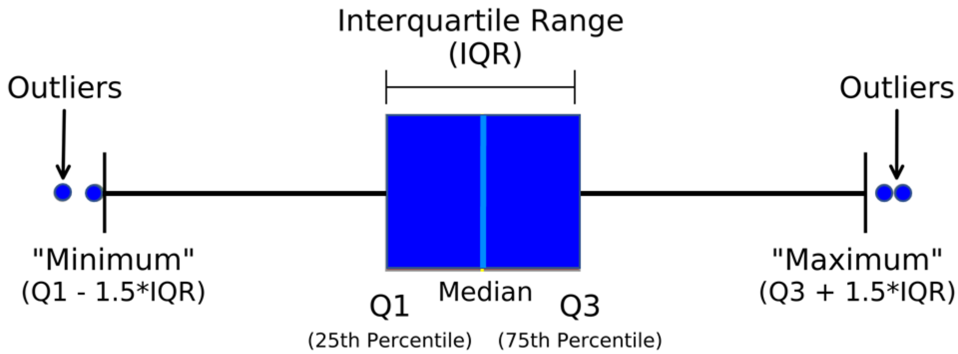
Draft Drywell Standards Research Needs and Gaps Memorandum, prepared by Geosyntec Consultants

APPENDIX D
California Stormwater Quality Data Compilation and Statistical Analysis

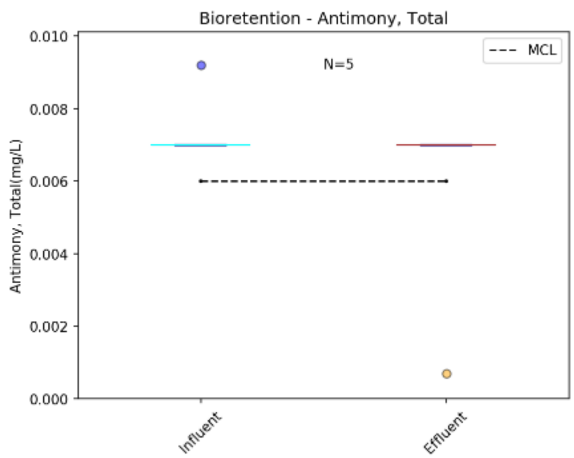
APPENDIX E
BMP Effectiveness Results for Pollutants Likely to Exceed MCLs

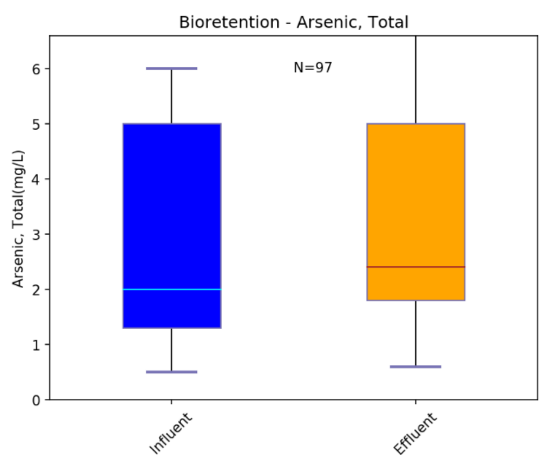
Additional BMP performance data for other pollutants identified in the land use-pollutant combination analysis (Section 2.2.2)

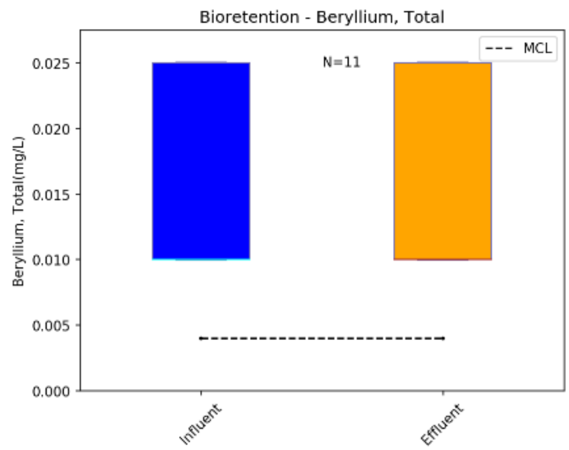
Legend for all plots

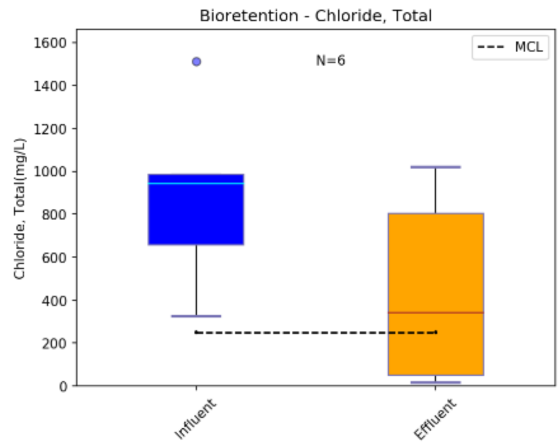


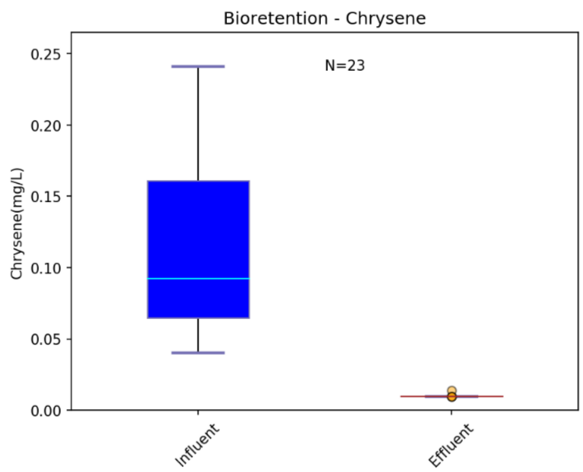
Bioretention

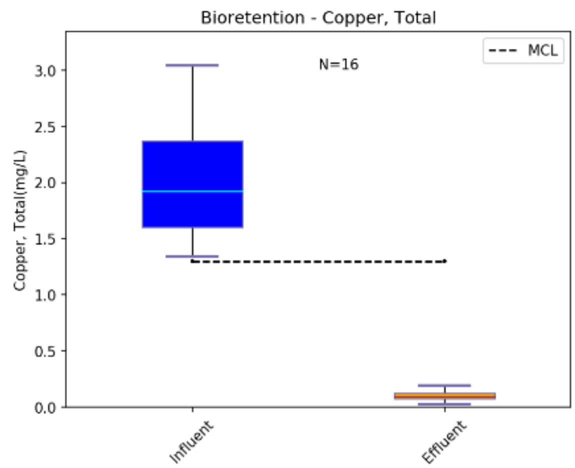


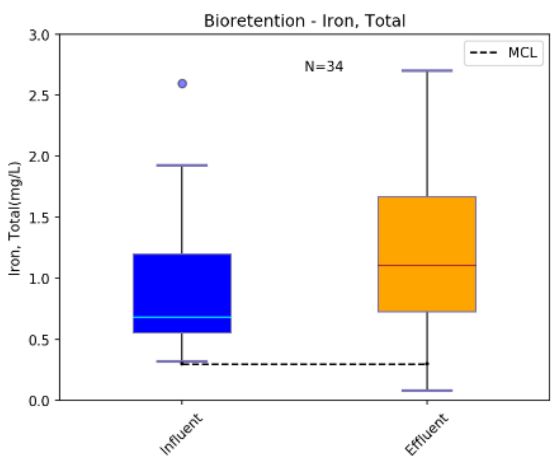


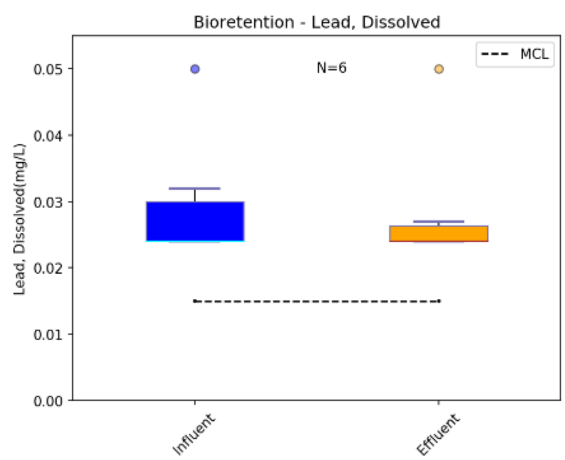

Bioretention - Beryllium, Total
N=11
MCL
Beryllium, Total(mg/L)
0.000
0.005
0.010
0.015
0.020
0.025
Influent
Effluent

