

BMP Performance Monitoring Data Compilation to Support Reasonable Assurance Analysis



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EXECUTIVE SUMMARY

Reasonable Assurance Analysis (RAA) is designed to provide confidence that long-term watershed planning to improve water quality will succeed. However, any plan that predicts future success has some level of uncertainty. For this project, we address the uncertainty associated with the effectiveness of flow-through structural best management practices (BMPs). Flow-through structural BMPs are engineered to treat pollutants in wet or dry weather runoff, perhaps provide some flow reduction, ultimately reducing pollutant concentrations and loads. We address uncertainty by compiling and summarizing BMP treatment effectiveness (i.e., influent vs effluent) monitoring data specifically from California.

A [web-based application](#) was developed that allows users to predict effluent concentrations simply by selecting the BMP type, pollutant of interest, and influent concentration¹. The web application also provides robust estimates of uncertainty for management decision making, including the probability of achieving an effluent concentration managers might be targeting. The uncertainty estimates from the web application can also be used for sensitivity analysis during RAA.

The web application is driven by a data set of flow-through BMPs compiled from California. Seven flow-through BMP types were targeted for compilation including vegetated swales, media filters, dry ponds, wet ponds, constructed wetlands, permeable pavement with underdrain, and bioretention systems with underdrains. We focused treatment effectiveness on representative stormwater pollutants including four total and dissolved trace metals (Cu, Pb, Zn, Hg), nutrients (nitrate, total kjedahl nitrogen, ammonia, phosphorus), polychlorinated biphenyls (total PCBs), bacteria (*Enterococcus*, *E. coli*), and flow.

This project roughly doubled the existing data set for flow-through BMPs in California. Influent-effluent monitoring of 81 different flow-through structural BMPs were compiled, totaling 1,700 site-events (e.g., storm-BMP combinations). The most site-events were compiled for vegetated swales (22.4%), media filters (21.5%), and constructed wetlands (38.6%). However, the vast majority of constructed wetland site-events were from just two BMPs, hindering extrapolation and uncertainty analysis to other constructed wetlands. The dry pond (5.8%), wet pond (7.4%), permeable pavement (0.1%), and bioretention systems (4.2%) provided too few site-events for conducting uncertainty analysis.

Similar to data limitations for BMP types, there were data limitations among pollutants for conducting uncertainty analysis. Over 550 site-events were compiled for Cu, Pb, Zn, Nitrate, Phosphorus, and flow among the four remaining BMPs. Less than 20 site-events were compiled for Hg and PCBs.

Based on the California data set compiled for this study, vegetated swales and media filters are best utilized to treat runoff for total trace metals. Median quantile regression indicates that treatment is typically more than 50% effective for Cu, Pb, and Zn. However, vegetated swales and media filters are not ideal for nutrients; median effectiveness estimates oftentimes exported

¹ https://sccwrp.shinyapps.io/bmp_eval/

Nitrate. Regardless, uncertainty estimates most frequently exceeded an order of magnitude regardless of BMP type or pollutant.

Despite doubling the existing BMP effectiveness data set for California, there remains insufficient monitoring for making informed decisions about what contributes most to uncertainty. Ultimately, BMP performance is a function of design, construction to meet design specifications, and maintenance to ensure the BMP functions at its optimal design specifications. The compiled data can initiate this effort, but will likely not be sufficient to provide many of these more detailed answers managers seek. Thus, BMP monitoring must continue for watershed planning to be successful, and multiple opportunities to link monitoring programs exist statewide.

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INTRODUCTION

Alternative Compliance Pathways (ACP) represent a relatively new strategy for managing stormwater discharges to achieve receiving water limitations (State Water Board Order WQ 2015-0075). This strategy allows municipal separate storm sewer system (MS4) dischargers to incorporate a well-defined, transparent, and finite alternative path to permit compliance beyond the traditional 5-year, iterative National Pollutant Discharge Elimination System (NPDES) permit (OWP 2018). Instead, ACP is based on long-term planning and implementation that can cut across multiple permit cycles, which may extend 20 years or more. Currently, ACP has been adopted in four different MS4 NPDES permits in California, with more expected in the near future and perhaps included in other statewide NPDES stormwater permits.

Because of the long-term planning associated with ACP, Reasonable Assurance Analysis (RAA) is often used to minimize uncertainty and improve confidence in desired outcomes. RAA typically employs the use of computer modeling or other quantitative techniques to demonstrate that a combination of specified best management practices (BMPs) or other control strategies will likely reduce pollutant loads or other stormwater impacts as necessary to result in achievement of NPDES compliance requirements (USEPA 2017). Regional Water Quality Control Boards (RWQCBs) have begun defining what constitutes minimum requirements for a sufficient RAA (LARWQCB 2014). Some RAA are utilizing state-of-the-art modeling technology to support their long-term planning because the costs associated with the ACP approach are estimated in the billions of dollars.

Despite requiring RAA there remains many sources of uncertainty that could impair the ability of ACP to achieve its intended long term compliance and achieving improved receiving water quality. In 2018, a workshop was held with stormwater regulators, dischargers, and modelers specifically to identify sources of uncertainty in RAA (OWP 2018). The workshop participants identified two general areas of uncertainty: 1) accuracy and precision of modeling existing conditions; 2) accuracy and precision of modeling management actions. Of course, within each of the two areas there are many specific factors that could lead to uncertainty, but of these two, workshop participants were most concerned about modeling management actions.

Predicting the effectiveness of BMPs is potentially a large source of uncertainty when modeling future management actions. BMPs can include both non-structural (i.e., street sweeping, public education, etc.) and structural (i.e., bioretention, media filters, etc.) devices. The information for how well non-structural BMPs perform is taken largely from the literature (e.g., Sartor and Gaboury 1984). The primary source of information for structural BMP performance is the International BMP Database (<http://www.bmpdatabase.org/>).

The International BMP Database has compiled effectiveness monitoring data – comparing influent to effluent concentrations or volumes – from thousands of BMPs across the globe. The International BMP Database is a truly unique resource, but BMP effectiveness monitoring data are predominantly from across North America and a small fraction are from California. Managers in California expressed concern about the applicability of BMP effectiveness monitoring data from regions such as the Pacific Northwest, Mid-west, or South-east.

This project is designed to answer the question “What is the uncertainty in flow-through BMP treatment effectiveness from California?” The goal is three-fold: 1) provide managers confidence

in how well the selected BMP(s) will work in watershed management planning; 2) provide some bounds for sensitivity analysis by RAA modelers; and 3) explore ways to reduce the uncertainty of BMP performance. Part of achieving this goal requires exploration of how best to assess effectiveness because no standard method for assessing effectiveness currently exists.

METHODS

Our general approach followed three steps:

- 1) Compile BMP data from California
- 2) Make estimates of BMP effectiveness
- 3) Make estimates of BMP effectiveness uncertainty

BMP Type and Pollutant Selection

Stormwater BMPs can be classified based on its scope, scale, or mode of operation. Stormwater BMPs can be structural or non-structural and their scope of applications can be limited to either source or treatment control or both. From such a wide array of available BMPs we selected seven BMPs based on a set of screening criteria. The primary criterion was only choosing BMPs which do not depend solely on infiltration because infiltration BMPs are assumed to be 100% effective. A complete list of BMPs considered and criteria used has been described in Appendix B. The types of BMP selected included:

- Media Filter
- Dry Pond
- Wet Pond
- Constructed Wetland
- Vegetated Swale
- Bioretention with Underdrain
- Permeable Pavement with underdrain

The next step of study design was to select a list of pollutants which represent the wide range of pollutant types found in stormwater throughout California. Therefore, we compiled data to investigate how effective BMPs in California are at removing fecal indicator bacteria (*E. coli* and Enterococci), nutrients (total nitrogen, total phosphorus, nitrate, total kjedahl nitrogen, ammonia), and dissolved and total trace metals (Cu, Zn, Hg, and Pb), and organics (PCBs).

Selected Data Types for Compiling BMP Effectiveness Data

To identify the appropriate data standards for managing the compiled information on BMP effectiveness, we compared and contrasted seven different existing stormwater databases (Appendix C). Each of these regional/national/international data compilations was evaluated for six different factors such as breadth, depth, applicability, acceptability, accessibility, and independence. Ultimately, the International BMP Database was selected as a robust data standard containing most of the data elements required to answer our study questions. We critically reviewed International BMP Database and provided slight modifications to use as the BMP data

standard for this project. In Appendix C, we describe each of the data fields included in our BMP data standard.

Data types selected for this project included:

- General BMP information (name, location, owner, etc.)
- BMP design information (design specifications, differing by BMP type)
- Storm information (rainfall date, timing and quantity)
- Monitoring information (Flow and water quality data)
- Maintenance and cost information

Identifying Appropriate Data Providers

We reviewed available local, regional, and state-wide databases to identify entities who may have implemented stormwater BMPs and collected BMP performance data for volume capture and/or contaminant reduction. Additional sources were identified through personal communications with stormwater managers from various cities and counties throughout California, including agencies and grantees for SWRCB Water Bonds (i.e., Props 13, 50, 84, 1), local bonds (i.e., Prop O), and local BMP implementation (TMDL or NPDES requirements).

We contacted 35 agencies throughout California requesting all available BMP data for the seven types of BMPs selected for this project (Table 1). Agencies contacted included public works agencies, flood control districts, municipalities, private consultants, and non-profits.

A 2-page fact sheet (Appendix D) was prepared as an information resource to accompany the data request. While data submittals using the data standard template was preferred, data submission in other formats (including CEDEN) was accepted.

Since much of the data was provided on the basis of anonymity, BMP owner and location was kept confidential in our data set. Randomly generated unique identifiers were created, and locations were constrained to Regional Water Quality Control Board (RWQCB) jurisdiction. When data generators decide their data can become publicly available, owner and location information can easily be added back into the California data set.

Table 1. List of Agencies solicited for BMP monitoring data.

| AGENCY | |
|---|---|
| 2 nd Nature | Glenn County |
| Alameda County Public Works Agency | Humboldt County |
| Alta Consulting | International BMP Database |
| CALTRANS | LA County Flood Control District |
| City of Eureka | Lake County Water Resources Department |
| City of Fort Bragg | Marin County Department of Public Works |
| City of LA | Modoc County Public Works Department |
| City of Laguna Hills | Napa county |
| City of Modoc | Orange County Public Works |
| City of Oakland Department of Public Works | Riverside County Flood Control District |
| City of Orland | Sacramento County Environmental Health Division |
| City of Sacramento | Sacramento County Environmental Management Department |
| City of San Diego | San Bernardino Public Works |
| City of San Jose Environmental Services Department | San Diego County Public Works |
| City of Santa Monica | San Francisco Public Utilities Commission |
| City of Santa Rosa | Shasta County |
| City of Trinidad | SMC CLEAN |
| City of Ukiah | Solano County Water Agency |
| City of Vallejo and Vallejo Sanitation and Flood Control District | Sonoma County Water Agency |
| City of Ventura | So Cal Coastal Water Research |
| Contra Costa County | US Army Corps of Engineers |
| Del Norte County | Ventura County Public Works |
| Fairfield-Suisin Sewer District | Yolo County |

Quality Control and Quality Assurance

Upon receiving a BMP dataset from a provider, the dataset was inspected for accuracy and consistency. We reviewed available reports, project images and drawings with identified sampling locations, and relevant monitoring and reporting programs to ensure provided data was adequate to assess effectiveness of the stormwater BMP. Although monitoring programs vary from one agency to another, a well-documented monitoring and reporting method was confirmed for collecting data from a specific site based on monitoring method descriptions, monitoring plans, sampling and analysis or quality assurance plans. Site visits or audits were not conducted. When necessary, unit conversion (i.e., mg/L to µg/L or Nitrate concentration to Nitrate as Nitrogen) was performed to standardize the data received. A variety of procedures were conducted on the compiled data set to ensure accuracy including random and non-random data audits, and 100% data audits for a subset of BMPs.

