Green Infrastructure (GI) & Low Impact Development (LID)

Long-Term Effectiveness Evaluation Needs for the SMC

White Paper

SMC LID Effectiveness Evaluation Background

In 2006 the San Bernardino County Flood Control District, with SMC Member Agencies and the California Stormwater Quality Association (CASQA) as project partners, submitted a State Proposition 40 grant proposal for the LID Guidance and Training Project. The project grant submittal was successful and $600,000 of funding was awarded to complete the following Tasks: 1) Compile and Evaluate Existing Information on LID BMP Effectiveness; 2) Coordinate with other Stakeholders; 3) Conduct Field Monitoring of LID Features; 4) Develop a LID Technical Manual with results of field monitoring. The duration of this initial phase of the project was from 2006 -2010, which culminated with posting of the Southern California LID Manual on the California LID Portal (www.californialid.org) in April of 2010.

In 2011 the SMC developed a revised approach to evaluate LID BMP effectiveness; an approach that includes water quality monitoring of LID features, and extensive coordination and data collection from other LID implementation projects in southern California. In 2011 and 2012 a draft revised Scope of Work was developed. The revised scope included updates to the monitoring and LID BMP effectiveness evaluation tasks for the Project, to coordinate completion of revised Scope tasks, and coordinate with CASQA and stakeholders to update the LID Manual as appropriate, based on effectiveness results and to manage the project progress in coordination with the SMC. From 2013 to 2014, Dr. Matt Yeager, with the assistance from Daniel Apt and Scott Taylor of Michael Baker International, worked with the SMC members to develop a Scope of Work (SOW) for this project, funded from remaining SMC funds allocated to the overall project.

In the development of the Southern California LID Manual and associated tasks and the development of the later SOW to evaluate LID BMP effectiveness the SMC recognized that LID concepts in Southern California are affected by differences associated with Southern California compared to the areas of the east coast where LID had been formulated and different from those areas such as the Pacific Northwest where LID has been successfully implemented. These differences include first and foremost the climate in Southern California as well as the fact that it is not uniform across Southern California. Overall the Mediterranean climate of Southern California is much dryer than other parts of the country where LID and GI have been successfully implemented, however there are many regional differences as the climate in the Southern California coastal plains, mountains, and deserts are very different and affect LID and GI implementation. Additionally, California is being affected by climate change that includes long periods of drought, a change in rainfall patterns with more intense storm events, and recent years of significantly higher rainfall totals well above average. The variability in rainfall with some years being less than the average of 12 inches per year and some years being more than three times the average has a significant affect on how LID and GI is implemented. With this variability in rainfall and changes in how California receives its precipitation (e.g. less snow pack) water supply is a primary concern, that also effects LID and GI. It is these differences, why the effectiveness of LID and GI needs to specifically be evaluated for Southern California and not rely upon effectiveness studies performed in other parts of the country.

SMC CLEAN Phase I (2015-2020)

In August of 2015 the SMC LID BMP Monitoring/Effectiveness project began with a consultant team that included Daniel Apt (project lead), Dr. Matt Yeager, Dr. Michael Trapp, and Scott Taylor. A Technical Advisory Committee (TAC) was formed and one of the first tasks was to brand the project. With input from the TAC the project was branded as the SMC California LID Evaluation and Analysis Network (SMC CLEAN). The tasks of the initial phase of the SMC CLEAN project included the following:

- Task 1 - Form and Coordinate a Project Technical Advisory Committee
- Task 2 - Research Existing Data
- Task 3 - Implement initial monitoring procedures in a beta test phase
- Task 4 - Summarize all monitoring data, make recommendations, and update the LID Manual
- Task 5 - Ongoing Collaboration with Project Partners