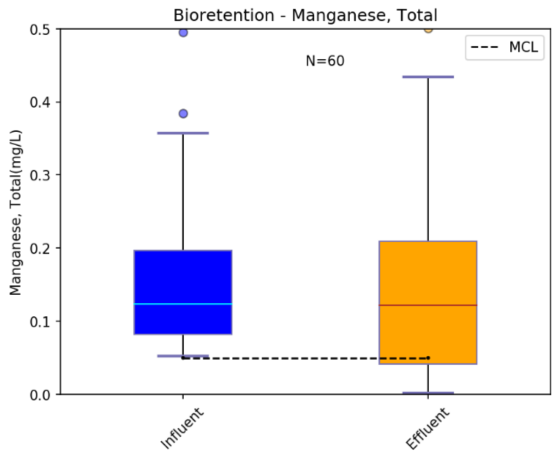

Bioretention - Chloride, Total
N=6
MCL
Chloride, Total(mg/L)
0
200
400
600
800
1000
1200
1400
1600
Influent
Effluent

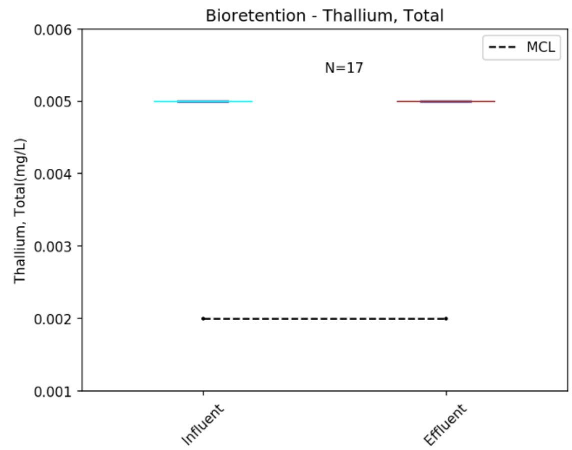

Bioretention - Chrysene
N=23
Chrysene(mg/L)
0.00
0.05
0.10
0.15
0.20
0.25
Influent
Effluent

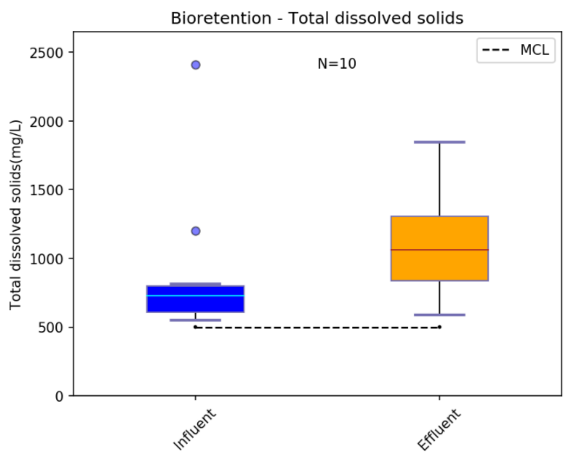

Bioretention - Copper, Total
N=16
MCL
Copper, Total(mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Influent
Effluent

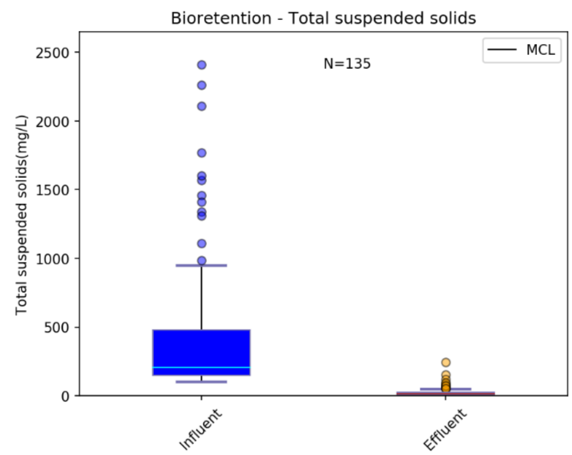

Bioretention - Iron, Total
N=34
MCL
Iron, Total(mg/L)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Influent
Effluent

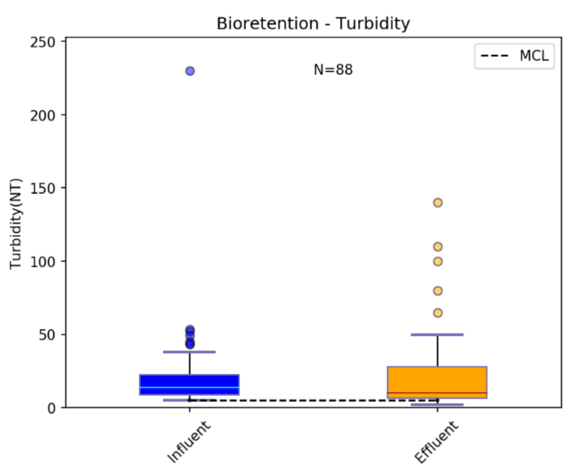

Bioretention - Lead, Dissolved
N=6
MCL
Lead, Dissolved(mg/L)
0.00
0.01
0.02
0.03
0.04
0.05
Influent
Effluent


Bioretention - Manganese, Total
Manganese, Total(mg/L)
0.0
0.1
0.2
0.3
0.4
0.5
N=60
MCL
Influent
Effluent

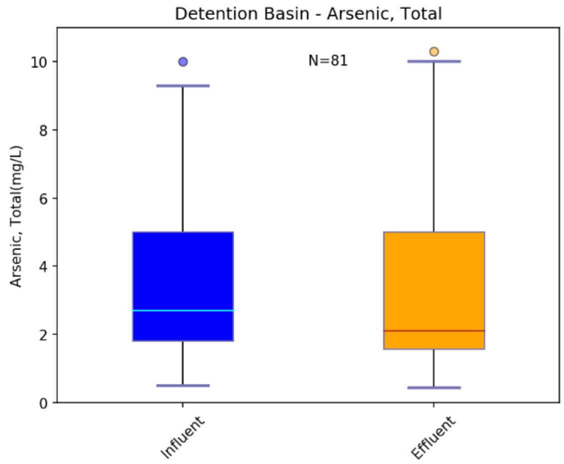

Bioretention - Thallium, Total
Thallium, Total(mg/L)
0.001
0.002
0.003
0.004
0.005
0.006
N=17
MCL
Influent
Effluent

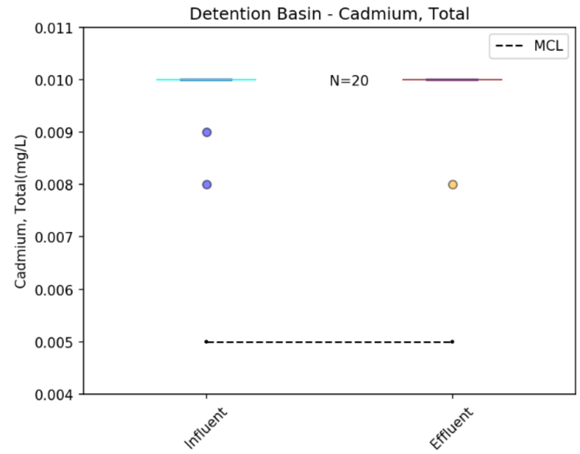

Bioretention - Total dissolved solids
Total dissolved solids(mg/L)
0
500
1000
1500
2000
2500
N=10
MCL
Influent
Effluent