Making Estimates of Effectiveness

Several approaches can be used for evaluating the effectiveness of a BMP. A brief overview (i.e., description, advantages, shortcomings) of the methods considered while evaluating BMP effectiveness is described below

Regardless of method, data were treated similarly for analysis. Paired data were either influent-effluent or preconstruction-postconstruction. Influent-effluent were paired by site-event. Arithmetic averages within a site-event for influent or effluent were utilized when multiple samples were collected during the same storm. Average preconstruction site-event data were paired with average post-construction site-event effluent data to create a single BMP-pollutant pair for BMPs using this study design. Pollutants less than detection limits were treated as zero.

Percent Reduction

Percent reduction (PR) is a simple, intuitive method to calculate BMP efficiency from a set of paired influent/effluent concentrations. PR is perhaps the commonly used BMP effectiveness method. In this study, we utilized only flow-weighted event mean concentrations (EMCs). The exception was for bacteria, which frequently are not composited.

The following general equation (equation 1) is used for calculating BMP efficiency using this approach:

$$\text{BMP Efficiency (\%)} = \frac{C_{in} - C_{eff}}{C_{in}} \times 100 \dots \dots \dots (1)$$

Here, C_{in} is the average inlet concentration or inlet EMC and C_{eff} is the average outlet concentration or outlet EMC. Uncertainty in the PR method was estimated as the standard deviation (SD) of the average PR for the specific BMP-pollutant pair.

The PR approach assigns an equal weight for all monitored storm events. For example, a monitoring event with a high inflow concentration or volume is treated similarly as an event with a lower inflow/cleaner stormwater. Such an assumption reduces potential biases in efficiency calculation when the monitoring data represents a comparable number of very large or very small storm events. It also mitigates impacts of highly polluted or very clean stormwater influent on the actual effectiveness calculation.

However, the PR method for BMP effectiveness calculation does not provide for changes in the relationship between the quality of incoming stormwater and expected BMP effectiveness for different storms. Moreover, due to equal weights assigned to each storm events, regional precipitation patterns (the occurrence of a many small and few large events or vice versa) may impact the BMP efficiency estimated using this approach. Finally, the actual calculation can create bias when very low concentrations are encountered.

Effluent Probability

The effluent probability method (EPM) calculates the cumulative frequency distribution of influent and effluent concentrations (or loads) for a stormwater BMP. The EPM graphically illustrates the probability of occurrence (or exceedance) of influent or effluent concentrations (or

loads) in a stormwater BMP. EPM treats all storms equally and does not require paired influent data.

EPM plots are generated using the following steps: a) monitoring are tested for normal distribution and log-transformed, if necessary; b) influent and effluent data are independently ranked (e.g., unpaired) from low to high, and added to a normal probability plot; c) influent and effluent data are tested for statistically significant differences.

EPM is sometimes regarded as the most comprehensive BMP evaluation tool that presents the “whole picture” of BMP performance (Strecker et al. 2002). EPM is particularly adept at estimating effluent concentrations, and estimating probability-based uncertainty estimates for effluent concentrations.

Because of the explicit disconnect between paired influent and effluent data, the primary challenge for using EPM as a predictive BMP effectiveness evaluation method is its inability to offer any numeric performance estimate based on influent data for an individual BMP.

To overcome this challenge and enable comparisons among assessment methods for this study, we utilized a PR-based approach for estimating effectiveness based on the average influent concentration and corresponding effluent concentration from the EPM. Uncertainty in the EPM was based on the SD of the average BMP-pollutant pair influent concentration.

Linear Regression

Linear regression (LR) differs from PR and EPM by quantifying the average relationship between the influent and effluent from a BMP based on single storm events. Linear regression analysis is a commonly applied statistical method and frequently utilized for estimating BMP effectiveness.

Linear regression for BMP effectiveness is performed in four steps: a) compile paired influent and effluent data; b) test for normal distribution and homogeneity of variance in both influent and effluent data, log-transform data if necessary to achieve normality and homogeneity; c) perform correlation analysis to determine if there is any monotonic relationship between influent and effluent concentrations; and d) employ linear best-fit regression statistics to quantify slope and y-intercept.

Linear regression improves on PR and EPM because the influent-effluent relationship enables the user to predict effluent concentrations from any specified influent concentration. Therefore, LR can accommodate either very large or very small influent concentrations and similar variations in effluent. In general, slopes approximating unity indicate little treatment effectiveness (i.e., influent and effluent concentrations are similar) and slopes decreasing from unity indicate increased treatment effectiveness (i.e., effluent concentrations are less than influent concentrations). For BMPs where relationships between influent and effluent are not necessarily expected (i.e., media filters), slopes may approach zero and the effluent concentrations are largely derived from the y-intercept.

Linear regression requires paired influent and effluent data and a large volume of data improves accuracy. Linear regression is also susceptible to bias from outlier data. So, a very small number of data points can disproportionately influence slopes and intercepts, artificially increasing or

decreasing effectiveness assessments. For this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations based on LR at the median influent concentration. Uncertainty in the LR method was calculated as the predicted effluent concentration at the average slope plus or minus one SD at the median influent concentration.

Quantile Regression

Quantile regression (QR) is a regression method that focuses on achieving least absolute deviation from specific percentiles of the influent-effluent distribution. Essentially, QR enables calculation of the influent-effluent relationship at different proportions along the relationship gradient. While QR is a very well-vetted statistical method, it has not been used for BMP effectiveness methods.

Quantile regression for BMP effectiveness is performed somewhat similarly to LR: a) compile paired influent and effluent data; b) select quantile desired from 5% to 95%; and c) employ quantile regression statistics to quantify slope and y-intercept for desired quantile. There is no need to test for normality or homogeneity of variance.

Quantile regression overcomes the limitations of LR by not being limited to just the average influent-effluent relationship, is less susceptible to bias associated with outlier data, and provides estimates of uncertainty by offering a statistical range for the expected removal.

Quantile regression requires paired influent and effluent data and a large volume of data improves accuracy, particularly at the ends of the quantile range.

For this project, we estimated BMP effectiveness as the predicted difference between influent and effluent concentrations based on 50th percentile QR at the average influent concentration. Uncertainty in the QR method was calculated as the predicted effluent concentration at the average influent concentration plus or minus one SD.

Making Estimates of Uncertainty and Exploring Potential Uncertainty Drivers

Regardless of assessment method, we set a minimum sample size of 20 BMP-pollutant pairs as a requirement to make robust estimates of effectiveness and effectiveness uncertainty.

We utilized QR for making estimates of uncertainty. The 50th quantile was used as the central tendency in for each BMP-pollutant pair. Then, QR was used to estimate the 10th and 90th quantile as the upper and lower bounds of performance for each BMP-pollutant pair. Using media filters as an example for interpretation purposes, at the 50th quantile QR, 50% of the media filters would perform better and 50% would perform worse. At the 90th quantile QR, 90% of the media filters would perform better and only 10% would perform worse.

In order to assess what factors could be influencing BMP uncertainty, the BMP-pollutant pairs were parsed by rainfall, geography, and age since construction. Rainfall was parsed into quartiles (25%) based on rainfall depth. Then, the quartile of largest storms and the quartile of smallest storms were compared to effectiveness estimates based on all storm sizes. For geography, BMP-pollutant pairs were parsed by Regional Water Quality Control Board (RWQCB). Then, effectiveness was compared between RWQCBs and all geographies combined. For time since

construction, BMP-pollutant pairs were parsed by year and performance was compared among years to assess if site-events from older BMPs performed as well as younger BMPs.

RESULTS AND DISCUSSION

Inventory of California BMPs

In total, there are 214 BMPs in the compiled effectiveness data set representing 1,700 different storm site-events (Table 2). While we accepted data for BMPs without water quality, the effort focused on obtaining BMPs with flow and water quality monitoring data. Eighty-one of the 214 total BMPs (38%) also contained water quality monitoring data.

The inventoried BMPs were distributed throughout California (Figure 1). Roughly half of the BMPs with water quality data were located in northern California (N= 38) and half in southern California (N=43).

The inventoried BMPs were spread across a range of time periods from before 2000 to 2018 (Table 4). Sixty-three percent of the influent-effluent paired data occurred prior to 2005.

A summary of the water quality inventory identified that only five BMP types had at least five different BMPs and 20 site-events with influent-effluent data pairs (Table 5). Of these, not all BMPs have more than 20 site-events for all pollutants. There were less than 20 site-events for mercury or PCBs for any BMP type. In contrast, trace metals and nutrients had hundreds of site-events and included up to four different BMPs including vegetated swales, media filters, dry ponds and wet ponds.

For the BMPs and pollutant pairs selected for this study, detection limits appeared not to be an issue for influent, but could be an issue for effluent (Table 6). Using the BMP with the greatest number of pollutant pairs as an example - vegetated swales - the frequency of non-detectable concentrations across all pollutants averaged 2.7% for influent. No pollutant had more than 3.4% frequency of influent non-detectable values. However, the frequency of non-detectable concentrations across all pollutants averaged 19% for effluent. Dissolved phosphorus was the pollutant with the greatest frequency of non-detectable effluent concentrations (30.5%). Total copper was the pollutant with the lowest frequency of non-detectable effluent concentrations (16.9%).

Table 2. Inventory of compiled BMP effectiveness data for California.

| BMP Category | Number of BMPs | | | | Number of Site-Events with Water Quality Data |
|-------------------------------------|----------------------|-------------------|----------------|-------------------------|---|
| | With Background Info | With Design Specs | With Flow Data | With Water Quality Data | |
| Vegetated Swale | 45 | 22 | 24 | 27 | 380 |
| Media Filter | 65 | 19 | 16 | 28 | 366 |
| Dry Pond | 7 | 6 | 8 | 6 | 99 |
| Wet Pond | 48 | 3 | 5 | 5 | 125 |
| Constructed Wetland | 5 | 1 | 1 | 2 | 657 |
| Permeable Pavement | 22 | 6 | 0 | 2 | 2 |
| Bioretention System with Underdrain | 23 | 12 | 3 | 13 | 71 |
| TOTAL | 214 | 69 | 57 | 81 | 1,700 |

Figure 1. Locations of California BMPs with water quality monitoring data.