With input from the SMC CLEAN TAC the focus of the first phase of the SMC CLEAN project was to evaluate bioretention/biofiltration systems as these are the most common LID BMP being implemented in Southern California. Discussions with the SMC CLEAN Technical Advisory Committee identified two primary needs to be addressed by the project. First, a short term need for a quantification of LID performance in southern California, needed to provide empirical data to calibrate estimates for compliance measures such as the recently developed watershed programs (i.e. EWMPs, WQIPs, etc.) and their associated watershed/water quality models [i.e. Reasonable Assurance Analysis (RAA), Reasonable Assurance Studies (RAS)]. The second is a long term need for a collaboration entity and clearinghouse of LID monitoring data in order to compile enough data to understand the effectiveness of various LID BMPs over time and understand how the differences in design, construction, and maintenance affect their performance. The following mission statement was intended to guide the SMC CLEAN project to address the short- and long-term goals:

> The mission of SMC CLEAN is to develop a thorough understanding of the effectiveness of LID BMPs in California both in the short term for use in calibration of watershed programs and the long term for modification of LID design, construction, and maintenance, through coordination with project partners and others performing LID monitoring and serving as a clearing house for LID monitoring information, developing targeted LID research questions and performing targeted LID monitoring based on these questions, analysis of LID monitoring data, and recommendations for the design, construction, maintenance, and monitoring of LID in updates to the Southern California LID Manual to ensure that LID BMPs are implemented in the most effective manner.

The following are the primary work products to date of the SMC CLEAN Phase I:

1. Work Plan
2. Targeted Research Questions
3. Standard LID Project Data-Information List
4. Monitoring Protocol
5. Updated Southern California LID Manual
6. LID & GSI Construction, Inspection, Maintenance, and Monitoring Guidance Manual

As the first phase of the SMC CLEAN project proceeded it became apparent that obtaining LID monitoring data was challenging as not many LID systems had been monitored in Southern California, and for many of the LID systems that had been monitored the data was not available or accessible. Additionally, it was identified that with the variability of factors that could affect performance of LID and GI systems (e.g. proper design, construction, maintenance) that not only water quality monitoring data was needed but the meta data associated with the design, construction, maintenance, and inspection of LID and GI systems was needed. This lack of both water quality monitoring data and meta data for LID and GI systems made it clear that a comprehensive evaluation of the effectiveness of LID and GI systems in Southern California would not be possible until this data could be collected and tracked for long periods of time to understand the effects of maintenance and other factors, and made accessible so analysis can be performed.

GI & LID Effectiveness Needs for the SMC

A key finding of the SMC CLEAN Phase I and previous LID effectiveness evaluation work performed by the SMC and its partner agencies, is that long-term monitoring and data for LID and GI projects in southern California is essential to truly understand the effectiveness of LID and GI systems in southern California. The primary need is for the collection, tracking, and access to monitoring and meta data (design, construction, maintenance, and inspection information) of LID and GI systems in Southern California to understand the effectiveness of various LID and GI BMPs with different designs and configurations as well as to understand how construction practices and maintenance activities may affect performance and effectiveness. Through collection, tracking, and access to monitoring data an understanding of how best to conduct monitoring of these systems can be obtained. With the collection of LID and GI systems monitoring and meta data analysis of this data can be performed so that design, construction, maintenance, and monitoring recommendations can be made so that LID and GI BMPs are implemented and maintained in the most effective manner.

As implementation of LID and green infrastructure (GI), driven by MS4 Permit and water quality requirements, becomes ever more prevalent, a comprehensive and quantitative understanding of the effectiveness of LID and GI in Southern California becomes more critical. The original emphasis on LID was focused in the Land Development sections of the MS4 Permits where permittees must ensure that new and redevelopment projects implement LID BMPs with sizing requirements designed to comply with volume-based retention standards instead of implementing conventional stormwater quality treatment devices. Most California Phase I MS4 permits now allow or require permittees to develop watershed management plans, which must ensure that discharges will achieve Water Quality Based Effluent Limits and not cause or contribute to exceedances of receiving water limitations. As these plans have been developed, LID in the form of GI has been identified as a significant piece of the compliance schema. In Los Angeles County an analysis of the Watershed Management Plans (WMPs) and Enhanced Watershed Management Plans (EWMPs) developed identified approximately 40% of the BMPs to meet compliance are based on implementation of LID and GI systems. Due to constraints of land availability and the high cost of land acquisition, (GI) is identified in most of these watershed management plans as a primary watershed control measure. As LID and GI becomes more prevalent in the stormwater quality regulatory schema, and serves as a fundamental tool for watershed and receiving water protection, understanding these systems' actual field performance becomes a requirement to demonstrate compliance.