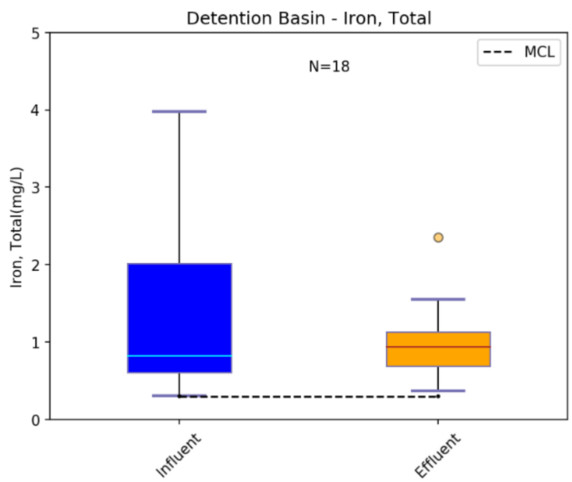

Bioretention - Total suspended solids
Total suspended solids(mg/L)
0
500
1000
1500
2000
2500
N=135
MCL
Influent
Effluent

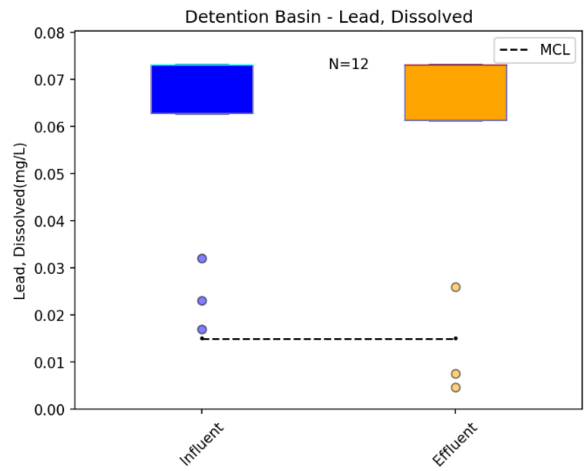

Bioretention - Turbidity
Turbidity(NT)
0
50
100
150
200
250
N=88
MCL
Influent
Effluent

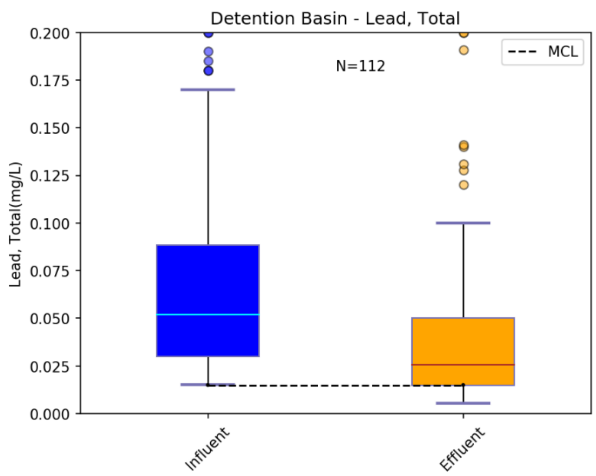
Detention Basin

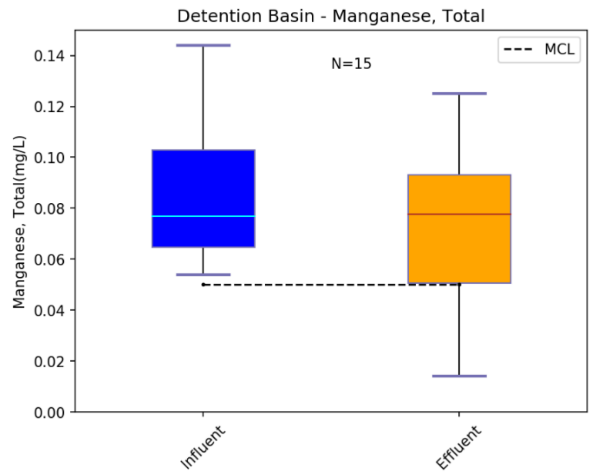


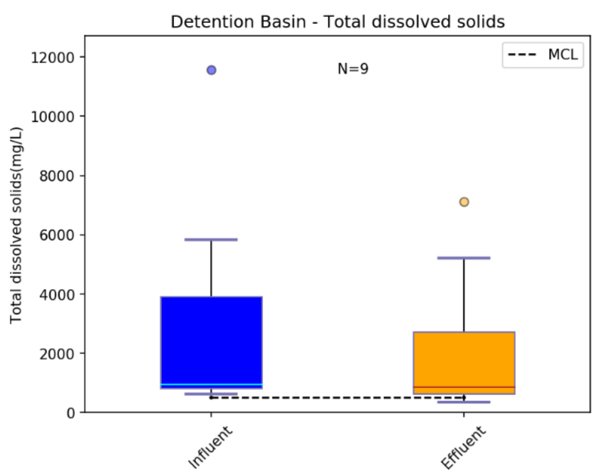


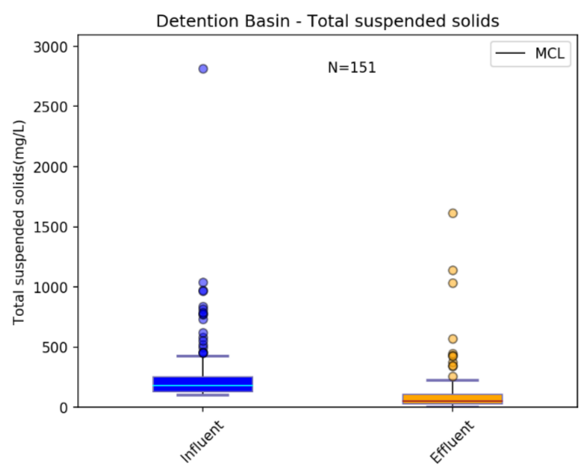


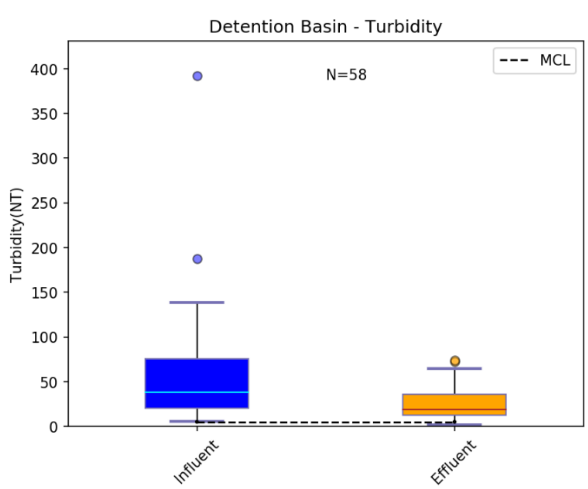



Detention Basin - Lead, Total
N=112
MCL
Lead, Total(mg/L)
Influent
Effluent

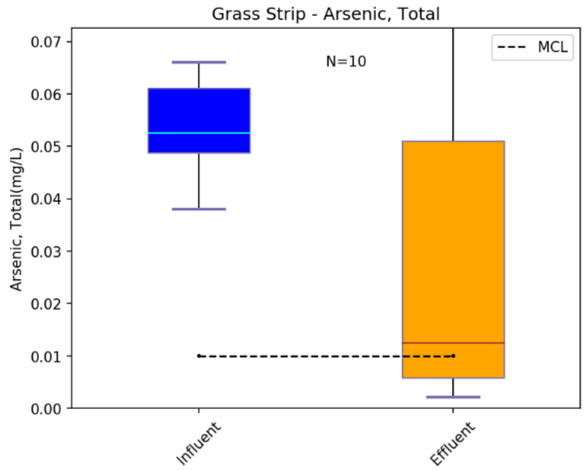

Detention Basin - Manganese, Total
N=15
MCL
Manganese, Total(mg/L)
Influent
Effluent