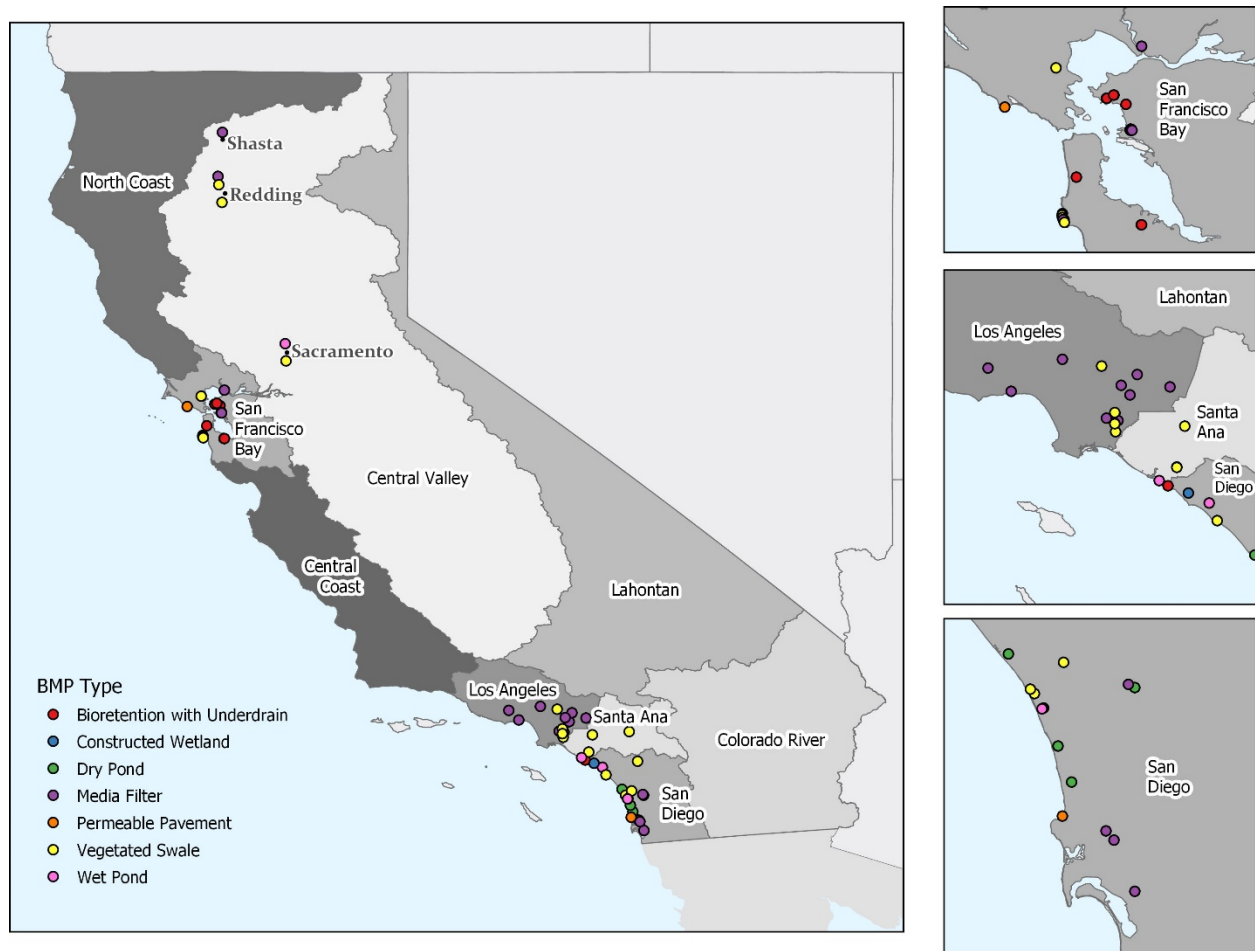


Table 3. Location of BMP effectiveness data in California.

| BMP Type | Regional Water Quality Control Board | | | | | Total |
|------------------------------|--------------------------------------|-------------|----------------|-----------|-----------|-------|
| | San Francisco Bay | Los Angeles | Central Valley | Santa Ana | San Diego | |
| Bioretention with Underdrain | 10 | | | | 3 | 13 |
| Constructed Wetland | | | | | 1 | 1 |
| Dry Pond | | 2 | | | 4 | 6 |
| Media Filter | 11 | 10 | 2 | | 5 | 28 |
| Permeable Pavement | 1 | | | | 1 | 2 |
| Vegetated Swale | 8 | 6 | 3 | 5 | 5 | 27 |
| Wet Pond | 2 | 1 | 1 | | | 4 |
| TOTAL | 32 | 19 | 6 | 5 | 19 | 81 |

Table 4. Inventory of BMP water quality data by 5-year time periods from before 2000 to 2019.

| BMP Type | Pre-2000 | 2000-2005 | 2006-2010 | 2011-2015 | 2016-2020 | Total Data Pairs |
|---------------------|-----------------|------------------|------------------|------------------|------------------|-------------------------|
| Bioretention | 0 | 0 | 0 | 0 | 51 | 51 |
| Constructed Wetland | 289 | 889 | 874 | 685 | 0 | 2737 |
| Dry Pond | 100 | 644 | 0 | 0 | 0 | 744 |
| Media Filter | 111 | 1312 | 234 | 267 | 43 | 1967 |
| Vegetated Swale | 0 | 1826 | 787 | 65 | 35 | 2713 |
| Wet Pond | 193 | 136 | 117 | 6 | 40 | 492 |
| Permeable Pavement | 0 | 0 | 0 | 1 | 0 | 1 |
| TOTAL | 693 | 4807 | 2012 | 1024 | 169 | 8705 |

Table 5. Number of influent-effluent pairs by BMP type in the California data set. To qualify there must be at least 5 BMPs per type and a total of least 20 pairs of influent-effluent water quality data for each pollutant. There were 6,972 total BMP-pollutant pairs.

| Analyte | Dry Pond | Media Filter | Vegetated Swale | Wet Pond |
|--|-----------------|---------------------|------------------------|-----------------|
| Dissolved Copper | 76 | 203 | 323 | 32 |
| Dissolved Lead | 76 | 206 | 323 | 31 |
| Dissolved Phosphorus | 41 | 56 | 59 | 17 |
| Dissolved Zinc | 76 | 208 | 323 | 32 |
| Enterococci | | 37 | | |
| Flow Volume | 95 | 199 | 333 | 32 |
| Nitrate-N | 75 | 197 | 329 | 4 |
| Total Copper | 76 | 206 | 344 | 95 |
| Total Kjeldahl Nitrogen | 76 | 164 | 335 | 91 |
| Total Lead | 76 | 209 | 344 | 94 |
| Total Nitrogen | | | | 76 |
| Total Phosphorus | 76 | 188 | 326 | 92 |
| Total Zinc | 76 | 205 | 345 | 95 |
| Total Pollutant Pairs by BMP type | 819 | 2078 | 3384 | 691 |

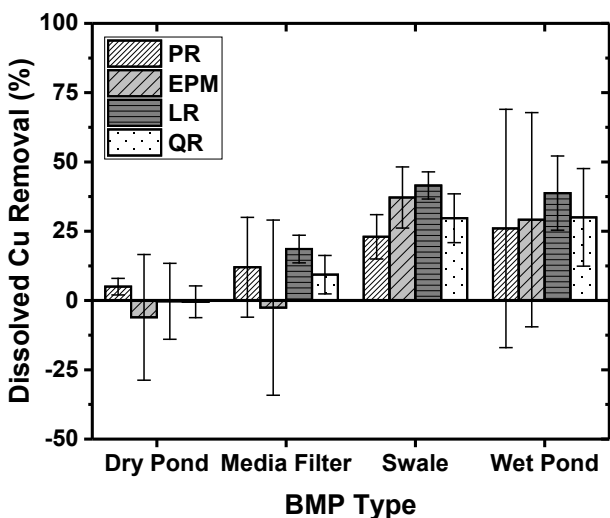
Table 6. Frequency of non-detected values in vegetated swales from the California BMP data set.

| Table 6 | Total No. Samples | | No. NDs | | Percent NDs | |
|-------------------------|--------------------------|----------|----------------|----------|--------------------|----------|
| Analyte | Influent | Effluent | Influent | Effluent | Influent | Effluent |
| Dissolved Copper | 323 | 323 | 10 | 55 | 3.1 | 17 |
| Dissolved Lead | 323 | 323 | 11 | 55 | 3.4 | 17 |
| Dissolved Phosphorus | 59 | 59 | 1 | 18 | 1.7 | 30.5 |
| Dissolved Zinc | 323 | 323 | 11 | 55 | 3.4 | 17 |
| Nitrate-N | 329 | 329 | 9 | 58 | 2.7 | 17.6 |
| Total Copper | 344 | 344 | 9 | 58 | 2.6 | 16.9 |
| Total Kjeldahl Nitrogen | 335 | 335 | 8 | 69 | 2.4 | 20.6 |
| Total Lead | 344 | 344 | 9 | 59 | 2.6 | 17.2 |
| Total Phosphorus | 326 | 326 | 8 | 61 | 2.5 | 18.7 |
| Total Zinc | 345 | 345 | 10 | 59 | 2.9 | 17.1 |

Comparing effectiveness estimation methods

Despite all four methods using the exact same data set, the four methods of assessing BMP performance do not provide the same estimate of effectiveness for pollutant capture and treatment. Using vegetated swales and dissolved copper as an example (Figure 3), percent reduction consistently had the worst performance of the four methods. In contrast, linear regression consistently had the best performance. The effluent probability method had the poorest precision; the standard deviation was consistently greater for this method compared to the other three methods. In contrast, quantile regression consistently had intermediate effectiveness estimates and amongst the best precision (smallest standard deviation). Based on these performance attributes, quantile regression was selected for the remaining assessments in this document.

Figure 2. Estimate of BMP performance for treating dissolved copper by vegetated swales in California. PR=Percent reduction; EPM=Effluent probability method; LR=Linear regression; QR=Quantile regression.



Comparing Effectiveness among BMPs

Vegetated swales and media filters were the best performing BMPs from the California-specific data set (Table 7). Based on median influent concentrations, vegetated swales had the best removal rates for dissolved and total copper, dissolved lead, and nitrate-N. Media filters had the best removal rates for total lead, dissolved and total zinc, and total phosphorus.

Based on median influent concentrations, dry ponds had improved performance removing total metals compared to dissolved metals, whereas wet ponds had improved performance removing dissolved metals compared to total metals (Table 7).

None of the flow-through BMPs in the California-specific data set performed well removing nutrients (Table 7). For example, median influent concentrations produced net export of nitrate from media filters. In comparison, median influent concentrations produced net export of total phosphorus from vegetated swales.

To equip stormwater regulated and regulatory agencies to better utilize the California-specific data set for stormwater planning and RAA, a [web application](https://sccwrp.shinyapps.io/bmp_eval/) was created². Simply by selecting the BMP type, pollutant of interest, and influent concentration, the web application predicts the effluent concentration based upon the compiled California-specific BMP monitoring data. Although quantile regression is the default calculation method, users can select percent reduction, effluent probability, or linear regression effluent estimation methods.