The SMC's work to date shows that a quantitative understanding of the effectiveness of LID and GI systems will require a significant amount of data, much more than currently available. The SMC should take a leading role in evaluating LID and GI effectiveness, especially in southern California, while continuing to coordinate, and expand this coordination, with other organizations (e.g. universities) and initiatives performing monitoring and effectiveness evaluations. Additionally, water quality monitoring data and meta data describing designs, materials, construction procedures, inspections, and maintenance information should be sought from others that are implementing, inspecting, monitoring, and maintaining LID and GI systems in Southern California to enhance the data set and support a more robust performance evaluation of different types of LID and GI systems in Southern California. As the primary stormwater monitoring organization in southern California, the SMC should actively seek LID/GI monitoring and meta data, and serve as a clearinghouse and coordination network for LID/GI monitoring effectiveness information for Southern California and potentially all of California. It will also be essential for the SMC to reach out and engage with other initiatives and organizations performing LID/GI monitoring and effectiveness evaluations using field and laboratory approaches, and in other regions, to gain the most comprehensive understanding of these systems.

LID/GI Monitoring Challenges & Solutions

Significant technical challenges must be overcome to collect robust quantitative water quality and hydrologic monitoring data from LID/GI systems. Robust monitoring data requires a strong experimental design and control of experimental conditions. Monitoring design also needs to ensure that data is comparable to other relevant data sets, which can partly overcome by a standard monitoring and sampling protocol. A monitoring plan should also be clear about the purpose and goals of the monitoring as there are many elements of research for LID and GI systems the monitoring plan can go beyond the intended purpose and goals. The use of standard LID and GI monitoring protocols (e.g. SMC CLEAN LID Monitoring protocol) is also acritical element to support the development of LID effectiveness data that can be properly compared.

Storm sampling is already challenging due to storm unpredictability and this is exacerbated by a lack of a consistent sampling protocol. Logistics of storm sampling can also be challenging if multiple sites are being sampled at the same time. Storm sampling can also be dangerous, and safety should always be considered first. The use of a standard protocol will help to reduce these challenges.

Most existing LID and GI BMPs are not designed for water monitoring so hydrologic instrumentation and water quality sample collection approaches typically must be improvised and are specific to each BMP. This poses challenges for the collection of both influent and effluent water quality samples and also being able to obtain flow measurements. Retrofit of existing built LID and GI BMPs to allow for accurate monitoring is in many cases not feasible due to costs. In many cases the configuration of LID and GI BMPs will not allow for monitoring as retrofits for monitoring are not feasible. In such cases complete replacement of the BMP is needed to be able to perform monitoring. These challenges can be overcome by the use of designs that integrate monitoring features and standard designs that integrate monitoring elements. The use of these types of designs should be considered even if monitoring is not considered for the immediate future as, retrofit of BMPs to integrate monitoring elements if needed in the future will always be more expensive. Development and use of standard LID/GI designs with integrated monitoring features (e.g. SMC CLEAN bioretention/biofiltration design with integrated monitoring) can facilitate monitoring by providing access points for flow instrumentation and influent/effluent sample collection.

Infiltration is a key treatment function in LID and GI BMPs however, it is very difficult to sample the water that is actually infiltrated. This presents challenges to truly understand the pollutant removal performance of these systems as well as understanding the actual volumes that are infiltrated. Solutions to this challenge include lining a portion of an infiltration based BMP and include and underdrain, which helps to understand pollutant removal performance. To better understand the volume infiltrated influent and overflow monitoring can be performed. Additionally, lined experimental BMPs with indirect measures of effluent (volume and mass balance combined with influent and overflow monitoring) underdrain sampling, lab-based column testing, and in-situ column testing, can help to address this challenge.