Detention Basin - Total dissolved solids
N=9
MCL
Total dissolved solids(mg/L)
Influent
Effluent


Detention Basin - Total suspended solids
N=151
MCL
Total suspended solids(mg/L)
Influent
Effluent


Detention Basin - Turbidity
N=58
MCL
Turbidity(NT)
Influent
Effluent

Grass Strip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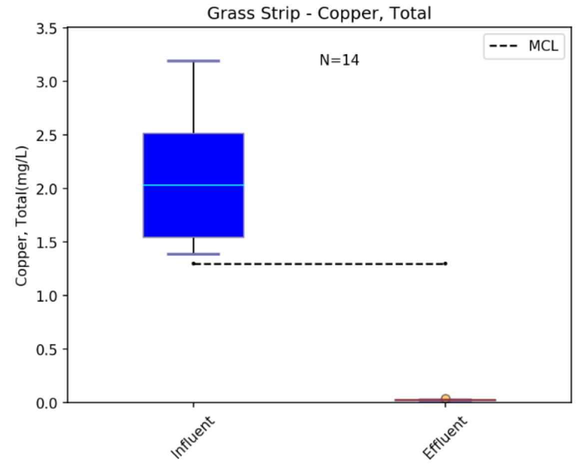
Arsenic, Total(mg/L)
N=10
MCL
Influent
Effluent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Copper, Total(mg/L)
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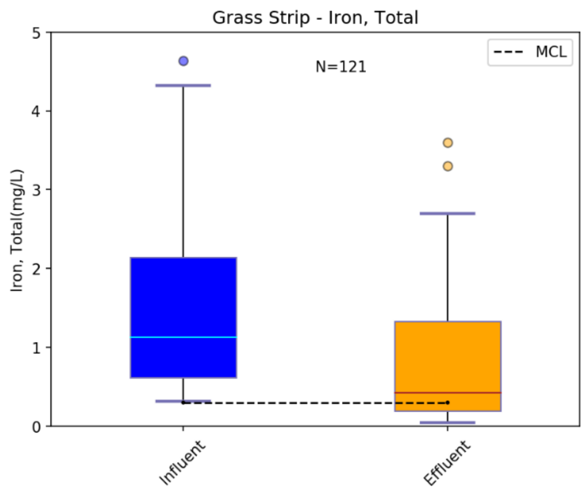
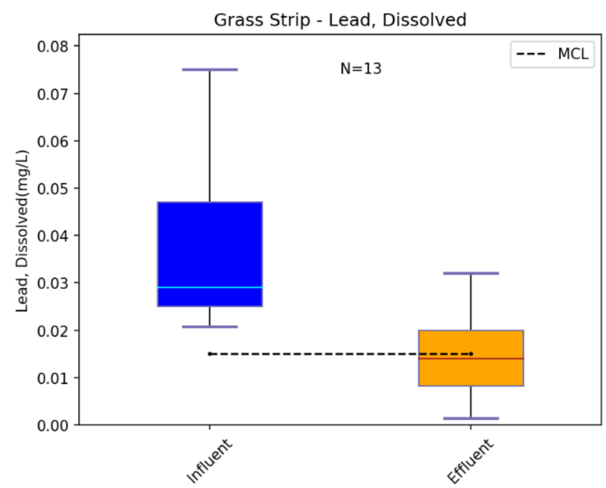
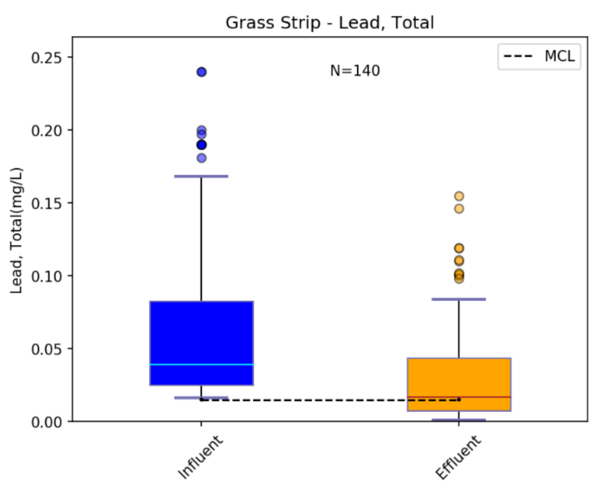
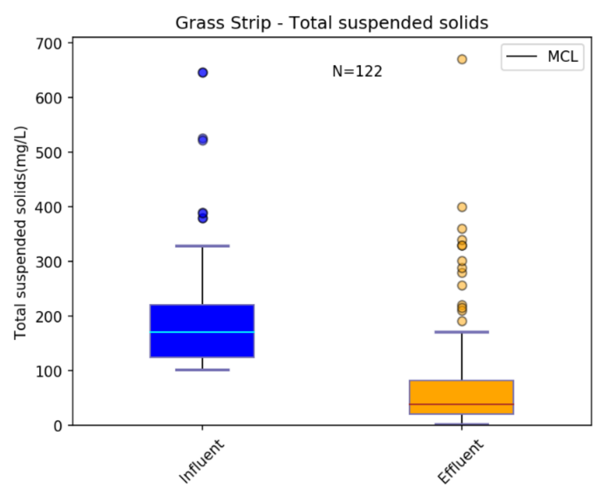
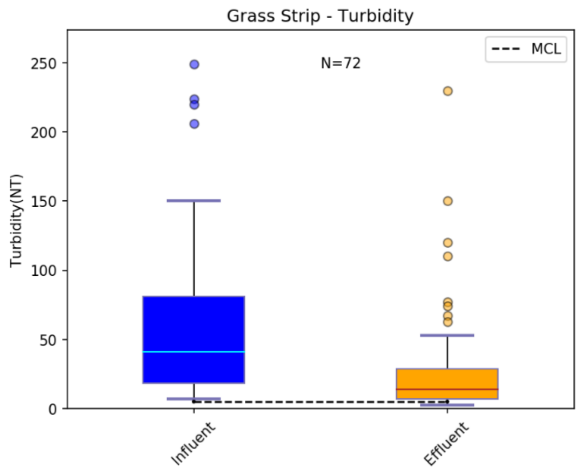
MCL
Influent
Effluent