² https://sccwrp.shinyapps.io/bmp_eval/

Table 7. Median BMP effectiveness for California-specific BMPs. Bolded numbers indicate the best performing BMPs.

| | Vegetated swale | | | | Media filter | | | | Dry Pond | | | | Wet pond | | | |
|------------------|------------------------|-------------------------------|----------------------------|-----------------------|---------------------|-------------------------------|----------------------------|-----------------------|-----------------|-------------------------------|----------------------------|-----------------------|-----------------|-------------------------------|----------------------------|-----------------------|
| | N | Median Influent Concentration | 50% Effluent Concentration | Removal Effectiveness | N | Median Influent Concentration | 50% Effluent Concentration | Removal Effectiveness | N | Median Influent Concentration | 50% Effluent Concentration | Removal Effectiveness | N | Median Influent Concentration | 50% Effluent Concentration | Removal Effectiveness |
| Dissolved Copper | 323 | 13.4 | 9.1 | 32.1% | 203 | 5.4 | 5.0 | 6.8% | 76 | 11 | 11.2 | -1.4% | 32 | 7.115 | 5.1 | 28.6% |
| Total Copper | 344 | 27 | 13.4 | 50.4% | 206 | 13.1 | 7.4 | 43.0% | 76 | 39.5 | 20.6 | 47.9% | 95 | 10 | 10 | 0.0% |
| Dissolved Lead | 323 | 1.3 | 1.0 | 23.9% | 206 | 1.0 | 0.9 | 9.0% | 76 | 2.1 | 1.8 | 10.2% | 31 | ID* | | |
| Total Lead | 344 | 10 | 6.9 | 31.5% | 209 | 7.2 | 2.1 | 71.3% | 76 | 54 | 19.5 | 63.9% | 94 | 1.8 | 1.6 | 12.7% |
| Dissolved Zinc | 323 | 52 | 22.1 | 57.4% | 208 | 53.3 | 0.3 | 99.4% | 76 | 52.5 | 50.2 | 4.3% | 32 | 22.5 | 15.2 | 32.4% |
| Total Zinc | 345 | 120 | 40.2 | 66.5% | 205 | 110 | 24.1 | 78.1% | 76 | 280 | 106 | 62.3% | 95 | 13.2 | 11.2 | 15.3% |
| Nitrate-N | 329 | 0.71 | 0.60 | 14.3% | 197 | 0.37 | 0.60 | -61.9% | 75 | 0.85 | 0.70 | 12.6% | 4 | ID | | |
| Total Phosphorus | 326 | 0.19 | 0.30 | -58.9% | 188 | 0.21 | 0.10 | 35.6% | 76 | 0.35 | 0.30 | 23.3% | 92 | 0.29 | 0.30 | 0.0% |

*ID=Insufficient data

Evaluating Uncertainty

The uncertainty estimates for BMP performance varied by BMP type and pollutant (Appendix A). As an example, quantile regression was utilized to assess confidence in vegetated swale removal rates given specific copper and nutrient levels (Figure 4). In this example, different quantiles were applied ranging from 10th to 90th percentiles. Thus, based on the median influent total copper concentration of 30 µg/l to a vegetated swale, there is a 50% probability (median) of the effluent concentration being 14.1 µg/l or lower. However, there is a 90% probability that the effluent concentration will be 27.3 µg/l or lower, and a 10% probability that the effluent concentration will be 4.42 µg/l or lower. To quantify uncertainty by quantile regression, see Appendix A for vegetated swale and media filters for all pollutant types inventoried.

The [web application](#) created for estimating effluent concentration using the California-specific data set will also allow regulated and regulatory managers to estimate uncertainty for any BMP-pollutant combination in the inventory. After selecting BMP type, pollutant of concern, and influent concentration, users can also select the quantile of their preference enabling improved site-specific decision-making. For example, the median quantile (50th percentile) is the default estimator, but managers can select greater quantiles for planning decisions that require more confidence. Alternatively, for any influent concentration managers input, the web application will produce a probability plot (from 5% to 95%) for the range of possible effluent concentrations based upon the California-specific data set. These uncertainty estimators are much more powerful for RAA applications compared to average reductions \pm 95% confidence intervals.

In an effort to assess underlying sources of variability in BMP performance, we parsed the data set by rainfall quantity and geography. Rainfall quantity appeared to make little difference in the performance of vegetated swales or media filters for removing total lead (Figures 5). The largest quartile of rainfall quantities had similar removal rates compared to the smallest quartile of rainfall quantities.

Geography did have an apparent effect on median removal rates (Figure 6). In this case, total lead removal in media filters from Region 9 (San Diego) exceeded the removal rate in Region 2 (San Francisco) by a factor of four. In contrast, total lead removal in vegetated swales from Region 2 exceeded the removal rate in Region 9 by a factor one-half. Unfortunately, insufficient data was available to identify if these differences (or lack of differences) in region or rainfall are real and what causative factors could lead to these differences such as underlying geology, pollutant delivery, BMP design specifications (i.e., sizing, plant pallet, etc.), or construction.

Sample size also limited our ability to assess if age affected BMP performance. However, using vegetated swales and zinc as an example with amongst the most data, age did appear to play a role in performance (Figure 7). There was an apparent decline in the effectiveness of media filters to treat dissolved zinc starting after year 4, but no apparent decrease was observed for total zinc. Media filters are designed to trap particles, so the continued performance of treating total, particulate-bound zinc is expected. However, the performance decline for dissolved zinc could be due to many factors including media type, design specifications, influent concentration and volume, and maintenance procedures. Insufficient data exists for teasing apart these factors.

Figure 4. Quantile regression illustrating the removal of (A) total zinc and (B) nitrate-N using vegetated swales. The quantiles represent uncertainty in the relationship of influent to effluent for the California-specific BMPs. For zinc, even the lowest confidence still results in some removal. For nitrate-N, however, the lowest confidence will result in nitrate export.

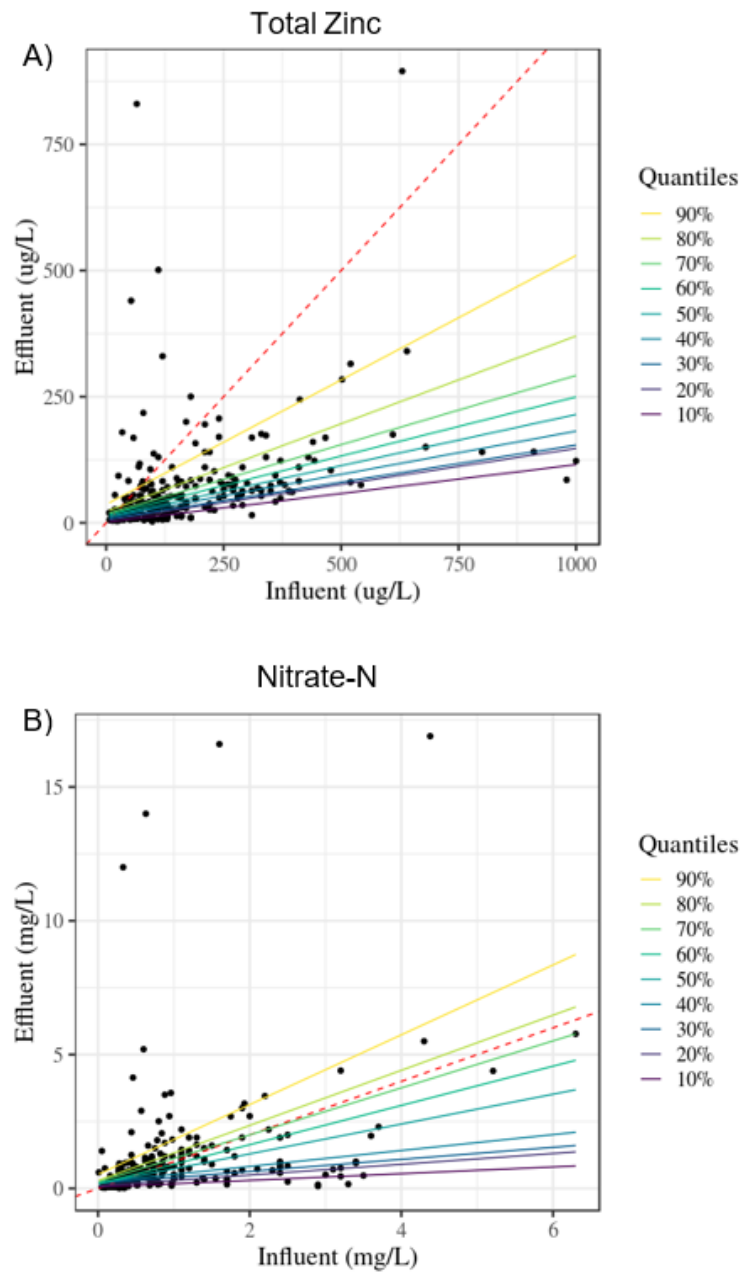


Figure 5. Median (SD) performance of vegetated swale and media filter for removing total lead based on quartiles (Q) of storm size. Q1 contains the storm events with the 25% smallest rainfall quantities in the data set. Q4 contains the storm events with the 25% largest rainfall quantities in the data set.

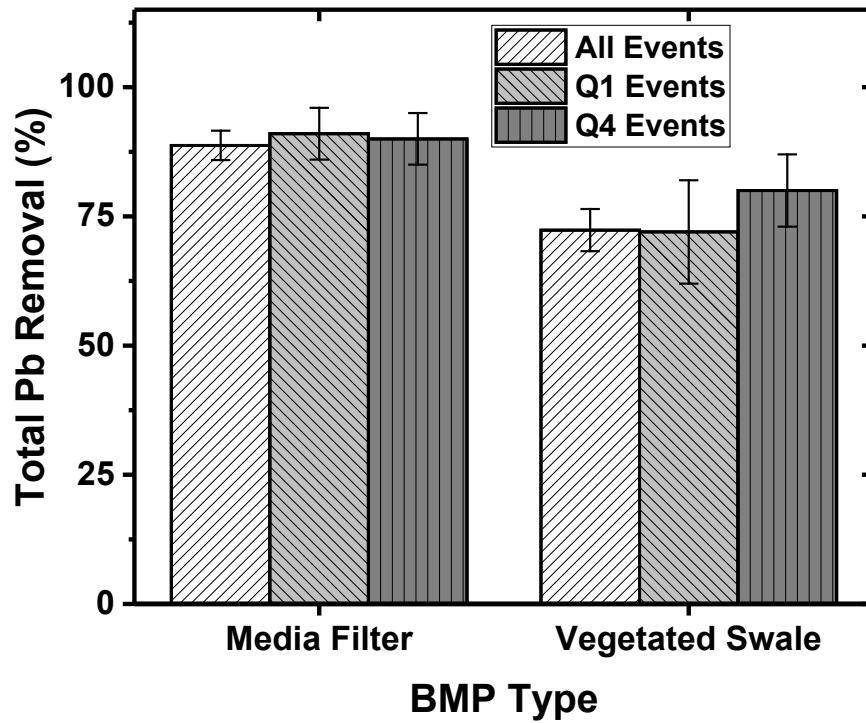


Figure 6. Median (SD) performance of vegetated swale and media filter for removing total lead based on region of the state. R2 is the San Francisco Regional Water Quality Control Board (RWQCB) jurisdiction, R4 is the Los Angeles RWQCB. R9 is the San Diego RWQCB.