The frequency of storm events in Southern California is another challenge. As identified above the Southern California climate is changing as just in the past decade Southern California has recorded as little as a few inches of annual rainfall as well as annual rainfall over 40 inches. This variability makes it extremely difficult to obtain monitoring data. Part of the solution is a longer time period (e.g. 10 years) for monitoring at LID and GI sites, which reduces the impact of this variability as the variability of a year to another year of the amount of rainfall received at a site is not as impacted as if monitoring only occurred for 2-3 years, where you could have 2-3 dry years in a row.

The variability of where storm events occur with the different climate variability regions (coastal plains, mountains, deserts) in Southern California presents another challenge. For a Southern California monitoring program with this variability, part of the solution is to have redundant sites across the different types of climate regions. This redundancy will help for comparability of data for the different types of climate regions which is also needed.

The variability of different types of climate regions in Southern California also presents a monitoring challenge as the configuration/design of some LID/GI BMPs will need to take into account these factors. These modifications to the configuration/design of LID/GI BMPs need to be considered in the monitoring and analysis of the monitoring data. Part of the solution is the establishment of multiple LID/GI monitoring sites for each of the configuration/design changes to be able to have comparable data.

Monitoring in-situ also poses challenges associated with control of a site and the different unknown factors (e.g. vandalism, dumping, etc.) that could affect the monitoring results. More controlled sites with reduced potential factors that may affect results are needed to help calibrate the various in-situ field monitoring data. Existing monitoring facilities like the Orange County Public Works (OCPW) Glassell

Yard LID retrofit and the Riverside County Flood Control and Water Conservation District (RCFCWCD) campus LID retrofit or other existing facilities or to future facilities that are in a controlled environment can provide data to help calibrate other monitoring sites. Long-term (e.g. 10 years) monitoring of these controlled sites are needed to understand how maintenance affects their performance.

LID/GI Data Interpretation Challenges & Solutions

A significant challenge with interpretation of LID and GI data is an incomplete data set. This can include a lack of hydrologic data due to sampling procedures, lack of instrumentation to collect hydrologic data, or instrument failure. This challenge can helped be overcome by a more controlled BMP testing approach with the construction of LID and GI facilities in contained environments (e.g. municipal yard) and standard BMP monitoring protocols.

Another data interpretation challenge is short-term data sets as it is difficult to quantify or determine trends with typical high data variability for short-term data sets. This can be due to lack of data due to variable climatic conditions in Southern California during short-term monitoring, where not enough storm events occur or storm events that do occur have shorter durations, which are problematic for gathering data. As identified above this challenge can be overcome by a long-term and controlled BMP monitoring program.

The variability in different LID and GI system designs and sizing offers a challenge to have comparable data. Numerous design manuals have been developed in California and even within Southern California there is significant variability in LID and GI designs. Although there have been efforts to develop standard designs applicable across jurisdictions (e.g. CASQA Standard Bioretention Designs) there are still a wide variety in designs for specific LID and GI systems such as bioretention systems. This variety of design configurations for the same LID BMPs poses a significant challenge for LID monitoring, however understanding how these design configurations affect BMP performance will be important moving forward. This challenge can in part be overcome by the development and adoption of standard designs by jurisdictions in Southern California. Monitoring can then focus on systems designed with the standard designs to evaluate performance. Additionally, using standard designs will help to ensure comparability between monitoring data for different specific LID and GI designs (e.g. bioretention/biofiltration systems).