Grass Strip - Iron, Total
Iron, Total(mg/L)
N=121
MCL
Influent
Effluent

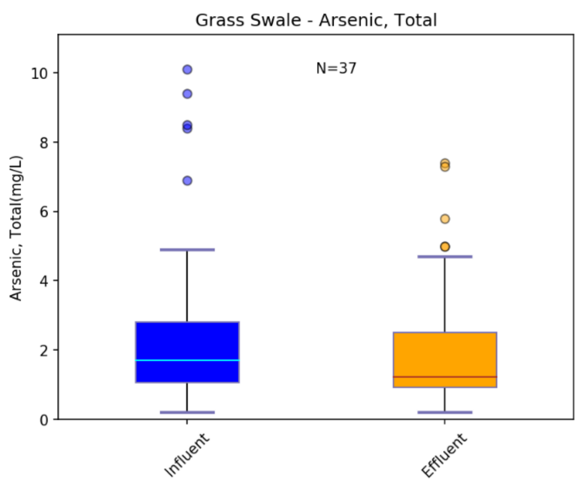

Grass Strip - Lead, Dissolved
Lead, Dissolved(mg/L)
N=13
MCL
Influent
Effluent

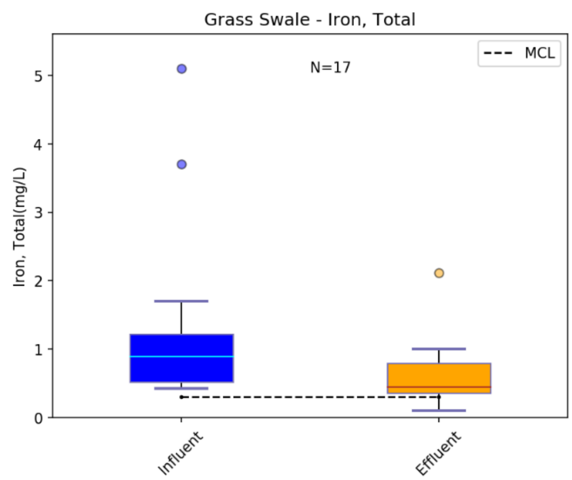

Grass Strip - Lead, Total
Lead, Total(mg/L)
N=140
MCL
Influent
Effluent

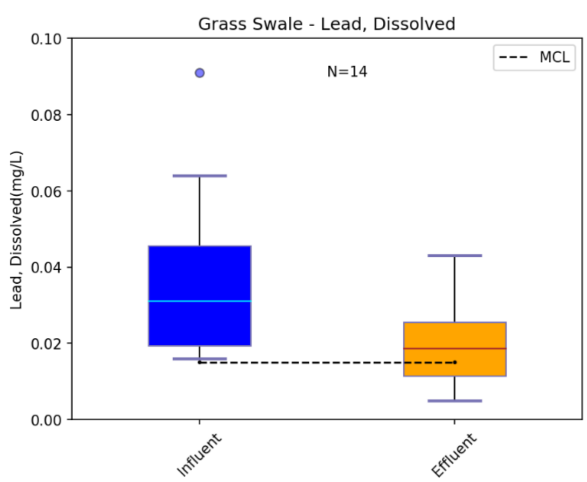

Grass Strip - Total suspended solids
Total suspended solids(mg/L)
N=122
MCL
Influent
Effluent