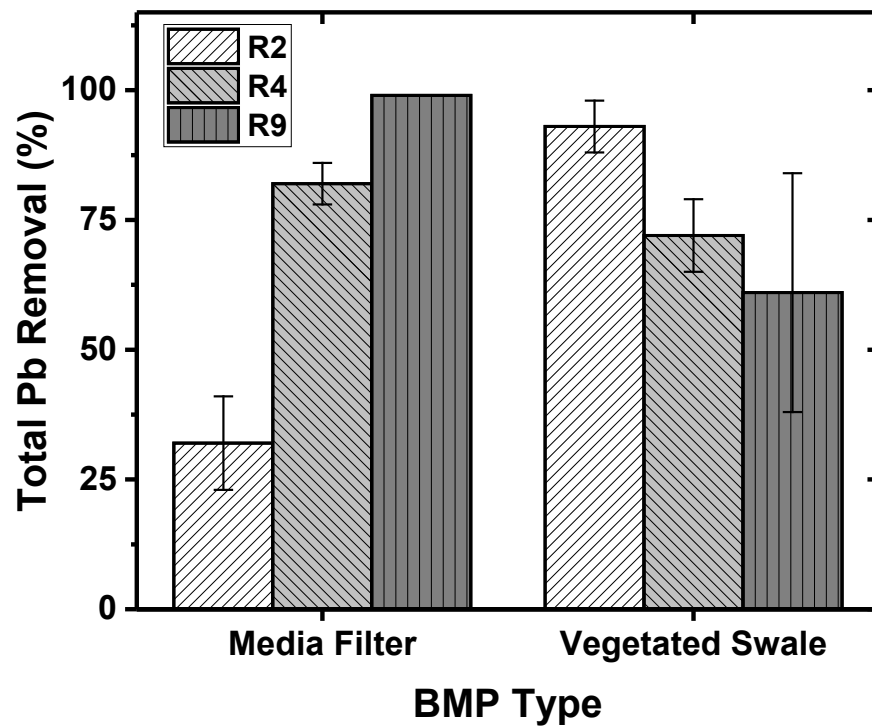
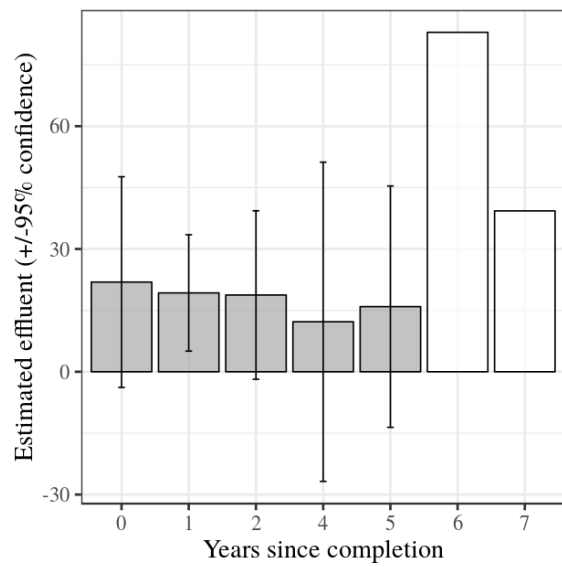
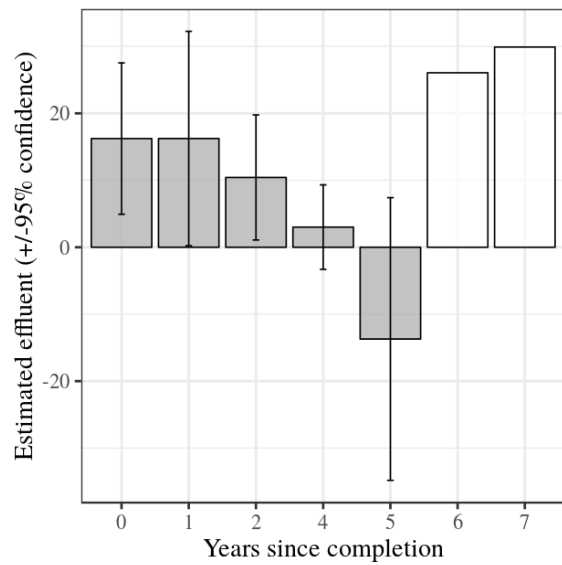


Figure 7. Median performance (SD) for media filters since year of construction for (A) dissolved zinc and (B) total zinc. Years six and seven have insufficient data to estimate uncertainty and are shown in white.



CONCLUSIONS

This project identified a series of important conclusions and recommendations that should benefit future RAA in California. These include:

- **The data compilation in this project roughly doubled the currently available BMP effectiveness data set for California-specific structural flow-through BMPs.**

Prior to this project, the most comprehensive data set for BMP effectiveness monitoring data was in the International BMP database. This valuable data set is the “go to” resource for BMP practitioners. While there are a multitude of BMPs in the International BMP database across North America, the number of BMPs from California targeted in this study were rather limited (N=41) and the data was over 10 years old. The effectiveness monitoring data compiled from this study increased the number of BMPs to 81, and total number of site-events to 1,700.

- **Quantile regression was the preferred effectiveness estimation method because it avoids the limitations of other existing methods.**

We evaluated four different BMP performance methods including percent reduction, effluent probability, linear regression, and quantile regression. Percent reduction, effluent probability, and linear regression are more commonly used methods, but are subject to bias, statistical assumptions, and only provides uncertainty about the mean. Quantile regression is commonly used in statistics, but not used in BMP performance evaluations. Quantile regression shared the advantages of the other methods, but is not prone to bias and provides robust estimates of uncertainty for the entire range of BMP performance.

- **This study and the associated [web application](#) provides the most up-to-date effectiveness estimates for California currently available for RAA.**

This report provides quantile regression curves for multiple BMPs and multiple pollutants. In addition, a web application was developed that allows users to query the BMP performance data set for any BMP, any pollutant, and at any quantile to estimate the probability of treatment success. Simply by inputting the expected influent concentration, the web app will instantaneously provide the probability of achieving any desired effluent concentration based on performance of similar, California-specific BMPs.

- **Despite the additional data and enhanced estimation method, there is insufficient monitoring for making informed decisions about what contributes most to uncertainty.**

Of the seven BMPs, only two had sufficient data for California-wide performance assessments; vegetated swales and media filters. In addition, there was sufficient data for assessments of metals, nitrate-N and total phosphorus, but insufficient data to assess performance for bacteria, mercury, or PCBs. Similarly, digging deeper into the data set to

identify sources of variability that could lead to improved BMP designs or applications was limited by total sample size.

RECOMMENDATIONS

- **Effectiveness and uncertainty estimates from this study provide realistic bounds for sensitivity analysis as part of RAA.**

Uncertainty estimates from this study can be interpreted as probability of success. These estimates, in turn, can be used by watershed managers as they design their watershed management plans including sensitivity testing in RAA models.

- **Opportunities exist for additional BMP performance monitoring to improve effectiveness and uncertainty estimates.**

There was insufficient data to assess performance of all the BMP types and pollutants targeted for this study. Moreover, there are other BMPs (e.g., infiltration BMPs, non-structural BMPs) that also lack assessment monitoring data. Ultimately, BMP performance is a function of design, construction to meet design specifications, and maintenance to ensure the BMP functions at its optimal design specifications. Additional effort will be required to create these monitoring data and to compile them into a publicly available dataset. There are a number of agencies that can help contribute to that effort including the State Water Resources Control Board (SWRCB), Southern California Stormwater Monitoring Coalition (www.SoCalSMC.org) and the Bay Area Stormwater Management Agencies Association (www.BASMAA.org).

- **Use the data standards established in this study for compiling new monitoring data.**

Part of this study was to create robust data standards for compiling and sharing BMP monitoring data. These standards can now be used for future data collection efforts including Water Bond monitoring requirements, NPDES Permit monitoring requirements, or independent studies. This will enable not just rapid compilation, but also a rapid QA evaluation, and seamless data analysis and visualization. The data standards are based on the best performing databases found nationally and detailed in Appendix B.

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Sartor, J.D. and D.R. Gaboury. 1984. Street sweeping as a water pollution control measure: Lessons learned over the past ten years. *Science of The Total Environment* 33: 171-183

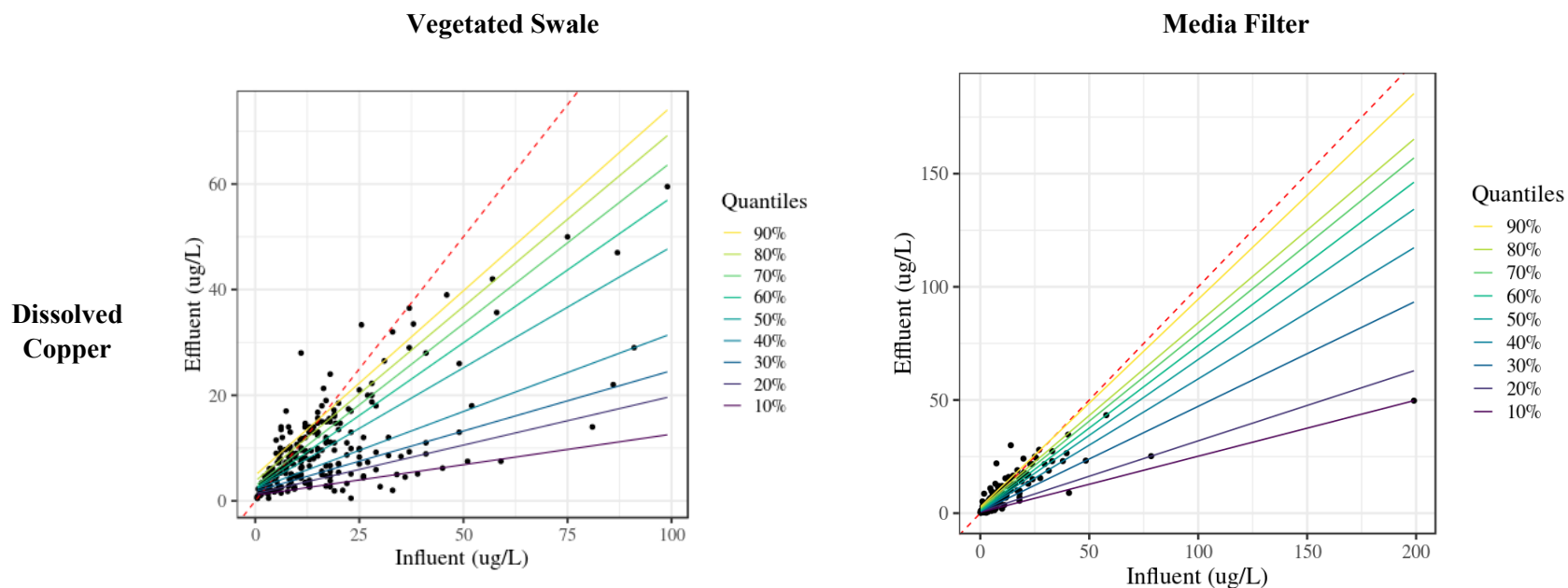
State Water Board Order WQ 2015-0075

Strecker, E., B. Urbonas, M. Quigley, J. Howell, and T. Hesse. 2002. Urban stormwater BMP performance monitoring. Vol. 1. EPA-821-B-02

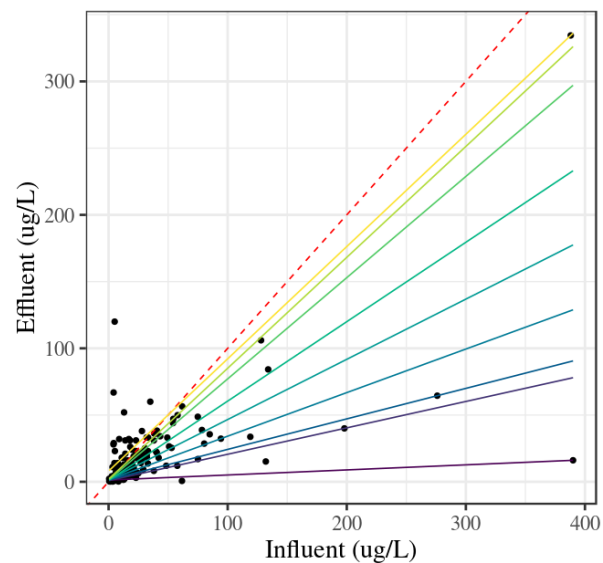
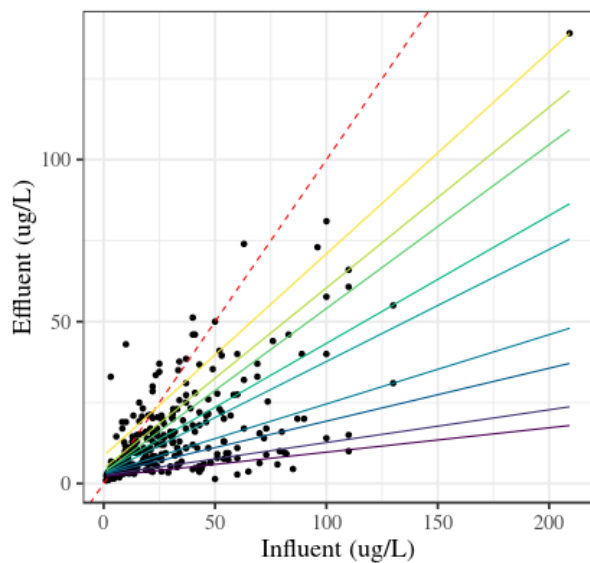
USEPA. 2017. Developing Reasonable Assurance: A Guide to Performing Model-Based Analysis to Support Municipal Stormwater Program Planning. A Report for the US Environmental Protection Agency (Region 9). Prepared by Paradigm Environmental. San Francisco, CA. 52 pp