Proper construction of LID designs is also an issue that needs to be considered and use of the construction guidance is critical for proper construction of LID and GI BMPs. The materials used for construction of LID and GI systems and the construction of the LID and GI BMPs is extremely important and has a significant impact on the performance of these systems. The use of poor or substandard materials and/or the inadequate execution of the approved design during construction can dominate the performance trend for these systems. Included is the challenge that the quality of the materials used for construction may not be known or documented. These challenges can be overcome by QA/QC of the materials used for construction LID and GI systems, construction protocols and inspections at specific points of construction, post-construction hydrologic testing for each site, training on all aspects of construction and materials, outreach to materials suppliers, the development of materials testing protocols, and testing and certification of materials.

Maintenance also poses a challenge for LID and GI monitoring but understanding how maintenance of LID and GI BMPs affects performance will be a critical piece to understanding the long-term effectiveness of LID and GI BMPs. We assume that the lack of maintenance in LID and GI systems causes poor BMP performance or failure, but we should understand how does lack of maintenance or inadequate maintenance incrementally affect performance. An understanding of what happens to performance if there is inadequate maintenance, such as if plants die or mulch is not replaced, is needed. This challenge is exacerbated by both a wide range of possible BMP conditions over time, the lack of maintenance documentation, and the lack of a formal maintenance plan for sites. Additionally, some designs can affect the ability of adequate maintenance to be performed. These challenges can be overcome in part by standard designs, materials QA/QC, standard maintenance procedures and protocols, standard maintenance data documentation, inspections, and training.

Long-Term LID/GI Monitoring Study

To have a thorough understanding of the performance of LID and GI BMPs a long-term study of 10 years is needed that will allow monitoring of a substantial amount of storm events and understand how LID and GI systems perform overtime and to understand a variety of factors, such as maintenance, that affect performance. There is a significant need to quantitatively understand the performance of LID and GI systems in Southern California so that specified designs will provide predictable water quality and hydrologic benefits. LID and GI systems are complex, and performance is affected by numerous factors. Performance data for LID and GI systems are difficult to obtain and therefore a long-term and more controlled monitoring approach is required. This need to quantitatively understand the performance of LID and GI systems in Southern California requires significant work in several areas that are in line with the mission of the SMC and SMC CLEAN. Several key elements of this work are briefly described and recommended in the sections below.

Research Focus

An important element of any future work of the SMC focused on effectiveness of LID and GI is to identify what the focus of future research should be. As part of the SMC CLEAN Phase I project the focus was on bioretention and biofiltration as the most common LID and GI BMP implemented in Southern California, however any future SMC work should identify if the scope of LID and GI BMPs should go beyond bioretention/biofiltration to include other LID and GI BMPs and if so, which targeted research questions should be answered for those BMPs. As an example of targeted research questions, the bioretention/biofiltration targeted research questions developed as part of the SMC CLEAN Phase I are provided in Attachment A. The SMC CLEAN Phase I bioretention/biofiltration targeted research questions are still valid and should be part of and be the primary research focus for the future SMC LID & GI effectiveness evaluation. Research being performed by others in California and around the country related to LID and GI should be evaluated to focus the SMC research and monitoring efforts to be able to best answer the existing and any new targeted research questions based on gaps in other research being performed and to best focus the SMC resources.

One potential additional area of focus for future SMC LID & GI effectiveness evaluation is the evaluation of the materials that are used for construction of LID & GI systems. As part of Phase I of the SMC CLEAN a LID & GI BMP materials survey is being completed that is intended to provide input as to the quality and protocols being used for assessment of the quality of the materials used in the construction of bioretention systems in California. The results of this study should be used to formulate a scope for bioretention materials study that may include column testing of the components bioretention soil media (BSM) sourced from suppliers of BSM materials and testing of identified BSM specifications in the state (e.g. BASMAA BSM Specification).

Collaboration & Communication

Collaboration with those entities both within and outside of the SMC member organizations should continue to 1) obtain data and information regarding the monitoring and effectiveness of LID and GI BMPs; 2) continue to engage those that have participated on the SMC CLEAN TAC either to continue the SMC CLEAN TAC or formulate a new TAC and draw on the experience and knowledge of TAC members; 3) pursue opportunities for joint monitoring projects; and 4) pursuit of funding to be able to monitor and evaluate the effectiveness of LID and GI BMPs. Communication should at a minimum take the form of 1) providing updated information on the SMC website about the effectiveness of LID and GI systems and the SMC efforts to evaluate their effectiveness; 2) providing forums or workshops about the effectiveness of LID and GI systems and the results of monitoring projects; and 3) publication of results of SMC efforts regarding LID and GI monitoring and effectiveness evaluations.