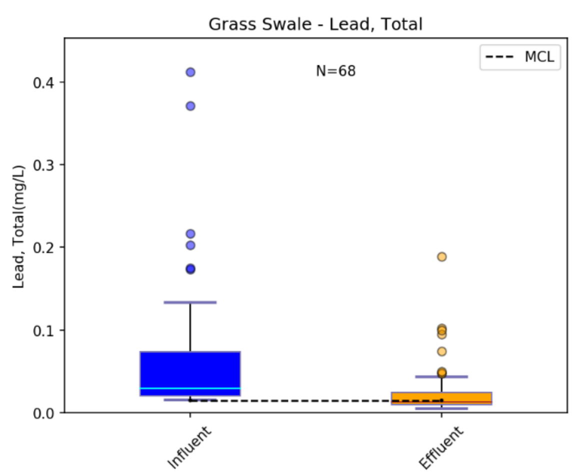

Grass Strip - Turbidity
MCL
N=72
Turbidity(NT)
Influent
Effluent

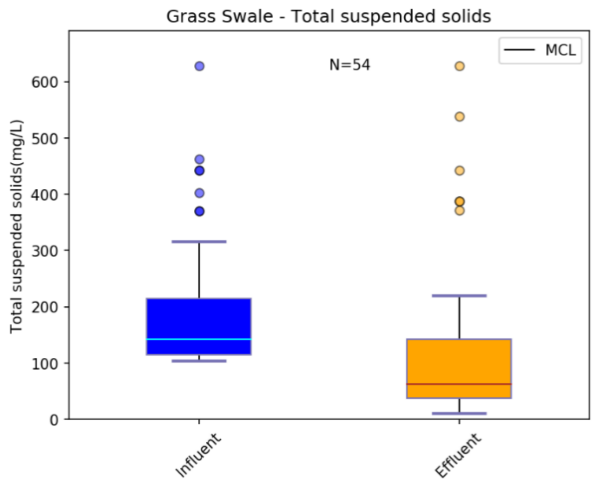
Grass Swale

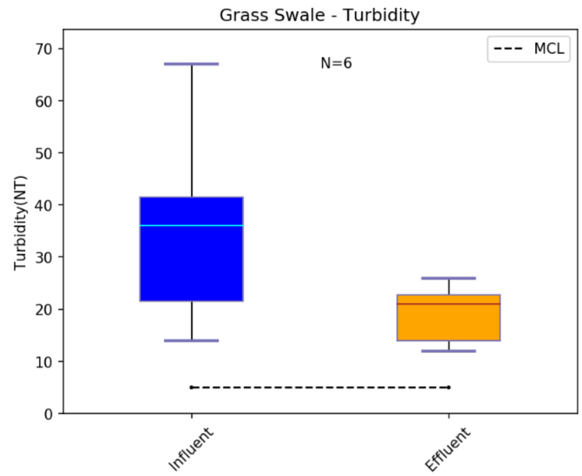

Grass Swale - Arsenic, Total
N=37
Arsenic, Total(mg/L)
Influent
Effluent


Grass Swale - Iron, Total
MCL
N=17
Iron, Total(mg/L)
Influent
Effluent

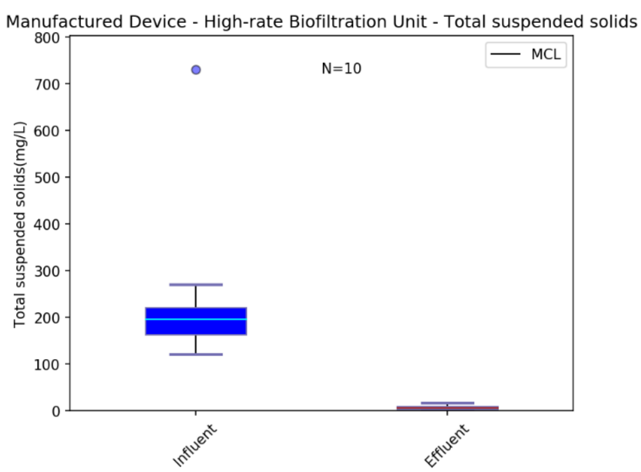

Grass Swale - Lead, Dissolved
MCL
N=14
Lead, Dissolved(mg/L)
Influent
Effluent


Grass Swale - Lead, Total
MCL
N=68
Lead, Total(mg/L)
Influent
Effluent

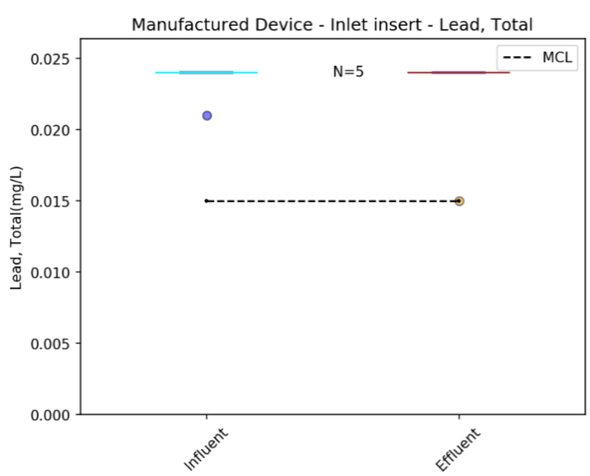


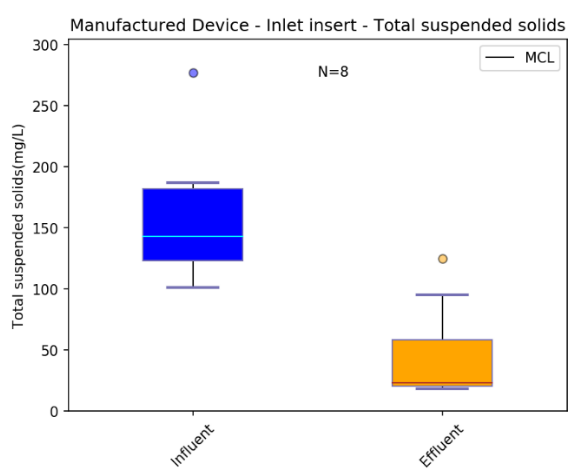


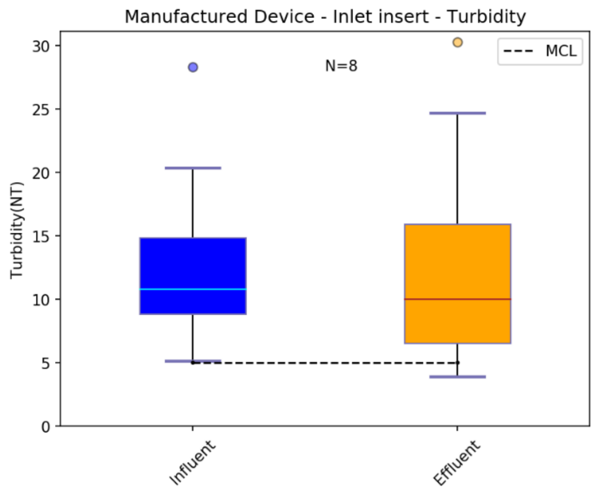
Manufactured Devices – High Rate Biofiltration Unit



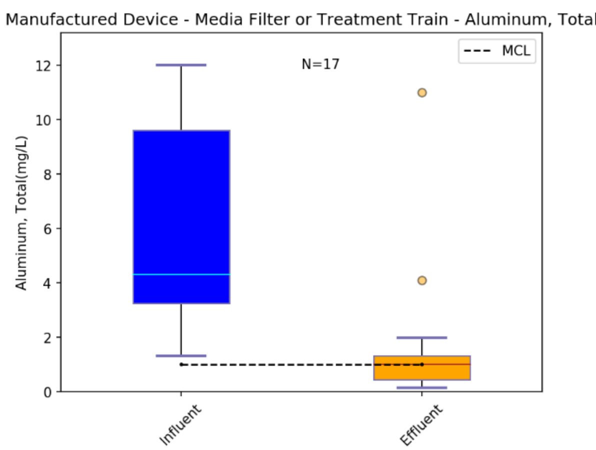
Manufactured Devices – Inlet Insert

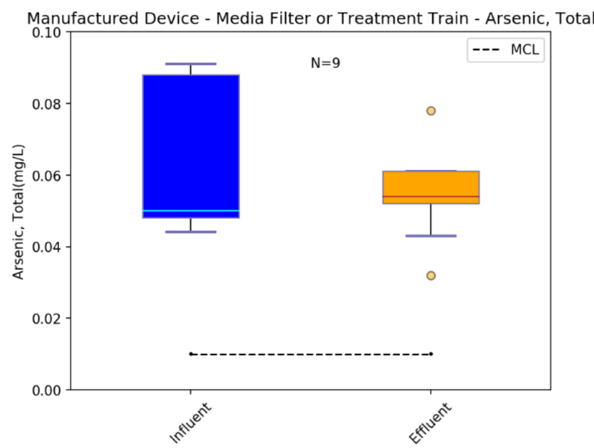


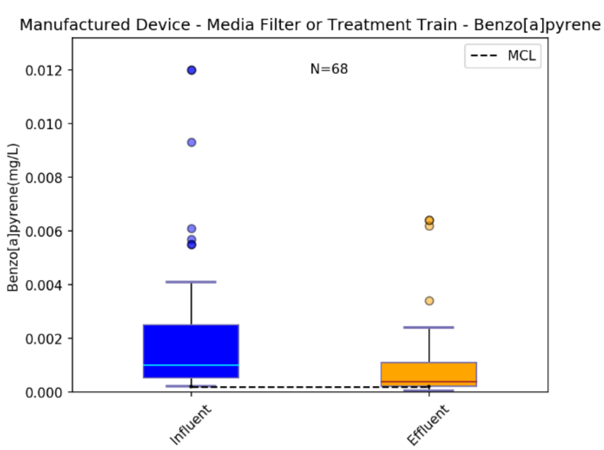


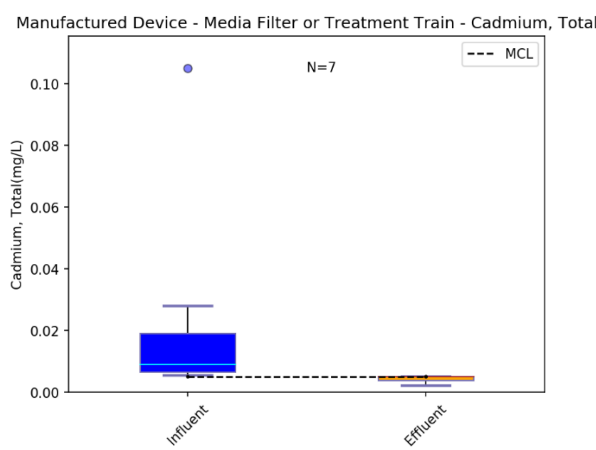


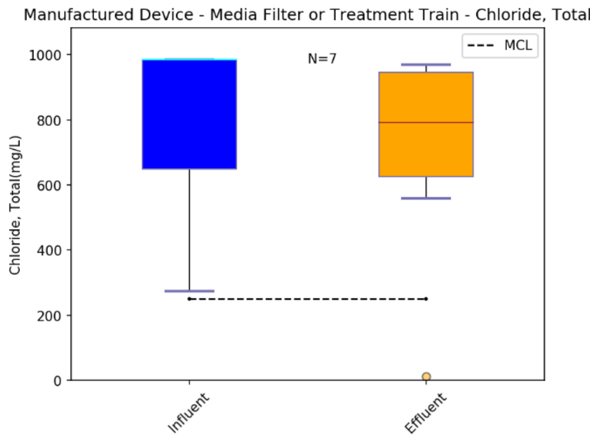
Manufactured Devices – Media Filter or Treatment Train