APPENDIX A: QUANTILE REGRESSIONS FOR VEGETATED SWALES AND MEDIA FILTERS

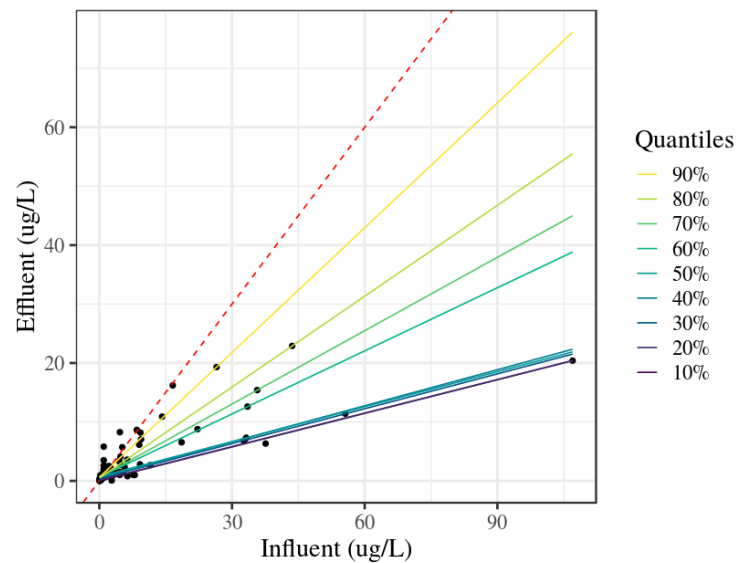
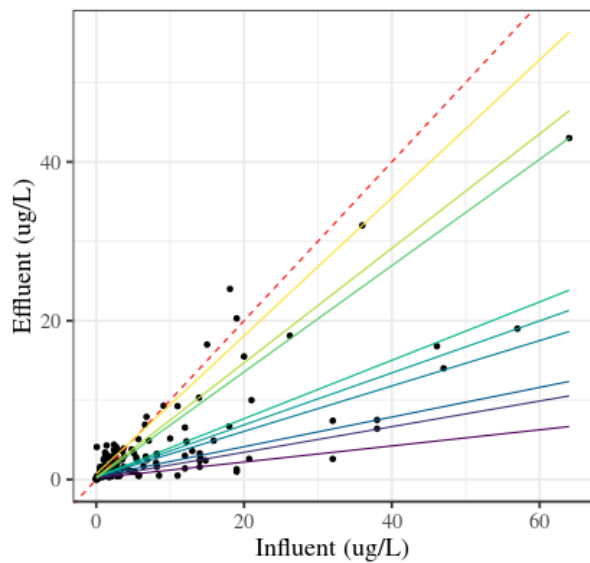
Influent vs. effluent relationships with quantiles from 10% to 90% defined by color. Dashed line represents the 1:1 line where no treatment occurs; quantile regressions to the right of the 1:1 have net removal of pollutants, quantile regressions to the left of the 1:1 have net export of pollutants.



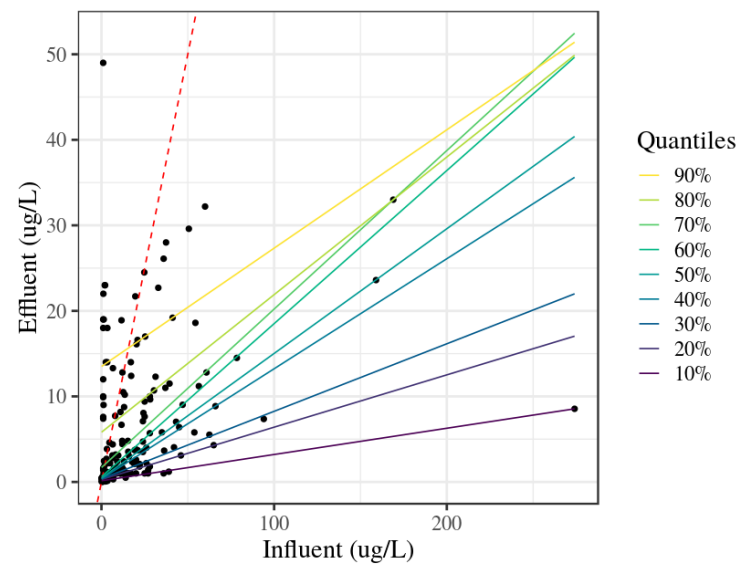
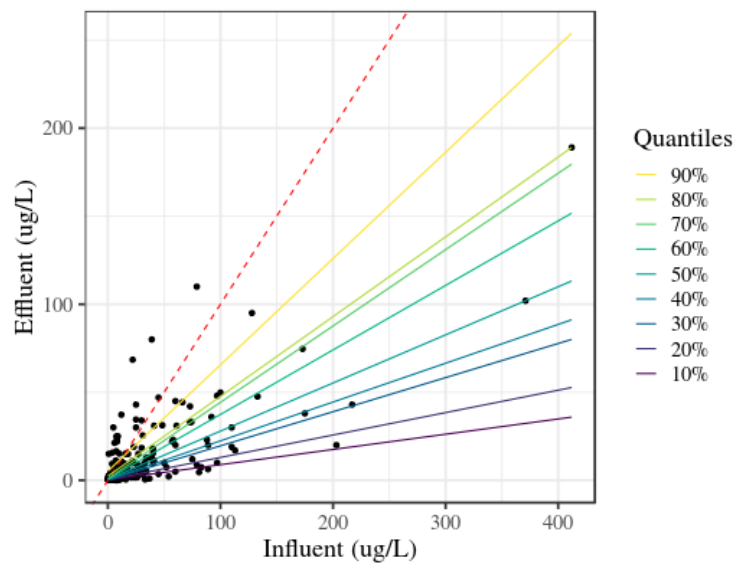
Total Copper



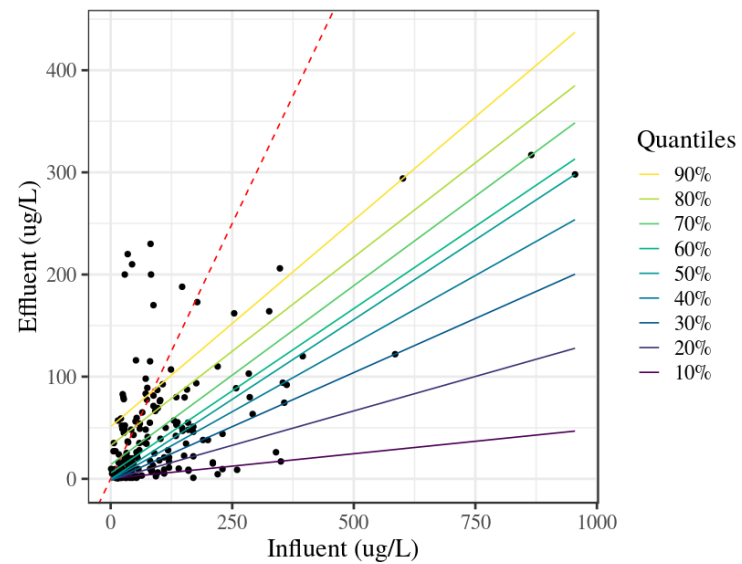
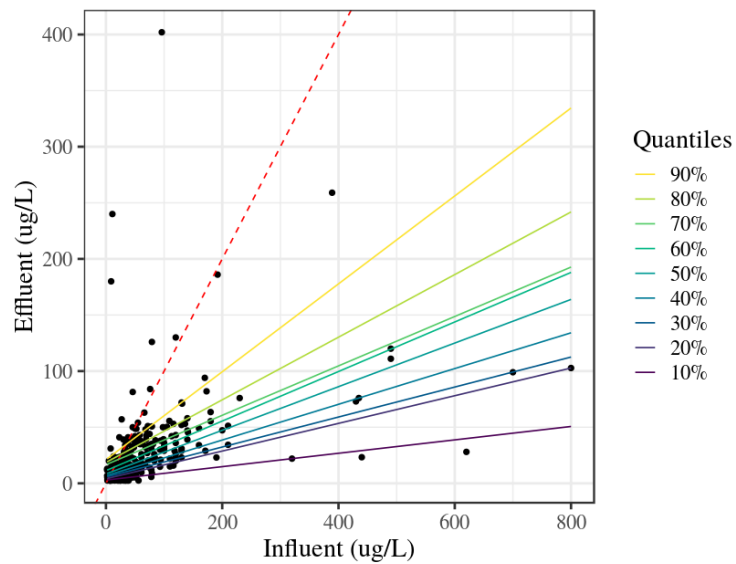
Dissolved Lead



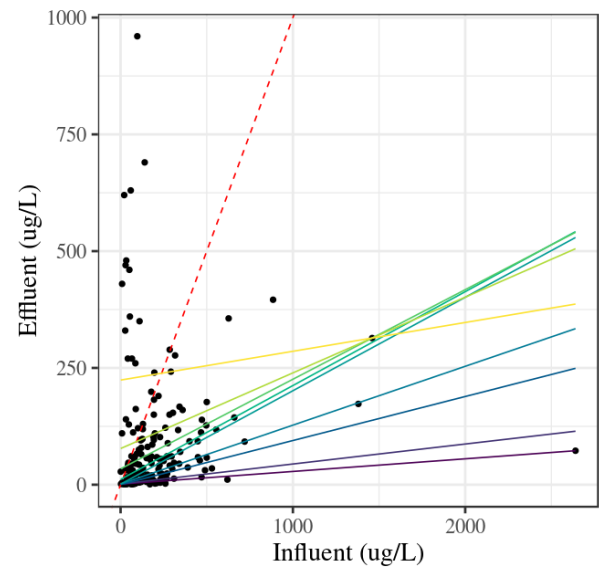
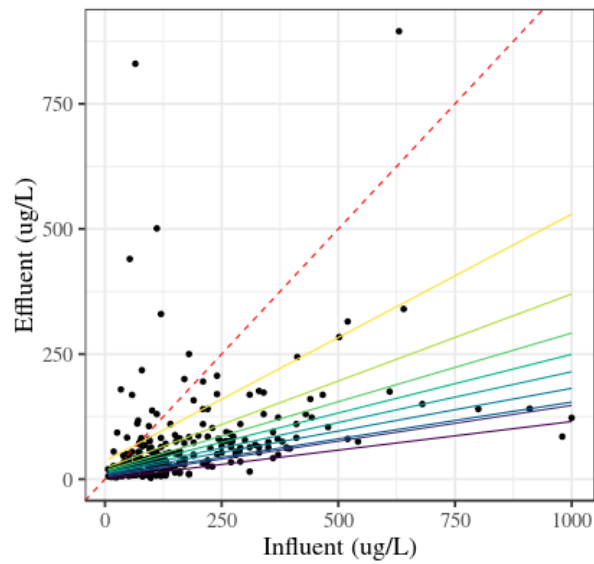
Total Lead