LID & GI BMP Data Submittal Tool & Portal

Based on evaluations as part of the SMC CLEAN Phase I project there is a need for the development of a LID & GI BMP Data submittal tool so that there is a central repository for collected LID monitoring and meta data in Southern California so that adequate data analysis can be performed to understand the primary elements that affect performance of LID & GI BMPs in Southern California. The LID & GI BMP Data submittal tool has the potential to have many functional elements, however the intent of the tool is to facilitate better data collection of monitoring and meta data so that more thorough analysis can be performed. A standard set of LID and GI information will need to be evaluated for the portal and the SMC CLEAN Standard LID Project Data-Information List can be used as source to identify the scope of data that the LID & GI BMP Data submittal tool should collect.

The identified standard set of LID and GI information will define the functional elements of the LID & GI BMP Data submittal tool. The functional elements of the portal should be evaluated to include elements that will encourage entities to use the tool and provide the critical monitoring and meta data needed to evaluate the performance of LID & GI BMPs. The LID & GI BMP Data submittal tool should include at a minimum of the following:

1. User friendly web-based data submittal interface that allows for streamlined data upload.
2. Database where LID & GI monitoring and meta data is stored
3. A web-based query tool/interface so that users can query data and information in the tool.
4. A map element to identify the location of LID & GI monitoring projects.
5. A reporting element so that queries and general information about the LID & GI

6. A mobile application that can be used for inspections and monitoring of LID & GI BMPs.
7. Federated data acquisition tool for obtaining data/information from other databases

LID & GI BMP Standards and Specifications

Many of the issues associated with the implementation of LID and GI systems is the variety of different designs for the same LID or GI system that make it difficult for contractors to construct these systems effectively. The SMC should evaluate the potential development of statewide LID & GI BMP standards and specifications for California. This will need to include coordination with the State Water Resources Control Board, CASQA, and others about the need for the development of statewide LID & GI BMP standards and specifications. The CASQA-LIDI standard bioretention plans and specifications, as a comprehensively peer reviewed set of plans and specifications should be considered for statewide LID & GI BMP standards and specifications for bioretention, biofiltration, pervious pavements, and green streets. This efforts should include coordination with ASTM about potential development of LID & GI BMP standards and specifications as part of the Greenbook: Standard Specifications for Public Works Construction. If the results of the evaluation for the development of statewide LID & GI BMP standards and specifications for California are positive an advisory group should be formed for their development.

California LID & GI BMP Testing and Certification Program

Based on input from the SMC CLEAN TAC there is a desire to evaluate the development of a California LID & GI BMP Testing and Certification Program. This effort should evaluate the need among MS4s, developers, regulators, academia, and manufacturers of proprietary LID & GI BMP systems for the development of a California LID & GI BMP Testing and Certification Program. Surveys and outreach should be performed to these groups and others to understand the need to develop a LID & GI testing and certification program in California. If the results of the evaluation is to develop a LID & GI testing and certification program in California an advisory group should be developed.

Monitoring Plan & Monitoring

Based on the results of the research focus described above a monitoring plan and associated QAPP should be developed for the SMC LID & GI long-term study. The monitoring plan should ensure data collection will support effectiveness metrics, including:

1. Water quality
2. Runoff, infiltration, and evaporation volume
3. Runoff timing
4. Design standards
5. Quality of materials and effective construction and installation
6. Ranking of performance from low to high
7. Determine how to integrate the information into the management systems

The monitoring plan should identify the proposed new/continuing monitoring sites, sampling parameters, schedule and budget. Based on the monitoring plan and associated QAPP monitoring of a selected set of LID & GI BMPs should commence. This will include monitoring at the identified sites in the monitoring plan to be accomplished through tasks led by the SMC and through in-kind services and coordination with other projects. The monitoring results should also be linked to any available monitoring data of downstream receiving waters. The monitoring plan should be revaluated every two years and additional monitoring sites should be evaluated.