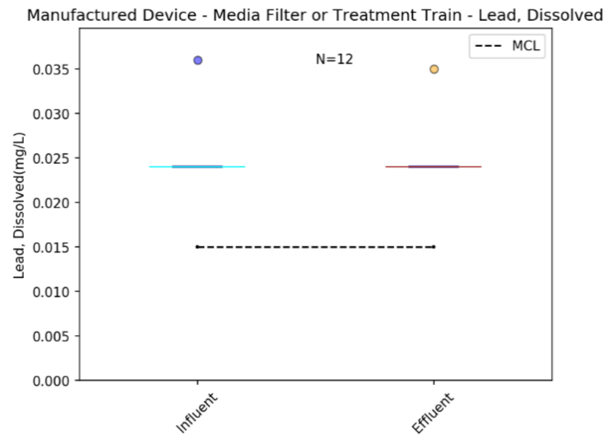


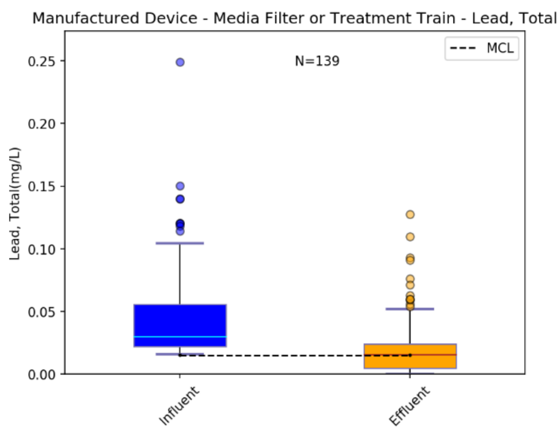


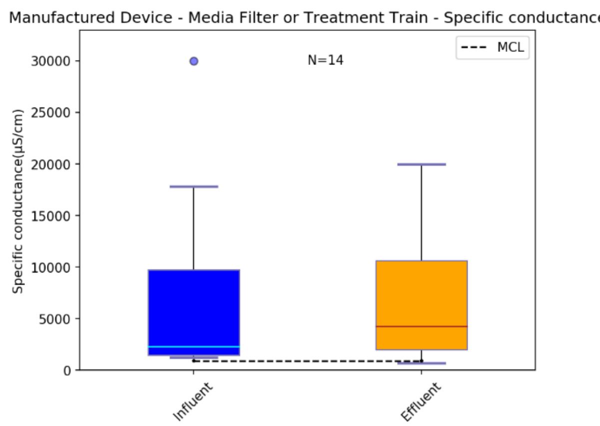


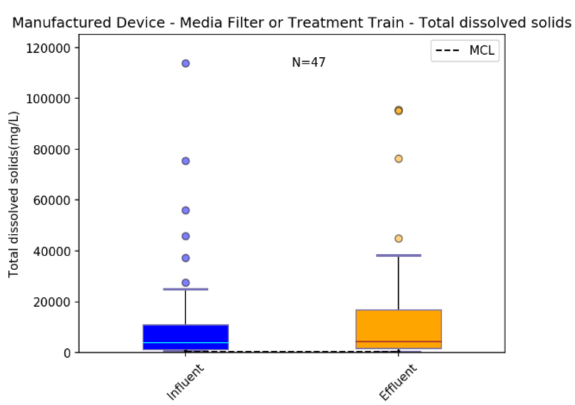


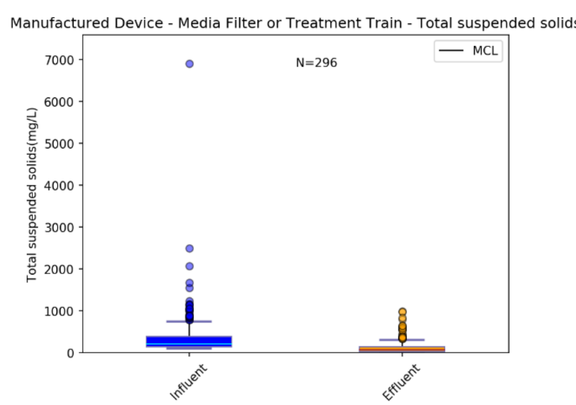

Manufactured Device - Media Filter or Treatment Train - Chloride, Total
Chloride, Total(mg/L)
N=7
MCL
Influent
Effluent

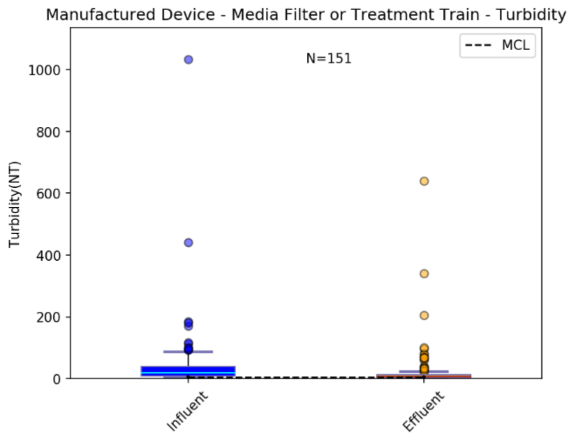

Manufactured Device - Media Filter or Treatment Train - Lead, Dissolved
Lead, Dissolved(mg/L)
N=12
MCL
Influent
Effluent

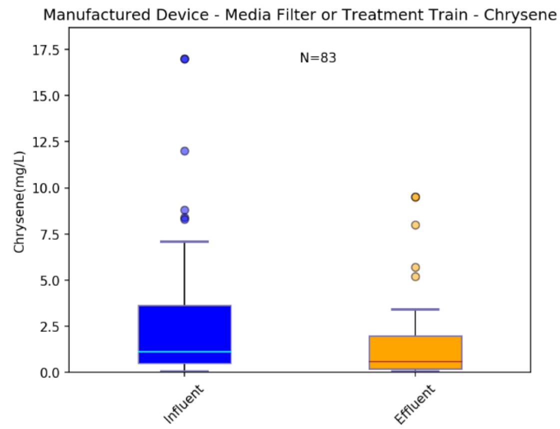

Manufactured Device - Media Filter or Treatment Train - Lead, Total
Lead, Total(mg/L)
N=139
MCL
Influent
Effluent


Manufactured Device - Media Filter or Treatment Train - Specific conductance
Specific conductance(µS/cm)
N=14
MCL
Influent
Effluent

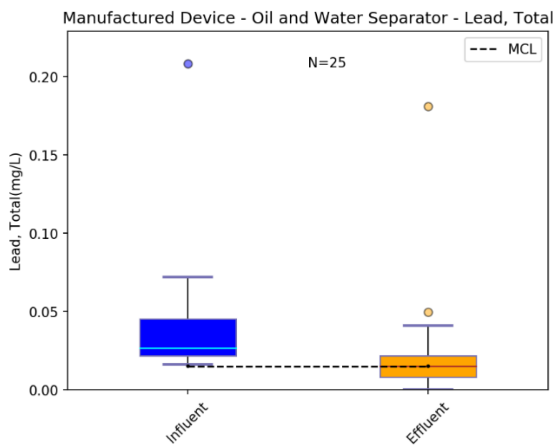

Manufactured Device - Media Filter or Treatment Train - Total dissolved solids
Total dissolved solids(mg/L)
N=47
MCL
Influent
Effluent

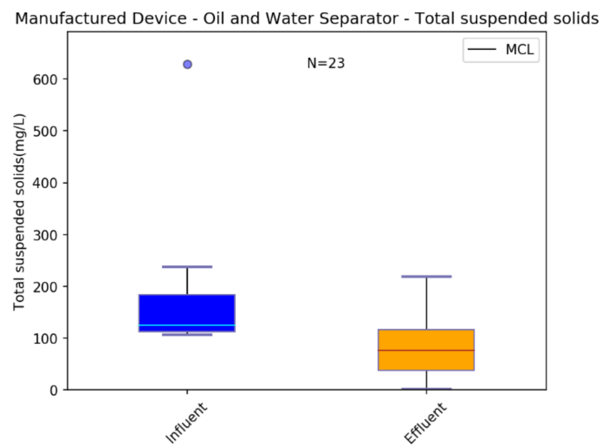

Manufactured Device - Media Filter or Treatment Train - Total suspended solids
Total suspended solids(mg/L)
N=296
MCL
Influent
Effluent

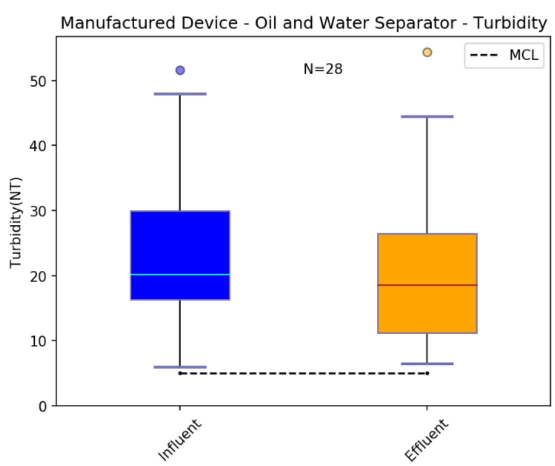




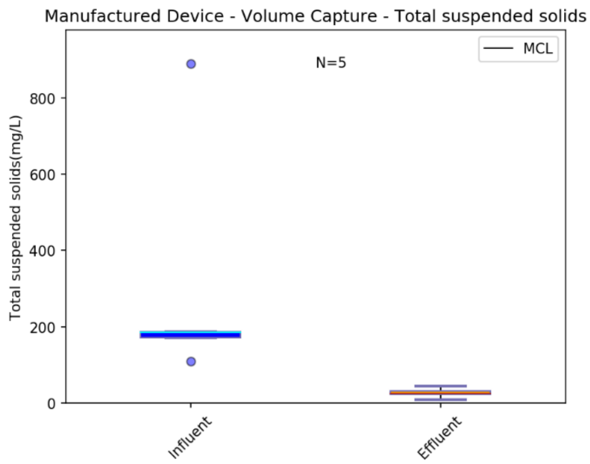
Manufactured Devices – Oil and Water Separator