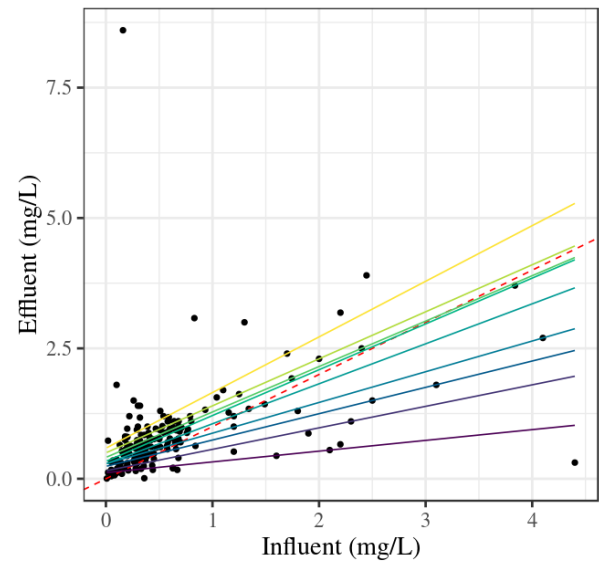
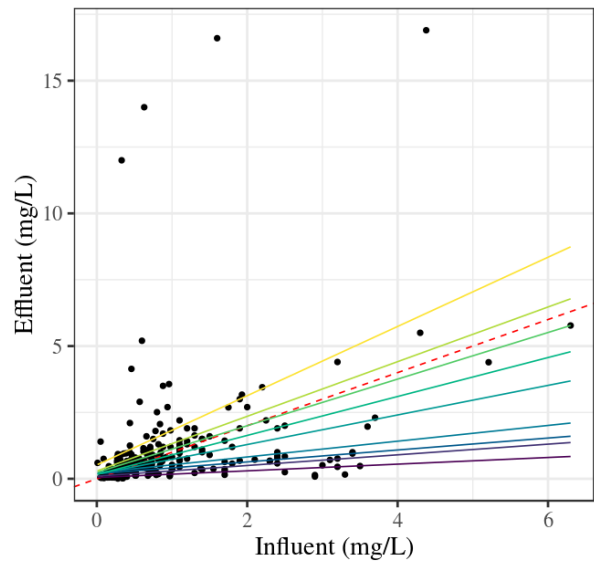
Dissolved Zinc



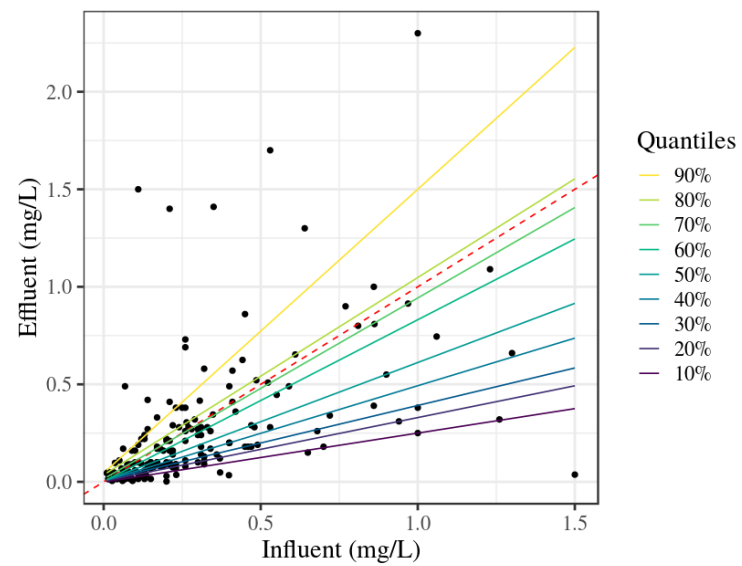
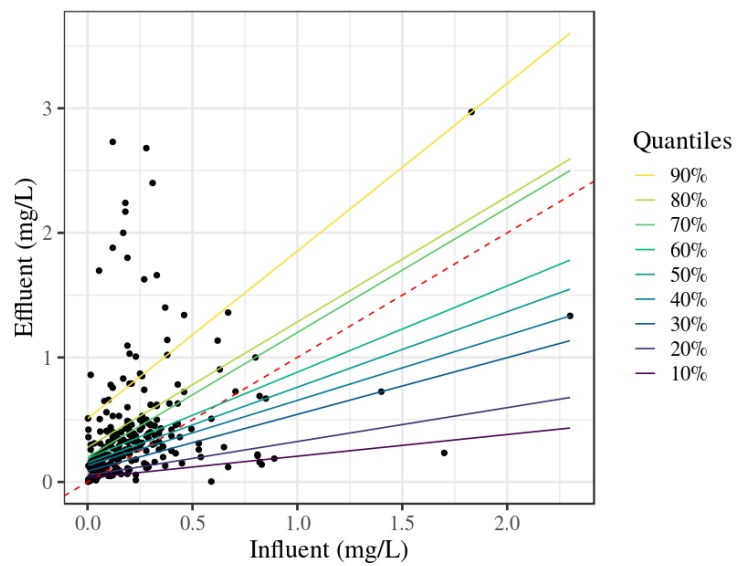
Total Zinc



Nitrate- N



Total P



APPENDIX B: BMP SELECTION CRITERIA

Table 1: Various BMPs used for stormwater capture and treatment. Definitions of various terms used in the table are provided in Attachment A. Asterisks represent relative level of effectiveness. Blue text indicates BMP is recommended for inclusion in this BMP effectiveness database.

| Scale of BMP | Primary Purpose | BMP Types | Stormwater Volume Moderation | | Stormwater Contaminant Removal | |
|-----------------|---|---|------------------------------|--------------|--------------------------------|------------------------|
| | | | Capture | Reduction | Suspended Contaminants | Dissolved Contaminants |
| Regional | Infiltration | Infiltration basin Infiltration trench | Assumed 100% | Assumed 100% | Assumed 100% | Assumed 100% |
| | Filtration | Media filters | ** | * | *** | ** |
| | Detention | Dry pond (a.k.a. detention pond/basin) | *** | * | * | * |
| | Retention | Wet pond (a.k.a. retention pond/basin) Constructed wetland | ** | ** | ** | ** |
| Distributed | Infiltration | Bioretention w/o underdrains Pervious pavement w/o underdrains Vegetated buffer strip | Assumed 100% | Assumed 100% | Assumed 100% | Assumed 100% |
| | Conveyance with filtration & infiltration | Vegetated swale | * | ** | ** | * |
| | Filtration | Bioretention with underdrains Pervious pavement with underdrains | ** | ** | *** | ** |
| Household Scale | Infiltration | Dry well | * | * | * | * |
| | Capture and Reuse | Rain barrel | ** | * | * | * |
| | Composite | Green roof | ** | ** | *** | * |

From the 15 BMPs in Table 1, seven priority BMPs were selected that are recommended for inclusion in the BMP effectiveness database. The criteria for BMP screening are described in Table 2. The seven selected BMPs are:

- 1) Media filters
- 2) Dry pond
- 3) Wet pond
- 4) Constructed wetland
- 5) Vegetated swale
- 6) Bioretention with underdrains
- 7) Pervious pavement with underdrains

The infiltration-based BMPs were not selected because, in California, these BMPs are considered zero discharge BMPs that are 100% effective in contaminant load reduction. Non-structural and household-scale BMPs were not selected because of limited data related to their performance, which preclude representative evaluation of their effectiveness. Bioretention systems and permeable pavements without underdrains were eliminated because, in the absence of an outlet, these BMPs primarily operate as infiltration BMPs.

Table 2. Evaluation criteria for prioritizing BMP selection.

| Criteria | Relevance to the project objectives |
|--|---|
| Does not depend solely on infiltration | Infiltration BMPs are assigned 100% load reduction. |
| Provides both volumetric and pollutant load reduction | Both are important in determining the efficiency of a BMP. |
| Is widely used in California | The scope of this project is the state of California. |
| Includes widely available, California-specific monitoring datasets | |
| Has established design standards | Due to design details, performance of two BMPs can greatly vary even if they are classified as the same BMP type. |

Glossary of Terms

Distributed BMP: Neighborhood scale stormwater BMP that receives, retains, and treats runoff on site. Typically, these are vegetated systems receiving runoff from a drainage area less than an acre. Stormwater captured in these BMPs are generally used for groundwater recharge. However, non-potable reuse of the treated water is also common. Some systems may also discharge water to the storm sewer systems after treatment.

Regional BMP: Stormwater BMP that captures runoff from an engineered drainage system with a large drainage area (up to 100 acres). Stormwater retained in these systems can be used for managed aquifer recharge or direct non-potable reuse.

Household BMP: Stormwater BMP installed at the household level primarily for capture and reuse.

Infiltration: Stormwater movement to subsurface or the soil surrounding the BMP.

Filtration: For this document, all processes involved in contaminant removal in a packed bed via chemical straining, sorption, precipitation, attachment, or ion exchange.

Detention: Stormwater storage for a limited period (<72 hr.).

Retention: Storage for an extended period, sometimes throughout the year.

Conveyance: Stormwater flow.

Infiltration Basin: Shallow, earthen depression that captures and infiltrates stormwater.

Infiltration Trench: Long, narrow, stone-filled BMP without outlet designed to store and infiltrate stormwater runoff.

Media Filters: Sand filters with a pre-treatment chamber for filtering or infiltrating stormwater. The filter may or may not have engineered amendments.

Dry Pond: Stormwater basin that detains runoff. Also known as detention basin, detention pond, and extended detention basin.

Wet Pond: Stormwater basin that has a permanent pool of water for a long period of time, i.e., throughout the season or during the wet season. Also known as retention basin, retention pond, wet extended detention pond, and wet basin.

Constructed Wetland: Shallower wet pond (<4 ft) with greater vegetation coverage.

Vegetated Buffer Strip: Flat vegetated area that receives sheet flow. Also known as biofiltration strip, grassed strip, filter strip, grassed filter, and grass buffer.

Vegetated Swale: Open, shallow, mild sloped, vegetated channel for conveying runoff downstream. Also known as grass swale.

Bioretention: Engineered, small-scale, vegetated, depressed area that captures, reduces, and infiltrates or filters stormwater runoff from the surrounding area. Also known as biofilter, rain garden, and porous landscape detention area.

Pervious Pavement: Permeable load bearing concrete or asphalt surface overlying detention basins. Also known as porous pavement, porous concrete, and permeable pavement.

Dry Well: Excavation lined with perforated casing and backfilled with gravel or stone that receives water from the roof.

Rain Barrel: Plastic (or concrete) water tank used to collect and store rainwater from a roof.

Green Roof: Soil media with vegetation overlying a traditional roof. Also known as living roof, vegetated roof, and eco-roof.

APPENDIX C: DATA STANDARDS

A data template was created in Microsoft Excel for entering and compiling data. Below are the data fields associated with the data template. This data template is comparable to the International BMP Database based on its scope, breadth, depth of information, applicability, acceptability and quality assurance, and accessibility.

Test Site Info

Test Site Name: Name of the project/BMP Site

Latitude, Longitude: North-South and East-West Coordinates of the BMP

City, County, Zip Code: Information related to geographical location of BMP test site

Number of BMPs: Note if there are more than one BMP at the site

Reference Datum: Coordinate system, e.g., geodetic datum associated with the latitude/longitude information

Data Source Info

Data Provider: Name of the organization submitting data

Data Source: Source of the submitted data. It could be a report (mention report name) or person (include point of contact information)

Year: Year of the data collected

BMP Layout Attached? Whether a layout/construction drawing of the BMP has been attached. Yes/No

QAPP/SAP Attached? Whether Quality Assurance Project Plans or Sample Analysis Plans have been attached.