Data Analysis & Recommendations

The project monitoring data and meta data developed though the future SMC LID & GI monitoring should be analyzed to answer the targeted research questions identified as part of the research focus analysis. Analysis of data should be performed at identified frequencies for the duration of the long-term study but at least 3 times during the 10 year project duration. Based on the data analysis the following recommendations and updates are proposed:

1. Update SMC CLEAN monitoring protocol based on lessons learned
2. Update SMC CLEAN Standard LID Project Data-Information based on lessons learned
3. Make recommendations for update of the LID & GI BMP Data Submittal Tool & Portal
4. Prepare interim project reports at to be identified frequencies
5. Prepare Draft Final Project Report and solicit input from the project TAC
6. Update the SoCal LID Manual based on data analysis
7. Prepare Final Project Report

Schedule

The proposed duration of the SMC Long-Term LID & GI Effectiveness Study is 10 years. Optimally the SMC Long-Term LID & GI Effectiveness Study would start shortly after the conclusion of SMC CLEAN Phase 1 (June 30, 2020).

Attachment A

SMC CLEAN Phase I Targeted Research Questions

SMC CLEAN Phase I Bioretention/Biofiltration Targeted Research Questions

Bioretention/Biofiltration Short-Term Targeted Research Questions

1. What are the pollution removal benefits of bioretention systems in Southern California?
    i. Calculate/characterize the pollutant removal benefits of bioretention systems with underdrains
    ii. Calculate/characterize the pollutant removal benefits of bioretention systems without underdrains.
    iii. If possible, discern whether changes in the bioretention soil matrix (BSM) being implemented in Southern California affects performance across pollutants.
2. What are the hydrologic benefits of bioretention systems in Southern California?
    i. Calculate/characterize the volume reduction of bioretention systems with and without underdrains with various site soil types.
    ii. Calculate/characterize the flow duration effects of bioretention systems.
    iii. Compare/evaluate the measured hydrologic benefits (volume and flow attenuation) with bioretention system design parameters.

Bioretention/Biofiltration Long-Term Targeted Research Questions

1. How do specific bioretention designs/configurations affect pollutant removal and hydrologic performance?
    i. What are the most common bioretention designs/configurations (isolate soil depth, aggregate depth, and underdrain configuration as the differentiating factors) being implemented in Southern California (identify maximum 3 configurations)?
2. How do different bioretention plants affect pollutant removal and hydrologic performance?
    i. How do systems with and without plants affect pollutant removal and hydrologic performance?
    ii. What are the effects of different plants as identified in studies by others?
3. How does maintenance for bioretention systems affect pollutant removal and hydrologic performance?
    i. What is the frequency of monitoring for an individual LID BMP that would need to be performed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
    ii. What type of maintenance records are needed to identify the pollutant removal and hydrologic performance effects of maintenance of an individual LID BMP?
    iii. Can preliminary conclusions be drawn regarding pollutant removal and hydrologic performance effects of maintenance with information currently being collected and if so, what are they?
4. What kind of impacts are evident from improper construction of bioretention systems and how are these impacts affecting pollutant removal and hydrologic performance?
    i. What are the typical construction errors that are seen with bioretention systems?

ii. What are the qualitative impacts affecting pollutant removal and hydrologic performance of the typical construction errors that are seen with bioretention systems?

5. What Southern California specific factors (i.e. climate) effect affect pollutant removal and hydrologic performance in comparison to bioretention data from project partners outside of Southern California?
    i. What are the translators for Southern California of performance from bioretention studies performed elsewhere?
    ii. How do bioretention design parameters (soil depth, aggregate depth, and underdrain configuration) affect the translators?