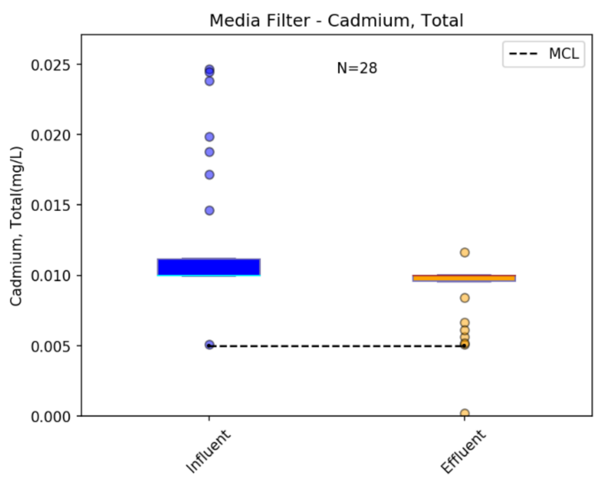


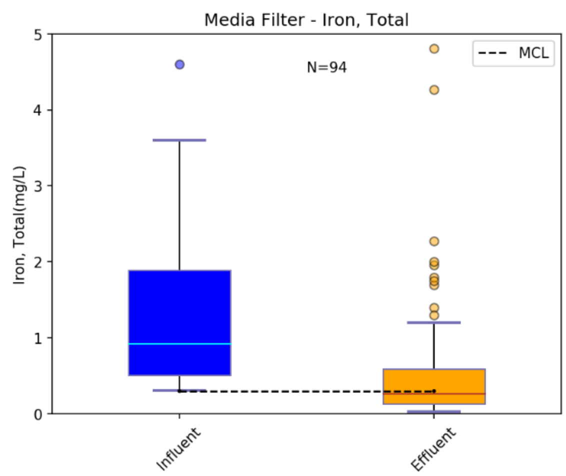


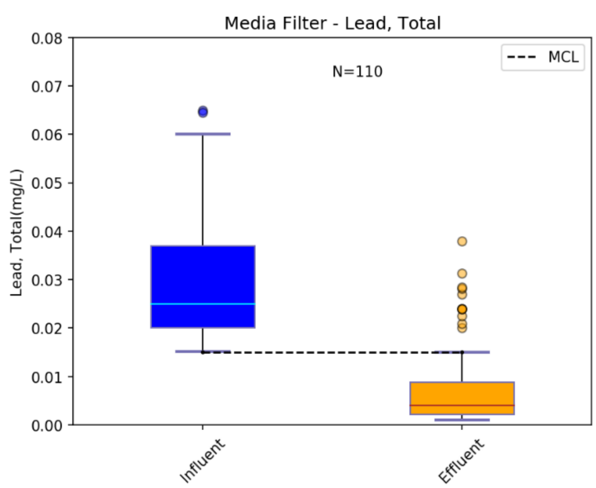
Manufactured Devices – Volume Capture

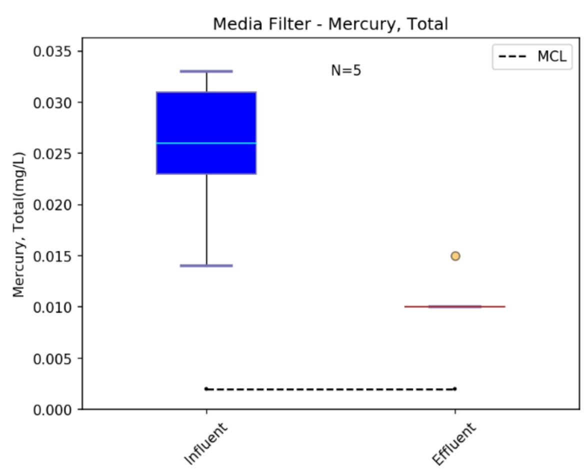


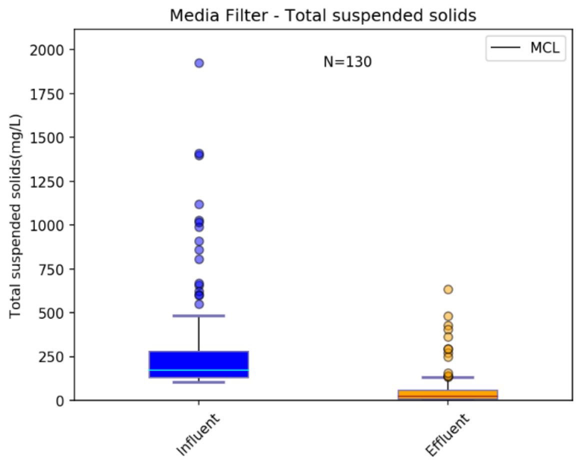
Media Filter

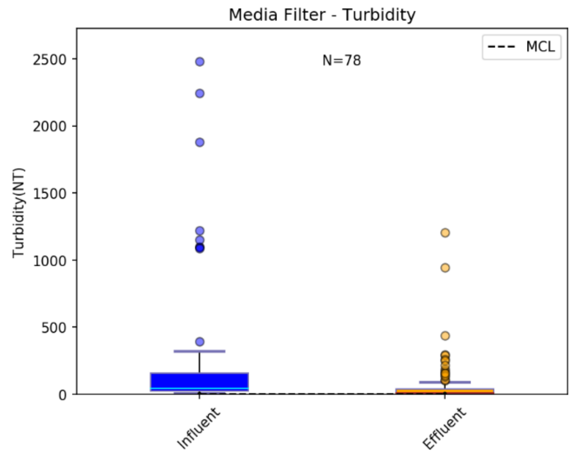


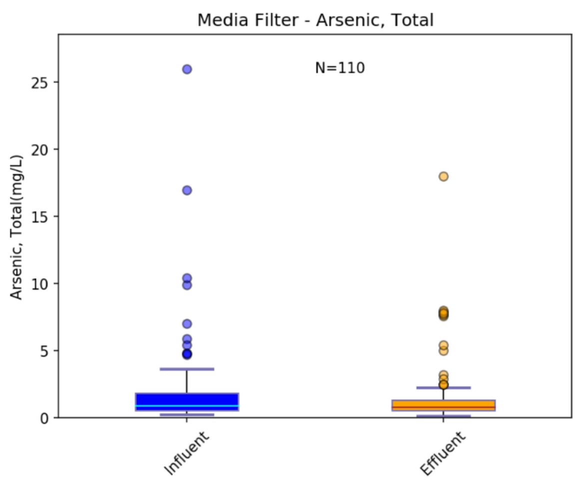







Media Filter - Total suspended solids
N=130
MCL
Total suspended solids(mg/L)
0
250
500
750
1000
1250
1500
1750
2000
Influent
Effluent


Media Filter - Turbidity
N=78
MCL
Turbidity(NT)
0
500
1000
1500
2000
2500
Influent
Effluent


Media Filter - Arsenic, Total
N=110
Arsenic, Total(mg/L)
0
5
10
15
20
25
Influent
Effluent

APPENDIX F

Drywell System Design Procedures, Guidelines for the American River Basin Region

APPENDIX G
Survey of Modeling Approaches, Guidelines for the American River Basin Region