Catchment Info

Watershed Name: Name of the watershed where BMP is located

Total Watershed Area: Total Watershed Management Area (in m²)

Land Use Info

Land Use Type: Dominant land use type for the watershed

% Land Use in Watershed: % Land use for the dominant land use type

BMP Info (General)

BMP Name: Identifying name for the BMP

Type of BMP: Select from dropdown menu

Basis of Design: Volume or flow-based design? Indicate values for design storm or treatment flow rate.

Purpose of BMP: Indicate primary purpose of BMP design: Pick from dropdown menu

Sources of Design Guidance: Indicate source/reference that was used to design the BMP (i.e., CASQA BMP manual, Southern California LID manual)

Date Facility Placed in Service: Date the BMP started operating

Number of Inflow Points: Indicate number of BMP inlets

Number of Outlet: Indicate number of BMP outlets

BMP Installed as Designed?: Pick from dropdown menu

Maintenance Type and Frequency: Note what maintenance activities are performed for the BMP at what frequency.

Retrofit?: Indicate whether any retrofit was performed after the BMP was put in place

Qualitative Evaluation of BMP Condition: Select from dropdown menu

Estimated Water Quality Benefit from BMP: Design goal for the BMP, i.e., X ac-ft/year of volume capture.

Tributary Area: Size of the tributary area (m²) that drains to the BMP

BMP Costs

Year of Cost Estimate: Basis of cost estimate

Total Facility Costs: Total cost of design, construction and installation of BMP

Maintenance Costs: Average annual maintenance costs per year

Other Costs: Any other relevant costs (average USD per year), i.e., costs related to retrofit or infrequent maintenance activities

Monitoring Events

Event Start Date, Event Start Time: Calendar date (mm/dd/yyyy) and time (24 hr format) of the storm event

Antecedent Dry Period: Time since the last storm event

QA/QC Description: Description of quality assurance/quality control activities

Total Precipitation: Total precipitation recorded for the storm related to the monitoring event

Monitoring Costs

Total Costs per Year: Average total monitoring costs (including study setup, sample collection, sample analyses) per year

Flow

Documents the flow conditions. Requested data include inflow, outflow and bypassed volumes.

Water Quality

Records the effluent quality achievable by various BMPs, quality of runoff relative to receiving water criteria and objectives, and evaluation of pollutant load reductions.

Sample Medium (from pick list): can be selected from a dropdown pick-list and includes: Groundwater, Surface Runoff/Flow, Soil, Dry Atmospheric Fallout, Wet Atmospheric Fallout, Pond/Lake Water, Accumulated Bottom Sediment, Biological, or Other.

Sample Type (from pick list): the type of samples provided including: Flow Weighted Composite EMCs (Event Mean Concentrations), Time Weighted Composite EMCs, Unweighted (mixed) Composite EMCs, or Grab Sample.

Analyte Name (from pick list): name of the constituent analyzed based on the USEPA's "modern STORET" nomenclature being used in USEPA's Water Quality Exchange (WQX) database. This is the preferred nomenclature for the BMP Database.

Sample Fraction (required for many parameters): the fraction of the water quality constituent that was analyzed (e.g., dissolved, total, total recoverable, etc.).

Value: the field or analytical result for the water quality sample.

Units of the measured constituent must be provided (e.g., mg/L, #/100 mL).

Qualifier: Qualifier, if any, for the data should be selected from the Water Quality Qualifier Codes pick-list codes, which include the following qualifiers:

- J = Estimated: The analyte was positively identified, and the associated numerical value is the approximate concentration of the analyte in the sample.

- R = Rejected: The sample results are unusable due to the quality of the data generated because certain criteria were not met. The analyte may or may not be present in the sample.
- U = Not Detected: The analyte was analyzed for but was not detected at a level greater than or equal to the level of the adjusted Contract Required Quantitation Limit (CRQL) for sample and method.
- UJ = Not Detected/Estimated: The analyte was not detected at a level greater than or equal to the adjusted CRQL or the reported adjusted CRQL is approximate and may be inaccurate or imprecise.

Bioretention:

A bioretention cell is an engineered, small-scale, vegetated, depressed area that captures, reduces, and infiltrates or filters stormwater runoff from the surrounding area. Bioretention cells are also known as biofilter, rain garden, and porous landscape detention area.

Type of Bioretention: Specific details on the bioretention basin, i.e., sloped, tree box filter, cell

Type of Pretreatment (if any): Any pretreatment at the bioretention entrance, including forebay/sedimentation basin

Bioretention Surface Area: Surface area at the media surface.

Average Ponding Depth: Average ponding depth or depth of freeboard (if any)

Internal Water Storage Volume (if any): Volume of submerged zone where a permanent pool of water remains in between storm events.

Volume of Submerged Zone: Volume of internal water storage or submerged zone.

Bioretention Media Type: Pick from dropdown menu

Bioretention Soil Media Specification: Details of bioretention soil media. Mention fraction (%) of sand, silt, clay, compost, or any other media components.

Bioretention Media Depth: Depth of the engineered soil media

Bioretention Media Phosphorus Content: Total phosphorus (mg/Kg of media) content of the bioretention soil media

Description of Plants: Type of the plants present. Mention relative coverage.

Design Infiltration Rate: Infiltration rate of the soil including safety factor for clogging.

Depth of Underdrain: Distance between the top of the media layer and the underdrain pipe

Gravel Layer Depth: Thickness of drainage layer

Impermeable Lining Description: Depth and type of any impermeable lining present

Media Layer Age: Time (days) since the media were last replaced

Dry Pond

Dry ponds are stormwater basins that detain runoff. These are also known as detention basins, detention ponds, and extended detention basins.

Water Quality Detention Volume: Runoff volume that captured and drained within the drawdown time

Detention Basin Area: Area of the bottom of the entire detention basin, including the bottom stage area.

Drawdown Time: Time required to empty the pond when it is completely full.

Volume of Micropool (if present): Volume of any permanent pool within the bottom-stage of the basin near the outlet

Forebay Volume: Volume of the forebay when water overflows to the main basin

Vegetation Cover within Basin: Description of the plants present

Design Basin Depth: Depth of the basin as designed

Field Measured Basin Depth: Existing depth of the basin

Outlet Description: Number of outlet and description

Depth of Design: surface water elevation to lowest orifice

Wet Pond

Wet ponds are stormwater basins that have a permanent pool of water for a long period of time, i.e., throughout the season or during the wet season. A wet pond is also as retention basin, retention pond, wet extended detention pond, and wet basin.

Permanent Pool Volume: Volume of permanent pool of water

Permanent Pool Length: Permanent pool inlet to outlet distance

Water Quality Surchage Detention Volume when Full: Total design detention volume aka water quality surcharge detention volume when full

Drawdown Time: Time required to empty the pond when it is completely full.

Forebay Volume: Forebay storage capacity

Description of Outlet: Total number of outlets and their descriptions

Vegetated Swale

Open, shallow, mild sloped, vegetated channel for conveying runoff downstream. Also known as grass swale.

Length, Width, Longitudinal Slope, Side Slope: Swale geometry

Maximum Flow Depth: Flow depth during 2-year storm

Design Velocity: Flow velocity during 2-year storm

Saturated Infiltration Rate: Hydraulic conductivity under existing conditions

Description of Vegetation: Grass species and density

Media Filters

Media filters are filtration BMPs with a pre-treatment chamber for filtering or infiltrating stormwater. The filter media may or may not have engineered amendments. Proprietary filtration boxes are also included in this category.

Media Filter Type: Select from dropdown menu

Forebay or Upstream Pool Volume: Sedimentation zone volume (if present)

Forebay or Upstream Detention Time: Sedimentation detention time (if any)

Filter Surface Area: Surface area of the filter at the media surface

Description and Thickness of Media Layers: If the media is layered, mention details for each media layers

Design Infiltration Rate: Design Hydraulic conductivity (inch/hr) of the filter under

Maximum Ponding Depth above Surface : Design freeboard

Porosity of Storage Layer: Porosity of the filter media

Depth to Underdrain (if present): Distance between filter surface and underdrain

Permeable Pavement

Permeable pavements are permeable, load bearing concrete or asphalt surface overlying detention basins. They are also known as porous pavements, porous concrete, and permeable pavements.

Pavement Type: Select from the dropdown menu

Surface Infiltration Rate: Infiltration rate under existing conditions

Design Infiltration Rate: Infiltration rate as designed

Permeable Pavement Surface area: Total area of pervious pavement

Total Storage Volume: Total subsurface storage available, including subsurface storage

Estimated Drain Time for Storage Layer: Emptying time for subsurface storage

Description of Water Treatment Layers (if present): Composition of soil media and depth if runoff treatment is provided

Depth to Underdrain: Distance between top of the surface layer and top of the underdrain

Depth to Impermeable Layer: Distance between top of the surface layer and lining/rock surface (if any)

Constructed Wetland

Constructed wetlands are shallower “wet ponds” (<4 ft) with greater vegetation coverage.

Volume of Permanent Pool: Volume of water storage that remains in the wetland for an extended period

Permanent Pool Length: Permanent pool inlet to outlet distance

Design Detention Volume: Total design detention volume for the wetland

Wetland Surface Area by Depth: Contour of the basin or percent wetland area by various depth (i.e., by 1 ft interval)

Drawdown Time: Basin emptying time

Forebay Volume: Forebay storage capacity

Forebay Surface Area: Surface area of forebay when full

APPENDIX D: PROJECT FACT SHEET FOR DATA REQUESTS

Building a California-specific data set to assess long-term stormwater BMP effectiveness

Stormwater managers cumulatively spend hundreds of millions of dollars every year designing and installing Best Management Practices (BMPs) to treat stormwater runoff. To make decisions about which BMPs to implement and where, managers often rely on watershed-scale modeling efforts to produce quantitative estimates of BMPs' long-term effectiveness. However, these estimates are often not based on locally collected BMP performance data, introducing considerable uncertainty into estimates of BMP performance effectiveness. To improve confidence and ensure optimal BMP performance, researchers are compiling a comprehensive, California-specific data set on BMP performance effectiveness.

Why a California-specific data set?

Most of the data on BMP performance effectiveness comes from the [International Stormwater BMP Database](#), which contains data sets that are not necessarily relevant to California climatic conditions. Even BMPs that share the same name can perform very differently depending on local climate conditions, soil types, contributing pollutant sources, and specific design specifications.

The California BMP data set will address these persistent challenges by serving up only performance effectiveness data specific to California. Because the data will be based on pollutants commonly found in California waterways, managers will be able to rely on the data set to support their BMP implementation decisions. The California BMP data set will include detailed guidance on how to use the data sets.



California BMP effectiveness data set now being built

The State of California has asked the Southern California Coastal Water Research Project Authority (SCCWRP) and the San Francisco Estuary Institute (SFEI) to compile statewide data set on performance effectiveness for stormwater BMPs. The California-specific data will provide tools, criteria and guidance to assist stormwater managers in selecting BMPs that achieve desired, long-term goals for performance effectiveness.

Key features of the California BMP effectiveness data set

The data set is being designed with a number of managerially relevant features in mind, including:

- » Data specific to all major geographic regions of California
- » Detailed analyses relating design and efficiency for each BMP type, including performance curves
- » Robust estimates of uncertainty
- » Relative rankings of BMP performance effectiveness for up to seven BMP types and a dozen pollutant types

Key benefits of the California BMP effectiveness data set

The data set will include a wealth of BMP effectiveness analyses. Stormwater managers will be able to use these insights to:

- » Reduce uncertainty in watershed management planning/RAA analyses for regulatory compliance
- » Compare among various alternative structural BMP types to meet water quality objective/TMDL targets
- » Identify BMP designs that provide optimized performance
- » Optimize maintenance schedule for various BMPs to ensure maximum long-term performance